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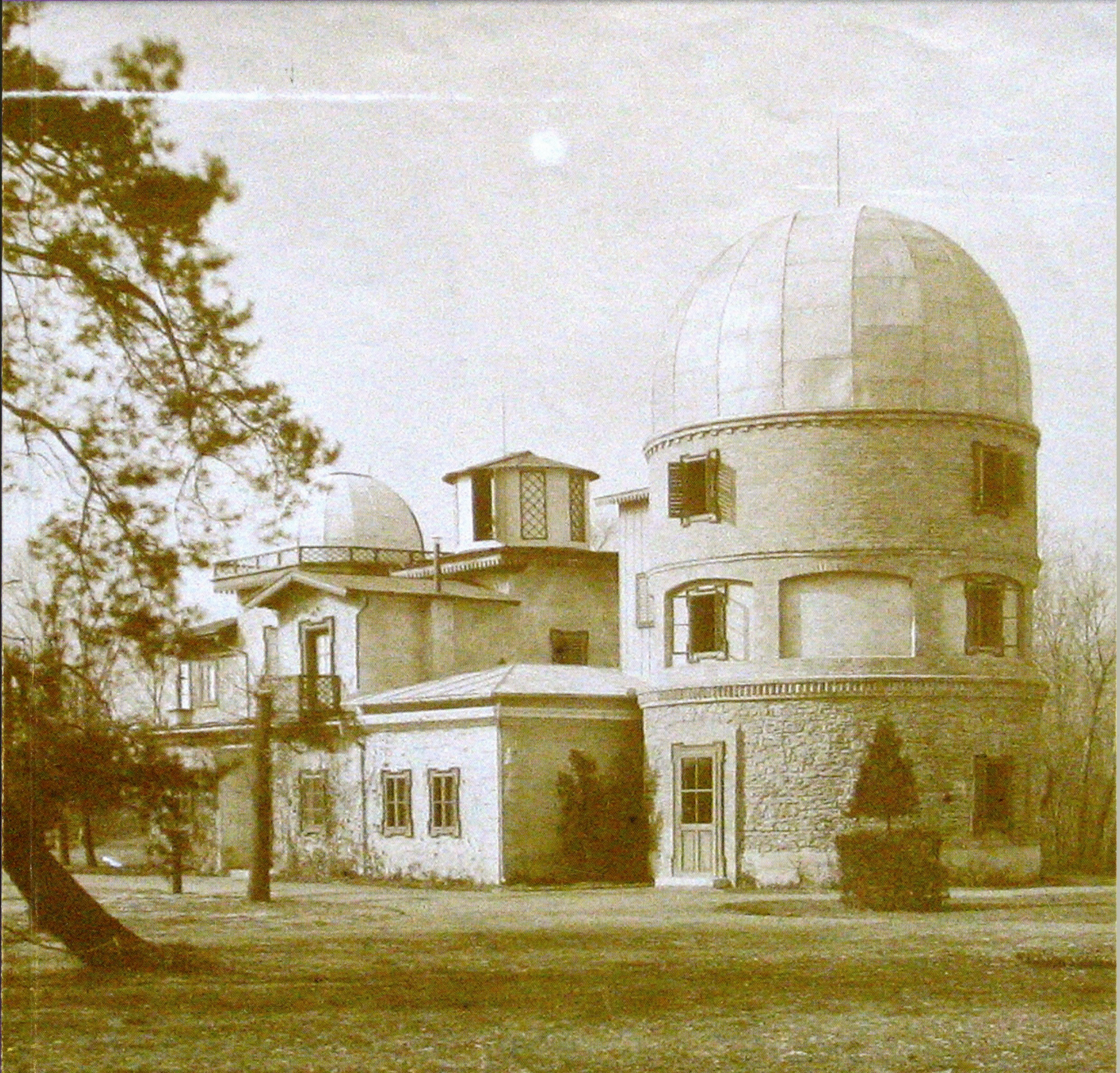

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COVER PHOTOGRAPH

This photograph shows Miklós Konkoly-Thege's attractive private observatory at Ógyalla in Hungary, which was established in 1874 and on 16 May 1899 was gifted to the Hungarian state. The two principal domes housed a 10.5-in Browning reflector and a 6-in Merz refractor equipped with a Zöllner spectroscope. This latter facility was used extensively by Radó Kövesligethy (1862–1934), who conducted pioneering stellar spectroscopy at the Ógyalla Observatory during the last two decades of the nineteenth century. Despite anticipating work subsequently carried out by Wien and Planck, Kövesligethy's achievements are little-known to contemporary astrophysicists and historians of astronomy. It is to be hoped that the paper by Lajos G. Balázs, Magda Vargha and Endre Zsoldos on pages 124-133 in this issue of *JAH*^{2} will go some way towards redressing this situation.

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THE ORIGIN AND MEANING OF -COLOURFUL DESCRIPTIONS IN CHINESE ASTRONOMICAL RECORDS

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Abstract: Oriental, especially Chinese, observations of transient celestial events are often compared with mundane objects: fruits, birds and containers are typical. The comparison is sometimes thought to indicate brightness of the heavenly object in question (for night-time apparitions). Here, the matter is examined in some detail. There is evidence that the earliest descriptions referred to form and/or colour (in particular, black for sunspots). Containers probably trace back to *beidou*, the northern (big) dipper, which was a potent symbol in Chinese astrological correspondences. It is noted that many of the comparison objects were round, and that Chinese thinking considered the Sun, Moon, planets and stars as round also. It is shown that the comparison objects used were not constant in time, but changed, with certain ones preferred for centuries. A notable period coincides with much of the Song and Yuan Dynasties (1075–1360), when sunspots were almost exclusively compared with the dark plum and jujube (Chinese date) fruits, while night-time comparisons were often with stars and planets. After 1375, night-time comparisons with bullets abruptly appear, and little else was used for two hundred years. I suggest that this was inspired by contemporary military events. Although the main purpose of the observations recorded in ancient annals was astrological, there is no concrete link between the comparison objects and prognostications. A passage dating back to the Latter Han Dynasty notes that stars have their "distant connections", and goes on to say, "In the wilderness stars denote articles and objects", while elsewhere they may relate to government or society. By coupling the transient (and hence shockingly inauspicious) events to mundane objects, the imperial astronomers may have sought to distance the state from their appearance. With the possible exception of comparisons with stars and planets, it seems highly unlikely that the objects were chosen to reflect the brightness of novae, comets, meteors, etc.

Keywords: Chinese descriptions, ancient records, comets, guest stars, sunspots, meteors

1 INTRODUCTION

Any reader of Chinese astronomical treatises is likely to be struck by the regular use of imaginative comparisons in describing celestial phenomena. As Needham (1959: 435) notes about sunspots, "… their size is often described 'as big as a coin', 'as big as a hen's egg', a peach, a plum, etc." Clark and Stephenson (1978: 389) call the descriptions "… particularly picturesque, often making an allusion to size or shape." Similar comparisons can be found in reports of comets (*hui xing*, 彗星), (super)novae (*ke xing*, 客星), meteors (*liu xing*, 流星), meteor showers (*liu xing yu*, 流星雨), solar eclipses (*ri shi*, 日食), aurorae (*ji guang*, 极光) and even meteorites (*yun shi*, 陨石). As indicated by Clark and Stephenson (1978: 389), in the case of sunspots (*tai yang hei zi*, 太阳黑子) the allusion is to shape or size. In the case of luminous objects, where the description 'as large as' also frequently occurs, it is usually assumed that the reference is to brightness. The adjective 'bright' (*ming*, 明) is, however, hardly ever used.

Li (1988) argues not only that the descriptions applied to comets and supernovae were intended to express brightness, but that they can be used to establish a 'magnitude' scale for such objects. He uses 'fuzzy logic' to derive the magnitudes corresponding to a variety of descriptions. In one specific instance, a strong case can be made. Seventeenth-century Korean astronomers (comparisons like those from China were also made in Korea and Japan) assiduously followed the variations in brightness of SN 1604 (often associated with Kepler), and the light curve one derives is in excellent agreement with European observations (Clark and Stephenson, 1977: 201). However, the Koreans only compared the supernova with planets and stars (as did the Europeans), and its appearance comes quite late in the history of Oriental (especially Chinese) astronomy. Can a brightness scale 'calibration' encompass peaches, plums, planets, ladles, crows, etc. (as Li suggests), or are we truly trying to compare apples with oranges?

Several years ago, Wang investigated the question in a doctoral dissertation, and some of his work has been published. The first of three articles (Wang, 2003a) argues that human perception of the celestial sphere is of a flattened dome with a mean radius of roughly 13 m. On this basis, the Chinese unit of length, *chi* (尺, about 30 cm), can be related to the Chinese degree of 365.25 to a circle. The linear-angular scale represented by the three traditional Chinese lengths (*zhang*, *chi*, *cun*) is said to belong to a system of measurement which also includes the 'as big as …' comparisons. The perceived flattening of the sky dome is a manifestation of the well-known Moon illusion (Rees, 1986). In his second article, Wang (2003b) argues that the comparisons in the case of sunspots referred to the area of the spot. The conclusions of his third article (Wang, 2003c) are based upon the fact that a bright object (even if point-like) will appear to be extended; the brighter the object, the more extended it seems to be. It is argued that what is perceived is the apparent area of a luminous body (even if point-like), and it is this which is related to the size of a comparison object. On the basis of meteor sightings recorded in Chinese annals, and their descriptions, Wang derives a brightness scale.[1]

In addition to the brightness issue, I have already alluded to the fact that some of the references might be to shape (Clark and Stephenson, 1978: 389). Other properties may be suggested as well, as will be discussed below. The Korean observations of 'Kepler's supernova' demonstrate the reliability and quality which ancient visual observations were capable of. It remains unclear, however, whether there was consistency in the comparisons over some two millennia, and throughout the Chinese sphere of influence. That there may not have been is suggested by a pair of observations which must refer to the same sunspot (Clark and Stephenson, 1978: 389): "Within the Sun there was produced a black spot as large as a date." (10 February 1185, China), and "On the Sun there was a black spot as large as a pear" (11 February 1185, Korea).

The primary source of the material used is a compendium of ancient Chinese astronomical events (Beijing Astronomical Observatory [BAO], 1988).[2] Much of the text relating to comets and novae (for the rest of this paper, the Chinese term 'guest star' will be used for both novae and supernovae) has been translated into English (Ho Peng Yoke, 1962), as have most of the sunspot records (Yau and Stephenson, 1988). Records after about 1600 have not been investigated in detail, as the Jesuit presence may have influenced the descriptions used. Although my main interest is in novae, comets and sunspots, I have found it necessary to investigate all phenomena reported (including meteors and aurorae). Some preliminary results have been presented elsewhere (Strom, 2001).

Figure 1: Rubbing of a Han Dynasty tombstone from Nanyang, Henan, China, showing a 'sun crow' (*yang wu*, 阳乌), a common design from that period.

2 CONSIDERATION OF THE AVAILABLE DATA

The descriptions to be considered typically follow the format:

> <celestial object> 'large as' (or 'like') <mundane object>

where 'large as' is almost always *da ru* (大如), and 'like' is *ru* (如). (I have never come across a comparison in which 'bright' is used instead of 'large'.) Some of the astronomical phenomena have names, used in the earliest records, which also suggest such a comparison. Comets, for example, can be broom stars (*hui-* [彗] or *sao-xing* [扫星]), candle stars (*zhu-xing* [烛星]), etc. One suspects that there may have been an earlier stage when the description, star like a broom (*xing ru hui* [星如彗]), might have been used, but I have never seen it in the early records. Comparisons with brooms do occur in the sixteenth century: in 1506 a star is first described as "like a bullet" (*ru dan wan* [如弹丸]), then "like a broom" (*ru zhou* [如帚]) (BAO, 1988: 433). However, these Ming expressions come rather late.

The discovery of the three Han tombs at *Mawangdui* (马王堆), with manuscripts in tomb no. 3 which included 29 drawings of comets and their astrological portents, has added considerably to our knowledge of early Chinese astronomy (Loewe, 1980). Many of the comets are linked to botanical objects (reed, straw, bamboo, etc.), and Loewe cites a description attributed to Han Yang (韩杨): "… the shapes of comets are like those of bamboo brooms, or the branches of trees." In fact most, if not all, of the *Mawangdui* descriptive names appear to relate to morphology.

Similarly, what is perhaps the earliest description, that of a planetary conjunction, was a morphological comparison. The five (naked-eye) planets, moving across the immutable backdrop of the constellations, were seen as minions of the heavenly emperor. Their gatherings (conjunctions) in twos and threes were akin to consultations among ministers. Less frequent were the convocations of four or, rarest of all, five in a general assembly of the heavenly powers. Such get-togethers once in a half-millennium or so were coupled to events of cosmological significance: the rise and fall of dynasties as Heaven's Mandate shifted. These grand conjunctions were described as like a "string of pearls," and have been linked (Pankenier, 1998a: 29, 31) to the rise of the Xia Dynasty (1953 BCE conjunction of the five planets), superseded by the Shang (1576 BCE), which in turn was followed by the Zhou (1059 BCE).

Let us briefly survey the descriptions used in more common astronomical events, following the order in the compendium (BAO, 1988) by starting with sunspots (156 sightings recorded up to 1600). The earliest comparison (BAO, 1988: 3) is to a copper coin (*qian* [钱]), although a coin is never mentioned again. Flying birds (magpie, swallow) then become the most popular, although fruits are also mentioned (BAO, 1988: 3). There is a long period when the *zao* [枣] or jujube (*Zizyphus*) and the plum (*Prunus salicina*), *li* [李], are mainly used, though after 1250, objects ranging from people to containers come in. The choice of birds in the early records is suggestive, given the Chinese mythology of there being a crow in the Sun (Zhou and early Han periods; in fact the 'sun-crow' – *yang wu* [阳乌] – carried the Sun across the sky; see Figure 1). It has been suggested (Needham, 1959: 436) that sunspots might therefore have been observed as early as the fourth century BCE. Perhaps it was in fact sunspots which inspired the sun-crow myth in the first place. The association of a dark silhouette against the solar disk with a flying bird is in any event quite natural; what else was likely to be seen high in the sky (in pre-aviation days)?

In a dozen instances, there is mention of a star in the Sun. Elsewhere I have argued (Strom, 2002) that these were probably observations of Sun-grazing comets near perihelion. None of the descriptions is similar to the comparisons discussed above (in fact, the sunspots and stars are not mentioned together). I assume they were a different phenomenon, and have excluded them from further consideration.

We continue our survey with the aurora borealis (northern lights, observed 169 times before 1600), which results as high energy electrons from the solar wind are guided by the Earth's magnetic field to near the pole. Among the descriptions used are fire, a rainbow, the shape of a cultivated bamboo grove (BAO, 1988: 32), banners and flags (BAO, 1988: 29) and walls. The colour red is particularly noted, and the light is described as like blood.

Another near-Earth phenomenon, meteorites, was also regularly observed and recorded (203 times up to 1600). Some of the reports describe both the passage through the atmosphere, and the fallen stone itself. Descriptions in the atmosphere include cloud like a curtain, smoke first like a red whirlwind (BAO, 1988: 67), spouting fire but scattered (BAO, 1988: 69) and simply fire. The sound was also described: thunder, thunder shock (BAO, 1988: 69), drum beat (BAO, 1988: 66) and *qing* (BAO, 1988: 66) [磬, percussion instrument made of stone or bronze]. As for the fallen stone itself, it was described as like an urn, large as an iron chopping block (BAO, 1988: 65) and a blue-green stone like a jade container (BAO, 1988: 69).

Eclipses, the next three categories, do not provide much material, as might be expected. The maximum phase of a partial solar eclipse which just fails to be total was described as unfinished like a hook (BAO, 1988: 132). An annular eclipse in 1292 was likened to a golden ring, with pearl or jade earrings on either side (BAO, 1988: 203). Lunar eclipses were occasionally accompanied by a reference to their colour: like blood (BAO, 1988: 263). And there were no special descriptions for lunar occultations of stars. For the eclipses, and other categories of this section, Table 1 provides a summary of salient facts. In the period before 1600, some 1200 solar and 700 lunar eclipses were registered.

The guest stars (novae; 68 records pre-1600) provide us once more with a wide range of comparison objects. Fruits are regularly used early on. Only after 1000 CE are there comparisons with planets and stars. Noteworthy are the frequent references to the pellet (bullet) from about 1400. (I should note, perhaps, that the BAO [1988] compendium separates comets from novae on the basis of motion, mention of a tail, other suggestion of extent, etc., and not just on the terminology *ke*- or *hui-xing*.) Comets, of which some 680 were observed up to 1600, earn descriptions not unlike guest stars, also being frequently compared with a bullet in the later references. One notable difference is that comets are often compared with containers—bowls, dippers, cups—especially before the Tang Dynasty. Only much later do the guest stars get the same treatment (SN 1572, for example, being described as large as a small cup, and also large as a bullet [BAO, 1988: 377]). Another striking comparison (though infrequent) is large as a fist (or hand) (BAO, 1988: 403)—as if the observer sighted along an outstretched arm.

Finally we have the meteors and their showers. For the latter, the most common reference is to rain, one of the most obvious and naturalistic descriptions. This is the earliest comparison known (Table 1), and may have been the inspiration which ultimately led to all the rest. Other objects include the usual fruits, containers and eggs. Some striking comparisons are: breaking up and falling like snow (BAO, 1988: 579); light shiny like lightning (BAO, 1988: 580); and flow like something woven (or knit) (BAO, 1988: 580). Meteors are most commonly compared with fire, although there is also the usual assortment of fruit, containers, cloth, etc. Sound, when mentioned, is likened to thunder. Meteors can be observed on any cloudless night; some 4300 were recorded before 1600. Only 142 of the much rarer meteor showers are mentioned, half before 1100 CE, and half between 1400 and 1600.

Most of the objects mentioned evoke vivid, concrete images in the mind of the reader, and one is struck by how apt, if not obvious, many of them are (rain, thunder, fire, curtain, rainbow, etc.). They are the sort of descriptions an astronomer today might use in a popular lecture. Of course the Han, Song and other astronomers were not writing for the man or woman in the street, but they would have needed to communicate their observations to the bureaucracy, the court, and ultimately to the emperor. One can imagine that the descriptions were perhaps, in the first instance, intended for such non-professionals. However, we should not forget that the observations had an astrological purpose, for which the descriptions may have played a role—a point to which we will return later.

Table 1: First records of comparison objects for different phenomena.

Phenomenon	First Comparison	Object	Other Descriptions Used
Sunspots	28 BCE	Copper coin	Bird, egg, plum, jujube
Aurorae	154 BCE	Mat	Fire, flame, rainbow
Meteorites	11th century BCE	Urn	Flames, thunder, stone
Solar eclipses	89 BCE	Hook	Golden ring
Lunar eclipses	307 CE	Blood	Red
Novae	48 BCE	Gourd	Fruit, bullet, planet
Comets	148 BCE	2-peck; peach	Bullet, container, fruit
Meteor showers	17-16th centuries BCE	Rain	Container, fruit, egg
Meteors	204 BCE	Fire	Cloth, container, gourd

3 STATISTICS AND SOME PATTERNS IN THE RECORDS

Comparisons of some kind or other are made in a large fraction of the recorded observations, but there are differences among the various categories. As noted above, there were no comparisons made for lunar occultations of stars, while for solar and lunar eclipses, comparisons occur in around 2% of the reports. Most of the other categories have rates ranging from about 30% (guest stars, aurorae) to 60% (meteors, meteorites). Comets are the exception, with comparisons in about 15% of the records (for the 23 recorded appearances of P/Halley there are only three instances). Perhaps the low fraction for comets arises since the generic name itself (‘broom star’) conjures up a vivid image. In the case of the *Mawangdui* manuscript (Loewe, 1980), each comet type is given a name, often botanical, but no comparison is made. For example, entry 613 begins: “see white drops” (*bai guan jian* [白灌见]); in only a couple of instances is the term *hui-xing* used.

For most of the phenomena, comparison is made with the word *ru* (like): e.g. ‘like a peach’. In the main, only for sunspots and guest stars was the wording *da ru* (large as) used (some 60% of all comparisons for these objects): e.g. ‘large as a plum’. But can ‘large’ be taken to mean bright for luminous objects?

3.1 Contradictory Evidence on the Meaning of ‘Large As’

To describe a bright star or planet as ‘large’ (rather than ‘bright’) is fairly common, and appears to occur in most languages. As noted in the Introduction, when Korean astronomers described SN 1604 as “large as Venus”, “smaller than Jupiter”, etc. (Clark and Stephenson, 1977: 196), there is little doubt that it was brightness which they were comparing (and we have the independent European observations to verify it). Similarly, for the SN of 1006 (which was known to be bright on several grounds), we have descriptions from outside China such as: “a large guest star … like Mars, and it was bright” (from Japan); “2½ to 3 times as large as Venus” (Arabic, from Egypt); “star of unusual size” (Latin, from St. Gallen); and “a large star similar to Venus in size and brightness” (Arabic, from Baghdad) (Stephenson and Green, 2002: 159-168). But with this last citation, we might wonder which “size” (apparently distinct from “brightness”) is referred to, Venus being unresolved with the naked eye.

Returning to the Chinese texts, it is perhaps worth noting that an early (ca. 80 CE) textual reference used to illustrate the meaning of the Chinese character for “large” (*da*, 大) states (Commercial Affairs Book Printing House, 1999: 56) that, “Large, and small [*xiao*, 小] are opposites ... ‘The Sun appears large rising and setting, at midday it is small.’[3]” This passage refers to the well-known Moon illusion (Rees, 1986), and interestingly here, large and small describe the (apparent) angular size and not the Sun’s brightness (which would appear less at sunrise and sunset than in the middle of the day). It is clear that “large” and “small” can refer to either extent or brightness in a celestial body.

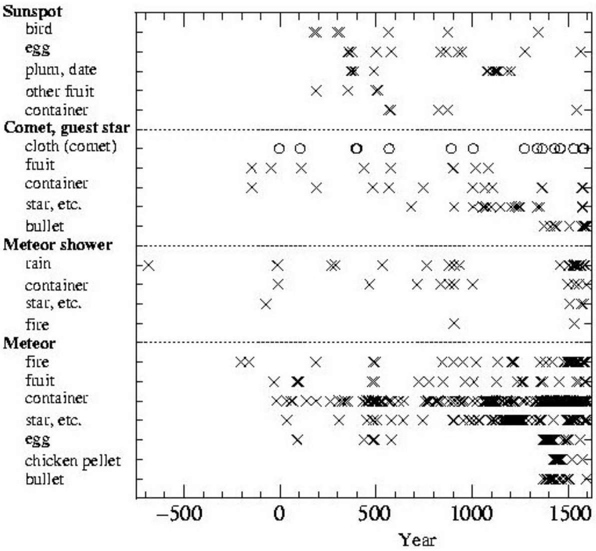

Figure 2: Usage of comparison objects for four transient celestial phenomena as a function of time (note that year 0 = 1 BCE, −500 = 501 BCE, etc.). Comets and guest stars (GS) are grouped together (for ‘cloth’ the symbol ○ is used, as guest stars are never so described).

In the case of objects whose extent can be readily discerned with the naked eye, the situation is somewhat different. The tails of comets are often described with an angular measure of their size. The term “large” is seldom used; rather, the tail may be described as “long” (*chang*, 长), and if discernibly wide, “broad” (*guang*, 广) as well. Yet at the same time, the comet may also be described as “large”. If this refers to the head, then the meaning might be ambiguous. Bright comets can extend for many—even several tens of—degrees; sunspots constitute extended objects at the other extreme, near (or beyond) where the naked eye can discern their extent. Nonetheless, descriptions like “large as a plum” (大如李) appear regularly in the written records. Clark and Stephenson (1978: 389) consider such descriptions to refer to shape or size. But if the reference is to the latter, then as Stephenson and Green (2002: 190) note, a literal comparison pushes imagination to the verge of credulity. For a large sunspot group (say 4′ arc) and typical comparison objects, the required viewing distance is around 100 m! To quote Stephenson and Green (ibid.), “… an explanation is lacking.”

Finally, to muddy the waters further (were it not already unclear enough), let us return to comets, and consider several passages from the Song Dynasty period. In addition to the usual, “large as …” there is a description of a comet in 1147, “small as Jupiter” (小如岁星 [BAO, 1988: 421]). (On the date in question Jupiter was a night-time object, with a magnitude of –2.3.) Then a few years later (1222) we read of another comet, “its body small like Jupiter” (其体小如木星 [BAO, 1988: 421]). Here, too, we may wonder: might size actually refer to extent rather than brightness? And in 1230 yet another comet is “large as Saturn but [its colour] not bright” (大如镇星而色不明 [BAO, 1988: 421]). (This is reminiscent of the Latin description in the *Tractatus de Cometis* of a comet seen in Ulm in early 1402: “Its size was rather greater than that of Venus ..., but not as bright.” (Kronk, 1999: 260-261).) Finally, what should we make of the following description of a meteor shower in March 461: “perhaps long, perhaps short, perhaps large, perhaps small” (或长, 或短, 或大, 或小 [BAO, 1988: 578])?

3.2 Pattern of Comparisons Over the Centuries

To get an overall picture of the objects which celestial apparitions were compared with, let us consider the situation for five of the topics in Table 1. (I exclude the eclipses because so few comparisons are made, and aurorae and meteorites because they are rather different phenomena to the main topic of interest, heavenly bodies.) For each phenomenon, a handful of broad comparison types (birds instead of magpies, swallows, etc.; containers instead of cups, bowls, etc.; and so forth) has been chosen to make the presentation clearer. Guest stars and comets have been combined, as there are few of the former, and this leads to no significant loss of information. Then for each phenomenon and comparison category, the usage as a function of time is shown in Figure 2.

There are several noteworthy patterns which emerge from this exercise. For sunspots, birds, fruits and eggs make most of the early running. Notable is the use of plums in the period 350-500, and plums and the *zao* (Chinese date) from 1075 to 1250. Containers, which occur frequently with other phenomena, are only mentioned occasionally. (No sunspots whatsoever are reported during the seventh and eighth centuries, a gap which also applies to guest stars. In fact, the Tang Dynasty saw something of a decline in reports of celestial phenomena generally, which may have resulted from the upheaval of the An Lushan revolt in 755.)

Among guest stars and comets, containers (especially the dipper) and fruits are the main comparison objects until about 1000. The use of other fruits stops just when the plum and *zao* become the object of choice for sunspots after 1075. It is most striking that from 1075 until 1360, planets and stars are extensively used. And then the pellet (bullet, *dan*, or *dan wan* – 弹, 弹丸) becomes the primary comparison object for some years after 1375 (actually first appearing in 1374 in a meteor description). Cloth (or cotton) is used for comet descriptions (referring to the tail) from the earliest times.

Meteor showers are described as like rain, and meteors are compared with fire, throughout. Meteor showers are also likened to containers during the recorded period (note that there are no showers reported in the seventh and eleventh to fifteenth centuries). Meteors are also compared with containers and (less frequently) fruit over the same interval. From the eleventh century onwards, the frequency of comparison with celestial objects increases dramatically (as do the meteor reports generally). Chicken and bird eggs are often mentioned in the fifth century, and then ignored for some eight hundred years. Then, from 1369, they reappear as chicken eggs (*ji zi* – 鸡子) and are used as frequently as containers for over fifty years. In 1374 the bullet (*dan* – 弹) enters and is used regularly, although less frequently. Then, quite suddenly in 1425, chicken egg is replaced by chicken pellet (*ji dan* – 鸡弹) and used with great frequency until 1463, when it just as abruptly disappears. Sound, when noted, is almost invariably compared with thunder (but this is not shown in Figure 2).

4 DISCUSSION

What is the origin of the usages and patterns we have just noted? Let us discuss some specific examples, which may provide clues.

4.1 The First Comparisons Come From Nature

The first recorded comparison objects (see Table 1) are rain for meteor showers, and fire for meteors, very vivid and apt choices as noted above. In the *Mawangdui* document, each of the comet drawings has a descriptive name, most of them being botanical (reed broom, straw broom, etc.), but also including "flute of Heaven," shield broom, pheasant (Loewe, 1980). Many of these may have been chosen because their shapes mimic the comets in question, but in the manuscript they appear as names, not comparison objects (the construction, star like a straw broom, is not used).

Although a copper coin is the earliest comparison recorded (BAO, 1988: 3) for sunspots, if we follow the suggestion of Needham (1959: 436), then this may have actually been preceded by a (black) bird, perhaps as early as the fourth century BCE. It could even be that the Chinese myth of a crow (*wu* [乌], which also means black) carrying the Sun (Figure 1) was inspired by a sunspot,[4] a clear example of Nature inspiring myth. The example of birds (Figure 3), and other complicated shapes which appeared later, suggests that form rather than size (however defined) was the original inspiration. The same statement would apply to meteors and their showers.

Most sunspots are, however, formless to the naked eye, and a more appropriate object would be small and simple in shape. Perhaps it was the early association with birds which led to their eggs being chosen (first in 354), specifically indicating whether it was a chicken egg (*ji luan* [鸡卵], BAO, 1988: 5), that of a duck (*ya luan* [鸭卵], BAO, 1988: 5), or goose (*e zi* [鹅子], BAO, 1988: 6). Eggs may have the right shape, but even the brown or spotted eggs of many birds are hardly black. Could this have been the inspiration for choosing the typically dark purple fruit of the plum (*li* [李]) to the exclusion of almost all other objects between 365 and 495?

If this speculation is correct, then the logic of the fourth and fifth century astronomers was certainly surpassed by their Song successors. Between 1075 and 1205, there are 21 comparisons with plums or *zao*s. The *zao* is a dark, nearly black, fruit. Unlike the plum, which is round, this Chinese date has an oval shape. It is tempting to speculate that the latter was used to describe sunspots which appeared to be elongated. (This may also explain the use of the pear by Korean astronomers to describe a sunspot in 1185 [see Section 1], for like the *zao* used in the Chinese description one day earlier, the pear is usually not round. The difference in colour would then reflect the fact that the Song astronomers had rigorously adopted dark fruits for comparison with sunspots.) There are references to only three other objects in this one hundred and thirty year period: a sunspot "like millet in size" (*ru su da* [如粟大]; one first compared to a plum, then likened to grain[5] (*ru li* [如粒]); and a spot of "form like a person" (*zhuang ru ren* [状如人]). The latter might refer to a large, anthropomorphic sunspot group.

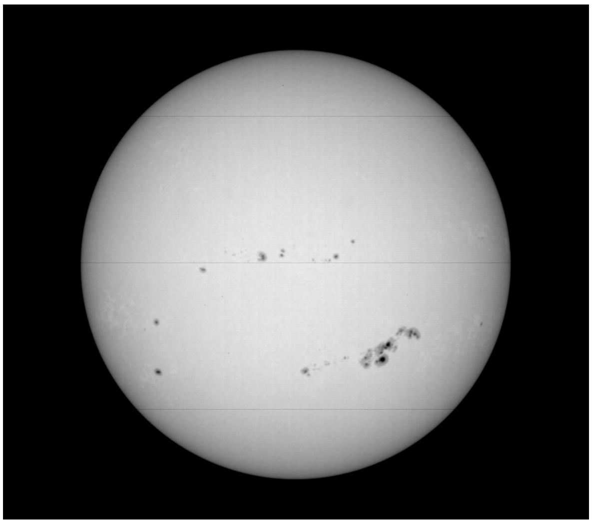

Figure 3: Image of the Sun, showing a large sunspot group (AR 9393) visible with the naked eye, seen with which it might appear to have the shape of a bird. The photograph was taken in white light on 30 March 2001, with one of the instruments of the Global Oscillation Network Group (photograph courtesy National Solar Observatory/AURA/NSF).

Just as the Song sky-gazers commence their systematic use of plums and dates to describe sunspots, they stop using fruits to compare with guest stars and comets (last report in 1021). Instead, there is almost exclusive reference to planets and stars between 1075 and 1360 (the Song practice being continued in the Yuan period as well). Planets (especially Venus) also became the preferred comparison objects for meteors throughout the Song. It seems unlikely that such systematic and well-coordinated changes arose by chance, but rather that they were intentional. The

Song Dynasty is often said to have been the most ‘scientific’ of China’s historical periods (Ronan, 1980: 50), and this systematic, consistent approach would seem to agree with that viewpoint (though as Cullen (1996: 92) notes, “… we need to tread very carefully to avoid interpreting the thought-patterns of ancient authors in terms of our modern preconceptions.”). It is possible that the comparisons with planets and stars do refer to brightness, but the matter would require further investigation.

4.2 The Importance of *Beidou (Ursa Major)*

In the period that comets and guest stars were compared with planets and stars, there is a single instance of another comparison object: a bright comet in 1106 was “like the mouth of a cup in size” (*ru bei kou da* [如杯口大]. This is but one of the numerous examples of containers as comparison object: cup, bowl, basin, jar, *fou* (缶, an ancient earthen utensil), dipper. Where did it begin?

Figure 4: Image of Comet Hyakutake (C/1996 B2) and *beidou* (‘Northern Dipper’) taken on 25 March 1996 (photograph copyright T.G. Matheson, reproduced with his permission).

The very first comparison, which involved a comet, was recorded in 148 BCE and described it as “large as a 20 litre vessel”[6] (*da ru er dou qi* [大如二斗器], BAO, 1988: 385). The word *dou* (斗) means both a unit of dry measure (now about 10 litres) and a utensil, the dipper. The seven brightest stars of the constellation *Ursa Major* (popularly called the ‘plough’ in Britain, and the ‘Big Dipper’ in the USA), are known in Chinese as the ‘northern dipper’, *beidou* (北斗), a key object in Chinese asteriography. In later comparisons, the *dou* as a utensil is used: “large as a dipper” (*da ru dou* [大如斗], BAO, 1988: 402). Although none of the references is to *beidou* as such (note that there is also a southern dipper, *nandou* [南斗]), it has been shown (Needham, 1962: 270) that the asterism was also just called *dou*. I speculate that an early comet, possibly passing near or through *beidou* (as did one in 613 BCE ([BAO, 1988: 383) and as recently as 1996, see Figure 4), but in any event with a shape which mimicked a dipper, was the original inspiration for the comparison.

The symbolic importance of *beidou* should not be ignored. It was seen as controlling the heavens:

> Sima Qian implies that supernatural influence emanates from the pole by calling the Big Dipper “Di’s chariot” and by portraying the Dipper’s movements as the efficient cause of transformations of yin and yang, the five elemental forces, the seasons, and all natural periodicities. (Pankenier, 1995: 140).

One early astrological system, the main principles of which are no longer known, is believed to have been based upon changes in the stars of *bei dou* (Pankenier, 1999: 265). As a pointer, the dipper served as a clock at night (Pankenier, 1998b: 192). Lodestone in the shape of a spoon, the “south seeking ladle” (*si nan zhi shao* [司南之杓]), was the first magnetic compass (Needham, 1962: 262; and see Figures 329-30). During the Xin Dynasty (9–23 CE) of Emperor Wang Mang, a ‘Ladle of Majesty’ (*wei dou* [威斗]) in the shape of *beidou* was constructed by imperial order. Spoon-shaped, and also called *dou* (钭), such ladles served a ritual purpose (Needham, 1962: 272-273).

There is an additional characteristic which the ladle and other containers shared: they were round. This is significant, because from earliest times Chinese mainstream philosophy regarded the Sun, Moon, planets and stars as round. Consider the words of Wang Chong (王充, ca. 80 CE, sceptical philosopher who believed otherwise):

> Again, the scholars assert that the bodies of the sun and the moon are quite spherical. When one looks up at them, their shape seems like that of a ladle or a round basket, perfectly circular. (Needham, 1962: 413).

Here, the shape of the ladle presumably refers to its container. Practically all of the vessels compared with comets and novae were distinctly round. Besides the ladle and several cups (cup or glass [*bei*, 杯]; wine glass [*jiubei*, 酒杯]; small cup [*zhan*, 盏]), there are the following:

> *wan* [碗]: “bowl; hemispherical vessel, wider than it is deep.” (Contemporary Chinese Dictionary [CCD], 2002: 1977);
> *hu* [斛]: “cubic measure used in former times, small at the mouth and large at the bottom.” (CCD, 2002: 819);
> *fou* [缶]: “(arch[aic].) earthen utensil with large body and small opening.” (CCD, 2002: 591);
> *weng* [瓮]: “urn; earthen jar with a bulging belly.” (CCD, 2002: 1441); and
> *pan* [盘]: “(arch[aic].) washbasin.” (CCD, 2002: 2012).

All of these have shapes which would have appeared roughly (hemi-)spherical. And when it comes to the (wine) glass, the phrase sometimes encountered was, ‘like the mouth of a cup’ (see above): in cross section, round.

4.3 Fruits to Bullets

Most of the fruits used in the comparisons are also spherical in shape: orange, peach and plum. The word usually translated as melon (*gua* [瓜]) is problematic, as *gua* can be a variety of fruits, including melon, pumpkin, etc. (“… any trailing or climbing plant of the gourd family.” (CCD, 2002: 701)). The oval-shaped *zao* was only used in comparison with sunspots. There is one striking, and significant, addition to make to this list.

A meteor recorded in 32 BCE was described as, “large as a *hu*” (*da ru hu* [大如瓠], BAO, 1988: 619; the entire description reads: *you liu xing da ru hu* [有流星大如瓠]). The *hu* is a “calabash gourd (*Lagenaria siceraria*); … plant with … columnar fruit which has a light-green peel” (CCD, 2002: 825). It is similar to a cucumber, but thinner and with a lighter colour (see Figure 5). What better way to describe a meteor trail?—long, thin, lightly coloured. This early record of a fruit comparison (while not the earliest) does suggest that fruits were mainly chosen for their shape. (The only other comparison with a *hu* that I have found refers to a meteorite which fell in 1393 (BAO, 1988: 71).) Note that there was also a Chinese asterism, the *hu gua* (瓠瓜 or 葫瓜) in Delphinus, which is rather *hu*-shaped (Ho Peng Yoke, 1962).

Fruits, as illustrated in Figure 2, were used regularly until about 1200 in comparisons with comets, novae and sunspots. Plums, as discussed above (Section 4.1), were used to describe sunspots during the chaotic period of the Eastern Jin and Liu-Song Dynasties. (Only once, during the Eastern Han Dynasty, was a comet or nova compared with a plum (BAO, 1988: 389).) The plum and *zao* were later similarly used by Song astronomers, while celestial objects replaced fruits for novae and comets, and this continued during the Yuan Dynasty. Then, quite abruptly at the beginning of the Ming Dynasty, bullets become the preferred comparison object. It seems highly likely that this was inspired by contemporary events, although the Ming aversion to anything associated with their former Mongolian (Yuan) rulers might have also played a role.

Firearms were invented in China between AD 850 and 880, some centuries after gunpowder (Ronan, 1980: 50), one of the earliest surviving examples dating from 1288 (Needham et al., 1986: 293). Thus, although reference could have been made to bullets from the thirteenth century onwards, it seems it was the extended period of carnage nearly one hundred years later, as rebellions overwhelmed Yuan rule, which triggered their use. The first mention in astronomical annals (in 1374) is when a meteor is compared with a bullet (BAO, 1988: 764). Two years later, the comparison is with a comet (BAO, 1988: 426), and thereafter comets and novae are compared with little else for two centuries.

The choice of a bullet (shot from a gun) for comparison with both meteors and comets seems typically appropriate. It provides a vivid image (especially if one imagines a gunshot in the dark) which at the time must have been experienced by much of the population: the nucleus (bullet) leaving behind a fiery trail. Moreover, a bullet is round (the modern conical shape was only introduced much later), just as the heavenly bodies were supposed to be. The comparison is as appropriate as the earlier naturalistic ones: rain for meteor showers, etc.

And while on the topic of firearms and gunpowder, there is a record of the sound of a meteorite being compared with an explosion rather than the usual thunder. In 1176, a meteorite's fall was "… compared with the letting off of a gunpowder projectile trebuchet, *ru fa huo pao*" (如发火炮). (Needham et al., 1986: 157). Such reports are again probably indicative of widespread use of explosives, in this case as the Mongols overwhelmed the Jurchen Jin, and finally overthrew the Southern Song to establish the Yuan Dynasty.

4.4 Were there Astrological Influences?

Chinese astrology was based upon a mapping of terrestrial realms and geography onto celestial asterisms ("field allocation," *fenye* [分野])—the Yellow River corresponded to the Milky Way, for example—combined with a principle of organic connectedness. As Needham and Wang (1956: 289) note, the "… idea of correspondence has great significance and replaces the idea of causality, for things are *connected* rather than caused." Events on the Earth might be reflected by changes in the heavens, something abnormal in the stars could be a precursor to trouble for the empire.

> The more unusual the changes and movements of the stars and planets, the more grave the implications, particularly since unanticipated events such as comets and eclipses were viewed with foreboding. (Pankenier, 2005: 24).

As a result, the ability to predict astronomical events was of paramount importance. Or, as Yabuuchi (1973: 93) notes, "The breadth of the Chinese ephemerides reflected the grave concern of Chinese rulers constantly to expand the demonstrable order of the sky, while reducing the irregular and ominous."

Figure 5: Photograph of the fruit of *lagenaria siceraria* (calabash gourd, the Chinese *hu zi*). The skin of this edible fruit has a light green colour (photograph from the late Professor H. St. John, reproduced with permission).

All of the phenomena considered here—sunspots, aurorae, comets, meteors, etc.—were unpredictable, in any event initially. Eclipses became predictable, to a degree at least, but the rest remained ominous. The prognostications for an unexpected event depended upon its location and nature. The new star of 1006 may be taken as an example (Stephenson and Green, 2002). Having specified its position, the *Song Huiyao Jigao* (ch. 52) goes on to say "… it belongs to the (terrestrial) division of Zheng and the (Jupiter) station of *Shouxing*." It then suggests that it was an auspicious star called *Zhoubo*, which "… presages great prosperity to the state over which it appears." The astrological implications thus depended upon location and nature of the event, and were not linked to its description (which in other records were given as, "form was like the half Moon" and "bright rays were like a golden disc" (ibid.)).

Correspondence was crucial to the interpretation of celestial events, or in the words of Berger (1990: 34): “Everything ‘here below’ has its analogue ‘up above’.” Although no specific astrological meaning can be assigned to the mundane descriptions discussed in this paper, a general significance can be construed from a statement found in the writings of the Latter Han polymath Zhang Heng. In his *Ling xian* (灵宪), Zhang notes: “… every [star] has its own distant connections. In the wilderness stars denote articles and objects; at court they denote officials; among people they denote human actions.” (quoted in Pankenier, 2000: 200). If there was an astrological significance, then by using mundane objects to describe comets, meteors, sunspots, etc., a court official would be downgrading its significance from politically weighty to something of no great concern: in the wilderness, far removed from the throne.

4.5 Similar Expressions in Other Chinese Texts: A Literary Connection?

Are there other examples of similar usage in Chinese writing? In the course of sampling Chinese literature, I have come across several instances. A number can be found in a Chinese classic, *Creation of the Gods* (*Feng shen yan yi* – 封神演义 – 2000), which although compiled in its final form during the Ming period, includes many tales from much earlier in Chinese literary history. Here are some typical examples:

face like the full Moon: 面如满月 (*Feng shen yan yi*, 2000: i, 308);
face like a purple jujube, eyes like bells: 面如紫枣眼如铃 (*Feng shen yan yi*, 2000: ii, 495);
mouth like a basin: 口如血盆 (*Feng shen yan yi*, 2000: ii, 467);
head the size of a city gate: 头有城门大 (*Feng shen yan yi*, 2000: ii, 815); and
a beam of brilliant light large as a cup’s mouth: 一道星光有盏口大小 (*Feng shen yan yi*, 2000: i, 263).

Although most of the descriptions are of people, the last example is strikingly similar to some of the astronomical ones. Note also the comparisons with containers, fruit and a celestial object.

Another example is from a story dating to the Tang Dynasty period, *Governor of the Southern Tributary State* by Li Gongzuo (ca. 770-850) (1999: 129-31). In the passage in question, a tortoise shell is described as, large as a dipper (大如斗). In this case the object described could well have the physical dimension of that to which it is compared. Once again the use of the dipper for comparison is most striking.

Finally, here is an example from poetry by Du Fu, perhaps China’s greatest poet. In a long poem entitled *Northern Expedition* (北征) we find the following description of wild berries (Du Fu, 2001): 或红如丹砂, / 或黑如点漆 (some red as cinnabar, / some black as lacquer). Again we have colourful descriptions by comparison, not unlike examples from *Creation of the Gods*.

It would appear that there has long been a literary tradition of using picturesque expressions to describe objects. This should not be too surprising, for the Chinese language itself is rich in vivid imagery.[7] The very characters, deriving as they do from hieroglyphs, often suggest concrete linkages.[8] Many of the literary expressions use exaggeration for emphasis, and should probably not be taken too literally. By the same token, caution is advisable when interpreting the astronomical comparisons. An interesting but unanswered question is whether the astronomical descriptions preceded and possibly inspired the literature, or vice versa.

4.6 An Alternative Interpretation

My feeling is that the comparisons used in the astronomical descriptions probably did not serve a single purpose, nor were they constant in time. There are periods when they may have been intended to represent object brightness, but I doubt that this was generally the case as was argued by Li (1988). In his more thorough investigation, Wang (2003a; 2003b 2003c) arrives at a conclusion similar to Li’s, and would no doubt dispute my interpretation. In particular, he says that “… records of ‘big as a peach’ … are not the metaphors that observers used freely …” but that they belonged to a traditional method of scientific thinking. When used to describe astronomical phenomena, the “… purpose was to show their apparent diameter, apparent scale or brightness.” (Wang, 2003a: 42). I do not disagree with this statement, but would dispute the notion suggested by Wang that the comparisons with luminous objects were intended to express brightness. If there is one strand fairly continuous down the centuries, then in my opinion it is that the comparison objects represented form, and in some cases colour.

Wang rightly considers how our perception of the celestial vault affects our interpretation of what we see in the sky (and a similar discussion is found in Rees, 1986, with references to earlier work). He argues that the conversion from linear to angular scale is based upon imagining that the comparison object is at a distance of ≈ 13 ± 2 m (his estimated radius for the celestial vault). However, as Stephenson and Green (2002: 190) have pointed out, in the case of sunspots the required distance is around 100 m. Wang (2003a: 42) describes the system used from the Warring States period to the Qing Dynasty as “… widely applicable …” geographically, and “… throughout history.” However, he ignores (or does not appreciate) the changes in comparison object over the course of time (see Sections 4.1 and 4.3, and Figure 2), which suggests that the scale (if there was one) was not static. In his third paper, Wang (2003c) uses objects and qualitative descriptions of the light from meteors (such as “bright,” “illuminating the Earth,” “illuminating the sky,” “faces were illuminated,” etc.) to calibrate a brightness scale. The use of meteor observations makes sense statistically, but some of the comparison objects cover a wide range of brightness: peaches stretch from the faintest “some bright” to “the Earth was illuminated,” while the *dou* (dipper) covers ten categories from “bright” to “the sky and Earth were illuminated.” The final conversion from comparison object to apparent magnitude via angular diameter strikes me as problematic.

5 CONCLUSIONS

The imaginative expressions used to describe celestial objects in Chinese astronomical annals date back to some of the earliest recorded observations. Moreover, the very names of the objects themselves are vivid, concrete expressions of form: *broom stars* for comets, *streaming stars* for meteors and *streaming star rain* for their showers. (Of course the names used in English have similar Greek roots: comet [κομήτης] = long-haired; meteor [μετέωρον] = thing in the air.) As argued above, the descriptions could have been invented to inform the non-expert, although they may have also been used for dramatic effect as in the literary comparisons.

While the Chinese descriptions are especially picturesque, early astronomical texts in European and other languages were not devoid of a degree of hyperbole. Comets, in addition to being 'hairy', were also described as *javelin-* (Kronk, 1999: 36), *horned-* (Kronk, 1999: 154), *sword-shaped-* (Kronk, 1999: 71), and *bearded*-stars (Kronk, 1999: 237). Many of the comparisons ('star like a …') are unsurprising: "like a little torch" (Kronk, 1999: 85), "column of fire" (Kronk, 1999: 172) and "like a lantern" (Kronk, 1999: 179). Arabic texts often referred to a "star with locks of hair" (Kronk, 1999: 161). And analogous to the Chinese 'broom' [*hui*], there was a comet called the "besom of destruction" (Kronk, 1999: 84), while elsewhere a description often encountered in the Chinese records was used: "like a veil of linen" (Kronk, 1999: 190) (though in China, silk would replace linen). Finally, some of the more unusual descriptions included: "swarm of bees" (Kronk, 1999: 69), "shape of a trumpet" (Kronk, 1999: 84), "swordfish" (Kronk, 1999: 88), "vision serpent" (Kronk, 1999: 108), "erect as a sacred cupressus" (Kronk, 1999: 160), and "width like the neck of a horse" (Kronk, 1999: 196) (with this last example, as in so many of the Chinese ones, it is difficult to know exactly how a linear measure should be related to an angular one).

So in both Oriental and Occidental descriptions, shape seems to have been the original essence of the objects chosen. This may have been followed by colour: the black crow for sunspots, succeeded by dark fruits (plum, *zao*); the light (and linear) *hu* for a meteor, and other light-coloured fruits (peach, orange) for comets and 'guest stars'; and finally the glow from the muzzle of a firearm. But there are other factors which may have influenced the choice of objects, of which reference has already been made to a philosophical one: heavenly bodies were believed to be round (Needham, 1959: 413). Similarly, possible connections with Chinese literature are suggested by several examples quoted above.

Although there is no direct evidence that the comparison objects chosen had astrological significance, the use of mundane descriptions would help to demystify the otherwise shocking appearance of unexpected events, and diminish their significance. By demoting stellar apparitions to the wilderness of mere worldly objects, court officials implied that the celestial event in question was actually far removed from imperial concern.

From the chronology of the comparison objects (see Figure 2), something of a pattern can be distilled. There is an initial period, which I will call *early naturalistic*, where vivid, concrete examples, mainly from Nature, are chosen (meteor shower = rain; comet = dipper; sunspot = bird; etc.). This leads to a time of *imaginative extension*, where the dipper inspires cups, bowls and containers in general (and they are extended to phenomena other than comets), birds suggest eggs (for meteors as well as sunspots), and the *hu* is succeeded by other fruits. There follows an epoch of *mature systematization*, where small, dark fruits are almost exclusively used for sunspots, while comets and guest stars are mainly compared with planets and other celestial objects, as are meteors. And finally, there is *late whimsical* imagery, epitomized by comparing meteors and comets with bullets. Some of the relationships are sketched in Figure 6.

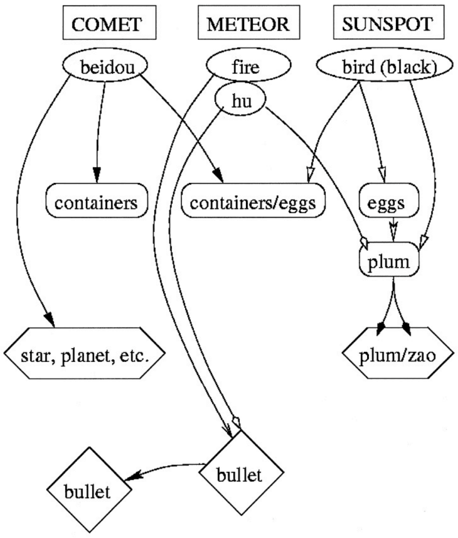

Figure 6: Sketch showing how some of the descriptions used in Chinese annals might have developed.

This investigation began with the notion that the comparisons in Oriental records might be linked to the magnitude of the (night-time) phenomena observed, as was certainly the case in the Korean observations of SN1604. Only the period of *mature systematization*, corresponding to the Song-Yuan Dynastic era, would seem to support such an interpretation. However, whether the comparisons with planets, etc., were that systematic would require further, detailed investigation. It is possible that these systematic Chinese observations were the inspiration for the later Korean ones. The fact that magnitude did not figure in most of the early comparisons should not surprise us. Few Oriental star atlases distinguished between bright and faint objects (Clark and Stephenson, 1977: 89), even in the Song period, and many determinative stars and asterism members were chosen for their location rather than prominence.

6 NOTES

1. This exposition of Wang's ideas is too brief to fully do justice to his research. The reader should consult the original articles for more information.
2. This compendium reproduces astronomical records from twenty-four imperial histories, the Qing draft history, the Ming and Qing actual collections, ten general, national local chronicles and other ancient books of records of astronomical phenomena, up to 1911.
3. The original quoted here comes from Wang Chong (王充), "*论衡• 说日*".
4. Clark and Stephenson (1978: 388) say that Needham (1959) makes a similar suggestion, but a fairly thorough search through his book has failed to locate the relevant passage.
5. Comparison with grain, and in particular millet, may be significant. Millet grains were used in China to

measure small openings (Needham, 1965: 145) and to gauge volume (Needham, 1965: 75). Perhaps here they indicate small sun spots.

6. An alternative translation would have "volume" instead of "vessel".
7. An example is the word for waterfall, *pubu* (瀑布), the second character of which means cloth: "river that falls ... looking like a piece of white cloth from afar." (CCD, 2002: 1503).
8. The character for man or male consists of two components: *li* meaning strength, depicted by a plough (力), and *tian*, for cultivated fields (田). Together they form *nan* (男): man, strong enough to plough farmland.

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8 REFERENCES

Beijing Astronomical Observatory (General Editor [北京天文台，主编]), 1988. 中国古代天象记录总. Nanjing [in Chinese].

Berger, P., 1990. *The Sacred Canopy: Elements of a Sociological Theory of Religion*. New York, Anchor Doubleday.

Clark, D.H., and Stephenson, F.R., 1977. *The Historical Supernovae*. Oxford, Pergamon Press.

Clark, D.H., and Stephenson, F.R., 1978. An interpretation of the pre-telescopic sunspot records from the Orient. *Quarterly Journal of the Royal Astronomical Society*, 19, 387-410.

Commercial Affairs Book Printing House (Editorial Board [编写组，商务印书馆]), 1999. 古汉语汉语常用子子典 [*Dictionary of Commonly-used Ancient Chinese Characters*]. Beijing [in Chinese].

(The) *Contemporary Chinese Dictionary*, 2002. Beijing, Commercial Press Publications.

Cullen, C., 1996. *Astronomy and Mathematics in Ancient China: The* Zhou bi suan jing. Cambridge, Cambridge University Press.

Du Fu, 2001. 杜甫诗选 [*Du Fu Selected Poems*]. Beijing.

Feng shen yan yi [封神演义], 2000. Vol. i, ii. Shanghai [in Chinese]; there is an English version, *Creation of the Gods*, Gu Zhizhong (tr.), 1992. Beijing.

Ho Peng Yoke, 1962. Ancient and mediaeval observations of comets and novae in Chinese sources. *Vistas in Astronomy*, 5, 127-226.

Kronk, G.W., 1999. *Cometography*. Cambridge, Cambridge University Press.

Li Gongzuo [李公佐], 1999. Governor of the southern tributary state [南柯太守传]. In 傯什，唐代传奇选 [*Selected Romances from the Tang Dynasty*]. Beijing.

Li Qi-Bin, 1988. A recent study on the historical novae and supernovae. In Börner, G. (ed.). *High Energy Astrophysics. Supernovae, Remnants, Active Galaxies, Cosmology*. Berlin, Springer. Pp. 2-25.

Loewe, M., 1980. The Han view of comets. *Bulletin of the Museum of Far Eastern Antiquities*, 52, 1-31.

Needham, J., 1959. *Science and Civilisation in China. Volume III.* London, Cambridge University Press.

Needham, J., 1962. *Science and Civilisation in China. Volume IV(1).* London, Cambridge University Press.

Needham, J., 1965. *Science and Civilisation in China. Volume IV(2).* London, Cambridge University Press.

Needham, J., Ho Ping-Yü, Lu Gwei Djen, and Wang Ling, 1986. *Science and Civilisation in China. Volume V(7).* London, Cambridge University Press.

Needham, J., and Wang Ling, 1956. *Science and Civilisation in China. Volume II.* London, Cambridge University Press.

Pankenier, D.W., 1995. The cosmo-political background of heaven's mandate. *Early China*, 20, 121-176.

Pankenier, D.W., 1998a. The mandate of heaven. *Archaeology*, 51.2, 26-34.

Pankenier, D.W., 1998b. Heaven-sent: understanding cosmic disaster in Chinese myth and history. In Peiser, B., et al. (eds.). *Natural Catastrophes during Bronze Age Civilisations: Archaeological, Geological, Astronomical and Cultural Perspectives.* Oxford, Archaeopress. Pp. 187-197.

Pankenier, D.W., 1999. Applied field-allocation astrology in Zhou China: Duke Wen of Jin and the battle of Chengpu (632 B.C.). *Journal of the American Oriental Society* 119, 261-279.

Pankenier, D.W., 2000. Seeing stars in the Han Dynasty: a review article. *Early China*, 25, 185-203.

Pankenier, D.W., 2005. Astronomy in early Chinese sources. In Mair, V.H., Goldin, P.R., and Steinhardt, N.S. (eds.). *Hawaii Reader in Traditional Chinese Culture*. Honolulu, University of Hawaii Press. Pp. 18-27.

Rees, W.G., 1986. The Moon illusion, *Quarterly Journal of the Royal Astronomical Society*, 27, 205-11.

Ronan, C.A., 1980. *The Shorter Science and Civilisation in China. Volume 1*. Cambridge, Cambridge University Press.

Stephenson, F.R., and Green, D.A., 2002. *Historical Supernovae and their Remnants*. Oxford, Clarendon Press.

Strom, R.G., 2001. Was there a brightness or 'magnitude' scale in historical Chinese records? Paper presented at the Fourth ICOA (Nanyang, China).

Strom, R., 2002. Daytime observations of sungrazing comets in Chinese annals. *Astronomy & Astrophysics*, 387, L17-L20.

Wang Yu-min, 2003a. Research on the chi system of records of historical astronomical phenomena. *Studies in the History of Natural Science*, 22, 42-53 [in Chinese, with English title and abstract].

Wang Yu-min, 2003b. Quantification and reduction about records of sunspots in annals. *Studies in the History of Natural Science*. 22, 329-335 [in Chinese, with English title and abstract].

Wang Yu-min, 2003c. Quantization on brightness about meteors in Chinese ancient recordings. *Acta Astronomica Sinica*. 44, 416-430 [in Chinese, with English title and abstract].

Yabuuchi Kiyoshi, 1973. Chinese astronomy: development and limiting factors. In Nakayama, S., and Sivin, N. (eds.) *Chinese Science: Explorations of an Ancient Tradition.* Cambridge, MIT Press. Pp. 93-94.

Yau, K.K.C., and Stephenson, F.R., 1988. A revised catalogue of far eastern observations of sunspots (165 B.C. to A.D. 1918). *Quarterly Journal of the Royal Astronomical Society*, 29, 175-197.

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CASSINI, RØMER AND THE VELOCITY OF LIGHT

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Abstract: The discovery of the finite nature of the velocity of light is usually attributed to Rømer. However, a text at the Paris Observatory confirms the minority opinion according to which Cassini was first to propose the 'successive motion' of light, while giving a rather correct order of magnitude for the duration of its propagation from the Sun to the Earth. We examine this question, and discuss why, in spite of the criticisms of Halley, Cassini abandoned this hypothesis while leaving Rømer free to publish it.

Keywords: velocity of light, satellites of Jupiter, longitude, Jean-Dominique Cassini, Jean Picard, Ole Rømer, Edmond Halley, James Bradley, Christiaan Huygens.

> *"The Danish astronomer Olaus Römer (1644-1710) discovered the velocity of propagation of light at the Paris Observatory in 1676."* Inscription on the north frontage of the Paris Observatory.

1 INTRODUCTION

The discovery of the finite nature of the velocity of light has been abundantly commented on by many authors. The general opinion is that it is due to Ole (or Olaus) Rømer (Figure 1),[1] who published it on 7 December 1676 in the *Journal des Sçavans*. The paper by Rømer (1676), well-written and very clear, shows that the discovery was made while studying the motion of the first Galilean satellite of Jupiter, Io (Figure 2). There is, however, some doubt about this discovery, which we will now try to dissipate. Before this, let us examine why the satellites of Jupiter were so actively observed during the seventeenth century.

Figure 1: Ole Rømer, engraving by J.G. Wolffgang (1735). Rømer appears here in full glory. After his return to Denmark, around 1681, he became Mayor and head of the police of Copenhagen, and also head of the State Council of the Realm (Library of the Paris Observatory).

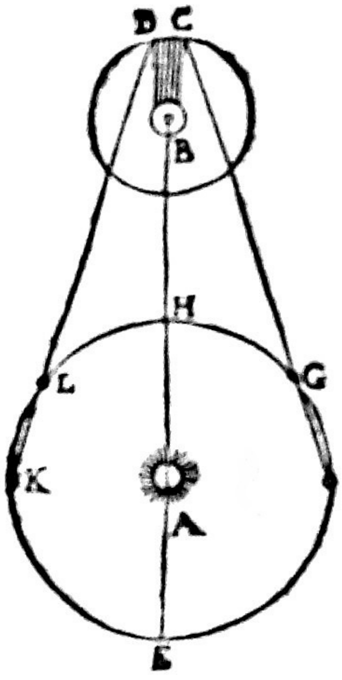


Figure 2: Rømer's drawing in his article of the *Journal des Sçavans*. The Sun is in A, Jupiter in B with its shadow cone, and the drawing is in the reference system Sun-Jupiter. Two positions of the Earth, L and K, are represented at the times of two emersions of the first satellite out of Jupiter's shadow; in D, the Earth moved away from Jupiter between these two observations, and the second one seems late because of the extra time required for the light to propagate. Conversely, immersions of the satellite in the shadow, in C, seem increasingly early when the Earth moves from a non-labelled point to G (Library of the Paris Observatory).

Immediately after he discovered the four main satellites of Jupiter, Galileo proposed that their motion could be used as a natural clock. In 1692 Jean-Dominique Cassini (Figure 3) wrote:

> It is not by curiosity alone that the most famous astronomers of the present century have observed with so much care the planet Jupiter; they mainly did it in order to obtain an exact knowledge of longitudes, on

> which the perfection of geography and navigation depends. They estimated that one would have a fast and secure way to determine longitudes, if one could find in the sky some rapid phenomenon which could be observed at the same time from very distant points on the Earth. This being assumed, comparing with each other the times of observations done simultaneously in different locations distant from each other from the East to the West, it would be easy to know by how much one of these places is more to the East than the other; which indicates their difference in longitude. (Cassini, 1692: 1-2; our translation)

Figure 3: Jean-Dominique Cassini, by Lépold Durangel (1879), from an old engraving. The Paris Observatory is on the background, with one of the long refracting telescopes used by Cassini, placed here by mistake on the roof of the building (Library of the Paris Observatory).

The eclipses of the Jovian satellites thus allowed clocks in different locations to be synchronized. Measuring with clocks synchronized in this way the times of meridian transit of the Sun or of the same star at each location, one obtains by subtraction the difference of longitude of these places after small well-known corrections are made. Prior to this, lunar eclipses were used, but as Cassini (ibid.) noted, "… these eclipses are not frequent enough, and they are so difficult to observe that one has not found in this way the longitudes of many places." Improvements in instruments allowed easy observations of Jupiter's satellites, at the very time when Cassini (Figure 3) took over the leadership of the Paris Observatory (which was founded in 1667 by the French Academy of Sciences). Cassini (1692: 2-3; our translation) continues:

> This only became possible in 1668, when Mr. Cassini published ephemerides from these satellites, and the method to calculate their eclipses. Since that time, one has performed at the Observatory a large number of observations, together with astronomers of the Academy sent especially by order of the King in all parts of the world, and with other astronomers with whom mail was exchanged; and by the means of these observations one found in the longitudes indicated on all maps a large quantity of errors which have been corrected for.

This was obviously of prime importance, so that Bernard le Bouyer de Fontenelle (1657–1757) was able to write:

> Were there no other use of astronomy than that drawn from Jupiter's satellites, it would justify well enough these huge calculations, these diligent and scrupulous observations, this large ensemble of instruments built with so much care; [and] this superb building [the Paris Observatory] raised for our science. (Fontenelle, 1740: 3; our translation).

In another text, Cassini (1693a) gives an historical account of the attempts to use Jupiter's satellites for longitude determination. One can find there the names of Galileo, Peiresc and Kepler, as well as lesser-known astronomers. Cassini claimed that it was possible to reach an accuracy of 15 seconds in the determination of the time of immersion or emersion of a satellite. A study by Suzanne Débarbat (1978) shows that this figure is somewhat optimistic: differences between the observers could reach half a minute, even for the eclipses of Io. But the accuracy of the observations of Jupiter's satellites was sufficient to show the irregularities in their motions, some of which were well understood and taken into account in the ephemerides, while others were not. It is in this context of systematic research that the discovery of the finite nature of the velocity of light occurred.[2]

2 THE DISCOVERY

Amidst the numerous texts which describe and comment on the discovery of the finite velocity of light, the poorly-known one by Urbain J.-J. Le Verrier (1811–1877), written in 1862 on the occasion of the first accurate measurement of this velocity by Léon Foucault (1819–1868), appears to us of particular interest. Le Verrier (1862) reminds us that the astronomer Jean Picard (1620–1682) was sent to Denmark in 1671 to measure the longitude difference between the old observatory of Tycho Brahe and the Paris Observatory, and that he was helped by a young man named Rømer, who "… showed such great abilities for astronomical works that Picard took him back to France where he became one of the most active members of the Observatory."

A letter from Cassini to Picard dated 3 October 1671 provides further information:

> M. Carcani will see that M. Colbert [the Prime Minister of France] knows how strongly you insist on the reward due to M^{r}. Bartholin for his work on the observations of Tycho, and will take care that the money is sent to him, as well as the fee due to the young man you recommand and who worked with you at Uranibourg, so that he can come to Paris. He will certainly do this rapidly so that no time is lost. (Cassini, 1671; our translation).

Erasmus Bartholin (1625–1698) was a famous physicist and astronomer from Copenhagen, and the young man was obviously Rømer. Colbert granted them 2,000 livres, as reported in another letter from Cassini to Picard dated 10 October. But let us continue with Le Verrier's text:

> This is Rœmer's discovery. Its extreme simplicity does not decrease its value. The contemporaries have first dismissed it; later, they attempted to divert a part of the merit to Cassini. It seems that in this respect the scientific habits are the same today as they were in that time ... When one considers the origins of a discovery, it is rare not to find some obscurity ... Should we ask ourselves if Rœmer is the sole author of the discovery of the velocity of light, in agreement with the only tradition of our time? (Le Verrier, 1862; our translation).

3 THE ROLE AND THE RESERVATIONS OF CASSINI

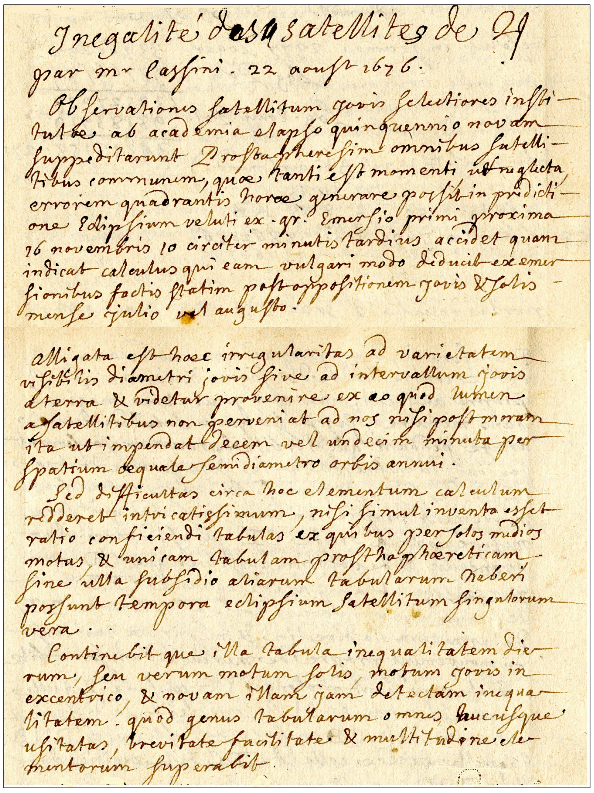
As remarked by Le Verrier (ibid.), the history of the discovery of the finite velocity of light is not entirely clear. Let us examine the chronology, which is of importance as in the case of many discoveries.

The minutes of the *Académie Royale des Sciences* are incomplete for the year of the discovery, between 18 July and 14 November 1676. The missing content can however be reconstructed, thanks to indirect sources that cite or copy it. Jean-Baptiste Du Hamel (1624–1706), Secretary of the Academy from its creation to 1697, reproduces in 1698 in his *Histoire de l'Académie* in Latin a text that he considers important and little known (Du Hamel, 1698: 143-146). Here is an English translation of what he wrote, based on a somewhat later manuscript that was translated into French:

> The different configurations of Jupiter's satellites being of great importance for Astronomy and Geography, Mr Cassini found it adequate to warn astronomers on 22 August by means of a public announcement about the way they will appear during the next year, in order to determine accurately their motions.
>
> But because one cannot find copies of this report anymore and since it is very short, we thought it opportune to reproduce it here. Selected observations of Jupiter's satellites made by the Academy during the past five years have displayed a new inequality common to all of these satellites, and which is of such importance that it could cause the prediction of their eclipses to be in error by up to a quarter of an hour. For example, the emersion of the first satellite on 16 November occurs about 10 minutes later than according to the calculation based on emersions observed immediately after the opposition of Jupiter. (Du Hamel, s.d.).

If one had doubts about the correctness of the transcription he gives next, another document which proves that Du Hamel is entirely reliable. Joseph Nicolas Delisle (1688–1768) and his collaborators collated before 1738 the minutes of the Academy (including the now missing ones) when preparing an ambitious, but never written, book on the history of astronomy. Their collation, which is literal, can be found in a manuscript register (Figure 4) conserved in the Library of the Paris Observatory (Anonymous 1, s.d.). Here is our translation of their text:

> Inequality of Jupiter's satellites, by M. Cassini. 22 August 1676
>
> The selected observations of the satellites of Jupiter decided by the Academy five years ago yielded a new prostapheresis [irregularity of motion],[3] the same for all the satellites, which is so important that it could give an error up to a quarter of an hour in the prediction of the eclipses; thus, for example, the next emersion of the first satellite on 16 November will occur about 10 minutes later than predicted by the calculation, which usually derives from the emersions which occurred immediately after the opposition of Jupiter and the Sun in the months of July or August.
>
> *This irregularity is related to a variation in the visible diameter of Jupiter, or to the distance of Jupiter from the Earth, and it seems to come from the fact that light arrives from the satellites with a delay such that it takes ten or eleven minutes [to cross] a distance equal to the half-diameter of the annual orbit.* [our italics].
>
> But the difficulty with this element would make the calculation very intricate if one could not find at the same time a method to build tables in which the true times of the eclipses of any satellite are obtained only from its mean motion and from a single prostapheric table, without help from other tables.
>
> This table will contain the inequality of the days or the true motion of the Sun [i.e. the inequality due to the eccentricity of the Earth's orbit], the eccentric motion of Jupiter [i.e. the inequality due to the eccentricity of the orbit of Jupiter] and this new, not previously detected, inequality. This sort of table will surpass all those in use until now thanks to its shortness, to the ease of its use and to the extent of the data.



Inegalité des satellites de ♃
par mr Caſſini. 22 aouſt 1676.
Obſervationes ſatellitum jovis ſelectiores inſti-
tutæ ab academia elapſo quinquennio novam
ſuppeditarunt Proſtaphæreſim omnibus ſatelli-
tibus communem, quæ tanti eſt momenti ut neglecta
errorem quadrantis horæ generare poſſit in prædicti-
one Eclipſium veluti ex. gr. Emerſio primi proxima
16 novembris 10 circiter minutis tardius accidet quam
indicat calculus qui eam vulgari modo deducit ex emer
ſionibus factis ſtatim poſt oppoſitionem jovis & ſolis
menſe julio vel auguſto.

alligata eſt hæc irregularitas ad varietatem
viſibilis diametri jovis ſive ad intervallum jovis
a terra & videtur provenire ex eo quod lumen
a ſatellitibus non perveniat ad nos niſi poſt moram
ita ut impendat decem vel undecim minuta per
ſpatium æquale ſemidiametro orbis annui.
Sed difficultas circa hoc elementum calculum
redderet intricatiſſimum, niſi ſimul inventa eſſet
ratio conficiendi tabulas ex quibus per ſolos medios
motus & unicam tabulam proſthaphæreticam
ſine ulla ſubſidio aliarum tabularum haberi
poſſunt tempora eclipſium ſatellitum ſingulorum
vera.
Continebit que illa tabula inequalitatem die-
rum, ſeu verum motum ſolis, motum jovis in
excentrico, & novam illam jam detectam inequa-
litatem. quod genus tabularum omnes hucuſque
uſitatas, brevitate facilitate & multitudine ele-
mentorum ſuperabit.

Figure 4: The manuscript of the text of Cassini of 22 August 1676. It is written on two pages, joined together here. It is very probably from the hand of Delisle (Library of the Paris Observatory).

The discovery of this manuscript—where the mentioned date is beyond any question because the excerpts of the Minutes of the Academy were copied in chronological order—solves definitively a date problem raised by the version of Du Hamel. In effect, the page setting of his book could raise a doubt about the date of the discovery to which it related.[4] On his side, Pedersen (1978) supposes that Du Hamel's memory was failing when he reproduced this text at the age of 75, and that his citation concerns Rømer rather than Cassini. The manuscript collation negates this hypothesis. The first written account of the discovery is thus undeniably by Cassini.

It is not known if the 16 November emersion for which a delay was predicted with respect to ephemerides was actually observed or not. However, another one had been observed on 9 November, with a delay of 10 minutes (Anonymous 2, 1676).

After the Minutes of the Academy are resumed, one reads for 21 November 1676:

> Römer read to the Company an account where he shows that the motion of light is not instantaneous, which he demonstrated by the inequalities in the immersions and emersions of the first satellite of Jupiter. He will confer with Messieurs Cassini and Picard in order to insert this report in the first Journal. (Our translation).

The mentioned account is from an article to be submitted to the *Journal des Sçavans*, which was published on 7 December 1676, as we have seen. However, Cassini soon raised objections about the hypothesis of the "… successive propagation of light …", and he attempted to raise other possibilities to explain an inequality that he did not clearly find in the eclipses of the other satellites:

> Saturday 28 November, the Company being assembled ... the immersions and emersions of the first satellite of Jupiter were again discussed, and the fact that the sum of immersions is shorter than the time of emersions, and it was considered relevant that Mr Cassini gives in writing the reasons he proposed, and Mons^r Römer will answer.
>
> [The following Saturday, 5 December] Mons^r Cassini read his observations on the inequalities of the motions of the satellites of Jupiter. (Minutes of the Academy of Sciences, 1676; our translation).

The objections of Cassini can be found in a later text (Cassini, 1693a: 391; our translation):

> [After correcting for the known inequalities] … there remain other inequalities in the motions of Jupiter's satellites, that differ from each other. When constructing my first tables, the motion of the fourth satellite looked to me more equal than those of all the others, and the first satellite seemed to approach the equality of the fourth. I noticed that in the second and the third there were more important inequalities, and I confessed that in the ephemerides I used some empirical equations which I derived from the observations [see later], whose causes I could not yet discover. Monsieur Romer explained very ingeniously one of these inequalities that he observed for several years in the first satellite by the successive motion of light, which needs more time to come from Jupiter to the Earth when it is more distant than when it is closer; but he did not examine if this hypothesis would suit the other satellites, which would require the same time inequality.

Cassini (1693b: 47; our translation) also writes:

> The Academy did indeed notice in the series of these observations that the time for a considerable number of immersions of the same satellite is appreciably shorter than for the same number of emersions, something which can be accounted for by the hypothesis of the successive motion of light: but this was not enough to convince the Academy that the motion of the light is indeed successive, because one cannot be certain that this time inequality is not produced by the eccentricity of the [orbit of the] satellite, or by irregularities in its motion, or by some other cause not yet understood, that might become clear in the future.

Thus Cassini abandoned the hypothesis of the finite velocity of light, because of irregularities in the motion of Jupiter's satellites that he could not understand. However, he had the intuitive feeling that some of them could result from the interaction between the satellites (but did he know of Newton's *Principia*?).[5]

Rømer's idea was accepted with enthusiasm by Christiaan Huygens (1629–1695), who had temporarily left Paris for the Netherlands in June 1676 and discovered them through the excellent English translation (by Halley?) of the *Journal des Sçavans* paper, which was published on 25 July 1677 in the *Philosophical Transactions of the Royal Society* (Rømer, 1677). Actually, Huygens needed a finite velocity for light in order to account for reflection and refraction in his undulatory theory (Costabel, 1978; Verdet, 1978), and he was very pleased with Rømer's theory.[6] In his *Traité de la Lumière* of 1690, which was written in 1678 (after he returned to France) and was shown to his colleagues at the Royal Academy of Science, in particular the "… famous Messieurs, Cassini, Romer and De la Hire …", Huygens reproduces the demonstration of Rømer, "… waiting for him to give every element for its confirmation." (Huygens, 1690: 467). Then he calculates the velocity of light from Cassini's and Rømer's data, and finds it

> … more than 600,000 times larger than that of sound, which is not at all the same thing as being instantaneous, since there is the same difference as between something finite and something infinite … (Huygens, 1690: 469).

In modern units, he found 230,000 km/s. Note that Huygens was the first scientist to give a numerical value for this velocity (Wróblewski, 1985); neither Cassini nor Rømer had attempted this, probably because they considered that the velocity was inconceivably large. There is in the *Histoire de l'Académie Royale des Sciences* for 1676 (on page 215) a figure for the velocity of light of "… 48,203 *lieues communes* of France [per second] …",[7] but one should realize that this text was only printed in 1733. The context suggests that it was written by Fontenelle some time after 1707.

4 WHY DID CASSINI PERSIST WITH HIS OPINION?

Cassini had doubts about the explanation of some astronomical phenomena several years before 1676. His certainties began to be shaken as early as 1671, on the matter of an apparent displacement of Polaris with respect to the North Celestial Pole, which he discovered.[8] This displacement was real, but neither Cassini nor Picard nor Jean Richer (1630–1696), who also observed it, could understand the cause, which was aberration. What is important for us here is that, probably for the first time in his career, Cassini was in doubt: would it ever be possible to do better than Tycho Brahe, who reached an accuracy of the order of one minute of arc in his observations?

This position of doubt was also his when he discussed the delays in the eclipses of Jupiter's satellites. His carefulness explains why he proposed several hypotheses on the same footing: either the delays were due to the finite velocity of light, or they came from other causes, like a variation in the diameter of Jupiter. The possibility of such a variation looks absurd to us, but in Cassini's time it was not, since nothing was known about the physical nature of the planets. Cassini himself discovered variable spots on Jupiter, and he thought that he saw dark zones on the satellites which made their apparent diameter variable.[9]

Cassini's doubts about the hypothesis of the finite velocity of light are those of an experienced scientist: as claimed by Fontenelle (1707: 79), "… an hypothesis must account for everything." Giacomo Filippo Maraldi I (1665–1729), Cassini's nephew who also worked at the Paris Observatory, writes: "In order for an hypothesis to be accepted, it is not enough that it agrees with some observations, it must also be consistent with the other phenomena." (Maraldi, 1707: 32). If one was unable to find the expected delays or advances in the eclipses of the other satellites of Jupiter, masked by irregularities that could only be seen without understanding them, one had to abandon their explication in terms of the successive motion of light. Maraldi also considered rightly that the eccentricity of the orbit of Jupiter, which is rather large, should affect by several minutes the delays or advances of the eclipses if they were due to the finite velocity of light, but he claimed in 1707 (ibid.) that he had not seen this effect (which however was found later!). Backed up by this new argument, Cassini stuck to his position until the end of his life. Conversely, Rømer threw himself without hesitation into promoting the hypothesis of the finite velocity of light. One should remember that his article was published with the agreement of Cassini and Picard, who let him take sole responsibility for this.

Rømer never made public a refutation of Cassini's arguments against the successive motion of light. However, this can be found in a letter in Latin that he wrote to Huygens on 30 September 1677, where (at Huygens' request) he provided details of the discovery (Huygens, 1888-1950, t. 8: 32-35). From this letter, it seems that Picard shared Cassini's doubts. Rømer gives four reasons which, according to him, explain why the advances or delays due to the finite velocity of light cannot be seen clearly in the three external Galilean satellites: their immersions and emersions are less frequent than for the first satellite; their motions are slower so that the timing of these events is less accurate; the uncertainties in the inclinations and nodes of their orbits might also give errors of several minutes for eclipses occurring obliquely in the shadow; and finally:

> It is certain that these satellites exhibit irregularities that are not yet determined, either due to eccentricity [of their orbits] or to some other cause, which produce discrepancies between observations and the theories of D. Cassini of time intervals two or three times larger than the one we are looking for and determine from the first satellite. (Huygens, ibid.; our translation).

This is not really an explanation, since Rømer, like Cassini and Picard, did not understand the reason for these discrepancies. Yet in another part of the letter, Rømer demonstrates in a most convincing way that no other cause than the finite velocity of light can account for the delays or advances in the eclipses of the first satellite.

In spite of Cassini's views, the idea of the finite velocity of light made its way into France and elsewhere. If Maraldi I did not take the velocity of light into account in his tables, the Swedish astronomer Pehr Wilhelm Wargentin (1717–1783) did in his *Tabulae pro calculandis eclipsibus satellitum Jovis*. Calculated in 1741, these were the best Jovian satellite tables available at the time (Wargentin, 1746). These tables, and to a lesser extent those of Giovanni Domenico Maraldi (1709–1788, a nephew of Maraldi I), were used by Jean-Sylvain Bailly (see Condorcet, 1763), Joseph-Louis Lagrange (1766) and Pierre-Simon Laplace (1788) in support of their theory of the motion of Jupiter's satellites.

5 HALLEY'S CRITICISMS

The English astronomer Edmond Halley (1656–1742) is well known for having shown that the comet to which his name has been given reappears regularly every 76 years or so. Halley (Figure 5) knew Cassini very well, and visited him at the Paris Observatory during the first months of 1681.[10] Halley was thus very aware of the work carried out at the Observatory on the satellites of Jupiter. In 1694, he published an adaptation for London of Cassini's new ephemerides for Jupiter's satellites (Halley, 1694). He acknowledged that they were rather exact, but he made important criticisms.

Figure 5: Edmond Halley (after Wikipedia Commons).

Halley's text of is very interesting. He adopts as 'most ingenious' Rømer's hypothesis, acknowledges Cassini's opposition, then gives details about the way the latter constructed his new tables. Maraldi I explained why Cassini did not take the eccentricity of Jupiter's orbit into account, "… which would occasion a much greater difference than the Inequality of Jupiter and the Earth's Motion, both of which are accounted in these Tables with great Skill and Address." Cassini introduced an inequality in the orbital motion of the first satellite, assuming that the eclipses occurred 14m 10s earlier when Jupiter was in opposition that when it was in conjunction (we do not understand why Cassini choose this value, which is too small); which corresponds to an inequality of 2º in the orbital longitude of the satellite as seen from Jupiter. Halley (ibid.) continues:

> But what is most strange, he affirms that the same Inequality of two Degrees in the Motion, is likewise found in the other Satellites, requiring a much greater time, as above two Hours in the fourth Satellite: which if it appeared by Observation, would overthrow Monsieur Romer's Hypothesis entirely ... [so] Monsieur Cassini has, by his *Praecepta Calculis* ... supposed that the Minutes thereof to be increased in the same proportion; as instead of 14′. 10″. in the First, to be 28′. 27″. in the Second, 57′. 22″. in the Third, and no less than 2h. 14′. 7″. in the Fourth; whereas if this second Inequality did proceed from the successive propagation of Light, this Æquation ought to be the same in all of them, which Monsieur Cassini says was wanting to be shown, to perfect Monsieur Romer's Demonstration; wherefore he has rejected it as ill founded. But there is good cause to believe that his motive thereto, is that he has thought not proper to discover.[11]

From the letter of Rømer to Huygens cited above, we can understand why Cassini used this 'most strange' trick when building the ephemerides for the external satellites: he had observed for them inequalities "… two or three times larger …" than for Io.

Halley then attempted to confirm the hypothesis of the finite velocity of light. Analysing various observations, some of which were made by Cassini, he showed that the inequalities for the third and the fourth satellites are much smaller than considered by Cassini, and were compatible with the idea of the successive propagation of light. Halley finally noted that Cassini's tables, printed in Paris by the Royal Printing Office, were full of mistakes "… which yet ought not in the least to be attributed to the Excellent Author, but rather to the Negligence of those employed by him."

Therefore, in spite of his admiration and respect for Cassini, Halley did not hesitate to strongly criticize his stubbornness in rejecting the idea of the finite velocity of light, and also the strange recipes he used to build the tables of the second, third and fourth satellites of Jupiter—which were fortunately much less observed than the first satellite.

6 CONCLUDING REMARKS

A text by Fontenelle (1707), the successor of Du Hamel as the Secretary of the Academy, summarizes the facts quite correctly, and we now see that there is no reason to contest it as has been done by several commentators (including Le Verrier):

> The observations of Jupiter's satellites made by the Academy from 1670 to 1675 lead to the discovery in their motion of an inequality not previously known ... M. Cassini and M. Roëmer, then a member of the Academy, after scrutinizing this anomaly, found that it depended of the distance of Jupiter from the Earth … They called it the second inequality ... A very ingenious conjecture on the cause of this inequality first came to the mind of the two astronomers. They imagined that the motion of light was not instantaneous as all previous philosophers believed, but that it took some time to spread ... M. Cassini proposed this idea in a writing published in August 1674 [actually 1676, for Fontenelle was fooled by the page setting of Du Hamel's book and made a further careless mistake], to announce to astronomers the second inequality he had discovered in the satellites of Jupiter. To gain their confidence, he predicted that this inequality would cause a delay of 10 minutes, with respect to the calculations, for an emersion of the first satellite due for the following 16 November.
>
> But M. de Cassini did not remain convinced for long that the successive propagation of light produced this second inequlity, while conversely M. Roëmer stuck to this hypothesis, and maintained it with such strength and subtlety that it became his own, and that a large number of skilled philosophers took it from him.
>
> Indeed, it was worthy of inspiring some sort of passion in a high-spirited man. Why should light be able to cross space instantaneously, but not a piece of marble [i.e. a material object]? The motion of the most subtle body can only be faster than that of a heavier and more massive object, but it cannot be instantaneous either ... If one wishes that the motion of light be not a real change of place, an effective transport, but a simple pressure of some subtle matter, an undulation, sound is another one but it does not spread in an instant. Moreover, the 14 minutes that light takes to cross the diameter of the Earth's orbit, i.e. 66 millions of lieues, makes it pleasantly easy to perform calculations on this motion, to compare it to that of sound, to build upon it elevated and subtle speculations, and all this persuades in favour of the hypothesis. (Our translation).[12]

However, convinced by the arguments of Maraldi I published in the same volume, Fontenelle concluded that

> … we must abandon, although perhaps with regret, the ingenious and attractive hypothesis of the successive propagation of light, or at least the only certain evidence that we thought we had for it, because a missed proof does not make a thing impossible. (ibid.).

As we have seen, the English astronomers were much less reluctant to adopt the hypothesis. In France, one would have to wait until 1728, the date of the discovery of aberration by James Bradley, to see scientists convinced that the propagation of light was not instantaneous. Bradley (1728) understood that

> … [if] Light was propagated in an Instant, then there should be no Difference between the real and visible Place of an Object … [and that] if Light was propagated in Time, the apparent place of a fixt Object would not be the same when the Eye is at Rest, as when it is moving in any other Direction, than that of the Line passing through the Eye and Object; and that, when the Eye is moving in different Directions, the apparent place of the Object would be different …

This is aberration. Bradley realized that his discovery confirmed at the same time the finite velocity of light and the revolution of the Earth around the Sun (the first observational proof of the hypothesis of Copernicus). He admitted, however, that since no one had yet succeeded in observing the annual parallax of the stars, which also resulted from the revolution of the Earth,

> … the Anti-Copernicians have still room to object against the Motion of the Earth; and they may have (if they please) a much greater Objection against the Hypothesis, by which I have endeavoured to solve the fore-mentioned Phænomena; by denying the progressive Motion of Light, as well as that of the Earth. But I do not apprehend, that either of these Postulates will be denied by the Generality of the Astronomers and Philosophers of the present Age. (ibid.).

But let us come back to our question: who discovered the finite velocity of light? If we take literally the text of 22 August 1676, then it was Cassini. This is also affirmed by Jean Étienne Montucla (1758: 579) who wrote:

> One generally attributes to Roemer the merit of having found an explanation both likely and ingenious of this

> phenomenon. But this is mistaken; one can see in a writing by Cassini, published in August 1675 [actually 1676], that this astronomer was the first author.

However, perhaps Cassini wrote on behalf of his team, which included Picard, Rømer and perhaps even Richer and Philippe de La Hire (1640–1718). This becomes a most convincing hypothesis when one reads the minutes of the Academy and considers the working methods at the Paris Observatory: it may be that the discovery was collective, and was due to both Cassini and Rømer, as suggested by Fontenelle (we should remember that Cassini was still alive when Fontenelle was writing his 'history', and that they both attended Academy meetings every Saturday). In any case, Cassini cannot be dismissed for this discovery, as proposed by some commentators, and we must acknowledge his eminent contribution to the solution "… of one of the most beautiful problems in physics." (Cassini, 1693b: 46). He behaved like an open-minded scientist, who left to others the possibility of promoting ideas opposite to his own beliefs; but he also showed some stubbornness when refusing to adopt the idea of the finite velocity of light, in spite of Halley's demonstration—which he could hardly ignore.

Even if the discovery of aberration solved in a definitive way the problem of the velocity of light, the situation surrounding the ephemerides of Jupiter's satellites remained unsatisfactory until the time of Lagrange and Laplace, in spite of the efforts of Wargentin and of Maraldi II. Empirical terms were still introduced in order to account for the observations in the best possible way. The ephemerides remained in use for determining longitudes until the end of the eighteenth century, because they were precise enough in the short-term to give time, hence longitude, within a few minutes: this only required a single eclipse observation, without need for comparison with a simultaneous observation in Paris. But this was only possible on land; observations of Jupiter's satellites made at sea were impossible in practice because of the motions of the ships. In this case, the solution finally came with the construction of precise marine chronometers by John Harrison (1693–1776) in England between 1737 and 1773. Good marine chronometers were also built in France by clock-makers like Ferdinand Berthoud (1727–1807), Duroy and Jean-André Lepaute (1709–1789), and were tested ashore and at sea by astronomers. By 1800, longitude could be determined within a fraction of a degree on voyages of one or two months' duration.

7 NOTES

1. Rømer's name is also spelt Römer, Roemer, Rœmer and even Romer.
2. The observations used in the discovery are collected in a manuscript by Rømer which was written two years later.
3. Astronomers used to call *prostapheresis* (modern equivalent: equation of centre) the difference between the mean and the true position of the Sun, of a planet or of a satellite.
4. Du Hamel inserts the text in question in page 145 of his book, in a chapter entitled "De rebus Astronomicis anni 1675" (beginning on page 143). In the margin of page 144 we find the mention 'Ann. 1675', but at the end of the chapter, on page 146, it becomes 'Ann. 1675 & 76'. It is clear, when reading the chapter, that the text dated 22 August is from the same year as the publication by Rømer, i.e. 1676, but some commentators confused the dates: for example, Montucla (1758) attributes the text to August 1675 and Fontenelle (1707) to August 1674.
5. Indeed, Cassini writes in an unpublished project for an 'Abrégé d'Astronomie' preserved in the Library of the Paris Observatory:

   > The observations show that aside from the known inequalities there are others which are larger in the second and the third satellite, and smaller in the first and the fourth. They clearly change their distances from Jupiter and anticipate or delay conjunctions and eclipses.
   >
   > Reason demands that there are three others similar to those of the Moon, and more difficult to disantangle, because one of them results from the equilibrium of all satellites together, which is continuously changing and produces effects on each satellite. Experience shows however that the sum of these inequalities is not large and that they do not prevent a prediction of the conjunctions and eclipses with approximately the same accuracy as for the predictions of those of the Sun and of the Moon. (Cassini, MS B4[2]; our translation).

6. On 14 October 1677 Huygens (*Oeuvres Complètes*, 1888-1950, t. 8: 36-37; our translation) wrote to Colbert, the Prime Minister of France:

   > I have seen recently with much pleasure the beautiful invention [sic] of Mr. Romer, to demonstrate that light takes time to propagate, and even to measure this time; this is a very important discovery, worthy of a confirmation by the Royal Observatory. As to myself, this demonstration suits me more especially as, in what I am writing about Dioptics, I supposed the same thing about light, and demonstrated with it the properties of refraction, and recently those of the Iceland Cristal.

7. These 'lieues de 25 au degré' measure 4,444 metres, so the velocity of light is calculated as 214,000 km/s, a figure somewhat smaller than that derived by Huygens and much smaller than the current value of 299,792.458 km/s.
8. Here is what Cassini observed, as documented in letters to Picard, written in Italian, and preserved in the Library of the Paris Observatory (Ms B4[3]). On 24 October 1671, Cassini wrote:

   > I already told you about the difference I found for the largest elevation of the Pole Star observed last fall, with respect to the present one ... I plan to set up a fixed telescope in order to see if this difference arises from the thing itself, or from the observation. (Our translation of the French translation Ms A4[2]).

   The "largest elevation" was the elevation of the Pole Star above the horizon at culmination. If it varied, this was because the Pole Star was getting closer or further from the North Celestial Pole. Picard wrote Cassini on 13 November 1671 that he had also seen this variation:

   > I can say that, unless the observations I have made last summer during several following evenings are wrong, the Pole Star must presently be at a distance from the Pole of 2° 28′ 30″ instead of 2° 28′ 10″. Whatever it may be, I have not much difficulty to imagine that the axis of diurnal motion of the Earth, by changing its parallelism [sic], might experience some periodical agitation or libration. This would be enough to account for these kinds of anomalies. (Our translation).

Cassini asked more questions of himself, before writing to Picard on 14 January 1672:

> I have found the largest elevation of the Pole Star similar to that last fall ... I examine if the differences ... could arise from the quality of the air, altered by the exhausts and the smoke from the city above which the visual rays propagate. [Note that Paris Observatory was located to the south of the city.] (Our translation).

He then writes Picard again on 11 February:

> The confrontation of the observations of the distance of the Pole Star to the Pole, made by you, by M. Richer and by myself, shows that the difference of the instruments, or our estimate, or the difference in the quality of the air, or all these things together do not allow an exactness better than a quarter or a third of a minute of time [probably of a degree]. (Our translation).

9. Du Hamel (1698: 27) comments on Cassini's observations as follows:

> There are some parts in the satellites that do not reflect light so that they are larger than they look. This is confirmed by the shadow of the fourth satellite [on the disk of Jupiter] because it sometimes looked more extended than the satellite itself. And because these kinds of spots do not always show up, and sometimes the satellites in the same situation with respect to Jupiter and the Sun do not always appear with the same magnitude, M^r Cassini believes that one may conclude that they rotate around their axis or that they suffer some physical changes which cause sometimes their spots to appear then to disappear, as it happens on Jupiter. One might also conjecture that there is a kind of atmosphere around the first satellite, from the fact that Mr Cassini sometimes could not see its shadow on Jupiter when it was crossing its disk. (Our translation).

10. Indeed, it is Cassini who suggested to Halley that some comets should appear periodically (see Cook, 1998: 115).
11. This sentence is somewhat obscure, but there is little doubt that Halley accuses Cassini of insincerity.
12. Cassini indeed adopted 14m 10s for his new tables instead of the 20 to 22 minutes announced before. The actual value is 16m 28s.

8 REFERENCES

The original documents available through http://gallica.bnf.fr are indicated by an asterisk. The Latin and French texts cited from these documents are not reproduced in the notes of this paper.

Anonymous 1 [very probably Delisle], s.d. *Recueil d'observations et de Dissertations Astronomiques Tirées des Registres Manuscripts de l'Académie Royale des Sciences*. Library of the Paris Observatory (Ms. B-2-7 (105)).

Anonymous 2 [Du Hamel?], 1676. Démonstration touchant le mouvement de la Lumière trouvé par M. Roemer. In **Histoire de l'Académie Royale des Sciences, avec les Mémoires de Mathématiques et de physique,* t. 10 (printed in 1730), *Mémoires*, 575-577.

*Bradley J., 1728. A letter from the Reverend Mr. James Bradley ... to Dr. Edmond Halley ... giving an account of a new discovered motion of the fix'd stars. *Philosophical Transactions of the Royal Society of London*, 35, 637-661.

*Cassini J.-D., 1692. Nouvelles découvertes de diverses Périodes de mouvement dans la Planete de Jupiter, depuis le mois de Janvier 1691 jusqu'au commencement de l'année 1692. *Mémoires de Mathématique et de Physique, tirez des Registres de l'Académie Royale des Sciences*, Année 1692, t. 10 (printed in 1730), 1-9.

*Cassini J.-D., 1693a. Les hypothèses et les tables des satellites de Jupiter, reformées sur de nouvelles observations. *Histoire de l'Académie Royale des Sciences, avec les Mémoires de Mathématiques,* t. 8; *Mémoires* (printed in 1730), 317-392.

*Cassini J.-D., 1693b. De l'origine et du progrès de l'astronomie et de son usage dans la géographie et la navigation. *Histoire de l'Académie Royale des Sciences, avec les Mémoires de Mathématiques,* t. 8; *Mémoires* (printed in 1730), 1-52.

*[Condorcet, M.J.A.N. Caritat de], 1763. *Histoire de l'Académie Royale des Sciences* pour 1763 (printed in 1768), 66-77.

Cook A., 1998. *Edmond Halley, Charting the Heavens and the Seas.* Oxford, Clarendon Press.

Costabel P., 1978. La propagation de la lumière sans transport de matière de Descartes à Huygens. In *Roemer et la Vitesse de la Lumière*. Paris, Vrin (Collection d'histoire des sciences, 3 – C.N.R.S.). Pp. 83-91.

Débarbat S., 1978. La qualité des données d'observations traitées par Roemer. In *Roemer et la Vitesse de la Lumière*. Paris, Vrin (Collection d'histoire des sciences, 3 – C.N.R.S.). Pp. 143-157.

Du Hamel, J.-B., 1698. *Regiæ Scientiarum Academiæ, in qua præter ipsius Academiæ originem & progressus, variasque dissertationes & observationes per triginta annos factas, quàm plurima experimenta & inventa, cum Physica, tum Mathematica in certum ordinem digeruntur.* Paris, Stephane Michallet.

Du Hamel, J.-B., s.d. *Extrait du 1er Volume de l'histoire de l'Académie par M^r Duhamel Concernant Particulièrement M. Cassini*. Library of the Paris Observatory (Ms B4(1)).

*Fontenelle, B. le Bouyer de, 1707. Sur la seconde inégalité des satellites de Jupiter. *Histoire de l'Académie Royale des Sciences avec les Mémoires de Mathématiques,* année 1707 (printed in 1730), *Histoire*, 77-81.

*Fontenelle, B. le Bouyer de, 1740. Préface ... In *Éloge des Académiciens, avec l'histoire de l'Académie des Sciences en 1699.* La Haye, van den Kloot. Pp. 1-30.

Halley E., 1694. Monsieur Cassini his new and exact tables for the eclipses of the first satellite of Jupiter, reduced to the Julian stile, and meridian of London. *Philosophical Transactions of the Royal Society of London*, 18, 237-256.

*Huygens C., 1888-1950. *Œuvres Complètes.* La Haye, M. Nijhoff, 22 volumes.

*Huygens C., 1690. Traité de la lumière. In *Œuvres complètes*, t. 19, 451-537.

Lagrange J.L. de, 1766. Recherches sur les inégalités des satellites de Jupiter causées par leur attraction mutuelle. *Prix de l'Académie Royale des Sciences pour 1766,* t. 9 ; reproduced in **Œuvres de Lagrange*, t. 6 (éd. 1867) Paris, Gauthier-Villars. Pp. 67-225.

Laplace P.S., 1788. Théorie des satellites de Jupiter, de Saturne et d'Uranus. *Histoire de l'Académie Royale des Sciences, avec les Mémoires de Mathématiques,* année 1788 (printed in 1791), 249-364; reproduced in his **Œuvres Complètes.* Paris, Gauthier-Villars (1878-1912), t. 4. Pp. 1-20.

*Le Verrier U.J.J., 1853. Mesure de la vitesse de la lumière dans le ciel et à la surface de la terre. – Conséquences pour le système du monde. *L'année Scientifique et Industrielle*, 7^e année, 37-54.

*Maraldi G.F., 1707. Considérations sur la seconde inégalité du mouvement des satellites de Jupiter, & sur l'hypothese du mouvement successif de la lumiere. *Histoire de l'Académie Royale des Sciences avec les Mémoires de Mathématiques,* année 1707 (printed in 1730), *Mémoires*, 25-32.

Meyer K., 1915. Om Ole Rømers Opdagelse af Lysets Tøven. *Naturvidenskabelig og Matematisk Afdeling*, 12, 105-145 (in Danish, with a French summary on pages 132-145).

Montucla J.E., 1758. *Histoire des Mathématiques ..., II.* Paris. *New Edition (1799-1802), Paris, H. Agasse.

Pedersen K.M., 1978. La vie et l'œuvre de Roemer. In *Roemer et la Vitesse de la Lumière*, Paris, Vrin (Collection d'histoire des sciences, 3 – C.N.R.S.). Pp. 113-128.

*Rømer O., 1676. DémonstratIon touchant le mouvement de la lumière trouvé par M. Römer de l'Académie Royale des Sciences. *Journal des Sçavans*, 233-236.

*Rømer O., 1677. A demonstration concerning the motion of light, communicated from Paris, in the Journal des Scavans, and here made English. *Philosophical Transactions of the Royal Society of London*, 12, 893-894 (The translation is probably by Halley, who was then the Secretary and Editor.)

Verdet J.-P., 1978. La théorie de la lumière de Huygens et la découverte de Roemer. In *Roemer et la Vitesse de la Lumière*. Paris, Vrin (Collection d'histoire des sciences, 3 – C.N.R.S.). Pp. 169-178.

Wargentin, P.W., 1746. Tabulae pro calculandis eclipsibus satellitum Jovis. *Acta Regiae Societatis Scientiarum Upsaliensis pro 1741*, 27-66.

Wróblewski A., 1985. De Mora Luminis: a spectacle in two acts with a prologue and an epilogue. *American Journal of Physics*, 53, 620-630.

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A NEWLY-DISCOVERED ACCURATE EARLY DRAWING OF M51, THE WHIRLPOOL NEBULA

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Abstract: We have discovered a lost drawing of M51, the nebula in which spiral structure was first discovered by Lord Rosse. The drawing was made in April 1862 by Jean Chacornac at the Paris Observatory using Léon Foucault's newly-completed 80-cm silvered-glass reflecting telescope. Comparison with modern images shows that Chacornac's drawing was more accurate with respect to gross structure and showed fainter details than any other nineteenth century drawing, although its superiority would not have been apparent at the time without nebular photography to provide a standard against which to judge drawing quality. M51 is now known as the Whirlpool Nebula, but the astronomical appropriation of 'whirlpool' predates Rosse's discovery.

Keywords: reflecting telescopes, nebulae, spiral structure, Léon Foucault, Lord Rosse, M51, Whirlpool Nebula

1 REFLECTING TELESCOPES AND SPIRAL STRUCTURE

The French physicist Léon Foucault (1819–1868) is the father of the reflecting telescope in its modern form, with large, optically-perfect, metallized glass or ceramic mirrors. Foucault achieved this breakthrough while working as 'physicist' at the Paris Observatory in the late 1850s. The largest telescope that he built (Foucault, 1862) had a silvered-glass, f/5.6 primary mirror of 80-cm diameter in a Newtonian configuration (see Figure 1). It was first used on the night sky in early 1862, from Paris, prior to transfer to the clearer skies of Marseilles two years later. Among the stream of first results presented to the Académie des Sciences by Urbain Le Verrier (1811–1877), Director of the Observatory, were confirmation of the existence of the just-discovered companion to Sirius (Le Verrier, 1862a; see also Holberg and Wesemael, 2007), observations of a transit of Titan across Saturn's disc (Le Verrier, 1862b) and a drawing of the spiral nebula Messier 51 in Canes Venatici (Le Verrier, 1862c).

Spiral structure had of course been discovered in M51 seventeen years earlier using another reflecting telescope, the 'Leviathan of Parsonstown' built by the Third Earl of Rosse (William Parsons, 1800–1867). The Leviathan incorporated a 6-foot diameter, f/9 primary metal mirror in a Herschelian (or Lemairean) configuration, and the discovery of spiral structure was made during the first months of operation in early 1845.[1] The news was announced by Lord Rosse in June of that year at the Cambridge meeting of the British Association for the Advancement of Science.

The drawing of M51 handed round in Cambridge was found in the Rosse archives some two decades ago and published by Hoskin (1982). Soon afterwards, in an article devoted to Foucault's development of the silvered-glass reflector, one of the authors of the present paper (Tobin, 1987: 162) regretted that the sketch made with Foucault's telescope was lost, because it would have provided an interesting comparison of the two telescopes' capabilities. This lament was repeated in his recent biography of Foucault (Tobin, 2003: 223).

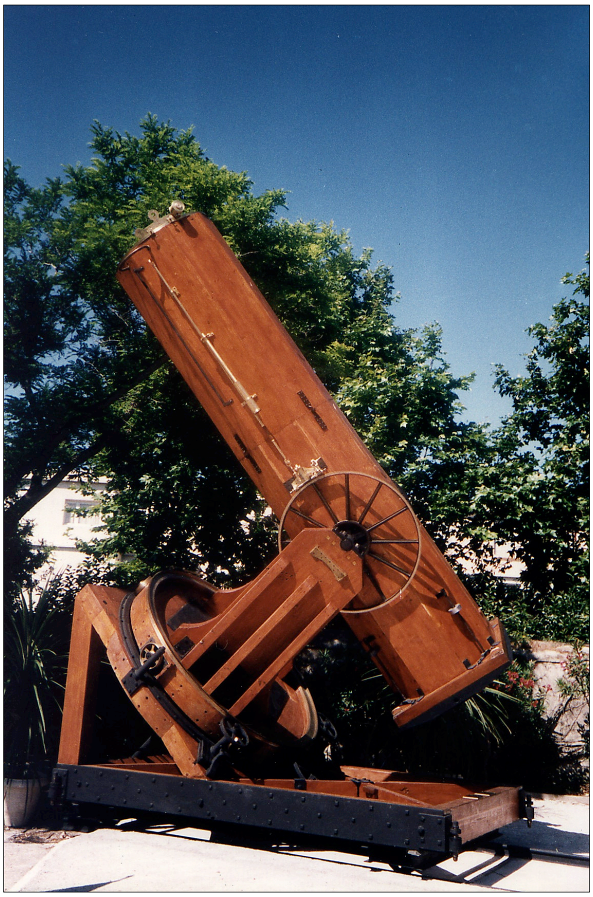


Figure 1: A recent photograph of Foucault's 80-cm reflector, at Marseilles Observatory (courtesy: Marseilles Observatory).

Well, the other author of this paper (Holberg) has now found the drawing! Logically enough, it was in the Paris Observatory archives, where the *carnets d'observation* of over thirty mid-nineteenth century observers have been preserved.[2] The observer assigned to the new 80-cm telescope was one Jean Chacornac (1823–1873).[3] Chacornac had begun a career in commerce in his natal Lyons and then Marseilles, where he was allowed to use the Marseilles Observatory's telescopes. He devoted himself to the study of comets and sunspots, and to the discovery of minor planets and its essential precursor of ecliptic mapping. In 1854 Chacornac transferred to Paris to continue ecliptic mapping as part of Le Verrier's reorganisation of the Paris Observatory. He was promoted to the grade of *astronome* (astronomer) in early 1857 and made a *chevalier* (knight) in the *Légion d'honneur* a few months later.

2 CHACORNAC'S DRAWING

The Chacornac *carnets* are small (approximately 100 × 160 mm). Some forty are bound together in seven volumes spanning March 1854 to February 1863. The *carnets* are not systematic observing logs—several could be in use at once—nor are they complete; for example, they do not contain the drawing of the nucleus of Comet Swift-Tuttle made on 23 August 1862 with the 80-cm telescope, presumably by Chacornac, and published the following month in the popular weekly magazine *L'Illustration* (Guillemin, 1862). Rather, the later ones in particular are personal notebooks in which Chacornac jotted down, mostly in pencil, all manner of items—train times, quotations, gossip, interesting books—besides often-summary information on his observations.[4] From 1859 he often protected the privacy of gossip and gripes by writing some words in shorthand, and at all times he used common astronomical abbreviations such as '☿' for Wednesday and '☉' for Sunday. Concerning the 80-cm telescope, he for example observed the Sun with the bare mirror on 23 October 1861, and the Moon the next day. He concluded: "As long as this telescope is not silvered, these trials do not seem interesting to me." The following "☿ 15 January" he noted that the mirror had been silvered, though the result was "… a little marbled …"; a silver layer deposited the previous Friday had been judged inadequate and had immediately been removed by Foucault. By the 17th, the 80-cm mirror was back in its tube and "we" (presumably at least Chacornac and Foucault) were observing Venus and the Orion nebula. On 9 March, Chacornac recorded Le Verrier's hopes and plans for transferring the telescope to Marseilles and wondered "What will become of all these castles [in the air]???" The following day Toulon made a bid to host the new observatory, offering more land. By 1 June it seemed the telescope (along with Chacornac) would go to Montpellier. "But I do not want this," Chacornac commented, adding that he might go if necessary, but he would prefer England or the colonies. As mentioned above, the telescope ultimately went to Marseilles, where a new observatory site was developed to accommodate it (Tobin, 1987).

The observation that interests us was made on 25 April 1862 and is reproduced at its original size in Figure 2. Chacornac's comment that it was made "with the No. 1" doubtless refers to a low-magnification eyepiece.[5] An additional annotation indicates that the intensity is over-represented near the centre of the principal nebula (where Chacornac has over-written "*plus faible*"—'fainter' on one of the spirals) and near the apparent cross-over, which he has marked "*m*". We note that Chacornac was possibly already used to sketching M51, because in a lecture at the Sorbonne some two decades later, a drawing of M51 was shown that had been made by him with Foucault's earlier 40-cm silvered-glass reflector, which entered service in 1859 (Wolf, 1886: 129).[6]

3 COMPARISON WITH OTHER IMAGES OF M51

To evaluate Chacornac's drawing, we must compare it with the contemporary and modern images reproduced in Figure 3. In Figure 4 we have lettered various features to facilitate discussion. When Messier discovered this nebula in 1773 he saw it as single, but within a few years Méchain had recognised that it was double (e.g. O'Meara, 2006). Among subsequent designations for the companion (nucleus *n*) is NGC 5195, with NGC 5194 for the main nebula (nucleus *N*). It is possible that it is the gravitational interaction with NGC 5195 that has produced the two long, prominent spiral arms that are the defining characteristic of so-called 'grand-design' spiral galaxies (e.g. Murdin, 2001: 3518).

Figures 3(a)-(c) show drawings that predate Chacornac's. Figure 3(a) reproduces John Herschel's drawing from 1833 in which the main nebula comprises a bifurcated ring (Herschel, 1833a: Plate X, Fig. 25). Our attention need not be detained by this drawing, for which Herschel was "… rather disposed to apologize for the incorrectness than to vaunt the accuracy." (1833a: 361). Figure 3(b) shows Lord Rosse's drawing as carefully reproduced in 1846 by John Pringle Nichol (1804–1859), Professor of Astronomy at the University of Glasgow, in his *Thoughts on Some Important Points Relating to the System of the World* (Nichol, 1846: Plate VI), while Figure 3(c) shows the somewhat different drawing published by Rosse himself in the Royal Society's *Philosophical Transactions* in 1850 (Rosse, 1850: Plate XXXV, Figure 1). No doubt there were others.[7] The French science chronicler Abbé François Moigno (1804–1884) asserted that Chacornac's drawing exhibited "… incomparably more details than those given by Herschel and Lord Rosse." (Anonymous, 1862a: 381). We can agree concerning Herschel, but concerning Rosse, Moigno has been carried away by his usual irrepressible enthusiasm for all things French. Chacornac's drawing (Figures 2 and 3(d)) is not as detailed as either of Lord Rosse's: it is more fairly characterized as a sketch. It should be noted, however, that examination of Chacornac drawings of other objects either in his observing logs or in printed form (e.g. Chacornac, 1867) shows that he was an accomplished draughtsman, and we can be sure that every pencil line in his sketch was carefully placed. When compared to a modern, *V*-band image (to approximate scotopic vision) in Figure 3(e), we see that Chacornac has seized the overall design of the M51 spirals far better than his predecessors. In the south-west quadrant, he has seen at least the root of the secondary component *a* of the principal spiral arm *A*, as well as the inner and outer parts of the other principal arm *B*, none of which was delineated by Lord Rosse. The two fingers of emission *f* and *g* that arise from the nucleus and the inner part of arm *A* flank a dust lane, and there are hints of this in the split nature of the inner part of Chacornac's spiral arm *A*. To the north-east, the zig-zag break *z* in *B* has been amalgamated with the outer part of *A* such that, as described by Chacornac in the written text accompanying Le Verrier's presentation to the Académie on 28 April, "… in this region the entanglement of arms presents the appearance of a spherical triangle." (Le Verrier, 1862c: 889). On comparison with Figure 3(e), we can understand that such a characterization could be given.

As for NGC 5195, Chacornac wrote that "… it too presents a spiral form and is not a planetary disc surrounded by a uniformly-distributed atmosphere." He clearly saw the halo *h* with inner darker regions to east and west of the nucleus *n*. Note that Chacornac was not using 'spiral' in the sense of modern extragalactic astronomy, but as a simple geometrical term. In this he followed Rosse (1850: 505) who characterized as 'spiral' any "… curvilinear arrangement not consisting of regular re-entering curves …" and who the year before Chacornac had given a new sketch of the outer nucleus, which he stated was "… unquestionably spiral." (Rosse, 1861: 728).

Concerning the nuclei *N* and *n* of this 'double nebula', Chacornac noted their "… clearly defined stellar appearance …", and added that

> … the central nebulosity of the larger presents, under strong magnification, the aspect of a *tourbillon* [vortex or whirlpool] of small stars about a central object that does not have the planetary character indicated by Lord Rosse. These stars are not the only new ones: one counts as many as nine, distributed along the spirals of the large nebula and which are not recorded on Lord Rosse's drawing.[8]

Had Chacornac read Rosse's paper carefully, he would have found that Rosse had already resolved the nuclei with his smaller 3-feet telescope and that his drawing explicitly omitted all stars whose positions had not been measured (Rosse, 1850: 510, 511; see also the diatribe against Chacornac presented in Darby, 1864: viii).

Continuing the comparison with Rosse's drawing, Chacornac remarked that "… the diverse branches of this spiral nebula intersect in a different fashion. The configuration of the brightest spirals, as our diagram indicates, restores credibility to Sir John Herschel's drawing". Well, perhaps ...

When we look at subsequent naked-eye drawings of M51,[9] we remain impressed by the quality of Chacornac's sketch. Figure 3(f) shows a drawing made a few months later by William Lassell (1799–1880) with his 48-inch speculum-metal reflector in Malta (Lassell, 1867: Plate VI, Figure 27). He has a similar cross-over to Chacornac's *m*, but saw no detail in NGC 5195 nor other finer details such as the secondary arm *a*. Figure 3(g) shows a drawing made by Rosse's assistant, Samuel Hunter, in 1864 using the Leviathan, although this was not published until 1879 (Rosse, 1879-80: Plate IV). After Chacornac's, this is the drawing that best stands comparison with a modern image of M51, but it too misses finer details such as the secondary arm *a*. The drawing made in 1884 by H.C. Vogel (1841–1907) with the new 27-inch Grubb refractor in Vienna is even more approximate (Figure 3(h), Vogel, 1884: Plate 3), missing the double nature of the spirals entirely and introducing a phantom outer arc towards the east-south-east.[10] Also approximate is the drawing made by Admiral W.H. Smyth (1788–1865), presumably in the 1850s or 60s (Figure 3(i)), and published posthumously (Chambers, 1890: viii, 74).

Sir Robert Ball (1840–1913; Astronomer Royal for Ireland 1874-1892) worked as Lord Rosse's 'astronomer' in 1865-1866, in succession to Hunter. Ball recalled that the discovery of spiral structure "… was received with some degree of incredulity. Other astronomers ... thought it must be due possibly to some instrumental defect, or to the imagination of the observer." (Ball, 1895: 286). "Spiral! hem! rather say, coil-tracings left on the face of the speculum by the grinder, or the polisher!" said others (as reported by Darby, 1864: viii). But Lord Rosse was vindicated in the 1880s when "… a witness never influenced by imagination …" came forward in the form of dry gelatine-bromide plates which provided the sensitivity needed to photograph nebulae (Ball, 1895: 286).[11] The Orion Nebula, visible to the naked eye, was the obvious first target, but telescopes were soon turned to M51. A.A. Common (1841–1903) reported that he took a 30-minute exposure with his 36-inch silvered-glass reflector in Ealing in 1883 (Common, 1888), but the first published photograph appears to have been taken on 11 April 1888 by Eugen von Gothard (Jenö Gothard, 1857–1909) using an ≈ f/7 10-inch Browning silvered-glass reflector at his private observatory at Herény, near Szombathely in Hungary (Vogel, 1888: plate).[12] Von Gothard's 2 hr 35 min exposure yielded an image of M51 that was only 4 mm across. It proved impossible to make an enlarged print (with the available optics, presumably) so Ingenieur S. Widt was employed to make a sketch, which we reproduce in Figure 3(j). In this drawing, we begin to see the fine details of modern blue-sensitive imagery, such as the *B* image reproduced in Figure 3(k).

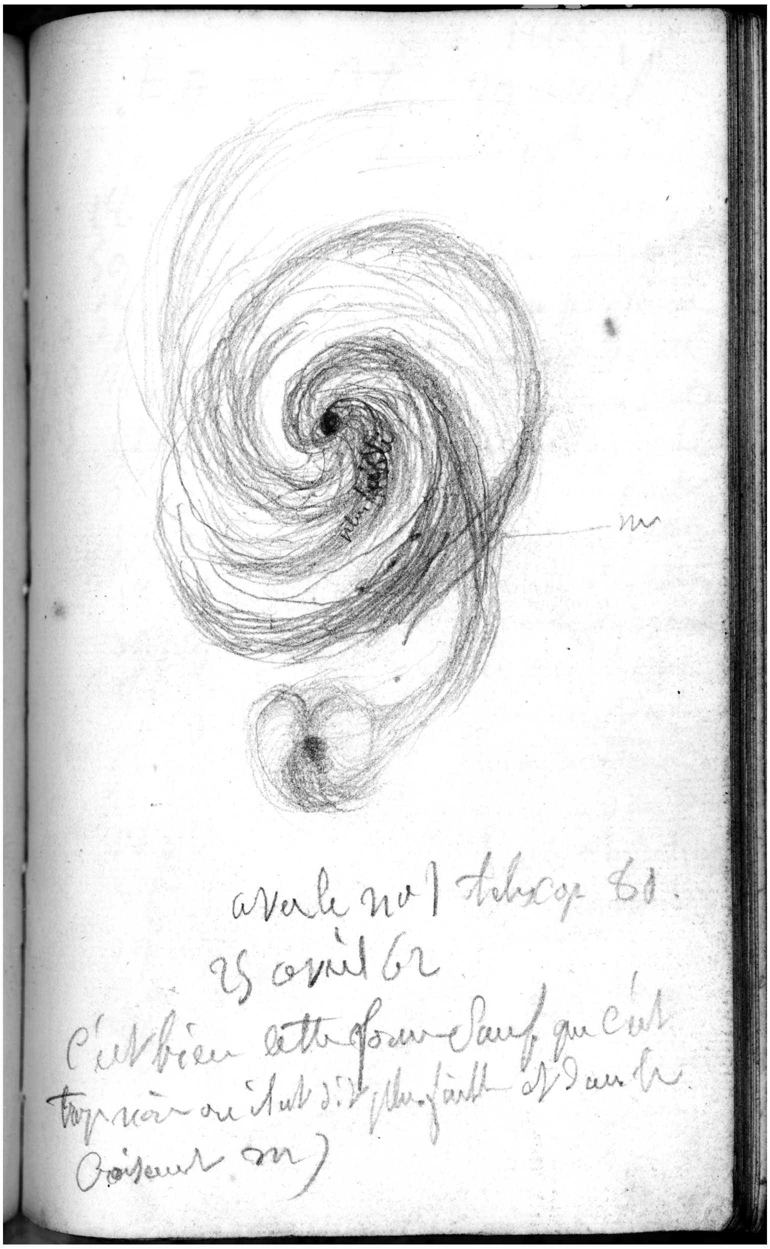
The following year (1889) saw the presentation of the first photographic enlargement of M51 to the Royal Astronomical Society, taken by Isaac Roberts on 28 April 1889 with a 20-inch silvered-glass reflector and a 4 hr exposure (Figure 3(l); Roberts, 1889).[13] Other nineteenth-century photographers of M51 included Carte du Ciel workers in Potsdam in 1891 (Schouten, 1919); S.K. Kostinsky (1867–1936) in Russia in 1896 (Kostinsky, 1916); W.E. Wilson (1851–1908) in Ireland in 1897 (Wilson, 1900; see also McNally and Hoskin, 1988); and J.E. Keeler (1857–1900) in California in 1899, using Common's telescope relocated to the Lick Observatory as the Crossley Reflector (Keeler, 1908).

4 SPECULUM METAL vs SILVERED GLASS

We now return to the question that sparked this paper: the relative optical quality of the Rosse and Foucault telescopes.

Much ink has been spilt concerning the image quality of the Leviathan. We will cite a nineteenth century example first. When discussing the advantages of reflectors for spectroscopy, the astronomy popularizer, Richard A. Proctor (1837–1888), noted (1869: 755) that heavy metal mirrors deform easily

> … [and] do not present objects in a perfectly distinct manner … It is on this account that we hear so little of any discoveries effected within the range of our own system by means of the great Parsonstown reflector. Far better views of the planets have been obtained by much smaller telescopes … [but resolution was less crucial] for the tiny cloudlets which shine from beyond the great depths of space.



avec le no 1 telescop 80.
25 avril 62
C'est bien cette forme sauf que c'est trop noir où il est dit plus faible et dans le croisement m)

Figure 2: Page from Chacornac's notebook dated "19 Avril 1862 au 19 Juillet 1862" on which he pencil-sketched the appearance of M51 through the 80-cm silvered-glass reflecting telescope at Paris Observatory. South is up. The notes read "*avec le N° 1 télescope 80. 25 avril 62. C'est bien cette forme sauf que c'est trop noir où il est dit plus faible et dans le croisement* m." On the drawing itself the central part of the arm coming out to the north is marked '*plus faible*' and the apparent cross-over of two arms is indicated '*m*' (courtesy: Bibliothèque de l'Observatoire de Paris.).

The Fourth Earl (Lawrence Parsons, 1840–1908) felt impelled to respond to this perceived slight on his late father's memory, and reprinted a letter from the always-eulogistical Robinson, who wrote of good observations of stars in 1845 and 1848 (Rosse, 1879-80: i), although another letter from observing assistant, G. Johnstone Stoney, was more measured (Rosse, 1879-80: iii), and Otto Struve remarked:

> … certainly with regard to definition (particularly where the mirror is considerably out of horizontal position) there are other instruments superior to it [the Leviathan]. (Rosse, 1879-80: v).

The Fourth Earl himself noted that every time the mirror was repolished, the Leviathan became

> … optically speaking a new one. It would be exceedingly difficult to give an estimate of its qualities in various seasons, and in the great majority of cases the value of an observation has been limited by bad atmospheric conditions [he is referring to poor seeing] rather than by imperfection of the instrument. (Rosse, 1879-80: 4).

The Fourth Earl added that the heavier of the two speculums made for the Leviathan was repolished frequently in early years when great efforts were being made to push the telescope's penetration to the utmost, and to improve the polishing process.

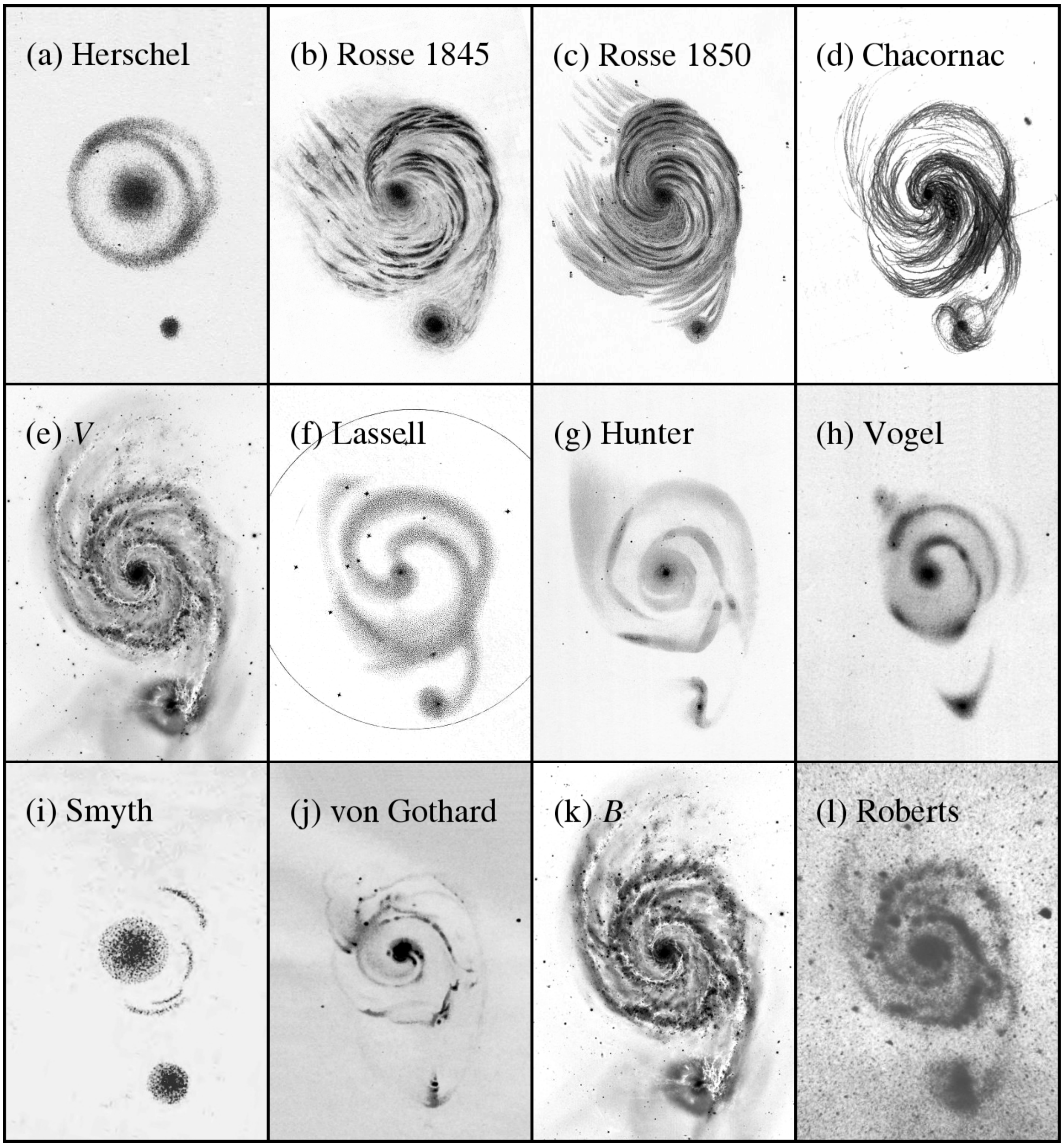


Figure 3: Twelve images of M51 plotted with the same orientation and scale. South is upwards and east to the right. The separation between the nuclei of the two nebulae is 4.6 arc minutes. (a) John Herschel's drawing of 1833. (b) Rosse's drawing of 1845, as given by Nichol (reproduced in negative). (c) Rosse's drawing of 1850. (d) Chacornac's drawing of April 1862. (e) Modern CCD image in the *V* band captured with the CFH12K camera on the Canada-France-Hawaii Telescope. (f) Lassell's drawing of June 1862. (g) Hunter's drawing of 1864, published in 1879. (h) Vogel's drawing of 1884. (i) Smyth's drawing published in 1890 (reproduced in negative). (j) Widt's drawing of von Gothard's photograph of 1888. (k) CFH12K CCD image in the *B* band. (l) Roberts' photograph from 1889 (reproduced in negative).

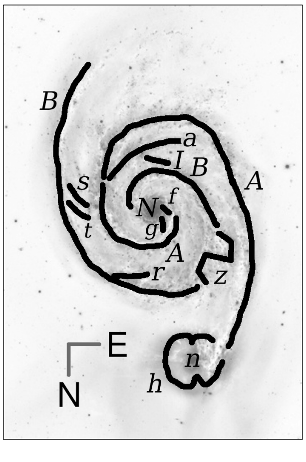


Figure 4: Identification of certain features in M51 (see the text). Catalogue designations specific to the principal nebula (surrounding *N*) include h1622, GC3572 and NGC 5194, with HI186, h1623, GC3574 and NGC 5195 for the companion.

An example of recent discussion of Leviathan image quality is provided by Thomson (2001), who compared Rosse descriptions and drawings with Digitized Sky Survey images and concluded that "… to have been able to see the amount of detail recorded in the descriptions I have selected, the telescope had to have been performing at an acceptable level." Yet much of this polemic seems unnecessary, for the Third Earl himself—who was renowned for his caution—recorded (1850: 502-503) that

> … we have not found that flexure, even to the extent of materially disfiguring the image of a large star, interferes much with the action of the speculum on the faint details of nebulae … [and that] it has often happened that a speculum which has subsequently proved to be incapable of very fine definition, has remained in the telescope during a succession of

> moderately good nights, when a great deal of work was done …

This was essentially Proctor's point.

What is remarkable about the early Rosse drawings is how both show long, thin structures (about 10 arcsec wide) within the spirals and to the south west. It is known that a low light levels, the eye is most sensitive to structure of a degree or so in extent, though the sensitivity extremum is broad, e.g. see Clark (1990; 2008) and Torres (2008). From information given by both these authors we have calculated that M51's spiral arms are sufficiently bright to be well above the detection threshold in both the Rosse and Foucault telescopes. Although we cannot be certain, we think the 'No. 1' eyepiece employed by Chacornac may have corresponded to 90× magnification[14] (and 7°, or about 7 resolution elements, between nuclei *N* and *n*), whereas the Leviathan was probably used at magnifications of 216 or more (Dewhirst and Hoskin, 1991: 263). (We note that both these minimum magnifications correspond to exit pupils slightly larger than the probable diameter of the observer's dark-adapted pupil.) It is now accepted that drawings of deep-sky objects need to be made using several magnifications,[15] and perhaps the thin structures noted in Figures 3(b) and 3(c) resulted from the higher magnification employed. Some of these fine structures are visible in both early Rosse drawings (e.g. at the eastern extremity of arm *A*, and on the outer south-east flank of arm *B*), but it is far from clear that the drawings represent independent observations. The double inner part of arm *A* in the 1850 drawing corresponds to a dust lane clearly delineated in the modern *V* image. But if they are real, what do the other long structures correspond to? They are missing of course from Herschel's drawing (lowest "… magnifying power habitually applied …" of 180×, Herschel, 1833b: 74), but also from Lassell's drawing, which was made mostly with 285× magnification (Lassell, 1867: 46), and, most-tellingly, from Hunter's drawing made with the Leviathan in 1864, which is much more alike in resolution of structure to the drawings made with other telescopes.

Kessler (2007) has noted the greater contrast between the arm and inter-arm regions in Rosse's 1845 drawing compared to his 1850 one, and has suggested that this may have been due to the desire to present a more visually-compelling image to the more-generalist audience at the British Association in the same way that the Hubble Heritage Project images of M51 are presented with more appealing colour and contrast than when the same imagery is reproduced in the scientific literature. Perhaps this was the case, but drawing nebulae was not an objective art. In a paper comparing the metal-mirrored Great Melbourne Telescope to Foucault's and other contemporary reflectors, Gascoigne (1996: 119) has noted a tendency for different observatories to develop individual artistic styles: "… drawings made with the Rosse telescope were bold and dramatic, those at Melbourne much more delicate." Rosse himself noted that in the feeble lamp-light necessary for sketching, the observer had a tendency to make stronger pencil marks than justified, and that in any case "… different eyes form a different estimate of the relative intensities of a nebula and its representation on paper." (Rosse, 1850: 509). Further, Figure 3(b) is considerably fatter, and Figure 3(c) is considerably thinner east-west than the reality; and the stars in the latter are on average some 20 arcsec different in location in the drawing from the measured positions tabulated by Rosse (1850: 510).[16] We conclude that the Rosse drawing should not be interpreted too literally. Indeed Rosse himself remarked concerning Figure 3(c) that "This nebula has been seen by a great many visitors, and its *general resemblance* to the sketch at once recognized even by unpractised eyes." (Rosse, 1850: 504; our italics).

What we find compelling about Chacornac's drawing is that he has seen the faint structures *a*, *r* and *h*, which are recorded on no other drawings. We find it difficult to believe that the Parisian sky was darker than at Parsonstown, and other things being equal, these features should have been more visible in the bigger telescope. We wonder if the Leviathan was more subject to scattered light. (Gascoigne (1996: 116) invokes scattered light as the reason why the Melbourne telescope failed to confirm Asaph Hall's discovery of the satellites of Mars.) Foucault himself was unimpressed by the Leviathan when he saw it in 1857: "Lord Rosse's telescope is a joke …" he wrote to a friend (Tobin, 2003: 204). In any case, it is clear that empirical polishing of speculum mirrors produced images which in no way rival modern ones. The spiral structure of M51 is visible in a modern reflector with 6-inches (150 mm) aperture (Clark, 2008), whereas it was not seen by John Herschel with 18¼-inches aperture but required Lord Rosse's 72 inches. Further, visual observations are not as uniform and reproducible as photographic plates or solid-state detectors. As Isaac Roberts (1889: 390) noted, "… all drawings alike fail to present to the eye proportions, details, and outlines as they are shown on photographs."

What is clear is that the combination of telescope and observer was better for the 80-cm than for any other nineteenth century drawing of M51, although of course this would not have been apparent at the time. We must regret that Chacornac never made a more polished drawing of M51 using Foucault's telescope. Perhaps he was put off by criticisms of its presentation to the Académie in the *London Review* a fortnight later (reprinted by Darby, 1864: viii), for soon afterwards he unambitiously claimed that he had no intention of comparing "… the Foucault telescope in point of power with the giant at Parsonstown." (Anonymous, 1862b: 482). There can, however, be little doubt of the 80-cm's superior optical performance, both because of its novel test-and-correct polishing procedure, and because, unlike the Leviathan, it *was* used for planetary and stellar observations, and continued in use for a hundred years. Gascoigne (1996) has pointed out that the speculum-mirrored Great Melbourne Telescope was more a conceptual than a technical failure: its major problem was that with an f/41 Cassegrain focal ratio it was only useful for drawing nebulae, which by the time it was built was an astronomical dead-end. The failure in the 1870s of large silvered-mirror telescopes at the Paris and Edinburgh Observatories (with apertures of 120-cm and 24-inches, respectively) set back the cause of reflectors, but ultimately the astonishing quality of nebular photographs obtained with metal-on-glass reflecting telescopes was a major factor that led to the dominance of these instruments in the twentieth century (see Osterbrock, 1985).

5 FROM M51 TO THE WHIRLPOOL NEBULA

While on the question of M51, it is interesting to inquire when the popular name 'Whirlpool' became associated with this object. The burgeoning availability of full-text search capabilities on digitized nineteenth century journals, newspapers and books makes it possible to address this question, and the example of the Whirlpool has been presented fully elsewhere as a case study (Tobin, 2008). To summarize the findings, the astronomical use of 'Whirlpool' probably originates with Nichol, who used it as early as 1833, well before the discovery of spiral structure, as a metaphor in discussion of the Kant-Laplace nebular theory for the origin of the Solar System (Nichol, 1833: 63). As early as three years after the Leviathan's discovery one finds reference to "Lord Rosse's Whirlpool or Spiral Nebula …" (Mitchel, 1848: 336) where it is unclear whether 'Whirlpool' and 'Spiral' are used nominatively for M51 alone or as descriptive of a class of objects of which M51 is but one. Both usages occur in subsequent decades, but by the beginning of the twentieth century 'spiral' had become associated with the class, with 'Whirlpool' reserved for M51 alone. The 'Whirlpool' appellation for M51 first appeared in an astronomical journal in 1903, in the *Astronomical Journal* (Schaeberle, 1903: 182).

6 CONCLUDING REMARKS

Le Verrier had a reputation for firing staff who incurred his displeasure, and he tried to remove Foucault at least twice (Tobin, 2003: 204, 211). In January 1862 Chacornac recorded that a M. Harlant, one of the *aides astronomes*, had been told to quit the Observatory

> … on account of recidivist behaviour and scaling the Observatory railings with a ladder … [and that] M. L[e] V[errier] had the intention of giving his position to someone else ... and it was imperative that he should be dismissed as soon as possible ...

On 3 February, Chacornac noted "First news of M. Biot's death. I have lost my ..." and then to preserve the privacy of his musings, he slipped in a word in shorthand, which we have been able to decipher as "Excellency", in the now-archaic sense of an excellent personality, followed by "L[e] V[errier] is going to [mistreat] me …" where "mistreat" is again in shorthand.[17] Here we can see forebodings of Chacornac's expulsion from the Observatory a year later. According to Le Verrier (1863), Chacornac had been "… carried away by Parisian life …" and had neglected his duties at the Observatory, failing, for example, to beat the Americans to the detection of the companion of Sirius. But, in addition, Chacornac was losing his reason, provoked possibly by unfounded accusations of theft of Observatory cash and other crimes. On the night of 3-4 June 1863 he roamed around Paris, ending up in police custody. Struck with *alienation mentale* at the age of 39, he was put on sick leave at half pay and retired to Lyons. Others saw these events less starkly. One of Chacornac's obituary writers, Georges Rayet (of Wolf-Rayet stars), later penned the following evaluation: "… his exaggerated sense of responsibility and anxieties repeatedly renewed ... slowly affected his health." (Rayet, 1873: 334). We can sense Le Verrier's baneful influence by reading between the lines of the "anxieties repeatedly renewed". The Abbé Moigno's comment was similar when he "… greatly regretted the very sad combination of circumstances that broke both his career and his strength." (Moigno, 1873). In Lyons, Chacornac constructed a small private observatory and devoted time to the study of sunspots.

Chacornac's sketch is the most accurate of the pre-photographic images of M51. Although it cannot be used to make a stringent comparison of the performance of the Foucault and Rosse telescopes, it does testify to the quality of both the French telescope and the French observer. We must regret that, unlike Rosse's drawings, it was not widely publicized. This perhaps reflects the institutional contexts. Lord Rosse, as an amateur, could choose to participate in nebular research, which was still in its descriptive phase (even though the discovery of spiral structure had immediately raised dynamical speculations).[18] At the Paris Observatory, however, where the dominant theme was analytical celestial mechanics, the study of nebulae was considered as marginal. Nevertheless, the major use of Foucault's telescope once in Marseilles was the discovery of over 500 faint nebulae (e.g. Esmiol, 1916), so it is fitting that one of its first uses should have been to produce such an astounding representation of the Whirlpool Nebula.

7 NOTES

1. As has recently been pointed out (Bailey, et al., 2005), some mystery surrounds the discovery of spiral structure. M51 was observed with the Leviathan by Rosse, Dr Thomas Romney Robinson and Sir James South in early March 1845, but spiral structure was not explicitly noted. Bailey et al. speculate (with plausible supporting evidence) that this was because the immediate concern was the nature of nebulae and their resolvability into stars; it was only once the observers had addressed this question that they remarked upon the extraordinary spiral structure.
2. All at call number F14.
3. Administrative files relating to Chacornac's career can be found in the Archives Nationales under call numbers F^{17} 2844(1), F^{17} 22785, F^{17} 40062 and L467033. For obituaries, see Rayet (1873) or the very-similar Fraissinet (1873). The latter disagrees with Poggendorff (1898: 256) concerning the date of death, which both (along with Figuier, 1874: 549) claim occurred in Villeurbanne, near Lyons. From the French *état civil* we have ascertained that Chacornac in fact died at St Jean en Royans, in the *département* of the Drôme, on 6 September 1873.
4. Despite their personal nature, their survival is presumably due to the authoritarian Le Verrier having deemed them to be Observatory property.
5. Venus was observed with "No. 3", presumably at higher magnification.
6. This drawing is not in Chacornac's notebooks, although there are splendid drawings of Jupiter and Saturn made with the 40-cm Foucault telescope on 6 May 1860.
7. A painting of Rosse surrounded by several drawings of spiral nebulae is reproduced by Brück (1988: Figure 7). Kessler (2007: 481) reproduces a sketch of M51 from the Birr Castle observing books as well as Rosse's BAAS drawing.
8. The absence of any stars on Chacornac's drawing—or any notes about them in his notebook—raises the

question of whether he might have made a second, more-detailed drawing that night, which would then have been the one presented to the Académie. We cannot exclude this possibility, but given the precision of the drawing presented here we do not believe it likely that he immediately embarked on a second drawing. Keen to keep up a stream of results from the new telescope, we feel Le Verrier would not have hesitated to present the sketch reproduced here, which does not contradict the following description provided by Moigno (1862): "The motion in spirals or vortexes of the nebular matter is perfectly outlined, and in addition one sees that the centres of the two vortices are occupied by two stars." As mentioned by Tobin (1987: note 44), there is no drawing in the *pochette* (file) relating to the meeting in the Académie archives.

9. Identified via the NASA Astrophysics Data System, general reading, and two 1870s bibliographies (Knobel, 1876 and Holden, 1877).
10. Holden (1877: 76) notes that an earlier drawing of M51 is to be found in some copies of Vogel (1867), but there was no drawing in any of the three copies that we have been able to consult.
11. For the development of astronomical photography, see Rayet (1887) or Norman (1938).
12. On von Gothard, see Vincze et al. (2003).
13. Roberts (1889) only discussed the photograph, which was reproduced later (Roberts, 1893: Plate 30).
14. Although the draft of the contract with the optician specifies a set of eight eyepieces (Observatory archives, MS 1060 III-B-11 "Paris le 18 septembre. Construction d'un télescope en verre argenté et du diamètre de $0,^{m}80$"), it is far from clear that these were immediately available, though the prism and relay lenses to bring the Newtonian focus outside the tube must have been. From Chacornac's jottings concerning eyepieces in his final notebook we think that he may have used an eyepiece borrowed from the 'micromètre de Gambey à fils fin' which we deduce had a focal length of 50.0 mm.
15. Clark (2008) presents a series of drawings of M51 made with a 12-inch telescope and different magnifications that illustrate the finer detail detected at higher magnification.
16. Mean difference calculated assuming the *nN* distance tabulated by Rosse is correct, whereas it is actually about 5% too small. Adopting the modern value reduces the mean difference by about 10%.
17. Chacornac's shorthand is essentially that devised by Aimé Paris (1798–1866), e.g. Paris and Queyras (1862).
18. E.g. Rosse's own comment on M51 (1850: 504) that "… we cannot regard such a system in any way as a case of mere statical equilibrium …"; or Nasmyth (1855).

8 ACKNOWLEDGMENTS

We thank Josette Alexandre and Dominique Monseigny of the Paris Observatory for providing an image of Chacornac's drawing; Hans Zinnecker for copies of other drawings; Jean-Charles Cuillandre for permission to use his modern images of M51; and François Wesemael for relaying census information on Chacornac.

9 REFERENCES

Anonymous, 1862a. The great Foucault telescope. *Intellectual Observer*, 1, 380-381.

Anonymous, 1862b. The Great Spiral Nebula. *Intellectual Observer*, 1, 481-482.

Bailey, M.E., Butler, C.J., and McFarland, J., 2005. Unwinding the discovery of spiral nebulae. *Astronomy & Geophysics*, 46, 2.26-2.28.

Ball, R.S., 1895. *Great Astronomers*. London, Ibister.

Brück, M.T., 1988. The Piazzi Smyth collection of sketches, photographs and manuscripts at the Royal Observatory, Edinburgh. *Vistas in Astronomy*, 32, 371-408.

Chacornac, [J.], 1867. L'éclipse de soleil du 6 Mars 1867 observée a Villeurbanne-lès-Lyon. *Annales des Sciences Physiques et Naturelles Publiées par la Société d'Agriculture de Lyon,* 3ème série, 11, 543-546 and plates.

Chambers, G.F., 1890. *A Handbook of Descriptive and Practical Astronomy, Volume III. The Starry Heavens.* Fourth edition. Oxford, Clarendon Press.

Clark, R.N., 1990. *Visual Astronomy of the Deep Sky.* Cambridge, Cambridge University Press.

Clark, R.N. 2008. http://www.clarkvision.com/visastro/index.html and links (accessed January 2008).

Common, A.A., 1888. Photographs of nebulæ. *The Observatory*, 11, 390-394.

Darby, W.A., 1864. *The Astronomical Observer. A Handbook to the Observatory and the Common Telescope.* London, Hardwicke.

Dewhirst, D.W., and Hoskin, M., 1991. The Rosse spirals. *Journal for the History of Astronomy*, 22, 257-266.

Esmiol, E., 1916. Réduction des observations de nébuleuses découvertes par M. Stephan. *Travaux de l'Observatoire de Marseille*, 4, xi-xvi and 1-67.

Figuier, L., 1874. *L'Année Scientifique et Industrielle: Dix Septième Année (1873).* Paris, Librairie Hachette.

Foucault, L., 1862. Note sur un nouveau télescope de l'Observatoire Impérial. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, 54, 859-861.

Fraissinet, A., 1873. Chacornac. *La Nature*, 1, 358-360.

Gascoigne, S.C.B., 1996. The Great Melbourne Telescope and other 19th-century reflectors. *Quarterly Journal of the Royal Astronomical Society*, 37, 101-128.

Guillemin, A., 1862. Une nouvelle comète. *L'Illustration*, 40, 175-176. [The drawing is reproduced as Figure 12.35 in Tobin, 2003.]

Herschel, J.W.F., 1833a. Observations of nebulae and clusters of stars, made at Slough, with a twenty-feet reflector, between the years 1825 and 1833. *Philosophical Transactions of the Royal Society of London*, 123, 359-505 and plates.

Herschel, J.F.W., 1833b. Remarks on a fifth catalogue of double stars. *Memoirs of the Royal Astronomical Society*, 6, 74-81.

Holberg, J.B., and Wesemael, F., 2007. The discovery of the companion of Sirius and its aftermath. *Journal for the History of Astronomy*, 38, 161-174.

Holden, E.S., 1877. Index catalogue of books and memoirs relating to nebulæ and clusters, etc. *Smithsonian Miscellaneous Collections*, 14, No. 311.

Hoskin, M., 1982. The first drawing of a spiral nebula. *Journal for the History of Astronomy*, 13, 97-101.

Keeler, J.E., 1908. The Crossley Reflector of the Lick Observatory. *Publications of Lick Observatory*, 8, 11-46 and plates (where M51 is reproduced as Plate 47).

Kessler, E.A., 2007. Resolving the nebulae: the science and art of representing M51. *Studies in the History and Philosophy of Science*, 38, 477-491.

Knobel, E.B., 1876. Reference catalogue of astronomical papers and researches. *Monthly Notices of the Royal Astronomical Society*, 36, 365-392.

Kostinsky, S., 1916. Probable motions in the spiral nebula Messier 51 (Canes Venatici) found with the stereo-comparator. *Monthly Notices of the Royal Astronomical Society*, 77, 233-234.

Lassell, W., 1867. Miscellaneous observations made with the four-foot equatoreal at Malta. *Memoirs of the Royal Astronomical Society*, 36, 33-51 and plates.

Le Verrier, U.J., 1862a. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, 54, 626-628.

Le Verrier, U.J., 1862b. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, 54, 1012.

Le Verrier, U.J., 1862c. *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, 54, 888-889.

Le Verrier, U.J., 1863. Letters to the Minister of Public Instruction dated 14 August and 10 October, in Archives Nationales Box F^{17} 22785.

McNally, D., and Hoskin, M., 1988. William E. Wilson's Observatory at Daramona House. *Journal for the History of Astronomy*, 19, 146-153, where M51 is reproduced from the original plate as a negative in Figure 4.

Mitchel, O.M., 1848. *The Planetary and Stellar Worlds.* New York, Baker & Scribner.

[Moigno, F.], 1862. *Cosmos*, 20, 513.

[Moigno, F.], 1873. Nécrologie. *Les Mondes*, 32, 101.

Murdin, P. (ed.), 2001. *Encyclopedia of Astronomy & Astrophysics*. Bristol, IOP.

Nasmyth, J., 1855. Suggestions respecting the origin of the rotary movements of the celestial bodies and the spiral forms of the nebulae as seen in Lord Rosse's telescope. *Monthly Notices of the Royal Astronomical Society*, 15, 220-221.

[Nichol, J.P.], 1833. On some recent discoveries in astronomy. *Tait's Edinburgh Magazine*, 4, 57-64.

Nichol, J.P., 1846. *Thoughts on Some Important Points Relating to the System of the World.* Edinburgh, William Tait. [Figure 3(b) is actually copied from the second edition of this book, 1848: Edinburgh, John Johnstone, Plate VII.]

Norman, D., 1938. The development of astronomical photography. *Osiris*, 5, 560-594.

O'Meara, S.J., 2006. Méchain's unsung discovery. *Sky & Telescope*, 112 (3), 62-63.

Osterbrock, D.E., 1985. The quest for more photons: how reflectors supplanted refractors as the monster telescopes of the future at the end of the last century. *The Astronomy Quarterly*, 5, 87-95.

Paris, A., and Queyras, H., 1862. *La Sténographie Popularisée*. Paris, Queyras.

Poggendorff, J.C., 1898. *Biographisch-Literatisches Handwörterbuch, Dritter Band (1858 bis 1883).* Leipzig, Barth.

Proctor, R.A., 1869. The Rosse telescope set to new work. *Fraser's Magazine for Town and Country*, 80, 754-760.

Rayet, G., 1873. Chacornac. *Revue Scientifique de la France et de l'Étranger*, 12, 334-335.

Rayet, [G.], 1887. Notes sur l'histoire de la photographie astronomique. *Bulletin Astronomique*, 4, 307-320 and 344-360.

Roberts, I., 1889. Photograph of the nebula M51 Canum Venaticorum. *Monthly Notices of the Royal Astronomical Society*, 49, 389-390.

Roberts, I., 1893. *A Selection of Photographs of Stars, Star Clusters & Nebulae*. London, Universal Press.

Rosse, The [Third] Earl of, 1850. Observations on the nebulae. *Philosophical Transactions of the Royal Society of London*, 140, 499-514 and plates.

Rosse, The [Third] Earl of, 1861. On the construction of specula of six-feet aperture; and a selection from the observations of nebulae made with them. *Philosophical Transactions of the Royal Society of London*, 151, 681-745 and plates.

Rosse, Hon. the [Fourth] Earl of, 1879-1880. Observations of nebulae and clusters of stars made with the six foot and three-foot reflectors at Birr Castle, from the year 1848 up to about the year 1878. *Scientific Transactions of the Royal Dublin Society (New Series)*, 2, i-v, 1-178 and plates.

Schaeberle, J.M., 1903. The ring nebula in Lyra and the dumb-bell nebula in Vulpecula, as great spirals. *Astronomical Journal*, 23, 181-182.

Schouten, W.J.A., 1919. Probable motions in the spiral nebula Messier 51 (Canes Venatici). *The Observatory*, 42, 441-444.

Tobin, W., 1987. Foucault's invention of the silvered-glass reflecting telescope and the history of his 80-cm reflector at the Observatoire de Marseille. *Vistas in Astronomy*, 30, 153-184.

Tobin, W., 2003. *The Life and Science of Léon Foucault: The Man who Proved the Earth Rotates*. Cambridge, Cambridge University Press.

Tobin, W., 2008. Full-text search capability: a new tool for researching the development of scientific language. The 'Whirlpool Nebula' as a case study. *Notes and Records of the Royal Society*, 62, 187-196.

Torres, J.R., 2008. http://www.uv.es./~jrtorres (accessed January 2008).

Thomson, M.J., 2001. Revealing the Rosse spirals. *Astronomy & Geophysics*, 42, 4.9-4.10.

Vincze, I.J., Jankovics, I., and Kovács, J., 2003. Gothard astrophotographic plate library: digitization and archiving of the original plates taken by Eugen von Gothard at the end of the XIX century. In Corbin, B., Bryson, E., and Wolf, M. (eds). *Library and Information Services in Astronomy IV.* Washington, U.S. Naval Observatory. Pp. 394-398.

Vogel, H.C., 1867. *Beobachtungen von Nebelflecken und Sternhaufen am sechsfüssigen Refractor und zwölffüssigen Aequatoreal der Leipziger Sternwarte ausgeführt.* Leipzig, Engelmann.

Vogel, H.C., 1884. Einige Beobachtungen mit dem grossen Refractor der Wiener Sternwarte. *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, 4(1), Nr. 14.

Vogel, H.C., 1888. Ueber die Bedeutung der Photographie zur Beobachtung von Nebelflecken. *Astronomische Nachrichten*, 119, 337-342 and plate.

[Wilson, W.E.], n.d. [but 1900]. *Astronomical and Physical Researches Made at Mr. Wilson's Observatory, Daramona, Westmeath.* London, printed for the author.

Wolf, C., 1886. Le rôle des grands instruments dans les observations astronomiques. *Ciel et Terre*, 7, 97-108 and 128-38; translated in *Astronomical Register*, 24 (1886), 197-205 and 225-232, where page 129 becomes page 225.

Dr William Tobin recently retired to France from a Senior Lectureship in Physics and Astronomy at the University of Canterbury, New Zealand. He has published a highly-illustrated, comprehensive biography of Léon Foucault (see references), the French adaptation of which was awarded the *Prix special du jury* of the *Prix du livre de l'astronomie—Haute Maurienne-Vanoise 2003.*

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ERNESTO VASCONCELLOS' *ASTRONOMIA PHOTOGRAPHICA*: THE EARLIEST POPULAR BOOK ON ASTRONOMICAL PHOTOGRAPHY?

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Abstract: Portugal, albeit with its own cultural distinctiveness, was not immune to the ideologies permeating nineteenth-century European society, in particular those concerning the social advantages of science and science popularisation. The country's high illiteracy rate hampered but did not prevent several popularisation efforts, which were usually led by professors and armed forces officers. In 1886 *Astronomia Photographica* (*Astronomical Photography)* a book popularising astrophotography, was published in Lisbon as part of a collection entitled *People and Schools Library*. The book seems an odd editorial choice given that, at the time, Portugal's major astronomical institutions pursued astrometric research and there was a virtual absence in the country of amateur astronomers. International astronomical developments, the author's interest in the scientific applications of photography and even the editorial timing are likely explanations for the publication of *Astronomia Photographica*, but we believe a definitive answer is still not available. The style of *Astronomia Photographica* is historical and informative, without being technical; clearly it is not a 'hands-on guide'. The contents of the book show that the author, Ernesto Júlio de Carvalho e Vasconcellos, a naval officer, contacted several experts and was aware of the latest developments in astronomical photography. What makes this a unique book is its content, and its inclusion in a popularisation collection with an exceptionally high circulation at such an early time.

Keywords: popularisation of science, astronomical photography, Ernesto de Vasconcellos

1 INTRODUCTION

Different motivations for the nineteenth-century trend of science popularisation have been proposed: a means to maintain social stability; a way of caring for the needs of literate, leisured and well-to-do social groups; or a process to provide 'useful knowledge' for the workshop and the home (Sheets-Pyenson, 1985). Conferences, periodicals and books played a complementary role in this effort. In particular there was the publication of low-price volumes dealing with a wide range of subjects. Sometimes these came in the form of collections, which every so often were called 'libraries' (Béguet, 1994). In Portugal during the nineteenth century

> … there was faith in this instruction. It was forcefully mentioned that ignorance makes man perverse and that education and instruction are the bases of the social edifice. Sometimes, in more practical reflections, the benefits for economic development were also considered. (Torgal, 1993).

In 1870, D. António da Costa, the first Portuguese Minister of Education, wrote that

> The universalisation of instruction multiplies the wealth of the nation … since popular instruction creates a large financial capital in the development of the spirit. With increasing knowledge workers and labourers are more capable and as a consequence industrial and agricultural goods will be more profitable.

Following international trend during the late 1830's, societies aiming to popularise scientific knowledge started to appear in Portugal. The high illiteracy rate threatened the sustainability of popularisation projects, but cheaper publications resulting from developments in printing techniques helped the sales, even if the illiteracy levels did not change significantly (Matos, 2000). *Popular Almanacs* (*Almanaques Populares*, 1848), *Books for the People* (*Livros para o Povo*, 1859), *Popular Education* (*Educação Popular*, 1870) and *Popular Library or Instruction for all the Classes* (*Bibliotheca Popular ou Instrucção para todas as Classes*, 1870) are all examples of serial 'libraries' that were published in Portugal during the nineteenth century (Torgal and Vargas, 1993). In this popularisation endeavour, university and polytechnic professors as well as armed forces officers played a fundamental role (Malaquias and Gomes, 2006).

2 THE *BIBLIOTHECA DO POVO E DAS ESCOLAS* COLLECTION

In 1870 David Corazzi (1845–1896) started a publishing house in Lisbon, and until 1880 the editorial line of the company, Empresa Horas Romanticas (see Figure 1), was essentially characterised by historical, sensational and science fiction novels. Corazzi was, for instance, Jules Verne's first Portuguese publisher (Viana, 1990). In 1881 Corazzi started a new collection of popular books entitled *People and Schools Library* (*Bibliotheca do Povo e das Escholas*, henceforth BPE), which aimed to be "Instructional Propaganda for Portuguese and Brazilians." The BPE books were available in Portugal and Brazil (where Empresa Horas Romanticas had an office), as well as through a wider distribution network (Domingos, 1885; Venâncio, 2004). Concern for the BPE southern hemisphere readers appears, for instance, in Volume 10, *Popular Astronomy* (*Astronomia Popular*), where one reads: "Our Brazilian readers will easily find all the stars indicated by taking as a starting point the beautiful constellation of the Southern Cross." (Mello, 1881). Nonetheless, the BPE authors were mainly Portuguese, with only two identified Brazilian contributors, José de Mello—the author of the *Popular Astronomy* book—and Viriato Silva (Nascimento and Santos. 2006). Many of these early authors were former students of the Lisbon Polytechnic School (Escola Politécnica de Lisboa) or members of the armed forces.

A BPE title contained 64 pages of low-quality paper in a 10.0 by 15.5 cm format. Each volume cost 50 reis, which was also the price in 1886 of *Campeão das Provincias*, a 4-page biweekly Aveiro newspaper. The books were illustrated, but the number of figures varied substantially from volume to volume depending upon the subject matter. Eight successive volumes constituted a series. Initially the books were published on the 10th and 25th of each month. The collection continued until 1913, but the bimonthly publication schedule was only maintained until 1885; from 1886 to 1891 volumes appeared, on average, monthly, and from 1892 an irregular pattern developed. In all, a total of 237 volumes was published (Domingos, 1985).

The range of BPE topics covered was rather extensive, and an indication of the variety can be ascertained by examining the titles of the first series: *History of Portugal*, *General Geography*, *Mythology*, *Introduction to the Physical and Natural Sciences*, *Practical Arithmetic*, *Zoology*, *Portuguese Chorography* and *Elementary Physics*. According to Domingo's (1985), the BPE did not have the concern, the necessity or the ability to organise knowledge or share it in a systematic way, but the underlying concept was an encyclopedia, a tree of knowledge in which the basic volumes would be published first, allowing for a later increment in subject matter and complexity, as well as permitting new ramifications to appear following the establishment of connections between different fields of endeavour. The BPE's first editor, Xavier da Cunha (1840–1920), recognised this explicitly while presenting the book *Steam Machines* (*Máquinas a Vapor*, BPE Number 74), that was inevitably preceded by *Mechanics* (*Mecânica*, BPE Number 66) and logically followed by *Stoker-machinist Manual* (*Manual do Fogueiro-machinista*, BPE Number 80). Cunha took as a model "… similar collections published in France, Italy and other countries that march in the vanguard of civilisation." But at the same time he planned to improve upon some of these foreign collections by having a broad editorial approach and publishing only high-quality volumes (Cunha, 1881). The gamble in producing a quality inexpensive project paid off, and the publication had both critical acclaim and popular success. The BPE received several international prizes and the Portuguese Government adopted various early books as textbooks for primary and secondary schools (Nascimento and Santos, 2006; Cunha, 1883).

The number of printed copies of the first two series was indicated in the books. While some discrepancy exists between circulation numbers quoted by different authors, we have verified that Number 6 and 7 had a print run of 12,000 while 15,000 copies of Number 11 were issued (see Domingos, 1985; Lacerda, 1881; Leitão, 1881; Nascimento and Santos, 2006; Sousa, 1881). We should point out that at the time these high edition numbers were exceptional for Portugal, and quite impressive even for larger countries such as Great Britain (Secord, 2001). A number of the earlier BPE volumes had several editions. For example, Number 10, *Popular Astronomy*, had a first edition of 15,000 copies in May 1881, and a second edition was printed approximately one year later (Mello, 1882; Nascimento and Santos, 2006). Unfortunately information concerning the number of copies printed ceased for the majority of the second and later editions, and from the third series onwards, i.e. above Number 16 in the collection. So it is tantalising to conjecture how many copies of *Astronomia Photographica* were printed, given that no factual information exists and the publisher's records are lost (Domingos, 1985). The copy of *Astronomia Photographica* that we found in the *Portuguese National Library* (Biblioteca Nacional) dates to 1915, and this might point to weaker sales than envisaged since this volume simply looks like a re-packaging of the leftovers from a previous edition (Vasconcellos, 1915). A new unchanged edition of a twenty-nine year old book—even if Vasconcellos was still alive—without any account of new developments that had occurred in astronomical photography, seems to us unlikely.

Figure 1: The headquarters of the BPE publisher, Empreza Horas Romanticas, in Rua da Atalaya, 40 Lisboa (after *Almanach Illustrado do Ocidente*, 1887).

3 THE AUTHOR OF *ASTRONOMIA PHOTOGRAPHICA*

Ernesto Júlio de Carvalho e Vasconcellos (see Figure 2) was born in Almeirim on 16 September 1852. He entered the Portuguese Navy in 1864, as 'Aspirante a Guarda Marinha', aged 11, and completed the preparatory course at the Lisbon Polytechnic School in 1872 and graduated from the Naval Academy (Escola Naval) in 1874. In 1878, after serving in various naval vessels, he was nominated auxiliary to the Hydrographic Section, a position that he held until 1880. In 1878-1879 he attended classes in 'Astronomy and Geodesy' and 'Mineralogy and Geology' at the Lisbon Polytechnic School, and 'Topography' and 'Practical Geodesy, Rivers and Canals' at the Military School (Escola Militar), all of which formed part of the degree of a hydrographic engineer. In 1880 Vasconcellos was granted approval to complete the degree (Arquivo da

Marinha Portuguesa, Livro Mestre B; C), and by 1883 he had completed the associated apprenticeship.

As early as 1881, Vasconcellos tried to obtain a teaching position in the Naval Academy. In his bid for the second discipline vacancy he wrote a dissertation published in 1884 entitled *A Astronomia Photographica* (*The Astronomical Photography*) (Vasconcellos, 1884). Vasconcellos failed in his objective, but an updated version of his dissertation was published two years later in the BPE collection. On 23 September 1884 the Portuguese Government appointed Vasconcellos to superintend the launch of the telegraphic cable between Dakar (Senegal) and Luanda (Angola), and he left for London on 26 July 1885 and returned to Lisbon on 6 January 1886 after completing the first part of his mission. On 29 May 1886 he embarked again from Lisbon to superintend the second leg of the telegraphic cable, returning to Lisbon on 10 November. The Government commended the successful completion of his mission. Three years later he was again nominated for a similar endeavour, this time to supervise the telegraphic connection between Luanda and Cape Town (South Africa) (Arquivo da Marinha Portuguesa, (b)). It is not surprisingly, therefore, that Vasconcellos' second book, published in 1889, was titled *Submarine Cables* (Cabos Submarinos) (Grande Enciclopédia Portuguesa e Brasileira).

Figure 2: At the time of publication of *Astronomia Photographica*, Ernesto de Vasconcellos was 33 years old, two years younger than shown in this photograph (after Sociedade de Geografia de Lisboa, 1931).

As the years progressed, Vasconcellos carved out a distinguished career as a Navy officer, cartographer and geographer. He published several articles and books in these two fields, and in particular he was an expert on the former Portuguese colonies. He taught at the Naval Academy and at the Colonial School (Escola Colonial), and represented Portugal at several international geographical congresses (Berne 1890, Berlin 1899, Geneva 1909, Sao Paulo 1910 and Rome 1913). He was twice a member of the Portuguese Legislative Assembly, and he served on several parliamentary commissions (Grande Enciclopédia Portuguesa e Brasileira).

Vasconcellos was accepted as a member of the Lisbon Geographical Society (Sociedade de Geografia de Lisboa, henceforth SGL) in 1878, three years after its foundation, and he was actively involved in Society business right up until his death. He belonged to the SGL committee for more than forty years, and from 1911 onwards he was the Society's Secretary (Sociedade de Geografia, 1881; Grande Enciclopédia Portuguesa e Brasileira). At the time of his death, on 15 November 1930, Ernesto Júlio Carvalho de Vasconcellos was an Admiral in the Portuguese Navy.

There is evidence that Vasconcellos had an early interest in the the scientific applications of photography. An 1881 article published in the SGL bulletin entitled *Phototopography or Photographic Topography* starts by stating that

> … one of the most interesting applications of modern science is surely the determination of the constitution of celestial objects by spectral analysis. This technique was first applied by Kirchhoff and later Rutherfurd, of New York, applied the photography to record the solar spectrum.

The article continues with a short explanation of the phototopography technique and its advantages, in particular in situations where maps must be speedily obtained, namely on expeditions (Vasconcellos, 1881). In *A Astronomia Photographica* Vasconcellos (1884) thanks Aimé Laussedat for advice provided concerning photographic matters. Laussedat not only developed the photogrammetry technique in the 1850's (Eder, 1945: 398) but he also pioneered the use of a horizontal telescope for photographing the 18 July 1860 solar eclipse (Laussedat, 1860).

Vasconcellos' contact with astronomy is more difficult to ascertain, the publication of *Astronomia Photographica* being his only known contribution in the field, and we believe it was restricted mainly to his student years. During his hydrographic engineering apprenticeship, Vasconcellos studied at the Lisbon Royal Astronomical Observatory (Real Observatório Astronómico de Lisboa) under the supervision of the institution's Director and Sub-director, Frederico Augusto Oom (1830–1890) and César Augusto de Campo Rodrigues (1836–1919) respectively (Vasconcellos, 1920). Following the 22 December 1870 total solar eclipse, João Carlos de Brito Capello (1831–1901), who worked at the Infante D. Luiz Observatory started a programme of daily solar photography to study possible connections between solar activity and the Earth's magnetic field. The photographs obtained were considered amongst the best available in the early 1870's, and one was published in the second volume of Secchi's *Le Soleil* (1877). However, this program had finished by 1880 (Bonifácio et al., 2007). Unquestionably, Vasconcellos was aware of this program's existence for in *Astronomia Photographica* there is a description of the equipment used and of the results obtained at the Infante D. Luiz Oobservatory. Vasconcellos (1886b) also thanks Brito Capello for allowing the study of a Jules Janssen solar photograph.

In 1881, as part of his engineer apprenticeship, Vasconcellos was sent to the Infante D. Luiz Observatory in order to practise the taking meteorological and magnetic observations, especially those with hydrographic applications (Moreira, 1881). Outside the Infante D. Luiz Observatory there were also abundant opportunities for Capello and Vasconcellos to meet, as both men were naval officers and members of the Lisbon Geographical Society, Brito Capello being one of the SGL founders.

Curiously, we found that later in life Vasconcellos played a small part in the planning of the famous 29 May 1919 British total solar expedition eclipse, which confirmed Einstein's Theory of General Relativity. Arthur Hinks, who was Secretary of the Royal Geographical Society, studied the possible geographical locations for the British expeditions. As such he wrote to the SGL asking for advice concerning Principe Island in the São Tomé Archipelago. As the Society's Secretary, Vasconcellos replied, and he gave a favourable assessment of Principe's location as described in Hinks' (1917) presentation to the Royal Astronomical Society in November 1917. Vasconcellos (1886a) had a personal knowledge of this island as he was responsible for the map of the island that was published in 1886. At its 10 November 1917 meeting the British Joint Permanent Eclipse Committee decided to send, if possible, expeditions to both Sobral (Brazil) and Principe Island (Dyson et al., 1920).

4 ASTRONOMICAL PHOTOGRAPHY IN THE NINETEENTH CENTURY

From its beginnings the scientific applications of photography and specifically in an astronomical context had been considered (Arago, 1858). Correctly exposed daguerreotypes of the solar surface, the solar spectrum, the partially-eclipsed Sun and the Moon were all obtained in the early 1840's. In the 1850's and 1860's photographs of the Sun, Moon, Donati's Comet and total solar eclipses were secured. Following these early successes and the disappointing 1874 transit of Venus results, the decade 1875-1885 saw a series of new and important achievements in this field. Briefly we should point to the following photographs: the Sun by Janssen in 1877; the spectra of celestial bodies by Draper and Huggins in 1879; the Orion Nebula by Draper and Common in 1880 and 1883 respectively; comets by Janssen in 1881 and Gill in 1882; cometary spectra by Huggins in 1881; the spectrum of the solar corona by Schuster in 1882; and the Andromeda Nebula by Roberts in 1885 (e.g. see Bajac and Saint-Cyr, 2000; de Vaucouleurs, 1961; Lankford, 1984; Mouchez, 1887; Norman, 1938; Rayet, 1887a). In 1885 Perry summarised this trend when he wrote:

> The award of the highest distinction in astronomy, the gold medal of the Royal Astronomical Society, two years in succession to those who have been most successful in celestial photography [A. Common in 1884 and William Huggins in 1885] is no doubtful sign of the great value attached to such work.

The possibilities open up by Gill's 1882 comet photograph and the brothers Paul and Prosper Henry's 1884 and 1885 stellar photographs prompted the idea of an all-sky photographic map (see de Vaucouleurs, 1961; Weimer, 1987). This led to the April 1887 International Astrophotographic Congress in Paris, thanks to the efforts of Admiral Mouchez and the Paris Academy of Sciences (Weimer, 1987).

By 1884 several articles concerning *Astronomical Photography* had been published both in specialist astronomical magazines and in the general non-astronomical literature. For example, see de la Rue's "Report of Celestial Photography in England" (1860), which was presented at the 1859 meeting of the British Association for the Advancement of Science, Brother's 1866 review of celestial photography in the journal *Academy Registry*, and Radau's 1878 article, "Les Applications Scientifiques de la Photographie", in the *Revue des Deux Mondes*. Several photographic books also included chapters dedicated to the topic, including *Les Merveilles de la Science* (Figuier, ca. 1870, 149-160), *Les Merveilles de la Photographie* (Tissandier, 1874, 249-262) and *Die Chemische Wirkung des Lichts und die Photographie in ihrer Anwendung in Kunst, Wissenschaft und Industrie* (Vogel, 1874; this was later issued in the International Scientific Series and published in Great Britain, the United States and France in 1875 and 1878).

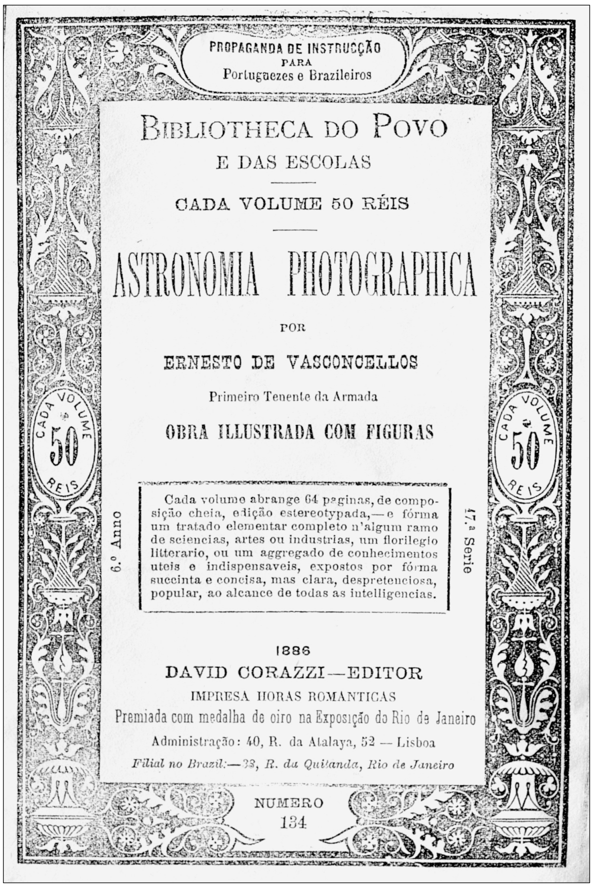
In addition, astronomical photographs were often displayed at international photographic and 'world' exhibitions. For example, the impact caused by Whipple's photographs of the Moon at the London Great Exhibition of 1851 is well known (see de Vaucouleurs, 1961; Hearnshaw, 1996). In 1876, the French Photographic Society (Société Française de Photographie) organized, an exhibition at the *Palais de l'Industrie* in Paris, which had the primary objective of

> … showing the utility of this Art [photography] by its numerous applications to the Sciences (Astronomy, Geography, Topography, Scientific Missions ...). (Davanne, 1876).

Photographic societies provided a natural forum in which recent developments in equipment and techniques were discussed. Consequently it is not surprising to find articles relating to astronomical photography in journals published by some of these societies. The increased use of photography as an astronomical technique also led to the appearance of photographers, or people with photographic skills, in typical astronomical environments, such as during eclipse and transit expeditions (e.g. see Duerbeck, 2004; Pang, 2002). Two examples of this interplay between photographers and astronomers are Alfred Brothers and Jules Janssen. Brothers, a Manchester photographer—better known today for his pioneering use of flash photography—obtained one of the only two successful photographs of the 22 December 1870 solar eclipse (see Brothers, 1871; Lenman, 2005). Jules Jansen, first Director of the Meudon Observatory in Paris, contributed significantly to the advancement of solar photography. He was also Honorary President of the French Photographic Society from 1891 to 1893 and 1900 to 1902, and the first President of the National Union of the French Photographic Societies (Union Nationale des Sociétés Photographiques de France), when it was created in 1892 (see Launay, 2000).

5 VASCONCELLOS' *ASTRONOMIA PHOTOGRAPHICA*

It was against this background of growing international interest in astronomical photography that Vasconcellos' *Astronomia Photographica* was published in 1886 as Number 134 in the BPE series (see Figure 3). Interesting developments were also happening at this time in the Portuguese photographic scene. The publication of a new monthly photographic periodical, *The Photographic Art* (*A Arte Photographica*), started in 1884, and two years later the first Portuguese international photographic exhibition opened in Porto, at the Crystal Palace (see Sena, 1998; Sociedade do Palácio de Cristal, 1886).



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NUMERO
134

Figure 3: The cover of *Astronomia Photographica*, BPE Number 134, published in 1886 (after Vasconcellos, 1886b).

An explanation for the BPE appearance of *Astronomia Photographica* is provided in the Foreword to the book, which is entitled "Two Introductory Words". The publication arises, it is claimed, as a natural consequence of the appearance earlier of the BPE volumes on *Popular Astronomy* (BPE, Number 10, 1881) and *Photography* (BPE, Number 78, 1884). Secondly,

> A recognition that "Niepce's art" favours enormously all sciences and arts: in this way the astronomer photographing the celestial bodies, the zoologist and the botanist photographing the specimens of the species they intend to study ... all find in the photography the most powerful and safe auxiliary, because it represents a faithful copy of all the objects needed by their multiple occupations. (Vasconcellos, 1886b).

On the basis of this statement, one is almost led to speculate if more photography books dealing with other specific scientific fields were planned. While none was published, the idea fits the pattern that a collection of this type may pursue.

The Foreword in *Astronomia Photographica* also included the recognition that "Up until today there has not been any published work on the subject of this book …" (Vasconcellos, 1886b), something that Vasconcellos (1884) had already referred to in the foreword to his 1884 dissertation. We should point out that the 1884 BPE publication on *Photography* was also "… an unprecedented event in Portuguese photography …" (Sena, 1998). While these are plausible arguments, we believe that further research is needed to better establish the reasons behind the publication of *Astronomia Photographica*. Was it a consequence of a slowdown of available collection titles? The year 1886 sees the end of the BPE bimonthly publication schedule, and only 19 of the expected 24 volumes (i.e. Numbers 121 to 139) were published in that year. *Astronomia Photographica* is Number 134. Or is there a connection between the book publication and a new effort to push for the implementation of a new astronomical photography research programme in Portugal taking account of the latest international developments? At the time, the main concern of the Portuguese observatories was astrometry, and no contribution was made by amateur astronomers (e.g. see Bonifácio et al., 2006b; Osório, 1986; Silva 1996). The idea of taking advantage of Portugal's favourable climate is presented in both the 1884 and 1886 editions, while discussing the possibility of photographing the corona outside of eclipse, a 'hot topic' at the time (Vasconcellos, 1884; 1886b; Becker, 2000). But the following citation in the BPE volume reveals a new agenda:

> If such an idea [Mouchez's Carte du Ciel] is to be carried out our observatories cannot stay idle especially given that the purity of our atmosphere aids the use of photographic means for the organisation of celestial charts. (Vasconcellos, 1886b).

The Director of the Lisbon Royal Astronomical Observatory, Frederico Augusto Oom, participated in the 1887 International Astrographic Congress but, in the end, no Portuguese observatory participated in the *Carte du Ciel* project (Weimer, 1987; Winterhalter, 1891).

The role that personal relations played in the publication of the book is still not clear. On the one hand, David Corazzi, publisher of *Astronomia Photographica*, was also a SGL member (Sociedade de Geografia de Lisboa, 1881). On the other, João Maria Jalles, author of the BPE's *Photography* and the collection's most prolific contributor (writing, amongst others, the volumes on *Mineralogy, Gravity, Optics* and *Mechanics*), married Carolina Amélia de Brito Capello in 1875, thereby becoming João Carlos Brito Capello's brother-in-law. In *Photography* the application of this technique to astronomy is not discussed, but in the chapter dedicated to Portugal there is a brief reference to the existence of the photographic meteorological instruments at the D. Luiz Observatory and to the fact that in the same observatory "... astronomical photographic work worthy of all appreciation has been done." (Jalles, 1884).

6 THE TEXT OF *ASTRONOMIA PHOTOGRAPHICA*

Realising that "… astronomical photography appears to be a study almost entirely new among us …" Vasconcellos presents the subject matter for a non-specialist audience. The text is therefore written

> … without formulae and in a way that allows the comprehension of all of the topics treated in the book ... and while it is written summarily and without any pretentiousness we believe it may fulfill the objectives of popular scientific promotion that this library [BPE] aims to diffuse amongst the people and in the school. (Vasconcellos, 1886b).

The language used is colloquial. Interesting items of news and short personal stories are also used to enliven the text. References and mathematical formulae are almost totally avoided. The only formulas present in the text are three that relate to the transits of Venus, and they are simple. The lack of references makes it difficult to access Vasconcellos' sources. We found quotations from several articles published in the *Comptes Rendus* by Janssen (1886) and Mouchez (1885a; 1885b; 1886) and from Vogel's (1878) *La Chimie de la Lumiére*. *Astronomia Photographica* is not a technical photographic compendium like Monckhoven's (1865) *Traité Générale de Photographie* or Abney's (1877) *Cours de Photographie*. Instead, *Astronomia Photographica* provides a review of astronomical photographic developments and results, ranging from Daguerre's unsuccessful attempt to obtain an image of the Moon in 1839 to the celestial photography pursued at the Paris Observatory. Within the rigid 64-pages limit—including covers—the book's index reveals the expected topics:

- Photography applied to the study of Astronomy (p. 4)
- Solar Photography (p. 9)
- Lunar Photography (p. 21)
- Stellar Photography (p. 23)
- Nebulae Photography (p. 32)
- Comet Photography (p. 35)
- Eclipses (p. 37)
- Photography applied to the observation of the transits of Venus (p. 48)
- Conclusion (p. 62)

The 1886 edition is basically an update of the 1884 content, but taking account of recent work done at the Paris and Meudon Observatories (as described in several papers published in *Comptes Rendus*, the latest of those dating from 11 January 1886). The update was probably completed by 29 May when Vasconcellos left Lisbon, since *Astronomia Photographica* was published no later than 21 August, (that is, before his November return to the city. Graphically, small changes were also made between editions in order to allow for an easier read: several paragraphs were broken up and extra space was introduced between them. Strangely, both editions contain only three figures, a rather small number for a book of this nature. The earlier BPE volumes *Popular Astronomy* and *Photography* had 15 and 10 figures respectively (Jalles, 1884; Mello, 1881). Drawings of a photoheliograph and a shutter are complemented by a diagram explaining the determination of the Earth-Sun distance via the observation of a transit of Venus. The unavailability of a good photoheliograph engraving is mentioned in both editions, a fact that might point to a hasty publication of this BPE volume (Vasconcellos, 1884; 1886b).

In the text, 34 out of 62 pages—or 55% of the total—deal with the topics of solar photography, solar eclipse photography and the application of photography to the transit of Venus. This is consistent with Portuguese expertise in this field up to this date, consisting of the daily solar photography programme carried out at the Infante D. Luiz Observatory in Lisbon, the 1870 solar eclipse expedition and the preparations for the failed transit of Venus expedition to Macao (Bonifácio et al., 2006a; Bonifácio et al., 2007).

Almost coinciding with the publication of *Astronomia Photographica*, two lengthy papers dealing with astronomic photography were printed in France: "La photographie astronomique à l'Observatoire de Paris et la Carte du Ciel" appeared in the *Annuaire du Bureau des Longitudes pour l'an 1887* (Mouchez, 1887) and "Notes sur l'histoire de la photographie astronomique" was serialised in the fourth volume of the *Bulletin Astronomique de l'Observatoire de Paris* (Rayet, 1887b). Both papers also materialised in book form. While Mouchez's effort is clearly focused on stellar photography, the topics covered by Rayet and Vasconcellos are similar. Nevertheless, a comparison of Rayet's and Vasconcellos' books shows two quite different approaches. Doing justice to its title and intended audience, Rayet's book stresses the historical developments of astronomical photography while Vasconcellos pays more attention to the latest research. A good example is provided by the treatment given by both authors to solar eclipse photography. Rayet ends his description with the 1871 eclipse, while Vasconcellos is mainly interested in the 1883 one. In 1886, Stein's second volume of the newer edition of *Das Licht im Dienste wissenschaftlicher Forschung* titled *Die Photographie im Dienste der Astronomie, Meteorologie und Physik* (Stein, 1886), was also published, the first 108 pages of which cover, in a manner more comprehensive than Vasconcellos' volume, the optical and technical aspects of astronomical photography, and present the results thus far obtained. In the following year, a more technical approach to the topic was presented in Konkoly's (1887) *Practische Anleitung zur Himmelsphotographie nebst einer kurzgefassten Anleitung zur modernen photographischen Operation und der Spectralphotographie im Cabinet*.

7 CONCLUSION

The 1886 publication of Vasconcellos' *Astronomia Photographica* in the BPE book collection is somewhat out of character given the interests of the small Portuguese astronomical community. The oldest Portuguese observatory, at Coimbra University, and the Lisbon Royal Astronomical Observatory were both involved in astrometric work and the recently-built Polytechnic School Astronomic Observatory was not fulfilling the research expectations raised at the time of its construction. Yet the preface claims that *Astronomia Photographica* fills a market void and is a natural progression of the BPE collection. The appearance of this book also coincided with an increased interest in astronomical photography, led mainly by recent advances in this field and by Admiral Mouchez's plan for an international collaborative astrographic sky map. We believe, nevertheless, that several important questions remain open and require further investigation. For instance, is the timing of the publication a tentative attempt to impress upon the general public and the Portuguese Government the need for greater financial support for this type of research, or was it a consequence of an editorial shortage of BPE titles? A better knowledge of the leading protagonists' personal relations would possibly help answer these questions, but unfortunately the publisher's records were lost. What is certain, however, is that the author, Ernesto de Vasconcellos, had a keen interest in the scientific applications of photography to astronomy and was well informed.

Astronomia Photographica is an up-to-date review of developments that occurred in astronomical photography from its beginnings through to the contemporaneous results obtained by the brothers Prosper and Paul Henry at the Paris Observatory.

The main objective of this paper is to point out to a wider audience the forgotten existence of this 'sui generis' publication, which may very well be the first popular book to be published that was dedicated solely to astronomical photography.

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9 REFERENCES

Abney, W., 1877. *Cours de Photographie*. Gand: Imprimerie C. Annoot-Braeckman.

Almanach Illustrado do Occidente. Lisboa, Lithographia Guedes (1887).

Arago, F., 1858. *Oeuvres Complètes. Tome 7*. Paris, Gide.

Arquivo da Marinha Portuguesa (a), Livro Mestre B, f. 84.

Arquivo da Marinha Portuguesa (b), Livro Mestre C, f. 199.

Bajac, Q., and Saint-Cyr, A. (eds.), 2000. *Dans le Champ des Étoiles. Les Photographes et le Ciel 1850-2000*. Paris, Éditions de la Réunion des Musées Nationaux.

Becker, B.J., 2000. Priority, persuasion, and the virtue of perseverance: William Huggins's efforts to photograph the solar corona without an eclipse. *Journal for the History of Astronomy*, 31, 223-243.

Béguet, B., 1994. La vulgarisation scientifique au XIXe siècle. In Béguet, B., Cantor M., and Le Men, S. (eds.). *La Science pour Tous*. Paris, Réunion des Musées Nationaux. Pp. 5-48.

Bonifácio, V., Malaquias, I., and Fernandes, J., 2006a. The 1870 Portuguese solar eclipse expedition – a preliminary report. In Afonso, J., Santos, N., Moitinho, A., and Agostinho, R. (eds.). *Past Meets Present in Astronomy and Astrophysics, Proceedings of the 15th Portuguese National Meeting*. Singapore, World Scientific. Pp. 89-92.

Bonifácio, V., Malaquias, I., and Fernandes, J., 2006b. Trying to start up the astrophysics research in Coimbra in the 1870's. The difficult move from the classroom to the Observatory. In Breda, A., Duarte, R., and Martins, M. (eds.). *Proceedings of the International Conference in Mathematics, Sciences and Science Education*. Aveiro, Universidade de Aveiro. Pp. 7-15.

Bonifácio, V., Malaquias, I., and Fernandes, J., 2007. Solar photography in the nineteenth century: the case of the Infante D. Luiz Observatory in Lisbon (1871-1880). *Journal of Astronomical History and Heritage*, 10, 101-113.

Botelheiro, A.P., 1985. *O Observatório da Tapada*. Second Edition. Lisboa, Observatório Astronómico de Lisboa.

Brothers, A., 1866. Celestial photography. *Astronomical Register*, 4, 25, 34-38, 62-66.

Brothers, A., 1871. Photographs of the solar eclipse of Dec. 21-22, 1870. *Monthly Notices of the Royal Astronomical Society*, 31, 167-171.

Costa, D., 1870. *Instrucção Nacional*. Lisboa, Imprensa Nacional. Cited by Torgal L.R. in *História de Portugal*, Volume 5, Chapter A instrução pública. Lisboa, Editorial Estampa, Círculo dos Leitores (1993). Pp. 609-651.

Cunha, X., 1881. *A Bibliotheca do Povo e das Escolas - Terceira Serie*, Chapter Duas Palavras ao Leitor. 3. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Cunha, X., 1883. *A Bibliotheca do Povo e das Escolas - Sexta Serie*, Chapter Quatro paginas de prologo. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Davanne, 1876. Lettre à Brito Capello dated 10 Fevrier 1876. Biblioteca do Instituto Geofísico, Lisboa (Correspondência Internacional 1876-1879).

de la Rue, W., 1860. *Report of Celestial Photography in England*. London, Taylor and Francis.

de Vaucouleurs, G., 1961. *Astronomical Photography*. New York, Macmillan.

Domingos, M.D., 1985. *Estudos de Sociologia da Cultura. Livros e Leitores do Século XIX*. Lisboa, Instituto Português do Ensino à Distância.

Duerbeck, H.W., 2004. The German transit of Venus expeditions of 1874 and 1882: organization, methods, stations, results. *Journal of Astronomical History and Heritage*, 7, 8-17.

Dyson, F.W., Eddington, A.S., and Davidson, C., 1920. A determination of the deflection of light by the Sun's gravitational field, from observations made at the total eclipse of May 29, 1919. *Philosophical Transactions of the Royal Society of London*, 220, 291-333.

Eder, J.M., 1945. *History of Photography*. New York, Dover.

Figuier, L, ca. 1870. *Les Merveilles de la Science*, *Volume 3*. Paris, Jouvet et Cie, Éditeurs.

Grande Enciclopédia Portuguesa e Brasileira, *Volume 34*. Lisboa e Rio de Janeiro, Editoral Enciclopédia, Limitada (n.d.).

Hearnshaw. J.B., 1996. *The Measurement of Starlight. Two Centuries of Astronomical Photometry*. Cambridge, Cambridge University Press.

Hinks, A.R., 1917. Geographical conditions for the observation of the total solar eclipse, 1919 May 28-29. *Monthly Notices of the Royal Astronomical Society*, 78, 79-82.

Jalles, J.M., 1884. *Photographia*, Volume 78. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Janssen, J., 1886. Note sur la constitution des taches solaires et sur la Photographie envisagée comme instrument de découvertes en Astronomie. *Comptes Rendus de l'Académie des Sciences de Paris*, 102, 80-82.

Konkoly, N., 1887. *Practische Anleitung zur Himmelsphotographie nebst einer kurzgefassten Anleitung zur modernen photographischen Operation und der Spectralphotographie im Cabinet*. Halle, Wilhelm Knapp.

Lacerda, J., 1881. *Chorographia de Portugal*, Volume 7. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Lankford, J., 1984. The impact of photography on astronomy. In Gingerich, O. (ed.). *Astrophysics and Twentieth Century Astronomy to 1950*. Cambridge, Cambridge University Press. Pp. 16-39.

Launay, F., 2000. Jules Janssen et la photographie. In Bajac, Q. and Saint-Cyr, A. (eds.). *Dans le Champ des Étoiles. Les Photographes et le Ciel 1850-2000*. Paris, Éditions de la Réunion des Musées Nationaux. Pp. 22-31.

Laussedat, A., 1860. Éclipse du 18 juillet: observations faites à Batna (Algérie). *Comptes Rendus de l'Académie des Sciences de Paris*, 51, 441-445.

Leitão, C., 1881. *Desenho Linear*, Volume 11. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Lenman, R. (ed.), 2005. *The Oxford Companion to Photography*. New York, Oxford University Press.

Malaquias, I. and Gomes, E.V., 2006. Some professors' contributions to science popularisation in 19th century Portugal. Paper presented at the 5th STEP meeting.

Matos, A., 2000. Os agentes e meios de divulgação científica e tecnológica em Portugal no século XIX. *Scripta Nova*, (69).

Mello, J., 1881. *Astronomia Popular*, Volume 10. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Mello, J., 1882. *Astronomia Popular*, Volume 10, Second Edition. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Monckhoven, D.V., 1865. *Traité Générale de Photographie.* Paris, G. Masson.

Mónica, M.F. (ed.), 2004. *Dicionário Biográfico Parlamentar: 1834-1910 N-Z*, *Volume 3*. Lisboa, Assembleia da República e Imprensa de Ciências Sociais.

Mouchez, E., 1885a. Carte photographique du ciel, à l'aide des nouveaux objectifs de MM. P. et Pr. Henry. Note de M. Mouchez. *Comptes Rendus de l'Académie des Sciences de Paris*, 100, 1177-1181.

Mouchez, E., 1885b. Photographie de cartes célestes dans la voie lactée, par MM. P. et Pr. Henry, de l'observatoire de Paris. Note de M. Mouchez. *Comptes Rendus de l'Académie des Sciences de Paris*, 100, 1479-1480.

Mouchez, E., 1886. Photographies astronomiques de MM. Paul Henry et Prosper Henry. *Comptes Rendus de l'Académie des Sciences de Paris*, 102, 148-152.

Mouchez, E., 1887. *Annuaire pour l'an 1887 par le Bureau des Longitudes*. Chapter "La photographie astronomique à l'Observatoire de Paris et la Carte du Ciel." Paris, Gauthier-Villars.

Nascimento, J., and Santos, V., 2006. Geografia geral para portugueses e brasileiros: a biblioteca do povo e das escolas. *Revista da Faced*, 10, 141-158.

Norman, D., 1938. The development of astronomical photography. *Osiris*, V, 560-594.

Osório, J.P., 1986. Sobre a história e desenvolvimento da astronomia em Portugal. In Academia das Ciências (ed.) *Colóquio sobre História e Desenvolvimento da Ciência em Portugal, Lisboa, 1985*, *Volume 1*. Lisboa, Academia das Ciências. Pp. 111-141.

Pang, A.S-K., 2002. *Empire and the Sun. Victorian Solar Eclipse Expeditions*. Stanford, Stanford University Press.

Perry, S.J., 1885. Astronomical photography. Cited in *Scientific American Supplement 11 April 1885*, 19 (484).

Radau, J-C.R., 1878. Les applications scientifiques de la photographie. *Revue des Deux Mondes*, 25, 872-890.

Rayet, M.G., 1887a. *Notes sur l'histoire de la Photographie Astronomique*. Paris, Gauthier-Villars.

Rayet, M.G., 1887b. Notes sur l'histoire de la photographie astronomique. *Bulletin Astronomique*, 4, 165-176, 262-272, 307-320, 344-360, 449-456.

Secord, J.A., 2001. *Victorian Sensation: The Extraordinary Publication, Reception, and Secret Authorship of Vestiges of the Natural History of Creation*. Chicago, University of Chicago Press.

Sena, A., 1998. *História da Imagem Fotográfica em Portugal - 1839-1997*. Porto, Porto Editora.

Sheets-Pyenson, S., 1985. Popular science periodicals in Paris and London: the emergence of a low scientific culture, 1820-1875. *Annals of Science*, 42, 549-572.

Silva, V.R., 1996. *Do Antigo Observatório Astronómico da Escola Politécnica e da sua Musealisação.* M.Sc. Thesis. Universidade Nova de Lisboa.

Sociedade de Geografia de Lisboa, 1881. Sócios Ordinários. *Boletim da Sociedade de Geografia de Lisboa*, 2(4).

Sociedade de Geografia de Lisboa (ed.), 1931. Almirante Ernesto de Vasconcelos. A sessão solene em homenagem à sua memória. *Boletim da Sociedade de Geografia de Lisboa*, 49.

Sociedade do Palácio de Cristal Portuense (ed.), 1886. *Exposição Internacional de Photographia*. Porto, Typographia Central.

Sousa, G., 1881. *Zoologia*, Volume 6. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Stein, S.T., 1886. *Das Licht im Dienste wissenschaftlicher Forschung, Die Photographie im Dienste der Astronomie, Meteorologie und Physik*. Halle. Wilhelm Knapp.

Tissandier, G., 1874. *Les Merveilles de la Photographie*. Paris, L. Hachette.

Torgal, L.R., 1993. A instrução pública. In Mattoso J. (Coord.). *História de Portugal*, *Volume 5*. [Lisboa], Editorial Estampa, Círculo dos Leitores. Pp. 609-651.

Torgal, L.R., and Vargas, I.N., 1993. Produção e reprodução cultural. In Mattoso J. (Coord.). *História de Portugal*, Volume 5. [Lisboa], Editorial Estampa, Círculo dos Leitores. Pp. 685-696.

Vasconcellos, E. de, 1881. Photopographia ou topographia photographica. *Boletim da Sociedade de Geografia de Lisboa*, 2, 717-718.

Vasconcellos, E. de, 1884. *A Astronomia Photographica*. Lisboa, Typographia da Viuva Sousa Neves.

Vasconcellos, E. de, (Coord.), 1886a. Carta da ilha do principe. Commissão de Cartographia. Lisboa, Pavia Lith.

Vasconcellos, E. de, 1886b. *Astronomia Photographica*, Volume 134. Lisboa, David Corazzi Editor - Empreza Horas Romanticas.

Vasconcellos, E. de., 1915. *Astronomia Photographica*, Volume 134. Lisboa - Paris. Livrarias Aillaut e Bertrand. Rio de Janeiro. Livraria Francisco Alves.

Vasconcellos, E. de, 1920. Almirante Campo Rodrigues. *Anais do Clube Militar Naval*, 51, 87-91.

Venâncio, G.M., 2004. Lisboa-Rio de Janeiro-Fortaleza: os caminhos da coleção "Biblioteca do Povo e das Escolas", traçados por David Corazzi, Francisco Alves e Gualter Rodrigues. I Seminário Brasileiro sobre Livro e História Editorial, 8 a 11 de Novembro de 2004 Casa de Rui Barbosa - Rio de Janeiro. http://www.livroehistoriaeditorial.pro.br/

Viana, M., 1990. David Corazzi, um editor português do século XIX. *Revista da Biblioteca Nacional*, 2.a série, 5 (2) Jul.-Dez. 1990, 109-132.

Vogel, H.W., 1874. *Die Chemische Wirkung des Lichts und die Photographie in ihrer Anwendung in Kunst, Wissenschaft und Industrie*. Leipzig, Brockhaus.

Vogel, H.W., 1875. *The Chemistry of Light and Photography*. London, Kegan Paul, Trench, Traubner & Co. (The International Scientific Series, Volume 15).

Vogel, H.W., 1878. *La Photographie et la Chimie de la Lumière*. Paris, Germer Baillière.

Weimer, T., 1987. *Brève Histoire de la Carte du Ciel en France*. Paris, Observatoire de Paris.

Winterhalter, A.G., 1891. Transactions of the International Astrophotographic Congress, held at Paris, April, 1887. In Belknap, G.E. (superintendent). *Observations Made During the Year 1885 at the United States Naval Observatory*. Washington, Government Printing Office. Pp. A-A354.

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RADÓ KÖVESLIGETHY'S SPECTROSCOPIC WORK

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Abstract: Kirchhoff and Bunsen's revolutionary discovery of spectral analysis in 1859 showed that observation of spectra made it possible to study the chemical composition of emitting bodies. Thermodynamics predicted the existence of black body radiation. The first successful spectral equation of black body radiation was the theory of continuous spectra of celestial bodies by Radó von Kövesligethy (published in 1885 in Hungarian, in 1890 in German). Kövesligethy made several assumptions on the matter-radiation interaction. Based on these assumptions, he derived a spectral equation with the following properties: the spectral distribution of radiation depended only on the temperature, the total irradiated energy was finite (fifteen years before Planck!) and the wavelength of the intensity maximum was inversely proportional to the temperature (eight years before Wien!). Using his spectral equation, he estimated the temperature of several celestial bodies, including the Sun. As a byproduct he developed a theory of spectroscopic instruments. He presented a comprehensive discussion on the quantitative relationship between astrophysical spectra and the observer, equipped with some kind of instrument (telescope, spectrograph, detector, etc.). We briefly summarize his main results.

Keywords: stellar spectra, spectral catalogues, spectral analysis, astrophysical instruments

1 KÖVESLIGETHY AND THE BIRTH OF ASTROPHYSICS

Developments in physics during the nineteenth century produced a theoretically-coherent basis for the first attempts in modeling the internal structure of celestial bodies in terms of combining the equations of hydrostatics and the polytropic state (Arny, 1990; Lane, 1870; Ritter, 1882; Schuster, 1884; Schwarz 1992). In order to link these calculations to the emitted light, a theory describing the mechanism of emission was required: the interaction of radiation and matter. Two discoveries had fundamental significance in this respect. Firstly, Kirchhoff and Bunsen (1860) showed that there was a direct correspondence between the emission line spectrum of gases and the chemical constitution of the emitting source.

In the second important discovery, Kirchhoff (1860) found that the wavelength dependence of the ratio $e(\lambda)/a(\lambda) = B(\lambda)$ was a universal function where $e(\lambda)$ referred to the emission and $a(\lambda)$ to the absorption properties of the source at a given wavelength λ. In the case when $a(\lambda) \equiv 1$ (i.e. the source absorbs totally the incoming radiation), $e(\lambda) \equiv B(\lambda)$. Kirchhoff showed that the *blackbody radiation*, $B(\lambda)$, depended only on the temperature of the source; however, he did not succeed in determining its functional form.

During these exciting times professional astronomy was completely absent in Hungary. The Observatory on St. Gellért Hill had been destroyed in the siege of Buda in 1849 (Kelényi, 1930; Réthly, 1948). After the failure of the war of independence, the Austrian Government decided not to rebuild the Observatory (and the present-day Citadella can be seen in its place). The science of astronomy had no more luck at the University of Pest, where the first active professional astronomer, nominated as a Professor, was Radó von Kövesligethy in 1897 (Petrovay, 2006).

Radó von Kövesligethy was a very interesting figure in the history of Hungarian astronomy. He was interested in a wide variety of scientific subjects. Our aim in this paper is to present an overview of this spectroscopic work.

This work, though little known nowadays, produced some startling results. In his obituary by K. Oltay (1935) it is claimed that he discovered the same law for which Wien received the Nobel Prize in 1911. Looking through his book on theoretical spectroscopy (Kövesligethy, 1890), one is surprised to find his temperature radiation equation, which has a quite similar run to the one that Planck published fifteen years later and which provided the basis for modern quantum theory. Kövesligethy also gave a theoretical explanation for Balmer's formula of the hydrogen lines.

Figure 1: Miklós (Nicholas) Konkoly-Thege in the early 1930s (courtesy: Gothard Observatory, Szomathely).

When this vast—not only in its results but also in its volume—work on theoretical spectroscopy appeared, Kövesligethy was merely 28 years old. What is more, he was five years younger than this when he first published his discoveries. It is worth examining the road that led him to these results at such a young age.

2 KÖVESLIGETHY'S EARLY LIFE

Radó Kövesligethy was born in Verona on 1 September 1862, the son of a captain in the Austrian Army, József Konek. His mother was Josephine Renz. After losing the battle of Königgrätz, Austrian troops stationed in Northern Italy had to withdraw in 1866. Because of this, József Konek had to leave his four-year old illegitimate son, Rudolf, in the care of his mother. The young mother and her son moved to her parents' house in Illereichen, Bavaria, and the boy lived in this idyllic little town until the age of eleven. This was probably the town where he attended elementary school. In 1872 Rudolf's mother married the lawyer Károly Kövesligethy, who came from an old Hungarian noble family. The following year Károly Kövesligethy adopted Rudolph, who began a new life, starting school in Pozsony (now Bratislava, Slovakia) under his new name of Radó Kövesligethy.

Kövesligethy later studied at the University of Vienna, where his astronomy teacher was Theodor von Oppolzer and he learnt physics from Joseph Stephan. In 1884 he earned his doctorate, the title of his dissertation being *Prinzipien der mathematischen Spectralanalysis*.

While a student Kövesligethy did his spectroscopic research with the help of the German scientist, H.C. Vogel, with whom he worked for some months in Vienna. Vogel was very satisfied with the performance of the young Hungarian astronomer, and so he asked Kövesligethy to continue working with him at the newly-established Observatory in Potsdam. However, after finishing his university studies Kövesligethy chose instead to join Miklós Konkoly-Thege (Figure 1), at the latter's well-equipped private Observatory at Ógyalla (Figure 2), where Kövesligethy had spent all his holidays since he was seventeen years of age.

It is worth examining the reasons of his choice. The Observatory in Ógyalla at this time was equipped with modern instruments, and research conducted with these was regularly published (e.g. see Kobold, 2004, and Vollmer *et al.*, 2004). However, it was primarily for emotional reasons that Kövesligethy chose Ógyalla.

Miklós Konkoly-Thege lost both of his sons at the same time in 1871, so it is not surprising that he started building his Observatory in the same year. His older son would have been the same age as Kövesligethy had he reached adulthood. Since he was a school boy Kövesligethy regularly spent Christmas and Easter at the Konkoly mansion surrounded by Konkoly's family, and Miklós Konkoly loved him like a son. Besides fatherly love, Kövesligethy found an intellectual mentor in Konkoly, who already had sent an article written by the young student to the *Monthly Notices of the Royal Astronomical Society* in 1882. Moreover, he was the one who later regularly discussed Kövesligethy's scientific results at the sessions of the Hungarian Academy of Science.

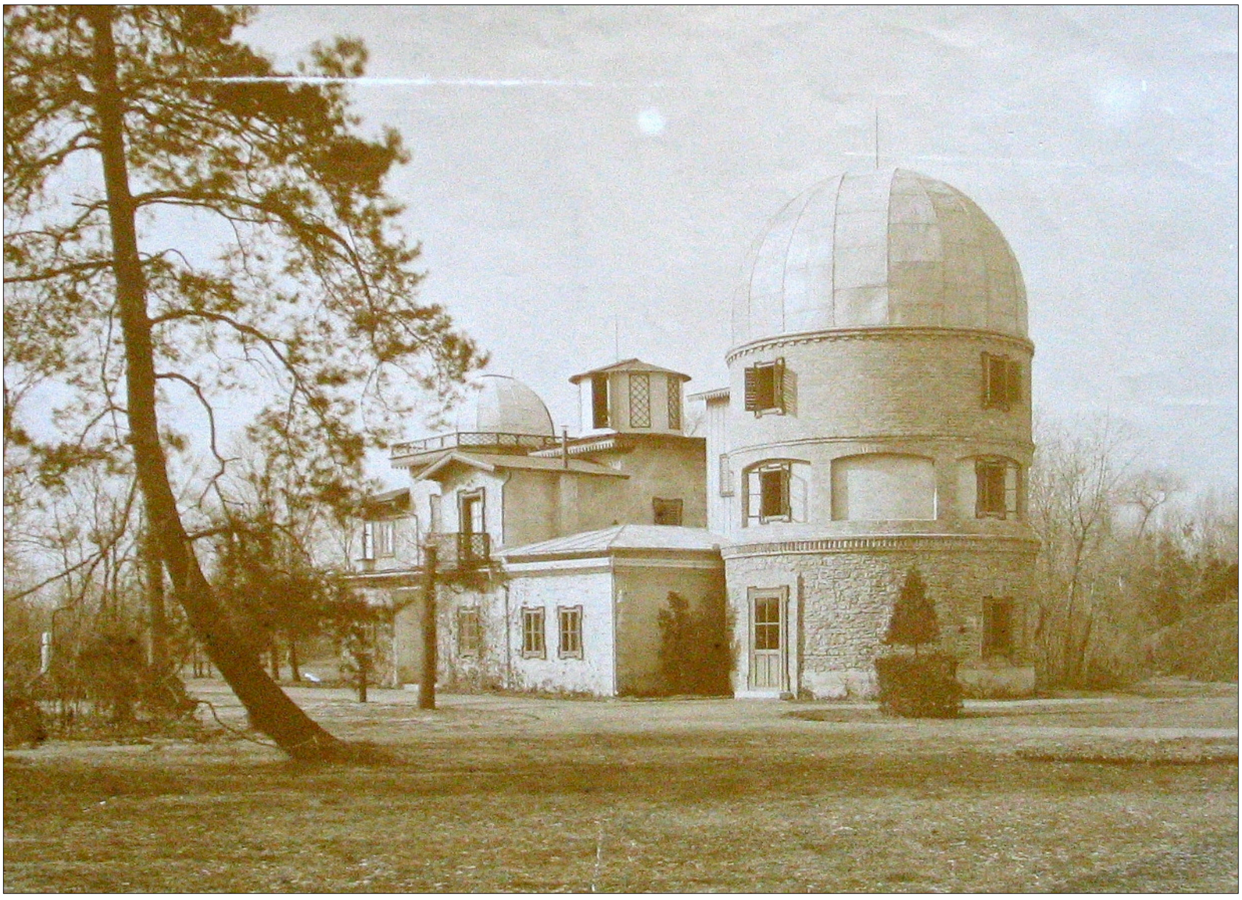

Figure 2: Konkoly-Thege's observatory at the end of the nineteenth century (courtesy: OMSZ – Hungarian Meteorological Service).

3 KÖVESLIGETHY AND THE SPECTROSCOPIC OBSERVATION OF STARS

Although Hungary lacked professional astronomy at the time, the general public was interested in this branch of science. Besides traditional astronomy, we also find the first report about the newly-emerging field of astrophysics: the journal *Természettudományi Közlöny* published a long article on spectral analysis, with a detailed introduction to astrophysics in its second volume (see Ábel, 1870). Even school annals showed interest: Arnold Ráth (1880) wrote a paper on "Spectroscopy in the service of astronomy" for the yearbook of the Lutheran Gymnasium in Budapest. The first book on astrophysics published in Hungarian appeared in 1882, and was written by a physics teacher, Ákos Szathmári, who worked first in Nagybecskerek (now Zrenjanin, Serbia), and later in Kolozsvár (now Cluj-Napoca, Romania) (Szathmári, 1882; Zsoldos, 2006). Although this book did not contain the results of any research carried out by its author—since a secondary school teacher had no opportunity to engage in such work—it was not simply a compilation of translations of various German or English books. Instead, Szathmári incorporated into his book the results of Hungarian scientists whenever he was able to do so.

Figure 3: Kövesligethy at Ógyalla in the 1880s (courtesy: OMSZ – Hungarian Meteorological Service).

What precisely were those results? In fact, they related directly to Miklós Konkoly-Thege and his Ógyalla Observatory. Konkoly built his own spectroscopes, and wrote a much-used textbook on astronomical spectroscopy (see Wolfschmidt, 2001). At first he observed the spectra of Solar System objects, especially meteors (Konkoly, 1872; 1873), then he became interested in classifying stellar spectra using the system developed by H.C. Vogel. Konkoly published a catalogue containing the classification of 160 stars, first in Hungarian, then in German, as was his custom (Konkoly, 1877; 1879a). The two versions differ in one interesting point, in that the Hungarian paper states that Konkoly started his classification at Vogel's request. According to Konkoly, when he was in Berlin around 1874-1875, Vogel asked him if he would help him in this work. There were supposed to be four participants: Vogel, Konkoly, Julius Schmidt (in Athens) and Louis d'Arrest (in Copenhagen). Since d'Arrest died shortly after the Vogel-Konkoly meeting and Schmidt and Vogel could not or would not observe, Konkoly (1877) was the only one who carried out the programme. It is therefore interesting that this request by Vogel has been left out of the German version of the catalogue (see Konkoly, 1879a).

Konkoly used two spectroscopes for his observations. He received one—made by Browning—from Vogel, while he purchased the second spectroscope from Merz in Munich (Konkoly, 1877; Wolfschmidt, 2001). Konkoly used Argelander's (1843) *Uranometria Nova* for identification purposes.

After the publication of his catalogue, Konkoly turned his attention to the spectroscopic properties of comets (e.g. see Konkoly, 1879b; 1880) before returning to the investigation of stellar spectra and publishing a short list of twenty stars (Konkoly, 1881). Two years later a further list contained more stars, but on this occasion it was noted that the observations had made by a "Mr Kövesligethy" (Konkoly, 1883).

When Kövesligethy first started working in Konkoly's observatory (Figure 3) he became interested in the supposed colour variations of α Ursae Majoris (Kövesligethy, 1881; 1882). His observations showed a periodic colour change—which was probably quite illusory (Zsoldos, 2004). Kövesligethy began observing stellar spectra in 1882 (Konkoly, 1883), using a Zöllner spectroscope with an Amici prism, attached to a 6-in Merz refractor. He thought that stellar spectroscopy was an important subject:

> Observing stars regularly with a spectroscope in a newborn idea; yet one can, nevertheless, draw conclusions from the results which, though not laws of nature themselves, are closely approximating reality. (Konkoly, 1883).

The classification of these 115 stars provided the training for the important work which started in 1876, namely the classification of stars in accordance with Vogel's request.

The observations began on 1 August 1883, and were intended to form the final catalogue which was considered an extension of the Potsdam catalogue of Vogel and Müller (1883) to southern declinations. Ninety nights were used for this purpose, the last one being 29 August 1886. On average, 36 stars were inspected each night, using the 16.2-cm Merz refractor and a Zöllner spectroscope. Kövesligethy was the observer and he drew each spectrum (e.g. see Figure 4). The original plan to observe each star twice failed because of unfavourable weather conditions at

Ógyalla. The observations were made near the upper culmination of the stars, in order to minimize the effects of the atmosphere. Several catalogues were used for identification purposes: the main ones were those of Lalande (Baily 1847) and Weisse (1846; 1863), but others, by Grant (1883), Schjellerup (1864) and Yarnall (1873), were sometimes consulted. Kövesligethy also observed the colours of the stars, using the Potsdam scale of colours. To avoid preconceptions in the classification, the colours were only estimated after the spectra had been inspected. When two observations gave discordant results, the star was observed again with the 25.4-cm refractor by both Konkoly and Kövesligethy.

The catalogue was first published in Hungarian (Konkoly, 1884; 1885; 1886), then in German (1887), and contained the spectral type (according to Vogel's system), the colour and the position (reduced to 1880.0 by Mr Ede Farkas) of 2,022 stars (the Hungarian version contains more stars). Although it was the work of Kövesligethy, conforming to the customs of the era, it appeared in Konkoly's name, as his director, but Konkoly never failed to emphasize that the work had been carried out by Kövesligethy.

After working on the catalogue, Kövesligethy returned to spectroscopic observations only once, during the supposed reappearance of S Andromedae in 1886 (see Zsoldos and Lévai, 1999). The observing log of the Kiskartal Observatory—where the observations took place—preserves the drawings of the spectra of the Andromeda Nebula, as recorded by Kövesligethy.

4 KÖVESLIGETHY'S THEORETICAL SPECTROSCOPIC STUDIES

4.1 Kövesligethy's Spectral Equation

It is well known that the quantum hypothesis of Max Planck, formulated in 1900, was the first to explain successfully the law of thermal emission of black bodies. Also well known are two earlier important attempts to explain this law. One of them was published by Wien in 1893, the other a few years later by Rayleigh (1900) and Jeans (1905). Both attempts failed in that they described correctly only one part of the spectrum: that of Wien reproduces only the blue side, while that of Rayleigh and Jeans only the red side, and both predicted an infinitely large value for the total radiated energy.

It is not well known that Kövesligethy (1890) solved these problems a few years earlier than the above-mentioned authors. Despite being published in Germany and even reviewed in *Beiblätter zu der Annalen der Physik und Chemie* (Ebert, 1890), his results were largely unknown.

Kövesligethy's spectral equation was part of a more comprehensive work which studied the possibility of gathering information on the physical conditions inside emitting celestial bodies by observing their spectra. Kövesligety assigned a basic significance to thermodynamics and thought it played the same role in interpreting the properties of the spectra as did the mechanics of Newton for the motion of the celestial bodies. He described the final aim of his spectroscopic studies in the following way:

> The spectral-theory described, and later revised in several points, in my work entitled 'Grundzüge einer theoretischen Spectralanalyse' has evolved with the explicit aim to lay astrophysics, which had mostly had a descriptive character that far, on a mathematical grounding. Provided that we do not regard celestial bodies and their systems as pure points any more, the mathematics describing their state and movement will also be joined by their thermodynamical details. This would only be possible, as proved among others by August Ritter's theses in Wiedemann's Annalen, if we were really able to measure the temperature and the density of the celestial bodies and can assume that they are bodies consisting of ideal gas.
>
> We can be successful only, assuming the state of the body as known, if its spectrum is known … It is clear that in this way the whole of astrophysics would become a science that can be discussed theoretically, and it represents the cosmic application of thermo-theory just as astronomy does for mechanics. (Kövesligethy, 1891).

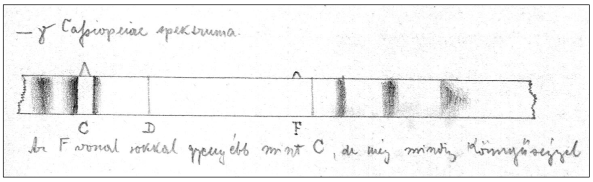

Figure 4: Kövesligethy's 1886 drawing of the spectrum of γ Cassiopeiae (Kiskartal observer's log book, Konkoly Observatory Library).

At that time it was a generally-accepted view that light originated from the oscillation of a hypothetical medium, the 'aether', which was present everywhere. As a starting point, Kövesligethy also accepted this view and assumed that, similar to matter, it also consisted of particles, or atoms. He assumed that the atoms of the radiating matter interacted with the 'aether particles', resulting in irradiated light. Starting from this hypothesis, he derived his spectral equation, which had a strikingly similar form to that of Planck (see Figure 5).

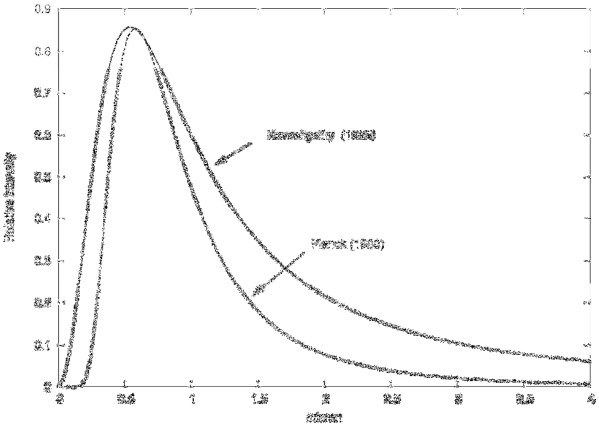

Figure 5: Comparison of Kövesligethy's (1885) and Planck's (1900) spectral equations.

Kövesligethy assumed that the particles of the radiating matter were distributed uniformly in space, i.e. their mutual distances are equal on the average. In equilibrium, the resultant acting forces were zero. If one moved a particle from the equilibrium position the resultant force of the other particles did not remain zero. In the case of a small displacement, there appeared a force proportional to it which tended to restore the equilibrium. Since it was valid for every particle of the radiating body, one arrived at a system of equations. By solving it, one obtained a relationship between the amplitude and the frequency, and because of the interaction between the oscillating particles and the aether, the dependence of the radiated light on wavelength. Proceeding this way, Kövesligethy derived his spectral equation, which appeared in printed form in 1886 in the contributions of the Hungarian Academy of Sciences.

Equation (1) shows the functional form of Kövesligethy's spectral equation:

$$L(\lambda) = \frac{4}{\pi}\mu\Lambda\frac{\lambda^2}{(\lambda^2+\mu^2)^2} \tag{1}$$

In this equation $L(\lambda)$ means the intensity at the wavelength λ, and Λ is that of the whole wavelength range. The constant μ is determined by the mean distance and interaction between the particles, and it is easy to see that it gives the wavelength at which the intensity of the radiation is maximum. It was known at that time that solid bodies begin to glow at the same temperature, independently of the kind of radiating matter. This was Draper's Law, which was discovered in 1847 (Draper, 1847). On the basis of this result Kövesligethy assumed that μ in his equation depended only on temperature, and he emphasized that his spectral equation represented what was predicted by Kirchhoff in 1860, and was not found in the preceding twenty-five years.

In contrast to the later solutions of Wien and Rayleigh-Jeans, Kövesligethy's equation had a finite radiated energy across the overall spectrum. This meant that the problem of black body radiation was solved by Kövesligethy fifteen years before Planck. An important property of Kövesligethy's spectral theory is that it also accounted for Wien's Displacement Law, appearing eight years before Wien proposed this. Based on this law it became possible to estimate the surface temperature of celestial bodies, including the Sun.

The parameter μ in Kövesligethy's spectral equation marks the wavelength at which the intensity of the spectrum is maximum, and depends on the average mutual distance and interaction of the particles of the emitting body. Upon compressing the body, the temperature will increase and the mutual distances between the particles will change, as will the parameter μ. Assuming a concrete form for the interaction between the particles, one may derive a relationship between μ and the temperature. Kövesligethy assumed that the strength of the interaction between the particles was inversely proportional to a positive power of the mutual distances. Starting with this assumption, he derived the following relationship between μ and the temperature, Θ, of the emitting body (and in the equation below the '0' index refers to a body of comparison):

$$\frac{\mu}{\mu_0} = \left(\frac{\Theta_0}{\Theta}\right)^{\left(\frac{n+1}{2(n-1)}\right)} \tag{2}$$

This equation gives Wien's Displacement Law, as derived by Kövesligethy in 1885. He found that the best choice of the parameter in the exponent was $n = 3$. With this selection the formula established an inverse relationship between the absolute temperature Θ and the wavelength μ of the maximum intensity in the spectrum. This is nothing else but Wien's displacement law.

In 1895, Paschen (1895) remarked that his empirical results—which are very similar to Wien's Displacement Law—can be explained by Kövesligethy's theory. Planck, however, apparently did not know of Kövesligethy's results. Modern quantum theory is based on Planck's results. Since Kövesligethy's work in the field of the theory of stellar spectra is largely unknown today, we summarize his relevant papers below.

4.2 The Two Parameter Equation of the Spectral Theory

Kövesligethy's spectral equation contains the two parameters, Λ and μ; the first of these relates to the thermodynamical state and the second to the temperature of the emitting body. Kövesligethy pointed out that the spectral equation alone was not enough to determine both parameters simultaneously. One needed a second equation to solve the problem completely. In order to do this, he derived an emission equation for a thick medium, by combining his spectral equation with that of Kirchhoff (Kövesligethy, 1898). Meanwhile, he mentioned that he obtained Wien's Displacement Law in one of his former works, and he pointed out that his equation describing absorption was supported by experimental results.

Kövesligethy also discussed the relationship between his spectral equation and thermodynamics. He investigated the temperature-dependence of the limits of the visibility of the spectrum with the previously-obtained spectral equation as the starting point. He found an equation of the second order between temperature and the limiting wavelength in the visible region of the spectrum.

Regarding the spectral theories, he pointed out that there was an important requirement that the function representing the spectrum had to have zero intensity at $\lambda = 0$ and $\lambda = \infty$. The theory of Vladimir Michelson (1888) describing the spectrum seemed to fulfill this requirement, but in some spectral ranges it predicted significantly less intensity than was observed. This could not be explained by the response function of the measuring instrument (see Section 4.4); even taking this into account, the predicted intensity still remained too low.

In order to derive the second parameter equation, Kövesligethy considered two bodies radiating heat face to face. Starting from his spectral equation he computed the energy balance between these bodies. Assuming the validity of his spectral equation, he applied the first law of thermodynamics to this special case. After dividing both sides of the equation by absolute temperature he then integrated it to obtain an expression for entropy.

Kövesligethy obtained an equation, valid at least for ideal gases, which gave a relationship between the parameters in the spectral equation (Λ and μ) and the thermodynamical variables (entropy (S) and absolute temperature (T)). One obtains the greatest change in entropy in the case of black body radiation. At the end of his paper Kövesligethy rediscovered Wien's Displacement Law.

Next he looked for a more general relationship between the thermodynamic properties of a body and the second law of thermodynamics. He introduced the concept of the total radiated energy, and he attempted to connect it to entropy.

In another paper Kövesligethy (1885) discussed Draper's Law, i.e. the shortest wavelength when radiation from a heated body becomes visible depends only on temperature and is independent of the properties of the material (see Figure 4 in Draper, 1878; cf. Draper, 1847; Lummer, 1918). Starting from the radiation law and this theorem, he derived a relationship known today as Wien's Displacement Law. Essentially, his main attempt was to establish a relationship between the variables in the spectral equation and the thermodynamic stage of the radiating medium.

Starting from the dissociation of a molecule consisting of several atoms Kövesligethy derived an expression valid for this case. Based on this expression, he obtained an integral expression which he simplified by making substitutions. He estimated the radiated energy from the spectral equation and set it equal to the thermodynamic heat variation of the body.

He wrote this equation for an arbitrary thickness n. As a result, he obtained a differential equation for the φ(S) function he was looking for. Substituting $n = 1$, he succeeded in simplifying the differential equation further and reducing it to a relatively simple form. In the end, he succeeded in obtaining a parameter equation for ideal gases which can be written explicitly.

Kövesligethy also developed this parameter equation into a series. The bulk of the section was devoted to the details of the computation. Since the equation has a great importance in astronomical applications, he gave a numerical example. He applied the equation by estimating the density of the solar chromosphere, referring to the work of Gyula Fényi (1896a; 1896b) and to the solar theory of Schmidt (1891; cf. Wilczynski, 1895).

At the end of his paper, Kövesligethy briefly summarized the astrophysical significance of the two parameter equations. He stated that based on these, one can obtain the temperature and entropy of the radiating medium. He pointed out the possibility of spectroscopic parallaxes.

4.3 The Spectra of Celestial Bodies

Following these calculations, Kövesligethy (1901) traced back the path of the light from the interior of the star to the observer (see Figure 6). The treatment of this problem admits the existence of a central nucleus of radius r_0 within the celestial body.

Kövesligethy gave an integral expression for the logarithm of the mean absorption within the celestial body. Using this expression, one can compute the intensity of the whole gas sphere representing a star. The concrete form of the integral mentioned above depends on the form of the equilibrium configuration of the gas sphere. The spectrum of the central nucleus can be taken as black body radiation.

Although Kövesligethy did not use a radiative transport equation, his way of thinking was quite modern. Next he started to derive the equation of state of celestial bodies. He assumed a non-rotating spherical equilibrium configuration and introduced the concept of an isentropic state. This means that when a particle changes its position its energy equals that of its surroundings in the new environment, so there is no exchange of energy.

Assuming an isentropic state, he derived an equation containing the pressure and the density. Furthermore, he derived a relationship between the pressure and the volume, the volume and the temperature, and the pressure and the temperature. In the end, he obtained an equation containing only the temperature. Using the Boyle-Gay-Lussac Law (as written by Kövesligethy), he arrived at a second order differential equation for the temperature:

$$\frac{d^2y}{dx^2} + \frac{2}{x}\frac{dy}{dx} + q^2 y^n = 0 \tag{3}$$

Equation (3) represent a differential equation for the dependence of the temperature y on the radius x in the stellar interior. The variables in the equation are scaled by the central temperature and the stellar radius. The q factor is a constant obtained from the basic physical parameters of the star (Kövesligethy, 1901).

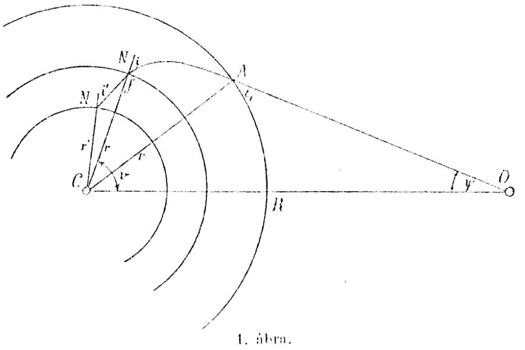

Figure 6: Path of a ray of light from the interior of a star to the observer (after Kövesligethy, 1901: 129).

Kövesligethy then discussed the solution of the equation. He estimated the constants necessary for the solution from the boundary conditions, which depend on the existence of a solid nucleus in the centre of the celestial body. At a certain polytrope index (n = 6/5), the gaseous sphere contracted into a point. Continuing this sequence of ideas, he obtained the solutions of the Lane-Emden Equation using a complicated series.

He also displayed graphically the y variable in the equation as a function of the x variable (Equation (3)). One can see that the case of $n = 5$ is special because at this value the $x – y$ relationship becomes singular.

After discussing the internal distribution of the mass of the celestial bodies he returned to the tracing of the route of the light within the star. He distinguished zones inside the celestial bodies, determined by whether a light ray tracing back from our eyes can reach a particular zone or not.

The spectral properties of light departing from a gaseous celestial body can be characterized by three parameters, while it needs seven if it contains a nongaseous nucleus. This fact can also be a useful guide line for multicolor photometry.

4.4 Theory of Astrophysical Instruments

In his book on theoretical spectral analysis, Kövesligethy (1890) gave a comprehensive theory of the instruments used in astronomical observations (e.g. see Figure 7). He pointed out that it was impossible to obtain the true spectrum from subjective observation directly. By observing the spectrum one had to distinguish two sources of subjectivity: the first one was the absorption and reflection in the instrument, which could be taken into account with a good approximation, while the second was the effect of the final sensor (i.e. the eye, photographic plate, or thermo column—Kövesligethy's phrase), which could not be described as simple absorption or reflection. There was no detailed theory of the absolute measurement of intensity at this time.

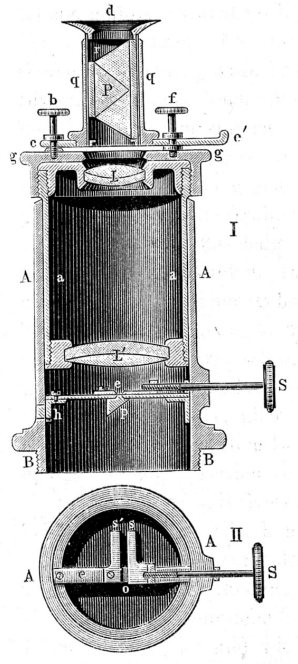

Figure 7: Ocular spectroscope used by Kövesligethy in the Ógyalla spectral program (after Konkoly, 1887b: 705).

The measured form of the spectrum originates in the so-called 'final layer' of the observer. The strength of the stimulus is produced by several photochemical processes in this layer, so Kirchhoff's Law is not applicable. In the simplest case, the strength of perception is proportional to the incoming intensity, where the proportionality is independent of the intensity. This proportionality factor is called sensitivity. The sensitivity factor becomes zero at the spectral limit of the stimulus, along with the differential quotient of the sensitivity curve. Kövesligethy gave a procedure for deriving functions of such sensitivity properties. These functions contain a part which might be derived from observations, and in the most simple case can be taken as constant. Using least square fitting one can show that the sensitivity function obtained in this way corresponds well to the experience.

It is not difficult to show that supposing $I = sL$, where I is the incoming energy, L is the strength of the stimulus and s is the factor of proportionality. According to Kövesligethy, this is a generalisation of Fechner's Psychophysical Law. In the case of photographic plates there can be more than one sensitivity maximum. In this case one has to apply a Fourier transformation instead of the procedure discussed thus far, and the Fourier coefficients of the series have to be determined empirically.

One of the most commonly-used sensors is the human eye, and there is a very complicated psychochemical connection between the neural sensation and the incoming radiation. The simplest way is to relate the objective intensity to the produced heat effect. Kövesligethy used a neutral grey wedge in his investigations. Using this wedge, he studied the spectrum of the Sun where he replaced the human eye with a thermometer. He also studied the dependence of the sensitivity of the eye on intensity.

Kövesligethy then turned to the study of the influence of air. All observations are made in a space filled with some medium. Consequently, one does not measure the wavelength valid in a vacuum, but rather that distorted by the refractive index. One can show that the distortion depends only on the medium in the immediate neighbourhood of the observer.

Kövesligethy estimated the effect of the atmosphere by considering layers of identical absorption. The distance between the boundaries of these layers becomes greater as one departs from the surface of the Earth. Kövesligethy derived the dependence of the absorption of a light source outside the atmosphere on density, pressure and temperature at the surface. In a plane parallel approximation, he obtained the generally known sec(z) relationship.

5 THE RECEPTION OF KÖVESLIGETHY'S WORK

Let us first look at the two spectral catalogues. The degree of their acceptance was quite different. Konkoly's first catalogue—containing the spectra of 160 fixed stars—was not referred to in the *Astronomische Nachrichten*, but it became known to astronomers nonetheless and was even mentioned in journals published in the United States (e.g. see Anonymous, 1877). This was rather reassuring for Konkoly and Kövesligethy. This catalogue was used for many years (Zsoldos, 1992), and was consulted during the preparation of the Henry Draper Catalogue (Pickering, 1891). However, since Konkoly and Kövesligethy used Vogel's spectral classification, the appearance of the Henry Draper Catalogue marked the end of the usefulness of their work.

Returning to his theoretical work, we may ask now, why Kövesligethy's theory remained almost unnoticed by his contemporaries? A possibility is the very difficult nature of his mathematics. Such long derivations are familiar to an astronomer specialized in celestial mechanics and astrometry, but they might be too much for an experimental physicist. Indeed, a fellow-member of the Hungarian Academy of Sciences, Lajos Schuller (1887), wrote in his review: "Since as I have said above the paper of Mr Kövesligethy does not contain experimental physics I am not an appropriate referee of his mathematics." Fortunately, there was at least one exception. In his Presidential Address to the British Association for the Advancement of Science, William Huggins (1891a; cf. 1891b; 1893), mentioned that Kövesligethy was one of those who had made a useful contribution in this field.

In Germany, however, the physicists understood his mathematics. As it has already been mentioned, Ebert (1890) reviewed Kövesligethy's book, and he realized the importance of Equation (1) by printing it in his report. Friedrich Paschen was also familiar with the theory, as this quote clearly shows:

> It deserves to be mentioned, however, that the theory of Kövesligethy leads to the two laws which here have no other than an empirical basis. (Paschen, 1895).

More interestingly, however, one of Wien's co-workers, Otto Lummer, knew about Kövesligethy's results and referred to them in his publications (see Lummer, 1900; 1918). It therefore seems reasonable to assume that Kövesligethy's works were known to the German physicists, so it is particularly strange that Wien choose not to refer to Kövesligethy's publiccations. However, we should note Wien's reluctance to quote foreign scientists, as is witnessed by his role in the 'Krieg der Geister' (i.e 'War of the spirit') during WWI (see Wolff, 2003).

Kövesligethy's theoretical work is mostly forgotten today. In his authoritative history of stellar spectroscopy, John Hearnshaw (1986) surprisingly mentions neither Kövesligethy nor Wien. However, in his study of the early history of Planck's law Kangro (1970) discusses Kövesligethy's theory in some detail, and he even reproduces some of the key equations (e.g. Equation (2), above), yet despite Kangro's lead, later writers neglect to mention Kövesligethy. For example, neither Garber (1976) nor Nugayev (2000) apparently knew about him, even though both referred to Kangro's book, and Nugayev (2000: 340) even stated that "… the classical theory of black-body radiation before Planck's efforts did not exist at all." He is clearly mistaken, since Kövesligethy's theory is a classical theory of black-body radiation, even if we know now that it is faulty. This is, however, no reason for omitting him from historical accounts of early theoretical developments in stellar spectroscopy.

6 EPILOGUE

Kövesligethy finished his spectroscopic work at the end of the nineteenth century, when he was just 38 years old at that time.

We must now speak briefly about the period after his spectroscopic work ended. As we already mentioned at the beginning of this paper, Kövesligethy was interested in a wide variety of subjects, as will be illustrated below.

Roland Eötvös, who was well known worldwide for his pendulum experiments, persuaded Kövesligethy to work with him in the Institute of Physics at Budapest University, and in the summer of 1891 Kövesligethy participated in the gravitational measurements that were carried out on Ság-hegy (Ság Hill) under Eötvös' leadership. In March 1904 Kövesligethy was appointed Professor of Cosmography and Geophysics at the University of Budapest, and in 1909 he was elected a full member of the Hungarian Academy of Science. Kövesligethy retired from his University of Budapest post in 1932 (and he died two years later at the age of 72).

At the beginning of the twentieth century, Kövesligethy's attention turned more and more towards seismology. The International Association for Seismology held its first meeting in Rome in 1906, and Kövesligethy was elected General Secretary of this organisation. In this same year he founded the first Seismological Observatory in Budapest, remaining Director of this institution up until his death.

Kövesligethy's sensitivity towards social problems is exemplified by the active role he played in the foundation of the 'scientific theatre' Uránia in Budapest in 1899. This is how Kövesligethy (1899) talks about the aim of this institution: "The Uránia Scientific Theatre is the most practical, most beautiful and the greatest means to achieving intellectual pleasure." By establishing this theatre he intended to communicate scientific knowledge to the wider public. This was typical of what was occurring in Western Europe at the end of the nineteenth century, when there was a firm belief among scientists that the basic problems of society could be solved by applying the results of science. At that time, the number of educated people in Hungary was relatively low, and it was an important task to try and overcome the shortcomings of the education that people typically received at school.

Figure 8: Radó Kövesligethy in the early 1930s (courtesy Konkoly Observatory Library).

Throughout his life, Kövesligethy carried out his research in cooperation with colleagues from abroad, and later he co-ordinated the research of foreign scientists from Budapest whilst General Secretary of the International Seismologic Society.

Another proof of Kövesligethy's versatile interest was his role in scientific expeditions. Closely connected with his research in seismology, he led two expeditions that aimed to examine the natural characteristics of the Adriatic Sea (Leidenfrost, 1937).

World War I caused wounds in the scientific world that would not heal for a long time. During the war a movement was started in Belgium whereby all scientists living in Entente countries who maintained links with their counterparts from the countries of the Central Powers should be pilloried. At the end of the war the International Seismologic Society was dissolved, but when it was reconstituted in Rome soon after under a new name—the Union Internationale

Géodésique et Géophysique—Kövesligethy (Figure 8) was not permitted to join, even though the discussion of his theory was on the agenda (see Kosztolányi, 1925).

We end this epilogue with a quote about Kövesligethy's humanity, using the words of his student, Antal Réthly. As a Professor of the University of Pest he had been the mentor of many mathematicians, physiccists and astronomers who later became well known. Kövesligethy was

> … an excellent lecturer … [He] was very popular among his students and he could solve even the most intricate problems with perfect ease. He maintained a closer relationship with some of his students who were absolutely fascinated by his informal manners. He liked his students and lent an understanding ear to everybody who ever turned to him and he tried to be helpful whenever he could. Both his civility and his politeness were almost proverbial. He had an all round intelligence, music, sculpture, painting, classical literature, all of these topics were equally interesting to him ... It was a perfect pleasure to attend a society when Kövesligethy was present, and nobody could put [*sic.*] him such a question which he did not answer satisfactorily. (Réthly, 1963: 9).

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8 REFERENCES

Ábel, K., 1870. A színkép-elemzés. *Természettudományi Közlöny*, 2, 311-333.

Anonymous, 1877. Editor's scientific record. *Harper's New Monthly Magazine*, 55, 146-151.

Argelander, F.W.A., 1843. *Uranometria Nova*. Berlin, Simon Schropp und Comp.

Arny, T., 1990. The star makers. A history of the theories of structure and evolution. *Vistas in Astronomy*, 33, 211-233.

Baily, F., 1847. *A Catalogue of those Stars in the* Histoire Céleste Française *of Jêrome de Lalande for which Tables of Reduction to the Epoch 1800 have been Published by Professor Schumacher*. London, Richard and John E. Taylor.

Draper, J.W., 1847. On the production of light by heat. *American Journal of Science* (2nd Series), 4, 388-402.

Draper, J.W., 1878. *Scientific Memoirs Being Experimental Contributions to a Knowledge of Radiant Energy*. New York, Harper & Brothers.

Ebert, H., 1890. Review of R. von Kövesligethy: *Grundzüge einer theoretischen Spectralanalyse*. *Beiblätter zu den Annalen der Physik und Chemie*, 14, 852.

Fényi, G., 1896a. Über einen neuen Gesichtspunkt und neue Erklärungen der Erscheinungen auf der Sonne. *Astronomische Nachrichten*, 140, 289-302.

Fényi, G., 1896b. New point of view for regarding solar phenomena, and a new explanation of the appearances on the surface of the Sun. *Astrophysical Journal*, 4, 18-37.

Garber, E., 1976. Some reactions to Planck's Law, 1900-1914. *Studies in History and Philosophy of Science* Part A, **7**, 89-126.

Grant, R., 1883. *Catalogue of 6415 Stars, for the Epoch 1870, deduced from observations made at the Glasgow University Observatory during the years 1860 to 1881*. Glasgow, James Maclehose & Sons.

Huggins, W., 1891a. Presidential Address to the British Association for the Advancement of Science, at Cardiff, August, 1891. *Report of the Sixty-First Meeting of the British Association for the Advancement of Science: Cardiff, 1891*. London, John Murray. Pp. 1-35.

Huggins, W., 1891b. Celestial physics. *Science*, 18, 239-244.

Huggins, W., 1893. Celestial spectroscopy. *Smithsonian Report for 1891*, 69-102.

Jeans, J., 1905. On the partition of energy between matter and aether. *Philosophical Magazine*, 10, 91-98.

Kangro, H., 1970. *Vorgeschichte des Planckschen Strahlungsgesetzes*. Wiesbaden, Franz Steiner.

Kelényi, B.O., 1930. Geschichte der ungarischen Astronomie. *Astronomische Abhandlungen des Kön. Ung. Astrophysikalischen Observatoriums von Konkoly's Stiftung in Budapest-Svábhegy*, 2, No. 2, 51-106.

Kirchhoff, G., 1860. Ueber das Verhältniss zwischen dem Emissionsvermögen und dem Absorptionsvermögen der Körper für Wärme und Licht. *Annalen der Physik und Chemie* (Folge 2), 109, 275-301.

Kirchhoff, G., and Bunsen, R., 1860. Chemische Analyse durch Spectralbeobachtungen. *Annalen der Physik und Chemie* (Folge 2), 110, 161-189.

Kobold, H.A., 2004. Blätter der Erinnerung. *Journal of Astronomical Data*, 10, Part 5.

Konkoly, N., von, 1872. Sternschnuppenfall am 27. November 1872. *Astronomische Nachrichten*, 80, 283-284.

Konkoly, M., von, 1873. Die Spuren eines ansehnlichen Meteors. *Astronomische Nachrichten*, 82, 289-290.

Konkoly, N., 1877. 160 álló csillag szinképe. *Értekezések a mathematikai tudományok köréből*, 5, No. 10.

Konkoly, N., von, 1879a. Spectra von 160 Fixsternen. *Beobachtungen angestellt am Astrophysicalischen Observatorium in O Gyalla in Ungarn*, Band I, 34-47.

Konkoly, N., von, 1879b. Spectroscopische Beobachtung des Cometen Brorsen. *Astronomische Nachrichten*, 95, 193-196.

Konkoly, N., von, 1880. Beobachtungen des Cometen Hartwig (1880d). *Astronomische Nachrichten*, 98, 311-314.

Konkoly, N., 1881. Astrophysikai megfigyelések az ó-gyallai csillagvizsgálón. *Értekezések a mathematikai tudományok köréből*, 8, No. 1.

Konkoly, M., 1883. Astrophysikai megfigyelések az ó-gyallai csillagvizsgálón 1882-ben. *Értekezések a Mathematikai tudományok köréből*, 10, No. 2.

Konkoly M., 1884. 615 Állócsillag spectruma. *Értekezések a Mathematikai tudományok köréből*, 11, No. 4.

Konkoly, M., 1885. 615 állócsillag spectruma. *Értekezések a Mathematikai tudományok köréből* 12, No. 5.

Konkoly, M., 1886. 855 Állócsillag spectruma. *Értekezések a Mathematikai tudományok köréből*, 13, No. 3.

Konkoly, N. Von, 1887. Spectroskopische Beobachtung der Sterne zwischen 0° und –15° bis zu 7.5ter Grösse. *Beobachtungen angestellt am Astrophysikalischen Observatorium in O Gyalla*. Band VIII, II. Theil.

Kosztolányi, D., 1925. Párbeszédek. Kövesligethy Radó. *Pesti Hírlap*, 47, No. 116 (May 24), 5.

Kövesligethy, R., 1881. Ueber den Farbenwechsel Alpha ursae majoris. *Wochenschrift für Astronomie, Meteorologie und Geographie*, 24, 313-314.

Kövesligethy, R., 1882. Ueber den Farbenwechsel des Sternes Alpha Ursae majoris. *Wochenschrift für Astronomie, Meteorologie und Geographie*, 25, 169-172.

Kövesligethy, R., von, 1885. A folytonos spektrumok elmélete. *Értekezések a mathematikai tudományok köréből*, 12, No. 11.

Kövesligethy, R., von, 1890. *Grundzüge einer theoretischen Spectralanalyse*. Halle, H.W. Schmidt.

Kövesligethy, R., von, 1891. Az ég elméleti physikájának alapvetéséhez. Magyar Tudományos Akadémia Könyvtára, Kézirattár, RAL.

Kövesligethy, R., von, 1898. Ueber den beiden Parametergleichungen der Spectralanalyse. *Vierteljahrsschrift der Astronomischen Gesellschaft*, 33, 309-334.

Kövesligethy, R., 1899. A Tudományos Színházról. *Uránia*, 1, 1-13.

Kövesligethy, R., von, 1901. Ueber das Spectrum der Himmelskörper. *Mathematische und Naturwissenschaftliche Berichte aus Ungarn*, 17, 127-165.

Lane, J.H., 1870. On the theoretical temperature of the Sun. *American Journal of Science* (2nd series), 50, 57-74.

Leidenfrost, Gy., 1937. *Kék Adria*. Budapest, Egyetemi Nyomda.

Lummer, O., 1900. Le rayonnement des corps noirs. *Congrès International de Physique de 1900*. Paris, Gauthier-Villars. Pp. 41-99.

Lummer, O., 1918. *Grundlagen, Ziele und Grenzen der Leuchttechnik (Auge und Lichterzeugung)*. München und Berlin, R. Oldenbourg.

Michelson, V., 1888. Theoretical essay on the distribution of energy in the spectra of solids. *Philosophical Magazine*, 25, 425-435.

Nugayev, R.M., 2000. Early quantum theory genesis in the intertheoretic context. *Annales de la Fondation Louis de Broglie*, 25, 337-361.

Oltay, K., 1935. Radó v. Kövesligethy. *Gerlands Beiträge zur Geophysik*, 43, 337-339.

Paschen, F., 1895a. On the existence of law in the spectra of solid bodies and on a new determination of the temperature of the Sun. *Astrophysical Journal*, 2, 202-211.

Petrovay, K., 2006. A Csillagászati Tanszék története. In Petrovay, K. (ed.). *A Csillagászati Tanszék negyed évezrede*. Budapest, Eötvös University (Publications of the Astronomy Department of the Eötvös University, Volume 16). Pp. 69-98.

Pickering, E.C., 1891. Preparation and discussion of the Draper Catalogue. *Annals of the Astronomical Observatory of Harvard College*, 26, Part I.

Rayleigh, Lord, 1900. Remarks upon the law of complete radiation. *Philosophical Magazine*, 49, 539-540.

Ráth, A., 1880. A spektroskop az astronomia szolgálatában. *A Budapesti ág. ev. főgymnasium Értesítője 1879/1880*, Budapest, pp. 3-31.

Réthly, A., 1948. A gellérthegyi csillagda 1849. évi pusztulása. *Csillagok Világa*, 1, 145-150.

Réthly, A., 1963. In memoriam Kövesligethy 1862–1934. *Annales Universitatis Scientiarum Budapestinensis de Rolando Eötvös Nominatae. Sectio Geologica*, 6, 5-9.

Ritter, A., 1882. *Anwendungen der Mechanischen Wärmetheorie auf kosmologische Probleme* (Zweiter Abdruck). Leipzig, Baumgärtners Buchhandlung.

Schjellerup, H.C.F.C., 1864. *Stjerne fortegnelse indeholdende 10000 Positioner af teleskopiske Fixstjerner imellem –15 od +15 Graders Deklination*. Kjøbenhavn, Bianco Lunes Boftrykkeri.

Schmidt, A., 1891. *Die Strahlenbrechung auf der Sonne*. Stuttgart, Metzler'sche Verlag.

Schuller, L., 1887. Véleményes jelentés dr. Kövesligethy Radó úrnak a szaggatott spektrumok elmélete című értekezéséről. Magyar Tudományos Akadémia Könyvtára, Kézirattár, RAL 96/87.

Schuster, A., 1884. On the internal constitution of the Sun. In *Report of the Fifty-Third Meeting of the British Association for the Advancement of Science; Held at Southport in September 1883*. London, John Murray. Pp. 427-429.

Schwarz, O., 1992. *Zur historischen Entwicklung der Theorie des inneren Aufbaus der Sterne von 1861 bis 1926.*). Berlin-Treptow, Archenhold-Sternwarte (Veröffentlichung der Archenhold-Sternwarte Berlin-Treptow, No. 22).

Szathmári, Á., 1882. *A Spectralanalysis és Alkalmazásai*. Nagy-Becskerek, Ignácz Dohány.

Vogel, H.C., and Müller, G., 1883. Spectroscopische Beobachtungen der Sterne bis einschliesslich 7.5$^{\mathrm{ter}}$ Grösse in der Zone von –1° bis +20° Declination. *Publicationen des Astrophysikalischen Observatoriums zu Potsdam*, 3, 127-226.

Vollmer, R., Vollmer, R., and Duerbeck, H.W., 2004. Some notes on 'Leaves of memory', the autobiography of Hermann Kobold. *Journal of Astronomical Data*, 10, Part 5.

Weisse, M., 1846. *Fixarum Praecipuarum Catalogus Novus*. Petropoli, Typis Academiae Scientiarum.

Weisse, M., 1863. *Positiones Mediae Stellarum Fixarum*. Petropoli, Eggers et Socios.

Wien, W., 1893. Eine neue Beziehung der Strahlung schwarzer Körper zum zweiten Hauptsatz der Wärmetheorie. *Sitzungsberichte der Königlich Preussischen Akademie der Wissenschaften zu Berlin, 1893*, 55-62.

Wilczynski, E.J., 1895. Schmidt's theory of the Sun. *Astrophysical Journal*, 1, 112-126.

Wolff, S.L., 2003. Physicists in the 'Krieg der Geister': Wilhelm Wien's 'Proclamation'. *Historical Studies in the Physical and Biological Sciences*, 33, 337-368.

Wolfschmidt, G., 2001. The pioneering astrophysical work of Miklós Konkoly. In Sterken, C., and Hearnshaw, J. (eds.). *100 Years of Observational Astronomy and Astrophysics. Homage to Miklós Konkoly Thege*. Brussels, VUB Press. Pp. 39-58.

Yarnall, M., 1873. Catalogue of stars observed at the United States Naval Observatory during the years 1845 to 1871. *Astronomical and Meteorological Observations Made at the United States Naval Observatory*, 11, Appendix III.

Zsoldos, E., 1992. The Ógyalla catalogues. In Vargha, M., Patkós, L., and Tóth, I. (eds.). *The Role of Miklós Konkoly Thege in the History of Astronomy in Hungary*. Budapest, Konkoly Observatory (Konkoly Observatory Monographs No. 1). Pp. 57-61.

Zsoldos, E., 2004. The beginnings of variable star astronomy in Hungary. In Balázs, L., Brosche, P., Duerbeck, H.W., and Zsoldos, E. (eds.). *The European Scientist. Symposium on the Era and Work of Franz Xaver von Zach*. Frankfurt am Main, Verlag Harri Deutsch (Acta Historica Astronomiae, Volume 24). Pp. 132-155.

Zsoldos, E., 2006. Az asztrofizika kezdetei Magyarországon: Szathmári Ákos (1855–1927). *Természet Világa*, 137, 572-573.

Zsoldos, E., and Lévai, Zs., 1999. 'Novae' over Kiskartal. *Journal for the History of Astronomy*, 30, 225-230.

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THE HYDROGEN ABUNDANCE IN STARS: A FIRST MAJOR STEP FOR QUANTITATIVE ASTROPHYSICS

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Abstract: Historiography has recognized that Saha's work in the early 1920s was the beginning of a quantitative era in astrophysics, and the deduction of the large hydrogen abundance in stars around 1930 was a major outcome of Saha's theory. In this paper, the development of stellar physics in these years is analysed, and the recognition of the hydrogen abundance is pointed out as the first major achievement of the quantitative era. This idea is sustained from two different points of view. First, there exists a tight scientific continuity from Saha's investigative papers up to Russell's 1929 paper where the hydrogen abundance was clearly worked out: the whole of the 1920s should therefore be considered as a scientific discontinuity that paved the way for modern stellar spectroscopy. Second, in 1932 the same conclusion was reached by Strömgren and Eddington, who were working on the problem of internal stellar structure. Thus, the hydrogen abundance can be viewed as the first major step of the quantitative era, as it led to the first sound theory of stellar structure, both for the inner and the surface regions of stars.

Keywords: stellar spectroscopy, stellar composition, Saha-Fowler equation, Eddington 'standard model'

1 INTRODUCTION

In the year 1835 the French philosopher, Auguste Comte, speaking of celestial bodies, wrote:

> We conceive the possibility to determine their shapes, distances, sizes and movements; whereas we shall never be able to study by any means their chemical composition, or their mineralogical structure … our positive knowledge about the celestial bodies is necessarily limited to their geometric and mechanical phenomena alone, without being able to pursue the other physical and chemical researches … which require them to be accessible to all our different observation methods. (Comte, 1835: 8-9; our English translation).

Figure 1: Megh Nad Saha, 1893–1956 (courtesy Wikipedia).

This often-cited quotation is very popular among astrophysicists as it points out what the state of the art in astronomy was at that time. Comte's opinion, which was readily shared by contemporary astronomers, was to be thoroughly dismissed within a few decades as astrophysics emerged and the physical structure of stars began to be investigated. Nevertheless, it took a long time before any firm knowledge about the chemical composition of stars—that Comte had explicitly cited—could be arrived at.

In fact, no sound knowledge in that respect could be reached before a theory of matter at the atomic level was available. The transition between the so-called 'qualitative' and 'quantitative' eras had to occur. The division into these two eras was suggested in an important paper by DeVorkin and Kenat (1983a). As these authors note, this idea was taken from a paper D.H. Menzel published in 1972 in the *Annals of the New York Academy of Sciences*. That paper was split in two parts, each of which dealt with one of the two eras: "The history of astronomical spectroscopy I - qualitative chemical analysis and radial velocities" and "The history of astronomical spectroscopy II - quantitative chemical analysis and the structure of the solar atmosphere". The watershed between them is the first application, starting from 1920 on, of atomic physics to the spectroscopic observations of stars. It was performed through the identification of the dependence upon temperature and gas pressure of the ionization and excitation of atoms, and the subsequent physical interpretation of the Harvard spectral sequence. That happened to be an event of the highest scientific importance, since such an interpretation had been awaited for a long time, implicitly ever since the first formulations of spectral classification some sixty years earlier.

The important achievements we are dealing with were gained by an entire community of astrophysicists, but we can recognise two special names among them: Megh Nad Saha (Figure 1) and Henry Norris Russell (Figure 2). The former was the man who first described the ionization of atoms in terms of gas temperature and pressure. The latter, in his turn, was greatly concerned with the problem of the physical interpretation of stellar spectra, after he had worked out the colour-magnitude diagram that in the 1930s was given his name (along with that of Hertzsprung). If we had to identify the beginning of the new era in one exact moment, we could do no better than to cite Saha's 1920 paper "Ionisation in the solar chromosphere", that contains his famous formula. At the same time that Saha, Russell and others were investigating the fruitful outcomes of the application of atomic theory to spectroscopy, Arthur Stanley Eddington was attacking the problem of stellar internal structure. Introducing into his stellar structure model such fundamental concepts as radiation pressure, the absorption coefficient and the mean molecular weight, he worked out his 'standard model'.

In this paper I want to discuss in detail the historical and scientific aspects of the contributions given by these scholars, pointing out in which way the two fields of investigation—Saha and Russell and their stellar surfaces, and Eddington and his stellar interiors—were due to meet in the years around 1930 when the prevalence of hydrogen in stellar composition was figured out.

2 THE SEARCH FOR A PHYSICAL INTEPRETATION OF THE HARVARD SPECTRAL SEQUENCE

The famous spectral sequence devised at Harvard University during five decades was worked out as an empirical task (Hearnshaw, 1986: 104-142). By the time the Harvard astronomers began to work on it, and in particular from 1901 onwards when Annie J. Cannon devised the familiar sequence O, B, A, F, G, K and M, nobody knew how to interpret physically the occurrence of a one-dimensional sequence, in which colour was strictly related to the visible spectral features.

Some light on that matter was cast at the beginning of the twentieth century, when stellar temperatures began to be measured on the basis of Planck's Law (Hearnshaw, 1986: 219-222). In the years 1905-1909, J. Wilsing and J. Scheiner at Potsdam visually measured colour temperatures of 109 stars, establishing in that way that colour was indeed a temperature-related parameter. The hottest star in their sample turned out to be λ Ori at 12,800 K, the coldest ones μ Gem and κ Ser at 2,800 K. The values were affected by large systematic errors, especially for hot stars.[1] As C.G. Abbot noticed, these errors were allegedly due to the fact that the contribution of dark lines had not been taken into account. In fact, line blocking and subsequent deviations from the black body curve are very severe in the blue region of stellar spectra, where hot stars mainly radiate. Further work was carried out at Potsdam by Wilsing and W.H.J. Münch upon another sample of 90 stars, but they still underestimated values for hot stars. By the same time, at Paris Observatory C. Nordmann visually assessed color indices for fourteen stars, observing them through red and blue filters. Then he derived temperatures from comparisons with Planck's curves.

Another way to tackle the problem was through photographic photometry. K. Schwarzschild was the leading pioneer in establishing these techniques. Essentially, in the years around 1900 he laid down the basic concepts and paved the way for the determination of colour indices that was performed by A. Hnatek in 1911. Hnatek tried to avoid the problems due to the greater sensitivity in the blue and the non-linear response of photographic plates by exposing calibration plates as well, and using these to reduce the stellar spectra that he recorded. He measured the temperatures of seven stars relative to Altair for which he adopted Wilsing and Scheiner's value of 7,100 K (500 K lower than the correct figure, which today is estimated to be around 7,600 K). H. Rosenberg exploited Schwarzschild's techniques, too. He took images of spectra for a wide sample of stars and derived their temperatures. He obtained reliable values for colder stars but too high ones for hot stars, especially in comparison to those of Wilsing and Scheiner, which, in their turn, were underestimated. The differences in some cases were astonishing: up to 10,000 K! The fact that the temperatures of hot stars are very difficult to deal with was not clear in those early days. In conclusion, we may say that by the mid-1910s the spectral sequence was generally thought to be a temperature sequence, although temperature measures were subject to large systematic errors. Nevertheless, the way in which spectral features were related to colour, and thus to temperature, was poorly understood. In other words, although everybody in the astrophysical community thought that temperature had to play a major role in the production of spectral lines, nobody knew exactly how this should happen.

Figure 2: Henry Norris Russell, 1877–1957 (courtesy Yerkes Observatory).

It is noteworthy that in the years around 1890, J. Norman Lockyer (Figure 3), an English amateur astronomer who devoted his spare time to astronomical spectroscopy, had a remarkable intuition on that matter. He observed that the spectrum of a given element shows different lines if it is heated up at different temperatures. He then surmised that as the temperature increases elements are split into smaller components that he called 'proto-elements', which were responsible for the so-called 'enhanced lines'. He wrote:

> I call the latter [lines obtained at higher temperature that Lockyer had previously referred to] "*proto-metallic*" lines, and consider the substances which produce them, obtained at the highest available laboratory temperatures, "proto-metals", that is, a finer form of the metal … (Lockyer, 1900: 57).

He further noticed:

> We have then to face the fact that on the dissociation hypothesis … the metals which exist at the temperature of the arc [i.e. at lower temperatures] are broken up into finer forms, which I have termed protometals, [that are responsible for the] enhanced spectrum … (Lockyer, 1900: 81).

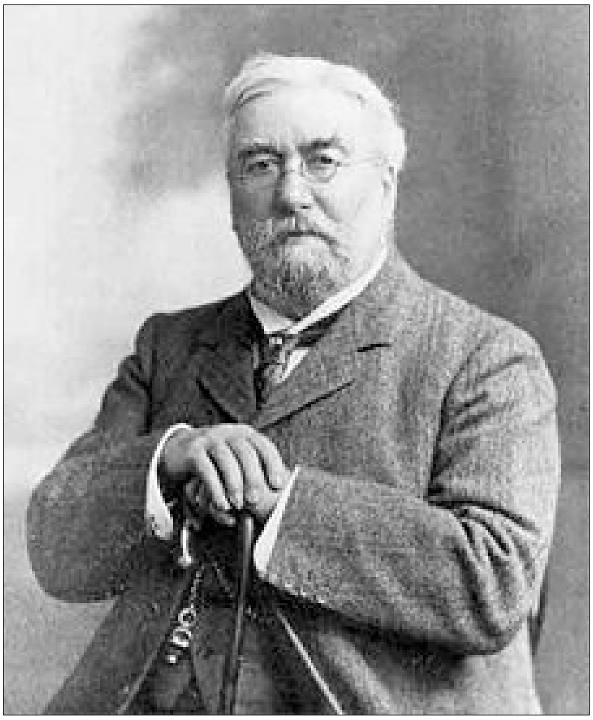


Figure 3: J. Norman Lockyer, 1836–1920 (after *Proceedings of the Royal Society*, 1909).

It is easy to see in Lockyer's proto-elements an anticipation of the concept of ionized elements. Lockyer's work on stellar spectra was the basis upon which he devised a theory of stellar evolution. This theory was based upon the so-called 'meteoritic hypothesis' (Lockyer, 1887; 1888), according to which all heavenly bodies were formed by meteor swarms that collided and then grouped together, driven by gravity. They first formed nebulae, then young, low-temperature stars that afterwards contracted and heated up. Finally the contraction stopped and the stars cooled down again. Lockyer thought he could describe this process by means of a colour-changing pattern, of the kind red → yellow → blue → yellow → red. This scheme in which a star passes twice throughout the spectral sequence was devised almost twenty years before Russell worked out a similar evolutionary process based upon the H-R Diagram (although today such evolutionary schemes are totally discarded). Lockyer's work involved remarkable insight, but it was quite odd at the same time. Russell's contemporary, H. MacPherson (1920: 226), noticed that in Lockyer's theory "… truth and error seem to have been strangely intermixed." while Hearnshaw (1986: 93) points out that "… his work on the enhanced lines illustrated Lockyer's unusual scientific insight, in spite of his unorthodoxy." In any case, apart from such intuitions, towards 1920 knowledge was still lacking, and the occurrence of spectral lines throughout the spectral sequence remained unexplained. Astronomers began to get frustrated about this. As E. Arthur Milne (1924: 95) observed some years later: "There appeared to be a definite relation between effective temperature and type of spectrum … but the connection was empirical. There was a gap in the logical argument."

If there was but one scholar longing for a theoretical explanation, that person was Russell. He had made major contributions to the field of stellar spectroscopy devising the colour-brightness (absolute magnitude) diagram, and his interests extended from stellar evolution to the determination of stellar masses in multiple systems. In the papers that he published in the years before 1920, that lack of knowledge is rarely stressed (and sometimes even a slight sense of defeat seems to emerge from Russell's words). For example, in 1919, just before learning of Saha's work, Russell wrote:

> There is now good reason to believe that the differences between the main classes of spectra arise from differences in the effective surface temperature of the stars, and that differences in their other physical characteristics play only a minor rôle in the spectra, but reveal themselves in differences in detail, formerly described as "peculiarities" when they were noticed at all. The investigation of these finer differences is to-day the most promising field in stellar spectroscopy. (Russell, 1919: 395).

In 1921, after Saha's work had been published and Russell had immediately realised its importance, he published in the *Publications of the Astronomical Society of the Pacific* the paper "The properties of matter as illustrated by the stars", that consisted of an historical synopsis of stellar physics up to that time. In it, the development of spectroscopy from its beginning was surveyed and great emphasis was placed on recent achievements: about 6 pages (of the 16) were devoted to a detailed discussion of atomic properties and their relation to spectra. An acknowledgment to Saha was explicitly given.

In 1922 Russell stressed once more the importance of Saha's contribution:

> The principles of ionization theory will evidently be of great importance throughout the whole world of astrophysics, and Dr. Saha has made an application of the highest interest to the question of the physical meaning of the sequence of stellar spectra …
>
> The possibilities of the new method appear to be very great. To utilize it fully, years of work will be required to study the behavior of the elements … in the stars, in laboratory spectra, and by the direct measurement of ionisation; but the prospect of increase of our knowledge, both of atoms and of stars, as a result of such researches, makes it urgently desirable that they should be carried out. (Russell, 1922: 143-144).

3 THERMAL IONIZATION AND EXCITATION

As we have seen, the long-awaited explanation came from 1920 onwards as the newborn Bohr-Sommerfeld theory of the atom met astrophysics, and that happened at first thanks to the work of a mathematically-skilled, Indian physicist, who was deeply interested in the developments that the theory of the atom was undergoing in Europe. He was Megh Nad Saha.

In 1920, Saha (1920a: 479) devised his famous formula

$$\log\left(\frac{x^2}{1-x^2}P\right) = -\frac{U}{KT} + \frac{5}{2}\log T + \log\frac{(2\pi\,\mathrm{m})^{3/2}K^{5/2}}{h^3} \qquad (1)$$

where x is ratio of ionized to total number of atoms, P the gas pressure, U the ionization potential, T the absolute temperature, m the mass of the electron, K is Boltzmann's constant and h is Planck's constant.

The formula had been obtained to describe ionization as a function of T and P in a gas constituted of only one element in local thermodynamic equilibrium. In devising this formula, Saha drew on the process of chemical dissociation presented by J. Eggert (1919), and extended this idea to the atomic realm (meaning ionization being analogous to dissociation). In fact, there was not really a sound basis that it could rely on. In 1923 Ralph H. Fowler, a mathematician who came to astrophysics after studying Emden's equation and who was greatly interested in mathematical physics, devised it on the ground of considerations in statistical mechanics. Fowler (1923: 21) found that

$$\log\left(\frac{x^2}{1-x^2}P\right) = -\frac{U}{KT} + \frac{5}{2}\log T + \log\frac{(2\pi\,\mathrm{m})^{3/2}K^{5/2}}{h^3} - \log b(T) \qquad (2)$$

This is the very same equation derived by Saha, the only difference being that a term $-\log b(T)$ appears, where $b(T)$ is the partition function and is usually of the order of unity (thus $\log b(T) \approx 0$).

But Fowler's contribution was not the first reference to Saha's work, as Russell had already mentioned it in 1922, when the American astrophysicist noticed that:

> If atoms of several different kinds, all capable of ionization, are present, the situation is somewhat more complicated. To use [Saha's] equation, introducing for P the value of the partial pressure of the vapor of each element separately, is inadmissible, since one of the products of the reaction - free electrons - is produced by all the ionizations. (Russell, 1922: 121).

Russell (ibid.) then went on to generalize Saha's equation in the case where different elements were simultaneously present. If we call a_1, a_2, … the numbers of atoms of different kinds; x_1, x_2, … the ratios of ionized to total atoms for the different elements; x^* the ratio of ionized to total number of atoms of all kinds ($x^* = \Sigma a_i x_i / \Sigma a_i$); then for the generic element Saha's equation becomes:

$$\frac{\mathrm{x_i}}{1-\mathrm{x_i}}\,\frac{\mathrm{x}^*}{1+\mathrm{x}^*} = \frac{\Omega_\mathrm{i}}{P} \qquad (3)$$

where

$$\log\Omega_\mathrm{i} = -\frac{5036\,U_i}{T} + 2.5\log T - 6.5 \qquad (4)$$

where U_i is the ionization potential of the considered element (and in Equation (4) the numerical values of the constants have been inserted).

Russell also studied the occurrence of further ionization states such as doubly-ionized atoms. He concluded that usually for any element "… there will not simultaneously be any noticeable proportion of atoms in all three states of ionization." (Russell, 1922: 125). A comparison with relative intensities of lines in the solar spectrum and in the spectra of sunspots confirmed the theory.

In 1923 Fowler, after his aforementioned contribution, returned to the topic and with E. Arthur Milne published the paper "The intensities of absorption lines in stellar spectra, and the temperatures and pressures in the reversing layers of the stars". The two scholars realized that they had to consider also the thermal dependence of atomic excitation, which relies on Boltzmann's distribution and which Saha had not taken into account. It is a fundamental feature if we consider that absorption lines of the optical series of elements such as H and He originate from excited levels:

> It is easy to calculate from Saha's theory as it stands the condition for the maximum intensity of lines like the H and K lines of calcium … As the temperature of Ca vapour increases the concentration of Ca^+ atoms steadily increases until (at a point where the proportion of neutral atoms is very small) second-stage ionisation sets in and the concentration of Ca^+ atoms diminishes.
>
> But Saha's theory has not hitherto accounted quantitatively for the maxima of such lines as the Balmer lines of hydrogen … Before an H atom can absorb a Balmer line the electron must be lifted into a 2-quantum orbit … Saha pointed out that as the temperature increases the fraction of atoms in the higher quantum states will increase, but stated that he could give no definite calculation. [We want to] point out that with the aid of the general theory of assemblies of atoms, electrons and radiation in statistical equilibrium, it is possible to determine the fraction of excited atoms under given conditions of temperature and pressure and to use this to discuss the intensities of lines such as those of the Balmer lines. (Fowler and Milne, 1923: 404-405).

Fowler and Milne started from an equation similar to Equation (2):

$$\log\left(\frac{x^2}{1-x^2}P_e\right) = -\frac{U}{KT} + \frac{5}{2}\log T + \log\frac{(2\pi\,\mathrm{m})^{3/2}K^{5/2}}{h^3}\sigma - \log b(T) \qquad (5)$$

This differs from Fowler's earlier equation in two respects:

1) P is replaced by the pressure of the electrons alone P_e, and Fowler and Milne (1923: 407n) acknowledge Russell's 1922 paper for this; and
2) The term σ is introduced, which is "… the number of valency electrons in the atom in equivalent orbits." (Fowler and Milne, 1923: 407). It was inserted as "… any one of the σ equivalent electrons may be removed in ionisation. In our applications $\sigma = 1$ or 2." (ibid, footnote).

From that starting point, they succeeded in incorporating the excited levels of an atom into an equation, describing them as a function of T. They called n_r the number of neutral atoms of a given element in the excitation state r, q_r the statistical weight, χ_r the energy of that state and χ_1 the energy of the ground state, and devised the formula:

$$n_r = \frac{q_r e^{-(\chi_1-\chi_r)/KT}}{b(T) + aT^{5/2}e^{-\chi_1/KT}} \qquad (6)$$

where the term a is given by:

$$\mathrm{a} = \frac{(2\pi\,\mathrm{m})^{3/2}K^{5/2}\sigma}{h^3 P_e} \qquad (7)$$

Fowler and Milne were able to calculate as a function of temperature and electronic pressure the percentage of ionized and excited atoms, i.e. the percentage of atoms in the proper conditions to absorb any set of spectral lines. The two scholars succeeded in estimating the electronic pressure to be about 10^{-4} atm and could thus plot the number of atoms capable of absorbing any set of spectral lines as a function of temperature (see Figure 4). This pressure estimate was made supposing that the Balmer lines should reach a maximum at 10,000 K and calculating for which pressure it actually happened. They further observed that such a value for pressure was suitable also for other elements. In the case of lines absorbed from excited states (like the Balmer series) the relation plotted in Figure 4 is Equation (6); for other series, formulae derived from Saha are used. In Figure 4, a scale of the temperature for the different spectral classes is deduced. It is obtained by assigning to the class where a certain set of lines shows a maximum of intensity, the temperature for which the absorption of those lines turns out to be the largest (for the given pressure). This method was called the method of *intensity maxima*. It can be applied to all lines, except those absorbed from the ground state of a neutral atom (that do not show an intensity maximum at any temperature). It allowed Fowler and Milne to calibrate the absolute temperature scale for spectral classes, and compare it with that devised from spectrophotometric measures. The two scholars noticed that a good agreement was reached, although they thought their temperature scale was only provisional, mainly because of uncertainty surrounding the pressure value: "… indeed, if a value $P_e = 10^{-4}$ atmos. can be assumed on other grounds, the temperature scale to which we are led is independent of any adjustment." (Fowler and Milne, 1923: 421).

In conclusion, by exploiting Saha's earlier work and utilizing the Boltzmann distribution, Fowler and Milne succeeded in describing the ionization and excitation states of atoms as a function of temperature and electron pressure. Their achievements are best summarised by the following formula:

$$N_{j,k}/N = f(T,P_e) \tag{8}$$

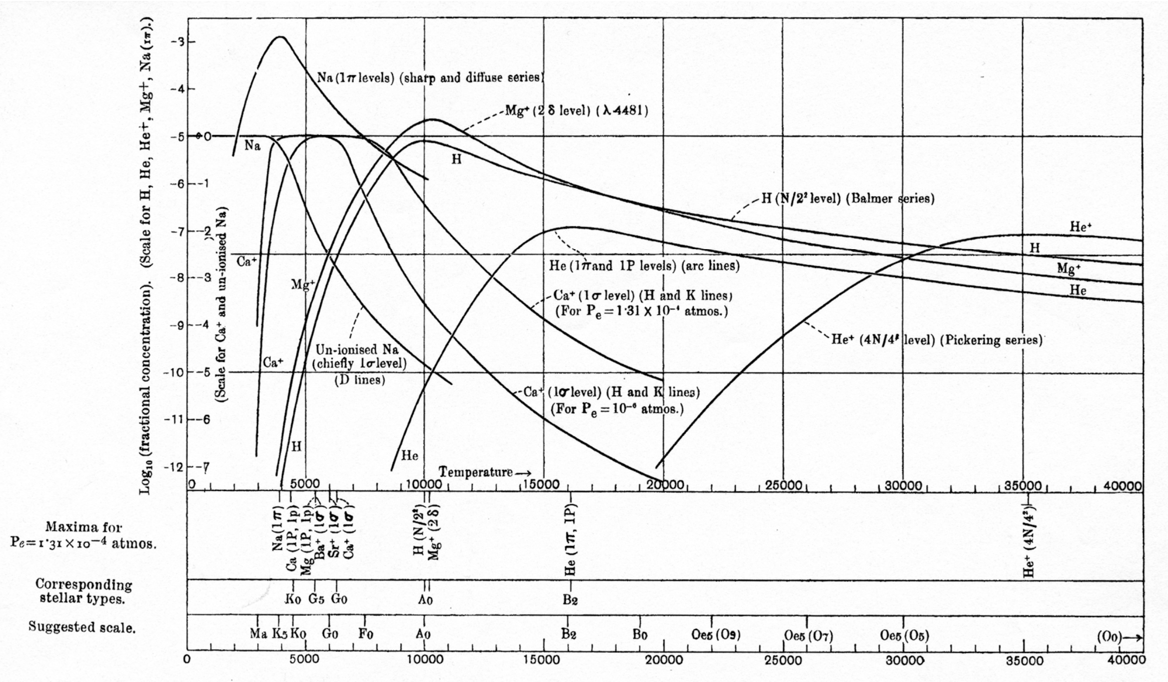
where $N_{j,k}$ is the number of atoms in the generic state of ionization j and excitation k, N the total number of atoms of that kind and $f(T,P_e)$ a proper function of T and P_e.

4 THE FIRST DETERMINATION OF THE CHEMICAL COMPOSITION OF STELLAR ATMOSPHERES

Fowler and Milne (1923) realized how their work could pave the way for the determination of the chemical composition of stellar atmospheres. In fact, from Equation (8) we have:

$$N_{j,k} = N \cdot \left(N_{j,k}/N\right) = N \cdot f(T,P_e) \tag{9}$$

So, if we can estimate the absolute number of absorbing atoms $N_{j,k}$ that contribute to create a certain line, we can work out the relative abundance of the relevant element through their (and Saha's) function $f(T, P_e)$. In other words, well-pronounced lines far from the optimum T and P_e conditions mean high abundance, and conversely, on the contrary, weak lines near the optimum conditions mean low abundance. Notice that the transition rates should be taken into consideration, as Fowler and Milne explicity stated. If we try to estimate $N_{j,k}$ at the intensity maximum of a certain set of lines, we can encounter problems due to line saturation, and thus it may be very difficult to evaluate $N_{j,k}$ without a theory of line-formation and line-broadening. In other words, we cannot calibrate the line intensity against the absolute number of absorbing atoms. It was some years later, after further progress, that this problem would be faced (see below in this Section). Fowler and Milne used a more feasible way, by trying to determine at which point in the spectral sequence a set of lines makes its first appearance (i.e. a so-called marginal appearance). They argued that if the absolute number of atoms needed to create a weak, just detectable, line could be determined, then formula (9) could be used to work out the abundance, N, of that element.



(*Note.*—The partial electron pressure $P_e = 1{\cdot}31 \times 10^{-4}$ is chosen so as to give a maximum for the Balmer lines at $T_{max} = 10{,}000°$. Curves for all elements are then calculated for this pressure. An alternative curve is given for Ca^+.)

Figure 4: Plot of the number of atoms capable of absorbing several sets of spectral lines as a function of temperature; a temperature scale is deduced (after Fowler and Milne, 1923: 420B; courtesy: Blackwell Publishing).

It was a couple of years later that Cecilia H. Payne (Figure 5) took up the suggestion (for Payne's contributions see Hearnshaw, 1986: 229-231, and DeVorkin and Kenat, 1983a: 124-127). In her Ph.D. dissertation, *Stellar Atmospheres*, she worked out the chemical composition of stellar atmospheres, starting from the standpoint that the chemical composition was the same for all stars and differences in spectra were only due to T and P_e. She had at her disposal the huge number of spectra analysed by Pickering and his collaborators at Harvard, and she defined a scale of intensity for different lines. Then she worked out a temperature scale from intensity maxima, fixing $P_{\mathrm{e}} \approx 10^{-4}$ in much in the same way that Fowler and Milne had done, and finally she could exploit the marginal appearances method and find abundances for eighteen elements. Payne's results showed that a very good agreement could be found with the composition of the Earth's crust, except for hydrogen and helium, which turned out to be several orders of magnitude more abundant in stars. According to Russell, these discrepancies were supposed to be spurious; he guessed that a similarity of chemical composition between the solar atmosphere, and perhaps the entire Sun and the Earth, as a consequence of the common birth of the two celestial bodies, was supposed by the 'Nebular Hypothesis'.

Payne's determination of the chemical composition of stellar atmospheres, the first to be performed, was a major achievement; as DeVorkin and Kenat (1983a: 126) underline: "Payne's thesis *Stellar Atmospheres* brought to maturity that which Saha's theory had first made possible." In other words, we may interpret Saha's work as a fundamental moment in history, not so much for the novelty of his formula—that indeed was not completely new as it was derived from a very similar one that Eggert had found to describe chemical dissociation—but rather as it paved the way, building a bridge between observational data and quantum theory, to the physical interpretation of the spectral sequence (as first performed by Saha himself and outlined in his 1920b and 1921 papers), and to quantitative spectral analysis (temperatures and chemical composition). Although it was not Saha himself who was the main actor in all these steps, *à la* Eddington, we can see that he played a major role.

As DeVorkin and Kenat (1983a: 126) underline, Payne could relate the fundamental theoretical refinements made by Russell, Fowler and Milne to the huge body of spectroscopic data available at Harvard while developing her doctorate thesis, and she also had a much greater knowledge of ionisation potentials, something which Saha lacked and explicitly complained about (see Saha, 1921: 153).

The problem of hydrogen abundance had been revealed for the first time, but much progress was still required. In fact, Payne's work still contained some 'stumbling blocks'. Apart from not considering transition rates, upon which very little was known at the time, it was bound to the subjective concept of marginal appearance: it was necessary to know precisely how many atoms contributed to the absorption of a faintly visible line, an approximate estimate being not enough. For this reason, from the second half of the 1920s the attention of astrophysicists was more and more drawn towards the problem of the mechanism involved in line formation—e.g. in their broadening, which influenced their visibility—and to the practical calibration of line intensity on the number of absorbing atoms.

As early as 1924 John Q. Stewart had dealt with this problem, in that year publishing a paper on "The width of absorption lines in a rarefied gas" in the *Astrophysical Journal*. Using a semi-classical theory of photon scattering in the solar atmosphere, he showed that the width of a line may be due to high abundance as well as to high pressure. He then proposed a relationship between line width and the number of absorbing atoms, also inferring what the minimum number of atoms was in order to give marginal appearance. Soon after, Stewart returned to the problem with Russell (Russell and Stewart, 1924), and evidence for a high hydrogen abundance emerged from their work, but this was not believed. In the following years astrophysicists tried in many ways to explain these strange results (e.g. advocating departures from thermodynamical equilibrium), until the high hydrogen abundance was finally accepted (as we shall see in the next Section).

Another major problem was that the line intensity was not by any means defined in a quantitative manner. Rowland's scale for the solar spectrum was still in use, and this assigned a number to each line that expressed its intensity. This was an arbitrary scale and was not physically defined, with all the inherent errors this could introduce.

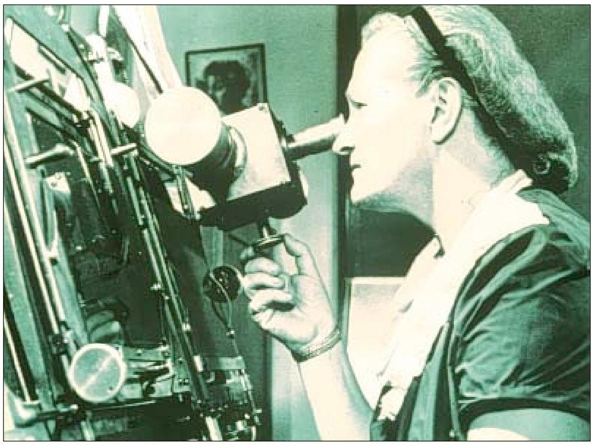


Figure 5: Cecilia H. Payne, 1900–1979 (courtesy Astronomical Society of the Pacific).

5 FINAL ACCEPTANCE OF THE ABUNDANCE OF HYDROGEN

The final rush that finished off the exploitation of Saha's theory saw once again Russell as a main character.[2] In 1928 Walter S. Adams, Charlotte E. Moore and Russell published a paper titled "A calibration of Rowland's scale of intensities for solar lines" in the *Astrophysical Journal*. By that time the theoretical intensities of lines within the same multiplet had become available, and the three scholars observed the different intensity of lines of some multiplets and compared them to the expected ones. In this way they succeeded in calibrating Rowland's scale to the number of atoms, although only approximately. Their most noteworthy conclusion was:

> The most obvious result of the present investigation is to emphasize the enormous differences in the number of atoms which are involved in the formation of the

> stronger and weaker Fraunhofer lines. From the weakest perceptible lines … to such lines as Hα or the great iron lines in the violet (λλ. 3720, 3735), this number increases by a factor of approximately a million. For the H and K lines, which are too strong to be calibrated, the factor must be much greater. (Adams, Russell and Moore, 1928: 8).

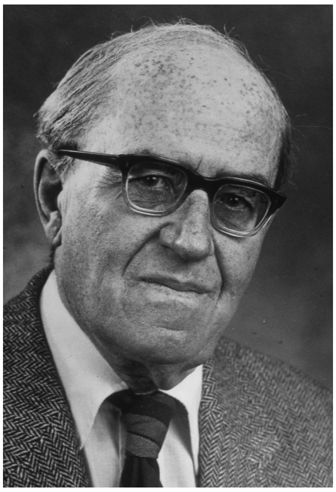


Figure 6: Albrecht Unsöld, 1905–1995 (courtesy www.phys-astro.sonoma.edu/…/unsoldSml.jpg).

In the same issue of the *Astrophysical Journal,* immediately following the above paper, there was another paper by Adams and Russell titled "Preliminary results of a new method for the analysis of stellar spectra". In it they sought to extend to the stars what they had just deduced from the solar spectrum, comparing the different line intensities.

Table 1: Comparison of the elemental abundances found by Payne and Russell.

Element	Payne (log *n* of atoms)	Russell (log *n* of atoms)
H	12.9	11.5
He	10.2	
C	6.4	7.4
O	8.0	9.0
Na	7.1	7.2
Mg	7.5	7.8
Al	6.9	6.4
Si	7.5	7.3
K	5.3	6.8
Ca	6.7	6.7
Fe	6.7	7.2

However, the conclusive link between theory and observation was offered in that same period by Albrecht Unsöld (Figure 6). Utilizing a semi-classical treatment of the scattering process, and considering only this to be effective in line formation, he exploited the developments that had occurred in quantum theory by this time, and established a relationship between the number of atoms and the widths of several strong lines (Unsöld, 1927; 1928). Observing lines of the same element (e.g. Ca and Sr) both in the neutral and in the ionized state, and assuming a proper value for the temperature of the solar surface, he could deduce the pressure using Saha's equation (it happened to be $P_e = 10^{-6}$ atm). With this value he could derive the abundances of elements present in only one ionisation state. The hydrogen abundance inferred from the Balmer lines resulted in an enormous value. In comparing his work with Payne's results, Unsöld commented:

> These [Payne's values] postulate that the mean chemical composition of all stars is the same … The agreement of the results is fine and constitutes a strong support to the opinion here yet in different occasions advocated, that the abundance of the chemical elements in the whole universe is constant. Hydrogen is thus for example ca. 5.10^6 times more frequent than Ca. C.H. Payne also arrives at ~ 10^6. (Unsöld, 1927: 777 and 781; our translation).

Although Unsöld remained skeptical about the hydrogen abundance, he had found the keystone that had been lacking. By linking quantum theory with the formation of spectral lines, he gave Russell just what was needed: the zero point of Rowland's scale necessary to pass from relative to absolute abundances.

Consequently, in his fundamental paper, "On the composition of the Sun's atmosphere", Russell (1929) could estimate the electron pressure in the very same way Unsöld had done (and he found a similar value), then derive total abundances, starting from those of the different ionisation and excitation states, through Saha's equation. Russell summarized his results in a table containing 56 elements and 6 molecular compounds, in which a comparison was performed with Payne's values. Their respective values for some elements are listed in Table 1. Russell (1929: 65) commented on the agreement with Payne's values, observing that

> … Miss Payne's results were determined by a different theoretical method … About the only common features are the observations of spectral lines and the use of the ionization theory.

The scenario Russell had to face was so very different from what he had foreseen, although no more unexpected: too many indications pointed towards a high hydrogen abundance. Nor could they be neglected any longer, or attributed to unknown explanations. Russell (1929: 79) was ready to admit it, and he called this new awareness "… reconnaissance of new territory." To conclude, we must observe that Russell had actually applied in a very crude way what was to be formalized as the curve of growth technique. In particular, Russell lacked the concept of equivalent width and was still tied to the old Rowland scale that was soon to be abandoned. Between 1927 and 1931, H. von Klüber, M. Minnaert, G.F.W. Mulders and B. van Assenbergh all introduced the idea of equivalent width as well as the curve of growth technique, thereby placing the determination of the chemical composition of stellar atmospheres on a firm physically base.

6 EDDINGTON AND THE OPACITY DISCREPANCY

In the years 1916-1924 Arthur Eddington (Figure 7) published a series of papers in the *Monthly Notices of the Royal Astronomical Society* in which we worked out his 'standard model' of stellar structure. Eddington applied the concept of radiative equilibrium, and pointed out the importance of radiation pressure in addition to gas pressure. He started from the idea that the stars were gaseous spheres in hydrostatic equilibrium and that the perfect gas law held. He took into consideration only giant stars, since he thought the ideal gas condition to be certainly fulfilled for their more rarefied gases (Eddington, 1916: 16). On the other hand, he thought that dwarf stars should not be in a condition of perfect gas, at least in the inner and denser regions. Eddington allegedly was influenced by the theory of stellar evolution that Russell had worked out to interpret the occurrence of giant and dwarf stars in the H-R Diagram. Russell had developed that theory in the very same paper in which he had presented the first graphical representation of the Diagram (Russell, 1914). According to Russell, stars begin their life as contracting giant stars. As the radius decreases the surface temperature increases, until contraction stops when the density becomes so high that the perfect gas condition ceases to hold. From that point on gas becomes highly incompressible and the star begins to cool, descending the Main Sequence.

Starting from the aforementioned hypotheses, Eddington succeeded in demonstrating that under these assumptions a star in radiative equilibrium can be described by a polytrophic model of index 3 (Eddington, 1916: 21). About the assumptions made by Eddington and their acceptability see Mestel (2004).

After having succeeded in determining the values of the status parameter in the interior of a star, Eddington wished to obtain an expression for the brightness *L*. This led him to introduce the absorption coefficient Γ, defined as the radiation amount absorbed per unit mass and cross-section. This was dependent upon the distance from the star's centre, as radiation absorption depends upon the physical conditions of matter. This is a natural step in a radiative model. As for Γ, Eddington came upon the work of H.A. Kramers (1923) where a dependence of the following kind was deduced for the photoionization processes:

$$\Gamma \propto \frac{\rho}{\mu T^{3.5}} \qquad (10)$$

Starting from this, Eddington (1924b: 310) succeeded in deducing a relevant formula, known as the 'mass-luminosity relation':

$$L \propto M^{7/5}(1-\beta)^{3/2}\mu^{4/5}T_e^{\ 4/5} \qquad (11)$$

where *L* is the star's luminosity, *M* its mass, T_e the effective temperature, μ is the mean molecular weight (i.e. the mean mass per particle expressed in units of hydrogen mass) and β is the ratio of the gaseous to total pressure and is tied to the stellar mass and to μ itself via the famous 'quartic' relation (Eddington, 1918: 210; 1924a:109):[3]

$$1-\beta = \text{const} \times M^2\mu^4\beta^4 \qquad (12)$$

Hence Equation (11) is more properly a luminosity – mass – mean molecular weight – effective temperature relation. It is possible to introduce in the formula the radius in place of the effective temperature, using the relationship $L = 4\pi\sigma R^2T^4$. In this way we have a luminosity – mass – mean molecular weight – radius relation.

The major role played by μ is evident from Equations (11) and (12). Eddington was to be involved with this parameter for a long time, but where could he turn to in order to estimate its value? This value depends upon two factors: (1) the chemical composition of stellar gases that determines which elements are present and in what amounts; and (2) the physical conditions of temperature and pressure that determine the ionization of different elements. In 1916, when he attacked this problem, Eddington could count on neither a theory of ionization as a consequence of *T* and *P* nor any trustworthy estimate of chemical composition. As we have seen, the theory would be developed by Saha in 1920, and only then could the chemical composition of stellar gases be deduced from spectra.

Relying upon hazy estimates of composition, Eddington tentatively supposed that stellar gases could be composed of monoatomic iron vapor, from which he thought a value $\mu = 54$ to be reliable (Eddington, 1916: 22). He then realized, however, that the high temperature of the stellar interiors should produce a high ionization degree, in agreement with atomic theory, in order to lessen considerably the value of μ. Eventually he embraced a position that was argued by other colleagues:

> The suggestion that at these high temperatures we are concerned with particles smaller than the atom was made to me independently by Newall, Jeans and Lindemann. … I had supposed that atomic disintegration [ionization], though undoubtedly occurring, could not have proceeded very far; but Jeans has convinced me that a rather extreme state of disintegration is possible, and indeed seems more plausible. (Eddington, 1917: 596-597).

Figure 7: Sir Arthur Eddington, 1882–1944 (courtesy Wikipedia).

From that standpoint, it followed that at sufficiently high temperatures μ had to assume a value around 2 irrespectively of chemical composition, as for most elements (other than hydrogen, of course!) atomic weight is about half of the mass number. Eddington (1917: 596) then opted for a value of $\mu = 2$, but he went on to often use the value 2.11, maintaining the hypothesis of ferrous material. Meanwhile, in his Bakerian Lecture delivered on 17 May 1917 (and published in Jeans 1919: 209-210) James Jeans expressed the view that the value $\mu = 54$ was much too high and that $\mu = 2$ was more reliable. By the way, the idea that Jeans and Eddington had to apply the hypothesis of ionization to high temperatures constituted the very first astrophysical application of the quantum theory of the atom.

It should be noted that the high degree of ionization undergone by matter in a stellar interior has a remarkable outcome: due to the much smaller dimensions of particles, the ideal gas law holds even at the very high densities of dwarf stars. Initially Eddington was not prepared to admit this, as he relied upon Russell's evolutionary interpretation of the giant-dwarf duality. The British astrophysicist had to change his mind when he realized that the mass-luminosity relation (i.e. Equation (11)) also fitted the data for dwarf stars (Eddington, 1924b: 308-309). Thus, he came to the conclusion that dwarf stars are also made of perfect gas. Eddington (1924b: 320) also realized that

> … in the interior of a star the atoms of moderate atomic weight are stripped down to the K level, and have radii of the order 10^{-10}cm; lighter elements, such as carbon and oxygen, are reduced to the bare nucleus. The maximum density, corresponding to contact of these reduced atomic spheres, must be at least 100,000, and any star with mean density below 1000 ought to behave as a perfect gas.

In that same paper, Eddington explicitly discarded Russell's theory of stellar evolution, interpreting the Main Sequence as a sequence of quasi-equilibrium points corresponding to different masses.

Another surprise was awaiting Eddington. The constant of proportionality in Equation (11)—that is undetermined so long as the constant in Equation (10) is also undetermined, from which Equation (11) follows—was deduced by Eddington from the observed values of M, L and surface temperature for Capella (a double system of giant stars of well-known dynamical features and parallax). But if the constant in Equation (10) is worked out purely from quantum theory rather than from observed values, it turns out to be about 10 times higher (and this is called the 'opacity discrepancy'). Owing to the major role played by μ in the mass-luminosity relation, it is clear that a change in its value could reduce or even eliminate the difference. Eddington soon realized that the μ value could be the key for solving the problem. In *The Internal Constitution of the Stars*, published in 1926, he noticed that if the percentage of hydrogen is around one third in mass, the lowered value of μ helps to remove the discrepancy:

> There is one way in which [the two values for the absorption coefficient, worked out from theory and from observational data] can be reconciled by an assumed chemical composition of the star, namely, by mixing a considerable proportion of hydrogen with a heavier element, say, iron … Hydrogen is the only element which can make these changes … I was formerly attracted by the view that stars, especially in the giant stage, contain a large proportion of hydrogen – the idea being that the stars are the main, if not the only, seat of the manufacture of the higher elements from protons and electrons, the star's heat being incidentally provided by the process.[4] But the low molecular weight involved is out of keeping with the general trend of astronomical evidence … I would much prefer to find some other explanation [for the discrepancy]. (Eddington, 1926: 244-245).

At that time almost nothing was known about the chemical composition of stars, as spectroscopy was just beginning to address the problem. Thus, Eddington did not feel confident to change the value of μ, as he thought such a hydrogen percentage to be much too high.

But in the following years, as we have seen, a greater concern arose among scholars who were dealing with spectroscopic problems. Eddington undoubtedly followed with interest the debate that finally led to the acceptance of the greater hydrogen abundances at the surfaces of stars. But what about their interiors? Was it possible that a different composition was to be found there? The idea was not odd, as it had been considered by S. Rosseland in 1925, who, on the basis of electrostatic considerations, was led to believe that a high surface abundance did not automatically mean a similar abundance in the interior of stars. However, the idea was later discarded.

In 1932 Bengt Strömgren published a paper titled "The opacity of stellar matter and the hydrogen content of the stars" that finally led Eddington to take part in the quest. Strömgren (1932: 122-123) referred explicitly to the doubts that Eddington had put forward, but noted that in light of the work on stellar spectra by Unsöld, Russell and others, they could be put aside:

> The main argument against the hypothesis [of the great hydrogen abundance] is that the high abundance of hydrogen required seems rather improbable at first sight. It is however now an established fact, after the work of W.H. Mc Crea, H.N. Russell and A. Unsöld ... that in the atmospheres of the Sun and the stars in general hydrogen occurs in the proportion of about one half by weight … We shall *trust* the theoretical value of the coefficient of opacity and *deduce* the molecular weight and hence the hydrogen abundance for the stars with known M, R and L, where Eddington trusted the molecular weight (no hydrogen) and deduced the coefficient of absorption.

Strömgren then calculated theoretically the opacity coefficient, and worked out the Emden-Eddington solutions (as he called them) for stars of known M, R and L. This led him to deduce a hydrogen abundance around one third of the total mass.

Eddington's classic paper on the subject, "The hydrogen content of the stars", was published in that same year. Its starting point is the observation of a strong μ-dependence in the mass-luminosity relation: even a small change in its value will change significantly the relation between M and L. Consequently, it was necessary to lower it to a value close to 1. Eddington (1932: 471) then observed:

> When the luminosity of a star is computed from its mass and radius with the value of the absorption coefficient obtained from pure physical theory, the result comes out too bright. This well-known discrepancy amounts to a factor 10 for diffuse or massive stars, and is still larger for the Sun and smaller stars in a less highly ionised condition. This result is subject to the reservation that the stars do not contain a large proportion of hydrogen.

This last statement was evidently the hypothesis he needed to reject, and to convince himself, Eddington calculated for the Sun—whose mass and radius were well-known—L as a function of μ, assuming a composition of hydrogen plus ferrous materials in variable proportions. The resulting curve was plotted in a diagram, where the difference between calculated and real luminosity for different hydrogen percentages was shown (see Figure 8).

Eddington noted that two values could be accepted for the abundance of this element: around 33% and almost 100%. Similar results were obtained for other stars, so that "… there must be some cause which makes the hydrogen content of the stars nearly uniform." (Eddington, 1932: 476). He thought the lower abundance to be more trustworthy:

> For each star there are two solutions - two possibe proportions of hydrogen consistent with the observed luminosity. In one solution the star is chiefly hydrogen (about 99½ per cent.) with only a trace of other elements. The other solution, which rightly or wrongly I have assumed to be the more probable, gives approximately 33 per cent. hydrogen in the Sun, Capella, Algol and Krüger 60. These stars were selected as having first-class observational data and covering a wide variety of mass and density … The surprising thing is the steadiness of the hydrogen content, shown not only in the four stars above mentioned, but in the general adherence of the star to a mass - luminosity curve. (Eddington, 1932: 472).

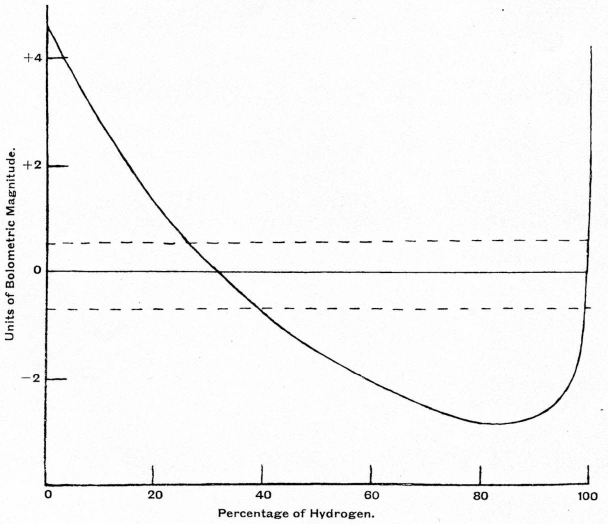
In fact, if the hydrogen percentages were very different from star to star, there should be a strong scattering in brightness for stars of similar mass and there would not be any mass-luminosity relation at all.

What other indications did Eddington have to induce him to believe in the unexpectedly-high presence of hydrogen? Was what he had worked out from the aforementioned deduction just a strong indication, or was it real proof? Eddington had adopted some questionable assumptions when developing his model, so the occurrence of any indication of a different kind was certainly welcome. As he pointed out:

> Partly by elimination of alternative explanations, and partly by the recent evidence of great abundance of hydrogen in stellar atmospheres coupled with our theoretical knowledge that hydrogen will not escape to the outside but will be kept stirred by currents set up in rotating stars, the hydrogen hypothesis has now come into prominence. If the proportion of hydrogen is given, the composition of the rest of the material makes very little difference to the luminosity. Thus if we are convinced that there is no other serious uncertainty in the problem, it is theoretically possible to determine the hydrogen content of a star of known L, M and R. We have simply to find what proportion of hydrogen mixed with other elements will give a luminosity agreeing with the observed luminosity. This is no longer a matter of speculative curiosity; such determinations are needed to compare with and check the determinations of abundance of hydrogen in stellar atmospheres made by H.N. Russell and others. (Eddington (1932: 472).

Eddington's choice for a percentage around 33% is evidently based on the fact that he thought it to be less extreme, much in the same way as Strömgren had done. In the decades that followed, further research would demonstrate that the extreme percentage is in fact much closer to reality.[5]

By the way, Eddington argued that even with a hydrogen abundance of around 33%, the mass-luminosity relation still deviated from observational data for the most massive stars. He came to that conclusion after analyzing the data for V Puppis, a star of 19 solar masses (which today is known to comprise two components of spectral types B1 and B3). The calculated luminosity turned out to be ~1.5 magnitudes too large, and the hydrogen proportion had to be increased to yield the expected one. Although Eddington (1932: 479) thought that "... there is some ground to think that the proportion of hydrogen in the most massive stars is greater than 33% ...", other factors could be at work. For example, he was aware of the uncertainty in the surface temperature for hot stars. Furthermore, by that time bolometric corrections were calculated in a semi-empirical way that had not undergone substantial improvement for many years. Scholars still tended to refer to the work carried out by Hertzsprung in 1906 (reference to this work, as well as 'state of the art' knowledge in this respect, is given in Eddington, 1926: 138-139). This could affect significantly the luminosity values of very hot stars that mainly radiate outside the visible region.



Theoretical Constitution of the Sun.

Figure 8: Plot of the brightness of the Sun versus the mass percentage of hydrogen. The value 0 corresponds to the real brightness and identifies two possible values for hydrogen (33% and 99.5%). The dotted lines correspond to other possible structures of the Sun obtained by hypothesizing on the distribution of energy sources other than those Eddington actually used (after Eddington, 1932: 476; courtesy: Blackwell Publishing).

7 CONCLUSIONS

During the 1920s and the beginning of the 1930s important developments took place in stellar astronomy. Previously, knowledge about the nature of the stars was essentially limited to the following achievements:

- Stars were thought to be hot gaseous bodies, and this was confirmed by spectra that highlighted the absorption by gaseous material nearby the surface. No quantitative chemical analyses had been carried out and in this regard not much more was known than Kirchhoff's qualitative analyses of the 1860s.
- Surface temperatures were assumed to be between 3,000 and 15,000 degrees. There were, however, no reasonable guesses for what the temperature might reach in the interiors of the stars. As regards gaseous pressure, precise calculations had not been made, although reasonable estimates for the inner regions could be worked out from the condition of hydrostatic equilibrium.
- A series of empirical regularities had been found—such as the Hertzsprung-Russell Diagram—made possible by the gathering of observational evidence and progress in detection equipment and techniques.

In the fifteen years from 1920, a transition took place from this set of empirical results to a new series of achievements which were based upon the sound theoretical background provided by the quantum theory of the atom. We have seen how this led to the merger of two fields of investigation, stellar surfaces and stellar interiors, and the progress astrophysics underwent is epitomized by the passage from a fragmentary set of results to a unitary and complete *corpus* of knowledge that included values for specific stellar parameters and the chemical composition of stellar interiors and surfaces. In this process we see the convergence of quantum theory, thermodynamics, spectroscopy and issues regarding the chemical composition of the Universe. The acknowledgement of the prevalence of hydrogen in stellar composition should be thought of as a meaningful moment in the history of astrophysics, as it was the first application of quantum theory to the stars that led scholars to depict a whole new reliable picture of stellar structure.

8 NOTES

1. More recent measures for λ Ori indicate a temperature of around 30,000 K (see http://webviz.u-strasbg. fr/viz-bin/VizieR).
2. A fine discussion of the reasons that kept scholars from initially admitting the high hydrogen abundance and later induced them to accept it can be found in DeVorkin and Kenat (1983b: 204-208). In this paper I do not intend to go into such detail; my main interest is in drawing a picture of the principal advances that were made possible by physical theory.
3. The constant in Equation (12) was estimated by Eddington (1924b: 309) to be 0.00309 if M is expres-sed in solar units.
4. Eddington long speculated about the nature of the process capable of supplying a star's energetic output. Here it is enough to say that in 1926 his ideas were merely speculative, but only a few years later light began to be cast upon this matter. Nevertheless, Ed-dington showed great insight when he guessed that hydrogen could play a key role. In this respect, giant stars should contain more hydrogen, so long as they were thought to be younger.
5. In historical perspective, it should be noticed that a mass-luminosity relation actually holds only if a law of energy release is known. Yet in the 1920s, Milne, Jeans and Vogt had pointed out how Eddington's relation was based upon an incomplete system of equations (see Cowling, 1966: 126). In any case, this should not cast a shadow upon the scientific and historical importance of Eddington's model or belittle his deep physical insight.

9 REFERENCES

Adams, W.S., and Russell, H.N., 1928. Preliminary results of a new method for the analysis of stellar spectra. *Astrophysical Journal*, 68**,** 9-36.

Adams, W.S., Russell, H.N., and Moore, C.E., 1928. A calibration of Rowland's scale of intensities for solar lines. *Astrophysical Journal*, 68, 1-8.

Comte, A., 1835. *Course de Philosophie Positive, X*. Paris, Bachelier.

Cowling, T.G., 1966. The development of the theory of stellar structure. *Quarterly Journal of the Royal Astronomical Society*, 7, 121-137.

DeVorkin, D.H., and Kenat, R., 1983a. Quantum physics and the stars (I): the establishment of a stellar temperature scale. *Journal for the History of Astronomy*, 14, 102-132.

DeVorkin, D.H., and Kenat, R., 1983b. Quantum physics and the stars (II): Henry Norris Russell and the abundances of the elements in the atmospheres of the Sun and stars. *Journal for the History of Astronomy*, 14, 180-222.

Eddington, A.S., 1916. On the radiative equilibrium of the stars. *Monthly Notices of the Royal Astronomical Society*, 77, 16-35.

Eddington, A.S., 1917. Further notes on the radiative equilibrium of the stars. *Monthly Notices of the Royal Astronomical Society*, 77, 596-612.

Eddington, A.S., 1918. On the conditions in the interior of a star. *The Astrophysical Journal*, 48, 205-213.

Eddington, A.S., 1924a. The absorption of radiation inside a star (second paper). *Monthly Notices of the Royal Astronomical Society*, 84, 104-123.

Eddington, A.S., 1924b. On the relation between the masses and luminosities of the stars. *Monthly Notices of the Royal Astronomical Society*, 84, 308-332.

Eddington, A.S., 1926. *The Internal Constitution of the Stars*. Cambridge, Cambridge University Press.

Eddington, A.S., 1932. The hydrogen content of the stars. *Monthly Notices of the Royal Astronomical Society*, 92, 471-481.

Eggert, J., 1919. Über den Dissoziationszustand der Fixsterngase. *Physikalische Zeitschrift*, 20, 570-574.

Fowler, R.H., 1923. Dissociation-equilibria by the method of partitions. *Philosophical Magazine*, 45, 1-33.

Fowler, R.H., and Milne, E.A., 1923. The intensities of absorption lines in stellar spectra, and the temperatures and pressures in the reversing layers of the stars. *Monthly Notices of the Royal Astronomical Society*, 83, 403-424.

Hearnshaw, J.B., 1986. *The Analysis of Starlight: One Hundred and Fifty Years of Astronomical Spectroscopy*. Cambridge, Cambridge University Press.

Jeans, J.H., 1919. Bakerian Lecture, 1917: The configurations of rotating compressible masses. *Philosophical Transactions of the Royal Society of London. Series A*, 218, 157-210.

Kramers, H.A., 1923. On the theory of X-ray absorption and of the continuous X-ray spectrum. *Philosphical Magazine*, 46, 836-871.

Lockyer, J.N., 1887. Researches on the spectra of meteorites. *Proceedings of the Royal Society*, 43, 117-156.

Lockyer J.N., 1888. Suggestions on the classification of the various species of heavenly bodies. *Proceedings of the Royal Society* 44, 1-95.

Lockyer J.N., 1900. *Inorganic Evolution as Studied by Spectrum Analysis*. London, Macmillan.

MacPherson, H., 1920. Recent theories of stellar evolution. *Popular Astronomy*, 28, 225-231.

Menzel, D.H., 1972. The history of astronomical spectroscopy. I: qualitative chemical analysis and radial velocities. II: quantitative chemical analysis and the structure of the solar atmosphere. *Annals of the New York Academy of Sciences*, 198, 225-244.

Mestel, L., 2004. Arthur Stanley Eddington: pioneer of stellar structure theory. *Journal of Astronomical History and Heritage*, 7, 65-73.

Milne, E.A., 1924. Recent work in stellar physics. *Proceedings of the Physical Society, London*, 36, 94-113.

Rosseland, S., 1925. On the distribution of hydrogen in a star. *Monthly Notices of the Royal Astronomical Society*, 85, 541-546.

Russell, H.N., 1914. Relations between the spectra and other characteristics of the stars. *Nature*, 93, 227-231, 252-258 and 281-286.

Russell, H.N., 1919. Some problems of sidereal astronomy. *Proceedings of the National Academy of Sciences of the United States of America*, 5(10), 391-416.

Russell, H.N., 1921. The properties of matter as illustrated by the stars. *Publications of the Astronomical Society of the Pacific*, 33, 275-290.

Russell, H.N., 1922. The theory of ionization and the sunspot spectrum. *Astrophysical Journal*, 55, 119-144.

Russell, H.N., 1929. On the composition of the Sun's atmosphere. *Astrophysical Journal*, 70, 11-82.

Russell, H.N., and Stewart J., 1924. Pressures at the Sun's surface. *Astrophysical Journal*, 59, 197-209.

Saha, M.N., 1920a. Ionisation in the solar chromosphere. *Philosophical Magazine*, 40, 472-488.

Saha, M.N., 1920b. Elements in the Sun. *Philosophical Magazine*, 40, 809-824.

Saha, M.N., 1921. On a physical theory of stellar spectra. *Proceedings of the Royal Society*, 99A, 135-153.

Stewart, J.Q., 1924. The width of absorption lines in a rarefied gas. *Astrophysical Journal*, 59, 30-36.

Strömgren, B., 1932. The opacity of stellar matter and the hydrogen content of the stars. *Zeitschrift für Astrophysik*, 4, 118-152.

Unsöld, A., 1927. Über die Struktur der Fraunhoferschen Linien und die Dynamik der Sonnenchromosphäre. *Zeitschrift für Physik*, 44, 793-809.

Unsöld, A., 1928. Über die Struktur der Fraunhoferschen Linien und die quantitative Spektralanalyse der Sonnenatmosphäre. *Zeitschrift für Physik*, 46, 765-781.

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FROM RESEARCH INSTITUTION TO ASTRONOMICAL MUSEUM: A HISTORY OF THE STOCKHOLM OBSERVATORY

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Abstract: The Royal Swedish Academy of Sciences (RSAS) (or Kungliga Vetenskapsakademien [KvA] in Swedish) founded 1739, opened its first permanent building, an astronomical and meteorological observatory, on 20 September 1753. This was situated at Brunkebergsåsen (formerly Observatorie Lunden, or Observatory Hill), on a high terrace in a northern quarter of Stockholm. This historic building is still sometimes called Gamla Observatoriet (the Old Observatory) and now is formally the Observatory Museum. This paper reviews the history of the Observatory from its function as a scientific astronomical institution to its relatively-recent relegation to museum status.

Key Words: national observatories, museums, Sweden, the Royal Swedish Academy of Sciences

1 INTRODUCTION

Even though an astronomical observatory was associated with Sweden's Uppsala University from the 1650s, The Royal Swedish Academy of Sciences (henceforth RSAS)—much like the English Royal Society and the French Academy—sought to establish a national observatory in the nation's capital, Stockholm. Nationalizing and co-ordinating astronomy from the capital was logical, given its important links to other allied scientific pursuits. And so from 1753, Stockholm Observatory became the centre of national and international matters relating to Swedish astronomy, geomagnetism, and geodesy. However, the focus was on research, not education, and the distancing of this facility from the universities was intentional. As such, Sweden soon converged with similar nations sharing, co-developing, and adopting discoveries and observations drawn from these disciplines, garnering the attendant cultural and financial rewards such centres of science permitted—from theoretical studies in astrophysics to practical land and sea navigation for the purposes of trade and defence. But in the course of time, great leaps in scientific knowledge, coupled with increasing population pressure, eventually turned the Observatory into an obsolete historical treasure trove. In this paper we summarise the changing fortunes of Sweden's national Observatory.

2 COMMISSIONING AND CONSTRUCTION

The plan to build a national observatory was first promoted on 4 June 1746 (Alm, 1930: 108),[1] although RSAS Secretary, Pehr Elvius (Figure 1), only formally conveyed the Academy's intentions on 28 June 1746 (RSAS, 1746b). Government support came from the influential Royal diplomat and politician, Anders Johan von Höpken, one of the Observatory's avid supporters for many years, and on 30 June 1746 the RSAS formally thanked the Government for providing a site at Brunkebergsåsen, a high terrace located in a northern quarter of Stockholm (Alm, 1930: 109).[2]

Elvius was a friend, astronomical observer and correspondent of Uppsala Professor Dr Anders Celsius. Another person who became a central figure in the plan to build the Stockholm Observatory was the architect, RSAS member and Public Works chief, Carl Hårleman (Figure 2). Hårleman's tenure as RSAS President in 1746 was therefore auspicious. Hårleman, who had executed Royal works elsewhere, relied on the influence of Carl von Linné (Linnaeus) and Elvius to guide him past competitors. In 1748 Hårleman was granted the assignment to build the observatory (Alm, 1930).[3]

Figure 1: Pehr Elvius (1710–1749) (courtesy: Uppsala Universitet).

The new Stockholm Observatory was hardly Government funded, as operating funds came from sales of the then-important *National Almanac*, which the RSAS had a monopoly on from 17 October 1747 (see RSAS 1747); a trust established by Sebastian Tham in 1727;

Figure 2: Carl Hårleman (1700–1753) (courtesy: Project Runeberg).

an interest-free loan from RSAS member, Claes Grill (a financier and Swedish East India Company's Governor); and probably from other sources. Sadly, Elvius died in September 1749, so he did not live to see the Observatory's inauguration on 20 September 1753. On 2 October 1749 (RSAS, 1749) his place as Secretary of the Academy was taken by Pehr Wargentin (Figure 3).

Figure 3: Pehr Wargentin (1717–1783) (courtesy: Wikimedia Commons).

Working with Stockholm City Engineer, Petter Tillaeus, Hårleman prepared numerous Observatory plans between 1746 and 1748. His sketches (e.g. see Figures 4 and 5) displayed ornate rococo decoration, both on the inside and the outside of the building, oval rotundas and corner niches with a rounded aspect. The Observatory featured a mid-axis and large, lighted rooms (featuring tall observation windows), plus an observation cupola on the roof known as 'Hårleman's Lantern' (see Figure 6).

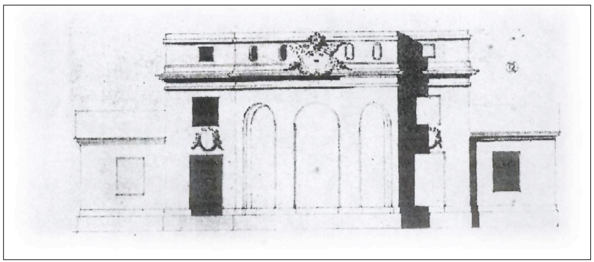

Figure 4: A south façade sketch by Hårleman, probably dating to 1747. Although intended, internal and external rococo embellishments, like escutcheons, were later omitted in favour of a plainer look, possibly as a cost-saving measure (Hårleman Collection, The National Museum, Sweden 6529; after Alm, 1930: 116).

The cornerstone of the Observatory was laid at Brunkebergsåsen on 26 May 1748, but a catastrophic fire on 8 June 1751 in the St. Klara parish (RSAS, 1751) delayed proceedings when it turned to ashes property owned by von Höpken, soon-to-be Observatory instrument-maker Daniel Ekström and others working to realize the Observatory. Wargentin heroically saved most of the Academy's instruments, and managed to salvage much personal property as well. Another less significant if tragic delay was caused by Hårleman's death on 9 February 1753, seven months prior to the opening of the Observatory. A commemorative coin was subsequently struck bearing his image (see Nordenmark, 1939).

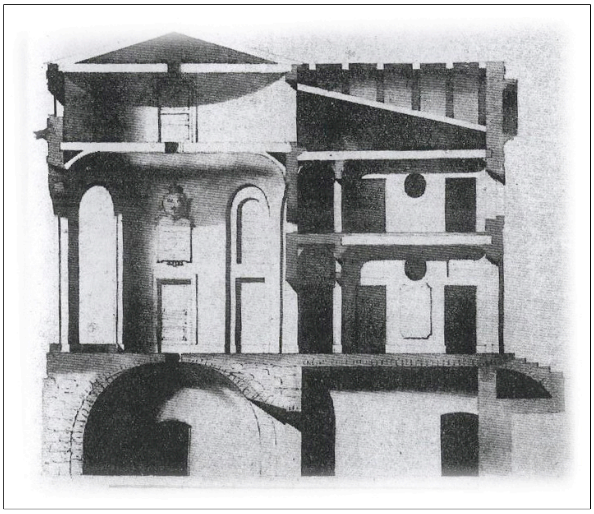

Figure 5: Three-floor cutaway sketch by Hårleman, probably dating to 1746. The main observation room is left, mid-centre. Note the upper floor access to the rooftop 'lantern' observing platform, the ornate escutcheon, and use of the cellar for a workshop, storage and the kitchen (Hårleman Collection, The National Museum, Sweden 6562, after Alm, 1930: 117).

Wargentin strove for inauguration amid all this, and his exchanges with the accommodating von Höpken were recorded on 24 March 1753 (RSAS, 1753a). An official report (dated 31 March 1754) indicated that Wargentin and Ekström had already moved into the Observatory, where Wargentin long would reside with his family—a pattern followed by succeeding Observatory heads. On 15 September 1753 Von Höpken announced that the Observatory would be ready for opening ceremonies in five days time (RSAS, 1753b). The inauguration began on 20 September 1753 at 10 a.m. when King Adolph Fredrik attended the blue ribbon ceremony for one and a half hours. During this interval he toured the rooms, studied the existing instruments (for he reportedly owned many personal ones himself) and met other dignitaries there (the protocol for this date lists the names of those who attended the ceremony; see RSAS, 1753c).

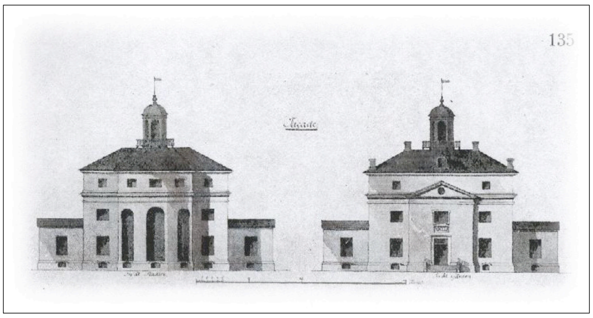

Figure 6: The Stockholm Observatory, showing the south façade (left) and the north façade (right). Note 'Hårleman's lantern' on the rooftop, which was replaced in the 1870s by a protected telescope dome (cf. Figure 13). These property inventory drawings were made by O.S. Tempelman in December 1807 (after Nordenmark, 1939: 135).

3 PER WARGENTIN: AN ENLIGHTENED AGENDA

Pehr Wargentin had been a diligent Celsius student, became a mathematical astronomer, and was a gifted and hard-working Royal bureaucrat. His influence on the Observatory is such that he deserves a separate biographical paper. He apparently was the 'master hand' behind the careful arranging and handling of funds to see Elvius' and the nascent RSAS' dream of obtaining their first actual scientific property become a reality. His quick election to Elvius' post gave him a much-needed salary. But his talents had been obvious and were well acknowledged even before Elvius' death. Wargentin, who previously had successfully championed calendar reform, had the education (a Master's degree under Celsius) and the demonstrated administrative talent and will to lead. He performed calculations necessary for the vital *National Almanac* in 1750, directly after the death of the Uppsala astronomer, Olof Petrus Hjorter. As RSAS Secretary, Wargentin saw to it that funds increased for the Observatory's growth, especially after 1754 when he aggressively promoted sales of the *Almanac*—which was not only important for astronomical studies but also for navigation, agriculture, and perhaps the military (RSAS, 1854; Sinnerstad, 1989).[4]

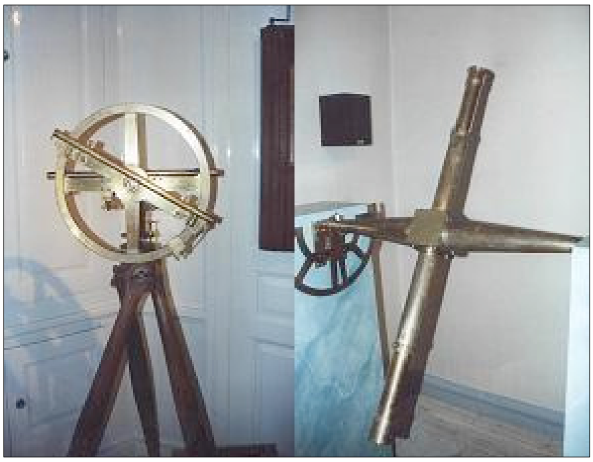

Figure 7: Period instruments at the Stockholm Observatory. On the left is the geographical circle by Daniel Ekström (near his original workroom) and on the right an eighteenth century transit instrument located in the 'Old Meridian Room' (photographs by the author).

Wargentin had a large list of international contacts—including Joseph Louis de Lagrange and RSAS foreign member, Pierre Simon Laplace—and he used it. He was well-salaried, but his workload was enormous so he justified it. He wrote the Academy's protocols; served as his own administrative staff; liaised often and directly with the Royal Government; edited all publications; and continued to work on Hjorter's *National Almanac*; even producing a quarterly "History of Science" report, which he was ordered to prepare. He groomed, kept in contact with, and paid researchers, such as they were. He mitigated the pique of powerful associate RSAS members; was responsible for all costs, and for the library; performed daily meteorological record-keeping; and contributed numerous scientific publications. He managed all this on top of an astronomical observing schedule, becoming a world authority on Jupiter, and particularly its satellites. He led the Observatory in this manner for more than thirty years, dying while still in office. At the Observatory, his influence as an astronomer was unmatched until the advent of Hugo Gyldén in the 1870s (see Bergström and Elmqvist, 2003).

3.1 Early Instrumentation

Before the inauguration of the Observatory, Wargentin was supplied with a small quadrant and two refractors, one five feet long and the other eight and a half feet long, the latter equipped with a micrometer (Nordenmark, 1939). Given a favourable financial report, orders were placed with a live-in instrument-maker, Daniel Ekström, whose workshop was in the Observatory basement. The undeniably talented and hard-working Ekström was originally a blacksmith, but had trained in England to improve his instrument-making skills. Like Hårleman, he apparently had been commissioned for Royal works. Ekström was ordered to produce a mobile quadrant of three foot radius, a four foot long transit instrument, an eight foot (radius) mural quadrant, a Machine Parallactique, a large reflector tube (dimensions not given) and a niveau (most likely a 'niveau à lunette', a brass surveying level). He succeeded in producing some instruments (e.g. see Figure 7), but died on 30 June 1755, having previously named two potential successors, his apprentices Johan Ahl and Zacharias Steinholz (RSAS, 1755). Of humble origins, Ekström left a family but few funds, so Wargentin kindly arranged a proper burial and a memorial for him, things otherwise denied him due to penury (RSAS, 1755).

The search for research-quality instruments continued. RSAS member Samuel Klingenstierna worked on problems relating to refraction highlighted by Isaac Newton. Klingenstierna and Wargentin wanted an achromatic lens suitable for use in astronomical telescopes. Experiments were performed and in a research paper published in 1754 Klingenstierna showed the problem in a new light, using Euclidean geometry, Snell's law and the sine theorem of triangles. Another paper by Klingenstierna, written in 1760, outlined the derivation of the equations for spherical and chromatic aberration. John Dollond and his son, well-known London telescope-makers, were in touch with both Leonard Euler and Klingenstierna regarding this, and obtained a copy of Klingenstierna's 1754 paper. Dollond managed to obtain a concave flint glass by 1757 and a set of positive (convex) crown glasses, and began constructing achromatic telescopes (see King, 1979: 145-148). In 1760 Wargentin ordered a nine-foot refractor from Dollond (see Figure 8), and a 6-inch f/6 transit instrument from John Bird. Pendulum clocks were purchased from Peter Ernst of Stockholm, and were regulated by transit observations. In addition, a number of astronomical instruments crafted earlier by Daniel Ekström for King Adolf Fredrik, were donated to the Observatory by King Gustav III in 1772 (Sinnerstad, 1989).

3.2 The Early Research Agenda

Before the Observatory's founding Wargentin carried out various observations. For example, in 1752 he contributed parallax-related observations to Nicolas Louis de la Caille. After the Observatory opened, he continued to make most of the astronomical observations himself, only obtaining an assistant (and his ultimate successor), Henric Nicander, on 13 November

1776. Wargentin's research programs hardly deviated from those in vogue at the time, prominent among these being exact planetary distances in the Solar System, the Earth's shape and cometary positions. For instance, in 1770 Wargentin reported that since 1742 twenty different comets had been studied. He also studied the important variable star o Ceti (Mira), faithfully recording variations in its magnitude for thirty-two years. Meanwhile, Lagrange and Laplace used Wargentin's Jovian satellite data and some of his other astronomical observations in French publications.

During the eighteenth century, solar parallax measurements loomed paramount, prompting cooperation between various national academies of sciences, including the nascent American Philosophical Society. During the preceding century, Halley indicated that Venus would transit the Sun on 6 June 1761 and on 3 June 1769, and that these rare seven-hour events could be used to determine the Earth-Sun distance (i.e. the Astronomical Unit). Among other nations, France, Russia and Britain (along with its colonies) were all active in reporting observations from different locations (see Woolf, 1959).

In 1761 Wargentin coordinated the Swedish program, assigning Physics Professor, Anders Planmann, the job of studying and recording the 1761 event from Lapland. Meanwhile, Wargentin, Klingenstierna and other observers, along with Prince Gustav, ladies, assorted Royalty and perhaps some diplomats, observed the rare event from the main observation room at the Observatory. Observations began there at 3:21 a.m. on 6 June, and lasted until 9:48 a.m.; fortunately the sky in the climatically-unstable Stockholm area remained clear throughout. The tall, wide windows at the Observatory were opened to accommodate the long telescopes, and a man with a deep strong voice called out the time during the transit. Up in Lapland, Planmann made a simple makeshift tree-bark observatory, and succeeded in obtaining a good suite of measurements. Yet despite all of these successful Swedish observations, there was considerable divergence in the measured contact times—even those obtained by Klingenstierna and his collaborators, observing from the same room—and this was also found to typify the international observations. Consequently, the 1761 transit produced little agreement as to the true value of the solar parallax, and attention quickly switched to the 1769 transit in the hope that it would yield improved results (see Woolf, 1959 for full details). As it happened, the view of the transit from Sweden on 3 June 1769 was poor, and no useful observations were made at the Stockholm Observatory.

Wargentin's diaries show that during his time at the Stockholm Observatory he was able to make astronomical observations on between 50 and 80 days per year. He also reflected on the fact that his European colleagues were able to accomplish more important observational work in the clearer and steadier climes to the south. He pointed out that Sweden was under polar twilight four months of the year, and he stressed the severity of Sweden's winters, despite the long dark nights. To help compensate for these geographical deficiencies, Wargentin used his network of international contacts to keep abreast of, and sometimes to help solve, astronomical problems.

4 GEODESY AND TOPOGRAPHY: 1784-1871

The agenda, budget, and reach of the Stockholm Observatory changed drastically after Wargentin's death in 1783, and a different emphasis was placed on activities for the next ninety years or so. During this period astronomy played a subservient role to geodesy at the Observatory.

We see in Wargentin's successor, Henric Nicander, a general pattern that was to characterise successive Directors of the Stockholm Observatory until 1871 (see Appendix 1). First was humble (or relatively humble) birth. Second, a bent for the pragmatic (Nicander patented practical devices and later championed social reform; Selander pushed currency reform, etc.). Third was aiding the military and university professors in the topographic corps, thereby linking the Observatory with the throne, the military and the universities. There was an overwhelming concern for geographical measurements that would benefit defence and/or trade; sometimes these measurements emphasized nationalistic concerns, which was not unusual at the time (e.g. Cronstrand was associated with the nationalistic Gothic League). Fourth, international astronomical contacts were marginalized, especially in what today would be called astrophysics, while geomagnetic research fared much better. Thus, it was not considered strange that the Observatory's Director should take an active part in map-making and studying Swedish coastal geography during the early to mid-1800s. This occurred while the Swedish observatories at Lund and Uppsala pursued more traditional astronomy-focussed research agendas and could argue for improved instrumentation. But for all this, the breadth of Stockholm Observatory's research widened.

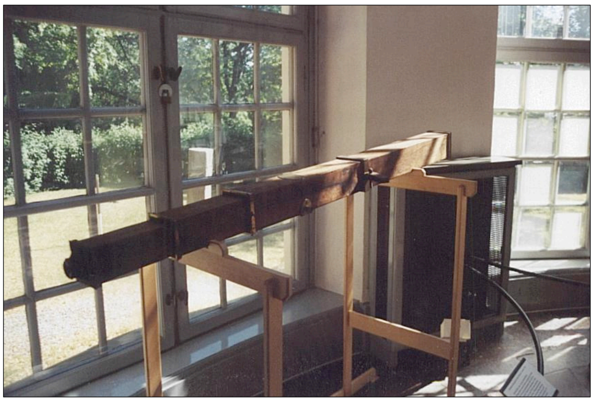

Figure 8: The Dollond refractor located in original main observation room facing the south lawn. Whether or not this is the instrument purchased in 1760 is not clear (photograph by the author).

4.1 A Geodesic Dynasty: Nicander, Svanberg, Cronstrand and Selander

Henric Nicander—Wargentin's Assistant for about a decade—was in place as Director by 21 January 1784 (RSAS, 1784), and continued Wargentin's work, but on a reduced scale. His appointment could have been a compromise whereby Johan Carl Wilcke was made Secretary of the Academy while Nicander received the Observatory Director's post since both men are referred to as 'Secretary' in the protocols around the time of Nicander's appointment.[5] Nicander's personal work in astronomy was apparently minor—even trivial—although this former mathematics Professor was considered a good administrator. Rather, he became involved in demographics and in social issues. Nicander was finally succeeded by Jöns Svanberg.

Figure 9: The marble Meridian Line (foreground), inlaid with steel, on south lawn of the Stockholm Observatory. This was used up to about 1825, and extends from the 'Old Meridian Room'. Note the carved stone and metal observation posts in the background (photograph by the author).

Svanberg moved into the Observatory on 18 May 1803—a sure sign he was now in charge—and during his term the first inventory and publication of the Academy's holdings was carried out. Svanberg stood out, as had Wargentin before him, for the numerous measurements he took, but all were ancillary to astronomy since Svanberg's interest was in the flatness of the Earth. French scientist (and RSAS foreign member) J.J. Lalande had asked the question: "Was it as much as Maupertuis had measured?" In 1799 Svanberg travelled to Lapland to investigate this matter and he found it to be much less than Maupertuis had indicated. Lalande's congratulations (see Sinnerstad, 1989: 65) promptly followed, believing his Swedish colleague had finally solved a fifty-year puzzle in geodesy. Svanberg then published a 200-page book with a detailed outline of the problem. Svanberg was also interested in solar and lunar eclipse (but he only issued summaries of these), and in the Jovian satellites. It is interesting that there was a reported increase in amateur involvement in the activities at the Observatory during Svanberg's Directorship, indicating that he supported both amateur astronomy and amateur-professional collaboration.

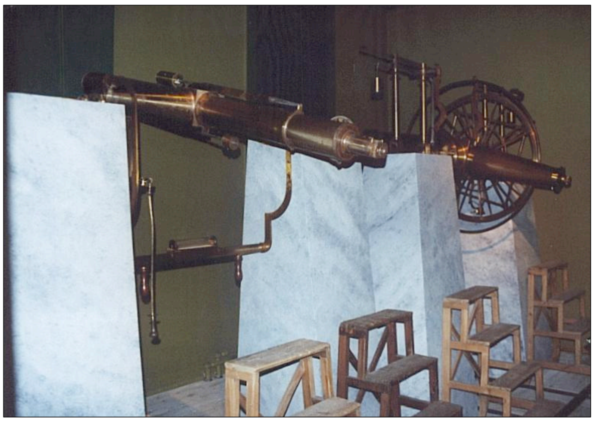

Figure 10: The Reichenbach and Ertel transit telescope (foreground) and meridian circle (background) of the 1820s, now on display in the 'New Meridian Room' at the Observatory (photograph by the author).

Simon Anders Cronstrand succeeded Svanberg as Stockholm Observatory Director on 22 June 1811. His 'reign' coincided with Jacob Berzelius' time as Academy Secretary, and concerns regarding the position of the Swedish borders, matters relevant to defence—and possible offence—as well as trade. A plaque on the south façade of the Observatory informs visitors that from 1757 to 1827 the Swedish meridian for time-keeping and map-making was located along a white marble line on the south lawn. Although a new Meridian Line was laid 18 meters to the west in 1827 and the original Meridian Line was abandoned it has been preserved and is still there (see Figure 9). The 'Old Meridian Room' is situated behind this line, and it now contains the transit instrument shown in Figure 7. Cronstrand also found time to write a book on practical astronomy. Eventually ill health forced him into the role of Observatory Inspector, and he was succeeded by Nils Haquin Selander on 13 September 1837.

Selander was perhaps the most internationally-focussed of his three predecessors. Having served as temporary Academy Secretary he was in addition to this a Board Member of the Swedish Bank, and worked on currency reform (including the adoption of decimal currency). Selander was also a member of Parliament and, like Svanberg and Cronstrand, he was a Professor in the Topographical Corps. His most notable achievement as Observatory Director was to participate in the Scandinavian leg (Torneå-Stuor-Oivi) of the Russian initiative to measure Earth's meridian. This was a colossal undertaking that extended from the Donau River in the south to the polar shores in the north, and the aim was to determine the Earth's dimensions more accurately (see Batten and Smith, 2006: 71-72). While international studies of the Earth's magnetic field were intensified during this period, they were carried out earlier—even in Cronstrand's time—by delegated observers (e.g. see RSAS, 1821).

4.2 Notes on Repairs and Instruments at the Observatory, 1797-1875

In Nicander's time (1797) the cellar area, which was formerly Ekström's workshop and Observatory kitchen, was repaired, and in the 1810s (during Cronstrand's Directorship) remedial work was carried out on the floor and cobblestones. A donation from deceased RSAS member Abraham Niclas Edelcrantz may have been used to purchase new astronomical instruments in 1823 (see RSAS, 1823), and the RSAS protocols from the period 1818-1824 are replete with references to new meridian-measuring equipment, how the resident instrument-maker Gabriel Collin (and perhaps his son) were to make it, and with persistent regularity how a certain military officer requested that a 'globverkstad' (perhaps a globe-making or special map-making workshop) be built at the Observatory on behalf of the Government (ibid.). The protocol for 11 March 1824 notes the need for a new pendulum, perhaps for the astronomical clocks associated with the transit work (RSAS, 1824a).

The new meridian room ('vestra flygelsrum') project foreshadowed in the 29 November 1824 financial report is described in the 2 February 1825 protocol (see RSAS, 1825a), and the intended instruments—a newly-purchased transit (probably by Reichenbach & Ertel) and a meridian circle—are mentioned. Discussions on the cost of this new facility are included in the 3 March 1825 protocol, which also refers to earlier deliberations held on 29 January and 23 February 1825 (RSAS, 1825b). Construction of the new meridian room was assigned to the architect Carl Christopher Gjörwell. Sketches of Observatory gates and fences were also prepared at this time, and Gjörwell's hand-wrought star patterns can still be seen on the existing gates.

Construction of the new room began in 1825, and it became operational in 1830 (see Figure 10). As if to underline the Stockholm Observatory's agenda in these years, the transit telescope was the only new 'cutting-edge' instrument of any size purchased since Wargentin's time. Installation of the new meridian line coincided approximately with the construction of the new meridian room, and Alm (1934) gives January 1827 as the date when the transit telescope was installed. Time-keeping and map-making were important activities at this time, and contact with the military was to continue, culminating in 1874 with the construction of a new dome specifically for the use of military personnel (see Alm, 19324, and '5' in Figure 11). From time to time mention is made in the protocols of new telescopes being obtained by the RSAS, but nothing resembling a major research telescope was purchased until the late 1870s.

The 'Great Magnet House' of 1838 (see Figure 11) was a joint project by Gjörwell and Samuel Enander early in Selander's term, with Enander apparently continuing this project after Gjörwell's death (see Alm, 1934). The building was for magnetic studies congruent with the geodesic and geophysical studies that predominated internationally at the time (e.g. RSAS foreign member Carl Friedrich Gauss's studies of geomagnetism). Meanwhile, plans for a new dome on the roof of the main Observatory building were agreed to in 1874, and J.E. Söderlund was appointed the renovating architect (RSAS, 1874).

5 HUGO GYLDÉN: AN ASTROPHYSICAL AGENDA

Hugo Gyldén (Figure 12) became Director on 10 May 1871, and was to lead the Stockholm Observatory for the next twenty-five years. Gyldén had a worldwide network of contacts and a reputation to match, and his leadership brought new equipment and a new research agenda to the Observatory and refocussed astronomical research on the National Capital. But like many capital city-located observatories of the late nineteenth century rapid urban growth meant that its days were numbered.

Gyldén had previously worked under Otto Struve at the Pulkovo Observatory, and he immediately transferred the research focus of the Stockholm Observatory to Solar System astronomy and theoretical astronomy. Celestial mechanics was his main theoretical concern, and he still had to produce the *National Almanac.* By 1879 he was performing parallax measurements and stellar statistics and was studying perturbations in planetary motion. Like others at the time he also turned to astrophysics, investigating the relationship between stellar luminosity and distance; researching stellar motion; and experimenting successfully with stellar photography. He also edited the *Vierteljahrsschrift* of the *Astronomische Gesellschaft* from 1889 until his death in 1896 (Bergström and Elmqvist, 2003).

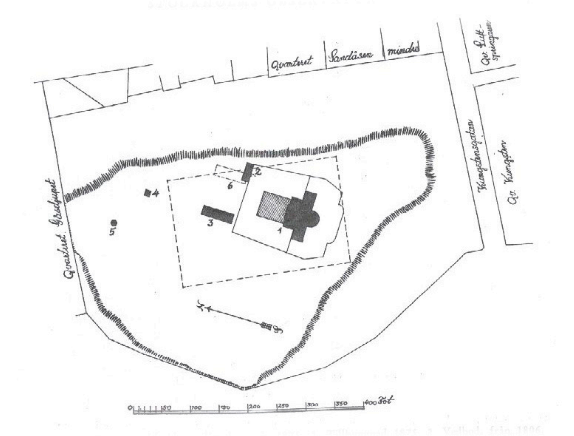

Figure 11: The Stockholm Observatory in 1875. 1: this building contained the 'New Meridian Room' (but a new dome was constructed on the roof in 1877); 2: a storeroom for firewood, which dates from 1806 (this area now houses outdoor meteorological instruments); 3: the 'Great Magnet House', which dates from 1838; 4: the 'Little Magnet House', which dates from the 1800s (this was later razed); 5: the dome for the use of the military general staff, which dates from 1874 (this, too, was later razed); 6: the annex which was built in 1881 but in 1875 was then in the planning stage—today it is a café (map after Alm, 1930: 167).

Unlike his opposite numbers at Uppsala and Lund Observatories, Gyldén was not hamstrung by a teaching schedule and could focus on research, but this did not prevent a number of the universities from making him offers (a particularly tempting one coming from Göttingen), and the nascent Stockholm University (Stockholm Högskola until 1960) even made him a Professor in 1888, without demanding any formal duties. This appointment would begin a collaboration between the Observatory and the University which would grow over time.

Figure 12: Hugo Gyldén, 1841–1896 (courtesy: Wikipedia Commons).

Figure 13: Stockholm Observatory today, showing the south façade (left) and the dome which replaced 'Hårleman's Lantern' in 1877 (cf. Figure 6). The 'great magnet house' in front of the north façade (not pictured) has a similar dome (photograph by the author).

5.1 Notes on Repairs and Instruments at the Observatory, 1875-1915

A new telescope and dome were priorities for Gyldén, given his research agenda, and Söderlund's 1874 drawings and costs estimate of 22,500 Swedish Krona for the dome (and perhaps even the telescope) were accepted (RSAS, 1874). Sadly, like Hårleman and Gjörwell before him, Söderlund would not live to see this project to completion, dying on about 5 August 1875 (RSAS, 1875). He was replaced by another architect, Per Ulrik Stenhammar, and the project continued—first under Stenhammar and later under the RSAS architect, F.G.A. Dahl—through to the unveiling in October 1877. Non-financial RSAS protocols from 1877 list the associated costs: the equatorial and passage (i.e. transit) instrument at 17,689 Krona (but with no mention of the actual telescope tube, or its manufacturer), with the dome and fees (which probably included telescope installation costs) coming to 33,000 Krona (RSAS, 1877). This was a very considerable sum, and it was necessary to dip into the RSAS reserve funds.

Figure 14: Carl Bohlin, (1860–1939) (courtesy: Astronomische Gesellschaft).

Presumably at some stage Gyldén also had extra living quarters for himself constructed in the main building, and it may be assumed that electricity was installed at the Observatory at about this time. Meanwhile, increased street and house lighting dating from this period of burgeoning urban growth in Stockholm must have begun to interfere with the astronomical observing.

The architect, Dahl, may also have been responsible for the dome that was installed on the roof of the Great Magnet House in the second half of the nineteenth century. This dome is similar to the dome on the main Observatory building (see Figure 13), and its design may have been 'borrowed' from Söderlund's earlier plans (although it was on a smaller scale). One of Dahl's last major projects for the Observatory was to design an observing facility for the solar eclipse of 1915 (*Kungl. Vetenskapakademiens Årsbok,* 1915).

The suite of astronomical instruments at the Observatory received a major boost in 1877 when a Repsold refracting telescope with an 18.9 cm Merz lens was purchased and installed in the new roof-top dome.[6] The telescope was used by Gyldén for micrometric observations of comets and planets and for determining stellar parallaxes, and in 1887 it was equipped with a camera for astrophotography (see Petander, 2001). In 1892 the camera was improved (ibid.)—leading to impressive results—and in this same year the Merz lens on the telescope appears to have been replaced by a larger Steinheil objective (ibid.).

6 DECLINE AND TRANSFER TO MUSEUM STATUS

6.1 The Growth of Astrophysics Under Bohlin

Karl (Petrus Teodor) Bohlin (Figure 14) was made Observatory head on 19 February 1897. Like his predecessor, Bohlin had worked at Pulkovo as well as having been at the Astronomisches Rechen-Institut (which at that time was still attached to the Royal Berlin Observatory). Up until February 1897 Bohlin had been a Professor of Astronomy at Uppsala, and upon accepting the post at Stockholm Observatory, like his predecessor, he became a Professor at the Stockholm Högskola.

In general, Bohlin continued the wide-ranging research agenda that Gyldén had set. He investigated planetary perturbations as experienced by the minor planets, linking the severe perturbations to Jupiter. A recognised authority on globular clusters and nebulae, one of Bohlen's most notable achievements was to measure the distance to the Andromeda Nebula. He was also inspired by Percival Lowell's work at Flagstaff, and carried out systematic observations of Mars during the favourable oppositions of 1909-1910 and 1911-1912. The aforementioned 1915 solar eclipse, and one in 1921, were also duly observed from the south lawn of the Stockholm Observatory.

By 1920, if the Gyldén-Bohlin research agenda was to continue at the Stockholm Observatory the pressing need was for state-of-the-art equipment, and darker skies (to combat Stockholm's growing light pollution). Bohlin called attention to these two issues in 1921 (see Sinnerstad, 1989), but they were only addressed when the RSAS set up a committee in January 1927 to look into establishing a new observatory on a more suitable site. Bohlin retired on 20 October 1927.

6.2 Lindblad, the Move to Saltsjöbaden, and Notes on the Observatory's Post-Scientific Importance

Bertil Lindblad took over the Directorship of the Observatory on 21 October 1927 and on 1 January 1928 moved to Observatory Hill with his family. He contributed significantly to Stockholm Observatory as its final administrator and as a research astronomer (e.g. see Bergström and Elmqvist, 2003), although this latter aspect is beyond the scope of this paper.

The RSAS committee gave Lindblad the daunting task of establishing a new RSAS observatory at Saltsjöbaden, 15 km to the east, at an elevated dark site on the Swedish coast. By this time, Sweden was a much wealthier nation than in Wargentin's or Cronstrand's day, and funding for the move to Saltsjöbaden came in the form of a grant from the Knut and Alice Wallenberg Foundation. The Saltsjöbaden Observatory opened in 1931, complete with an English-made research telescope,[7] and went on to distinguish itself as a research institution.

The City of Stockholm exercised its ancient legal right to take over the Brunkebergsåsen site in 1931 and turned it into a park. In September 1939 a statue of the Centaur by sculptor Sigrid Fridman was installed at the north-eastern corner of Observatory Hill, and is still readily visible to those visiting the eastern sector of the park (see Figure 15).

On 1 May 1934 the Geographical Institute at the Stockholm Högskola moved into the Observatory buildings, the city of Stockholm having granted permission for use of the premises at a nominal fee. Polar studies were the main preoccupation of the Institute, providing an interesting link with the era when magnetic studies were carried out at the Observatory. Adolf Erik Nordenskiöld observed the auroral ring around the North Pole in 1878-1879 during the RSAS-supported Vega Expedition to the North Pole, and assumed that the centre of this ring was sited near the geomagnetic and geographical North Poles.[8] He considered the geomagnetic pole to be the 'pole of the Northern Lights', which later assisted K.R. Birkeland, an observer on the 1902-1903 Norwegian Aurora Polaris Expedition, who found a connection between the Sun, aurorae and geomagnetic storms. Cultural and natural geography at the Institute initially shared the Observatory facilities, but in 1960 the two were separated and the cultural geography staff moved to another site.

7 CONCLUDING REMARKS

On 1 April 1985 the Geographical Institute moved to the Stockholm University campus at Frescati, and for a while the old Observatory faced an uncertain future. From the start, its elevated position and domed structure appealed to the local Muslim community, and the City considered selling it to them. However, a foundation called Stiftelsen Observatoriekullen took on the task of making this, one of the oldest existing original astronomical observatories undisturbed by war, into a museum for the history of science by 1985. Their plan succeeded, but hit a snag on 20 September 1991—ominously, 238 years to the day since its original inauguration—when financial problems caused it to close the doors. Eight years later, the RSAS resumed ownership of the property and the Gamla Observatoriet was opened to the public once more. By offering guided tours, attracting strollers to its new café, continuing outreach to selected professional and amateur astronomers, atmospheric scientists and historians, and attracting grants, this unique Swedish scientific museum continues to gain momentum. Hope is eternal that this gem of astronomical heritage will remain open and in the bosom of its founding institution for centuries to come.

Figure 15: The statue of the Centaur (photograph by the author).

8 NOTES

1. In support of this claim, Alm (1930: 108) refers to RSAS, 1746a.
2. Alm (1930: 109) notes that at the time the Government reserved the right to re-acquire the property if the RSAS should no longer require it.
3. Alm (1930: 114) states that the permission to build is mentioned in Stavenov, 1927: 197.
4. Mapping probable diseases at this time with the almanac's aid was pointed out by Dr Tore Frängsmyr (pers. comm., May 2008).
5. The 'make' of this telescope was not listed in the RSAS protocols at the time, but this information is included in an inventory of the Observatory's instruments that was prepared in 2 July 1925 (see Petander, 2001).
6. At Saltsjöbaden the old Repsold refractor was initially used as a training telescope or a guide telescope—or both—but it was eventually dismantled and placed in storage.
7. Artefacts associated with Nordenskiöld's polar exploration are now on display at the Observatory, reflecting the era when the Geographical Institute occupied the building.

9 ACKNOWLEDGEMENTS

I wish to thank Professors Emeritus Olof Beckman and Tore Frängsmyr from Uppsala University, and Inga Elmqvist (Söderlund), Director of the Observatory Museum, for discussing the Observatory's history. I also am grateful to Peter Branden of the Observatory Museum for access to a wide variety of secondary sources, and Maria Asp and Anne Miche de Malleray, archivists at the RSAS' Center for the History of Science in Stockholm for helping me access delicate original records during the researching of this paper. Finally, I wish to thank Drs Hilmar Duerbeck and Wayne Orchiston for commenting on the manuscript and for helping produce the final version of this paper.

10 REFERENCES

The following abbreviation is used:

RSAS = Royal Swedish Academy of Sciences.

Alm, H., 1930. *Stockholms Observatorium: Geografisk Institution vid Stockholm University Sedan 1934.* Stockholm, Särtryck ur Samfundet S:T Eriks Årbok.

Batten, A.H., and Smith, J.R., 2006. Measuring the world: excursions in geodesy and astronomy. *Journal of Astronomical History and Heritage*, 9, 65-75.

Bergström, C., and Elmqvist, I. (eds.), 2003. *Huset närmast Himlen, Stockholms Observatorium 250 År.* Observatoriet Museets Skriftserie Nr. 5. Bidrag till Kungl. Vetenskapsakademiens Historia Nr. 36. (Jubileumsskrift: Stockholm).

Dahlgren, E.W., 1915. *Kungl. Vetenskapakademiens Personförteckningar 1739-1915.* Stockholm, Almqvist & Wiksell.

Helmfrid, S., 2000. *Ett Museums Tillkomst: Stiftelsen Observatoriekullen 1885-1999.* Stockholm, Observatoriet Museets Skriftserie Nr. 2.

King, H.C., 1979. *The History of the Telescope*. New York, Dover.

Kristenson, H., 1990. *Vetenskapens Byggnader Under 1800-Talet*. Lund, Grahns.

Kungl. Vetenskapakademiens Årsbok. No author or publisher listed (1915).

Lindroth, S., 1967. *Kungl. Svenska Vetenskapsakade-miens Historia 1739-1818, I. II.* Stockholm, Almqvist & Wiksell.

Lindblad, B., 1940. Hugo Gyldén, in series on "Levnadsteckningar över sv. Vetenskapsakademiens ledamöter." bd 7, s. 5 ff [Lindblad on Gyldén's work concerning planetary perturbation. Quoting Gyldén's "Om Ett Bevis för Planetsystemets Stabilitet," from Öfversigt Af Kongl. Vetenskapsakademien Förhandlingar, 1886, Nr. 3, s. 45].

Nordenmark, N.V.E., 1939. *Pehr Wilhelm Wargentin, Kungl. Vetenskapsakademiens Sekretarare och Astronom 1749-1783*. Stockholm, Almqvist and Wiksell.

Personregister Till Kva:s Protokoll för 1742-1790; 1791-1830. (Probably private; no date, publisher, location other than it being in Swedish in book form).

Petander, E., 2001. *En Översikt Över Instrumentinsam-ligen och Verksamheten vid Stockholms Observatorium Mellan 1871 och 1931.* (Unpublished Thesis [Uppsatts till Observatoriet Museet]).

RSAS, 1746a. Economic protocol dated 4 June (Ekon. Protokol, 1746, notariens, fol. 25 & Ekon. Prot. 1746: II).

RSAS, 1746b. Protocol [=diary] dated 28 June (intent to build) (p. 133: RSAS Dagböcker 1742-1751).

RSAS, 1747. Protocol dated 17 October (importance of almanac sales, monopoly established) (p. 197, 5: RSAS Dagböcker 1742-1751).

RSAS, 1749. Protocol dated 2 October (Wargentin as astronomical observer, secretary) (p. 273: RSAS Dagböcker 1742-1751).

RSAS, 1751. Protocol dated 8 June (fire) (pp. 364-365: RSAS Dagböcker 1742-1751).

RSAS, 1753a. Protocol dated 24 March (delays) (p. 423: RSAS Dagböcker 1752-1763).

RSAS, 1753b. Protocol dated 15 September (von Höpken's official announcement of intended opening) (p. 436: RSAS Dagböcker 1752-1763).

RSAS, 1753c. Protocol dated 20 September (the inauguration) (pp. 436-438: RSAS Dagböcker 1752-1763).

RSAS, 1754. Protocol dated 26 January (almanac sales) (p. 455: RSAS Dagböcker 1752-1763).

RSAS, 1755. Protocol dated 5 July (Ekström's demise and his suggested successors) (pp. 499-500: RSAS Dagböcker 1752-1763).

RSAS, 1784. Protocol dated 21 January 1784 (Nicander and Wilcke are both listed as 'Secretary') (p. 1469: RSAS Dagböcker 1784-1790).

RSAS, 1821. Protocol, p. 8 ('Astronomiske observatör Kniberg' performs magnetic observations at the Observatory).

RSAS, 1823. Protocol, pp. 76-77 ('Globverkstaden' first discussed with the Observatory head by the Swedish military—probably the Navy).

RSAS, 1824. Protocol dated 24 March (new clock pendulum). RSAS RSAS Dagböcker 1822-1826).

RSAS, 1825a. Protocol dated 2 February (the west annex, or 'new meridian room', receives tentative approval, indicating that the new transit and the existing meridian circle are to be installed there) (p. 12: RSAS Dagböcker 1822-1826).

RSAS, 1825b. Protocol dated 3 March (cost discussions of the new room referred to on 29 January and 23 February 1825) (pp. 25-26: RSAS Dagböcker 1822-1826).

RSAS, 1874. Protocol (Dagböcker) pp. 105 (8:7), 127 (8:18) (cost estimates, south façade dome, instruments).

RSAS, 1875. Protocol (Dagböcker) p. 59. (Per Ulrik Stenhammar, 'architect', replaces Söderlund, whose death is noted as 5 August 1875 according to secondary sources).

RSAS, 1877. Protocol (Dagböcker) pp. 53-54. (A new dome and all related costs are inventoried; no mention of the inauguration of the dome).

Sinnerstad, Ulf, 1989. Astronomy and the first observatory. In Frängsmyr, Tore (ed.). *Science in Sweden: the Royal Academy of Sciences 1739-1989.* Canton, Science History Publications.

Skottsberg, C., 1957. *Kungl. Vetenskapakademiens Personförteckningar 1916-1955.* Stockholm, Almqvist & Wiksell.

Stavenov, K.E., 1927. *Carl Hårleman, En Studie*. Uppsala, Frihetstidens Arkitekturhistoria.

Woolf, H. 1959. *Transits of Venus. A Study of Eighteenth Century Science*. Princeton, Princeton University Press.

APPENDIX 1: STOCKHOLM OBSERVATORY DIRECTORS FOLLOWING WARGENTIN

The following information is based on Dahlgren (1915), *Personregister …* and Skottsberg (1957).

Nicander, Henric (1744–1815) named Wargetin's assistant on 13 November 1776 (Personförteckningar, 1739-1915). Elected RSAS Secretary in 1784 (Personregister: 1742-1790).

Svanberg, Jöns (1771–1851) moved into the Observatory to live on 18 May 1803 (Personregister: 1803:20: 1791-1830), and assumed control of all Observatory instrumentation on 4 April 1804; he was made RSAS Secretary on 30 May 1804 (and also had religious orders unrelated to RSAS duties) (Personregister: 1804:52, 55:c: 1791-1830).

Cronstrand, Simon Anders (1784–1850) became Observatory Director on 22 June (or possibly July?) 1811 ("1811 22/6 § 7") (Personregister: 1811:19: 1791-1830).

Selander, Nils Haquin, became Observatory Director on 13 September 1837 (Personförteeckningar 1739-1915).

Glydén, Johan August Hugo, became Observatory Director on 10 May 1871 (Personförteeckningar 1739-1915).

Bohlin, Karl Petrus Teodor became Observatory Director on 19 February 1897 (Personförteeckningar 1739-1915).

Lindblad, Bertil became Observatory Director on 21 October 1927 (Personförteeckningar 1915-1955).

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A SHORT HISTORY OF TWO NINETEENTH CENTURY GERMAN INSTRUMENTS AT THE BOLOGNA OBSERVATORY: THE 16-CM STEINHEIL REFRACTOR AND THE ERTEL & SOHN MERIDIAN CIRCLE

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Abstract: Recent work to restore and set up the materials exhibited at the Museo della Specola of the University of Bologna provided an opportunity to review the history of two important German instruments from the mid-nineteenth century, an Ertel & Sohn meridian circle and a Steinheil refractor. Purchased by the Directors of the Bologna Observatory to revitalise local astronomical research, which had gradually declined over the years, both instruments have intriguing histories because, despite the fact that they were essentially underused, they also contributed to two important research projects. Lorenzo Respighi used one of them—the Ertel & Sohn meridian circle—for an experiment in physical optics related to the debate on whether light was undulatory or corpuscular, and it was essentially a forerunner of 'water-filled telescopes'. The other, a Steinheil refractor to which a Tauber spectroscope was attached, was the largest and most important instrument used by the Italian expedition to India, organised by Pietro Tacchini to observe the transit of Venus across the Sun in 1874.

Keywords: Instrumentation, observatories, Italian astronomy, nineteenth-century astronomy

1 THE BOLOGNA OBSERVATORY

At the beginning of the eighteenth century Luigi Ferdinando Marsili—a Bolognese count, a man-at-arms, a versatile scientist with a broad range of interests and a skilled organiser—gave the city a large collection of instruments, naturalistic collections and books that had been housed in his *palazzo* until then and were used by Bologna's most prominent scholars.[1] One of the provisos of Marsili's donation, which was made official on 11 January 1712, was that (Fantuzzi, 1770: 229):

> … a place would be found for them that was big enough and suitable enough to house them; a chemical laboratory would be set up; there would be enough rooms for a sizeable library; an observatory tower would be put up; stipends put aside for the professors; funds provided for the purchase of books, and machines for physics experiments …

The Istituto delle Scienze di Bologna was thus established and in 1714 it was merged with the Accademia delle Scienze, which in turn had developed from the existing Accademia degli Inquieti, founded in 1690-1691 by the young astronomer Eustachio Manfredi and a group of friends (Baldini, 2007; Bònoli, 2007b; Bònoli and Piliarvu, 2001: 176; Tabarroni, 1981). Manfredi, who had already coordinated the astronomical activities of the observatory set up at Marsili's *palazzo*, was appointed to oversee work on the large new observatory slated to be built on top of the Palazzo Poggi, which the Bologna Senate had purchased to house the Istituto delle Scienze. It took many years to complete the observatory, due also to financial reasons. Consequently, Manfredi was unable to commence his observations there until 1726.

Bologna's astronomical school, which took up the seventeenth-century legacy of both the University of Bologna, with astronomers such as Giovanni Domenico Cassini and Geminiano Montanari, and the Jesuit college, with Giovanni Battista Riccioli and Francesco Maria Grimaldi, enjoyed a prestigious reputation throughout Europe in the eighteenth century. It played a leading role in astronomical research, thanks to the work of Manfredi and his successor, Eustachio Zanotti, both of whom became Fellows of the Royal Society of London in 1728 and 1740, respectively.[2]

During the nineteenth century, however, the school encountered a number of setbacks and the observatory was gradually sidelined from Italy's scientific scene, due above all to political circumstances. These problems, which commenced with Napoleon's campaigns and continued with the Restoration ushered in by the Congress of Vienna, culminated with the difficult unification of the Kingdom of Italy (Bònoli and Poppi, 2001 and 2006; Bònoli et al., 2005; Poppi and Bònoli, 2002). It was during this period that Bologna ceased to be the prestigious main university of the Papal States.

In the meantime, following Napoleon's reforms the Istituto delle Scienze and the annexed observatory became part of the University of Bologna. During the nineteenth century more than ten astronomers succeeded each other at the helm of the observatory itself and as holders of the Chair of Astronomy; moreover, this professorship remained vacant for nearly twenty years. Among these astronomers, at least two can be credited with augmenting the observatory's instrumentation, in an attempt—which turned out to be futile—to inject new life into Bologna's listless astronomical studies.

Consequently, two important German-made instruments were brought to the Bologna Observatory and despite the fact that their use was quite limited, they ultimately proved to be significant.

The historical site of the Bologna Observatory still exists. Until just a few years ago it housed the Department of Astronomy of the University of Bologna and the Bologna Astronomical Observatory of the National Institute of Astrophysics. Today it is the home of the Museo della Specola of the University (Figure 1), and the instruments employed by Bologna astronomers over the course of three centuries are exhibited in the very same rooms in which they were originally used (Baiada et al., 1995).

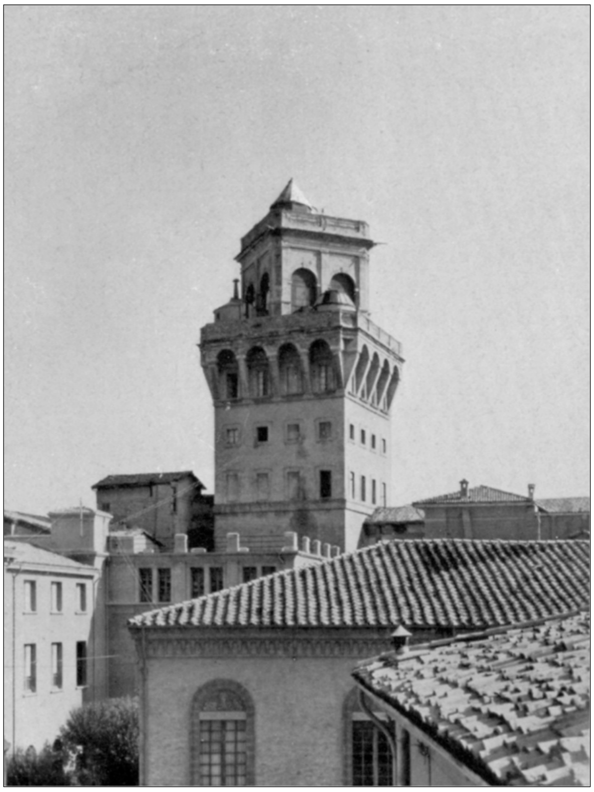

Figure 1: This photograph from the early 1950s shows the Observatory tower, which rises over the rooftops of the main campus of the University of Bologna. The dome visible in the foreground on the terrace of the second-to-last floor of the tower (which has since been replaced by a lift) housed the Steinheil telescope. The dome to the left of the terrace, on the same floor, is the one that was built in 1850 to hold the Ertel & Sohn meridian circle and was restored in the late 1900s (courtesy: Archive of the Department of Astronomy, University of Bologna).

2 IGNAZIO CALANDRELLI, LORENZO RESPIGHI AND THE ERTEL & SOHN'S MERIDIAN CIRCLE

Ignazio Calandrelli (1792–1866), who was born in Rome and was the nephew of the better-known Giuseppe Calandrelli, Director of the Observatory of the Collegio Romano, was appointed to teach mathematics while he was still a student (Bònoli and Piliarvu, 2001: 211). After graduating with a degree in philosophy and theology, he was ordained a priest and in 1845 was invited to Bologna to head the Observatory; he was also appointed to the Chair of Mathematics and Optics at the University of Bologna, but remained there for only a short time. Following the uprisings for independence in 1848, Pope Pius IX summoned him to Rome to head the Capitoline Observatory. During his short stay in Bologna he attempted to modernise the Observatory's array of instruments, most of which dated back to the late eighteenth century, and obtained funds from the Pontifical Government to purchase a meridian circle from the German company Ertel & Sohn.

In 1806 Traugott Lebrecht Ertel (1777/8–1858) entered the workshop of Reichenbach, Liebherr and Utzschneider as an employee. After changing fortunes and divisions of the workshop, in August 1815 Reichenbach made Ertel his business partner. Ertel rapidly became his successor and the faithful continuer of his construction technique. Together they signed many instruments with the name Reichenbach und Ertel. After Reichenbach withdrew in 1820, however, Ertel continued on his own until he was joined by his son Georg (1813–1863), with whom he established Ertel & Sohn, which would stay in business as Ertel-Werke until 1984 (Brachner, 1987a; Preyss, 1962). Ertel also built meridian circles for the Christiania, Glasgow and Warsaw Observatories and, in Italy, for the Roman observatories of the Capitol and the Collegio Romano (the latter was subsequently moved to the Astrophysics Observatory of Catania in 1885), and for the Istituto Idrografico della Marina in Genoa (later moved to the Brera-Milan Observatory in 1924). The meridian circle that Calandrelli ordered from him in 1846 was thus unquestionably on a par with the instruments used by the era's most important observatories for astrometric measurements. Calandrelli decided to set up a special area for it (Figure 2), building an oval room next to the large upper room in the Observatory tower that had been built for observations using the large telescopes with a long focal length typical of the seventeenth and eighteenth centuries (see the original project in Parmeggiani, 1848). Four granite pillars were embedded in the floor to support the telescope axis, and rails were mounted in order to hold the wrought-iron trolley used to reverse the telescope. This operation was essential for estimating certain measurement errors through observations conducted before and after the inversion. The focal length was 5 feet (153.4 cm), it had a 4" (10.2 cm) objective lens and the diameter of the divided circle was 30" (76 cm). The instrument had two micrometers and four celestial eyepieces, as well as a water level with a leaf-spring support in order to check the horizontality of the axis. The words Ertel & Sohn, München are engraved on one of the arms of the divided circle.

As reported in Bologna chronicles of the era (Bottrigari, 1960: 244), one of the Ertels went to Bologna in 1851 to oversee the set-up of the instrument built by the father-and-son team:

> The famous artist, Mr Ertel of Munich, has been in Bologna for some time: he is currently installing his large meridian circle at the observatory of our University, in those rooms that were expressly built based on the plans and under the supervision of our architect Filippo Antolini.

He was assisted by Calandrelli, who had returned from Rome specifically to check the operation of the meridian circle he had ordered. While he was there, he drew up his *Uso del Circolo Meridiano*, with instructions on how to fine-tune and use it (Calandrelli, 1851).

Despite the fact that this type of instrument requires the utmost stability, its installation on one side of the tower, at a height of about 37 m from the ground, made it difficult to use and somewhat inaccurate. As a matter of fact a meridian circle on the top of a tower was not state-of-the-art at that time. Moreover, the fact that instruments of this kind were inadequately built, hard to use and less accurate than expected is demonstrated by the fact that the hundreds of observations made with a similar Ertel & Sohn meridian of the same size, installed in 1844 at the Washington Observatory (now the U.S. Naval Observatory), went unpublished for reasons that the Director, M.F. Maury (1846: 3), explained to the Secretary of the Navy, Hon. George Bancroft:

> I have been induced to suspect the existence, in the Meridian Circle, of error as to figure, divisions, unequal flexure, or some other imperfection not clearly ascertained. Owing to this circumstance … I have concluded not to publish the observations (several hundreds) made with it, until I shall have satisfied myself with regard to it.

In any event, the Bologna instrument essentially went unused—although it is unclear if this is attributable to inaccuracy, inadequate placement, the transfer of the man who had ordered it, the fact that other local astronomers were not interested in using it or the lack of appropriate observation programmes—until Lorenzo Respighi (1824–1889) found an entirely new application for it several years later (Bònoli, 2007c; Bònoli and Piliarvu, 2001: 214). Respighi was one of the most important Italian astronomers of the mid-nineteenth century and, along with Pietro Tacchini, Angelo Secchi and Giuseppe Lorenzoni, he founded the Italian Society of Spectroscopists and *Memorie della Società degli Spettroscopisti Italiani*, respectively the world's first astrophysics society and journal (Chinnici, 1999; 2007). Appointed full Professor of Astronomy and Optics at the University of Bologna in 1851 and then Director of the Observatory the following year, he filled the position that had been vacant for several years after Calandrelli's transfer to Rome. Due to political reasons, however, he too was sent to Rome to head the Capitol Observatory, succeeding Calandrelli there as well. Following the end of pontifical rule in Bologna and the establishment of the Kingdom of Italy, he was suspended from his Professorship for several years and left the city for avowed "… reasons of conscience …" in 1865.[3]

Despite adverse political conditions, during the short time that he worked at the Bologna Observatory Respighi was never deterred from his research activity. It was during this period, using the Ertel & Sohn meridian circle as a zenith instrument and a basin of mercury for reflected observation, that he compiled a catalogue of the declinations of more than 2,000 stars (Respighi, 1864):

> I was able to take advantage of this flaw in our meridian circle, i.e. the fact that it is set at a great height from the ground, to create a sort of zenith telescope from the meridian telescope.

Nevertheless, the most interesting use of the telescope came with Respighi's work in the early 1860s for a singular and delicate experiment in physical optics (Gualandi, 2004). The astronomer focused the telescope through a hole drilled in the floor to observe a clear cavity filled with water, set on the level 8 m below. Under the container of water, he placed a piece of glass with impurities that formed little air bubbles; the glass was illuminated by a light source beneath it. Respighi wondered if the bubbles would show small systemic shifts as if they were zenith stars. His experiment involved observing the possible presence of small ellipses travelled over the course of a day that—based on an idea posited during the previous century by the Jesuit scientist Ruggiero Boscovich (1785: 248-314)—could be explained as apparent 'diurnal aberration' (i.e. generated by the combination of the velocity of light and that of the Earth's rotation).

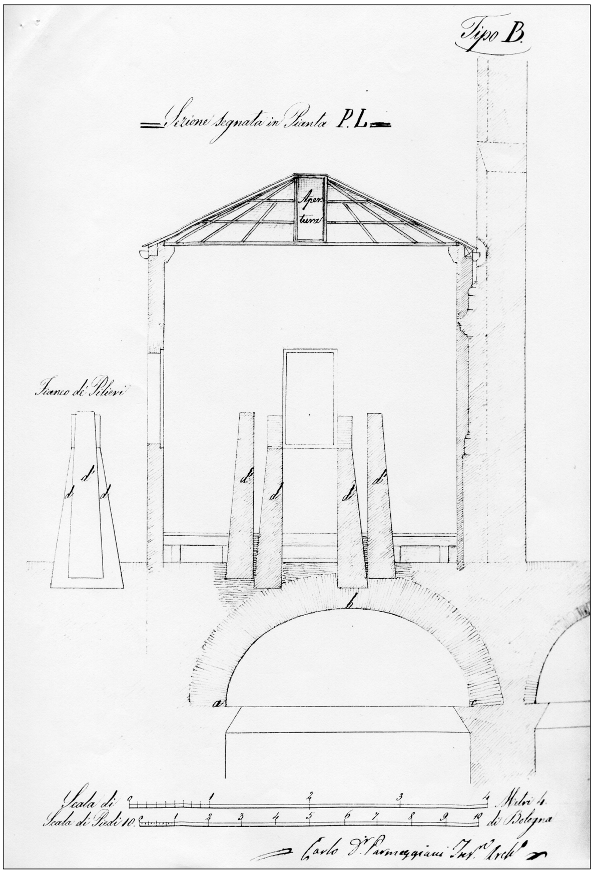

Figure 2: Section of the project for the oval room designed to house the Ertel & Sohn meridian circle (after Parmeggiani, 1848). Note the anchorage of the pillars supporting the instrument (courtesy: Archive of the Department of Astronomy, University of Bologna).

The experiment originally involved a variant to the annual observation cycles to record the apparent stellar trajectories subject to the effect of 'annual aberration'. The ellipse of the annual aberration of starlight is formed by an apparent path, described over the course of a year, which is derived from the combination of the velocity of light and the velocity of the Earth's revolution around the Sun (Gualandi and Bònoli, 2008). According to Boscovich, the size of the ellipses could theoretically be altered by refraction introducing a new medium in the path of light rays. With respect to what would have been expected in observations without a basin of water, the experiment should have demonstrated if the velocity of light travelling first through water and then through air generated wider or narrower ellipses. Boscovich's idea was to build a water-filled telescope through which it would be possible to discover the extent to which the new medium of refraction affected the size of the ellipses and thus the path of the light rays through the new medium.

Examined in this manner, the small trajectories of the bubbles would theoretically indicate how the passage from one refracting medium (water) to another (air) affected light rays, an effect that would then be summed with the Earth's rotation. Through his observations using the 'modified' Ertel & Sohn meridian circle, Respighi discovered that the apparent motion predicted by this theory did not occur, and he attributed its absence to the action of the surrounding ether, numerically expressed by the 'Fresnel coefficient'. As important as these details may be, an in-depth discussion would digress from the topic of this paper.

Figure 3: What remains today of the Ertel & Sohn meridian circle, repositioned in its original dome. One of the pillars is visible in the background (courtesy: Museo della Specola, University of Bologna).

Respighi's contribution has now been forgotten, yet it makes him a forerunner of the work envisaging the installation and use of water-filled telescopes, which had been theorised since the eighteenth century but were impossible to build due to the level of precision required by such measurements (see Pedersen, 2000). In effect, the idea that Respighi had borrowed from Boscovich went back to 1785.

In the intentions of those who devised and built them, these instruments were supposed to confirm the corpuscular theory of light by showing the variation in the velocity of light as it passed through two different propagation media. According to nineteenth-century physicists, however, the construction of water-filled telescopes would bear out the exact opposite: it would prove the wave theory of light. The experimental datum that was expected to prove one theory or the other was the measurement of a decrease (according to the Newtonian corpuscular theory) or increase (as instead predicted by Huygens's wave theory) of the velocity of light passing from one refractive medium to another less dense medium. Water-filled telescopes would later become rather successful, above all following George Airy's famous experiment of 1871 (Airy, 1872; Satterthwaite, 2003).

With the observations conducted in Bologna, Respighi attempted to contribute to the debate between two Northern European astronomers—Martin Hoek (1834–1873) and Wilhelm Klinkerfues (1827–1884), Observatories—regarding confirmation of the wave theory of light, which he was convinced would be demonstrated by measurements made using the meridian circle. With his zenith observations, Respighi thought he had measured variations in the constant of aberration while also providing experimental proof of the Earth's rotation. The Ertel & Sohn meridian circle thus enjoyed what would effectively turn out to be its only 'moment of glory', and it would never again be put to any significant use.

After gathering dust for decades, in the mid-twentieth century the instrument and its support pillars were dismantled. A large hole was then made in the floor of the small oval room that had housed it in order to permit observations using the tessellated telescope installed two floors below it in the tower. This was a highly original project devised by Guido Horn d'Arturo (1879–1967), Director of the Astronomical Observatory of the University of Bologna at the time (Abetti, 1981; Bònoli, 2003, 2007a), to create a large-diameter light collector using a mosaic of specially aligned smaller mirrors, thereby avoiding the technical difficulties and high costs involved in creating a single large mirror (Bònoli and Zuccoli, 1999). As a result, this telescope is rightly considered the predecessor of modern multi-mirror telescopes (Jacchia, 1978). Horn first developed the project in 1932 with a prototype that had a diameter of 1 m. In 1952 he completed his definitive instrument, which had a total diameter of 1.8 m and was composed of 61 hexagonal segments; it had a focal length of 10.4 m. Consequently, the floor that once held the Ertel & Sohn meridian circle served as the focal plane with the plate-holding chassis of the tessellated telescope, which Horn used to expose tens of thousands of plates of the zenithal sky of Bologna.[4]

When the upper part of the Turret Room of the Museo della Specola was renovated in the late twentieth century, the floor was also restored and the Ertel & Sohn instrument was reinstalled there (Figure 3). However, many of the large mechanical and optical parts of the meridian circle have disappeared, making functional restoration impossible. Furthermore, the floor—in which a hole had been bored and then closed up again—is now too fragile to hold the original pillars.

3 LORENZO RESPIGHI, PIETRO TACCHINI AND THE STEINHEIL REFRACTOR

As we have noted, in 1851 Lorenzo Respighi (Figure 4) replaced Calandrelli at the helm of the Bologna

Observatory and he immediately showed greater dynamism than his predecessors, boasting interests that ranged from astronomy to physics and optics. The new Director's pressing desire to turn the Observatory around is evident in a letter dated 1857 and addressed to the Directors of the most important Italian observatories. In it, Respighi declared that he was "… burdened by the obligation to improve the conditions of this establishment, which unfavourable circumstances have rendered completely idle and forgotten for many years." Thus, he sought their assistance in order to create a national astronomical research network (Respighi, 1857a). That same year he submitted a request to Pope Pius IX to upgrade the instruments at the Bologna Observatory (Respighi, 1857b), asking for a contribution in order to purchase "… the most essential astronomical instrument, and that is an equatorial telescope in keeping with the current needs of science …", a refractor that had been ordered the previous year from the Bavarian optician Carl August Steinheil (1801–1870).

This was a particularly lively historical period for physics and astronomy, and Italy's leading figures in these fields attempted to carve out a place for themselves in the heated scientific debates of these years. This was not only the era of the birth of astrophysics, but also of the development of Maxwell's equations of electromagnetism and the triumph of Stokes's and Fresnel's wave theory of light.

By the eighteenth century, Italian optics had lost the leading role that—along with Holland—it had enjoyed in Europe in the previous centuries. Consequently, Italy was forced to depend on other countries (England and then Germany) that could produce lead glass (flint glass) to correct chromatic aberration.[5] Consequently, it had become routine to import precision optical devices.

Towards the 1850s Bavaria had established an important tradition in the construction of optical instruments. Carl August Steinheil was one of the standard-bearers of this tradition and he became enormously successful during this period. In a detailed profile, Alto Brachner (1987b) defined the Physics Professor, who devoted his career to making instruments, as the "… mental successor of Fraunhofer." A pupil of Friedrich Bessel, Steinheil was fully a part of the nineteenth-century German astronomical tradition, working with eminent figures such as the chemists Justus Liebig and Robert Bunsen, and the physicist Gustav Kirchhoff. In 1855 King Maximilian II decided to rely on Steinheil to uphold the tradition of the school of Bavarian opticians and summoned him to Munich from Vienna, where the scientist was working on telegraph networks.

It was Steinheil's workshop that Respighi contacted in 1856 in order to expand the instrumentation at the Bologna Observatory, which—as already noted—was experiencing one of the nadirs of its history. The telescope he ordered was built in the spring of 1858 and was already in use by the summer, as indicated by the fact that Ernst W. Tempel, who planned to purchase one for Venice, requested information about its operation (Steinheil, 1858; Tempel, 1858). It was a refractor with a German equatorial mount and an achromatic lens with a diameter of 16.24 cm, composed of "… one crown bi-convex lens and one flint convex-concave lens …" (the brass ring holding the lens reads "Steinheil in München n.° 1026"), and with a focal length of 260 cm (Baiada et al., 1995: 142). It had seven 'celestial' eyepieces, a helioscope and a finder with an aperture of 4.5 cm. It was installed in a dome on one of the side terraces of the tower. Fraunhofer and Steinheil had delivered larger lenses prior to this, so at the time this 16-cm telescope was only of moderate size, yet it ranked fourth of all Italian refractors after the 28.3-cm and 23.8-cm Amici refractors, built in 1841 and 1854, at the Florence Observatory, and the 17.5-cm Fraunhofer & Reichenbach refractor which was installed at the Capodimonte Observatory in Naples in 1815.

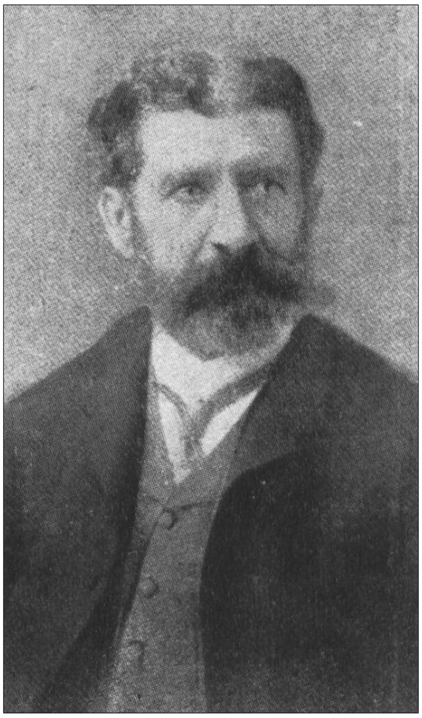

Figure 4: Lorenzo Respighi (1824–1889) (courtesy: Archive of the Department of Astronomy, University of Bologna).

However, the political situation changed rapidly and, with the plebiscite of March 1860, Bologna rid itself of pontifical rule, joining the new Kingdom of Italy less than a year later. As we have seen, Respighi was busy using the meridian circle to catalogue the stars, and was working on his experiments in physical optics, so the new refractor went virtually unused.

After Respighi was transferred to Rome in 1865, the post of Observatory Director was vacant for approximately twelve years and was finally assigned to Antonio Saporetti (1821–1900), a controversial figure who held it until the end of the century but was clearly incapable of valorising the institution he represented (Bònoli and Piliarvu, 2001: 213; Poppi and Bònoli, 2002). According to Giovanni V. Schiaparelli (1900):

> The contrast between [Saporetti] and Respighi could not have been sharper, nor could it have been any clearer that the value of a scientific institution depends first and foremost on the knowledge and character of the people called upon to direct it.

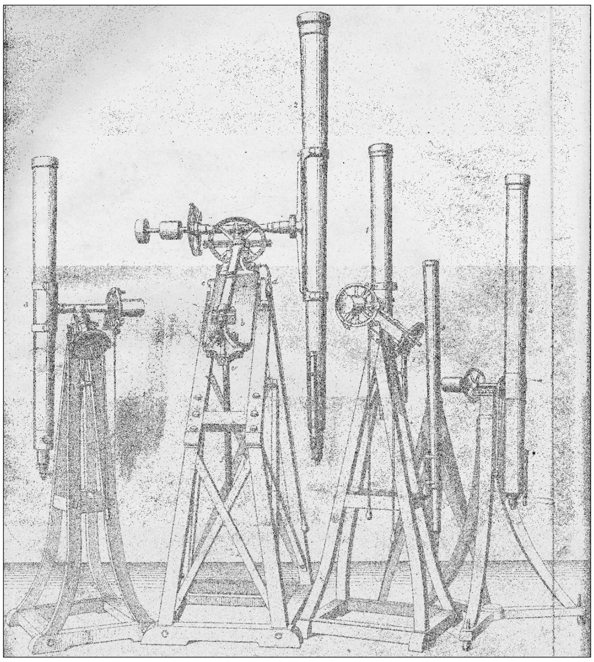

Figure 5: The telescopes used for the 1874 India expedition, portrayed with the field mounts made by the workshop of the Padua Astronomical Observatory (after Tacchini, 1875a). From left to right: the Turin Fraunhofer equatorial, the Bologna Steinheil telescope, the Padua Starke equatorial, the Palermo Dollond telescope and the Padua Starke altazimuth telescope.

The Steinheil instrument was thus destined to become obsolescent very quickly, due above all to the progress that England and the United States had made in the construction of optical systems for large refractors. In 1851 the British instrument maker William Simms produced a type of flint glass for a 33-cm achromatic lens and began to work on a 40-cm one, whereas the American company of Clark & Sons made the 76-cm Pulkovo refractor in 1885. In 1874, however, Pietro Tacchini (1838–1905), who was at the Palermo Astronomical Observatory, asked if he could use the Steinheil telescope for an important scientific expedition (Tacchini, 1875a). Tacchini was one of the most versatile Italian astronomers of the era, not only from a scientific viewpoint but also a 'political' one, due to his connections at the Ministry of Public Instructions as well as his ability to organise and coordinate Italian astronomical research. As we have already noted, Tacchini, Secchi, Lorenzoni and Respighi founded the Italian Society of Spectroscopists and the journal *Memorie* in 1871 (Chinnici, 1999 and 2007; Lugli, 2001).

Figure 6: The dome that housed the Steinheil refractor at the Italian station in Muddapur, India. Pietro Tacchini is on the left, by the Tauber spectroscope from Palermo, which was adapted to the telescope (private archive).

The goal of the expedition to Muddapur (India) was to observe the most eagerly awaited astronomical event of the era, the transit of Venus across the Sun on 9 December 1874. This event, which had not occurred since 1769, was fundamental for calculating the Sun's exact parallax, thereby allowing scientists to deduce the dimensions of an Astronomical Unit and thus the correct scale of distances within the Solar System (Chinnici, 2003; Pigatto and Zanini, 2001). The Kingdom of Italy had been united only a few years earlier following the Italian army's entry into Rome in 1870 and the end of the millenary Papal States. Consequently, participating in an astronomical event that had mobilised hundreds of astronomers around the world for coordinated observations offered Italian astronomy—whose reputation Tacchini was attempting to restore—a chance to gain great international visibility.

In 1874 Tacchini sent a report to the Ministry of Public Instruction, hoping to reorganise the eleven Italian observatories on which the Government was wasting limited funding, personnel and instruments (Tacchini, 1875b). Moreover, in his report Tacchini suggested downgrading the Bologna Observatory to a simple meteorological observatory (along with those of Modena and Parma), but his proposal was never fully implemented, as the Bologna Observatory was merged with the local university and thus became the University Astronomical Observatory (Bònoli and Poppi, 2001; Poppi et al. 2005). Nevertheless, Tacchini was chiefly interested in the Observatory's main instrument—the Steinheil refractor—for an extremely delicate task, with which he planned to supplement the observations made using four other instruments that he was taking on the expedition to India. In other words, he wanted to determine the contacts of the transit of Venus using an original method that called for observing the solar limb using a spectrograph adapted to the telescope's focal plane. As Secchi wrote in Part One of the publication presenting the results of the observations (Tacchini, 1875a):

> Among the various methods proposed for this observation, there is also the one referred to as spectroscopic, which seems capable of yielding extraordinary precision, eliminating most of the inevitable problems of direct observation. This method is completely new and in 1874 it was used for the first time for such observations.

Once the Bologna instrument was obtained, the workshop at the Padua Observatory prepared it for the expedition, along with four other instruments from the observatories of Palermo, Padua and Turin, by creating special field mounts that were easy to transport and suitable for the latitude of the observation site (Figure 5). The Tauber spectroscope from the Palermo Observatory was mounted on the Steinheil, the largest instrument used by the expedition (Figure 6), and Tacchini personally handled the observations with this instrument.

At the end of the expedition, described in a publication the following year (Tacchini, 1875a) and recently presented in detail in this journal by Pigatto and Zanini (2001), Tacchini tried to keep the instrument for his own institution, not only because of its quality but also because he knew it was not being used at Bologna. Moreover, he continued to hope that his project for reorganising the astronomical observatories would be implemented, thereby closing the one in Bologna and redistributing its instruments. However, Saporetti (Figure 7), who had just filled the long-vacant position at the helm of the Bologna Observatory, promptly asked Tacchini to return the Steinheil telescope. Following several requests, the instrument was reluctantly returned in December 1876, arriving in Bologna "… greatly improved …" (Saporetti (1877) by the work that had been done at the workshop of the Padua Observatory.

The story of this telescope and the dispute surrounding it did not end here, however, and the correspondence preserved at the Department of Astronomy of the University of Bologna shows that the University Chancellor and the Minister for Public Instruction became involved in it. Just a year later, Tacchini undiplomatically asked if the telescope had ever been used and, if so, what the results had been (Tacchini, 1878); there is no trace of Saporetti's reply, if indeed he replied at all.

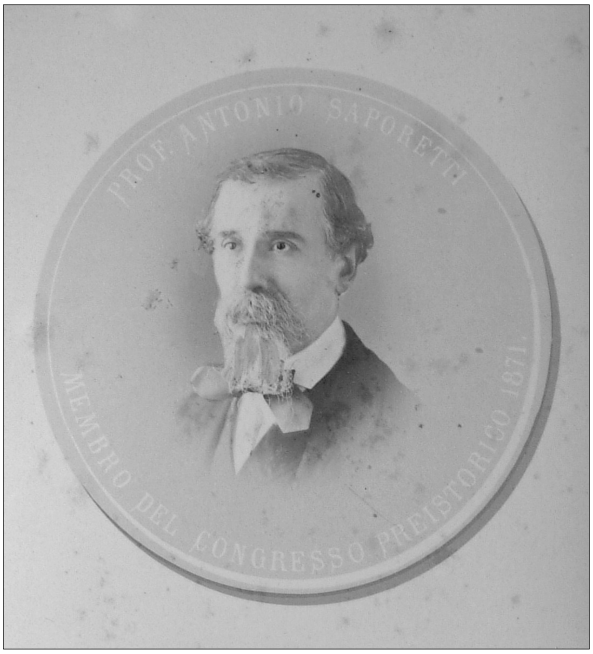

Figure 7: Antonio Saporetti (1821–1900) (courtesy: Archive of the Department of Astronomy, University of Bologna).

Tacchini then requested the Steinheil telescope again for an expedition for the spectroscopic observation of the corona during the solar eclipse of 6 May 1883, which was visible from the Pacific Ocean and was especially important because its totality lasted 5 minutes. Unfortunately, the Italian expedition was never organised, due to the lack of funding from the Ministry of Public Instruction. Tacchini himself only managed to participate as a guest of the French mission, which was coordinated by Jules C. Janssen, and he went to Caroline Island, in what is now Kiribati.

This time, however, Saporetti was forced to answer, due also to the fact that Tacchini asked the Ministry to step in. Nevertheless, his negative response clearly mirrors the resentment he had harboured towards Tacchini's old project to downgrade the Bologna Observatory (Saporetti, 1883a and 1883b):

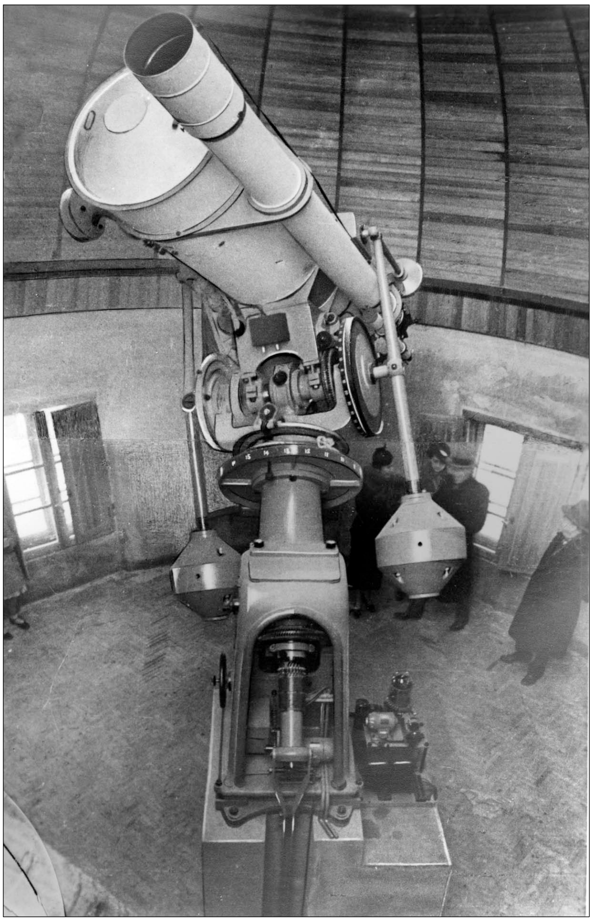

Figure 8: The 60-cm Zeiss reflecting telescope, photographed in the dome at Loiano a few days after it was inaugurated in 1936. In the foreground, the long tube of the guiding telescope on which the 16-cm achromatic lens from the Steinheil telescope was used for about 30 years. On the right, Guido Horn d'Arturo (courtesy: Archive of the Department of Astronomy, University of Bologna).

> … as soon as I heard that you wanted our instrument (a few months ago) and I officially informed the person so requesting it on your behalf that, on my part, I had no problem with it, I spoke to our illustrious professor, Rector Magni … and others from the University and was told that it could not be loaned under any circumstances. Furthermore, courses in the theory and practice of Astronomy have already commenced this year and the university students at the Chair of Astronomy come here to conduct these observations and learn about the main astronomical instruments, namely the Steinheil Equatorial and the Ertel Great Meridian Circle ... I regret that you plan to contact His Excellency the Minister or may already have done so, but he will be convinced that, as mistreated, derelict, neglected and abandoned as this observatory may be, he will nevertheless not wish for the death that may be in the minds of many, perhaps by turning it into a simple meteorological [observatory] as you have proposed.

We have no knowledge of any further use of the telescope since then. Moreover, we do not know if it was repositioned in the dome of the Observatory tower, on its original equatorial mount or on the field mount that Tacchini had made for the mission. It was not until much later—in 1936—that the top-quality lens was reused as a guiding telescope objective lens for the 60-cm Zeiss reflector (Figure 8) at the newly-built Loiano Observing Station of the Astronomical Observatory of the University of Bologna, situated on

Mount Orzale about 40 km from Bologna, at an altitude of approximately 800 m above sea level. It would remain here until the 1960s, when the guiding telescope was replaced. What remained of the old Steinheil refractor—the objective lens and the wooden tube with an iron mount—ended up hanging on a wall in a room at the Observatory, whereas a box with several eyepieces was tucked away in a drawer in the mechanical workshop. The dome of the tower where it had originally been housed was demolished during this period to make room for a lift.

Figure 9: The Steinheil telescope following restoration work, on the wooden mount that was made by ARASS (Association for the Restoration of Ancient Scientific Instruments) of Milan, which also made the hour and declination circles. In the background, the large desk that was used by Guido Horn d'Arturo, to whom the room in which the telescope is exhibited is dedicated (courtesy: Museo della Specola, University of Bologna).

The problem of restoring an instrument of unquestionable historical value arose several years ago when the decision was made to set up a new room at the Museo della Specola. The room was named after Guido Horn d'Arturo, who was the Director of the University Observatory and Professor of Astronomy for more than thirty years (with a hiatus due to racial persecution, as he was Jewish) and promoted the renaissance of Bologna's astronomical research in the twentieth century. This room, which now houses the prototype of the tessellated telescope designed by Horn and the 60-cm Zeiss mirror, also proved to be the ideal location for the Steinheil telescope (Figure 9), which was once again placed near the instrument (the Zeiss mirror) with which it shared the final phases of its scientific 'career'.

However, there was no trace of its original mount. Consequently, a wooden mount, like the field mount that had held the telescope during the expedition, was created for it. The mount was reconstructed based on photographs and drawings that Tacchini had published concerning the Indian expedition and on period photographs from the Padua Observatory, which were kindly provided by Luisa Pigatto. The mount was built on a smaller scale so that the telescope could be set up in the museum room. The work, whose goal was to restore the instrument to its 1874 conditions but without erasing the signs of history and time, was conducted by ARASS (Association for the Restoration of Ancient Scientific Instruments) of Milan, with the supervision of the staff from the Museo della Specola in Bologna (Poppi et al., 2003). In addition to the mount, ARASS also made the hour and declination circles of the instrument, based on available drawings and photographs. For the 2004 transit of Venus, the Steinheil telescope—which had been used to observe the same astronomical event from India one hundred and thirty years earlier—was exhibited in its new setting in the Museo della Specola of the University of Bologna.

4 NOTES

1 For biographical notes on Count Marsili (or Marsigli) see Stoye (1994).

2 For a reconstruction of the activities of the Observatory of the Istituto delle Scienze of Bologna see Baiada et al. (1995: 13-80) and references cited therein. For a history of the teaching of astronomy at the University of Bologna and a biographical overview see Bònoli and Piliarvu (2001). For an overview of the city's scientific milieu in the seventeenth century, in which the University, the Jesuit College and private academies operated, see Cavazza (1990) and Borgato (2002). Information on astronomy in Bologna during this period can also be found in Heilbron (2001).

3 The reasons that Respighi left Bologna are cited in the transposition of one of his autographic works, dated 1 December 1864, by a certain Mr. Bianchi who, "… on behalf of the Ministry …", wrote to Respighi from Turin on 11 January 1865, in *Fondo Respighi*, Archive of the Astronomical Observatory, Rome (Scatola I). See also Horn d'Arturo (1963).

4 For a complete bibliography of the works of Horn d'Arturo, see the website of the Archive of the Department of Astronomy, Bologna: *Fondo Horn d'Arturo*, M. Zuccoli (ed.), at www.bo.astro.it/~biblio/Archives/Galleria/hornbib.html.

5 The reasons that led to the decline of Italy's great glassmaking and instrumental tradition represent a topic that has never fully been clarified (but see Bònoli, 2002; Brenni, 1985; and Proverbio, 2000).

5 REFERENCES

Abetti, G., 1981. Horn d'Arturo, Guido. In Gillispie, C.C. (ed.). *Dictionary of Scientific Biography. Volume 6*. New York, Charles Scribner. Pp. 507-508.

Airy, G.B., 1872. On a supposed alteration in the amount of astronomical aberration of light, produced by the passage of the light through a considerable thickness of refracting medium. *Proceedings of the Royal Society of London*, 20, 35-39.

Baiada, E., Bònoli, F., and Braccesi, A., 1995. *Museo della Specola. Catalogue*. Bologna, Bologna University Press.

Baldini, U., 2007. Manfredi, Eustachio. In *Dizionario Biografico degli Italiani. Volume 68*. Rome, Istituto della Enciclopedia Italiana Treccani. Pp. 668-676.

Bònoli F., 2002. Riccioli e gli strumenti dell'astronomia. In Borgato, M.T. (ed.). *Giambattista Riccioli e il merito scientifico dei Gesuiti nell'età barocca. Biblioteca di Nuncius – Studi e Testi, No. 44*. Florence, Olschki. Pp. 133-157

Bònoli, F., 2003. Horn d'Arturo, Guido. In *Dizionario Biografico degli Italiani. Volume 61*. Rome, Istituto della Enciclopedia Italiana Treccani. Pp. 729-730.

Bònoli, F. 2007a. Horn d'Arturo, Guido. In Hockey, Thomas (ed.). *The Biographical Encyclopedia of Astronomers. Volume I*. New York, Springer. Pp. 525-526.

Bònoli, F. 2007b. Manfredi, Eustachio. In Hockey, Thomas (ed.). *The Biographical Encyclopedia of Astronomers. Volume II*. New York, Springer. Pp. 733-735.

Bònoli, F. 2007c. Respighi, Lorenzo. In Hockey, Thomas (ed.). *The Biographical Encyclopedia of Astronomers. Volume II*. New York, Springer. Pp. 964-965.

Bònoli, F., Foderà Serio, G., and Poppi, F., 2005. La ricerca astronomica in Italia al momento dell'Unità: uomini e strutture. In *Atti dei Convegni Lincei n. 217. Cento Anni di Astronomia in Italia 1860-1960*. Rome, Bardi Editore. Pp. 29-72.

Bònoli, F., and Piliarvu, D., 2001. *I Lettori di Astronomia Presso lo Studio di Bologna dal XII al XX Secolo*. Bologna, Clueb.

Bònoli, F., and Poppi, F., 2001. Astronomy in Bologna in the 19th Century. In Gariboldi, L., and Tucci, P. (eds.). *History of Physics and Astronomy in Italy in the 19th and 20th Centuries. Source, Themes and International Context*. Milan. Pp. 83-89.

Bònoli, F., and Poppi, F., 2006. L'astronomia a Bologna dalla Repubblica Cispadana alla Restaurazione. In Pigatto, L., and Xausa, F. (eds.). *Astronomi del Territorio Marosticense alla Specola di Padova*. Marostica. Pp. 231-257.

Bònoli, F., and Zuccoli, M. (eds.), 1999. *Guido Horn d'Arturo e lo Specchio a Tasselli*. Bologna, Clueb.

Borgato, M.T. (ed.), 2002. *Giambattista Riccioli e il Merito Scientifico dei Gesuiti nell'età Barocca*. Firenze, Olschki.

Boscovich, R, 1785. *Opera Pertinentia ad Opticam, et Astronomiam*. 2(3). Bassano, Remondini.

Bottrigari, E., 1960. *Cronaca di Bologna. Volume II.* Berselli, A. (ed.). Bologna, Zanichelli.

Brachner, A., 1987a. *Mit den Wellen des Lichts, Ursprünge und Entwicklung der Optik im süddeutschen Raum*. München.

Brachner, A., 1987b. C.A. Steinheil, a Munich instrument maker. *Bulletin of the Scientific Instrument Society*, 12, 3-7.

Brenni, P., 1985. Italian scientific instrument makers of the nineteenth century and their instruments. In de Clercq, P.R. (ed.). *Nineteenth-century Scientific Instruments and their Makers*. Leiden, Museum Boerhaave. Pp. 183-203.

Calandrelli, I., 1851. *Uso del Circolo Meridiano. 24 Ottobre 1851*. MS, Archive of the Department of Astronomy, Bologna (cart. 32/6).

Cavazza, M., 1990. *Settecento Inquieto. Alle Origini dell'Istituto delle Scienze di Bologna*. Bologna, Il Mulino.

Chinnici, I., 1999. Nascita e sviluppo dell'astrofisica in Italia nella seconda metà dell'Ottocento. In Tucci, P. (ed.). *Atti del XVIII Congresso Nazionale di Storia della Fisica e dell'Astronomia*. Milan.

Chinnici, I., 2003. Transito di Venere 1874: una spedizione italiana in Bengala. *Giornale di Astronomia*, 29(4), 45-53.

Chinnici, I., 2007. The 'Società degli Spettroscopisti Italiani': birth and evolution. *Annals of Science*. In press.

Fantuzzi, G., 1720. *Memorie della vita del Generale Co: Luigi Ferdinando Marsili*. Bologna, L. dalla Volpe.

Gualandi, A., 2004. Lorenzo Respighi e il cannocchiale ad acqua. *Giornale di Astronomia*, 30(1), 30-37.

Gualandi, A., and Bònoli, F., 2008. The search for stellar parallax and the discovery of the aberration of light: observational evidence of the Earth's revolution, Eustachio Manfredi and the 'Bologna case'. Manuscript.

Heilbron, J., 2001. *The Sun in the Church. Cathedrals as Solar Observatories*. Cambridge, Harvard University Press.

Horn d'Arturo, G., 1963. Astronomia e Politica. *Coelum*, 31, 105-109.

Jacchia, L., 1978. Forefathers of the MMT. *Sky and Telescope*, 55(2), 100-102.

]Lugli, M.U., 2001. *Pietro Tacchini*. Modena, Il Fiorino.

Maury, M.F. (ed.), 1846. Appendix. In *Astronomical Observations Made During the Year 1845 at the National Observatory, Washington. Volume I.* Washington, Gideon.

Parmeggiani C., 1848. Preventivo della Spesa per erigere in uno dei quattro triangoli della prima Terrazza della Specola di Bologna una nuova Camera Astronomica da collocarvi il Circolo Meridiano di Ertel, Progetto dell'Ing.e Arch.o Carlo D.r Parmeggiani, 5 maggio 1848. MS with drawings, Archive of the Department of Astronomy, Bologna (cart. 28/X).

Pedersen, K.M., 2000. Water-filled telescopes and the prehistory of Fresnel's ether dragging. *Archive for History of Exact Sciences*, 54, 499-564.

Pigatto, L., and Zanini, V., 2001. Spectroscopic observations of the 1874 transit of Venus: the Italian party at Muddapur, eastern India. *Journal of Astronomical History and Heritage*, 4, 43-58.

Poppi, F., and Bònoli, F., 2002. L'astronomia a Bologna nel XIX secolo. *Giornale di Astronomia*, 28(4), 41-56.

Poppi, F., Bònoli F., and Chinnici, I., 2005. Il progetto Tacchini e la riforma degli osservatori italian. In *Atti dei Convegni Lincei n. 217. Cento anni di astronomia in Italia 1860-1960*. Roma, Bardi Editore. Pp. 121-169.

Preyss, C.R., 1962. *Von Reichenbachs Werkstatt zum Ertel-Werk für Feinmechanik 1802 – 1962*. München.

Proverbio, E., 2000. Il difficile reperimento di vetro ottico in Italia nella seconda metà del Settecento. *Quaderni di Storia della Fisica*, 6, 63-85.

Respighi, L., 1864. Sulle osservazioni circumzenitali delle stelle. *Memorie dell'Accademia delle Scienze dell'Istituto di Bologna*, II (2a s.), Bologna. P. 12.

Respighi, L., 1857a. Lettera ai Direttori di altri Osservatori astronomici, Bologna 10 Agosto. MS, Archive of the Department of Astronomy, Bologna (cart. 42).

Respighi, L., 1857b. Lettera a Papa Pio IX … MS, Archive of the Department of Astronomy, Bologna (cart. 42).

Saporetti, A., 1877. Lettera al Rettore della R. Università di Bologna L. Calori …, Bologna 22 Febbraio. MS, Archive of the Department of Astronomy, Bologna (cart. 43).

Saporetti, A., 1883a. Lettera a Tacchini, Bologna 12 Febbraio. MS in *Fondo Tacchini.* Archive of the Astronomical Observatory, Rome (scatola I).

Saporetti, A., 1883b. Lettera al Rettore della R. Università di Bologna F. Magni …, Bologna 17 Febbraio. MS, Archive of the Department of Astronomy, Bologna (cart. 43).

Satterthwaite, G.E., 2003. Airy's zenith telescopes and 'the birth-star of modern astronomy'. *Journal of Astronomical History and Heritage*, 6(1), 13-26.

Schiaparelli, G.V., 1900. Lettera al Ministro Guido Bacelli, Milano 15 Aprile. MS, Archive of the Department of Astronomy, Bologna (cart. 60).

Steinheil, C.A., 1858. Lettere a Respighi, Monaco 23 Febbraio, 25 Marzo, 18 Aprile, 10 Settembre. MSS in *Fondo Respighi*. Archive of the Astronomical Observatory, Rome (scatola V).

Stoye, J., 1994. *Marsigli's Europe: 1680-1730: The Life and Times of Luigi Ferdinando Marsigli, Soldier and Virtuoso*. New Haven, Yale University Press.

Tabarroni, G., 1981. Manfredi, Eustachio. In Gillispie, C.C. (ed.). *Dictionary of Scientific Biography*. *Volume* 9. New York, Charles Scribner. Pp. 77-78.

Tacchini, P., 1875a. *Il passaggio di Venere sul Sole dell'8-9 dicembre 1874 Osservato a Muddapur nel Bengala*. Palermo, Stabilimento Tipografico Lao.

Tacchini, P., 1875b. Sulle attuali condizioni degli Osservatorii Astronomici in Italia. *Memorie della Società degli Spettroscopisti Italiani*, Palermo, Appendice al vol. IV, 1-20.

Tacchini, P., 1878. Lettera a Saporetti, Roma 3 Maggio. MS, Archive of the Department of Astronomy, Bologna (cart. 43).

Tempel, E.W., 1858. Lettera a Respighi, Venezia 31 Luglio. MS in *Fondo Respighi*. Archive of the Astronomical Observatory, Rome (scatola V).

Francesco Poppi obtained a degree in astronomy from the University of Bologna in 2000. After a four-year fellowship in the Department of Astronomy, where he conducted historical research on nineteenth century Italian astronomy, he is now involved with the public outreach activities of the

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BOOK REVIEWS

***Star Maps: History, Artistry, and Cartography*, by Nick Kanas (Springer Praxis Publishing, 2007), pp. 382, appendices, index, 207 illustrations. ISBN 978-0-387-71668-8 (softcover), US$34:95, 240 x 165 mm.**

San Francisco Bay Area author Nick Kanas is an avid collector of celestial maps and charts. He has taken his many years of collecting expertise and condensed it into a marvelous book on this fascinating aspect of enjoying the night sky (for a reproduction of the front cover see Figure 1). His book is filled with 207 color and black & white images of celestial maps from all ages. The surviving celestial maps from Mesopotamia, Egypt, China, India and other ancient cultures influenced Greek, Roman, and Islamic sky watchers who in turn produced their own representations of the night sky. Once knowledge of these earlier maps became known to Renaissance European cartographers, the art and craft of representing the night sky on paper reached a high point of refinement, and their maps have become highly prized collectors items, not only for showing the heavens but for their artistry as well.

From the opening chapter devoted to explaining the difference between celestial and cosmological maps to the final chapter covering modern maps and atlases, you will find something fascinating on almost every page. The author describes the maps for each period and talks about how particular map styles were developed over the years and the relationships between them. Where a map or chart is illustrated, he discusses details shown on the map and gives you a good understanding of the map's place in cartographic history. As you progress through the ages, you can see how one age influences the work of later eras. I found this to be a very fascinating aspect of this comprehensive work. I have read a number of books on the history of celestial cartography, but none with the depth and wealth of information on this important part of the history of astronomy.

One of the appendices lists celestial cartographers in alphabetical order, and includes information on the works that each individual produced. This is certainly a very useful part of this book. Another appendix provides tips on collecting celestial maps and what pitfalls to avoid.

Mr. Kanas presents a vast and valuable body of knowledge on this subject and has done so in a lucid manner that I found very easy to follow and a real joy to read. Even though the small size of the book meant that images of the maps would be small, they are reproduced to such a fine point that details on all of them remain easily readable. I highly recommend this book to students of the history of astronomy or anyone interested in observing the night sky.

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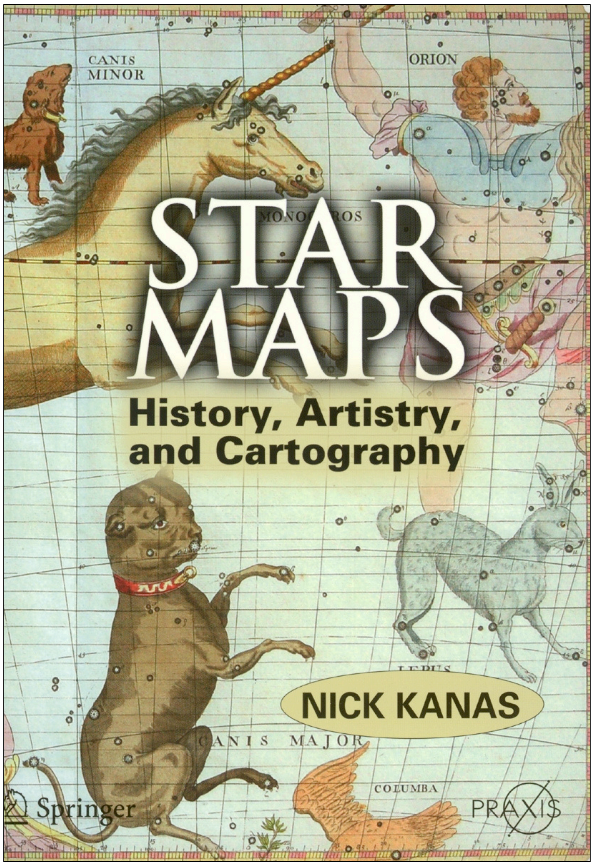

Figure 1: The attractive front cover of Nick Kanas' book.

***Proxima: The Nearest Star (Other Than the Sun!)*, by I.S. Glass (Cape Town, Mons Mensa, 2008), pp. viii + 88, ISBN 978-0-9814126-0-3 (paperback), $R100 + postage & charges etc. (available from glass.ian@gmail.com), 210 x 148 mm.**

Every astronomer knows of Proxima Centauri, that supposed wayward sibling of Alpha Centauri and the closest star to the Earth after the Sun, but how many know the fascinating history of its discovery? There can be no excuse now that IR astrophysicist and historian of astronomy, Ian Glass, has prepared a charming little book on the subject. Ian hails from the South African Astronomical Observatory in Cape Town, and how particularly appropriate given that South African-based astronomers were intimately involved in the initial investigations of both Alpha Centauri and Proxima.

Apart from introducing the concept of parallax and discussing 61 Cygni, the first two chapters in *Proxima: The Nearest Star* … focus on Alpha Centauri and introduce us in quick succession to the work of Nicolas Louis de Lacaille, Manuel Johnson, Thomas Henderson, Thomas Maclear, John Herschel David Gill and his assistant, William Elkin. Using a 4-in Repsold heliometer, Gill and Elkin derived a parallax of 0.71 ± 0.01″; as Glass (page 32) reminds us, this value is "… within the errors, the same as the modern one."

The saga surrounding the discovery and initial investigation of Proxima Centauri occupies the next two chapters of the book, but what makes these particularly interesting pages is not just the scientific story but also the human drama surrounding the two leading protagonists, R.T.A. Innes and J.G.E.G. Voûte. By any criterion Robert Thorburn Ayton Innes was an exceptional character. A former amateur astronomer, this charming yet unconventional Scot emigrated to Sydney where he ran a successful wine business before obtaining a clerical post at the Cape Observatory through the services of Australia's leading nineteenth century astronomer, John Tebbutt. Innes was immersed in an affair at the time so he booked his wife into Callum Park Psychiatric Hospital in order that his mistress could accompany him and his three young sons on the voyage to Cape Town! Later he was to obtain the founding Directorship of the Transvaal Observatory in Johannesburg, where he made no attempt to hide his private life (as happily portrayed by Dirk Vermeulen in his entertaining 2006 book, *Living Among the Stars at the Johannesburg Observatory*). More conventional both in outlook and lifestyle was the Indonesian-born Dutchman, Joan George Erardus Gijsbertus Voûte, who had independent means and from 1913 worked as a volunteer observer at the Cape Observatory (having previously spent several years at Leiden Observatory).

Soon after Innes announced the discovery of Proxima Centauri in *Union Observatory Circular* No. 30 in 1915, Voûte began observing it at the Cape with a view to determining its parallax. Innes did likewise in Johannesburg, and the race was on to publish. To Innes' chagrin, Voûte's paper appeared in a 1917 issue of *MNRAS* several months before his own contribution in *Union Observatory Circular* No. 40. The next 12 pages of Glass' book document the ensuing battle between these two astronomers to refine their parallax values and interpret Proxima Centauri's true status: was it part of the Alpha Centauri system, and if so was it closer to the Earth than the two principal components?

After disposing of the historical material, Glass turns his attention to "Modern studies of Alpha and Proxima" in the final chapter of his book. Table 5.1 contains 'vital statistics' on both stars, while Figure 5.2 explores the orbits of α_1 and α_2 Centauri before Glass raises that fundamental question, "Is Proxima in orbit around α?" This is his conclusion:

> [Proxima and Alpha Centauri] … are in some way connected, whether because they are moving away together from the same place of origin or because Proxima is actually in orbit around α. Unfortunately, it is not easy to determine whether either of these possibilities holds true … There is hope, however, that the question can be resolved with the aid of large telescopes and improved spectrographs in the not-too-distant future. (Page 75).

To those who are avid variable star observers Proxima Centauri is well known as a flare star, and Glass goes on to describe this aspect, before discussing the possibility that Proxima has a planetary system:

> At present, all that can be said is that there is no planet around Proxima with a mass greater than 0.8 of Jupiter's and an orbital period in the range 1 to 2.7 years. (Page 79).

Proxima: The Nearest Star … is a charming little book and seems designed primarily for the interested layman, yet it will appeal equally to astronomers with a passion for the history of our discipline. I thoroughly recommend it as a valued and eminently affordable addition to your bookshelf.

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***James Van Allen: The First Billion Miles*, by Abigail Foerstner (University of Iowa Press, 2007), pp. 376, ISBN 0-87745-921-5 (hardback), 978-0-87745-921-7 (paperback), $37.50, 240 x 160 mm.**

During the last 50 fifty years we have sent robotic spacecraft to explore the region near the Earth, all of the planets except Pluto, and craft that are still heading toward the outer edge of the Milky Way Galaxy. The contributions of one man, James Van Allen of the University of Iowa, set him apart from all of the other early space pioneers as the 'father of spacecraft instrumentation'. This biography of astrophysicist and space pioneer, James Van Allen, by science writer Abigail Foerstner (see Figure 2), places him in his times and beautifully tells us the history of the man and his scientific accomplishments. If you know anything about space exploration, you probably know of the Van Allen Radiation Belts that encircle the Earth, but you may not know that Van Allen is also an unsung hero of World War II.

Before I read this book, I was unaware that James Van Allen had helped to develop the proximity fuses used in anti-aircraft shells. Proximity fuses cause a shell to explode when it gets near an aircraft, so it does not have to hit the target in order to bring down an enemy plane. Shortly after thousands of these shells were delivered to the American troops in the South Pacific in 1943 the shells began failing to explode. Van Allen was sent out to the Pacific to find out what the problem was. He discovered that the batteries in the shells were deteriorating. Van Allen and a crew of Navy gunner's mates worked around the clock in the heat and sultry humidity at Tillage to replace thousands of shell batteries. The secret proximity fuse-armed shells were then very effective in shooting down hundreds of Japanese fighters in defense of our naval forces.

However, James Van Allen's greatest achievements centered around his teaching physics and astronomy at the University of Iowa, which in turn supported his efforts to explore the source of cosmic rays and his discovery of the radiation belts that bear his name. Foerstner gives life to what otherwise might be a dull reading of a scientist's life. She takes us to Van Allen's early attempts using weather balloons with instruments and a combination of weather balloon with an instrument package inside a rocket attached to the balloon. This was called a 'rockoon' and was used to lift his instruments to higher elevations than the balloons alone could go. Van Allen worked with the German scientists who were brought to the U.S. after World War II to teach us how to build and launch the V-2 rockets that we had captured. These German rocket scientists were lead by Wernher von Braun. Van Allen was able to insert various packages of Geiger counters and telemetry instruments into the rocket nose cones in furtherance of his search for the source of cosmic rays.

In addition to his teaching assignments, Van Allen also served as the head of the Physics Department and oversaw the construction of his instruments in the laboratory and workshops located in the basement of the Physics Building. A number of his graduate students worked on the instruments at Iowa, then went on to lead other spacecraft instrumentation efforts at private and government facilities. These former colleagues kept in touch with Van Allen, and many of them came to his 90th birthday scientific colloquium celebration held in October 2004. One of the photographs in the book that I really like shows Van Allen at the colloquium holding up a T-shirt that which states: "Actually I am a Rocket Scientist".

The subtitle of the book refers to the fact that when James Van Allen died at the age of 92 in 2006 his radiation detectors on board the *Pioneer 10* spacecraft were still working after 30 years in space and sending back data from a distance of over 8 billion miles from Earth. For her compelling and informative biography, Foerstner has combined the drama of early spaceflight failures and successes, 'cold war' politics that led to the 'Space Race', Van Allen's dealings with his numerous graduate students and their efforts to create the instrument packages for many of the space flights, and events in Van Allen's personal life. She was able to interview her subject for a number of years before he died and was given access to his personal journals and papers. I highly recommend this fascinating book and enjoyed my look into the life and times of one of America's greatest rocket scientists.

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Figure 2: The front cover of *James Van Allen…*

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