Journal of Astronomical History and Heritage, 12(3), 189-200 (2009).

GENERAL-PURPOSE AND DEDICATED REGIMES IN THE USE OF TELESCOPES

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Abstract: We propose a socio-historical framework for better understanding the evolution in the use of telescopes. We define two regimes of use: a general-purpose (or survey) one, where the telescope governs research, and a dedicated one, in which the telescope is tailored to a specific project which includes a network of other tools. This conceptual framework is first applied to the history of the 80-cm reflector at the Toulouse Observatory, which was initially anchored in a general-purpose regime linked to astrometry. After a transition in the 1930s, it was integrated into a dedicated regime centered on astrophysics. This evolution is compared to that of a very similar instrument, the 80-cm reflector at the Marseille Observatory, which was converted to a dedicated regime with the Fabry-Perot interferometer around 1910, and, after a period of idleness, was again used in the survey mode after WWII. To further validate our new concept, we apply it to the telescopes at the Washburn Observatory, the Dominion Astrophysical Observatory and the Meudon Observatory. The uses of the different telescopes illustrate various combinations of the two regimes, which can be successive, simultaneous or alternating. This conceptual framework is likely to be applicable to other fields of pure and applied science.

Keywords: telescope, general-purpose regime, dedicated regime, practices

1 INTRODUCTION

The role played by the telescope in the evolution of our knowledge of astronomy often remains hidden, even though it is obviously essential.

A number of studies have been carried out about astronomers' light collectors, for example, William Herschel's telescopes (Bennett, 1976; Hoskin, 2003), and the 12-inch telescope at Lowell Observatory that was used to search for trans-Neptunian planets and led to the discovery of Pluto (Giclas, 1980). More contemporary instruments have also been the subject of historical analysis. Gibson (1991) traced the technical difficulties linked to the construction of the Canadian liquid mirror telescope. The history of the British Isaac Newton telescope, in contrast with that of more recent British telescopes in the Canary Islands, reveals the influence, in both periods, of the scientific and technical context of such a project (Smith and Dudley, 1982). As for the itinerary that led to the construction of the Anglo-Australian 150-inch telescope, it reflects the political stakes which the United Kingdom had to face at the time, and in particular the difficult choice between two possible partners (see Gascoigne et al., 1990; Lovell, 1985). Bell's (2006) study of the construction of large telescopes by the Warner & Swasey Company provides evidence of the ties between science and industry in the field of astronomical instrumentation.

In France, Véron (2003) has shown the difficult installation of the equatorial in the eastern tower of the Paris Observatory. Davoust (2000) has described the construction and use of several telescopes at the Pic du Midi Observatory in a very special local environment that required unusual human qualities. The work of Audouin Dollfus with the large telescope at Meudon shows the successive uses of an instrument of exceptional dimensions (Dollfus, 2006a; 2006b; 2006c). Tobin (1987) has related the history of the Foucault telescope at the Marseille Observatory and has tried to learn lessons from it for the management of future astronomical projects. The large number of these analyses does not, however, exhaust the potential for historical research into any specific instrument.

The goal of the present paper is to examine how telescopes structure, or otherwise influence, research in astronomy, and to establish a general pattern for their often changing role in assisting (or leading) astronomical research. We are concerned with telescopes that were considered large at the time of their first light. The telescopes selected for study are all reflectors, except for the Washburn and Meudon telescopes, which are refractors. The historical period of interest starts with the beginning of astronomical photography (the 1880s), and ends with the advent of modern large telescopes in the 1960s and 1970s.

We first describe a general conceptual framework for evaluating the role of telescopes, and define two regimes, a regime of general use (or a survey regime) and a dedicated regime. We then carry out a detailed assessment of the role of one specific instrument, the 80-cm telescope at the Toulouse Observatory, and establish its successive roles. We then move on to a comparison with another telescope of the same size in a very similar environment, revealing similar roles, but with a different chronological order. Finally, the pattern which emerges from this comparison is tested on the history of other telescopes, taken from the literature, thus providing a conceptual framework for analysing the history of astronomical instruments.

2 THE GENERAL AND DEDICATED REGIMES OF USE

The large reflectors and refractors built toward the end of the nineteenth century by and large match the technical and scientific criteria set up by astronomers. In this sense, large telescopes are comparable to the generic instruments defined by Shinn (1993; 2001): their flexibility, optical quality and their ease of use allowed them to satisfy a large range of demands. Telescopes thus fit in a specific technological context, one strongly marked by the determination of the position of celestial objects—i.e. astrometry. This first regime of use, which we call the 'general regime' or 'survey regime', considers observing as a global activity of the observatory. The instruments are not dedicated to a specific task; rather, they fit in a general scientific pol-

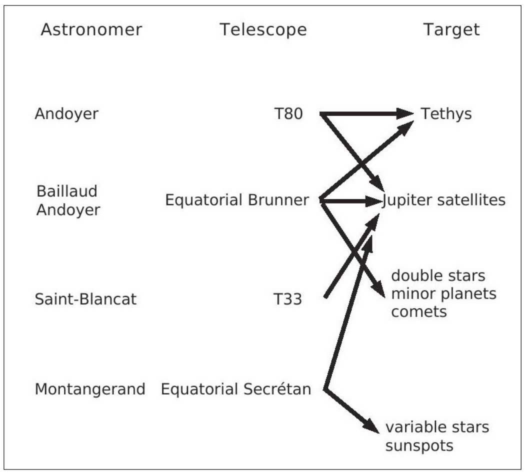

Figure 1: The general-purpose regime at the Toulouse Observatory in 1886-1887.

icy as defined (explicitly or implicitly) by the director, that of gathering measurements. In a sense, it is a survey mode, where the instruments are put to the task of measuring whatever can be measured with them. One can thus state that it is the instrument, not the astronomer, which drives the science that is carried out. The astronomer is content to observe using the available tools.

An example of this general regime can be found in the annual report of the Toulouse Observatory for 1885-1886, which was organized around the instruments (see Figure 1). There were four telescopes, an astronomer was in charge of each of them, and they all participated to the best of their performances in the observation of a series of targets. Except for the 33-cm telescope, they were all used for several programs.

At the other extreme is the dedicated regime, which corresponds to very focused and more oriented scientific practices. Here again, the technical, scientific and political contexts determine and shape the uses of the telescope. A specific kind of celestial target, a new dynamic recruit to the team of astronomers, the emergence of an innovative technology (e.g. the microphotometer), a new scientific program or even an entirely new field which compels teams or institutes to reorient their activities, are among the factors that can impose a dedicated regime upon certain instruments. The telescope is then associated with a definite practice, its mechanical and optical performances are overhauled, and new auxiliary instrumentation is acquired in response to new observational goals. The general scientific policy of the observatory is no longer the dominating factor in the use of the telescope; it is

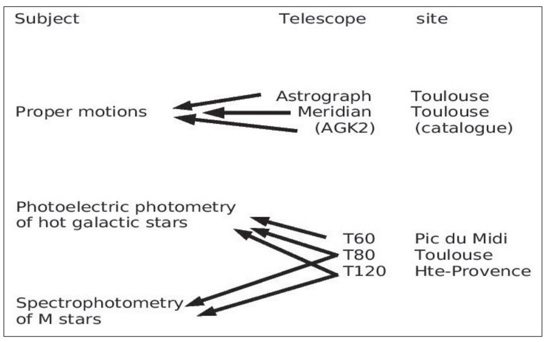

Figure 2: The dedicated regime at the Toulouse Observatory in 1957-1958.

rather a combination of new performances of the telescope and its tailoring to a specific program.

An example of this second regime is found in the annual report of the Toulouse Observatory for 1957-1958, which is now organized by scientific fields (see Figure 2). Astrophysics is divided into two programs, which makes use of three telescopes, only one of which is local. The 60-cm telescope is located at the Pic du Midi Observatory and the 120-cm reflector at the Haute-Provence Observatory. In other words, the astronomers do not satisfy themselves solely with the locally-available telescopes in order to pursue their scientific programs. The latter clearly drive the use of the telescopes.

As pointed out by a referee, the dichotomy in the roles of telescopes can be seen in different ways. This can be the tension between astronomers who want to undertake research on a specific topic of their choice and those who use the available instruments for the purpose(s) for which they were originally designed. This can also be the distinction between scientific programs shaping the instruments and the available instruments determining the programs. But, from a socio-historical point of view, it is essential to consider the telescope as an inanimate actor with a role to play in the conduct of scientific research.

At any rate, we do not propose these generalist and dedicated regimes as two rigid ideals, to which all telescopes have to conform. The main point of this paper is to show the flexibility of these concepts, allowing them to shed new light on the most diverse situations. One of the characteristics of these two regimes of use is precisely the diversity of practical situations and thus of possible combinations of the two regimes: successive, simultaneous and alternating. We insist on the point—and the historical examples that we present bear this out—that there is no unique historical process setting once and for all the uses of a telescope in a quasi-teleological order, moving it in time from the general to the dedicated regime. Again, our empirical approach accounts for a large variety of historical situations, whilst offering a coherent framework for their socio-historical understanding.

3 THE 80-CM TELESCOPE AT THE TOULOUSE OBSERVATORY

We begin with the long history of the 80-cm telescope at the Toulouse Observatory (Figure 3), focusing on the role of the instrument in the order of practices and on its possible implication in scientific policies. We strive to understand how the different uses of such a technical object are related to the successive research projects.

The 80-cm telescope was in fact the final outcome of a long quest to equip the Toulouse Observatory with a large instrument. The initial project, in 1845, called for a mural circle. When, in 1863, the Director of the Observatory learned of Foucault's experiments with an 80-cm mirror, he reoriented his quest in favor of an 80-cm telescope. Numerous hurdles prevented the instrument from being acquired before 1877, and it actually was only put to full use in 1887 (Lamy, 2009).

From 1887 to 1970, the 80-cm telescope fitted into two principal, distinct and successive techno-scientific regimes. Within the first regime, service was organized around the instruments. The purpose of astronomers was to make a detailed inventory of the night sky. The main concern of the Director was thus to put all the instruments of his institution to good use toward that goal. In other words, the technological tools directed scientific activity. After a transitional phase in the 1930s, the second regime was organized around a discipline: astrophysics. The physical knowledge of stars, their composition and their structure dominated most of the scientific activity within the Toulouse Observatory, especially in the period following WWII. From then on, astrophysics structured the service.

We will now attempt to distinguish how the 80-cm telescope was modified and used in these two distinct scientific cultures.

3.1 The First Regime: The Telescope Directs Scientific Activity (1887-1935)

During this first period, the 80-cm telescope was an undifferentiated instrument in the global research strategy of the Toulouse Observatory, which was centred on astrometry. In practice, this meant observing stars and noting their positions, as well as those of planets and their satellites. However, each instrument had a specific role which took into account its particular capacities as far as possible.

The Observatory's services were organized around the instruments and one astronomer was responsible for each. Three astronomers worked at the Toulouse Observatory in 1884, five in 1890 and seven in 1900. These astronomers were helped in the dome by one or several assistants, and by the caretaker in some instances. Between 1880 and 1931, the observers running the 80-cm telescope were, successsively: Benjamin Baillaud, Charles Fabre, Henri Andoyer, Eugène Cosserat, Henry Bourget, Alphonse Blondel and Emile Paloque.

Toulouse Observatory was one of the eighteen institutes participating in the Carte du Ciel project. The astrograph was the principal technical tool of this photographic survey, but the 80-cm telescope was also used in this context, along with all the other instruments at the site. The astronomer Henry Bourget made several "… pictures of photographic calibrations for the international catalogue photographs." (Baillaud, 1903: 53; our translation). In 1903, he noted that "… one easily obtains on the same plate 60 stars belonging to 25 or 30 different photographs of the catalogue." (ibid.). In 1888, the telescope was also used to measure numerous very weak stars in one of Herschel's catalogues (Baillaud, 1889).

Baillaud's field of scientific interest was celestial mechanics. He examined Saturn's satellites with the 80-cm telescope, whose collecting power was an asset in this endeavour. The purpose there was to construct and refine the ephemerides of the satellites. Baillaud (1891: 40; our translation) indicated that "… this work for which this instrument is appropriate will be pursued for a long time with a view to determining elments of the orbits."

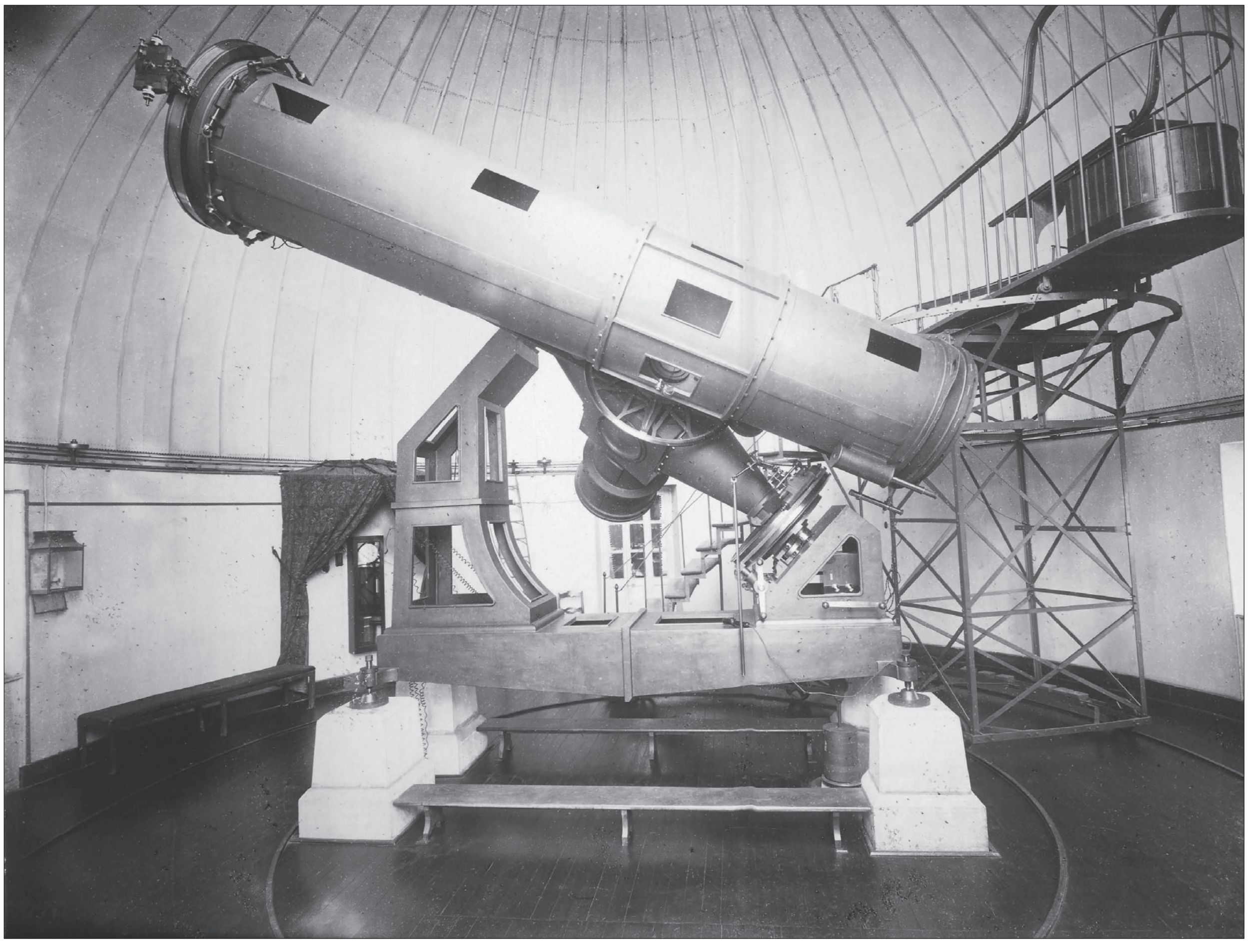

Figure 3: The Toulouse Observatory 80-cm reflector (courtesy OMP Archives).

Baillaud's successors as Director of the establishment after 1908, Eugène Cosserat and Emile Paloque, occasionally pursued this research. Cosserat mentioned in 1910 that he had spent twenty-two evenings that year at the telescope "… continuing the observation of the satellites of the large planets …" (Cosserat, 1910: 62, our translation; cf. Baillaud, 1891). Meanwhile, Paloque explained that he had made eighteen visual observations of Rhea, Dione, Titan, Tethys and Hyperion, as well as "… 32 observations of Jupiter's satellite I; 34 observations of Jupiter's satellite II; 38 observations of Jupiter's satellite III; 32 observations of Jupiter's satellite IV." (Paloque, 1926: 65; our translation).

The telescope was also used under special circumstances. In 1892, the Toulouse astronomers examined Comets Wolf, Denning, Swift, Winnecke, Brooks I, Brooks II and Holmes with this instrument (Baillaud, 1892).

This 'classical' use of the telescope centering on astrometry and on survey work does not necessarily mean that the large collecting power of the instrument was wasted: the photographic work on the star clusters and nebulae for the *New General Catalogue*, begun in the 1890s (Bourget, 1900), is visible evidence of the desire to make the most of its technical and visual potential.

Bourget, who was in charge of the telescope at the time, first concentrated his efforts on developing photographic techniques, making all sorts of attempts and trying all kinds of practical combinations. In 1895, the telescope received "… minor modifications intended to assist its use for celestial photography." (Baillaud, 1896: 38-39; our translation). However, the flexing of the tube caused by the guiding telescope disturbed photographic operations (Baillaud, 1897). The year 1898 was decisive because it saw "… the question of photography beyond its trial period and definitely solved." (Bourget, 1898; our translation). Further technical improvements were made in the years that followed. Three items were introduced that collectively allowed: the stopping at a distance of the clockwork movement; the hour angle to be locked and unlocked from a given point in the dome; and the telescope to be moved in hour angle during an exact number of 2-minute lapses of time (Baillaud, 1899). Taking photographs with repeated short exposures was simplified by the building of an automatic shutter, which was run by a metronome, thus ensuring a constant exposure time.

Bourget was trying to innovate in an extremely competitive scientific field. He confessed that he had "… never dreamt of rivalling the clever observers who … have obtained such fine images of nebulae and clusters." (Bourget, 1900; our translation). His purpose was completely different. He felt that "… a good use of the telescope would be to try to obtain the best possible small images, appropriate for precise micrometric measurements." (ibid.). Forced to do without the guiding telescope, he suggested following "… the guide star, with the help of the slow-motion levers, behind the sensitive plate through a hole made in the gelatine." (ibid.). The Toulouse astronomers judged this solution satisfactory because "… the loss of one star on the photograph is greatly compensated for by the improvement of the images." (Baillaud, 1898: 42; our translation).

Bourget (1900) began a programme of photographing galactic nebulae and clusters. These images "… were made for the purpose of measuring the positions of the stars they contain." (Baillaud, 1899: 55; our translation). He therefore used "… a micrometer … on a microscope with a movable plate … which was placed at his disposal by the [Toulouse] Faculty of Sciences." (ibid.). The experimental setup designed for the Carte du Ciel project inspired Bourget, who realized that it would be "… very interesting and hardly inconvenient to print on the images a graticule analogous to those used for the sky survey." (ibid.). Furthermore, he "… imagined a procedure which allowed the photographic printing of the graticule, in bright red, on an already developed image." (ibid.).

This scientific undertaking begun by Bourget was pursued sporadically after his departure for the Marseille Observatory in 1907. In 1909, Eugène Cosserat (page 67; our translation), explained that he had "… used the telescope to obtain images of clusters NGC 1960, NGC 2099, NGC 5846, NGC 6093 …", and in 1926 Emile Paloque (page 64; our translation) mentioned that he had "… located the images of clusters and nebulae already photographed by H. Bourget in 1898 and 1899."

To emphasize how subtle the distinction between the two regimes of usage of a telescope can be, we point out that if Baillaud had based his analytical perturbation theory of the minor planet Pallas on observations made at one of the telescopes rather than on archival data, this would have been a case of a telescope being used in the two regimes simultaneously.

3.2 An Era of Transition: Paul Lacroute, the 80-cm Telescope and the Genesis of Astrophysics at the Toulouse Observatory (1935-1945)

One astronomer who played a considerable role in the genesis of a genuine astrophysical project at the Toulouse Observatory was Paul Lacroute. Already in 1934 the Director, Emile Paloque (1934: 173; our translation), wished "… earnestly for a future appointment which will bring the Observatory an astronomer/physicist who can get the most out of this [80-cm telescope] …" Paloque's prayers were answered when Paul Lacroute, a physics graduate with a Doctor of Science, was named 'trainee assistant-astronomer' and started work at the Observatory on 1 February 1935; Paloque (1935) immediately assigned the 'great Gautier telescope' to him.

Lacroute decided to use the telescope for astrophysical research. To do this, he renewed the technical equipment associated with the telescope, which until then was strictly for photography. From then on, auxiliary astrophysical equipment was adapted to the telescope, and the technical chain of data analysis was expanded by the acquisition of measuring instruments.

A radial-velocity spectrograph (Figure 4) was ordered from the Strasbourg Observatory in 1936 and delivered the following year (Paloque, 1936). In 1937 and 1938, Lacroute obtained "… 163 images of stellar spectra, about a hundred of which were long exposures, associated in particular with the study of hot stars with variable emission lines." (Paloque, 1938: 171; our translation). The variability was evidence of transient phenomena in the atmospheres of such stars. Furthermore, Lacroute drew up plans for a high-dispersion spectrograph (Paloque, 1936). Finished in November 1938, this instrument was immediately mounted on the telescope, and Lacroute was able to continue "… to study particularly interesting irregular variables." (Paloque, 1939: 137; our translation).

Measuring the precise positions of the centres of the lines in these spectra required the use of a recording micrometer, and in 1939 the Caisse Nationale de la Recherche Scientifique, a new institution created in 1934 by Jean Perrin (Picard, 1990), provided a subsidy for the purchase of "… a recording microphotometer … from the English company 'Casella' …" (Paloque, 1939: 137; our translation). The technical adjustments also aimed for easier comparison of the stellar spectra with the reference spectra, which included lines of known wavelengths used to determine the other lines. During 1940-1941, Lacroute developed an assembly so that he could juxtapose the two spectra. In the process, he "… recut and polished the small prisms with sharp edges that allowed a better juxtaposition of the stellar spectra and the comparison spectra on the plate." (Paloque, 1941: 146; our translation).

The astrophysical research programme carried out by Lacroute led him to an important discovery in 1942. Helped by the Dutch astronomer, Willem Dirks, a refugee in France during WWII, the Toulouse astronomer noticed that "… the spectrum of the star 67 Ophiuchi, presented P Cygni type emission lines." (Lacroute and Dirks, 1942; cf. Paloque, 1942: 176). The P Cygni profiles proved the existence of an expanding gas shell around the star.

Lacroute's work and the scientific direction he moved towards transformed astronomical practice not only in the 80-cm telescope dome, but in the very organization of the Observatory. In 1942, the Director, Paloque, asserted that the purpose of "… the efforts made by Mr Lacroute with remarkable activity and rare competence …" was to organise a complete spectrographic service (Paloque, 1942: 175; our translation). It was in fact an astrophysical service, to which the instrment had become subordinated, but Paloque retained the instrumentalist's mindset peculiar to the first techno-scientific level. It is therefore no surprise that he had not initiated the new regime. With Lacroute, the instrument was used for specific and innovative observations which were no longer integrated into an overall organization. Its scientific use gradually became autonomous with respect to the other instruments.

Passage from practices centred on astrometry to the deployment of the new astrophysical discipline was accelerated at the Toulouse Observatory by the impossibility of exploiting the results previously obtained with the 80-cm telescope. In 1943, Lacroute obtained several photographic plates of clusters in order to "… study the influence of centering on the accuracy of star positions measured on these images." (Paloque, 1942: 130; our translation). His purpose was to find out whether there was "… any point in deducing stellar motion from the comparison of new images taken at the Telescope with old images of clusters." (ibid.) taken by Bourget. Lacroute noted that "… the result of this study was clearly negative, the slightest defect in centering causing prohibitive errors in the measured positions." (ibid.). Because of centering defects, Bourget's first-epoch plates could not be used for measuring proper motions. Thus, the final attempt to use the 80-cm telescope in a classical astrometric undertaking was a failure and confirmed the wisdom of the techno-scientific change begun by Lacroute.

3.3 The Second Regime: The Telescope in the Service of a Science Project (1945-1970)

Lacroute left the Toulouse Observatory in 1945 to join the Strasbourg Observatory (Paloque, 1946), and his efforts to organize astrophysical activity around the 80-cm telescope were pursued and increased by Roger Bouigue, who replaced him in 1947.

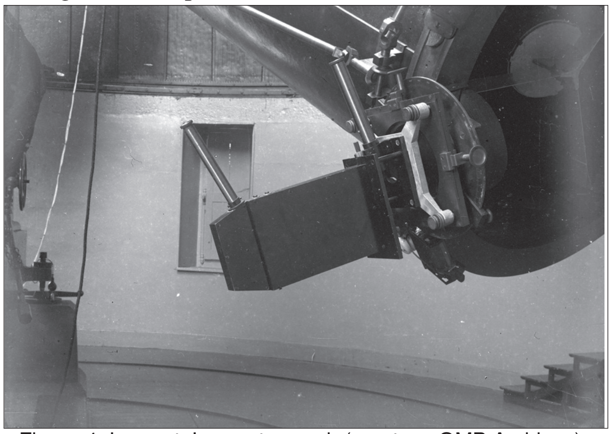

Figure 4: Lacroute's spectrograph (courtesy OMP Archives).

Under the impetus of Bouigue, the auxiliary instrumentation and the mechanisms for gathering information developed considerably, thus expanding what Latour (1989: 606) has called the 'metrological chain'. The 1950s were especially fruitful for the development of spectrographs adapted to the telescope. In 1952, a recording system "… of the comparison spectrum was entirely reconstructed." (Paloque, 1952: 179; our translation). Thus, the spectrum of iron was obtained differently. Henceforth, fluorescent tubes were used to produce other comparison spectra (ibid.). Now it was possible to record stars of magnitude 7, "… in particular those whose spectra presented wide atomic lines." (Paloque, 1952: 180; our translation). In 1955, Bouigue drew up plans and calculated the optics for a "… spectrograph with prisms capable of being associated with the 80-cm telescope … which should allow the study of weak stars over a fairly wide spectral range (4000 to 8000 Å)." (Paloque, 1956: 5; our translation). By the following year, several nights were dedicated to obtaining the spectra of cold M-type stars with the new spectrograph (Paloque, 1957), and at the same time astronomers obtained "… a Soleillet-type sampling spectrograph covering the entire spectral range of 3600-8000 Ångstroms with a perfectly flat plane." (Paloque, 1957: 225; our translation). The end of the decade was particularly important for the astrophysical equipment on the 80-cm telescope. During the 1959-1960 academic year, Bouigue started the construction of an electronic spectrocomparator as well as a double-grating spectrograph with double dispersion for variable stars. The former instrument "… should allow the rapid and precise measurement of stellar spectra accompanied by a comparison spectrum with a view to determining the stars' radial velocity." (Paloque, 1960: 344; our translation). Meanwhile, the double-grating spectrograph was intended for the " …

systematic study of spectra of cold variable stars … [in order to] specify the evolution of atmospheric characteristics in the course of these stars' pulsations." (ibid.).

Bouigue also innovated in the development of photoelectric photometers. In 1952 and 1953 he prepared a "… cell with a Lallemand electron photomultiplier which, associated with coloured filters, should permit the determination of intensity of luminosity of bands with much more advantageous conditions than the spectrograph." (Paloque, 1953: 157; our translation). Installation of this new apparatus (Figure 5) required the creation "… from scratch of a photometer adapted to the focus of the large telescope in order to make photometric measurements of stars and nebulae in seven different spectral bandwidths." (Paloque, 1954: 189; our translation). In 1954, a Meci electronic recorder was associated with the Lallemand cell in order to obtain "… photoelectric measurements of very luminous stars … in various spectral bandwidths." (Paloque, 1955: 195; our translation).

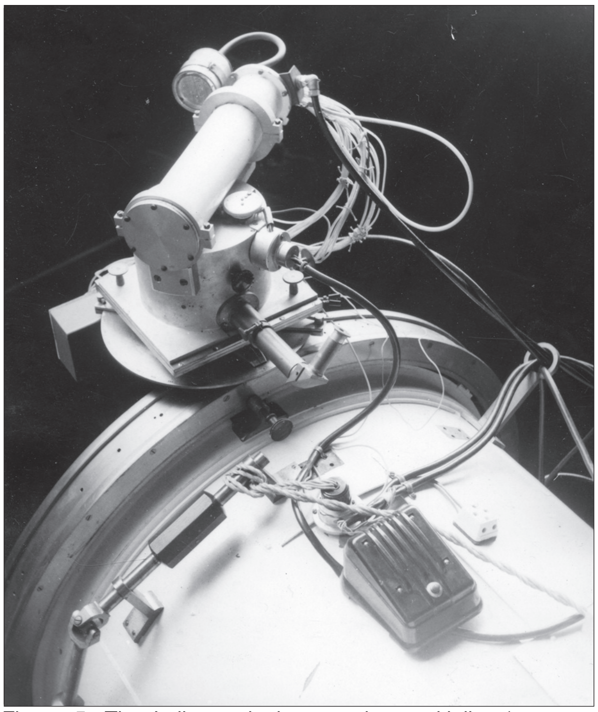

Figure 5: The Lallemand electron photomultiplier (courtesy OMP Archives).

In the same period, the telescope itself underwent only two transformations: the addition of a mounting plate at the focus in 1956 (Paloque, 1957), and the change from a Newtonian to a false Cassegrain focus (Bouigue, 1966). These modifications were not required for scientific reasons but were justified by a desire for greater comfort for the observer. The longer focal length meant that the astronomer was no longer required to observe from the top of a high ladder, and the mounting plate simplified the attachment of auxiliary instrumentation at the focus. Thus, the telescope was no longer the object of innovation in this era of scientific optimization, for it had reached its technical maturity and was used to the maximum of its intrinsic capability.

The addition of the auxiliary instrument even further extended the network in which the telescope was included. Maintaining these instruments required the recruitment of new specialised technical personnel, so four positions for technicians and assistants were created for the astrophysical division or were transferred from the Carte du Ciel group between 1950 and 1962. Furthermore, two scientists were hired in 1956 and 1957 to make observations and to carry out the new research programme.

The setting up of an astrophysical division required the creation of a network of actors and auxiliary instruments that constituted a number of intermediaries between the observations and the scientific results. The telescope was integrated into a techno-scientific network that aimed at imposing astrophysics as the heart of scientific activity at the Toulouse Observatory.

As a result, the range of astrophysical research at the Observatory was expanded, and the telescope was used in collaborative studies with other observatories. Thus, from 1954 (Paloque, 1955) the Toulouse Observatory and the Marseille, Pic du Midi and Haute-Provence Observatories participated in "… photoeletric measurements of photographic and visual magnitudes of galactic stars." (Paloque, 1960: 343; our translation). Similarly, in 1958-1959 the Toulouse Observatory and its 80-cm telescope took part in a campaign organized by the Stockholm Observatory to examine the star β Lyrae (Paloque, 1959). From this time on, research projects were part of national and international collaborations and exchanges.

This greater exchange of information and scientific data spurred the growth in Toulouse of a culture of technical exchange around the 80-cm telescope. This reflector and its auxiliary equipment were gradually inserted into a national network of instruments, and Paloque (1952: 180; our translation) noted that "… the very satisfying results obtained with this telescope give Toulouse Observatory important possibilities that are currently unique in France, which has attracted several Parisian researchers looking for spectra."

In 1956-1957, an astronomer at the Milano-Merate Observatory, Pietro Broglia, came to Toulouse in order to learn how to carry out photoelectric observations and manufacture interference filters (Paloque, 1957). In this way, the Toulouse researchers spread the competence acquired with the telescope. They also went to other institutes to gather photometric and spectroscopic data needed for their research. Exchanges were particularly frequent with the Haute-Provence Observatory.[1]

When Bouigue became Director of the Toulouse Observatory in 1961 the astrophysical division became a priority, and from then on its activities were listed first in the annual reports (e.g. see Bouigue, 1962: 286-287). Light pollution finally put an end to the use of the 80-cm telescope in the early 1970s.

In summary, the history of the 80-cm telescope reveals that this reflector went through two distinct regimes of usage in the course of its lifetime. It was first a general-purpose instrument used in a wide range of exploratory and/or inventory projects, which did not often make full use of its technical potential. Then, after a latent period which was linked to the absence of motivated users, it became the main tool of a wide-ranging astrophysical research project, until environmental factors eventually led to its demise.

The question that now arises is whether this history, and the pattern of use that it reveals, are specific to this instrument, and thus only of anecdotal interest, or if, on the contrary, it is but one example of a general pattern for the evolving role of telescopes in astronomical research.

4. COMPARISON WITH THE HISTORY OF THE 80-CM TELESCOPE AT THE MARSEILLE OBSERVATORY

It is apt to start our critical assessment of the above pattern by comparing it with one associated with the history of an identically-sized telescope used in a rather similar context at another French observatory.

While the history of Marseille Observatory may be rather different from that of the Toulouse Observatory, the two institutes were in fact on an equal footing in terms of funding, staff and instruments in the period of interest. The 80-cm telescope at the Marseille Observatory (Figure 6) came into operation in 1864, more than twenty years earlier than the Toulouse reflector, and was finally closed down in 1965, a few years before the Toulouse telescope stopped being used. During the period under discussion the two institutes had comparable numbers of scientific staff: between three and five astronomers.

The initial use of the Marseille telescope was similar to that seen at Toulouse. Indeed, the Director of the Marseille Observatory, Edouard Stephan (selected by Le Verrier in 1866), was a graduate of the École Normale Supérieure, just like Tisserand and Baillaud. He began with a programme to inventory nebulae, but the telescope was also used to observe comets, occultations of stars and transits of Mercury (Tobin, 1987). These programmes were typical of the general-purpose or exploratory regime.

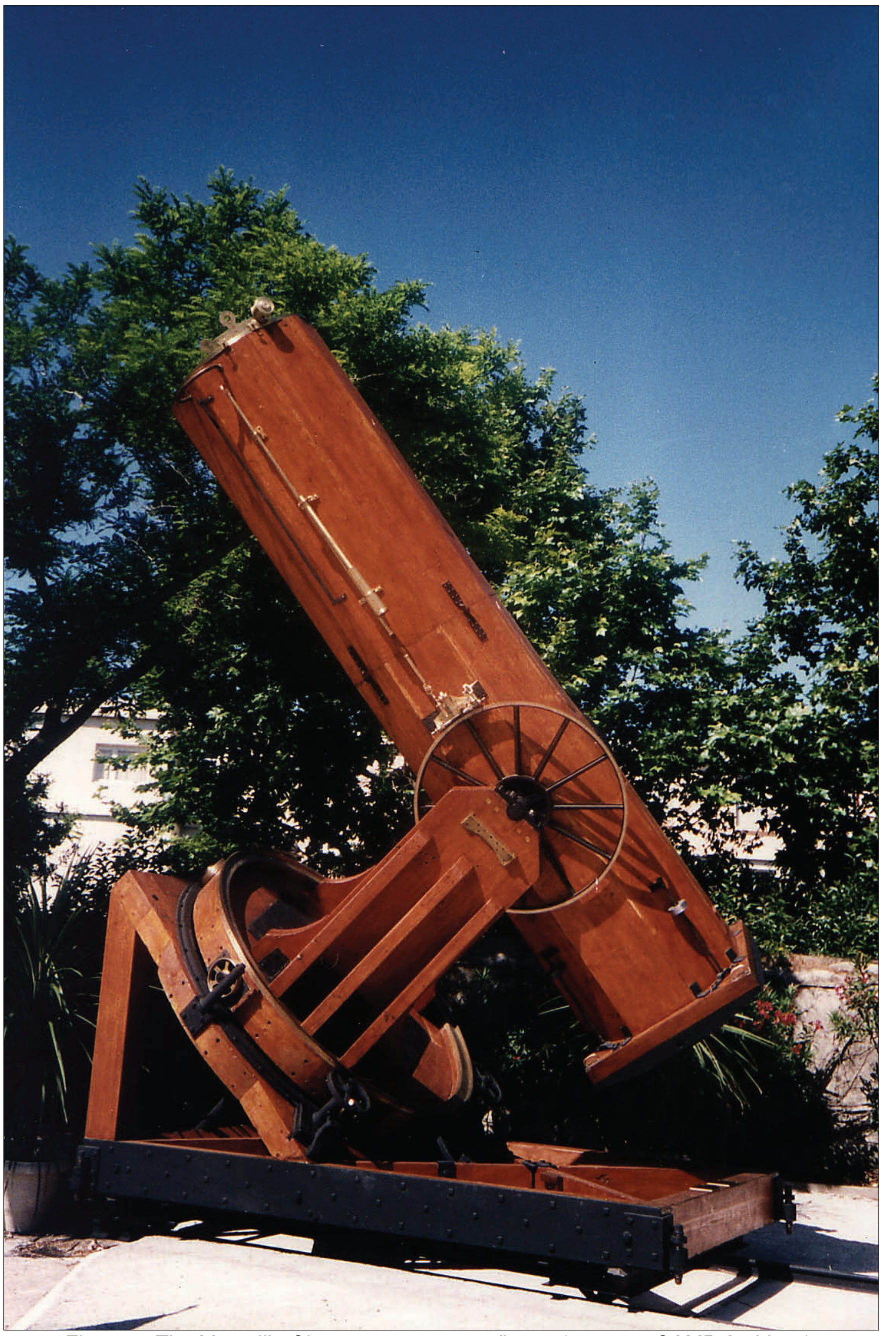

Figure 6: The Marseille Observatory 80-cm reflector (courtesy OAMP Archives).

Significant changes then occurred at the Marseille Observatory through the influence of three academics from the Faculty of Sciences, Charles Fabry, Alfred Pérot and Henri Buisson, who dedicated themselves to furthering astrophysics. They developed an interference etalon that would be called the Fabry-Pérot filter and was used to measure radial velocities. In 1902, they applied their procedure to the Sun, but it was not necessary to use a telescope since a simple heliostat was sufficient to capture solar light (Fabry and Buisson, 1902; Fabry and Perot, 1902). In 1911, they turned their attention to the Orion Nebula using the 26-cm equatorial, and noted: "We hope to be able to employ it [their filter] with instruments which are more powerful and better adapted to the purpose, in particular with a reflecting telescope." (Fabry and Buisson, 1911; our translation). This eventually came to pass in 1914 when Fabry, Pérot, Buisson and a new collaborator, Henry Bourget, used the Marseille Observatory's 80-cm telescope to obtain fourteen images with 1-2 hour exposure times (see Buisson and Fabry, 1914). A question then arose about how the Marseille observers managed to obtain such long exposures since Baillaud in Toulouse claimed it was impossible. The answer lay in the use of interferogrammes, which meant that tracking defects had less effect on the quality of the images.

The Marseille astronomers thus were twenty years ahead of their colleagues in Toulouse, and had moved to a different level of practice where the instrument was integrated into and subordinate to a specific scientific project. Another remarkable innovation is that they decided to publish their results in English in four issues of the *Astrophysical Journal*, thereby reaching an international audience, which the Toulouse astronomers never did, with one notable exception (see Lacroute, 1942). However, this research did not last. Fabry, Pérot and Buisson were not on the staff of the Marseille Observatory, which made it difficult to institutionalize a service entirely dedicated to astrophysics. Then the outbreak of WWI prevented the development of large-scale scientific initiatives at both the Marseille Observatory and the Toulouse Observatory.

After the War, the Marseille astronomers no longer used their telescope, which was in poor condition (Fabry and Buisson, 1911). This is rather surprising, since one of the Directors during this period was Bourget, who had previously put the Toulouse reflector to good use with his photographic inventory of nebulae.

The Marseille telescope was only used once more when Robert Jonckheere joined the Observatory staff at the beginning of WWII. An experienced observer of binary stars since his youth (he was born in 1888), he resumed observing these systems and systematically measuring the separations and position angles of the components (Jonckheere, 1941a; 1941b; 1941c). However, his publications only listed the measurements themselves, with no astrophysical applications, which Jonckheere left to future generations of astronomers. In other words, this use of the telescope falls in the survey mode. The history of use of the 80-cm Marseille telescope is therefore rather different to that of its Toulouse counterpart. We can identify the two regimes—general-purpose and dedicated—but in the present case, they appeared in a cyclical order. The first regime, from 1866 to 1907, was essentially one of general-purpose, searching for and cataloging new nebulae, as well as observing targets of opportunity. The telescope then found itself in the dedicated regime quite early on (from 1914) compared to the situation at the Toulouse Observatory, thanks to the very innovative project introduced by Fabry, Pérot and Buisson. After a long period of inactivity (1914-1941), the telescope was then used by Jonckheere for a survey project, in the spirit of the general-purpose regime.

This return to scientific practice centered on the instrument and astrometry may be partially explained by Jonckheere's training. Unlike Baillaud, Lacroute and Stephan, who were graduates of the École Normale Supérieure, he was self-taught, with no academic degrees or scientific training, and he was therefore more inclined to pursue themes of interest to amateur astronomers, thus using the telescope in the framework of the first scientific regime. Another more compelling reason is that, after WWII, the astronomers at the Marseille Observatory preferred to use the larger aperture telescopes at the recently-founded Haute-Provence Observatory for their astrophysical research.

We now examine historical accounts of other large telescopes to put the above results in the broadest possible context.

5. THE CASE OF OTHER TWENTIETH CENTURY TELESCOPES

5.1 The 15.6-inch (39.6-cm) Refractor at the Washburn Observatory

The succession of regimes for this telescope is identical to the one that typifies the Toulouse instrument. In the early days of the Washburn Observatory, namely between 1884 and 1922, the *Publications of Washburn Observatory* essentially report survey work with the refractor (and the meridian instrument): micrometric observations of double stars and of faint stars near bright stars with known proper motions, observations of long-period variable stars, and of the minor planet Eros in 1900-1901 (see Leibl and Fluke, 2004). These programmes are characteristics of the first, general-purpose, regime.

The appointment of Joel Stebbins as Director in 1922 changed all this. Like Lacroute, who brought innovative projects and a spectrograph to the Toulouse Observatory, Stebbins contributed to the Washburn Observatory a new scientific project and new auxiliary instrumentation, namely a photoelectric photometer (ibid.). His first task was to test and improve the photometer, and then to search for small-scale light variations from known spectroscopic binaries. He then developed a project to monitor bright variable stars, particularly eclipsing binaries.

After this transition period, in 1930 to be precise, Stebbins embarked with two colleagues, Charles M. Huffer and Albert E. Whitford, on a project to investigate the reddening of stars, star clusters and galaxies, using the 15.6-inch refractor and the Mount Wilson 60-inch and 100-inch telescopes (ibid.)—just as the Toulouse astronomers also used the Haute-Provence and Pic du Midi telescopes for their projects. One outcome of their research was the law of interstellar reddening (ibid.). In this dedicated regime, the 15.6-inch refractor was only one among several telescopes used in a global strategy to pursue a scientific project.

5.2 The 72-inch (1.83-m) Reflector at the Dominion Astrophysical Observatory

This telescope presents an interesting intermediate case in our binary classification, in that the two regimes are simultaneously present after 1927 (see Batten, 2004).

The 72-inch telescope became operational in 1918, and was essentially used over the years for taking stellar spectra (Wright, 1968). The first scientific project, by J.S. Plaskett, involved the spectroscopic observation of binary stars, mostly of O-type, in order to determine stellar masses (Wright, 1968: 269). This type of research continued uninterrupted at least until the 1980s (with W.E. Harper and later Alan Batten), although observations were also carried out with the 48-inch reflector after it went into operation in 1962. This survey work fits into the first regime, despite the fact that another telescope was used, because the 72-inch could very well have been used. In 1927, Plaskett and J.A. Pearce initiated a survey of radial velocities of O- and B-stars in order to determine the solar motion and later the constants of galactic rotation (Wright, 1968: 276). Other projects of the 1920s and 30s involved the physics of emission lines in early-type stars, which was carried out by H.H. Plaskett and R.K. Young (Wright, 1968: 275). While not of survey type, these studies still fit into the first regime, since they made use of the available instrument with no alterations, thus letting the instrument lead research.

The arrival of C.S. Beals in 1927 marks the beginning of the second regime, but not the end of the first one. He implemented important changes to the existing auxiliary instrument, increasing the dispersion of the spectrograph and devising a method for including spectrophotometric calibration spots on the photographic plates, facilitating a study of the intensity and shape of spectral lines (Wright, 1968: 277). In order to record the data from the plates, he further developed a microphotometer in 1936 and an intensitometer in 1944. The science that he did with these data was perhaps not very different from that of Plaskett and Young, but the difference lay in the strategy: he adapted the telescope to his project, while the others worked the other way around. After the departure of Beals in 1946, the work in this regime was pursued by Andrew McKellar and Kenneth Wright (Wright, 1968: 280-281).

Further initiatives in the spirit of the dedicated regime included more adaptations of the spectrograph for new (high) dispersions in 1938, 1946 and 1955; observations with other telescopes (at the McDonald Observatory and the Curtis-Schmidt telescope at Portage Lake Observatory in Michigan); and the acquisition in 1962 of a 48-inch (1.22-m) telescope to be used as an experimental adjunct to the 72-inch reflector.

One may wonder why the changes made to the telescope by Beals and his co-workers did not eliminate the first regime of usage, which continued along with the second one. A possible answer may be found in a statement by Wright, who became Director in 1966. In his view, the research scientists were expected "… to select problems that are within the capabilities of the instruments at the Observatory …" (Wright, 1968: 271), suggesting that the telescope should direct research, while "… the general policy [was] to encourage each research scientist to carry on investigations in the fields in which he is most interested …" (ibid.) leaving room for personal initiatives, and thus for another regime of usage. But, he concluded: "... there is a strong tendency to continue along the general lines that have been established over the years." (ibid.).

5.3 The 83-cm Refractor at the Meudon Observatory

The history of the large refractor at the Meudon Observatory has been studied in detail by Dollfus (2006a; 2006b; 2006c). This instrument provides another example of passage from a general-purpose to a dedicated regime.

Jules Janssen established this Observatory toward the end of the nineteenth century to explore the new field of physical astronomy, and the giant refractor, built in 1897, was destined to explore the physical properties of celestial objects by way of both visual and photographic observations (Dollfus, 2006c). The instrument was perfectly adapted to this task, thanks to its long focal length and high optical quality.

The first observations, in 1898 and 1899, were of planets. The astronomers considered at one point conducting a "… systematic survey of planetary surfaces …" (Dollfus, 2006c:79; our translation), and organising it into a permanent monitoring service, but, at the time Meudon Observatory did not have the resources for such a project. The photography of star clusters became an important field of investigation for the large refractor at the turn of the century, and its optical qualities enabled it to resolve the central regions of clusters into stars (Dollfus, 2006c). At about the same time, it was possible to photograph stars surrounded by nebulosity. To Dollfus (ibid.) all of these experiments were meant to validate the potential of the refractor.

Henri Deslandres, who arrived in Meudon in 1897, was a spectroscopist. Although Janssen was still the Director, he was already 75 years old, so we can safely assume that Deslandres was *de facto* in charge, and this is reflected in the fact that all the instruments would be used for spectroheliography and the measurement of radial velocities. Direct photographic observations, for which the refractor was ideally suited, were soon discontinued (ibid.), and the telescope was mainly used to identify spectroscopic binaries. However, it was occasionally used for other purposes: spectroscopic studies of Nova Persei in 1901, the rotation of Uranus in 1902, observations of Comet Borelly in 1903 and of Jupiter in 1903 and 1904 (see Dollfus, 2006c: 90-94, 96-97, 98, 99-100). These investigations, together with those made with other instruments at the Observatory, clearly put the large refractor in the general-purpose regime.

After 1903, Deslandres devoted himself to spectroheliography and lost interest in the refractor, marking an important break in the use of the instrument (Dollfus, 2006c).

The large refractor was only used anew to the full extent of its visual potential with the arrival of Eugène-Michel Antoniadi, a wealthy independent astronomer. From the end of 1910 through into the 1930s, he studied the planet Mars in detail, making drawings and maps of its surface, and he finally put an end to the controversy over Schiaparelli's 'canali' (ibid.). He also made detailed drawings of Mercury, the surface of which is notoriously difficult to observe as it is so close to the Sun, and he occasionally studied Jupiter and Saturn (ibid.).

In 1924, Bernard Lyot, the inventor of the coronagraph, decided to apply his newly-designed polarimeter to the study of polarised light reflected off planetary surfaces, and mounted it on the large Meudon refractor, thus initiating a field of research that would be pursued well into the 1980s by the Meudon planetary astronomers, albeit mostly with other telescopes (ibid.).

Occasionally the large refractor was also used to observe other celestial objects, such as cometary nuclei or doubtful double stars, targets where its optical qualities were fully exploited.

After WWII, Paul Muller, a newly-arrived astronomer from the Strasbourg Observatory, temporarily modified the regime of usage of the large refractor in order to pursue his lifelong work on visual double stars. Between 1956 and 1974, under the sponsorship of the IAU, he secured 1000 position angles and separations for these stars (ibid.). Later he was transferred to the Nice Observatory, where he continued his quest with the 76-cm refractor at that institute. Just like Jonckheere at the Marseille Observatory, he limited his publications to measurements and the computation of orbital elements, putting the telescope in the survey regime of usage.

The large refractor returned to the dedicated regime in 1965, when, under the impetus of Jean Focas and in conjunction with similar observations made at the Pic du Midi Observatory, it was again used to study planetary surfaces. The highlight of that period is probably the analysis of the Martian atmosphere by Shiro Ebisawa, between 1973 and 1989. Drawings and photometric measurements obtained using the large refractor enabled him to study the seasons, as well as clouds and dust storms on the red planet (ibid.).

If one sets aside the post-WWII relapse into the general-purpose regime, very much in phase with a similar pattern for the 80-cm reflector at the Marseille Observatory, the large refractor at the Meudon Observatory displays the now-familiar pattern of passage from a general-purpose regime of observations for their own sake to the dedicated regime of exploration of planetary surfaces, where the instrument is perfectly adapted to the goal—imaging—and progressively becomes one element in a multi-telescope strategy for acquiring the necessary data for a single coherent project of planetary astronomy.

6 CONCLUDING REMARKS

We have analysed the history over almost a century of the 80-cm reflector at the Toulouse Observatory, and revealed its changing role in the conduct of astronomical research. In the first half-century of its existence, this was a general-purpose telescope, used for a multifaceted exploration of the night-sky and of the Sun. The telescope was then leading research, as the duty of astronomers was to make the best use of it, collecting data for future—but at that stage mostly undefined—research. The arrival of Pierre Lacroute, an astrophysicist, changed this role in the 1930s, and the telescope became dedicated to the study of stellar spectra for astrophysical purposes, until its demise in the early 1970s. In this second regime of usage, the telescope was only one of several tools in a strategy to pursue an astrophysical project.

In order to look for a common pattern in the use of telescopes, we then briefly examined the history of similar instruments at other observatories over the same time span. The 80-cm reflector at the Marseille Observatory was a good starting point since this instrument was identical in aperture, and because it was at a provincial French observatory it was used in a very similar scientific context. This reflector was used in the general-purpose regime for most of its lifetime. Only in 1914 did it make a brief incursion into the dedicated-purpose regime, when Fabry and his collaborators used it to test and exploit their now-famous interferometer.

The two regimes of usage can be identified in the history of other telescopes, generally moving from general-purpose to dedicated regime, with occasionally a relapse back to the former. For the 15.6-inch refractor of Washburn Observatory, the change to a dedicated project, the photometry of stars and the law of interstellar reddening, occurred in 1922 with the arrival of Stebbins. With the 72-inch telescope at the Dominion Astrophysical Observatory (DAO) it happened in 1927 with the arrival of Beals, and it occurred in 1910 with the 83-cm refractor at the Meudon Observatory when Antoniadi joined the staff.

The common point of all these regime changes is the arrival of a new astronomer on the staff. Only in two cases does the newcomer provoke a relapse back to the general-purpose regime. In one case, that of the DAO 72-inch, the two regimes continued alongside each other, presumably because old habits die hard.

The two regimes of telescope usage reflect the way scientists progress, first by exploring the field, gathering data, classifying them, and only later by pursuing specific leads suggested by the patterns emerging from these data. Our proposed conceptual framework for analysing the history of telescopes is thus relevant to the period when astronomy moved from systematic, instrument-led exploration to more focussed, project-led research.

The trend for telescopes to move from general to dedicated purpose continues to this day, when large multi-purpose telescopes such as the four ESO VLTs and the two Kecks in Hawaii, are used to explore the cosmic frontier in all fields, while other telescopes, such as the SLOAN 2.5m telescope at Apache Point Observatory, ESA's Hipparcos space astrometry mission, or the Wilkinson Microwave Anisotropy Probe of NASA, have been designed for specific tasks. However, the situation is now much more complex than in the past century, and our simple conceptual framework generally does not apply, as the various actors around large telescopes have different goals. The managers of telescopes are concerned with optimising the outputs of their instruments in terms of data and publications, while for science teams the telescope is but one tool in their strategy.

While recent works in the social studies of science provide numerous examples of instruments built—in part or totally—by scientists to pursue their own research (Clarke and Fujimura, 1996), analyses of the structuring effect of an instrument completely organising the research of a scientific realm are scarce (but see Vinck, 1992), and the main contribution of this paper is perhaps to show that the historical analysis of a scientific instrument can combine these two approaches with profit.

We have revealed a permanent structuring tension between institutionalised science policies and the relative autonomy of astronomers in their research projects, leading to a more intense (and possibly efficient) use of the telescope. Such a tension is probably even more striking in contemporary research, as we alluded to above. The variety and multiplicity of contexts allows us to better understand how one or the other component of the tension prevails, and provides a wider view of the actors' fields of action and of potentially constructive outside effects (such as institutions and research programs).

The use of a 'long time span' (Braudel, 1969) in the study of instruments provides a balance between the macro-approach which tends to underestimate local arrangements, and the micro-analysis which may neglect the wider stakes of science policies. In maintaining the interplay between macro and micro, one can grasp, for a given instrument, the importance of individual opportunities, of collective choices and the mode of integrations of technological innovations, as well as paradigm changes and other mutations in science. The role of these various elements depends on the epoch and the context, and at a given stage they define the prevailing potentials and stakes.

In closing, we suggest that the concept of the two different types of regimes—general purpose or exploratory and dedicated—as presented here be further tested and extended by investigating the interplay between the academic and industrial spheres over the same period. Surely the instrument-makers must have influenced the path of scientific research, or was it the other way around?

7 NOTES

1. For example, Bouigue, Chapuis, Pédoussaut and Rochette made three observing runs in January, May and July 1959 with the 1.2-m telescope at the Haute-Provence Observatory (Paloque, 1959), while in October 1959 and June 1960 Bouigue and Pédoussaut used the large spectrograph with the 1.93-m telescope (Paloque, 1960).

8 ACKNOWLEDGMENTS

We thank one of the referees, Dr Alan Batten, for very valuable comments which led to major improvements to this paper.

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