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.

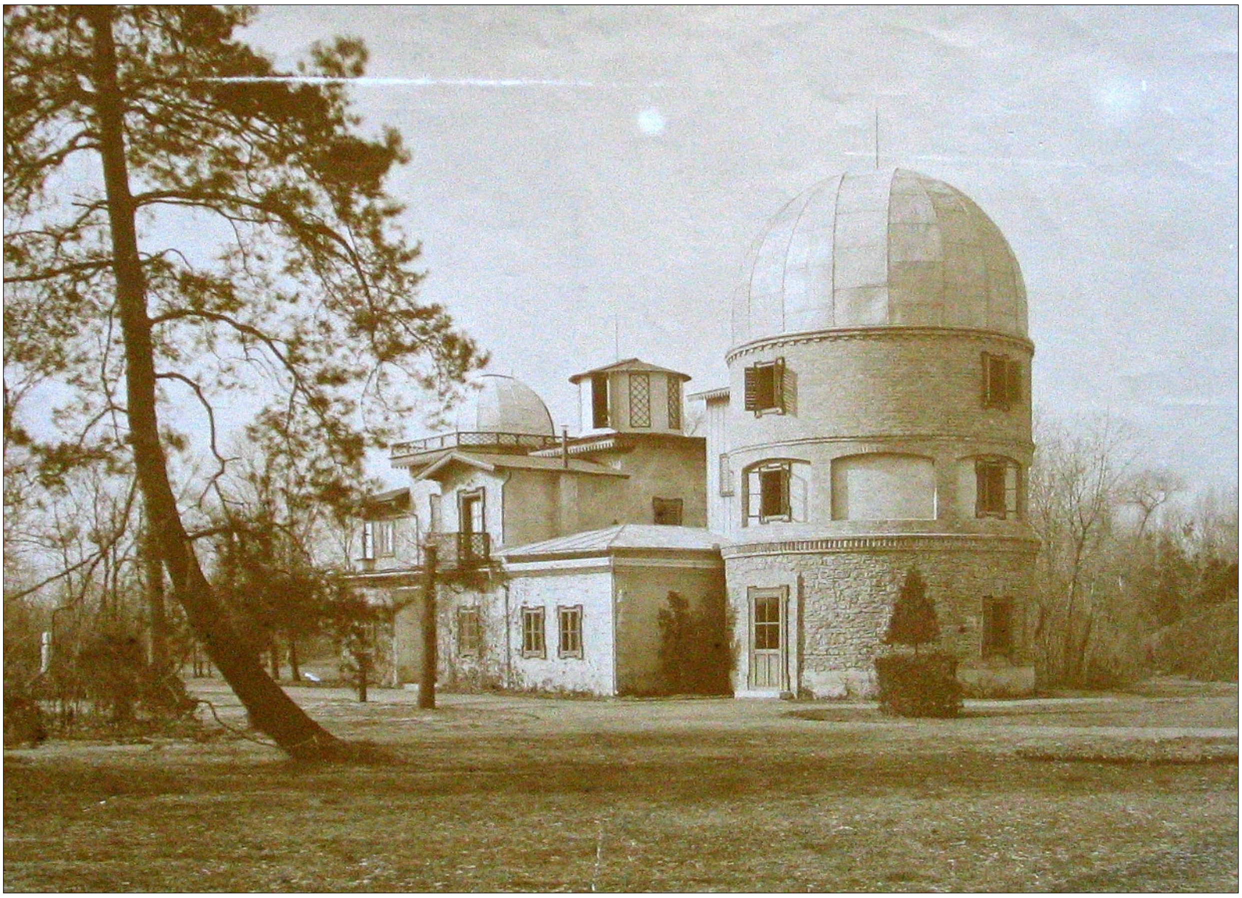

Figure 2: Konkoly-Thege's observatory at the end of the nineteenth century (courtesy: OMSZ – Hungarian Meteorological Service).

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 abovementioned 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 thermotheory just as astronomy does for mechanics. (Kövesligethy, 1891).

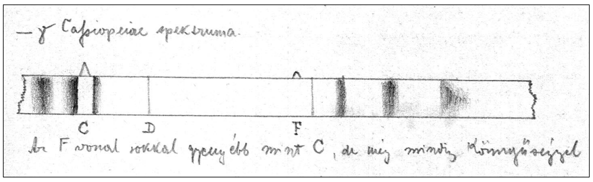

Figure 4: Kövesligethy's 1886 drawing of the spectrum of γ Cassiopeiae (Kiskartal observer's log book, Konkoly Observatory Library).

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).

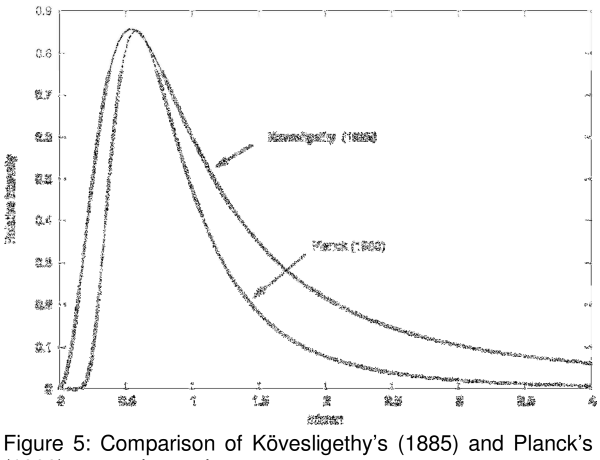

Figure 5: Comparison of Kövesligethy's (1885) and Planck's (1900) spectral equations.

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:

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

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):

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

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:

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

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).

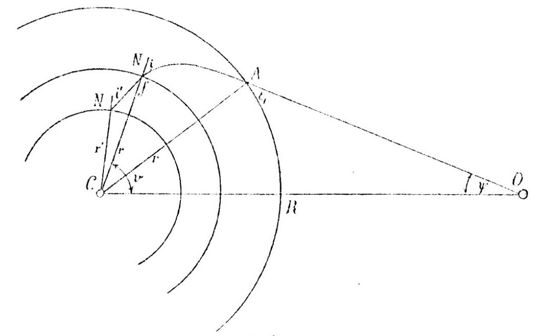

Figure 6: Path of a ray of light from the interior of a star to the observer (after Kövesligethy, 1901: 129).

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.

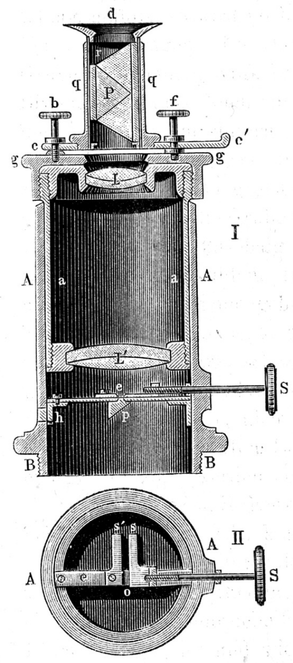

Figure 7: Ocular spectroscope used by Kövesligethy in the Ógyalla spectral program (after Konkoly, 1887b: 705).

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).

7 ACKNOWLEDGEMENTS

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