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KARL SCHWARZSCHILD

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The death of Karl Schwarzschild[1] is a loss to science, all the harder to bear because he was taken away, not "full of years," but when at the summit of productivity.

Not long before his illness Schwarzschild said to the writer: "We have reached the height of life, before long we shall go downward." He did not live to see that time. He died standing. If he had known beforehand that his life would be so short, he could not have used it to better purpose.

Karl Schwarzschild was born at Frankfort-on-the-Main, the son of a Hebrew merchant. Like so many other prominent men, he was the only member of the family who took to science. He manifested his scientific abilities as a schoolboy, at the age of sixteen, when he published two advanced papers on the determination of orbits of double stars, which were printed in 1890 in the *Astronomische Nachrichten*. The next publication, in 1892, contains observations of variable stars. This shows how the direction of Schwarzschild's activity was already fixed in his student years—theory first, practice in the second place. He found his right place at once. "From the beginning," he once said to me, "I have been interested in all branches of astronomy." We may add

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[1] Born October 9, 1873; died May 11, 1916.

now: "in all with success." In fact, the many-sidedness of Schwarzschild was astonishing. His high mathematical capacity, so uncommon in the practical astronomer, made him treat the most difficult problems of our science with startling virtuosity from a theoretical point of view. Still it was mathematical sense, not mathematical knowledge, that he most appreciated in others. He had nothing of the inapproachable authority. He was the born teacher and understood how to make the most complicated things clear—so clear that the students were even said to complain that they missed the sensation of dealing with abstruse problems. The readiness with which Schwarzschild grasped the essential point in everything was perhaps his strongest characteristic; the tedious details were left for others of less capacity.

It will be almost impossible for one man to give an adequate sketch of the whole of his scientific labor, because it covered such a wide field. I shall confine myself to some of his papers which are most nearly in the line of this *Journal*, of which he was a collaborator. I have lying before me a complete list of Schwarzschild's papers, carefully selected by Professor Ludendorff. I am sure that Schwarzschild himself would have been astonished to learn that this list contains about 120 numbers.

When we look at the more especially astrophysical work of Schwarzschild, it must be borne in mind that mathematical analysis was what chiefly interested him. An outline of his astrophysical publications alone will therefore cover only the smaller part of his work.

It is characteristic of his papers that they never contain simply bare data, but rather give observations as illustrations for some new method or other item which forms the gist of the communication. Many pearls are hidden in places where we should not naturally look for them. His original paper, of the year 1896, on the measurement of double stars with the aid of a variable objective-grating, in order to diminish the systematic errors of observation, contains also the first measure of an effective wave-length.

Schwarzschild took his degree at Munich in 1896 on a paper treating of Poincaré's theory of rotating liquid bodies. Afterward he was for three years assistant at the von Kuffner Observatory at

Ottakring, near Vienna. It is here that he created the efficient method of photographic stellar photometry with the aid of extra-focal images. In the elaborate paper written on the subject he also gave the well-known formula for a second approximation (the reciprocity law being the first) of the law of density of photographic films, viz., density$=f$ (intensity$\times$exposure-time^q), where the exponent q is a constant. This second approximation has proved to be of good service in the case of long exposure-times used in stellar photometry. Besides photographic magnitudes of a few hundred stars in the Pleiades, Praesepe, and h, χ Persei, the paper contains photographic observations of the two variable stars η Aquilae and β Lyrae. These two last objects both yield a good example of how Schwarzschild's papers never missed the point. The observations of η Aquilae led up to the discovery of the color-variation in the Cepheid variables by showing that the photographic range of variation exceeds the visual range. The photographic observations of β Lyrae, on the other hand, compared with the visual observations of others, yielded a proof of the independence of the velocity of light of the wave-length.

The next two years, from 1899 to 1901, Schwarzschild was active as a privat-docent in the University of Munich.

In the year 1901, at the age of scarcely twenty-eight, he was appointed professor of astronomy and director of the observatory in the University of Göttingen. There he felt at home, not least on account of the especially mathematical sphere of this university. Göttingen he loved above all the other places where he worked. It was also there that he found his wife.

One of the best-known astrophysical works of Schwarzschild during that directorship is the "Göttingen Actinometry," which is to be considered as a continuation of his work on photographic stellar photometry started at Vienna. For the purpose he constructed the *Schraffierkassette*. Instead of using the disk of the intra- or extra-focal star-image for measurement in the microphotometer, the new method effects the necessary broadening of the image mainly through a small and regular shaking of the plate. The main advantage of this device is the considerable increase in the useful part of the field.

The Göttingen Actinometry, completed with this instrument, contains photographic magnitudes of the 3500 stars brighter than 7.5 in the *Bonner Durchmusterung* in the zone 0° to +20° declination. It thus comprises in this region the same stars as the visual Potsdam photometry. The material therefore yields the color-index of every star. Besides this, about 165 stars of the North Polar region were included. A single plate covers 1^h in α and 20° in δ, the focal length being 46 cm. The accuracy reached is considerable, the mean error being about $0^{M}\!.03$ for the catalogue magnitude of a star between 5 and 8. It is an interesting fact in connection with the question about the general constancy of the light of the stars that, in spite of the increased accuracy of the single observation, only very few new variables were found or suspected. Among these few the most interesting is the bright variable SZ Tauri, with small range, of the type of ζ Geminorum.

The color-indices of the Göttingen Actinometry showed that the connection between color and spectrum of small dispersion was very intimate—twenty-five cases of considerable discrepancy could practically all be reduced to defective spectral classification. The statistics of color-indices brought to light among the stars between $4^{M}\!.5$ and $7^{M}\!.0$, visual Potsdam scale, a curious minimum of the number of stars of intermediate color. The fact is intimately related to the phenomenon of "giant" and "dwarf" stars. The predominance of white stars in the Milky Way is also clearly brought out.

In 1905 Schwarzschild went to Algiers to observe the total solar eclipse. Photographs of the flash spectrum were obtained with a spectrograph of "ultra-violet" glass. In the same year he investigated the distribution of ultra-violet light (λ about 320 $\mu\mu$) on the surface of the sun from photographs taken at Jena, using a layer of metallic silver as a color-filter.

Among the several popular papers by Schwarzschild we call attention to a lecture on celestial mechanics, delivered in 1903. It was printed at six different places and deserves special mention for astrophysicists, because it gives an unusually clear outline of theoretical astronomy. In that lecture a sentence occurs which throws a flashlight on his way of teaching. He says: "Poincaré's work is shrouded in an atmosphere of abstract reasoning which hides his conceptions as the veil which hid the statue at Sais. I have felt the more justified in attempting a simple presentation of Poincaré's work, as this veil has been more rarely lifted than looked upon with respectful awe."

Schwarzschild devoted considerable attention to the construction and the theory of instruments. Among his most valuable contributions on the subject belong his researches on geometrical optics, dating from 1905. He based them on the known theorem of the shortest light-path, the "Eikonal," and developed therefrom the theory of optical instruments. He showed the possibility of constructing a double mirror in the Cassegrain arrangement, which would give a field practically as perfect as that of a photographic refractor of the *carte du ciel* type, in spite of a ratio of aperture to focal length of 1 to 3.5.

Another instrumental invention dating from the time of his residence at Göttingen is the hanging zenith-camera for the determination of the latitude. The instrument yielded as a by-product the declination of 375 stars near the zenith. Furthermore, he constructed a special compass for the navigation of airships.

In 1909 Schwarzschild was appointed director of the Astrophysical Observatory at Potsdam. It was with a heavy heart that he left Göttingen. The new position as the head of an extensive institute claimed much time for non-scientific matter, and it is an evidence of Schwarzschild's indefatigable application that his productivity did not seem to suffer. Not only that; he took the keenest interest in the special work of every member of the staff. His invaluable help was never appealed to in vain; the readiness with which it was given was, for the writer, even a real danger to discretion.

During Schwarzschild's short directorship at Potsdam the most notable instrumental improvement was the regrinding of the two objectives of the great refractor. For the rest, his theoretical and practical work is so many-sided that it is difficult to give a coherent description of it all.

No wonder that the problems of stellar statistics, so accessible to mathematical treatment, especially appealed to his mind. His best-known achievement in this field is the ellipsoidal hypothesis of stellar movements. As the distribution of stellar velocities showed marked deviations from the Maxwellian law, Kapteyn advanced his hypothesis of two star-streams. But Schwarzschild showed that the unitary consideration would fit the observations nearly as well, if the Maxwellian velocity was only taken different in different directions. In other papers Schwarzschild gave a general solution of the integral equations of stellar statistics. In the continuation of these investigations he obtained among other things the interesting result that the stellar velocity, relative to the sun and projected on the sphere, cannot increase more than to double its amount, for 8 magnitudes decrease in absolute brightness.

In quite another field lie Schwarzschild's investigations relating to the theory of the tails of comets. From the year 1901 dates his well-known theoretical investigation on the pressure of light on small spherical particles. Under the action of the sun such a particle will be attracted proportionally to its volume and repelled by the pressure of light proportionally to its surface. Consequently there will be a determined size of the particle at which these two forces counterbalance each other. On still smaller particles the pressure of light will predominate, and they will hence be repelled from the sun. All this, however, is true only down to a size comparable to the wave-lengths of light, where diffraction begins to play a prominent part and the effect of repulsion is stopped. The maximum ratio between repulsion and attraction is of the order of 20 to 1.

When Halley's comet reappeared in 1910, photographs suitable for photometric use were obtained by the expedition to Teneriffe, equipped by the Potsdam Observatory. This material was discussed by Schwarzschild and showed the important result that the decrease in intensity of the comet's tail with the distance from the head is in the main explained by the corresponding decrease in density. In other words, the luminosity of the repelled particles is retained during their path along the tail, just as would be the case if it were due to resonance of the light of the sun.

At Potsdam, Schwarzschild developed an elaborate theory for the determination of radial velocities with the objective-prism, proposed by E. C. Pickering, and he tried the method practically on the group of the Hyades. In the course of similar work he discovered the strong bright K line in the second-type spectrum of the short-period spectroscopic binary σ Geminorum. The fact may prove to be of special interest in connection with the question about the constitution of the absolutely bright yellow stars.

To the theory of equilibrium of stellar atmospheres, more particularly that of the sun, Schwarzschild has made most valuable contributions. It is natural that this complicated question could be considered only in its main aspects, and his treatment of the subject is a testimony to his intuitive power of recognizing the essential points. In the comparison between the spectrum of the sun—especially the region of the calcium lines H and K—in the center and near the border of the disk he came to the conclusion that the diffusion of light in the sun's atmosphere probably substantially accounts for the observed facts.

Schwarzschild's last paper, written during his illness, bears on the application of the quantum-theory to spectral series. The ardent wish for scientific occupation did not leave him until the last. It seemed incredible to the visitor at his sickbed that he was a man so near death. At such an occasion one feels the mastery of a strong spirit over earthly misery.

Looking backward on his life, we can only preserve in our mind the rich memories he has left behind and try to understand what made him such an unusual man. If I were to name the most characteristic of Schwarzschild's qualities, I would not hesitate to say "elasticity." His mind was always susceptible to new impressions. He had a happy ability for forgetting all petty things—he never brooded over them. It was perhaps the secret of his freshness that he never loaded his mind with immaterial subjects. He was always on the lookout for new ideas. He was in every respect at full development, as if there were nothing more latent in him. Owing to this, he may perhaps not have had much appreciation of dormant capabilities in others—he wanted to see everything in action as it was in himself. He considered the theoretical mastery over the subject as the highest step on the ladder of the human mind; compared with this, the practical realization was an inferior matter. His judgment about persons and things was quick and sharp and nearly always to the point. At the same time he liked to be contradicted. It was no empty phrase he once used: "I cannot get on with a man who is respectful to me." He wanted "pure" science. A particularly fascinating charm surrounded Schwarzschild. At his loss we feel poorer.

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1917