THE PHOTOGRAPHY OF NEBULÆ.

SINCE the year 1880, when Henry Draper, of New York, achieved the first success in photographing nebulæ, namely, the great nebula in the constellation of Orion, the progress made in this branch of astronomy has been both rapid and secure. In this country Common and Isaac Roberts, in France Janssen and the brothers Henry, in Germany Max Wolf, and in the United States W. H. Pickering, Barnard, and Keeler, all have helped to obtain the high standard of excellence which prevails to-day.

Both refracting and reflecting telescopes have been rivalling each other to obtain the mastery in this particular branch, and I think that it is generally conceded to-day that the latter have won the day. The great success achieved is no doubt partly due to the important progress made in the preparation of the photographic dry plate, but a closer scrutiny of the whole situation brings into the light the peculiar skill of the man at the telescope. Isaac Roberts, for instance, had not a very large reflector to work with, one of only 20 inches aperture, yet his skill in tuning up his instrument and his very careful "following" were rewarded by the magnificent set of wonderful photographs which he was able to secure.

Again, Keeler, with the Crossley three-foot reflector, an instrument made in 1879 by Dr. Common, which only reached the United States in 1895, achieved his success only by making a very careful study of and alterations in the telescope and its accessories. While the changes he made were small, they had, as he said, "greatly increased the practical efficiency of the instrument, and therefore, small as they are, they are important." Unfortunately, Keeler died soon after he had commenced his photographic study of the nebulæ, but the handsome volume published as a tribute to his memory ("Publications of the Lick Observatory, vol. iii., 1908"), and containing splendid reproductions from his negatives, will give the reader some impression of the fineness of his work.

Beautiful as the photographs which up to the present time have been secured are, there was inherent in them some defects which it might have seemed impossible to eliminate. There is little doubt but that all these photographs must now be consigned to the second position, to be replaced by those that are the work of Prof. G. W. Ritchey, of the Mount Wilson Observatory.

Prof. Ritchey is one of the band of valuable men which Prof. George E. Hale was fortunate enough to surround himself with in the establishment of the Mount Wilson Solar Observatory. Prof. Ritchey was previously one of the staff of the Yerkes Observatory, and was in charge of the instrument shop at that observatory, and this shop was regarded of very great importance, since it alone rendered possible the construction and frequent improvement of instruments of new type or special design; provision was also made for optical work on a large scale. At the Mount Wilson Observatory the instrument shop was naturally of fundamental importance, and it was not long before the figuring and mounting of a 5-foot reflector was undertaken. This instrument was first tested visually in December of the year 1908, and the first celestial photograph was secured in the same month of that year. The instrument, mounting, dome, building, and accessories were all carried out from the plans of Prof. Ritchey, and it is with this powerful instrument of research and close attention to refinements that he has been able to make this progress in the photography of nebulæ.

In the efficient working of a reflecting telescope it is of great importance to secure as far as possible equal temperature conditions for the telescope, dome, and inside and outside air. Thus the telescope and mirror must not be allowed to be heated up during the daytime because change of temperature causes a deformation of the reflecting surface of the mirror and an alteration in the length of the telescope itself. Again, bright sunshine on the dome causes the building to become heated, and this in turn affects the telescope and mirror and produces temperature errors.

It is chiefly the elimination or practically the almost complete elimination of such temperature changes that has allowed Prof. Ritchey to secure his admirable photographs, and a brief account of the way he has achieved success will be of interest. In the first place, tests were carried on in the optical shop to determine how large a *daily* variation of temperature was permissible without seriously affecting the figure of so large and thick (19·4 cm. at edge, 17·5 cm. at centre a mirror. By allowing the air temperature about the mirror to rise and fall uniformly for twelve hours

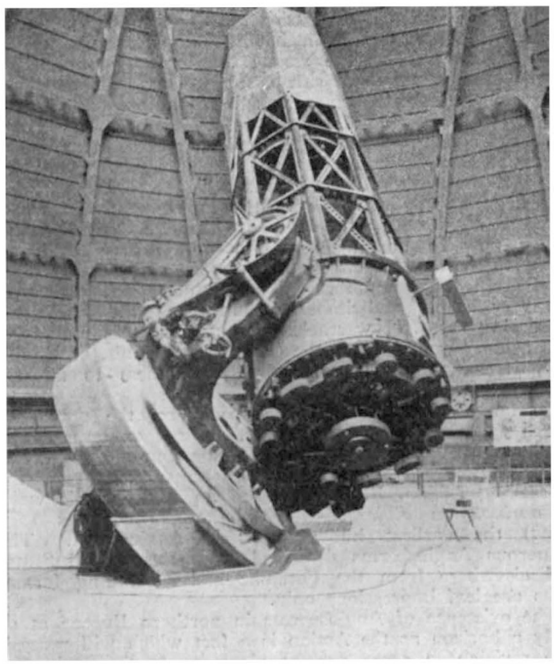

FIG. 1.—The 60-inch reflector mounting in dome.

respectively through 0° F. to 10° F., the most marked effect on the mirror was a decided disturbance of the figure on the outer zones of the surface for a distance of 3·5 or 4 inches in from the edge, these zones becoming too high as the temperature rose, and receding and even becoming too low when the temperature fell. The remaining zones were only slightly affected and the change of focal length of the mirror was small. It was finally decided that a daily variation of the large mirror of 2° F. was the maximum variation that could be permitted without perceptible injury to the sharpness of photographic star-images. When it is mentioned that the daily variation of the temperature in the unprotected dome in clear weather in the latter half of June, 1909, at Mount Wilson averaged 20° F., it will be gathered that the mirror must have altered its figure very considerably. The contraction of the steel skeleton tube was also very noticeable, for the apparent change of focal length found during the night frequently amounted to 0·04 inch.

To maintain a nearly constant temperature, Prof. Ritchey now encloses the greater part of the telescope during the daytime in a light, removable room or chamber, with insulating walls, which he calls the "canopy." The walls of this consist of four thicknesses of fine woollen blankets quilted between covers of white canvas, while the floor is of mats two inches thick, made of cheap woven hair, sewed between covers of heavy canvas. At the upper south portion of the canopy the head end of the skeleton tube projects, and this opening is closed airtight by a folding wooden cover lined with wool felt. In addition to these precautions the large mirror is protected by a short cast-iron tube, and by the airtight covers which protect its surface. Arrangements are made for moving the canopy easily and entirely out of the way of the telescope when in use, and replacing it when observing is completed. While the telescope was protected in the above manner, a sun shield was used to reduce the daily variation of the dome. This consists of gores of heavy white canvas laced to a

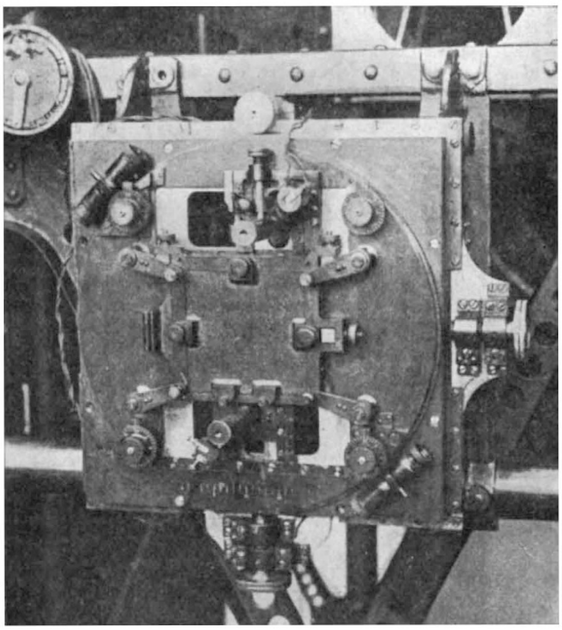

FIG. 2.—The new photographic plate carrier on the 60-inch reflector.

strong framework of steel pipe. The canvas was thus retained two feet from the steel covering of the dome, due provision being made for the free circulation of the air beneath the canvas. In this way the daily variation in the dome was decreased to 10° F. in July, while the change in focus of the mirror was reduced to 0·02 inch.

By the combination of shield and canopy, the inside daily variation of temperature in the latter was only 3·8° F. in August and September, and the apparent alteration of focus reduced to 0·005 inch. Prof. Ritchey proposes, in future, two improvements when he still further hopes to reduce this daily amplitude of variation, first to place in the canopy a small refrigerating apparatus with a controlling thermostat, and, second, to enclose the complete telescope in the canopy.

With these refinements in controlling temperature changes, he adopts the knife-edge method of focussing the stellar images, a most important consideration in stellar or nebular photography. By this means he is able to locate the focal plane to within 0·001 inch. With the help of his new plate-carrier, the focal plane and the plane of the film of the photographic plate can with certainty be made to agree within 0·0003 inch While making an exposure he has occasionally to remove the plate to check the position of the focal plane of the mirror. Since the adoption of the canopy and shield he has found that re-focussing about every half-hour in the early part of the night, and about every three-quarters of an hour after 11 p.m., is sufficient for accurate working.

The efficiency of the whole instrument is such that Prof. Ritchey states:—

"All of the uncertainties which usually occur in making long exposures with very large instruments are eliminated. A plate can be exposed night after night, if desired, with the assurance that no error in focus greater than one or two-thousandths of an inch can occur, and that no rotation of field can take place without immediately being detected and corrected. Both of these conditions are absolutely necessary for the finest results with an instrument so powerful and sensitive as the 60-inch. . . . On the best of these negatives, with exposures of eleven hours, the smallest star-images are 1·03 seconds in diameter."

To ensure the finest of final products, Prof. Ritchey lastly abandons the use of rapid plates, which, as is well known, are always associated with coarseness of grain, and employs Seed "23" plates almost exclusively.

A close examination of the reproductions of some of the nebulæ which he publishes with his latest communication indicates in a striking manner the wonderful sharpness and richness in detail of his photographs. It is interesting in this respect to compare Ritchey's photograph of the spiral nebula Messier 51 Canum Venaticorum, with that of Keeler, reproduced in vol. viii. of the "Publications of the Lick Observatory" (plate 47), those of Isaac Roberts in vols. i. and ii. of his "Photographs of Stars, Star Clusters, and Nebulæ" (plates 30 and 15 respectively), and, lastly, that by Ritchey himself, taken with the 2-foot reflector of the Yerkes Observatory, and published in vol. ii. of the "Publication of the Yerkes Observatory" (plate 29).

Bearing in mind the differences in quality of the reproductions to which references above are given, the superiority of Ritchey's latest achievement is well marked.

In a more recent announcement (*Monthly Notices*, R.A.S., vol. lxx., Supplementary Number, No. 9), and dated September 17, Prof. Ritchey directs attention to very important conclusions which he is able to arrive at from his recent photographs. These are that the spiral nebulæ are not only distinguished by many sharply-marked characteristics from all other classes of nebulæ, but that the spirals themselves exhibit marked differences from each other in regard to the distribution of the nebulous stars, differences which, as he states, possibly correspond to successive stages of development.

It is in the presence of such photographs as these, and more especially those where the nebulæ are of a spiral nature, that one's attention is directed to the question of the origin of stars themselves.

"All self-luminous bodies," as Sir Norman Lockyer states in the first of his General Conclusions at the end of his work 'The Meteoritic Hypothesis,' "in the celestial spaces are composed either of swarms of meteorites or of masses of meteoritic vapour produced by heat. The heat is brought about by the condensation of meteor swarms due to gravity, the vapour being finally condensed into a solid globe."

Such a photograph as that of Messier 51 seems to represent the above words in picture form. Prof Ritchey, in commenting on these spirals, which he has most recently photographed, says, that they all "contain great numbers of soft star-like condensations which I shall call *nebulous stars*. They are possibly stars in process of formation. In general they lie in streams which follow the curvature of the convolutions. Together with the smooth nebulous material in which they are apparently floating, and out of which they are apparently forming, they constitute the convolutions."

While a detailed study of individual nebulæ endorses the meteoritic hypothesis regarding the formation of stars, the hypothesis itself requires the presence of a considerable quantity of self-luminous or non-luminous matter scattered throughout space. The recent advances in the photography of nebulæ have, however, very considerably altered the generally conceived notions regarding the amount of nebulous matter distributed in the heavens. After Keeler turned his attention towards photographing nebulæ, he soon found that he was able considerably to increase the number of known nebulæ with the aid of the Crossley reflector. In this research he reached two important conclusions:—

(1) "Many thousands of unrecorded nebulæ exist in the sky. A conservative estimate places the number within reach of the Crossley reflector at about 120,000. The number of nebulæ in our catalogues is but a small fraction of this." (2) "Most of these nebulæ have a spiral structure."

In the preface to the volume containing Keeler's photographs it is stated:—

"The number already discovered and catalogued did not exceed 13,000. Later observations with the Crossley reflector, with longer exposure-times and more sensitive plates, render it probable that the number of nebulæ discoverable with this powerful instrument is of the order of half a million."

While the above estimate relates to the capacity of the Crossley reflector, what number of additional nebulæ should be added when the very much greater efficiency and aperture of the Mount Wilson Observatory's reflector is taken into account? Prof. Ritchey, as has been shown above, has demonstrated the far-reaching capacity of this instrument and its enormously improved efficiency for nebular photography. Further, when the 100-inch reflector of the same observatory is brought into use, what will then be the approximate number of known nebulæ?

Again, while all these instruments can only record the existence of self-luminous matter in space, what estimate should be made for the number of regions in the sky in which matter which is not luminous is present? The only conclusion that can at present be drawn is that amount of matter distributed in space is really enormous compared to that which is generally conceded to be the case. If, as very probably is the case, this non-luminous matter is as frequently distributed as that which is luminous, then any hypothesis to explain inorganic evolution must be founded on a meteoritic basis.

The work of modern large reflecting telescopes in adding to our knowledge of the probable amount of nebulous matter in space is of very great importance, and the magnificent success of Prof. Ritchey in his latest achievement forms another opportunity for the hearty congratulations of all astronomers to be extended to him. Prof. Ritchey is to be envied, not only for working in a country where astronomy in all its branches is so well fostered, but for being one of the members of the staff of the Solar Observatory on Mount Wilson, an observatory which is so magnificently endowed. On that mountain, when it is decided that a spectroheliograph, which we in this country would consider of very large dimensions, would be capable of accomplishing better research if another of double its size were instituted, then promptly the necessary funds are forthcoming, and the instrument is taken in hand, built, and brought into use. Again, no sooner is a 60-inch mirror found to be a very great advance in celestial photography than one of 100 inches in diameter is immediately projected, and all necessary arrangements for its completion and erection are made. With such facilities for research, so incentive to those who are employed in the investigations, no wonder that work of the highest quality and importance can be turned out; for this reason this country, like many others, is being left far behind.

WILLIAM J. S. LOCKYER.

FIG. 3.—Spiral Nebula Messier 51 Canum Venaticorum. Photographed with the 60-inch reflector and the new plate carrier. Exposure 3h. 55m., February 7 and 8, 1910. Notice the roundness of the star images.