INTRODUCTION

BOOK I

MY PRINCIPAL aim in presenting these photographs has been to give pictures of some of the most interesting portions of the Milky Way in such form that they may be studied for a better understanding of its general structure. They are not intended as star charts. Such photographic charts have already been made by Wolf and Palisa and by Franklin-Adams. They are probably more useful for the identification of individual stars. But these do not give us a true picture of the parts of the sky shown, for there are structures and forms that cannot well be depicted in ordinary charts, and it has seemed to me that some of these are of the utmost importance in the study of the universe at large. These photographs may, therefore, be considered as supplementary to the regular charts in that they show the details of the clouds, nebulosities, etc. In this form, however, it is always difficult to identify the individual small stars. To overcome this difficulty charts have been prepared corresponding to each photograph and giving on the same scale a set of co-ordinates, and all the principal stars and objects of especial interest. The most useful reference stars are numbered, as are the dark objects. These charts and the tables, which give fuller data about the reference stars, will be found in Part II. It is recommended that in studying any photograph the reader should open Part II to the corresponding chart, and then he will have before him the photograph or plate, the author's text descriptive of it, the chart, with its co-ordinates, including most of the stars of the *Bonner Durchmusterung*, and the table supplementary to the chart.

The Milky Way has always been of the deepest interest to me. My attention was first especially attracted to its peculiar features during the period of my early comet-seeking. Indeed, there is no work in observational astronomy that gives one so great an insight into the actual heavens as that of comet-seeking. The searcher after comets sees more of the beauties of the heavens than any other observer. His telescope, though small, usually has a comparatively wide field of view, and is amply powerful to show him most of the interesting parts of the sky. To him the Milky Way reveals all its wonderful structure, which is so magnificent in photographs made with the portrait lens. The observer with the more powerful telescopes, and necessarily more restricted field of view, has many things to compensate him for his small field, but he loses essentially all the wonders of the Milky Way. To me the views of the galaxy were the most fascinating part of comet-seeking, and more than paid me for the many nights of unsuccessful work. It was these views of the great structures in the Sagittarius region of the Milky Way that inspired me with the desire to photograph these extraordinary features, and one of the greatest pleasures of my life was when this was successfully done at the Lick Observatory in the summer of 1889.

DESCRIPTION OF THE BRUCE PHOTOGRAPHIC TELESCOPE[1]

My experience at the Lick Observatory with the Willard portrait lens impressed me with the importance of that form of instrument for the picturing of large regions of the heavens.

[1] Extracted from Professor Barnard's article in the *Astrophysical Journal*, **21**, 35–48, 1905.

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That lens, which was purchased at second hand from a photographer in San Francisco, was made for, and originally used in, taking portraits—from which fact its name has come. These large short-focus lenses were necessary in the days of wet-plate photography to gather a great quantity of light and to give a brilliant image to lessen as much as possible the time of sitting. But when the rapid dry plates came into use these lenses were no longer needed, and much smaller, more convenient, and less expensive lenses took their place. The great light-gathering power for which they were so valuable in the wet-plate days makes then specially suitable for the photography of the fainter celestial bodies. They were made on the Petzval system and consisted of two sets of lenses, from which fact they are also called "doublets." In this paper I shall refer to them mainly as "portrait lenses," as that name appeals more directly to me.

The main advantage of the portrait lens lies in its grasp of wide areas of the sky and its rapidity of action—this last result being due to its relatively short focus. The wide field makes it especially suitable for the delineation of the large structural details of the Milky Way; for the discovery of the great nebulous regions of the sky; for the investigation of meteors and the determination of their distances; and especially for the faithful portrayal of the rapid changes that take place in the forms and structures of comets' tails.

The portrait combination is not intended in any way to compete with the astrographic telescopes, or with any of the larger photographic refractors or reflectors. It must be considered as supplemental to these, because their limited field confines them to small areas of the sky. There is a great and valuable work for these larger telescopes, however, in the accurate registration of the places of the stars, for parallax, and, in the reflector, for depicting the features of the well-known nebulae, etc.

There is, I think, however, a question as to the most advantageous size for a portrait lens, and I have believed that the best results can be obtained with an instrument of moderate size; or, in other words, I believe that a portrait lens can be made too large to give the very best results, just as it can be too small. It is also true that both large and small portrait lenses are individually valuable. There is a kind of supplementary relationship between them. The small one will do work that the large one cannot do; and the reverse of this is equally true; for though the small one is quicker for a surface—such, for instance, as the cloud forms of the Milky Way present to it—the larger one, mainly on account of its greater scale, will show details that are beyond the reach of the smaller one. Another important fact is that as the size of the lens increases, the width of the field rapidly diminishes, and width of field is one of the essential features of the value of the portrait lens.

There would, therefore, seem to be a happy mean, when the available funds limit the observer to one lens only.

As a matter of experience, it has seemed to me that a lens of the portrait combination about 10 inches in diameter would best serve the purpose of the investigations that have just been outlined.

For several years I had tried to interest someone in the purchase of such a lens, but without success. Finally, I brought the matter before Miss Catherine

W. Bruce, who had done so much already for the advancement of astronomy. In the summer of 1897 Miss Bruce placed in my hands, as a gift to the University of Chicago, the sum of $7,000 for the purchase of such an instrument and for the erection of a small observatory to contain it.

The instrument consists of a 5-inch guiding telescope and two photographic doublets of 10 and $6\frac{1}{4}$ inches aperture, rigidly bound together on the same mounting. An unusual delay was produced by my anxiety to get the best possible lens for the purpose.

The long exposures demanded in the work of an instrument of this kind require an unusual form of mounting to give an uninterrupted exposure. The mounting of the Willard lens was an ordinary equatorial and was not made specially for it. It did not permit an exposure to be carried through the meridian, except in southern declinations. This was a great drawback since in a long exposure it was necessary to give all the time on one side instead of dividing it up to the best advantage on each side of the meridian.

There were two forms of mounting in use that would permit a continuous exposure. These were (1) the English form of equatorial mounting, which is a long polar axis, supported at each end with the tube swung near the middle; (2) the Potsdam astrographic equatorial, in which the polar axis projects far enough to allow the telescope to swing freely under the pier. Neither of these mountings has appeared to me to be entirely the best form for the purpose.

With the short length of this instrument it seemed that if the pier itself were bent to form the polar axis, the telescope could be made to swing freely under the pier in all positions of the instrument. With this idea in view, I went to Cleveland to confer with Messrs. Warner and Swasey on the matter. Mr. Swasey at once took the deepest interest in the proposed telescope, and eventually evolved the scheme that was ultimately adopted in the mounting. The result was entirely satisfactory, and the mounting is, I believe, the best for the purpose that has yet been made.

The next question was the lens, and here is where the delay occurred. It was my wish to get the widest field possible and the shortest relative focus consistent with such a field. This proved to be a problem of the most extreme difficulty. Dr. Brashear, who was appealed to for the optical part, entered heartily into the subject. So earnest was he in his endeavors to fulfil the required conditions that he made at least four trial lenses of 4 inches diameter and upward. But my ideal was evidently too high and one not attainable with optical skill.

In the interests of the matter I made a visit to Europe to see if better results could be had there, but, in the end, it proved that Brashear's lenses more nearly fulfilled the requirements than any that I saw elsewhere.

In the meantime, Mr. Brashear, with characteristic faith in his skill, ordered the glass and made a 10-inch doublet on his own responsibility. This lens gave exquisite definition over a field some 7° in width and could by averaging be made to cover at least 9° of fairly good definition. Though this did not come up to the width of field originally proposed, it was finally accepted, as it seemed the best that could be obtained.

The glass disks were made by Mantois, of Paris,

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and delivered to Brashear in May of 1899, and the lenses were completed in September, 1900.

The following information about the 10-inch lens was supplied me by Dr. Brashear:

> The general construction is that which was first found by Petzval years ago, and has proven itself quite the best where great angular aperture with sharp definition is imperative. The curves have been somewhat modified from our experience in the construction of other lenses—particularly of those made for Dr. Max Wolf, of Heidelberg, Germany. It departs, however, from the ordinary practice of opticians in being corrected for short wave-lengths of light. This would be quite objectless in a camera which is to be used for portraits, but is not without moment in astronomical photography.
>
> The materials employed were specially chosen for their transparency—the flint being very light and the crown very white. The focal lengths of the front and rear combinations are in a ratio of about 7 to 12, while the focal length of the system is very nearly five times the aperture. The focal length you may find very slightly modified; indeed, it is our custom to balance the inevitable zonal differences of magnification, which difficulty is found the most formidable to all constructors of astronomical photographic objectives.

The focus of the 10-inch, determined from the photographs, is 50.3 inches (127.8 cm), and the scale is therefore 1 inch = $1^\circ\!.14$ or $1^\circ = 0.88$ inch. The ratio, $a/f = 1/5.03$, I believe to be the best for the purpose.

The accumulation of interest had by this time permitted the purchase of a $6\frac{1}{4}$-inch Voigtländer lens of 30.9 inches (78.5 cm) focus, which had been in commercial use.

As indicated, the telescope is really triple in character, there being three tubes bound rigidly together on the same mounting—the 5-inch visual telescope for guiding, and the 10-inch and $6\frac{1}{4}$-inch photographic doublets. For each of the photographic lenses there is an inner tube, with focusing scale, which can be racked back and forth for the adjustment of focus. There is considerable change of focus in the 10-inch lens between winter and summer. The change in the focus of the 6-inch is small, however, and requires very little correction.

The plate-holder for the 10-inch carries a plate 12 inches square, while the one for the $6\frac{1}{4}$-inch carries a plate 8×10 inches.

In the matter of a guiding telescope the limited means would not permit of anything larger than 5 inches, which is sufficiently powerful for ordinary purposes, though for the photography of comets a large one would have been desirable. The guiding telescope I used with the Willard lens at Mount Hamilton was only $1\frac{3}{4}$ inches in diameter. Of course, the question of a double-slide plate-holder was considered; but in a small telescope like this the tubes are so rigidly bound together that such a device is not necessary to insure faithful guiding. Furthermore, for work of this kind the double-slide plate-holder would be seriously objectionable.

A high-power eyepiece is used on the 5-inch for guiding in conjunction with a right-angled prism. This is more convenient than direct vision, especially when photographing at high altitudes. The eyepiece has an adjustable motion to the extent of 2° in any direction, thus insuring the finding of a suitable guiding star. This is also valuable in photographing a comet, as it permits the displacement of the comet's head to one side of the center of the plate, thus securing a better representation of the tail.

Two spider-line cross-wires in the eyepiece are used for guiding. They are illuminated by a small

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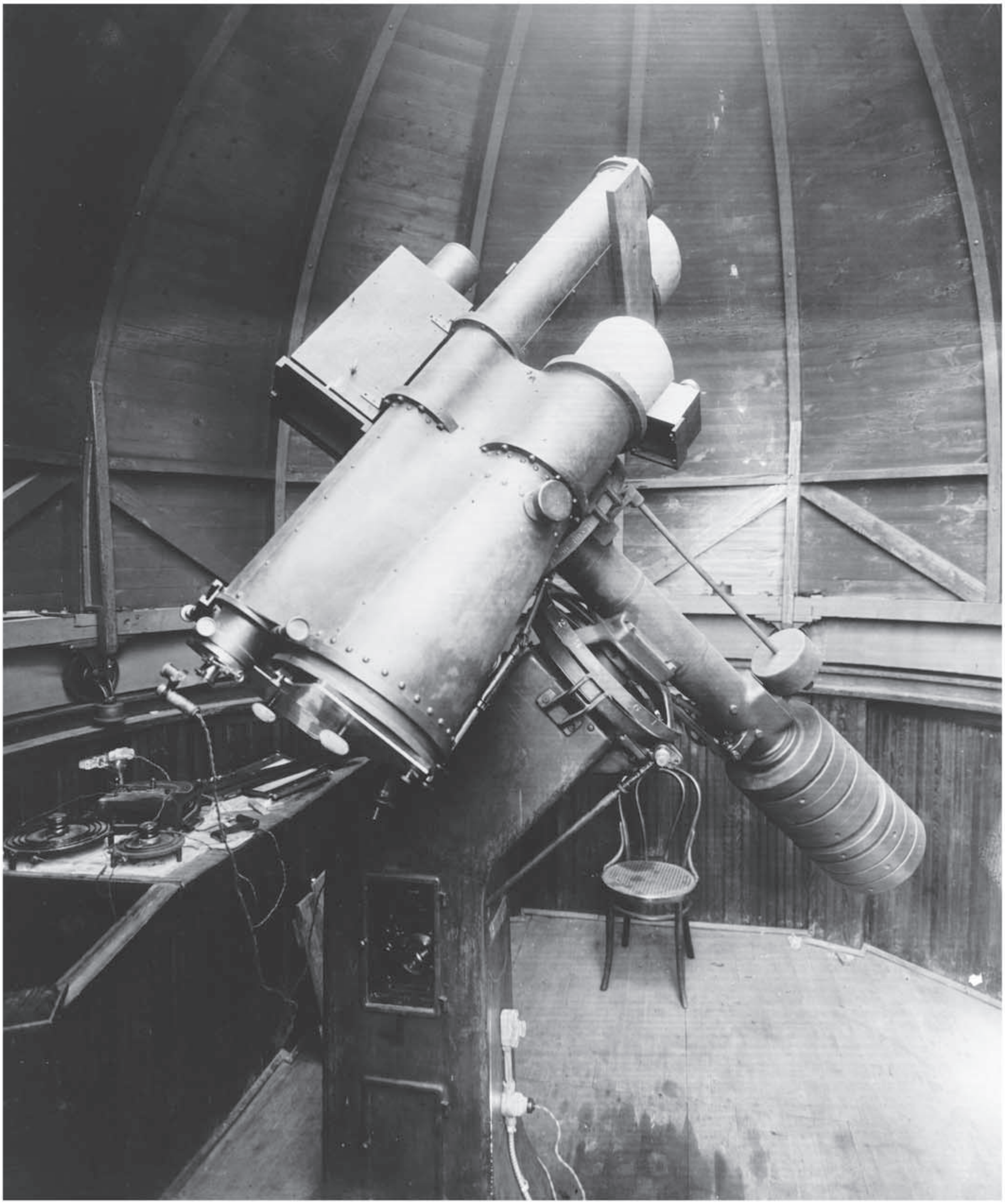

THE BRUCE PHOTOGRAPHIC TELESCOPE IN ITS DOME AT THE YERKES OBSERVATORY electric lamp by the aid of two small reflecting surfaces which throw the light perpendicularly on the wires. The intensity of the illumination is readily regulated. By this means almost the smallest star visible in the 5-inch can be used for guiding purposes.

The illustration will give a better idea of the Bruce telescope than any mere words can do. Indeed, there are very few things about it that need explanation. One feature, however, will not be clear without a description, viz., the method of adjustment for latitude in case the telescope were removed to a different latitude. It was intended that the instrument should be portable when occasion required, for the purpose of observing eclipses, etc., and for possible transportation to the southern hemisphere.

The pier really consists of two parts. Just above the clockroom it separates into two pieces which are bolted together on the inside of the pier, and hence no break appears in the continuity of the pier.

For change of latitude, it is only necessary to insert a wedge-shaped section between these two parts of such an angle that it will produce the required change of latitude. This ordinarily would necessitate only a slight change in the length of the driving-rod which is adjustable. No other means of adjustment seemed feasible.

As it was possible that the instrument might some time go to the southern hemisphere, Messrs. Warner and Swasey were asked to insert some sort of gearing that would readily permit of a reversal of the motion of the clock. The device they introduced is extremely simple and efficient. In a couple of minutes' time the motion can be changed from west to east. At the point where the driving-rod joins on to the worm-screw for driving the worm-wheel carrying the telescope, the small gear-wheel which makes the connection can be reversed and placed on the other side of the gear-wheel at the end of the driving-rod; this will reverse the direction of motion of the worm-wheel and hence of the telescope.

The telescope is supplied with fine and coarse right-ascension and declination circles; the fine circles are divided on silver and are read by verniers.

The slow motions for guiding are brought down conveniently to the plate-end of the instrument.

The pier is very heavy, weighing some 1,200 or 1,300 lb. (550-600 kilos). This great weight is necessary to support the overhanging mass of the telescopes and the top of the pier.

The driving-clock is of Warner and Swasey's regular conical pendulum pattern, which by all means seems to be the best form of driving-clock. It is a beautiful piece of mechanism and performs satisfactorily, though we intend to introduce an electric control for work with it hereafter.

The instrument was finally finished and placed in position in its observatory in April of 1904.

The photograph shows the compact and rigid form in which the tubes are mounted, and it will at once be seen how the combination can swing freely under the overhanging pier.

As will be noted, the design is a new one, and although Messrs. Warner and Swasey have made at least one mounting of this kind (for the Tokyo Observatory) before the Bruce telescope was commenced, it was made from their design for the present instrument, so that the Bruce is the original of this particular form of mounting.

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As I have said, small portrait lenses have their special advantages as well as the larger ones. Where it is possible, it is desirable that two or more lenses should be used on the same mounting, a very important point being that they mutually verify each other. Duplicate lenses would not seem to be either the most economical or the best arrangement. In that case they would serve only as a verification and could have no other value, unless indeed one of the plates should meet with an accident or be defective—circumstances that would not be of sufficiently frequent occurrence to justify the extra outlay. The best plan would seem to be to have one of the instruments decidedly different from the other so that an independent series of pictures of the same region could be secured on a very different scale. Photographs with these, at the same time that they mutually verified each other, would have other values peculiar to themselves.

The 10-inch and the $6\frac{1}{4}$-inch, therefore, mounted together, give a very desirable variety in respect to scale, at the same time that the 6-inch is sufficiently powerful to be an almost perfect verification of anything the 10-inch may show.

One minor source of trouble with both these lenses, but worse in the case of the 10-inch, is that the commercial plates that are used are never flat. In one sense this is a distinct advantage as the emulsion is placed on the concave side of the plates; this helps to flatten the field. But the curvature is not always the same, for some plates are curved more than others. This is equivalent to a frequent change of focus with the larger lens. Once in a very long while the emulsion is put on the convex side of the plate. This puts the sensitive surface too much inside the focus and the result is a spoiled picture.

The Bruce Obsevatory is a wooden building of size, 15 × 33 feet, with the greater length lying east and west. The dome, which is central, is 15 feet in diameter and revolves on 8-inch roller-bearing iron wheels.

The large field of the Bruce telescope made a wide opening in the dome a necessity. It was therefore made 4 feet wide, which seems ample for all purposes. The telescope rests on a brick pier, and the observing-room is reached by a small stairway against the inner south wall of the building.

The altitude of the telescope above sea-level is about 1,040 feet (317 meters). Its latitude is 42°34′.

THE WORK AT MOUNT WILSON

Through the interest and courtesy of Professor George E. Hale and the generosity of Mr. John D. Hooker, of Los Angeles, I spent the spring and summer of 1905 in photographic work at the Solar Observatory of the Carnegie Institution on Mount Wilson, California. Mr. Hooker's generous grant made it possible to transport the Bruce telescope to Mount Wilson, where it was installed from February until September, 1905, in a temporary wooden structure, from which the roof could be slid off, giving an unbroken view of the sky. The altitude of the station was about 5,900 feet (1,800 meters), above the sea, and its latitude 34°13′.

The main object of this expedition to Mount Wilson was to secure the best possible photographs of the Milky Way as far south as the latitude would permit.

But little time was available for independent investigations in other parts of the sky, though the conditions for such work were often superb. During this period 154 plates were obtained with the 10-inch Brashear doublet, and 151 with the $6\frac{1}{4}$-inch Voigtländer doublet, the exposures being simultaneous, almost without exception. The original negatives of 40 of the 50 photographs in this volume were made during this time at Mount Wilson.

During many of the exposures at Mount Wilson two additional cameras were used, being attached to the mounting of the instrument, as shown in the picture. These were a Clark lens of 3.4 inches aperture and 20 inches focus and a so-called "lantern" lens of aperture 1.6 inches and focal length of 6.3 inches. With the Clark lens about 110 negatives were obtained and about 90 with the stereopticon lens.

GENERAL REMARKS ON THE MILKY WAY

The development of astronomical photography, especially where portrait lenses are used, has brought to our knowledge the existence of large areas of faint diffused nebulous matter in different parts of the sky. Some of these have been shown by the spectroscope to be gaseous, while it leaves others either in doubt or distinctly not gaseous. As one is not called upon to decide as to the gaseous nature of this matter, it will be strictly correct to speak of it as "nebulosity." This term seems to have come into use or to have been adopted as more satisfactory and explanatory than the word "nebula," which is more readily applicable to the older known forms of the nebulae as seen with the visual telescope. It seems now to belong distinctly to those large, diffused areas of matter mostly shown on small-scale photographs within the last thirty years, such as those revealed in Taurus near the Pleiades and south of the Hyades and in Ophiuchus and the Scorpion, and in other parts of the sky. Though these are not strictly confined to the Milky Way they are generally found in connection with it, some of the finest being in the Milky Way itself. There seems to be some evidence of such masses being apparently connected with some of the brighter regions of the Milky Way, a large bed of it being found in $\alpha = 18^h 8^m$, $\delta = -21°$ near one of the smaller bright star clouds in Sagittarius and in the region of the star Gamma Cygni, where it appears in the form of nebulous tufts and masses over a large area, and in the region of the North America nebula.

While I was at Mount Wilson in 1905 I made a few exposures at various points in a search for diffused nebulosities. The extraordinary nebulosities in Scorpio and Ophiuchus which I found by photography in 1894—those of Rho Ophiuchi, Nu Scorpii, etc.—suggested the immediate region of the upper part of the Scorpion as a suitable hunting-ground. Trial plates were exposed on Rho Scorpii, Pi Scorpii, and elsewhere. The photographs of the region of Pi showed a very remarkable, large, straggling nebula extending from Pi to Delta Scorpii, with branches involving several other naked-eye stars nearby.

With the exception of the great curved nebula in Orion and some of the exterior nebulosities of the Pleiades, this nebula is quite exceptional in its extent, and in the peculiarities of its various branches. A simple description of it would be inadequate to give a fair conception of these features. It is difficult

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to reproduce properly the photograph because of the faintness of some of the extensions of the nebula. Enough can be shown, however, to give some idea of its general structure (Plate 11).

From a long familiarity with the transparency of comets, we perhaps came too soon to the conclusion that the nebulae also are transparent. Unfortunately, it is not possible to either prove or disprove the transparency of the nebulae in the same manner as we do that of the comets, for the nebulae do not conveniently move about over the sky as the comets do. Though we cannot test this question by moving the nebula over different parts of the sky, we can as safely prove it by considerations almost as convincing. These nebulous masses often occur in regions where the sky is uniformly covered with stars, as in the case of the nebula about Nu Scorpii and the region of Rho Ophiuchi. In these cases there is a noticeable lack of stars within the confines of the nebulosity and in some cases a total disappearance of them as if their light were cut out by the intervening nebulosity. An inspection of these photographs, therefore, seems to show that the same nebula may be partly or totally transparent. Also the less luminous parts seem to be the more opaque. Frequently there is a curious apparent mixture of stars and nebulosity—a free mixture, one might say—where though seemingly mixed together there is no apparent condensation of the nebulosity about any of the stars. This apparent association without visible connection happens too frequently to be due to chance.

Some of these, such as the nebulosities exterior to the Pleiades, and elsewhere, are of such irregular brightness as to compel attention. But there are other regions in which a film of this faint nebulosity uniformly covers the sky for considerable distances. From the wide and uniform distribution of this nebulosity it is not always possible to prove its existence because it covers the entire plate uniformly and cannot be distinguished from the sky-fogging always present on long exposures. But there are certain cases where a dark body projected against it is unmistakably revealed. A very striking case of this kind occurs in Sagittarius in the region of the small, bright star cloud in $\alpha = 18^h 8^m$, $\delta = -18°$. In this star cloud (shown on Plate 31) are two black spots, the western of which is the more conspicuous and definite. I have already shown that this spot is a real dark object seen by contrast with the brighter region against which it is projected. On the original negative the eye at once picks this object out as being the darkest part of the entire plate. Such effects sometimes are produced by contrast and may not be real. I have cut holes the size of this spot in a black paper mask with other opening of the same size. With one of the openings over the spot, excluding the stellar background, it is readily seen that this spot, by comparison with other parts of the sky equally free of stars, is very much darker than any other part of the plate. Furthermore, the outline of the eastern edge of the spot is sharply defined, not against the stars but against a thin film of more luminous material. There is scarcely a star close to this outline. This thin, lighter film against which we see the spot permeates the entire star cloud and the rest of the plate. It is this nebulosity that makes the star cloud so conspicuous and not the abundance of stars.

In regard to a region of diffused nebulosity near

Omicron Persei I quote from an article of mine in the *Astrophysical Journal* (**41**, 253–258, 1915):

> Attention has been called frequently in this journal and elsewhere to regions of this kind which are of special interest—where apparently an intimate connection exists between the vacancies and the large masses of nebulosity. It has been shown in these papers that there is evidence of the existence of some kind of dark or partly luminous matter between us and the fainter stars which, by obscuring the stars, produces the apparent vacancies, and that the diffused nebulosities, referred to above, are the visible evidence of this matter. Regions of this kind were found in Scorpio, in Ophiuchus, and in Taurus. In *Publications of the Lick Observatory,* **11,** Plate 16, I called attention to a condition like this near the star Omicron Persei in the lower right corner of that photograph. Some of the nebulosity is shown faintly, and it was suggested that a long exposure at that point would perhaps show more of this matter, its presence being indicated by the otherwise unexplained absence of the small stars.
>
> On November 21, 1914, I gave an exposure of 6 hours and 41 minutes on this region with the Bruce 10-inch and 6-inch telescopes. A large, feebly luminous nebulosity with considerable detail in it is shown on these plates. The more obscure parts of this nebula are excessively faint, but the brighter details are well shown. The nebula fits into the vacancy referred to and seems (by obscuring their light) to account for the absence of the small stars. It will be noticed, as in other cases to which I have called attention, that in the brighter part of the nebula west of Omicron Persei the background of small stars is continuous. It is only where the nebulosity is very feeble that the stars seem to be more or less missing.

The photograph referred to above is reproduced as Plate 3 of this *Atlas.*

This region of Omicron Persei is intimately connected with the more remarkable one shown on Plate 5, which lies south and east of the present object. The dark lanes in this region in Taurus seem to be due mainly to an abrupt absence of stars. They are so distinct and definite that they look artificial, as if they had been made with a stencil. They occur in a luminous region against which they appear in strong contrast, though broken in parts of their length. The strange thing is that the small stars, which are so thickly strewn over the sky here, seem, with few exceptions, to have disappeared, as if the "lanes" had hidden them. Though they are free from stars they apparently are not free from the faint nebulosity.

The faintly luminous film that covers all of the southern half of the plate seems to be beyond the general stratum of stars, for all the stars appear to shine on or in it. The lanes appear to be due in part to the absence of stars. At the same time they seem also to be in the substratum of nebulosity. In places they become blacker than the background on which they appear. This is specially noticeable in the great, partly dark nebula itself, for it is very much darker than the sky against which the stars are seen. In fact, the dark lanes seem to do two things—they blot out the stars, and at certain places they blot out the feeble nebulous background on which the stars shine. Here, as in many other places, one gets the impression that the stratum of stars is not very deep or thick (see *ibid.,* **25**, 218–225, 1907).

Some of the dark markings of the catalogue, which follows, may be only vacancies among the stars, but I have tried to avoid such as much as possible. In many cases, however, there seems to be no other interpretation of the appearance than that of an obscuring body. In some cases the dark body itself can be distinctly seen on the photograph, such as Nos. **33**, 72, **133**, and others, so that there need be no hesitation in accepting the fact that such bodies exist.