INVESTIGATIONS

OF

THE HENRY DRAPER MEMORIAL.

CHAPTER X.

PROGRESS DURING THE YEARS 1891 TO 1894.

As stated in the Preface to this Volume, it was originally intended to publish in Part II. a discussion of the photographs taken with the 8-inch Draper telescope in the form in which the early photographs taken with the Bache telescope were discussed in Part I. The number of photographs taken with each telescope is, however, so large, — nearly two thousand a year, — that such a discussion would occupy too much space, and that already published sufficiently illustrates the character of the work. The catalogue alone of the plates so far taken with the two instruments would fill an entire volume. Part II. of this Volume will, therefore, be devoted to illustrations of portions of the recent work of the Henry Draper Memorial. The present chapter, with the plates at the end of the volume, illustrates the progress that has been made in photographing charts and spectra of the fainter stars, especially at the station in Arequipa, Peru, which is maintained by the Boyden Fund with the aid of the Henry Draper Memorial.

Photographs have been taken continuously by the Harvard College Observatory for several years with four instruments, the 8-inch Draper telescope, the 11-inch Draper telescope, the 8-inch Bache telescope, and the 13-inch Boyden telescope. The first and second of these instruments are mounted at Cambridge, the third and fourth at Arequipa, Peru. Stars which are too far south to be visible at Cambridge can be photographed at the southern station. All of the principal investigations are planned to cover the entire sky, the northern photographs being taken at Cambridge, the southern at Arequipa. The same methods and plans of work are adopted at both stations, and in general all four telescopes are kept constantly employed throughout every clear night. The two 8-inch telescopes are similar, each having for an objective a Voigtländer portrait lens whose aperture is 8 inches. The plates used measure eight by ten inches, and cover a field about 10° square. Under favorable conditions, with exposures of ten minutes, stars of the thirteenth magnitude are photographed, and with exposures of an hour those of the fifteenth magnitude are obtained. By placing prisms over the objectives, spectra of all the brighter stars are photographed. Generally, two dispersions have been used, one formed by a prism having a refracting angle of about 13°, which makes the interval between the line Hβ, wave-length 4861, and Hϵ, wave-length 3970, equal to 0.6 cm.; the other, formed by a 5° prism, makes the same interval 0.2 cm. The notation for the hydrogen lines proposed by Professor Vogel has here been adopted. With the smaller dispersion and an exposure of one hour, spectra of stars as faint as the eleventh magnitude have been obtained. Two prisms, having angles of about 7°, are now attached to the 8-inch Draper telescope so that they can each be rotated around the axis of that instrument. Any desired dispersion, not exceeding that given when their thick edges are placed in the same direction, can thus be obtained. In this case the distance from Hβ to Hϵ is 0.7 cm. When reversed, each being turned 90°, they neutralize each other and reduce the dispersion very nearly to zero. The effect of the prisms is to convert points of light into linear spectra. A suitable width is given by allowing the stars to slowly traverse the photographic plate. The telescope is moved by a clock having a Bond spring-governor which is released electrically every two seconds by a sidereal clock in an adjacent building. By varying the rate of this clock any desired width may be given to the spectra. For equatorial stars having exposures of an hour, an hourly rate of twelve seconds will give a width of one millimeter to the spectra, which is about the proper amount for the dispersion used with this instrument. If wider, the fainter stars are lost, if narrower, the characteristics of the spectra are not easily seen. The rate must be increased for polar stars, and is varied at will by placing weights upon the pendulum of the control clock. As many as four prisms having faces a foot on a side, and refracting angles of 10° to 15°, have been used simultaneously in front of the object-glass of the 11-inch Draper telescope. This dispersion can be advantageously employed with stars of the first and second magnitude. The interval between the lines Hβ and Hϵ is then about 8.0 cm. One of these prisms has now been sent to Peru, and when placed in front of the 13-inch Boyden telescope gives spectra in which the distance between the lines Hβ and Hϵ is 2.2 cm. The spectra of the southern stars of the fifth magnitude and brighter are being photographed in this way. Two prisms are ordinarily used with the 11-inch Draper telescope, making the interval from Hβ to Hϵ equal to 3.7 cm. Owing to the weight of these large prisms difficulty was at first caused whenever they were placed in front of the objective, since it was necessary to attach iron castings to the other end of the telescope, and also to the end of the declination axis, to counterpoise them. Much time was saved by substituting for the prisms cast-iron rings near the objective, whenever the prisms were removed. A still more convenient arrangement is now used. The prisms are balanced on trunnions passing through their centre of gravity. These trunnions are placed at the end of a lever which in turn is counterpoised by a weight at its further end. The prisms can thus be turned over, or moved laterally, without disturbing the balance of the telescope. The dimensions are such that the prisms may be placed over the object glass, or against the side of the tube, at will. A link-motion serves to bring them to either of these positions, where they are held firmly by pins. A few seconds only are required to place them over the objective for photographing spectra, or by the side of the tube and close against it so that they do not interfere when photographic charts are to be made.

A number is assigned to every photograph taken with each of these instruments. This number is marked upon the corner of the plate, and also upon the paper cover in which it is kept. To distinguish the different series, a letter is prefixed, the letter B being used for photographs taken with the Bache telescope, C for those taken with the 11-inch Draper telescope, I for those taken with the 8-inch Draper telescope, and X for those taken with the 13-inch Boyden telescope. The numbers of plates taken with these instruments before January 1, 1895, were 12,777, 7,397, 12,164, and 6,281 respectively.

When photographic charts are to be taken with the 8-inch telescopes it is not generally necessary to use a finder and to follow the motion of a star by means of the slow motions. The polar axis can be adjusted so as to be very nearly parallel to the axis of the earth, and the electric control regulates the motion of the telescope with an accuracy that leaves little to be desired. A great part of the exposures are limited to ten minutes, and owing to the short focal length the deviation of the images from a circular form is ordinarily insensible. With exposures of an hour it is more difficult to obtain circular images, and with runs of several hours suitable slow motions and a finder, or some similar device, become indispensable. A star called a "guiding star" is continually watched in the finder in the usual way, and the cross-wires are kept upon its image by means of the slow motions of the telescope. With the greater focal length of the 11-inch and 13-inch telescopes these difficulties are proportionately increased, and circular images can seldom be obtained with exposures of more than ten minutes without the aid of the finder.

Professor Bailey found that it was impossible to obtain perfectly circular images with the 13-inch telescope, with long exposures, however carefully a star was followed in its finder. The latter has an aperture of 8 inches and a focal length of 118 inches. The difficulty appeared to be in the unequal flexure of the tubes of the telescope and finder, and perhaps in the motion of one or both of the lenses in their cells. Both of these difficulties were avoided by following the images formed by the photographic telescope itself, instead of those of the finder. In the tail-piece of the principal telescope an eye-piece was inserted by the side of the photographic plate, and was used precisely like a finder. Although the image was corrected for the photographic and not for the visual rays, the plates described later show that excellent results may be obtained in this way. As the region from which the star to be followed could be selected was somewhat limited in area, the whole tail-piece was made to rotate around the axis of the telescope. The available area was thus greatly increased without diminishing the field of the photograph, since the latter was circular, and turning the plate did not change its position but only the orientation of the stars upon it. This plan was not only devised by Professor Bailey, but carried out by him very successfully with the aid of Peruvian mechanicians. He was equally successful in carrying out the plan given below, according to a description sent him from Cambridge. While the above method ordinarily gave circular images, it appeared that with long runs, especially on regions near the pole, the images were elongated, however carefully the guiding star was followed. More careful examination showed that in different parts of the plate this elongation increased with the distance from the guiding star, so that in photographing a cluster, for instance, the images of each star would be nearly circular if the guiding star was near, but became much elongated in the portions of the plate most distant from this star. Obviously the remedy is to rotate the plate in its own plane. The axis of rotation selected was that of the eye-piece used in following. A second eye-piece was added on the opposite side of the axis of the telescope, and its position could be varied at will with regard to the first eye-piece, so that its cross-wires could be made to coincide with a second star. The observer then followed, as before, with the first eye-piece, moving the telescope by its slow motions in right ascension and declination, but at intervals looked at the image of the star in the second eye-piece, and if it showed any sign of deviating from the cross-wires, it was made to coincide with them by rotating the plate. This of course should not disturb the position of the first eye-piece. By this means circular images could be obtained with long runs in all parts of the sky. It seems to be theoretically impossible without this, or an equivalent device, to obtain circular images when the run is long.

The causes of the elongation of the photographic images of the stars may be divided into three classes. First, those tending to change the right ascension or declination of all the stars on a plate by the same amount. For instance, deviation of the rate of the driving clock from sidereal time and flexure of the telescope provided there is no torsion. Secondly, a change in position angle of the stars such as would be caused by torsion. All instrumental errors, such as errors of altitude or azimuth of the polar axis, or motion of the lens in its cell, may be resolved into these two classes. Thirdly, a change in scale of the plate in one direction, such as that which is a part of the effect of atmospheric refraction. The first of these errors is completely remedied by the use of an eye-piece to follow a guiding star. The second may be remedied, as shown above, by the use of two eye-pieces. No practicable remedy has been found for the third source of error, which fortunately is generally insensible, as a large part of the effect of differential refraction falls into the first and second classes. If the telescope is moved by the slow motions in right ascension and declination, only such errors, as, for instance, rate of the driving clock, will be corrected. Change in refraction and flexure can evidently be only partially remedied in this way.

An important error due to the change in flexure with the hour angle, which probably occurs in all forms of mounting, belongs to the second class. In the German equatorial it is due to the connection of the telescope with the end of the declination axis, which bends unequally according as the telescope is on the meridian or distant from it. In the English and fork mountings, where the telescope is supported on both sides, the two supports act independently when the telescope is in the meridian, but when turned through six hours, so that one support is under the other, the flexure is diminished, the two supports acting like a truss.

The crown lens of the 13-inch telescope is reversible, and its two faces have different curvatures. In one position, with the two lenses in contact, the spherical and chromatic aberrations were corrected for the visual rays. Reversing the crown lens, and separating it from the flint lens, the aberrations were similarly corrected for the photographic rays. This plan was devised by the writer and Messrs. Alvan Clark & Sons, in 1887, and the 13-inch telescope was the first working instrument constructed in this way. It will be recollected that the same plan was proposed independently, and almost at the same time, by Sir George G. Stokes and Sir Howard Grubb. It was feared that by separating the lenses the field would be reduced, and that the images at a distance from the centre might be poor. An examination of the original negatives, however, shows that this apprehension is unfounded, since the images are nearly circular, even at a distance of 70′ from the centre of the plate.

In attempting to represent photographs of the stars on paper, the first question to be decided is whether they shall be shown as negatives, the lights and shades being inverted as in the original photographs, or as positives, showing the objects as they actually appear to the eye. In the case of charts, although we always see the stars as bright objects on a dark background, yet experience has shown that in the most convenient maps in use the stars are dark and the background light. This form is also, of course, much more convenient when any manuscript notes are to be added to the chart. For these reasons, the charts in the present volume have a white background, although probably equally faint stars can be represented either way. In the case of spectra, it is still more difficult to decide. As, however, the engraving is ordinarily to be compared with a photographic negative, it will probably be found more convenient if the lights and shades are inverted in both. One soon becomes accustomed to regard a line as light in the spectrum, although it is dark in the print, just as in a star map an object is regarded as brighter than another, although it is represented by a larger and darker dot. In all the plates, the northern portion of the region represented is placed at the top.

In describing the position of any point on the plates contained in this volume, it will be found convenient to give, in brackets, its abscissa and ordinate expressed in millimeters, from an origin at the left-hand lower corner of the chart.

A picture of the Arequipa station of the Harvard College Observatory, as seen from the southwest, is shown in Plate I. of this volume. The cost of establishing this station, and the greater part of the cost of maintaining it, is defrayed by the Boyden Fund of the Observatory. The station is situated about two miles north of the city of Arequipa, and is about eight thousand feet above the level of the sea. Its approximate longitude is $4^h\ 45^m\ 30^s$ west of Greenwich, and its latitude is $-16°\ 22'$. It is therefore about eighteen miles west of the Cambridge station of this Observatory. It was established, and the principal buildings erected, under the direction of Professor William H. Pickering, who had charge of this station from February, 1891, to March, 1893. Since then, Professor Solon I. Bailey has been in charge. The residence of the astronomer in charge, which faces to the south, is seen to the right of the engraving. The building to the west of it, and partially concealing its lower portion, is the laboratory which contains the rooms for experimental work and for developing the plates. Passing to the left, the next building is a shed containing a visual telescope having an aperture of five inches. The roof of this building is made in two parts, counterpoised as described in Astronomy and

Astrophysics, XII. 207. This building is partially concealed by the thermometer shelter and a telegraph pole carrying wires to the different buildings. The next building contains a reflector which is one of the two similar instruments constructed by Mr. Common for observing the second solar eclipse of 1889. Its aperture is 20 inches, and its focal length only 42 inches. Behind this building is another containing the principal clocks, and near it is a pier carrying a small transit instrument. The next building contains the Bache telescope. The roof is counterpoised like that of the building containing the 5-inch telescope. The next building contains the 13-inch Boyden telescope, and consists of a square base surmounted by a cylindrical drum covered with canvas. To the right of this building, near the ground, is seen the edge of a tank used for measuring the amount of evaporation of an exposed surface of water. To the left of this is a pier which was used as a station in a survey of the surrounding country, and in front of it is a telescope having a Voigtländer portrait lens as an objective. The aperture of this lens is 2.5 inches, and its focal length is about 9 inches. Plates are taken with this telescope with runs of four hours to photograph very faint nebulous regions like the great spiral nebula in Orion. To the left of the plate is a building containing sleeping rooms for two of the assistants. To illustrate the method described above for indicating any point on a plate by its co-ordinates, the position of the top of the pier used in the survey may be given as [57,90], which means that it is 57 millimeters from the left-hand edge of the plate, and 90 millimeters above its lower edge.

Plate II., which represents the Southern Cross, is given as an example of the charts taken with the Bache telescope. It was obtained by contact printing from Plate B 9414, which was taken on May 9, 1893, with an exposure of 127 minutes. The scale is $180'' = 0.1$ cm. The region covered extends in right ascension from about $11^h\ 40^m$ to $13^h\ 0^m$, and in declination from $-55°$ to $-65°$. The five principal stars going from north to south are γ, δ, β, ϵ, and α *Crucis*, [73,173, 116,140, 32,119, 99,107, and 86,53], their photometric magnitudes are 1.6, 3.1, 1.5, 3.5, and 1.0, and their magnitudes according to the Argentine General Catalogue, 2.0, 3.4, 1.7, 4.0, and 1.3. A moment's inspection shows that the photographic magnitudes are very different from the visual magnitudes. The stars α and β have spectra of the first type, δ of the second, γ and ϵ of the third. Stars of the third type are very red in color, and accordingly γ appears much fainter than δ; while ϵ is so faint that it would not be selected as one of the principal stars. Its position [99,107] is a little above the point midway between α and δ. Visually, it is so conspicuous that it is commonly inserted in representations of the Cross, as for instance on the postage stamps issued by the Brazilian Government. The absence of stars in the left-hand lower corner of the photograph is a striking feature. This is the "Coal-sack," of Herschel. The presence of an occasional star like [74,41] in its darkest portion, shows that it is not entirely devoid of stars. If, as has been suggested, the absence of stars is due to an absorbing medium, those seen may be this side of it. The well-defined ring having a diameter of about 0.6 cm. around each of the brighter stars is due to total reflection of the light from the back of the plate. It may be avoided, if thought necessary, by painting the back of the original photographic plate black, before it is exposed, so that the light diffused from the image on the film is absorbed instead of reflected. Several remarkable clusters are shown in the photograph. The most conspicuous is κ *Crucis*, N. G. C. 4755 [19,104]. N. G. C. 4103 [134,89] and N. G. C. 4349 [92,77] are also fine clusters. The marking at [126,191] is a defect in the original negative.

As stated on page xiv of this Volume, a circular prism 2 cm. in diameter, and having a refracting angle of 10′, has been cemented to the centre of the object-glass of the Bache telescope. This diverts about a hundredth part of the light of every bright star, and forms a second image, five magnitudes fainter than its principal image, about 5′ from it. In Plate II. all the brighter stars have such images to the right and a little above, about 1.5 millimeters distant. These secondary images will be found convenient in comparing the light of the bright and faint stars. Thus, if a star is of the fifth magnitude its companion will be of the tenth magnitude.

It is obvious from Plate II. that the scale adopted, $180'' = 0.1$ cm., is too small for star-charts, if faint stars are to be represented, especially in the vicinity of the Milky Way. It is doubtful if all the stars on Plate II. can be seen by the normal eye without a magnifying glass. In any case they are too near together to be conveniently studied. Even in the centre of the plate the images are slightly elongated, owing to failure to exactly follow their apparent motions. This elongation is not wholly objectionable, since the faint stars are thus more readily distinguished from defects. The elongation becomes marked near the corners of the plate, the light passing through the lens so obliquely that the effect is like that of a cylindrical lens. This is to be expected, since the region covered is about ten degrees square.

The region surrounding the Trifid Nebula in Sagittarius is shown in Plate III., which is a direct copy, by contact printing, of Plate B 9784, taken at Arequipa on July 12, 1893, with an exposure of 120 minutes. The scale, like that of Plate II., is $180'' = 0.1$ cm. The region covered extends approximately in right ascension from 17^h 35^m to 18^h 15^m, and in declination from —19° to —29°. The Trifid Nebula, N. G. C. 6514, is near the centre, at [88,122]. To the south, and following [81,95], is the conspicuous object, N. G. C. 6523. The structure of the adjacent portion of the Milky Way is well shown in the lower part of the plate. Among the brightest clusters which appear on this plate are N. G. C. 6603 [30,200], in the left-hand upper corner, N. G. C. 6494 [113,202], N. G. C. 6568 [40,145], and N. G. C. 6531 [80,132]. The objects [29,54] and [23,51] are due to defects in the original negative. The star DM. —21° 4864 magn. 7.8 [60,156] is one of the brightest stars whose spectrum is of the fifth type. DM. —19° 4854 magn. 9.6 [61,193] is also of this type, but is faint. It is the southern of three stars in nearly the same right ascension. The variable star X *Sagittarii* is seen at [155,24]. Besides N. G. C. 6514 and 6523, five other gaseous nebulæ 6445, 6537, 6565, 6567, and 6578 occur in this region. They form nearly one tenth of the entire number hitherto discovered in all parts of the sky, although the ratio of the areas is about as one to four hundred. The nebulæ 6537, 6565, 6567, and 6578 are very minute and can scarcely be distinguished from stars except by their spectra. They were found by the writer by sweeping with the 15-inch equatorial, placing a direct vision prism behind the eye-piece. The positions of these objects on Plate III. are most easily described by referring them to brighter stars, giving the distances in millimeters. These distances may be converted into minutes of arc, if preferred, by multiplying by three. N. G. C. 6445, which is W. Herschel II. 586, is most readily found from DM. —19° 4711 magn. 7.4 [148,181], DM. —19° 4709 magn. 9.5 is about 1.7 mm. to the right, and the nebula is about 0.2 mm. to the left and below the latter star. N. G. C. 6537 may be found from DM. —19° 4832 magn. 6.9 [73,186]. A faint star is 2.1 mm. to the right, and 1.8 mm. below, and the nebula is 0.4 mm. to the left and 0.1 mm. below this star. N. G. C. 6565 is 0.8 mm. to the left and 0.2 mm. below DM. —28° 14259 magn. 10 [48,17], which is the upper of three stars in nearly the same right ascension. The nebula has two stars near it, one 0.2 mm. above, the other 0.2 mm. below it. N. G. C. 6567 is at the intersection of two lines of stars. DM. —19° 4910 magn. 9.3 [33,198] has a faint star 0.2 mm. to the right and 0.3 mm. above it. The nebula is 0.6 mm. to the right and 0.9 mm. above DM. —19° 4910. N. G. C. 6578 is 0.2 mm. to the right and 1.9 mm. above DM. —20° 4995 magn. 6.5 [27,172]. This nebula is very faint, and must not be mistaken for a brighter object 0.2 mm. to the left and 0.6 mm. below.

The Small Magellanic Cloud or Nubecula Minor is represented in Plate IV., Figure 1. It is a contact print from Plate B 10367 taken with the Bache telescope on October 4, 1893, with an exposure of 250 minutes. The scale is 180″ = 0.1 cm., and the region covered extends in right ascension from $23^h\ 50^m$ to $1^h\ 50^m$, and in declination from —71° to —75°. The most conspicuous object is the cluster 47 *Tucanæ* N. G. C. 104 [128,45], the finest globular cluster in the sky with the exception of *ω Centauri*. Both of these clusters will be discussed more at length later, and represented on a large scale in Plates VI. and IX. Other remarkable clusters are N. G. C. 362 [67,73], N. G. C. 371 [68,48], and N. G. C. 346 [74,46].

The Large Magellanic Cloud or Nubecula Major is represented in Plate IV., Figure 2. It is a contact print from Plate B 10286 taken with the Bache telescope on September 18, 1893, with an exposure of 185 minutes. The scale is 180″ = 0.1 cm. and the region covered extends in R. A. from $4^h\ 20^m$ to $5^h\ 50^m$, and in Dec. from —65° to —72°. There are so many clusters in this region that it is difficult to enumerate them. 30 *Doradus* N. G. C. 2070 [35,53] appears to be partly stellar and partly gaseous, and is perhaps the nucleus of the whole system. It seems to be the centre of a great spiral, and to bear the same relation to the entire system that the nebula in Orion bears to the great spiral nebula, which covers a large part of that constellation. Among other conspicuous clusters are N. G. C. 1769, 1773, and 1776 at about [112,107], N. G. C. 1929, 1934, 1935, 1936, and 1937 at about [64,78], and N. G. C. 1903 and 1910 at about [71,53].

One of the most remarkable portions of the sky is that surrounding the variable star *η Carinæ*, commonly known as *η Argus*. It is represented on three different scales, in Plate V. Figure 1 is a contact print of a portion of Plate B 9420 taken on May 10, 1893, with an exposure of 78 minutes. The scale is 180″ = 0.1 cm. and the region represented extends in R. A. from $10^h\ 10^m$ to $11^h\ 20^m$, and in Dec. from —57° to —62°. Figure 2 represents the central portion of this plate enlarged three times. The position of the centre for 1900 is R. A. = $10^h\ 40^m.6$, Dec. = —59° 3′. As the scale is 60″ = 0.1 cm. the region covered is about 90′, or $11^m.7$, in right ascension and 110′ in declination. Figure 3 has the same centre and is on a scale of 10″ = 0.1 cm. It therefore extends over about 15′, or $1^m.8$, in right ascension, and 18′ in declination. The original negative, X 4692, was taken with the 13-inch Boyden telescope on May 18, 1893, with an exposure of 120^m. It has been enlarged about four and a quarter times, since its scale is 42″.4 = 0.1 cm.

The advantages of the different scales may be compared by means of Plate V. The number of stars shown in a given region does not differ greatly in the photographs taken with the two instruments. The larger angular aperture of the smaller instrument about compensates for the smaller diameter of its objective. As stated above, the scale of 180″ = 0.1 cm. is evidently too small to show faint stars conveniently in the vicinity of the Milky Way. Moreover, the images of the faint stars are so minute that they cannot be seen without a magnifying glass. A good photograph must, therefore, always be enlarged when engraved, or many of the stars will be lost. To enlarge it three times, making the scale of 60″ = 0.1 cm., is a great improvement. This is the scale of the star charts of Peters and Chacornac, and, in 1886, the writer recommended that these charts should serve as models as regards scale and size for a photographic map of the sky (Proc. Amer. Acad. XI., p. 207). The scale was afterwards adopted by the Astrophotographic Congress, and is likely to be the standard scale in the future when large portions of the sky are to be represented. This scale is still inadequate when the stars are densely distributed, and if the focal length of the telescope exceeds 344 cm., the original negative must be reduced in scale instead of enlarged. The scale of 10″ = 0.1 cm. will therefore be found convenient. It serves to show nearly all the stars that can be seen upon the original negative, without rendering the images inconveniently large. Unfortunately, it cannot be used except for small portions of the sky, since to represent the entire sky about one hundred and twenty thousand plates like those illustrating this volume would be required.

The principal clusters and nebulæ shown in Plate V., Fig. 1, are those near the centre, which are all included under the designation N. G. C. 3372 at [92,61]. The cluster at [116,89] is identical with N. G. C. 3293, whose position as given by Herschel and Dreyer precedes the true place by two minutes of time, but is stated to be only approximate. Its true position for 1900 is R. A. = 10^h $32^m.0$, Dec. = −57° 43′. This cluster, like *κ Crucis*, N. G. C. 4755, is one of the finest coarse clusters in the sky, but as in the case of the Pleiades the stars differ greatly in brightness. N. G. C. 3532 [39,78] is also one of the finest coarse clusters. The stars in this cluster are much more nearly of the same brightness than those in N. G. C. 3293 and 4755. The position of N. G. C. 3324 [112,79] is nearly that of A. G. C. 14528. The nebula a little above it at [113,81], around A. G. C. 14525, has not received a separate number in Dreyer's Catalogue. On the other hand, six numbers, N. G. C. 3576, 3579, 3581, 3582, 3584, and 3586, are given to the clusters and nebulæ near [27,28]. The cluster [139,99] around A. G. C. 14295, magn. 5.4, does not appear in Dreyer's Catalogue, but N. G. C. 3247 precedes it $1^m.7$, south 23′. Herschel, however, describes the latter object as "stars involved in evident nebula," and states that the position is very rough. N. G. C. 3199 was observed by Herschel on four nights, and is described by him as very large and bright. Its position on the photograph is [166,93], but no nebulosity is visible in this place, although there is a curved line of stars like that described by Herschel. The cluster [29,48] is

N. G. C. 3572, and [24,37] is N. G. C. 3590. The intermediate clusters are not given by Dreyer. The only other objects in this region contained in Dreyer's Catalogue are N. G. C. 3255 [137,39], N. G. C. 3496 [57,47], N. G. C. 3503 [52,57], and N. G. C. 3519 [46,27], which are visible in the photograph, but are not conspicuous objects.

Many of the discrepancies mentioned above are of course unavoidable in such a compilation as the Catalogue of Dreyer, but they show the necessity of a reobservation and classification of the clusters and nebulæ according to their relative brightness and prominence. This could probably best be done by a comparison of photographs taken under the same conditions.

The variable star η *Carinæ* appears in Figure 3 at [17,39]. The star [13,40] follows it $4^s.5$ and is 15″ north. It is No. 125 of the catalogue on page 625 of Volume XIV. of the Cordoba Observatory, where its magnitude is given as $9\frac{3}{4}$. The star [15,45] which follows $2^s.1$, north 59″ is No. 123, magnitude $8\frac{1}{2}$, in the same catalogue. The star η *Carinæ* is No. 122, magnitude $7\frac{3}{4}$.

The cluster ω *Centauri*, whose position for 1900 is R. A. $= 13^h\ 20^m.8$, Dec. $= -46°\ 57'$, is undoubtedly the finest in the sky. It is represented in Plate VI. on a scale of $10'' = 0.1$ cm. The original negative, X 4695, was taken with the 13-inch telescope on May 19, 1893, with an exposure of 120^m. A discussion of the number of stars in this cluster, and the law regulating their distribution, will be found in Chapter XI. The region covered by Plate VI. measures about 30′ by 38′. Only five catalogue stars appear upon it. They are Z. C. 13^h 1108, magn. 9, [152,102], 1164, magn. $8\frac{1}{2}$, [92,171], 1232, magn. 9, [15,148], 1235, magn. 9, [15,34], and 1240, magn. 9, [9,86]. Two variable stars have been found in this cluster. One [135,148], whose position is R. A. $= 13^h\ 20^m\ 6^s.93$, Dec. $= -46°\ 52'\ 24''.6$ (1900), was found by Mrs. Fleming on August 3, 1893. It has a faint companion about 10″ north, preceding. It is sometimes brighter than the star [135,129] and sometimes fainter than it. The other variable, R. A. $= 13^h\ 20^m\ 14^s.52$, Dec. $= -46°\ 53'\ 21''.4$, (1900), [127,142], was found by the writer on August 12, 1893. It is the southern of four stars nearly in line. The next to it is about 7″ distant, nearly north and a little following. This variable is sometimes brighter than the star at [136,153].

Plate VII. serves to illustrate the spectra obtained by placing a prism in front of the object-glass. This plate was made by contact printing from the original negative B 9431, taken with the Bache telescope on May 13, 1893, with an exposure of 140 minutes. The scale is $180'' = 0.1$ cm., and the region covered extends in right ascension from $10^h\ 00^m$ to $11^h\ 20^m$, and in declination from $-55°$ to $-65°$. The region represented in Figure 1 of Plate V. is, therefore, included in

Plate VII., and both are upon the same scale. More than a thousand spectra are visible on B 9431, with sufficient distinctness to be conveniently classified.

In the portion of the plate near the centre, which contains the variable star η *Carinæ* [81,120], the spectra are so near together and so dense that the individual stars cannot be recognized. They are readily distinguished in the original negative, since many more grades of intensity can be recognized on a glass plate than on a paper print. The fainter spectra would be lost if the print was made light enough to show the lines in the denser spectra. The greater portion of the stars in this part of the sky have spectra of the first type, since it is in the Milky Way. In these stars the continuous spectra are traversed by a series of well-marked dark lines (light in the print) at shorter and shorter intervals as the wave-length diminishes, that is, as we approach the lower end of each spectrum as represented in the print. These lines are $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, $H\zeta$, $H\eta$, $H\theta$, and $H\iota$, and their corresponding wave-lengths are 4861, 4341, 4102, 3970, 3889, 3836, 3798, and 3771. Several of the other hydrogen lines, of shorter wave-length, are visible in the negative, and perhaps one or two more can be detected in the print. These spectra are prevalent in clusters like the Pleiades. The cluster near the bottom of the plate [80,30] is a good example, as is also N. G. C. 3523 [30,140] in the left-hand portion of the plate. The first of these clusters does not appear in Dreyer's Catalogue. About twenty spectra of the first type can be counted in the print, and many more in the original negative in each of these clusters. Such spectra are designated as of Class A in the Draper Catalogue. (See p. 265.) The star A. G. C. 14955 [55,105], which is the variable star T *Carinæ*, is an example of a star of the second type, Class G in the Draper Catalogue, and has a spectrum resembling that of the Sun. A. G. C. 14441, magn. 6.9, [106,96], has also a spectrum of the second type, Class K in the Draper Catalogue. The stars A. G. C. 15344, magn. $7\frac{1}{2}$, [11,145], and A. G. C. 13922, magn. 6.8, [167,132], are examples of the third type, Class M.

Sixty-three stars have so far been discovered whose spectra are of the fifth type, and consist mainly of bright lines. Fourteen of these, or nearly a fourth of the entire number, are in the region covered by Plate VII. The most conspicuous are Z. C. 10^h 2684, magn. $8\frac{3}{4}$, [90,141], [165,97], which is not a Catalogue object, A. G. C. 14626, magn. $7\frac{1}{4}$, [90,121], A. G. C. 15305, magn. 8, [19,95], and A. G. C. 15220, magn. $8\frac{1}{2}$, [35,5]. The object [167,74], which somewhat resembles the spectrum of a star of the fifth type, is a defect in the original negative. The different classes of stars of the fifth type are shown by these spectra. The first of these stars, Z. C. 10^h 2684, appears also on Plate V., Fig. 1, at [101,79]. Since its light is nearly monochromatic, its spectrum is conspicuous as compared with the spectra of other stars whose images on the chart are equally bright. Two stars, A. G. C. 14969, magn. $8\frac{1}{2}$ and 14971, magn. $7\frac{3}{4}$, shown in Plate V., Fig. 1, at [64,47], and [64,46] have interesting spectra which are shown at [53,107] on Plate VII. The hydrogen lines $H\beta$, $H\gamma$, and $H\delta$ are bright in their spectra, which closely resemble that of the variable star, η *Carinæ*. These stars, however, like η *Carinæ*, appear now to be constant in brightness. No sensible change is shown on nineteen photographs taken during the last five years.

In Plate V., Fig. 1, a star is shown at [172,72] whose approximate position for 1900 is R. A. $= 10^h\ 10^m.4$, Dec. $= -58°\ 21'$. This star was found by Mrs. Fleming, on August 31, 1893, to have the hydrogen lines bright in its spectrum on Plate B 9374, taken on May 5, 1893, with an exposure of 95 minutes. An examination of chart plates of this region showed that it was a variable star whose times of maxima occurred on the Julian Days represented by the formula, 2,411,058 + 383 E. The first of these numbers indicates that a maximum occurred on J. D. 2,411,058, which is February 24, 1889; the second shows that the period is 383 days. The spectrum is visible on Plate B 9431, but it is too faint to appear in Plate VII. at [162,134].

After the completion of the plates already described, photographs were received from Arequipa of some of the objects here represented, but with much longer exposures. Two of them are accordingly given in Plate VIII., on a scale of $10'' = 0.1$ cm. Figure 1 represents the cluster ω *Centauri*, and is enlarged four and a quarter times from X 5560, taken with an exposure of 180^m on June 1, 1894, and an additional exposure of 180^m on June 2, 1894, making 360^m, or 6^h, in all. The scale is the same as that of Plate VI., and the apparent increased size of the cluster is wholly due to the increase in size and number of the images of the stars. The ordinates of Plate VIII., Fig. 1, are less than those of Plate VI. by about 65 mm., while the abscissas are nearly the same. Thus the stars Z. C. 1108 and 1164 are [152,102] and [92,171] in Plate VI., and [152,37] and [91,106] in Plate VIII.

Plate VIII., Fig. 2, represents the region near η *Carinæ* on the same scale and with the same centre as Plate V., Fig. 3. It is enlarged four and a quarter times from X 5555, taken with exposures of 195^m, 210^m, 214^m, and 205^m, on May 25, 26, 27, and 28, 1894, making the total exposure 824^m, or $13^h\ 44^m$. The images are slightly elongated, but those on another negative, X 5554, taken with exposures of 170^m and 175^m, on May 23 and 24, 1894, are almost perfectly circular notwithstanding the long exposures. The structure of the nebulosity in this region is much better shown in Plate VIII. than in Plate V., Fig. 3. The abscissas on the first of these plates are greater than those on the second by about 41 mm., while the ordinates are nearly the same. Thus the co-ordinates of η *Carinæ* on the two plates are [57,38] and [17,39], respectively.

Plate V., Fig. 3, has been compared by the writer with a bromide print representing the same region a year later, and printed from the negative, X 5555, used in preparing Plate VIII., Fig. 2. The bromide was used instead of the plate, since the latter had not been made when the comparison was begun. Excluding the stars too faint to appear in Plate V., and those too bright in Plate VIII. to be fairly compared, 508 stars were found, none of which showed any certain evidence of variation. A similar comparison was made of Plate VI. with a bromide print from the same negative as Plate VIII., Fig. 1. The upper and lower portions of Plate VI. were not covered by the bromide. The regions thus omitted formed strips 12 and 25 mm. wide, respectively. The central portion of the cluster, covering a region 50 mm. = 8′.3 in diameter, was also omitted since the stars in this region are too numerous to be conveniently examined. The total number of stars compared was 3221. Of these 1034 are outside of a circle 120 mm. = 20′ in diameter. In general, the relative magnitudes of the stars agree so well that the eye readily detects any considerable difference in any particular star. In six cases only was such a difference perceptible, which was confirmed by examining the original negatives and showed that the stars were variable. The positions of these stars in Plate VI. are [144,136], [127,145], [121,151], [109,144], [76,206], and [30,118]. The fifth of these stars is north of the region covered by Plate VIII., Fig. 1; the positions of the others are [143,70], [126,80], [120,86], [108,78], and [29,52]. To distinguish these stars from each other, and from those described on page 208, the numbers 1 to 8 will be provisionally applied to them. The variable found by Mrs. Fleming at [135,148] in Plate VI. will be called ω *Centauri* 1, that at [127,142] will be 2, and the other variables will be numbered in the order in which they are described above. It will be noticed that 1, 2, 3, 4, 5, and 6 all lie within about three minutes of arc of 2, and 4 is only 20″ distant and nearly north of it. Star 3, [144,136] in Plate VI., is about equal in brightness to the faint star to the left of it and 1.4 mm. distant, and in Plate VIII. it is much brighter. Star 4 is the second of the line of four stars described on page 208, of which the fourth is star 2. In measuring star 2, Mrs. Fleming at first used star 4 as a comparison star, and had noticed that it was sometimes brighter and sometimes fainter than an adjacent comparison star, thus independently indicating its variability. In Plate VI. it is brighter and in Plate VIII. fainter than the star immediately below it and between it and star 2. Star 5 is much brighter in Plate VI., and much fainter in Plate VIII., than the star 1.5 mm. to the right of it. Star 6 is surrounded by a ring of stars, and is much fainter in Plate VI. than in Plate VIII. Star 7 is fainter than the star 2 mm. to the left of it, but is much brighter on the negative from which Plate VIII. is printed. Star 8 in Plate VI. is fainter, and in Plate VIII. is brighter, than either of the three stars to the left and below it.

The cluster 47 *Tucanæ* is second only to the cluster *ω Centauri*. It is represented in Plate IX. from photographs taken on three different dates. In each case the original negative was taken with the 13-inch Boyden telescope, and was enlarged four and a quarter times to a scale of $10'' = 0.1$ cm. Figure 1 was made from Plate X 5212, taken on September 8, 1893, with an exposure of 208 minutes; Figure 2, from X 3894, on December 24, 1891, exposure 60 minutes. Figure 3, from X 5289, on October 2, 1893, exposure 30 minutes. The larger size of the cluster in Figure 1 is wholly due to the longer exposure, the scale being the same in all three cases. Thus the star A. G. C. 328, magn. $8\frac{3}{4}$, [84,103], is about 6′ north of the cluster, and appears in each case about 36 mm. above it. The only other catalogue star is A. G. C. 319, magn. $8\frac{3}{4}$, seen near the bottom of Figure 1, [91,4]. These stars are also visible close to the cluster in Plate IV., Figure 1. When the edition of Plate IX. was printed it was found that several defects, which might be mistaken for stars, appeared in Figure 1, near [52,81]. They had not appeared in the proof, and are readily distinguished with a magnifying glass. The print is so light that the edge is not easily traced, but stars may be identified by the difference in their co-ordinates.

A remarkable collection of six variable stars has been discovered in the south following portion of this cluster. Three of these, Figure 1, [85,56], [82,48], and [56,72] were found by Professor Bailey and undergo large changes in light. Three others, [91,51], [62,38], and [79,56], were found by Mrs. Fleming, and vary by about one magnitude. These stars may be designated as 47 *Tucanæ* 1, 2, 3, 4, 5, and 6, in the order in which they are given above. The positions of these stars in Figures 2 and 3 may be found by subtracting 45 and 23 from the co-ordinates of Figure 1. Star 2 is conspicuous in Figure 2, 8 mm. below star 1, while in Figure 3 it is invisible. Star 3 is bright in Figure 3, near the centre of the left-hand edge, and is invisible in Figure 2. The star [48,39] in Figure 2 is a little fainter, and in Figure 3 a little brighter, than A. G. C. 328. The variability of this star was suspected by Professor Bailey, but its proximity to the centre of the cluster renders accurate measurement of its light uncertain. A discussion of the positions and variations in magnitude of all the variables mentioned above and of those near *ω Centauri* will be given later. Since Plate IX. was printed, much better photographs of 47 *Tucanæ* have been obtained.