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THE HENRY DRAPER MEMORIAL

BY ANNIE J. CANNON

THIS memorial was established in 1886, at the Harvard College Observatory by Anna Palmer Draper, the widow of the distinguished investigator and astronomer, Dr. Henry Draper, who was Professor of Physiology and Chemistry at the University of the City of New York. In his undergraduate days, Dr. Draper became interested in photography, which was then in its infancy. A visit to Birr Castle, Parsonstown, in 1857, to see the famous six-foot reflector of the Earl of Rosse, is said to have increased his interest in astronomy, so that upon his return to America he constructed two reflecting telescopes for his private observatory at Hastings-on-Hudson. After the marriage of Dr. Draper to Anna Palmer in 1867, they resided in the summer at Dobbs Ferry, two miles distant from the Hastings Observatory. It was their custom to drive to the observatory in the evening, and so great was Mrs. Draper's interest that he never went without her. She assisted him by recording, calling out the time, and coating the glass plates. Dr. Draper made numerous photographs of the moon, of the Nebula of Orion, and was the first to photograph the absorption lines in the spectrum of a star. The spectrum of Vega,

PLATE X.

Henry Drapers M. D. LL.D.

Born, March 7, 1837; died, November 20, 1882.

taken by him in August, 1872, showed four dark hydrogen lines. He also obtained the spectra of other bright stars, and of the Great Nebula of Orion. Dr. and Mrs. Draper resided in New York City in the winter, where their spacious home was the scene of many brilliant entertainments and where scientific men were accustomed to gather and enjoy the delightful hospitality. In November, 1882, they gave a dinner to the members of the National Academy of Sciences, gathered in New York. At this brilliant dinner, when, as a great novelty, the Edison incandescent bulbs were arranged by Dr. Draper to light the table, and when so much mirth and geniality prevailed, the guests could not have had a suspicion that they would never see Dr. Draper again. He moved about talking with one and another, among them being Professor Edward C. Pickering, who expressed his great interest in the photographs of stellar spectra taken at Hastings, even offering to measure them if they might be sent to Cambridge. Immediately after dinner, Dr. Draper was seized with a severe chill, the fore-runner of pneumonia which caused his death in a few days. The portrait of Dr. Draper is shown in Plate X. Mrs. Draper, wishing to establish a memorial to her husband, at first thought of erecting an observatory in New York City. This proved impracticable, however, and her attention was called to the experiments then being made in the photography of stellar spectra by Professor Pickering, the Director of the Harvard Observatory.

It will be remembered that the first photograph ever taken of a star was made at the Harvard Observatory under the direction of Professor W. C. Bond on July 17, 1850. In 1882, Professor E. C. Pickering's attention was called to the possibilities of celestial photography by Professor W. H. Pickering, and a small grant from the Rumford Fund of the American Academy enabled him to make some preliminary experiments. Two years later, by means of a larger grant from the Bache Fund of the National Academy, he procured a Voigtländer lens, 8 inches in aperture and with a focal length of about 45 inches. This

telescope, as shown in Plate XIV. was mounted in such away that polar stars are easily obtained, and no reversal is required when a star crosses the meridan. Professor Pickering commenced his photographic investigations of stellar spectra, by means of a 13° prism placed before the object glass of this telescope. He had already made visual observations with a spectroscope attached to the 15-inch Equatorial and had discovered eighteen gaseous nebulæ and three stars of Class *O*, often called the Wolf-Rayet type. The objective prism had been used previously by Secchi in his visual observations of the spectra of about 400 stars, and was at this time first applied to the photography of stellar spectra. It has the advantages that there is only a very small loss of light, and that spectra over the entire field are obtained. Any desired width can be given to the spectra by varying the rate of the clock. The original plan to obtain the spectra of all the brighter stars and of the fainter ones in certain regions proved too large for the Bache appropriation, but just at this critical time Mrs. Draper became interested and provided means for continuing the investigation as a memorial to her husband. With his characteristic breadth of vision, Professor Pickering laid out this great work, announcing in 1887, in the First Annual Report of the Henry Draper Memorial, that Mrs. Draper had already enlarged the scope of the work, "so that the final results shall form a complete discussion of the constitution and condition of the stars," including a catalogue of the spectra of all stars north of – 24° of the sixth magnitude and brighter, with a detailed study of the brighter stars.

As soon as the photographs were obtained, the work of classifying the spectra was undertaken, and was soon placed under the charge of Mrs. Fleming. At once the greatest difficulty was encountered. How were the various kinds of stellar spectra shown on these photographs to be designated? The divisions into five types made by Secchi proved altogether inadequate to represent the numerous differences seen on the photographs. A new system had to be adopted which would permit the reader to understand the various aspects of the

spectra as shown by the photographs. Therefore, the letters of the alphabet from *A* to *Q* were assigned to stellar spectra. This classification is purely empirical, being based wholly on the external appearances, without any idea of expressing differences of temperature or stages of evolution. Any system of designation which could assemble all similar spectra under one name was deemed to be sufficient, for, it was stated that whenever a theory could be found to account for all the observed facts, any other name could be substituted and any other order assigned to the classes. The futility of attempting more at this early epoch is shown by the passing of Vogel's classification, in which the aim was made to explain the phase of development of each star. In the Draper classification, the letter *A* was assigned to spectra of the first type, showing the broad hydrogen lines, as in Sirius, the line *K* of calcium also generally being present. When other lines were seen, such as those at wave-lengths 4026 and 4471, the spectra were called *B*. The letters *C* and *D* were used to represent spectra of the first type, having certain peculiarities, such as double lines or bright bands, which were even then suspected to be instrumental rather than real. The letters *E* to *L* were assigned to spectra assumed to be of the second type, with the remark that Class *F* might be considered to be intermediate between the first and second types. The letters *M*, *N*, *O* and *P* were given, respectively, to spectra of the third type, the fourth type, the fifth type, consisting mainly of bright lines, and the gaseous nebulæ. *Q* was left for spectra so peculiar as not to be included under any of the former letters. The first classification of a large number of photographic stellar spectra was made according to this system by Mrs. Fleming and was published in Volume XXVII. of the Harvard *Annals*. It was called the Draper Catalogue and contained 10,351 stars.

Realizing the importance of extending the investigations over the entire sky, in 1889 Professor Pickering sent an expedition to South America, at first in charge of Professor S. I. Bailey, and later of Professor W. H. Pickering. The 8-inch telescope was

taken and, after trials of several places, was finally set up in Arequipa, Peru, where a permanent station was established. Plate XII gives a view of this station. The Observatory and a comfortable residence for the staff were erected at an elevation of 8,000 feet, at the foot of an extinct volcano, El Misti, which is 19,200 feet high. Besides the 8-inch Bache Telescope, the 13-inch Boyden and 24-inch Bruce Telescopes were mounted later at Arequipa. To fill the place of the Bache Telescope in Cambridge, Mrs. Draper furnished a second, and nearly similar, instrument.

All the photographs are stored in the rectangular brick building, seen in Plate XI, which shows the main station of the Observatory, at Cambridge. One of the stack rooms for storing plates is shown in Plate XIII. Each compartment contains 100 original glass negatives, 8 × 10 inches in size. The collection resembles a library of books, of which each negative is the only existing copy, and being glass, is very fragile.

While the general survey of the whole sky was made with the 8-inch telescopes, excellent spectra of the brighter stars were obtained with Dr. Draper's 11-inch photographic lens, having a focal length of 153 inches, which had been remounted in Cambridge. The brighter stars could thus be photographed with a dispersion of 8.00 cm., from $H\beta$ to $H\epsilon$, by means of four prisms nearly a foot square, placed before the object glass. Among the earliest results, it was stated in 1887 that the H line in α Cygni was found to consist of two components, and the lines $H\gamma$ and $H\delta$ were bright in o Ceti. Also that U Orionis which was at first supposed to be a Nova, had a spectrum similar to that of o Ceti, thus furnishing additional evidence that it is a variable of the same class. In 1888, photographs were taken of the spectrum of β Persei at the star's maximum and minimum light to show possible changes, but gave only negative results. These early data are interesting as marking the beginning of the extensive work of the Memorial on the spectra of the variable stars.

The detailed study of the spectra of the bright northern stars was assigned to Miss A. C. Maury, a niece of Dr. Draper.

The photographs used by Miss Maury are excellent ones, taken with the 11-inch telescope, and of large dispersion, which enabled her to detect small peculiarities and make detailed study of wave-lengths and intensities of lines. She formed 22 groups of spectra, using Roman numerals instead of letters to designate them, and calling attention to differences in the width of the lines by assigning the letters *a*, *b*, *c*, respectively, to spectra with medium, wide and narrow lines. Miss Maury's results were published in Volume XXVIII., Part I. of the *Annals* and formed a catalogue of 681 stars. One of Miss Maury's important discoveries was that the spectrum of β Lyræ changes in a remarkable manner, which, in her opinion can be partially explained by the presence of a third body.

The revelations of these early photographs of stellar spectra were truly remarkable. It was almost as if the distant stars had really acquired speech, and were able to tell of their constitution and physical condition. Spectra of such stars as Arcturus were obtained on a scale so as to show 500 solar lines between the sodium line *D* and the calcium line *K*. These lines were compared with lines in the sun by means of Rowland's map of the solar lines. No one could do this patiently, line for line, noting in many cases the perfect agreement, and not be convinced that the distant star is a glowing body on the same order as our own luminary.

In 1888, Professor Pickering made the unique discovery that the lines in the spectrum of ζ Ursæ Majoris, the familiar "Mizar", were double on one photograph, while certainly single on others. At first, it seemed possible that this doubling might be due to a photographic defect, about which he was so strenuously warned in those days. But there were the double $H\beta$, $H\gamma$, $H\delta$, $H\epsilon$, and even better seen, the fine line *K* of calcium and 4481, due to magnesium. Additional photographs soon confirmed the duplicity, and the first very close binary, since called spectroscopic binary, was discovered. A short time later, Miss Maury found the same peculiarity in the spectrum of β Aurigæ, the second of these systems to be known. Plate XV.

shows photographs of the spectrum of β Aurigæ, with line K single and double. Later, V Puppis was found to be a close binary by Professor Pickering, μ^1 Scorpii by Professor Bailey, ζ Centauri by Mrs. Fleming, and π Scorpii by the writer. All of these binaries consist of two stars nearly equal in brightness, revolving around a common centre of mass, with rapid velocity, in periods from one to twenty days. There are now more than 300 spectroscopic binaries known, but in most of them one component is so much fainter that its lines are not visible on the photographs and its presence is revealed only by the variable velocity of the system in the line of sight.

One of the most interesting discoveries from the photographs of this memorial was made by Professor Pickering in 1897. He found that the spectrum of a second magnitude star, lettered ζ in the constellation of Puppis, contained, besides the well-known series of hydrogen lines, a second rhythmical series of absorption lines, at first supposed to be due to some substance unknown on the earth, but later assumed to be due to hydrogen under conditions unfamiliar to us. These lines were also found to be present in stars of Class O, but as emission lines. They were never produced in the laboratory until 1913, when Professor Fowler succeeded in obtaining them from a mixture of hydrogen and helium in a tube, and they are now generally believed to be due to helium.

The detailed classification of the spectra of the bright southern stars was undertaken by the writer in 1897. The results are published in Volume XXVIII., Part II., of the *Annals*, forming a catalogue of 1122 stars. The photographs for this investigation were taken at Arequipa with the 13-inch Boyden Telescope and have a dispersion somewhat greater than those taken in Cambridge with the 11-inch Draper Telescope. A modification of the system of letters used for the Draper Catalogue was adopted at this time. In various ways, some of the perplexing problems of the early days had already been solved. The stellar sequence was found to be in some respects less complex than was at first supposed.

The appearances for which some of the letters, such as *C*, *D* and *E*, had been assigned, were not confirmed by later and better photographs. Therefore, these letters were dropped from the sequence. In 1891, Professor Pickering wrote, "The principal question now outstanding is to determine what substance or substances cause the characteristic lines in the spectra of stars of the Orion type." This question was settled by Sir William Ramsay's discovery of helium in 1895, and the subsequent identification by Vogel of the lines characteristic of spectra of the Orion type with the new terrestrial element. Hence the so-called Orion stars, which were first known to prevail in that constellation, became helium stars. As it had been clearly proved by the Harvard classification that these spectra precede the Sirian spectra, it was necessary to place the letter *B*, which had been assigned to the Orion stars, before the letter *A*, or to change all the stars previously lettered *A* and *B*. Since several thousand had already been published, the change of the order of the letters was the only practicable course. This inversion of letters is variously regarded by astronomers as an advantage or a drawback to the system. The original letters that persisted were *B*, *A*, *F*, *G*, *K*, *M*, to represent the sequence as far as it was then established. This sequence is shown in Plate XVI. But, as was found in classifying the bright southern stars, the letter *B* could not stand for all the helium stars with their various intensities of lines and differences in number of lines present. Therefore, the writer adopted the plan of dividing into tenths the intervals between spectra represented by successive letters in the sequence. Thus the various subdivisions of *B* stars were called, *B*1 *A*, *B*2 *A*, *B*3 *A*, *B*5 *A*, *B*8 *A*, and *B*9 *A*, later abbreviated to *B*1, *B*2, etc. The width of the lines was also carefully noted in this investigation, as had been done by Miss Maury for the northern stars, and remarks were used to designate those stars whose lines are certainly broad, as α Eridani, or certainly narrow, of division "*c*," as *b* Puppis and ζ^1 Scorpii. Spectra having narrow lines have proved to be of unusual interest, due to the fact that stars with such spectra

have great intrinsic brilliancy and generally very small proper motions.

Therefore a list was made of all spectra known to have narrow lines, and published in Volume LVI., page 162 of the *Annals*. This list includes 96 stars and is probably complete down to the fifth magnitude for both northern and southern stars.

One of the most interesting results of this study of the excellent photographs of the southern stars was the subdivision of the spectra of Class *O* into a progressive series and the discovery of such spectra as that of 29 Canis Majoris which supplied the needed link between spectra of Class *O* and Class *B*. This spectrum resembles Class *O* in the presence of the "Pickering" series, first found in ζ Puppis, called in the Harvard *Annals*, the "additional" hydrogen lines, and also resembles Class *B*0 in the helium and other absorption lines. Thus it happened again that the natural order of the alphabet must be broken, for *O* was then placed before *B* in the stellar sequence. Photographs with the objective prism have not established the position of stars of the fourth type, Class *N*, but Professor Hale's work indicates that they follow Class *M*.

Mrs. Fleming, in her regular survey of the large number of spectra photographed with the various instruments, discovered numerous peculiar and interesting objects. Among them may be mentioned 91 stars of the fifth type, whose spectra consist mainly of bright lines, 69 stars of the helium type with bright lines, 59 gaseous nebulæ, more than 300 variable stars and 10 new stars. The early photographs of variable stars which are bright at maximum, such as o Ceti, *R* Hydræ, *R* Leonis, *U* Orionis, and *R* Cassiopeiæ, showed that their spectra are identical in essential points. Hence, in 1890, Professor Pickering stated that this method could be used for the discovery of such objects, without the necessity of watching the sky. The first variable actually discovered in this way was *R* Cæli, whose variability was confirmed by chart photographs, showing it to be of the seventh magnitude in October, 1889, and only the tenth

magnitude in February, 1890. This method, by which more than 200 variable stars have been discovered on the photographs of the Henry Draper Memorial, is illustrated in Plate XVII, which show the variable *RR* Scorpii, *165030*. The spectrum is of Class *Md*, the banded type, having H_γ and H_δ bright. The chart photographs show the variable when bright and when faint. It has so far been possible to confirm on chart photographs the variability of all stars showing this class of spectrum. A photograph, taken November 3, 1887, of a region in Perseus held a secret of its own for three years, for not until 1890, while making a careful examination of this plate, was it discovered by Mrs. Fleming that the spectrum of one star in this field showed bright lines. No trace of the object could be found on photographs before November, 1887, or after December, 1887. This object is called Nova Persei, No. 1. This discovery was so long after the outburst that very little is known of its history, although the reality of the object was confirmed by several images on chart plates in November and December, 1887. The Draper Memorial photographs continued to yield new stars, as Nova Normæ, discovered in 1893, Nova Carinæ and Nova Centauri in 1895. The latter Nova had a spectrum resembling Class *N*, unlike any other new star so far photographed. This Nova appeared very near the nebula, N. G. C. 5253, and in this respect resembled *S* Andromedæ, which appeared in 1885 in the Great Nebula of Andromeda. Nova Sagittarii, No. 1, appeared in 1897, and Nova Aquilæ, No. 1, in 1898. Six years intervened before Nova Aquilæ, No. 2, was discovered in 1905, and four years more before Nova Aræ and Nova Sagittarii, No. 2, appeared in 1910. Two new stars found by Miss Leavitt, and three by the writer, were not discovered by means of their spectra, but by chart images on plates of the Harvard Map of the Sky. Memoirs on peculiar spectra, spectra of double stars and spectra having bright lines, have been published from time to time as a part of the Henry Draper Memorial.

One disadvantage of spectra obtained with the objective prism is that a comparison spectrum cannot be used, as is

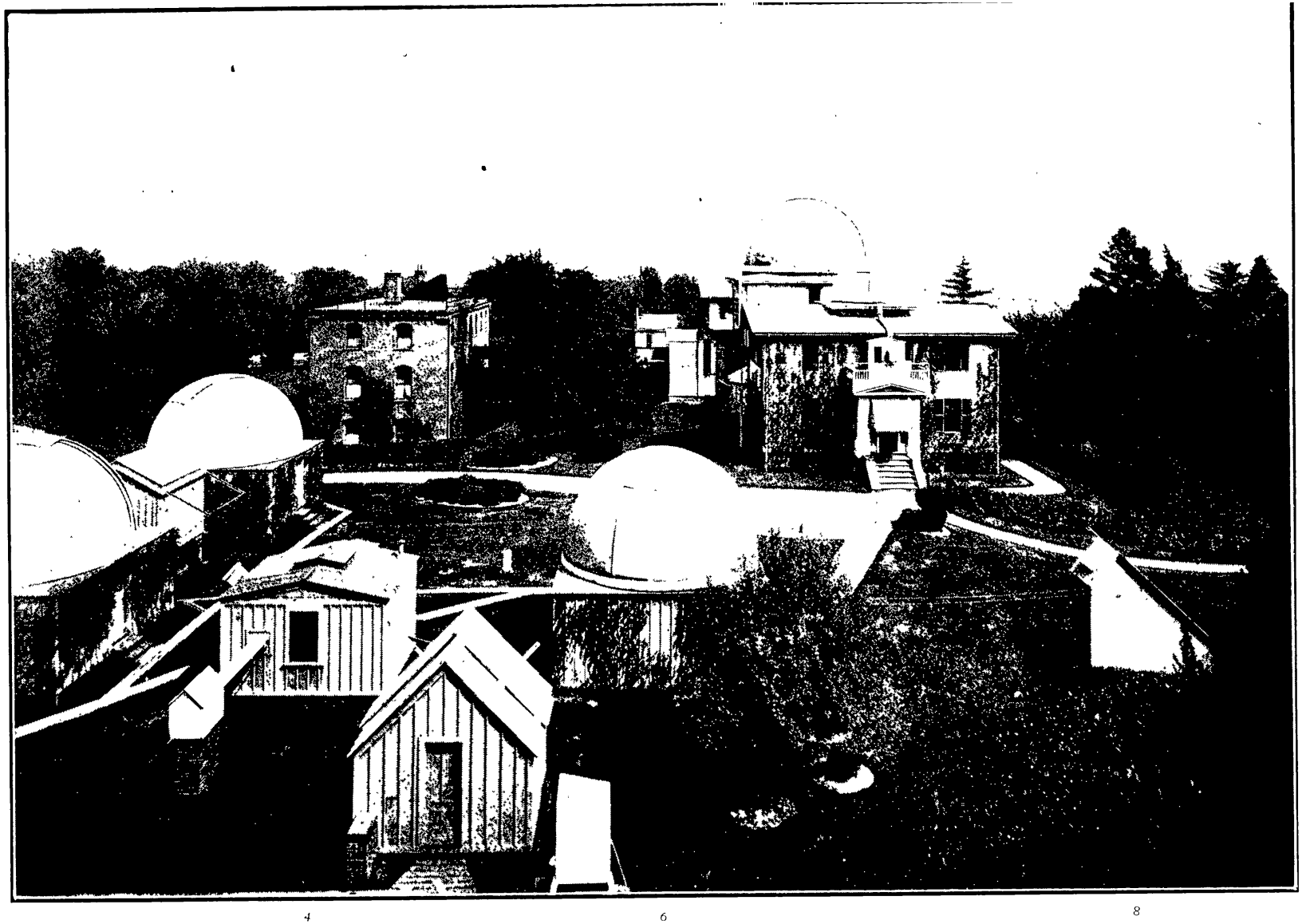
done with the slit spectroscope. As early as 1887, experiments with absorbing mediums, as hyponitric fumes, were made by Professor Pickering, as stated in the First Report of the Henry Draper Memorial. The spectra are photographed so that the starlight passes through a tank containing such a substance, and lines resulting from absorption of this terrestrial medium are scattered among the lines resulting from absorption in the star's atmosphere. It was hoped that accurate measures could thus be made of the stellar lines, referred to some fixed terrestrial lines. But the substances experimented with gave lines which were too wide and ill-defined for satisfactory results. In 1910, Professor Pickering asked Professor Robert W. Wood, of Baltimore, what substance would give the narrowest absorption lines. He replied that the 4272 band of neodymium chloride might answer the purpose, and filled a ray filter with such a solution. By means of this filter, photographs have been made which show a sharp neodymium line among the stellar lines of all the spectra sufficiently bright on the plate. Excellent photographs are now being taken by this method with the 16-inch Metcalf Telescope, from which interesting results are expected.

Lest the spectrographic work of this Memorial should appear to dwarf other investigations, it should be stated that a large number of variable stars have been measured on chart plates, so that their periods and light curves could be determined. The great collection of photographs of the Memorial has also been used for many purposes, and will long be available for objects yet undiscovered. The case of the interesting minor planet Eros, originally called *D Q*, may be cited. When found by Witt in 1898, it was announced to be of the eleventh magnitude, with a remarkable orbit, bringing it nearer at times to the earth than even the planet Mars. By the aid of an ephemeris furnished by Mr. S. C. Chandler, search was made by Mrs. Fleming for this object at the oppositions of 1893 and 1896, but this was very laborious and wearisome owing to the uncertainty of the ephemeris, an error of 1″ in daily motion being sufficient

to change the right ascension in 1894 by one half hour. At last it was found on a photograph taken with the 8-inch Draper Telescope on June 5, 1896. With the aid of this position, the ephemeris was corrected by Mr. Chandler, so that Eros was readily picked up on plates taken during the bright opposition of 1893 and 1894. The life history of any other object not too faint, which may yet be discovered, can doubtless be studied as satisfactorily as Eros, on photographs extending as far back as 1890.

Within the last five years, an increased interest has arisen in the classification of stellar spectra. This is mainly due to the discoveries of Professor Campbell and Professor Kapteyn concerning the relation between the radial velocity of the stars and their spectral type, and of Professor Lewis Boss concerning a similar relation between proper motion and spectrum. Professor Campbell announced in 1910 that a comparison of the average motion of 17 km. per second for stars of Classes *G*, *K*, and *M* with the motion of only 7 km. per second for the *B* stars showed unmistakably that the radial velocities of stars are functions of their spectral types. Other interesting relations have also been found, such as a progressive increase in distances between components and in periods of binary stars, according to whether the type of spectrum is early or late.

Since the Draper Memorial collection contains photographs of stellar spectra over the entire sky, observations were commenced by the writer in October, 1911, for a New Draper Catalogue. A regular progress has been made since January, 1912, 5,000 or more stars being classified each month. The classification is now completed for the northern stars, and nearly as far as 18^h for the southern. The photographs were taken with the 8-inch telescopes at Cambridge and Arequipa and cover a region about 8° square. A portion of one, taken October 27, 1911, is shown in Plate XVIII. The spectrum of the variable star, *R* Cygni, is seen near the centre of this region, with $H\beta$, $H\gamma$ and $H\delta$ bright. The gaseous nebula, + 50°2869, whose spectrum consists of bright lines, as well as various spectra of classes *A*, *F*, *G*, *K* and *M* are also seen.



4 6 8

HARVARD COLLEGE OBSERVATORY, CAMBRIDGE STATION

(1) The 28-inch Reflector. (2) The 8-inch Draper Telescope. (3) The 24-inch Reflector. (4) The 12-inch Meridian Photometer. (5) The Photographic Library. (6) The 11-inch Draper Telescope. (7) The 15-inch Equatorial. (8) The 15-inch Polar Reflector.

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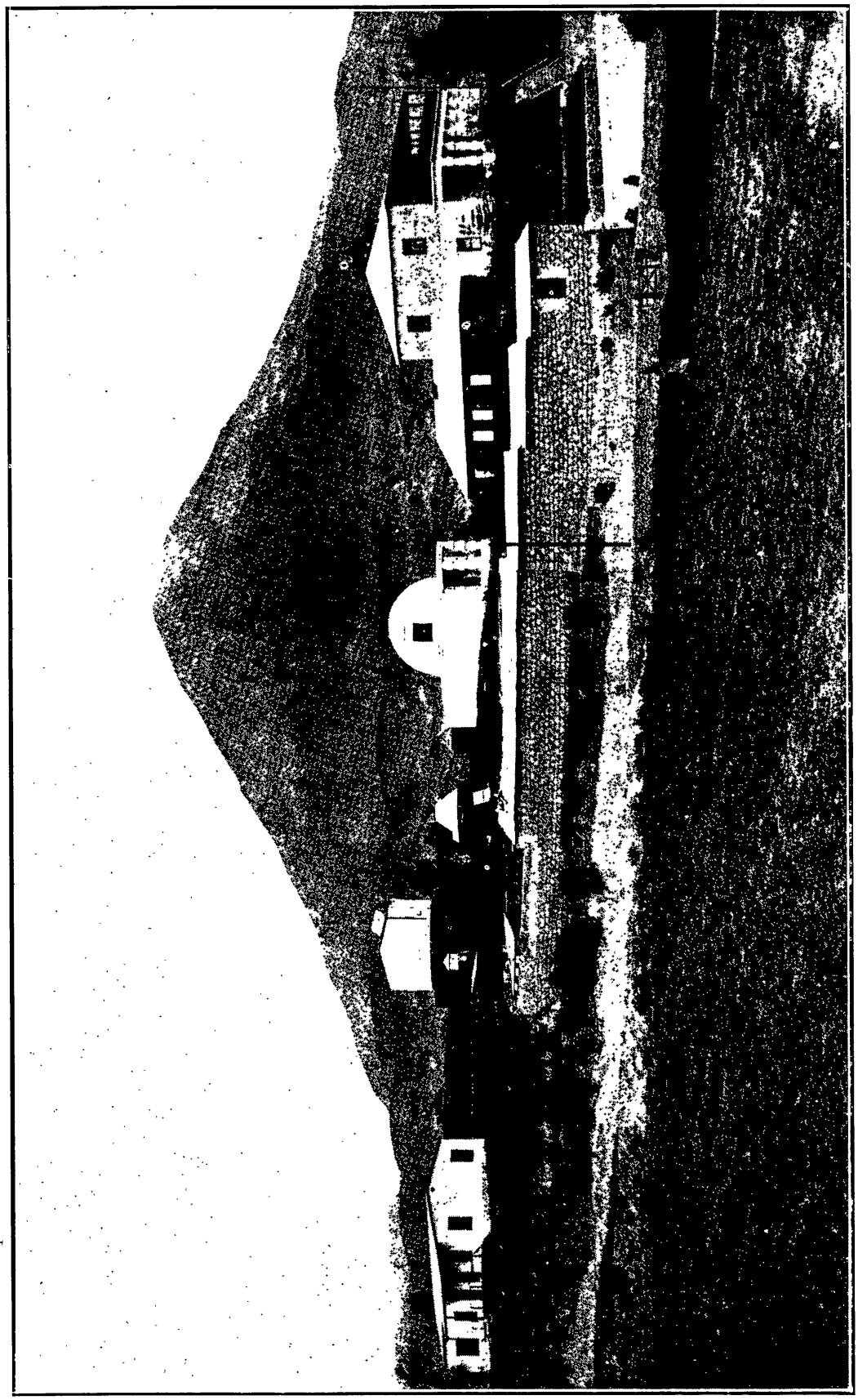


HARVARD COLLEGE OBSERVATORY, AREQUIPA STATION

Elevation 8000 feet; El Misti, 19,200 feet high, in background.

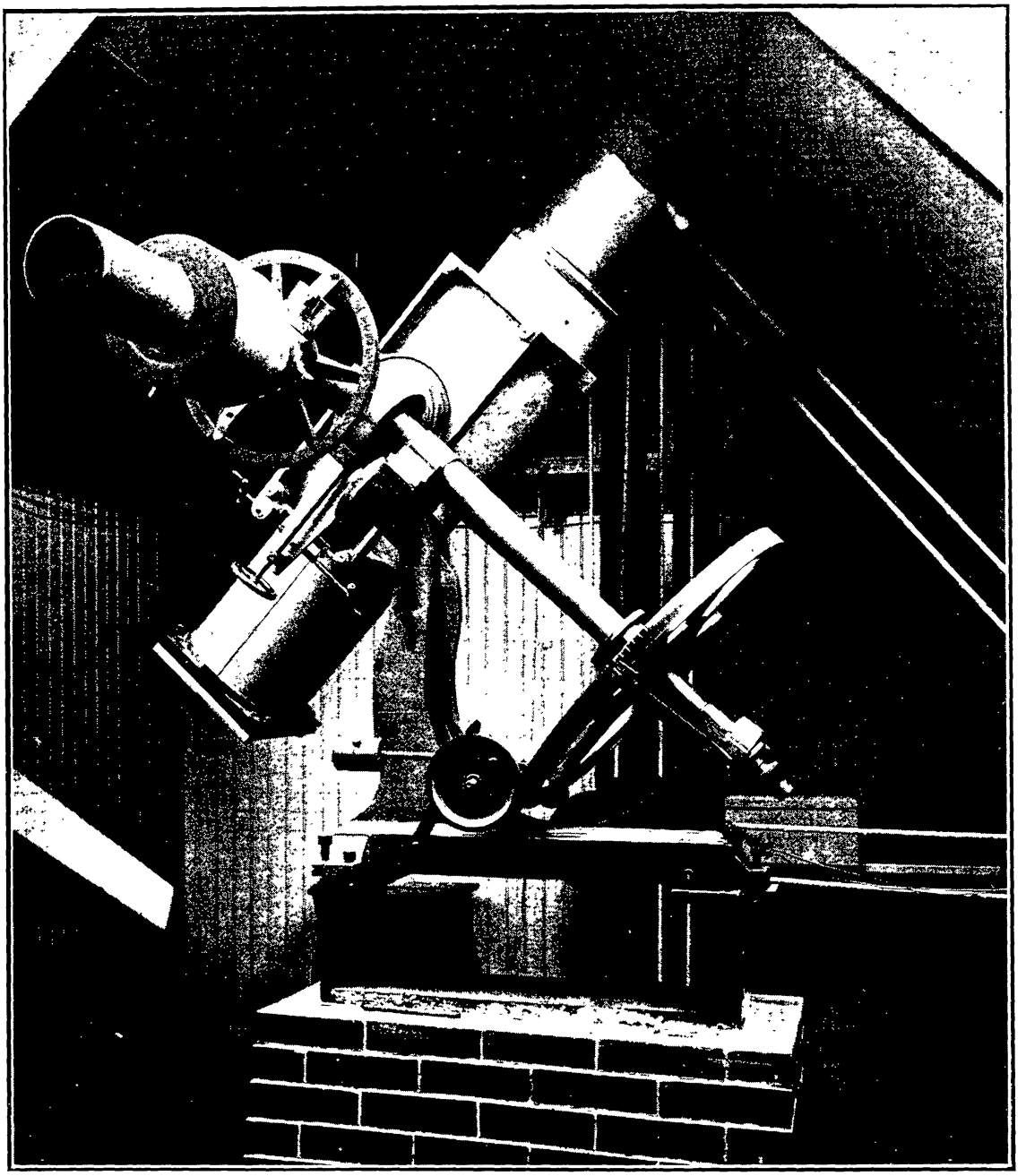
(1) Cottage for Assistants. (2) The 13-inch Boyden Telescope. (3) The 8-inch Bache Telescope.
(4) The 24-inch Bruce Telescope. (5) The Laboratory. (6) The Residence.

PLATE XIII.

STACK ROOM FOR HOLDING PHOTOGRAPHIC PLATES

Each compartment holds 100 original glass plates, 8 × 10 inches in size.

PLATE XIV.



THE 8 INCH DRAPER TELESCOPE

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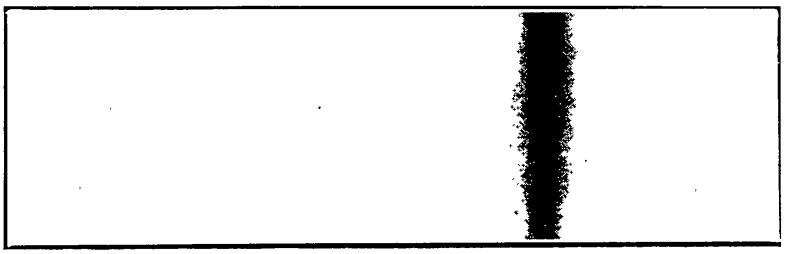
PLATE XV.

1889, December 30d 17h.6 G.M.T.

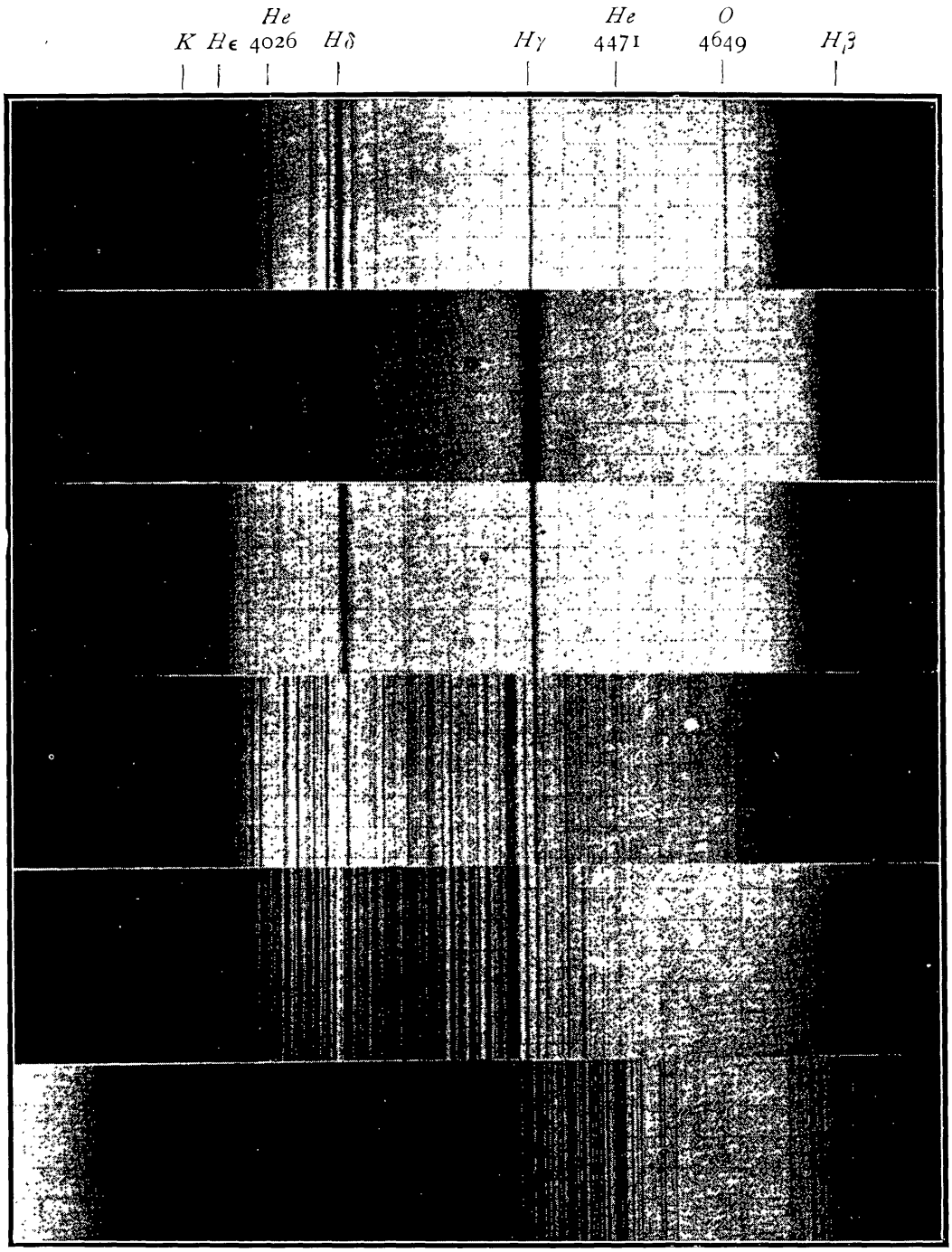


1889, December 31d 11h.5 G.M.T.

SPECTRUM OF β AURIGÆ

A typical spectroscopic binary. The K line is shown single on December 30, 1889, and double one day later.

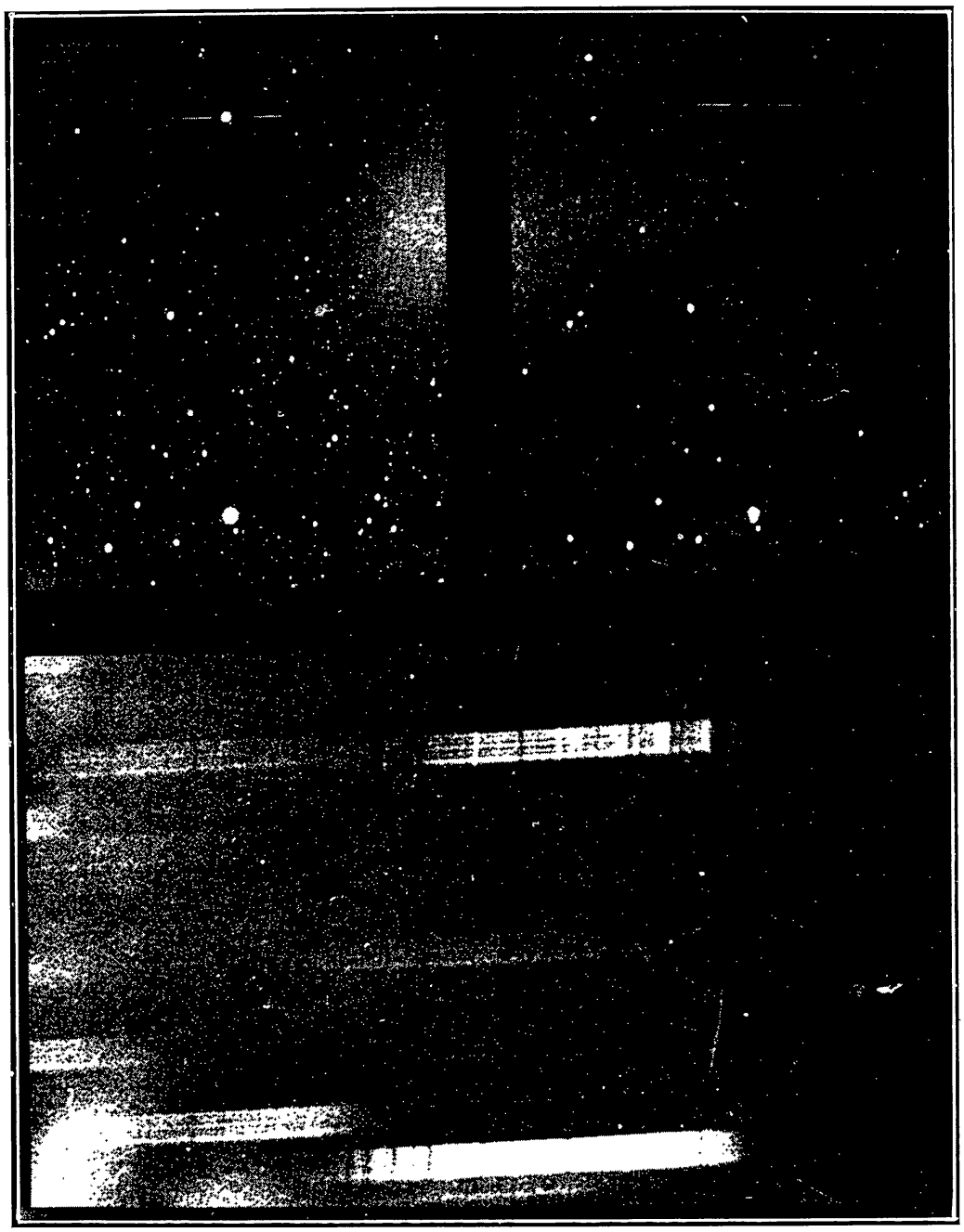
PLATE XVI.



TYPICAL STELLAR SPECTRUM

(1) ε Orionis (Alnitam) ..... *Bo*
(2) α Canis Majoris (Sirius)..... *Ao*
(3) α Carinæ (Canopus)..... *Fo*
(4) α Aurigæ (Capella)..... *Go*
(5) α Boötes (Arcturus) ..... *Ko*
(6) α Orionis (Betelgeuse) ..... *Ma*

PLATE XVII.



METHOD OF DISCOVERING VARIABLE STARS BY BRIGHT LINES IN THEIR SPECTRA

Above, left : photograph showing star *RR* Scorpii bright.
Above, right : photograph showing star faint.
Below : photograph of spectrum.

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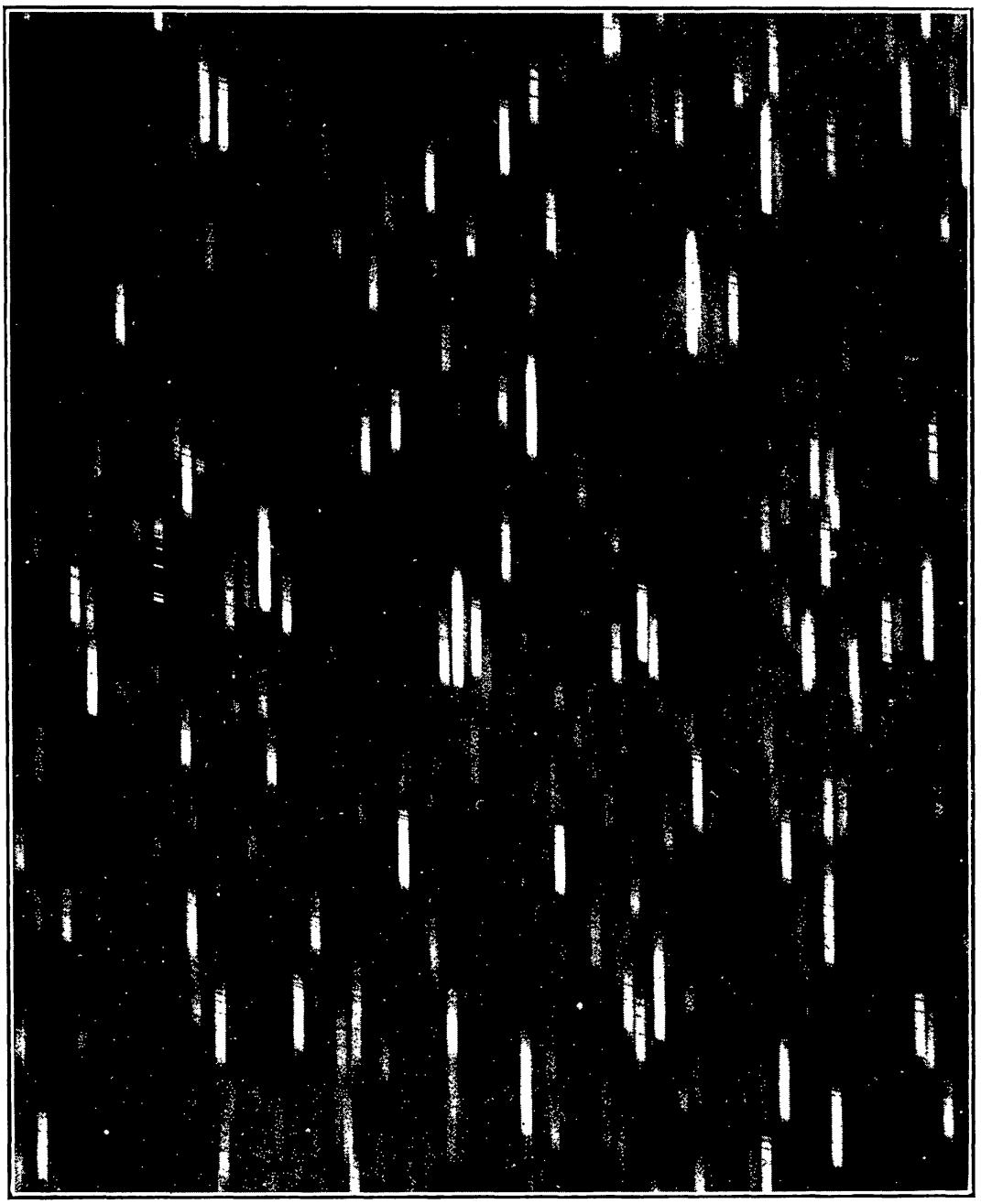
PLATE XVIII.

N



SPECTRA OF STARS IN REGION OF *R* CYGNI

Exposure, 80 minutes; 8 inch Draper Telescope. Enlarged 1·14 times original.

R Cygni, 49 mm. = 1·9 in. from left edge; 60 mm. = 2·4 in. from bottom.
Gaseous nebula, 17 mm. = 0·7 in. from left; 70 mm. = 2·8 in. from bottom.
Class *M* star, 10 mm. = 0·4 in. from right; 63 mm. = 2·5 in. from bottom.

By the generosity of Mr. George Agassiz, a member of the Board of Visitors, additional assistants have been available to make the identifications and reductions, and the whole work has been placed on a systematic basis. At present 199,196 spectra have been classified. About 150,000 of these are identified, the facts being copied on Library Bureau cards, which are placed in cases in the order of right ascension, where they may be consulted readily for any purpose. The spectra of more than 8,000 stars have already been sent to astronomers in England, Denmark, France, Germany, Holland and Italy, as well as in America, where they are being used for various purposes, such as color index, parallax, radial velocity, proper motion, and double star investigations. It is hoped that the observations for the New Draper Catalogue will be finished in six months, and that printing may be started soon after that time. When the classification is completed, a careful study will be made of the distribution of the various classes of stellar spectra, as a portion of the contribution of the Henry Draper Memorial to the greatest of all investigations, the constitution of the sidereal universe. The problem is so vast that we might despair of any completed result of our tasks were it not for the wonderful correlation revealed during the last five years, among apparently disjointed investigations. That every fact is a valuable factor in the mighty whole should encourage each worker, remembering Argelander's words in 1844, when making an earnest plea for more zealous observations of the variable stars, "Each step brings us nearer the goal, and if we can not reach it, we can at least work so that posterity shall not reproach us for being idle, or say that we have not made an effort to prepare the way for them."

HARVARD COLLEGE OBSERVATORY,
CAMBRIDGE, MASSACHUSETTS,
April 17, 1915.