Bull. Astr. Soc. India (1982) 10, 60–71

NOTES FOR THE OBSERVER

by T. P. Prabhu

1. Astronomical photography

Spectroscopy and photometry, aided by the "art"—as it was then called—of photography, gave birth to the modern science of astrophysics in the middle of the last century. Photography provided a very good means of obtaining a permanent record of what an astronomer was visually observing and measuring. He therefore took a keen interest in the development of this new technique. The early experiments with photography by Niepce and Duguerre were first announced to the scientific world by the French astronomer Francois Arago (1839). John Herschel discovered in 1819 the fixing action of sodium thiosulphate (hyposulphite) and also coined the word 'photography' in 1839.

The history of celestial photography can be divided into five periods in which the photographic technique was successively improved.

(i) *Daguerreotype* (*1839–1851*)

The first photographic plate was a thin film of silver on a copper base, sensitized by iodine vapour. After exposure the plate was developed in mercury vapour and fixed in a solution of sodium thiosulphate. John Draper, father of the well-known amateur astronomer Henry Draper, obtained at Harvard a photograph of the moon in 1840 which is the earliest recorded attempt at celestial photography. French optician Lerebours obtained an overexposed photograph of the sun in 1842 while a proper exposure was obtained by Fizeau and Foucoult in 1845. First photographs of stars—Vega and Castor—were obtained by Bond and whipple at Harvard in 1850.

(ii) *Wet collodion* (*1851–1879*)

The Daguerreotype had a very low sensitivity. The Bond-and-Whipple photograph of Vega needed a 100 s exposure with a 15-in telescope. The wet collodion process was introduced by G. Le Gray of France in 1851. The method consisted in spreading a thin homogeneous film of nitro-cellulose on a clean glass plate, dipping it into a solution of silver nitrate saturated with silver iodide, and exposing while it was still wet. The image was developed in a bath of iron sulphate and acetic acid. The gain in sensitivity over the Daguerreotype was two orders of magnitude. At a suggestion by John Herschel, systematic solar patrol was started by W. de la Rue at Kew in England (1858). Photoheliographs were soon installed at the Vilnius observatory in Russia (1861) and at the Royal Greenwich observatory (1873). While the earlier refractor lenses were corrected only for the visual region of the spectrum, achromatic telescopes were designed and constructed during this period specially corrected for blue and violet to which the photographic plate is the most sensitive. Other notable achievements of this period include the photographs of the solar eclipse of 1860 during which the limb prominences were recorded unambiguously for the first time by de la Rue and Pietro Secchi.

The eclipse photography soon became popular. One of the best corona photographs during this period was obtained by Lord Lindsay at the Indian eclipse of 1871, when the sun was very active. The wet collodion had a very good resolution and at Meudon J. Janssen—who had earlier discovered helium during the Indian eclipse of 1868—could record solar granulation of 1–2 arcsec in size as early as in 1877.

(iii) *Silver bromide emulsions (1879–1939)*

The wet collodion was very cumbersome to use. The use of gelatin as a vehicle for the silver halide emulsion, introduced by R. L. Maddox in 1871, overcame this difficulty. Shortly, in 1873, Hermann Vogel discovered accidentally the techniques of sensitizing the emulsion to longer wavelengths, using dyes. These improvements made it feasible for the photographic emulsions to be coated in factories and supplied to the user. F. C. L. Wratten set up a company in England in 1877 while George Eastman set up another in New York in 1880. Several other companies soon followed. The sensitivity of the emulsions was increased by another order of magnitude. Thus the photography of planets, comets and nebulae became possible. Notable photographs of this period include those of the Orion nebula by Henry Draper (1880) and Andromeda nebula obtained by Isaac Roberts (1882). These results were so encouraging that the photographic surveys like the Cape photographic Durchmusterung, the Harvard patrol and Carte du Ciel projects were soon begun.

Though the first photographic record of solar spectrum was obtained on a Daguerreotype by John Draper in 1843, higher dispersion was possible only after the gelatin emulsion was introduced. Also the discovery of dye-sensitization extended the spectral range that could be recorded. Rowland's tables were compiled during this period (1886–1889) which include nearly 20,000 lines. Photographic spectroscopy was soon extended to stars, comets and the gaseous nebulae notably by Huggins, Henry Draper and E. C. Pickering. Pickering introduced the idea of an objective prism and started the spectroscopic survey which culminated in the Henry Draper catalogue (1918–1924) which lists more than 225,000 stars brighter than 10th or 11th magnitude classified by Miss A. J. Cannon.

The most remarkable instrument designed during this period using the photographic detector was the spectroheliograph. It was invented in 1892 by G. E. Hale at Harvard observatory and independently by H. Deslandres at Meudon observatory. A spectroheliograph is used to obtain a monochromatic image of the sun with a spectral purity comparable to the most sophisticated monochromatic filters. The instrument differs from a conventional spectrograph in having an extra slit in the image plane of the spectrum which isolates the spectral band of interest. During the exposure, the entire spectroheliograph is moved keeping the image of the sun—formed at the entrance slit—and the camera stationary. Thus the solar image is scanned in the spectral band of interest and the image recorded on the photographic plate.

Extensive photographic observations of the sun and the solar spectrum were initiated at a few observatories at the turn of this century. Photographs and spectrograms of the sun were being obtained at the Kodaikanal observatory as early as

1901. Comet 1901a was also photographed the same year. A spectroheliograph was installed in 1904 and had been greatly improved by 1907, the year when J. Evershed joined as the assistant director. The wealth of the spectroheliographic and photoheliographic data for the past 75 years available at Kodaikanal observatory proves the usefulness of the photographic emulsion as a data storage medium. Figure 1 shows the first spectroheliograph installed at Kodaikanal and figure 2 the spectroheliogram obtained on 1909 April 16 in the light of K line of ionized calcium. The sensitivity of the silver bromide emulsions was successively improved towards the end of the last century and photography soon surpassed the limit of the visual observations. J. Scheiner succeeded in obtaining a spectrum of the Andromeda nebula in 1899 from potsdam observatory. Further milestones are Miss H. Leavitt's discovery of period-luminosity relationship of Cepheids in Magellanic Clouds and Hubble's discovery of Cepheids in the Andromeda nebula (1924). The extragalactic nature of spiral nebulae was thus established beyond doubt and soon the discovery of the expansion of the universe was to follow (Hubble 1929).

(iv) *Reducing the reciprocity failure* (*1939–1964*)

The major drawback of the photographic emulsions is that if the intensity of light is reduced by, say, a factor of two, the exposure time needed to record it is more than doubled. This property, known as low intensity reciprocity failure (LIRF), hampered the photography of the fainter astronomical objects. This problem was solved by the introduction of special astronomical plates by Eastman-Kodak in the 1940s. These plates—distinguished by a letter 'a' in their designations (*e.g.* 103a-O, IIa-O)—helped in gaining at least one magnitude in normal exposures. The emulsions 103a-O and 103a-E were employed in the Palomar sky survey between 1949 and 1957. Modern quantitative astronomical photography begins with these emulsions. Further developments in astronomical emulsions have become possible primarily due to the close coordination between the astronomers and the Eastman-Kodak company.

(v) *Modern astronomical emulsions* (*1964–1981*)

The trend of increasing the emulsion sensitivity has been reversed in the recent years since Albert Rosse (1946) applied communication theory to photographic detection of signals. John Merchant and A. G. Millikan of Kodak research laboratories put this theory into practice in the 1960s. Thus the emulsions IIIa-J and IIIa-F resulted from an optimization of grain size, contrast and photon efficiency. Despite the decrease in emulsion sensitivity, detection threshold is improved by more than a magnitude.

A wise application of the modern photographic emulsion requires a knowledge of hypersensitizing techniques. The concept of hypersensitization dates back to Fox Talbot who discovered in 1843 that heating an emulsion prior to exposure increases its sensitivity. Abney and King reached an apparently contradictory conclusion 50 years later that a chilled emulsion increases efficiency during long exposures. I. S. Bowen and L. T. Clark summarized in a paper in 1940 all the hypersensitizing techniques—water bathing, pre-exposure, ammoniating, mercury-vapour treatment and high temperature baking. Various hyper-sensitization techniques are widely being employed since then. Nitrogen-baking and hydrogen-soaking of IIIa-J, and chilled-water treatment of IV-N have become standard practices. The hypersensitization

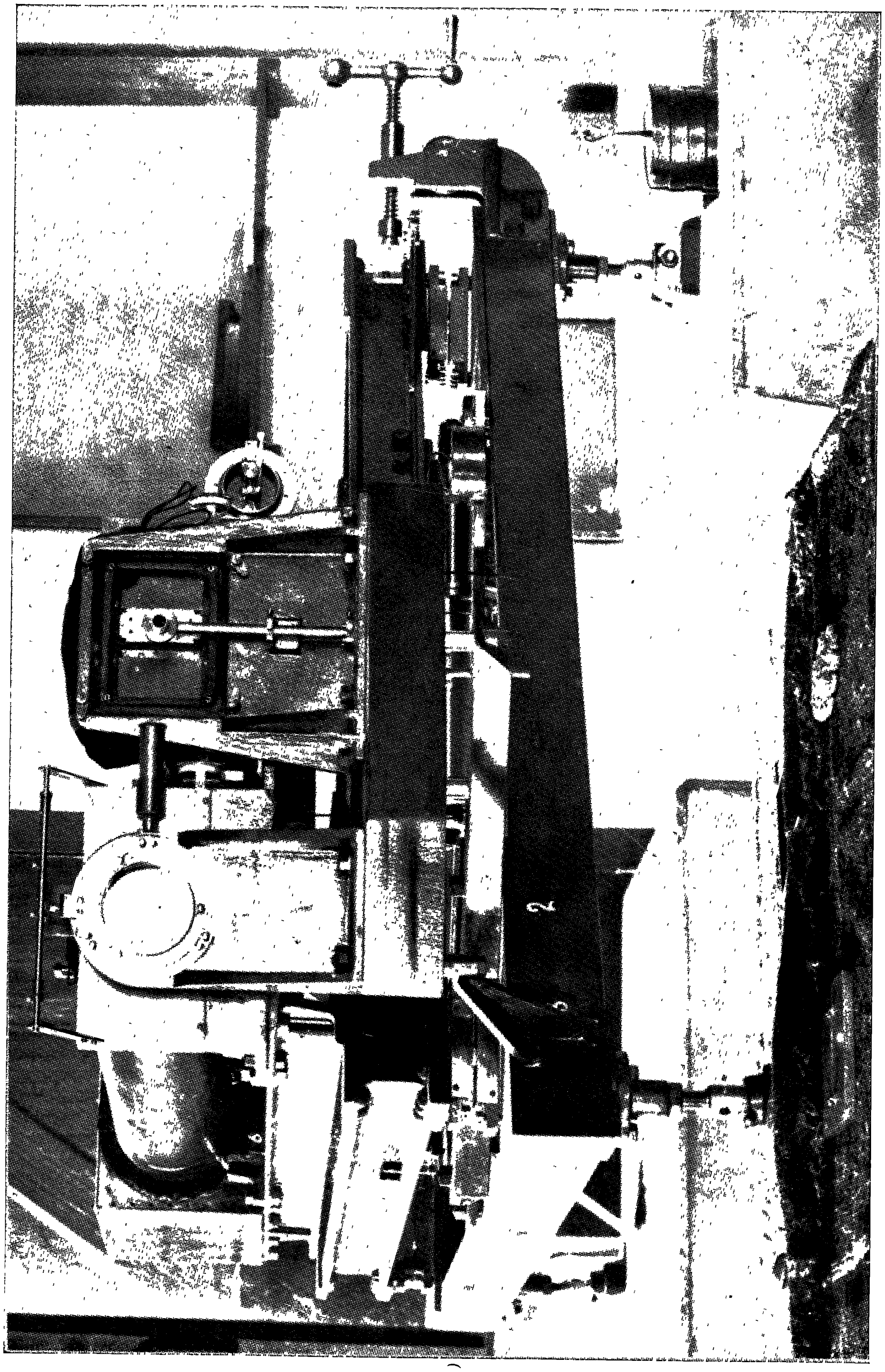

Figure 1. The spectroheliograph at Kodaikanal observatory installed 1903 (courtesy: Indian Institute of Astrophysics, Kodaikanal).

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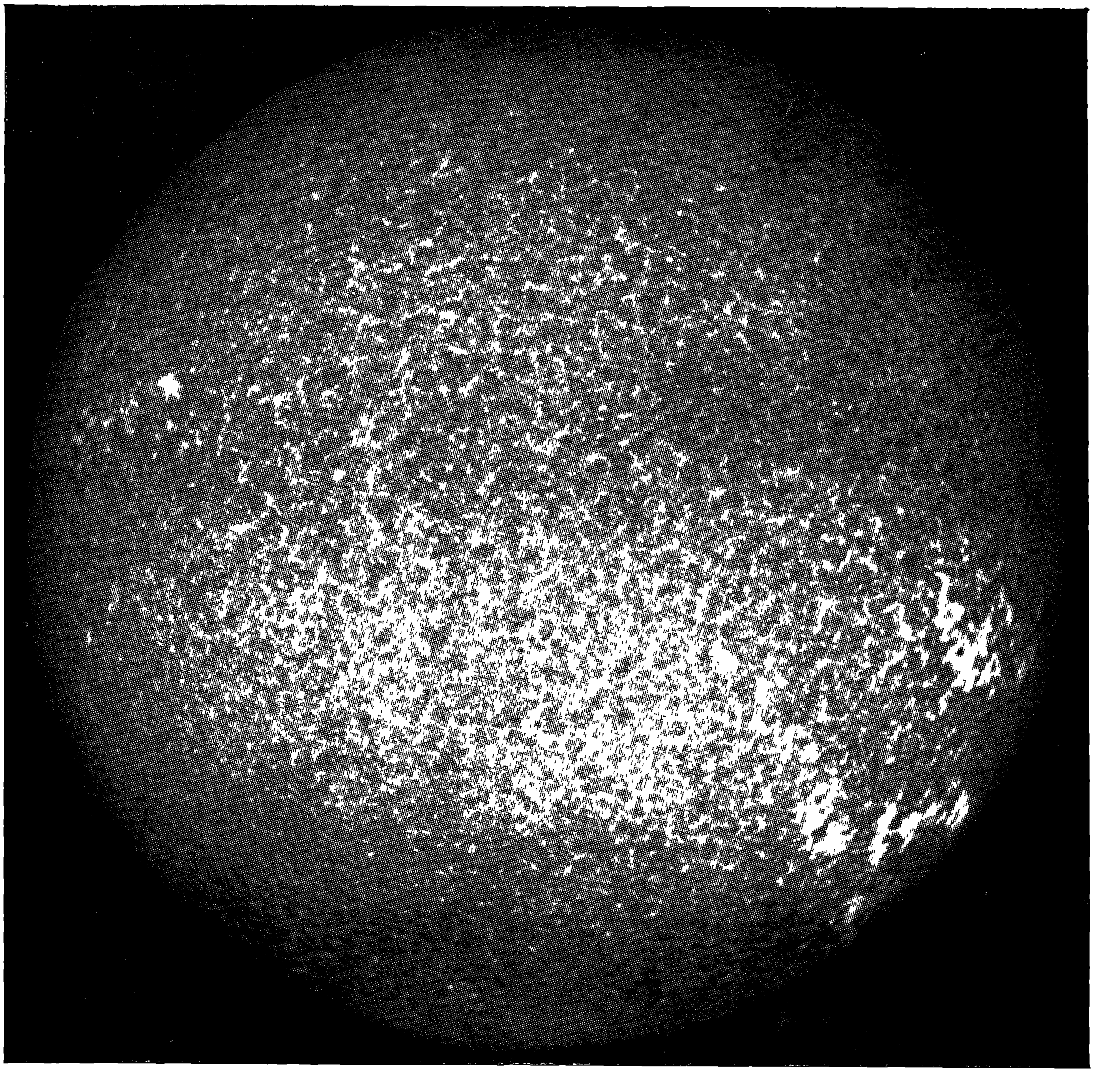

Figure 2. The positive print of the spectroheliogram in the K line of ionized calcium obtained at Kodaikanal 1909 April 16. The large bright patches known as calcium flocculi or 'plages' appear in the vicinity of sunspots and disturbed areas (courtesy : Indian Institute of Astrophysics, Kodaikanal).

techniques produce in general greater gain at longer exposures as compared with the untreated emulsions. That is, the hypersensitization reduces the low intensity reciprocity failure.

Photographic emulsion is easy to operate, and the best results can be obtained with a minimal knowledge of its hypersensitization, calibration, resolution, output signal-to-noise ratio and the detective quantum efficiency. Thus the photographic emulsion continues to be an efficient two-dimensional detector-cum-storage medium, despite the threat by the modern solid-state array detectors.

2. Variable stars

Figure 3 shows an AAVSO chart for a few long-period and semi-regular variables in Cancer. Among these, X Cancri varies semi-regularly between 9.3 mag and 10.9 mag with a period of about 170 days. This star falls in the range covered by the apparent path of the moon in the sky and is occasionally occulted by the moon. Thus its angular diameter has been measured at the McDonald observatory using high time-resolution lunar occultation records (Barthold *et al.*, 1972, *Astr. J.* 77 756). The angular diameter of 8.79 milli-arcsec implies a true radius of 20 $R_\odot$ since the trigonometric parallax is known to be 0.045 arcsec. X Cancri is a carbon star with an HD spectral classification of N3. The effective temperature scale of carbon stars has been highly uncertain (see, however, Tsuji, 1981, *J. Ap. Astr.* **2**, 95). The only available method of determining the temperature directly is to combine the multicolour photometric data with the angular diameter. X Cancri has thus played an importaut role in our understanding of the effective temperature scale of N-type carbon stars.

RT Cancri is another semi-regular variable in the field which varies between 8.3 mag and 9.4 mag with a period of about 90 days. Besides this periodicity, the mean light also varies with a longer periodicity of about 540 days. Thus, while some of the maxima are brighter, some others are fainter. RT Cancri is a giant of spectral type M5.

There are two long-period variables in the field shown in figure 3: R Cancri and V Cancri. R Cancri was discovered by Schwerd in 1829. It varies between 6.2 mag and 11.8 mag with a period of 361 days. It has crossed a maximum in 1981 December and is due for another in 1982 December. V Cancri, discovered by Auwers in 1870, has a shorter period of 272 days during which it varies between 7.5 mag and 13.9 mag. Its next maximum is expected in 1982 May–June. It has a 13th magnitude companion 10 arcsec away (Parkhurst, 1918, *Astr. J.* **31**, 111), which is probably not related to it physically. While R Cancri has a spectral type M, V Cancri is a S type star, varying between S0e at some maxima to S4.9e at later phases. S type stars are characterized by atomic lines of Zr I, Tc I, Ba II and Nd II and the molecular bands of ZrO, YO and LaO. The angular diameter of V Cancri has also been measured by lunar occultation techniques and amounts to 2.8 milli-arcsec (McGraw & Angel, 1974, *Astr. J.* **79**, 485). This star is so far away that a determination of its trigonometric parallax cannot be made, but a distance of 1300 pc is estimated using a statistical parallax (Barnes, 1973, *Ap. J. Suppl.* **25**, 369). This value yields an absolute radius of 400 $R_\odot$ for V Cancri. A comparison with photometric parameters yields a temperature of 2055 K.

Moving towards the east of these variables, we have the well known long-period variable R Leonis (figure 4) discovered by Koch 200 years ago. This was one of the first few variables discovered (see this column, 1981 September). N. R. Pogson made extensive observations of R Leonis, totalling 174 magnitude-estimates between 1854 and 1881. Of these, 117 were made in England and 56 from Madras. The remaining one was taken on board the steamship Pera on 1861 January 8 using the captain's seaglass of 2.5 in aperture. R Leonis varies between 4.4 mag and 11.3 mag becoming visible to the naked-eye at maximum. Chandler (1905, *Astr. J.* **24**, 1) on the basis of observations between 1757 and 1901, obtained a period of 312.8 days. He also noted the possibility that the period could be varying. Pogson's estimate of the period was 312.6 days which agrees with the later AAVSO estimates. Lockwood & Wing (1971, *Ap. J.* **169**, 63) obtained a slightly smaller period of 309.3 days from 30 infrared measures taken over six cycles in the 1960s. The next maximum is expected in 1982 May. Nather & Wild (1973, *Astr. J.* **78**, 628) applied lunar occultation techniques to estimate the angular diameter of R Leonis. Their estimate of 67 milliarcsec implies an enormous value of 1800 $R_\odot$ for the radius, if we assume a distance of 250 pc based on its statistical parallax. The spectrum of R Leo has been studied well, and the physical pulsation—covering a range of 140 $R_\odot$—measured. Extensive infrared spectroscopy by Kenneth Hinkle (1978, *Ap. J.* **220,** 210) and by Hinkle & Barnes (1979, *Ap. J.* **227,** 923; *Ap. J.* **234,** 548) has improved our understanding of the atmospheric structure of Mira type variables.

RY Sagittarii at minimum

N. Kameswara Rao from Indian Institute of Astrophysics, Bangalore, writes :

RY Sagittarii ($\alpha_{1982} = 19^h\ 15^m\ 22^s$, $\delta_{1982} = 33°\ 33'\ 14''$) is the second brightest star of the R Coronae Borealis type, which are carbon-rich irregular variables. RY Sgr is now undergoing a light minimum (*IAU Circ. No. 3662*). A direct plate taken on 1982 February 28 at the 1-m telescope of the Kavalur observatory by R. Rajamohan and K. K. Scaria at my request gives $m_v \sim 12.0$. RY Sgr would stay at the minimum for a few weeks and take a few months to attain its normal brightness of $m_v \sim 6.0$. It is an interesting object to observe in the coming months, and photoelectric measurements would be all the more desirable. See figure 5 for an identification chart

3. Lunar occultations

The earliest records of telescopic observations of lunar occultations are of Gassendus (1621) and Bullialdus (1623). These observers did not have clocks and deduced the time from the altitude of a reference star. Use of the clock commences with Hevelius (1939). As the art of determining the time improved, so did the accuracy of determining accurate times of occultation, especially at the Paris Observatory between 1680 and 1720. Good occultation records were made by Delisle at St Petersburg for the next three decades. Beginning with 1750 there have been continuous series of observations at Greenwich and Paris.

Precise times of lunar occultations are valuable since they can be translated into the instantaneous position of the moon if the geographical latitude and longitude of the observer are known accurately. These observations have been used, beginning with Simon Newcomb (1870), in studying the secular variation in moon's motion. Observations of lunar occultations have also helped in determining lunar limb profiles accurately. The grazing occultations have been particularly useful in these studies. The observer may simply record how often the star disappeared behind the rugged profile and reappeared subsequently. A photoelectric record with time marks would be very much superior to the simple count of disappearances. The determination of lunar limb profiles in this fashion yields the details of the lunar surface more accurately as compared to the photographic observations from groundbased telescopes. Thus, the occultation observations have been helpful even in planning the first landings on the moon.

During the last decade, fast photoelectric records have been increasingly used for the determination of the angular diameters of the stars. P. A. MacMahon

(1909, *M.N.R.A.S.* **69**, 126) had already speculated on recording photographically the time taken by the star to disappear behind the lunar disk. He expected that a star of 0.001 arcsec diameter would disappear in 1/500 s. Arthur Eddington (1909, *M.N.R. A.S.* **69**, 178), pointed out that a star of small angular diameter would give rise to a Fresnel diffraction pattern at the edge of the moon. The width of the pattern would be 0.008 arcsec and hence the diameters smaller than this are not measurable. J. D. Williams (1939, *Ap. J.* **80**, 467) showed that the stars with angular diameters ranging between 0.001 and 0.010 arcsec would modify the diffraction pattern in such a way that the angular diameters can still be estimated.

While the earliest attempt of recording the Fresnel diffraction fringes was photographic (M. A. Arnulf, 1936, *Comptes Rendus* **202**, 115), more accurate fast photoelectric methods were introduced by A. E. Whitford (1939, *Ap. J.* **89**, 472). As the occultation progresses, the diffraction fringes ('shadow bands') move across the observer. Thus, the photoelectric traces made with a high time resolution over the duration (0.1–0.2 s) of occultation would record the fringe pattern. Good summaries of the method and instrumentation have been published by R. E. Nather, D. S. Evans and M. M. McCants in 1970 (*Astr. J.* **75**). Detailed account of the instrumentation in operation at the Kavalur observatory is published by J. C. Bhattacharyya & A. Sundareswaran (1977, *Kodaikanal Obs. Bull. Ser. A* **2**, 69).

Another application of the lunar occultation techniques is in the discovery of close double stars. When the separation between two stars is less than the atmospheric seeing, it is not possible to discover their duplicity visually. One may push this limit slightly farther by studying the shape of the combined image of such double stars on astrographic plates. On the other hand, if such a system is occulted by the moon, the light would be seen to dim suddenly as the western component is occulted, and vanish fully only after the eastern component is also occulted. The total duration of occultation can thus be translated into the separation between the components. For a projected separation of 0.1 arcsec along the position angle of the occultation, the duration of occultation would be one-fifth of a second, which is not very hard to estimate. Fast photometric techniques allow one to discover double stars down to a separation of $\sim$ 0.001 arcsec. If the same occultation is observed from two different locations such that the position angles of the occultations are different, the true angular separation between the two stars and also the position angle can be derived.

The irregularities in the moon's limb over the length-scales of a few tens of metres affect the shape of the diffraction fringes. Thus, a comparison of the theoretical profile with the observed one yields also some information on the structures of such a size. Nather & Evans (1970) also discuss the possibility of improving the astrometric accuracy to 0.001 arcsec using lunar occultation techniques.

4. Artifical meteors

P. V. Kulkarni from Physical Research Laboratory, Ahmedabad, writes :

A group of observers onop of Gurushikhar (latitude 23° 38′ 58″, longitude 72° 46′ 39″E, altitude 1681 m) was engaged in making sky brightness measurements 1981 December 25. At 12^{h} 58^{m} UT (17^{h} 28^{m} IST) a bright moving object was noted by

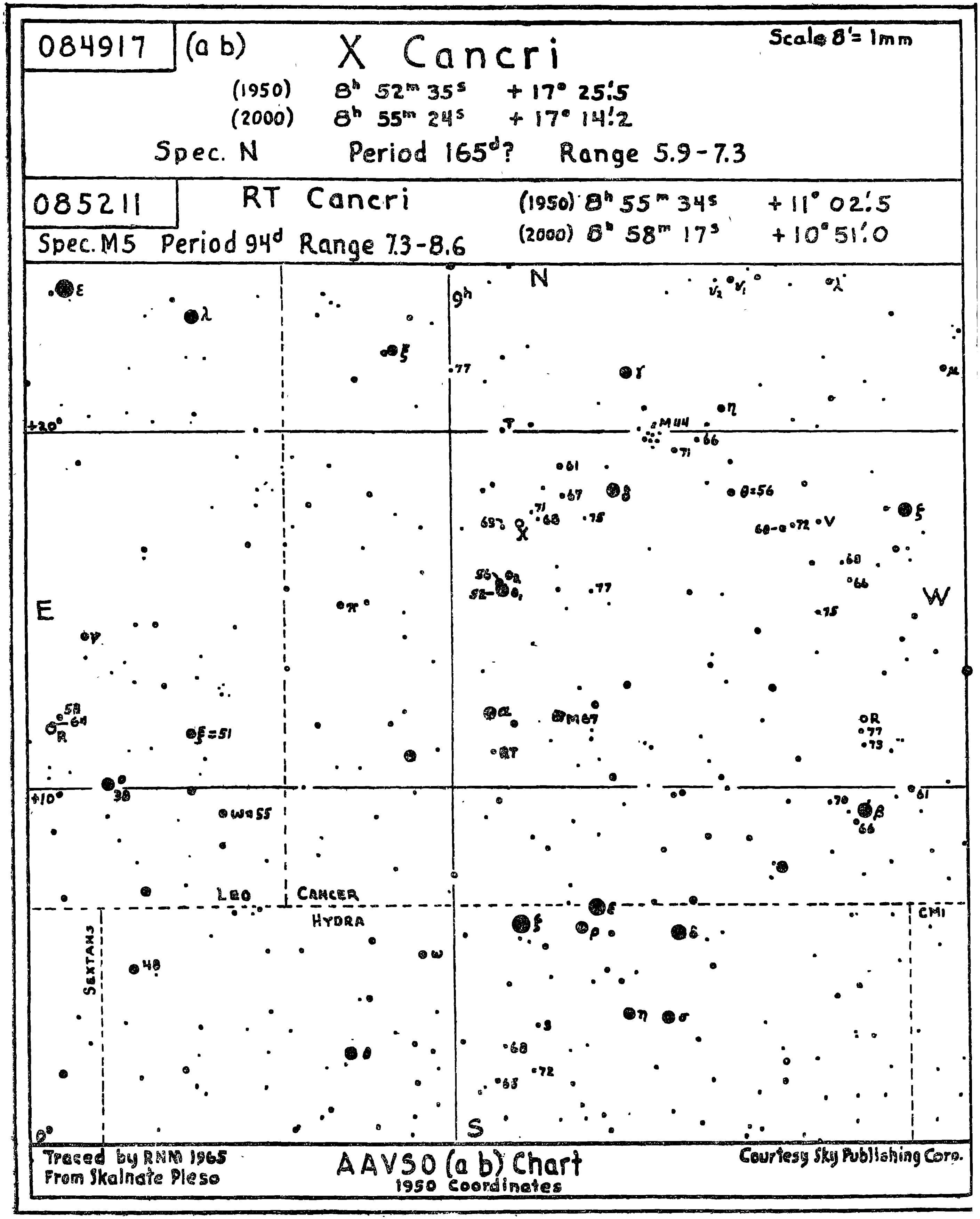

Figure 3. Identification chart for X Cancri (courtesy: AAVSO).

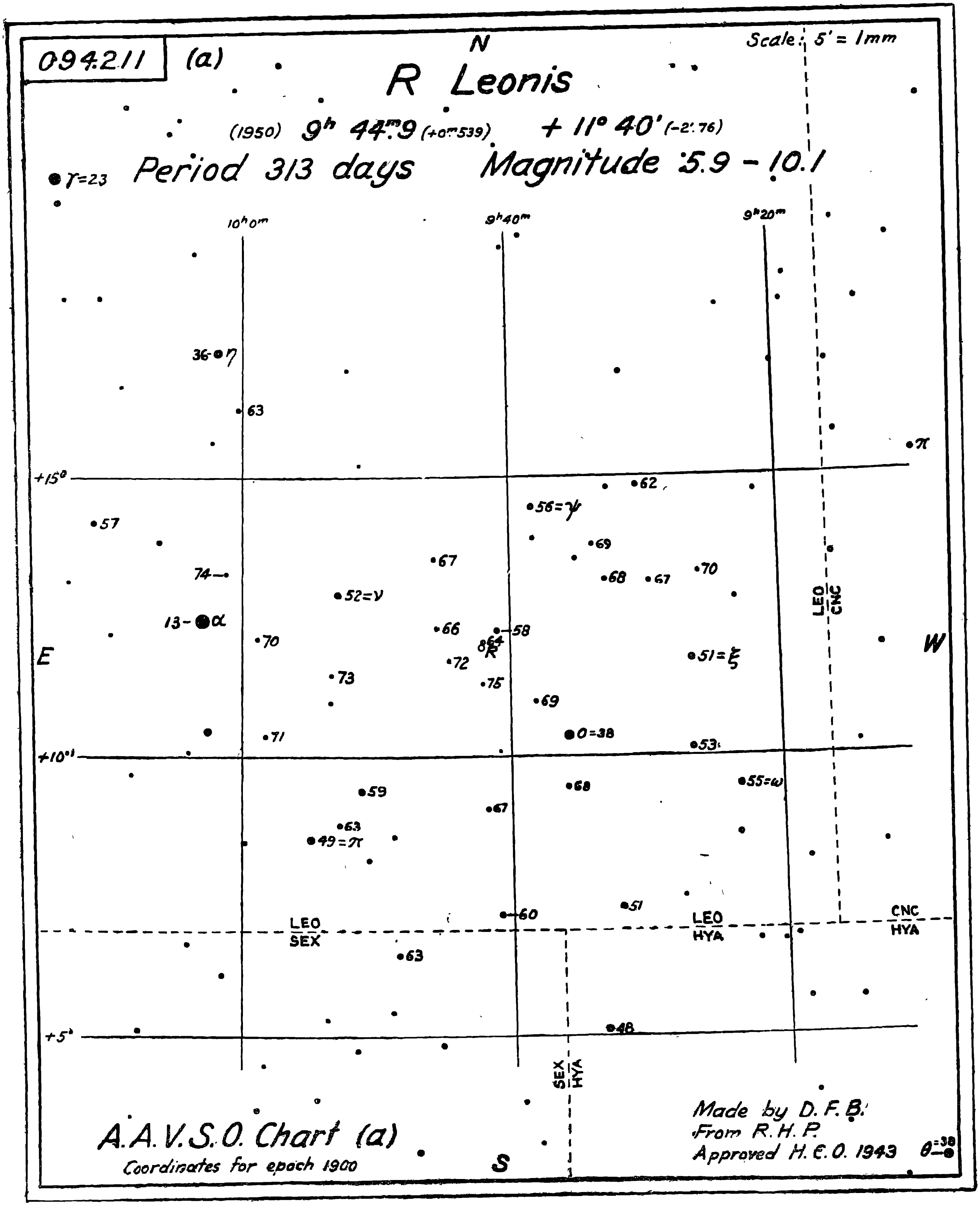

Figure 4. Identification chart for R Leonis (courtesy: AAVSO).

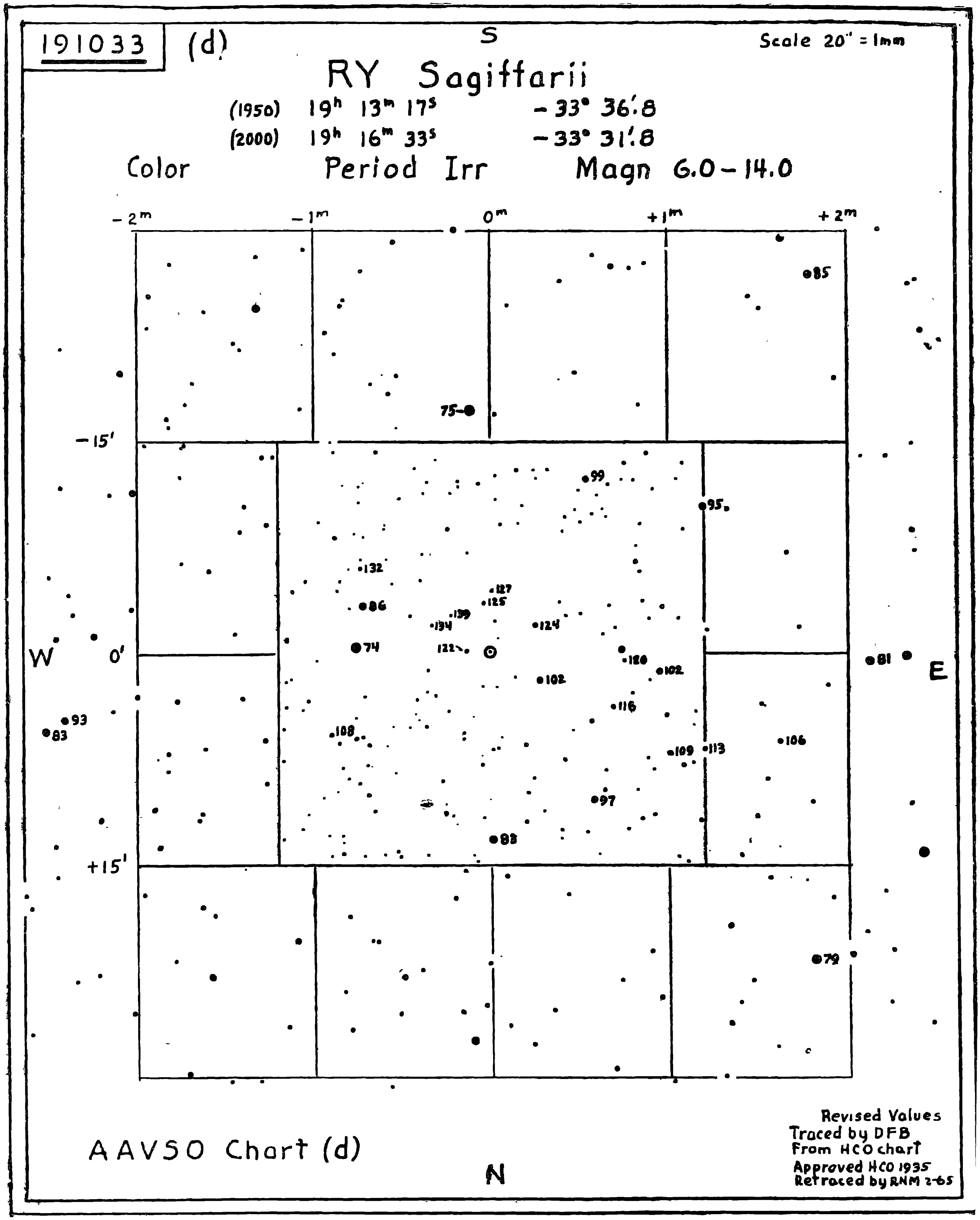

Figure 5. Identification chart for RY Sagittarii (courtesy: AAVSO).

atleast six observers. The object had a horizontal trajectory of low altitude from west-south-west towards east-north-east and a brightness of —2.5 mag. It left a visible trail of short duration throughout its appearance. During the interval of 18 s when it was visible, it covered an angle of 50°. Towards the end of its trajectory, the object showed a fluctuation in intensity before vanishing abruptly from view. The near-horizontal trajectory and its small inclination to the equator lead to the conclusion that the phenomenon was due to the re-entry of a low inclination satellite into the earth's atmosphere. Such phenomena are likely to be a common occurrence in the years to come as more and more satellites are launched.