A New-Star-Counting Device

H. TANABE AND K. MORI

Tokyo Astronomical Observatory

1 *INTRODUCTION*

Measurements of the magnitude distribution and integrated color of stellar fields in many parts of the sky by the star-counting method are important for studies of the structure of the Galaxy and the distribution of interstellar matter. On the other hand, in quantitative studies of the airglow and zodiacal light, we have to know the integrated brightness of the star field in order to subtract the background light from the measured light.

Up to the present, these star-counts have been made only for limited areas of the sky, since these measurements were made by using a reading microscope, and they would require much time and labor to extend the measurements to larger sky areas.

Recently, we completed a new star-counting instrument, which was designed by one (H.T.) of the authors so as to reduce the time and labor for the measurements. By using this instrument, we have started to measure the diameters of the star-images on the National Geographic Society and Palomar Observatory Sky Survey Atlas down to its limiting magnitude, which is about 20th magnitude.

2. *INSTRUMENT*

Before designing the instrument, we examined several methods of measurement for star-images, which have various sizes and are distributed randomly, with a certain accuracy and speed and without repetition or drop-out.

After these considerations we reached the conclusion that the human eye is still best in discriminating between the star and non-star images such as the images of nebulae and other heavenly bodies, small scratches and dust on the photographs, and non-uniform background, and in measuring individual stars separately in the case of complicated superposed images of more than two stars.

Our star-counting instrument consists of three parts: a projector which enlarges the original photograph 30 times, a measuring part with a Wollaston prism, and a tape-punch with an analogue-digital converter.

Figure 1 shows the principle of measurement of this instrument. A movable Wollaston prism is set in the optical path of the enlarging projector, and it splits a star-image into two separated images on the screen. Since the distance of separation of two images on the screen depends on the distance, L, of the prism from the screen, we can find the diameter of an original star-image from L_1, the distance at which separated images on the screen contact each other. To obtain the magnitude of each star from the diameter of the star-image, an experimental diameter-magnitude relation should be used. This relation would be found from stars whose magnitudes are known, for instance, the stars in the North Polar Sequence.

Figure 2 shows the screen of the projector. We can see several pairs of star-images separated by the Wollaston prism. At this prism position, one pair of images of the brightest star is in contact and the other smaller pairs are not. The star in contact is a 13th magnitude star.

Two photographs of the same field, in blue and red are set in the instrument as shown in Figure 3. They can be moved in both X and Y directions, and we can measure the diameters of blue and red images of a same star in succession by turning a mirror.

The Wollaston prism can be moved through a range of 400 mm along the optical axis of the projector, and the stars from 7.5 to the limiting magnitude are measurable. The accuracy of measurement of the prism position, L, is within ± 1 mm, which corresponds to less than ± 0.001 mm on the photograph.

Figure 4 shows the control panel, the screen and the tape-punch. We can operate the motions of photographs and prism, and the tape-punch at this position while watching the screen. Time required

https://doi.org/10.1017/S0252921100032449 Published online by Cambridge University Press

to measure the blue and red images of one star using this instrument is about 10 sec, which is much faster than that of the reading microscope method used by Takahashi and Huruhata.[1]

Figure 5 shows the diameter-magnitude relation found from measurements of the stars in the North Polar Sequence, but the ordinates of this figure are the prism position, L, which has a linear relation with the diameter The photographic and visual magnitudes of these stars are well determined, but their red magnitudes in the region of 6200∼6700Å are not well known. In this figure, their red magnitudes are taken from the values by Nassau and Burger,[2] and also from estimates with the formula given by Minkowski and Abell,[3]

$$(P-R)=1.6\,(P-V), \tag{1}$$

where P, V, and R are photographic, visual, and red magnitudes respectively.

From Figure 5, we deduce that the accuracy of measurement with this instrument is about ± 0.5 magnitude. It is supposed that this error is mainly due to the unsharpness of the boundary of star-images. However, the merit of this instrument is a possibility of measuring a great number of stars in a wide area of the sky within comparatively short time, even if the accuracy is not so high.

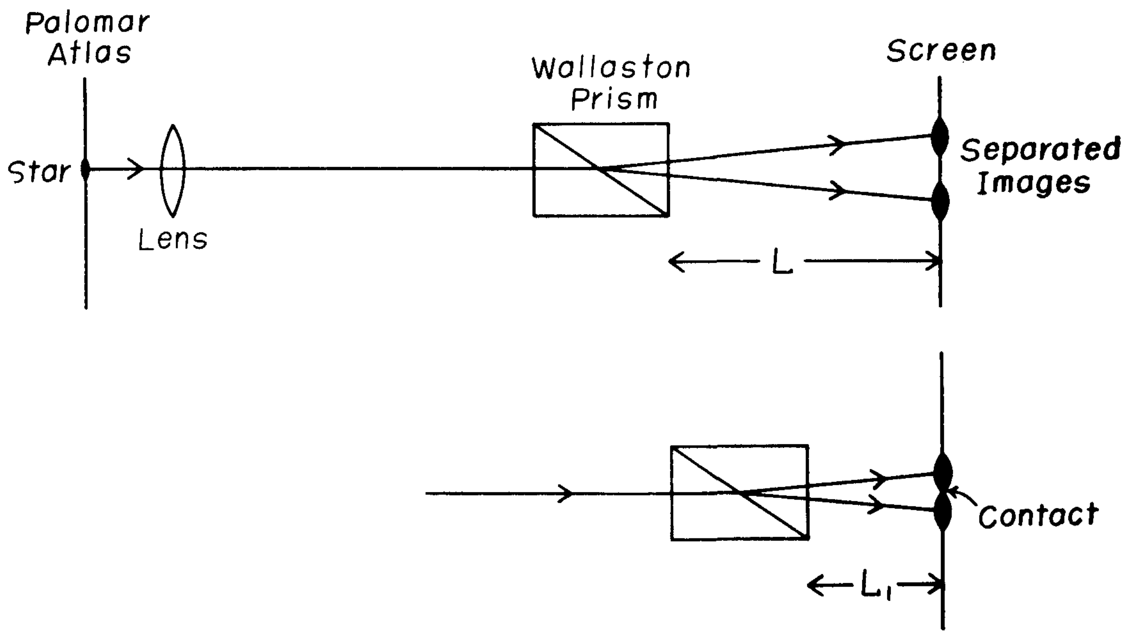


Fig. 1
Principle of measurement

3. *MEASUREMENTS*

As the first step of our plan, we measured the stars in two regions; the regions of the North Celestial Pole (Plate No. 570, 19^h43^m, $+90°00$) and the North Ecliptic Pole (Plate No. 550, 18^h12^m, $+66°00$), which are basically important for the studies of the airglow and zodiacal light.

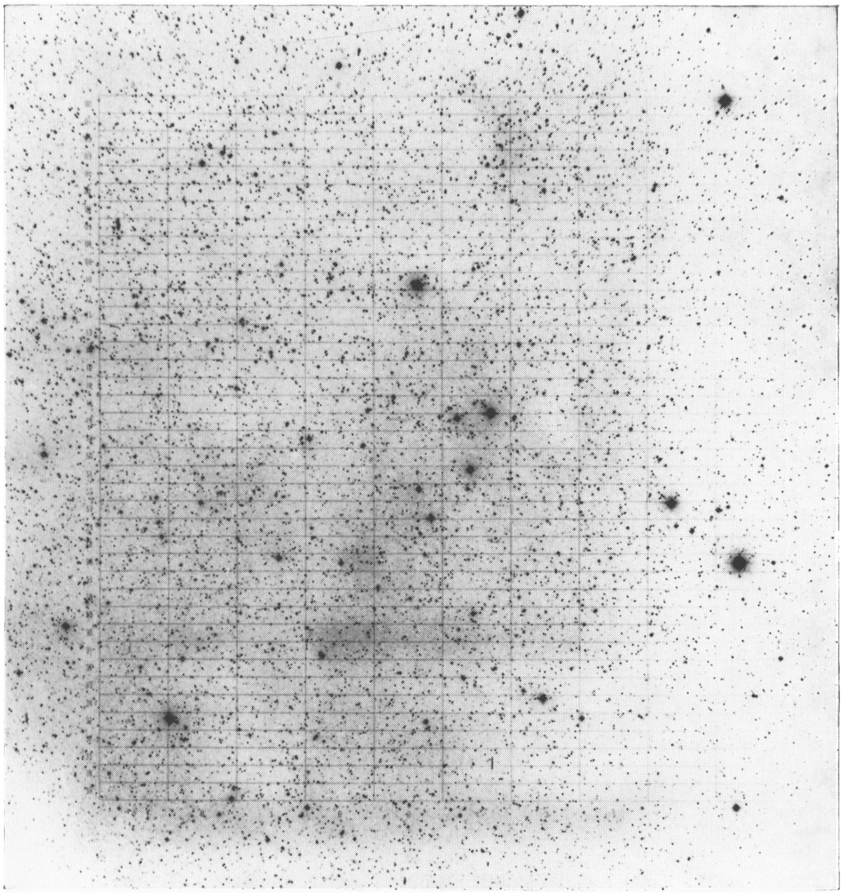
One of the two glass plates, which are put on the photographs, has a réseau of 100 mm (corresponding to 1°52′) square at the center of the photograph. The réseau has 400 sections and the size of one section is 10 mm × 2.5 mm.

The positions of stars referred to the réseau were recorded photographically, as shown in Figure 6, for identification of the stars and for reproducibility.

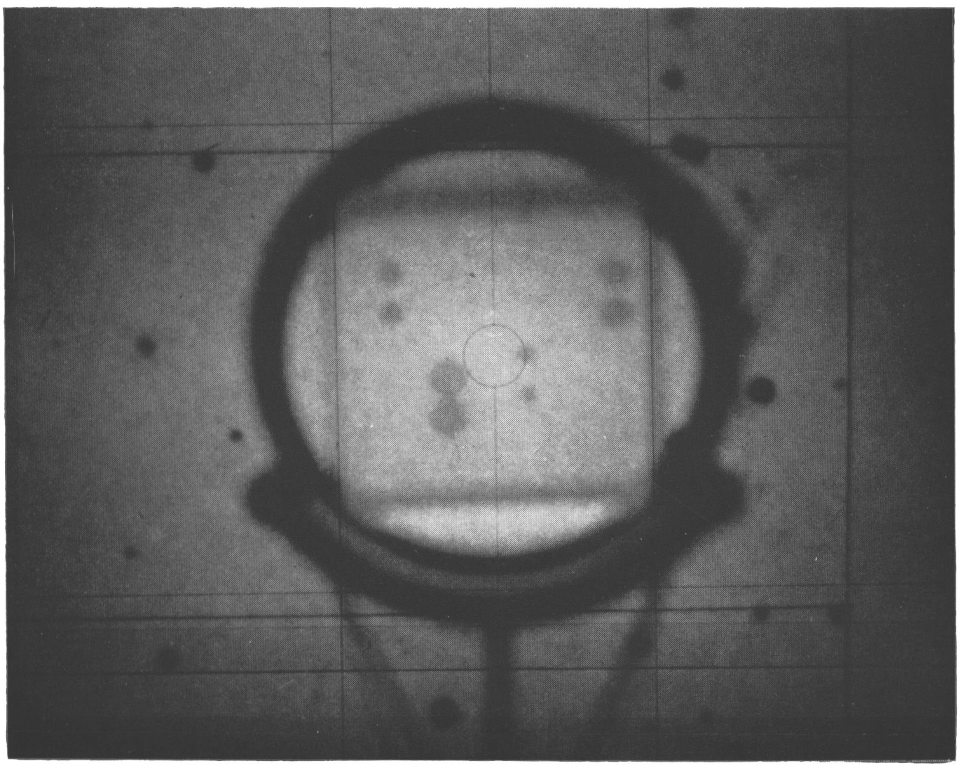
A pair of diameters, or rather the corresponding prism position (L_1), of the blue and red images of all the stars in each section were measured successively, and the data were punched out.

In addition to the star measurements, the number of nebulae in every section were counted with division into three classes of size: large, medium, and small.

13 077 stars in an area of 3.48 square degrees for the North Celestial Pole and 14 001 stars in 2.61 square degrees for the North Ecliptic Pole were measured.



TANABE AND MORI Fig. 6
Measured star field at the North Ecliptic Pole.



TANABE AND MORI Fig. 2
Star images projected on the screen.

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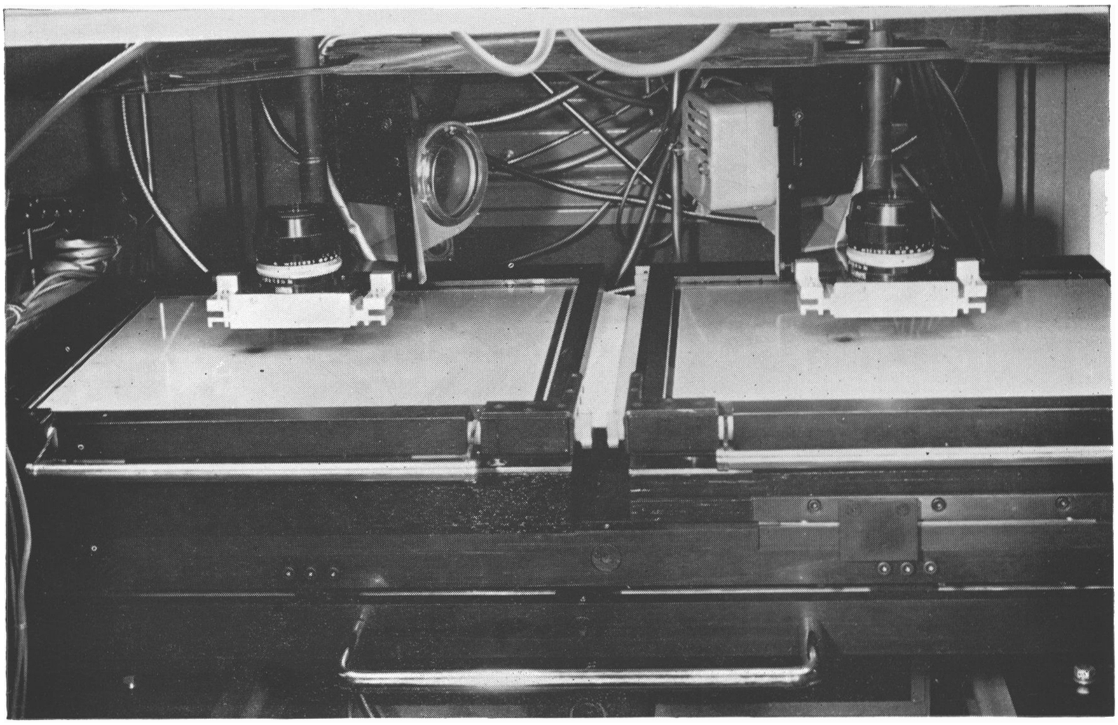

TANABE AND MORI Fig. 3
Two Palomar Atlas prints set on the movable table.

TANABE AND MORI Fig. 4
Control panel.

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4. *REDUCTION AND RESULTS*

The distributions of the blue and red magnitudes with intervals of 0.5 magnitude were obtained by the computer from the data tapes using the empirical relations shown in Figure 5.

The diameter-magnitude relations in Figure 5, which were found from the stars in the North Polar Sequence, would not be exactly applicable to the measurements in the photographs of other regions of the sky. However, since the Palomar Sky Atlas was made with great care,[3] we have assumed here that the relations in Figure 5 hold in other regions of the sky.

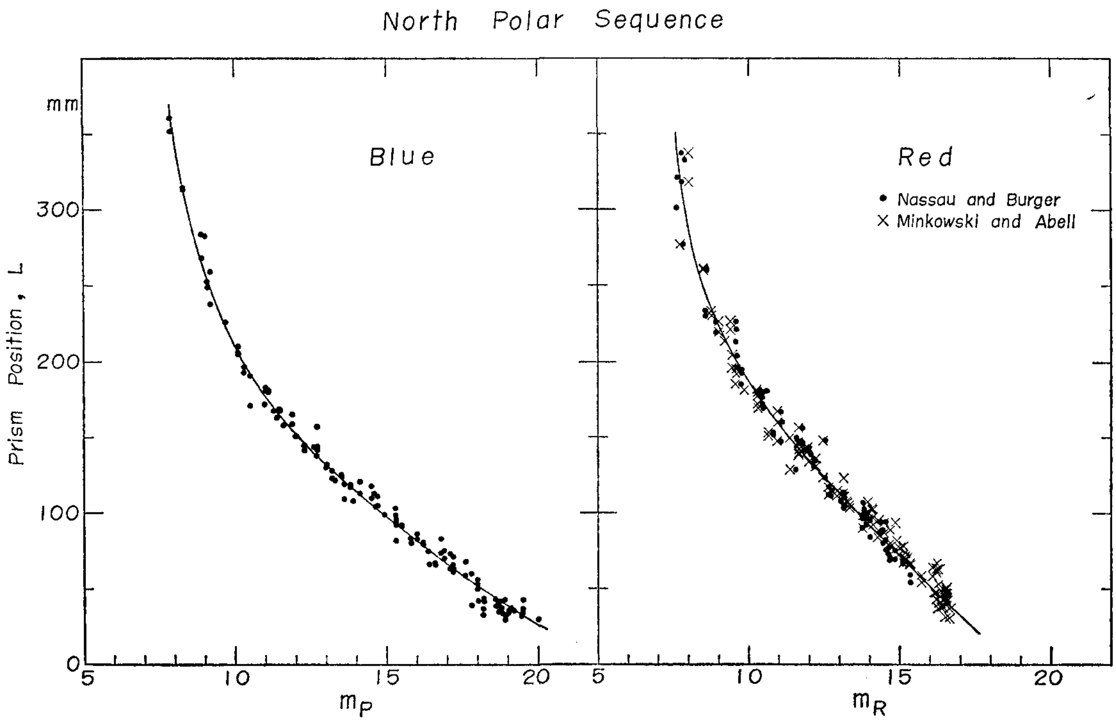

Fig. 5
Magnitude-diameter relation of the stars in the North Polar Sequence.

Figure 7 shows the blue and red magnitude distributions per square degree for the two sky regions. From this figure, we find that the limiting magnitudes of the Palomar Sky Atlas in both regions are 20.0 for the blue and 17.5 for the red.

In order to obtain the integrated brightness of the star fields, the magnitude distributions of the stars fainter than the limiting magnitudes must be known in addition to the results shown in Figure 7. For this purpose, the method used by Roach and Megill[4] was used. Letting N_m be the number of stars per square degree brighter than magnitude m averaged over the same galactic latitude, the rate of change of $\log_{10}N_m$ was obtained. Since the galactic latitudes of the North Celestial Pole and the North Ecliptic Pole are approximately the same, $b \approx +30°$, the values of N_m for the photographic magnitude at $b = \pm 30°$ were taken from Allen's table[5] and $d(\log_{10}N_m)/dm$ was obtained by the least-squares method;

$$\frac{d(\log_{10}N_m)}{dm} = 0.456 + 0.00562m - 0.000956m^2. \qquad (2)$$

From this equation, we can find that $d(\log_{10}N_m)/dm$ at $b = \pm 30°$ becomes zero at 25th magnitude. Then the blue magnitude distributions in Figure 7 can be extended to this magnitude.

For the red magnitude distributions, we assumed that $d(\log_{10}N_m)/dm$ in the region fainter than the limiting magnitude is linear, and extended the distributions so as to give the same total number of stars as that of the blue ones.

The results of our star-counts are shown in Figure 8 and Table 1. In Figure 8, the contributions from the stars of each magnitude to the integrated brightness are shown, and it is seen that the contri-

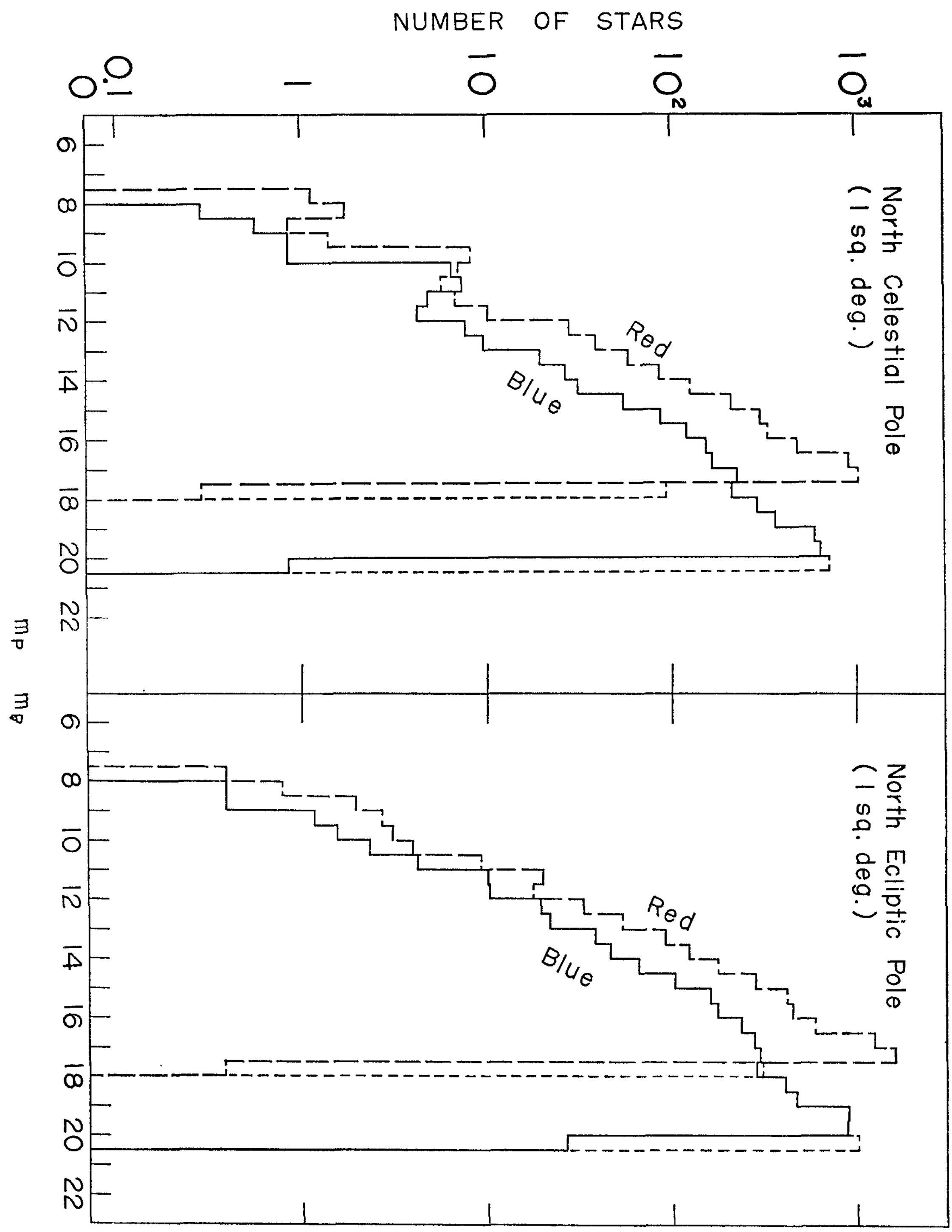

Fig. 7
Number of stars in 1 square degree for each half magnitude.

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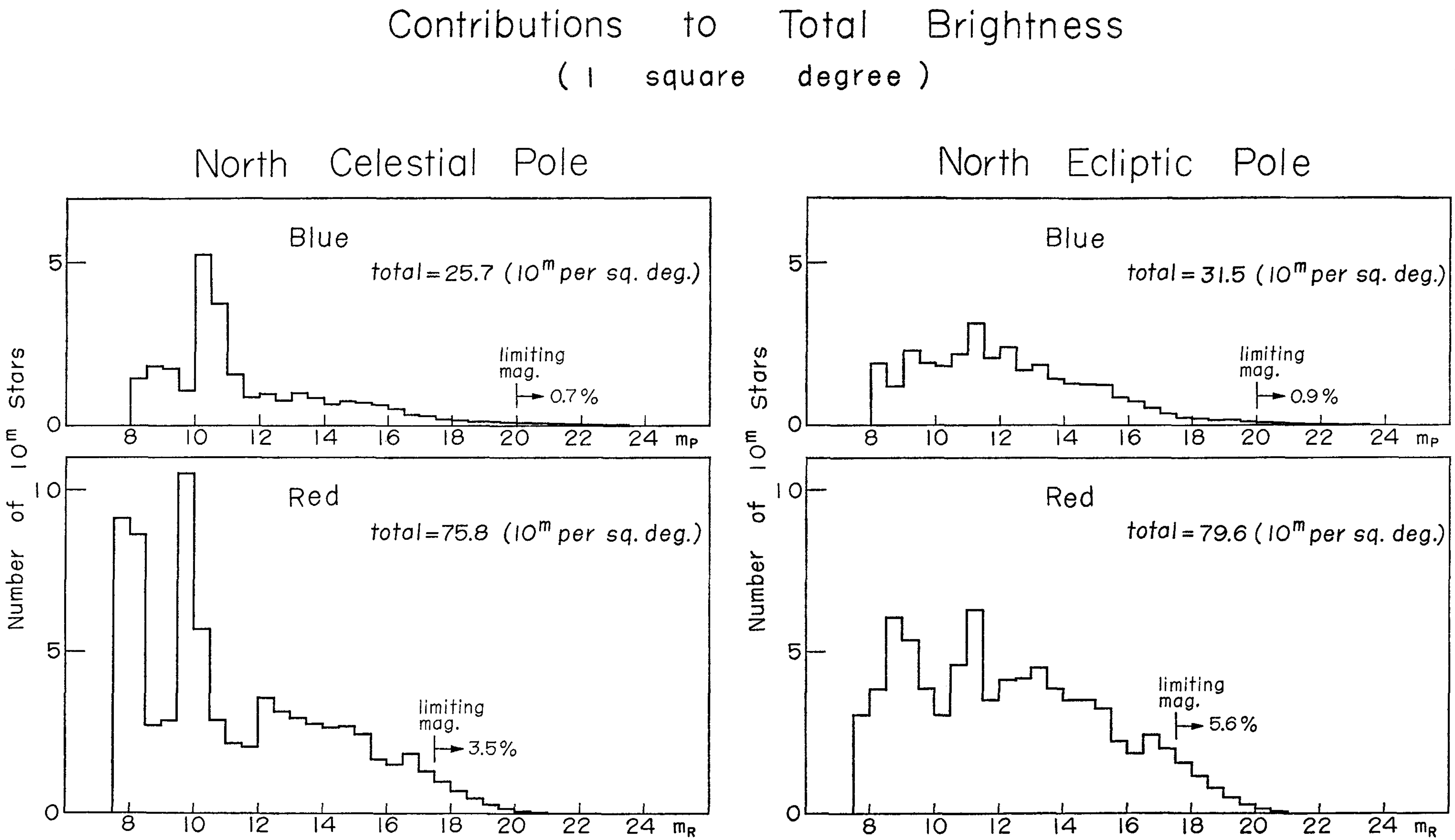

Fig. 8

Contributions of stars for each half magnitude to the total brightness.

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butions from the stars fainter than the limiting magnitudes are less than a few per cent. In Table 1, the integrated brightnesses in numbers of 10th visual magnitude stars were estimated from measured blue and red magnitudes using equation (1), and our results compared to the values obtained by Roach and Megill.[4]

Integrated Starlight

	North Celestial Pole: present work	North Celestial Pole: Roach, Megill	North Ecliptic Pole: present work	North Ecliptic Pole: Roach, Megill
photographic, $S_{10}(p)$	26	29	32	34
visual, $S_{10}(v)$	(51)	55	(57)	66
red, $S_{10}(r)$	76		80	
color, $m_p - m_v$	$+0\overset{m}{.}72$	$+0\overset{m}{.}68$	$+0\overset{m}{.}63$	$+0\overset{m}{.}72$

Nebulae

	m_p	North Celestial Pole: number (per sq. deg.)	North Celestial Pole: $S_{10}(p)$	North Ecliptic Pole: number (per sq. deg.)	North Ecliptic Pole: $S_{10}(p)$
large	~15	1.44	~0.01	4.60	~0.04
medium	~17	9.48	~0.01	73.56	~0.09
small	~19	408.9	~0.08	1488.5	~0.30
total		419.8	~0.10	1566.7	~0.43

Fig. 9

The contributions to the total brightness from the nebulae, whose magnitudes were assumed from the catalogue of Zwicky and Herzog,[6] to be ~15 (large), ~17 (medium), and ~19 (small), are very small.

5. *ACKNOWLEDGEMENTS*

The authors express their appreciation to Dr. M. Huruhata, director of Tokyo Astronomica Observatory, for invaluable advice and encouragement.

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