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利用基本天体测量仪器开展天文测光研究

朱 紫 [1,2]

(1. 中国科学院陕西天文台 临潼 710600)
(2. 中国科学技术大学天体物理中心 合肥 230026)

摘 要

讨论有关天体测量中的测光问题，介绍一些地面天体测量仪器和空间天体测量望远镜的测光研究。给出一种测光资料的处理方法，并建议利用 DCMT 开展天文测光课题研究。

关 键 词 技术：测光 — 天体测量 — 仪器设备：检测器

Photometry on Fundamental Astrometric Instruments

Zhu Zi[1,2]

(1. Shaanxi Astronomical Observatory, The Chinese Academy of Sciences, Lintong 710600)
(2. Centre for Astrophysics, University of Sciences and Technology of China, Hefei 230026)

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Abstract

The Problem of astrometric photometry is discussed in this paper. The photometric capabilities on both the ground-based astrometric instruments and space telescopes are presented. A method of the photometric reduction is introduced. A photometric plan on the DCMT is proposed.

Key words techniques: photometry—astrometry—instrumentation: detectors

1 Introduction

The photometry of stars is of fundamental importance to astronomy. The measurement of the energy output of stars at several wavelengths leads to information on the models of stellar structure and atmosphere. The color of stars, as determined by measurements at two different spectral regions, gives information on the star's temperature. Photometry is often needed to

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establish a stellar distance and size. The Hertzsprung–Russell diagram, the key to understanding stellar evolution, is based on photometry and spectroscopy. Sometimes the photometric measurementsare used as a probe of interstellar dust. Many stars are variable in their light output either due to internal changes or to an occasional eclipse by a binary partner. In both cases, the light curves obtained by photometry lead to important information about the structure and character of the stars, especially at several wavelengths. So photometry is one of the most important observational techniques in astronomy.

As the main goal, astrometry aims at the determination of accurate positions of stars in order to establish a high precise reference frame. In modern astrometry, the way of photoelectric observation is widely used. It means the determination of stellar positions is realized by photometric observation of stars. For example, on the most astrometric instruments, the photomultipliers or CCDs are often accepted as detectors, so that the astrometric observation of stars gives the output quantities of one or two dimensional photon counts. From those observed quantities we mainly focus on the astrometric parameters to study the accurate positions of stars and to derive the proper motion and parallax. But the investigation of the photometric information from astrometric observations is also very significant. Some observation is made at several wavelengths, like at the U, B, and V bands. Although the purpose of the observation is mainly focused on the investigation of the influence of color equation on the positional errors of stars and color corrections,yet from that we could also determine the stellar magnitudes at each observing band and establish a photometric system which could be approximated to a standard photometric system, for example, to the standard UBV system of Johnson and Morgan[1]. These observations could play an important role in astrophysical sense.

2 Observation

Astrometry has a very enormous observational production. The meridian circle, a sort of the ground-based fundamental astrometric telescope, can make about one hundred thousand observations of stars per year, when the moving slit micrometer is accepted(CMC8 1994)[2]. The meridian circle equipped with a CCD detector of CRAF/Cassini 1024×1024 chip (12μ pixel) and observing in drift scan mode, can observe about 9000 stars per hour[3]. The space astrometry has even more observing production. A CCD space astrometry system could contain 400 million stars of observational program for frequent observation in the period of 5 years and obtain the photometric information in a broad-band[4].

At present, two kinds of detectors are widely used in astrometry, namely the photomultiplier and the Charge-Coupled Device (CCD). The multi-slit photoelectric micrometer proposed by Hoeg[5] is equipped for observation on the traditional meridian circle and astrolabe. The main part of the micrometer is composed of a scanning of fixed slit plate (cf. Zhu 1990)[6], a photomultiplier and a photon counting system. During the scanning of the micrometer, photons from the star light will be collected when the star transit the field of view. Several observing strategies have been developed for making area CCD observation. A number of telescopes employ CCD in drift scan mode[7], in which the telescope is kept stationary and the sky image is clocked across the CCD at the diurnal rate. Because of high quantum efficiency and direct imaging capabilities, observation with the CCD is more significant both for astrometry and photometry than with the photomultiplier. A star image scanned by a slit and a CCD micrometer is shown in (*a*) and (*b*) of the Figure 1.

Photometric observation by the multi-slit micrometer on the Tokyo Photoelectric Meridian Circle (PMC) was reported by Yoshizawa *et al.*[8,9] Helmer *et al.*[10,11] described photoelectric observation on the Carlsbery Automatic Meridian Cirde (CAMC). A CCD Observation on the Flagstaff Astrometric Scanning Transit Telescope (FASTT) with a drift mode was discussed by Stone and Monet[12], Stone[3]. HIPPARCOS, the ESA space astrometric satellite with the Image Dissector Tube (IDT), had missions both of astrometry and photometry. The results of photometry were given by Kovalevsky[13], Morando[14] and Hoeg[15].A new generation of CCD space astrometric satellite with a huge observing capability was proposed by Hoeg[4], which is named ROEMER. Table 1 shows the photometric performances of these projects.

Very recent photometric results derived from the first 30 months observations by HIPPARCOS, combining with its solution of stellar parallaxes, led to the determination of absolute magnitude. Taking the ground-based B V color indices, the HR diagram was thereafter constructed by Perryman *et al*[16]. Further investigation should provide us with very significant and rich information for astrophysics.

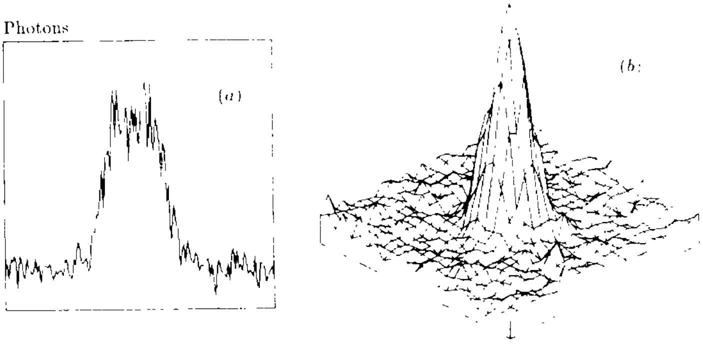

Figure 1 The output quantity of the observation by a slit micrometer in (*a*) and by a CCD in (*b*)

Table 1 Photometric Performance of Astrometric Project
(W=broad-band, PMP=Photoelectric MultiPlier, IDT=Image Dissector Tube)

Project	Mag Accuracy	Limiting Mag	Bands	detector
PMC	0.08mag	12.3	W	PMP
CAMC	0.05mag	15.4	W,V	PMP
FASTT	0.05mag	17.5	W	CCD
HIPPARCOS	0.02mag	13.0	W,U,V	IDT
ROEMER	0.005mag ($M_V < 12$)	18.0	W,UBVRI	CCD

3 Reduction of Magnitude

For reduction of magnitude we could here consider only the observation by the V-shaped slit micrometer. The fixed slit scanning or the CCD's observation can be discussed in the similar way. The micrometer on the Danish-Chinese Meridian Circle (DCMT) adapted a V-shaped moving slit described by Li *et al*[17]. During the whole time of the observation for a star, the V-shaped slit plate scans a small field of the sky centered on the back-and-forth with a specified scan amplitude. Thus the image motion relative to the slit has a speed of $V_i = V_{\rm s} \pm 15\cos\delta$, here $V_{\rm s}$ is the constant speed of scanning. For one transit of image to a slit, the observed output quantity in the continuous case is expressed as

$$s(t) = f(t-\tau) + n(t), \tag{1}$$

where

$$f(t-\tau) = A_{\rm m}\int g(t_1 - (t-\tau))w(t_1){\rm d}t_1 + b.$$

The $f(t-\tau)$ is the average image profile, and $n(t)$, the additive noise. The b is the background counts. The amplitude $A_{\rm m}$ is proportional to the flux from the observed star. The $g(t)$ denotes the space distribution of stellar image, and $w(t)$, a trapezoid weighting function which is dependent on the parameters of the slit and on the stellar motion. The detailed description for these functions and parameters in above equation were expressed by Zhu[18].

The contribution of the sky background can be subtracted very precisely from the observed total photon counts in the case of such scanning observation. The performance of observational noises was discussed by Lena[19]. For observation of brighter star, the main contribution of noise should be caused by the Poissonian stochastic processing.

Because the slit width in the direction of scanning (right ascension) is constant, the flux from the observed star F is proportional to the speed of relative image motion $V_{\rm I}$ and to the total photon counts of image profile C, which are obtained by integration of the counts from the profile minus the background counts. Thus

$$F \propto V_{\rm I} \cdot C_*$$

After Pogson magnitude scale, we can derive the error of magnitude reduction $\sigma_{\rm m}$, which may be described as the intrinsic imprecision of magnitude determination and is the lower limit of total errors. That is expressed as

$$\sigma_{\rm m} = \frac{2.5}{\ln 10}\frac{N}{C_*} = 1.086\frac{N}{C_*} = 1.086\left(\frac{S}{N}\right)^{-1}, \tag{2}$$

where N is the total noises in the star profile in the region of integration, and S/N denotes the signal to noise ratio. The Poissonian noise plays a dominant role for the bright star observation. In this case, the total noise could be described as

$$N = \sqrt{C_* + C_{\rm sky}},$$

where $C_{\rm sky}$ is total sky background counts of the integral region.

From the mean error σ of image location estimation by using a trimmed median filter (cf. Hoeg 1970 and Yoshizawa 1993)[5,20]

$$\sigma = \frac{\sqrt{C_* + C_{\rm sky}}}{2(C_*/s)} = \frac{s}{2} \times \left(\frac{S}{N}\right)^{-1}$$

we can find that the astrometric imprecision is proportional to the photometric imprecision. Or in other words, the astrometric location error consists of two error sources, namely the photometric imprecision and the atmospheric influence, because here s is the seeing size.

The reduction of magnitude of the observed stars is given by the following expression

$$m = m_{\rm V} + (D_0 + D'(t - t_0)) + (K_0 + (K'(t - t_0)) \sec z \tag{3}$$

where $m_{\rm V}$ is the observed magnitude; D_0 and K_0 are the zero point and the coefficient of extinction at time t_0; while D' and K' are their respective rates of change. The sec z is the air mass at the zenith of z. Thirty to forty magnitude standard stars could be chosen each night, and these four constants are determined from a least-squares solution based on the well determined magnitude standard stars.

Because of the difference between the observed magnitude and a standard system caused by the instrument system, the observed magnitude must be transformed to the standard photometric system (cf. Henden 1982)[21]. The transformation is as follows

$$M = m + aC + b \tag{4}$$

where a and b are constant which are unique to the photometer in use and C is the standard color of the star.

4 Proposal

The DCMT (Danish-Chinese Meridian Circle) was mounted in April 1990 at Shaanxi Astronomical Observatory. Its focal length is 2667.5 mm and the effective aperture is 240 mm. It has a plate scale of 77.325 arcsec/mm. The field of view is about 10 arc-minutes. The telescope has a optical system of total reflection. So the instrument itself should have not the color equation introducing in the photometric observations. We propose to equip the telescope with a set of CCDs on the field of view, each of which has a filter that establishes a photometric system approximate to the standard system. Considering a CCD of 800 × 800 pixels with pixel size of 9μm, or a 512 × 512 CCD with pixel size of 15 μm, it could cover nearly all the field of view. With respect to the astrometric accuracy, the pixel size should not be too large. If the drift scan mode is adopted, the exposure time will be about 38 seconds for the observation of equatorial stars. Suppose three CCD systems are equipped on the DCMT and a set of filters in U, B, and V are adapted, then we could observe stars at the same time at three colors. The observation could establish an approximate UBV standard system . The photometric observation of DCMT could provide a mass of stars with the mean error of magnitude of 0.02 mag and the limited magnitude of about 16 mag.

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