Observations of small bodies in the Solar system with the 50/70-cm Schmidt telescope of the Rozhen NAO

A. Kostov[1], T. Bonev[1], B. Bilkina[1], V. Krumov[1,2], G. Borisov[1], V. Ivanova[1]
[1] Institute of Astronomy, Bulgarian Academy of Science
[2] Department of Astronomy, University of Sofia
akostov@astro.bas.bg, vkrumov@astro.bas.bg
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Abstract. Observations of small bodies in the Solar system is the main field of research of sector "Solar system" in the Institute of Astronomy at the Bulgarian Academy of Sciences. In this work we present our methods for observing comets and asteroids with the 50/70 cm Schmidt telescope, and the following data reduction. The astrometric parameters of the Schmidt telescope are presented and discussed. As an example we present astrometrically and photometrically reduced observations of comet 9P/Tempel 1.
Key words: Schmidt telescope, small bodies, astrometry, photometry, Solar system

Наблюдения на малки тела от Слънчевата система с 50/70 cm Шмит телескоп на НАО-Рожен

А. Костов, Т. Бонев, Б. Билкина, В. Крумов, Г. Борисов, В. Иванова

Наблюденията на малки тела от Слънчевата система са основната задача на сектор "Слънчева система" на Института по астрономия към БАН. Ние представяме спецификата на кометните и астероидни наблюдения с Шмит телескопа на НАО-Рожен. Изследвани и дискутирани са астрометричните параметри на телескопа. Описани са процедурите за обработка на изображения. Представени са резултатите от обработените наблюдения на кометата 9P/Tempel 1.

Introduction

The Schmidt telescopes are usually used in researches which require wide field of view. These researches include astronomical surveys, comet and asteroid observations, observations of extended objects, search for novae and their photometry in nearby galaxies. One of the most popular surveys, the Palomar Observatory Sky Survey, was made with the 48-inch Palomar Schmidt telescope. Presently some of the leading programs dealing with small bodies, are conducted with Schmidt telescopes (LONEOS, ADAS, CSS, NEAT). In this paper we describe observations of small bodies in the Solar system obtained with the Schmidt telescope of the National Astronomical Observatory, Rozhen.

1 The Rozhen Schmidt telescope

The focal length of the telescope is 172 cm. The detector used is a ST8 CCD camera. This imaging CCD has a full frame resolution of 1530×1020 pixels of 9 micrometer squared, which yields a scale of 1.08 arcsec/px, and a field of view (FOV) $= 27.5 \times 18.4$ arcmin. The filters available are U, B, V, R, I. Our images were obtained predominantly with Bessel B and R filters.

2 Astrometry

For the astrometrical reduction we need reference stars in the observed FOV. Because of the orbital motion of comets and asteroids the FOV of almost every new observation is different from the previous one. In the case of CCD astrometry the situation is more difficult because of the small FOV. Under these conditions we need a catalogue with reference stars which is rich enough to guarantee the presence of sufficient number of stars in every observed FOV. In our work we use the USNO-A2.0 Catalog of Astrometric Standards. We developed a software package which performs simultaneous derivation of positions and photometric calibration of the observations. After manual selection of 3 stars this software makes automatically identification of all reference stars in the FOV and derives the astrometric solution. Our astrometric solution is a linear one. In order to verify if we should implement terms of higher order to the linear model we checked our measurements for two possible systematic errors:(1) radial dependence of the residuals between measured and catalogue positions of the reference stars (USNO), caused by spherical aberration, and (2) dependence of the residuals caused by the differential refraction.

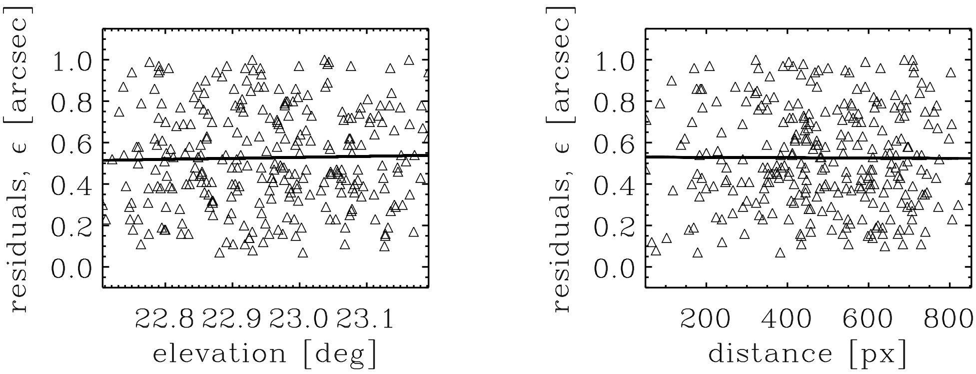

Fig. 1. Dependence of the residuals due to the differential refraction (left). Radial dependence of the residuals (right).

Fig. 1 (left) shows the dependence of the residuals on elevation. The residuals are derived from an image obtained at 23° above the horizon. The expected differential refraction at this zenith distance is 2.2 arcsec for a FOV of 20 arcmin. The residuals are randomly distributed and do not show any systematic dependence on elevation. Fig. 1 (right) shows the radial dependence of the residuals. The residuals are randomly distributed and do not exhibit systematic deviations with increasing distance from the optical axis. We shall show that the reason for this result is the small FOV. The total difference ϵ shown in Fig. 1 is defined as $\epsilon = \sqrt{(\Delta\alpha\cos\delta)^2 + (\Delta\delta)^2}$, where $\Delta\alpha$ and $\Delta\delta$ are the differences between our solution and the catalogue coordinates of right ascension and declination, respectively. Analysis of the Schmidt telescope optical system was performed about 20 years ago. At this time the telescope was used with photographic plates which covered a FOV of $5^\circ \times 5^\circ$. The coefficient of distortion found by this analysis was $c = -0.103 \times 10^{-6}\,\mathrm{mm}^{-2}$, comparable to the coefficients of distortion derived for other similar instruments [Ryl'kov *et al.* (1996)]. The value of the optical aberrations is proportional to d^2, where d is the distance from the optical axis. With the above mentioned coefficient we obtain a displacement of 0.3 px at the corners of our detector. This value is inside of the residuals used by our software as criterion for selection of the reference stars.

3 Photometry

The reference stars which were used for the astrometry serve as a source of photometric standard stars. Justification for use of the USNO catalogue for photometry is given by [Gonzaléz-Pérez *et al.* (2001)]. The comparison of the USNO magnitude system with the Landoldt standards shows that the median error in the USNO magnitude is 0.15 magnitudes. The mean standard error in the USNO magnitude is 0.26 magnitudes.

The photometric accuracy of this catalogue is rather poor, but its usage has the advantage to offer a large number of stars, spread over a great magnitude range. Thus, an increase of the accuracy of our photometric calibration is reached by using a large number of standard stars. The number of standard stars is different for the different images, having a mean value of more than 200.

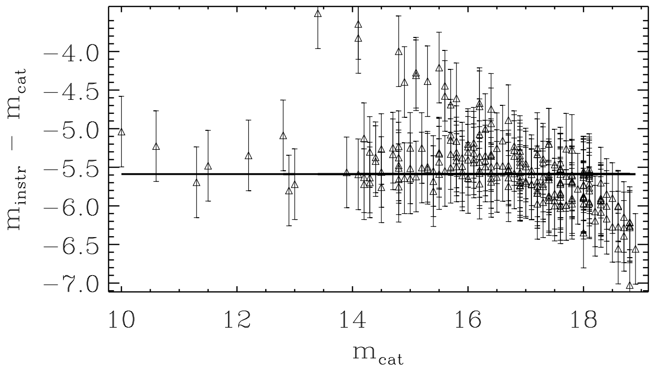

Fig. 2. Comparison between our instrumental magnitudes and catalogue magnitudes.

Fig. 2 shows the comparison of our instrumental magnitude with the catalogue magnitudes. The consistency of both systems is rather good for stars brighter than magnitude 17. The observed systematic decrease of the instrumental magnitude for stars fainter than magnitude 17 will be a subject of a further study. With the photometric parameters found we derive the total magnitudes of the observed objects and make maps of the surface brightness of comets. Usually we use $1 \times \sigma$ over the background level as the faintest limit in our maps. In the R-band the sky brightness itself has a level of about 20 magnitude/arcsec^2. This level is reached with a signal-to-noise ratio of about 10 for exposures of 2 minutes. In shorter exposures the sky background is read-out-noise dominated.

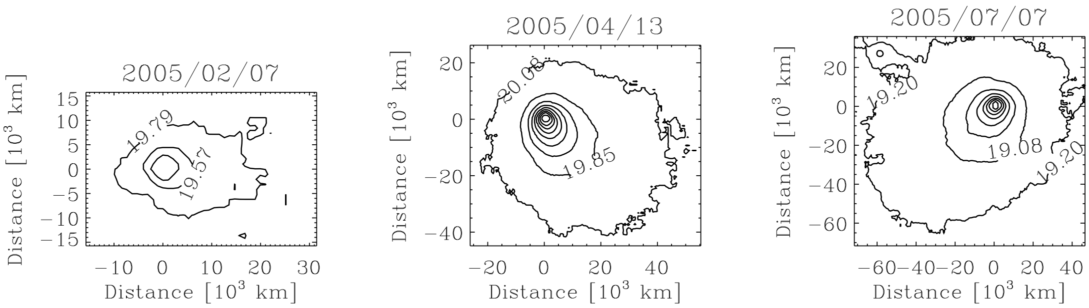

Fig. 3. Surface brightness distributions of comet 9P/Tempel 1. The labels at the contours show the brightness in magnitude/arcsec^2. The value of the outermost isophote is $1{\times}\sigma$ above the sky background, where σ is the background noise. The origin of the coordinates is at the comet photocenter. North is up, East to the left.

Fig. 3 shows contour maps of comet 9P/Tempel 1, created from 3 calibrated R-band images. The tailward extension of the comet increase from about 20×10^3 km. on February 07 to about 80×10^3 km. on July 07, 2005. Over the same time interval the distance to the outermost contours in sunward direction increases from below $10{\times}10^3$ km to more than 30×10^3 km.

The total magnitude of the comet is derived by integrating the brightness of the comet between $1 \times \sigma$ over the sky background and the peak value at the comet photocenter. The results of this integration are presented in Fig. 4. The left panel in this figure shows the variations of the total brightness of the comet as a function of the time to perihelion. The most remarkable feature in this light curve is the maximum of the comet activity about 60 days before perihelion. This is consistent with the results of narrowband photometry and spectral measurements reported by [Farnham *et al.* (2004)]. A peak in activity of this comet, 80 to 60 days before perihelion, was found by [Lara *et al.* (2006)], also. The right panel in Fig. 4 shows the total brightness dependence on heliocentric distance. If we ignore the variations caused by phase changes, the total magnitude of a comet is given by: $m = m(1,1) + 5\,log(\Delta) + 2.5\,n\,log(r)$ [Meisel *et al.* (1982)], where $m(1,1)$ is the magnitude of a comet at $r = \Delta = 1$ AU, and n is the photometric parameter giving the variation of the comet activity with heliocentric distance.

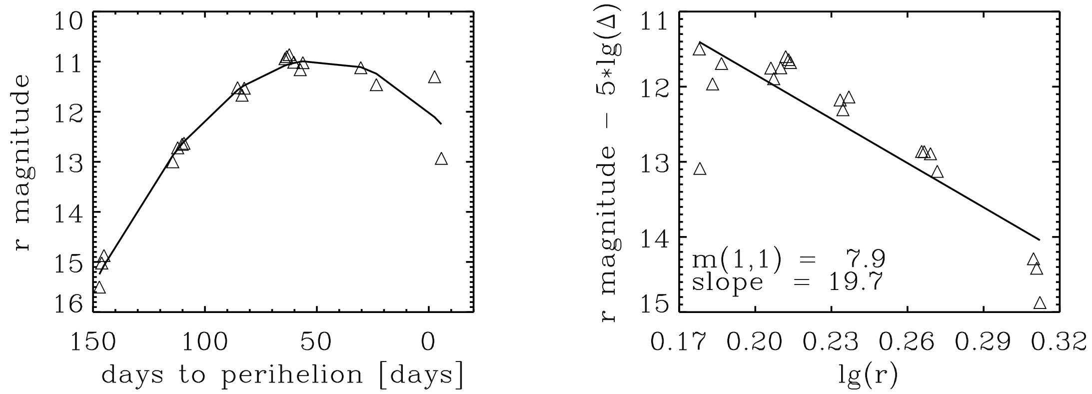

Fig. 4. Left: R magnitudes versus time to perihelion (days to 2005-Jul-05). The light curve exhibits a maximum about 60 days before perihelion. Right: R magnitudes corrected for the geocentric distance (Δ, AU) of the comet, versus heliocentric distance (r, AU).

¿From a linear fit to the data presented in the right panel of fig. 4 we obtain following photometric parameters for comet 9P/Tempel 1: $m(1,1) = 7.9$, and $n = 7.9$ (= 19.7/2.5). The found value for n is in the upper range of values reported for other comets [Meisel *et al.* (1982)]. This rather high value is consistent with the mean variation of the dust production on heliocentric distance derived for comet 9P/Tempel 1 by [Lara *et al.* (2006)].

Conclusions

Analysis of the astrometric parameters of the Schmidt telescope has shown that no effects caused by spherical aberration or differential refraction can be measured in the available FOV. At the same time the FOV is large enough to allow identification of sufficient number of reference and standard stars and thus to reach reliable astrometric and photometric results. The Schmidt telescope is an efficient instrument for the study of small bodies in the Solar system, and especially, for analysis of the surface brightness of extended objects.

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