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ASTEROID SEARCH RESULTS FOR DIGITIZED ASTROPLATES OF 1.2m TELESCOPE IN BALDONE

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ABSTRACT. The work on the mass search for asteroids on astroplate images and the determination of their coordinates was begun in 2016. The basis for current search was the processing results of digitized photographic plates and films obtained at the observatory in Baldone in 1967-1993.

Observations with a single exposure in different spectral bands were carried out using the 1.2m Schmidt telescope in Baldone. We used all observations in the U Johnson's spectral band (on plates) and significant part of them in V band (on films). Photometric band U was realized by combining emulsion ORWO Zu1 (Zu2 or Zu21 or Kodak 103aO or IIaO) with UG1 filter. For films with A600 emulsion and filter ZS17 a photometric band V was implemented.

Based on the results of digital processing about 300 U-plates and more than 1460 V-films, a preliminary catalog of 1700 asteroid positions was compiled. Among the objects in this catalog are asteroids of particular interest. These include the distant objects (136108) Haumea and (136472) Makemake and some Main belt asteroids, the positions of which were fixed on the plates many years before their own discoveries.

All observed positions of asteroids were compared with ephemeris DE431. An analysis of the convergence of the observed positions with their theoretical data for different spectral bands showed that the observations on V-films are better consistent with theory.

However, the internal accuracy of determining coordinates from U-plates, on the contrary, is higher than from V-films. This discrepancy is especially noticeable for right ascension, when the root-mean-square errors on V-films can reach values exceeding 1.8 arc seconds. These significant errors are a consequence of the curvature unevenness of the film surface during scanning.

Keywords: catalog, asteroid positions

АНОТАЦІЯ. Робота з масового пошуку зображень астероїдів та комет на фотографічних пластинках минулих років та визначення їх координат розпочата у 2016 році. Основою для цього були результати обробки оцифрованих фотографічних пластинок та плівок, отриманих в обсерваторії в Балдоне в 1967-1993 роках.

Спостереження з однією експозицією в різних спектральних смугах системи Джонсона проведені за допомогою 1,2-метрового телескопа Шмідта в Балдоне. Використані всі спостереження у спектральній смузі U (пластинки) та значна їх частина у V смузі (плівки). Фотометричну смугу U було реалізовано шляхом поєднання емульсії ORWO Zu1 (Zu2 або Zu21 або Kodak 103aO або IIaO) з UG1 фільтром. Для плівок з емульсією A600 та фільтром ZS17 була реалізована фотометрична смуга V.

На основі результатів цифрової обробки близько 300 U-пластинок та понад 1460 V-плівок було складено попередній каталог 1700 положень астероїдів. Серед об'єктів цього каталогу є астероїди, які представляють особливий інтерес. До них віднесені віддалені об'єкти (136108) Haumea і (136472) Makemake та деякі астероїди Головного поясу, положення яких було зафіксовано на цих пластинках за багато років до їх відкриття.

Усі спостережувані положення астероїдів порівнювали з ефемеридою DE431. Аналіз збіжності спостережуваних положень з їх теоретичними даними для різних спектральних смуг показав, що спостереження на V-плівках краще відповідають теорії.

Однак внутрішня точність визначення координат за U-пластинками, навпаки, вища, ніж за V-плівками. Ця розбіжність особливо помітна у прямому піднесенні, коли значення середньоквадратичної похибки на V-плівках можуть перевищувати 1.8 кутових секунд. Ці значні похибки обрахунку координат є наслідком нерівномірності викривлення поверхні плівки під час сканування.

Ключові слова: каталог, положення, астероїд

1. Introduction

The purpose of this work is to search for images of small bodies of the Solar System from digitized plates of clusters observations in 1967-1993 at the astronomical observatory in Baldone. Determining the coordinates and compiling a catalog of asteroid positions are the main tasks of this work.

In 1965, a Schmidt SmA camera was installed in Baldone on the territory of the Astronomical Observatory of

the Institute of Astronomy of the University of Latvia with the following parameters: diameter of the mirror - 120 cm, diameter of the correction plate - 80 cm, focal length - 240 cm, field of view 446' x 446' min. The first effective observations were obtained in December 1966.

Over 40 years of photographic observations on various programs, the Baldone's collection of astronegatives including more than 22,000 direct images in a wide range of exposures. Among them there are approximately 780 photographic plates in U spectral band exposed with a UG1 filter, 4600 films in V band exposed with a ZS17 filter (Eglitis et al., 2016a).

From 2013 the regular digitization and processing of photographic astroplates started in Baldone observatory. The plates were digitized using Epson Expression 10000XL and 11000XL commercial scanners with the resolution 1200 dpi. The further software for scan processing was developed and implemented in MAO NASU to process the digitized astronomic negative plates as well as to obtain the final product in the form of a catalogue of positions and stellar magnitudes for all registered objects on the plate. For detail the techniques of astroplate digitization and further processing and determination of coordinates and magnitudes of stars are described in the series of publications (Andruk et al., 2016a; 2016b; Protsyuk et al., 2014). The special modernized programs were developed at MAO NASU for constructing individual characteristic curves and determining stellar U, V values with a single exposure (Andruk et al., 2019).

The equatorial coordinates α, δ and stellar magnitudes of all objects on the plates were obtained in the reference system of Tycho-2 at the epoch of exposition of each plate. The magnitudes of all objects are obtained in the system of photoelectric standards.

2. Results

The processing results (Eglitis et al., 2016a; 2017; 2018) of digitized photographic observations of star clusters in UBVR bands at the Baldone observatory during 1967-1996 were used for a global search for small bodies of the Solar system. An online internet service from JPL was used for this (https://ssd.jpl.nasa.gov/sbfind). The first stage of this search was begun in 2016. As a result 87 images of minor planets from 9.8 to 17.1 stellar magnitude and 2 images of comets were identified on 152 plates (Eglitis et al., 2016b). Now we continued this work and carried out the search for asteroids based on the results of processing the remaining plates observed in U, V bands. A total of 272 plates were used in the U band and more than 1,400 films in the V band. Asteroids and comets were detected on 107 plates (361 positions) in U band and 223 films (1401 positions) in V band. Their positions were compiled into a preliminary catalog.

In addition, in vicinity of each position of the asteroid, stars from the Gaia DR2 catalog were selected to determine the possible coverage of the images of stars with an image of the asteroid on the plate. In these cases, the coordinates or magnitudes of the asteroid are determined ambiguously on the plate. Such asteroid positions were excluded from the compiled catalog.

The quantitative distribution of all used photographic observations over the years compared to the number of effective observations for the search for asteroids is presented in Fig. 1 and Fig. 2.

As a result of reduction processing with the reference catalog of Tycho-2, the root-mean-square (RMS) errors σ of determining the coordinates of stars on the plates were obtained. For U-plates, the internal accuracy of determining the coordinates of stars is approximately in the range of 0.05-0.53 arc seconds. For V-films, the range of RMS errors is much wider, especially for right ascension, when these values reach 1.8 arc seconds. This may be due to the uneven curvature of the film surface during scanning (Table 1).

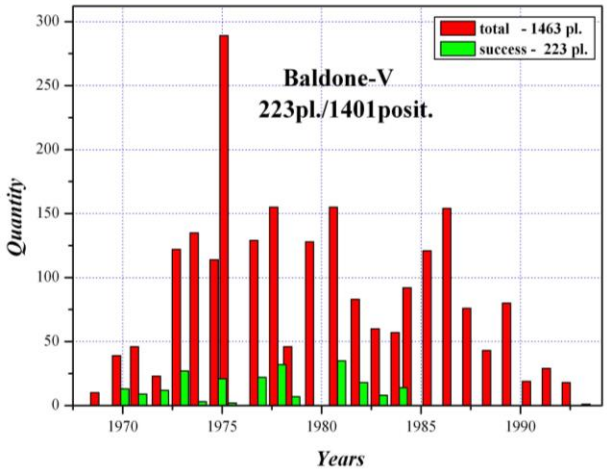

Figure 1: Distribution on time scale of all observations in V band in Baldone observatory.

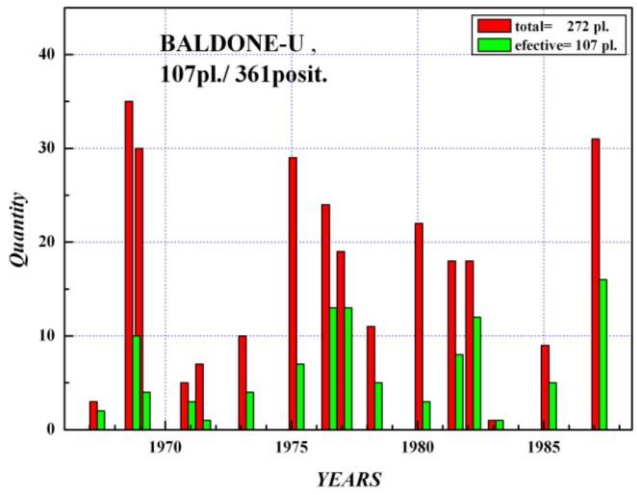

Figure 2: Distribution on time scale of all observations in U band in Baldone observatory.

Table 1: Ranges of root-mean-square errors of determining the coordinates of stars for U and V plates.

107 U-plates			**223 V-films**		
σ_{RA}, arcsec	σ_{Dec}, arcsec	σ_{U}, mag	σ_{RA}, arcsec	σ_{Dec}, arcsec	σ_{V} , mag
1	*2*	*3*	*4*	*5*	*6*
0.05-0.53	**0.05-0.34**	**0.01-0.39**	**0.05-1.76**	**0.06-0.63**	**0.12-0.53**

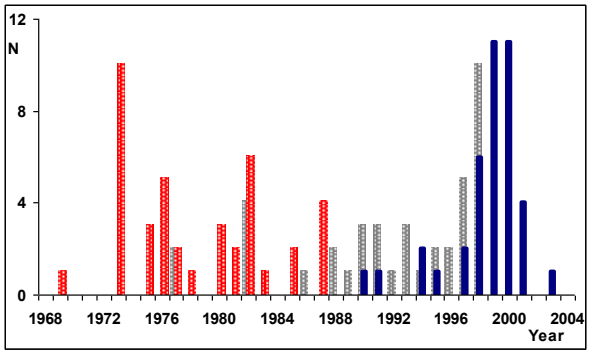

Figure 3: Observational moments for 40 asteroids in Baldone and their first observations according to the MPC database (http://www.minorplanetcenter.net/db_search)

Using JPL ephemeris, an analysis of O-C differences was performed for 361 positions of asteroids identified in U-plates. Of particular interest are the 40 positions of asteroids fixed on the U-plates in the period 1969-1987. These Main belt asteroids have been discovered by automatic telescopes during 1998-2003 in the LINEAR (http://www.ll.mit.edu/linear), LONEOS (https://asteroid.lowell.edu/asteroid/loneos) and NEAT projects (http://neat.jpl.nasa.gov).

The MPC database contains a small number of their positions obtained from observations no earlier than 10-20 years before the official discoveries of asteroids. There are no earlier observations of these asteroids.

Figure 3 for each of these 40 asteroids shows the observational moment of asteroid in 1969-1987 in Baldone (left side), the first productive moment of its observation in 1977-1998 in the world (in the center and according to the MPC), the moment of its official discovery (right side). For many of these asteroids, their observations in Baldone are the earliest and over the next 10-25 years, there are no observations of these asteroids. Using the digitized archives of previous photographic observations in Baldone, this interval can easily be filled with new identified and processed observations.

However, such asteroid positions should have high accuracy for further kinematic and dynamic solutions of asteroid orbits. After comparison with an ephemeris, the obtained values of the O–C differences for many interesting asteroids have a large scatter and can reach 5 arc seconds. This may be due to great random errors in determining the coordinates of the asteroids or insufficiently accurate recorded moments of observation. On the one hand, these are faint (16-18^m) objects with low signal/noise level. For example, for the faint stars (16-18^m), the random error component of the coordinate determination increases rapidly and reaches 1.5 - 2 arc seconds on plates from the FON project (Shatokhina et al., 2019).

On the other hand, great O-C values are not always the result of errors in determining the coordinates of asteroids. For example, images of asteroid 9414 were identified on plates obtained in 1982-1985 in Baldone observatory and in the FON (Kyiv part) project (Shatokhina et al., 2018). The O-C values for these two positions are approximately 4 arc seconds. However, they are in good agreement with each other and with the O-C values for the other nearest MPC positions. In addition, the Baldone archive has about 10-15 unprocessed observations of this asteroid for the same time period and in different spectral bands of UBVR. Their processing can significantly supplement the existing observations of asteroid 9414 with new data.

The work on identifying asteroids by V-films is not finished. A large range of errors in determining coordinates due to the curvature unevenness of the film surface during scanning does not always allow this to be done quickly and unambiguously. However, the films contain unique information in previous years about the locations of TNO and other interesting objects in the Solar system. Therefore, the processing results will be carefully analyzed and, possible, re-digitized.

3. Conclusion

Long-term sets of photographic observations made in previous years can become the basis not only for creating catalogs of coordinates of stars and galaxies but also for determining precise positions of small bodies of the Solar system. Using the digitized photographic plates of the archives of the Baldone Observatory, we can identify faint moving objects up to 18^m and determine their coordinates and magnitudes with high accuracy. Among those may be objects which were discovered much later than were fixed on those astronegatives, and unique asteroids and comets including selected trans-Neptunian distant objects.

Using data about precise positions and magnitudes of asteroids, some tasks of refining ephemeris, studying changes in asteroid orbits over time, non-gravitational effects in the evolution of asteroid's orbits, constructing light curves and phase dependencies can be solved.

Cooperation with Ukrainian Virtual Observatory (UkrVO) gives the opportunity to expand this work, involving numerous additional files of digitized observations and different services and software for modern processing of observation and, ultimately, to increase the number of new original data about Universe.

Intensive work on the creation of catalogs of stars and galaxies and small bodies of the Solar system based on digitized photographic observations of star clusters of archives in Baldone was successfully carried out with the active support of UkrVO [Vavilova et al., 2016; 2017].

The main results of such studies have been previously reported at different conferences.

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