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Preface

Dear colleagues,

This file represents the proceedings from the second ASTROPLATE workshop about astronomical glass plate negatives.

This proceeding put together selected lectures in the form of articles from the workshop.

The ASTROPLATE workshop held in Prague, Villa Lanna, in March 2016 represented another major event in an investigation, archiving, and digitization of astronomical photographic archives including all aspects. This volume represents the collection of papers related to presentations and posters presented at the conference.

The photographic emulsion was the only medium for creating and storing images in astronomy for more than 100 years, from the discovery of photography up to the beginning of the era of electronic imaging devices (mostly CCD) in early 1980. And the same was valid for all other areas working with photographs including other sciences, national museums, and archives, etc. The astronomers need to save indeed a rich variety of types of images ranging from direct images of stars and other celestial objects to wide field images covering large sky areas to various types of spectral images, both wide-field with many spectral images, to just single recorded spectrum. I have got the opportunity to visit and work with more than 50 astronomical photographic archives.

In last few years, I have found an increasing number of damaged or even very damaged plates in these collections, the two main types of damage being the released emulsion layer and various types of yellow spots known as gold disease. We have established a consortium with specialists working in chemistry and photography restoration, to exploit the cause of these damages. It became obvious that if we want to save the large scientific cultural and historical heritage included in these archives, we need both national and international collaboration. At the same time, scanning of photographic records started at numerous institutions, with different approaches, technologies, and methods. Again, it became evident that wider collaboration is necessary to optimize the digitization procedures in all aspects including metadata treatment. This was the background of the idea to organize the second ASTROPLATE international workshop in Prague, where specialists of all involved disciplines could meet and discuss their results. We were very impressed by the response of the community, and by the high level of the contributions presented at the ASTROPLATE conference. Unfortunately, many of our colleagues were unable to attend this time for various reasons. We plan to organize the 3rd ASTROPLATE conference in spring 2019, in Bamberg. The 2nd ASTROPLATE is then planned for March 2021, very probably again in Prague.

Rene Hudec, ASTROPLATE2016 SOC chair

Petr Skala Proceedings Editor

Proceedings are published without language correction.

Contents is on the responsibility of author of the separate articles.

Contents

Asteroids from digitized processing of photographic observations in Baldone

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Abstract

Digital processing of photographic plates of star fields allows, in addition to the main tasks to carry out a massive search for images of small bodies of the solar system and to determine their coordinates. From the observations of earlier epoch, you can extract information about the locations of these bodies well before discovering them. We analyzed the results of 27 observations of clusters in UVBR bands and 7 of Pluto observations made on the 1.2-m Schmidt telescope of the Observatory of University of Latvia in Baldone. At the moment, it has identified 50 positions and magnitudes of asteroids weaker than 14m.5 for 1967-1991.. Among them 11 positions for 7 asteroids which at the time of observation were the earliest of the world\'s known observations of these asteroids. Analysis was carried out. In order to determine the accuracy results of 2 to 7 scans of plates where performed.

Keywords: Astrometry, photometry, photographic archive, asteroids.

Results

34 plates of Pluto and clusters observations in UVBR bands on the 1.2-m telescope of the Schmidt telescope of Baldone Observatory, University of Latvia were used to search for asteroids (Tab. 1.). The images were digitized by the scanner EPSON EXPRESSION 10000XL and processed using advanced complex LINUX / MIDAS / ROMAPHOT programs. The equatorial coordinates and magnitudes of all objects on the plates were obtained. In detail, the process of digitization of images and their further processing and determination of coordinates/ magnitudes of solar system bodies are described in papers [1-6]. On 15 plates were discovered asteroids. List and characteristics of these plates are shown in Table 1. In the same table the standard errors σ obtained using Tycho2 reference stars are given for each plate. Table 2 is a catalog record of coordinates and magnitudes of 32 asteroids (given at http://baldonesobservatorija.lu.lv). These objects cover magnitude range from 9.8 to 17.1. The comparison with the JPL DE431 ephemeris (http://ssd.jpl.nasa.gov/horizons) is given. The table presents also O-C difference in both coordinates (DA; Del), and B-V (U-V, R-V), where B - blue V_{eph} – visual, R -red approximate magnitudes of asteroids.

To estimates the accuracy of processing, Pluto plates were scanned 6 times with 2400 dpi. On the plate N18828 six position of Pluto (13m.67) and 6 asteroids: 787 (13m.01), 3003 (16m.10), 3158 (16m.38), 3223 (15m.14), 5441 (16m.08), 14012 (17m.12) were determined. On processing results of these plates are made Fig.1 - dependency value rms-error of the coordinates from the average magnitude of each asteroid. With increasing magnitude rms-error increases, which leads to greater than 2 arcsec O-C for 16 asteroids magnitude. These determinations in the table have not been included. There may be several reasons for the increase in errors: absence of weak or enough weak reference stars in Tycho2, non-point image of asteroids due to their motion and others. However according to the data of 18828 records depending O-C on the speed of the asteroid's motion is not detected.

Table 1. Used plates from Baldone archive

№ plate	Object	Expos., min	Band	σ RA, arcsec	σ DEC, arcsec	σ MagB(T)
26	12 Com	16	U	.101	.100	.104
38	12 Com	16	U	.110	.097	.140
2492	NGC 2129	5	V	.143	.827	.381
2496	NGC 2129	20	R	.084	.066	.468
3511	NGC 2129	14	B	.094	.089	.274
12492	Pluto	10	B	.072	.068	.291
12511	Pluto	10	B	.094	.089	.287
15645	Gal. 39	20	U	.107	.096	.142
15646	Gal. 87	21	U	.105	.087	.269
15652	Gal. 96+97	21	U	.115	.100	.144
15654	Gal. 100	21	U	.104	.098	.190
15661	Gal. 96+97	21	U	.105	.091	.123
15663	Gal. 100	21	U	.108	.086	.145
15677	Gal. 39	21	U	.100	.092	.135
18828-1	Pluto	7	B	.061	.070	.383

32 asteroids (N100, 354, 501, 508, 787, 1289, 1449, 1556, 1560, 1593, 1837, 1964, 2048, 2222, 2659, 2734, 3003, 3008, 3223, 3292, 4095, 5588, 5877, 5914, 7346, 7472, 8260, 11974, 14221, 16506, 22282, 26629) are identified on plates which have orbit types: Main Belts, Hungarias and Mars-crosser. For 16 of these Minor Planet Center has recommended the continuation of regular observations. Additionally, 13 asteroids that presented in the catalog, have chronologically earliest observations among all known in the world (Tab. 2.), many years before discovering data.

Conclusion

On photographic plates of Baldone Observatory can be detected asteroids with high accuracy up to 16 magnitude. Among those may be objects which discovered much later than observed, those whose observation number is critical or not enough for reliable solutions orbits equations. The presence of the archive of all observations in time scale 1969-2002 will give possibilities to select and process the interesting asteroids of the last century. Cooperation with UkrVO gives the opportunity to expand this work, involving numerous additional files of observations and, ultimately, to increase the number of new original positions. From this view Baldone observatory could compete with modern observations. A necessary condition for obtaining high-precision series of observations of asteroids - the presence of a confident moment of observations within a second time. This requirement follows from the great speed of motion of asteroids on the celestial sphere.

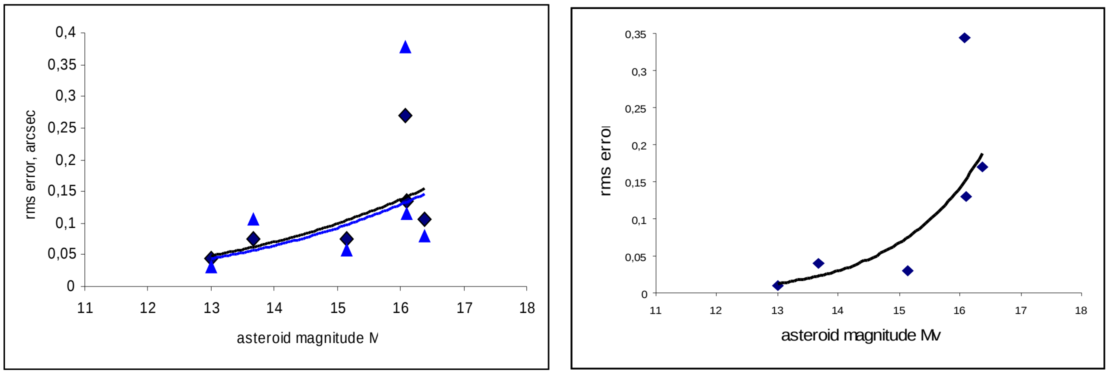

Fig.1. Dependence of rms-error values on the average magnitude of the asteroids (on the right - on the right ascension and declination, on the left - on the magnitude)

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Uranus and Neptune from UKRVO digital archive: structure, quality analysis // Odessa Astron. Publ., 2015, Vol.28, N2, p. 204-206.

Table 2. Asteroids observed in Baldone before their discovering data

Object number	Object name (discovering date)	Observed coordin.		Mag (obs)	O-C		B-V or U-V or V-R
		α	δ		Δα	Δδ	
Nplate= 2492; UT=1973-01-01.869005 (ephemeris JPL DE431)							
2222	Lermontov (1977)	055721.505	+232045.485	14.22	-.51	-.67	-.59
4095	Ishizuchisan (1987)	060542.953	+215512.142	15.87	-.75	.15	-.64
5588	Jennabelle (1990)	061027.128	+234945.758	16.50	.04	-2.00	.03
8260	(1984 SH)	060916.957	+215506.721	18.25	-.33	.60	1.27
14221	(1999 WL)	055454.716	+223035.140	15.62	.56	-.06	-.85
Nplate=2496; UT=1973-01-01.883241							
5877	Toshimaihara (1990)	055150.141	+232721.981	15.25	1.03	-.36	-1.38
7346	Boulanger (1993)	055557.298	055557.298	15.40	.45	.10	-1.38
11974	Yasuhidefujita (1994)	060111.237	+214944.567	15.63	.32	-.16	-1.43
22282	(1995 RA)	061122.090	+233152.166	15.33	-.42	.17	-1.21
26629	Zahller (2000)	055504.277	+225918.455	16.12	.37	.23	-.99
Nplate= 3511; UT=1974-03-12 21:16:54 (ephemeris JPL DE431)							
2659	Millis (1981)	060658.341	+222218.864	16.59	.38	-1.06	-.18
Nplate=15652; UT=1987 03 24.954630 (ephemeris JPL DE431)							
5914	Kathywhaler (1990)	122048.075	+122110.133	17.13	.52	-.41	.70
Nplate=15661; UT=1987 03 25.929259 (ephemeris JPL DE431)							
7472	Kumokiri (1992)	123316.961	+131747.445	16.16	.35	.09	.28

Astrometric and photometric processing of Pluto digitized photographic observations 1961-1996

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Abstract

A catalog of equatorial coordinates and magnitudes of Pluto for the period 1961-1996 has been derived from digitized photographic observations from the combined digital archive of UkrVO Observatory and the Institute of Astronomy of University of Latvia. Improvement of software processing of digitally scanned images allowed single images to be extracted from multiple exposures of Pluto images represented on a single astronegative. As a result of the new aproach 22 new coordinate measurements of Pluto observations have been added to the 80 already in this catalog. Comparison has been made with the JPL DE431 ephemeris and the results analyzed.

Keywords: Astrometry, photometry, photographic archive, minor planets.

Introduction

Preparation and implementation of the New Horizons space mission, among other tasks, to intensify efforts to clarify the ephemeris of the Pluto-Charon [1,2,3]. Creation of dynamic model of the motion of Pluto Orbite, Dynamique et Integration Numerique raised the issue of insufficient positional observational data for the planet over the long period of time. One the sources of information is the arrays of photographic data collections of observatories, which transferred to digital form and processed using high-precision stellar catalogs, can serve as a reference system for reliable checking and correcting the ephemeris of the planet [4]. At the same time, modern methods of transfer photographic images to digital format and the software processing of digitized astronomical images require additional studies to be able to retain a high level of objective information and recognition of systematic distortions introduced by the telescope or the scanner. Combining position of the planet obtained from the work of contemporary space missions with previous planetary positions determined from ground-based observations will test and significantly improve its theory of motion.

Observations

Pluto is a fairly complex object for observation by ground-based instruments - distance, size and the inclination of the orbit against ecliptic creates some technical difficulties, particularly, use of exact methods of laser and radar are impossible. At the same time, since discovery of Pluto, observations have only cover a little more than one third of the planet's orbit. Therefore, every successful series of observations, as well as single nightly observation are important and needs to be recorded in catalog and processed. In the most complete library from the VizieR database of currently 13348 catalogs available only 6 contain astrometric position of Pluto, obtained by different methods of observation [1,2,4,5,6,7]. Moreover, photographic surveillance provides information of positions of the planet during the early ages.

The combined digital archive of Ukrainian Virtual Observatory (UkrVO) (http: // g ua.db.ukr-vo.org) at the beginning of 2016 contains 59 digital images and metadata files on more than 40 thousand negatives obtained on 36 stationary instruments in different observatories of Ukraine and conditions while at expeditions [8,9]. Among observation are 77 plates with images of Pluto, exposed using a five telescopes of three observatories and 2 plates from other observational programs with images of Pluto as a secondary subject. The information processed also included 5 Observatory of Baldone records that where not included in the earlier research [5].

Critically viewed observational material is not homogeneous: locations of observatories in different time zone, different sizes of plates, fields and scales, amount and duration of exposures, the emulsions of different sensitivity, different weather conditions and degree of preservation of photographic material. However, this collection of astroimages and its reprocessing contributes significantly to the overall database of astrometric positions of Pluto, covering the missing time periods, preceding the space missions.

Previously, analysis was performed of 59 plates dated 1961-1990 and catalog of astrometric positions and photometric evaluations of planet was created [10]. Analysis of the results and the further improvement of methods of digitization and additional research in methods of scanning, the development of methods for identifying and removing errors while scanning, it is possible to increase the potential accuracy of the photographic material [11]. In the new treatment included where previously treated plates (at the same time rescanning of them was performed) and not previously used ones.

Digitalizing

Scanning was performed on two flatbed scanners of the same type that have been previously examined for bias. The optimum settings for scanning was 16-bit gray TIFF format. With scanners Epson Perfection V750 Pro and Epson Expression 10000XL additional studies were conducted of the carriage mechanics and optical distortion. Random and systematic errors were obtained by repeated scanning of the same plates in different periods and under different temperature conditions. 6 time rescanning of 15 plates prepared by ZA and ST in Nikolayev and Baldone telescopes was performed. It was proven, that the repeated scanning and averaging the results for one plate greatly reduces the random component of error of scanning and increasing the number of reference stars reduces the systematic component [11].

Processing

Standard image processing was performed in the environment of LINUX / MIDAS / ROMAFOT (www.eso.org/sci/software/esomidas) with an advanced set of original programs [12] which were developed in parallel to the Main AO of National Academy of Sciences and Research Institute Nikolaev AO. We created the package of programs for image processing with the following parameters: images with resolutions from 600 to 2400 dpi, image size up to 20000x20000 pixels and field of view up to 20 degrees. PC with 2GB of RAM is enough to work in full mode.

The programs may carry out:

-elimination of the image defects, such as spots, scratches, inscriptions,

-identification of stars in the image,

-allocation and exclusion from further processing of stellar images obtained during the second and the third exposures,

-exclusion of diffraction satellites of bright stars for images obtained with a diffraction grating,

-control of identification,

-reduction using models with different equations.

Results

Comparing the position of the planet of the digitized images with corresponding coordinates of the measurement of the same plate in previous years it should be noted that due to the capabilities of scanners increased quantity of images suitable for processing, increased internal precision, which in turn depends explicitly on the size of the plate and, respectively, the number of reference stars. Separate treatment of individual exposures increased the number of received position of the planet led to the conclusion that in the case of processing such a faint object as Pluto, the duration of exposure affects the accuracy of the estimation of magnitudes. For each instrument, and a particular type of emulsion, respectively under the same conditions of observation, periods of exposure limits exist below which obtained photometric values are underestimated, and on the other hand, above which the photometric values are derived oversized compared to the ephemeris. This issue requires further study and evaluation. As a supporting system for the equatorial coordinates of Pluto library “Tycho-2" was used.

Improvements in scan processing software allowed securely separate close images of Pluto on one plate. As a result of the new treatment we recorded 22 new positions from all the 80 positions of Pluto in this catalog (see http://baldonesobservatorija.lu.lv). The mean values of O-C for all 80 provisions constitute -.10 -.14 arc seconds on both coordinates (RA, Dec) and their standard errors are 0.58 and 0.55 arc seconds, respectively.

To eliminate the influence of factors as differences in geo- and helio-centric distances and phase angles obtained in the magnitude of Pluto were brought to the center of the opposition.

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Present status of the photographic archive of the Tashkent and Kitab astronomical observatories in Uzbekistan

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Abstract. A preliminary review of astrophotography archive of the Tashkent astronomical observatory (TAO, at present the Ulugh Beg Astronomical Institute (UBAI) is presented. More than 15.000 photographic glass negatives were obtained using Tashkent's normal astrograph (TNA) installed in 1895 and Kitab Double Astrograph by Zeiss (DAZ) installed in 1975.

At present the complete collection of about 15000 plates (including the plates obtained in Kitab) are stored in UBAI in a moderately good condition. In 2014 – 2015 a part of the archive has been digitized using a commercial flatbed scanner machine Epson Expression 10000XL with a spatial resolution of 1200 dpi. This work is in an active phase now.

The archive consists of images of galaxies, planets, their satellites and asteroids, planetary nebulae and star clusters. In addition a few hundred plates contain images of different objects and phenomena such as comets and variable stars, solar eclipses, the transit of the Mercury through the solar disk and so on.

A more detailed content of the UBAI archive and future prospects on its scientific utilization will be discussed.

I. Introduction

The photographic plate archive of the Ulugh Beg Astronomical Institute (UBAI) consists of two parts. The first part obtained at the Tashkent's normal astrograph (TNA) during period 1895-1986. Second part was obtained at the Double astrograph of Zeiss firm (DAZ) installed at the territory of the International Kitab latitude station which is a branch of UBAI in 1975. Observation at DAZ continued up to 2004. Main characteristics of the TNA and the Kitab's DAZ as well as coordinates of both instruments are presented in Table 1.

Table 1

Main characteristics of the Tashkent's normal astrograph and the Kitab Double Zeiss astrograph

Parameter	TNA	Kitab DAZ
ID	*TAS033*	*TAS040A (tube 1) & TAS040B (tube 2)*
Code of the observatory	*192*	*186*
Longitude	*69° 17′.0*	*66° 53′.0*
Latitude	*41° 19′.5*	*39° 08′.0*
Altitude	*482 m*	*690 m*
Aperture	*0.33 m*	*0.40 m*
Focal length	*3.43 m*	*3 m*
Scale	*60 ″/mm*	*69 ″/mm*
Field	*2°÷2.5°*	*5.5°÷6.0°*
Glass plate size (max)	*16x16 cm*	*30x30 cm*

In 2014 a project on sprucing up and digitization of the photographic archive started at UBAI. Five main tasks were under consideration:

- Collecting all plates in UBAI in specially equipped room.
- Dispatching plates to closets according to dates and programs.
- Classification of plates according to WFPDB standard.
- Choosing appropriate method and digitization of plates.
- Scientific analyses of the material.

Present status of the project and future prospects will be presented in this paper.

2.1 Present status of the project

A special room for preservation of plates was prepared in UBAI main building. It was equipped with special closets. Air-conditioning system allows keeping room temperature around + 25 C. Uzbekistan has very dry climate. Humidity here during dry seasons never exceeds 25-30%. All plates obtained in DAZ were delivered from Kitab to Tashkent and collected in UBAI.

2.2 Dispatching plates

At the end of 19th century the Tashkent Astronomical Observatory (TAO) ordered a photographic refractor (a normal astrograph) for the executing observations in frame of the Carte du Ciel program. However TAO as well as Pulkovo observatory was not permitted to participate in that program and observations at Tashkent's normal astrograph (TNA) were started in 1895 in frame of an observing program of the TAO. It included following objects: star clusters, star formation areas, variable stars, galaxies, nebulas, major and minor planets, comets, eclipses etc. Beside individual programs, TAO was involved to International observing programs such as photographing of Pleiades organized by Schwarchshild. The last observing program carried out at TNA was observation of the Halley comet during its appearance in 1985/1986 in frame of the International Halley Watch (IHW). Kitab's DAZ was also involved to this program. Its aim was to supply Soviet Vega-1 and Vega-2 space missions, as well as European Giotto and Japanese Sakigake and Suisey with precise positions of the comet. According a bulletin of coordination center of the IHW program TAO (UBAI) using both TNA and DAZ astrographs provided with 267 precise positions of Halley comet and take first place among 104 observatories involved to the IHW[1].

During its 90 years of active observing period, they were obtained about 10000 photographic plates.

In 1930's a fruitful idea of using position of far galaxies for compilation of proper motions absolute system came to consideration. A preliminary catalogue of 226 galaxies in 48 selected places was compiled using TNA observations [2]. After that enormous observing work on the first epoch for that catalogue was began in Tashkent. Up to 1968 more than 1000 plates were obtained for that program. These negatives probably are the most valuable part of the TNA archive. Moreover, during 1975-1992 more than 700 negatives for that program were obtained also in Kitab's DAZ.

In 1975 the Double astrograph of Zeiss firm (DAZ) was installed at the territory of the International Kitab latitude station which is a branch of TAO. It operates until 2004 and during about 30 years of its operation, they were received about 5000 negatives. One of the most important project carried out in DAZ in 1980's was photographing of selected subsystems of the galaxy. For this purpose there were obtained about 400 plates with photographs of 54 close (up to 54 Kpc) stellar clusters and 47 star forming regions which includes O and T associations as well as a number of globular clusters. These plated are not analyzed yet.

2.3 Classification of plates

Completing Plate Archive information database has been carrying out according to Wide-Field Plate Database (WFPDB) format. By March 2016 about 30% of plates have classified.

2.4 Digitization of plates and scientific analyses

Digitization of the photographic plates was carried out using Epson Expression 10000XL flatbed scanner with the spatial resolution of 1200 dpi. Testing of digitization method was done in frame of Photographic Sky Survey (abbreviation in Russian is FON) project. This project was initiated in the Main Astronomical observatory of the National Academy of Sciences of Ukraine in 1980's [3]. They were involved six observatories of the former SU having similar astrographs, including Kitab's DAZ. Observational part of the FON program was carried out in 1982-1995.

During this period in Kitab's DAZ there were exposed more than 2600 photographic plates. The first stage of the processing of the photographic material includes the scanning of the 1900 photographic plates in zones of the southern sky with declination between -2 and -18 degrees. Analyses of digitization of two sets of plates are in good agreement. Further work on this direction is on the process [4].

3. Future prospects

In 2014 UBAI signed an agreement with National Astronomical Observatories of the Chinese (NAOC) Academy of Sciences on the modernization of 1-m Zeiss-1000 telescope of the Maidanak observatory in Uzbekistan. At present the telescope upgraded and equipped with a CCD camera produced by Andor an Oxford Instruments Company iKon-XL 4k X 4k, 15x15μm/pixel. The FOV designed is 37'X 37' and after using focal reducer, it could be enlarged to 1deg x 1deg.

With this CCD camera, we plan to provide at Maidanak observatory in cooperation with colleagues from NAOC in 2016-2020 Strömgren-Crawford (SC) **ubyvbeta** Deep Sky Digital Survey: Image Survey + Spectroscopic Survey. One of the important scientific goals of the project is providing in combination with LAMOST Survey and GAIA Mission 6-D Structure of the Galaxy (R.A., Dec., D, v, z, p.m.). We can possibly partly use for this task photographic archives of UBAI and China.

4. Conclusion

Photographic glass archive of the Ulugh Beg Astronomical Institute contains of about 15 thousand plates obtained for the period 1895 – 2004. The process of sprucing its up and digitization started in 2014 and will probably last until 2017. Scientific use of the archive in combination with photometric surveys at the Maidanak observatory as well as setting up a virtual observatory in the future is planned.

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U-magnitudes of stars and galaxies from the digitized astronegatives of Baldone Schmidt telescope

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Abstract

To the moment, there is the acute shortage of definitions of U-magnitudes of stars on the celestial sphere. Photographic observational archive of 1.2m Baldone Schmidt telescope contains 753 astronegatives in 253 fields exposed in Johnson U-band. The general purpose of the work is to provide U-magnitudes of all objects (stars, galaxies, asteroids, etc.), recorded on these plates. The first results of U-plates image processing give the positional accuracy of Tycho-2 stars about 0.1 arcsec and the photometric accuracy in the U-band in the range 0.1^m-0.2^m. The catalogue of positions and U-magnitudes of 68 784 objects is presented.

Keywords: digital image processing, ultraviolet, star catalogues

Introduction

In general, the wide band photometric determinations in the ultraviolet spectral range (UV) are made in the vicinity of flare stars (or the supernova), in the fields of active galaxy nuclei, in the star formation regions and in the fields of clusters. The significantly greater contribution of UV data is in works devoted to studies of a dwarf nova, quasars and black holes [8,9]. However, UV photometric observational data are considerably less than those derived in the blue, visible and infrared spectral ranges as it is clear from the VisieR database collection of catalogs and publications.

Baldone Observatory of Institute of Astronomy, Latvian University possesses the photographic collection of 22 000 astroplates obtained using 1.2 m Schmidt telescope. The observational period started in 1966 and lasted for 39 years. The area of the sky, covered by a single plate is approximately 19 square degree and contains from 10 000 to 50 000 images of different celestial objects. The image scale is of 72 " / mm.

Observational material and its digitizing

The archive of the Baldone Schmidt Telescope includes 734 UV images in 253 different sky areas obtained in photometric U band, which is close to the standard U system. Combinations of photographic emulsions and filters used at Baldone observatory to provide U system are ORWO ZU21 and ZU2 with filters UG1 and UFS3.

The plates from the UV collection are scanned with flatbed scanners EPSON EXPRESSION 10000XL and EXPRESSION 11000XL. The preliminary research showed that scans, obtained with the spatial resolution of 1200 dpi (1.81"/pix) provide the same accuracy as the scanned with 2400 dpi ones. But, in this case, the savings in the processing time on the seven core high-speed computers is about three times per plate. In addition, the volume of the data stored in the computer memory significantly reduced.

The behavior traits of Epson Expression 10000XL scanners resulted in astrometric and photometric accuracy, and the optimum mode of their application are studied previously. Note, that the random errors of the scanner for astronegatives of the Baldone Schmidt telescope are 0.04 arcsec and 0.015^m in positions and magnitudes respectively.

All images were obtained as TIFF-files and transferred into the FITS for further processing. Standard image processing procedure is performed in the environment of Linux / MIDAS / ROMAFOT (www.eso.org/sci/software/esomidas) with an advanced set of original programs established by the astronomers of Main Astronomical Observatory of Ukrainian National Academy of Sciences. Tycho2 catalog is used as astrometric and photometric reference system.

Steps of digital image processing

Principles of digital image processing as applied to astronegatives were realized in the series of works for the creation of catalogs of celestial objects [1]. Briefly, they are:

1. Preliminary image processing in MIDAS/ROMAFOT software to obtain pixel coordinates X, Y and instrumental estimations of magnitudes of fixed objects.
2. Separation of objects into sets of two expositions for each plate.
3. Selection of Tycho-2 reference stars' set into reference file for each plate.
4. The preliminary solution of equations for rectangular and equatorial coordinates of the set of reference stars.
5. Correction of the rectangular coordinates of objects for the scanner systematic errors.
6. The reduction of rectangular coordinates X, Y of all fixed objects into the Tycho-2 reference system.
7. The reduction of instrumental photometric estimations to the Johnson photoelectric U_{pe} magnitudes.

The detailed description of the above said procedures is given in [2].

Astrometric reduction

For all plates included into the processing the equations (1) were used for the determination of the tangential coordinates as on the step of scanner systematic errors' Δα, Δδ diagnosis, so for the final reduction:

$$\xi_i = a_1+a_2X_if_{\frac{1}{2}i}+a_3Y_if_i+ a_4R_im_i+a_5f_{\frac{1}{2}i} + \sum b_{lm}X_i^lY_i^m, \quad (l=0\div 6,\ m=0\div 6,\ l+m=n,\ n=1\div 6) \qquad (1)$$
$$\eta_i = c_1+c_2X_if_{\frac{1}{2}i}+c_3Y_if_i+ c_4R_im_i +c_5f_{\frac{1}{2}i} + \sum d_{lm}X_i^lY_i^m, \quad (l=0\div 6,\ m=0\div 6,\ l+m=n,\ n=1\div 6)$$

Here, i = 1,2,…N – number of reference stars; X_i, Y_i and R_i – rectangular coordinates and distances of stars from the centers of plates; m_i – photometric measured data of stars; $f_{½i}$ – diameters of star images; coefficients a,b,c,d describe different aberrations of the telescope optics and residual systematic errors of the scanner. The detailed description of the error elimination procedure is given in [2].

Photometric reduction

Data from the catalogs [3-7] were used for the characteristic curve plotting, accounting for the photometric field error and the final reduction of instrumental photometric data into the Johnson photoelectric U_{pe} magnitudes. The characteristic curves of astronegatives are restored using photometric data of two expositions. The approximation of characteristic curves and U_{ph} determination for 24 plates was made by the rms solution of the equations (2):

$$U_{ph\,i} = e_1 + e_2X_i + e_3Y_i + e_4R_i + e_5R_i^2 + e_6R_i^4 + \sum f_n m_i^n, \quad (n=1,2,\dots 5), \qquad (2)$$

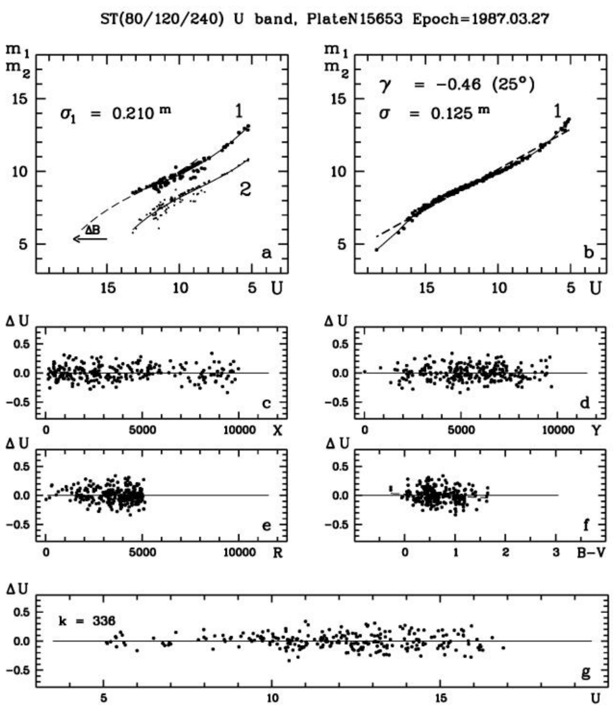

Fig. 1. The results of the photometric solution for plates with two expositions.

Here, i = 1, 2,…N is the number of photoelectric data for standard star on the plate; X_i, Y_i and R_i are the rectangular coordinates and the distances from the center of the plate; m_i – instrumental photometric evaluations; coefficients e_2, e_3, e_4, e_5, e_6 define the field photometric equation; f_1, f_2, f_3, f_4, f_5 describe the functional form of the characteristic curve. The equation (2) was chosen as minimizing the errors of the reduction in the best way.

The results of the photometric solution are given in Fig. 1. Here panels a and b show the characteristic curves for two expositions. Panels c, d, e, f, g show the differences ΔU of U-magnitudes derived from the characteristic curve and their photoelectric values.

The catalogue of U-magnitudes

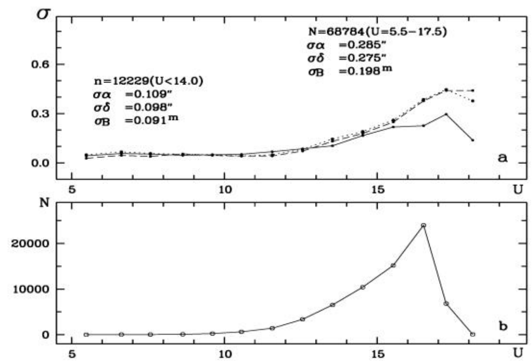

Fig.2. The trend of the internal errors for positions σα, σδ and magnitudes σU with U-magnitude (panel a) and the histogram of the distribution of the number of objects with U-magnitudes.

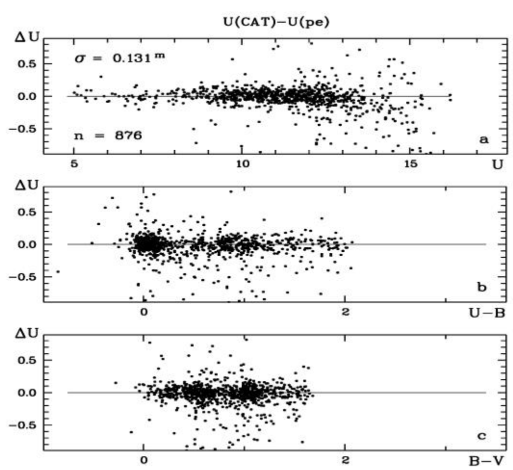

Fig.3 . The comparison of derived U-magnitudes with photoelectric ones.

After the processing of 24 digitized plates, exposed by Baldone Schmidt telescope in the U spectral band the catalogue of positions and U-magnitudes was obtained in the area of the meridian section of the Galaxy. The catalogue includes data of 68 784 stars and galaxies. The reference system of the catalogue is Tycho-2, magnitudes are obtained in the system of photoelectric standards. The positional internal accuracy of the catalogue is $\sigma_{\alpha\delta}$= ±0.28" for all objects and the photometric one is σ_U = $\pm0.20^m$ (for stars in the interval U = 8^m -14^m the errors are $\sigma_{\alpha\delta}$ = ±0.11" and σ_U = $\pm0.09^m$ correspondingly). The convergence of results with the Tycho-2 reference system is $\sigma_{\alpha\delta}$= ±0.06" for 5 814 Tycho-2 stars. The convergence with photoelectric U_{pe}-magnitudes is σ_B = $\pm0.13^m$ for 876 reference stars. The results of the comparison are given in Fig.3, where the differences ΔU=U(CAT)-U(pe) are represented in relation to photoelectric U-magnitudes and color-indices U-B, B-V.

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Observatoire de la Côte d'Azur plates archive: contribution to scientific heritage in the Gaia era

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Abstract

The Observatoire de la Côte d'Azur (OCA), formerly Observatoire de Nice, owns 16 000 photographic plates or films taken during more than 60 years (1935-1996). They concern mainly instruments at OCA sites, the Nice Zeiss binocular astrograph and the Calern Schmidt telescope, but also collections from other observing sites. An important protection operation was undertaken in 2012 to preserve these astronomical photographic plates with a secured storage. A study of these plates will be realised including the archiving, preservation and documentation aspects (database realisation with digitalization of observing logs).

Keywords: preservation, Schmidt telescope, astrograph, asteroids, astrometry

1 Introduction

The *Observatoire de la Côte d'Azur*, formerly *Observatoire de Nice*, founded in 1879 has from its origins, dedicated an important part of its research to astrometry, in particular with the installation of a large meridian circle made by the Brunner brothers (1887) and then a Zeiss binocular astrograph (1931). In the 1970s, astrometry observations were enriched by the construction of a Schmidt telescope at the Calern observatory (some 60 km from the *Observatoire de Nice*). This observing site was administrated since 1974 by the CERGA (*Centre d'Etudes et de Recherches en Géodynamique et en Astrométrie*). In 1988, the CERGA and the *Observatoire de Nice* merged into the *Observatoire de la Côte d'Azur* (hereafter OCA). Nowadays, OCA owns collections of plates taken with its Zeiss astrograph and its Schmidt telescope, and also collections from other observing sites.

2 A set of 16 000 plates and films taken during more than 60 years (1935-1996)

2.1 The Calern observatory Schmidt telescope

This instrument, also known as "TESCA" (*TElescope de SChmidt de CAlern*), is a pure Schmidt camera with a 1.52 m spherical primary mirror with a focal length of 3.16 m [1]. The Schmidt lens is in fused silica and has a diameter of 90 cm. Both were polished by J. Texereau (1919-2014). The mount is a fork equatorial with oil film bearings. Between 1978 and 1996, the observing team (J.-L. Heudier, Ch. Pollas, A. Maury *et al.)* produced some 3 600 astronomical images on glass plates and soft film (30 x 30 cm). The estimated limiting magnitude for these plates is Mb = 20.1 (B photographic magnitude).

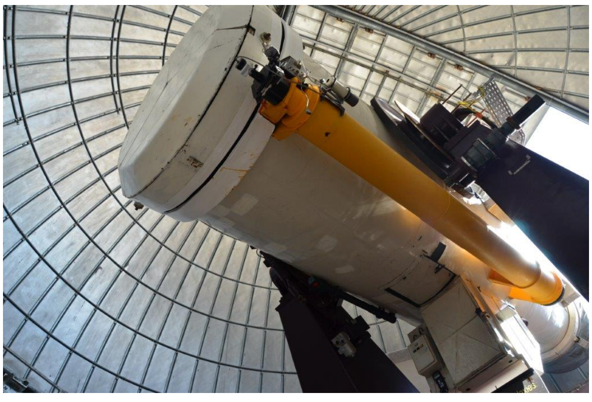

Figure 1: TESCA, the Calern observatory Schmidt telescope. (© OCA).

During those 18 years, several science topics were addressed:

- Solar System objects (search and characterization of asteroids and comets, satellites of major planets, construction of secondary catalogues for occultation programs, astrometry of minor objects).
- Stellar dynamics in clusters.
- Optical counterparts for gamma, UV, IR and radio objects detected by space-borne instruments.
- Supernovae and variable stars.

- Quasars, nebulas.
- Space debris location.

2.2 The binocular Zeiss astrograph

This instrument has been provided as war damages by the German optical manufacturer C. Zeiss. This twin refractive astrograph (see Figure 1) was installed at the *Observatoire de Nice* in 1935, on a massive German-style equatorial mount. Both optics have a focal length of 2 m and a diameter of 40 cm (aperture ratio: F/5). Since its first light in 1935, some 8 000 astronomical images have been taken on glass plates with various formats (9 x 12 cm, 13 x 18 cm, 16 x 16 cm, 18 x 24 cm, 24 x 30 cm, and 30 x 30 cm). The estimated limiting magnitude for these plates is Mv = 15 (V photographic magnitude). Mostly, two observing teams were involved: **A. Patry** (1902-1960) and **M. Laugier** (1896-1976), who produced some **2 500 plates from 1935 to 1961**, and **B. Milet**, who produced **5 500 plates from 1965 to 1978**. Most of these plates correspond to Solar System minor objects. A Zeiss measuring machine was used for plate metrology.

Figure 2: The Zeiss binocular astrograph at *Observatoire de Nice*. (Marc Heller © OCA).

3 Astronomical images from other observing sites

The OCA historical plate collection has been enriched by several astronomical images (glass plates and soft films) from other institutes:

- 3 290 images on soft film (diameter: 17.5 cm) taken by the Schmidt telescope at Meudon observatory from 1961 to 1975. Estimated limiting magnitude: M = 16 (photographic magnitude).
- Few plates from the "*Carte du Ciel"* program taken at various observatories (Algiers and non-identified observatories). See *e.g.* Figure 3.
- Some 50 glass plates (meridian plates and solar images) taken at the Pic du Midi observatory by O. Calame in the 1960s.
- Some 710 plates (various formats) mostly from or for C. Veillet, taken mainly at the Danish Telescope 1.50 m (ESO) and Pic-du-Midi, but also at the CFHT, at Manchester Univ., at the *Observatoire de Haute-Provence* and Chiran observing station (1970s, 1980s). Subjects: mostly Solar System objects (the Moon, Jupiter, Saturn, Uranus, Neptune, Pluto), nebulae, clusters, galaxies.

4 A strong will to preserve this collection

In autumn 2012, **an important protection operation** was undertaken by the OCA Heritage service for the 16 000 photographic plates and films which had been stored for several years in precarious conditions of preservation - very high and fluctuating relative humidity, unstable temperature, presence of dust - at the Calern observatory (the Nice astrograph plates had already been moved there during the 1990s). This operation involved three distinct phases:

- **Secured storage**. All the plates have been moved and stored in one single room (see Figure 4). An air-drying facility has been set up in this room and in the original places, to gradually change the air temperature and relative humidity, in order to avoid thermal shocks, and then, to maintain correct and stable preserving conditions. This operation involved tedious and delicate handling operations for more than 11 000 fragile plates. Specially designed containers have been constructed, to ease and secure the moving operations.

- **Classification and inventory** of the plates that were not inventoried before moving (about 9 000).
- **Plate preservation.** A quality control has been performed on sample plates randomly selected in each series of our collection. Most of the selected plates have revealed to be still well preserved. These plates have been dry-cleaned to remove dust. Then, they have been inserted in neutral paper folders.
  By now, all the 16 000 plates and films are stored in a controlled atmosphere in conformity with the standards given by the French National Archives and the CRCC – *Centre de Recherche sur la Conservation des Collections* [2] [3].

Figure 3: A new secured storage facility for astronomical plates, located at the Calern observatory. The complete OCA's plate collection has been moved there in February 2013. (© OCA)

5 A general referencing operation

With the aim of documenting these collections of astrometric images with the best accuracy, a general referencing operation has been launched in 2013. To accomplish this tedious task a collaboration with several researchers was set up to collect as much information as possible on these plates.

In order to gather all this information, a database has been conceived: a flexible and complete classification scheme has been designed and implemented under MySQL in order to link plates, observation logs and celest objects.

For the Zeiss astrograph collection, no inventory existed before 2013. All available observer's logs have been digitized and linked with plates. The same for the Meudon Schmidt logs.

Plates from the Calern Schmidt telescope (Figure 7) already been inventoried by Ch. Pollas (TESCA team) in 2 000, have been integrated in the database and completed.
Up to now the database contains 12 600 plates and 7 000 observation logs linked, digitized or transcribed.

Plates from other collections are currently been inventoried, in order to ease their future integration in our plate database (less numerous, about 800).

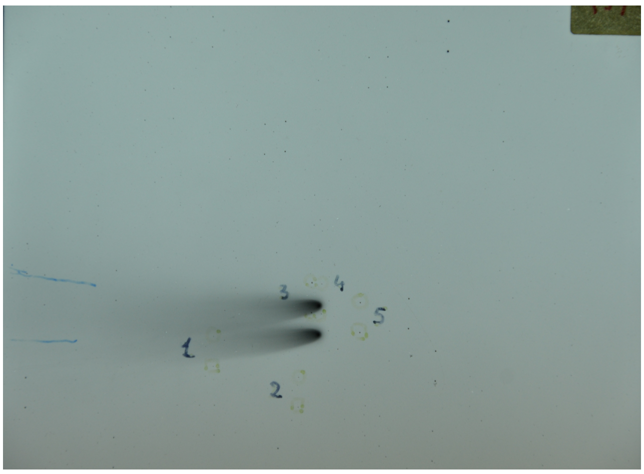

Figure 4: Bennett Comet. Nice astrograph plate n°1974 taken by B. Milet.

March 30.15820, 1970. 16x16 cm. (© OCA)

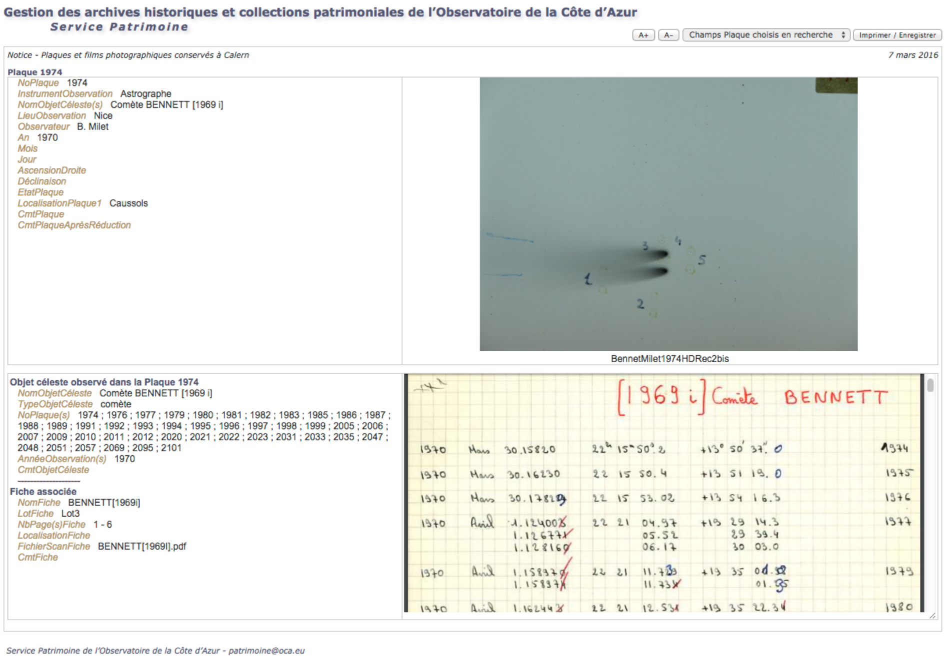

Figure 5: Database issue corresponding to the B. Milet plate n°1974 (Figure 5). (© OCA)

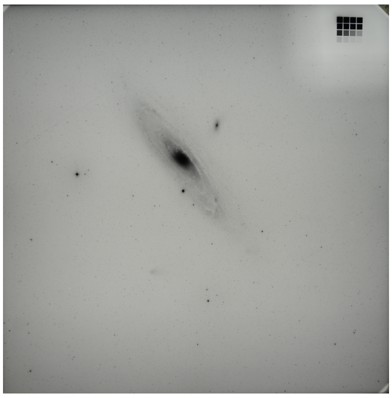

Figure 6: Calern Schmidt telescope plate n°1387 taken by TESCA team.
September 9th, 1985. 30x30 cm. (© OCA)

6 Upcoming steps

The next step will be a long-term operation of high resolution digitization of the most suitable plates, as part of the project NAROO (IMCCE, Paris Observatory). The last step will be the scientific exploitation itself by astronomers from OCA (some of them are deeply involved in the GAIA program, and thus interested in astrometry and proper motion determination, for example) or from other institutes (IMCCE, *Observatoire de Paris*,…). [4]

Preserving and referencing astronomical plates in such a collection is only the first step in the long process that will lead to the exploitation of the important scientific data these plates contain. The preserving effort has to be continued (reconditioning, the condition of the plate needs to be checked frequently). The referencing effort has to be pursued and refined. The existing informations in Wide Field Plate Database, WFPDB, Tsvetkov et al., 1997 [1], will be completed.

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Current status of digitizing Polish astroplate archives

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Abstract

This paper should be regarded as an update to our previous article "Preservation of Polish astronomical plates – digitization, calibration, publishing" (Kuligowska et al., Astroplate 2014, Proceedings of a conference held in March, 2014 in Prague, Czech Republic, Published by the Institute of Chemical Technology, Prague, 2014., p.48). We briefly present the current status of the Polish astronomical plate archives with particular emphasis on the statistics of plates digitized over the past two years. The general condition of the plates and their targets are also discussed. At the end we present examples of their scientific use and some scope for the further research.

Keywords: astronomical plates, astronomical data, archives, digitalization

1 Introduction

Currently-identified Polish archives of astronomical plates are mainly housed at the Astronomical Observatory of the Jagiellonian University in Cracow, the Nicolaus Copernicus University in Toruń, Adam Mickiewicz Universiy in Poznań, and the Nicolaus Copernicus Astronomical Center in Warsaw. In the frame of the PLGrid Plus project (Domain-oriented services and resources of the Polish Infrastructure for Supporting Computational Science in the European Research Space – PLGrid Plus [1]), a large part of these archives was digitized, calibrated and prepared for publication or published online. The main goal of this work was to preserve these fragile and valuable data, as well as to complete their online archive in a form accessible to the wider scientific community. Here we present the preliminary results of this effort.

2 Polish plates statistics

In this paper we report only on the plate archive located in Cracow and Toruń. Although we know that large resources of astro plates are also stored in other Polish observatories, currently we do not have access to them due to either the lack of proper decisions or local human resources to work with these archives (i.e. to scan them). One of the reasons is also the difficulty in obtaining funds for such operations. Regardless of this, in the last two years a large number of Polish plates localized in two of the above important scientific centres – the Astronomical Observatory of the Jagiellonian University in Cracow and the Centre for Astronomy at Nicolaus Copernicus University in Toruń – have been successfully digitized, supplemented with a coordinate grid, calibrated and provided to the astronomical society.

It is estimated that originally about 4000 plates were made with the 30 cm Maksutov and 50 cm Cassegrain telescopes in Cracow Observatory in the years 1960–1980, however only about 1200 of the "small" (6×9 cm) plates have been preserved to this days. There are also 400 13×18 cm ("big") plates taken with the 60 cm focal length Zeiss Tessar Astrograph. The total results of scanning include 379 digitized 13×18 cm plates (149 GB of disk space) and 1166 6×9 cm plates (118 GB). The time needed to scan one 13×18 plate was equal to about 15–20 minutes. There still remain a few dozen of the "big" plates to scan in the near future.

In the Toruń Centre for Astronomy, there were resources of nearly 12000 plates made with several telescopes since 1949 to 1993. Specifically there are 10882 scanned and digitized plates (with objects, fields or spectra) including around 3000 "big" and "small" plates (16×16 cm and 9×12 cm, respectively) made with the 90 cm Schmidt telescope, as well as around 1200 plates with spectra made with the 90 cm Schmidt-Cassegrain telescope. Two separate archives (including around 100 plates) are still waiting for preservation.

To sum up, one can assume that nearly 90% of the total resources of Polish astronomical plates from Cracow and Toruń have been digitized up to the present. The remaining ones are supposed to be scanned by the end of 2016. Unfortunately, due to difficulties with obtaining access to the archives of other Polish observatories, further work aimed at exploring and digitizing these archives is currently not being carried out. As has been previously mentioned in the Astroplate 2014 Proceedings ([2]), we used an Epson 10000 XL Scanner with a special adapter for scanning transparent materials. Initially, all the plates were scanned only once and only after prevacuuming. We also plan to scan them again in two perpendicular directions.

3 Status of the preservation of plates

In the case of both observatories, a relatively large part of the archived plates (up to 20%) have deteriorated or are physically broken. In many cases their emulsion layer is completely destroyed (transparent). There are also numerous severely yellowed plates. This is due to the very bad conditions in which these data carriers were previously stored (high humidity and moisture in the rooms, exposition to light, dust, mould etc.). Thanks to the valuable remarks of our colleagues from Prague, we will try to remove some of these factors as far as possible, and then digitize selected plates again.

Digitized plates are selected on the basis of the instrument and the date of exposure and sorted by their consecutive numbers. The development of their data and metadata for the purpose of publishing in the Polish Virtual Observatory is currently in progress. Data are available within the Astrodata service (a service of AstroGrid-PL project [1]). For the original plates, dedicated protective conditions are planned to be implemented in the archive of the Nicolaus Copernicus University library in Toruń.

4 The targets of the astroplates

Polish resources are very diverse in terms of photographed objects. They contain, among others, imaging plates and spectra, plates with calibrators, plates targeted at variable stars, novae, quasars, the Moon, comets, and selected Milky Way fields. There are also recently discovered large plates of as yet uncertain origin. We believe there is a high probability that they contain the so-called *Jagiellonian Field* (Rudnicki et al. 1973 [3]) – one of the first-ever cosmological surveys made. It creates a question of particular interest due to the fact that we may be in possession of the oldest plates of this type (deep survey of galaxies and quasars) in the world.

Aside from the date and serial number which are common to all preserved plates, quite a few have been marked after being developed to indicate the target objects. The observing logs for plates are again unavailable in most cases. This implies that most often it is only possible to recognize the photographed fields and targets due to the presence of other easily visible objects.

5 Current and future scientific use of the Polish astroplate archives

Since the scanning, calibrating, supplying with metadata and publishing the majority of the Polish plate resources was only performed in very recent times, the recovered data at this time has only been preliminarily used for purely scientific purposes. However, one of the most interesting examples of such a use was the inclusion of selected and digitized data from Toruń in searching and confirmation of gravitational microlensing [4], which was an encouragement to digitize all of Toruń astronomical plate archives.

It is planned to use all the digitized plates from Poland to extract the parameters of new and previously known asteroids (such as their magnitudes and orbital elements). This can be quite easily done using star catalogs and the proper software to identify any “additional” objects in the recognized

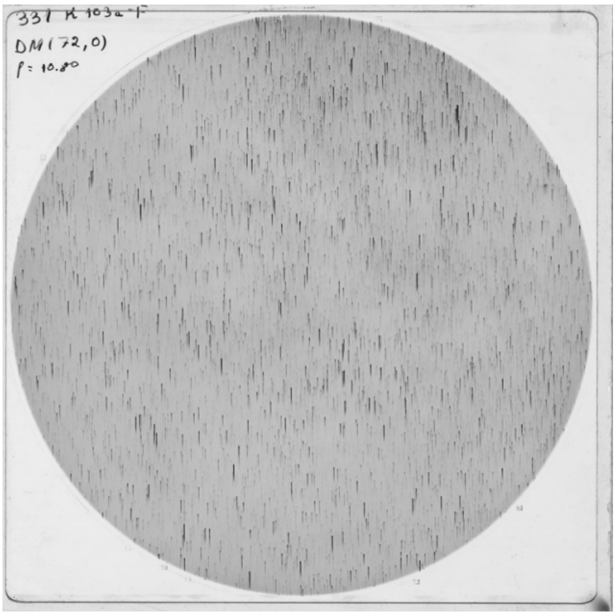

Figure 1: An example of a low dispersion spectral plate from Toruń Observatory.

fields. The impressive results recently obtained by Ilgmars Eglitis from Baldone Observatory of University of Latvia (presented at the Astroplate 2016 Conference, Prague) suggest that this type of research may be extremely effective in the search for asteroids and comets, including NEO objects. His preliminary work resulted in identifying 50 positions of asteroids weaker than 14 mag. – and among them 11 positions of 7 asteroids which, at the time of these observations, were the earliest known observations of these objects in the world. The number and diversity of Polish plates gives us the opportunity to conduct similar studies.

Another important issue is the process of identifying and publishing the digitized images. Calibrated plates with an overlaid coordinate grid can be successfully used to derive the exact time the observations were performed, and also to confirm or discover which objects were being targeted. For example, 46 of the existing 13×18 cm Cracow plates are known to be associated with observations of comets. One of these is no. 56, of C/1969 Y1 Bennett, taken on the night of 10–11th April 1970 (fig.2). Note that, although we do not have any original record of the exact time of observation, because comets exhibit fairly rapid motion across the sky, we can work backwards using a modern ephemeris to deduce when the photograph was taken. In this case the position of the head of the comet relative to the the field stars indicates the image must have been taken at about 02:26 UT on the morning of 11 April 1970. Available literature indicates that Comet Bennett was observed a few nights later from Poznań [5] and probably from Warsaw [6], but its Cracow observations do not appear to have been previously published.

To conclude, even the limited digitized part of all the Polish resources of astronomical plates may have an important scientific impact. Of particular interest is the possibility of comparing the actual digital sky images with similar observations of the same fields, but performed several decades ago. Digitizing the surviving archives provides and maintains this possibility for a very long time, especially in comparison to attempts to preserve the physical plates themselves.

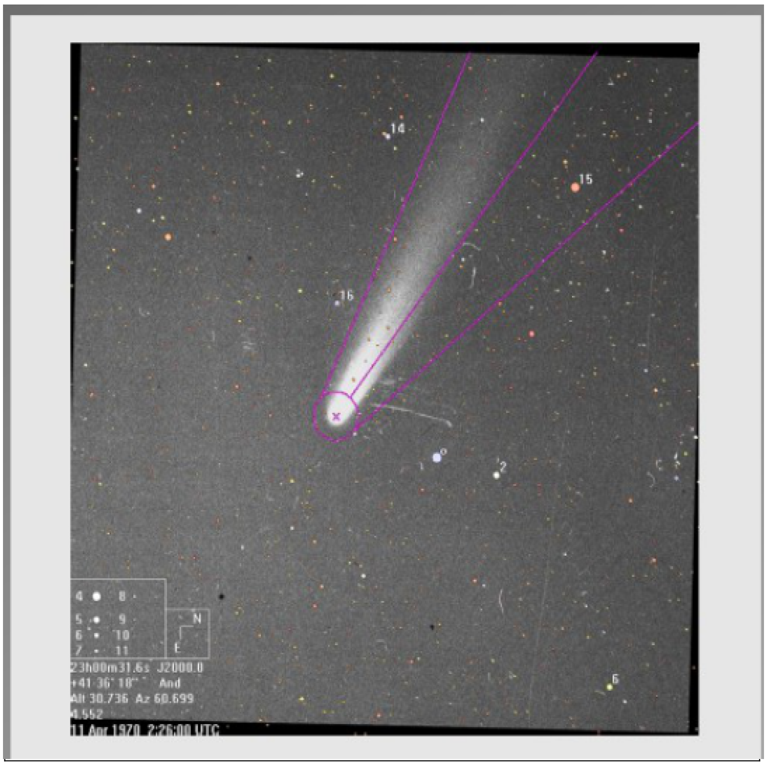

Figure 2: Enlargement of 13×18 cm Astrograph plate no. 56 showing the comet C/1969 Y1 Bennett with an overlaid chart. The stars omicron, 2, 6, 14, 15 and 16 Andromedae are marked. The plate image was rotated slightly to match the chart projection. Field size of this enlargement is approx. $4.5^{c}irc$. The software used is Guide 9 from Project Pluto.

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Metadata salad at the Cordoba Observatory

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Abstract

The Plate Archive of the Cordoba Observatory includes 20.000 photographs and spectra on glass plates dating from 1893 to 1983. This contribution describes the work performed since the plate archive was transferred to the Observatory Library in 2011. In 2014 an interdisciplinary team was assembled and a research grant from the National University of Cordoba was obtained with the objectives of preserving the glass plates and generate public access for astronomers and other audiences. The preservation work not only includes practical intervention to improve conservation conditions for the whole archive, but also a diagnose of the preservation conditions for the plates and identification of best practices for cleaning the plates. The access envisioned through digitization requires not only the scanning of all the plates, but also careful definition and provision of metadata. In this regard, each institutional level involved – in this case: archive, library, astronomical observatory and public university - demands and provides different bibliographic practices, involving multiple standards of description and coding.

Keywords: National Argentine Observatory, Photographic Archives, Photographs on Glass Plates

Introduction

The Córdoba Observatory was founded in 1871 as Argentine National Observatory (Observatorio Nacional Argentino). Domingo F. Sarmiento and the U.S. astronomer Benjamin A. Gould met in 1865 in Boston where Gould expressed to Sarmiento his intentions to create a complete catalog of the southern sky. Once elected president, Sarmiento offered Gould the creation and direction of a new scientific institution: the Argentine National Observatory in the mediterranean city of Córdoba[1]. Benjamin A. Gould would not reach completely his ambitious goal: his "Uranometría Argentina" was indeed the first complete star catalog of the Southern hemisphere, but the observations had to be made without instruments since the Franco-Prussian War blocked the shipping of all equipment. After the war, Gould and his staff continued their work and published several works, for example the Zone Catalog (1884) and the General Argentine Catalog (1886). Gould returned in 1885 to the United States. But Benjamin A. Gould was also a pioneer of astronomy photography. His "Cordoba Photographs: photographic observations of star-clusters", published in 1897, were the first systematic use of photography in astronomy. The original plates of the "Cordoba Photographs" on wet collodion are actually part of the Harvard Plate Collection.

In 1954 the Argentine National Observatory was transferred to the National University of Córdoba and changed its name to Astronomical Observatory of Córdoba (Observatorio Astronómico de Córdoba).

The Plate Archive of the Cordoba Observatory

The Plate Archive of the Observatory includes ca. 20.000 photographs and spectra on dry plates created between 1893 and 1983. From 1880 on, dry plates with silver bromide emulsions replaced other photographic mediums like albumen and collodion plates. The main advantages of dry plates were the feasibility of industrial manufacture and their stability who allowed storage and distribution while maintaining photographic permanence [2]. The Plate Archive of the Córdoba Observatory is organized in series responding to their scientific origin like Astrographic Catalog, Carte du Ciel, Pulkovo Zones, Sun, Planets, Comets and Minor Bodies, Globular Clusters, Magellanic Clouds, Southern Galaxies and others. In addition there are also photographs of the Observatory, its construction, staff, instruments, activities and the Fonds of spectra [3]. The sizes of the plates varies from 5.5 x 8.5 cm to approximately 20 x 30 cm. Most of them have data written on their borders and have been stored in their original boxes. Only the most recent plates from the 40's on have cardboard enclosures with some data about the plate. The Observatory kept also observation log books with additional information. The location of the Plate Archive in a location below ground without ventilation and summer temperatures up to 32º C / 89.6º F and 80% moisture was far from optimal. Since neither the enclosures nor the boxes met the requirements for long term conservation, through the project "Recovery, value enhancement and dissemination of the heritage of astronomical photographs of the Plate Archive of the Astronomical Observatory of Córdoba" the replacement of all enclosures and boxes has started. The main goals of the project are the preservation of the plates and to generate access for astronomers and other public through digitization and metadata creation. In 2016 the Plate Archive was relocated to a climate controlled storage.

Creating access (Metadata salad)

The Plate Archive was organized in 1996 and most plates recorded in a basic inventory. A group of astronomers under the leadership of Jesus Calderon nearly completed a catalog of astronomical plates. In 2012 the Archive was transferred to the Observatory library. Digitization of 500 plates started in 2012 through a grant from the Bunge and Born Foundation. In 2015 the Observatory acquired a scanner to digitize the whole Archive. Regardless of the digitized images, to publish these images to end users, first the the recipients of the images have to be defined and with it their requirements regarding descriptive metadata.

The Plate Archive is first of all an archive, a "... documentary by-product of human activity retained for their long-term value"[4]. As an archive the application of standards of archival organization and document description follows established and approved practices. On the second instance, the Córdoba Plate Archive is a special collection of a library and that means that its records have to coexist with norms, practices and software used by the library without losing its identity as archive. It is also part of an astronomical observatory and its natural users are astronomers who in turn have their own standards of identification and data description. But astronomers are not the only recipients of the photographs; as a part of a national University -a public institution- the Plate Archive needs also to be included in the outreach and scientific dissemination activities of the Observatory and offer final results to the general public. Each one of the institutional levels: archive, library, observatory and university, have their own ideas, expectations and standards on how information and data should be organized and displayed. It is also important to keep in mind that the original photograph (plate) and the digital image are two different documents, one derived from the other and that both need a proper and specific description even if they share part of the data.

The term "metadata" is formed by a combination of the greek μετα, meta, that means means "after" or "beyond", and the latin "datum", "something given" and is used in this combination with the meaning "data about data." According to Taylor & Joudrey, the concept of metadata refer to "structured information that describes the attributes of information resources for the purposes of identification, discovery, selection, use, access, and management"[5].

1. Metadata in archives

Archivists have their own theoretical-practical corpus that is different from other documentary disciplines like librarianship or museology. One of their basic principles is the "Respect des fonds" who unites two basic principles of archival organization. The principle of provenance requires that all records created, assembled or maintained by an organization or an individual are represented together and distinguishable from the records of any other organization or individual. The principle of original order means that the order of the records that was established by the creator should be maintained by physical and/or intellectual means whenever possible to preserve existing relationships between the documents and the evidential value inherent in their order. Both principles form the basis for archival descriptions [6]. These principles requires to group documents and record their data according the order in they are found or reconstruct the original order and represent the data consistent with these principles. The physical organization of an archive is structured from the most general to the most specific, identifying and creating hierarchical relations between different levels of arrangement. Metadata for archives need to recognize and represent these hierarchies.

One of the pillars of archival description is the International Standard Archival Description (General), in short ISAD(G), published by the International Council of Archives in 2000. ISAD(G) is a standard widely used in Argentina since there are no national archival standards. ISAD(G) includes five levels of arrangement: fonds, subfonds, series, subseries, file and item [7].
For an archive that is part of a library, there is another standard of interest: "Describing Archives: a Content Standard" (DACS) is the official standard of the Society of American Archivists. DACS is the U.S. embodiment of ISAD(G) and is also compatible with the Anglo American Cataloging Rules and Resource Description Access (RDA), both library standards. DACS offers the documentalist much more detail and data fields to construct an adequate description than ISAD(G). DACS offers also "crosswalks" between DACS, RDA and Marc21, a library coding standard. In spite of the benefits of DACS for archives who are part of a library, there is no Spanish translation available who could promote its use in Spanish speaking countries.
DACS recognizes and recommends other more standards for specific materials. For archives with graphic materials, including photographs it advocates "Descriptive Cataloging of Rare Materials (Graphics)" (DCRM(G)). This norm was published in 2013 by the Rare Book and Manuscript Section de la Association of College and Research Libraries. For a Plate Archive, chapter 5 "Physical Description Area", is of special interest because it offers rules to create more detailed descriptions of the medium and their material. A wealth of examples are also included [8].

2. **Metadata in libraries**

Actually most libraries in Argentina still use the Anglo American Cataloging Rules, second edition, while in other countries the transition to the new cataloging code, "Resource Description and Access" (RDA) is underway. Even though the Anglo American Cataloging Rules include a chapter about manuscripts that is applicable to archives, it is RDA who has incorporated much more elements of archival practice for example access point for families and devised titles.
Libraries have also a large tradition of coding rules. The Marc 21 Bibliographic Format (former Usmarc Format) is an important international standard supported by most common bibliographic utilities. In the United States, archives started to incorporate their records in library public access catalogs in the 80's in spite of the more limited nature of library catalog data in comparison to archival finding aids. But their inclusion in library catalogs facilitated the access of archival documents for end users. The most important problem for archives who use library coding formats is the poor aptitude of Marc21 to handle hierarchical relationships and to group records. But in practice the limitations to represent multilevel relations are mostly originated in library software packages more than the coding format itself.

3. Metadata in observatories

Astronomy is a scientific discipline with its own tradition of publication and sharing of primary data like images and spectra. The universal standard for digital images in astronomy is the FITS (Flexible Image Transport System) format. Unlike other metadata, the FITS format includes embedded metadata and is structurally very different to file formats used in the archival and library community like Marc21 or XML based formats.
As a very specialized file format, FITS is not useful for outreach or dissemination purposes. For these activities, more generally used file formats like JPEG or PNG and conventional content management systems or document repository software are much more suited. As an institution belonging to a national University who was a pioneer in including outreach as one of its fundamental goals, the Observatory has an important outreach and dissemination activity. The library participates in these activities and propose to publicize the images of the Plate Archive for a general public through the institutional repository of the National University of Córdoba. This requires careful planning of file format conversion, define resolution and size of the images to be displayed and also the creation of appropriate metadata for a more diverse user community. The repository of the University uses the DSpace software and in spite of its

ability to accommodate different metadata schemes, the use of the Dublin Core Scheme will facilitate the dissemination of the information through the OAI-PMH protocol.

Metadata processing for several kinds of users

Faced with a variety of applicable norms and standards, for the Plate Archive of the Córdoba Observatory three lines of action were defined. 1) Describe the photographic plates with the compatible standards DACS and RDA and complement the physical description with DCRM(G). This decision allow the implementation of Marc21, the use of standard library software and the creation of links between plate data and publications. 2) Use of the FITS format for the digital images of the Archive and offer access to the astronomical community through the Nuevo Observatorio Virtual Argentino (NOVA), a member of the International Virtual Observatory Alliance (IVOA). 3) Batch loading of selected images of some plates for the general public in the institutional repository of the University in a standard file formats (JPEG or PNG) and with a document description in the Dublin Core Schema.
All metadata in the Archive starts with a base record who includes text written on the plate, information recorded on the enclosure, box or log books and the observation of the documentalist. This base record is then converted to the secondary formats: Marc21 for the library system and the public catalog, FITS header and Dublin Core record for the repository. At this point a automatized procedure exists for the Marc21 format.

Is is important to reclaim Plate Archives as an important scientific but also cultural heritage. Using standards permits incorporation, sharing and reuse of digital data through different networks: astronomical, libraries, archives and other heritage organizations for a broad and diverse user community.

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Center of space researches and technologies and astronomical photographic plates library

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Abstract

Today on the basis of Engelhardt astronomical observatory (EAO) the Centre of cosmic researches and techniques and Astropark within the framework of Program of the Kazan Federal University development is being created. The Center has the following missions: education, science, astronomical tourism. In EAO there is a big glass library containing the photographic plates as well. Many plates are the pictures of stars, planets, the Moon with stars etc. It is scheduled to perform digital scanning and processing these plates.

Keywords: cosmic researches and techniques, astropark, education, science, astronomical tourism, astronomical photography observations, glass plates library,

Introduction

The Engelhardt Astronomical observatory was founded in September 21, 1901 and for 115 years it is one of the leading observatories in Russia. The development of astronomy in Kazanhas come to the new millennium with traditional directions ofEAO astronomy. They are astrophysics, astrometry and celestial mechanics, which includes planetology and meteor astronomy, cosmic astrometry and celestial mechanics. There are two main projects: observation program with the telescope RTT-150 which has been installed in Turkey and the creation of Center of space researches and technologies based on the Engelhardt Astronomical Observatory.

1. Center of space researches and technologies

The project requires formation and development of two radio-physical polygons which are associated with the observatory’s territory, using the available resources of the observatory and astronomy, radiophysics, radioastronomy, radioelectronics departments [1]. The aim of this project is creation of an unique educational-scientific, scientific and technological world-class complex in the study of near and far space. Educational activities in the field of practical work and retraining, educational-industrial and scientific practice for students and graduates of the Kazan University and other educational and scientific institutions of Russia, the near and far abroad will be implemented on the basis of EAO. There are the following practice areas: astronomy, geodesy and remote sensing, radio physics.

There are departments of scientific and technological programs realization: space astronomy and geodesy, applied astrophysics, radioastronomy.

The practice base in astronomy, terrestrial and satellite geodesy, topography, radiophysics and radioastronomy fields are supposed to be the main component. The activities of all departments will be coordinated in a single center of near and far space study.

Research and Educational Center on the basis of the Astronomical Observatory will be the first world's educational-academic complex, which will combine the existing Astronomical Observatory with the modern planetarium. Such approach will allow to add the planetarium operation with real observations, using the existing telescopes, celestial bodies and astronomical phenomena (planets, stars, galaxies and nebulae, comets and asteroids, meteor streams, solar and lunar eclipses, satellites, etc.) and provide with "immersion" of Astropark visitors in a professional environment of the universe knowledge, the expansion and motivation of public's interest in historical and modern scientific thought.

Metrological polygon, which is used by Russian cosmos for testing the navigational equipment on the data of satellite GLONASS grouping observations, was built at the EAO in 2010 bythe inter-regional centre for applied navigation technologies and services, and the polygon of the satellite navigation technologies and services processing.

The creation of the complex of scientific equipments, the Center of near and far space research, involves the design and installation of the most accurate high-tech devices which interconnected with it and with each other in scientific and productive terms in addition to the existing observational database of the KFU: 13 m radio telescope for radio interferometer with a very long observations bases (VLBI) in conjunction with the Institute of Applied Astronomy RAS;Quantum-optical system "Sazhen TM" for specifying the satellite's orbit elements and supporting the GLONASS system;The system of optical widefield monitoring of the celestial sphere with subsecond temporal resolution "Mini-Mega TORTORA" together with the special Astronomical Observatory of RAS. Itis going to provide detection and investigation fly phenomena with previously unknown location in the near and far space. The main way of getting information is the wide optical monitoring of the celestial sphere with a high temporal resolution. The main task is finding the new and study of the known non-stationary objects of different nature and localization and the task requires the monitoring process. The continuously updated dynamical picture of the near and far space with subsecond temporal resolution is going to be obtained for the first time in the world. Robotic multi-channel (9 lenses) optical complex with the visual field of about 900 square degrees and a time resolution of 0,1 secondhas been made for the constant observations. This complex accumulates information about all the stationary and transient (in time and space) sources of the optical radiation, localized in the celestial hemisphere (20000 square degrees) with the glitter up to 17,5 stellar magnitude. The single complex of monitoring and on-line analysis of the observed events which is equipped with IT-center (with the display system, processing and keeping the obtained observational data) is set up in EAO on the basis of the system of wide-angled monitors.

The Planetarium is the main element of the educational components of the center for the near and far space study. Today, there are more than 2500 planetariums including 1200 in the USA, 540 – in Europe, 400 – in Japan (today there is no planetarium which combined with the existing astronomical observatories, so it confines their effectiveness). Russia is significantly behind developed countries in terms of this parameter. Today, there are only 32 planetariums in Russia (all these planetariums are located within the cities). Most of them have become technically and morally out of date. There are some attempts to modernize the planetarium's network (Moscow and Kaluga planetariums were reconstructed, the modern planetarium was built in Yaroslavl for the last two years), but they are not systematic.

The complex of future Kazan planetarium is going to include both the planetarium and the Astropark. The creation of the first in the world planetarium with the Astropark is technologically, methodologically and geographically integrated with the existing world-class astronomical observatories at EAO will promote Kazan astronomy development to a new qualitative level. The planetarium will show: the position and motion of stars and planets at any latitude and in any time in past or present, or future; astral sky for an imaginary observer on the Moon, Mars, Venus; audio-visual simulation of the space flight; travelling to other planets, etc. in fact, it is a high-tech interactive experimental educational laboratory which makes a significant contribution to the development of innovative capacity, training and education.

Planetarium at EAO consists of dome room, laboratory building, demonstration telescope with a lookout area and auxiliary facilities. Full dome system project including the star ball and a system for the projection of high resolution will be set in the planetarium; they will perform a demonstration of research and educational astronomical programs in landscape mode and perform audio-visual simulation of space travel and events. Planetarium's hall accommodates more than 100 people and can be transformed for scientific conferences, lectures and other events (up to 150 seats).

Astropark territory which is located around the planetarium is going to include a park and architectural complex consisting of alleys system, small architectural forms, decorative sculptures and recreation areas with individual landscape beautification.

The project also involves the construction of an industrial complex to accommodate up to 400 people (students, graduates, trainees, teachers and researchers) which according to modern international standard will provide the accommodation, practice sessions, research activities, food and rest.

2. EAOGlasslibrary

At EAO there is a glass library that contains a large archive of photographic plates, covering the period of more than 90 years, and obtained by different telescopes [2, 3, 4]:

1) A photographic survey of the sky (FON) 30X30 - 1746 plates;
2) Photographic catalog (size 30X30) - 700 plates;
3) The Moon with Stars - 612 plates;

4) Positive images - 272 plates;
5) Comets, asteroids, moons - 159 plates;
Schmidt Telescope:
6) Selected Areas of Kapteyn - 1500 plates;
7) Comets and asteroids - 950 plates;
8) Radio sources - 253 plates;
9) Variable Stars - 350 plates;
10) New and supernovae - 300 plates;
11) Random objects - 250 plates;
Meniscus telescope :
12) Selected Areas of Kapteyn - 1070 (2130) plates.
Total: 10292 plates.

It is planned to convert the astronomical photographic plates into digital form. In order to get an acceptable size of final data (tens of MB) and no loss of astronomical data some compression methods with resolution up to 20 microns will be used.

3. Conclusion

Today the development of astronomy and space geodesy in Kazan takesa new qualitative level and in the future we are expecting a lot of important discoveries.

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Ground-based and space photographies of the Moon: production, reduction, storage

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Abstract

In Engelhardt astronomical observatory (EAO) there is a big archive of the unique photographs of the Moon with stars and its reduction is being carried out. The observations of the Moon are made to solve three problems: studying the rotation of the Moon, the mapping of the nearside of the Moon and its marginal zone, investigation of the dynamic time scale. Several works about determination the ephemeris time and its using for analyzing selenodetic reference coordinates systems were made on the basis of plates of the Moon. Today we are carrying out the reduction of the lunar images and their transformation into digital form.

Keywords:photographs of the Moon with stars, selenocentric dynamical systems, selenodedic reference coordinates

Introduction

Currently the Moon is a subject of research in many space experiments in astronomy and planetary science. Modern space missions "Clementine" and "Lunar Reconnaissance Orbiter" (LRO) and "KAGUYA (SELENE)" swiftly and radically changed the situation in the study of the Moon [1]. Today there are the prospects in industrial and robotic exploration of the Moon and creating long-term manned lunar bases. Development of these space technologies imposes special requirements on the results of coordinate - time support. It is including the development of reference systems, establishing mutual orientation of dynamic and inertial coordinate systems and investigation of the dynamics and geometry of the celestial bodies.In article the brief history of the development of photographic positional observations of the Moon in Kazan University and Engelhard Astronomical Observatory from the end of the last century until present is describes. All aspects of research on the Moon, its rotation and gravitational field are considered as well as other questions in this report. In Kazan University and Engelhard Astronomical Observatory (EAO) much attention has been paid to investigations of the Moon and its rotation.

1. History of the development of photographic positional observationsof the Moon in Kazan

In EAO photographic observations of the Moon have been made to solve three problems: the study of rotation of the Moon, the mapping of the nearside of the Moon and its marginal zone, establishment of a uniform scale of the ephemeris time. In 1949 I. V. Belkovich constructed a special horizontal astrograph with the coelostat and additional mirror. The objective of the telescope had a diameter 20 cm and focal length 8 m.Three photographic images of the Moon have been obtained on plates of 13x18 cm. The stellar fields were photographed on separate plates for determining the scale. Three images of the Moon were used to determine the orientation of the plates and it was sufficient to research the Physical libration of the Moon (PLM).

In 1949-1952 Sh. T. Habibullin obtained many pictures of the Moon, from which 40 plates were chosen to research PLM. The constant *f*of PLM was calculated by two methods: the Bessel-Wihmann and the Koziel. The results of reduction of photographic observations of the Moon confirmed the suitability of Habibullin's method for studying the rotation of the Moon [2, 3].

The study of non-uniformity of rotation of the Earth and the establishment of a uniform scale of ephemeris time became the most important problems in astronomy and geodinamic in the middle of XX century. In 1953 the American astronomer W. Marcowitz, introduced the special dual-rate moon-position camera, which allows one to photograph the Moon and stars simultaneously. In 1958 such observations were begun in EAO by refractor Zeiss with a doublet photovisual objective (D=148 mm, f=2580 mm). During 1958-1961 an employee of EAO, N. G. Rizvanov obtained 435 plates of the Moon with stars. As a result of reduction of the plates the corrections of ephemeris time for the next epoch were determined: 1958.25, 1959.61, 1960.43, 1961.37 [3].

In order to explore the Moon with space-rocket equipment, it was necessary to prepare cartographical maintenance of its visible side. That is why the determination of selenocentric coordinates of the lunar objects became the most important problem in selenodesy during 1960-1970. It was perfectly obvious that large-scale star-callibrated lunar photographs would more correspond for solving this problem. Unfortunately, to obtain such photographs was technically difficult. That is why observers took photographs of the Moon without stars on large-focus telescopes. Thus there were difficulties with the determination of their scale, orientation and zero-point. The first large-scale star-callibrated lunar photographs were obtained in EAO with a horizontal telescope by N.G.Rizvanov in 1964. For this purpose the telescope was modernized [2] and several dozens plates were obtained. Then on their basis the astronomer of EAO S. G. Valeev made selenodetic investigations [3].

Later the observations of the Moon with stars by the horizontal telescope were made with the camera of N. F. Bistrov [3]. In 1970 the telescope was transferred to a mountain station in the region of Zangesur ridge. About 1000 photographs of the Moon with background stars were obtained during the period of 1970-1975. At that stage the work was carried out in cooperation with the Institute of Space Researchers AS USSR [3]. A number of selenodetic problems were solved on the basis of these observations. In selenodesy for the first time the catalogue of selenocentric coordinates of 264 craters was constructed by relating them to the stars, that is "by the absolute method" [2, 3]. The catalogue of selenodesic positions of 120 craters was constructed on the basis of coordinates of 10 craters determined by EAO heliometer measurements relative to stars [3]. A number of works were carried out to study the figure of the marginal zone of the Moon [4]. Parameters of physical libration were determined. The maps of the marginal zone of the Moon related to the centre of its mass were made and thus the orientation of the ellipsoid axis of the Moon inertia was determined [4].

The mapping of the lunar surface on the basis of space photographs in EAO was carried out in 70-80 years in cooperation with the Institute of Space Researchers AS USSR. The topographical characteristics of the dark side of the Moon and its marginal zone were determined by photographs obtained from the spacecraft "Zond-6,-8" transferred for this purpose in EAO from the Institute of Space Researchers AS USSR. The sea East region of the Moon received much consideration [3].

A number of selenodesic studies were executed by S. G. Valeev on the basis of ground-based and space photographs of the Moon [2]. He developed the method of regression analysis for solving the problems of photographic astrometry and selenodesy.

2. Photographic observations of the Moon with stars

For a long time the lunar photographic observations have been carried out at the Kazan University with the horizontal long-focus telescope. These observations are used for the solution of certain lunar problems. The elaboration of methods for obtaining large- scale star-calibrated lunar photographs was stimulated by the wish to avoid the insufficiencies typical for previous lunar study methods based on the photograph measurements made with long-focus telescopes of large apertures. In these works the distinctive particularity is a plate constants definition with respect to the lunar points with known selenocentric coordinates. This calibration of lunar photographs was subject to the systematic errors to the coordinates of the measured points on the lunar surface [5]. The reduction method with reference to the stars surrounding the Moon provides a calibration independence of astrophotography from previous selenocentric systems. It determines an absolute barycentric coordinates system referred to the principal directions of the axes of lunar inertia with an accuracy of the errors of measurement, of the theory of lunar motion, the rotation, and of the coordinates of the reference stars. The method of taking large-scale star-calibrated lunar photographs by means of the horizontal telescope (F = 8000mm, D = 200 mm) on separate plates is based on the photography of the Moon and stars on two separate plates. The lunar plate is located in front of the star plate 3 mm closer to the objective. At the time of exposure, the lunar plates moves in regard to fixed stars

3. Reductions lunar observations

By solving the problem of high-precision condensation and expansion of Kazan selenocentric catalogue (KSC) on the visible side of the Moon and lunar far side were obtained following new results [6]:a) the analysis and investigation of the accuracy of basic net contained in ULCN were carried out; b) the decryption of common objects for coordinate systems which are being explored was executed; c) the extension of the mathematical content package Transformation of selenodetic coordinates (TSC) was carried out; d) the development of TSC as an expert system of universal transformation planet's coordinates was executed; e) the possibility of applying the ARM-approach to the problem transformation coordinates(TC) on common objects, which allows to find optimal parameter estimation and model structure of TC, was confirmed; f) the method of structural-parametric identification of the adequate model of the TC, based on ARM-approach, in terms of interpolation (concentration) and extrapolation (extending) selenocentric net was developed; g) TSC software allowing in an automated way of identifying common objects to obtain the coordinates of the objects considered directory in the system Kazan selenocentric catalogue (KSC-1162) as in the orthogonal transition matrix for the deterministic models was developed; d) the union selenocentric catalog (USC) which gives a view of the discrepancies between the coordinates for the original and reduced versions of catalogs for different models was obtained.

Conclusion

The solutions carried out in this work allows us to make fundamental global coordinate system on the Moon which will serve as the basis for the mass of the homogeneous expansion by photographic materials from the spacecraft during steady-state study and practical exploration of the Moon.

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The historic light curve of GR290 from plate archives

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Abstract

We have investigated the past light history of the luminous blue variable star GR 290 (M33/V532, Romano's Star) in the M 33 galaxy, since 1901, using archival plates of Heidelberg, Pulkovo, Hamburg, and Yerkes. The light curve showed that for at least half a century the star was in a low luminosity state, with B ∼18, at variance with the behaviour of the last 60 years. We can rule out a recurrence time scale of about 40 years like that recently proposed for Var C in the same galaxy.
Keywords: astronomical plates digitization; photographic photometry; stars: Luminous Blue Variables

1 Introduction

GR 290 (Romano's star) was discovered as a variable star in the nearby galaxy M33 by Giuliano Romano (1978) at the Asiago Observatory: this star is now also known as V 532/M33. Likely it is a luminous blue variable (LBV), similar to the Hubble-Sandage (1953) variables, but its evolutionary stage has been recently questioned by Polcaro et al. (2016). Its published light curve starts since 1960 (Kurtev et al. 1996, Polcaro et al. 2016 and references therein) and shows a slow increase up to 1990, a large major peak in 1993, and a slow decrease up to present, with several minor oscillations. The total observed range is from B=18.6 to B=16.0.

2 General remarks

The recent fast progresses in internet connections and plate digitization allowed us to do in a reasonably short time a search for old M33 plates in several astronomical plate archives and to make homogeneous photometric measures of pre-discovery plates of this star. The explored archives are listed in Table 1.

Given the expected faintness of the star, smaller patrol telescopes could not provide useful data. Unfortunately, we have not still been able to recover the original 100-inch plates used by Hubble and Sandage (1953) in their pioneering paper on the LBV stars in M33.

We used the photometric sequence defined by Viotti et al. (2006) ranging from B=14.8 to 17.8. A local astrometry was performed with IRAF/ccmap taking as free parameters the scale and the rotation angle. Aperture photometry of the digitized plates was made with IRAF/apphot using an aperture matched to the stellar PSF. The stellar fields near GR 290 and near the comparison stars are not crowded, so there is no problem in finding the sky level. The adopted photometric aperture radius was selected to be comparable to the FWHM of the stars, typically 3 arcsec. Some concern is rather due to the inhomogeneity of the emulsion in several plates: this is a major source of photometric uncertainty. A linear fit between instrumental and reference magnitudes gave generally good results. Sometimes we excluded the brightest (partially saturated) stars of the sequence. In few cases a parabolic fit was used instead of a linear one: an example of parabolic fit is shown in Fig. 1. To estimate the photometric accuracy of our magnitudes we measured also a field star of comparable magnitude and used its deviation from the fit as a photometric error, which resulted to be about 0.2 mag.

2.1 Hamburg plates

The Hamburg plate archive is accessible on-line at the website [1] .

[1] http:// plate-archive.hs.uni-hamburg.de/ index.php/en/

Table 1: Archives searched

Observatory	telescope	plates
Hamburg	(1m F/3 Newton)	9
Heidelberg	(72cm F/3.9 reflector)	13
MAST	(Palomar 120/180cm F/3 Schmidt)	4
Pulkovo	(330mm F=3467mm, astrograph)	6
Yerkes	(60cm F/3.87 reflector)	14

Several telescopes have been in use at the Observatory, but for our star only the 9 plates from the 1m telescope were deep enough to show our star. The plates have four different types of Agfa emulsions and no filters and range from the year 1914 to 1930. Given the fast telescope focal ratio, they are substantially affected by coma but the region around GR 290 is fairly usable for aperture photometry.

All plates were digitized in transparency mode at the Hamburg Observatory with Epson Expression 10000 XL scanners, at 2400 dpi, giving a scale of 0.74 arcsec/pixel. No astrometry is included in the original scans.

We transformed the plate transparency into pseudo-intensity with the formula (Nesci et al. 2005) I=(U-B)/(T-B), where:

T is the transparency of a given pixel,

U the average transparency of the unexposed plate and

B the transparency in the center of saturated stars.

For each plate, a linear fit between instrumental and nominal magnitudes was derived and found quite satisfactory, with a slope near to the ideal case of 1.00; from these fits we derived the magnitude of GR 290 together with the rms deviation of the comparison stars from the calibration and the slope of the linear fit.

2.2 Heidelberg plates

Useful plates containing GR290 were obtained with the Walz 72cm reflector; they were digitized with the Heidelberg Nexscan F4100, with a resolution from 100 to 200 pixels per millimeter. Access to the plates is provided at the following link [2]. We found 13 plates of M33, 8 plates gave just upper limits, while 5 plates showed the star measurable. The astrometric solution is included in the fits files but we had to remake it to get compatibility with the IRAF/apphot centering routine.

2.3 Pulkovo plates

The 6 useful plates found in the Pulkovo archive in the years 1935-38. They have been digitized with a Canon 5D MarkII camera in RAW format (CR2) and converted into FITS grayscale format using MaximDL under Windows XP. Astrometric solution was performed with IRAF/ccmap giving a scale of 1.2 arcsec/pixel.

There is no unexposed area in the plate scans, so we could not use the actual plate fog level for the intensity conversion and simply assumed I=1/T. The star was always near the plate limit, so the photometric errors are substantial (0.2 mag), but we can rule out that the star was in a bright state in this time interval.

2.4 Yerkes plates

Fourteen plates were recovered from Yerkes archive, most of them made with the 24 inch telescope, ranging from 1901 to 1952.

The 1901 plate is the oldest observation recovered, taken by G. W. Ritchey on 1901 August 15. A second early image was recovered by scanning the photographic reproduction of a plate taken on the nights of 4 and 6 September 1902 and published on the Decennial Publication of the Yerkes Observatory (Ritchey 1904). One of the plates (G107a) was made with the 60 inch telescope of Mt. Wilson, and another one (cl-204) with an unidentified telescope of similar focal length.

[2] http://dc.zah.uni-heidelberg.de/lswscans/res/positions/fullplates/form

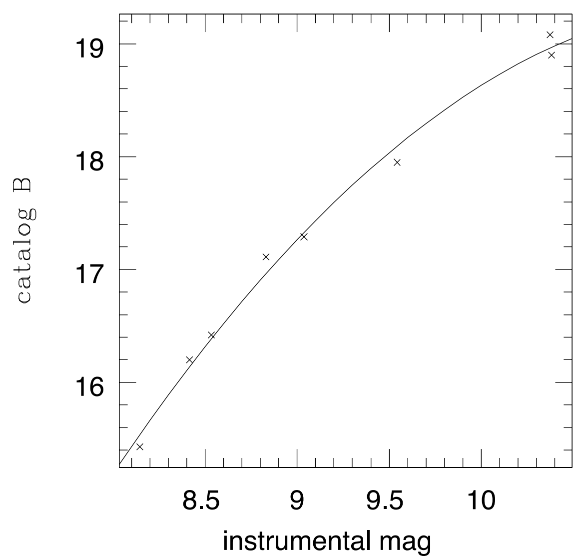

Figure 1: The parabolic calibration curve for plate Ry8 (Yerkes, year 1901): instrumental magnitudes in abscissa, reference magnitudes in ordinate.

Table 2: Palomar plates

Plate	date	rms	slope	mag
POSS-IE	21-12-1949	0.11	2.22	18.68
Quick-V	18-10-1982	0.06	1.86	17.81
POSS-IIR	05-10-1991	0.03	2.42	16.04
POSS-IIB	30-09-1991	0.05	2.58	16.54

The Yerkes plates were scanned with an EPSON 10000XL at 2400 dpi. Only the relevant plate sections were scanned, in transparency mode, and saved as greyscale TIFF files (14 bit). The files were then converted to fits format with MaximDL and then analysed with IRAF. As for the Pulkovo plates, we could not use the actual plate fog level for the intensity conversion and a simple I=1/T formula was used. For 10 plates only upper limits could be derived, using the faintest visible star of the comparison sequence; in the other plates the star was always found at the quiescent level (B$\sim$18).

2.5 Palomar plates

Some digitized plates from the Palomar Observatory Sky Surveys (First, Second and QuickV) were retrieved from the MAST archive hosted at the Space Telescope Science Institute [3]. These plates are provided already with positive intensities, so we did not need any conversion of the data. Only one plate was taken before the start of the Asiago monitoring, with a red filter, while the corresponding blue plate was not present. Given the small dependence of the B-R color index ($\sim$0.1) of this star from the luminosity (Polcaro et al. 2016) we could convert the R magnitude into B with good confidence within our errors level. Our magnitudes are reported in Table 2: we remark the substantially smaller deviations of the reference stars from the calibration curve (column rms) and the steeper slope (about 2 instead of 1) likely due to the algoritm used to convert the plate scans from transparency to intensity by the digitization teams of the Surveys.

[3] *http://archive.stsci.edu/cgi-bin/dss_ plate_ finder/*

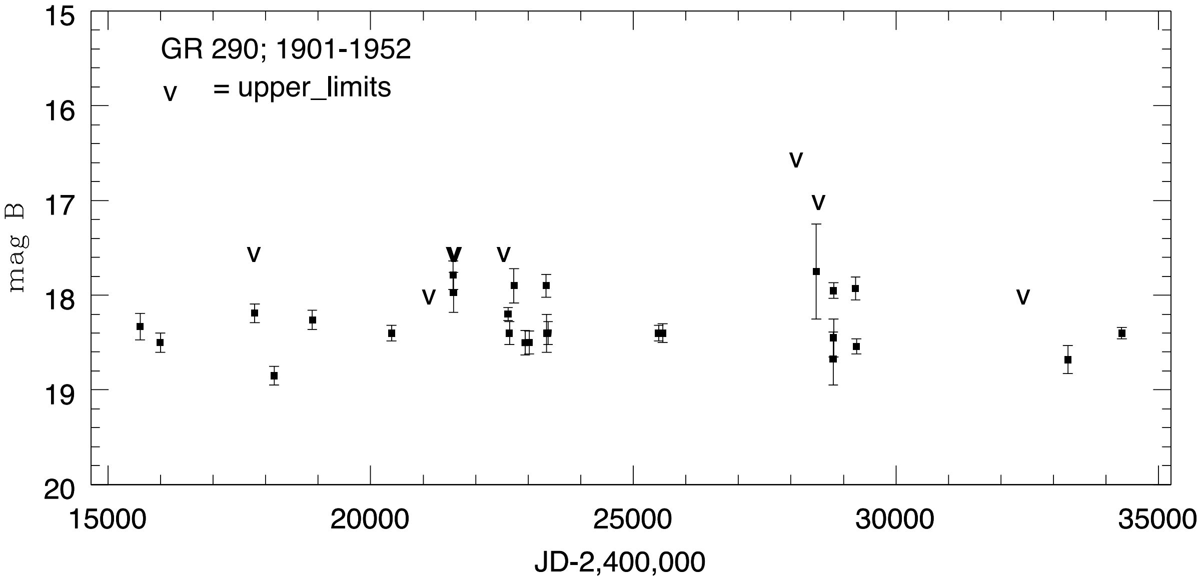

Figure 2: The historic light curve of GR 290 from 1901 to 1952. No evidence of long lasting bright states like that of the years 1988-1996 is present.

3 Results

The overall light curve of GR 290 is shown in Fig.2. The star was basically stable, with small fluctuations, but without large and long-lasting flares like those observed in the 1990s (MJD $\sim$49000); it was always fainter brighter than B=17.7.

The digitization of archive plates, even if made with different devices, has provided photographic magnitudes since the very beginning of the XX century: this allowed building a light curve more than a century long, bringing scientifical information not retrievable by other means.

Historic light curves of other LBVs from plate archives may help to better understand the evolution of this kind of stars. A very recent example is the study of Var C in M33 (Burggraf et al. 2015): this star showed two maxima at B$\sim$15.5 lasting about 5 years, around years 1947 and 1986, separated by 42 years. Evidence of a previous maximum around 1908 is however very badly sampled. At variance, in the case of GR290 we can rule out a recurrence of $\sim$150000 days (41 years) or smaller on the basis of our historic light curve.

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Photographic Survey of the Northern Sky: hidden reserves

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Abstract

Catalogue FONAC of 2 million stars down to 14^m was obtained in the last decade of the past century using the photographic plates of the survey with wide-field astrographs (FON). But the photographic observational material was not used in its entirety. The application of the commercial scanners for the digitizing of the FON collection of photographic plates from UkrVO Joint Digital Archive permits to obtain the stellar catalogue with 17 million entries – the total amount of objects fixed on the photographic plates. The thorough investigation of scanner impact onto the positional and photometric accuracy of the results allows to find the optimum scanning parameters for the elimination of scanner gear errors. The image processing was made on the basis of MIDAS/ROMAFOT software, with the authors' own development routines which allow getting photometric evaluations and positions of objects as well on the frames with linear dimensions of 13 000x 13 000 pixels. Two stellar catalogues are created according to the procedure adopted to the date: the catalogue of objects in 60-degree zone (1.2 million objects in the band N56-N64 degrees) and the catalogue of the circumpolar region (~2 million stars in the cap from N58 degree). The accuracy of both catalogues is ± 0.11" and $\pm 0.06^m$ for stars brighter than 14^m (± 0.23 " and $\pm 0.12^m$ for catalogues in total. At the moment, the 70% of digitized FON collection is processed.

Keywords: processing of the digital astronegatives, catalogues

Introduction

The idea of the four-fold overlapping photographic survey of the Northern sky with the network of wide angle telescopes of the same type was formulated for the first time as the joint observational program for several observatories of the former USSR in the 70s of the 20-th century [1]. MAO NASU became the chief organization of this program. Every participating observatory completed its share of observations. The active photographic observations at Kiev in the framework of this program started in October 1981, the last negatives of Kiev contribution were obtained in July 1998. In total, the DWA (Double Wide-angle Astrograph (D/F=40/200, 103"/mm)) collection of plates numbers 2200 frames with dimensions 8x8 degrees. The active observers of the program were G.A.Ivanov, A.I.Yatsenko, L.K.Pakuliak, V.I.Belan and others.

The processing of the Kiev collection started in the 1990s. Measurements of stars were made using PARSEC coordinate measuring machine. Because at that time we did not have access to the collections of other participating observatories, then the creation of the first version of the catalog was limited to the area of working fields of plates (4°x4°) with n-fold overlap in narrow zones at the edges of working fields.

Principles and methods

The first version of FONAC was obtained in 2000 and includes 2 million stars down to B=14^m [2]. By mid- 2016 it is planned to complete the new version of the catalogue of positions and B-magnitudes of stars based on the methods of digital image processing of astronegatives and containing near 17 million objects. The digitizing of plates has been carried out using Microtek ScanMaker 9800XL TMA and Epson Expression 10000XL commercial scanners. Positions and B-magnitudes have been obtained from the processing of single scans per plate without using the frame turned by 90є. The maximum possible accuracy of the results is achieved by applying the relevant procedures of the scanner error elimination. This permits to save resources for data storage and processing time in a half without the losses in accuracy [18]. The tests of scanners, principles and steps of the processing of digital images are presented in the series of papers [3,4,5,6,7,8,9,11,12,13,21]. The results of software tests are given in [10,14,15,16,17,19,20,22].

The Kiev collection of the FON program usually have 2-fold field overlap. For the certain areas with the height of ±2° from the center of the plate the principle of 2-fold overlap in declination is implemented. The overlapping along the strips on the right ascension is made with 4°/cosδ shift of plate centers. The centers of adjacent strips are spaced apart from each other by 4є on declination. The number of plates in processed strips are the next: 88° – 8, 84° – 25, 80° – 24, 76° – 53, 72° – 51, 68° – 58, 64° – 50, 60° – 102, 56° – 106, 52° – 115, 48° – 129, 44° – 126, 16° – 124, 12° – 114, 8° – 117, 4° – 124, 0° – 128. The total amount of the completely processed plates is 1 450, the number of registered objects of different nature is 83 343 000 and positions and B-magnitudes are obtained for 11 152 000 stars and galaxies. Fig.1 shows the distribution of the number of objects N depending on the multiplicity of measurements K.

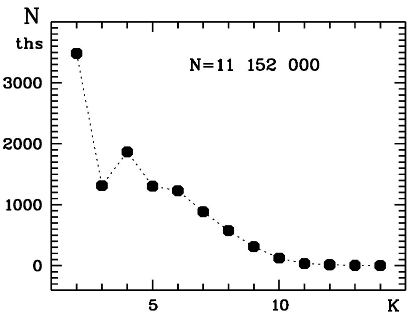

Fig.1. The distribution of the number of objects N depending on the multiplicity of measurements K.

Steps of the catalogue creation

1. Plate digitizing and transformation of tiff-images into fits format.
2. Preliminary image processing in MIDAS/ROMAFOT software to obtain pixel coordinates X, Y and instrumental estimations of magnitudes m, f_S of fixed objects.
3. Astrometric reduction of all objects into the Tycho-2 reference system at the epoch of plate exposure.
4. Reduction of instrumental photometric estimations m into the photoelectric B_{pe} magnitudes.

5. Calculation of mean values of equatorial coordinates α, δ and stellar magnitudes B for stars and galaxies in the limits of RA-overlapping of scans for each RA stripe. Elimination of artefacts.

The catalogue includes those objects that have been registered, identified and obtained calculated coordinates and magnitudes for at least two plates. The composition of the list of objects is made by 2 criteria: on coordinates the differences should not exceed 2" and on magnitudes should not exceed $\pm 2^m$, taking into account variable stars.

The errors of coordinates and magnitudes for k-measurements are obtained from (1):

$$\sigma_\alpha = (\sum(\alpha_k-\alpha_c)^2/k(k-1))^{½}, \quad \sigma_\delta = (\sum(\delta_k-\delta_c)^2/k(k-1))^{½}, \quad \sigma_B = (\sum(B_k-B_c)^2/k(k-1))^{½} \qquad (1)$$

6. Averaging of coordinates and magnitudes in the sectors overlapping on declination. In those sectors all objects have data for two zones: $\alpha_{1,2}$, $\delta_{1,2}$, $B_{1,2}$, $\sigma_{\alpha 1,2}$, $\sigma_{\delta 1,2}$, $\sigma_{B1,2}$. The final values of coordinates and magnitudes and their errors are calculated according to (2) and (3):

$$\begin{aligned} \alpha &= (\alpha_1/\sigma_{\alpha 1}{}^2 + \alpha_2/\sigma_{\alpha 2}{}^2) \ / \ (1/\sigma_{\alpha 1}{}^2 + 1/\sigma_{\alpha 2}{}^2) \\ \delta &= (\delta_1/\sigma_{\delta 1}{}^2 + \delta_2/\sigma_{\delta 2}{}^2) \ / \ (1/\sigma_{\delta 1}{}^2 + 1/\sigma_{\delta 2}{}^2) \qquad (2) \\ B_{ph} &= (B_1/\sigma_{B1}{}^2 + B_2/\sigma_{B2}{}^2) \ / \ (1/\sigma_{B1}{}^2 + 1/\sigma_{B2}{}^2) \end{aligned}$$

$$\begin{aligned} \sigma_\alpha &= (1 \ / \ (1/\sigma_{\alpha 1}{}^2 + 1/\sigma_{\alpha 2}{}^2))^{½} \\ \sigma_\delta &= (1 \ / \ (1/\sigma_{\delta 1}{}^2 + 1/\sigma_{\delta 2}{}^2))^{½} \qquad (3) \\ \sigma_B &= (1 \ / \ (1/\sigma_{B1}{}^2 + 1/\sigma_{B2}{}^2))^{½} \end{aligned}$$

Fig. 2 and 3 demonstrate the results of the solution for individual zones. On the left, there is the trend of positional errors with the star magnitude (within the areas overlapping on both coordinates) for declination zones. For each zone, the errors of averaged coordinates and star magnitudes are shown. On the right, the histograms of the distribution of objects depending on the stellar magnitude are given as well as the final amount of identified objects k_i in the overlapping areas of each zone.

7. Preparation of the catalogue and its complement with proper motion data from UCAC4.

Conclusions

The comprehensive software was developed and implemented in the Department of the Astrometry 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 of stars and galaxies. Two stellar catalogues are created according to the procedure adopted to the date: the catalogue of objects in 60-degree zone (1.2 million objects in the band N56-N64 degrees) and the catalogue of the circumpolar region (~2 million stars in the cap from N58 degree). The accuracy of both catalogues is ± 0.11" and $\pm 0.06^m$ for stars brighter than 14^m (± 0.23 " and $\pm 0.12^m$ for catalogues in total).

The algorithms and methods of plate digitizing and processing as well as the software is now applied to the total set of exposured plates of the FON project with the aim of creating the catalogue of positions and B-magnitudes of the whole northern sky from 0є to 90є on declination.

At the moment, the 70% of digitized FON collection is processed. The total amount of objects is expected to be near 17 million star and galaxies. The accuracy of the upcoming catalogue is expected to be the same as in two above-said catalogues, created by the same principles.

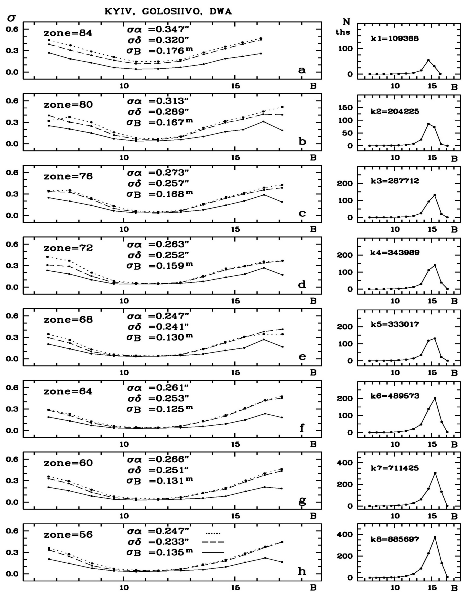

Fig.2

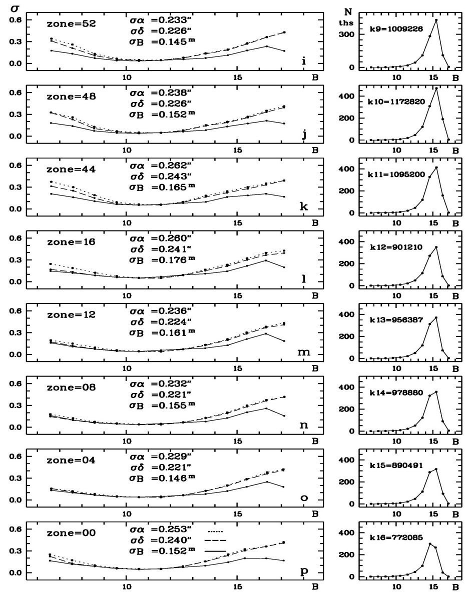

Fig.3

Trend of the positional errors σ_α, σ_δ and magnitudes σ_B for each declination zone of FON and histograms of the object distribution with B-magnitudes.

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The original astrometric software package for digitized photographic plates

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Abstract

General algorithm for the data processing for the digitized photographic plates was developed in 2005 - 2014 (Andruk 2005, Yatsenko 2011, Protsyuk, 2014) and has been already applied in Kiev (Andruk 2016), Kitab (Andruk 2015) and Nikolaev (Protsyuk 2014). This algorithm uses the MIDAS routines to extract objects from the images (up to 32000 x 32000 pixels size) and to measure the rectangular coordinates of the found objects as well as their instrumental magnitudes, intensities and diameters (FWHM). One of the big problem of the digitized images scanned using the Epson Expression 10000XL or similar scanners are systematic errors in measured coordinates along the scanned direction (Y-axis) due to the irregular scanning speed. A seemingly logical solution to scan each plate twice with the rotating by 90° was already investigated (Andruk 2015). The results were for the astrometric purposes not satisfied and furthermore it leads to double time by scanning procedure and to double memory place by storage the data. We present an original astrometric solution for this problem which can correct scanner systematic errors using only one digitized images. The experience of the using this software package by the creating of catalogues of the zero zone of the Kitab observatory (Muminov 2016) and Kiev 60 zone (Andruk 2014) showed that on such a way the errors in positions can be achieved 0.06" in both directions and errors in magnitudes 0.1 mag.

Keywords: processing of the digital astronegatives, catalogues

Introduction

In this work the astrometric processing steps with a goal to obtaining the equatorial coordinates are demonstrated on the example of reduction for plate No. 219, exposed for the FON project in 1983.11.03 ($\alpha=23^h27^m18^s$, $\delta=59^o55'$) using the DWA telescope DWA (Double Wide-angle Astrograph D/F = 40/200, 103 "/mm). The tests of scanners, principles and steps of the processing of digital images are presented in the series of papers [4, 6, 7, 8, 9 ,10, 15, 19]. The results of software tests are given in [1, 2, 3, 5, 11, 12, 13, 14, 16, 17, 18, 20, 21].

Correction for scanner systematic errors

Scanners have a systematic astrometric errors. Especially large these error values are along the Y-axis, i.e., along the CCD-line movement direction. The amplitude of the difference of the equatorial coordinates between observed and catalogue values reaches $\Delta_{\alpha\delta}$ = ±2.5" and $\Delta_{\alpha\delta}$ = ±5" for the scanners Epson Expression 10000XL and Microtek ScanMaker 9800XL TMA respectively. When scanning with a spatial resolution of 1200 dpi a photographic plate of the size 30x30 cm (8°x8°) has a working field of approximately 1300 x 1300 px. For the correction of measured X, Y coordinates for scanner systematic errors was developed a following algorithm. The length of the scanned image in pixels ($L_Y \approx 13000$) along the Y-axis is divided on the number of reference stars (for the study area, for example from the Tycho2 catalog K ≈ 7300). Thus we have an initial step of approximation $s = L_Y/K \approx 2$ px, i.e., on each step with the length s must be at least one star from the Tycho2 reference catalog. If there are two or more reference stars in one step, the reference points are calculated for the middle of the step, as an average deviation of these stars $\Delta X = \Delta\alpha/M$ and $\Delta Y = \Delta\delta/M$ (where M is the scan scale, 1 px is approximately 2".17) from the true position on the plate; in the absence of the reference stars in one step the calculation of deviations of reference points ΔX, ΔY are done by the interpolation using the values of two adjacent reference points. In the reduction process the values of deviations for defined stars ΔX, ΔY are computed by interpolation relative to the neighboring reference points. The details about scanner systematic errors are demonstrated on the panels 1e, 2e and 3e of the figure 1.

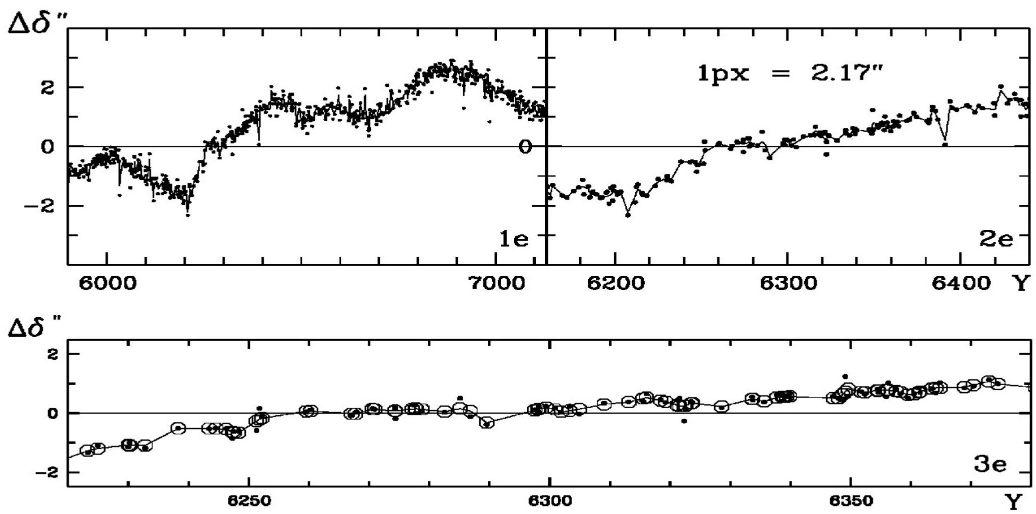

Figure 1. The correction of the scanner systematic errors.

The points correspond to the real value of deviations and continuous line is responsible for the reduction numerical model. Note that the full reduction of the rectangular coordinates X, Y in the system of the equatorial coordinates α, δ is done for the three successive cycles (approximations), in each cycle the length of the step is increased by the value of the step itself. The values of the errors of the differences between the equatorial coordinates of the calculated and catalogue values σα, σδ are the same or have very close values for the third and fourth cycles.

The astrometric solution and magnitude equation

For the both stage of image processing: correction for the scanner systematic errors Δα, Δδ and reduction of the rectangular coordinates X, Y to the equatorial coordinates α, δ in the system of Tycho2 catalogue the tangential coordinates ξ, η are calculated by the least squares method using the formulas (1):

$$\xi_i = a_1+a_2X_if_i+a_3Y_if_i+ a_4R_im_i+a_5f_i + \sum b_{lm}X_i^lY_i^m, \ (l=0\div6, m=0\div6, l+m=n, n=1\div6) \qquad (1)$$
$$\eta_i = c_1+c_2X_if_i+c_3Y_if_i+ c_4R_im_i+c_5f_i + \sum d_{lm}X_i^lY_i^m, \ (l=0\div6, m=0\div6, l+m=n, n=1\div6)$$

where i = 1.2, ... N is the number of the stars of the TYCHO2 catalogue on the plate; X_i, Y_i and R_i – coordinates and distance of star images relative to the center of the plate; m_i – instrumental photometric magnitudes of stars; $f_{½i}$ – diameters of star images; the coefficients a_2, a_3, a_4 and c_2, c_3, c_4 are responsible for the coma; the coefficients a_5, c_5 –take into account the influence of the magnitude equation (calculated separately); the coefficients of the full sixth-order polynomial b_{lm} and d_{lm} (27 members) in the generalized case describe the aberrations of telescope together with the additional systematic errors of the scanner. The panels 1a and 1c on the figure 2 show the differences Δα, Δδ between the calculated and the catalogue values relative to the B values of the Tycho2 catalogue given before the correction for the scanner systematic errors. The same differences Δα, Δδ but after the correcting for the scanner systematic errors are presented on the panels 2a and 2c of the figure 2.

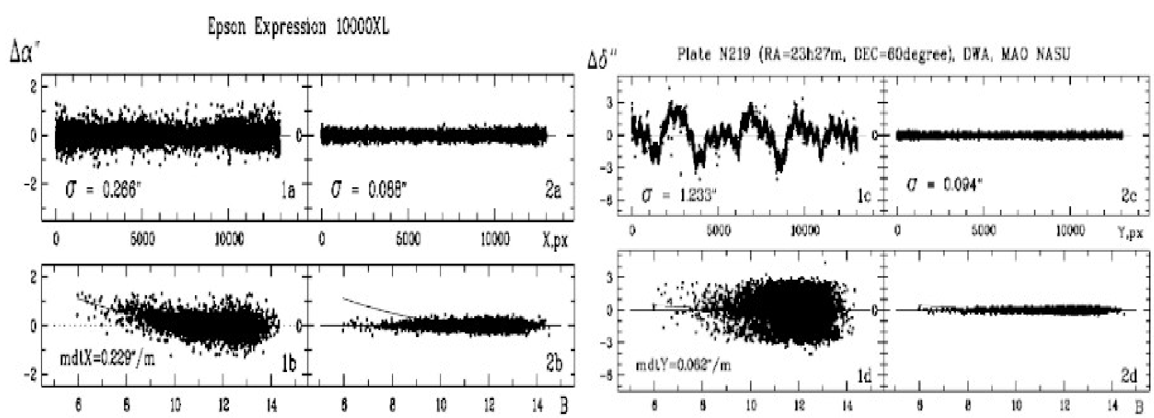

Figure 2. The differences Δα, Δδ between the calculated and the catalogue values relative to the B values of the Tycho2 catalogue before (panels 1a, 1c) and after the correction for the scanner systematic errors (panels 2a, 2c).

During the calculating of the tangential coordinates ξ, η the special attention is given to accounting of the magnitude equation for two coordinates mdtX and mdtY (magnitude equation for the X, Y coordinates, respectively). This was possible because of the photographic plates for the FON project were made with two exposures on the same plate. It was found that for the photographic plate exposed on astrographs, the magnitude equation becomes significant for stars from B ≈ 11 mag and differences $\Delta\alpha$, $\Delta\delta$ increase with the increasing of the brightness of stars. The diagnostic of the magnitude equation is shown in figure 2 (panels 1b, 1d, 2b, 2d) for the long exposure of stars on the test plate.

Conclusion

The described astrometric software package was applied for the normal scanning (Y axis is parallel to the δ-axis of the equatorial coordinates system) as well as for the scanning with the rotation by 90° (Y-axis is parallel to the α-axis of the equatorial coordinates system) with the goal to investigate the possibility of the improving of an astrometric solution. The scanning of the test plate with the rotation by 90°gives reduction errors in the equatorial coordinate system 25% greater than the normal scanning. This is the expected result because the scanning with the 90° rotation presumes that the irregular movement of the CCD-line scanner (along the Y-coordinate) actually leads to irregular change of the plate scale along the α coordinate relative to the lower and upper parts of the scanned image. So the double scanning does not influence the accuracy of the reduction significantly. Moreover it leads to the increasing of the processing time and the storage memory. Using this software package for the normal scanning showed that on such a way the errors in positions can be achieved 0.06" in both directions and errors in magnitudes 0.1 mag.

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The photographic plates archive of Pulkovo Observatory

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Abstract

The glass plate archive of Pulkovo Observatory contains about of 50 thousands of astronegatives with observations of more than 1400 target objects. These plates were obtained during 1893–2007. Many astronomical tasks require long-term observations. As a result, digitization of astroplates and analysis of extracted images are relevant. Since 2000 we develop the processing methods to improve accuracy, increase productivity and take in account the safety of the photographic plates. In 2012, we proposed a new method of digitization, measurement and calibration of photographic plates using of digital photo camera. More than 9,000 of photographic plates with observations of double stars were digitized and measured with this method. The single-exposure measurement accuracy is within the range of 0.1 - 3.5 micron, 1.4 micron in both coordinates on average. Probably, this range of accuracy is depend on the quality of the photographic material. At present, we perform a new reduction of major planet satellites observations. The new method with modern catalogs data gives an increase in the coordinates accuracy of 2-3 times compared with the previous results

Keywords: astronomical photography, digitization, astrometric reduction

Introduction

The photographic observations were initiated at Pulkovo Observatory with the Normal Astrograph (D/F=350/3460 mm) that had been the main astrometric instrument for a long time. Sergey Kostinsky made observations with this telescope since 1894, and these astronegatives became the basis of the Pulkovo glass archieve. Telescope was rebuild after the World War II in 1948. Also, at the early 50's the short focus double astrograph AKD (100/700 mm) and a 26-inch Zeiss refractor (650/10413 mm) were installed. The high-precision observations of double and multiple stars, planets and natural satellites, stellar parallaxes were continued using 26-inch refractor. Pulkovo glass archive contains about 22 000 plates obtained by 26-inch refractor, 16 000 - by the Normal Astrograph and 1 400 - by the AKD telescope.

More than 8000 plates were obtained by the Expeditionary astrograph during expeditions in the 60 - 80s at Chile, Bolivia, Azerbaijan (Ordubad). Most of the photographic plates were obtained for Pulkovo's photographic catalog of the southern sky FOKAT. About 400 astronegatives were taken by the Lunar-Planetary telescope during expeditions to Ordubad and Bolivia.

Archive stores the observations of planets and satellites, Pluto, Moon, comets, globular and open clusters, galaxies, visual double stars, parallactic observations, Kapteyn zones, geodetic stars, galactic and extragalactic radio sources, and also unique series of observations 61 Cygni - 1250 photographic plates taken during 1897-2005. In 2007, photographic observations were ended. The online catalog of plates (obtained by 26-inch refractor and Normal astrograph) is available at

`http://www.puldb.ru/db/plates/`

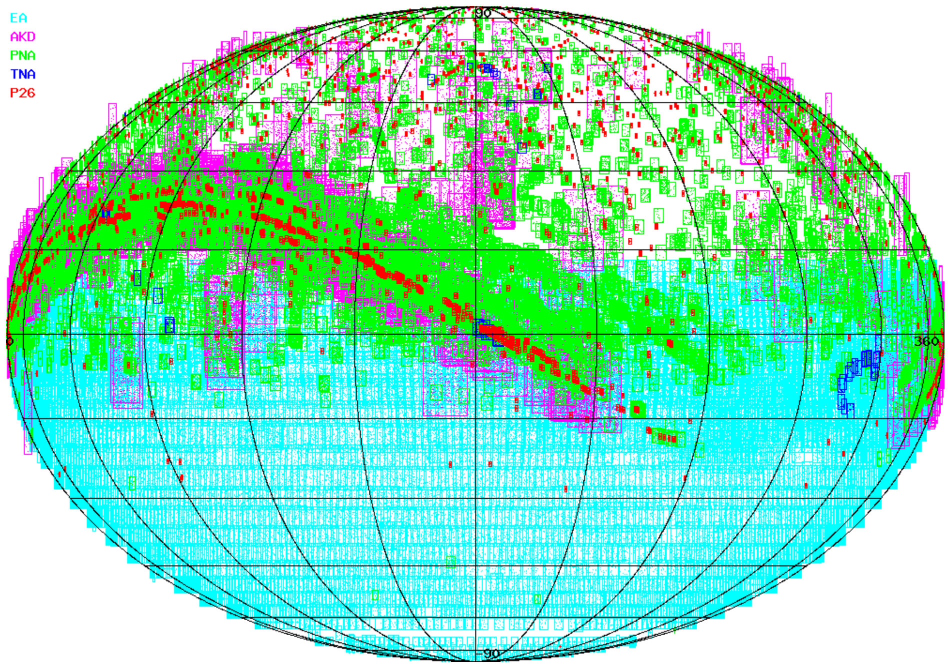

Figure 1. The distribution of plates on the celestial sphere. Cyan areas – Expedition astrograph FOKAT program; pink – AKD, green – Normal Astrograph (Pulkovo), blue – Normal Astrograph (Tashkent), red – 26-inch refractor.

Digitization and measurement

The plates were measured using the “Ascorecord” machine with visual pointing, the “Fantasy” automatic complex [1], and the UMAX scanner (600 ppi) [2]. In 2010, the measurement and calibration technique for wide fields digitized by the scanner Microtec (3200 ppi) was developed. About 2000 plates with asteroids observations were digitized and measured [3].

The methods mentioned above had some shortcomings: the measurements with the “Ascorecord” were highly inefficient, and their accuracy was low; the “Fantasy” complex was inaccessible for use because of technical problems; the scanners have irregular systematic errors and are also inefficient.

A method of measurement and calibration of plates digitized with the Canon EOS 5D Mark II digital camera and a long-focus Jupiter 21M lens was proposed in 2012 [4]. The method was tested on a series of parallactic observations for the visual double star ADS 8002 at the 26-inch refractor. The measurements were calibrated using a template predigitized with the ROB Digitizer [5] in

2008. A reduction model that, apart from linear terms, included a cubic polynomial was used to take into account the aberrations. The internal accuracy of the measurements was about 1 μm, which is 20 mas for the plates obtained at the 26-inch refractor. This method and the results of its testing, including the stability, comparison of the accuracy with other methods are described in the paper [6].

1.1 Photographic observations of visual double stars

Above of 9000 photographic plates taken from 1961 to 2007 were digitized. During the measurements, we selected 6488 good-quality plates. We obtained a total of 7248 relative positions for the components of the pairs of stars from the plates and derived 2129 yearly mean positions from them. The measurement accuracy of a single exposure is within the range from 0.1 to 3.5 μm, which corresponds to the range 2–70 mas for the scale of the 26-inch refractor (See Fig. 2), on average, 1.4 μm (28 mas) in both coordinates. The accuracy of determining the star image centers is limited by the emulsion quality, its shifts, the objective aberrations, and the atmospheric conditions during the observations. The observed range of measurement errors can be explained by the scatter of the observational data quality. In our opinion, the achieved accuracy of measurements is essentially the limiting one for such photographic plates, as evidenced by our comparison with the results of measurements with the high-precision "Fantasy" measuring machine, which has a higher resolution (the optimal resolution is 4 μm/pixel). The series of observations for five double stars were measured previously with the "Fantasy" measuring complex. For comparison, these plates were digitized with the Canon camera and measured according to the above technique. The systematic differences between the news results and "Fantasy" measurements are insignificant [6].

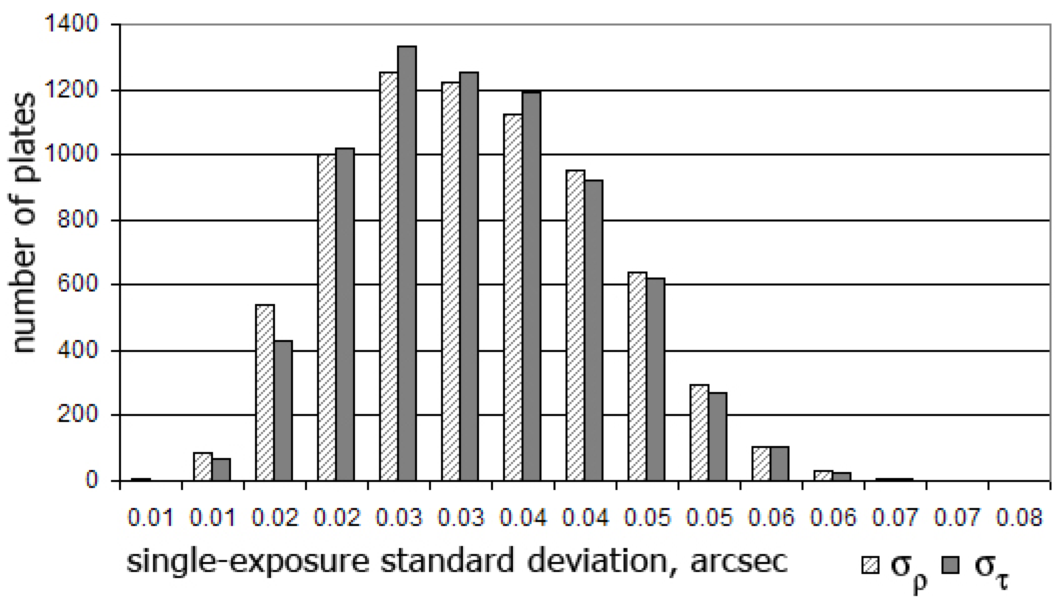

Figure 2. Measurement accuracies. The hatched and gray columns correspond to the measurements in the radial and transversal directions, respectively.

1.2 New astrometric reduction of saturnian satellites observations

The plates with Saturn and it's main satellites were chosen as the first stage of re-processing of old photographic observations using new method. Observations were made with 26-inch refractor and Normal Astrograph in 1972-1974. About 150 plates were digitized and re-measured. The TYCHO-2, UCAC2 and UCAC4 catalogues were used as a reference. Equatorial coordinates of 2-nd - 6-th and 8-th satellites of Saturn were calculated and now available in the Pulkovo Observatory astrometrical data base www.puldb.ru. The errors of satellites positions are about 80-90 mas for observations with 26-inch refractor and 150-185 mas for Normal Astrograph. The accuracy of new reduction is in the 3 times better in comparison with old reduction performed using a reference AGK3 catalogue. Precision of Saturn’s satellites ephemeris is about 50-60 mas according to observations with 26-inch refractor. It is concluded that it is reasonable to re-process the large array of old observations using the new method of digitization and measurement and modern reference catalogues in order to increase the accuracy of solar system bodies’ positions. First results of new reduction are presented in the paper [7].

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The Wide-Field Plate Database in the Virtual Observatory

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Abstract

For many years, the Wide-Field Plate Database (WFPDB) has provided researchers and archivarians alike with a unique resource to map and unlock the treasures hidden in the world's plate archives. Access so far has been provided through a web page, which is fine for a set of pre-defined queries. Advanced searches, including matching against uploaded tables, need more advanced tools. The Virtual Observatory (VO) community provides these in the form of the Table Access Protocol (TAP) and several clients available for it.

In our contribution, we briefly describe the provision of the WFPDB data through the Heidelberg data center of the German Astrophysical Virtual Observatory (GAVO). The main part of the contribution is a worked example of an advanced query pattern within WFPDB-through-TAP.

Keywords: Astronomical databases, Digital plate archive, Astrometry, Virtual Observatory, Table Access Protocol

1 Introduction

In recent years, great efforts were made to digitise photographic plate archives all over the world, and thus to stop the degradation of this considerable part of our cultural heritage. In Heidelberg, for instance, the digitisation of the Heidelberg Königstuhl Archives that encompasses almost 25,000 photographic plates dating from the late 19th century to our days accompanied by a unique collection of observation journals may now be considered completed. Our archives have been published to the Virtual Observatory (VO) and the web [1]. Due to its VO integration, standard all-archive queries can be used to discover our data.

Despite all digitisation efforts, the global situation is less satisfactory. For a large number of plate archives, scanning is severely incomplete or has not even started. This is where the Wide-Field Plate Database [2] comes in. Already in the mid-1990s, the idea was born to create a meta-data archive providing the information for wide-field ($> 1°$) photographic plates stored in numerous archives all over the world and was realised by the creation of the WFPDB. To facilitate the exploitation of this metadata catalog, we have made it accessible through the VO protocol TAP.

This contribution starts with a terse outline of the underlying technology. Following this, it describes the table schema of WFPDB as published in GAVO's TAP service and gives some metrics. The main part is then dedicated to an illustration of the kind of interactions TAP enables with data.

2 Wide-Field Plate Database and Virtual Observatory

2.1 Table Access in the Virtual Observatory

The Table Access Protocol [3] is a VO standard for querying astronomical databases. It provides means to discover the **structure** of the underlying database (e.g., names and descriptions of tables, semantics and units of columns), to **transmit** freely-definable queries in a standard SQL dialect called Astronomical Data Query Language (ADQL [4]), and to **retrieve** the result after the job has finished.

To operate such TAP services, astronomers make use of clients. For TAP, clients are built into the popular TOPCAT data analysis package. TAPHandle[1] lets users operate TAP in a common web browser.

2.2 Overview of the WFPDB

The Wide-Field Plate Database[2] is a metadata archive giving a rough spatial, temporal, and spectral coverage of currently about 600,000 photographic plates from 136 archives. In the long term, it is planned to extend the database to cover all wide-field photo plates in the world. It is estimated that there are about 2,500,000 such plates originating from more than 200 telescopes and stored in 572 archives.

Since technically the WFPDB consists of tables, the natural Virtual Observatory approach to provide its data is through TAP. The mapping chosen for the TAP publication of the WFPDB was to split up the data set into a `main` table that has one row per plate and an `archives` table that has, essentially, one row per instrument archive.

Metadata given for each plate includes:

- a globally unique plate identifier, which essentially encodes an instrument identifier and a local plate number,
- the centre of the plate as ICRS RA und Dec,
- UT date and time of the plate exposure as well as the exposure time,
- a target object and its type,
- the emulsion, filter, and effective bandpass,
- plate size, a quality assessment, the digitisation status, plate availability,
- various flags indicating problems in the metadata, and
- the observer and free-form notes.

For each archive, we give

- an identifier, that, together with a site code (for instruments that were moved around) and an archive part (for archives split over multiple places) uniquely identifies creation and curation of the plates
- data about the archive, including some basic statistics, its location, and contact person
- the location of the instrument and its properties (diameter, focal length) as well as when it was operated

3 A Worked-Out Example

To demonstrate the usage scenarios for WFPDB enabled by its availability within the VO, here is a use case in which we look for photographic plates with novae outbursts near the plate centre. In our example, we will make use of two VO tools, the Web Interface to the Relational Registry (WIRR for short) [5] and the Tool for OPerations on Catalogues And Tables better known as TOPCAT [6][3].

The Virtual Observatory Registry (VO Registry) is a database for metadata on astronomical "resources" – essentially data services and the like. One way to access registry data is WIRR. To use it, we open a web browser to `http://dc.g-vo.org/WIRR` and set up a search defined by the two constraints

[1] `http://saada.unistra.fr/taphandle/?url=http://dc.g-vo.org/tap`.

[2] `http://www.wfpdb.org/`.

[3] These instructions were written based on TOPCAT 4.3; with newer versions, they may require slight adaptations. If in doubt, contact the authors.

```
Text Fields    match    nova
Column UCD     like     time.epoch
```

The second criterion sets a constraint on the so-called Unified Content Descriptor (UCD), a formal vocabulary for astronomical data [7] specifying the type of a quantity. Demanding a `time.epoch` in our query makes sure that the catalogues found will have time stamps.

Among the results is the Catalog and Atlas of Cataclysmic Variables [8]. To query it, copy the URL below its "SCS" label (which indicates that the service can be queried using the VO Simple Cone Search protocol). Then launch TOPCAT, open its built-in cone search client (in the menu "VO" → "Cone Search") and paste the SCS URL from WIRR into the field "Cone URL". Pulling the entire catalogue – i.e., (RA/Dec/Radius) = (0/0/180) – yields a position, and for many novae, the years of their outbursts. For further processing, the sky coordinates need to be converted into decimal degrees, which can be done in TOPCAT using the functions `hmsToDegrees()` and `dmsToDegrees()`, respectively[4]. To make TOPCAT interpret the field `nova_yr` as a float, the function `parseFloat()` should be used.

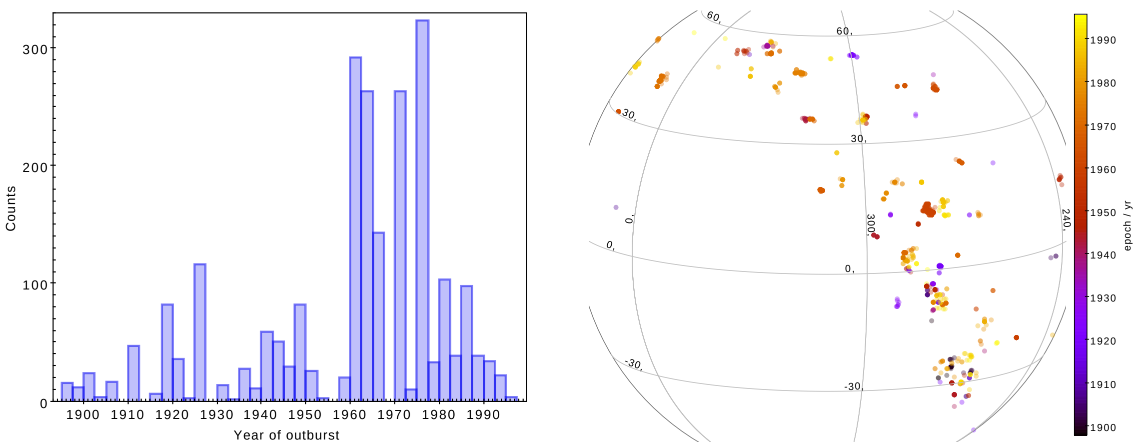

Figure 1: Visualisation of the plates probably containing novae, prepared using TOPCAT: A histogram of the epochs and a sky plot showing locations and color-coded epochs for the plates found for a part of the sky.

To find plates that may contain records of these novae we open TOPCAT's TAP window ("VO" → "Table Access Protocol (TAP) Query"). In order to find the TAP service carrying WFPDB, simply type "wfpdb" into the "Keywords" field and have TOPCAT search. The result list should show the GAVO DC TAP service. When you double click it, TOPCAT will retrieve the service's table metadata; again, type wfpdb under "Metadata" to locate the wfpdb tables and select `wfpdb.main`.

To make a user's life easier, TOPCAT provides help in phrasing the ADQL query in terms of the "Examples" button. "Upload" → "Upload Join" will fill the text field which can then be edited in order to find plates with novae within a circle of 2° around the plate centre:

```
SELECT
    *
    FROM wfpdb.main AS db
    JOIN TAP_UPLOAD.t1 AS tc
    ON 1=CONTAINS(POINT('ICRS', db.raj2000, db.dej2000),
        CIRCLE('ICRS', tc.RA, tc.Dec, 2.))
    WHERE epoch BETWEEN nova_yr AND nova_yr+1
```

Change the number behind "Max Rows" from 2000 (default) to 1,000,000,000. TAP's response to the query is a table with 2342 rows, i.e, 2342 photographic plates have been found in the Wide-Field Plate Database with novae near the plate centre. The year of outburst for these novae is given in Figure 1.

[4]Clicking "Views' → "Column Info" in the menu provides the table columns' overview together with the options to replace existing columns or to add new ones.

As mentioned above, not nearly all of these plates are already in the VO and thus readily accessible. For the rest, one will have to resort to classic way of contacting the archive curators. Although WFPDB currently does not allow a precise link from a plate to its curator when archives are split or instruments were moved – this will be changed in the near future – performing a SQL JOIN between the archives and main tables using the instr_id column is close enough. In TOPCAT, the corresponding query would look like this:

```
SELECT DISTINCT instr_id, contact
    FROM wfpdb.archives
    JOIN tap_upload.t2
    USING (instr_id)
    ORDER BY instr_id
```

The number after tap_upload.t needs to be adapted to the TOPCAT table ID, which is the number before the colon in the main window table list. In our example, the result table of our first query has the ID "2".

4 Conclusion

The availability of a curated copy of the WFPDB data within the VO enables straightforward access to its contents even with advanced queries as well as seamless integration with a wide wealth of additional resources. In this case we have demonstrated how the solution to a relatively involved data discovery problem can be approximated using some ad-hoc queries withing minutes.

Acknowledgements

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Photometric variability of the novalike object V380 Oph in 1976–2016.

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Abstract

We combined photographic, photoelectric and CCD observations of the nova-like variable V380 Oph to get a light curve spanning the time range of 40 years. While the typical high-state brightness of V380 Oph was $R \sim 14.5$, two low-brightness episodes identified in 1979 ($B_{pg} \sim 17.5$) and 2015 ($R \sim 19$) confirm its classification as a VY Scl-type "anti-dwarf nova". The Fourier period analysis of photoelectric and CCD V and B observations obtained in 2002–16 revealed the presence of two periods $0^d.148167$ and $4^d.287$, that may be associated with negative superhumps and disc precession. We also compared measurements obtained with the iris micro-photometer and flatbed scanner at the same plates and found an agreement within the expected accuracy of photographic photometry.

Keywords: photometry, antidwarf novae, orbital period

1 Historical overview

V380 Oph was discovered as a variable star by C. Hoffmeister (1929). Hope (1938) suggested that the object belongs to the class of Mira-type stars. Meinunger (1965) examined the photographic plates of Sonneberg Observatory and concluded that the star might be either an eclipsing binary or a RR Lyrae-type variable. Bond (1979) first suspected that V380 Oph may be a cataclysmic variable (CVs). Shafter (1983, 1985) showed that the spectra of V380 Oph exhibited strong Balmer emissions and HeII 4686 Å line. By analysis of radial velocities he found the orbital period as $\sim 0^d.158$. The first detailed photometric study of V380 Oph was carried out by Shugarov et al. (2005, 2007). The authors analyzed ~ 220 photographic (1976 – 90) and ~ 1300 photoelectric and BVR_C CCD (2002 – 04) observations and showed that the object was at a low state ($\sim 17.5pg$) in 1979, and $\sim 14^m$ at other times. They found two periods of $0^d.14817$ and $4^d.5135$ in 2002 – 04 data, probably related to the orbital period and disc precession, respectively. Rodriguez-Gil et al. (2007) used Hα radial velocities to find the orbital period $0^d.154107$ and classified object as the SW Sex-type system. The short orbital period of V380 Oph and detected large depression of luminosity include it also in VY Scl-type novalike CVs (anti-dwarf novae). DW UMa is another example of a system displaying both VY Scl and SW Sex features (Dhillon et al., 2013).

2 The photographic, photoelectric and CCD photometry.

During 1976–1995 about 220 photo-plates of the 66 Oph field, covering the position of V380 Oph, were obtained using the 40 cm astrograph of the Southern Station of the Sternberg Astronomical Institute (SAI) in Crimea. In the past, the V380 Oph plates were measured by an iris micro-photometer. Recently, the same plates were digitized with a flatbed scanner (Kolesnikova et al., 2008). Thus, we have photographic magnitudes, obtained by different methods. Since the plate size is large (30 x 30 cm), the digitized plate was divided into $1^\circ \times 1^\circ$ subfields that were processed independently of each other. The magnitude scale was calibrated using APASS B magnitudes of all UCAC4 stars in the subfield (Sokolovsky et al., 2014). V380 Oph, visible in two overlapping subfields, was measured twice on each plate using two different sets of comparison stars. Fig. 1 (left) shows the measured magnitude of the variable at the first section of the plate versus its magnitude at the second section of the same plate. There is a very good correlation between the two independent measurements of the variable star. The standard deviation (SD) of $\sim 0^m.05$ reflects the calibration uncertainty associated with the choice of a specific set comparison stars.

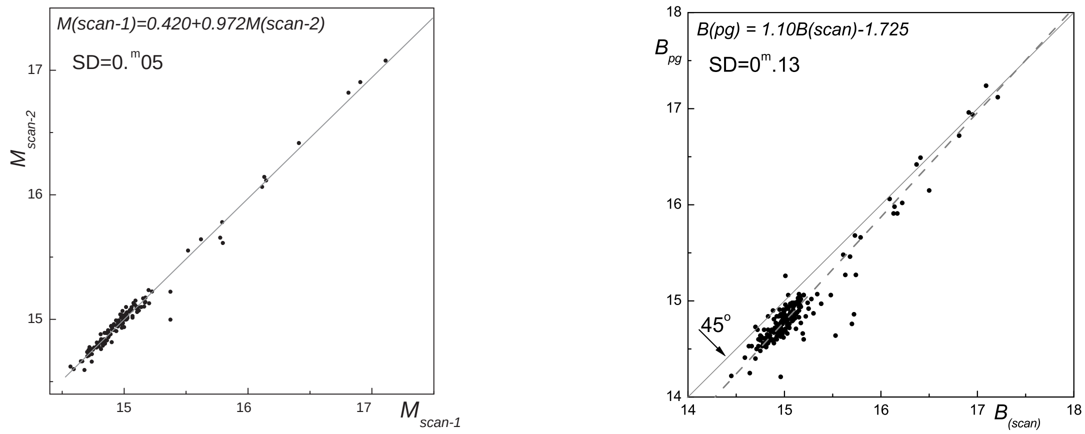

Figure 1: Left: Measured magnitude of the variable at the first section (subfield) of the photographic plate versus its magnitude at the second section of the same plate for 220 plates taken in 1976–95. Right: The dependence of V380 Oph magnitude measured by micro-photometer versus its magnitude obtained by scanning of the photographic plate.

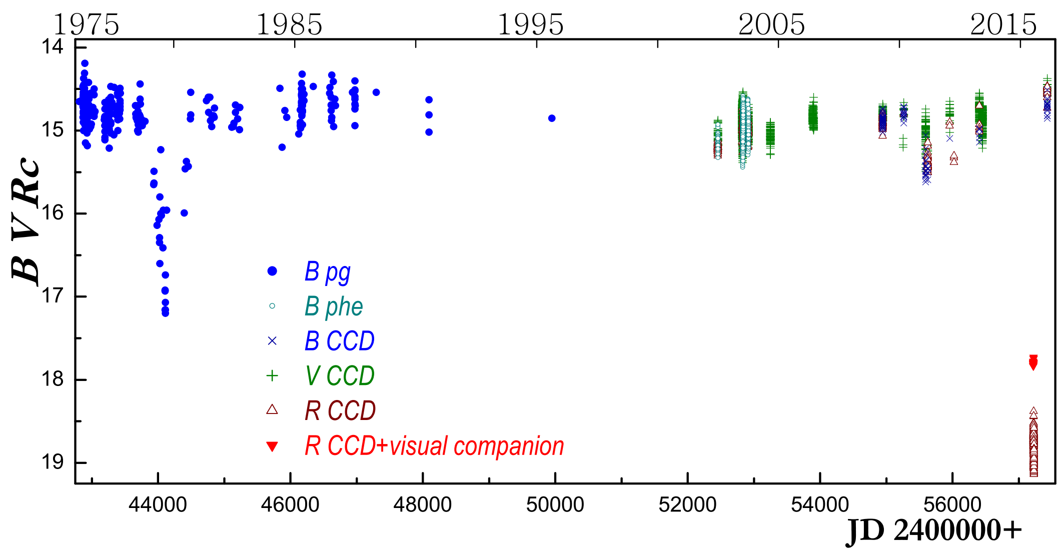

Figure 2: The light curves in BVR_C bands during the last 40 years. The depressions were detected in 1979 and 2015.

We used the average of these two magnitude measurements obtained for each plate. Fig. 1 (right) shows the magnitude B_{scan}, obtained by scanning, with respect to the magnitude B_{pg}, measured by the micro-photometer. There is a small systematic discrepancy of magnitudes and the slope of the curve differs from 45°. We applied the transformation equation $B_{pg} = 1.10 \cdot B_{scan} - 1.725$ and averaged the magnitudes measured by micro-photometer and scanning methods to construct the final photographic light curve. The SD of $0^m.13$ is close to the expected measurement accuracy on photo plates. The B_{pg} magnitudes of V380 Oph (1975-96) are presented in Fig. 2 together with our photoelectric and CCD photometry obtained at the 60-125 cm telescopes in Russia and Slovakia (2002-16). A deep fading of brightness up to 4^m was detected in 2015. At the same time the optical companion $\sim 21^m$ located southwest from V380 Oph at an angular distance $\sim 5''$ was seen.

Photoelectric and CCD observations have obviously a better accuracy and time resolution than the photographic ones. The period $P_2 = 4^d.287$, found by Fourier period analysis of V and B 2002–16 data, is 5% shorter than the value reported by Shugarov et al. (2005). The V phase light curve is shown in Fig. 3 (left). We subtracted the wave associated with P_2 from the V and B data and found by Fourier period analysis of the residuals the best period $P_1 = 0^d.148167$ (Fig. 3, right), in full agreement with the value found by Shugarov et al. (2005) from 2002–04 observations.

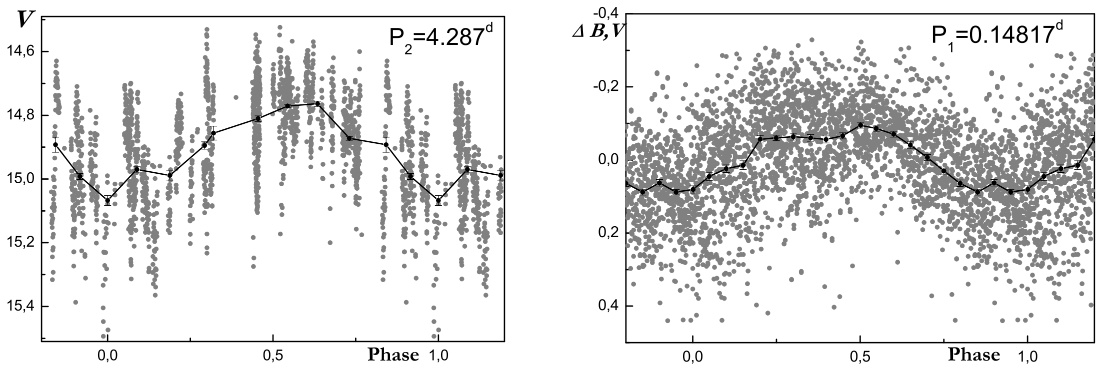

Figure 3: Left: The V light curve folded with the period of $4^d.287$. Right: The phase diagram of the B, V data residuals after removing the $4^d.287$ wave, folded with the period of $0^d.148167$.

3 The joint analysis of archival photographic and modern observations and final remarks

The Fourier period analysis of photographic data did not reveal the period of $0^d.148$, although there were some indications of periodicities close to this period with small probability. The amplitude of the P_1 component is about $0^m.15$ (see Fig. 3, right), close to the limit of precision of photographic measurements. Therefore, 220 photographic observations obtained in the interval of 20 years are insufficient for the purpose of periods search. In addition, there is strong flickering in V380 Oph that further complicates periodicity searches.

Photographic observations are still relevant and important to study long-term high-amplitude brightness variations. Through these observations we found the low state of V380 Oph in 1979 and suggested the existence of a short period. More precise photoelectric and CCD photometry allowed us to find the period close to the orbital one, which can be interpreted as the period of negative superhumps (Rodriguez-Gil et al., 2007).

This article continues the study of CVs and related objects by our group using the archive negatives of the SAI and other observatories. Earlier we obtained detailed light curves of classical, symbiotic and X-ray novae: V1500 Cyg (Harevich et al., 1975), V616 Mon (Shugarov, 1976), HR Del (Shugarov, 1967), HM Sge (Dokuchaeva, 1977; Chochol et al., 2004), V1680 Aql (Antipin et al., 2002), FG Ser (Shugarov, et al., 2014), V838 Mon and V445 Pup (Goranskij at al., 2004, 2007, 2010), V718 Per (Goranskij et al., 1996), Q Cyg (Shugarov, 1983), V404 Cyg (Osminkina et al., 1990). The negatives of SAI archive allowed Kurochkin (1972) to discover the optical period of X-ray source HZ Her. We found or investigated the eclipses of CVs: AC Cnc (Shugarov, 1984; Baidak & Shugarov, 1986), IP Peg (Goranskij et al., 1985), UU Aqr (Volkov et al., 1986), BE UMa (Kurochkin & Shugarov, 1992), AY Psc (Shugarov, 1984; Kazennova & Shugarov, 1992), DW UMa (Kazennova & Shugarov, 1992). We detected and studied optical variability of CVs and related objects: V795 Her (Mironov et al, 1985), V361 Lyr and V363 Lyr (Galkina & Shugarov, 1985), AN UMa (Shugarov, 1975), BQ Cam (Goranskij, 2001), V1341 Cyg and V818 Sco (Basko et al., 1976), EF Peg (Tsesevich et al., 1979), 2MASS J01333949+3045405 (Sharov et al, 1997), QR And (Katysheva & Shugarov, 2003), DV Dra (Pavlov & Shugarov, 1985) and many other stars.

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Variable stars identification in digitized photographic data

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Abstract

We identify 339 known and 316 new variable stars of various types among 250000 lightcurves obtained by digitizing 167 30×30 cm photographic plates of the Moscow collection. We use these data to conduct a comprehensive test of 18 statistical characteristics (variability indices) in search for the best general-purpose variability detection statistic. We find that the highest peak on the DFT periodogram, interquartile range, median absolute deviation, and Stetson's L index are the most efficient in recovering variable objects from the set of photographic lightcurves used in our test.

Keywords: variable stars, photographic photometry

1 Introduction

The simplest way to find a variable object is to compare its brightness on two images of the sky taken at different times. However, this works well only if the amplitude of brightness variations over that time is large compared to measurement errors associated with the images. If we have a lightcurve that includes measurements of an object's brightness at multiple times, in principle, we may "average out" individual measurement errors and recover a small-amplitude variability. Two problems complicate this in practice: poor knowledge of measurement errors (which is especially true for photographic data) and a priori unknown pattern of object's variations. One may overcome the first problem by assuming that objects that are close to each other in the sky and have similar brightness are measured with about the same accuracy on a given set of images. To overcome the second problem one needs a variability indicator that responds to a wide variety of brightness variation patterns.

In this work we compare 18 statistical characteristics (Table 1) that quantify "how variable" an object is. The indices belong to three classes: *i)* scatter-based indices quantifying the scatter of brightness measurements in a lightcurve; *ii)* correlation-based indices characterize the degree of correlation between the consecutive brightness measurements; *ii)* period-search methods look for periodic brightness variations.

The last column of Table 1 refers to the publications in which one may find the definitions of these indices, so here we mention only the more unconventional ones. The interquartile range[1], IQR [e.g. 1] is a robust measure of scatter. It includes the inner 50% of measurement values (i.e. excludes 25% of the brightest and 25% of the faintest flux measurements). Unlike the commonly used root mean square, the IQR is insensitive to outliers. To use [2] and [3] period search techniques as "variability indices" we compute the periodogram in the 0.1–10 d with steps in frequency corresponding to a phase shift of 0.01 between the first and the last points in a lightcurve. The value of the highest peak on the periodogram is then used as a variability index.

2 Comparison technique and results

To test the performance of the variability indices we use 167 30×30 cm photographic plates ($10^\circ \times 10^\circ$ field of view with a limiting magnitude of ~ 17.5 pg) of the 104 Her field. The plates are obtained with a 40 cm $F = 160$ cm astrograph in 1976-1994, digitized with a flatbed scanner and split into 173 $52' \times 52'$ partly overlapping subfields that were independently processed with the

[1]`https://en.wikipedia.org/wiki/Interquartile_range`

VaST[2] software. The lightcurves of 250000 stars were extracted and searched for variability using the technique discussed by [4, 5, 6, 7]. The dataset includes 339 known and 316 new variable stars, among them 341 eclipsing binaries, 165 RR Lyrae stars and 139 red periodic, semi-periodic and irregular variables. Having constructed the comprehensive list of true variable stars, we investigate how well these variables can be extracted from the dataset using various variability indices.

To quantify the quality of candidate variables selection provided by each variability index following [8, 9, 10], we compute the completeness C and purity P:

$$C = \frac{\text{Number of selected variables}}{\text{Total number of confirmed variables}} \tag{1}$$

$$P = \frac{\text{Number of selected variables}}{\text{Total number of selected candidates}} \tag{2}$$

as well as the fidelity F_1-score[3] which is the harmonic mean of the two parameters:

$$F_1 = 2(C \times P)/(C + P). \tag{3}$$

$F_1 = 1$ for a perfect selection when all true variables and no false candidates pass the selection criteria while $F_1 = 0$ if no true variables are selected.

For each variability index we estimate its expected value and its scatter, σ, as a function of magnitude (Fig. 1). Candidate variables are then selected as objects having their variability index value $> n\sigma$ above the expected value of this index for the object's magnitude. The selection is repeated for n in the range 0–50. The resulting C, P, and F_1 values as a function of n are presented in Fig. 2. The selection resulting in the highest F_1-score is used to compare the indices. This way the optimal cut-off value $n\sigma$ is used for each index. The distribution of the expected index values for a given magnitude is non-Gaussian, therefore a simple choice like a 3σ cut-off might not be the optimal one for some indices.

The results of variability indices comparison are presented in Table 1. The table presents the information taken into account by each index (in addition to the measured magnitudes themselves) that may include estimated photometric errorbars, order of points in a lightcurve and exact times of observations. It presents the maximum F_1-score reached by a selection using each index. We consider the index with the highest value of $F_{1\ \mathrm{max}}$ as the most efficient in selecting true variable stars. Since F_1 characterizes only the selected candidates, but does not take into account the rejected, presumably non-variable, objects, Table 1 also lists a fraction of objects that do not pass the selection (at the cut-off value corresponding to $F_{1\ \mathrm{max}}$), $R_{F_{1\ \mathrm{max}}}$, as an auxiliary measure of variability index performance. Finally, Table 1 reports the maximum completeness, C_{max}, reached by each index at a selection cut-off of $n\sigma$ where $n \geq 0$. The values of $C_{\mathrm{max}} < 1$ indicate that the index cannot recover some variable stars, even at a low selection threshold (corresponding to a large number of false candidates). All $F_{1\ \mathrm{max}}$, $R_{F_{1\ \mathrm{max}}}$, and C_{max} values presented in Table 1 are the median values computed over the 173 subfields.

3 Conclusions

Table 1 indicates that the highest peak on the DFT periodogram, IQR, MAD, and Stetson's L index are the most efficient in recovering variable objects from the set of photographic lightcurves used for the test. These indices can be recommended for the future searches of variable objects using photographic lightcurves. Some correlation-based indices (like the I index) are only able to recover objects varying on timescales longer than the typical lightcurve sampling time and, therefore, are not good general-purpose variability indicators for (typically) sparsely sampled photographic lightcurves. Constant stars with corrupted measurements (e.g. due to blending with a nearby star) may pass the selection threshold even for the best identified variability indices. The need to reject such badly measured stars through a visual inspection of lightcurves and images so far prevents a full automation of variability searches.

[2] `http://scan.sai.msu.ru/vast/`

[3] The C and P parameters are often referred to as "recall" or "sensitivity" or "true positive rate" and "precision", respectively. See `https://en.wikipedia.org/wiki/Precision_and_recall`

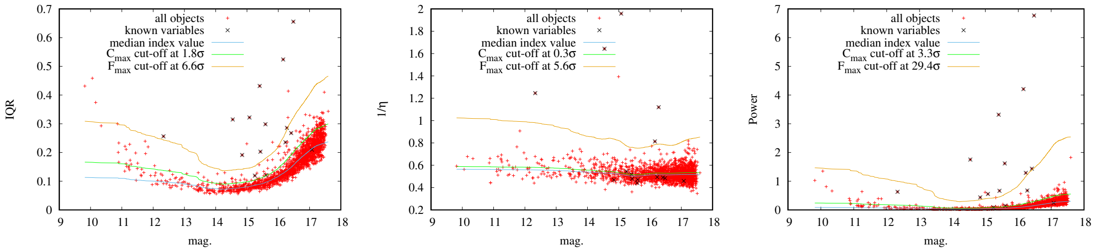

Figure 1: Variability indices IQR, $1/\eta$, and the highest DFT peak plotted as a function of magnitude for one of the $52' \times 52'$ subfields. Variable stars are marked with 'x'. The curves represent the expected values of the indices for a given magnitude and selection thresholds corresponding to the best trade-off between the completeness and purity of the candidates list ($F_{\max}$) and the maximum completeness of the list ($C_{\max}$).

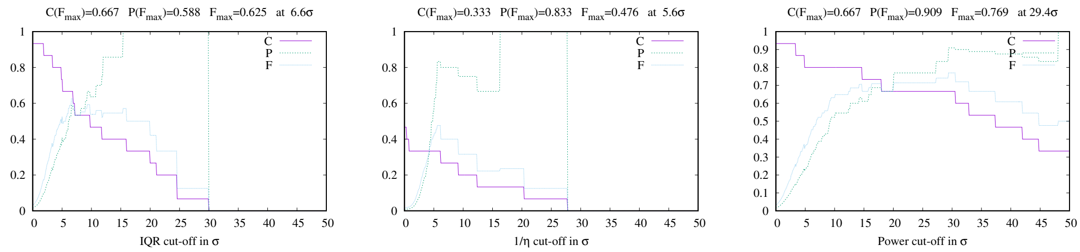

Figure 2: Variable star selection completeness (C, Eq. 1), purity (P, Eq. 2), and F_1-score (Eq. 3) as a function of selection threshold for the variability indices IQR, $1/\eta$, and the highest DFT peak. The plots are for the dataset presented at Fig. 1.

Table 1: Variability indices

Index	Errors	Order	Time	$F_{1\ \max}$	$R_{F_{1\ \max}}$	$C_{\max}$	Ref.
Scatter-based indices							
χ^2_{red}	✓			0.111	0.979	1.000	[11]
σ				0.182	0.987	1.000	[7]
MAD				0.400	0.995	1.000	[12]
IQR				0.400	0.995	1.000	this work
RoMS	✓			0.333	0.994	1.000	[13]
σ^2_{NXS}	✓			0.200	0.990	1.000	[14]
v	✓			0.039	0.932	1.000	[15]
Correlation-based indices							
l_1		✓		0.250	0.997	0.667	[16]
I	✓	✓	✓	0.154	0.989	0.667	[17]
J	✓	✓	✓	0.250	0.994	1.000	[18]
J(time)	✓	✓	✓	0.250	0.995	0.750	[19]
L	✓	✓	✓	0.400	0.996	1.000	[18]
E_x	✓	✓	✓	0.222	0.993	1.000	[20]
$1/\eta$		✓		0.250	0.998	0.667	[21]
$\mathcal{E}_{\mathcal{A}}$		✓	✓	0.014	0.860	0.600	[22]
S_B	✓	✓		0.143	0.987	1.000	[23]
Period search							
L − K		✓	✓	0.087	0.981	1.000	[2]
DFT		✓	✓	0.500	0.995	1.000	[3]

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Sonneberg Sky Patrol Archive — Photometric Analysis

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Abstract

The Sonneberg Sky Patrol archive so far has not yet been analyzed systematically. In this paper we present first steps towards an automated photometric analysis aiming at the search for variable stars and transient phenomena like novae. Early works on the sky patrol plates showed that photometric accuracy can be enhanced with fitting algorithms. The procedure used was a manually supported click-and-fit-routine, not suitable for automatic analysis of vast amount of photographic plates. We will present our progress on deconvolution of overlapping sources on the plates and compare photometric analysis using different methods. Our goal is to get light curves of sufficient quality from sky patrol plates, which can be classified with machine learning algorithms. The development of an automated scheme for finding transient events is in progress and the first results are very promising.

Keywords: Photometry on photoplates

1 Introduction

The Sonneberg Plate archive with more than 275,000 plates is one of the largest plate collections in the world. Photometric observations in Sonneberg took place from about 1925 to 1995 and can be divided into two programs, Field Patrol and Sky Patrol. The Sky Patrol campaign was launched to provide a continuous record of the northern hemisphere in two different colors, some parts are covered with more than 3,000 photographic plates over a time period of 50 years. Thus, the Sky Patrol archive is very valuable source for studying the variable sky, especially of variations on long time scales.

Although more than 7 million photographic plates exist taken in the 20th century all over the world, efforts on automated analysis started just in the last decade. The most prominent pipelines for automated analysis, sorted alphabetically, are DASCH [1], PyPlate [2] and VaST [3]. These pipelines are based on Source Extractor (SExtractor), a package developed for CCD photometry, to determine star intensities or magnitudes from photographic plates.

Kroll et al. [4, 5] had chosen another approach. They fitted a model with a logarithmic intensity characteristics to single isolated stars on digitized Sonneberg photographic plates. For selected stars they were able to determine the brightness with an accuracy between 0.07 and 0.12 mag. However, the analyzed stars were manually selected and crowded fields could not be fitted.

In the following we will discuss two different methods we used for photometry of the Sonneberg Sky Patrol plates. Before analyzing the plates, astrometric solutions were calculated with solve-field [6] on a small sections ($1^\circ\times 1^\circ$ or $2^\circ\times 2^\circ$) of the images.

2 Photometry using Source Extractor

The SExtractor package supplies coordinates, magnitudes, ellipticity etc. for every resolved object found in an astronomical image. For analyzing digitized photographic plates SExtractor can be switched to the PHOTO mode [7]. In this mode data are preprocessed in order to correct the logarithmic characteristics of photographic plates

$$I = \frac{\gamma}{\ln 10} 10^{-0.4\cdot m_0} 10^{\frac{D}{\gamma}} \tag{1}$$

where D is the pixel value, m_0 the zero point of magnitudes and γ the contrast index of the emulsion. The photometric procedures of SExtractor remain unchanged after transformation of the data.

One can also perform PSF photometry with SExtractor. Therefore one uses PSF Extractor (PSFEx) to create a model of a point spread function for star images. However, this fails on photographic plates due to the non linear characteristics, which produces star images of varying widths in dependence of the magnitudes. Unfortunately PSFex can not transform the data before calculating the point spread function as in SExtractor. Therefore we applied the exponential transformation of the digitized images (eqn. 1) as a first step and then used PSFex and SExtractor for PSF photometry.

For magnitude calibration the APASS (AAVSO Photometric All-Sky Survey) catalog [8] was chosen as reference. In the left part of fig. 1 the instrumental magnitudes are plotted in dependence of the catalog magnitudes. We analyzed the blue sensitive plates. However, their spectral sensitivity does not match the one of the Johnson B filters used by APASS. Thus, the spectral sensitivity has to be corrected by a color term as proposed by DASCH [1]

$$m_{\mathrm{cat}} = B_{\mathrm{cat}} + c(B_{\mathrm{cat}} - V_{\mathrm{cat}}) \tag{2}$$

where m_{cat} is APASS catalog magnitude transformed in plate system, B_{cat} and V_{cat} APASS Johnson B and V magnitude respectively and c is the color term.

Since the linearity of the characteristics nearly has been restored by the applied transformation the best correlation between instrumental and catalog magnitude could be determined by optimizing the Pearson correlation coefficient r while varying the color term (right part of fig. 1). This method is faster than repeatedly fitting the calibration curve for different values of color terms and analyzing the scattering of the residuals. And, the Pearson coefficient curves are much smoother, which enables a reliable determination of the minima.

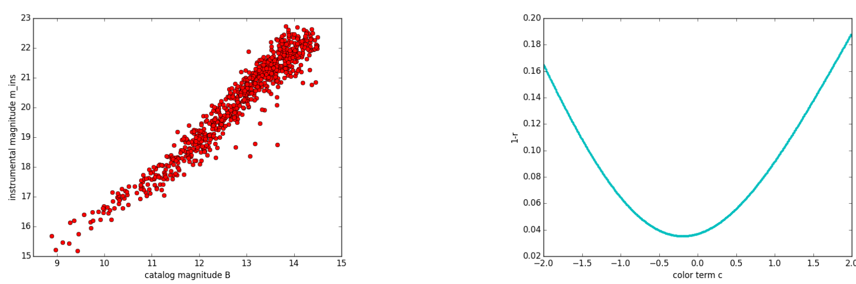

Figure 1: Calibration and color term. Left: dependency between catalog magnitude B and instrumental magnitude from SExtractror. Right: $1 - r$ in dependence of color term c.

Photometric calibration was calculated for every single plate separately which allowed us to generate calibrated light curves for given objects. Photometric rms values of 0.15 mag were achieved for resolved objects that show no variability (fig. 2). A larger rms value usually is evidence of a variable star, e.g. ST Lyr in fig. 2.

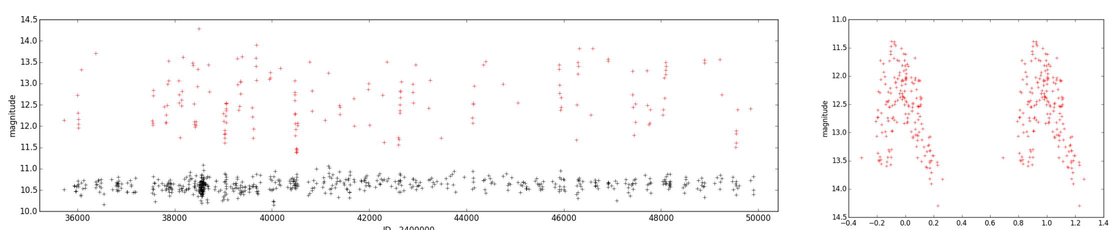

Figure 2: Lightcurves. Left: lightcurve of a constant star, rms of 0.14 (black) and lightcurve of a variable star, rms of 0.6 (red). Right: ST Lyr, folded lightcurve of variable at the known period of 300.5 days.

3 Adapted PSF Fitting

We also made some effort in fitting the digitized Sky Patrol plates with astropy [9] using the model

$$f(x,y) \sim \log\left(A \cdot e^{-\left[\frac{(x-a)^2}{\sigma_x^2} - 2\rho\frac{(x-a)(y-b)}{\sigma_x\sigma_y} - \frac{(y-b)^2}{\sigma_y^2}\right]} + A_0\right) \tag{3}$$

where $f(x,y)$ is a pixel value of digitized image.

After background estimation, finding and labeling the stars, the data are exponentially transformed, in order to use the built-in Gauss2D function within the model. In fig. 3 an example of a fit to a small section of one of the plates is shown.

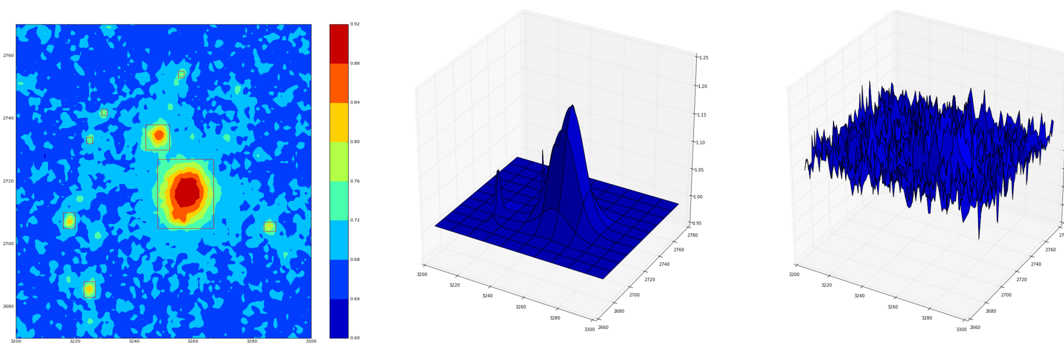

Figure 3: Adapted PSF fitting. Left: labeled stars in original digitized photographic plate. Center: model of the fitted function. Right: residuals after subtracting the fitted model.

The results are very promising. Subtracting the model from the data we found an average of the residuals of 0.2% with a standard deviation of 1.4%, which is in good agreement with the standard deviation of the background of 1.1%.

4 Search for transient phenomema

The Sonneberg plate archive furthermore might turn out to be a valuable database of transient phenomena of the 20th century, like novae, asteroids, etc.. In order to develop an automated scheme for searching such events in the plate archive we started with a simple approach: a good quality plate of a series was chosen as a reference, which then was subtracted from all images of the series. To take into account fluctuations of the plate quality a high threshold was set to identify signals within the differences of the images. This method is quite similar to Pickering's positive–negative method [10].

We analyzed the blue sensitive plates (labeled "pg") of the "20h+40" field, i.e. the center of the field is close to γ Cygni. The images were cut in sections of 1°× 1°, to get rid of background drifts across the field. In a first step the centers of these sections were chosen from the position of known nova events during the observation campaign.

Several nova events were easily identified within the investigated series. As an example we present here our results of the Nova Cygni 1986 (V1819).This nova was discovered by M. Wakuda, Japan, 1986, August 4.7 as star of $m_V = 9.5$ mag [11]. It was classified as a slow nova, the visible magnitude was $m_V = 13$ mag on July 28.6 [12], the nova reached its maximum of $m_V = 8.5$ mag on August 9, 1986 [13].

We find a steep rise in brightness between July 29th and Aug 2nd, and in the blue sensitive series the brightness reached its maximum of about $m_B = 9.5$ mag on Aug 2nd. This was already noted by I.I. Andronov et al., who manually analyzed this nova event in the same series of the Sonneberg plates [14], and it proofs, that our procedure is capable of detecting nova events in the Sonneberg Skypatrol plates!

Within the analyzed sections of the series we additionally found several transient events on one or two following images only. These events clearly could be distinguished from scratches, but could not be identified with nova events. Further investigations are necessary to classify these events.

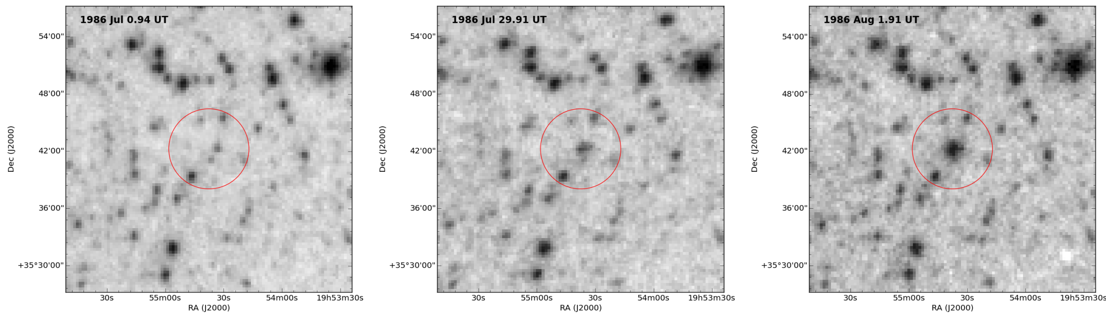

Figure 4: Nova Cygni 1986 (V1819) in the Sonneberg Skypatrol plates. Left: latest photo plate before the nova, July 1st. Center: the first appearance of the nova on July, 29th. Right: The nova's first maximum on Aug, 2nd.

We are aware, that we might miss transient events with setting a high threshold. But the results so far are very promising. The next steps will be to normalize the images, to estimate the quality of the images e.g. from the statistics of the background and then to analyze the differences to the reference images while variing the threshold.

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Investigation of binary X-ray sources with photographic plates

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Abstract

We show that cataclysmic variables with their strong long-term activity are promising objects for investigating their light curves in photographic data. Photographic observations can significantly extend the mapped time segment. They even give us the possibility to study these objects in the time intervals before their discovery. Also unpredictable and rare events like outbursts can be discovered on archival photographic plates. We document the use of digitized plates for measuring the brightness of the cataclysmic variable (dwarf nova) DT Oct. We show that the brightness on these plates can be measured by the software designed for treatment of CCD images. Accuracy of 0.02–0.03 mag can be achieved if the signal of the object is significantly larger than the background.

Keywords: Instrumentation: miscellaneous. Methods: data analysis. Methods: observational. Radiation mechanisms: general. Accretion, accretion disks. Novae, cataclysmic variables.

1 Introduction

Archives of photographic plates are important for monitoring of a large part of the sky. Most transients (objects with outbursts) were discovered only in outburst, not in quiescence before this event – a lot of "sleeping" transients exist and monitoring is important for discovering them. Monitoring is also inevitable for a search for rare, unexpected and unique phenomena even of the already known objects. Cataclysmic variables (CVs) and related objects with their strong activity are promising objects for this investigation.

CVs are binaries with the orbital period $P_{\rm orb}$ typically of hours in which matter transfers onto the white dwarf (WD) from its late-type, lobe-filling companion star (see Warner 1995 for a review).

CV with a "non-magnetized" or a mildly magnetized WD has the accretion disk which embeds the WD. This disk is often the dominant source of the optical radiation. A thermal-viscous instability of the accretion disk (e.g. Hameury et al. 1998) plays an important role in the activity of CVs. It produces outbursts of dwarf novae (DNe), which is a type of CVs. This outburst begins when the accretion disk switches from the cold to the hot state after accumulating a sufficient amount of matter. This causes a strong increase of temperature and viscosity of the disk matter, resulting in its accretion onto the WD at a large rate. In the optical band, the luminosity (representing thermal emission of the disk) increases by 2–5 mag, typically for several days or weeks. This large brightening is thus easily detectable on the photographic plates. Some DNe in outburst appear as the new objects on the photographic plates even in the "empty" places where no previously known object was located.

2 Interactive measuring on digitized photographic plates

For determining the magnitudes of the variable objects on the digitized plates, we used the code Aperture Photometry Tool (APT), v. 2.4.9 [1]. This code is designed for investigating CCD images. It uses interactive analysis of the image, which is important for our purpose because we need to evaluate the quality of the plate. The reason is that the quality of the stellar images can differ from plate to plate because of the differences of pointing and sharpening. Also the role of the plate defects and the background can be assessed by visual inspection.

[1] http: //www.aperturephotometry.org/aptool/apt-updates/aperture-photometry-tool-v-2-4-9-available-now/

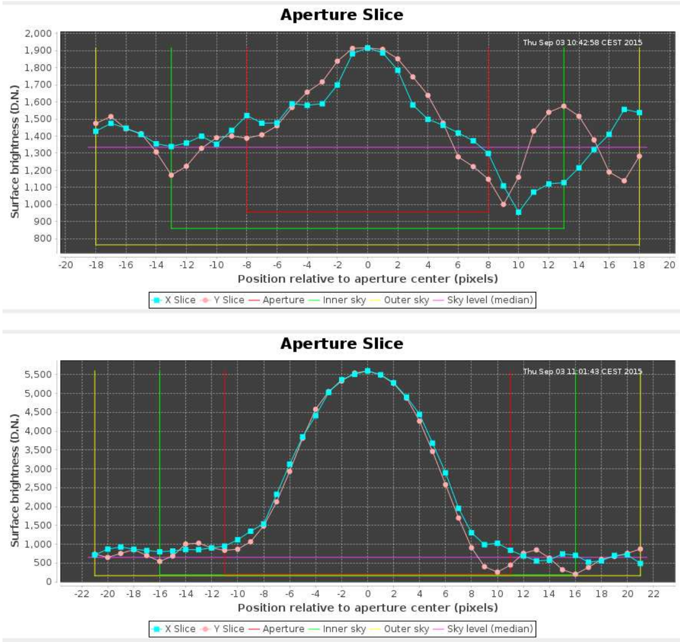

Figure 1: Profiles of DT Oct on digitized plates. **a)** A slice of DT Oct in quiescence (the roughness of the background plays a large role). **b)** A slice of DT Oct in outburst.

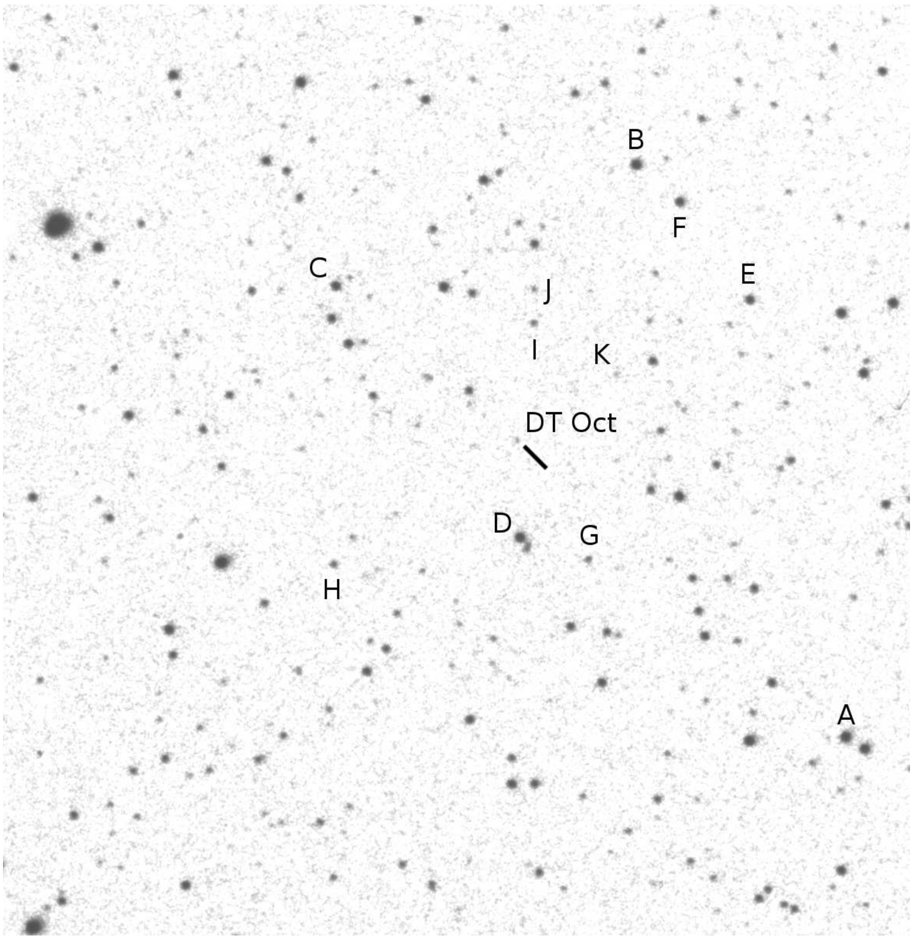

Figure 2: Part of a Bamberg plate. DT Oct and the brighter comparison stars (adopted from AAVSO (Henden 2015)) are marked. North is on the top, East to the left.

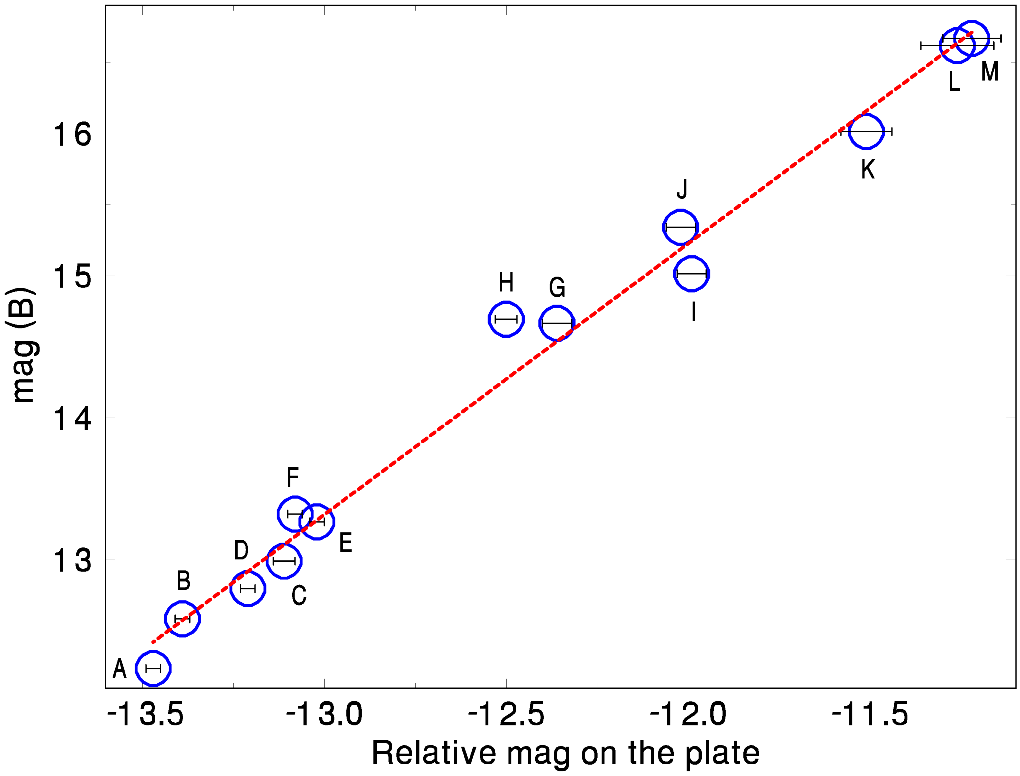

Figure 3: Relation of the cataloged magnitudes of the comparison stars for DT Oct and their magnitudes on the Bamberg plates. AAVSO magnitudes in the B band are plotted on the vertical axis. The magnitudes determined by the software are on the horizontal axis. Each comparison star is abbreviated as in Fig. 2.

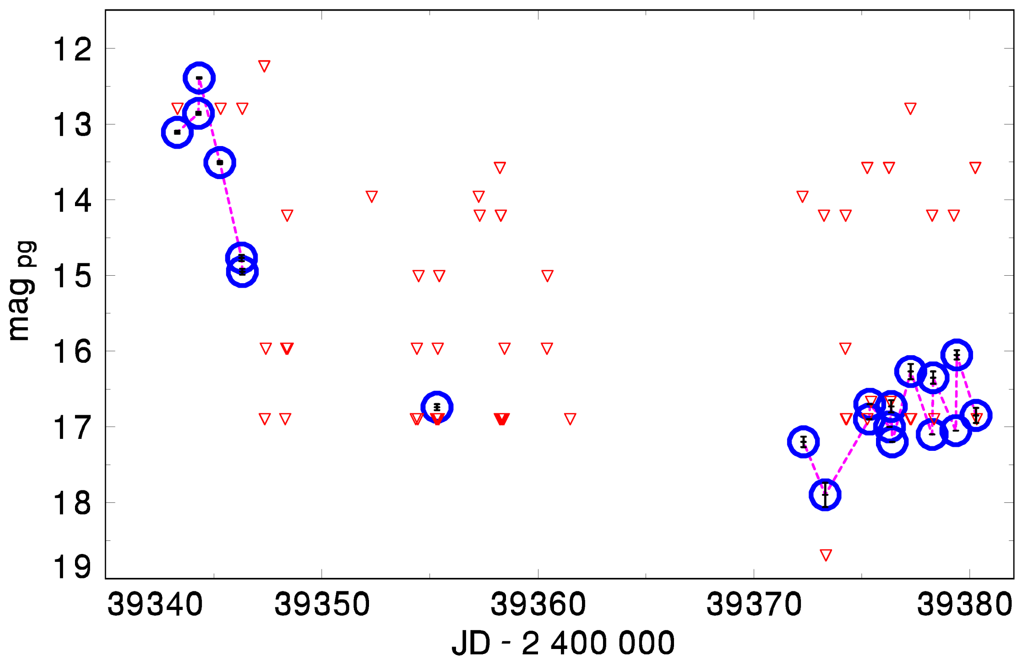

Figure 4: Detail of the Bamberg photographic light curve of DT Oct. Open circles denote the detections. Also their standard deviations are shown, but they are often smaller than the size of the symbol. Open triangles represent the upper limits of brightness.

We found a necessary procedure which has to be made before starting the measurement of brightness. Since the digitized plate has the background which has a bigger signal than the stars (this is the reverse from CCD images), the stars appear as the dips from the high background. To measure the brightness of the stars, it is thus necessary to invert the signal to have the stars as the peaks from the background. To lower the observing error, the signal of the resulting background has to be lowered (some constant value of the signal has to be subtracted).

We applied this method to the dwarf nova DT Oct. Figure 1 shows the profiles of DT Oct on the digitized plates. The noise caused by the roughness of the background plays a large role in quiescence. On the other hand, this background plays a much smaller role when DT Oct is in outburst, by about 5 magnitudes brighter than in quiescence.

Figure 2 shows part of a Bamberg plate with DT Oct and the comparison stars marked. A relation of the cataloged magnitudes of these comparison stars for DT Oct and their magnitudes on the Bamberg plates is displayed in Fig. 3. The relation among the magnitudes of the individual stars in the catalog is different from the one for the magnitudes determined on the plate by the software.

We found that measuring the brightnesses on digitized plates which we present in this paper yields precise light curves. A detail of the Bamberg photographic light curve is displayed in Fig. 4. The uncertainty of brightness is about 0.02 mag in outburst when the star extends over a lot of pixels. This uncertainty increases to about 0.1–0.2 mag in quiescence when the star is almost 100 times fainter. Mainly the roughness of the background is important in this low state.

3 Conclusions

We showed that it is possible to investigate the digitized photographic plates by software designed for interactive analysis of CCD images. We analyzed the cataclysmic variable DT Oct (NSV 10934) which can be identified with a bright ROSAT X-ray source (1RXS J184050.3-834305) (Kato et al. 2002). We showed that accuracy of 0.02–0.03 mag can be achieved if the signal of the object is significantly larger than that of the background. This accuracy is even comparable to that of the CCD observations.

We note that the long-term activity of DT Oct is little known because this object is located close to the southern celestial pole. Only a few relatively recent outbursts of this CV were observed by CCD and visual methods (e.g. Kato et al. 2002; Henden 2015). The plates from the Babmerg archive which were obtained in the sixties and the beginning of the seventies are important for studying the activity of this object on long time scales.

Investigating the archival plates is important also because the activity of some X-ray binary systems like CVs undergoes large changes on timescale of decades. Photographic data can significantly extend the mapped time interval, and to discover such changes. Unpredictable and rare events (flares, outbursts, transitions between the states) can be discovered on these plates.

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The Digitizing NAROO project

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Abstract

The NAROO project (New Astrometric Reduction of Old Observations) has primarily a scientific goal: making a new astrometric reduction of old observations, mainly photographic plates in order to model more easily either the dynamics of solar system bodies or any fast evoluting system.

Keywords: natural planetary satellites – sub-micrometric digitizer.

Introduction

We present a project of setting up of a centre for sub micrometric digitizing of photographic plates and images analysis. This project will endorse the making of a new reduction of old observations for « observing in the past », the creation of a centre for digitizing photographic plates and image analysis, the use of the new Gaia reference catalogue for the new astrometric or photometric reduction.
Our goal is mainly to emphasize the astrometry of solar system bodies from observations made from the end of the XIXth century until the end of the XXth century. Photometry and spectroscopy will also be included in our project. Note that this project is not for saving only the photographic plates but for digitizing and analyzing them.

The context of the project

The scanning of photographic plates is performed by several observatories with different purposes. The precursors were the MAMA digitizer in the observatoire de Paris and Starscan at the U.S. Naval Observatory which were not really digitizers but automatic measuring machines.

Several projects of digitizing or automatic measuring of plates have been conducted more recently. However, our project arrives after the improvement of several techniques:

- progresses in the technology of sub-micrometric digitizers
- arrival of the Gaia reference catalogue allowing to calibrate old images thanks to accurate proper motions of stars (cf figure 1)
- the progress of our knowledge in the dynamics of the solar system. Tidal and non-gravitational effects are now sufficiently known and modeled to be measured through observational data. Enlarging the sample of data is necessary and only accurate measurements will help to quantify the effects we look for.
- the increase of the power of computers allowing the analysis of large images.

The tests made on the more recent digitizer (DAMIAN at the Royal Observatory of Belgium) with the best star catalogues such as UCAC waiting for Gaia and all the above items encouraged us to build a new sub-micrometric digitizer and to start digitizing the large collection of photographic plates of the solar system objects made during the XXth century. Our center of digitization will also welcome photometric and spectroscopic plates looking forward for progresses in our knowledge of the observed objects.

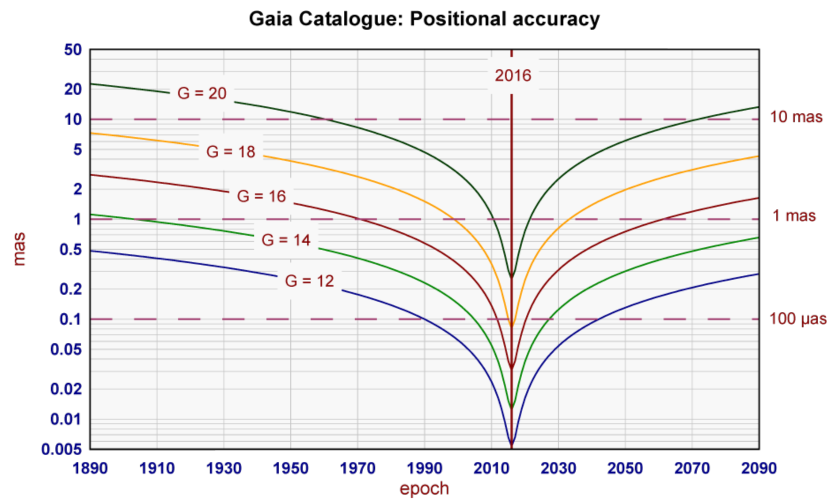


Figure 1: the accuracy of the Gaia reference catalogue allowing to "observe in the past"

The scientific goals

There are several scientific goals to be fulfilled thanks to our project. First, by providing a coherent reference system for all data, the extrapolation of the ephemerides of solar system objects will become more confident.

By increasing the astrometric accuracy of one order of magnitude, we will be able to quantify small effects such as the dissipation of energy due to tides in the natural satellites systems: internal structure and scenarios for the formation should be validated. We would explain the thermal equilibrium of Io and the geysers on Enceladus by looking for an acceleration in the motion of the icy satellites.

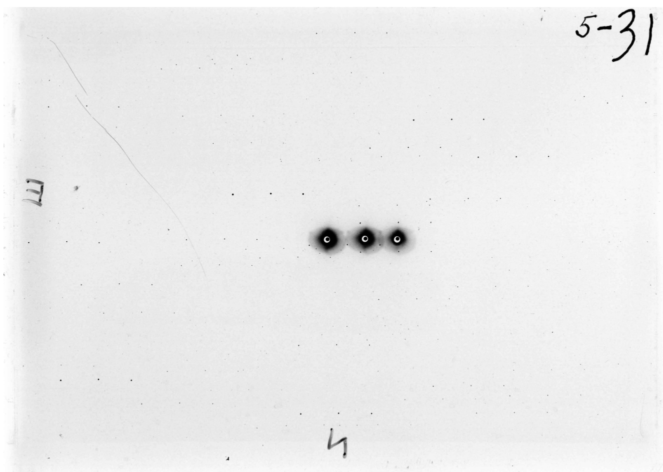
Concerning the Saturnian system, we look for old data helping to validate the scenarios of formation and evolution of the satellite system.

The astrometry of solar system objects is worth to be made because of the fast motion of these objects needing large sample of data spread on a long interval of time. Starting at the end of the XIXth century with the same accuracy of nowadays observations will help to reach our goals. Same, the evolution of variable stars could be determined through old data. Old observations were used but with a level of accuracy too small and the Gaia reference catalogue will increase the accuracy of old data thanks to a new reduction of digitized plates.

Examples of old plates worth to be re-reduced :

The plates including natural planetary satellites are first selected because of the complexity of the dynamics needing a large set of data. Fortunately they were extensively observed and we will select the best photographic plates for our purpose: use of long focus instruments for revealing small satellites close to their planet or astrographic plates showing satellites far from their planet. We will also select plates made during specific periods of time in order to optimize the fit of theoretical models. It would not be possible to digitize all available plates and we will choose observations for the best sampling of data. Figure 2 shows a plate of the Martian satellites. The digitization of such plates allow to make more accurate measurements at a time where few data were available, thanks to image analysis. It allows also to detect more reference stars not used at the time of the first reduction. Our first tests show that the astrometric accuracy of such plates is similar than the accuracy of Mariner measurements made at the same time (table 1).

Besides the natural planetary satellites whose fast motions request enlarging the sample of data, we look forward making pre-discoveries of objects such as TNO, NEO, comets, irregular satellites which were on Schmidt plates made during the XXth century well before their discovery. A Schmidt plate contains so much stars and other objects that they have never been all identified. The Gaia catalogue will permit to identify all objects until magnitude 20 so that objects which were not known at the date of the observation will be re-discovered. We will observe these objects in the past.



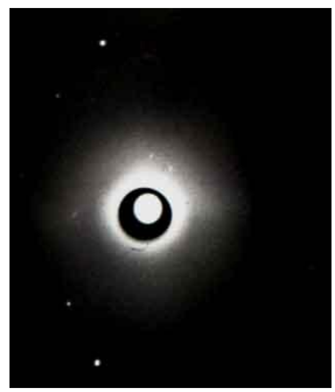


Figure 2:
Three exposures of the Martian system with a detail (positive) on Phobos, Deimos near their planet. The accuracy of the reduction is the same as the accuracy of the observations by mariner made at the same time.

The first results

We have collaborations with laboratories owning sub-micrometric scanners and photographic plates (USNO-Washington DC, ROB-Bruxelles, Bucharest Astronomical Institute, QMUL-London, OCA-Nice). We made an inventory of existing plates scientifically interesting and we found a large number of interesting available plates (until 200 000 plates) especially plates from refractors the focal length of which being from 3 to 20 meters or from reflectors (Schmidt plates). We made tests by scanning Galilean, Saturnian and Martian plates with ROB-DAMIAN digitizer.

We got first encouraging results with the Martian satellites astrometric positions (Table 1) the accuracy of which being the same than for Mariner data made at the same date.

	$\overline{(O-C)}_{\alpha\cos\delta}$ NOE	$\sigma_{\alpha\cos\delta}$ NOE	$\overline{(O-C)}_{\delta}$ NOE	σ_{δ} NOE
Mars	–1.8	56.9	–5.3	50.7
Phobos	6.0	58.3	–1.7	48.6
Deimos	4.3	41.9	–3.1	47.3

Table 1
O-C and standard error in mas for the Martian system

Conclusion

Our goal is now to organize a « centre for digitizing and analyzing photographic plates » in Paris Observatory (Meudon site) for not only new astrometric reductions but also for photometric purpose or saving and archiving patrimonial plates. We will make inventories of plate archives with objects, field, quality of plates, dates, …, all available through a common web site (Virtual Observatory?) and selecting plates to be analyzed. We will prepare a specific databases for files of digitized plates made available to the scientific community
We look forward the arrival of the Gaia reference star catalogue in order to be able to make new reductions and to make the old plates valuable for to-day scientific research.

Acknowledgements

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The Wide-Field Plate Database in the context of development to Astroinformatics

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Abstract

We describe the Wide-Field Plate Database (WFPDB www.wfpdb.org) as a basic source of data for the wide-field astronomical photographic plates obtained with professional telescopes worldwide in a context of the development of the Astroinformatics recourses.

Our priority is to integrate the WFPDB system into the Virtual Observatory (VO) structures (e.g. German Astrophysical Virtual Observatory, GAVO) and thus utilize our experience and efforts in astronomical archives processing, data reduction, etc. We intend to implement the major protocols, necessary to turn the WFPDB into a fully featured VO service.

The forthcoming steps of the WFPDB development are: International collaboration for plate catalogues inventory - the main aim of the project Humboldt Astroinformatics Networking; Plate digitization according to the VO standards in FITS format with equal criteria and parameters; Preprocessing and the photometry of digitized plates; Free access to the files of digitized photographic plates by the VO tools.

Keywords: Wide-field astronomical photographic observations, databases, digital plate archives, virtual observatory, astroinformatics.

Introduction

Since the last decades of the 20th century the astronomical observations with CCD cameras have needed methods of image processing with volume of some MB of data. Subsequent sky surveys needed already pipeline routines for image processing with volume of GB of data. The archives of Virtual Observatory (VO) required volume of TB of data. The constantly increasing volume of data - already of order of PB, coming from the new sky surveys of the Large Synoptic Survey Telescope and the Square Kilometre Array Telescope put the obligatory requirements for use of the Astroinformatics approaches.

We consider how the increasing volume of data is reflected on the established since 1991 Wide-Field Plate Database (WFPDB, www.wfpdb.org), which practically is a wide-field unique telescope, giving access to the astronomical photographic observations, done systematically worldwide in the period 1880 ~ 2000 and stored worldwide. Another paper topic is how the WFPDB underwent transformation to a featured VO service. Additionally the processing of large amount of data from the running plate digitization put demands for using the methods of Astroinformatics.

Wide-Field Plate Database

At the moment the WFPDB includes the metadata for about 600 000 plates (or 24% of all known two millions and half wide-field plates), with assigned unique identifier, encoding an instrument identifier and a local plate number. The WFPDB (Fig. 1 presents its meta-model) provides the available plate data – for spatial-, temporal-, spectral-, and physical characteristics, semantic object classification, its digitization and availability, giving the person for further contact. One can find also all sky distribution of the plate centres, time-histogram of the archive observations, plate previews (with dominant 600 dpi resolution, in TIFF or JPG file format), scanned plate logbooks and plate envelopes.

Parts of the WFPDB are the Catalogue of Wide-Field Plate Archives (CWFPAs in XLS, CSV, ASCII and VOT file formats), and the Catalogue of Wide-Field Plate Metadata. In the actual version 7.1 of the CWFPAs (November 2015) to the unique archive identifier (coincident with the instrument identifier) two codes were added taking in view the different archive storage places and the instrument movements.

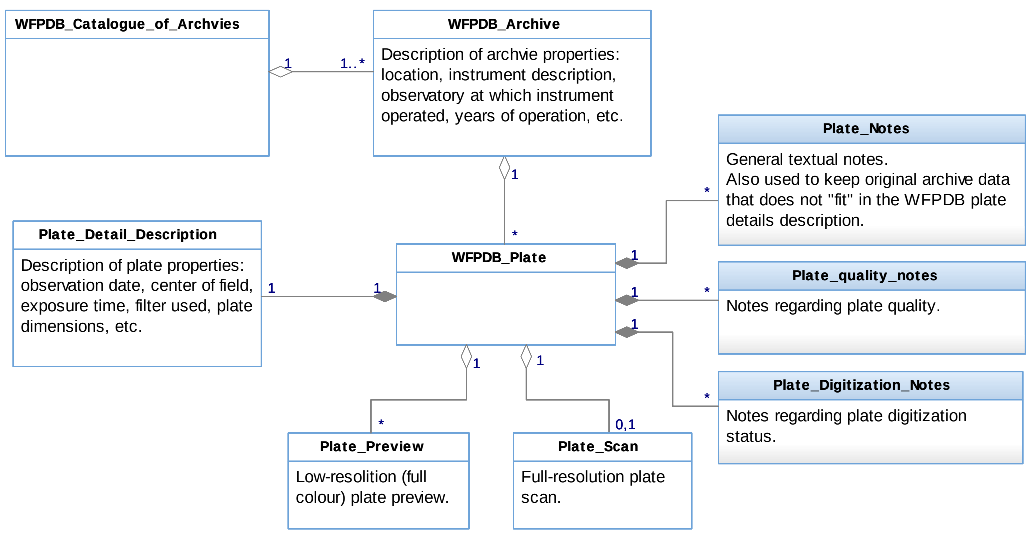

Figure 1: WFPDB meta-model.

The biggest wide-field plate collections are stored in Harvard and Sonneberg. With the efforts of astronomers, networking and information technology specialists, and librarians, as well as with the help of the WFPDB working team (in Potsdam, Bamberg, Hamburg, Heidelberg, Odessa, Kiev, Lvov, Bucharest, Budapest, Brussels, Belgrade) the process of plate archiving is running actively. The plate digitization is also a running process with the new mass scanning paradigm of the flatbed scanners, which replaced the precise but slow scanners as PDSs, SuperCOSMOS, PMM at USNO Flagstaff, GAMMA at STScI, MAMA, etc. The flatbed scanners as Epson Expression 1640XL or 10000XL, Epson Perfection V700 Photo, or the novel Epson V800 (used in Bosscha Observatory) can scan a plate with size 16x16 cm with resolution 2400 dpi for 5 min. The volume of the output FITS/TIFF file is about 400 MB. The largest plate scanning projects with a special emphasis on the earliest historic astronomical plates are running or completed in Harvard, Sonneberg [1], Bamberg [2], Hamburg [3], Potsdam [4], Pulkovo, Rozhen, Jena, Kiev, Konkoly, Szombathhelly, etc.

WFPDB Integration into Virtual Observatory

The steps to the WFPDB integration into VO have begun with the development of the equal criteria and parameters for plate digitization according to the VO standards (using FITS format files); preprocessing and photometry of digitized plates by the VO tools, as well as free access to the files of digitized photographic plates (e.g. the Potsdam Carte du Ciel plates and their link to the VO).

A pilot project for creating closer links between scientific papers published in Information Bulletin on Variable Stars and the data - included in the WFPDB, on which the papers are based upon gave a possibility of re-use of the plates, which is one of the goals of VO [5].

The integration of the WFPDB into the German Astrophysical Virtual Observatory as a VO structure turned the WFPDB into a fully featured VO service with interoperating data archives and software tools through Table Access Protocol as a VO standard for querying astronomical databases [6].

WFPDB development to Astroinformatics

For searching plates we developed a visualization of some WFPDB data - AstroWeb (http://wfpdb.org:8000/chameleon/astroweb/astroweb.phtml) on the base of the same data-set as the WFPDB search system.

Figure 2: Humboldt Astroinformatics Network web site.

The standard WFPDB requirements for content and data structure need a pipeline software tools for time conversion - the predominant cases are local sidereal time (LST) or local daylight saving time (DST) to universal time (UT), and coordinates conversion (usually equatorial coordinates to J2000). The software https://github.com/nkirov/timetool and https://github.com/nkirov/epochtool is written in C++ using Qt cross-platform application and UI development framework (http://qt.digia.com/). Running project is a development of software tools for image processing of the flare star search monitoring multi-exposure plates, as well as for Carte du Ciel triple images plates.

For some recently incorporated plate catalogues we provide an accurate World Coordinate Systems (WCS) fits of the plates using ASTROMETRY.NET (http://nova.astrometry.net/).

For plate collections inventory and exchange of experience an international collaboration is strongly desired. It is the main aim of the running project Humboldt Astroinformatics Networking and of the established Humboldt Astroinformatics Network Web Portal (Fig. 3) which to be a starting point at any searches, presentations, retrievals, publishing preservation and dissemination of information concerning Astroinformatics in Bulgaria and Germany; to give computational education; to facilitate the historical and cultural heritage research in both countries; to active a social networking, combining Science Portal and Public Portal, as well as the Citizen Science (done by voluntary contributors together with professional scientists); to link to other existed already scientific organizations portals, self-referential portals and some astronomical image processing home pages and wikispaces (e.g. Astroplate Wiki at: https://www.plate-archive.org/wiki/index.php/Main_Page) for further exchange of knowledge, software and archival procedures, as well as for improving the standardization of metadata, catalogue data and scientific tools.

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From plate scans to light curves: calibrating extracted data and building the APPLAUSE database with PyPlate

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Abstract

We have developed methods for extracting and calibrating data from digitized photographic plates and have implemented the workflow in the PyPlate software. PyPlate can be used to locate sources in direct images, calibrate source positions and magnitudes, process plate metadata, and write results to a database. Effectively, raw scans are turned into light curves of potentially millions of objects. We have used PyPlate for processing 51517 plate scans in order to build the APPLAUSE database.

Keywords: Techniques: photometric – Astrometry – Catalogs

1 Introduction

Extraction and calibration of data from digitized photographic plates are important for bringing plate data into current scientific use. At the Astroplate 2014 conference we presented a workflow for plate digitization, data extraction and publication [1]. The workflow involves source extraction from direct images with the SExtractor software [2], initial astrometric calibration with the Astrometry.net software [3], and refined astrometric calibration in sub-fields with SCAMP [4]. The recursive solving of astrometry in sub-fields allows for elimination of complex image distortions, like ones produced by commercial flatbed scanners. The outlined data processing steps are implemented in the Python package PyPlate[1].

In this paper we present the implementation of photometric calibration in PyPlate and report on applying PyPlate for building the APPLAUSE database[2].

2 Photometric calibration

As a result of source extraction with SExtractor, we get instrumental magnitudes. Once astrometric calibration has been carried out, pixel coordinates are transformed to sky coordinates. This enables us to match extracted sources with stars in a photometric catalogue.

We combine reference photometry from two catalogues, Tycho-2 and UCAC4. We take B and V magnitudes fainter than 10 from UCAC4. For brighter stars, we use the BT and VT magnitudes from Tycho-2 and transform them to B and V.

Each photographic plate has a unique color response that can be characterized with the color term C, as explained in [5]. Magnitudes in the plate natural system, m, are related to the standard magnitudes:

$$m = V + C(B - V). \tag{1}$$

Blue plates with the color response close to the B passband, have $C \approx 1$. In order to determine C for a given plate, we try a series of C values from -3 to 4. We calculate reference magnitudes using Eq. 1 and then fit a calibration curve that transforms instrumental magnitudes to the natural system. The correct C value corresponds to the smallest scatter of residuals about the calibration curve (Fig. 1).

In the next step we fit calibration curves in eight equal-area concentric annular bins, using the estimated C value to calculate reference magnitudes. Instrumental magnitudes are then transformed to the plate natural system. For stars with known $B - V$ color index, we also calculate B and V magnitudes. The limiting magnitude of a given plate is estimated during the photometric calibration and is the magnitude at which the number density of instrumental magnitudes falls below 20% of the peak number density.

[1] `https://www.plate-archive.org/applause/project/pyplate/`
[2] `https://www.plate-archive.org/applause/`

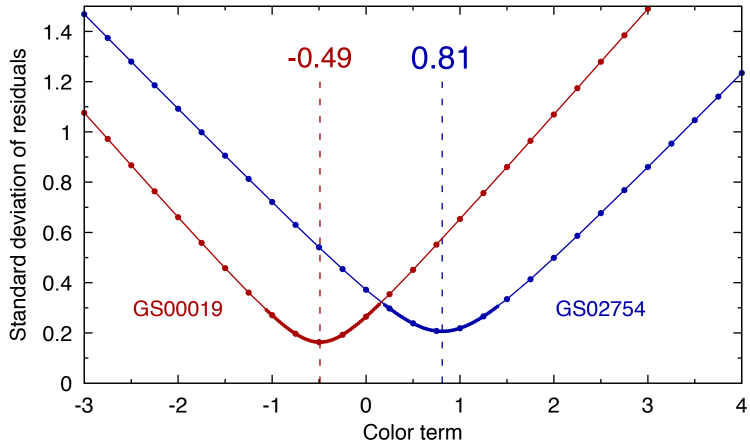

Figure 1: Estimation of color term for two plates by looking for a minimum scatter of residuals about the calibration curve. GS00019 is a red-sensitive plate ($C = -0.49$), while GS02754 is blue-sensitive ($C = 0.81$).

3 PyPlate software and the APPLAUSE database

PyPlate has been developed for processing digitized images and metadata related to a wide variety of astronomical photographic plates. PyPlate provides means to organize metadata transcribed from logbooks, observer notes, envelopes, etc., and to build a database of plates, related metadata, and extracted data from images.

The `metadata` module can be used to import metadata from CSV files, carry out calculations with observation timestamps and coordinates, and write well-structured data to a MySQL database and to FITS files with appropriate headers[3]. The `solve` module provides methods for processing plate images, including source extraction, astrometric and photometric calibrations, and cross-matching of source lists with external catalogues. Image processing can be parallelized using the `pipeline` module, taking advantage of available computing resources.

PyPlate has been used to build the APPLAUSE database, with 51517 plate scans in Data Release 2. We found astrometric solutions to 41010 direct images and carried out photometric calibration for 38735 images. Overall, we extracted 2.59 billion sources from the scans. The total size of published data is 30 TB. Our experience shows that PyPlate can be used for processing plate data ranging from small to large batches.

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Open Star Clusters in the Zvenigorod Observatory Plate Archive

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Abstract

We have compared new kinematically detected open star clusters out of the MWSC IV catalogue with the Zvenigorod Astrograph plate archive. Archive was obtained by photographic sky survey and was scanned by observatory efforts early. It covers most of the North sky, which allows detect a lot of objects. We present a list of new discovered open clusters, interested for the future investigations by our AD- and NND-methods. Additional information for clusters will improve understanding of their morphology, internal structure and parameters.

Keywords: plate archive, Zvenigorod observatory, open star clusters.

1 Introduction

Zvenigorod Astronomical Observatory is a department of Institute of Astronomy of the Russian Academy of Sciences (INASAN). Observatory longitude 36° 45.5' 10, latitude 55° 41.9'11, altitude 197 m, [1]. The visibility conditions allow to observe objects with -34 degrees on the north declination. There are interesting plates with -15 degrees north for the astrometry (due to refraction). The main part of our plates have been scanned and the resulting images can be used to study along with modern CCD-observations. Our data are available in archive Center in Sofia (Wide-Field Plate Database (WFPDB) [2]).

We presented a collection of photographic plates received according to official science INASAN Programs at the last Conference [3]. They include a monitoring of field stars, comets, asteroids, Mars and Pluto. However on the plates were got other objects, which are not the subject of the study. Here we are looking for new objects that were not in the purpose of the study, but got to the photographic plate. This allows us to set new tasks with using of scans archive. In the past years, there were considerable efforts at the observatory aimed to observe the sky field stars for compilation of photometric catalog FOKAT (sky area from -2° on +90°, 1980-92 years). Modern CCD-observations are concentrated mainly on the study of small bodies of the Solar system [4]. In this work we report about searching of open clusters on the photographic plates of the Carl Zeiss Astrograph.

In connection with the release of the full version of the global Milky Way Star Clusters catalogue (MWSC) we set the goal to investigate the cluster's structure and their stellar population, using our astronomical negatives. To this purpose, sky areas, overlapping by plates, are compared with the regions occupied by clusters. The catalogue of newly detected open cluster MWSC IV [5, 6] is used.

2 Astrograph Carl Zeiss Plate archive

3703 negatives were obtained and fixed in log since 1972 to 2005 with the Carl Zeiss Astrograph . Width of the plate field equals 8.5° x 8.5°, its size is 30 x 30 cm. The Table 1 shows first five records of the plate Catalog, from which the desired material is selected. The columns are index number, name of the object on the observation program, observer's name, time of exposure (min), mark multiplicity of the exposures on the same plate, UT exposure start time, observation date, equatorial coordinates RA, DEC (degree) of the optic plate center (J2000). About plate archive see [7].

Table1: Plate Catalogue of the Astrograph (first five records, full data - [2]).

№	Object name	Observer	Exp. Time	Multiple Exp	UT	Date	RA	DEC
0001	*asteroid 594*	Yurevich	5.0		18:16:00	1978-04-12	07 29 44	+09 28 48
0002	*asteroid 7*	Yurevich	5.0		18:57:18	1978-04-12	09 27 39	+07 38 58
0003	*asteroid 582*	Yurevich	15.0	3	19:16:25	1978-04-12	12 30 49	+25 58 25
0004	*asteroid 594*	Yurevich	5.0		19:32:00	1978-04-16	07 34 45	+10 29 28
0005	*asteroid 532*	Yurevich	5.0		19:54:00	1978-04-16	15 34 26	+07 04 57

The exposition equal to 2.0 minutes provides a magnitude depth in B = 11.0mag, 5.0 minutes – up to B=12magn, 15 minutes – 14.5 mag. Figure 1 shows a fragment of the photographic plate with the cluster stars, which allows to see the quality for individual stars of various brightness.

The project: "Electronic library service of the astronegatives produced on Zvenigorod Observatory" was included for Russian Virtual Observatory [8]. The scan's files are kept on DVD, SATA and USB disks. The plates catalogue was constructed in the WFPDB format (on a computer readable form, ASCII). Work scans of the plates are in the FITS format, with resolution 1600 dpi, 700 Mb each scan. Preview images for Internet in JPEG format, 300 dpi, 3 Mb and for press in TIFF, 1200 dpi, 600 Mb. The observational log page was scans too (JPEG, 300 dpi and TIFF, 600 dpi, color).

The online information about our work, science groups, tools, volumes and characteristic of the plate and film libraries is presented at: 1) on the INASAN site http://www.inasan.ru/rus/scan/ and 2) in Bulgaria [2]. Getting data about archive and each plate, viewing of the plate images, selection plates by the parameters. To search information use: IDobs – “ZVN”, IDins – “040” for Astrograph.

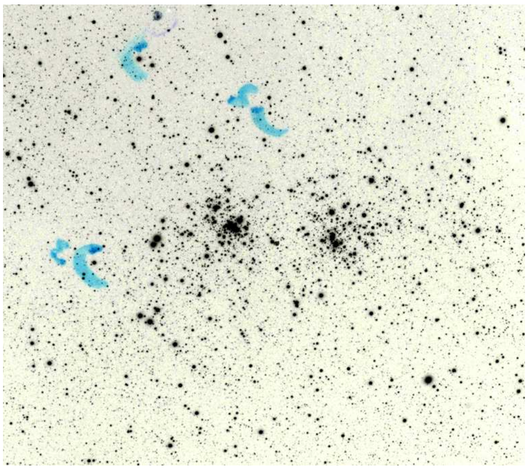

Figure 1: The fragment of plate number ZVN040_000983 scan with a star field and h and hi Persei open cluster near the center. The image quality is good for scans and modern tools of processing. By color paint marked the some stars needed for processing.

3 The Open clusters Data

The MWSC IV contains 63 new open clusters [6]. It is made as result of the search for unknown density maxima in kinematic space. It is based on PPMXL [9] and 2MASS [10].

Table 2: The list of MWSC IV OC data. First five records, full data in [6].

MWSC	RA	DE	r2	pmRA	pmDE	d	E(B-V)	logt
4005	002.865	-85.480	0.165	9.31	-1.47	1159	0.250	9.375
4114	091.965	-78.220	0.240	0.23	5.86	962	0.260	9.400
4116	094.800	-59.970	0.225	-0.92	8.55	1743	0.291	9.125
4119	106.515	-57.230	0.205	-2.80	9.81	2347	0.458	8.985
4131	124.822	+42.035	0.220	-1.05	-7.67	1058	0.083	9.400

The our list includes (Table 2) the cluster MWSC number, equatorial coordinates RA, DE (deg, J2000), the total apparent cluster radii r2 (deg) and the numbers n2 of highly probable cluster members within r2, the proper motion components pmRA and pmDE (mas/yr), color excess, distances from the Sund (pc), the cluster age (log yr).

4 Results and Conclusions

It is shown that archive which belongs to a small observatory has many applications due to not only official observation programs, but also to simultaneously obtained images of star clusters. In this research a newly discovered clusters images were found. They were identified kinematically and have not clearly highlighted the concentration of stars in the celestial sphere. For these reasons, these clusters were not of special observations and our findings have a scientific value.

The archive browsing has identified plates covering the clusters area, see Table 3. In the first and third columns of Table 3 is MWSC catalog [6] number, in the second and fourth is the number of plates, which are found for this cluster. The identification was carried out by equatorial coordinates. The plates got into that list, if its and cluster's fields are overlapped. Totally there were found plates for 18 clusters.

Table 3: Number of plates, covered MWSC IV clusters area

MWSC number	Number of plates	MWSC number	Number of plates
4131	6	4375	5
4194	3	4383	5
4288	12	4409	8
4290	1	4547	2
4301	7	4555	1
4312	1	4561	3
4316	6	4602	7
4317	2	4622	3
4330	1	4674	16

In Table 4, we presented data about the most interesting clusters for which the number of selected records turned over five. Table 4 provides the cluster MWSC number, equatorial coordinates on the J2000 epoch, galactic coordinates l and b, the total apparent cluster radii r2 and the numbers n2 highly probable cluster members within r2, the proper motion components pmRA and pmDE, the distances from the Sun d, and the ages log t(yr).

All clusters from Table 4 are newly detected, [5]. To MWSC data you can add cluster apex values, calculated with AD-method and parameters, defined on plates. In rectangular coordinates of stars can be used NND-method to search the space substructures inside the clusters.

Table 4: The main parameters of the clusters are presented for more than five plates

MWSC	RA	DE	l	b	r2	pmRA	pmDE	n2	logt
4131	124.822	+42.035	178.664	33.536	0.220	-1.05	-7.67	37	9.400
4288	251.047	-00.135	17.003	27.915	0.350	-0.10	-7.85	87	9.015
4316	257.617	+51.570	78.642	36.379	0.225	-4.74	1.56	35	9.230
4409	273.840	+31.725	58.789	21.009	0.220	0.29	-4.72	106	8.850
4602	315.690	+10.765	59.287	-22.880	0.230	3.11	-3.62	81	8.785
4674	350.535	+84.010	120.487	21.563	0.210	-2.25	0.10	63	9.550

Clusters located usually no more than three degrees from an optic center on plates , and it is suitable for different measurement positions and brightness of stars. The depth does not exceed the value of 15.3 mag. (with exposition time equal 20 min), which is much less than for 2MASS catalogue [10]. The observations were made in the interval 1978 - 1996 years.

This work is a search for open clusters in our archive of observational data. The above examples of scientific tasks allow positively assess the relevance of archives. Next stage is definition of stellar parameters on plates and calculation cluster parameters, analysis of this data, search for possible substructures in these clusters by applying our NND (near nighbourhood distance) and AD (apex diagrams) methods. Scans also can be used as an epoch in combination with others to determine the proper motions.

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