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THE WIDE-FIELD PLATE DATABASE: DEVELOPMENT AND ACCESS VIA INTERNET*

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Abstract. The motivations and results from the first 1.5-year period of the project "Wide-field Plate Database (WFPDB): Development and Access via Internet" (DO-02-273/18.12.2008), approved for funding through a competition held by the Bulgarian National Science Fund in the field of Promotion of Research in Priority Areas, are described. The main direction of the development of the project is digitization and preservation of, and web access to, the astronomical plate archives of the 2-m RCC and the 50/70 cm Schmidt telescopes of the Rozhen National Astronomical Observatory received in the period 1979–1998. The basis of the work is set out in Tsvetkov (2006) [1] and Tsvetkova & Tsvetkov (2006) [2], motivating the project over the past 10 years. The WFPDB (`www.wfpdb.org`) represents a unique virtual instrument in astronomical research, which allows obtaining information on existing astronomical observations of celestial objects over the past 130 years with the professional astronomical telescopes

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Key words: astronomical photographic plates, plate library, astroinformatics, large astronomical databases, image processing, data centres.

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at observatories around the world. Briefly, this is a unique virtual telescope working as a "Time Machine" for obtaining information on historical observations of minor planets, comets, stars and galaxies. The project also aims to continue and expand the successful work initiated during the past 15 years by extending the provision of technical work on the base, and improving and extending the internal LAN (`www.skyarchive.org`), which ensures rapid online access to data, based on international standards of the International Virtual Observatory Alliance (IVOA) and the European Virtual Observatory (EURO-VO). The main results of this paper are described in detail in the annual report project of July 15, 2010: `http://trillian.magrathea.bg:8181/DATABASE_FNI_273_2010July/`

1. Introduction. Astronomical plate digitization and web access to large amounts of digitized data sets have to conform to the standard relational database and to expand opportunities for search and retrieval of data (see `www.wfpdb.org/search`). It was also necessary to expand the volume of the database and to create new computer-readable versions of catalogues of photographic observations with their inclusion in the Wide-Field Plate Database (WFPDB). For this purpose it was necessary to improve and expand the program packages for data reduction of the original plate catalogues to the WFPDB by including data and images of the original catalogues and "previews" of the scanned photo-plates. The main directions of this project are: (1) to increase the WFPDB up to 600 000 plates ($\sim$25% completeness), (2) improving WFPDB in terms of opportunities for search and retrieval of data from the database—data for original catalogues and "previews"—digital images of archived photographic plates for rapid visualization of observations made on-line and photometric studies, (3) establishing a numerical procedure for photometric calibration of photographic surveys as a tool for efficient photometric studies, (4) making available the archive of photographic observations with the 2m RCC telescope of NAO Rozhen producing an inventory and including the plates of NAO Rozhen 50/70 cm Schmidt telescope with digitisation of selected samples, (5) studying the evolution of non-stationary stars by photometry of digitized photographic observations.

2. Technical support and internal local network development. In order to achieve the objectives of the project it was necessary to improve the local computer network service of the WFPDB. This is related to one

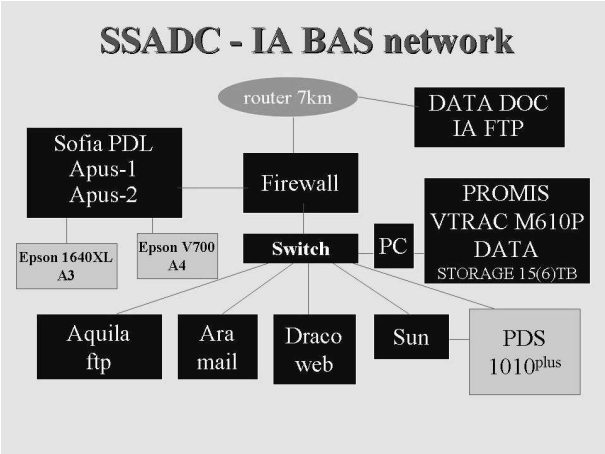

Fig. 1. Block diagram of the network of the Sofia Plate Digitization Laboratory (SPDL) of the Sofia Sky Archive Data Centre with the main servers, Perkin-Elmer micro-densitometer PDS 1010^{Plus} and flatbed scanners EPSON 1640 XL and EPSON V700

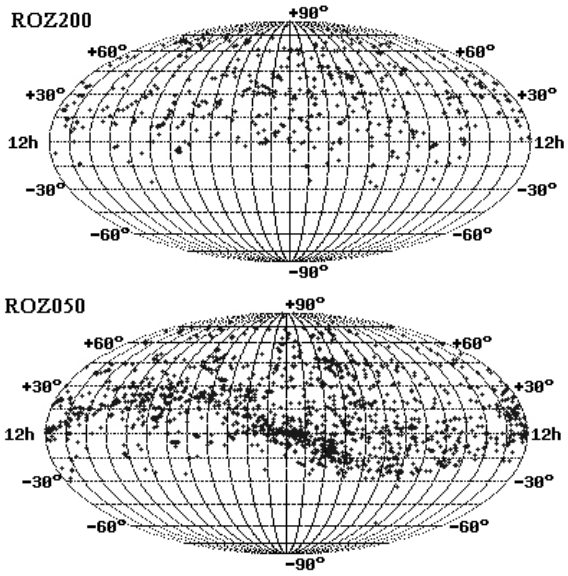

Fig. 2. All-sky distribution of the plate centres for the listed in the WFPDB plate collection of the Rozhen wide-field telescopes: the 2 m RCC (ROZ200 with 1984 plates and 50/70/172 cm Schmidt (ROZ050 with 7359 plates)

of the most important tasks of the project—digitization of photographic plates. It is connected with the need for very large capacity for storage of the digitized plate images. It is known that the volume of a separate digitized plate is from several hundred MB to 1 GB depending on the size of the plate and the selected resolution of the scanning. For this purpose the LAN is equipped with a storage platform of data storage with high capacity up to 10–15 TB. At the Sofia Sky Archive Data Centre (SSADC) the device PROMIS VTRAC M610p with capacity of 6 TB at present was purchased and installed. It is expected that it will be expanded to 15 TB in the next contract period. Furthermore, the project's computer system used for image digitization and processing with specialized software packages was renovated. The LAN has been expanded with three new computers to scan the plates in Sofia and NAO Rozhen. For this purpose the SSADC network was improved and renovated with the necessary routers, collectors and devices to stabilize the voltage—UPSs. Fig. 1 shows the block diagram of the SSADC and the laboratory of astro-plate digitization, the network with the main servers, the Perkin-Elmer microdensitometer PDS1010$^{\mathrm{Plus}}$, and the integrated data storage system Promis-VTRAC M610p.

3. Maintenance of standard relational database with advanced search and data retrieval—organizing databases of images. The WFPDB database management system is based on the Firebird SQL Server platform for Linux (`http://draco.wfpdb.org/search/`) developed in an earlier period. Now a new enhanced search page is introduced. New choices in WFPDB are extended with parameters of observations—the original logbooks and "previews"—compressed images of the original plates. Figs. 2–4 show samples of search in the WFPDB with a copy of the original logbook of observations and an example of plate "preview"—the all-sky plate distribution in this case is for the updated catalog ROZ200 of the 2m RCC telescope of the NAO Rozhen.

Under construction is a website home page of the WFPDB in the form of a Wiki platform. A prototype of the page can be seen at:

`http://trillian.magrathea.bg:2500/home/published/`.

A new WFPDB mirror was established and maintained at the Institute of Mathematics and Informatics, Bulgarian Academy of Sciences. An important part of the WFPDB is the StarGazer version 3.0, which can display and link existing catalogues with the region of observation obtained by the plate search in the database at: `http://trillian.magrathea.bg:8080/stargazer/`.

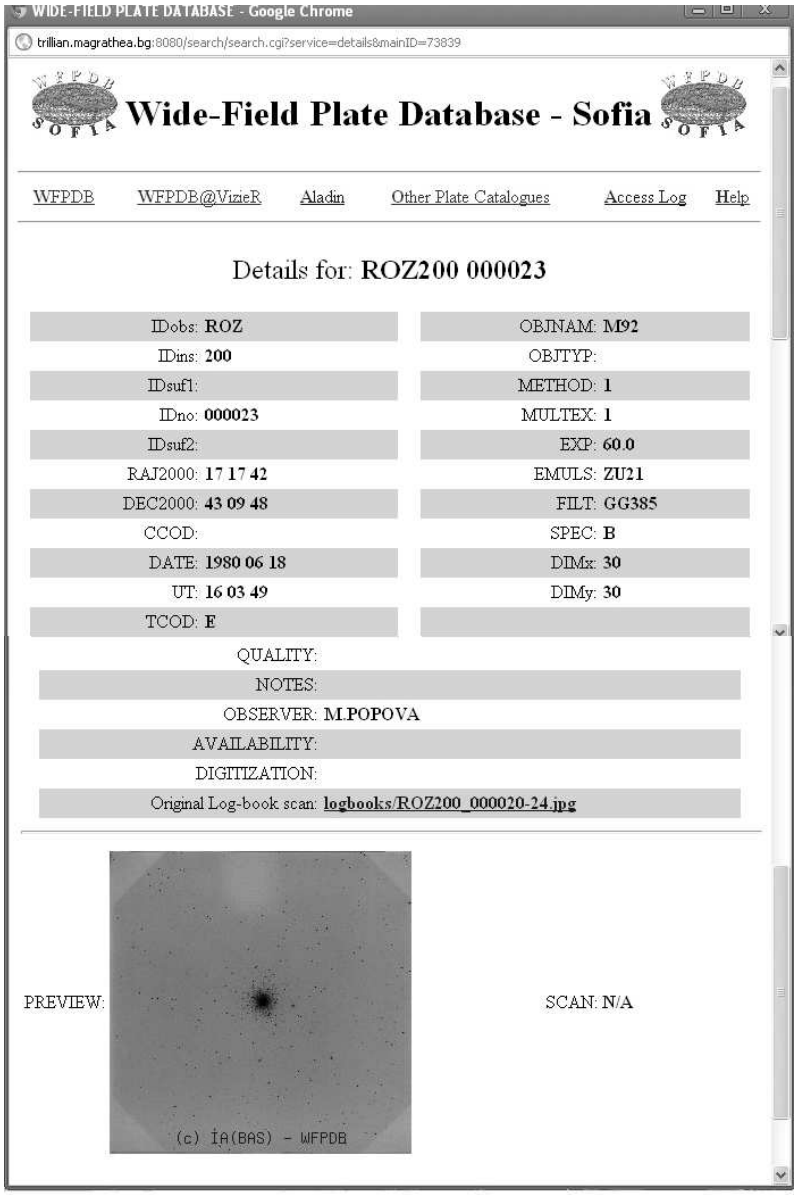

Fig. 3. An example of plate search in the WFPDB giving a plate preview

4. Expanding the program package for data reduction of the original plate catalogues.

- New advanced packages were developed for:
- Data reduction from the original plate catalogues to the accepted WFPDB standards;
- An Optical Character Recognition (OCR) tool for converting the typed original plate catalogues in table form to electronic form applied to the plate catalogue of the Brashear astrograph of the Tokyo Astronomical Observatory (see Kirov, Tsvetkov, Tsvetkova and Kalagrarskiy, at: `http://aquila.skyarchive.org/DATABASE_NFNI273/publications/Chepelare_Kirov_KTS_DKG.pdf`);
- Inclusion of images from original catalogues and "previews". (See Kirov and Tsvetkov, `http://aquila.skyarchive.org/DATABASE_NFNI273/publications/Ohrid_mil_nik_slides.pdf`);
- Reading FITS and row TIF files and converting row TIF → FITS using standard packages, as well as our own software packages;
- Data conversion and creation of tables in WFPDB format (Package CuneiForm);
- Connection of scanned images of astronomical photographic plates from the WFPDB and the page images from the original astronomical journals;
- Segmentation of images from logbooks (experimental version of the software);
- Linking records of astronomical photographic plates from WFPDB and images of original pages of astronomical journals.

From the given access to the plate logbooks from the site of the Harvard Observatory (`http://hea-www.harvard.edu/DASCH/ExposureData/LogJpeg/`) a mirror was made to all astronomical logbooks of the Harvard Observatory (the whole amount of data is 47GB, see: `http://aquila.skyarchive.org/Astroinformatics/2_IA/1_IMI/Ohrid_mil_nik_slides.pdf`).

4.1. Creating computer-readable versions of the wide-field plate catalogues and their inclusion into WFPDB. WFPDB currently provides information on 563 612 plates from 133 photographic archives (`http://www.skyarchive.org/images/wfpdb_new.png`) with different observing instruments. It represents about a quarter of the total number of photographic plates in the world.

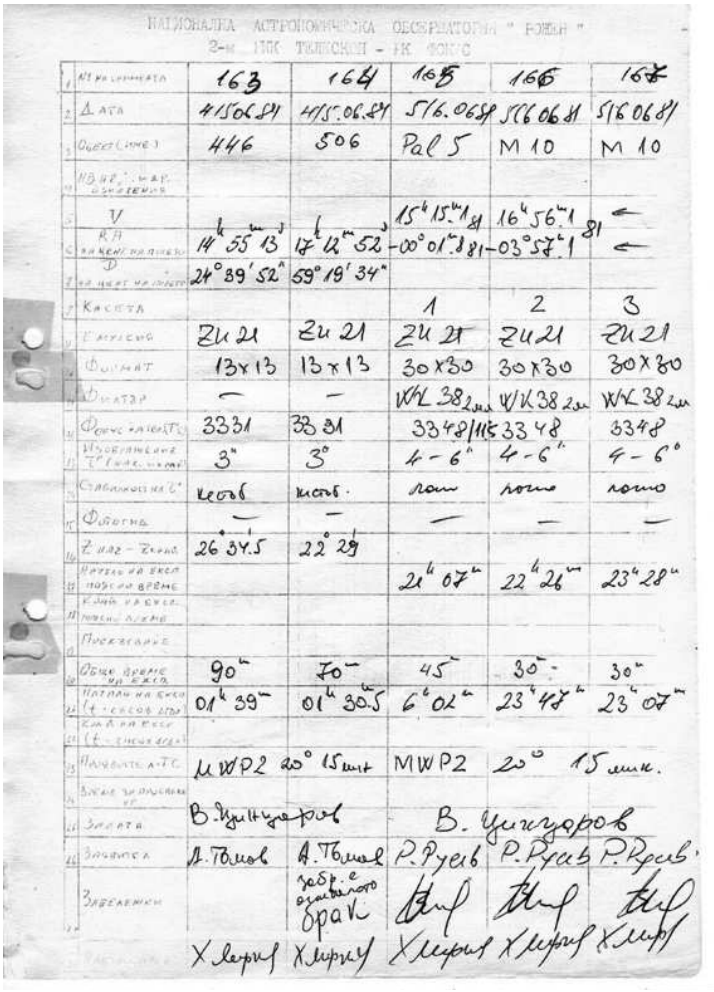

Fig. 4. A sample of the original plate logbook (plates ROZ200_000163-167) included in the WFPDB as a new opportunity of the extended search

We plan to include about 50 000 plates into the WFPDB within the 3-year period of the project, with the database reaching 600 000 complete observations. It has to be reported, however, that the most important activity in the expansion of WFPDB is particularly labour-intensive and involves several difficulties. A significant part of the catalogues still has no computer-readable versions and in these cases the team that supports WFPDB has to produce similar versions. In some cases, there are even no diaries of observations and the only option is taking

the information directly from the photographic plates or envelopes in which they are stored.

Table 1. New WFPDB catalogues with a total of 23 358 new plates

WFPDB Catalogue Identifier	Plate Number
MYK012	7438
TOK016	868
TOK020	1577
GUA040A	8486
GUA040B	649
GUA040E	3656
GUA070A	570
QUI021A	66
QUI021B	48
Total number	23358

Data for added new catalogues during the first phase of the contract (exactly 23 358 new plates) is given in Table 1. These catalogues are available via Internet.

A new updated version of the Catalogue of Wide-Field Plate Archives (CWFPAs), version June 2010 with a total of 473 archives, was prepared. In the contract period the number of records has increased from 440 to 473, or 33 new archives were added. The increase of the number of direct plates in the catalogues during the contract period is about 221 000.

5. Digitization of the photographic plates—preparation of digital images with low and high resolution according to the WFPDB requirements. About 3000 plate scans (preview images) of the Belgrade Astronomical Observatory and 1000 scans from Bucharest have been delivered to the WFPDB in order to be included into the database.

Substantial development work on creating specialized digital archives of plates within eScience and electronic connection between IBVS and WFPDB (Interlinking IBVS with WFPDB) was done with the new flatbed scanner of Konkoly observatory;

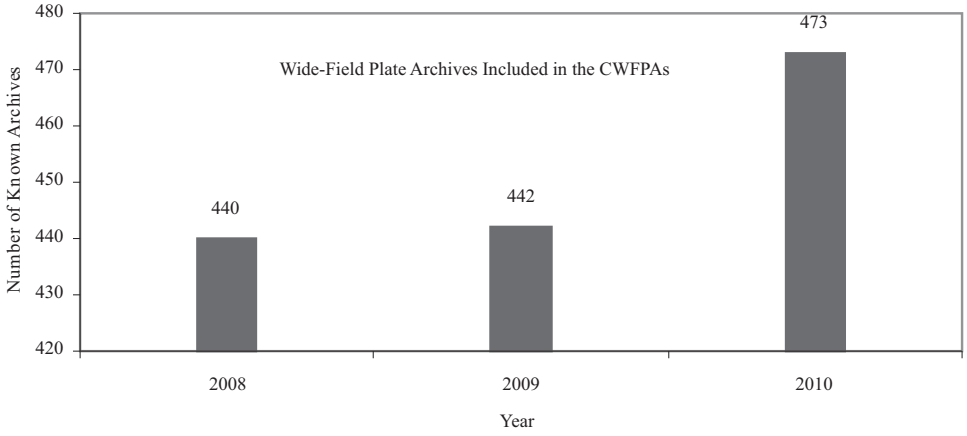

Fig. 5. Status of the CWFPA version June 2010

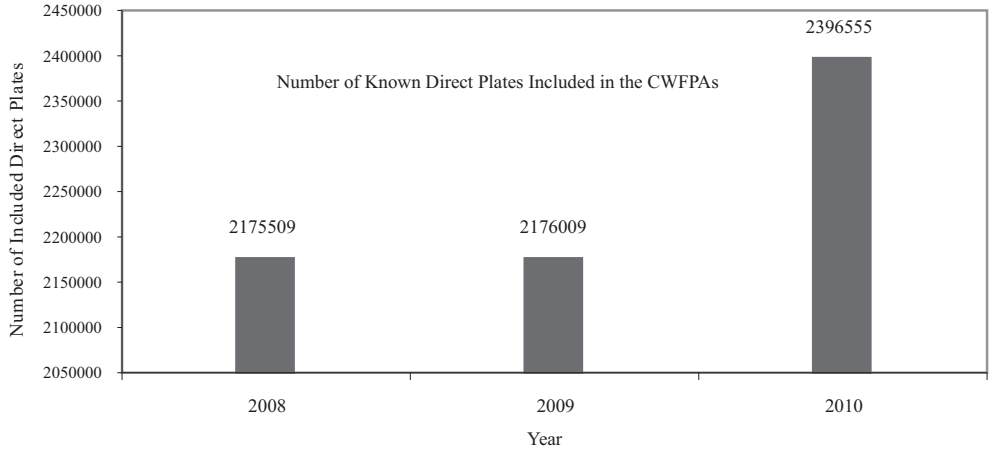

Fig. 6. Increase of the number of direct plates in the CWFPA version June 2010

• 31 plates in Orion (with a total volume of data about 14.1 GB) with an EPSON PERFECTION V750 PHOTO were scanned; high resolution scans—2400 dpi, previews—1200 dpi; the sizes of the output files are: in JPG format $\sim$ 1.5 MB, TIFF $\sim$ 52 MB, FITS $\sim$ 419 MB;

• 22 plates in the Pleiades (total volume of data about 10.3 GB) and 64 plates in the regions of stellar clusters and associations (total volume of data about 26.2 GB).

Plate scanning laboratories were established with standard methods of

scanning at astronomical institutes in Germany (Potsdam, Bamberg, Jena), Hungary (Konkoly), Romania (Bucharest), Belgrade, Ukraine (Kiev—Main Astronomical Observatory), Russia (Moscow—INASAN Zvenigorod) and others. The methodology (know-how) for plate digitization with EPSON flatbed scanners was spread also in the astronomical institutes in Prague, Tatranska Lomnica, Cluj, Zvenigorod, etc.

A new version of WFPDB, including new archives and catalogues, is about to be published at the Astronomical Data Centre in Strasbourg. Within this task WFPDB was extended with digital images on photographic plates. The plates were scanned twice with precise commercial scanners (flatbed) of type EPSON 10000XL, 1640XL and V700—once at low-resolution colour and 8 bit, and again with high-resolution 16 bit gray—FITS format. The purpose of scanning with low resolution, which is within 600–1200 dpi ($>\sim$ 40−20 μm), is to prepare digital images for rapid visualization of observations included in WFPDB. This provides an opportunity for preliminary examination (preview) of the selected sky region (plate) and its evaluation in terms of area covered by the celestial sphere, the visibility of certain objects, the limit magnitude (related to duration of exposure), image quality and others. The developed technology for plate scanning is accepted in observatories in Europe as a standard. Images of plates with high resolution, typically 1200–2400 dpi ($<\sim$ 20−10 μm), are designed for photometry. These images are in grayscale. The preview image is taken in colour, aiming for recording the original marks on the plate glass made by the astronomer during the visual inspection of the plate. Fig. 6 shows the Rozhen digital plate laboratory equipped with a flatbed scanner EPSON 10000XL.

The typical duration of a scan for one 30×30 cm plate with the cleaning, fitting on the scanner, setting scanning parameters, filling in the header file with the information and visual inspection of the resulting scan is about 30–40 minutes. The memory needed is about 0.7 GB. Only the scanning time of a plate with dimensions 30×30 cm (cleaned before scanning) with the EPSON 10000XL with 2400 dpi resolution is about 18 minutes. In some cases, when very high resolution (of a few μm) was needed, or for test and calibration measurements (densities to 5.0 D), the photographic plates were digitised by the high-precision microdensitometer PDS1010$^{\rm Plus}$ in SSADC (see `http://aquila.skyarchive.org/DATABASE_NFNI273/publications/reports/Nicola_Petrov_CHEPELARE.pdf`).

The technology of scanning plates with the same type of scanner is described in detail in the report of L. Schmadel from the Heidelberg Astronomical Rechen-Institute for accurate astronomical measurements using the same scanner. In this project the digitization of a great amount of plates like Palomar sky sur-

Fig. 7. Laboratory for scanning plates in NAO Rozhen, equipped with a scanner EPSON 10000XL (A3) and computer system-APUS-3

veys plates (POSS) of size 36×36 cm is described. `http://aquila.skyarchive.org/DE_plate%20archives_pub/Heidelberg/Digitization_Stoss.ppt`

5.1. Digitization of the plate archive of the 2m RCC telescope of NAO Rozhen (ROZ200). The digitisation of the plates obtained in the RC focus of the 2m telescope of NAO Rozhen is one of the most important tasks in this contract. This is why a special inventory and search for the plates, which were stored by the individual observers, were made.

According to the information existing in the WFPDB, the ROZ200 catalogue contains information about 1984 plates obtained in the period 1979–1993; afterwards the photographic observations were *de facto* suspended by the CCD cameras. With additional plates obtained by this telescope, especially with short exposures, which were not included in WFPDB, the number of the plates reached 2115. The number of the available plates in Rozhen and Sofia is about 880. The rest of the plates are still kept by individual observers or astronomers at home or abroad. A request for their return and for centralized storage in NAO Rozhen was made. The plates obtained in the RC focus of the 2m telescope are of scale $12.89''/$ mm, mostly of size 30×30 cm or 16×16 cm, and they cover a sky region of one square degree.

The photographic plates of the 2m telescope were scanned at low resolution (600 dpi) for previews and at high resolution (1600 dpi) for FITS scans. A

resolution of 1600 dpi corresponds to 15.9 μm/pixel and to the amount of 0.20" per pixel. This value is comparable to the resolution of the CCD camera VersArray/1300B, which is currently used for observations with the 2m telescope of NAO Rozhen with pixel size of $0.26''$. Therefore it is suitable for efficient photometric image processing. With this resolution the volume of the scan of one plate is about 700 MB. Up to now, in accordance with the project programme for 2010, 496 plates from the plate library of the Institute of Astronomy have been scanned: 424 plates in Rozhen and 72 in Sofia with a size of 30×30 cm. To date (July 2010) of the catalogued 2115 plates from different observers 1100 plates were collected (1015 plates, which constitute about 50%, are unavailable). The data from the scanned plates is available on the servers of the IA SSADC and NAO and a digital archive of photographic observations of the 2 m RCC telescope will be organized.

5.2. Digitization of selected photographic plates from the archives of the 50/70-sm Schmidt telescope of NAO Rozhen (ROZ050). The first step is the inventory of the available plates of this telescope. From those presented in the catalogue of the WFPDB for this telescope (ROZ050) over a period of about 20 years 7348 wide-field photographic plates mainly of small bodies of the Solar system, variable stars, star clusters and galaxies have been catalogued. The field of the telescope is $4.5^\circ \times 4.5^\circ$ at a scale of image $120''$/mm and the dimensions of the plates are square 16×16 cm^2 and 13×13 cm^2. Available in the plate library of IA with NAO are 1331 plates. The digitization of these photographic plates is also done in two steps—"previews" at 1200 dpi (20 mic/mm) in TIF and JPG format and detailed scans in FITS format at 2400 dpi (10 mic/mm ($1.2''$/pixel). So far with the methods used 49 plates were preliminarily digitized with the new EPSON Perfection V700 scanner in Sofia. Along with this goes digitization of selected samples for studying different types of stellar objects: (a) eruptive stars; (b) minor planets; (c) nonstable stars not having reached the main sequence yet; and others. 200 more Schmidt plates are digitized and are available on the servers of NAO Rozhen and Sofia.

6. Study of the accuracy of the restoration and development of numerical procedures for photometric calibration. The important task was testing the accuracy of the methods used especially with the available (commercial) flatbed EPSON scanners and with the high accuracy microdensitometer PDS 1010 Plus. The task was divided into two stages: Investigation of the accuracy of digitization using the standard "driver" of the

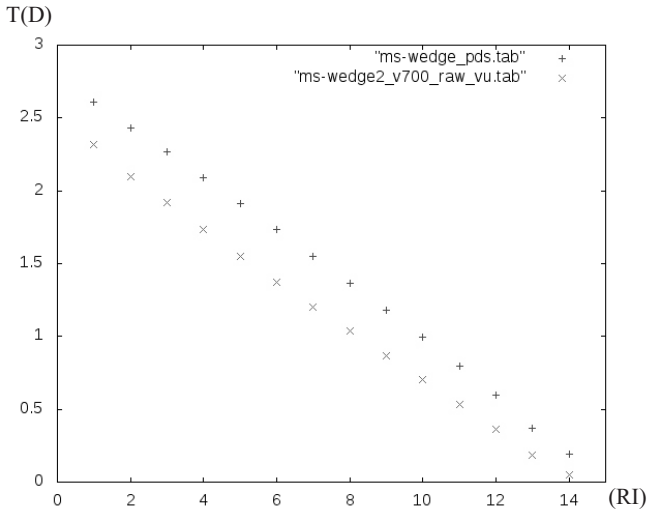

Fig. 8. Comparative chart for photometric scan of EPSON V700 and PDS1010 Plus

EPSON scanner (TWAIN-driver) and a new one of the commercial VueScan (`http://www.hamrick.com`) and using the standard calibration procedure of de Vaucouleurs (1984) [3]. It was shown that the VueScan driver (professional version) gives better scanning results compared with the standard TWAIN EPSON driver and it is comparable with those obtained with microdensitometer PDS1010$^{\mathrm{Plus}}$ (see Figure 8 from `http://aquila.skyarchive.org/DATABASE_NFNI273/publications/ reports/budell-2010.pdf`). In this connection we plan to prepare a special software package and to replace the currently used "FitsScan" driver of S. Motola (Barbieri et al. [3]) based on the EPSON TWAIN driver, which allows receiving data directly form the VueScan row-tiff format to a standard FITS format applied to astronomical images.

In case of absence of internal calibration (e.g., photometric wedges), which is often the case in photographic wide-field observations, there was proposed and tested a method of passing in the relative intensities, using profiles of star images. Restoration of the characteristic curve by this method was first proposed by de Vaucouleures (1984) [4]. In this case it is obtained that the method of stellar profiles allows constructing the characteristic curves of astronomical emulsion, which by its nature is comparable to that obtained from the photometric wedge. This method allows obtaining an internally consistent set of stellar magnitudes with optimum accuracy. See: `http://aquila.skyarchive.org/DATABASE_NFNI273/publications/reports/Mapkov-atall-CHEP_2010%20.pdf` (see Fig. 9).

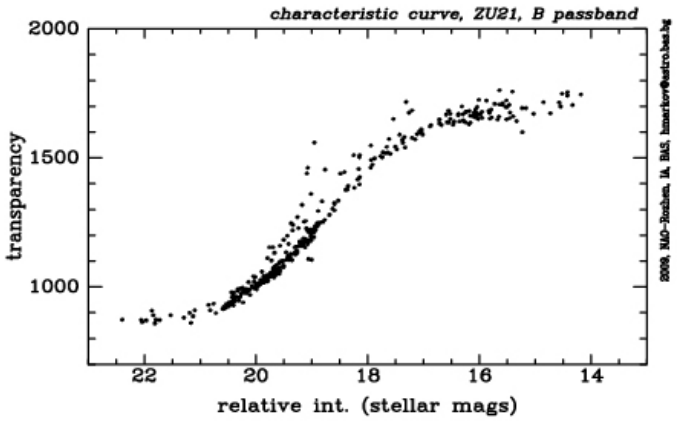

Fig. 9. Chart of the photometric scan of a 30×30 cm^2 plate of the 2m RCC telescope, emulsion ZU21 (B) in the EPSON 10000XL star cluster M13 obtained in the calibration procedure applied to photometric plate processing

In this direction research and development of technology and software for reading FITS and ROW TIF files and converting them from ROW-TIF (product of the new program VueScan) in FITS were carried out.

A test for digital aperture photometry of saturated star images was also performed (Innis et al. [5]).

7. Research and results from the use of astronomical photographic plates in the WFPDB.

Within the framework of research and application of WFPDB is the photometric study of long-term behaviour of different types of variable stars presented as a dissertation: `http://aquila.skyarchive.org/Astroinformatics/DISERTATIONS_PhD_275/Ana_Borisova_PhDthesis/`

The main results of this work can be summarized as follows:

– Creating a database of wide-angle photographic astronomical observations in the Pleiades as an annex and extension of WFPDB;

– Combining data observations in a period of 115 years, the photographic observations (about 4000 plates);

– Hosting web-access data available through the interface of the WFPDB;

– Performing photometric studies of selected southern active variable stars using the digitized Bamberg Southern Sky Survey plates. The analysis of the long-period variability of CF Oct and YY Men confirms the observed rotation

periods and indicates the presence of long-term changes in the brightness as well as in BBW 76 and YZMen. In the frame of this work the rotation cycles of long-term activity of the star CF Oct were examined: the cyclic activity was proved using the method of Bayesian statistics. The conclusions are in agreement with the hypothesis of differential rotation of the star's photosphere. The existence of two cycles of approximately 7.13 and 9.81 years was demonstrated with a high probability, and indications for the registration of three harmonics cycles with period 9.81 years, 6.66 years and 3.3 years were obtained.

The FU Orionis (FUors) bursts of two stars in a phase before reaching the main sequence were studied. The physical causes are attributed to thermal changes of the nearby stellar disk. In the case of V1735 Cyg the star is located in the nebula IC 5146—a complex of active star formation. Based on the observed outburst and spectral properties, V 1735 Cyg is classified as an object FUOrioni and we are trying to build historically the light curve of V1735 Cyg. 82 plates from the 50/70-cm Schmidt telescope Rozhen collection taken in the region of IC 5146 were inspected. They were scanned with the Epson 1640XL scanner with 1600 DPI resolution, which corresponds to 16 μm/pixel. Aperture photometry was applied using the package DAOPHOT. Analysis of existing photometric data shows a slow decline in star brightness—1.8 mag (R) for 44 years, which is typical for FU Ori type stars. The data from the search shows that V 1735 Cyg should be added to the group of FU Orionis type and that the time scale of the FUOR phenomenon.

It is necessary to continue the research done on the basis of other existing historical photographic observations of V 1735 Cyg made by: the 67/92-cm and 40/50-cm Schmidt telescope at Asiago (Italy), 105/150-cm Schmidt telescope at Kiso Observatory (Japan), the 60/90-cm Schmidt telescope at Rome Observatory at Campo Imperatore (Italy), 134/200-cm Schmidt telescope in Tautenburg (Germany) and 40 cm telescope of Sonneberg Observatory (Germany). (`http://aquila.skyarchive.org/DATABASE_NFNI273/publications/T_Peneva_A&SS-2009.pdf`)

Another similar star of FU Orionis candidate that was investigated is V733 Cep, situated in the constellation Cepheus, discovered by Persson in 2004[6]. The star is located in the L1216 dark cloud near OB3 association Cepheus. On the bases of the WFPDB search 192 photographic plates obtained in the field of V733 Cep in different observatories were found and digitized. The results of our photometric study form the digitized plates confirmed the affiliation of V733 Cep to the particular group of objects FU Orionis [6, 7]. It is shown for the first time that in the optical band the star increases its brightness in the period 1971–

1993. During the period 1993–2004 V733 Cep reaches its maximum brightness and the observed outburst amplitude exceeds 4.5 (R) magnitudes. In the BVRI photometric system the data show that from February 2007 to October 2009, the brightness of V733 Cep decreases slowly. The development of the observed color index also suggests that currently V733 Cep is comparatively faint. The long-term light curve of V733 is very similar to the usual light curves of another objects of type FU Orionis variable stars (Peneva et al. [7, 8]).

8. Conclusions. The important results from the work programme under contract DO-02-273 in the first period of the grant can be summarized as:

1. The SSADC local computer network was improved and equipped with a new data storage capacity (PROMIS VTRAC V610p) of 15 TB (at present only 6TB are ordered). Steps been taken to integrate the network of the Sky Archive Data Center to the network of the Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences.

2. "Mirrors" of the database exist—WFPDB at the Institute of Mathematics and Informatics, BAS, and at the Institute of astronomy and National Astronomical observatory:
`http://trillian.magrathea.bg:8080/`, (`www.wfpdb.org`)
`http://trillian.magrathea.bg:8080/search/`,
`http://trillian.magrathea.bg:8080/stargazer/`,
`http://trillian.magrathea.bg:8080/hyperleda/`,
`http://docs.astro.bas.bg/~pi/Data/www/picindex.html`,
`http://www.wfpdb.org/7_BSAC/`

3. The Catalogue of the Wide-Field Plate Archives (CWFPA) was updated to a new version (5.5), which includes information about new American observatories possessing such observations. So during the first stage of the project the number of records increased by 33 new archives containing 221046 plates—the total number of records reached number 473, the database (WFPDB) grew by 23 358 plates.

4. 15 publications have appeared on the topic of the project, 4 of them in journals with high impact factors. More than 20 reports were presented at international conferences, six of them as invited talks.

5. An international conference on Astroinformatics with more than 65 participants, 50% of them from abroad `http://aquila.skyarchive.org/7_BSAC/`, was organized. An international Workshop in Potsdam, Germany, was also organized to discuss a project on digitization of European cultural heritage (historical

astronomical plates) in the frame of the 7th Framework Programme (`http://www.aip.de./groups/plate_archive/meetings.html`).

6. The project research team have provided and continue to provide expert assistance to astronomical institutes and observatories in Europe (Bamberg, Potsdam, Bucharest, Budapest, Moscow, Belgrade etc.) for the organization, digitization and use of their photographic archives.

7. A doctoral thesis was defended connected with the topic of the project. "WFPDB (Database of Wide-Field Photographic astronomical observations): Application for long-photometric study of different types of variable stars" [9].

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