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UKRVO JOINT DIGITIZED ARCHIVE AND SCIENTIFIC PROSPECTS

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Abstract. The UkrVO (Ukrainian Virtual Observatory) database consists of about 200 000 astronomical photographic plates and 500 000 CCD frames containing unique astronomical information for formulating important scientific tasks. This database is compiled from observations conducted in 1898–2011 at the observing sites of 8 Ukrainian observatories, with about 60 instruments. This paper deals with some principal scientific projects where the UkrVO databases are used, namely, the creation of the Joint Digitized Archive (JDA); compilation of new stellar catalogues; search for optical counterparts of gamma-ray bursts; spectroscopic study of solar flares and solar active formations; development of software for searches for new small bodies of the solar system.

Key words: virtual technologies, virtual observatory, astronomical databases

1. THE UKRVO JOINT DIGITIZED ARCHIVE (JDA)

1.1. Brief description of the JDA

Development of the Joint Digitized Archive (JDA) of observational data is one of priority scientific projects of the UkrVO (www.ukr-vo.org). The UkrVO database consists of about 200 000 astronomical plates and 500 000 CCD frames which result from observations of celestial objects performed in 1898–2011 at observing sites of 8 Ukrainian astronomical observatories, with about 60 instruments. These data archives are the following: (a) photographic observations of 1898–1990; (b) CCD observations since 1990; (c) spectroscopic observations in the optical, UV, radio (from millimeters to decameters) and gamma ranges since 1940 (see Vavilova et al. 2010, 2012). Being in operation as the *Local Data Archives* (LDAs) of the observatories (owners of archives), they have an essential heterogeneity.

The aim of the JDA project is to join local digitized archives, preliminary formatted in accordance with the common input IVOA data standards. The necessity

of introducing such standards is obvious: LDAs have different level of readiness and systematization for including them into the JDA. Integration of new LDAs at the UkrVO site in the form of search interfaces provides access to distributed servers of the observatories, first, where the LDAs are physically located. In particular, the joint data archives of the Main Astronomical Observatory, National Academy of Sciences of Ukraine (MAO NASU), and of the Mykolaiv observatory are available through search site pages of both observatories. We consider it as a test prototype of the JDA control mechanism.

The JDA informatics system is intended to include tools for UkrVO registry; joint interconnected databases control and administration; user-oriented search interfaces; online services for data analysis and processing; software teaching application of VO tools in scientific research; deployment of pan-Ukrainian infrastructure of observational data placed in the Internet; and development means for the JDA proper (Vavilova et al. 2011).

Information on the current JDA status is available through the UkrVO web site. Table 1 presents the data about some largest UkrVO digitized archives, which are used in our current scientific projects and will be mentioned in this paper: digitizer type ((1) Epson Expression 10000XL; (2) Microtek ScanMaker 9800XL; (3) EpsonPerfection 3200 Photo; (4) Epson Perfection V200 Photo; (5) Automated Microphotometer ADMF-XY); observational instruments and programs; digitized image resolution; quantitative data about the archives (total number of plates, number of scanned plates, number of calibrated images); positional and photometric image uncertainties. For example, such archives as GUA040A, GUA040C, GUA040D, and GUASOL include the data obtained at the MAO NASU; among them, GUA040C and GUA040D are in frame of the Northern Sky Survey observational program in 1980–1998 (FON). The MYK012 and LAO010 digitized archives are developed respectively at the Mykolaiv and L'viv observatories. The CRI017A/B and CRI040A/B/C digitized archives are based on observations conducted at the Crimean Astrophysical Observatory in the frame of projects like the "G. A. Shajn Plan Patrol Observations Sky Survey" (SPPOSS) and "Small Body Patrol Observations Sky Survey" (SBPOSS).

1.2. JDA image calibration, management and VO tools

1.2.1. Calibration of digitized images in MIDAS/ROMAFOT

The MIDAS/ROMAFOT software package is applied for preliminary processing of UkrVO digitized images. It allows us to obtain astrometric and photometric characteristics of stellar objects without application of any additional calibration accessories. Initially, ROMAFOT was designed for processing CCD frames; because of this, the formats of data exchange and registration were changed as well as frames of large size ($13\,000 \times 13\,000$ pixels) were automatically cut into overlapping strips along the X axis and processed separately at the final step. After this, the following steps of image calibration are realized in the MIDAS environment:

- Search and markup of overexposed images; analysis of overexposed double images; restoration of all overexposed images (photometric restoration of the missing top part of the Gaussian curve);
- Determination of a flat field frame in order to eliminate photometric field errors. It is estimated individually for each scan, after removal of registered objects, by iterative method, with simultaneous isolation of the spatial envelope curve

Table 1. UkrVO largest digitized archives.

Archive index	LAO010.	GUA040A	MYK012	GUA040C GUA040D	CRI017A/B CRI040A/B/C	GUASOL
Digitizer	2	1, 2	3, 4	1, 2	2	5, 6
Obs. instruments	50/10 cm Zeiss	Double Long Focus Astrograph $F/D =$ 5500/400	Zeiss Zona Astrograph $F/D =$ 2040/160	Double Wide Angle Astrograph $F/D =$ 2000/400	Astrographs with 17 and 40 cm aperture	Solar telescopes ATsU-5 , ATsU-26
Obs. programs	Var.stars Small bodies	Var.stars Galaxies Fund. stars Small bodies	Small bodies	Photogr. survey of Northern sky (FON)	SPPOSS SBPOSS	Spectral Solar flares & active regions
Digitized image resol., dpi	1200, 1600	1200	1200	1200, 300–900	240, 300, 1800	Spatial resolution 3 arcsec
Dynamical range, bits	8, 16	8	8	8, 16	16	
Total number of plates	8500	8486	8209	6131	10620	1440
Number of scanned plates	2000	189	4000	2400	1099	200
Number of calibrated images	–	–	–	1000	–	100
Positional uncertainty	–	30–60 mas	84 mas	110–160 mas	–	4.17 μm
Photometric uncertainty	–	0.15 mag	0.2–0.5 mag	0.2 mag	–	0.01–0.03

of the photometric field inherent to the plate (plate background) (Andruk et al. 2005);

• Search and selection of objects (stars, galaxies, etc.) above the previously estimated noise level. With this aim, photometric section is performed above a specified level (as a rule, this level is determined by the sum of calculated averages of the flat field and three its dispersions), and pixels exceeding this level are marked (they form the object diaphragms in the projection of the section). Thus, the final image is a modified frame with non-distorted objects, where the space between object images is filled with the average flat-field value (Andruk & Pakuliak 2007);

• Processing of the modified frame in ROMAFOT software for astrometric and photometric calibration and estimation of detected objects' characteristics in the full range of star magnitudes in package mode.

1.2.2. JDA management and VO tools

The Database of Golosiiv Plate Archive (DBGPA), being considered a prototype of the JDA of photographic observations from all Ukrainian plate archives, includes about 26 000 plates of the Golosiiv collection. Currently, the DBGPA embraces also data for more than 10 000 plates from collections of Mykolaiv, L'viv and Kyiv astronomical observatories. The DBGPA primary goal was to create

suitable tools for remote operations with digitized photographic archives. The lately started process of LDA digitization has explosively enlarged data volumes, and it has become necessary to develop tools for data administration search. At transition from an online archive to a VO resource and owing to specifics of problems to be solved, we developed our own tools for data manipulation, which are necessary for archive filling and its structure upgrade as well as for its intended aggregation with other LDAs of the same type.

The DBGPA is built in the MySQL environment. DBGPA V2.0 consists of three functional interfaces targeted at different user groups. The editor interface, with authorized access to different sets of privileges, is aimed at new instrumental archive creation, data correction and verification, arrangement of digitization in a user-friendly way, its control, etc. The administrative interface is developed for database integrity support, monitoring of errors and correction logs, current database backup, user access control, etc. Structurally, it is a component of the editor interface with the highest privileges. The user interface provides open access to the data search engine and includes tools for visualization of search results, such as a star map from star catalogue data in the area of the photographic plate; overlapped scheme for selected plates; graphic presentation of archive statistic data as bar charts; distribution of plate centers on the celestial sphere, etc. The functionality of the software package has been recently enhanced with additional modules on the Java and Flash ActionScript platforms that permit to immediately place digitized images into the storage space, create preview images, record them in the common database and make them available online for a remote user, giving him flexible instruments for browsing image details with zooming. In the editor interface, additional functionality is provided, such as "on-fly" transformation into a different graphic format, cutting out image fragments, etc.

Further development of software tools on the basis of the DBGPA includes:

- Upgrade of user interface with services that can allow to transform the search page of the database into an instrument providing access to the data and to image-processing tools, including those developed by the IVOA;
- Development of the editor interface by including modules providing a possibility of operative aggregation of different-type archives (CCD, spectral, etc.) to the combined database together with tools of their shared administration;
- Development of means for presentation of any astronomical information (catalogues, tables, presentations, etc.), published on the UkrVO and DBGPA pages, in formats recommended by the IVOA for data restoration, storage and transition.

Currently, a comprehensive software package is in project, being intended to make the digitized photographic archives actually virtual (www.mao.kiev.ua/ardb/erratum.php).

The Observational Database of the Mykolaiv Observatory was created as a data retrieval system for all accumulated observations. Its search engine is based on scripts written in the PHP language and MySQL database management system. The database includes text data and images obtained during the whole history of the observatory, it contains information about 8 400 photographic plates and more than 30 000 CCD frames. Access to the database is available at the observatory site (www.mao.nikolaev.ua) as well as at the UkrVO website (www.ukr-vo.org). The web interface allows a database user to set the frame center and radius, time of observation, type of image detector, as well as to select any combination of objects, parameters of plates and CCD frames, observational instruments. Search

results contain a table of photographic plates and/or a table of CCD frames, which meet all specified search criteria. Preview images were specially prepared to be included into the database. First, preview images were filtered by using the PUMA software package for alignment and background normalization of CCD images. Second, preview images were transformed from FITS into JPG format by using the ImageMagick software package. For primary maintenance and content management of the plate archive, we use a separate FoxPro database, which provides all available textual information about photographic plates contained in paper log books of observations as well as scanned images. The database has an extensive range of features for editing, analyzing, and displaying information about all photographic plates of the Mykolaiv observatory's archive and possesses additional possibilities to perform astronomical calculations, edit scanned images, and export data in various formats.

A special software package for searching and visualizing of processed CCD images was developed to sample data according to established user criteria, to view and save search results in tabular form, to generate graphic files containing detected objects, to save resulting FITS files for further viewing and analysis. To provide web access to the observational database via a stand-alone Java application, namely Aladin, we developed a PHP script and a configuration file containing a description of the Mykolaiv Observatory's server settings. Scanning of paper-based catalogues, optical characters recognition, compilation of 27 catalogues in the VOTable format were made to provide access to all stellar catalogues created in this observatory (they are available on the web sites of the observatory and the UkrVO).

2. SCIENTIFIC PROSPECTS WITH THE UKRVO JOINT DIGITIZED ARCHIVES

2.1. New catalogues

2.1.1. FONAC star catalog enhancement down to 16 mag

The catalogue of positions and stellar magnitudes of 1 108 603 stars in a 60° zone of declination, obtained from digitized images of FON plates (see Table 1), is the practical realization of the aforementioned MIDAS/ROMAFOT software application. Plates were taken with the Double Wide-angle Astrograph of the MAO NASU with two-fold overlapping scheme in centers of plates and four-fold overlapping at their edges. The exposures were double, with durations of 45–60 sec and 16–28 min, shifted by 1 arcmin along both coordinates. 102 plates (204 frames) were used for elaboration of astrometric and photometric calibration procedures (see Section 1.2.1). The combined processing of the scan pair (the second scan was made with rotation clockwise by 90° on the scanner pad) as well as the proper procedure of removing their residuals, allows to significantly reduce systematic errors caused by scanner mechanics.

Plate calibrations were made with respect of the Tycho-2 catalogue. The calibration model we selected was a third-degree polynomial with additional brightness terms. Residuals for reference stars, averaged in a 10–20 pixel area, were used as corrections for scanner systematic errors before the second iteration. R.m.s. errors of unit weight are ±230 mas and ±330 mas for X and Y for separate processing of two scans and ±200 mas, ±230 mas for the combined procedure. Photomet-

ric curves of the two exposures, built using photoelectric and CCD standards for different plates, give the photometric accuracy 0.19–0.21 mag in the B band.

The total number of registered objects is about 5.5 millions. After data averaging over two- and four-fold areas, the resulting catalog comprises 1.1 million entries. Its positional accuracy, estimated by comparison with the PPMX and UCAC catalogues, is ±230 mas, the photometric uncertainty being ±0.18 mag (Yatsenko et al. 2011). For 10–13 mag stars, the positional accuracy is comparable to that of the PARSec radial-scanning coordinate meter, previously used for measurements of photographic plate. At present, about 2500 selected astronomical negatives are digitized and are in processing for the creation of this new catalogue.

2.1.2. Star catalogue of positions and proper motions in selected fields of the ecliptic zone

To create the catalogue of star positions and proper motions in the ecliptic zone, plates for scanning and image processing were taken from the archive of the Mykolaiv Observatory. It contains more than 8400 plates obtained with the Zonal Astrograph (D = 160 mm, F = 2.04 m, FoV = 5° × 5°). Selected plates, obtained from 1972 to 1993, were scanned in 2009–2011 with the resolution of 1200 dpi. Raw data processing, including image filtration and recovery of bright stars, was performed using the MIDAS software package. Further data reduction and analysis of the results were carried out using our own software and Tycho-2 as the reference catalogue.

In 2009, 50 selected photographic plates (20 cm×20 cm, 5° × 5°) were scanned and reduced to obtain coordinates and proper motions of 17 000 stars in selected fields. About six scanned images per object were used to compile the catalogue of stellar positions and proper motions in the ecliptic zone. The catalogue contains stars in the ICRS system, with magnitudes from 7 to 14, most of them between 11 and 13 mag; the mean epoch of observations was about 1977. The sample standard deviation of positional measurements is about 0.06 arcsec in RA and 0.07 arcsec in DEC. The r.m.s. error of (O–C) residuals is about 0.09 arcsec for coordinates and 0.005 arcsec/year for proper motions. External evaluation of the accuracy of proper motions was obtained by comparison to the PPMX catalog. It is planned to obtain the second version of the catalogue of positions and proper motions of more than 100,000 stars near the galactic plane using old photographic observations scanned in 2010–2011 together with current CCD observations.

2.1.3. Catalogue of spectral types and photographic magnitudes of 3340 Stars in Perseus

A catalogue of spectral types and photographic magnitudes of 3340 stars brighter then 12.5 mag in a 45° field in Perseus (Brodskaya & Shajn 1958) was created at the Crimean Astrophysical Observatory (CrAO) and published in 1958. It was compiled in the frame of the so-called "G. A. Shajn Plan", aimed at studies of stellar and dust components of the Galaxy, of spatial distribution of groupings of early-type stars, and at discoveries of stars exciting Galactic nebulae. However, till 2011, it had a limited distribution because of its non-digitized format (like many other lists of celestial bodies observed in the CrAO, only a paper version was published; see Shlyapnikov 2007 for details). For example, only 9 objects from this catalog are mentioned in SIMBAD (http://cdsbib.u-strasbg.fr/cgi-bin/cdsbib?1958IzKry..20..299B).

The principal problem when preparing the digitized version of the catalogue

was lacking coordinates for the catalogued objects. The catalogue was divided into six zones by declination; each star had a corresponding zone number. Such notation, with markers presented in a finding chart, is necessary, in the classical case, to find an object for its subsequent extraction from a catalogue. It is obvious that such practice, widespread in mid-20th century, is currently not acceptable. To eliminate this problem, astrometric calibration was performed using the ALADIN interactive sky atlas and other databases, including Tycho-2 as the reference catalogue, that allowed to determine star positions on the identified maps of the catalogue.

Taking into account that more than 50 years have passed since the creation of this catalogue and that new information had been accumulated for catalogued stars, it was decided to complement the original catalogue with corresponding information. First of all, coordinates we have derived for the stars allow to compare stellar magnitudes with data from other catalogues. After adopting the standard photographic B system, m_{pg}, and taking into account correlations for stars of the F, G, K and M spectral types specified in the original catalogue, and also after re-calculation of V magnitudes and exclusion of some objects as indicated in notes to the catalogue, we found no substantial changes in photometric relations. For subsequent analysis, we selected only the objects that had B or V magnitudes showing differences in excess of 0.5 mag between the original data and the Tycho-2 reference catalogue.

Another point of interest was that new variable stars could be discovered in the Milky Way area of this catalog for these 50 past years. We decided to undertake such a search. For example, cross-correlation of VSX objects and stars of the original catalogue, performed in the +56° field, revealed 28 VSX objects among the catalogued stars. However, after checking positions for 19 objects in this sample, we found that only one of them coincided with NSV 15561, so the remaining stars from this sample needed confirmation. Detailed data on the digitized version of the Catalogue of spectral types and photographic magnitudes of 3340 stars brighter than 12.5 mag in a 45° field in Perseus will be published in 2011.

2.1.4. Catalogue of stars with solar-type activity

A catalogue of 5535 dwarf stars with different kinds of solar-type activity (Gershberg et al. 2011), i.e., the objects with dark spots, hydrogen and calcium chromospheric emission, transient flares in various spectral ranges, radio and X-ray emission of star coronas, was created at the CrAO. The negatives (wide-field plates) with direct sky images from the CrAO plate stacks were used. The Catalogue of stars with solar-type activity, the GTSh10 Catalogue, is avaiable through Aladin.

Necessary components of preliminary work were (1) search for plates by star coordinates and calculated limiting magnitudes with IVOA tools for image viewing and processing; (2) preliminary photometry of selected objects. Two collections from the CrAO plate stacks satisfy our criteria. They are: (1) about 1,500 plates with images taken through an objective prism in 1947–1965 using a 167-mm astrograph with the "Dogmar" objective and 40 cm astrographs according to the "G. A. Shajn Plan" (Bondar & Shlyapnikov 2009) and (2) about 10 000 images taken in the frame of the "Crimean Survey of Minor Planets" in 1963–1999 with a double 40 cm astrograph (Chernykh & Chernykh 2002). Most plates were taken with long exposures and contain faint objects. One of the problems when working with the plates was accounting for changes in the geometry of projection of plates

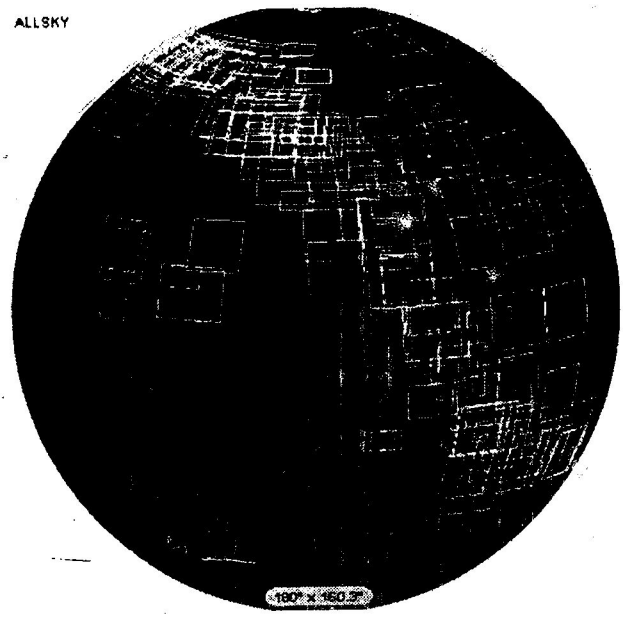


Fig. 1. The distribution of plates taken in the frame of the "G. A. Shajn Plan" in 1947–1965 on the celestial sphere.

on the celestial sphere in the circumpolar region. For its solution and for further astrometric calibration, data on the coordinates of plate corners was applied. The distribution of the plates obtained in the frame of the "G. A. Shajn Plan" is shown in Figure 1.

2.2. Study of solar flares and active regions

The UkrVO archive of active-region spectrograms contains about 1500 photographic plates (13 × 18 cm), with ORWO WP1, WP3, WO3 type emulsions (see Table 1). It was obtained during long-term spectroscopy of non-stationary processes with solar horizontal telescopes ATsU-5 (Kyiv) and ATsU-26 (North Caucasus, Mt. Terskol) from 1976 to 1990. It includes spectra of flares, plages, chromospheric surges, spots in different spectral ranges: 4900, 5200, 5400, 5900, 6100, 6300 and 6500 Å. H_α images were simultaneously obtained with the HALLE interference-polarization filter. Photometry of the spectra is performed with the automatic digital two-coordinate microphotometer ADMF-XY (Parusimov 1981) in the MAO NASU, allowing to obtain high-quality recordings of digital spectra, to measure optical densities, and to process the data. The GAOSOl archive allows us to solve the following problems: study of changes in the physical state of the solar lower atmosphere at different stages of development of flares and before them; study of thermodynamic conditions in plages, faculae, chromospheric surges, spots and pores during a cycle of solar activity; emergence of active regions on the Sun, etc. For example, processed spectra were applied to the flares on 1979 May 22 and 24, June 3 and 5, October 7; 1981 May 16; 1990 September 3, 4, 7, making it possible to reveal new characteristics of variations in photospheric thermodynamic conditions during the flares (see, for example, Alikaeva & Kondrashova 2006).

2.3. Search for new small bodies of the solar system

The effective CoLiTec software for detection and evaluation of parameters for signals from celestial objects on digital images was developed by Savanevich et al.

(www.neoastrosoft.org). Input data for the CoLiTec software are series of digital images (digitized photographic plates or CCD images) of an area of the celestial sphere and a star catalog. The interframe processing module checks defective pixels of the CCD matrix and compensates large background elements using a low-cut filter. Spatial convolution is performed within a particular part of the image, using Fourier transformation that permits to reduce operating memory requirements. Determination of coordinates and signal amplitudes on the frames (formation of marks), based on the mathematical mechanism of classified samples using a model describing distribution of arrival coordinates of noise photons as a flat surface with an arbitrary slope is performed in the module of interframe processing (Savanevich et al. 2010). Parameters are evaluated only for those signals that were received from celestial objects around the local maxima of the image, with sufficient energy. Selection of such peaks is based on comparison between spatial convolution criteria of the flux detected in the vicinity of the image peak and the form of the estimated signal. Evaluation of objects' equatorial coordinates is performed via Turner's method using uniformly distributed reference stars and an iteration procedure based on the least-squares method (LSM), rejecting abnormal observations at each iteration. When forming the weighted generic LSM matrix of measurement errors, we also consider the dependence of determination errors of equatorial coordinates on the visible objects brightness level and their coordinates in the coordinate system of CCD frames. As a result, we obtain a set of marks. These marks represent evaluation of estimated magnitudes and equatorial coordinates of celestial objects, as well as evaluation of program objects coordinates in the reference-frame coordinate system.

Interframe processing of data received from the same part of the celestial sphere for detection of objects with nonzero proper motion is also available. This method permits to accumulate energy of signals received from objects along the motion trajectory, with parameters unknown due to the multiple-value transformation (after-threshold accumulation of the statistics of signals received from an asteroid along all its possible motion trajectories). Besides, hierarchical implementation of multiple-value transformation stabilizes computational cost of the method.

As for successful implementation of the CoLiTex (CLT) software, the following should be mentioned. By 2011 September 1, the CLT software has been fruitfully used at two observatories: the Andrushevsk Astronomical Observatory, Ukraine (since 2010 May; code 50) and the Russian remote ISON-NM observatory (since 2010 November 27; code 15). By that time, observers have performed about 140 thousand measurements and discovered over 480 celestial objects. Among them, two comets, C/2010 X1 (Elenin) and P/2011 NO1; one Jupiter's Trojan asteroid (2011 QJ9, ISON-NM); one NEA (2011 QY37, ISON-NM) were discovered at the ISON-NM observatory.

3. CONCLUSIONS

The UkrVO is an actively developing project at the national level in Ukraine (on 2011 October 19 UkrVO became an IVOA member).

In this paper, we described the UkrVO priority tasks, such as the development of the Joint Digitized Archive of observations performed in 8 observatories of Ukraine since 1898, works on its interoperability, administration and software development. Besides the JDA, we also pay attention to the UkrVO Astronomical Image Heritage archive, which will include the oldest photographic images of the

solar-system bodies, stellar and extragalactic objects acquired in 1898–1950s (the first version is available at ukr-vo.org/history/). Another application of the glass plate archive is the revision of star fields in the vicinity of registered gamma-bursts in order to identify the GRB optical counterparts and to study all objects in a small area around the supposed GRB place. The catalogue of objects around GRBs is now in preparation.

New progress in the UkrVO development is related to software being developed for processing ground-based and space-borne multi-wavelengths observations of galactic and extragalactic objects. This is being done in the frame of the "Virtual Roentgen and Gamma Observatory" (VIRGO.ua) project (http://virgo.org.ua/?lang=en&mfc=home). We also work on application of mathematical methods to studies of the galaxy clustering, for example, of the methods earlier developed by us for SDSS releases (Melnyk et al. 2006; Elyiv et al. 2009); on modification of the CoLiTex software (cd, subsection 2.3, http://neoastrasoft.com/main/?lang=ru) for calibrating JDA images; on creation of a common administrative system with the World Data Center in Ukraine (http://wdc.org.ua/en/geoinformatics) in the fields of geophysics and solar-terrestrial physics.

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