Recent activities of the Armenian Virtual Observatory (ArVO)

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Abstract

The Astrophysical Virtual Observatories (AVOs) have been created in a number of countries using their available databases and current observing material as a collection of interoperating data archives and software tools to form a research environment for processing complex data-intensive and compute-intensive research workflows. The Armenian Virtual Observatory (ArVO, https://www.aras.am/Arvo/arvo.htm) is a project of the Byurakan Astrophysical Observatory (BAO) aimed at the construction of a modern system for data archiving, extraction, acquisition, reduction, use, and publication. ArVO is based on the Digitized First Byurakan Survey (DFBS, https://www.aras.am/Dfbs/dfbs.html) and is the Armenian contribution to the International Virtual Observatories Alliance (IVOA, https://ivoa.net/). One of the ArVO's main tasks is to create and utilize a global Spectroscopic Virtual Observatory, which will combine data from DFBS and other low-dispersion spectroscopic databases, as well as provide the first understanding on the nature of any object up to B = 18^m. This is important as among all astronomical data, a large spectroscopic database is especially useful for understanding the nature of all observed objects. Hence, ArVO will utilize the DFBS as an appropriate large spectroscopic database. In the frame of ArVO, BAO collaborates with the Institute of Informatics and Automation Problems (IIAP, https://iiap.sci.am/) of the National Academy of Sciences of Armenia to develop software ecosystem for ArVO satisfying the IVOA standards. Besides the DFBS, ArVO provides access to the Digitized Second Byurakan Survey (SBS) database, the Byurakan photographic archive, and BAO 2.6 m and 1 m Schmidt telescopes modern observations.

Keywords: *Astronomical Data, Surveys, Catalogs, Digitization, DFBS, Archives, Virtual Observatory, ArVO, IVOA*

1. Introduction

The Armenian Virtual Observatory (ArVO, Mickaelian et al. 2006a, Mickaelian & Mikayelyan 2021, Mickaelian et al. 2016, Mickaelian et al. 2020b, Mickaelian et al. 2023, www.aras.am/Arvo/arvo.htm) was created in 2005, after the accomplishment of the Digitized First Byurakan Survey (DFBS, Mickaelian et al. 2021, Mickaelian et al. 2006b, Mickaelian et al. 2007, Mickaelian et al. 2019, www.aras.am/Dfbs/dfbs.html, Fig. 1), a collection of 1874 objective-prism low-dispersion astronomical plates with some 40 mln spectra for 20 mln objects (UNESCO Documentary Heritage since 2011; Mickaelian et al. 2021).

Initiated by the Byurakan Astrophysical Observatory (BAO), ArVO became one of the national projects of the International Virtual Observatory Alliance (IVOA, www.ivoa.net) in the same year. ArVO aims at construction of a modern system for data archiving, extraction, acquisition, reduction, use, and publication. ArVO supports several technical and research projects, such as the Global Spectroscopic Database built based on DFBS (Mickaelian et al., 2008a). Quick optical identification of radio, infrared (IR) or X-ray sources is possible by plotting their positions in the DFBS or other spectroscopic plate and matching all available data. The achievement of new projects by combining data is so crucial that the International Council of Scientific Unions (ICSU, currently the International Science Council, ISC) recently created the World Data System (WDS, https://worlddatasystem.org/) for unifying data coming from all science areas, and BAO has also joined it due to the DFBS and ArVO projects (Mickaelian et al., 2006a, 2009).

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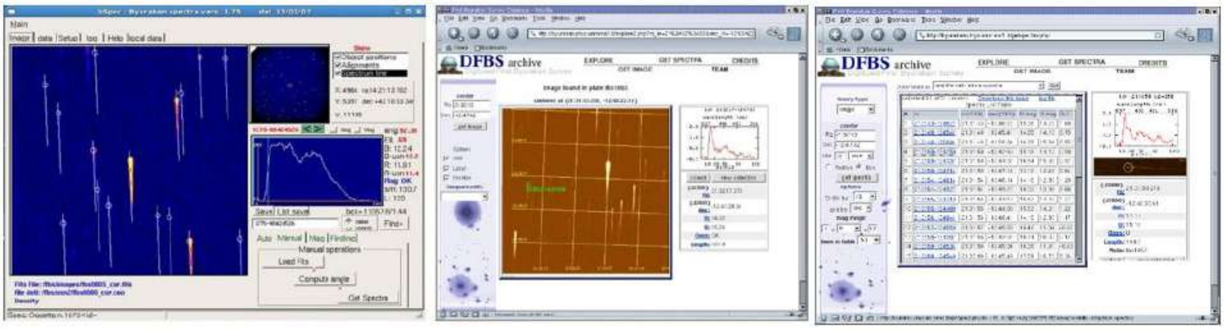

Figure 1. The Digitized First Byurakan Survey (DFBS) dedicated software bSpec (Mickaelian et al., 2010) for extraction and analysis of the low-dispersion spectra and DFBS webpage "Get Spectra" mode interfaces.

A detailed review on ArVO for the first 10 years of activities is given by Mickaelian (2015) and a recent paper by Mickaelian et al. (2023). BAO Observational Archive has been summarized in a table providing instruments, methods, years, and number of obtained photographic plates (Mikayelyan et al., 2021, p. 98).

Virtual Observatory (VO) is a collection of interoperating data archives and software tools that utilize the Internet to form a scientific research environment where astronomical research programs can be conducted. In the same way as a real observatory consists of telescopes, each with a collection of unique astronomical instruments, VO combines a collection of data centres each with a unique collection of astronomical data, software systems and processing capabilities. The main goal is transparency and distributed access to available data worldwide, which helps scientists discover, access, analyze, and combine space and laboratory data from heterogeneous data collections in a user-friendly manner (Mickaelian & Mikayelyan, 2021).

VOs have been created in a number of countries since 2000. The IVOA was established in 2002 as a coordinating body to develop and agree the vital interoperability standards upon which the VO implementations are constructed. So far, countries with the most developed astronomy have VO projects and Armenia is among these 20 (in addition, 2 European projects, Euro-VO and ESA, are IVOA members). ArVO was accepted by IVOA in 2005 and has been one of its projects until now (Figure 2).

Figure 2. The International Virtual Observatory Alliance (IVOA) with its 24 projects, 22 national and 2 European ones.

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IVOA software stack is mainly used for data discovery (Aladin, Astroscope, VOExplorer, Datascope), spectral analysis (VOSpec, SPLAT, EURO- 3D, Specview), data visualization and reduction (VOPlot, Topcat, VisIVO, STILTS) or spectral energy distribution (SED) construction and fitting (VO- SED, Yafit, easy-z, GOSSIP).

The development of the ArVO project includes Armenian astronomical archives and present telescope data preservation, cross-correlations of direct images and low-dispersion spectra, creation of joint low- dispersion spectral database (DFBS/DSBS/HQS/HES/Case) and many other technical and scientific projects (Mickaelian et al., 2017a; Figure 3).

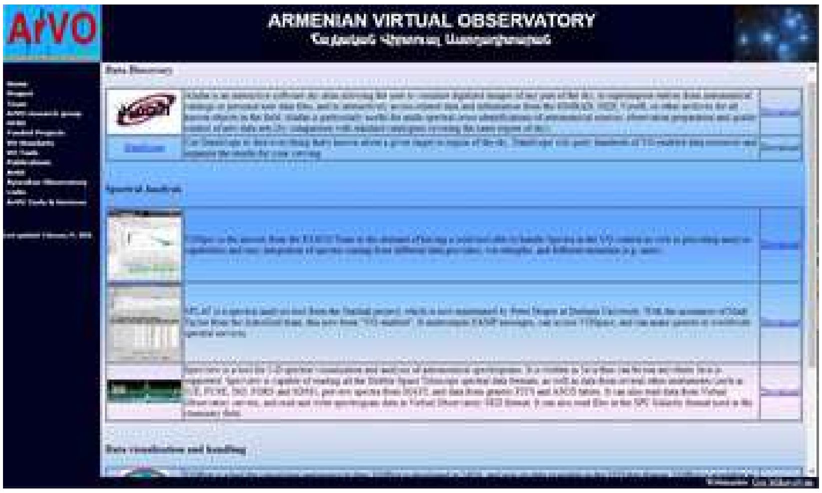

Figure 3. The ArVO webpage gives access to a number of recommended VO projects for data discovery, spectral analysis and data visualization and handling.

2. ArVO projects and developments

In addition to DFBS, some other projects are active in the framework of ArVO (Mickaelian et al., 2008b):

a) Digitized Second Byurakan Survey (DSBS, started in 2003). SBS is a deeper (limiting magnitude 19.5^m 20^m) survey compared with FBS but smaller in its area, 650 sq. degrees,

b) Digitization and automated MIDAS reduction of FBS Blue Stellar Objects (BSOs) 2.6m slit spectra (Sinamyan & Mickaelian, 2009, Figure 4, left panel). Some 700 slit spectra were digitized and reduced automatically,

c) Digitization of photometric chain observations in the Coma field (star- ted in 2004, Figure 4, central and right panels). These plates were obtained with the purpose of search for flare stars. However, many other variable objects appeared in some fields and new projects for their study were initiated,

d) Optical identification of IR sources in Bo¨otes field of Spitzer Space Telescope (SST; 2005, the first science project using DFBS/ArVO) (Hovhannisyan et al., 2009),

e) Optical identifications of X-ray, IR and radio sources. Spectroscopic data are especially useful and efficient in identifying definite types of objects as optical counterparts of non-optical sources. We have accomplished projects for IRAS, SST, ROSAT and NVSS sources.

The most advanced ArVO project was the Search for asteroids in DFBS jointly with IMCEE (Observatoire de Paris, France) colleagues (Berthier et al., 2009; Mickaelian et al., 2019; Sarkissian et al., 2012; Thuillot et al., 2007), for which VO software Aladin and SkyBoT (Sky Body Tracker; https://ssp.imcce.fr/webservices/skybot/) are being used (Figure 5). The bright ($< 15^m$-16^m) asteroids observed in DFBS are being studied, which are divided into “fast” and “slow” ones depending on their motion during the typical DFBS plate exposure time (20 min), more or less than 3” (the typical width of low-dispersion spectra). All asteroid spectra are being extracted after they have been found using SkyBoT. Sample spectra are being modeled similarly to Solar spectra. New candidate asteroids are being searched

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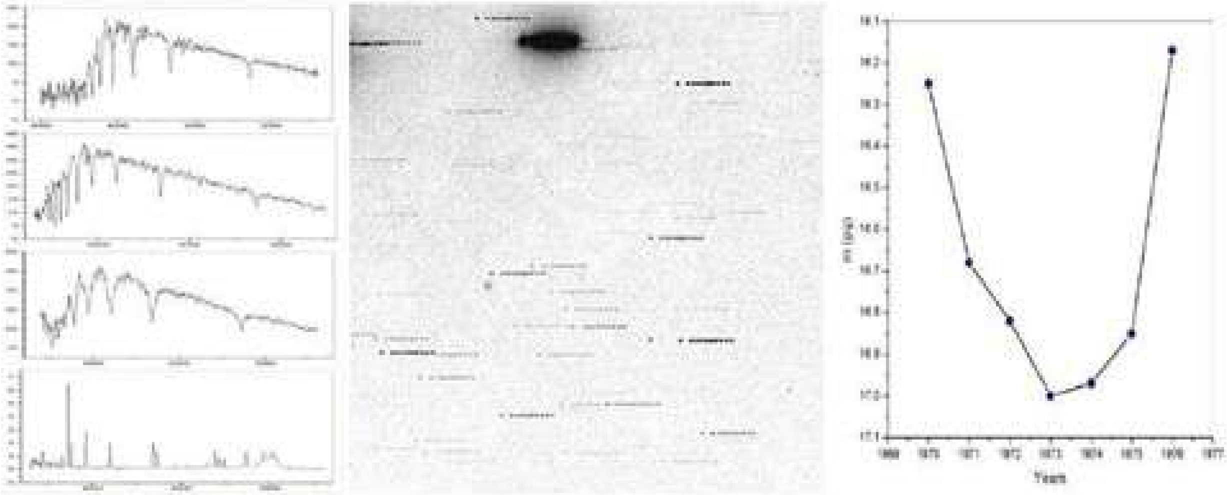

Figure 4. ArVO projects Spectroscopic study of FBS Blue Stellar Objects (BSOs) and Variability of ON 231.

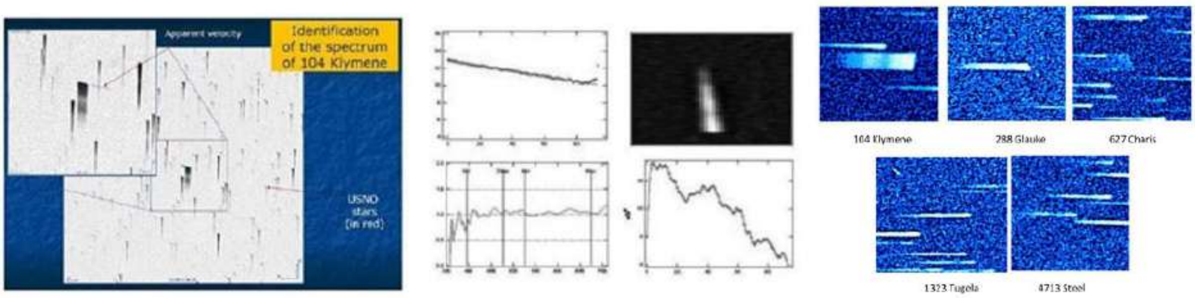

Figure 5. ArVO research projects: search for asteroids in DFBS by means of SkyBoT sowtfare and the software EXATODS (Extraction and Analysis TOol of DFBS Spectra). On the right: extracted images of 5 asteroids.

using these spectra and through comparisons with other catalogues. Spectral analysis of asteroid spectra is being accomplished aimed at obtaining definite physical parameters.

Since 2008, ArVO also is a collaboration between BAO and the Institute of Informatics and Automation Problems of the National Academy of Sciences of the Republic of Armenia (IIAP). In this collaboration, many joint astrophysical computational projects have been carried out working with large data sets and High-Performance Computing (HPC) environments. The on-demand computational and data resources of the National Research Cloud Platform is used by ArVO, a complex national IT infrastructure consisting of both communication and distributed computing infrastructures (Astsatryan et al., 2004, 2021b). Dr. Hrachya Astsatryan from IIAP is ArVO Technical Manager, while Aram Knyazyan defended his Ph.D. thesis on ArVO software development and utilization. Scientific studies have been supported by international projects and collaborations, such as Euro-VO, VO-France, and other VO projects.

3. ArVO Tools and Services

In collaboration with IIAP, several ArVO tools & services have been developed and evaluated, including the DFBS archive, the ArVO Data Discovery tool, catalogue cross-matching service, and DFBS spectra extraction service (the latter is still in development; Astsatryan et al., 2010, 2016, 2021b, Knyazyan et al., 2011).

In 2015-2021, **BAO Plate Archive Project** was completed (Mickaelian et al., 2017b, 2020a, Mikayelyan et al., 2021; `www.aras.am/BAO/PlateArchive`, Figure 6), which will significantly complement the ArVO data. All BAO observational material (some 37,500 plates and other carriers) was digitized and a complete database was created. An interactive BAO observations sky map is planned to be built. Current observational data obtained from 2.6m and 1m Schmidt telescopes will also be incorporated into ArVO. The project also aims to utilize the digitized data for future science projects.

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Figure 6. BAO Plate Archive Project webpage.

3.1. Data processing tools

The DFBS archive page gives access to all DFBS data, to view the plates, and spectra of their sources. More about the DFBS archive you can read here (http://byurakan.phys.uniroma1.it/).

The ArVO Data Discovery tool allows access to all available data that are being dynamically updated by astronomers and developers (http://arvo.sci.am).

3.2. Data discovery services

The catalog cross-matching service (http://arvo.sci.am/crosscorrelation/crosscor.html) compares two catalogs line by line. The same object is present in both catalogs if the difference in the coordinate values is smaller than a prior determined particular value. The root-mean-square (RMS) error of the coordinate distance for each pair of sources is calculated to evaluate the deviation of two catalogs, which can be uploaded or available on the server. The RMS has right ascension and declination values to specify both the RMS x and RMS y errors. The service allows you to upload your catalogs or own lists, run the service, and download the resulting output list. The suggested service is more accurate than the classic cross-correlation methods.

The simple image access service (Knyazyan et al., 2017) is based on the Simple Image Access (SIA) Protocol of IVOA, providing capabilities to dis- cover, describe, access, and retrieve multi-dimensional image datasets. The input query parameters are passed through HTTP get method, while the output is a VOTable, an XML table format. The service allows users to search for image data for a given region in the sky. Additional parameters may optionally be used to further refine the query. The size, scale, projection, and so forth of the ideal output image can be specified, and the service will return references to images that most closely match what is requested.

The Astronomical objects classification service (Knyazyan et al., 2016) classifies the spectra of UV-excess galaxies, quasars, compact galaxies, and other objects in the survey based on convolutional neural networks (CNN). A three-step image processing algorithm has been developed to extract data from spectral images:

- An image thresholding algorithm partitions an image into a foreground and background
- Conversion of astronomical coordinates (RA and DEC) into pixel co- ordinates (x and y) for each astronomical object

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- The spectral images represented as vectors are used as the input data for training and testing CNN models

The experiments show a good correspondence between the predicted and measured values, such as the overall accuracy being within 87%. Linear regression techniques have been implemented to forecast the number of objects in the DFBS survey that expected at least six million carbon stars, three million hot subdwarfs, and one million Markarian galaxies.

Catalogue cross-matching service includes a new cross-correlation program, which is doing the correlation of uploaded or available on server catalogues using as correlation radius for each pair of sources their RMS average error multiplied by some input constant. You can upload your catalogues, run the service, and download the resulting list. The new program is more accurate than the classic cross-correlation methods (http://arvo.sci.am/crosscorrelation/crosscor.html). We have run several projects using this service (Abrahamyan et al., 2012, 2015, 2018).

Spectra Extraction service will include a tool which extracts astronomical spectra catalogs from uploaded fits files (http://arvo.sci.am/extraction/index.html).

4. Meetings and Schools

ArVO has organized individual sessions at the largest ever meeting held in Armenia, Joint European and National Astronomical Meeting (JENAM- 2007), Computer Science and Information Technologies (CSIT-2009) Conference (jointly with IIAP) and other symposia and workshops. A Conference of Young Scientists of CIS Countries *"50 years of Cosmic Era: Real and Virtual Studies of the Sky"* was held in November 2011. An international symposium *"Astronomical Surveys and Big Data"* (https://bao.am/meetings/meetings/ASBD) dedicated to the 50th anniversary of the Markarian Survey and the 10th anniversary of ArVO was held 5-8 Oct. 2015 in Byurakan, Armenia. We intended to combine astronomers and computer scientists with heavy involvement in astronomical surveys, catalogs, archives, databases, and VOs. IVOA and national VO project leaders were involved.

In 2020, two international events related to data science were organized. The International Symposium *"Astronomical Surveys and Big Data 2"* (ASBD-2) was held on Sep 14-18, 2020 (https://www.bao.am//meetings/meetings/ASBD2/). This was the 2nd such meeting organized by the Byurakan Astrophysical Observatory (BAO); the 1st one was in 2015 with the participation of astronomers and computer scientists. This time, also astronomers and computer scientists participated, in total 91 participants from 24 countries. During the meeting, large astronomical surveys were reviewed and discussed, a tribute was given to Markarian and other important surveys, and the future of astronomical research by joint efforts of astronomers and computer scientists was discussed (Mickaelian, 2020). The 3rd such meeting is planned for September 15-19 2025 (Figure 7) (https://www.bao.am/meetings/meetings/ASBD3/).

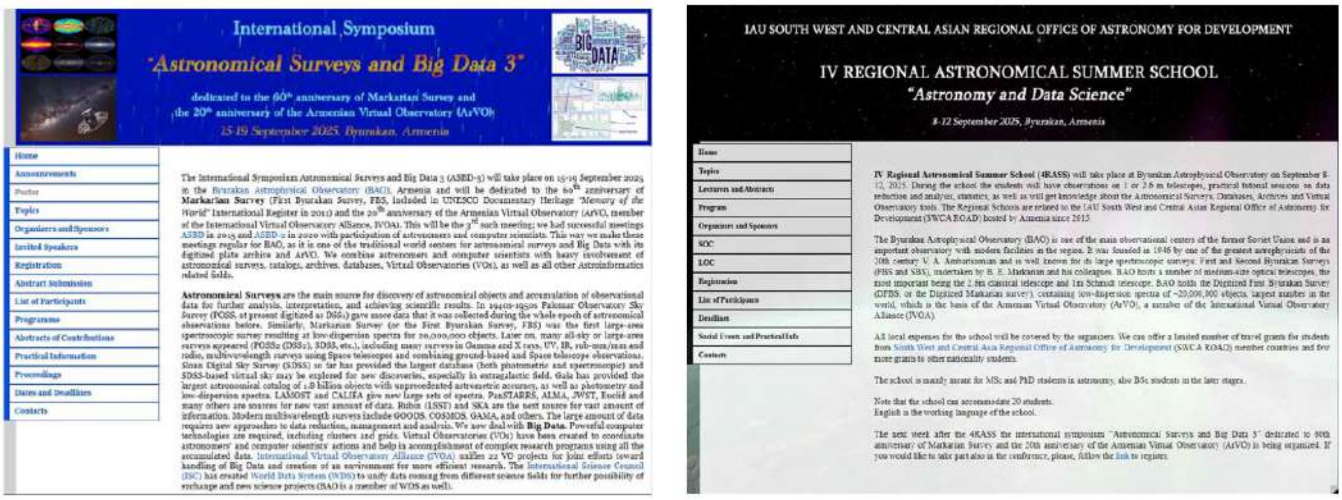

Figure 7. The webpages of the international symposium "Astronomical Surveys and Big Data – 3" (ASBD-3) and 4^{th} Regional Astronomical Summer School (4RASS) to be held in September 2025 in the Byurakan Astrophysical Observatory (BAO).

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The 7th Byurakan International Summer School (7BISS) for Young Astronomers on *"Astronomy and Data Science"* was held on Sep 7-11, 2020 (https://www.bao.am//meetings/meetings/SS2020/index.html). Because of the COVID-19 pandemic, the summer school was held online. Fifty young astronomers and 12 lecturers from 21 countries participated in 7BISS. Moreover, an opportunity was created for the public sector to take part in the school as listeners. In the framework of the school, participants had 15 lectures and 11 practical tutorial sessions on Astronomical Surveys, Digitization of astronomical data, Astronomical Catalogues, Databases and Archives, Astrostatistics and Astroinformatics, Big Data in Astronomy and Virtual Observatory tools. Among the famous lecturers were IAU Vice-President Ajit Kembhavi (India), co-founder of Astroinformatics Ashish Mahabal (USA), Chair of International Virtual Observatory Alliance (IVOA) Chenzhou Cui, Fabio Pasian (Italy), Markus Demleitner (Germany), Oleg Malkov (Russia) and others. All presentations are available online: https://www.bao.am//meetings/meetings/SS2020/programme.html. The Byurakan Summer School once again proved the importance of Astronomy in the development of Data science and e-Science.

On 8-12 September 2025, another summer school, this time Regional (RASS) will be organized with a subject *"Astronomy and Data Science"* (https://www.bao.am/meetings/meetings/4RASS/) (Figure 7).

Several other meetings organized by ArVO were also held in recent years, including summer schools where data science was always present.

5. ArVO collaborations

ArVO Project Manager Areg Mickaelian has attended the IVOA Interoperability meetings, ADASS meetings and WDS Forums several times, and as a member of the IVOA Executive Committee, he regularly participates in IVOA Exec teleconferences organized several times each year. ArVO young team members have attended and presented contributions in Euro-VO, NVO other meetings and schools. The VO subject has always been present in the Byurakan International Summer Schools (BISS) series since 2006, where a number of outstanding foreign lecturers have taught.

ArVO funded projects include several ANSEF grants (PS-450, PS-702 and PS 2968) and CRDF grant ARP1-2849-YE-06 in 2007-2010 *"Digitized First Byurakan Survey and Armenian Virtual Observatory"*, as well as the above mentioned ISTC grants in collaboration with IIAP ISTC A-1451 *"Development of Scientific Computing Grid on the Base of Armcluster for South Caucasian Region"* and ISTC A-1606 *"Development of Armenian-Georgian Grid Infrastructure and applications in the fields of high energy physics, astrophysics and quantum physics"*. Others were COST Action TD1403 *Big Data Era in Sky and Earth Observation* (BigSkyEarth) in 2015-2019, BAO Plate Archive Digitization and e-Database in 2015-2018 and is BAO Plate Archive e-Database and Scientific Usage in 2020-2021.

In the frame of ArVO and GAVO collaboration in 2017-2019 (MES- BMBF project *"Building a high-performance research environment through German and Armenian Astrophysical Virtual Observatories"*), more than 30 visits were accomplished between Armenia and Germany (BAO and ARI Heidelberg). Areg Mickaelian, Aram Knyazyan, Daniel Baghdasaryan, Hrachya Astsatryan, Gor Mikayelyan, and Hayk Abrahamyan participated in the project, as well as some other young scientists attended workshops organized in the frame of the projects. German scientists visited to Armenia to lecture at workshops and training schools. Joachim Wambsganss, Markus Demleitner and Hendrik Heinl participated from GAVO. The collaboration products included the DFBS classification and SIAP/SSAP services (SIAP, 2015; SSAP, 2012) for DFBS (Demleitner et al., 2020a,b)).

Other collaborations were with OV-France / OV-Paris projects with the participation of Philippe Prugniel, Alain Sarkissian, Jerome Berthier, William Thuillot and Pierre Le Sidaner. It included the creation of the DFBS database, SIAP/SSAP services, and search and verification of asteroids ephemeris. The Armenian-Italian collaboration was with the Universita Napoli Federico II. Prof. Giuseppe Longo led the Italian Astroinformatics team.

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