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Astronomy and Computer Science: From Astrostatistics to Virtual Observatories

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Abstract

Interdisciplinary and multidisciplinary sciences over the last few decades have become the major booster of science development. The most important discoveries occur just at the intersection of sciences and in collaboration of several fields. There appeared such intermediate fields as mathematical physics, physical chemistry, biophysics, biochemistry, geophysics, etc. In Astronomy, Astrophysics has long been the main field, and at present Archaeoastronomy, Astrochemistry, Astrobiology, Astroinformatics (which is tightly related to Virtual Observatories) are developing. Science fields and disciplines related to Astronomy and Data/Computer Science; namely Astrostatistics, Computational Astronomy/Astrophysics, Astroinformatics and Virtual Observatories, Laboratory Astrophysics, Big Data in Astronomy and Data Science are discussed. International organizations, international meetings, international journals related to the area are described. Some recent developments in this field in Armenia are also given.

Keywords: Interdisciplinary Sciences; Astrostatistics; Astroinformatics; Virtual Observatories; Big Data; Laboratory Astrophysics

Introduction

Current trends in astronomy development

At present Astronomy is not only an individual science discipline but also an area providing vast amount of data for all natural (and partially also other) sciences; data coming from the Universe are much bigger and open new possibilities to expand our knowledge in all fields. By studying the features of the current stage of development of astronomy, we have distinguished several current tendencies:

- Broader usage of modern astronomical instruments and research methods (telescopes, various modes of spectroscopy (IFU, MOS, etc.), active and adaptive optics, digital receivers, data reduction and analysis software and systems);
- Multiwavelength studies (γ-rays, X-rays, UV, optical, IR, submm, mm, and radio; using space telescopes, etc.) and Multimessenger studies, including the development of neutrino, cosmic rays, and gravitational wave astronomy; variety of data - one of the necessary requirements for Big Data;
- Results based on large-scale astronomical data processing (Astrostatistics, computational astrophysics, Virtual Observatories, computer modeling, visualizations, simulations, Laboratory Astrophysics, etc.);
- The expansion of connection of Astronomy to other science fields (Astro Particle Physics, Astrochemistry, Astrobiology, close connection with Optics, Mechanics, Spectroscopy, Atomic and Nuclear Physics, Informatics, mathematical modeling, and with other spheres of culture).

The International Astronomical Union (IAU) has one of its divisions, Division B - Equipment, Technology and Data Sciences (related to Optics, Modern Technologies, Astroinformatics, and Virtual Observatories). The abovementioned tendencies in astronomy are also evident by a number of interdisciplinary and multidisciplinary IAU commissions and working groups, the International Virtual Observatory Alliance (IVOA), regularly held "Astronomical Data Analysis Software and Systems" (ADASS) Conferences, International Science Council (ISC, formerly ICSU) CODATA and World Data System (WDS), the International Planetary Data Alliance (IPDA) and others. All these organizations were established recently, mainly in the 2000s.

Related Subjects and Methods

Astronomy and informatics

One of the most widely used applications of the Computer Science is Astronomy, which is associated with a vast amount of information in it. At present, this branch is called Astroinformatics, which includes mathematical modeling, Astrostatistics, work with large repositories and databases, Computational Astronomy, Virtual Observatories, etc. Numerous astronomical software and systems have been developed, in particular the All Sky Virtual Observatory (ASVO). The development of astronomy is particularly facilitated by the use of modern methods in astronomy education, including in the form of computer games, public professional astronomical programs. Regular conferences are held on "Astroinformatics", "Big Data in Astronomy", "Astronomical Data Analysis Software and Systems". Detailed reviews on Big Data in Astronomy and Computational Astrophysics are given in Mickaelian (2020) and Mickaelian and Astsatryan [1].

In this paper we present and discuss activities related to Astronomy/Astrophysics and Data/Computer Science. There are many fields and disciplines that have appeared during the recent decades and especially during the recent several years, such as:

- Data Reduction and Data Analysis; Astronomical Software Systems
- Digitization of astronomical data
- Astronomical Catalogues, Archives and Databases, Data Mining
- Astrostatistics
- Computational Astronomy/Astrophysics
- Cross-correlations of data from different catalogues
- Modeling, Visualization, Animations, Simulations
- Astroinformatics
- Machine Learning (ML), Deep Learning
- Virtual Observatories (VO)
- Laboratory Astrophysics
- Big Data in Astronomy; Data Science
- Artificial Intelligence (AI).

Data Reduction and Data Analysis, Astronomical Software Systems are typically dedicated ones, as astronomical data are different and unique. The images and spectra are being obtained in a standard file format - FITS (Flexible Image Transport System), an open standard defining a digital file format useful for storage, transmission and processing of data: formatted as multi-dimensional arrays, or tables. Before working on real astronomical data, we first carry out data reduction - transformation of images and spectra for getting rid from extra effects: cosmic particles, dark currents, flat fielding, background, etc. After that, powerful image and spectra software systems allow obtaining scientific results.

Digitization of astronomical data

Older astronomical data have been obtained mainly on photographic carriers during 1870s-1990s. Later on, after the start of the digital era in astronomy, when IPCS and CCDs became the main carriers, astronomers wished also to homogenize their research by using old data in the same formats as the new ones. Therefore, digitization projects began in all observatories and data centers. An IAU initiative, Task Force (then Working Group, WG) Preservation and Digitization of Photographic Plates (PDPP) was formed in 2001. Its mandate is to encourage efforts to digitize plates, and to act as a watchdog (e.g., to send alerts if report arrives that an observatory is making moves to disband its plate archive). At present the WG belongs to IAU Commission B2.

Astrostatistics is a powerful tool for handling any size of information and providing results on very large datasets [2,3]. Astrostatistics is a discipline which spans astrophysics, statistical analysis and data mining. It is used to process the vast amount of data produced by automated scanning of the Universe, to characterize complex datasets, and to link astronomical data to astrophysical theory. Many branches of statistics are involved in astronomical analysis

including nonparametrics, multivariate regression and multivariate classification, time series analysis, and especially Bayesian inference.

Computational Astronomy/Astrophysics refers to the methods and computing tools developed and used in Astronomical and Astrophysical research. Like computational chemistry or computational physics, it is both a specific branch of theoretical astrophysics and an interdisciplinary field relying on computer science, mathematics, and wider physics. Well-established areas of astrophysics employing computational methods include magnetohydrodynamics, astrophysical radiative transfer, stellar and galactic dynamics, and astrophysical fluid dynamics. A recently developed field with interesting results is numerical relativity. Computational astrophysics as a field makes extensive use of software and hardware technologies. These systems are often highly specialized and made by dedicated professionals.

Astroinformatics is an interdisciplinary field of study involving the combination of astronomy, data science, machine learning, informatics, and information/communications technologies. Astroinformatics as a distinct field of research was inspired by work in the fields of Bioinformatics and Geoinformatics, and through the eScience work. However, at present Astroinformatics is probably the most advanced interdisciplinary field related to computer science. Astroinformatics is primarily focused on developing the tools, methods, and applications of computational science, data science, machine learning, and statistics for research and education in data-oriented astronomy. Early efforts in this direction included data discovery, metadata standards development, data modeling, astronomical data dictionary development, data access, information retrieval, data integration, and data mining in the astronomical Virtual Observatory initiatives.

Virtual Observatories combine real observations and create a research environment for much more efficient science. There are different observatories (hence, different accessible sky at given geographical latitudes and time zone at given geographical longitudes), different telescopes (different technical parameters), ground-based and space observatories, different epochs (for proper motions, variability, and transients), wavelength ranges (Gamma-, X-ray, UV, optical, IR, submm/mm and radio), other than photons carriers of information (neutrinos, cosmic particles, gravitational waves, etc.), different observing methods (imagery, astrometry, photometry, spectroscopy, polarimetry, speckle-interferometry, etc.). The combination of everything and creation of Standards and Tools allows efficient research and overall understanding of the Universe, as much as it is possible.

Laboratory Astrophysics is the study of astrophysical phenomena in the laboratory (Earth- or space-based). This might include various aspects of Astrochemistry (chemical reactions under extreme conditions of temperature, density, and irradiation), plasma physics, spectroscopy, meteorite analysis, fluid dynamics, magnetohydrodynamics and others [4].

Results and Discussion

Related international organizations

Data Science related management and organization is being arranged by a number of international organizations founded during the recent decades:

International Science Council's (ISC) Committee on Data (CODATA; https://codata.org) was established as ICSU Committee on Data for Science and Technology in 1966. CODATA exists to promote global collaboration to advance open science and to improve the availability and usability of data for all areas of research. There are 3 priority areas: 1) promoting principles, policies and practices for Open Data and Open Science; 2) advancing the frontiers of data science and 3) building capacity for Open Science by improving data skills and the functions of national science systems needed to support open data. The headquarters is in Paris, France;

ISC World Data System (WDS; https://www.worlddatasystem.org) was created by the ISC General Assembly in 2008. WDS goals are to preserve quality assured scientific data and information, to facilitate open access, and promote the adoption of standards. Member organizations of the WDS join voluntarily in one of the four membership categories: Regular, Network, Partner, and Associate Members. Members contribute their data holdings, data services or products. The headquarters is in Tokyo, Japan;

The Research Data Alliance (RDA; www.rd-alliance.org) is a research community organization started in 2013 by the European Commission (EC), the American National Science Foundation (NSF) and National Institute of Standards and Technology, and the Australian Department of Innovation. Its mission is to build the social and technical bridges to enable open sharing of data. The RDA

vision is researchers and innovators openly sharing data across technologies, disciplines, and countries to address the grand challenges of society. RDA has over 8,800 individual members from 137 countries;

The Digital Curation Centre (DCC; https://www.dcc.ac.uk) was established in 2005 to help solve the extensive challenges of digital preservation and digital curation and to lead research, development, advice, and support services for higher education institutions in the United Kingdom. It actively collaborates with CODATA, WDS and RDA;

International AstroInformatics Association (IAIA; http://astroinformatics.info) is a professional, non-profit organization intended to support and advance the growing field of Astroinformatics and all of its constituents. Its goals are to: foster the development of the global Astroinformatics community, increase the professional recognition of the field, provide a forum for the exchange of ideas and tools, and facilitate new collaborations, organize the topical Astroinformatics conferences and workshops, provide an interface with other X-informatics communities, provide an interface with the related, affiliated, and sponsoring societies in astronomy and astrophysics, data science, applied computer science and engineering, and other related disciplines, etc.;

International Astrostatistics Association is affiliated with the International Statistical Institute, the IAU WG on Astrostatistics and Astroinformatics, the American Astronomical Society (AAS) WG on Astroinformatics and Astrostatistics, the American Statistical Association Interest Group in Astrostatistics, and the Cosmostatistics Initiative. All of these organizations participate in the Astrostatistics and Astroinformatics Portal Web site (https://asaip.psu.edu/);

Information Theories and Applications International Scientific Society (ITHEA ISS; http://www.ithea.org) is aimed to support growing collaboration between scientists from all over the world. Till now, the ITHEA ISS has been joined by more than 4000 members from 53 countries from all over the world. It was established in 2002 by the Institute ITHEA to extend the possibilities for international scientific collaboration by wide range of concrete activities;

International Virtual Observatory Alliance (IVOA; https://www.ivoa.net) is a worldwide scientific organization formed in June 2002. Its mission is to facilitate international coordination and collaboration necessary for enabling global and integrated access to data gathered by astronomical observatories. An information system allowing such an access is called a Virtual Observatory (VO). The main task of IVOA so far has focused on defining standards to ensure interoperability of the different VO projects already existing or in development. The members are 2 European projects (Euro-VO based in ESO and ESA-VO) and 20 national projects from USA (USVOA), Canada (CVO), Japan (JVO), China (China-VO), India (VO-India), Australia (ASVO), UK (AstroGrid), Germany (GAVO), France (OV-France), Italy (VObs.it), Spain (SVO), Netherlands (NLVO), Hungary (HVO), Russia (RVO), Ukraine (Ukr-VO), Armenia (ArVO), Brazil (BRAVO), Argentina (NOVA), Chile (ChiVO) and South Africa (SA^3). IVOA has Working Groups (WG) and Interest Groups (IG), like Applications, Data Access Layer, Data Modeling, Grid and Web Services, Resource Registry, Semantics, VO Query Language, VOTable, and Theory. The work of the IVOA focuses on the development of standards. It holds 2 interoperability meetings and 3-4 Executive Committee meetings annually to arrange its activities [5-7].

International Planetary Data Alliance (IPDA; https://planetarydata.org) founded in 2006, is a closely cooperating partnership to maintain the quality and performance of data from planetary research using instruments in space. Specific tasks include promoting the international exchange of high-quality scientific data, organized by a set of standards to facilitate data management. NASA's Planetary Data System is the de facto standard for archiving planetary data. Member organizations participate in both its Board and on specific projects related to building standards and interoperable systems. The members are: USA National Aeronautics and Space Administration (NASA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR, German Aerospace Center), UK Space Agency (UKSA), Centre National d'Études Spatiales (CNES, National Centre for Space Studies), Agenzia Spaziale Italiana (ASI, Italian Space Agency), Russian Space Research Institute (Институт Космических Исследований, ИКИ), China National Space Administration (CNSA), Indian Space Research Organisation (ISRO), United Arab Emirates Space Agency (UAE Space Agency), Armenian Astronomical Society (ArAS, temporarily substituting the Armenian Space Agency, ArSA) and the Europlanet Society;

Among the astronomical institutions (astronomical observatories, astronomical institutes and university astronomy depart-

ments) there is a specialized institution focused on computational astronomy/astrophysics; Universität Heidelberg - Astronomisches Rechen-Institut (ARI, Astronomical Calculation Institute, Germany; https://www.ari.uni-heidelberg.de). It was founded in 1700 and beginning in 2005, the ARI became part of the Center for Astronomy at Heidelberg University (Zentrum für Astronomie, ZAH). The scientific activities at the ARI cover a broad range of research areas including cosmology, gravitational lensing, galaxy evolution, stellar dynamics, astrometry, satellite missions, and calendrical calculations. ARI is involved in various local, European, and worldwide scientific networks and collaborations. ARI plays a leading role in the preparation of the Gaia satellite mission of the ESA. ARI also operates a special high-performance computer for calculating gravitational interactions.

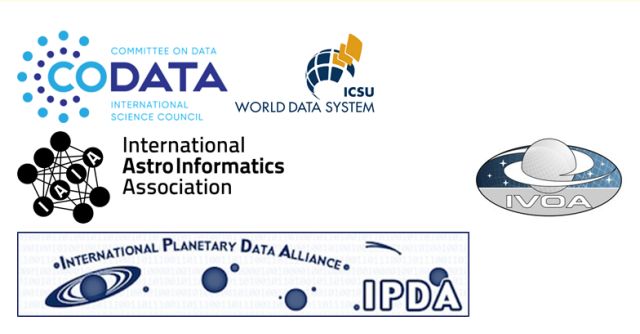

Figure 1: International organizations related to astronomy and data/computer science. Logos of ISC CODATA and WDS, IAIA, IVOA and IPDA.

Related international meetings

A number of international meetings related to Data Science and Astroinformatics are being organized:

- International Data Week (IDW) is organized jointly by CODATA, WDS and RDA and gathers many experts from the related fields. In frame of it, Scientific Data Conference (SciDataCon) is being organized by RDA and is part of IDW. The next IDW will be held on November 8-11, 2021 in Seoul, Korea, however, most probably, it will be online. In 2023, IDW will be held in Salzburg, Austria on October 23-26;
- WDS Members' Forum is the major WDS event and consists of scientific sessions, members lightning talks, panel discussions and plenary sessions. The last such event was held on September 23, 2020;
- Astronomical Data Analysis Software and Systems (ADASS) Conference Series are being organized annually since 1991 (ADASS XXVIII 2019). The conference provides a forum for scientists and programmers concerned with algorithms, software and software systems employed in the acquisition, reduction, analysis, and dissemination of astronomical data. The next 31st ADASS will be held on October 24-28, 2021 in Cape Town, South Africa (ADASS XXXI);
- AstroInformatics Conferences are week-long meetings held since 2010, featuring research presentations, workshops, poster sessions, and networking opportunities designed to stimulate the development of Astroinformatics. The last one was held on November 15-20, 2020 at Harvard University, USA;
- Statistical Challenges in Modern Astronomy (SCMA) conference series is being organized since 1990s and is the major event for astrostatisticians. The next meeting (SCMA VII) will be held on June 7-10, 2021 hosted by the Penn State Center for Astrostatistics, USA;
- Astronomy ("Dot Astronomy") conference series aims to build a dynamic and creative community of scientists and educators to exploit the potential offered by modern computing and the internet in the era of data-driven astronomy. Rather than scientific questions, the focus is on innovative use of the web to develop new research tools. The next meeting is planned for 2021 to be held in ESAC, Madrid, Spain;
- A number of the International Astronomical Union (IAU) Symposia and Colloquia, as well as many IAU General Assembly sessions and focus meetings have been held on the related subjects; Astronomy and Big Data, Astroinformatics, virtual observatories, etc (Figure 2).
- IVOA Interoperability Meetings (IVOA Interops) are the main platform for the IVOA community (VO national projects, etc.) to discuss developments in frame of VOs projects. The last IVOA Interop was held on November 13-15, 2020 in Granada, Spain. Typically, two IVOA Interops are being held annually; spring and autumn ones. The latter typically follows ADASS Conference;

Figure 2: International meetings and a book related to astronomy and computer science. From left to right: ADASS XXI and ADASS XXVII Conferences Proceedings published by the Astronomical Society of the Pacific Conference Series (ASPCS), and the book "Statistical Methods for Astronomical Data Analysis" (Springer, 2014).

nomical observatories and institutes. Many schools have been organized by Euro-VO, ESA-VO, USA NVO, GAVO and other organizations. BAO has also started to have important contribution in teaching and training young specialists in this area. The last, 7th Byurakan International Summer School (BISS) in 2020 was devoted to "Astronomy and Data Science".

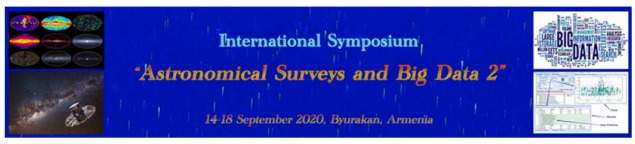

Figure 3: International Symposium "Astronomical Surveys and Big Data 2", where the relation of astronomy to Big Data was discussed. A similar meeting was held in 2015, both in Byurakan, Armenia.

- Astronomical Surveys and Big Data (ASBD) international symposia series is suggested by BAO to get together astronomers working on surveys and large databases and computer/data scientists to review and discuss large astronomical surveys to summarize observational data obtained in astronomy, as well as astronomical catalogues, databases and archives, learn and discuss how large observational data sets are changing astronomy, introduce tools and techniques for working with large data sets, discuss the future of astronomical research by joint efforts of astronomers and computer scientists. Two meetings have been held in 2015 (ASBD) and 2020 (ASBD-2);
- Astroplate workshops (international workshops on scientific use, digitization and preserving astronomical photographic records) are being held every two years, typically in Prague (Czech Republic) or any other European location. Astronomers and Data Scientists gather to report and discuss recent development on astronomical plates; digitization projects, analysis software systems, preservation, creation and maintenance of databases, etc. The last such workshop (Astroplate III) was held in 2019 in Bamberg, Germany;
- International Summer and Winter schools related to Astroinformatics are organized in many data centers and astro-

Related international journals

A number of international journals and other periodicals related to Data Science and Astroinformatics are being published:

- Data Science Journal (DSJ) is the journal of ISC CODATA. It is a peer-reviewed, open access, electronic journal, publishing papers on the management, dissemination, use and reuse of research data and databases across all research domains, including science, technology, the humanities and the arts. Its Impact Factor is 0.85;
- International Journal of Data Science and Analytics (JDSA) is being published by Springer and brings together thought leaders, researchers, industry practitioners, and potential users of data science and analytics, to develop the field, discuss new trends and opportunities, exchange ideas and practices, and promote transdisciplinary and cross-domain collaborations;
- Astronomy and Computing (A&C) is a peer-reviewed scientific journal covering research on applications computer science in astronomy published by Elsevier. It was established in 2013 and is abstracted and indexed in the Astrophysics Data System, INSPEC and Scopus. The latest Impact Factor is 1.854. The journal welcomes contributions on a variety

of topics including scientific software engineering, computational infrastructure, computational techniques used for astrophysical simulations, visualization, data management, archives, and virtual observatory, data analysis, data mining and statistics, data processing pipeline and automated systems, semantics, data citation and data preservation;

- Journal of Astronomical Data (JAD) is a refereed open access journal and publishes sets of astronomical data. It is being published by the Astronomy Group, University of Brussels, Belgium since 1995;
- International Journal "Information Theories and Applications" (IJ ITA) is a peer review journal of the international organization ITHEA. It has been established as an independent scientific media in 1993 and at present is a world-wide well-known international journal with great auditory;
- SCAN-IT (WGSS Newsletter) is the periodical by the IAU Task Force "Preservation and Digitization of Photographic Plates" (PDPP) and publishes papers related to astronomical plate archives and their digitization;
- IVOA Newsletter is a biannual newsletter for astronomers intended to highlight new capabilities of VO tools and technologies for doing astronomy research. It also lists recent papers, and upcoming events. It was established in 2008 and 23 issues have been released.

We show in figure 4 examples of journals related to astronomy and computer science.

Figure 4: International journals related to astronomy and computer science. From left to right: Astronomy and Computing, CODATA Data Science Journal, and International Journal of Data Science and Analytics.

Astronomy and computer sciences in armenia

The Byurakan Astrophysical Observatory (BAO; https://www.bao.am) has always been one of the world centers for astronomical surveys. The most famous, the Markarian Survey (also called the First Byurakan Survey, FBS; Markarian, *et al*. [9]) was carried out in 1965-1980 by B. E. Markarian and his colleagues and covers 17,000 sq. deg. of the extragalactic sky. In 2002-2007, Areg Mickaelian and his team digitized the Markarian (the First Byurakan) Survey (FBS, digitized version - Digitized First Byurakan Survey, DFBS; Mickaelian, *et al*. [10]; Massaro, *et al*. [11]; https://www.aras.am/Dfbs/dfbs.html), which later in 2011 entered the UNESCO "Memory of the World" documentary heritage list, one of the rare science items in all UNESCO lists. DFBS was accomplished in collaboration with Italian, USA and German colleagues. Based on the DFBS, the Armenian Virtual Observatory (ArVO; Mickaelian, *et al*. [12,13], https://www.aras.am//Arvo/arvo.htm) was created in 2005, a joint result by astronomers and computer specialists (one of the authors of this paper, AMM, is the Project Manager of ArVO and Executive Committee member of IVOA). ArVO is a collaboration between BAO and the Armenian Institute for Informatics and Automation Problems (IIAP; Astsatryan, *et al*. [14]). In addition, ArVO collaborates with a number of other European and national VO projects on either technical developments or science projects.

Figure 5: Official logos of the Digitized First Byurakan Survey (DFBS) and the Armenian Virtual Observatory (ArVO).

In recent years, BAO and the Armenian Astronomical Society (ArAS; https://www.aras.am), has taken serious steps to strengthen the connection between astronomy and other sciences and culture, including the Data and Computer Science. Most efforts started in the International Year of Astronomy (IYA-2009) when inter- and multi- disciplinary approach to astronomy and related fields was also initiated. A Workshop in frame of the International Conference

on "Computer Science and Information Technologies" (CSIT-2009), Conference for Young Astronomers "50 Years of Cosmic Era: Real and Virtual Studies of the Sky" in 2011, "Relation of Astronomy to other sciences, culture and society" (RASCS) meeting in 2014, "Astronomical Surveys and Big Data" (ASBD) in 2015 (and ASBD-2 in 2020), ArVO-GAVO Workshops (2017-2019), 7th Byurakan International Summer School for Young Astronomers (7BISS) "Astronomy and Data Science" in 2020 were organized. PhD studies of young computer scientists on astronomical/astrophysical subjects were conducted and a number of software systems was created and a number of tasks were fulfilled. Astroinformatics infrastructural department was established in 2017 in BAO at present led by one of the authors (GAM). A number of projects were conducted and accomplished, including:

- ANSEF project PS-450 "Digitization of the First Byurakan Survey" in 2002;
- CRDF project ARP1-2849-YE-06 "Digitized First Byurakan Survey and Armenian Virtual Observatory" with Cornell University, N.Y., USA in 2007-2010;
- ISTC project ISTC A-1451 "Development of Scientific Computing Grid on the Base of Armcluster for South Caucasian Region" in collaboration with IIAP in 2007-2009;
- ANSEF project PS-702 "Science with Armenian Virtual Observatory" in 2007;
- ISTC project ISTC A-1606 "Development of Armenian-Georgian Grid Infrastructure and applications in the fields of high energy physics, astrophysics and quantum physics" in collaboration with IIAP in 2008-2010;
- ANSEF project PS 2968 "Study of Multiwavelength Properties of Markarian Galaxies using Virtual Observatory" in 2012;
- COST Action TD1403 Big Data Era in Sky and Earth Observation (BigSkyEarth) in 2015-2019 (a number of secondments for participation in meetings and schools were held, as well as Small Term Scientific Missions, STSM);
- BAO Plate Archive Project (PAP) is active since 2015 and will end in 2021 with full digitization of BAO archival photographic plates (taken in 1947-1991), creation of an electronic database and an interactive sky map for future investigations;
- ArVO-GAVO (MES-BMBF, BAO with ARI Heidelberg) collaborative research project "Building a high-performance research environment through German and Armenian Astrophysical Virtual Observatories" in 2017-2019 [15].

A number of refereed and conference papers based on Astroinformatics and VO research have been published [16-25]. They give the results of studies using Astroinformatics and VO tools, related projects and other activities.

Conclusion

In table 1 we give a comparative list of the largest astronomical surveys and catalogues showing the Big Data progress in astronomy during (mainly) 2000s.

Astronomy may be regarded as the leader of Inter- and Multi-Disciplinary Sciences, as most of the natural sciences are developing based on new data coming from the Universe provided by Astronomy. Astrophysics, Astrochemistry, Astrobiology, Planetary Science (Astrogeology), Astroinformatics and other fields are being rapidly developed and play an important role in understanding of the nature.

In this paper we focused on Astronomy and Data/Computer Science and discussed many aspects of Big Data coming from the Space and their analysis and usage for various science disciplines.

As the trends of science development, one can regard a number of developments of both individual fields of natural sciences, which is already gradually happening and the development of science in general:

- Establishment and further development of interdisciplinary sciences between individual science disciplines and Astronomy (like Astrophysics, Astrochemistry, Astrobiology, Planetology, etc.);
- Further development of Big Data science and computer technologies based on new data coming from the Space and being used for various science fields. Development of e-Science like the creation of Virtual Observatories (VOs) in Astronomy;
- Integration of the scientific data and all information to combined and homogeneous databases, like CODATA and WDS created by the International Science Council (ISC).

In all these trends both astronomy and computer science play a decisive role, as astronomy is the field providing vast amount of data from the Universe useful for all science disciplines, namely

Survey or Catalogue	Short	Years	Range	Number of objects	Data Volume
Digitized First Byurakan Survey	DFBS	2002-2007	opt	20 000 000	400 GB
Gaia Early Data Release 3	Gaia EDR3	2013-2020	opt	1 811 709 771	1.4 TB
Palomar Digital Sky Survey	DPOSS	1983-2006	opt	1 050 000 000	3 TB
Two Micron All-Sky Survey	2MASS	1997-2001	NIR	470 992 970	10 TB
Green Bank Telescope	GBT	2000-2020	radio		20 TB
Galaxy Evolution Explorer	GALEX	2003-2012	UV	65 266 291	30 TB
Sloan Digital Sky Survey Data Release 16	SDSS DR16	2000-2020	opt	932 891 133	40 TB
Wide-field Infrared Survey Explorer (AllWISE)	WISE	2009-2011	IR	747 634 026	175 TB
SkyMapper Southern Sky Survey	SkyMapper	2008-2020	opt	500 000 000	500 TB
Panoramic Survey Telescope and Rapid Response System, expected	PanSTARRS	2010-2020	opt	1 919 106 885	~40 PB
Large Synoptic Survey Telescope/Vera Rubin Observatory, expected	LSST/ VRO	2022	opt	37 000 000 000	~200 PB
Square Kilometer Array, expected	SKA	2027	radio	4 000 000 000	~4.6 EB

Table 1: Big data in astronomy: the largest astronomical surveys and catalogues.

Physics, Chemistry, Biology, Geology and Informatics itself and computer science is the one handling in a modern way all this data and providing tools for efficient science studies and results.

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