Astronomical Surveys and Active Galaxies

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Abstract

Astronomical Surveys are the main source for discoveries in astronomy. We are giving the most important parameters the significance of the surveys, their main products: images, photometric, spectroscopic and other data. Among the surveys, namely extragalactic ones, most important are those for Active Galaxies (both Active Galactic Nuclei (AGN) and Starburst (SB) Galaxies), and particularly the AGN. These objects reveal many spatial and physical characteristics helping understanding the Universe. We give a brief review of our searches and studies for Active Galaxies.

Keywords: *Multiwavelength Astronomy – Astronomical Surveys – Big Data in Astronomy – Active Galaxies – Active Galactic Nuclei – Starburst Galaxies*

1. Astronomical Surveys

Most of astronomical discoveries in old times happened by chance. Having relatively narrow fields of view, astronomers, planning their observations could not make pre-selections among the vast number of objects. The invention of the wide-field telescope by Bernd Schmidt in 1930 led to construction of Schmidt telescopes with Field of Views (FoV) of several degrees (the area covering a few dozens of degrees) and systematic study of large fields, Astronomical Surveys. 8 big Schmidt telescopes were built in 1940s-1970s, and 4 modern ones were built in recent decades. The Byurakan Astrophysical Observatory (BAO) installed a 1m Schmidt telescope which was operational in 1960-1991 with its 3 objective prisms, the largest at the time. It was re-operated in 2015 with a new equipment for multi-band photometry and digital receiver.

The Importance of Astronomical Surveys is very high. Here are the main arguments and justifications:

- Discovery of new cosmic objects
- Distinguishing types of cosmic objects and their abundance in the Universe
- Spatial distribution: Stellar (Galactic) Astronomy and Extragalactic Astronomy (including Cosmology); as well as kinematics and dynamics
- The geometry of Space
- Luminosity functions of Cosmic objects, their evolution
- The development of Multiwavelength and Multimessenger Astronomy
- Statistics of different objects and their properties

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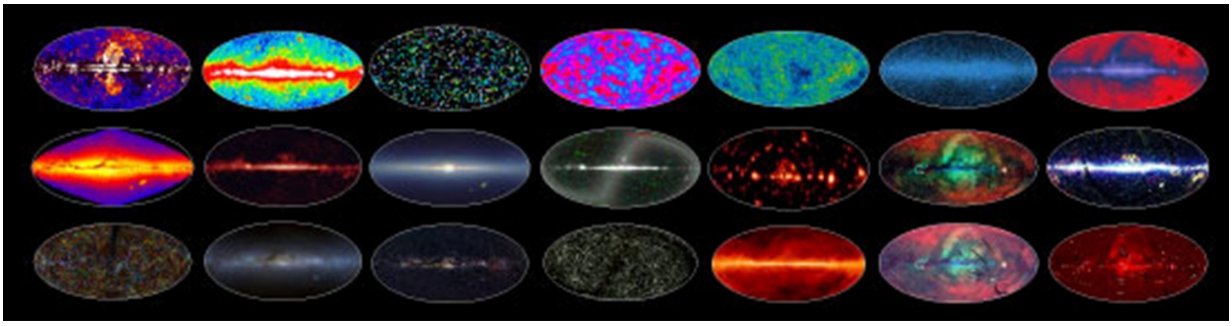
- Revelation of astrophysical laws and regularities based on large statistics

The main parameters of Astronomical Surveys are:

- Method (photometric, multiband, multiwavelength, spectroscopic: objective prism, polarimetric), methodology
- Sky area: location and coverage (all-sky, large area, deep surveys in small areas)
- Wavelength range (otherwise, given in energies – for high-energy range, or frequencies – mostly for radio)
- Spatial and spectral resolution, spectral dispersion
- Sensitivity (in fluxes, energies, etc.) / limiting magnitude
- Completeness (detection limit, classification limit)



2. Wide Field Plate Data Base (WFPDB)

In the WFPDB (www.skyarchive.org), there are 414 archives, 2,204,725 plates from 125 observatories, obtained between 1879 and 2002 (the digital observations started in early 1990s and now they are active in all modern telescopes). They include 2,128,330 direct and 64,095 objective prism plates. Among the biggest plate collections there are: Harvard (USA) – 600,000 plates; Sonnenberg (Germany) – 270,000; Italy (all Italian archives) – 87,000; Kyiv (Ukraine) – 85,000; SAI (Moscow, Russia) – 50,000; etc. BAO archive has a collection of 37,500 plates.

Among the wide field observations and all-sky and/or large area astronomical surveys, one should mention the Palomar Observatory Sky Surveys (POSS), namely POSS1 and POSS2. Based on these observations, a number of catalogs and databases were built (APM, MAPS, USNO, GSC, etc.).

3. Multiwavelength Astronomy

3.1. Gamma-ray Astronomy and cosmic gamma-ray sources

Among gamma-ray observatories, one should mention the CGRO – Cosmic Gamma Ray Observatory, 1990 that provided ~1300 discrete gamma-ray sources; and its 2704 BATSE detected gamma-ray bursts.

Later on, GLAST (Fermi, 1873 sources), INTEGRAL (723 sources), Swift (9387 sources), BeppoSAX (1087 sources) and some others were launched and provided more gamma-ray sources. Many of them are still unknown.

3.2. X-ray Astronomy and cosmic X-ray sources

ROSAT is among the most important X-ray telescopes and X-ray surveys, especially if considering the importance of all-sky surveys. ROSAT made an all-sky X-ray survey in 0.1-2.4 keV energy range and resulted in these catalogs:

- ROSAT All-Sky Survey Bright Source Catalogue (ROSAT BSC). 18,806 sources (Voges et al. 1999)

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- ROSAT All-Sky Survey Faint Source Catalogue (ROSAT FSC). 105,924 sources (Voges et al. 2000)

In Table 1, we give the most important X-ray surveys and projects, mostly the all-sky and large area ones.

Telescope	Country	Years	Energy (keV	Results	Number of sources
Uhuru (SAS-1)	USA	1970-1973	2 - 20	Sky survey	339
HEAO-1	USA	1977-1979	0.25 - 10 000	Sky survey	842
Einstein (HEAO-2)	USA	1978-1981	0.2 - 20	Pointed deep observations	1435
EXOSAT	ESA	1983-1986	0.04 - 80	Sky survey	1210
Granat	France, Russia	1989-1999	2 - 100 000	Pointed deep observations, Sky survey	1551
ROSAT	Germany	1990-1999	0.07 - 2.4	Sky survey	124 730
ASCA (Astro-D)	Japan	1993-2001	0.4 - 10	Sky survey, spectral observations	1190
Rossi XTE (RXTE)	USA	1995-2012	2 - 250	Sky survey	321
BeppoSAX	Italy	1996-2002	0.1 - 300	Gamma bursts, broad-band spectroscopy	253
Chandra (CXO)	USA	1999-pres.	0.07 - 10	Pointed deep observations	380 000
XMM-Newton	ESA	1999-pres.	0.25 - 12	Pointed deep observations	372 728
INTEGRAL	ESA	2002-pres.	15 - 10 000	Pointed deep observations	1126
Swift	USA	2004-2008	0.2 - 150	Sky survey, gamma bursts	1256

Table 1. The list of the most important X-ray surveys and projects.

The list of known types of cosmic X-ray sources is the following:

- Solar System bodies
- bright stars
- stellar hot coronae
- late-type (M) dwarfs
- white dwarfs (WD) and hot subdwarfs
- X-ray binaries
- intermediate mass X-ray binaries
- cataclysmic variables (CV)
- magnetars
- Supernovae remnants (SNR)
- bright galaxies
- Active Galactic Nuclei (AGN)
- blazars
- clusters of galaxies

3.3. UV Astronomy and cosmic UV sources

In Ultraviolet (UV), less surveys have been carried out, however, the NASA Galaxy Evolution Explorer (GALEX) was rather efficient and productive; it observed the sky in two wavelength bands; Far-UV (FUV) and Near-UV (NUV) and provided the catalogs AIS (All-sky Imaging Survey) and MIS (Medium-depth Imaging Survey), totaling in 82,992,086 UV sources (Bianchi et al. 2017). The immediate neighboring to optical short UV wavelength range was observed by Hubble Space Telescope (HST), however no systematic all-sky survey was made.

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3.4. IR Astronomy and cosmic IR sources

Among the most important ones are:

- Two Micron All Sky Survey (2MASS) (Cutri et al. 2003). J(1.25), H(1.65), and K_s(2.17), brighter than 1mJy sources (to a 3 sigma limiting sensitivity of 17.1, 16.4 and 15.3 mag in the three bands, respectively), resolution 2", 470,992,970 sources, including ~300,000,000 stars and 1,650,000 galaxies
- IRAS Point Source Catalog (PSC): all-sky, 12, 25, 60, 100 μm (0.4, 0.5, 06, 1.0 Jy sensitivity limit), 245,889 sources (IRAS Catalog of Point Sources, 1986)
- IRAS Faint Source Catalog (FSC): high galactic latitudes, 180,000 sources (Moshir et al. 1990)
- AKARI (ASTRO-F or IRIS – InfraRed Imaging Surveyor, Feb 2006), 68.5 cm telescope, wavelength range 2-180 μm, 13 bands.
- Infrared Camera (IRC), 9 and 18 μm, sensitivity ~ 50 and 120 mJy. Spatial resolution is about 9.4", 877,091 sources (851,189 observed at 9 μm and 195,893 at 18 μm)
- Far-Infrared Surveyor (FIS), 65, 90, 140, and 160 μm, ~430,000 sources
- Wide-Field Infrared Survey Explorer (WISE). NASA, 14.12.2009. 40 cm (16 inch), Four infrared wavelength bands at 3.4, 4.6, 12 and 22μm. The FoV is 47 arcmin wide. 747,634,026 sources

We give in Table 2 the list of the most important IR surveys and projects and in Table 3, the IR ranges and their characteristics, as well as cosmic objects that radiate in the given wavelength range.

Telescope or project	**Countries**	**Years**	$\lambda(\mu)$	**Results**	**Number of sources**
IRAS	USA	1983	8-120	sky survey	405 769
ISO	Europe	1996	2.5-240	IR spectra	~30 000
Spitzer	USA	2003	3-180	IR deep images and spectra	4 261 028
AKARI	Japan	2006	7-180	sky survey	1 298 044
Herschel	Europe	2009	55-672	far IR	
WISE	USA	2010	3-28	sky survey	563 921 584
DENIS	Europe	1996	0.82, 1.24, 2.16	Southern sky survey	355 220 325
2MASS	USA	2003	1.24, 1.66, 2.16	sky survey	470 992 970

Table 2. The list of the most important IR surveys and projects.

Spectral range	$\lambda(\mu)$	**T (K)**	**Studied cosmic objects**
Near IR	(0.76-1) - 5	740 - (3000-5200)	cold red stars, stellar envelopes,planetary nebulae
Mid IR	5 - (25-40)	(92.5-140) - 740	planets, comets and asteroids, stellar radiation heated dust, protoplanetary disks, gas-dust nebulae
Far IR	(25-40) - (200-350)	(10.6-18.5) - (92.5-140)	cold gas radiation, central regions of galaxies, very cold molecular clouds

Table 3. IR ranges and their characteristics, as well as cosmic objects that radiate in the given wavelength range.

3.5. Radio Astronomy and cosmic radio sources

Radio astronomy has been mainly done from ground-based observations. Here are the most important radio all-sky surveys:

- **GB6:** 6cm (4.85GHz), 0<DEC<75, S⩾18mJy, 75,162 sources

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- **87GB:** (Gregory et al. 1991), also 6cm (4.85GHz), 54,579 sources
- **Westerborck Northern Sky Survey (WENSS, WN):** (de Bruyn et al. 1998), 92cm (330MHz), 229,420 sources
- **NVSS:** (Condon et al. 1998): all-sky at 21cm (1.4GHz), S>2.5mJy, 1-7 arcsec (>15mJy-2.5mJy), 1,773,484 sources
- **FIRST:** 10,000 sq.deg., 21cm (1.4GHz), S>1mJy, 5 arcsec, high galactic latitudes (>30deg), 811,117 sources (White et al. 1998)
- **8C:** A deep 38-MHz radio survey of the area declination >+60 deg (Rees 1990)

At present astronomers distinguish the *sub/mm* and *mm* wavelength range between IR and radio. A few telescopes worked in this range (ex. James Clerk Maxwell Telescope (JCMT) in Hawaii, 15m diameter) and later on a few large facilities were built, most important among them – ALMA (Atacama Large Millimeter/submillimeter Array, ESO) in Chile, an interferometer array of 54×12.0m and 12×7.0m antennas.

4. The overall picture of the astronomical surveys

In Figure 1 we give the distribution of astronomical surveys by number of objects and limiting magnitude. Gaia has provided a catalog with the largest number of objects, 1.8 billion objects. A few others also have more than 1 billion objects (ex. USNO-B1.0). They provide objects till 22-23 magnitude. On the other hand, we have deep surveys (HDF, HUDF, SDF, FDF, GOODS, COSMOS) providing smaller number of objects but with limiting magnitudes up to 30 and fainter.

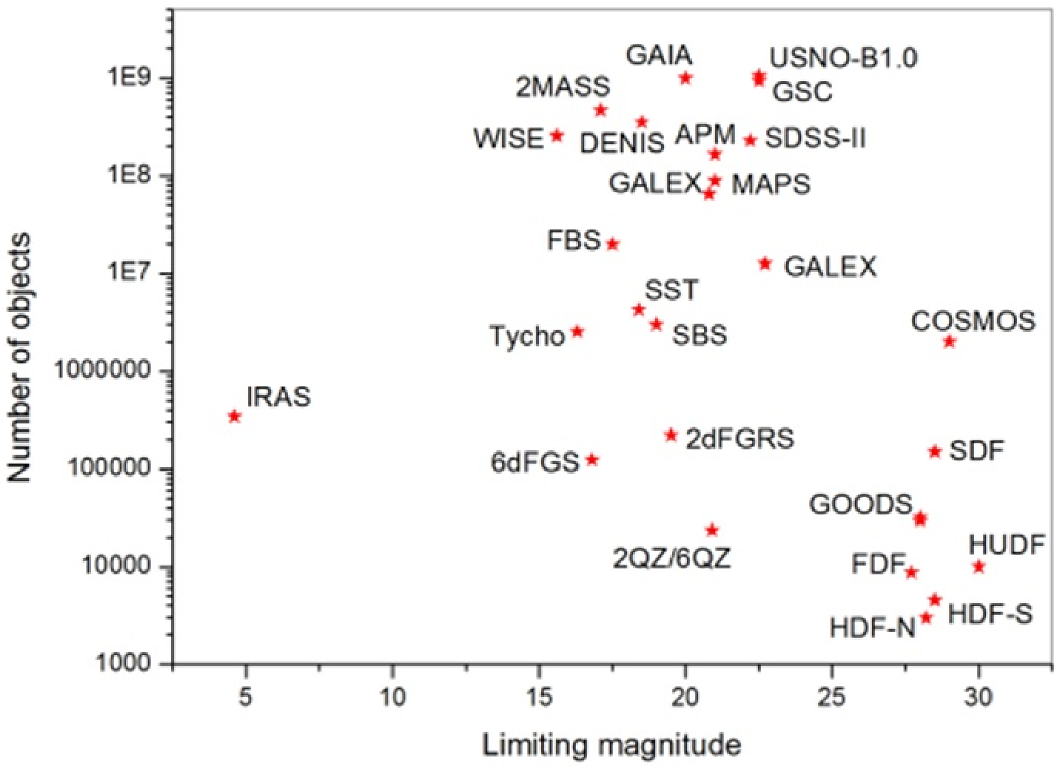

Figure 1. The distribution of astronomical surveys by number of objects and limiting magnitude.

Table 4 gives the list of all-sky and large-area astronomical catalogs in increasing wavelength range from gamma-rays to radio built on the basis of surveys (both ground-based and Space) and their main parameters: name, years, spectral range, sky area covered, sensitivity (limiting magnitude) and the number of sources. Though 44 catalogs are listed, the list is still not complete.

We give in Table 5 and Figure 2 the numbers of catalogued astronomical objects at different wavelength ranges and their distribution. Though the figure is in logarithmic scale, however the numbers are so different that some ranges are not even seen. But not only the number of objects is important and not only the

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numbers of objects make up Big Data in astronomy. Very often, we obtain hundreds, thousands, and millions of data units from one single astronomical object, ex. when we obtain its high-resolution spectrum or make a decomposition analysis of the spectral lines, where hundreds of profiles are checked and analysed for each solution (Figures 3 and 4).

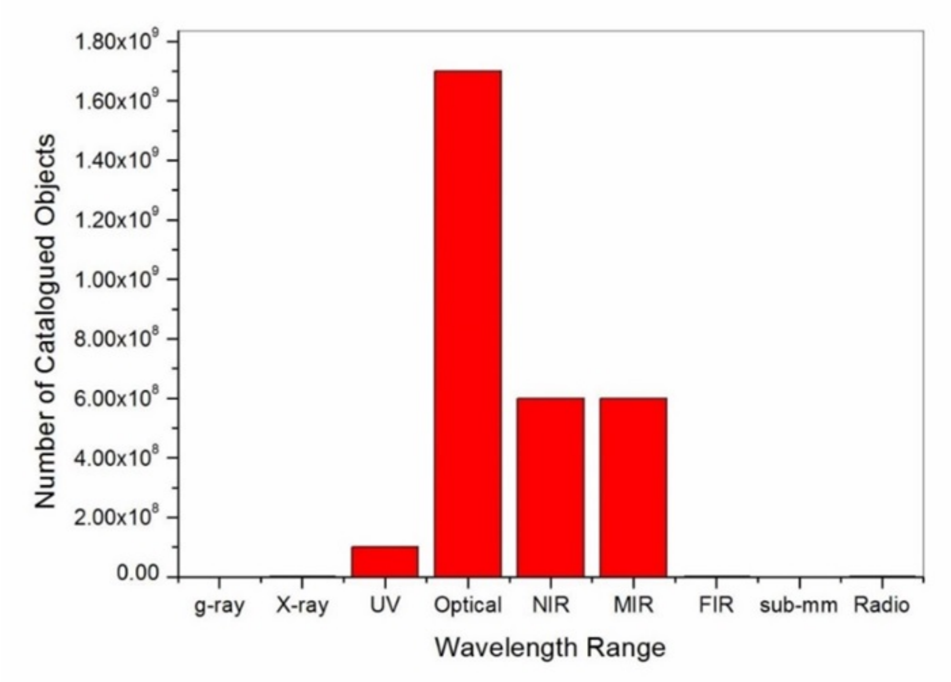

Figure 2. The distribution of the numbers of catalogued astronomical objects at different wavelength ranges.

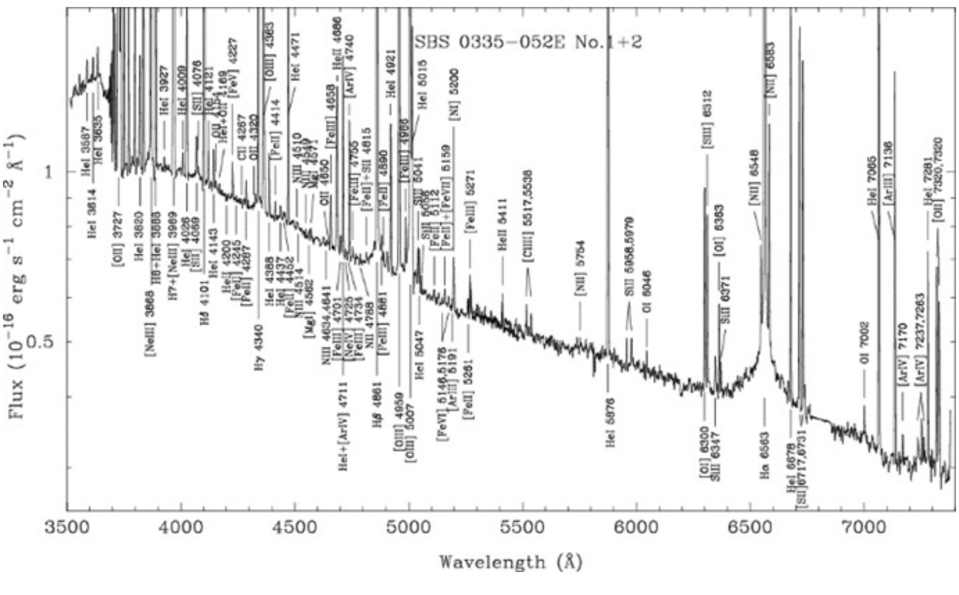

Figure 3. . The high-resolution spectrum of the BCDG SBS 0335-052E, where hundreds of spectral lines can be distinguished and measured.

5. Big Data in Astronomy

Volume – the quantity of generated and stored data. The size of the data determines the value and potential insight, whether it can be considered big data or not.
Variety - the type and nature of the data. This helps people who analyze it to effectively use the resulting insight. Big data draws from text, images, audio, video; plus, it completes missing pieces through data fusion.

Velocity - in this context, the speed at which the data is generated and processed to meet the demands and challenges that lie in the path of growth and development. Big data is often available in real-time.

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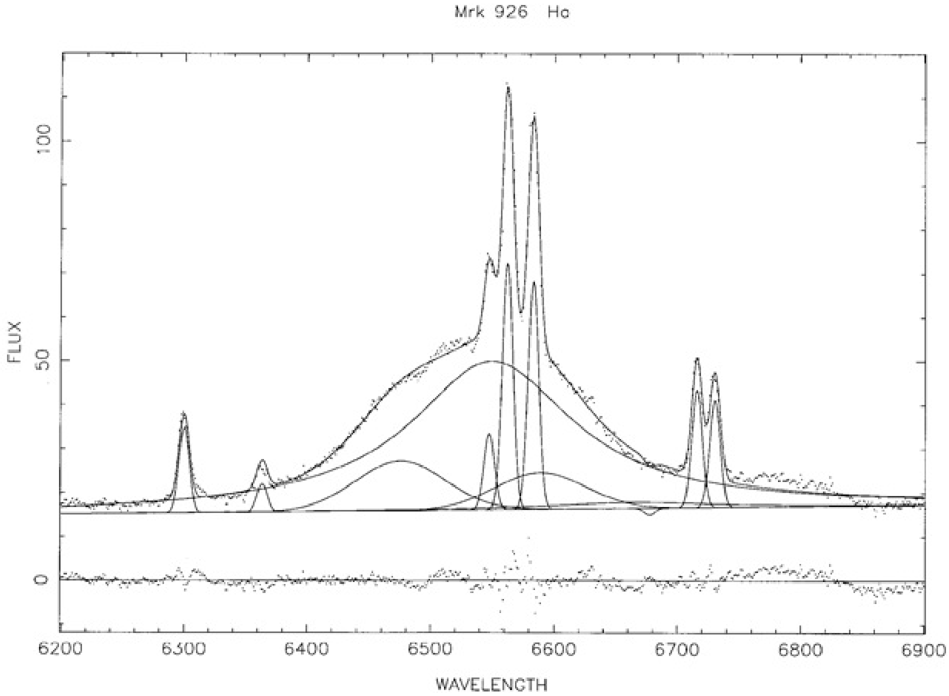

Figure 4. Decomposition analysis of the spectral lines for Mrk 926 H-alpha region with one of the solutions, where H-alpha summarizing profile is presented as having 3 broad line components and 1 narrow line.

Veracity - the data quality of captured data can vary greatly, affecting the accurate analysis.

In Astronomy, all these criteria are well met; we have the largest amount of data coming from the Universe, there is a wide variety of them, the velocity of accumulation is rather high as well and the veracity is maintained by astronomical standards, Virtual Observatory (VO) methods, etc. To give an understanding of data volumes in Astronomy, we give in the Table 6 a number of important astronomical projects with their information volumes.

6. Active Galaxies

Most of the surveys given above have tight relation to Active Galaxies, especially the non-optical ones, as many Active Galaxies strongly radiate in gamma-ray, X-ray, UV, IR and radio.

We can substantiate the importance of Active Galaxies as follows:

- The origin and evolution of galaxies
- Morphology
- Interacting and Merging galaxies
- Star Formation in galaxies
- Luminosity function of galaxies
- Radiation mechanisms
- Radiation mechanisms
- Presence of relativistic jets
- The theory of Super-Massive Black Holes (SMBH)

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- Energetic resources
- The cosmological role of active galaxies

7. Recent Results related to Studies of Active Galaxies in Byurakan

Studies for Active Galaxies have been for many years one of the main research topic in Byurakan. Since 1990s, we have introduced the multiwavelength approach to these studies and many new interesting results appeared. In Table 7, we give the list of all our group works related to multiwavelength search and studies of active galaxies. The consecutive columns present: years of the projects, authors involved, survey name or description and its short name, objectives and number of objects discovered/revealed or studied.

These studies reveal many important characteristics of AGN and SB, as well as allow revealing outliers at different distributions and diagrams, which very often appear to be unique or rare objects.

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Survey, Catalogue	**Years**	**Spectral range**	**Sky area (deg^2)**	**Sensitivity (mag/mJy)**	**Number of sources**
Fermi-GLAST	2008-2014	10MeV-100GeV	Alll-sky		3,033
CGRO	1991-1999	20keV-30GeV	All-sky		1,300
INTEGRAL	2002-2014	15keV-10MeV	All-sky		1,126
Swift	2004-2008	14-150keV	All-sky		84,979
XMM-Newton	1999-2014	0.25-12keV	Pointed		372,728
Chandra	1999-2014	0.07-10keV	Pointed		380,000
ROSAT BSC	1990-1999	0.07-2.4keV	All-sky		18,806
ROSAT FSC	1990-1999	0.07-2.4keV	All-sky		105,924
GALEX AIS	2003-2012	1344-2831A	21435	20.8”	65,266,291
GALBX MIS	2003-2012	1344-2831A	1,579	22.7”	12,597,912
APM	2000	opt b, r	20,964	21.0”	166,466,987
MAPS	2003	opt O, E	20,964	21.0”	89,234,404
USNO-A2.0	1998	opt B, R	All-sky	21.0”	526,280,881
USNO-B1.0	2003	opt B, R, I	All-sky	22.5”	1,045,913,669
SuperCOSMOS	2001	opt B, R, I	All-sky	22.5”	1,900,000,000
GSC 2.3.2	2008	opt j, V, F, N	All-sky	22,5”	945,592,683
FBS	1965-1980	3400-6900A	17,056	17,5”	20,000,000
SBS	1978-1991	3400-6950A	965	19.0”	3,000,000
HQS	1985-1997	3400-5300A	14,000	19,0”	16,000,000
HES	1990-1996	3400-5300A	9,000	18,0”	5,000,000
Tycho-2	1989-1993	opt BT, VT	All-sky	16,3”	2,539,913
SDSS photo	2000-2015	opt u, g, r, i, z	14,555	22.2”	932,891,133
SDSS spectro	2000-2015	3000-10800A	14,555	17.7”	4,355,200
DENIS	1996-2001	0.8-2.4μm	16,700	18.5”	355,220,325
2MASS PSC	1997-2001	1.1-2.4μm	All-sky	17.1”	470,992,970
2MASS ESC	1997-2001	1.1-2.4μm	All-sky	17”1	1,647,599
WISE	2009-2013	3-22μm	All-sky	15.6”	747,634,026
AKARI IRC	2006-2008	7-26μm	38,778	50my	870,973
Spitzer	2003-2009	3-180μm	Pointed	0.6μJy	4,261,028
IRAS PSC	1983	8-120μm	39,603	400mJy	245,889
IRAS FSC	1983	8-120μm	34,090	400mJy	173,044
IRAS SSSC	1983	8-120μm	39,603	400mJy	16,740
AKARI FIS	2006-2008	50-180μm	40,428	550mJy	427,071
Herschel	2009-2013	55-672μm	Pointed	6mJy	340,968
ALMA	2011-2014	0.3-9.6mm	Pointed	50μJy	
Planck	2009-2011	0.35-10mm	All-sky	183mJy	33,566
WMAP	2001-2011	3-14mm	All-sky	500mJy	471
GB6	1986-1987	6cm	20,320	18mJy	75,162
NVSS	1998	21cm	33,827	2.5mJy	1,773,484
FIRST	1999-2015	21cm	10,000	1mJy	946,432
SUMSS	2003-2012	36cm	8,000	1mJy	211,080
WENSS	1998	49/92cm	9,950	18mJy	229,420
7C	2007	198cm	2,388	40mJy	43,683
VLA LFSS	2007	406cm	All-sky	700mJy	92,963

Table 4. The list of all-sky and large-area astronomical catalogs in increasing wavelength range from gamma-rays to radio and their main parameters.

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Wavelength range	**Number of objects**
Gamma-ray	10 000
X-ray	1 500 000
UV	100 000 000
Optical	2 400 000 000
NIR	600 000 000
MIR	600 000 000
FIR	500 000
Sub-mm/mm	100 000
Radio	2 000 000

Table 5. The numbers of catalogued astronomical objects at different wavelength ranges.

Surveys, Projects	**Short**	**Range**	**Information Volume**
Digitized First Byurakan Survey	DFBS	opt	400 GB
Digital Palomar Observatory Sky Survey	DPOSS	opt	3 TB
Two Micron All-Sky Survey	2MASS	NIR	10 TB
Green Bank Telescope	GBT	radio	20 TB
Galaxy Evolution Explorer	GALEX	UV	30 TB
Sloan Digital Sky Survey	SDSS	opt	140 TB
SkyMapper Southern Sky Survey			500 TB
Panoramic Survey Telescope and Rapid Response System, expected	PanSTARRS	opt	40 PB
Large Synoptic Survey Telescope, expected	LSST	opt	200 PB
Square Kilometer Array, expected	SKA	radio	4.6 EB

Table 6. Data volumes in big astronomical projects.

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Years	Authors	Survey	Short	Objectives	Number
1986-2001	H. Abrahamian, A. Mickaelian	First Byurakan Survey, 2nd Part	FBS BSOs	QSOs and Seyferts	1103
1994-2010	A. Mickaelian et al.	Byurakan-IRAS Galaxies	BIG	IRAS galaxies	1278
2001-pres.	A. Mickaelian	Bright AGN	AGN	Statistical studies of bright AGN	10 000
2002-2006	A. Mickaelian et al.	Byurakan-Hamburg-ROSAT Catalogue BHRC	BHRC	ROSAT sources	2791
2003-2010	A. Mickaelian et al.	Spitzer ULIRGs	Spitzer	ULIRGs	32
2010-pres.	A. Mickaelian et al.	Markarian galaxies	Mrk	Markarian galaxies	1544
2010-pres.	G. Paronyan, A. Mickaelian, et al.	HRC/BHRC AGN content	X-ray AGN	X-ray AGN	4253
2015-pres.	H. Abrahamyan, G. Mikayelyan, A. Mickaelian	IRAS PSC/FSC Combined Catalog extragalactic sources	IRAS	IRAS galaxies	145 902
2013-2018	H. Abrahamyan, A. Mickaelian et al.	Variable radio sources at 1400 MHz	NVSS/FIRST	Variable radio sources	6301
2013-pres.	A. Mickaelian, G. Paronyan, et al.	Search for X-ray/ radio AGN	ROSAT/NVSS	X-ray/ radio AGN	9193
2014-pres.	H. Abrahamyan, A. Mickaelian et al.	MW study of Blazars	BZCAT	Blazars	3561
2018-pres.	G. Mikayelyan, A. Mickaelian et al.	IRAS PSC/FSC Combined Catalogue ULIRG/HLIRG	ULIRG/ HLIRG	High luminosity IR galaxies	114
2001-2007	A. Mickaelian, et al.	Fine analysis of AGN spectra	Bright AGN	Physical properties of AGN	90
2002-pres.	A. Mickaelian, et al.	Search for new AGN in DFBS	DFBS AGN	New bright active galaxies	10 000
2006-pres.	A. Mickaelian, et al.	Fine classification of active galaxies	Mickaelian classification	Active galaxies accurate types/subtypes	10 000

Table 7. The list of BAO "Astronomical Surveys" research department projects related to multiwavelength search and studies of active galaxies.

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