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Multiwavelength search for and studies of active galaxies

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We present surveys and related studies of active galaxies carried out at the NAS RA V. Ambartsumian Byurakan Astrophysical Observatory (BAO). This has been one of the main research subjects at BAO for many years since the mid-1950s, when Viktor Ambartsumian suggested the hypothesis of the activity of the galactic nuclei. A number of surveys of and searches for active galactic nuclei (AGN) and other active galaxies were accomplished during the 1960s–1980s. Since the mid-1990s, our research group carried out new surveys and studies of active galaxies based on the First Byurakan Survey (FBS or Markarian Survey) and then a number of others. Here we also present the recent results of studies on active galaxies (both AGN and starbursts) by the Extragalactic Group of the Byurakan Astrophysical Observatory (BAO) Research Department "Astronomical Surveys". These studies are characterized by a multiwavelength approach to the statistical analysis of a large amount of data obtained in different wavelengths, from X-ray to radio. A fine classification scheme for active galaxies has also been suggested. Results on HRC/BHRC sample objects (optical identifications of ROSAT X-ray sources), studies of Markarian galaxies in UV and multiwavelength SEDs, abundance and star formation determinations in Mrk galaxies from SDSS spectra, revised optical classification of LINERs, study and classification of SDSS spectra for Byurakan-IRAS galaxies, summary of observations and study of Byurakan-IRAS galaxies (BIG objects), discovery of new bright ULIRGs from the IRAS PSC/FSC Combined Catalogue and their spectral classification, radio variable sources at 1400 MHz and their optical variability, classification of BZCAT objects having uncertain types (BZU objects), and optical variability of blazars are presented.

Keywords: Active galaxies, AGN, starburst galaxies, quasars, Seyfert galaxies, LINERs, composite spectrum objects, HII, IRAS galaxies, variable sources

1 Introduction

The Byurakan Astrophysical Observatory (BAO) has always been famous for surveys of active galaxies. These search works started just after Viktor Ambartsumian's

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hypothesis of active galactic nuclei (AGN) in the mid-1950s. At present Markarian, Arakelian and Kazarian galaxies, Shahbazian compact groups of compact galaxies are well known. Many active galaxies were discovered from the Second Byurakan Survey (SBS). Thousands of new objects have been published as Byurakan-IRAS or Byurakan-Hamburg-ROSAT sources. Here we give a list of the most important surveys carried out in the 1960s–2000s.

Byurakan Surveys of active galaxies (1960s–2000s):

- **First Byurakan Survey (FBS) – Markarian Survey**, *1515 UVX (Markarian, Mrk) galaxies; B. E. Markarian, V. A. Lipovetsky, J. A. Stepanian, 1965–1980*: 1515 UV-excess (UVX) galaxies, Markarian galaxies' catalogues *(Mazzarella & Balzano 1986, Markarian et al. 1989).*
- **High Surface Brightness Galaxies – Arakelian Galaxies (Akn)**, *621 galaxies; M. A. Arakelian 1975.*
- **Second Byurakan Survey (SBS) – QSOs, UV-excess and Emission-line Galaxies;** *B. E. Markarian, J. A. Stepanian, V. A. Lipovetsky, L. K. Erastova, V. H. Chavushian, 1978–1991:* UVX and emission line galaxies, QSOs (∼3600 objects, including 1863 galaxies; 600 QSOs, 170 Sy, 12 BLL).
- **Shahbazian's Compact Groups of Compact Galaxies;** *377 objects; Baier et al. 1974.*
- **Kazarian Survey:** 706 UVX (Kazarian) galaxies; *Kazarian et al. 2010.*
- **Second Part of the FBS: Blue Stellar Objects (FBS BSOs)**, *1103 objects; H. V. Abrahamian, A. M. Mickaelian, 1987–1996: QSOs and Seyferts.*
- **Optical Identification and Study of IRAS Sources**, *1278 Byurakan-IRAS Galaxies (BIG objects); A. M. Mickaelian et al., 1995–2004: ULIRGs, AGN and SB.*
- **Optical Identification and Study of ROSAT Sources;** *4253 ROSAT AGN from BHRC (Byurakan-Hamburg-ROSAT Catalogue); A. M. Mickaelian et al., 2002–2006: AGN and SB.*

2 Multiwavelength search for and studies of active galaxies

Recent results of the Extragalactic Group of BAO Research Department "Astronomical Surveys" are related to multiwavelength studies of active galaxies using a large amount of data from X-ray, UV, optical, IR and radio ranges, with heavy use of cross-correlations, classifications of activity types using our observations and SDSS spectra, building diagnostic diagrams, spectral energy distributions (SEDs), etc. Results on HRC/BHRC sample objects (optical identifications of ROSAT X-ray sources), studies of Markarian galaxies in UV and multiwavelength SEDs, abundance and star formation determinations in Mrk galaxies from SDSS spectra, revised optical classification of LINERs, study and classification of SDSS spectra for Byurakan-IRAS galaxies (BIG objects), summary of observations and study of Byurakan-IRAS galaxies, discovery of new bright ULIRGs from the IRAS PSC/FSC Combined Catalogue and their spectral classification using SDSS spectra, radio variable sources at 1400 MHz and their optical variability, classification of BZCAT objects having uncertain types (BZU objects), and optical variability of blazars are given in individual sections.

2.1 First Byurakan Survey QSOs and Seyferts

After the publication of the FBS BSOs 11 lists, 2 papers were devoted to these studies related to bright QSOs and Seyferts, which comprise 12% of all FBS BSOs. In Paper I (Mickaelian et al. 1999), we compared the surface density of QSOs in the Bright Quasar Survey (BQS; Green & Schmidt 1983) and in the First Byurakan Survey (FBS) and concluded that the completeness of the BQS is of the order of 70% rather than 30–50% as suggested by several authors. A number of new observations recently became available, allowing a re-evaluation of this completeness. We now obtain a surface density of QSOs brighter than $B = 16.16$ in a subarea of the FBS covering ∼2250 deg^2, equal to 0.012 deg^{-2} (26 QSOs), implying a completeness of 53+/–10% (Mickaelian et al. 2001). Redshifts are in the range of 0.063–2.73, absolute magnitudes, $-20.3^m \ldots -29.9^m$. A new bright QSO ($B = 14^m$, Mabs = -24.6^m) at $z = 0.118$ was discovered.

2.2 Markarian galaxies in UV and multiwavelength studies

The results are given in (Mickaelian et al. 2018a). The UV properties of 1152 Markarian galaxies have been investigated based on GALEX data. These objects have been investigated also in other available wavelengths using multi-wavelength data from X-ray to radio. Using our classification for activity types for 779 Markarian galaxies based on SDSS spectroscopy, we have investigated these objects on the GALEX, 2MASS and WISE color–magnitude and color–color diagrams by the location of objects of different activity types and have revealed a number of loci. UV contours overplotted on the optical images revealed additional structures, particularly spiral arms of a number of Markarian galaxies. UV (FUV and NUV) and optical absolute magnitudes and luminosities have been calculated showing gradual transition from AGN to composites, HIIs and absorption line galaxies from (average M) -17.56^m to -15.20^m in FUV, from -18.07^m to -15.71^m in NUV and from AGN to composites, absorption line galaxies and HII from -21.14^m to -19.42^m in optical wavelengths and from (average L) 7×10^9 to 4×10^8 in FUV, from 1×10^{10} to 5×10^8 in NUV and from AGN to composites, absorption line galaxies and HII from 7×10^{10} to 1×10^{10} in optical wavelengths. We give in Figure 1 the distribution of GALEX FUV and NUV magnitudes by redshifts for 1152 Markarian galaxies.

2.3 Abundance and star formation determinations in Mrk galaxies from SDSS spectra

The results are given in (Gyulzadyan et al. 2018). We analyze the oxygen and nitrogen abundance and specific star formation rates (sSFR) in Markarian galaxies from Sloan Digital Sky Survey (SDSS) spectra. The Data Release 7 (DR7) of SDSS contains photometric data for more than 1000 and spectral information for more than 700 Markarian objects. The Mrk sample has played a central role in the task of distinguishing between the astrophysical different types of phenomena that occur in AGNs. In the course of the Markarian Survey, more than 200 Seyfert galaxies, and hundreds of starbursts, blue compact, and H II galaxies were discovered. The Markarian Survey remains perhaps the best-known source of such objects in the local

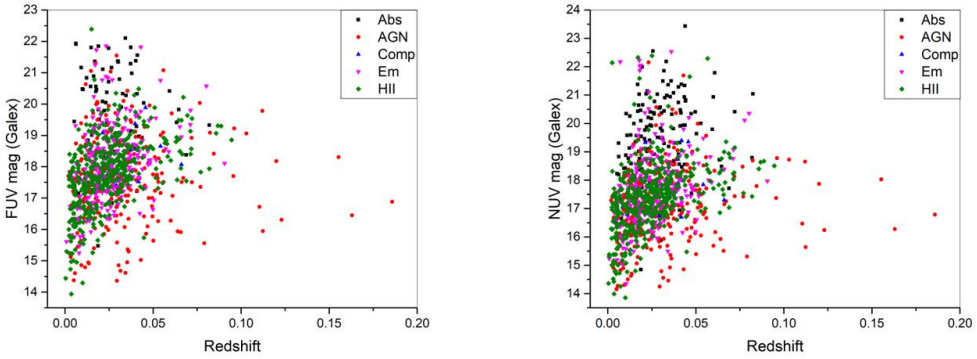


Figure 1 The distribution of GALEX FUV and NUV magnitudes by redshifts for Markarian galaxies. As expected, AGNs and composites are detected at higher redshifts due to their higher luminosities.

universe. We have measured their line fluxes and derived the O and N abundances using recent calibrations. We have compared the oxygen and nitrogen abundances derived from global emission-line Sloan Digital Sky Survey (SDSS) spectra of galaxies using (1) the Te method and (2) two recent strong-line calibrations: the ON (oxygen–nitrogen) and NS (nitrogen–sulphur) calibrations. The behaviour of the [N/H] ratio in underabundant regions strongly supports a partially primary origin of nitrogen. The star formation rate (SFR) is one of the main parameters used to analyze the evolution of galaxies through time. In the local Universe, the Hα luminosity derived from IFS observations can be used to measure SFR, at least in statistically significant, optically-selected galaxy samples, once stellar continuum absorption and dust attenuation effects are accounted for.

2.4 Activity types of galaxies selected from HRC/BHRC sample

The results are given in (Paronyan et al. 2018; 2019a; 2019b). In this study we carry out detailed spectral classification of 371 (173+198) AGN candidates from the Joint HRC/BHRC sample, which is a combination of HRC (Hamburg-ROSAT Catalogue) and BHRC (Byurakan-Hamburg-ROSAT Catalogue). These objects were revealed as optical counterparts for ROSAT X-ray sources; however, spectra for 371 of them are given in SDSS without definite spectral classification. We studied these 371 objects using the SDSS spectra and revealed the detailed activity types for them. Three diagnostic diagrams and direct examination of the spectra were used to obtain a more confident classification. We also identified these sources in other wavelength ranges and calculated some of their parameters. In Figure 2 we give examples of SDSS DR15 spectra for some classified HRC-BHRC objects.

We give in Table 1 the distribution of the activity types of objects for the Joint HRC/BHRC Catalogue.

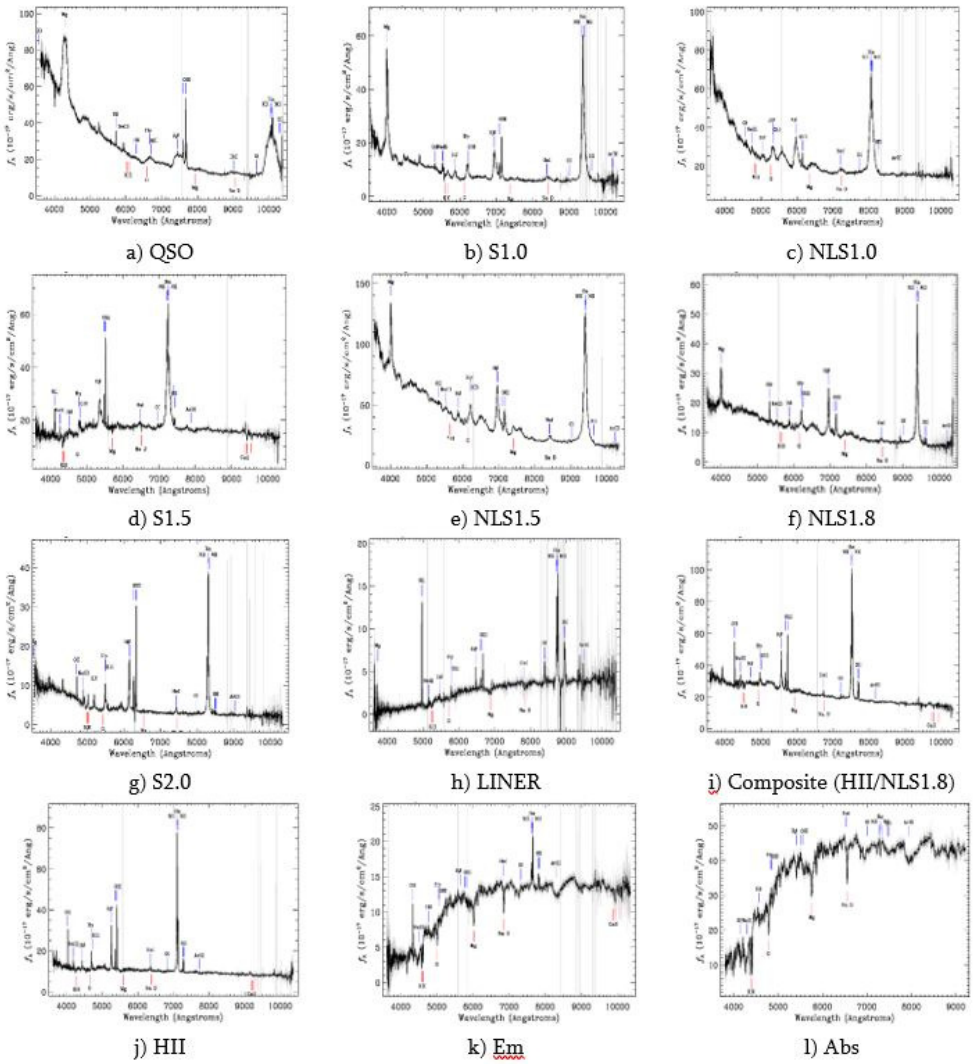


Figure 2 Examples of SDSS DR15 spectra for some HRC-BHRC objects. a) QSO, b) S1.0, c) NLS1.0, d) S1.5, e) NLS1.5, f) NLS1.8, g) S2.0, h) LINER, i) HII/NLS1.8, j) HII, k) Em, l) Abs.

2.5 Revised optical classification of LINERs

The results are given in (Abrahamyan et al. 2018a). This work is dedicated to a reclassification of LINERs. For our investigation we use the Véron–Cetty & Véron Catalogue, 13th edition. In this catalogue, 926 LINERs are included. Cross-correlation of these sources with SDSS DR14 gives 176 objects which have spectra in SDSS. Having medium-resolution spectra from SDSS we have reclassified these sources. As a result, 54% of these sources have changed their classification. We give in Figure 3 the dependence of absolute magnitude vs. redshift for LINERs.

Table 1 Distribution of activity types for all HRC/BHRC extragalactic objects using SDSS DR12 spectra and other available data.

Type	Number	Fraction (%)
BL Lac + HPQ	320+13	7.02
QSO	1309	27.59
Sy 1.0-1.5	1876	39.54
Sy 1.8-2.0	111	2.34
Sy:	37	0.78
LINER	21	0.44
AGN	82	1.73
AGN:	451	9.50
Starburst/HII	25	0.53
Abs	8	0.17
Bright galaxy	492	10.37
Total	**4745**	**100.0**

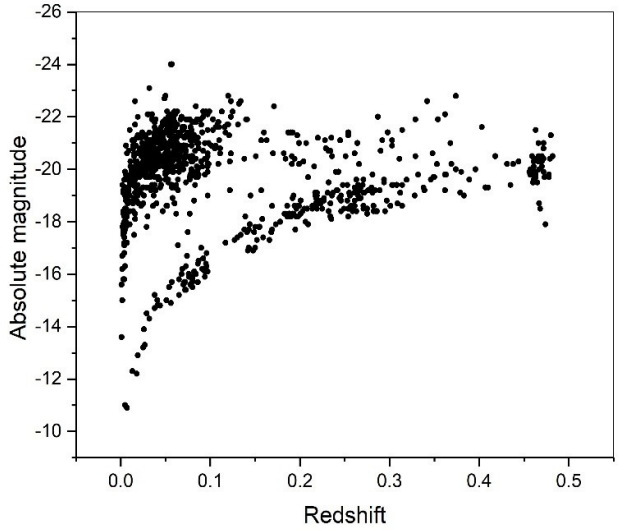


Figure 3 Absolute magnitude vs. redshift for LINERs.

2.6 Observations and study of Byurakan-IRAS galaxies

The results are summarized in (Mikayelyan et al. 2019a). A general analysis of optical spectroscopic data on 257 Byurakan-IRAS Galaxies (BIG objects) obtained with the BAO 2.6 m, SAO 6 m, OHP 1.93 m telescopes and taken from SDSS spectroscopic database was carried out. 149 star-formation regions (SB) galaxies, 42 galaxies with active nuclei (AGN), and 28 galaxies with a composite spectrum were identified. The spectra of 21 galaxies show signs of emission, but without the possibility of more precise determination of their activity type (we assign them as Em), 13 galaxies appear to have star formation rates that do not exceed normal (we assign them as

HII), and 3 are absorption galaxies (we assign them as Abs). We give in Table 2 the distribution of 257 BIG objects by activity types.

Table 2 Distribution of 257 BIG objects by activity types.

Activity type	Number of objects	%	Activity type	Number of objects	%
HII	149	58.0	AGN	13	5.1
Composite	22	8.6	Em	21	8.2
HII/LINER	4	1.5	Norm	13	5.1
HII/Sy	2	0.8	Abs	3	1.1
LINER	12	4.6	Unknown	1	0.4
Sy	17	6.6	**All**	**257**	**100.0**

In Figure 4, we give two examples of IRAS BIG pairs and multiples resolved by means of DSS2 images and in Figure 5, BAO 2.6 m telescope ByuFOSC focal reducer CCD image of BIG 284 = IRAS 12120+6838.

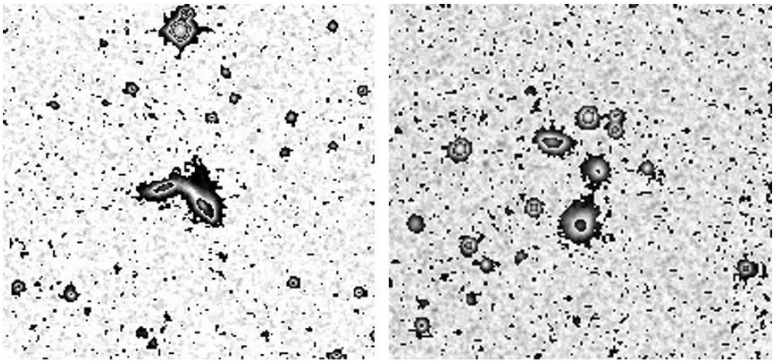


Figure 4 Two examples of IRAS BIG pairs and multiples resolved from DSS2 images.

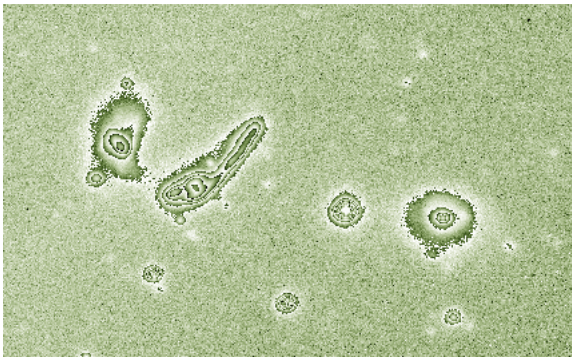


Figure 5 BAO 2.6 m telescope ByuFOSC focal reducer CCD image of BIG 284 = IRAS 12120+6838.

2.7 Study and classification of SDSS spectra for Byurakan-IRAS galaxies

The results are given in (Mickaelian et al. 2018). The sample of Byurakan-IRAS galaxies (BIG) has been created based on optical identifications of the IRAS Point Source Catalogue (PSC) at high galactic latitudes. As a result, 1178 galaxies have been identified. 172 of them have been observed spectroscopically with Byurakan Astrophysical Observatory (BAO, Armenia) 2.6 m, Special Astrophysical Observatory (SAO, Russia) 6 m and Observatoire de Haute Provence (OHP, France) 1.93 m telescopes. Later on, spectra were obtained for 83 BIG objects more in the Sloan Digital Sky Survey (SDSS). We have extracted and studied these spectra, classified them and measured spectral features. Diagnostic diagrams have been built to distinguish starbursts (SB), LINERs and Seyfert galaxies. Cross-correlations were made for these objects with multiwavelength (MW) catalogues and their physical properties were studied. Among these 83 objects, 55 HII, 8 Seyfert galaxies, 2 LINERs, 4 other AGN, 6 composite spectrum objects, and 8 other emission-line galaxies have been revealed. Three of these objects are Ultra-Luminous InfraRed Galaxies (ULIRG). We give in Figure 6 the dependence of L_{ir} and L_{fir} vs. redshift.

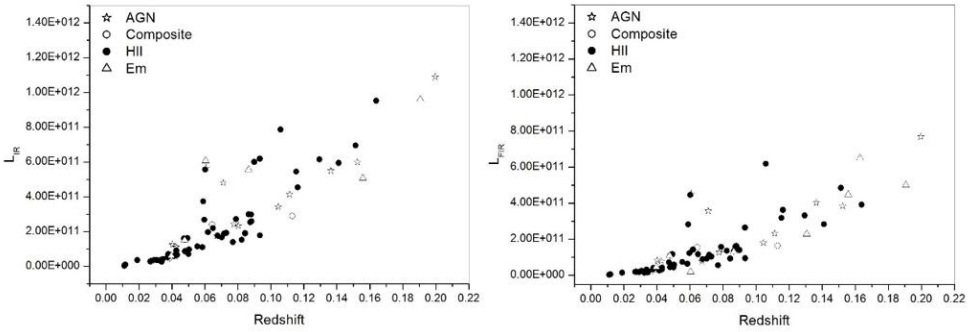


Figure 6 The dependence of L_{ir} and L_{fir} (in L_{sun}) vs. redshift.

Based on the IR luminosities and selecting the outliers from Figure 6, we have identified a new class of IR-Excess (IRX) galaxies. In Table 3 we give a list of IRX galaxies found from a BIG sample.

Table 3 IRX galaxies found from BIG sample.

BIG name	SDSS r	Redshift	Activity type	M_r	L_{IR}	L_{FIR}	f21 (mJy)
BIG 382	15.04	0.05891	HII	–21.84	3.85 E+11	2.82 E+11	16.5
BIG 284c	15.48	0.06018	HII	–21.45	5.16 E+11	4.45 E+11	21.5
BIG 284a	15.54	0.06065	Sy1.9	–21.41	5.24 E+11	4.52 E+11	
BIG 093	15.78	0.07099	Sy2	–21.50	4.41 E+11	3.57 E+11	10.6
BIG 406	16.10	0.10587	HII	–22.00	7.77 E+11	6.18 E+11	14.4

2.8 IRAS PSC/FSC Combined Catalogue extragalactic sample

To increase the efficiency of using IRAS PSC and FSC, which contain a lot of common sources, one needed a joint catalogue of all IRAS point sources with improved data based on both catalogues. We have combined these two catalogues and obtained 345,163 sources, including 73,770 common associations with improved data. In addition, we have made cross-correlations with AKARI/IRC, AKARI/FIS and WISE Catalogues. As a result, we created a catalogue with high positional accuracy and with 17 photometric measurements from 1.25 μ to 160 μ wavelength range (based on 2MASS, WISE, IRAS, and AKARI). The work was carried out by means of Virtual Observatory (VO) tools, namely the cross-correlation software created at BAO (Figure 7).

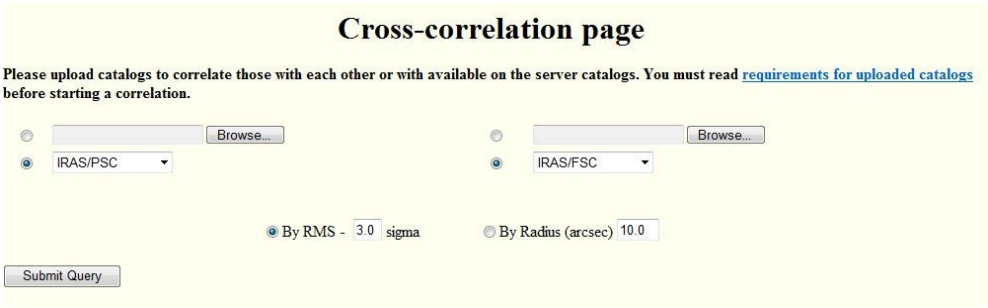


Figure 7 Cross-correlation software created within the framework of the Armenian Virtual Observatory (ArVO).

At least half of all sources are extragalactic ones, which include bright galaxies, AGN and especially many starburst galaxies that are important for star-formation phenomena and in many cases for study of the interrelationship between starburst, interactions and nuclear activity. The total number of genuine galaxies is 78,240 objects. We use all available data from IRAS PSC/FSC: 2MASS JHK, WISE w1, w2, w3 and w4, AKARI-IRC 9 and 18, IRAS 12, 25, 60 and 100, AKARI-FIS 65, 90, 140 and 160. There are 18,567 active galaxies according to the VCV-13, BZCAT v5 and SDSS QSOs Catalogues. The fraction of active galaxies is 23.7%. Cross-correlations with X-ray and radio have been carried out and more AGN candidates have been revealed. Redshifts are available for 22,970 objects. We have also calculated MW flux ratios. We studied the interrelationship between SB, nuclear activity and interactions / merging phenomena for some 17,500 interacting/merging pairs and multiples in IRAS Extragalactic Sample (IRAS-EG).

2.9 Discovery of new bright ULIRGs from the IRAS PSC/FSC Combined Catalogue and their spectral classification

The results regarding the discovery of new ULIRGs are given in (Mikayelyan 2018). High-luminosity IR galaxies (LIRGs, ULIRGs, and HLIRGs) are important for studies related to star-formation processes in the early Universe, as their luminosity allows their detection at large distances. High IR indicates active star-formation and often

starburst processes, which is typical of HII (starburst, SB) and AGN. An interesting question is whether the starburst triggers AGN or vice versa or there is no direct impact. Considering that very often such objects manifest a double and multiple structure, it is also interesting to investigate the interrelationship between the SB, nuclear activity and interactions or merging. We have analyzed the IRAS PSC/FSC Combined Catalogue for the search for new bright ULIRGs. By means of the SDSS DR14 data, namely redshifts for those objects having spectroscopy, we have calculated the IR luminosities and have found 114 very high-luminosity IR galaxies; 107 ULIRGs and 7 HLIRGs. Among them, 48 new ULIRGs and 7 new HLIRGs have been discovered. These objects have been studied by SDSS color–color, luminosity–redshift and other diagrams. Further studies will include the content of the sample for activity types and other available data. We give in Figure 8 (left panel) SDSS u-g vs. g-r color–color diagram and in Figure 8 (right panel), the IR luminosity vs. redshift for 114 newly revealed ULIRGs and HLIRGs.

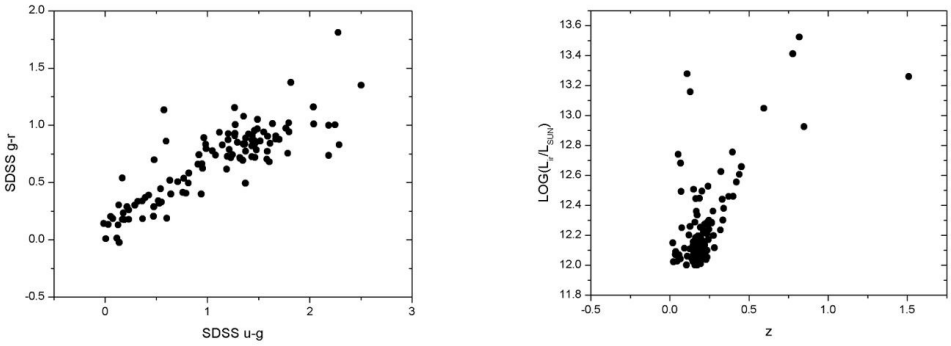


Figure 8 (Left panel) SDSS color–color diagram for 114 newly revealed ULIRGs and HLIRGs. (Right panel) IR luminosity vs. redshift for 114 newly revealed ULIRGs and HLIRGs.

The results on spectroscopic studies of new ULIRGs are given in (Mikayelyan et al. 2019b). The newly revealed 114 ULIRGs were distinguished and classified based on SDSS for the activity types; 1 BLL, 2 quasars, 29 Seyferts of types 1.0–1.8, 5 Seyferts of type 2, 14 LINERS, 36 HII, 14 objects with a composite spectrum (composites) were identified. Among type 1 Seyfert galaxies there are many objects with narrow lines. We give in Figure 9 typical examples of SDSS spectra for each activity type.

2.10 Radio variable sources at 1400 MHz and their optical variability

The results are given in (Abrahamyan et al. 2018b). In the present study we have cross-correlated the NVSS and FIRST Radio Catalogues having radio flux measurements at the same 1.4 GHz frequency. This way we benefit from repeated observations from both catalogues, as they give more accurate positions and fluxes and, more importantly, reveal large differences between the two measured fluxes, thus allowing us to establish a radio variability. As a result, 79,382 radio variables have been revealed, including 6301 with flux differences at 1.4 GHz larger than 15 mJy, 1917 with flux differences >45 mJy and 260 with flux differences >200 mJy. By using a special

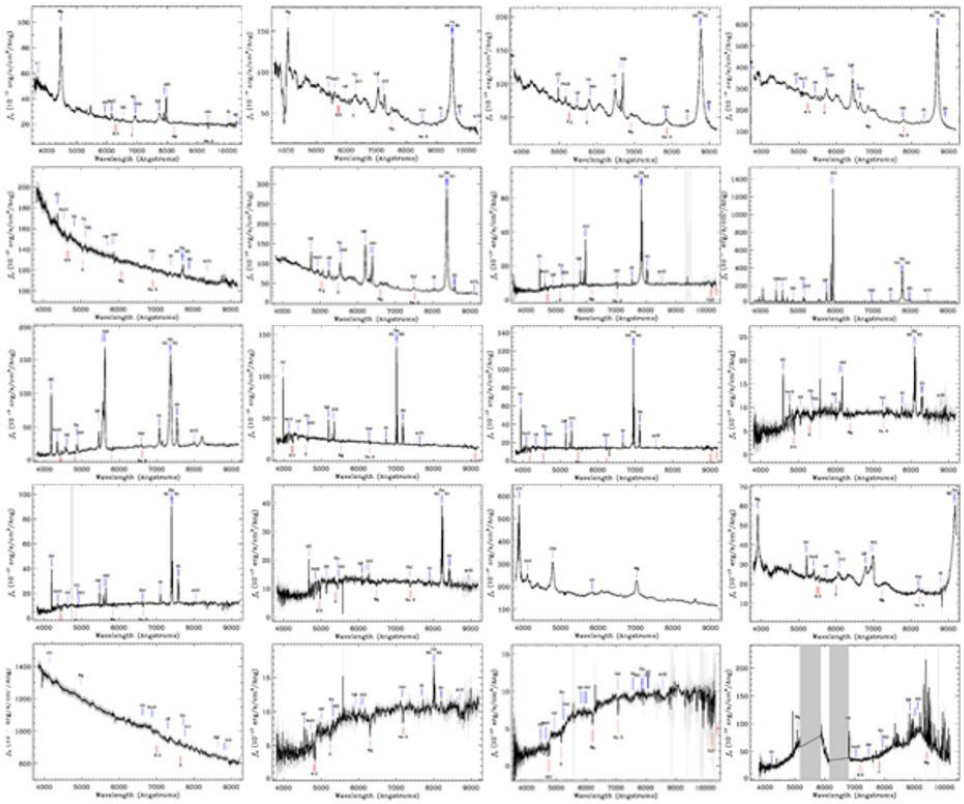


Figure 9 Typical examples for each activity type (from left to right and from top to bottom): S1.0, NLS1.0, S1.2, NLS1.2, S1.5, NLS1.5, S1.8, S2.0, LINER, HII, S1.9/HII, S1.9/LINER, LINER/HII, NLAGN, QSO, NLQSO, BL Lac, Em, Abs, Unkn.

technique (Mickaelian & Sinamyan 2010, Mickaelian et al. 2011), 2425 optically variable objects out of 6301 radio sources have been revealed. 2425 radio sources with both high radio and optical variability have been divided into four categories. 1206 (19%) out of 6301 radio sources have activity types from available catalogues and 619 (25.5%) out of 2425 radio sources with simultaneously radio and optical variability have activity types from available catalogues. In addition, 279 radio sources out of 2425 have a high variability in the optical range. We have established their activity types when available. The IR fluxes and colors for the 6301 variable radio sources have been studied. Color–color diagrams show that most of the "unknown" sources are galaxies. The activity types for 110 (42%) out of 260 extremely high variable radio sources also have been retrieved. We give in Table 4 the distribution of the activity types of 6301 radio sources having a radio variability and in Table 5, the distribution of the activity types of 2425 radio sources having both radio and optical variabilities.

Table 4 Activity types of 6301 radio sources having a radio variability.

No.	Activity type	Numbers
1	Blazar (BZB, BZG, BZQ, BZU)	308
2	QSO	639
3	Sy 1.0 / Sy 1	19
4	Sy 1.2	2
5	Sy 1.5	6
6	Sy 1.9	2
7	Sy 2.0/Sy 2	9
8	AGN	97
9	Starburst	1
10	FSS (Flat-Spectrum radio source)	87
11	USS (Ultra-Steep-Spectrum radio source)	36
Known (total)		**1206 (19%)**
Unknown		**5095 (81%)**
Total		**6301 (100%)**

Table 5 Activity types of 2425 radio sources having both radio and optical variabilities.

No.	Activity type	Numbers
1	Blazar (BZB, BZG, BZQ, BZU)	176
2	QSO	333
3	Sy 1.0/Sy 1	9
4	Sy 1.5	6
5	Sy 2.0/Sy 2	5
6	AGN	45
7	FSS (Flat-Spectrum radio source)	41
8	USS (Ultra-Steep-Spectrum radio source)	4
Known (total)		**619 (25.5%)**
Unknown		**1806 (74.5%)**
Total		**2425 (100%)**

2.11 Classification of BZCAT objects having uncertain types

This research (Abrahamyan et al. 2019a) was aimed at understanding some optical properties of blazars having uncertain types (BZU) in the BZCAT Catalogue v5. Cross-correlation with SDSS revealed 43 BZU objects that have spectra in SDSS out of the total 227 BZUs. We have carried out a spectral re-classification for these 43 blazar candidates for activity types. As a result, 37 (86%) objects out of 43 changed their previous type. We give in Table 6 the new classification of former BZU objects and in Table 7, a spectral classification of these objects for activity types using SDSS spectra.

Table 6 New classification of BZU objects.

No.	Old	New	Numbers
1	BZU.	BZB	1 (2%)
2	BZU	BZG	14 (33%)
3	BZU	BZQ	22 (51%)
4	BZU	BZU	6 (14%)
All			**43 (100%)**

Table 7 Spectral classification using SDSS spectra.

No.	Activity type	Numbers
1	Abs	1
2	BLL	1
3	Em	4
4	LINER	2
5	NLQSO	1
6	QSO	17
7	QSO 1.2	3
8	QSO 1.5	1
9	Sy 1.2	1
10	Sy 1.5	2
11	Sy 1.8	1
12	Sy 2.0	3
13	Unknown	6
Total		**43**

2.12 Optical variability of blazars

The results are given in (Abrahamyan et al. 2019b). The analysis of blazars' parameters from BZCAT leads to a conclusion that they do not have the same properties. The preliminary criterion to include an object in the catalogue was the strong radio emission; however, two types of radio sources were selected: BL Lacertae (BLL) objects and flat spectrum radio quasars (FSRQ). As some properties are typical of blazars (strong radio emission, optical variability, continuum optical spectra, polarization, high luminosity, etc.), using the optical data, we investigated them to clarify which property plays the most significant role in their classification as blazars. We found that 60% of blazars have optical variability. We use a technique developed based on POSS1 and POSS2 photometry and group the variability into extreme, strong, medium, and low classes. In the optical range, 51 blazars have powerful variability (extreme variables), and 126 are high variables. In addition, for 63% of blazars, radiation in X-ray was detected; and for 28%, radiation in gamma rays. We give the average statistical characteristics of blazars based on our analysis and calculations. Here we give in Figure 10 absolute magnitude vs. redshift for BZCAT blazars.

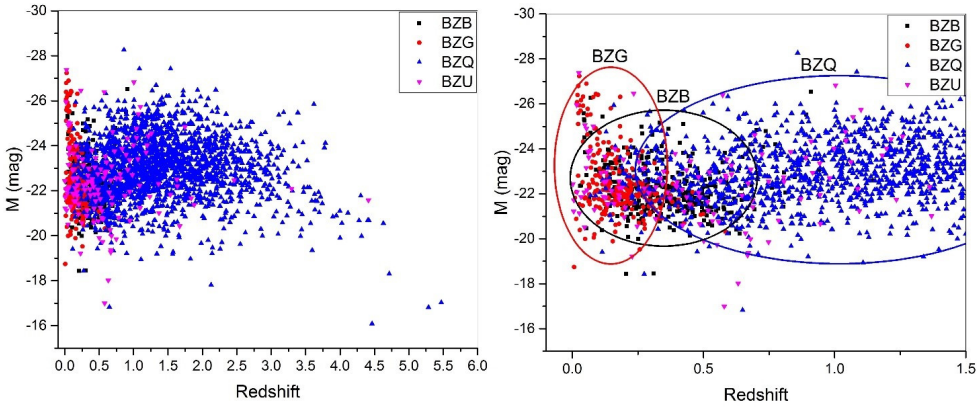


Figure 10 Absolute magnitude vs. redshift for BZCAT blazars.

We have also calculated the average flux ratios of blazars for various ranges, namely radio to optical, X-ray to optical and radio to X-ray. The results are given below:

radio/opt (average) = 17.996 (for 1810 objects)
X/opt (average) = 0.052 (for 1101 objects)
radio/X (average) = 86.197 (for 1860 objects)

Other average characteristics of the blazars are: average radio spectral index $\alpha = -0.154 \pm 0.01$ (for 1435 objects), average optical variability $\Delta R = 1.2 \pm 0.13$, $\Delta B = 0.98 \pm 0.11$, average radio variability |FIRST-NVSS|-3σ = 38.01 mJy (for 805 objects).

2.13 Fine analysis of emission-line spectra of active galaxies

We have carried out fine analysis of the emission-line spectra of active galaxies using spectral line decomposition software SPECTRAI, which analyses the summarizing spectrum and gives the possible line profiles that could be components of the total. Line positions (redshifts), line intensities and line widths (FWHM) are being used for dozens of lines, including the most prominent ones: hydrogen Balmer series lines (Hα 6363, Hβ 4861, Hγ 4340, etc.), oxygen lines ([OIII] 4959 and 5007, [OII] 3727 and [OI] 6300), nitrogen lines ([NII] 6548 and 6483), sulphur doublet ([SII] 6716/6731), helium lines HeI 5876 and HeII 4686, etc. Results from a spectral study of the quasar Kaz 102 have been obtained. It has been shown that its spectrum varies as a whole; that is, the parameters of both the lines and the continuum change. Based on a comparison of results presented previously and in this last paper, it is concluded that over a time of approximately 27.5 years the equivalent widths and relative intensities of the lines have increased, while their half widths have decreased. The spectral composition of Kaz 102 has also changed: new lines, HeII λ4686, [OIII] λ4363, and others, appear in the spectra of 2000 and 2001 which were not observed in the spectra taken in 1973. The electron density, and the mass and effective radius of the gas component are determined to be $2{\cdot}10^7$ cm^{-3}, $2{\cdot}10^4$ M$_\odot$, and 0.2 pc. In Figure 11 we give two examples of spectra that underwent fine analysis using software SPECTRAI; H-alpha region for both Akn 564 and Mrk 926.

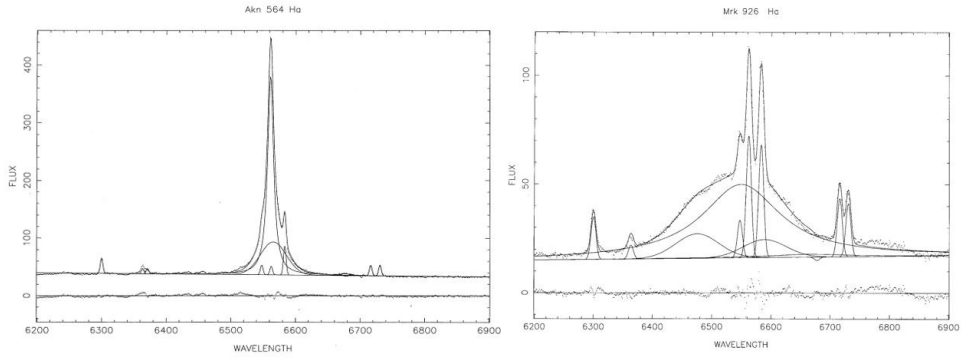


Figure 11 Two examples of spectra fine analysis by means of the decomposition software SPECTRAI; H-alpha region for both Akn 564 and Mrk 926.

2.14 AGN classifications: fine classification of activity types and subtypes

Based on the classification of many thousands of galaxies for activity types taken from our various samples (X-ray, optical, IR, radio), we developed a fine classification scheme for active galaxies (both AGN and starbursts), where QSOs have subtypes like Seyferts (Q1.0, Q1.2, Q1.5, Q1.8, Q1.9, Q2.0), narrow line QSOs are introduced (NLQ: NLQ1.0, NLQ1.2, NLQ1.5, NLQ1.8, NLQ1.9), subclasses for narrow line Seyfert 1s are used (NLS1.0, NLS1.2, NLS1.5, NLS1.8, NLS1.9) and composite spectrum objects have their subtypes (Sy/LINER, Sy/HII, LINER/HII, as well as Sy/LINER/HII). This classification scheme much better describes all fine details in the optical spectra and allows further study of active galaxies by the subtypes to better understand the unified model and the physical properties of AGN and starbursts.

The main results are the introduction of a fine classification scheme for active galaxies using homogeneous SDSS spectroscopy. This became possible for the first time, as SDSS quality spectra had not been available before. A detailed description of the types and subtypes of active galaxies is given, many of them being introduced for the first time.

3 Summary

A number of interesting results have been obtained in the field of multiwavelength studies of active galaxies, including X-ray, IR and radio sources identified with AGN and starbursts. Among the important results one could mention:

- Study of SDSS spectra of 371 optical identifications of HRC/BHRC Sample ROSAT X-ray sources (Paronyan et al. 2018; 2019a; 2019b). These sources were also identified in other wavelength ranges and some of their parameters were calculated.
- The UV properties of 1152 Markarian galaxies were investigated based on GALEX data (Mickaelian et al. 2018a). Using our classification for activity types for

779 Markarian galaxies based on SDSS spectroscopy, we have investigated these objects on the GALEX, 2MASS and WISE color–magnitude and color–color diagrams by the location of objects of different activity types and have revealed a number of concentrations.

- Abundance and star formation determinations in more than 700 Markarian galaxies from SDSS Spectra (Gyulzadyan et al. 2018). We have measured their line fluxes and derived the O and N abundances using recent calibrations. The behavior of the [N/H] ratio in under-abundant regions gives strong support to a partially primary origin of nitrogen.
- Revised optical classification of objects classified as LINERs in the Véron–Cetty & Véron Catalogue, 13th edition (Abrahamyan et al. 2018a), where 926 LINERs are included. We found 176 objects having spectra in SDSS DR14. The re-classification of these objects led to 54% of them to change their activity types.
- Study and classification of SDSS spectra for Byurakan-IRAS Galaxies (Mickaelian et al. 2018). To the previously observed 172 BIG objects (with BAO, SAO and OHP telescopes) 83 BIG objects were added having spectra in SDSS. Among them, 55 HII, 8 Seyfert galaxies, 2 LINERs, 4 other AGN, 6 composite spectrum objects, and 8 other emission-line galaxies have been revealed. Three of these objects are ULIRGs. The observations and study of 257 Byurakan-IRAS Galaxies were summarized in Mikayelyan et al. (2019a).
- Discovery of new bright ULIRGs from the IRAS PSC/FSC Combined Catalogue (Mikayelyan 2018). By means of the SDSS DR14 data, namely redshifts for those objects having spectroscopy, we have calculated the IR luminosities and have found 114 very high-luminosity IR galaxies; 107 ULIRGs and 7 HLIRGs. Among them, 48 new ULIRGs and 7 new HLIRGs have been discovered. Spectral classification of these ULIRGs was carried out (Mikayelyan et al. 2019b): 1 BLL, 2 quasars, 29 Seyferts of types 1.0–1.8 (including narrow-line), 5 Seyferts of type 2, 14 LINERs, 36 HII, 14 objects with a composite spectrum (composites) were identified.
- Radio variable sources at 1400 MHz were studied and their optical variability was revealed (Abrahamyan et al. 2018b). As a result, 79,382 radio variables have been revealed, including 6301 with flux differences at 1.4 GHz larger than 15 mJy. By using a special technique (Mickaelian & Sinamyan 2010, Mickaelian et al. 2011), 2425 optically variable objects out of 6301 radio sources have been revealed.
- Classification of BZCAT objects having uncertain types was carried out (Abrahamyan et al. 2019a). 43 BZU objects were found to have SDSS spectra and as a result, 37 (86%) objects changed their previous type.
- Optical variability of blazars was studied (Abrahamyan et al. 2019b). We found that 60% of blazars have optical variability. In the optical range, 51 blazars have powerful variability (extreme variables), and 126 are high variables. In addition, for 63% of blazars, radiation in X-ray has been detected and for 28%, radiation in gamma rays.

Below, we give a summary of projects on the search for and studies of active galaxies by our group during the 1990s–2010s.

Project	Years	Objectives	Objects	References
FBS QSOs/Seyferts	1986–2001	Bright QSOs and Seyferts	1,103	Mickaelian 2000a; 2002b; 2003; 2004a; 2008; Mickaelian et al. 1999; 2001
IRAS BIG sample	1994–2010	AGN, SB, ULIRGs	1,278	Mickaelian 1995; 1997; 2000b; 2001a; 2001b; 2002; Mickaelian et al. 1997; Mickaelian & Gigoyan 1998a; 1998b; Mickaelian & Sargsyan 2004a; 2004b
IRAS BIG spectroscopy	1997–2019	AGN, SB, ULIRGs	257	Mickaelian et al. 1998; 2001; 2002a; 2003; 2018b; Balaian et al. 2001; Mickaelian 2003; 2004b; Sargsyan & Mickaelian 2006; Mickaelian & Sargsyan 2010; Mikayelyan et al. 2019
ROSAT BSC/FSC sources	2002–2006	Search for new AGN	6,003	Véron–Cetty et al. 2004; Mickaelian et al. 2006
Bright AGN	2001–pres.	Statistical analysis	∼10,000	
Mrk galaxies	2010–pres.	Spectral and MW studies	1,515	Mickaelian et al. 2013; 2018a; Gyulzadyan et al. 2018
IRAS PSC/FSC extragalactic sample	2011–pres.	Large IR galaxies sample	145,902	Hovhannisyan et al. 2011; Abrahamyan et al. 2015
IRAS PSC/FSC ULIRGs	2018–2019	IRAS PSC/FSC ULIRGs	114	Mikayelyan et al. 2018; 2019
Spitzer ULIRGs	2003–2010	High IR/opt flux ratio galaxies	32	Sargsyan et al. 2008
SB/AGN Spitzer spectra	2011	SB/AGN Spitzer spectra	301	Sargsyan et al. 2011

Project	Years	Objectives	Objects	References
HRC/BHRC AGN	2010–pres.	AGN content in X-ray	4,253	Mickaelian et al. 2016; Paronyan et al. 2018; 2019; 2020
NVSS-FIRST variability, etc.	2013–pres.	Study of radio variability	6,301	Abrahamyan et al. 2018a
Radio AGN	2020	Contents of radio AGN	1,864	Abrahamyan et al. 2020
LINERs	2018	Physical properties of LINERs		Abrahamyan et al. 2018b
ROSAT-NVSS sources	2013–pres.	Search for new AGN, statistics	9,193	Paronyan et al. 2014
MW study of blazars	2014–pres.	New blazars, definition	3,561	Abrahamyan et al. 2019a; 2019b
Fine analysis of emission-line spectra	2001–2007	Physical properties of AGN	90	Kazarian & Mickaelian 2007
SBS QSOs in WISE	2017	QSOs	450	Erastova & Mickaelian 2017
DFBS AGN	2002–pres.	New bright active galaxies	∼10,000	
Fine classification of active galaxies	2006–pres.	Accurate types and subtypes	∼10,000	Mickaelian et al. 2020

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List of used abbreviations

2MASS – 2 Micron All-Sky Survey
AGN – Active Galactic Nucleus
BAO – Byurakan Astrophysical Observatory (Armenia)
BIG – Byurakan-IRAS Galaxy
BLL – BL Lacertae object
BSC – Bright Source Catalogue
BZCAT – Roma Blazar Catalogue
BZG – BZCAT Galaxy
BZQ – BZCAT Quasar
BZU – BZCAT Uncertain type object

DR – Data Release
FIRST – Faint Images of the Radio Sky at Twenty-centimeters
FSC – Faint Source Catalogue
FSRQ – Flat Spectrum Radio Quasars
FSS – Flat Spectrum radio source
FUV – Far UltraViolet
GALEX – Galaxy Explorer
BHRC – Byurakan-Hamburg-ROSAT Catalogue
HLIRG – Hyper-Luminous InfraRed Galaxy
HRC – Hamburg-ROSAT Catalogue
IFS – Integral Field Spectroscopy
IRAS – InfraRed Astronomical Satellite
LINER – Low Ionization Nuclear Emission-line Region
LIRG - Luminous InfraRed Galaxy
NUV – Near UltraViolet
NVSS – NRAO/VLA Sky Survey
OHP – Observatoire de Haute Provence (France)
POSS1 – Palomar Observatory Sky Survey 1
POSS2 – Palomar Observatory Sky Survey 2
PSC – Point Source Catalogue
SAO – Special Astrophysical Observatory (Russia)
SB – StarBurst galaxy
SDSS – Sloan Digital Sky Survey
SED – Spectral Energy Distributions
SFR – Star Formation Rate
ULIRG – Ultra-Luminous InfraRed Galaxy
USS – Ultra Steep Spectrum radio source
WISE – Wide-field Infrared Survey Explorer

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