

Multiwavelength search and studies of active galaxies

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Abstract

We review the field of active galaxies (both AGN and Starbursts) focusing on their multiwavelength search and studies at the Byurakan Astrophysical Observatory (BAO). Many famous historical surveys carried out in Byurakan are known and many more are active and ongoing. We give examples of studies in optical wavelengths, IR, radio and X-ray, as well as multiwavelength studies. The studies are characterized by multiwavelength approach to statistical analysis of large amount of data obtained in different wavelengths. 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. At the end, we briefly present our new fine classification of active galaxies based on all our previous studies.

Keywords: *Active Galaxies – Active Galactic Nuclei – QSO – Blazar – Seyfert galaxy – LINER – Starburst galaxy – Markarian galaxies*

Introduction

The Byurakan Astrophysical Observatory (BAO) was always active in surveys, especially extragalactic ones. Here is the list of the most important surveys carried out by BAO astronomers (Table 1).

Table 1. Most important extragalactic surveys by BAO astronomers.

| Years | Authors | Survey | Short | Type of objects | Number of objects |
|-----------|--|--|------------|--------------------------------------|-------------------|
| 1965-1980 | B. Markarian, V. Lipovetsky, J. Stepanian | First Byurakan Survey (Markarian Survey) | FBS | UV-excess galaxies | 1544 |
| 1973-1979 | R. Shahbazian | Shahbazian Survey | Shkh | Compact groups of compact galaxies | 377 |
| 1976 | M. Arakelian | Arakelian Survey | Akn | High surface brightness galaxies | 621 |
| 1978-1991 | B. Markarian, J. Stepanian, L. Erastova, V. Chavushyan | Second Byurakan Survey | SBS | UVX and Emission-line galaxies, QSOs | 3600 |
| 1979-2005 | M. Kazarian et al. | Kazarian Survey | Kaz | UV-excess galaxies | 706 |
| 1987-1996 | H. Abrahamian, A. Mickaelian | First Byurakan Survey, 2nd Part | FBS BSOs | QSOs and Seyferts | 1103 |
| 1995-2004 | A. Mickaelian et al. | Byurakan-IRAS Galaxies | BIG | IRAS galaxies | 1278 |
| 2002-2006 | A. Mickaelian et al. | Byurakan-Hamburg-ROSAT Catalogue | BHRC | ROSAT sources | 4253 |
| 2018 | H. Abrahamyan, A. Mickaelian et al. | Variable radio sources at 1400 MHz | NVSS/FIRST | Variable radio sources | 6301 |

The importance of active galaxies is rather high as they play crucial role in many aspects, such as:

- Formation and evolution of galaxies
- Morphology

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- Interacting and merging galaxies
- Star formation in galaxies
- The luminosity function of galaxies
- Radiation mechanisms
- Multiwavelength activity
- The presence of relativistic jets
- The theory of supermassive black holes
- Energy sources
- Cosmological role of Active Galaxies

The recent results on active galaxies are related to their multiwavelength studies using large amount of data from X-ray, UV, optical, IR and radio ranges, namely large-area or all-sky surveys, with heavy use of cross-correlations, classifications on activity types using our observations and SDSS spectra, building diagnostic diagrams, Spectral Energy Distributions (SEDs), etc. For classification of SDSS spectra, we have used our new approach that is focused on detailed analysis of the most important emission lines and introducing fine details, like subtypes for the main broad-line Seyfert galaxies and narrow-line Seyfert ones. 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 (for spectra having higher signal-to noise ratio), revised optical classification of LINERs, study and classification of SDSS spectra for Byurakan-IRAS Galaxies (BIG objects), summary of observations and study of BIG objects, discovery of new bright ULIRGs from the IRAS PSC/FSC Combined Catalogue (compiled earlier by our group) and their spectral classification using SDSS spectra, 6301 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.

Optical studies of active galaxies

Among the optical studies, most important are studies of Markarian (Mrk) galaxies and FBS Blue Stellar Objects (BSOs). We have carried out a homogeneous classification for activity types for Markarian galaxies by means of the SDSS spectra. 779 Mrk galaxies appeared to have SDSS spectroscopy (due to smaller sky area covered by SDSS compared to Markarian Survey). We give in Table 2 the distribution by activity types for these 779 Mrk objects.

Table 2. The distribution by activity types for these 779 Mrk objects based on SDSS spectroscopy.

| Type | Number | % | Type | Number | % |
|-----------|--------|-------|--------------|------------|---------------|
| HII | 533 | 68.42 | QSO | 2 | 0.26 |
| Composite | 31 | 3.98 | NLS1.5 | 5 | 0.64 |
| LINER | 12 | 1.54 | NLS1.2 | 8 | 1.03 |
| Sy 2.0 | 4 | 0.51 | NLS1 | 4 | 0.51 |
| Sy 1.9 | 5 | 0.64 | AGN | 11 | 1.41 |
| Sy 1.8 | 8 | 1.03 | Em | 52 | 6.68 |
| Sy 1.5 | 11 | 1.41 | Abs | 65 | 8.34 |
| Sy 1.2 | 21 | 2.70 | Star | 3 | 0.39 |
| Sy 1.0 | 4 | 0.51 | TOTAL | 779 | 100.00 |

Infrared Studies of Active Galaxies

IRAS Point Source Catalog (PSC) served as the main source for identification and study of IR galaxies, among which there are many Active Galaxies, as well as high-luminosity IR galaxies (ULIRGs, HLIRGs).

In Figure 1 we give infrared and far-infrared luminosities of IRAS galaxies vs. redshift. The outliers are objects with especially high IR/FIR luminosity, so called IR-excess galaxies. This way we have introduced a new class of objects.

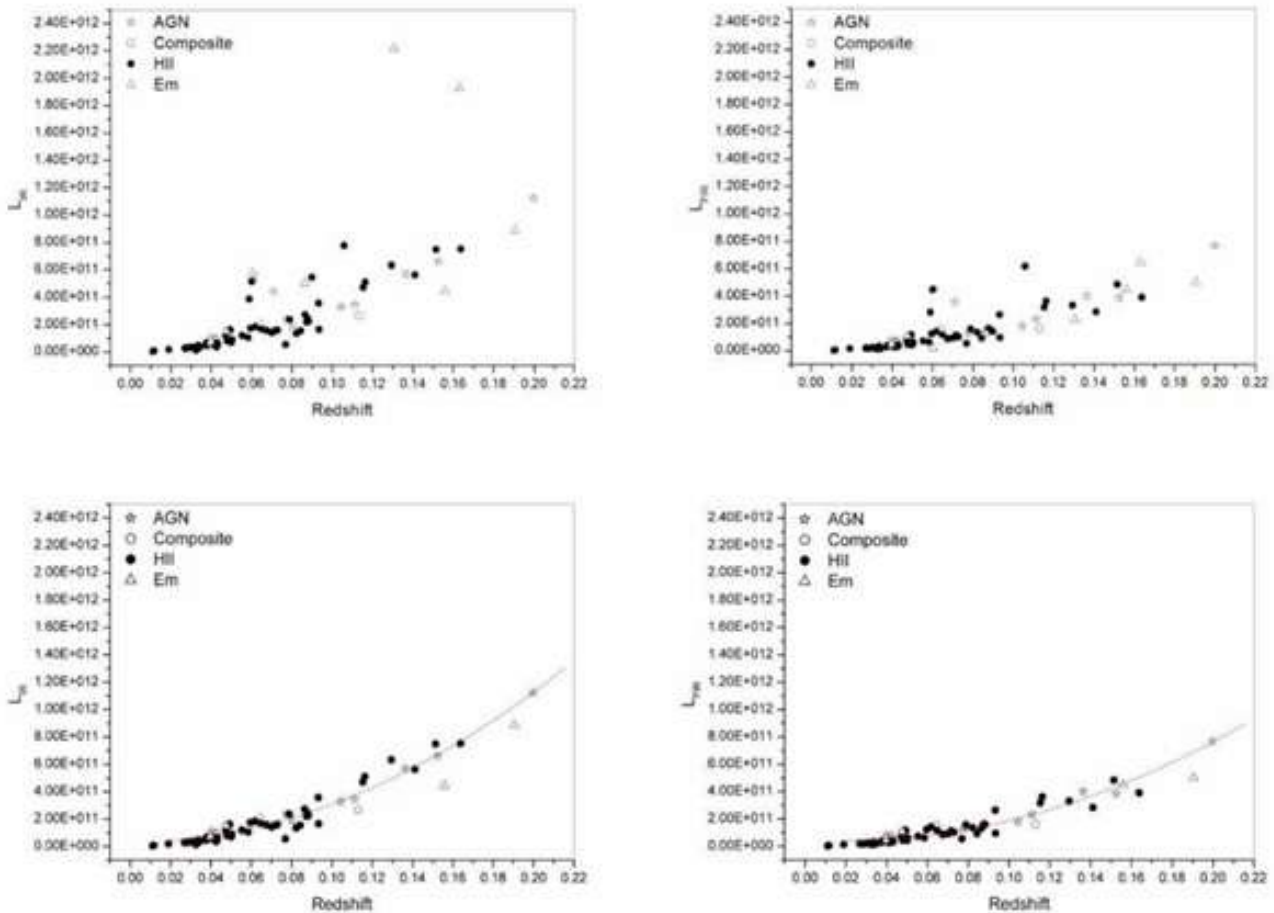


Figure 1. Infrared and Far-Infrared luminosities of IRAS galaxies vs. redshift. The outliers are objects with especially high IR/FIR luminosity, so called IR-excess galaxies.

High-luminosity IR galaxies

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 to detect them at large distances. High IR indicates active star-formation and often starburst processes, which is typical to HII (starburst, SB) and/or existence of Active Galactic Nuclei (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 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 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 included the content of the sample for activity types and other available data. The classification for their activity types resulted in: 1 BLL, 2 Quasars, 29 Seyfert types 1.0-1.8, 5 Seyfert type 2, 14 LINERS, 36 HII regions, and 14 objects with Composite spectra (Composites). Among the type 1 Seyfert galaxies there are many objects with Narrow Lines (NLS1s).

Radio Studies of Active Galaxies

We have carried out several projects on studies of radio galaxies and radio properties of active and normal galaxies.

Radio variable sources at 1400 MHz and their optical variability

We have cross-correlated 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 important, reveal large differences between the two measured fluxes, thus allowing to establish 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 technique, 2425 optically variable objects out of 6301 radio sources have been revealed. 2425 radio sources with both high radio and optical variability into four categories have been divided. 1206 (19%) out of 6301 radio sources have activity types from available catalogues and 619 (25.5%) out of 2425 radio sources with at the same time radio and optical variability have activity types from available catalogues. In addition, 279 radio sources out of 2425 have high variability in 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.

Blazars

The definition of Blazars has several criteria, both historical and introduced by ourselves. We list here all related physical parameter that may define a Blazar:

- Selected radio sources
- X-ray and gamma-ray emission
- Radio spectral index is $\alpha = -0.154 \pm 0.01$ (based on 1435 objects)
- Average flux ratio radio/opt = 17.996 (based on 1810 objects)
- Average flux ratio X/opt = 0.052 (based on 1101 objects)
- Average flux ratio radio/X = 86.197 (based on 1860 objects)
- Average optical variability: $\Delta R = 1.20 \pm 0.13$, $\Delta B = 0.98 \pm 0.11$
- Average radio variability: $|\text{FIRST-NVSS}| - 3\sigma = 38.01$ mJy (based on 805 sources)
- Absolute magnitudes (SDSS_r band): $M_{BZB} = -22.19$, $M_{BZG} = -22.44$, $M_{BZQ} = -22.97$, $M_{BZU} = -22.42$, $M_{All} = -22.78$.

Classification of BZCAT objects for activity types

Having 3561 objects in the BZCAT catalogue v.5, it is important to clarify what physical type of objects are included. They are divided into 4 groups: BZB (BL Lac objects), BZQ (Flat Spectrum Radio Quasars, FSRQs), BZG (Blazar-like extended objects; galaxies) and BZU (Uncertain type). Another paper of this volume is dedicated to these studies (Abrahamyan et al.), so we will not focus on this topic in details.

X-ray Studies of Active Galaxies

Optical identifications of ROSAT Faint Source Catalogue (FSC) led to revelation of many new interesting optical objects, including a big number of extragalactic ones. The Joint HRC/BHRC Catalogue is based on the combination of two major studies; optical identification projects of ROSAT BSC and ROSAT FSC, both based on Hamburg Quasar Survey (HQS) low-dispersion spectra. The 1st one was published by Zickgraf et al. (2003; A&A 406, 535) and resulted in 5341 identified BSC sources and the 2nd one was published by

Mickaelian et al. (2006; A&A 449, 425) and resulted in 2791 identified FSC sources. While the 1st project used only HQS, in the 2nd one we used HQS, DSS1 and DSS2 to find faint objects and to achieve almost 100% result for studies X-ray sources.

A work was carried out to reveal all X-ray galaxies in HRC/BHRC Combined Catalogue (Paronyan et al. 2018) by cross-correlations with known catalogs of AGN and galaxies, their optical images (including DSS1/DSS2 and SDSS) and other parameters (radio, IR, X-ray properties, etc.). We have carried out classification of X-ray galaxies for their activity types using SDSS spectroscopic database and have revealed active galaxies (AGN and Starbursts). The classification has been carried out according to our new scheme and many narrow-line objects (Seyferts and Quasars) have been revealed.

Activity types of HRC/BHRC objects

In this study we carried 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 were 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 more confident classification. We also identified these sources in other wavelength ranges and calculated some of their parameters.

The Database of Markarian galaxies

We have created a Database of Markarian galaxies with multiwavelength data (MW) including all possible information from gamma-ray, X-ray, UV, optical, IR, sub-mm/mm and radio domains (<https://www.bao.am/activities/projects/21AG-1C053/mg/>). In Figure 2 we give an example of such page for the famous Blazar Mrk 421 with its various images and numerical data.

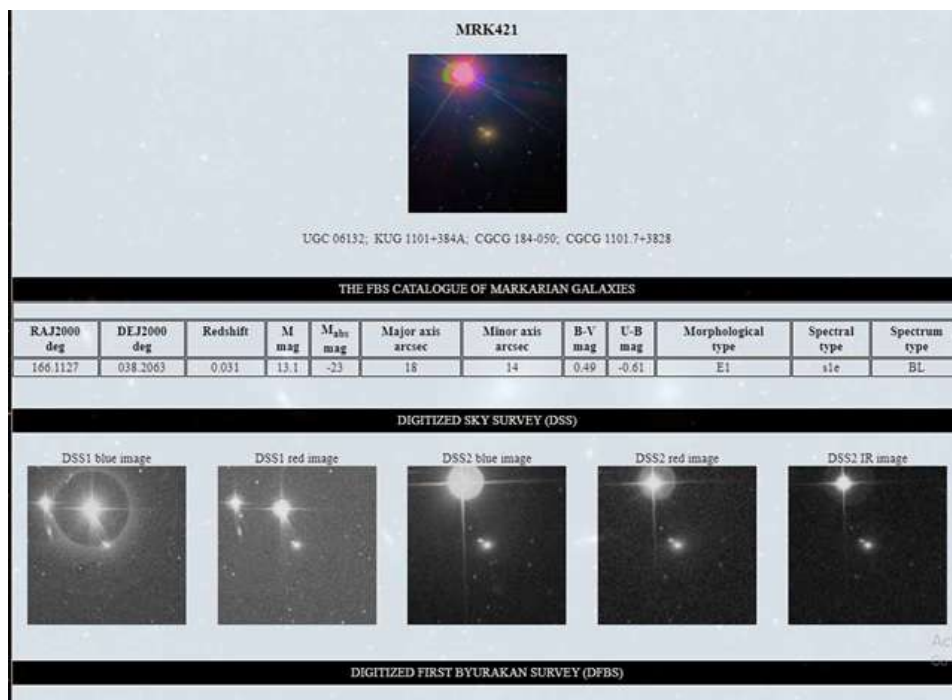


Figure 2. An example of the individual page for the famous Blazar Mrk 421 with its various images and numerical data.

Fine Classification of Active Galaxies

We have carried out a detailed Fine classification of the emission-line spectrum of active galaxies (<https://www.bao.am/activities/projects/21AG-1C053/mickaelian/>). One of the most important results is

the introduction of subtypes for Narrow-Line Quasars (NLQ) similar to Narrow-Line Seyfert 1 galaxies (NLS1: NLS1.0, NLS1.2, NLS1.5, NLS1.8, NLS1.9, introduced by Osterbrock & Pogge 1985). These galaxies have soft X-ray detected by ROSAT surveys and have the same physical nature as X-ray QSOs, hence this classification scheme will extend their luminosity range to higher ones. We have introduced NLQ1.0, NLQ1.2, NLQ1.5, NLQ1.8 and NLQ1.9, though the last 2 subtypes are extremely rare and are rather difficult to reveal.

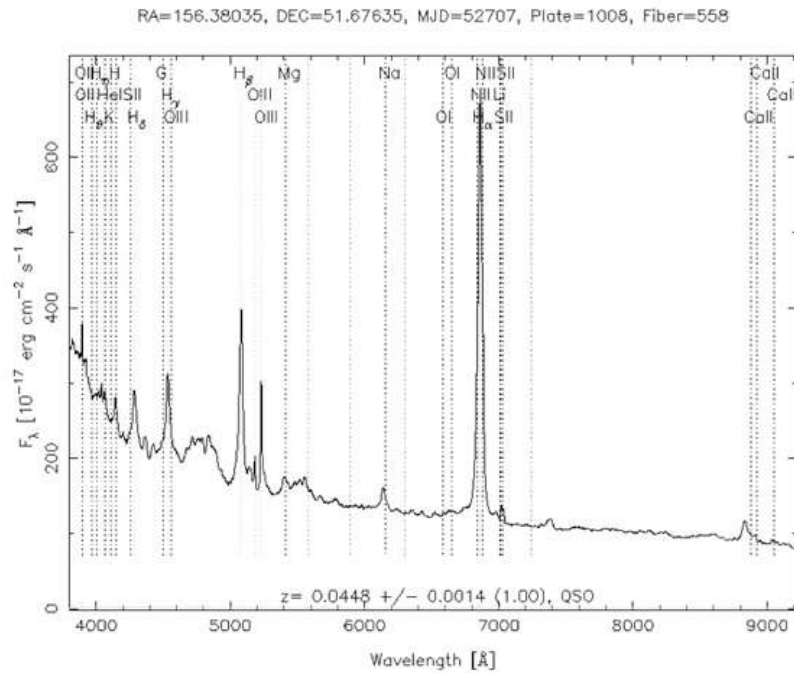


Figure 3. An example of Narrow Line Seyfert Galaxy having comparatively narrow broad lines (H-alpha, H-beta, etc.) and two bumps on both sides of H-beta, consisting of many FeII and some other lines. Such objects also have strong soft X-ray radiation.

Our classification scheme may be given as the following:

- Broad Line QSOs – BLQ (BLQSO) – Q1.0, Q1.2, Q1.5, Q1.8, Q1.9
- Narrow Line QSOs – NLQ (NLQSO) – NLQ1.0, NLQ1.2, NLQ1.5, NLQ1.8, NLQ1.9
- Broad Line Seyferts – BLS (S, Sy, Sey) – S1.0, S1.2, S1.5, S1.8, S1.9 (Osterbrock 1981)
- Narrow Line Seyferts – NLS (NLS1, Osterbrock & Pogge 1985) – NLS1.0, NLS1.2, NLS1.5, NLS1.8, NLS1.9
- Narrow Line AGN – NLA (NLGN) – S2.0, LINER (Heckman 1980), HII (Sargent & Searle 1970)
- Composite Spectrum objects – Comp (Veron et al. 1997) – HII/LINER, HII/Sy, LINER/Sy, HII/LINER/Sy.

In addition, we will introduce two more novelties:

- Diagnostic Diagrams for BLS (based on decomposition of line profiles into broad and narrow lines for S1.2, S1.5, S1.8, S1.9 types and further classification of objects by diagnostic diagrams),
- Classifications based on the shorter wavelength range of QSOs; classification by L-alpha, CIV, CIII and MgII lines.

Summary of the Results

In Table 3 we list all our accomplished or ongoing projects on multiwavelength search and studies of active galaxies. We give the years, authors, name of the survey, short designation, objective or types of objects discovered and studied, and the number of objects.

Table 3. Summary of the accomplished and ongoing projects on multiwavelength search and studies of active galaxies.

| Years | Authors | Survey | Short | Objectives | Number of objects |
|------------|--|---|---------------------------|--|-------------------|
| 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 | ROSAT sources | 2791 |
| 2003-2010 | L. Sargsyan, 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, A. Mickaelian et al. | IRAS PSC/FSC Combined Catalogue 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, H. Abrahamyan 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 ULIRGs/HLIRGs | 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 | Accurate types and subtypes of active galaxies | ~10 000 |

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