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Markarian survey and Markarian galaxies

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Abstract. Markarian survey (or the First Byurakan Survey, FBS) was the first systematic survey for active galaxies and was a new method for search for such objects. Until now, it is the largest objective prism survey of the sky (17,000 deg^2). It was carried out in 1965–1980 by B. E. Markarian and his colleagues and resulted in discovery of 1517 UV-excess (Markarian) galaxies. They contain many active galaxies, as well as powerful gamma-, X-ray, IR and radio sources (Mrk 180, 231, 421, 501, etc.), BCDGs (Mrk 116) and interacting/merging systems (Mrk 266, 273, etc.). They led to the classification of Seyfert galaxies into Sy1 and Sy2 and the definition of Starbursts (SB). Several catalogs of Markarian galaxies have been published (Mazzarella & Balzano 1986; Markarian *et al.* 1989; Bicay *et al.* 1995; Petrosian *et al.* 2007) and they are accessible in all corresponding databases. Markarian survey also served as a basis for search for UVX stellar objects (including QSOs and Seyferts), late-type stars and optical identification of IR sources. At present the survey is digitized and DFBS database is available. I will review the main characteristics of the Markarian survey, its comparison with other similar surveys and the importance of Markarian galaxies in modern astrophysics.

Keywords. surveys – catalogues – techniques: spectroscopic – galaxies: active – galaxies: Seyfert – galaxies: starburst – virtual observatory tools

1. Introduction

The history of active galaxies goes back to 1943, when Carl Seyfert published a list of 8 galaxies with broad emission lines (Seyfert 1943). Later on radio galaxies were discovered (Bolton *et al.* 1949). In 1956 Guillermo Haro published a list of blue galaxies (Haro 1956). Viktor Ambartsumian (1958) paid attention to some active processes and observing data connected with the central regions of some galaxies: blue/UV colors, emission lines, radio emission, outflows, etc. He predicted that more such objects should exist and new forms of activity may be found; this idea was in fact the very beginning of the unified scheme suggested much later by Antonucci & Miller (1985). Similar discussions and direct indication on massive nuclei were given by Woltjer (1959). Predicted by Ambartsumian new types of active galaxies were the quasi-stellar objects (QSOs) discovered in 1963 (Schmidt 1963) and the list of galaxies with anomalous colors (Markarian 1963). To discover new such objects, find out what was their fraction and provide some statistics for further studies, Markarian conducted in 1965 a survey for UV-excess (UVX) galaxies. Some more types of active galactic nuclei (AGN) and other active galaxies were found in further works, such as BL Lac objects (Schmitt 1968), Starburst (SB) galaxies (Weedman 1977), LINERs (Heckman 1980), etc.

The big variety of AGN types allows speaking about "AGN zoo", as all these types have certain pecularities and need a reliable classification. First attempts to classify Seyferts were done in mid-1960s, when differences between NGC 4151 and NGC 1068 were noticed (prototypes of Sy1 and Sy2). Later on Weedman & Khachikian (1968) obtained the first spectra of Markarian galaxies and classified Seyferts into Sy 1/2 classes. Osterbrock (1981) introduced subclasses of Seyferts: 1.0, 1.2, 1.5, 1.8, 1.9 and 2.0. Later

on Osterbrock & Pogge (1985) found galaxies with Sy 1 features having narrow Balmer and other permitted lines, Narrow-Line Seyfert 1 (NLS1) galaxies; these objects also show strong FeII and soft X-ray. We use NLS also for other subtypes of Sy1 (NLS1.2, NLS1.5, etc.), as well as NLQSOs have been observed. For narrow line AGN (Sy2, LINER and SB), the classification is given by so called diagnostic or BPT (Baldwin, Phillips, Terlevich) diagrams (Baldwin *et al.* 1981; Veilleux & Osterbrock 1987). Anyway, due to the variety of their types and forms of activity, there is no final classification; very often classes refer to various properties, such as the morphology, optical spectrum, colour and/or spectral energy distribution (SED), radio loudness, polarization, etc.

2. Markarian survey

In 1965, Markarian started the first observations of the First Byurakan Survey (FBS), which was aimed at covering the northern extragalactic sky by objective prism plates to search for UVX galaxies. The first list was published in 1967 (Markarian 1967) and altogether 15 lists of 1500 galaxies were published by Markarian, Lipovetski and Stepanian.

The selection of the low dispersion (1800Å/mm at Hγ) provided a chance to follow SED and notice some broad (both emission and absorption) lines on one hand, and avoid overlaps on the other hand. Low-dispersion spectra cover the range 3400–6900Å, and there is a sensitivity gap near 5300Å, dividing the spectra into red and blue parts. It is possible to compare these parts, easily distinguishing red and blue objects.

2050 Kodak IIAF, IIaF, IIF, and 103aF photographic plates in 1133 fields ($4^\circ \times 4^\circ$ each, the size being 16cm×16cm) have been taken. FBS covers 17,000 deg^2 of all the Northern Sky and part of the Southern Sky at high galactic latitudes ($|b| > 15^\circ$). The limiting magnitude on different plates changes in the range of 16.5–19.5 in V, however for the majority it is 17.5–18. Each FBS plate contains low-dispersion spectra of some 15,000–20,000 objects, and there are some 20,000,000 objects in the whole survey.

We give in Table 1 the main observing and resulting characteristics of the FBS – Markarian survey. Though FBS spectra seem to be very similar, a thorough eye inspection with the help of $7^\times$ lens provided opportunity to select peculiar spectra. To explain how difficult was the selection of peculiar spectra in the FBS, we give in Fig. 1 a standard FBS field and a collection of spectra of relatively rare interesting types of objects. Such spectra altogether are less than 5% among all in the FBS fields.

Markarian survey was an outstanding study for all extragalactic (as well as galactic) astronomy; its main features may be given as:

- Markarian survey is the first systematic objective-prism survey,
- It is the largest objective-prism survey of the Northern sky (17,000 deg^2),
- It introduced a new method of search for active galaxies,
- Revelation of 1517 UVX galaxies: some 300 AGN and some 1000 HII galaxies,
- Classification of Seyferts into Sy1 and Sy2 types (Weedman & Khachikian 1968),
- Definition of Starburst (SB) galaxies (Weedman 1977),
- Discovery of many new Blue Compact Dwarf Galaxies (BCDG),
- Revelation of 1103 FBS Blue Stellar Objects (BSOs; Mickaelian 2008) and 1045 Late-type Stars (Gigoyan & Mickaelian 2012),
- Optical identification of 1577 IRAS sources (samples of Byurakan-IRAS Galaxies (BIG; Mickaelian & Sargsyan 2004) and Byurakan-IRAS Stars (BIS; Mickaelian & Gigoyan 2006)); discovery of many new AGN and ULIRGs.
- Markarian survey led to many other objective prism surveys with better spectral resolution and deeper limiting magnitudes, including the Second Byurakan Survey (SBS, Markarian *et al.* 1983, Stepanian 2005).

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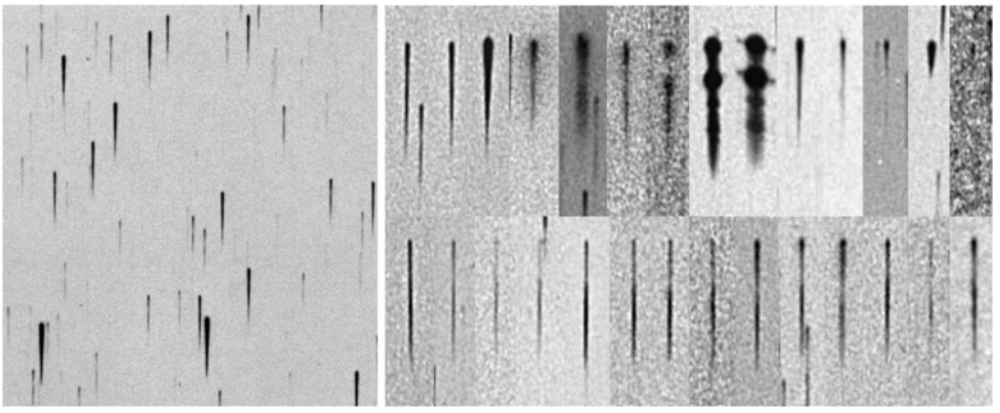

Figure 1. A standard FBS field showing similarity of most of the low-dispersion spectra and a collection of spectra of relatively rare interesting types of objects: Markarian galaxies, planetary nebulae, late-type stars (M and C), QSOs, CVs, white dwarfs and subdwarfs.

Table 1. Main observing and resulting characteristics of the FBS – Markarian survey.

Items	**Description**
Authors	B. E. Markarian, V. A. Lipovetskiy, J. A. Stepanian
Years	1965–1980
Telescope	BAO 102/132/213cm (40"/52"/84") Schmidt
Equipment	1.5° objective prism
Emulsions	Eastman Kodak IIAF, IIaF, IIF, 103aF
Plate size	4°×4°, 16×16 cm
Spectral range	3400–6900$\AA$ with a sensitivity gap at 5300AA
Dispersion	1800$\AA$/mm at Hγ, 2500AA/mm near Hβ
Scale	96.8"/mm
Spatial resolution	2.4"
Limiting magnitude	17.5^m–18.0^m in V
Sky area	$\delta > -15°$, all RA except the Milky Way ($\|b\| > 15°$)
Total coverage	17,000 deg^2
Number of fields	1139 (each 16 deg^2), distributed by 28 declination zones
Number of plates	1874 (at least one plate with m = 17 in each field)

3. Markarian galaxies

Markarian galaxies have nuclei with excessive amounts of ultraviolet emission compared with other galaxies (so-called UV-excess). So far, 1517 Markarian galaxies are known, as well as many more similar UVX galaxies exist. Markarian galaxies have been published in a series of 15 papers in Astrophysics (Astrofizika) and then listed in several catalogs. We give in Table 2 all major lists and catalogs of Markarian galaxies providing accurate positional, morphologic, photometric, multiwavelength data and images.

Fig. 2 shows the distribution of Markarian galaxies on the celestial sphere by equatorial coordinates RA and DEC and Fig. 3 shows the distribution of various types of Markarian galaxies by Galactic coordinates lII and bII.

Markarian galaxies have been studied by various observational methods, such as spectroscopically (Weedman & Khachikian 1968; Arakelyan *et al.* 1973; Markarian *et al.* 1988 and references therein), morphologically (e.g. Korovyakovskii *et al.* 1981), as well as in different wavelength ranges (see below). Petrosian *et al.* (1989) have studied double and multiple structure of some Markarian galaxies. Carone *et al.* (1996) received spectra for

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Table 2. Lists and catalogs of Markarian galaxies.

Authors	Years	Description	Number of objs.
Markarian *et al.*	1967–1981	15 original lists of galaxies with UV-excess	1500
Kojoian *et al.*	1978–1984	Accurate optical positions	1500
Mazzarella & Balzano	1986	The first catalog of Markarian galaxies	1500
Markarian *et al.*	1989	The First Byurakan Survey. A catalogue of galaxies with UV-continuum	1517
Bicay *et al.*	1995	A multifrequency radio continuum and IRAS faint source survey of Mrk galaxies	899
Markarian *et al.*	1997	The FBS Catalogue of Markarian galaxies	1517
Petrosian *et al.*	2007	Markarian Galaxies. I. The Optical Database and Atlas	1544

Table 3. Most important Markarian galaxies for various matters of extragalactic astronomy.

Mrk galaxies	Description
Mrk 231	the closest ULIRG, BAL QSO and most luminous IR galaxy in the Local Universe
Mrk 421, Mrk 501	are among the highest known energy sources
Mrk 116 (=IZw18)	the most metal-deficient (BCDG) (Mrk and SBS)
Mrk 938	the first dynamic merger discovered observationally
Mrk 110	intermediate between NLS1 and BLS1 (FWHM = 4900 km/s); understanding BLS1s and NLS1s differences
Mrk 6	shows variations of spectral lines typical of different types of objects (Sy2 & Sy1); very high H column density in X-rays
Mrk 926	one of the rare Sy1 galaxies having LINER properties
Mrk 766	one of the most important NLS1 galaxies
Mrk 273	a wonderful double-double nuclei galaxy
Mrk 266	has a multiple structure nuclear region
Mrk 231, Mrk 507	super strongest FeII emitters (FeII $\lambda 4570/\mathrm{H}\alpha > 2$)
Mrk 530, Mrk 993, Mrk 1018	change their spectra from Sy1.9 to Sy1.0

the Sy1 galaxy Mrk 509 and studied its optical continuum and emission-line variability. Petrosian & Turatto (1986) investigated the relation of Markarian galaxies with Zwicky clusters. Santos-Lleo *et al.* (2001) have carried out a monitoring of the optical and NIR spectrum and MIR imaging of the Sy 1 galaxy Mrk 279. Some Markarian galaxies have also been reported to have jets.

Markarian galaxies are rather important for various extragalactic studies, such as: Mrk 231 is the most luminous infrared galaxy (ULIRG) in the Local Universe, Mrk 116 is the most metal-deficient blue compact dwarf galaxy (BCDG) (most of the BCDGs are Mrk and SBS galaxies), Mrk 421 and 501 are among the most powerful sources, etc. We give in Table 3 some selected Markarian galaxies that are most important for various matters of extragalactic astronomy. Detailed studies of these and similar objects are given in other papers of this symposium.

Altogether 292 Markarian galaxies are present in the Catalog of QSOs and AGN (Veron-Cetty & Veron 2010) having activity types BLL, HPQ, QSO, Sy 1.0–1.2–1.5–1.8–1.9–2.0, NLS1, LINER, and HII. However, Markarian galaxies contain many more active ones, as not all have been classified for activity types.

Markarian galaxies have been observed in all wavelength ranges, from γ-ray to radio. E. g., they have been observed with the Arecibo radio telescope and for about 20% of them weak radio emission was detected (Tovmassian & Terzian 1974). Kojoian *et al.*

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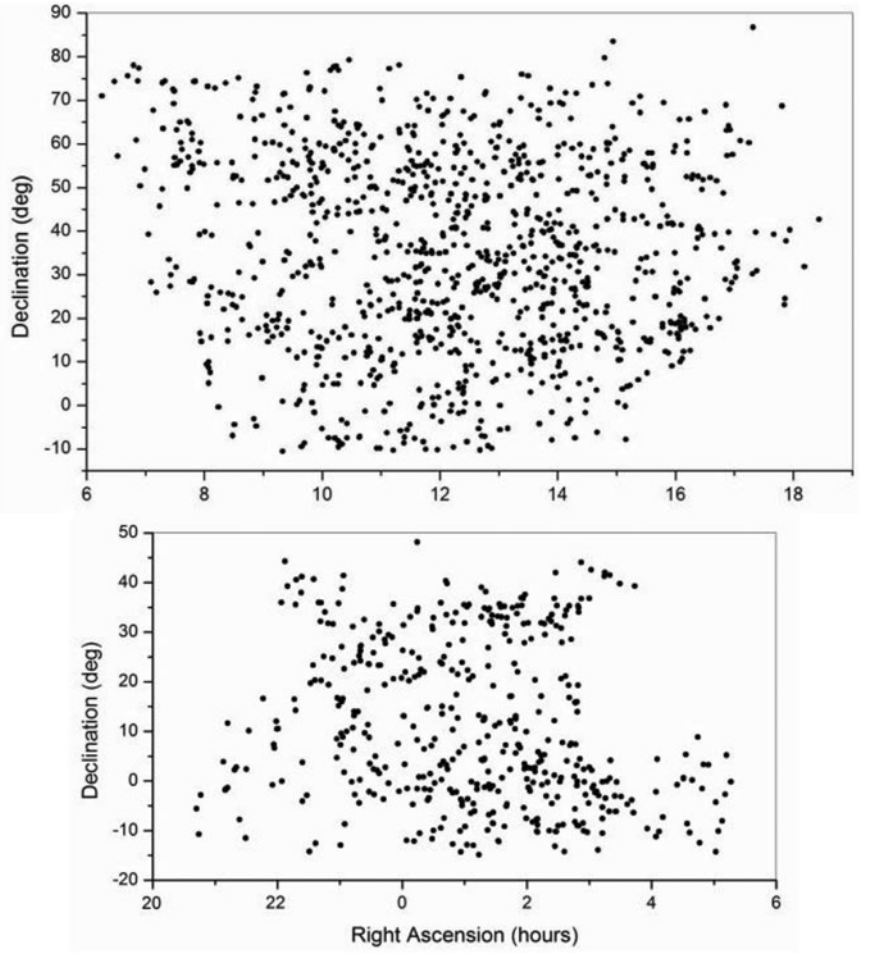

Figure 2. Distribution of Markarian galaxies on the celestial sphere by equatorial coordinates.

(1976) have studied the radio spectra of Markarian galaxies. Kandalyan & Petrosyan (1989) have studied Markaryan galaxies as FIR sources. They are targets for all modern ground-based and space telescopes as well. E. g. the blazars Markarian 421 and 501 have been detected in all high- and very high energy surveys, such as ROSAT (Voges *et al.* 1999, 2000), ASCA (Ueda *et al.* 2005), BeppoSAX (Ciliegi *et al.* 2003), Chandra (Evans *et al.* 2010), XMM (2010), INTEGRAL (Bird *et al.* 2010), Fermi (Nolan *et al.* 2012), as well as observations by systems as the High-Energy Stereoscopic System (H. E. S. S.; Aharonian *et al.* 2005), MAGIC, the Very Energetic Radiation Imaging Telescope Array System (VERITAS; Arlen *et al.* 2013), Nuclear Spectroscopic Telescope Array (NuSTAR; Harrison *et al.* 2013), etc.

We have carried out studies of Markarian galaxies (Mickaelian *et al.* 2013), including their revised spectral classification based on the SDSS spectra (Ahn *et al.* 2013), studies of their multiwavelength (MW) properties, etc. Examples of MW SEDs for three famous Markarian galaxies (Mrk 180, Mrk 231 and Mrk 421) are given in Fig. 4. These SEDs have been built and taken from the Italian Space Agency (ASI) Data Science Center (ASDC, http://tools.asdc.asi.it/SED/) using the ASDC SED builder tool.

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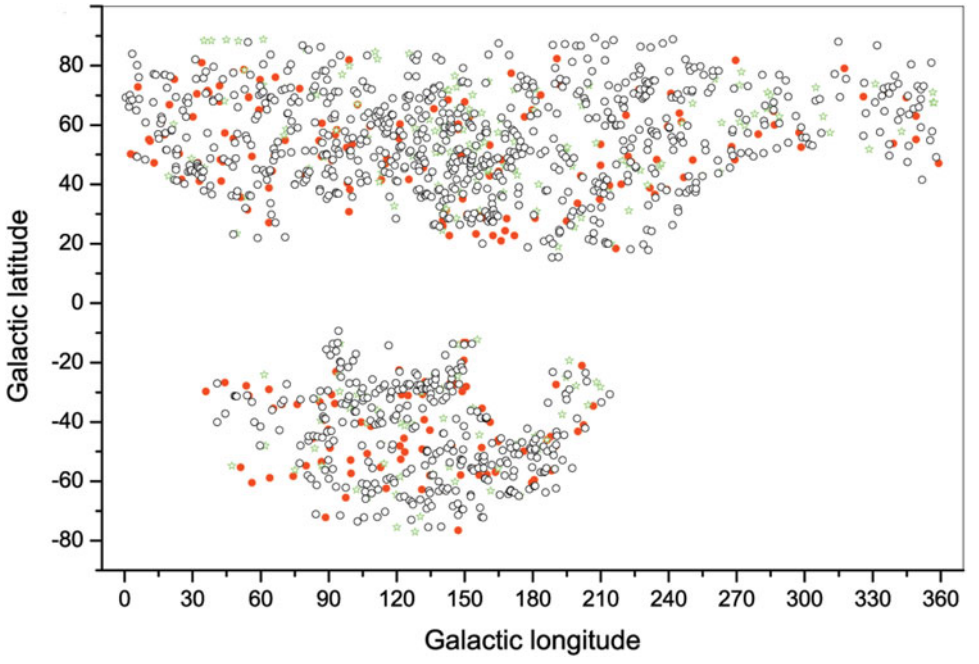

Figure 3. Distribution of Markarian galaxies on the celestial sphere by Galactic coordinates. Filled circles are AGN, stars are Starburst and HII galaxies, and open circles are galaxies without a sign of activity.

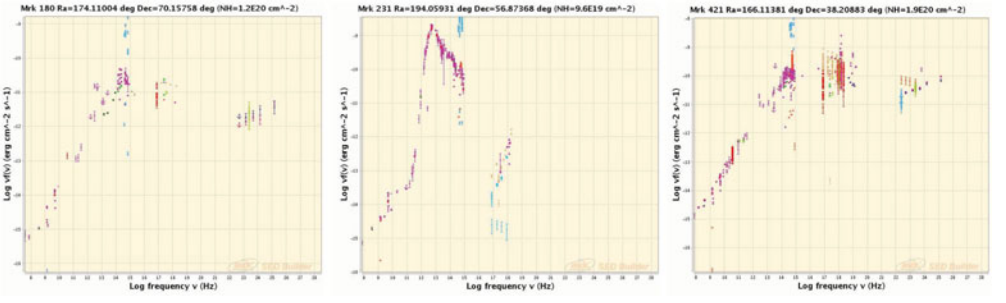

Figure 4. Spectral Energy Distribution (SED) of three famous Markarian galaxies: (from left to right) Mrk 180, Mrk 231 and Mrk 421.

Many more UVX and emission-line galaxies have been discovered in similar to Markarian surveys or by other studies. These are Arakelian galaxies having high surface brightness (Arakelian 1975), Kazarian UVX galaxies (Kazarian *et al.* 2010), the University of Michigan emission-line galaxies (UM; MacAlpine *et al.* 1982), Case Low-Dispersion Northern Sky Survey galaxies (CG; Pesch *et al.* 1991), the Montreal blue galaxies (Coziol *et al.* 1994), SBS UVX and emission-line galaxies (Stepanian 2005), Kiso UV galaxies (KUG; Miyauchi-Isobe *et al.* 2010), Hamburg/SAO emission-line galaxies (Pustilnik *et al.* 2005), GALEX UV-luminous galaxies (Hoopes *et al.* 2007), etc.

4. Digitized First Byurakan Survey – DFBS

The Digitized First Byurakan Survey (DFBS; Mickaelian *et al.* 2007; Massaro *et al.* 2008) is the digitized version of the Markarian survey (or FBS). It is a collaborative

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Table 4. Main scanning and resulting characteristics of the DFBS.

Items	**Description**
Teams	Byurakan Astrophys. Obs., Univ. Roma "La Sapienza", Cornell Univ.
Years	2002–2005
Instrument	Epson Expression 1680 Pro scanner
Scanning options	1600 dpi (15.875μ pix size), 16 bit, transparency mode, "scanfits"
Plate size	9601×9601 pix, 176 MB file
Spectra	107×5 pix (1700μ in length)
Dispersion	33 $\AA$/pix average (22–60 $\AA$/pix), 28.5 at Hγ
Spectral resolution	50$\AA$ (average)
Astrometric solution	1" rms accuracy
Scale	1.542"/pix
Photometry	0.3^m accuracy
Data volume	1874 plates, ∼400 GB
Number of objects	∼20,000,000 (∼40,000,000 spectra)

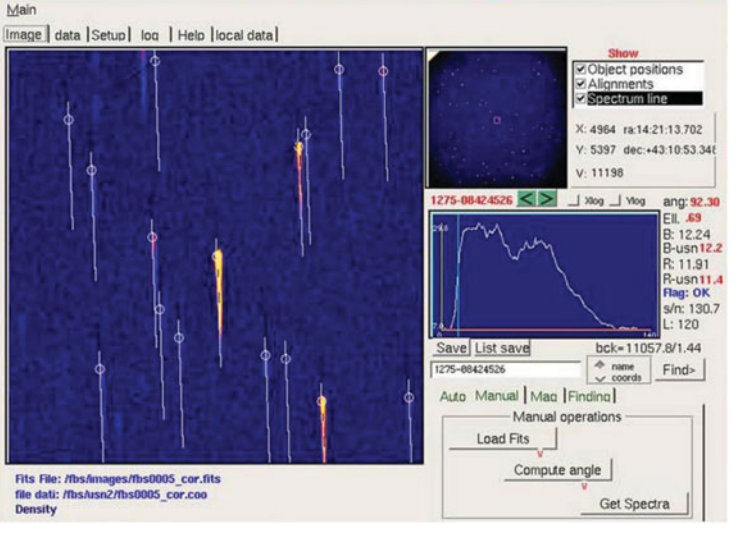

Figure 5. bSpec – DFBS spectra extraction and analysis software.

effort of the Byurakan Astrophysical Observatory, Universita di Roma "La Sapienza" and MIGG s.r.l. (Italy), Cornell University (USA), and Hamburger Sternwarte (Germany). It included scanning of the plates, high accuracy (1" rms) astrometric solution, extraction software for images and spectra, photometric and wavelength calibration of the spectra, classification, creation of DFBS catalog and database, construction of user interface and webpage. Later on, the Armenian Institute of Informatics and Automation Problems (IIAP) also joined the project to reproduce the DFBS database in Armenia in frame of the Armenian VO project. 1874 FBS plates have been scanned. We give in Table 4 the main scanning and resulting characteristics of the DFBS.

Fig. 5 shows a fragment of "bSpec" – DFBS spectra extraction and analysis dedicated software written by Giuseppe Cirimele.

For the classification, templates for main types of objects discovered from FBS have been used; UVX galaxies, QSOs, white dwarfs, subdwarfs, cataclysmic variables, carbon stars, as well as stars of all spectral types (from O to M). The DFBS database is presently stored on a dedicated PC at Universita di Roma "La Sapienza" and can be

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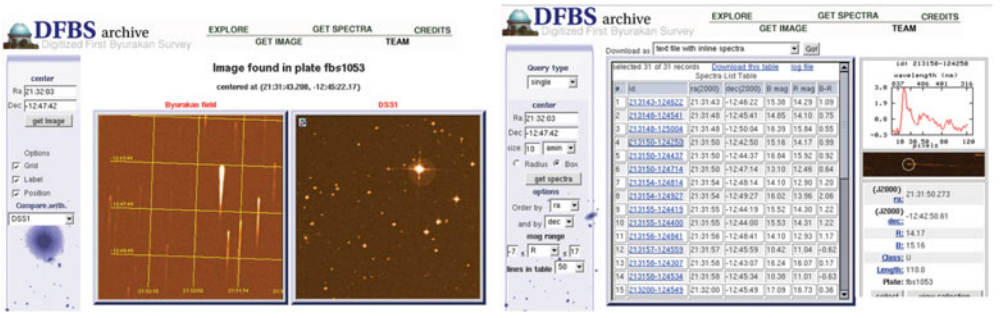

Figure 6. DFBS web interface: "Explore" and "Getspectra" modes.

accessed through web interface (http://byurakan.phys.uniroma1.it/). The user interface (the DFBS web portal) provides access to general information on the FBS and DFBS. It presently allows the following operations: 1) showing DFBS sky coverage, 2) Plate list, 3) Explore, allowing the display of a portion of plate around a given central RA, DEC position, interactive selection of one or more spectra, their collection and downloading, 4) Get Image, allowing users to select a portion of a plate in FITS format and all the spectra of this portion present in the database for downloading, as well as downloading of the whole selected field, 5) Get Spectra, allowing downloading all the spectra in the database within a given distance from a selected central position (cone search). Fig. 6 shows two webshots from the DFBS web interface: modes "Explore" and "Get Spectra".

5. Summary and conclusions

Markarian survey was the first systematic search for active galaxies, and Markarian galaxies led to discovery of many new AGN, spectral classification of Seyfert galaxies and definition of a new class of active galaxies, Starburst ones. Until now, Markarian survey is the largest area spectroscopic survey and the DFBS contains the largest amount of spectra (some 20,000,000 objects).

We give in Table 5 a comparison of the main characteristics of large spectroscopic surveys. The first five surveys are objective prism ones and have been done using Kodak emuslions and only SDSS has been done with CCD using u, g, r, i, and z filters. In all cases, the most important goals were to discover active galaxies, as well as SDSS also has carried out the largest ever galaxy redshift survey ($\sim$ 1 million objects). Such surveys are also an ideal tool for optical identifications of X-ray, IR, and radio sources; such projects have been carried out using FBS (Mickaelian 1995) and HQS (Zickgraf *et al.* 2003; Mickaelian *et al.* 2006).

Markarian survey led to the discovery of 1517 UVX galaxies, including some 300 AGN and some 1000 HII galaxies. Classification of Markarian galaxies provided Sy1 and Sy2 types and the definition of Starburst galaxies. Many new BCDG were discovered as well. The continuation of the FBS for stellar objects revealed FBS Blue Stellar Objects and FBS Late-type Stars, as well as optical identifications of IRAS sources have been carried out resulted in discovery of new ULIRGs and AGN. Markarian survey also led to many other objective prism surveys.

Markarian galaxies are reliable objects for MW studies of active galaxies, as they are bright enough and have been detected in all ranges of electromagnetic radiation; from γ-ray to radio. In one of the recent works, we have collected all available MW data from all-sky or large-area catalogs and have built MW SEDs for Markarian galaxies using 38 photometric points (Fermi, INTEGRAL, ROSAT, GALEX FUV/NUV, UBV, POSS I/II OjEN, SDSS ugriz, 2MASS JHK, WISE w1/w2/w3/w4, Spitzer IRAC/MIPS, AKARI

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Table 5. Comparison of the main characteristics of large spectroscopic surveys.

Surv.	**Years**	**Telescope & Equipment**	**Sky area & Surface** (deg^2)	**Disp. Hγ** *Å*/mm	**Sp. range** *Å*	**V**$_{lim}$
FBS	1965 – 1980	BAO 1m Schmidt 1.5 prism	$\delta > -15$, $\|b\| > 15$ 17,056	1800	3400-6900	17.5
SBS	1978 – 1991	BAO 1m Schmidt 1.5, 3, 4 prisms	$49 < \delta < 61$, $\|b\| > 30$ 965	1800/900/280	3400-6950	19.0
Case	1983 – 1995	KPNO 91cm 1.8 prism	$\delta > 30$, $\|b\| > 30$	1350	3400-5300	18.0
HQS	1985 – 1997	CAHA 81cm 1.7 prism	$\delta > 0$, $\|b\| > 20$ 14,000	1390	3400-5300	19.0
HES	1990 – 1996	ESO 1m Schmidt 4 prism	$\delta < 2.5$, $\|b\| > 30$ 9,000	280	3400-5300	18.0
SDSS	2000 – 2014	Apache Point 2.5m Double MOS	$\delta > 0$, $\|b\| > 30$ 14,555	res. 2.5*Å*	3800-9200	22.0

9/18/65/90/140/160 μm, IRAS 12/25/60/100 μm, radio 4.85 and 1.4 GHz, 843, 612, 326, 152 and 38 MHz). These SEDs provide a possibility to group objects by their shapes and compare to existing physical properties to find various relations and refine the AGN classifications.

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