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The Digitized First Byurakan Survey – DFBS

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Abstract. The First Byurakan Survey (FBS) is the largest spectral survey in the Northern sky. One can select objects by color, broad absorption and emission lines, and SED; classify and investigate them. The digitization of the FBS is aimed at making a DFBS database available for the astronomical community. Besides scanning, we are creating plate solutions, extraction software, wavelength and flux calibration, templates for different types of objects, numerical classification, a catalog of objects, a database of spectra, a user interface and a DFBS web page. New research projects based on the DFBS are possible, including a search for new QSOs and other AGN, a continuation of the second part of FBS, and identifications of radio, IR and X-ray sources. The DFBS database will be available at the end of 2004.

1. *FBS* and its Low-dispersion Spectra

The First Byurakan Survey has been carried out by B. E. Markarian, V. A. Lipovetski and J. A. Stepanian during 1965–1980 with the Byurakan Observatory 102/132/213 cm (40″/52″/84″) Schmidt telescope using a 1.5° prism (Markarian et al. 1989). 2050 Kodak IIAF, IIaF, IIF, and 103aF photographic plates in 1133 fields (4°×4° each, the size being 16 × 16 cm) have been taken. FBS covers 17,000 deg^2, being all of the Northern sky and part of the Southern sky ($\delta > -15°$) at high galactic latitudes ($|b|$ >15°). In some regions, it even goes down to $\delta = -19°$ and $|b|$=10°. The limiting magnitude for the majority of plates is $17.5^m - 18^m$. The scale is 96.8″/mm and the dispersion is 1800 Å/mm near Hγ and 2500 Å/mm near Hβ (mean spectral resolution being about 50 Å). Low-dispersion spectra cover the range 3400–6900 Å, and there is a sensitivity gap near 5300 Å, dividing the spectra into red and blue parts. It is possible to compare the red and blue parts of spectra (easily separating red and blue objects), check the spectral energy distribution (SED), note some broad emission

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and absorption lines, and thus reach some understanding of the nature of the objects.

The FBS is made up of zones (strips), each covering 4° in declination and all right ascensions except the Galactic plane regions. In all there are 28 zones, which are named by their central declination (eg., zone +27° covers $+25° < \delta < +29°$). The zones and the neighboring plates in right ascension overlap by about 0.1° (as the exact size of a plate is 4.1°×4.1°) thus making the whole area complete. 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.

2. Results Obtained on the Basis of the *FBS* Plates

Markarian Galaxies The FBS was conducted originally as a search for galaxies with UV-excess (UVX). The discovery of 1515 UVX galaxies by Markarian and colleagues (later called Markarian galaxies) was the first and the most important work based on the FBS plates (Markarian 1967; Mazzarella & Balzano 1986; Markarian et al. 1989). The study of Markarian galaxies brought to discovery many new Seyferts and the first spectral classification of this type of object (Weedman & Khachikian 1971), as well as the definition of starburst galaxies (Weedman 1977). Among them, there are 181 Seyferts, 17 LINERs, 13 QSOs, 3 BLLs, 95 starburst and 26 HII galaxies, radio, IR, X- and gamma-ray sources, interacting and merging objects, and galaxies with double and multiple nuclei. Markarian galaxies are the subject of study for the understanding of the AGN phenomenon; starburst activity and evolution of galaxies; high-luminosity IR radiation; AGN variability; double and multiple structure of the nucleus; composite spectrum AGN; galaxy interactions and merging; connections between different types of active galaxies; early stages of evolution of galaxies; and other important topics of modern extragalactic astronomy. The Markarian survey was a new search method and the first systematic survey for AGN.

FBS Stellar Objects The second part of the FBS was devoted to the discovery and study of blue (UVX) stellar objects (Abrahamian & Mickaelian 1996). It was carried out in 278 FBS fields, in a 4009 deg^2 area of the FBS ($+33° < \delta < +45°$ and $\delta > +61°$). The main purpose of this work was the discovery of new bright QSOs, Seyferts, planetary nebulae nuclei, cataclysmic variables (CV), white dwarfs (WD), subdwarfs, etc. 1103 objects have been selected, including 716 new blue stellar objects. Spectroscopic observations have revealed 42 new bright AGN (Mickaelian et al. 2001). The local density of QSOs and the completeness of the Bright Quasar Survey (BQS) (Schmidt & Green 1983) has been re-estimated. A number of interesting WDs and CVs have been discovered too, such as the new bright SW Sex type CV (Mickaelian et al. 2002). The catalog of the FBS blue stellar objects is available at CDS (Abrahamian et al. 1999).

A survey for late-type stars is being carried out as well (Gigoyan et al. 2002). 1184 late M-type and carbon stars have been selected so far in an area of 10,830 deg^2, including 778 new ones. Surveys on carbon stars at high galactic latitudes are very rare. Discovery and study of such objects is necessary for the study of the kinematics and chemical composition of the Galactic halo.

Identification of IRAS Sources The program of optical identifications of IRAS sources on the basis of the FBS plates (Mickaelian 1995) has resulted in the identification of 1577 IRAS PSC sources (IRAS 1996) in the area $+61° < \delta < +90°$ with a surface of 1504 deg^2. In this area, FBS plates have better limiting magnitudes (on average: 18.1 in V). 1178 of the identified sources are galaxies. Two samples have been compiled: BIS (Byurakan-IRAS Stars) (Mickaelian & Gigoyan 2001), and BIG (Byurakan-IRAS Galaxies) (Mickaelian & Sargsyan 2004). Observations revealed a number of Seyferts, LINERs, and composite spectrum AGN (Mickaelian 2004). The BIG sample contains AGN, high-luminosity IR galaxies, groups of galaxies, interacting/merging galaxies, etc. The study of BIG objects leads us to an understanding of the interrelationship between AGN and starburst activity induced by galaxy interactions and merging. The subsample of galactic objects contains new planetary nebulae, AGB stars, late M and carbon stars. Some of them have excessive IR fluxes, indicating extended dust shells, and a number of stars show evidence of variability.

Table 1 presents the summary of the FBS-based projects. 300 of the discovered objects are AGN (Véron-Cetty & Véron 2003). FBS initiated also the Second Byurakan Survey (SBS) with a deeper limiting magnitude ($19^m - 19.5^m$) but a smaller area (~1000 deg^2) (Stepanian, Chavushyan, & Erastova 2004). There are plans to digitize the SBS and construt a similar database as well.

Table 1. Projects undertaken on the basis of the *FBS*

Project	Years	Authors	Area	Objects
Markarian galaxies	1965-1980	Markarian, Lipovetsky, Stepanian	17000	1515
Blue stellar objects	1987-1996	Abrahamian, Mickaelian	4009	1103
Late-type stars	1987-2002	Abrahamian, Gigoyan	10830	1184
IRAS galaxies (BIG)	1995-2003	Mickaelian	1504	1178
IRAS stars (BIS)	1995-2001	Mickaelian, Gigoyan	1504	370
All programs	1965-2003		17000	5350

3. The Digitized First Byurakan Survey (*DFBS*)

3.1. Scanning and Storage

The plates have been digitized with an EPSON EXPRESSION 1680 Pro (A4 size) scanner using the scanning direction along R.A. (to avoid the uncertainties along δ (= wavelength) scanners may have, compared to professional microdensitometers). Thus, we obtain an absolute accuracy along wavelengths. The plates are located with the emulsion in contact with the scanner glass plate. Scanning is being done in positive transparency mode controlled by a PC (Windows-2000 OS). An "ad hoc" program *scanfits* by Stefano Mottola writes the resulting image directly into FITS format with corresponding information in its header.

The automatic normalization of scanners does not work properly for astronomical plates. The scanner options, however, allow us to set manually the data number (DN) for the darkest and brightest areas of the image. A black paper sheet is used to cover one of unexposed plate corners to allow measurement of the effective zero (lower limit) of the DN, and an unexposed corner is used as an upper limit. With these settings, DN span the range 0 (dark) to 16383 (transparent). A 16-bit density range is used (the maximum for gray-scale mode). In practice the black corner counts are ~600 DN and the plate veil counts ~14000 DN. Taking into account the size of the photographic grains of Kodak II plates (25–30 μm), we decided first to scan the plates with a resolution of 2400 dpi (10μm/pix). However, tests showed that there is no additional information given by higher resolution. We preferred then 1600 dpi. The pixel size is 15.875 μm (1.542″), and the width of spectra is 5 pixels which is sufficient for further reduction. The length of a spectrum is 1.7 mm; we obtain 107 pixels along the wavelength scale.

We scan the actual image area (15 × 15 cm) with 9601×9601 pixels (an odd number is given to have a single pixel for the plate center). The time for scanning one plate was about 8 minutes at the beginning, and about 4 minutes after increasing the PC's memory. The whole process (setting the plate and parameters, writing image data in the file header, scanning and saving) takes ~ 10–12 min. We obtain a 175 MB file for each plate, and 3 plates of data can be stored on a single CD, or 25 plates on a 4.7 GB DVD. Since June 2002, some 70% of the FBS plates have been digitized and stored on CDs and DVDs so far (Table 2). We plan to finish the scanning of all plates within 2003.

Table 2. Data for the Digitized Part of the *FBS*

Zone	Fields	Plates	Area (deg^2)
8 high-δ zones (+63 to +88.5)	113	182	1503.9
–13	35	54	512.8
– 9	67	108	994.8
– 5	67	100	1003.2
– 1	68	120	1022.0
+ 3	68	87	1020.4
+ 7	65	97	970.0
+11	61	105	959.6
+15	58	102	897.6
+19	60	90	909.2
+23	61	95	900.8
+27	56	105	842.8
+31	55	83	851.6
All zones	834	1328	12,388.7

3.2. Plate Solution

A procedure to find the plate solution (pixels-to-coordinates conversion) for the DFBS plates is made by one of the authors (RN) using the Tycho catalog stars and the IRAF package. It is a manual process in a two-step procedure. The first step requires the identification of about 20-25 bright stars from the Tycho catalogue. A 9^m limit is given for a first guess. We assume the intensity peak in the red part of the spectrum as the star position. Then we overplot on the image the coordinates of the bright stars. A plate solution is then computed using the IRAF task *ccmap* and written in the FITS header using the task *ccsetwcs*. The second step is based on the first one and refines it. It uses all Tycho stars present in the field, and the IRAF *ccfind* task finds all these stars using the first plate solution. Then a second solution is computed and written in the FITS header as at the first step. We have 5 free parameters: x and y for the plate center (transformed into α and δ), rotation angle, and scales in x and y.

The positional accuracy obtained is typically 1 pixel rms, quite sufficient for safe object identification. The star identification and preparation of the input files requires ~1 hour. A cookbook with a detailed description of this procedure is available for users who request a plate not yet astrometrically calibrated.

3.3. Extraction of Spectra

A catalogue-driven procedure for the spectra extraction has been created by one of us (RN), written as an IRAF script, including FORTRAN programs. The list of all objects present in USNO-A2 down to the plate limit and included in the sky area is converted into pixel coordinates with the IRAF task *cctran*. Then an image section including a well-exposed star is selected and the spectrum is extracted with IRAF/*apall* in interactive mode. This process allows us to derive the orientation of the spectra on the plate and defines the template for subsequent automatic extractions. Finally all listed spectra are extracted automatically by *apall*, assuming as sky value the mode of an area 21×150 pixels centered on each spectrum (the typical FWHM of a spectrum is 5 pix and the length 107 pix, so we have the spectrum in the extracted field). With this method we lose only a small number of variable objects present in DFBS but absent among the bright objects of USNO. Figure 1 shows 4 extracted 1D low-dispersion spectra of F- and M-type stars, and 2 AGN with emission lines.

3.4. Wavelength Calibration

The red cutoff of the FBS spectra is rather sharp, so that it can be used as a reference point, but is mildly sensitive to the brightness and spectral type of the object. For calibration, we use stars of intermediate brightness and types to have a definite red edge, but not overexposed. We use WDs, subdwarfs, CVs, and QSOs with known redshift from available catalogs having broad Balmer, He, and some other (QSOs) lines. There are 10 main references points: λ-start (3400 Å), Hζ, Hϵ, Hδ, Hγ, HeII λ4686 Å, Hβ, sensitivity "gap" (5300 Å), Hα, and λ-end (6900 Å). The calibration based on these points is sufficient for a coarse spectral classification. However, we plan to make up a good dispersion curve and transform all spectra into wavelengths. The dispersion is strongly non-linear: the wavelength scale is 22 Å/pix at the blue edge, and ~ 60 Å/pix

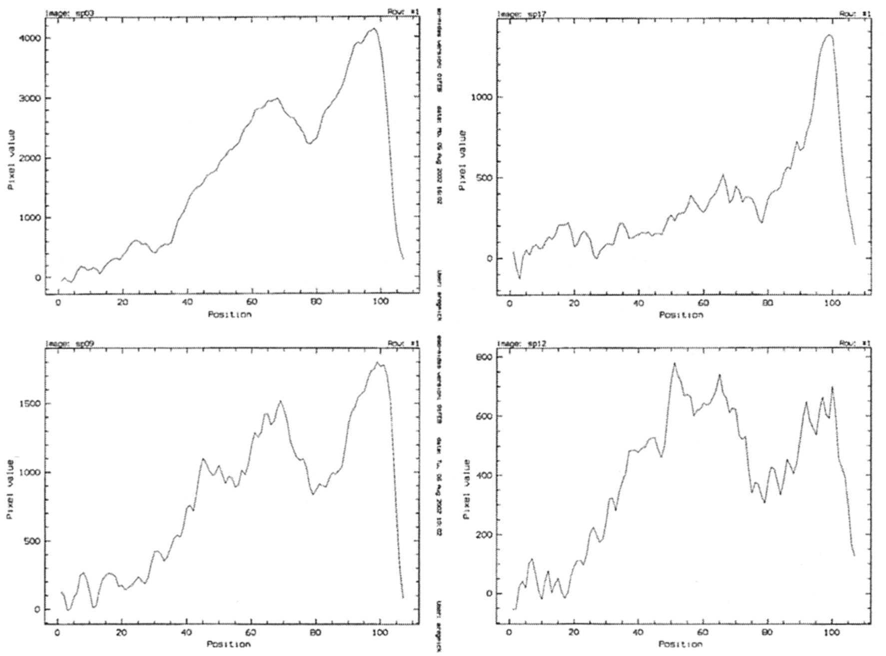

Figure 1. FBS spectra of F- and M-type stars, and 2 AGN.

at the red, mean dispersion being 32.7 Å/pix. At Hγ it is about 28.5 Å/pixel. However, the spectral resolution is 1.5-2 times worse, as the photographic grains occupy 1.5–2 pixels.

3.5. Density-to-intensity and Flux Calibration

The density-to-intensity (I) calibration is made from the original DN according to an approximate formula I=(V–B)/(T–B), where V is the average DN value for the unexposed plate, B for the black corner, and T for a given pixel. Furthermore, we have carried out a number of trials to obtain an accurate sensitivity (response) curve for Kodak F emulsion. Finally, we obtain the real SED for objects and make a transformation for all extracted spectra. This will be significantly better for classification. We plan also to make some rough photometric calibration (I-to-flux conversion) using photometric standards. It is estimated, that up to 0.3^m accuracy may be reached. However, we don't require photometry, as the MAPS catalog is available (Cabanela et al. 2003).

3.6. Multiband Photometry

Plans for making multiband (UBVR) photometry are active. The accuracy estimated that can be achieved is 0.3^m, however, it will be 1.5–2 times worse for V band, which falls near the sensitivity gap, as well as for U (3660 Å) for faint red objects, and R (6930 Å) for faint blue objects, when the values will be near the background level (in fact, the R values will be systematically underestimated, as our spectra cover only half of its bandwidth, but on the other hand, sensitivity of the emulsion is the highest in this range).

To link our data to the MAPS (POSS) O (4050Å) and E (6450Å) magnitudes, we try to measure these values as well. In fact, these bands are better suited for our spectra, and they are being measured with higher accuracy.

3.7. Classification

We use 2 methods. First is based on making template spectra for different types of objects from available catalogs. Then we search for similar objects (QSO, BLL, Sy, CV, WD, sd, M, C, etc.) among the FBS low-dispersion spectra. The success rate depends on the limits of given parameters: we can select either a small number of good candidates missing a fraction of objects, or a large number of candidates with a contamination of other types, but having all objects of interest. Thus a compromise should be made depending on the given task. This method is good for a quick search for objects of interest.

The second approach is based on making a numerical classification for all FBS spectra. The classification principles are based on the relation of magnitudes and widths of the spectra (for separation of stellar and diffuse objects), SED, ratio of the red and blue parts (color), length of the spectrum, spectral lines, etc. They are based on criteria worked out during our previous FBS-based projects. Our classification will be linked to the general one using standard objects. This approach is good for working with all objects in the field.

3.8. The *DFBS* Catalog and Database

A catalog of all FBS objects with positional, photometric and spectral information (some 20,000,000 objects) will be created after extraction of all objects from the plates. This will allow a quick access to DFBS without extraction of large 2D images. It will be linked to most common databases (SIMBAD, NED, etc.) too. However, the complete DFBS database will contain all data on objects and their spectra. Both 2D and 1D spectra will be available. Each 1D spectrum will be presented as a small table of 107 rows corresponding to recorded pixel data. The DFBS catalog and spectra, and corresponding software, will be written on DVDs (20 plates of data on each) and distributed to the main astronomical centers. The whole DFBS database will occupy 100 DVDs.

DFBS will be a significant contribution to the Astrophysical Virtual Observatories, especially for its unique spectral information. By our estimates, the DFBS database will be available at the end of 2004.

3.9. Web Page and User Interface

A preliminary site has been open at Universita di Roma La Sapienza since the beginning of 2003 (http://astro1.phys.uniroma1.it/DFBS/fbs.htm). A description of the FBS and DFBS, instructions for making plate solutions and the extraction of objects, some example spectra, and the list of digitized plates are available. The list of all FBS plates is available in the Wide-Field Plate Database (WFPDB) at http://draco.skyarchive.org/search_test/.

The complete DFBS web page will be available at the end of 2004 in Byurakan (Armenia), with mirror sites in Rome (Italy) and Cornell University

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(USA). It will give access to full information on FBS and DFBS, the catalog of objects, database of 2D and 1D spectra, and classification. A user interface will enable the use of the FBS data together with the DSS, APS, USNO, and other databases, the extraction of spectra of any object present in the catalog, comparison of the fields and data with corresponding ones from other surveys, etc.

4. Future Research with the *DFBS*

The DFBS provides the possibility for the search for many new objects, such as:

- New bright QSOs (m<18^m). The numerical criteria for selection of candidate QSOs will be more efficient, and one can expect some 200 new QSOs with m<16.1^m, and some 1000 fainter objects.
- New Markarian (UVX) galaxies. Having 1D records for all Markarian galaxies we will continue homogeneous selection of such objects missed by eye.
- New blue stellar objects. The 2nd part of the FBS will be continued for the whole area and some 4500 objects are expected.
- New BCDGs. 22 Markarian galaxies and 135 SBS galaxies are candidate BCDGs. These two surveys have given the vast majority of such objects.
- Optical counterparts of IR, radio, X-ray and other sources (optical identifications). The IRAS identifications program will be continued and identifications of radio and X-ray sources will be made.
- Late-type stars (M, S, carbon stars).
- Planetary nebulae. There still may be faint undetected planetary nebulae at high galactic latitudes, which are easy to select by their emission lines.
- All emission line stars (CV, etc). Their emission lines are sometimes of low contrast. A computer analysis will detect them much better.
- Non-UVX white dwarfs. A lot of WDs without UVX are present in the FBS plates, which are not included in the Second part of the FBS. They may complement the sample of high-latitude WDs.
- Studies of star and galaxy clusters. It is desirable to study clusters using homogeneous data, especially having the low-dispersion spectra of all objects.

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