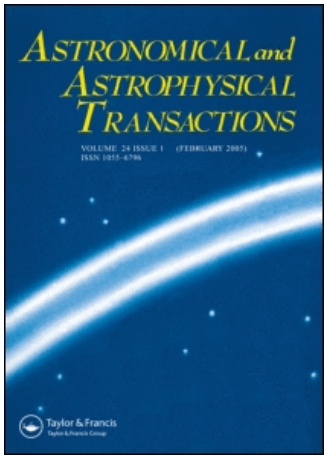

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MULTIWAVELENGTH SEARCH FOR AND STUDIES OF ACTIVE GALAXIES: AN INTERNATIONAL COLLABORATION BETWEEN THE BYURAKAN OBSERVATORY AND OBSERVATOIRE DE HAUTE-PROVENCE*

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An international collaboration on the multiwavelength search for and studies of active galaxies between the Byurakan Astrophysical Observatory (Armenia) and Observatoire de Haute-Provence (France) has been ongoing since 1997. The blue stellar objects of the first Byurakan survey have been studied in order to reveal and build a sample of new bright quasistellar objects and to determine their surface density. On the basis of optical identifications of 1577 IRAS point sources, a new (Byurakan–IRAS galaxy) sample of IRAS galaxies has been constructed and studied. 90 bright Seyfert 1 galaxies have been observed with a high resolution to make a fine analysis of their emission line profiles and to study their emission line regions. A new programme of investigation of Roentgen Satellite (ROSAT) sources identified by the Hamburg quasar survey has been conducted to search for new narrow-line Seyfert 1 galaxies. Databases and observations in the optical, infrared, radio and X-ray ranges are being used.

Keywords: Multiwavelength search for active galaxies; Internal collaboration

1 INTRODUCTION

An international collaboration on active galaxies between the Byurakan Astrophysical Observatory (BAO), Armenia, and Observatoire de Haute-Provence (OHP), France was started in 1997 in the framework of the French–Armenian cooperation programme 'Jumelage'. The first studies concerned the search for new quasistellar objects (QSOs) and Seyfert galaxies among the blue stellar objects (BSOs) of the first Byurakan survey (FBS). Later, Infrared Astronomical Satellite (IRAS) galaxies, narrow-line Seyfert 1 (NLS) galaxies, Hamburg–ROSAT active Galactic nuclei (AGNs) were envolved in the collaboration as well. In all, eight visits of Armenian scientists to France and three visits of French scientists to Armenia have been made during 1997–2002 for joint research work, observa-

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tions and participation in meetings. The BAO 2.6 m and the OHP 1.93 m and 1.20 m telescopes have been used for the joint observations, and more than 60 nights have been allocated for the above-mentioned programmes. The results have been reported in a number of international meetings, including the IAU Symposia, Vols. 194, 204 and 205, IAU Colloquium, Vol. 184, Joint European and National Astronomical Meeting (JENAM) 2000, 2001 and 2002, the Conference on The New Era of Wide-Field Astronomy in 2000, and invited seminars in Marseille, Cornell, Cambridge, Bonn, Rome and Byurakan. The collaboration includes four topics:

(i) search and study of QSOs and Seyfert galaxies among the FBS BSOs;
(ii) optical identification and study of IRAS galaxies;
(iii) analysis of the emission lines of bright Seyfert galaxies;
(iv) optical identification and study of ROSAT FSC (Faint Source Catalogue) sources.

We present a summary report on our collaboration with some of the results obtained so far, as well as some perspectives for future research.

2 STUDY OF QUASISTELLAR OBJECTS AND SEYFERT GALAXIES FROM THE FIRST BYURAKAN SURVEY

The second part of the FBS (Markarian et al., 1989) was conducted in 1987–1996 (see Mickaelian (2000) and references therein) for selection and further study of BSOs on the basis of the FBS observational material (Markarian et al., 1989). The main purpose of this work was to discover new bright QSOs, Seyfert galaxies, other compact galaxies, cataclysmic variables (CVs), white dwarfs (WDs), hot subdwarfs, HBB stars and other peculiar stellar objects. 1103 objects have been selected, including 716 new BSOs. In all, 11 lists have been published and the FBS BSOs catalogue is available at Centre de Donnees Stellaires (CDS) (Abrahamian et al., 1999). The completeness of the sample for objects with brightnesses B of magnitude less than 16.5 and $U - B < -0.5$ has been estimated as about 67%. Subsamples of candidate QSOs, WDs, CVs and other objects have been constructed for their further detailed studies.

On the basis of the low-dispersion spectra and other available data, 50 FBS BSOs have been selected as highly probable candidate bright QSOs. Cross-correlation of the FBS lists with the ROSAT RASS (ROSAT All-Sky Survey) and WGACAT catalogues (Voges et al., 1999) and radio catalogues (in particular, the NRAO/VLA Sky Survey (NVSS) (Condon et al., 1998)) revealed a dozen or more candidate objects. Additionally, these catalogue sources have been cross-correlated with the US Naval Observatory USNO-2.0A (Monet et al., 1996) and Astronomical Society of the Pacific (Pennington et al., 1993) catalogues to check whether the FBS had missed QSOs and Seyfert galaxies. All these candidate objects have been checked in the FBS low-dispersion plates and observed during 1997–2000 with the BAO 2.6 m (ByuFOSC focal reducer) and OHP 1.93 m (Carelec spectrograph) telescopes, and also some objects have been observed during this period by other astronomers. We have discovered 12 new bright QSOs and Seyfert 1 galaxies, including an object at $z = 0.118$ of magnitude 14. A number of new interesting stars (CVs, WDs, etc.) have been revealed as well. The newly discovered QSOs bring the total number of FBS QSOs to 42 (Véron-Cetty and Véron, 2001). As a result, we have constructed the most complete sample of bright QSOs (B of magnitude less than 16.6) over a large area (2250 $\deg^2$, the subarea of the FBS common with the Palomar–Green survey with $|b| > 30^\circ$ (Green et al., 1986)). This allowed us to estimate their surface density as 0.012 $\deg^{-2}$. The completeness of the bright quasar

survey (Schmidt and Green, 1983) has been revised to 53%, which is higher than the estimates of the previous workers (Mickaelian et al., 1999; 2001a; Véron et al., 1999). An interesting bright (of magnitude 14, and $M = -24.6$) narrow-line QSO FBS $0732 + 396$ has been found at $z = 0.118$ with strong Fe I emission lines. A new ROSAT AGN RXS $J170535 + 3340$ having unusual line ratios typical of NLS1 galaxies has been discovered as well.

In all, there are 108 bright (B of magnitude less than 17.0) AGNs in the FBS subarea with $|b| > 30^\circ$, including 40 objects discovered firstly in the FBS (Véron-Cetty and Véron, 2001). FBS QSOs and Seyfert galaxies have red shifts of 0.063–2.00 (QSOs with larger red shifts are very red, and it is difficult to distinguish them in the FBS spectra) and absolute B magnitudes in the range from -20.3 to -29.9.

More than 450 spectra of FBS BSOs have been obtained earlier in Byurakan with the 2.6 m telescope and the Universal Astronomical Grating Spectrograph (UAGS). They contain QSOs, Seyfert galaxies, CVs, WDs, planetary nebulae nuclei, etc., but have not been published yet. 50 of these spectra have been scanned with the Machine Automatique de Mesures Astronomiques (MAMA) (Observatoire de Paris) by J. Guibert and R. Chesnel to reveal low-contrast spectral features. Five known QSOs have been revealed, confirming the nature of these objects, including one discovered during our observations at OHP. 15 other objects have continuous spectra and may turn out to be QSOs, BL Lacs or DC WDs (Mickaelian et al., 2002d).

It is worth mentioning that we have discovered also a new bright (V of magnitude 12.6) cataclysmic variable among the ROSAT sources during the search for new QSOs, and it appeared to be an interesting object of rare SW Sex-type nova-like variables with a period outside the previously known period range (Mickaelian et al., 2002a).

For reduction of the ByuFOSC spectra, an automatic reduction procedure in MIDAS extbao (and other auxiliary programs) have been created on the basis of a similar procedure used at OHP (extohp and auxiliary programmes written by M. P. Véron-Cetty). These procedures have been installed at the 2.6 m telescope and have been successfully used for reduction of other observations as well.

3 OPTICAL IDENTIFICATIONS AND STUDY OF IRAS GALAXIES

A programme of mass optical identifications of all IRAS (1988) Point Source Catalogue (PSC) sources in a large (1487 deg^2) area on the basis of low-dispersion spectra of the FBS (Markarian et al., 1989) was conducted in the region with $+61^\circ < \delta < +90^\circ$ at Galactic latitudes $|b| > 15^\circ$ (see Mickaelian (2002), and references therein). In all, 1577 IRAS PSC sources have been identified. Among the identified sources, there appear to be late-type stars, planetary nebulae, candidate QSOs, single and multiple galaxies and small groups. The identified galaxies are the most interesting counterparts of the infrared (IR) sources. The identifications resulted in construction of a new sample of IRAS galaxies, namely the Byurakan–IRAS Galaxy (BIG) sample, containing 1967 objects, including 789 previously known galaxies in this area and 1178 newly identified galaxies.

Studies of BIG objects include spectroscopic follow-up for the brighter (V of magnitude less than 18) objects (aimed at measuring their red shifts and classification), a red shift survey (Mickaelian et al., 2002b); the discovery and study of new AGNs and ultrahigh-limunosity infrared galaxies (ULIGs), two-dimensional spectroscopy of interacting and merging systems, the search for obscured IRAS galaxies, and the study of starburst, AGN and interaction phenomena and their interrelationship. Medium-dispersion spectral observations have been car-

ried out for the BIG objects during 1997–2002 using three telescopes (Mickaelian et al., 1998; 2002c,e; Balayan et al., 2001): the Special Astrophysical Observatory (SAO), Russia 6 m (UAGS and Multi-Pupil Fibre Spectrograph (MPFS) spectrographs), the OHP 1.93 m (Carelec spectrograph) and the BAO 2.6 m (ByuFOSC and Scorpio) telescopes. In all, 346 spectra for 229 BIG objects corresponding to 181 IRAS sources have been obtained so far. Red shifts are in the range 0.008–0.173, the absolute magnitudes are between -17.5 and -23 and the calculated far-IR luminosity is in the range $3 \times 10^9 < L_{fir}/L_\odot < 7.5 \times 10^{12}$ (for $H_0 = 50$), including three ULIGs already revealed. Classification of the spectra has been made and activity types of the galaxies have been estimated on the basis of the emission line ratios (Veilleux and Osterbrock, 1987). Most of objects classified already are of an H II nature, 21 are Seyfert 2 galaxies, seven are LINERs (Low Ionization Nuclear Emission - Line Region) and four are of composite AGN nature. Objects having a composite spectrum (two distinct emission nebulae, for instance a H II region and a Seyfert galaxy, superimposed on the slit) should be observed again with higher resolution (less than 3 Å) to study the profile of the various emission lines and to identify the nature of the emission objects (Véron et al., 1997).

All BIG objects have been grouped into several subsamples on the basis of their appearance, structure and nature: AGNs (Seyfert galaxies, LINERs, composite-spectrum objects, etc.), high-luminosity IR galaxies (luminous IR hyper-galaxies, ULIGs and high-luminosity IR galaxies (Sanders and Mirabel, 1996)), interacting galaxies and mergers, and distant groups (many of these being compact groups).

The interacting and merging BIG objects are of special interest owing to the star formation, nuclear activity and interaction phenomena occurring there, giving the possibility of studying connections between these phenomena in order to understand high-luminosity IR radiation. Investigations of the sample of interacting and merging BIG objects have been started already and are aimed at the following: spectral observations of separate components (confirmation of physical connections and classification of objects); the search for AGNs in pairs, two-dimensional spectroscopic observations with the SAO MPFS and Byurakan VAGR multipupil spectrographs to study the spectra of different parts, their velocity fields and dynamics; a morphological study (deep imagery) with the 2.6 m telescope with different filters; study of the fine structure of interaction regions. Cross-correlations with radio, X-ray and other catalogues together with data obtained allow us to determine the accurate region where the IR comes from and to decide whether only one of the components is responsible for it. This is important for understanding how the IR is produced and connections between interactions and IR radiation. Among 766 associations with NVSS (Condon et al., 1998), in two thirds of cases, radio positions give the exact component responsible for the IR; however, in one third of cases, the IR comes from the centre of the whole system and may be connected with the interactions (Mickaelian et al., 2001b).

4 ANALYSIS OF EMISSION LINE PROFILES OF SEYFERT 1 GALAXIES

A programme of fine analysis of emission line profiles and detailed spectroscopic classification of bright Seyfert 1 galaxies (including NLS1 galaxies) has been ongoing at the OHP for the last 3 years. It is aimed at studying the differences between the classical broad-line Seyfert 1 (BLS1) and NLS1 galaxies (Osterbrock and Pogge, 1985) and correlations between Fe II and Balmer lines (full width at half-maximum (FWHM)), Fe II and [O III], and better understanding of the physics of AGNs central regions. NLS1 galaxies are important for verification of the unified model and for understanding the broad-line region of the AGNs. However, it appears that there is not a strict separation between the BLS1 and NLS1 galaxies

(the linewidth limit at 2000 km s^{-1} is arbitrary), and the intermediary objects may fill the gap. Moreover, the transition objects may be the most important for the unified scheme.

High-dispersion spectroscopy of 90 Seyfert 1 galaxies having intermediate FWHMs has been carried out during 2000–2002 at the OHP 1.93 m telescope with the Carelec spectrograph and a 600 lines mm^{-1} grating giving a 0.9 Å $pixel^{-1}$ dispersion, the spectral resolution being 3.2 Å. Seyfert 1 galaxies from the catalogue by Véron-Cetty and Véron with V of magnitude less than 16 and $z < 0.1$ have been selected to study their emission line profiles and to make a fine classification, including the well-known NGC, Mrk, Zw, IRAS, ROSAT, Akn, Kaz and other objects. The analysis is made using the special program SPECTRAI to fit the spectral lines profiles to the observed spectra (Véron et al., 1980). A comparison was made between the Hα and the Hβ ranges observed in the framework of the same project. The spectra of Seyfert 1 galaxies 3C 120, Zw 229.015, Mrk 509, Zw 493.002, Akn 564, Mrk 926, NGC 985, 1H 2107-0907, Mrk 543, 3C 120 and H 1934-063 have been analysed, and the line profiles for all components have been established.

In most cases, the Balmer lines (and other permitted lines, such as He I, He II and Si II) are characterized by two broad components (two Gaussian profiles or one Gaussian and one Lorentzian) and one or two narrow components, and the forbidden lines ([N II], [O III], [O I], [S II], etc.) by the same one or two narrow components. Fe II and other Fe lines are often significant in the observed spectra. Together with the main emission lines (Balmer, [O III] and [N II]), the emission lines of He I, He II, O I, Si II and others are often present. There are objects with a number of high-ionization lines ([Fe V]–[Fe X], [A III]–[A V], etc.) contrary to LINERs having strong low-ionization lines (Heckman, 1980). As there are some spectra where high-ionization lines play an important role, we have constructed diagnostic diagrams using the [Fe VII] (6086 Å)-to-Hα ratio versus [O I] (6300 Å)-to-Hα ratio and also the [Fe VII] (6086 Å)-to-[O I] (6300 Å) ratio versus the [O I] (6300 Å)-to-Hα ratio. Thus we try to classify objects by the strength of their high-ionization lines. The distribution is well arranged and the objects are in a sequence according to the ionization degree, with a good separation for those objects that we believe are of special interest.

5 STUDY OF NEW ACTIVE GALACTIC NUCLEI FROM THE HAMBURG–ROSAT IDENTIFICATIONS

5341 ROSAT BSC (Bright Source Catalogue) sources (Voges et al., 1999) have been optically identified by means of low-dispersion spectra of the Hamburg quasar survey (Zickgraf et al., 2002). 42% of them are AGNs that are good candidates for NLS1 galaxies. Since 2000, a collaboration of our both Armenian and French teams has started with the Hamburg quasar survey team (D. Engels and F.-J. Zickgraf) and ROSAT (W. Voges) with participation of scientists from Instituto Nacional de Astronomia, Optica y Electronica (INAOE) (Puebla, Mexico) and Beijing Astronomical Observatory (China) to study the Hamburg–ROSAT identifications and to select NLS1 galaxies for further detailed investigation. Moreover, sources from the ROSAT FSC have been identified and are being observed as well. Beside NLS1 galaxies, X-ray sources identified with AGNs contain other interesting subsamples: QSOs, BLS1 galaxies, BLLs (BL Lacertae), etc., and they will be studied also. An X-ray and optically flux-limited sample of some 1000 Seyfert 1 galaxies will be created. Follow-up spectroscopy and a further detailed study are planned (the follow-up spectroscopy has already been started), including snapshot spectroscopy of low S/N to confirm the candidate, to determine the red shift and to classify it according to spectral line properties, high- or medium-resolution spectrophotometry of subsample of NLS1 galaxies and others.

X-ray sources contain a wide range of objects, and even our by-product objects (CVs, WDs, etc.) are rather interesting for problems of stellar physics and evolution.

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