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Several New Active Galactic Nuclei Among X-ray Sources Detected by *INTEGRAL* and *SWIFT* Observatories

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We present the results of the optical identifications of a set of X-ray sources from the all-sky surveys of *INTEGRAL* and *SWIFT* observatories. Optical data were obtained with Russian-Turkish 1.5-m Telescope (RTT150). Nine X-ray sources were identified as active galactic nuclei (AGNs). Two of them are hosted by nearby, nearly exactly edge-on, spiral galaxies MCG −01−05−047 and NGC 973. One source, IGR J16562−3301, is most probably BL Lac object (blazar). Other AGNs are observed as stellar-like nuclei of spiral galaxies, with broad emission lines in their spectra.

For the majority of our hard X-ray selected AGNs, their hard X-ray luminosities are well-correlated with the luminosities in [OIII],5007 optical emission line. However, the luminosities of some AGNs deviate from this correlation. The fraction of these objects can be as high as 20%. In particular, the flux in [OIII] line turns to be lower in two nearby edge-on spiral galaxies, which can be explained by the extinction in their galactic disks.

Keywords: X-ray sources — gamma-sources — active galactic nuclei — optical observations

INTRODUCTION

The all-sky surveys in hard X-rays give a valuable information on the populations of objects, which are difficult to observe due to the presence of absorption in optical and soft X-rays. The most sensitive to date are recently completed *RXTE* (XSS, Revnivtsev et al., 2004) and *INTEGRAL* (Krivonos et al., 2007) all-sky surveys, and on-going *SWIFT* all-sky survey (Tueller et al., 2007).

These surveys contains a large number of known nearby active galactic nuclei (AGNs), cataclysmic variables, X-ray binaries, located in Galactic plane. However, it turns out, that a considerable number of sources, up to 20–30% of their total number, can not be identified with previously known objects. In order to make a complete use of the capabilities of these surveys for statistical studies, one need to identify all the X-ray sources with optical objects and to determine their nature.

The work on optical identifications of hard X-ray sources from the all-sky surveys was started on Russian-Turkish 1.5-m Telescope (RTT150) (Bikmaev et al., 2006a,b). In this paper we present the results on the extragalactic objects — active galactic nuclei, obtained in frames of this work during Autumn 2006 – Spring 2007. Some of these results were immediately published in astronomical circulars (Burenin et al., 2006a,b; Mescheryakov et al., 2006; Burenin et al., 2007). Here we discuss the results of these observations in more detail.

OBSERVATIONS

A characteristic property of X-ray telescopes on board *INTEGRAL* and *SWIFT* observatories is that their accuracy of the localization of X-ray sources, in many cases, is insufficient to unambiguously associate the X-ray source with a certain object in optical band. The error box of *INTEGRAL* and *SWIFT* hard X-ray sources usually is about few arcminutes. When observing in optical band, even at high Galactic latitudes, one will find a considerable number of galaxies and stars in the error box of that size. At low Galactic latitudes, the field of that size contain so large number of stars, that it is impossible to directly associate the X-ray source with any optical object.

In order to obtain more accurate positions of hard X-ray sources one can use the observations in softer X-ray band, where the positions of X-ray sources can be measured much more accurately. First, one can use the data of *ROSAT* All-Sky Survey (Voges et al., 1999). In case of strongly absorbed X-ray sources, which are not detected in *ROSAT* All-Sky Survey, one can use the data of pointed observation of *Chandra*, *XMM*-Newton telescopes or X-ray telescope aboard *SWIFT*, in harder X-ray band.

The data for some hard X-ray sources were obtained

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in dedicated Chandra observations (Sazonov et al., 2005, 2008). An extensive program of observations of *SWIFT* and *INTEGRAL* hard X-ray sources is also carried out with *SWIFT* X-ray telescope (XRT, see, e.g., Tueller et al., 2007). We downloaded all necessary additional open data from *HEASARC*[1] archive.

For our optical observations we first selected the hard X-ray sources, with the positional accuracy enhanced in one or another way. All optical data were obtained with Russian-Turkish 1.5-m Telescope (RTT150), using medium and low resolution spectrometer *TFOSC*[2]. In most cases we used 54 mkm slit, which corresponds to $0.96''$ size in the sky. We mostly used grism #15, which give the best throughput and the most wide spectral coverage (3500–9000 Å). In this setup, the spectral resolution was ≈ 12 Å (FWHM). In those cases, where we needed higher spectral resolution, we used other grisms. The data were reduces using standard *IRAF*[3] software.

RESULTS

The list of X-ray sources, which we were able to identify in Autumn 2006 – Spring 2007, is presented in Table 1. In the Table for each X-ray source we give its name, coordinates, R magnitude, type of the object and redshift. The coordinates are given in 2000 epoch, using USNO B1.0 catalog (Monet et al., 2003) as a reference frame. For nearby galaxies we give the coordinates of active nuclei or the maximum of emission near the center of the galaxy, where the optical spectrum was obtained. R band magnitudes are given for reference and are taken from *USNO-B1.0* catalog. The designation of object types are as follows: Sy1,2 — Seyfert galaxy of type 1 or 2; BL Lac — BL Lacertae object. The AGNs redshifts were measured using only narrow lines, like [OIII] 4959,5007, [NI] 5199, [OI] 6300, [SII] 6716,6731, and also in some cases [OII] 3727, [NeIII] 3869 and narrow parts of Balmer lines. The errors of z measurement should not be larger than 0.0001.

The finding charts, where the arrows show the optical objects identified with hard X-ray sources, are shown in Fig. 1. For the sources IGR J01528−0326 and IGR J02343+3229 the arrow show the position of the slit of the spectrometer. In the charts we show the direct images in r' filter (*SDSS*), obtained with RTT150 telescope. In case of X-ray source IGR J16562−3301, when we not able to obtain the direct image of sufficient quality, the image taken from DSS-II red plate is shown.

Fig. 2 shows spectra of optical objects, which were used to identify the types of the objects. All spectra are converted to physical fluxes, using the observations of spectrophotometric standard stars from the list of Massey et al. (1988). In cases of nearby galaxies MCG −01−05−047 and NGC 973 (X-ray sources IGR J01528−0326 and IGR J02343+3229), only small fraction of the flux of the central parts of the galaxies fall into the slit of the spectrometer. This produce the uncertainty of the photometric calibration of the emission line flux, because the real angular size of the line emitting region is unknown. For this objects we corrected the flux for the slit size, assuming that the angular radius of the emitting region is equal to $9''$and $12''$correspondingly, where the angular sizes are taken so that we obtain the *upper* estimate of the flux in emission lines. In other cases the slit size correction was applied, assuming that the source is point-like, which is a good approximation, since all the other AGNs have the stellar-like nuclei.

Due to the uncertainty of photometrical conditions during our observations, photometric calibration may contain significant systematic errors, especially in blue part of the spectrum $\lambda < 5500$ Å. The spectra in Fig. 2 are not corrected for the Galactic interstellar extinction. The spectrum of X-ray source IGR J16562−3301 is shown in CCD counts, because it was observed at very large zenith angles and the overall form of its spectrum is strongly distorted.

Notes on individual objects

IGR J01528−0326 — The source is unambiguously identified with nearby edge-on spiral galaxy MCG −01−05−047. Optical spectrum of the central part of the galaxy shows narrow emission lines H_α, [NII],6583 and [SII],6716. From the intensity ratio $\lg([\mathrm{NII}],6583/H_\alpha) \approx 0$, we conclude that this source most probably is a Seyfert 2 AGN (Veilleux and Osterbrock, 1987).

IGR J02343+3229 — The source is identified with nearby edge-on spiral galaxy NGC973. Optical spectrum of the central part of the galaxy shows narrow emission lines [OIII],5007, H_α, [NII],6583 and [SII],6716. The emission lines intensity ratios can be estimated as $\lg([\mathrm{OIII}],5007/H_\beta) > 0.7$ and $\lg([\mathrm{NII}],6583/H_\alpha) \approx 0.4$. Therefore, this source is most probably a Seyfert 2 AGN (Veilleux and Osterbrock, 1987).

IGR J03334+3718 — The source was detected also in *ROSAT* All-Sky Survey (1RXS J033316.2+371815), which allow to measure more accurate position with the error circle $\approx 10''$. After that this source is unambiguously identified with the galaxy with stellar-like nucleus. The optical spectrum of the nucleus contains redshifted emission lines — broad Balmer lines, and also narrow lines [OIII] 4959,5007 and others, which allow to identify it as Seyfert 1 AGN.

IGR J13038+5348 — This source was observed by SWIFT XRT. Using these data, we determined the

[1] http://heasarc.nasa.gov/
[2] http://astroa.physics.metu.edu.tr/tug/tfosc.html
[3] http://iraf.noao.edu

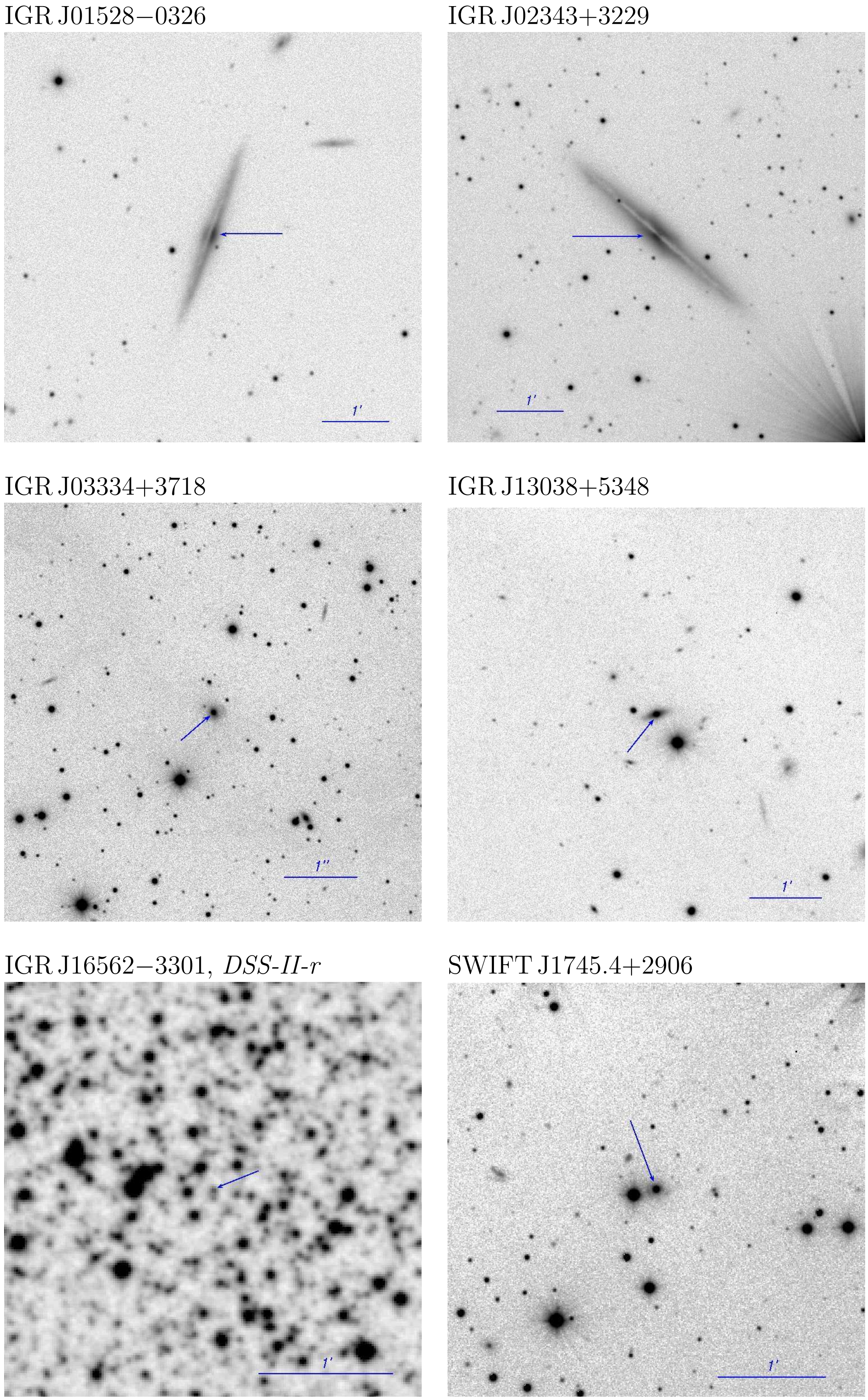

Fig. 1. — Optical images of the fields of hard X-ray sources.

Table 1. Optical identifications of hard X-ray sources

Name	α	δ	m_R	Type	z	Other
	(J2000)					name
IGR J01528−0326	01 52 48.90	−03 26 47.9	9.3	Sy2	0.017197*	MCG −01−05−047
IGR J02343+3229	02 34 20.27	+32 30 18.6	9.8	Sy2	0.016195*	NGC 973
IGR J03334+3718	03 33 18.78	+37 18 11.4	13.5	Sy1	0.05583	
IGR J13038+5348	13 03 59.50	+53 47 30.2	12.9	Sy1	0.03016	MCG +09−21−096
IGR J16562−3301	16 56 16.77	−33 02 12.8	17.5	BL Lac	?	
SWIFT J1745.4+2906	17 45 38.28	+29 08 22.2	14.2	Sy1	0.11040	
SWIFT J1930.5+3414	19 30 13.81	+34 10 49.8	15.8	Sy1	0.06326	
1RXS J193347.6+325422	19 33 47.16	+32 54 26.2	13.4	Sy1	0.05794	
RX J2135.9+4728	21 35 54.02	+47 28 22.3	13.2	Sy1	0.02523	SWIFT J2156.2+4728

* Redshifts are taken from *NED*: http://nedwww.ipac.caltech.edu/

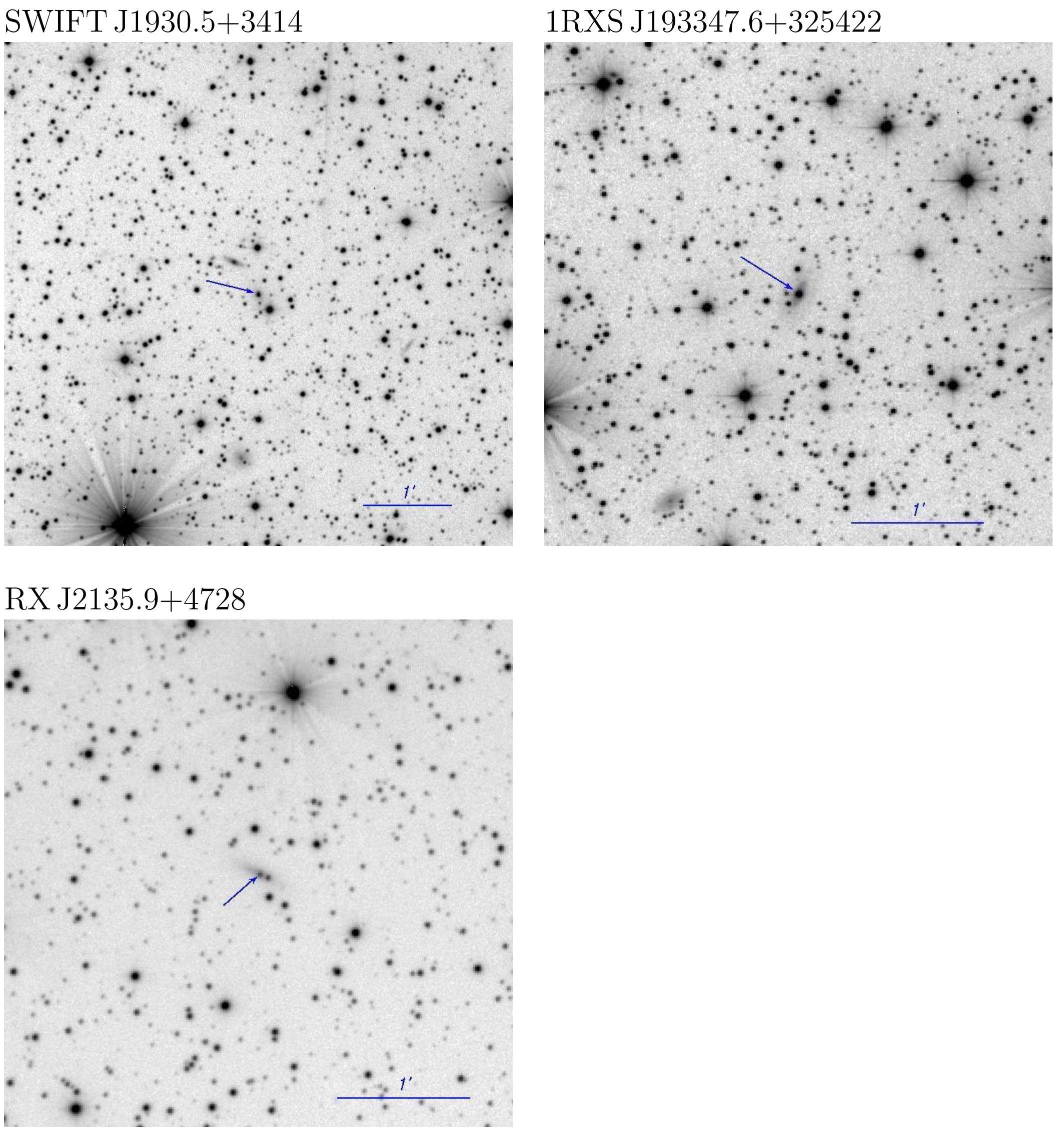

Fig. 1. — *Continued.*

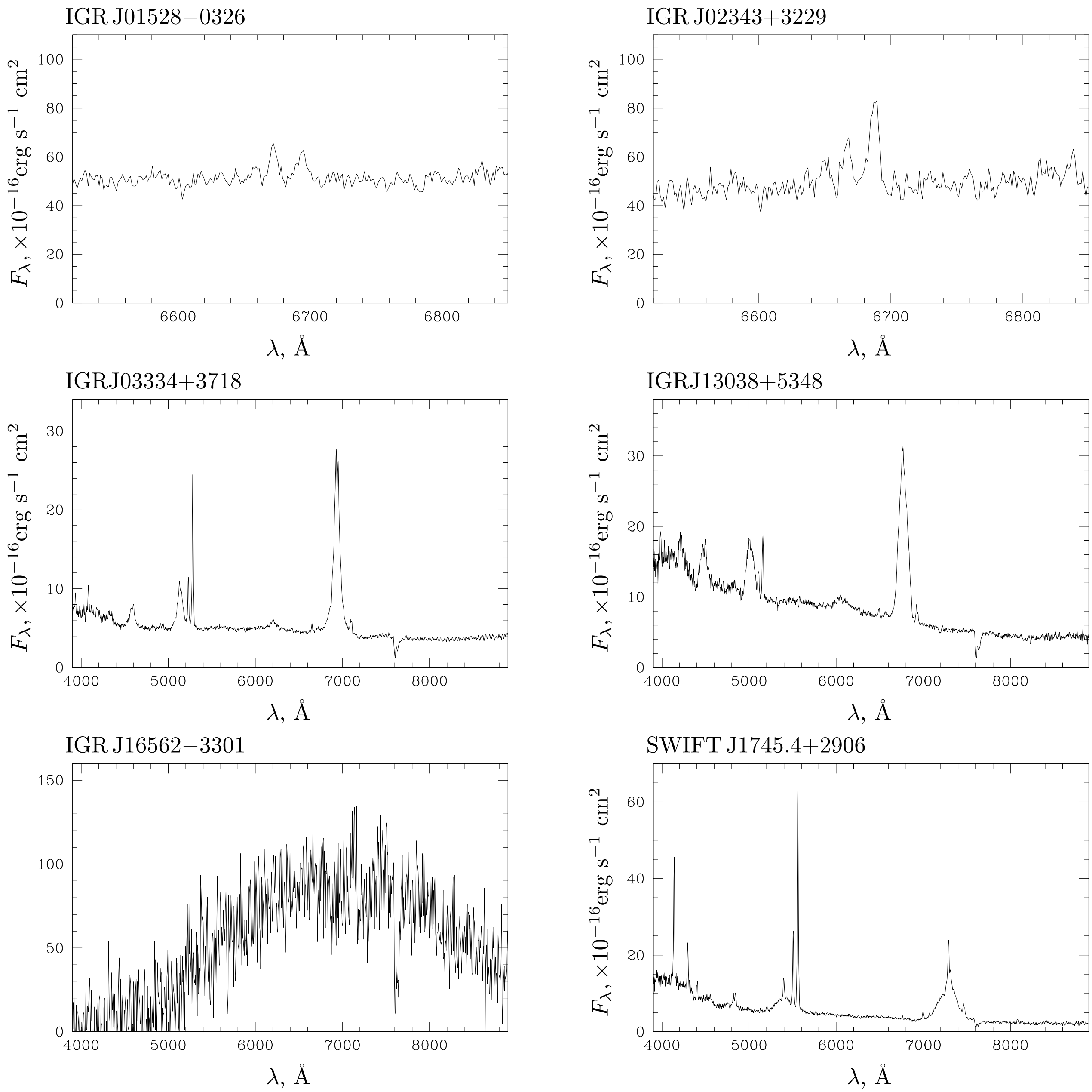

Fig. 2. — Spectra of optical objects, which were identified with hard X-ray sources.

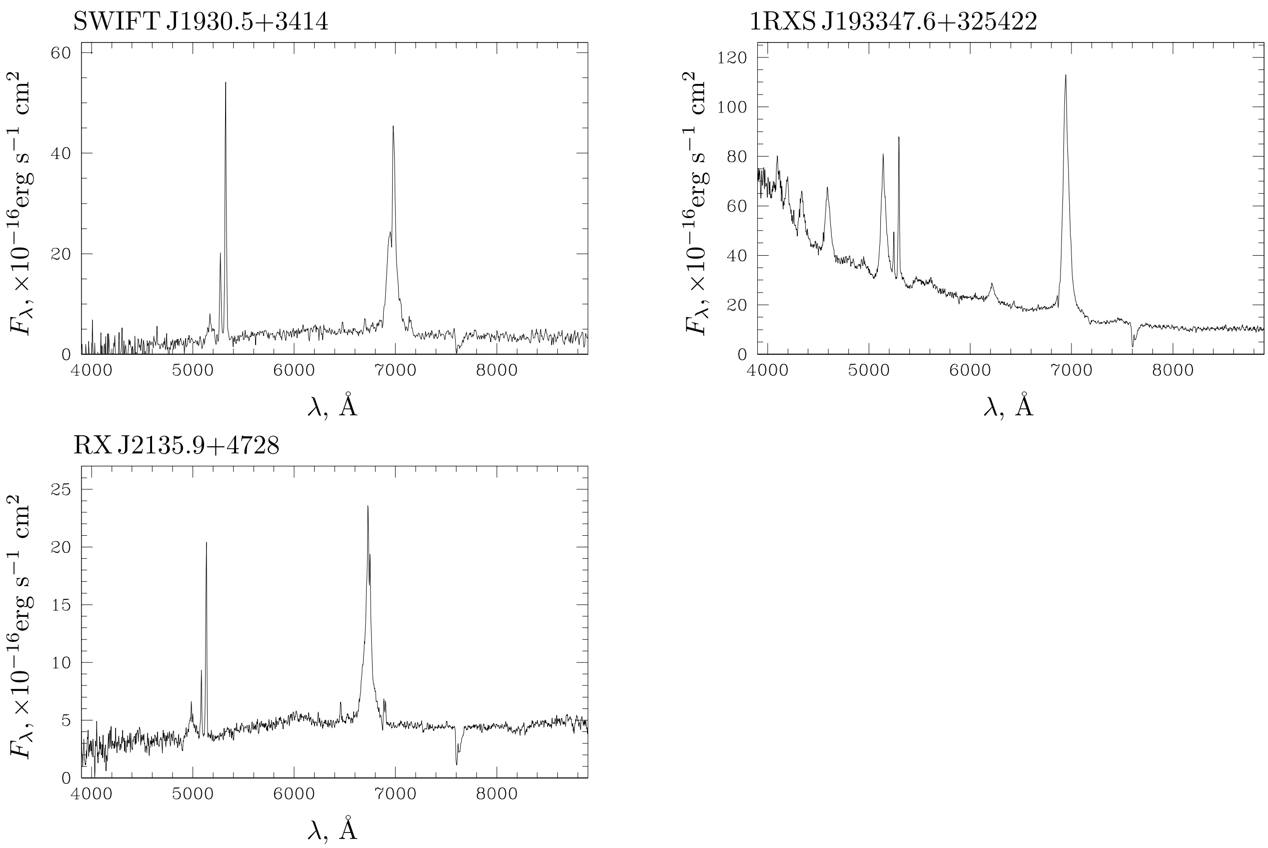

Fig. 2. — *Continued.*

source position with the few arcseconds accuracy, which allow to associate this source with bright nearby galaxy MCG +09−21−096. It was previously detected as an emission line galaxy in Second Burakan Spectral Survey (Markaryan et al., 1983–1985; Bicay et al., 2000). The spectrum of the central part of this galaxy contain broad Balmer and narrow emission lines, identifying this object as a Seyfert 1 AGN.

IGR J16562−3301 — The accurate position of hard X-ray source was obtained using SWIFT XRT data (Tueller et al., 2006). Using the same X-ray data we determine even more accurate position of this source. Systematic uncertainty of XRT aspect solution was strongly reduced using two other X-ray sources which were identified with two relatively bright stars in optical band (Burenin et al., 2007). In this way we obtain the following X-ray source coordinates α, δ: 16:56:16.82, −33:02:12.5 (J2000, here the astrometry was done relative to *UCAC2* catalog). The positional error here should be almost purely statistical and is about 1.5″.

These coordinates agree with the position of very bright radio source NVSS J165616-330211 (the flux is about 0.4 Jy at 1.4 GHz). The coordinates of the only optical object, which is coincide with both X-ray and radio sources, are given in Table 1. In the optical spectrum of this object there are no bright emission lines (Fig. 2). All these data allow to conclude, that this source is a BL Lacertae object. In order to measure its redshift, the spectrum with much higher signal-to-noise ratio is needed.

SWIFT J1745.4+2906, SWIFT J1930.5+3414, 1RXSJ193347.6+325422 — These hard X-ray sources were detected by SWIFT observatory. The SWIFT XRT data, available in public domain, allowed to unambiguously identify these objects with the galactic nuclei. The optical spectra, obtained with RTT150 telescope, show that all of them are Seyfert 1 AGN (Fig. 2).

RX J2135.9+472 — As Seyfert 1 AGN this object was identified earlier, in frames of the work on optical identifications of X-ray sources from *ROSAT* All-Sky Survey (Motch et al., 1997). However, this object was not included in *NED* database, and we identified this object independently. In Table 1 we provide more accurate redshift, as compared to that published by Motch et al. (1997). Apart of the galactic nucleus, there is another one stellar like object in the image of the galaxy (see Fig. 1). We obtained the spectrum of this source and show that this is a chance projection of a star.

Table 2. The AGN luminosities in X-ray 17–60 keV band and in [OIII],5007 emission line.

Name	lg L_X	lg $L_{[OIII]}$
IGR J01528−0326	43.02	<39.08
IGR J02343+3229	43.35	40.16
IGR J03334+3718	44.15	42.05
IGR J13038+5348	43.80	40.56
SWIFT J1745.4+2906	44.71	42.50
SWIFT J1930.5+3414	44.12	42.21
1RXS J193347.6+325422	—	42.13
RX J2135.9+4728	43.24	41.04

DISCUSSION

In Table 2 we give the luminosities in hard X-rays (17–60 keV) and in [OIII],5007 emission line[4]. The fluxes in X-rays are taken from the catalogs of INTEGRAL and SWIFT all-sky surveys (Krivonos et al., 2007; Tueller et al., 2007). In last case the fluxes were converted to 17–60 keV band assuming power law spectrum with photon index $\Gamma = 1.8$. There is no X-ray flux for the source 1RXS J193347.6+325422 in Table 2, because this source is not included in current version of SWIFT survey catalog. The fluxes in [OIII],5007 emission line are corrected for the Galactic interstellar extinction using data from Schlegel et al. (1998).

In Fig. 3 we show the relation between the luminosities in 17–60 keV X-ray band and in [OIII],5007 line. Here we also add the data for AGNs, which we optically identified earlier (Bikmaev et al., 2006a). The data for the main part of AGNs are well agree with the known correlation (see, e.g., Heckman et al., 2005). Excluding three lower points in Fig. 3, we find that the mean and the dispersion of the luminosities ratio logarithm are equal 2.13 ± 0.08 and 0.27 respectively, in good agreement with the results for AGNs, selected mainly in optical band (Heckman et al., 2005).

In contrast to optically selected AGNs, our sample contain AGNs with much lower luminosity [OIII] line, as should be expected for their X-ray luminosities. First, these are two nearby AGNs in MCG −01−05−047 and NGC 973, nearly exactly edge-on galaxies. As it was noted above, in the calibrations of their spectra there is a considerable uncertainty, due to the unknown angular size of the line emitting region. However, their spectra were calibrated so that to obtain an *upper* estimate of [OIII] line fluxes (see above) and the lack of luminosity in this line should exist anyway. Most probably, this lack of luminosity in [OIII] line is explained by the extinction in the disks of the galaxies, since in these two cases the galaxies are turned

[4] To convert fluxes into the luminosities we use the cosmological model with $\Omega = 0.3$, $\Lambda = 0.7$, $H_0 = 71$ km s^{-1} Mpc^{-1}.

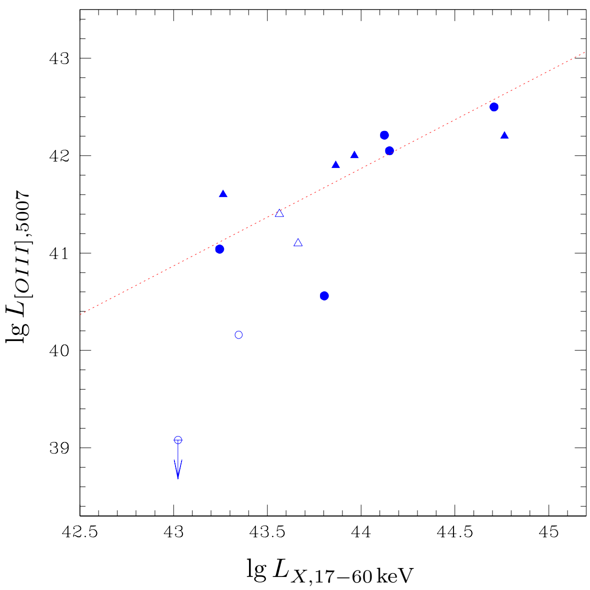

Fig. 3. The relation between the luminosities in X-ray 17–60 keV band and in [OIII],5007 emission line. Filled and open symbols show Seyfert galaxies of type 1 and 2 respectively. Circles show the data from our present work, triangles — the data which we obtained earlier (Bikmaev et al., 2006a). Dashed line show the dependency $\lg L_X/L_{[OIII]} = 2.13$ (see text).

nearly exactly edge-on. From the observed thickness of the disk, we estimate that the size of absorbed region should not be larger than ≈1 kpc.

In Fig. 3 the point, correspondent to the AGN in hard X-ray source IGR J13038+5348, is also shifted down. In the optical image of this source (Fig. 1) on can see that here the galaxy is also approximately edge-on. However, in the optical spectrum of this object there are broad Balmer lines. Probably, the other mechanisms of the weakening of narrow forbidden lines are in effect in this case.

In their work Heckman et al. (2005) conclude, that AGN samples, selected using [OIII] emission line flux are as complete as those selected in hard X-rays. In our work we are faced on with few cases, where the logarithm of the [OIII] line and hard X-ray luminosities ratio was significantly lower than ≈ 2.1. These objects should modify the selection of AGN using their flux in [OIII] line and change the form of the AGN luminosity function in [OIII] line as compared to that in hard X-rays. The fraction of these AGNs may be less than $\sim 20\%$ (as it follows from Fig. 3), since here we consider only, probably, most absorbed AGNs, which were not known earlier and were detected only using observations in hard X-rays.

CONCLUSIONS

In this paper we present our new results of the observations of the fields of unidentified hard X-ray sources, detected in statistically complete all-sky surveys. The observations were carried out using Russian-Turkish 1.5-m Telescope (RTT150). Nine X-ray sources were identified with the active galactic nuclei. Two of them are hosted by nearby, nearly exactly edge-on, spiral galaxies MCG −01−05−047 and NGC 973. One source, IGR J16562−3301, is most probably BL Lac object (blazar). Other AGNs are observed as stellar-like nuclei of spiral galaxies, with broad emission lines in their spectra. All of them, excluding probably IGR J16562−3301, are nearby objects — their redshifts are $z < 0.1$, as for the majority of AGNs in INTEGRAL All-Sky Survey. Almost all of them are located at high Galactic latitudes $|b| > 5°$.

Taking in account the data, which we obtained earlier (Bikmaev et al., 2006a), we show, that the luminosities in hard X-rays (17–60 keV) and in [OIII],5007 emission line, $\lg L_X/L_{[OIII]} \approx 2.1$, are well correlated, as expected, for the majority of AGNs selected in hard X-rays. However, few AGNs considerably deviate from this correlation. For example, the flux in [OIII] line turns to be lower in AGNs in two nearby edge-on spiral galaxies MCG −01−05−047 and NGC 973, which can be explained by the extinction in their galactic disk. The fraction of AGNs, for which the [OIII] line fluxes are significantly deviate from that correlation, may be about 20%, which should significantly modify [OIII] line AGN selection and the form of the AGN luminosity function in [OIII] line as compared to that in hard X-rays.

In result of the recent works on optical identifications of hard X-ray sources (e.g., Bikmaev et al., 2006a,b; Masetti et al., 2006, and also this work), the catalog of INTEGRAL All-Sky Survey (Krivonos et al., 2007) is now almost complete at high Galactic latitudes. Now there are only few X-ray sources, which remain optically unidentified, in this catalog at Galactic latitudes $|b| > 5°$. At the same time, only in subsample of AGNs from this survey, 33 out of 127 objects were unknown before the survey was started (Sazonov et al., 2007).

At low Galactic latitudes there are few tens of hard X-ray sources from INTEGRAL survey, which are not optically identified yet. We will continue our works on their optical identifications. Optical objects, associated with some of these objects turn to be too faint for the observations with RTT150. Now we submitted the proposals to observe these fainter objects with larger telescopes.

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Note: When this paper was already accepted for publication we have noticed that one of our hard X-ray sources IGR J16562−3301 was independently identified as BL Lacertae object by Masetti et al. (2008), who also measured its redshift $z = 2.40$.

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