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Optical Identifications of Five INTEGRAL Hard X-ray Sources in the Galactic Plane Region

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Abstract — The results of optical identifications of five hard X-ray sources in the Galactic plane region from the INTEGRAL all-sky survey are presented. The X-ray data on one source (IGR J20216+4359) are published for the first time. The optical observations were performed with 1.5-m RTT-150 telescope (TUBITAK National Observatory, Antalya, Turkey) and 6-m BTA telescope (Special Astrophysical Observatory, Nizhny Arkhyz, Russia). A blazar, three Seyfert galaxies, and a high-mass X-ray binary are among the identified sources.

Key words: *X-ray sources, gamma-ray sources, active galactic nuclei, X-ray binaries, optical observations*

INTRODUCTION

The INTEGRAL all-sky survey carried out during the last few years (see, e.g., Krivonos et al. 2007) provides an opportunity to study the nearby active galactic nuclei (AGNs), accreting white dwarfs, high-mass and low-mass X-ray binaries, symbiotic stars, etc. The advantage of INTEGRAL energy range (17–60 keV) is that it allows to be almost completely free from the selection effect related to photoabsorption of X-ray emission both near the observed X-ray source and on the line of sight in the Galactic interstellar medium.

A considerable number of hitherto unknown hard X-ray sources have been discovered during this survey. Our group performs optical identifications of these sources in the northern sky with the Russian Turkish 1.5-m RTT-150 telescope (Bikmaev et al., 2006a,b; Burenin et al., 2008). In this paper, we present the results of optical identifications of a set of sources from the INTEGRAL all-sky survey located near the Galactic plane.

OBSERVATIONS

As usual, for our observations we chose a number of northern-sky objects ($\delta > -30°$), for which accurate positions in the sky were known from observations with the X-ray telescopes onboard ROSAT, Chandra, and SWIFT observatories. The Chandra data for several sources were obtained in frames of projects proposed by our group (Sazonov et al., 2005, 2008). We retrieved all necessary additional publicly available X-ray data from the HEASARC archive[1].

The optical observations of the sources were carried out with RTT150 telescope in the spring and summer of 2007, using two instruments — the CCD photometer based on the thermoelectrically cooled Andor CCD and the low- and medium-resolution spectrometer TFOSC[2].

For spectroscopy we used low resolution grism #15, which give the highest efficiency and the most wide spectral range (3300–9000 Å). In this setup spectral resolution is ≈ 15 Å (FWHM). In addition, some of the sources were observed with 6-m BTA telescope in the fall of 2007, using spectrometer SCORPIO (Afanasyev and Moiseev, 2005). The data were reduced using the standard IRAF[3] and DECH[4] (Galazutdinov, 1992) software packages.

RESULTS OF OBSERVATIONS

The list of studied sources and their classifications are given in the table 1. The coordinates of the optical objects are given at epoch J2000, according to the astrometric solutions in RTT150 direct images, which were obtained relative to the USNO-B1.0 catalog (Monet et al., 2003). The magnitudes were measured using direct images obtained with RTT150. The photometric calibration was done using the observations of standard stars from Landolt (1992). Below, the X-ray data and the results of optical observations for each source are discussed in more detail.

RX J0137.7+5814

The position of the X-ray ROSAT source RX J0137.7+5814 (Voges et al., 1999) and the

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[1] http://heasarc.nasa.gov/

[2] http://astroa.physics.metu.edu.tr/tug/tfosc.html

[3] http://iraf.noao.edu

[4] http://www.gazinur.com/Download.html

Table 1. The list of identified sources

Name	α, δ (J2000)		R_c	z	Type[1]
RX J0137.7+5814	01 37 50.45	+59 14 11.6	17.63	?	BL Lac
IGR J20216+4359	20 21 49.04	+44 00 39.4	19.14	0.017	Sy2
IGR J21343+4738	21 34 20.37	+47 38 00.4	13.79	–	HMXB
IGR J23206+6431	23 20 36.58	+64 30 45.2	19.41	0.07173	Sy1
IGR J23523+5844	23 52 22.00	+58 45 32.7	18.62	0.1620	Sy2

[1] Sy1, Sy2 — type 1 and 2 Seyfert galaxies; BL Lac — BL Lacertae object; HMXB — High Mass X-Ray Binary;

corresponding hard X-ray INTEGRAL source (Krivonos et al., 2007) coincides, within the error limits, with the bright radio source 87GB 013433.2+575900 whose position is known with an accuracy of $\approx 6-10''$. Only one star with magnitude $R < 18$ lies within this $10''$ circle (Fig. 1, upper panel).

The spectra of this source were obtained with RTT150 during several nights. In addition, the spectrum of this object was also taken with the 6-m BTA telescope using the SCORPIO spectrometer (Afanasiev and Moiseev 2005). Because of poor weather conditions during these observations we failed to perform measurements with the required high signal-to-noise ratio. Nevertheless, the data were of comparable quality to those from RTT150.

The combined RTT150 and BTA spectrum of the optical object corrected for the Galactic extinction $E(B-V) = 0.85$ is shown in Fig. 1 (lower panel). Telluric absorption bands (near 6900, 7200, and 7600 Å) and, probably, some unidentified absorption lines (e.g., the line at 4914 Å) are clearly seen in this spectrum. However, the spectrum exhibits no detectable stellar absorption line and there are no emission lines that are observed in AGN spectra. Together with the presence of the intense radio emission, this suggests that RX J0137.7+5814 is a blazar or, more precisely, a BL Lac object. More sensitive optical observations of the source are needed in order to measure its redshift.

IGR J20216+4359

The hard X-ray source IGR J20216+4359 was discovered in an incomplete set of INTEGRAL observations of the Cygnus region (observations from January 14, 2004, to November 4, 2004; orbits 153–251). In this series of observations, the source was detected at a high confidence level ($\approx 5.5\,\sigma$, Fig. 2). Its coordinates are α=21 21.8, δ=+43 59 (J2000), the positional accuracy is $\approx 3'$. The hard X-ray flux (17–60 keV) from the source was $\approx$ 1.1 mCrab, which corresponds to the energy flux of $\approx 1.6\times10^{-11}$ erg s^{-1} cm^{-2} for the powerlaw spectrum with a photon index 2. In the complete set of observations of the Cygnus region, the source is detected at a confidence level of only $\approx 3\,\sigma$ which corresponds to a flux of 0.6 ± 0.2 mCrab.

The field around IGR J20216+4359 was observed by ASCA observatory on June 10, 1993. The source was detected at a statistically significant level in these observations, which allow to improve its coordinates: α,δ: 20 21 48.1 +44 00 32 (J2000, the accuracy is $\approx 20''$, Fig. 3) and to measure its spectrum in the standard X-ray range 0.8–10 keV. The source turned out to be strongly absorbed, i.e., the equivalent photoabsorption column density measured from the shape of its X-ray spectrum is $n_H L = (13 \pm 2) \times 10^{22}$ cm^{-2} (the photon index was fixed at $\Gamma = 1.7$ due to poor statistics). This value is considerably higher than that in the Galactic interstellar medium, which is $\approx 10^{22}$ cm^{-2} (Dickey and Lockman, 1990). The strong internal X-ray photoabsorption is typical for type 2 Seyfert galaxies.

The Seyfert galaxy was found in the error box of IGR J20216+4359 using optical RTT150 observations. This galaxy is marked by the circle in Fig. 3. Its spectrum (Fig. 4) exhibits forbidden [OIII] and [NII] emission lines, which indicate the high AGN activity (see, e.g., Baldwin, Phillips and Terlevich, 1981; Kauffmann et al., 2003). The absence of broad $H\alpha$ and $H\beta$lines in the AGN spectrum confirms the classification of this AGN as a type 2 Seyfert galaxy. The redshift of the galaxy measured using narrow [OIII] and [NII] lines is $z = 0.017$.

IGR J21343+4738

The hard X-ray source IGR J21343+4738 was discovered during deep observations of the Galactic-plane region in Cygnus (Krivonos et al., 2007; Bird et al., 2007). More detailed studies of the sources behavior showed it to be variable. Fig. 5 shows the IBIS/INTEGRAL images of the sky field around IGR J21343+4738 in different observing periods. IGR J21343+4738 is detected at a statistically significant level in the IBIS/INTEGRAL observational data only in the series of observations from December 27, 2002, to February 21, 2004 (Fig. 5, left panel).

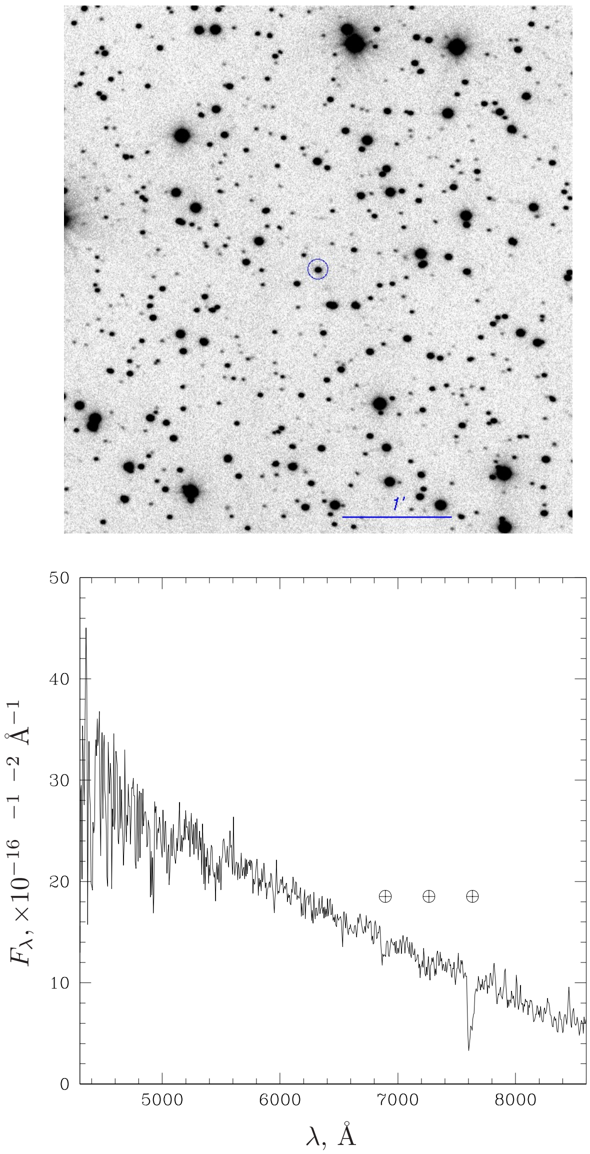

Fig. 1. Upper panel — optical image of the field around the source RX J0137.7+5814 from RTT150 Rc-band observations. The circle marks the $\approx 6''$ error circle of the position of the radio source 87GB 013433.2+575900. Lower panel — combined optical spectrum of RX J0137.7+5814 obtained from RTT150 and BTA observations corrected for the Galactic extinction $E(B-V) = 0.85$.

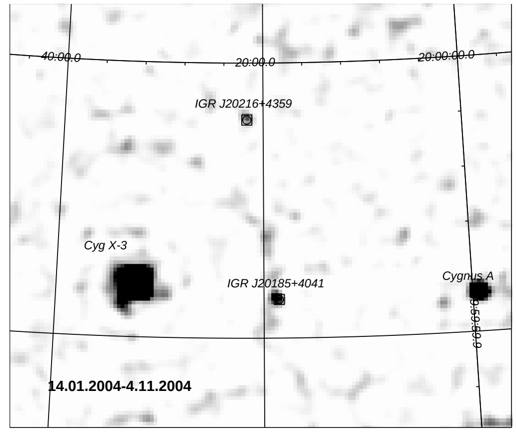

Fig. 2. The IBIS/INTEGRAL image of the field around the source IGR J20216+4359 in the 17–60 keV energy range.

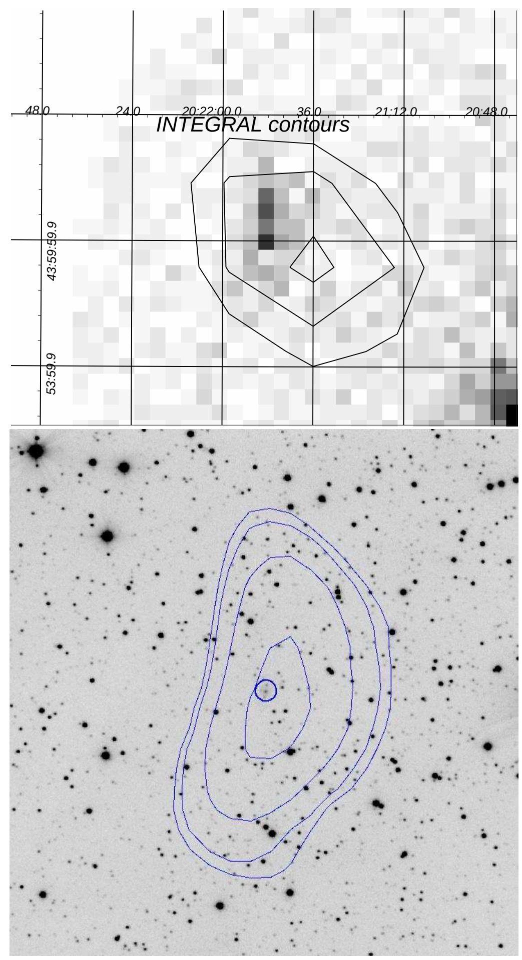

Fig. 3. Upper panel — the ASCA image of the field around the source IGR J20216+4359 in the energy range 4–10 keV obtained during the observations on June 10, 1993. The contours show the 4.0, 4.5, and 5σ IBIS/INTEGRAL flux levels. Lower panel — optical image of the field around IGR J20216+4359 from RTT150 observations. The contours indicate the ASCA position of the X-ray source. The circle marks the galaxy whose active nucleus is an X-ray source.

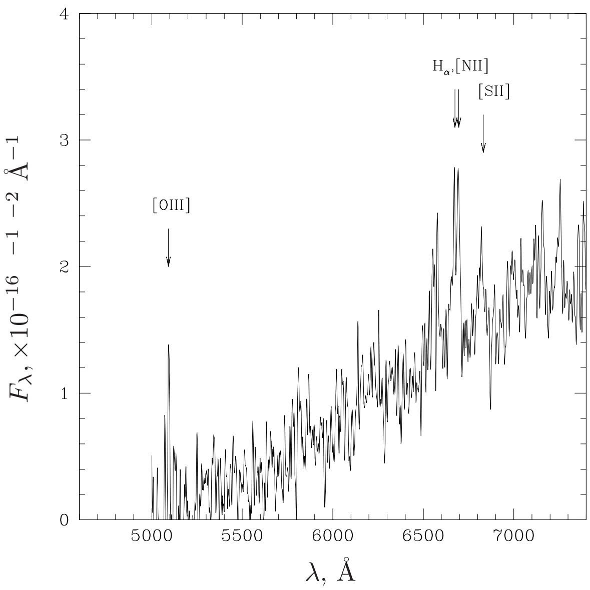

Fig. 4. The spectrum of the optical counterpart of the source IGR J20216+4359, obtained with RTT150 telescope, not corrected for the Galactic extinction.

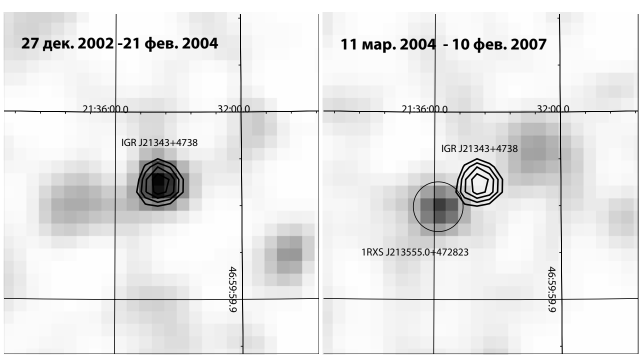

Fig. 5. INTEGRAL 17–60 keV hard X-ray images of the field around IGR J21343+4738 from December 27, 2002, to February 21, 2004 (left), and from March 11, 2004, to February 10, 2007 (right). The source IGR J21343+4738 was clearly detected in the first observing period and was below the threshold in the second one. The AGN 1RXS J213555.0+472823 is detected near IGR J21343+4738 during the second observing period. The contours in the images denote the regions of equal statistical significance of the flux in the image obtained in the first observing period starting from 3.5σ and with 0.5σ steps.

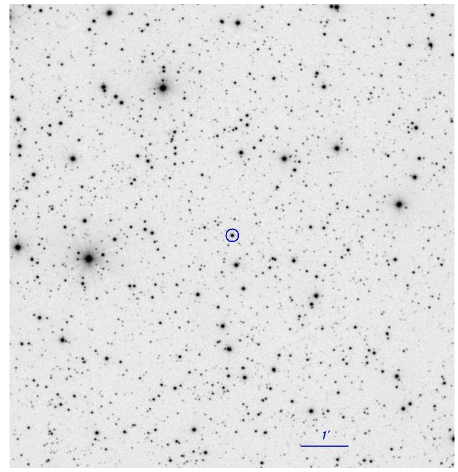

Fig. 6. The direct image of the field of the source IGR J21343+4738 in filter R, obtained with RTT150 telescope.

The mean 17–60 keV flux from the source was 1.6 ± 0.3 mCrab in this series of observations, which corresponds to the flux $\approx (2.3 \pm 0.4) \times 10^{-11}$ erg s^{-1} cm^{-2}.

The source is not detected in the map of this field averaged over the period from March 11, 2004, to February 10, 2007 (Fig. 5, right panel). In this series of observations, the exposure time was much longer than that in the first one and the upper limit on the source 17–60 keV flux was 0.5 mCrab (2σ), suggesting its transient nature. Due to the higher sensitivity, the AGN RX J2135.9+4728 (Burenin et al., 2008) is detected in this image near the location where the source IGR J21343+4738 was previously found. This AGN is located at a distance of $\approx 15'$ from IGR J21343+4738, which is considerably larger than both the IBIS localization accuracy and its angular resolution. Using the other bright sources in the IBIS field of view, we checked that the astrometric errors in these observations are small.

The field around IGR J21343+4738 was observed by the Chandra observatory on December 18, 2006 (Sazonov et al., 2008). Based on the INTEGRAL observations, one may expect the sources brightness to drop significantly compared to that in the first observing period. However, the high sensitivity of the Chandra observatory allows to detecd a weak hard X-ray source in the error region of the hard X-ray source IGR J21343+4738 that can be unambiguously associated with the optical object with the following coordinates α, δ: 21 34 20.37 +47 38 00.4 (J2000). The finding chart for this field is shown in Fig. 6.

The spectrum of this object (Fig. 7) shows signatures of B3 star. In particular, in addition to the overall shape of the spectrum, the fairly intense HI and HeI absorption lines that are too strong for A type stars and and the absence of strong HeII absorption lines typical

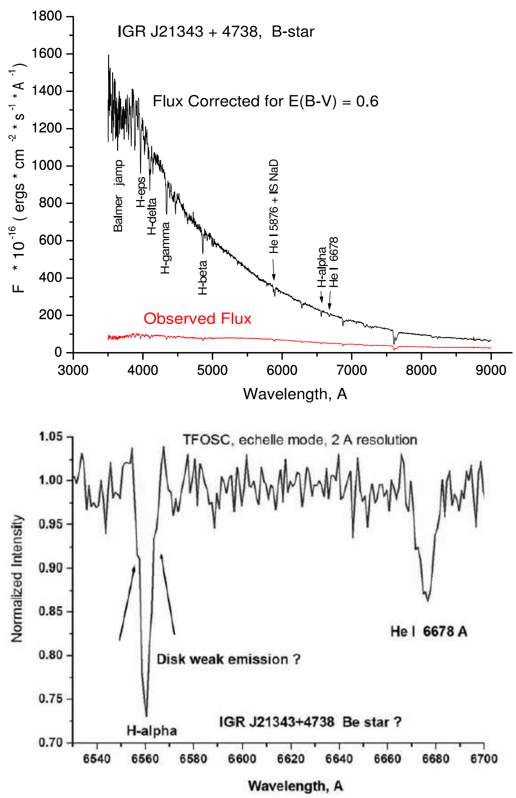

Fig. 7. Upper panel — spectrum of the optical object identified with the source IGR J21343+4738. Lower panel — higher-resolution spectrum of the source near the $H\alpha$ line. The arrows indicate the possible contribution from weak emission lines of the equatorial disk of a massive optical star.

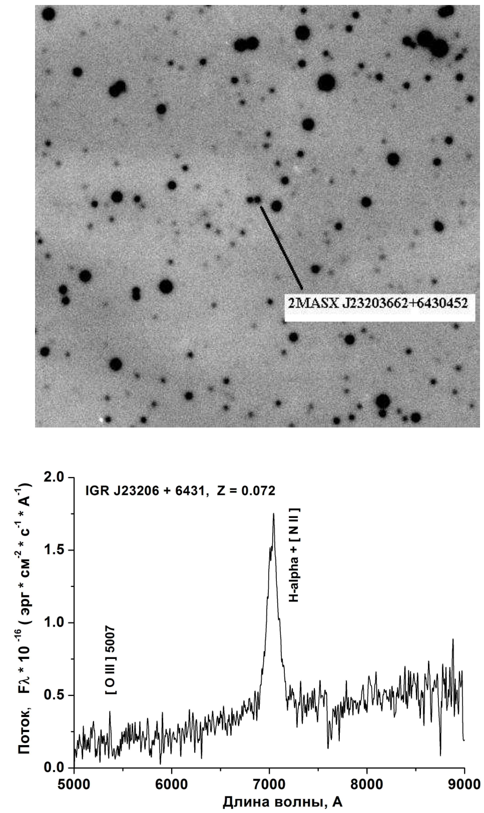

Fig. 8. Optical R-band image of the IGR J23206+6431 field (upper panel) and optical spectrum of the source from RTT150 observations (lower panel).

of O stars point to the B spectral type. This implies that the X-ray source is most likely a high-mass X-ray binary. In this case, the transient nature of this source in X rays is not unusual, especially in view of the recent discovery of a large number of the so-called fast X-ray transients in highmass X-ray binaries (see, e.g., Chaty, 2007).

In our optical observations we detected $H\alpha$ line in absorption, not in emission, as it is usually observed in high-mass X-ray binaries. It may be related to the long-period evolution of the equatorial disk wind from the optical companion similar to what is observed for some Be systems (see, e.g., Norton et al., 1991). The higher resolution echelle spectrum obtained with the TFOSC spectrometer (resolution ≈ 2 Å, Fig. 7, lower panel) showed that $H\alpha$ line is more narrow than HeI,6678 Å, which may indicate the presence of a weak double-peaked emission from the equatorial disk of the optical star.

IGR J23206+6431

The hard X-ray source was discovered in the IBIS/INTEGRAL images of the Galactic plane region, which were obtained after the catalog of the all-

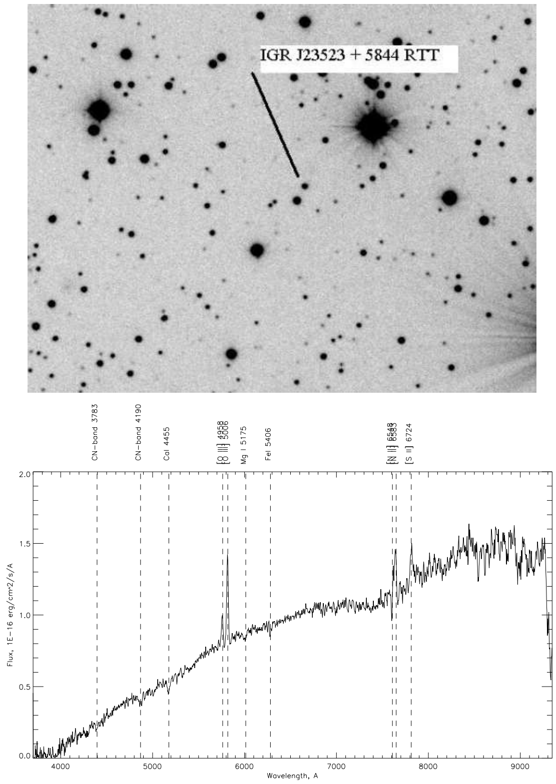

Fig. 9. Upper panel — optical image of the field around the source IGR J23523+5844 obtained with RTT150 telescope. Lower panel — optical spectrum of the source obtained with BTA, not corrected for the Galactic extinction.

sky survey (Krivonos et al., 2007) was published. The time-averaged 17–60 keV flux from the source is 0.6 ± 0.1 mCrab or $\approx 8.7 \times 10^{-12}$ erg s^{-1} cm^{-2}. This source was observed with the X-ray telescope onboard SWIFT observatory, which allowed to unambiguously identify it with the galaxy 2MASX J23203662+6430452.

Figure 8 shows the direct image of the sources field (upper panel) and its optical spectrum (lower panel) not corrected for the Galactic extinction obtained with RTT150. The optical spectrum of this object exhibits redshifted broad $H\alpha$ and narrow [OIII],5007 lines. Thus, this source is a type 1 Seyfert galaxy. Its redshift derived from the [OIII] line is $z = 0.07173$. Preliminary information about the optical identification of this source was immediately published in astronomical circular (Bikmaev et al., 2008).

IGR J23523+5844

The hard X-ray source was observed by Chandra observatory on January 14, 2007 (Sazonov et al., 2008). The X-ray absorption column density estimated from the Chandra X-ray spectrum is $n_H L = (3.7 \pm 0.5) \times 10^{22}$ cm^{-2}, which is much higher than the absorption column density in our Galaxy (Dickey and Lockman, 1990). This is a distinctive feature of type 2 Seyfert galaxies in X-rays.

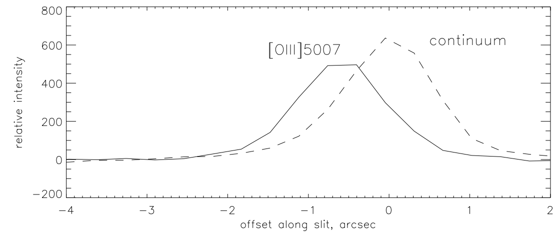

Fig. 10. Intensities of the continuum and [OIII] line emission from the AGN IGR J23523+5844 along the slit of SCORPIO spectrometer.

The accurate position of the X-ray source allowed to identify this source with the optical object whose coordinates are given in the Table 1. The finding chart for the field near this object is shown in Fig. 9 (upper panel) and its optical spectrum obtained with 6-m BTA telescope using spectrometer SCORPIO (Afanasyev and Moiseev, 2005) is presented in Fig. 9 (lower panel). The spectrum of the optical object exhibits Ca, Mg, Fe, and other absorption lines as well as intense narrow [OIII] 4959,5007, [SII] 6717,6731, and probably [NII] 6548,6583 forbidden emission lines. Here, the flux ratio of the [OIII] 5007 and $H\beta$ lines is definitely larger than 10, implying that the object can be identified as Seyfert galaxy (e.g., Baldwin, Phillips and Terlevich, 1981; Kauffmann et al., 2003). The absence of an intense broad $H\beta$ line suggests that this can be a type 2 Seyfert galaxy.

The redshift is $z = 0.1620$, the $H\alpha$ and [NII] 6548,6583 lines fall into the atmospheric 7600 A absorption band and their observations are complicated by the subtraction of a complex sky background. However, we can state that the spectral feature that remains near the 7600 Å band after the correction for the atmospheric absorption is more red than $H\alpha$ line and, most likely, is the [NII] 6583 forbidden line. The spectrum also exhibits no signs of the narrow $H\beta$ and [OII] 3727 lines which are usually observed in the spectra of type 2 Seyfert galaxies. For example, the lower limit on the flux ratio of the [OIII] 5007 and $H\beta$ lines is ≈ 20 here, while the maximum value of this ratio for optically selected AGNs is about 15 (see, e.g., Baldwin, Phillips and Terlevich, 1981; Veilleux and Osterbrock, 1987; Kauffmann et al., 2003). Probably it can be explaned by strong absorption of the narrow emission lines regions.

We note that the [OIII] line emission in this AGN is spatially shifted from the continuum emission. This is clearly seen from the intensity distribution of the emission along the slit of the spectrometer SCORPIO shown in Fig. 10. The difference in [OIII] line and continuum surface brightness distributions is observed in some nearby AGNs, for example, in Markarian 34 or Markarian 78, and reflects the fact that the emission in narrow forbidden lines originates at distances of 1–2 kpc from the central black hole (e.g., Haniff et al., 1988). In addition, in the case of IGR J23523+5844, this agrees with the suggestion that the central regions near the AGN are strongly absorbed (see above) and the observed emission in narrow forbidden lines originate only at considerable distances from the AGN.

Thus, all our data taken as a whole suggest that IGR J23523+5844 is most likely a type 2 Seyfert galaxy, although its optical spectrum may have some peculiarities related to strong absorption of the central narrow emission line regions. In their paper recently published in preprints, Masetti et al. (2008) also identified this source as a probable type 2 Seyfert galaxy.

CONCLUSIONS

In this work we presented information on the optical identifications of five hard X-ray sources from the INTEGRAL all-sky survey located in the Galactic plane region. The X-ray data on one INTEGRAL source, IGR J20216+4359, are published for the first time. A blazar (RX J0137.7+5814), three Seyfert galaxies (IGR J20216+4359, IGR J23206+6431, and IGR J23523+5844), and a high-mass X-ray binary (IGR J21343+4738) are among the identified sources.

In this paper we concentrated on the objects near the Galactic plane, i.e., in the region that is traditionally avoided by observers in optical band because of strong Galactic absorption and high stellar density. We see, that the INTEGRAL data allow to discover new, previously unknown nearby AGNs that would be very difficult to found in optical. As expected, among the hard X-ray sources in the Galactic plane there is also a large number of Galactic sources, mostly high-mass X-ray binaries.

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