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New Nearby Active Galactic Nuclei among INTEGRAL and RXTE X-ray Sources*

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Abstract—We present the first results of a campaign to optically identify X-ray sources discovered in the all-sky surveys of the RXTE and INTEGRAL observatories. Six newly discovered sources proved to be hitherto unknown nearby active galactic nuclei ($z < 0.1$). Spectrophotometric studies of these sources were performed with the Russian–Turkish 1.5-m telescope (RTT150). We measured their redshifts and parameters of the strongest emission lines.

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INTRODUCTION

During the last decade, significant progress has been achieved in understanding the properties of active galactic nuclei (AGNs) and their evolution. In particular, the increase in the density of low-luminosity AGNs was shown to have occurred more recently (at much lower redshifts) than the increase in the density of high-luminosity AGNs (see, e.g., Steffen et al. 2003; Ueda et al. 2003).

Observations of the cosmic X-ray background suggest that AGNs with large intrinsic photoabsorption constitute the bulk of it (see, e.g., Hasinger 2004), with the fraction of absorbed AGNs increasing with their decreasing X-ray luminosity (Ueda et al. 2003; Sazonov and Revnivtsev 2004).

It is contended in the widely accepted "unification theory" of AGNs (see, e.g., Antonucci and Miller 1985; Krolik and Begelman 1988; Setti and Woltjer 1989; Antonucci 1993) that the absorption observed in the X-ray and optical spectra of AGNs owes its origin to a molecular torus around the central black hole. To test the various theories for the origin of this absorption (i.e., the AGN unification theory) and to accurately estimate the AGN volume density in the local Universe ($z < 0.1$), one must study a large sample of AGNs at the smallest possible distances. Unfortunately, the deep surveys of extragalactic fields conducted recently by the new-generation Chandra and XMM X-ray observatories (Brandt et al 2001; Hasinger et al. 2001) offer no possibility of obtaining such a sample due to poor sky coverage.

It is rather difficult for X-ray telescopes to cover a large fraction of the sky due to their small fields of view. Until recently, virtually the only available all-sky survey at energies above 2 keV has been the HEAO1/A2 survey conducted with the A2 collimated spectrometer (Piccinotti et al. 1982).

A recent all-sky survey by the RXTE observatory (XSS–RXTE Slew Survey; Revnivtsev et al. 2004) allowed one to significantly improve the sensitivity and to considerably increase the sample of nearby AGNs (Sazonov and Revnivtsev 2004). However, since the energy range of this survey (3–20 keV) is affected by photoabsorption in the AGN spectra, its sensitivity to highly absorbed AGNs ($\log(N_H L) > 23$) is low, which biases the sample significantly. The hard X-ray surveys to be conducted by the INTEGRAL (Revnivtsev et al. 2006, in preparation) and SWIFT (Gehrels et al. 2004; Markwardt et al. 2005) observatories will allow one to improve the situation dramatically.

At present, the INTEGRAL observations (Winkler et al. 2003) have covered much of the sky and revealed a number of AGN candidates (see, e.g.,

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Table 1. List of discovered AGNs and their main parameters.

Source	R.A. (J2000)	Dec. (J2000)	R_c	z	$\log L_{5500\,\text{Å}}$	$\log L_{[\text{O III}],\lambda5007}$	$\log L_x$	$\text{FWHM}_{\text{H}_\alpha}$, km/s	Type
XSS J05054−2348	05 05 45.7	−23 51 14	16.6	0.0351	42.84	41.1	43.6	<685	Sy2
XSS J16151−0943	16 15 19.1	−09 36 14	14.8	0.0650	44.08	42.0	43.9	1600	Sy1
IGR J18559+1535	18 56 00.6	+15 37 58	16.6	0.0838	44.32	42.2	44.7	3200	Sy1
IGR J19473+4452	19 47 19.4	+44 49 42	17.2	0.0532	43.42	41.4	43.5	<685	Sy2
IGR J21277+5656	21 27 45.4	+56 56 35	16.6	0.0144	43.45	41.6	43.2	1600	Sy1
XSS J21354−2720	21 34 45.1	−27 25 56	15.8	0.0670	43.68	41.9	43.8	1190	Sy1.5?

Note. The X-ray fluxes were calculated to the 2–10 keV energy band by assuming a power-law AGN spectrum with a slope of $\Gamma = 1.8$. The measured X-ray fluxes were taken from the RXTE (3–20 keV; Revnivtsev et al. 2004), Chandra (2–10 keV; Sazonov et al. 2005), or INTEGRAL (17–60 keV; Revnivtsev et al. 2006, in preparation) surveys. The R_c magnitude was measured within a $5''$ aperture.

Sazonov et al. 2005; Revnivtsev et al. 2006, in preparation). A large fraction of the AGN candidates are difficult to identify optically, because the positions of these sources determined by the INTEGRAL telescopes ($\sim 2'$–$3'$) are not accurate enough.

It is especially difficult to identify sources without counterparts in other catalogs that have more accurate positions, e.g., the ROSAT all-sky survey catalog (Voges et al. 1999).

The number of nearby ($z < 0.1$) X-ray luminous ($L_{\text{X}} > 10^{42-43}$ erg s^{-1}) AGNs is moderately large. For example, the most sensitive all-sky X-ray survey (XSS) to date contains only $\sim$75 AGNs with redshifts $z < 0.1$. Therefore, even a few nearby AGNs added to this sample are of value.

Recently we (together with S. Sazonov, E. Churazov, and A. Vikhlinin) initiated a program of optical identifications of sources from the RXTE and INTEGRAL all-sky surveys. In this paper, we present the first results obtained during this project. The optical data were obtained with the Russian–Turkish 1.5-m telescope (RTT150, TÜBITAK National Observatory, Antalya, Turkey). For the first series of observations, we chose only sources with relatively accurate positions determined by the ROSAT, Einstein, Swift, or Chandra (Sazonov et al. 2005) observatories. Six studied XSS and IGR sources were identified with AGNs in nearby galaxies.

OBSERVATIONS

We first chose northern-sky ($\delta > -30°$) objects with the most accurate positions in the sky provided by the Einstein, ROSAT, Chandra, or Swift observatories for our observations as part of the program of identifying RXTE and INTEGRAL sources. A list of studied sources is presented in Table 1.

The observations were performed with RTT150 during August 8–13, September 5–10, and October 4–9, 2005, using two instruments: a CCD photometer and low-resolution spectrometer (TFOSC).

The CCD Photometer

The CCD photometer is mounted at the Cassegrain focus of the telescope (1 : 7.7) and consists of a thermoelectrically cooled back-illuminated 2 K×2 K Andor CCD array and a filter wheel. The CCD array provides a $8' \times 8'$ field of view with an image scale of $0.24''$ per pixel. During our observations, we used a standard Johnson–Kron–Cousins $UBVRI$ filter set. This setup was used for direct imaging and photometry of RXTE and INTEGRAL source fields. The data reduction included bias subtraction, flat fielding, and photometric image calibration using standard stars (Landolt 1992).

Table 2. Parameters of AGN spectral lines

Source	$H_\gamma, \lambda4340$			$H_\beta, \lambda4861$			[O III], $\lambda4959/\lambda5007$		$H_\alpha, \lambda6563$		
	(1)	(2)	(3)	(1)	(2)	(3)	(2)	(3)	(1)	(2)	(3)
XSS J05054−2348	10	18	3	<15	18	2	34/102	5/14	<15	80	10
XSS J16151−0943	26	30	48	33	94	173	16/52	29/96	35	398	827
IGR J18559+1535	–	–	99	69	115	419	16/47	58/171	70	542	1480
IGR J19473+4452	<10	4	1	<14	7	2	24/69	8/22	<15	32	7
IGR J21277+5656	20	52	20	37	169	80	28/77	15/40	35	515	164
XSS J21354−2720	12	18	12	17	40	30	35/107	26/81	26	160	134

Note. For each line, the table gives its FWHM, Å (1), equivalent width, Å (2) and luminosity in units of 10^{40} erg s^{-1} (3). The spectral resolution in these observations was $\Delta\lambda \sim 15$ Å. The hydrogen line widths were corrected for the instrumental resolution. The accuracy of determining the line equivalent widths (EW) is $\sim$10–15%.

The TFOSC Spectrometer

The TÜBITAK Faint Object Spectrograph and Camera[1] (TFOSC) is a direct imaging and low-to-medium resolution spectrometer similar to DFOSC and other instruments of this series produced at the Copenhagen University Observatory (Denmark). It was produced and delivered to the RTT150 telescope only recently. In this paper, we present the first scientific results obtained with the TFOSC spectrometer.

To prevent losses of light, we chose a slit width of 100 μm (corresponding to 2.6″ in the sky). For this study, we used grism no. 15, which provides the highest light efficiency and the widest spectral range (3300–9000 Å). In this case, the spectral resolution is 12–15 Å (600–800 km s^{-1})

Grism no. 7 (the spectral range is 3900–6750 Å) provides a better spectral resolution (7 Å), but for objects with redshifts $z > 0.03$, the spectral region with the important group of H_α and [N II], $\lambda\lambda$6548, 6584 Å lines is outside the CCD field and additional observations with grism no. 8 (5800–8000 Å) are required. Spectra with a higher spectral resolution (grisms nos. 7 and 8) for some of the objects from Table 1 will be presented in a separate paper.

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

The total signal accumulation for each object consisted of separate 5- and 10-min exposures, depending on the source brightness and the telescope position. For each object, we took from two to six exposures. Inside the series of spectral images, we also obtained the spectra of neon and helium lamps for wavelength calibration. In addition, we obtained the spectra of spectrophotometric standards at the corresponding zenith angles on each night. The spectral data obtained were analyzed with a modified version of the DECH software package (Galazutdinov 1992). The absolute wavelength calibration accuracy is $\sim$1 Å.

For the photometric calibration of the spectra obtained, we used our observations of spectrophotometric standards. We also applied a correction for the interstellar extinction toward the sources using a neutral hydrogen map from Dickey and Lockman (1990).

RESULTS

We obtained deep (a limiting magnitude of $R_c \approx 23.5^m$) images for all AGN candidates using the CCD photometer. These fields are shown in Fig. 1. The circles in Fig. 1 indicate the error regions of these sources obtained by the RXTE, ROSAT, Chandra, INTEGRAL, and Swift observatories. In several cases, the localization accuracy was high enough

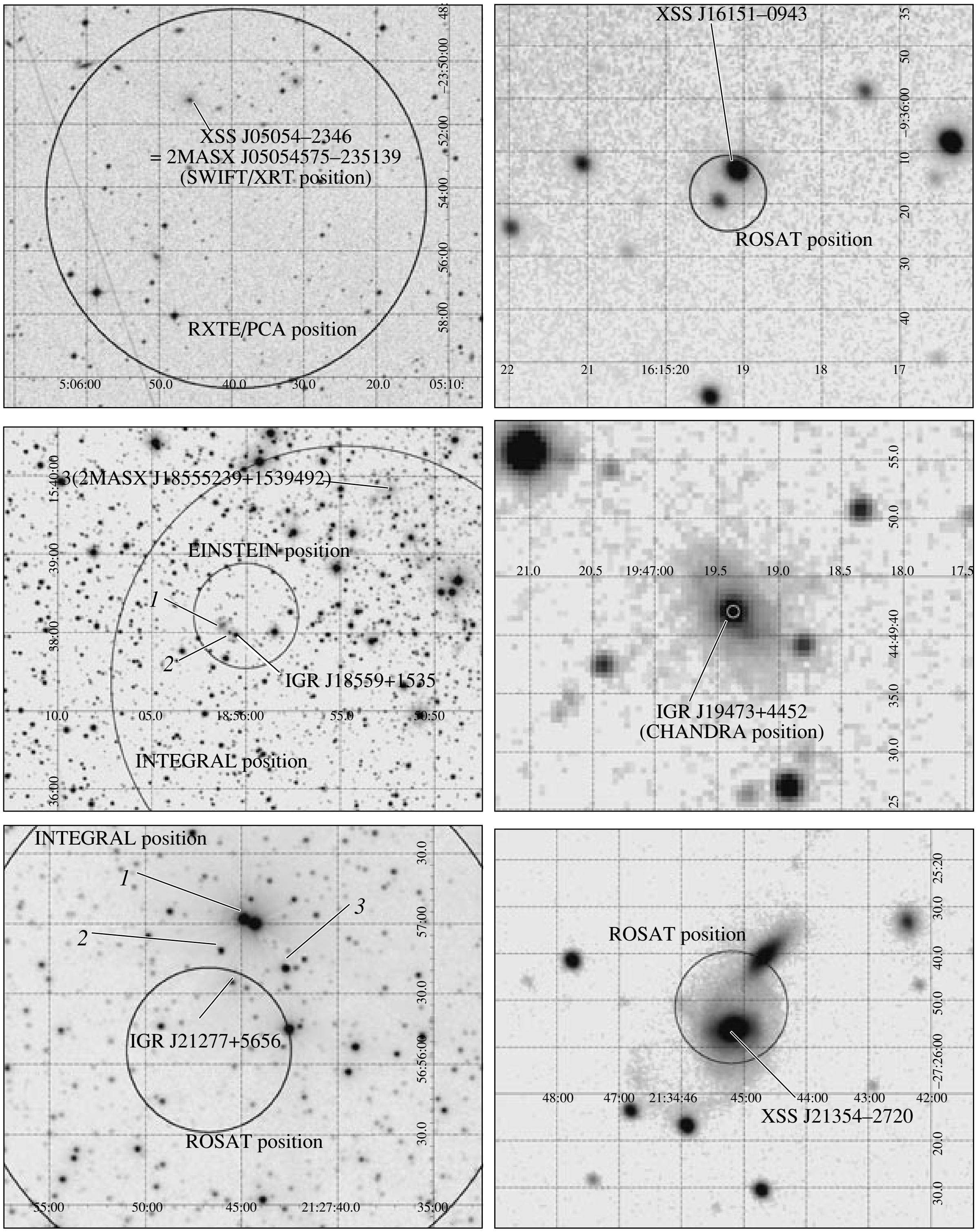

Fig. 1. RTT150 images of the sky fields in the R_c band around unidentified X-ray sources from the RXTE and INTEGRAL all-sky surveys.

($0.5''-10''$) for the X-ray sources to be reliably identified with their optical counterparts. If more than one relatively bright ($R_c \lesssim 16$) optical counterpart was within the error region, we took the optical spectra of several objects. These objects are marked by numbers in Fig. 1.

For all these X-ray sources, we found optical counterparts with intense emission lines of H_α and

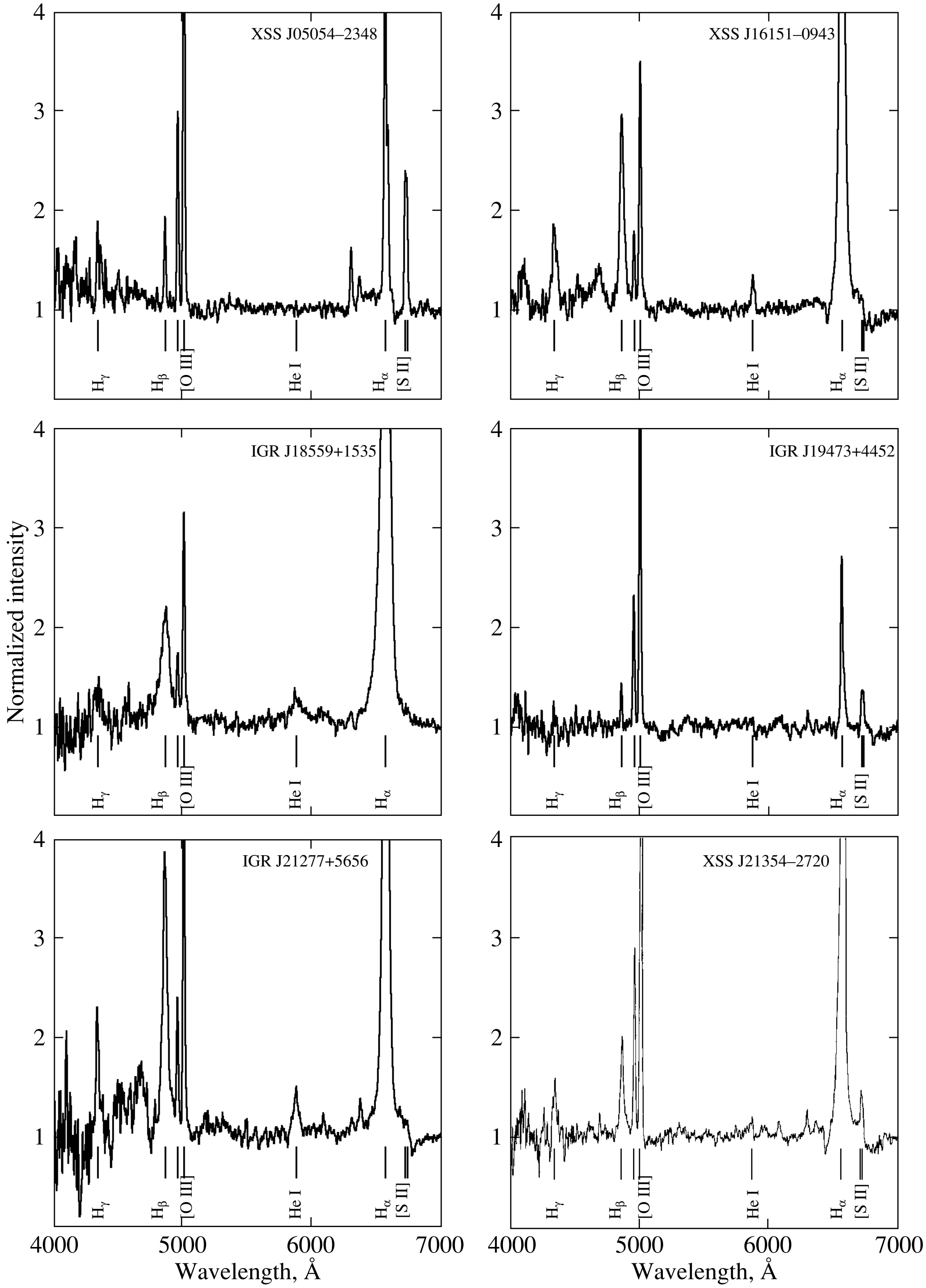

Fig. 2. Spectra of the discovered AGNs in relative intensities (normalized to the continuum flux).

[O III] with redshifts $z > 0$, which clearly shows the presence of nearby galaxies. The hydrogen line widths and the H_α, H_β, [O III], and [N II] flux ratios point to the presence of an active nucleus (the arrows in Fig. 1). Some parameters of the spectra obtained are presented in Tables 1 and 2. The spectra normalized to the continuum flux are shown in Fig. 2.

Studies of deep images of the discovered AGNs

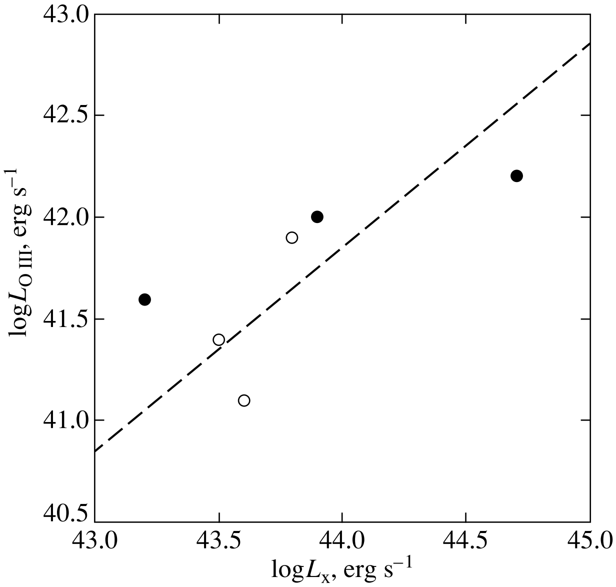

Fig. 3. Correlation between the optical luminosity of AGNs in the [O III] λ5007 Å emission line and their X-ray luminosity. The open and filled circles indicate type-2 and type-1 Seyferts, respectively. The dashed line indicates a linear correlation with $\log L_{\rm x}/L_{\rm [O\,III]} \sim 2$.

revealed an extended source around the AGN—their host galaxies. The angular sizes of the galaxies at the image sensitivity limit are $\sim$10″–20″, which correspond to their linear sizes of $\sim$10–20 kpc.

Figure 3 shows a correlation between the X-ray luminosity of an AGN and its luminosity in the [O III], λ5007 line. As has been repeatedly shown previously (see, e.g., Heckman et al. 2005), these two quantities strongly correlate with one another. Our measurement of the AGN luminosities in X-rays and the oxygen line are consistent with this behavior, bearing in mind the possible variability of the AGN luminosity on the time scales of several months and years between our X-ray and optical AGN measurements.

CONCLUSIONS

We have performed a series of observations of sky fields around unidentified X-ray objects from the RXTE and INTEGRAL all-sky surveys with the RTT150 telescope. Using the TFOSC low-resolution spectrometer, we obtained the spectra for a number of objects within the error regions of these X-ray sources. In all cases, we detected relatively bright ($R_c \lesssim 17$) objects with strong emission lines typical of AGNs. We measured the redshifts of these AGNs and main parameters of their emission lines, which allowed them to be classified as Seyfert 1 or Seyfert 2. Six newly discovered AGNs in the local Universe are a significant supplement to the available catalogs of nearby AGNs. Thus, we see that a continuation of our campaign to optically identify RXTE and INTEGRAL AGN candidates will help improve our knowledge about the demography of supermassive black holes in the local Universe.

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Note. When this paper had already been accepted for publication, the paper of Masetti et al. (2005), who also identified one of our objects (IGR J18559+1535) with an AGN, was published.

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