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XSS J00564+4548 and IGR J00234+6141: New Cataclysmic Variables from the *RXTE* and *INTEGRAL* All-Sky Surveys*

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Abstract—We present the results of our optical identification of two X-ray sources from the *RXTE* and *INTEGRAL* all-sky surveys: XSS J00564+4548 and IGR J00234+6141. Using optical observations with the 1.5-m Russian–Turkish Telescope (RTT150) and publicly accessible X-ray data from the *SWIFT* Orbital Observatory, we show that these sources are most likely intermediate polars, i.e., binary systems with accreting white dwarfs that possess a moderately strong magnetic field ($\lesssim 10$ MG). We have found periodic optical oscillations with periods of ≈ 480 and ≈ 570 s. These periods most likely correspond to the rotation periods of the white dwarfs in these systems. Further optical RTT150 observations of these systems will allow their parameters to be studied in more detail.

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INTRODUCTION

The *ROSAT* All-Sky Survey (RASS, Voges et al. 1999) is a major source of information about the population of low-luminosity X-ray binaries. These X-ray binaries have luminosities of $\sim 10^{30-33}$ erg s^{-1} and are seen in RASS only to distances of $\sim$1 kpc or smaller, i.e., they are distributed over a fairly large part of the sky. Deeper *ROSAT*, *Chandra*, and *XMM-Newton* pointings cannot provide more data on these sources, since fainter objects can be found only in the Galactic plane, where these telescopes have surveyed an insufficiently large part of the sky and observations are hampered appreciably both in soft X rays, to which the telescopes are particularly sensitive, and in the optical range due to interstellar absorption and an overly large number of faint stars. In addition, nearby objects are more interesting, because they are bright and, hence, can be studied in more detail.

For some classes of X-ray sources, the RASS energy band (0.2–2.4 keV) has considerable disadvantages. For example, the spectra of accreting white dwarfs with magnetic fields $\sim 10^6$ G often have significant intrinsic photoabsorption by the matter falling to their polar caps. The soft (< 2 keV) X-ray emission from these white dwarfs can thus be strongly suppressed compared to harder (> 3 keV) X-ray emission.

The most sensitive all-sky X-ray survey to date in this harder energy band is the *RXTE* Slew Survey (XSS, Revnivtsev et al. 2004). This survey contains useful information about the population of nearby low-luminosity X-ray binaries. In fact, XSS and RASS contain comparable numbers of these binaries, despite the significant difference in the total numbers of detected X-ray sources. For example, the total number of known intermediate polars is 44 (Ritter and Kolb 2003), while the number of these objects among the identified XSS sources is 13 (Revnivtsev et al. 2004; Sazonov et al. 2005). Chromospherically active stars with much softer X-ray spectra that were not detected in XSS constitute the overwhelming majority of RASS X-ray objects identified with bright stars.

Unfortunately, because of the low XSS angular resolution, the nature of some sources cannot be established. At the time the paper was written, the nature of 18 of the 294 XSS sources had not been determined. The general characteristics of the

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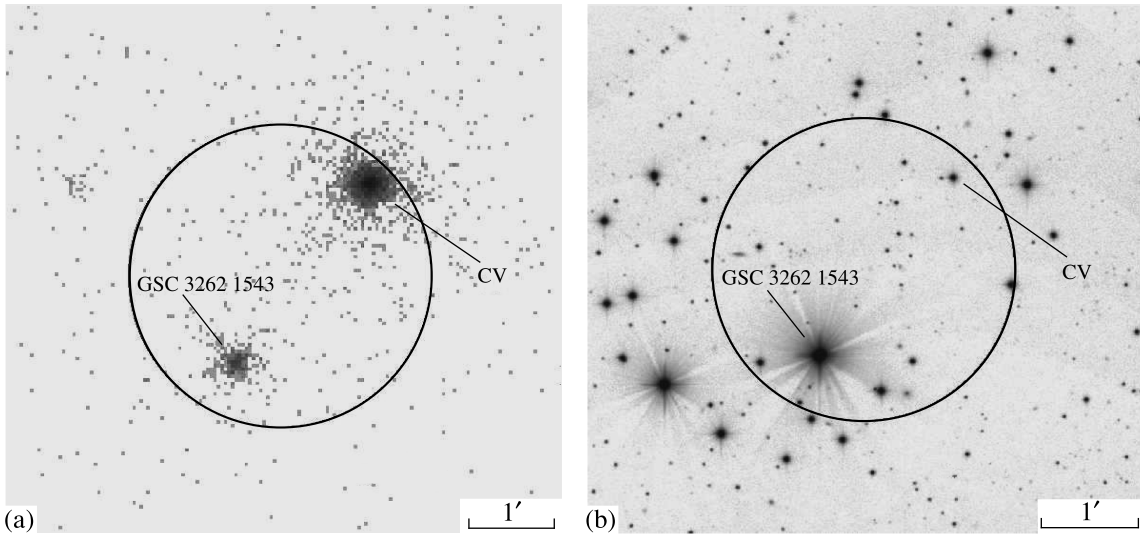

Fig. 1. Images of the XSS J00564+4548 field: (a) *SWIFT*/XRT X-ray image, the error circle of the *ROSAT* source is shown; (b) RTT150 optical R-band image. In both images, north is at the top and east on the left. The scale is the same and is shown in the images.

unidentified XSS objects suggest that most of them should be nearby active galactic nuclei (AGNs), but there must also be Galactic binaries, mostly accreting white dwarfs, among them (Revnivtsev et al. 2004).

The total number of known accreting white dwarfs is small (see, e.g., Ritter and Kolb 2003) and the discovery of any set of such objects gives useful information for studying the population of white dwarfs in the Galaxy. The detection of accreting white dwarfs in a statistically definite sky survey is particularly useful. This allows the space density of such binaries and their total contribution to the Galactic X-ray emission to be directly calculated (see, e.g., Sazonov et al. 2005). That is why the optical identifications of objects from the *RXTE* and *INTEGRAL* all-sky surveys are of great interest.

In 2005, we initiated a program of optical identifications of X-ray sources from the *RXTE* and *INTEGRAL* all-sky surveys with the 1.5-m Russian–Turkish telescope (RTT150). Within the framework of this program, we have identified six hitherto unknown nearby ($z < 0.1$) AGNs (Bikmaev et al. 2006). In this paper, we show that, according to the *SWIFT* X-ray and RTT150 optical observations, the sources XSS J00564+4548 and IGR J00234+6141 are binary systems with accreting white dwarfs, presumably intermediate polars.

OBSERVATIONS

The optical data used here were obtained with two RTT150 instruments: the CCD photometer and the TFOSC low-resolution spectrometer. These instruments and the data reduction methods that we used for optical identifications of *RXTE* and *INTEGRAL* objects were briefly described by Bikmaev et al. (2006).

XSS J00564+4548

The RXTE object XSS J00564+4548 was identified with the *ROSAT* X-ray source 1RXS J005528.0+461143. The localization accuracy of this X-ray source, $\approx 40''$ (1σ), is too low to reliably identify this source with any optical object in this field.

During May–October 2005, the XRT telescope onboard the *SWIFT* observatory (Gehrels et al. 2004) performed four observations of the field of this source. These observations revealed that there are actually two X-ray sources in this field, with both of them giving comparable contributions to the flux from the *ROSAT* source. X-ray and optical images of this field are shown in Fig. 1 and X-ray spectra of the two sources are shown in Fig. 2. One of the sources is reliably identified with the star GSC 3262 1543, $V \approx 11^m$. Its X-ray spectrum suggests that this is either a single chromospherically active late-type star or a close RS CVn binary (see, e.g., Schmitt et al. 1990). This X-ray source is soft and could not be detected in RXTE, while the second X-ray source is much harder (see Fig. 2). Thus, XSS J00564+4548 must be identified with the second, harder X-ray source and with the optical star with the coordinates $\alpha = 00^h55^m20\overset{s}{.}0$ and $\delta = +46°12'57''$ (J2000).

The X-ray spectrum of the second source can be best fitted by a power law with photoabsorption with a photon index $\Gamma \sim 0.8 \pm 0.1$ and photoabsorption $N_H L = (0.22 \pm 0.05) \times 10^{22}$ cm^{-2}. The Galactic

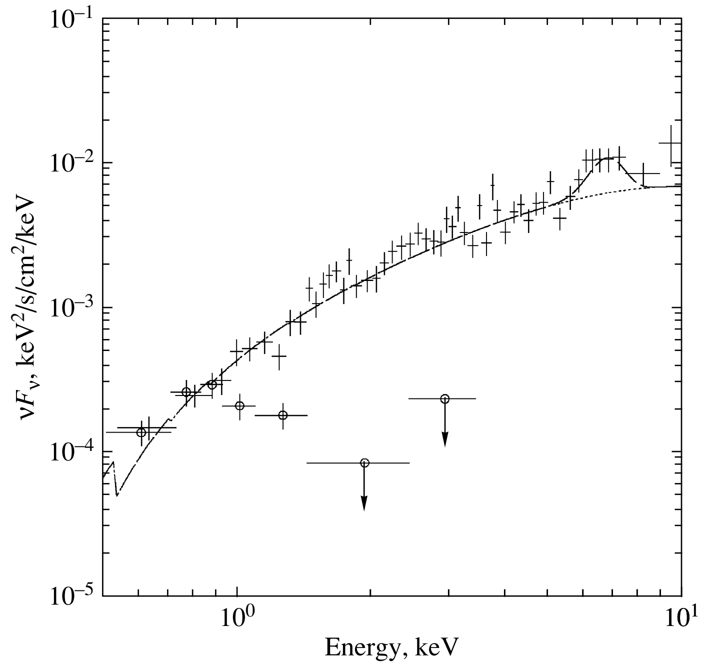

Fig. 2. Spectra of two X-ray sources detected by *SWIFT*/XRT in the error circle of RXS J005528.0+461143. The open circles indicate the spectrum of GSC 3262 1543, a presumably chromospherically active star, and the crosses indicate the spectrum of a cataclysmic variable.

absorption toward this object estimated from 21-cm radio observations is 0.11×10^{22} cm^{-2} (NRAO maps were used, Dickey and Lockman 1990), which may indicate that part of the photoabsorption is intrinsic and originates in the polar region of the accreting white dwarf.

The photon index is not typical of extragalactic objects that might be expected at such a high Galactic latitude, mostly AGNs. However, it corresponds to the typical photon indices of accreting white dwarfs, cataclysmic variables (CVs).

At the detection threshold, the spectrum exhibits

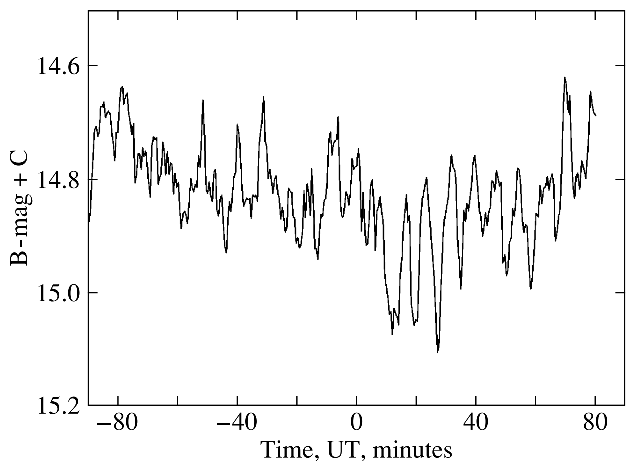

Fig. 3. RTT150 light curve of XSS J00564+4548 obtained on October 28, 2005.

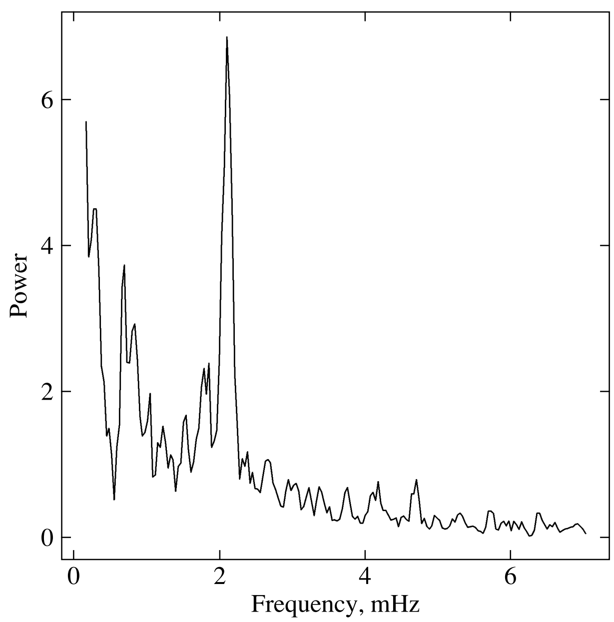

Fig. 4. Power spectrum of the optical variability in XSS J00564+4548. The indicated power is an averaging of the periodograms constructed by the Lomb–Scargle method (Lomb 1976) from all observations. The power peak at a period of $(480\ s)^{-1}$ is clearly seen.

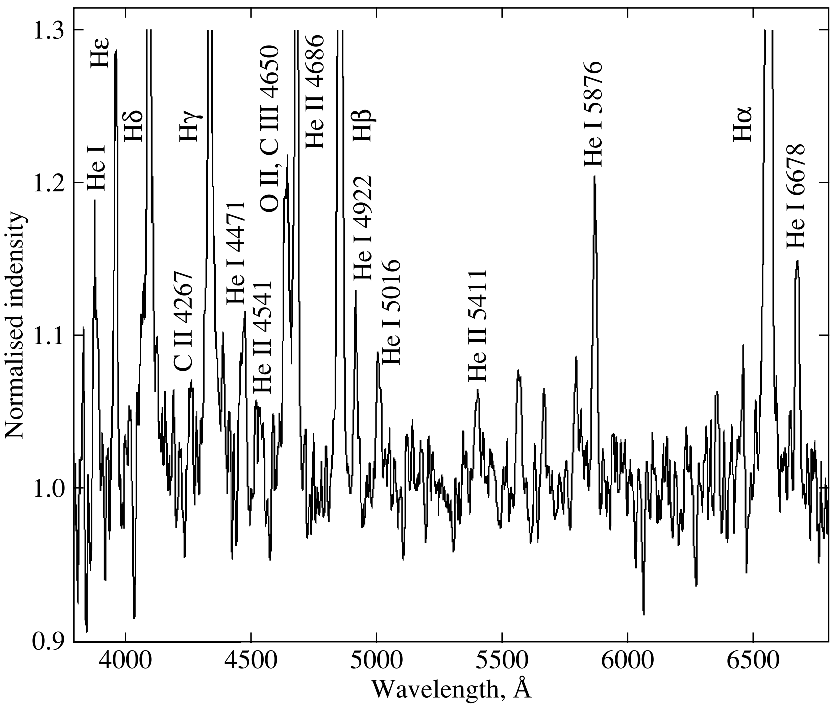

Fig. 5. Optical spectrum of XSS J00564+4548 obtained with RTT150 on November 29, 2005.

a broad emission feature near ≈ 6.7 keV, which is also typical of CVs and atypical of AGNs. The decrease in the best χ^2 value when fitted by a model with an emission line in the shape of a Gaussian compared to the model without any line corresponds to a 99.9% probability that this feature actually exists in the spectrum. The equivalent width of this emission feature is $EW = 1.06 \pm 0.30$ keV, which is also expected for optically thin plasma emission from accreting white dwarf.

To test the hypothesis about the nature of XSS J00564+4548, we performed several optical photometric observations: on August 18 and 20, September 11, and October 19, 20, 21, 22, 23, 26, and 28, 2005. In Fig. 3, the light curve of the optical source obtained on October 28 is shown as an example. Analysis of the light curves revealed a clear variability of the optical source with an amplitude $\Delta B \approx 0.3$ on time scales as short as ~50–100 s, which allows the source to be completely excluded from candidates for AGNs (such a large variability on such short time scales is completely atypical of AGNs, accreting supermassive black holes). A further analysis of the variability revealed a clear periodicity in the light curve. Figure 4 shows the power spectrum of the optical variability obtained by averaging the Lomb–Scargle periodigrams (Lomb 1976) over all observations. The power peak at a period of $(\approx 480\,s)^{-1}$ is clearly seen in this figure. The measured optical period of 480 s indicates that this is most likely not the orbital period of the binary system, which is typically of the order of several hours for such binaries, but the rotation period of a magnetized white dwarf.

We emphasize that we have no direct information that the optical variability period corresponds precisely to the rotation period of the white dwarf and not to the orbital period of the binary. However, only a few CVs with orbital periods < 1 h are known to date (Ritter and Kolb 2003). Most of them are AM CVn

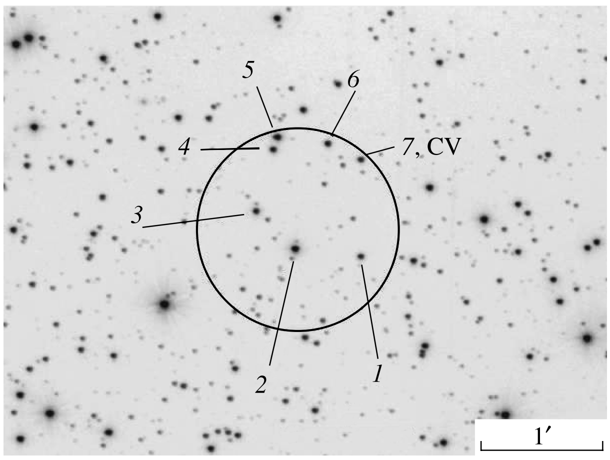

Fig. 6. Optical image of the IGR J00234+6141 field. The numbers indicate the sources for which optical spectra were taken. North is at the top and east is on the left; the scale is shown in the image.

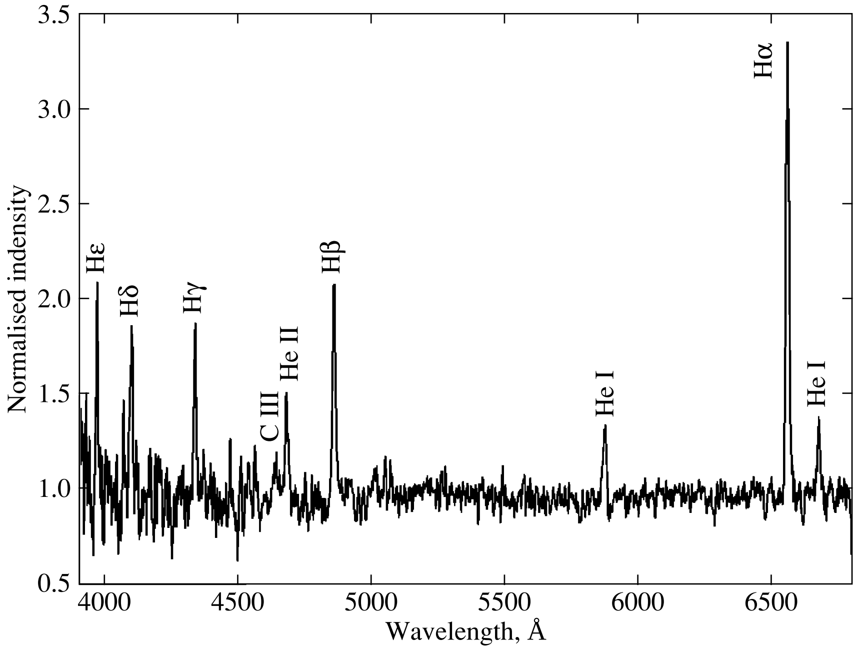

Fig. 7. Optical spectrum of IGR J00234+6141 obtained with RTT150 on October 8, 2005.

variables, systems without any hydrogen lines in their optical spectra, since accreting matter in these binaries comes from a degenerate star. The RTT150 optical spectrum of XSS J00564+4548 (Fig. 5) exhibits intense emission lines, including hydrogen ones, typical of the accretion disks around white dwarfs (see, e.g., Williams and Ferguson 1982; Schmidt et al. 1986. Therefore, matter in XSS J00564+4548 is most likely accreted from a normal star. Such systems usually have orbital periods of the order of several hours (Ritter and Kolb 2003).

The magnetic field of the white dwarf in this system must be strong enough to generate pulsating X-ray emission—to produce a channel of matter infall to the polar cap. On the other hand, its strength cannot be larger than $\sim$10 MG, because otherwise the magnetic field would be so strong that it could be frozen in the surface of the companion star and the orbital period of the binary would be equal to the rotation period of the white dwarf (see, e.g., Patterson 1994). Thus, based on optical and X-ray data, we can classify this object with confidence as an intermediate polar, i.e., an accreting white dwarf with a moderately strong magnetic field ($\lesssim$ 10 MG).

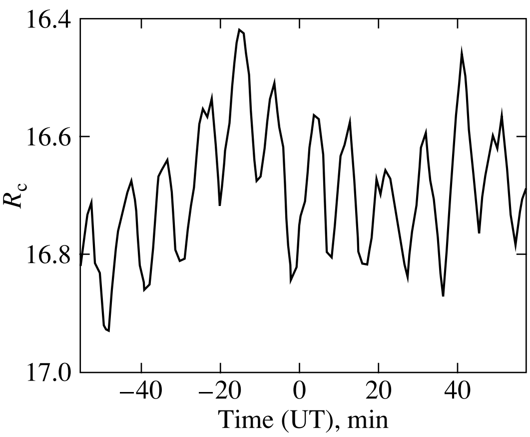

Fig. 8. R_c-band light curve of IGR J00234+6141 obtained with RTT150 on September 10, 2005.

IGR J00234+6141

The X-ray source IGR J00234+6141 was discovered during deep *INTEGRAL* observations of the supernova remnant Cas A (Den Hartog et al. 2005). The position of the source (accuracy $\approx 3'$) agrees with that of the *ROSAT* source 1RXS J002258.3+61411 with a much higher localization accuracy ($\approx 10''$). Such a good localization accuracy allowed us to search for the optical companion of the X-ray source by exhaustion.

In October 2005, we took spectra for the seven brightest optical objects in the *ROSAT* error circle (Fig. 6). In one case, the object exhibited strong emission lines without any noticeable redshift, indicating that this is a Galactic object. The spectrum of this source is shown in Fig. 7. The set of emission lines suggests that we are dealing with a cataclysmic variable, an accreting white dwarf (see, e.g., Williams and Ferguson 1982; Schmidt et al. Grandi 1986).

The X-ray source IGR J00234+6141 must be identified with this CV, since the probability of finding by chance such a variable in the *ROSAT* error circle is negligible. The coordinates of this object are $\alpha = 00^h22^m57\overset{s}{.}6$ and $\delta = +61°41'08''$ (J2000).

In January 2006, this object was independently observed spectroscopically (Halpern and Mirabal 2006). Based on their optical spectrum, these authors also concluded that this object is a CV and that the X-ray source IGR J00234+6141 must be identified with it.

The optical photometric light curves obtained on September 10, 2005 revealed a clear periodicity with a period of 570 s. Part of the light curve, where this periodicity is clearly seen, is shown in Fig. 8 as an example. As in the case of XSS J00564+4548 (see above), the short optical period suggests that it correspond to the rotation period of the white dwarf. Thus, just as in the previous case, we can classify this object as an intermediate polar, a weakly magnetized accreting white dwarf.

CONCLUSIONS

Using optical RTT150 and X-ray *SWIFT* observations, we identified two *RXTE* and *INTEGRAL* X-ray sources: XSS J00564+4548 and IGR J00234+6141. The derived optical spectra and photometric periods suggest that these sources are most likely accreting binary systems with magnetized white dwarfs, intermediate polars.

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