THE OPTICAL COUNTERPART TO IGR J11435-6109

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ABSTRACT

We present photometry and spectroscopy of the possible optical counterparts to the *INTEGRAL* source IGR J11435-6109. We show that the object within the *ROSAT* error circle is an M type star and is not related with the *INTEGRAL* source. Two objects emerge as possible candidates. Star #1 appears to be a B3Ve star and therefore the system could be classified as a Be/X-ray transient. It is located at a distance of $\approx$ 4.5 kpc, obscured by circumstellar material. If the identification is correct, this will be the Be/X-ray system with the latest optical counterpart known so far. On the other hand, candidate Star # 2 appears as a very faint, red object, in the outer rim of the *ROSAT* circle.

Key words: X-ray binaries.

1. INTRODUCTION

IGR J11435-6106 was discovered as a transient hard X-ray source during *INTEGRAL* satellite raster scans of the Galactic Plane [3] on November 23, 2004. The *INTEGRAL* source position (R.A.= $11^{\rm h}$ $43^{\rm m}$ $52^{\rm s}$, Decl.= -61° 09' 00", equinox 2000.0, error radius 2.5'), was consistent with that of the faint *ROSAT* source 1RXS J114358.1-610736.

Later [4], using archival *BeppoSAX* data, refined the position to R.A. = $11^{\rm h}$ $44^{\rm m}$ $00.4^{\rm s}$, Decl. = -61° 07' 16" (J2000.0) with a 99%, confidence error circle radius of 1.4'. They confirmed a possible pulsation period of 161.76 ± 0.01 s, previously suggested by [7] and, in turn, discovered a larger period of 52.5 d which can be regarded as the orbital period of the system. This was confirmed using *RXTE* data [1, 10].

Recently, Revnivtsev et al. [6] reported a sudden brightening of the source observed with *INTEGRAL*. The source brightness, in the energy band 17-60 keV, gradually increased from $\leq$ 0.5 mCrab, on June 2-10, 2005 up to $\approx$ 15 mCrab on June 20-21, 2005 thus confirming the transient nature of the source.

In this paper we report on the properties of the possible optical counterparts to IGR J11435-6109. We will show that the X-ray source is not related with 1RXS J114358.1-610736, which turns out to be a late type active star. The most likely counterparts are: a Be star, close to the error circles of several X-ray telescopes or an emission line star in the rim of the *ROSAT* error circle.

2. THE OBSERVATIONS

2.1. Photometry

Standard Jonhson BVR photometry was conducted on the nights of Dec 14 and 15, 2004 with the New Technology 3.5m Telescope (NTT) on La Silla, Chile, under programme 074.D-0529(A). The telescope was equipped with the EMMI instrument [2]. For the imaging we used the BIMG ($\leq$ 500 nm) and RILD ($\geq$ 400 nm) modes which gave spatial resolutions of 0.37"/pix and 0.17"/pix respectively as well as fields of view of 6.2'$\times$6.2' and 9.1"$\times$ 9.9' respectively. A set of standard star fields were followed throughout the night, at a range of air masses, in order to derive the standardization equations. This equations were subsequently applied to the programme star and the values averaged for both nights since the differences were within the photometry errors. This resulted in the magnitudes quoted in Table 1.

2.2. Spectroscopy

Simultaneously, medium resolution spectroscopy in the blue band was obtained with the RILD mode, equipped with grism # 5 and 1" slit in order to perform the spectral classification. This gives a nominal dispersion of 0.83Å/pixel and a resolution of 1100.

Spectroscopy around Hα was obtained using REMD mode with grism #6 and 1" slit and 2$\times$2 binning, which gives a dispersion of 0.4Å/pixel and a resolution of 5000.

Table 1. Photometry for the possible optical counterparts obtained at the NTT during the nights of 14th and 15th December 2004.

Star	B	V	R
USNO-B1.0 0288-0337948 (Star #1)	13.97 ± 0.03	13.52 ± 0.02	13.03 ± 0.02
USNO-B1.0 0288-0337502 (Star #2)	17.71 ± 0.04	16.43 ± 0.03	15.44 ± 0.03

2.2.1. M star

Since a preliminary identification of IGR J11435-6109 with 1RXS J114358.1-610736 had been proposed ([3]), we first took a spectrum of the only star within the error circle of the *ROSAT* source (about 1" from the nominal position of the *ROSAT* source), namely USNO-B1.0 0288-0337417 (RA: 11^h 43^m 58.5^s, Decl: -61° 07' 37"). The spectrum corresponds to an M type star, with pronounced TiO molecular bands (Fig. 1). 1RXS J114358.1-610736 is hence associated with an active corona and is not the same source as IGR J11435-6109.

2.2.2. Star #1

Subsequently, we performed slitless spectroscopy of the field. Close inspection revealed a moderately bright nearby object with Hα in emission. This is USNO-B1.0 0288-0337948 (RA: 11^h 44^m 10.7^s, Decl: -61° 07' 02"). The magnitudes listed are $B_2 = 13.17, R_2 = 12.95, i = 11.61$. The object lies within the *BeppoSAX* WFC error circle for IGR J11435-6109 (about 1.2' away from its nominal position) and also about 1.2' away from the *Einstein* position for 2E 1141.6-6050. It is 3' away from the center of the *INTEGRAL/IBIS* error circle.

In Fig. 2 we show the spectrum in the classification region. From its analysis a spectral type of B3 might be deduced. The luminosity class is moderately low, V or IV.

The red spectrum shows clearly emission in Hα, although the underlying absorption wings are still visible. Therefore, a spectral type B3Ve is deduced for this source. The Hα line exhibits a double peak structure. This is typical of Be stars circumstellar disks.

From the photometry in Table 1 and the deduced spectral type we can estimate the total infrared excess to be $E^{tot}(B-V) = (B-V)-(B-V)_0 = 0.45-(-0.21) \simeq 0.7$. From this, a small amount will be of circumstellar origin. According to Torrejón et al. (2005) [9], this will be around $E^{cs}(B-V) \approx 0.1$. Therefore, the true interstellar reddening must be around $E^{is}(B-V) = 0.6$

On the other hand the observed $V = 13.52$ must be somewhat overluminous due to the circumstellar emission. Assuming an overluminosity of 0.03 mag we can derive a distance modulus of 13.3 which translates into a distance

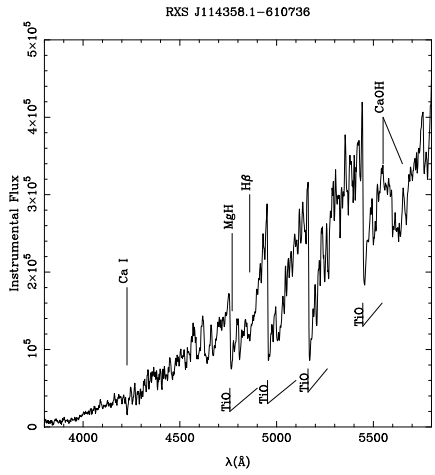

Figure 1. NTT spectrum for the ROSAT source candidate 1RXS J114358.1-610736. Note the presence of prominent TiO molecular bands. This spectrum corresponds to a M type star.

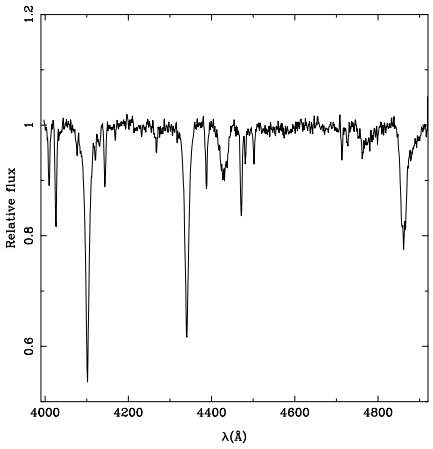

Figure 2. Blue NTT spectrum, in the spectral classification region, of Be star # 1.

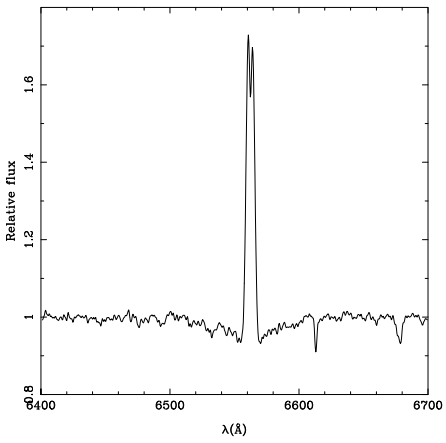

Figure 3. NTT spectrum around the Hα line for the Be star #1. The line presents double peak structure. This is typical of Be star circumstellar disks.

of $d \sim 4.5$ kpc. For this distance, the X-ray luminosity of the source is around $5{\times}10^{35}$ erg s^{-1}, which is somewhat low for typical Be/X-ray binary pulsars.

2.2.3. Star #2

Close inspection of our slitless spectroscopy images reveal a second, very faint, candidate with a prominent emission line, in the rim of the *ROSAT* error circle. This is USNO-B1.0 0288-0337502 = 2MASS J11440030-6107364. The magnitudes of this object are listed in Table 1. The object appears very red with $(B-V) = 1.28$. Unfortunately , no spectrum is available for this object at this time. Therefore, no indication about the spectral type can be given and we can not proceed the analisys any further in this paper. An observation of this third candidate is, currently, in progress.

3. DISCUSSION

Given its X-ray and optical properties, IGR J11435-6109 could emerge as a Be/X-ray transient system.

The system contains a NS and shows up as a pulsar. The long timescale observations reveal an orbital period of 52 days. The system is therefore in a relatively wide orbit and shows periods of quiescence during which it can not be detected.

The interstellar H column ($N_H \approx 0.3 \times 10^{22}$ cm^{-2}) is much lower than the H column deduced from X-ray observations $N_H \approx 9 \times 10^{22}$ cm^{-2} [4]. Therefore, a lot of circumstellar matter must be present close to the X-ray source. This is consistent with the system being a Be/X-ray binary.

If the optical counterpart is Be star #1, this is the latest found so far for a Be/X-ray binary. These systems appear to be restricted to a very narrow spectral range, from B0 to B3, [5]. The main part of these objects have been found to cluster around B0. Few systems containing later types are known and none beyond B2 in the Galaxy. Therefore, IGR J11435-6109 would be the first such system found.

On the other hand, the optical counterpart could be the emission line star #2, which is very red, faint, and at the outer limit of the *ROSAT* error circle. Observations of this third candidate are, currently, in progress.

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