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Letter to the Editor

The nature of 1WGA J1958.2+3232: A new intermediate polar

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Received 10 November 1999 / Accepted 20 December 1999

Abstract. We present low and intermediate resolution spectroscopy of the optical counterpart to the recently discovered pulsating X-ray source 1WGA J1958.2+3232. The presence of strong H\(_i\), He\(_i\) and He\(_{\sc{ii}}\) emission lines together with the absence of absorption features rules out the possibility that the object is a massive star, as had recently been suggested. The observed X-ray and optical characteristics are consistent with the object being an intermediate polar. The double-peaked structure of the emission lines indicates that an accretion disc is present.

Key words: stars: individual: 1WGA J1958.2+3232 – stars: binaries: close – stars: novae, cataclysmic variables – book reviews – X-rays: stars

1. Introduction

There are several types of X-ray sources which display significant modulation in their X-ray lightcurves, among which isolated neutron stars, anomalous X-ray pulsars and two types of well characterised binary systems: accreting X-ray pulsars (accreting neutron stars with strong magnetic fields \(B \gtrsim 10^{11}\) G) and magnetic cataclysmic variables (accreting white dwarfs with moderate magnetic fields \(B \gtrsim 10^{5}\) G). Recent systematic analysis of \textit{ROSAT} observations has resulted in the detection of several new such sources. However, given the limited spectral information of the \textit{ROSAT} data and the impossibility of determining the intrinsic luminosity of the sources, the classification of these objects depends on the identification of their optical counterpart. X-ray pulsators are generally part of a high mass X-ray binary (HMXRB) and their optical spectra are those of the massive companion, without any significant contribution from the vicinity of the neutron star. In cataclysmic variables (CVs), on the other hand, the white dwarf is accreting from a late-type unevolved star and the optical spectrum is dominated by emission from the accretion disc (if present) or the accretion stream (when the magnetic field is too strong to allow the formation of an accretion disc). In polars (AM Her stars), the magnetic field \((B \gtrsim 5 \times 10^{6}\) G) is dominant: there is no accretion disc and the orbit and spin periods are synchronised. In magnetic CVs with weaker magnetic fields (intermediate polars) rotation is not synchronous and an accretion disc, an accretion stream or both can be present.

Strong modulation (at an 80% level) was discovered in the X-ray signal from the \textit{ROSAT} PSCP source 1WGA J1958.2+3232 by Israel et al. (1998). The pulse period was poorly determined at 721±14 s, though a later ASCA observation allowed the derivation of a much more accurate value 734±1 s (Israel et al. 1999). The energy spectrum was fitted by a simple power law giving a photon index \(\Gamma = 0.8^{+1.2}_{-0.6}\) and a column density \(N_{\text{HI}} = (6^{+24}_{-5}) \times 10^{20} \text{ cm}^{-2}\). Given these parameters and the fact that the source was close to the Galactic plane, Israel et al. (1998) were unable to decide whether the source was a low-luminosity persistent Be/X-ray binary (see Negueruela 1998; Reig & Roche 1999) or an intermediate polar (see Patterson 1994).

Later Israel et al. (1999) located an \(V = 15.7\) emission line object inside the 30" X-ray error circle, which is the optical counterpart. Based on a low signal-to-noise spectrum, Israel et al. (1999) classified the object as a Be star, in spite of the evident presence of strong He\(_{\sc{ii}}\) \(\lambda 4686\)\AA\, emission, which is never seen in classical Be stars (in Be/X-ray binaries, if at all present, it only shows as some in-filling in the photospheric line). Based on some features that they identified as interstellar lines, they speculated that the optical counterpart was a slightly reddened B0Ve star at a distance of 800 pc. However, if a B0V star was slightly reddened, it should have an apparent magnitude \(V \approx 6\) rather than \(\approx 16\), and a very large reddening is unlikely given that the extinction in that direction has been measured to be small (Neckel & Klare 1980). This led us to obtain higher resolution spectra of the source. In this paper we show that the optical properties of the object clearly identify it as an intermediate polar, rather than a Be/X-ray binary.

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2. Observations

2.1. Optical spectroscopy

We observed the optical counterpart to 1WGA J1958.2+3232 on July 12, 1999, using the Intermediate Dispersion Spectroscopic and Imaging System (ISIS) on the 4.2-m William Herschel Telescope (WHT), located at the Observatorio del Roque de los Muchachos, La Palma, Spain. The blue arm was equipped with the R300B grating and the EEV#10 CCD, which gives a nominal dispersion of $\sim 0.9\,\text{Å/pixel}$ over $\sim 3500\,\text{Å}$. The red arm was equipped with the R1200R grating and the Tek4 CCD, which gives a nominal dispersion of $\sim 0.4\,\text{Å/pixel}$ at H$\alpha$. The exposure time was 1500 s. The data were processed using the Starlink packages ccdpack (Draper 1998) and figaro (Shortridge et al. 1997) The extracted spectra are displayed in Figs. 1 and 2.

We obtained lower resolution spectroscopy using the 1.3-m Telescope at the Skinakas Observatory (Crete, Greece) on July 26, 1999. The telescope is an f/7.7 Ritchey-Cretien and was equipped with a $2000 \times 800$ ISA SITe chip CCD. This camera has $15\,\mu\text{m}$ pixels and reaches maximum efficiency ($\sim 90\%$) in the red, at around H$\alpha$. The spectrum (a 1800-s exposure) was taken with a 1300 line mm$^{-1}$ grating and a $320\,\mu\text{m}$ width slit ($6''7$) which gave a dispersion of 1 Å pixel$^{-1}$. The spectrum, which is displayed in Fig. 3, was reduced using figaro.

2.2. Optical photometry

We obtained Strömgren photometry of the field using the 1.3-m Telescope at Skinakas Observatory on August 16, 1999 (JD 2,451,407). The telescope was equipped with a $1024 \times 1024$ pixel SITe CH360 CCD. The size of the pixels was $24\,\mu\text{m}$, representing approximately $0''.5$ on the sky. The source was observed through standard $u, v, b, y$ filters with exposure times of 1200, 900, 600 and 300 seconds, respectively. A sufficient number of standards were observed in order to compute the atmospheric extinction coefficients and allow the transformation to the standard system.

The results are displayed in Table 1. We have also obtained measurements for the only other star of similar brightness which was inside both the ASCA and ROSAT error circles – dubbed “candidate A” by Israel et al. (1999). As can be seen, the values of $y$ for the proposed optical counterpart and candidate A are
of the cataclysmic variable or the beat period between the spin
the observed X-ray variation should represent the spin period
Given that the X-ray flux is strongly pulsed and an accretion disc
depend on the orbital phase at which the observation was taken.
The exact shape of the lines must
H
The double-peaked shape can be seen in greater detail in the
no displacement from the rest wavelength within the resolution
(determined by fitting a single Gaussian to the profile) show
seen in the weaker He
i
ii
The asymmetry is still stronger in the He
i
transitions are also in emission. The Balmer lines are all double-
features allow spectral classification to the spectral subtype.
In the spectrum of 1WGA J1958.2+3232, on the other hand,
as is typical in intermediate polars, He
i
λ4686 Å and the Bowen complex are strongly in emission. Many other He
i
transitions are also in emission. The Balmer lines are all double-
profile of H\(_\alpha\) is modified by the interstellar Ca\(_{ii}\) λ3968 Å line).
The asymmetry is still stronger in the He\(_{i}\) lines and can be
seen in the weaker He\(_{i}\) lines. The centroids of emission lines
(determined by fitting a single Gaussian to the profile) show
no displacement from the rest wavelength within the resolution achieved. The blue peaks of the H\(_{i}\) and He\(_{i}\) lines are displaced by \(\sim 250 \text{ km s}^{-1}\).

Fig. 3 displays H\(_\alpha\) and He\(_{i}\) λ6678 Å at higher resolution.
The double-peaked shape can be seen in greater detail in the
H\(_\alpha\) line. This is evidence for the presence of an accretion disc
surrounding the white dwarf. The exact shape of the lines must
depend on the orbital phase at which the observation was taken.
Given that the X-ray flux is strongly pulsed and an accretion disc
is present, the object must be an intermediate polar. Therefore
the observed X-ray variation should represent the spin period
of the cataclysmic variable or the beat period between the spin
and orbital periods, since it should be an asynchronous system.
The sharpness of the peaks indicates that the 25-min exposure
does not represent a significative portion of the orbit (otherwise
the peaks would be blurred). This is consistent with expected
orbital periods of a few hours.

In the lower resolution spectrum taken two weeks later
(Fig. 3), H\(_\alpha\) and the He\(_{i}\) are single-peaked and red-dominated,
indicating that the source was observed at a different orbital
phase. Even though the resolution is rather lower than in the
WHT spectrum, a peak separation similar to that measured in
the first spectrum \(v \approx 375 \text{ km s}^{-1}\) should have been resolved.
The interstellar Na\(_{i}\) lines are not detectable above the noise
level. Due to their weakness and the irregularity of the contin-
num, no diffuse interstellar bands (DIB) can be measured
even in the higher resolution spectra. We set upper limits for the
Equivalent Width (EW) of the DIBs at λ4430 Å and λ6613 Å
as EW < 400 m\(\text{Å}\) and < 50 m\(\text{Å}\), both of which are consistent
with \(E(B - V) < 0.2\) (Herbig 1975). This is in accordance
with the measurements of interstellar absorption in this direc-
tion \(l = 69\degree, b = 1.7\) by Neckel & Klare (1980), who find
\(A_V < 0.5 \text{ mag and } A_V < 1.0 \text{ mag at } 1 \text{ kpc for the two fields}
between which 1WGA J1958.2+3232 approximately lies."

In the WHT observations, we set the slit in such a way as to
also observe the nearby star dubbed “Candidate A” by Is-
rael et al. (1999), which is about 40′′ away from the optical
counterpart to 1WGA J1958.2+3232, and therefore could pro-
vide some information on the reddening in that direction. Even
though Israel et al. (1999) claim that this object is an early-type
star, comparison with the spectra of several stars taken from the
electronic database of Leitherer et al. (1996) shows that its spec-
tral type is F8V (see Fig. 4). We cannot see the λ4430 Å DIB
down to the level of the many weak features in the spectrum,
which gives an upper limit of EW \(\approx 300 \text{ m} \text{Å}\). From the mea-
sured \((b − y) = 0.59 \pm 0.07 \text{ and the intrinsic } (b − y)_0 = 0.350
for an F8V star (Popper 1980) we obtain the interstellar redd-
ening \(E(b − y) = 0.24\). Using the relation of Crawford &
Mandewewala (1976) \(E(B − V) = 1.35E(b − y)\), this implies
\(E(B − V) = 0.32\), significantly higher than the upper limit
that could be derived from the interstellar λ4430 Å DIB, which
implies \(E(B − V) < 0.13\), according to the relation by Herbig
(1975). Assuming \(M_V = +4.2\) for a main-sequence F8 star
(Deutschman et al. 1976) and the standard reddening \(R = 3.1\),
this star is situated at a distance \(d \approx 0.9 \text{ kpc}\). given its brightness, 1WGA J1958.2+3232 should be located at a distance \(d > 1.5 \text{ kpc}\) (see Israel et al. 1998), i.e.,
farther away than the F8V star and therefore would have a higher
reddening. If the reddening is \(E(B − V) > 0.3\), the soft X-ray
flux could be absorbed, which would explain the relatively low
\(L_X/L_{\text{opt}}\) of the source when compared to less distant interme-

<table>
<thead>
<tr>
<th></th>
<th>(y)</th>
<th>(b)</th>
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<th>(u)</th>
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<tbody>
<tr>
<td>1WGA J1958.2+3232</td>
<td>15.77±0.04</td>
<td>15.94±0.04</td>
<td>16.12±0.05</td>
<td>16.48±0.07</td>
</tr>
<tr>
<td>Candidate A</td>
<td>15.55±0.05</td>
<td>16.15±0.05</td>
<td>16.56±0.07</td>
<td>17.60±0.16</td>
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Table 1. Observational details of the optical photometry.
Fig. 4. Spectrum of the star called Candidate A in Israel et al. (1999), which is only $\sim 40''$ from 1WGA J1958.2+3232. The comparison spectra correspond to HD 5015 (top, F8V) and HD 22879 (bottom, F9V) and are taken from the database of Leitherer et al. (1996).

diate polars (see Israel et al. 1998). We note that the interstellar lines indicate a lower reddening, but in the F8V star this estimate is also rather lower than the photometric determination of the reddening.

With a pulse period of 734 s, this system falls in between the two groups of short and long period intermediate polars defined by Norton et al. (1999), and characterised by different X-ray pulse shapes. Clearly further X-ray observations of the source are needed and either RXTE or Chandra could provide more detailed timing observations. Also, future time-resolved photometric and spectroscopic observations are needed in order to determine the orbital period and whether the observed X-ray pulsations correspond to the spin period.

4. Conclusions

Based on intermediate-resolution spectroscopy, we conclude that 1WGA J1958.2+3232 is an intermediate polar, rather than a Be/X-ray binary. From the magnitudes measured for the object and a very nearby F8V star we can estimate that 1WGA J1958.2+3232 is situated at a distance of 1 – 1.5 kpc and moderately reddened with $E(B – V) \lesssim 0.3$.

Acknowledgements. The WHT is operated on the island of La Palma by the Royal Greenwich Observatory in the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofísica de Canarias. The observations were taken as part of the ING service observing programme. Skinakas Observatory is a collaborative project of the University of Crete, the Foundation for Research and Technology-Hellas and the Max-Planck-Institut für Extraterrestrische Physik. The authors would like to thank Dr. GianLuca Israel for his help with this work and Drs D. di Martino and A. J. Norton for their helpful comments on the draft. We are also grateful to Drs E. V. Paleologou and I. E. Papadakis for helping with the spectroscopic and photometric observations at Skinakas Observatory, respectively. IN is supported by an ESA external fellowship. PR acknowledges partial support via the European Union Training and Mobility of Researchers Network Grant ERBFMRX/CT98/0195. JSC is supported by a PPARC research assistantship.

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