*Letter to the Editor*

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

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**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 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 *ROSAT* observations has resulted in the detection of several new such sources. However, given the limited spectral information of the *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 *ROSAT* PSPC source 1WGA J1958.2+3232 by Israel et al. (1998). The pulse period was poorly determined at $721\pm14$ s, though a later *ASCA* observation allowed the derivation of a much more accurate value $734\pm1$ 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 $N_{\mathrm{H}} = \left(6^{+24}_{-5}\right) \times 10^{20}$ 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 II $\lambda4686$Å 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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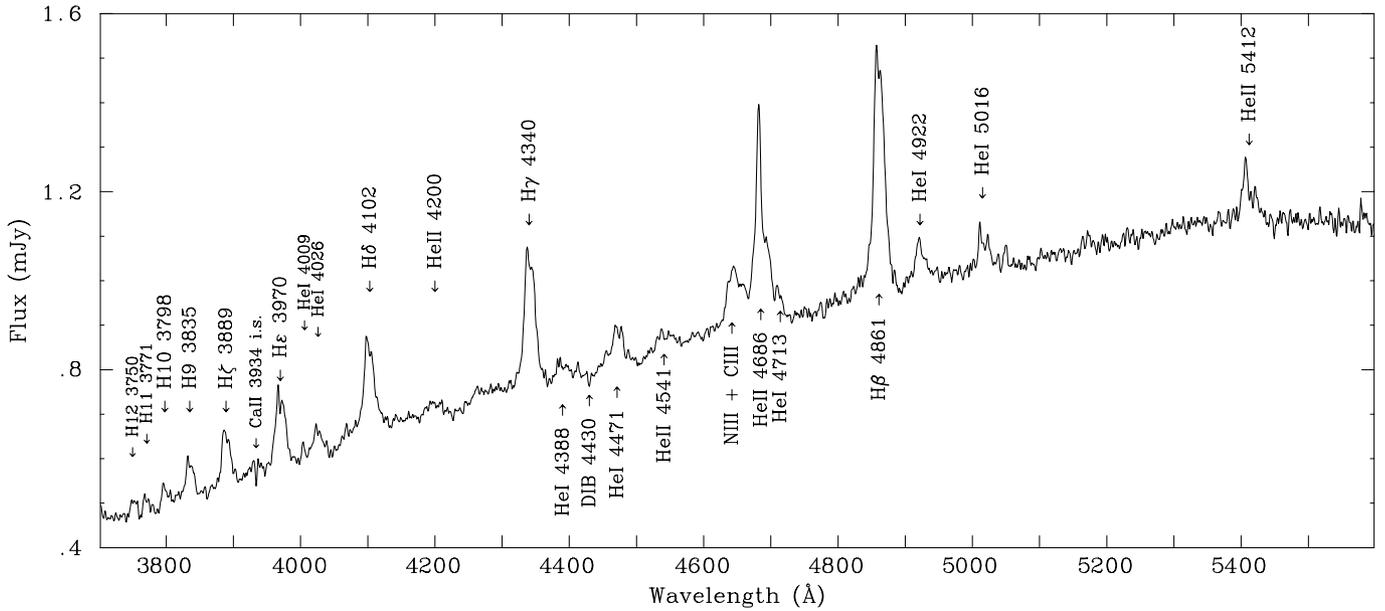
**Fig. 1.** Blue spectrum of the optical counterpart to 1WGA J1958.2+3232, taken on July 12, 1999, with the WHT and ISIS. Emission lines are marked.

## 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 $\sim 0.9$ Å/pixel over $\sim 3500$ Å. The red arm was equipped with the R1200R grating and the Tek4 CCD, which gives a nominal dispersion of $\sim 0.4$ Å/pixel at H$\alpha$. The exposure time was $1500$ s. The data were processed using the *Starlink* packages CCDPACK (Draper 1998) and FIGARO (Short-ridge 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 $15\mu$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 $\mu$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 $24\mu$m, representing approximately $0''.5$ on the sky. The source was observed
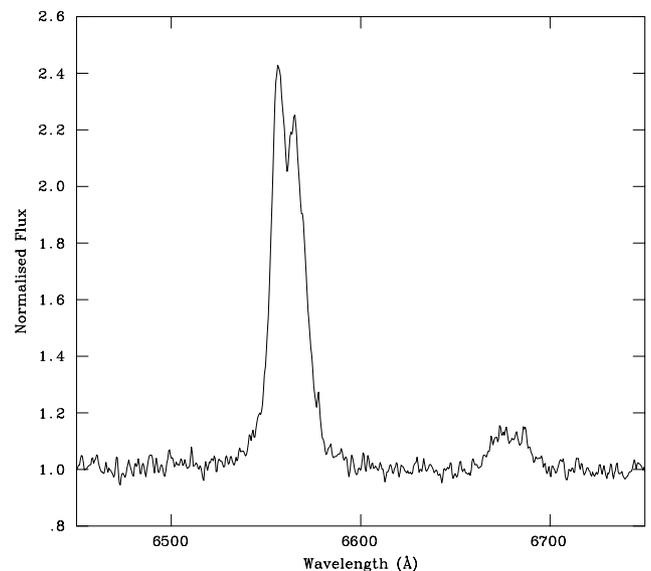


**Fig. 2.** H$\alpha$ and He I $\lambda 6678$Å emission lines in the optical counterpart to 1WGA J1958.2+3232. Spectrum taken with the WHT and ISIS on July 12, 1999.

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

**Table 1.** Observational details of the optical photometry.

|  | $y$ | $b$ | $v$ | $u$ |
|---|---|---|---|---|
| 1WGA J1958.2+3232 | 15.77±0.04 | 15.94±0.04 | 16.12±0.05 | 16.48±0.07 |
| Candidate A | 15.55±0.05 | 16.15±0.05 | 16.56±0.07 | 17.60±0.16 |
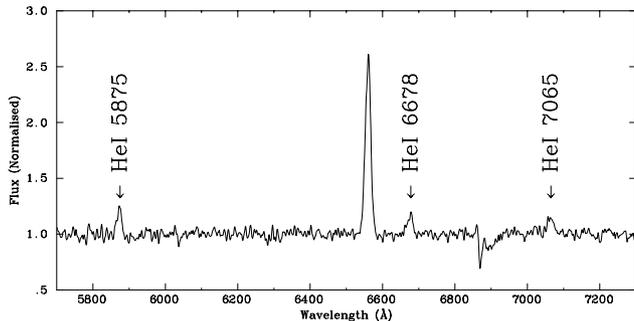


**Fig. 3.** Low-resolution spectrum of the optical counterpart to 1WGA J1958.2+3232, taken on July 26, 1999, with the 1.3-m telescope at Skinakas.

compatible with the $V$ values obtained by Israel et al. (1999) – 15.7±0.2 and 15.4±0.2 respectively.

## 3. Discussion

The blue spectrum of the optical counterpart to 1WGA J1958.2+3232 is displayed in Fig. 1. The spectrum is typical of a cataclysmic variable with no obvious absorption stellar features and strong emission in all Balmer lines (down to H12). The absence of photospheric features rules out the possibility that 1WGA J1958.2+3232 is a Be/X-ray binary – see, for example, Steele et al. (1999), where it is shown that even for the Be stars with the strongest emission veiling, the photospheric 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 II $\lambda$4686Å and the Bowen complex are strongly in emission. Many other He I and He II transitions are also in emission. The Balmer lines are all double-peaked and asymmetric with a stronger blue peak (note that the profile of H$\epsilon$ is modified by the interstellar Ca II $\lambda$3968Å line). The asymmetry is still stronger in the He II 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 II lines are displaced by $\sim 250\,\mathrm{km\,s^{-1}}$.

Fig. 2 displays H$\alpha$ and He I $\lambda$6678Å at higher resolution. The double-peaked shape can be seen in greater detail in the H$\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 ($v \approx 375\,\mathrm{km\,s^{-1}}$) 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 continuum, 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 $\lambda$4430Å and $\lambda$6613Å as EW$< 400$ mÅ and $< 50$ mÅ, 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 direction ($l = 69\deg, b = 1.7$) by Neckel & Klare (1980), who find $A_V < 0.5$ mag and $A_V < 1.0$ mag at 1 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 Israel et al. (1999), which is about $40''$ away from the optical counterpart to 1WGA J1958.2+3232, and therefore could provide 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 spectral type is F8V (see Fig. 4). We cannot see the $\lambda$4430Å DIB down to the level of the many weak features in the spectrum, which gives an upper limit of EW $\approx 300$ mÅ. From the measured $(b - y) = 0.59 \pm 0.07$ and the intrinsic $(b - y)_0 = 0.350$ for an F8V star (Popper 1980) we obtain the interstellar reddening $E(b - y) = 0.24$. Using the relation of Crawford & Mandwewala (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 $\lambda$4430Å 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 $d \approx 0.9$ kpc.

Given its brightness, 1WGA J1958.2+3232 should be located at a distance $1 \lesssim d \lesssim 1.5$ 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 $L_\mathrm{x}/L_\mathrm{opt}$ of the source when compared to less distant interme-

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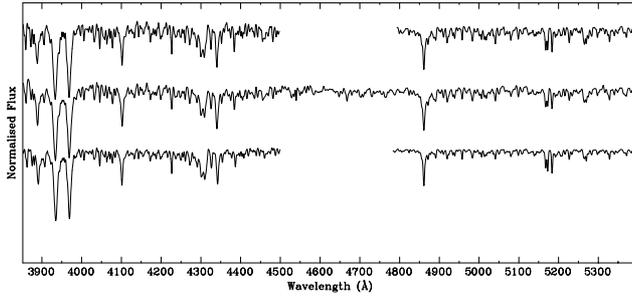


**Fig. 4.** Spectrum of the star called Candidate A in Israel et al. (1999), which is only $\sim 40''$ from 1WGA J1958.2+3232. The comparison spectra correspond to HD 5015 (top, F8V) and HD 22879 (bottom, F9V) and are taken from the database of Leitherer et al. (1996).

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 $E(B-V) \lesssim 0.3$.

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