Astron. Astrophys. 335, L17–L20 (1998)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

Infrared photometry and spectroscopy of the supersoft X-ray source RX J0019.8+2156 (= QR And)

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Received 27 January 1998 / Accepted 7 April 1998

Abstract. We present JHK photometry and spectroscopy of RX J0019.8+2156. The spectrum appears to be dominated by the accretion disc to at least 2.4 μm, over any other source of emission. We find Paschen, Brackett and He II lines strongly in emission, but no He I. There are satellite lines approximately 850km s^{-1} either side of the strongest, unblended hydrogen lines. These satellite lines may be the spectral signature of jets from the accretion disc.

Key words: accretion, accretion disks – ISM: jets and outflows – stars: emission-line – X-rays: stars – infrared: stars – stars: individual: RX J0019.8+2156

1. Introduction

The 'supersoft' X-ray sources form a new and exciting but inhomogeneous class of X-ray objects. Though a few members of the class were known before ROSAT, it is this observatory which has characterised the class as objects with temperatures of 15–80 eV and luminosities approaching the Eddington limit for a solar mass object, i.e. 10^{36}–10^{38} erg s^{-1}. The model which best fits the observations has a white dwarf steadily or cyclically burning hydrogen-rich material accreted onto its surface at $\sim 10^{-7}$ M$_\odot$ yr^{-1} (van den Heuvel et al. 1992).

van den Heuvel et al. (1992) theorise that this material may be supplied by a near main-sequence A/F companion star, more massive than the white dwarf and in a close binary orbit, which is overflowing its Roche lobe. Such systems are known as close binary supersoft sources (CBSS), for further discussion of the nature of the class see Kahabka & van den Heuvel (1997).

35 supersoft X-ray sources have so far been identified within our galaxy, M31, the Local Group galaxy NGC 55, the LMC & SMC (listed in Kahabka & van den Heuvel 1997). Of these systems RX J0019.8+2156 (hereafter RX J0019) is the only northern hemisphere CBSS identified, so far, in our galaxy. RX J0019 is a close binary with a $15\overset{h}{.}85$ period and both short-term and long-term optical variability, with orbital variability of $\Delta V \sim 0.5$ (Beuermann et al. 1995, hereafter B95; Greiner & Wenzel 1995). UBVRI photometry at photometric maximum and minimum reveal a very blue continuum, in common with other CBSS. The optical and UV spectra show Balmer α and He II lines, especially $\lambda\lambda$1640,4686Å, in emission with enhanced blue wings, but no He I lines (B95). Balmer β and γ lines exhibited P-Cygni type profiles.

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Table 1. Spectroscopic and photometric JHK magnitudes and spectral indices. JHK fluxes were obtained from spectra by fitting the continua with low order polynomials and letting the flux be the value of the fit at 1.25, 1.6 and 2.2 μm. The photometric phases were calculated using the ephemeris of Will & Barwig (1996). The spectral index, α, was calculated for spectra dereddened by E(B–V)=0.1.

Band	Photometry			Spectroscopy		
	ϕ_{phot}	mag	mJy	ϕ_{phot}	mJy	α
J	0.35	12.00	24.09	0.89	14.7	0.82
H	0.35	11.97	15.97	0.91	9.6	–
K	0.36	11.83	11.49	0.97	7.6	0.85

2. Observations

We have used the United Kingdom Infrared Telescope (UKIRT) to make photometric and spectroscopic infrared observations of RX J0019, in service mode.

2.1. Photometry

The photometric observations were carried out 1994 December 14, with the IRCAM3 array operating in $0\overset{''}{.}286$ per pixel mode. Integration times ranged from 5–20 s. SA 114–750 was used as the photometric standard assuming K=12.02, J–K=–0.09 and H–K=–0.04. The results are given in Table 1 and plotted, after dereddening by E(B-V)=0.1 (B95), in Fig. 1. Errors are typically

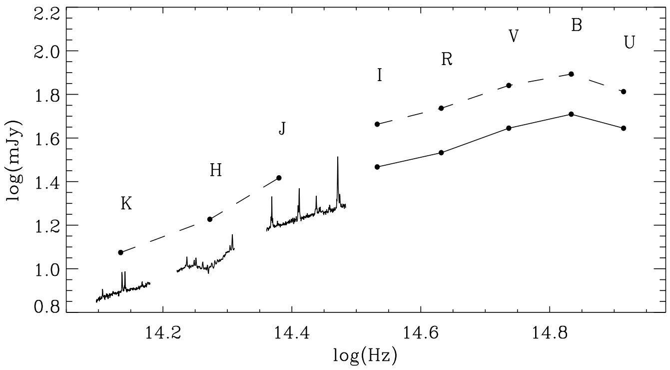

Fig. 1. Dereddened optical–infrared energy distribution of RX J0019. Solid and dashed lines correspond to photometric minimum and maximum, respectively. UBVRI data are from B95.

5%. These photometric observations were originally presented in Fender & Bell Burnell (1996).

2.2. Spectroscopy

JHK spectra of RX J0019 were taken by CGS4 using the 75 lines/mm grating, on 1997 August 13. To produce each stellar spectrum a series of short exposures were taken, alternated with equal length exposures of a piece of nearby blank sky. Krypton, Xenon and Argon lamp spectra were taken in order to perform wavelength calibration. Observations of a nearby bright star, HR133 (K=6.65, J–K=0.02, H–K=0.01), were taken in order to remove atmospheric spectral features and to flux calibrate the observations.

UKIRT staff flat fielded the target and standard star observations, subtracted the sky exposures from the corresponding stellar observations, and then averaged these sky subtracted images to produce a *reduced group* of observations. From the reduced groups we optimally extracted (Horne 1986) the stellar spectra and differences in exposure times were corrected for.

The arc spectra were then extracted, the lines identified and dispersion relations found by fitting low order polynomials. The dispersion calibrations were subsequently applied to the target and standard star spectra. The J-band spectrum was taken using the second order of the spectrograph and had 13.2Å resolution. The H and K-band spectra were taken with the first order of the spectrograph and had 26.4Å resolution.

The removal of atmospheric features from the target star spectra and flux calibration were achieved by dividing by an A star spectrum, whose hydrogen absorption lines had been interpolated across, and multiplying by a blackbody (BB) spectrum. The BB spectrum was calculated using the effective temperature of the A star ($T_{\rm eff}$ was assumed to be 8810K for an A2IV star) and its JHK magnitudes. However, it proved impossible to interpolate across the hydrogen lines between ~ 1.8 and $2.1\ \mu$m, where there are a series of strong atmospheric bands. Hydrogen lines in this region of the target star were hence discarded as unreliable. Generally, the fluxes of the CGS4 spectra should be correct to better than 20%.

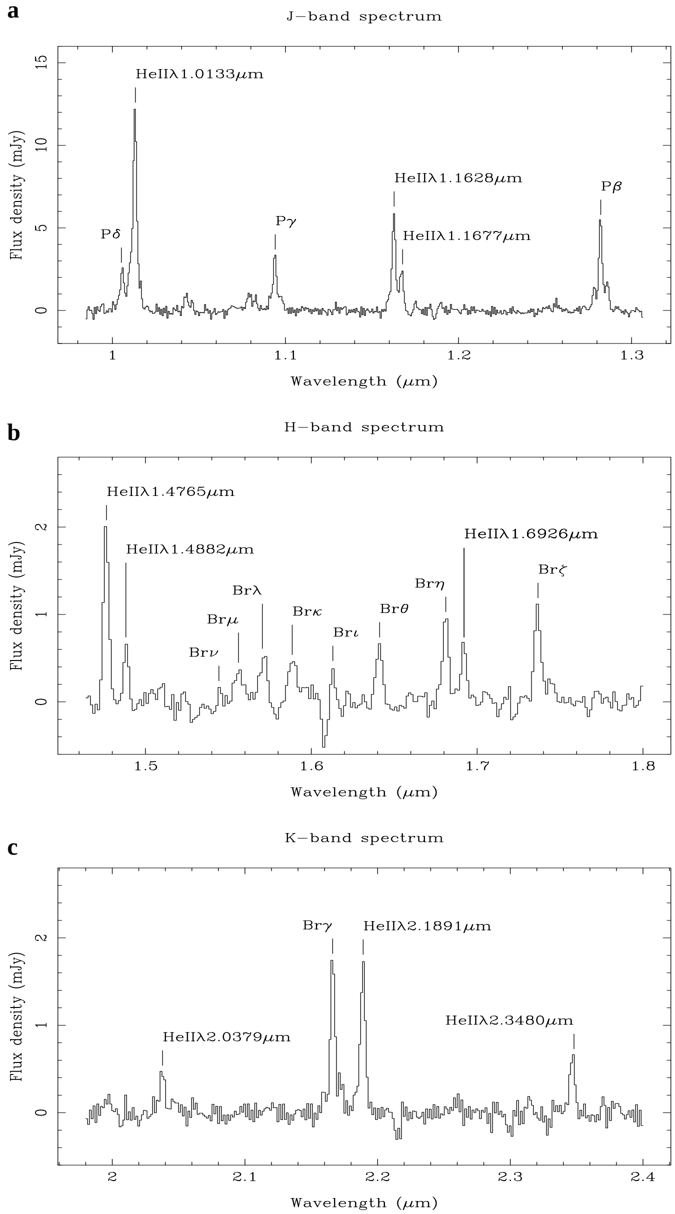

Fig. 2a–c JHK continuum subtracted RX J0019 CGS4 spectra, showing hydrogen Paschen and Brackett, and He II lines in emission. No He I emission is observed.

In addition to the infrared observations, the possible detection of a jet (see below) motivated us to look for a radio counterpart. However, approximately 2 hr of observations with the Ryle Telescope at 15 GHz failed to detect a counterpart to a 3 σ limit of 1.5 mJy (G.G. Pooley, private communication).

3. Results

The infrared source was positively identified with the optical counterpart indicated in Greiner & Wenzel (1995). After dereddening by E(B–V) = 0.1 mag (B95) and using the extinction coefficients of Cardelli et al. (1989) our photometric and spectroscopic data are plotted in Fig. 1. The continua of the dereddened J and K spectra are reasonably flat, hence we can measure

Table 2. Fluxes and equivalent widths of unblended He II emission lines, not contaminated by atmospheric features. Compare with EW(He IIλ4686Å) $\sim$ 10 Å (B95). The FWHM were calculated by fitting single Gaussians.

λ_{rest} (μm)	Flux (10^{-15}erg s^{-1})	Flux density (mJy)	EW (Å)	FWHM (km s^{-1})
1.4765	11.1±2.2	0.72±0.15	7.0±1.4	775±156
1.4882	2.9±1.9	0.19±0.13	1.9±1.2	648±361
1.6926	3.4±0.9	0.25±0.06	3.2±0.8	715±194
2.0379	2.0±0.8	0.18±0.07	3.5±1.4	659±304
2.1891	5.5±0.7	0.52±0.07	11.4±1.5	637±80
2.3480	1.8±0.7	0.20±0.07	4.5±1.7	571±194

the spectral indices for them, we find they are 0.82 and 0.85 respectively (see Table 1). The photometry was taken around maximum light, whereas the spectroscopy was taken around minimum light. From Fig. 1 it appears that the difference in flux between maximum and minimum light in the infrared is comparable to that seen in the optical. Both the photometry and spectroscopy hint at a dip in flux around the H band and/or an excess of flux around J or K.

The CGS4 spectra reveal the Paschen, Brackett and He II lines to be strongly in emission (Fig. 2). No He I emission or absorption is observed. The equivalent width of He II λ2.1891μm, found to be 11.4Å, is comparable with the value of $\sim$ 10Å found for He II λ4686Å by B95. The features of the infrared spectrum are therefore consistent with those of the optical and UV. The fluxes, flux densities, equivalent widths and FWHM were measured for each unblended He II line and are recorded in Table 2. No photospheric absorption features, such as CO bands, are observed in the spectra.

Close inspection of the three strongest, unblended HI lines observed in the infrared spectra (Brackett γ, Paschen β and γ) reveal a strong emission line close to the rest wavelength of the lines, and weaker emission features to either side (see Fig. 3). No other HI or He II lines correspond to the wavelengths of the weaker emission lines. Although some of the wavelengths correspond roughly with He I lines, there is no evidence for He I emission elsewhere in either the infrared or optical spectrum of RX J0019. In general, the red feature is noticeably stronger than the blue. This structure does not seem to be present, at least to the same degree, in the He II lines.

4. Discussion

No photospheric absorption lines are seen in the infrared spectrum taken at minimum light, indicating that either the underlying spectral type of the donor is not later than F, we are seeing the system at low inclination and irradiation is supressing absorption, or the accretion disc is dominating the emission. Through the optical and IR to at least 2.4 μm the orbital modulation of flux appears to be nearly constant, implying that they are dominated by the same component. The continuum is flatter than that expected for a stellar photosphere, suggesting the accretion disc is dominant.

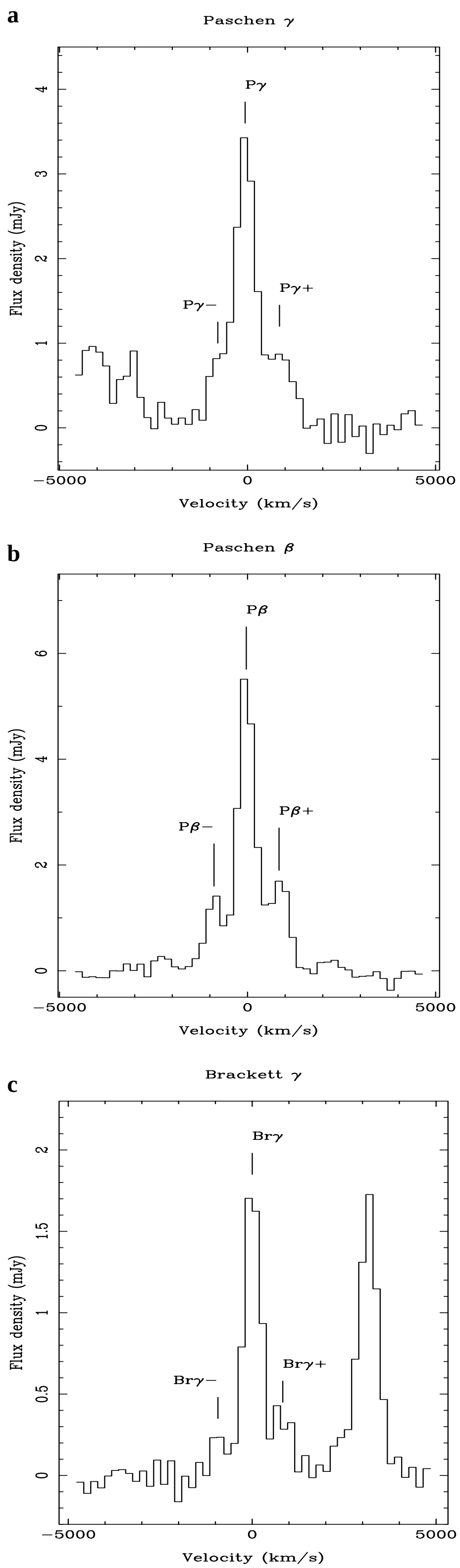

Fig. 3a–c HI lines in emission, continuum subtracted. Note the red- and blue-shifted components, labelled with + and – signs respectively, which are signatures of high velocity components, possibly jets.

Given the variability of the source over a variety of timescales (Greiner & Wenzel 1995), simultaneous multiwave-

Table 3. Parameters of fits to HI lines using 3 Gaussians per line, where velocities are relative to the laboratory wavelengths.

Spectral feature	V_{peak} (km s^{-1})	FWHM (km s^{-1})	Peak flux (mJy)
Pγ–	–790 ± 197	542 ± 441	0.8 ± 0.4
Pγ	–64 ± 52	577 ± 159	3.4 ± 0.5
Pγ+	+850 ± 260	1026 ± 614	1.0 ± 0.3
Pβ–	–891 ± 45	488 ± 114	1.4 ± 0.3
Pβ	–33 ± 14	525 ± 37	5.5 ± 0.3
Pβ+	+838 ± 44	606 ± 114	1.7 ± 0.2
Brγ–	–931 ± 163	386 ± 430	0.3 ± 0.2
Brγ	+2 ± 33	531 ± 85	1.8 ± 0.2
Brγ+	+832 ± 167	556 ± 438	0.4 ± 0.2

length observations of RX J0019 would be necessary to properly determine the relative contribution of light sources, and consequently place constraints on the spectral class of the donor, inclination of and distance to the system.

One explanation of the satellite lines to Pγ, Pβ and Brγ is that they are the infrared signature of jets, similar to the Doppler shifted components of the Balmer α, β and He II λ4686Å lines of another supersoft source, RX J0513.9-6951 (hereafter RX J0513, Crampton et al. 1996; Southwell et al. 1996), in which $v_{\rm jet}\cos i \sim 3800\,{\rm km\,s^{-1}}$. With this interpretation in mind we fitted each of these three composite lines profiles with three Gaussians. The details of these Gaussians are given in Table 3. The mean separation of the satellite lines from the core is $844\pm76\,{\rm km\,s^{-1}}$, and their mean FWHM is $600\pm220\,{\rm km\,s^{-1}}$. Assuming the jet interpretation is correct, and the jets are perpendicular to an accretion disc which lies in the plane of the binary, the true velocity of the outflow is simply a function of the inclination angle ($v_{\rm jet} = (844/\cos i)\,{\rm km\,s^{-1}}$.). Following Shahbaz et al. (1997) we can also estimate the opening angle of the jet, $\phi = \sin^{-1}(\Delta v/v_{\rm obs}\tan i)$, where Δv is the FWHM of the satellite lines and $v_{\rm obs}$ the observed velocity.

Meyer-Hofmeister et al. (1997) model orbital modulation of the system with a best-fit inclination of 56°, corresponding to a outflow velocity of $\sim 1500\,{\rm km\,s^{-1}}$ and an opening angle of 28°. Hachisu & Kato (1998) model outbursts of the source with an inclination of 45°, corresponding to a velocity of $\sim 1200\,{\rm km\,s^{-1}}$ and a very large opening angle of 45°. An inclination angle of around 75° would be required to derive the same velocity as the jet in RX J0513, and would imply a much more collimated jet ($\phi \sim 10°$). Alternatively the lower jet velocity could be intrinsic and reflect the lower escape velocity required from a lower mass white dwarf. Indeed Hachisu & Kato (1998) argue for a mass of around 0.6 $M_\odot$ for the white dwarf in RX J0019, around half that estimated for RX J0513 (Southwell et al. 1996).

Note added in manuscript – Just before submission we became aware of a related work by Becker et al. (1998). They have found transient satellite lines around hydrogen and He II lines in optical spectra of RX J0019. They also interpret the satellite lines to be the signature of jets and find $v_{jet}\cos i \sim 800\,{\rm km\,s^{-1}}$, consistent with this work.

Acknowledgements. We thank the staff responsible for the UKIRT service program for their assistance in obtaining these observations. The UKIRT is operated by the Observatories on behalf of PPARC. The data were reduced using FIGARO software and computers provided by STARLINK. Thanks to T. R. Marsh for the use of his MOLLY software for spectral analysis. HQ acknowledges receipt of a PPARC studentship. RPF was supported during the period of this research initially by ASTRON grant 781-76-017 and subsequently by EC Marie Curie Fellowship ERBFMBICT 972436. We thank Guy Pooley for making the radio observations for us, and acknowledge useful discussions with Andre van Teeseling, Peter Kahabka, Rob Hynes and Martin Still.

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