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The K-band spectrum of the cataclysmic variable RXJ 0502.8+1624 (Tau 4)

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Abstract. We present the K-band spectrum of the cataclysmic variable RXJ 0502.8+1624 (Tau 4). The spectrum shows a broad, smooth hump, with no absorption lines from the secondary star visible. This result indicates that the infrared light of this system is dominated by cyclotron emission, and, in combination with the optical spectrum and X-ray properties, suggests that Tau 4 is a polar-type cataclysmic variable (CV).
The system was chosen for study because the broadband JHK colours of Tau 4 are consistent with an L-type dwarf, suggesting that this system might harbour an elusive sub-stellar secondary star. The result presented here, along with the recent discovery of cyclotron emission in the cataclysmic variable EF Eri, suggests that care must be taken when using the broadband JHK colours of CVs when targeting searches for sub-stellar secondary stars.

Key words. binaries: spectroscopic – stars: individual: Tau 4 – novae, cataclysmic variables – infrared: stars – stars: low-mass, brown dwarfs

1. Introduction

Cataclysmic variables (CVs) are semi-detached binary stars consisting of a white dwarf primary and a Roche-lobe filling secondary star. Evolutionary models predict that as the secondary transfers mass to the white dwarf, the period of the binary star decreases. Eventually, the mass of the secondary drops below the hydrogen-burning limit and the secondary star becomes degenerate. This change in the structure of the secondary star means that further mass loss is accompanied by an increase in the orbital period (see Kolb 1993, for example). This is often used to explain the orbital period minimum which is observed in CVs at around 80 min. Evolutionary models (e.g Howell et al. 1997) suggest that around 70 per cent of CVs should have passed the orbital period minimum and should therefore contain sub-stellar secondary stars.

The observational evidence for these sub-stellar secondaries was critically examined by ourselves in an earlier paper (Littlefair et al. 2003). We concluded that despite their predicted abundance amongst the CV population there is as yet no direct evidence that any CVs possess a sub-stellar secondary star[1]. In that paper, we remarked that there were a number of CVs whose JHK colours were highly suggestive of a sub-stellar secondary, and suggested that these CVs be followed up with infrared spectroscopy. One such system is Tau 4.

RXJ 0502.8+1624 (Tau 4) was first identified as a CV by Motch et al. (1996), who observed selected sources from the ROSAT all sky survey (RASS). Their optical spectrum showed narrow Balmer and Helium emission lines, including the HeII λ4686 line. The emission lines showed a broad component underlying a strong, narrow peak. The X-ray hardness ratios and the ratio of HeII to Hβ equivalent widths (Motch et al. 1996), is typical of the polar class of magnetic CV, as is the characteristic emission line structure (Warner 1995). These properties, taken together, are good indicators that Tau 4 is a polar. The infrared counterpart of Tau 4 was securely identified by Hoard et al. (2002). They found infrared colours of $J - H = 0.95$ and $H - K = 0.88$, and a K-band magnitude of $K = 14.66$, consistent with those of an L3 dwarf star (see Fig. 2), suggesting that a sub-stellar secondary may dominate the infrared light of this system. Here we present the K-band spectrum of Tau 4. The observations and data reduction techniques applied are outlined in Sect. 2. The spectrum is presented in Sect. 3 and the results are discussed in Sect 4. Our conclusions are presented in Sect. 5.

2. Observations and data reduction

On the night of 2002 November 25 we obtained 2.0560−2.4730 μm (~270 km s^{-1} resolution) spectra of

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[1] Indirect evidence exists from modelling of the SED, use of a superhump period-mass ratio relationship and radial velocity studies of the emission lines.

the CV Tau 4 with NIRSPEC (McLean et al. 1998) on the 10-m Keck-II telescope on Mauna Kea, Hawaii. A total exposure time of 900 s was obtained between airmasses of 1.02−1.04 in photometric conditions. The seeing was approximately 0.7 arcsec and the slit width was set to 0.76 arcsec. Observations of the A2V star HD 2127 were also taken to correct for the effects of telluric absorption and to provide flux calibration. Both stars were observed with a slit position angle of zero degrees. Using the equations of Filippenko (1982) to estimate the effects of differential refraction we estimate the slit losses at 2.4 μm relative to 2.2 μm to be less than 1%. We therefore conclude that wavelength-dependent slit losses are not significant for our data.

NIRSPEC introduces curvature and distortion in both the spatial and dispersion directions. Prior to extraction of spectra, these effects were removed using the WMKONSPEC package in IRAF. Following the removal of the distortion, the nodded frames were subtracted, the residual sky removed by subtracting a polynomial fit, and the spectra extracted. There were two stages to the calibration of the extracted spectra. The first was the calibration of the wavelength scale using argon arc-lamp exposures; the fifth-order polynomial fits to the arc lines yielded an error of less than 0.13 Å (rms). The second step was the removal of telluric features and flux calibration. This was performed by dividing the spectra to be calibrated by the spectrum of the A2V standard, with its prominent stellar features interpolated across. We then multiplied the result by the known flux of the standard at each wavelength, determined using a black body function set to the same effective temperature and flux as the standard. As well as providing flux calibrated spectra, this procedure also removed telluric absorption features from the object spectra. A final, average spectrum was produced by co-adding the spectra in the rest frame of the binary centre-of-mass. The resultant spectrum resulted in a signal to noise ratio which varies smoothly from 35 around 2.1 μm to 20 at 2.35 μm.

3. Results

Figure 1 shows the Keck spectrum of Tau 4 in the *K*-band. The spectrum is dominated by a smooth hump-shaped continuum. There is no evidence for the emission line of Brackett-γ. The spectrum shows possible evidence for ^{12}CO absorption lines from the secondary star. The reality of these features is highly uncertain: the spectrum is quite noisy and the ^{12}CO lines occupy a region of the spectrum which can be badly affected by telluric absorption. In addition, the continuum shape of the spectrum is not consistent with the continuum shape of late-M or L-type dwarfs (see McLean et al. 2003, for example). The continuum shape is, however, consistent with cyclotron emission (see Ferrario et al. 1993). Circularly polarised cyclotron emission is routinely used to measure the field strengths in polars, where the magnetic field is typically 10−80 MG. By contrast, only three intermediate polars (which show lower field strengths) have to date shown significant polarisation, and no intermediate polar has had its field strength measured from cyclotron harmonics (Buckley 2000). Detection of cyclotron emission in Tau 4 is therefore strong confirmation of the polar nature of this object.

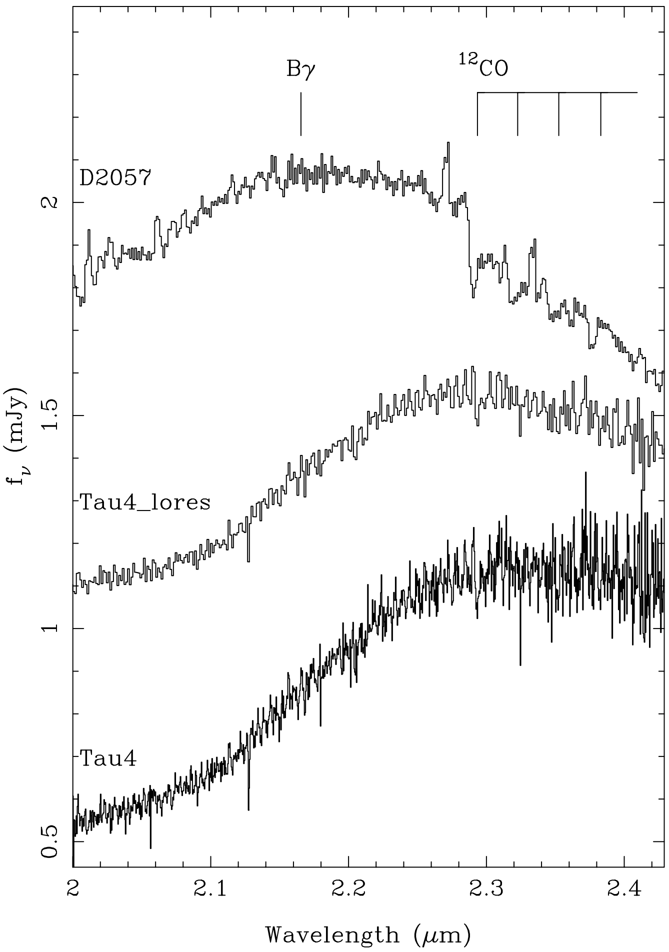

Fig. 1. *K*-band spectrum of Tau 4 (*bottom*). Also shown is the Kendall et al. (2004) spectrum of the L1.5 dwarf DENIS-P 205754.10-025229.9 (*top*), and our spectrum of Tau 4, binned to match the resolution of the brown-dwarf spectrum (*middle*). The spectra have been normalised, and an offset added for clarity.

4. Discussion

Figure 2 shows the colours of CVs from the 2nd incremental data release of the 2MASS survey (Hoard et al. 2002). One thing that is immediately apparent from this diagram is that there are a small number of CVs whose infrared colours are consistent with those of late-type dwarf stars. There are also several stars, such as EF Eri, whose infrared colours are very different from the population as a whole. Littlefair et al. (2003) suggested that these systems were good candidates for CVs with sub-stellar secondary stars. Tau 4 is one of these objects.

From the *K*-band spectrum in Fig. 1, however, it is apparent that the infrared light in Tau 4 is dominated by cyclotron emission. This result shows that the characteristic humps of cyclotron emission can mimic the near-IR colours of a late-type secondary star, and must inevitably cast doubt on the nature of the other CVs in this region of the colour-colour diagram. This result is further strengthened by the evidence presented in Harrison et al. (2004). The authors present time-resolved *H*

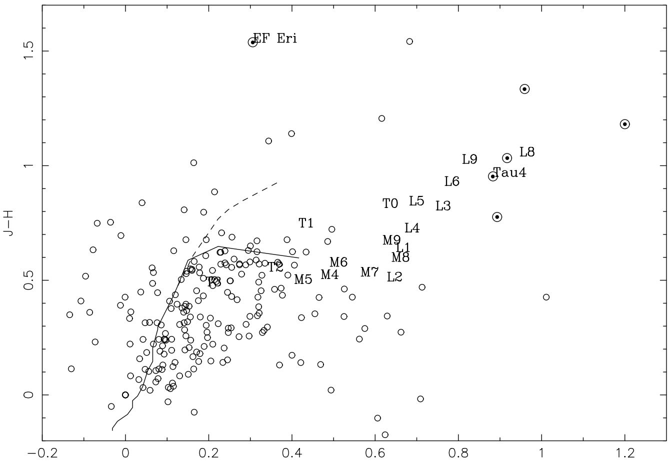

Fig. 2. Infrared colour−colour diagram for CVs and late-type dwarfs. The open dots show the CVs from the 2nd incremental data release of the 2MASS survey (Hoard et al. 2002). Those CVs whose colours suggest they might possess sub-stellar secondary stars are marked with large dots surrounded by circles. The positions of late-type dwarfs (from Leggett et al. 2002) in the colour-colour diagram are represented by a text string indicating their spectral type. The solid curve shows the position of the main sequence from spectral-types O9 to M5; the dashed curve shows the position of the giant sequence from spectral-types G8 to M5 (Cox 2000). The colours of the main sequence and late-type stars were put on the 2MASS photometric system using the transformations of Carpenter (2001).

and *K*-band spectroscopy of EF Eri, whose infrared colours are also highly unusual (see Fig. 2). These spectra show that the infrared light in EF Eri is also dominated by cyclotron emission. Although Harrison et al. (2004) may have detected faint traces of the secondary star around phase 0, the secondary star certainly does not make a *significant* contribution to the near-IR light in this system. The conclusion is that EF Eri's unusual near-IR colours are not due to the secondary star, but to cyclotron emission.

Tau 4 and EF Eri represent the only two systems with unusual IR colours in Fig. 2 for which infrared spectra have been obtained. Given that the infrared light in both these systems is dominated by cyclotron emission it is now clear that not all CVs which occupy the same region of the $J - H$ vs. $H - K$ colour−colour diagram as late-type stars possess late-type secondaries which dominate the near-IR light. This will inevitably reduce the efficiency of using near-IR colours as a selection method for CVs with late-type secondaries, but does not mean there are no CVs in which a late-type secondary dominates the near-IR light.

5. Conclusions

We present the *K*-band spectrum of the CV Tau 4. The spectrum shows a broad, smooth continuum hump, which is most likely to be cyclotron emission. The *K*-band spectrum, in combination with the emission lines seen in the optical spectrum, suggest that Tau 4 belongs to the polar class of magnetic CVs. Given the detection of cyclotron emission in Tau 4 and EF Eri, we conclude that near-IR colours alone are not sufficient to infer the presence of a late-type secondary star.

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