Observations of the Polar ST Leonis Minoris during an Extreme Low State: Identification of the Secondary Star

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Abstract. We present near-infrared (1.85–2.47 μm) spectroscopic observations of the polar ST Leonis Minoris (ST LMi) in an extreme low-state. The near-infrared spectra, showing no emission lines whatsoever, are produced solely by the secondary star. We have fit the average spectrum with a series of stellar atmosphere models and found the secondary star to have an average temperature of 2800 ± 100 K. However, the phase-resolved spectra show a strong variation in the near-infrared spectra as a function of orbital phase, corresponding to a variation in the surface temperature of the star, ranging from about 3100 K to 2700 K.

1 Introduction

As part of a program to study and understand the evolution of the secondary stars in cataclysmic variables (see Ciardi et al. 1998a and references therein), we spectroscopically observed the polar ST Leonis Minoris (ST LMi, Porb = 113.9 min, V = 15–17; Downes, Webbink, & Shara 1997). Polars experience variations in mass transfer rates which lead to luminosity changes of 3–5 mag in the optical, referred to as high and low states. In a high state, the near-infrared (NIR) and optical emission of the polar is dominated by the accretion material in the form of strong emission lines and cyclotron radiation (e.g. Warner 1995). In typical low states, the accretion material emission, although present, is reduced significantly in intensity, at which time the secondary generally is observable (e.g., Warner 1995). Polars, without the confusion of a large ~10 000 K accretion disk, provide a unique environment to study the stellar components (e.g. Ciardi et al. 1998b).

We present NIR spectra of ST LMi which indicate that the system was observed during a near-zero accretion state. We have used the observations to identify the secondary star and directly associate an average temperature with the star. In addition, the phase resolved spectra demonstrate that the surface temperature of the star ranges from 3100 K to 2700 K, so that a spectral type may not give a unique description of a CV secondary star.
2 Observations

K-band spectroscopy of ST LMi from the 3.8 m United Kingdom Infrared Telescope (UKIRT) was obtained in May 1997. The NIR spectroscopy was acquired with the UKIRT Cooled Grating Spectrometer 4 (CGS4) equipped with a 256 × 256 InSb array. The observations utilized a 75 line mm\(^{-1}\) grating, a 150 mm focal length, and a 1\arcsec 22 slit width. Details of the observations and data reduction can be found in Ciardi et al. (1998a).

3 Results

In Figure 1a the average NIR spectrum is shown, and it is clear that ST LMi displayed no visible signs of emission lines. The continuum shape of the May NIR spectrum is dominated completely by the H\(_2\)O opacity features from the secondary star (note the downturns in the flux on either side of 2.3 \(\mu\)m). In addition, the CO bandheads at 2.29, 2.32, 2.35, and 2.38 \(\mu\)m are clearly visible (Fig. 1a). These features are only \(\sim\)8% below the level of the continuum and are normally filled in by emission due to accretion processes and not visible in NIR spectra during a high state (e.g., Ferrario, Bailey, & Wickramasinghe 1993).

Assuming that the flux in the NIR spectrum is produced solely by the secondary star, we have fit the data with a series of main sequence red star models in order to determine the temperature. Details of the models and the fitting procedure are given in Ciardi et al. (1998a). Based upon the chi-squared test, we find that a temperature range of 2800 ± 100 K best fits the average spectrum.

The main sequence spectral type for a \(T_{\text{eff}} = 2800\) K star is \(\sim\)M5 V (Leggett et al. 1996) which agrees with that predicted for ST LMi from the empirical orbital-period—spectral-type relationship derived from the work of Patterson (1984) and Sproats, Howell, & Mason (1996). The 2.2 \(\mu\)m flux corresponds to a magnitude of \(K = 14\) which is 0.3 mag fainter than the \(K\) magnitude of ST LMi during the faint phase of a high state (Bailey 1985). At a distance of 128 pc (Cropper 1990), the secondary star has an absolute magnitude of \(M_K = 8.5\), in good agreement with absolute magnitudes expected for late-M type stars (Leggett et al. 1996).

However in Figure 1b, we present three of the individual NIR spectra obtained at different points during the orbital period. These spectra were chosen to highlight some of the changes seen in the spectra as a function of orbital phase. Note the dramatic change in both the continuum shape and the line strengths at various phases. It is clear from this figure that a single temperature model can not be used to represent the true structure of the secondary star. Interestingly, the goodness of the model fits also changes with orbital phase. For example, the 2900 K model fits the data (phase 0.7) in the continuum and the absorption features quite well, while the 2700 K model (phase 0.0) fails to reproduce the continuum but does reasonably well with the absorption features. The extremes of the apparent spectral type for this star go from M6.5 to M3, an apparent change in mass, radius, and temperature of 0.1–0.3 \(M_\odot\), 0.1–0.3 \(R_\odot\), and 2700–3100 K. Clearly, the secondary star does not really change mass and radius as a function of orbital phase, but this preliminary result calls into question the usefulness of assigning main sequence spectral types to the secondary
Figure 1. (a) The orbitally averaged NIR spectrum (thick line) is shown along with the best fit 2800 K model (thin line). (b) Three of the individual spectra (thick lines) are shown along with the best fit stellar atmosphere models (thin lines). Note the strong variations in the continuum shape and absorption features. The spectra at phases 0.2 and 0.7 have been vertically shifted by 2 mJy and 4 mJy, respectively.

stars in CVs. A detailed analysis of these spectra as a function of orbital phase in currently in preparation (Howell, Ciardi, & Dhillon, in preparation).

References

Cropper, M. 1990, Space Science Reviews, 54, 195

Questions: Murray asked whether the secondaries were significantly different from main sequence stars. Ciardi replied that the colors and temperatures were consistent with the expected spectral types.