ISO OBSERVATIONS OF XX OPH

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ABSTRACT

We present ISO SWS and PHOT-P observations of the binary XX Oph. The UIR features seen in ground-based data are confirmed. The near infrared is modelled by a 3400 K log g = 3.5 giant, which is likely to be underabundant in carbon. There is an infrared excess at long wavelengths, corresponding to emission by dust having temperature 336 K and β—index 0.4.

Key words: XX Oph; Model atmospheres; UIR emission

1. INTRODUCTION

XX Oph is a binary system consisting of an early type star (B0V) and a late giant (~MIII?) (de Winter & The 1990, Evans et al. 1993 and references therein). It is sometimes classed as a Be star (e.g. de Winter & The 1990) and sometimes as a symbiotic (Khlopov et al. 1985).

It was shown to be heavily reddened by Lockwood et al. (1975), who estimated the AV to be ~4. Polari- metric observations by Evans et al. (1993), however, showed that the polarization is consistent with only a modest degree of interstellar (IS) reddening, corresponding to AV = 1.7: there is clearly a major circumstellar (CS) component of reddening. While this is not unusual, what makes the extinction of XX Oph peculiar is that the extinction is prominent only in the blue, i.e. the reddening law is far steeper than normal IS or even CS reddening laws.

The reason for its anomalous reddening became clear with the discovery of UIR emission (Evans 1994): PAH molecules absorb strongly in the in the blue and (apart from the well-known emission at specific wave- lengths – see e.g. Allamandola, Tielens & Barker 1989) give no infrared (IR) excess. We thus have strong CS extinction rising sharply in the blue with negligible IR emission.

We have observed XX Oph with ISO in an attempt to further understand its circumstellar environment and the cool component.

2. OBSERVATIONS AND DATA REDUCTION

XX Oph was observed with the SWS on 1997 February 18 using the AOT SWS-01; the target- dedicated time was 6750 sec. It was also observed with ISOPHOT, using AOT PHT-03; the target- dedicated time was 955 sec. The PHOT-P observa- tions were made in point photometry mode. The aperture was 180", and we chopped in triangular mode 180" to sky at regular intervals. Measurements were made of the internal Fine Calibration Sources to provide flux calibration.

The PHOT-P data were reduced and calibrated using PIA version V7.2.2(e) (Gabriel et al. 1997). The data were deglitched, and at 20 and 25 μm detector drifts were modelled and accounted for; at 60 and 100 μm there were too few points for accurate drift modelling, so none was applied. The background measurements were subtracted, and the signal losses due to chopped observations were accounted for. The power calibration was made using the FCS1 median for P2, and the FCS2 median for P3, to determine the flux in each detector at each wavelength. The values of the FCS measurements differed from the default values by less than 10%. The PHOT-P data were colour corrected assuming a blackbody flux distribution with tem- perature 3000 K, corresponding to the effective temperature of the cool component (Evans et al. 1993; Evans 1994). On the basis of ground-based and IRAS data any IR excess due to dust emission is weak and so an incorrect assumption of temperature for colour- correcting the data will not contribute significantly to the errors in the colour-corrected fluxes.

3. THE M GIANT

The spectral energy distribution (SED) in the near-IR is dominated by the cool star. We have calculated model atmospheres using version 10.3 of the general model atmosphere code PHOENIX. Details of the code and the general input physics are discussed in Hauschildt et al. (1998, HAB, and references therein; see also http://dilbert.physast.uga.edu/~yeti/). The models for XX Oph were calculated with the same
Our combined molecular line list includes about 500 million molecular lines; these are treated with a direct opacity sampling technique where each line has its individual Voigt (for strong lines) or Gauss (weak lines) line profile. The lines are selected for every model from the master line list at the beginning of each model iteration to account for changes in the model structure; see HAB for details. This procedure selects about 190 million molecular lines for a typical giant model with an effective temperature of about 3500 K. The models were calculated on the parallel supercomputer of the University of Georgia.

In order to find the best fitting model for the photosphere of XX Oph we have constructed solar abundance giant model atmospheres in the range $2000 \leq T_{\text{eff}} \leq 4000$ K, $0.0 \leq \log g \leq 6.0$ for a stellar mass of $5\,M_\odot$ (the models with $\log g > 3.5$ were taken from our model database). A comparison of the spectrum of XX Oph with the synthetic spectra resulted in a best-fitting model with the parameters $T_{\text{eff}} = 3400$ K, $\log g = 3.5$. This is significantly higher than the $T_{\text{eff}}$ deduced by Evans et al. (1993) because the TiO bands, on which Evans et al. based their $T_{\text{eff}}$, form at about 2500 K in the model described here. Keeping these model parameters fixed, we lowered the abundance of carbon relative to solar to reduce the strength of the CO bands in an attempt to improve the fits. The results are shown in Fig. 1. Note that these are preliminary results and that a fit to the combined optical+IR spectrum, possibly including the effect of irradiation by the hot star, will be required for a detailed analysis.

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**Figure 1.** The IR SED of XX Oph. The SWS data (filled squares) have been smoothed using a 30 Å Gaussian filter. Late giant model as described in text. Open squares: ISOPHOT data; filled circles: ground-based JHKL photometry from Evans et al. (1993).

**Figure 2.** UIR emission in XX Oph.
4. THE UIR FEATURES

The UIR features at 8.7, 11.2 and 12.6 μm are confirmed by the ISO data; in addition, the UIR features at 6.25 and 7.7 μm are also detected (see Fig. 2).

Beintema et al. (1996) and Molster et al. (1996) have given a preliminary discussion of the UIR emission bands as seen by the SWS. From the tabulation of Beintema et al. the peak flux of the 3.29 μm UIR feature is \( \sim 5 \times \) weaker than that of the '7.7', and the integrated flux is \( \sim 5 \times 10^{-1} \) weaker. On this basis we would expect the 3.29 μm feature in XX Oph to have peak and integrated fluxes of \( \sim 0.6 \) Jy and \( 8 \times 10^{-14} \) W m\(^{-2}\) respectively. At 3 μm the M7 star has a flux of \( \sim 32 \) Jy and so the apparent absence of the 3.29 μm feature can presumably be attributed to the fact that it is swamped by the flux from the M star.

5. CIRCUMSTELLAR DUST

The data in Fig. 1 clearly show that there is an excess longward of \( \sim 6 \) μm, which we attribute to emission by dust in the XX Oph system. Fitting a function of the form \( 1/\nu^2 B_\nu(\nu, T) \) to the IR excess gives \( T = 336 \pm 20 \) K and \( \beta = 0.4 \pm 0.1 \). The IR excess is clearly incompatible with blackbody emission but also seems inconsistent with amorphous grains, for which \( \beta \approx 1 \). The fit is included in Fig. 1.

![Figure 3. H\textsc{i} Br-α in XX Oph.](image)

In view of the presence of UIR emission and no clear evidence for silicate dust, we suppose that the dust is carbon, for which we take the emissivity from Evans et al. (1997). Assuming grain radius \( a = 0.1 \) μm, the dust mass is \( 2 \times 10^{-7} \) M\(_\odot\). The dust temperature also provides constraints on the location of the dust. In the radiation field of the B star alone, 336 K carbon dust would have to be at distance \( \sim 1.5 \times 10^{16} \) cm from the star; the corresponding figure for the M star is \( 1.7 \times 10^{16} \) cm.

6. EMISSION AND ABSORPTION LINES

XX Oph is a well-known emission line object (see de Winter & Thé 1990). In the SWS wavelength range we see a number of H recombination lines including Br-α λ4.05 (see Fig. 3) and Pf-α λ7.46. Wavelengths and line fluxes have been determined by fitting gaussians to the line profiles; the weighted mean velocity from the FWHM values is 127 km s\(^{-1}\).

While the Br-α line seems to show evidence of a P-Cygni profile (see Fig. 3), there are other absorption features in the 4 μm wavelength range that lead us to conclude that this is not in fact the case. We see \( ^{28}\)SiO (2.0) (bandhead at 4.003 μm), (3.1) (4.043 μm; see Rinsland & Wing 1982) and (4.2) at 4.084 μm. However Pf-α λ3.74 does seem to show evidence of a P-Cygni profile, indicating a terminal velocity of 737 km s\(^{-1}\); consistent with observations at optical wavelengths (see e.g. de Winter & Thé 1990). There is no clear evidence for a P-Cygni profile in any of the other lines, although the situation in the case of Pf-α and Hα-β is complicated by the fact that they are close to the strong '7.7' UIR feature.

If the H recombination lines are optically thin, the flux ratios Br-β/Pf-α = 8.36, while the ratio Hα-β/Pf-γ = 0.56, independently of electron density and temperature. The observed values are 8.90 and 0.67 respectively. Given the flux calibration uncertainty, the observed values are consistent with expectation.

The first overtone CO features are seen in absorption at 2.2 μm (see Fig. 4). However there is no clear evidence for the fundamental at 4.6 μm, to a limit of 10% below the apparent continuum. There is also a series of absorption features around 3 μm, which we attribute primarily to OH and H\(_2\)O (see Fig. 4).

7. CONCLUSIONS

The SWS and ISOPHOT observations of XX Oph confirm the presence of UIR features and further, reveal the presence of a dust continuum at 336 K. Comparison with model atmospheres shows that the M giant is somewhat hotter than previously believed – 3400 K as compared to 2500 K – and there is a suggestion that C is depleted in the giant relative to solar. A complete discussion however must await a determination of the effects of irradiation of the M giant by the B star.

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Figure 4. (a) CO in XX Oph; (b) OH and H$_2$O in XX Oph

REFERENCES

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