The spectroscopic orbit and other parameters of AE Arae

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Abstract. We present an analysis of optical and near infrared spectra of the symbiotic system AE Ara, composed of an M 5.5 III giant similar to the Galactic Bulge M giants and a hot luminous companion. In particular, we have determined for the first time spectroscopic orbits based of the radial velocity curves for the red and the hot component from the M-giant absorption lines and from the wings of He II $\lambda$4686 emission profiles, respectively. We have also studied spectral changes and photometric variations in function of both the orbital phase and activity. The resulting physical parameters of the binary components and the nature of the hot component activity are briefly discussed.

1. Introduction

The aim of this work was to determine periods and spectroscopic orbits of symbiotics, for which observational data already exists but have yet not been analyzed. High resolution spectra for AE Ara were collected with the 2.15 m telescope of CASLEO at San Juan, Argentina, during the period 1990–2001. We have also collected all published optical spectroscopic data (see Mikolajewska et al. 2002 for references) as well as visual photometry from the Variable Star Section Circulars of The Royal Astronomical Society of New Zealand (RASNZ; Fig. 1).

We have measured the radial velocities of the cool component from the M-type absorption lines. The individual radial velocities were obtained by gaussian fitting of the line profiles an a mean value was calculated for each spectrum. In addition, we have determined the radial velocities of the broad emission wings of H\textalpha, H\beta and HeII$\lambda$4686 which are formed in the inner region of the accretion disk or in an extended envelope near the hot component (see. Quiroga et al. 2002; Mikolajewska et al. 2002 for details of the method).

Optical emission line fluxes were also derived, either by integrating the line profile or by fitting Gaussian profiles, as well as the [TiO]$_1$ and [TiO]$_2$ indices.
Figure 1. Visual light curve of AE Ara in 1978–98. Dots: visual observations from RASNZ, open circles: $V$ mags calculated from our spectra, FES counts and literature. Bars mark times of photometric minima given by our ephemeris (see text).

as defined by Kenyon & Fernandez-Castro (1987).

2. Orbital period and spectroscopic orbits

We have analyzed the RASNZ visual photometry using the period-search method described by Schwarzenberg-Czerny (1997). We have found a significant frequency peak ($\sim 3\sigma$) at $\sim 0.00125$ day$^{-1}$ which represents light changes with amplitude of about 0.4 mag and period of about 800 days.

The radial velocities, emission line fluxes, and $[\text{TiO}]_1$ indices (Fig. 2), all show the same periodicity, which we attribute to the orbital period. In all cases, the most regular changes have been obtained with 812-day period, giving the ephemeris

$$\text{Min} = \text{JD} 2450217 (\pm 3) + 812 (\pm 2) \times E.$$ (1)

The broad emission line wings of HeII 4686 show the highest amplitude and a mean velocity similar to the red giant systemic velocity. They are clearly in antiphase with the M-giant curve which suggest that they are formed in a same region very near to the hot component (Fig. 2). Our best orbital solution for the M giant is consistent with a circular orbit and the time of the spectroscopic conjunction coincides with the photometric minimum. The orbital solutions in Table 1 and Fig. 2 are obtained assuming $e = 0$ and the spectroscopic conjunction given by Eq.(1).

Combining the semi-amplitudes of the M giant and the HeII emission wing component from Table 1 gives a mass ratio $q = M_g/M_h = 4.4 \pm 1.5$, the component masses of $M_g \sin^3 i \sim 1.7 \text{M}_\odot$ and $M_h \sin^3 i \sim 0.4 \text{M}_\odot$, and the binary separation $a \sin i \sim 2\text{AU}$. 
Table 1. Orbital solutions for AE Ara

| Component        | $\gamma$ [km s$^{-1}$] | $K$ [km s$^{-1}$] | $f(M)$ [$M_\odot$] | $A \sin i$ [AU] |
|------------------|-------------------------|-------------------|---------------------|-----------------|
| M abs            | $-15.7 \pm 0.3$         | $5.4 \pm 0.3$     | $0.0133 \pm 0.0021$ | $0.40 \pm 0.02$ |
| Wings (HeII 4686)| $6.6 \pm 4.6$           | $23.7 \pm 6.5$    | $1.12 \pm 0.57$     | $1.76 \pm 0.38$ |
| Wings (H$\beta$)| $-8.9 \pm 1.5$          | $8.3 \pm 2.0$     | $0.048 \pm 0.062$   | $0.62 \pm 0.12$ |

Figure 2. (left) Phase plot of quiescent visual magnitudes, H$\alpha$ emission line fluxes, and [TiO]$_1$ indices. (right) Phased radial velocity data and circular orbital solution from Table 1. The solid line repeats the orbit of the M giant and the dotted line – the HeII emission wing solution, respectively. Closed symbols refer to quiescent state, open circles refer to outburst phase.
3. The hot component and its activity

The visual light curve of AE Ara (Fig. 1) display a very deep minimum near MJD 46950 (φ ∼ 0 according to our ephemeris) and two bright maxima around MJD 46700 (φ ∼ 0.7) and MJD 47300-400 (φ ∼ 0.5 − 0.6). The fact that the minimum is practically as deep as usually strongly suggests that the hot component is responsible for this brightening.

The optical brightening is accompanied by an increase in emission line fluxes (Fig. 2) and broadening of the emission line wings. Near the bright visual maximum around MJD 46700, however, the HeII 4686 emission line flux was suppressed indicating a decrease of the hot component temperature, possibly because of increasing optical depth in the hot component wind.

The observed changes in the emission line profiles are typical of symbiotic stars at outbursts, especially symbiotic novae, and suggest enhancement of a wind from the hot component surface. Such wind seems to be permanently present in AE Ara as suggested by a presence of broad wings in HeII 4686 emission line, as well as a broad CIV 5802,5812 emission lines. The CIV lines are typical for early type Wolf-Rayet (W-R) WC stars and subluminous W-R stars found in some planetary nebula, and they are rarely observed in symbiotic systems. For example, they were detected during late outburst phase in the symbiotic nova AG Peg, and at some phase of the recent outburst of AS 338. In AE Ara, the CIV lines are almost as strong as HeII 4686, and their full width is of about 600 km s$^{-1}$, similar to the FW of the HeII line. Both the CIV and HeII probably arise from the hot component wind. The presence of such a wind is also suggested by the large contribution of the hot component to the optical continuum. In fact, the $UBV$ colours of the hot component (derived from the $UBV$ data corrected for contribution from the M 5.5 III star) are very similar to those of the hottest W-R/WC stars, which strongly suggests presence of an extended expanding atmosphere. We estimate the mass loss rate $\dot{M}_h \sim a few \times 10^{-8} - 10^{-7}M_\odot\,yr^{-1}$ from the intensities of HeII 1640 and HeII 4686 emission lines.

The presence of an extended photosphere and moderate velocity wind, makes it difficult to estimate properly the effective temperature and luminosity from the available data. Although, a star with $T_h \sim 70\,000 - 80\,000$ K and $L_h \sim 1000 - 2000L_\odot$, accounts for our observations, both better spectroscopic observations especially in the ultraviolet as well as detailed models will be necessary to get accurate and reliable physical parameters of the hot component.

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