Notices to investigation of symbiotic binaries

I. Effective temperatures of cool components

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Abstract. A comparison of synthetic spectra for cool giants with the observed broad-band optical/IR photometry is suggested to estimate the effective temperature, $T_{\rm eff}$, of cool components in symbiotic binaries. The uncertainties of such estimates are within a range of 100 – 300 K. Here we demonstrated this approach on EG And and AX Per, and found $T_{\rm eff}$(EG And) = 3 500 +200/−100 K and $T_{\rm eff}$(AX Per) = 3 400±150 K. These results agree well with those obtained from empirically determined dependencies of effective temperature upon spectral type.

Key words: stars – binaries – symbiotics – individual: EG And, AX Per – fundamental parameters

1. Introduction

Symbiotic stars are long-period ($P_{\rm orb} \approx 2-3$ years, or more) interacting binaries, in which a red giant or supergiant transfers matter to a hot, more compact object (e.g. a white dwarf or main sequence star). In major cases the mass transfer mechanism happens via accretion from a stellar wind or, in very few cases, via Roche-lobe overflow. Symbiotic stars are subject to outbursts which can last from weeks to decades. The outburst commences with a 2-3 magnitude rise in the optical continuum. P-Cygni profiles seen in early stages of the outburst indicate mass ejection at 100-500 $\rm km\,s^{-1}$. Symbiotic stars are important to our understanding of fundamental aspects of astrophysics including accretion onto compact objects, (thermonuclear) outbursts, (bipolar) mass outflows, the study of late type giants – particularly mass loss and their fundamental parameters, the late stages of binary star evolution, etc.

The extremely different temperatures of the sources of stellar radiation, the presence of nebular radiation and the (variable) mass outflow from both the stars result in very complex observed characteristics. To understand their nature we need long-term multifrequency observations to recognize how spectrophotometric parameters vary with both the orbital phase and the wavelength. In addition, as the first step in studying processes of interaction in symbiotic systems, we

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have to know fundamental parameters of the components (masses, radii, luminosities) as well as the distance and orbital elements of the binary.

The aim of this series of papers is to introduce some methods which could be easily applied in investigation of, for example, symbiotic binaries. They are required to be of a simple use, but rigorous, to help in the interpretation of the observed data. In the current contribution a method of direct determination of the effective temperature of the cool components in symbiotic binaries is described. In Section 2 we explain basic principle of the method and demonstrate it for EG And and AX Per. Our results are compared with those obtained by current method. In Section 3 we show a possibility to determine distances to eclipsing systems.

2. Principle of the method

To estimate the effective temperature of the cool component in a symbiotic binary, it is suggested that its observed spectral energy distribution, given by the optical/IR broad-band photometry, is compared to the synthetic spectra of the cool giants. At present, broad-band photometry is available for many systems (e.g. Munari et al., 1992; Ivison et al., 1995; Kamath and Ashok, 1999), and there is also a grid of synthetic spectra for cool giants elaborated by Hauschildt et al. (1999). So, the principle of the method is selection of a synthetic spectrum, which matches best the observed fluxes. Our determination relies mainly on (well known) strong sensitivity of the optical/near-IR part of the spectrum to the effective temperature. Already O'Connell (1973) and White and Wing (1978) noted that the absorption features of TiO molecular bands at $\lambda6180$ and $\lambda7100$ represent good temperature indicators. Generally, they become more pronounced at lower temperatures.

In addition to $T_{\rm eff}$, the most important parameters defining the profile of synthetic spectra are the gravitational acceleration at the giant's surface, g, and the metalicity of its atmosphere (see Fig. 9 and 10 of Hauschildt et al. (1999)). For typical quantities of the cool giants in symbiotic binaries, masses $M_{\rm g} \approx 1\,{\rm M}_{\odot}$ and radii $R_{\rm g} \approx 100\,{\rm R}_{\odot}$, $\log(g) \leq 0.5$ (g in $cm\,s^{-2}$). Comparing the profile of synthetic spectra for different metalicity, [M/H], with those observed for symbiotic stars (cf. Kenyon and Fernandez-Castro, 1987; Schulte-Ladbeck, 1988) we can assume well [M/H]$\sim$0. In addition, a study of Nussbaumer et al. (1988) revealed that symbiotic objects fit best the CNO abundance ratios of normal red giants. On a sample of 24 symbiotic stars they found that C/O $\sim$ (0.1 – 0.6). In the Hauschild's et al. (1999) models this corresponds to a parameter C = 8.3068 and 8.5135 (i.e. C/O abundance by number to be 0.2734 and 0.4401) in their 'Giants.old'-set of spectra. Below, in Sect. 2.1, we used this set of models. However, performing many trials for different quantity of C, we found that it is of minor importance in comparing the spectra to broad-band photometry.

Originally Tsuji (1978) found that the effective temperatures of M-giant stars do not depend critically on assumed composition of model atmospheres.

According to photometric measurements, the cool components in many symbiotic stars show an intrinsic variability (e.g. Kamath and Ashock, 1999), plus observations in the V, R bands can be contamined from strong emission lines (e.g. [O III] 5007, He I 5875, [Fe VII] 6087, He I 7065), which are also present in spectra of many symbiotics. As a result, applying this method to symbiotic stars, we suggest to use mean values of available data.

In practice, first, we suggest to comparing the logarithm of the observed and calculated flux with a range of $T_{\rm eff}$ to scale the modeled spectra to observations in the $H, K, L, (M)$ bands. Emphasis is given to the L band, where the model continuum is flat and free of deep absorptions, and thus it should match the measured flux best. Second, we select that going throughout the broad-band photometric fluxes in the V, R, I bands. To estimate an upper and lower limit of possible $T_{\rm eff}$, it is sufficient to compare two other spectra corresponding to a higher and lower temperature, respectively, and which are unambiguously distinguished by eye to be off the measured values. According to our experience, the uncertainty of such an approach is about $\pm(100 - 300)$ K in the temperature range 3 000 to 3 900 K. Due to a strong sensitivity of the TiO molecular bands to temperature, estimates for lower temperatures are more accurate than for higher ones (e.g. Tsuji, 1978). However, each case has to be judged individually.

Finally, as the measured fluxes represent emitted energy in broad spectral regions (a few × 100 - 1000Å) we do not need to know the precise shape of sharp absorption features of which the cool spectrum is very rich. Therefore, to compare the photometric fluxes to the models, we can use smoothed calculated spectra, for example, with a filter of 50 Å width and a resolution of 25 Å.

To illustrate this approach, we applied it here to the systems of EG And and AX Per. The example of AR Pav is presented in Skopal et al. (2000).

2.1. Examples of EG And and AX Per

EG Andromedae: Optical and infrared measurements of EG And were summarized by Skopal (1997, reference therein). The magnitudes were converted to absolute fluxes with the calibration of Henden and Kaitchuck (1982), and corrected for $E_{\rm B-V} = 0.05$ (Mürset et al., 1991). According to Wilson and Vaccaro (1997) the giant in EG And fills up 90 to 100 % of its Roche lobe, so we used a grid of synthetic spectra calculated for $\log(g) = 0$. The result of our determination of the effective temperature is illustrated in Fig. 1. In this way we estimated $T_{\rm eff}$ of the cool component in EG And as

$$T_{\rm eff}(\text{EG And}) = 3\,500\ +200/-100\,\text{K},$$

where the uncertainties were judged by eye. Because of the sensitivity of the near-infrared part of the spectra to $T_{\rm eff}$, the resulting temperature does not lie at the center of its possible range. In addition to $T_{\rm eff}$, we determined also the

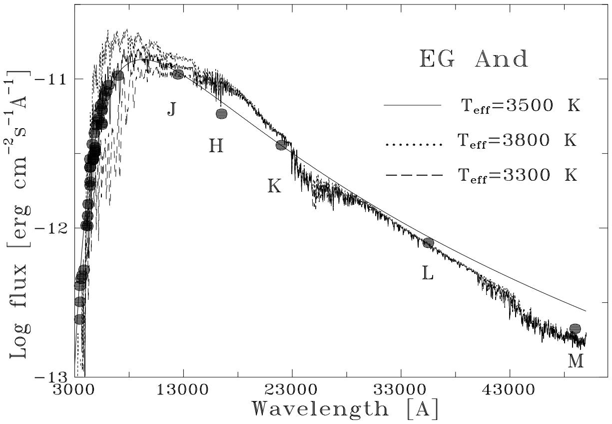

Figure 1. Optical/infrared energy distribution of EG And (●). Comparison with synthetic spectra for $\log(g) = 0$ suggests $T_{\rm eff}$ ~3 500 K with extreme values of 3 300 and 3 800 K. The full smooth line represents the best fit of the observed fluxes by a Planckian function for $T_{\rm c} = 3\,130$ K.

colour temperature by fitting the measured fluxes using blackbody radiation as $T_{\rm c}$(EG And) = 3 130 ± 40 K. It is of interest to compare our results to those given by empirical relations between spectral type ST, colour index $V-K$, $T_{\rm eff}$ and $T_{\rm c}$ for cool giants, recently published by Belle et al. (1999). For the spectral type of the red giant in EG And, M 3 (Mürset and Schmid, 1999) and the index $V-K = 4.5$, the results can be summarized as follows:

	our method	ST/T	$V-K/T$
$T_{\rm eff}$ [K]	3500±200	3573±22	3740±30
$T_{\rm c}$ [K]	3130±40	—	3025

We can see that our estimate of $T_{\rm eff}$ agrees well with that suggested by the empirically determined $ST/T_{\rm eff}$ dependencies. The colour temperature of 3025 K given by the $V-K$ index is also close to our value, but the corresponding $T_{\rm eff}$ = 3740 K is above our estimate. When judging these differences, it is needed to bear in mind that the $ST/T_{\rm eff}$ and $V-K/T_{\rm eff}$ relations are of *statistical* nature, but our approach represents a *direct* method.

AX Persei: We summarized the infrared photometry of AX Per as published by Swings and Allen (1972), Szkody (1977), Taranova and Yudin (1982), Munari et al. (1992), Ivison et al. (1995) and Kamath and Ashok (1999). The magnitude in the visual band was adopted as $V = 12.0$ as observed during the eclipse (Skopal 1994). Conversion to fluxes was made according to the calibration of Henden and Kaitchuck (1982), which were dereddened for $E_{\rm B-V} = 0.27$. According to the mass and radius of the giant in AX Per, $M_{\rm g} = 1\,{\rm M}_{\odot}$ and $R_{\rm g} = 102\,{\rm R}_{\odot}$ (Mikołajewska and Kenyon (1992) and Skopal (1994)), we used a

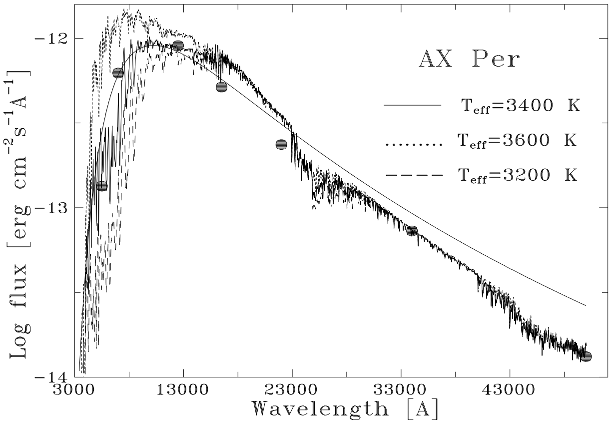

Figure 2. As in Fig. 1, but for AX Per. Comparison of measured fluxes to synthetic spectra for $\log(g) = 0.5$ suggests the effective temperature $T_{\rm eff} \sim 3\,400$ K with extreme values of 3 200 and 3 600 K. Solid smooth line is a Planckian function for $T_{\rm c} = 2\,830$ K, which fits observations best.

grid of synthetic spectra calculated for $\log(g) = 0.5$. We estimated the effective temperature of the giant in AX Per as

$$T_{\rm eff}({\rm AX\,Per}) = 3\,400{\pm}150\,{\rm K}$$

(Fig. 2). The sensitivity of the visual/near-infrared part of the giant's spectra to $T_{\rm eff}$ suggests its uncertainty is about 100 to 200 K. The average fluxes in the photometric bands can be approximated with blackbody radiation as $T_{\rm c}({\rm AX\,Per}) = 2\,830 \pm 50$ K.

The comparison of our results to those given by empirical relations according to Belle et al. (1999) for the spectral type M 4.5 (Mürset and Schmid, 1999) and $V - K = 6.1$ is summarized in the following Table:

	our method	$ST/T/R$	$V-K/T/R$
$T_{\rm eff}$ [K]	3400±150	3450±37	3560±65
$T_{\rm c}$ [K]	2830±50	—	2480
$R_{\rm g}$ [$R_\odot$]	102±3[a]	123±6	161±10

a - according to Skopal (1994)

The agreement between the parameters given by our method and the empirical $ST/T_{\rm eff}$ relation is satisfactory, but the $V - K/T_{\rm eff}$ relation gives more deviate quantities. However, radii according to both statistical relations do not agree with the direct determination of $R_{\rm g}$ from the shaping of the eclipse (Skopal, 1994).

3. Distance to eclipsing systems

During active phases the hot component in many symbiotic systems expands in radius and creates an optically thick shell around its mass core. In the case of a high orbital inclination we can observe a narrow minimum in the light curve due to the eclipse of the blown hot star by its giant companion. Such situation gives opportunity to determine directly the radii of both stars. Having the radius and the effective temperature of the giant, we can estimate its angular diameter, $\theta = R_{\rm g}/d$, which defines the distance, d. The bolometric luminosity of the giant can be written as

$$L = 4\pi d^2 F_{\rm g}^{\rm obs} = 4\pi R_{\rm g}^2 F_{\rm g}, \tag{1}$$

where $F_{\rm g}^{\rm obs}$ refers to the flux at the Earth's surface and $F_{\rm g}$ is the emitted flux at the stellar surface. The effective temperature is defined in terms of the star's luminosity and radius by $L = 4\pi R_{\rm g}^2 \sigma T_{\rm eff}^4$. Thus using Eq. (1) we can express the angular diameter in terms of $T_{\rm eff}$ and $F_{\rm g}^{\rm obs}$ as

$$\theta = \sigma^{-1/2} \left(\frac{F_{\rm g}^{\rm obs}}{T_{\rm eff}^4} \right)^{1/2} . \tag{2}$$

For example, the angular radius of the giant in AX Per for the observed bolometric flux (given by the synthetic spectrum) $F_{\rm g}^{\rm obs} = (1.35 \pm 0.25) \times 10^{-8} {\rm erg\,cm^{-2}\,s^{-1}}$, is

$$\theta = (1.33 \pm 0.17) \times 10^{-9}.$$

The uncertainty in $F_{\rm g}^{\rm obs}$ was estimated from a range of bolometric fluxes, $1.10 - 1.63 \times 10^{-8} {\rm erg\,cm^{-2}\,s^{-1}}$, given by the limiting temperatures of 3 200 and 3 600 K. The uncertainty in θ was inferred from that of $F_{\rm g}^{\rm obs}$ and $T_{\rm eff}$. Corresponding distance for $R_{\rm g} = 102 \pm 3\,{\rm R}_{\odot}$ is

$$d = 1\,730 \pm 230\,{\rm pc},$$

where its uncertainty was determined from that of θ and $R_{\rm g}$. This value agrees within uncertainties with that derived by Ivison et al. (1993), but here we determined it in a more trustworthy way. Finally, the corresponding bolometric luminosity of the giant in AX Per is

$$L_{\rm g} = 4\,\pi\, d^2 F_{\rm g}^{\rm obs} = 1\,250 \pm 400\,{\rm L}_{\odot},$$

where the uncertainty results from that of d and $F_{\rm g}^{\rm obs}$. Uncertainties in this Section represent mean square errors of the mean value.

4. Conclusion

A comparison method, between the broad-band optical/IR photometry and the synthetic spectra of cool giants, was suggested to estimate the effective temperature of cool giants in symbiotic binaries. There are two main advantages of this approach:

1. At present, broad-band optical/IR photometry is available for many symbiotic systems, or, at least, can be more easily obtained than high-resolution spectra. The method can be applied also for systems with unknown spectral type of the cool component.
2. It is a direct method. It implies that the estimate of $T_{\rm eff}$ is trustworthy within uncertainties of 100 – 300 K. Effective temperatures obtained from the model-atmosphere analyses provide a good cross check to $T_{\rm eff}$ suggested by the empirically determined dependencies of $ST/T_{\rm eff}$.

As a consequence, other parameters, the distance to the system and the luminosity of the giant, can also be estimated within corresponding uncertainties, if the stellar radius is known.

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