Periodic variations in the light curves of symbiotic stars

A. Skopal

Astronomical Institute of the Slovak Academy of Sciences
059 60 Tatranská Lomnica, The Slovak Republic

Received: December 13, 1994

Abstract. A group of classical symbiotic binaries exhibits a periodic variation in the optical continuum due to orbital motion. This variation is usually ascribed to a reflection effect. However, we demonstrate that the reflection effect is not the correct interpretation of the light curves for some of those symbiotic stars. Our approach in solving this problem is based on the assumption of the presence of circumstellar matter located mostly between the components of a symbiotic binary. We assume that the observed wave-like variation of the brightness can be produced by a different projection of the circumstellar nebulosity into the line of sight along the orbital cycle. Two examples, EG And and V443 Her, are discussed in more detail.

Key words: stars – binaries – symbiotic – circumstellar matter

1. Introduction

The periodic, wave-like variation in the star's brightness along the orbital cycle, with a relatively large amplitude (~1 mag or higher) even for binaries with a very low value of the mass function, depending on the wavelength ($\Delta U \geq \Delta B \geq \Delta V$), is the common feature of a group of classical symbiotic stars (e.g. EG And, BD-21.3873, [T CrB], RW Hya, SY Mus, V443 Her, He2-467, AG Peg, V1329 Cyg; AS 338, AG Dra, Z And, BF Cyg). The relation of these variations to the orbital motion was independently confirmed for selected symbiotic stars by measuring the radial velocities reflecting orbital motion of their cool components (e.g. Garcia & Kenyon 1988). At the spectroscopic conjunction - cool component in front - we always observe a minimum in the star's brightness.

This behavior is notoriously ascribed to a reflection effect. In this model the hot component irradiates and heats up the facing giant's hemisphere which causes a variation in the star's brightness when viewing the binary at different orbital phases. This natural explanation of the variability in the optical continuum is still very popular (e.g. Kenyon 1982, Dobrzycka et al. 1993). However, to explain the relatively large amplitude of the light curves (often > 1 mag) observed in extended binaries, by this effect, constrains an extremely high luminosity for their hot components. For example, Formiggini & Leibowitz (1990) derived the

Contrib. Astron. Obs. Skalnaté Pleso **25**, (1995), 45- 52.

luminosity of $10^4\,L_\odot$ for the hot component in AX Per ($P_{\rm orb}$= 680 d, $i = 90°$, $T_{\rm hot} \sim 10^5$ K and M5 III giant as the cool component) in quiescence, in order to explain variations only of $\Delta m_{\rm pg} \sim 0.2 - 0.3$ by their quantitative model for the reflection effect. On the other hand, even the large $\Delta m_{\rm pg} \sim 2.5$ mag amplitude of the photographic light curve of AS 338 ($P_{\rm orb}$=434 d, $i \sim 90°$, $T_{\rm hot} \geq 10^5$ K, M5 III) was also ascribed to the reflection effect (Munari 1992). As the parameters of both systems are quite similar, their light curves - extremely different in amplitudes - cannot simply be explained by the same effect.

Another example arguing against the reflection effect being responsible for such behavior in the light curves, is the symbiotic star He2-467 ($P_{\rm orb}$= 488 d, no eclipses identified, $T_{\rm hot} \sim 10^5$ K, G6 III). Munari & Buson (1992) again ascribed its wave-like light curve with amplitudes of $\Delta U = 1.8$, $\Delta B = 0.3$ and $\Delta V = 0.1$ mag to the reflection effect. However, in this case there is a conflict between the spectral type of the cool component, G6 III (R$\sim$10 to 15 $R_\odot$), and the too large amplitude in the U band. Due to a relatively small radius, approximately of 10 - 20 $R_\odot$, the G-type giant can capture only a very small fraction of the hot component radiation, ~0.05%. This value is by ~2 orders of magnitude smaller than that for an M giant; this means that the G-type cool component in the symbiotic binary can only produce a hardly detectable reflection effect. Generally, the interpretation of the wave-like brightness variation in symbiotic stars by the reflection effect must be called into question in its wider use.

In this paper we suggest another possibility on explaining the wave-like variability in the light of symbiotic stars.

2. The idea

Our idea is based on the assumption of the presence of circumstellar matter located mostly between the components of the binary and possessing the geometry of common potentials. We assume that the observed wave-like variations can be reproduced by different projection of the circumstellar nebulosity into the line of sight at different orbital phases. The presence of this material can generally be caused (i) by the outbursting activity of the hot component, and/or (ii) by mass transfer from the giant star via the L_1-point onto the *non-synchronously* rotating compact component. The first possibility results from the fact that during the outburst the relatively slowly, order of hundreds of $km\,s^{-1}$, ejected material by the hot component is observed. This material can then easily reach the regions of the common potentials of the binary. This case can be amplified by the rotation of the hot component in the system, which can thus effectively spread the ejected material during the outburst in the binary – a part of which can impact the faced red giant's hemisphere, and cause a strong emission region on it (Skopal 1994), the second part can remain in the binary within its common potentials, or partly be liberated from the system in accord with its kinetic energy. In two cases at least, AG Peg and V1329 Cyg, we observed the formation of wave-like variations in the light-curve just after the outburst. The second possibility could essentially be due to a nonsynchronous rotation of the small compact star in the long-period ($\approx$ years) symbiotic binary. In this case, the radius of the critical surface of the hot component shrinks, and thus a part of the mass transferred from the red giant via the L_1-point can be directed straight to the locations of common binary potentials.

3. The model

We will test the behavior of the optical continuum using the model suggested by Skopal et al. (1993). The basic characteristics of the model can be summarized as follows:
(i) The geometry of the circumstellar material is defined by the common equipotential surface of the binary containing the Lagrangian point L_2 closely resembling the common envelope corotating with the binary. A circular orbit with synchronously rotating components is assumed.
(ii) The envelope radiates in accord with the linear limb darkening law. The observed light corresponds to the integrated flux coming from its actual projection onto the sky. Due to the presence of extremely different temperature regimes in the symbiotic binary, we introduce the ratio I_h/I_c of specific intensities of the hot to the cool component part of the envelope.

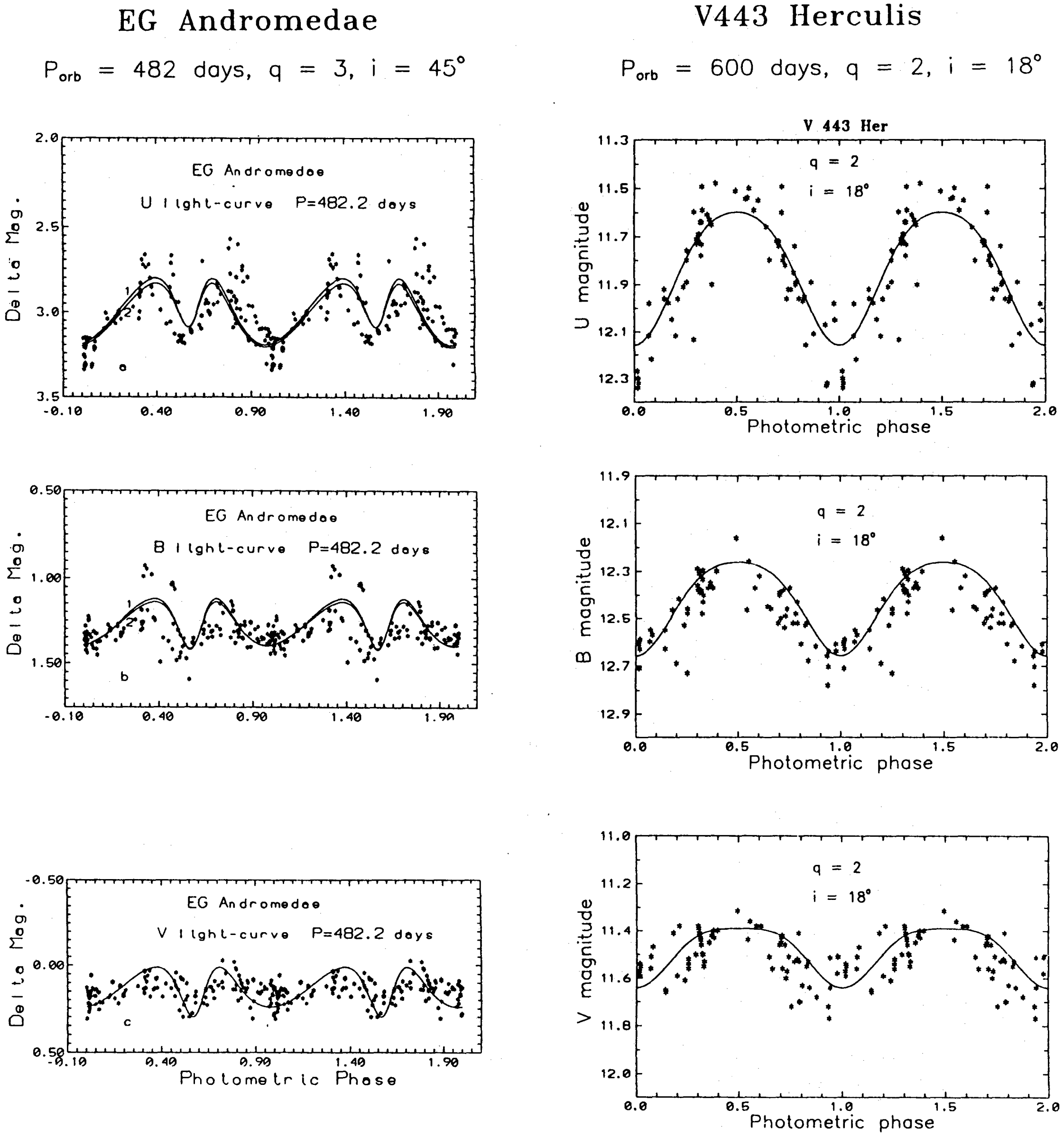
The model requires the parameters defining the orbital motions of the binary components. For our examples, EG And and V443 Her, the parameters of the spectroscopic orbit were taken from Skopal et al. (1991) and Dobrzycka et al. (1993), respectively.

A schematic picture of the model suggested above for a symbiotic binary producing the periodic wave-like variation of the optical continuum along the orbital motion is depicted in Fig. 2.

4. Application to EG And and V443 Her

4.1. Optical continuum

To demonstrate the reliability of the model suggested above, we selected two symbiotic binaries, EG And and V443 Her, for which all the basic parameters required by the model are well known. Both systems have perfectly covered UBV light curves, well defined spectroscopic orbits and there are sets of observed spectrophotometric parameters including evolution of the H_α line profile along the orbital cycle (e.g. Oliversen et al. 1985, Skopal et al. 1991, Munari 1993). Moreover, the reflection effect is not a correct interpretation of their light curves. A double wave in the light curve observed during one orbital cycle of EG And (see Fig. 1) is not possible to explain by this effect, because of the presence of the secondary minimum at the position of the superior conjunction of the cool



EG Andromedae

P_{orb} = 482 days, q = 3, i = 45°

V443 Herculis

P_{orb} = 600 days, q = 2, i = 18°

Figure 1. The UBV light curves for symbiotic binaries EG And and V443 Her. The full lines represent the solution using our model.

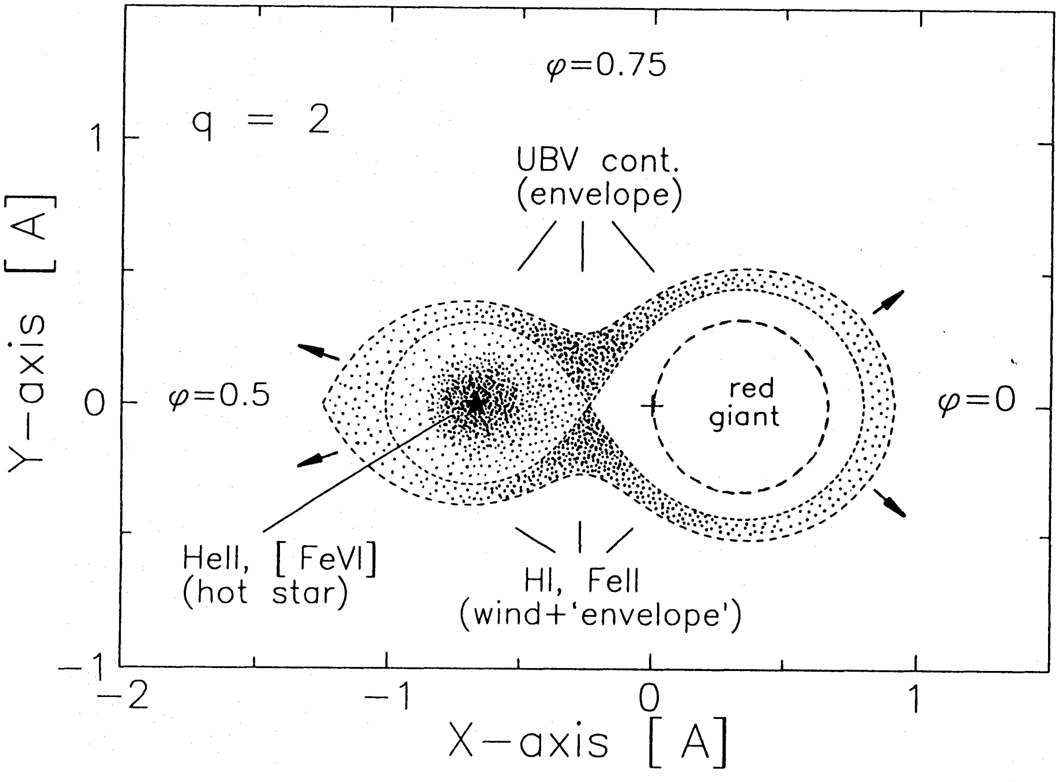


Figure 2. Schematic figure for the symbiotic binary exhibiting the wave-like variation in the light curve along the orbital cycle. The circumstellar matter located mostly between the components of the binary is suggested to be responsible for this behavior. Parameters q=2 and $R_{\rm giant}$=110 $R_{\odot}$ of V443 Her were used. The scale is in units of the separation A of the binary components.

component, in which a maximum of the reflected light should be observed. Reflection effect in V443 Her was discussed in detail by Skopal (1995). He estimated that the light of the hot component captured by the red giant's hemisphere in this system can cause a modulation only of $\sim$0.01 mag, which disagrees with the observed $\sim$1 mag wave in the U band. Here, to illustrate our approach, we present the main results of modelling the light curves of these symbiotic systems. A detailed analysis is given by Skopal et al. (1993) and Skopal (1995).

The theoretical curves were fitted to the observed data by trial and error. The values of the resulting parameters are considered best by eye estimate, without the application of any formal fitting algorithm. Our preferred models of the UBV light curves for EG And ($P_{\rm orb}$ = 482 days, mass ratio q = $M_{\rm cool}/M_{\rm hot}$ = 3, inclination of the orbit i = 45°) and V443 Her ($P_{\rm orb}$ = 600 days, q = 2, i = 18°) are shown in Fig. 1.

The difference between our idealized model and the reality can be caused by the inhomogeneously distributed material in the envelope; (i) due to possible motions of circumstellar matter along inner trajectories of the common potentials it will be concentrated more at the orbital plane; (ii) strong radiation of the hot component can cause a higher dilution of the 'envelope' from its side. This can result in the generation of a radiation-driven hot component wind as indicated by the P-Cygni profiles in the UV region, more pronounced around orbital phase 0.5, as observed, for example, in EG And (Sion & Ready 1992, Vogel 1993); (iii) viewing the system under a very low inclination angle, and for the reasons mentioned in (i) and (ii), we can observe parts of the 'envelope' which are closer to the hot component and thus receive a more significant contribution in the ultraviolet. These arguments indicate that the circumstellar matter contributing to the optical continuum in these systems should be more concentrated between the components of the binary.

In spite of these possibilities which are not included in our model, we feel that the level of accuracy in the observed data, and what we are trying to explain - shapes and amplitudes of the light curves only - do not warrant a more elaborate theoretical representation.

4.2. Ultraviolet properties

As one from our examples, EG And, has been studied intensively with the IUE satellite, we shall try to give a qualitative description of the basic properties in its ultraviolet spectrum using our model.

Variation in both the HeII 1640 Å fluxes and the hot star wind indicated by the absorption component of the P-Cygni profile of the CIV 1550 Å line along orbital motion (Oliversen et al. 1985, Munari 1989, Sion & Ready 1992, Vogel 1993) have the same character as that in the optical continuum – a wave-like behavior with minima at the inferior conjunction of the red giant. Both the HeII fluxes and the hot star wind have their origin in a region around the hot component. According to our model they will be attenuated by the circumbinary nebulosity between and around the components of the binary (Fig. 2). Then the phase dependent column density of the material between the emitting source and observer will cause the phase dependent attenuation of the hot component radiation. In EG And we observe a maximum in the HeII flux and the strongest absorption component in the P-Cygni profile of the CIV line at orbital phase ~0.5 (hot star in front) and a disappearance of both at phases ~0 (cool star in front). Here it is important to note that we observe a gradual variation, no sudden change resembling that of an eclipse, is observed.

Another proof of validity of our model is the behavior in the far ultraviolet continuum (1200 to 1500 Å) around the minimum of the optical light. Currently it is ascribed to the effects of Rayleigh scattering of the hot component light by the wind of the cool giant. In such a case a part of the neutral material located between the source and observer can contribute to the Rayleigh attenuation of the far UV radiation. In the model of Vogel (1991) and Vogel et al. (1992) this is the neutral wind material shaped in a cone surrounding the red giant with the axis coinciding the line joining both components. However, this geometry constrains the orbital inclination to be very close to 90° to pass the line of sight through the neutral region of the cool wind. That why Vogel (1991) states that EG And is an eclipsing binary. Unfortunately, the behavior in the optical continuum, which does not account for a high inclination (Skopal et al. 1991, 1993, Munari 1993) was ignored in Vogel's modelling. On the other hand there could be enough amount of neutral material in the circumstellar environment when viewing the system from the cool component side, in accord with our model, even for a lower orbital inclination. An observational indication of the presence of a dense circumstellar material surrounding the binary is the absence of highly ionized emission lines (e.g. HeII) in the optical domain, although a very hot star is present (T_h ~80 000 K [Mürset et al. 1991]). This (paradoxical) observation can be explained just due to a strong attenuation of the hot component radiation by the cool circumstellar material.

5. Conclusion

It is shown that the periodic wave-like variation in the optical continuum of a group of classical symbiotic stars can be produced by the circumstellar matter in the binary. This material is located mostly between its components and approximately has the geometry of common potentials. The radiation of the hot component is transferred through this material, which absorbs photons preferentially below the Lyman absorption limit and re-radiates them at longer wavelength - in the Balmer and Paschen continua. Different projection of this emission region onto the sky then causes a different contribution to the optical continuum resulting in the (double) wave-like shape of the light curves along the orbital cycle.

Although our simple model can differ from that what is actually taking place in more aspects, as mentioned in Sect. 4, we believe that our approach is adequate for studying the gross changes of observed spectrophotometric parameters.

Acknowledgements. The author thanks the referee, D. Chochol, for his comments.

References

Dobrzycka, D., Kenyon, S.J., Mikolajewska, J.: 1993, *Astron. J.* **106**, 284

Formiggini, L., Leibowitz E.M.: 1990, *Astron. Astrophys.* **227**, 121

Garcia M.R., Kenyon, S.J.: 1988, In *The Symbiotic Phenomenon, IAU Coll. 103*, eds. J. Mikolajewska et al., Kluwer Academic Publ., Dordrecht, p. 27

Kenyon, S.J.: 1982, *Publ. Astron. Soc. Pac.* **94**, 165

Munari, U.: 1989, *Astron. Astrophys.* **208**, 63

Munari, U.: 1992, *Astron. Astrophys.* **257**, 163

Munari, U.: 1993, *Astron. Astrophys.* **273**, 425

Munari, U., Buson, L.M.: 1992, *Astron. Astrophys.* **255**, 158

Mürset, U., Nussbaumer H., Schmid H.M., Vogel M.: 1991, *Astron. Astrophys.* **248**, 458

Oliversen, N.A.: Anderson, C.M., *Stencel, R.E., Slovak, M.H.* **1985**, Astrophys. J. 295620

Sion, E.M., Ready Ch.J.: 1992, *Publ. Astron. Soc. Pac.* **104**, 87

Skopal, A.: 1994, *Astron. Astrophys.* **286**, 453

Skopal, A.: 1995, *Astron. Astrophys.* (submitted)

Skopal, A., Chochol, D., Vittone, A., Blanco, C., Mammano, A.: 1991, *Astron. Astrophys.* **245**, 531

Skopal, A., Vittone, A., Errico, L.: 1993, *Astrophys. J., Suppl. Ser.* **209**, 79

Vogel, M.: 1991, *Astron. Astrophys.* **249**, 173

Vogel, M.: 1993,*Astron. Astrophys.* **274**, L21

Vogel, M., Nussbaumer, H., Monier, R.: 1992, *Astron. Astrophys.* **260**, 156