ORBITAL PARAMETERS OF THREE SYMBIOTIC STARS

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ABSTRACT. The optical light curves of the three symbiotic stars AG Dra, AX Per and AG Peg, in the U, B and V photometric bands, in the quiescent states of these stars, are interpreted on the basis of a "reflection" model for the observed light variations. A least squares fit of a numerical model that is constructed to the observed magnitudes of the stars yields the value of few of the orbital elements of these binary systems. Some predictions are made on the basis of the model and its parameter values about the detailed structure of the light curves of the three stars, and of the expected structure of radial velocity curves of the cool components in these systems.

I. INTRODUCTION

The reflection effect was mentioned in this colloquium more than once as an interpretation or a possible interpretation for the observed light curves (LC's) of a few symbiotic stars (SS's). Also in the very first talk of this meeting, Dr. David Allen stressed the need for orbital elements of SS's. Our work is an attempt to test whether the reflection effect can indeed account for observed LC's of SS's. At the same time we examine whether with a quantitative analysis of the effect one can perhaps also derive the value of a few orbital elements of symbiotic star systems from their observed optical LC's.

We have found photometric data for 3 SS's, AG Dra, AX Per and AG Peg, that show in their quiescent state a smooth light variation with one minimum and one maximum point per cycle. The three system are also characterized by LC's that are dominated by a periodic component for a long time. Our analysis is applied to these periodic variations, which according to the reflection interpretation are due to the orbital revolution of the system.

II. DATA AND MODEL

The discrete points in Figure 1 represent the observed LC of AG Dra in the U, B and V photometric bands, folded onto the known photometric period of this star of 554 days. The points in Figure 2 are the B and V observed LC's of AX Per, folded onto its period of 681 days. The discrete points in Figure 3 represent the U, B and V observed LC's of AG Per, folded onto the period of 815.7 days. This period was chosen by us on the basis

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of a power spectrum that we have computed for all the data points that we had on our bands. Note that in all 3 figures the variation cycle is displayed twice. Data for the figures were taken from Meinunger 1979, Taranova and Yudin 1982, Kenyon 1982, Belyakina 1970, Fernie 1972, Oliversen and Andersen 1982 and Meinunger 1983.

We assume that the observed flux in each photometric band is composed out of 3 components: 1) The flux of the cool star in the system. 2) The flux of the hot star. 3) The "reflected" flux from the hemisphere of the cool star that is facing the hot star.

Component (1) is phase independent. Component (2) is also constant, except when eclipse occurs. If the apparent disk of the cool star eclipses the hot star, which in our model is treated as a point source, the contribution from this star vanishes. If there is no eclipse during the entire orbital cycle, the second component of the observed flux adds up to the first one and both terms are considered together as a single contribution of a DC component to the LC.

Most of the phase dependence is contained in the 3rd. contribution. In deriving an explicit expression for this term we assume that a plane parallel beam of the hot star radiation is illuminating the near hemisphere of the cool star. A fraction β of the infalling energy is reradiated from this hemisphere in the photometric band under consideration, with an angular distribution that can be represented by a limb darkening law, with a limb darkening parameter μ. The LC is given by the model in a parameter form, as a pair of functions $\mu(\theta)$ - the magnitude of the system, and $x(\theta)$ - the observed phase corresponding to a phase angle θ. The two functions depend on the model parameters that include the orbital inclination angle, the eccentricity of the orbit, the radius of the cool star in the system, the direction angle to the periastron point in the orbital plane, the limb darkening coefficient and a few others.

Further details of the mathematical representation of the model are given in Formiggini and Leibowitz 1987.

III. RESULTS

We applied a least squares procedure to find the set of parameter values that give the best fit of the model LC to the observed measurements. We have found 2 minimum points for AG Dra, 2 for AX Per and 1 for AG Peg. The solid curves in Figures 1, 2, and 3 are the plots of the (first) best solution for each star. Figure 4 displays again the observed LC's of AG Dra, with the second model solution for this star. Note that the two solutions for AG Dra imply that this system is undergoing an eclipse phase. The second solution for AX Per which predicts an eclipse of the hot component in this system too, may probably be rejected because it requires that the luminosity of the hot component is larger than that of the cool star, in the entire optical spectral region. This requirement is not supported by the observed optical spectrum of this star.

IV. DISCUSSION

Figures 1,2,3 and 4 show that the reflection effect may indeed account for the observed periodic variations in the LC of the three stars AG Dra, AX Per and AG Peg. The model also enables one to derive the values of a few orbital elements of these systems, some of them within a rather limited range of uncertainty. In particular we feel that the values of the eccentricities are well established because they persist in all local minima that we have encountered in our optimization procedure. It seems that if the periodic variations are indeed caused by the orbital motion in the system, the geometry of the orbit determines the structure of the LC in a unique or in a close to unique way.

The discrete points in Figure 5 are the measured radial velocities of the cool star in AG Dra, as measured by Dr. Mike Garcia and presented by him in this colloquium. The smooth curve in the figure is the radial velocity curve that is computed with the orbital elements from our model. It is clear that these elements are consistent with the radial velocity observational results.

The two solutions for AG Dra that are plotted in Fig. 1 and 4 differ from each other mainly by the value of the parameter r. The first one has a small r, namely a giant as the cool star in this binary system. The large value of r in the second solution implies that the cool star in AG Dra is a supergiant. There is no way to distinguish between these solutions on the basis of the photometric data alone, because both have the same statistical significance. The supergiant solution may be slightly questionable because a star with the dimensions implied by this solution is expected to be tidally distored. The ellipsoidal geometry of such a star is generally noticeable in the LC's of close binary systems, e.g. massive x-ray binaries. No indication for an ellipsoidal effect can be found in the LC of AG Dra.

Our claim of an eclipse in the LC of AG Dra can be checked by high quality photometric measurements near phase 0.5 of this system.

ACKNOWLEDGEMENT

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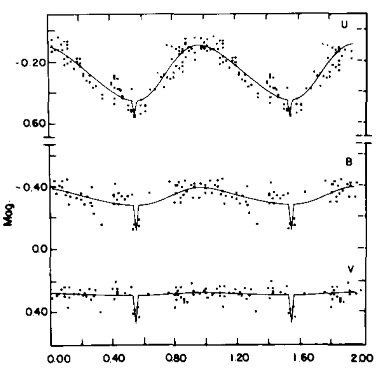

Figure 1. Light curves of the star AG Dra in the three photometric bands U,B and V, folded onto its binary period of 554 days. Discrete points are observations. Smooth curve is the best fitted "giant" solution of our reflection model.

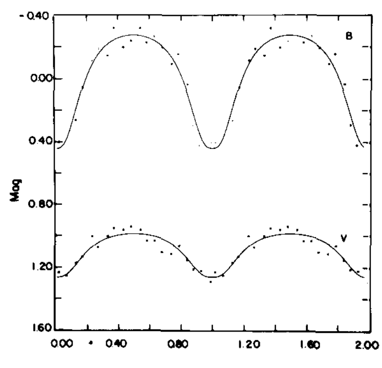

Figure 2. Same as in Figure 1 for the star AX Per.

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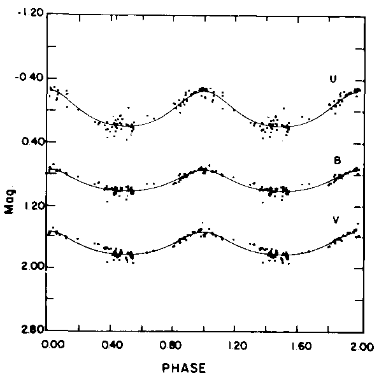

Figure 3. Same as in Figure 1 for the star AG Peg.

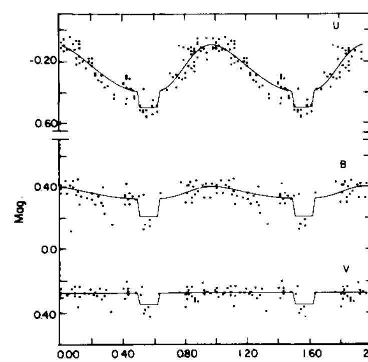

Figure 4. Same as in Figure 1 Smooth curve, the supergiant solution.

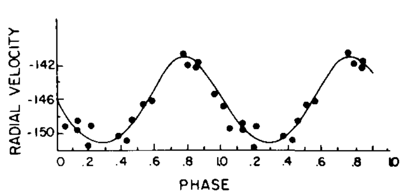

Figure 5. Radial velocity curve of the cool component in the binary system AG Dra. Points are observations. Smooth line is the theoretical curve computed with the orbital elements from our model.

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