Part 2. The Status of Stellar Variability
Section 2D. Other Binary Systems

Light Curve Solution for Early-type Binary Systems With Radiative Interaction

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Abstract An eclipse light curve analysis code based on the logistics of the *Wilson-Devinney* approach has been developed to account for the effects of radiation pressure due to the mutual irradiation of the components of close binary systems. The radiative forces exerted by luminous, hot stars may cause geometric deformations of stellar surfaces and influence the binary configuration and evolution.

1. Modified Roche model

First attempts to include radiation pressure in a structural close binary model used as a measure the dimensionless parameter

$$\delta = \frac{F_{\mathrm{rad}}}{F_{\mathrm{grav}}} = \text{const.} \qquad (0 \leq \delta < 1),$$

with F_{rad} and F_{grav} being the radiative and gravitational forces exerted by the companion on the surface of the irradiated star. Accordingly, a reduced gravitational potential

$$(1 - \delta_{1,2}) \quad \frac{G\,M_{1,2}}{r}$$

was introduced instead of the pure graviational terms of the binary Roche potential due to the fact that both F_{rad} and F_{grav} depend on $1/r^2$. This is a reasonable treatment of the *inner* radiation pressure emerging from the center of each star and acting on its own surface layers in a radial (perpendicular) direction. However, the interaction between the radiation of one component and the surface of its companion cannot be treated in this simple way for three reasons:

1. radiation pressure acts only on the facing side of the irradiated star, while the use of a reduced gravitational term in the Roche potential would act isotropically, with no regard for geometrical effects;

2. the action of radiation pressure obeys a cosine law concerning the angle of incidence on the surface, i.e., the irradiated surface has to be considered in its true geometric shape;

3. earlier attempts assumed a point source for the irradiating star, which is obviously not a good representation for a close binary system.

Our new approach fully accounts for the mentioned geometrical effects:

1. the angle of incident flux is determined for each surface element of the irradiated star;

2. no radiation pressure is assumed to act behind the horizon of the irradiated component;

3. the irradiating star is evaluated in its full extent and shape instead of assuming a point source.

These presumptions can be combined in the definition of a function $\delta(x,y,z)$ to be determined by numerical calculation. For a detailed description the reader is referred to Drechsel *et al.* (1995). The δ functions are normalized by the characteristic values δ_1 and δ_2 of the two components, giving the efficiency of radiation pressure for perpendicular irradiation. Our numerical procedure allows for the mutual irradiation of both components with $\delta_{1,2}$ values in the range $0 \leq \delta < 1$ in systems with arbitrary mass ratios q.

2. Application: light curve analysis

The modified Roche model has been used as a more realistic binary model for close and hot systems and serves as basis for a refined calculation of eclipse light curves. The general logistics of the *Wilson-Devinney* approach (Wilson and Devinney 1971) are used for this purpose. The conventional differential corrections scheme is replaced by the more flexible and numerically stable simplex algorithm (Kallrath and Linnell 1987) —the non-linear parameter optimization method, which allows for a simultaneous adjustment of the radiation pressure parameters $\delta_{1,2}$, together with the usual set of quantities describing the structure and properties of the binary system.

The feasibility of the new method has been demonstrated by photometric solutions of many OB systems, e.g., IU Aur (Drechsel *et al.* 1994), AB Cru (Lorenz *et al.* 1994), SZ Cam (Lorenz *et al.* 1998), V606 Cen (Lorenz *et al.* 1999), V1331 Aql (Lorenz *et al.* 2005), or V1182 Aql (Mayer *et al.* 2005). It is beyond the scope of this paper to list the detailed parameters and absolute dimensions obtained from a correlation with spectroscopic observations. We wish to note here only that the application of the MORO code (Drechsel *et al.* 1995) yielded improved light curve solutions compared to conventional attempts, even though these systems are only moderately hot. It is therefore expected that reliable absolute dimensions of numerous O-type stars can be derived. Their masses, radii, and luminosities will be compared with modern binary case A and case B evolution theories (e.g., de Loore and De Greve 1992).

A detailed description of the MORO code was published by Drechsel *et al.* (1995).

3. Conclusions

Radiation pressure effects are important for close OB-type binaries. A numerical method was developed to incorporate the mutual irradiation of the binary components in the computation of the potential field. Implications for the binary structure and evolution are many-fold:

- the geometry of equipotential surfaces, especially of the stellar photospheres, depends on the strength and efficiency of radiation pressure exerted by one or both binary components;
- the positions of the Lagrangian points are shifted, and the extent and shape of the Roche lobes are changed;
- radiative forces counteract the tendency to take up inner contact in L_1, and may prevent or delay the onset of mass exchange;
- on the other hand, *outer contact* configurations of detached systems with surfaces incorporating L_2 or L_3 can be induced above a certain critical radiation pressure efficiency;
- obvious consequences exist for the evolution of systems with hot and luminous components such as WR or X-ray binaries.

References

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