CBS - A PROGRAM FOR CLOSE BINARY SYSTEM LIGHT CURVE ANALYSIS

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ABSTRACT.

CBS is a new program for binary system light curve analysis, it generates synthetic light curves for a binary system, accounting for eclipses, tidal distortion, limb darkening, gravity darkening and reflection; it is also possible to compute the light contribution and eclipses of an accretion disk. The bolometric light curve is generated, as well as curves for the U,B,V,R,I colour bands. In the following we give a brief description of the first version of the program and show some preliminary results.

1. Introduction

For many years the photometric analysis of binary systems has been performed by the rectification method developed by Russel (1912, 1952); with this method the light curve is analysed in terms of the eclipses of two limb darkened spherical disks by removing off-eclipse effects such as reflection and tidal distortion. The Russel method was improved by different authors, using an analytical approach (Kopal 1959), but the detailed computations of close binary systems light curves, with strong tidal and reflection effects, can be done only with computers, by numerical calculation.

In the seventies, when powerful computers became available to astronomers, many light synthesis programs were written by different authors, such as Wilson and Devinney (1971), Wood (1971), Lucy (1968), Linnel (1984) and others. The most popular of these is the Wilson-Devinney program, which represents the stars, deformed by tidal and rotational forces, by means of equipotential Roche surfaces, assuming central condensation, synchronous rotation and circular orbits. The gravity darkening effect is considered. Reflection is treated in an approximate way: the geometry is simplified by considering the irradiating surface as a point source, and a term is introduced in the albedo coefficient to account for its shape. For the eclipse computation the surfaces of the two stars are represented by a number of surface elements (usually about thousand); for each phase the star closer to the observer is analysed first and an analytical approximation for the boundary of the visible part of the star is computed from the boundary surface elements. This is used to exclude the eclipsed part of the second star when summing the light of all the visible surface elements. The differential correction method is used to obtain the best parameters for the light curve.
The Wilson Devinney program gives a satisfactory solution for the light curves of most close binary systems; but most of the modern interest in close binary systems is focused on accretion disks phenomenonology and stars with a collapsed companion. A Wilson type approach can’t handle accretion disks and complex geometrical configurations; in fact only few attempts have been done up to now in representing the disk contribution to the light curve (Wilson, Caldwell 1978; Horne 1985).

In order to consider the contribution of hot spots and accretion disks we have written a new light synthesis program, which uses a different approach, suited to handle complex geometrical configurations. We are still developing the program; the present version isn’t optimized, doesn’t treat overcontact binaries and hot spots, doesn’t contain a minimum finding algorithm to look for the best parameters; all these features will be included in a future version.

2. Program description

The CBS program computes the light curve for a system consisting of two stars and an accretion disk; the two stars can be represented by spheres or Roche equipotential surfaces, the disk as a thick ring.

The stars and the disk are described by a number of surface elements; for each of them the temperature is obtained by a gravity darkening law, the emitted bolometric luminosity is computed by assuming a Plank law. Also the position, orientation and approximate extension of each surface element are stored in memory.

The reflection effect is treated following the vector method of Chen and Rein (1969), considering multiple reflections and the full geometry of the system. The computing time increases here as the square of the number of surface elements, but a very detailed calculation isn’t necessary for reflection; for this reason we group more surface elements together into a ”coarse surface element”, used only in this part of the program. To calculate the reflected light we consider all the possible light paths between two coarse surface elements of the two stars which don’t intercept the disk and all the paths between a star and the disk which don’t intercept the other star; a transmission function is computed for each path, including linear limb darkening and an input-given albedo coefficient. These functions are used to compute the energy transmitted along each path and a reflected luminosity for each surface element, which is added to the bolometric one.

The light received by the observer at each phase is obtained by projecting the surface elements into the visual plane. The visual plane is divided into a number of cells; a surface element is eclipsed if it falls into the same cell of another surface element which is closer to the observer. The case of more than one surface element of the same object falling into the same cell and the case of a surface element with a projected dimension greater than a single cell are properly treated. The received light is obtained by summing over all the non-eclipsed surface elements, assuming a linear limb darkening law.

This approach to the eclipse computation is not limited to treat a particular geometry and can be used for disks with hot spots, spheres and Roche lobe stars without any change. Its disadvantage is the high number of surface elements needed to represent the
objects. To obtain more than about 1% accuracy in the eclipse computation we need about 10000 surface elements for each object, this means a computer memory of some tenths of Mbytes, a common value for many modern workstations. The present version of the program computes the light curve of an Algol type binary, with 100 phase values, in about 10 minutes on a Microvax 3300 computer using 15000 surface elements for each star. A forthcoming optimized version will give better performances.

The input of the program consists of the pole temperature of the stars, the limb, gravity darkening and albedo coefficients, the orbit inclination and some parameters describing the system geometry as the presence of the disk, its height and radius, the Roche potentials etc. A number of run parameters of the program, as the number of surface elements, the number of visual plane cells, the normalization parameters etc. can also be given by the user.

In fig.1 we show the light curve of IM-Aur (BV 267), an example of a semi-detached Algol type variable. The system parameters are those obtained by Rafert (1990); for the first star: \( T = 12000, \Omega = 3.103x = 0.75, g = 0.63, A = 1 \); for the second: \( T = 5945, \Omega = 2.4913x = 0.675, g = 0.32, A = 0.8 \). \( i = 75.20^\circ, q = 0.3114 \). We didn’t put disk or hot spots. The continuous line is the monochromatic light curve at 5410A, obtained by CBS; the dashed line is obtained by the Wilson-Devinney program and the dots are observations from Margoni et al. (1966). The difference between the two synthetic light curves is due to the different treatment of reflection. The overall agreement with observations is good.

In fig.2 the effects of reflection and limb darkening are shown: the dashed line is a light curve obtained without reflection contribution, the dotted line without limb darkening.

**Acknowledgements**

We are grateful to Professor C. Bartolini, for comments, discussion and moral support, and to Doctor M. Lolli for discussions and the data files to test the program.

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Fig. 1. IM-Aur: the CBS light curve (continuous), the Wilson light curve (dashed) and the data points (dots).

Fig. 2. IM-Aur: the CBS light curve (continuous), without reflection (dashed) and without limb darkening (dotted).