ANALYSIS OF THE LIGHT CURVES OF SZ CAM USING AUTOMATIZED FOURIER TECHNIQUES

E. BUDDING
Dept. of Astronomy, University of Manchester, England

(Received 3 June, 1976)

Abstract. UBV light curves of the early type close eclipsing binary system SZ Cam have been investigated using recently developed frequency-domain techniques. The combination of both minima in the analysis results in a distinct methodological improvement over the single minimum method discussed hitherto. This improvement has two aspects: (i) increased accuracy of the determined elements, (ii) agreement of the results of the two-minimum method with those of the single-minimum method provides a criterion whereby the self-consistency of the underlying model with its representation of the light curve in the regions between minima by a cosine series and the empirically determined coefficients of such a series may be assessed. Such a 'self-consistent' solution is found, and a further step towards a realistic representation is made by including the 'photometric perturbations'. It is confirmed from these three light curves that the less massive star is overluminous. A probable tendency for the limb-darkening coefficient of the more massive star to increase with decreasing wavelength is also noted.

1. Introduction

In a series of recent papers (Kopal, 1975a, b, c, d, e; Kopal et al., 1976; Smith, 1976; Kopal, 1976a, b – hereafter referred to as Papers I–IX, respectively) methods have been pointed out in which the light curves of close binary systems can be investigated by reference to frequency-domain analysis in contrast to the more traditional approaches of time-domain analysis.

It has been shown that in certain restricted cases the relevant expressions which relate to the sought 'elements' of the system – the set of parameters whose numerical values will characterize a particular theoretical specification of the apparent intrinsic brightness of the star as a continuous function of the orbital phase, which would normally bear a close relationship to actual observations – reduce to a particularly simple form. Such would be the case, for instance, when we may neglect any physical effects arising from the proximity of the two components on the observed light changes, i.e. that the light level outside of eclipses is sensibly constant, when the eclipse under consideration is complete, that is culminating in an eclipse of total or annular kind, and when plausible simplifying assumptions can be made about the distribution of the emergent flux over the apparent stellar surfaces. If, for instance, we were to assume that these surfaces appeared as disks of uniform brightness (no limb-darkening), then a minimum of four integrals of the light loss at an eclipse with respect to different even powers of the sine of the phase \( A_{2m} \) \((m \geq 0)\) are theoretically necessary and sufficient to implicitly determine the fractional luminosity of the eclipsed component \( L_1 \), and the three geometrical elements \( r_1, r_2 \) and \( \sin i \) (see Appendix). Since, in fact, \( A_0 = L_1 \)
for the total eclipse and is simply a common factor of all other $A_{2m}$-moments, as they have been called, the problem would reduce to that of finding the three lowest moments $A_2$, $A_4$ and $A_6$, from which the elements can be determined by simple linear equations such as are given in Paper I. These relationships of the undarkened case moments to the elements appear to have a basic role to play in the frequency domain approach, for if the limb-darkening effect can be represented adequately well by suitable functions of the radial variable (symmetric about the centre) over the disks of the stars, the resulting moments appropriate for limb-darkened stars, $\bar{A}_{2m}$, are found to be expressible as linear combinations of terms directly relatable to corresponding terms in the expressions for the undarkened case moments factored by simple rational functions of coefficients of the chosen limb-darkening function (see Paper II).

The direct connection between the elements and appropriately chosen but simple integrals of the light curve lends a certain elegance, and perhaps also speed, to this approach to light curve analysis, at least in the restricted cases. In more general cases in which the condition of complete eclipses is relaxed and proximity effects are allowed to play their part, some of this directness appears to be lost and certain of the familiar complications of these cases – determinacy and physical significance of parameters and so on – re-emerge, though with different effects on calculation procedures than in the time domain analysis situation. Thus, for instance, provided we can represent proximity effects by suitable functions of the phase, i.e. generally as an expansion in powers of the cosine of this argument, Kopal has shown (Paper V) how such effects can simply be subtracted from empirically obtained integrals derived in the same way as for the proximity-free case to leave residues attributable to eclipse effects.

Even in such general cases then, it seems possible to regard the integrals obtained in essentially the same way as in the restricted case as relatable to, or somehow perturbed forms of, such restricted case integrals and thence to determine the underlying elements. Moreover, since the lower order integrals at least, by their very nature tend to smooth out noise, elements derived by the method in question ought to be, in some sense, noise free – though their relationship to optimal elements defined, for example, by curve-fitting on an equiprobable least-squares principle remains to be clarified.

The attractiveness of the Fourier approach to eclipsing binary light curve analysis as developed by Kopal and others is thus not in doubt. As a test of its efficacy to practical examples it was decided to study derived solutions of the light curves of SZ Cam – a well known star showing moderate proximity effects and grazing annular-total eclipses (see, for instance, Budding, 1973, 1974, 1975). Various possibilities in the method of application of the derived relationships connecting the geometrical elements of the eclipsing binary with certain Fourier integrals of the light curve to practical cases have been discussed in the literature already quoted. In this paper the stages through which procedures passed in this particular case will be outlined with a conscious look towards numerical or practical features.