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ON THE MACHINE COMPUTATION OF THE ORBITS OF ECLIPSING BINARIES

D. M. Popper

Department of Astronomy
University of California, Los Angeles

RESUMEN

El empleo de programas de computadora para la solución de curvas de luz de binarias eclipsantes implica un progreso notable. Se discuten brevemente algunas prácticas deseables en el uso de dichos programas.

ABSTRACT

The use of computer programs in the solution of light curves of eclipsing binaries marks a great advance. Some desirable practices in the use of computer programs are discussed briefly.

Key words: STARS-ECLIPSING BINARIES

I. INTRODUCTION

The application of high-speed computers to the solution of light curves of eclipsing binaries marks a great step forward in our ability to make optimal use of observations of good precision. Cester and his colleagues at Trieste (Cester *et al.* 1979) have tabulated published solutions of 166 eclipsing binaries obtained by modern computer methods. They also give references to a number of papers in which computer programs are described. In a paper soon to be published (Popper and Etzel 1981), results are given of the application of a very efficient computer program, based on the integration scheme of Nelson and Davis (1972), to seven detached eclipsing systems. It is not my purpose to discuss or compare the different computer schemes, but rather to make some general comments about their application in practice.

Along with the obvious very great advantages of these computer programs, their use can also lead to the adoption of some rather poor practices, and it is on some of these that I wish to comment briefly. Most of these practices arise because the computing machine does nearly all the work, and the investigator is not required, as he was in the older methods, to look at the observations and to carry out several operations with them himself. Another practice associated with machine solutions is the listing of "final astrophysical results", without specifying the quantities derived directly from the light curve that would convey to the reader a clearer understanding of the nature of the system. In the following, some more detailed points are discussed. Some of the discussion applies primarily to the relatively simple cases of detached components, where the points I wish to make stand out most clearly.

II. SMALL ORBITAL ECCENTRICITIES

Unless primary eclipses in a system are total, it is necessary that both minima be obtained in order to derive a solution. In that case, some information on $e \cos \omega$ is derivable. But only 16 of the systems in the Cester *et al.* (1979) catalogue have values of $e \cos \omega$ given. Lucy and Sweeney (1971, 1973) have argued that small eccentricities should not and probably do not exist in close binaries. In our study (Popper and Etzel 1981), however, only one out of six systems with well-defined secondary minima has $e \cos \omega$ equal to zero within observational error, while values of 0.010, 0.008, 0.004, and 0.003 were well determined.

III. LIGHT VARIATION BETWEEN MINIMA

"Rectification" procedures are not employed in computer analyses, and one includes all observations, both inside and outside eclipses, in the solution. The coefficients of the old-fashioned Fourier series contain, nevertheless, important information, useful both in describing the nature of the light curve and in testing the model used in the computer analysis. These coefficients are predictable from the mass ratio, limb-darkening, gravity-darkening, and reflection coefficients that are either explicitly or implicitly employed in the solution. How well do the observed coefficients agree with those predicted? If the agreement is poor, what is the effect of the disagreement on the parameters obtained in the solution, and what is the nature of the disagreement? In three of our systems with relatively small tidal distortion of the components, the observed coefficient of $\cos 2\theta$ agrees with that predicted only if the magnitude of the reflection effect is considerably smaller than given by the standard theory.

IV. SURFACE FLUXES AND LIGHT RATIOS

Surface fluxes are fundamental quantities relating to the radiation leaving a star, and the flux ratio for the two components is derivable directly from the photometric observations (with minor corrections for limb darkening) for systems with nearly circular orbits and nearly spherical stars. Yet even in such simple cases, this ratio is not generally given. One may find in published results that, if he computes the ratio of fluxes from the ratio of the two values of ℓ/r^2, the flux ratio is not in good agreement with that obtained directly from the depths of the two minima. One reason for the discrepancy may be that the values of the ℓs and rs contain the uncertainties of the solution, while the observed depths do not.

Another practice that is unfortunate is to publish temperatures rather than flux ratios. Temperatures depend on the model used and are much less directly related to the observations than fluxes. Furthermore in a consistent solution, the flux ratio should be correlated with the difference in color index of the two components. The situation is even worse if, as in numerous published solutions, in particular those of the Cester *et al.* (1979) catalogue, only the bolometric luminosity ratios are given, and not those derived in the solution. The bolometric ratios depend on the adopted temperatures, adopted wavelengths, assumed spectral energy distributions, etc. When neither the surface-flux ratio nor the light ratio in the observed wavelength band is given, the reader is at a loss to know what the photometric solution really is. He is unable, for example, to compare the photometric light ratio with that found from spectrograms, a comparison that is important in judging the validity of a photometric solution. In this connection, the use of a computer does not necessarily remove the potential ambiguity as to whether primary eclipse is a transit or an occultation.

V. COLOR INDICES

Light curves should *always* be observed in at least two wavelength bands on a color system related directly to a well-established standard system by observation of numerous standard stars. In most published solutions, the color indices of the two components, required for our understanding of the nature of the stars, can be obtained only from the light ratios in the two bands, and as noted, even these may not be given. But as in the case of the flux ratio, the color index of a component can be obtained directly from the observations, in this case from the color of the light lost during its eclipse if the eclipse is fairly deep, without reference to the solution with all its uncertainties. Allowance must be made fo the difference in limb darkening in the two color band:

VI. OTHER USEFUL QUANTITIES

Quantities that tend not to be published any more ar approximate values of the depths and widths of th minima and fractional light of the eclipsed star covere at mid-eclipse. While it is true that the ultimate purpos of a solution is to obtain parameters describing the stars it is very helpful in evaluating a solution to have som concept of the nature of the light curve and of th geometry of the system.

VII. UNCERTAINTIES OF THE DERIVED PARAMETERS

A great advantage of computer analysis of light curve is the ability to obtain mean errors of the parameter from application of the least-squares or other algorithm But it is a common result that the mean errors of th radii or of the orbital inclination are much smaller tha the differences in the values derived in different wave length bands or in independent observations. Hence th significance of the internal mean errors is in doubt, an they should not generally be accepted as realisti evaluations of the uncertainties of the parameters. A example will serve to illustrate the point. For V805 Ac there are the Cester *et al.* (1978) analysis of Fresa observations and our analysis of my V observation (Popper and Etzel 1981) for comparison (Table 1 We have found that Wood's program, employed by Ceste *et al.*, gives essentially identical results as our prograr

TABLE 1

PHOTOMETRIC SOLUTIONS FOR V805 AQL

Observer	k	r_1	i
Fresa[a]	0.739 ± 0.006	0.199 ± 0.002	82°.2 ± 0°.
Popper[b]	0.768 ± 0.017	0.187 ± 0.002	85°.9 ± 0°.

a. Cester *et al.* (1978).
b. Popper and Etzel (1981).

when applied to the same observations. We see that th differences in k (ratio of the radii), r_1, and i from th two sets of observations, are respectively 2 times, times, and 9 times the larger mean errors in the value: In my opinion, such discrepancies between internal an external mean errors arise, at least in part, from tw interrelated factors: 1) the very great sensitivity of th results to the observations over very small portions o

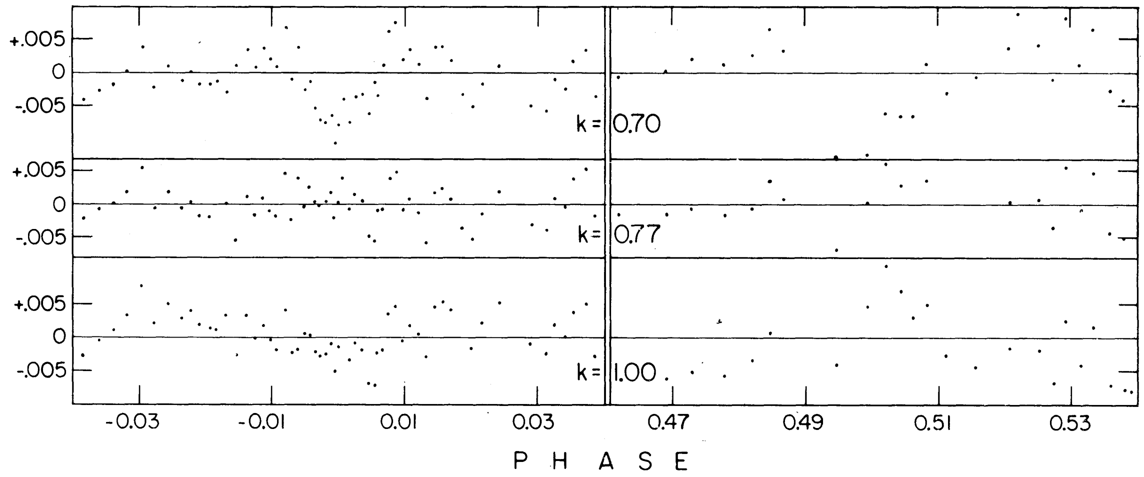

Fig. 1. Residuals for 3 solutions of the V observations of V805 Aql. The unit is the light of the system at quadrature.

ıe light curve near mid-eclipses, and 2) the existence of ossible systematic "night errors" in the observations. he first point is illustrated in Figure 1, showing the ›siduals within minima for 3 solutions in our investiga- on of V805 Aql. Although the formal mean error in k ± 0.017, values between 0.74 and 0.95 give good fits › the observations, with systematic trends in the ›siduals less than 0.002 light units. (The standard eviation of a single plotted point from the predicted ght curve is ± 0.003.) The availability of a relatively mple, inexpensive program enables one to carry out umerous tests of this kind. Other examples may be ›und in Popper and Etzel (1981). Figure 2 illustrates ıe nature of night errors. This effect is well known to bservers who look at their observations carefully and o not just throw them all into one large computer pot.

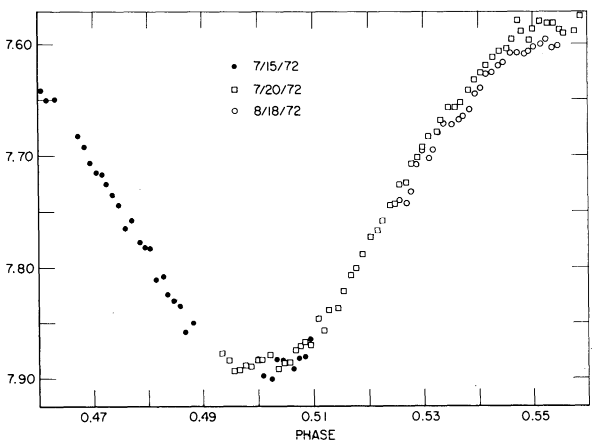

Fig. 2. Observations of V805 Aql in secondary minimum.

The point to be made is that the errors in the observations on a given night may have a different error pattern from that of random observations made on different nights. The critical parts of a light curve near mid-eclipse will typically be obtained on only a small number of nights. Hence the precepts of the method of least squares (or other similar algorithm), which require that errors in the observations be uncorrelated, may be violated. It is immaterial from the standpoint of this discussion whether the larger night-to night scatter is a consequence of intrinsic variability of one component of the binary, of variability of the principal comparison star, or some other cause. It should be noted that the effects illustrated in both of these figures are only a few thousandths of a magnitude. Night errors as large as those shown in Figure 2 are not, of course, always present.

VIII. CONCLUSION

The conclusion to be drawn is that great care must be exercised in evaluating meaningful uncertainties of the parameters found in a photometric solution. Perhaps the most reliable approach is to have available two completely independent sets of observations obtained at different times by different observers.

Finally, it should go without saying that use of an automatic computing program cannot provide meaningful results in cases where the older methods show the solution to be indeterminate. Examples are: 1) a partial primary eclipse with no information from the secondary minimum; 2) both minima partial eclipses of approximately equal depth, but not very deep; 3) asymmetrical light curves. It is true that use of a program, however injudicious, may provide results. Accepting the results as having physical meaning is even more injudicious.

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DISCUSSION

Sofia: Why did you choose to compare your analysis method with the one by D.B. Wood rather than the more sophisticated one by Wilson and Devinney, for example?

Popper: Programs such as the Wilson-Devinney must be employed for deformed components. But in detached, little distorted stars, the use of such a system constitutes over-kill, and is vastly more expensive than a program such as ours. We can afford, for detached systems to carry out many solutions to experiment with different choices of parameters, etc. It is easy to misuse the more complex programs when applied to uncomplicated systems.

Pacheco: Does your computer program use an atmospheric model or compute fluxes from a black-body law?

Popper: Our program uses results directly from the observations, including the fluxes in the observed spectral region. The use of model atmospheres or of Planck functions should be entered into only afterwards. My plea is for users of computer programs to convert their results to some system other than that observed as a separate operation, and not require the readers to guess what the direct results are.

Daniel M. Popper: University of California, Department of Astronomy, Los Angeles, CA 90024, EUA.