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A METHOD FOR THE ANALYSIS OF LONG SERIES OF VISUAL OBSERVATIONS OF RED, SMALL AMPLITUDE VARIABLE STARS

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Abstract. This paper proposes a method that corrects the spurious effects induced by systematic differences in the estimates made by a great number of visual observers. Their own systematic error is calculated individually for each observer and the duly corrected estimates then analyzed using weighted means. The method has been applied to numerous series of visual estimates obtained by GEOS observers on variable stars of late spectral type and a comparison with photoelectric measures shows its efficiency. This method could be especially useful in the analysis of visual series secured on long-period or irregular variables.

1. Introduction

The usefulness of the visual observations of variable stars is much of a controversial matter. Series of visual estimates of Mira and U Gem-type stars spanning long intervals are currently accepted and used. First elements of eclipsing binaries and RR Lyr stars fainter than 11 mag and of amplitude grater than 0.5 mag are frequently established from visual observations: many such examples can be found in the *Journal of the AAVSO*, *BBSAG Bulletin*, *GEOS Circular*, *Variable Stars*, etc. On the contrary, results obtained by independent visual observers on bright periodic variables of amplitude smaller than 0.5 mag are contradictory and such as to allow their credibility to be questioned (Szeidl, 1980). On the other hand, the observation of such stars can easily be managed by amateurs using their own photoelectric instrumentation or working in collaboration with Astronomical Observatories. As regards the RR Lyr stars, a carefully balanced assessment of visual versus photoelectric results was made by Szeidl and Szabados (1984).

The problems set by irregular and semi-regular stars of late spectral type are more controversial. Too bright for an adequate photographic survey, their photoelectric observation would demand telescope-time distributed over several consecutive years. It is obvious that an increase of the number of non-professional observers equipped with photoelectric instruments would ensure, in the years to come, a good coverage of the activity of such stars. In that sense, the policy of the major visual observer associations developing their own photoelectric sections must be pointed out. There, however, remains the problems set by the enormous amount of information contained in extended series of visual observations available on semi-regular and irregular variable stars of late spectral type.

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1987Ap&SS.134..135R

What sort of difficulty can be encountered when using such series? Visual estimates covering a period of ten years can be used not only to get an idea of the light curve but also to find possible periodicities. Mantegazza (1982) has obtained significant results from the visual observations of μ Cep secured by Hassenstein (1938), while he could not derive any conclusion from visual estimates by the A.A.V.S.O., owing to the presence of important systematic errors. The same problem had already been encountered for the same star by Larsson-Leander (1964) who concluded that, as regards red variables with small amplitudes: 'long series of estimates, made by one and the same observer, might show much smaller scatter and more closely reproduce the real variations'. It appears obvious that the poor results are caused by the existence of a systematic difference between observers which is quite unsuspectedly introduced into the processing of the estimates: apparent variations are thus induced and the error intrinsic to the method of visual observation is thereby magnified. Recently, Percy *et al.* (1985) have pointed out the presence of systematic errors in visual estimates of ρ Cas by the A.A.V.S.O., though they could not assess its numerical importance.

The procedure (called ALCEP method) described in the present paper allows the correction of such errors for series secured by a great number of visual observers and yields data which is more directly usable. This guarantees a light curve which is more representative of the fundamental characters of the variation of brightness and ensures a real improvement of the accuracy as the number of observers and estimates increases. Moreover, the assessment of the mean error, made in a more correct manner, gives a better idea of the confidence one can place in the results.

2. The Method

To implement this analysis, the observing period is first divided into equal time-intervals, during which the variation of the star can be considered as negligible. To do this, the time-scale and the amplitude of the variation have to be known beforehand. As a rule, the star may vary by 0.05 mag in each time-interval without compromising the quality of the results. It follows from this that a great number of estimates must be available with such a distribution over the observing period as to have a good number of them in each time-interval.

The ALCEP method is based on the fact that each visual observer generates an error distribution characterized by a systematical difference Δm and a standard deviation σ. In such a case, it is not permissible to assume that the arithmetic mean of all the values, regardless of the observers, is the best estimate of the real value. It is, therefore, necessary to calculate for each time-interval the mean

$$\overline{m} = \frac{\sum_z^N \left(\sum_k^{n_z} (m_{kz} - \Delta m_z)/\sigma_z^2 \right)}{\sum_z^N n_z/\sigma_z^2}, \tag{1}$$

where N is the total number of observers, n_z the number of estimates made by the zth

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1987Ap&SS.134..135R

observer in the interval considered, Δm_z and σ_z, respectively, the systematic difference and standard deviation relative to the zth observer. However, to calculate $\overline{m}$, it is necessary to have a previous knowledge of Δm_z and σ_z^2 defined as

$$\Delta m_z = \frac{\sum_j^{N_z} (m_{jz} - \overline{m})}{N_z} , \tag{2}$$

$$\sigma_z^2 = \frac{\sum_j^{N_z} (m_{jz} - \overline{m})^2}{N_z - 1} , \tag{3}$$

where $\overline{m}$ is the mean magnitude for the interval including estimate m_{jz} and N_z the total number of estimates made by the zth observer. Obviously, such a problem can be solved by an iterative process only. Thus, initial values of Δm_z and σ_z^2 being given, it is possible to calcumate $\overline{m}$, use it to determine new values of Δm_z and σ_z^2 and repeat the procedure. The iteration will stop when, on the ith run, each $\overline{m}$ value will differ from that calculated in the previous run by less than ± 0.01 mag. To start with, initial values $\Delta m_1 = \Delta m_2 = \cdots = \Delta m_N = 0$ and $\sigma_1^2 = \sigma_2^2 = \cdots = \sigma_N^2 = 1$ may be used, which amounts to calculating the usual arithmetic mean. This run will be termed 'iteration 0'. At the end of the first iteration an evident change in the shape of the light curve can already be noted as well as a good definition of Δm_z and σ_z^2. A possible improvement would consist in the calculation, on each run, of the curve which fits best mean magnitudes $\overline{m}$ (for instance by means of a Fourier analysis) and using in relations (2) and (3) the magnitude interpolated for the time of observation instead of $\overline{m}$. This improvement, which was used for most of the application examples described in the following section, would considerably reduce the effect of a variation of the star within the limits of the time-interval. It would, however, demand a good coverage of all the observing season.

3. Applications

The ALCEP method was applied to estimate secured by GEOS on V449 Cyg, EU Del, IS Gem, OP Her, and ρ Per. In every case, the number of iterations was never superior to 5. Considering the bulk of about 350 values of Δm and σ obtained, it is possible to evaluate the importance of systematic and random errors. Figure 1 shows the histogram of the distribution of Δm. As can easily be noted, systematic differences of the order of 0.10 mag are fairly common. The fact that all the observers used the same comparison sequence is most important: if different sequences were used, the importance of this error would increase. Particular care must, therefore, be taken when processing series from different associations as these may have used different comparison sequences or different values for the magnitudes of the same comparison stars.

Figure 2 shows the histogram of the standard deviations: a typical error for an average observer is between ± 0.06 and ± 0.10 mag. Observers with $0.10 < \sigma < 0.15$ mag are still fairly numerous and it is even possible to find extreme values $\sigma < 0.05$ mag and

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1987Ap&SS.134..135R

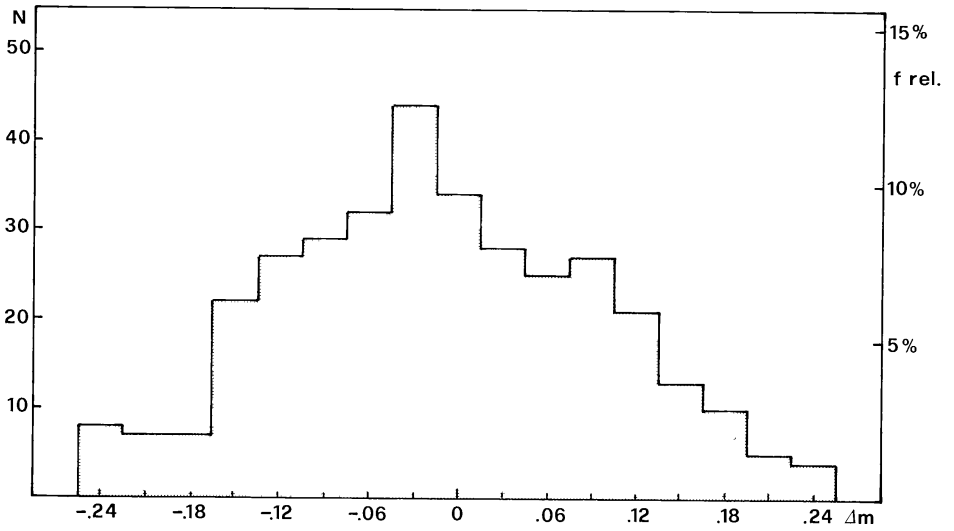

Fig. 1. Histogram of the distribution of about 350 Δm obtained in the course of the processing of visual estimates of V449 Cyg, EU Del, IS Gem, OP Her, and ρ Per. The central value is different from 0 as we used weighted means.

$\sigma > 0.15$ mag. The latter values, however, are characteristic of observers who made very few estimates and cannot, therefore, be considered as an indication of higher or smaller accuracy.

It, therefore, seems that an average visual observer can make estimates with a standard deviation $\sigma = 0.08$ mag, but affected by a systematic error of the same order. This explains why series by individual observers may appear more reliable when compared with those obtained by a great number of observers but uncorrected for systematic differences. It also follows clearly that lumping the greatest possible number of visual estimates and correcting them for systematic differences entails a real improvement of the accuracy.

IS Gem. The star is classified as an SRd but recent photoelectric measures (Poretti and Fumagalli, 1985) show that its brightness does not vary by more than 0.01 mag. The gradual transformation of the light curve into a straight line, from iteration 0 (using

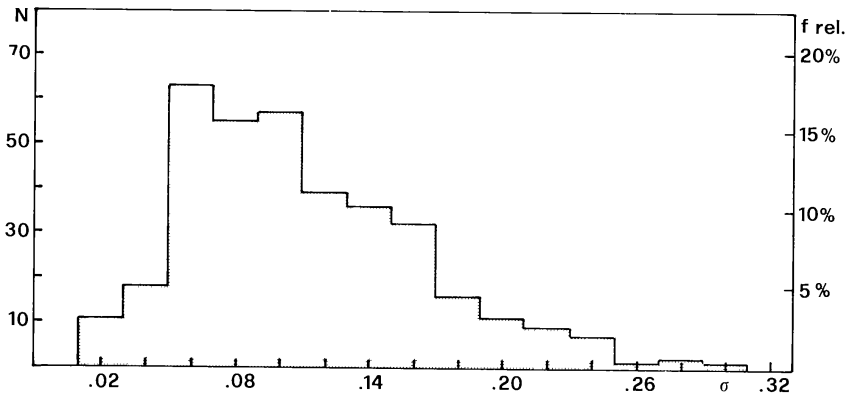

Fig. 2. Histogram of the distribution of about 350 standard deviations obtained in the course of the processing of visual estimates of V449 Cyg, EU Del, IS Gem, OP Her, and ρ Per.

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1987Ap&SS.134..135R

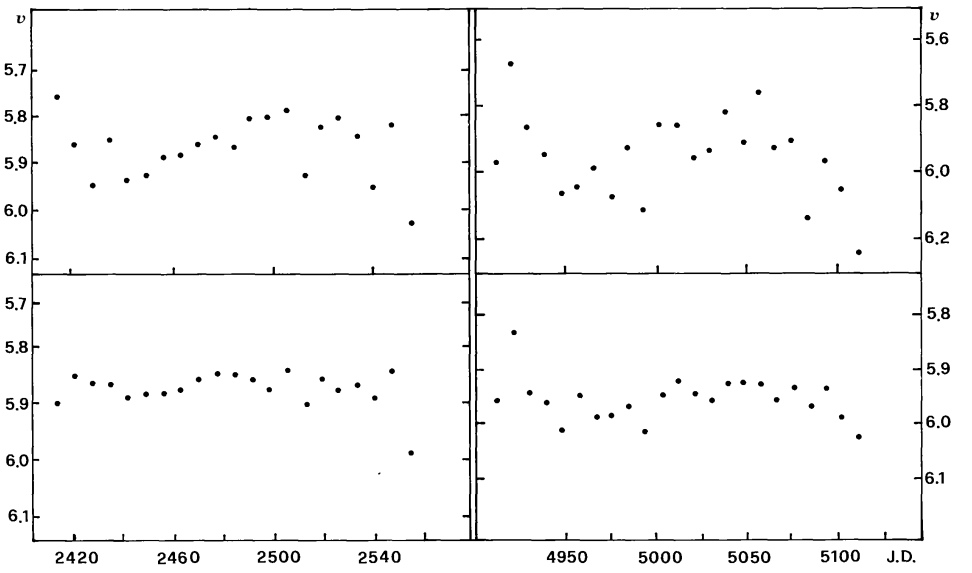

Fig. 3. *Left*: 1974–1975 light curves of IS Gem. *Right*: 1981–1982 light curve of IS Gem. *Top*: curves obtained on iteration 0. *Bottom*: curves obtained on the last iteration.

ordinary arithmetic means and without any correction) to the last iteration (using corrected and weighted means) is shown in Figure 3 which refers to the 1974–1975 and 1981–1982 observing seasons. The reduction of the scatter is also worth noting: the errors on the individual points are ranging from ± 0.02 to ± 0.07 mag and it is consequently easy to surmise a constant brightness. The same trend is also present in the light curves for the other years, thus evidencing the capacity of the ALCEP method to reveal the true nature of the light curve by correctly evaluating the intrinsic error. The processing of 2050 visual estimates made by GEOS observers was described by Fumagalli (1987). Table I sums up the data for 7 years of monitoring: it gives, for each observing season, the number of observers involved, the total number of visual observations, the arithmetic mean m_0 of all the estimates (regardless of the observer), the mean $\overline{m}$ obtained from the estimates corrected for the systematic difference and the respective standard deviations. It is worth noting how, in the case of m_0, the standard deviation

TABLE I

Summary of the 1974–1982 observations of IS Gem

Season	N obs.	N est.	m_0	s.d.	$\overline{m}$	s.d.
1974–1975	17	377	5.86	±0.18	5.82	±0.15
1975–1976	23	490	5.82	±0.13	5.82	±0.12
1976–1977	8	207	5.85	±0.12	5.82	±0.11
1977–1978	14	243	5.90	±0.17	5.95	±0.12
1978–1979	8	112	5.89	±0.14	5.89	±0.10
1979–1980	9	176	5.92	±0.14	5.86	±0.12
1980–1981	11	219	5.96	±0.21	6.00	±0.11
1981–1982	15	226	5.95	±0.20	5.90	±0.15

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1987Ap&SS.134..135R

takes on different values and how it increases as the mean magnitude varies, a clear indication of the major influence of systematic errors. For $\overline{m}$, on the other hand, the standard deviation is nearly constant and comparable with that of an average observer. The variation of the mean magnitude is caused by different observers joining in or leaving the patrol, which stresses the importance of the systematic differences. It follows that unless the star be always monitored by the same observers or unless the observers be in very great number, variations of the mean magnitude of 0.2 mag may be introduced by changes in the group of observers from one year to another. The influence of this effect may be reduced by analyzing data in batches covering several years rather than processing them by separate observing seasons. Figure 3 also shows how a star of constant brightness can be transformed into a variable star of amplitude 0.4 mag when one rests satisfied with simply averaging the estimates of a great number of observers.

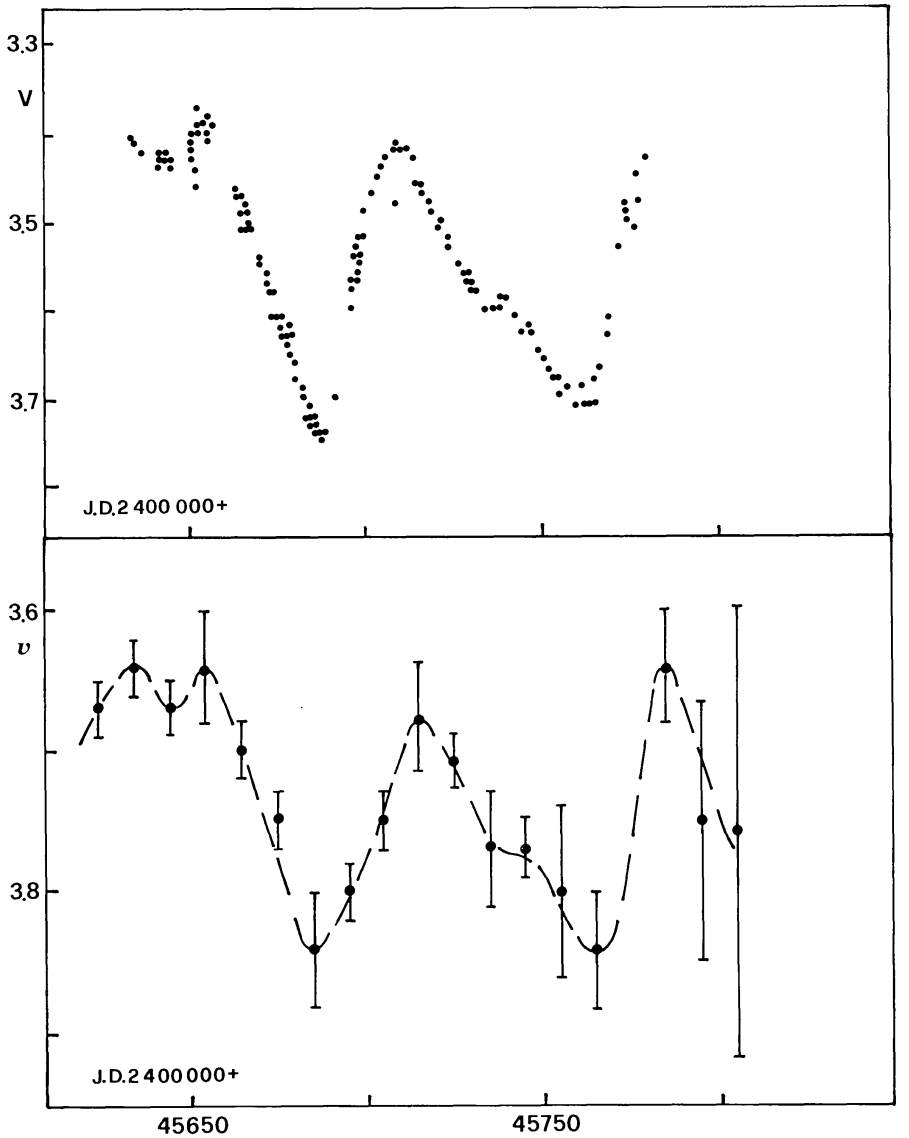

Fig. 4. Light curves of ρ Per during the 1983–1984 observing season. *Top*: photoelectric. *Bottom*: visual; error bars are $\pm 2\sigma$.

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1987Ap&SS.134..135R

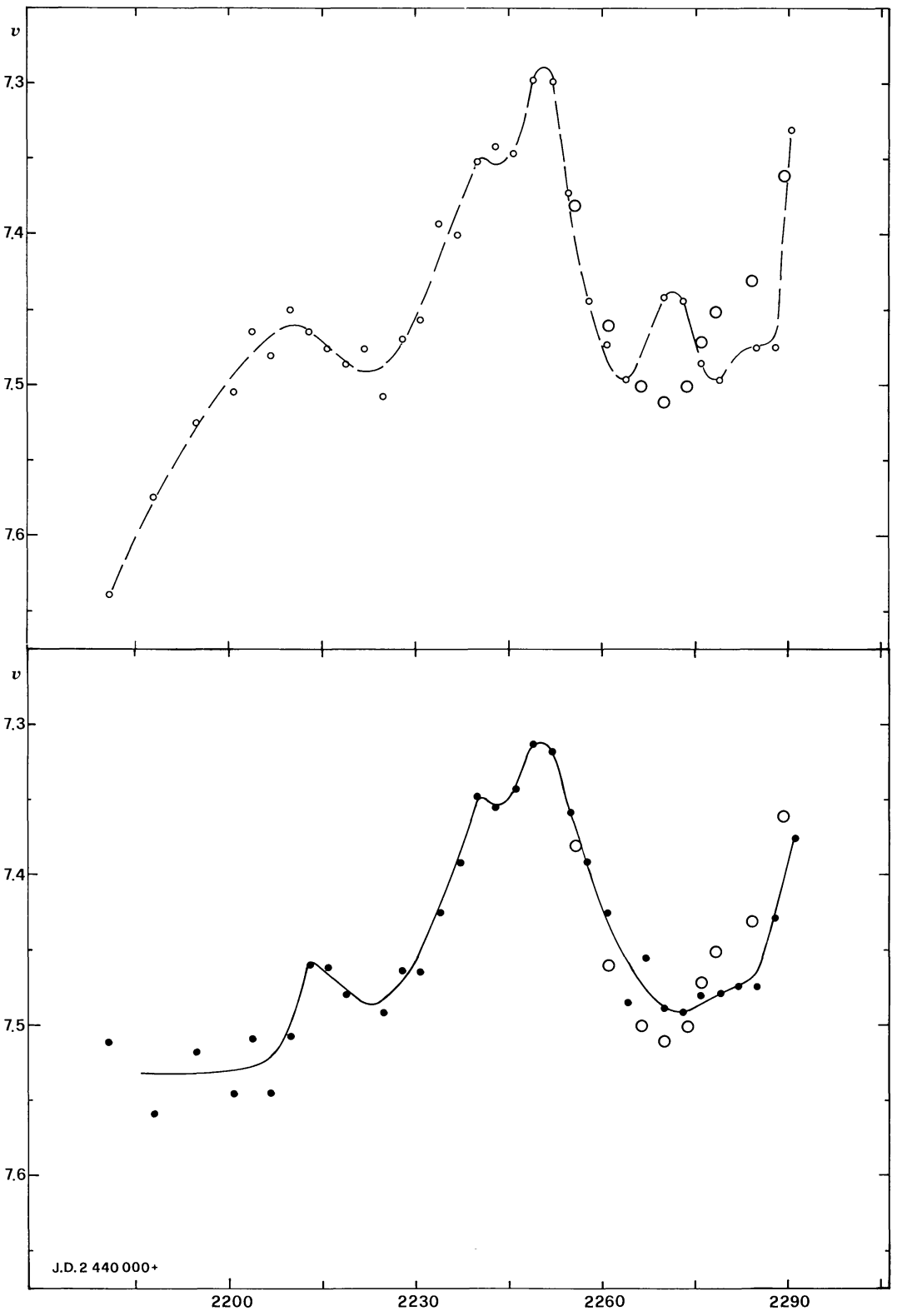

Fig. 5. Visual light curve of V449 Cyg: the photoelectric measures (circles) are reported for comparison. *Top*: means obtained on iteration 0 and best interpolating curve. *Bottom*: means obtained on the last iteration and best interpolating curve.

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1987Ap&SS.134..135R

ρ Per. The processing of 4587 visual estimates made by GEOS observers between 1974 and 1984 was made by Boistel (1987). Figure 4 (bottom) shows the visual curve obtained by 16 observers totalling 708 estimates. During the same period, Boyd *et al.* (1984) secured the photoelectric observations reported in Figure 4 (top). The perfect agreement on the trend of variations and the times of extrema is worth noting. Visual and photoelectric amplitudes differ notably and a strong systematic difference (0.25 mag) between the two sets of data is to be noted (see Boistel, 1987, for discussion). The analysis of 10 years of visual observations by GEOS members shows that the light curve is strongly variable, suggesting that ρ Per might be a multiperiodic star: the apparent period, as shown by Figure 4, is between 40 and 60 d.

V449 Cyg. The processing of about 1400 visual estimates secured by GEOS in the summer of 1974 was described by Figer (1975). At the same time, L. Baldinelli made 9 photoelectric *V* measures: it is, therefore, possible to get further information on the accuracy of visual estimates. Figure 5 shows how the application of the ALCEP method makes the final light curve more closely fitting the photoelectric measures: the standard deviation changes from ± 0.049 mag (iteration 0) to ± 0.033 mag (second iteration).

OP Her. The processing of 1800 visual estimates secured by GEOS in the summer of 1974 was described by Figer and Remis (1978). In this case also, it was possible to compare the final light curve with photoelectric *V* measures with results very similar to those for V449 Cyg. Here again the presence of a strong systematic difference (0.28 mag) between visual and photoelectric observations is worth noting (see Figer and Remis, 1978, for discussion).

EU Del. The light curve obtained in 1975 by 30 GEOS observers totalling 851 visual estimates shows a quasi-periodic variation with an amplitude 0.5 mag and of variable shape. These results are similar to those obtained photoelectrically by Wisse (1981) and Landis (1984). In the years 1976, 1977, and 1978 the curve shows very small variations, but some periodicity is still discernible.

4. Conclusions

The correction of the systematic error allows a noticeable improvement of the quality of the results that can be obtained from an analysis of extended series of visual estimates, and this especially in the case of variable stars of late spectral type and with small amplitudes. The use of computer-assisted processing by many variable star observer associations makes it easy to take in consideration the methodological hints given in the present paper and the publication of the final light curves can thus meet more easily the criteria of quality required for them to be of real use.

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1987Ap&SS.134..135R

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