THE THIRTY-TWO YEAR CYCLE IN ALGOL

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Abstract

Five new photoelectrically timed minima of Algol are reported, JD (hel.) 2443909.6538, 2444167.7182, 2444236.5321, 2444560.5340, and 2444623.6188. The ephemeris of Frieboes-Conde, Herczeg, and Hog (2434705.5493 + 2^d.86732442E) is still a good predictor if a correction term with 32-year periodicity is added.

Apsidal motion is eliminated as the cause for the 32-year periodicity in the times of primary minimum because times of secondary minimum derived from observations in the literature do not fit that model, the deviation being at least 6 sigma. Likewise the 32-year effect appears to be unrelated to asymmetry in the light curve, at more than a 3 sigma confidence level.

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1. Introduction

The eclipsing binary star system Algol has attracted the attention of astronomers from the time of William Herschel in the 1700's. It has been known for more than a century that the eclipses do not recur at precisely constant intervals. There have been many studies of the period of Algol, for example by Hellerich (1919), Ferrari (1934), Eggen (1948), and Frieboes-Conde *et al*. (1970). With centuries of eclipse observations and scores of investigators to analyze them, the results are somewhat contradictory. However, at least two important results seem to emerge from recent works: 1) there are substantial but erratic changes in the orbital period, and 2) there is a 32-year cyclic effect in the data.

The latest substantiated orbital period change occurred in 1952 as reported by Frieboes-Conde *et al*. The present author has pointed out that eclipse timings indicated a more recent change around 1975 (Mallama 1978). However, the author's latest observations presented in Sections 2 and 3 of this paper are more in agreement with the older ephemeris.

The 32-year cyclic effect is still present in all the latest observations, but the long-held belief that it is due to rotation of the line of apsides of the binary's orbit has recently been challenged by Soderhjelm (1980) and by Walter (1980). In Section 4 all of the available photoelectric observations of Algol's secondary eclipse are reviewed. The analysis of these data seems to eliminate apsidal motion as the cause of the 32-year cyclic phenomenon. In the last section, it is shown that light curve asymmetry probably can be ruled out also.

2. New Observations

Five eclipses of Algol were observed between 4 February 1979 and 18 January 1981. The observations were carried out with the 30-cm and 91-cm Cassegrain telescopes at NASA's Goddard Space Flight Center, using a 1P21 photomultiplier tube and blue and yellow filters closely matching B and V of the international UBV system. The comparison star, π Persei, was chosen because it is close to the variable, is bright, has almost exactly the same B-V color index as Algol at mid-eclipse, and is not known to be variable itself. The comparison star was observed within a few minutes before and after every observation of the variable.

The data for each timing came from 18 to 45 measurements of Algol obtained with each of the two filters during each eclipse. Differential magnitudes were computed and corrected for extinction. The rms errors are generally less than 0.01 magnitude.

3. Current Ephemeris

The five times of minimum derived from this study are listed along with three other recent observations in Table I. The errors quoted for the author's results are equal to one-half of the difference between the times obtained from the blue and yellow filter data. The O-C values are relative to the linear ephemeris (page 86, eq. 3) of Frieboes-Conde et al. (1970). The O-C diagram in Figure 1 is a plot of the O-C values from Table I along with those of 23 other photoelectric minima observed since 1964, compiled by Soderhjelm (1980) and by Mallama (1978). The lines represent the O-C expected from the 32-year effect according to Hellerich (1919), Pavel (1950), and Kopal et al. (1960). Notice that the data points are still fairly well represented by all three formulae. Further, notice that the tendency for data to fall below the lines around JD 2443000 (1976) has ceased, and by JD 2444500 (1980) the data again are well represented by the expected 32-year effect. Thus it appears that the data are still adequately represented by the ephemeris of Frieboes-Conde et al. There may have been a brief period decrease in the late 1970's which was offset by a similar rapid increase, or perhaps this variation is just another unexplained anomaly in the O-C record of Algol.

4. Analysis of 32-Year Effect and Secondary Minima

Part of the most recent portion of the 32-year cycle is visible in Figure 1. The influence of this cycle over the long history of Algol observations is shown more completely in the O-C diagrams of Eggen (1948) and Soderhjelm (1980), where it can be seen as far back as 1845. This is about the time at which Hellerich (1919) starts his 32-year ephemeric term. Thus, in 1981 the cycle is repeating for the fifth time, and there is no reason to doubt its reality.

When this kind of repeatability is detected in the times of minimum for an eclipsing binary, it is customary to assume that it is due either to a rotation of the line of apsides of the binary orbit, or to the light-time effect as the eclipsing pair orbits a more distant, third companion. Frieboes-Conde et al. (1970) have convincingly eliminated the light-time argument. They show that the motion of the eclipsing pair should cause a detectable astrometric shift, but that astrometric observations do not reveal such a shift.

By the process of elimination it has been reasoned that apsidal motion is causing the 32-year cycle in the times of primary minimum. Recently two separate investigators have challenged this belief. Soderhjelm (1980), in an analysis of the photometry of Algol, has concluded that a model light curve can be fitted better to a circular orbit than to an eccentric orbit with the characteristics inferred from the 32-year cycle. He speculates that the 32-year phenomenon may be due to mass transfer between the binary star components that is modulated by a "magnetic cycle." Walter (1980) asserts that evidence for eccentric orbits in Algol systems in general is lacking, and when present is really due to the influence of circumstellar material on spectroscopic observations. Having argued that the orbits are circular, he suggests that the variation in the times of primary minimum is due to distortion of the shape of the primary eclipse by gas streams in the circumstellar space. The 32-year periodicity in Algol itself is then argued to be due to the effects of the gas stream which follow a supposed 32-year precession cycle of the primary star in that system.

The most direct method for deciding the question of apsidal motion is to compare the observed and predicted times of secondary minimum as a function of phase in the 32-year cycle.

For apsidal motion in an orbit with small eccentricity we would expect to see a sinusoidal O-C variation in the times of secondary minimum that is a mirror image (across O-C = 0) of the variation in the times of primary minimum. See Figure 2a. Thus, if we refer all phases of observation to a contemporary time of primary eclipse, we should find that the phase of secondary eclipse relative to that of primary eclipse oscillates around 0.5 with an amplitude which is twice as large as the amplitude of either primary or secondary O-C variation alone, and 180 degrees out of phase with primary. See Figure 2b. For each set of observations analyzed in this paper, the phases of all the observations near secondary eclipse are referred to a time of primary minimum observed during the same season. Then the observed phase of secondary minimum is computed from the observational data, and the predicted phase is computed from an ephemeris of the 32-year cycle. When these pairs of phases are plotted, they should fall along a straight line with a positive slope of unity if they support the apsidal motion hypothesis.

The observational data that were analyzed are listed in Table II, along with some comments. These data are believed to be a comprehensive group of the relevant data. Several other data sets were examined but they were excluded because of insufficient observations near secondary minimum, too much noise in the data, or because the depth of secondary eclipse in the passband of the observations was too shallow to make an accurate timing. In all cases, except for the observations of Smart (1937), the phases are referred to one time or to an average time of primary minimum observed in the same season. This reference reduces the error that would be incurred using a general ephemeris supposed to cover many years, and avoids the need for correcting observations for the light-time effect due to Algol C with still another uncertain ephemeris. Furthermore, since the depth of primary eclipse is about ten times greater than that of secondary in visible light, the error in the times of primary is negligible compared to that of secondary. Smart's observations could not be handled in this way because he did not list the original times for data near secondary eclipse, only normal phases which he computed himself.

The observed phase of secondary minimum was calculated by applying the method of Kwee and Van Woerden (1956), which also provides an error estimate. The results are presented in Table III. The errors quoted in the third column are derived from the Kwee-Van Woerden calculations in those cases where only one passband was observed, but they represent the standard deviation of the mean where two or more passbands were observed. In either case, a small amount has been added to account for errors in the ephemerides themselves. The predicted phase of secondary is listed in the last three columns of Table III for the ephemerides of Hellerich (1919), Pavel (1950), and Kopal et al. (1960), respectively.

Plots showing the relation between predicted phase and computed phase of secondary minimum are shown in Figures 3a, b, and c. The data points do not fall along the diagonal lines representing the relation expected for apsidal motion. Even without further mathematical treatment it seems that there is no evidence for apsidal motion in the Algol system. These graphs seem to indicate, too, that the phase of secondary is a little later than 0.5.

Statistical results of this analysis are given in Table IV, which shows the parameters of least squares fitting of the data to straight lines. While a slope of +1.0 is expected for apsidal motion, the slopes found for all three ephemerides are negative. Standard deviation error bars of the slopes, also given in Table IV, indicate that the negative slopes are not significant (they are all less than 2 sigma) but that the deviations from a slope of +1.0 are significant (they are all greater than 6 sigma). The intercept of the y-axis is near 0.503 for all three data sets, indicating that the phase of secondary minimum may be a little later than expected. However, this result is only at the 2 sigma level.

We conclude that the observed data disagree with the apsidal motion prediction at the 6 sigma (more than 99 per cent confidence) level.

5. Discussion

The results of Section 4 suggest that the 32-year cycle is not due to apsidal motion. Since the light-time effect has already been ruled out, we are left with the hypotheses of Walter (1980) and of Soderhjelm (1980). Walter's idea is that a 32-year precessional motion changes the geometry wherein the hot star is partially obscured by gas streaming. Thus the light curve of primary eclipse is distorted and the time of minimum is systematically shifted. Soderhjelm suggests that a 32-year magnetic cycle modulates the mass loss from the system, thus causing a cyclic variability in the orbital period. Either of these mechanisms could have caused the temporary O-C shift observed by the author in the late 1970's.

Notice, however, that these hypotheses predict different phase behavior for secondary minimum. Soderhjelm's involves an oscillating orbital-period change, so the phase of secondary minimum with respect to primary minimum should be constant. Walter's hypothesis, on the other hand, invokes a shift in the observed time of primary minimum relative to true conjunction, so the phase of secondary minimum should appear shifted by a corresponding amount if it is referred to the observed primary. In fact, the amount of the shift should be one-half of the amount expected for apsidal motion. Relating the phase of secondary to primary is exactly what was done in the analysis reported in the previous section. Thus the expected "slope" of observed versus computed phase of secondary would be +0.5 in the context of Walter's hypothesis. The values in Table IV and their errors demonstrate, however, more than a 3 sigma deviation from this prediction. Thus it appears that the 32-year cycle is not due to the obscuring effect of gas streaming and the supposed asymmetry of the light curve.

In closing, it is worthwhile to note that the 32-year ephemerides of Hellerich (1919), Pavel (1950), and Kopal *et al*. (1960) all predict a minimum in the phase of primary eclipse between 1983 and 1986 (also see Figure 1). So observers may wish to time primary and secondary minima more frequently during those years to follow this interesting phenomenon.

6. Acknowledgements

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TABLE I

Recent Photoelectric Minima of Algol

JD (hel.)	O - C*	Error	Reference
2443032.250	$-0^{d}.0092$	-	Rucinski (1979)
3060.923	-0.0095	-	Rucinski (1979)
3442.2895	+0.0026	-	Ebersberger *et al*. (197
3909.6538	-0.0070	$\pm 0^{d}.0010$	This paper
4167.7182	-0.0017	0.0006	This paper
4236.5321	-0.0036	0.0005	This paper
4560.5340	-0.0093	0.0005	This paper
4623.6188	-0.0056	0.0003	This paper

* relative to Frieboes-Conde *et al*. ephemeris:
MinI = JD 2434705.5493 + $2^{d}.86732442$E

TABLE II

Observational Data

Reference	Passband	Comments
Stebbins, 1910	no filter	Phase of secondary computed in this paper is very close to the one computed by Stebbins himself.
Stebbins, 1921	no filter	Phase of secondary computed in this paper is very close to the one computed by Stebbins himself.
Smart, 1937	no filter	Results of this paper are based on normal points listed by Smart; no JD's are listed for points near secondary minimum.
Hall, 1939	8660 Å	Paper presents IR and visual data, but only IR during secondary.
Stebbins and Gordon, 1975	b,g,r,i	Phases are explicitly corrected for Algol C light-time effect by Gordon; u and v passbands have too much scatter for the small eclipse depth to be used for timing.
Herczeg, 1959	3700, 4500, 6000 Å	-
Herczeg, 1964	Red	-
Chou, 1962	-	-
Chen and Reuning, 1966	IR	Paper presents IR and orange data, but there is too much scatter in the orange to be used for timing.
Wilson *et al*., 1972	4350, 5500 Å, V	-
Guinan *et al*., 1976	H_α (wide and narrow)	Paper presents H_α and H_β results, but the latter are not suitable for accurate timing.

TABLE III

Phases of Secondary Minimum

Source	Observed Secondary		Mean	Predicted Phase of Secondary		
	Phase	Error	Julian Date	Hellerich	Pavel	Kopal *et al.*
Stebbins, 1910	0.5045	±0.0010	2418700	0.4938	0.4923	0.4981
Stebbins, 1921	0.5045	0.0041	2422300	0.5074	0.5070	0.5064
Smart, 1937	0.5015	0.0049	2427700	0.4938	0.4949	0.4936
Hall, 1939	0.5008	0.0014	2429000	0.4916	0.4913	0.4945
Stebbins and Gordon, 1975	0.5002	0.0002	2433400	0.5055	0.5041	0.5062
Herczeg, 1959	0.4949	0.0024	2436300	0.5064	0.5081	0.5016
Herczeg, 1964	0.5008	0.0010	2437000	0.5041	0.5062	0.4992
Chou, 1962	0.5045	0.0037	2437239	0.5030	0.5054	0.4984
Chen and Reuning, 1966	0.5048	0.0031	2437600	0.5014	0.5038	0.4972
Wilson *et al.*, 1972	0.5031	0.0042	2438800	0.4963	0.4983	0.4943
Guinan *et al.*, 1976	0.5005	0.0030	2440900	0.4916	0.4913	0.4949

TABLE IV

Statistical Analysis of Observed versus Predicted
Phases of Secondary Minima (Figure 3)

Ephemeris	Slope	Y-Intercept
Hellerich	-0.134 ± 0.185	0.5028 ± 0.0021
Pavel	-0.152 ± 0.128	0.5030 ± 0.0011
Kopal *et al.*	-0.194 ± 0.114	0.5034 ± 0.0014

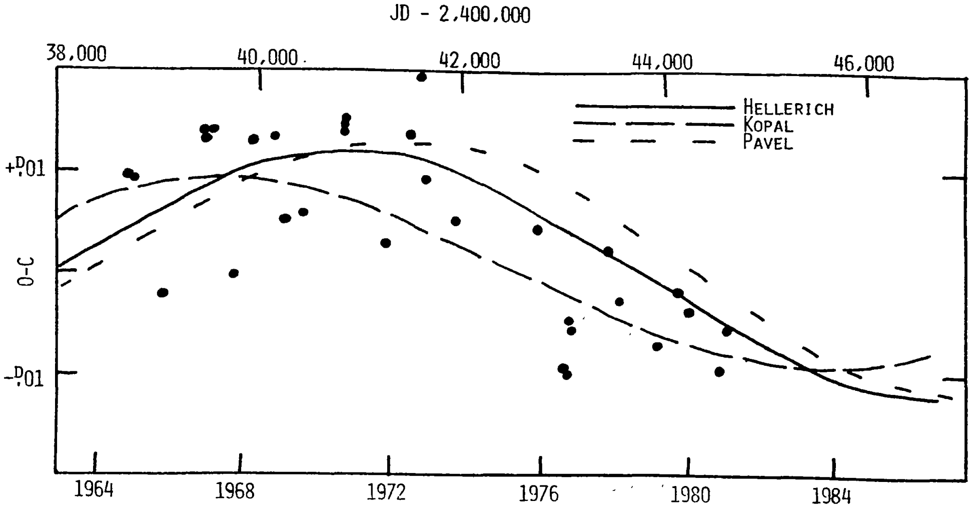

Figure 1. The O-C of Algol from 1964 to 1981, including the data from Table I. The dots are observed data points, while the lines correspond to the predictions based on the 32-year cyclic terms of Hellerich (1919), Pavel (1950), and Kopal *et al*. (1960).

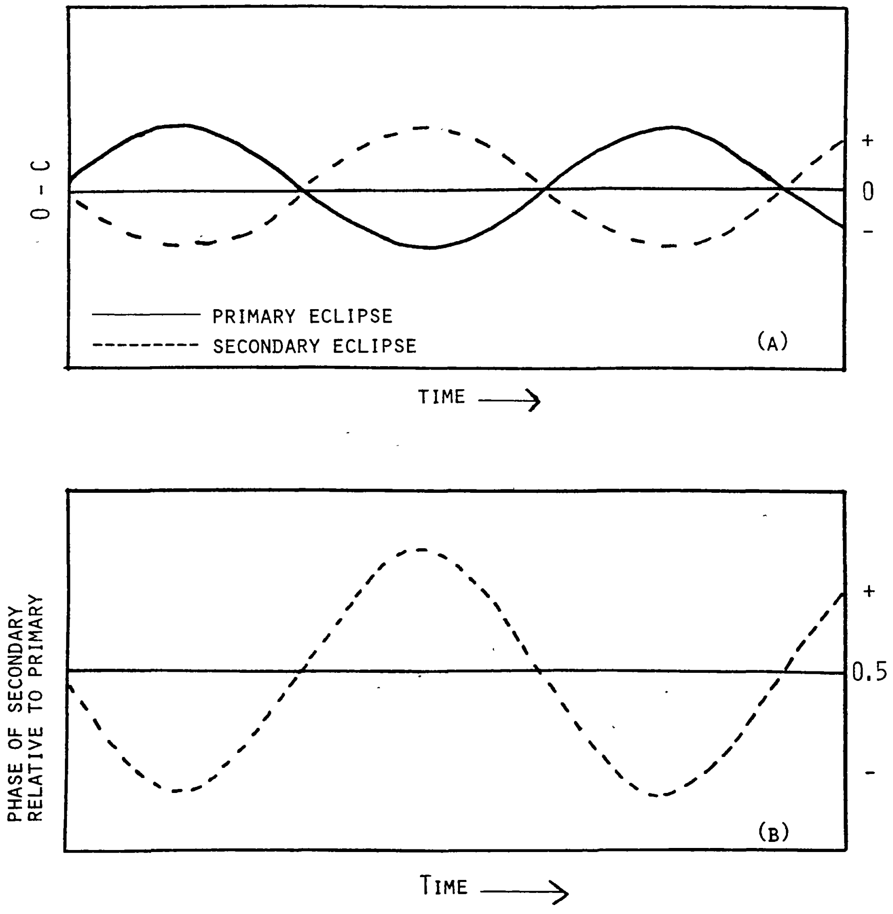

Figure 2. The effect of apsidal motion on the times of primary and secondary minimum.

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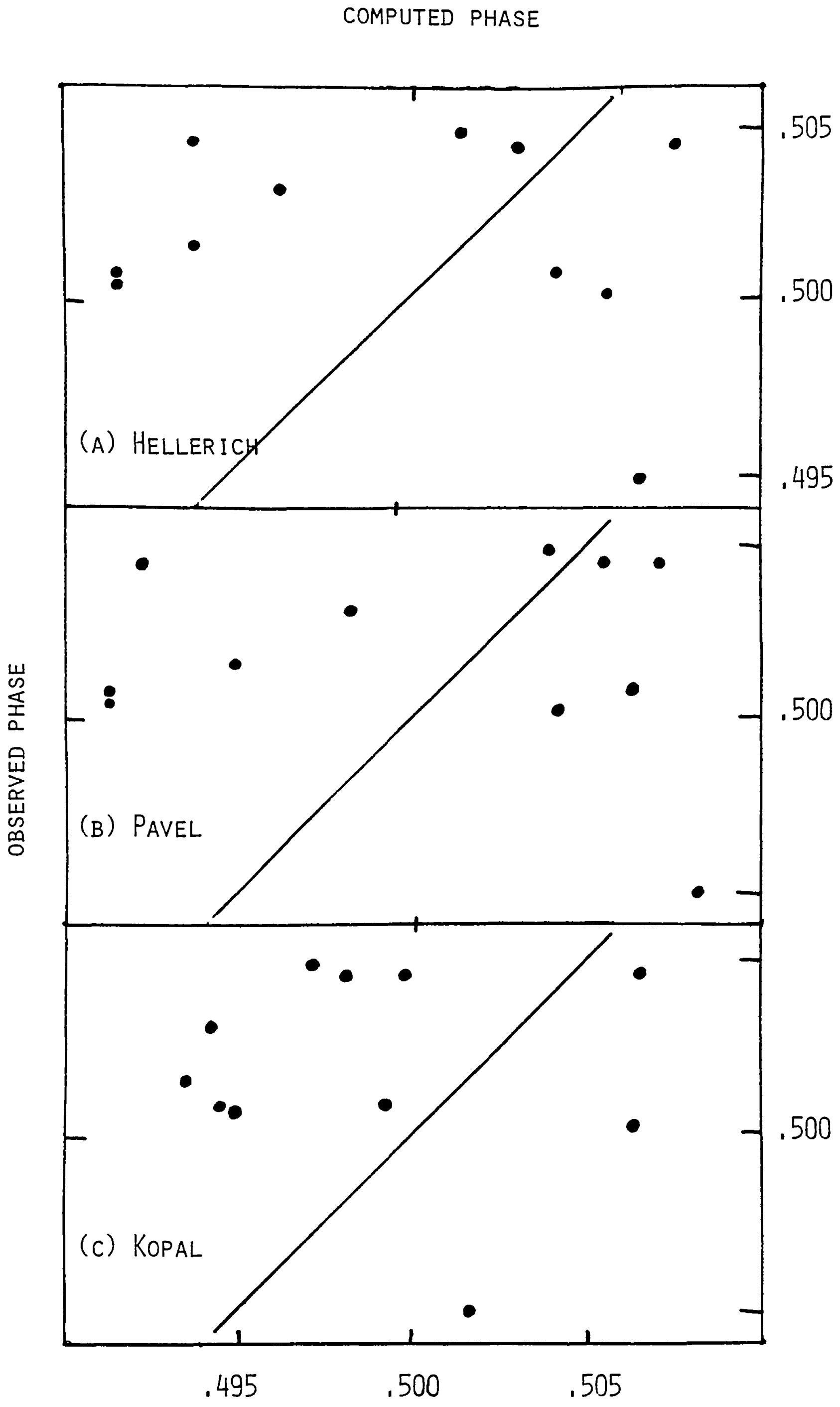

Figure 3. The observed versus calculated phase of secondary minima based on the hypothesis of apsidal motion. The observed data points do not fall along the diagonal lines, which represent the predictions.