

PERIOD VARIATION OF THE CEPHEID ZETA GEMINORUM

HELMUT A. ABT AND SAUL G. LEVY

Kitt Peak National Observatory,* Tucson, Arizona

Received 1974 January 3; revised 1974 January 18

ABSTRACT

In anticipation of the coming lunar occultations of ζ Gem on 1974 March 4 and 31, we derive a new ephemeris based on 70 years of radial-velocity measurements. The phases at the two occultations are predicted to be 0.96 and 0.65 phases, respectively, after light maximum. The period decreases at a steady rate of 3^s1 per year, which is 4 times the evolutionary rate for a 7 $M_{\odot}$ Cepheid in the fundamental mode. However, it is also possible that the period decrease is due to a light-time effect in a long-period (>225 years) binary having a low-mass secondary.

Subject headings: Cepheids and W Virginis stars — lunar occultation — stars, individual — stellar evolution

I. INTRODUCTION

The predicted lunar occultations of ζ Gem on 1974 March 4 and 31 and the consequent possibility of relatively direct determinations of the radius of a classical Cepheid raises again questions about the period of this star because the Cepheid's phases during the occultations will be important parameters. It has been known (Guthnick 1920) since 1920 that the period is variable. Initial attempts (Guthnick 1920; Rabe 1920; Becker 1924) involved fitting a sine curve to the ephemeris on grounds that the cause of the variation might be a light-time effect in a binary system with an assumed circular orbit. Nielsen (1930) showed that a steady linear decrease in period would best satisfy the times of light maxima and noted that the rate of decrease of 3^s6 per year is unusually large for a Cepheid. Makarenko (1963) felt that ζ Gem is one of many variables that show discontinuities in their ephemerides, but a smooth variation would fit the light data just as well.

Radial-velocity measurements (Campbell 1901; Henroteau 1925; Jacobsen 1926; Rufus 1932) have been used primarily for determinations of level effects, although they could also be used for independent information on the ephemeris. There have been no recent spectroscopic studies of this star. With the expectation that the passage of 40 years would permit the formation of new conclusions about the period change, we were in the process of collecting a new set of spectra when the prediction of occultations encouraged an early analysis.

II. PERIOD CHANGES

Coudé spectra of 13.3 or (after JD 2,442,000) 16.9 Å mm⁻¹ reciprocal dispersion were obtained in 1968–1973 with the 2.1-m telescope. With a Grant comparator we measured the same 26 lines of Fe I, H I, and Sr II in all the spectra to avoid differences in the mean velocities

* Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

RADIAL VELOCITIES OF ζ GEMINORUM

Helio. JD (2,440,000+)	Radial Velocity and p.e. (km s ⁻¹)	Helio. JD (2,440,000+)	Radial Velocity and p.e. (km s ⁻¹)
163.012...	− 4.4±0.5	226.820...	+15.3±0.5
163.976...	− 2.4±0.6	227.737...	+22.1±0.5
164.888...	+ 5.2±0.6	286.777...	+ 4.0±0.5
197.975...	+21.8±0.4	607.764...	+ 1.6±0.5
198.977...	+18.6±0.5	608.747...	+ 0.5±0.5
222.964...	− 1.2±0.4	2032.972...	+ 7.9±0.6
224.862...	− 3.8±0.6	2033.874...	+15.2±0.6
225.930...	+ 4.8±0.5		

due to the significant level effects. Only the mean velocities are listed in table 1. Monitors of standard stars for radial velocities indicate an insignificant correction of +0.7 km s⁻¹, which has not been applied.

All the published velocity curves, including uninterpreted Mount Wilson measures (Abt 1970), have been compared with Campbell's curve, which is the best defined one. The results of the comparison made with several assumed ephemerides are listed in table 2. Column (4) gives the mean velocities relative to that of Campbell's curve. The first conclusion is that, with one exception, the curves agree within 1 km s⁻¹ in mean velocity. Since the observations for the exceptional curve by Rufus overlap in time those by Jacobsen and Henroteau, we conclude that the cause of the exception is a lack of standardization of the velocities to the Lick system. We conclude that there is no convincing evidence here for a motion in a binary system having a secondary of large mass [$>0.8 (\sin i)^{-1} M_{\odot}$], assuming an orbital period of 225 years and a Cepheid mass of 7 $M_{\odot}$.

The last four columns of table 2 give the phase shifts relative to Campbell's curve for various ephemerides. The first three assume (1) Jacobsen's constant period of 10^d15253, (2) Becker's ephemeris for motion in a

TABLE 2
RESULTS OF COMPARISONS OF RADIAL-VELOCITY CURVES

OBSERVER (1)	OBSERVING INTERVAL (2)	MEDIAN CYCLE (3)	$\Delta\gamma$ (km s ⁻¹) (4)	PHASE SHIFTS			
				Const. P (5)	Becker (6)	Nielsen (7)	Present (8)
Campbell.....	1898-1900	410	0.0	0.000	0.000	0.000	0.000
Jacobsen.....	1923	1267	-0.1	0.000 $\pm$ 0.005	-0.006	-0.003	-0.015
Henroteau.....	1924	1300	+0.6	+0.020 $\pm$ 0.010	-0.006	+0.019	+0.006
Rufus.....	1923-1925	1323	+7.7	+0.020 $\pm$ 0.010	-0.006	+0.020	+0.006
Mount Wilson.....	1933-1938	1820	-0.1	-0.015 $\pm$ 0.015	-0.022	+0.024	-0.002
Present.....	1968-1973	2914	+0.5	-0.155 $\pm$ 0.015	-0.177	+0.070	+0.001

circular binary orbit with a period of 143 years, and (3) Nielsen's linear decrease in period by 3^s.6 per year. None of these fit the recent observations within the probable errors of their determination. The last column is for a modification (light maximum = JD 2,410,639.801 + 10^d153527E - 0^d000,000,491E²) of Nielsen's ephemeris, using the same initial period but a smaller decrease. It fits the data well. The period (the derivative of the ephemeris) is $P = 10^d153527 - 0^d000,000,982E$, which corresponds to a rate of decrease of 0^s.085 per cycle or 3^s.1 per year.

The mid-times between ingress and egress for a sublunar point are UT 1974 March 4.144 and 31.402 or JD 2,442,110.644 and 2,442,137.902, respectively, with a variation of up to $\pm 0^d067$ for other observers on the Earth. Ingress and egress occur up to $\pm 0^d017$ before or after mid-time, again depending on the location of the observer. The predicted cycles and phases after light maximum from the new ephemeris are phases 3099.963 and 3102.649 $\pm$ 0.023, where the uncertainty includes uncertainties in the ephemeris, the location of the observer, and the interval between ingress and egress. These phases occur respectively 0.23 phase after and 0.09 phase before minimum radius of the Cepheid at times when the radial velocities are 0 and +17 km s⁻¹, and decreasing in both cases.

III. INTERPRETATIONS

Let us reconsider the possibility that binary motion causes the period variation. A period as short as 143 years fails to predict phases correctly. Presumably we can find a period long enough such that the sine term simulates a quadratic term to any desired accuracy. The shortest orbital period that gives a sinusoidal ephemeris compatible with the probable errors in fitting radial-velocity curves is 225 years. For the complete

range of possible secondary masses ($0 < M_2 \leq M_1$) and for reasonable parameters for the Cepheid, the binary separation is 0^s.19-0^s.25. Such a double star could have gone undetected by visual observers, particularly if the secondary is much fainter than the primary. No secondary lines are seen in the spectra. Also, parallax and proper-motion studies would not have revealed a primary motion with so long a period. Finally, the light travel time during a pulsational cycle is small for a binary and predicts a velocity amplitude of only 0.03 km s⁻¹. Therefore we cannot eliminate at this time the possibility that the period changes are caused by the light-time effect in a binary with a period probably greater than 225 years and either a low-mass secondary or a very small inclination, i.e., $M_2 < 0.8 (\sin i)^{-1} M_\odot$.

The alternative explanation is that the period decrease is an evolutionary effect as the Cepheid moves left in the H-R diagram. The rate of period change is 15 times faster than is predicted by Iben (1966) for the lower evolutionary track to the left in the temperature-luminosity diagram of a 5 $M_\odot$ star, but only 4 times the evolutionary rate for either lower or upper track to the left for a 7 $M_\odot$ star, according to Hofmeister, Kippenhahn, and Weigert (1964). In view of the uncertainties about Cepheid masses, the position of ζ Gem in a temperature-luminosity diagram, the pulsational mode of ζ Gem, and perhaps in the stellar models, the disagreement may yet disappear.

We thank Drs. D. S. Evans and D. W. Dunham for informing us of the coming occultations, the Royal Greenwich and U.S. Naval Observatories for the published lunar positions, and the referee for helpful comments.

REFERENCES

- Abt, H. A. 1970, *Ap. J. Suppl.*, **19**, 387.
 Becker, F. 1924, *Der Veränderliche Stern ζ Geminorum* (Berlin: thesis).
 Campbell, W. W. 1901, *Ap. J.*, **13**, 90.
 Guthnick, P. 1920, *Astr. Nach.*, **211**, 389.
 Henroteau, F. 1925, *Pub. Dom. Obs. Ottawa*, **9**, 105.
 Hofmeister, E., Kippenhahn, R., and Weigert, A. 1964, *Zs. f. Ap.*, **60**, 57.
 Iben, I. 1966, *Ap. J.*, **143**, 483.
 Jacobsen, T. S. 1926, *Lick Obs. Bull.*, **12**, 138.
 Makarenko, E. N. 1963, *Variable Star Bull.*, **16**, 388.
 Nielsen, A. N. 1930, *Medd. Ole Rømer Obs.*, No. 5.
 Rabe, W. 1920, *Astr. Nach.*, **219**, 135.
 Rufus, W. C. 1932, *Pub. Obs. Univ. Michigan*, **4**, 151.