

Computational Modeling of the Eclipsing Binary EG Cephei

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Abstract

Three new times of minima from 1989 and 1990 are found for the eclipsing binary system EG Cephei. A photometric mass ratio of 0.48 and temperatures of 8500K and 5750K were calculated. The period change in the system was also investigated regarding the possibility of a third star. If it is present, a third body should have an orbital period ≈ 70 years and a mass $\geq 0.16M_{\odot}$.

Introduction

Eclipsing binary stars are very useful in determining many characteristics of stars necessary for testing theories of stellar evolution. They are classified phenomenologically by their light curve shape. EG cephei is an EB or β Lyrae type binary. When it was first discovered as a variable star its period of 0.5446 days was published (Strohmeier 1958), and a photoelectric light curve and analysis was completed by Cochran (1967) and shortly after by Keel et al. (1973).

The goal of this paper is to analyze several nights of photometric data from Mount Laguna Observatory (MLO) to determine multiple parameters of the system and investigate the period change which is clear from the published times of minima. The analysis primarily used a binary modeling program known as the Wilson-Devinney method (1971).

Observations and Reductions

EG Cephei was observed over eight nights in 1989 and 1990 at MLO with the 24" telescope in the Strömgen ybv filters. The analysis for this internship began after several processes had already been carried out. The comparison and check stars used were HD 194400 and HD 194130.

The data had been reduced with standard techniques to produce for each filter the magnitude, time, and phase of EG Cep. Asymmetry in the secondary minimum suggested a possible star spot. This parameter was added to the model and the resultant fit can be seen to match quite well with the observations (see Fig. 1). All modeling of the MLO data done during this internship included the star spot on the secondary component.

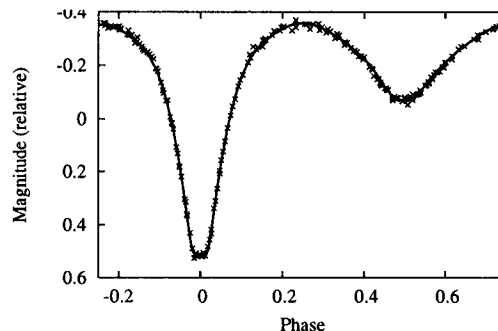


Fig. 1: Lightcurve of EG Cep

Analysis

Since the observations and reductions had been completed earlier, most of the internship consisted of analysis of the reduced data. The primary problem encountered was in using the Wilson-Devinney program for iterations. W-D is a differential corrector program that does one cycle and then outputs suggested corrections to the input parameters as well as a value for the fit ($\sum res^2$). Since there were several free parameters and about 10 runs were needed to converge for a set of initial conditions, an automated method of corrections was necessary. To resolve this, a program was written using the Python language to read the output file of W-D and add the appropriate corrections to the input file.

Temperature and Mass Ratio

The first task was modeling of the three nights of data to determine the physical characteristics of the system. This required determining the temperature of the two stars and the mass ratio between them. To determine the temperature of the primary star the W-D input file was modified to allow the temperature of the secondary star, the surface potential and luminosity of the primary star be free parameters. The secondary star was treated as filling its Roche lobe.

The primary star temperature and the mass ratio (q) were then fixed and iterations were performed until the residuals stabilized at a minimum. This process was repeated for a range of mass ratios, $0.4 \leq q \leq 0.7$ and a range of primary star temperatures $7500 \leq T_1 \leq 9000$ K. These ranges were selected based on previously published values for the system. The resulting fits to the data demonstrate the optimal primary star temperature of 8500 ± 250 K with a mass ratio of 0.48 ± 0.01 (see Fig. 2).

Once the mass ratio and primary star temperatures had been determined, the W-D program was able to determine several other parameters of the system. Below are the most important variables used in the model. The absolute dimensions of the system were calculated by including unpublished radial velocity data from MLO by Angione and Sievers.

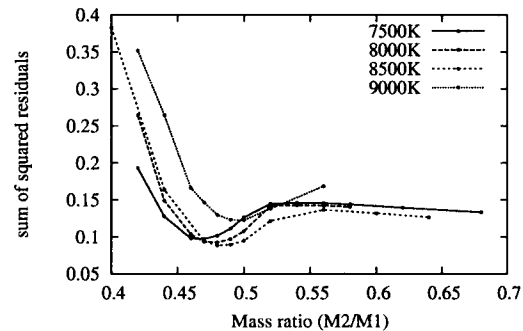


Fig. 2: temperature and mass ratio

System	Star 1	Star 2
Period = 0.5446 days	$T_1 = 8500\text{K}$	$T_2 = 5750 \pm 250\text{K}$
Inclination = 88.577°	$M_1 = 1.45M_\odot$	$M_2 = 0.70M_\odot$
$\frac{M_2}{M_1} = 0.48$	$\bar{r}_1 = 1.57R_\odot$	$\bar{r}_2 = 1.15R_\odot$
	$\Omega_1 = 2.892$	$\Omega_2 = 2.837$
	$g_1 = 1.00$	$g_2 = .32$
	$A_1 = 1.00$	$A_2 = .50$

Table 1: Wilson Devinney parameters for EG Cep (uncertainty ± 1 in last digit except where stated)

In Table 1, the masses and average radii are relative to the sun. The Ω potentials specify a constant potential energy on the surface of each star. The second star has a fixed Ω value representing a filled Roche lobe, typical of β Lyrae binaries. The parameter g is the gravity darkening parameter, and A is the bolometric albedo for the reflection effect. The values given for the primary and secondary stars are typical for radiative and convective envelopes respectively.

Period Change

The next task involved determining the times of minima, adding these times to those already published, and fitting the resultant O-C diagram. The Kwee algorithm (Kwee & van Woerden 1956) was used to determine the three times of minima. The Kwee program was written in Fortran and had to be modified to read in the data correctly. Estimates of the times of minima, duration of primary eclipse, and the times and magnitudes for each filter were input into this program. The algorithm reflects the data points from one side of the curve to the other, and then interpolates the time of minimum. The resulting times of minima were submitted to the Information Bulletin on Variable Stars (see Table 2).

HJD	Error	Filter
2447732.8995	.0003	uvb
2448067.8419	.0003	uvby
2448121.7603	.0003	uvby

Table 2: EG Cep times of minima

These three times of minima were compiled with minima from recently published data (Chocol et al. 1998; Bakis et al. 2005; Cook et al. 2005; Nelson 2005; Kim et al. 2006). The list of minima were combined with the period given by Chocol et al. of 0.5446216 days to produce the graph of observed – calculated (O-C) times of minima.

There is clearly a trend in the O-C diagram however there are not quite enough data points to determine whether the cause of the period change is mass transfer or a third star. This is because the trend would be parabolic for mass transfer, and sinusoidal for a third star. There is also the possibility of both of these conditions being present.

Since there had been previous articles suggesting the presence of a third star in the system, this possibility was investigated in more detail. Using a simple differential corrector Fortran program, a sinusoidal fit was applied to the O-C diagram (see Table 3). The sine fit was found to be

$$F(x) = 0.894 \times 10^{-2} \sin(0.135 \times 10^{-3} x - 11.0)$$

where the period of the third star can be found directly from the period of the sine curve and the period of the binary system giving a value of $P = 70$ years. We may also extract from this

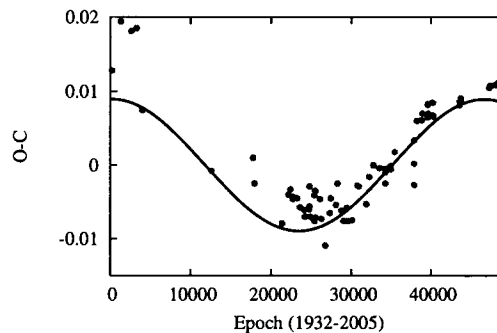


Fig. 3: O-C diagram with sine fit

curve what the minimum mass of the third star could be from the following equation (Mayer 1984).

$$\frac{m_3^3 \sin i_2^3}{(m_1 + m_2 + m_3)^2} = \frac{A^3}{P_2^2} \cdot 5.22 \times 10^6$$

In this equation, m_1, m_2 and m_3 are the masses of the component stars, A is the amplitude of the sine curve, and P_2 is the period of the third star in years. The angle between the orbital plane for the third star i_2 and the binary system are taken to be concentric so the $(\sin i_2^3)$ term reduces to unity and the value for m_3 becomes a minimum. Solving this equation for the mass gives a value of $m_3 \geq 0.16M_\odot$. These parameters for the third star have significant uncertainty due to the nature of the data being a small part of a potential sine wave.

Conclusions

After numerous runs with the Wilson-Devinney computer model, several parameters have been determined with reasonable precision. From the data analyzed, the eclipsing binary EG Cephei has an inclination of $88.577 \pm 0.001^\circ$, temperatures of 8500K and $5750K \pm 250K$, and masses of $1.45M_\odot$ and $M_2 = 0.70M_\odot \pm 0.01$. EG Cephei is a binary system that requires a few more years of observation to determine if a third star is present. Two of the parameters that could be derived for a potential third star are the minimum mass ($0.16M_\odot$) and the period of orbit (70 years). Typical values for third light were added to the W-D model, however they did not contribute significantly to the fit, suggesting little influence on the system.

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