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The early B-type eclipsing binary GT Cephei: A massive triple system?

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HIGHLIGHTS

- GT Cep is a semi-detached close binary system with an orbital period of 4.91 days, containing a massive star.
- I have obtained its spectroscopic observations and revealed radial velocities of both components.
- Combining the analyses of radial velocities and photometric observations we have measured the absolute parameters of system.
- The components are shown to be a B2V primary and a A0IV secondary.

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ABSTRACT

GT Cep is a semi-detached close binary system with an orbital period of 4.91 days, containing a massive star. I have obtained spectroscopic observations and derived radial velocities of both components. Combining the analyses of radial velocities and available photometric observations we have measured the absolute parameters of both components of GT Cep. The components are shown to be a B2 V primary with a mass $M_{\rm p} = 10.70 \pm 0.50$ $M_\odot$ and radius $R_{\rm p} = 6.83 \pm 0.19$ $R_\odot$ and a A0 IV secondary with a mass $M_{\rm s} = 2.58 \pm 0.14$ $M_\odot$ and radius $R_{\rm s} = 7.56 \pm 0.21$ $R_\odot$. My analyses show that GT Cep is a classical Algol-type binary with a less massive secondary filling its *Roche* lobe. Using the UBVJHK magnitudes and the interstellar reddening of $E(B-V) = 0.61$ I estimated the mean distance to the system as 854 ± 43 pc. The O–C residuals have been analysed as the consequence of a light-time effect superimposed on an upward parabola. My analysis indicates that the eclipsing binary revolves around a third-body with a period of about 57.5 yr in an orbit with a radius of 40 AU. The lower limit for the mass of the third star has been estimated to be 7 $M_\odot$ for the inclination between 70° and 90°.

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1. Introduction

One of the most important parameters in stellar astrophysics is the mass of stars. Eclipsing binaries with well-defined multipassband light curves and accurate radial velocities for both components provide us with definitive empirical masses, radii, effective temperatures and luminosities. In order to better understand the physics of binary systems and test the predictions of theoretical models, it is thus important to quantitatively analyse the properties of massive binary systems with well-constrained orbital parameters. In this context studies of the rare early B-type massive stars has major highlights.

The relatively bright eclipsing binary GT Cep (HD 217224, HIP113385, $V = 8.13$, $B - V = 0.34$) was discovered to be an eclipsing binary system by Strohmeier et al. (1962), who derived an orbital period of 4.908756 d using the 12 times of minima obtained from photographic observations. They obtained the first photographic light curve of the system and classified it as an Algol-type binary. A first spectroscopic study was carried out by Fitzgerald (1964) who obtained the spectroscopic orbit and classified the primary component as a B3 star. Later on the photographic study made by Bondarenko and Tokareva (1975) who revised the orbital period and obtained a light curve containing rather a deep primary minimum and a shallow secondary minimum. Bartolini et al. (1984) obtained UBV light curves and analysed using the Wood's method.

Photometric observations of GT Cep were also obtained by the Hipparcos satellite (GT Cep being identified as HIP 113385 (ESA, 1997)) and later in the context of the Northern Sky Variability Survey (Wozniak et al., 2004). Although GT Cep has been studied on many occasions its astrophysical parameters were not firmly established. On the other hand Ibanoglu et al. (2006) divided the semi-detached Algol-type binaries (SDABs) into two groups. The orbital angular momenta of SDABs with periods $P < 5$ days and $P > 5$;days are 45 and 25 per cent smaller than those detached

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binaries with similar mass. The specific angular momenta of systems with $P > 5$ d are larger than those of $P < 5$ d for the gainers of the same mass. The spins of the mass gaining stars point out a sharp distinction between short and long period orbit systems at an orbital period of 5 days. The orbital period of GT Cep is very close to this discriminating period.

This paper is organised as follows. I present new spectroscopic observations and radial velocities of both components of the eclipsing pair. By analysing the previously published light curves and the new radial velocities I obtain orbital parameters for the components. Combining the results of these analyses we obtain absolute physical parameters of both components. In addition, I conclude with a brief discussion of the system's evolutionary status.

2. Observations

The present study is the result of a collaboration in which two data sets were obtained at two different in the roughly same latitude observatories, using the two telescopes and spectrographs.

The first dataset was obtained with the REOSC Echelle spectrograph mounted on the 182 cm telescope at the Asiago Observatory in Italy, with exposure time ranging from 30 to 45 min. The instrument covers the spectral domain between 3900 and 7300 Å, divided into 27 orders. The average signal-to-noise ratio (S/N) and resolving power $\lambda/\Delta\lambda$ were about 120 and ~50 000, respectively. Four *échelle* spectra of GT Cep were taken from March 17, 2009 to July 8, 2011.

12 *échelle* spectra of GT Cep were collected with the Turkish Faint Object Spectrograph Camera (TFOSC)[1] attached to the 1.5 m telescope between August 22, 2011 and August 2, 2013, under good seeing conditions. Further details on the telescope and the spectrograph can be found at http://www.tug.tubitak.gov.tr. The wavelength coverage of each spectrum was 4000–9000 Å in 12 orders, with a resolving power of $\lambda/\Delta\lambda \sim 7000$ at 6563 Å and an average signal-to-noise ratio (S/N) was ~120. I also obtained high S/N spectra of the early type standard stars 1 Cas (B0.5 IV), HR 153 (B2 IV), τ Her (B5 IV), 21 Peg (B9.5 V) and αLyr (A0 V) for use as templates in derivation of the radial velocities.

I applied the same reduction procedure to both datasets. The electronic bias was removed from each image and I used the 'crreject' option for cosmic ray removal. Thus, the resulting spectra were largely cleaned from the cosmic rays. The *échelle* spectra were extracted and wavelength calibrated by using Fe-Ar lamp source with help of the IRAF[2] ECHELLE PACKAGE (Simkin, 1974).

3. Radial velocities and atmospheric parameters

3.1. Period determination

A total of 22 times of mid-primary minimum and one secondary of GT Cep were collected from the literature and listed in Table 1. The starting epoch and orbital period are taken from the *Hipparcos* and Kreiner (2004), respectively. Therefore the following ephemeris was used to determine the cycle number and O–C (I) residuals,

$$MinI(HJD) = 2\,448\,503.19 + 4^{d}.9087946 \times E. \quad (1)$$

The O–C (I) residuals, indicating the differences between observed times of mid-eclipses and calculated ones using this ephemeris are listed in the third column of Table 1. These residuals for all the times of mid-eclipses of the GT Cep are plotted against the epoch numbers in the top panel of Fig. 1. The trend of the O–C (I) residulas can be described by an upward parabolic curve superimposed on a sine-like variation. It is obvious that the change of the O–C (I) residuals is a result of at least two separate causes. Because GT Cep is a semi-detached Algol-type binary, the system could be transferring mass from less massive component to the more massive primary leading to an upward parabolic change of orbital period, i.e., indicating that the orbital period is continuously increasing.

Recently Liao and Qian (2010) suggested that cyclic period changes are a common phenomenon in close binary systems. Cyclic variations in the orbital periods are usually explained by magnetic activity in one or both components, by an apsidal motion, and or by the light-travel time effect around common-center with a third-body. Since GT Cep is composed of a B2 V and a A0 IV star that contain convective core and radiative atmosphere. This suggests that the cyclic changes in the O–C residuals can not be originated from the magnetic activity cycle mechanism. We can, therefore, easily ignore the possibility of solar-like activity in both comments. Both the light and radial velocities of the system point out a circular orbit for the system. In addition, the O–C (I) residual obtained for the mid-secondary eclipse seem to follow the same trend as the primary minimum. Therefore, we may rule out the apsidal motion as a possible cause of orbital period change. Therefore such a sinusoidal/cyclic change in the orbital period of GT Cep can only be explained by an orbital motion around a third-body. We analysed the O–C (I) residuals under an assumption of a combination of mass-transfer and third-body, i.e. the eclipsing pair is orbiting around a third-body. We may compute the times of light minimum with a formula as

$$T_{\rm ec} = T_1 + P_1 \times E + Q \times E^2 + \delta T, \quad (2)$$

where T_1 is the starting epoch, E is the integer eclipse number and P_1 is the orbital period of the eclipsing pair. While the third-term represents the parabolic change in the O–C residuals the time delay or advance of any observed eclipse is caused by the influence of a third-body can be represented by a fourth-term. The light-time effect δT is depended up on the semi-major axis of the eclipsing pair around the barycenter, inclination, eccentricity and longitude of the periastron of the third-body orbit. I have used the conventional formulae given by Ibanoglu et al. (2000). A linear least squares solution was applied to the data and the coefficient of the third-term and the parameters for the third-body orbit were obtained. The coefficient of the quadratic-term, originated from the mass transfer between the components is calculated as $Q = 1.28 \times 10^{-9} \pm 0.22 \times 10^{-9}$ days cycle^{-1}. A secular period increase has been calculated as $dP/dt = 1.90 \times 10^{-7}$ d yr^{-1} which corresponds to 1.64 s century^{-1}, indicating that mass transfer from less massive to the more massive star at a rate of $dM/dt = 4.4 \times 10^{-8}$ M$_\odot$ yr^{-1}.

The parameters of the third-body orbit are listed in Table 2. My calculation suggests that the eclipsing pair revolves around a third-body, in an eccentric orbit with $e = 0.047$, and with a period of about 57.5 ± 2.3 years. The projected radius of the orbit of the eclipsing pair around the center-of-mass is about 13.80 ± 0.52 AU. Using these values I obtained a mass function as 0.796 ± 0.060 M$_\odot$. The O–C (II) residuals were obtained after subtracting the continuous period increase and the light-time effect, and are plotted in the bottom panel of Fig. 1.

3.2. Radial velocity

To derive the radial velocities, the sixteen spectra obtained for the system are cross correlated against the template spectra of standard stars 1 Cas, HR 153, τ Her, 21 Peg and αLyr on an order-by-order basis using the FXCOR package in IRAF. The standard stars' spectra were synthetically broadened by convolution with the

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[1] http://tug.tug.tubitak.gov.tr/rtt150_tfosc.php.

[2] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy,Inc. (AURA), under cooperative agreement with the National Science Foundation.

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