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Photometric study of the eclipsing binary GR Bootis

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HIGHLIGHTS

- We present time-series CCD photometry and low-resolution spectra for the eclipsing binary GR Boo.
- We analyze the variations of the orbital period and determine a new ephemeris formula.
- We firstly perform photometric analysis of GR Boo using the W-D program.
- The evolutionary status and physical nature of GR Boo are briefly discussed.

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ABSTRACT

We present CCD photometry and low-resolution spectra of the eclipsing binary GR Boo. A new ephemeris is determined based on all the available times of the minimum light. The period analysis reveals that the orbital period is decreasing with a rate of $dP/dt = -2.05 \times 10^{-10} d\ yr^{-1}$. A photometric analysis for the obtained light curves is performed with the Wilson–Devinney Differential Correction program for the first time. The photometric solutions confirm the W UMa-type nature of the binary system. The mass ratio turns out to be $q = 0.985 \pm 0.001$. The evolutionary status and physical nature of the binary system are briefly discussed.

1. Introduction

GR Boo was found in the ROTSE survey project by Akerlof et al. (2000) and identified as W UMa type eclipsing binary. Based on the survey data, Blattler and Diethelm (2001) provided light curves of GR Boo for the first time, and gave the linear epoch formula,

$$Min.I(HJD) = 2,451,996.5840 + 0^d.376670 \times E$$

Woźniak et al. (2004) compiled the NSVS catalog based on the ROTSE survey, in which GR Boo is number NSVS 7788990, and gave the light curve of GR Boo. Gettel et al. (2006) compiled 1022 contact binaries which were found in the ROTSE survey project into the catalog GGM2006, in which GR Boo is numbered as GGM2006 7788989. The parameters of GR Boo were given as : the period of 0.376675 days, the dimmest average magnitude in V band of 11.891 mag, the amplitude of variation of 0.439 mag, the absolute V magnitude of 4.462 mag ,the distance of 253 pc. Hoffman et al. (2009) derived the color index and a period of 0.37672 days based on the NSVS catalog. Pi et al. (2013) calculated an updated ephemeris and the change rate of the orbital period of GR Boo, and gave the new linear and quadratic ephemerides:

$$\begin{aligned} Min.I(HJD) &= 2,451,996.5849(\pm 0.0005) \\ &\quad + 0^d.37666986(\pm 0.00000008) \times E \\ Min.I(HJD) &= 2,451,996.5838(\pm 0.0003) \\ &\quad + 0^d.376671(\pm 0.000001) \times E \\ &\quad - 1^d.2(\pm 0.1) \times 10^{-10} \times E^2 \end{aligned}$$

However, no photoelectric study of the binary system has been available. The physical nature of the star system is not known. In order to get the photometric orbit solution, and further analyze the period change of this binary system, CCD photometric observations were carried out from 2011 to 2015. Light curves in V and R bands and new minimum times were obtained. In addition, we also obtained a low resolution spectrum of this eclipsing binary. In this paper, we present our study of GR Boo based on these observations.

2. Observations and data reduction

The CCD photometric observations were carried out using three telescopes from 2011 to 2015. Two nights of data in V and R bands were obtained with the 85 cm telescope located at the Xinglong station of the National Astronomical Observatories of China(NAOC), which was equipped with a PI 1024 × 1024 CCD camera at the main

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1384-1076/

Table 1
Coordinates and brightness in *V* of the variable, comparison and check stars.

Star	Name	R.A.(J2000)	DEC.(J2000)	m_V
Obj	GR Boo	14 59 54.54	+25 54 33.62	11.51
Comp	GSC 02020–00659	14 59 40.45	+25 51 44.90	10.96
Check	GSC 02020–00910	15 00 19.54	+25 49 48.90	12.32

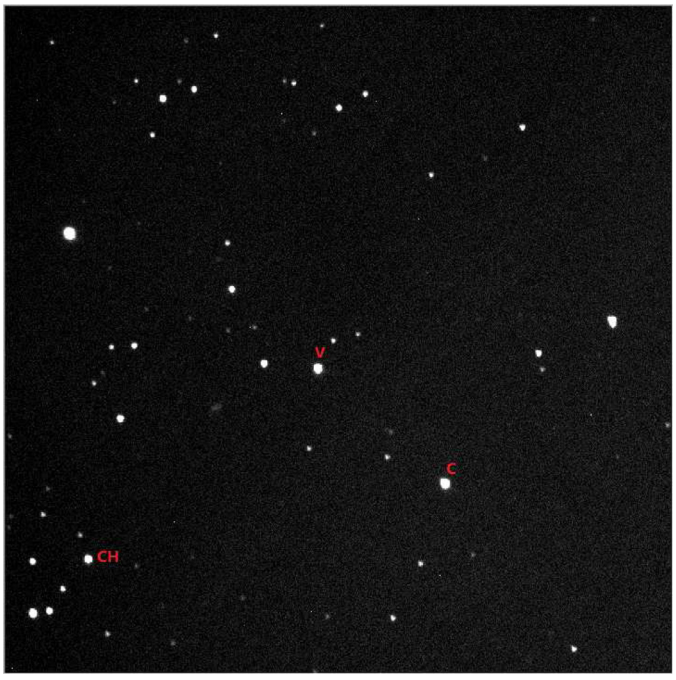

Fig. 1. A CCD image of GR Boo in V observed with the 85 cm telescope of Xinglong station. GR Boo, the comparison star and the check star are indicated.

focus, based on Zhou et al. (2009), corresponding to an image scale of 0.96 arcsec per pixel. The other three nights of data in *V* and *R* bands were obtained with the 60 cm telescope located at Xinglong station. The image scale is 1.056 arcsec per pixel. The last two nights of data in *V* and *R* bands and one night of data in *B*, *V*, *R* bands were collected with the 60 cm telescope located at the Yunnan Astronomical Obseratory (YNAO), equipped with a *DW*436 2048 × 2048 CCD camera, with an image scale of 0.37 arcsec per pixel. We selected GSC 02020–00659 and GSC 02020–00910 as the comparison star and check star, respectively. The coordinates and brightness in *V* of GR Boo, the comparison star and the check star are listed in Table 1. Fig. 1 shows a CCD image of GR Boo in *V* with the 85 cm telescope. Table 2 lists the information of the new photometric observations for GR Boo. The preliminary processing of the CCD frames (bias substraction and flatfield correction) was performed with the standard routines of CCDPROC in the IRAF software. Photometry was made using the DAOPHOT package. We applied a series of apertures to make the photometry. The best aperture was determined according to the least of the deviations of the magnitude differences between the comparison star and the check star.

Spectroscopic observations for GR Boo were made on May 14, 2012 using the 2.16m telescope located at Xinglong station. The BFOSC low-dispersion spectrometer was used during the observations. The used grating was *G*7 with a slit width of 1.8" and a line dispersion of 95 *x*00*C*5; /*mm*. The center wavelength was at 530 nm with the wavelength range of 380–680 nm. The data were reduced with IRAF and the obtained low-resolution spectrum is shown in Fig. 2. Comparing with the spectrum flow library from Pickles (1998), the spectral type of GR Boo was preliminarily identified as *G*3*V* − *G*4*V*.

Table 2
Photometric observations for GR Boo.YN60 = Yunnan Astronomical Obseratory 60 cm telescope, XL60 = Xinglong Astronomical Obseratory 60 cm telescope, XL85 = Xinglong Astronomical Obseratory 85 cm telescope.

Date	Telescope	Filter	Frames	Hours
2011 May 07	YN60	V	80	4.4
2011 May 07	YN60	R	80	4.4
2011 May 15	XL60	V	155	4.9
2011 May 15	XL60	R	154	4.9
2012 Feb 13	YN60	V	65	4.9
2012 Feb 13	YN60	R	65	4.9
2013 May 03	XL60	V	218	7.6
2013 May 03	XL60	R	218	7.6
2013 May 06	XL60	V	122	4.9
2013 May 06	XL60	R	122	4.9
2013 Jun 12	XL85	V	147	3.3
2013 Jun 12	XL85	R	147	3.3
2013 Jun 13	XL85	V	263	5.8
2013 Jun 13	XL85	R	263	5.8
2015 Jan 27	YN60	V	133	2.0
2015 Jan 27	YN60	R	132	2.0
2015 Jan 27	YN60	B	132	2.0

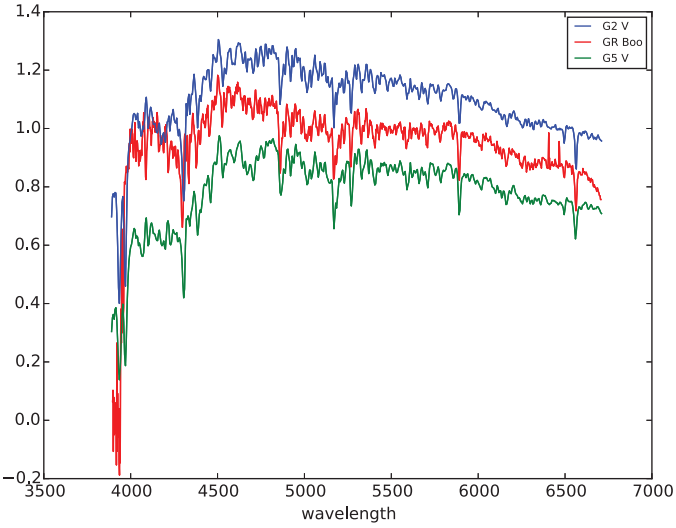

Fig. 2. The red: The spectrum of GR Boo, observed with the 2.16 m telescope of Xinglong station. The blue and green line are G2V and G5V from the Pickles (1998). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

3. Period changes

8 new minimum times were obtained in total from the obtained light curves. We also collected minimum times from the literature since 1999. Table 3 lists all the minimum times we have obtained, with which one can perform period analysis of the system. Using the method of least square fitting, we determined the new linear and quadratic ephemerides, as:

$$Min.I(HJD) = 2,451,996.5462(\pm 0.0003) + 0^d.37666954(\pm 0.00000004) \times E \quad (1)$$

$$Min.I(HJD) = 2,451,996.5838(\pm 0.0002) + 0^d.37666954(\pm 0.00000006) \times E - 1^d.126(\pm 0.005) \times 10^{-10} \times E^2 \quad (2)$$

The $O-C$ residuals for all the times of minimum light according to the linear and quadratic ephemerides were calculated and listed in Table 3. According to the quadratic ephemeris, we plot the $O-C$