No.71 **Feb. 2021**

ISSN 0917-2211

Variable Star Bulletin

The flat bottom of the primary minimum of Algol-type system BR Cyg

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Received 2021 Jan. 26

1 Introduction

BR Cyg (A5 V+F0 V, V=9.4-10.6 mag) is an Algol-type system and its period is relatively short (1.3326 day). Wehinger (1968) carried out blue and yellow band photoelectric photometry in 1959 and 1960. He reported that the light curve at the primary minimum indicated a total eclipse shape (duration 38 min) in the yellow band. Curiously however, the light curve he obtained in the blue band indicated a partial eclipse (see his Fig. 1). Wehinger (1968) analyzed the light curves and he concluded that the solution derived from the yellow band is real, i.e. the primary minimum is a total eclipse. He also mentioned that the minimum in yellow cannot be explained as the result of an atmospheric eclipse, for the observed effect is opposite of what would be expected. Although Wehinger (1968) suggested the existence of a gas stream, he was not able to provide a definite explanation for this curious phenomenon.

Piotrowski & Różyczka (1973) suggested the possibility of variations in the primary minimum shape, although they did not provide detailed explanations to support this. Subsequently, Terrell & Gross (2005) performed CCD photometry with B, V, $R_{\rm c}$, and $I_{\rm c}$ filters on June 2005 and they reported that there were no total-eclipse shapes in their light curves in all bands.

Although the total eclipse was denied, I can not completely rule out the possibility of the flat bottom in V-band, because 1) Wehinger (1968) declared that instrumental errors can be ruled out. 2) Mr. Kazuhiro Nakajima carried out CCD photometry in V-band on March 2005 and the flat bottom (duration ∼30 min) appeared in his light curve (Fig. 1). Since *Kepler* observed BR Cyg (KIC 9899416) as described in the next section, I analyzed this data to solve the curious flat bottom mystery.

2 *Kepler* Light Curves

Kepler observed BR Cyg during four quarters (Q2, Q6, Q10, Q16) from Jun. 2009 to Jan. 2013 [1]. A total of 92 primary minima were recorded in the short cadence mode (exposure time ∼1 min). I analyzed all primary minima and found that all light curves clearly showed partial eclipses, i.e. there are no flat bottoms at mid-primary minimum. Fig. 2 displays the composite of light curves obtained in Q2 (a total of 22 eclipses) as an example.

3 Discussions

No flat bottom is observed in the Kepler data as mentioned in the previous section. However, if the flat bottom appears only near the V-band, there is a possibility that it was buried in the other colors, for the width of the effective wavelength of this space telescope is very wide (approximately 410 - 910 nm).

[1] http://keplerebs.villanova.edu/overview/?k=9899416

If this holds true, what is a reason for the flat bottom? The primary minimum of Algol-type system RZ Cas is due to the partial eclipse and the flat bottoms are frequently observed during the middle of the minimum (e.g., Narusawa et al. 1994). Ohshima et al. (1998, 2001) found a δ Sct type, nonradial pulsation in the primary component of this system. This has led us to understand that the flat bottom is synthesized with the light variation of the partial eclipse and those of the oscillations, i.e. when the light maximum of the δ Sct pulsation coincides with the center of eclipse, the flat bottom is observed. Can this be the case for BR Cyg? Actually for δ Sct pulsation stars, the amplitude is larger in shorter wavelengths. However, the flat bottom is not observed in the blue filter for BR Cyg, therefore I consider it to be a different phenomenon from RZ Cas. Terrell & Gross (2005) also did not observe any evidence of pulsation.

Plavce (1966) mentioned a flat bottom (duration 38 min) at the mid-primary eclipse of another Algol system S Equ. According to Soydugan et al.'s analysis (2007), the primary constituent is slightly seen behind the secondary component at the primary minimum, in other words the primary minimum of S Equ is a so called "grazing eclipse". For this reason, it is predicted that the light curve changes to a shape that resembles a total eclipse depending on the observational resolution. However according to Terrell & Gross's analysis (2005), a substantial portion of the primary star of BR Cyg is seen behind the secondary star, therefore the cause of the flat bottom of BR Cyg is not that of S Equ.

Fig. 3 indicates the O-C diagram of BR Cyg for photoelectrically and CCD observed primary minima from *the (B-R)-Generator für die Lichtenknecker-Database of the BAV* [2]. The $O-C$ values were calculated utilizing the following ephemeris provided by GCVS 5.1 [3].

$$\text{Min I} = \text{HJD } 2441539.4654 + 1.332564151\,E. \tag{1}$$

Since the diagram shows that the orbital period from 1950 to present is constant, even if the flat bottom is a non-contiguous phenomenon, the occurrence rate is not related with the orbital period.

I would like to note that the O'Connell effect was observed in *Kepler*'s data for BR Cyg (Fig. 4). Although the reason why the flat bottom appears remains unclear, it may be noteworthy to examine the influence of spots on the surface of the star(s) on the light curve shape for future studies.

I expresses my sincere thanks to K. Nagai for sharing data of $vsnet-ecl$ obtained by K. Nakajima. I would also like to acknowledge Y. Nakamura and Y. Taguchi for their help and support.

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[2] http://www.bav-astro.de/LkDB/index.php?lang=en
[3] http://www.sai.msu.su/gcvs/gcvs/gcvs5/gcvs5.txt

VSOLJ
c/o Keiichi Saijo National Science Museum, Ueno-Park, Tokyo Japan

Editor Seeichiro Kiyota
e-mail:skiyotax@gmail.com
Publishing Masahiko Momose

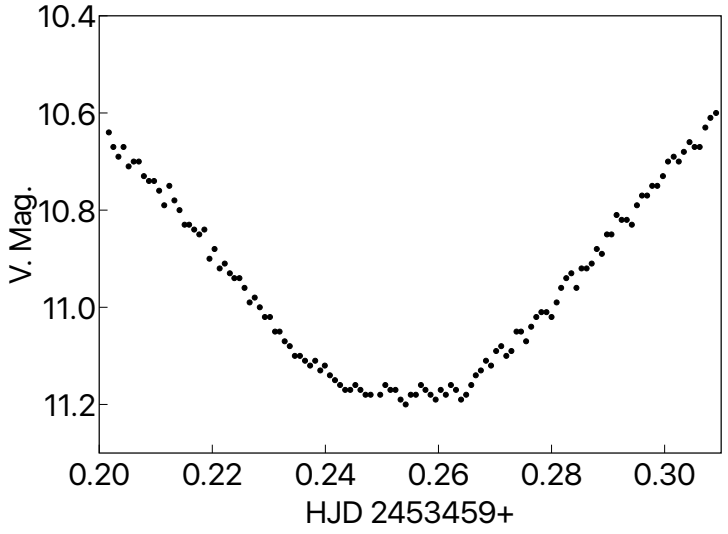

Figure 1: A primary minimum of BR Cyg in V-band on March 29, 2005 observed by K. Nakajiam (from $vsnet - ecl$).

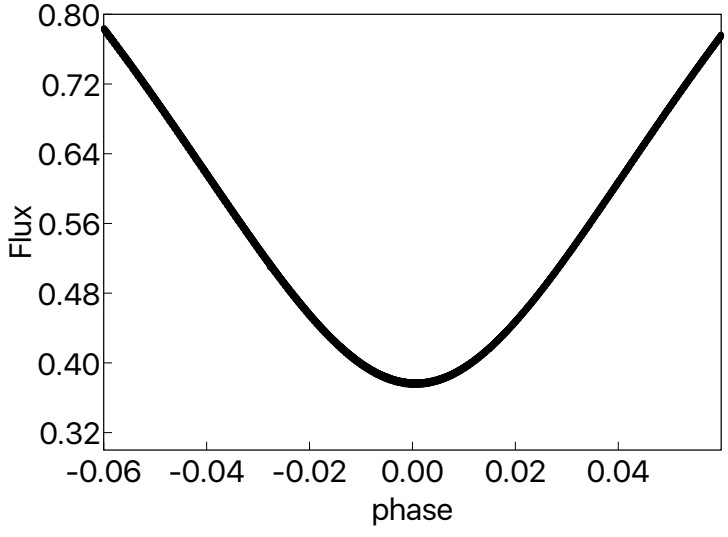

Figure 2: Primary minima of BR Cyg obtained by *Kepler* (Q2, a total of 22 eclipses).

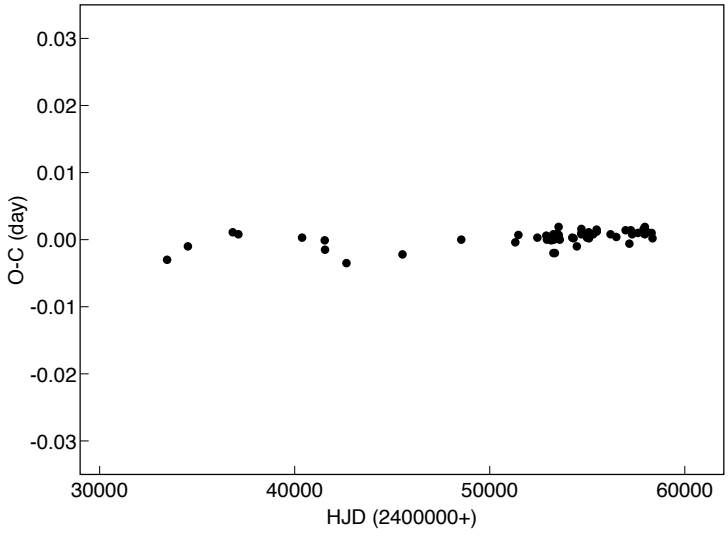

Figure 3: O-C diagram of BR Cyg for photoelectrically and CCD observed primary minima from *the (B-R)-Generator für die Lichtenknecker-Database of the BAV* .

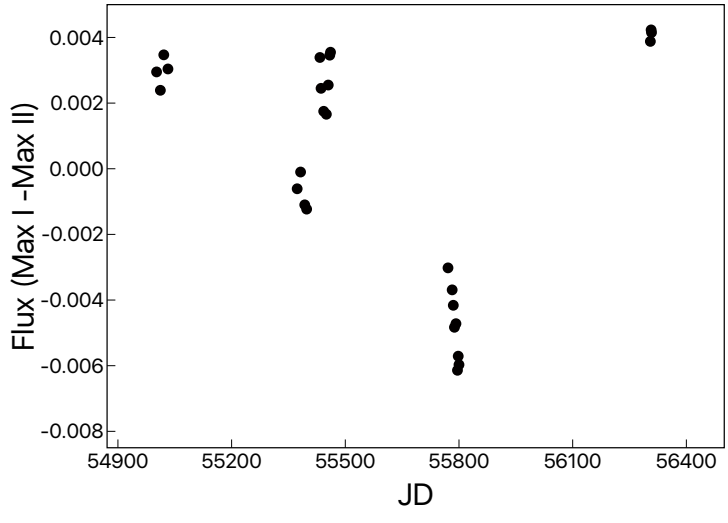

Figure 4: The O'Connell effect of BR Cyg based on *Kepler* (y axis indicates flux of Max I -Max II). Errors are ∼0.0002.