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Short Period Light Variation of the Algol-type Binary U Coronae Borealis

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Abstract

The short period variability in the light curve of U CrB, an Algol-type binary, was examined with the published data of van Gent(1989a). The period of variability was approximately 0.05 d and the amplitude was 0.05 mag. The superposition of several modes was suggested. The properties of the light variability were compared with those of the early-type main-sequence pulsating stars.

Key words: binaries: close – binaries: eclipsing – stars: indivisual: U CrB – stars: oscillations

1. Introduction

U Coronae Borealis (B6V + F8III - IV, $V = 7.66$, $P = 3.452$ d) is an Algol-type eclipsing binary system. The spectral type F8III - IV of the secondary was determined by Batten & Tomkin (1980). The system is one of the active Algols proposed by Olson (1982), together with U Cep, U Sge, RW Tau, and RZ Cas, based on the violent changes of light curves at the primary minima. Olson (1982) described that the primary minima of U CrB is a partial eclipse with variable depth.

Photoelectric photometry covering the whole phase of U CrB was carried out by van Gent (1989a) at the wavelengths 474 nm, 672 nm, 781 nm, and 871 nm. The star HD137147 was used as the comparison at the earlier stage, and HD136654 was used after the variability of HD137147 was detected by Olson (1980). The appearance of a flat segment continuing 1.2 h was found by Heintze (1990) in the light curve of van Gent. Such a flat portion appeared also in the light curve reported by Olson (1982, fig. 6). Heintze (1990) considered that these flat segments are the evidence of the totality of the eclipse of U CrB.

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The temporal appearance of the flat bottoms and the sharp minima in the light curve suggests possible existence of a short period intrinsic variability such as RZ Cas (Ohshima et al. 2001). Taking into account the recent discovery of the stellar pulsation of the Algol type binaries, we may suppose that the temporal appearance of the flat segments at the primary minima of U CrB would be evidence for the pulsation of a component of the system. We reanalyzed the photometric data of van Gent (1989a), and confirmed the short period variability of a period of several hours. The partial eclipse type light curve was found in other photometric data. We discuss the nature of a possible stellar pulsation.

2. Reanalyses of photometric data

We studied the published data of photometric observations of van Gent (1989a), and have found several evidences of a short period variability.

a) First we examined the color at the bottom of the primary minimum. The color in the primary minimum would be redder than that at out-of-eclipse phase when the eclipse was total, because only the red component (G3.5III) was seen. In this case, $m(471\text{ nm}) - \text{m}(761\text{ nm}) \approx 0.5$ and $m(672\text{ nm}) - \text{m}(871\text{ nm}) \approx 0.2$ were expected for the effective temperature of 5350 K following Heintze (1990), who used the spectral type of G3.5III for the secondary. We checked the data at the primary minimum showing the flat bottom on the night of HJD 2444731, and have found $m(474\text{ nm}) - \text{m}(781\text{ nm}) = -0.4$ and $m(672\text{ nm}) - \text{m}(871\text{ nm}) = -0.1$. These are comparable with those during the out-of-eclipse phase, $m(474\text{ nm}) - \text{m}(781\text{ nm}) = -0.7$ and $m(672\text{ nm}) - \text{m}(871\text{ nm}) = -0.2$. From these analysis, we conclude that the parimary minima is not caused by a total eclipse.

b) The light curves of the primary minimum on the night of HJD 2445052 were examined. We show the light curve at 474 nm in Fig. 1. The light curve is in asymmetry which can be evidence the superposition of the eclipse and the pulsation of the star (see, e.g., Ohshima et al. 2001).

c) The light curves of the out-of-eclipse phase were found to show oscillations. The light curve at 781 nm on HJD 2444987, phase 0.18 - 0.21, is indicated in Fig. 2. It shows the oscillatory change with an amplitude of 0.05 mag with a period of 1.2 h. Fig. 3 shows the light curve at HJD 2445027, phase 0.74 - 0.77. The oscillatory change with the period slightly longer than 0.07 d is likely identified. Such an irregularity of the light curve was mentioned by the observer himself, but considered as an effect of the circumstellar matter.

To study the nature of the short period irregularity of the light curve, we examined the color dependency of the luminosity for the whole data in the out-of-eclipse phase. The relationship between the brightness at 474 nm and the color, $m(474\text{ nm}) - \text{m}(781\text{ nm})$, was studied. The diagram looked convincing that the blue phase coincides with the bright phase (Fig. 4). The correlation coefficient was 0.622. This gives suggestion to the pulsation nature of the short period variability.

Because the light curves implied a multiperiodic nature, the variety in the period obtained from each observation was reasonable. The multiperiodic and seemingly irregular variations are common in the stellar pulsation of the early-type stars. In order to separate each mode, a sufficiently long timespan campaign properly scheduled for this system will be necessary.

3. Photometric observations

The short period light variation was also found in other photometric observations. Two of the authors (S. N. & Y. N.) observed U CrB on two nights of April 12, 1995 and April 5, 1996 at Dodaira Observatory of the National Astronomical Observatory of Japan. The 91-cm reflector equipped with the multichannel polarimetric photometer (Kikuchi et al. 1979) was used. We observed the primary minima with the comparison star HD136654. The light curve at 455 nm on April 5, 1996 is shown in Fig. 5. Their results did not show any characteristics of the total eclipse as once observed by Olson (1982).

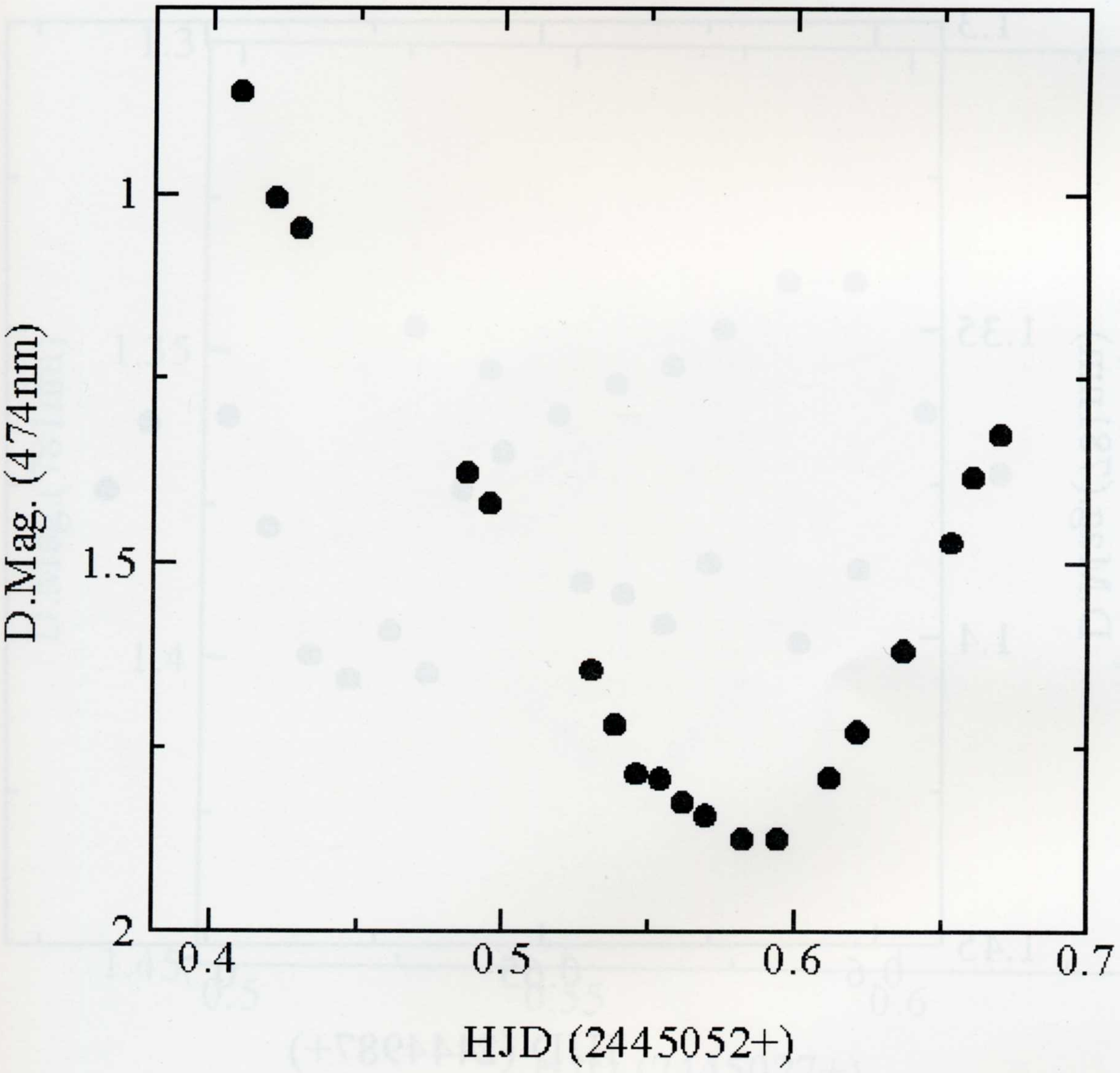

Fig. 1. Light variations at a primary minimum of U CrB. The published data of van Gent (1989a) is used. The light curve is not symmetric.

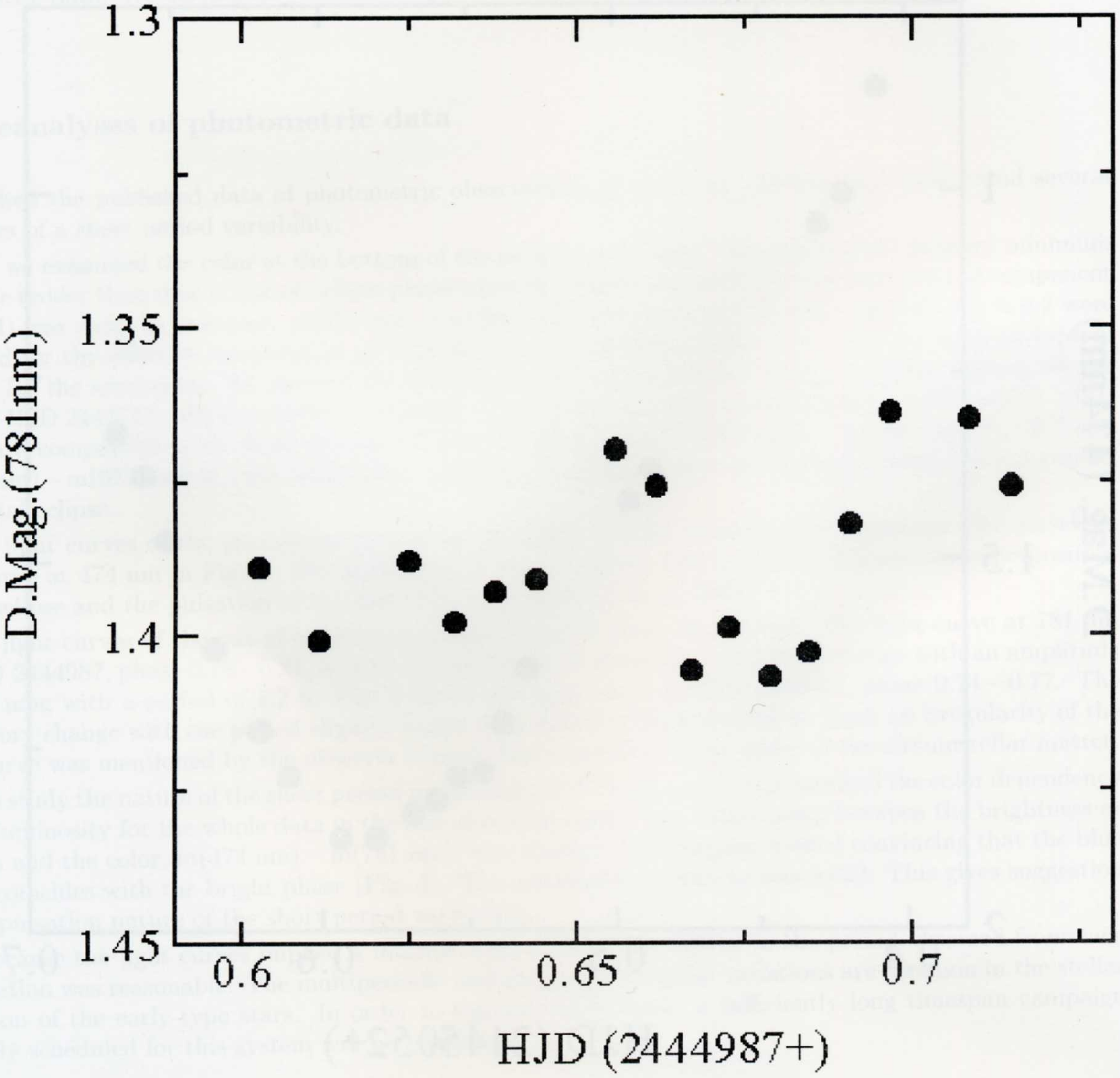

Fig. 2. Out-of-eclipse light variations on HJD 2444987. The published data of van Gent (1989a) is used. The short period variability can be seen.

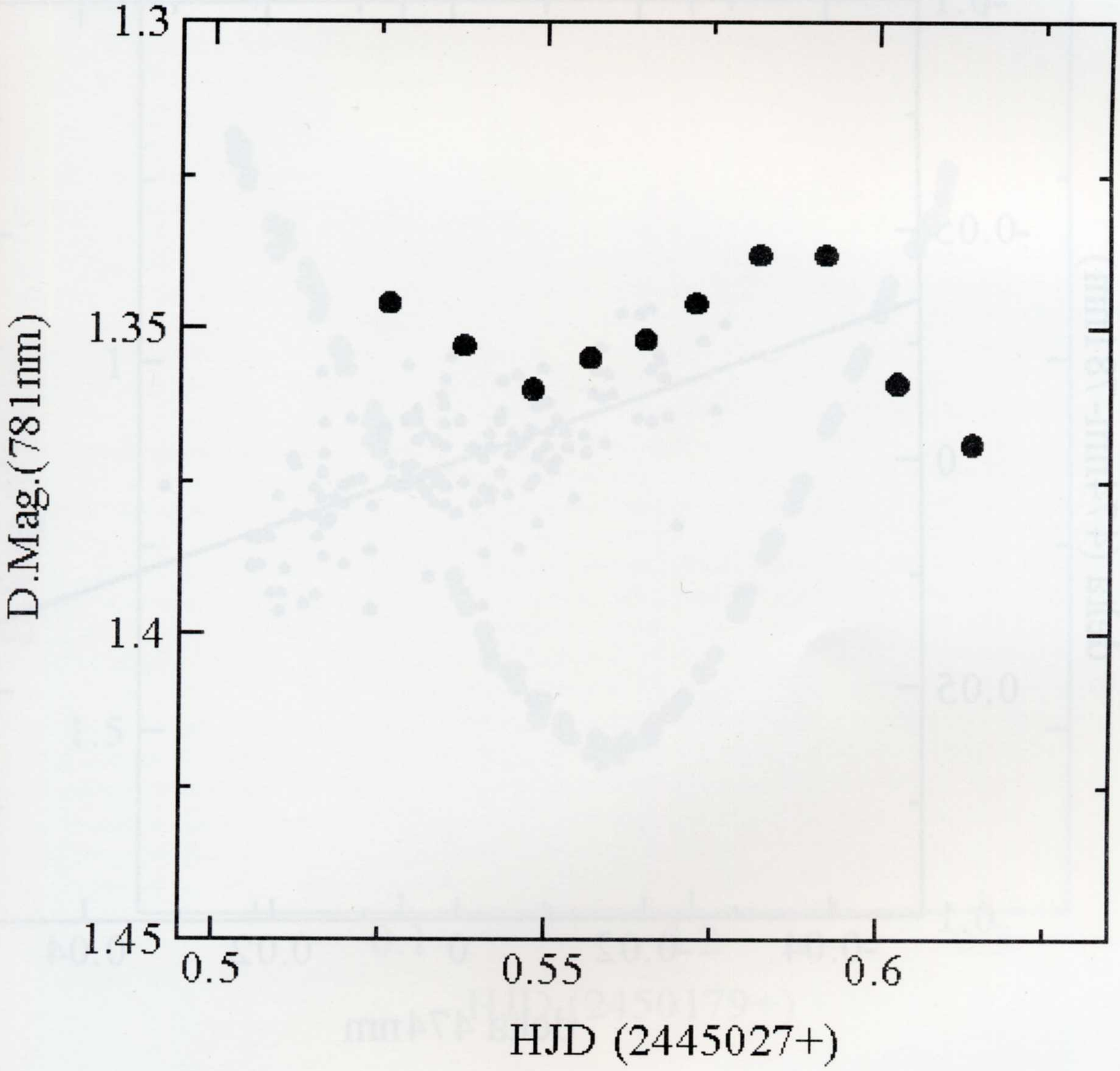

Fig. 3. The same as Fig. 2 but on HJD 2445027.

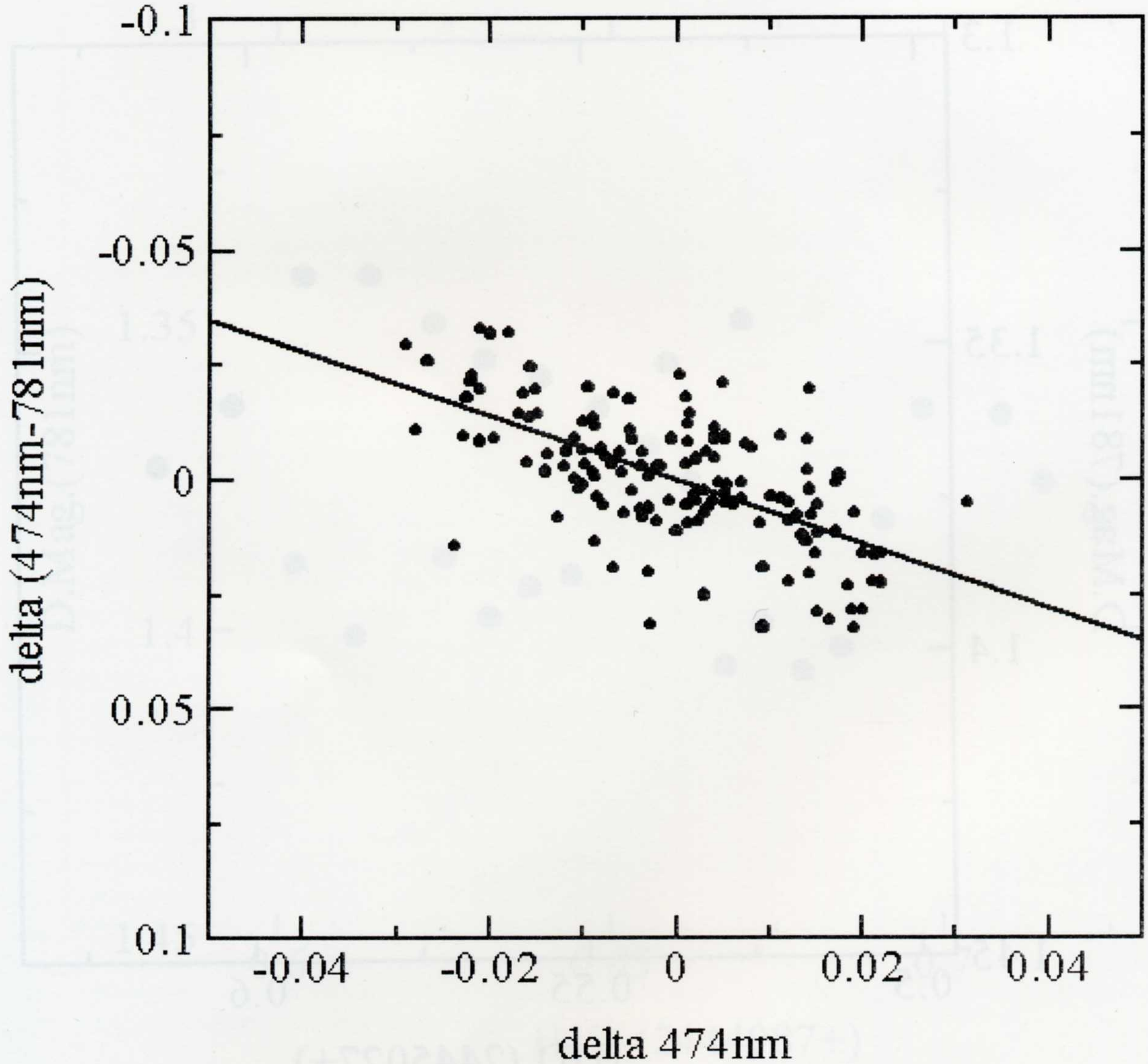

Fig. 4. Correlation of the brightness with the color. The whole out-of-eclipse data in van Gent (1989a) are used.

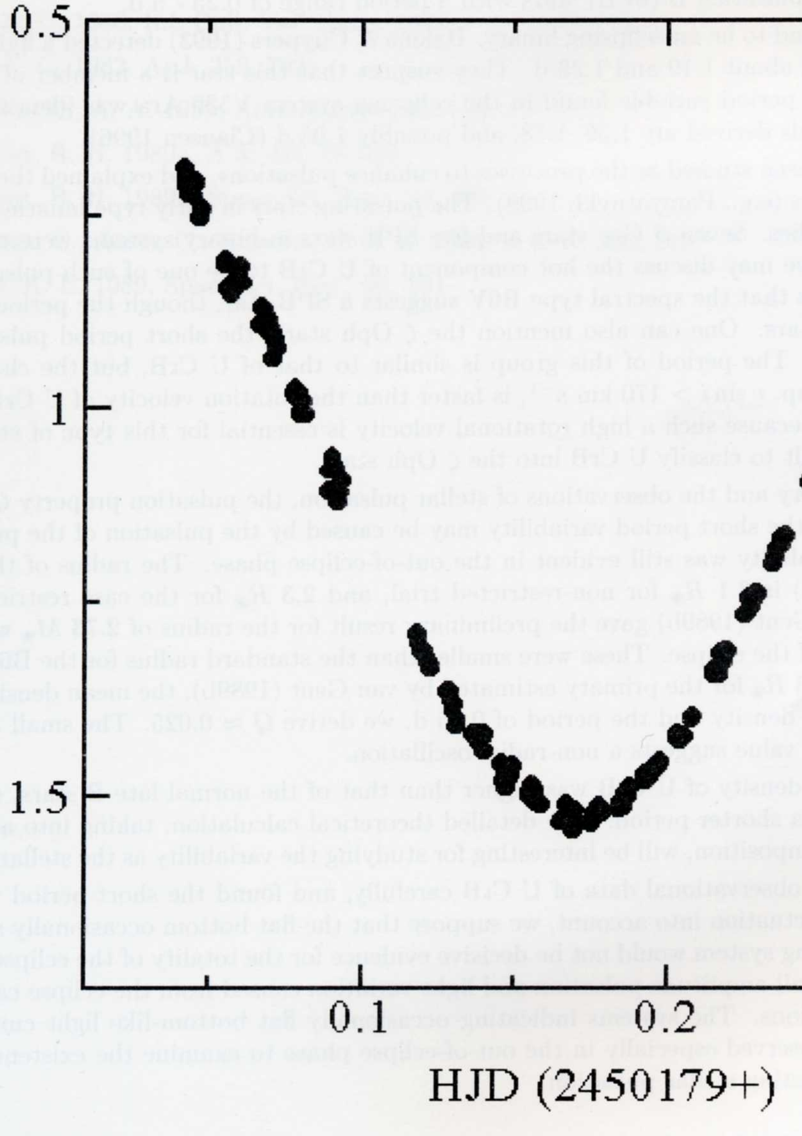

Fig. 5. Light curve at 455 nm in the primary minimum on April 5, 1996. The observation was performed at Dodaira Observatory of the National Astronomical Observatory of Japan. No feature indicating the total eclipse is shown.

4. Discussions

In this section, we discuss the nature of the short period light variations of U CrB. As indicated in the existence of the color-brightness relation, we may assume the origin of the short period variability to be of stellar pulsation. Among known B stars, many pulsating stars have been discovered (Waelkens et al. 1998). The pulsating stars in and close to the main sequence consisted of two groups. The stars of the bright and hot group were the β Cep stars which pulsate with a period range of 0.1 - 0.4 d, and those of the faint and cool group were the slowly pulsating B (SPB) stars with a period range of 0.25 - 5 d.

The star HR2680 is found to be an eclipsing binary. Balona & Cuypers (1993) detected a light variation with approximate period of about 1.19 and 1.28 d. They suspect that this star is a member of the 53 Per class (SPB). Another short period variable found in the eclipsing system V539 Ara was identified to be a SPB star because the periods derived are 1.36, 1.78, and possibly 1.08 d (Clausen 1996).

The κ-mechanism has been studied as the processes to enhance pulsations, and explained the instability strip of β Cep and SPB stars (e.g., Pamyatnykh 1999). The pulsating stars in early type binaries have been found by spectroscopic studies. Seven β Cep stars and five SPB stars in binary systems were reported by Aerts et al. (1998). Thus we may discuss the hot component of U CrB to be one of such pulsating stars. The point to be discussed is that the spectral type B6V suggests a SPB star, though the period is outside the known range of SPB stars. One can also mention the ζ Oph stars, the short period pulsating stars in late O- or early B-type. The period of this group is similar to that of U CrB, but the characteristic rotation velocity of the group, $v \sin i > 170$ km s^{-1}, is faster than the rotation velocity of U CrB, $v \sin i =$ 50 km s^{-1}(Wilson 1989). Because such a high rotational velocity is essential for this type of star (Balona & Kambe 1999), it is difficult to classify U CrB into the ζ Oph stars.

For comparing the theory and the observations of stellar pulsation, the pulsation property Q ($\equiv P\sqrt{\bar{\rho}}$) is useful. We assumed that the short period variability may be caused by the pulsation of the primary, the B6V star, because the variability was still evident in the out-of-eclipse phase. The radius of the primary estimated by Heintze (1990) is 3.1 $R_{\odot}$ for non-restricted trial, and 2.3 $R_{\odot}$ for the case restricted to the totality of the eclipse. van Gent (1989b) gave the preliminary result for the radius of 2.73 $M_{\odot}$ without the assumption of the totality of the eclipse. These were smaller than the standard radius for the B6V star, 5.2 $R_{\odot}$. From 4.98 $M_{\odot}$ and 2.73 $R_{\odot}$ for the primary estimated by van Gent (1989b), the mean density of 0.245 $\rho_{\odot}$ was obtained. Using the density and the period of 0.05 d, we derive $Q \approx 0.025$. The small amplitude, multiperiodicity, and this Q value suggests a non-radial oscillation.

Because the calculated density of U CrB was higher than that of the normal late B stars, the similar pulsation property gives us a shorter period. The detailed theoretical calculation, taking into account the difference in the chemical composition, will be interesting for studying the variability as the stellar pulsation.

We have examined the observational data of U CrB carefully, and found the short period variability. Taking the observational fluctuation into account, we suppose that the flat bottom occasionally seen in the light minimum of the eclipsing system would not be decisive evidence for the totality of the eclipse. It seems that superposition of the small amplitude pulsation and light variation caused from the eclipse can produce flat bottom-like light variations. The systems indicating occasionally flat bottom-like light curves at the light minimum should be observed especially in the out-of-eclipse phase to examine the existence of short period light variations suggesting stellar pulsation.

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