Outburst Photometry of the Eclipsing Dwarf Nova GY Cancri

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Abstract

We observed the ROSAT-selected eclipsing dwarf nova GY Cnc (=RX J0909.8+1849) during the 2001 November outburst. We refined the orbital period to be 0.1754425(5) d. The fading portion of the outburst was indistinguishable from those of typical dwarf novae with similar orbital periods. However, the signature of orbital humps (or a hot spot) was far less prominently observed in the orbital light curves and eclipse profiles than in usual dwarf novae with similar orbital periods. The combination of low frequency of outbursts and the apparent lack of slowly rising, long outbursts in GY Cnc is difficult to reconcile within the standard framework of dwarf novae. We suspect that GY Cnc may be the first above-the-gap counterpart of unusual eclipsing dwarf novae HT Cas and IR Com.

Key words: accretion, accretion disks — stars: binaries: eclipsing — stars: dwarf novae — stars: novae, cataclysmic variables — stars: individual (GY Cancri)

1. Introduction

Cataclysmic variables (CVs) are close binary systems consisting of a white dwarf and a red-dwarf secondary transferring matter via Roche-lobe overflow. Dwarf novae are a class of CVs showing outbursts, which are believed to be a result of instabilities in the accretion disk [see Osaki (1996) for a review].

Depending on orbital inclination, some dwarf novae show a various degree of eclipses. Eclipses in such dwarf novae provide a powerful tool in studying the time-variation of the structure of accretion disks (e.g. Horne 1985: Wood et al. 1989).

GY Cnc (=RX J0909.8+1849 = HS 0907+1902) is a CV identified in the course of the Hamburg/RASS identifications of ROSAT sources (Bade et al. 1998). The dwarf nova nature was suspected upon the recognition of an apparent outburst on Guide Star Catalog (GSC) (Kato et al. 2000). During the 2000 February outburst, several observers independently discovered that the object shows deep eclipses (Kato et al. 2000 and references therein; Günsicke et al. 2000). Thorstensen (2000) further studied the object spectroscopically, and obtained component masses. Thorstensen (2000) reported that a modeling with a flat, Keplerian disk did not yield a good fit to the observed profile of the quiescent Hα emission line. Shafter et al. (2000) studied the object during post-outburst quiescence, and derived orbital parameters. Shafter et al. (2000) found that the bright spot (hot spot) is less conspicuous in GY Cnc compared to IP Peg, the eclipsing dwarf nova having similar orbital parameters. These observations suggest a some degree of peculiarity in GY Cnc compared to other dwarf novae above the period gap.

In spite of independent eclipse detections, the observation of the 2000 February outburst turned out to be rather fragmentary. We present first-ever complete photometric coverage of the declining branch of the 2001 November outburst.

2. Observation

The 2001 November outburst was detected by J. Gunther and E. Morillon (AFOEV), and was reported to VSNET. Following this alert, we conducted time-series CCD photometry on five consecutive nights (November 24 through 28), which entirely covered the declining branch of the outburst. We obtained additional snapshot photometry on November 30 and December 1, thereby confirming that the object almost reached quiescence. The observations were done using an unfiltered ST-7E camera (system close to \( R \)) attached to the Meade 25-cm Schmidt-Cassegrain telescope. The exposure time was 30 s. The images were dark-subtracted, flat-fielded, and analyzed using the Java-based PSF photometry package developed by one of the authors (TK). The differential magnitudes of the variable were measured against GSC 1404.1852 (Tycho-2 \( V \)-magnitude 11.08), whose constancy was confirmed by comparison with GSC 1404.778 (Tycho-2 \( V \)-magnitude 11.12). Barycentric corrections to the observed times were applied before the following analysis. The log of observations is summarized in table 1. The overall light curve is shown in figure 1.

3. Results and Discussion

3.1. Outburst Frequency

There are three known outbursts (2002 February, 2000 October, 2001 November) between 1999 March and 2002 April, when the object was regularly monitored by VSNET. This suggested a regular outburst cycle of about 1 year, which is consistent with the observed orbital period 0.1754425(5) d. The outbursts were characterized by deep eclipses (Kato et al. 2000). During the 2001 November outburst, we observed the fading portion of the outburst, which was indistinguishable from those of typical dwarf novae with similar orbital periods. However, the signature of orbital humps (or a hot spot) was far less prominently observed in the orbital light curves and eclipse profiles than in usual dwarf novae with similar orbital periods. The combination of low frequency of outbursts and the apparent lack of slowly rising, long outbursts in GY Cnc is difficult to reconcile within the standard framework of dwarf novae. We suspect that GY Cnc may be the first above-the-gap counterpart of unusual eclipsing dwarf novae HT Cas and IR Com.

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Table 1. Log of observations.

| Date               | BJD (∗ (start–end)) | N † | Mag ‡ | Error § |
|--------------------|---------------------|-----|-------|---------|
| 2001 November 24   | 52238.110–52238.381 | 598 | 2.243 | 0.011   |
| 2001 November 25   | 52239.179–52239.344 | 298 | 2.768 | 0.015   |
| 2001 November 26   | 52240.179–52240.350 | 302 | 3.487 | 0.011   |
| 2001 November 27   | 52241.103–52241.357 | 525 | 4.169 | 0.010   |
| 2001 November 28   | 52242.154–52242.381 | 125 | 4.441 | 0.029   |
| 2001 November 30   | 52244.351–52244.356 | 11  | 4.772 | 0.085   |
| 2001 December 1    | 52245.129–52245.375 | 88  | 4.448 | 0.093   |

* BJD = 2400000.
† Number of frames.
‡ Averaged magnitude relative to GSC 1404.1852.
§ Standard error of the averaged magnitude.

Fig. 1. Overall light curve of the 2001 November outburst. The last three points and error bars represent nightly averaged magnitudes and errors of snapshot observations.

Fig. 2. Long-term light curve from observations reported to VSNET. Large open circles and small dots represent positive observations and upper limits, respectively.

VSNET observers. The light curve drawn from the available observations is shown in figure 2. Although there are unavoidable gaps in observations (GY Cnc is located close to the ecliptic), the lack of outbursts immediately following the 2000 October and 2001 November outbursts strongly suggests that the typical interval of outbursts is an order of 200–300 d. This value is one of the longest recurrence times among dwarf novae with similar orbital periods (Simon 2000b; Cannizzo et al. 1988).

3.2. Eclipse Ephemeris

After subtracting linear declining trends, the mid-eclipse times were determined by minimizing the dispersions of eclipse light curves folded at the mid-eclipse times. The error of eclipse times were estimated using the Lafler–Kinman class of methods, as applied by Fernie (1989). The validity of the estimated errors has been confirmed by an application to different ranges (in eclipse depth) of the data. Table 2 summarizes the observed times of the eclipses (labeled as “this work”), together with the published eclipse times summarized in Kato et al. (2000). The times from Kato et al. (2000) were converted into the Barycentric Julian Date (BJD) system, common to the present observation. The cycle count (E) follows the definition by Kato et al. (2000).

Using these eclipse times, we obtained the following linear ephemeris. The orbital phases used in the following figures and discussions are based on the following equation:

$$BJD_{\text{min}} = 2451586.21271(8) + 0.17544251(5)E.$$  (1)

3.3. Outburst Light Curve

As shown in figure 1, the object showed an almost linear decline during the first four nights. The mean rate of de-
Table 2. Eclipses and $O - C$'s of GY Cnc.

| Eclipse   | Error | $E$ | $O - C$ | Ref. |
|-----------|-------|-----|---------|------|
| 51581.8263 | ⋯     | −25 | −34     | 1    |
| 51582.0017 | ⋯     | −24 | −39     | 1    |
| 51585.6861 | ⋯     | −3  | −28     | 1    |
| 51586.21255| ⋯     | 0   | −16     | 2    |
| 51586.38834| ⋯     | 2   | 13      | 3    |
| 51586.91465| ⋯     | 4   | 17      | 2    |
| 51587.96813| ⋯     | 10  | 100     | 2    |
| 51588.31802| ⋯     | 12  | 0       | 2    |
| 51588.8969 | ⋯     | 21  | −10     | 1    |
| 51590.07239| ⋯     | 22  | −5      | 2    |
| 51590.7742 | ⋯     | 26  | −1      | 1    |
| 51590.9496 | ⋯     | 27  | −5      | 1    |
| 51590.94997| ⋯     | 27  | 3       | 2    |
| 51591.12457| ⋯     | 28  | −5      | 2    |
| 51599.7219 | ⋯     | 77  | 12      | 1    |
| 52238.15700| 4     | 3716| −6      | 4    |
| 52238.33258| 3     | 3717| 7       | 4    |
| 52239.20975| 5     | 3722| 4       | 4    |
| 52241.31496| 9     | 3734| −1      | 4    |

* Eclipse center, BJD$-2400000$.  
† Estimated error in $10^{-5}$ d.  
‡ Cycle count.  
§ Against equation (1). Unit in $10^{-5}$ d.  
∥ Reference.  
1: Gänsicke et al. (2000), 2: Kato et al. (2000) , 3: T. Vanmunster (vsnet-alert 4210), 4: this work

...This value almost exactly fits the well-known Bailey’s relation... (figure 3). This finding indicates that the fading part of the GY Cnc is indistinguishable from those of typical dwarf novae. The rising portion of the outburst was not observed; the last negative observation reported to VSNET was made 8 d before the detection of the outburst.

3.4. Orbital Modulations

Figure 4 shows phase-averaged light curves during the decline phase (2001 November 24–27), after subtracting the linear decline (0.65 mag d$^{-1}$). Orbital phases were calculated against equation (1). On November 24, the light curve showed a moderate (~0.1–0.2 mag) reflection effect and a possible shallow secondary eclipse around phase 0.5 (Figure 5). These findings indicate a substantial amount of irradiation from the outbursting disk on the secondary star. The presence of the possible phase 0.5 eclipse suggests that the heated surface of the secondary was partially eclipsed by the optically thick accretion disk, as in IP Peg (Littlefair et al. 2001). GY Cnc in outburst thus would be an excellent target for detecting “mirror eclipses” of profiles of emission lines.

On the second night (November 25), the light curve outside the eclipses became flatter, indicating a lesser degree

Fig. 3. Relation between orbital periods and rates of decline of well-observed dwarf novae. The data (dots) are mainly taken from a compilation by Patterson et al. (1997) based on Warner (1987,1995), excluding an helium system CR Boo, and including newly measured systems (DX And: Kato, Nogami 2001; WX Cet Kato et al. 2001; IR Com: Kato et al. 2002). The dotted line indicates a linear regression ($\log T_{\text{decay}} = −0.25 + 0.79 \log P_{\text{orb}}$) from the available data. The location of GY Cnc is shown with an open circle.

Fig. 4. Phase-averaged light curves of GY Cnc during the decline phase (2001 November 24–27). Each point represents an average of 0.01 phase bin.
of irradiation as the outburst faded. On the third night (November 26), a hump (orbital phase 0.6–0.9) became detectable, but it is far less prominent than in other high-inclination dwarf novae (e.g. U Gem Krzeminski 1965). There may be a dip-like structure around phase 0.4–0.5, whose origin is unknown. On the fourth night (November 27), a “shoulder” became evident between orbital phases 0–0.2, which is likely to be associated with the hot spot.

3.5. Eclipse Profile

Figure 6 shows enlarged profiles of the eclipses. On the third night (November 26), only the egress part of an eclipse was observed. On other nights, entire phases of eclipses were observed. On the first two nights (November 24 and 25), the eclipses were “V”-shaped, as is usual for a high-inclination dwarf nova in outburst (cf. Baptista et al. 2000). However, GY Cnc shows a some degree of peculiarity in that at least some of eclipses show almost identical ingress and egress [For example, the mean rates of variation between 0.01 < |phase| < 0.04 are 50 and 52 mag d^{-1} for ingress and egress on November 24, respectively. On November 25, the corresponding mean rates are 68 and 64 mag d^{-1}. Estimated errors are 2 mag d^{-1}]. This is contrary to what is expected and predicted for an effect of the presence of a hot spot (Shafter et al. 2000). This finding suggests that the accretion disk in outbursting GY Cnc has a brighter portion in the trailing direction (i.e. the opposite direction to the expected hot spot). Figure 7 shows a comparison eclipses between GY Cnc and IP Peg, observed ~2 mag above the quiescent level. A pre-eclipse orbital hump and a slower egress are already prominent in IP Peg, while the light curve outside the eclipse is virtually flat in GY Cnc.

Table 3 lists eclipse widths, which are defined as the durations when the object is more than 0.2 mag fainter than the mean magnitudes outside the eclipses. The data on November 26 were not used because they lack ingress/egress observations. The width of eclipse dramatically decreased between November 24 and 25, which indicates a dramatic shrinkage of the luminous part of the accretion disk. The decrease of the width stopped between November 25 and 27, which suggests that the inner luminous part of the accretion disk disappeared, i.e. almost the entire disk again became in low temperature state (cf. Osaki 1996). This finding is compatible with the observation that the object was only ~0.5 mag above its quiescent magnitude on November 27 (cf. Figure 1).

3.6. Nature of GY Cnc

As shown in above subsections, orbital humps in GY Cnc were less prominent than in other high-inclination dwarf novae even during the later stage of an outburst. In conjunction with the absence of asymmetric features of eclipses which are expected from a hot spot (subsection 3.5), we conclude that the hot spot is weaker in GY Cnc than in other dwarf novae. This is in agreement with the finding by Shafter et al. (2000), who studied the object in post-outburst quiescence. Such a feature may be a consequence of a smaller mass-transfer rate (M) than in other dwarf novae above the period gap. Although the low occurrence of outbursts (subsection 3.1), may be explained by the assumption of a small mass-transfer rate or a low quiescent viscosity (Ichikawa, Osaki 1994), low-M systems above the period gap tend to show slowly rising long outbursts (cf. CH UMa, Simon (2000b); DX And Simon (2000a)). This is a natural consequence of disk-instabilities arising from the inner accretion disk (cf. Smak 1984: see also discussions in Simon (2000b)). In contrast to DX And and CH UMa, no known outbursts of GY Cnc are slowly rising, long outbursts.

In conjunction with a relatively high $L_X/L_{opt}$ (Bade et al. 1998), we suggest an alternative explanation. As proposed in Kato et al. (2002), two dwarf novae (HT Cas and IR Com) show common properties (whose origin is not yet well understood): relatively high $L_X/L_{opt}$, low frequency of outbursts, and little evidence of orbital humps, all of which are common to GY Cnc. We suspect that GY Cnc may be the first counterpart of HT Cas or IR Com above the period gap.

Although there is no strongly supporting observational evidence, a truncation of the inner accretion disk by the
magnetic field of the white dwarf, as in intermediate polars (IPs), could also be a viable explanation. In such a condition, the truncation effectively suppresses disk instabilities in the inner accretion disk, thereby lengthening outburst intervals (Angelini, Verbunt 1989). Some IPs show dwarf nova-type outbursts, the best known examples being DO Dra\(^4\) (Wenzel 1983; Szkody et al. 2002), TV Col (Szkody, Mateo 1984; Hellier 1993), EX Hya (Hellier et al. 1989) and HT Cam (Ishioka et al. 2002; Kemp et al. 2002). Most of them show brief (and often small) outbursts, which often show a precipitous decline during its final stage [e.g. HT Cam showed a decline rate of 4 mag d\(^{-1}\) during its late stage of an outburst (Ishioka et al. 2002)]. Such presence of a precipitous decline is naturally explained if the inner part of the accretion disk is magnetically truncated (Ishioka et al. 2002). From this viewpoint, the lack of departure in GY Cnc from the Bailey’s relation throughout the outburst decline (subsection 3.3) seems to less favor the possibility of the IP interpretation. This IP possibility could be more directly tested by future attempts to directly detect spin pulses or X-ray modulations arising from a magnetized white dwarf.

4. Conclusion

We observed the ROSAT-selected eclipsing dwarf nova GY Cnc (=RX J0909.8+1849) during the 2001 November outburst. We refined the orbital period to be 0.17544251(5) d. The fading portion of the outburst was indistinguishable from those of typical dwarf novae with similar orbital periods. However, the orbital light curves and eclipse profiles show a lesser signature of orbital humps (or a hot spot) than in usual dwarf novae with similar orbital periods. We suspect that GY Cnc may be the first above-the-gap counterpart of unusual eclipsing dwarf novae HT Cas and IR Com.

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\(^3\) DO Dra has been the source of some confusion regarding its designation. Some authors call the same variable YY Dra, however, we use the designation DO Dra, following the official nomenclature by the GCVS (Kholopov et al. 1985; Kholopov, Samus 1988.

\(^4\) Other IPs showing outbursts include GK Per, XY Ari and V1223 Sgr.
Fig. 7. Comparison of eclipses between GY Cnc and IP Peg, observed $\sim$2 mag above the quiescent level. The observation of IP Peg was done on 1995 December 23 (during the fading branch of an outburst). A pre-eclipse orbital hump and a slower egress are already prominent in IP Peg, while the light curve outside the eclipse is virtually flat in GY Cnc.

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