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On the nature of embedded precursors in long outbursts of SS Cyg stars as inferred from observations of the IW And star ST Cha

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Abstract

We observed the IW And-type dwarf nova ST Cha and found that standstills were terminated by brightening at a constant brightness level during standstills. This finding is not consistent with a model of IW And-type dwarf novae assuming repeated enhancements of the mass-transfer rate from the secondary. We found that one outburst in ST Cha had a shoulder during the rising branch at the same level in which standstills were terminated by brightening. This phenomenon is very similar to what are called "embedded precursors" in SS Cyg stars. We propose that these embedded precursors in both SS Cyg stars and the IW And star ST Cha occur when the disk reaches the tidal truncation radius. If this is the case, precursors in SS Cyg stars and SU UMa stars are different in origin on the contrary to the idea suggested by Cannizzo (2012).

1 Introduction

Superoutbursts of SU UMa-type dwarf novae (SU UMa stars) are considered to arise from when the disk reaches the 3:1 resonance, which triggers tidal instability (Whitehurst 1988; Hirose and Osaki 1990; Lubow 1991). Although this picture of the thermal tidal instability (TTI) model (Osaki 1989; Osaki 1996) was once challenged by Smak (2013), analysis of the Kepler high-precision observation of V1504 Cyg and V344 Lyr concluded that the TTI model is the only viable model for ordinary SU UMa-type dwarf novae (Osaki and Kato 2013a; Osaki and Kato 2013b; Osaki and Kato 2014).

On the other hand, it has been shown that light curves of SS Cyg stars, in which the 3:1 resonance is unlikely to occur, show a complex feature during their long outbursts using high-precision photometry (Cannizzo, 2012). These outbursts start with a precursor-like part as in superoubursts of SU UMa-type dwarf novae, and Cannizzo (2012) called the phenomenon "embedded precursor". Following this discovery, Cannizzo (2012) supported van Paradijs' traditional idea (van Paradijs, 1983) that long outbursts in dwarf novae above the period gap and superoutbursts in systems below the period gap constitute a unified class. In this picture, long outbursts in SS Cyg stars and superoutbursts in SU UMa stars are essentially the same and superhumps in SU UMa stars appear as the result of the long durations of superoutbursts enabling the 3:1 resonance to grow. Whether this traditional picture or Osaki's TTI model is correct has long been discussed (see Osaki and Kato 2013a). To solve this issue, it is necessary to understand whether "embedded precursors" in SS Cyg stars and precursors in SU UMa-type superoutbursts are the same phenomenon or not.

In the meantime, a new subclass of dwarf novae IW And stars (Simonsen 2011; Kato 2019) have been recognized and have been receiving attention both from observational and theoretical sides (Simonsen 2011;

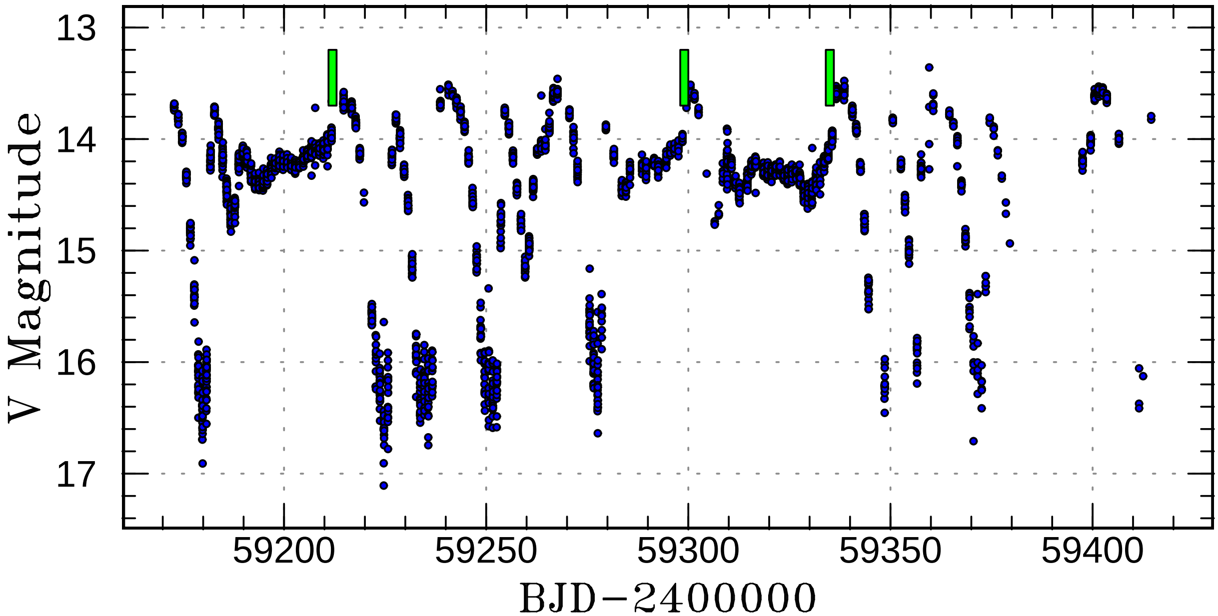

Figure 1: V-band light curve of ST Cha during the 2020–2021 season. IW And-type cycles were repeated three times. The vertical green bars represent the epochs when standstills were terminated by brightening.

Szkody et al. 2013; Hameury and Lasota 2014; Kato et al. 2020; Kimura et al. 2020a; Kimura et al. 2020b; Kato and Kojiguchi 2020; Kimura and Osaki 2021; Lee et al. 2021; Kato et al. 2021).

ST Cha is one of IW And stars (Simonsen et al. 2014; Kato 2019). One of the authors (FJH) obtained time-series photometry between 2015 and 2021. During the 2020–2021 season, this object showed typical IW And-type behavior.

2 Results and Discussion

The V-band light curve in the 2020–2021 season is shown in figure 1. In three intervals BJD 2459190–2459212, 2459283–2459299 and 2459309–2459336, this object showed standstills terminated by brightening and subsequent fading (dip). The second standstill was followed by brigthening, a small dip, and immediately another standstill. This sequence standstill–brigthening–dip is the basic definition of IW And stars (Kato, 2019) [The depths of dips are usually variable, and in some cases they are completely missing. This type of variation is referred to as "heartbeat". See the case of HO Pup in Kimura et al. (2020b)]. During the first two standstills, the object slowly brightened suggesting that the disk mass was building up during these standstills. The third standstill was more complex with temporary fading (BJD 2459328–2459332), but followed by brightening. We performed a period analysis using these three standstills without yielding a statistically significant period. This may indicate the lack of an orbital or superhump signal in this system or it may be simply due to the lack of sensitivity of a period longer than 0.2 d, which was limited to the durations of nightly runs.

We found the constancy (V=14.0) of brightness when these standstills started rising to brightening which terminated these standstills. Although the IW And-type phenomenon lasted shorter than in the 2020–2021 season, the same value was obtained from observations of the 2015–2016 season (figure 2). The same phenomenon was also observed in BO Cet (Kato et al., 2021). Hameury and Lasota (2014) suggested a model of IW And stars in which repeated enhancements of the mass-transfer rate from the secondary cause brightening at the end of standstills. In this model (although Hameury and Lasota themselves did not consider it very realistic), timings of these enhancements of the mass-transfer rate is determined by the secondary, not by the state of the disk, and the disk luminosity at the onset of brightening is not expected to be constant. Our observations, however, suggest that brightening occurs when the luminosity of the disk reaches a certain level (such as determined by the disk mass or radius).

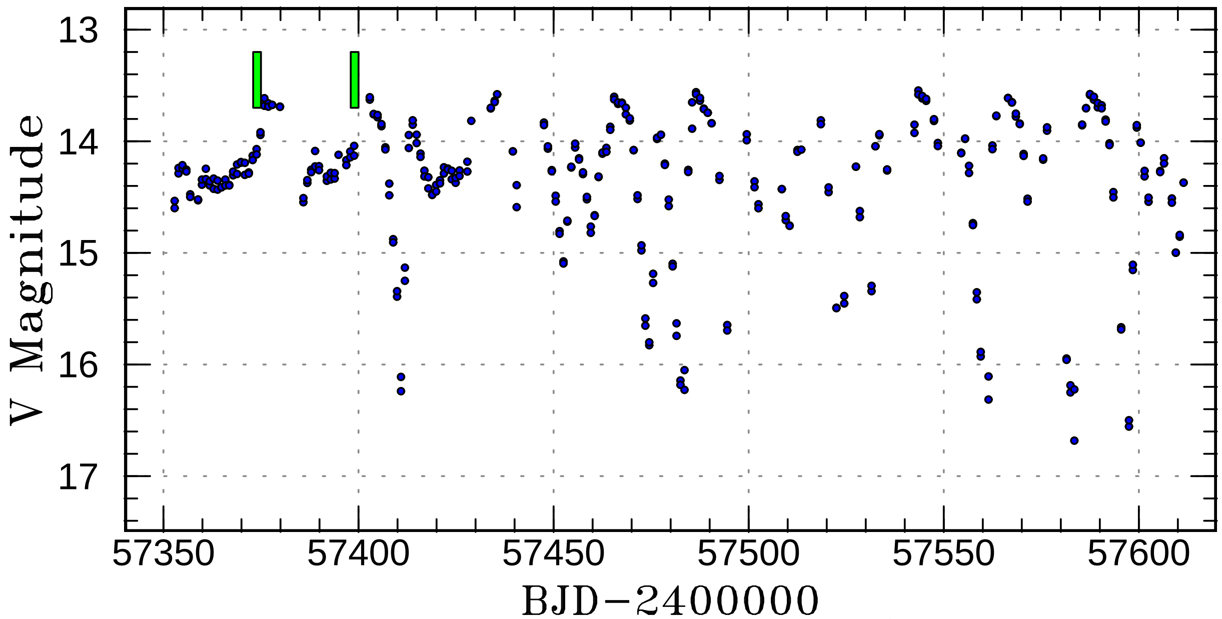

Figure 2: V-band light curve of ST Cha during the 2015–2016 season. IW And-type cycles were repeated at least twice early in the season. The vertical green bars represent the epochs when standstills were terminated by brightening.

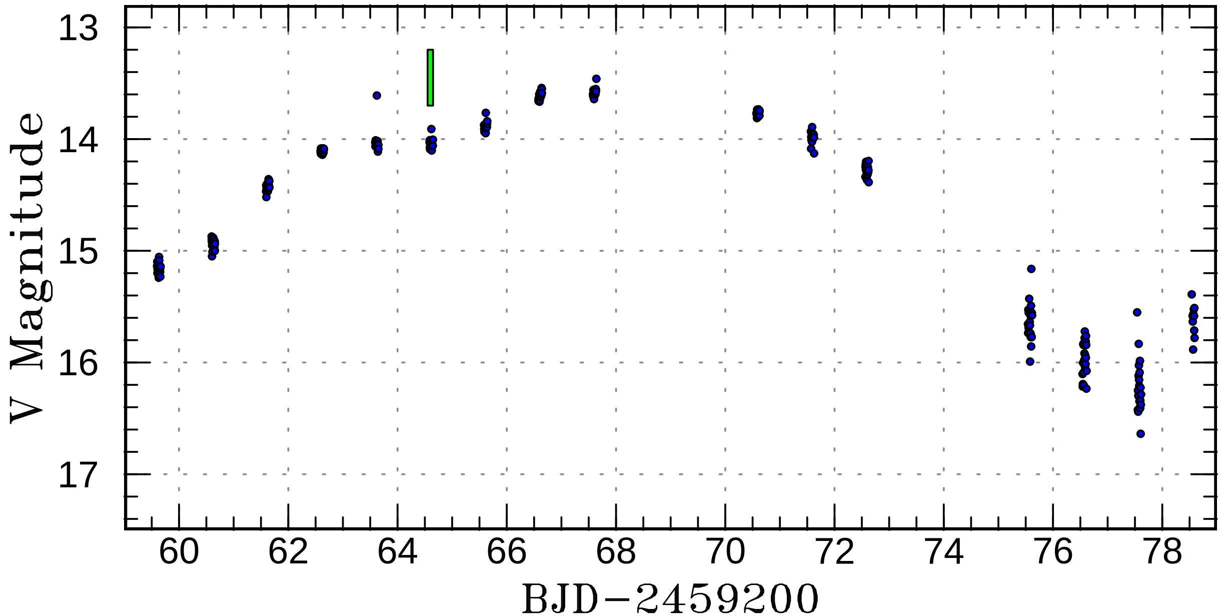

Figure 3: Outburst of ST Cha with a shoulder (embedded precursor). The vertical green bar represents the end of the shoulder.

There has been direct observational determination of the disk radius by M. Shibata et al. in preparation which indicates that the disk radius in IW And-type standstills grows with time and that standstills are terminated by brightening when the disk radius eventually reaches the tidal truncation radius. The constancy of brightness at which standstills are terminated by brightening in BO Cet and ST Cha are also supportive of this idea. The constant brightness when standstills are terminated by brightening can be considered as the state when the disk reaches the tidal truncation radius. In ST Cha, we found an outburst with an apparent shoulder or "embedded precursor" (figure 3) similar to the ones observed in SS Cyg stars by Cannizzo (2012). During this outburst, the shoulder had the same brighteness as stated above.

Considering the similarity of embedded precursors in SS Cyg stars with the phenomenon in ST Cha, we propose that embedded precursors in SS Cyg stars refer to a phenomenon in which the disk in these systems reaches the tidal truncation radius. If this is correct, the causes of precursors in SS Cyg stars and SU UMa stars are different since the tidal truncation radius is outside the radius of the 3:1 resonance in SU UMa stars.

Acknowledgments

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