Abstract

ER UMa stars are a recently recognized small subgroup of SU UMa-type dwarf novae, which are characterized by the extremely high outburst frequency and short (19–48 d) supercycles. From the current thermal-tidal disk instability scheme, they are considered to be high mass-transfer SU UMa-type dwarf novae, and comprise a link to permanent superhumpers below the period gap. They do not only provide an opportunity to test the applicability of thermal-tidal instability model but also pose problems on the origin of high mass-transfer in short orbital-period cataclysmic variables. A historical review of this subgroup and recent topics of ER UMa stars, the unique pattern of superhump evolution and the “helium ER UMa analog” (CR Boo), are also discussed.

1 Introduction

Before the discovery of ER UMa stars (or RZ LMi stars), there had been a well-known standard (or classical) picture of SU UMa-type dwarf novae. SU UMa-type dwarf novae, a subclass of dwarf novae, show two types of outbursts — normal outbursts and superoutbursts — which are now explained by the fruitful combination of thermal and tidal instabilities (Osaki 1989). During superoutbursts of SU UMa-type dwarf novae, superhumps appear
which are a result of the tidal instability. In the canonical view of SU UMa-type dwarf novae, the mass-transfer from the secondary is governed by the angular momentum loss by the gravitational wave radiation (GWR), which is a strong function of the secondary mass, or the orbital period. SU UMa-type dwarf novae were thus considered to be a one-parameter system, whose system parameters are a strong function of the orbital period.

There have been classically known exceptions to this view. One is what is called “WZ Sge stars”, which show extremely low outburst frequencies and the predominance of superoutbursts. There have been arguments whether WZ Sge stars can be understood as a natural extension of SU UMa-type dwarf novae to the lowest mass-transfer end, or whether there are a need for other relevant mechanisms or physics. The other is the presence of novalike (NL) stars (and classical novae) in the period gap or below the period gap, suggesting the presence of systems having mass-transfer rates higher than the canonical picture. The unambiguous interpretation of superhump-like modulation in the NL stars was difficult because they can be also interpreted as the intermediate polar effect. The discovery of ER UMa star has drastically changed the canonical picture of SU UMa-type uniformity, and provided a missing, and smooth link between (classical) SU UMa-type dwarf novae and NL stars below the period gap.

2 History of ER UMa stars

Back to ER UMa itself, ER UMa (PG 0943+521) was discovered as an ultraviolet-excess object (Green et al. 1986). The lack of variability information classified it as an inconspicuous novalike cataclysmic binary. However, by several groups differently and independently motivated, the unique variability of this object began revealing itself in early the 1990’s. Among them, M. Iida (VSOLJ) in 1992 was the first to visually discover dwarf-nova outbursts in this object (Iida 1994). His subsequent observations led to the present variable star designation (ER UMa). Follow-up collaborations by amateur and professional observers tentatively classified the object as an Z Cam-type dwarf nova as judged from the presence of “standstill”-like plateau stages. Another was by a systematic follow-up study of the only complete (magnitude-limited) sample of cataclysmic variables (CVs): the PG survey. Misselt and Shafter (1995) detected the photometric period of 1.6 hour in ER UMa, but its origin was not fully pursued at the time of initial discovery. The third was the product of the robotic telescope (RoboScope), which enabled long-term automated observations of NLs and old
Figure 1: Representative light curve of an ER UMa star (DI UMa)

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of superoutbursts (Kato and Kunjaya 1995). ER UMa was thus confirmed to be an SU UMa-type dwarf nova, and dramatically broke the shortest record of supercycle length $T_s$ (the short known at that time was $T_s \sim 130$ d for YZ Cnc). The subsequently discovery of the “ER UMa-twin”, V1159 Ori (Nogami et al. 1995a, 1995b; this object was independently studied by Patterson et al. 1995), and the detection of superhumps in RZ LMi (Robertson et al. 1995; Nogami et al. 1995b) quickly led to a concept of small subgroup of SU UMa-type dwarf novae having the shortest supercycle lengths (Fig. 3 and Table 1). Up to now, another member, DI UMa, has been added (Kato et al. 1996a).

3 Questions arisen by ER UMa stars

The discovery of ER UMa stars soon invoked several questions previously disregarded in the canonical context of SU UMa-type dwarf novae. The first question was whether such short supercycles (48 to 19 d) can be reproduced by the standard disk instability model for SU UMa-type dwarf novae (Os-
Figure 3: Distribution of supercycle among SU UMa stars. ER UMa stars occupy the separated region below $T_s \sim 50$ d.

Figure 4: Superhumps in ER UMa

Osaki (1995a) could reproduce the light curve of ER UMa by increasing the mass-transfer rate by a factor of $\sim 10$. In his model, supercycles longer than $\sim 40$ d could be reproduced; Osaki (1995a) further revealed that as the mass-transfer rate increases beyond this point, the durations of superoutbursts and supercycles lengthen, and finally systems reach a thermally stable, but tidally unstable state. Osaki (1995a) considered this state corresponds to “permanent superhumpers”. Osaki (1995b) also showed the shortest case of 19-d supercycle (RZ LMi) can be reproduced by assuming the reduced tidal torque, whose physical origin has not yet been well understood.

The second is the origin of high mass-transfer rates. In the canonical view, the evolution and the mass-transfer below the period gap are primarily governed by the gravitational wave radiation. The supercycle length, which, in the scheme of thermal-tidal disk instability, is roughly inversely propor-
Figure 5: Distribution of supercycle among SU UMa stars. ER UMa stars occupy the separated region below $T_s \sim 50$ d.

Figure 6: Superhump period versus supercycle length. Usual SU UMa stars and WZ Sge stars are on the dashed line, while ER UMa stars occupy a small separated region.

The third is the (space) number density problem. The number of known ER UMa stars is four out of $\sim 40$ known SU UMa-type dwarf novae. The evolutionary time scale being inversely proportional to the mass-transfer rate, the probability of encountering such systems is $\frac{1}{10}$ of usual SU UMa-type dwarf novae, if ER UMa stars are truly high mass-transfer systems. The observed numbers (although statistically incomplete) suggests either 1) if ER
UMa stars are evolutionally distinct populations from usual SU UMa-type dwarf novae, the source (progenitor) of such systems should be as numerous as usual SU UMa-type stars, or 2) if ER UMa stars and usual SU UMa-type stars are interchanging states of the same population, systems must accrete half of mass during the ER UMa state. The discussion on the impact on the CV evolution below the gap should require further observational constraints, e.g. independent estimates of mass-transfer rates in ER UMa stars, unbiased surveys of dwarf novae and searches for secular changes as expected from nova-dwarf nova alternations.

4 Large-amplitude superhumps during early superoutburst

ER UMa stars in common additionally have other peculiar features in contrast to usual SU UMa-type dwarf nova. Among them is the appearance of
Figure 8: Light curve of the “helium ER UMa star”, CR Boo folded by the supercycle 46.3 d. The alternation of long superoutburst and short outbursts is remarkably similar to that of ER UMa.

large-amplitude early stage superhumps (Kato et al. 1996b). These superhumps are seen in all known ER UMa stars, and quickly develop during the rise to superoutbursts. They quickly decay in a few days, and usually-looking superhumps appear (this growth was observed at the discovery moment of ER UMa) in a week (Fig. 5), but the phase is reversed to the initial superhumps. Large-amplitude early (super)humps and the later growth of usual superhumps are also observed in WZ Sge-type stars (e.g. AL Com, Kato et al. 1996c), but the main difference is that the superhump period remain basically unchanged through the superhump evolution in ER UMa stars.

5 Helium ER UMa stars?

Double-degenerate helium CVs, also called AM CVn stars, are considered as helium counterparts to hydrogen-rich (usual) CVs. Among them, AM CVn and HP Lib correspond to superhumping novalike variables (permanent
Table 1: Known (hydrogen) ER UMa stars

| other name | ER UMa  | V1159 Ori | RZ LMi | DI UMa |
|------------|---------|-----------|--------|--------|
| maximum (V)| 12.4    | 12.8      | 14.2   | 15.1   |
| minimum (V)| 15.2    | 15.4      | 17.0   | 18.0   |
| $P_{SH}$ (d)| 0.06573 | 0.0641    | 0.05946| 0.0555 |
| $T^*_n$ (d)| 43      | 48        | 19     | 25     |
| $T^*_K$ (d)| 4.4     | 4.0       | 3.8    | 4      |

* supercycle length
† recurrence time of normal outbursts

For more information of the individual light curves, see [http://www.kusastro.kyoto-u.ac.jp/vsnet/LCs/index/index.html](http://www.kusastro.kyoto-u.ac.jp/vsnet/LCs/index/index.html).

superhumpers), CR Boo, V803 Cen and CP Eri are SU UMa-type analogs, and GP Com may be a helium counterpart to WZ Sge stars. We have recently shown (Kato et al. 1998) CR Boo shows 46.3-d supercycle and its behavior closely analogous to ER UMa itself (Fig. 6). V803 Cen may be a similar object having a likely supercycle of ~60 d, but also seems to show different (ER UMa-like and quasiperiodically rapidly outbursting) states.
6 References

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Note on the online version

This is a LaTeX typeset of the proceeding paper Disk Instabilities in Close Binary Systems. 25 Years of the Disk-Instability Model. Proceedings of the Disk-Instability Workshop held on 27-30 October, 1998, at Hotel Brighton City, Yamashina, Kyoto, Japan. Edited by S. Mineshige and J. C. Wheeler. Frontiers Science Series No. 26. Universal Academy Press, Inc., 1999., p.45. (1999dich.conf...45K). Since the original style file was an old one, I used a standard \LaTeX class to reproduce it. Although the layout is different from the one in the print, the text and figures are the original ones.