Recent Progress of Research of Dwarf Nova Evolution by small telescopes (with VSNET)

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and VSNET Collaborations

NASA

What is VSNET?

VSNET
Intensive An International Mailing List on Variable Stars

- Variable Star NETwork
  organized by Kyoto U. since 1990s

- We provide information about variable stars and call for observations through our mailing lists (vsnet-alert, vsnet-outburst, etc.)

40cm telescope in Kyoto U.

- The VSNET mailing lists have up to 1300 subscribers from more than 50 countries all over the world.
  The size of our collaborator’s telescopes are 15-65 cm.

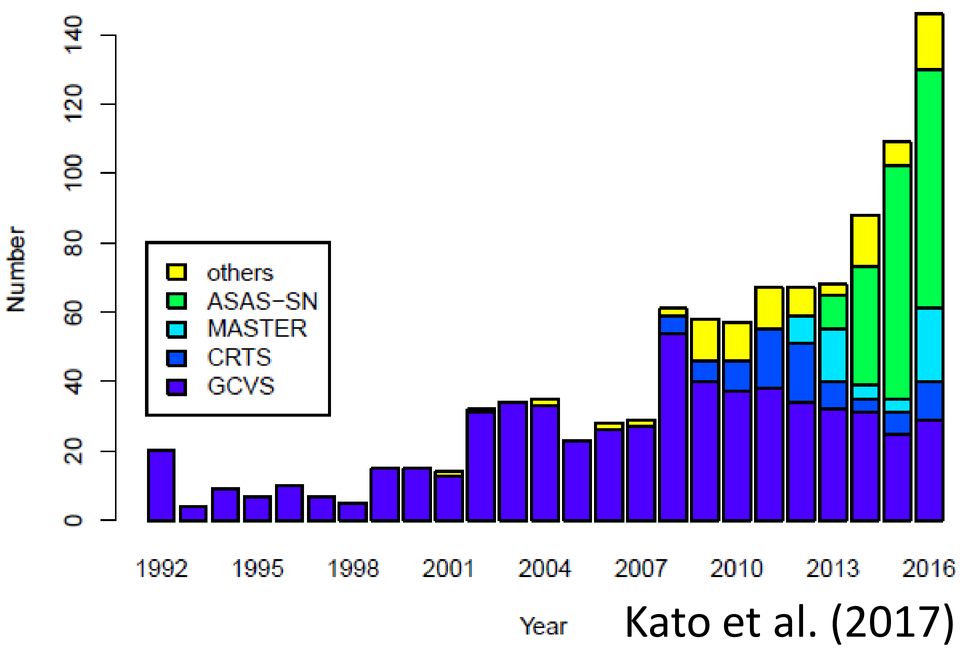
Our Targets

- Dwarf Nova (main target because of the large number)
- X-ray Binary
- AM CVn-type (Helium-rich) Dwarf Nova

- All Variables & Transients in which graduate students are interested (GRB, Be star, Pulsating star, Superflare and so on…).

Increasing Number of Dwarf Novae

Number of Observed Superoutbursts



Kato et al. (2017)

Number of observed WZ Sges

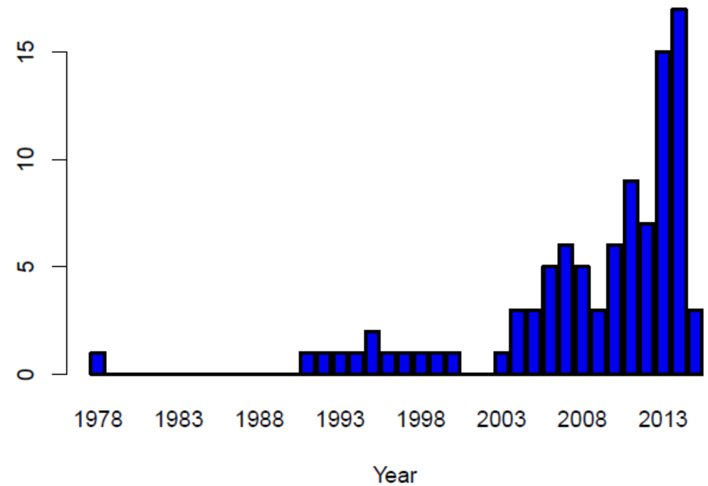
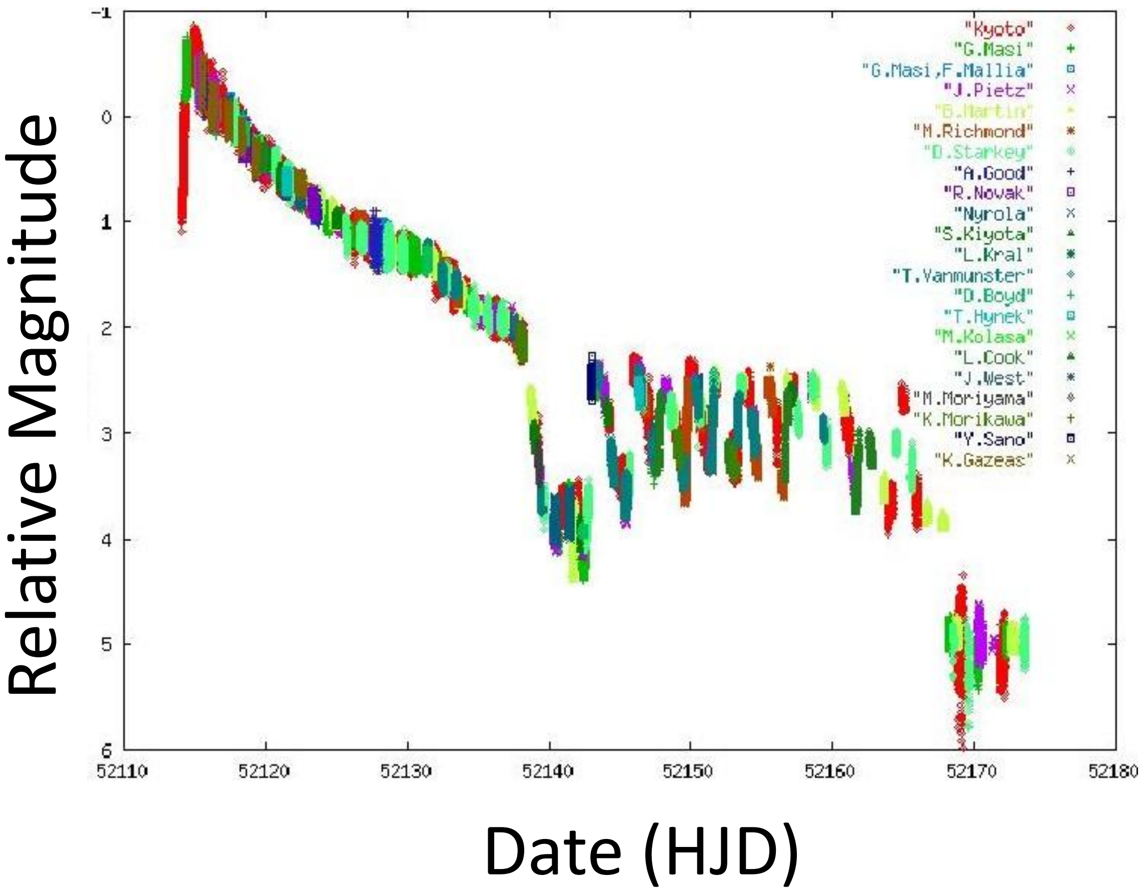


Fig. 1. Year of recognition of WZ Sge-type properties. The sample is the objects in table 6. Note that the year 2015 includes only January.

Kato (2015)

- Kyoto U. team cannot observe all of them.
- Cooperation with worldwide observers who have small telescopes is essential

An Example: the 2001 superoutburst of the Dwarf Nova WZ Sge



Each color represents each observer.

The light curve of the 2001 superoutburst of WZ Sge.

Although the previous outburst occurred in 1978, the rising phase was discovered by a high school student.

He reported to VSNET, then 22 observers around the world started to observe this rare phenomenon.

Another Example: the 2015 outburst of the Black hole Binary V404 Cyg

(Kimura et al. 2016)

★ represents all collaborators.

This observational campaign was performed

by about 60 people in 15 countries and 35 telescopes.

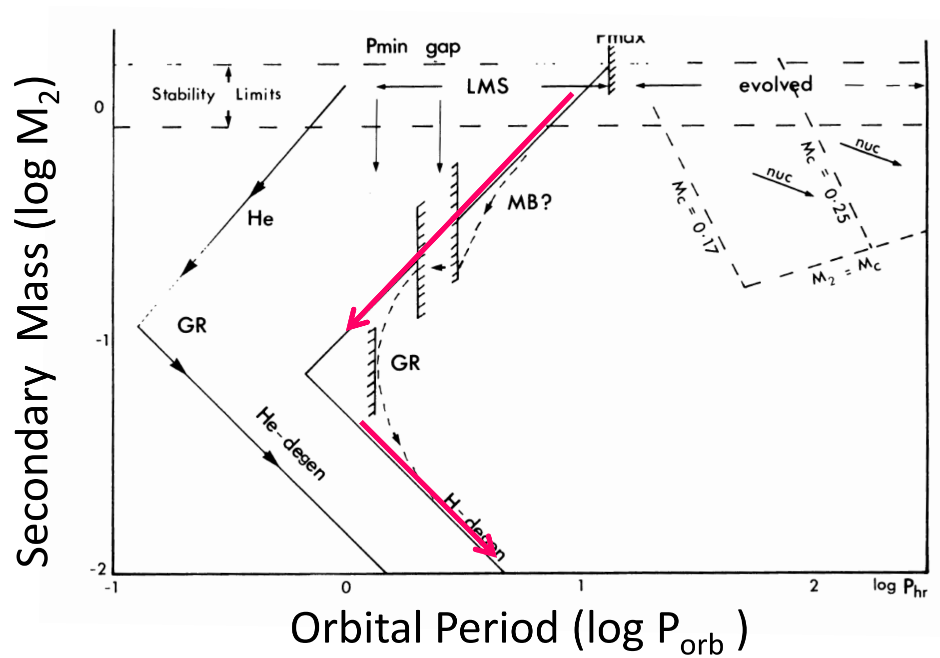
The result was published with ``Nature''.

Aims of our Research

- Evolutionary path of DNe
  - Period Minimum Problem
  - Period Spike Problem
- Mechanism of Outbursts
  - Superhump
    - superhump stages
    - Pdot (period derivative of superhump)
  - Rebrightening

Evolution of Cataclysmic Variables

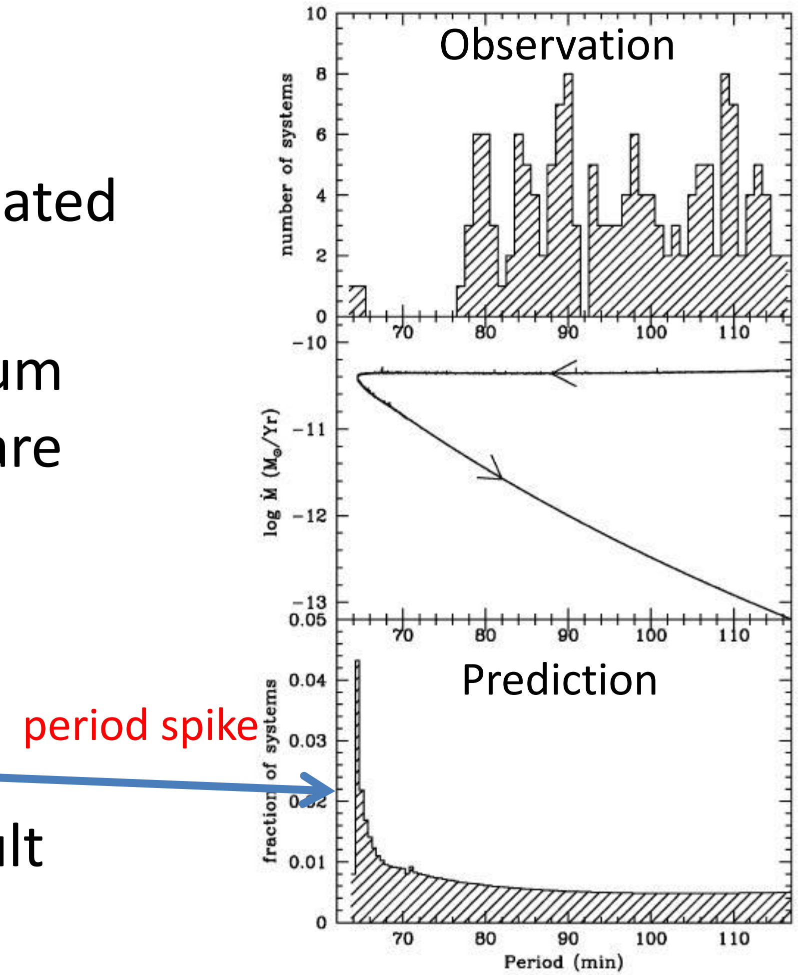
- CVs lose their angular momentum due to the gravitational wave.
- Because secondaries lose their mass via the RLOF, CVs evolve from top to bottom.
- Two pink lines are drawn on the assumption that the mass-radius relation of a secondary.
  Namely, the upper line means a path of normal secondaries,
  the lower line means a path of degenerated secondaries.
  (low mass)



King (1988)

Period Minimum & Period Spike

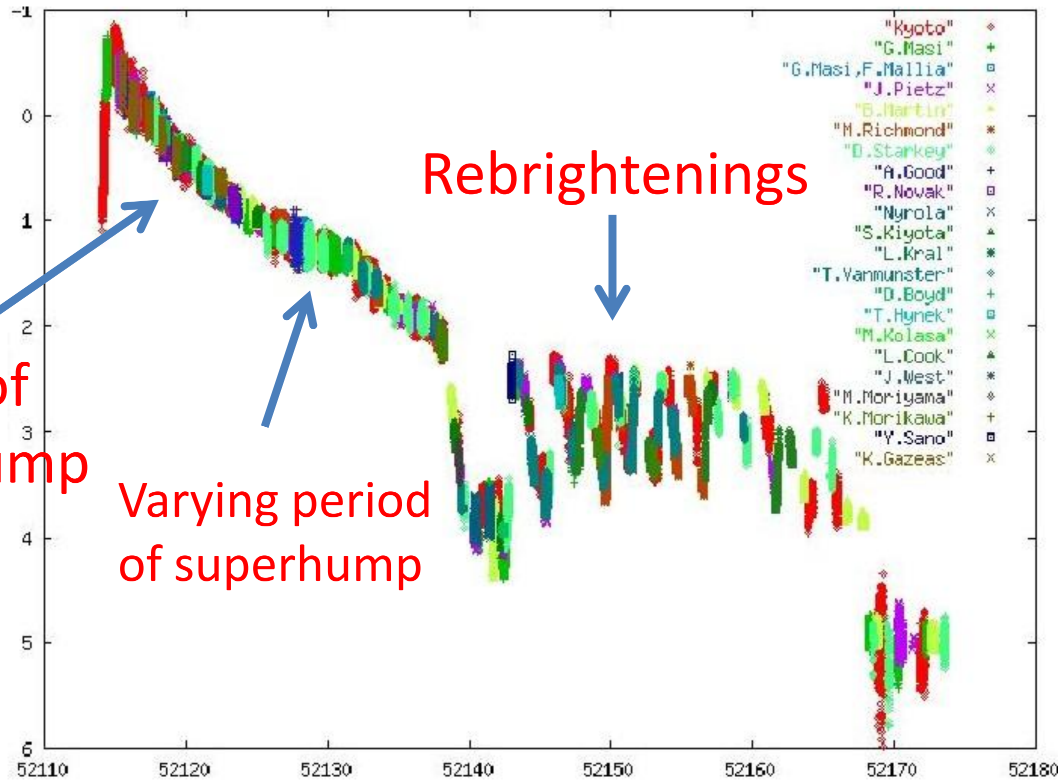
- Barker & Kolb (2003) computed the evolutionary path and estimated the theoretical distribution.
- CVs evolve to the period minimum for several Gyr. -> 70 % of CVs are beyond the period minimum (called period bouncers).
- The majority of CVs are placed around the period minimum. However, the observational result didn't show such spike.
- The period minimums are also different from each other.



Barker & Kolb, 2003

Unsolved Outburst Behaviors

- Dwarf nova outbursts are basically explained by the thermal and tidal instabilities. (cf. Osaki 1989, Warner 1995)
- We have not understood the detail mechanism.



Dwarf Novae

- CVs > dwarf novae > SU UMa-type > WZ Sge-type

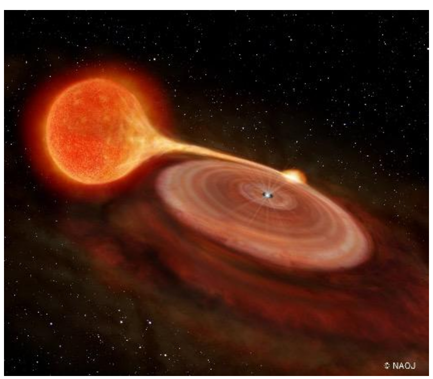
(Cataclysmic Variables)

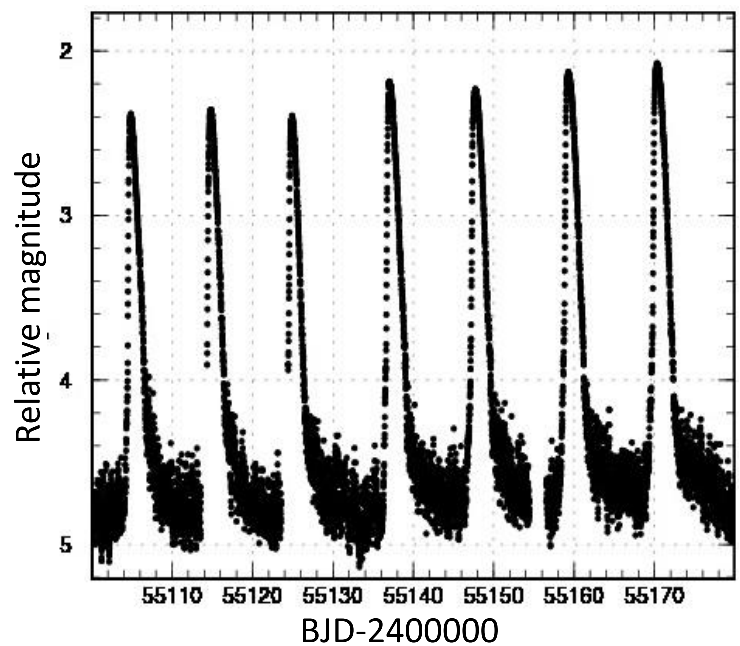
dwarf novae (DNe)

show outburst

amplitude : 2-5 mag

duration : several days



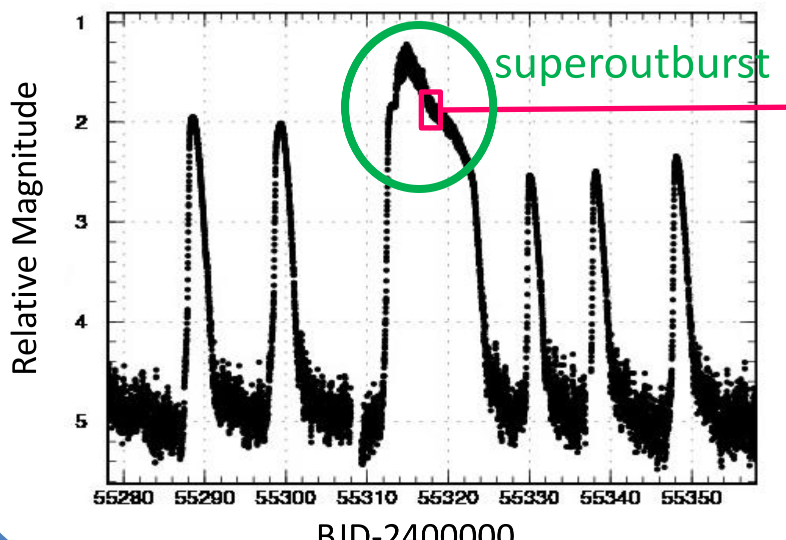


SU UMa-type Dwarf Novae

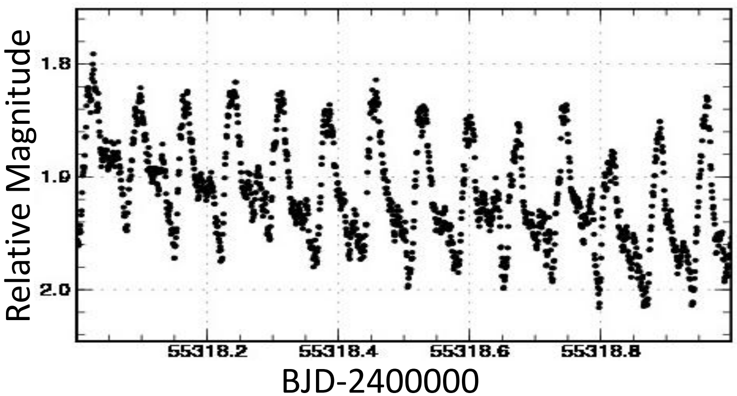
- CVs > dwarf novae > SU UMa-type > WZ Sge-type

SU UMa-type dwarf novae

- occasional superoutbursts
- during superoutbursts show superhumps



superhumps



light variations whose period is a few percent longer than the orbital period

tidal instability triggered by 3:1 resonance

WZ Sge-type Dwarf Novae

- CVs > dwarf novae > SU UMa-type > WZ Sge-type

WZ Sge-type dwarf novae

- infrequent superoutbursts (amplitude ~ 8 mag)
- show early superhumps

triggered by 2:1 resonance

The period is very close to orbital period

Why are they important in photometric surveys of CVs?

- Most of CVs around the period minimum are SU UMa-type DNe, and WZ Sge-type DNe.
- Using new method, we can estimate precise mass ratios q by using superhump periods. q is roughly compatible with the secondary mass.

Estimation Method of Mass Ratio

Superoutburst is caused by
the thermal-tidal instability

3:1 resonance

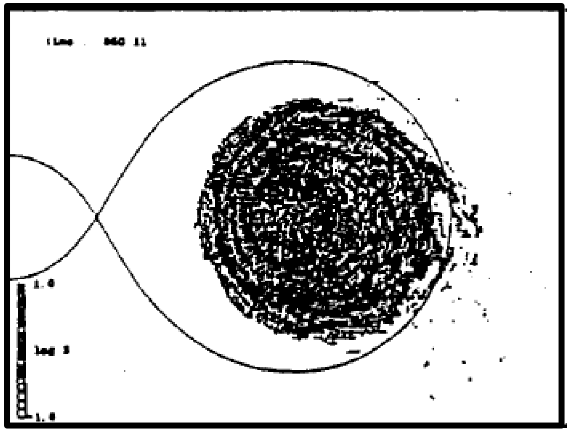
between the fluid flow and the binary motion

$$r_{3:1} = 3^{-\frac{2}{3}}(1+q)^{-\frac{1}{3}}$$

Precessing eccentric disk (prograde)

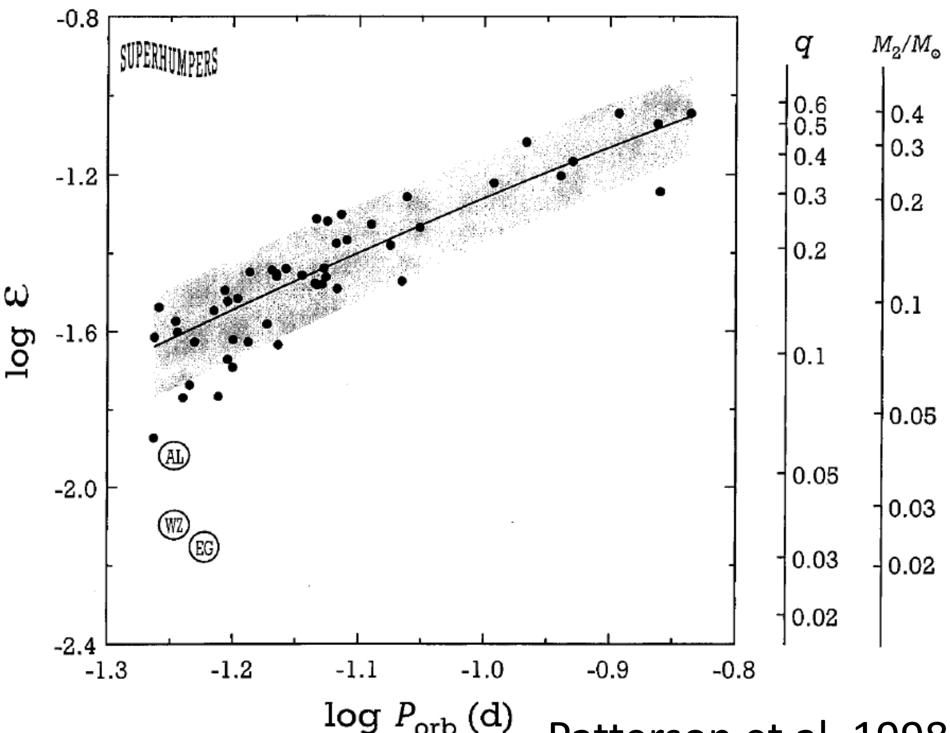
Superhumps $\frac{1}{P_{\rm sh}} = \frac{1}{P_{\rm orb}} - \frac{1}{P_{\rm pr}}$,

Hirose & Osaki 1990

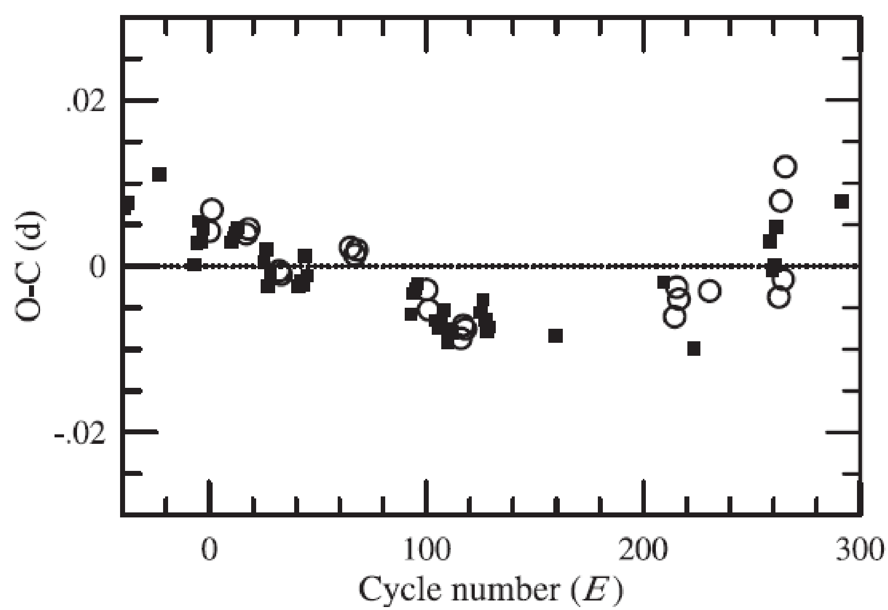


Estimation Method of Mass Ratio from Superhump Period

- Well-known empirical relation between superhump period P_{SH} and q.



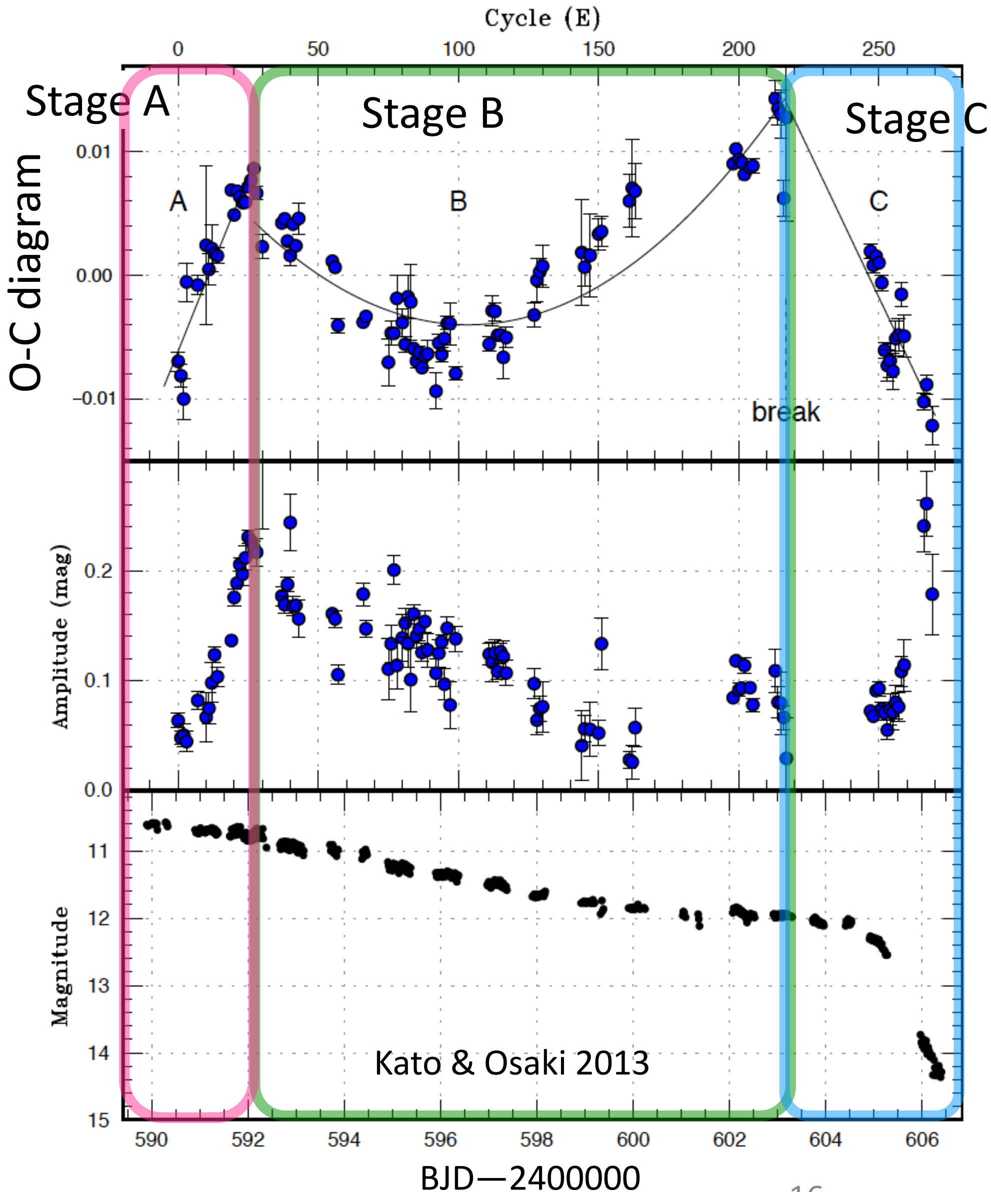
Patterson et al. 1998



the O-C diagram of superhumps of EG Cnc

Kato et al. 2004

Classification of Superhumps



- Stage A: Initial growing stage with a long period
- Stage B: Fully developed stage with a systematically varying period
- Stage C: a shorter, almost constant period

Kato et al. (2009)

▪Precession frequency (Lubow, 1992)

$$\nu_{pr} = \nu_{dyn} + \nu_{pressure} + \nu_{stress}$$

~ 0 in stage A ~ 0

(An Example of SW UMa)

Comparison of Mass Ratio between eclipse and stage A

- Good correlation!

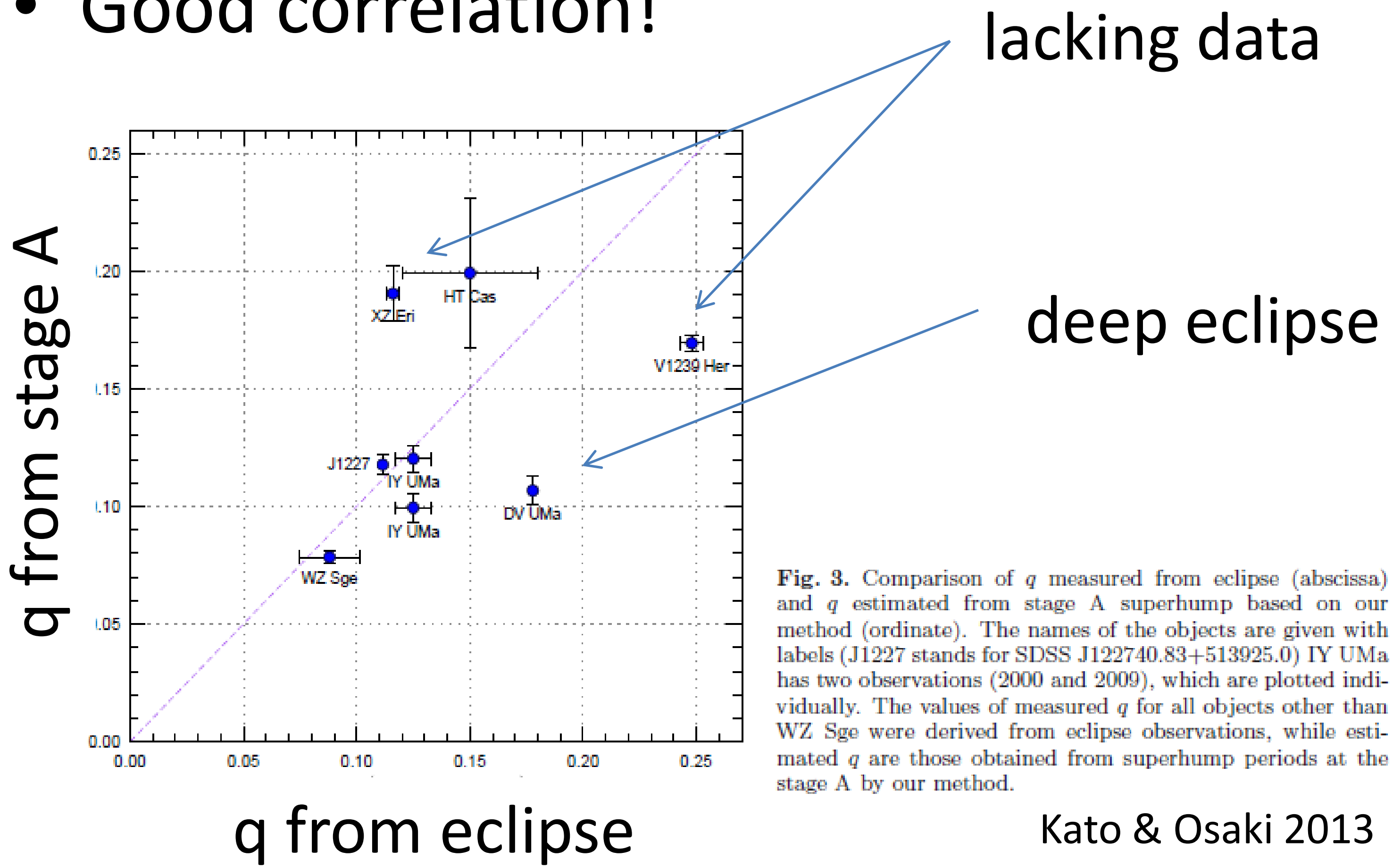


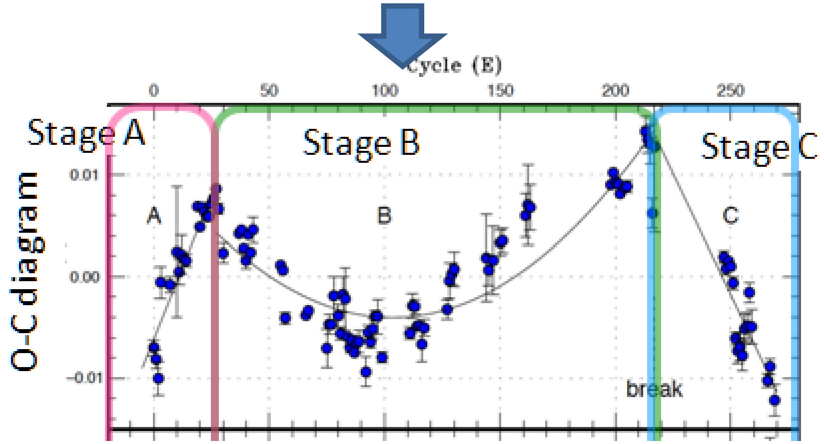
Fig. 3. Comparison of q measured from eclipse (abscissa) and q estimated from stage A superhump based on our method (ordinate). The names of the objects are given with labels (J1227 stands for SDSS J122740.83+513925.0) IY UMa has two observations (2000 and 2009), which are plotted individually. The values of measured q for all objects other than WZ Sge were derived from eclipse observations, while estimated q are those obtained from superhump periods at the stage A by our method.

Kato & Osaki 2013

Statistical Research

Pdot Statistics

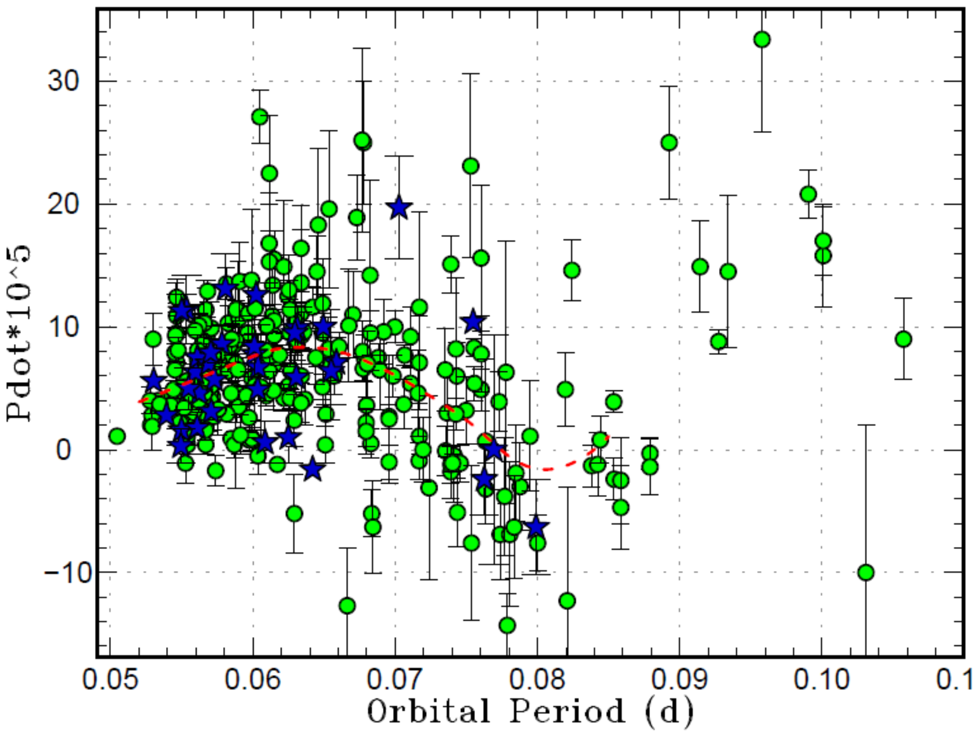
- We have published the series papers "**Survey of Period Variations of Superhumps in SU UMa-Type Dwarf Novae**", called "**Pdot paper**" every year since 2009.
- We have summarized the outbursts behaviors of SU UMa/WZ Sge-type DNe observed in the year and provided the statistics.
- "Pdot" means the period derivative in stage B superhumps



- We don't know the origin of the period variation in stage B.

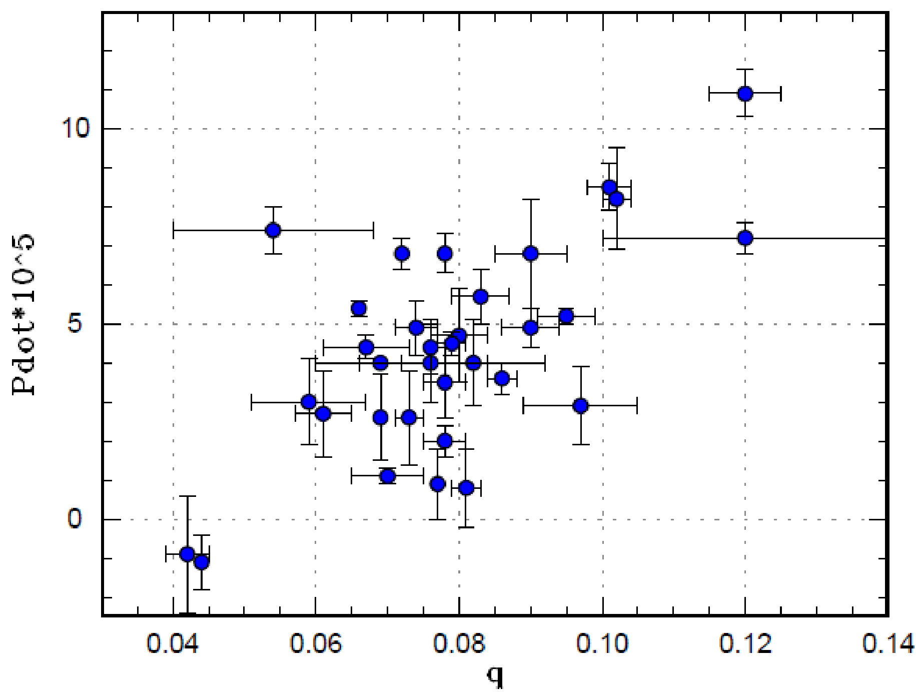
Pdot diagra

Pdot of SU UMa and WZ Sge stars



Kato et al. in 2017

Pdot of WZ Sge stars



Kato 2015

Revealed Period Spike and Minimum

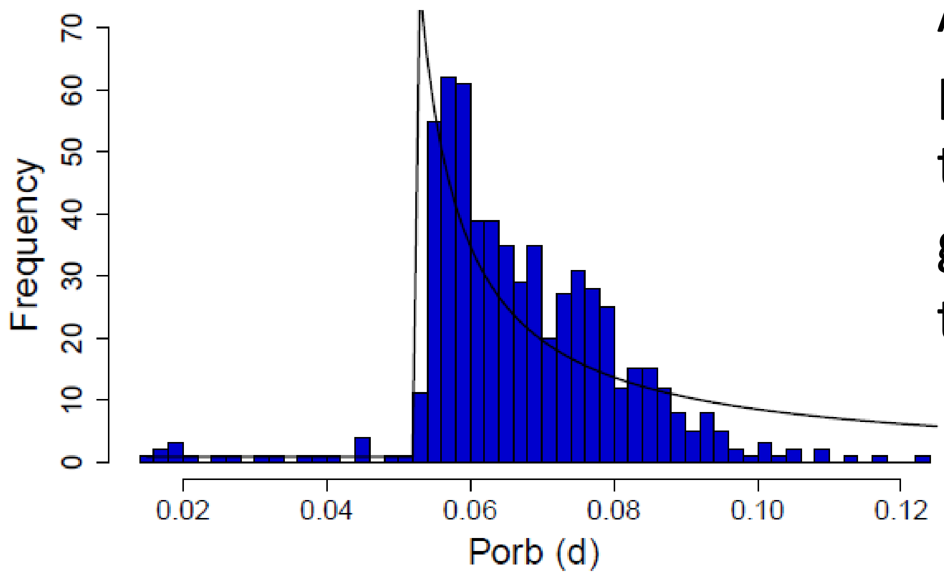


Fig. 165. Distribution of superhump periods in this survey. The data are from Kato et al. (2009), Kato et al. (2010), Kato et al. (2012a), Kato et al. (2013), Kato et al. (2014b), Kato et al. (2014a), Kato et al. (2015a), Kato et al. (2016a) and this paper. The mean values are used when multiple superoutbursts were observed. (Upper) distribution of superhump periods. (Lower) distribution of orbital periods. For objects with superhump periods shorter than 0.053 d, the orbital periods were assumed to be 1% shorter than superhump periods. For objects with superhump periods longer than 0.053 d, we used the calibration in Kato et al. (2012a) to estimate orbital periods. The line is the model distribution to determine the period minimum (equation 6, see text for the details).

Although this model does not properly reproduce the location of the period spike, we can see the global trend of the CV distribution theoretically predicted.

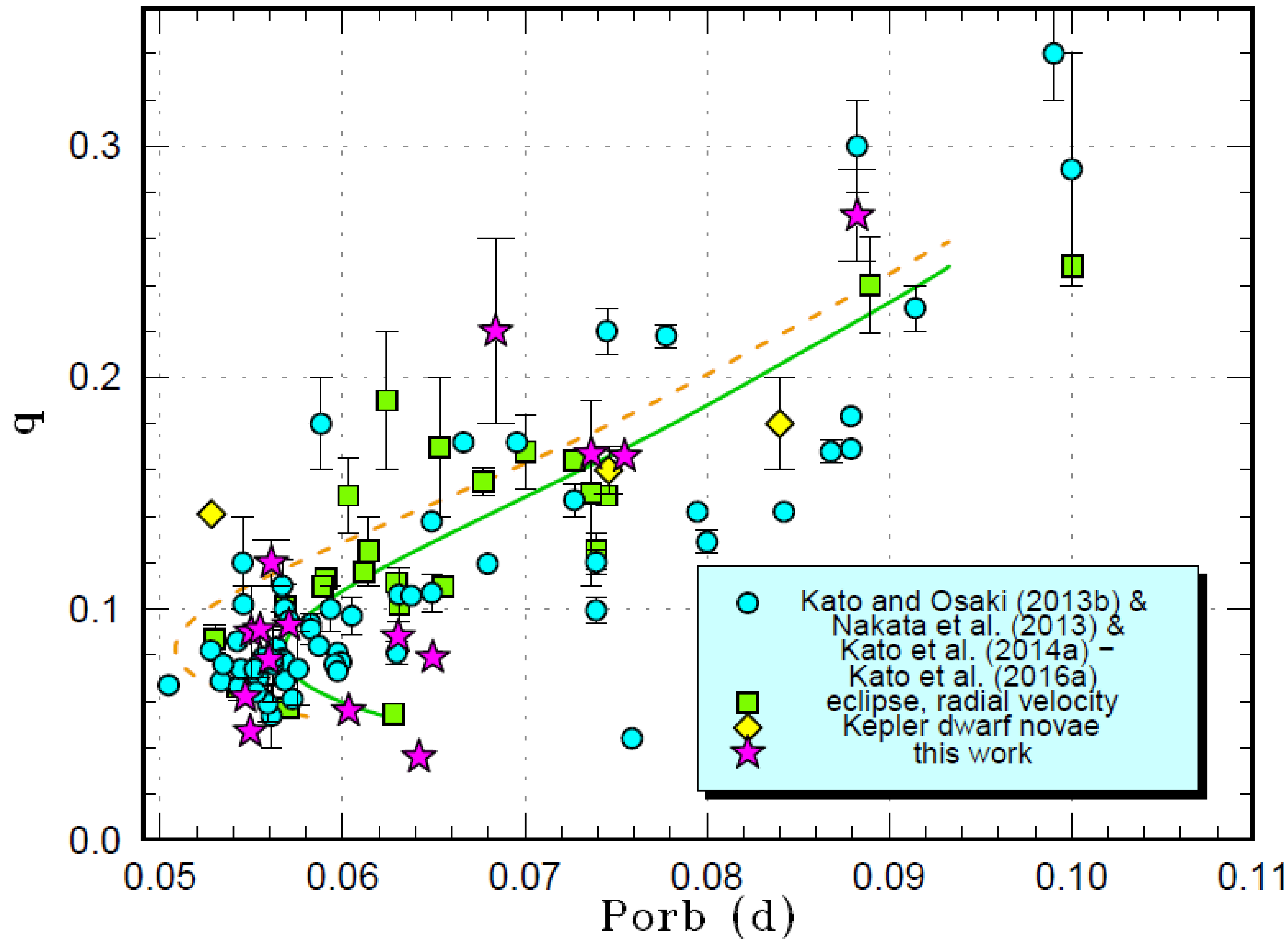
the following period distribution $D(P_{\rm orb})$:

$$D(P_{\rm orb}) \propto \begin{cases} c_1, & (P_{\rm orb} \leq P_{\rm min}) \\ 1/(P_{\rm orb} - c_2), & (P_{\rm orb} > P_{\rm min}). \end{cases}$$

$$P_{\rm min} = 0.052897(16).$$

$$c_1 = 1.93(25),\ c_2 = 0.0471(7)$$

Evolutionary Track and Period Bouncers



The list of period bouncer candidates which showed outbursts.

～2013

2014～

Object*	P_{shB} (d)†	Amp‡	Delay§	Decrease#	Profile¶	Decline**	References††
MASTER J2112	0.060221(9)	0.10	~12	2.2%	B	0.127(1)	1
MASTER J2037	0.061307(9)	0.11	–	2.2%	B, slow	0.052(1)	1
SSS J1222	0.07649(1)	0.12	≥9	0.93%	E, slow	0.020(1)	2, 3
OT J1842	0.07234	0.08	~30	–	E, slow	0.045(1)	2, 4
OT J1735	–	–	–	–	slow	0.038(1)	5
OT J0754	0.070758(6)	0.05	–	2.0%	slow	0.0189(3)	6
OT J2304	0.06635(1)	0.13	–	1.3%	slow	0.0340(4)	6
ASASSN-14cv	0.06045(1)	0.07	14	2.0%	B	0.087(1)	7, 8
PNV J1714	0.060084(4)	0.09	11	2.0%	B	0.108(1)	7, 8
OT J0600	0.063310(4)	0.06	–	2.1%	B	0.080(1)	7, 8
PNV J172929	0.06028(2)	0.12	11	1.7%	D	0.094(1)	8
ASASSN-15jd	0.064981(8)	0.09	10	–	e	0.088(2)	9
ASASSN-15gn	0.06364(3)	0.10	11	–	–	0.0635(7)	10
ASASSN-15hn	0.06183(2)	0.10	12	2.2%	–	0.080(3)	10
ASASSN-15kh	0.06048(2)	0.08	≥13	1.7%	–	0.0601(6)	10
ASASSN-16bu	0.06051(7)	0.10	9	0.62%	slow	0.024(1)	10
ASASSN-16js	0.06093(2)	0.23	10	1.2%	–	0.085(1)	11
ASASSN-16dt	0.064610(1)	0.08	~23	0.79%	E, slow	0.0282(6)	This work
ASASSN-16hg	0.062371(14)	0.12	≥6	–	e, B	0.090(2)	This work

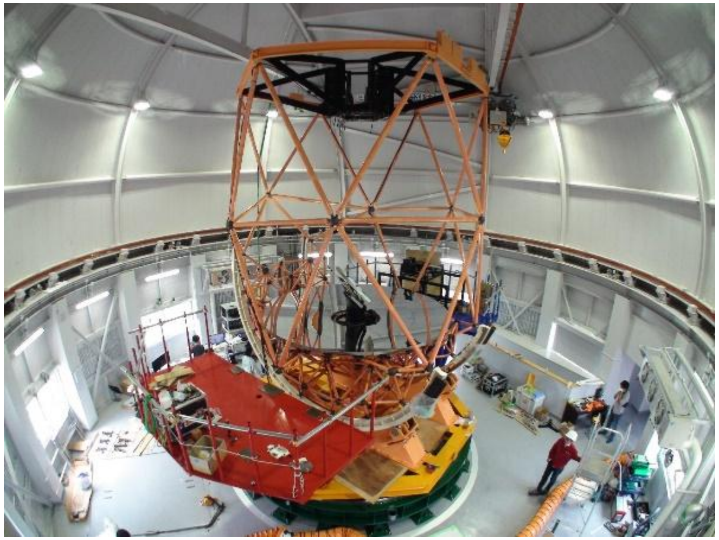
Kimura et al. 2018

Thanks to large survey projects, the number of period bouncers are rapidly increasing. We expect to these objects fill the gap between theory and observation.

Next Step of our Research

New Kyoto University 3.8m Telescope

- Kyoto University found a 3.8m telescope "Seimei" this July, and fine adjustments are ongoing now



Kyoto Univ. Okayama
3.8m SEIMEI telescope

- One of the aims of "Seimei" is ToO Observations for transients.
- Kyoto University can use half of the observation time. (Note that Kyoto U. has some other research groups.)
- The first instrument is low resolution ($\lambda/\Delta\lambda \sim 2{,}000$) spectrograph.

Conclusion

- The number of transients exclusively increase owing to large survey projects
- For the effective follow-up observations, small telescopes play an important role.
  - Lower price instruments give us more man power.
- Thanks to many observers, the period spike and minimum became visible.
- New mass ratio estimation method are gradually revealing the hidden population of period bouncers.
- From next year, the VSNET team can use the 3.8m “Seimei” telescope. The collaboration between small and large telescopes will show us more information.

Thank you

- thank you