Dwarf Novae in the Shortest Orbital Period Regime

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DN in the shortest P_{orb} regime

- Two interesting points of view
  - Binary evolution
    - Final stage of the low-mass binary evolution
  - Dynamics of accretion disks
    - Extreme mass-ratio
    - Strong tidal effect

In the view point of

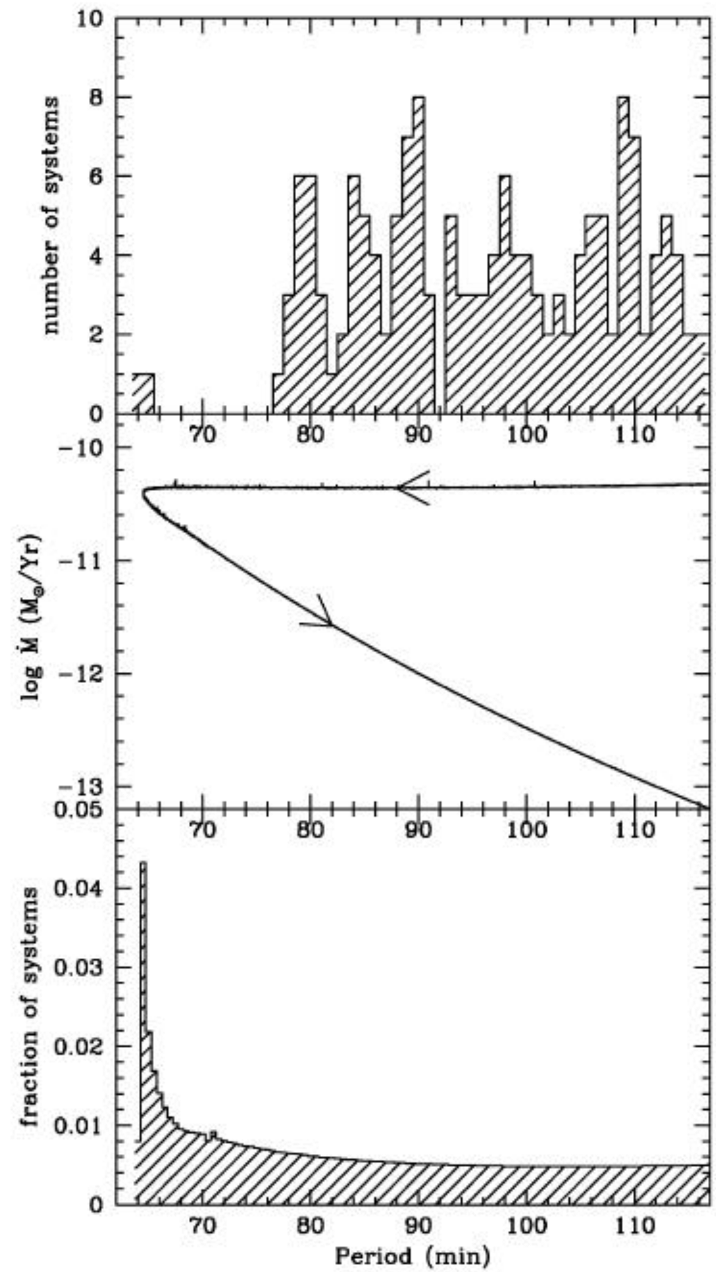
Binary evolution

- WZ Sge-type DNe as a “missing” population
  - Uemura+10 (PASJ, 62, 613)

Problems in the P_{orb} distribution

- Period spike problem
- Period minimum problem

Porb distribution
(the figures from Barker & Kolb 2003)

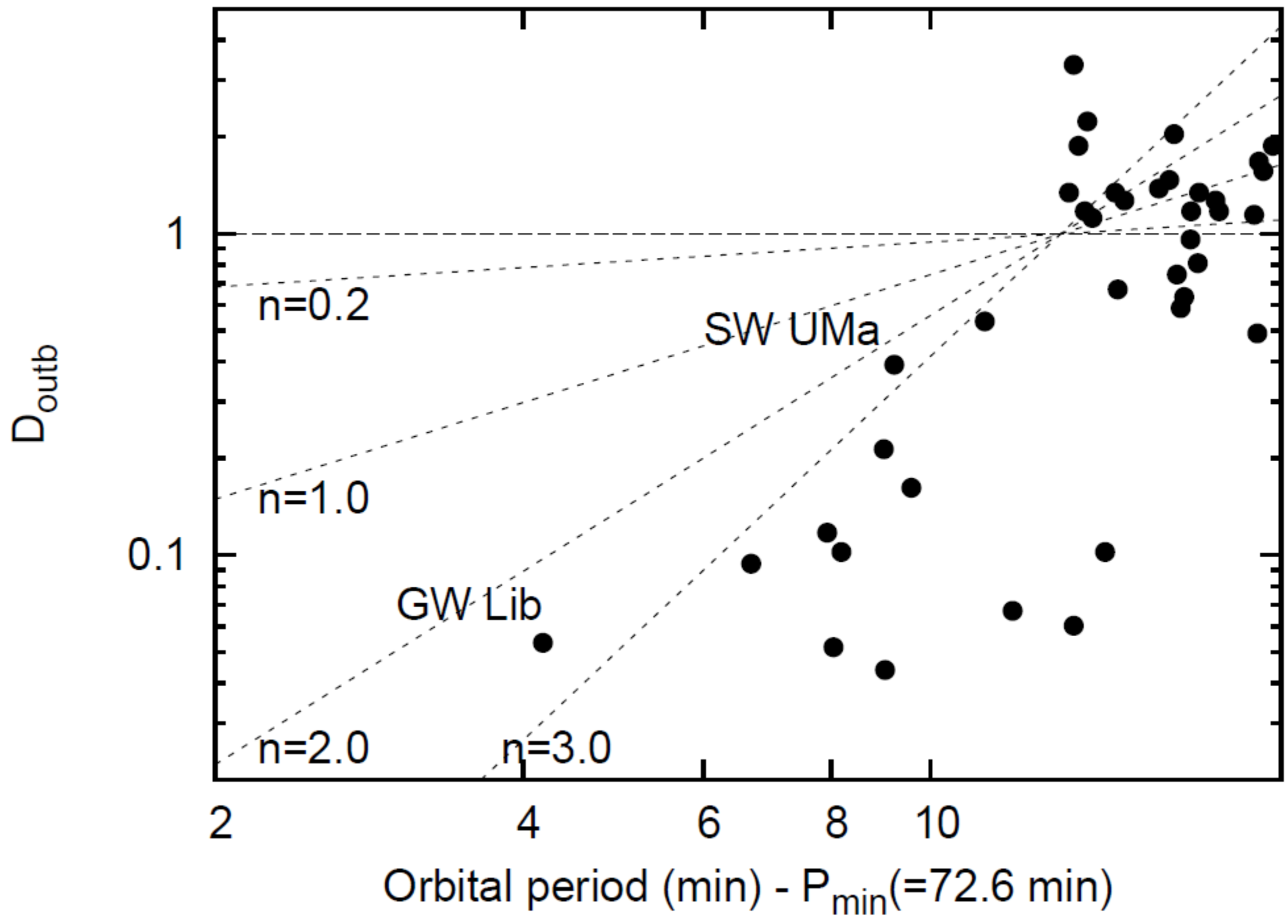


P_{orb} dependence on recurrence times

- Long recurrence time of superoutbursts (Ts) near P_{min}
- Intrinsic population of WZ Sge-type DNe (=very long Ts)???

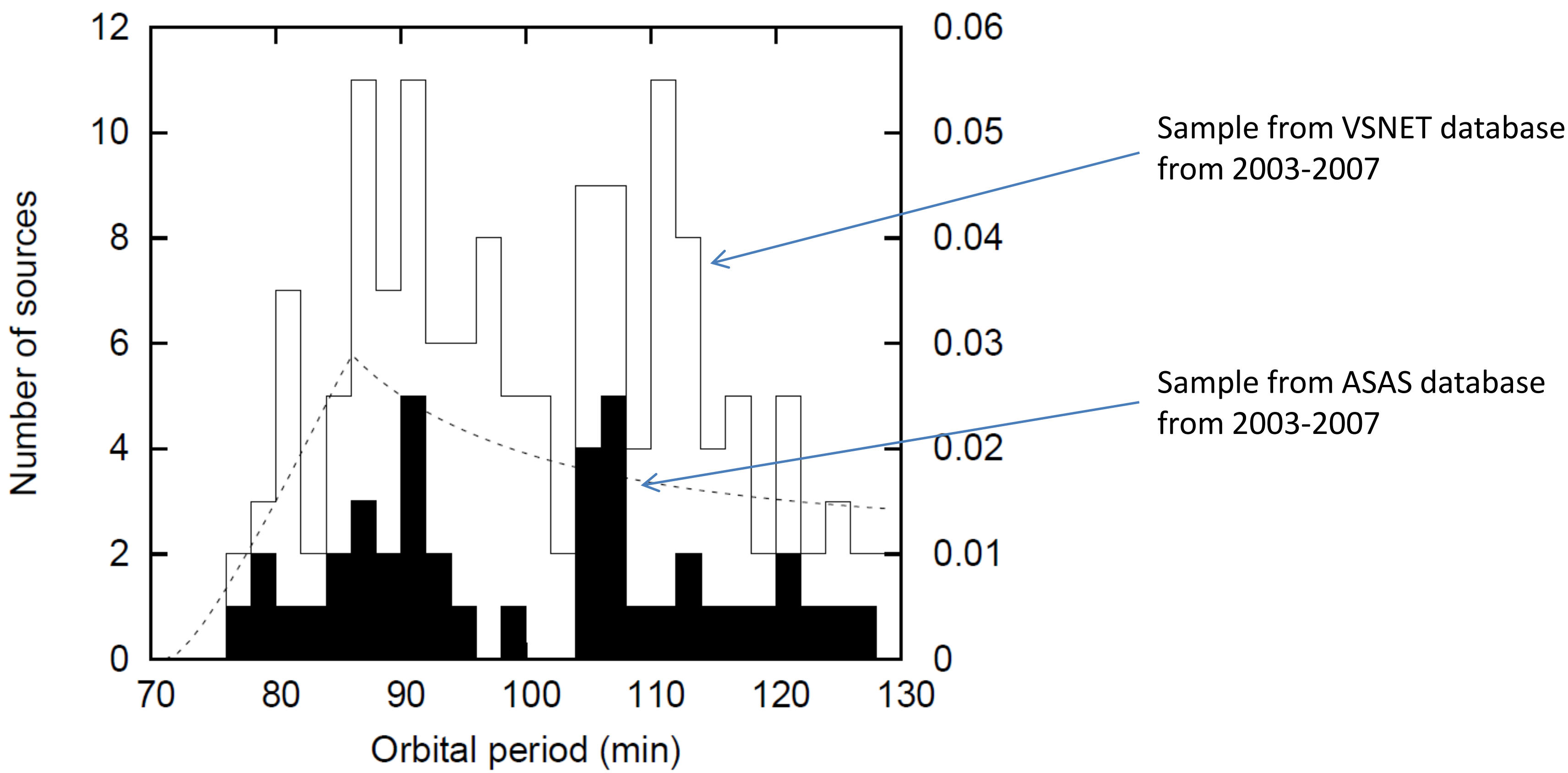
Detectability of outbusts
= 1/Ts
(normalized at 300 d)

Uemura+10



Bayesian estimation of the intrinsic P_{orb} distribution of DNe

- Sample: DNe whose superoutbursts are detected in a certain period of time with a certain equipment.
  - "Observed sample" = "intrinsic distribution" x "outburst detectability"
- Estimation of the intrinsic distribution, using a Bayesian analysis



Models

- Observed distribution, Q, Outburst detectability (D_{outb}), Intrinsic distribution, I

$$Q(a, P_{\mathrm{min}}) = D_{\mathrm{mag}} \cdot D_{\mathrm{outb}} \cdot I(a, P_{\mathrm{min}}) / A_Q(a, P_{\mathrm{min}})$$

The intrinsic distribution.
(The form has no physical meaning)

$$I(p) = \begin{cases} p^{-\alpha} e^{-\alpha/p} / A_I & (p \geq 1) \\ 0 & (p < 1) \end{cases}$$

$$p = P_{\mathrm{orb}} - P_{\mathrm{min}} + 1 \ (\mathrm{min})$$

Detectability depending on the absolute magnitude.

$$D_{\mathrm{mag}}(P_{\mathrm{orb}}) \propto 10^{-0.6 M_V (P_{\mathrm{orb}})}.$$

$$\begin{array}{ll} M_{V,\mathrm{SU}}(P_{\mathrm{orb}}) = C_1 - 0.383 P_{\mathrm{orb}} & (P_{\mathrm{orb}} \geq P_{\mathrm{crit}}) \\ M_{V,\mathrm{WZ}}(P_{\mathrm{orb}}) = C_2 & (P_{\mathrm{orb}} < P_{\mathrm{crit}}) \end{array}$$

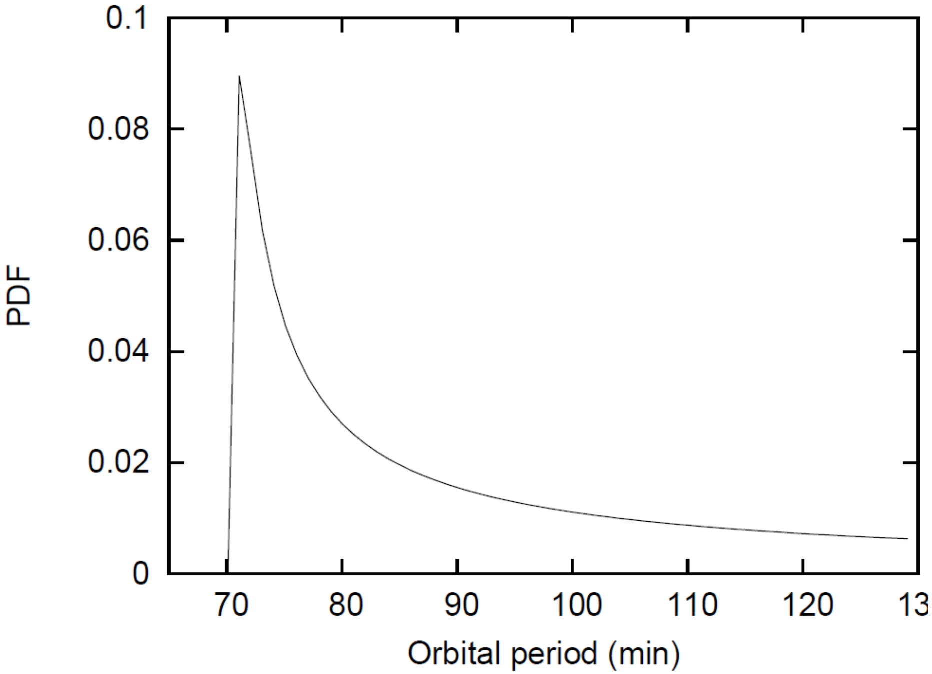
Detectability of outbursts depending on the recurrence time.

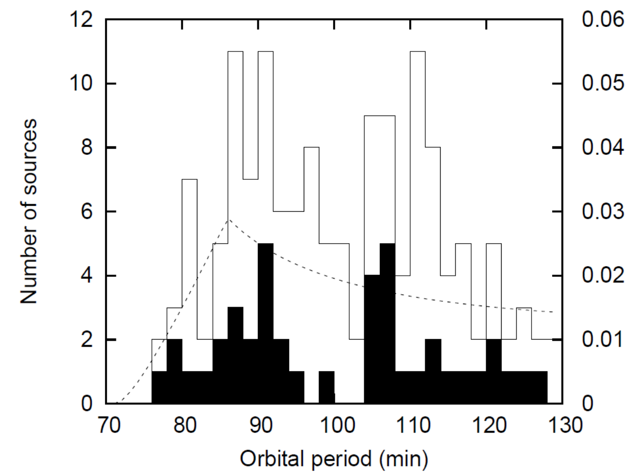
$$D_{\mathrm{outb}}(P_{\mathrm{orb}}) = \begin{cases} 1 & (P_{\mathrm{orb}} \geq P_{\mathrm{crit}}) \\ \left(\frac{P_{\mathrm{orb}} - P_{\mathrm{min}}}{P_{\mathrm{crit}} - P_{\mathrm{min}}} \right)^n & (P_{\mathrm{orb}} < P_{\mathrm{crit}}) \end{cases}$$

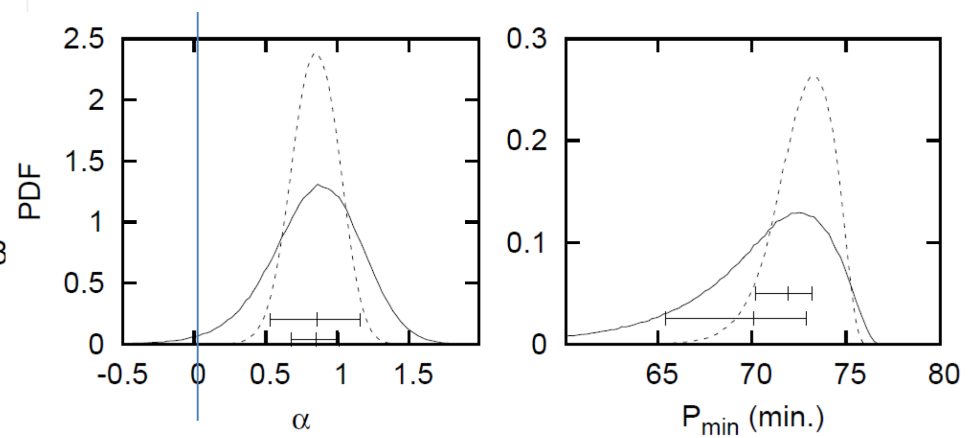
Estimating α and P_{min}, with Markov-Chain Monte Carlo method

Results

- The intrinsic distribution has a "period spike" and shorter P_{min}.







(Flat distribution)

Among sources between 70—130 min, 59 % of sources are concentrated between 70—86 min.

Summary 1

- Our experimental approach showed that WZ Sge-type DNe could be a part of “missing population” near P_{min}.
- The result depends on the assumed form of the intrinsic distribution.
  - Another form?
- The result should be tested by another sample, or another period of time.

In the view point of Dynamics of accretion disks

- New type of tomography:

  Early superhump mapping

  (Uemura+11, in prep.)

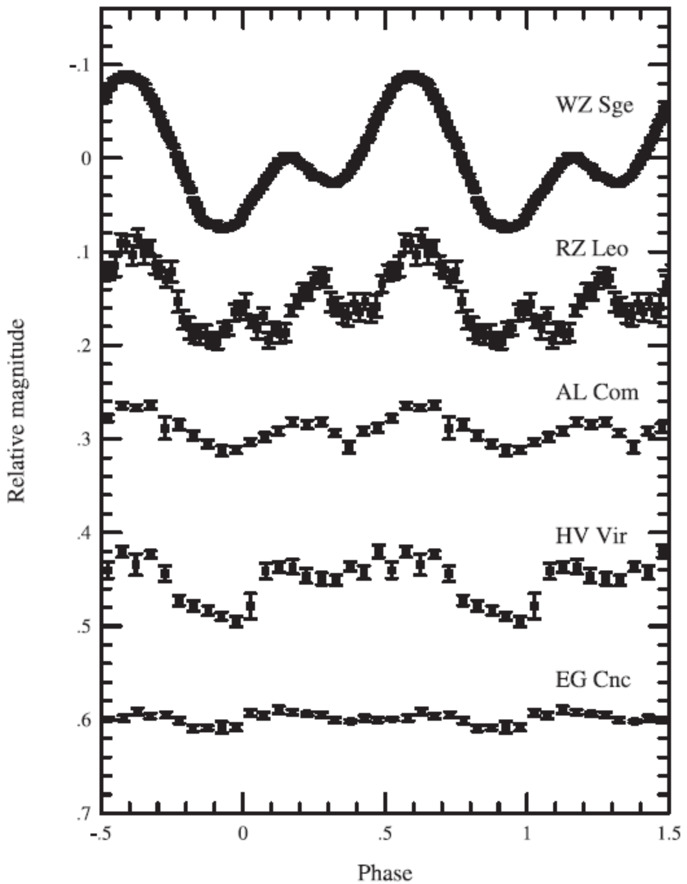
Early superhump

- Only observed in WZ Sge-type DN
  - Period = Porb
  - Doubly-peaked profile

- Rotation effect of non-axisymmetric structure of accretion disks

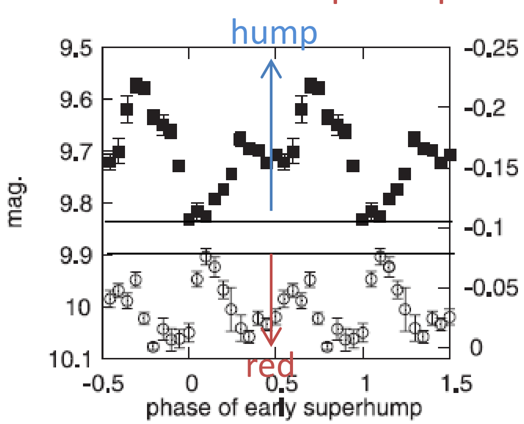
Zoo of early superhumps (Kato , et al. 2002).

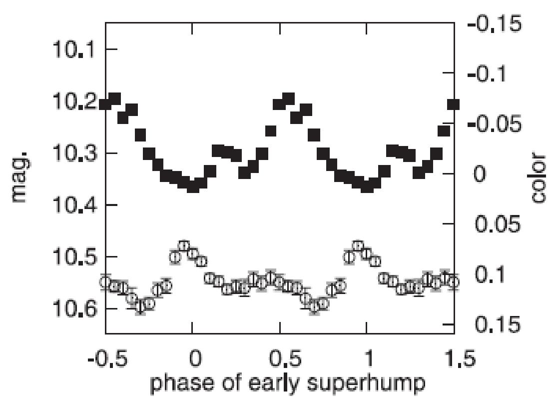
Larger amplitude in edge-on systems.



Color variation in early superhumps of V455 And (Matsui, et al. 2009)

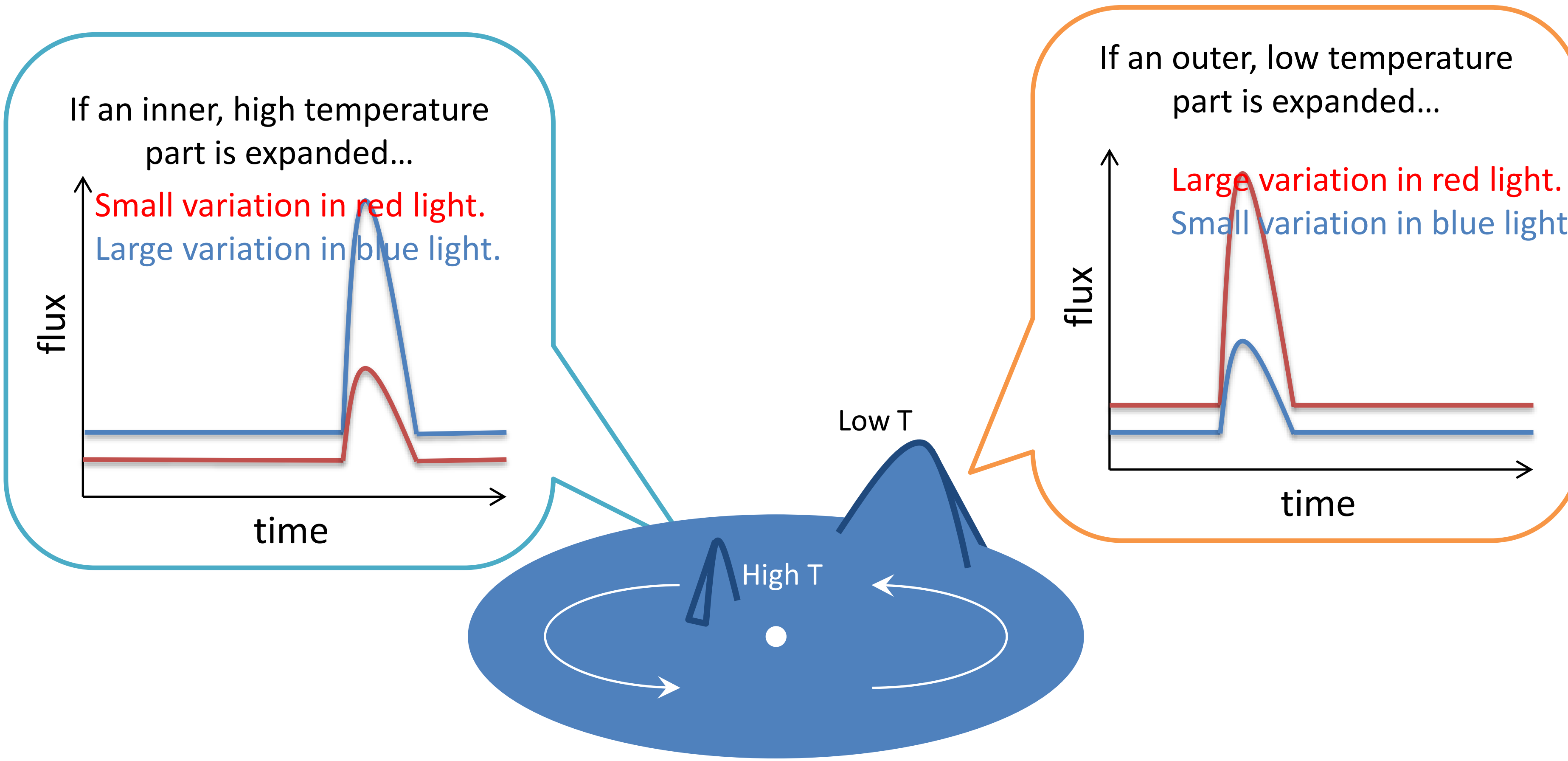
Red color of hump component →vertically elongated structure?





Reconstruction of the accretion-disk structure from early superhumps

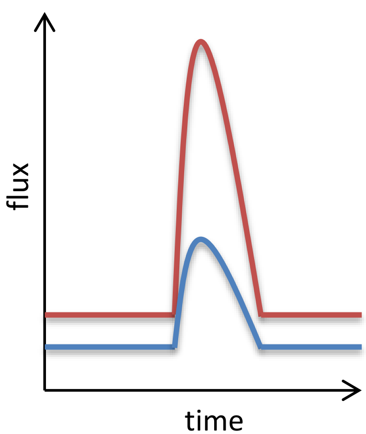
- Phase information →azimuthal structure in disks
- Color information →radial structure in disks



Details of our Bayesian model

Input

Multiband light curves



Model

Bayesian estimation of the height, h(i,j)

$$P(h) \propto L[f_{\nu,obs}(\phi), f_{\nu,model}(\phi)]\pi(h)$$

Posterior likelihood prior

＊Likelihood function (defined by the observed and model LC)

$$L \propto \prod_{i,j} \exp - \frac{[f_{\nu_i,obs}(\phi_j) - f_{\nu_i,model}(\phi_j)]^2}{2\sigma^2}$$

＊Prior distribution

（locally smoother）

$$\pi_{\rm smooth}(h) \propto \prod_{l,m} [\exp - \frac{(h_{l,m} - 2h_{l-1,m} + h_{l-2,m})^2}{2w^2}$$
$$\exp - \frac{(h_{l,m} - 2h_{l,m-1} + h_{l,m-2})^2}{2w^2}],$$

（default image to be h=0.1r）

$$\pi_{\rm disk} \propto \begin{cases} \prod_{l,m} \exp - \frac{(h_{l,m} - h_{{\rm disk},l,m})^2}{2h^2_{{\rm disk},l,m}} & (h_{l,m} \geq 0) \\ 0 & (h_{l,m} < 0) \end{cases}$$

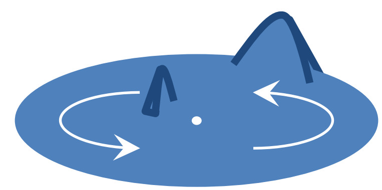
＊Estimation of “h” is done with Markov-chained montecarlo (MCMC)

＊The temperature distribution is like an standard disk model, as

$$T = T_{\rm in}(\frac{r}{r_{\rm in}})^{-3/4}$$

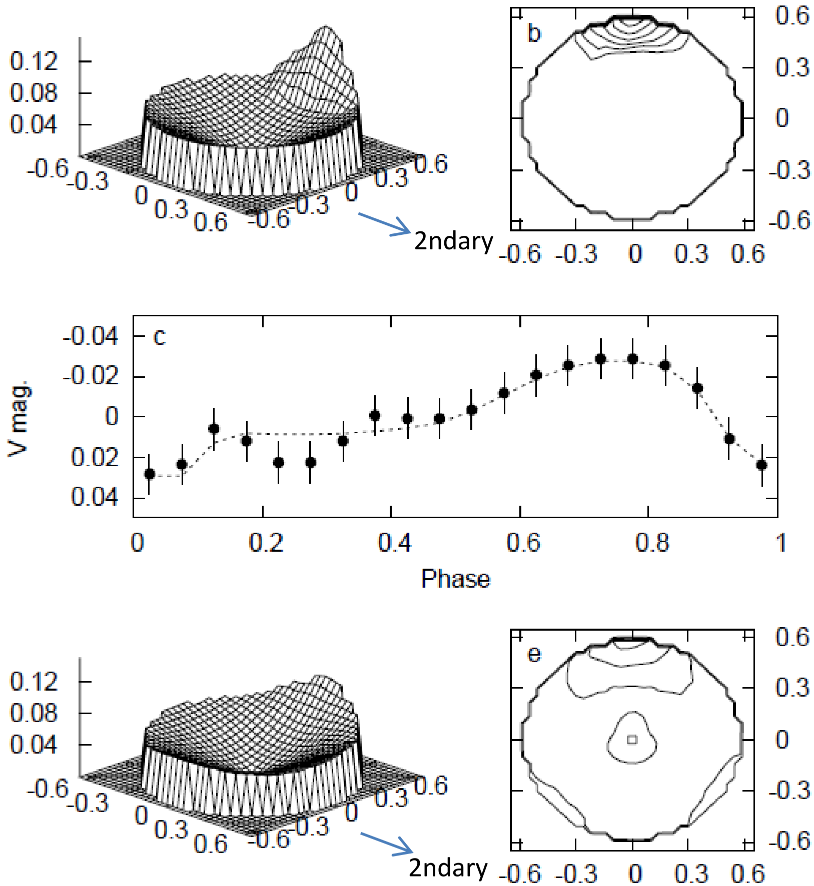
Output

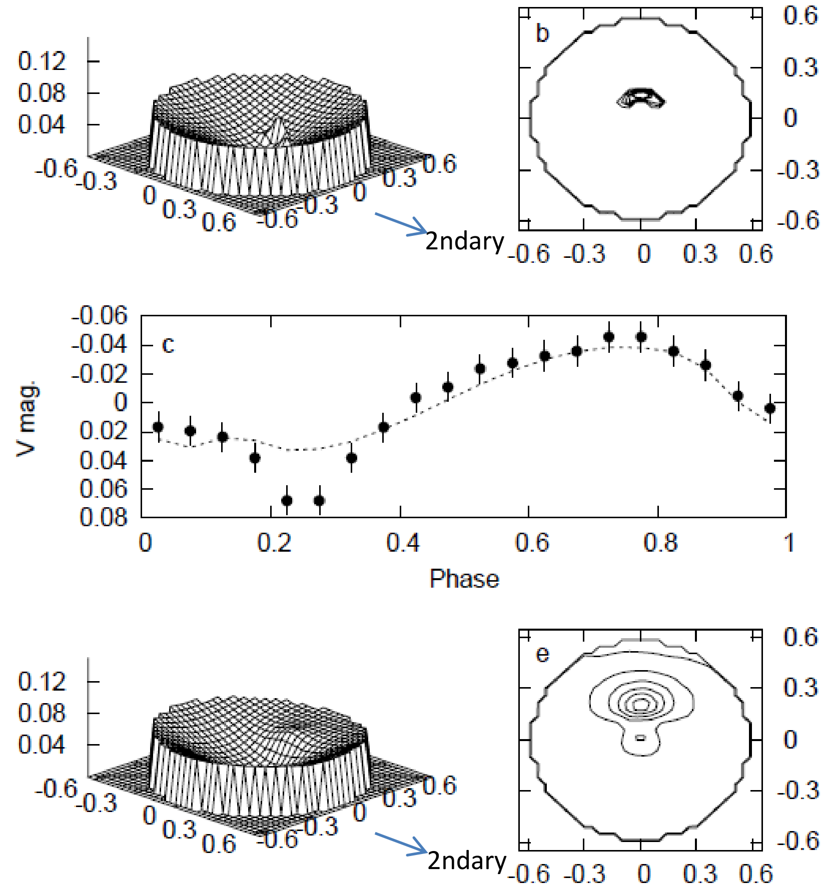
Height map of disk



Demonstration with artificial data sets

- Working as expected
  - Outer structures are reconstructed to be outer, and vice versa
  - Smoother structures than assumed, due to the prior distribution.



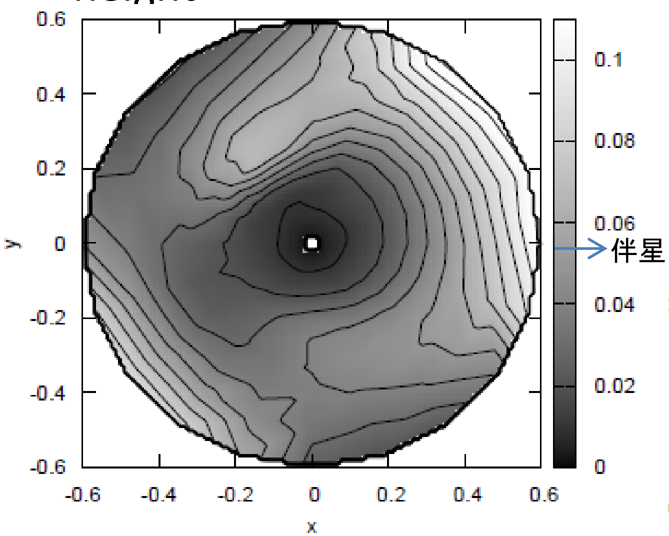


Reconstruction of the disk from early superhums in V455 And:

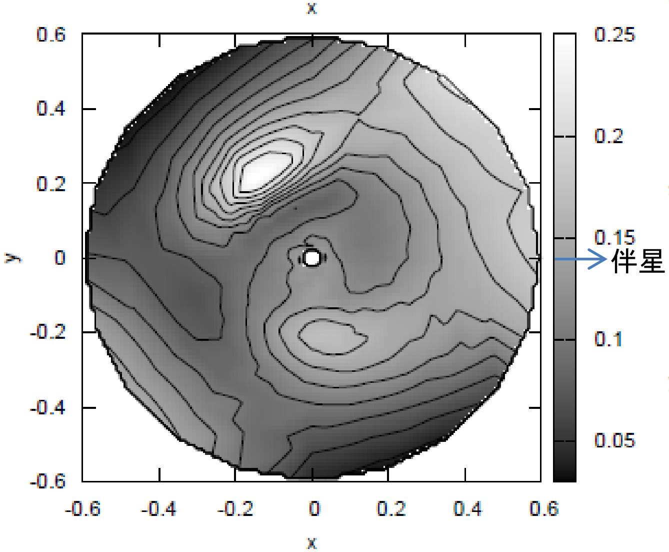
The 5th day of the superoutburst

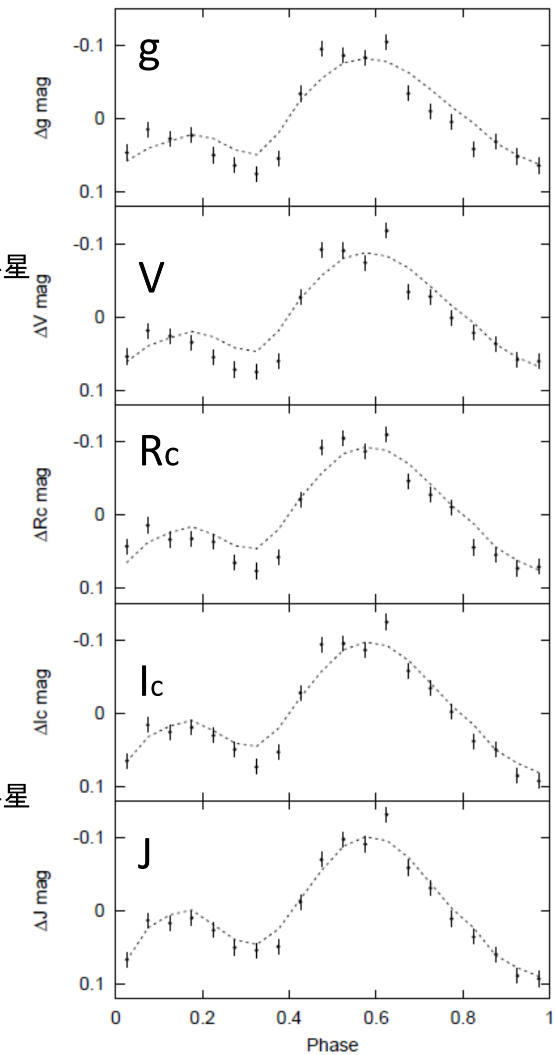
- 5-band data (g,V,R,I,J)
- Flaring outermost parts making primary and secondary maxima of the light curve
- “arm”-like structures

height



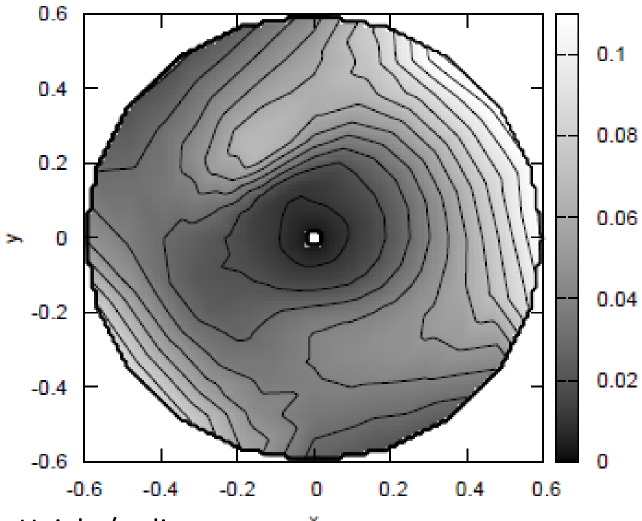
Height/radius



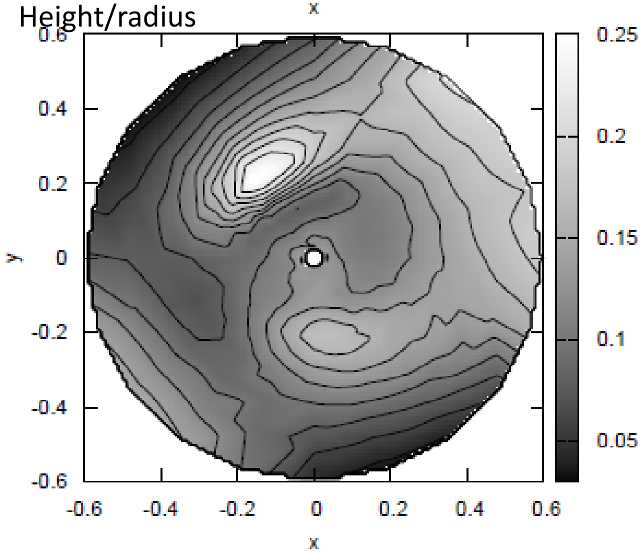


Comparison with theoretical models

height

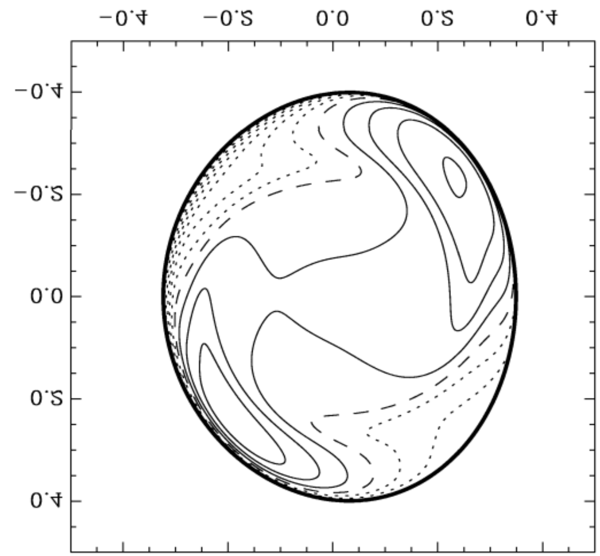


Height/radius

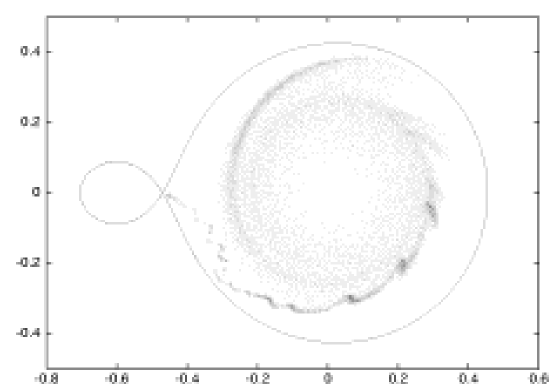


- Tidal distortion? 2:1 resonance?

Theoretical image of the height distortion
by the tidal effect（Ogilvie 2002)



SPH simulation of the 2:1
(Kunze & Speith 2005)



Reconstructed disks are similar to the disk distorted by the tidal effect, but the upper-left flaring part cannot be explained.

Summary 2

- We have developed a Bayesian model which reconstruct the height map of disks from the multi-band light curves of early superhumps.
- The reconstructed disk has flaring outermost parts making the primary and secondary maxima of the light curve, and “arm”-like structures.
- The structure is similar to the disk structure distorted by the tidal effect, but the part for the secondary minimum cannot be explained.
- Future work:
  - Does the model make similar results for another objects?
  - How the disk evolves with time?
  - Can the reconstructed disk explain the emission-like profile in WZ Sge stars?