Superhumps

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Photometric Study of the Dwarf Nova VW Hydri

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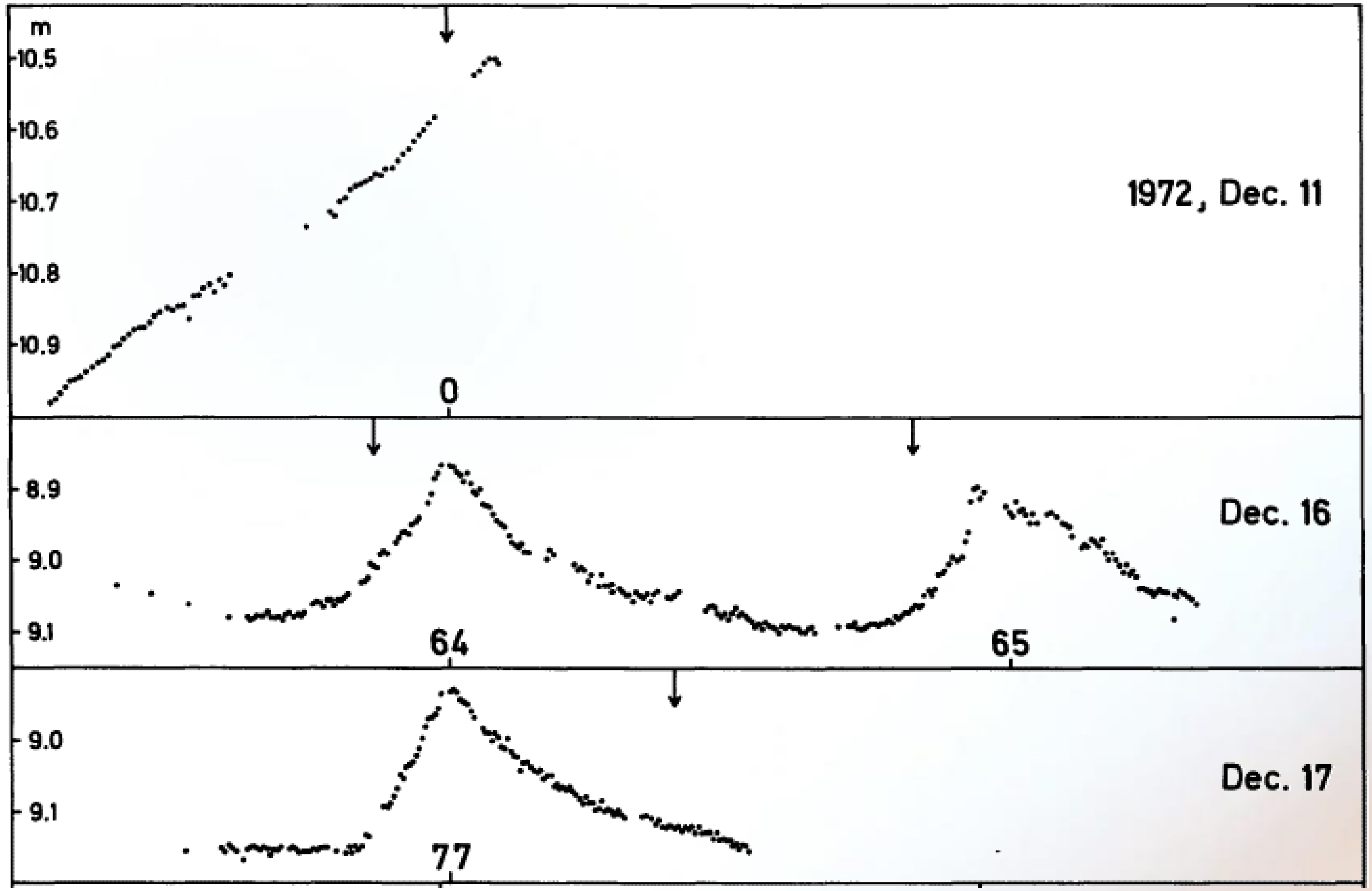
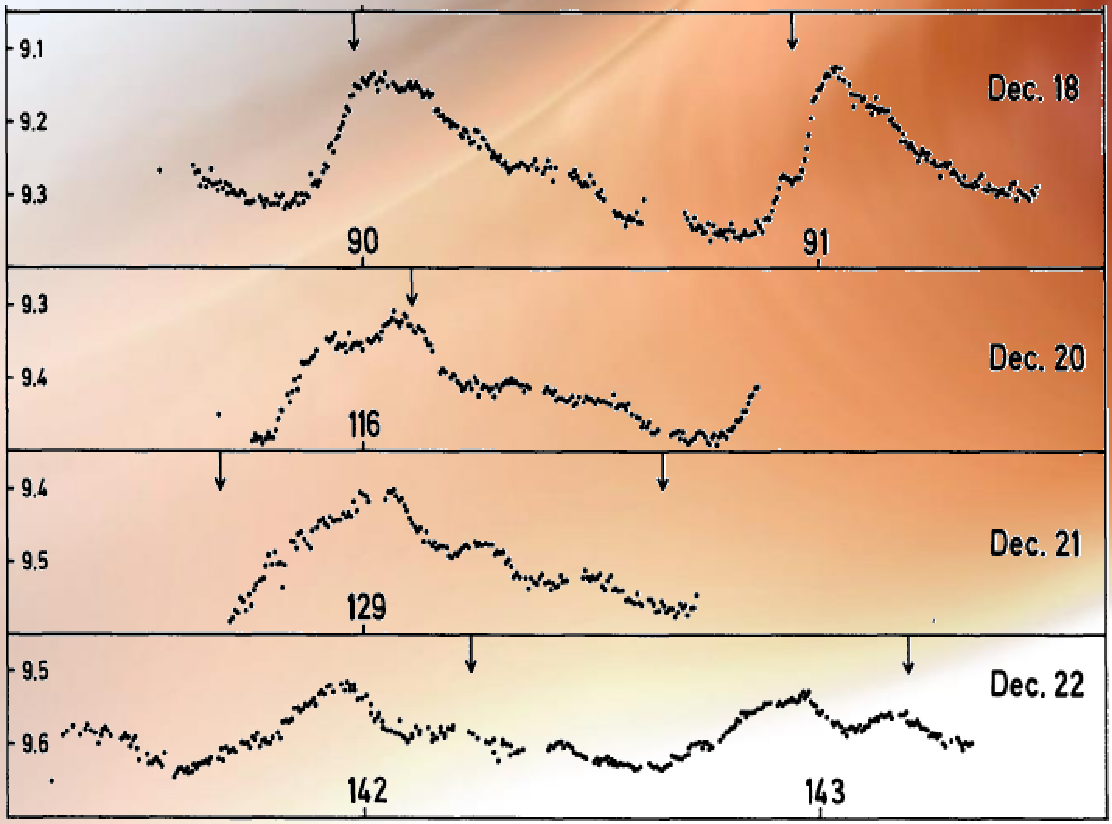
Summary. Extensive photoelectric observations of VW Hyi have been carried out during minimum light and eruptions. In the minimum stage VW Hyi shows a periodically repeating hump (similar to that of U Gem) from which an orbital period of $0\overset{d}{.}07427111$ has been derived. No eclipses are present.—The two types of eruptions known previously for VW Hyi correspond to different physical processes: The short eruptions (lasting $\sim 4^d$) resemble again those of U Gem; the minimum hump disappears in bright phases. During the long eruptions (lasting $\sim 17^d$) a pronounced peak-structured light curve has been observed with periodicities of $\sim 0\overset{d}{.}0768$. Significant colour variations with this period are also present. During one long maximum a separation of the repeating feature into two peaks is found. A first attempt has been made to interpret qualitatively the observed facts by an interaction between gas streams from the inner lagrangian point and ejected matter proceeding from the white dwarf component.

Key words: dwarf novae — eruptive variables — gas streams in close binary systems


m
10.5
10.6
10.7
10.8
10.9
0
1972, Dec. 11
8.9
9.0
9.1
64
65
Dec. 16
9.0
9.1
77
Dec. 17


9.1
9.2
9.3
90
91
Dec. 18
9.3
9.4
116
Dec. 20
9.4
9.5
129
Dec. 21
9.5
9.6
142
143
Dec. 22

So what was observed?

- Dwarf novae (SU UMa) with very small orbital periods (< 0.1 d)
- Additional periodic variations of brightness during long superoutbursts
- No such variability during short-term outbursts
- Detected periods are slightly (up to few per cent) larger than the orbital periods of those systems

Instability mechanisms

- Originally two theories were suggested:
  - Mass-transfer bursts
  - Disk instabilities
- Later they transformed into inside-out disk instability outbursts that allow alterations of short and long outbursts
- What about those variabilities with non-orbital periods?

Superhumps

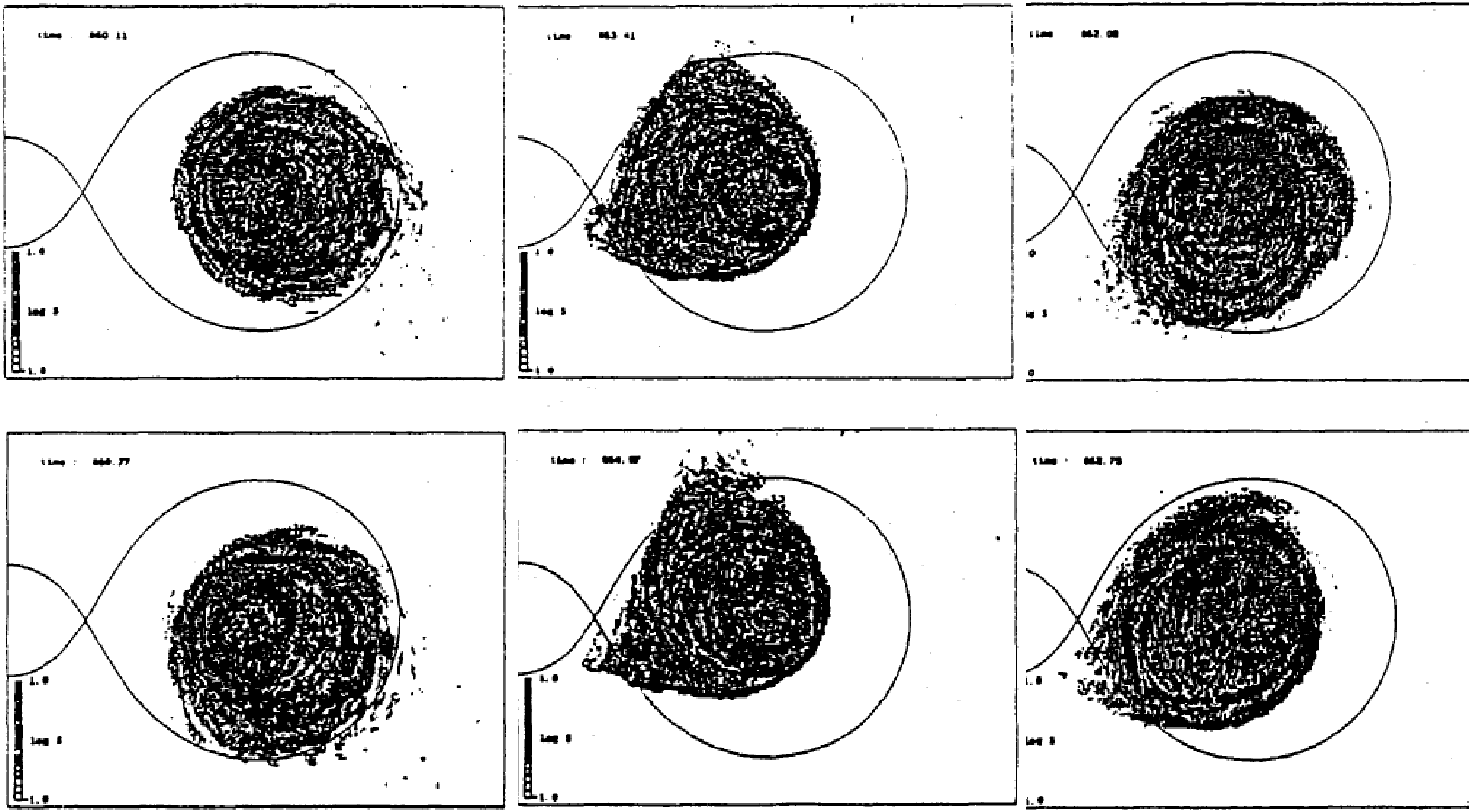
- A phenomenological explanation was suggested that superhumps can be explained by tidal instabilities that lead to disk distortion into eccentric form.
- Later simulations showed that accretion disks in SU Uma-like systems can develop eccentric instabilities, causing disks to slowly precess.
  - Simulations also imposed an empirical limit onto mass ratios. Superhumps developed predominately in systems with $q < 0.25$
- It is also possible for a disk to precess in opposite direction, creating "negative superhumps" with periods slightly smaller that the orbital.

Superhumps

The accretion disk of a typical DN CV that is in quiescence has a low disk viscosity and thus inefficient exchange of angular momentum. As a result, the mass transfer rate $\dot{M}_{L1}$ through the inner Lagrange point L1 is higher than the mass transfer rate $\dot{M}_1$ onto the primary. Thus, mass accumulates in the disk until a critical surface density is reached at some annulus, and the fluid in that annulus transitions to a high-viscosity state. High-viscosity state expands to other disk regions and lead to normal outburst. In this state, $\dot{M}_1 > \dot{M}_{L1}$ and the disk drains mass onto the primary white dwarf.

Superhumps

- During each Dwarf Novae outburst, however, the angular momentum transport acts to expand the outer disk radius slightly, and after a few to several of these, an otherwise normal DN outburst can expand the outer radius of the disk to the inner Lindblad resonance (near the 3:1 corotation resonance).
- While viscous dissipation within the periodically flexing disk provides the dominant source of the superhump modulation, the accretion stream bright spot also provides a periodic photometric signal when sweeping around the rim of a non-axisymmetric disk. The bright spot will be most luminous when it impacts most deeply in the potential well of the primary, and fainter when it impacts the rim further from the white dwarf primary.



Superhumps

- Resonance occurs when the frequency of radial motion of a particle in a disk is commensurate to the angular frequency of the donor star
- Resonance occurs if

$$k(\Omega - \omega) = j(\Omega - \Omega_{\mathrm{orb}})$$

where Ω is mean angular frequency of a particle,

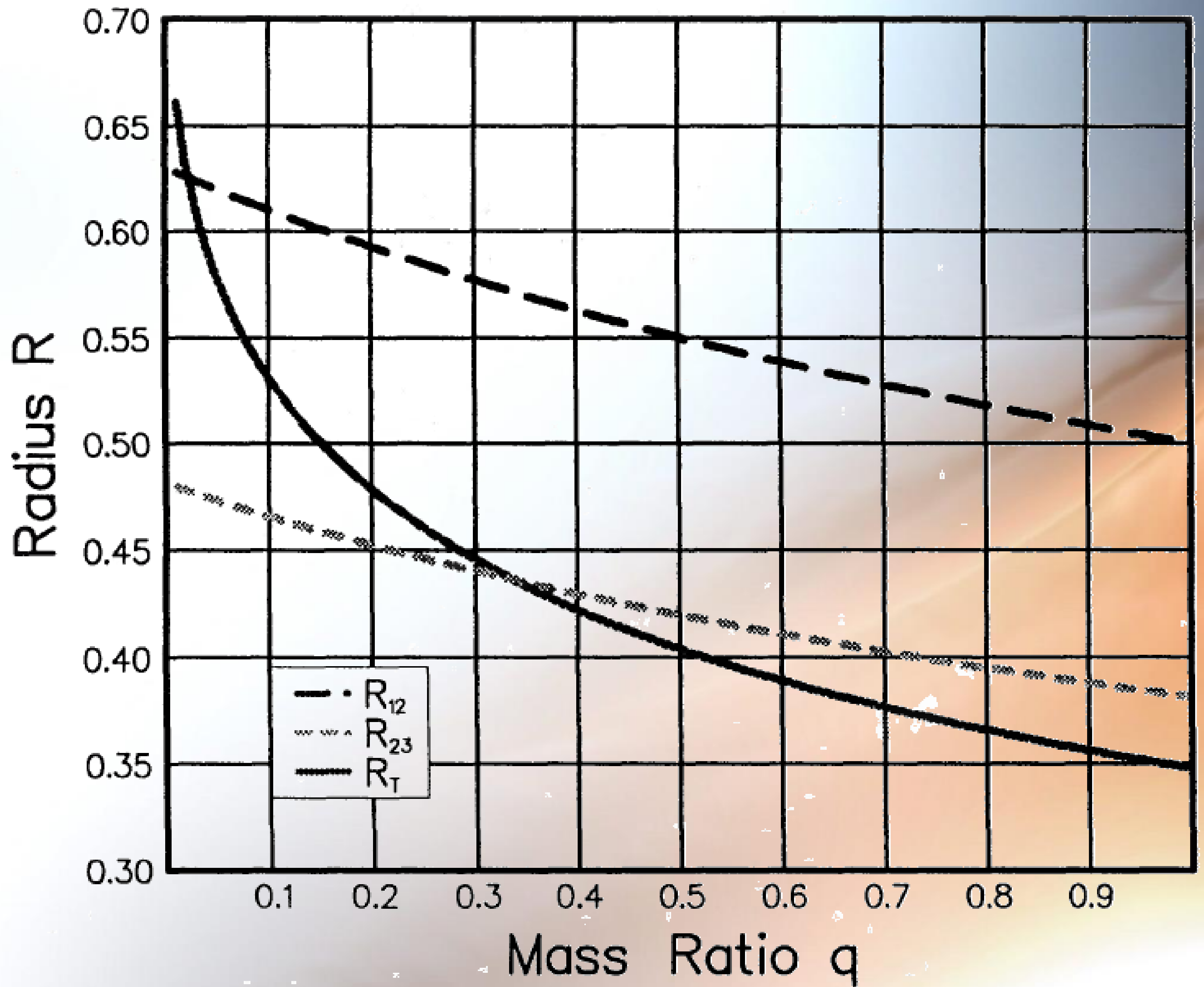
ω – precession frequency,
Ω_{orb} - orbital frequency

Superhumps

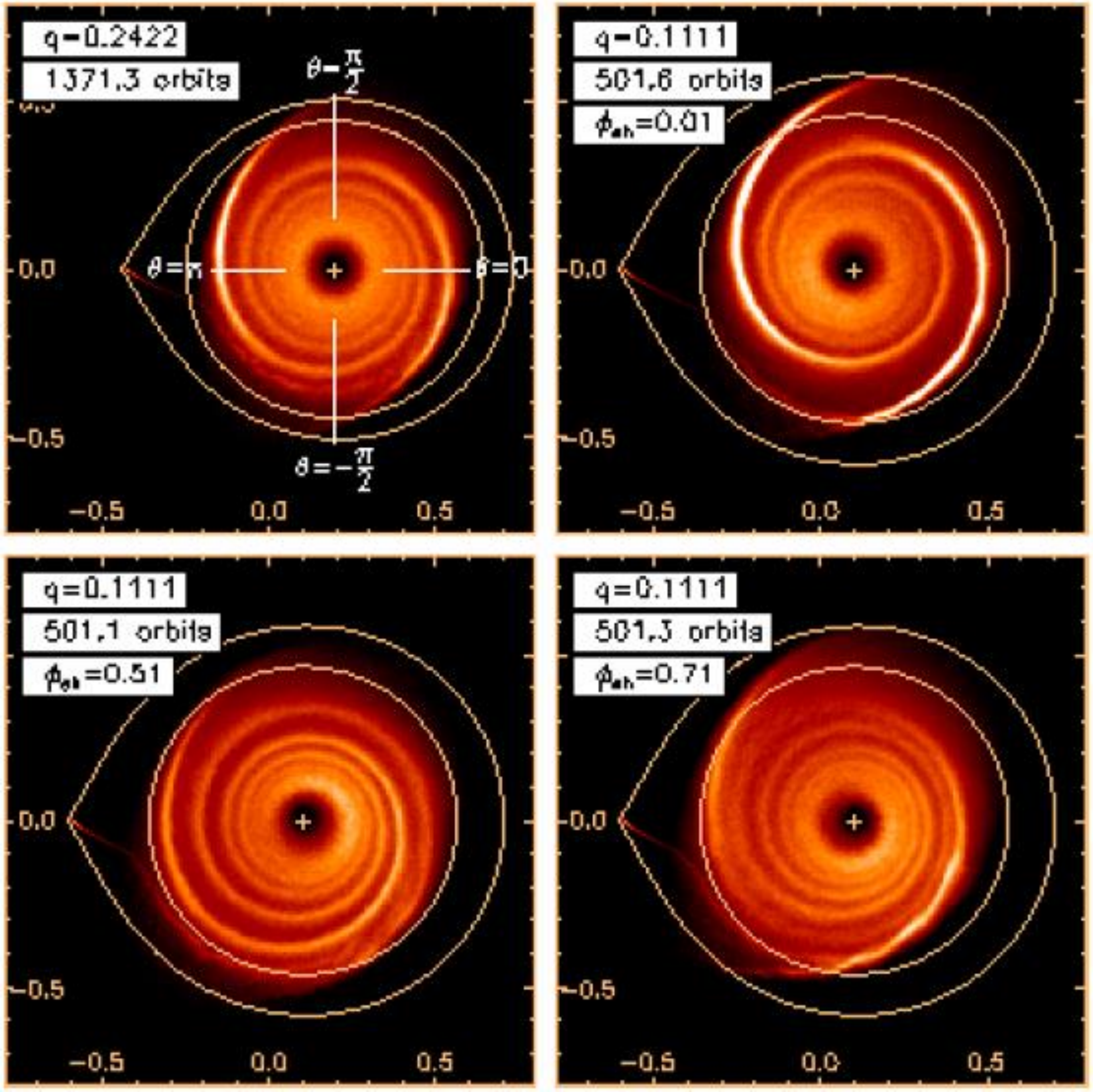
- Instabilities occur with commensurabilities like j:j-k,
but the growth rate goes like e^k, e is eccentricity of an orbit.
- At what distance a given resonance can occur?

$$\frac{R_{j,k}}{a} = \left[\frac{j-k}{j}\right]^{\frac{2}{3}} (1+q)^{-1/3} \leq \frac{R_T}{a} = \frac{0.45}{0.6 + q^{-2/3}\ln[1+q^{-1/3}]}$$

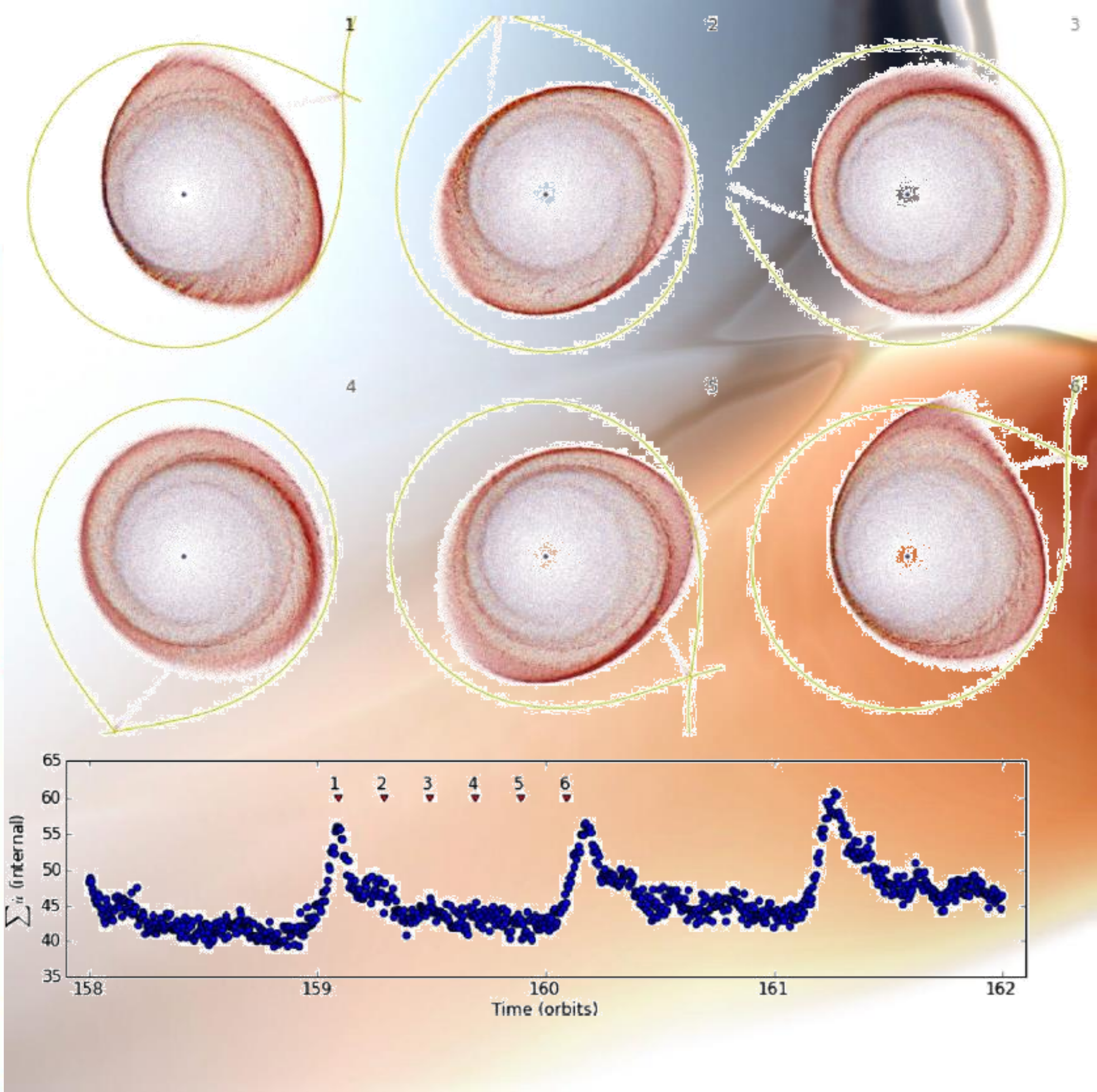
- The 2:1 resonance can happen only for q < 0.025
- The second most powerful resonance of 3:1 happens for
q < 0.33



0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
Radius R
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Mass Ratio q
R_{12}
R_{23}
R_T



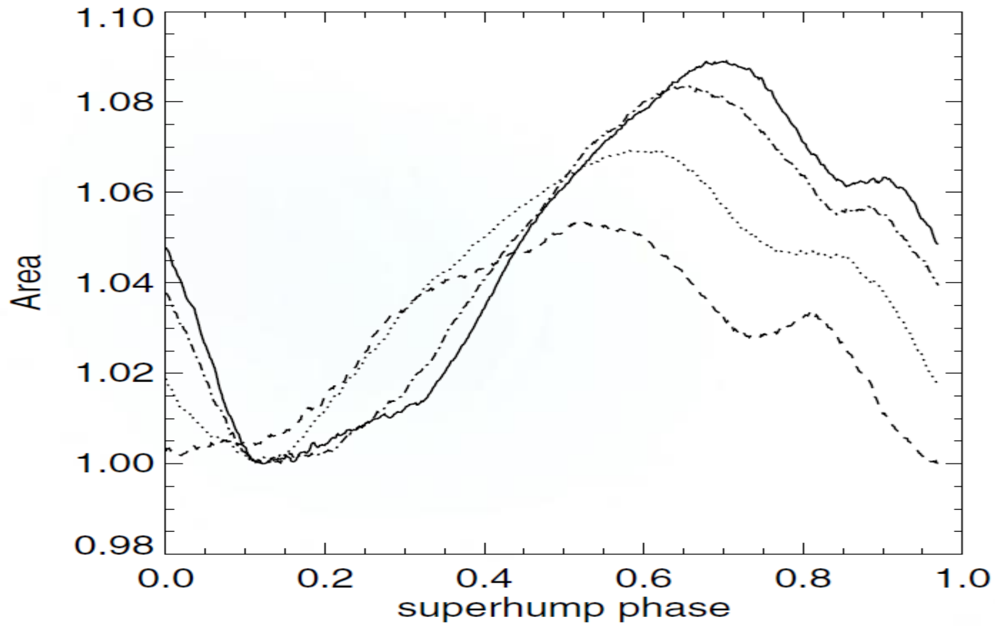
q=0.2422
1371.3 orbits
θ=π/2
θ=π
θ=0
θ=−π/2
q=0.1111
501.6 orbits
φ=0.01
q=0.1111
501.1 orbits
φ=0.51
q=0.1111
501.3 orbits
φ=0.71



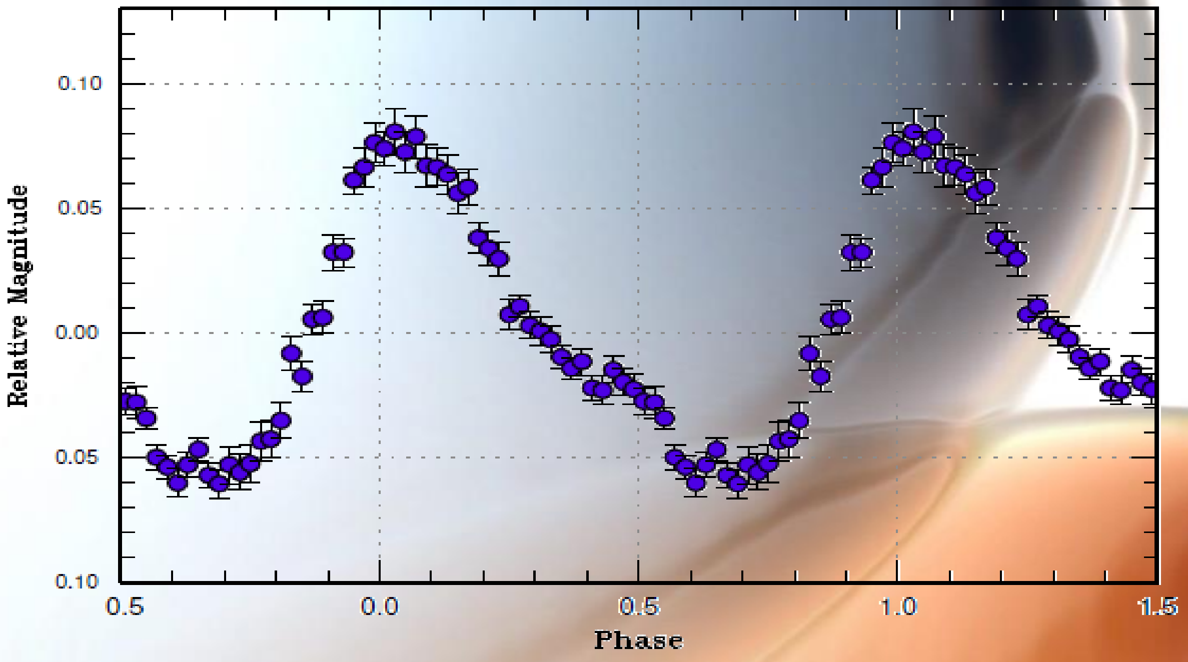
1
2
3
4
5
6
Σ (internal)
Time (orbits)

What about low-mass X-ray binaries?

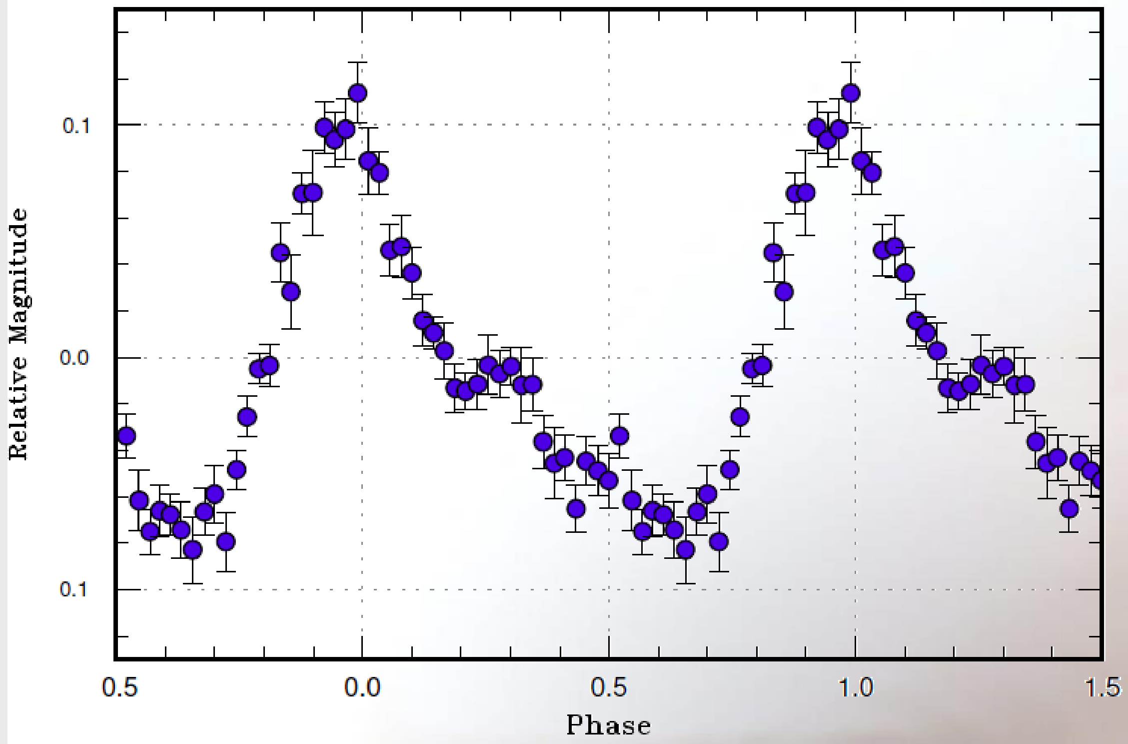
- LMXBs in some sense are similar to dwarf novae, but the accreting object is a BH or a NS.
- Due to the significant mass of an accretor (especially when it is a BH), the mass ratio q is usually quite low, allowing tidal instabilities to develop in the disk.
- However, significant contribution of irradiation in case of LMXBs renders applied to the CVs explanation of superhumps invalid.
- This theory can be "rescued" if we consider that efficiency of radiation reprocessing by disk varies with superhump period, which can be achieved by varying disk surface area



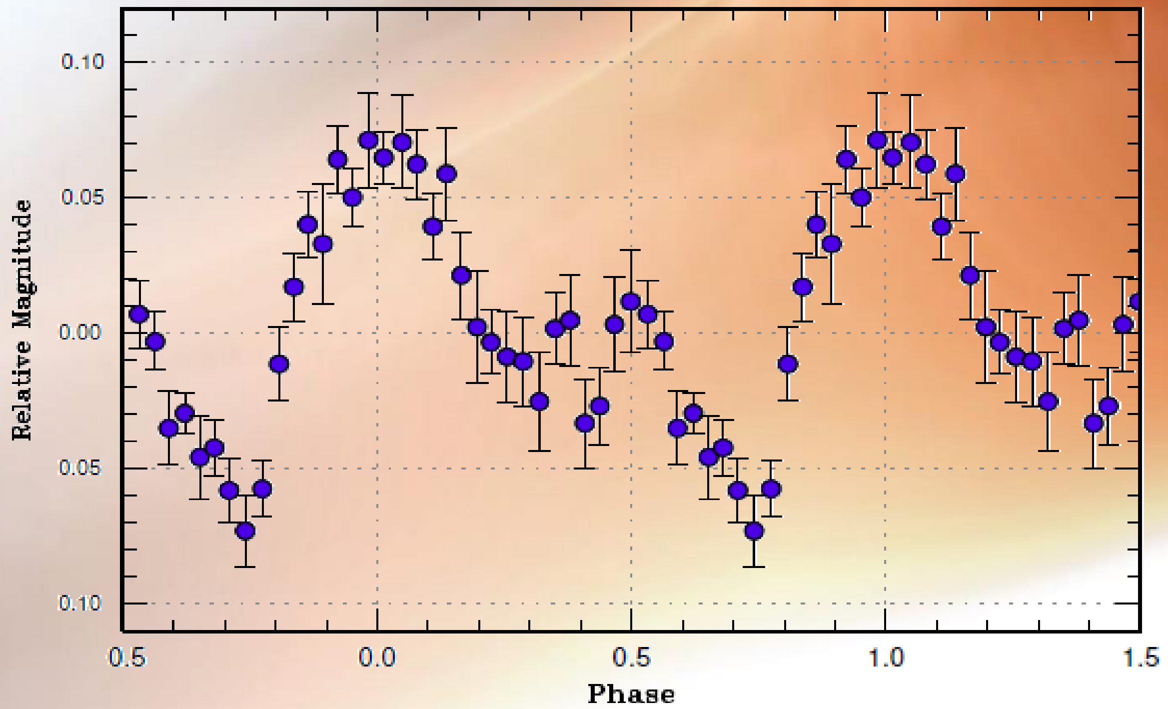
Area
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.0
0.2
0.4
0.6
0.8
1.0
superhump phase



Relative Magnitude
0.10
0.05
0.00
0.05
0.10
0.5
0.0
0.5
1.0
1.5
Phase



Relative Magnitude
0.1
0.0
0.1
0.5
0.0
0.5
1.0
1.5
Phase



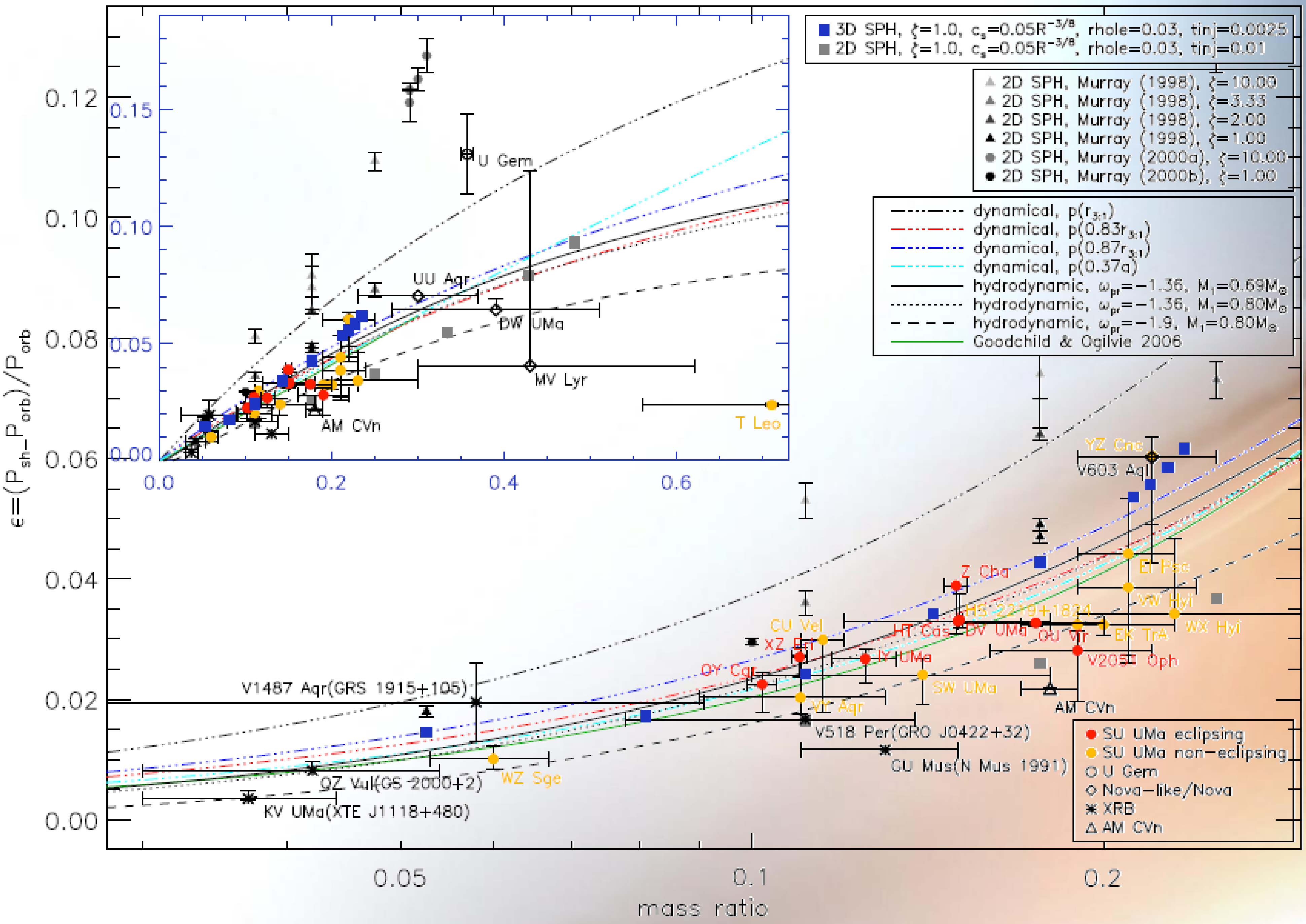
Relative Magnitude
0.10
0.05
0.00
0.05
0.10
0.5
0.0
0.5
1.0
1.5
Phase

Superhump period excess

$$\Delta P = \frac{P_{\mathrm{sh}} - P_{\mathrm{orb}}}{P_{\mathrm{orb}}} = \frac{3}{4}\frac{q}{\sqrt{1+q}}\left(\frac{r_{\mathrm{d}}}{a}\right)^{3/2} = \frac{1}{4}\frac{q}{\sqrt{1+q}}\,\eta^{3/2},$$

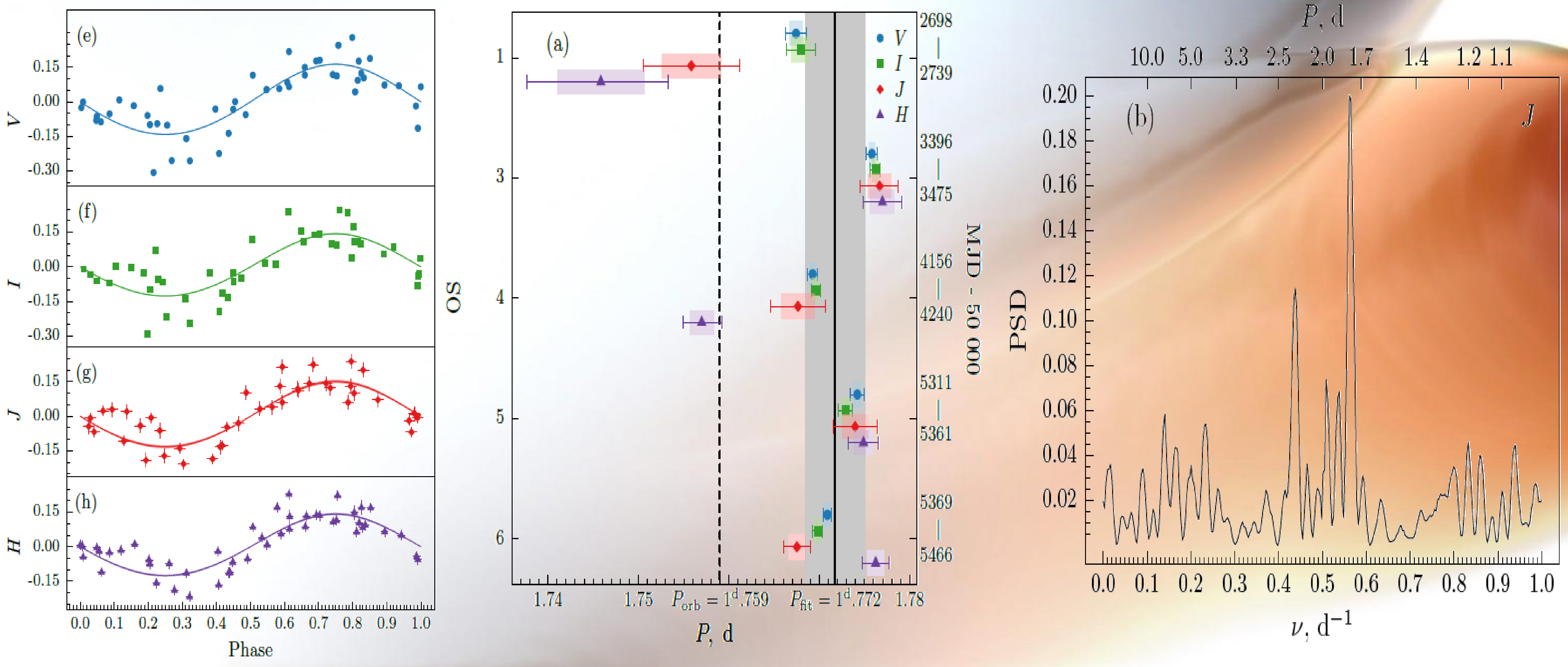
η is in [0.6, 1.0], typically 0.8. This relation is empirical.

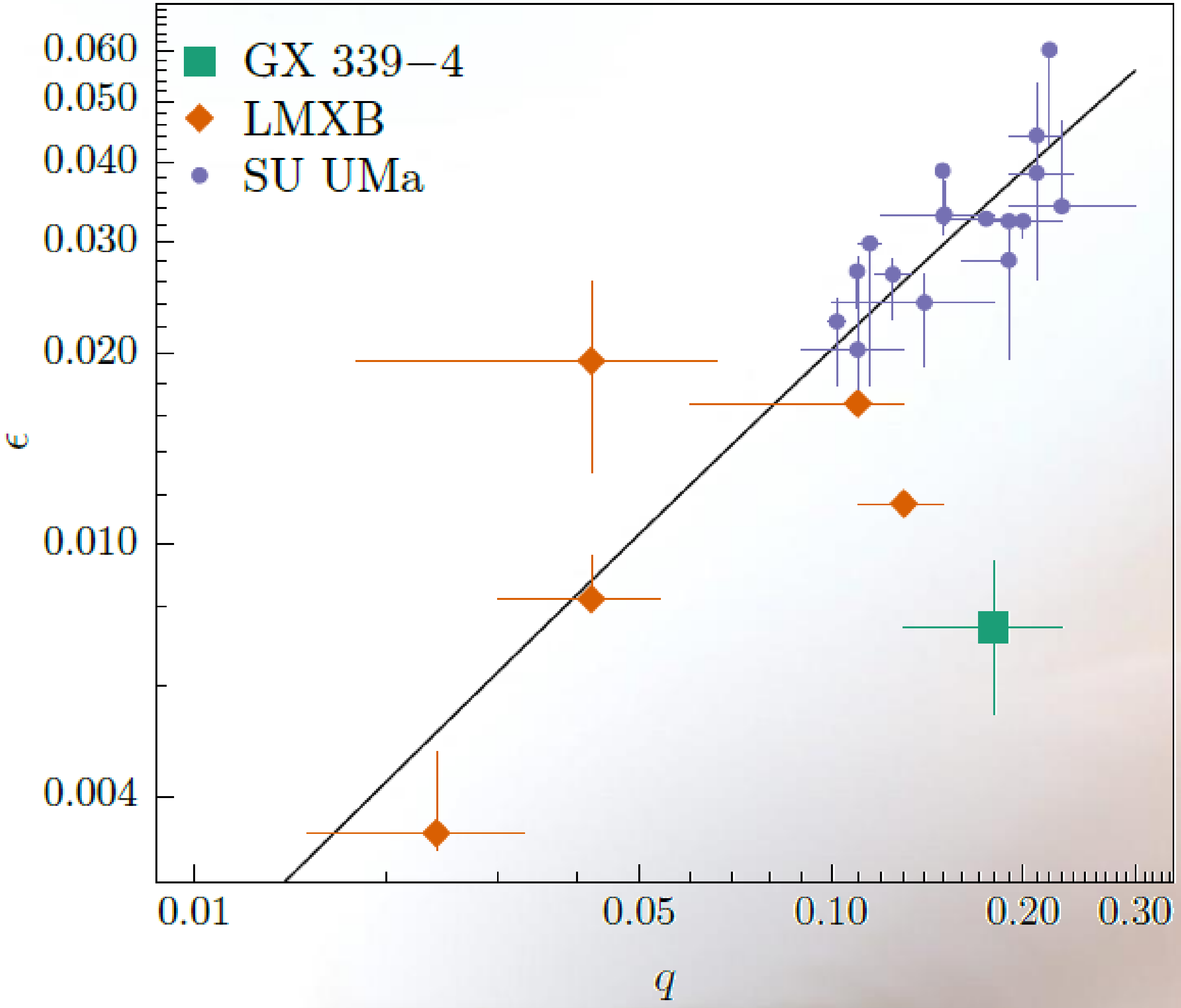
Superhumps can be observed at any inclination angles, but different period harmonics will appear in PSD



3D SPH, ζ=1.0, c_s=0.05R^-3/8, rhole=0.03, tinj=0.0025
2D SPH, ζ=1.0, c_s=0.05R^-3/8, rhole=0.03, tinj=0.01
2D SPH, Murray (1998), ζ=10.00
2D SPH, Murray (1998), ζ=3.33
2D SPH, Murray (1998), ζ=2.00
2D SPH, Murray (1998), ζ=1.00
2D SPH, Murray (2000a), ζ=10.00
2D SPH, Murray (2000b), ζ=1.00
dynamical, p(r_3:1)
dynamical, p(0.83r_3:1)
dynamical, p(0.87r_3:1)
dynamical, p(0.37a)
hydrodynamic, ω_pr=−1.36, M_1=0.69M_⊙
hydrodynamic, ω_pr=−1.36, M_1=0.80M_⊙
hydrodynamic, ω_pr=−1.9, M_1=0.80M_⊙
Goodchild & Ogilvie 2006
SU UMa eclipsing
SU UMa non−eclipsing
U Gem
Nova−like/Nova
XRB
AM CVn
ε=(P_sh−P_orb)/P_orb
mass ratio
U Gem
UU Aqr
DW UMa
MV Lyr
AM CVn
T Leo
YZ Cnc
V603 Aql
Z Cha
EI Psc
VW Hyi
HS 2219+1824
WX Hyi
HT Cas
DV UMa
OU Vir
EK TrA
CU Vel
XZ Eri
IY UMa
V2051 Oph
OY Car
SW UMa
YZ Aqr
AM CVn
V1487 Aqr(GRS 1915+105)
V518 Per(GRO J0422+32)
GU Mus(N Mus 1991)
OZ Vul(GS 2000+2)
WZ Sge
KV UMa(XTE J1118+480)

GX 339-4 exhibiting superhumps?





System	Donor Spect. Type	q	i [deg]	M_x [$M_\odot$]
BW Cir	~G5 IV	$0.12^{+0.03}_{-0.04}$	<79	>7.0
GX 339-4	–			>6.0
XTE J1550-564	K2/4 IV	≈0.03	74.7±3.8	7.8–15.6
4U 1543-475	A2 V		20–40	2.7–7.5
H1705-250	K3/M0 V	≤0.053	60–80	4.9–7.9
"			48–51	
GS 1124-684	K3/5 V	**0.13±0.04**		
"			60^{+5}_{-6}	5.0–7.5
"			54^{+20}_{-15}	$5.8^{+4.7}_{-2.0}$
"			54±2	7.0±0.6
GS 2000+250	K3/7 V	**0.042±0.012**		
"			65±9	8.5±1.5
"			43–69	4.8–14
"			**58–74**	**5.5–8.8**
A0620-00	K2/7 V		<50	>7.3
"		**0.067±0.010**		
"		0.060±0.004		
"				
"			63–74	4.1–5.4
"			31–54	10^{+7}_{-5}
"	K3/7 V		38–75	3.3–13.6
"			41±3	11.0±1.9
"			**51±0.9**	**6.6±0.3**

Thank you!