Symbiotic stars: challenges to binary evolution theory

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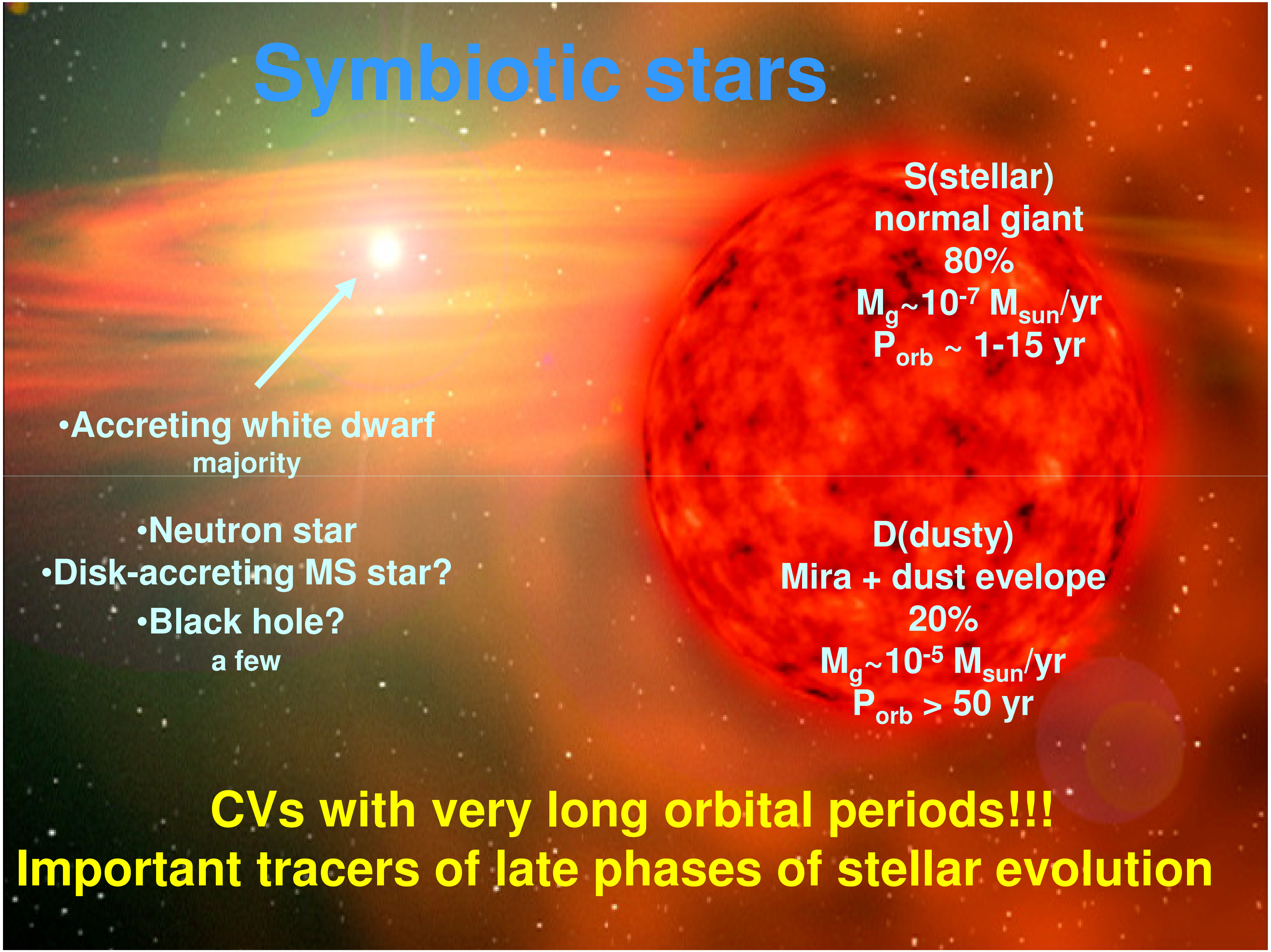
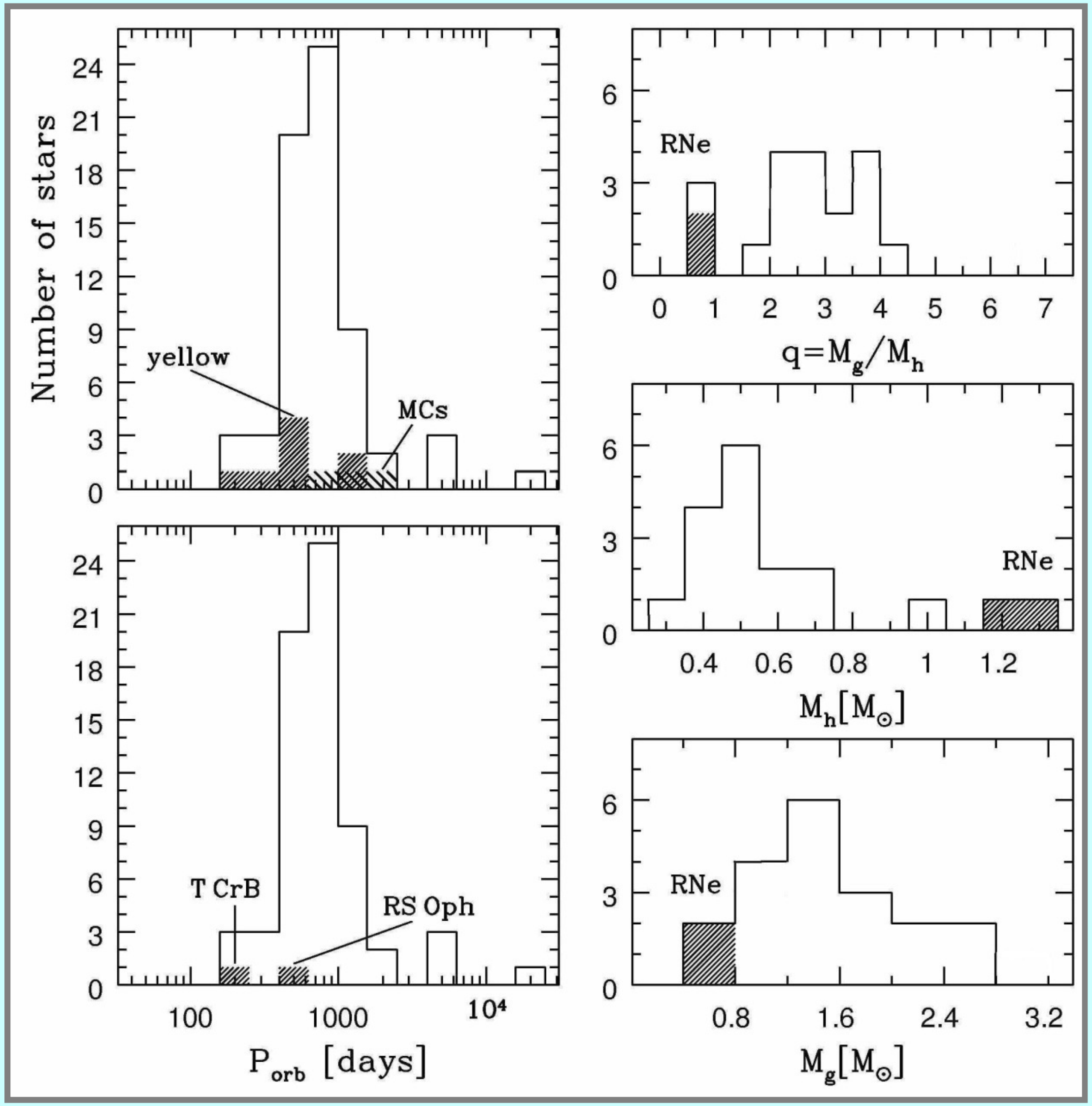

Symbiotic stars
S(stellar)
normal giant
80%
$M_g \sim 10^{-7}\ M_{sun}/yr$
$P_{orb} \sim$ 1-15 yr
•Accreting white dwarf
majority
•Neutron star
•Disk-accreting MS star?
•Black hole?
a few
D(dusty)
Mira + dust evelope
20%
$M_g \sim 10^{-5}\ M_{sun}/yr$
$P_{orb} > 50$ yr
CVs with very long orbital periods!!!
Important tracers of late phases of stellar evolution

Points to be addressed

- Orbital parameters
- The hot component & its activity
- The cool giant & mass transfer

Orbital parameters



- **70 SyS – known orbital periods**
  (Belczyński et al. 2000, Mikołajewska 2003, 2004; Gromadzki et al. 2007)

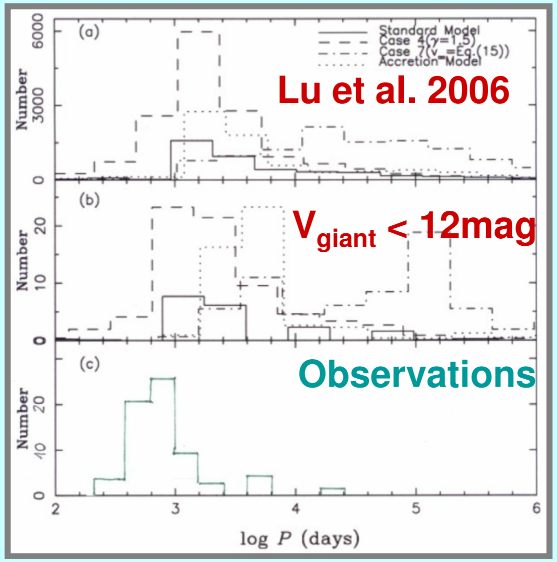
- **34 SyS – known spectroscopic orbits for the cool giant**
  (Mikołajewska 2003; Hinkle et al. 2006 – V2116 Oph; Brandi et al. 2006 - Hen3-1761; Fekel et al. 2007, 2008:)

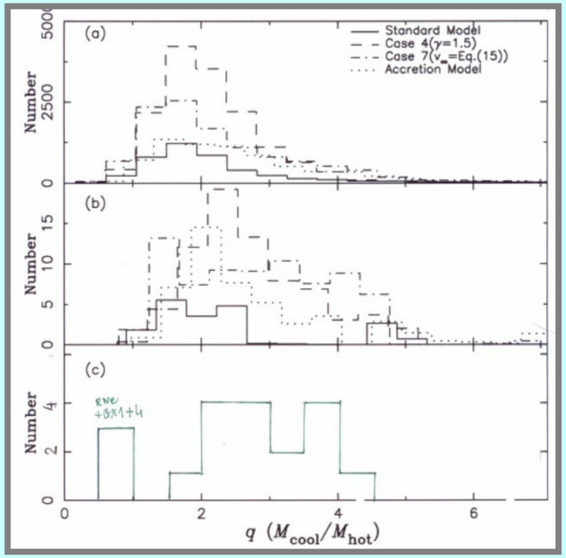
- **19 SyS – mass ratios**
  (Mikołajewska 2003; 2007)

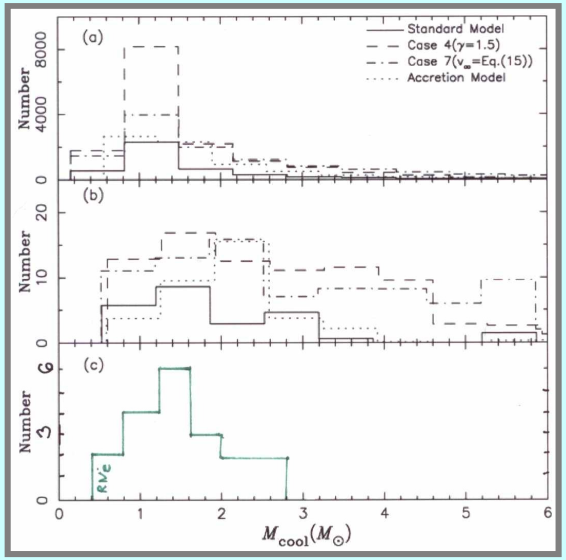
In both symbiotic RNe:

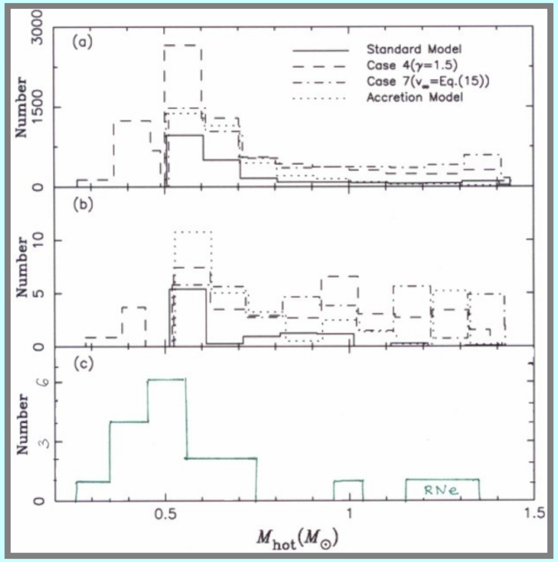
- **$M_g<M_h$, and the lowest among SyS**
- **M_h~1.1-1.4 M_{sun} - the highest among SyS**

Orbital parameters: comparison with population synthesis model predictions









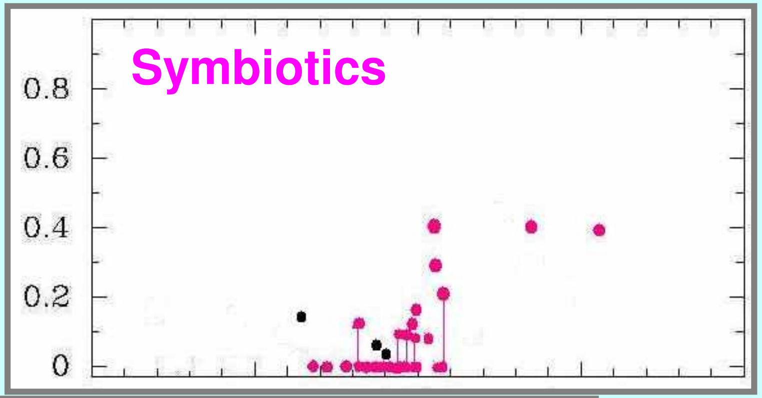
PSM:

- does not reproduce P distribution: 65% observed SyS have P~400-1000 d, and only 20% above 1000 d
- overestimates the wd mass

▼

Need more advanced model for mass transfer: at present the model assumes symbiotics are detached and interact only via stellar wind

e-P diagram



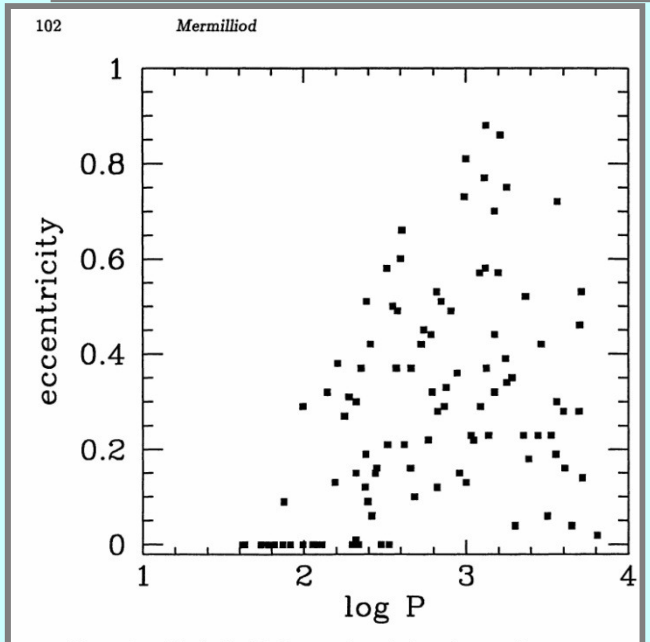


Figure 4. The (e, log P) diagram for red giants in open clusters.

Symbiotics:

- ***e*** **much lower for at any *P* ⇨mass transfer and tidal interaction have taken place**
- **Most (>85%) with P<~900 days have circular orbits ⇨ RLOF**

How they avoided CE & dramatic shrinkage of P?

Note that RLOF is dynamically unstable for $q=M_{giant}/M_{comp}<q_{crit}\sim<1$

i.e. for ANY possible q!!!

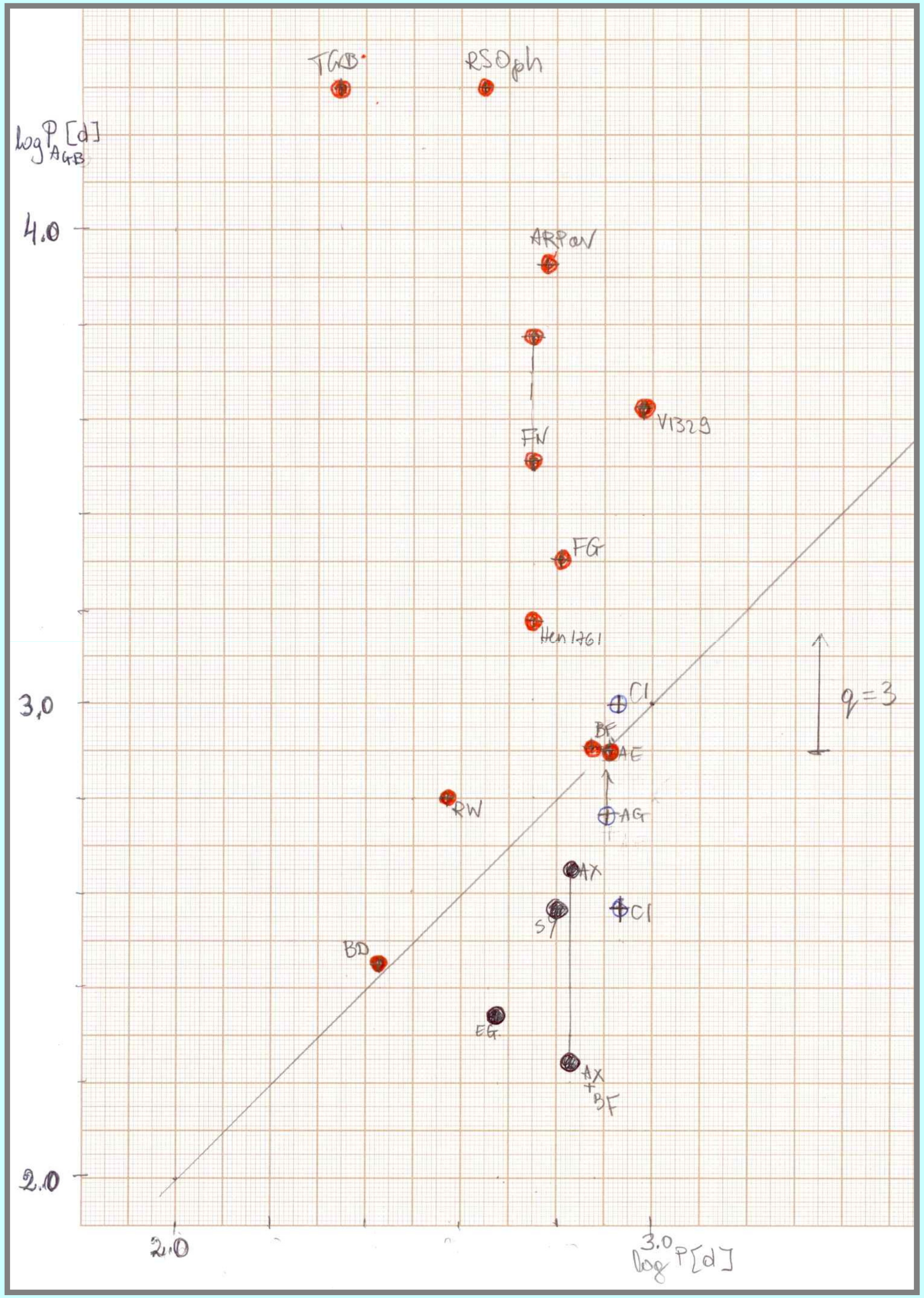
Mass estimates

Table 2. Mass estimates for symbiotic binaries

Star	P [days]	Ecl.	i [deg]	$q = M_g/M_h$	$M_g [M_\odot]$	$M_h [M_\odot]$	Com.
EG And	481	Y	90	3.8	1.5 ± 0.6	0.4 ± 0.1	ET
AX Per	680.8	Y	90	2.4	0.9 ± 0.2	0.37 ± 0.06	BA
			$\gtrsim 70$	2.4	$\lesssim 1.1$	$\lesssim 0.44$	
BX Mon	1276	Y	90	3.9	1.0 ± 0.3	0.25 ± 0.05	BA
			$\gtrsim 62$	3.9	$\lesssim 1.4$	$\lesssim 0.36$	
SY Mus	625	Y	90	3	1.3 ± 0.25	0.43 ± 0.05	ET
		Y	89	2.6	1.1	0.4	LCS
RW Hya	370.2	Y	90	3.3	1.6 ± 0.3	0.48 ± 0.06	ET
		Y	76	3.2	1.6	0.5	LCS
T CrB	227.57	N	~ 60	0.6	0.7 ± 0.2	1.2 ± 0.2	LCS
KX TrA	1350	?	90	2.4	1.0 ± 0.3	0.41 ± 0.04	He II W
			135	2.4	2.7	1.2	SP
AE Ara	812	N	60	3.9	2.0 ± 1.2	0.51 ± 0.2	He II W
RS Oph	455.7	N	$50 - 60$	0.6	$0.7 - 0.8$	$1.2 - 1.4$	H I W, BA
FG Ser	650	Y	90	2.8	1.7 ± 0.7	0.60 ± 0.15	ET
AR Pav	604.5	Y	90	2.5	2.5 ± 0.6	1.0 ± 0.2	He II W, BA
			$\gtrsim 70$	2.5	$\lesssim 3$	$\lesssim 1.2$	
			74	2.3	2.2	0.95	LCS
			90	2.3	2.0 ± 0.5	0.87 ± 0.15	ET
FN Sgr	568.3	Y	90	2.1	1.4 ± 0.2	0.66 ± 0.08	BA.
			$\gtrsim 70$	2.1	$\lesssim 1.7$	$\lesssim 0.8$	
BF Cyg	757.2	Y	90	3.5	1.8 ± 0.6	0.51 ± 0.1	UVEL
			80	3	1.2	0.4 LCS	
CI Cyg	855.3	Y	90	3	1.3 ± 0.3	0.43 ± 0.04	He II EL
			≥ 79	3	≤ 1.6	≤ 0.52	
V1329 Cyg	956.5	Y	86	2.8	2.1 ± 0.5	0.74 ± 0.08	H I W, SP
AG Peg	816.5	N	$\lesssim 60$	3.9	$\gtrsim 1.8$	$\gtrsim 0.46$	He II EL
V2116 Oph	1161	N		$\lesssim 0.9$	$\lesssim 1.3$	$\lesssim 1.4$	
Hen -1761	562.2	?	$\lesssim 90$	4.4	$\gtrsim 2.6$	$\gtrsim 0.59$	BA
BD-21 3873	281.6	N	60	2	0.9	0.45	LCS

BA – blue absorption system; UVEL – ultraviolet emission lines; He II W – He II emission wings; H I W – H I emission wings; He II EL – He II emission line; SP – i from spectropolarimetry; ET – the cool giant mass from $v \sin i$ and evolutionary tracks (Mürset et al. 2000, and references therein; Schild et al. 2001); LCS – light curve synthesis combined with radial velocity curve (Belczyński & Mikołajewska 1998).

SyS with Mh>~0.45 Msun should experience RLOF before the present WD was formed



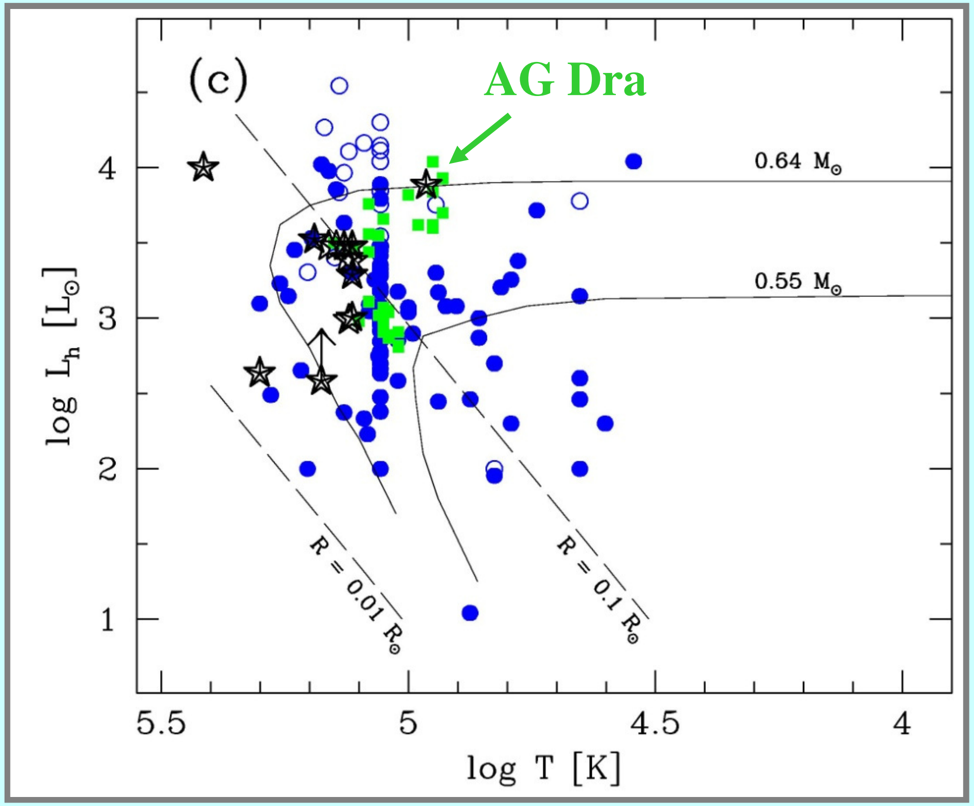
M(wd) ⇨ R_{GB}(wd)
q_{GB}=M_{GB}(wd)/M_g & RLOF ⇨
P_{AGB}=f(q,M)

- **Incompatible with the PSM assumptions**
- **Systems with CO WDs & intermediate mass progenitors have shrunk**
- **Behaviour of some systems with low mass (<0.5) WDs confusing**
- **In some systems (e.g. AX Per, CI Cyg) the core mass of the present RG >~ M(wd)**

In which phase of the BE S-type symbiotics are at present?

How they interact?

The hot component



Quiescence:

•Overlap with central stars of PNe

•TNR-powered white dwarfs

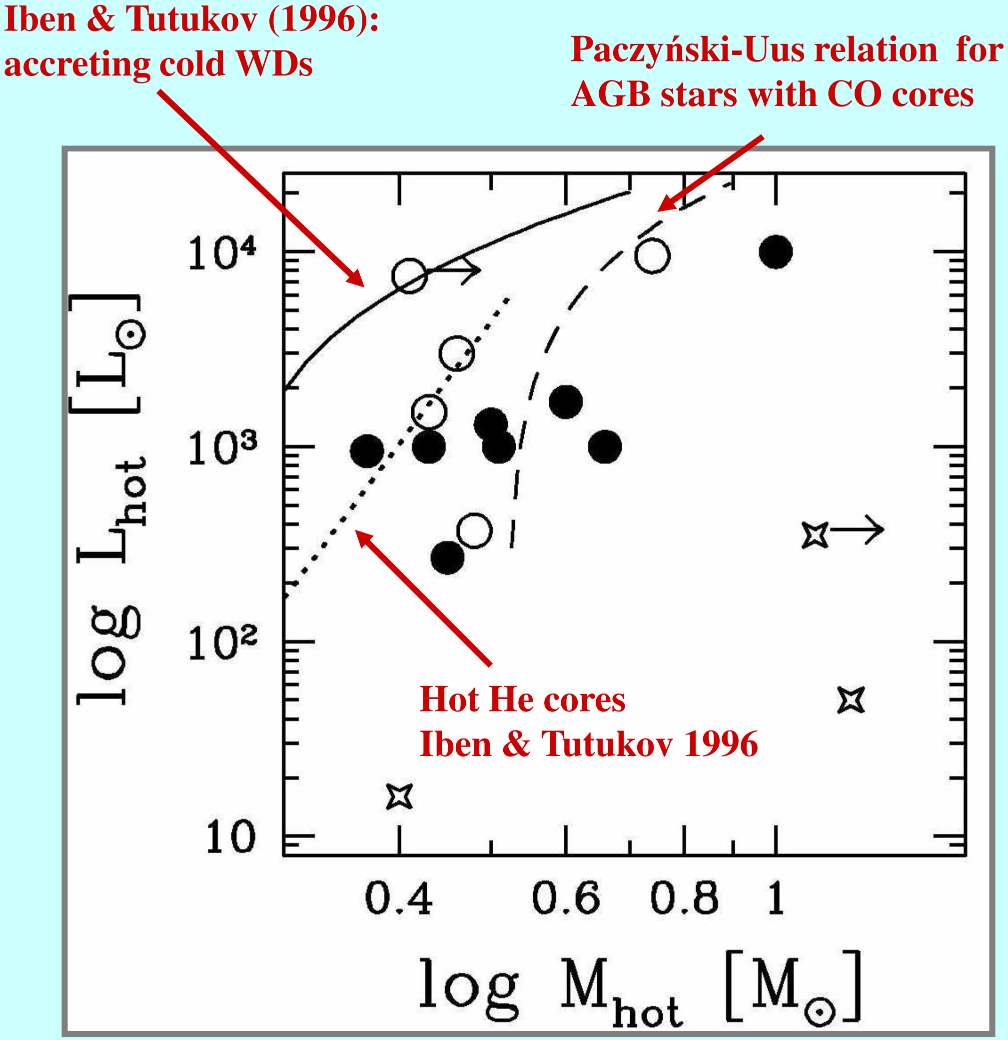
•Stable /quasi-stable H-shell burning of the accreted matter or very slow TNR on low mass wd's

•Galactic and MC SyS overlap in HR diagram; MC systems are among the hottest and brighest systems

However:

Far UV SEDs for RW Hya, SY Mus and EG And indicate much lower T than emission lines (Sion et al. 2002, 2004)

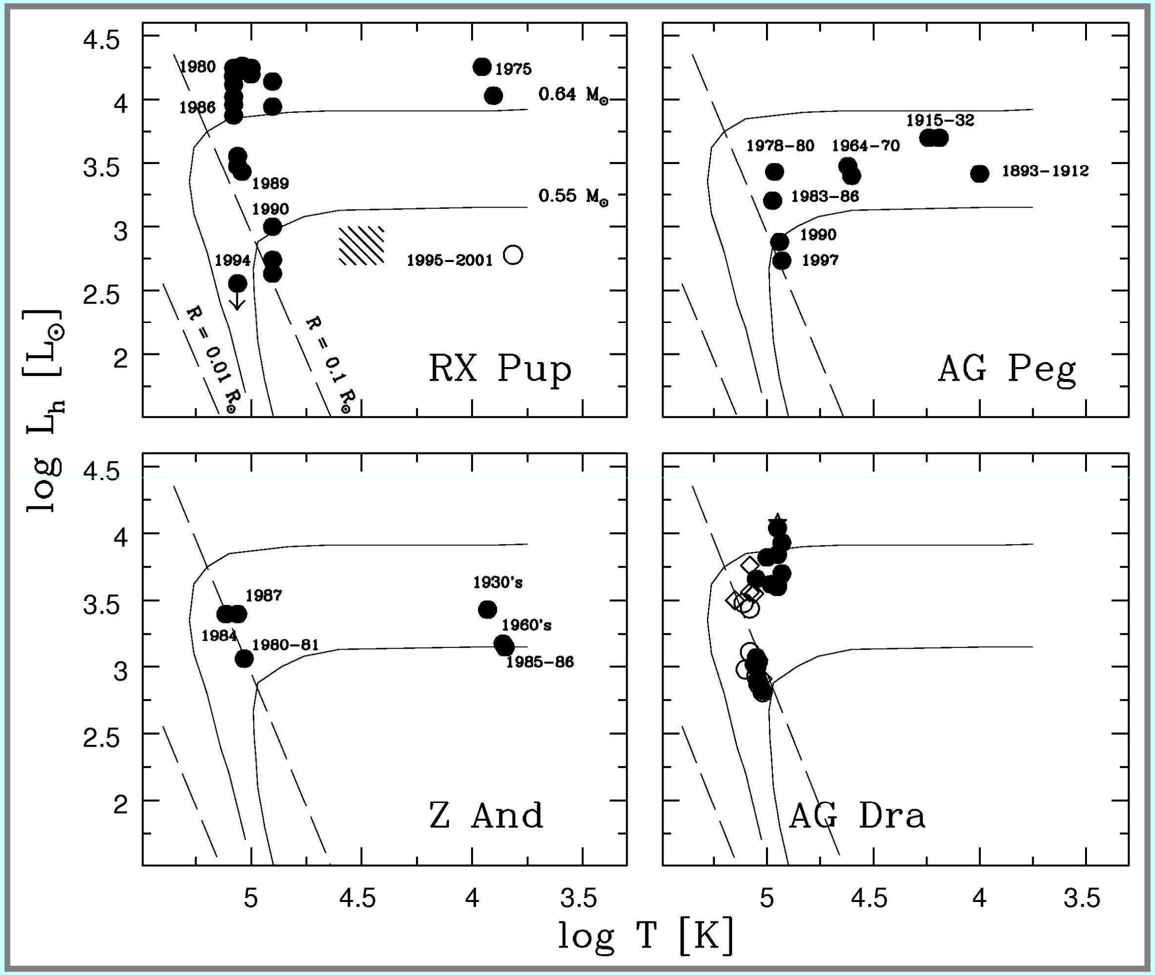
The hot component



•HCs cluster around the M-L relations for stars leaving the AGB with a CO core and the RG with a He core

•Symbiotic WDs could still be hot at the onset of the mass transfer from the cool giant

The hot component



Outbursts:

•Symbiotic novae (AG Peg, RX Pup + 6); both S- and D-type

•Stable (RW Hya, SY Mus) – must accrete ~10^{-8} M_{sun}/yr

or

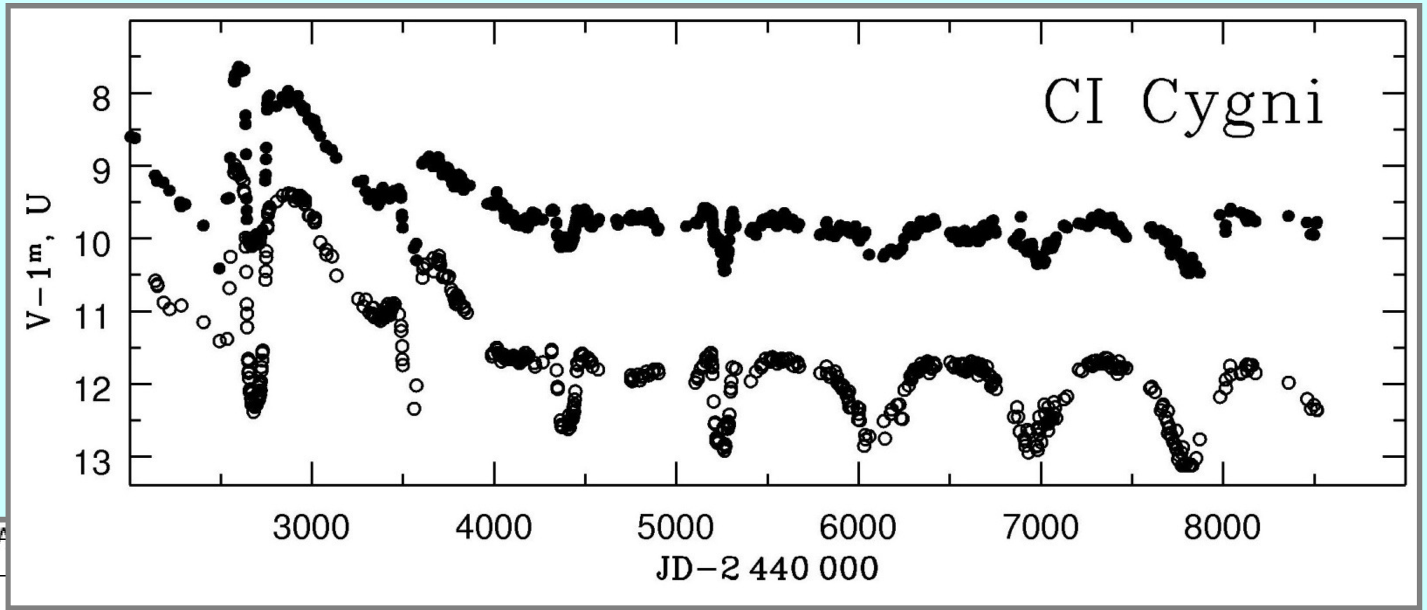
extremely slow symbiotic novae:

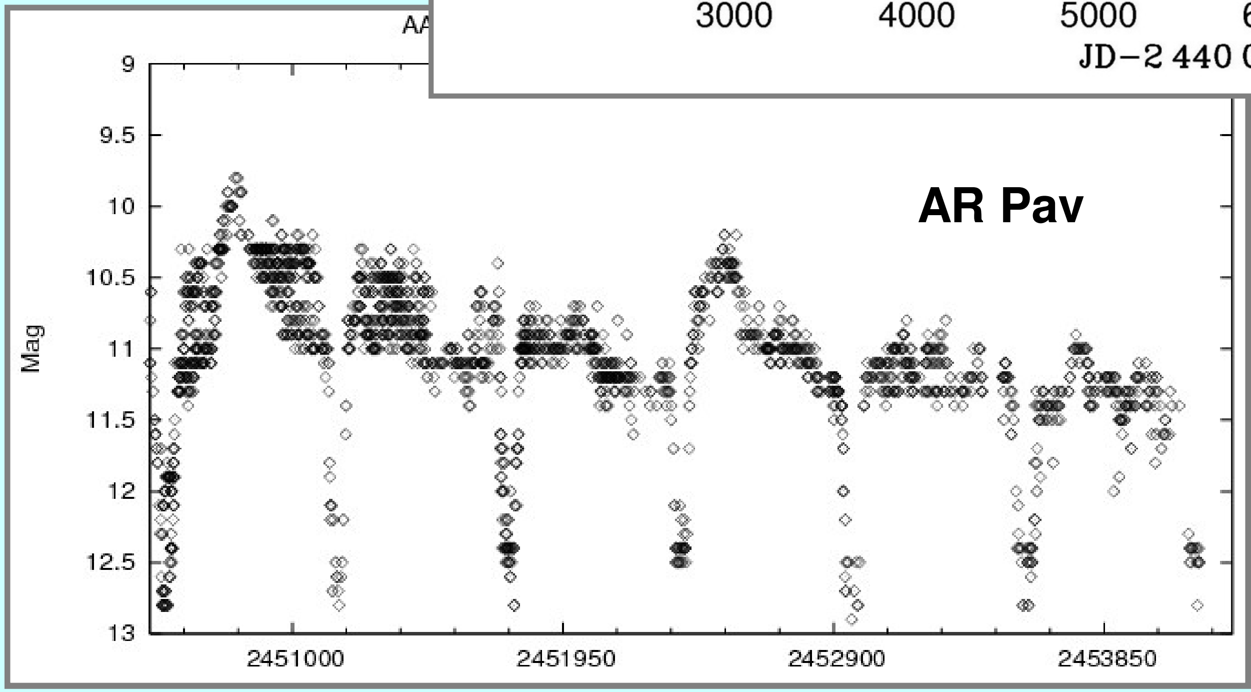
both S- and D-type majority?

•Multiple outbursts Z And-type:

only S-type how many?

Multiple outburst Z And-type activity





Multiple outburst Z And-type activity

• Timescales ~ a few yr, optical amplitudes ~1-3 mag, τ_{rec}>10 yr

• L_{out} ~ L_{quiet} within a factor of 2-3

• Ellipsoidal, H/R < 0.5, B/A/F continuum source during outburst tracing the hot componet orbit

• Narrow eclipses during outburst and sinusoidal changes at quiescence

• Double-T structure: UV/optical emission lines require a much hotter source with same L as the B/A/F continuum

• Moving humps/secondary periodicity ~10-15% shorter than P_{orb} visible in the optical and near-IR

Can be explained by combination-nova scenario: accretion disc instability on more or less stably burning WD

(JMik 2001; 2002; Sokolski et al. 2005)

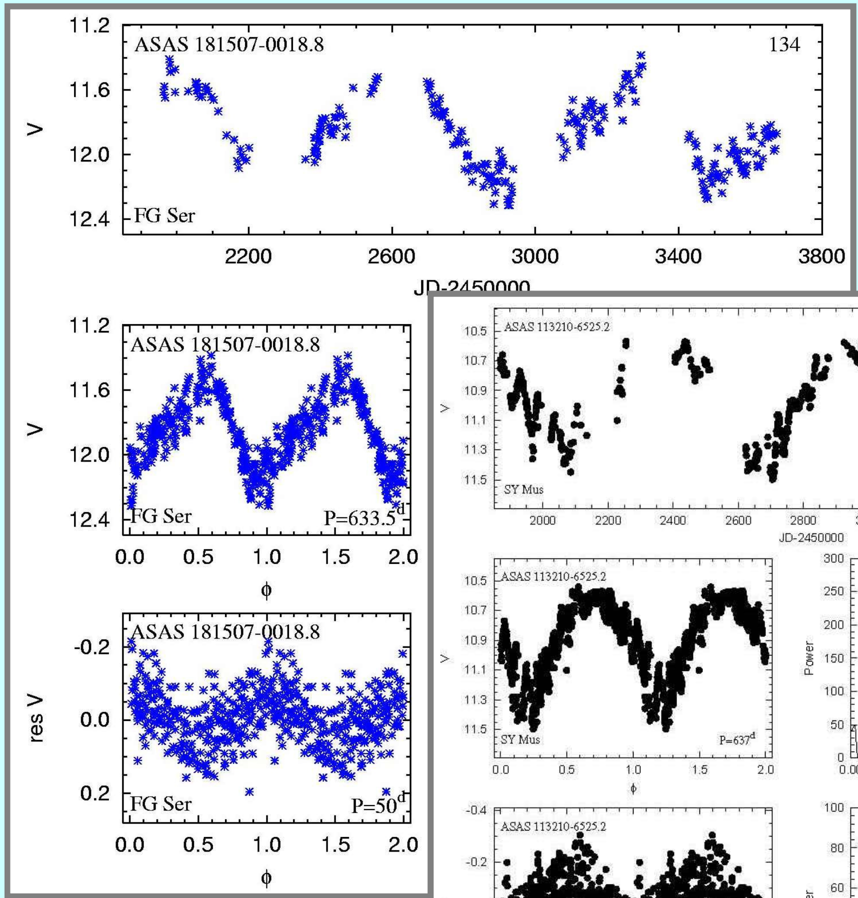
The link between the SyRNe & Z And-type symbiotics

- **Both the activity of Z And-type SyS and the high & low states of SyRNe due to unstable disc-accretion onto WD**
- **The WDs in Z And-type SyS burn the accreted hydrogen more or less stably wheras in SyRNe they don’t**

To power the hot component

relatively high,
$>\sim 10^{-8}$ M_{sun}/yr, accretion rate
required

The cool giant



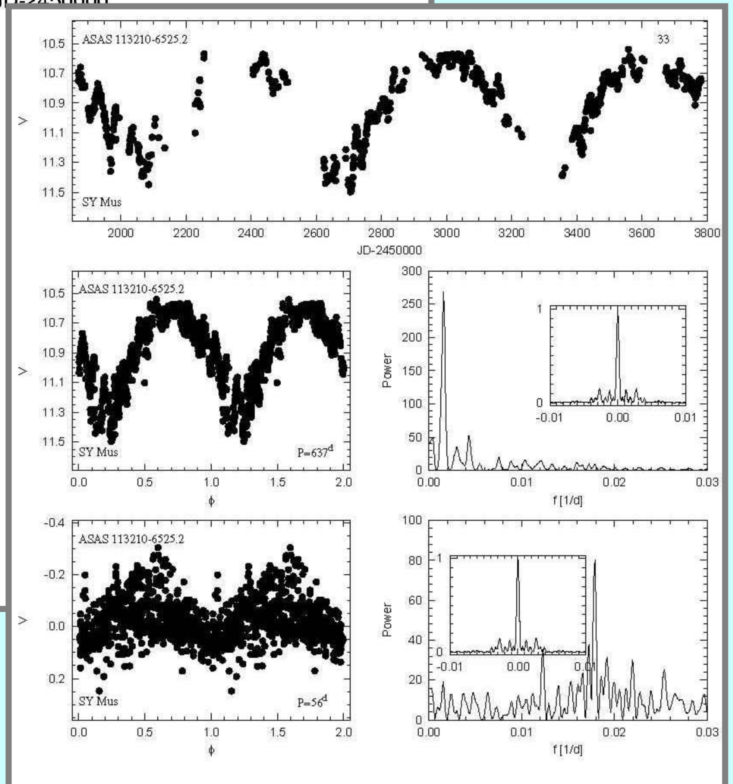


Figure 6: Light curves of .

S-types:

Sp types M3-M6, with a peak at M5

Most contain SRb variables & thus may have mass loss rates ~a few 10^{-7} M_{sun}/yr (Gromadzki et al. 2007)

Mass transfer in S-type symbiotics:

via stellar wind?

YES because:

Sp types, *v*sin*i* indicate R_g ~0.4-0.5 R_{RL}
no evidence for ellipsoidal variability,

(e.g.Nussbaumer & Co, Zamanov et. al.)

Red giant radii & rotation

50 SyS – $v_{rot,g}$ sin *i*

(Fekel et al. 2003, 2007, 2008; Zamanov et al. 2006; Hinkle et al. 2007)

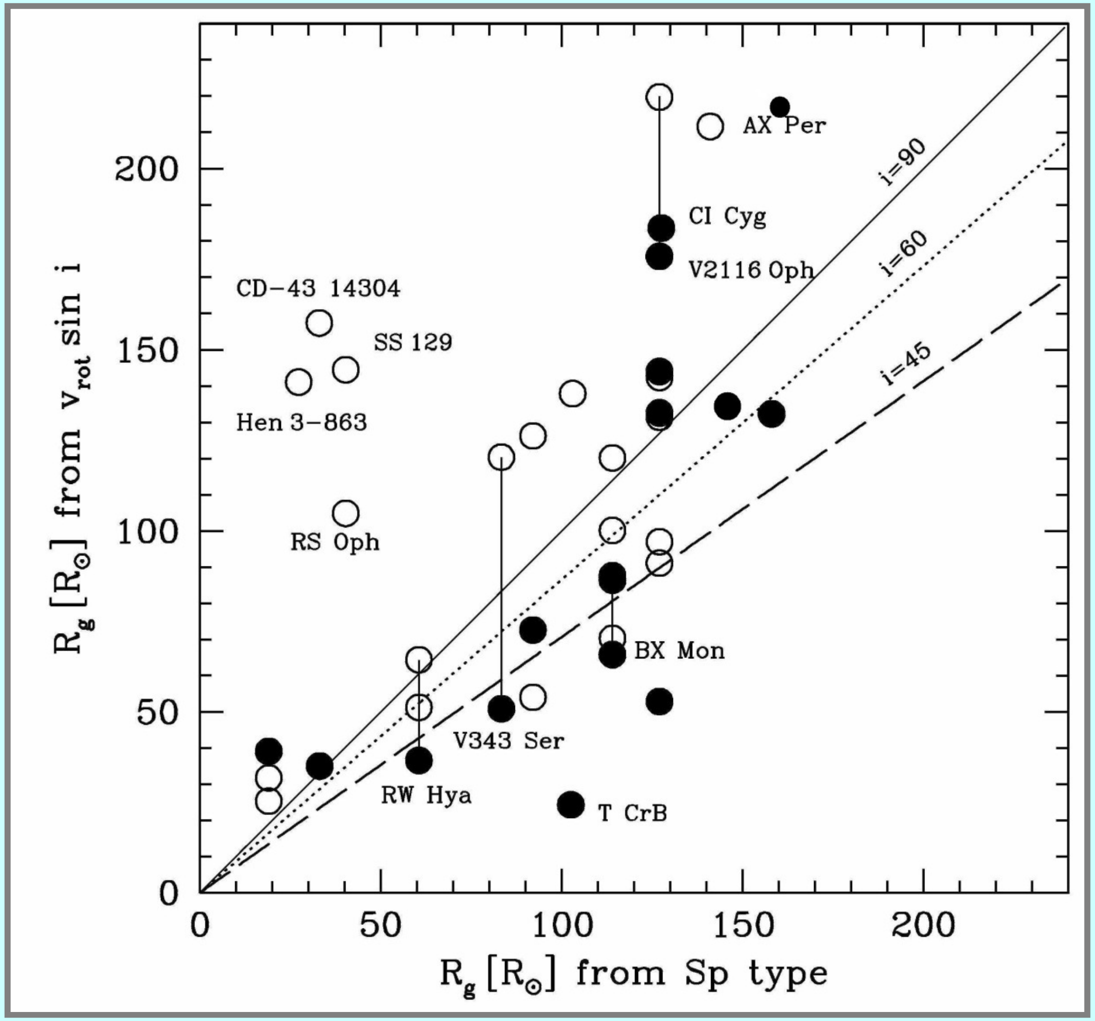
33 SyS – also P_{orb}

Are the giants synchronized?

Yes if P_{orb} < 1000d

$\tau_{synch} <\sim 10^4$ yr for M4 III and $P_{orb} <\sim 1000$ d

Red giant radii & synchronization



Generally the radii derived from v*sin*i agree with the radii predicted by Sp type R_g~0.4-0.5 R_{RL}

but

in some SyS they are larger although consistent with R_g~R_{RL}

RS Oph: symbiotic recurrent nowa

4 *Brandi, Quiroga, Ferrer, Mikołajewska and García*

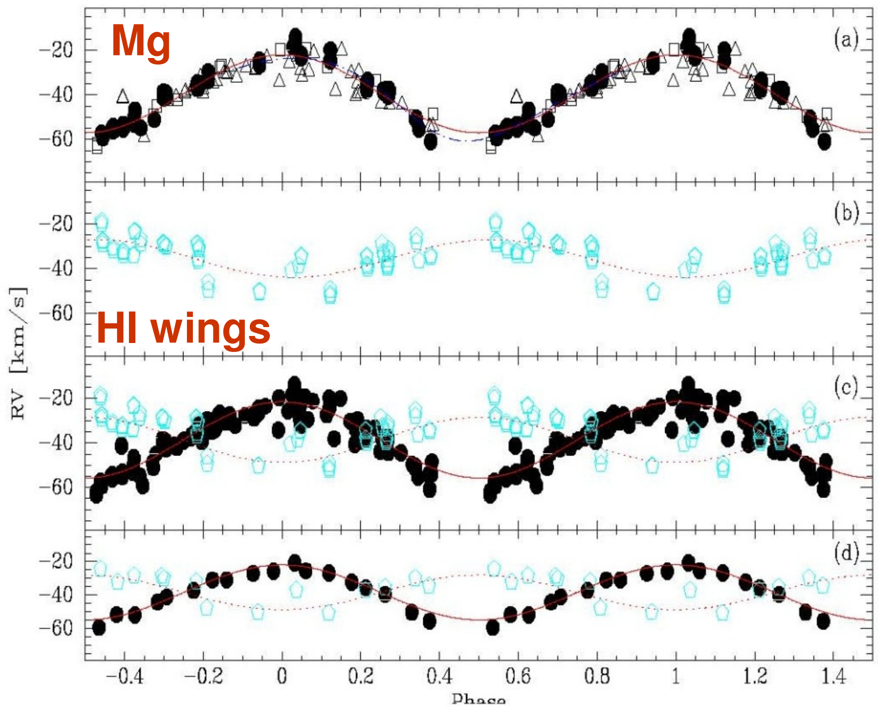


Figure 1. Radial velocity curves and orbital solutions for RS Oph. The data are phased with the period of 453.6 days and $T_0 = 2445156.94 \pm 5$ (the time of the maximum positive velocity of the M giant). (a) M-giant. Filled circles represent our data and open triangles and squares, the DK's and Fekel's data, respectively. Solid line gives the best circular fit and dash-dot line gives the eccentric orbit (e=0.14). (b) The Hα wings (hereafter open symbols) and the best circulat solution (red dot line). (c) Combined circular solution for the M-giant (hereafter filled circles) and the Hα wings. (d) The same with binned data.

Brandi et al. 2008 (ASPC 401); 2009 (A&A, in press):

q=Mg/Mh=0.59+/- 0.05

a sin i = 240 Rsun

Mg $\sin^3 i$ = 0.35 Msun

Mh $\sin^3 i$ = 0.59 Msun

Mh $\lesssim$ 1.4 Msun ⇨ i $\gtrsim$ 49°

$K_g/v_g \sin i$ ⇨ $q_{min} \sim 0.7$ ⇨ RLOF?

then: d~3 kpc

Whereas other estimates (Barry et al. 2008): d~1.5 kpc

Mass transfer in S-type symbiotics:

via stellar wind?

YES because:

Sp types, *v*sin*i* indicate R_g ~0.4-0.5 R_{RL}
no evidence for ellipsoidal variability,

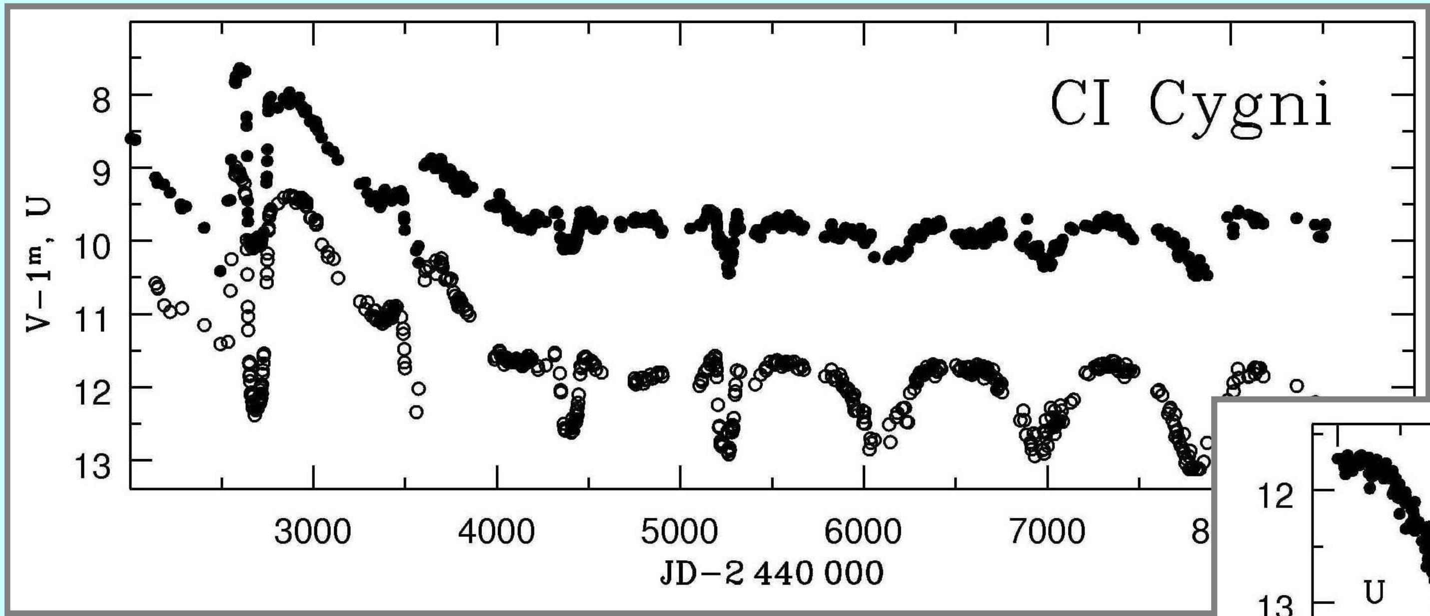
or

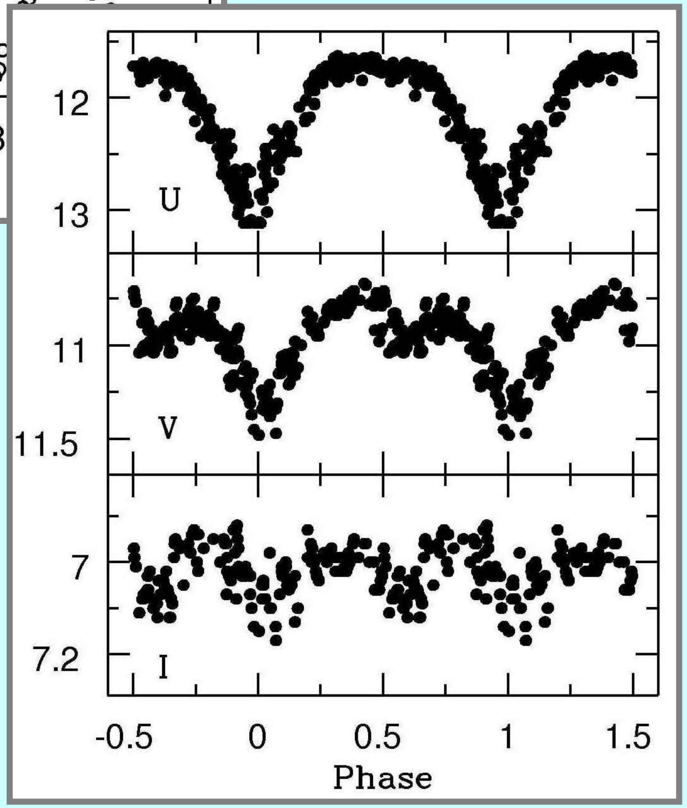
Roche lobe owerflow?

YES in multiple outburst systems (JMik et al. 2001; 2002, etc...)

need red/near-IR photometry at quiescence to see the ellipsoidal variability

Multiple outburst symbiotics





CI Cyg: quiescent LC (Mik 2001)

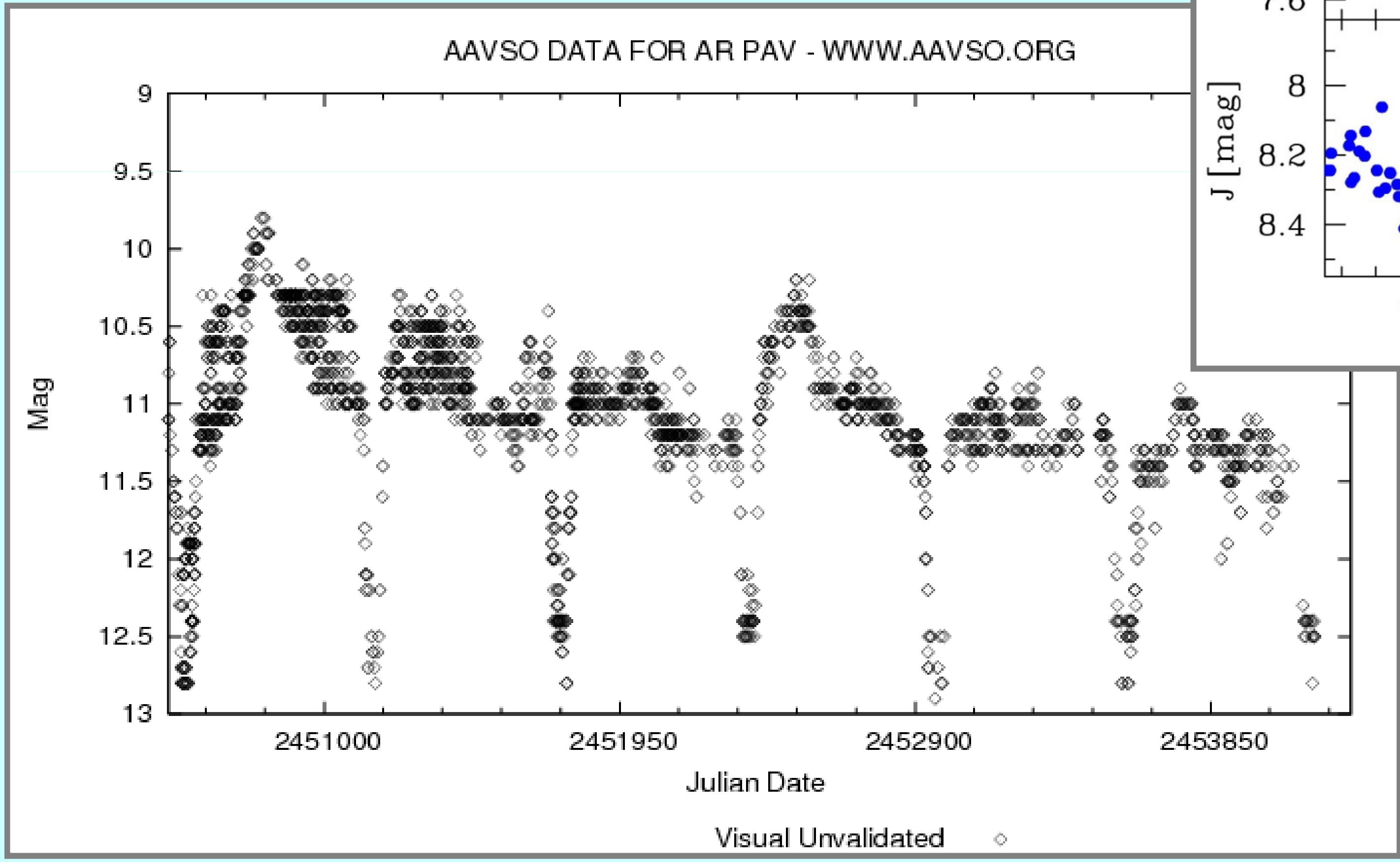
sinusoidal

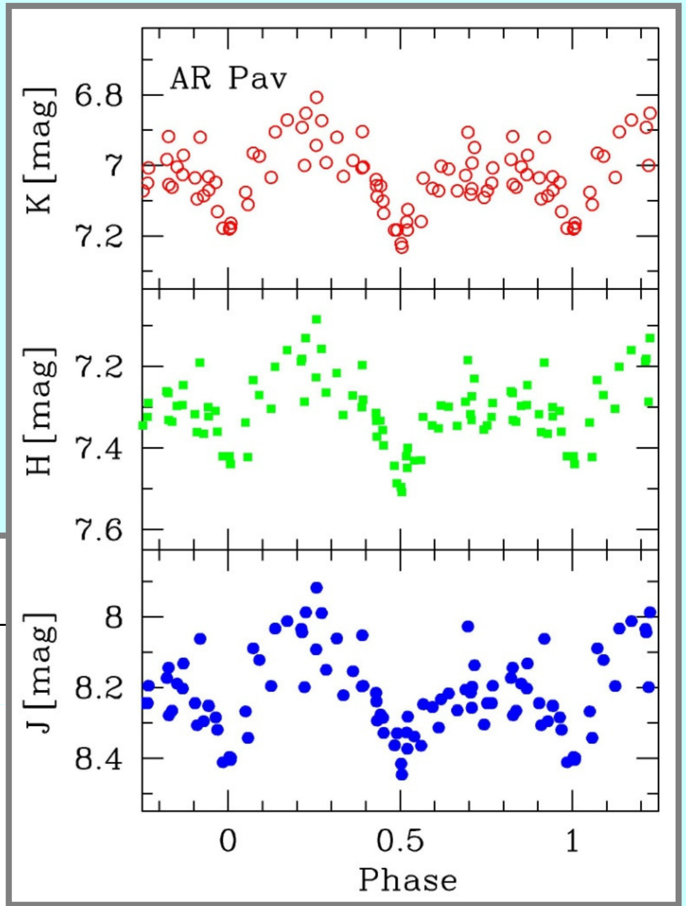
but

with P_{orb} in U & $P_{orb}/2$ in VRI...

AR Pav:

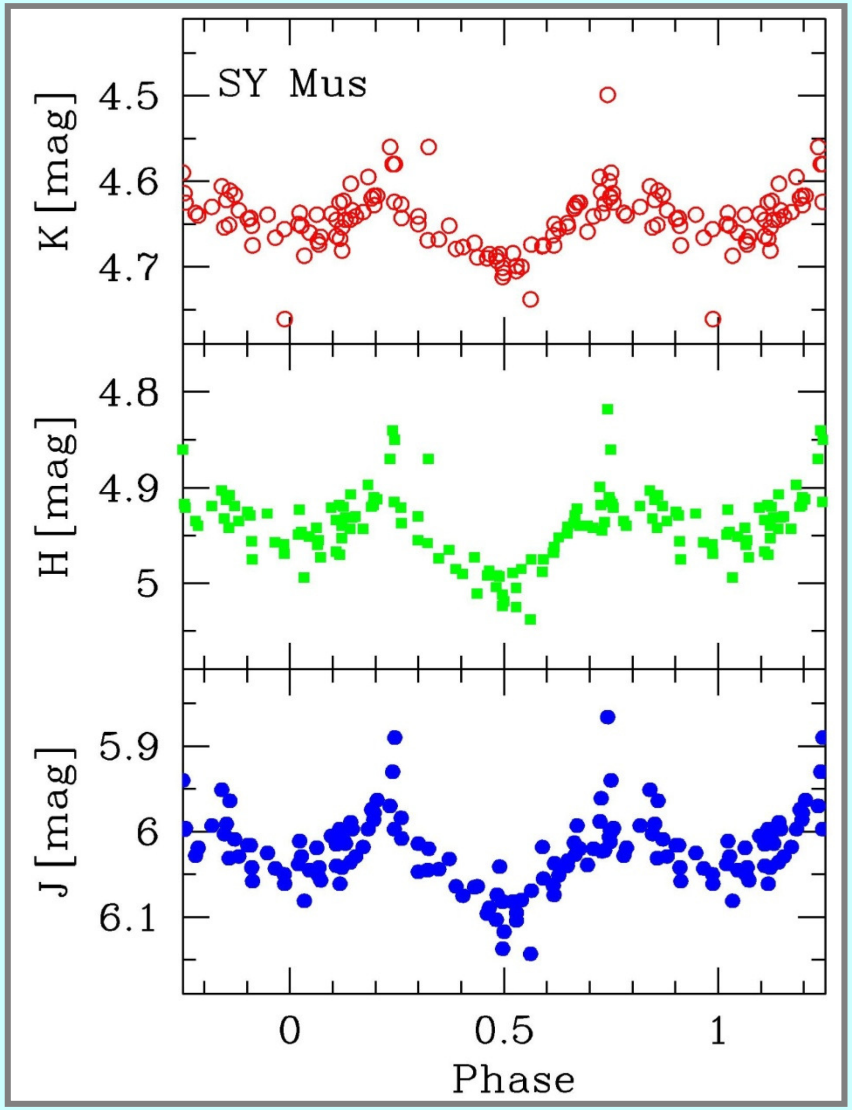
- A/F continuum most of time
- Secondary P, also visible in JHK ...

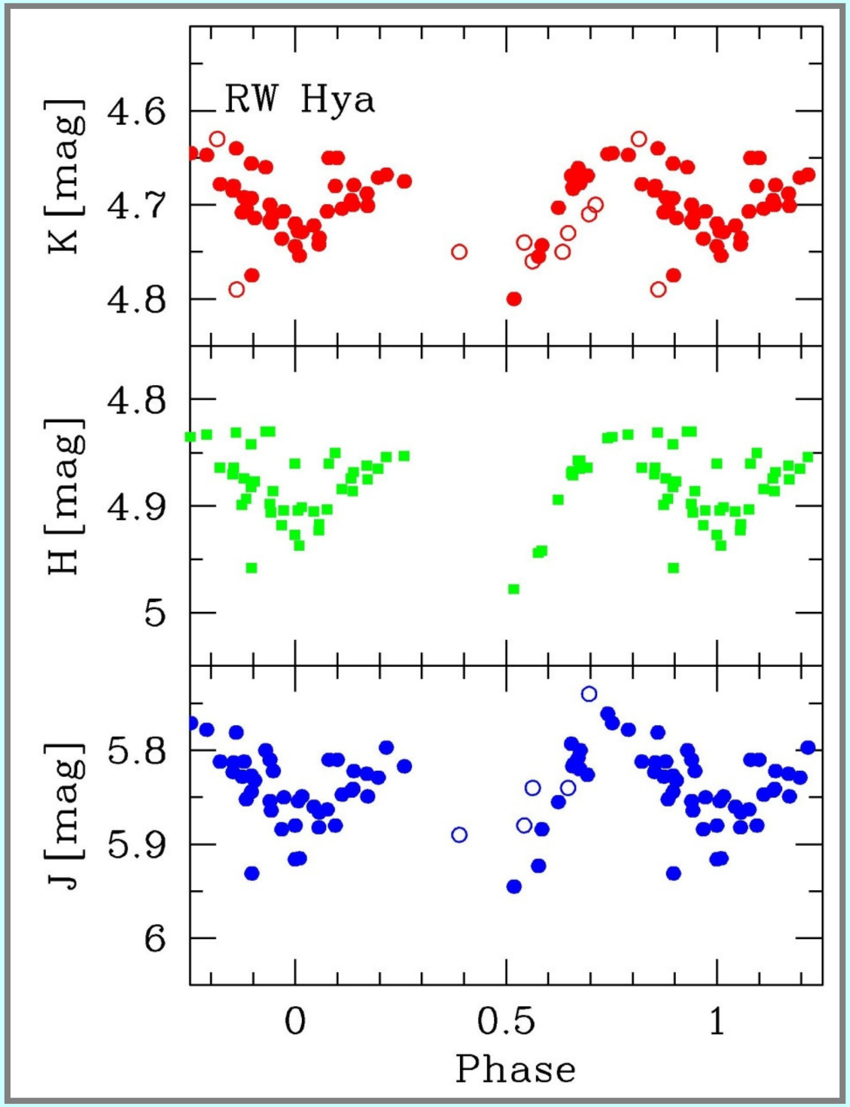




… and even my best examples of the stable SyS!!!

(Rutkowski et al. 2007)





Ellipsoidal variability in SyS:

- Absent in symbiotic novae (AG Peg)
- Present in *all* (i>60; LC available) multiple outburst SyS
  all have P_{orb} <1000^{d} and circular (e~0) orbits
- Present at least in some steady SyS (near-IR)
- Present in SyRN T CrB; need near-IR for RS Oph

Roche-lobe owerflow
can be quite common in S-type SyS

Stability of mass transfer in RL-filling SyS

Ellipsoidal variability requires RL-filling factor >~0.9

note that the photosperic R_g varies by ~2x with λ,

so WHICH R_g has to fill the RL?

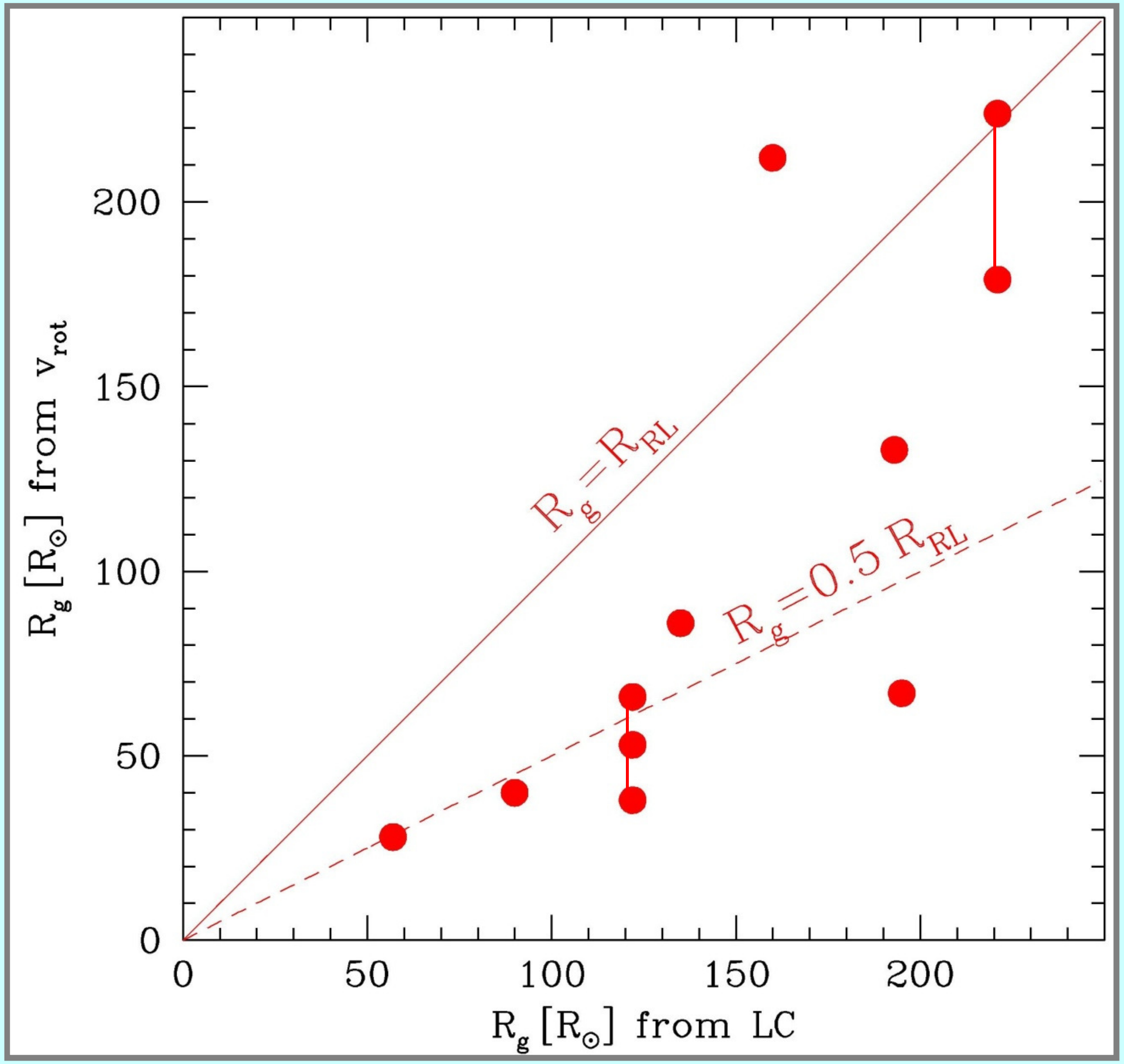
$q \sim 2\text{-}3 > q_{crit}$ in ALL SyS with ellipsoidal LCs

need a new mechanism stabilizing RLOF in SyS

No good solution thusfar proposed ☹

Promising wind-RLOF (Podsiadlowski & Mohamed 2007)

The RG radius – *v*sin*i* problem



What about the radius/v sin i ?

- Asynchronous rotation?

unlikely because of circular orbits

- RL shinkage (up to 2-3 times!) expected in luminous stars with strong winds if some force drives the mass loss & almost compensates the gravity (e.g. Schuerman 1972)

very promising in Sys with strong (10^{-7} M_{sun}/yr) and nearly constant speed winds

Conclusions:

Symbiotic binaries pose many challenges to binary evolution theory. In particular, understanding the mass transfer and accretion in these systems is not only essential for understanding their present status but also for estimating their rates

as well as

for ANY interacting binaries ivolving evolved giants (case C evolution)