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A second generation of planets in post-common-envelope systems?

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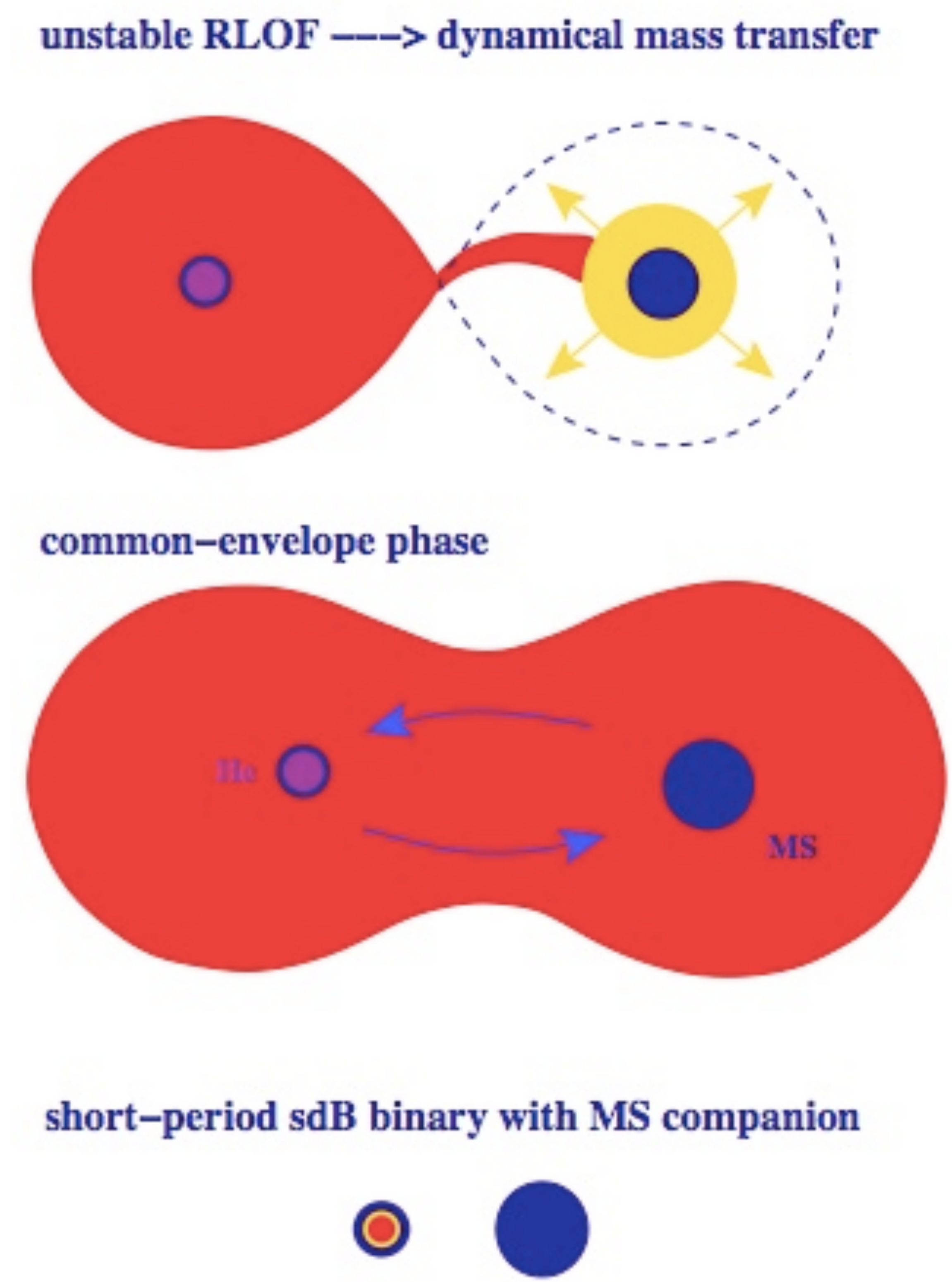
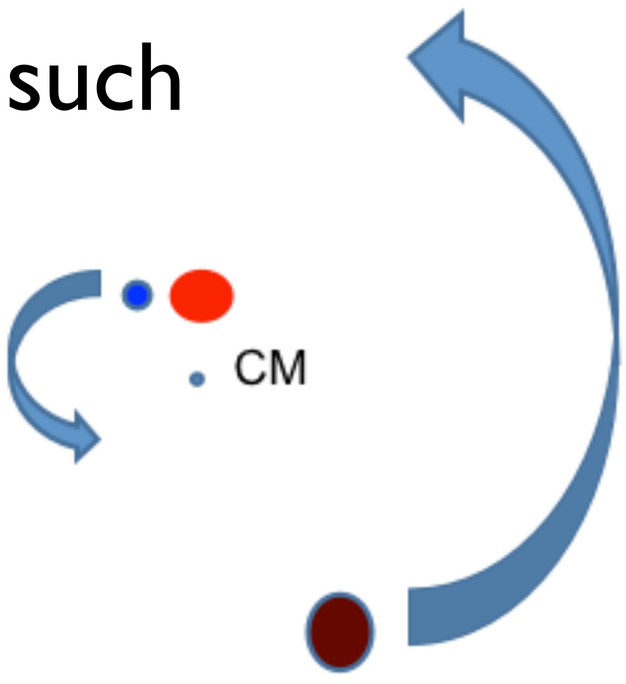
Formation of compact evolved binary systems

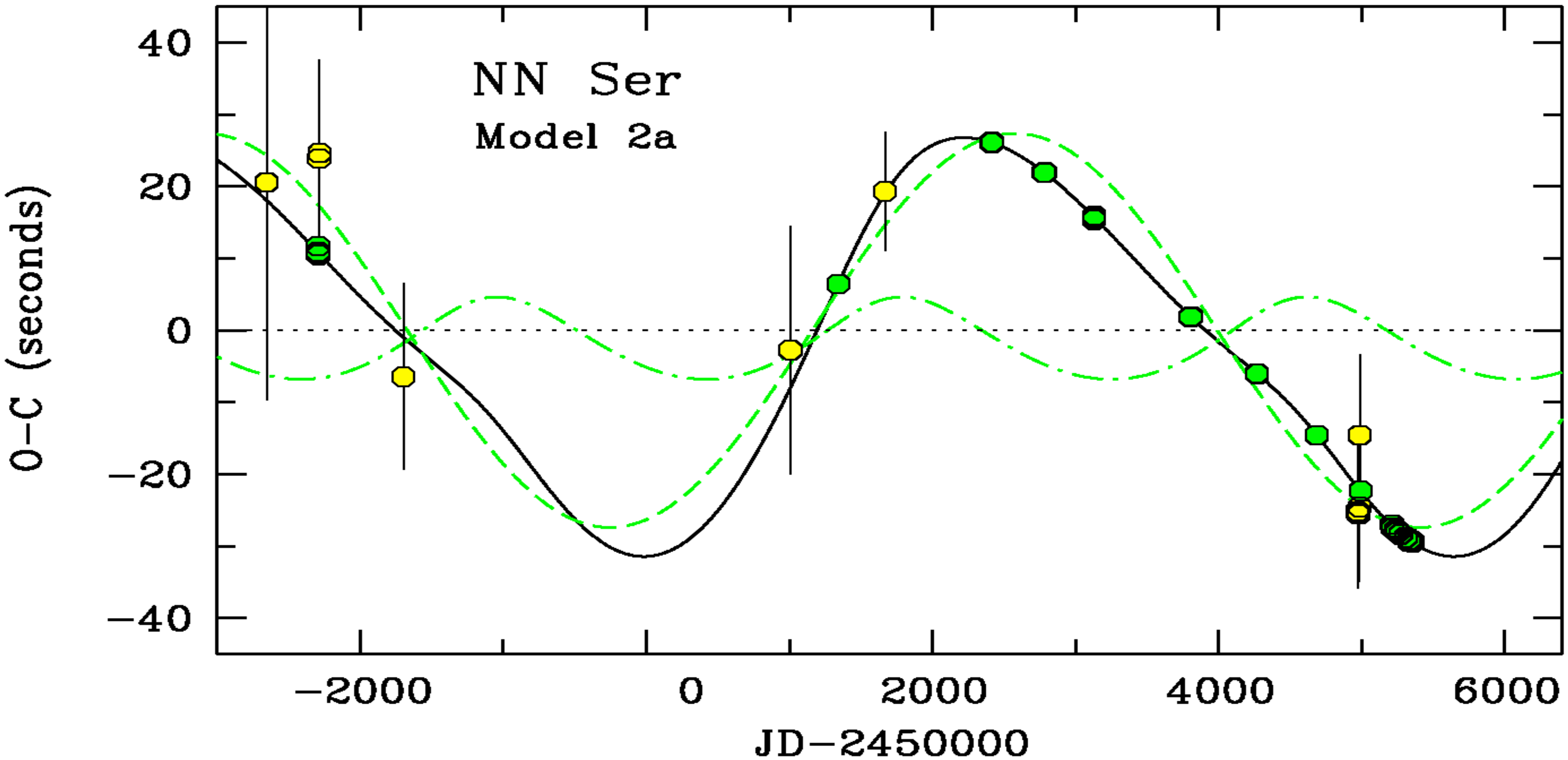


Planetary search through eclipsing time variations



- Eclipsing binaries are oriented to the observer such that both stars regularly overlap.
- The overlap leads to periodic variations in the observed magnitude.
- In the presence of a planet the center of mass shifts towards the planet.
- Depending on the properties of the planetary orbit, a second signal with the period of the planetary orbit is modulated onto the eclipses.

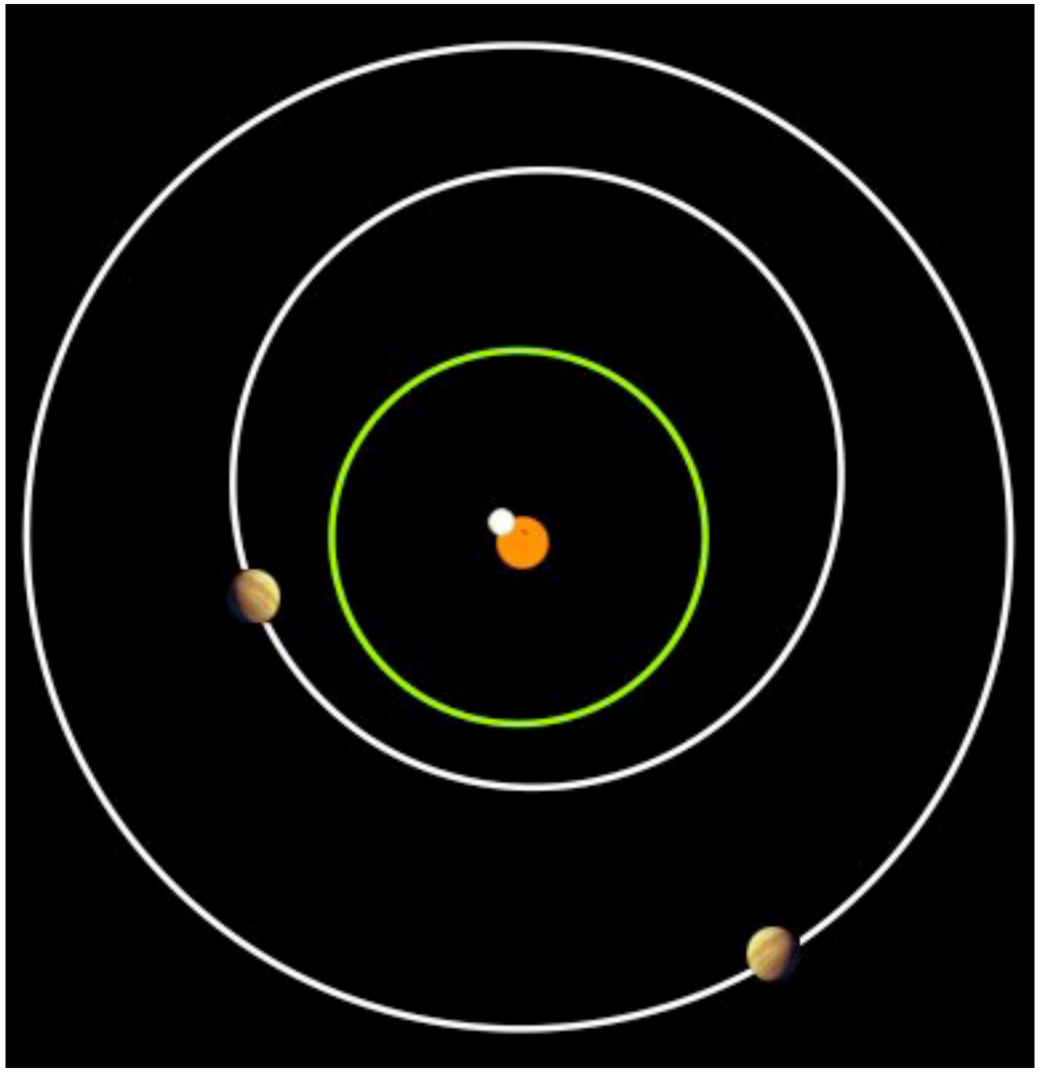
The observed signal in NN Ser



Beuermann et al. (2010, 2013)

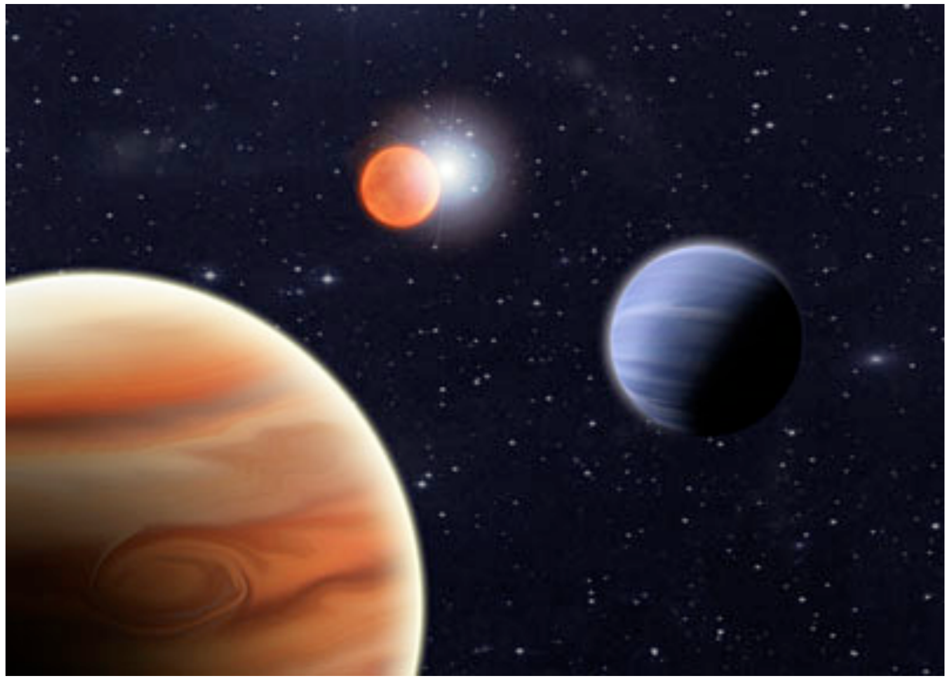
The planets in NN Serpentis

- Inner planet:
  1.7 Jupiter masses
  major axis: 3.4 AU
  orbital period: 7.7 years
- Outer planet:
  7.0 Jupiter masses
  major axis: 5.4 AU
  orbital period: 15.5 years
- moderate eccentricities



Beuermann et al. (2013)

First generation scenario



- The planets in NN Ser have orbits with major axes of 3.4-5.4 AU.
- Before the formation of the common envelope, the system is expected to have a size of about 1 AU.
- Stable orbits require a separation of 3-4 times the binary radius.
- The mass loss during the common envelope phase should increase the orbits by a factor of ~3.
- The orbits should thus be wider than observed!

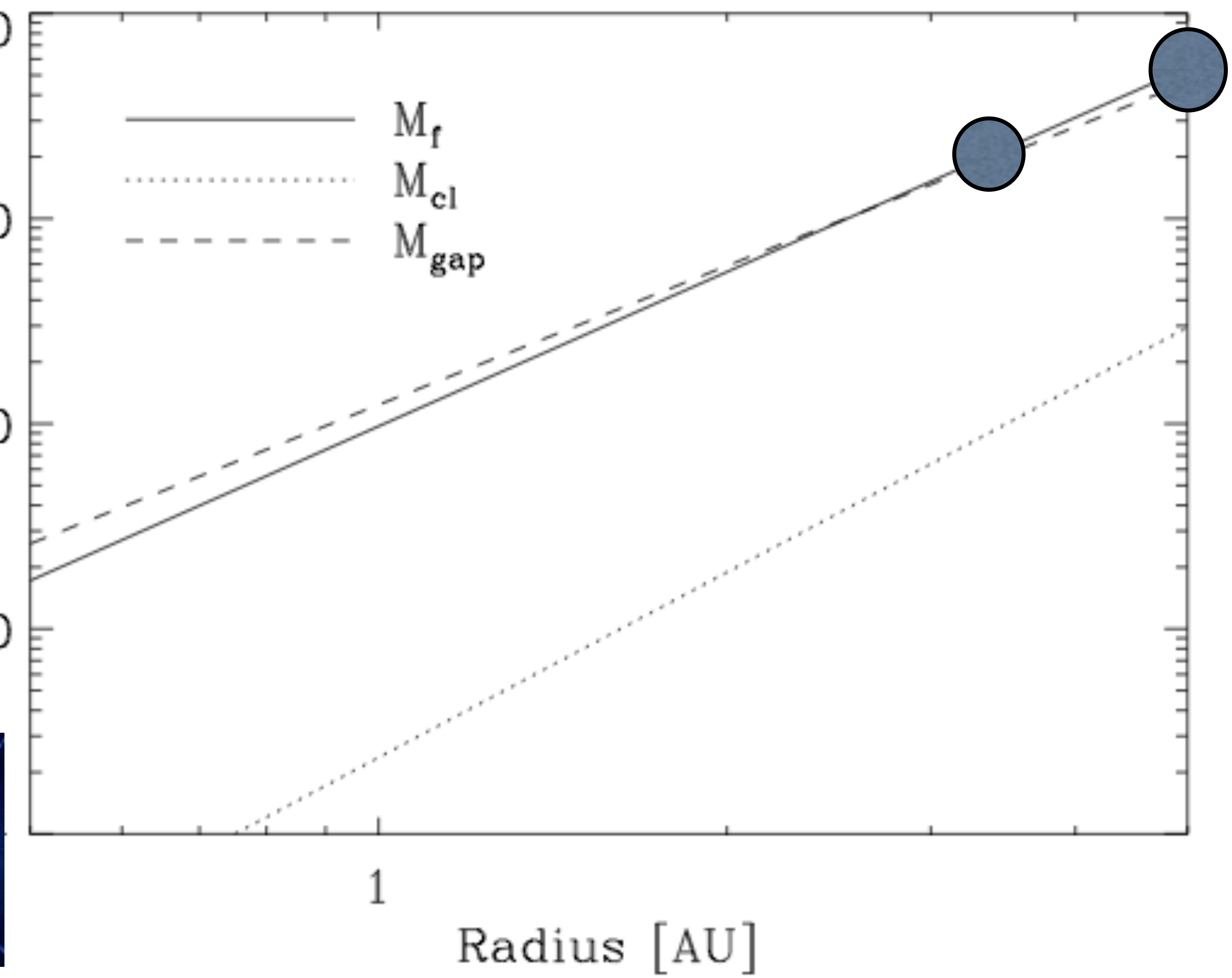
Völschow et al. (2014); see also Mustill et al. (2014)

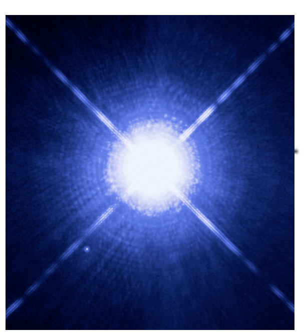
Second generation scenario

- Idea: Can planets form from the material which is ejected during the common-envelope phase?
- Approach:
  - Adopt Kashi & Soker (2011) model for CE phase; estimate of total ejected mass and ejected mass which remains bound to the system (~0.12 solar).
  - Apply model for self-gravitating disks assuming self-regulation (Toomre Q~1).
- Expected planetary masses consistent with observational results.

Schleicher & Dreizler (2015)

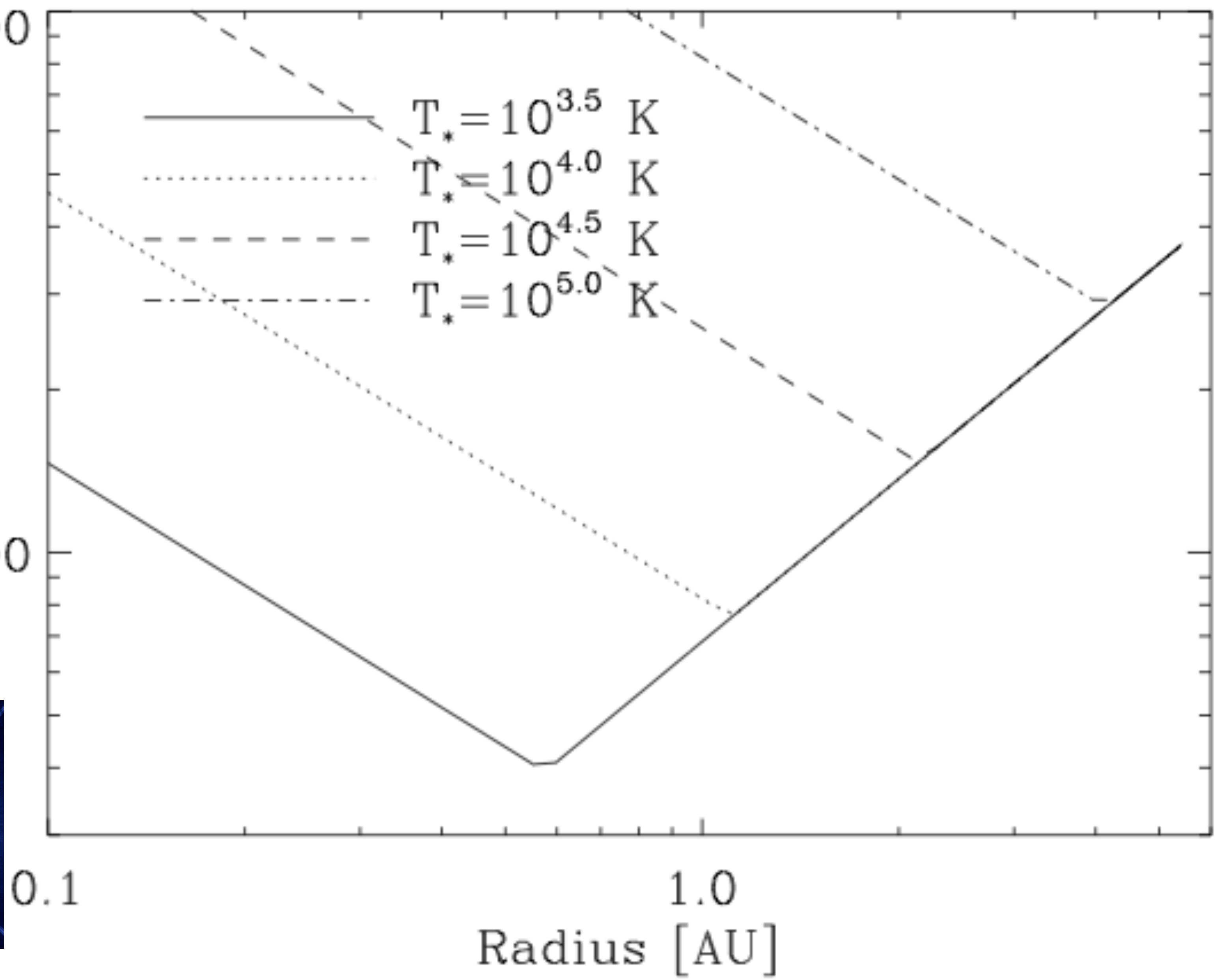
Expected planetary masses

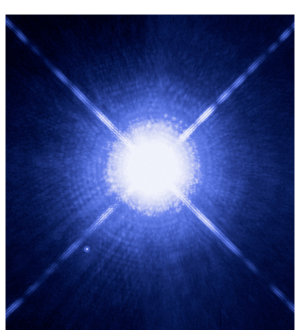




Schleicher & Dreizler (2014)

Stabilization in the interior by radiation feedback





Schleicher & Dreizler (2014)

Alternative interpretation: the Applegate mechanism

- The timescales of the planetary orbits are comparable to the timescales for the stellar dynamo.
- Idea: Can magnetic fields induce quasi-periodic changes in the stellar quadrupole moment, leading to the observed eclipsing time variations?
- Applegate (1992):
  Thin-shell model requires $\Delta Q = -\frac{\Delta P}{P} \cdot \frac{a_{bin}^2 M_{sec}}{9}$
- Change in angular momentum: $\Delta J = -\frac{GM^2}{R}\left(\frac{a}{R}\right)^2 \frac{\Delta P}{6\pi}$
- Energy to transfer the angular momentum:

$$\Delta E = \Omega_{\mathrm{dr}} \Delta J + \frac{(\Delta J)^2}{2 I_{\mathrm{eff}}}$$

Application to other systems

System	E_{sec}/erg	$\Delta E_{min}/E_{sec}$	$\Delta E/E_{sec}$	$\Delta E/E_{sec}$	$\Delta E/E_{sec}$	$\Delta E_{min}/E_{sec}$	δ_{min}
		Applegate (1992)	Tian et al. (2009)	This paper			
		(see eq. 5)	(see eq. 7)	Const.dens.	Two-zone	Full model	
HS 0705+6700	$2.2 \cdot 10^{39}$	7.2	7.3	3,300	138	140	0.731
HW Vir	$2.0 \cdot 10^{40}$	4.8	1.3	720	108	104	0.724
NN Ser	$2.7 \cdot 10^{39}$	3.2	3.3	1,100	64.0	64.0	0.732
NSVS14256825	$8.3 \cdot 10^{38}$	5.3	5.4	3,200	101	102	0.733
NY Vir	$1.4 \cdot 10^{39}$	58	56	2,800	-	1970	0.694
HU Aqr	$1.4 \cdot 10^{40}$	0.10	0.10	240	1.87	1.94	0.732
QS Vir	$3.0 \cdot 10^{40}$	0.039	0.040	170	0.708	0.77	0.775
RR Cae	$5.2 \cdot 10^{39}$	2.8	2.9	560	59.5	59.2	0.725
UZ For	$4.1 \cdot 10^{39}$	0.14	0.15	360	2.61	2.69	0.733
DP Leo	$2.9 \cdot 10^{39}$	0.021	0.021	150	0.378	0.383	0.736
V471 Tau	$2.0 \cdot 10^{42}$	0.014	0.014	12	0.263	0.258	0.84
RU Cnc	$1.4 \cdot 10^{43}$	0.074	0.076	1.7	-	-	-
AW Her	$8.5 \cdot 10^{42}$	608	618	270	-	-	-
HR 1099	$3.7 \cdot 10^{43}$	0.21	0.22	10	-	6.74	0.64
BX Dra	$3.5 \cdot 10^{43}$	0.00016	0.00016	0.92	0.00292	0.0565	0.52
SZ Psc	$9.9 \cdot 10^{43}$	0.12	0.13	4.7	-	4.84	0.61

Völschow, Schleicher, Perdelwitz & Banerjee, submitted

Summary

- The presence of planets has been proposed in post-common-envelop systems to explain the observed eclipsing time variations.
- The first generation scenario appears unlikely in NN Ser, as the previous orbits would have been unstable before the mass loss.
- A second generation scenario where planets form from the ejecta during the common envelope phase may naturally explain the mass scale of the planets.
- The main alternative is the Applegate mechanism, suggesting quasi-periodic changes in the quadrupole moment of the secondary as a result of magnetic activity.
- With the finite-shell model by Brinkworth et al. (2006), we have shown that the Applegate mechanism is clearly ruled out in the majority of observed systems.