Tatooine's Future

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NASA GSFC

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Technion University
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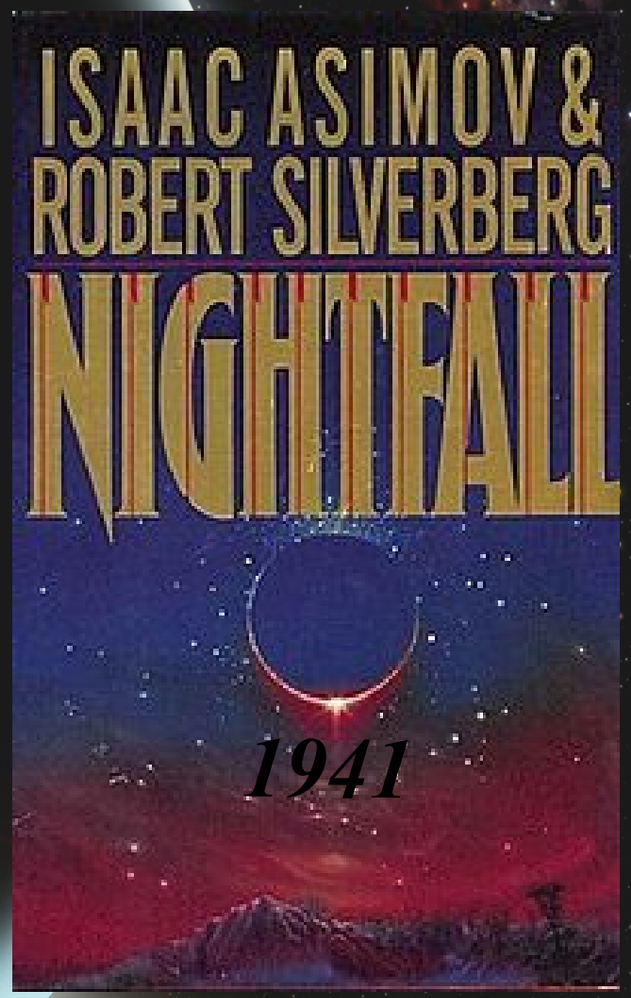
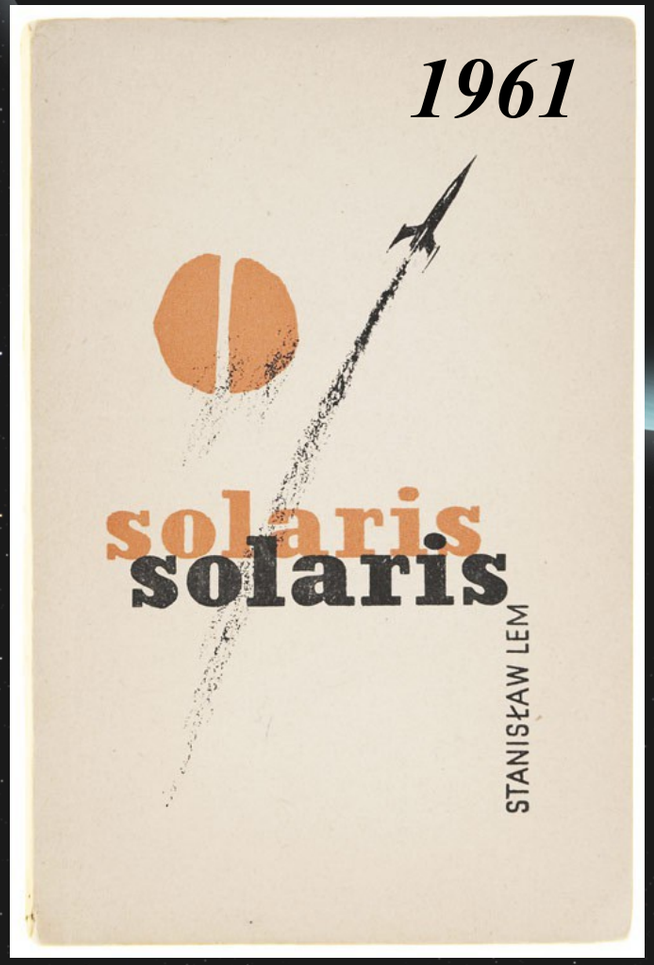
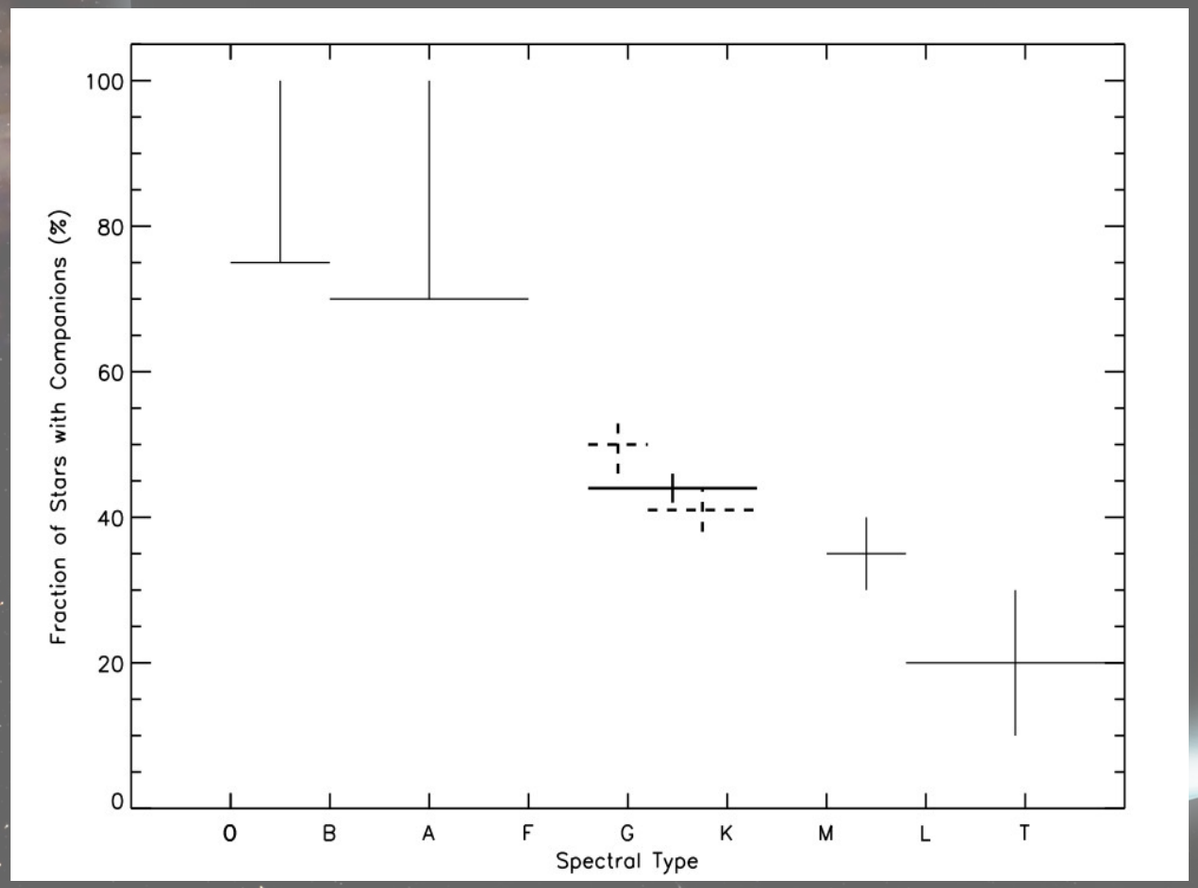
"Sur les autres mondes" Lucien Rudaux (1937)
INTERPRÉTATIONS D'EFFETS QUE POURRAIENT PRÉSENTER DES PAYSAGES A LA SURFACE DE PLANÈTES ÉCLAIRÉES PAR DEUX SOLEILS DIVERSEMENT COLORÉS.

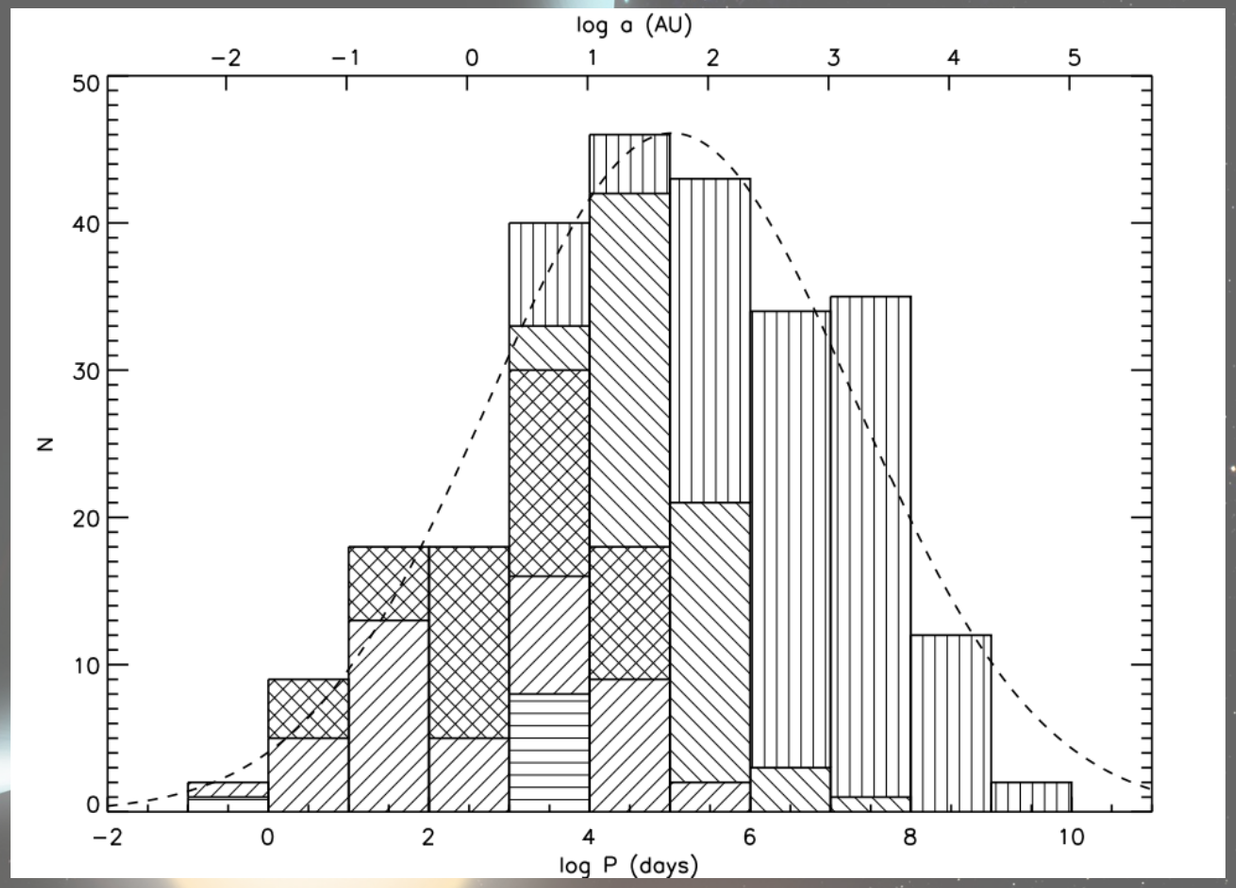

ISAAC ASIMOV &
ROBERT SILVERBERG
NIGHTFALL
1941


1961
solaris
solaris
STANISŁAW LEM


Star Wars (1977)

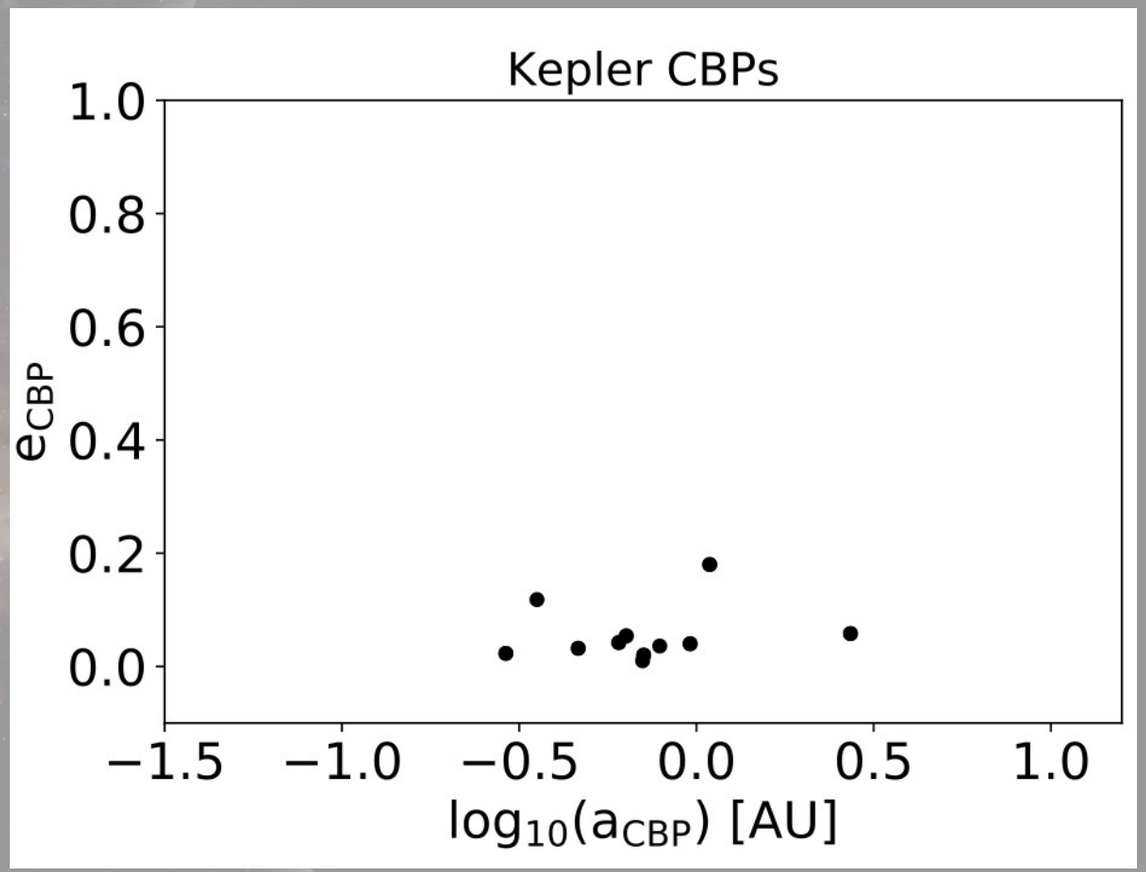
Stellar Multiplicity

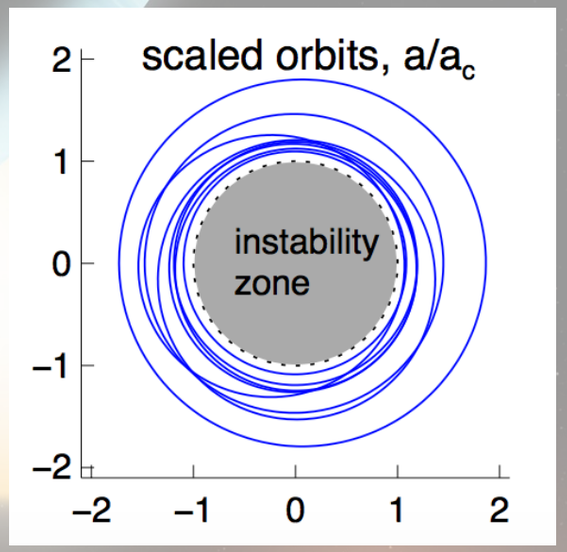




Raghavan et al. 2010

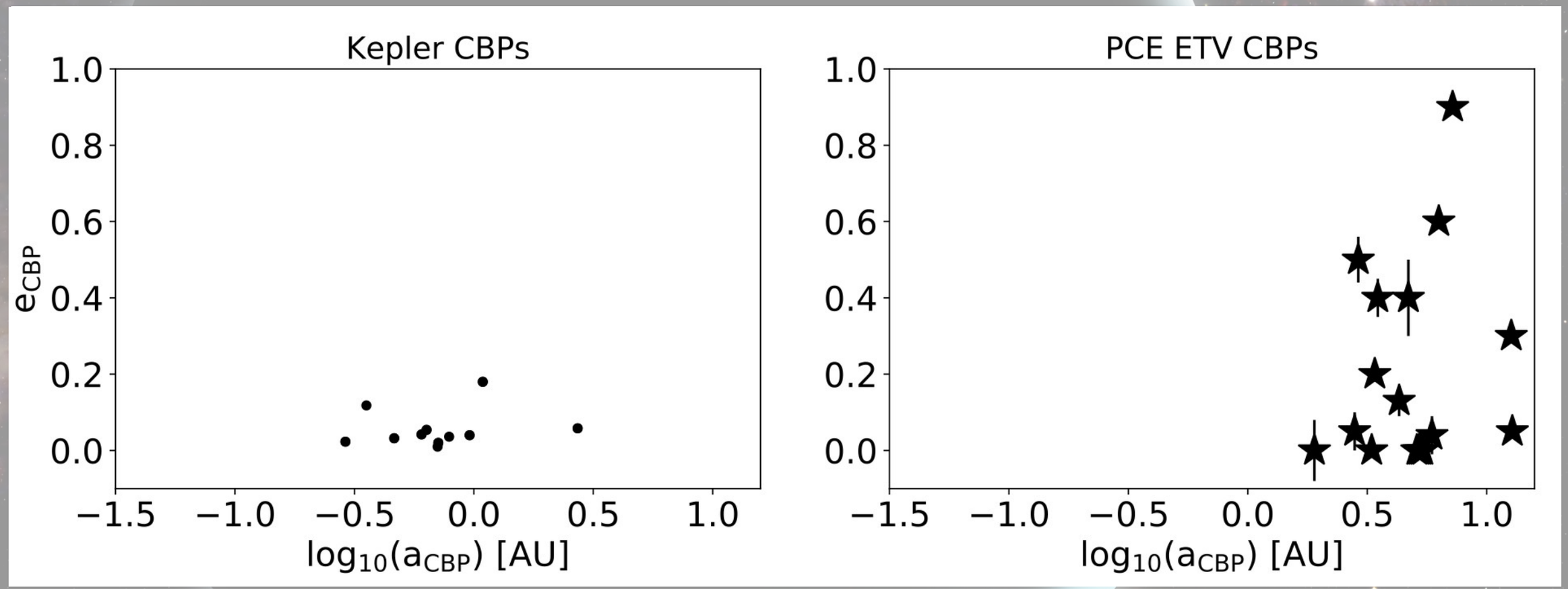
Known CBPs

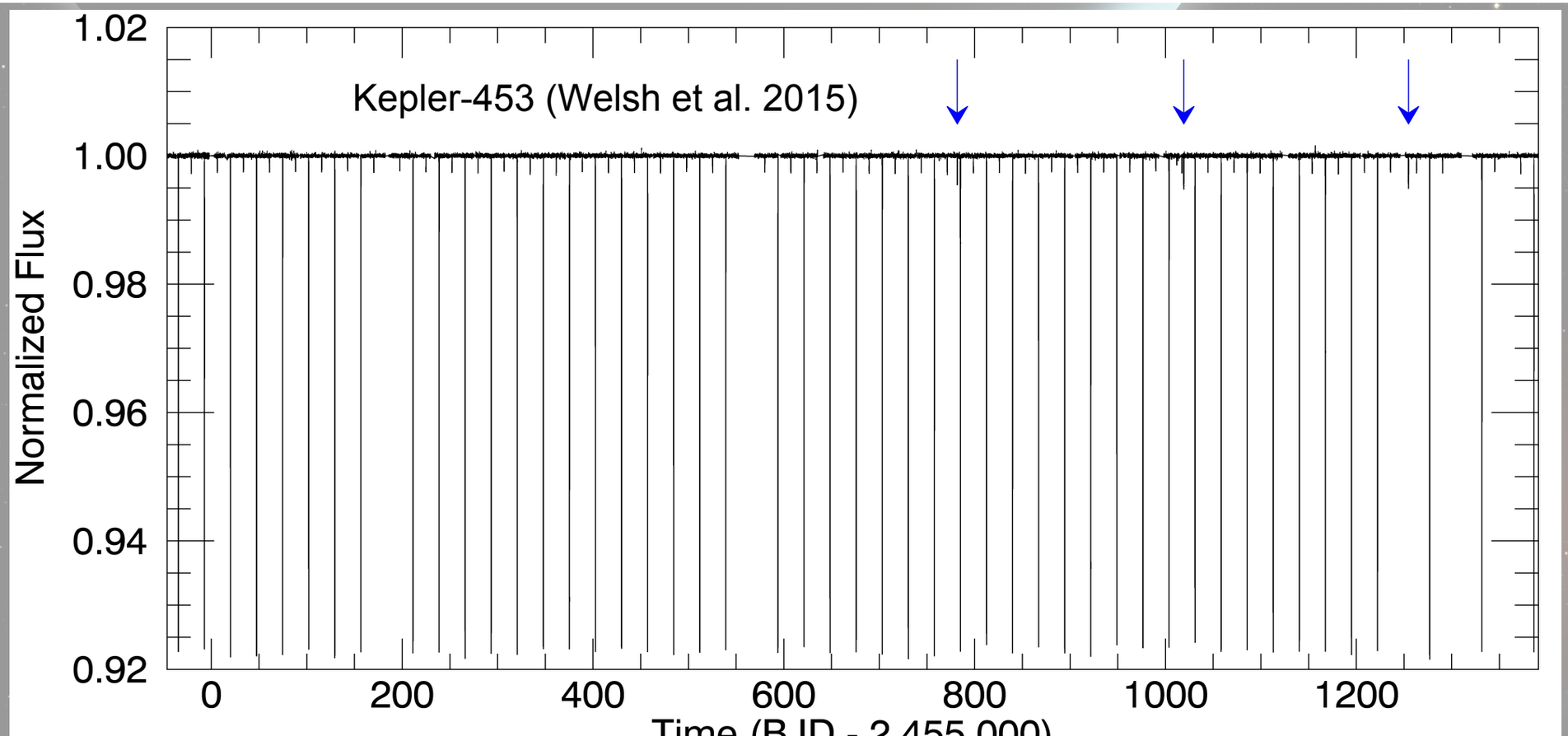




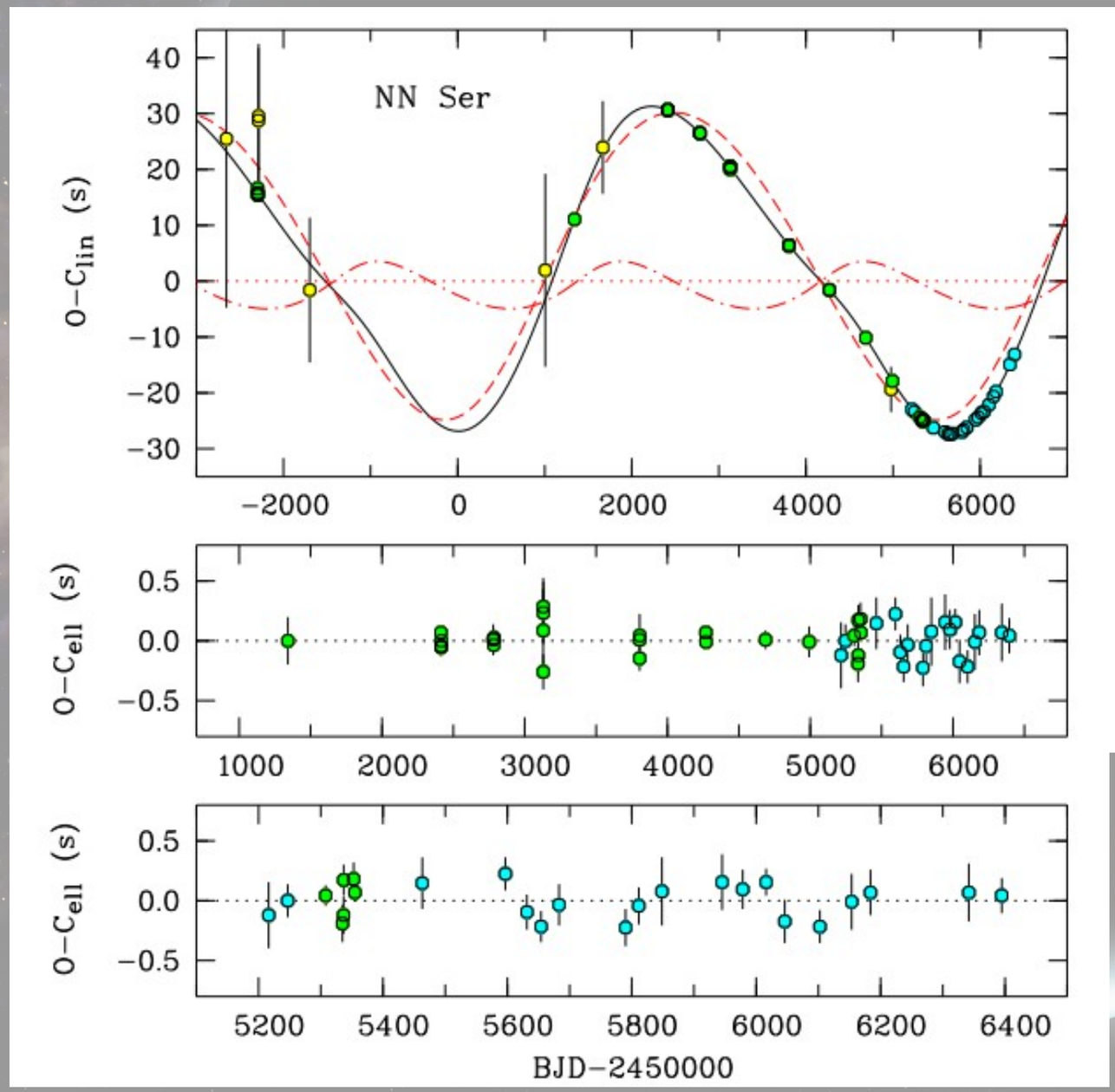
Winn & Fabrycky 2014

Known CBPs

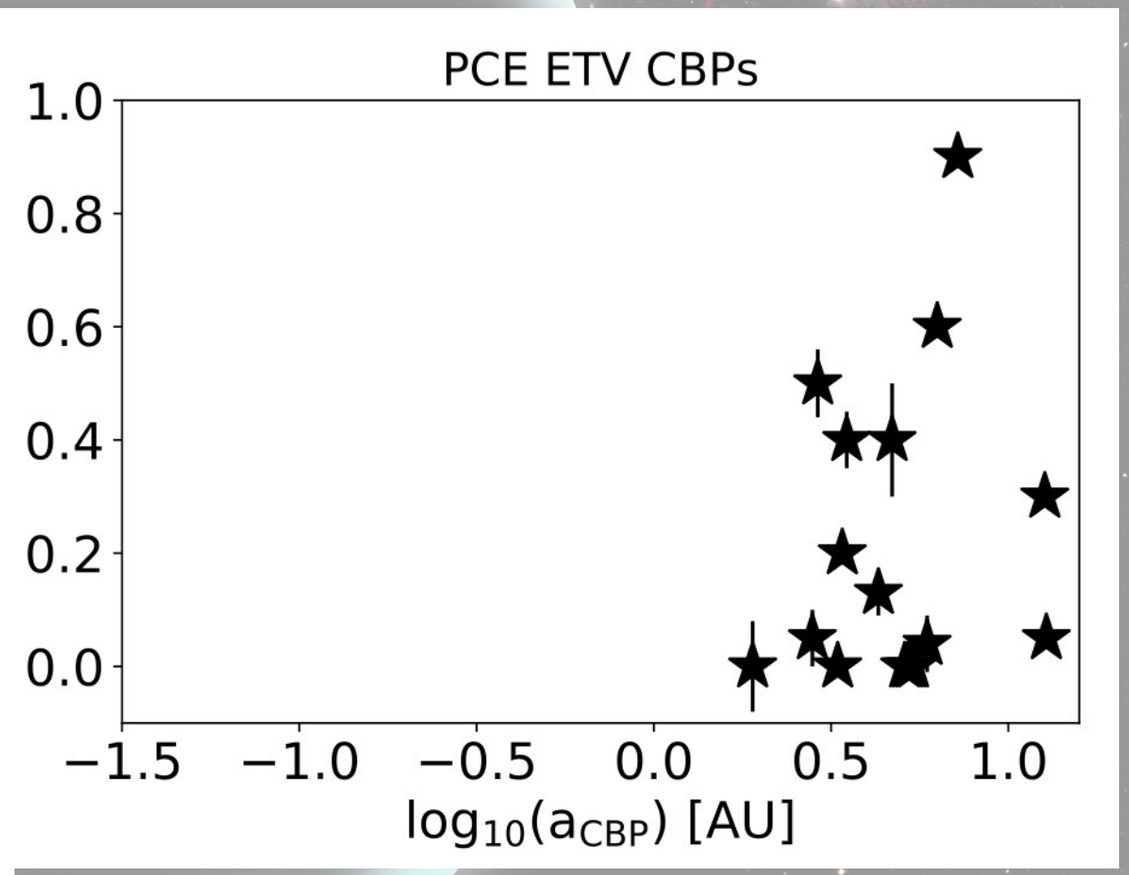

Kepler CBPs
PCE ETV CBPs
e_{CBP}
$\log_{10}(a_{CBP})$ [AU]
1.0
0.8
0.6
0.4
0.2
0.0
−1.5
−1.0
−0.5
0.0
0.5
1.0


Kepler-453 (Welsh et al. 2015)
Normalized Flux
Time (BJD - 2,455,000)
1.02
1.00
0.98
0.96
0.94
0.92
0
200
400
600
800
1000
1200

Known CBPs

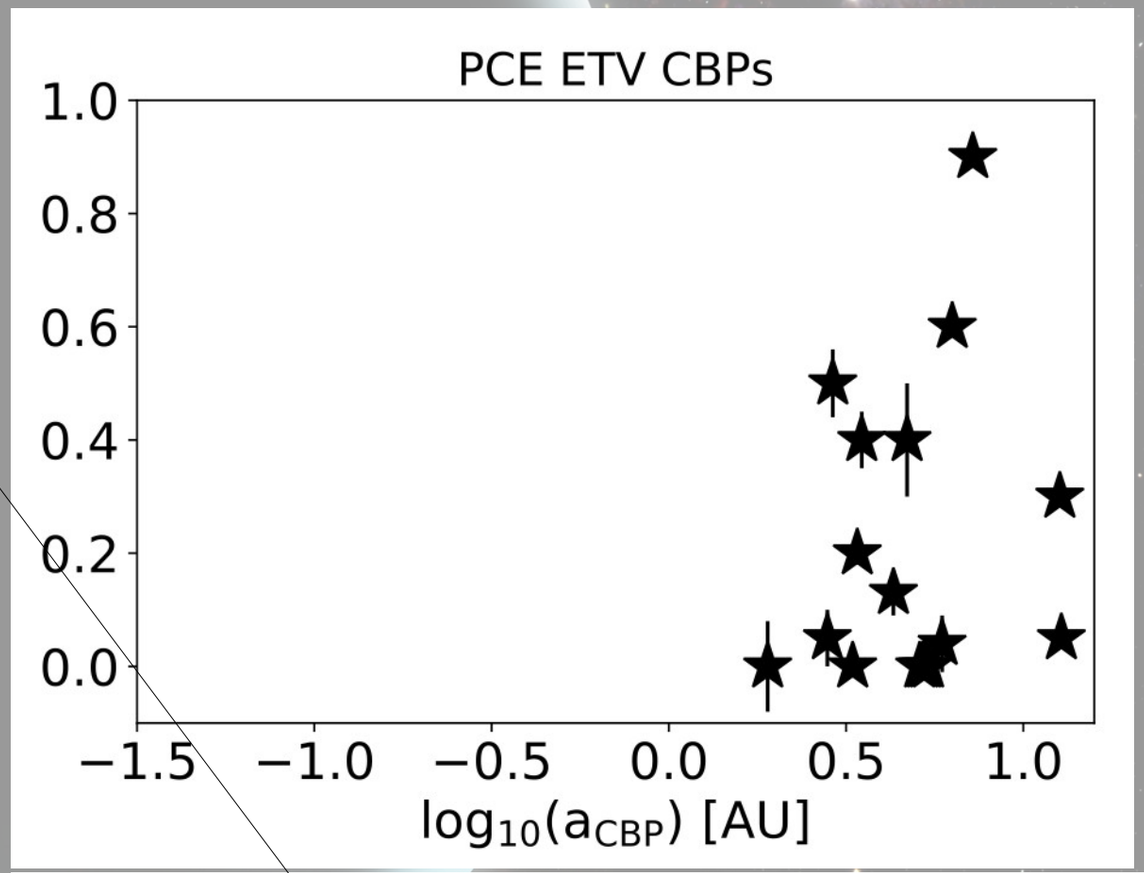


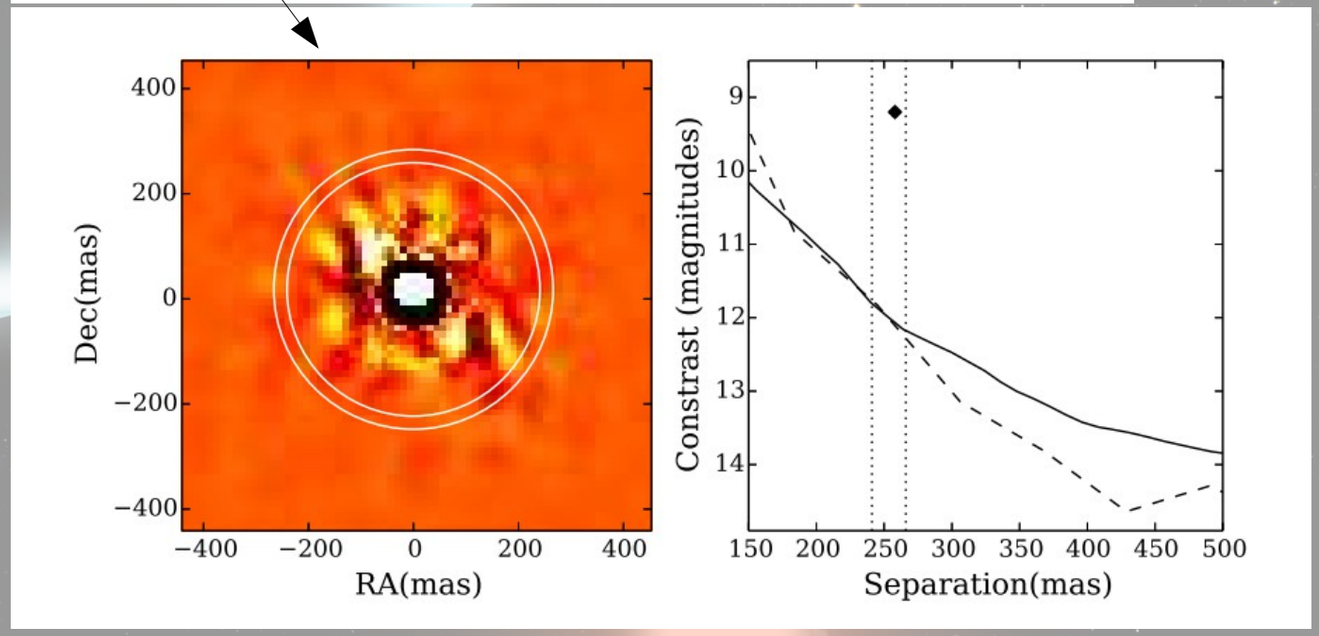
Beuermann et al. 2013



Known CBPs

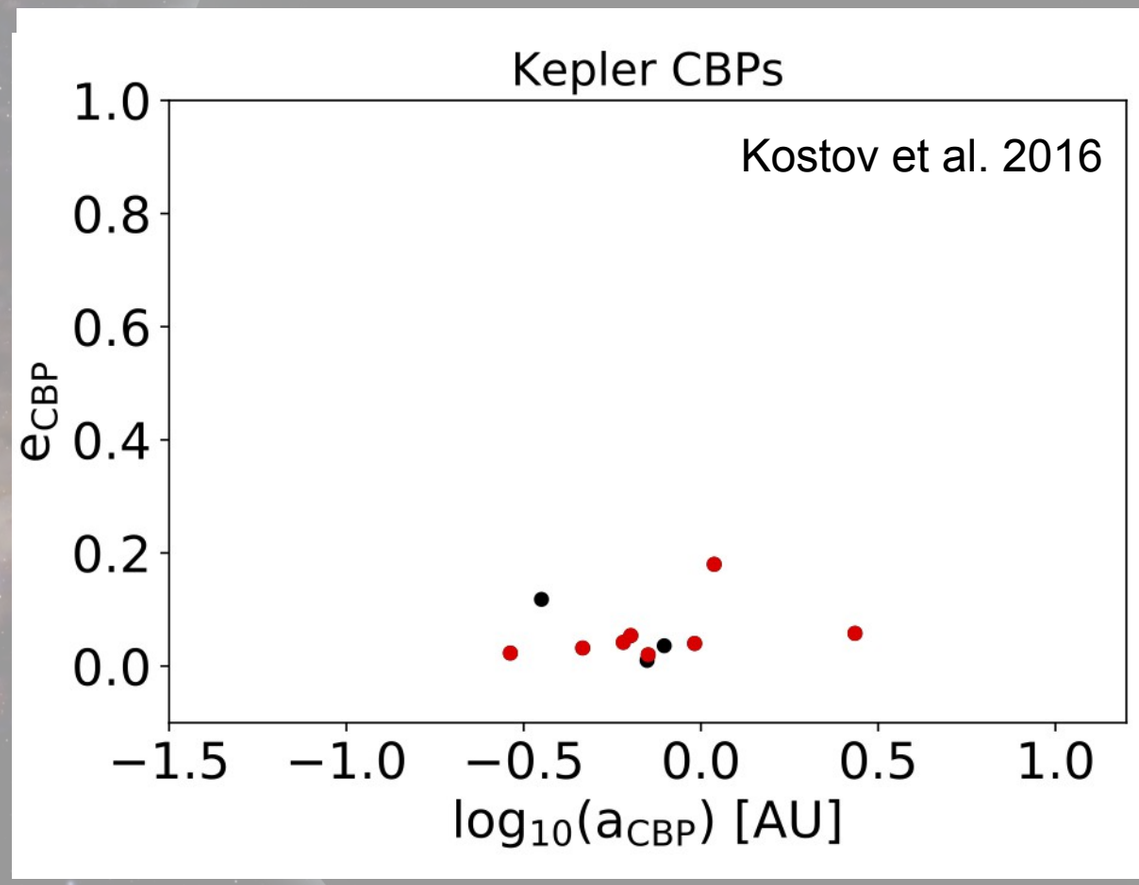
Target	Orbit [AU]	Mass [MJup]	
V 471 Tau	12	4.6 — 111	Timing, Imaging ??
SZ Her	17, 27	190, 220	Timing, Unstable
RZ Dra	24	70	Timing, Unstable
RR Cae	5	4	Timing
HW Vir	4.7, 13	14.3, 30 — 120	Timing, Unstable
NSVS 14256825	2, 2.9	2.8, 8	Timing, Unstable
HU Aqr	4	7	Timing, Unstable
HS 0705+6700	3.5	32	Timing
HS 2231+2441	5	14	Timing
UZ For	2.8, 6	7, 7.7	Timing
NY Vir	3.3, 5	2.3, 2.2	Timing
NN Ser	3.4, 5	2.3, 7	Timing
QS Vir	6, 7	9, 57	Timing, Unstable
DP Leo	8	6	Timing

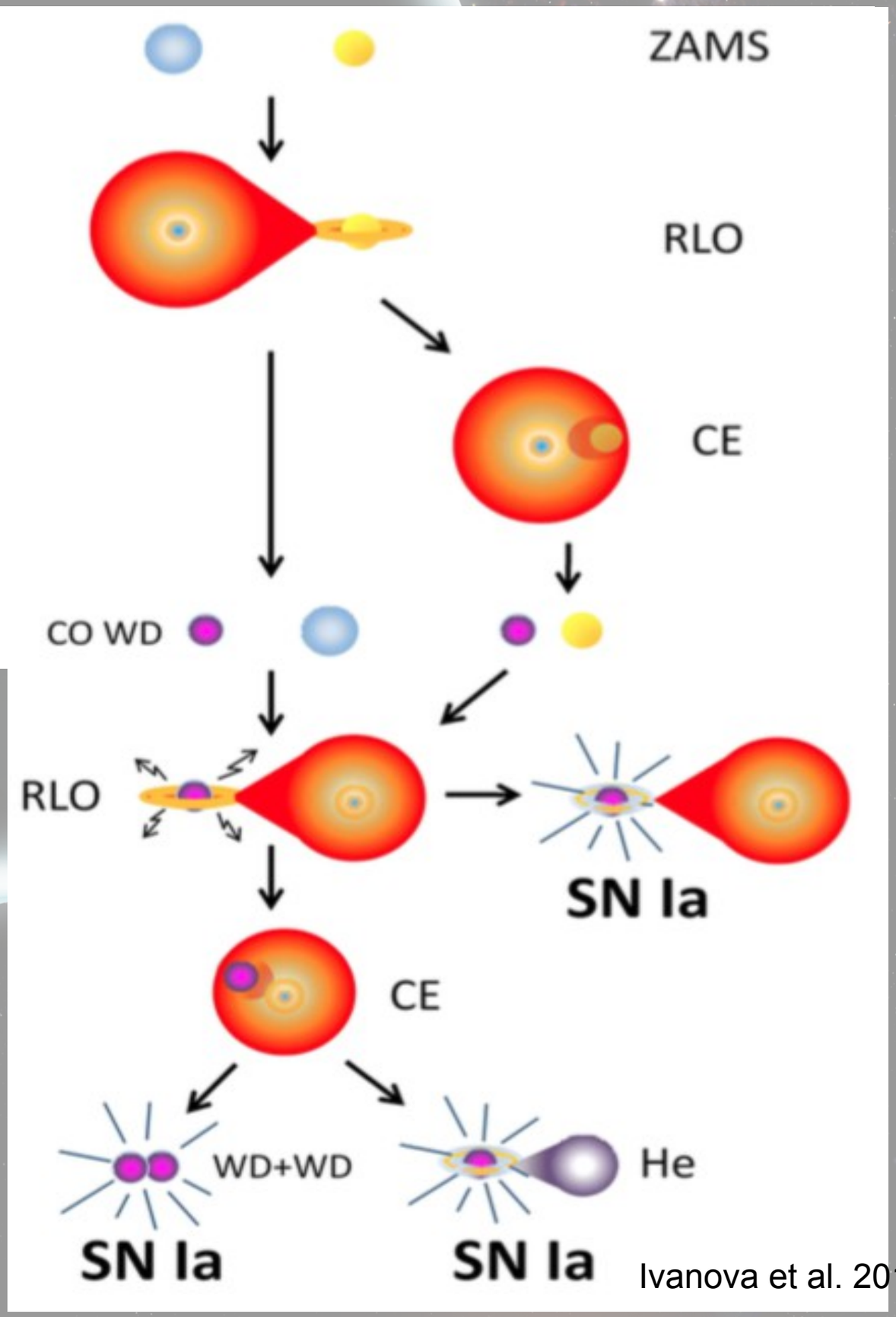




Hardy et al. 2015

Known CBPs

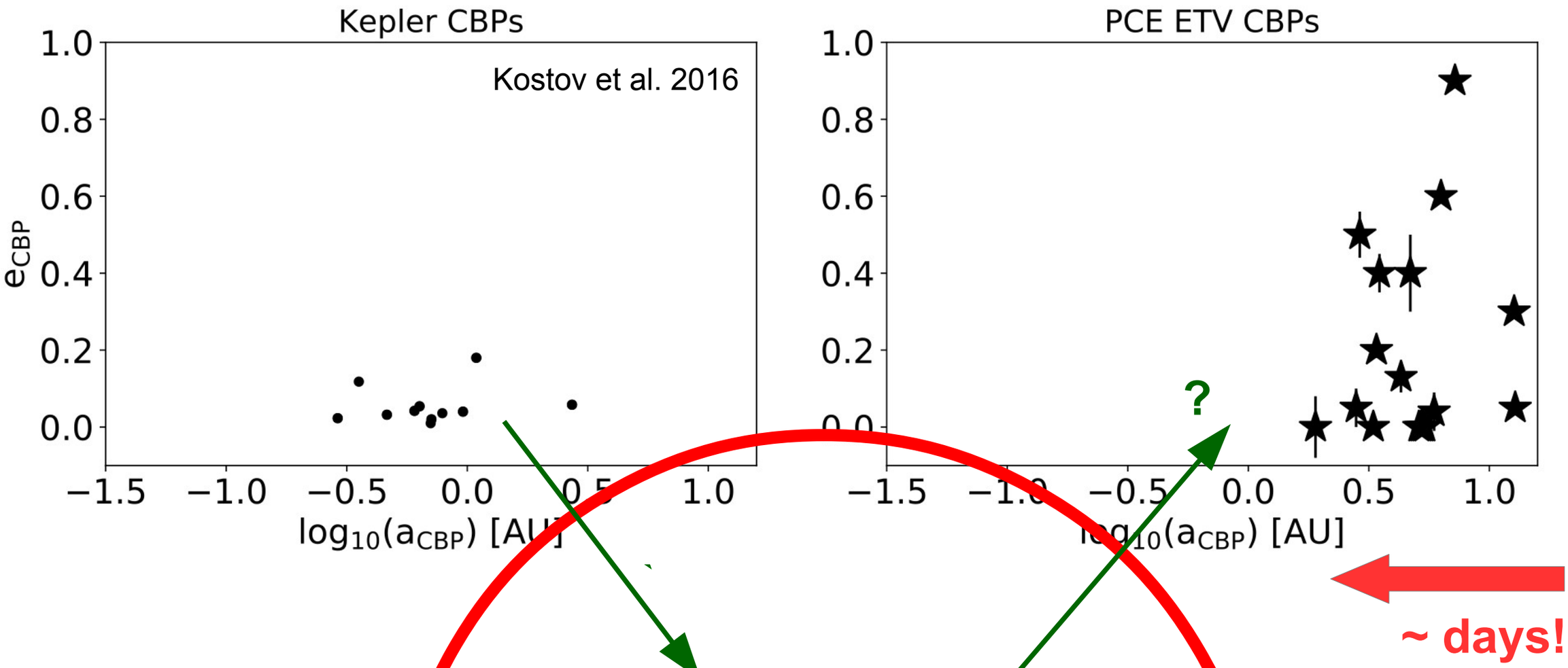




Ivanova et al. 2013

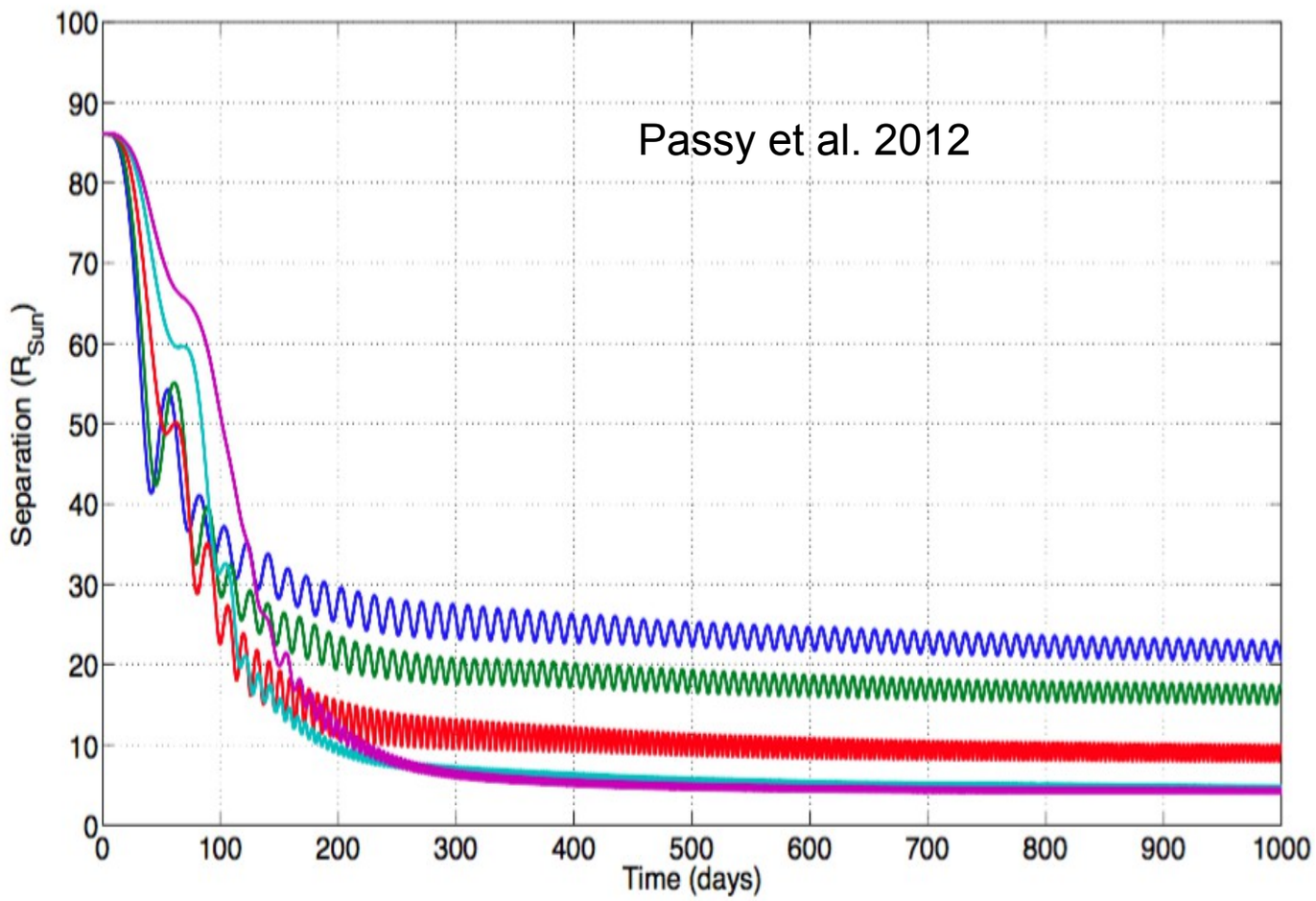
"CE is one of the most important unsolved problems in stellar evolution, and arguably the most significant and least-well-constrained major process in binary evolution" (Ivanova et al. 2013).

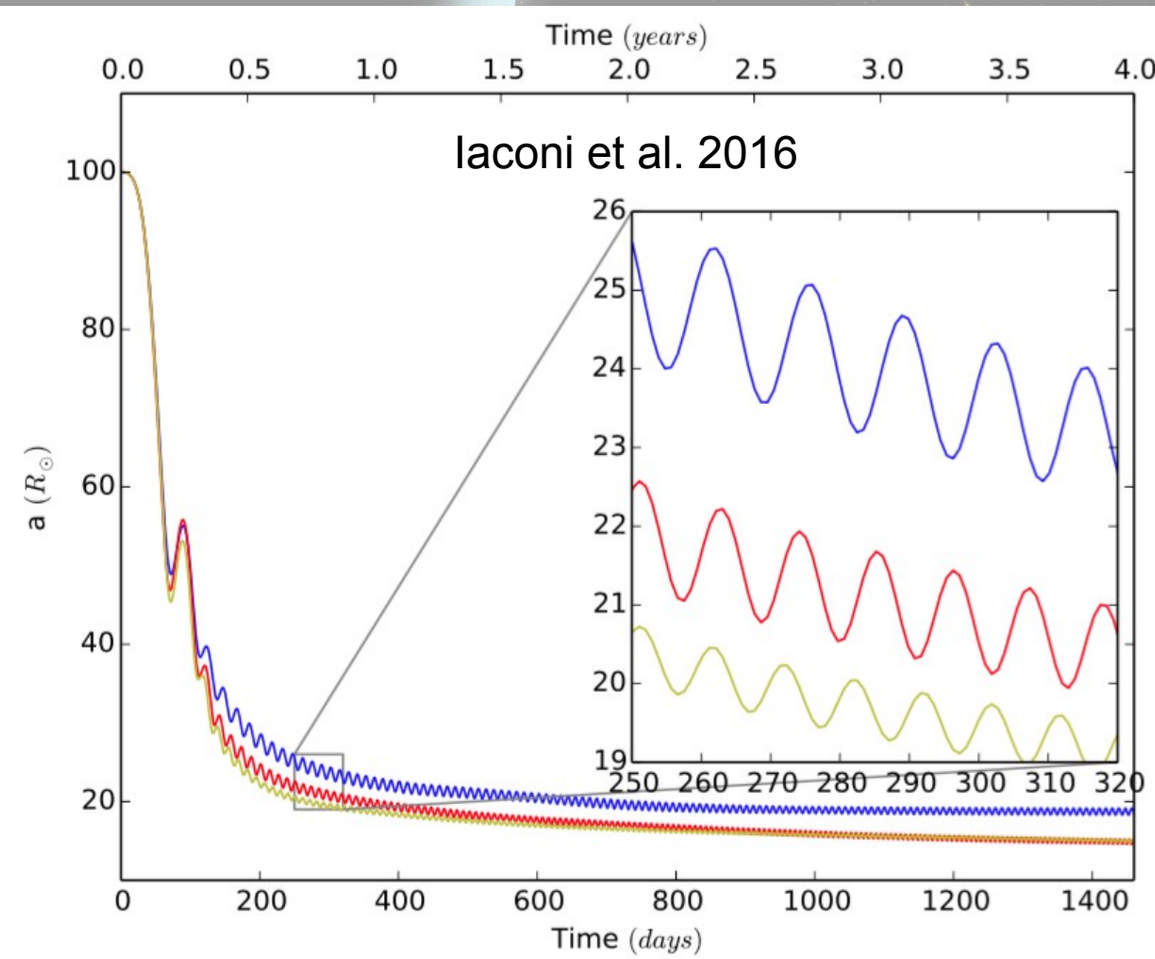
Known CBPs



Movie credit: Sebastian Ohlmann, HITS

CE Simulations





Binary Star Evolution

(BSE code, Hurley et al. 2002)

Time†† [Gyr]	M_1 [$M_\odot$]	M_2 [$M_\odot$]	Stell. Type	Stell. Type	a_{bin} [$R_\odot$]	e_{bin}	R_1/R_{Roche}	R_1/R_{Roche}	Evol. Stage
Kepler-38†									
0.0	0.95	0.25	1	0	31.6	0.10	0.05	0.03	INITIAL
12.36	0.95	0.25	2	0	31.6	0.10	0.10	0.03	KW CHNGE
13.01	0.95	0.25	3	0	31.61	0.10	0.14	0.03	KW CHNGE
13.72	0.94	0.25	3	0	31.86	0.10	1.00	0.03	BEG RCHE
13.72	0.75	0.25	3	15	0.51	0.00	1.00	0.03	COMENV
13.76	0.47	0.00	10	15	0.00	-1.00	0.00	-1.00	KW CHNGE
15.00	0.47	0.00	10	15	0.00	-1.00	0.00	-1.00	MAX TIME
Kepler-38‡									
0.0	0.95	0.25	1	0	31.59	0.10	0.05	0.03	INITIAL
12.36	0.95	0.25	2	0	31.60	0.10	0.10	0.03	KW CHNGE
13.01	0.95	0.25	3	0	31.45	0.09	0.14	0.03	KW CHNGE
13.70	0.94	0.25	3	0	24.58	0.00	1.00	0.04	BEG RCHE
13.70	0.91	0.25	3	15	0.37	0.00	1.00	0.04	COMENV
13.75	0.66	0.00	4	15	0.00	-1.00	0.00	-1.00	KW CHNGE
13.88	0.63	0.00	5	15	0.00	-1.00	0.00	-1.00	KW CHNGE
13.89	0.55	0.00	6	15	0.00	-1.00	0.00	-1.00	KW CHNGE
13.89	0.52	0.00	11	15	0.00	-1.00	0.00	-1.00	KW CHNGE
15.00	0.52	0.00	11	15	0.00	-1.00	0.00	-1.00	MAX TIME

††: Time in the online supplement is in Myr.
†: NTCP.
‡: TCP.

P(CE, BSE) = 0 … P(CE, actual) ~ 1 year ~ P(CBPs)

Kostov et al. 2016

Single star mass loss

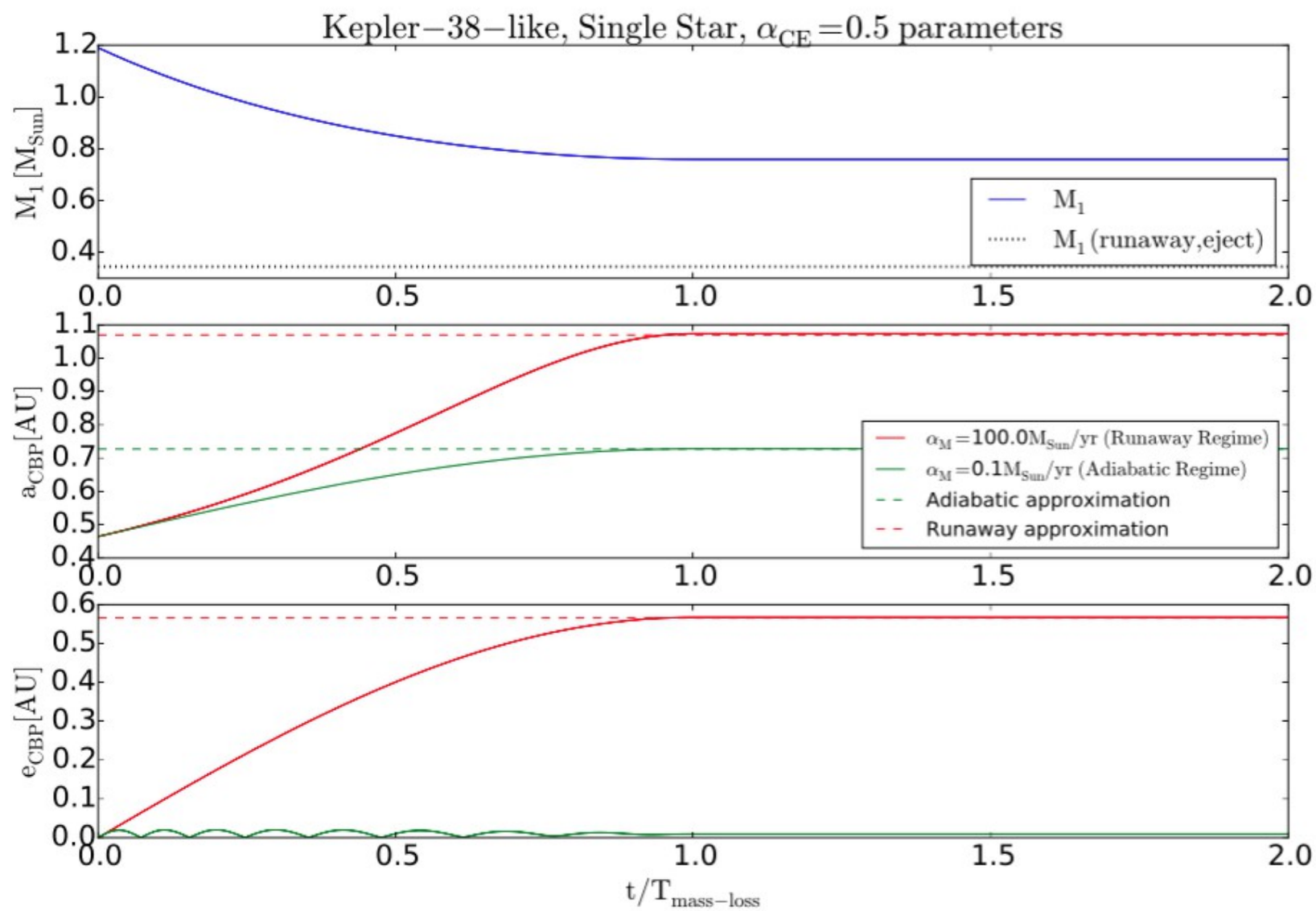
$$\Psi \equiv \frac{\alpha_M}{n\mu} = (2\pi)^{-1}\left(\frac{\alpha_M}{1 M_\odot\ yr^{-1}}\right)\left(\frac{a_{p,0}}{1\ AU}\right)^{\frac{3}{2}}\left(\frac{\mu}{1\ M_\odot}\right)^{-\frac{3}{2}}$$

$$\begin{aligned} e_{runaway}|_{f=0^\circ} &= e_0\left(1-\frac{\alpha t}{\mu_0}\right)^{-1} + \left(\frac{\mu_0}{\alpha t}-1\right)^{-1} \\ &= e_0\frac{\mu_0}{\mu} + \left(\frac{\mu_0}{\mu}-1\right), \end{aligned}$$

and

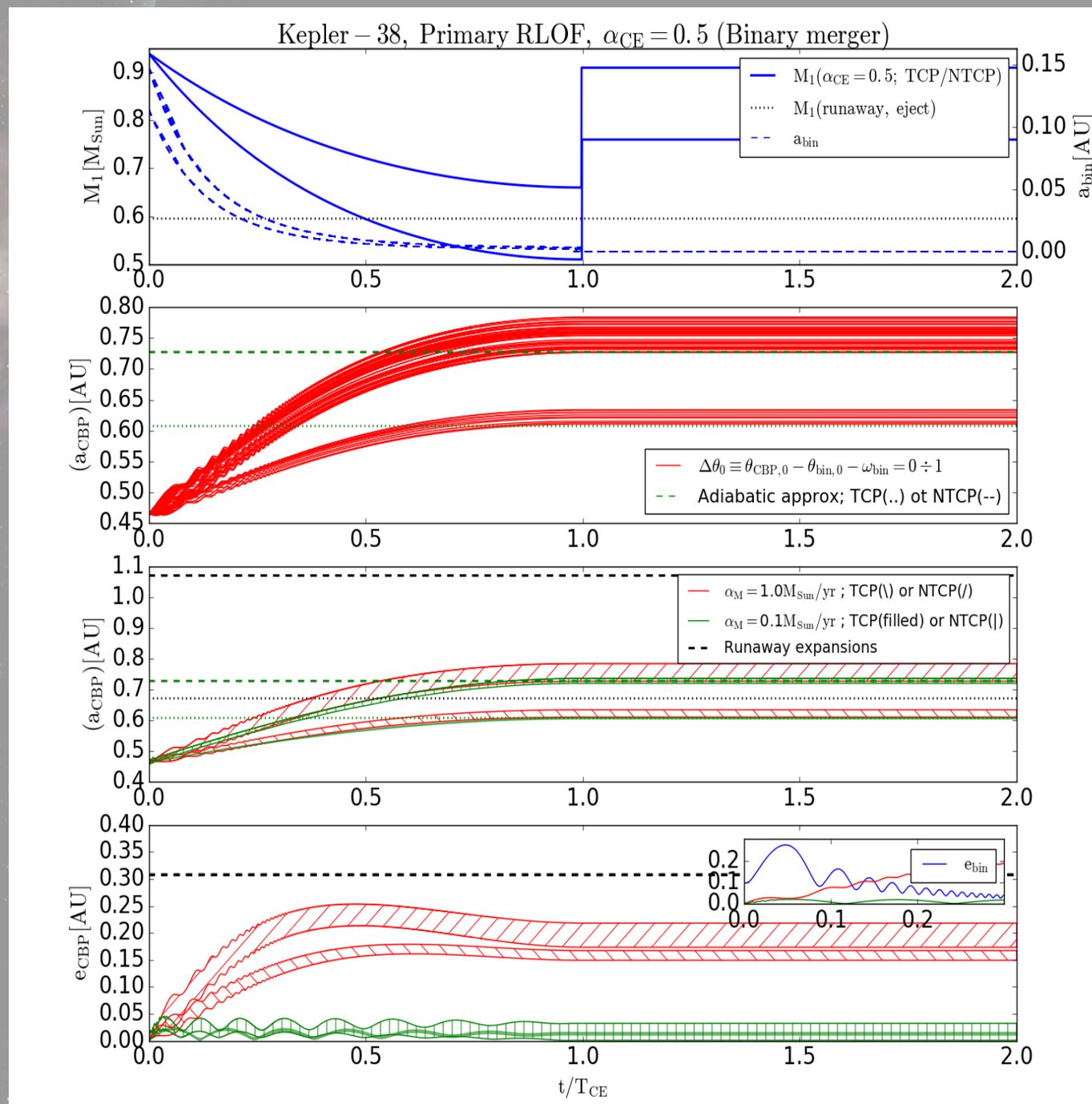
$$\begin{aligned} e_{runaway}|_{f=180^\circ} &= e_0\left(1-\frac{\alpha t}{\mu_0}\right)^{-1} - \left(\frac{\mu_0}{\alpha t}-1\right)^{-1} \\ &= e_0\frac{\mu_0}{\mu} - \left(\frac{\mu_0}{\mu}-1\right). \end{aligned}$$

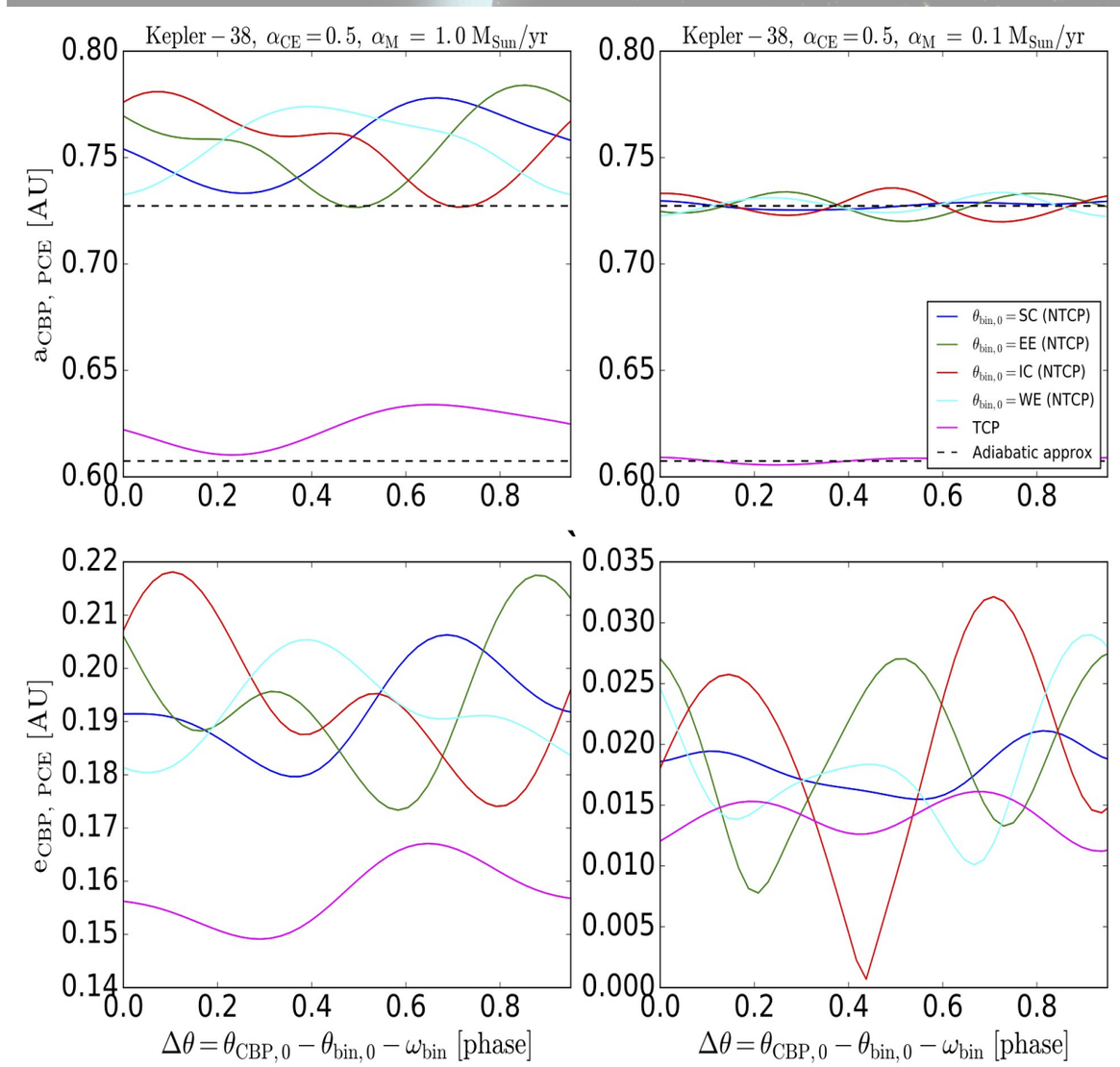
Veras et al., 2012; Veras 2016



Kostov et al. 2016

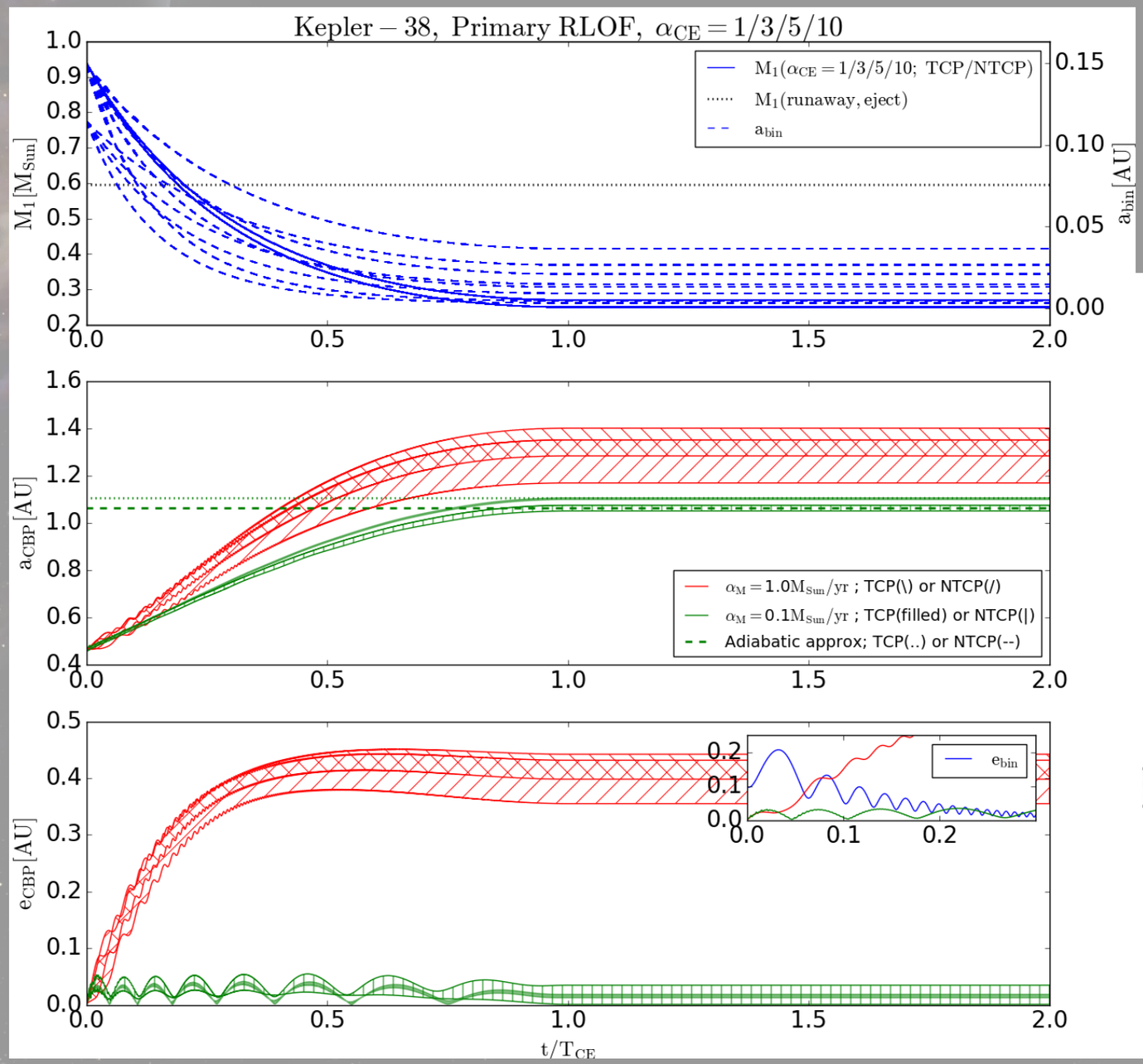
Kepler-38 primary CE

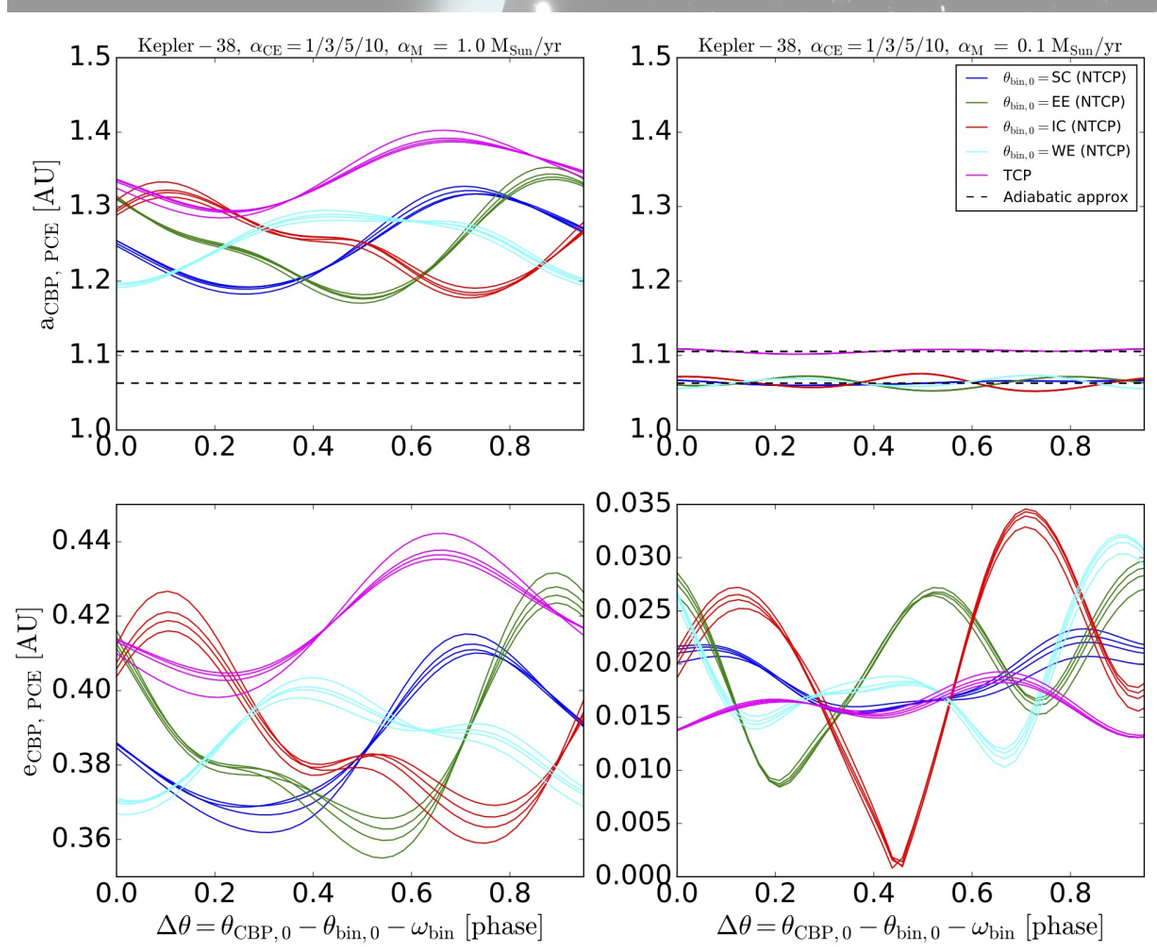




Kostov et al. 2016

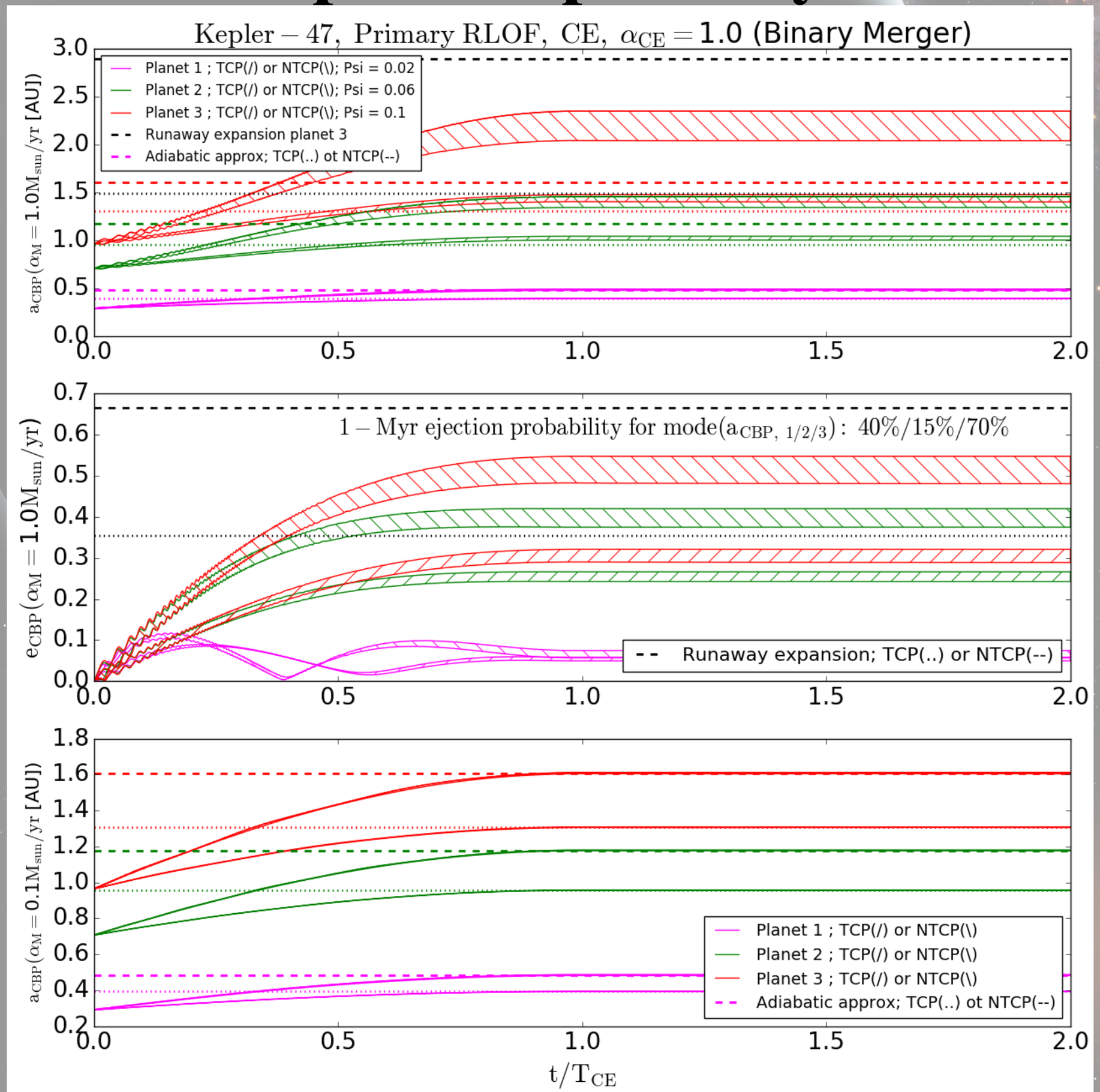
Kepler-38 primary CE





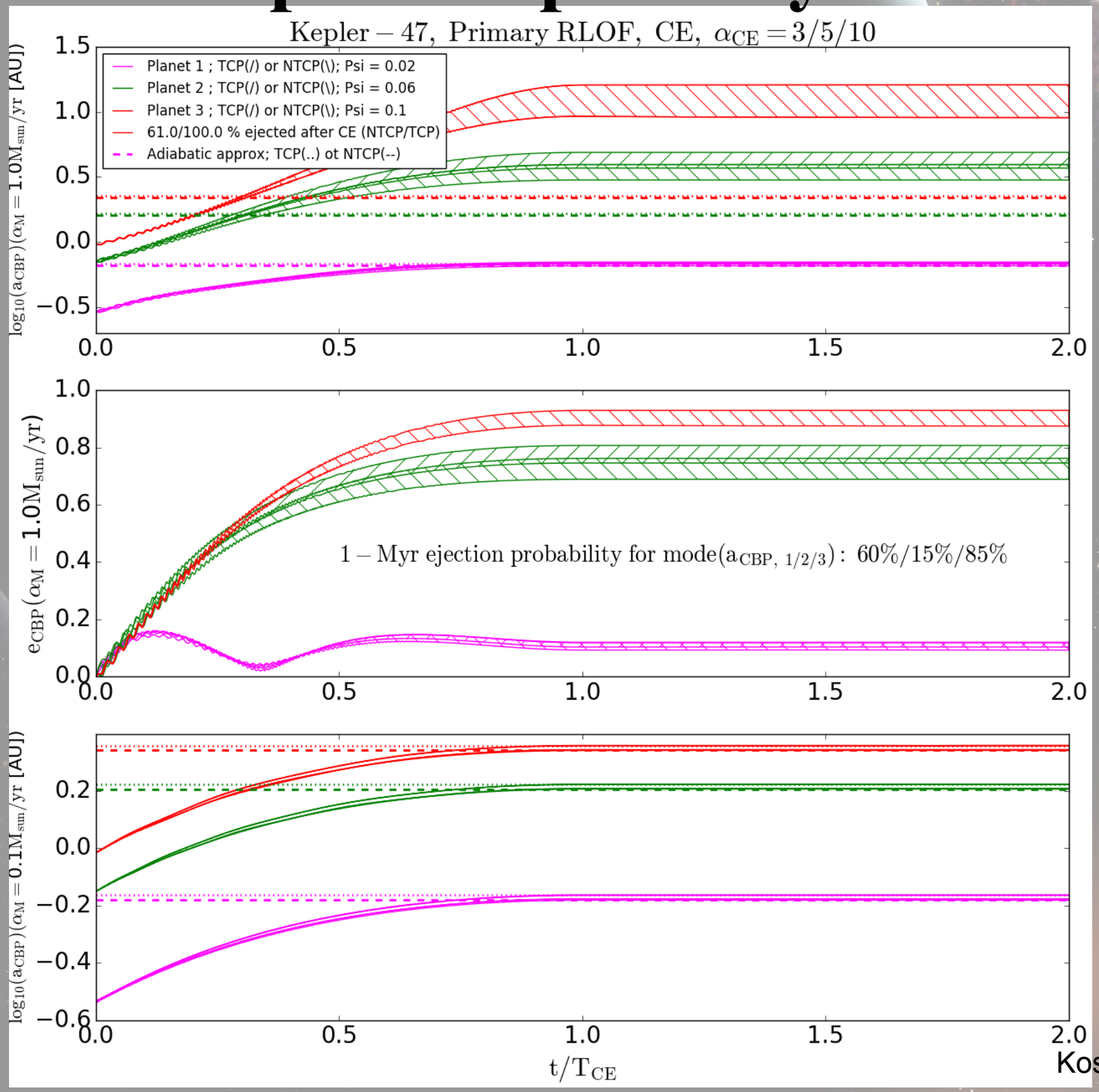
Kostov et al. 2016

Kepler-47 primary CE



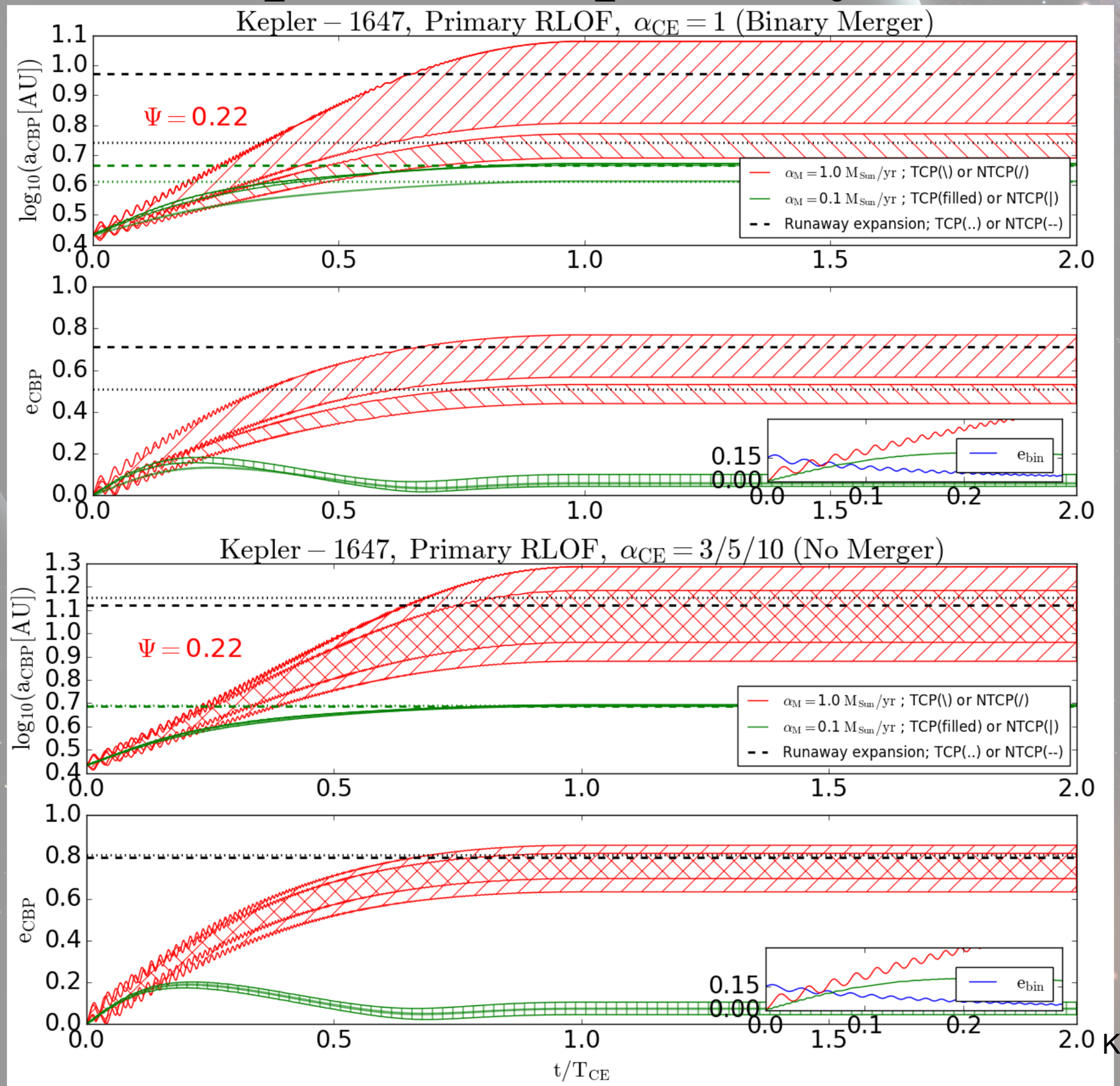
Kostov et al. 2016

Kepler-47 primary CE



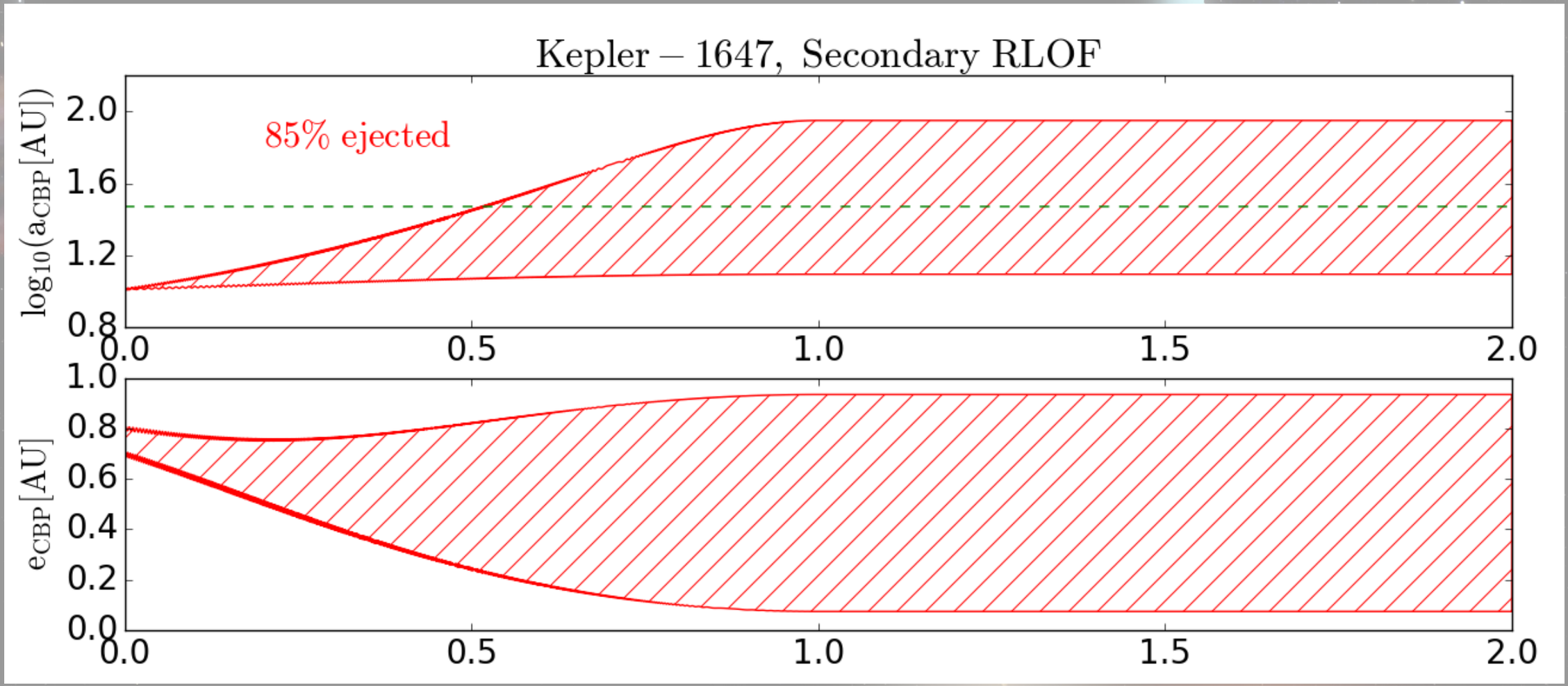
Kostov et al. 2016

Kepler-1647 primary CE



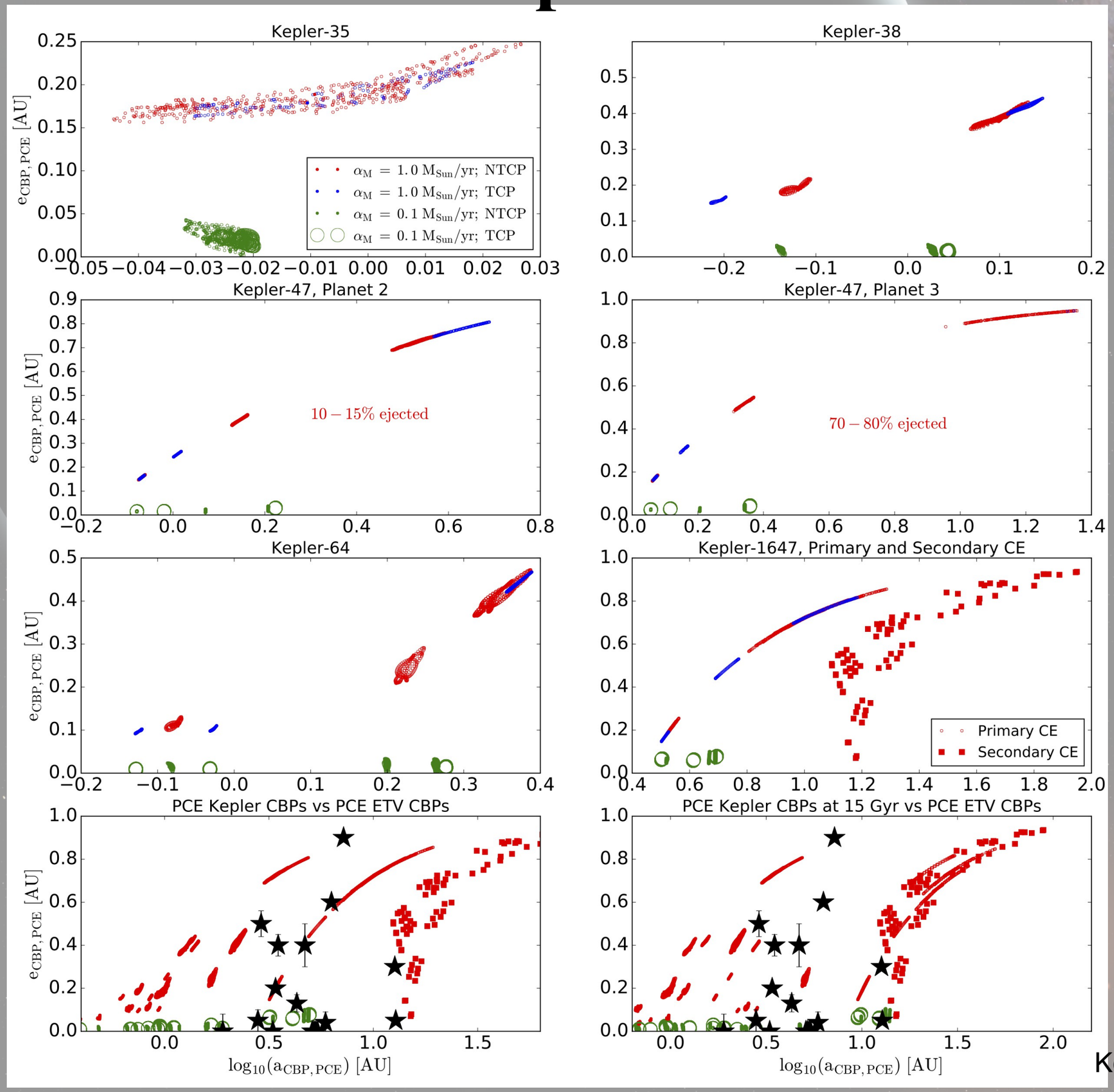
Kostov et al. 2016

Kepler-1647 secondary CE



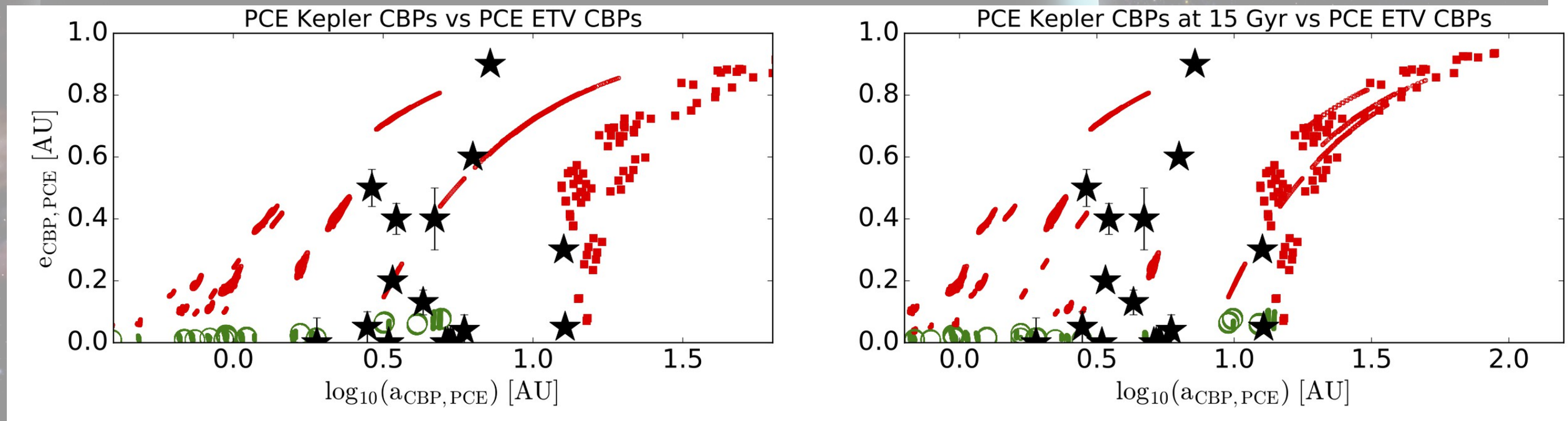
Kostov et al. 2016

PCE Kepler vs ETV



Kostov et al. 2016

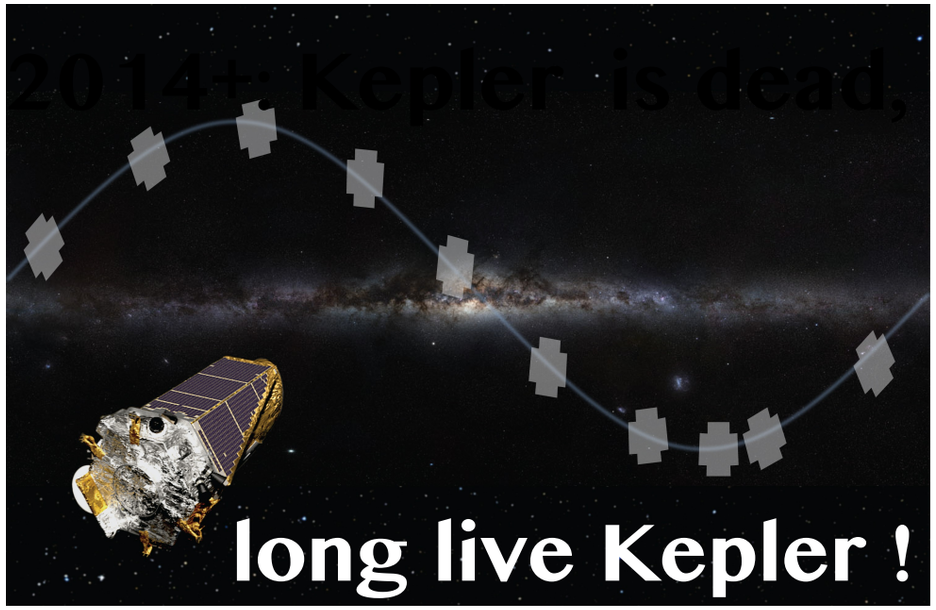
Summary



- CBPs dynamically survive through CE evolution → 2 Suns > 1 Sun (e.g. Villaver & Livio 2007)
- Kepler's CBPs after CE qualitatively consistent with PCE ETV CBP candidates
- 10-100 AU post-CE orbits – good for imaging, ETV
- 1st generation formation (Bear & Soker 2014; Schleicher & Dreizler 2014) vs 2nd generation (Perets 2010) vs mixed (Perets 2010)?
- CBPs inside PN? (Soker 1998; Bear & Soker 2016)

Image credit: NASA/ESA

What's next?



Stay tuned!