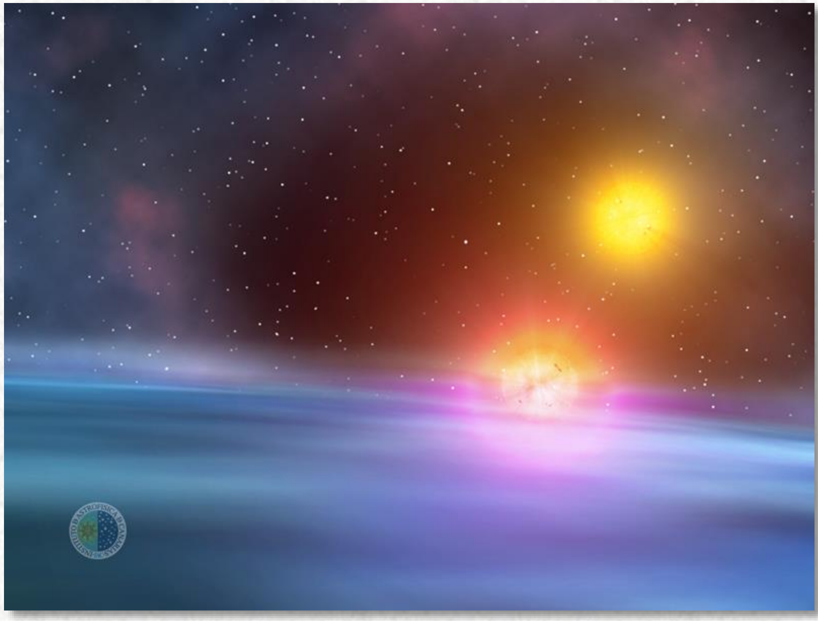
Circumbinary Planets: current issues



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PLATO WP 112510
Photometric detection of circumbinary planets

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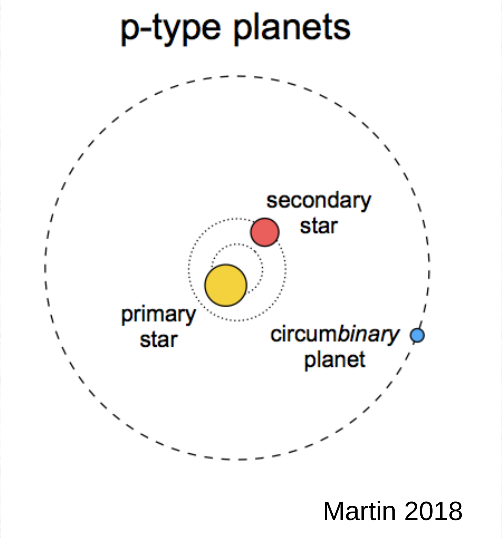
Amaury Triaud, David V. Martin, Francesca Faedi, Aviv Ofir, Jean Schneider

Circumbinary Planets (CBP)

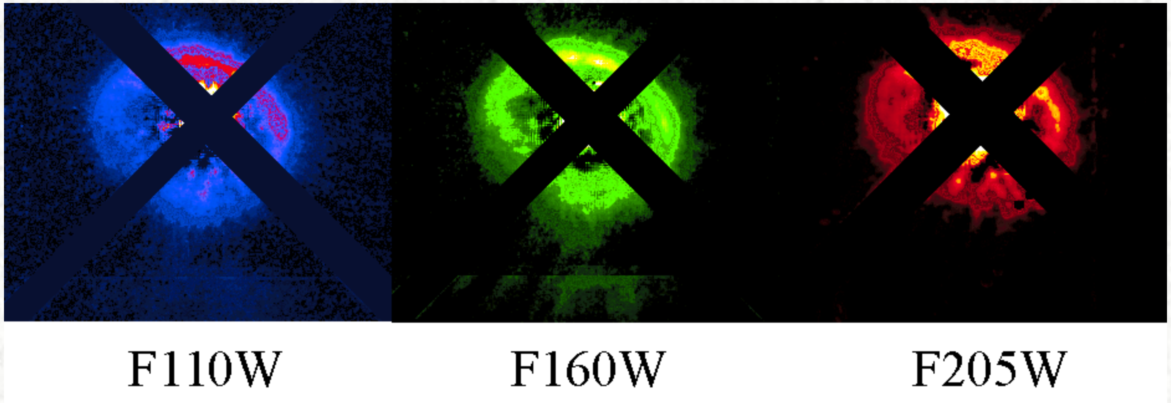


Planet Tatooine, Star Wars 1977

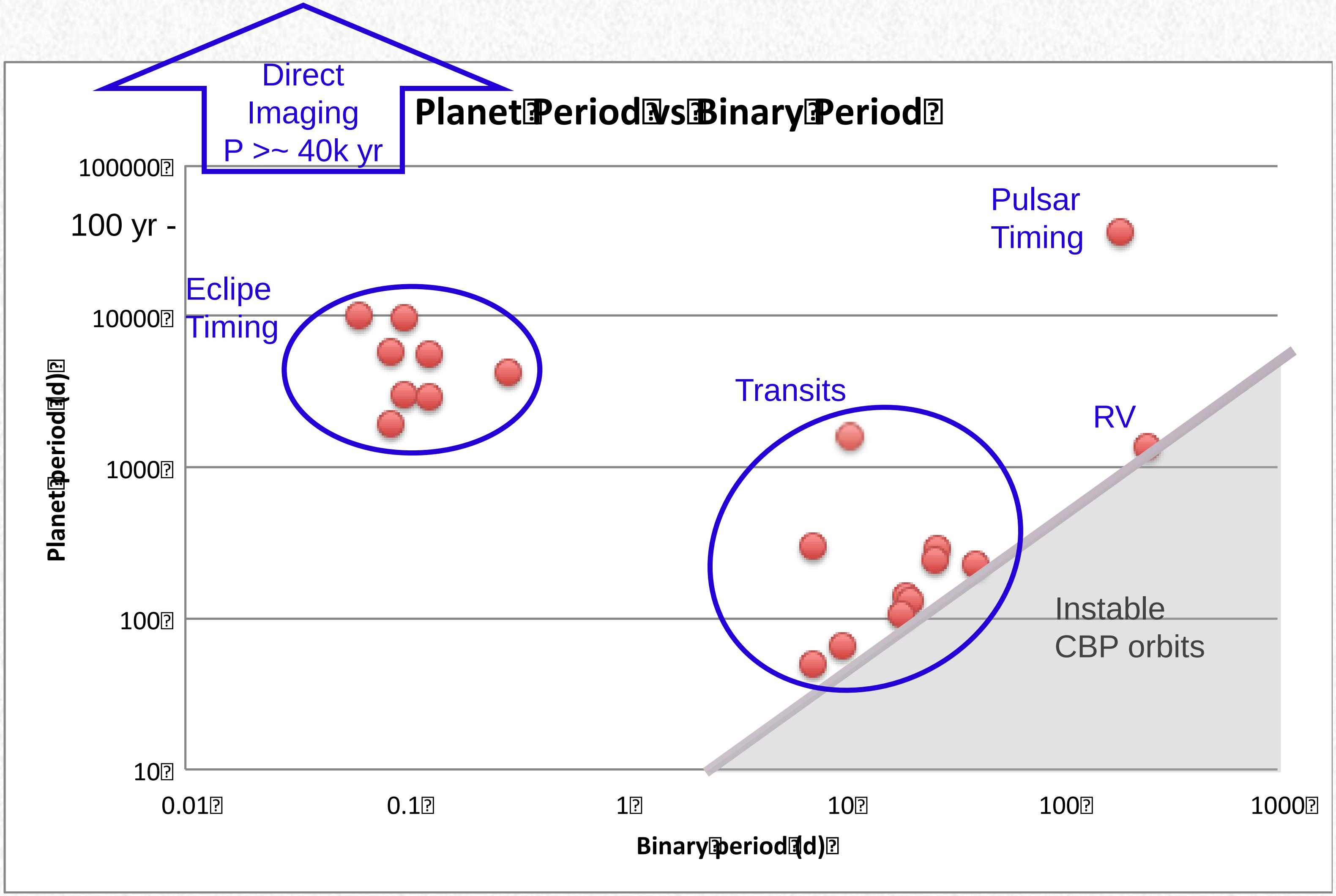
Backer 1993: Timing of PSR B1620-26: Pulsar-WD binary plus low-mass object = planet?

Only 10-12 yrs later accepted as CBP, 2.5M_{jup}, P=100y (Sigurðsson+03, Backer+ 05, Rasio 05 etc)

MacCabe et al 2003: HST-NICMOS obs of Circumbinary disk of GG Tau

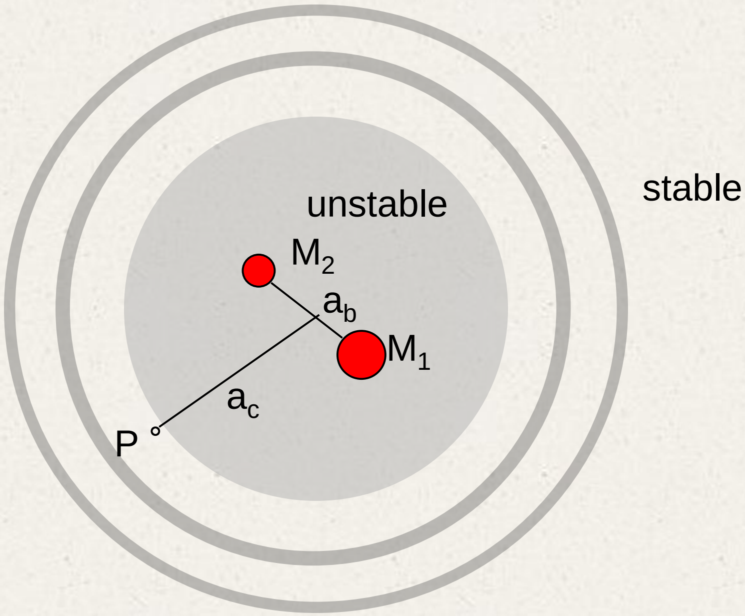


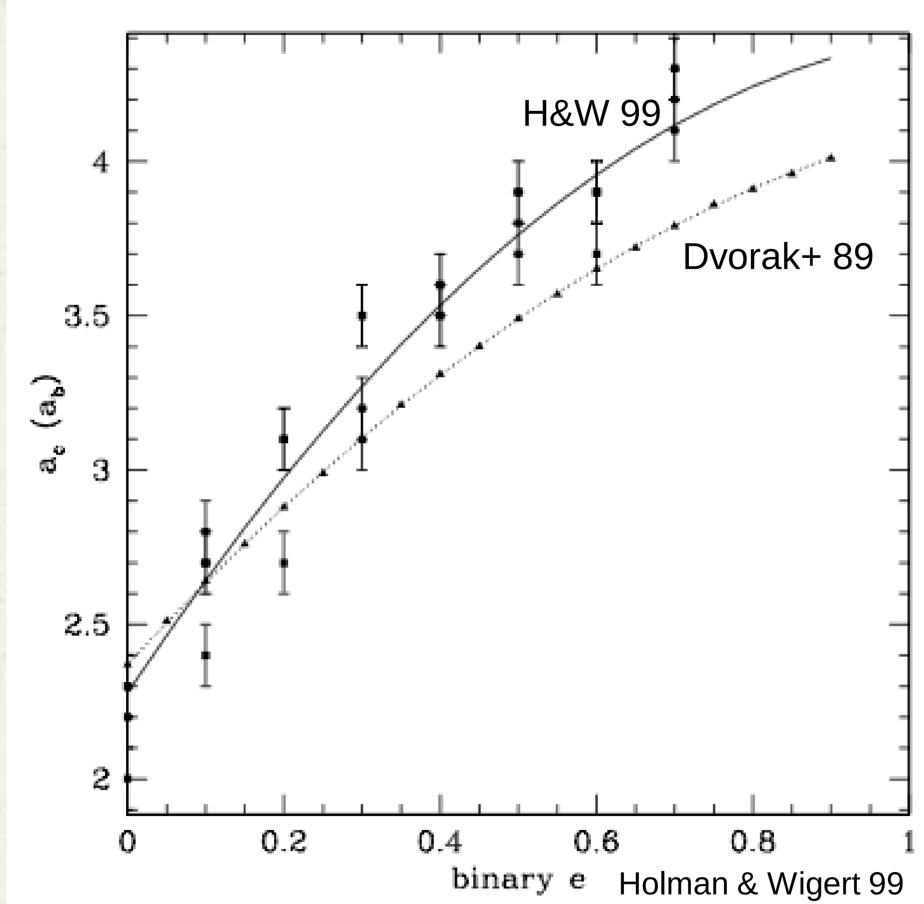
26 known CBPs[1]: Distinct populations pending on discovery method



[1]Nasa Exoplanet Archive, circumbinary flag =1

Stability of P-type planet orbits



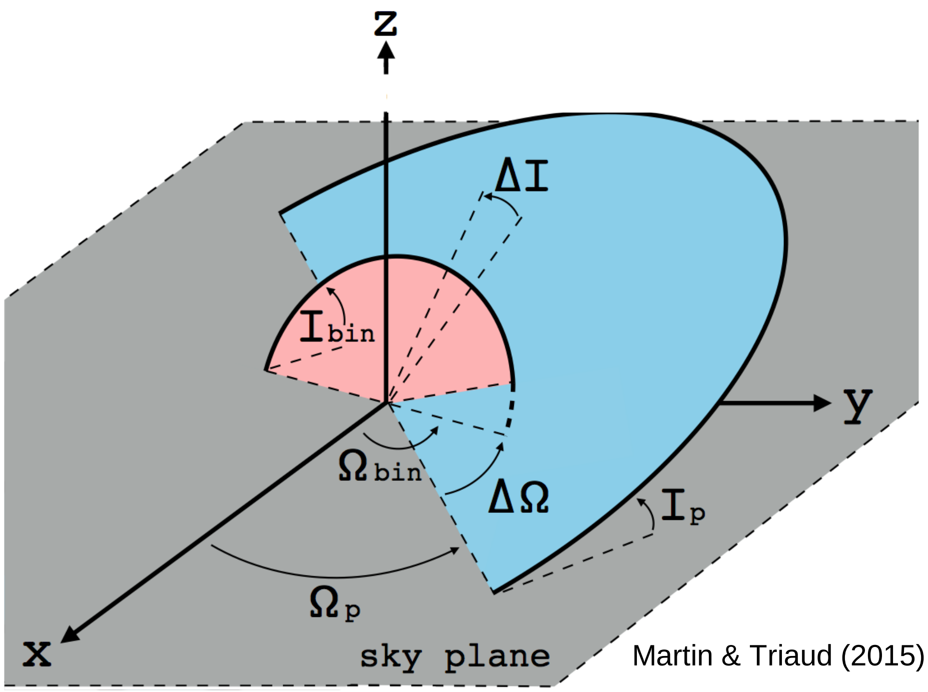


a_b: Binary separation
a_c: planet minimum stable semimaj. axes

Dvorak+ 1989, Holman & Wiegert 1999, coplanar case:
for e_{bin}=0 :
a_c/a_b ~ 2.3
P_c/P_b ~ 3.5
little dependency on $\mu = M_2/(M_1+M_2)$

The mutual inclination Δi

Currently known transiting systems nearly coplanar: Δi < few degrees



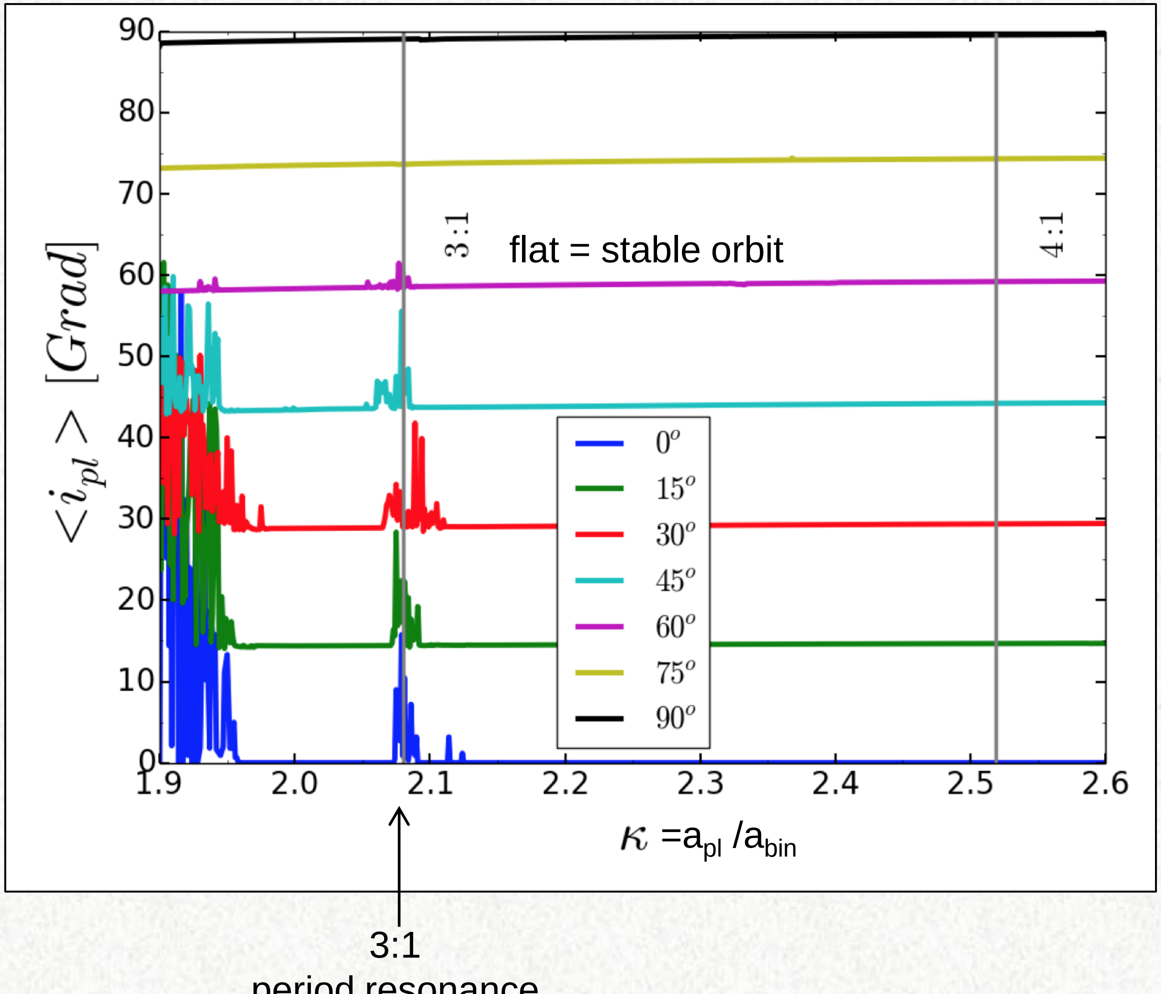
Martin & Triaud (2015)

Planet orbital plane

Binary orbital plane

Orbital stability of mutually inclined CBPs

Non coplanar:
critical inner orbit (a_c) varies by ±20% against coplanar case (Wiegert & Holman 97, Chambers+ 02)
Pilat-Lohinger+ (2003): detailed sims for : Δi ≤ 50 deg



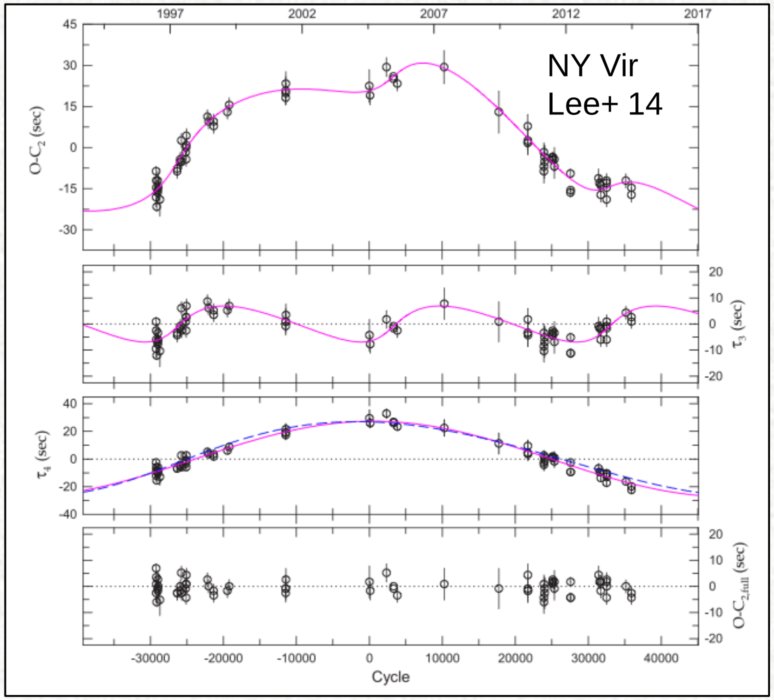
Henríquez Ortiz, Master-th. 2016:

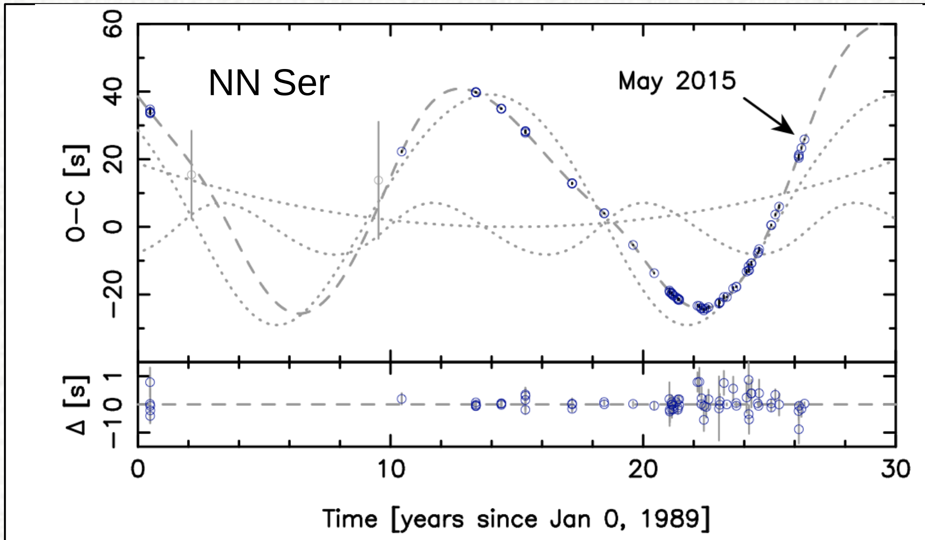
At high Δi > 60 deg :

smaller inner orbits remain stable
less sentitive to 3:1 period resonance

CBPs discovered by timing

Obs. of period resp. Eclipse time variation (ETV)





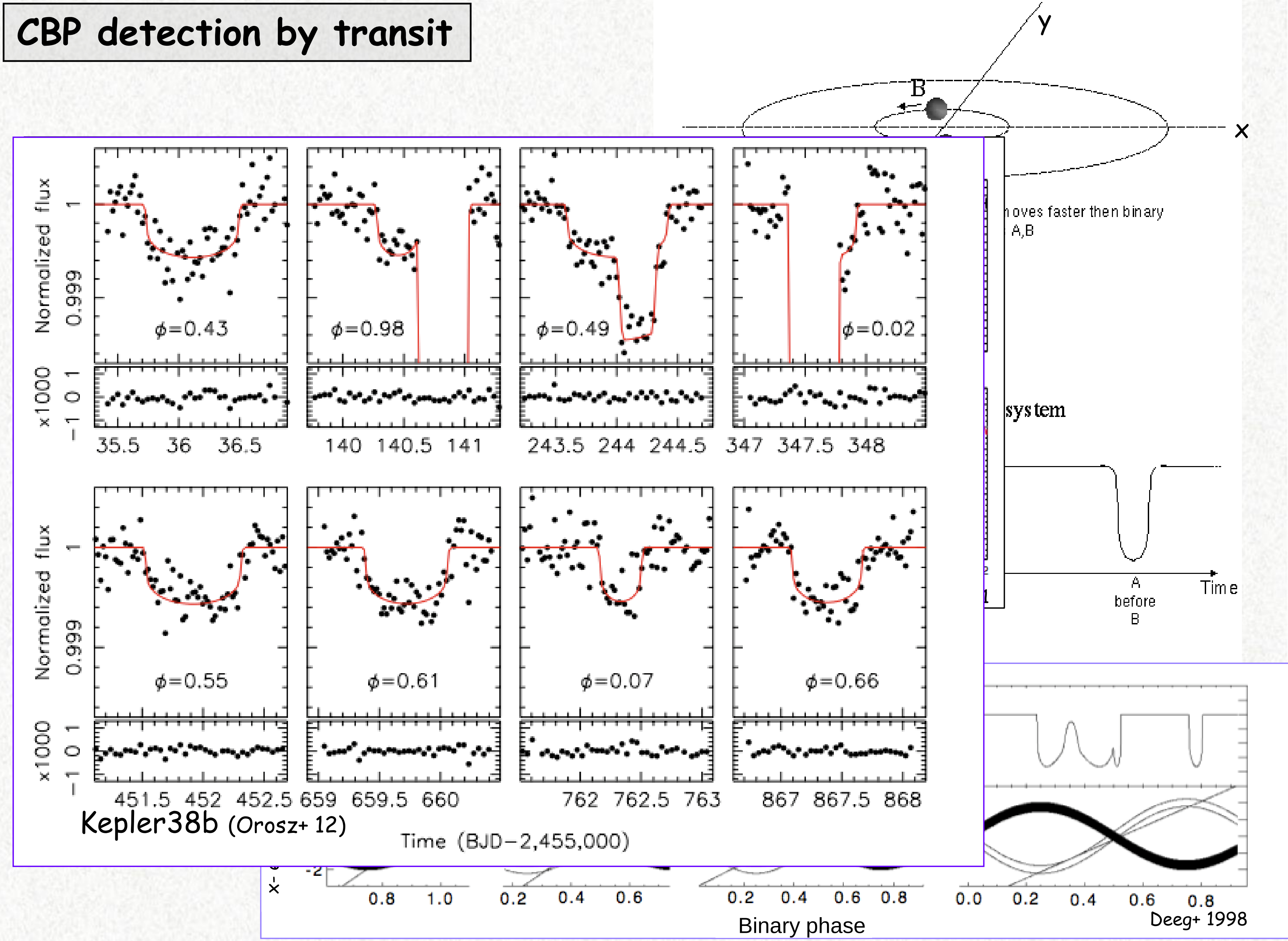
Marsh 2018, adapted from Bours+ 2016

All 10 EBP discovered by ETVs:
- ETV from light-time (Rømer) effect
  (Not from TTV-like orbital dynamical effect):

- All on evolved stars with compact component:
  Pulsars, ecl. binaries dM /WD;   dM/sdB.

Long time-baselines are essential!

CBP detection by transit

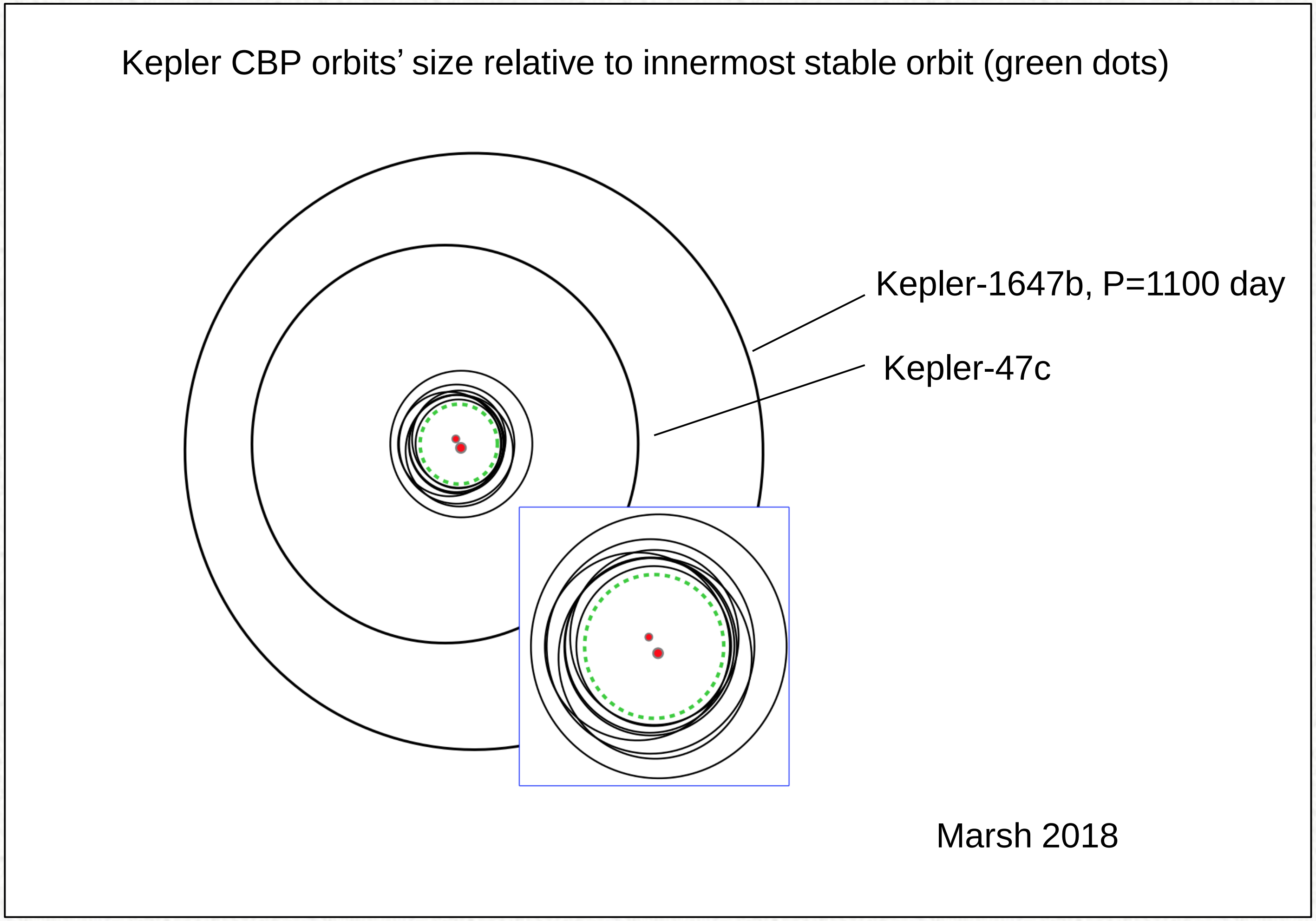


Kepler38b (Orosz+ 12)

Deeg+ 1998

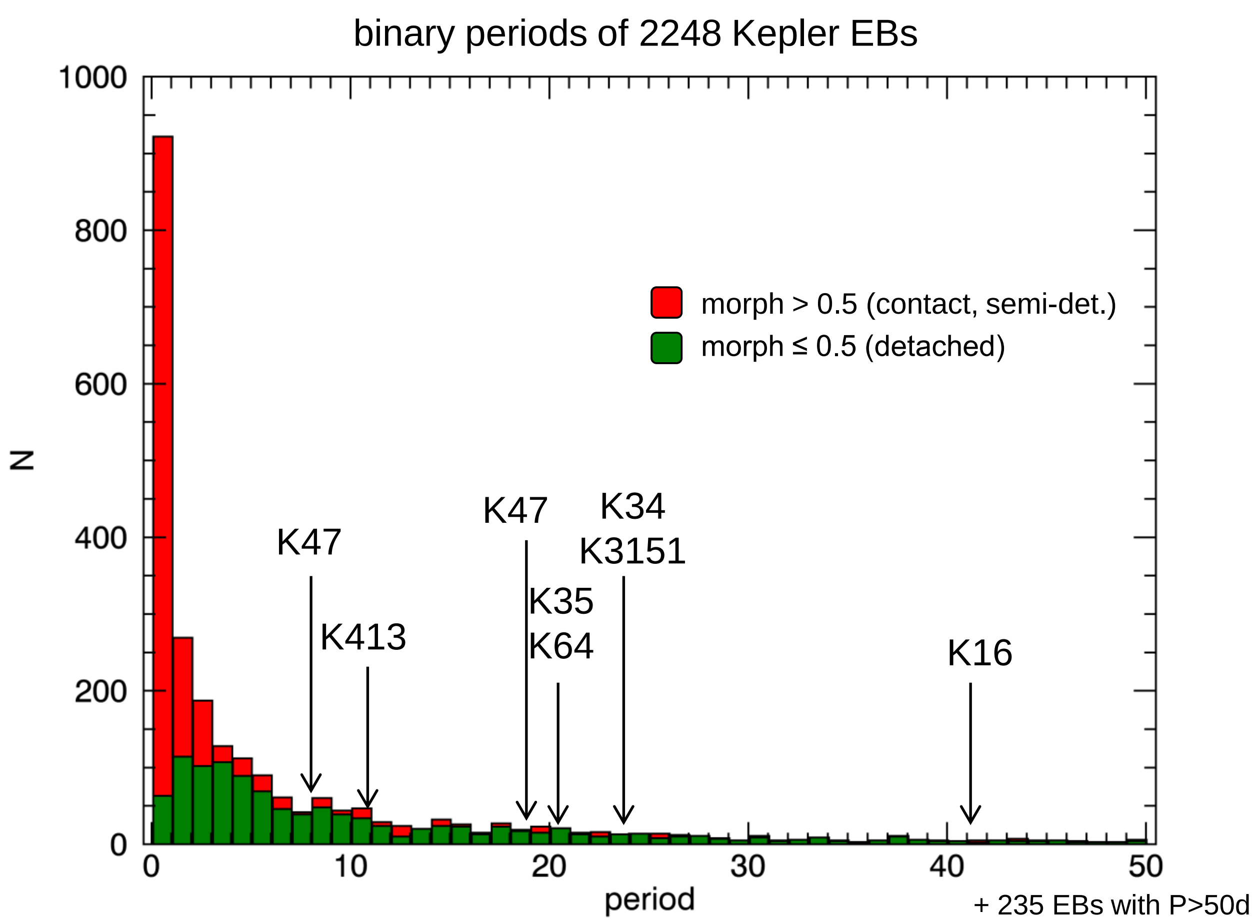
Transiting CBP orbits

Very most close to inner stability limit



Martin and Triaud (2014), Li et al (2016): pile-up not a selection effect, likely inwards migration

Distribution of EB periods / of CBP hosts



Source: Kepler EB catalog, V3beta Nov'14
http://keplerebs.villanova.edu/

Also Klagyivik, Deeg+ (2017): No short-periodic CBPs in COROT sample (2290 EBs)

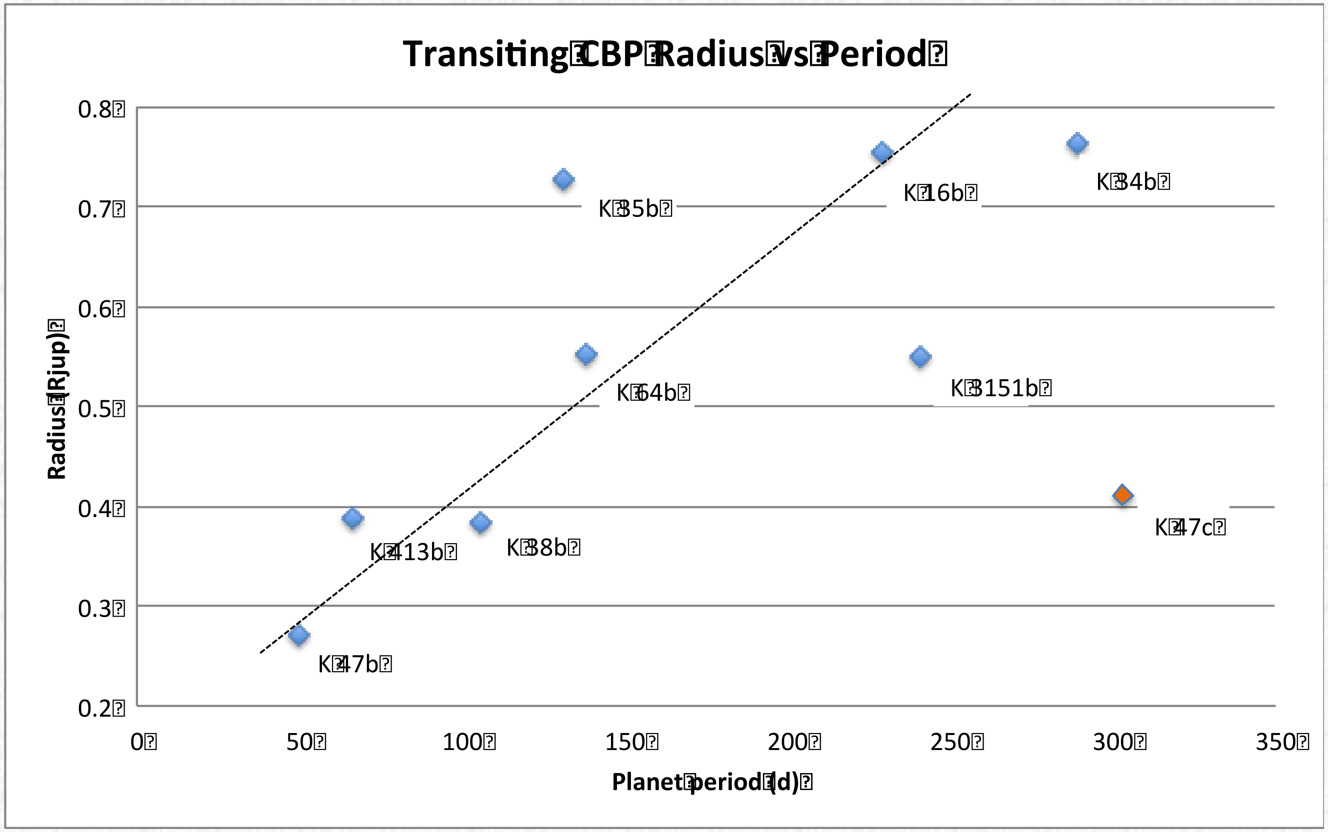
No planets around binaries with P_{bin} < 7day ?

Martin+ (2015), Hamers+ (2016):

- Short periodic binaries form in triple systems

- posterior dynamical evolution either ejects planets, or moves to undetectable (wide ,inclined) orbits

Radius - period relation of the *inner* CBPs



Source: Exoplanet.eu

CBP transits may come and go: Mutually inclined orbits

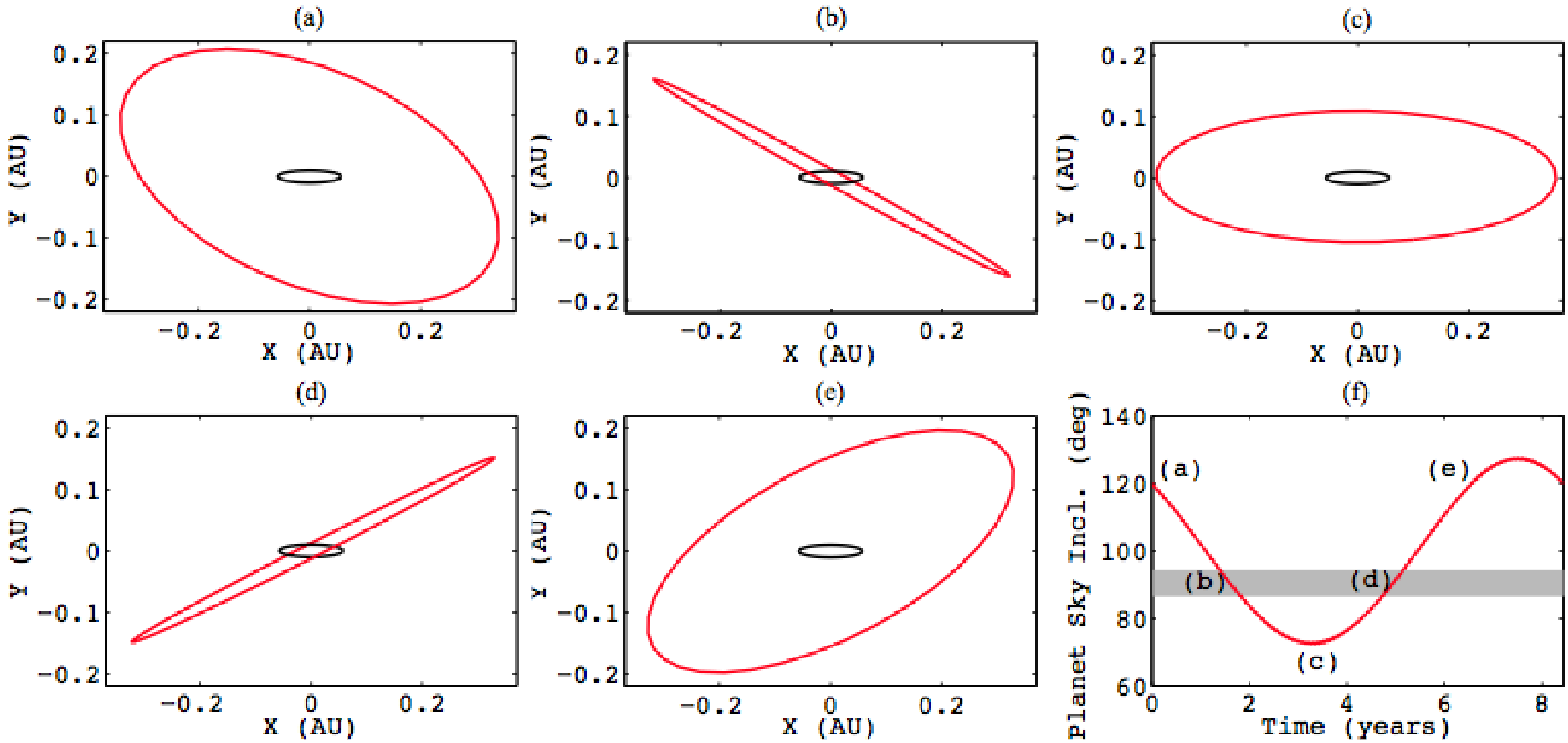
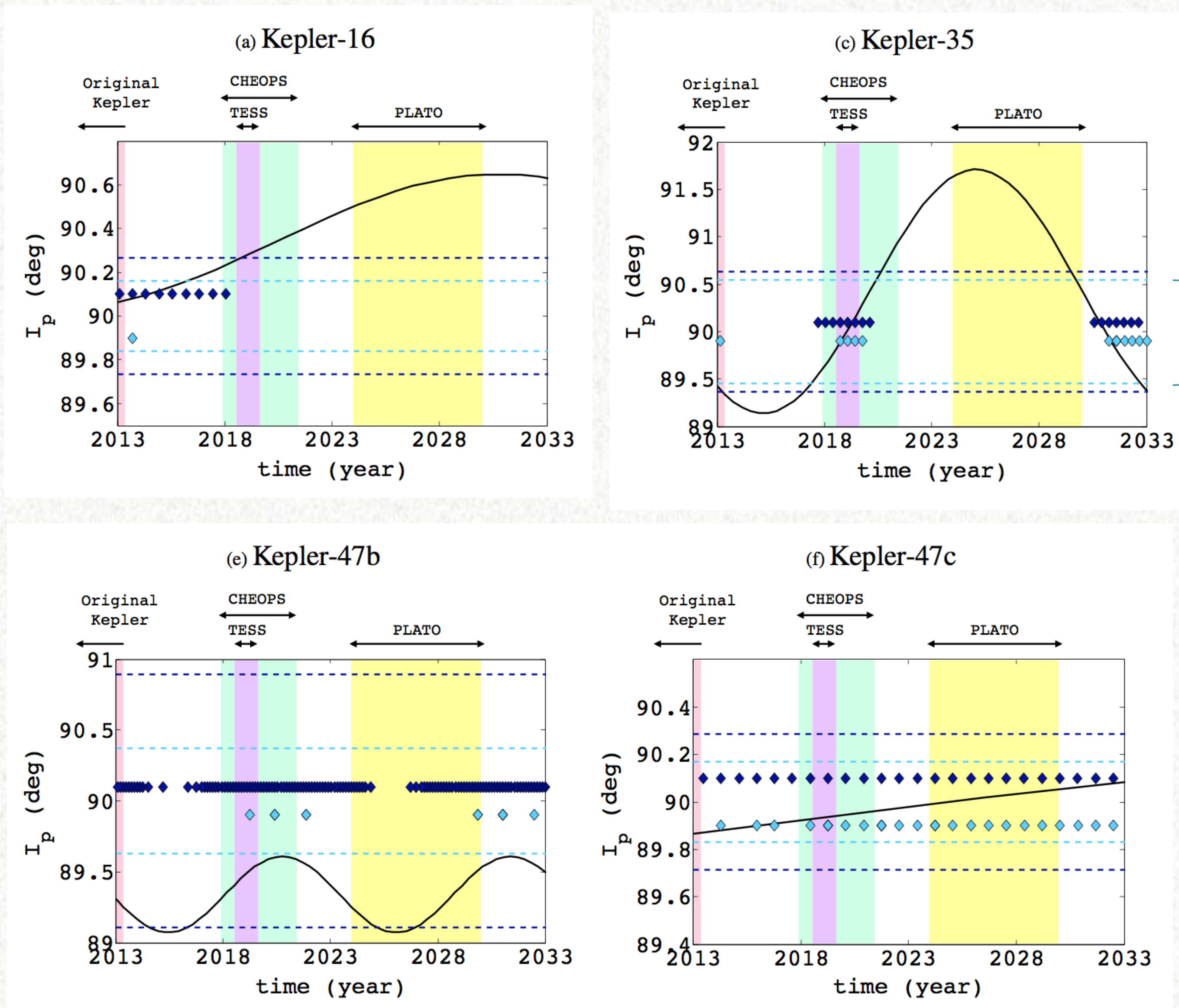


Fig. 3: Orbital precession of the osculating Keplerian orbit of a 55 day circumbinary planet (outer, red) inclined by 30° with respect to a 10 day equal-mass binary (inner, black). The different panels show different epochs of the precessing period. Those times are labelled and displayed in panel (f) where we draw the planet's precessing orbital inclination with respect to the plane of the sky as a function of time. The grey band illustrates the range of sky inclinations for which the planet has a chance to transit. The overlap of the red line with the grey band corresponds to epochs of transitability.

Martin & Triaud 2014

Future transit occurences of known CBPs

Martin & Triaud (2016)



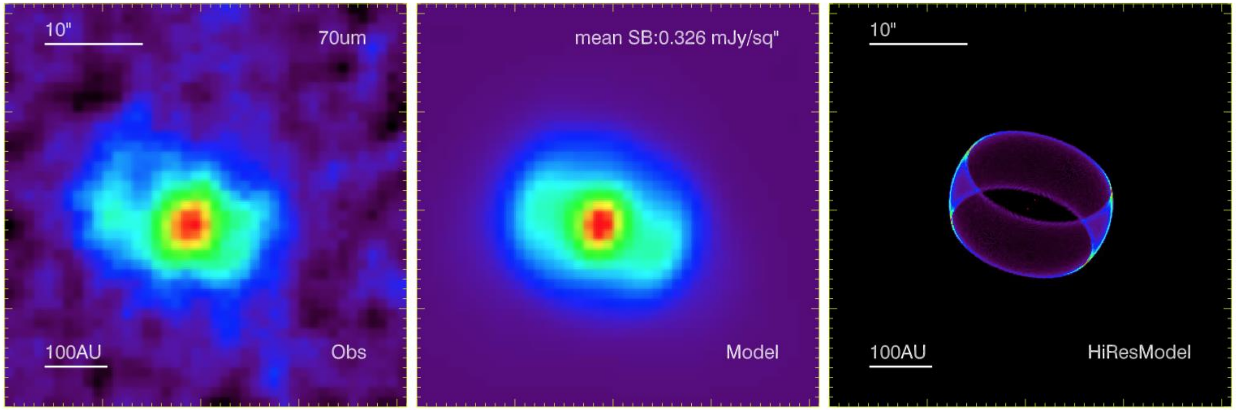
Limits of I_p for transits across primary /secondary star

Fraction of time when I_p within limits:
few% to 100%.
Typical: 30-50%

-> 2-3 times more CBPs among *known* Kepler EBs, that were not discovered due to precession.

Still to be detected: CBPs with strong mutual inclinations

Polar CBPs around eccentric EBs?



70µm num. sim $\Delta i = 90^\circ$ num. sim $\Delta i = 90^\circ$

99 Hercules
e_{bin}=0.76, P_{bin} = 56yr

Herschel obs.
Kennedy + 2012:
best fit for $\Delta i = 90^\circ$

Martin R.G & Lubow 2017: CB protoplanetary disks align perpendicular to eccentric binary if initially above critical inclination (for 99 Her: above $\Delta i = 20^\circ$)

Zanazzi & Dong 2017: long-term num. sims: inclination evolution faster than planet formation
-> polar CBP's around eccentric EBs likely

Also: 'winking binaries': inclined precessing disk?
KH15D circumb. disk with $\Delta i = 10^\circ - 20^\circ$; (Winn+ 2004 etc.)
WL 4 (Plavchan+ 2008)
YSO YLW 16A (Plavchan+ 2013)

both works unitless; may apply also to short-periodic EBs

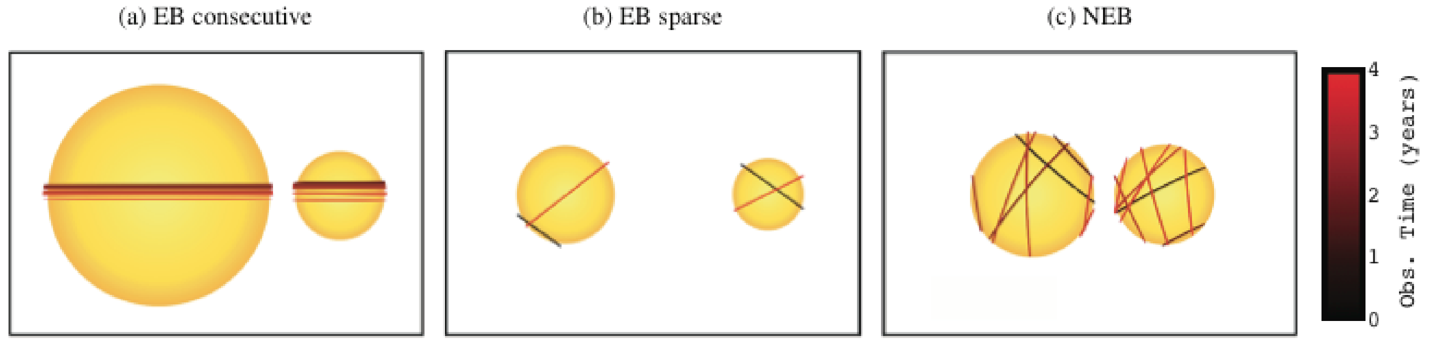
Most circumb. disks however coplanar (Watson+ 2011, Kennedy+ 2012)

Detection of CBPs with large mutual inclinations

Martin & Triaud 2014: Detection of CBPs even around non-eclisping binaries:

High probabilities to detect:

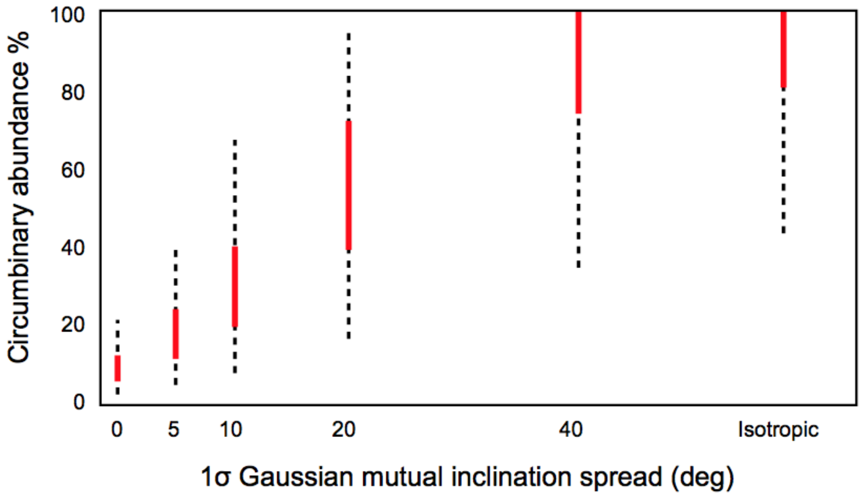
- if observing long enough (decades, for sparse transit events)
- if strongly inclined systems really exist



Martin & Triaud 2014

Likely only single transits detected; CBPs difficult to verify, characterize

Fractional abundance of CBPs of 4-10REarth as function of width of mutual inclination distribution $\sigma_{\Delta i}$



Martin 2017, adapted from Armstrong+ 2014

likely: $\sigma_{\Delta i}$ <~ 5° : CBP abundance similar to planets around single stars

less likely: $\sigma_{\Delta i}$ > 20° : Most binaries would have CBPs

(but only CBP with small Δi detected)

bimodal distribution also possible

PLATO CBP detection: status and expectation

Kepler, CoRoT: ~1.5% of sample stars are EBs
(Kepler: Ecl. Binary catalogue, Vilanova Univ.; CoRoT: Klagyvik+ 2017, Deleuil+ submitted)

- Kepler: 10 CBP detected, all by transits, rather long periods 50-1100d
- Absence of CBP on shorter-periodic binaries? Likely but not proven
- Abundance of CBPs with strong mutual inclination, incl. on non-eclipsing EBs unkown (revision of mono-transit events; follow-up of EBs with ETV signals)

PLATO:
Long Duration fields, 2-3 yrs: ~ 267k stars 80ppm/√h
To first order, multiply Kepler detection rates by 1.66 -> 15-20 'Kepler-like' CBP

Step & Stare, 2-5 months: 10^6 stars
Reduced detection capability for longer-periodic (p>0.2yr) CBPs.
Assuming that ½ of known Kepler CBP detected in such data: -> 20-40 CBP

Issues for CBP detection with PLATO

PLATO Input catalogue for Long Fields:
Should estimate abundance of all binaries (eclips. / non-eclips) with P ≤ 1yr

(Halbwachs+ 2003: 13.5% of MS stars, 1d < P < 10yr)

TESS, GAIA (RV's) -> detect binaries
TESS, pre-launch photometric monitoring -> longer baselines for EB timing

The case of CBP on non-eclipsing binaries: -> potential to be determined

All CBP detection efforts: profit from longer monitoring phase, 2 x 2yr <-> 1 x 3yr + step & stare

CBP detection algorithm for PDC vs. independent work on L1 data ?

Thank you

¡Gracias!