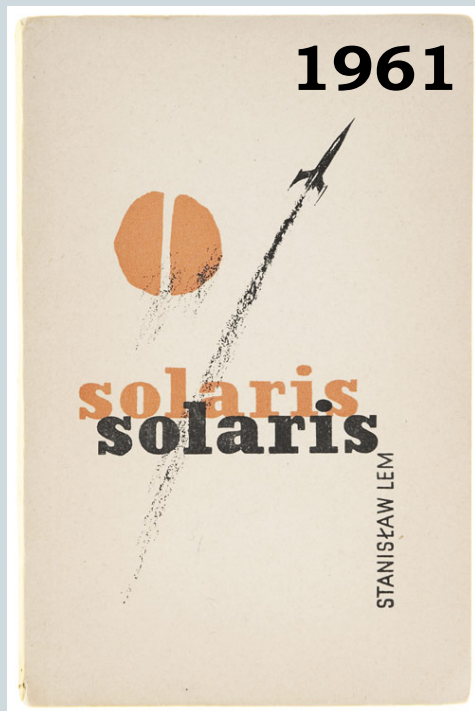
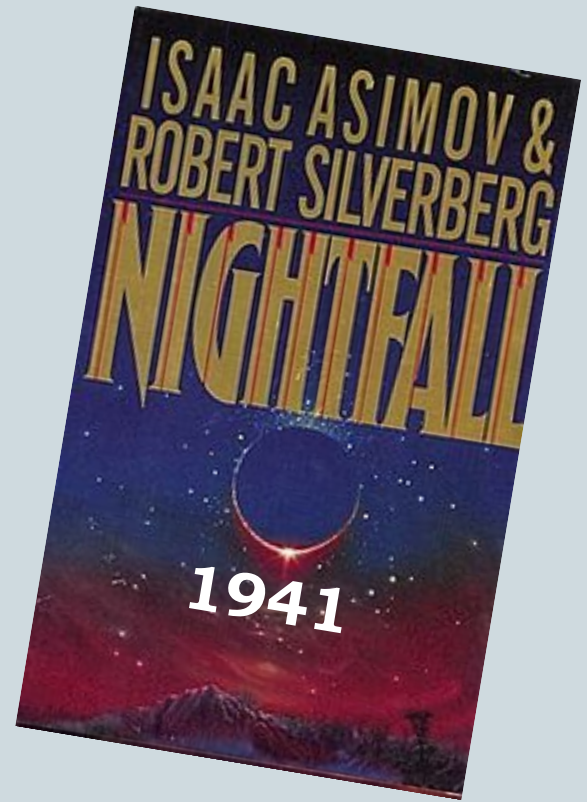




Planets with two suns

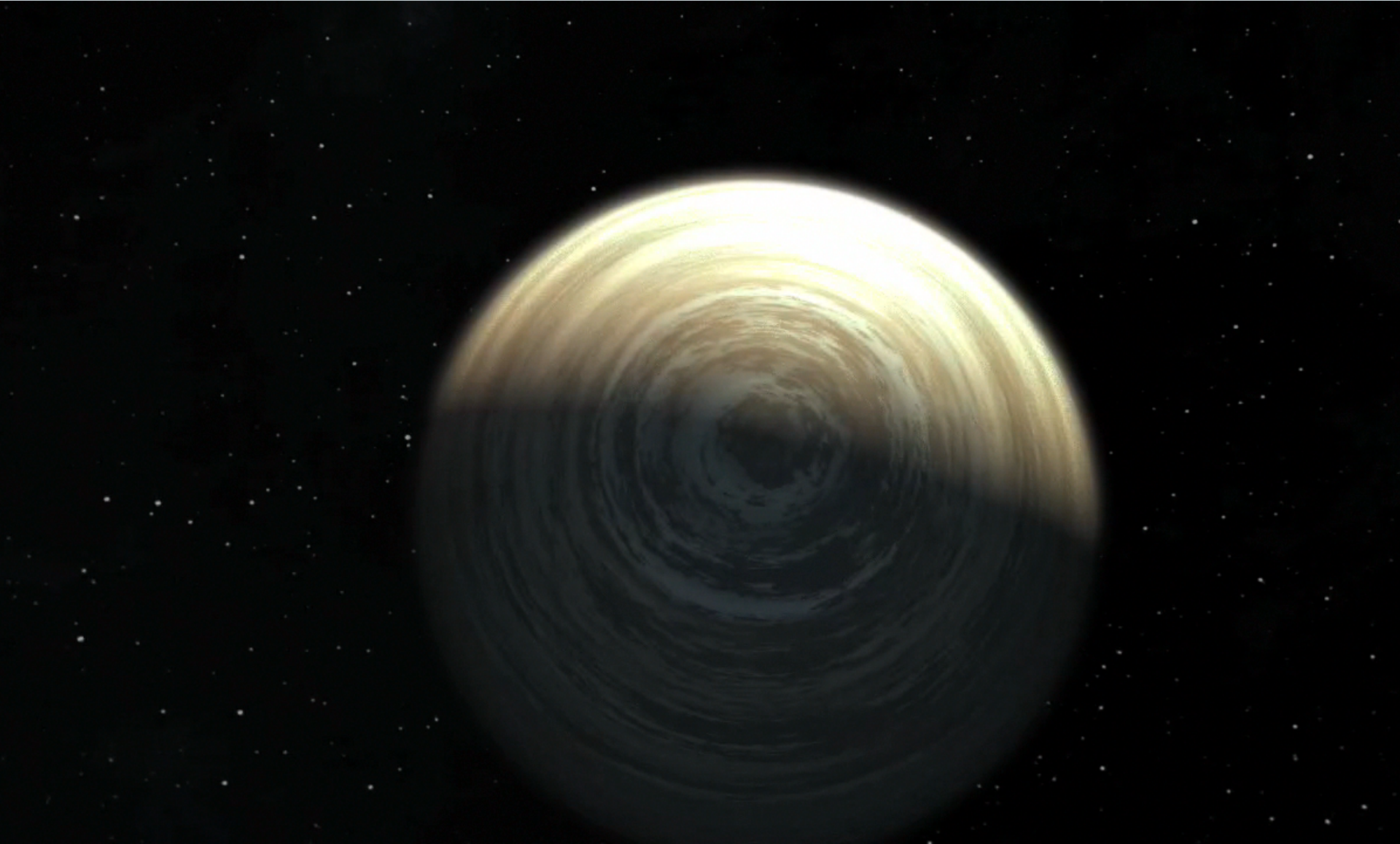
Veselin Kostov
University of Toronto

31st International Colloquium, IAP
June, 30, 2015

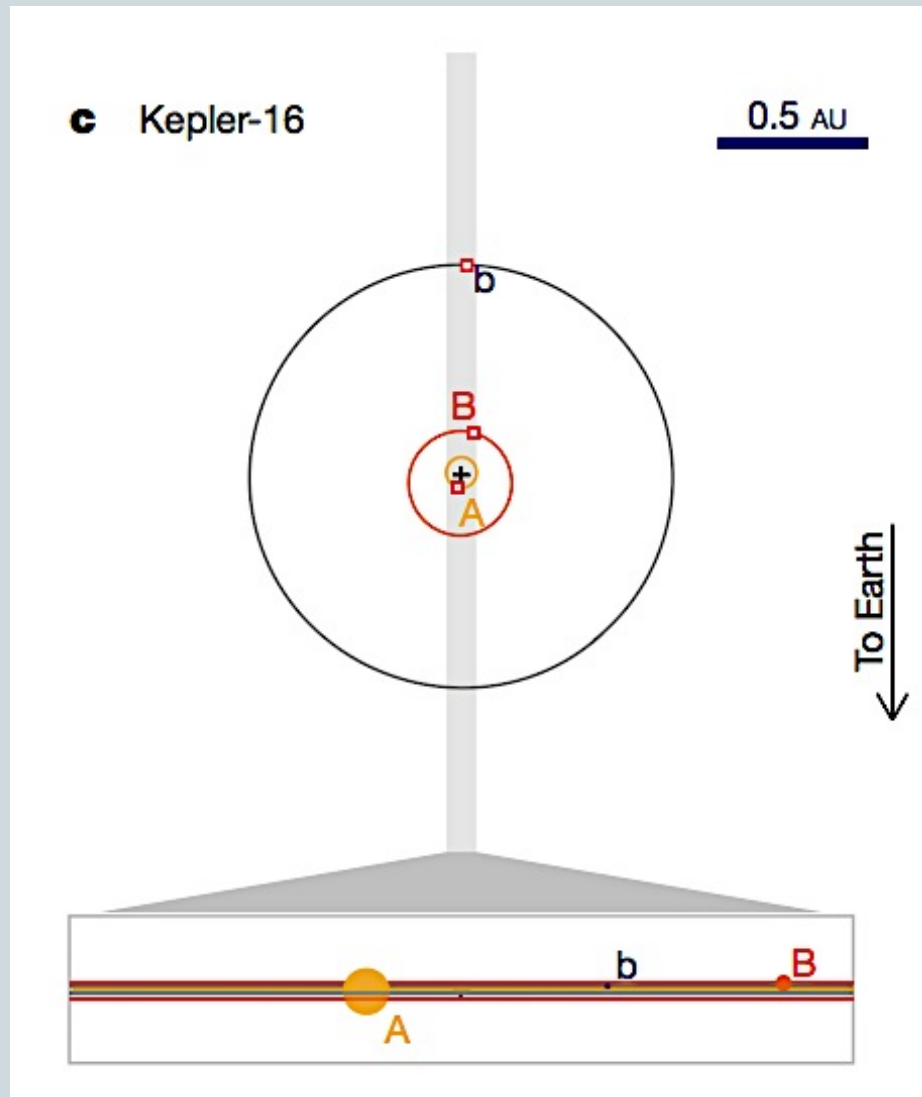


2011: First **confirmed transiting** CBP (MS)

(Movie Credit: NASA/JPL-Caltech/Tim Pyle)



2011: First **confirmed transiting CBP (MS)** In the extended HZ (Kepler-16, Doyle et al. 2011)



$$R_p = 0.75 R_{\text{Jup}}$$
$$P_p = 230 \text{ days}$$

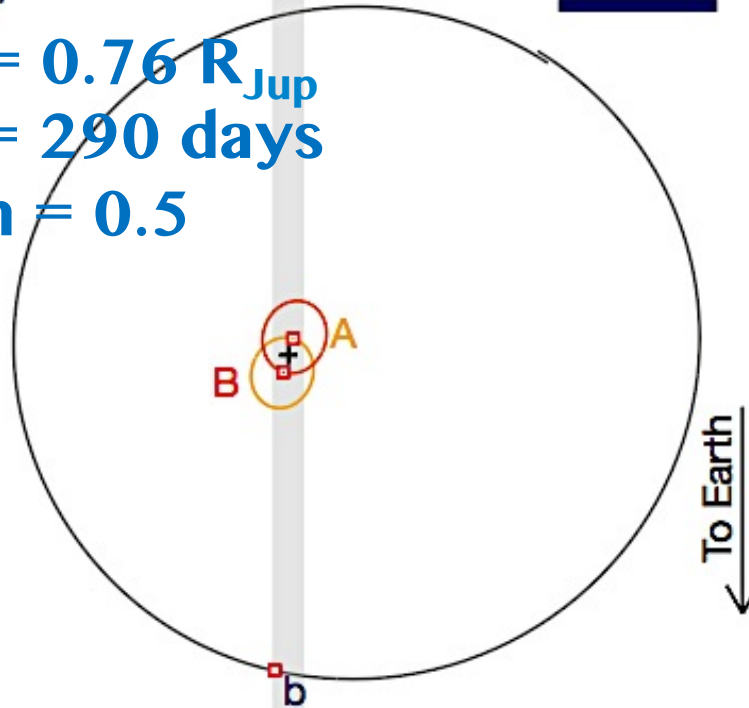
2012: Two CBPs around **Solar-type** stars

(Kepler-34 and -35, Welsh et al. 2012)

a Kepler-34

$R_p = 0.76 R_{Jup}$
 $P_p = 290$ days
 $e_{bin} = 0.5$

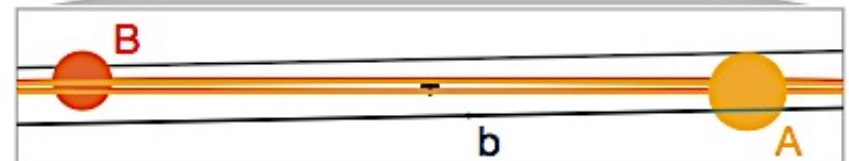
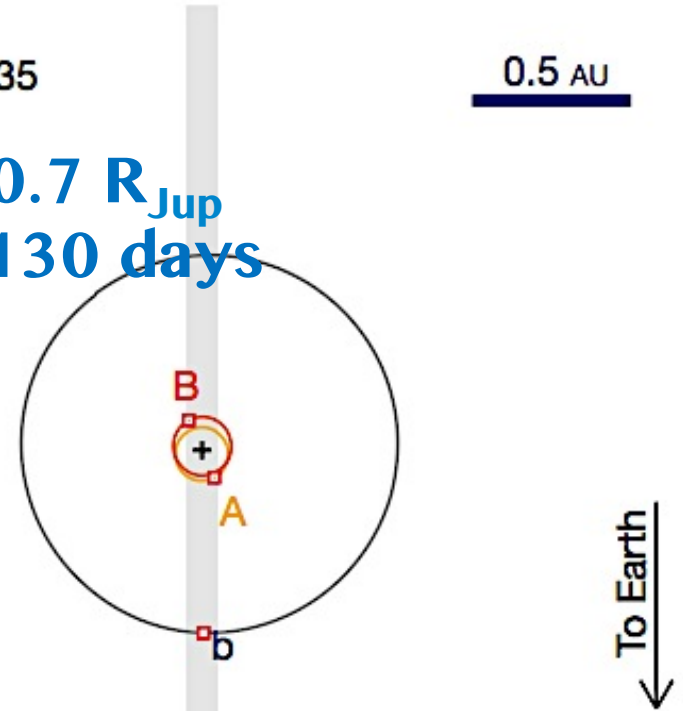
0.5 AU



b Kepler-35

$R_p = 0.7 R_{Jup}$
 $a_p = 130$ days

0.5 AU



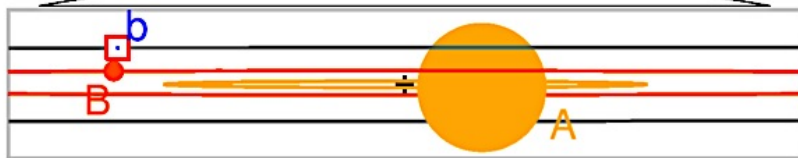
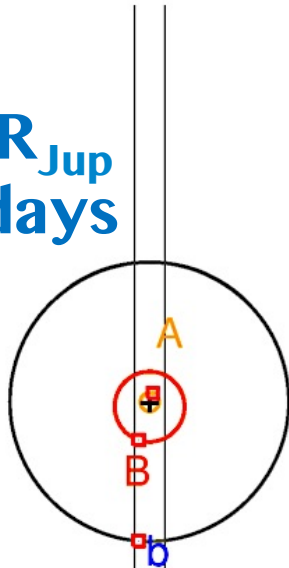
2012: Neptune-sized CBP; multiplanet CB system

(Kepler-38, Orosz et al. 2012a); (Kepler-47, Orosz et al. 2012b)

Kepler-38

$R_p = 0.39 R_{Jup}$
 $P_p = 106$ days

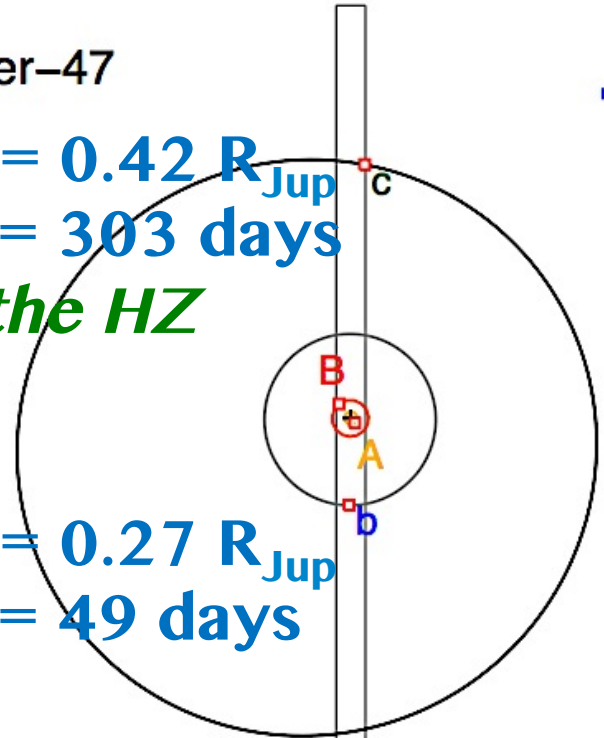
0.5 AU



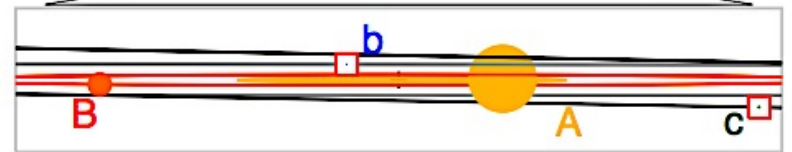
Kepler-47

$R_p = 0.42 R_{Jup}$
 $P_p = 303$ days
In the HZ

0.5 AU



$R_p = 0.27 R_{Jup}$
 $P_p = 49$ days

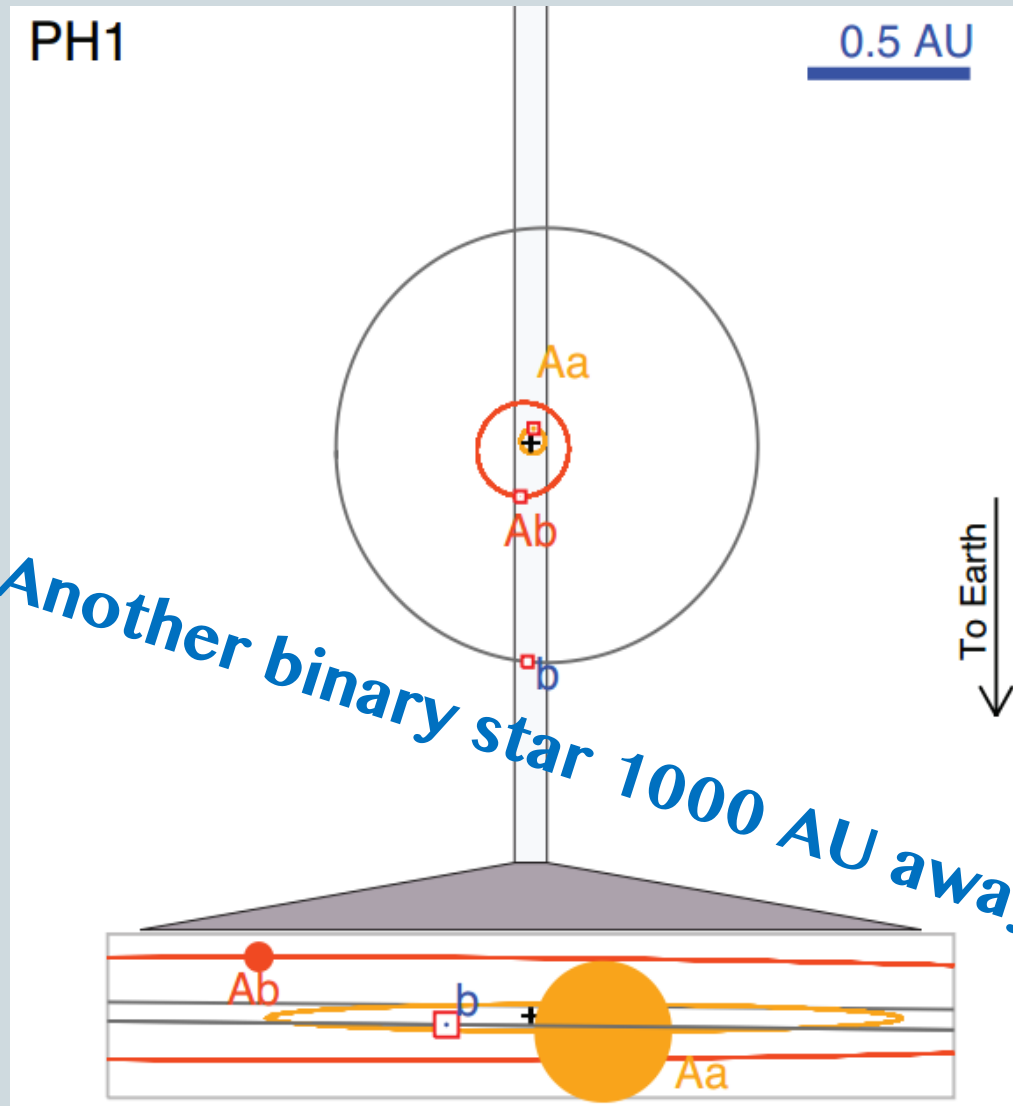


To Earth
↓

To Earth
↓

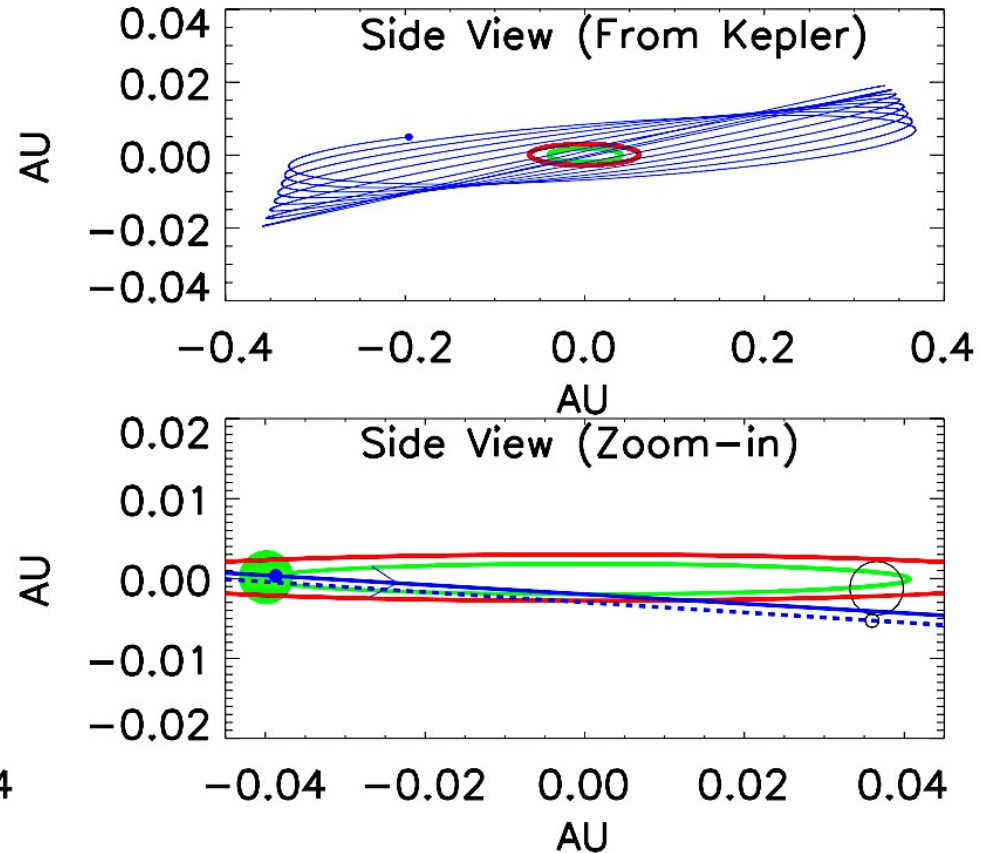
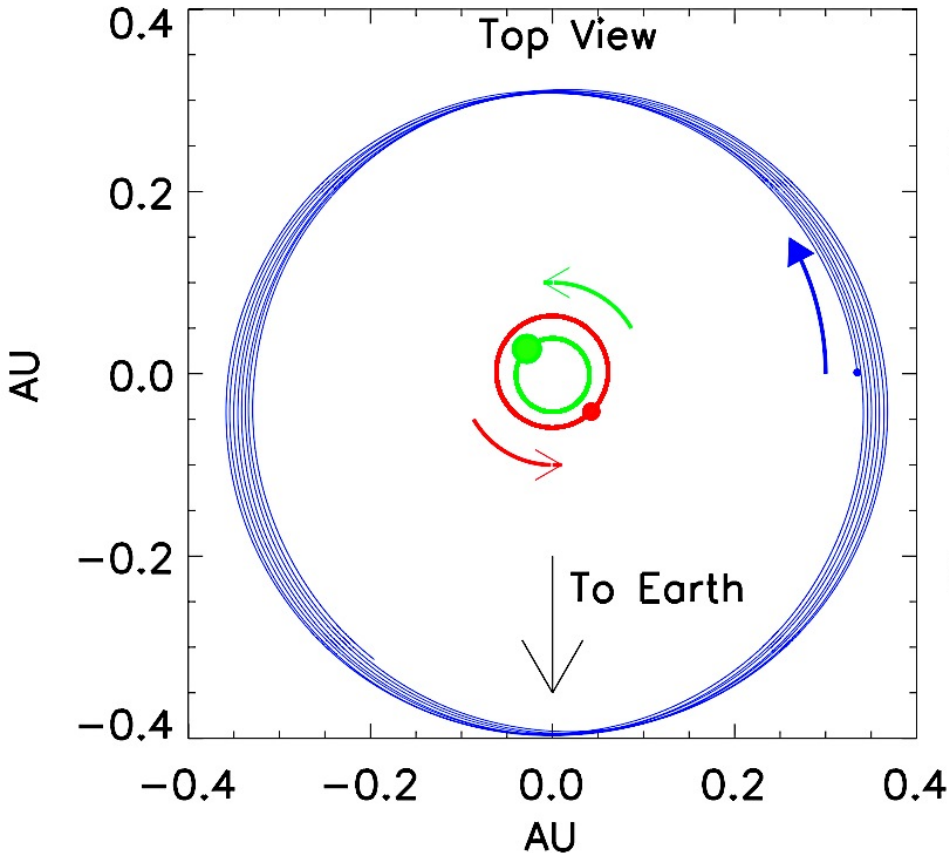
2013: CBP in a **quadruple** stellar system

(Kepler-64, Kostov et al. 2013; Schwamb et al. 2013)



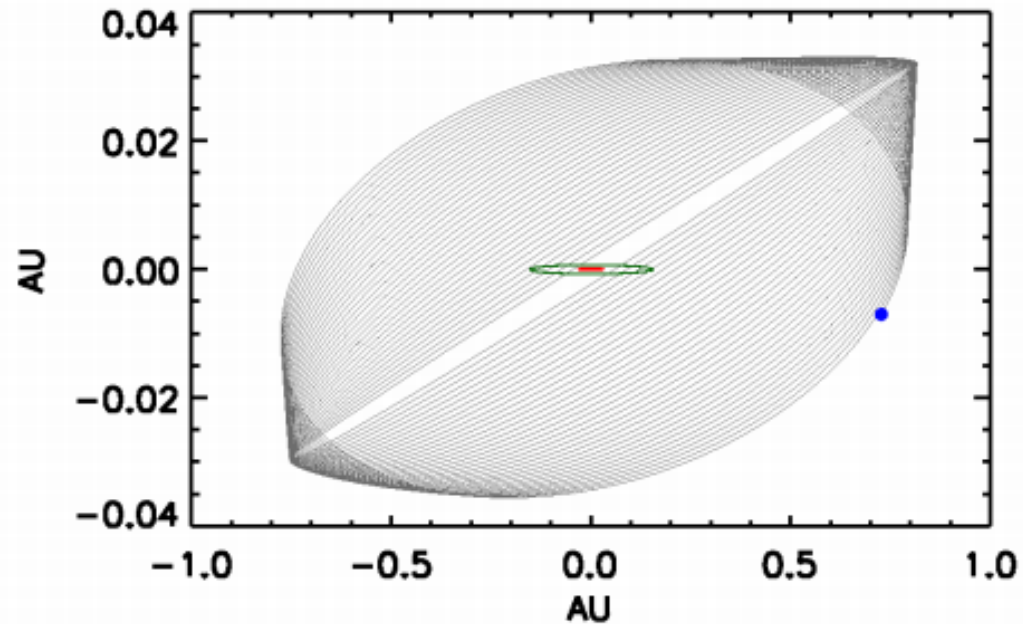
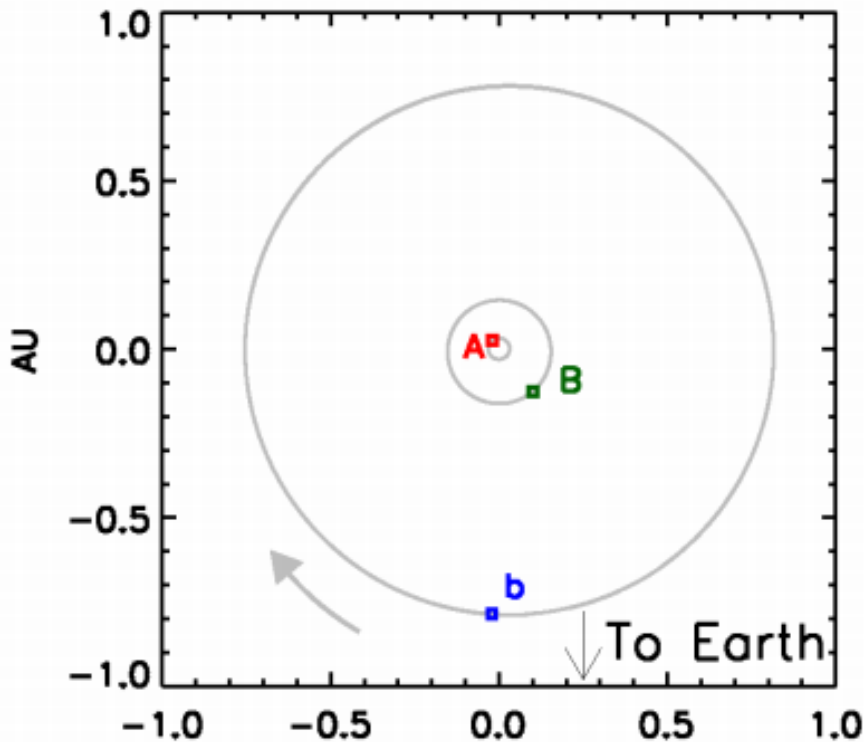
$R_p = 0.57 R_{\text{Jup}}$
 $P_p = 139 \text{ days}$

**2014: Slightly misaligned CBP that
“missed” more often than it “hit”**
(Kepler-413, Kostov et al. 2014)



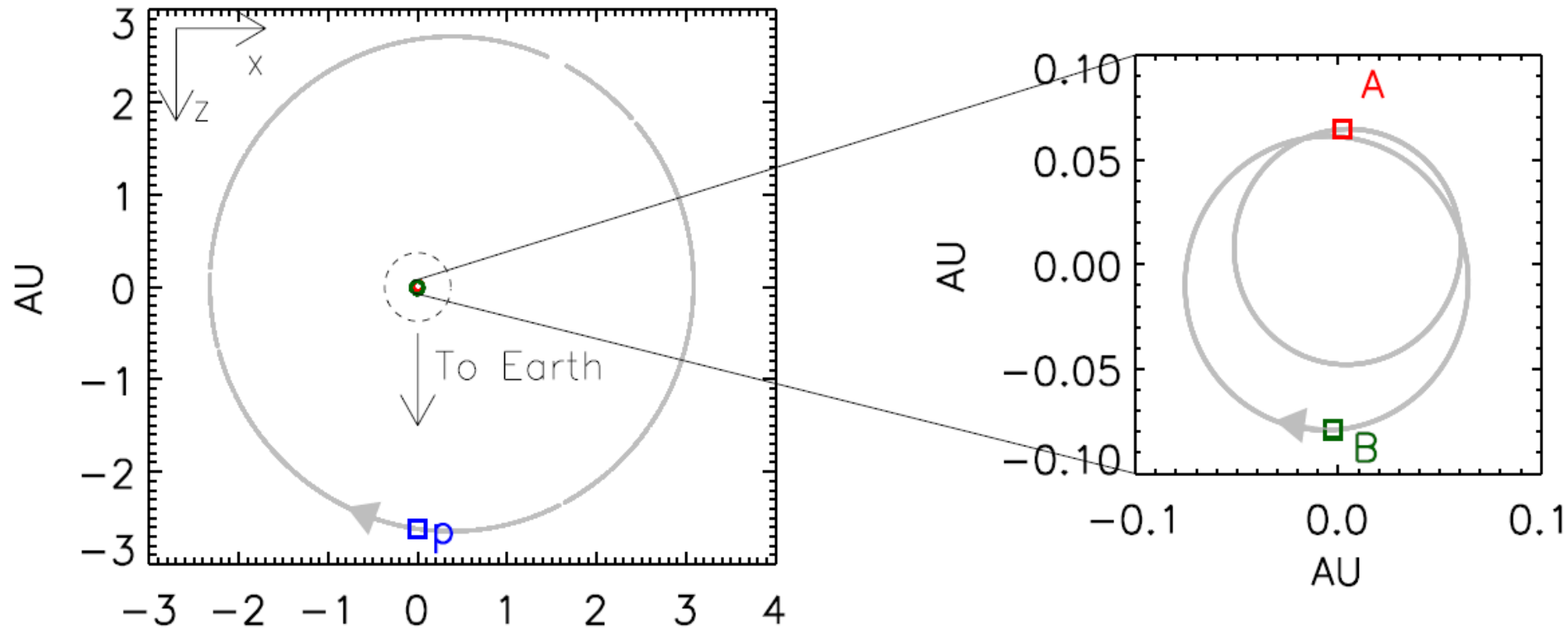
$R_p = 0.56 R_{\text{Jup}}$
 $P_p = 66 \text{ days}$

2015: Slightly misaligned CBP that **did not start transiting until 800 days into the mission; **in the HZ****
(KOI-3151, Welsh et al. 2015)



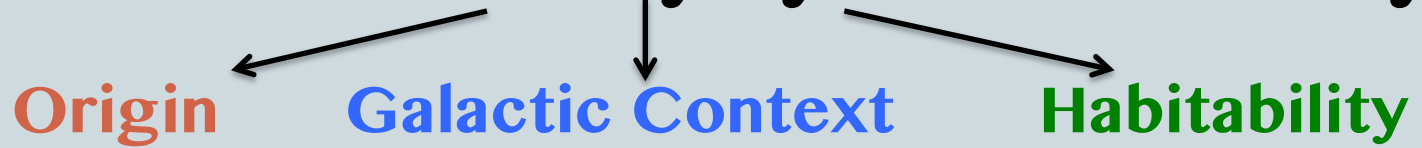
$R_p = 0.55 R_{\text{Jup}}$
 $P_p = 240 \text{ days}$

2015: CBP that was at inferior conjunction **only twice** during *Kepler* (KOI-2939, Kostov et al. in prep.)

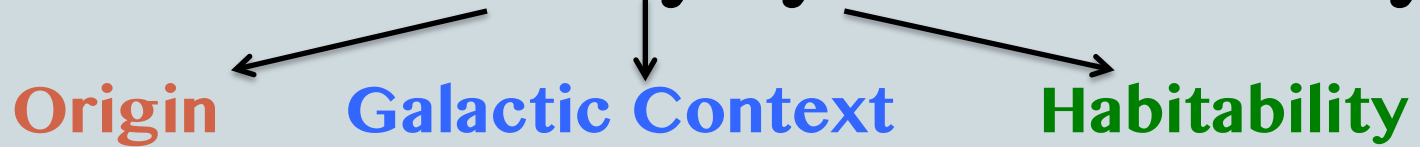


$R_p = 1.1 R_{Jup}$
 $P_p = 1100$ days

Planets in MS Binary Systems -- Theory



Planets in MS Binary Systems -- Theory



- *Formation* : common; Saturn-size and smaller; (nearly) co-planar
- *Migration* : towards the outer edge of the precursor CB cavity
- *Dynamics* : stability (distance from the critical limit); orbital precession

[e.g. Pierens & Nelson (2007ab, 2008, 2013); Alexander (2013); Foucart & Lai (2013, 2014); Marzari et al. (2013); Martin et al. (2013); Meschiari (2013); Paardekooper et al. (2012); Youdin et al. (2012), Rafikov (2013, 2014); Thebaut & Haghighipour (2014); Kley & Haghighipour (2014, 2015); Liu et al. (2014); Martin & Triaud (2014); Hamers et al. (2015); Martin et al. (2015); Bromley & Kenyon (2015); Chavez et al. (2015); Silsbee & Rafikov (2015); Hinse et al. (2015); Armstrong et al. (2015)]

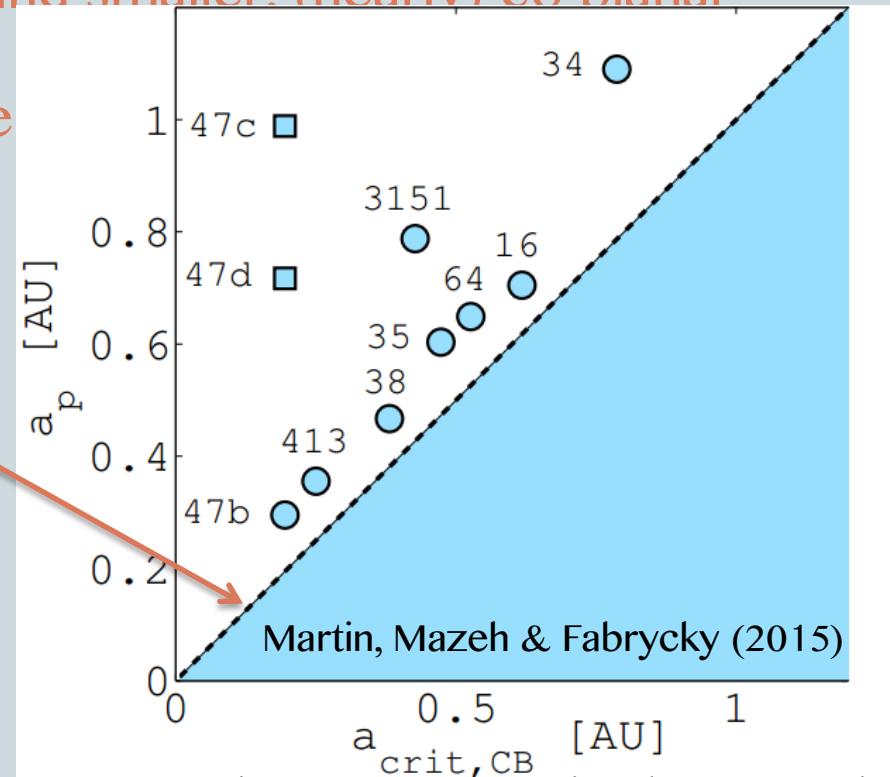
Planets in MS Binary Systems -- Theory

Origin

Galactic Context

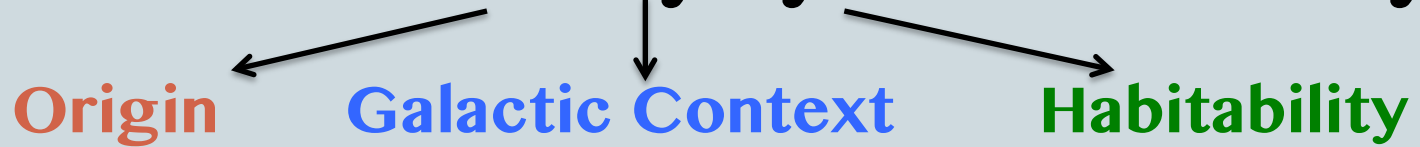
Habitability

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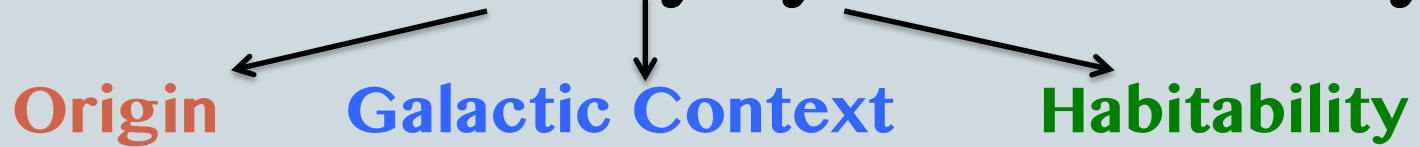
Planets in MS Binary Systems -- Theory



- *Formation* : common; Saturn-size and smaller; (nearly) co-planar
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- *Host systems* : types of binaries capable of supporting CBPs
- *Planet occurrence frequency* : fraction of close binary stars with CBPs

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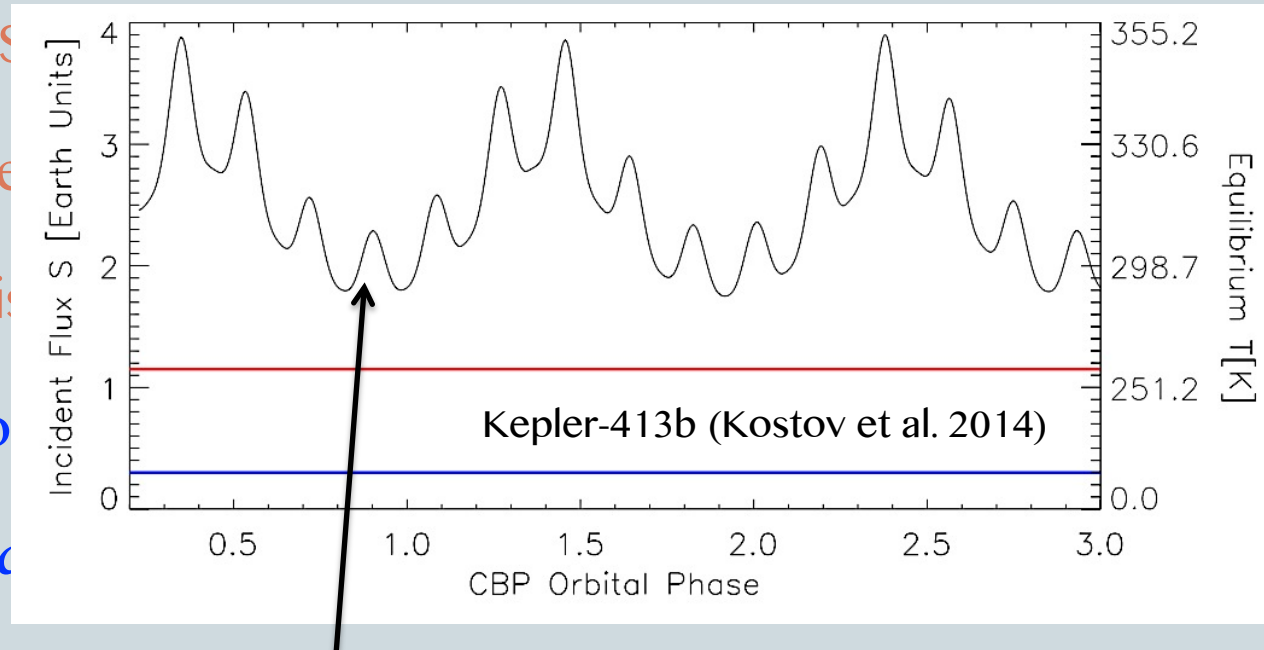
Planets in MS Binary Systems -- Theory

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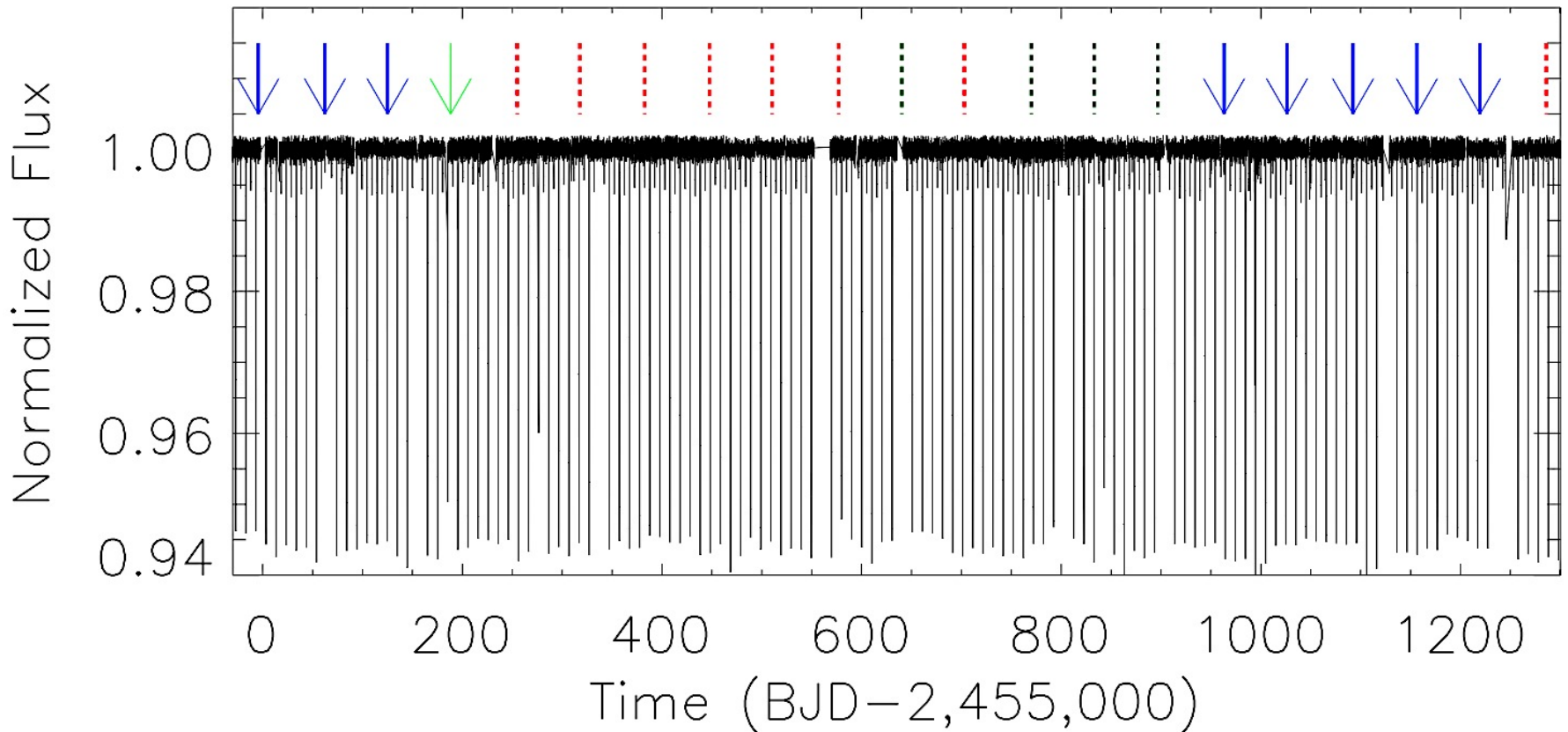


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Prediction -- Missed Transits!

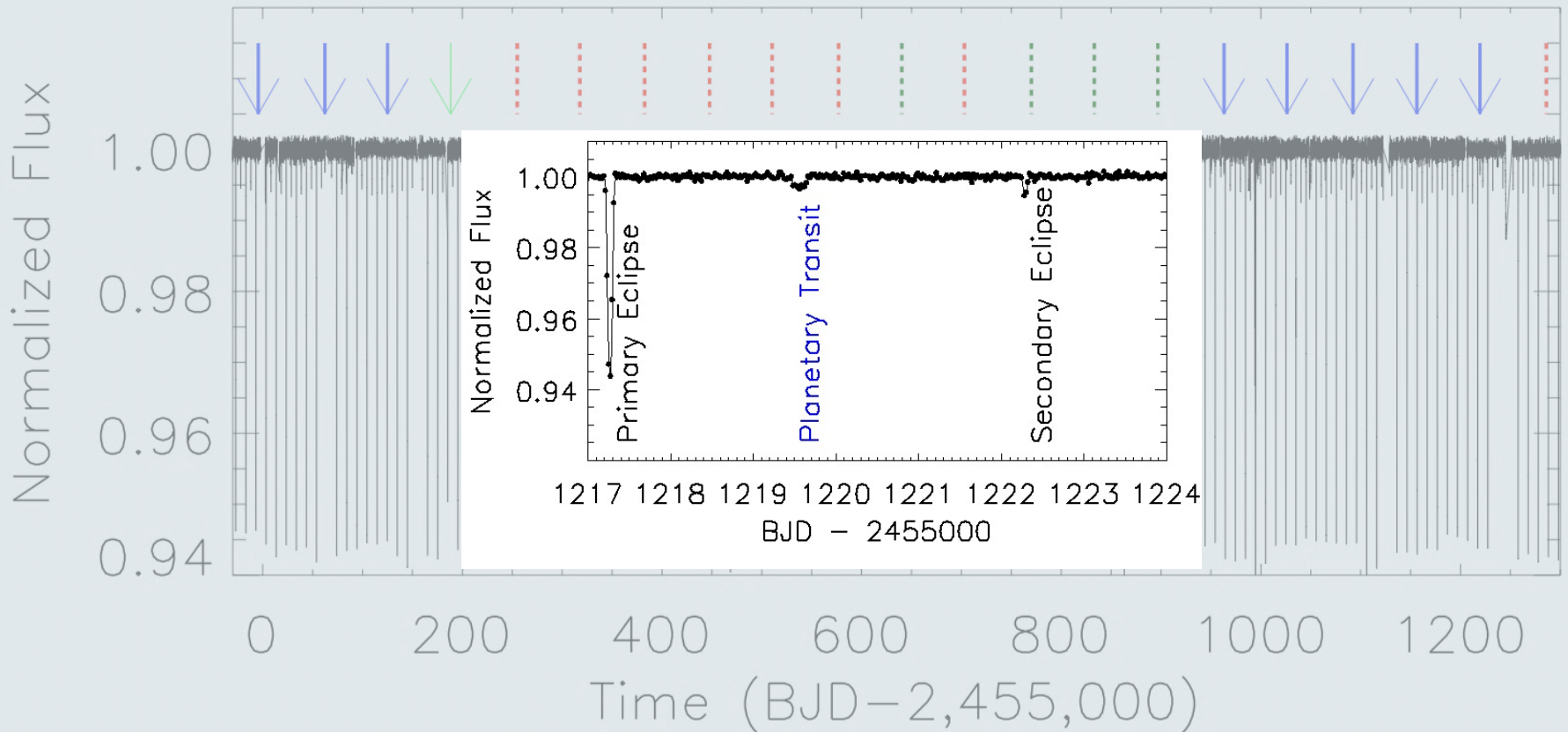
Blue = Transit Red = Miss Dark Green = Data Gap



Light curve of CBP system Kepler-413 (Kostov et. al 2014)

Prediction -- Missed Transits!

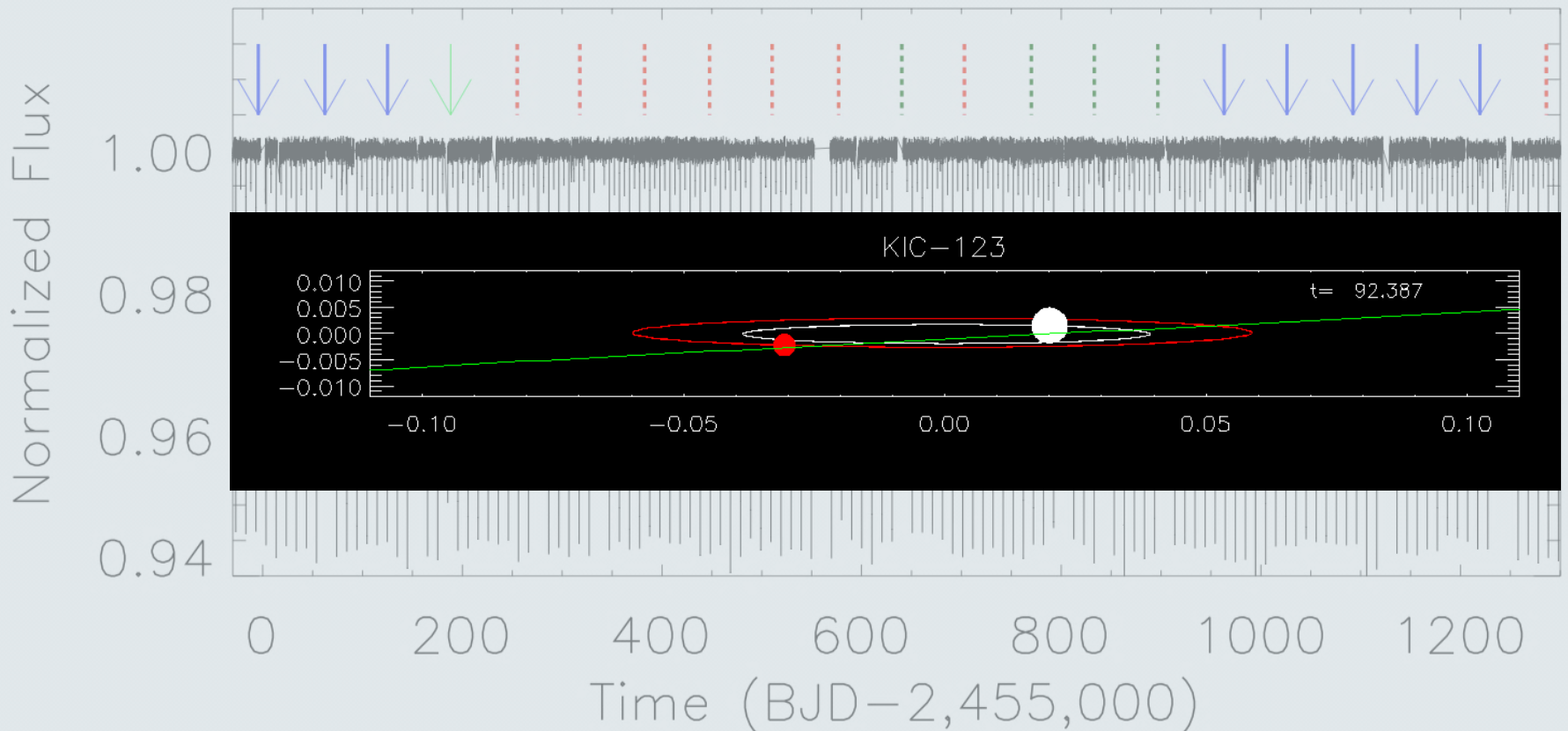
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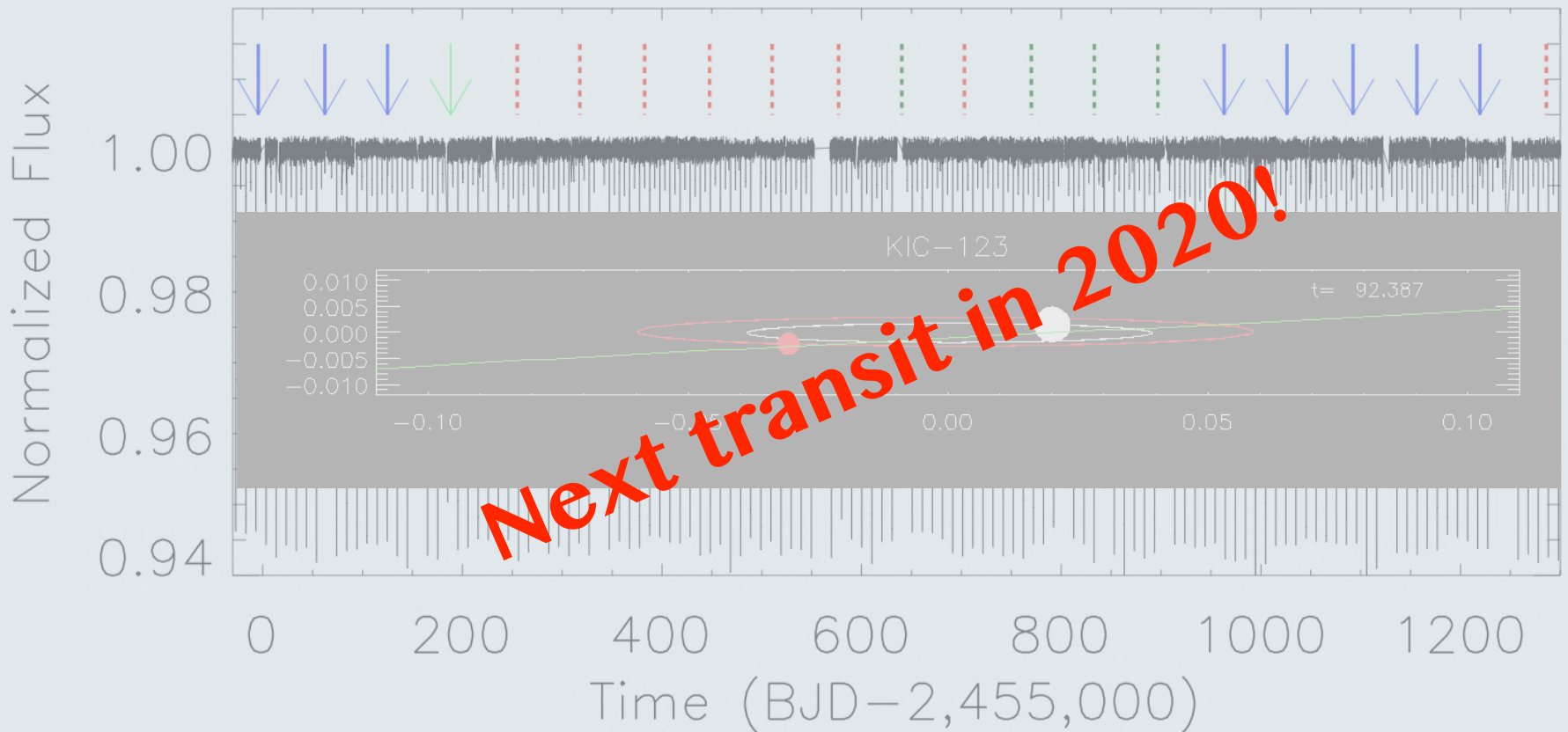
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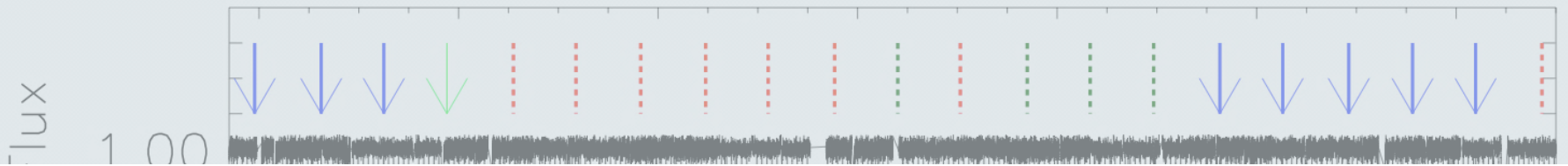
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Prediction -- Missed Transits!

Blue = Transit

Red = Miss

Dark Green = Data Gap



On the occultations of a binary star by a circum-orbiting dark companion

J. Schneider

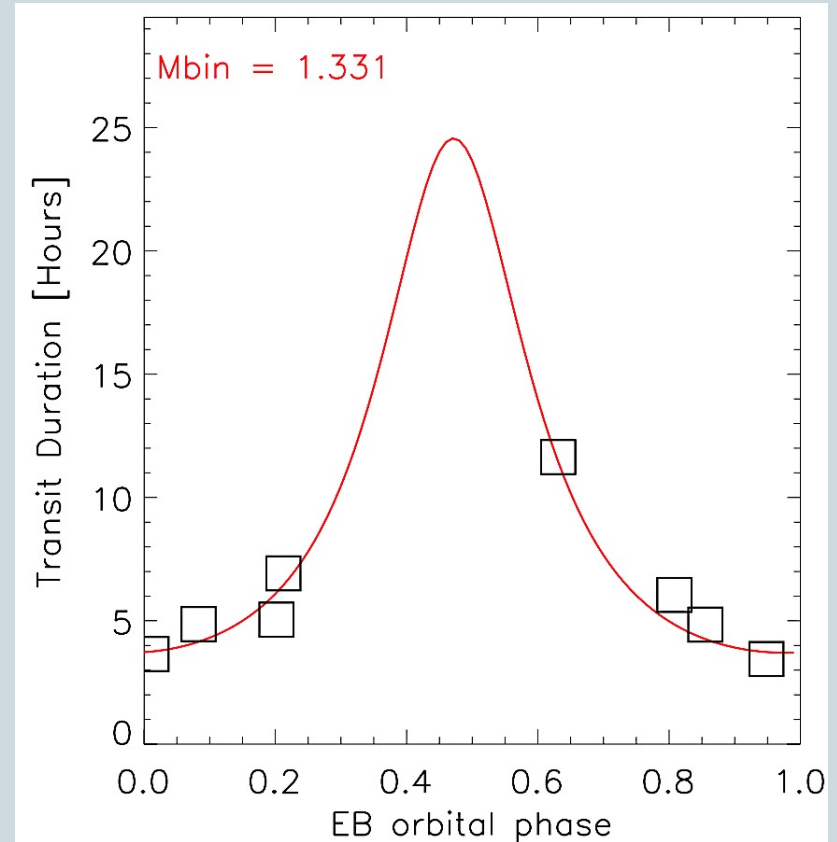
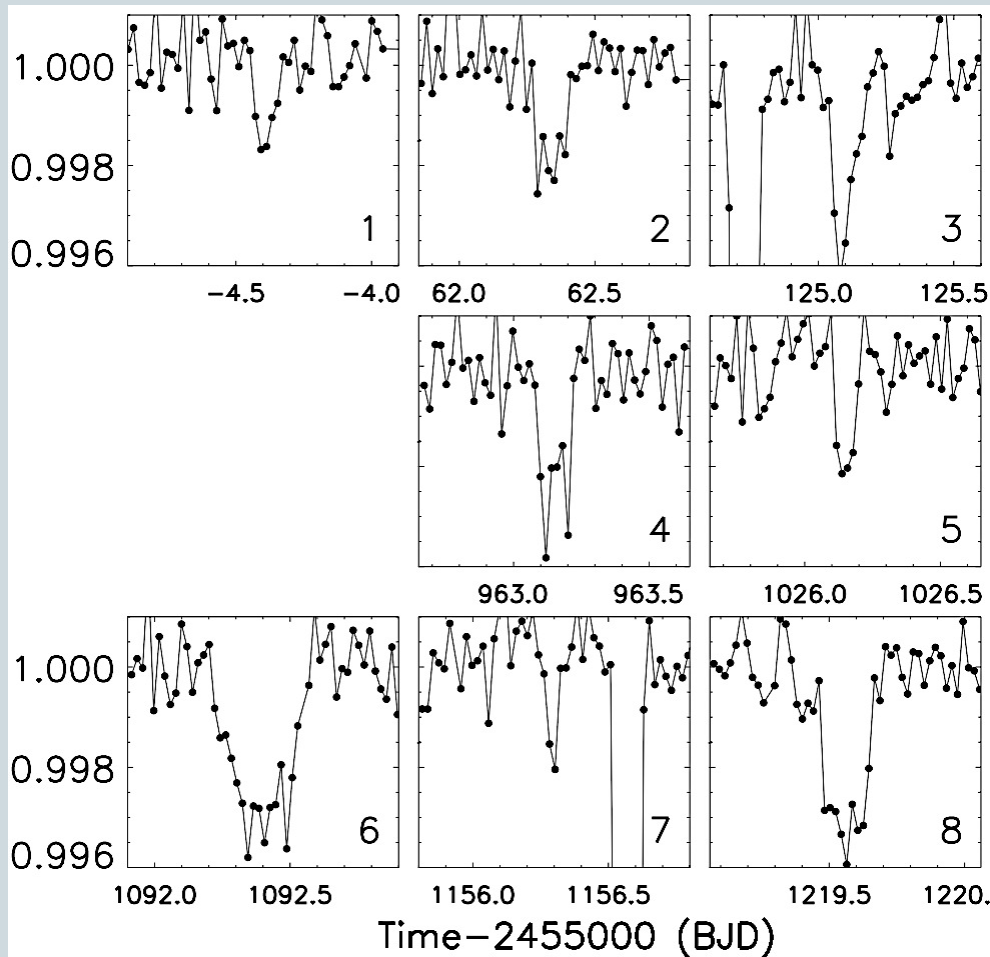
CNRS-UPR 176, Observatoire de Paris, 92195 Meudon, France

Received 12 August 1993; revised 6 May 1994; accepted 6 May 1994



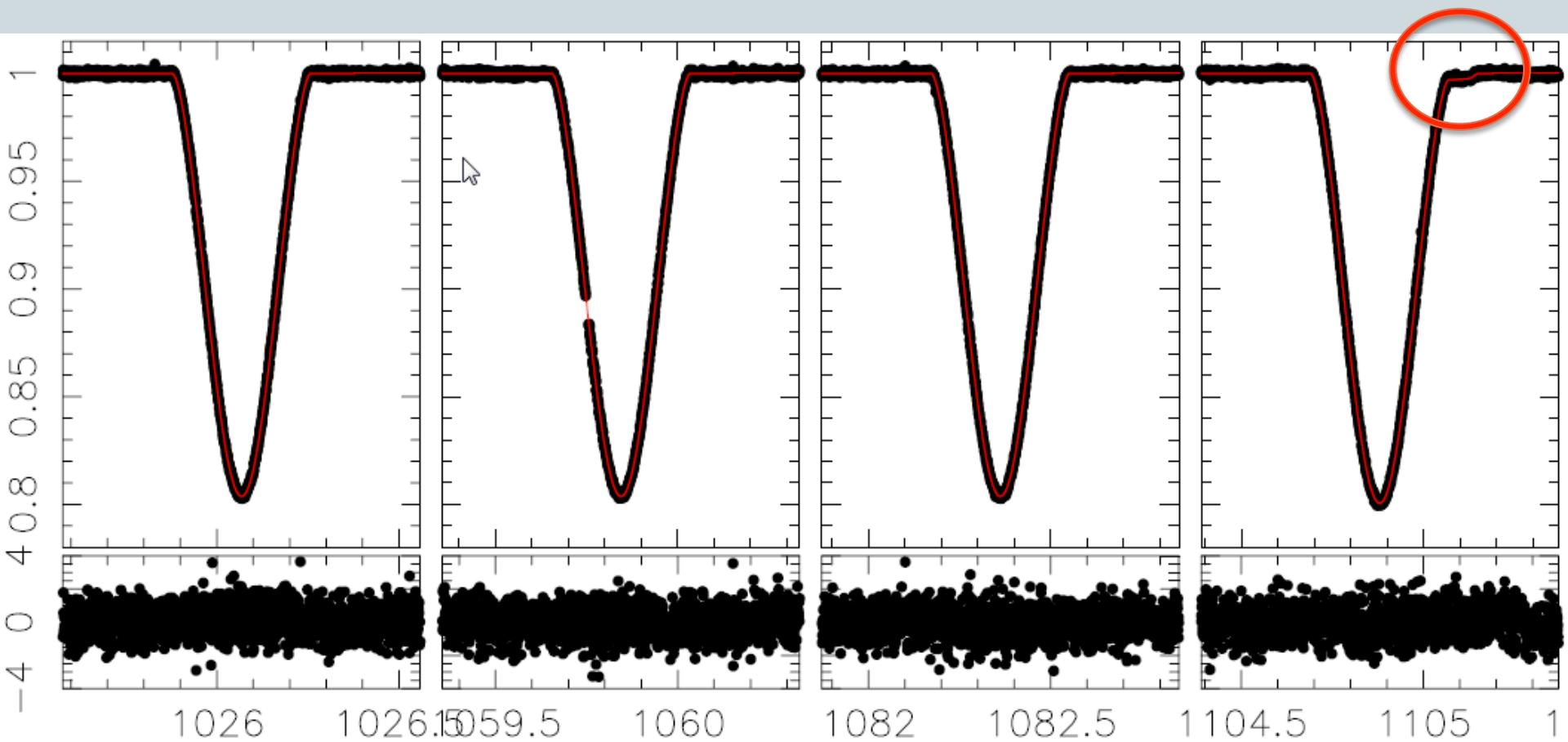
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Aperiodic Transits



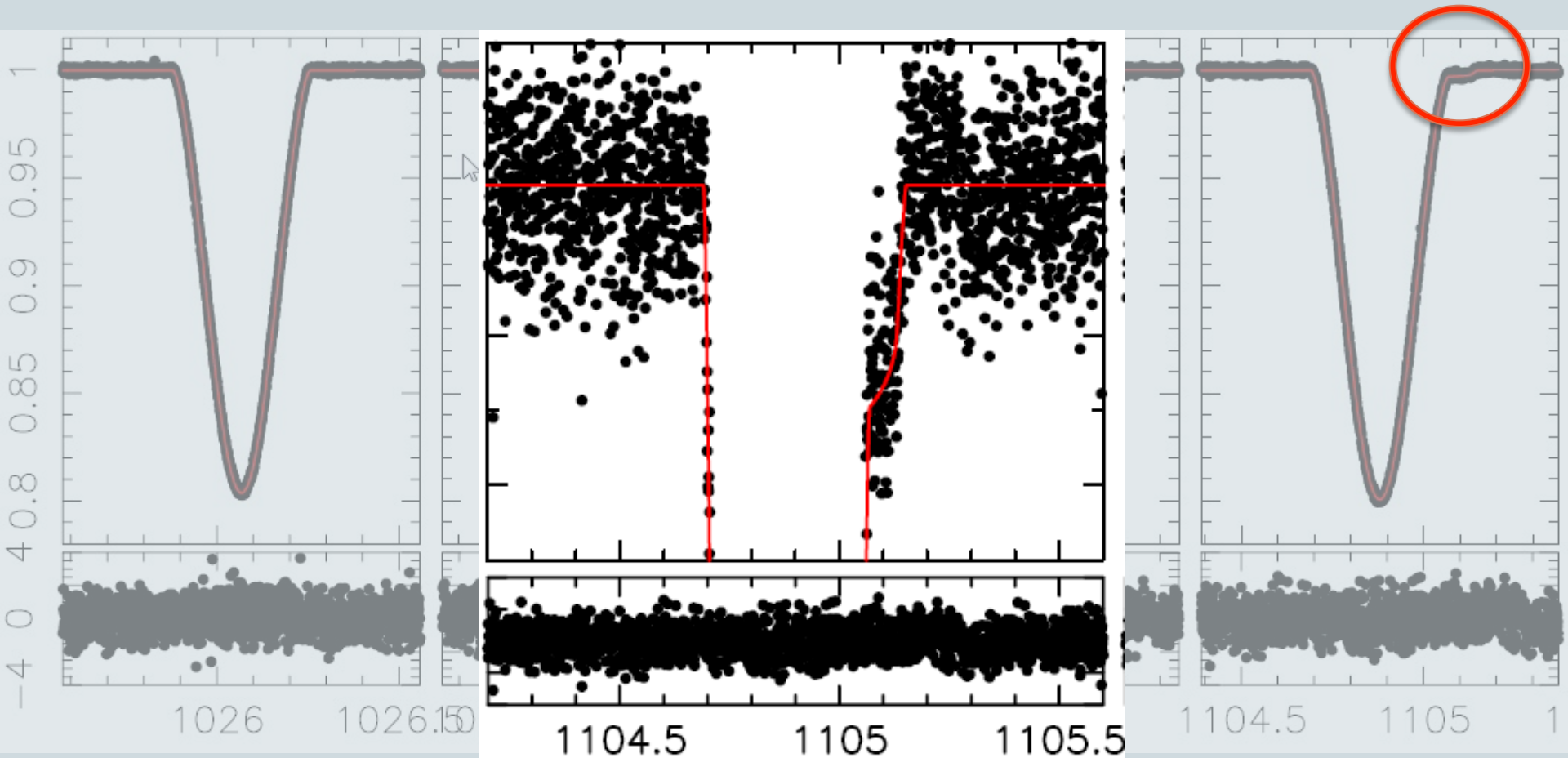
Kepler-413b (Kostov et al. 2014)

Blended Transits



KOI-2939 (Kostov et al. in prep.)

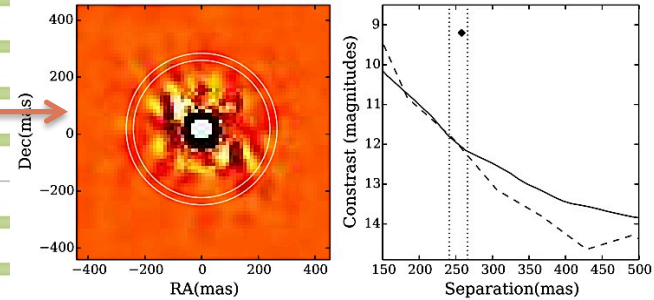
Blended Transits



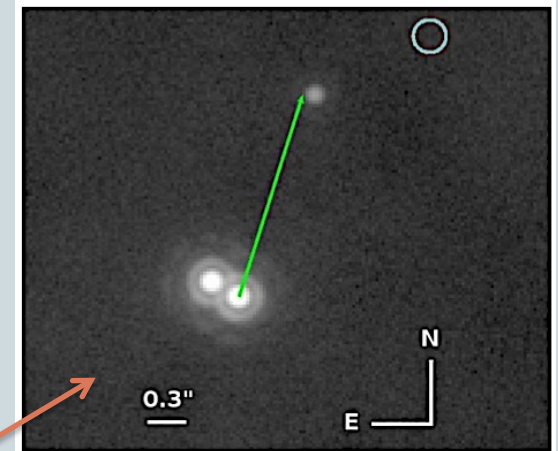
KOI-2939 (Kostov et al. in prep.)

CBPs candidates (non-transiting, not *Kepler*)

Target	CBP orbit [AU]	CBP mass [M _{jup}]	Comments
PSR B1620-26	23	2.5	
HD 181086	0.4		
CM Dra	1.2	1.5-3	
V 471 Tau	12	46--111	
SZ Her b	17	190	Unstable
SZ Her c	27	220	Unstable
RZ Dra	24	70	Unstable
RR Cae	5	4	
HW Vir c	4.7	14.3	Unstable
HW Vir d	13	30--120	Unstable
NSVS14256825 c	2	2.8	Unstable
NSVS14256825 d	2.9	8	Unstable
HU Aqr	4	7	Unstable
HS 0705+6700	3.5	32	
HS 2231+2441	5	14	
UZ For c	6	7	Stable
UZ For d	2.8	7.7	Stable
NY Vir c	3.3	2.3	Stable
NY Vir d	5	2.2	Stable
NN Ser c	5	7	Stable
NN Ser d	3.4	2.3	Stable
QS Vir	6	9	Unstable
QS Vir	7	57	Unstable
DP Leo	8	6	
2MASS J01033563	84	12--14	Direct Imaging



V 471 Tau
(VLT SPHERE, Hardy et al. 2015)

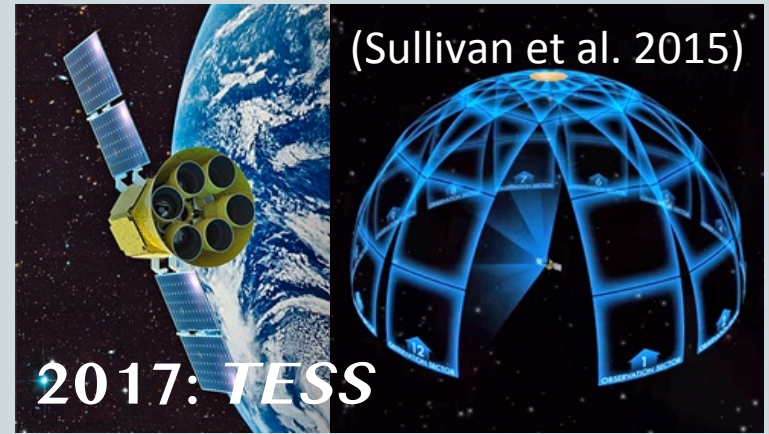


2M J0103
(VLT NACO, Delorme et al. 2013)

What's next?



What's next?

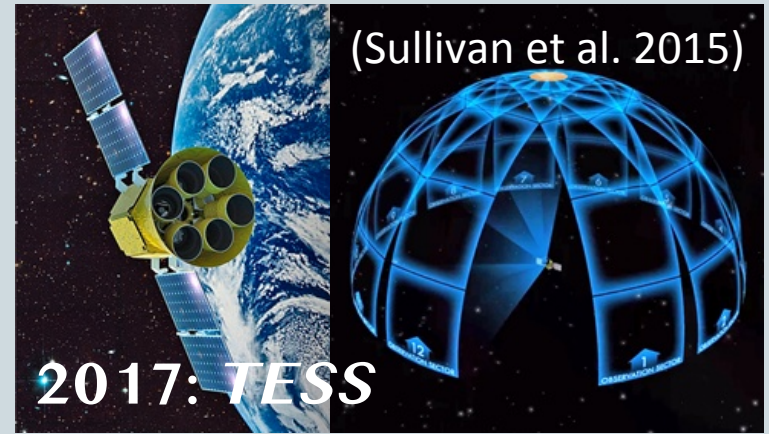


What's next?



Also see Amaury's talk,
Thursday 9 am

What's next?

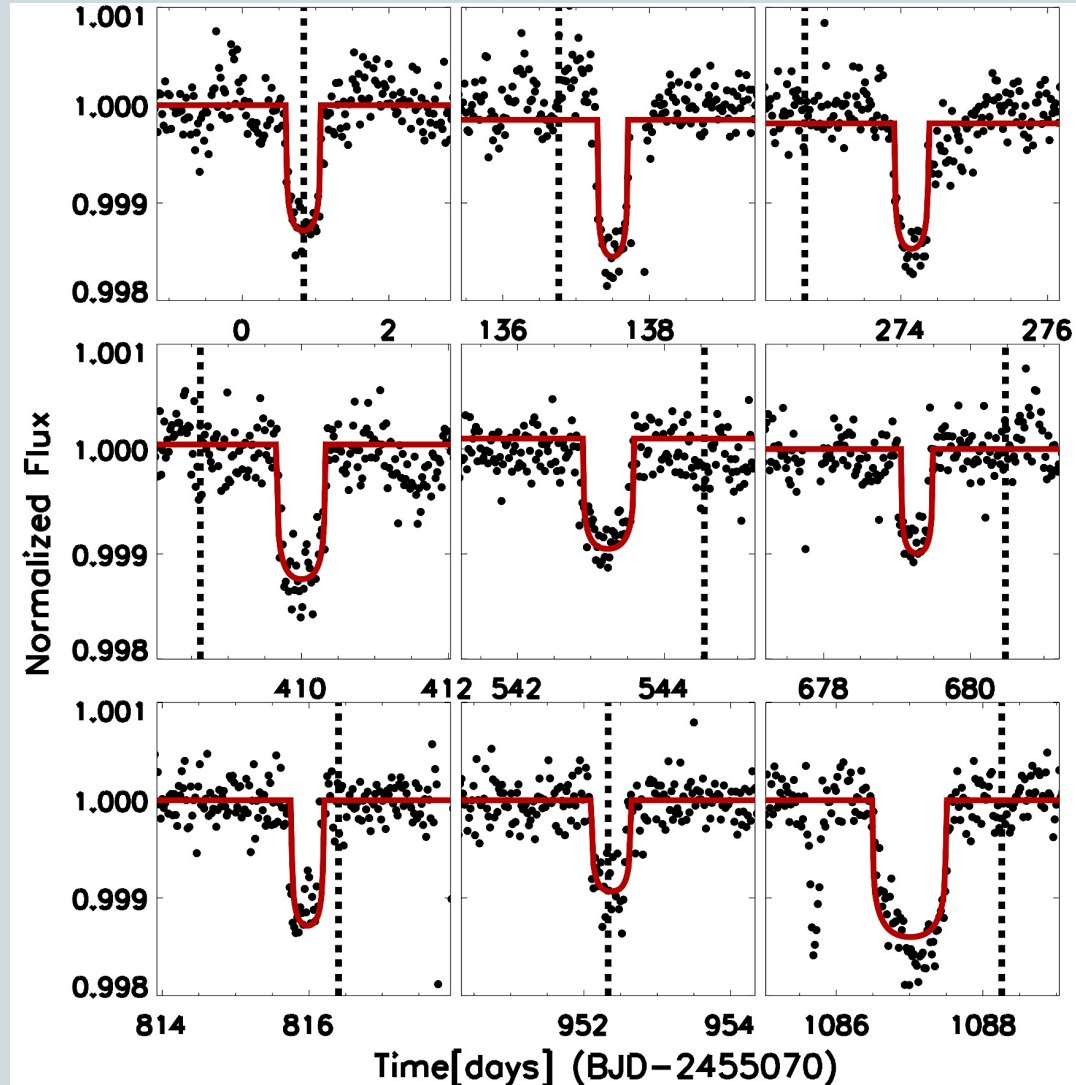


Stay tuned!



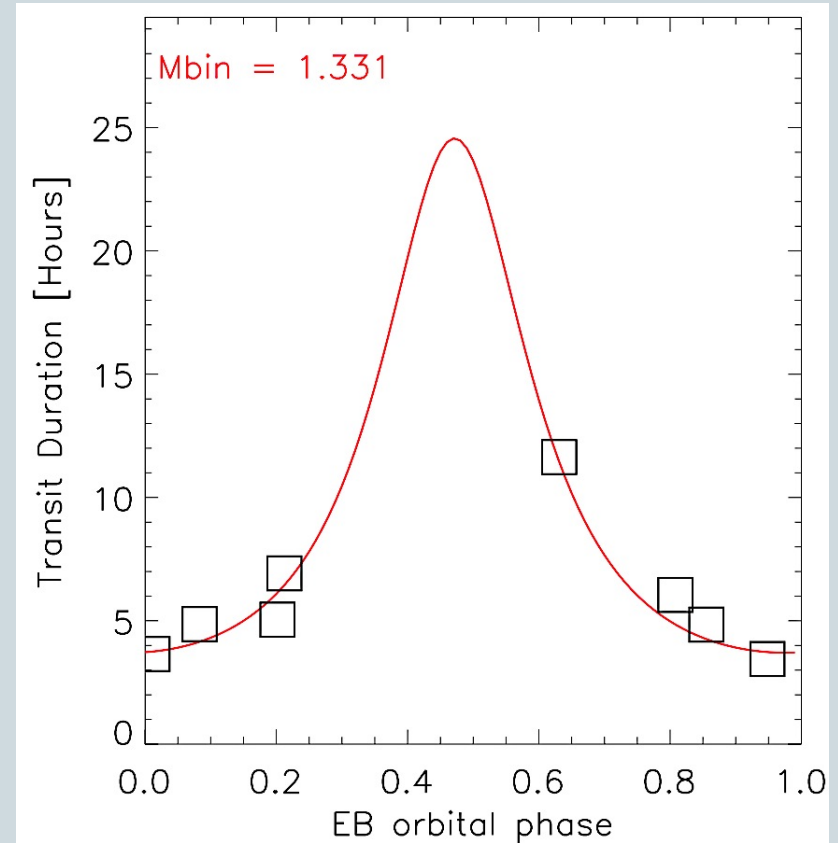
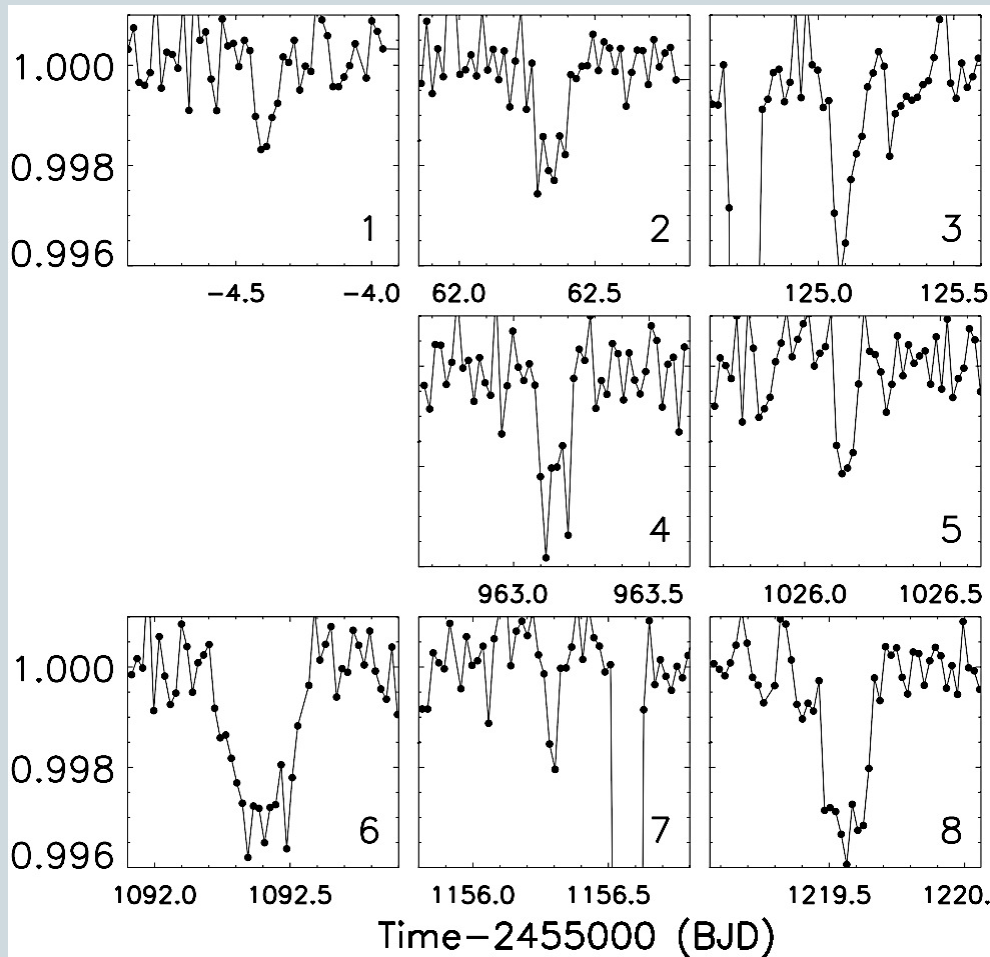
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Aperiodic Transits



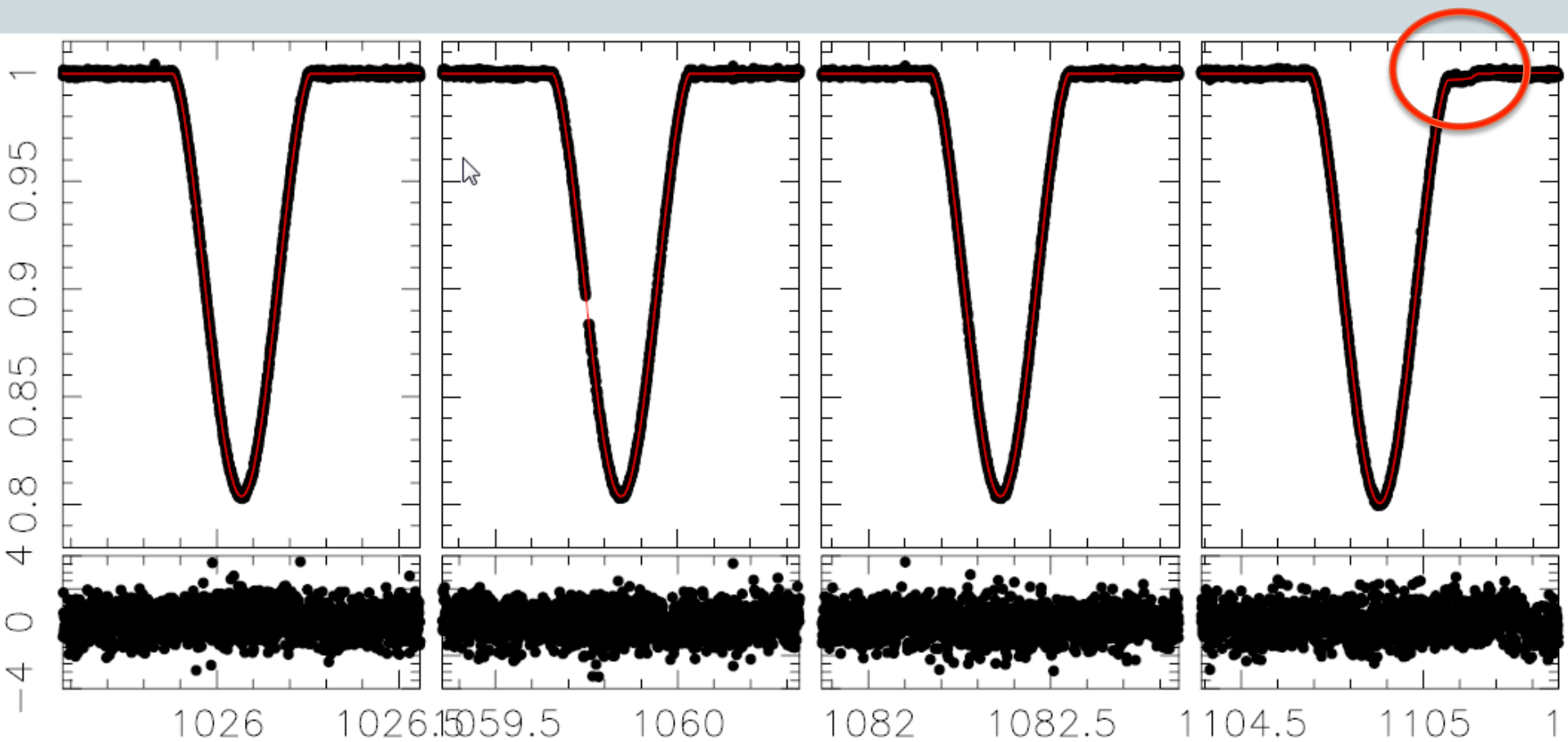
Kepler-64b (Kostov et al. 2013; Schwamb et al. 2013)

Aperiodic Transits



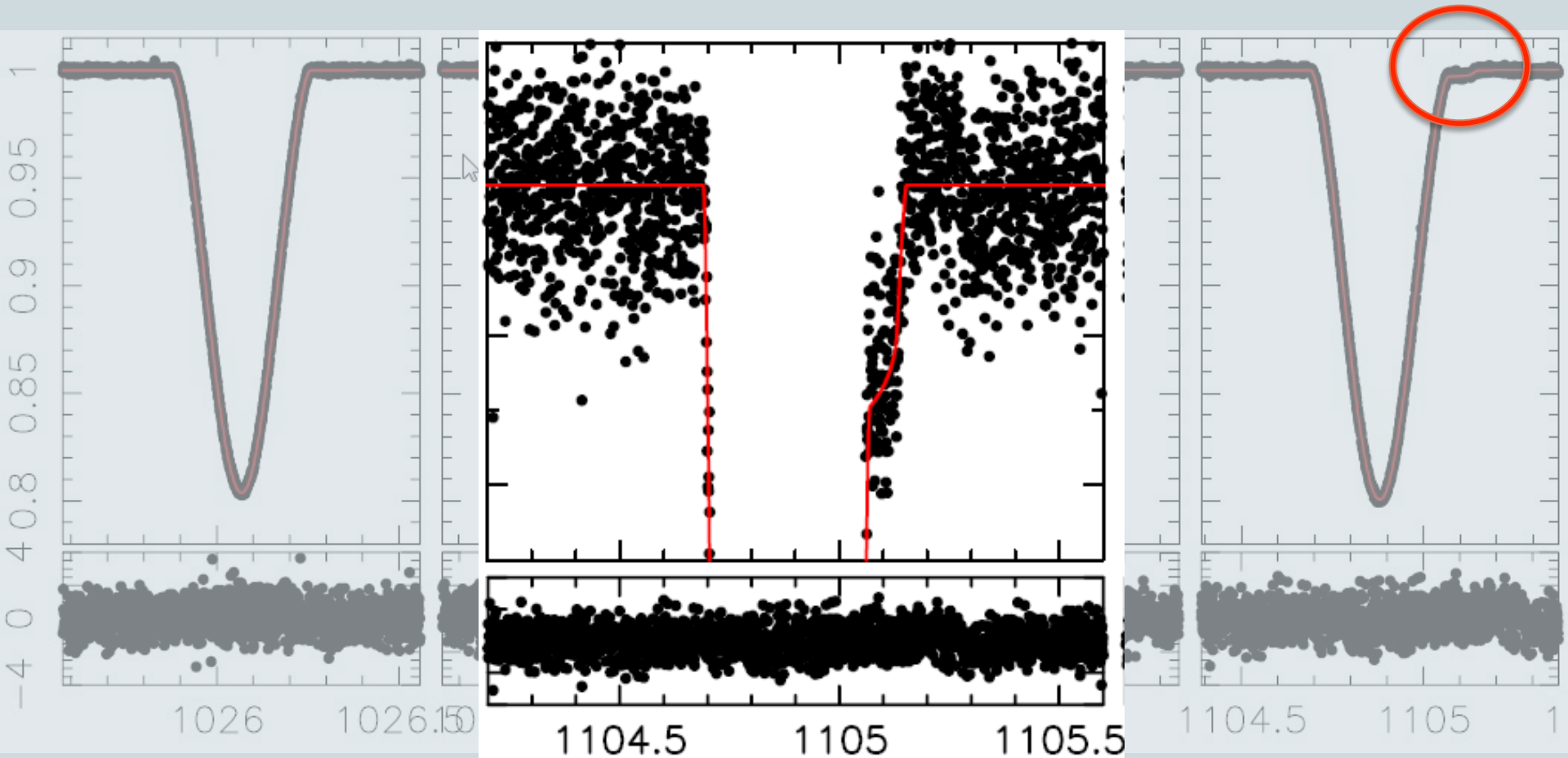
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