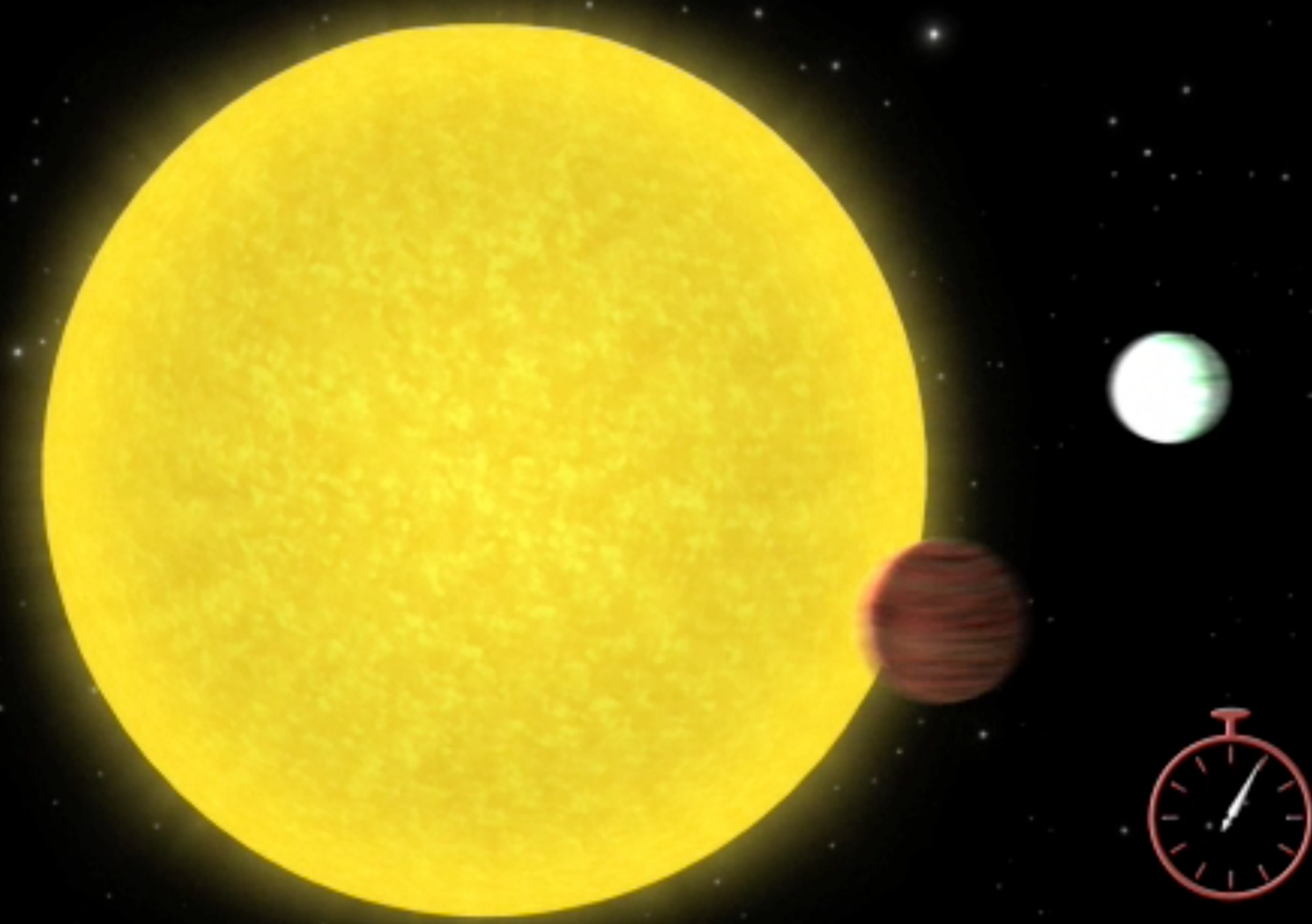
10th RESCEU/Planet^2 Symposium Planet Formation around Snowline
@University of Tokyo (Nov.28, 2017)

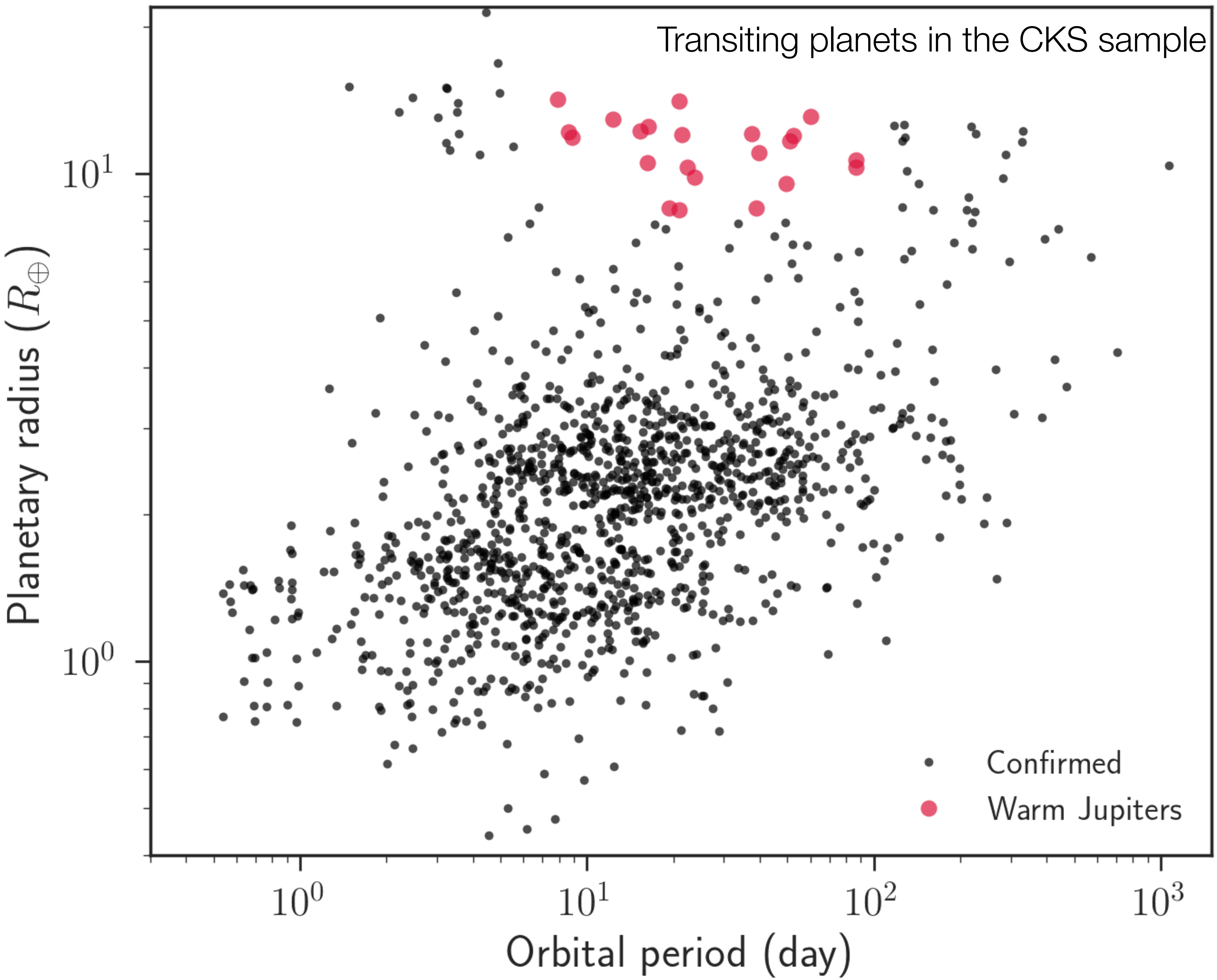
Eccentric companions to two Kepler planets: Clues to the formation of warm Jupiters



Kento Masuda (Princeton University/Sagan Fellow)

image credit: NASA Ames Research Center/Kepler Mission

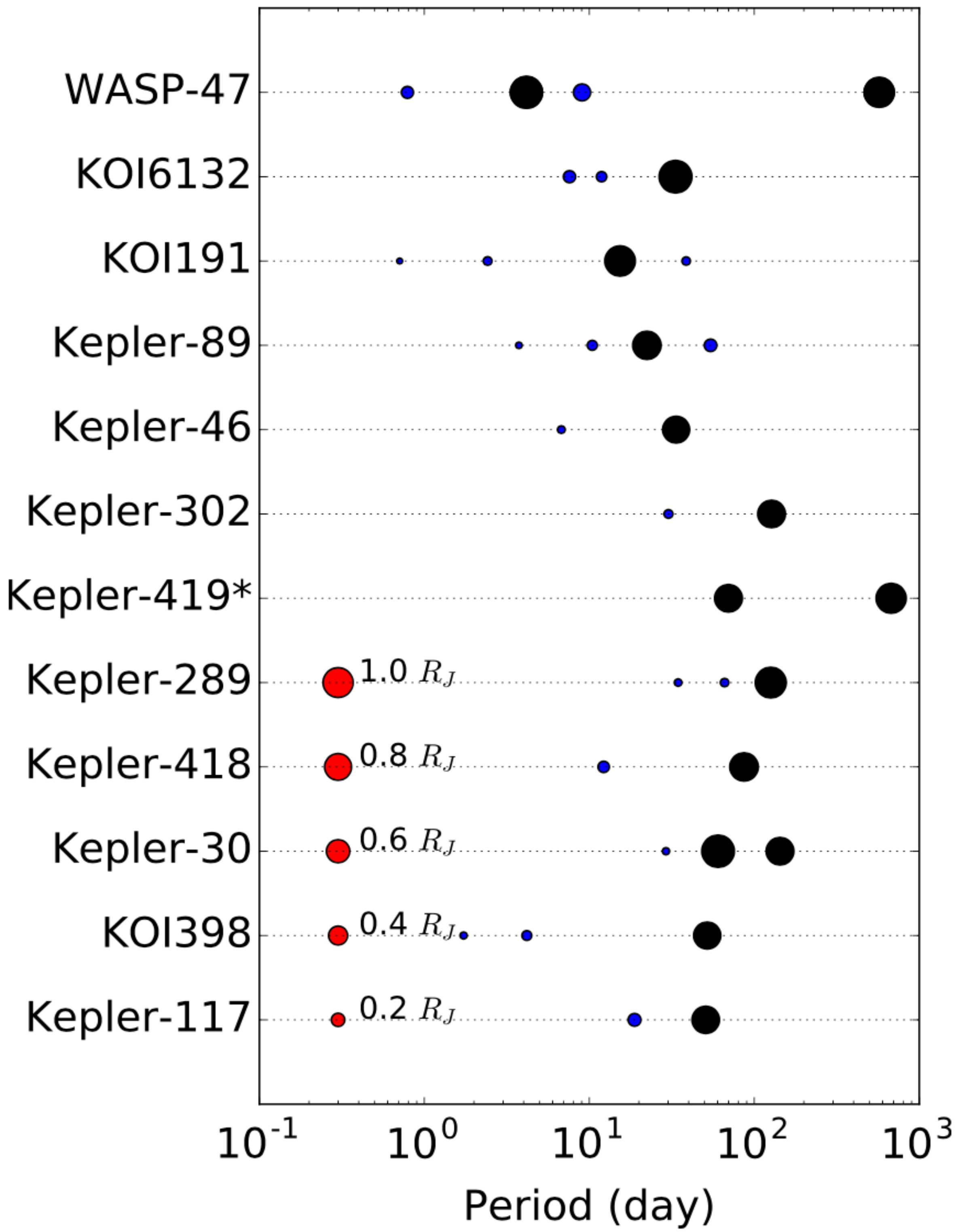
Warm Jupiters: more clues to the migration



Warm Jupiters in multi-transiting systems: quiet formation

Huang et al. (2016)

- 10/27 in multi-transiting systems
- flat planetary orbits -> disk migration (or in-situ formation)



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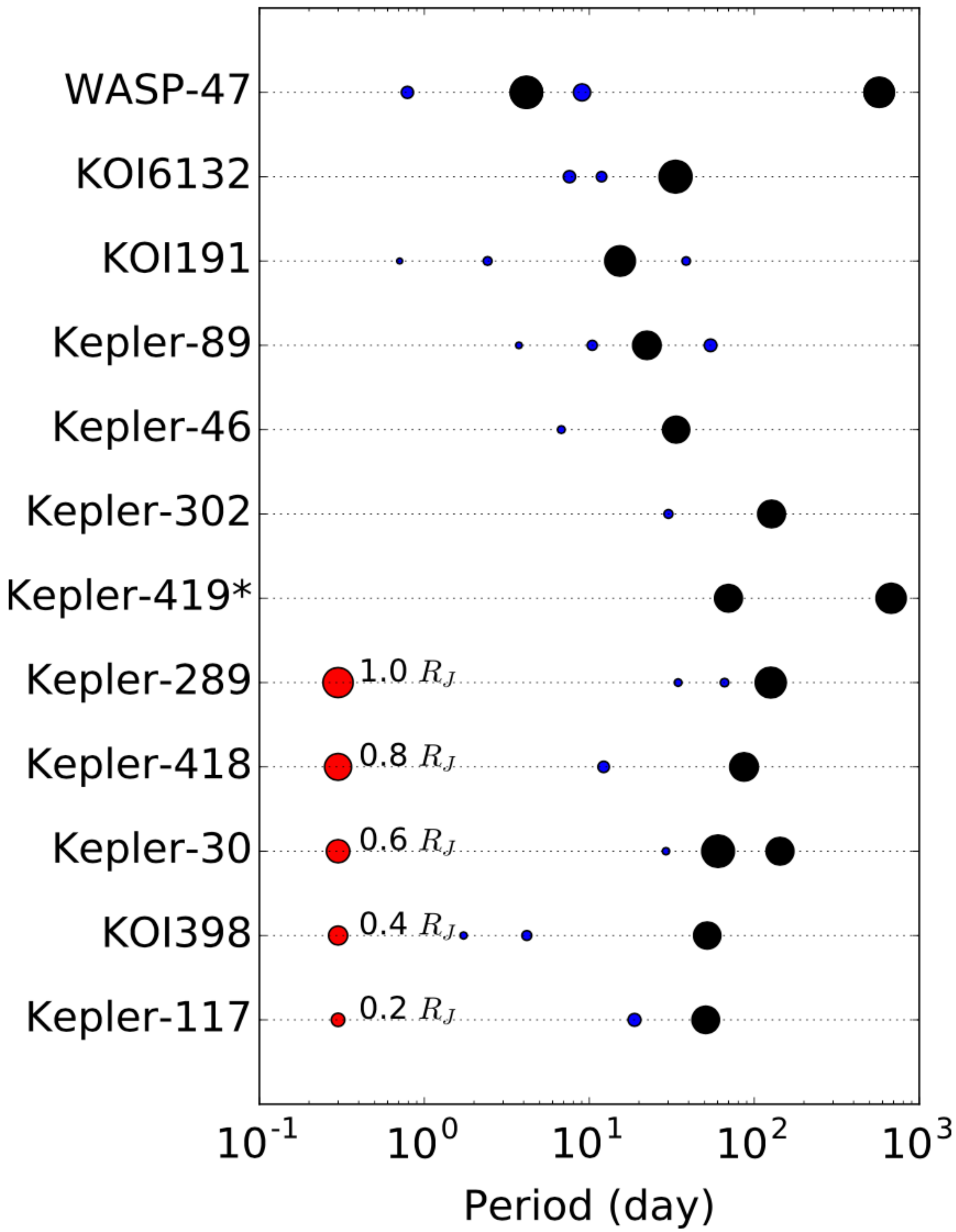
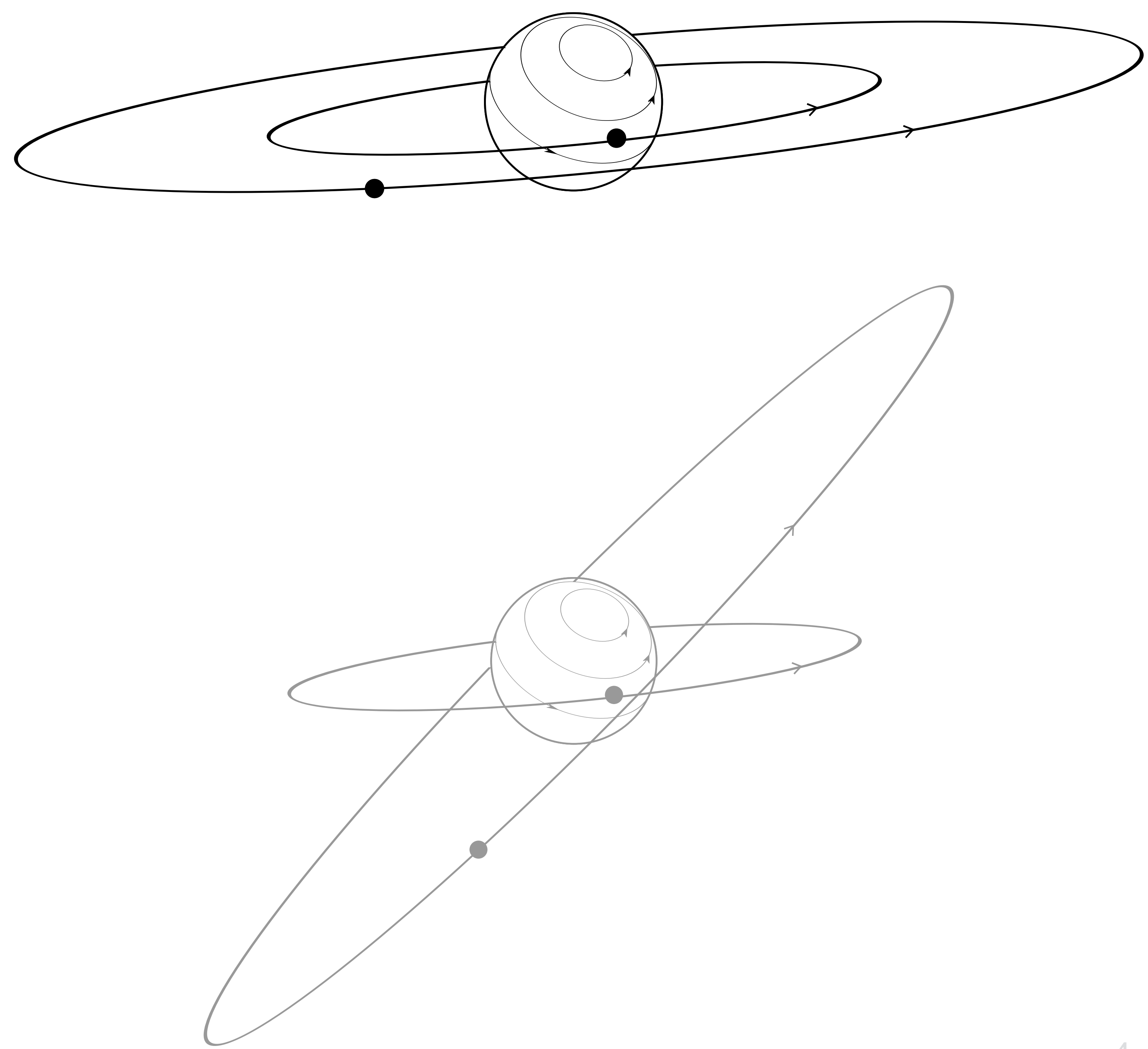
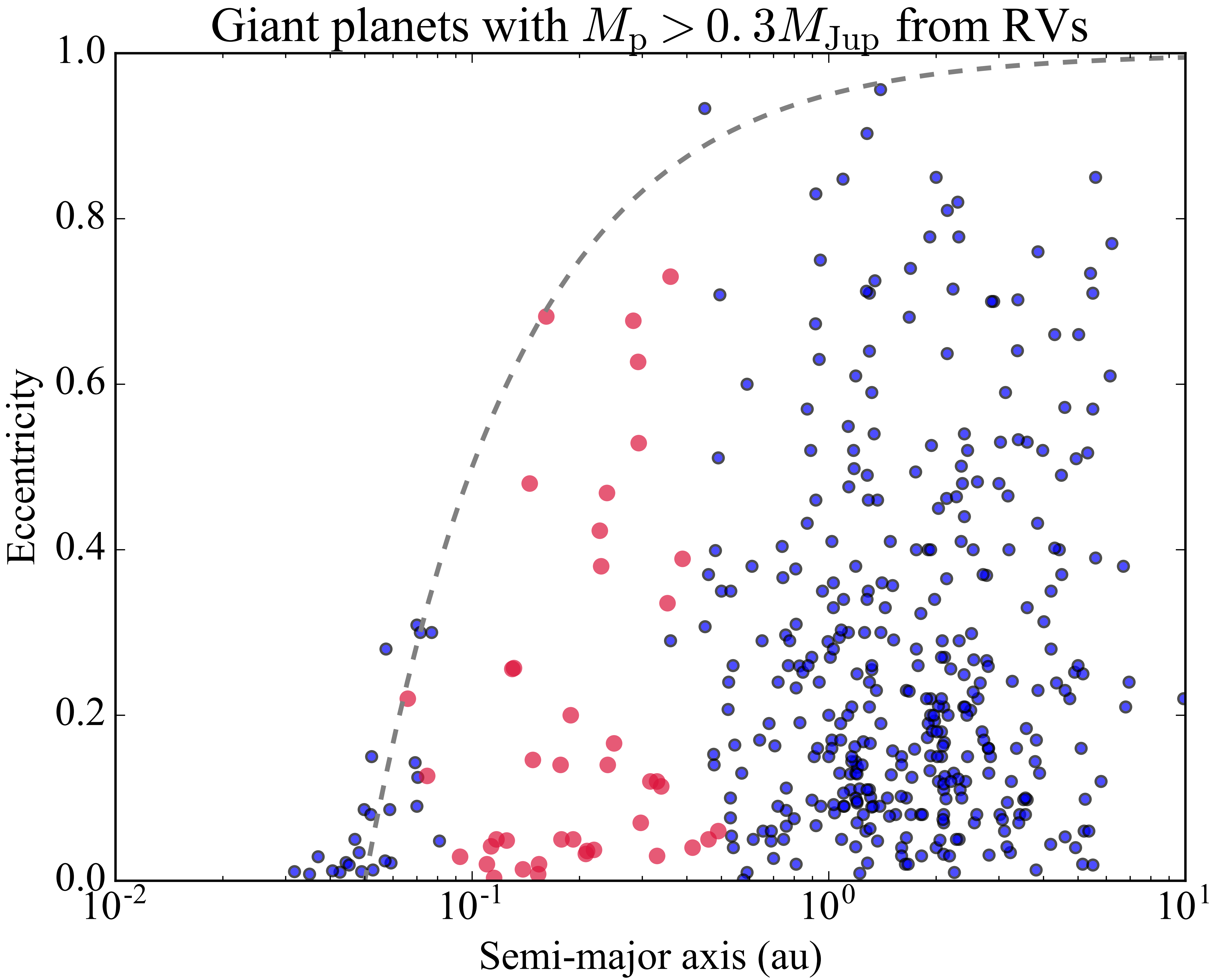
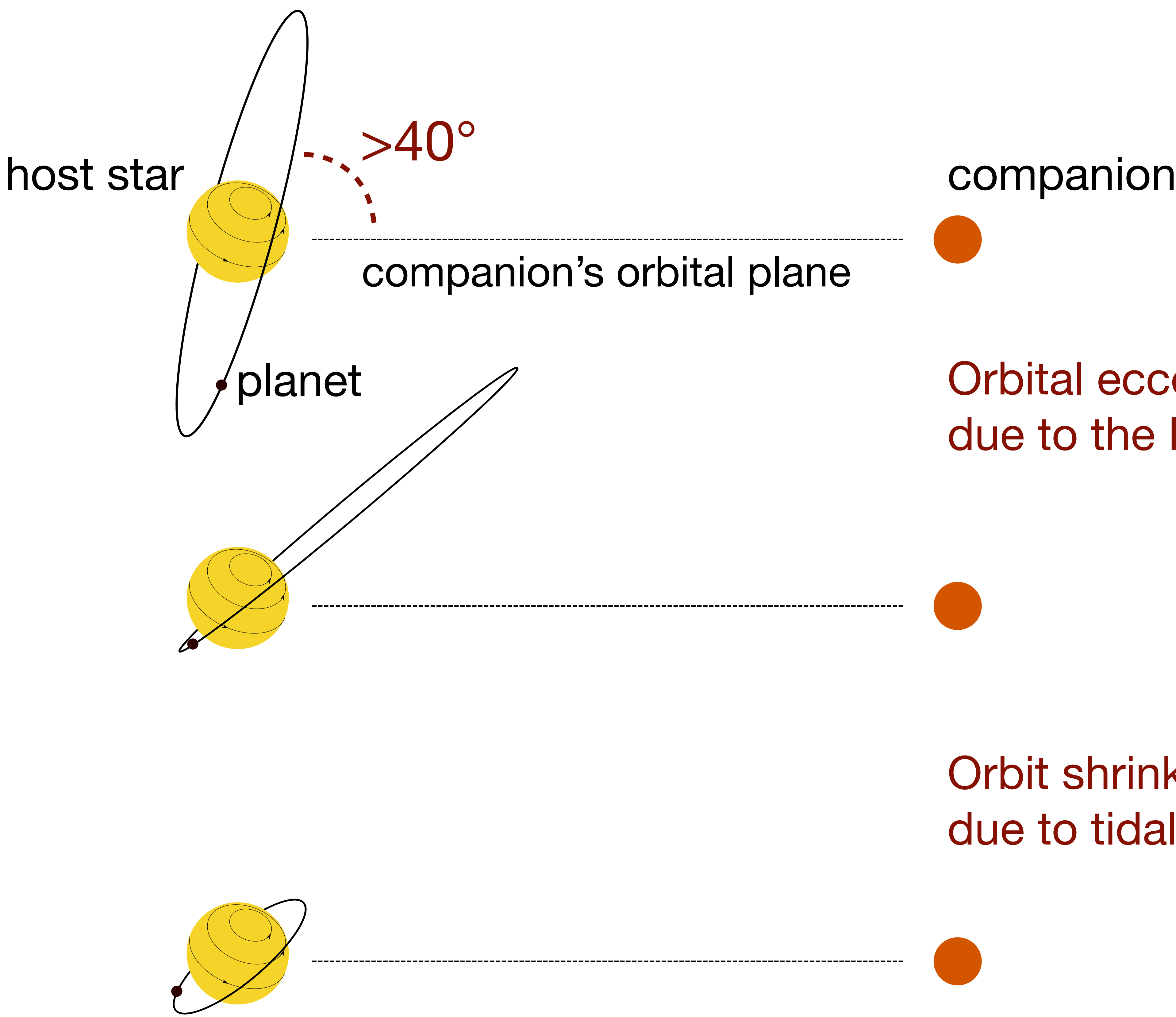




Eccentric warm Jupiters from RVs: dynamical origin?



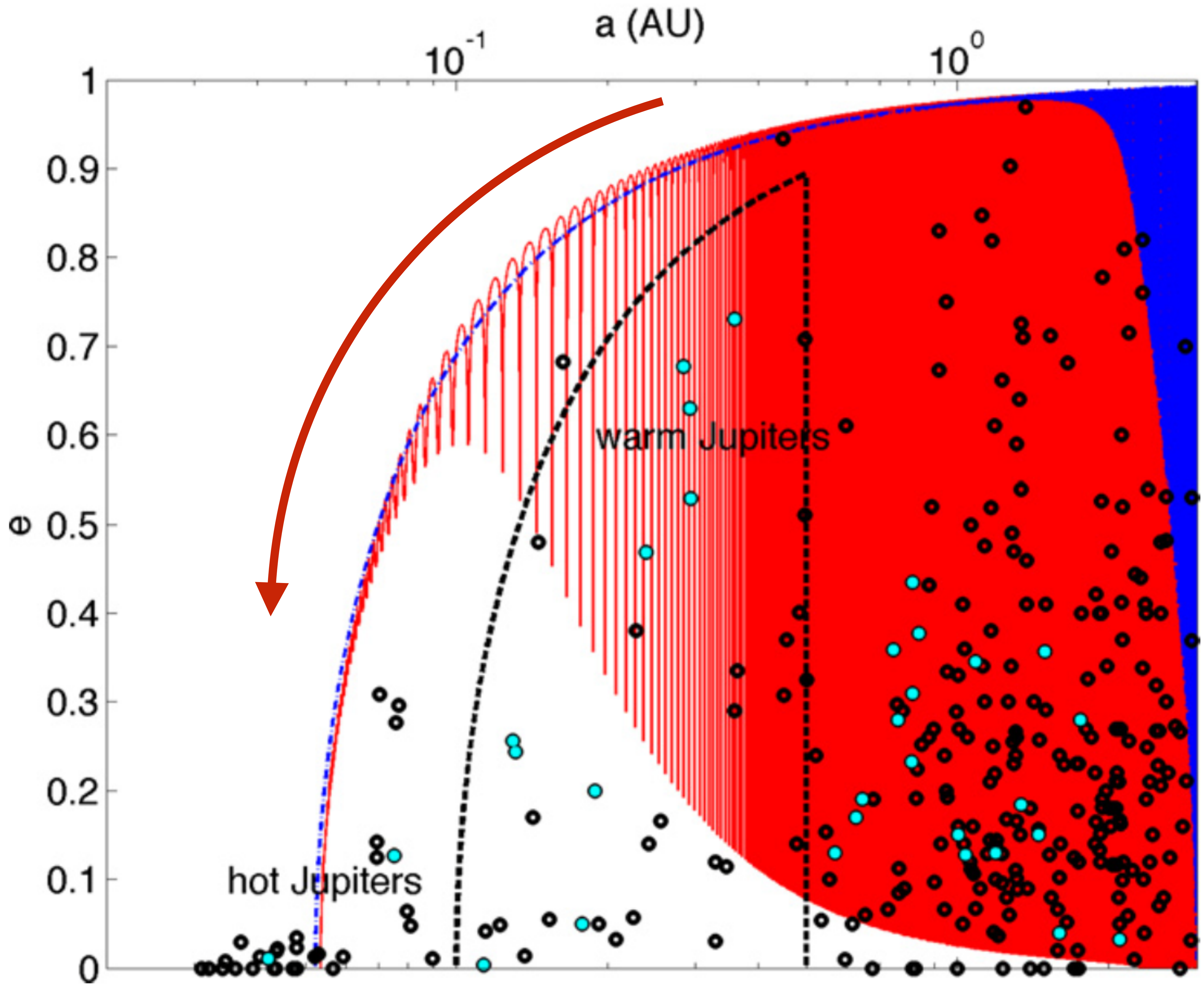
“High-e” migration due to an inclined companion



Orbital eccentricity oscillates
due to the Kozai cycle

Orbit shrinks & circularizes
due to tidal friction at periastron

"High-e" migration due to an inclined companion
— Eccentric warm Jupiters as **"proto-hot Jupiters"**



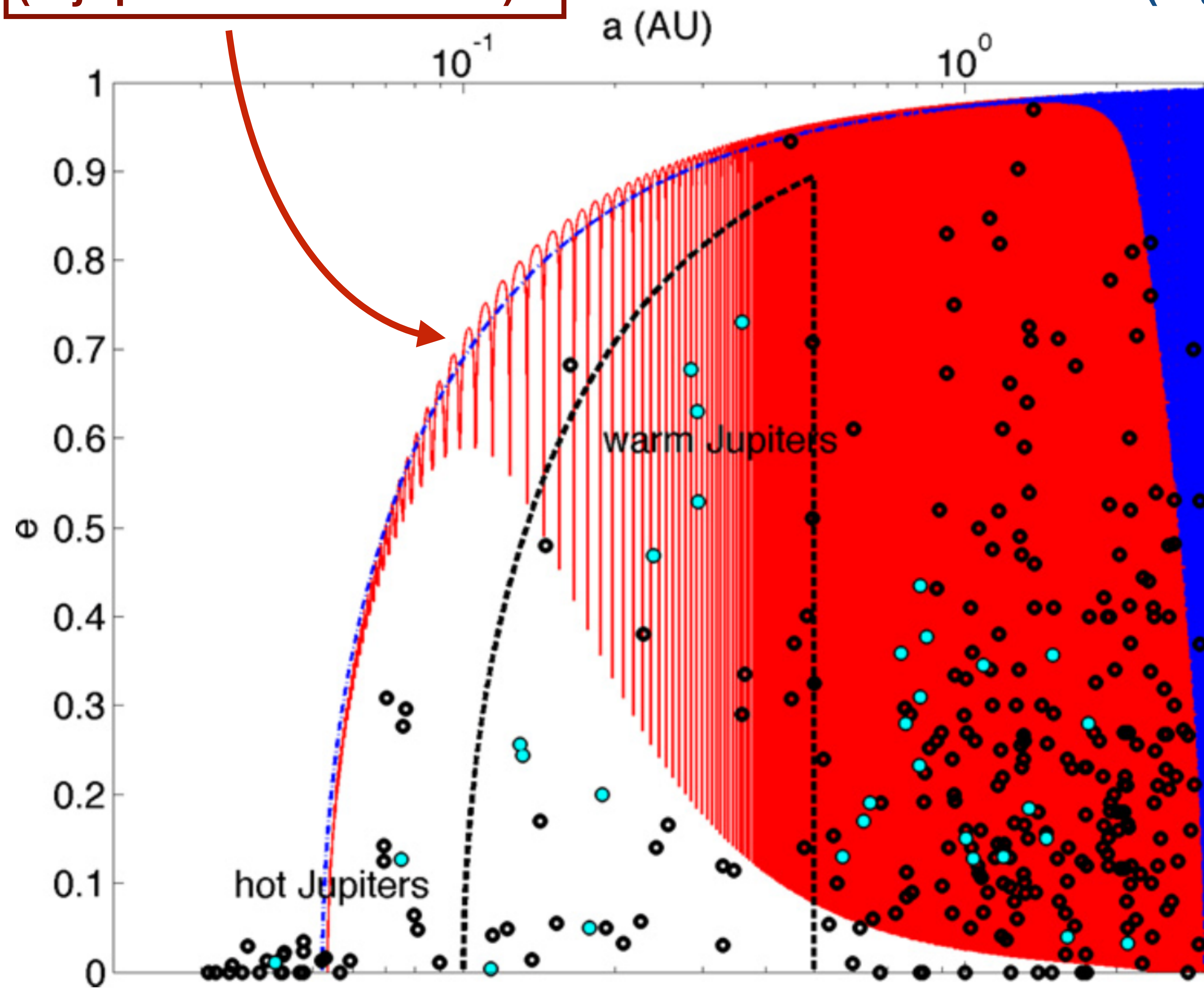
← Dong et al. (2014)

Wu & Lithwick (2011)
Dawson & Chiang (2014)
Petrovich & Tremaine (2017)

“High-e” migration due to an inclined companion

Close companion
(Mjup-Msun @3-30au)

Distant companion
(e.g. Msun @1000au)



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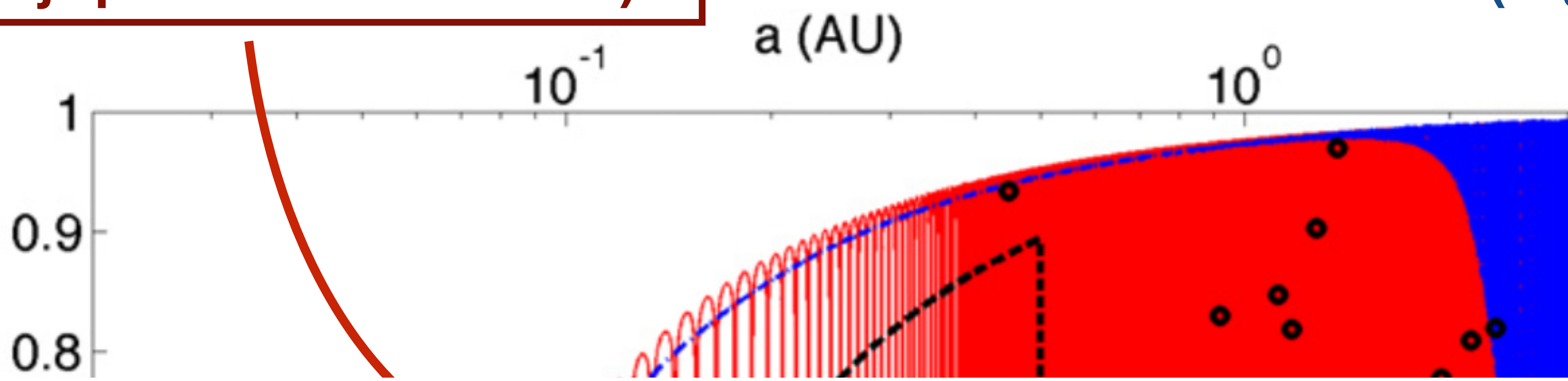
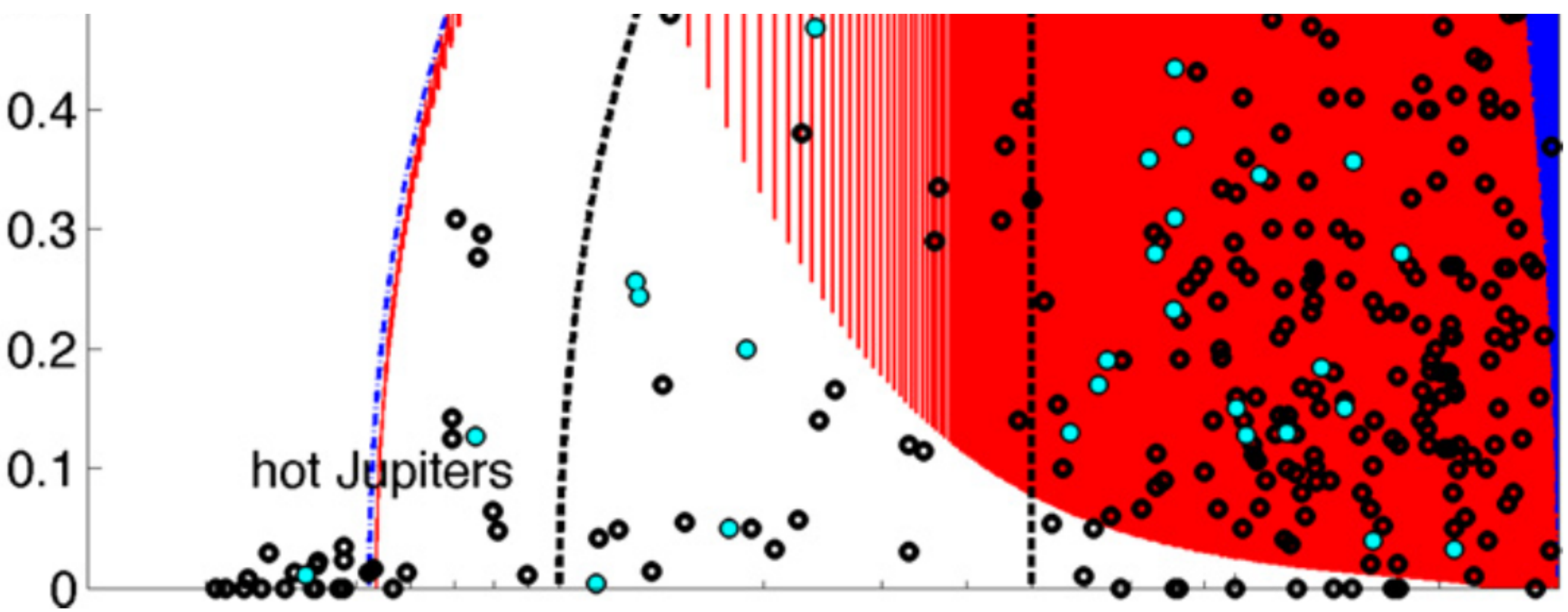


Eccentric WJs need close companions on mutually-inclined orbits (if they are proto-HJs)



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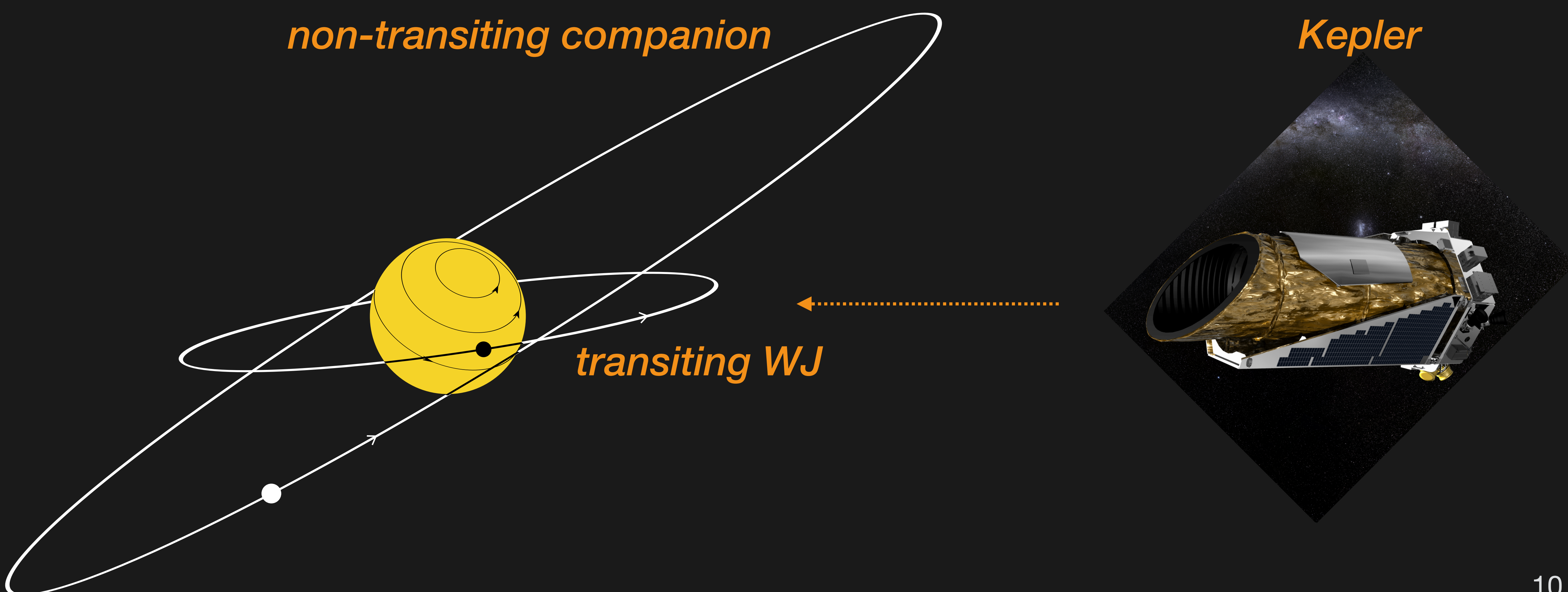
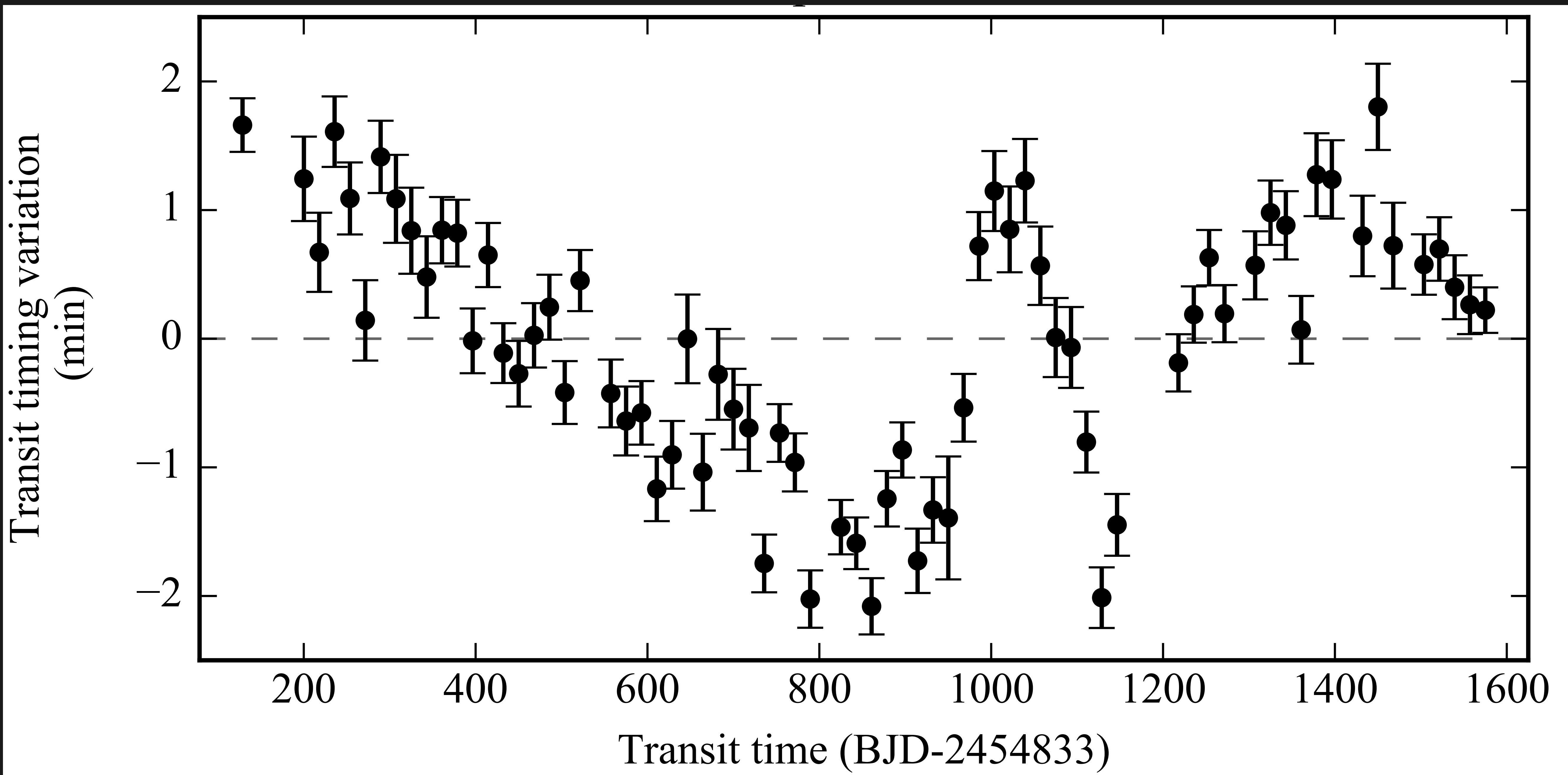
Search for mutually-inclined close companions to *Kepler* transiting warm Jupiters

- inclined companion -> non-transiting
- companion causes transit timing variations of the WJ
- 23 confirmed WJs in single-transiting systems analyzed
  -> detection in two systems



Kepler-448: WJ (18d, 1.2R_J)+F dwarf



Masuda (2017)

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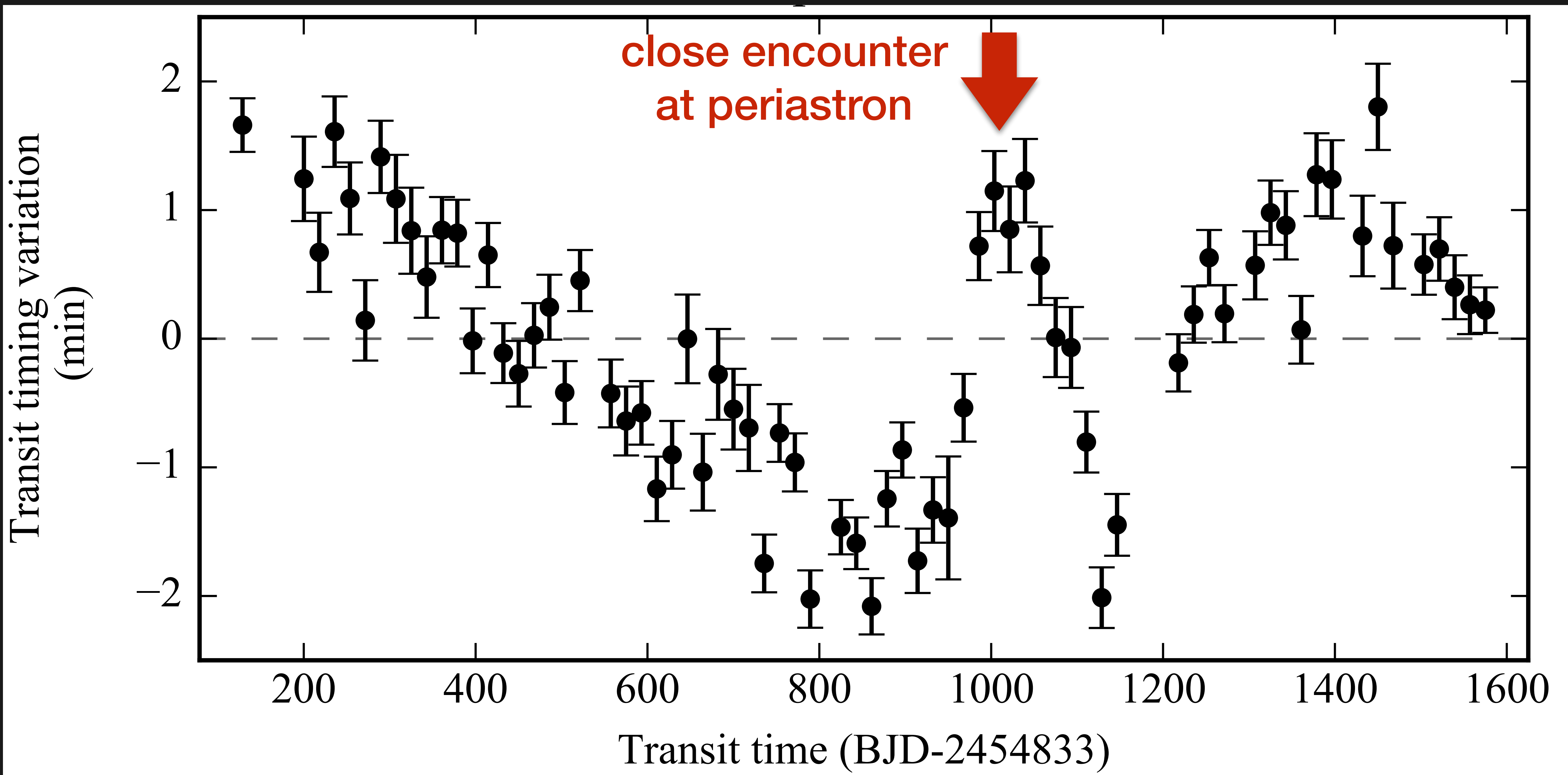

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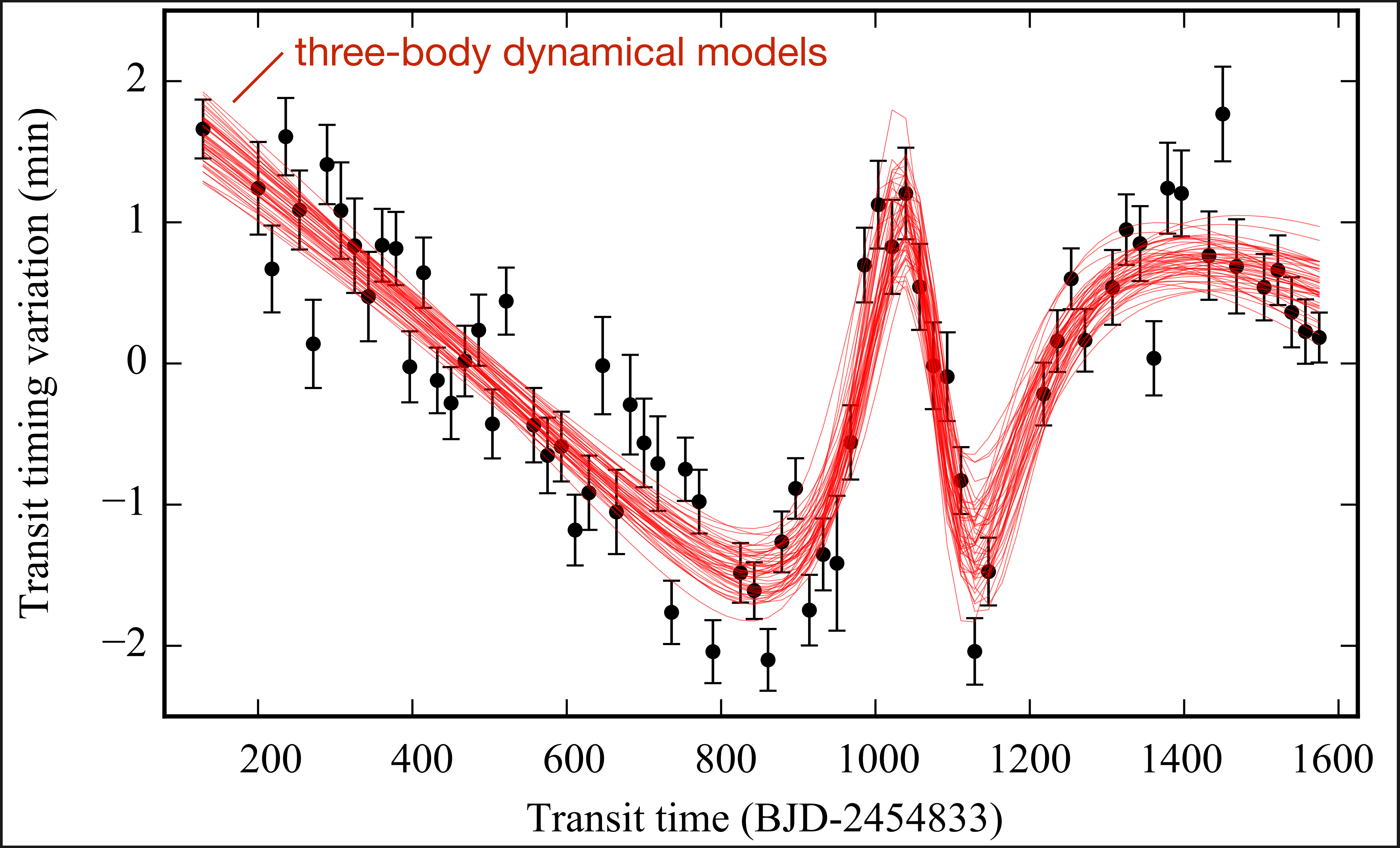


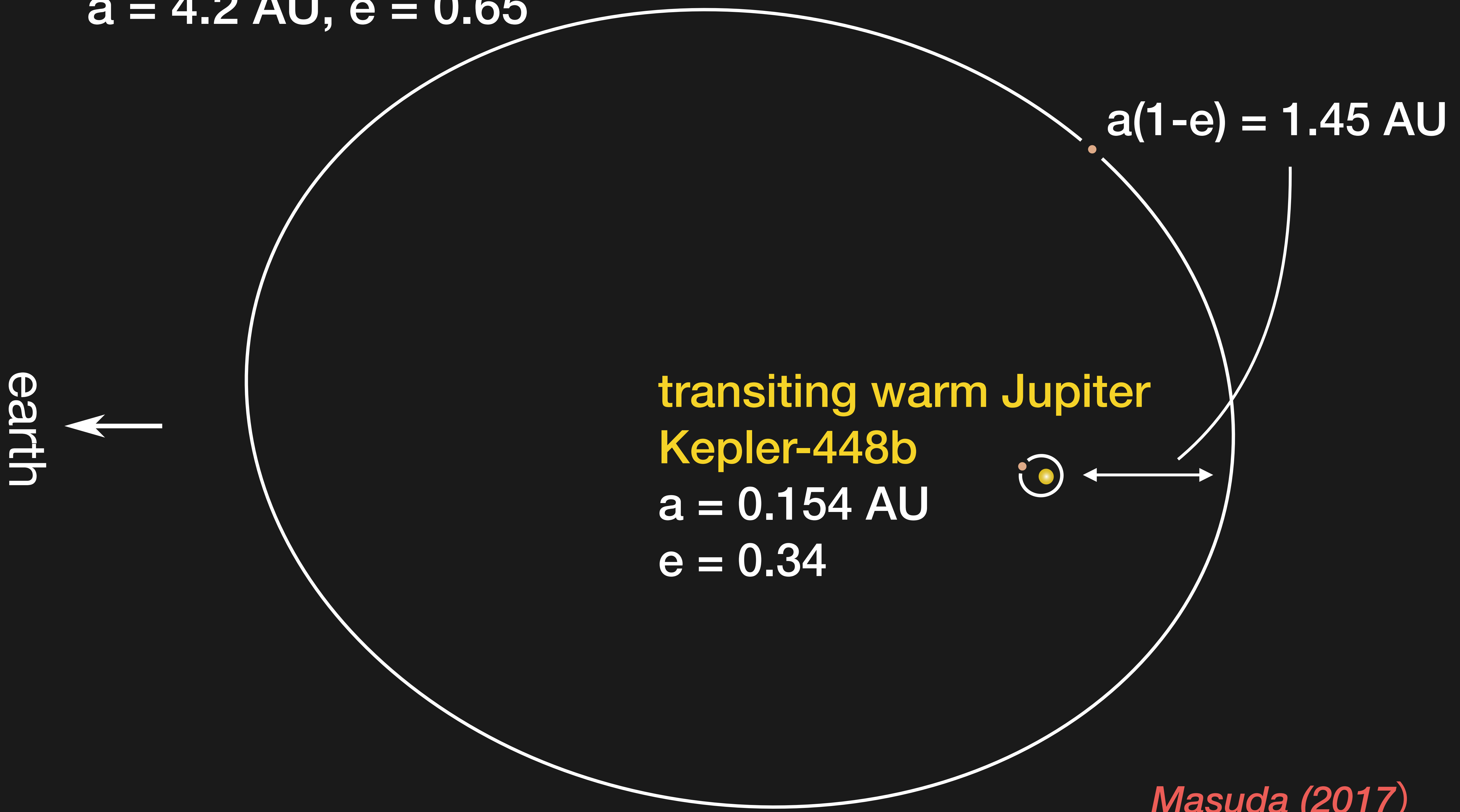
Masuda (2017)

Kepler-448: brown dwarf on a close/eccentric orbit

non-transiting companion

M = 22(+7, -5) M_J

a = 4.2 AU, e = 0.65



transiting warm Jupiter

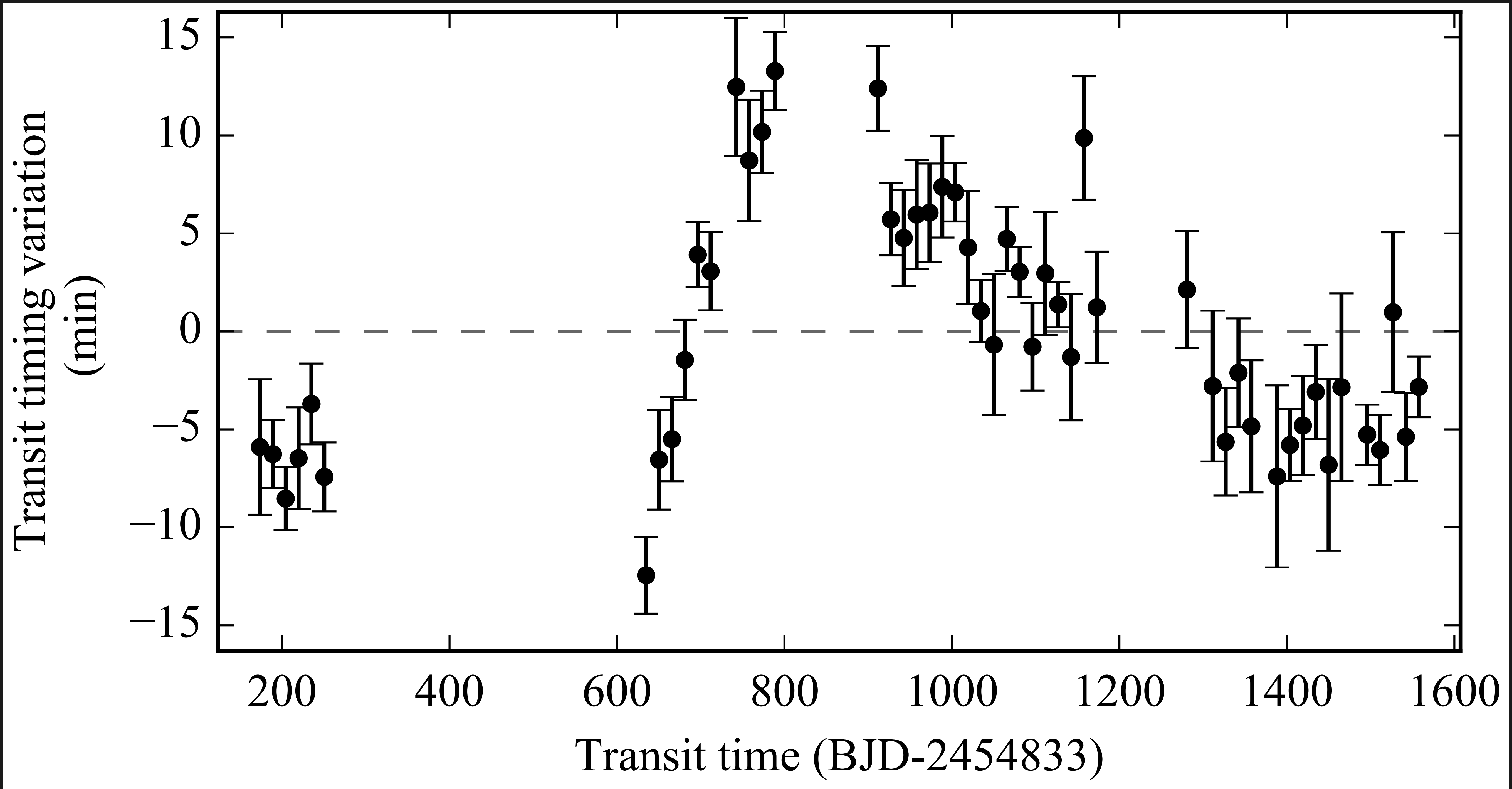
Kepler-448b

a = 0.154 AU

e = 0.34

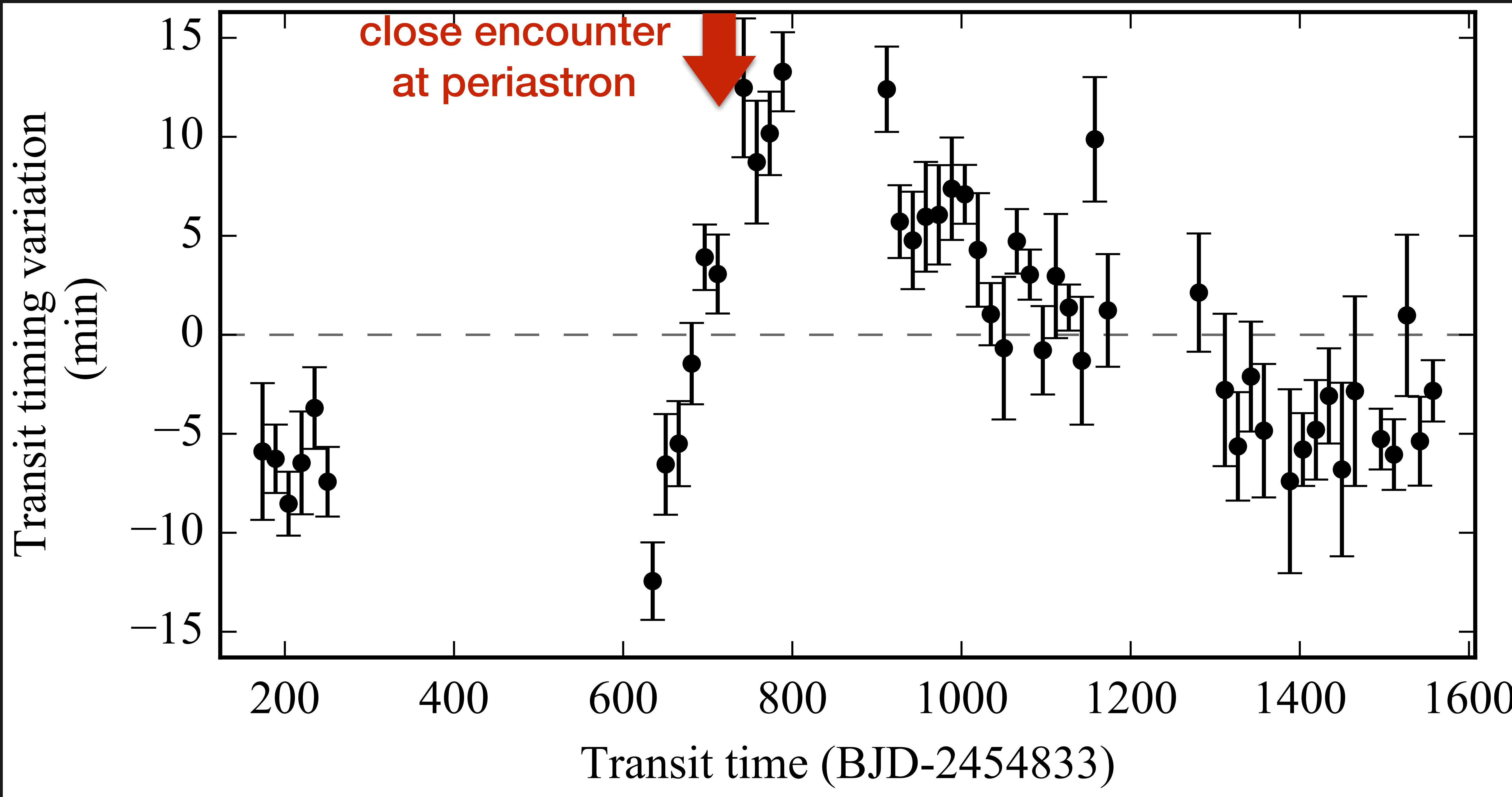
Masuda (2017)

Kepler-693: WJ (15d, $0.9R_J$)+K dwarf



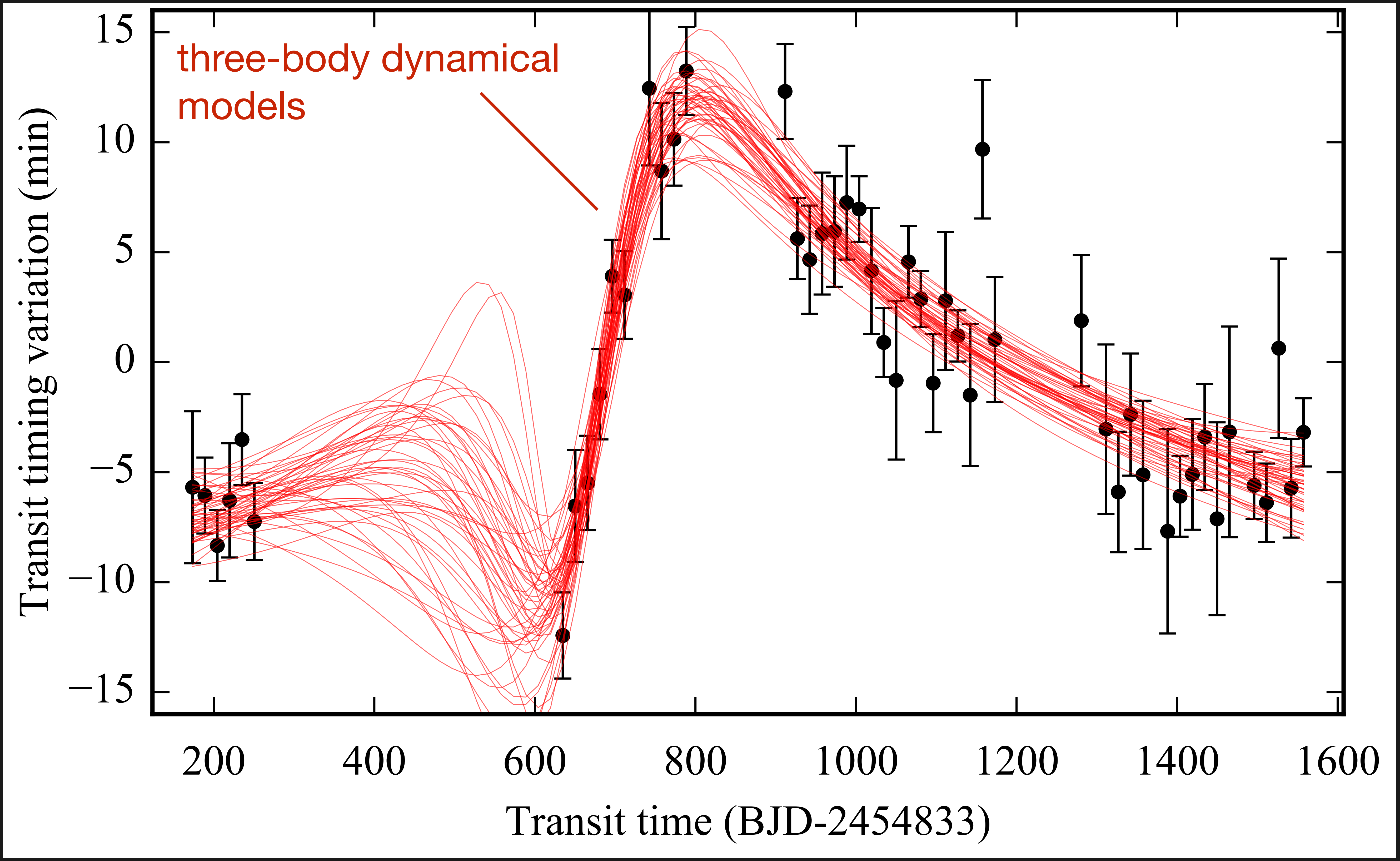
Masuda (2017)

Kepler-693: WJ (15d, 0.9R_J)+K dwarf



Masuda (2017)

Kepler-693: WJ (15d, 0.9R_J)+K dwarf



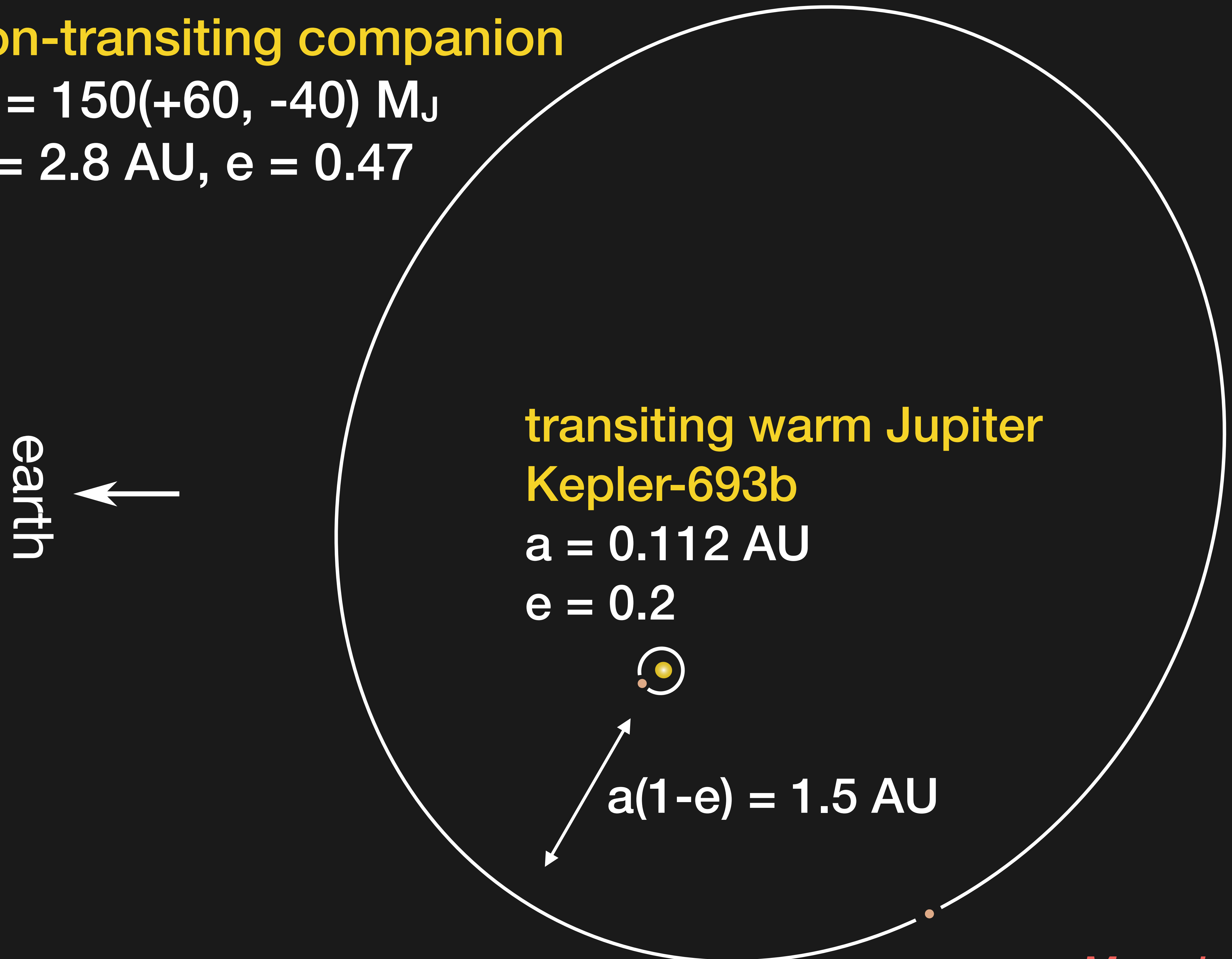
Masuda (2017)

Kepler-693: close & eccentric low-mass star

non-transiting companion

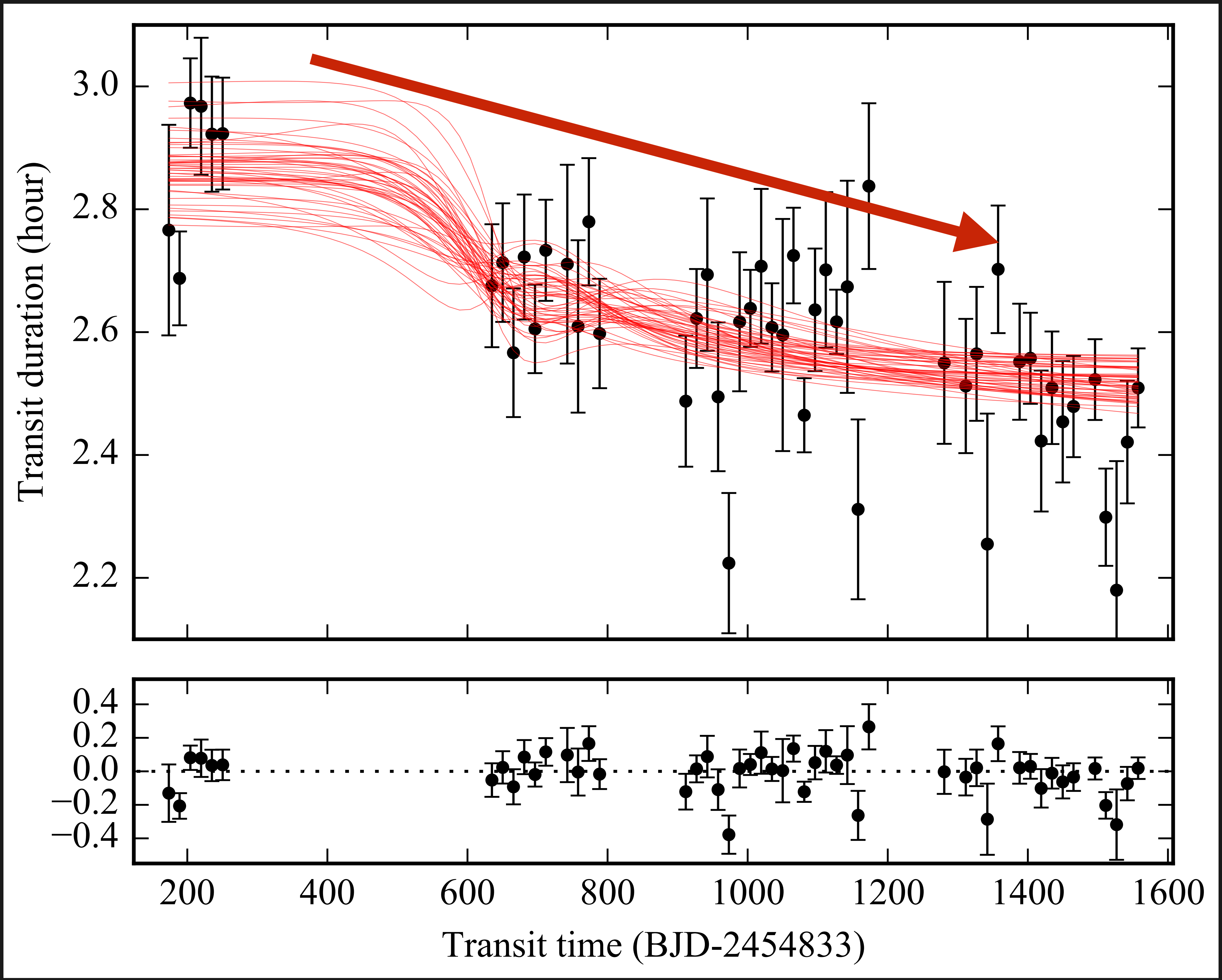
$M = 150(+60, -40)\ M_J$

$a = 2.8$ AU, $e = 0.47$



Masuda (2017)

Transit durations indicate a large mutual inclination



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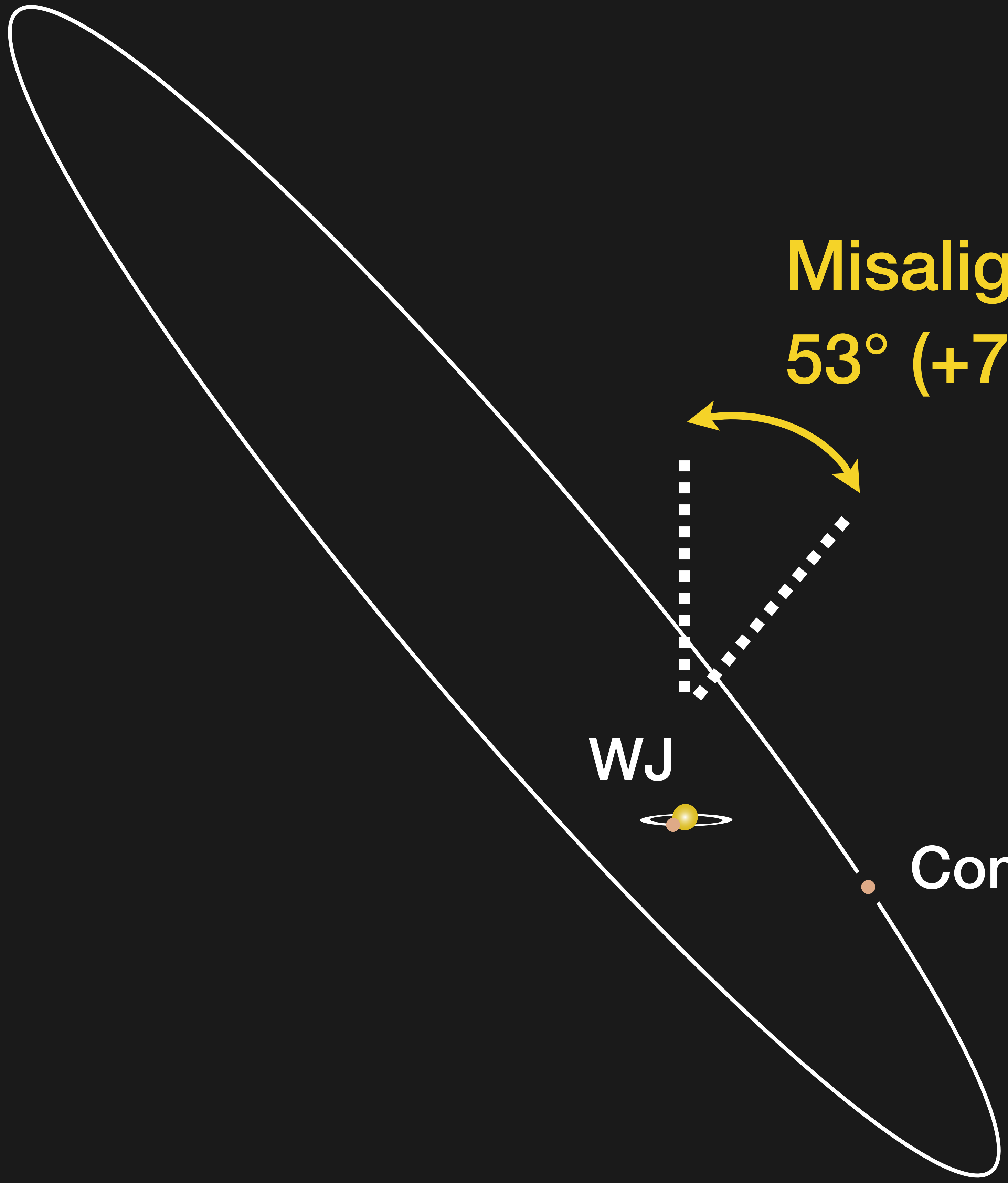

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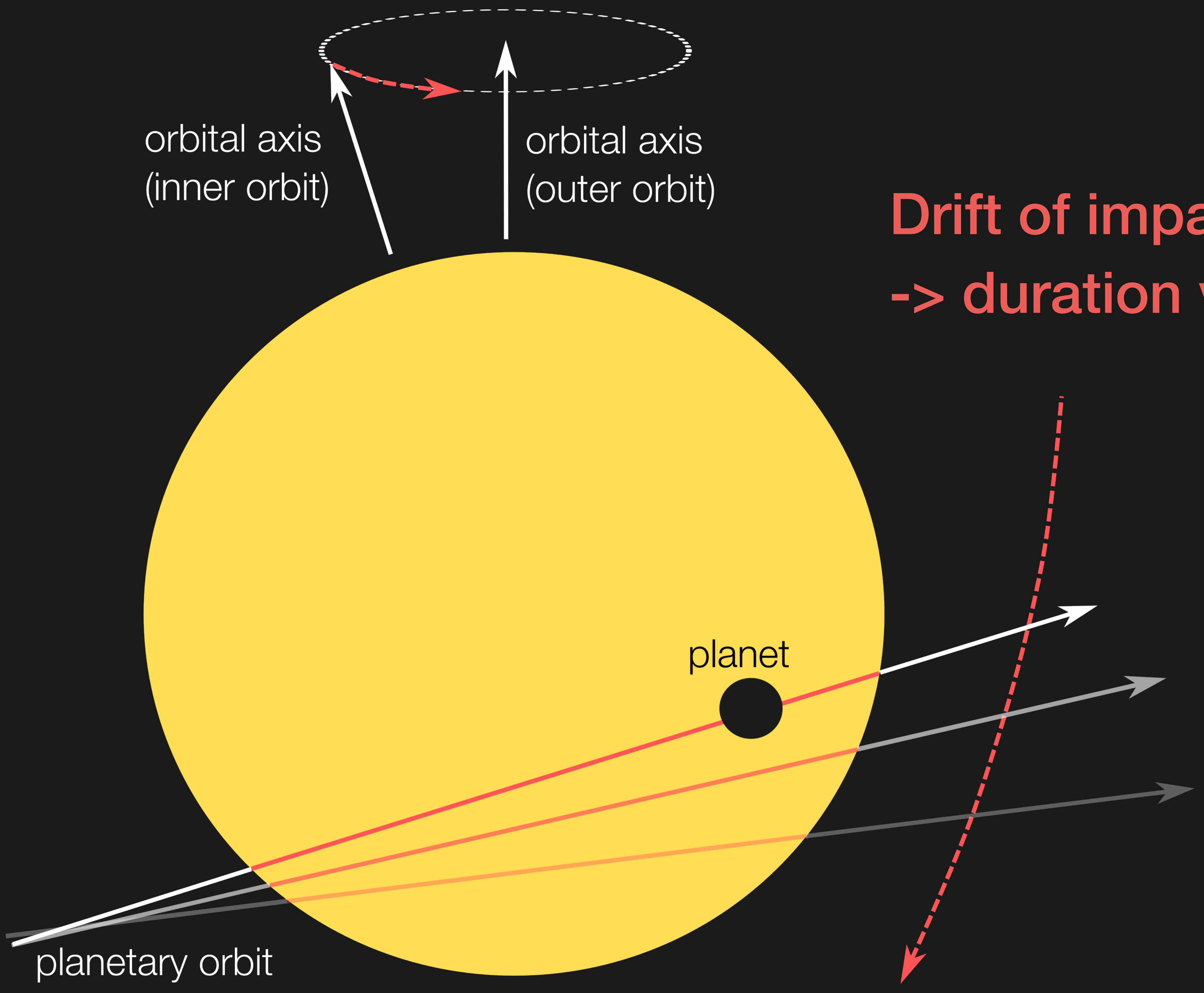
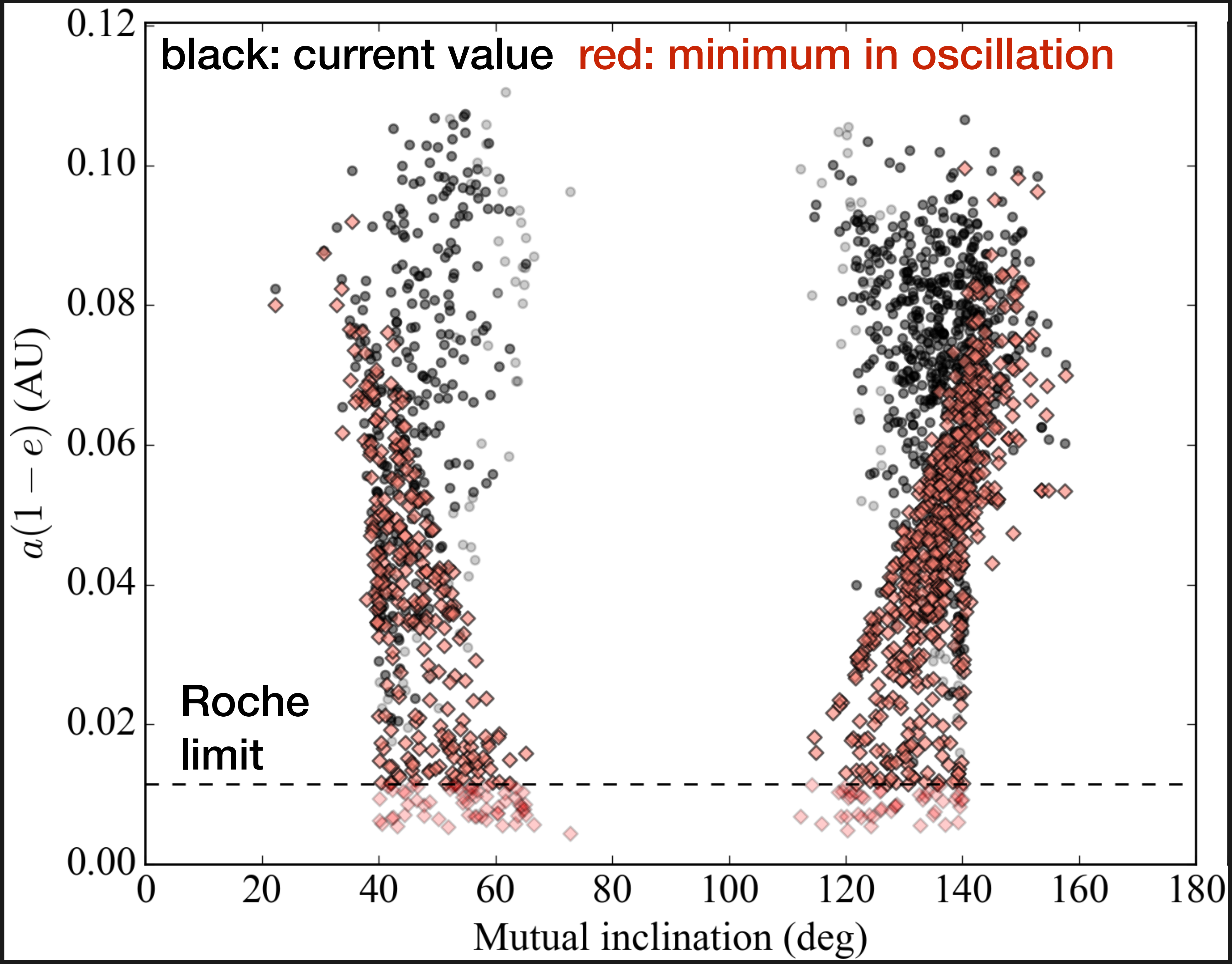


Drift of impact parameter
-> duration variation

Kepler-693b as a proto-hot Jupiter

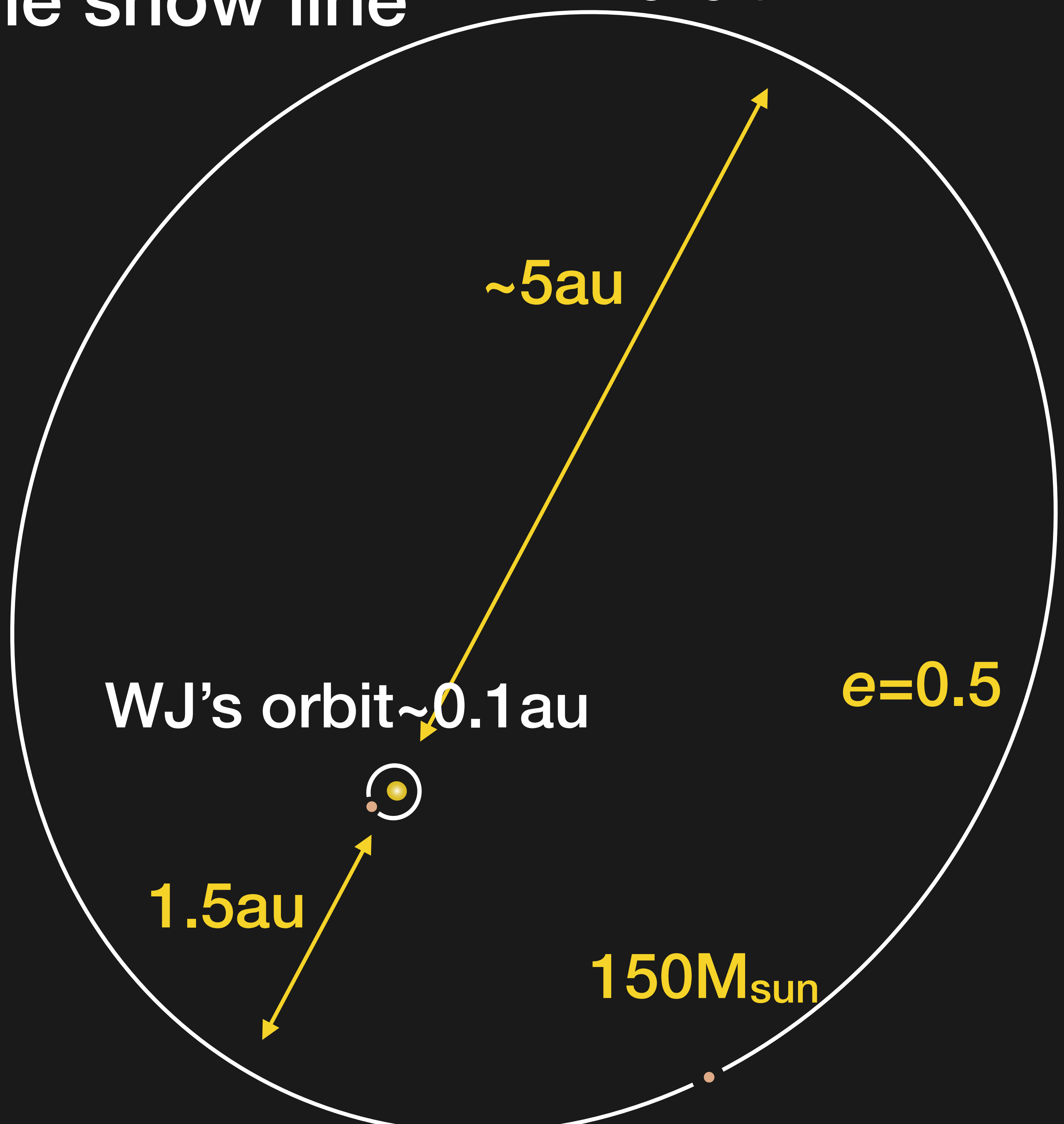
- Secular eccentricity excitation can bring $a(1-e)$ to <0.05au
- Possibly evolving to become a hot Jupiter



Masuda (2017)

How did the high-e migration start?

Outer companion is too close
for WJ migration across the snow line



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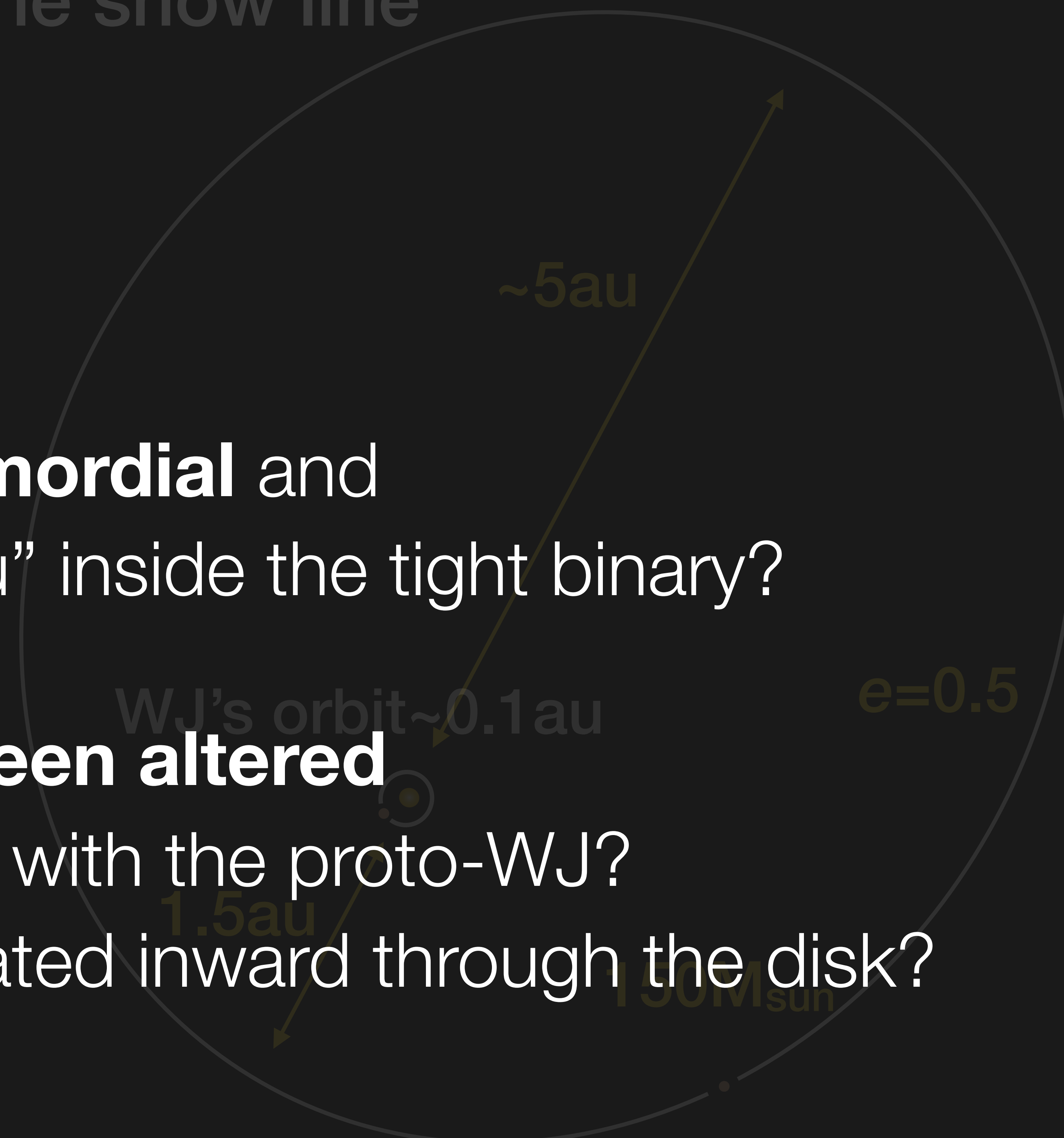

Companion's orbit is primordial and

1. proto-WJ formed "in situ" inside the tight binary?

Companion's orbit has been altered

2. via dynamical scattering with the proto-WJ?
3. after the proto-WJ migrated inward through the disk?

Summary

- Two transiting & eccentric warm Jupiters with non-transiting, (sub-)stellar companions with **$a(1-e)$=1.5au**
- Kepler-448: **20M_J** companion, mutual inclination=?
- Kepler-693: **low-mass star (150M_J)** inclined by **50deg**
  - eccentricity oscillation demonstrated
  - tidal dissipation may turn it into a hot Jupiter
- Support the “proto-hot Jupiter” picture, but companion’s small $a(1-e)$ suggest some other process contributing to the inward migration