Formation and evolution of planetary systems:

What have we learnt from transit methods?

Clément Baruteau

CNRS / IRAP, Toulouse

Planet formation & evolution: transits highlights

- Misaligned hot Jupiters
  → high-eccentricity migration, tides

- Close-in, compact multiplanet systems
  → in situ growth vs. disc migration

- Circumbinary planets
  → “extreme” planet formation

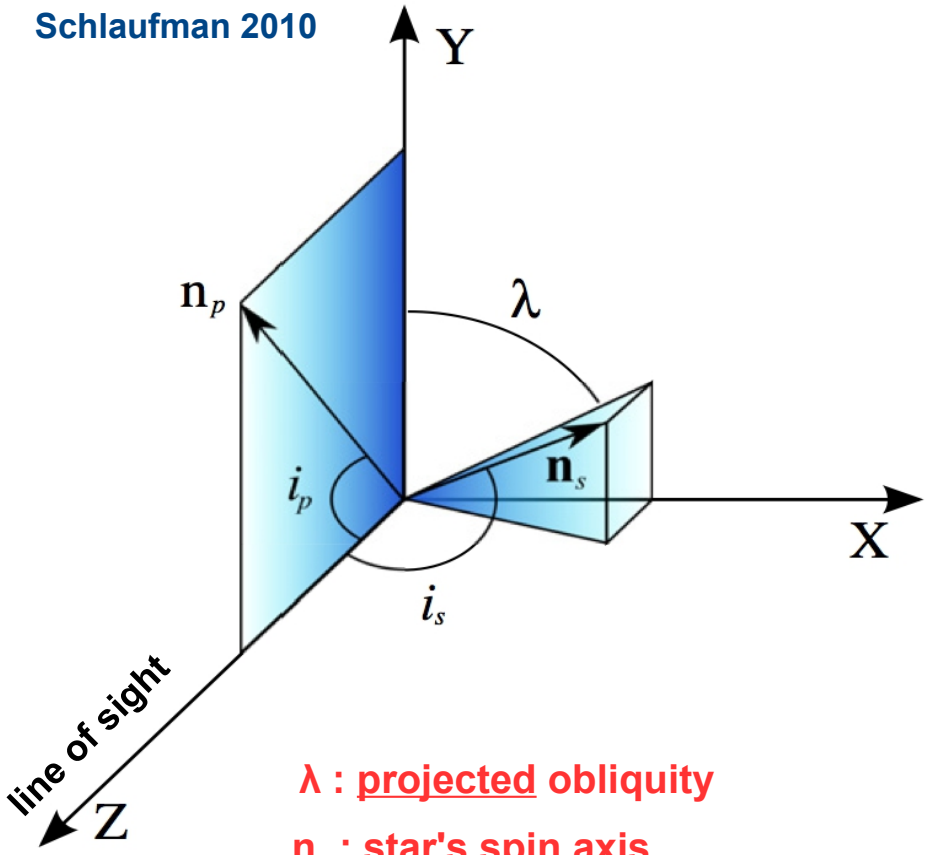
- Planets around post main sequence stars
  → impact of stellar evolution on close-in planets?

Talk outline

- Misaligned hot Jupiters
  → high-eccentricity migration, tides
- Close-in, compact multiplanet systems
  → in situ growth vs. disc migration
- Circumbinary planets
  → “extreme” planet formation
- Planets around post main sequence stars
  → impact of stellar evolution on close-in planets?

Planets obliquities: constraints on migration scenarios?

Schlaufman 2010



λ : projected obliquity

n_s : star's spin axis

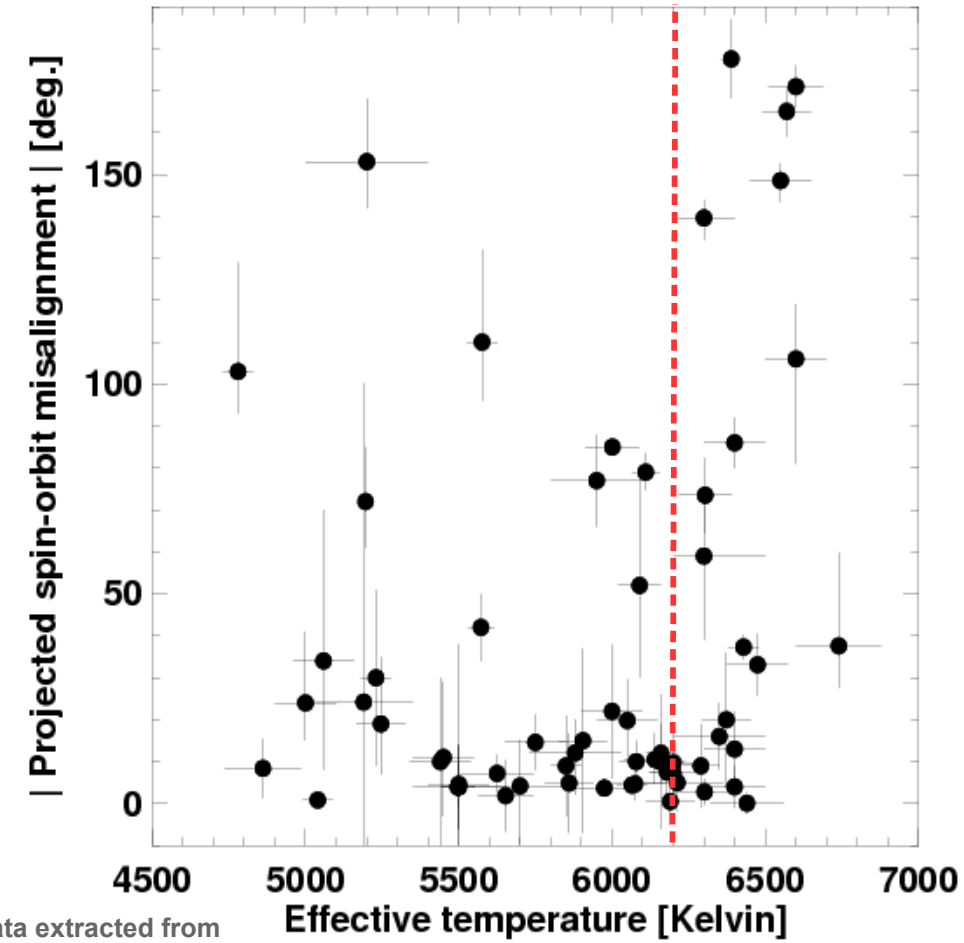
n_p : planet's orbital axis

ψ = acos(n_s.n_p) : true obliquity

- Rossiter-MacLaughlin effect
  - e.g., Winn+ 2005
- Planet-starspot crossings
  - e.g., Sanchis-Ojeda+ 2011
- Constraining true obliquity (ψ) with stellar spin axis angle (i_s)
  - e.g., Huber+ 2013, Chaplin+ 2013

Planets obliquities: constraints on migration scenarios?

OBSERVATIONS



data extracted from exoplanets.org (06/2014)

□ (Why) do **hot** Jupiters around **hot** stars tend to have **high obliquities?**

Planets obliquities: constraints on migration scenarios?

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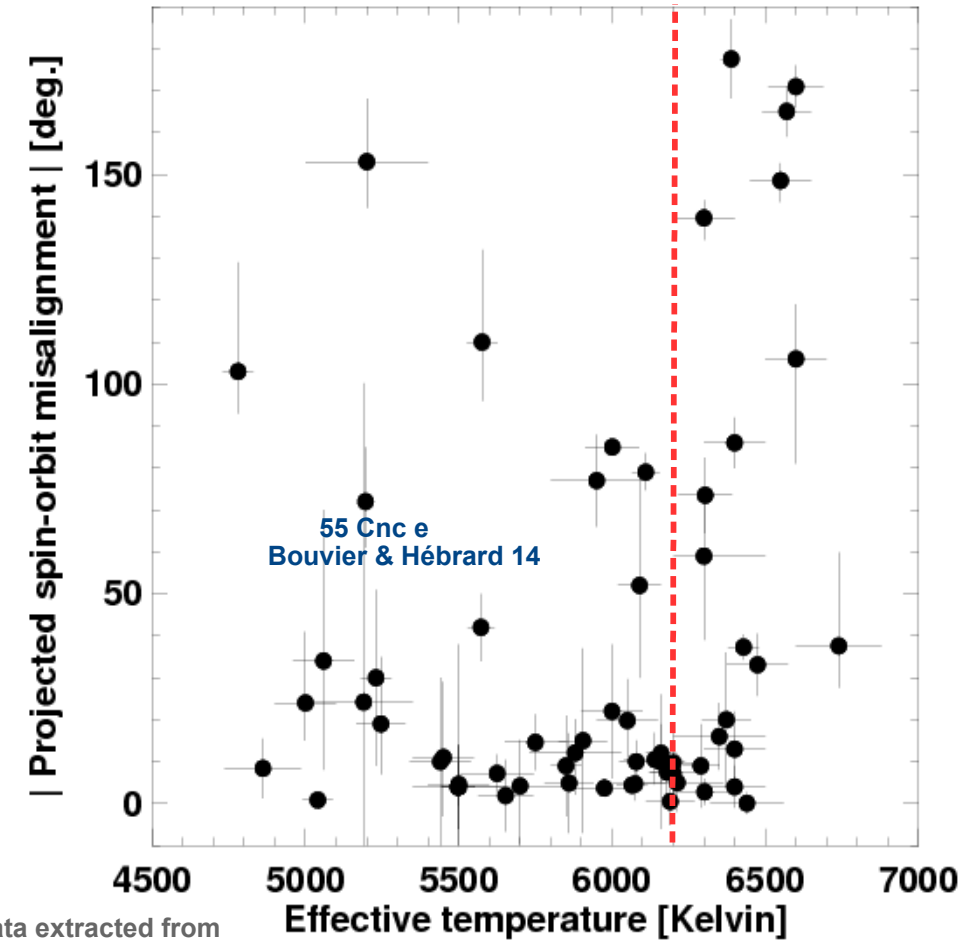

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□ (Why) do **hot** Jupiters around **hot** stars tend to have **high obliquities?**

MODELS

□ **Disc migration** is a natural source of **aligned** hot Jupiters

→ disc misaligned by nearby stars?

Bate+ 2010, Batygin 2012

→ tidal flip of stellar axis?

Cebron+ 2013, Barker & Lithwick 2014

Planets obliquities: constraints on migration scenarios?

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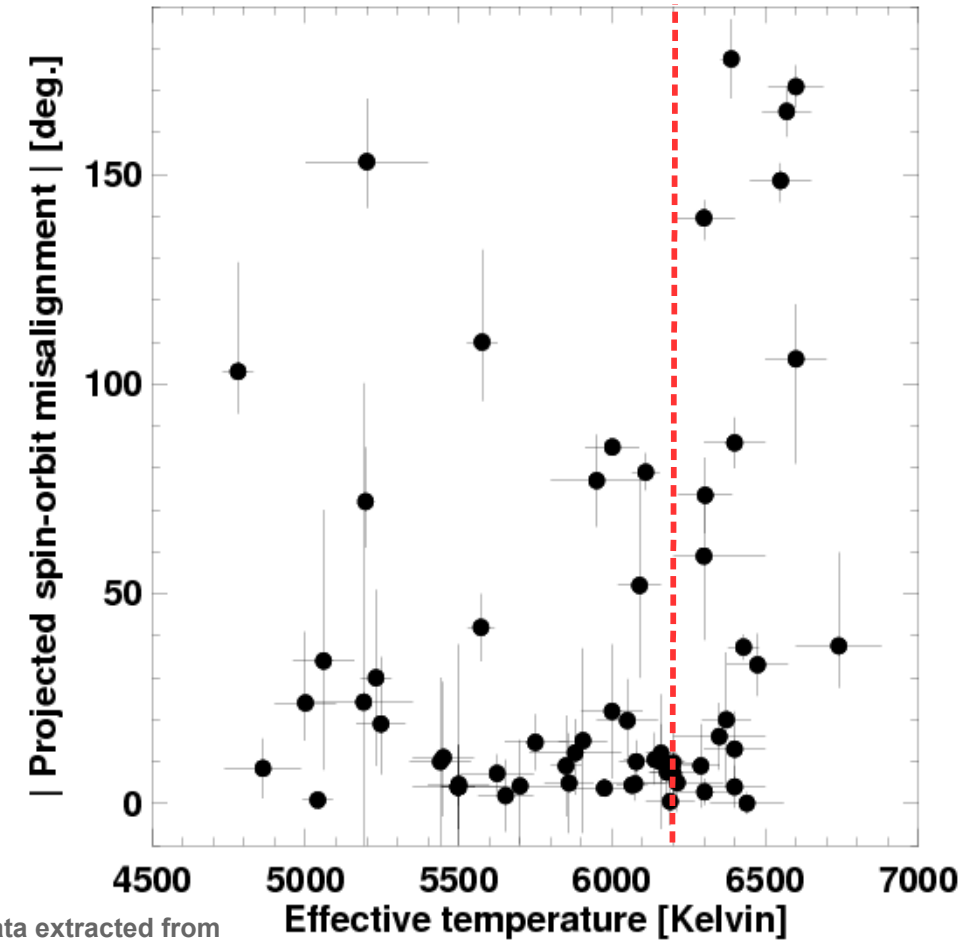

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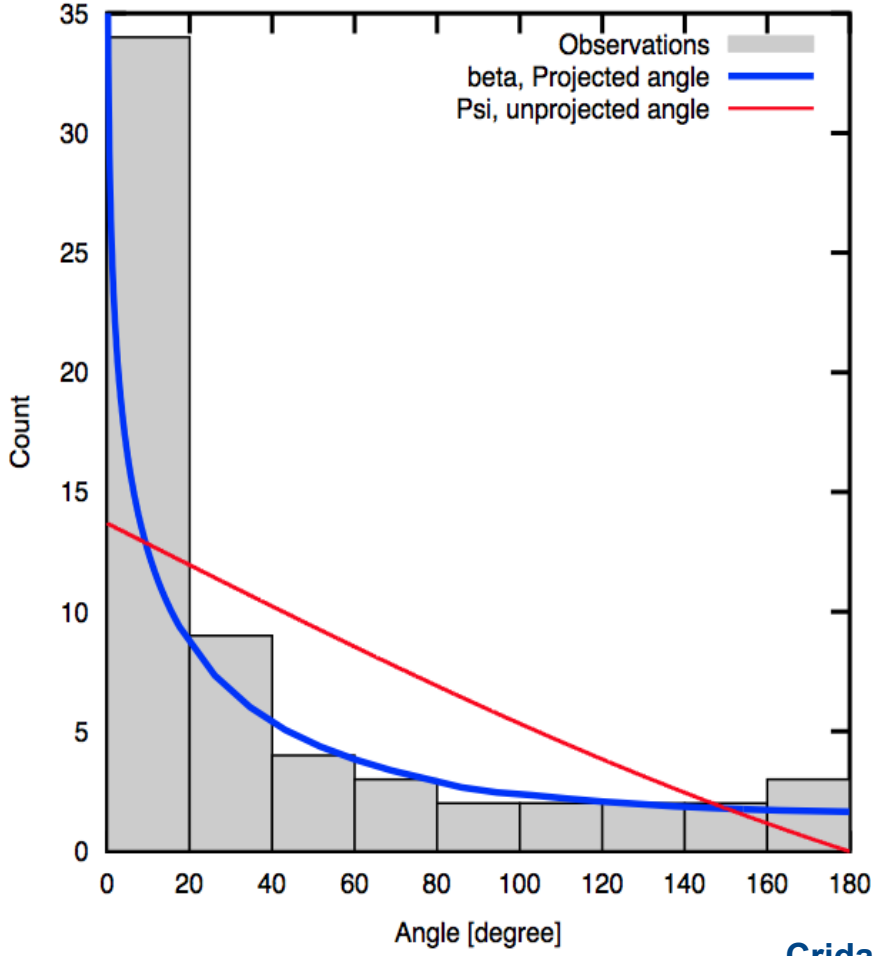
□ **High-eccentricity migration** followed by **tidal circularization** is a natural source of **misaligned** hot Jupiters

→ can **all** hot Jupiters form this way?

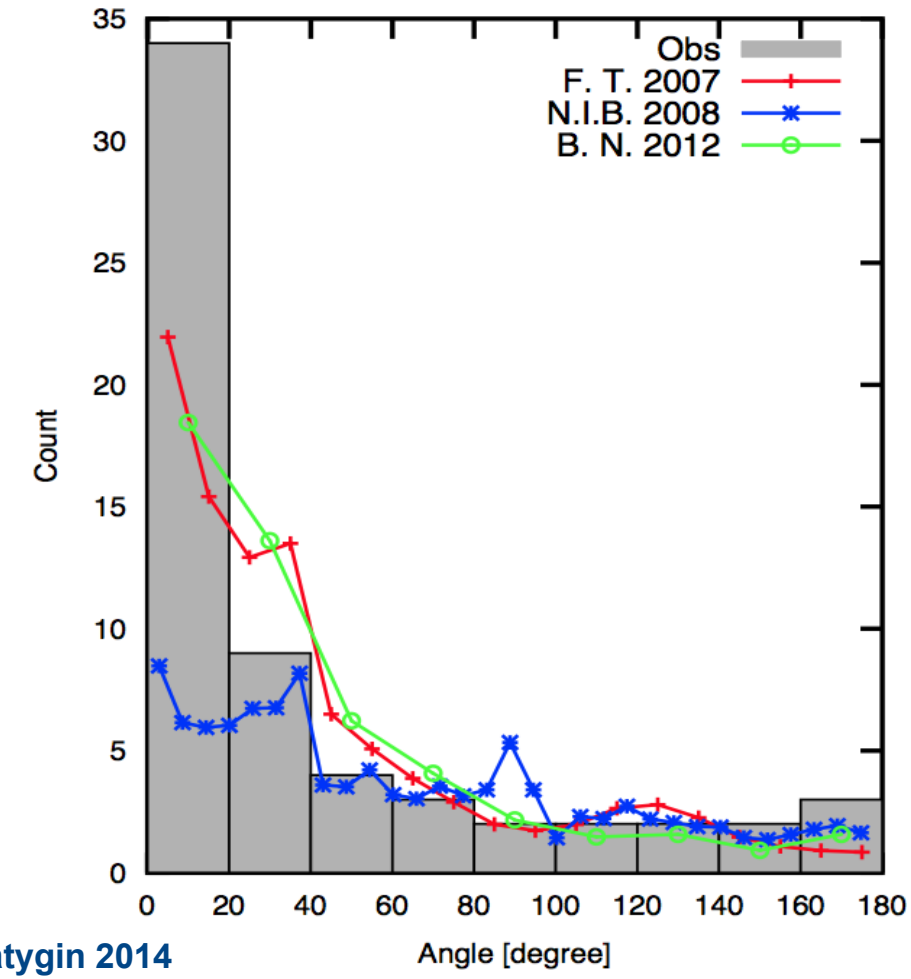
Triaud+ 2010, Albrecht + 2012, but see Rogers & Lin 2013, Lai 2012

Planets obliquities: constraints on migration scenarios?

- Disc misaligned by nearby stars



- High-eccentricity migration + tides



Crida & Batygin 2014

Planets obliquities: constraints on migration scenarios?

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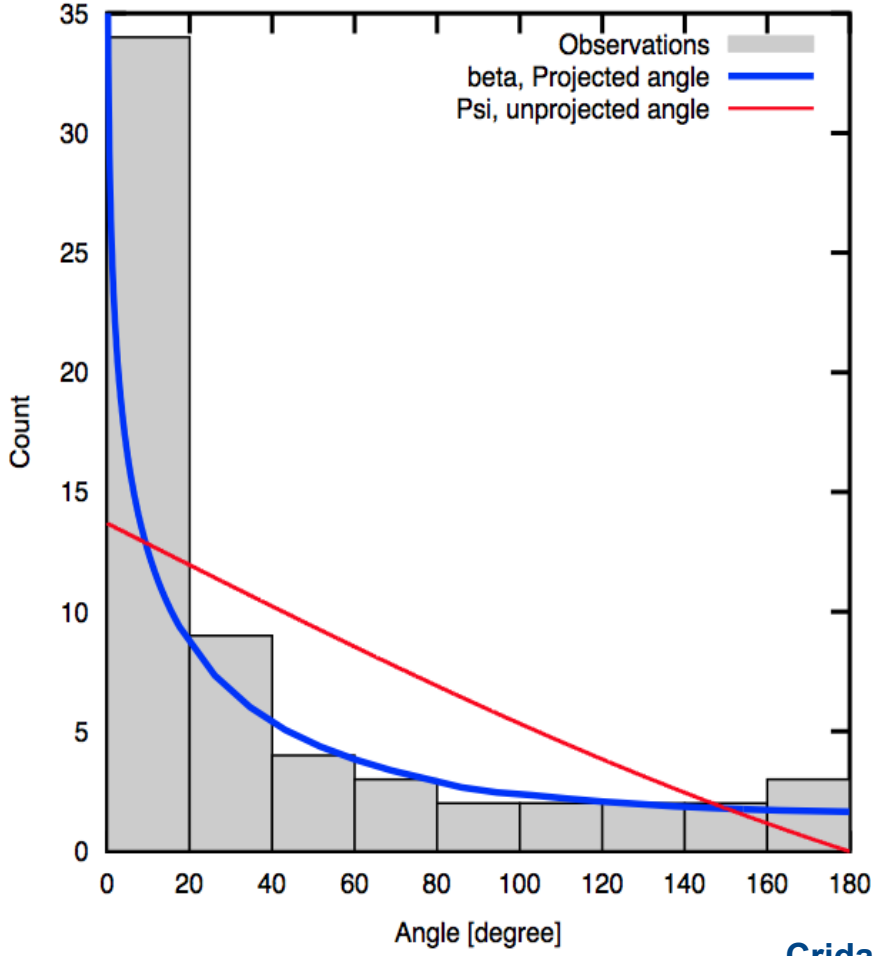

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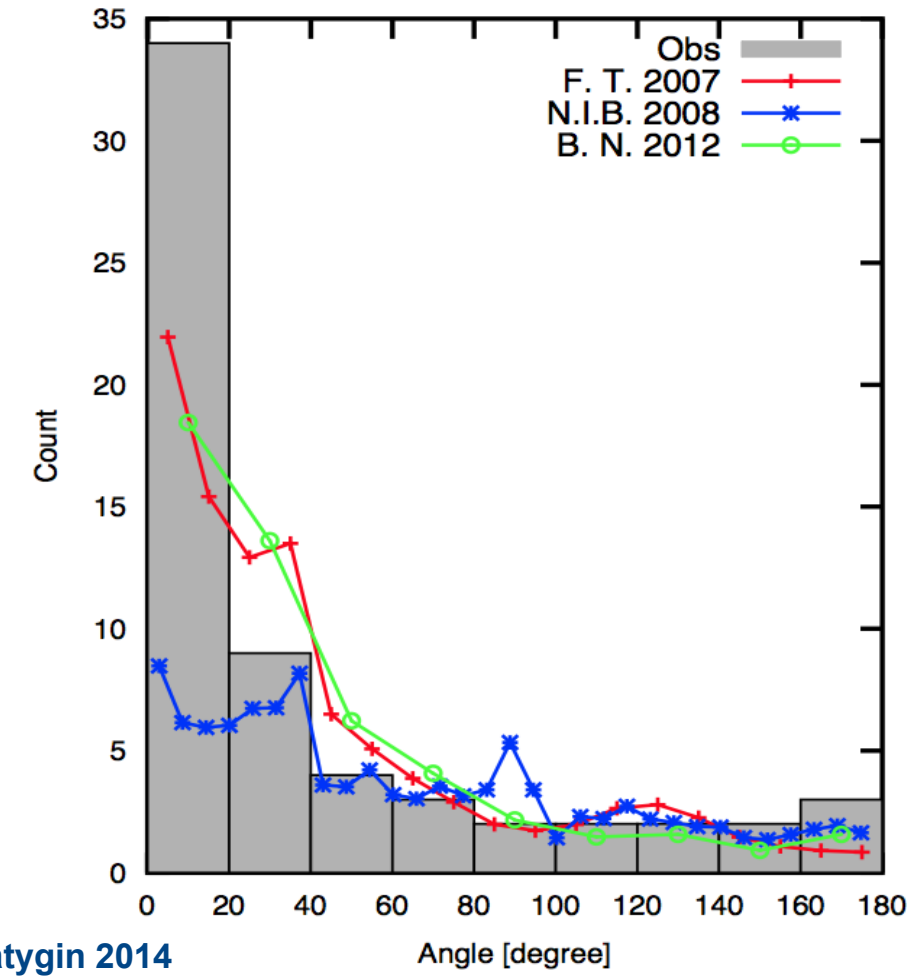


Crida & Batygin 2014

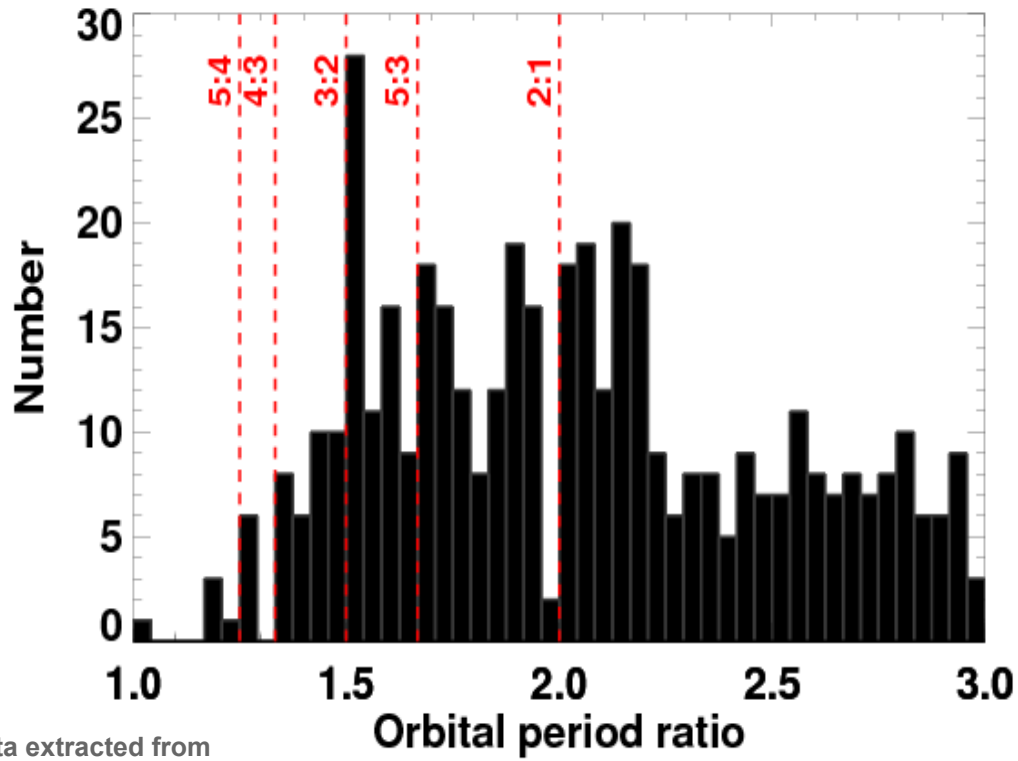
→ disc migration needed to account for number of aligned hot Jupiters.

→ observations cannot (yet) distinguish between misalignement mechanisms

Architecture of *Kepler*'s **confirmed** multiplanet systems

OBSERVATIONS

→ 836 planets in 335 systems
66% of 2 planets, 22% of 3, 12% of 4 and more



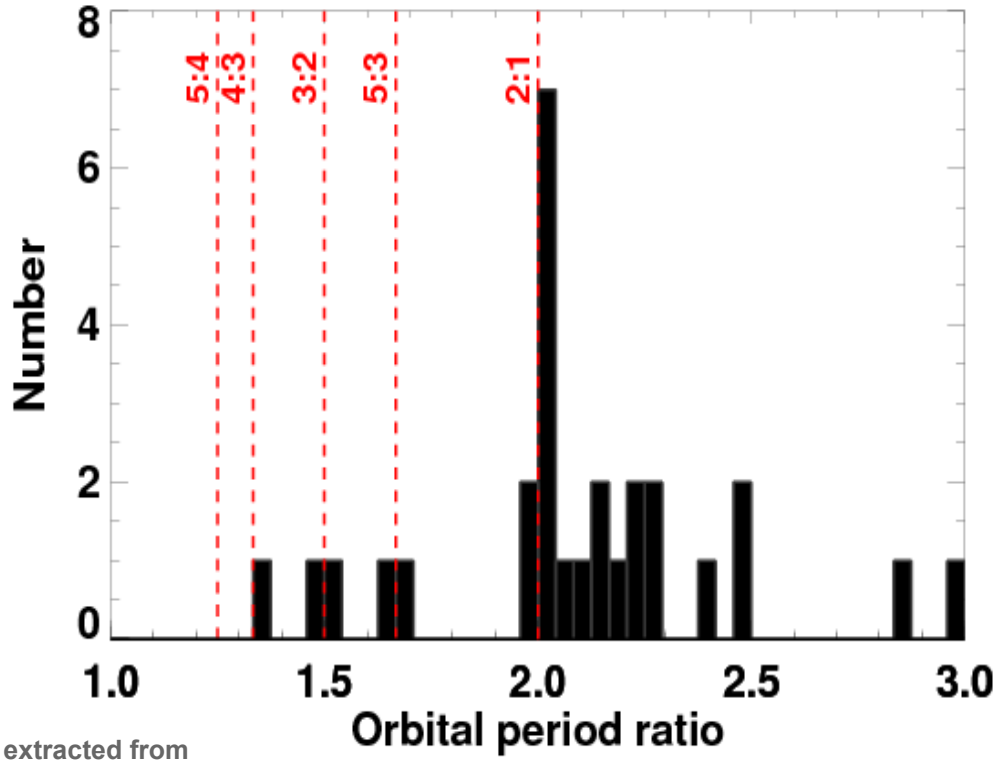
data extracted from
exoplanets.org (06/2014)

□ Many planet pairs are ***not* in resonance**, but those near resonances tend to have period ratios slightly **greater** than resonant

Architecture of *Kepler*'s **confirmed** multiplanet systems

OBSERVATIONS

→ 171 planets in 68 systems
66% of 2 planets, 23% of 3, 11% of 4 and more



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- Same trend for RV-detected multiple systems?

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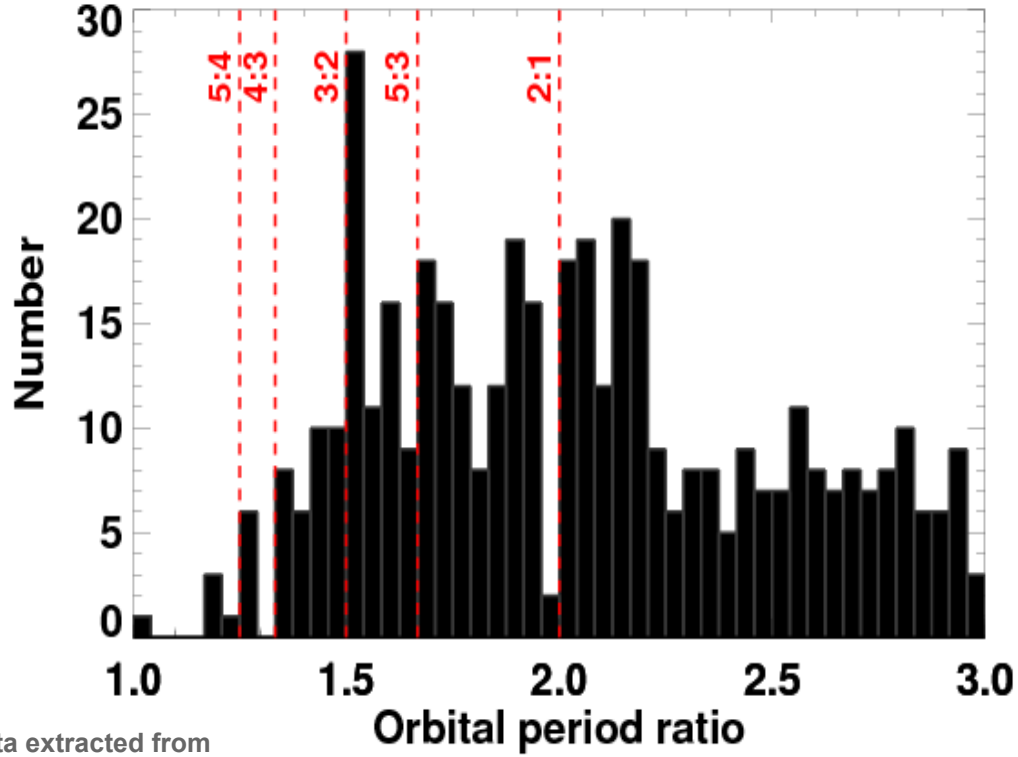

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□ Unseen companions?

Steffen 2013

3/2 x 5/4 = 1.875!

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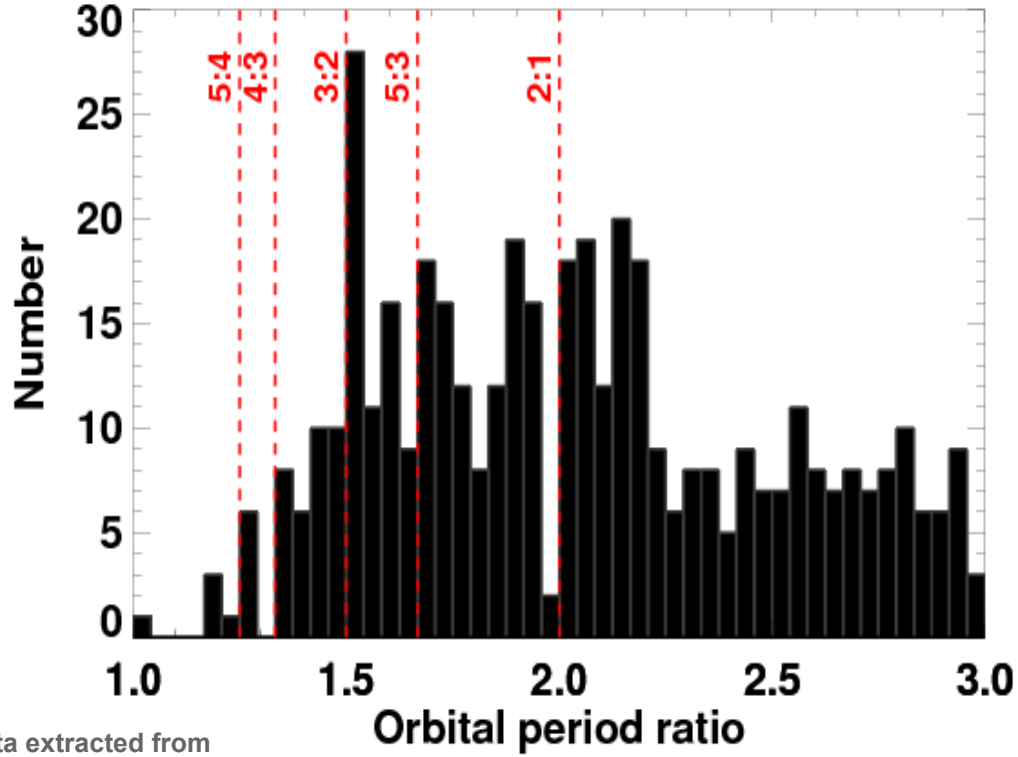

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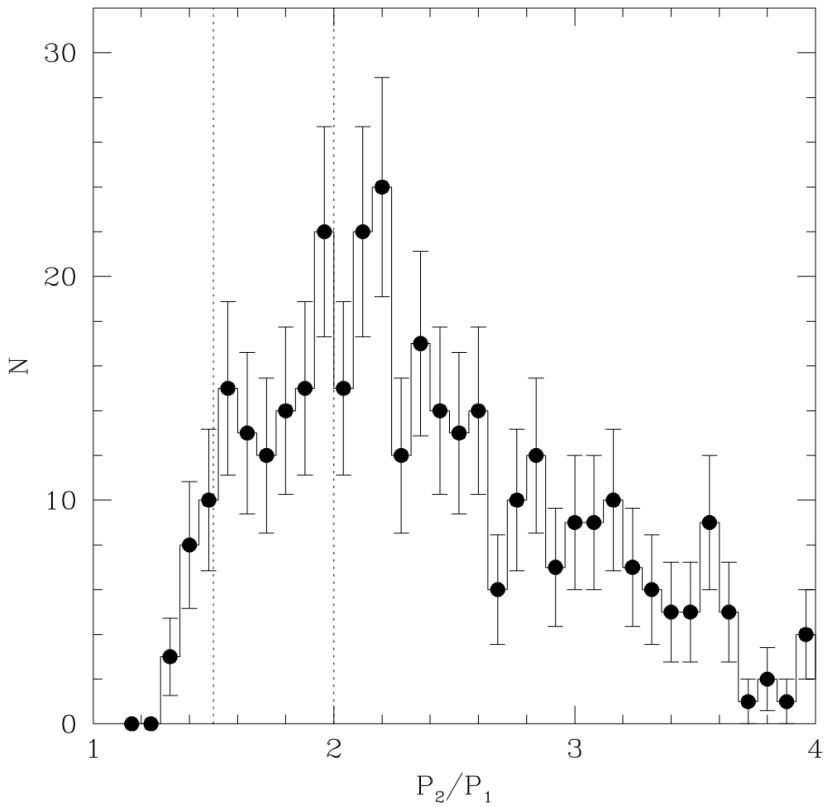
MODELS

□ In-situ growth of planet embryos

Hansen & Murray 2013; see also Raymond & Cossou 2014 and talk by Elisa Quintana



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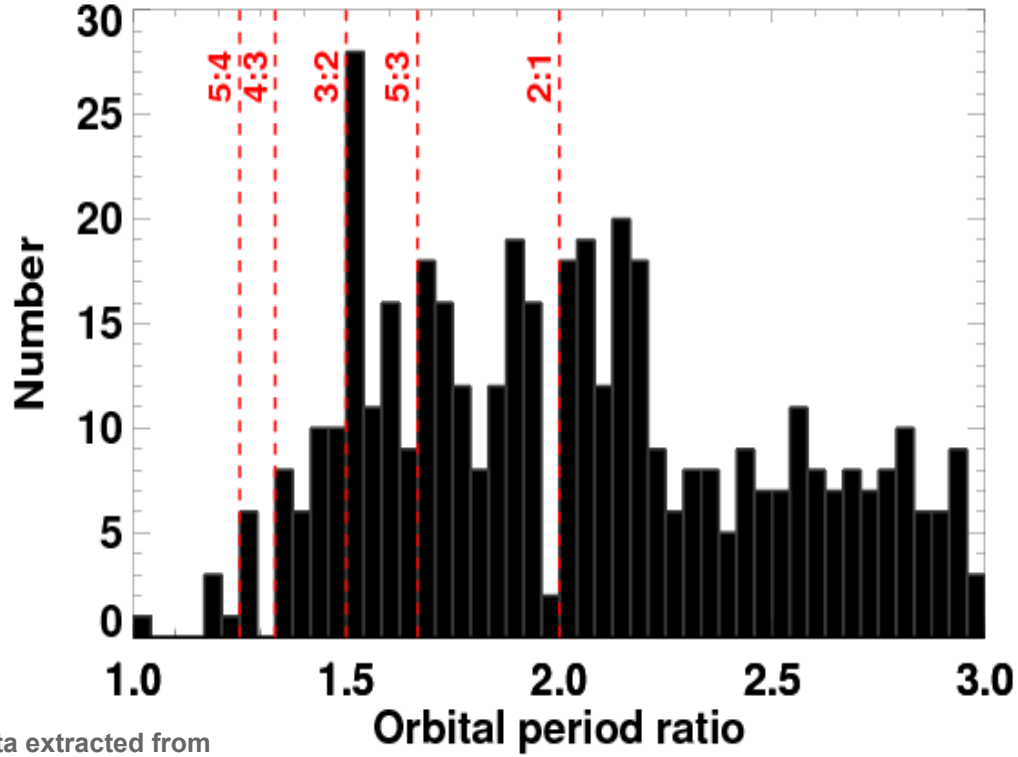

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□ In-situ growth of planet embryos

□ Tidal dissipation of close-in resonant planetary systems

Papaloizou 2011, Lithwick & Wu 2012, ...

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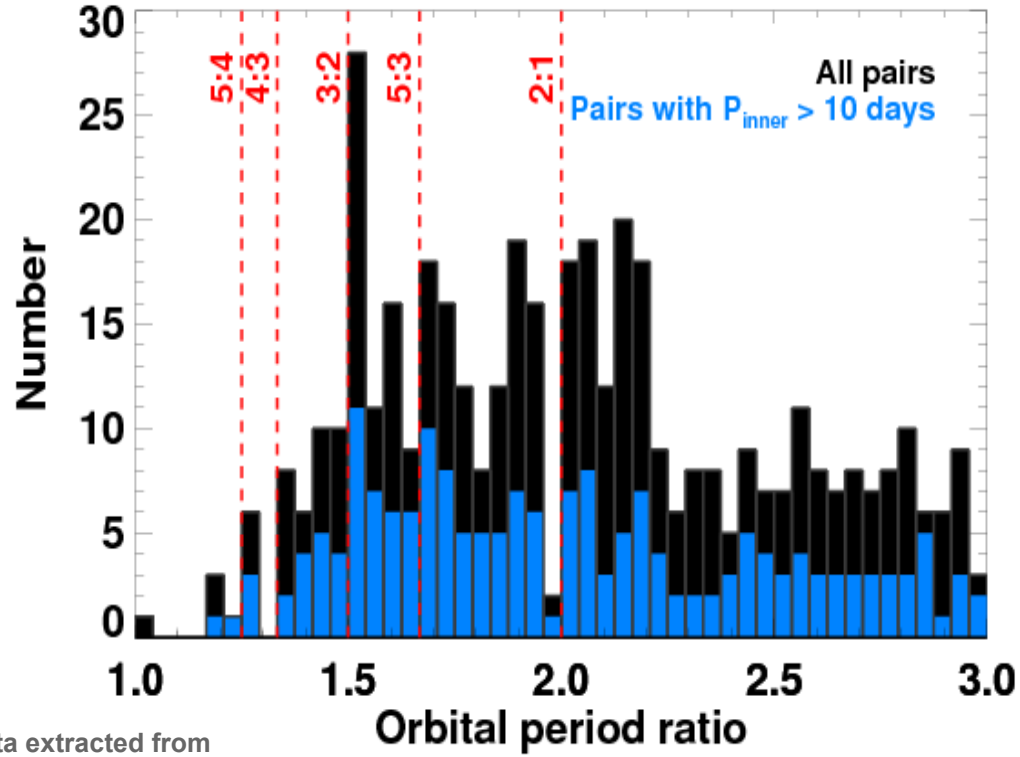

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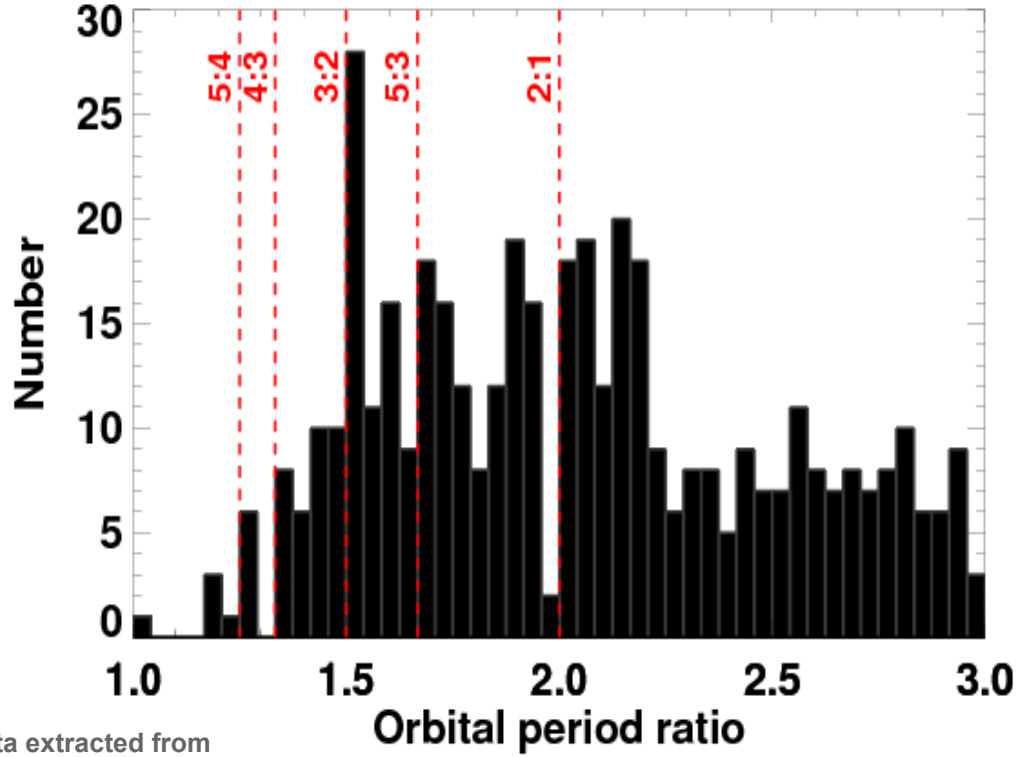

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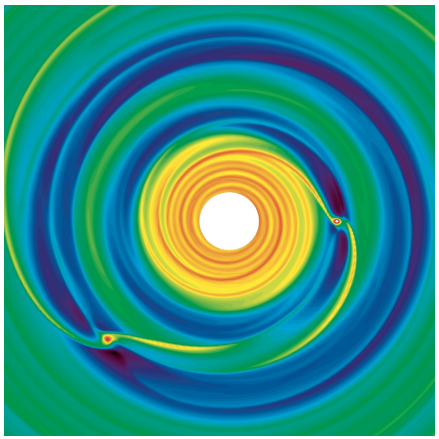
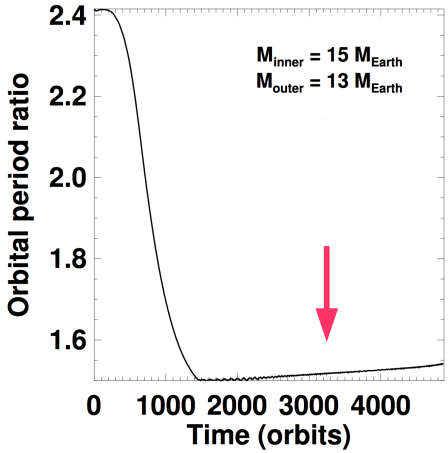
□ Tidal dissipation of close-in resonant planetary systems

□ Disc-migration of partial gap-opening planets

Baruteau & Papaloizou 2013





Formation and evolution of planetary systems: what have we learnt from transit methods?

□ Many mechanisms contribute to the orbital evolution of planetary systems

→ disc and high-eccentricity migrations, interactions with host and nearby stars all play some role.

□ Importance of stellar evolution in planetary evolution

□ More observations to constrain evolution models

→ CHEOPS (2017), TESS (2017), PLATO (2024)...