Star-planet interactions and dynamical evolution of exoplanetary systems

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Star-planet interactions

Close-in planets (a<0.15 AU), around MS late-type stars

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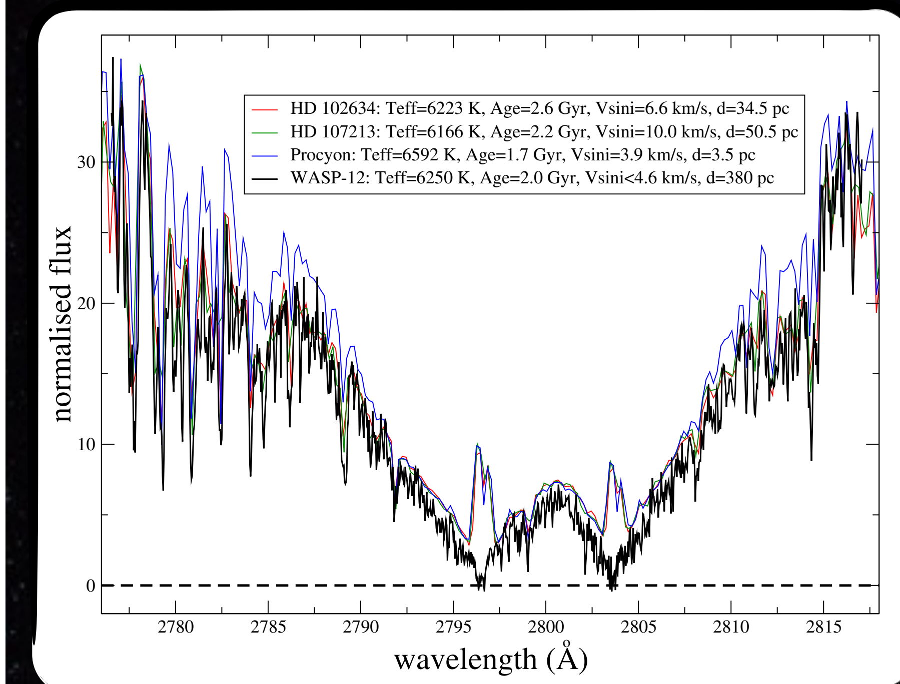
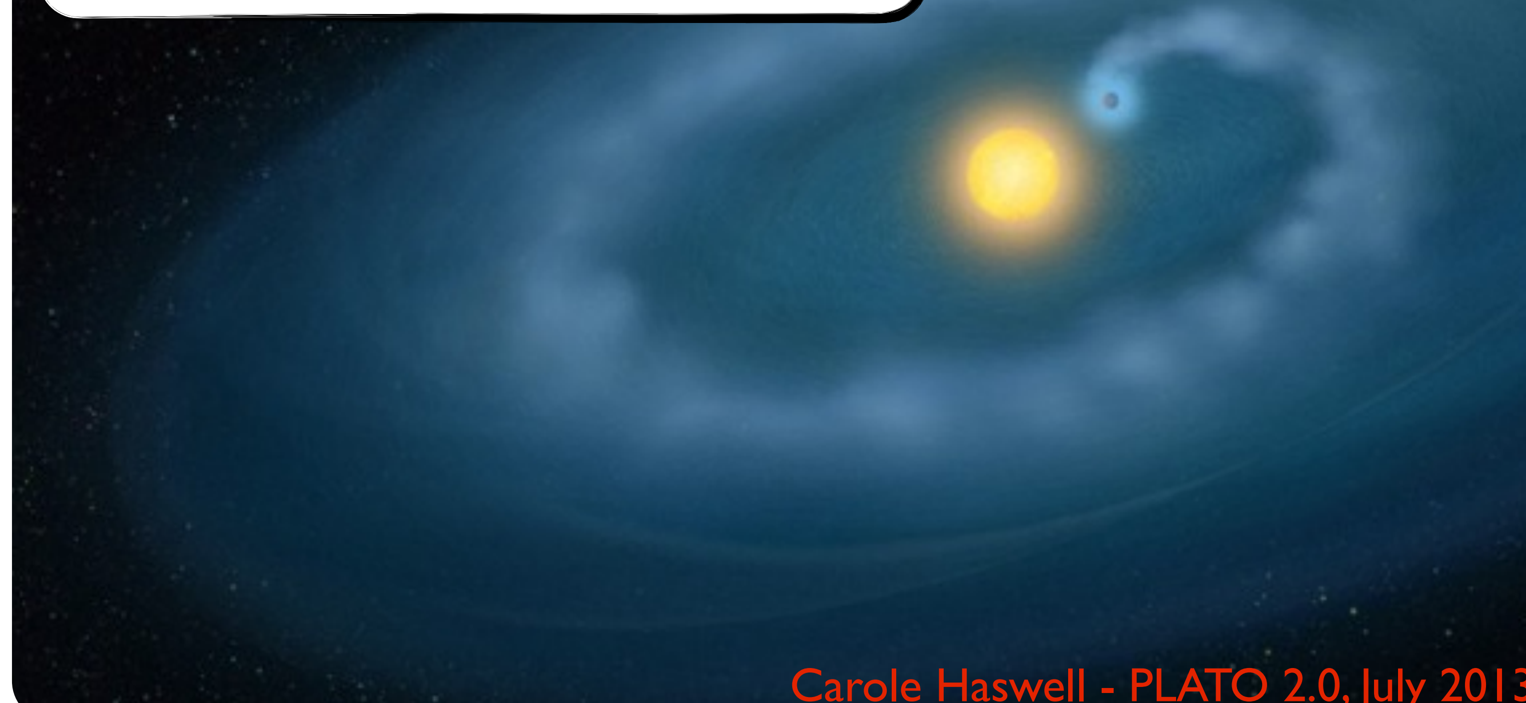
- Irradiation
  - EUV flux (1-100nm)
    - ➡ evaporation

The WASP-12 systems is shrouded in diffuse gas

Haswell et al 2012



The stellar disc is obscured at all observed phases



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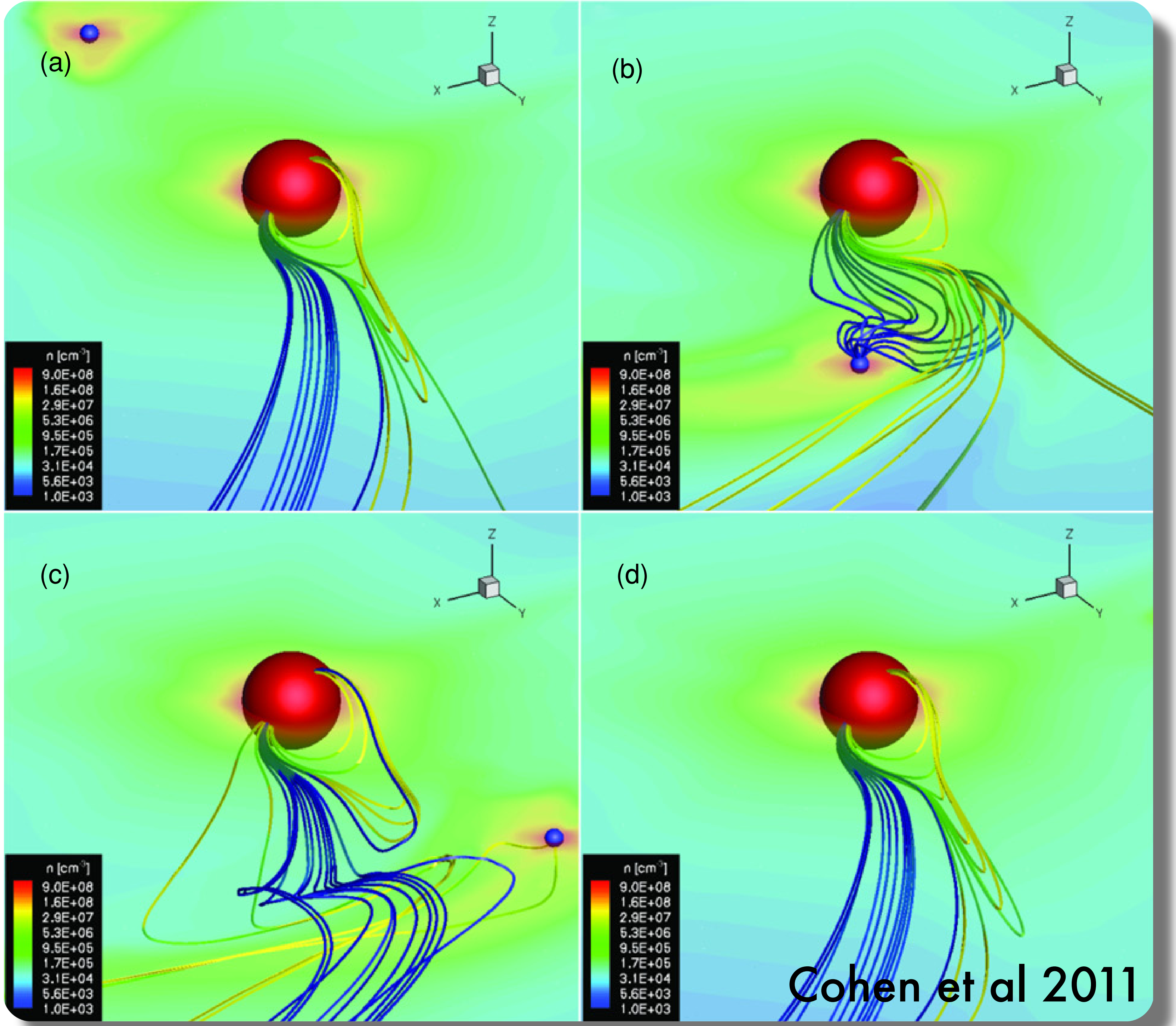
- Magnetic filed(s)
  - Sub-alfvénic regim, magnetic reconnections possible

Time-dependent MHD simulations of HD 189733



Cohen et al 2011

Star-planet interactions

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- Irradiation
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- Magnetic filed(s)
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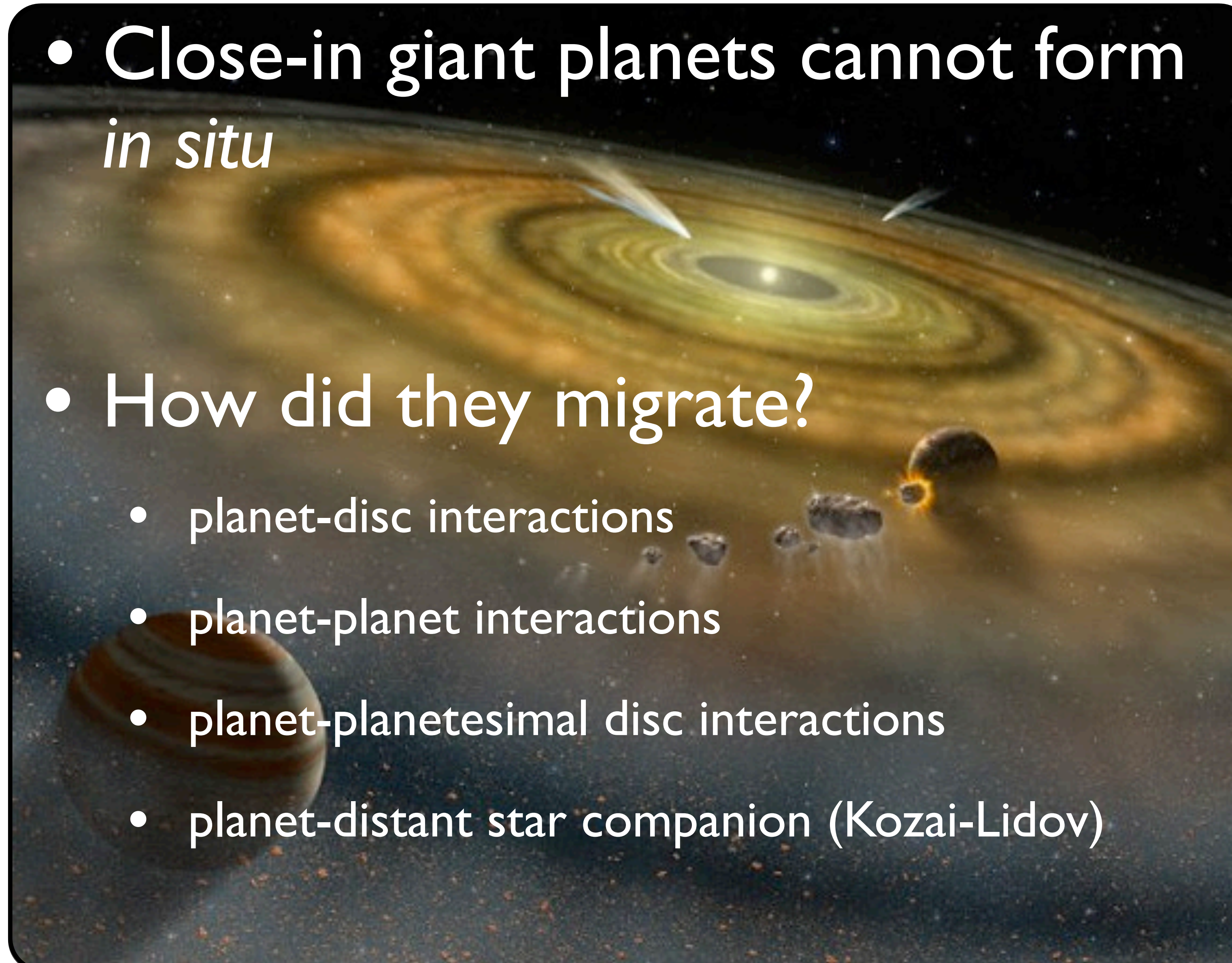
- Gravitation
  - Tidal torque $\propto a^{-6}$



- Close-in giant planets cannot form *in situ*
- How did they migrate?
  - planet-disc interactions
  - planet-planet interactions
  - planet-planetesimal disc interactions
  - planet-distant star companion (Kozai-Lidov)

- The end of migration is the beginning of tidal interactions

Tidal evolution outcome

Barker & Ogilvie 2009

Tidal circularization time (for co-planar orbit)

$$\tau_e \approx 16.8\mathrm{Myr}\left(\frac{Q'_\star}{10^6}\right)\left(\frac{m_\star}{M_\odot}\right)^{\frac{8}{3}}\left(\frac{M_J}{m_p}\right)\left(\frac{R_\odot}{R_\star}\right)^5\left(\frac{P_{\mathrm{orb}}}{1\mathrm{d}}\right)^{\frac{13}{3}}$$

$$\times\left[\left(f_1(e)-\frac{11}{18}\frac{P_{\mathrm{orb}}}{P_\star}f_2(e)\right)+\frac{Q'_p}{Q'_\star}\left(\frac{m_\star}{m_p}\right)^2\left(\frac{R_p}{R_\star}\right)^5\left(f_1(e)-\frac{11}{18}f_2(e)\right)\right]^{-1}$$

Tidal alignement time (for circular orbit and small inclination)

$$\tau_i \approx 70\mathrm{Myr}\left(\frac{Q'_\star}{10^6}\right)\left(\frac{m_\star}{M_\odot}\right)\left(\frac{M_J}{m_p}\right)^2\left(\frac{R_\odot}{R_\star}\right)^3\left(\frac{P_{\mathrm{orb}}}{1\mathrm{d}}\right)^4\frac{12.5\mathrm{d}}{P_\star}\left[1-\frac{P_{\mathrm{orb}}}{2P_\star}\left(1-\frac{I\Omega}{h\mu}\right)\right]^{-1}$$

Tidal inspiral time (neglecting tides in the planet and for circular and co-planar orbit)

$$\tau_a \approx 12.0\mathrm{Myr}\left(\frac{Q'_\star}{10^6}\right)\left(\frac{m_\star}{M_\odot}\right)\left(\frac{M_J}{m_p}\right)\left(\frac{P_{\mathrm{orb}}}{1\mathrm{d}}\right)^{\frac{13}{3}}\left(1-\frac{P_{\mathrm{orb}}}{P_\star}\right)^{-1}$$

Tidal evolution outcome

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$\tau_e \approx 4$ Myr, for $e = 0.4$ and $P_\mathrm{orb} = 3$ d

Tidal alignement time (for circular orbit and small inclination)

$$\tau_i \approx 70\mathrm{Myr}\left(\frac{Q'_\star}{10^6}\right)\left(\frac{m_\star}{M_\odot}\right)\left(\frac{M_J}{m_p}\right)^2\left(\frac{R_\odot}{R_\star}\right)^3\left(\frac{P_\mathrm{orb}}{1\mathrm{d}}\right)^4\frac{12.5\mathrm{d}}{P_\star}\left[1-\frac{P_\mathrm{orb}}{2P_\star}\left(1-\frac{I\Omega}{h\mu}\right)\right]^{-1}$$

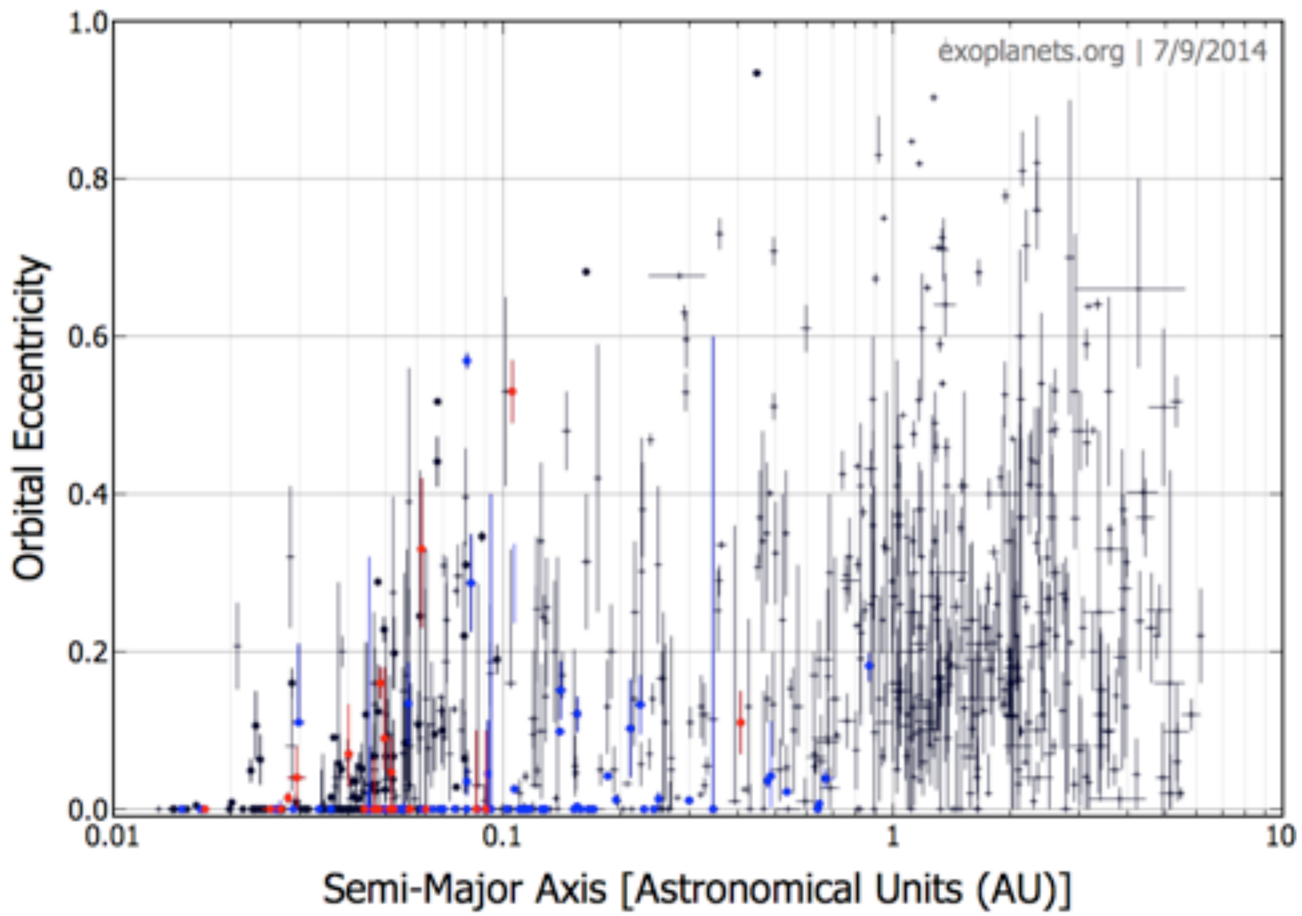
$\tau_i \approx 6$ Gyr, for $P_\mathrm{orb} = 3$ d and $P_\star = 12.5$ d

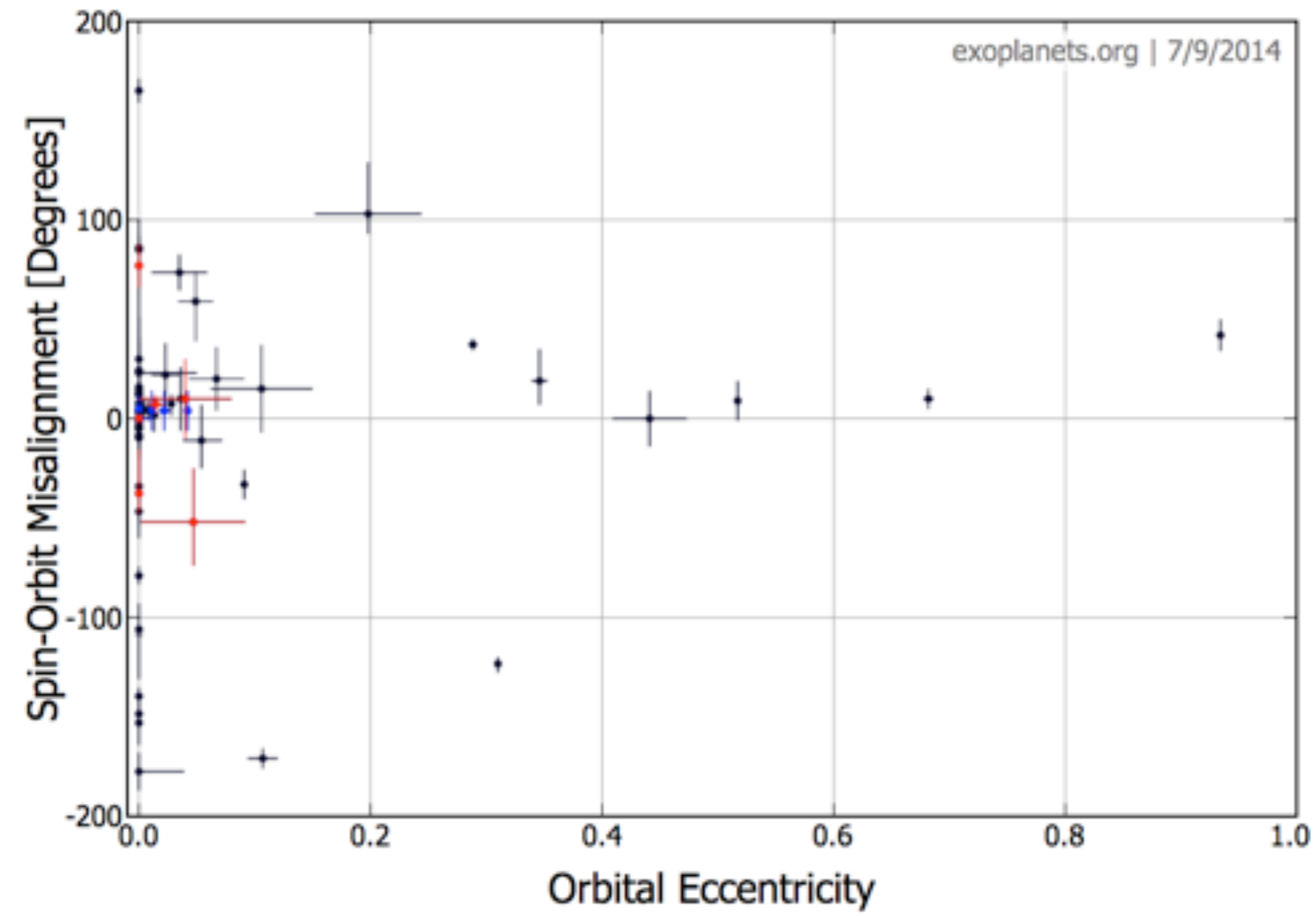
Tidal inspiral time (neglecting tides in the planet and for circular and co-planar orbit)

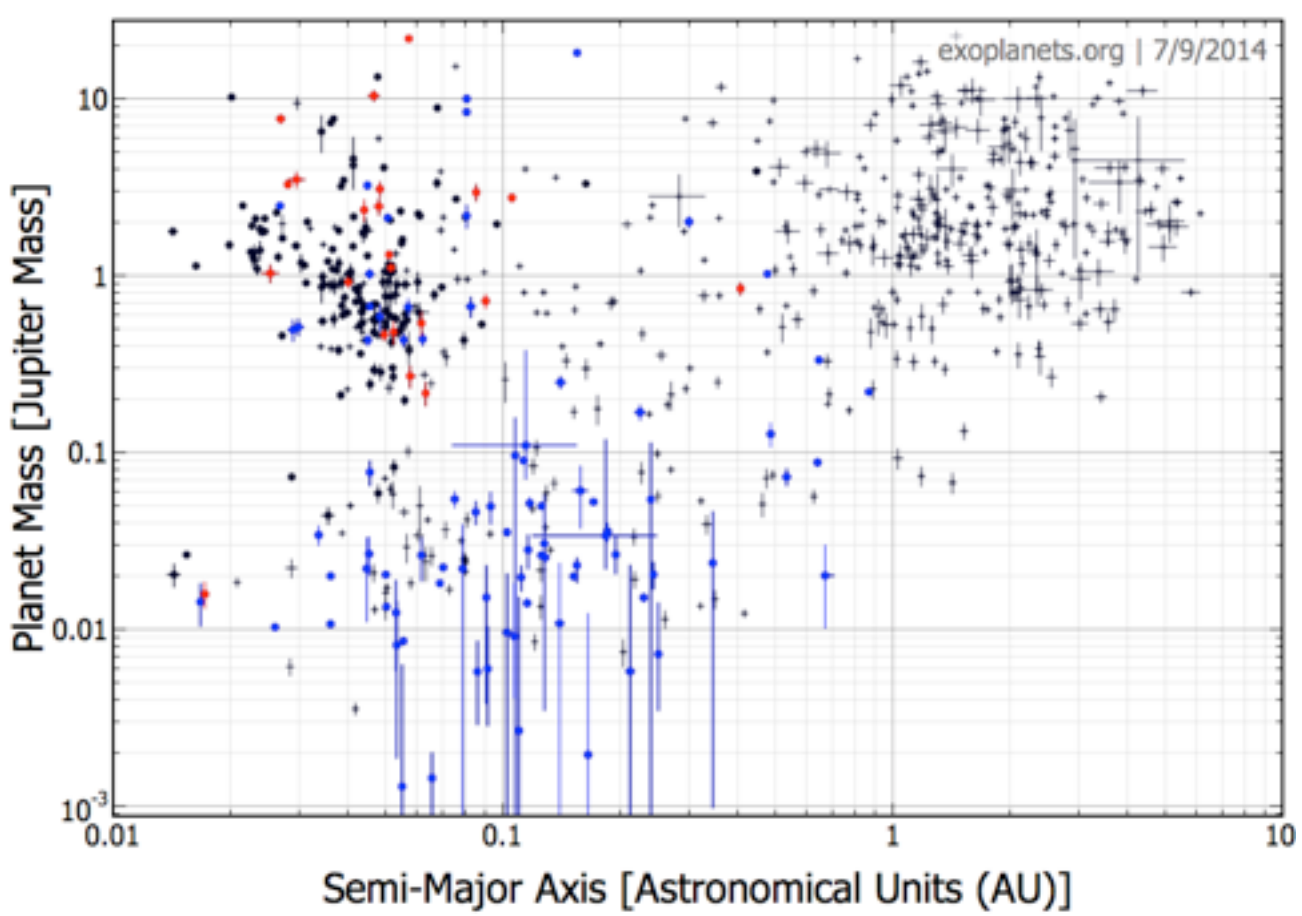
$$\tau_a \approx 12.0\mathrm{Myr}\left(\frac{Q'_\star}{10^6}\right)\left(\frac{m_\star}{M_\odot}\right)\left(\frac{M_J}{m_p}\right)\left(\frac{P_\mathrm{orb}}{1\mathrm{d}}\right)^{\frac{13}{3}}\left(1-\frac{P_\mathrm{orb}}{P_\star}\right)^{-1}$$

$\tau_a \approx 2$ Gyr, for $P_\mathrm{orb} = 3$ d and $P_\star = 12.5$ d

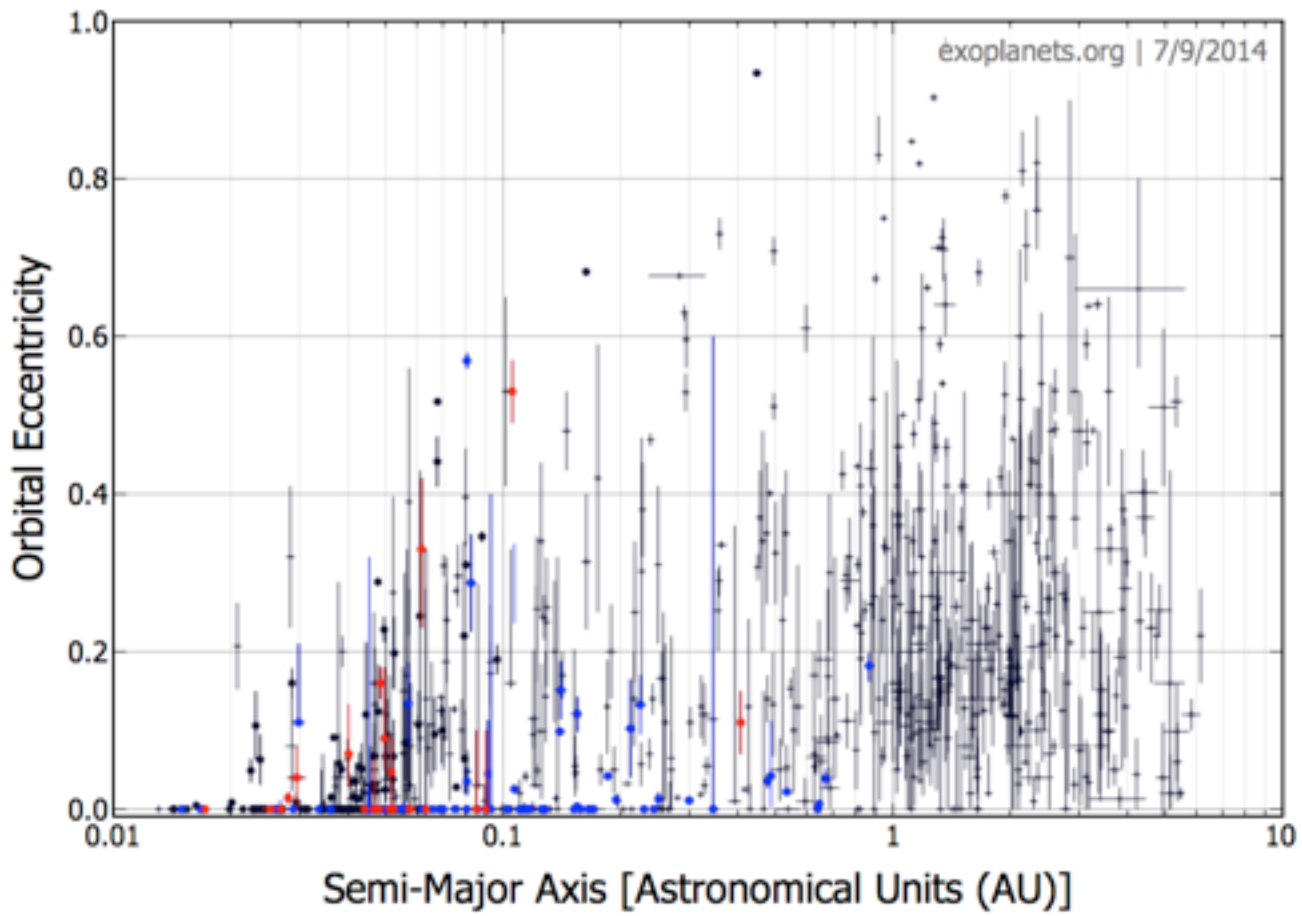
Observations

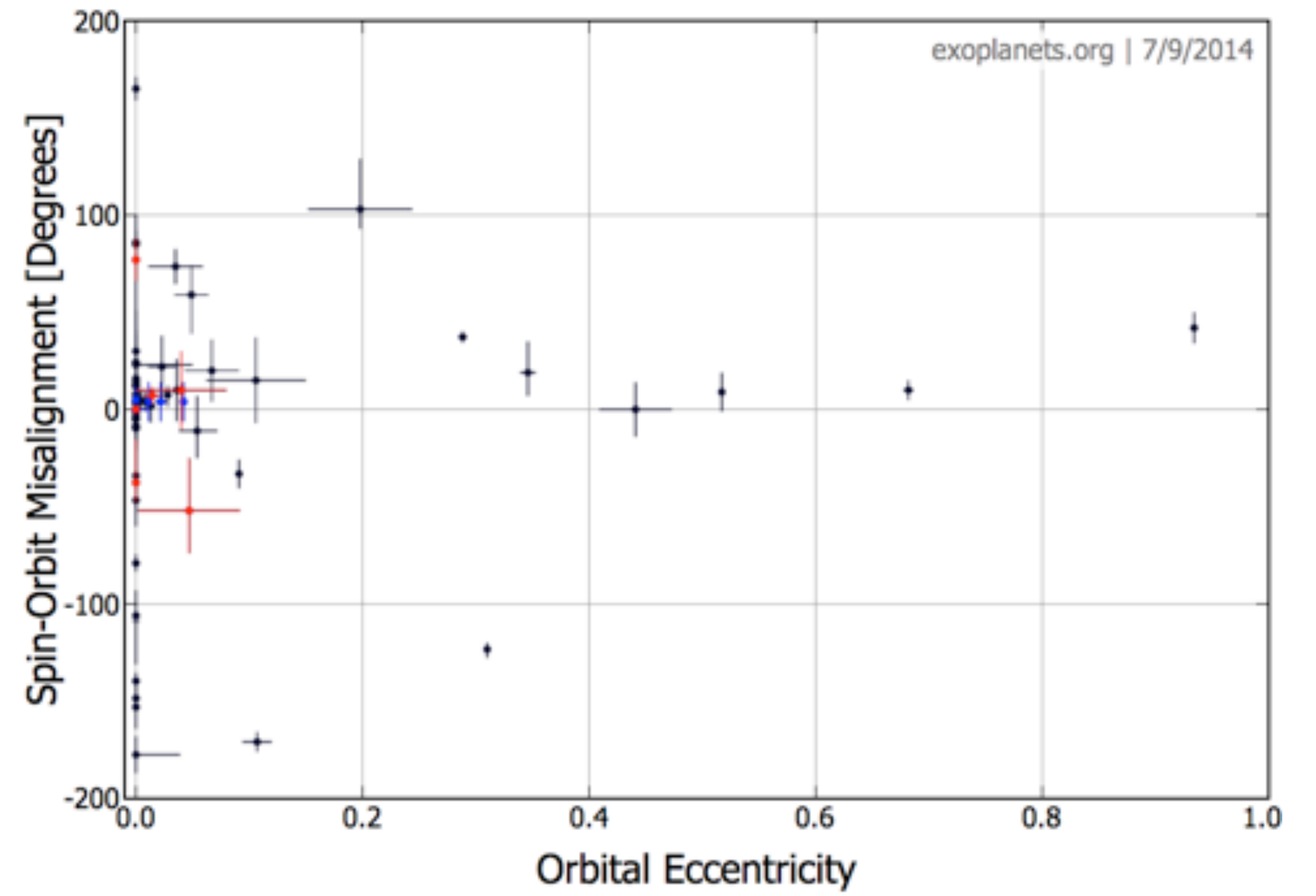


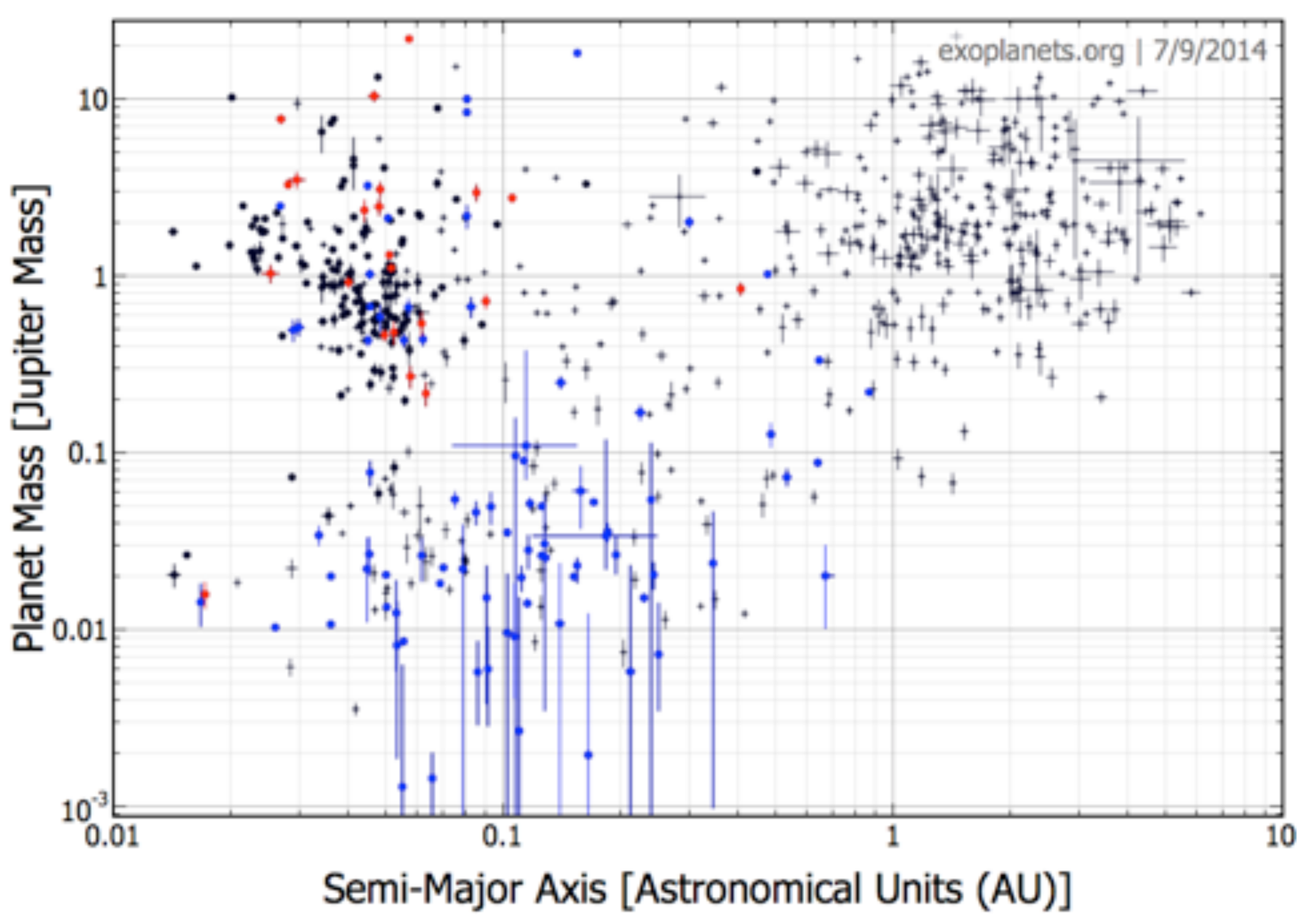




Observations







- How efficient is tidal dissipation?
- observational constraints:

Jackson et al 2008, Matsumura et al 2008, Deleuil et al 2012, Carone & Patzold 2007, Lanza et al 2011...

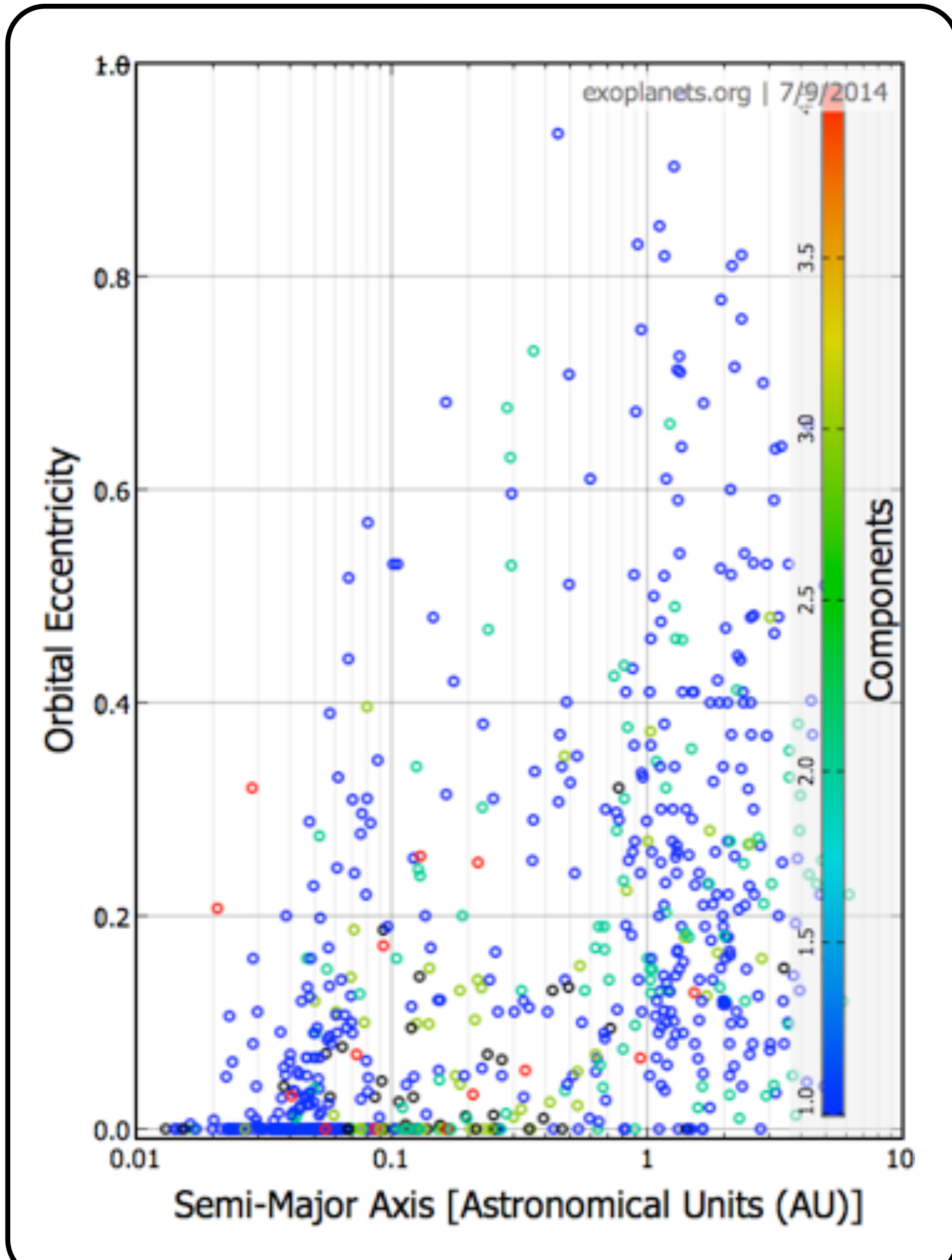
➡ See next talk

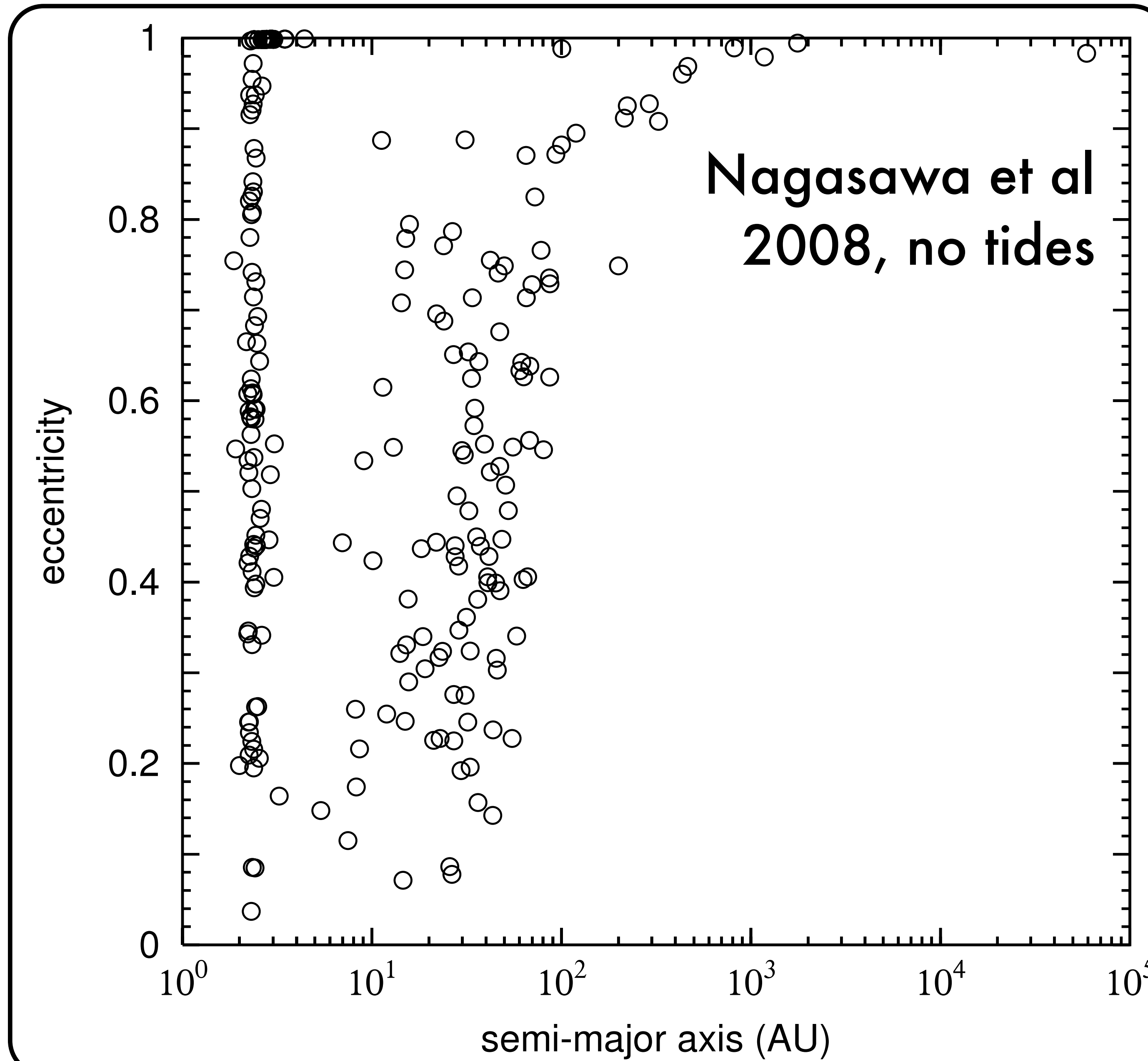
Excentricity

Origin?

Planet-planet scattering

(Rasio & Ford 1996, Weidenschilling & Marzari 1996)



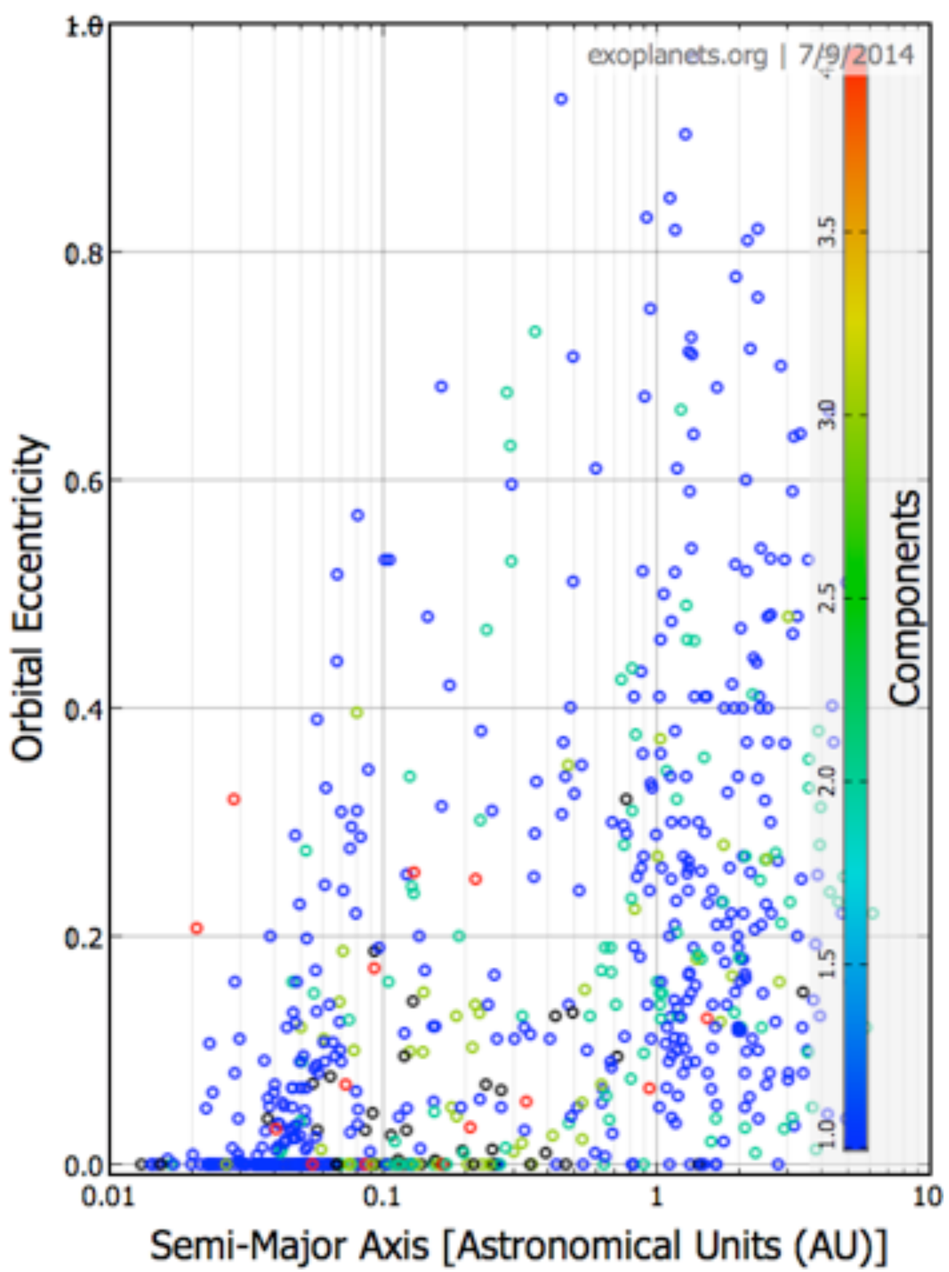


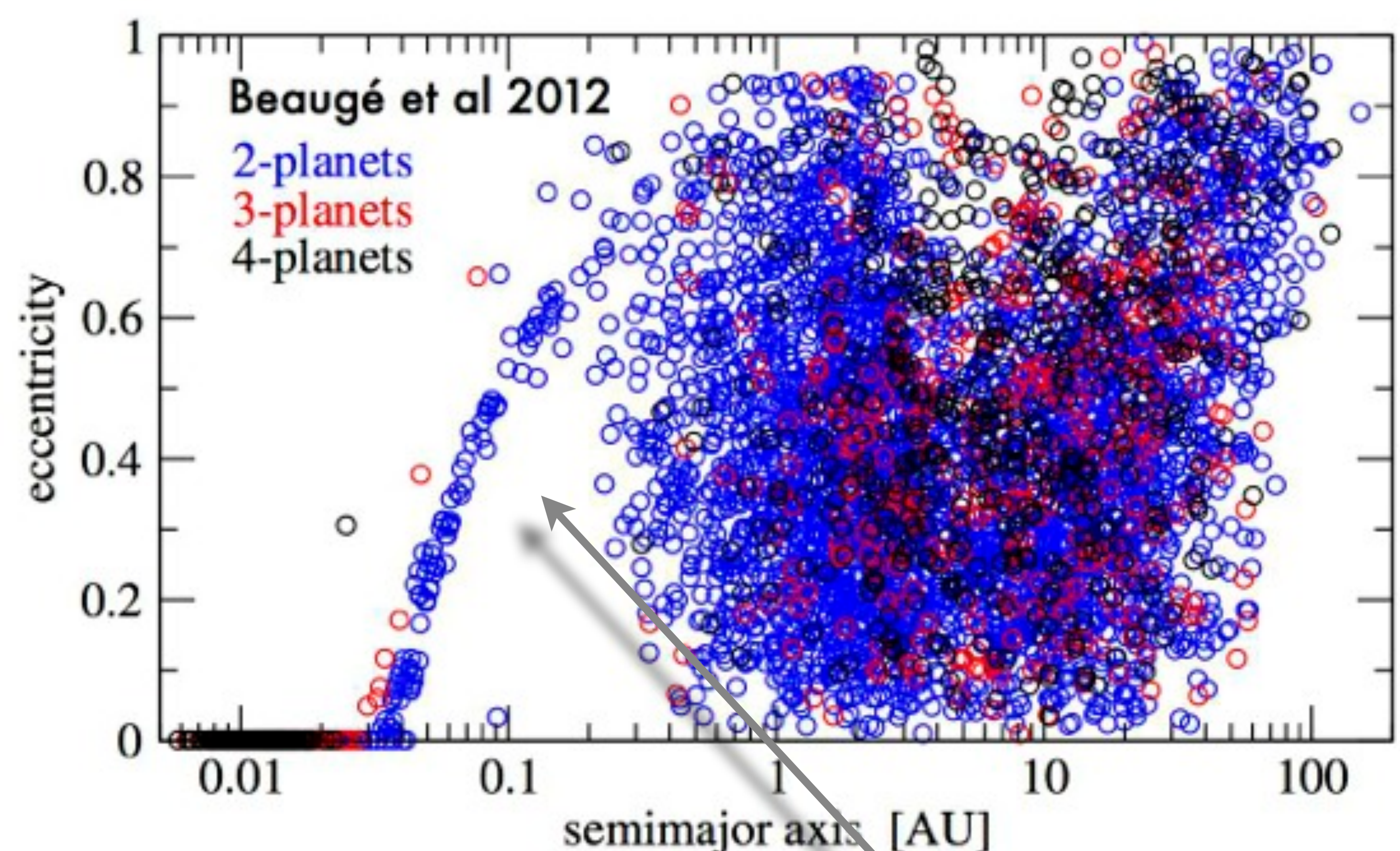
Excentricity

Origin?

Planet-planet scattering & tidal circularization

(Nagasawa et al 2008)



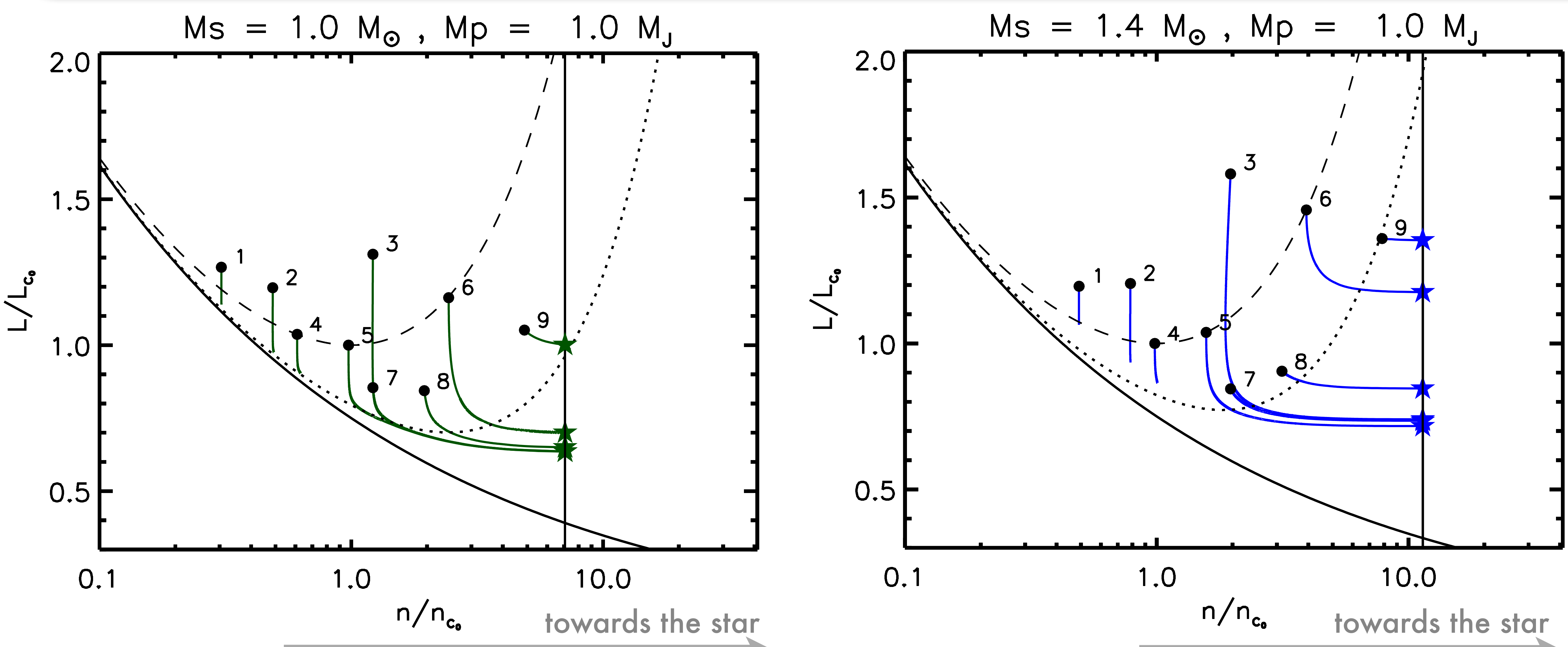


$$Q'_p \sim 10^6 - 10^7$$

Spread?

Role of angular momentum loss

- G-type stars loose angular momentum from their magnetized wind, F-type stars too but less so
- The dynamical evolution of orbital elements is driven by the resultant of the wind torque and the tidal torque



Damiani & Lanza, under revision

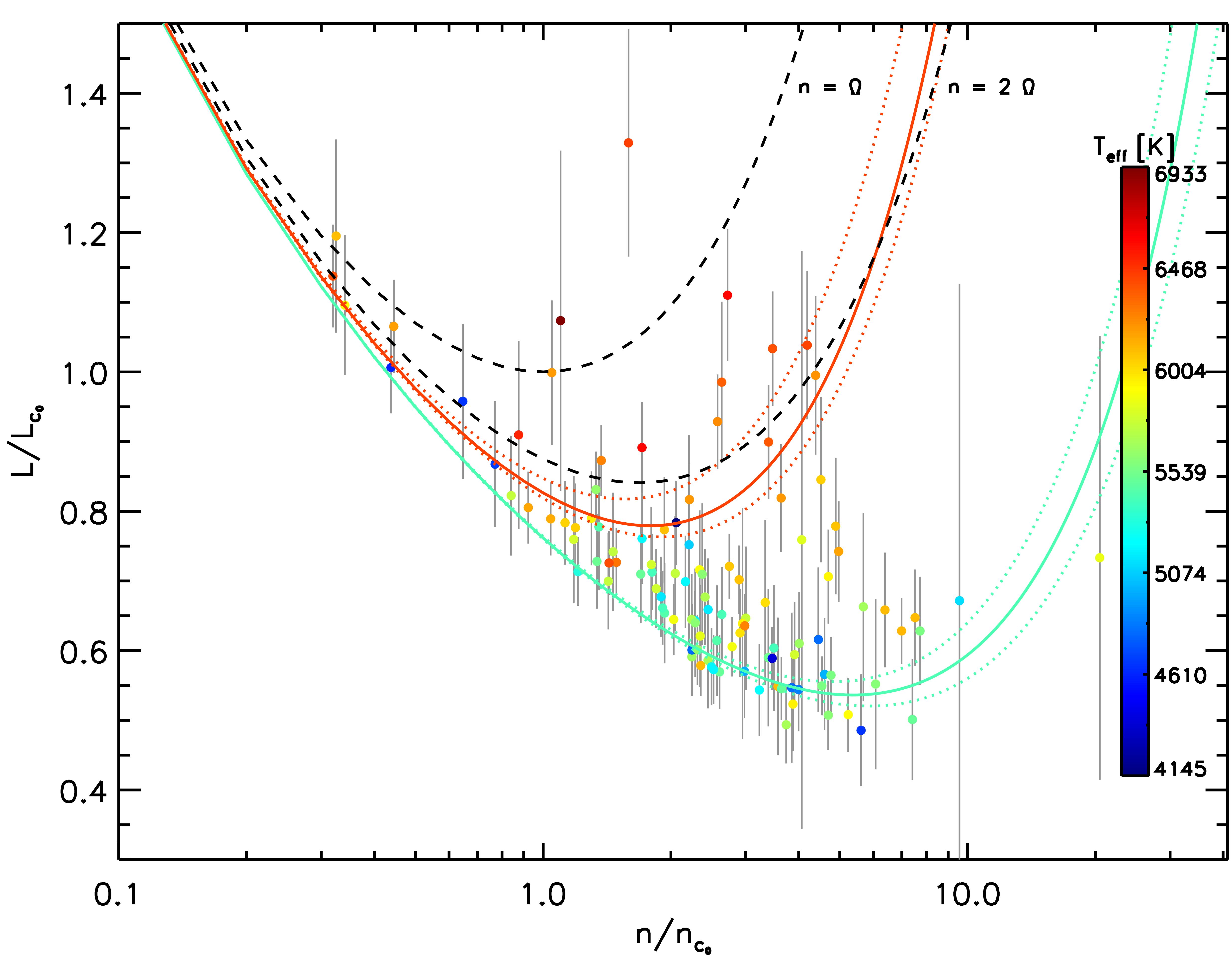
Role of angular momentum loss

- G-type stars loose angular momentum from their magnetized wind, F-type stars too but less so
- The dynamical evolution of orbital elements is driven by the resultant of the wind torque and the tidal torque
- The wind efficency dependance on stellar parameters is not well known but
  - ➡ Could explain the spread in excentricity (Dobbs-Dixon et al 2004)
  - ➡ Could explain the spin/orbit misalignement (Dawson 2014)
  - ➡ Could explain the delay of the tidal decay (Damiani et al 2014)

Conclusion

- Understanding star-planet interaction is a necessary step to confront observations and predictions of formation/migration models
- For hot-Jupiters around late-type stars the magnetized wind torque can be comparable (and opposite) to the tidal torque
- By providing accurate masses, radii and orbital parameters, CoRoT and Kepler have helped put constraints on tidal dissipation efficency and magnetic braking
- Better ages and stellar physics are essential to understand exoplanetary systems dynamics (we need PLATO)


Thank you!



Damiani & Lanza, under revision