The role of tidal dissipation on the evolution of planetary systems

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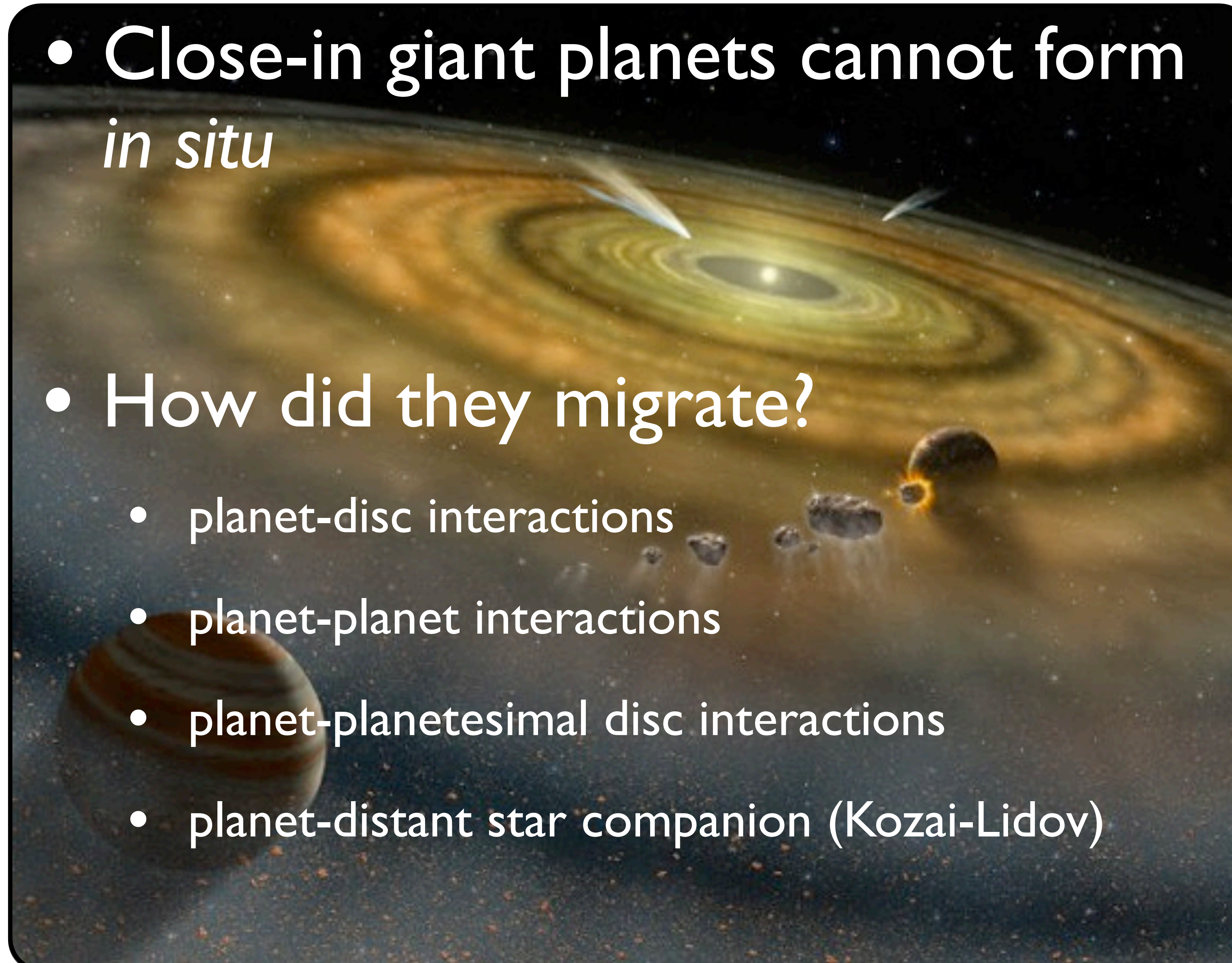
Tidal interactions in exoplanetary systems

- No exomoons discovered yet!
- Tidal torque $\propto a^{-6}$
- Close-in planets ($a<0.15$ AU), around MS late-type stars



- 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)

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

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

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

Tidal alignement time (for circular orbit and small inclination)

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

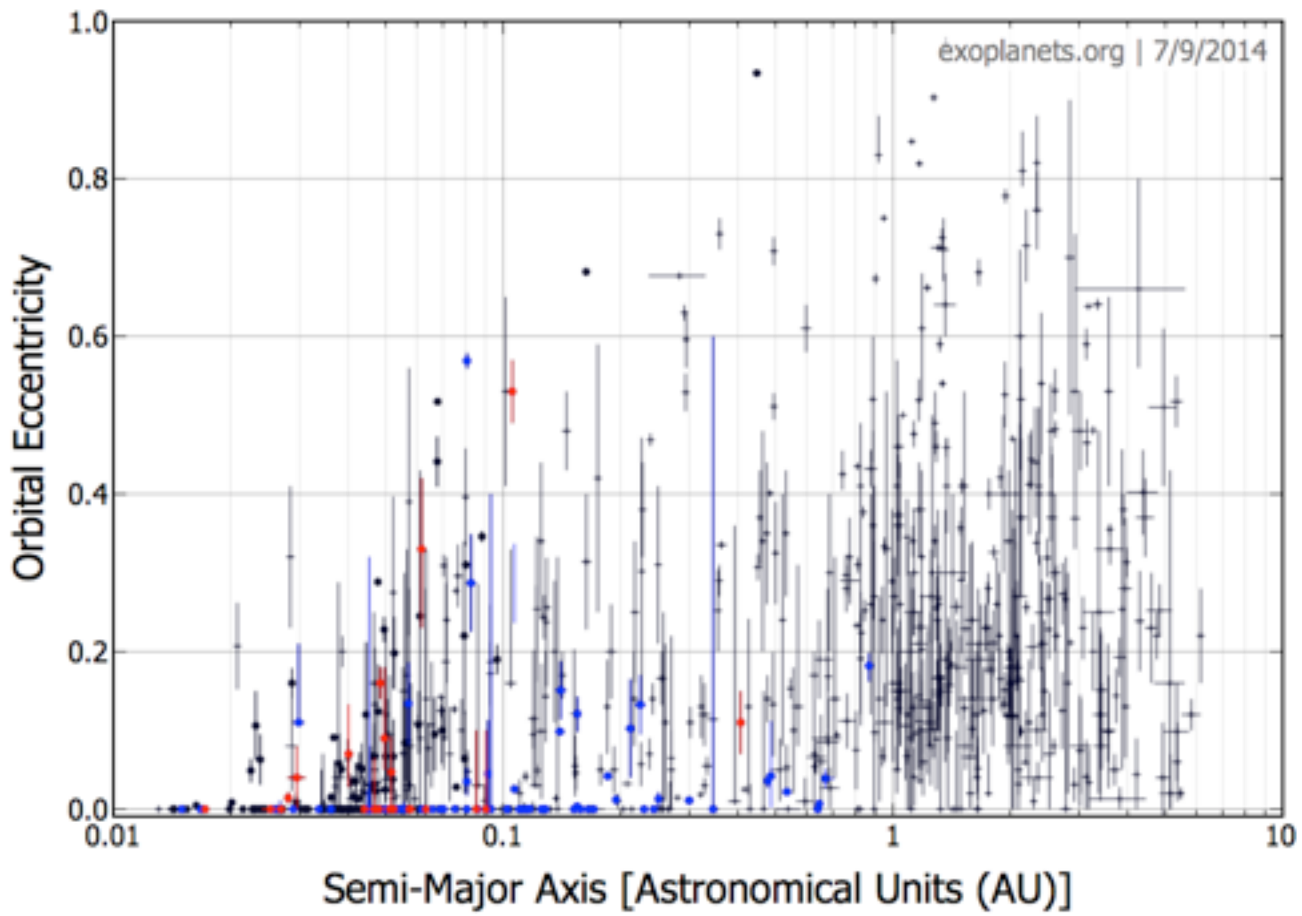
$\tau_i \approx 6$ Gyr, for $P_{\mathrm{orb}} = 3$ d and $P_\star = 12.5$ d

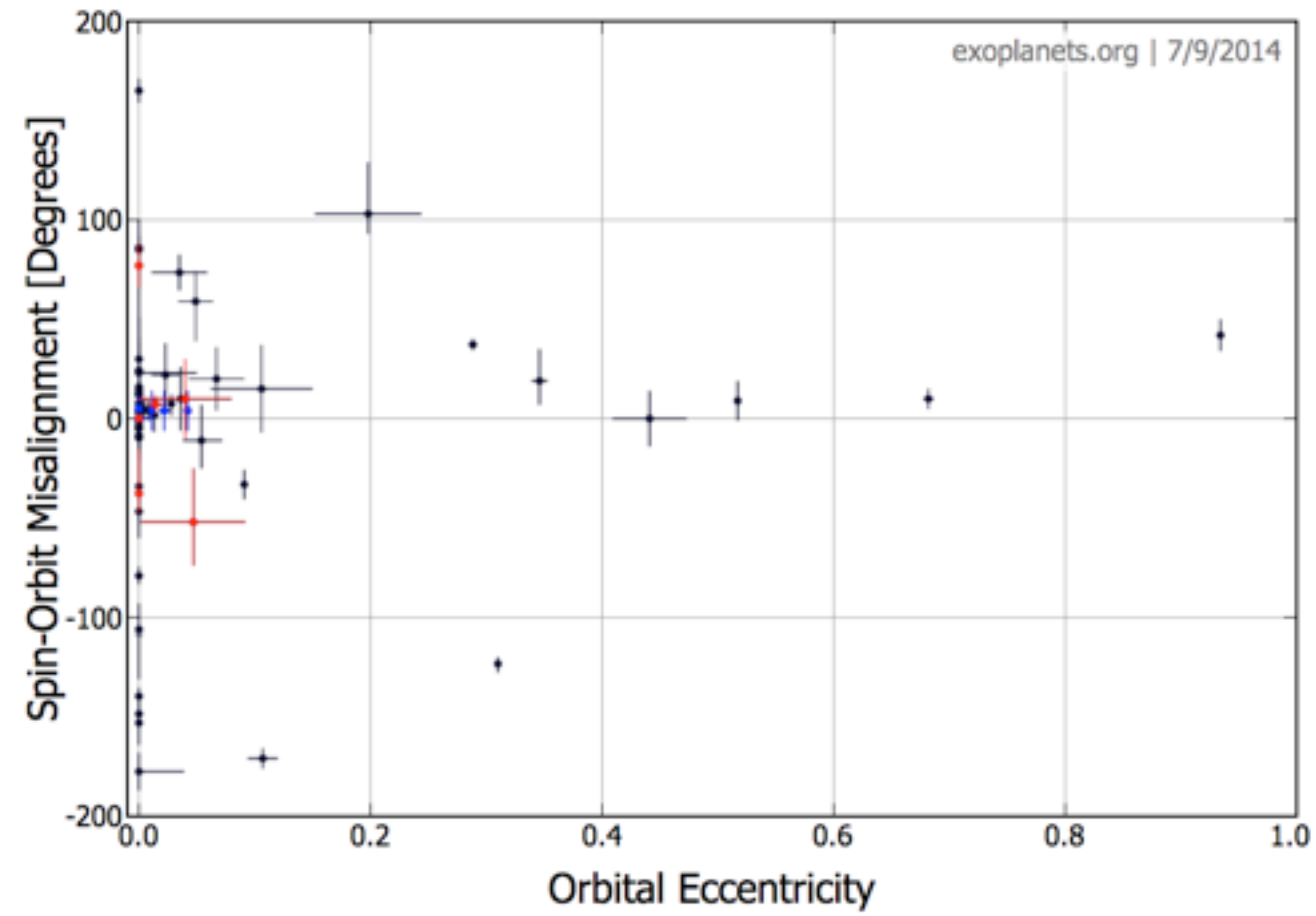
Tidal inspiral time (neglecting tides in the planet and for circular and co-planar orbit)

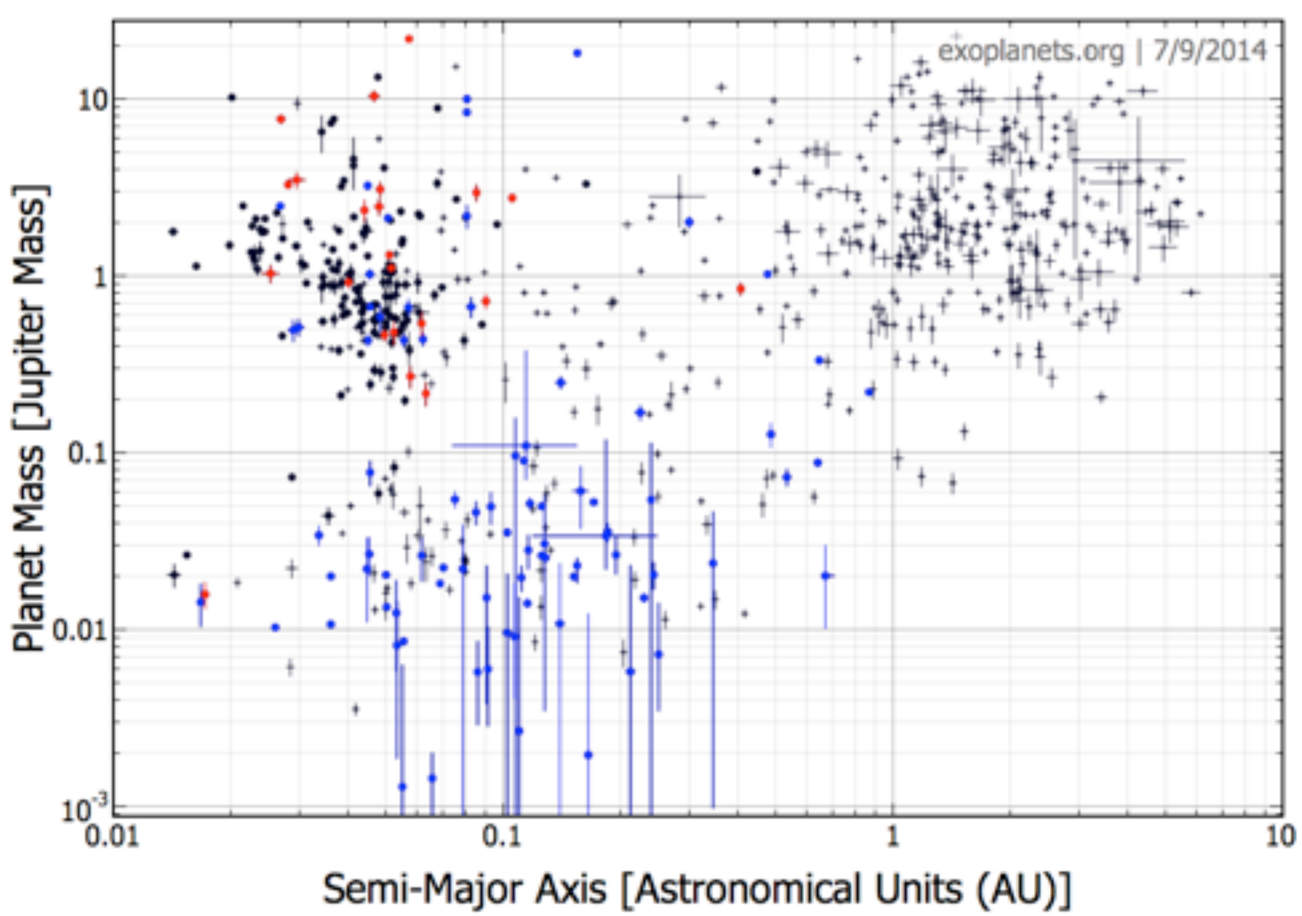
$$\tau_a \approx 12.0\mathrm{Myr} \left(\frac{Q'_\star}{10^6}\right) \left(\frac{m_\star}{M_\odot}\right) \left(\frac{M_J}{m_p}\right) \left(\frac{P_{\mathrm{orb}}}{1\mathrm{d}}\right)^{\frac{13}{3}} \left(1 - \frac{P_{\mathrm{orb}}}{P_\star}\right)^{-1}$$

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

Observations







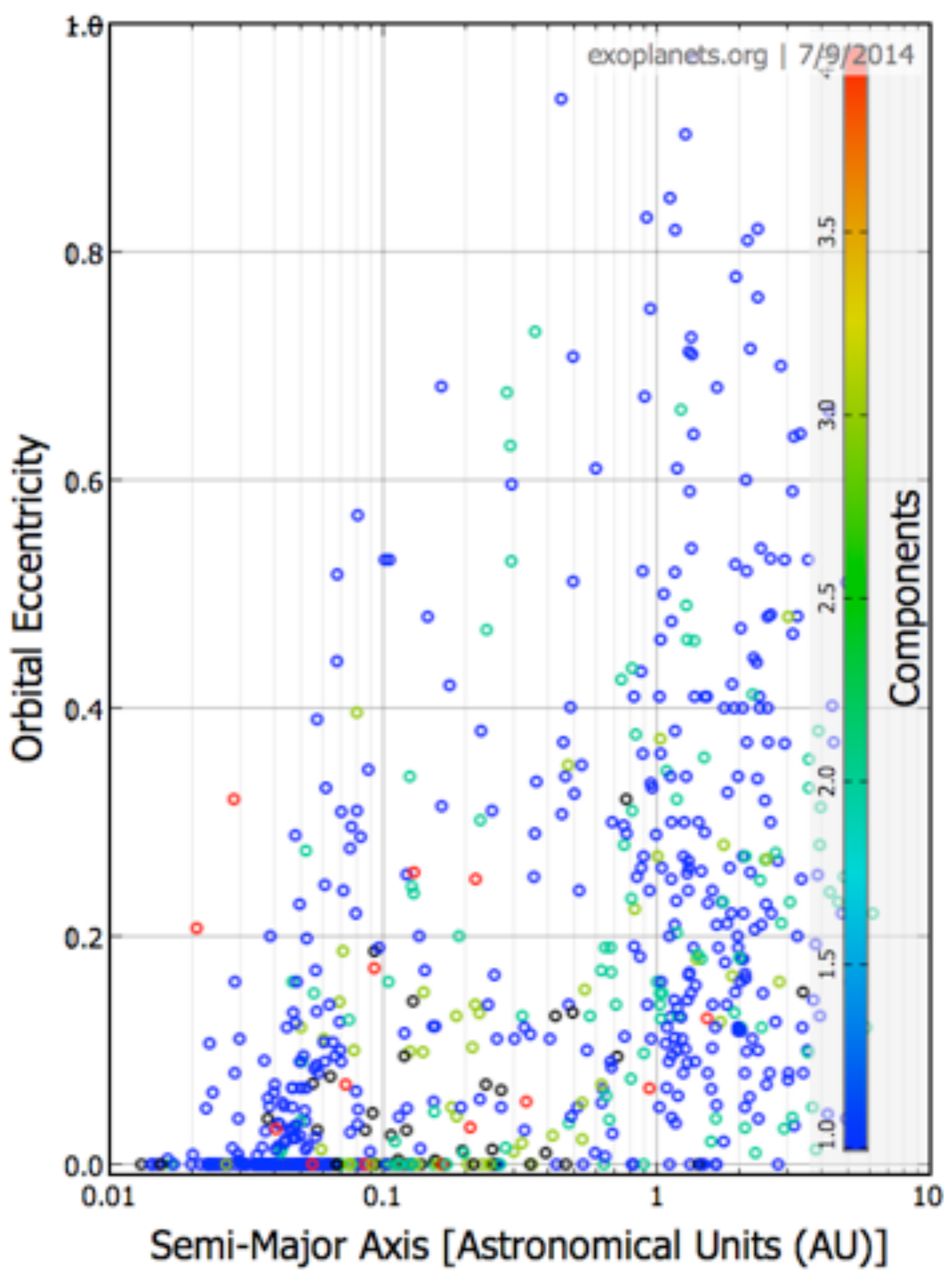
- How efficient is tidal dissipation?
  - observational constraints: Jackson et al 2008, Matsumura et al 2008, Deleuil et al 2012, Carone & Patzold 2007, Lanza et al 2011...

$10^4 \leq Q'_p \leq 10^7$, $10^5 \leq Q'_s \leq 10^9$

➡ See next talks

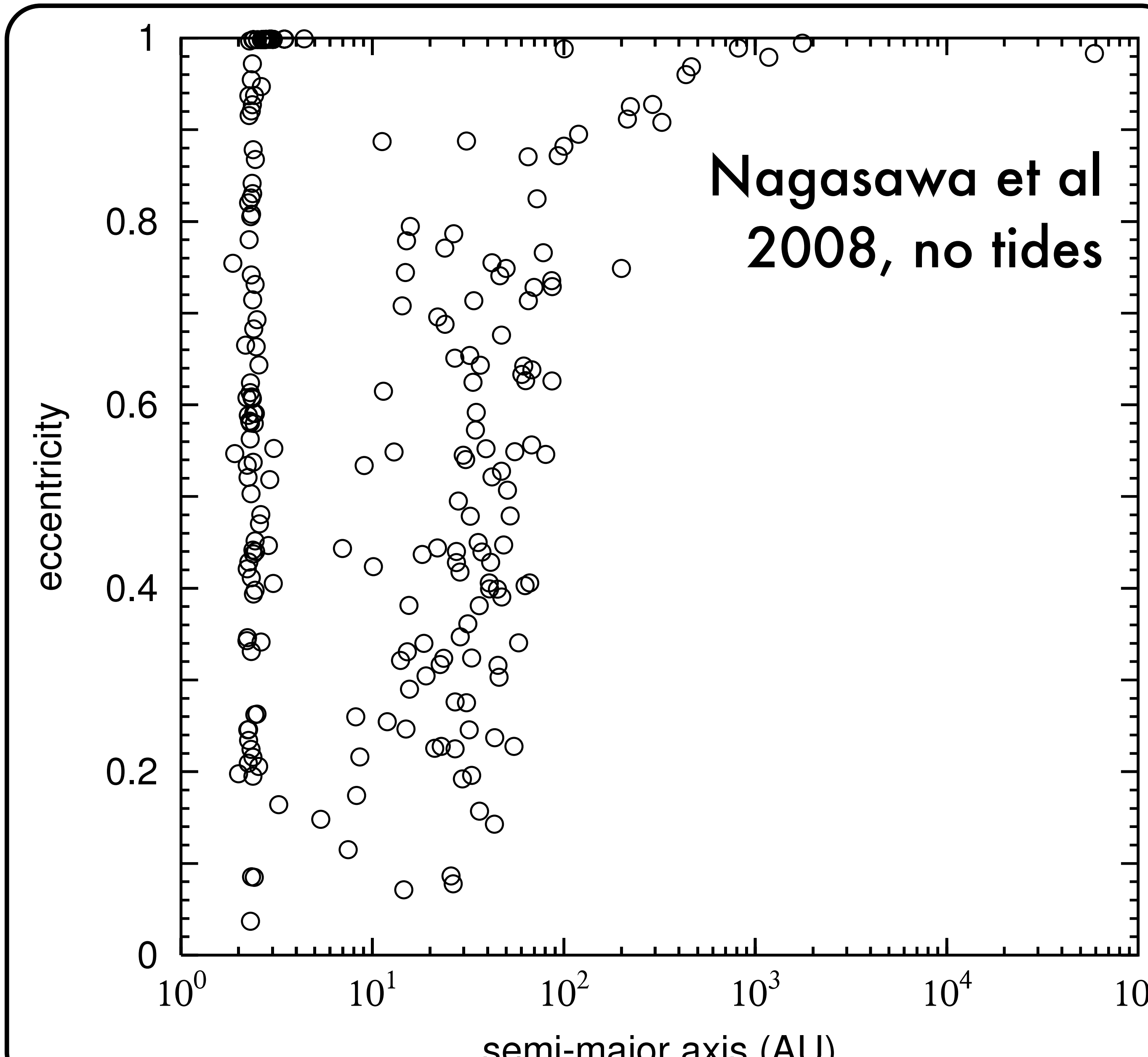
Excentricity

Origin?



Planet-planet scattering

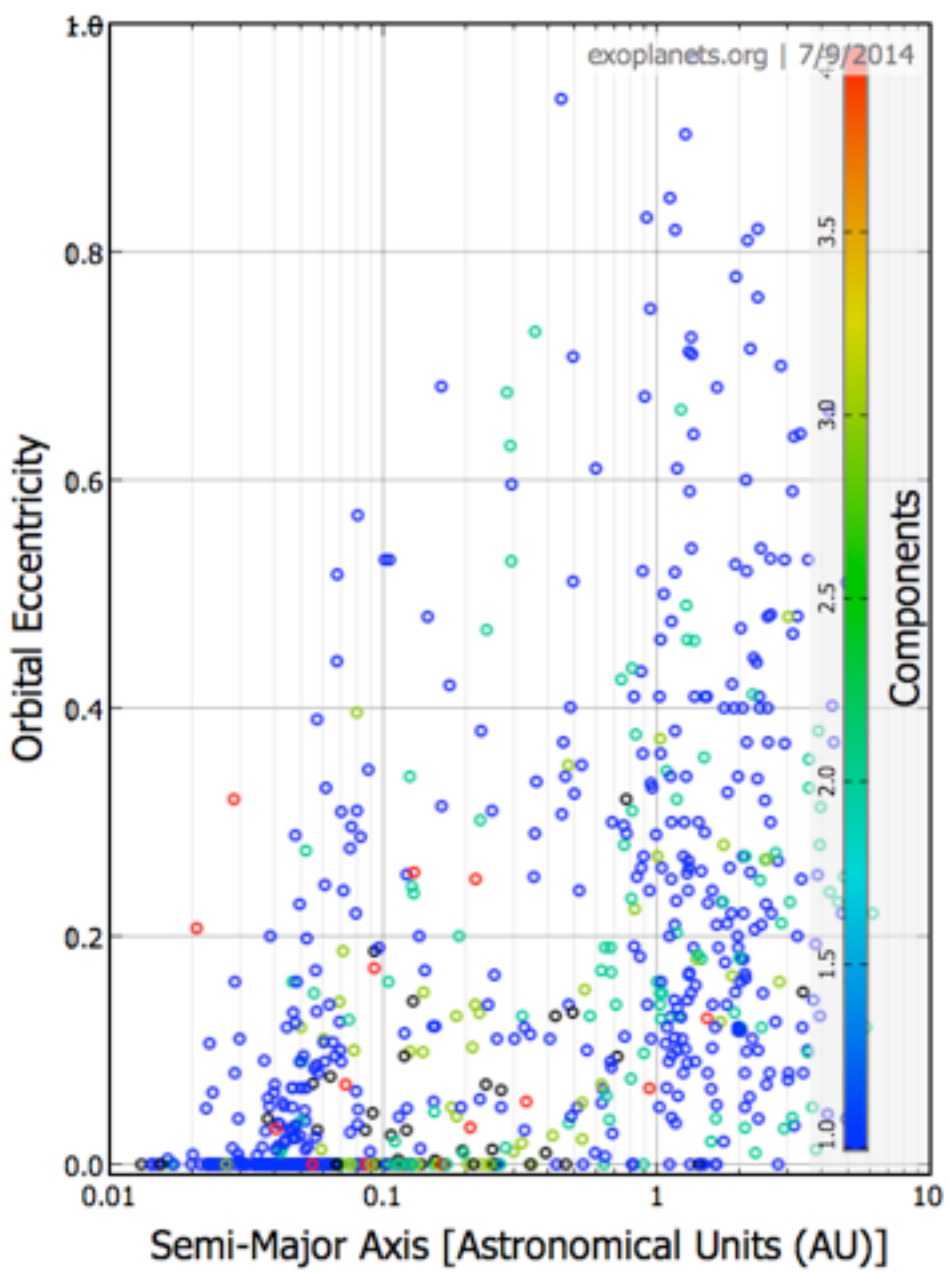
(Rasio & Ford 1996, Weidenschilling & Marzari 1996)

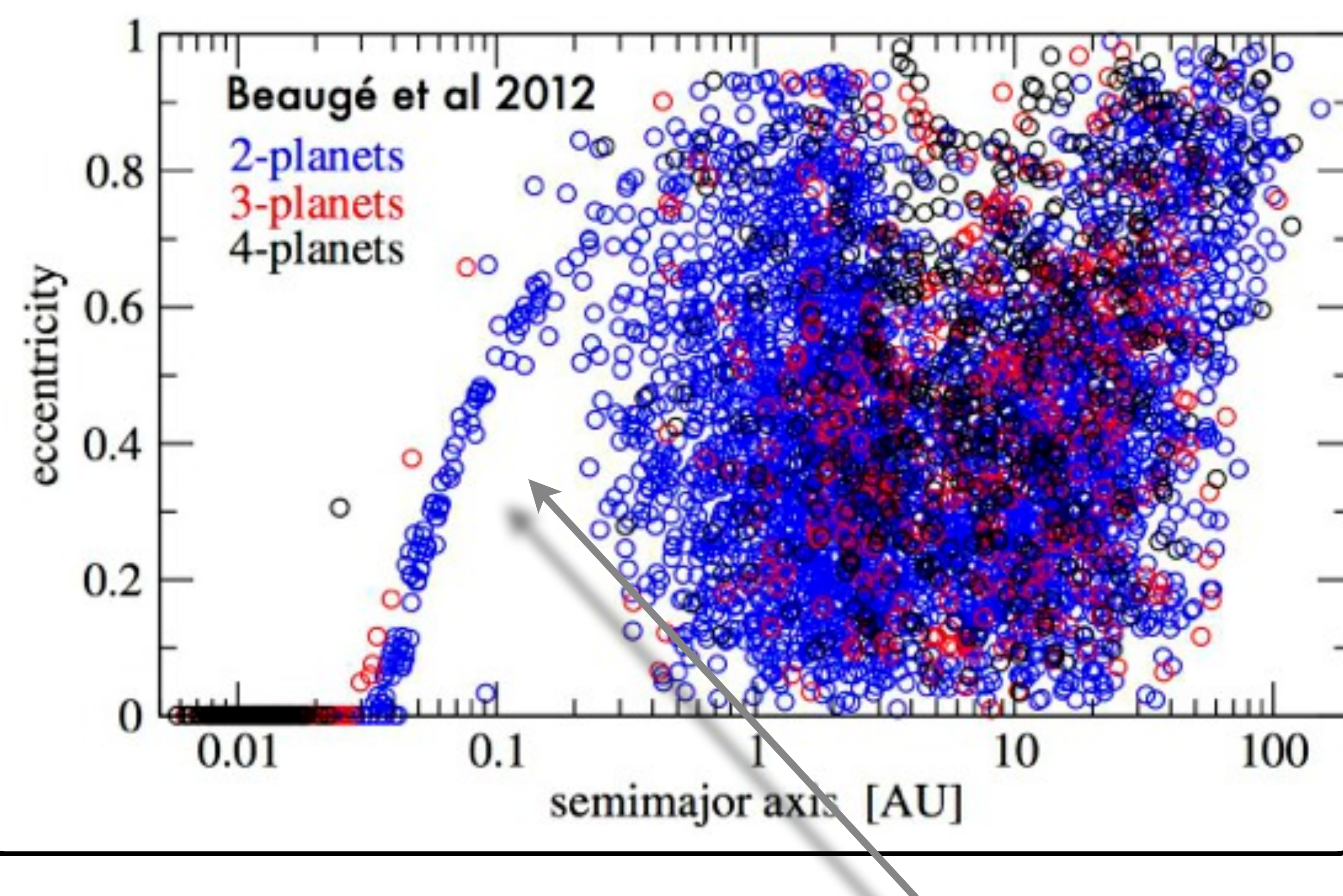


Excentricity

Origin?

Planet-planet scattering &
tidal circularization
(Nagasawa et al 2008)



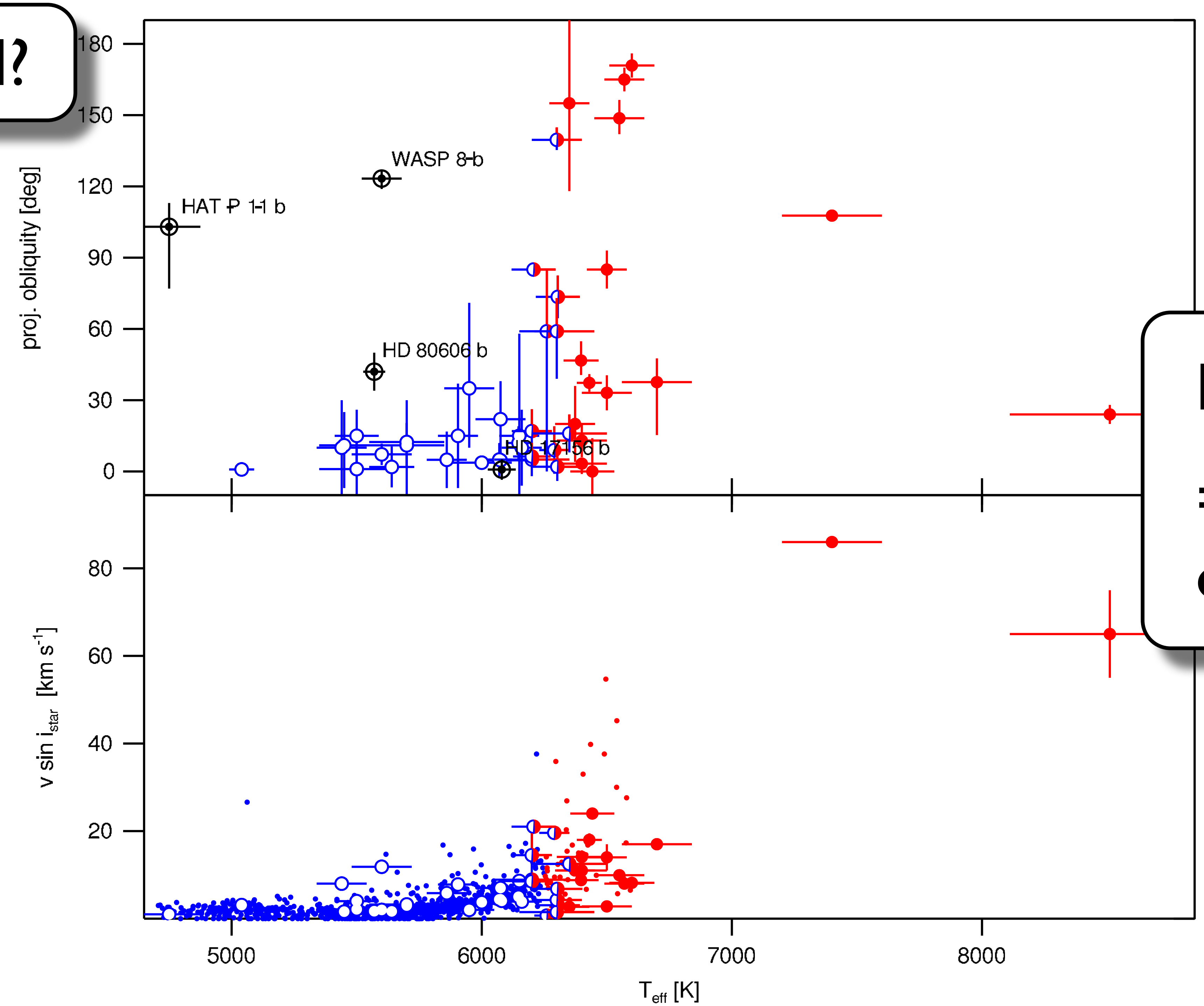


$Q'_p \sim 10^6 - 10^7$

Spread?

Obliquity

Primordial?

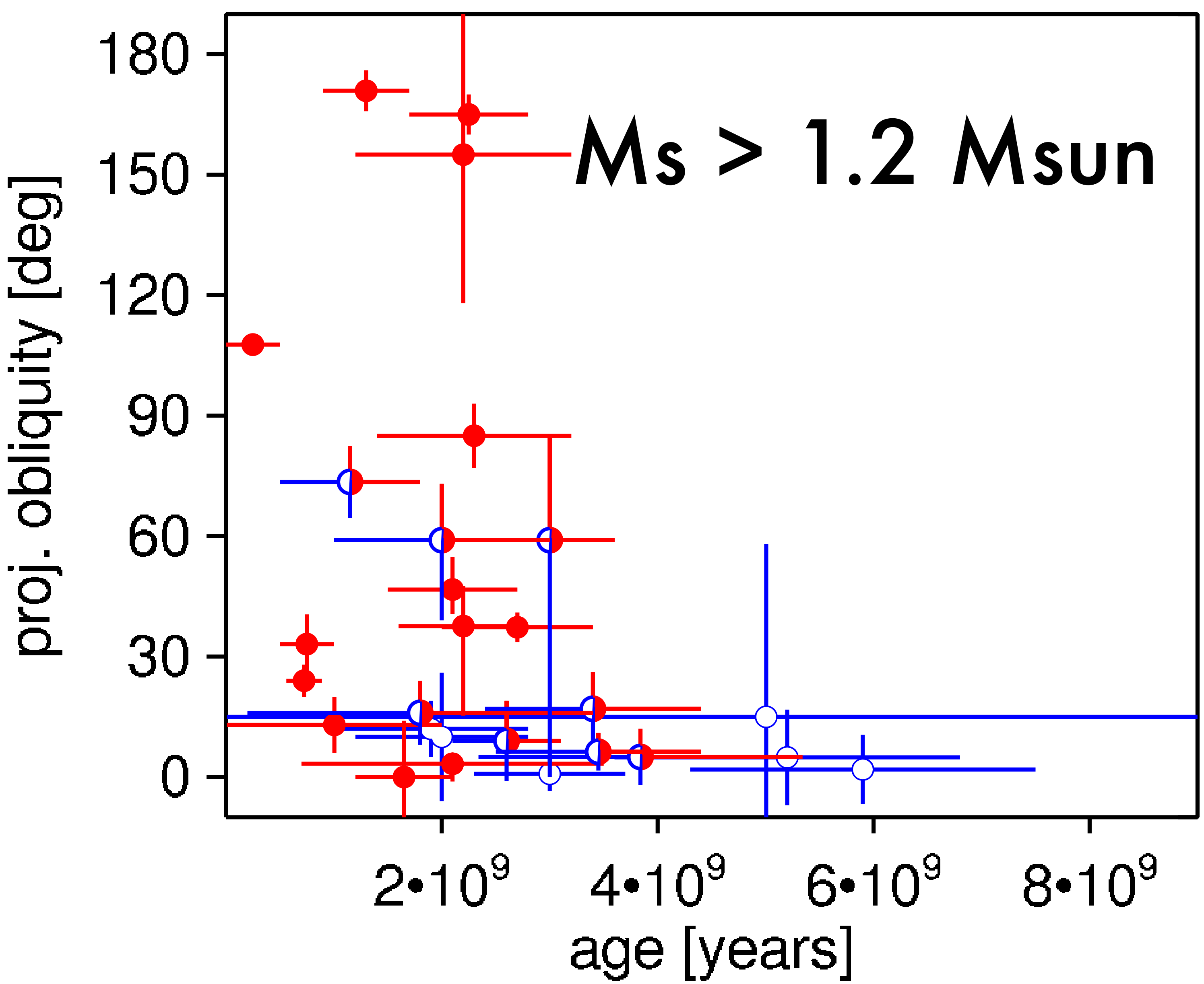


Hot star

=> high obliquity?

Figure 20. Projected obliquities and projected stellar rotation speeds as a function of the stellar effective temperature. Upper panel: measurements of projected obliquities as a function of the effective temperature of the host star. Stars which have temperatures higher then 6250 K are shown with red filled symbols. Blue open symbols show stars with temperatures lower then 6250 K. Stars which measured effective temperature include 6250 K in their 1σ interval are shown by split symbols. Systems which harbor planets with mass $<0.2\,M_{Jup}$ or have an orbital period more then 7 days are marked by a black filled circle with a ring. Lower panel: projected stellar rotation speeds $v \sin i_\star$ of the stars in our sample. In addition, $v \sin i_\star$ measurements of stars in the catalog by Valenti & Fischer (2005) are shown as small dots.

Obliquity

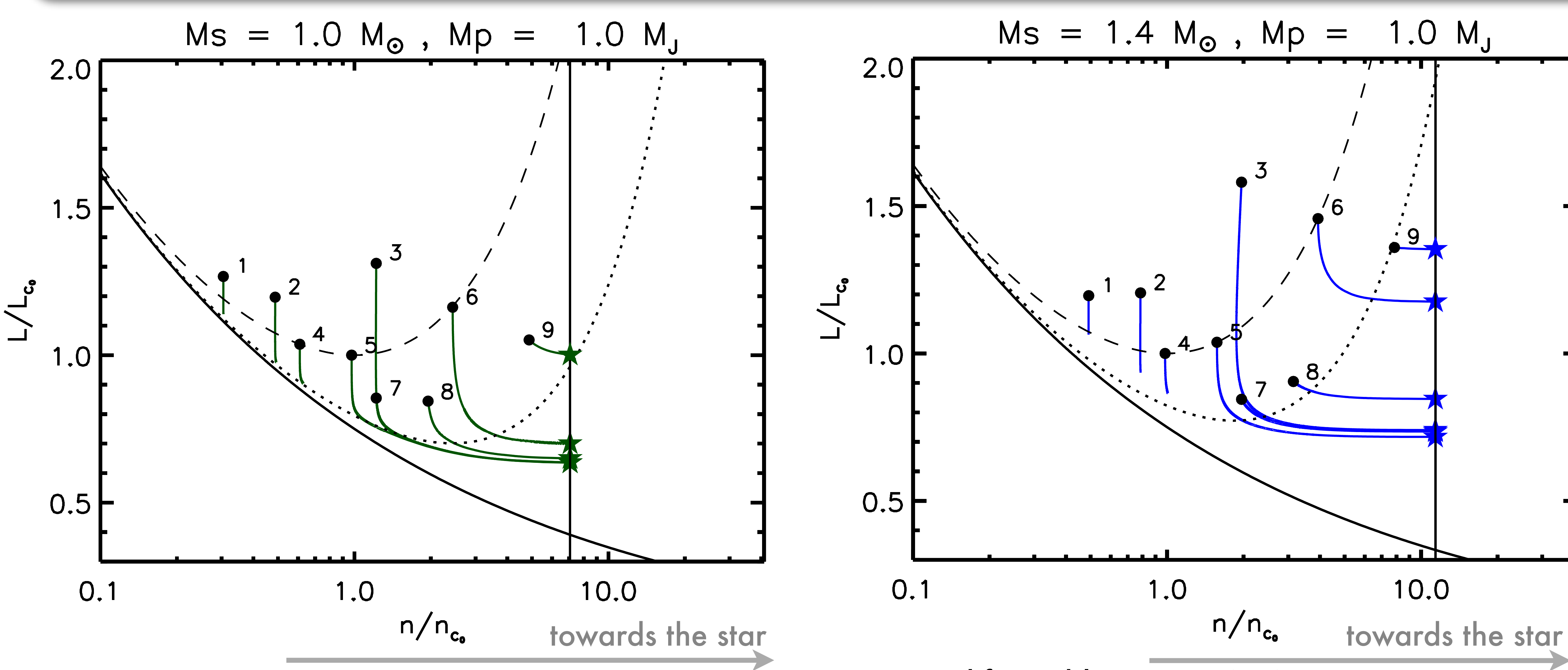


Albrecth et al.2012

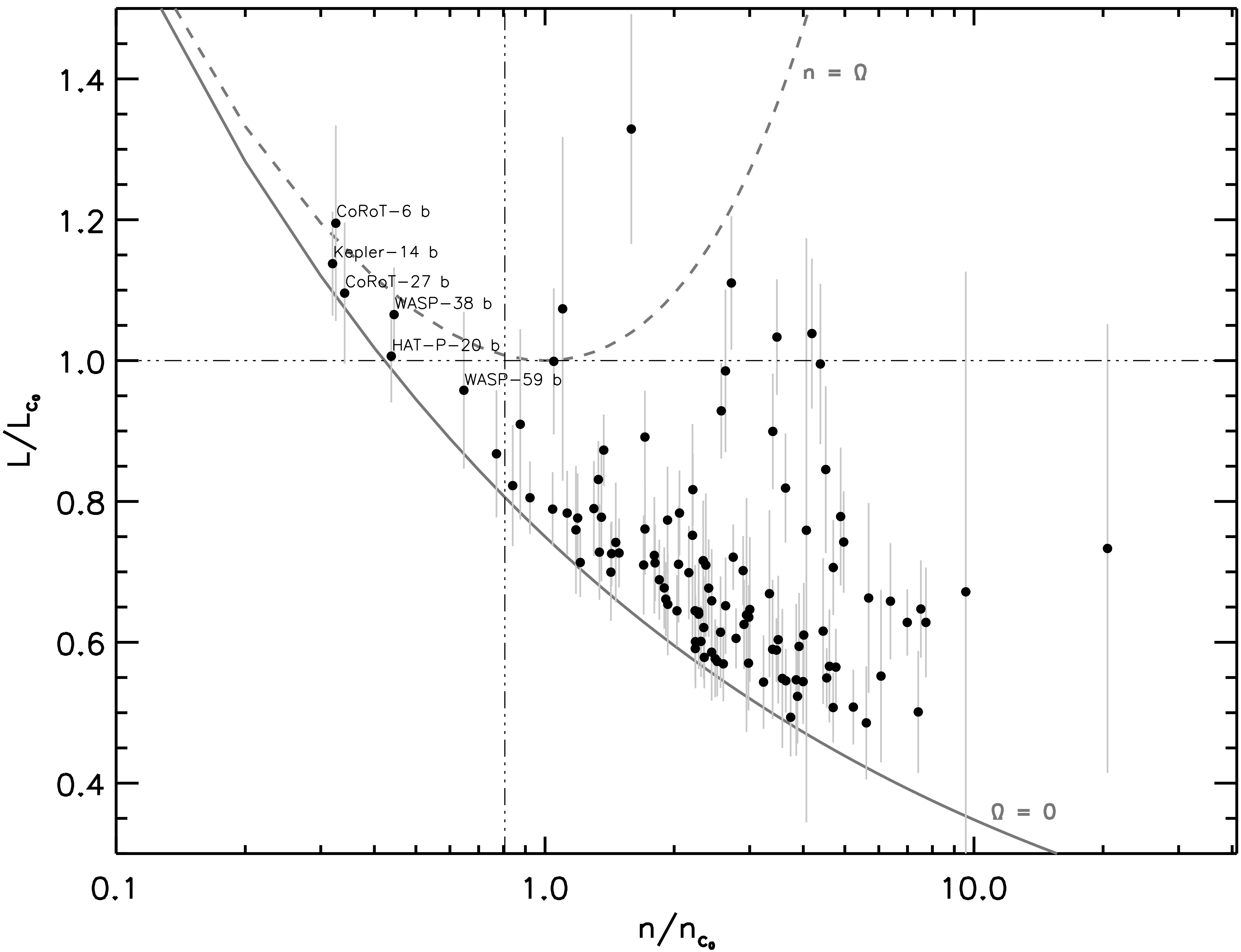
- Development of the convective envelope with time
- Initially random
- Tidally damped

Role of angular momentum loss

- G-type stars lose 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, accepted for publication in A&A



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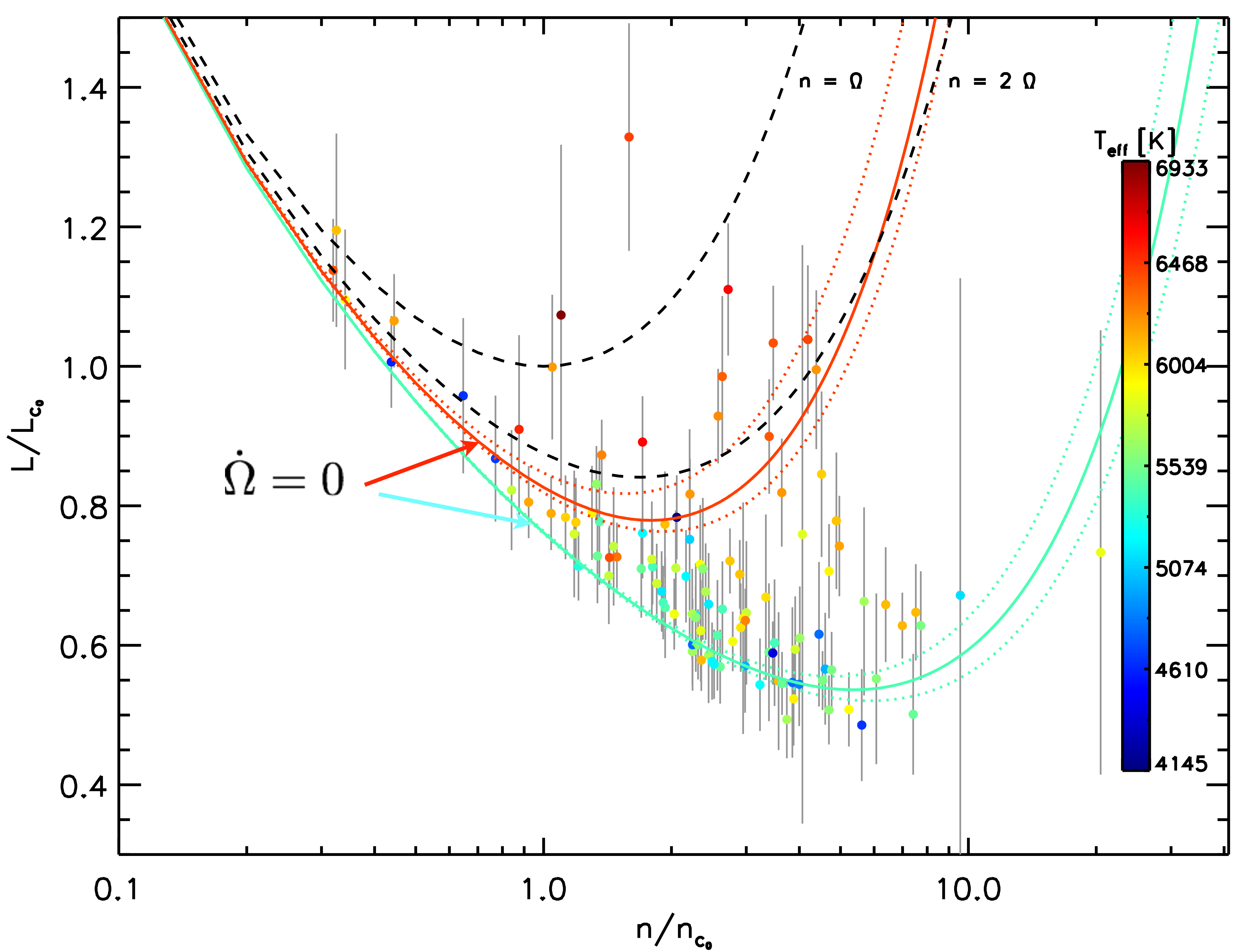

Damiani & Lanza, accepted

Role of angular momentum loss

- G-type stars lose 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
- Dynamics and environemental effect in mutli-planet systems are fundamental to assess the habitability
- Better ages and stellar physics are essential to understand exoplanetary systems dynamics (we need PLATO)


Thank you !