Dynamics of exoplanetary systems, links to their « habitability »

Seminar in Nice
02/12/14

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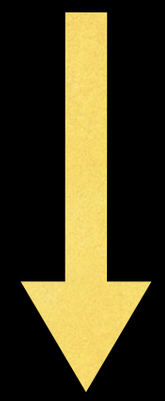
Outline

- ★ A bit of perspective
- ★ A few words about tides
- ★ Planets around brown dwarfs
- ★ Kepler-186

Tides



Climates

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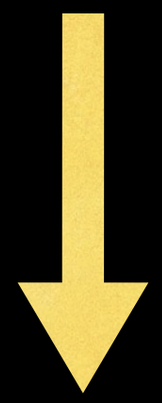
Tides



Climates

Exoplanets discoveries

Planet orbiting a Sun like star

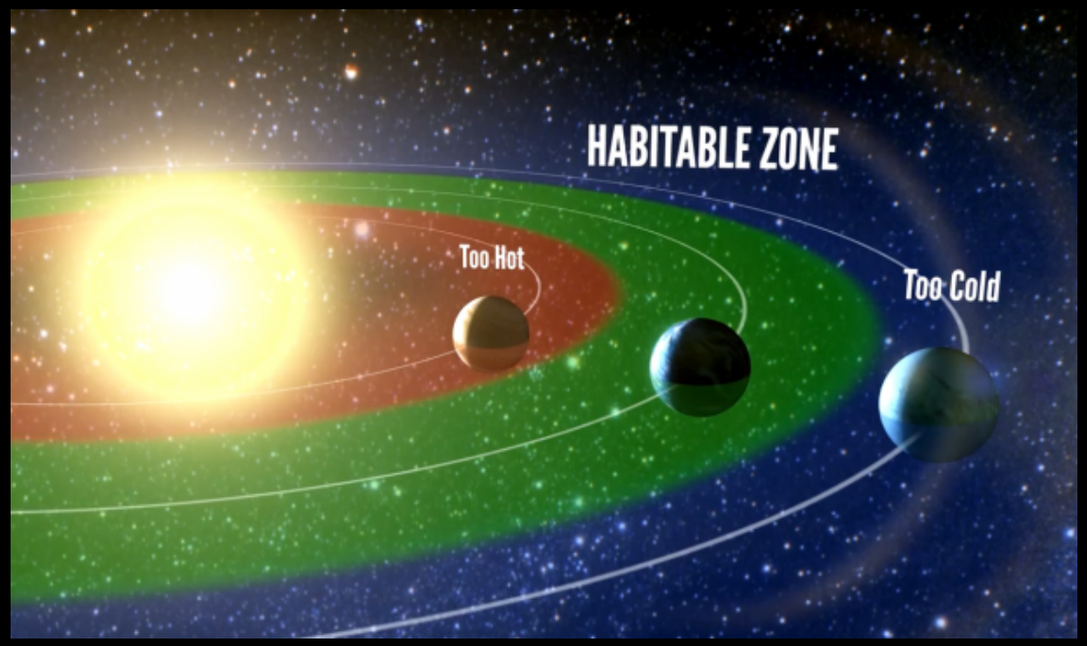
Rocky planet

Planet in the habitable zone

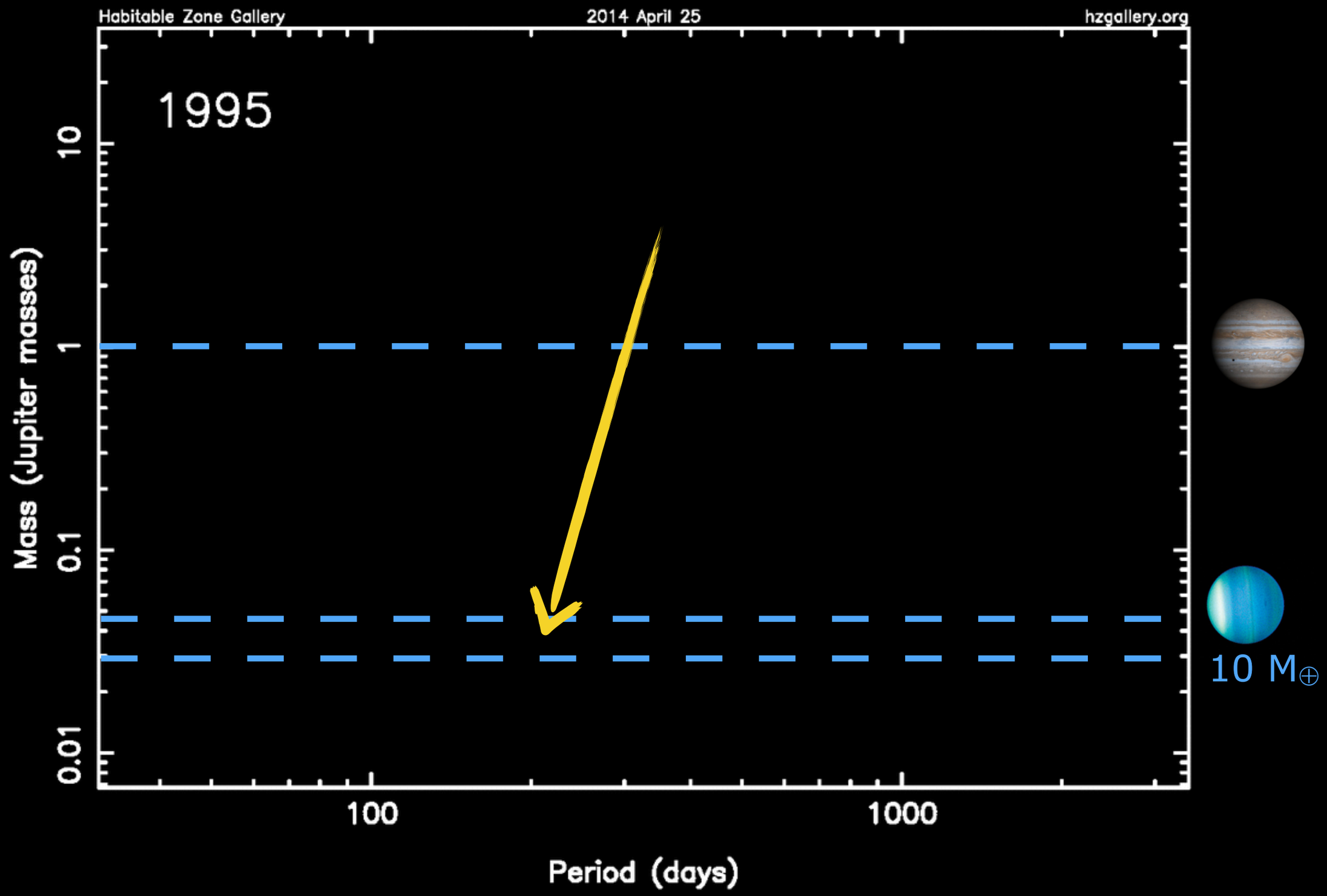
Habitable zone planets

« Habitable zone »

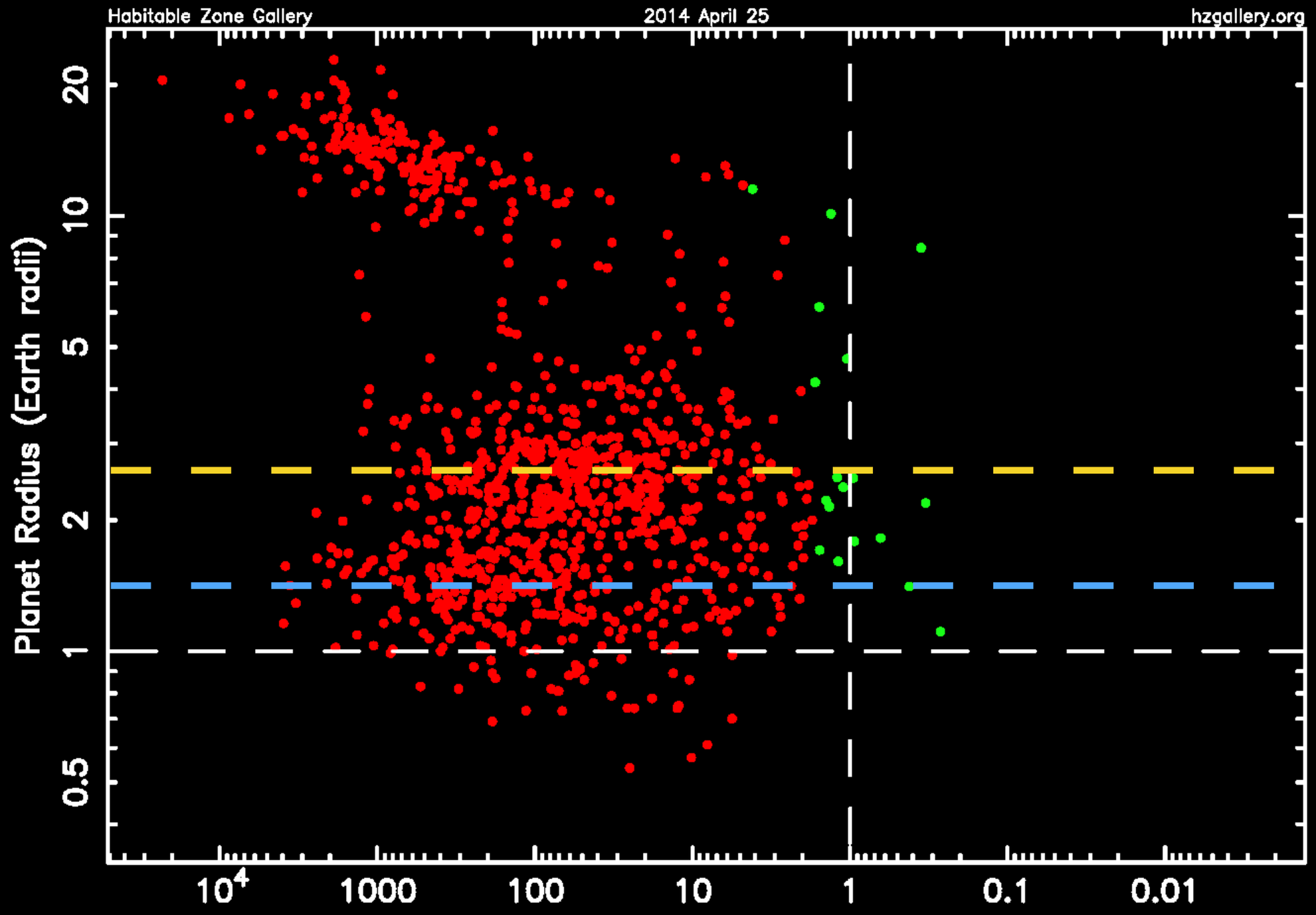
region around a star in which a planet could potentially host surface liquid water

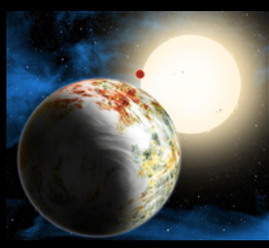


Habitable zone planets



Habitable zone planets





rocky

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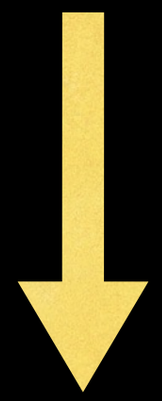
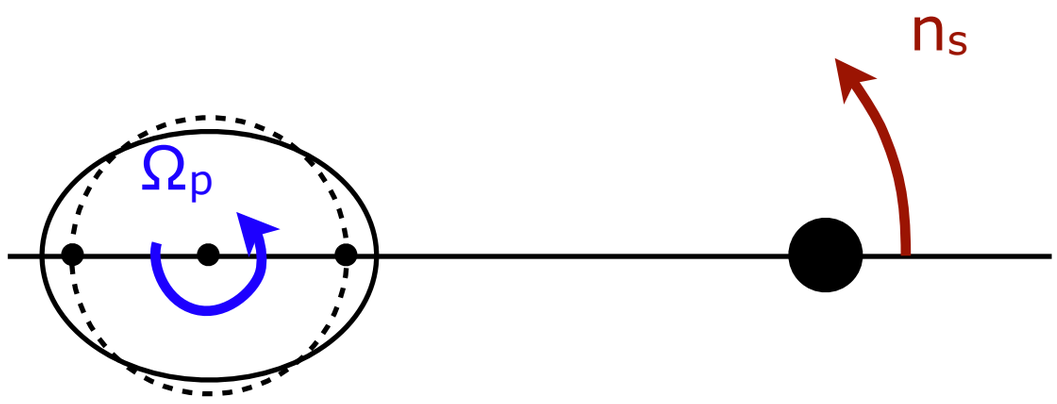


Climates

Constant time lag model

Mignard 1979; Hut 1981; Leconte et al. 2010

Constant time lag model



Ω_p

rotation frequency of primary

n_s

orbital frequency of secondary $\propto$ 1/P

★ $\Omega_p = n_s$

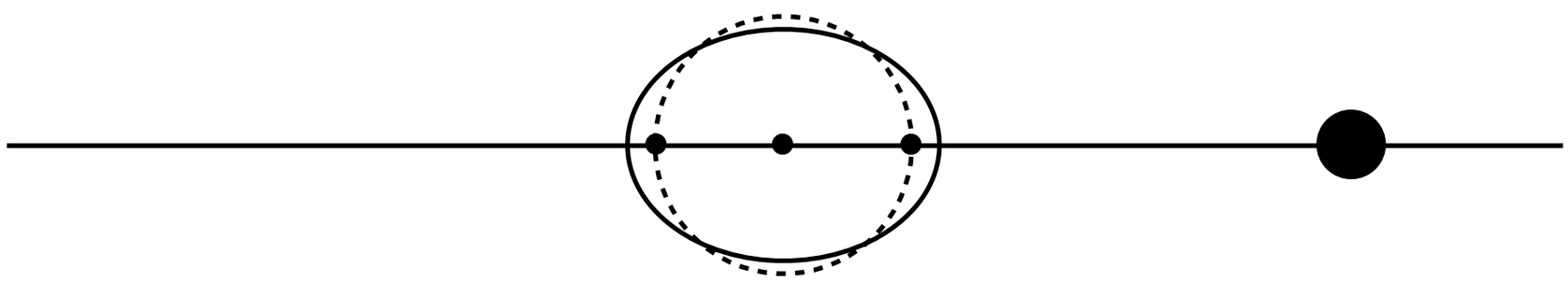
★ $\Omega_p < n_s$

★ $\Omega_p > n_s$

Constant time lag model

$$\Omega_p = n_s$$

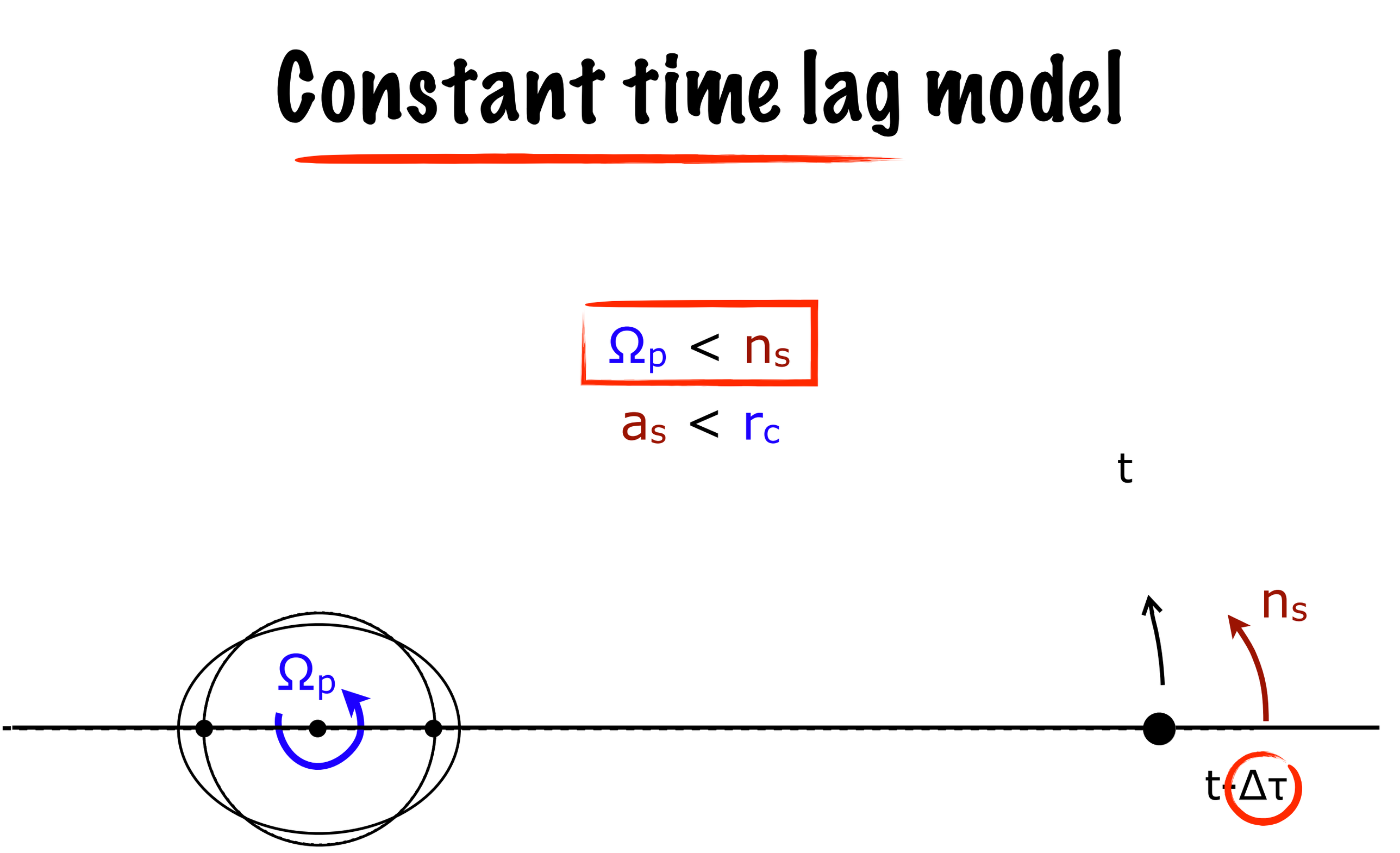
orbital distance of secondary $a_s = r_c$ corotation distance



Constant time lag model

$$\Omega_p < n_s$$

$$a_s < r_c$$



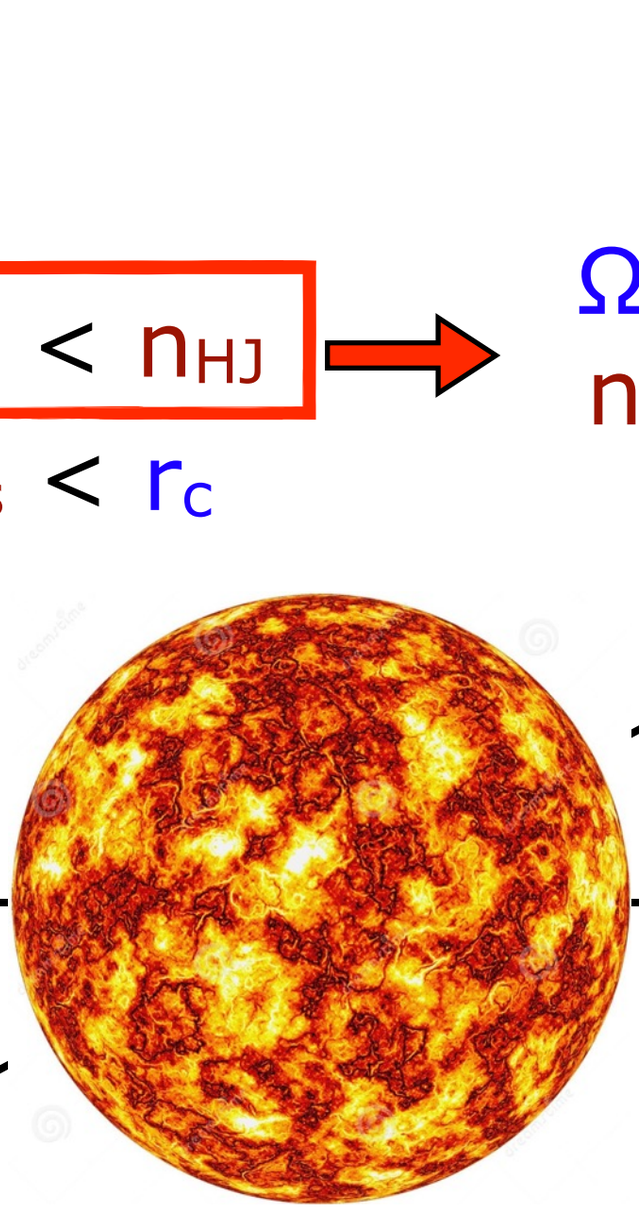
Constant time lag model

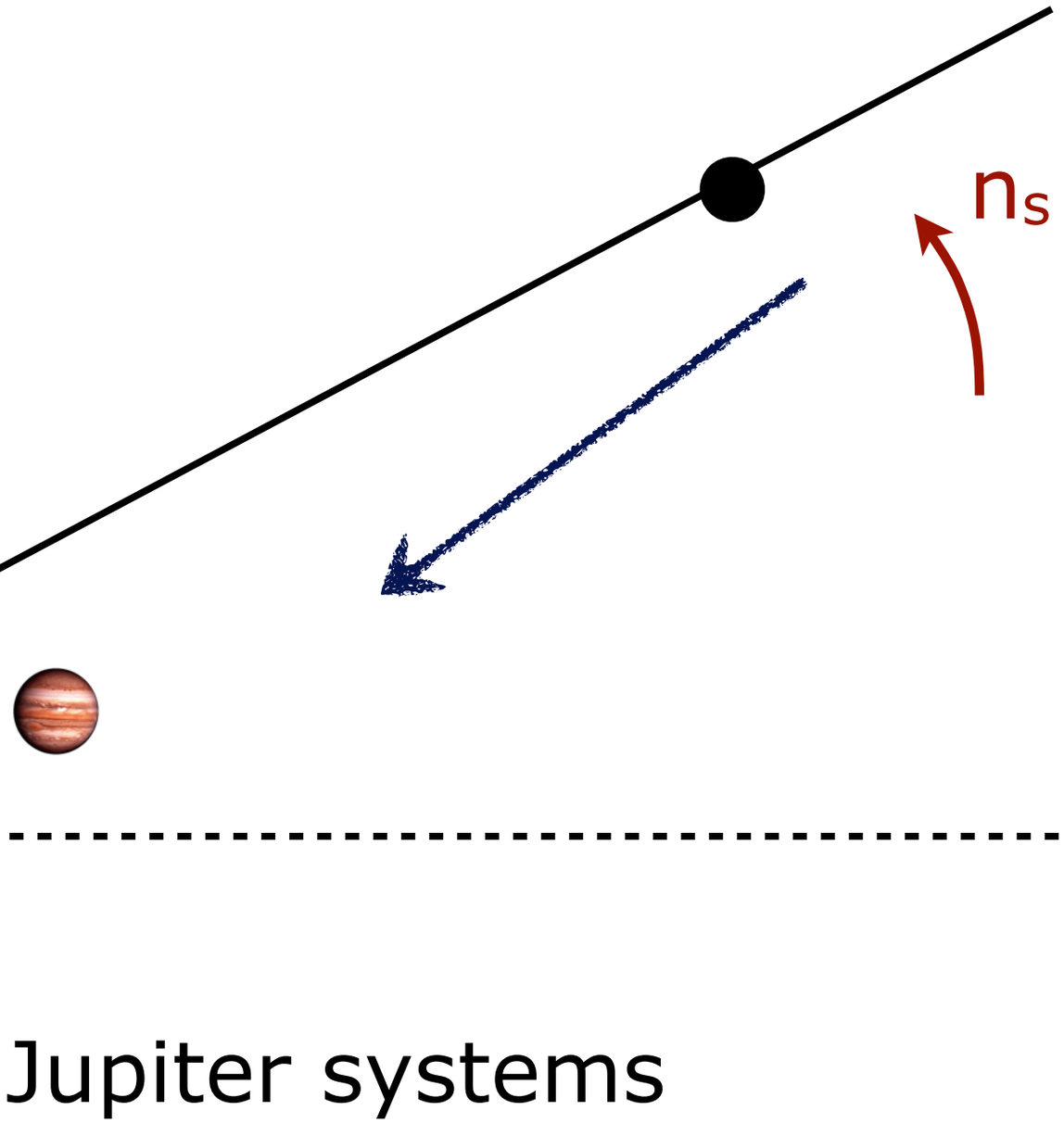
$\Omega_\star < n_{HJ}$

$a_s < r_c$

Ω_p ↗

n_s ↗



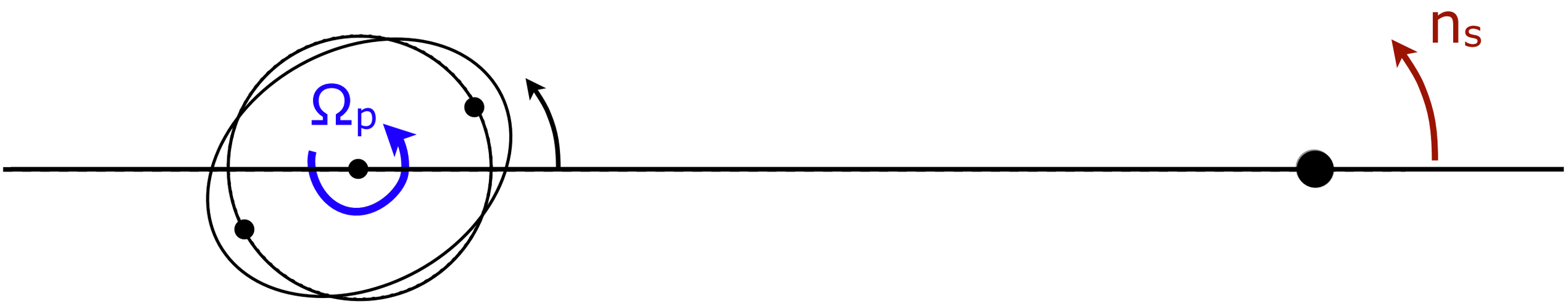


Hot Jupiter systems

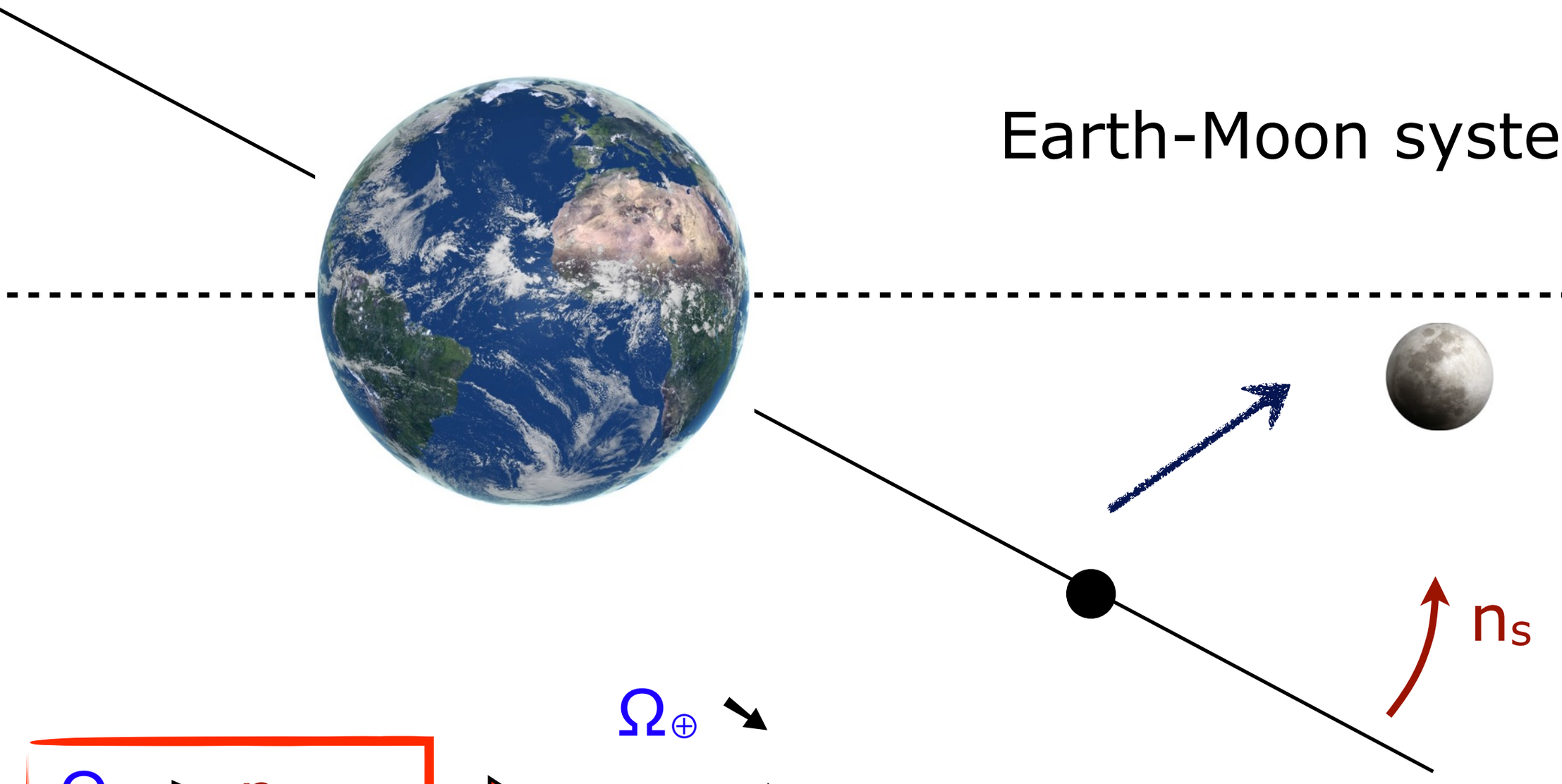
Constant time lag model

$$\Omega_p > n_s$$

$$a_s > r_c$$



Constant time lag model



$\Omega_\oplus > n_{moon}$

$a_s > r_c$

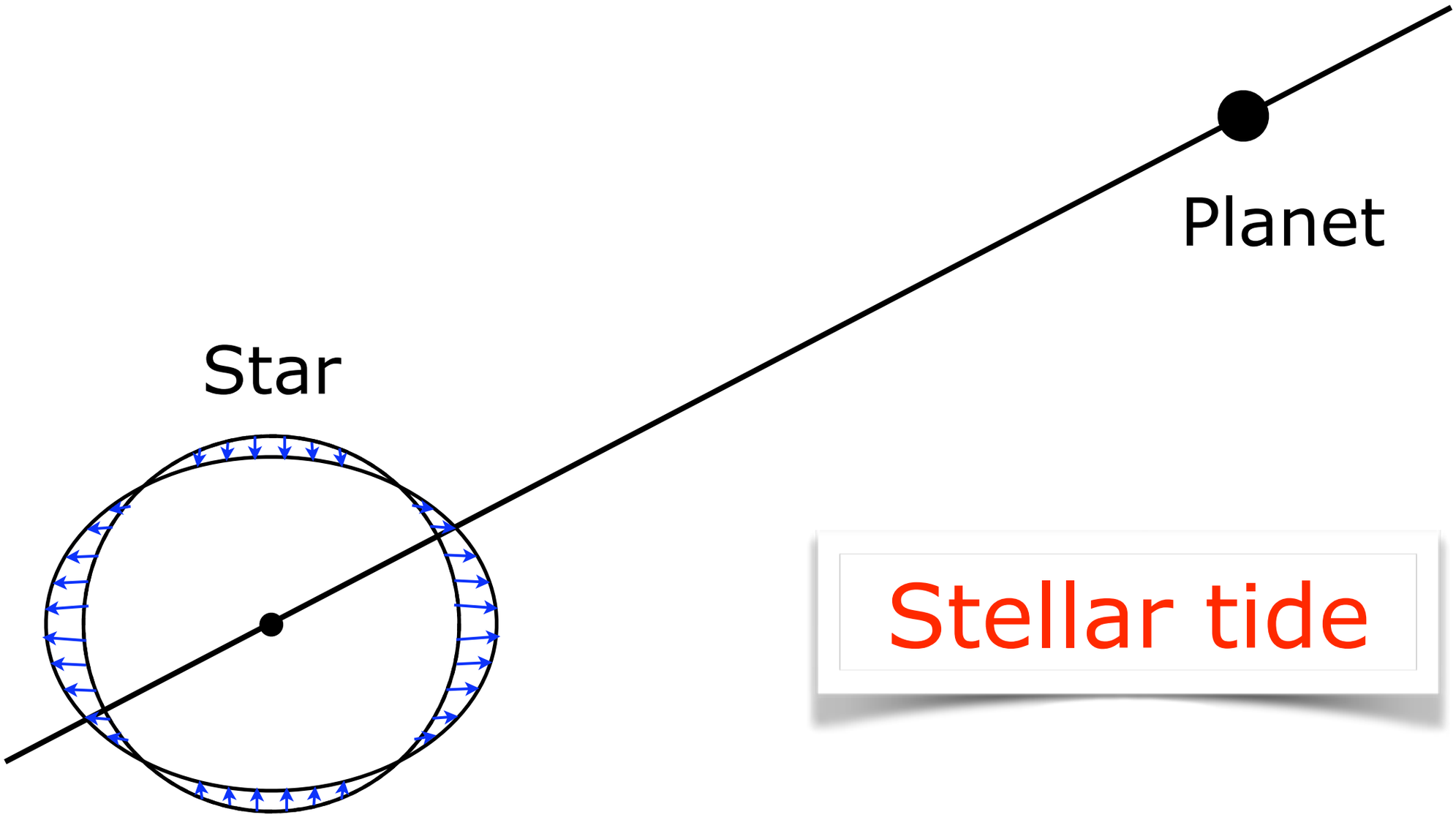
$\Omega_\oplus$ ↘

n_{moon} ↘

a_{moon} ↗

Tidal evolution

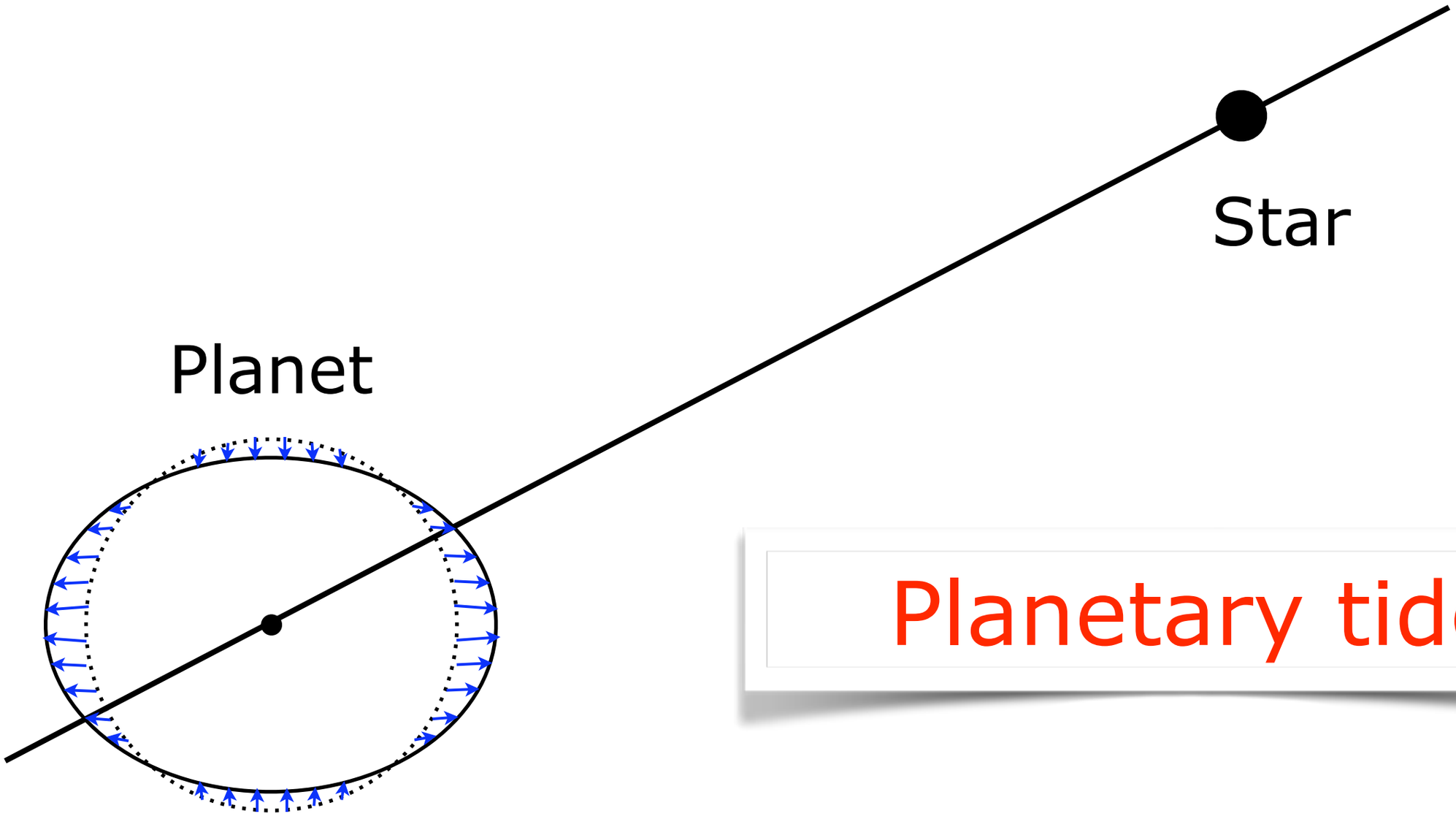
Constant time lag model



Stellar tide

Tidal evolution

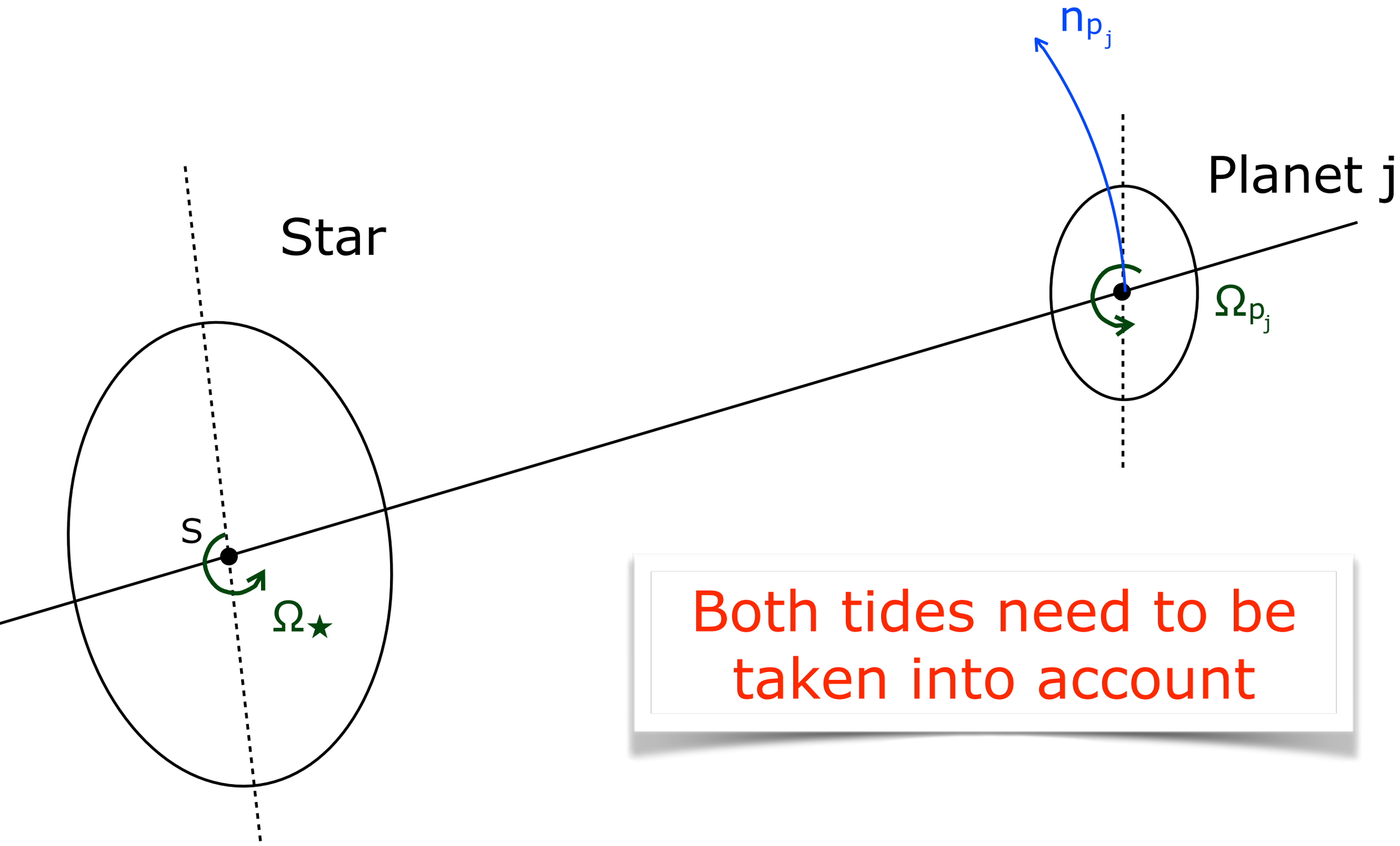
Constant time lag model



Planetary tide

Tidal evolution

Constant time lag model



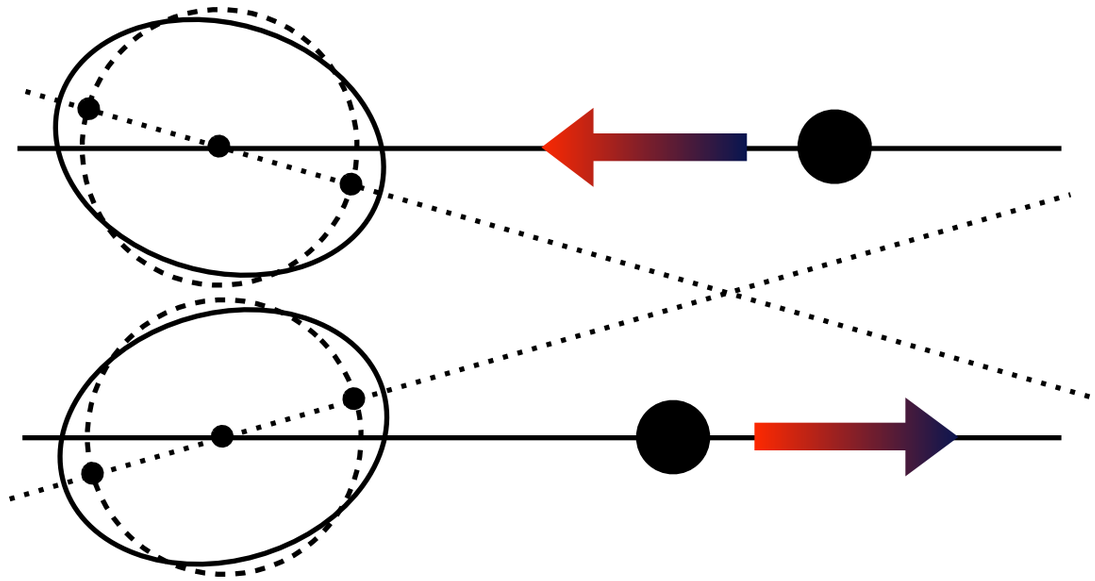
Both tides need to be taken into account

Tidal evolution

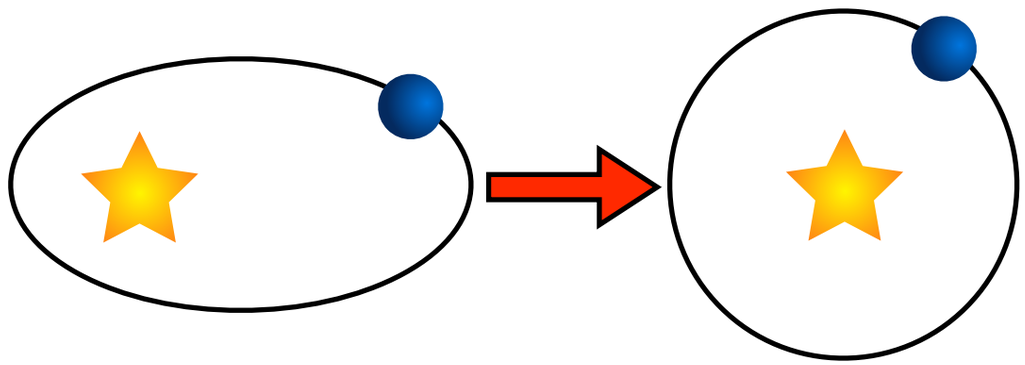
Stellar tide

★ planet inside corotation
⇒ planet migrates inward

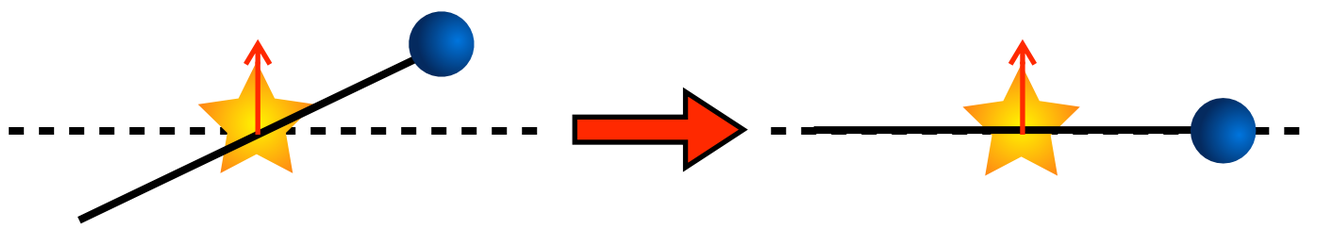
★ planet outside corotation
⇒ planet migrates outward



★ eccentricity decreases



★ inclination of planet decreases



Tidal evolution

Planetary tide

Planet has low moment of inertia:
bulges get aligned quickly
Synchronization

Tidal evolution

Planetary tide

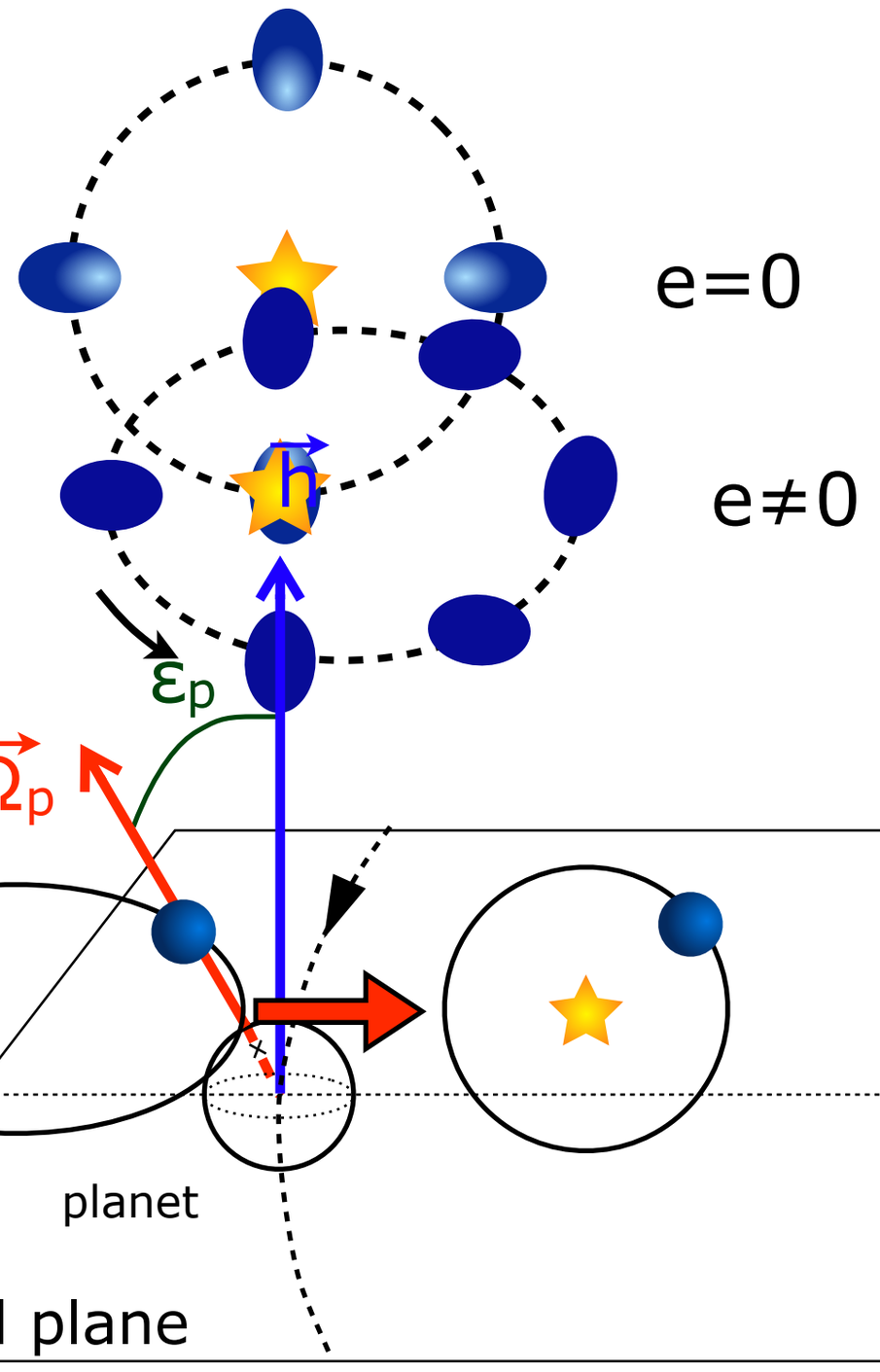
★ e=0: quick synchronization

★ e≠0: quick pseudo-synchronization

★ obliquity of planet decreases

★ eccentricity decreases

★ planet migrates inward



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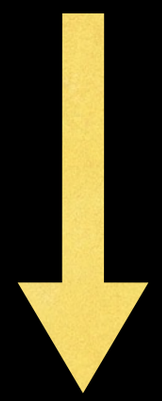
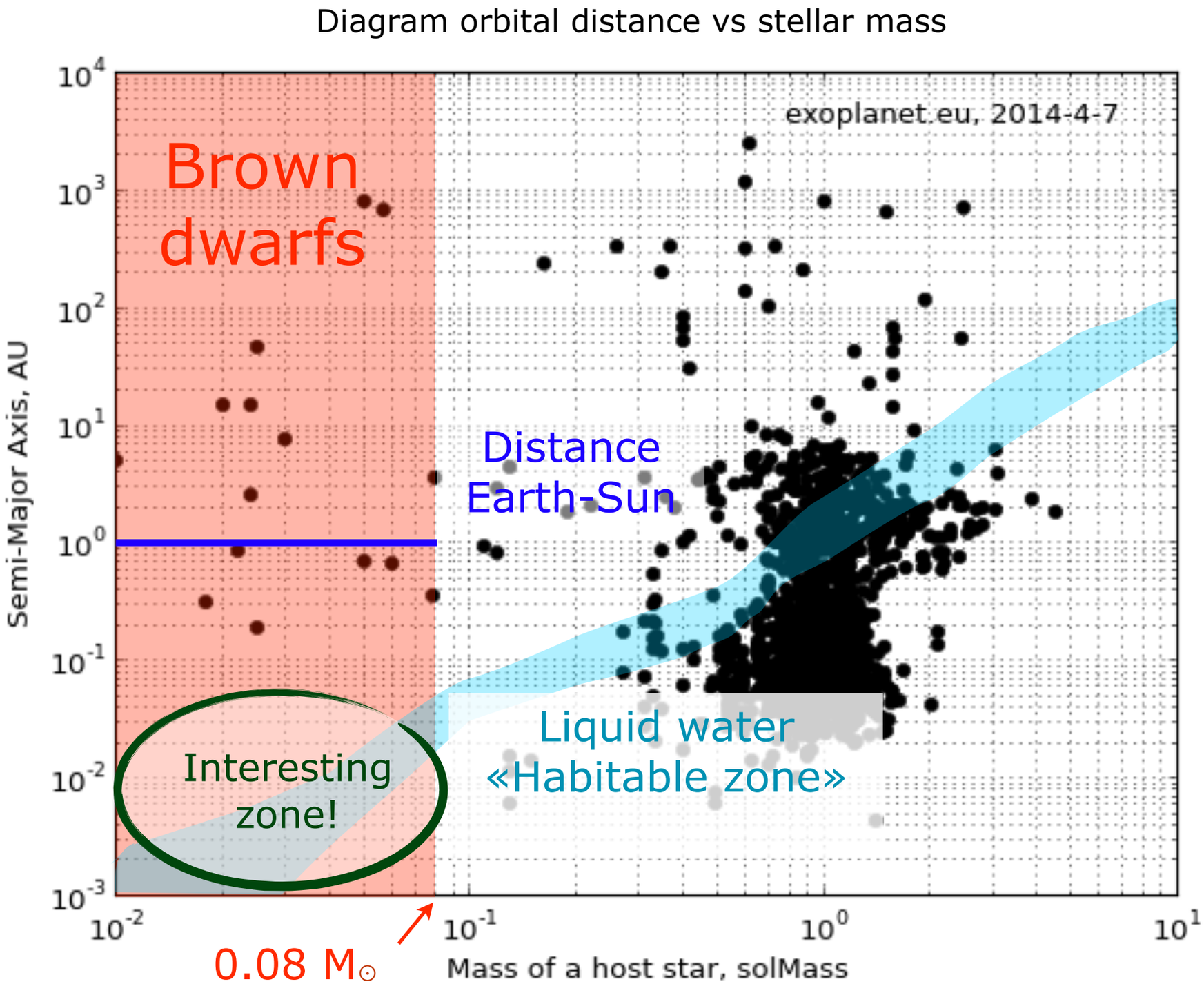


Climates

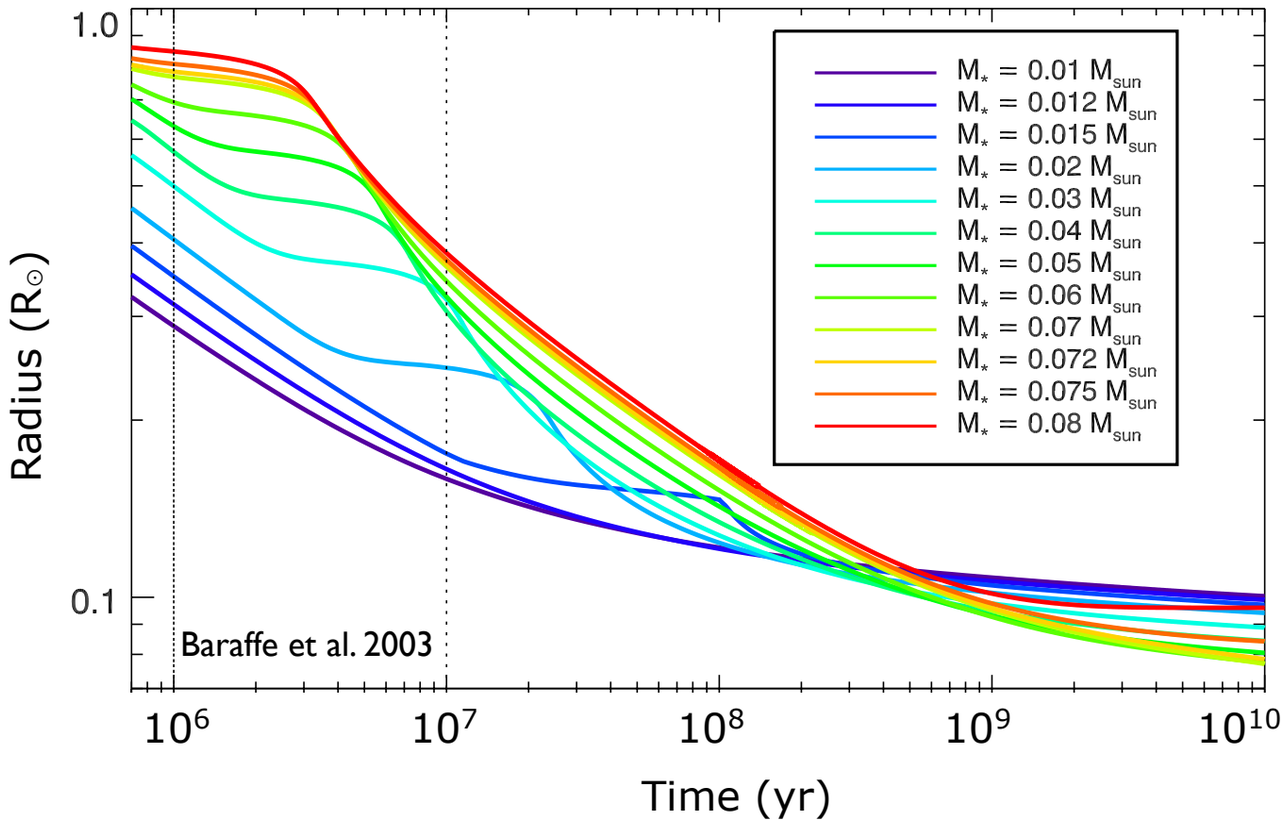
Planets around brown dwarfs



Planets around brown dwarfs

Evolution of brown dwarfs

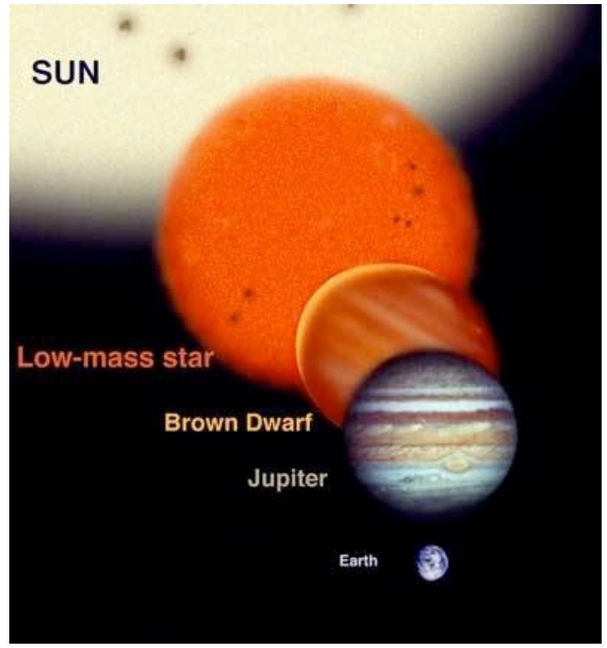
Radius and rotation period of BDs of different masses



Contraction ⇒ spin-up

Some BDs have rotation periods of ~1 hr

(Herbst et al. 2007)

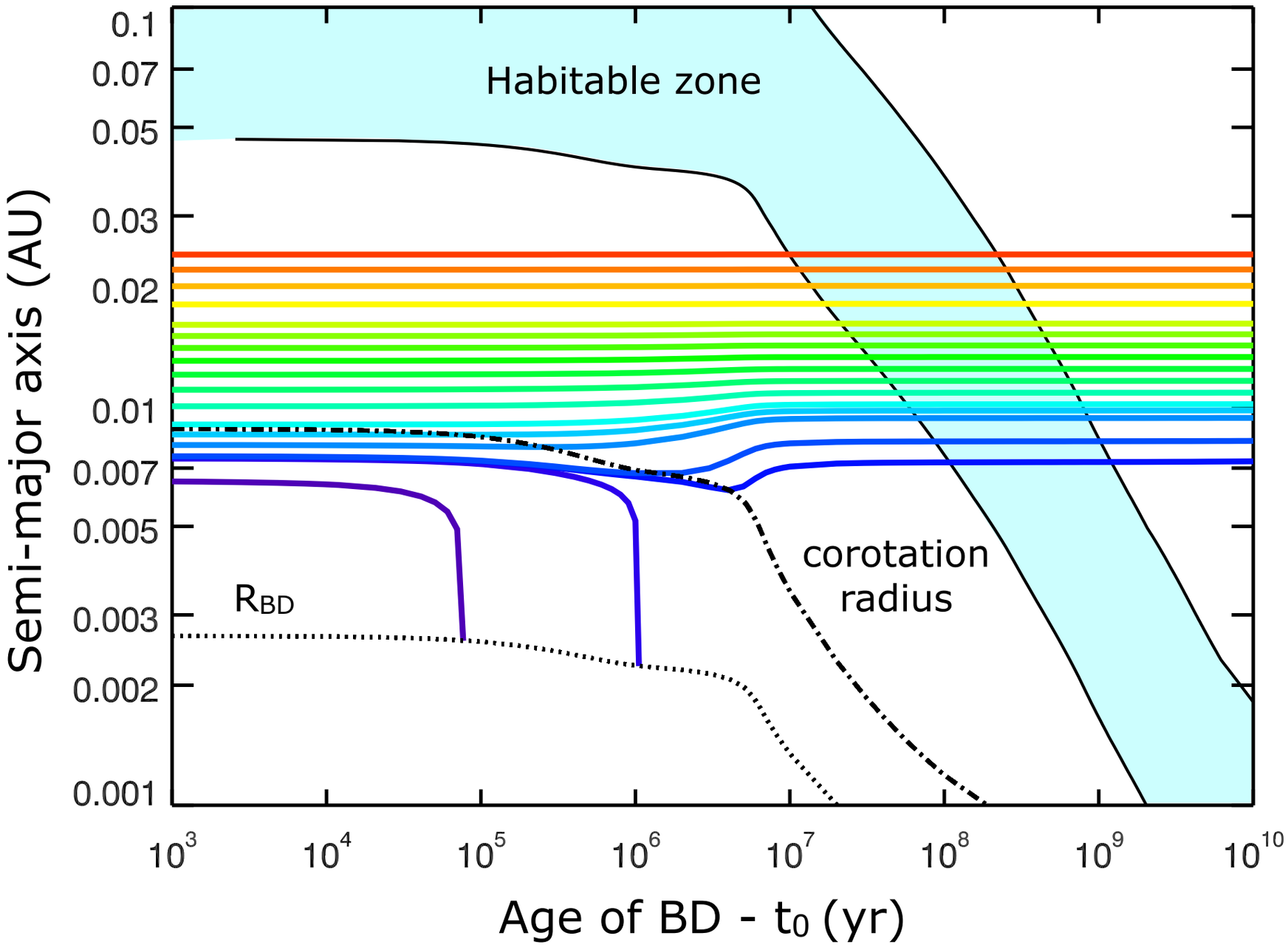


$R_{BD} = R_{BD}(t)$

$P_{BD} = P_{BD}(t)$

Planets around brown dwarfs

Aquability of an Earth mass planet



M_{BD}= 0.04 $M_\odot$

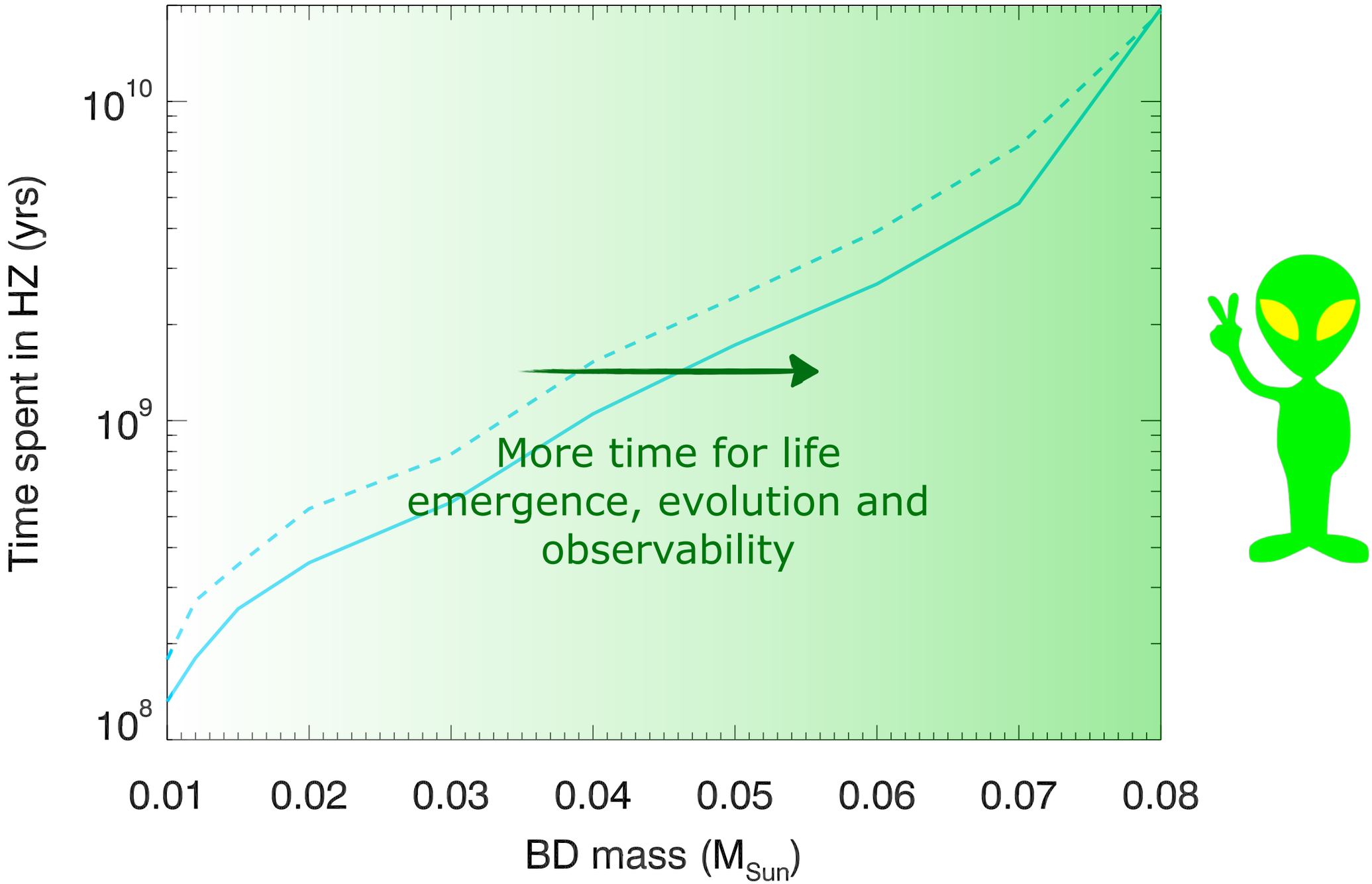
M_p = 1 $M_\oplus$

Orbit almost circular
no obliquity
no inclination

Bolmont et al. 2011

Planets around brown dwarfs

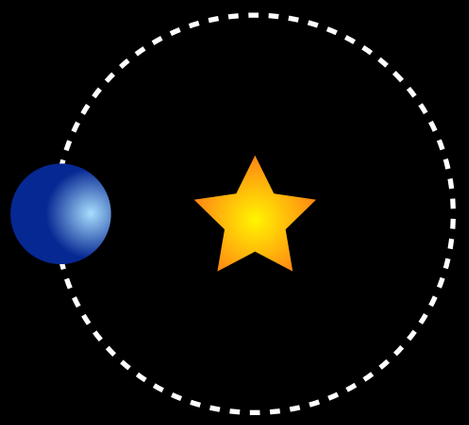
From aquability to habitability?



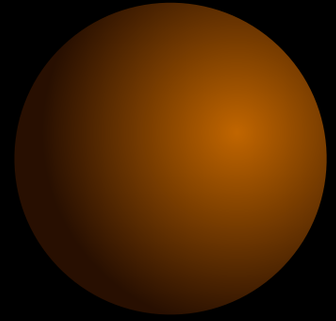
Planets around brown dwarfs

Habitable zone

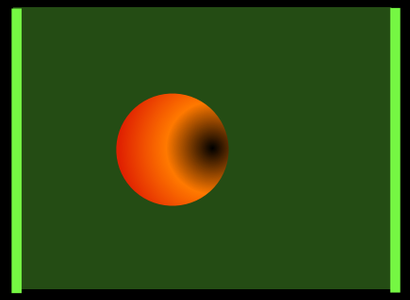
★ If planet is alone, when it reaches the habitable zone:



Danger for aquability: cold trap?



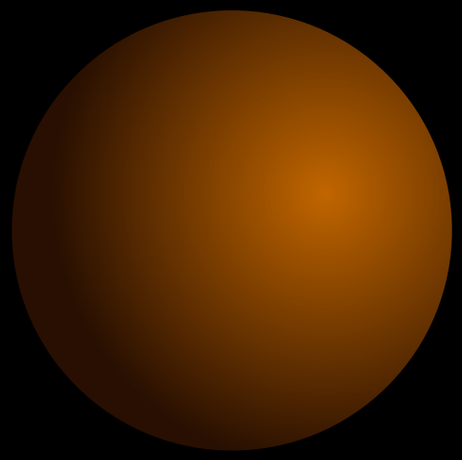
Habitable zone



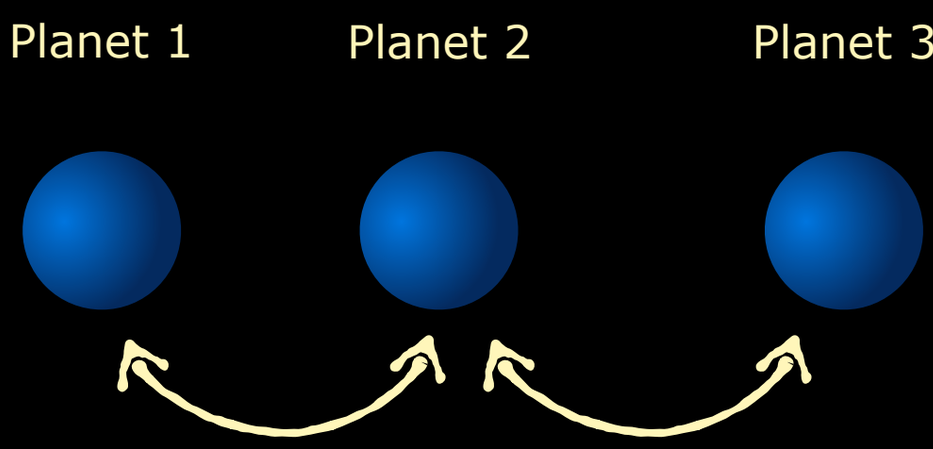
★ What if the planet is part of a multiple system?

Planets around brown dwarfs

Tidal effects in multi-planet systems

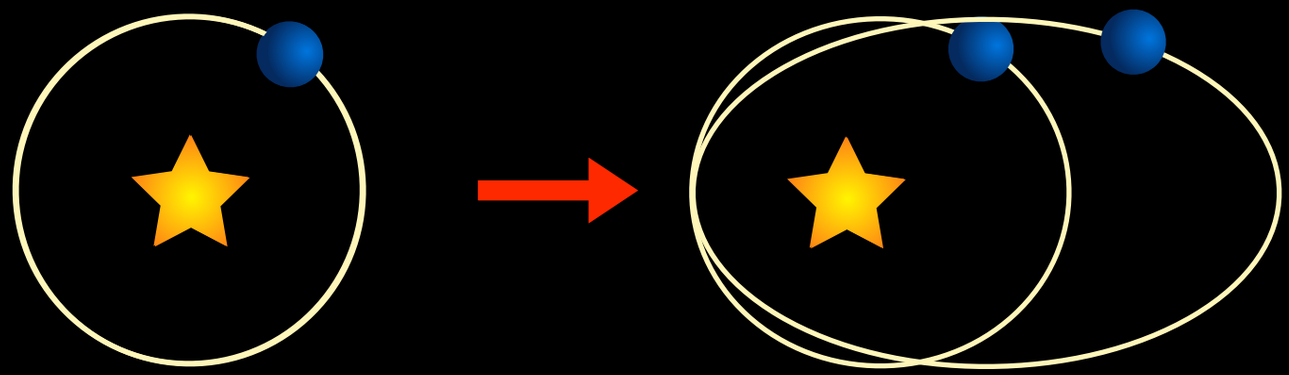


Brown dwarf



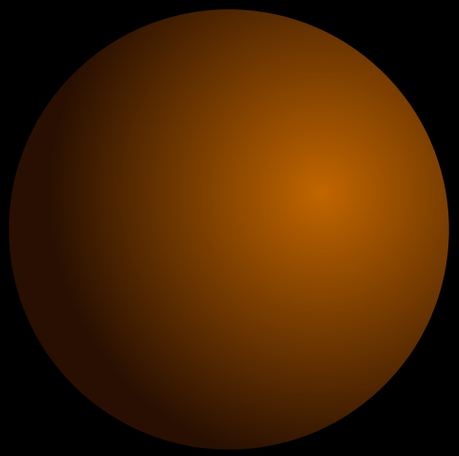
Gravitational interactions between planets

No Resonances



Planets around brown dwarfs

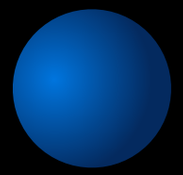
Tidal effects in multi-planet systems



Brown dwarf

Planet 1

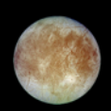
Planet 2



Planet 3

Jupiter

Io



Europa

Ganymede

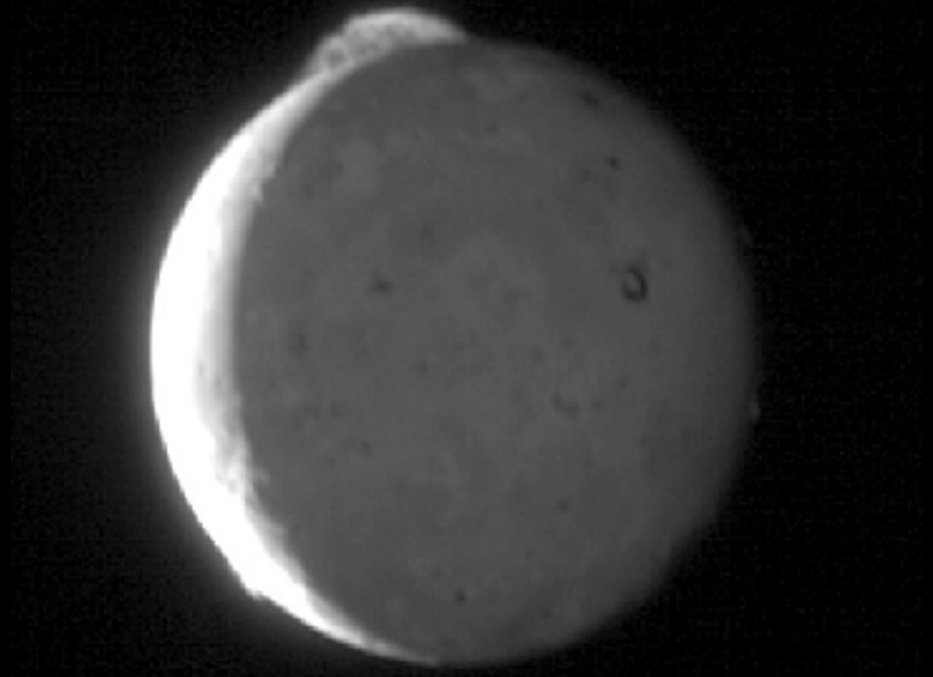
Planets around brown dwarfs

Tidal effects in multi-planet systems

Tidal effect in Io → strong volcanism

Tidal heat flux is ~3 W/m^2 > ~40 x Earth's flux (radioactivity)

Spencer et al. 2000 Pollack et al. 1993

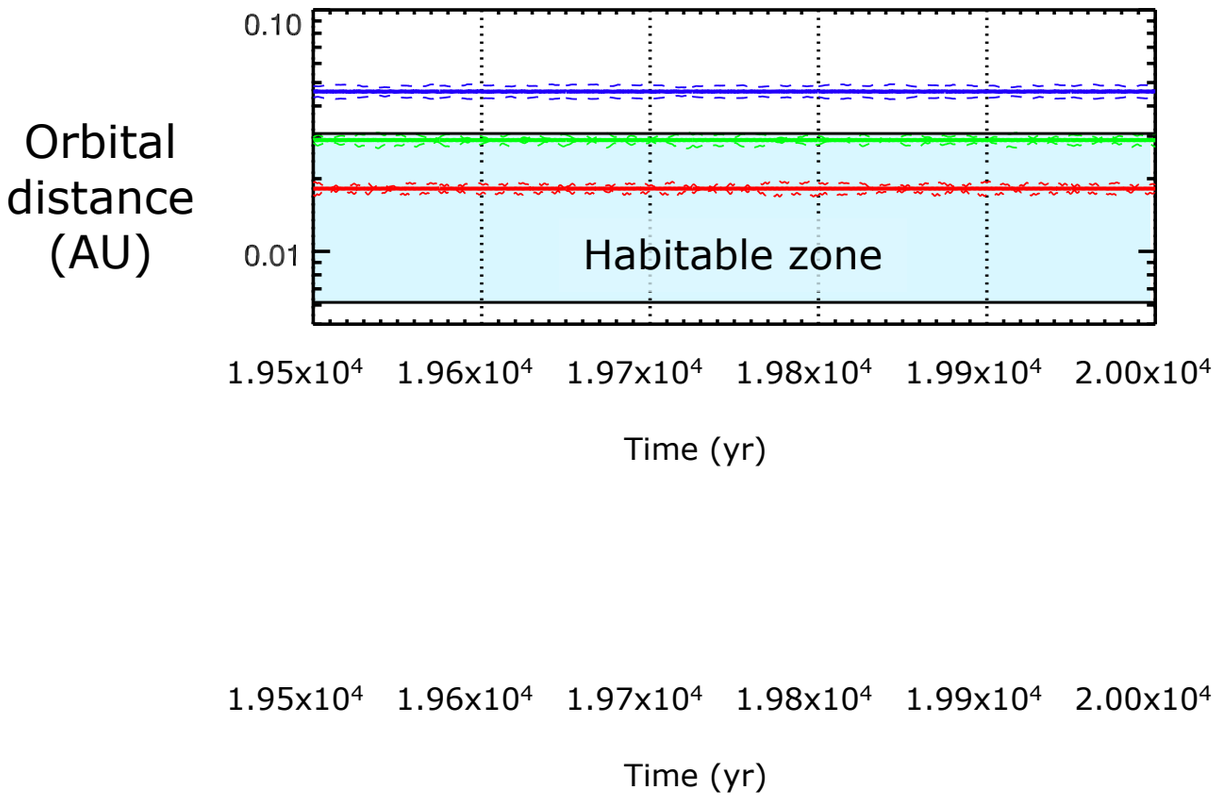


Images from *New Horizons* showing volcano Tvashtar

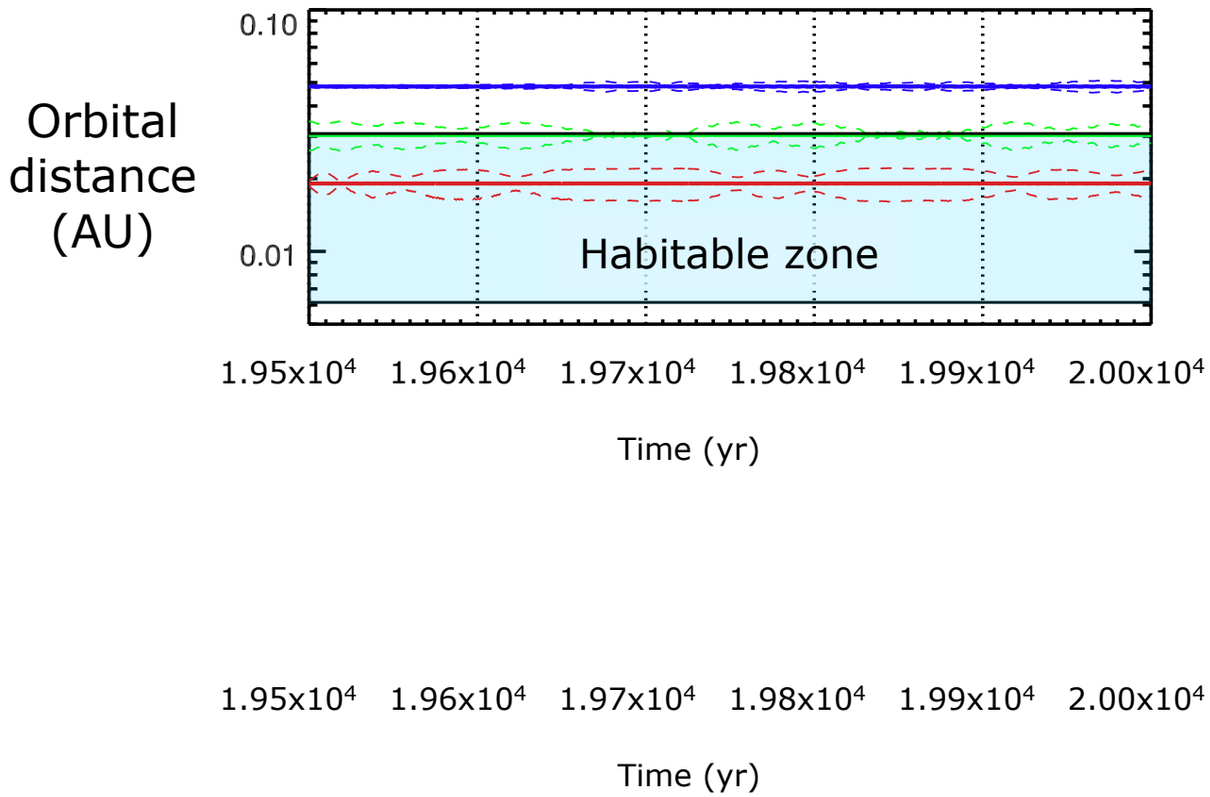
Planets around brown dwarfs

Tidal effects in multi-planet systems

Non resonant system



Resonance 2:1



Discussed in Barnes et al. (2010) for planets around M-dwarfs

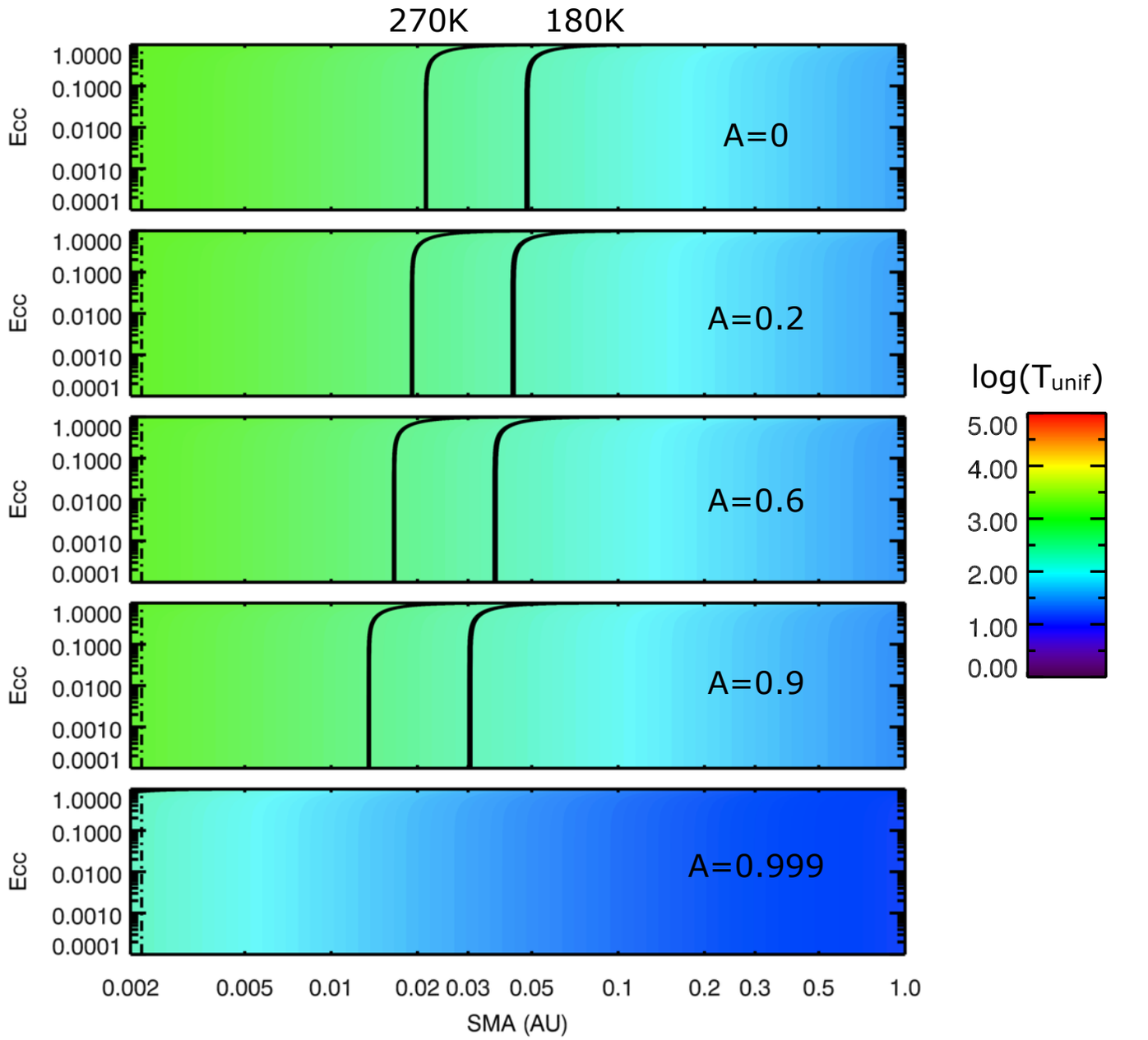
Planets around brown dwarfs

Effect of tidal heating

$\sigma_p = 0$

Uniform temperature of a planet

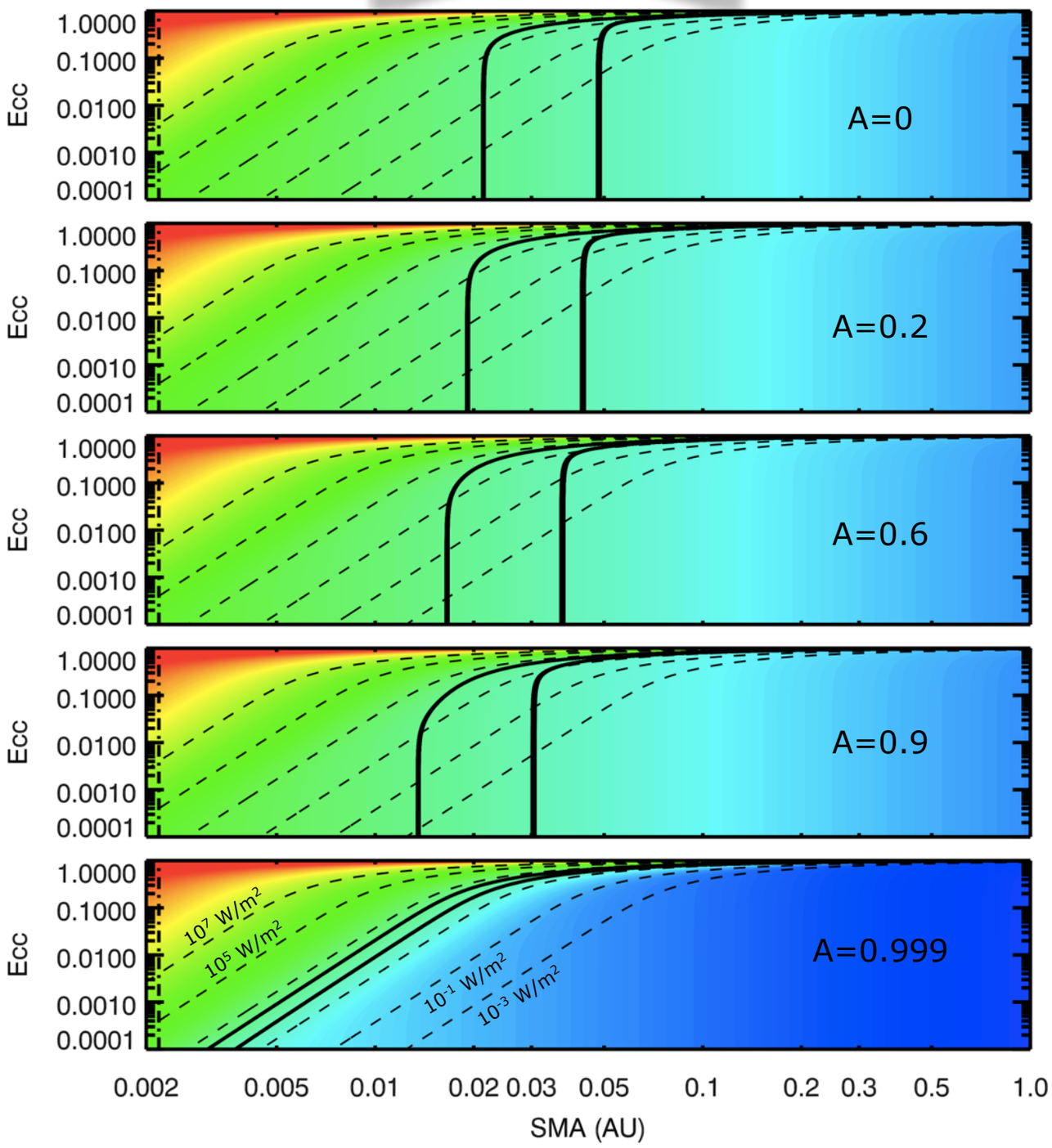
$$T_{\rm unif}(a, e, A) = \left(T_{\rm eq}^4 + \frac{\phi_{\rm tides}}{\sigma_{\rm SB}} \right)^{1/4}$$

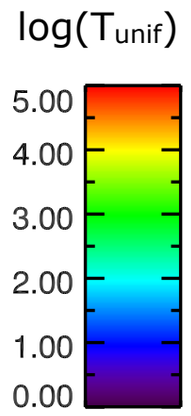


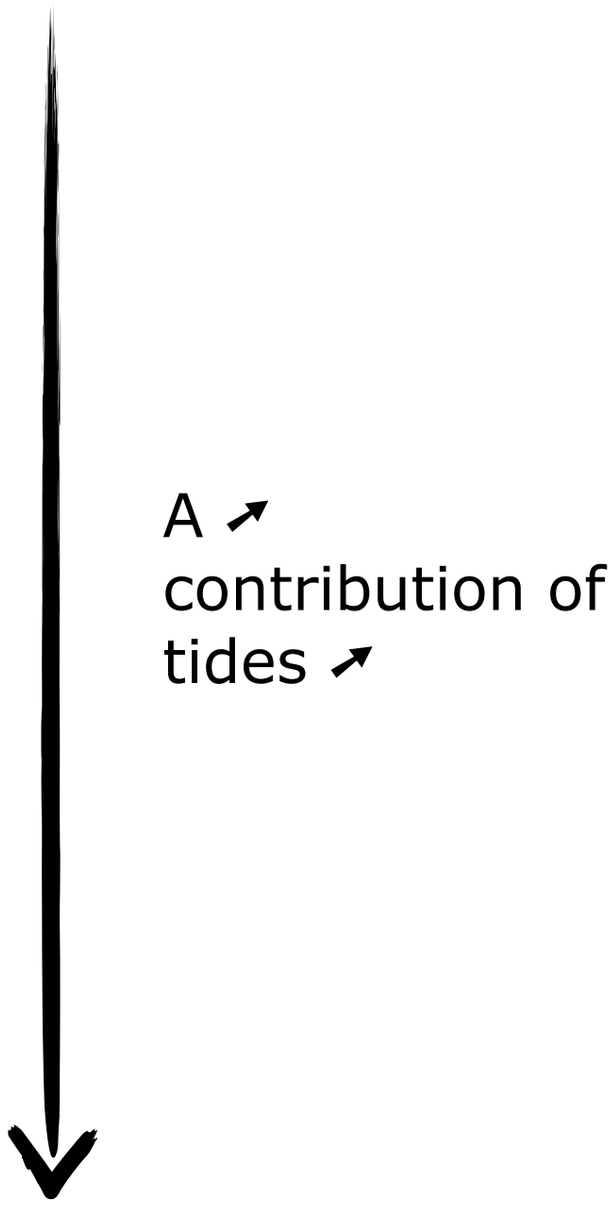
Planets around brown dwarfs

Effect of tidal heating

$\sigma_p = 0.1\sigma_\oplus$







Planets around brown dwarfs

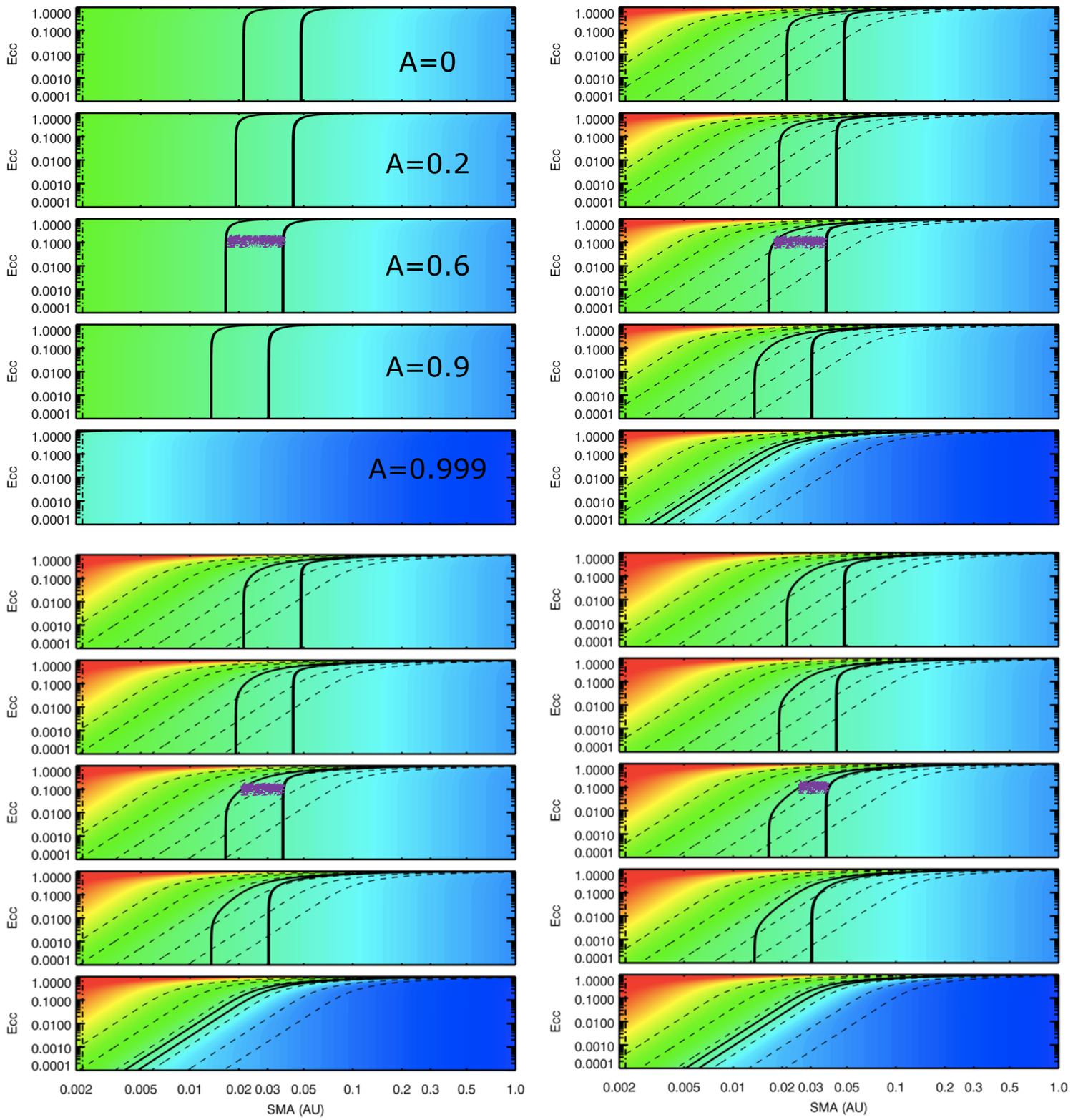
Effect of tidal heating

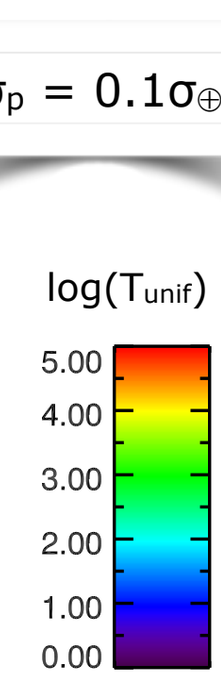
$\sigma_p = 0$

$\sigma_p = 0.1\sigma_\oplus$

$\sigma_p = 1\sigma_\oplus$

$\sigma_p = 10\sigma_\oplus$

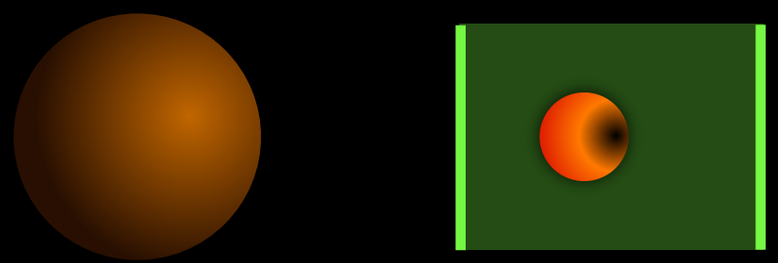




Planets around brown dwarfs

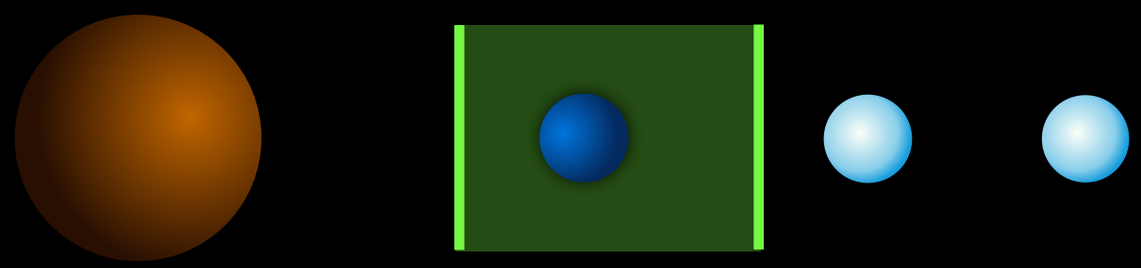
aquability?

- 1 planet: synchonized, no obliquity: $\Phi_{tides} = 0$ W/m^2



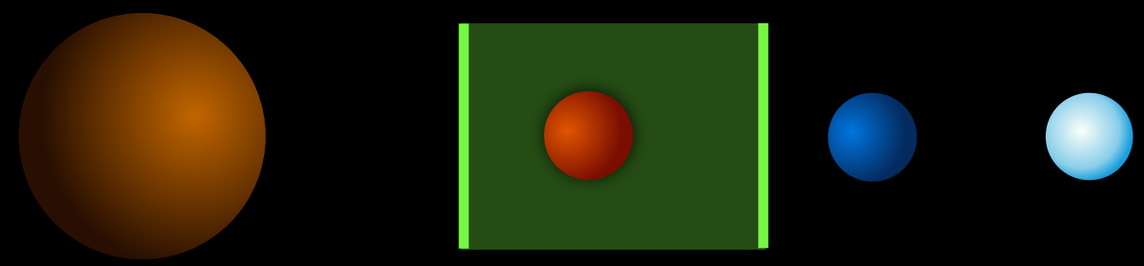
1 planet
danger?

- +1 planet: other dangers
  - $(\Phi_\star + \Phi_{tides})_{avg} < 300$ W/m^2, aquability



Several planets
no resonances

  - $(\Phi_\star + \Phi_{tides})_{avg} > 300$ W/m^2, no aquability



Several planets
resonances

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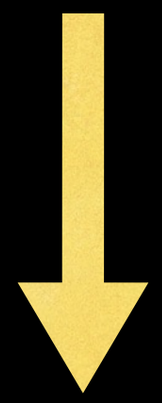
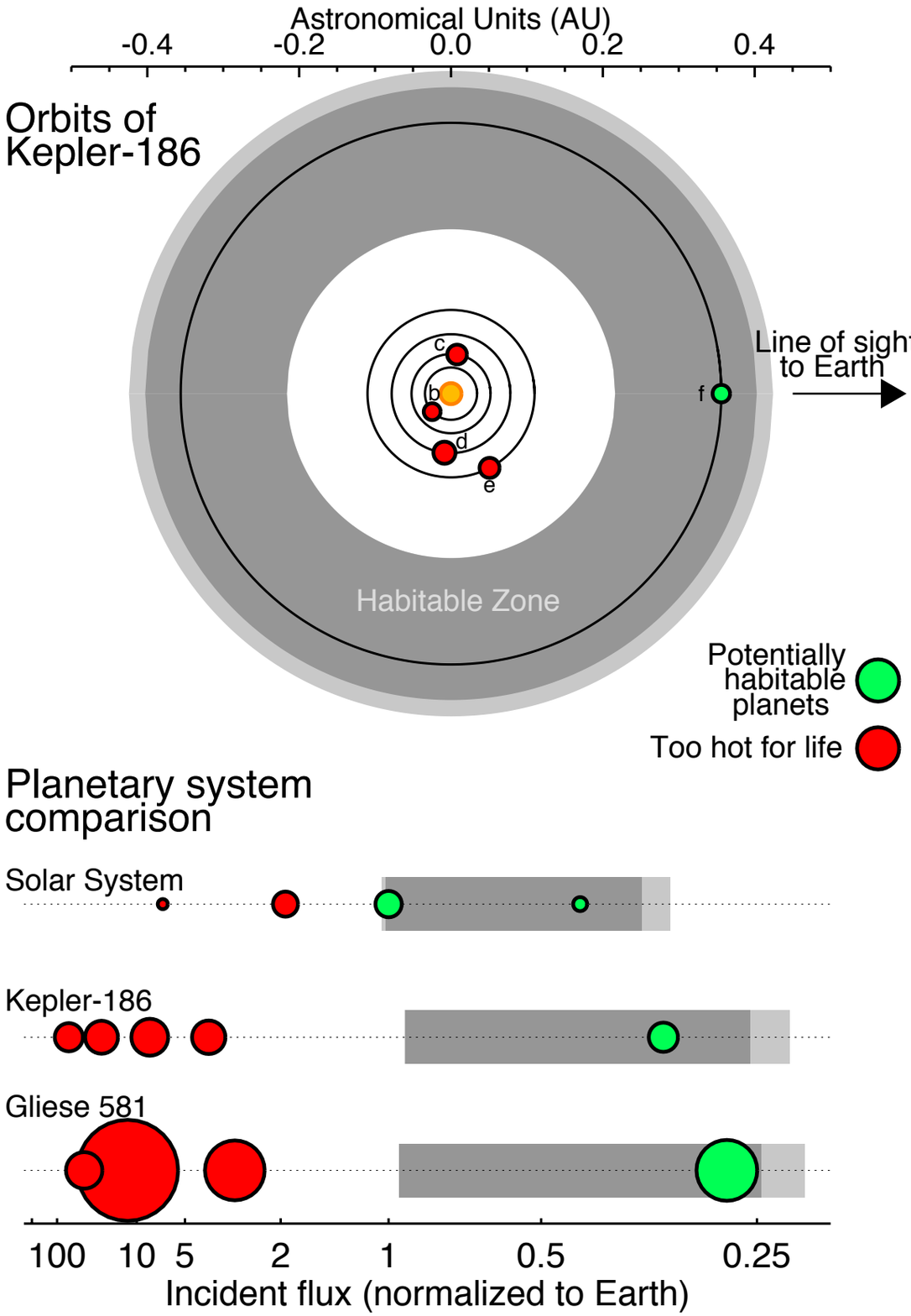


Climates

Kepler-186f



$M_\star = 0.48\ M_\odot$

Planets

$1 < R_p/R_\oplus < 1.4$

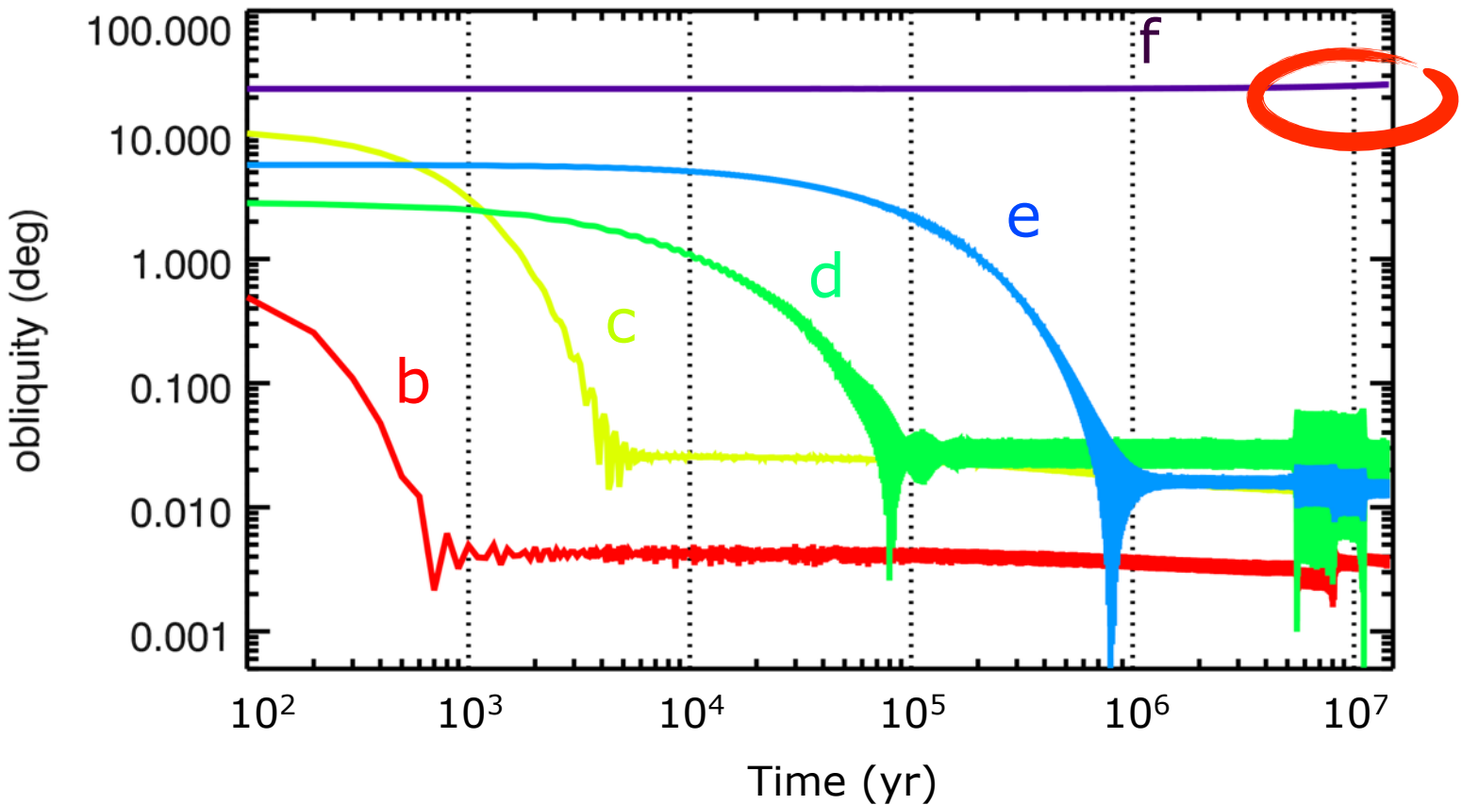
$0.04 < a/AU < 0.4$

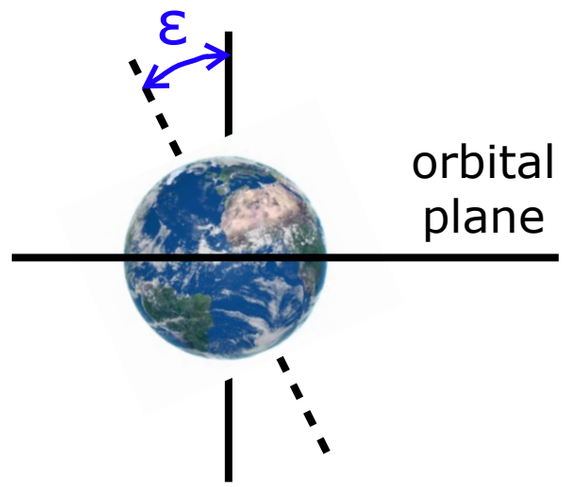
Quintana et al. (2014)

Bolmont et al. (2014)

Kepler-186

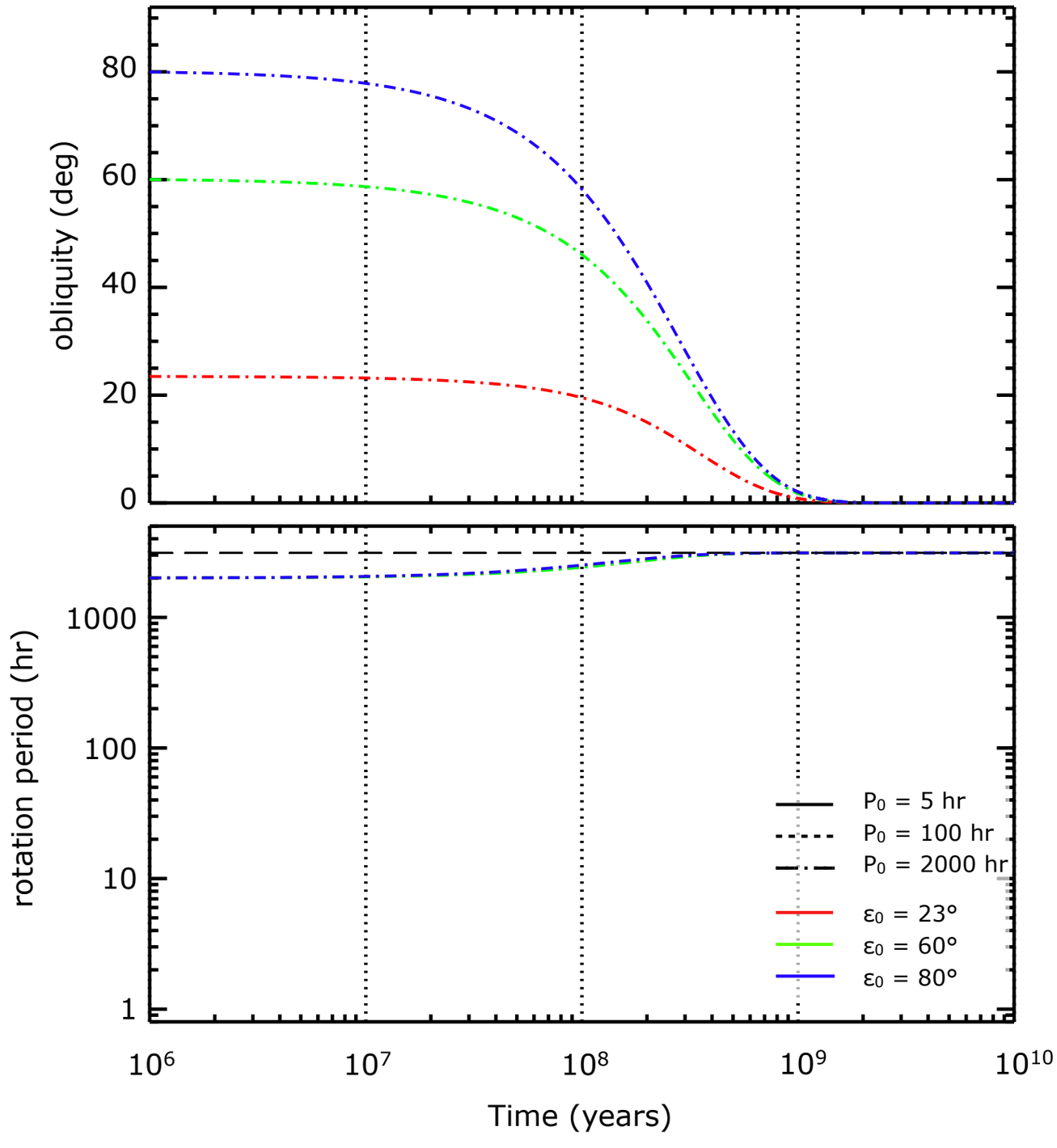
Evolution

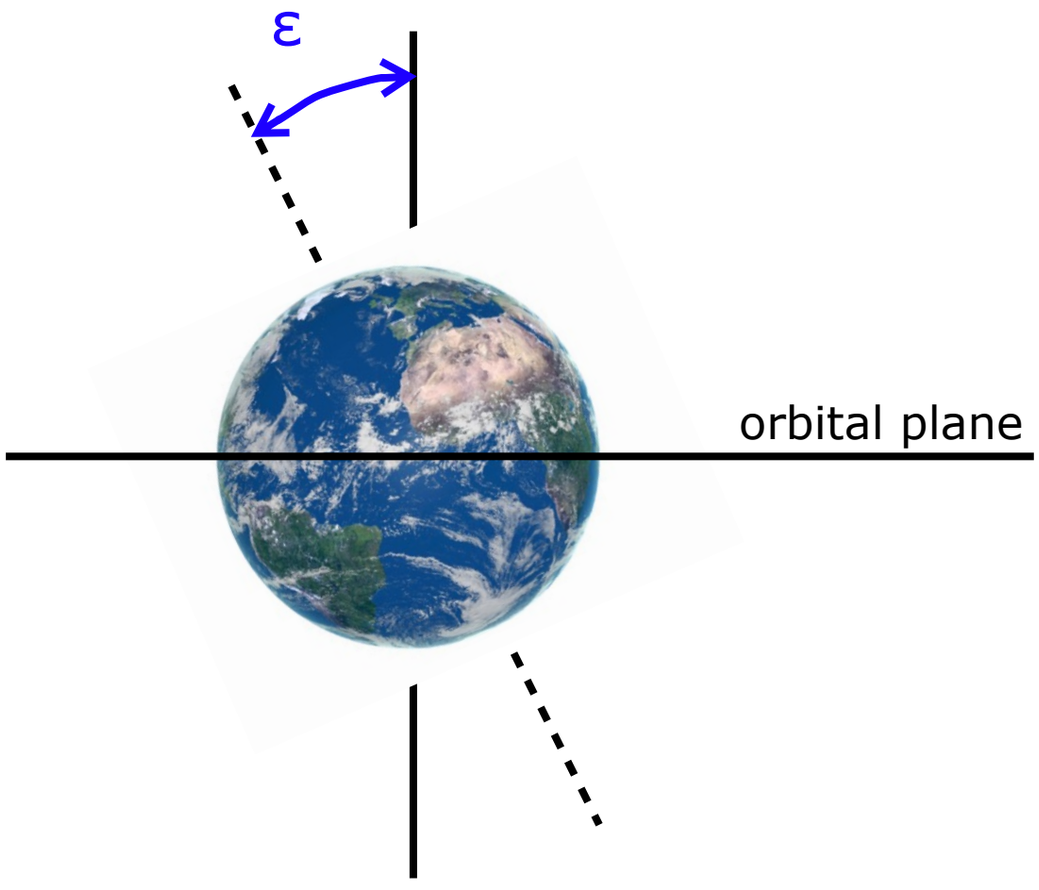




Kepler-186

Aquability of Kepler-186f ?

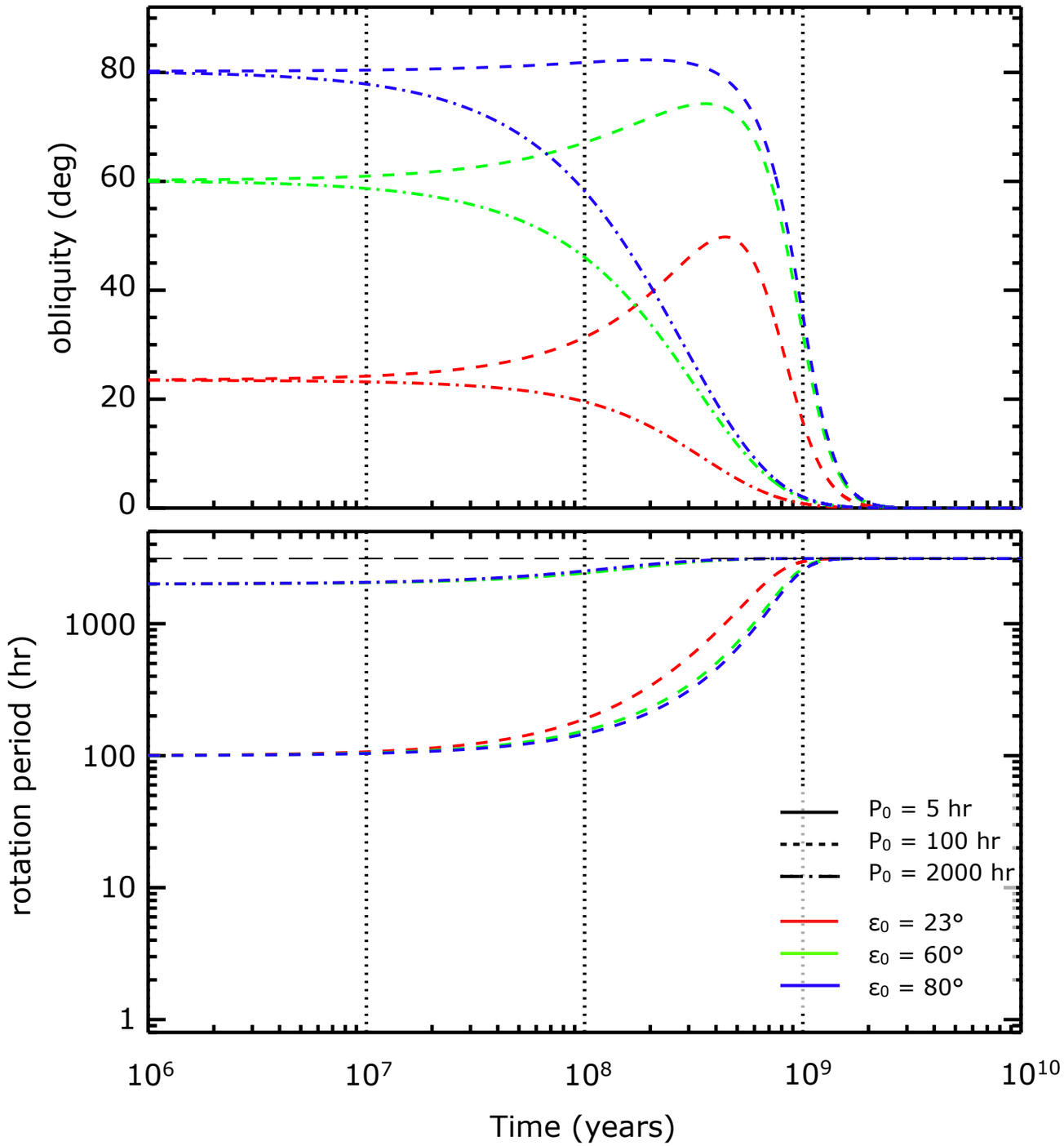


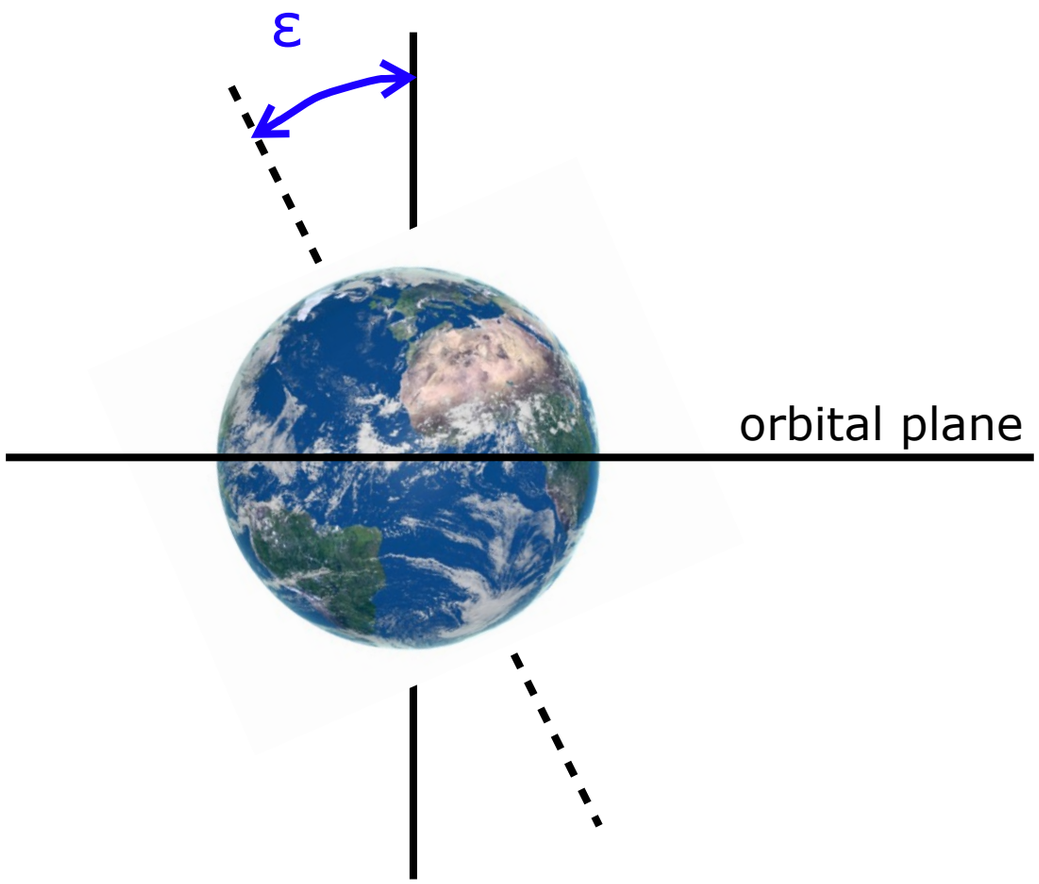


Assuming Earth composition
Assuming Earth dissipation

Kepler-186

Aquability of Kepler-186f ?

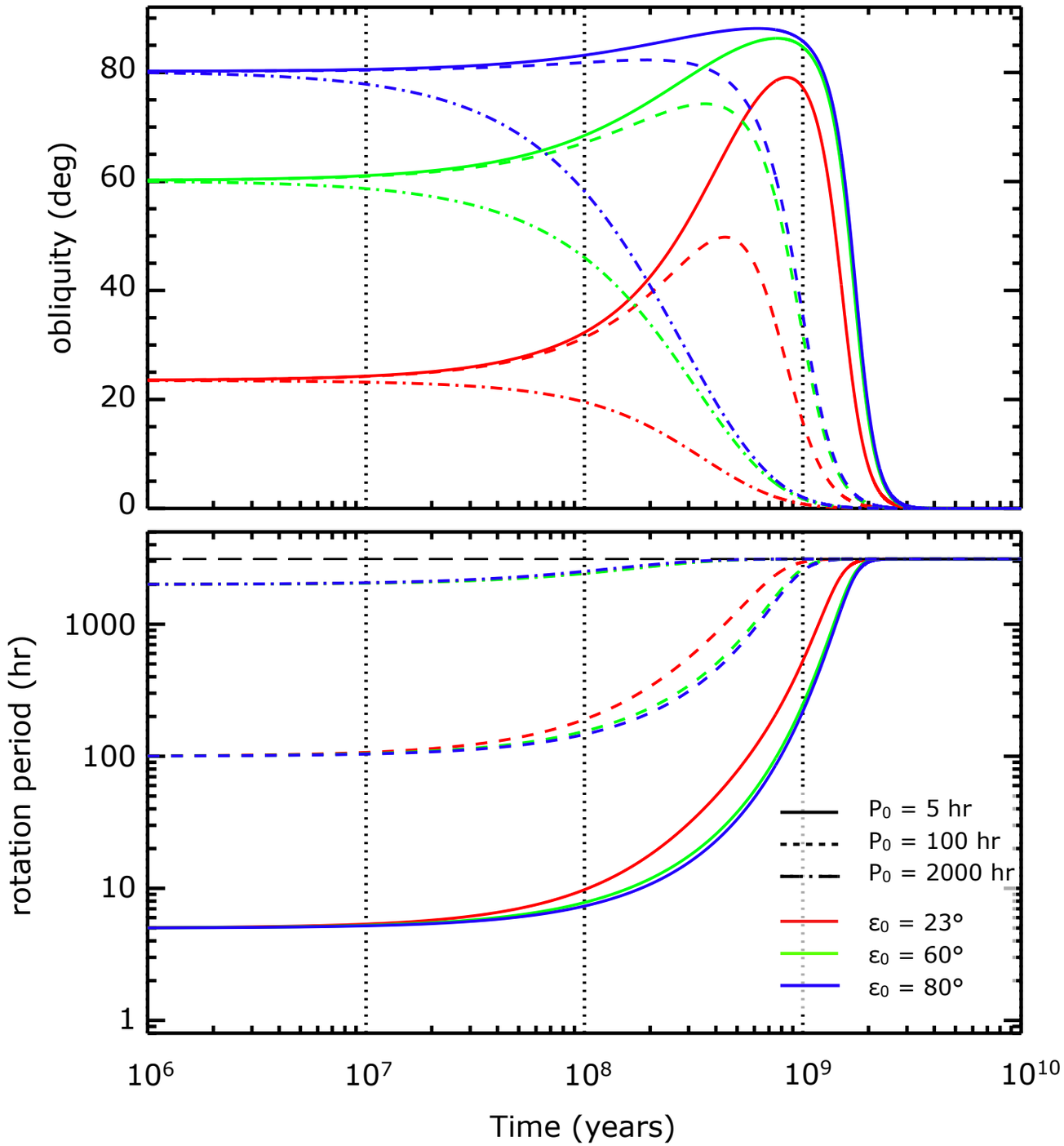


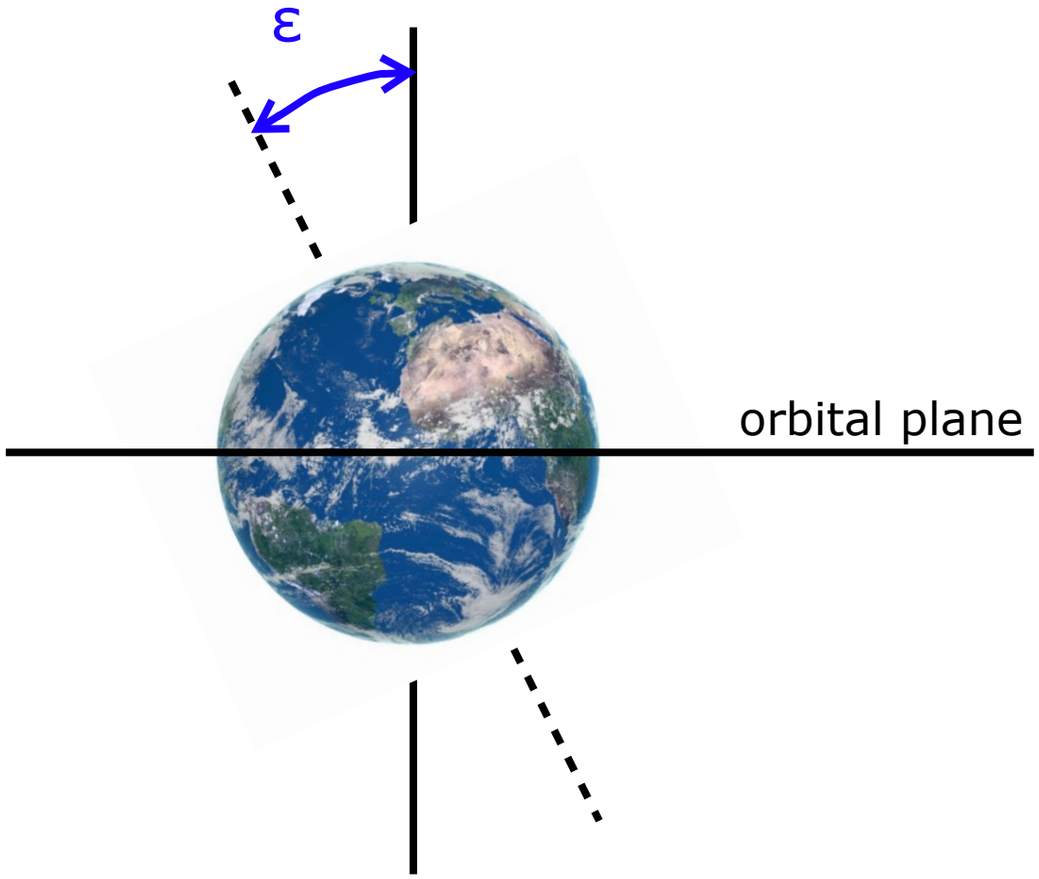


Assuming Earth composition
Assuming Earth dissipation

Kepler-186

Aquability of Kepler-186f ?





Assuming Earth composition
Assuming Earth dissipation

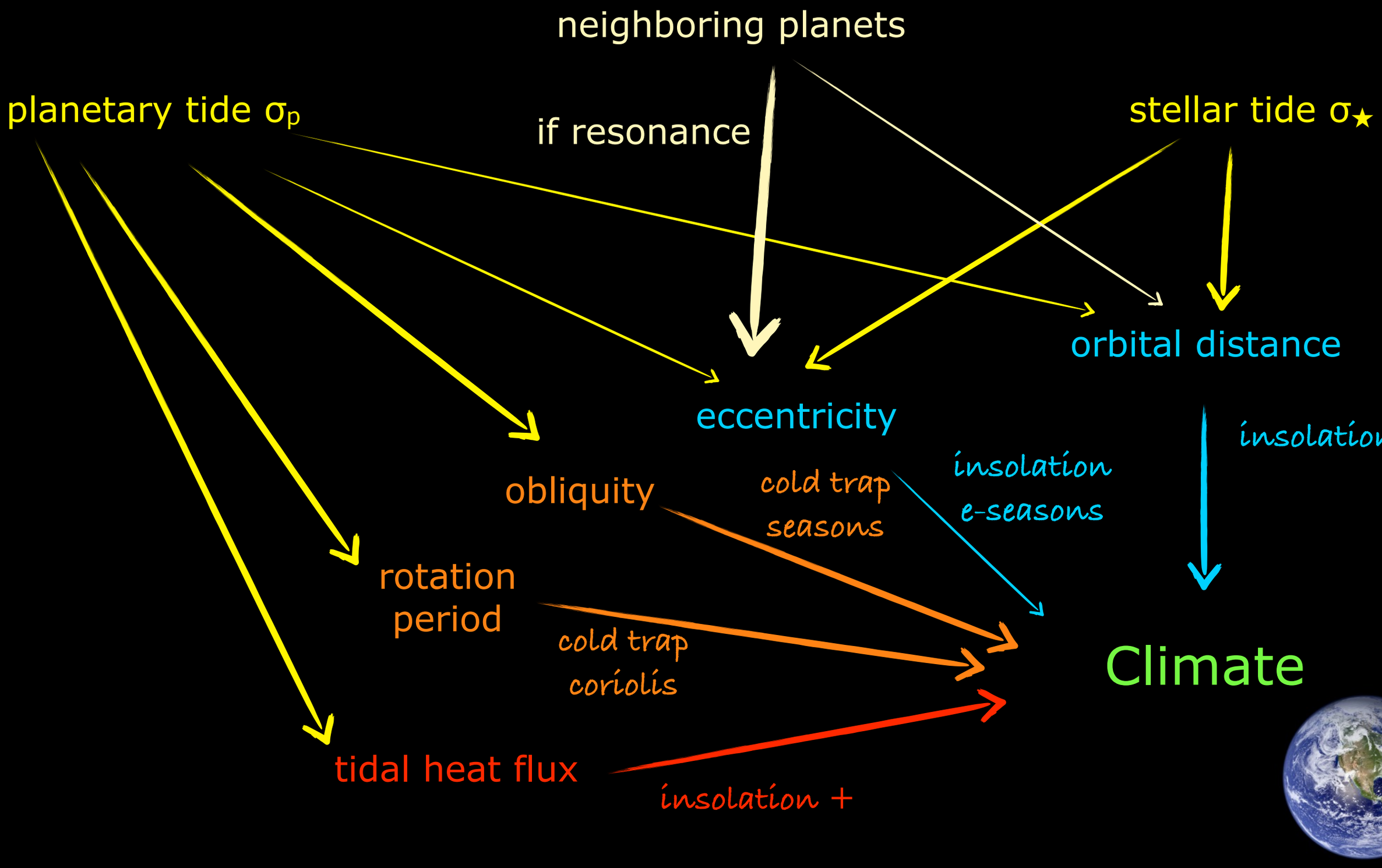
Kepler-186

- age ≳ 4 Gyr

★ Kepler-186 b, c, d and e are very likely to be pseudo-synchronized (P_{rot} > 3.75 days), and have equilibrium obliquities (~0.1°)

★ Kepler-186 f might be in the process of pseudo-synchronization, its obliquity may have high values
➜ impact on its climate

Tides and climate



Merci !

Thank you !