Dynamics of exoplanetary systems, links to their habitability

Star-planet interactions and the habitable zone
18/11/14

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Outline

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

Tides

↓

Climates

Outline

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Climates

Exoplanets discoveries

Planet orbiting a Sun like star

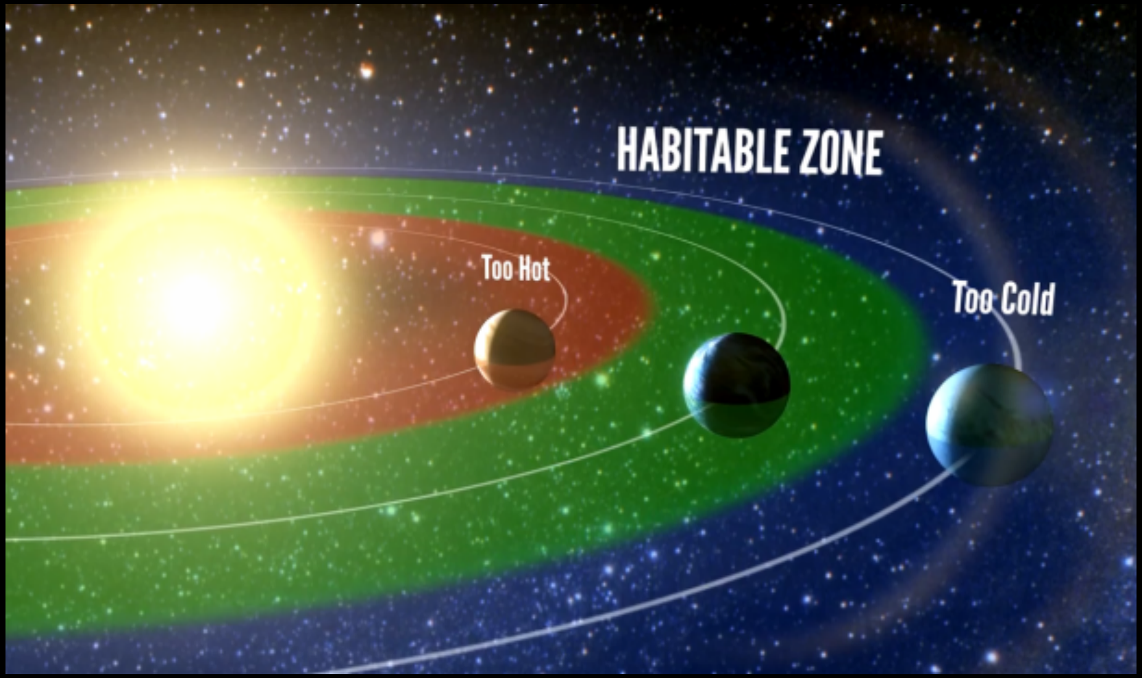
Rocky planet

Planet in the habitable zone

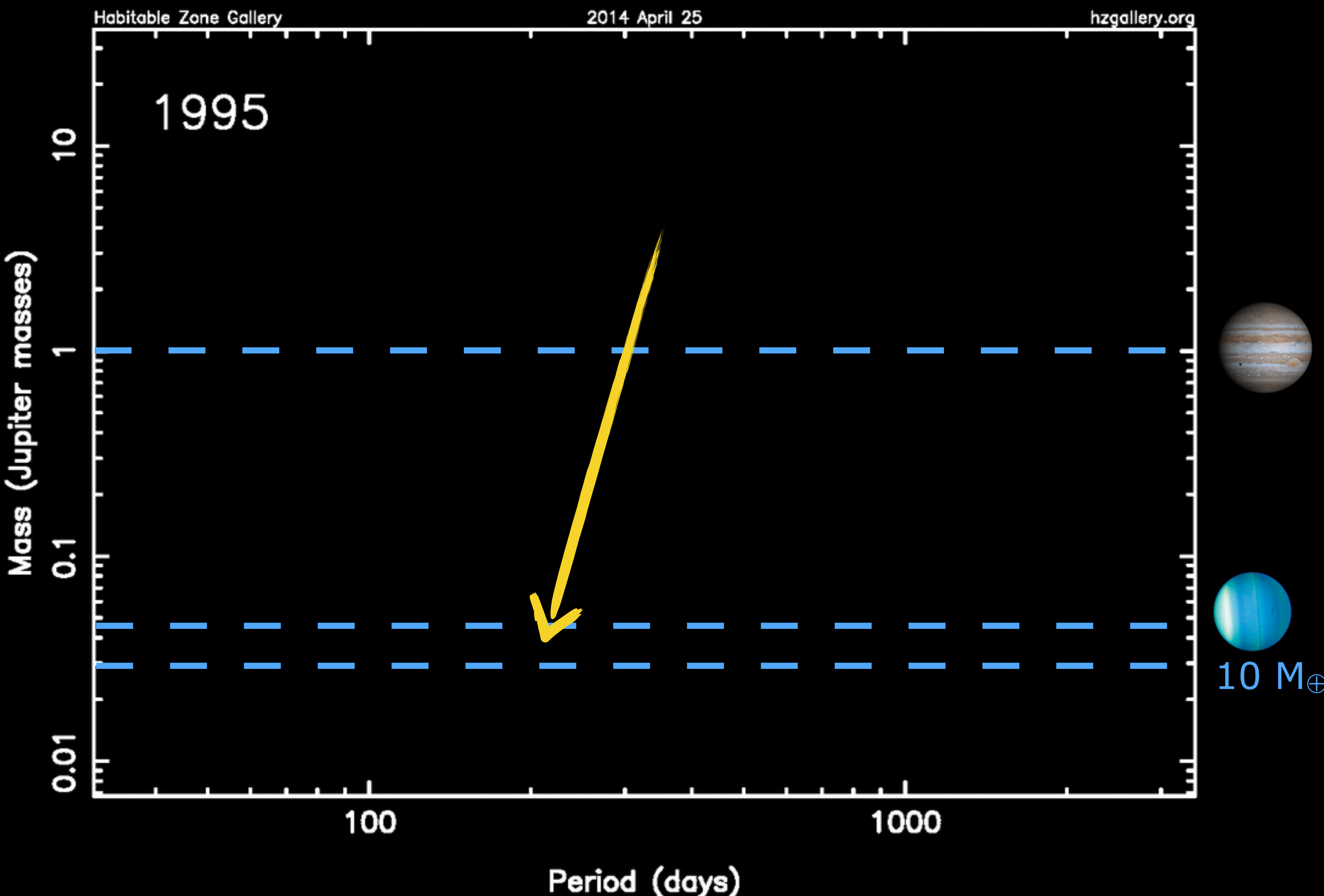
Habitable zone planets

« Habitable zone »

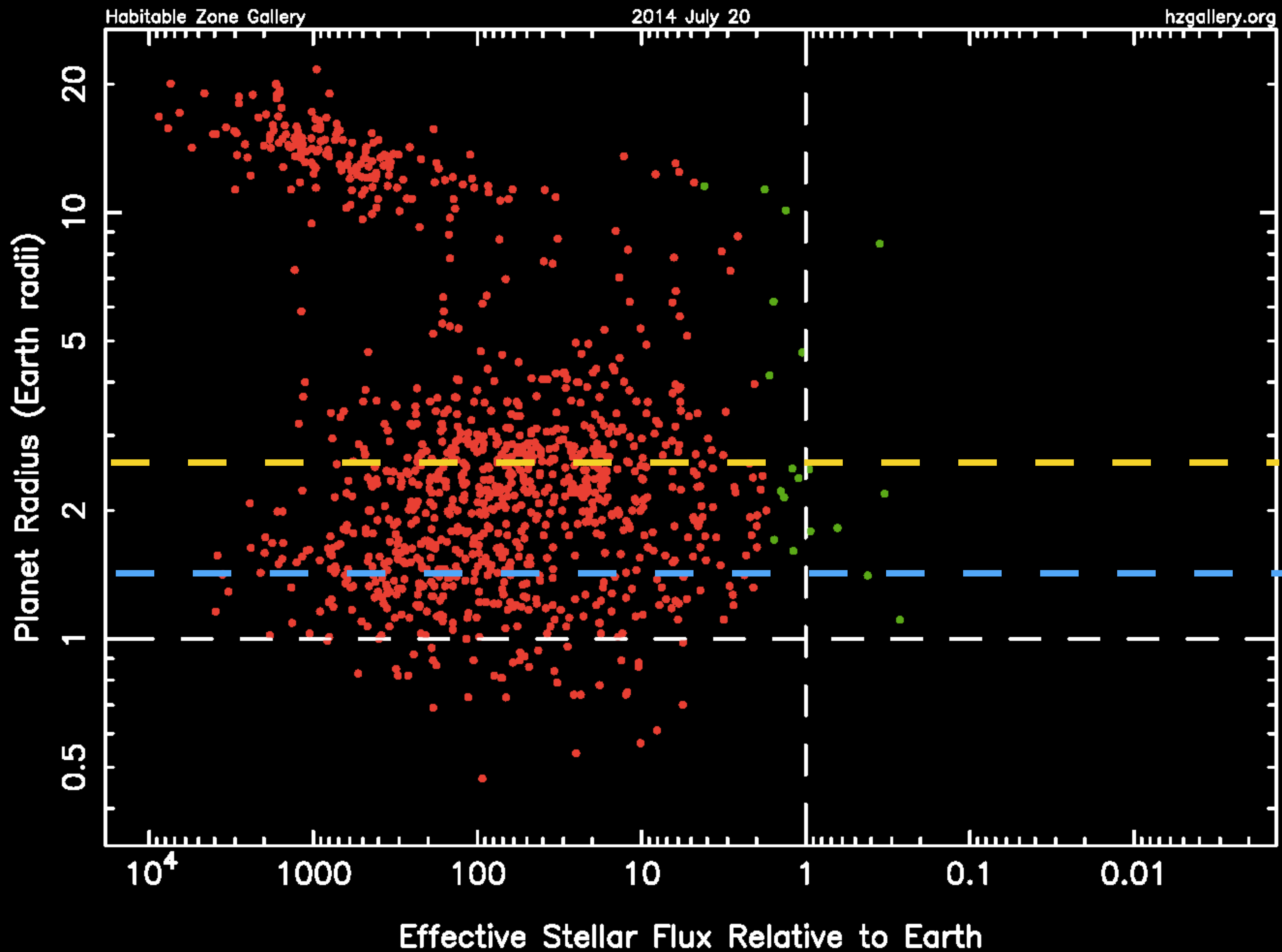
region around a star in which a planet could potentially host surface liquid water

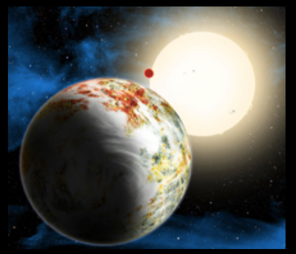


Habitable zone planets



Habitable zone planets





rocky

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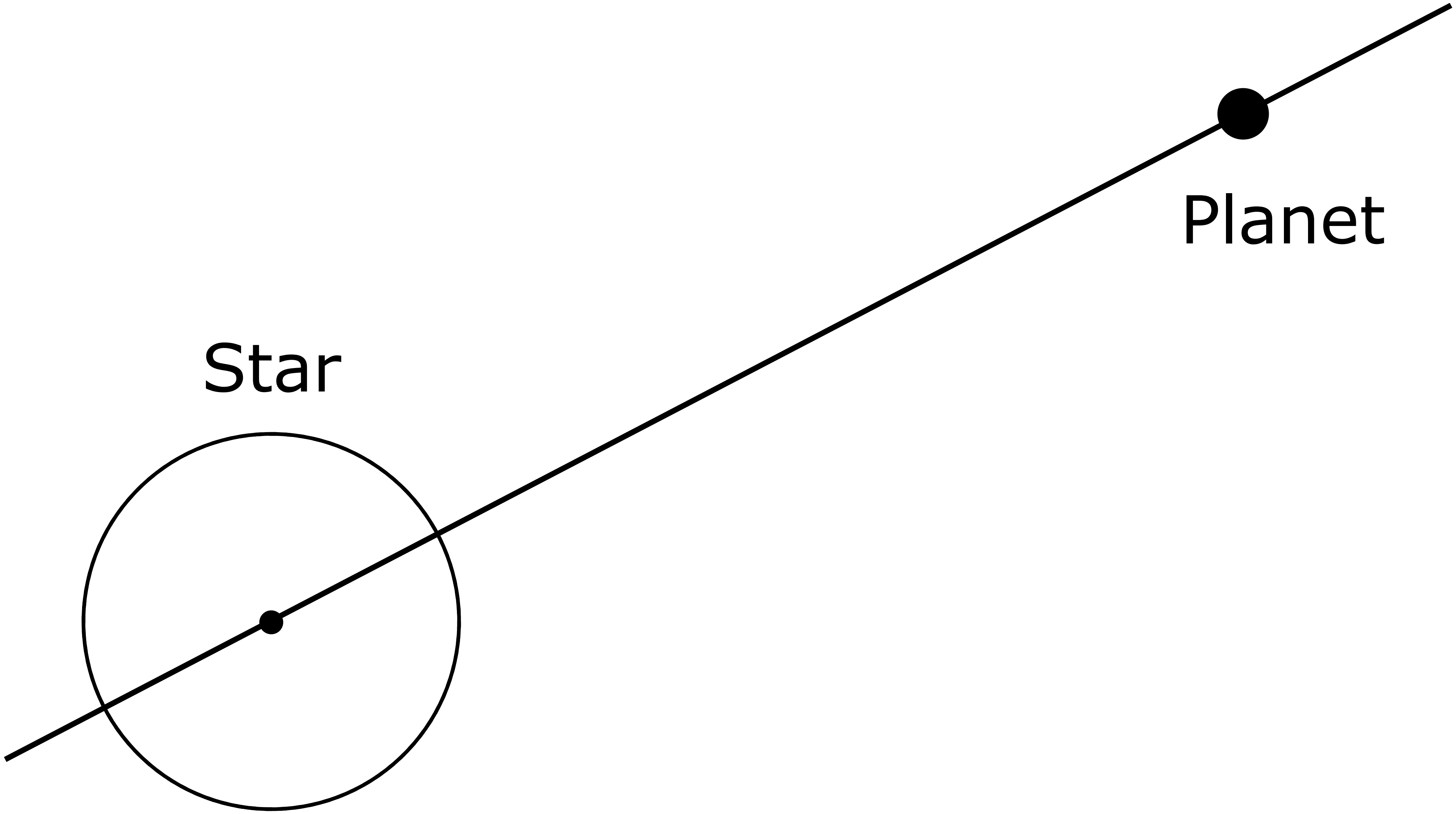
Tidal evolution

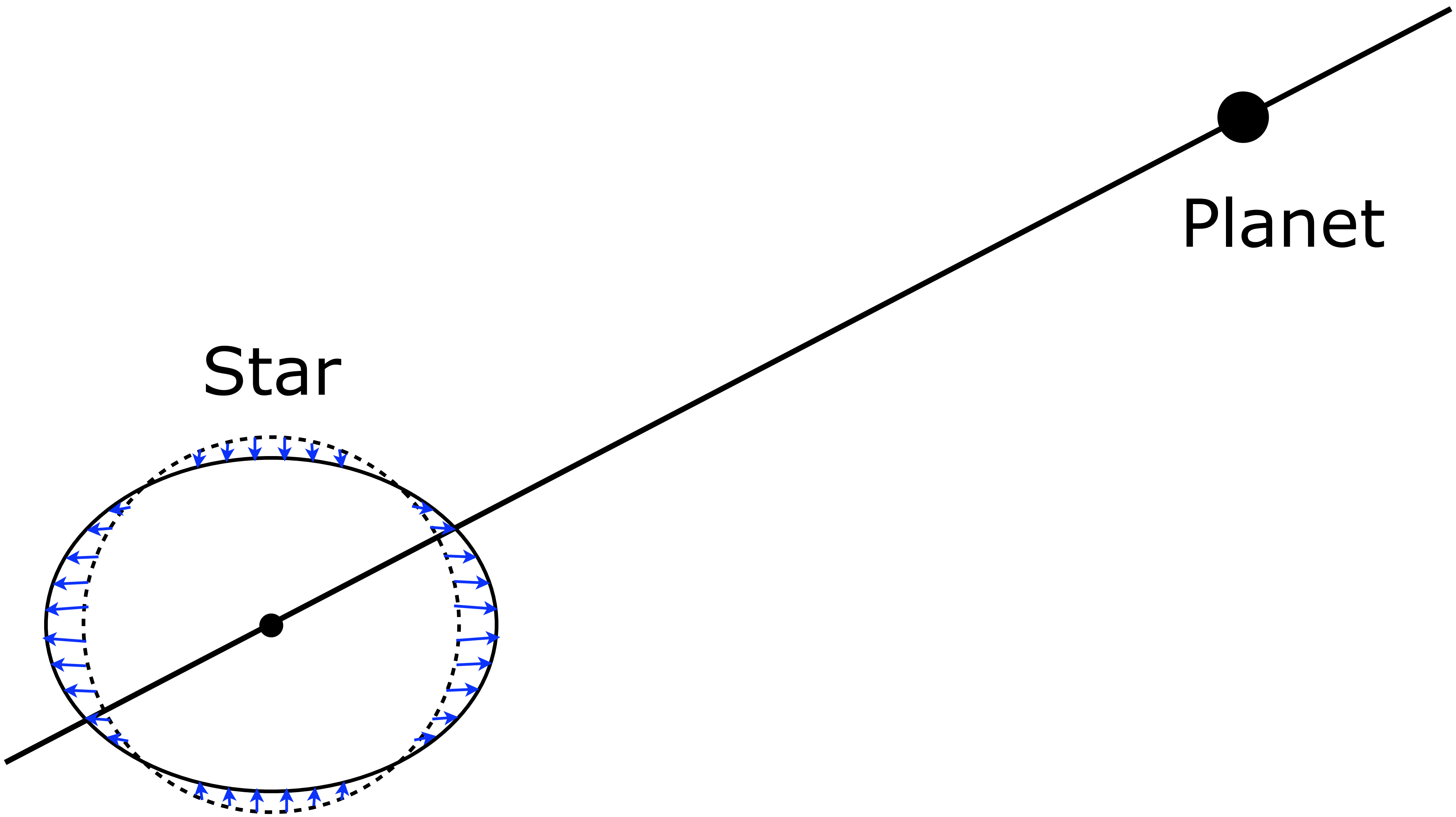
Constant time lag model



(Mignard, 1979; Hut, 1981; Leconte et al., 2010)

Tidal evolution

Constant time lag model



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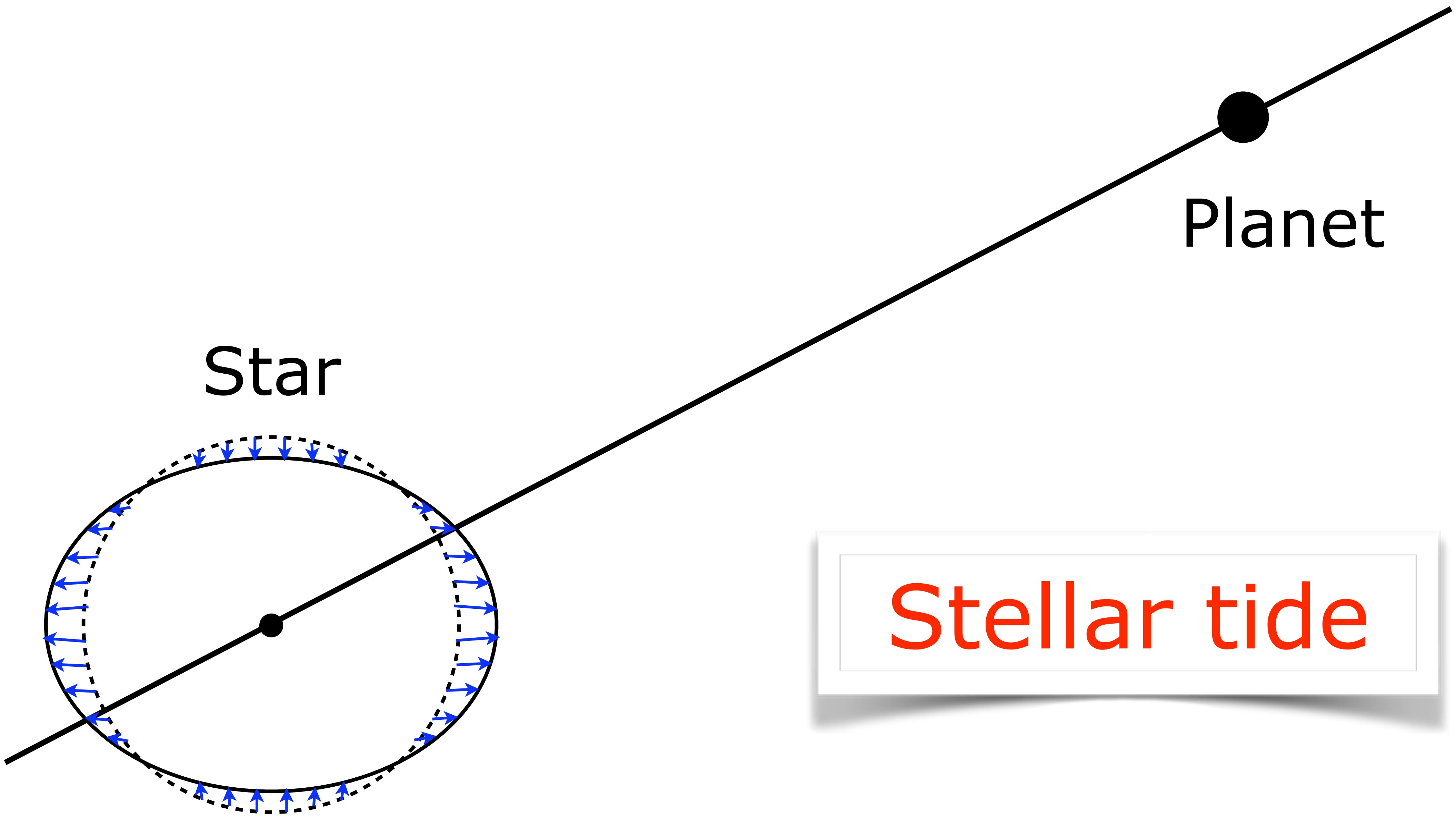
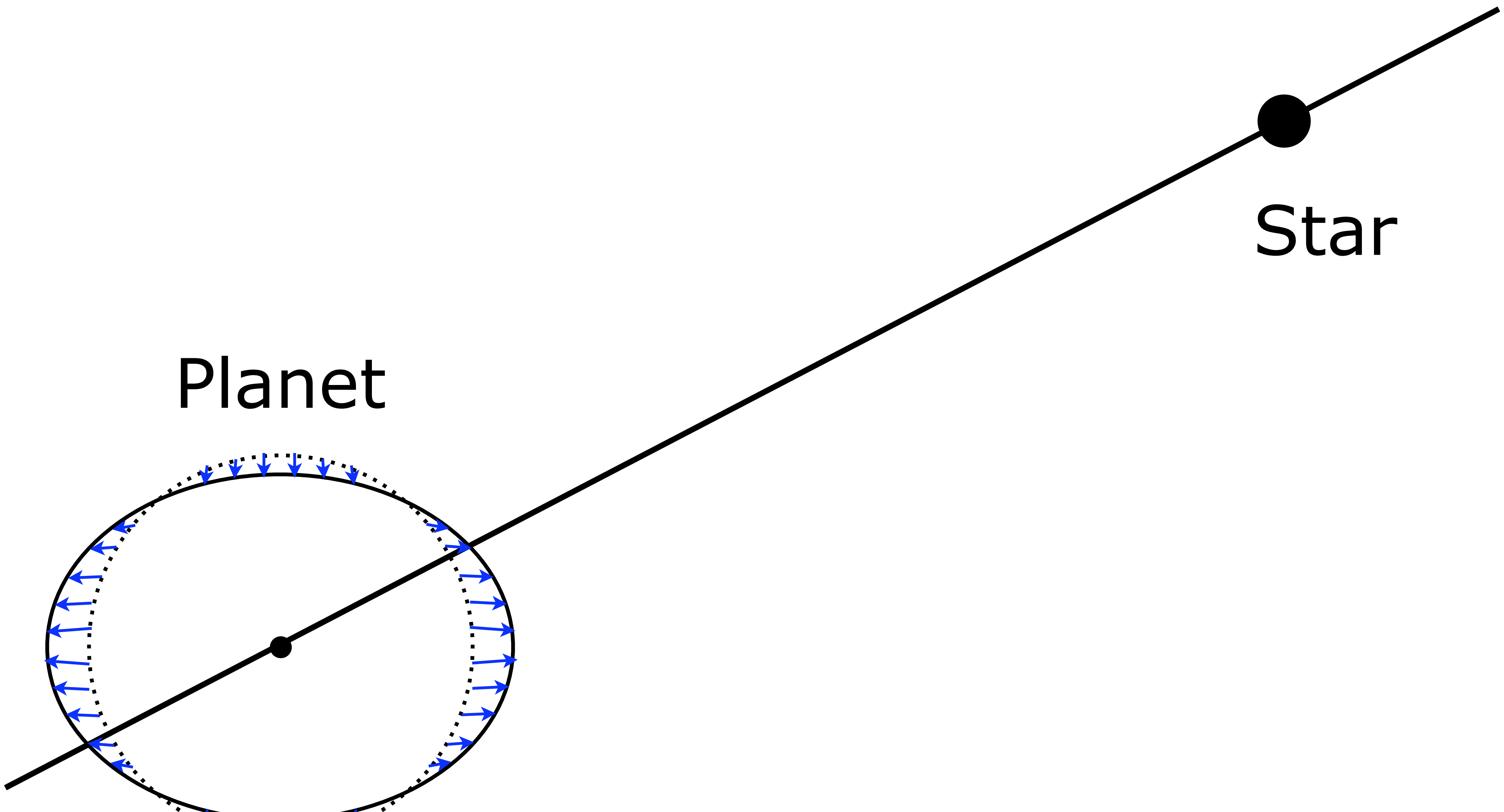


Stellar tide

(Mignard, 1979; Hut, 1981; Leconte et al., 2010)

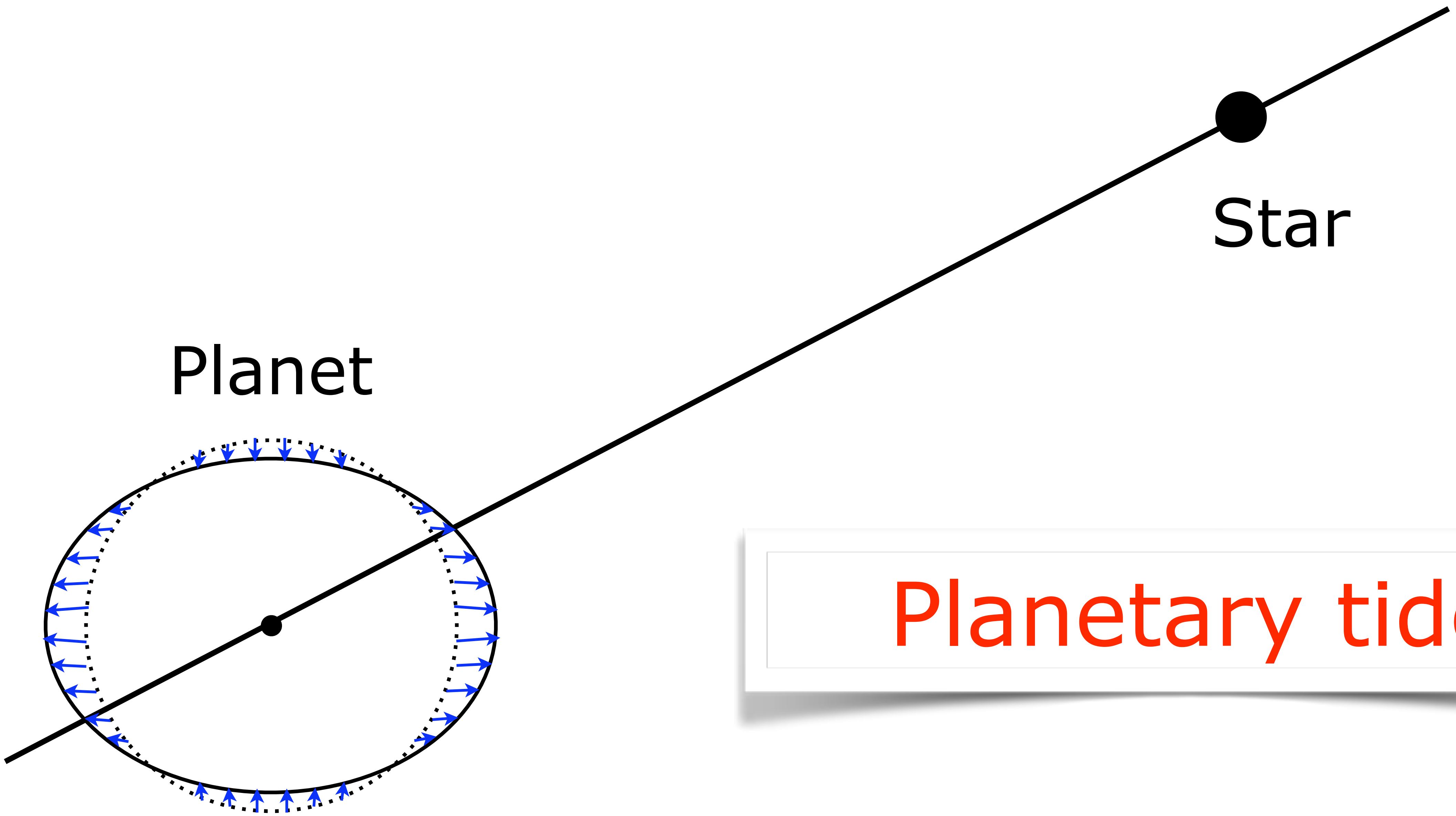
Tidal evolution

Constant time lag model



Tidal evolution

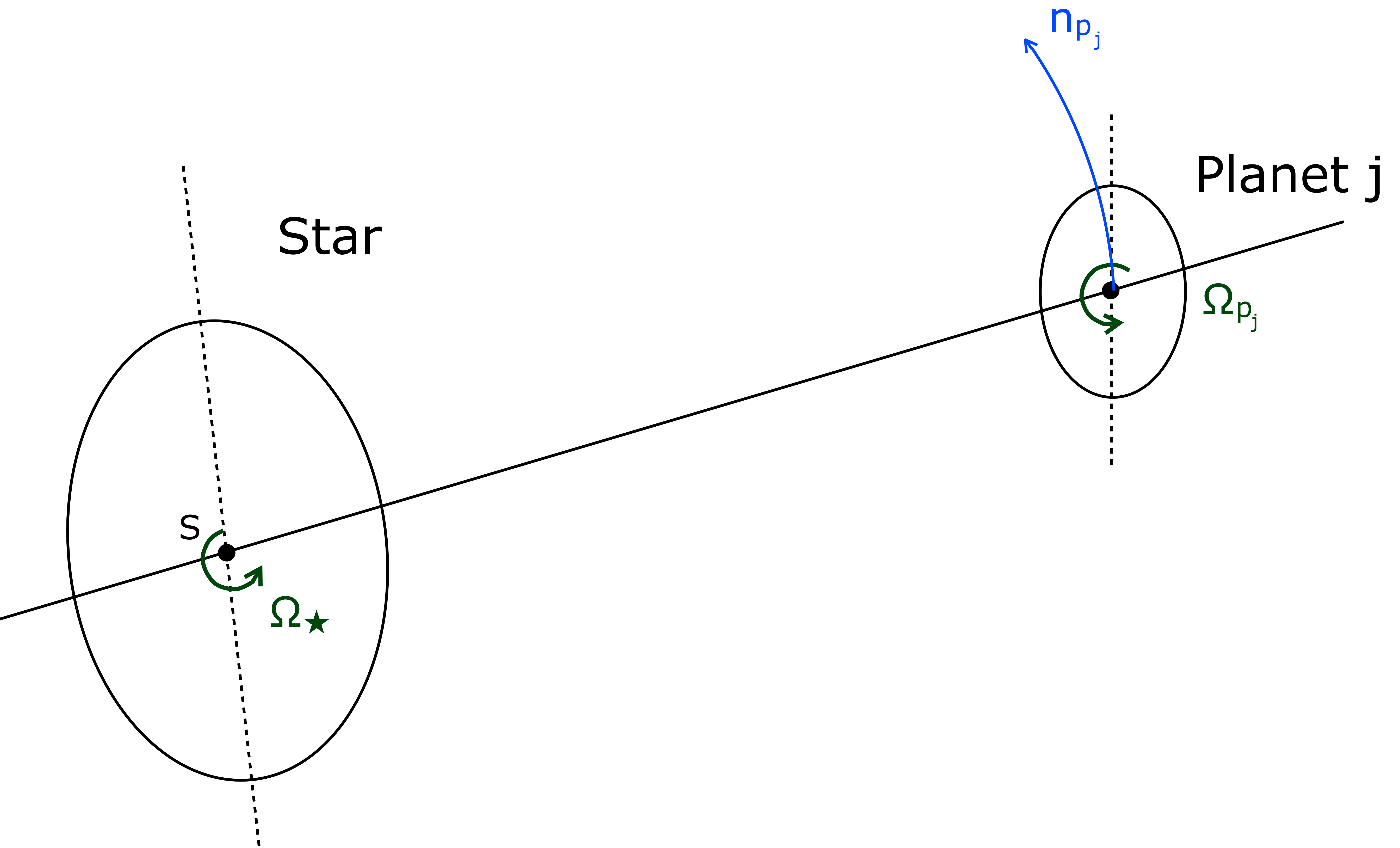
Constant time lag model



Planetary tide

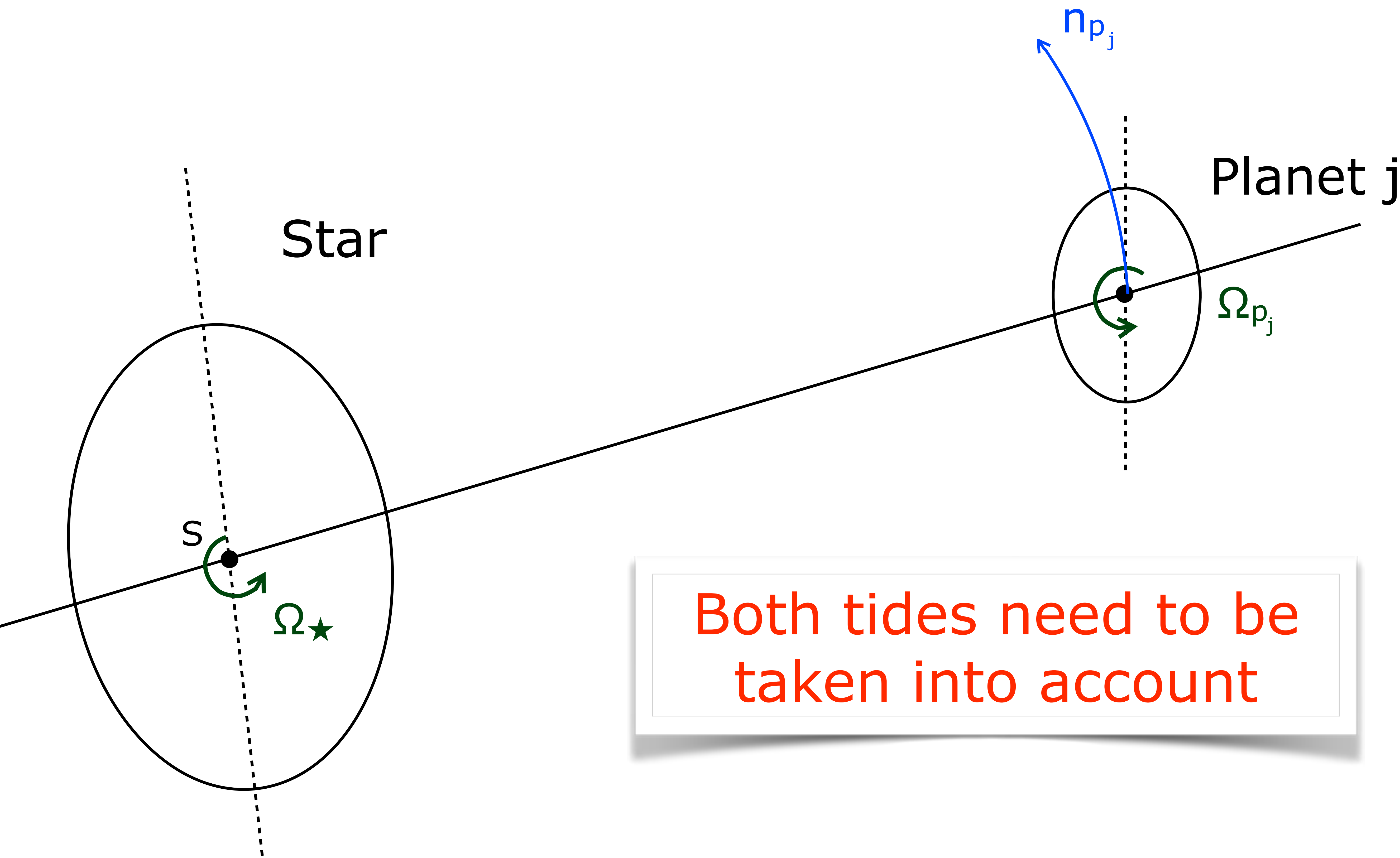
Tidal evolution

Constant time lag model



Tidal evolution

Constant time lag model

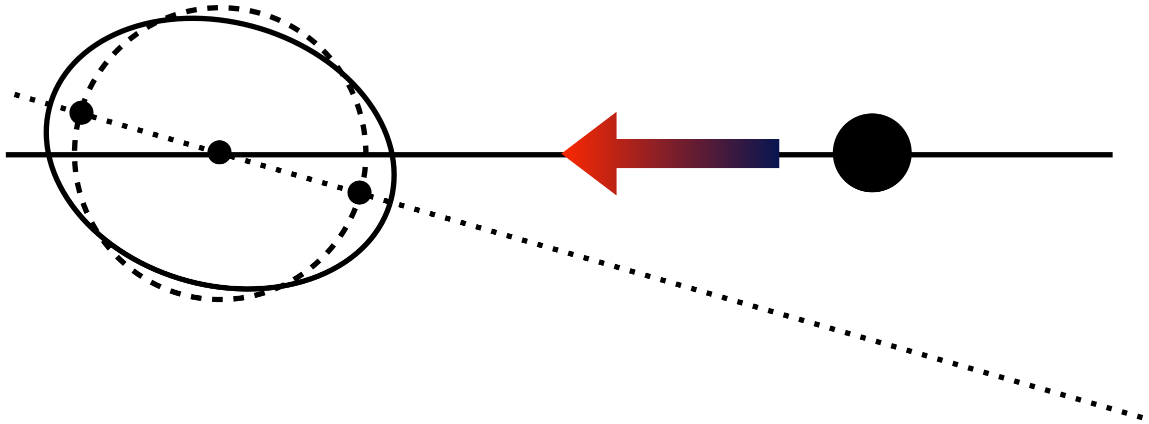


Both tides need to be taken into account

Tidal evolution

Stellar tide

★ planet inside corotation
⇒ planet migrates inward

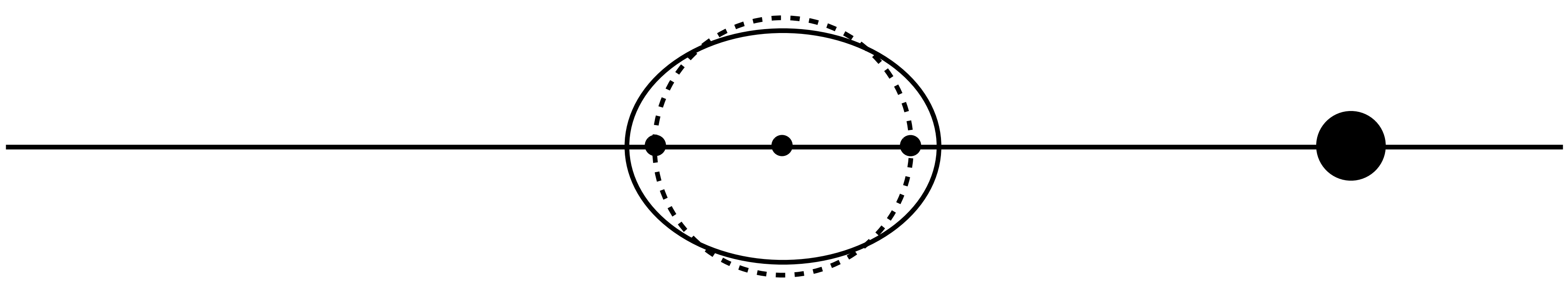


Tidal evolution

Stellar tide

$$\boxed{\Omega_\star = n_p}$$

orbital distance of planet $a_p = r_c$ corotation distance



Tidal evolution

Stellar tide

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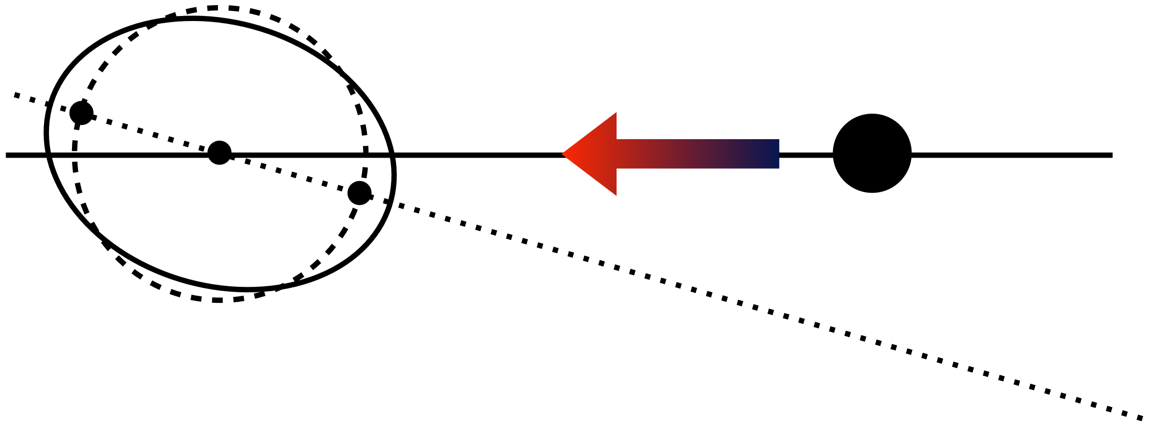

Tidal evolution

Stellar tide

★ planet inside corotation
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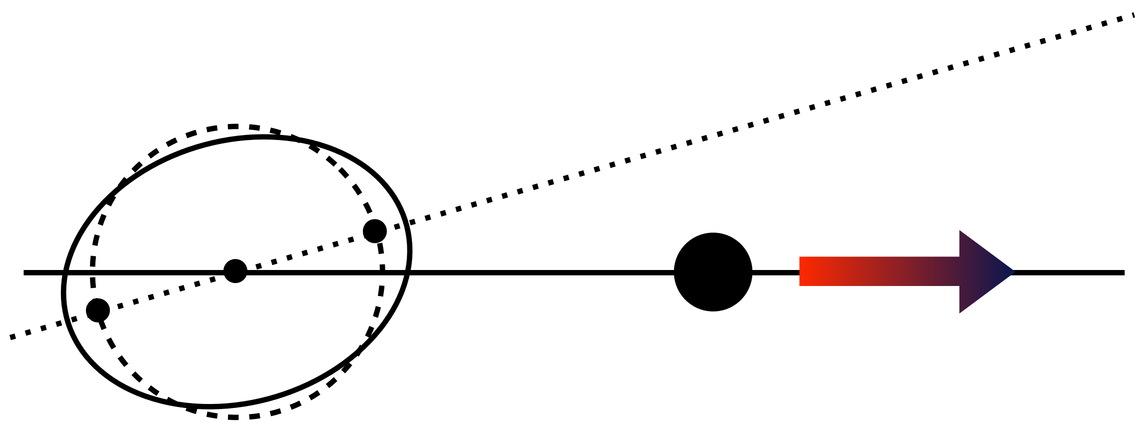
★ planet outside corotation
⇒ planet migrates outward



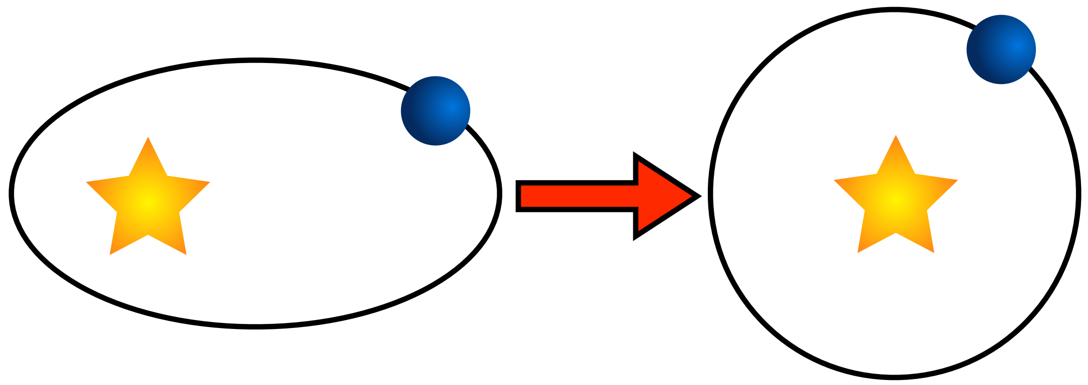
Tidal evolution

Stellar tide

★ planet inside corotation
⇒ planet migrates inward

★ planet outside corotation
⇒ planet migrates outward

★ eccentricity decreases



Tidal evolution

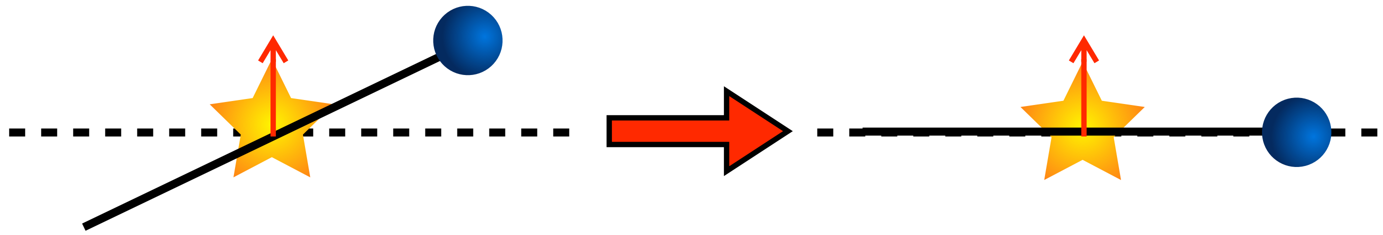
Stellar tide

- ★ planet inside corotation
  ⇒ planet migrates inward

- ★ planet outside corotation
  ⇒ planet migrates outward

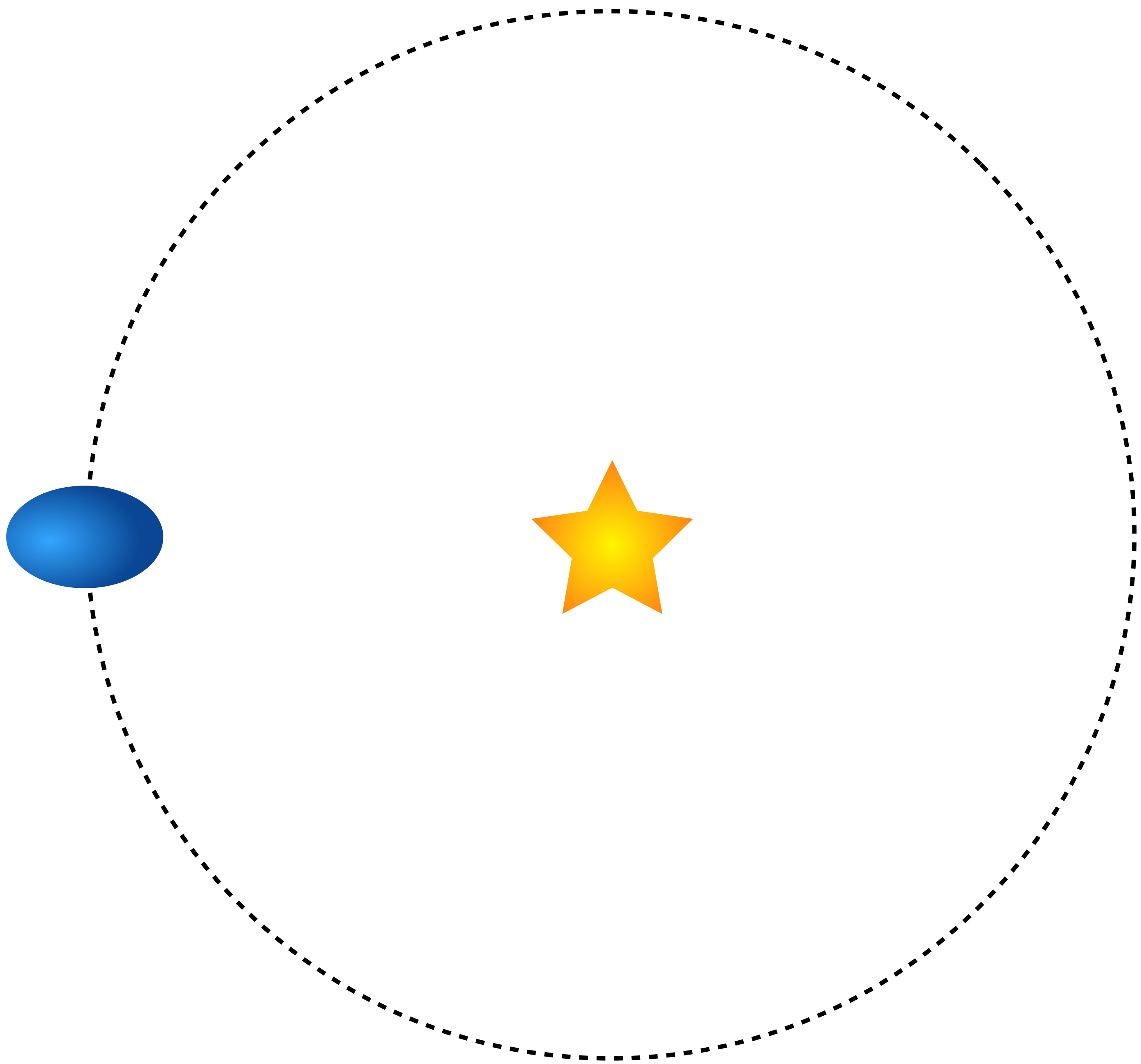
- ★ eccentricity decreases

- ★ inclination of planet decreases



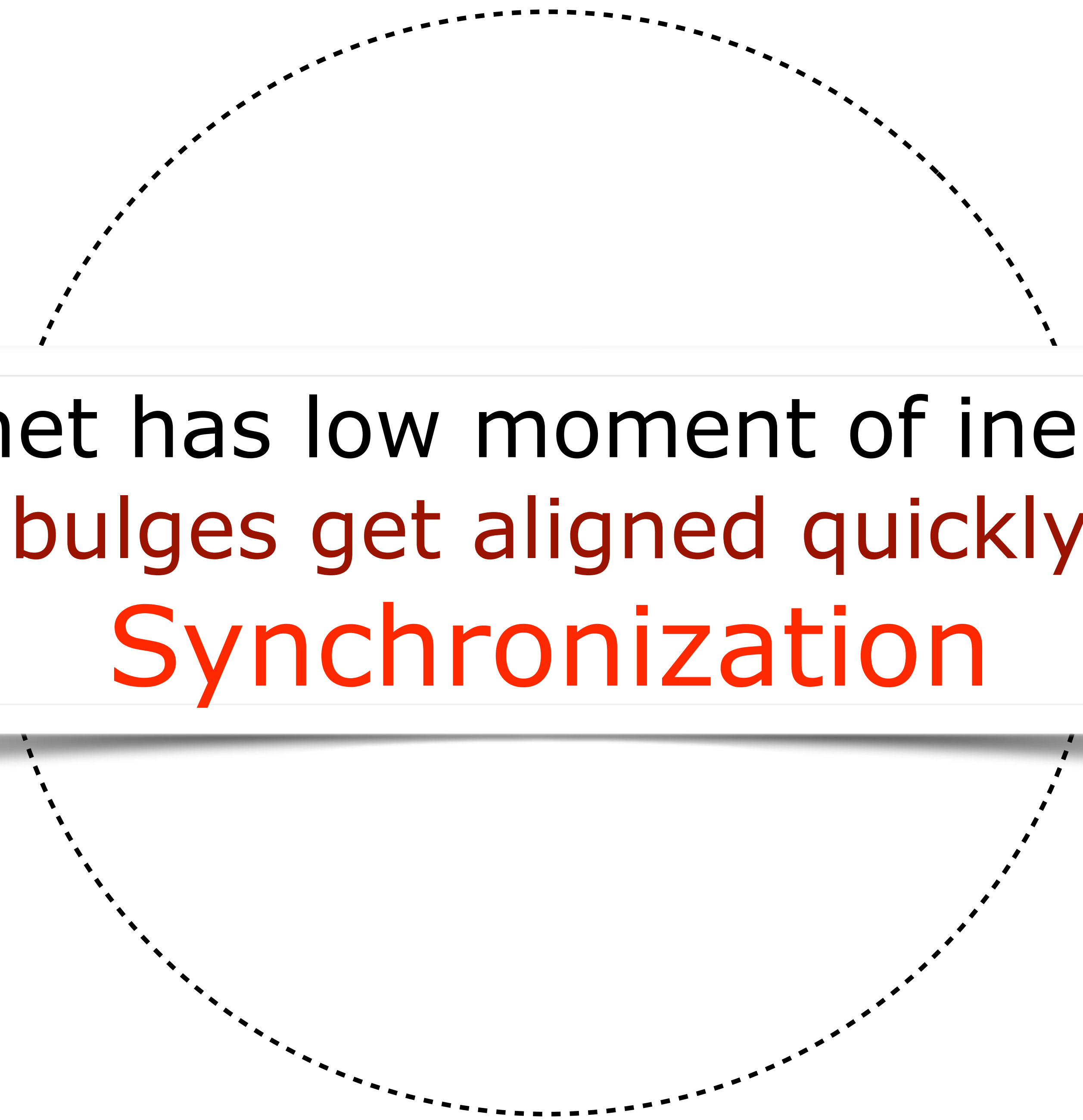
Tidal evolution

Planetary tide



Tidal evolution

Planetary tide



Planet has low moment of inertia:

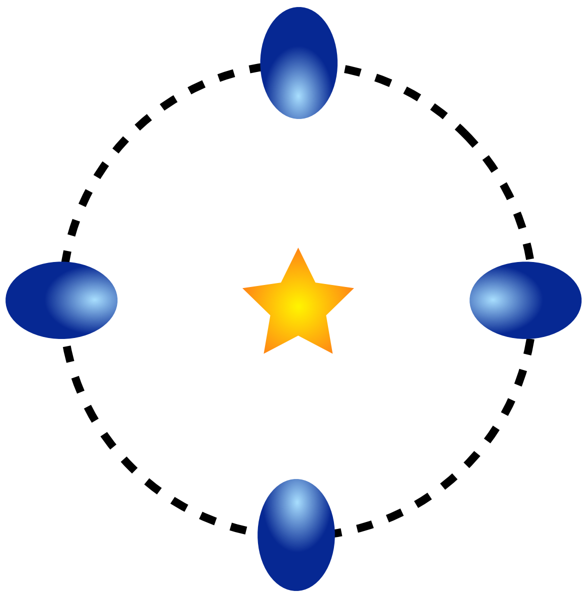
bulges get aligned quickly

Synchronization

Tidal evolution

Planetary tide

★ e=0: quick synchronization

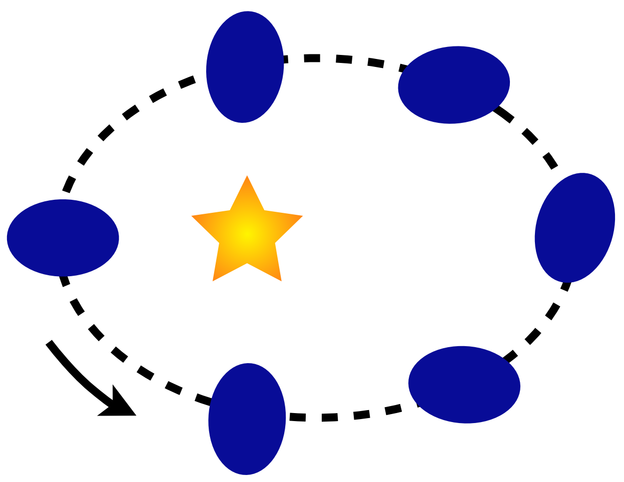


e=0

Tidal evolution

Planetary tide

- ★ e=0: quick synchronization
- ★ e≠0: quick pseudo-synchronization

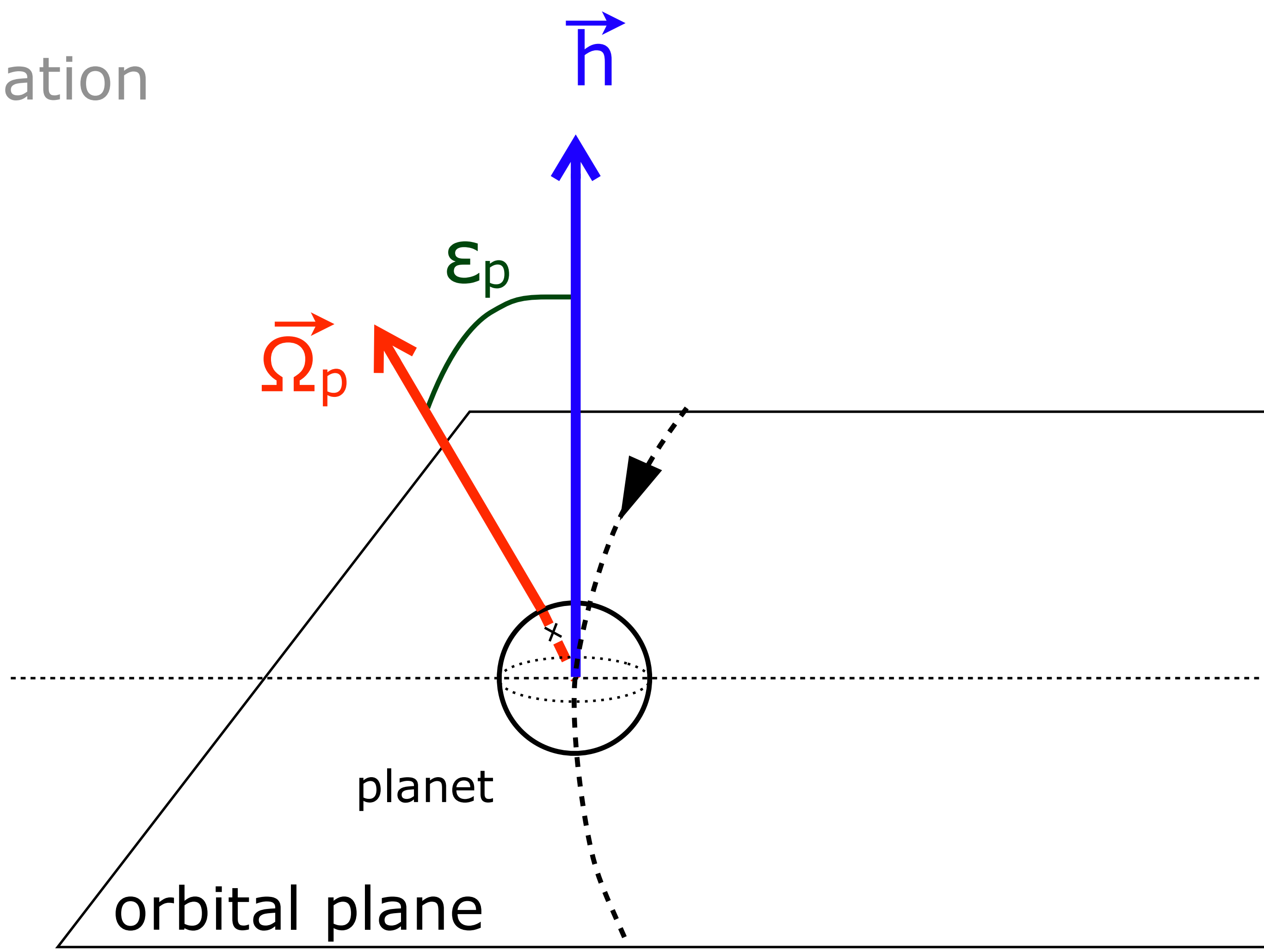


e≠0

Tidal evolution

Planetary tide

- ★ e=0: quick synchronization
- ★ e≠0: quick pseudo-synchronization
- ★ obliquity of planet decreases



Tidal evolution

Planetary tide

- ★ e=0: quick synchronization
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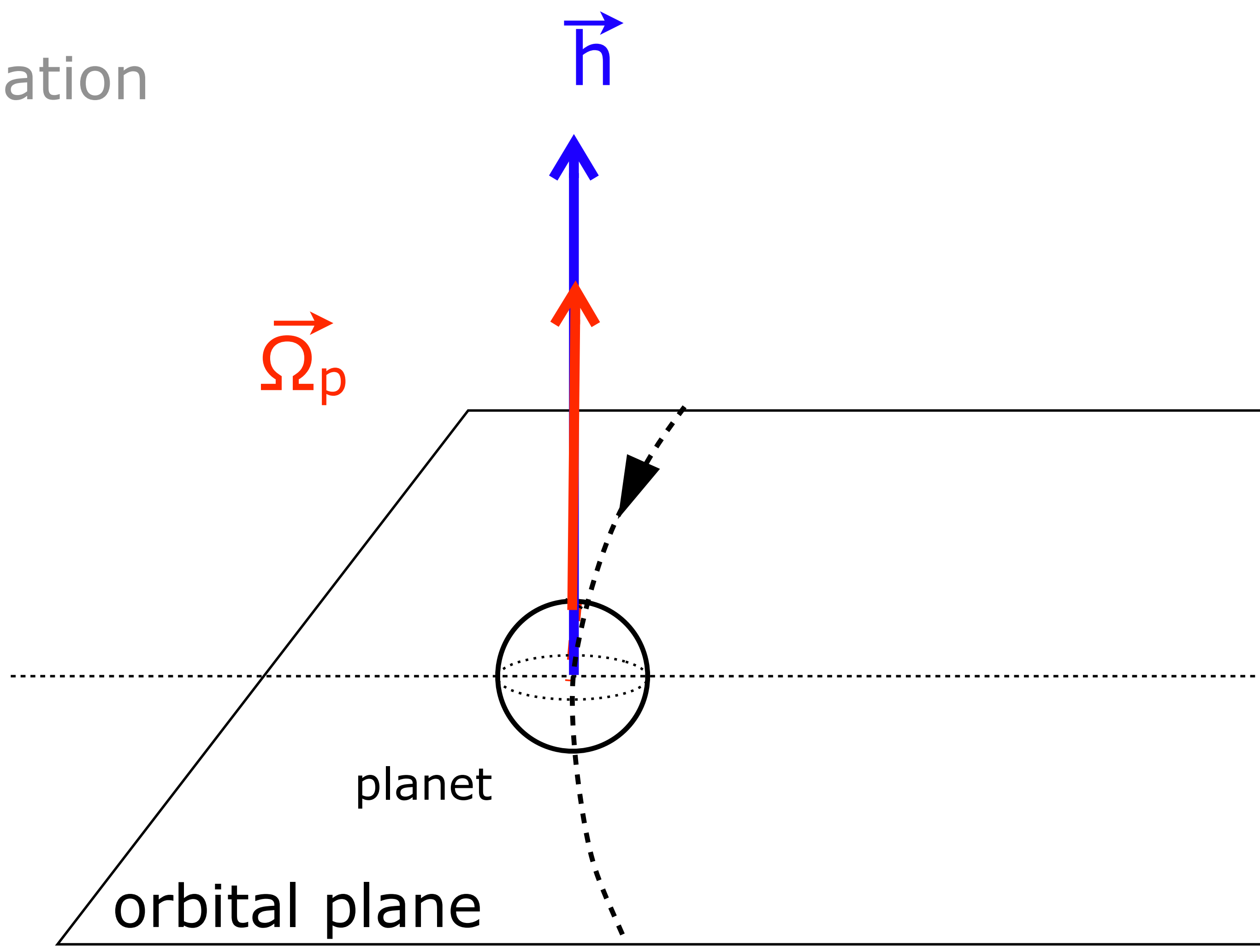

Tidal evolution

Planetary tide

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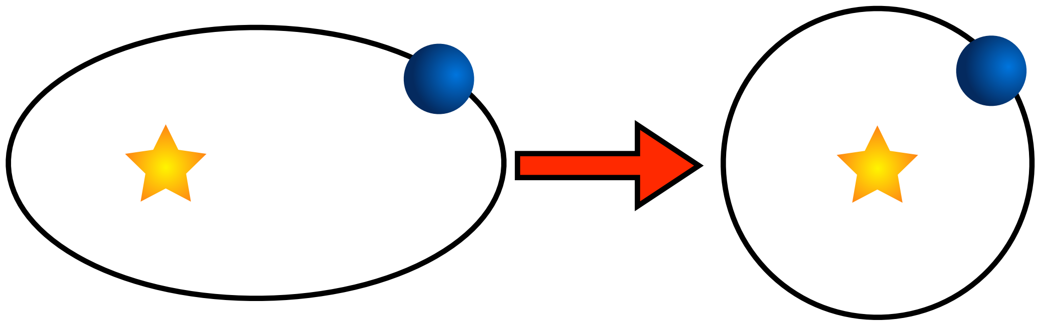

Tidal evolution

Planetary tide

- ★ $e=0$: quick synchronization
- ★ $e\neq0$: quick pseudo-synchronization
- ★ obliquity of planet decreases
- ★ eccentricity decreases
- ★ planet migrates inward

Outline

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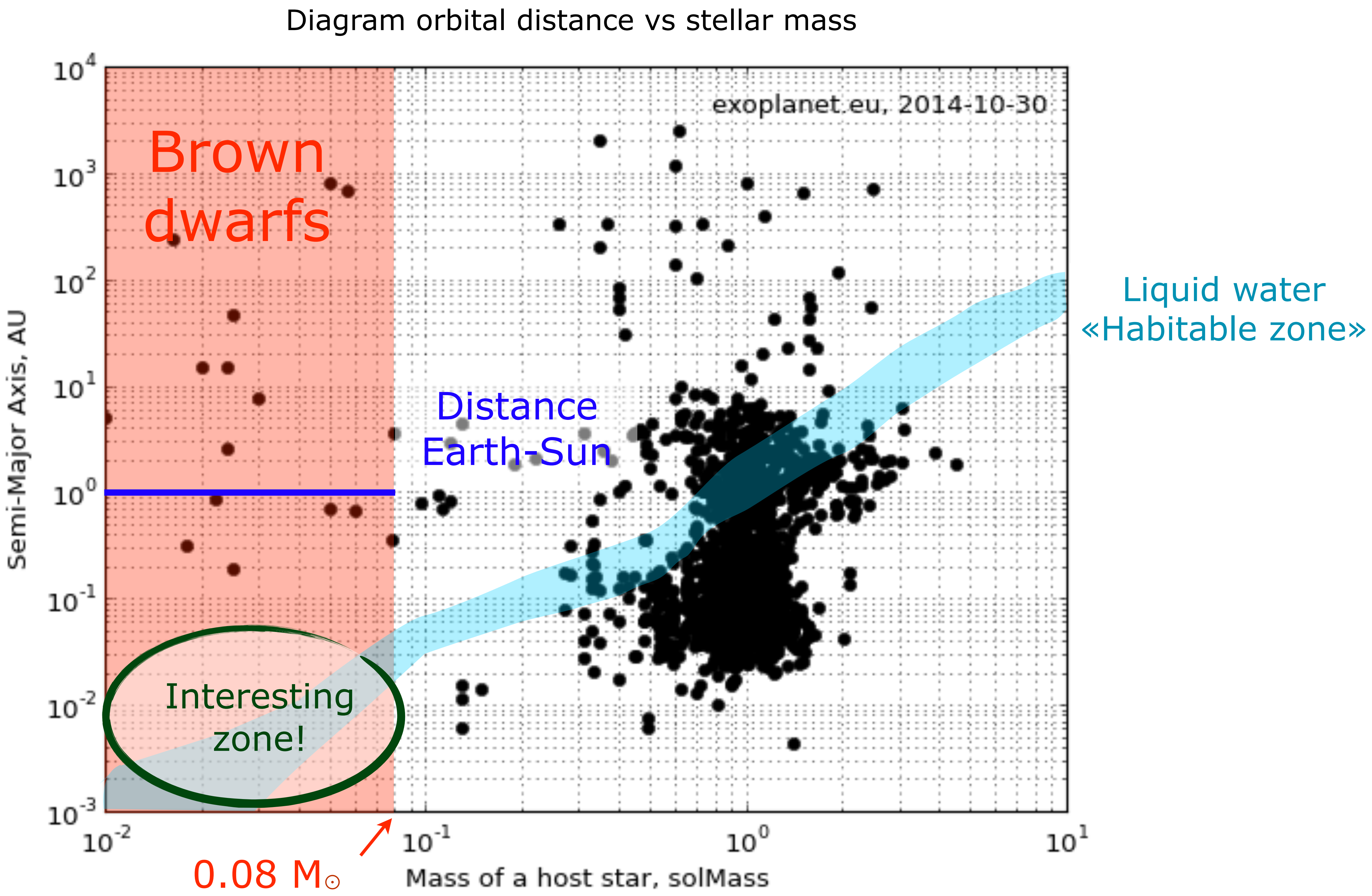
- ★ Kepler-186f

Tides

Climates

Planets around brown dwarfs



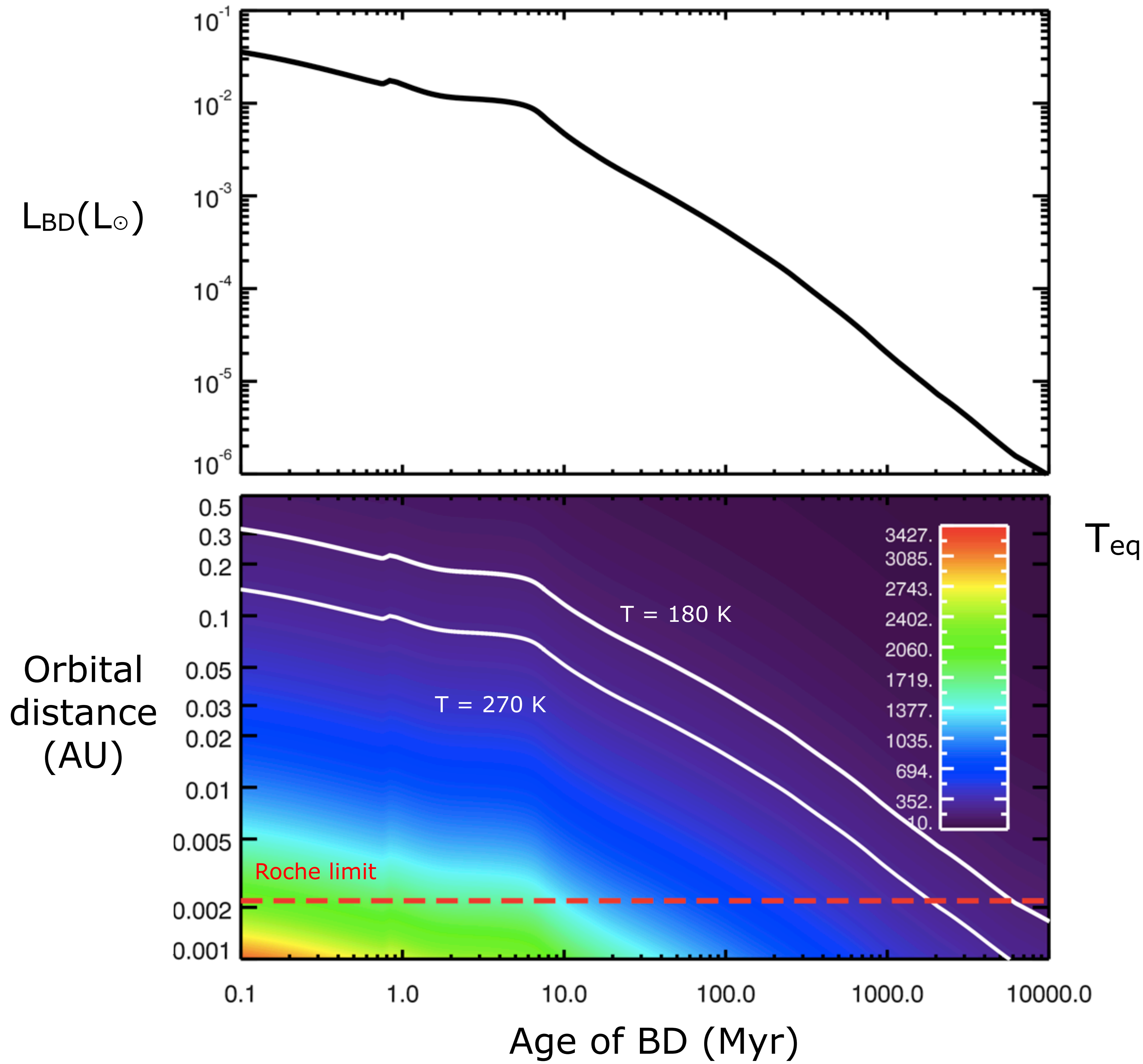
Planets around brown dwarfs

Cooling brown dwarf and habitable zone

$M_{BD} = 0.04\ M_\odot$

$M_p = 1\ M_\oplus$

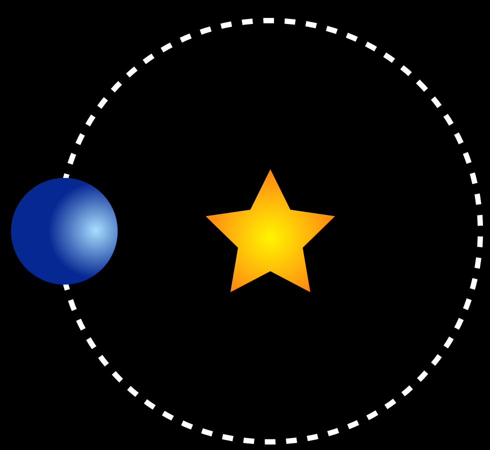
A=0.5



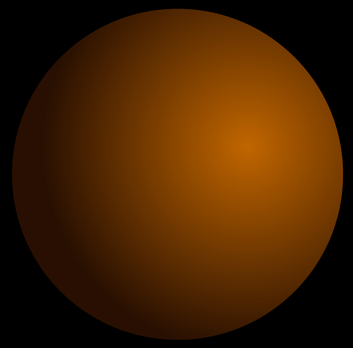
Planets around brown dwarfs

Habitable zone

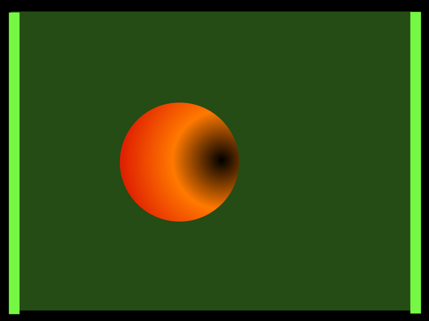
★ If planet is alone, when it reaches the habitable zone:



Danger for
aquability:
cold trap?



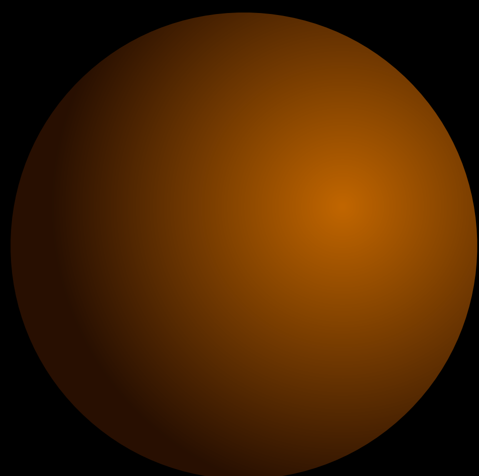
Habitable zone



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

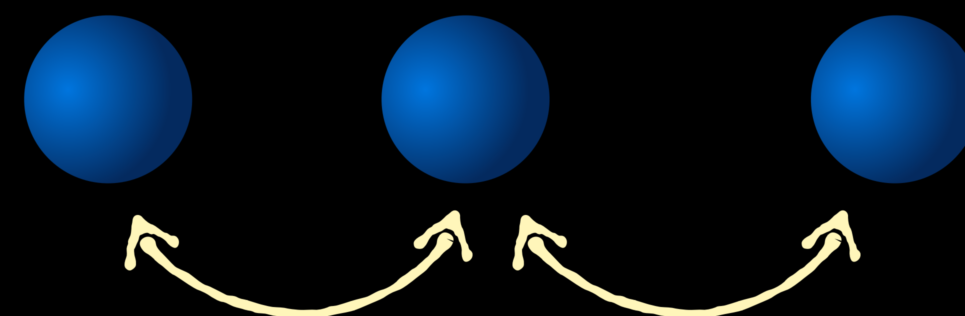
Planets around brown dwarfs

Tidal effects in multi-planet systems



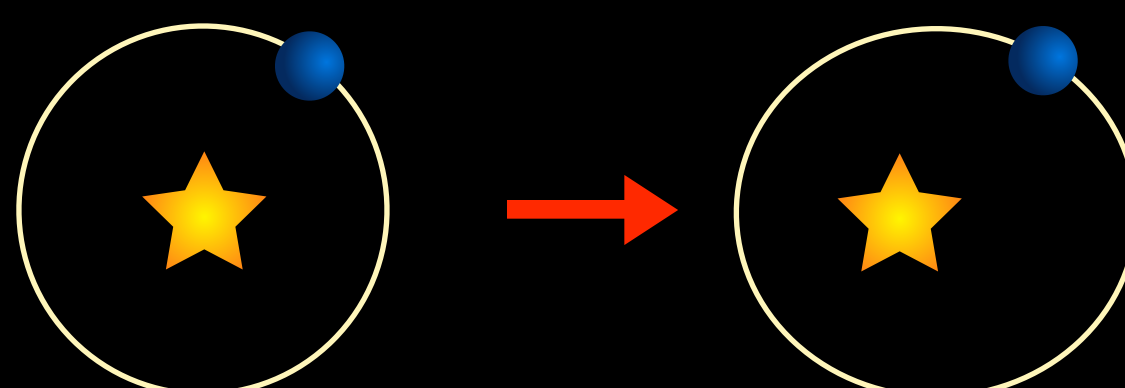
Brown dwarf

Planet 1 Planet 2 Planet 3



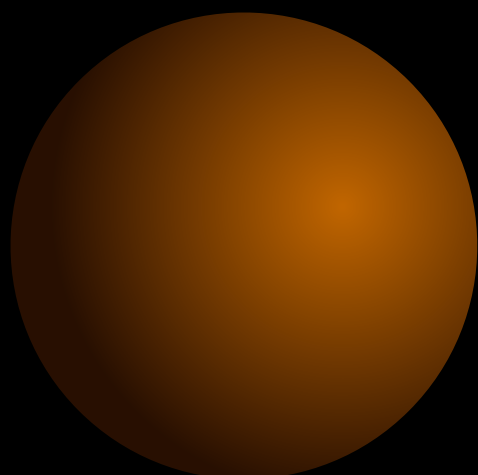
Gravitational interactions between planets

No Resonances



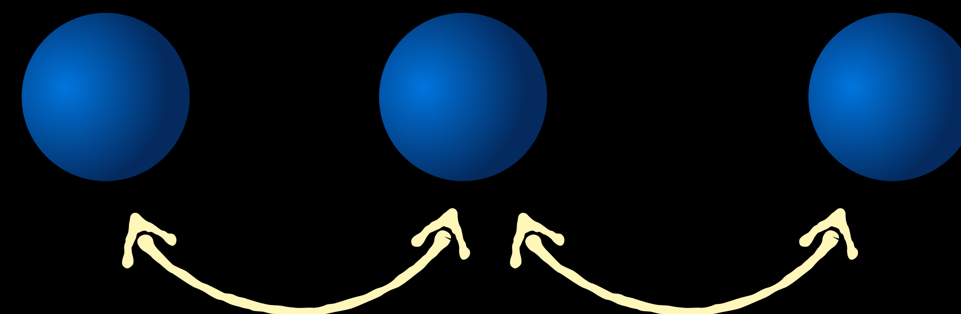
Planets around brown dwarfs

Tidal effects in multi-planet systems



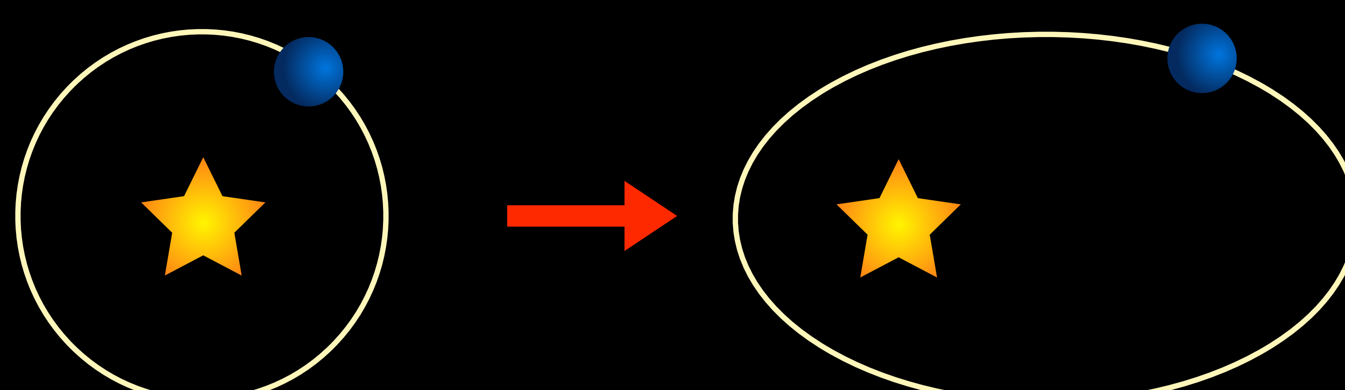
Brown dwarf

Planet 1 Planet 2 Planet 3



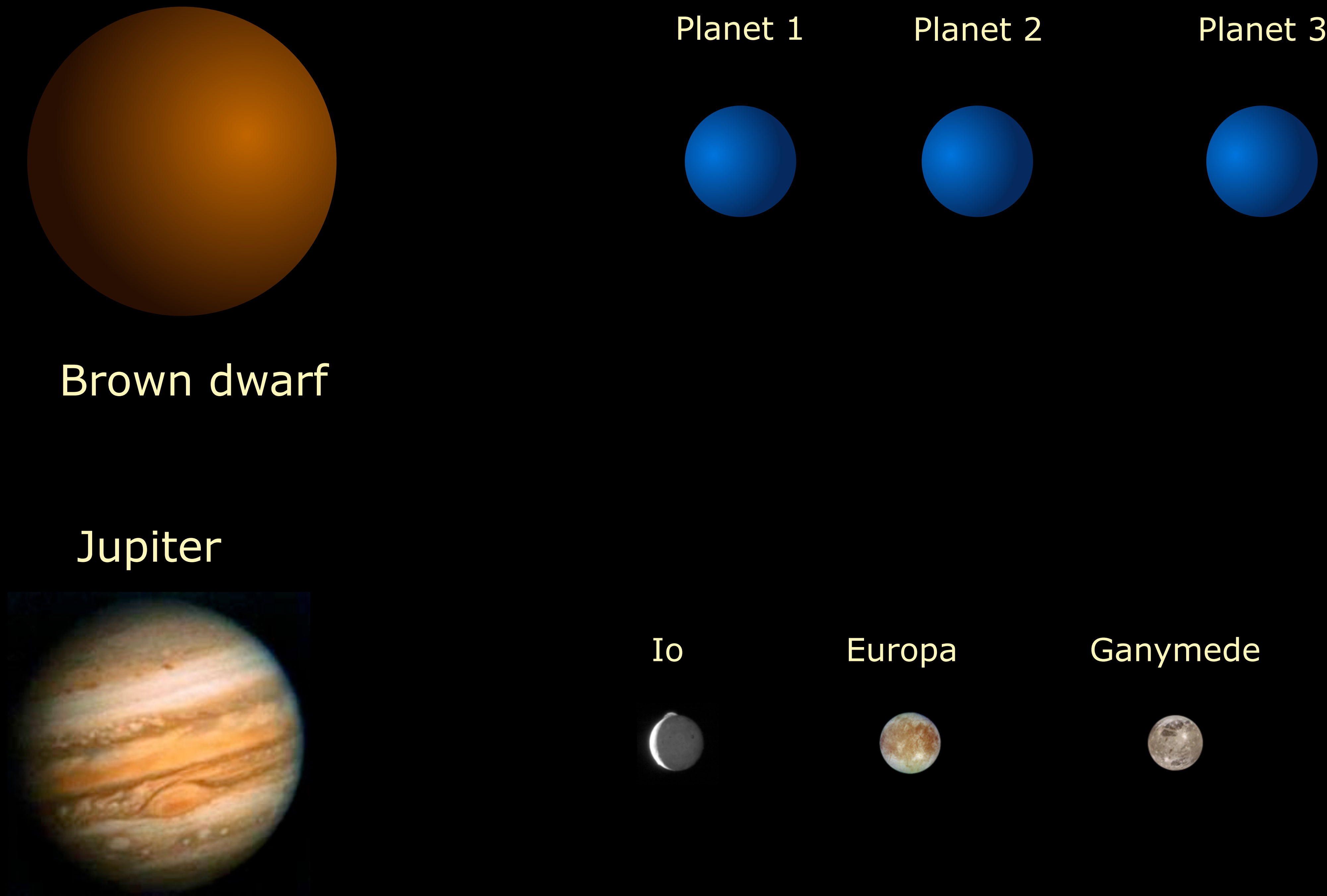
Gravitational interactions between planets

Resonances



Planets around brown dwarfs

Tidal effects in multiple systems



Planets around brown dwarfs

Tidal effects in multiple systems

Tidal effect in Io → strong volcanism

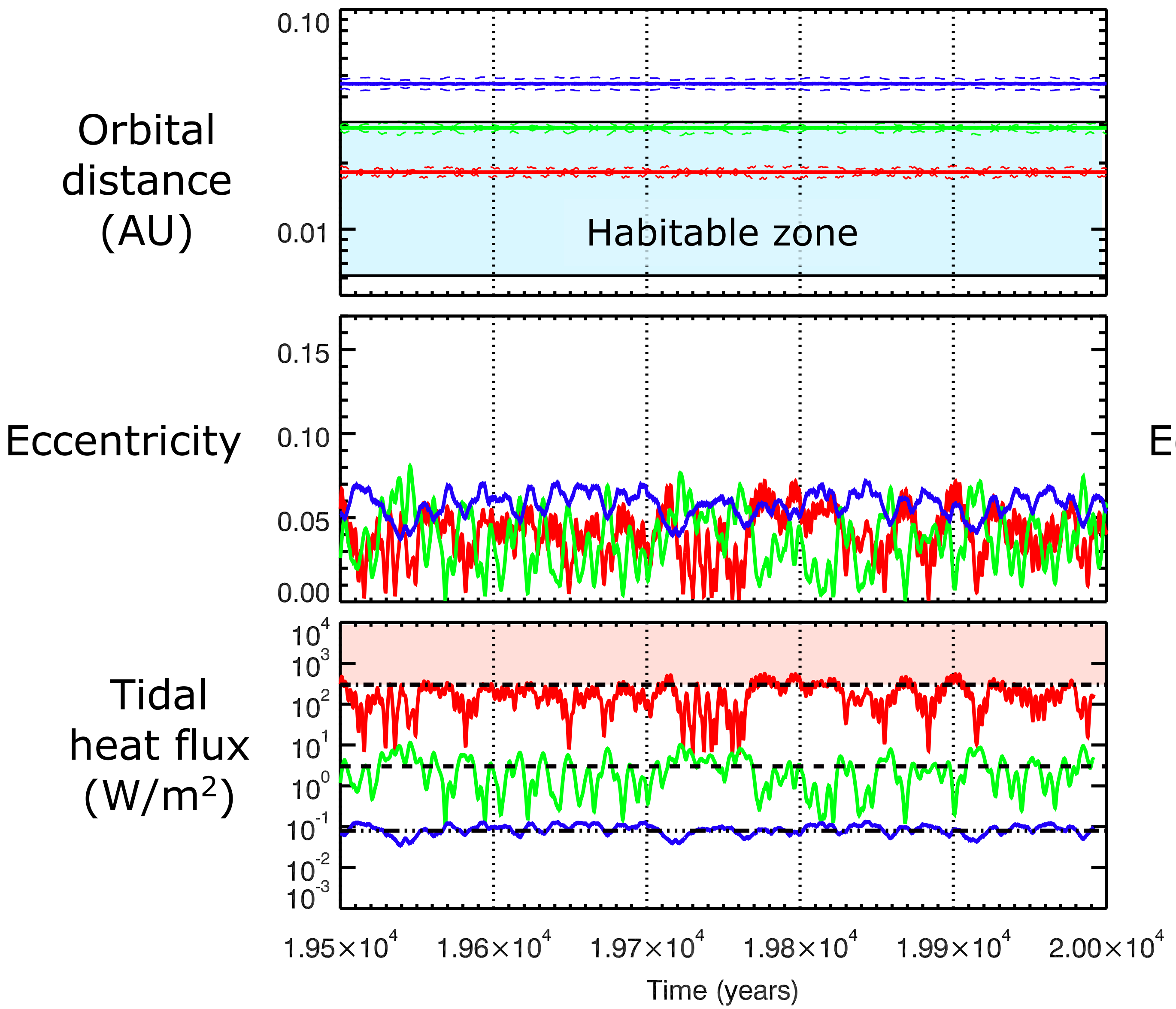
Tidal heat flux is ~3 W/m^2 > ~40 x Earth's flux (radioactivity)
(Spencer et al. 2000) (Pollack et al. 1993)

Images from *New Horizons* showing volcano Tvashtar

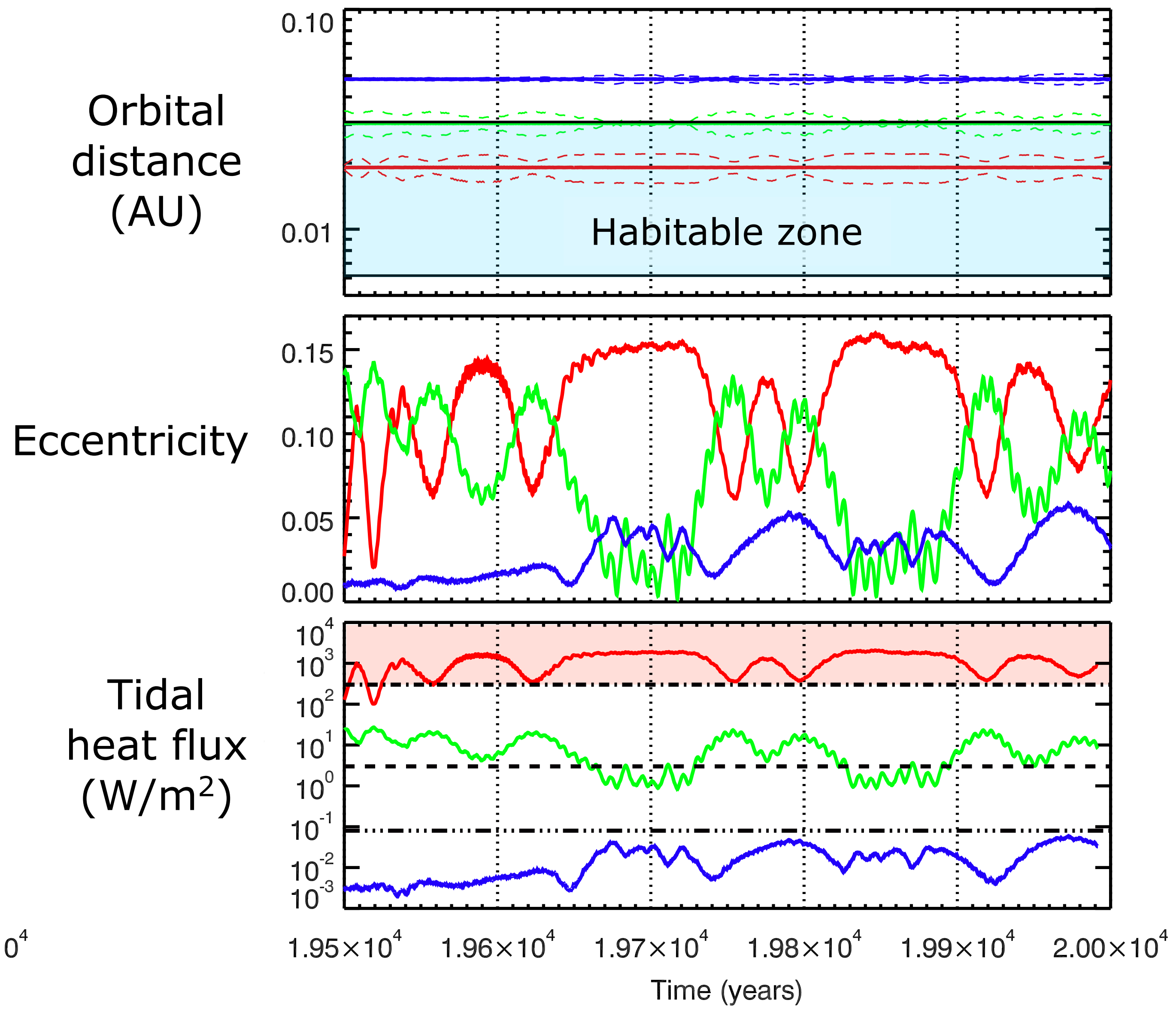
Planets around brown dwarfs

Tidal effects in multi-planet systems

Non resonant system



Resonance 2:1



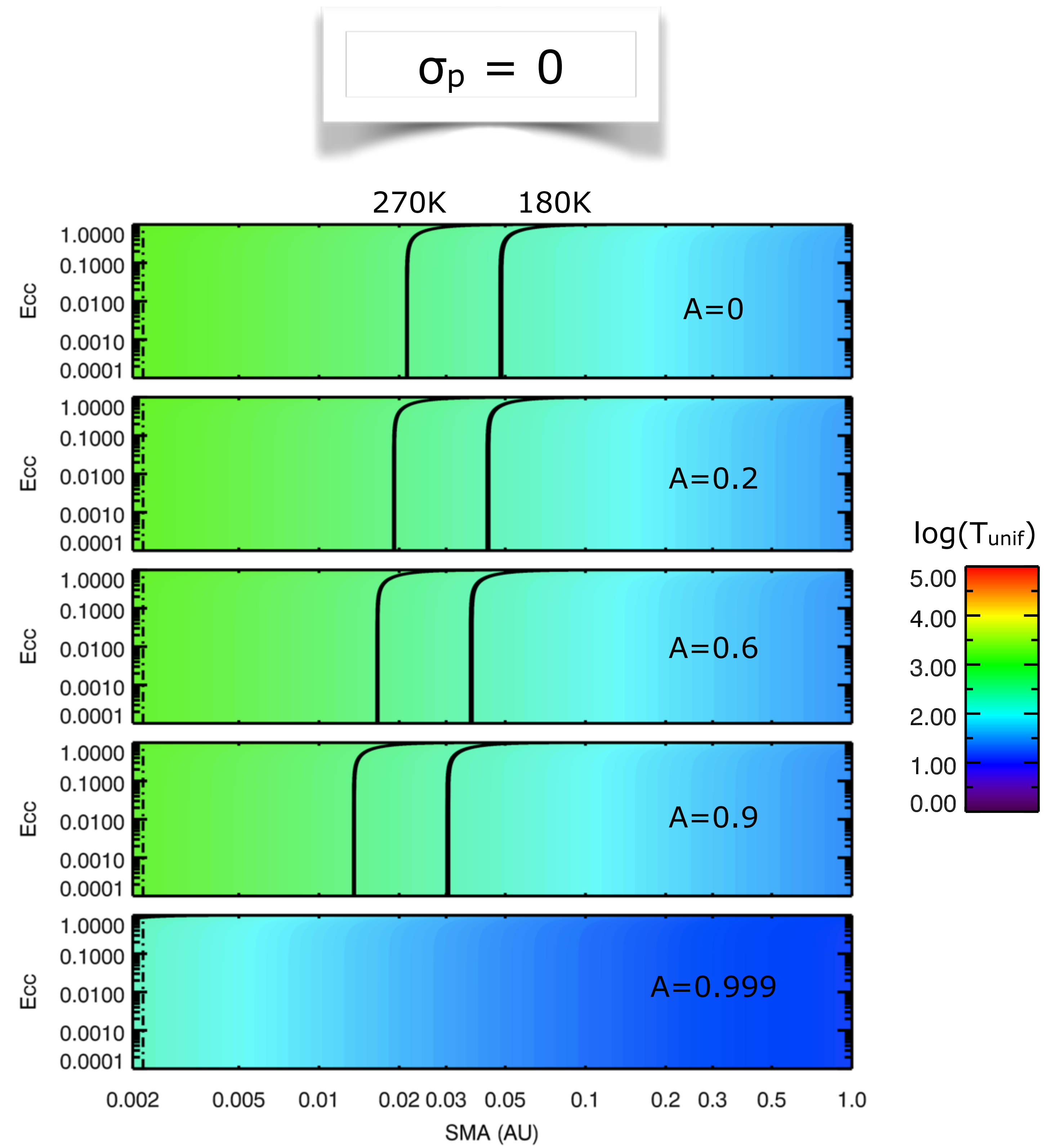
Discussed in Barnes et al. (2010) for planets around M-dwarfs

Planets around brown dwarfs

Effect of tidal heating

Uniform temperature of a planet

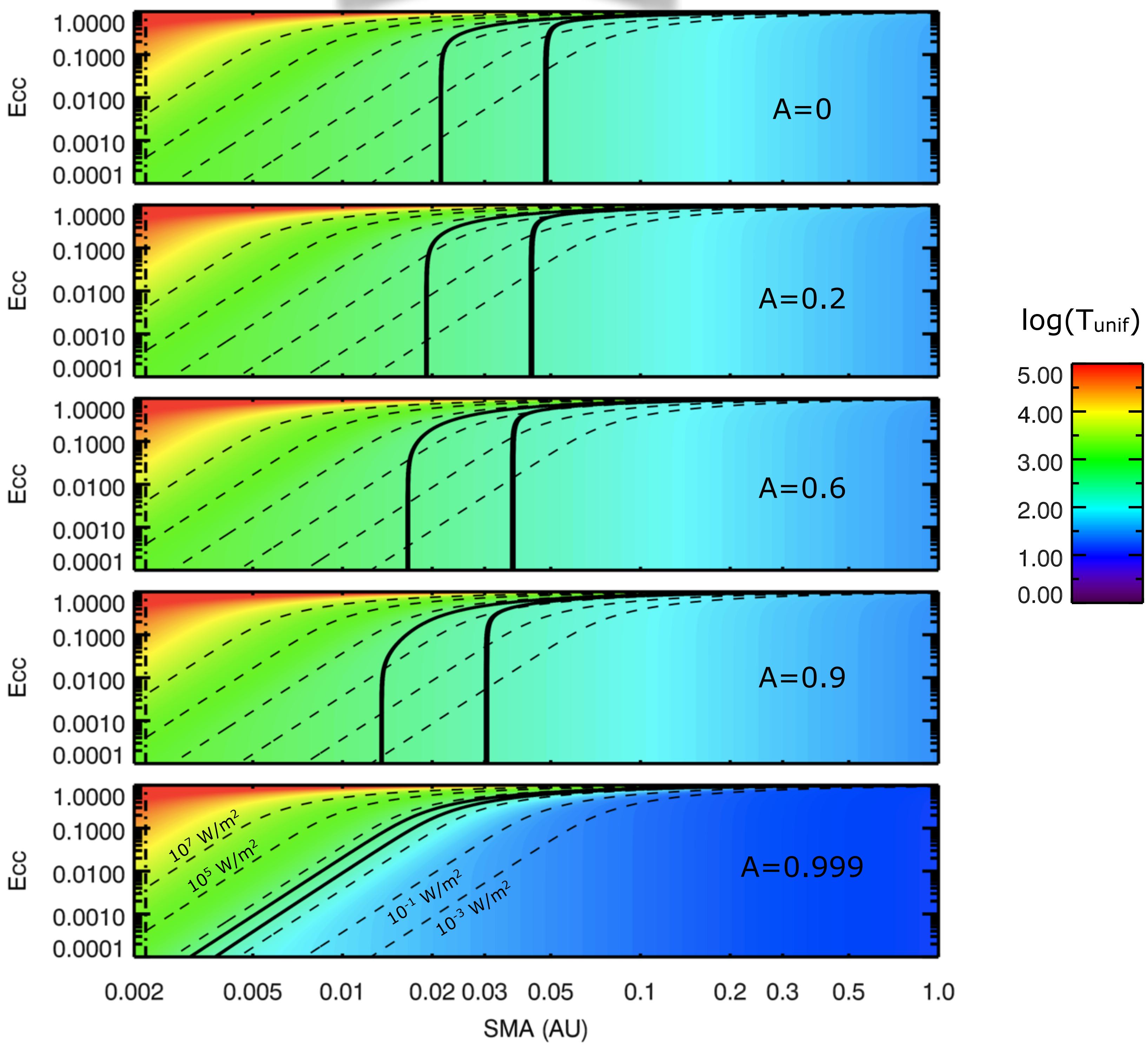
$$T_{\rm unif}(a, e, A) = \left(T_{\rm eq}^4 + \frac{\phi_{\rm tides}}{\sigma_{\rm SB}} \right)^{1/4}$$



Planets around brown dwarfs

Effect of tidal heating

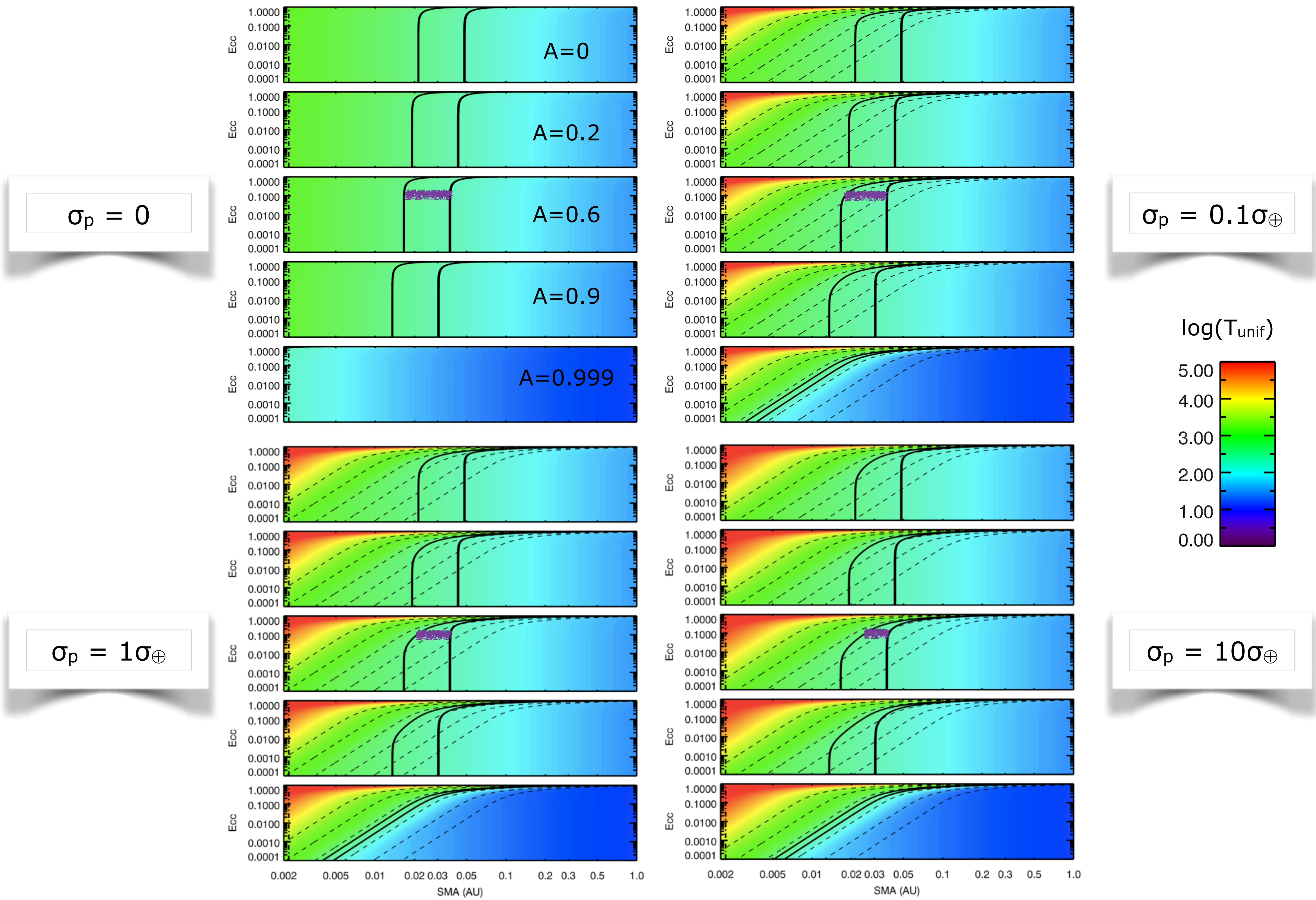
$\sigma_p = 0.1\sigma_\oplus$



A ↗
contribution of tides ↗

Planets around brown dwarfs

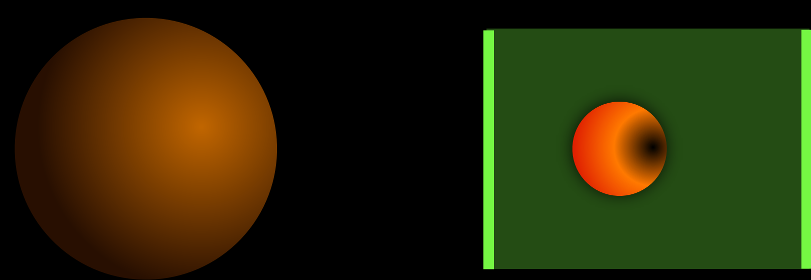
Effect of tidal heating



Planets around brown dwarfs

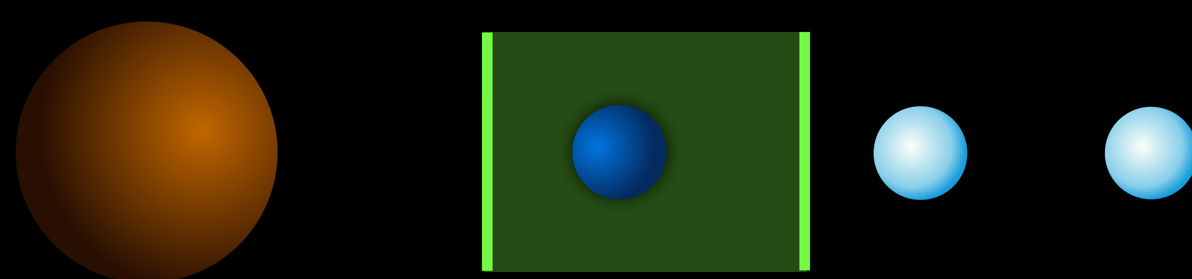
aquability?

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



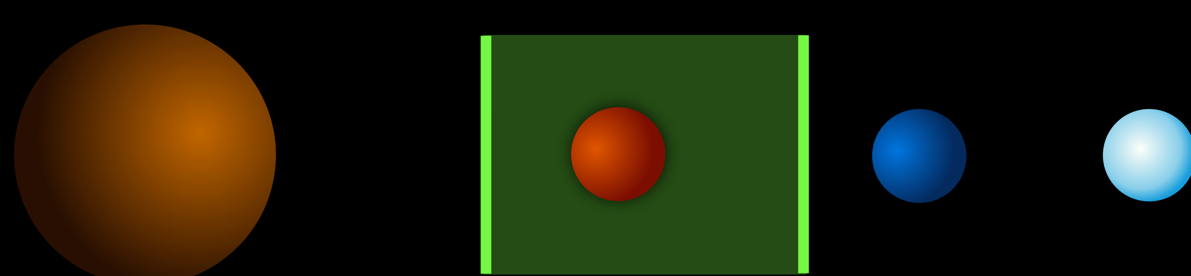
1 planet
danger?

- +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



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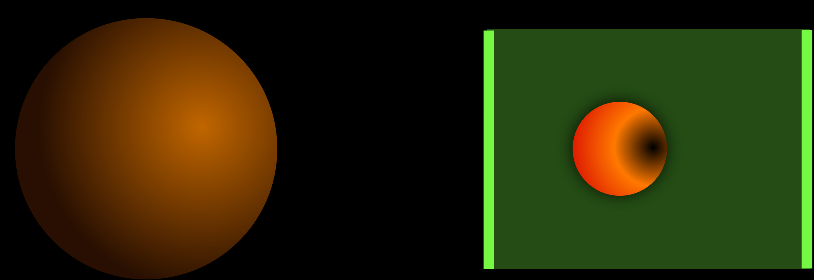

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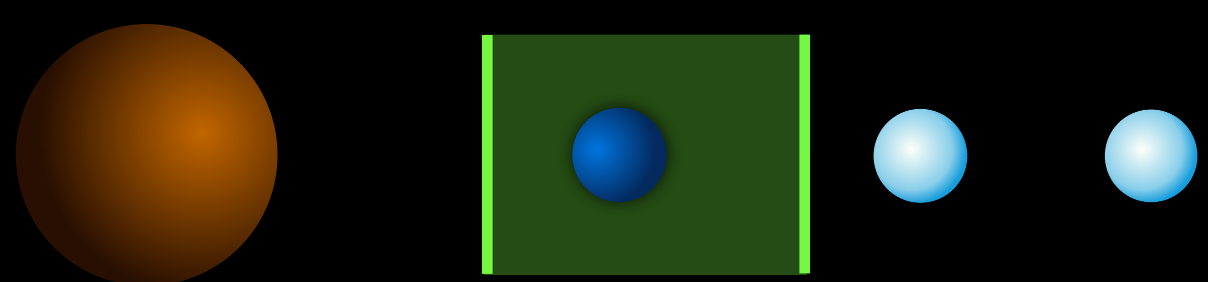

Several planets
no resonances

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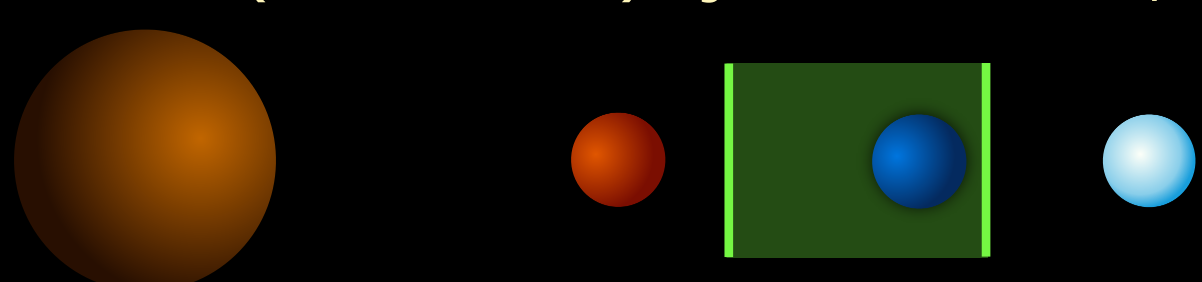

Several planets
resonances

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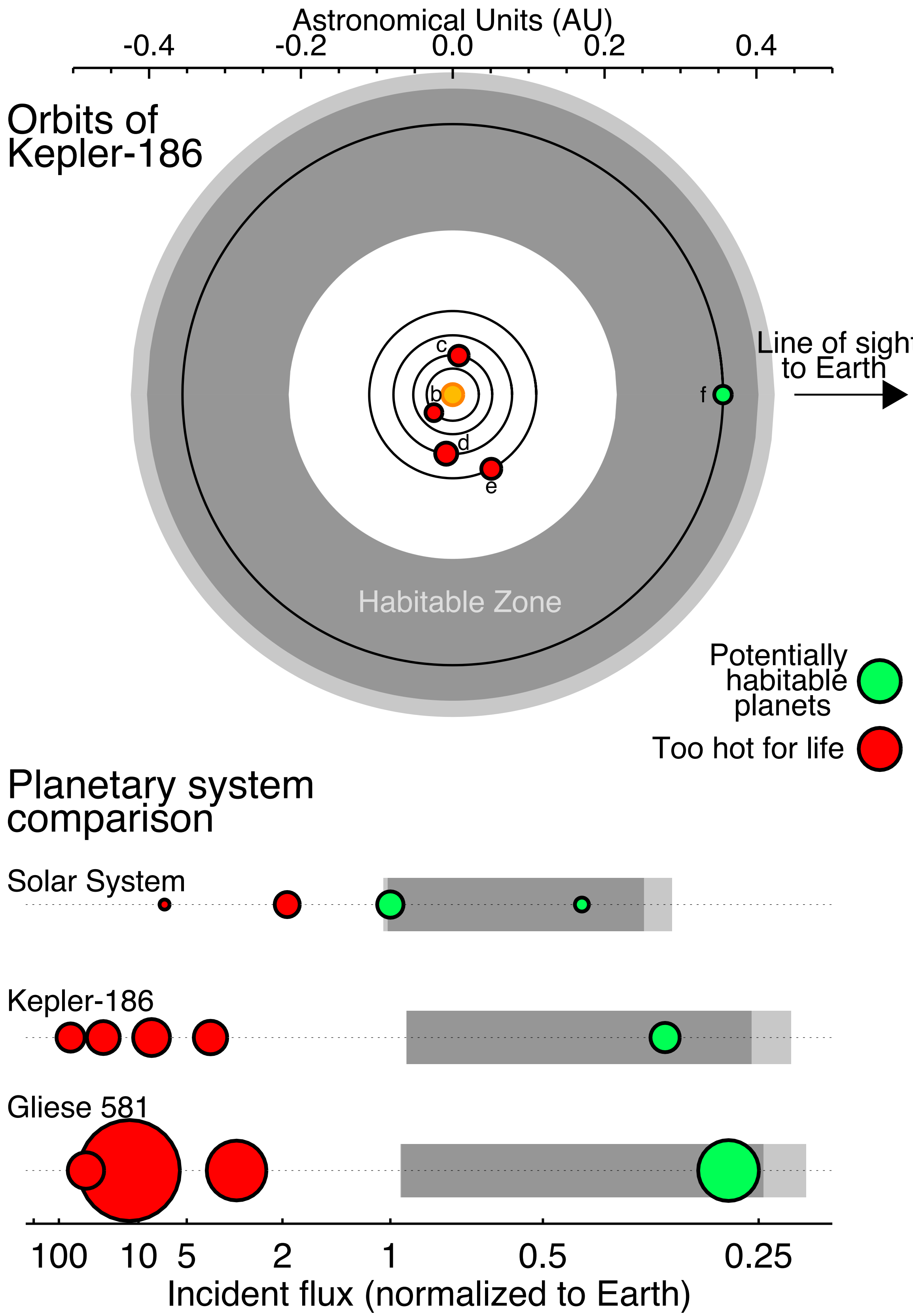


$M_\star = 0.48\ M_\odot$

Planets

$1 < R_p/R_\oplus < 1.4$

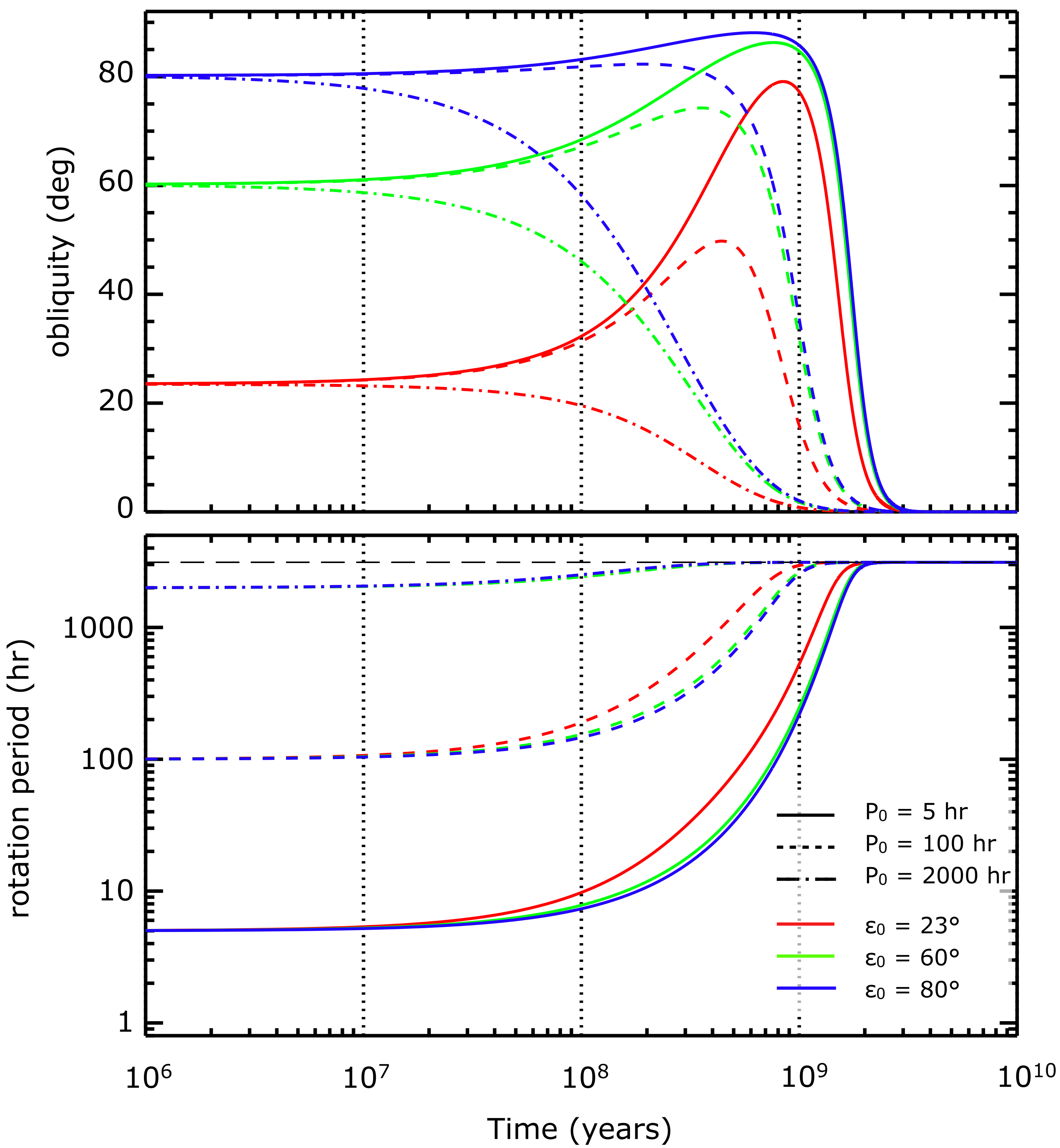
$0.04 < a/AU < 0.4$

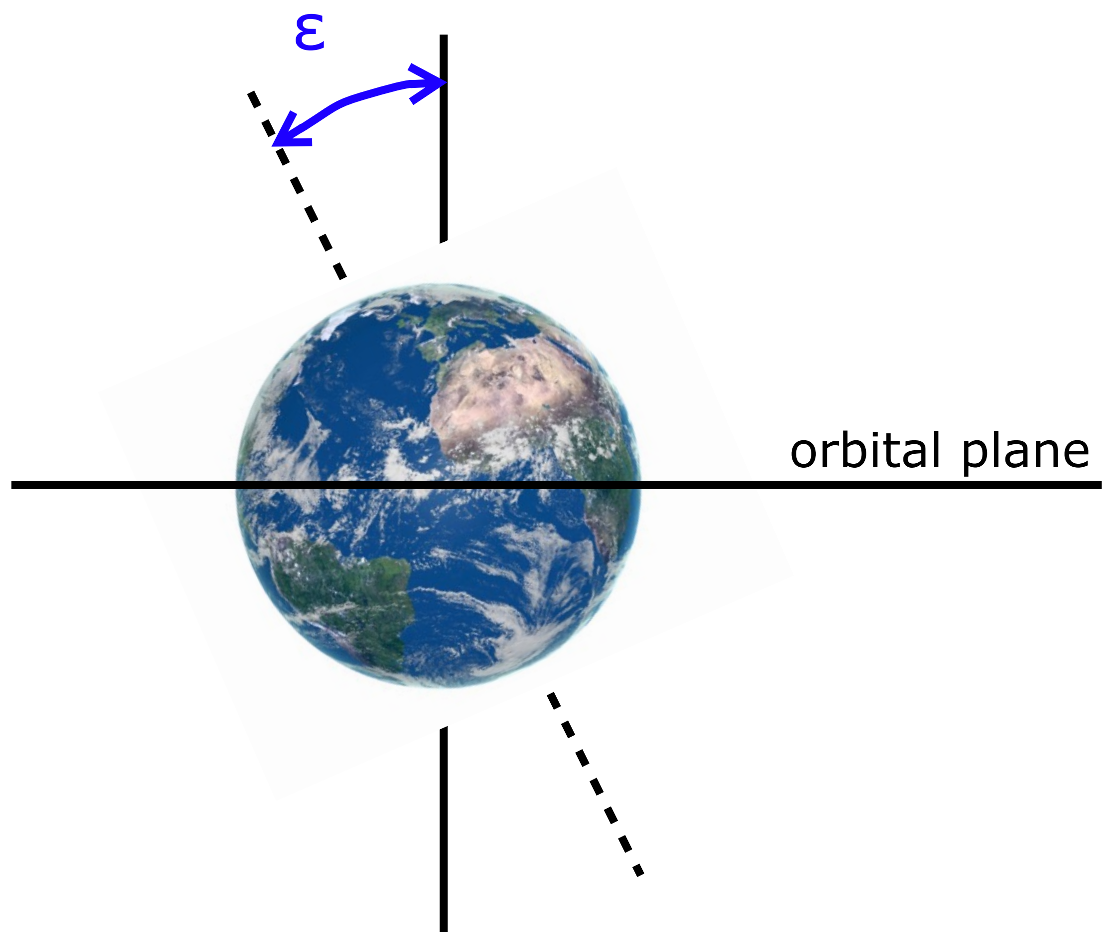
Quintana et al. (2014)

Bolmont et al. (2014)

Kepler-186f

Aquability?





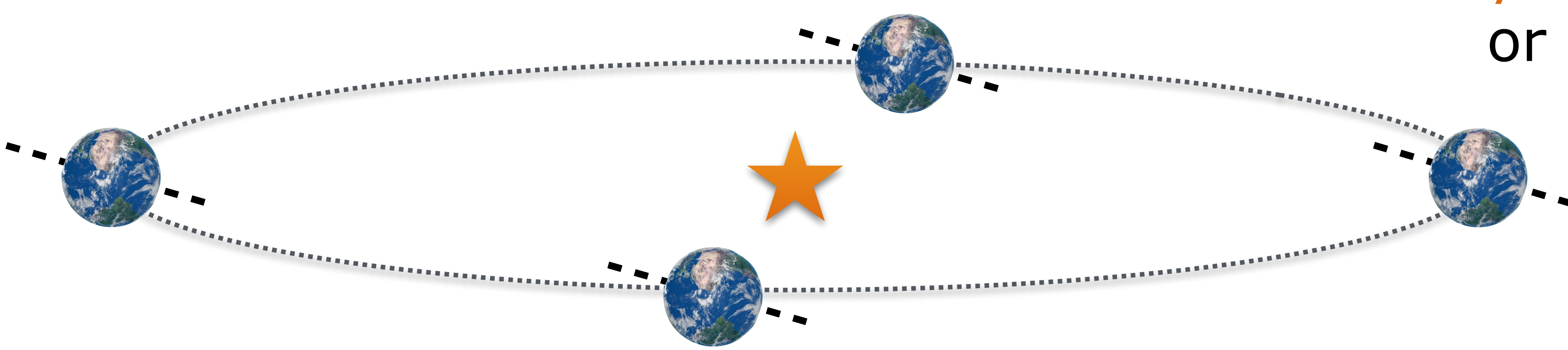
Assuming Earth composition
Assuming Earth dissipation

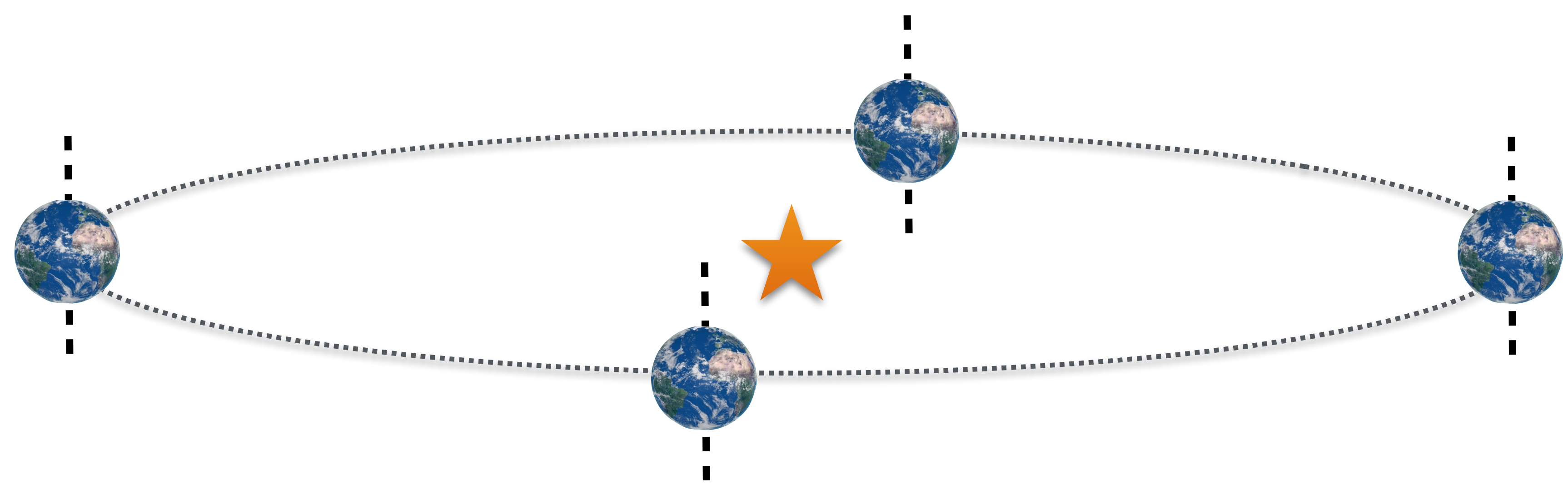
Bolmont et al. (2014)

Kepler-186f

Aquability?

young system
or small dissipation





old system
or big dissipation

Limitations & improvements

- ★ Tidal model: constant time lag model
  equilibrium rotation = pseudo-synchronous rotation
  but observations show otherwise (Mercury...)...

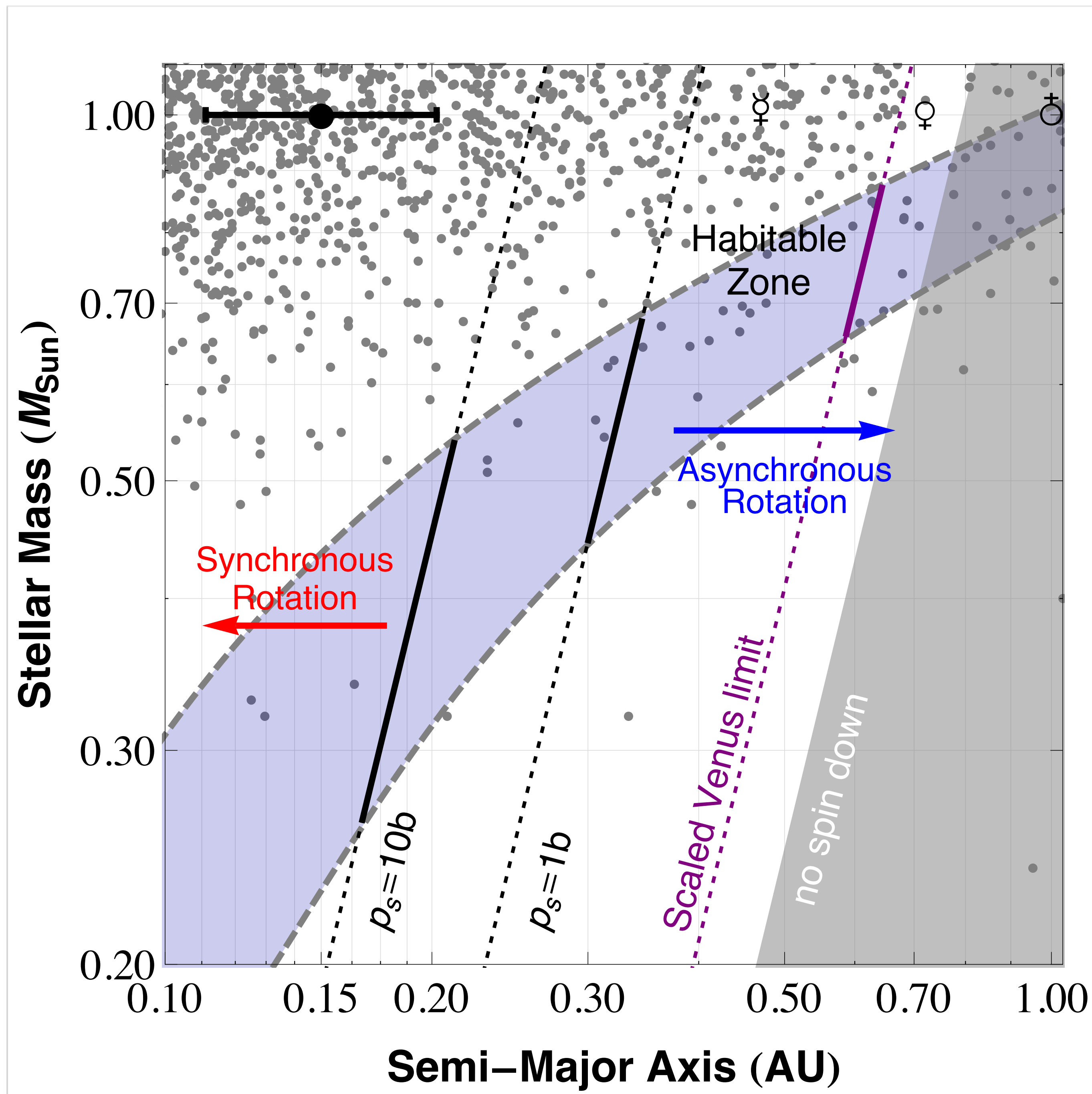
  ➜ improve the tidal model we use here
  (e.g., see next talks!)

- ★ Missing physical phenomena?

  ➜ include the effect of the atmospheric tide
  Chapman & Linden (1970), Gold & Soter (1969), Ingersoll & Dobrovolskis (1978), Correia & Laskar (2001, 2003)

Limitations & improvements

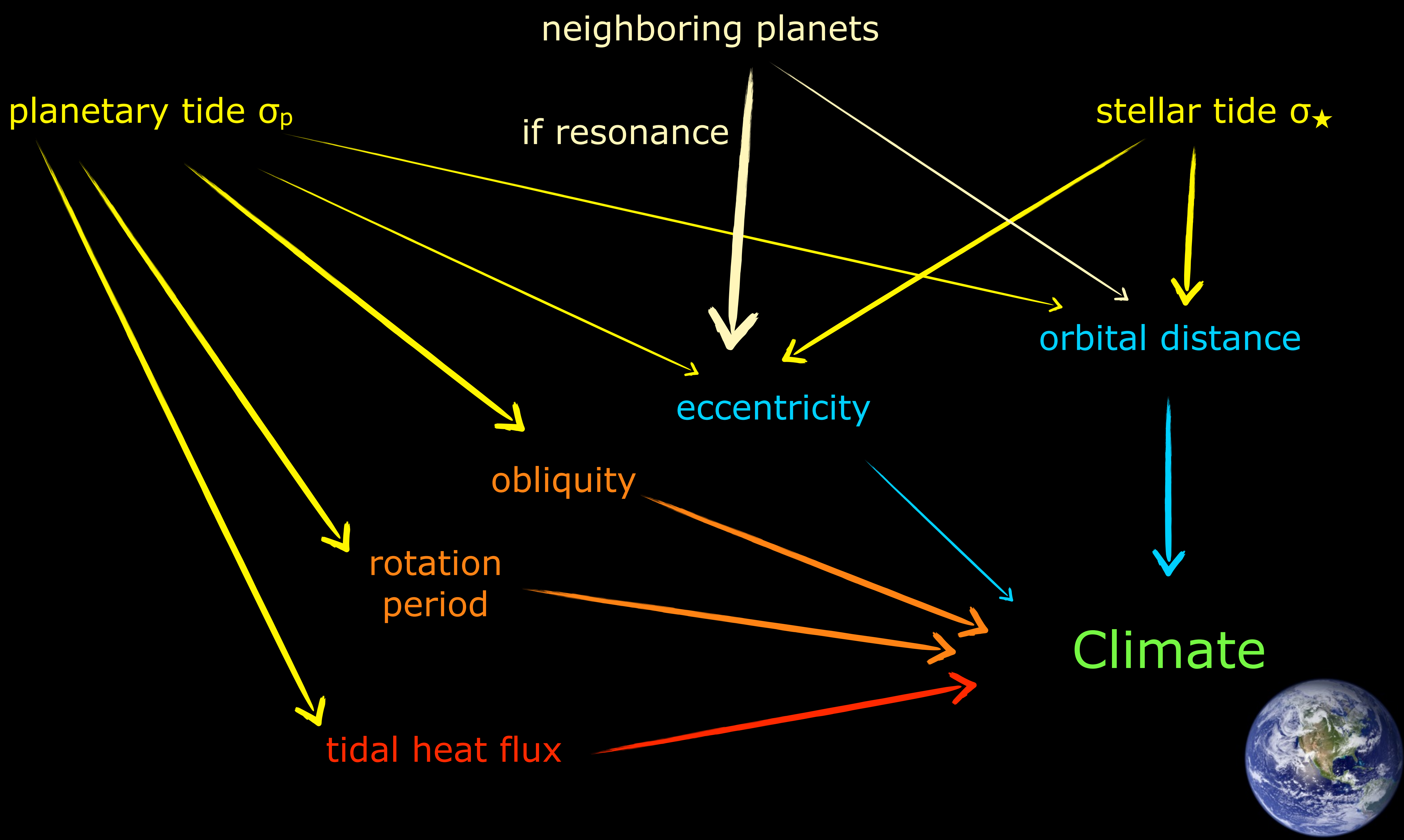
Atmospheric tide



Leconte et al. (2014, in review)

under embargo

Tides and climate




Thank you !