# Evolution and habitability of planets around Cool Dwarfs


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# The road so far...

2007-2010 ENS de Lyon

2010-2013 Doctorate in the Laboratoire d'Astrophysique de Bordeaux
Sean N. Raymond, Franck Selsis

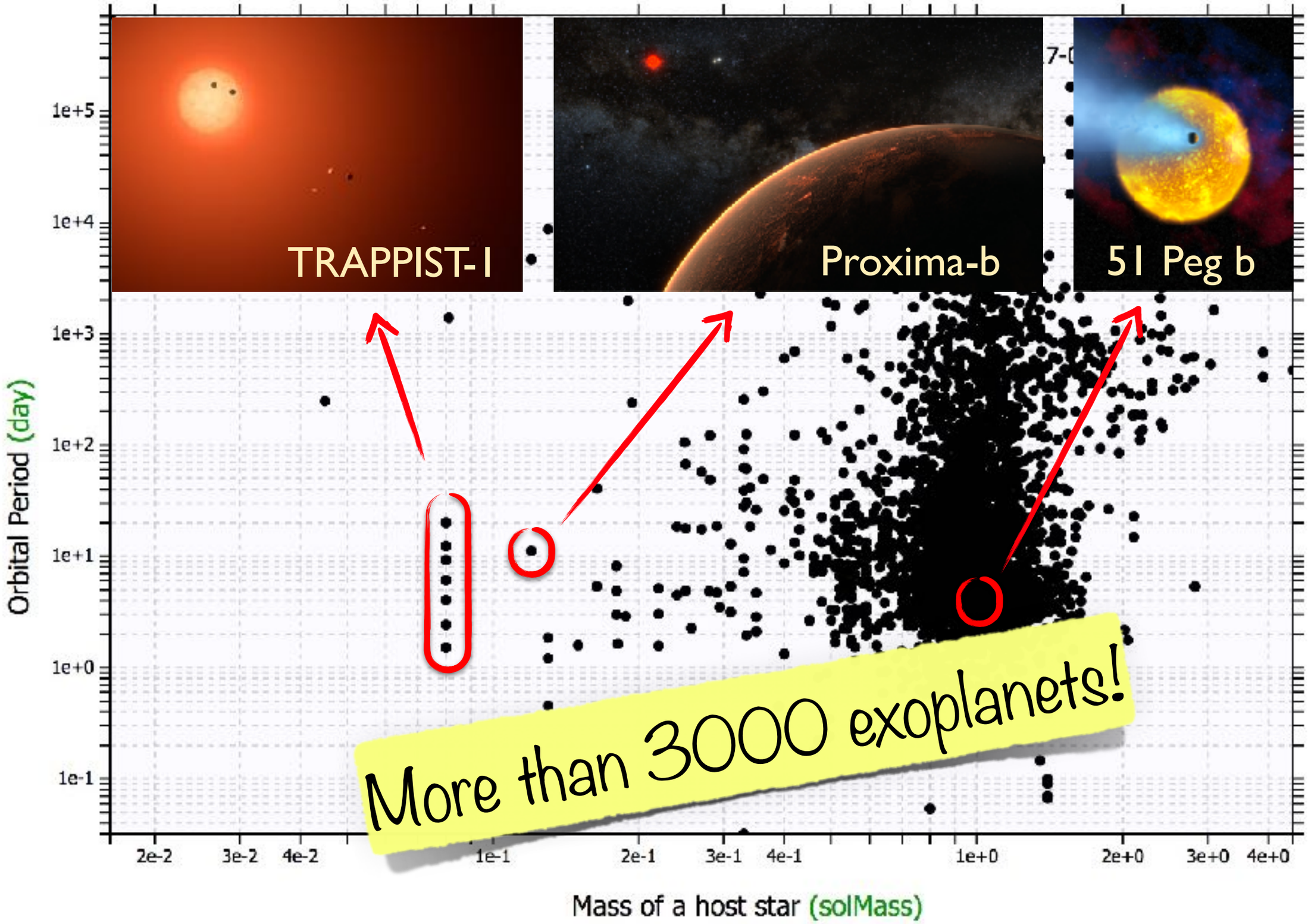
2013-2014 Post-doc at the Laboratoire d'Astrophysique de Bordeaux

2014-2016 Post-doc at the University of Namur (Belgium)

2016-now Post-doc at CEA, Saclay
↳ ERC SPIRE with Stéphane Mathis

Office n°XXX

# Exoplanet discoveries



# Why UCDs are interesting targets?

Habitable Zone

Very numerous

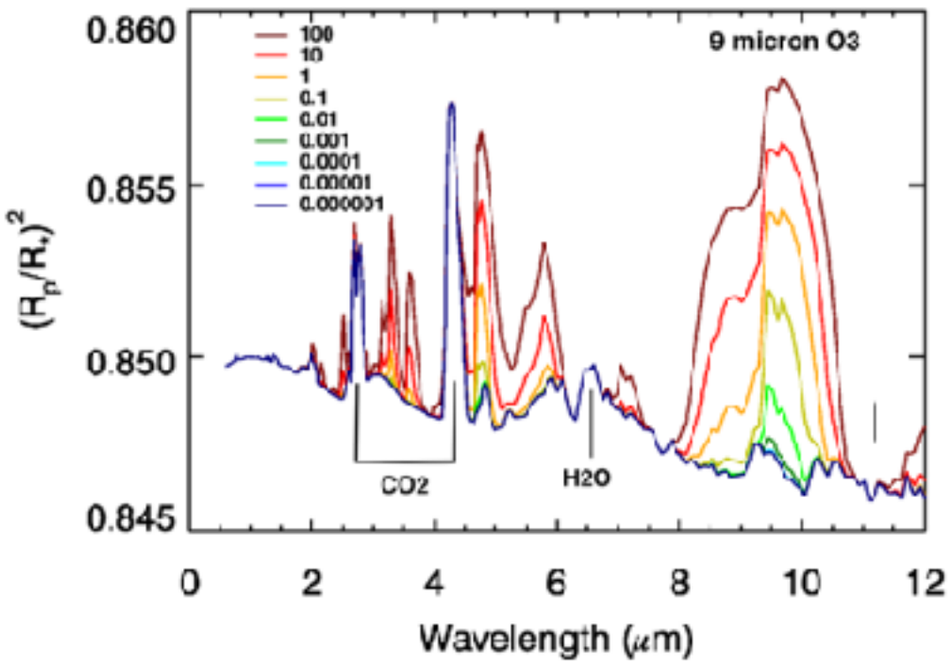
Easier to detect

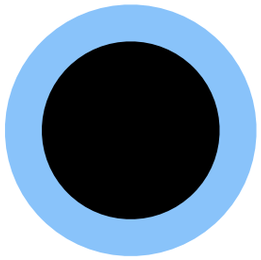
only HZ planets we will be able to characterize

# Perspective JWST observations

Synthetic transmission spectra

Ozone feature at ~9μm



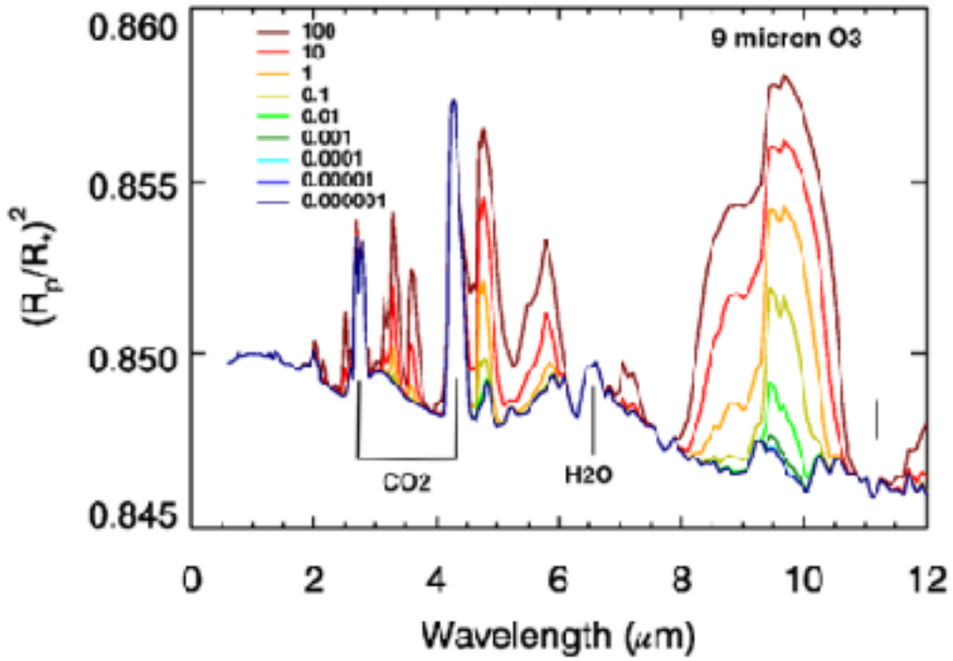



Belu et al. (2011), Barstow & Irwin (2016)

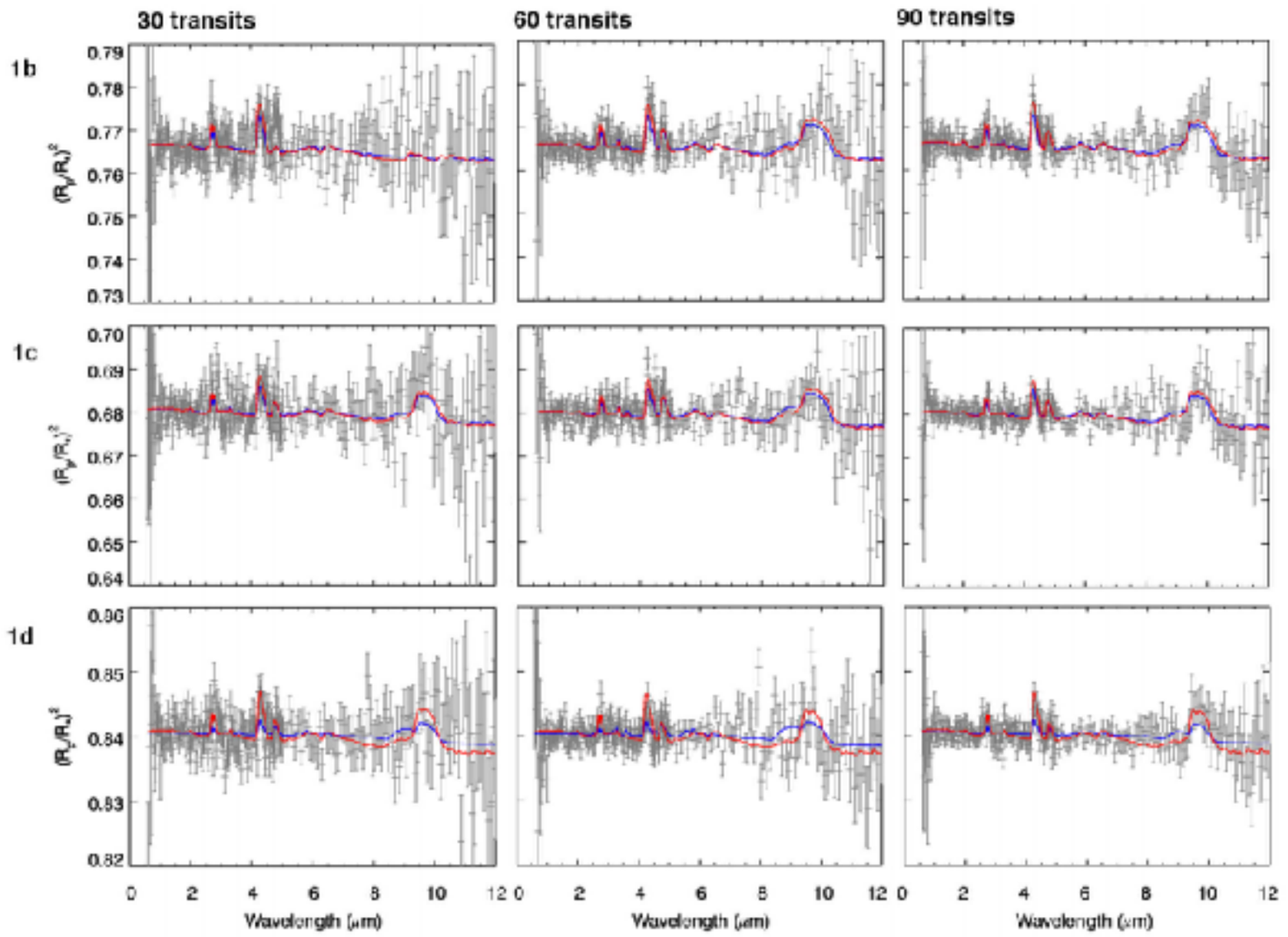
# Perspective JWST observations

Synthetic transmission spectra

Ozone feature at ~9μm




Simulated JWST observations

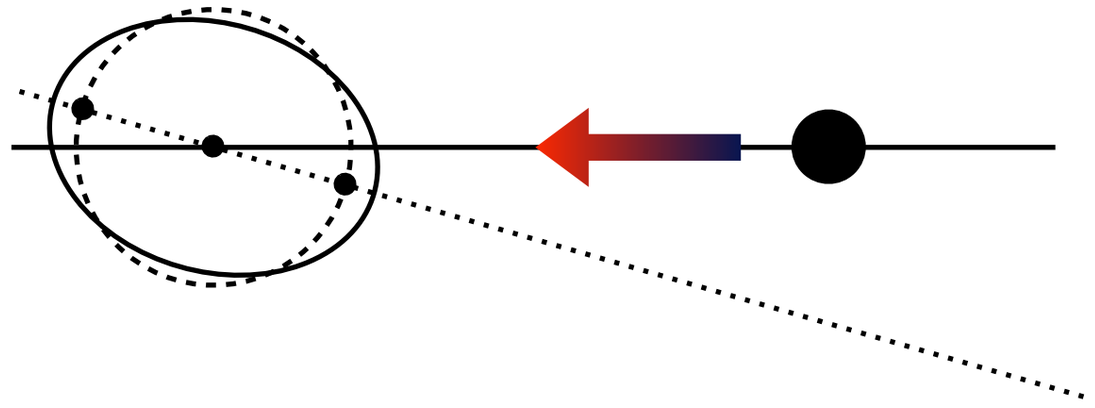



Barstow & Irwin (2016)

# Tidal evolution

## Stellar tide

★ planet inside corotation
⇒ planet migrates inward

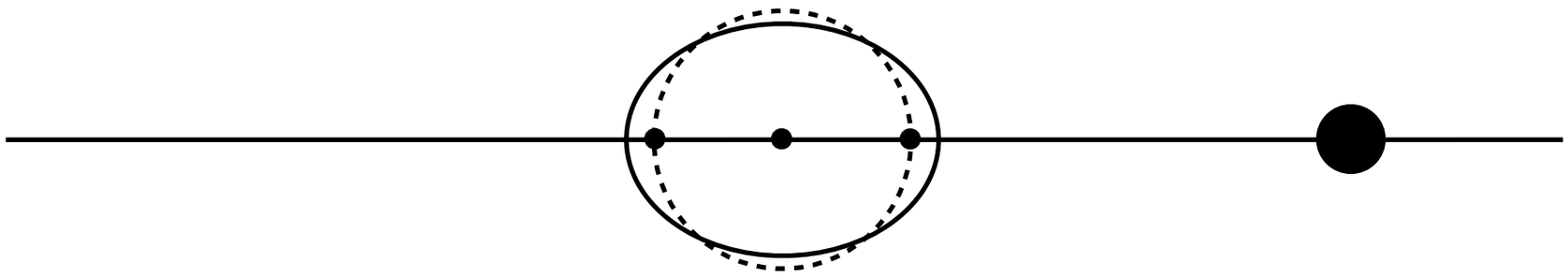


# Tidal evolution

## Stellar tide

$$\Omega_\star = n_p$$

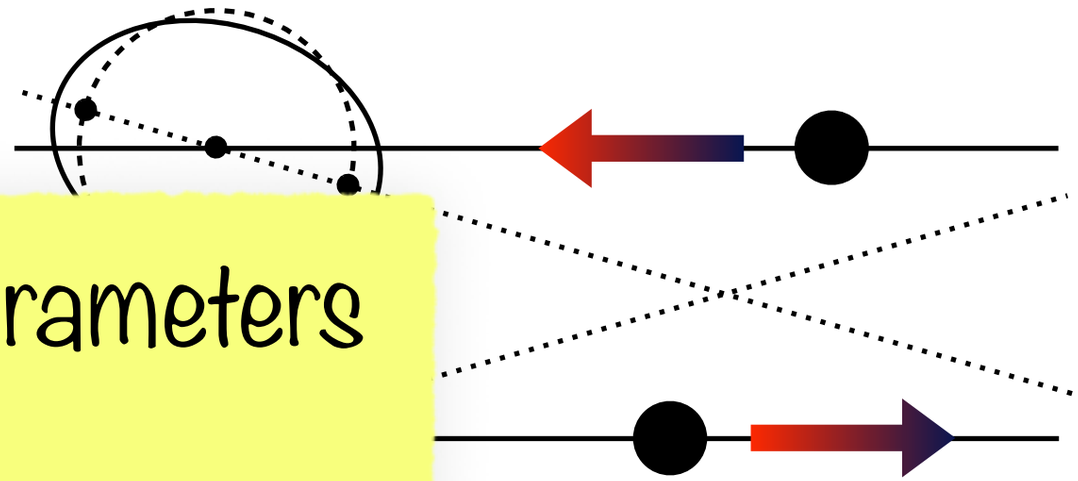
orbital distance of planet $a_p = r_c$ corotation distance



# Tidal evolution

## Stellar tide

★ planet inside corotation (HJ)
⇒ planet migrates inward

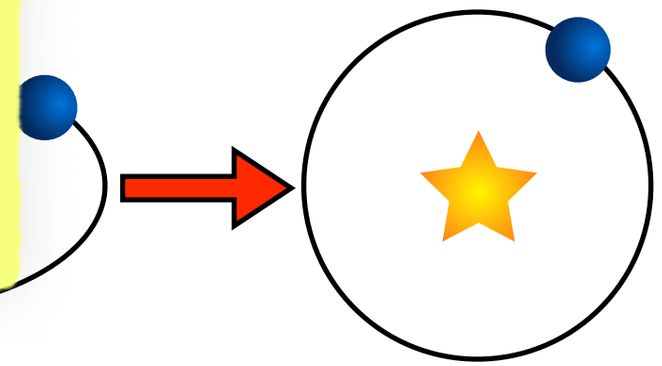


★ planet outside corot
⇒ planet migrates o

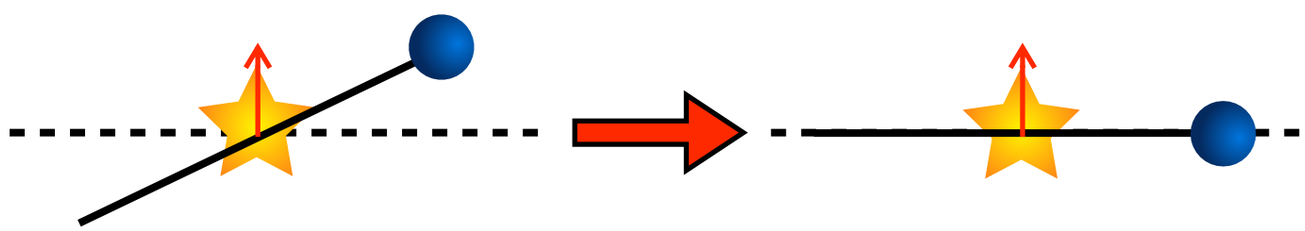
Important parameters

- radius: R★
- rotation: Ω★
- dissipation: σ★

★ eccentricity decreas



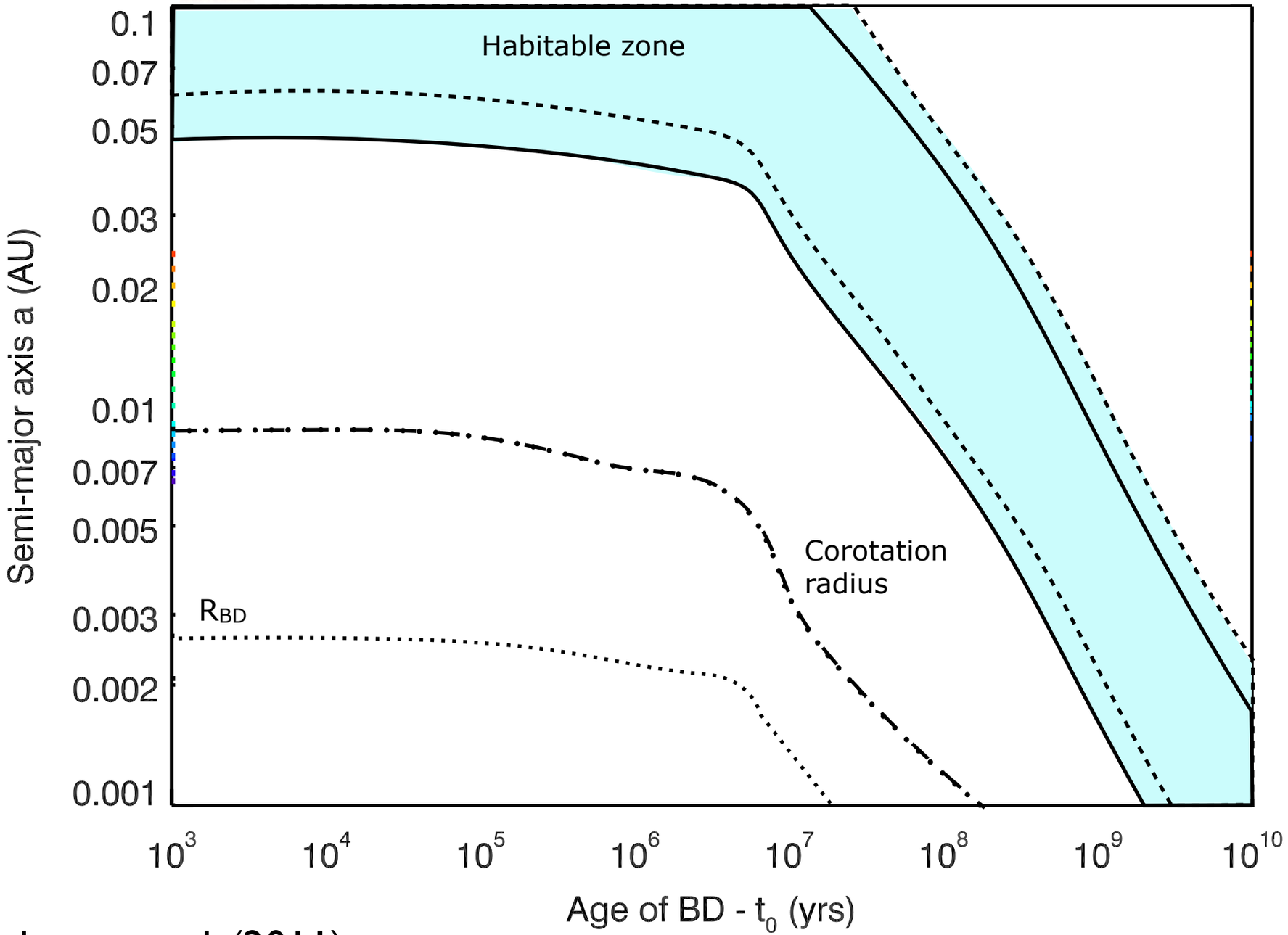
★ inclination of planet decreases



# Planets around UCDs

## Importance of taking into account an evolving primary

Brown dwarf of 0.04 $M_\odot$, planet of 1 $M_\oplus$




Bolmont et al. (2011)

1) Radius decreases

2) Spin evolves

3) Luminosity decreases

(BD models from Leconte et al. 2011b )

# Planets around UCDs

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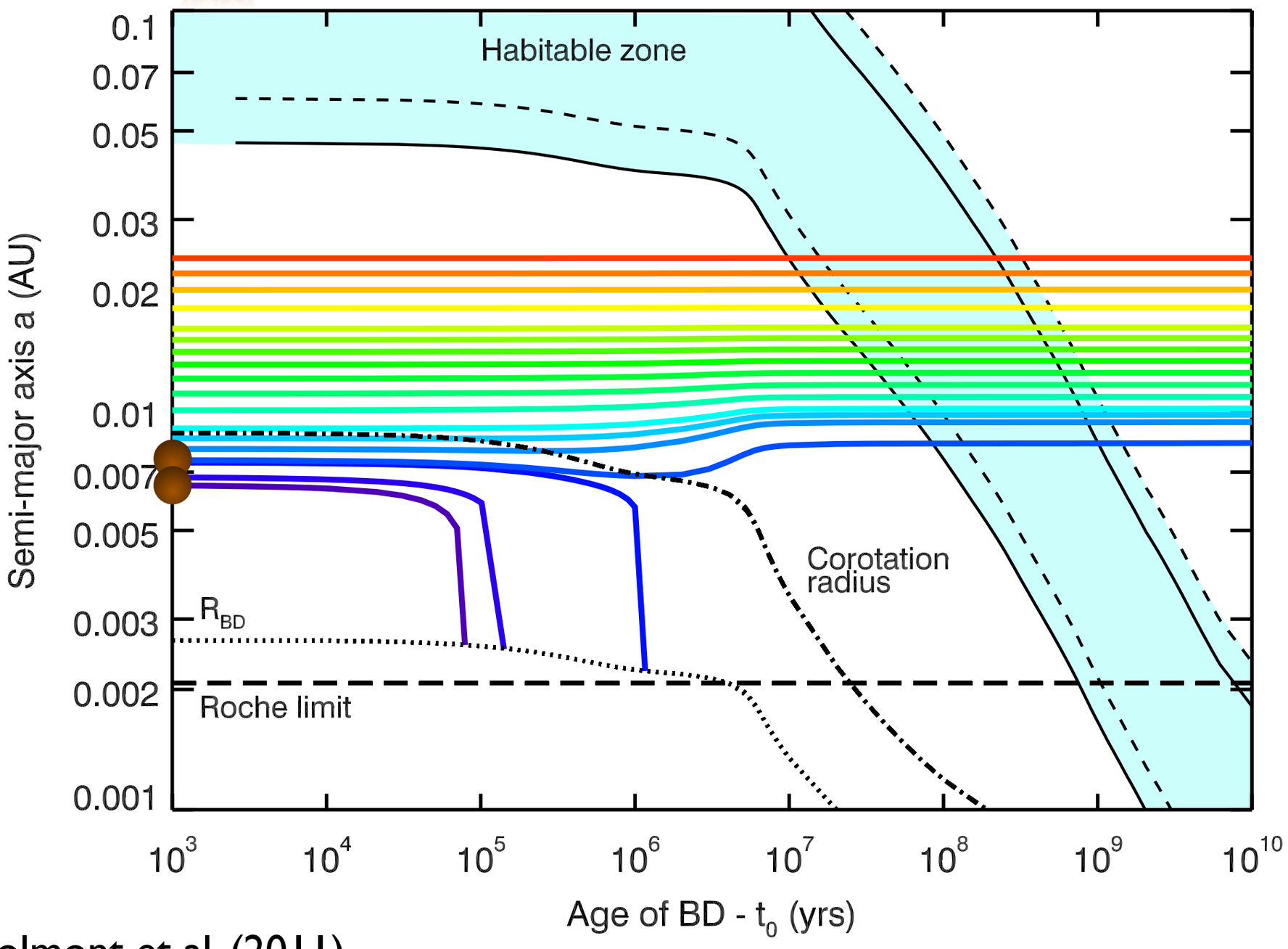


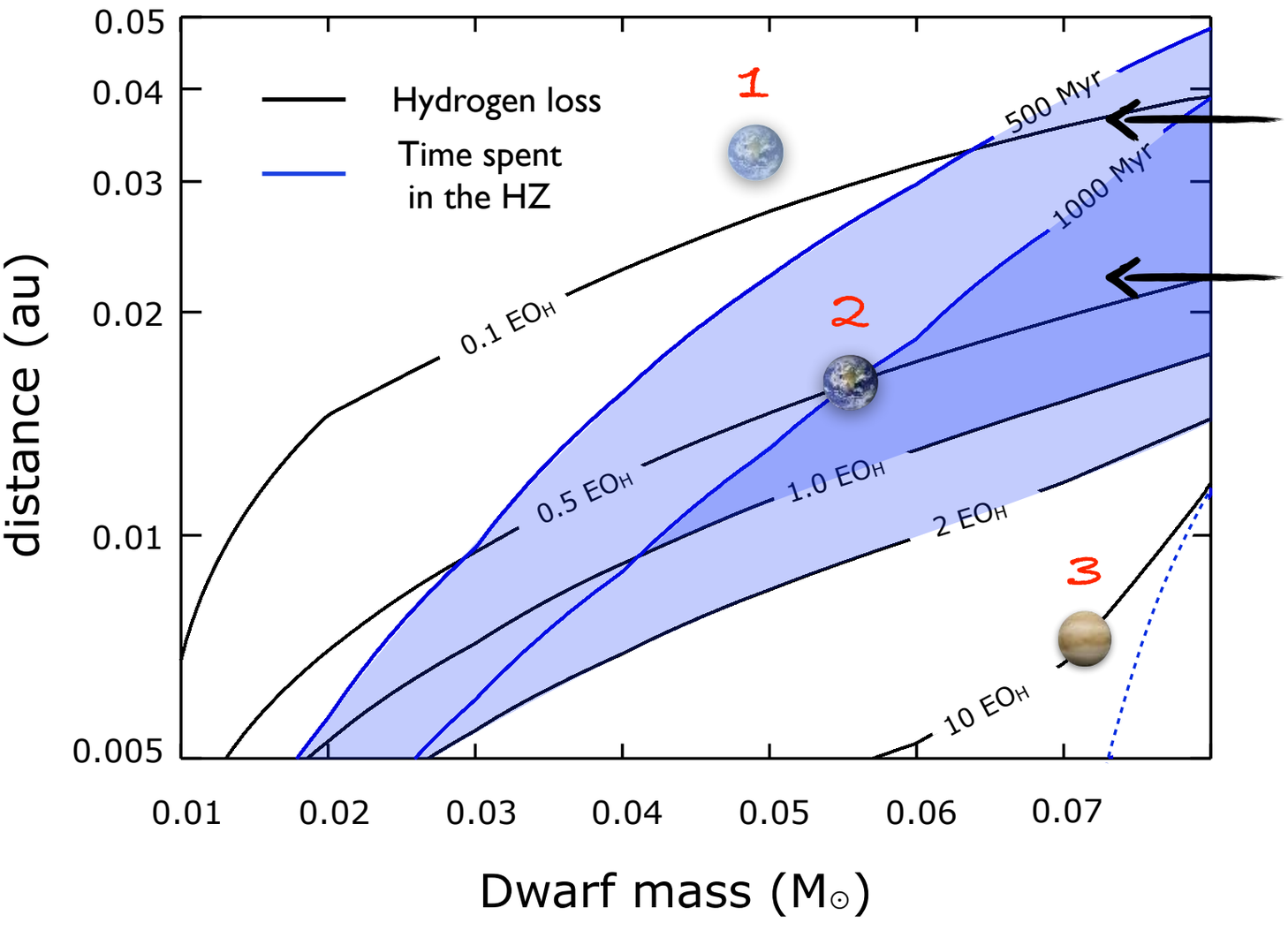

Bolmont et al. (2011)

Tides are important!

1) The farther the planet, the most probable the survival
2) Planets are saved by shrinking corotation radius
3) The evolution "stops" after ~50 Myr
4) The farther the planet, the less time interior to the HZ
5) The farther the planet, the less time in the HZ

# Water loss from terrestrial planets orbiting UCDs

## Results




planets lose less than 2 $EO_H$ and spend more than 500 Myr in the HZ

planets lose less than 1 $EO_H$ and spend more than 1 Gyr in the HZ

Nota Bene

1 $EO_H$ = 1 Earth Ocean equivalent of Hydrogen

Bolmont et al., 2017

# TRAPPIST-1

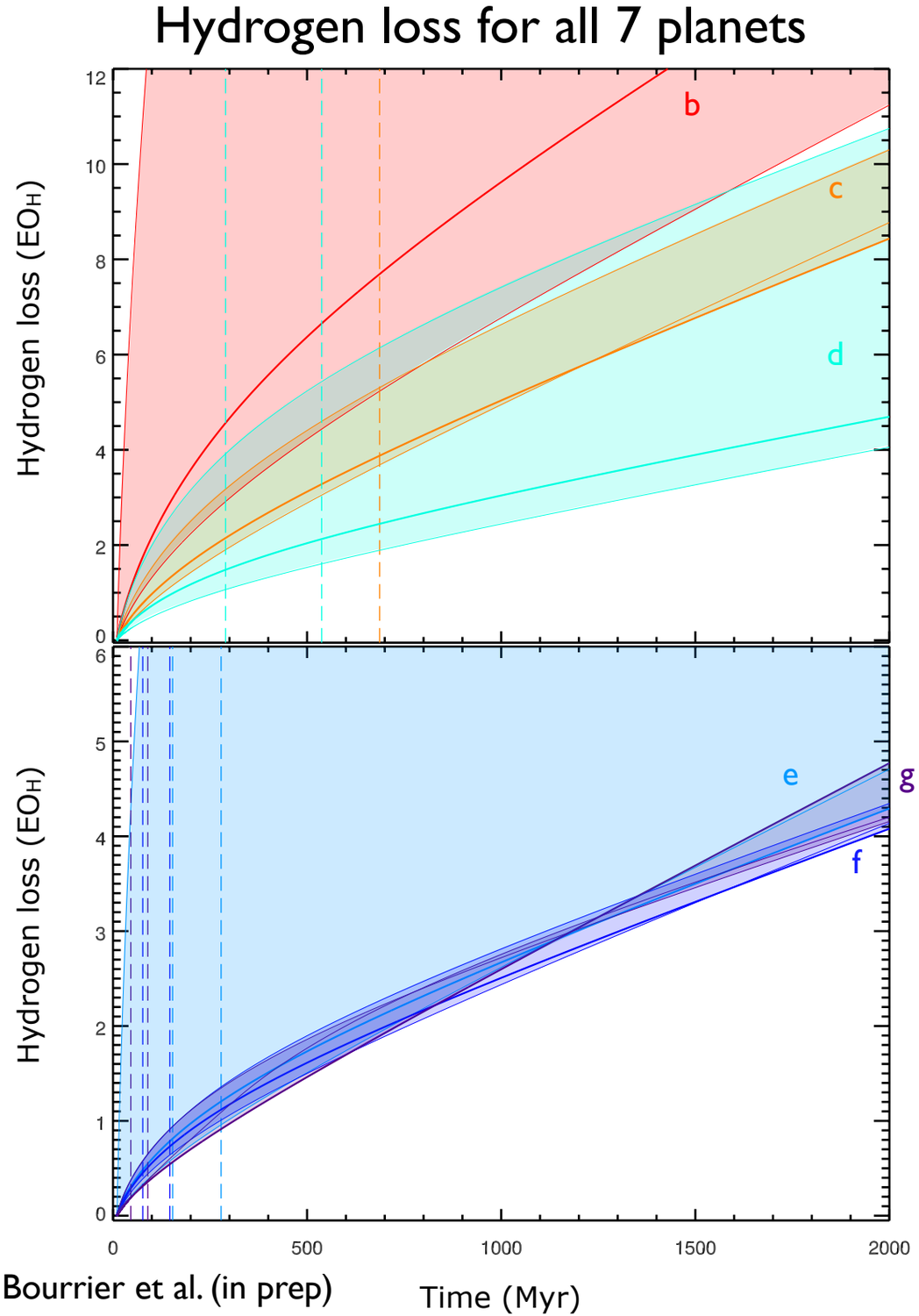
$M_\star = 0.080 \pm 0.009\ M_\odot$

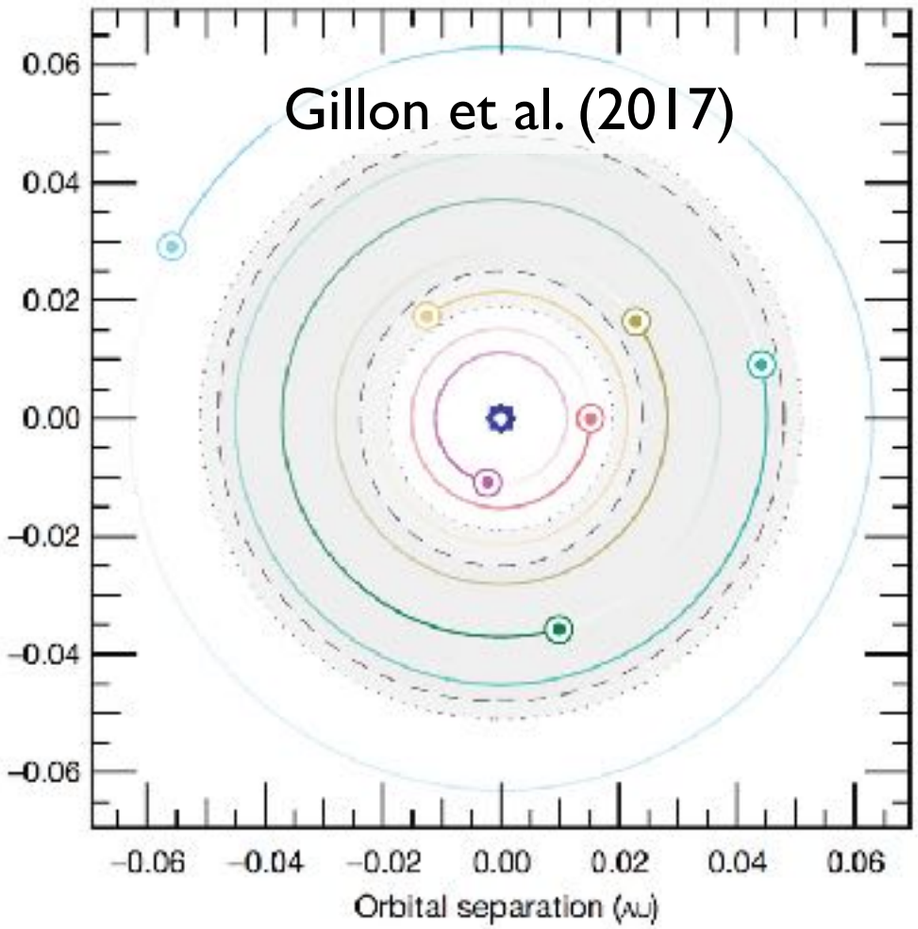
(Gillon et al., 2016,
Gillon, …, Bolmont et al., 2017)

7 planets of the size of the Earth!

# Water loss from terrestrial planets orbiting UCDs

## What about the planets of TRAPPIST-1?




Huge uncertainty on mass!

➡ Huge uncertainty on hydrogen loss

# Water loss from terrestrial planets orbiting UCDs

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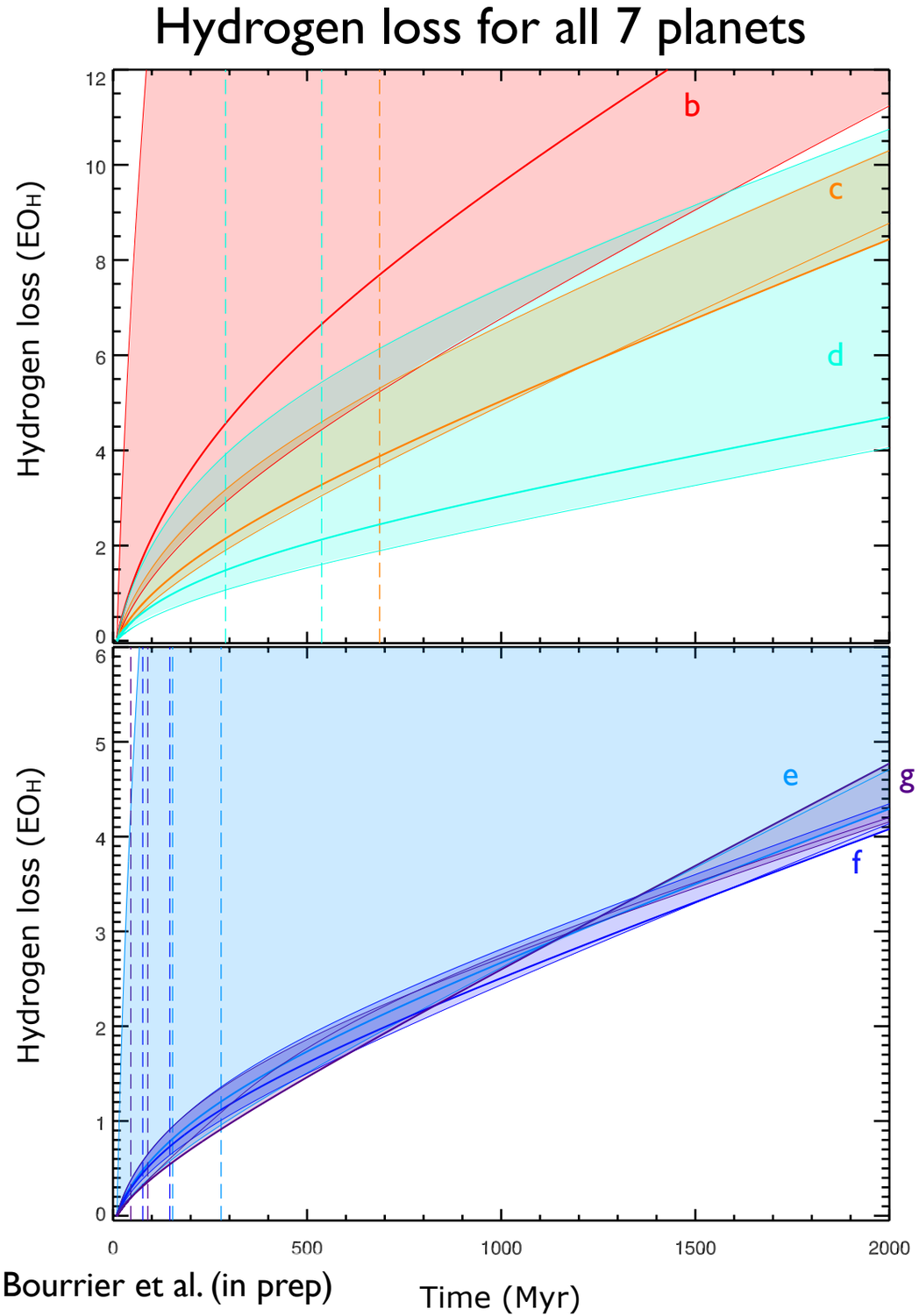



### Water loss processes

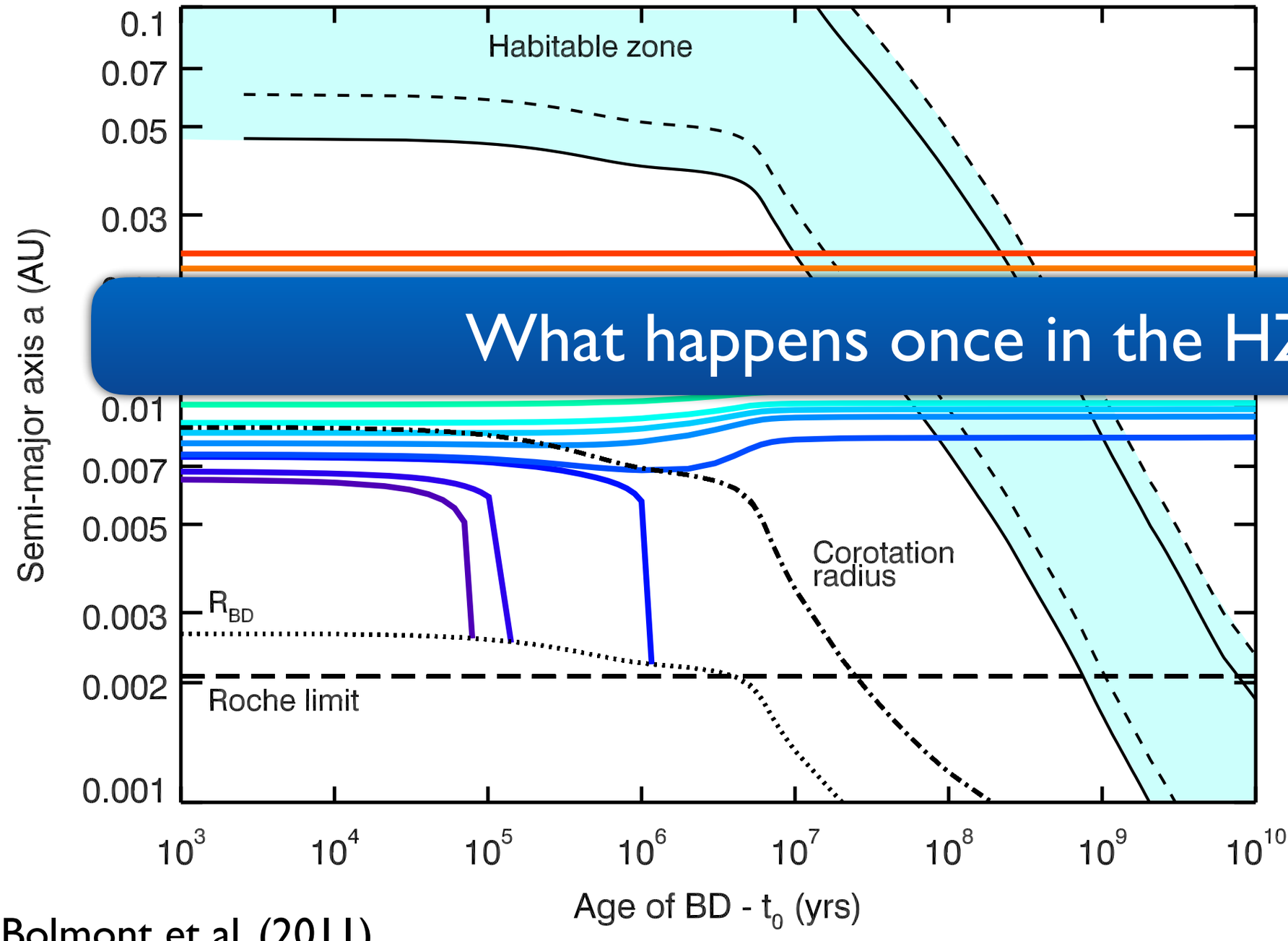
- A lot of uncertainties
- Non hydrodynamical processes?
- Age of the star?
- Loss continues in the HZ?

### Future

- Estimates of masses ⇒ densities
- JWST observations

# Planets around UCDs

## Importance of taking into account an evolving primary



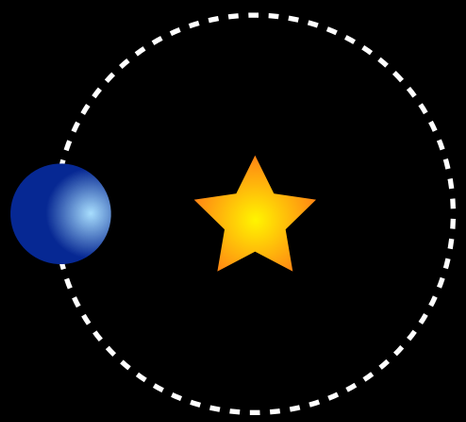

What happens once in the HZ?

Bolmont et al. (2011)

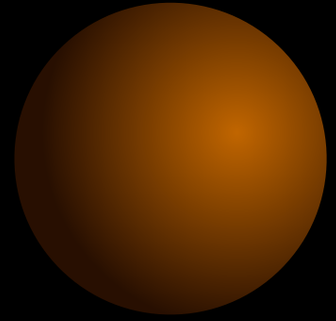
# Planets around UCDs

## Importance of taking into account an evolving primary

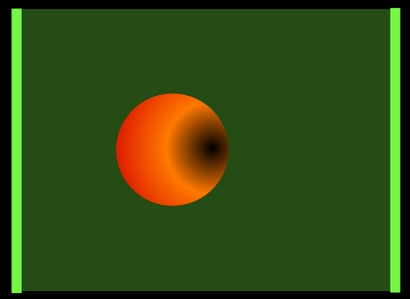
★ If planet is alone, when it reaches the habitable zone:



Danger for aquability: cold trap?



Habitable zone



# Possible climates of planets around UCDs

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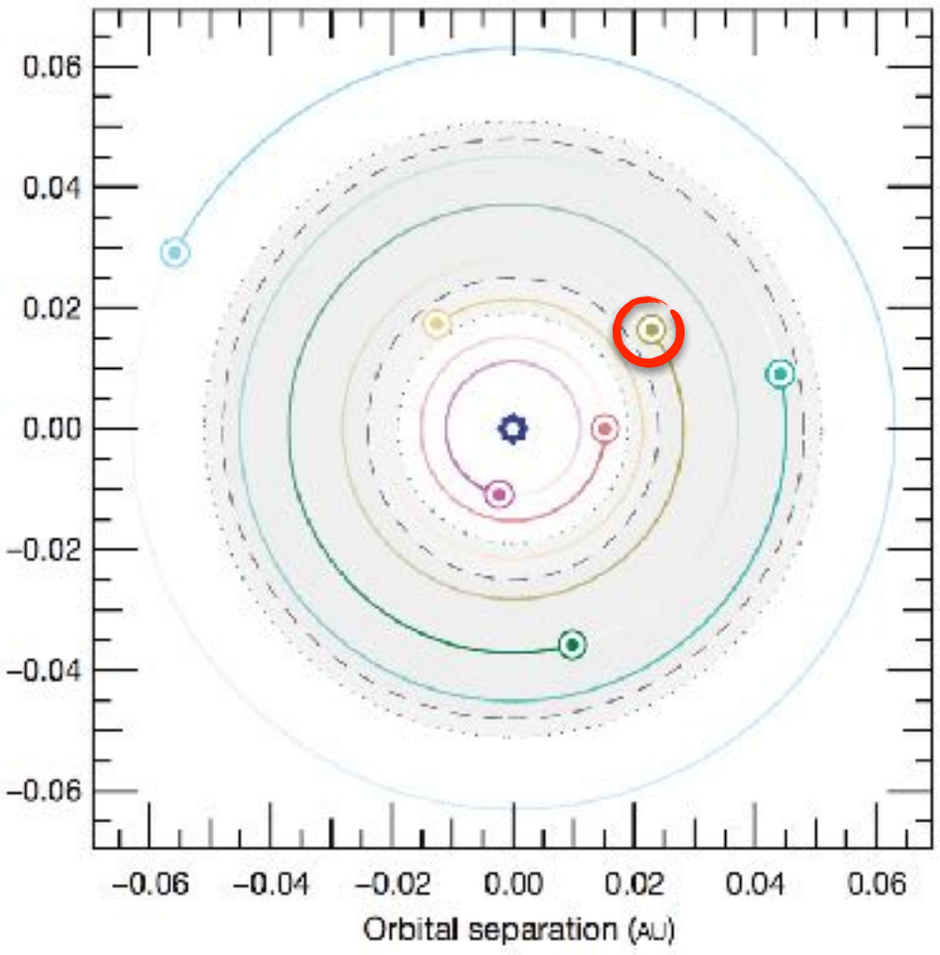
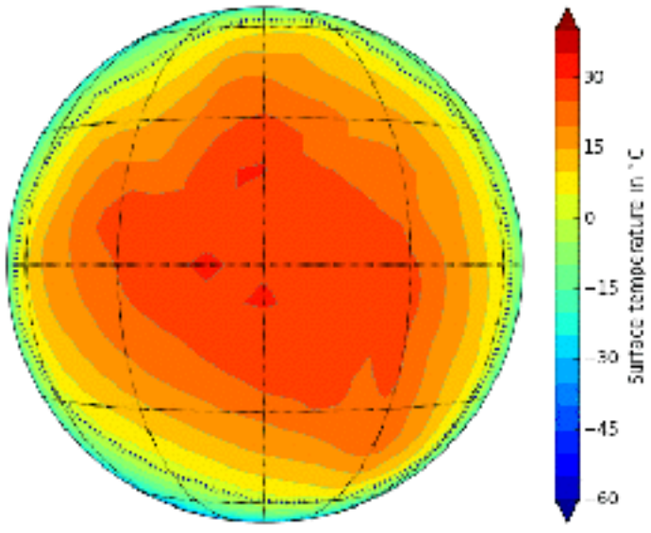



We assume water-rich, tidally locked, circular orbits and no obliquity




TRAPPIST-1e
always has a patch of liquid water at the substellar point,
whatever the atmosphere!

Turbet, …, Bolmont et al. 2017, in prep

# Possible climates of planets around UCDs

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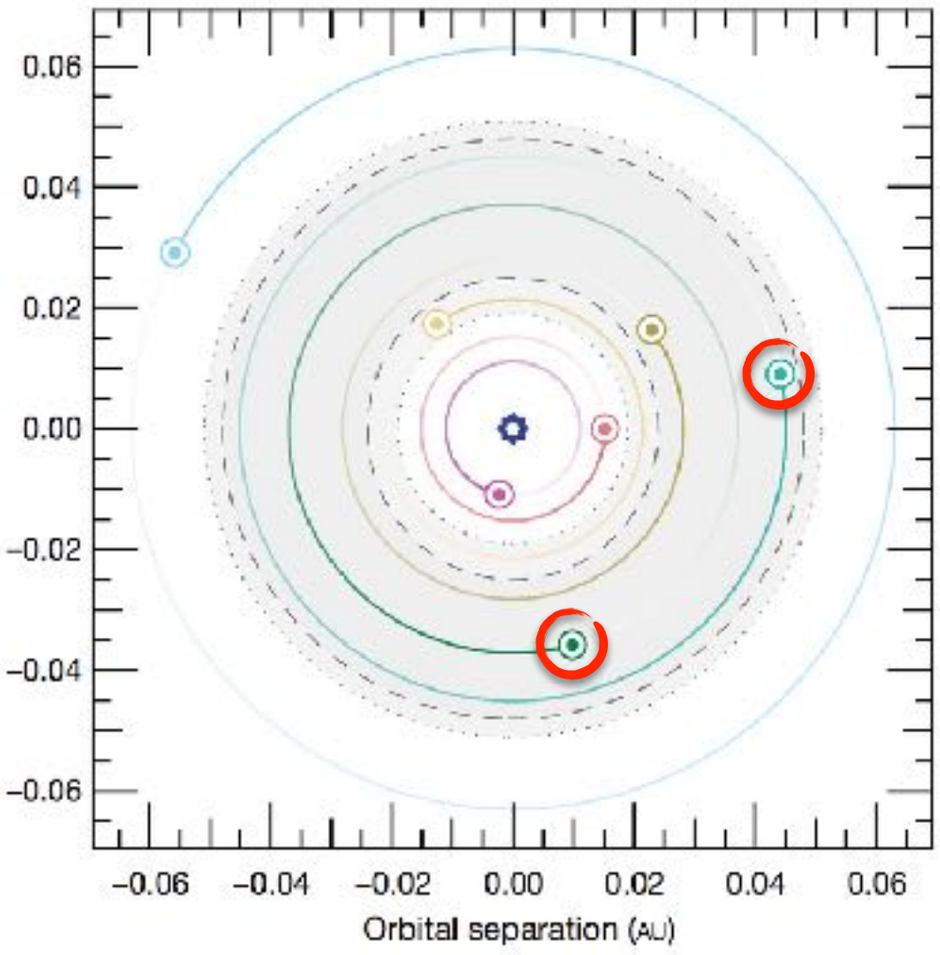


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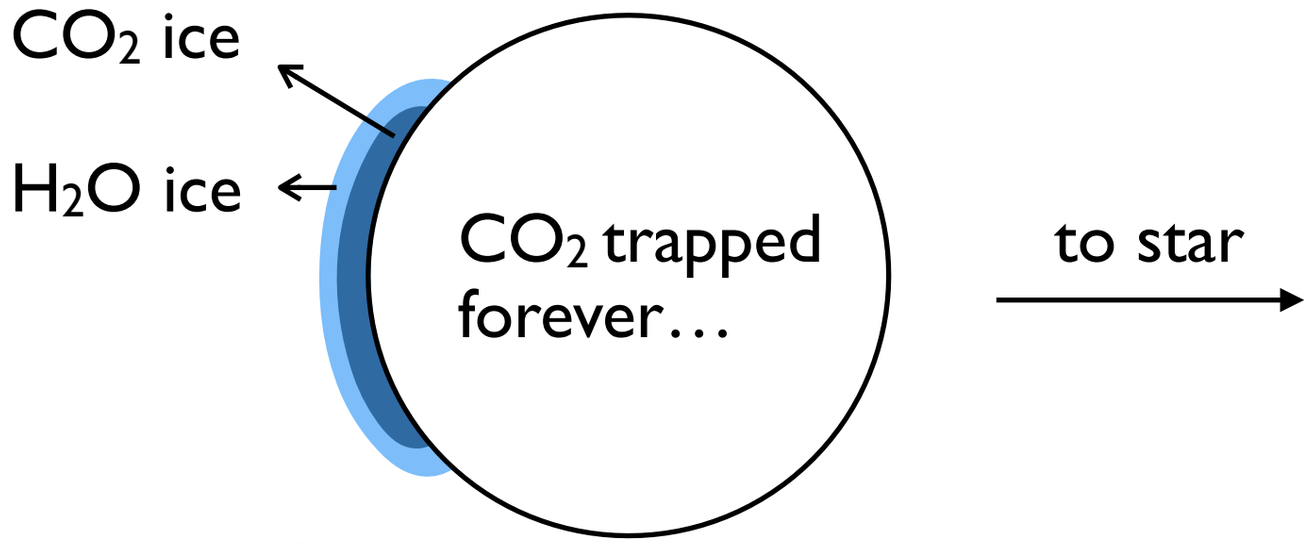


TRAPPIST-1f & g
could have surface liquid water for certain atmospheric properties!
… but for others, they could be snowballs…

Turbet, …, Bolmont et al. 2017, in prep

# Planets around UCDs

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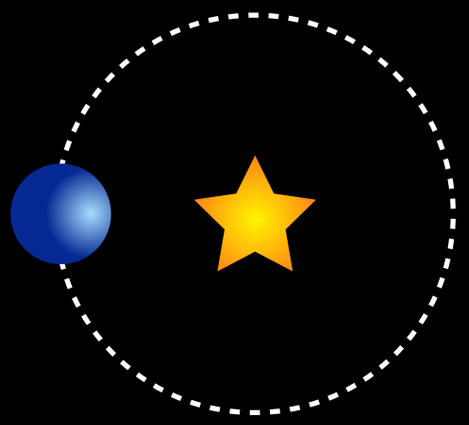
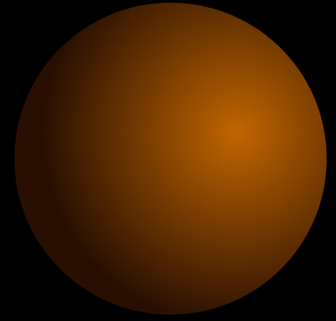
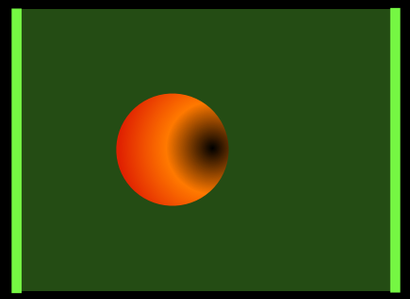
★ If planet is alone, when it reaches the habitable zone:



Danger for aquability: cold trap?



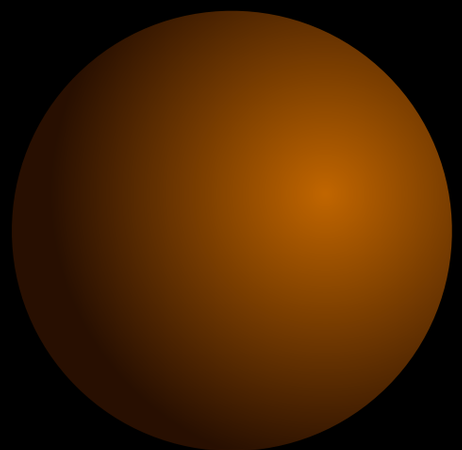
Habitable zone



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

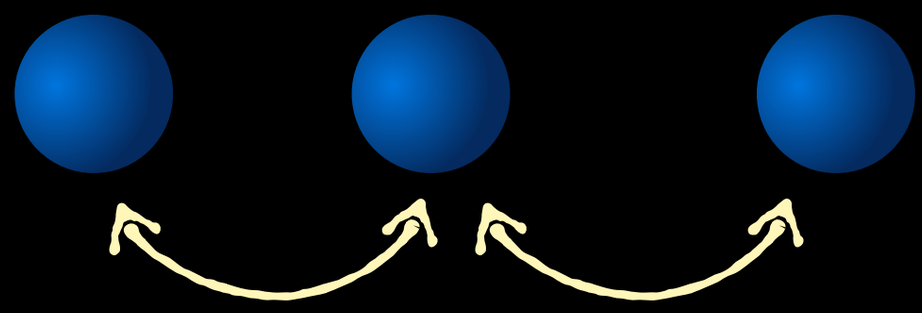
# Planets around UCDs

## Tidal effects in multi-planet systems

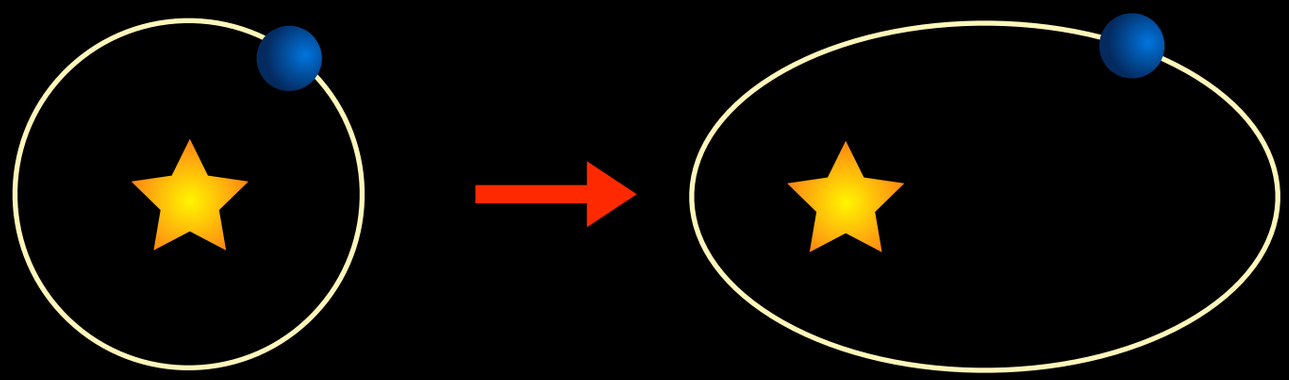


UCD

Planet 1 Planet 2 Planet 3



Gravitational interactions between planets



# Planets around UCDs

## Tidal effects in multi-planet systems

Tidal effect in Io ➙ strong volcanism

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

Images from *New Horizons* showing volcano Tvashtar

# Mercury-T

## A tool for the community

Free download from: http://www.emelinebolmont.com/ (Bolmont et al., 2015)

N-body code Mercury

(Chambers, 1999)

Dynamical evolution

\+ Tidal forces and torques

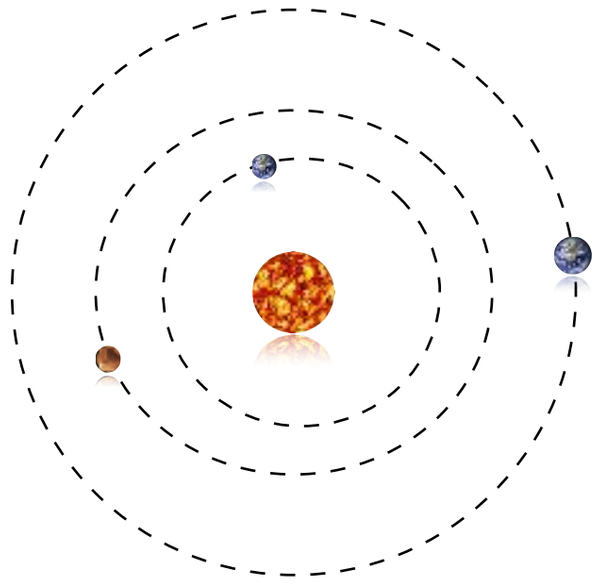
\+ Effect of the rotation-flattening of bodies

\+ General relativity

\+ Radius evolution of star/ brown dwarf

➜ Planets Orbital evolution

➜ Planets and stellar rotational evolution



# Tidal effects in multi-planet systems

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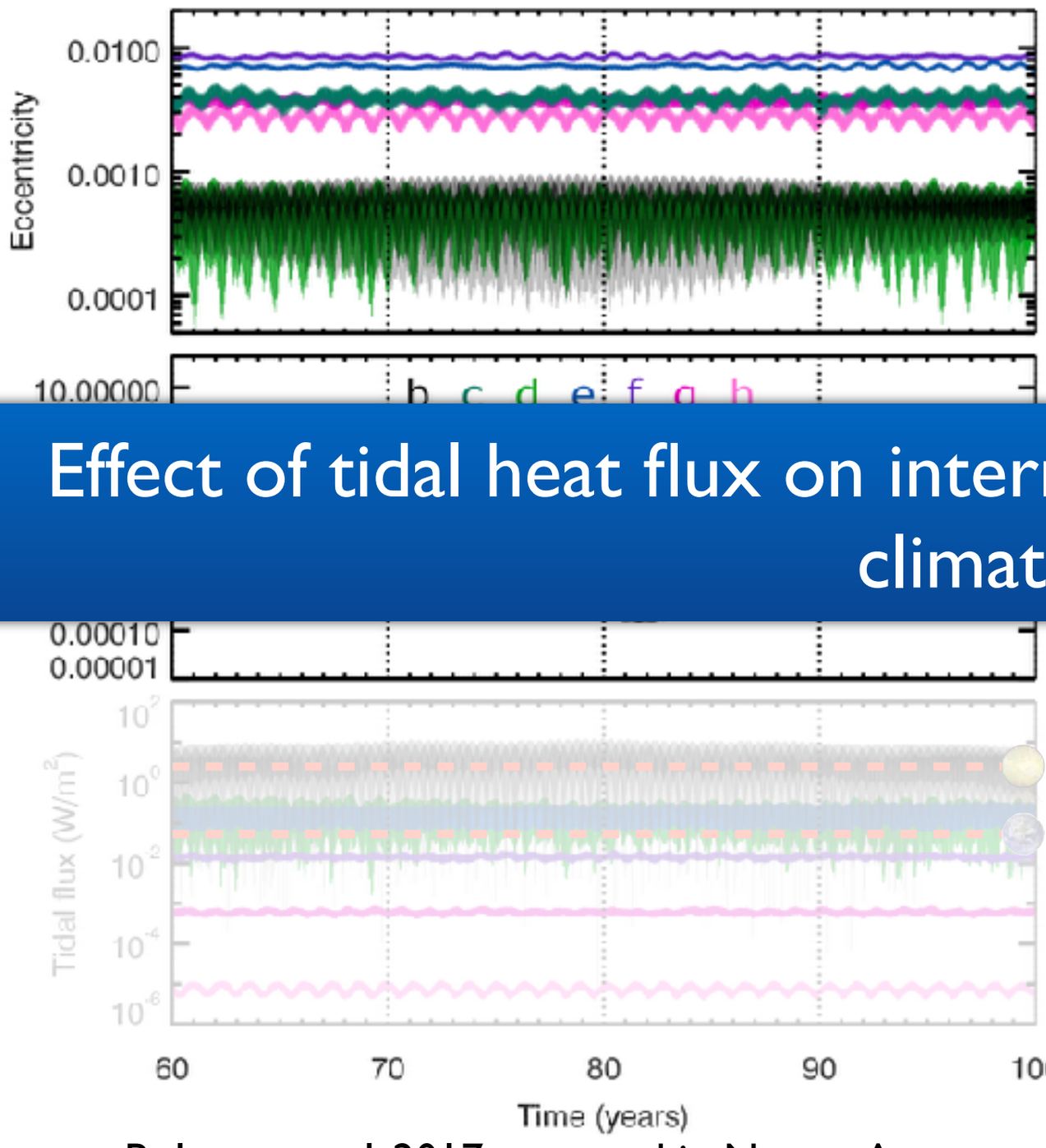



N-body simulations with tides using Mercury-T (Bolmont et al. 2015)

**Effect of tidal heat flux on internal structure, volcanism and climate?**

tidal heating lower than Earth's

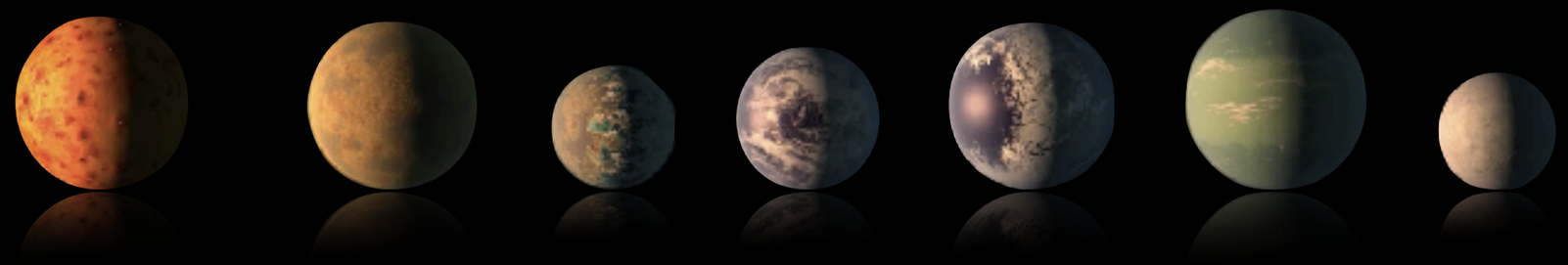
Trappist-1c, d and e:
tidal heating higher than Earth's

Trappist-1b:
tidal heating higher than Io's

Luger, …, Bolmont et al. 2017, accepted in Nature Astronomy

# TRAPPIST-1

N-body simulations



Destabilization of the system
after only 0.5 Myr

N-body + general relativity + tides simulations

Stable system over > 15 Myr

(another example: Kepler-62 in Bolmont et al., 2015)

# Thank you !