Planets on eccentric orbits: limits of the mean flux approximation

Pathways towards
Habitable Planets
13-17/07/2015

Emeline BOLMONT
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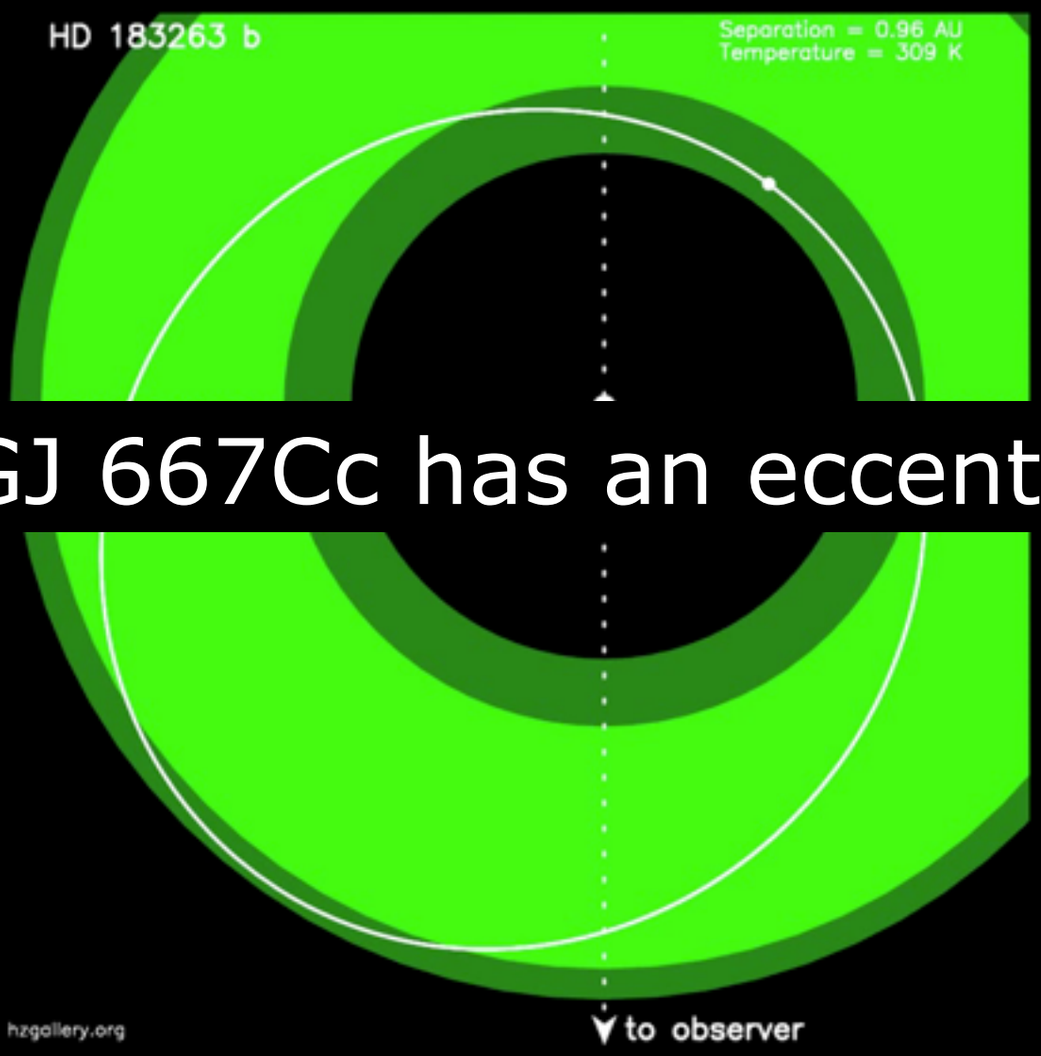
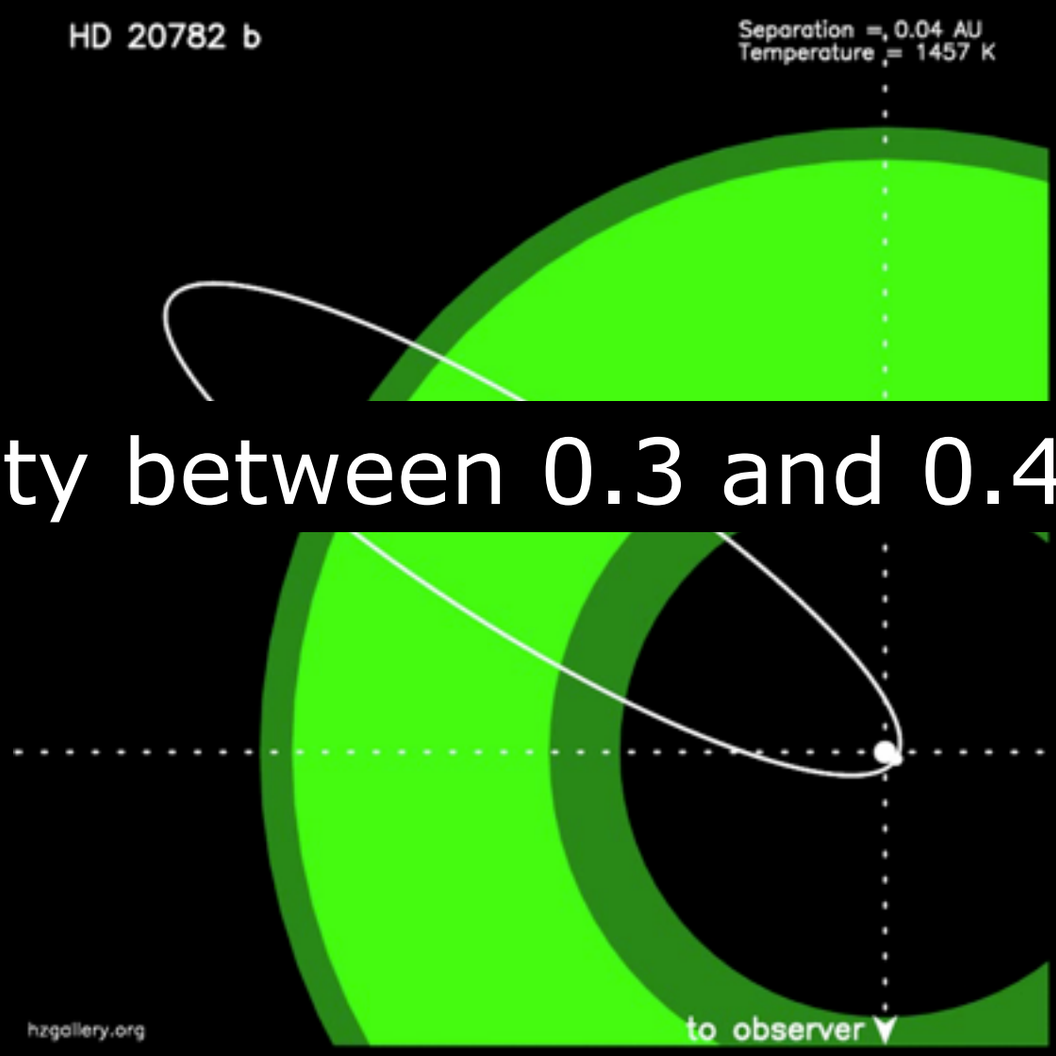
Limits of the mean flux approximation

"Habitable zone" planets on eccentric orbits

eccentricity = 0.36

eccentricity = 0.97





GJ 667Cc has an eccentricity between 0.3 and 0.4

hzgallery.org (S. Kane, D. Gelino) using Kopparapu et al. 2013, 2014

Limits of the mean flux approximation

Previous studies

Some previous studies have been done about that, among them:
Williams & Pollard (2002), Spiegel et al. & Dressing et al. (2010), Wordsworth et al. (2011), Linsenmeier et al. (2015)

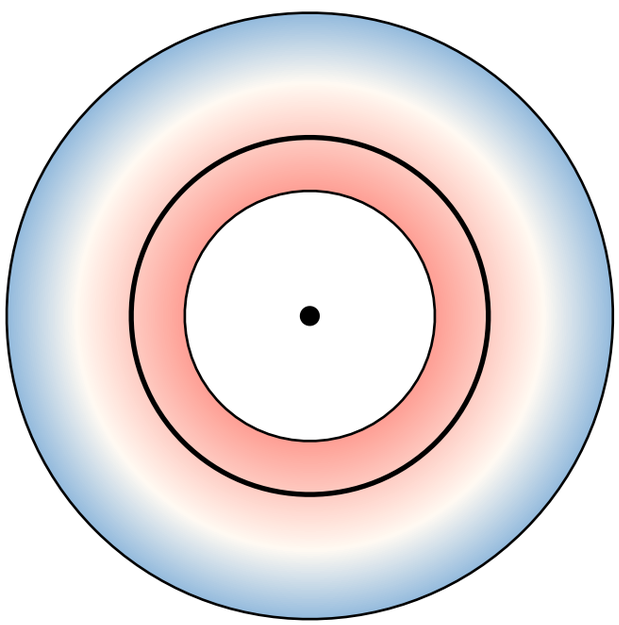
We perform here a parametric study, looking at planets of different eccentricities orbiting different kind of stars.

Limits of the mean flux approximation

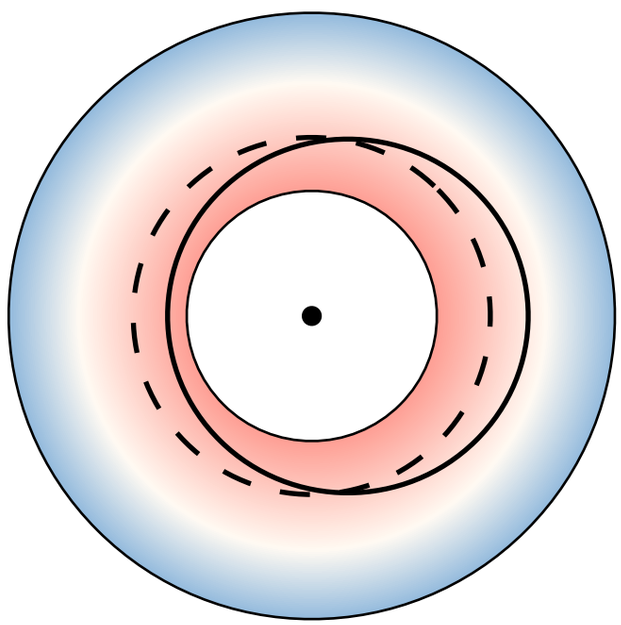
Question(s): how robust is the mean-flux approximation to assess the habitability of planets?

Are these equivalent?

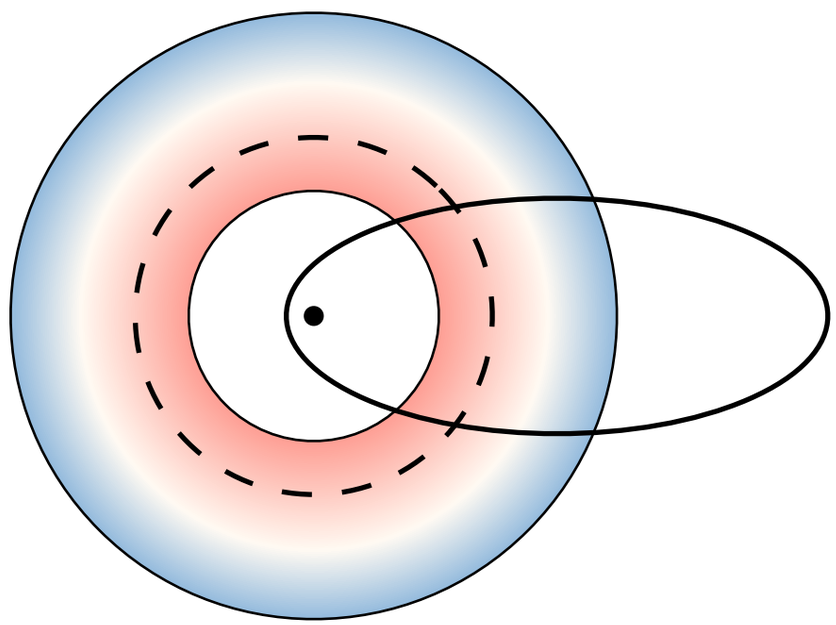
e=0.0



e=0.2



e=0.9



Limits of the mean flux approximation

Question(s): how robust is the mean-flux approximation to assess the habitability of planets?

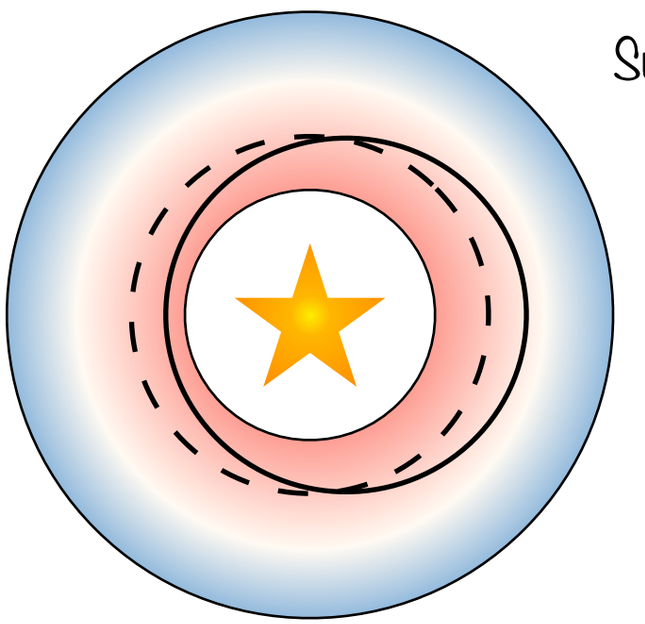
Does it depend on the host star?

Are these equivalent?

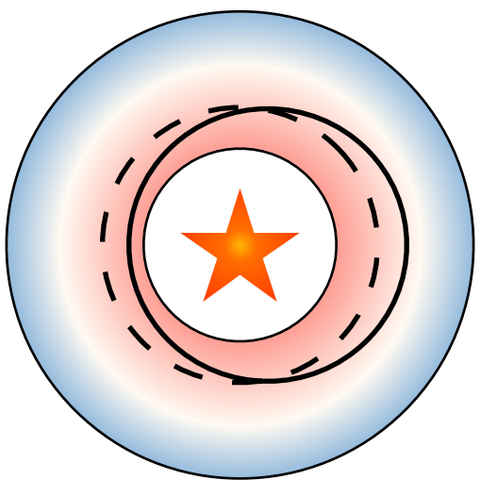
$L_\star = 1\ L_\odot$

$L_\star = 10^{-2}\ L_\odot$

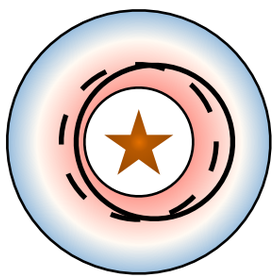
$L_\star = 10^{-4}\ L_\odot$



Sun



M-dwarf



Brown dwarf

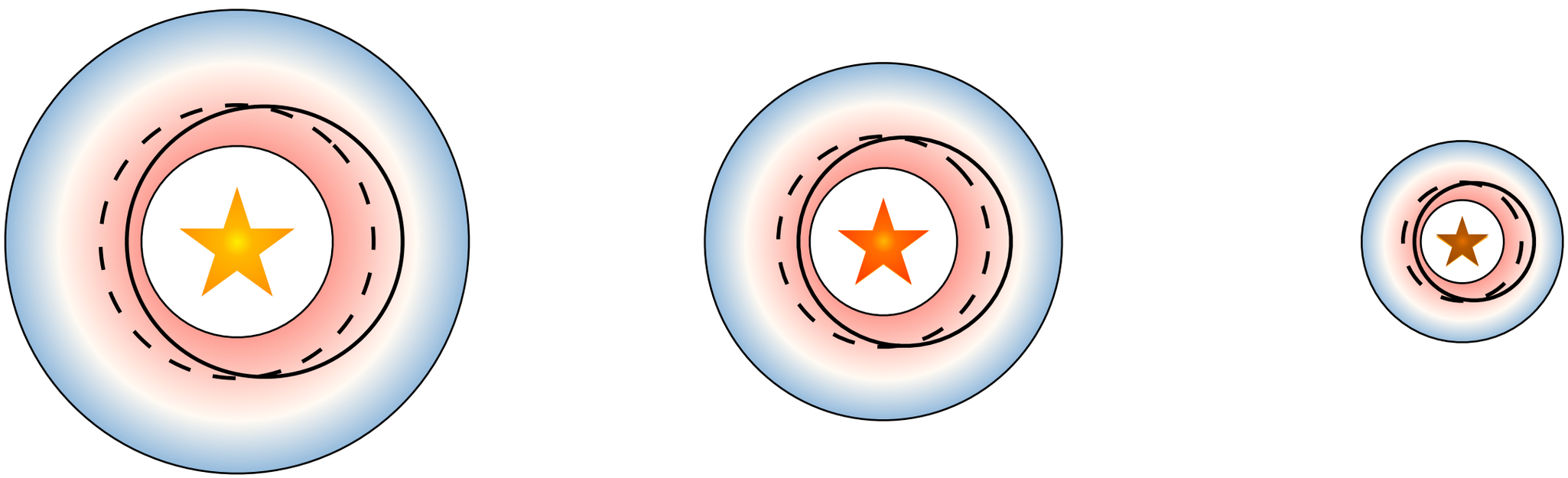
Limits of the mean flux approximation

Question(s): how robust is the mean-flux approximation to assess the habitability of planets?

Does it depend on the host star?

First, we do not take into account the spectral dependance of the star

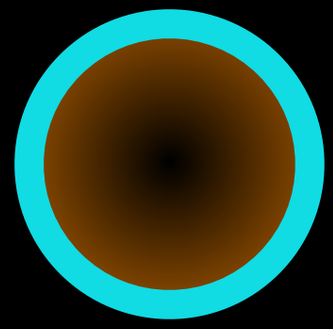
$L_\star = 1\ L_\odot$ $L_\star = 10^{-2}\ L_\odot$ $L_\star = 10^{-4}\ L_\odot$



Limits of the mean flux approximation

Climate simulations

We investigated the "habitability" of an ocean planet receiving a mean insolation flux of $F_\oplus$ = 1366 W/m^2



$M_p = 1\ M_\oplus$

$R_p = 1\ R_\oplus$

surface = infinite water source

We assess here the "habitability" of a planet based on the sea ice cover

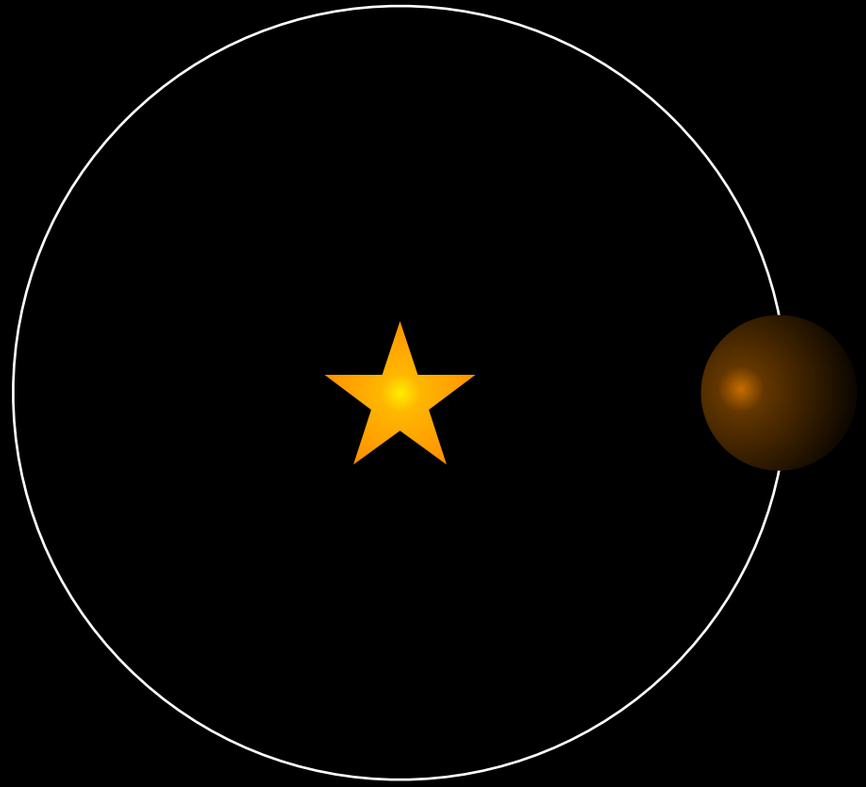
(as in Spiegel et al. 2008, Linsenmeier et al. 2015)

A planet is here considered habitable if it has a part of its ocean ice-free

Limits of the mean flux approximation

Climate simulations

The planet is on a synchronous orbit, with a zero obliquity



Limits of the mean flux approximation

Question: how robust is the mean-flux approximation to assess the habitability of planets?

Planet of semi-major axis a, eccentricity e

Planet of semi-major axis r, eccentricity 0

$r = a\,(1-e^2)^{1/4}$

e	r (AU)	peri (AU)	apo (AU)
0	1.000	1.00	1.00
0.05	1.001	0.95	1.05
0.1	1.003	0.90	1.10
0.2	1.011	0.81	1.21
0.4	1.045	0.63	1.46
0.6	1.119	0.45	1.79
0.8	1.292	0.26	2.33
0.9	1.516	0.15	2.88

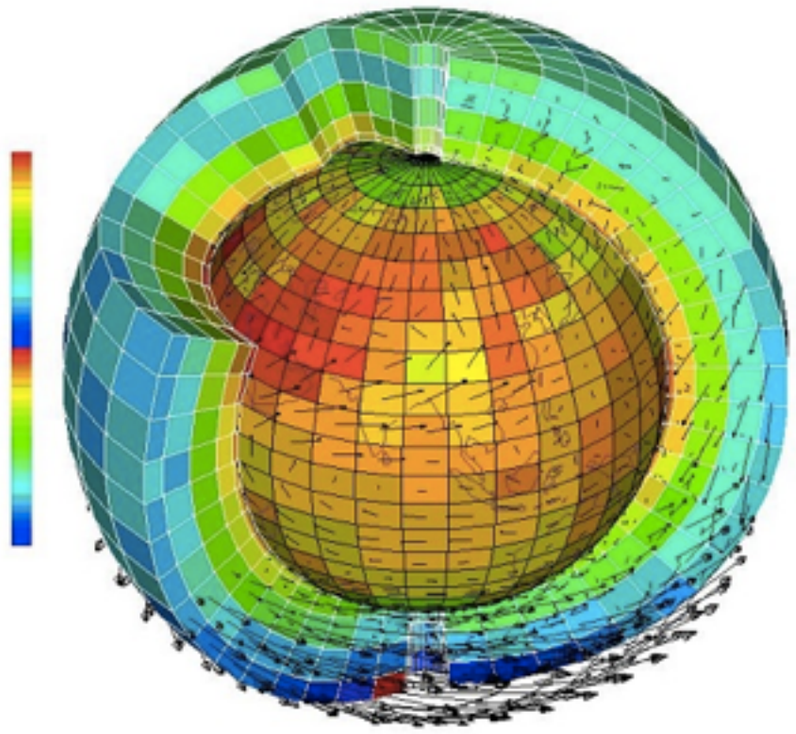
	Year (day)		
e	1 $L_\odot$	10^{-2} $L_\odot$	10^{-4} $L_\odot$
0	365.5	22.85	1.967
0.05	365.9	22.87	1.968
0.1	366.9	22.94	1.974
0.2	371.2	23.21	1.997
0.4	390.2	24.40	2.099
0.6	432.1	27.02	2.325
0.8	536.2	33.52	2.885
0.9	681.4	42.60	3.666

Bolmont et al., in prep

Limits of the mean flux approximation

Climate simulations

We performed climate simulations with the LMD generic global climate model
(Wordsworth et al. 2010, 2011, 2013; Selsis et al. 2011, Forget et al. 2013)



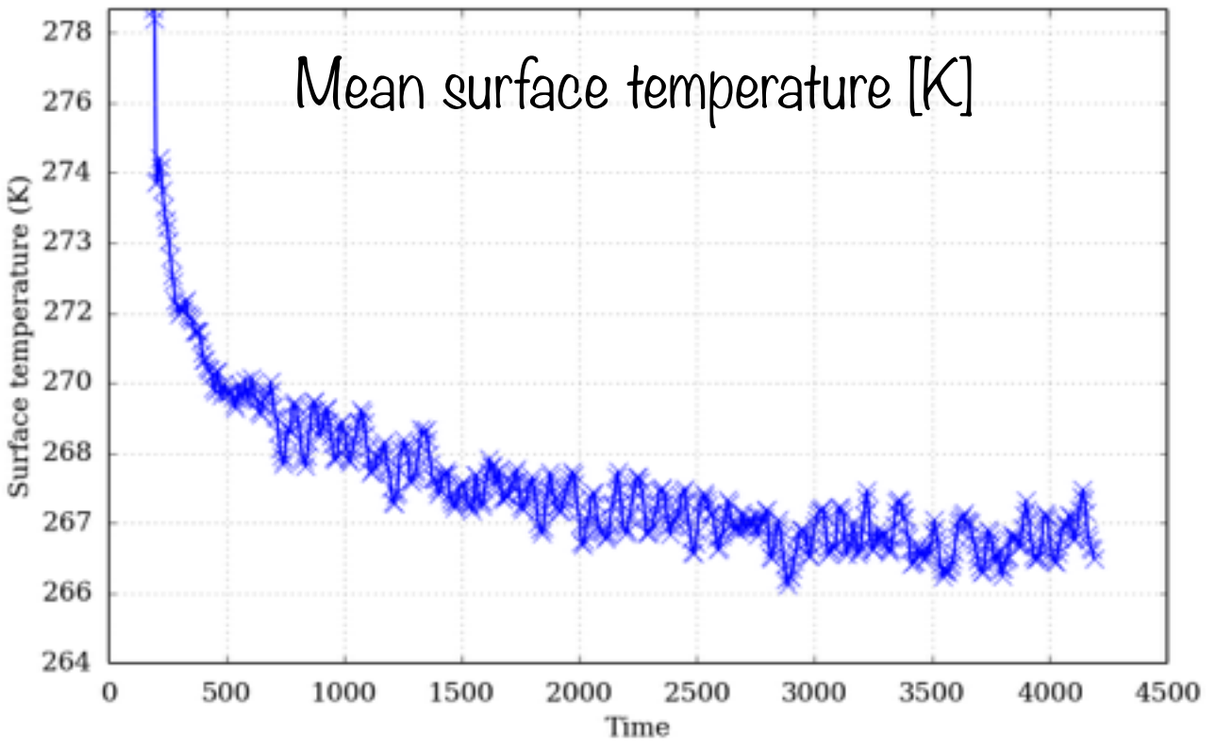
- Spatial resolution: 64x48x30 (long, lat, alt)
  Radiative transfer (correlated k): 38x36 (thermal, stellar)
- Atmospheric composition: N_2, CO_2 (376 ppmv)

- Water cycle: variable amounts of water vapor and ice
  Albedo of surface water: A_{oc} = 0.07, Albedo ice/snow: A_{ice} = 0.55
- Thermal inertia of the oceans: I_{oc} = 18000 J $s^{-1/2}$ m^{-2} K^{-1}
  Maximum ice thickness: h_{ice} = 1 m

Limits of the mean flux approximation

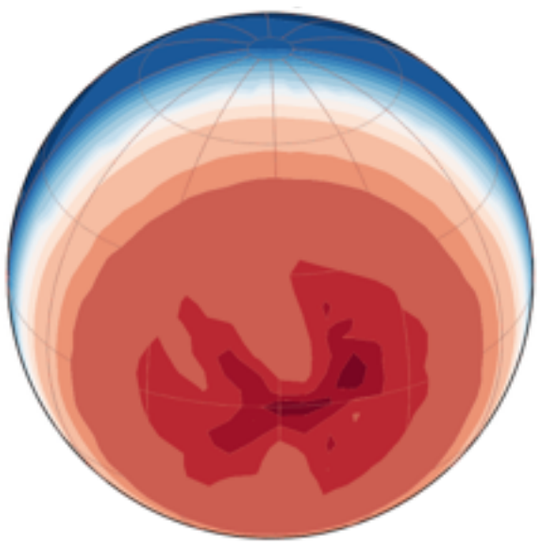
$L_\star = 1\ L_\odot$

e=0.0
P = 365 day



Planet reaches equilibrium
after 10 orbits (10 years)

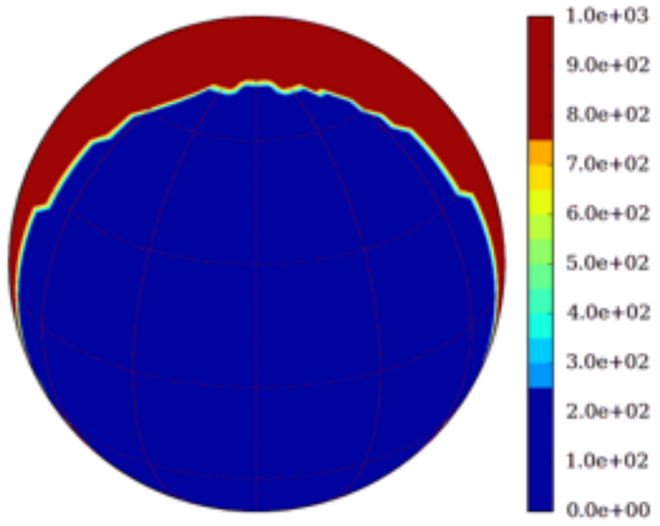
Surface temperature [K]



← hot

← cold

Surface ice coverage [kg/m^2]



← ice

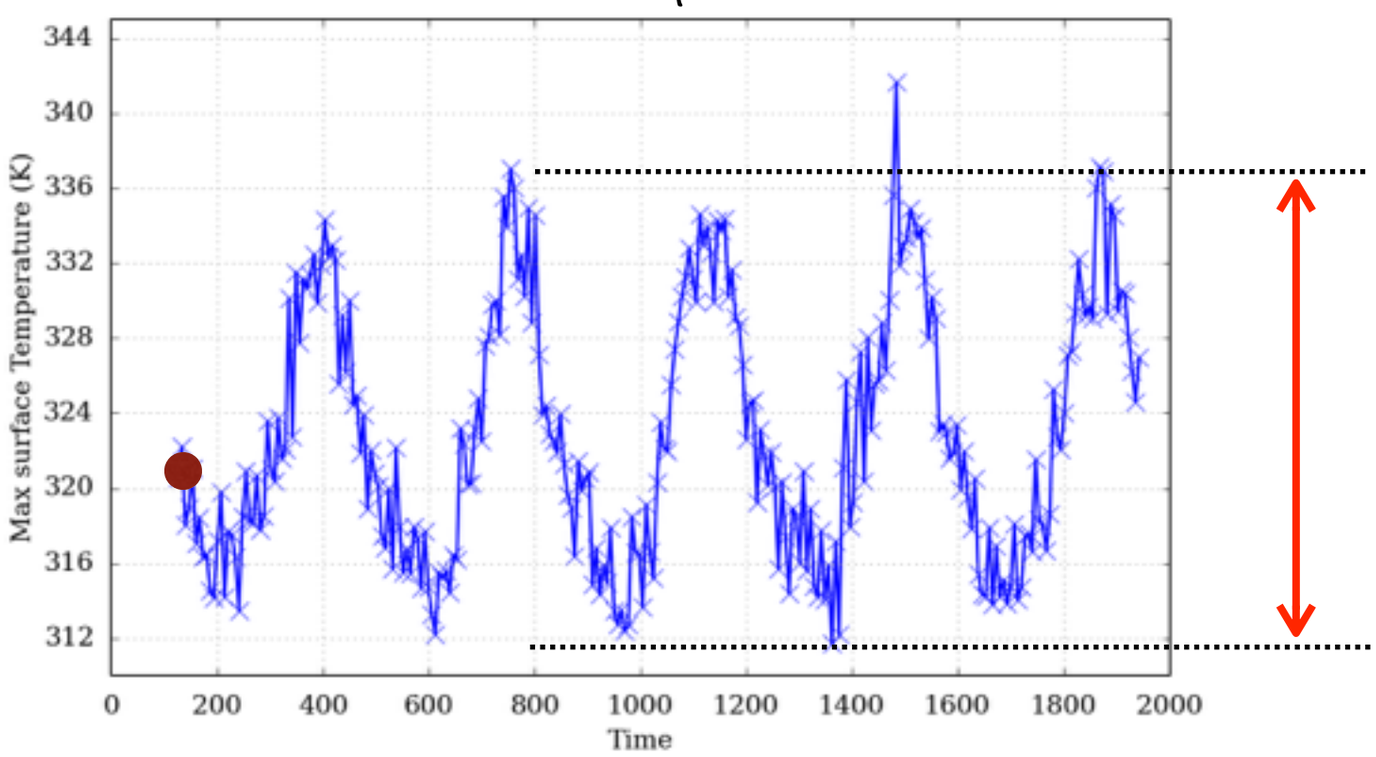
← water

Bolmont et al., in prep

Limits of the mean flux approximation

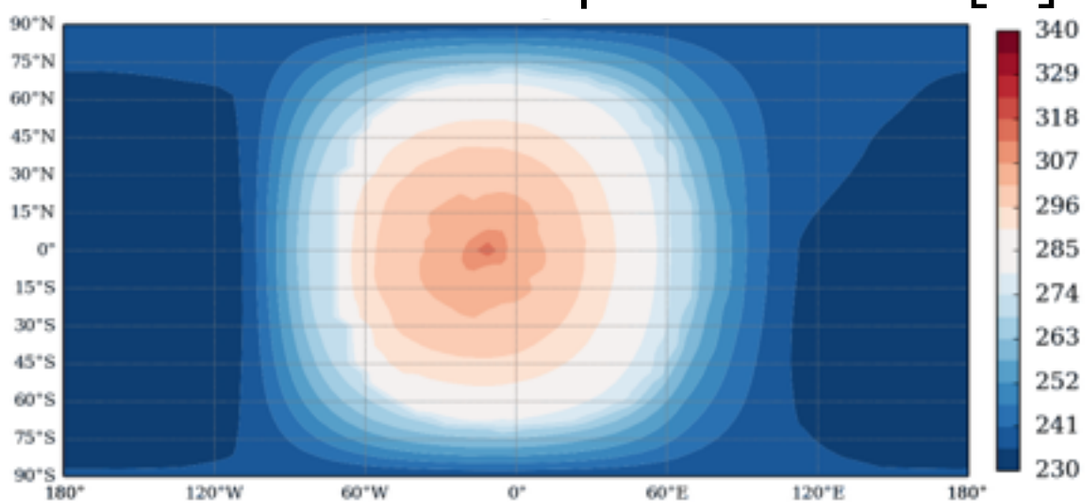
$L_\star = 1\ L_\odot$

e=0.2
P = 371 day

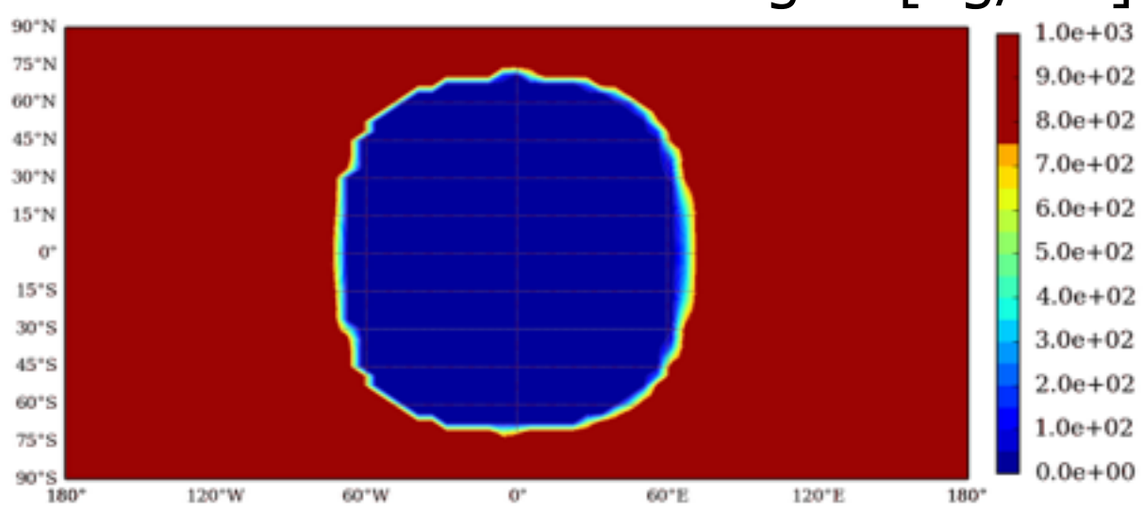


On the day side: ~30K temperature oscillations in 371 days

Surface temperature [K]



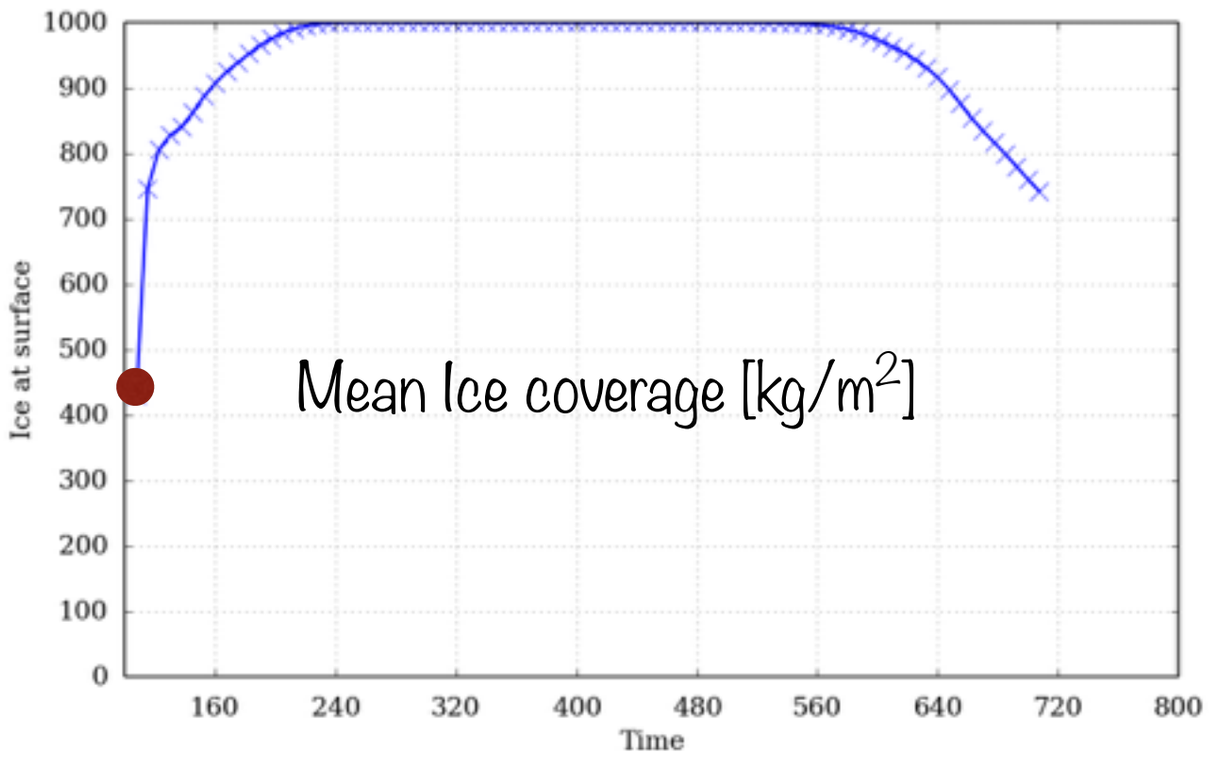
Surface ice coverage [kg/m^2]



Limits of the mean flux approximation

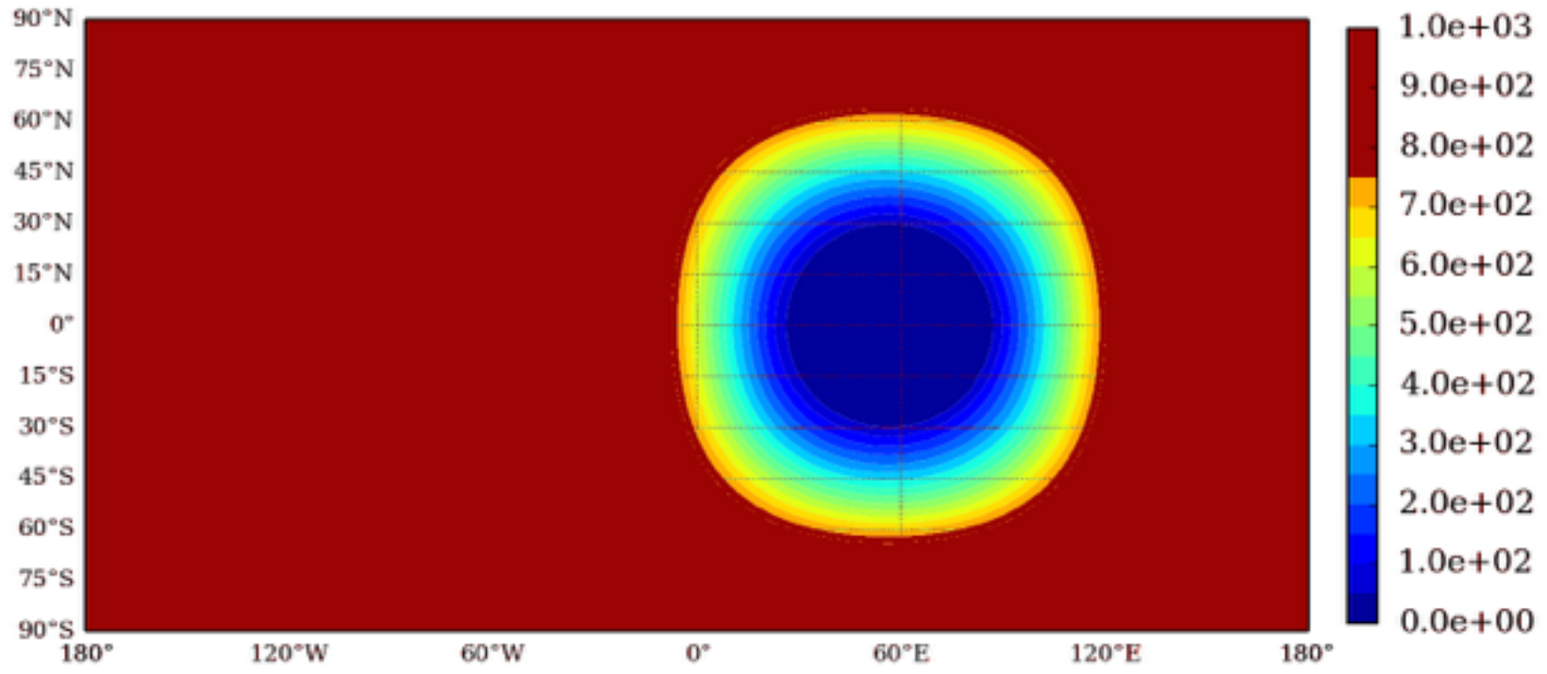
$L_\star = 1\ L_\odot$

e=0.6
P = 432 day



Only temporally habitable!

Surface ice coverage [kg/m²]

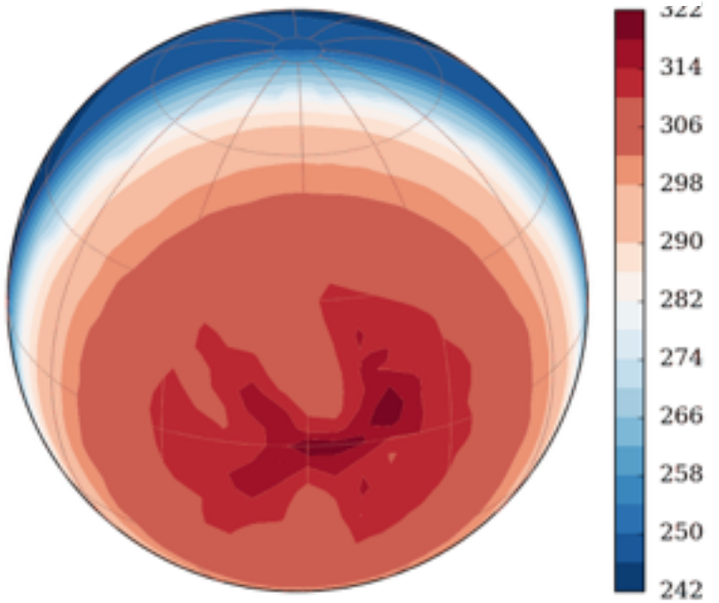


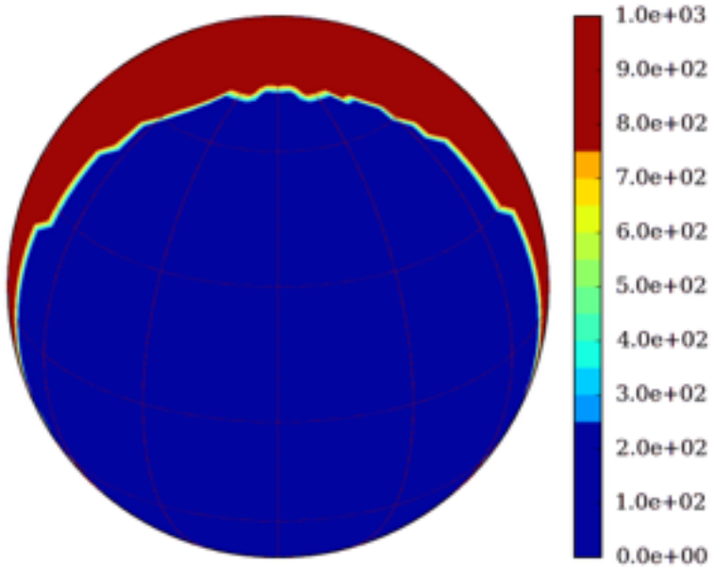
Limits of the mean flux approximation

$L_\star = 10^{-2}\ L_\odot$

$L_\star = 1\ L_\odot$
P = 365 day

Surface temperature [K]

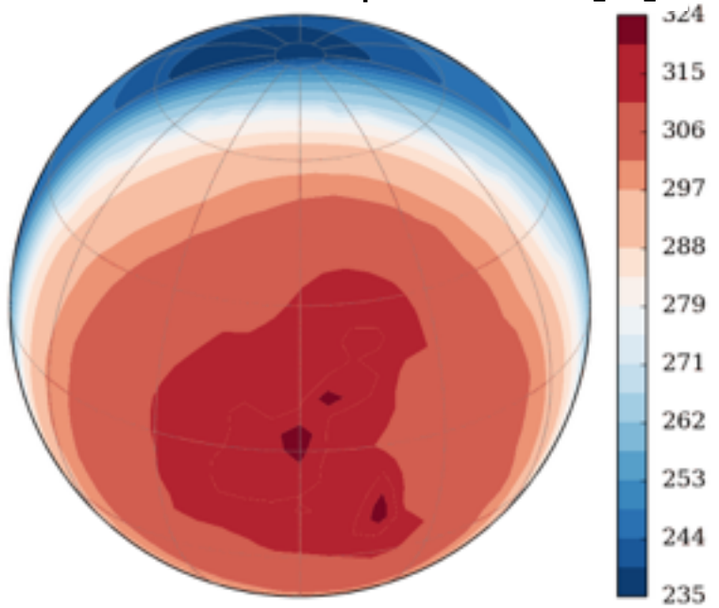


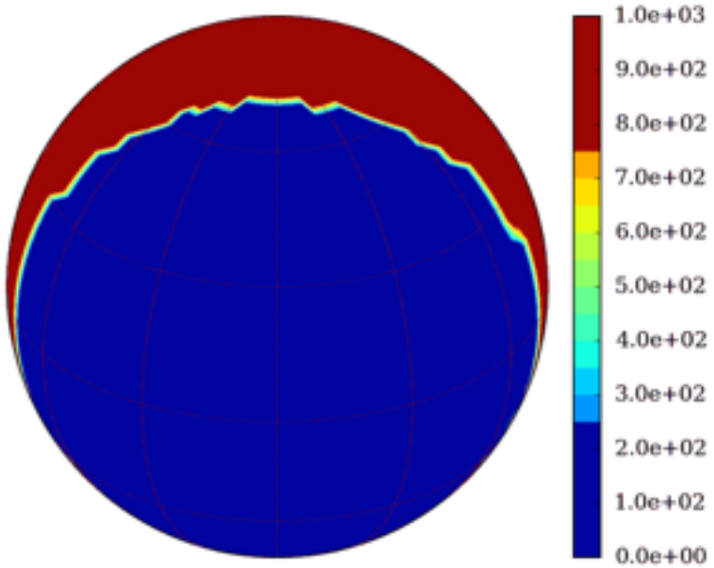


Surface ice coverage [kg/m^2]

$L_\star = 10^{-2}\ L_\odot$
P = 22.9 day

Surface temperature [K]



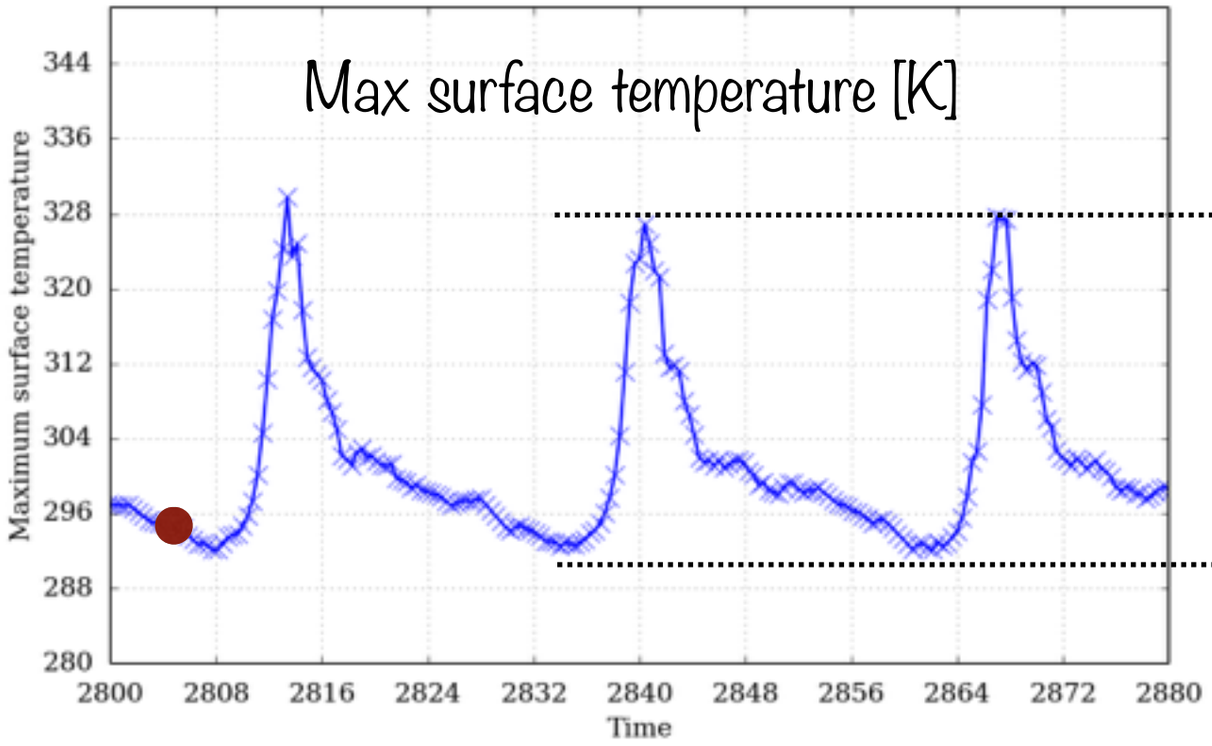


Surface ice coverage [kg/m^2]

Limits of the mean flux approximation

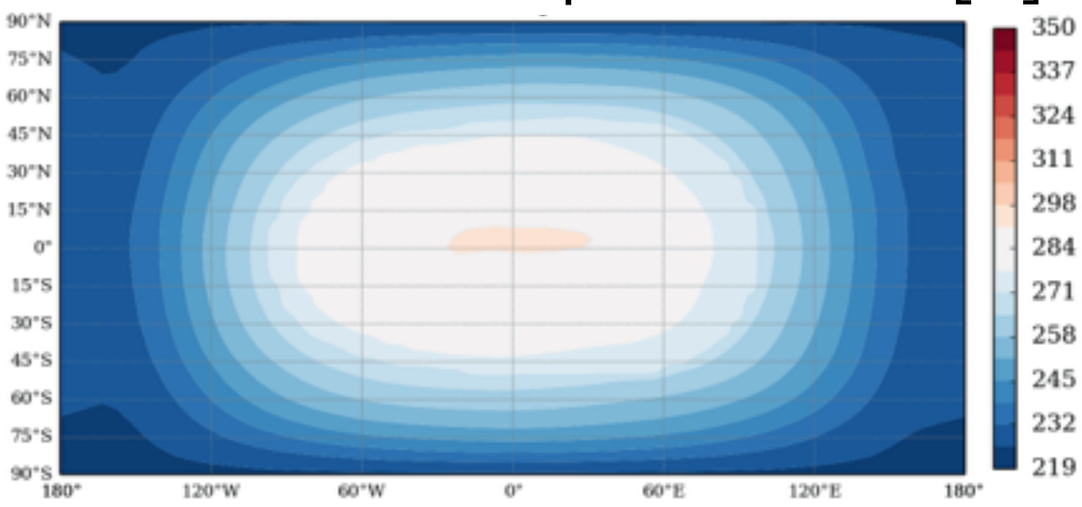
$L_\star = 10^{-2}\, L_\odot$

e=0.2
P = 23.2 day

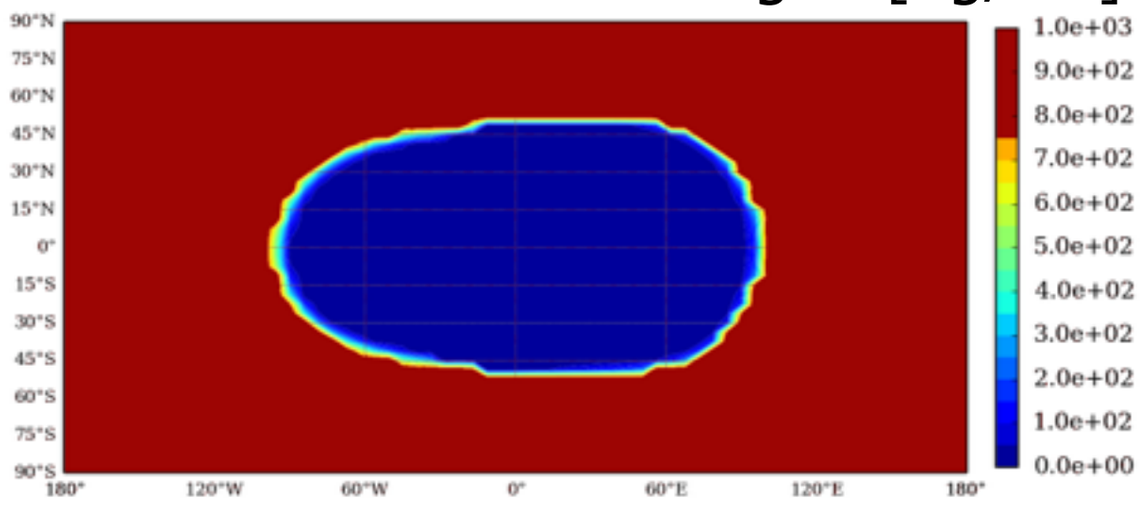


On the day side: 40K temperature oscillations in 20 days

Surface temperature [K]



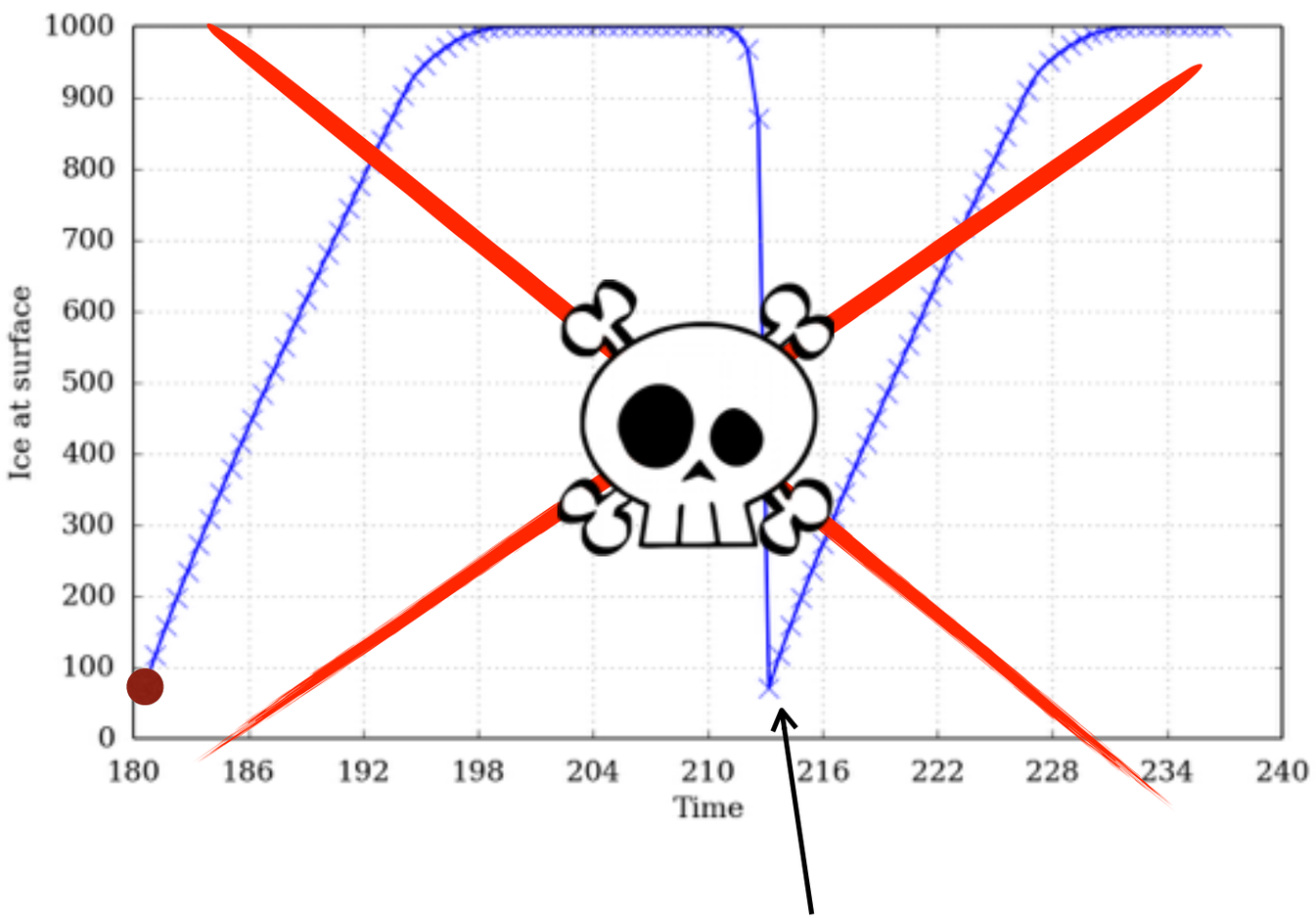
Surface ice coverage [kg/m^2]



Limits of the mean flux approximation

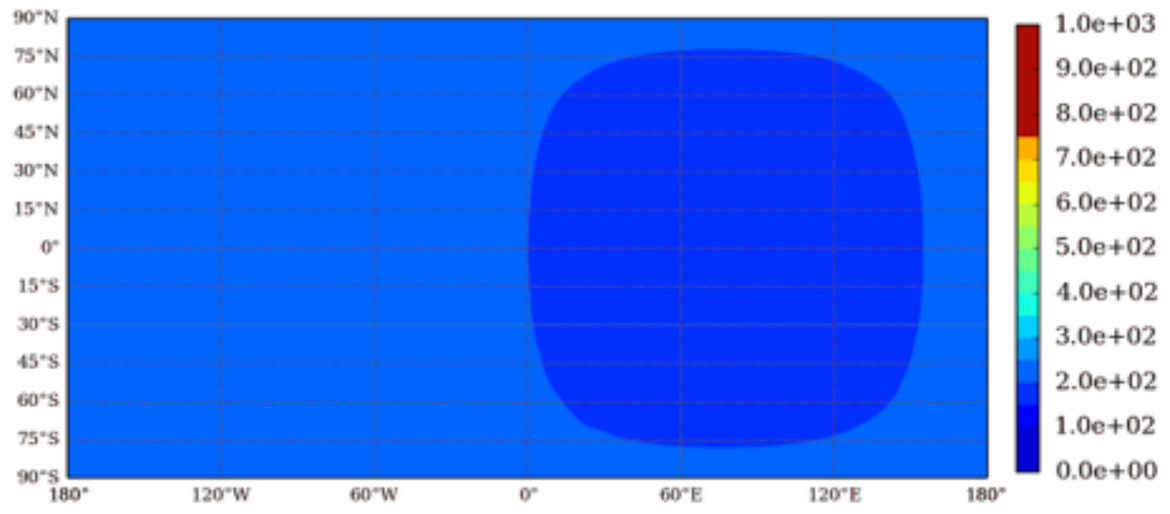
$L_\star = 10^{-2}\, L_\odot$

e=0.9
P = 42.6 day



Thin layer of ice

Surface ice coverage [kg/m²]

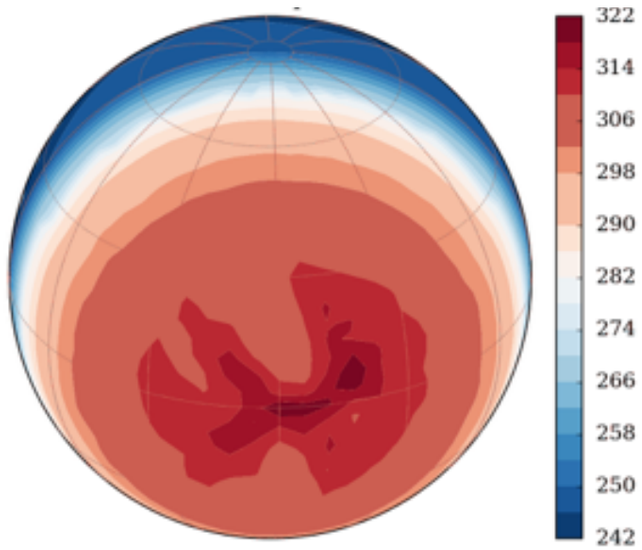


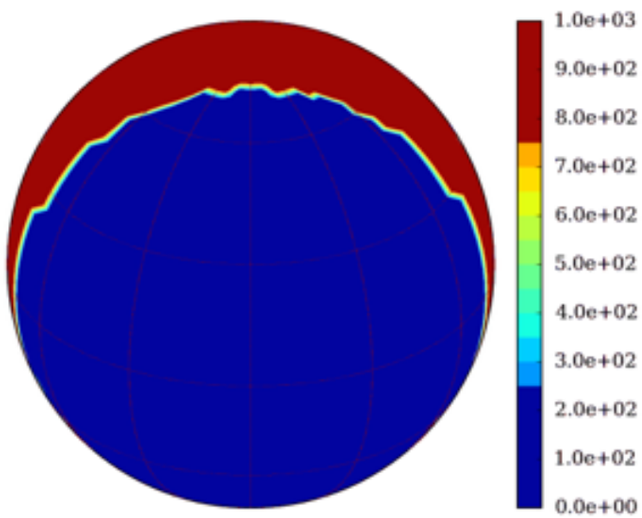
Limits of the mean flux approximation

$L_\star = 10^{-4}\ L_\odot$

$L_\star = 1\ L_\odot$
P = 365 day

Surface temperature [K]

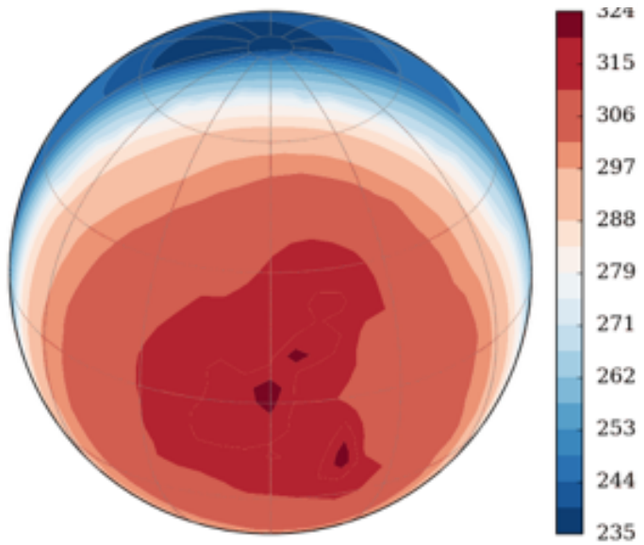


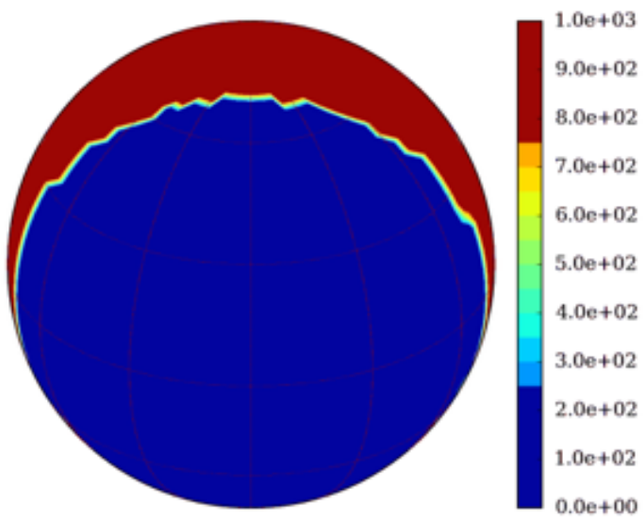


Surface ice coverage [kg/m^2]

$L_\star = 10^{-2}\ L_\odot$
P = 22.9 day

Surface temperature [K]

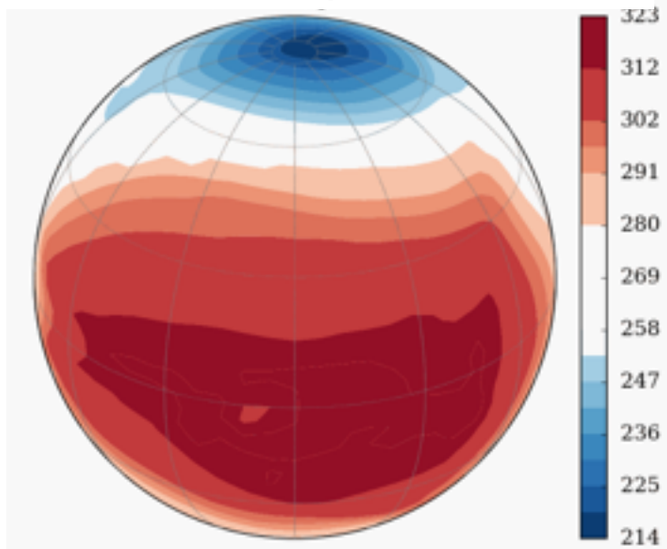


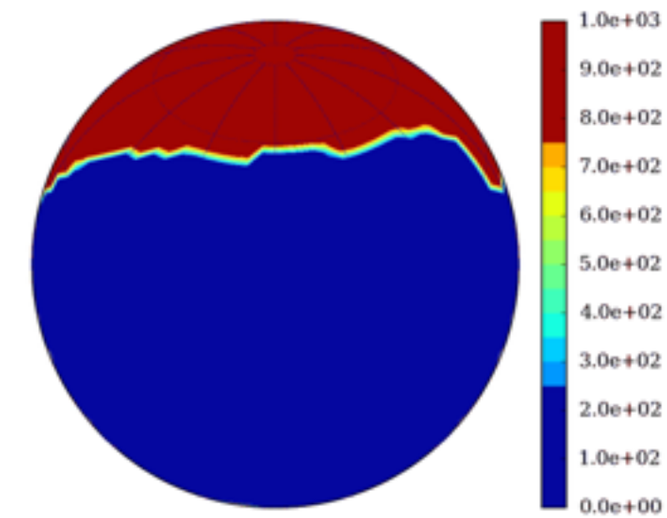


Surface ice coverage [kg/m^2]

$L_\star = 10^{-4}\ L_\odot$
P = 1.967 day

Surface temperature [K]



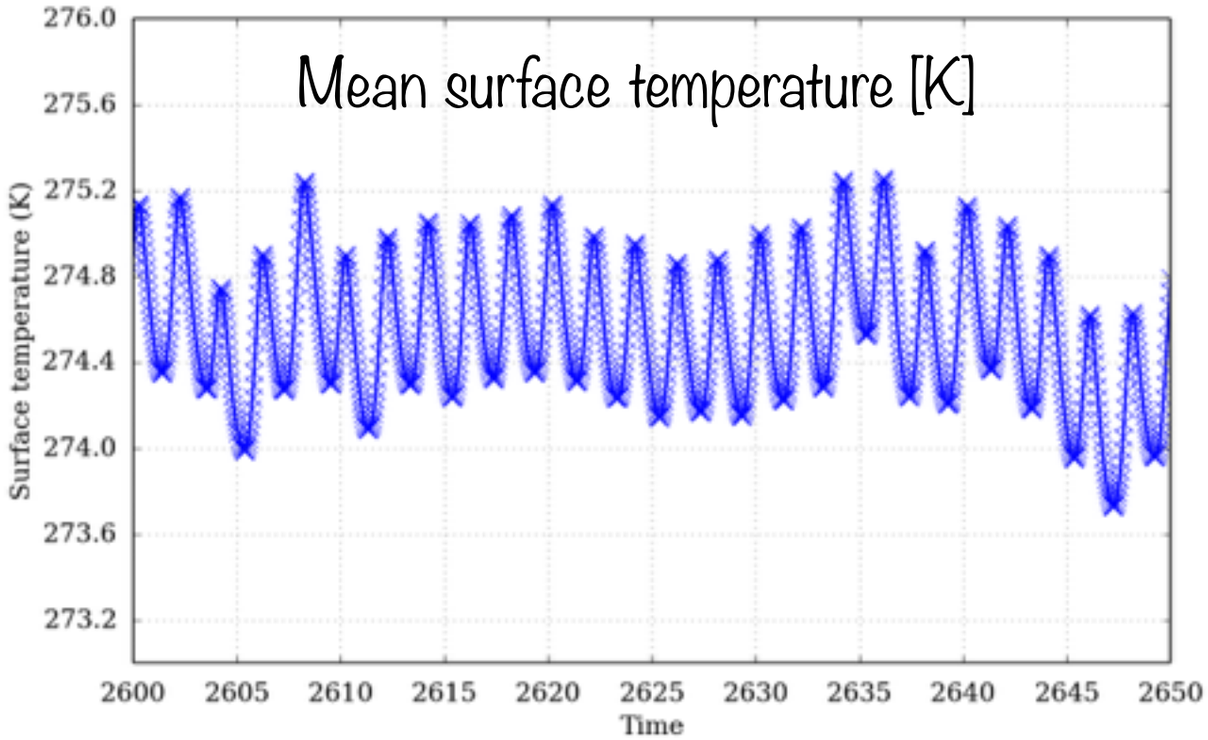


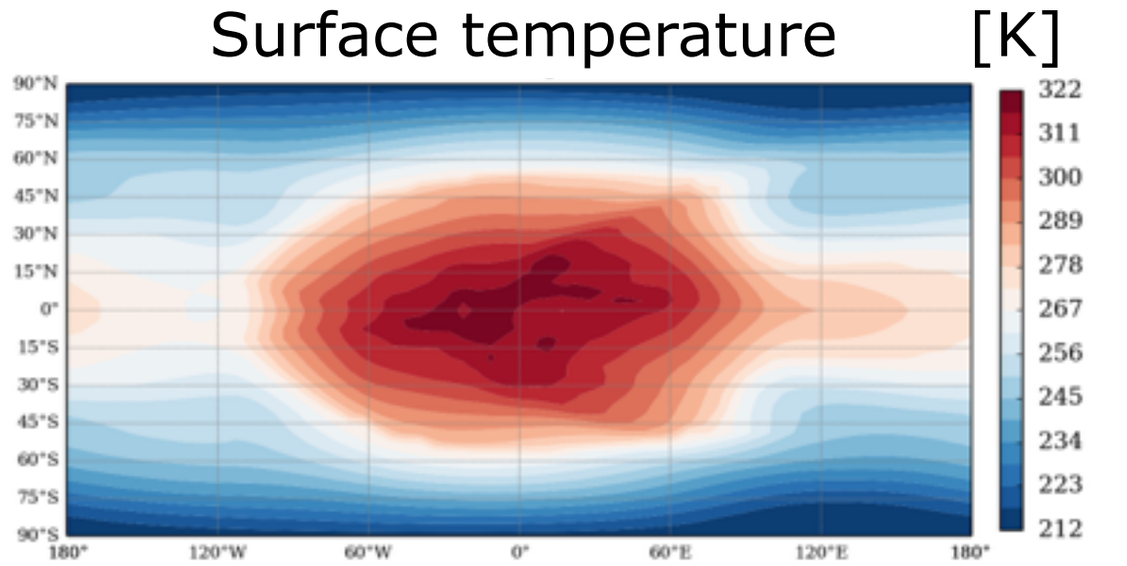
Surface ice coverage [kg/m^2]

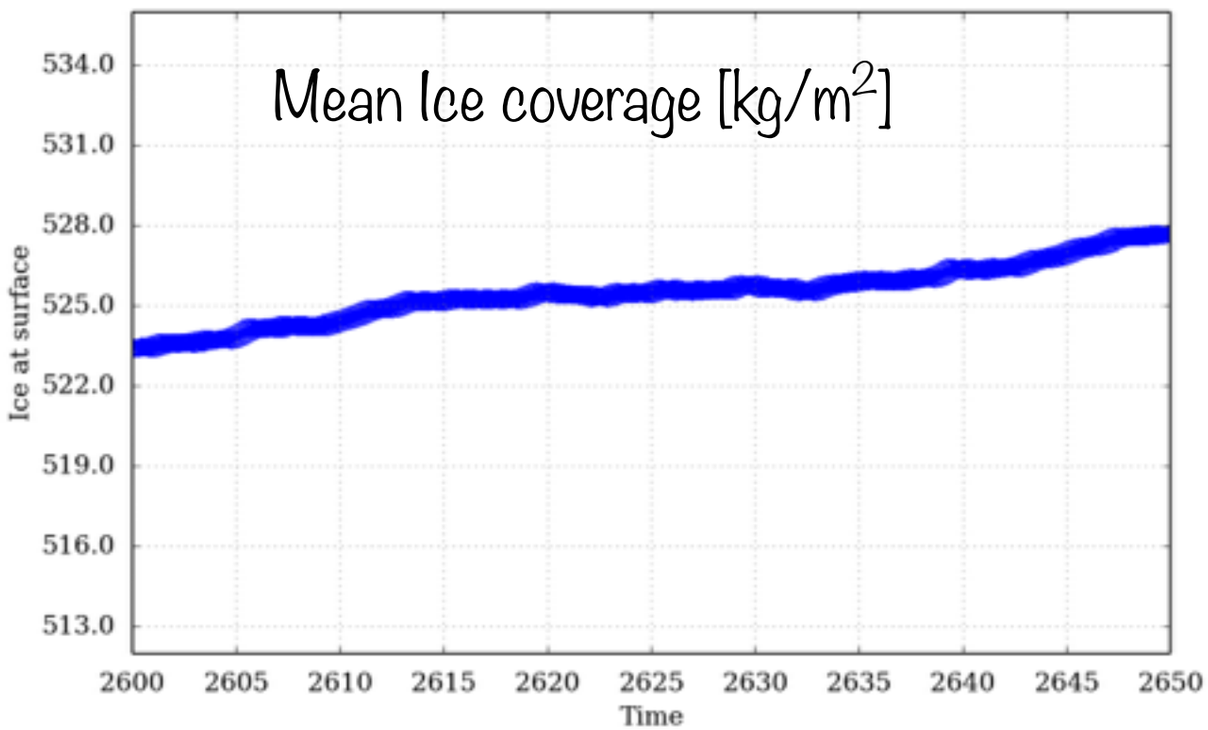
Limits of the mean flux approximation

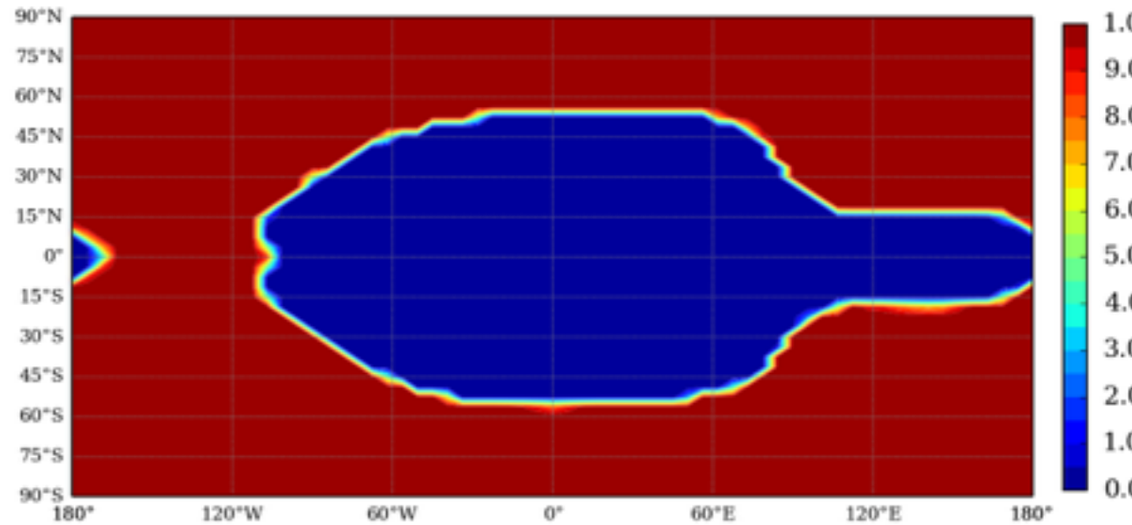
$L_\star = 10^{-4}\, L_\odot$

e=0.2
P = 1.997 day





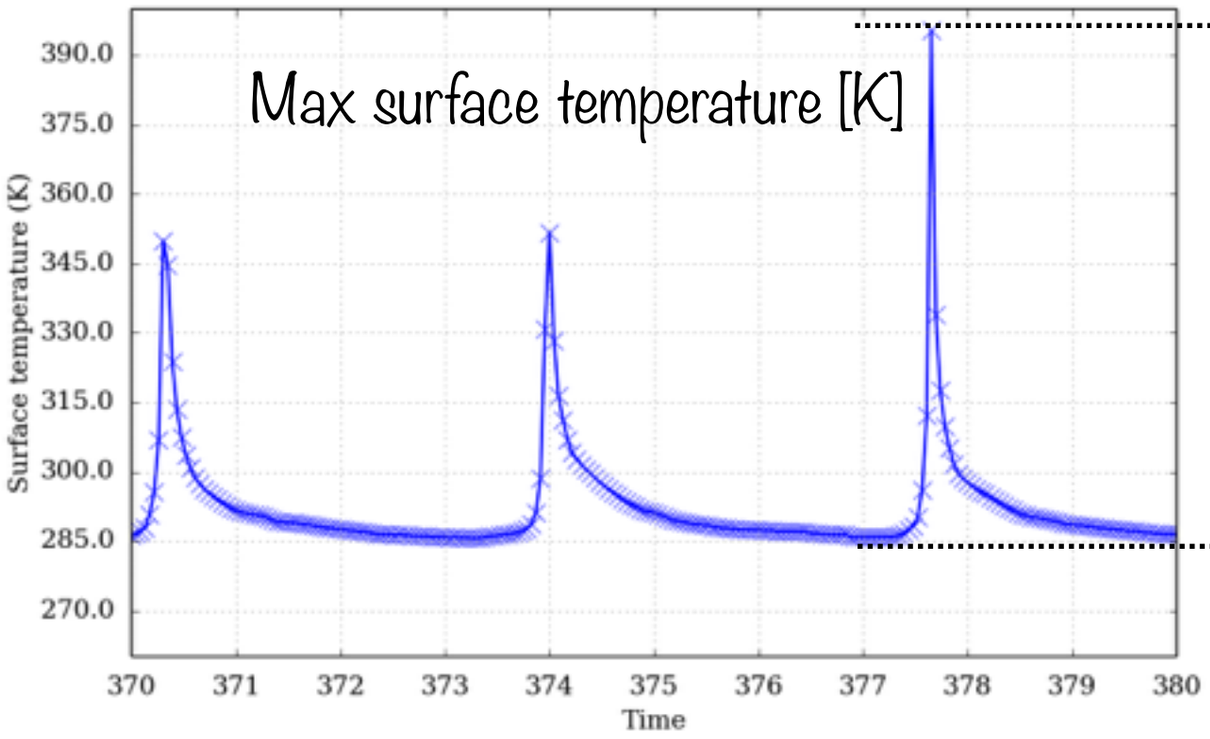




Limits of the mean flux approximation

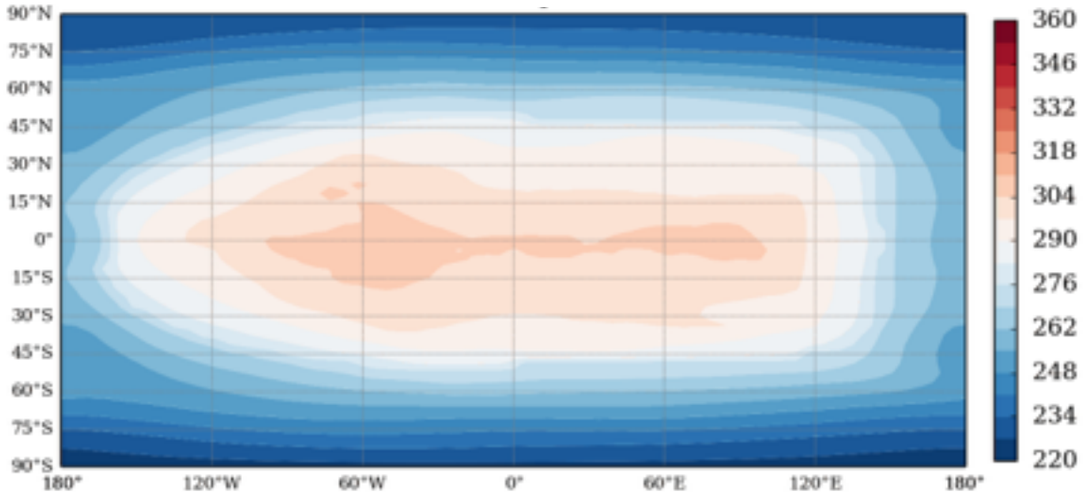
$L_\star = 10^{-4} L_\odot$

e=0.9
P = 3.666 day

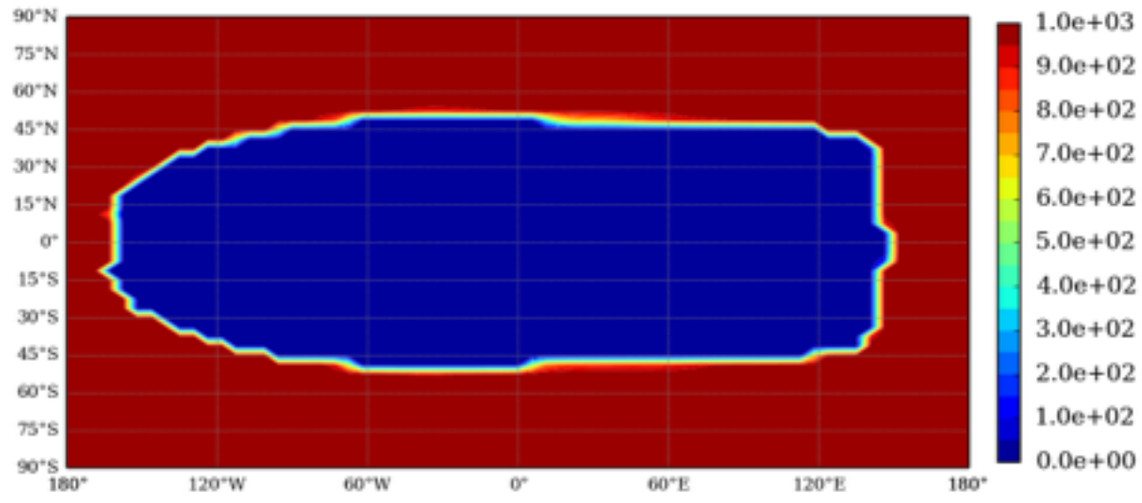


On the day side: up to 100K temperature oscillations in 4 days!

Surface temperature [K]



Surface ice coverage [kg/m^2]



Limits of the mean flux approximation

Habitability of eccentric ocean planets

Habitability = presence of surface liquid water

- Tidally locked ocean planets are only locally habitable on the day side.

- For low eccentricities, for all $L_\star$, the planets are locally habitable
  For $L_\star = 10^{-4}\ L_\odot$, for all ecc, the planets are locally habitable

- Planets around luminous stars with high eccentricities are only temporally habitable around periastron (for $e \gtrsim 0.6$ for $L_\star = 1\ L_\odot$, for $e \gtrsim 0.8$ for $L_\star = 10^{-2}\ L_\odot$). For $L_\star = 10^{-2}\ L_\odot$, $e = 0.9$, the planet is never habitable.

- For moderate to high eccentricities, the day side temperature variations over a period of 365 days ($L_\star = 1\ L_\odot$) to 4 days ($L_\star = 10^{-4}\ L_\odot$) can be huge, this could have detrimental consequences for eventual life forms.

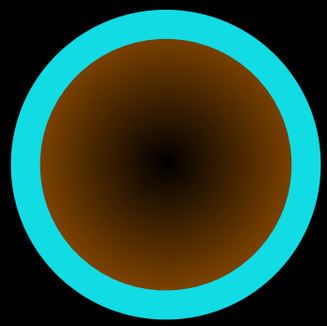
Limits of the mean flux approximation

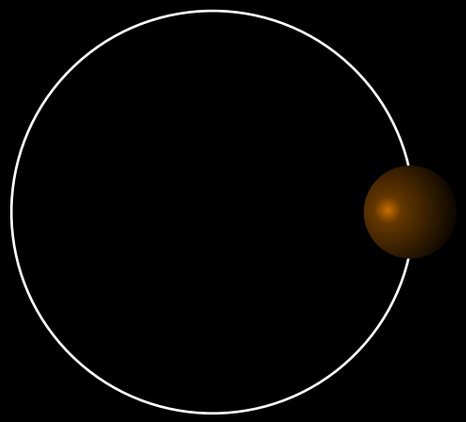
Habitability of eccentric ocean planets

Habitability = presence of surface liquid water

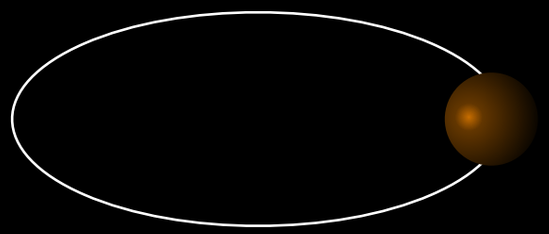
For the planets we consider here…

Ocean planets





Synchronous rotation
zero obliquity



The higher the eccentricity of the planet or the higher the luminosity of the star, the less reliable is the mean flux approximation

Limits of the mean flux approximation

Next steps

- Take into account the spectral type of the stars (with François Forget and Martin Turbet, LMD)

  ➡ Effect on the ice-albedo feedback

- Consider other types of planets

  ➡ Earth-like planet, land planet, a planet with a Pangea-like continent, a planet with archipelagos

- Change the rotation rate of the planet

- Change the obliquity of the planet

- Investigate the impact of the tidal heat flux on the climates

- Investigate the effect of eccentricity oscillations on the climates

Thank you!

Thank you!

Limits of the mean flux approximation

$L_\star = 1\ L_\odot$

e=0.9