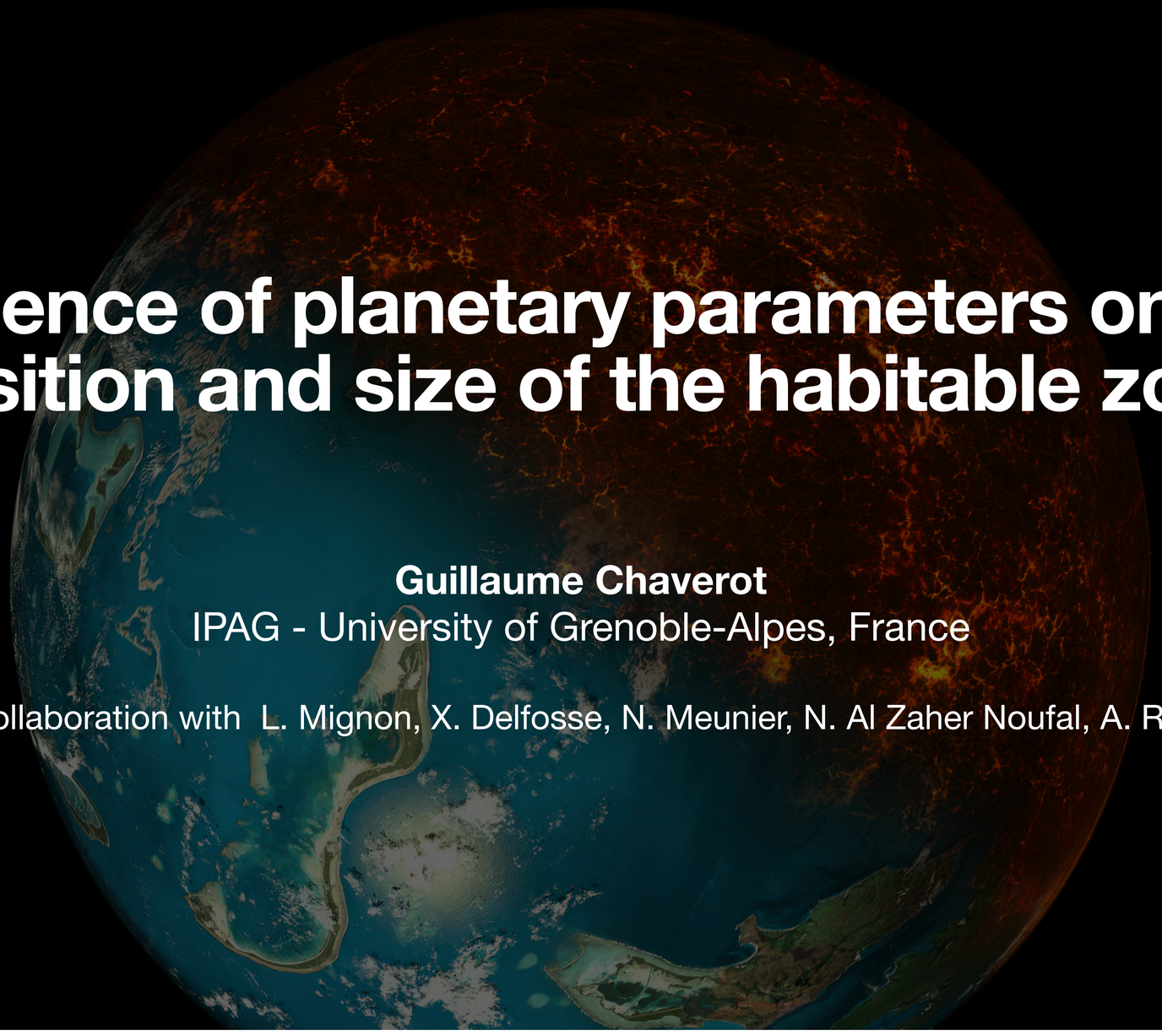
Influence of planetary parameters on the position and size of the habitable zone



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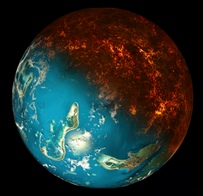
In collaboration with L. Mignon, X. Delfosse, N. Meunier, N. Al Zaher Noufal, A. Revol

IPAG Institut de Planétologie et d'Astrophysique de Grenoble
cnes
UGA Université Grenoble Alpes
Origin of Life Université Grenoble Alpes
Swiss National Science Foundation



The Habitable Zone

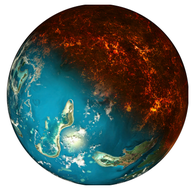
First concept: Huang (1959), Hart (1978)

Evaporated water

Frozen water

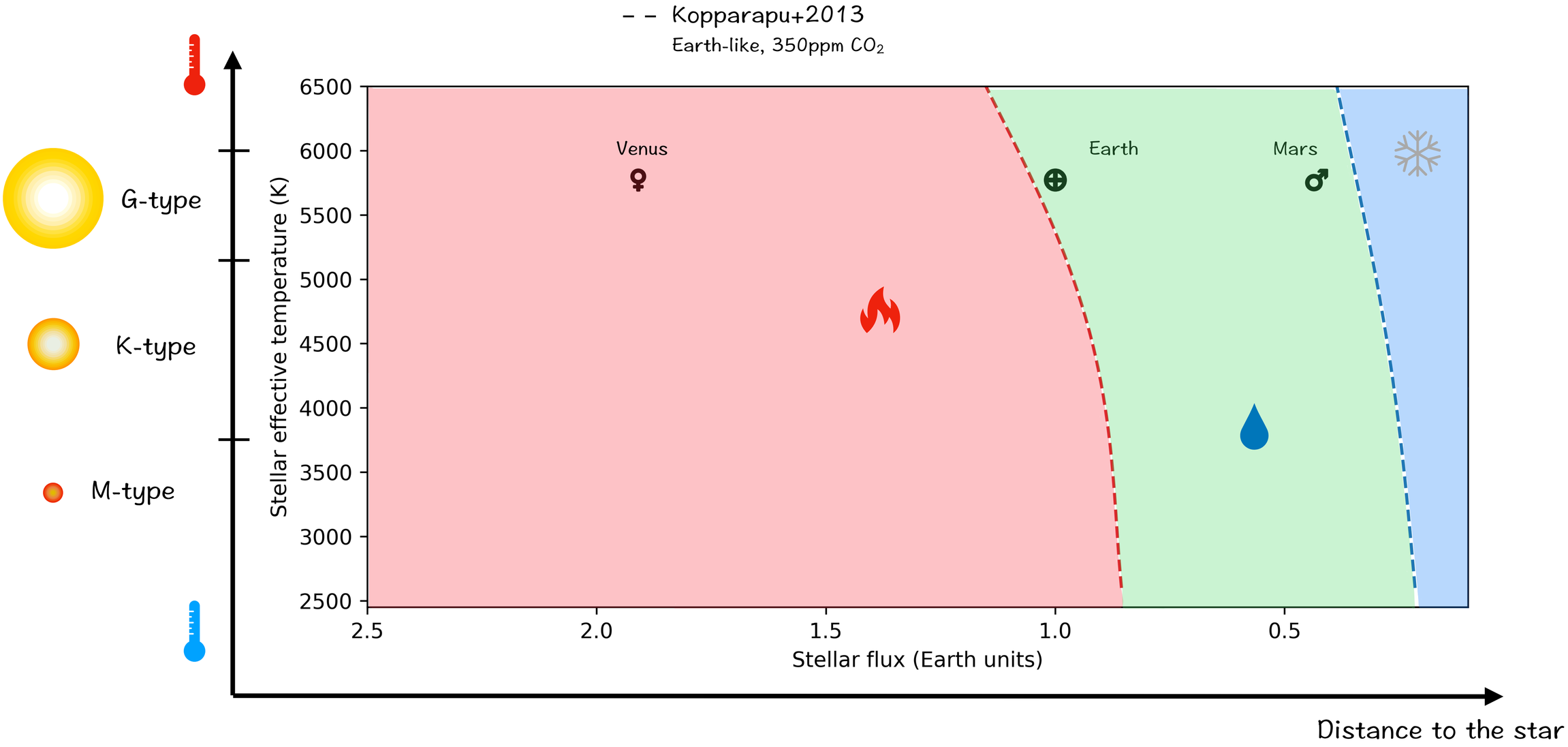
Liquid water

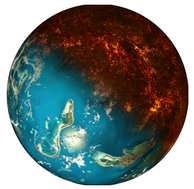
Credit: NASA/JPL-Caltech



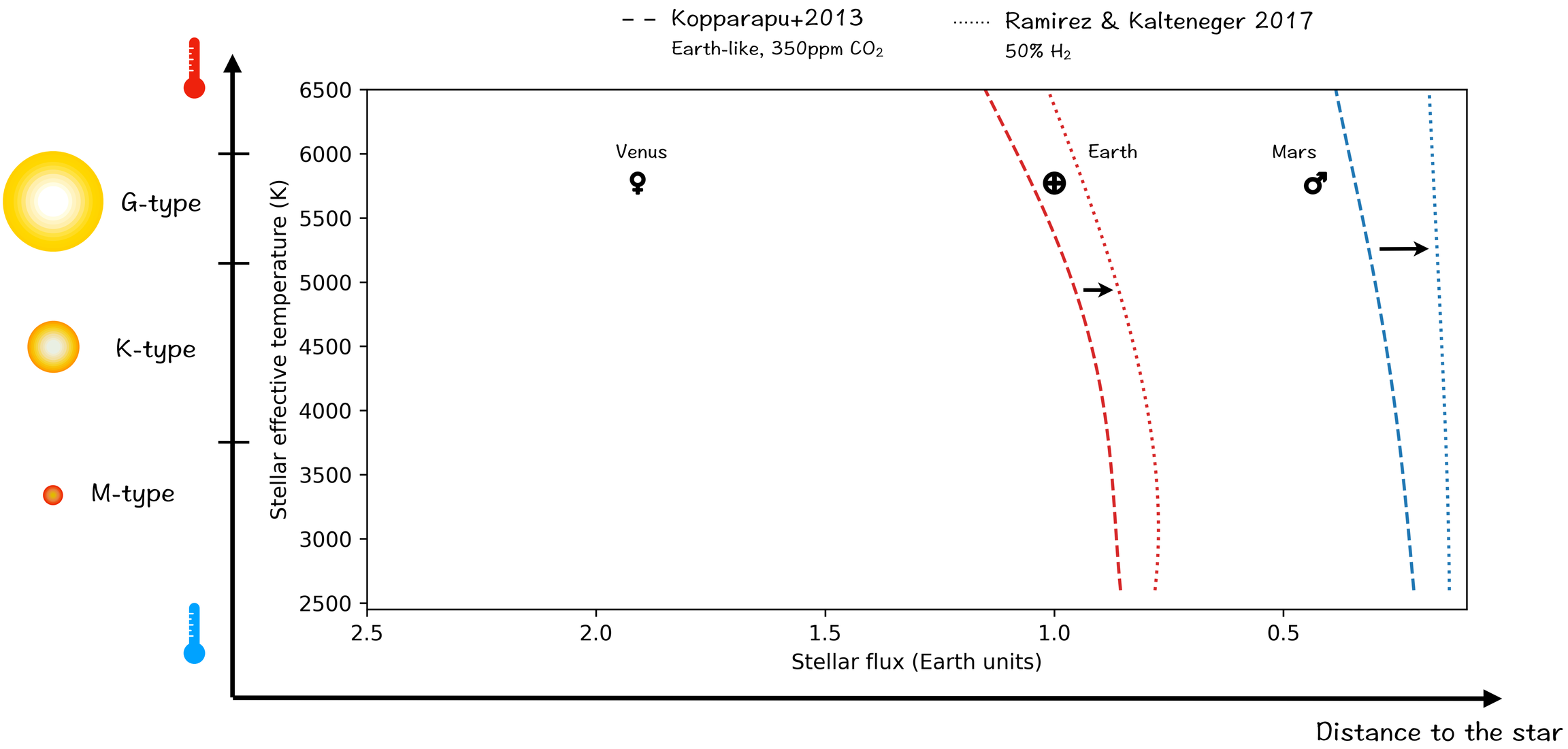
The Habitable Zone

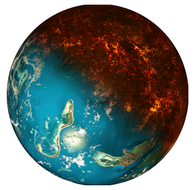
The 'Recent Venus' limit is not physically driven



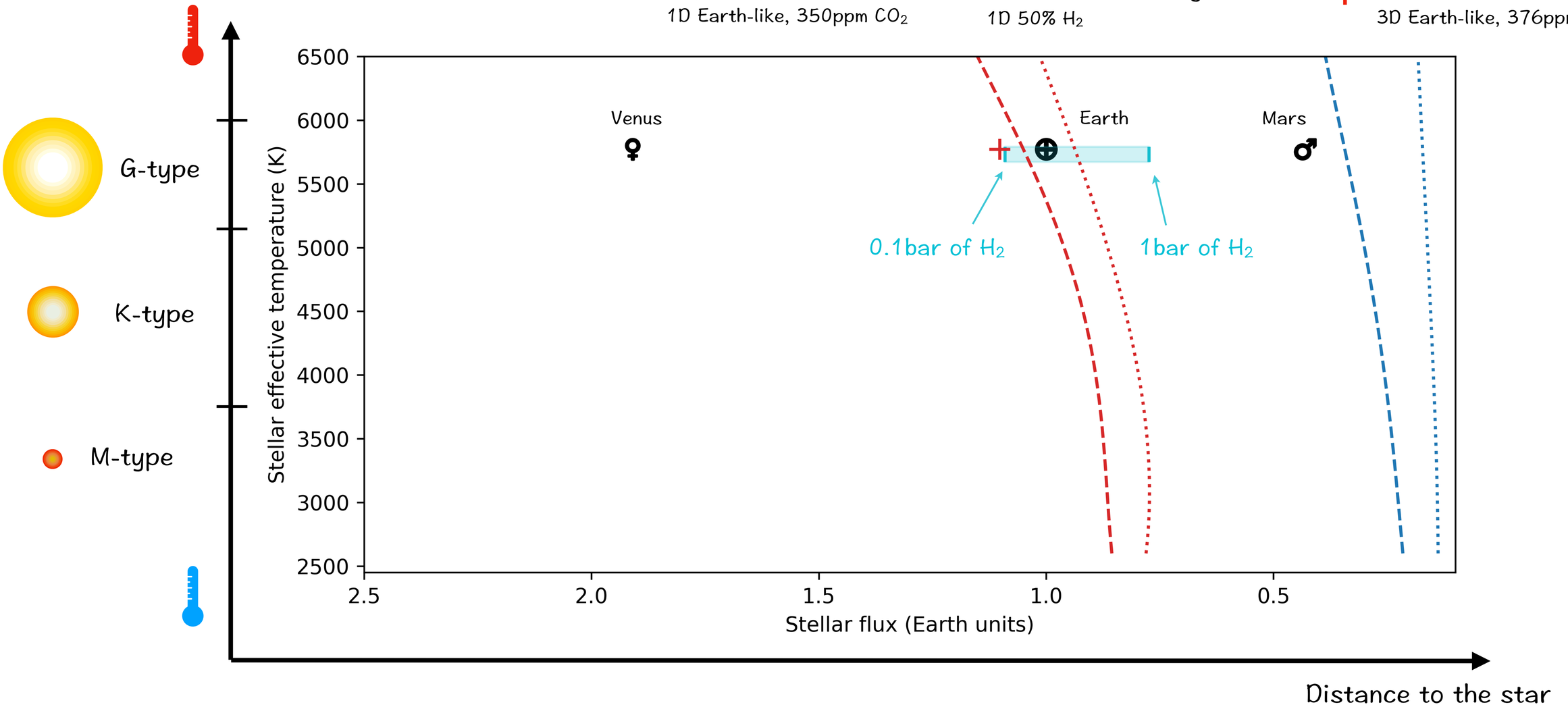


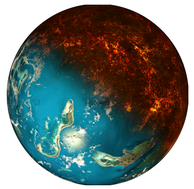
The Habitable Zone





The Habitable Zone





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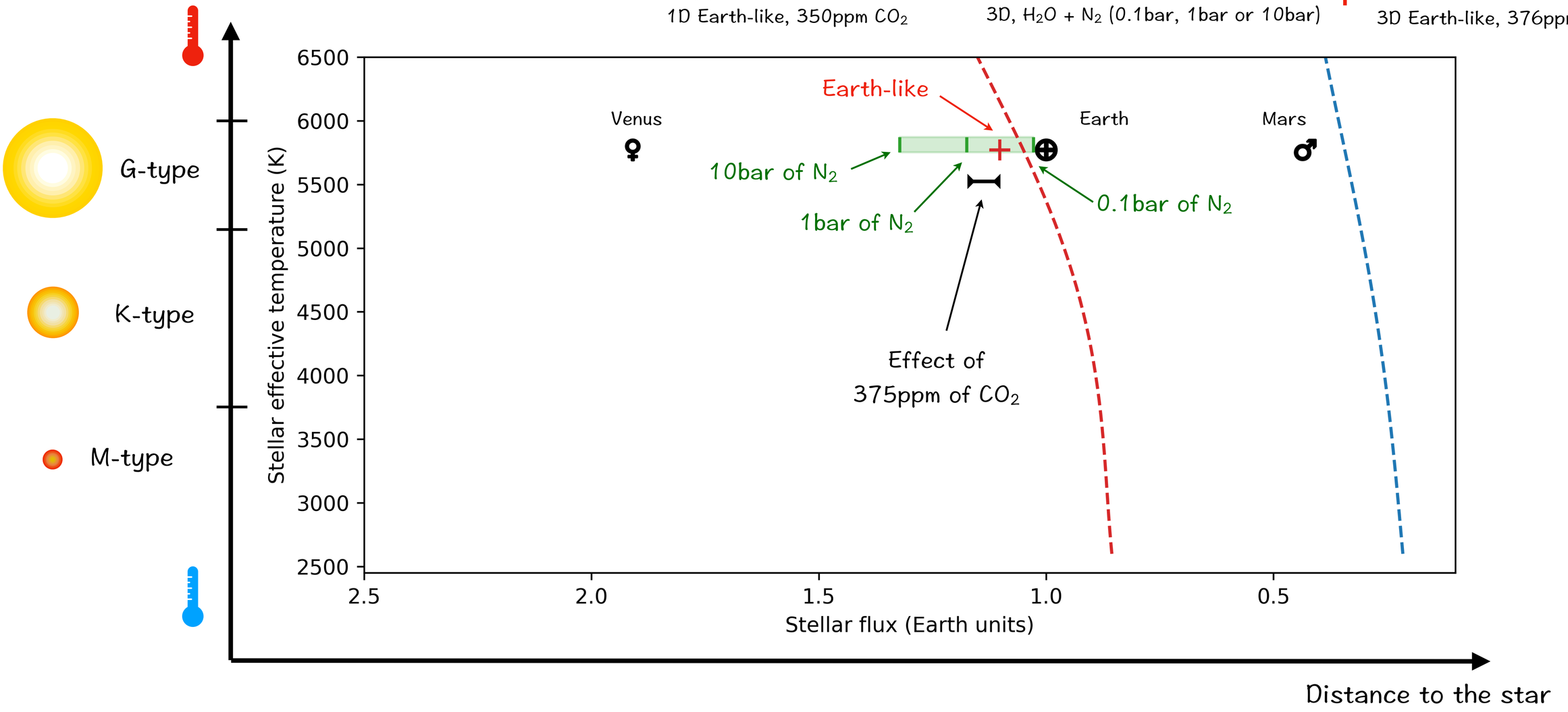
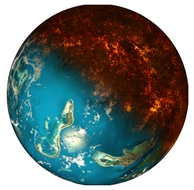
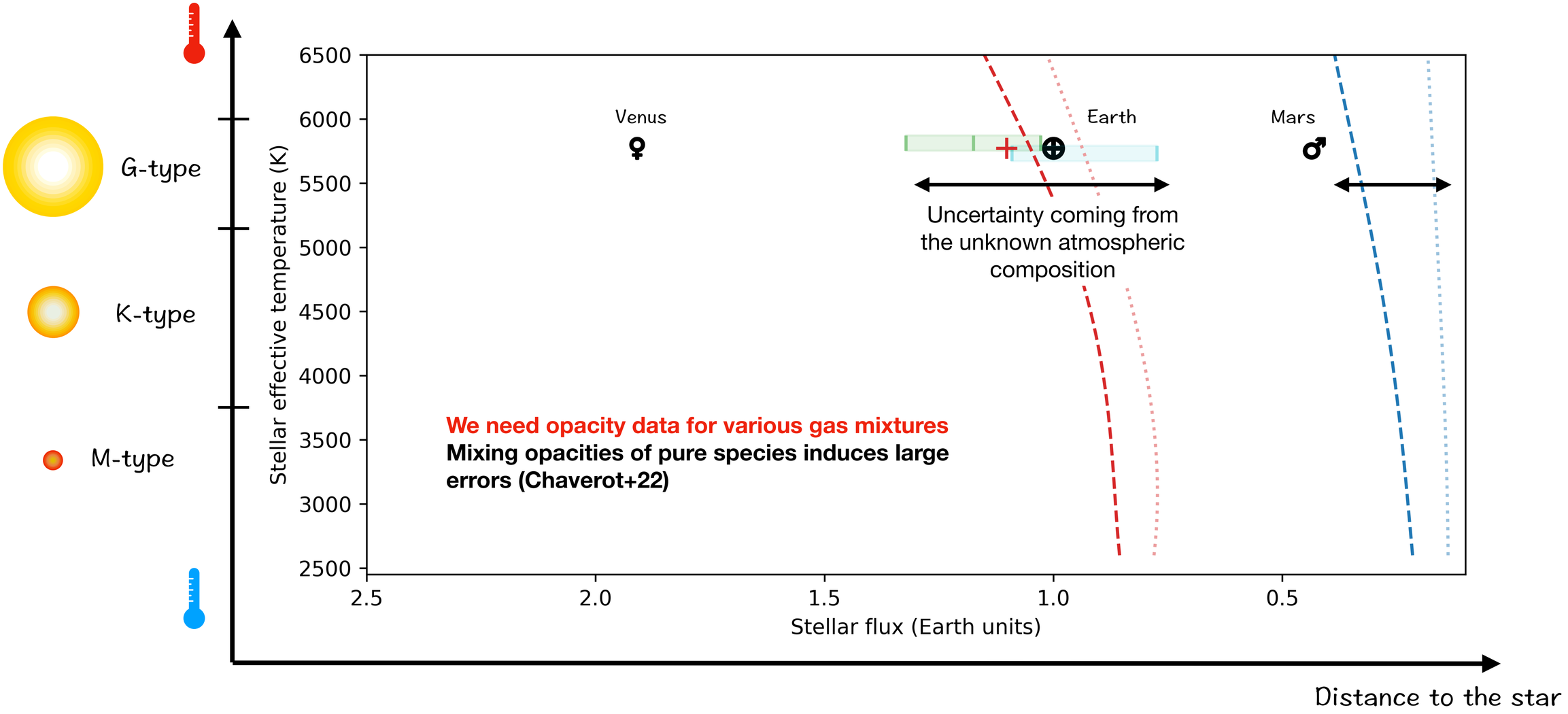
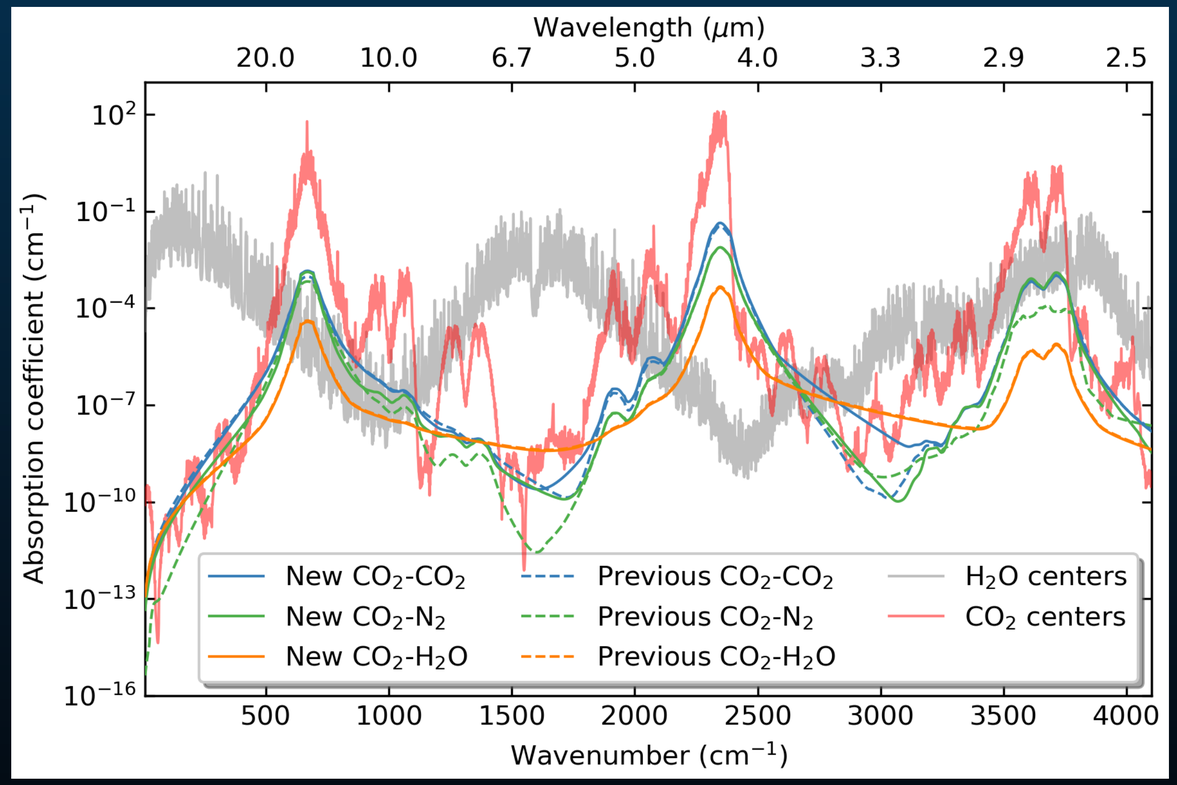




Issue of the unknown atmospheric composition



New opacity data for CO_2 gas mixtures

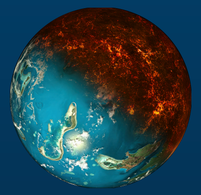


Chaverot et al. (2025)

- Correlated-k tables for CO_2+H_2O+N_2 mixtures
- Original continua of CO_2 mixtures
- Large update of correction factors (Chi factors) based on lab measurements

Accessible on zenodo:
-> doi.org/10.5281/zenodo.16795590

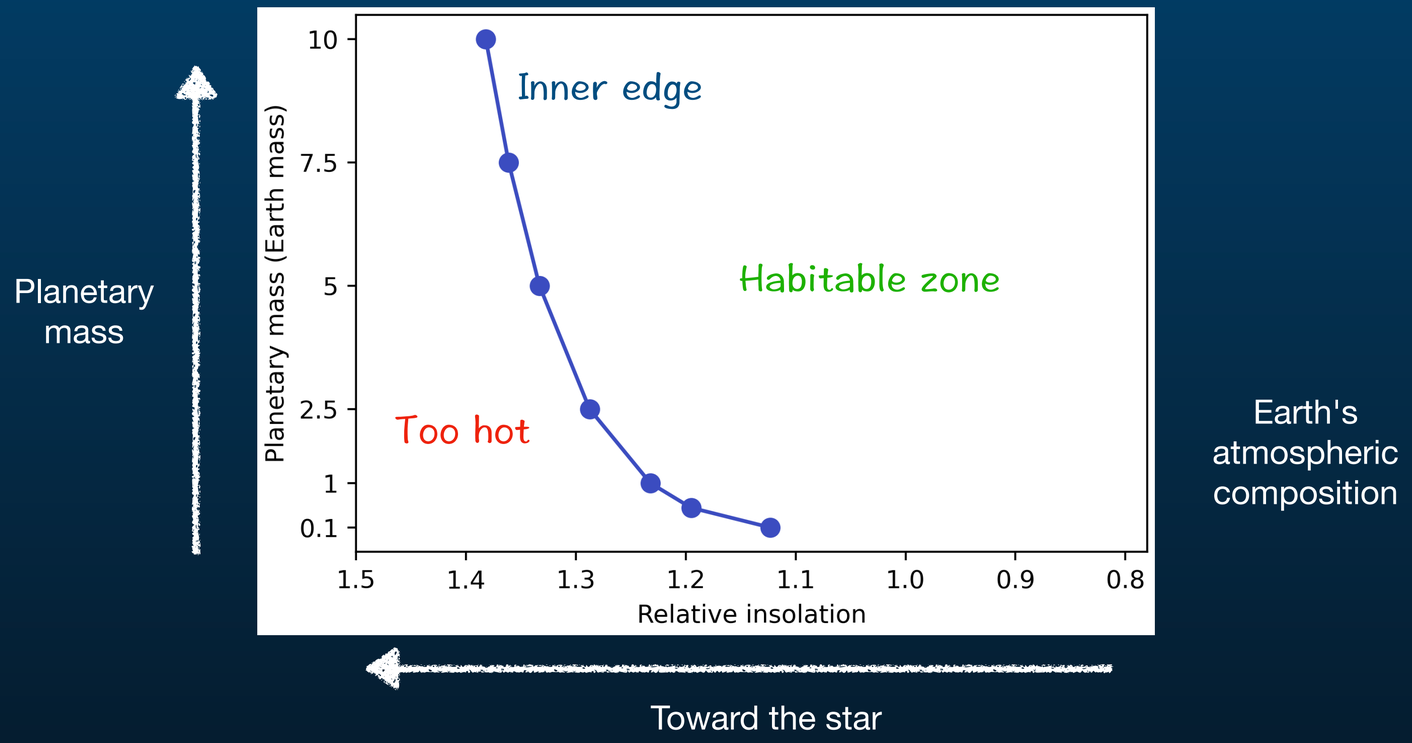
See also Chaverot et al. (2025)



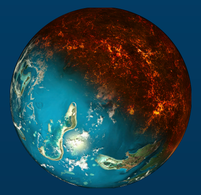
Planetary mass

Kopparapu et al. (2014)

More massive planets = larger HZ



Chaverot et al. (in prep.)



Planetary mass

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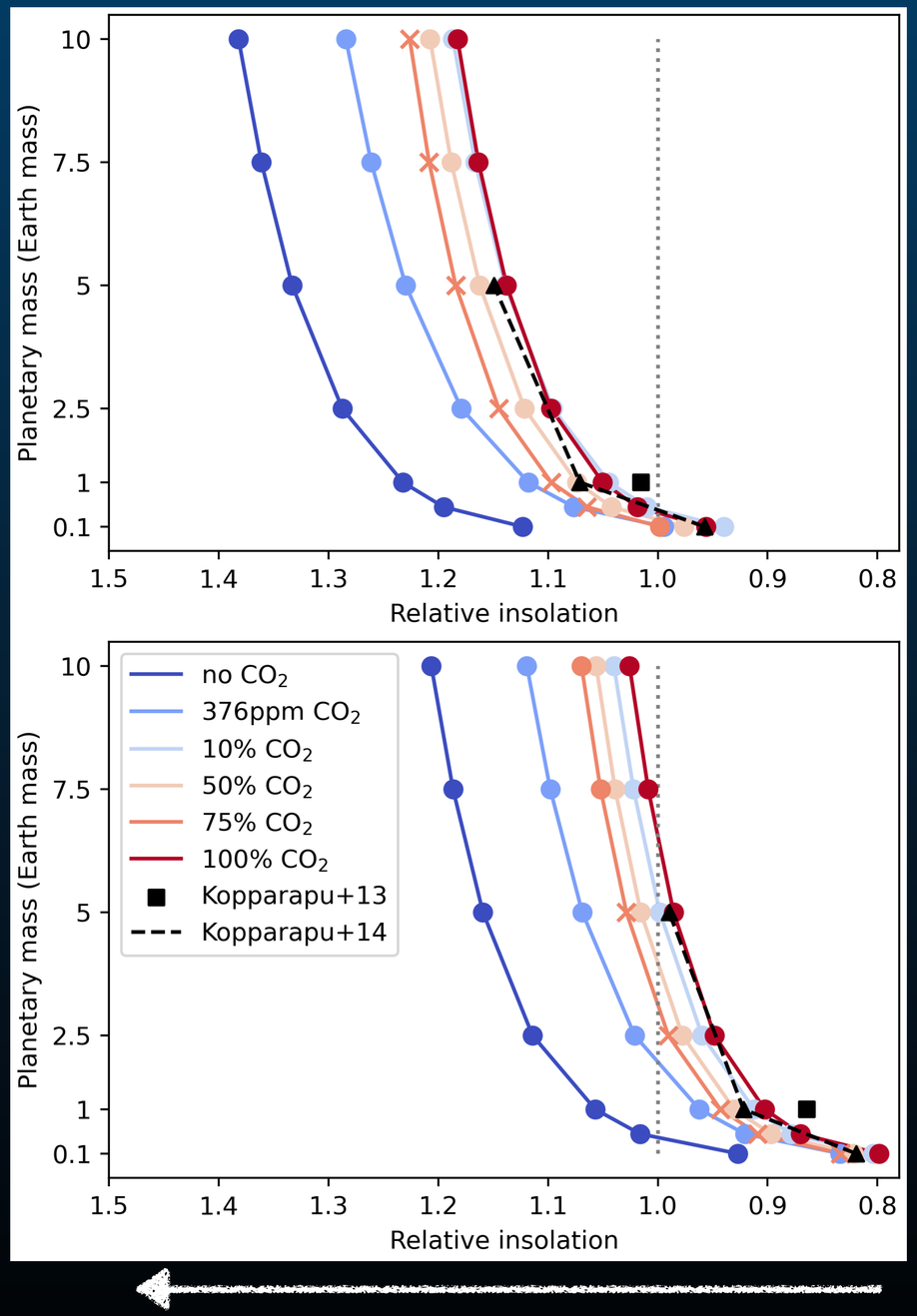
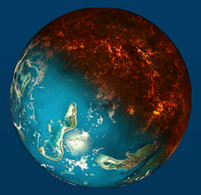
True for every atmospheric composition

Chaverot et al. (in prep.)





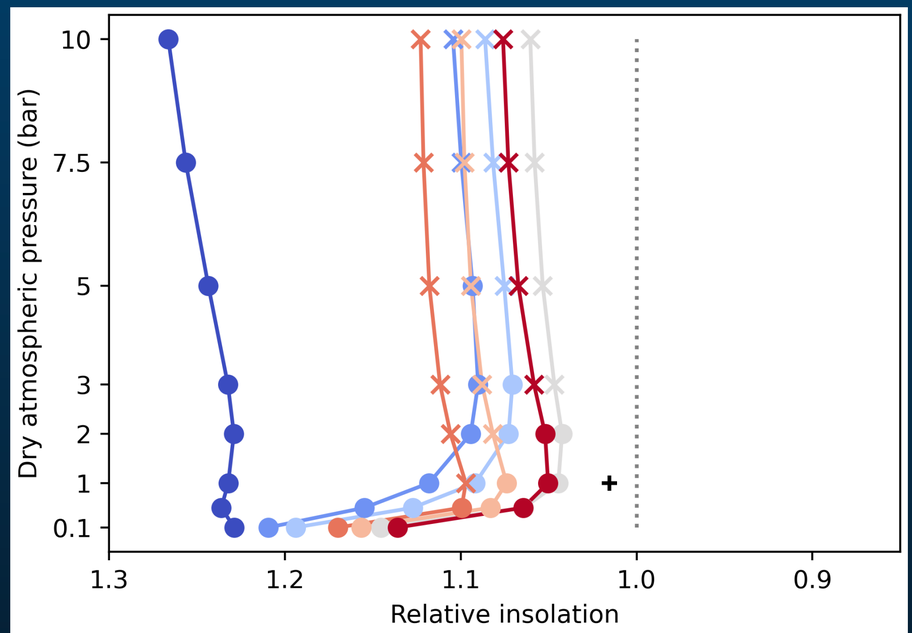
Atmospheric pressure

Atmospheric pressure

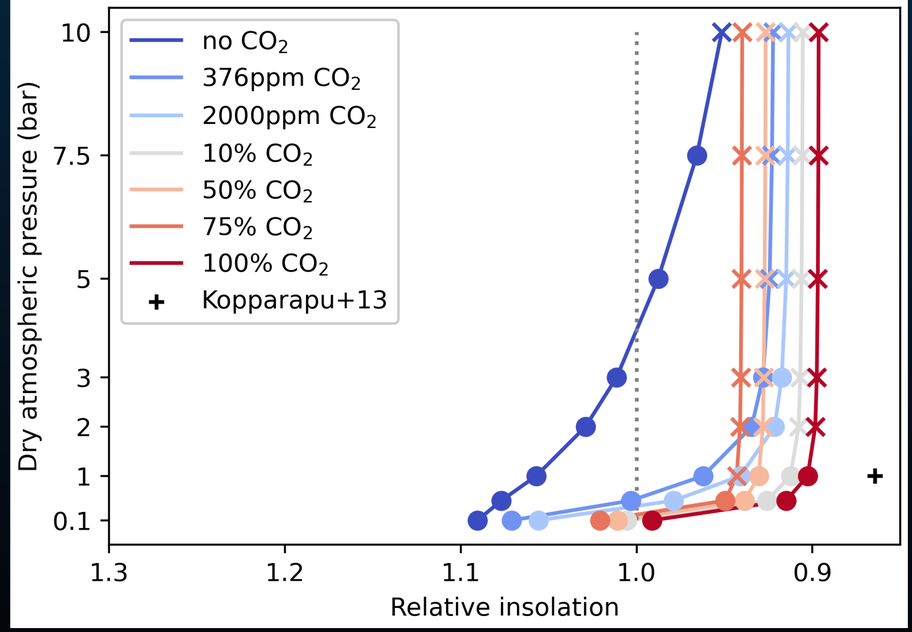
Thin atmospheres = larger HZ

No change beyond 3 bar of atmosphere, but hot equilibrium states

Atmospheric pressure



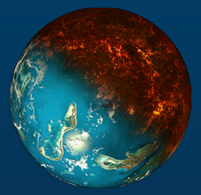
G-dwarf (5500K)



M-dwarf (3000K)

Toward the star

Chaverot et al. (in prep.)



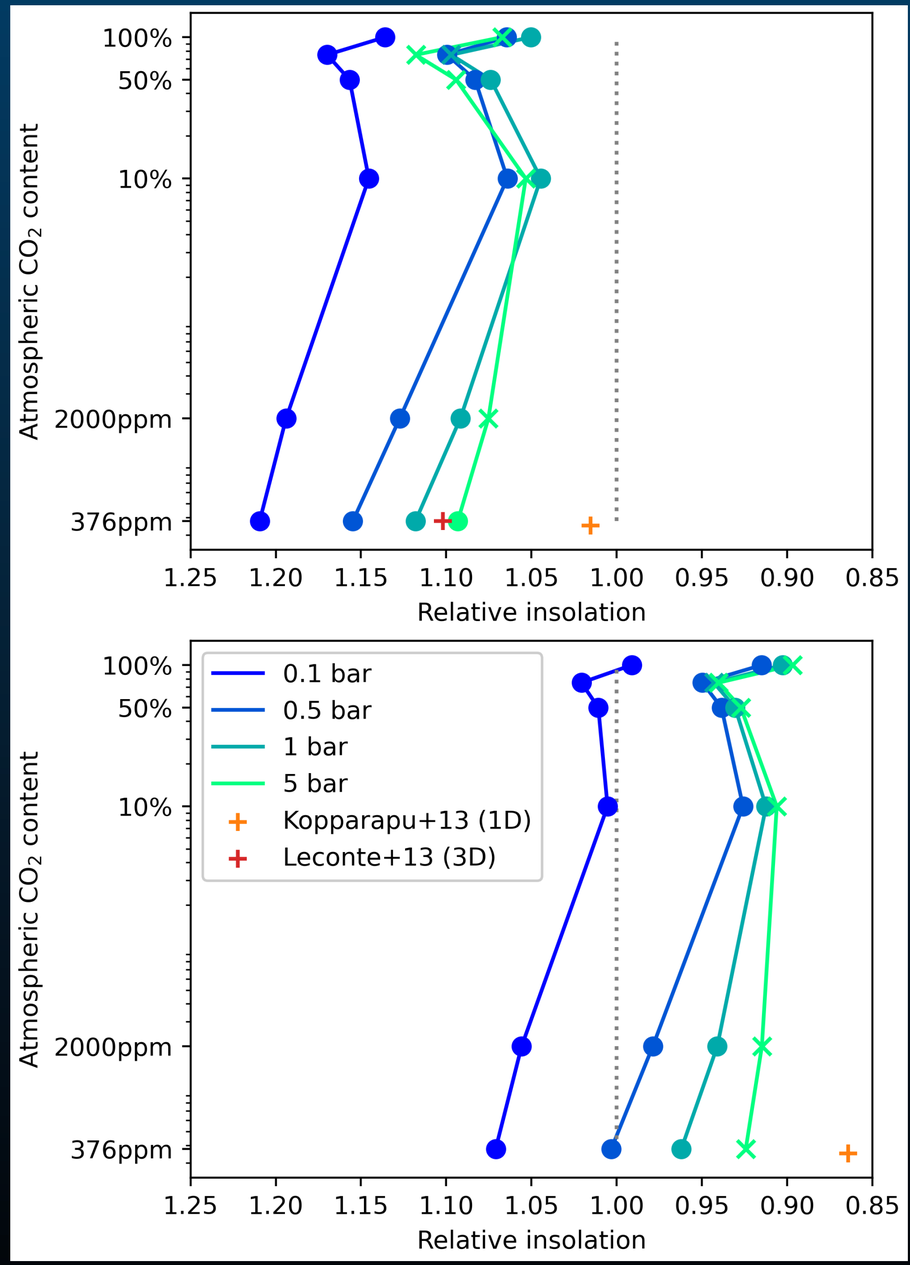
Atmospheric composition

CO_2 content

Non linear dependence between the position of the inner edge and the atmospheric composition

Competition between greenhouse effect and rayleigh scattering

CO_2 content



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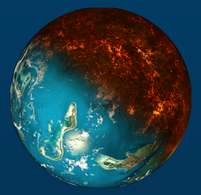
Chaverot et al. (in prep.)



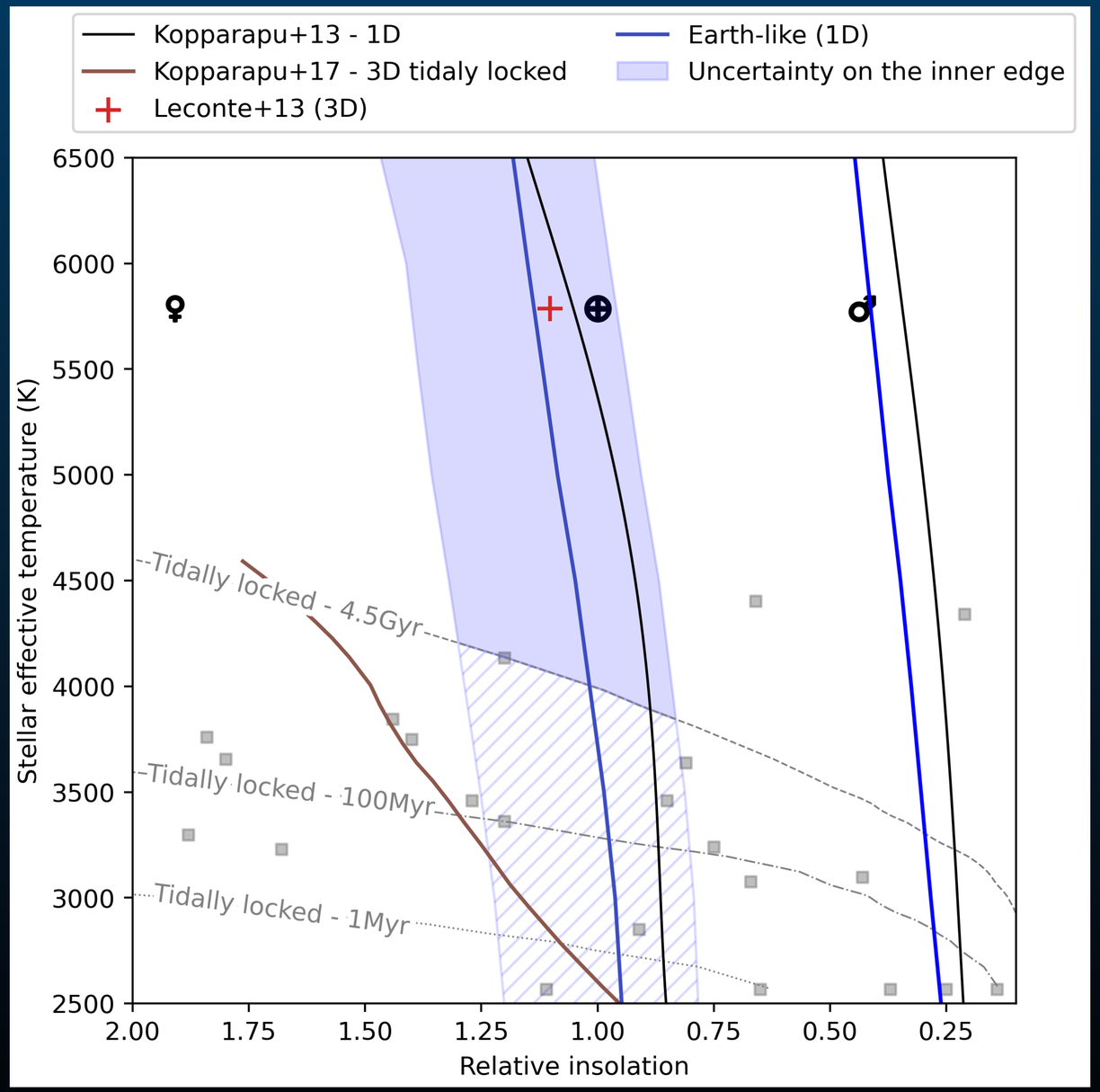
Various stellar types

Planetary parameters induce uncertainty on the inner edge of the HZ

- ~1/2 of the size of the HZ itself

For stars < 4000K, planets in the HZ are tidally locked

- requires 3D climate modelling
- Kopparapu+13,14 not applicable



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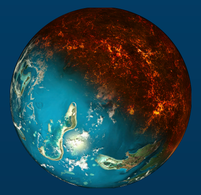

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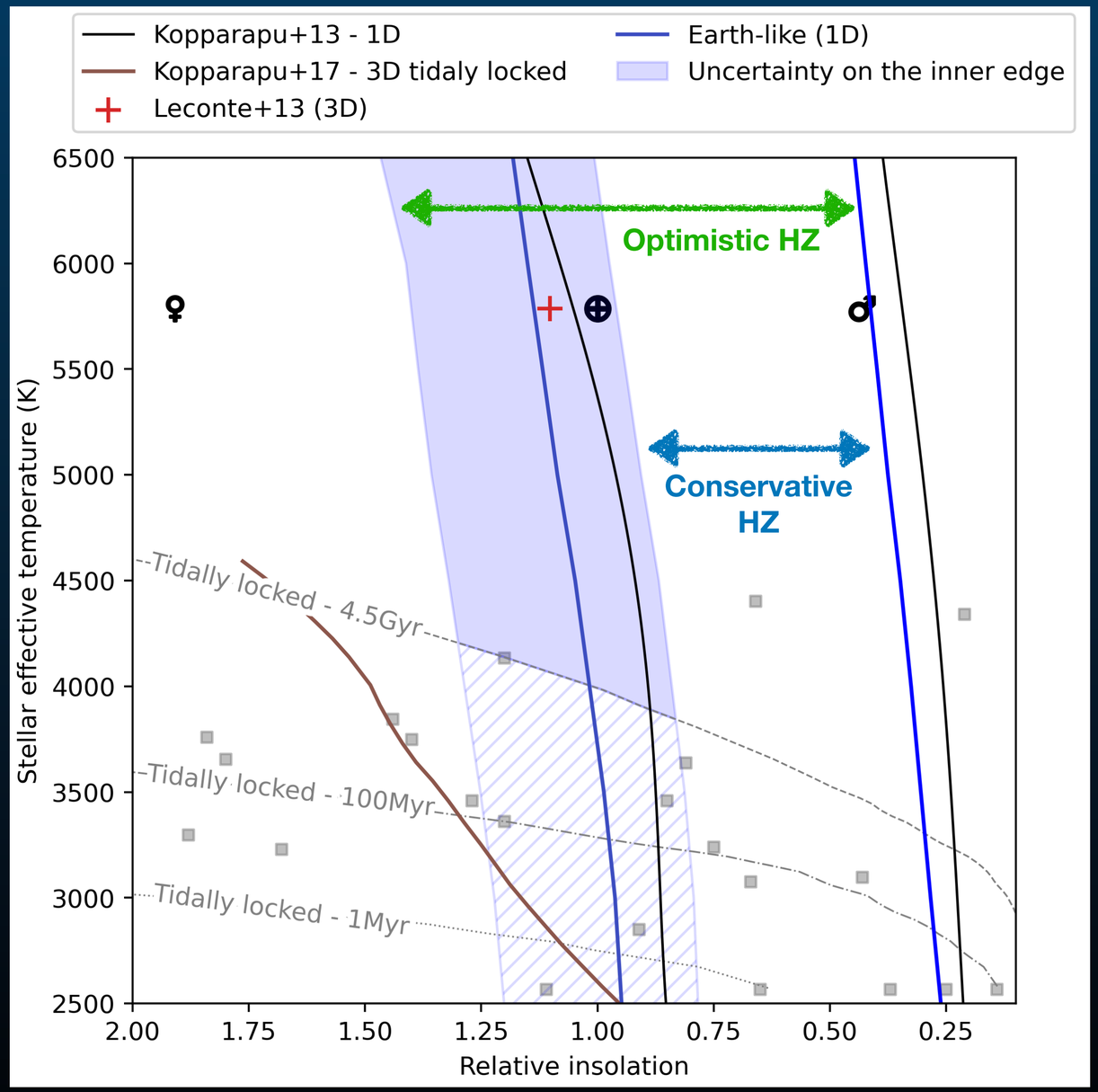

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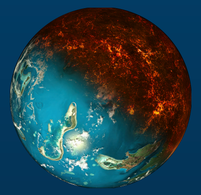

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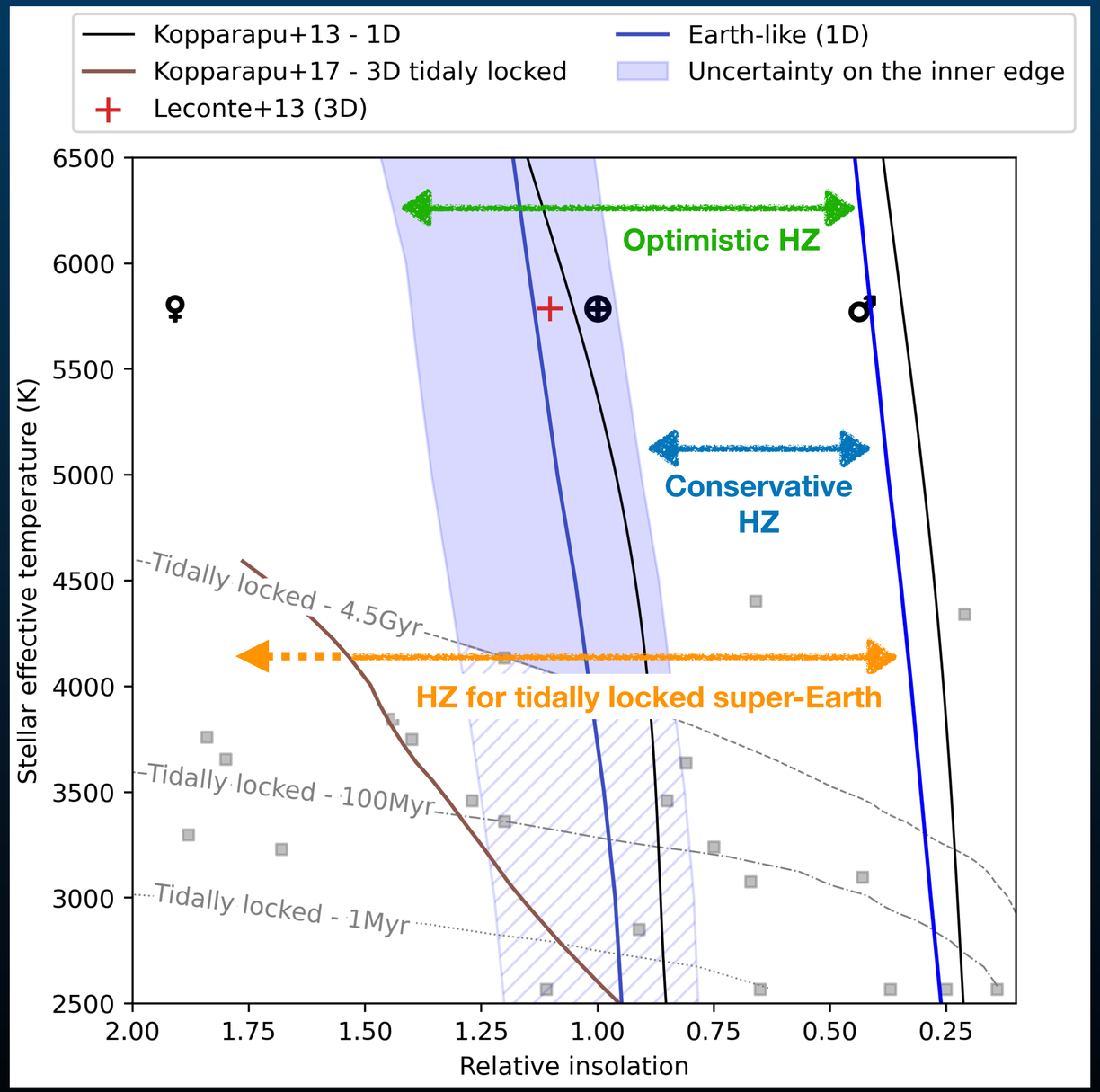
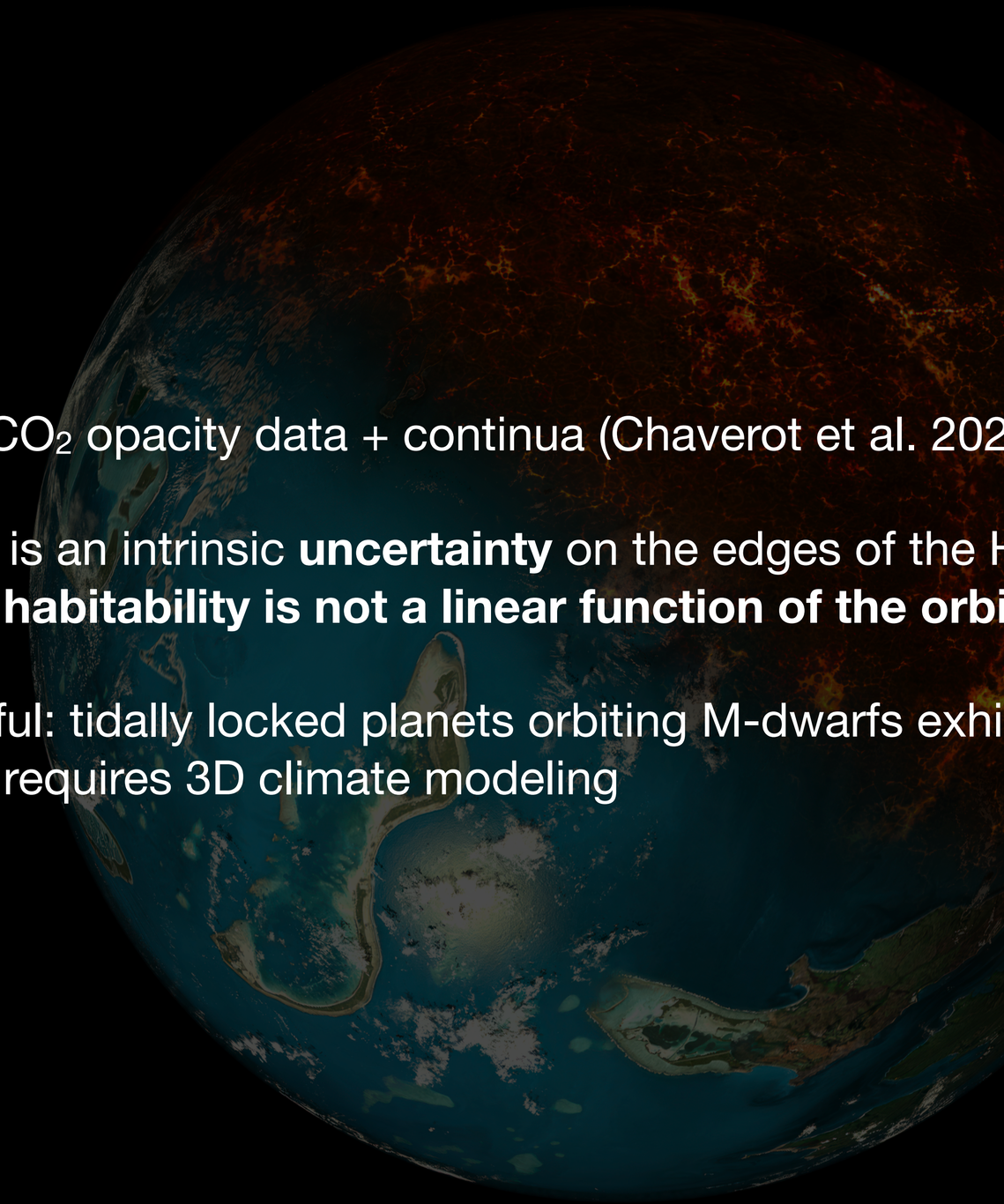
Sweet spot for massive planets around K-type stars (~4200K)



Chaverot et al. (in prep.)

Conclusions



Zenodo repository

1. New CO_2 opacity data + continua (Chaverot et al. 2025)

2. There is an intrinsic **uncertainty** on the edges of the HZ
   -> habitability is not a linear function of the orbital distance

3. Carreful: tidally locked planets orbiting M-dwarfs exhibit very different climates
   -> requires 3D climate modeling