ATMOSPHERIC EVOLUTION OF LOW-MASS PLANETS:
The role of the host star

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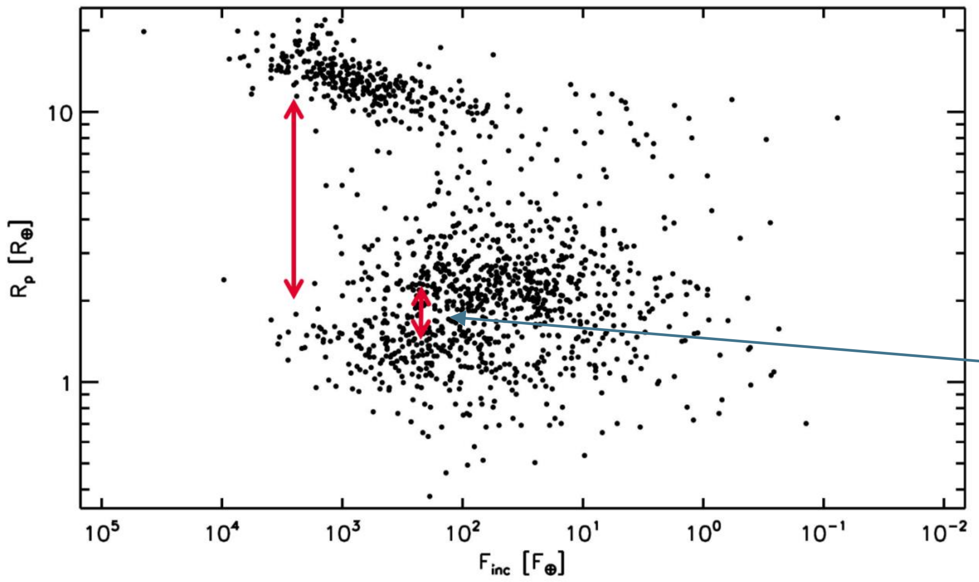
ATMOSPHERIC ESCAPE IS IMPRINTED IN THE POPULATION OF LOW-MASS PLANETS

Atmospheric escape plays a major role the evolution of individual planets and, hence, has imprints on the whole planetary population

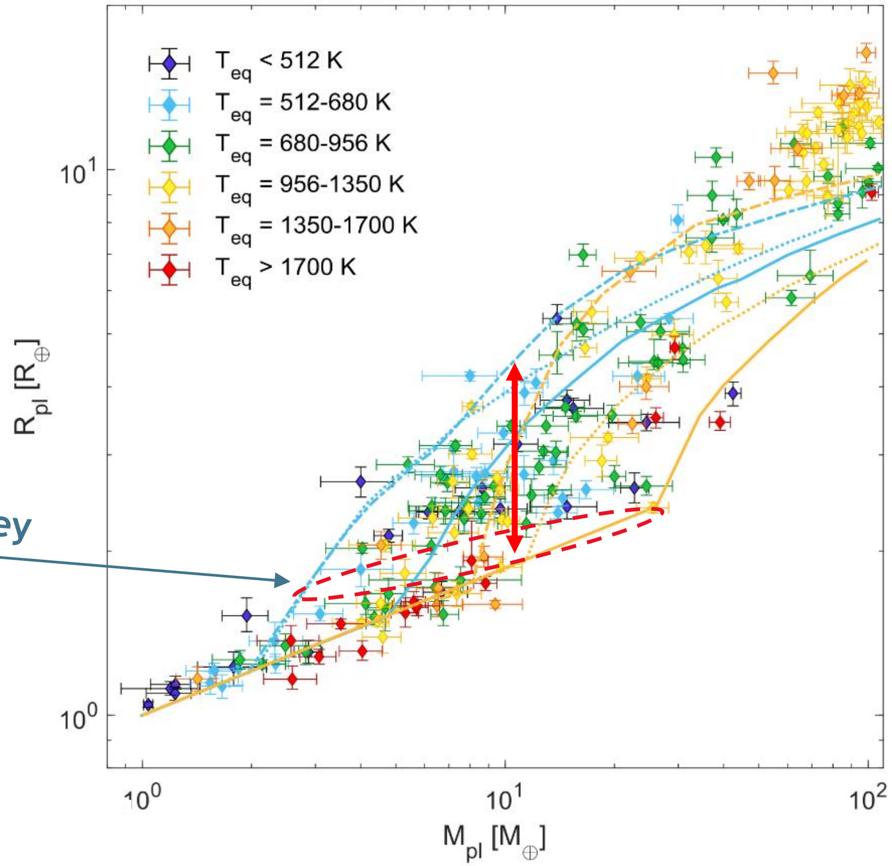
- Population of low- to intermediate- mass planets
- Formation and composition of secondary atmospheres
- Planetary habitability

Mullally et al. 2015



Radius valley

Kubyshkina&Fossati, 2022



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DIVERSITY OF ATMOSPHERIC ESCAPE PROCESSES

- **Atmospheric escape**
  - Thermal processes
    - Jeans escape
    - Hydrodynamic escape
  - Non-thermal processes
    - Tidal effects
    - Interaction with stellar winds
    - XUV driven

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    - Erosion of the atmosphere;
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  - **XUV driven**
    - Photochemical escape;
    - Charge exchange*;
    - Sputtering*;
    - Auroral outflows.

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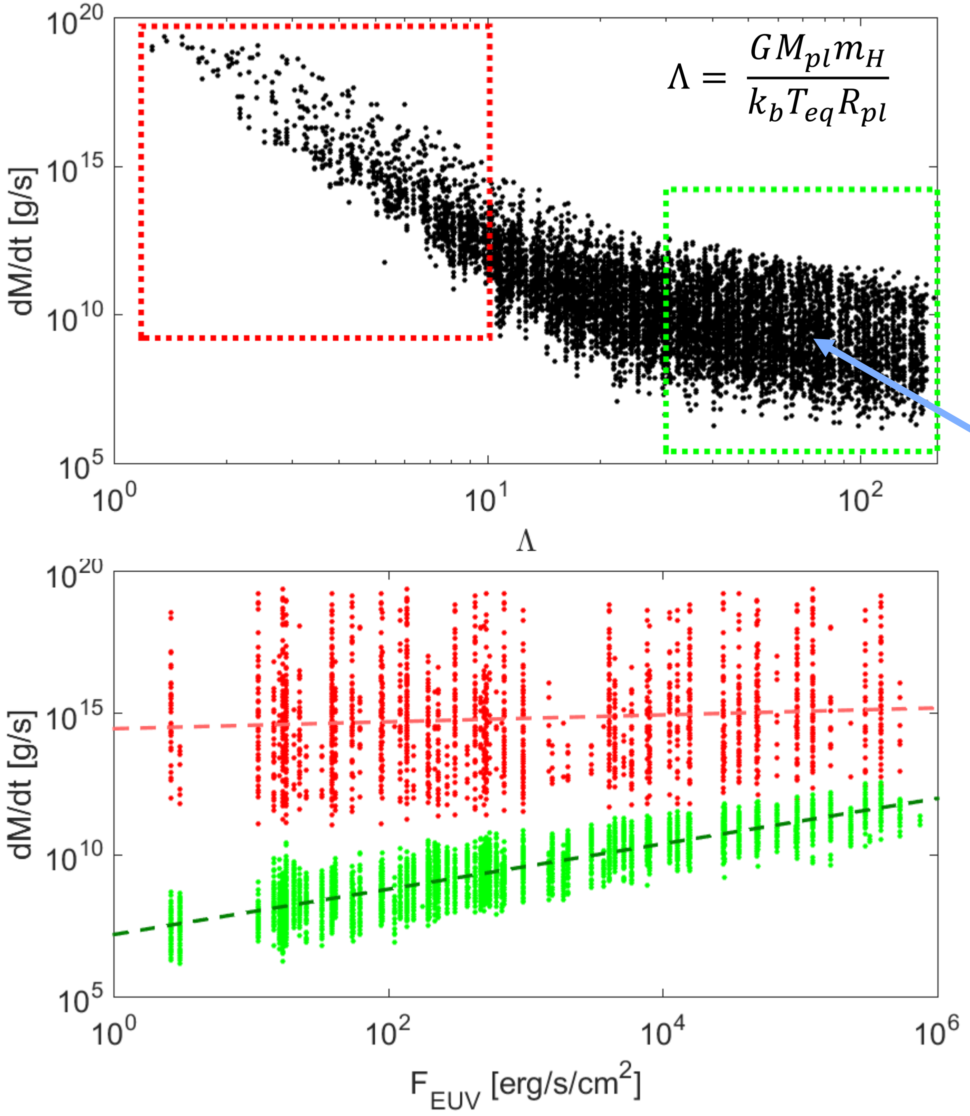
HYDRODYNAMIC ESCAPE OF PRIMORDIAL H/HE ATMOSPHERES: MASS LOSS RATES

Kubyshkina et al., 2018, Kubyshkina&Fossati 2021



<u>HD model:</u>

- **1D, hydrogen atmosphere**
- **X-ray+EUV heating**
- **Lyα-cooling**
- **H_3^+-cooling**
- **ionisation, recombination, dissociation, …**
- **Constant heating efficiency of 15%**

<u>Grid ranges:</u>

M_*: 0.4:1.3 M_{sun}
M_{pl}: 1:109 M_{earth}
R_{pl}: 1:10 R_{earth}
T_{eq}: 300:2000 K
XUV: young to evolved stars

Specific Λ corresponds to specific relation between the thermal and gravitational energies; the spread is produced by different XUV levels and orbital parameters

doi.org/10.5281/zenodo.4643823

H–dominated atmospheres on terrestrial–mass planets: see the review by Owen+2020

https://ui.adsabs.harvard.edu/abs/2024NatAs...8..920G/abstract

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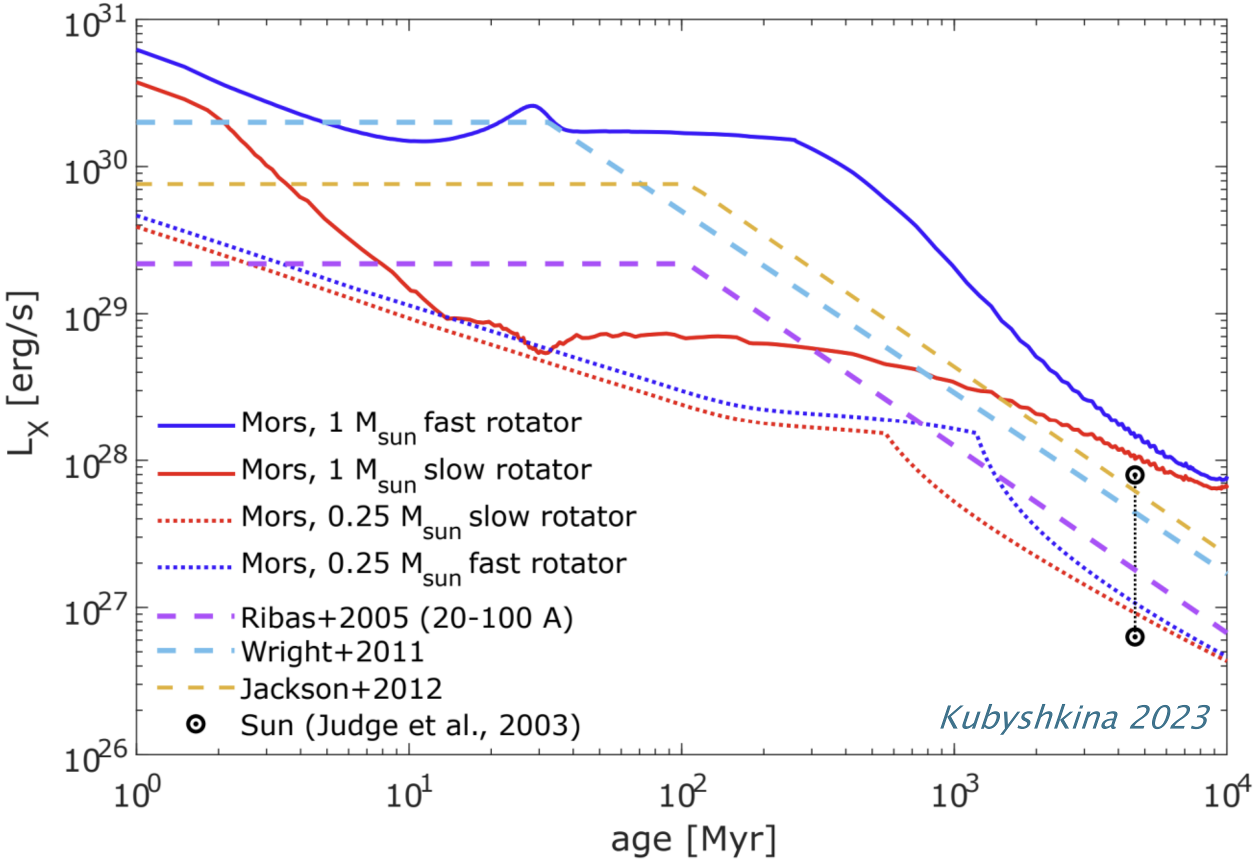
STELLAR IRRADIATION VARIES DRAMATICALLY

In the case, if the planetary atmosphere is gravitationally well bound and the planet is sufficiently irradiated, the atmospheric escape is guided by stellar XUV/wind.



*Mors code: Johnstone et al., 2021

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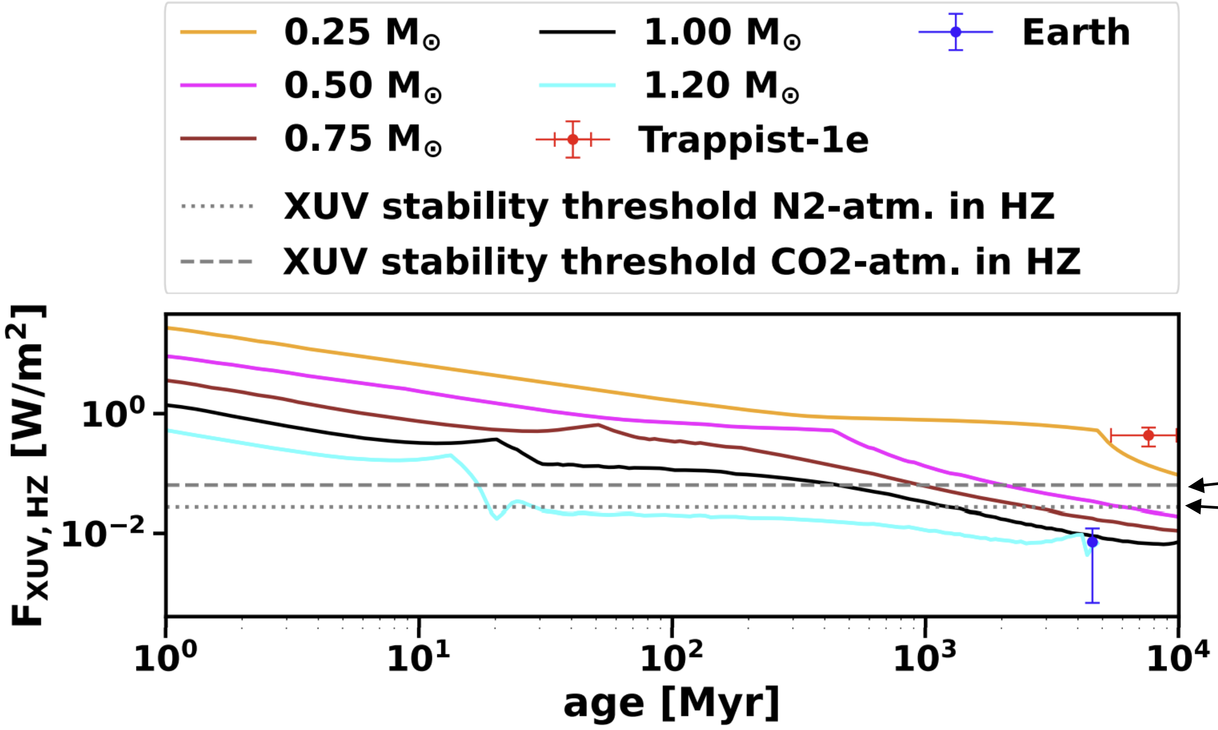
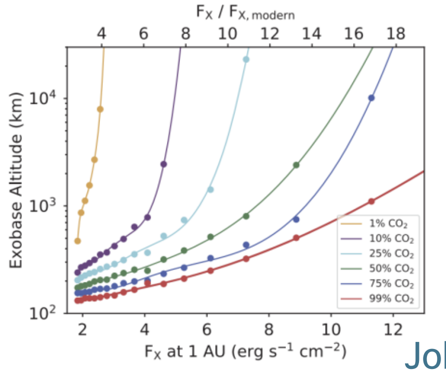


Kubyshkina et al. 2025 (under review in SSR)

Mors code: Johnstone et al., 2021



Johnstone et al., 2021b

thermal stability threshold

99% CO_2 + 1% N_2

10% CO_2 + 90% N_2

(Van Looveren et al. 2024)

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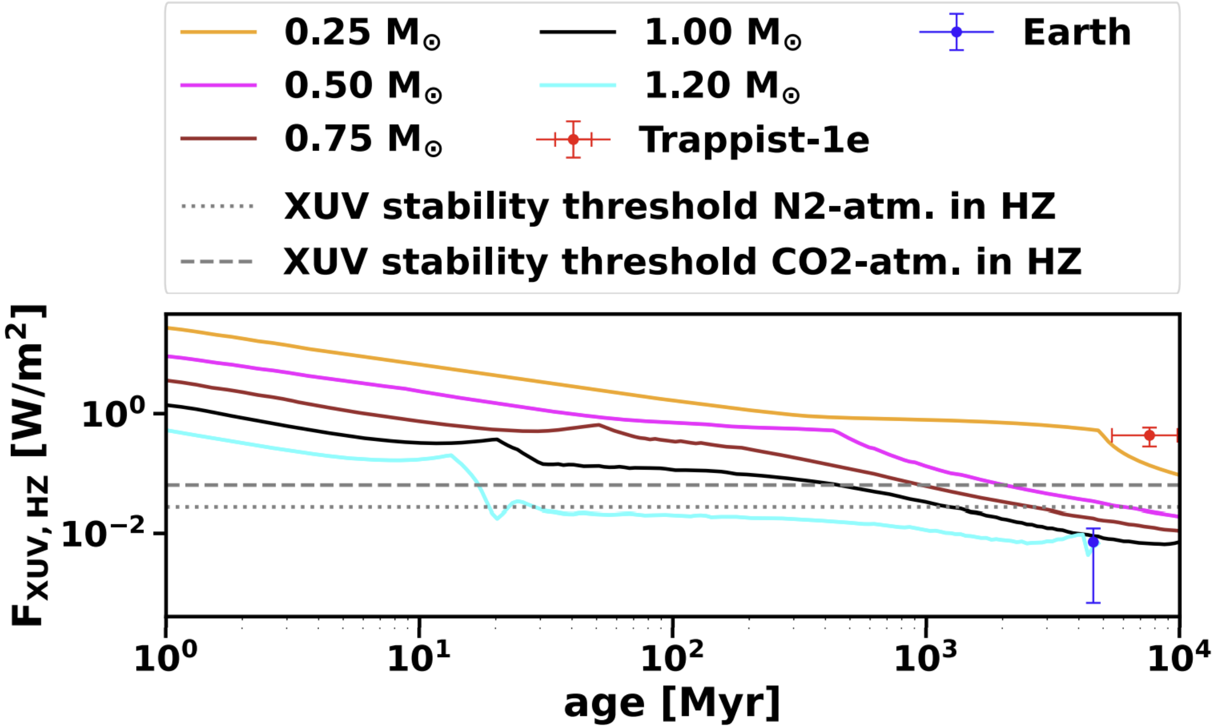

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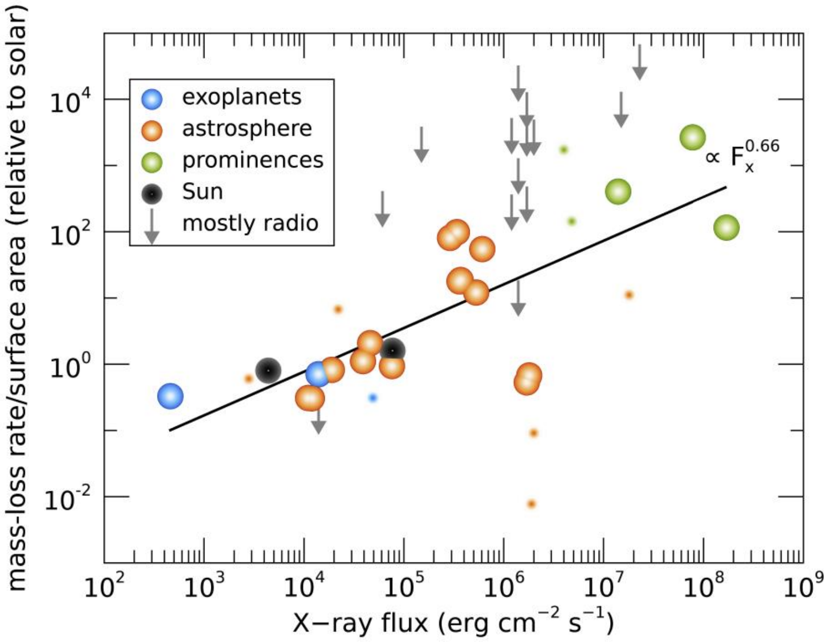

Vidotto, 2021

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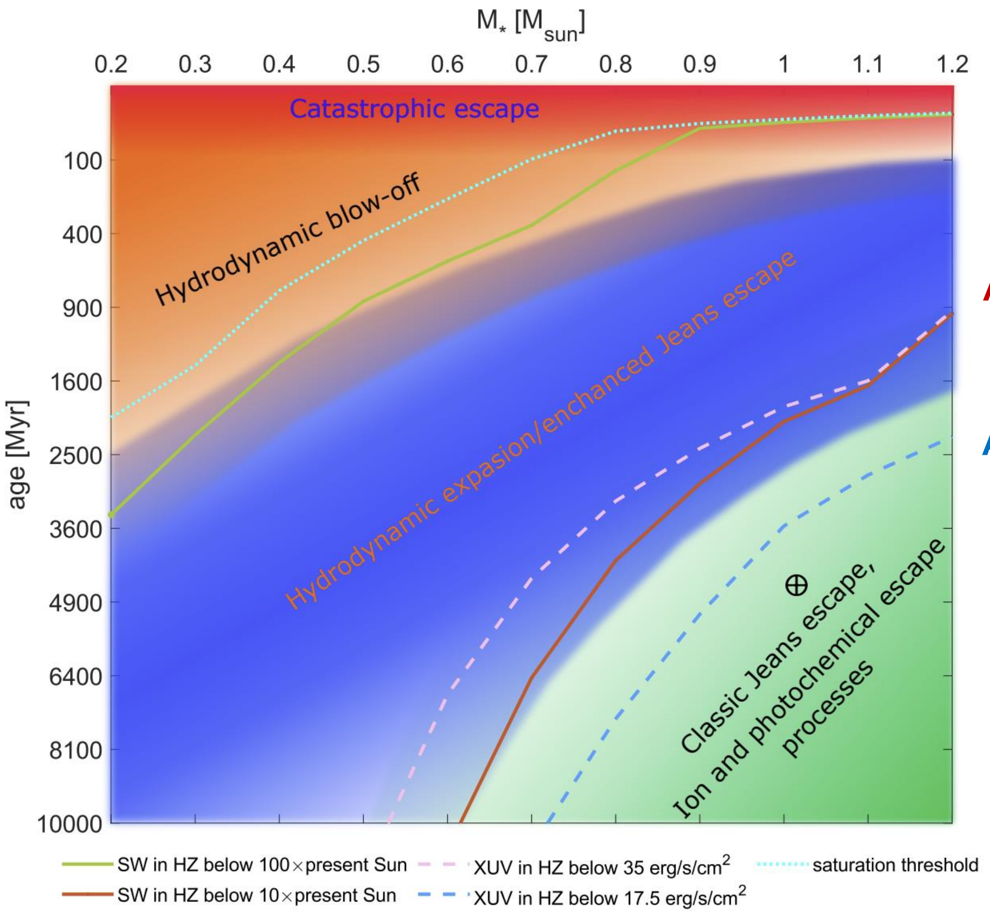
STELLAR MASS AFFECTS THE DURATION OF DIFFERENT ESCAPE PHASES



Atmosphere is (probably) stable against stellar wind

Atmosphere is stable against XUV

Kubyshkina et al. 2025 (under review in SSR)

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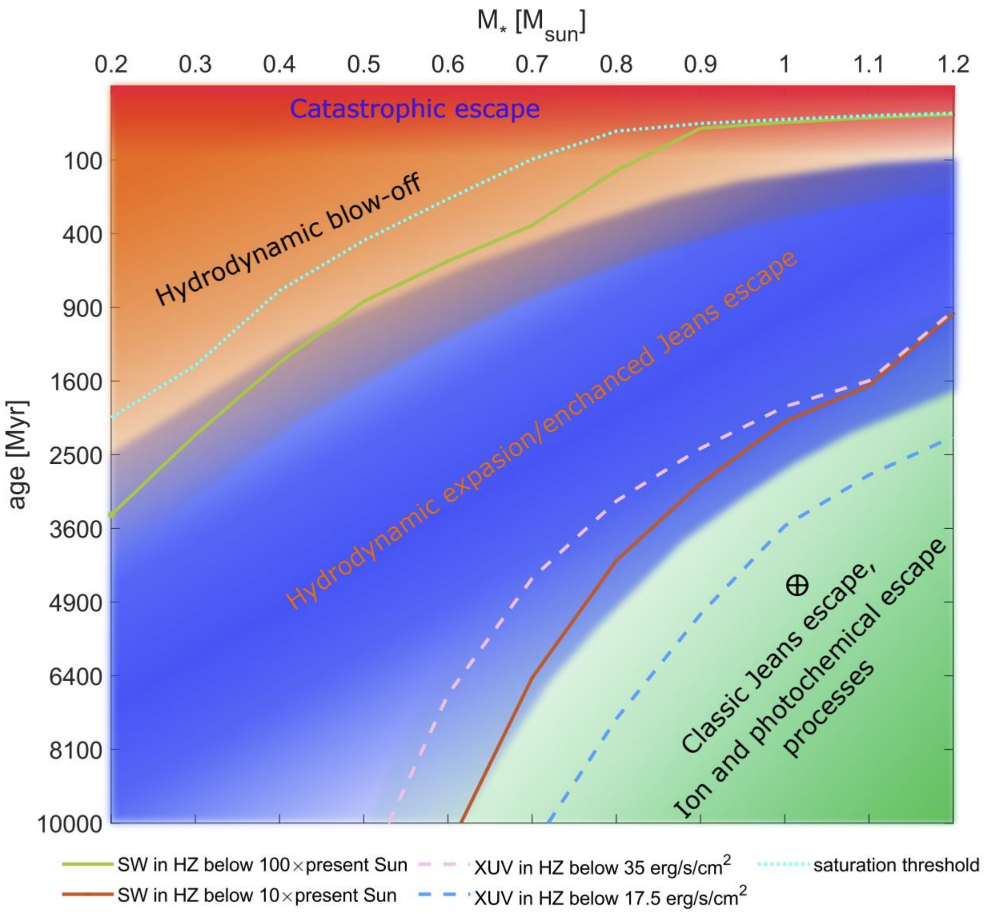

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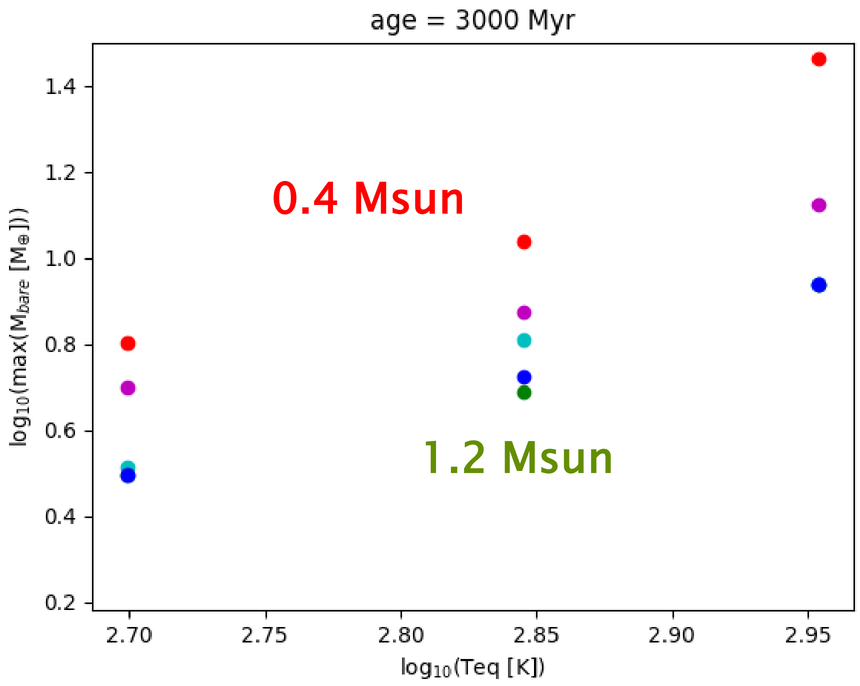

Minimum mass to keep a H/He atmosphere

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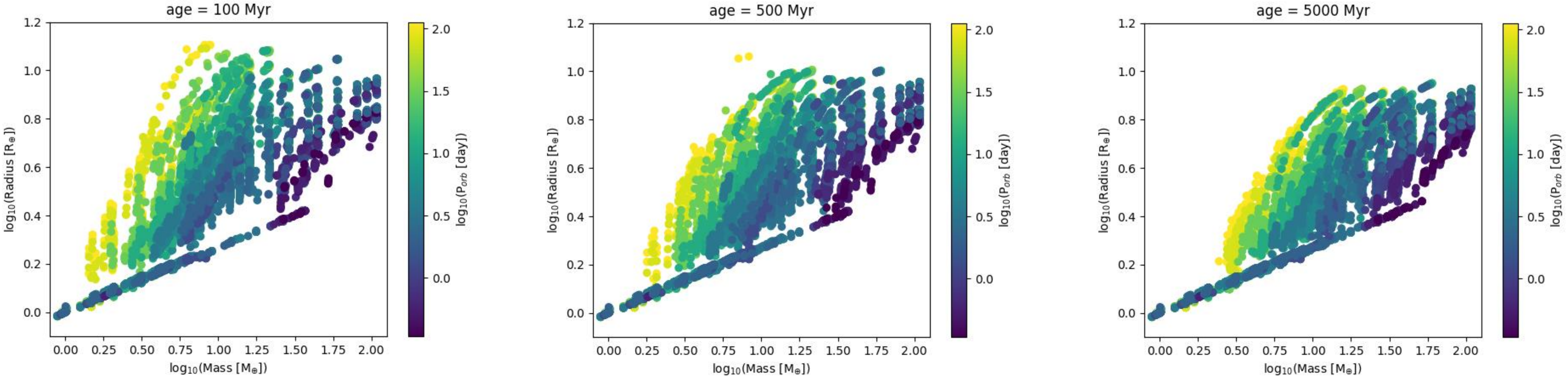
STELLAR MASS AFFECTS THE DURATION OF DIFFERENT ESCAPE PHASES

Grid of atmospheric evolution models: P_{orb} <=100 days, M_{star} 0.4–1.2 M_{sun}, $P_{0,rot}$ = 1–15 days, M_{pl} 1–100 $M_{\oplus}$,

$f_{at,0} \sim 0.5\text{–}10 f_{mordasini2020}$

Evaporation model based on Reza et al., 2025



Kubyshkina et al. 2025 (in prep.)

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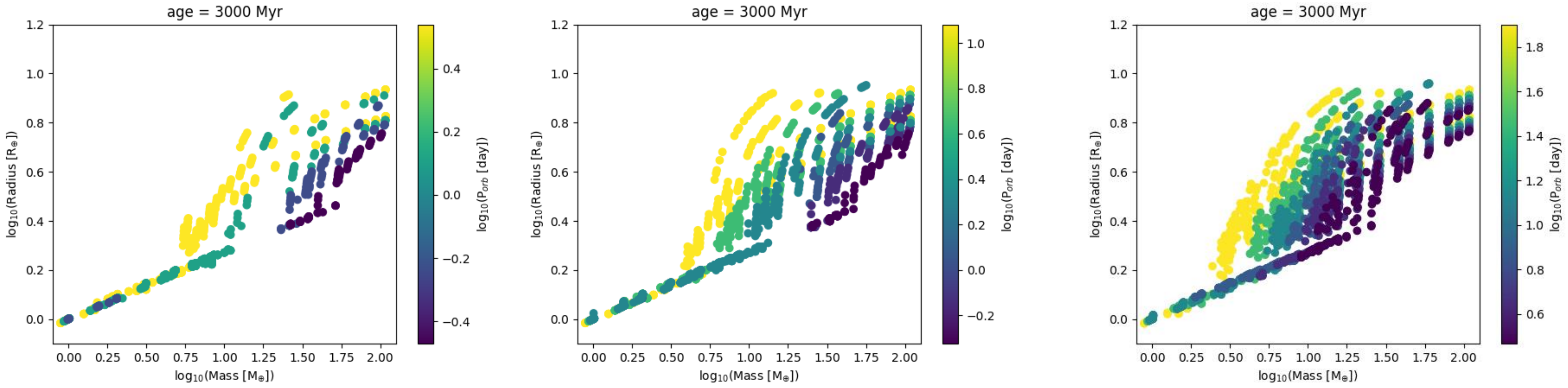
0.4 Msun **0.6 Msun** **1.0 Msun**



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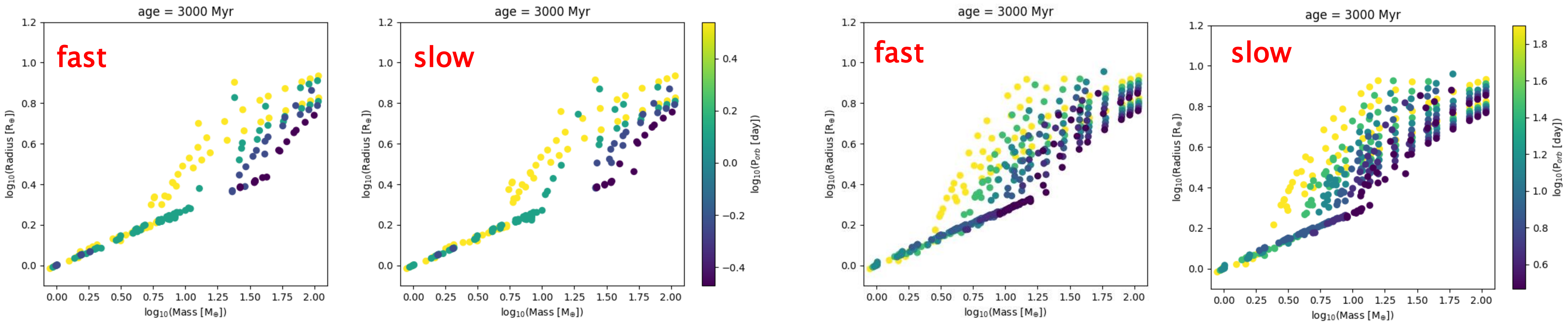
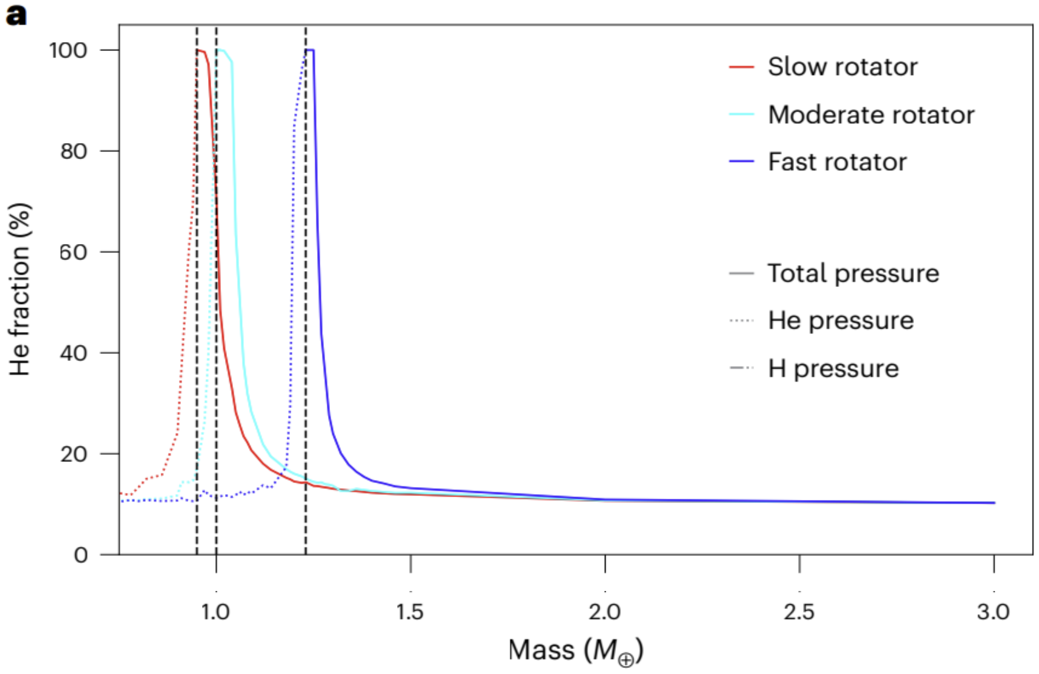


Kubyshkina et al. 2025 (in prep.)

ATMOSPHERIC FRACTIONATION

He-dominated atmospheres can exist around Earth-mass planets in the habitable zone



Lammer et al. 2025 (2-fluid hydrodynamic model)

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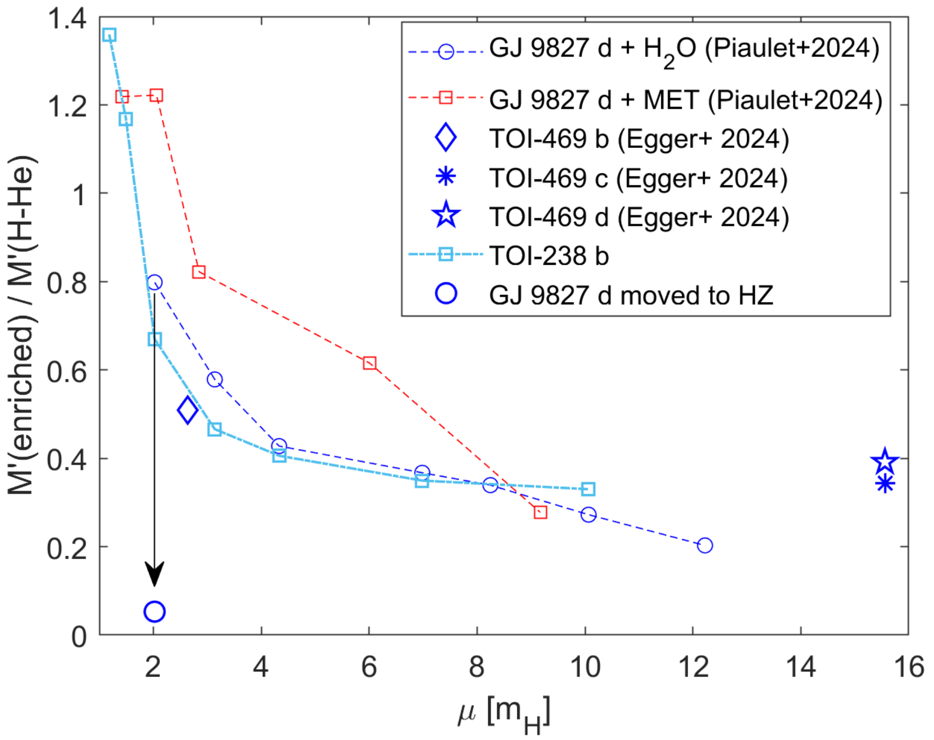
DOES WATER/METAL-ENRICHMENT ALWAYS MAKE AN ATMOSPHERE STABLE?

CHAIN model:

1–fluid hydrodynamic code + Cloudy (Kubyshkina et al., 2024)



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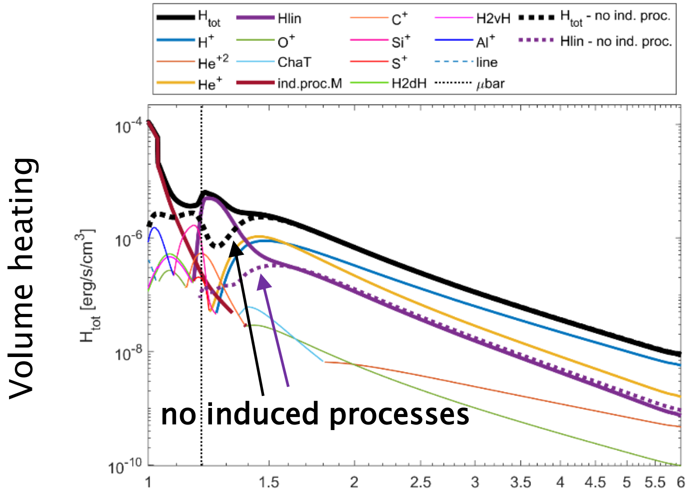
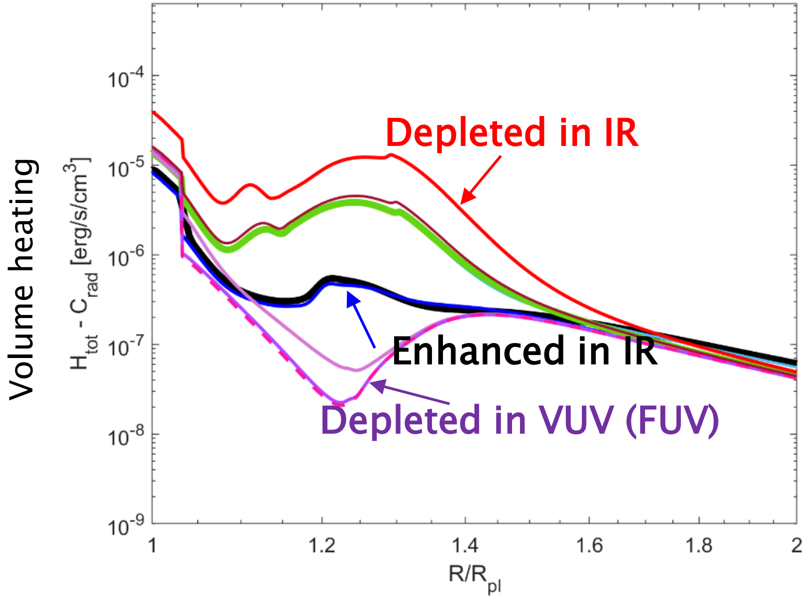




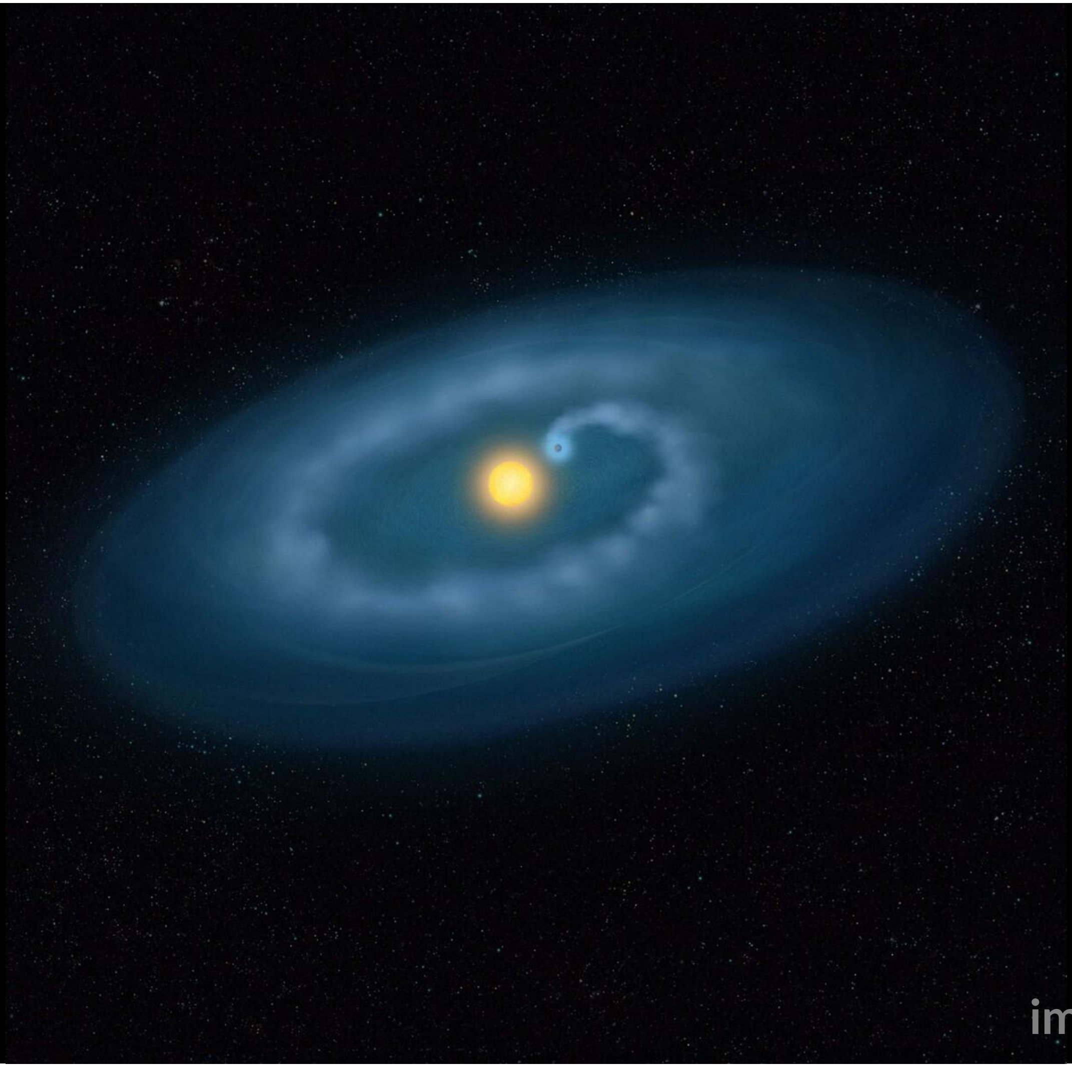
See also e.g.

Yoshida et al., 2022
García Munoz 2023
Yoshida and Gaidos 2025

TAKE AWAY

- Parameters of the host star affect most of the atmospheric escape processes
- Accurate characterization of the planet-hosting stars at their present is crucial for the interpretation of the observations; however, a more statistical approach is needed to understand to understand stellar (hence, planetary) evolution.
- Duration of different evolutionary phases can be very different for planets orbiting stars of different types.

THANK YOU



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