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Fonds de recherche
Nature et
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Québec

Resolving Gas-Poor Planet Formation Beyond 1 AU

Theoretical Predictions for Roman Microlensing Surveys

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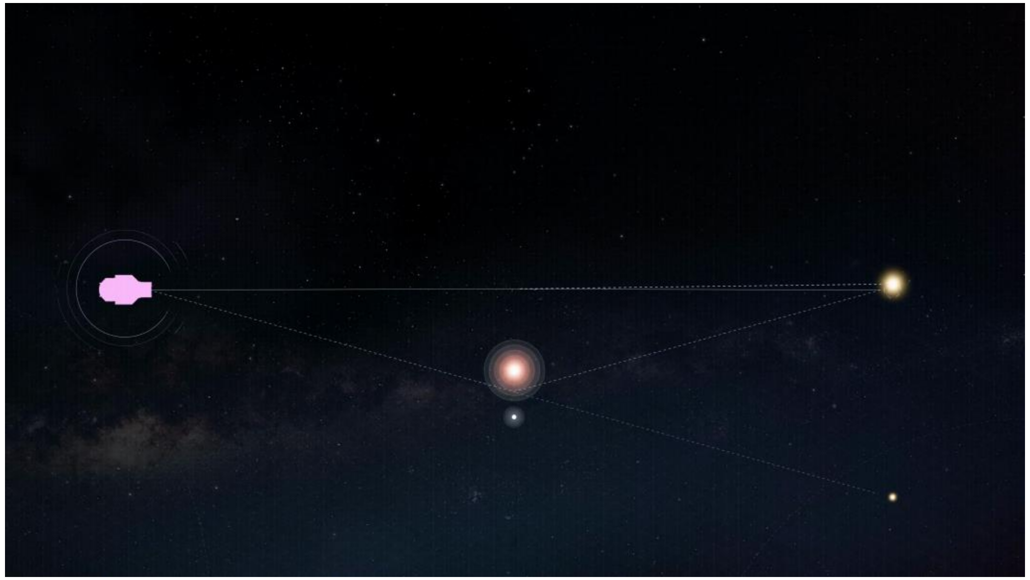
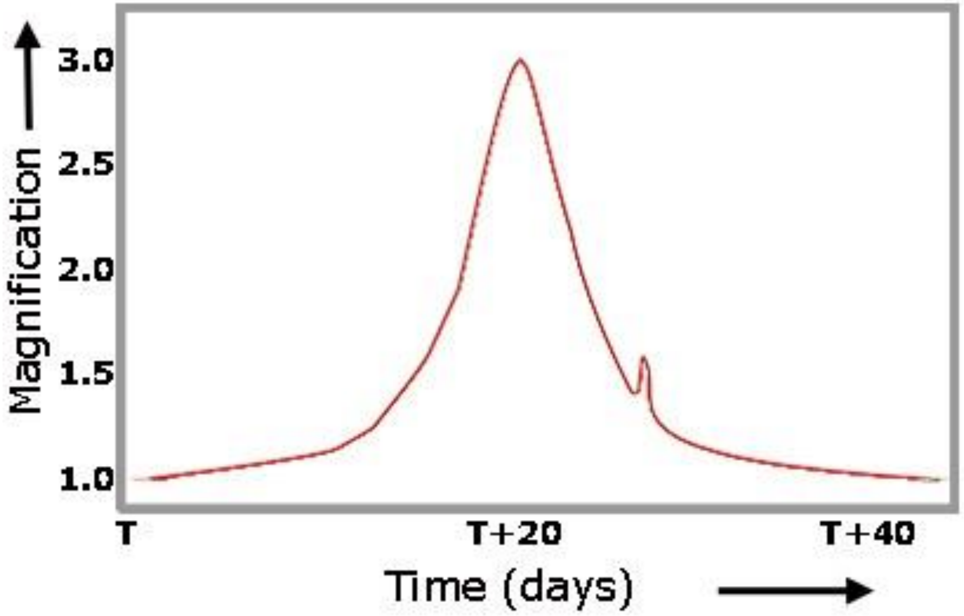
Roman Microlensing Exoplanet Surveys (2026)



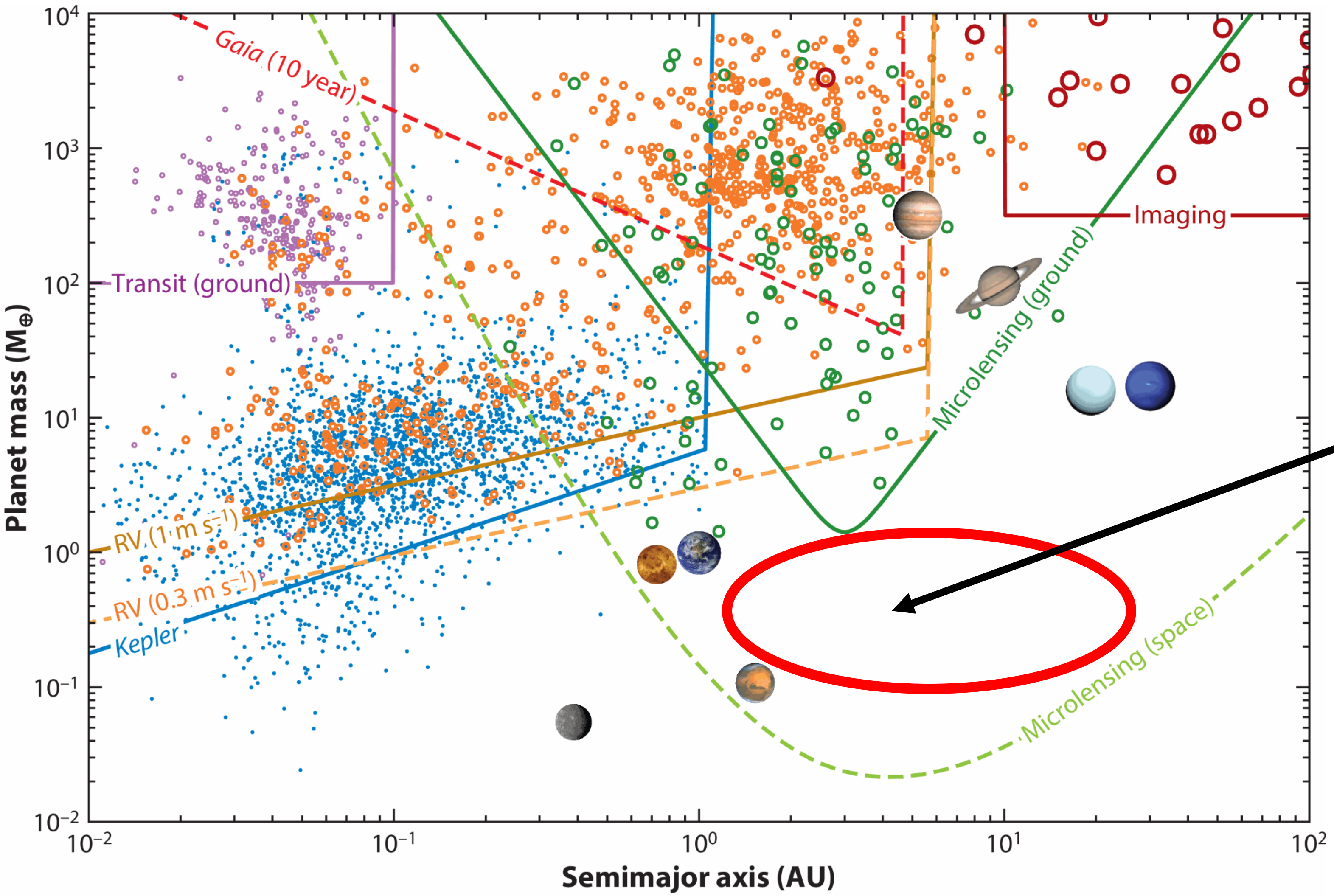
Roman Space Telescope Microlensing Animation
NASA Goddard's Scientific Visualization Studio

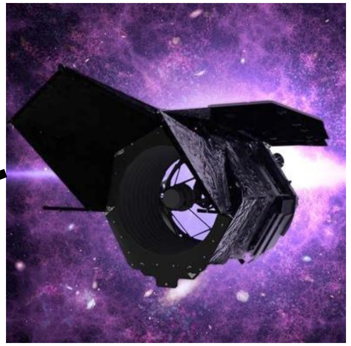


Microlensing light curve Copyright: ESA

- Chance event
- Probes semi-major axis a and planetary mass M_p as functions of the lens mass $q = M_p/M_l$
- Need to assume a stellar mass function through galactic models. $\langle M_l \rangle \sim 0.3 M_\odot$
- Optimal at the Einstein radus $R_E \sim 3.5\mathrm{AU}\sqrt{\frac{M_l}{M_\odot}}$

Exoplanet Demographics past 1 AU

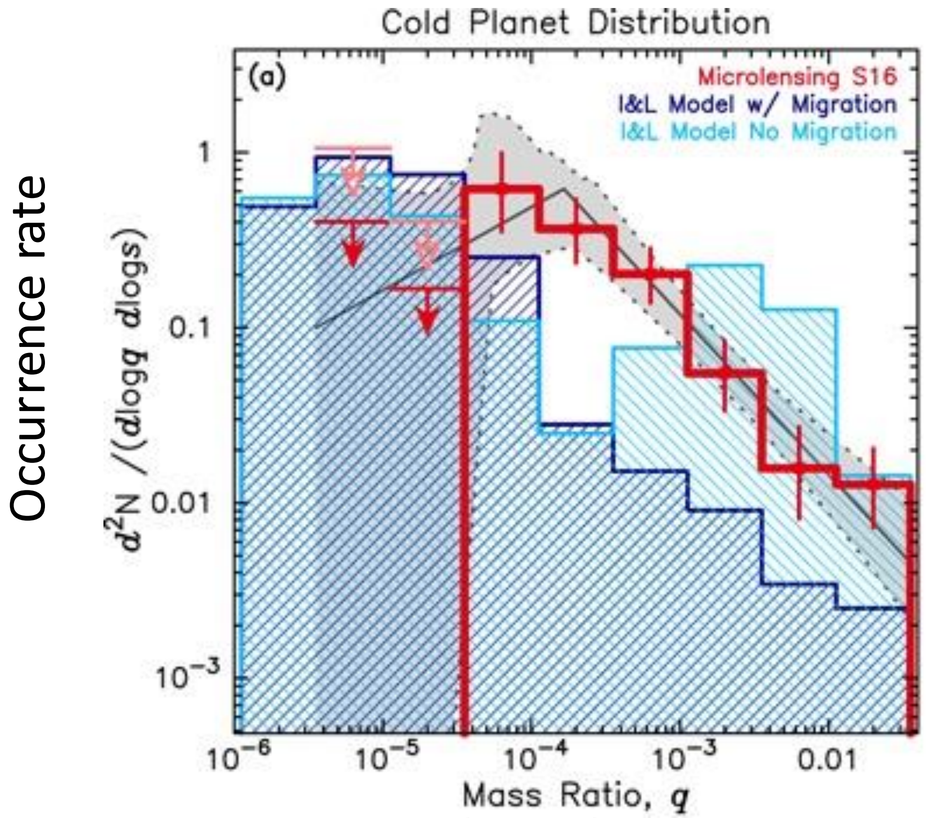




Zhu & Dong 2021

A break in the distribution?

Observations

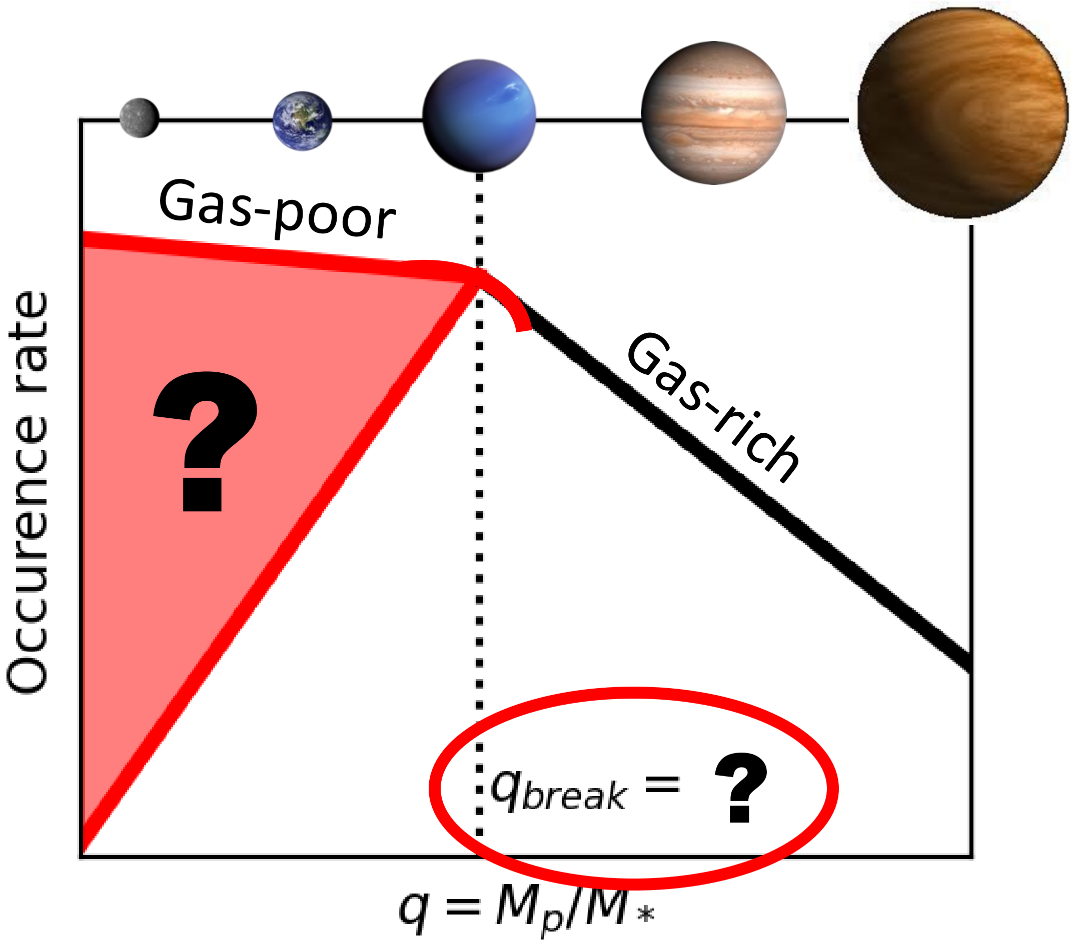


$M_p \approx 15 M_\oplus$ for $M_* \approx 0.5 M_\odot$

Suzuki et al. (2018)

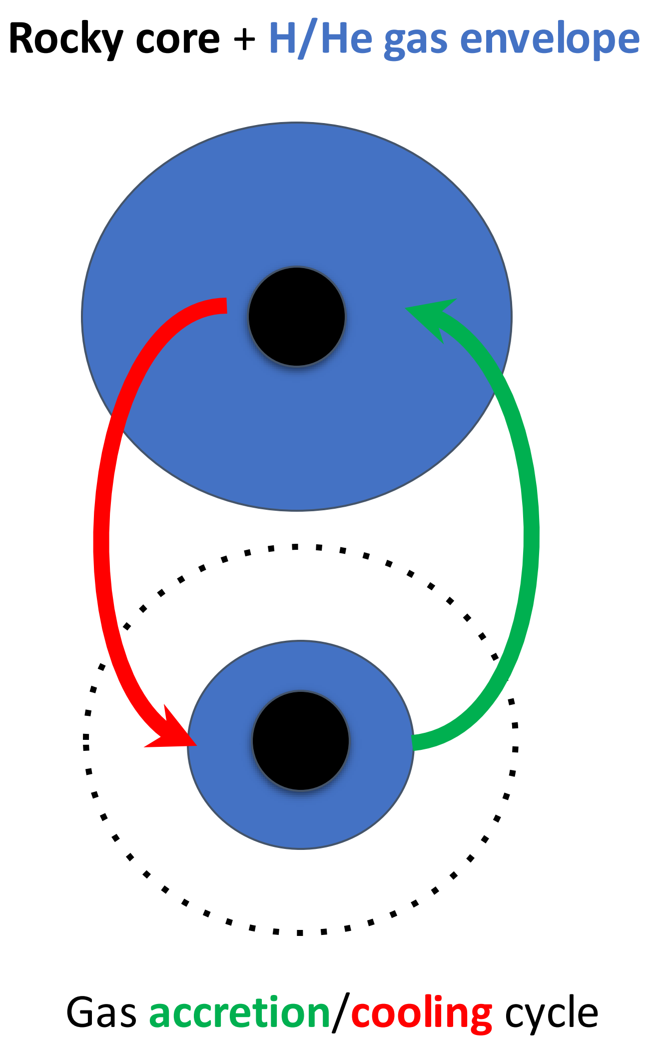
- Sample from the MOA collaboration
- 30 microlensing planets for 1474 events
- Potential break in the Planetary Mass Function (PMF)

Theory

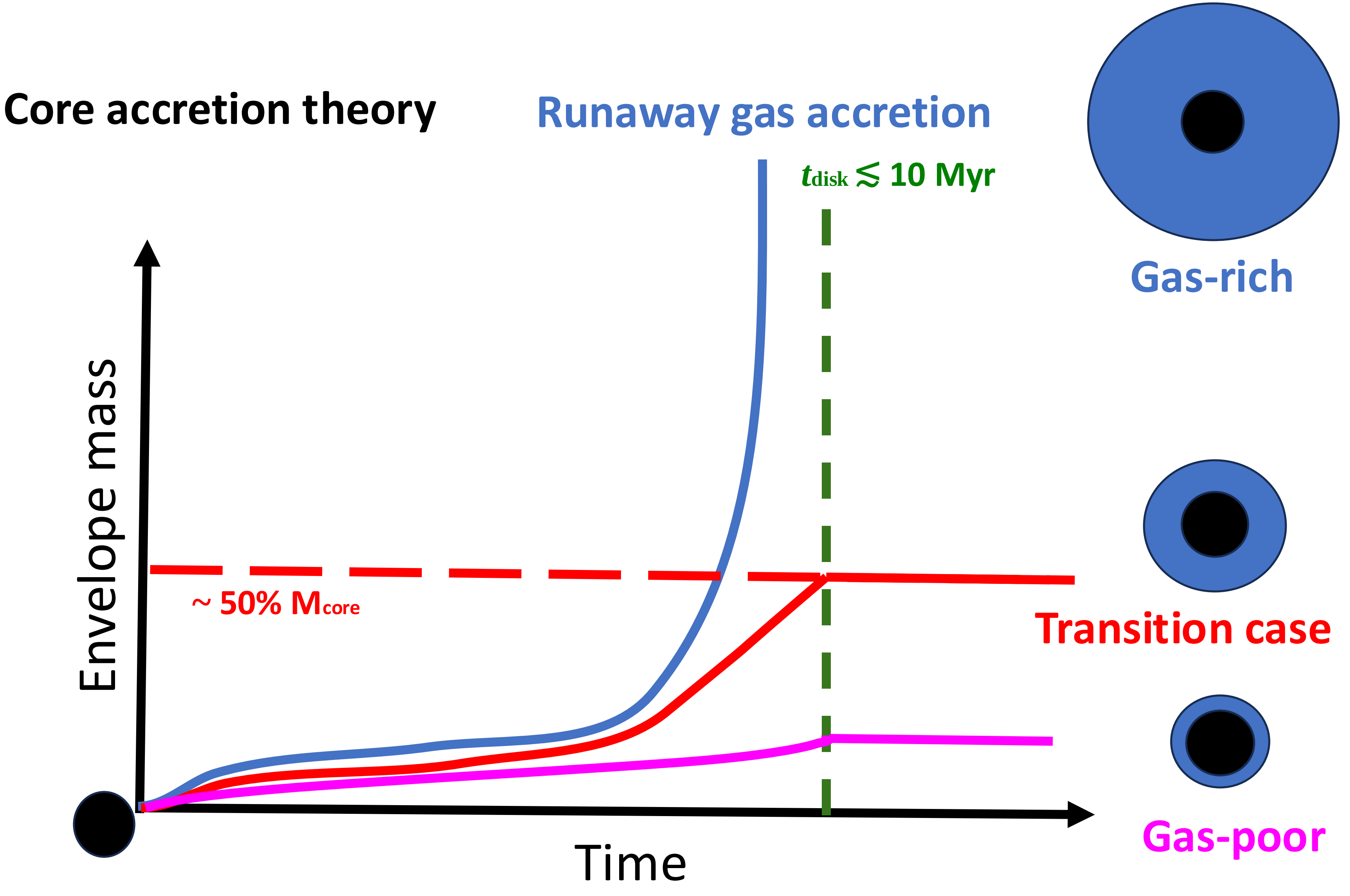


- q_{break} is set by the gas-poor vs. gas-rich transition
- This transition is set by the physics of planet formation and the conditions of the star and its disk.

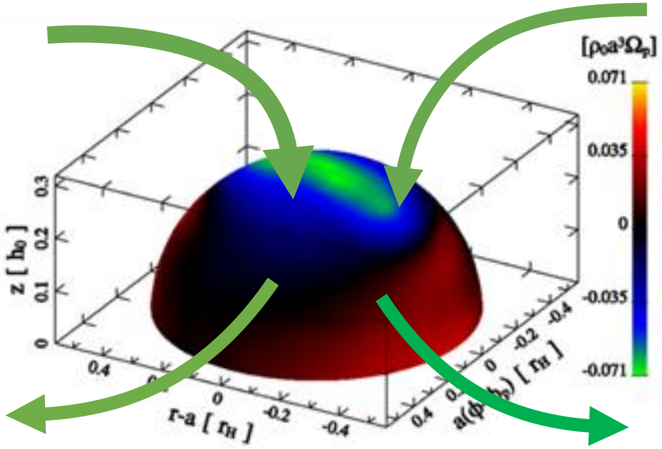
Relating a break to formation scenarios



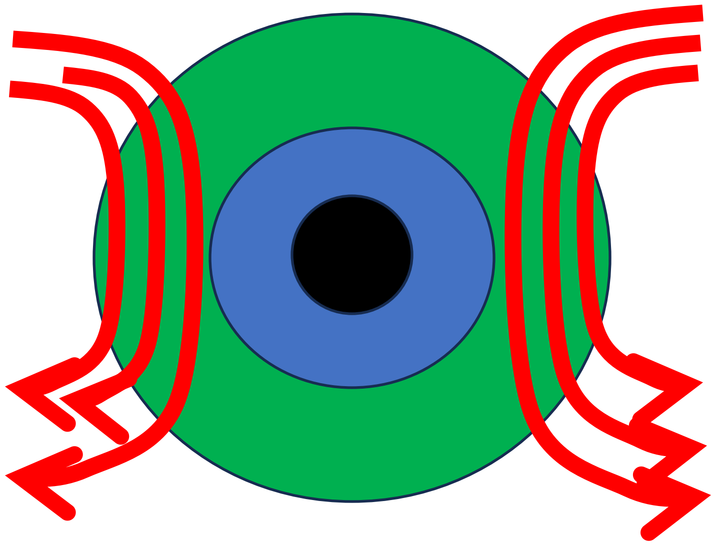
Pollack et al. (1996), Mizuno (1980), Stevenson (1982), Ikoma et al. (2000)

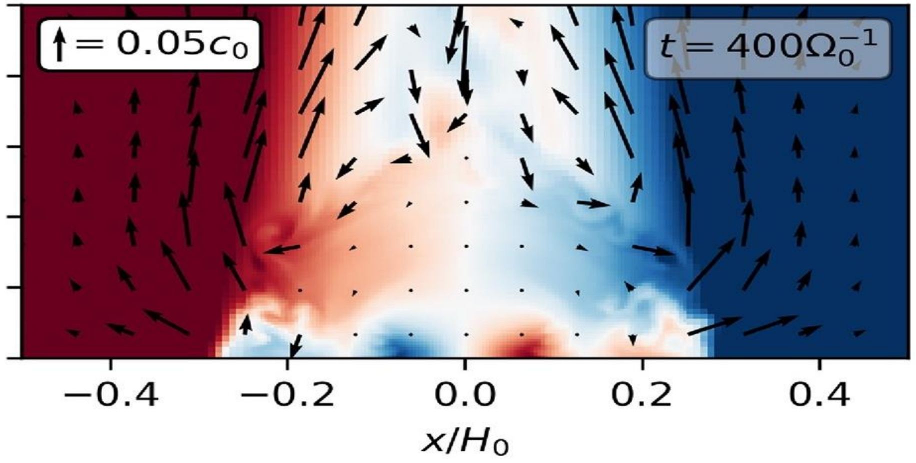


Atmospheric recycling



Fung et al. (2015)





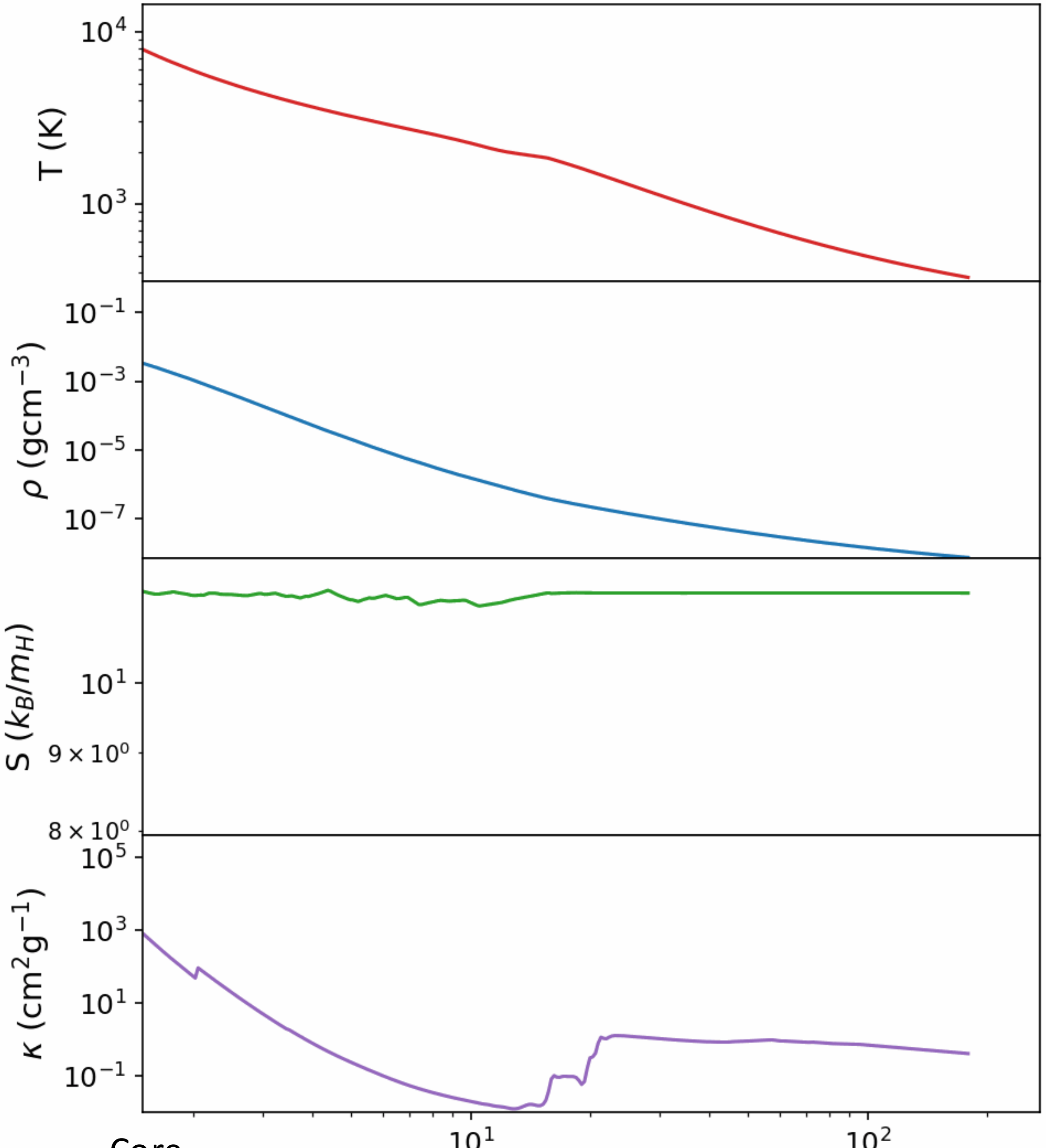
Bailey & Zhu (2024)

- Exchange flows of gas between the protoplanetary disk and a forming envelope

- Effectively creates a **flow**-dominated **outer advective layer** where the disk **injects entropy** into the **envelope and delays cooling**.

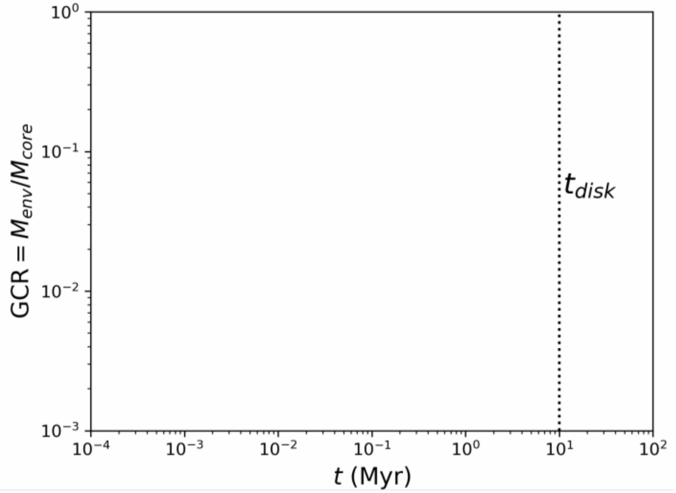
- Advective flows can penetrate down to a depth $\alpha_{adv} \sim$ 20–30 % of the envelope.
- Need a realistic treatment of this **advection of entropy** in simulations

Effect of entropy advection?

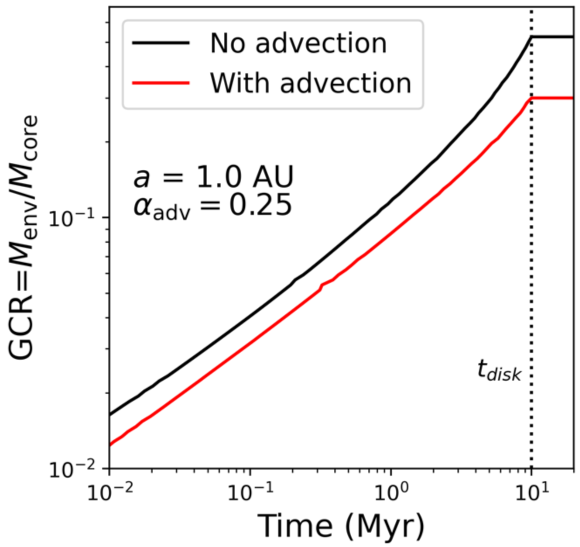


Core

Outer boundary



- 1D quasi-hydrostatic atmospheric model
- Realistic equation of state and opacity.

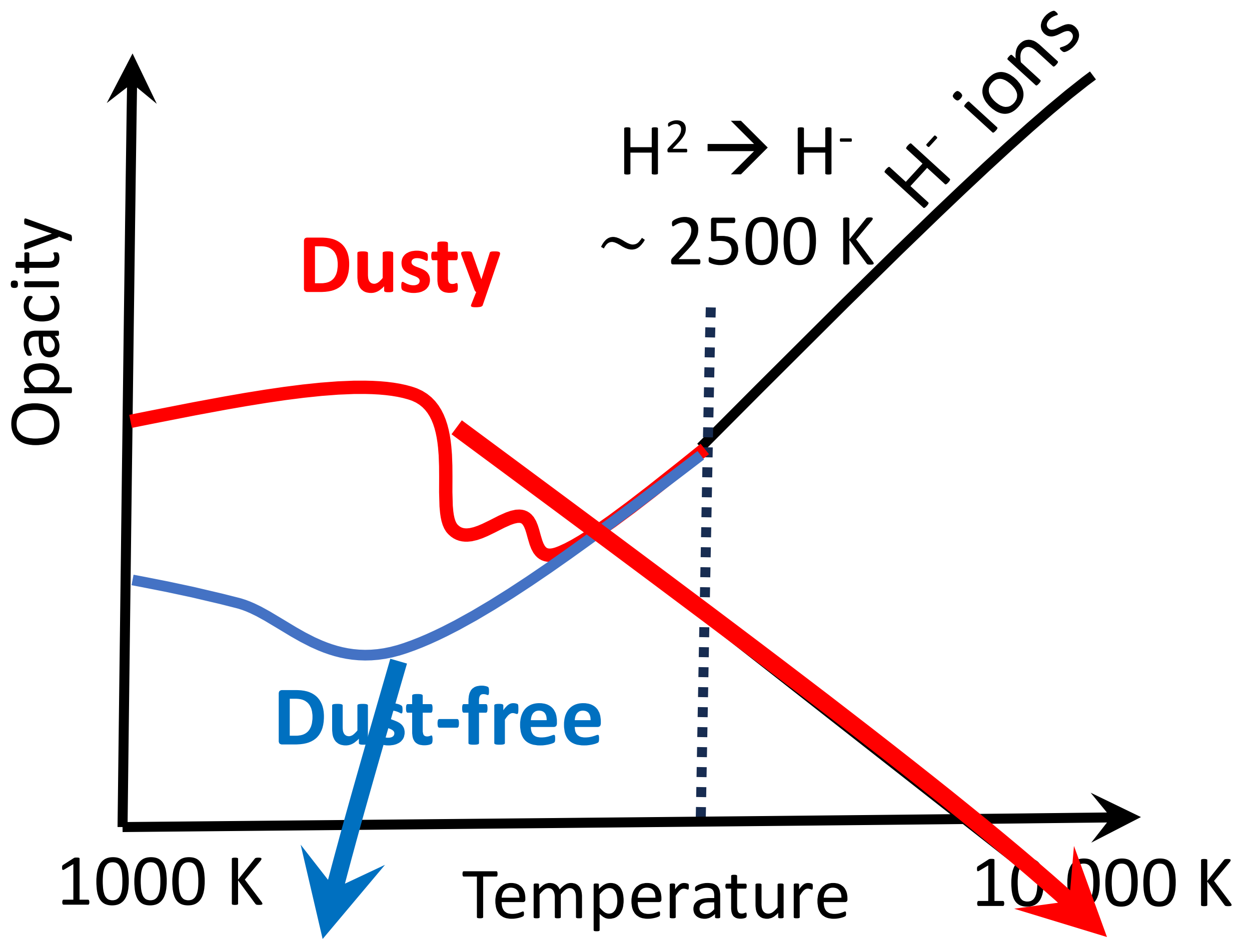


Only an order unity effect! Savignac & Lee (2024)

Opacity controls accretion rates

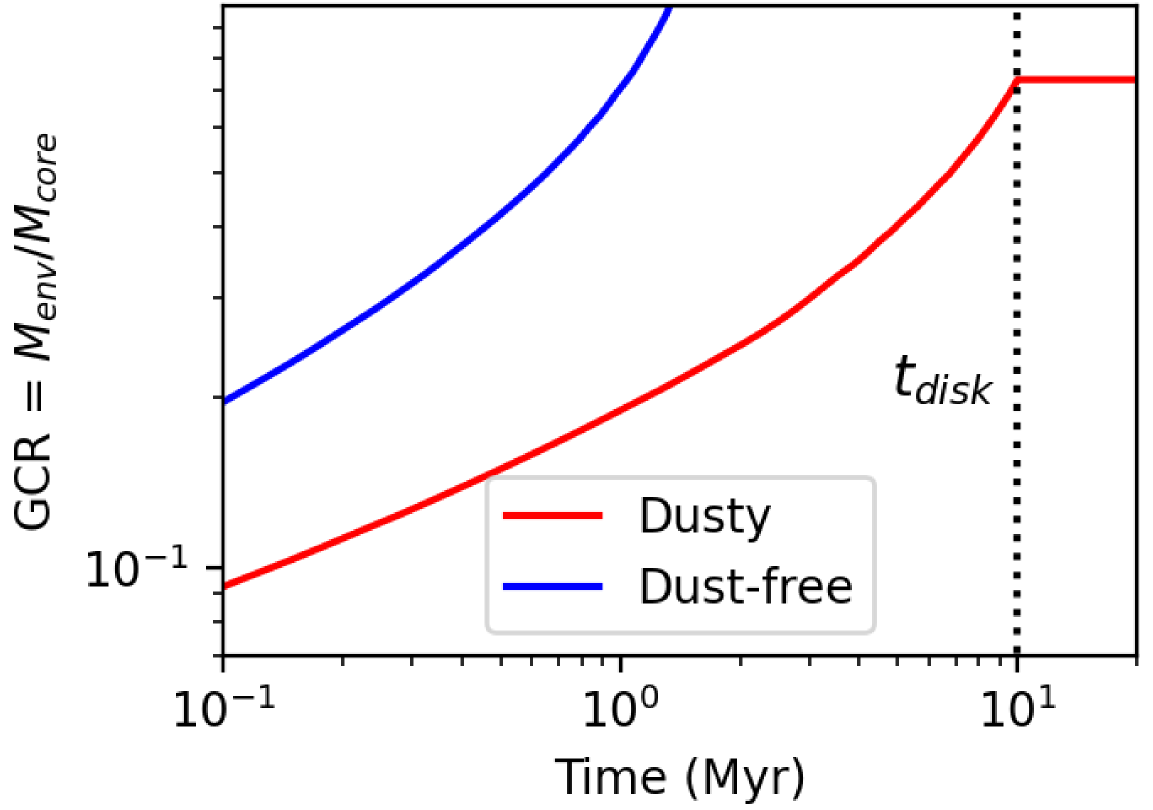
(Ikoma et al. 2000; Piso et al. 2015, Lee et al. 2014)

Do metals take the form of dust at low *T*?



Dust-free → More efficient cooling

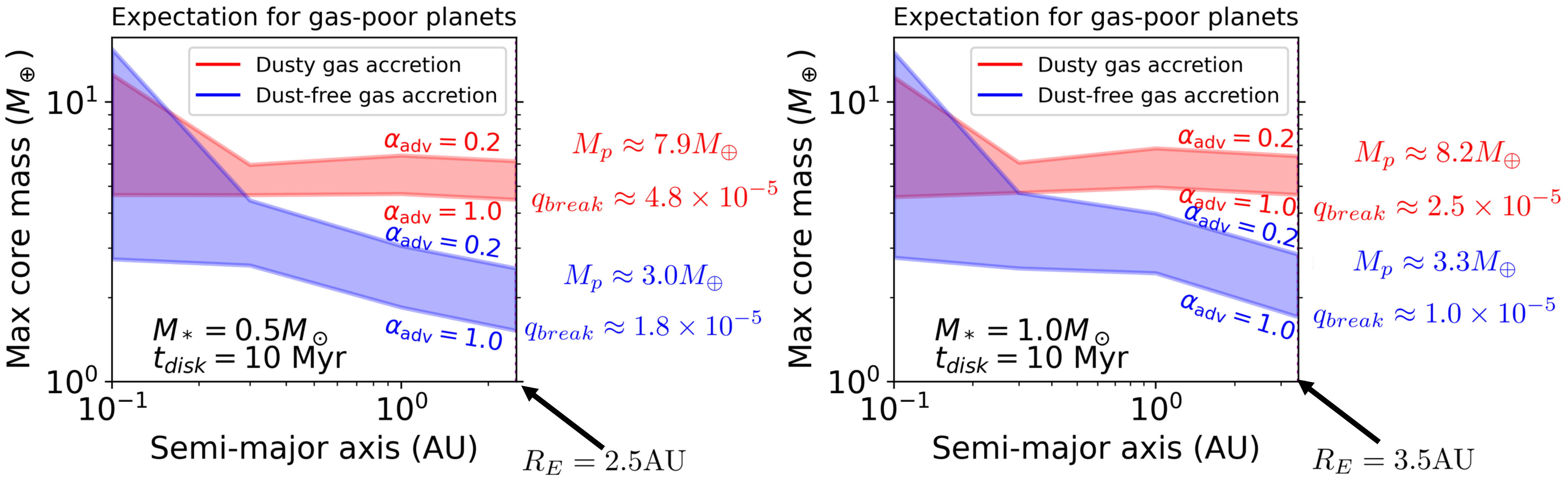
Dusty → Slows down accretion



Decreases with disk temperature

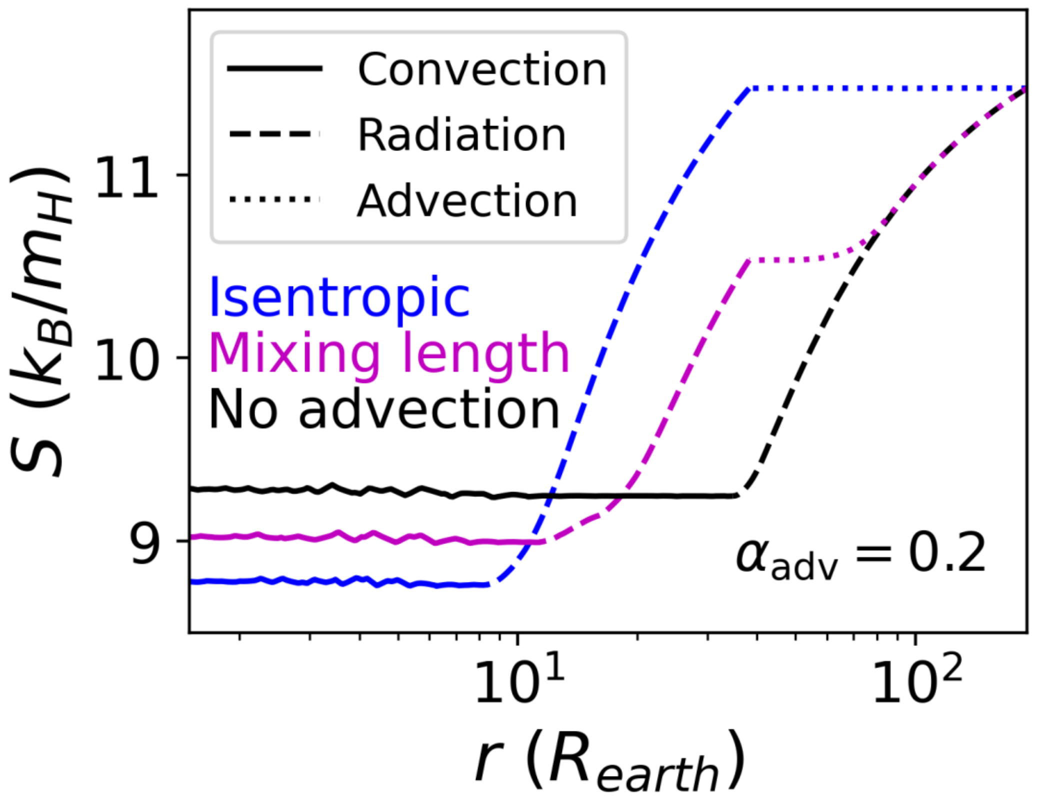
Independent of boundary conditions

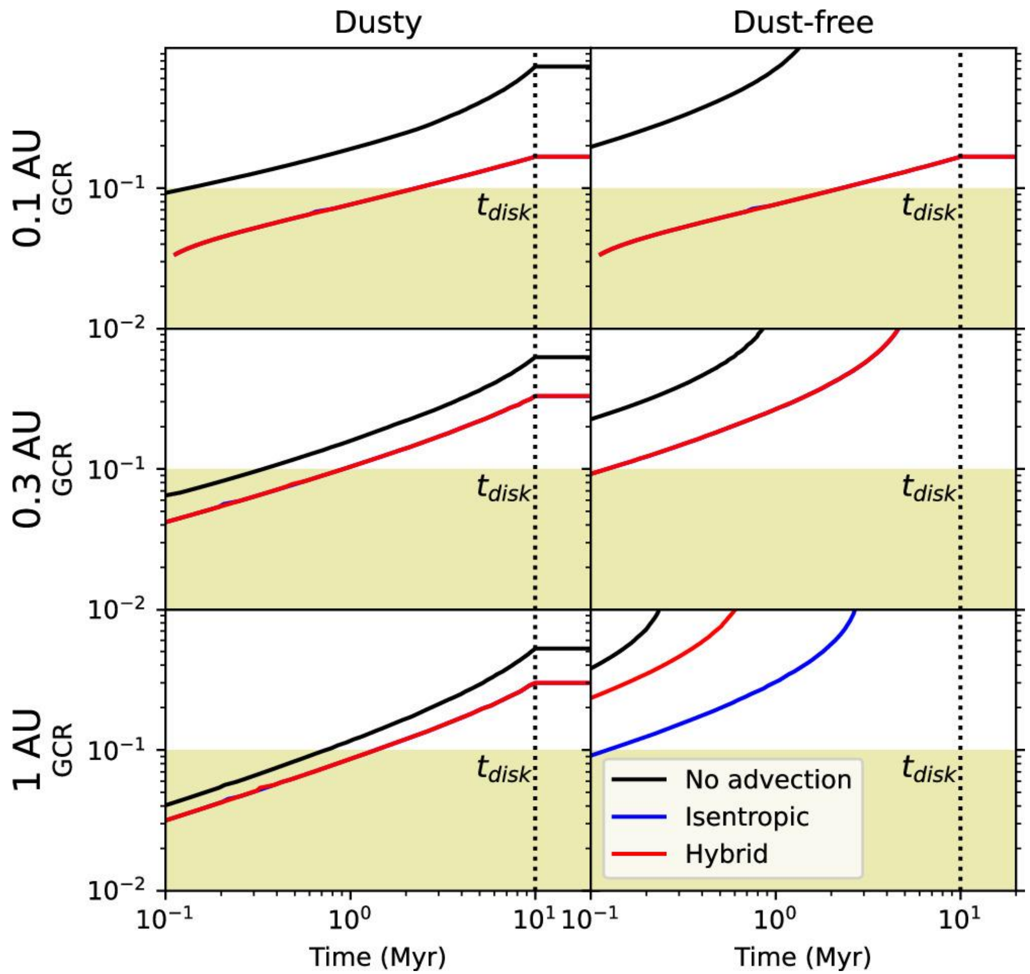
Final Predictions



- Smaller star → $T_{disk} \propto M_*^{2/7}$ (Chachan & Lee 2023) → Less opacity → Faster gas accretion
- **Degeneracies between different opacities (thus composition) can be resolved past 1 AU!**
- Roman will indirectly probe the composition of the disk at large distances.
- Possibility for comparison with atmospheric characterization done closer in with JWST!

Extra: Entropy advection model





Savignac & Lee (2024)