From Formation to Observation

Thermal and Structural Evolution of Planetary Interiors

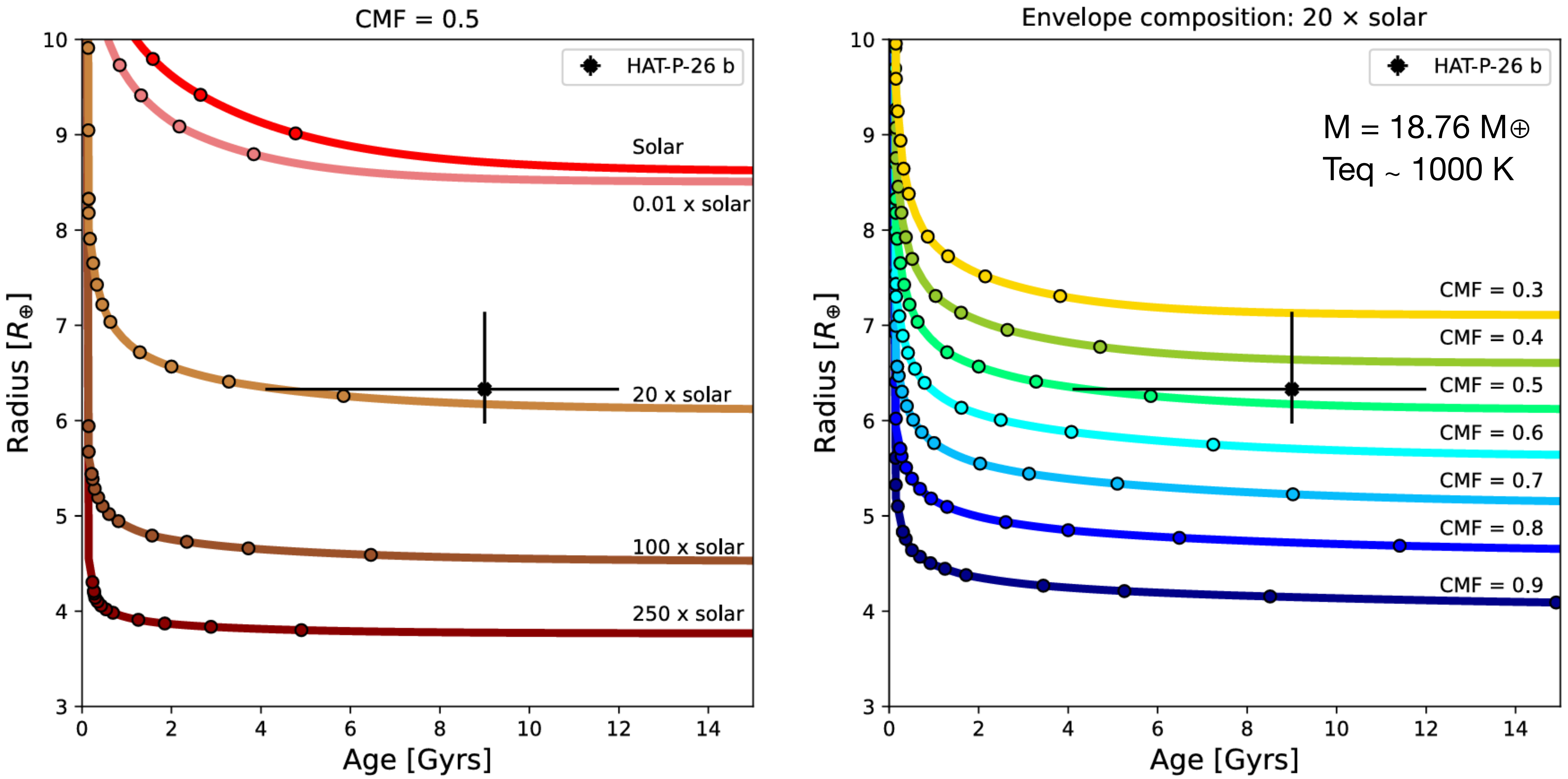
Allona Vazan

“Layers of Understanding”, MPIA, April 2026

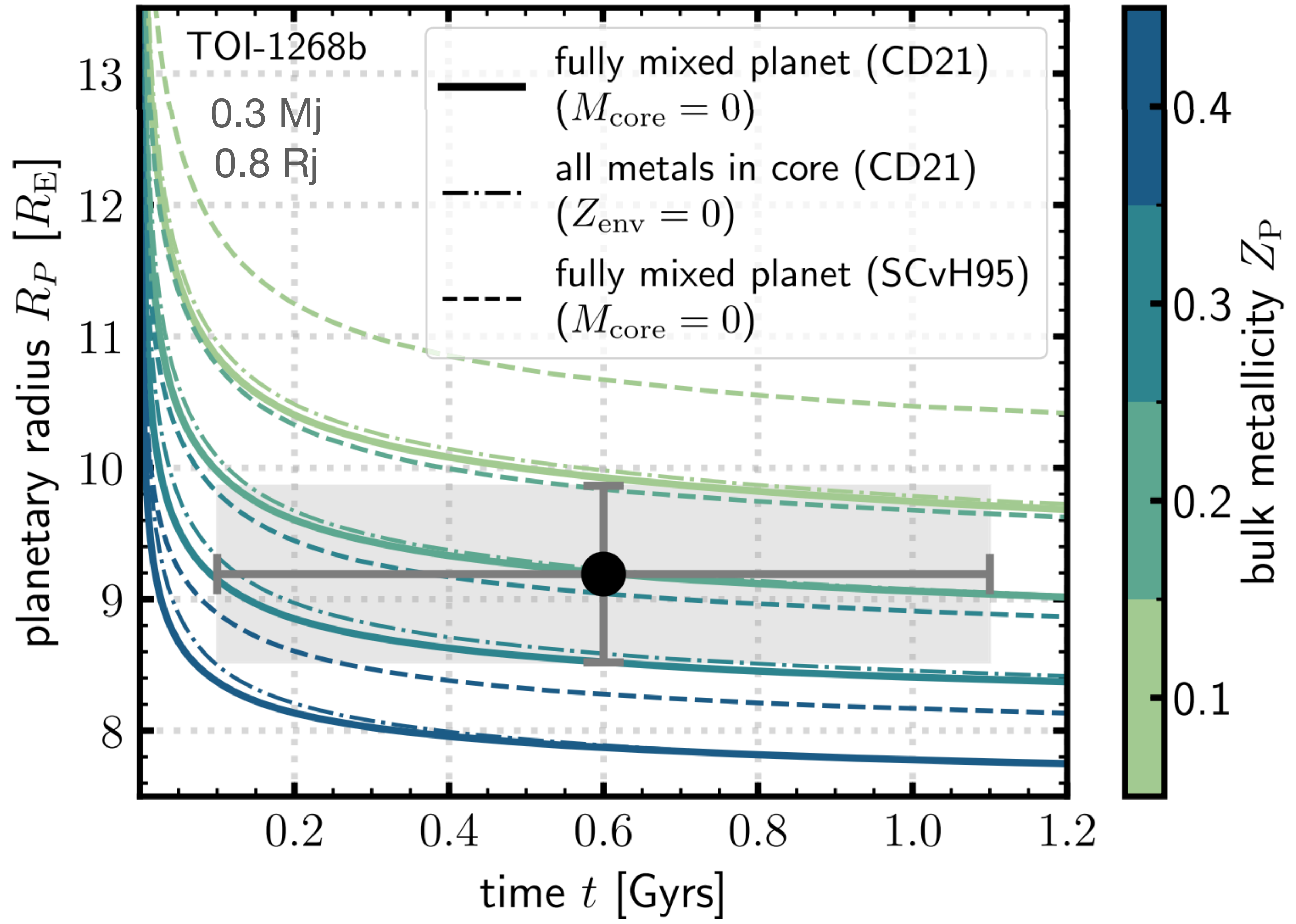
ARCO
Astrophysics Research Center
of the Open university

THE OPEN
UNIVERSITY
OF ISRAEL

Observables are snapshots in time



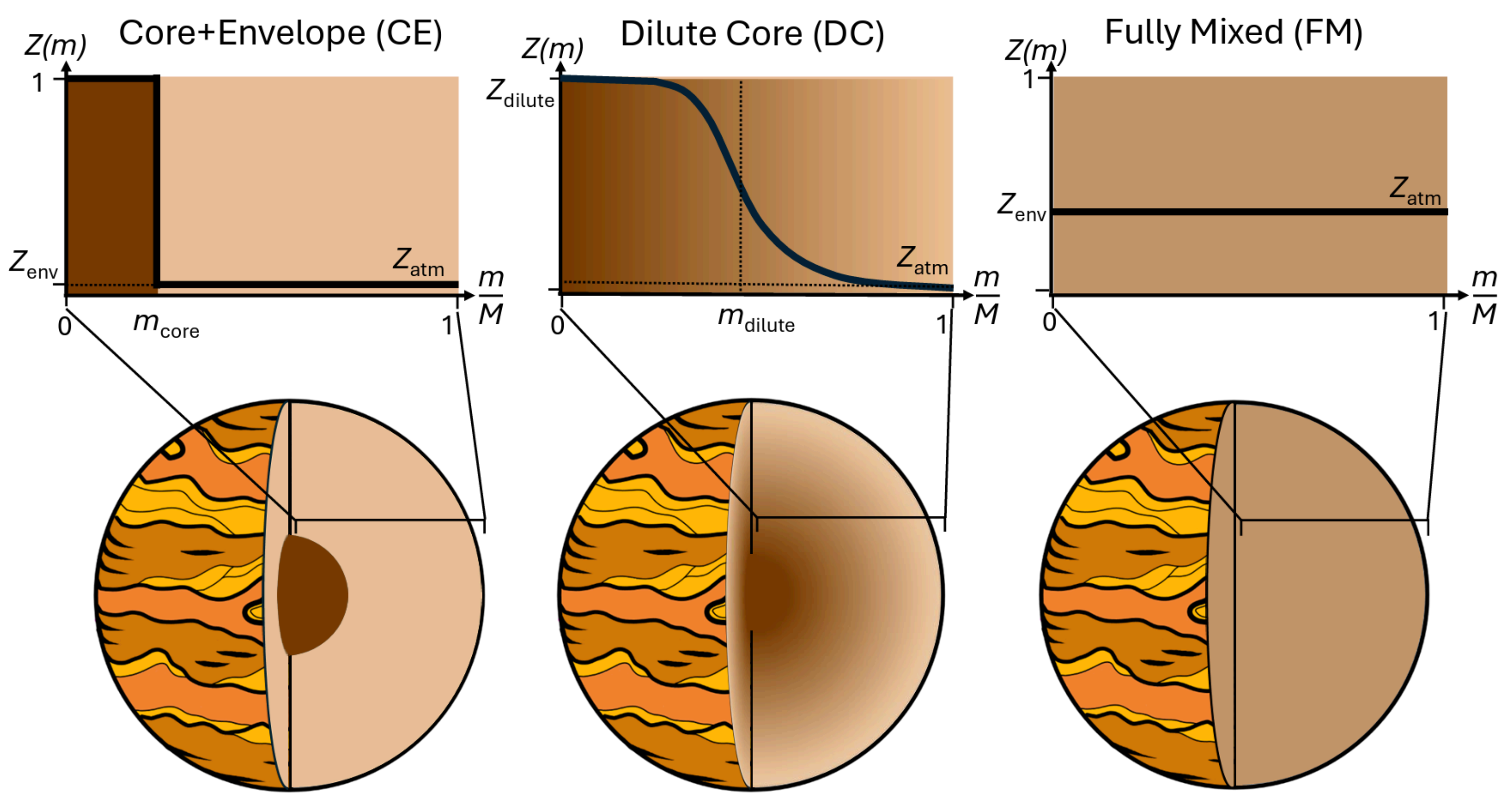
Acuna et al. 2024



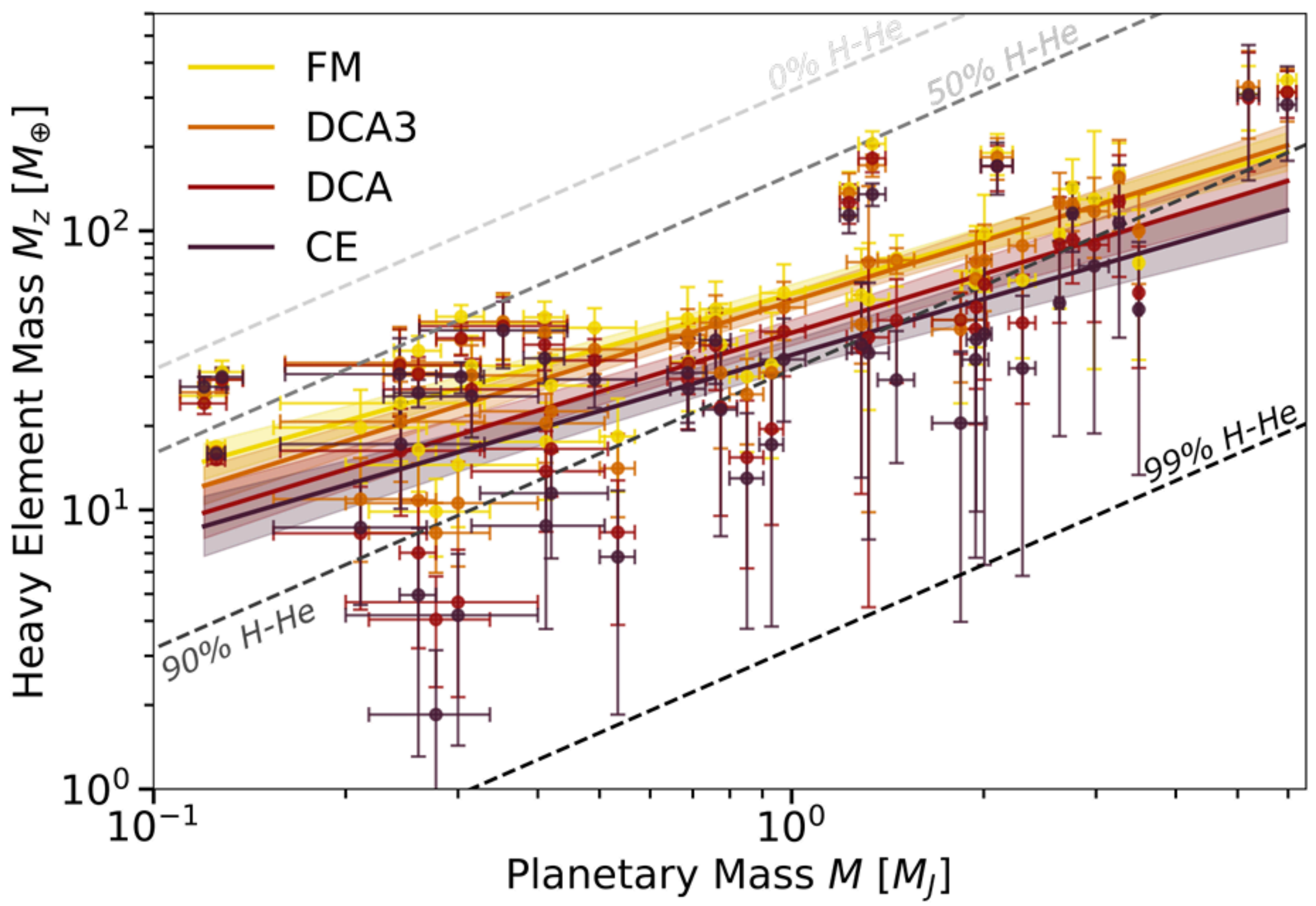
Poster & Redmer 2024

Radius-Mass relation encapsulates composition, interior structure, and dynamical interior processes

Observables are snapshots in time

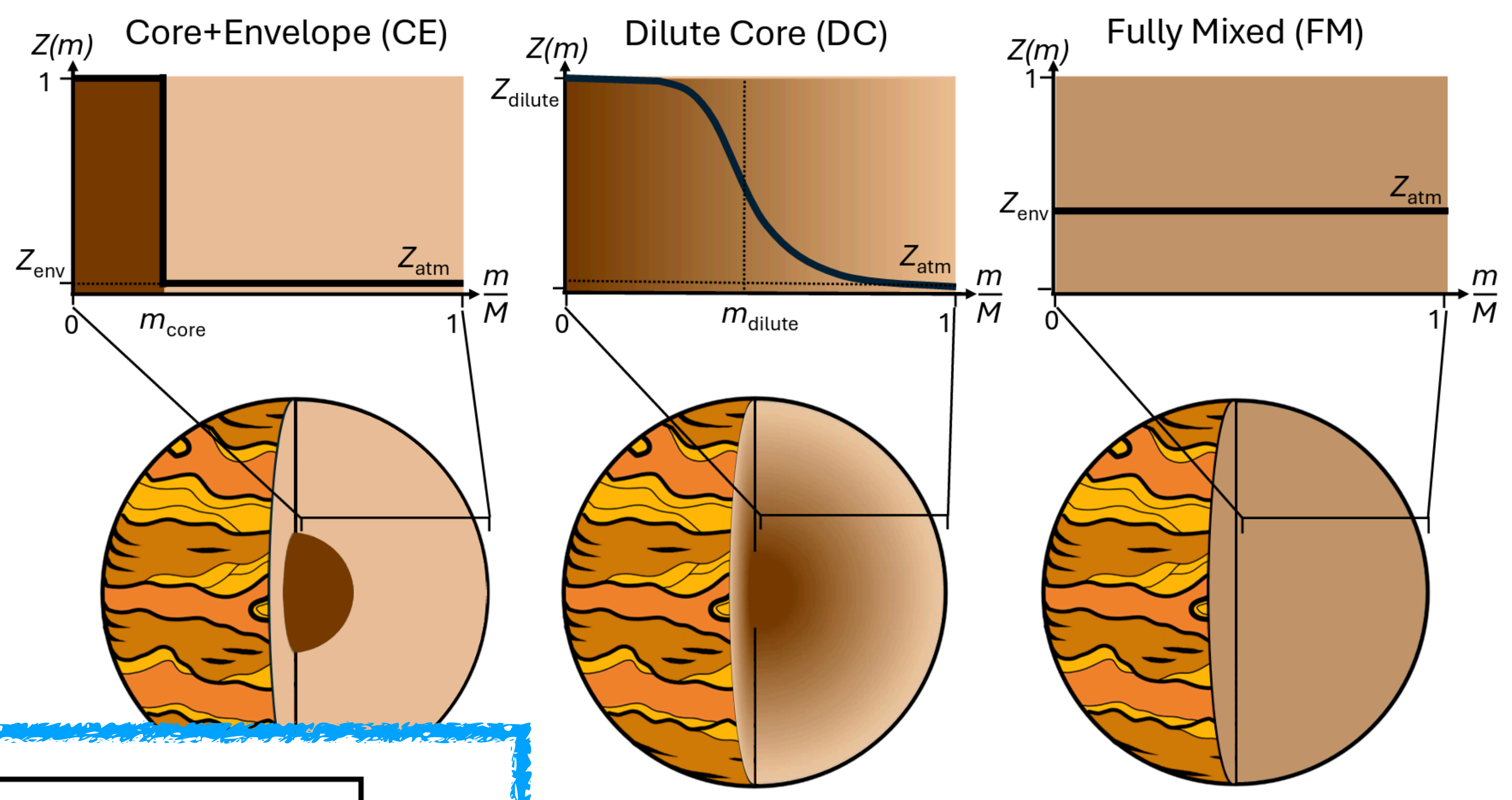


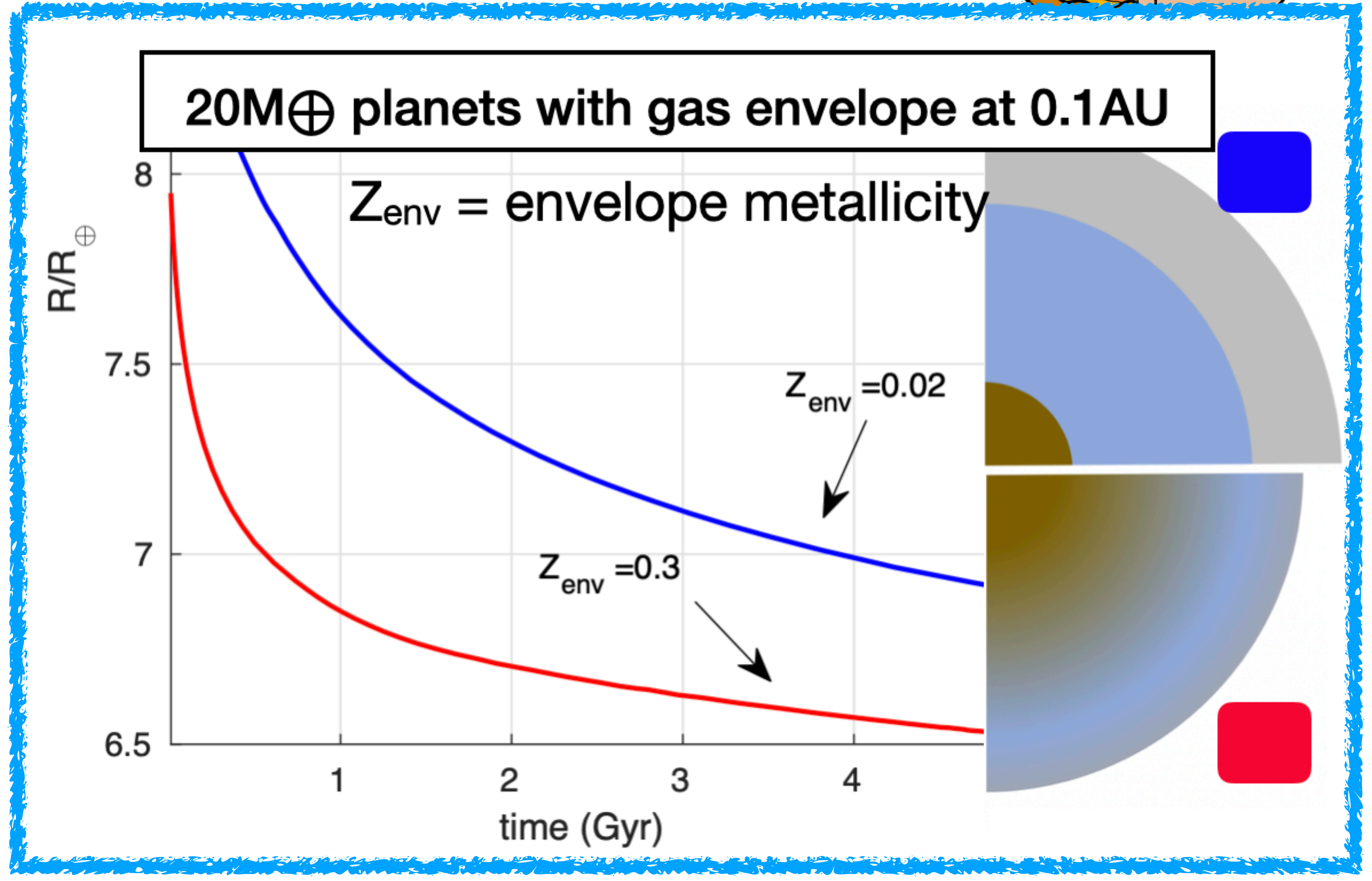
Peerani et al. 2026



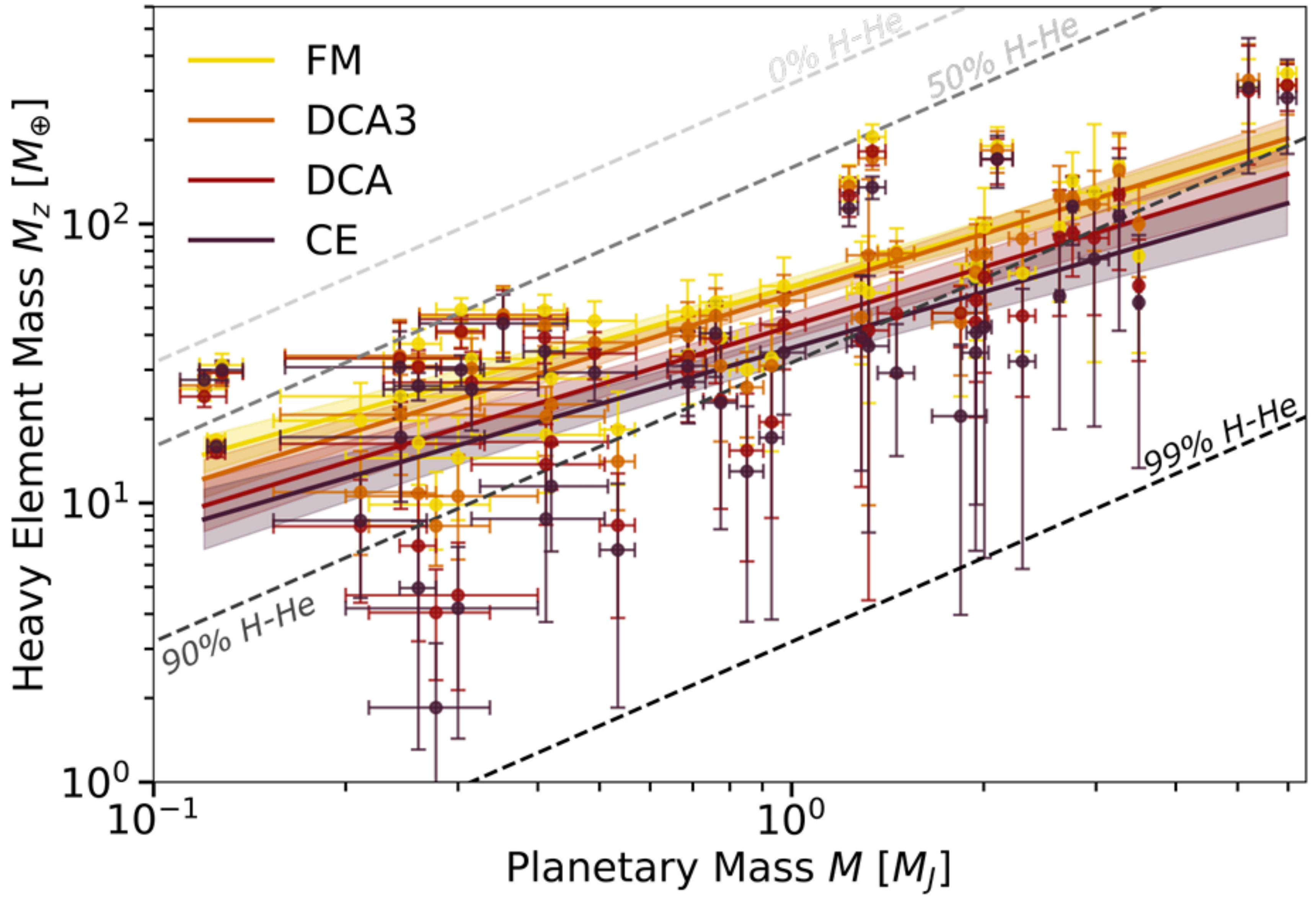
structure effect + cooling effect

Observables are snapshots in time



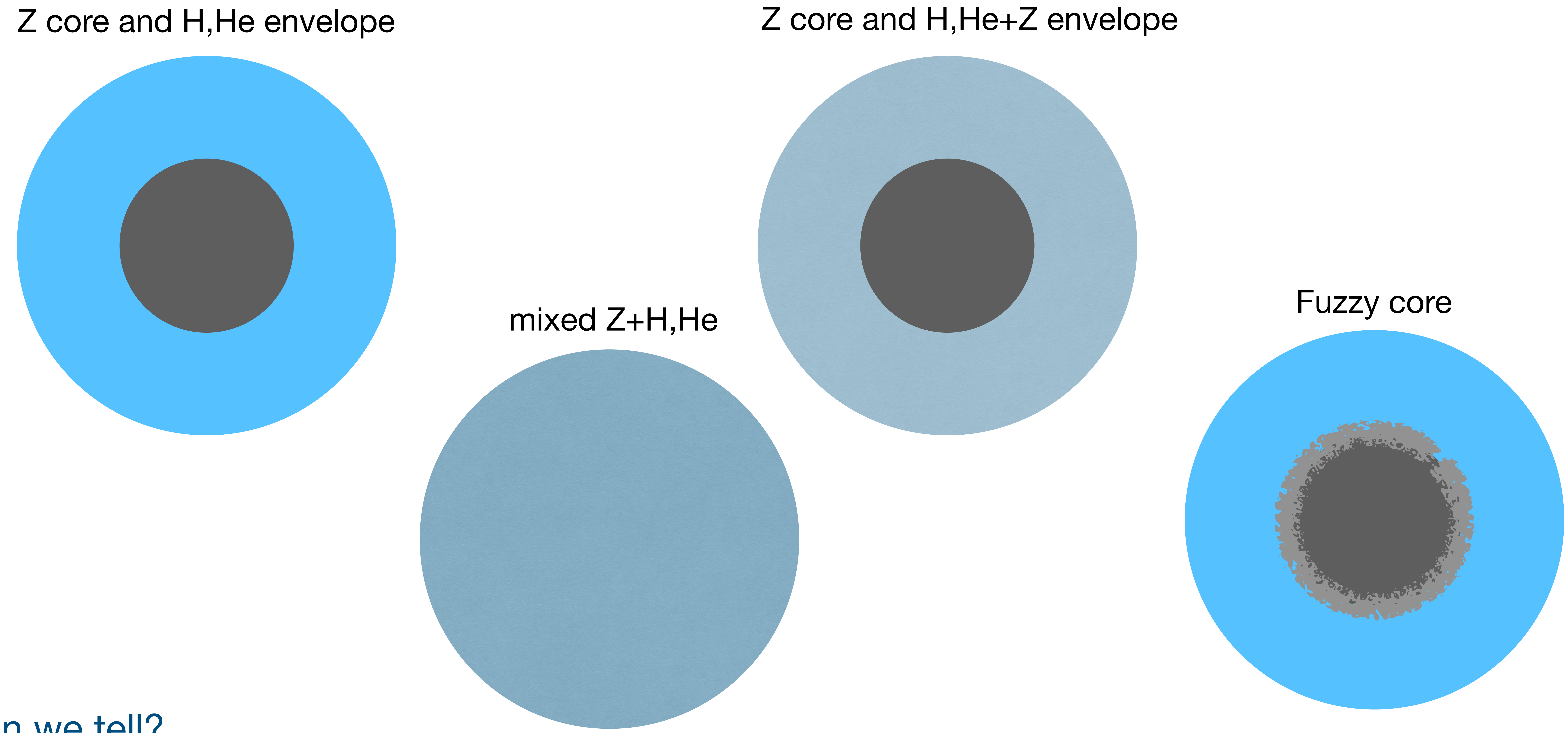


Peerani et al. 2026



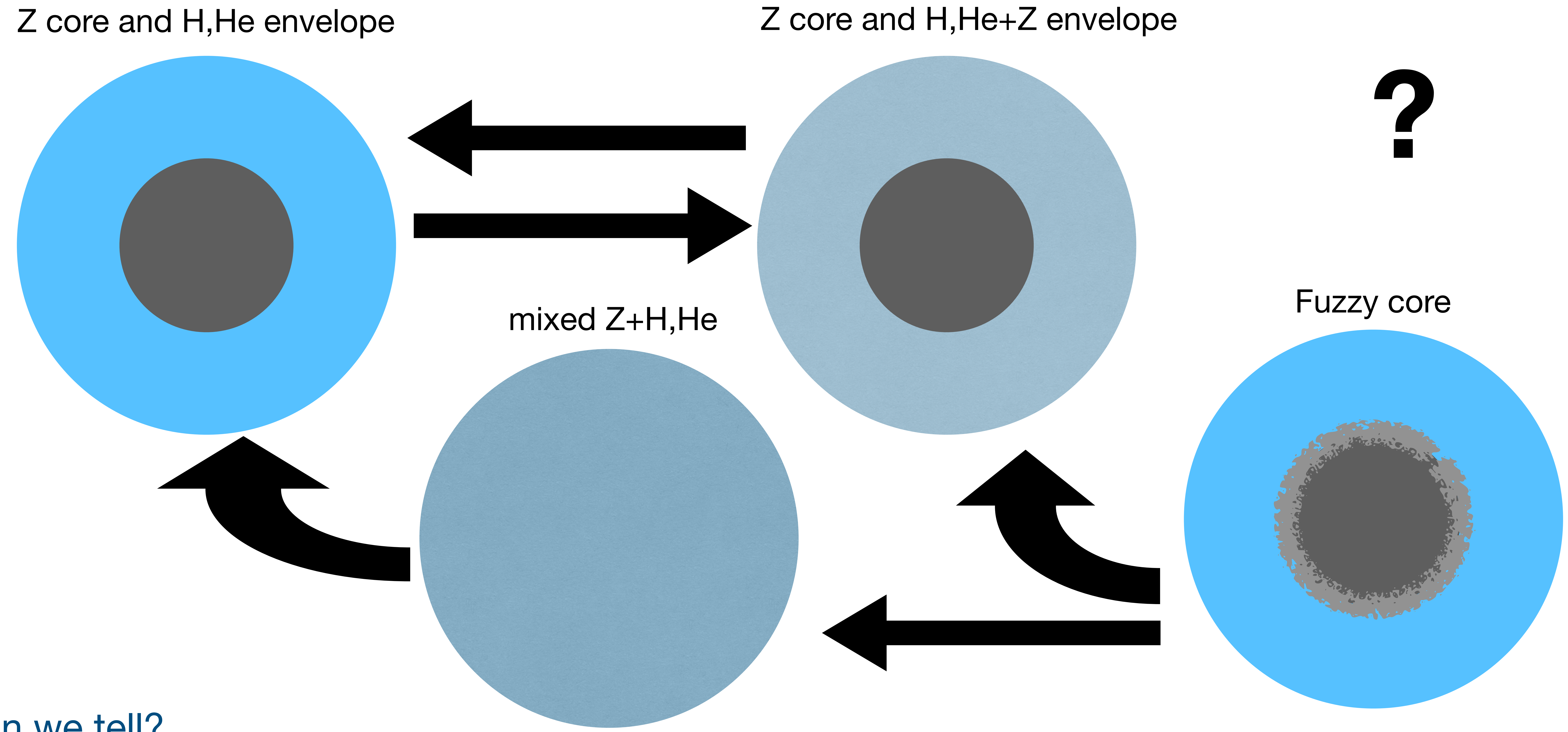
structure effect + cooling effect

Observables are snapshots in time



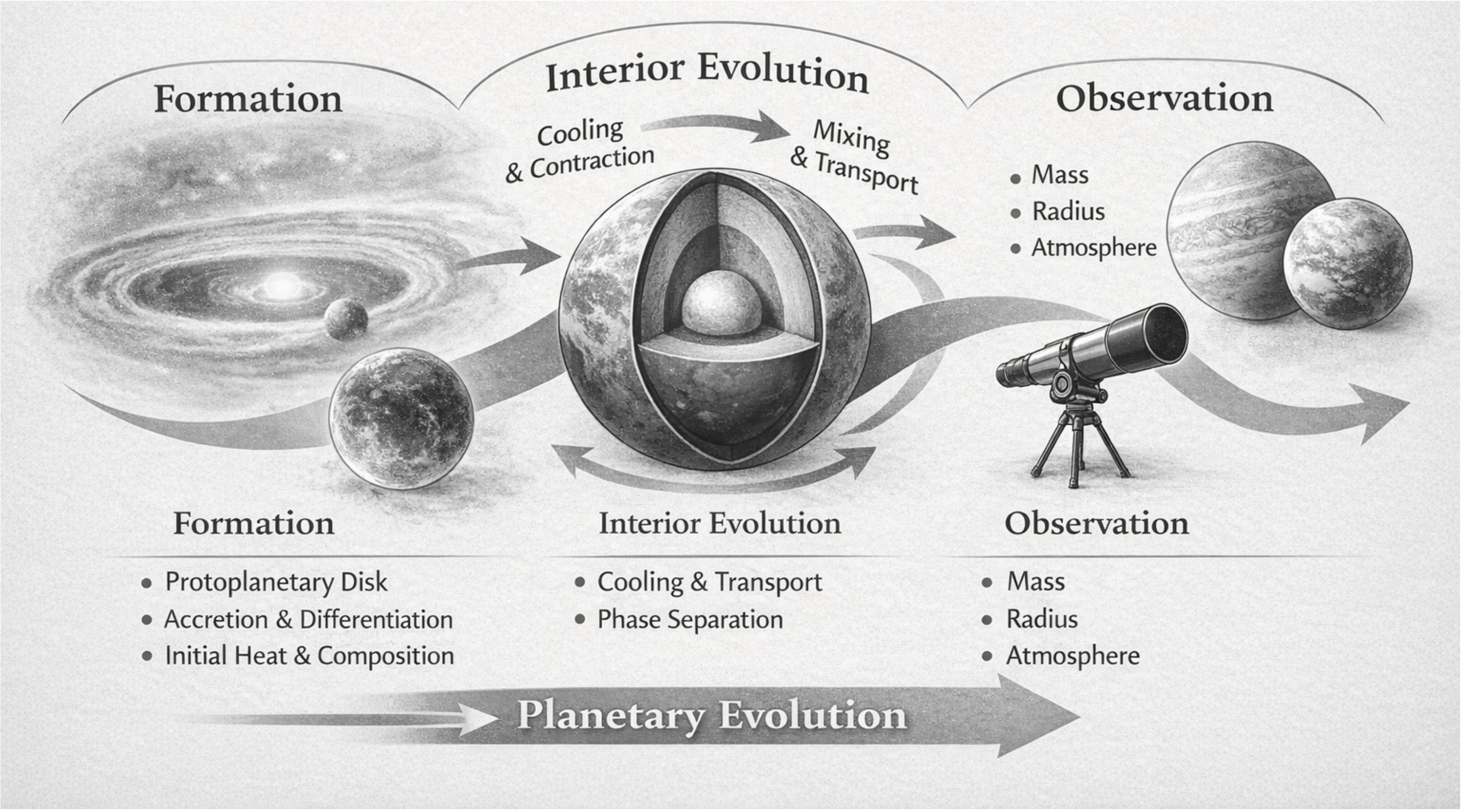
How can we tell?

Observables are snapshots in time



How can we tell?

From formation to observation:
Planetary evolution



See the whole story in order to understand and interpret observations correctly

The evolution of planetary evolution

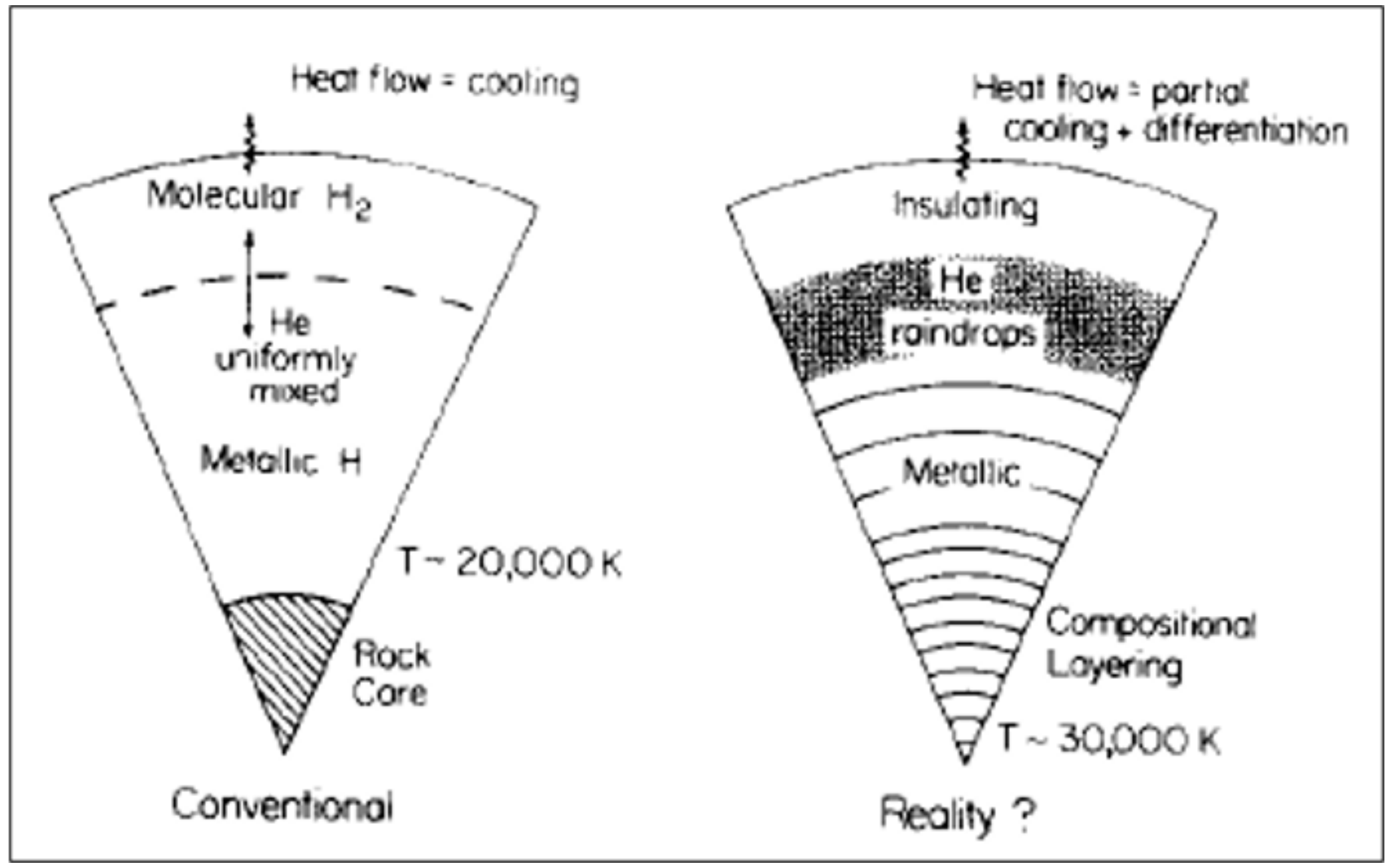
Structure evolve, composition evolve, observables evolve

Interior snapshot in time	**Thermal evolution**	Structure evolution
hydrostatic structure	**adiabatic**, non-adiabatic, semi	physical: mixing, settling
composition distribution	diffusion: radiative / conductive	chemical: equilibrium?
equation of state	initial energy budget	solubility / miscibility
energy content	stellar effects (tides, magnetic, ..)	high pressure production

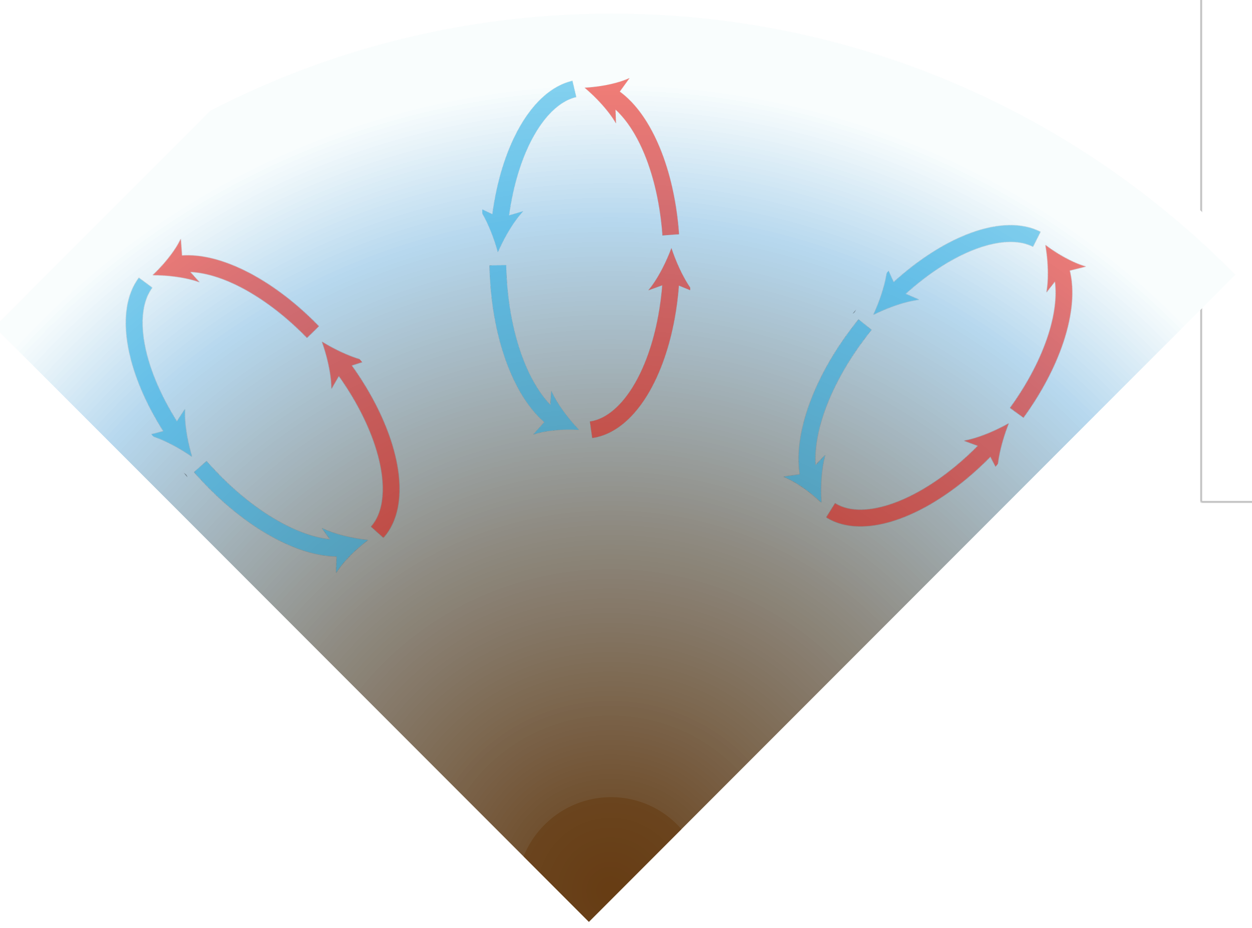
The three depends on each other in inverse order

Energy transport

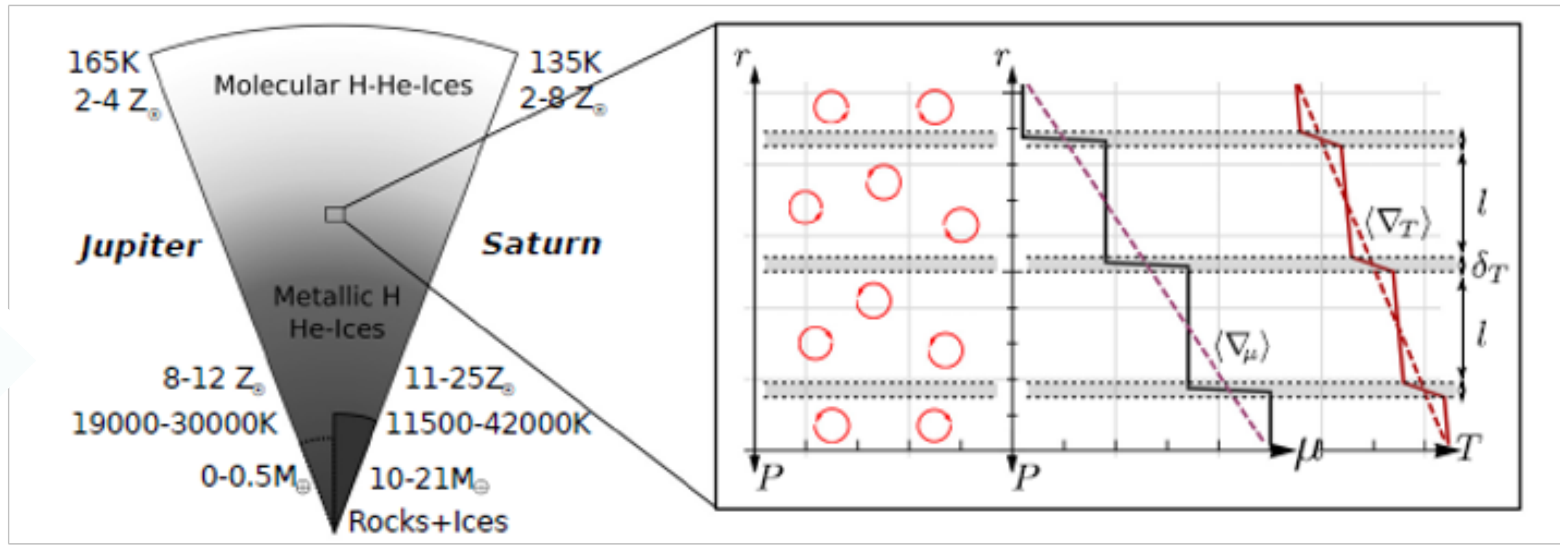
In planets with gradual composition distribution



Stevenson 1985



$$\nabla_R > \nabla_A + \nabla_{Ledoux}$$



Leconte & Chabrier 2012

also:
Chabrier & Barrafe 2027
Leconte & Chabrier 2013
Mirou et al. 2012
Wood et al. 2014
Graud et al.

The stability of composition gradients is a competition between gradients: temperature and mean molecular weight

Accordingly, some regions in the planet become, time-dependently:

convective (adiabatic) radiative / conductive (non-adiabatic) or layered-convective (semi-adiabatic)

The evolution of planetary evolution

Structure evolve, composition evolve, observables evolve

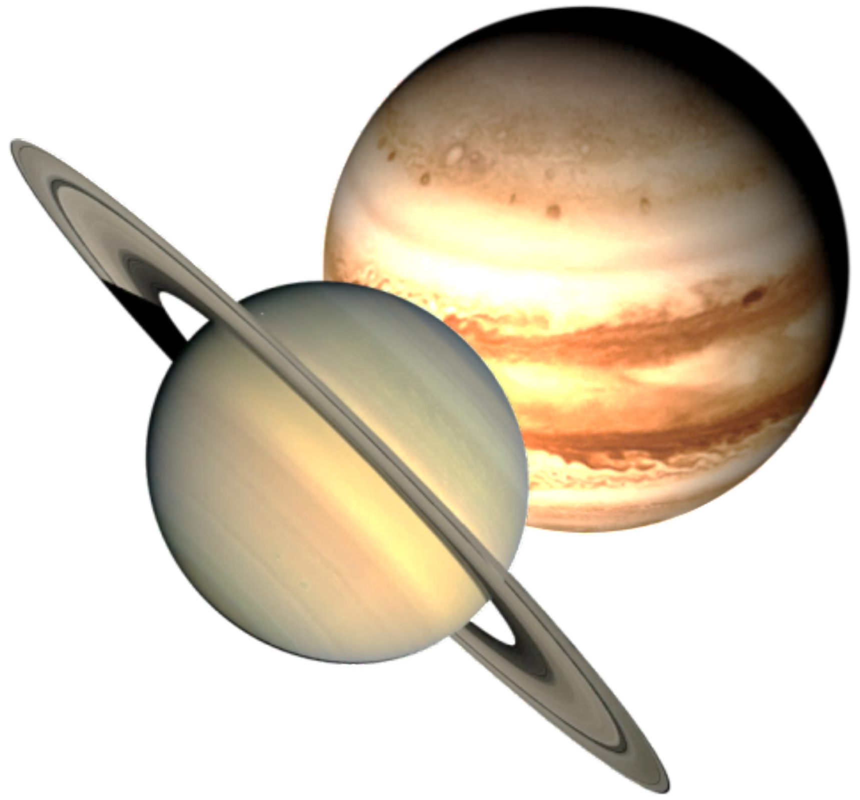
Where to start???

Structure affects the thermal evolution and radius, BUT the structure is not directly detectable…

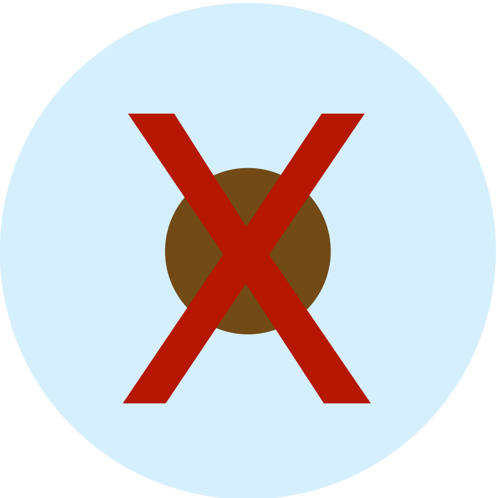
How can we build the layers of understanding?

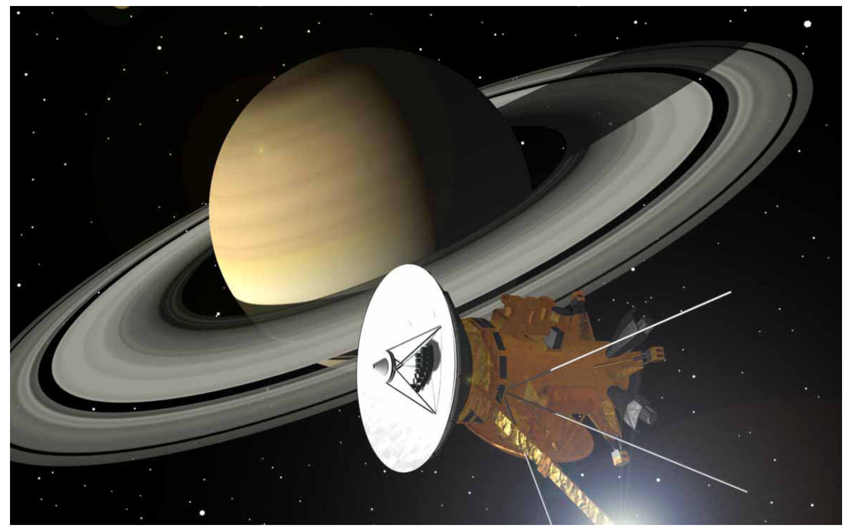
1) solar system
2) explore the starting point
3) theoretical physics (thermodynamics, fluid dynamics, …)
4) Theoretical and experimental chemistry (equilibrium, high-p labs, DFT/MD simulations)

Indications from solar system
Jupiter and Saturn

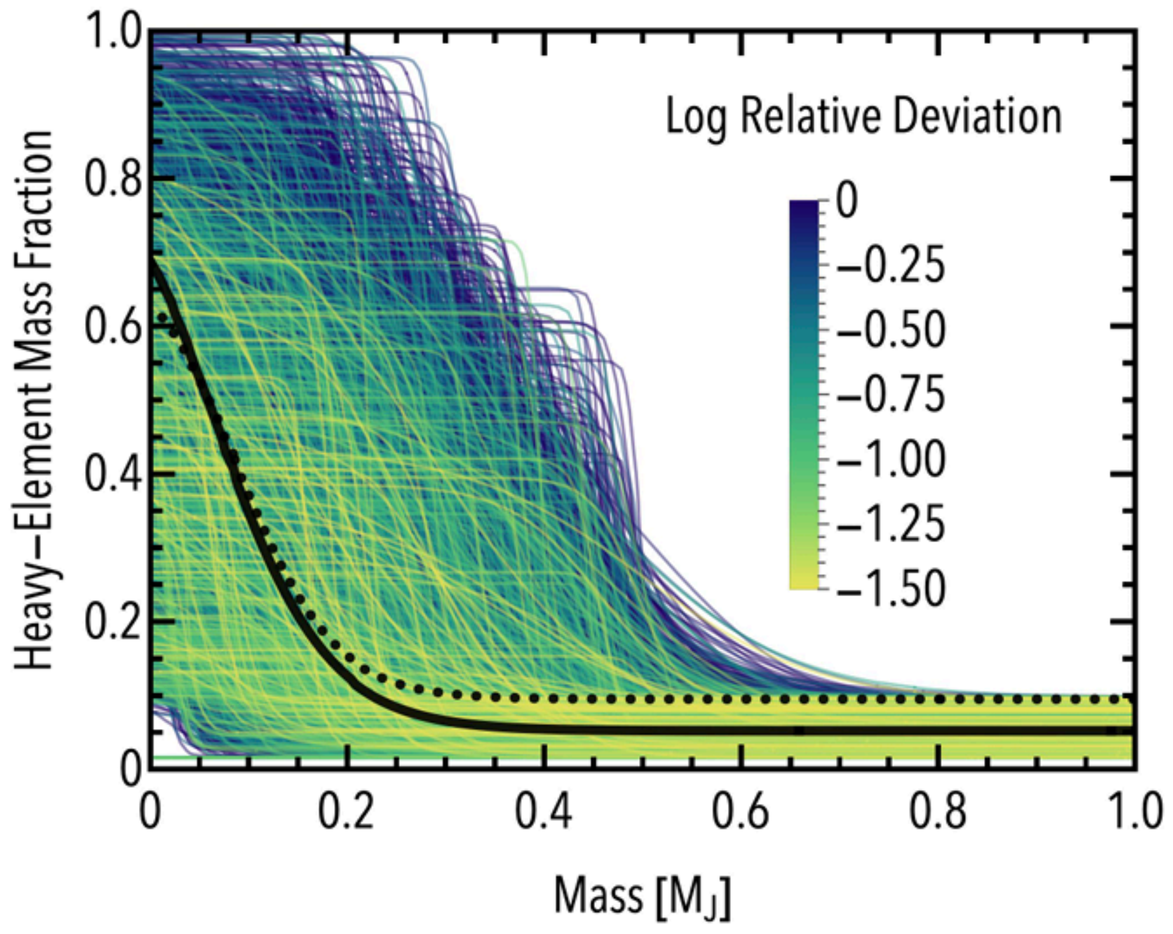


Inhomogeneous formation and evolution models are required to reproduce the present-day properties measured by the **JUNO** and **CASSINI** space missions

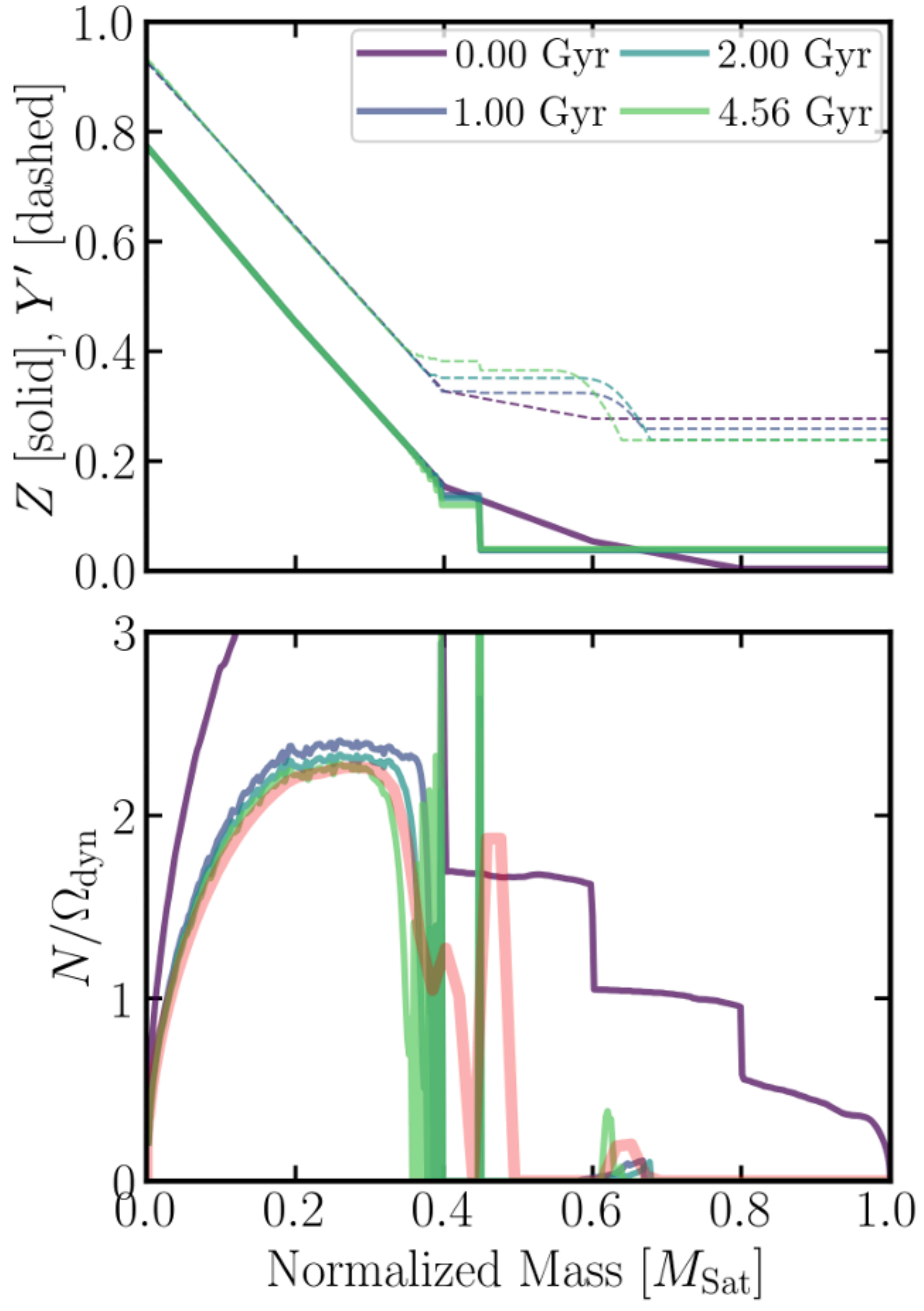




Vazan et al. 2016
What et al. 2017
Helled & Stevenson 2017
Vazan et al. 2018
Mankovich et al. 2023
Militzer & Hubbard 2024
Tejada Arevalo et al. 2025
Sur et al. 2025
…

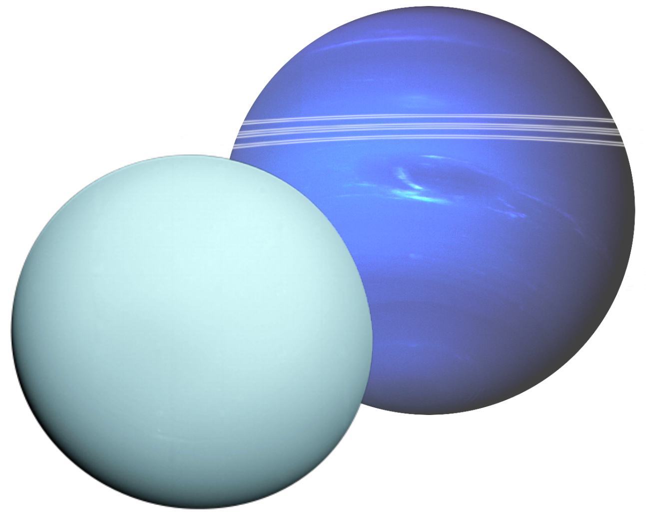


Knierim et al. 2025



Su et al. 2026

Indications from solar system
Uranus and Neptune

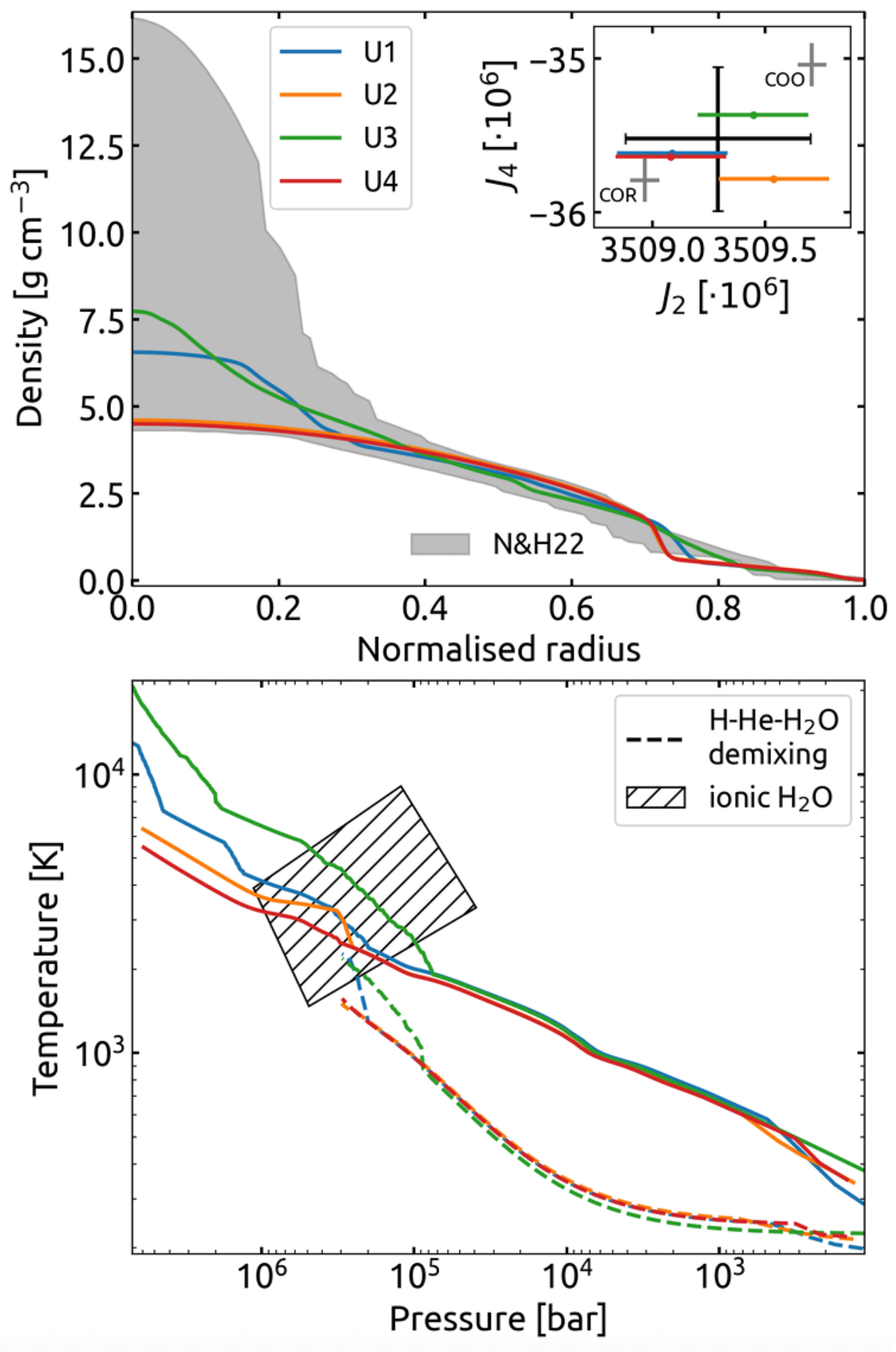


Simple convective interior model is not consistent with all the measurements of Uranus (Fortney et al. 2011, Nettelmann et al. 2013) and Neptune (Shceibe et al. 2019).

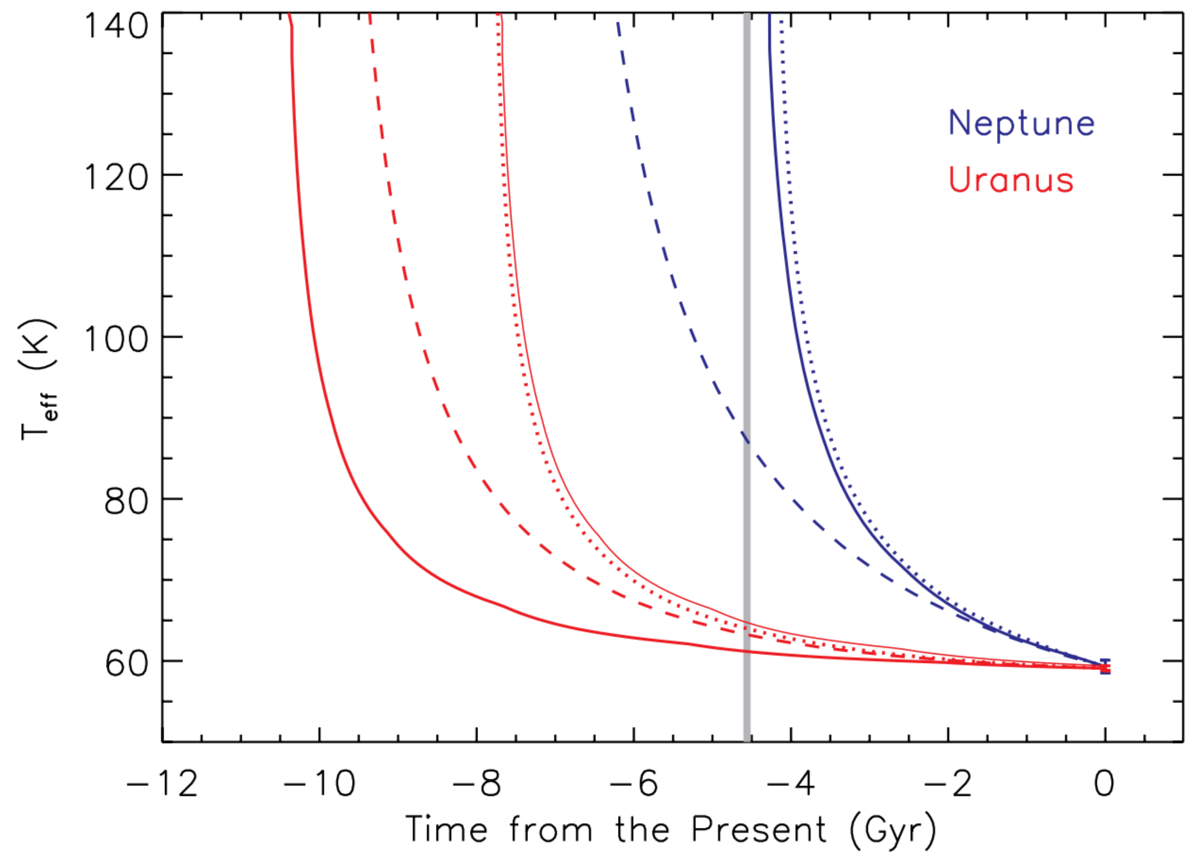
Alternative: non-uniform composition distributions (affects cooling)

(Podolak et al. 1991, Marley et al. 1995, Helled et al. 2011, Nettelmann et al. 2016, Kurosaki & Ikoma 2017, …).

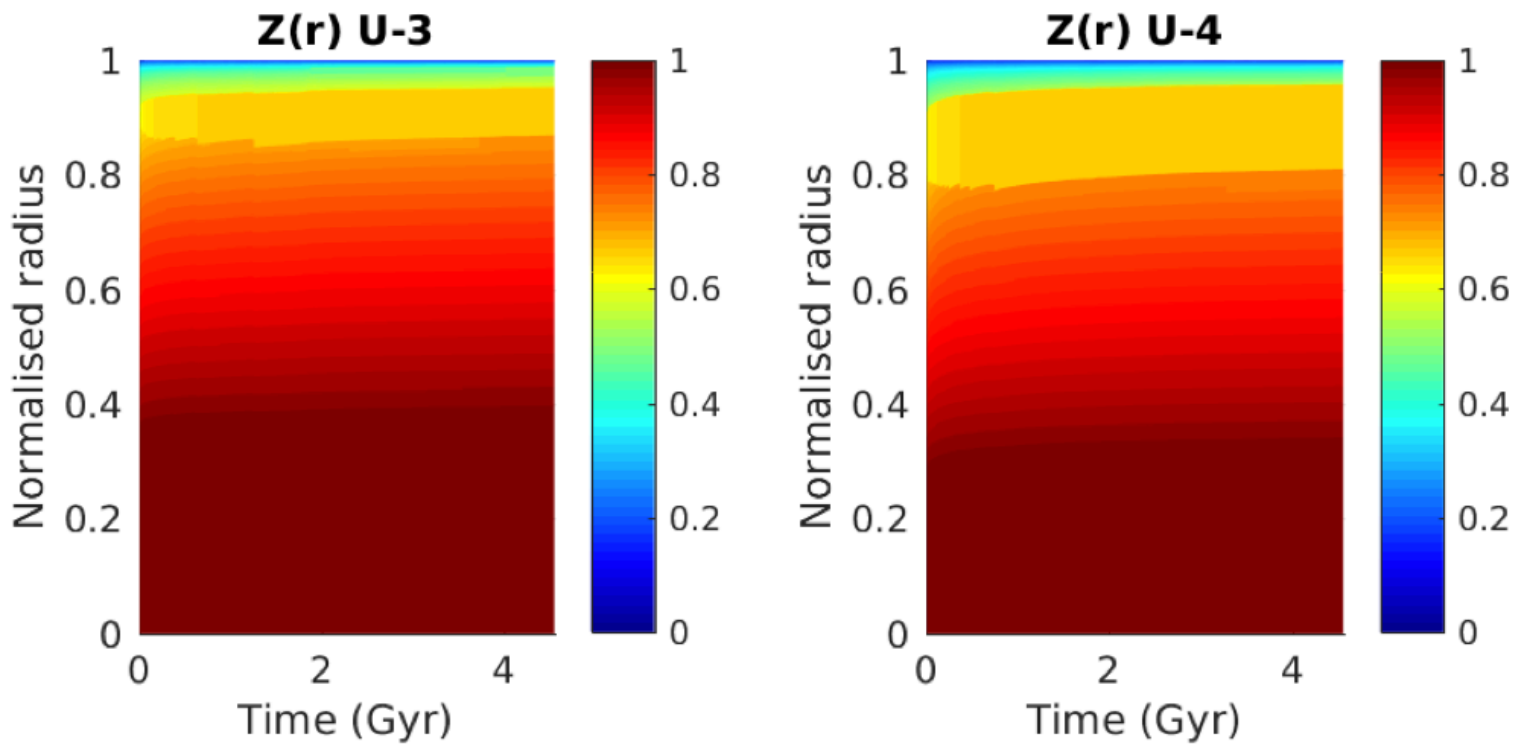
Stable composition gradients explain U&N measurements



Morf & Helled 2025



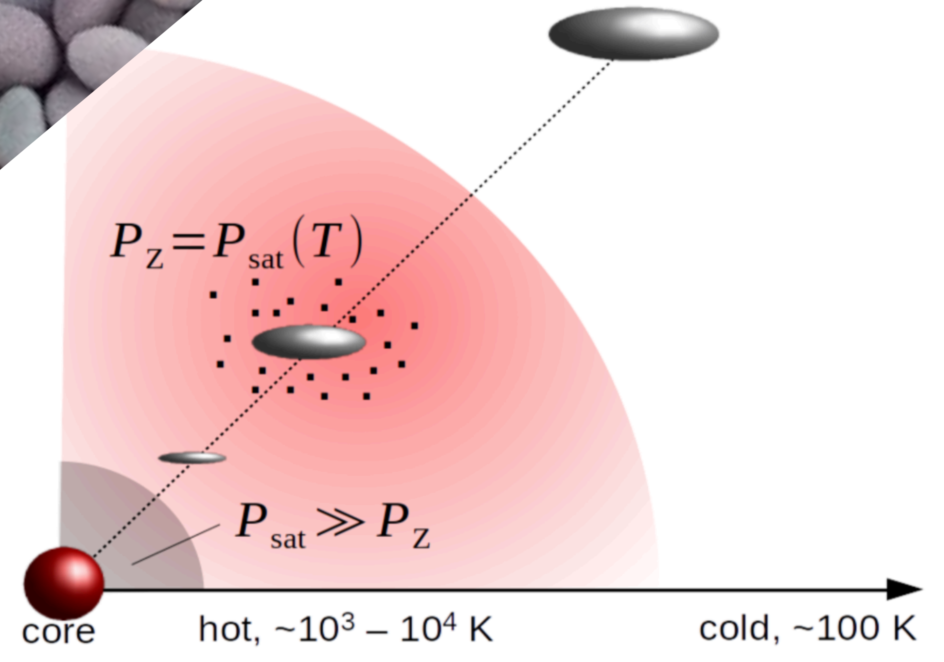
Fortney et al. 2011



Vazan & Helled 2020

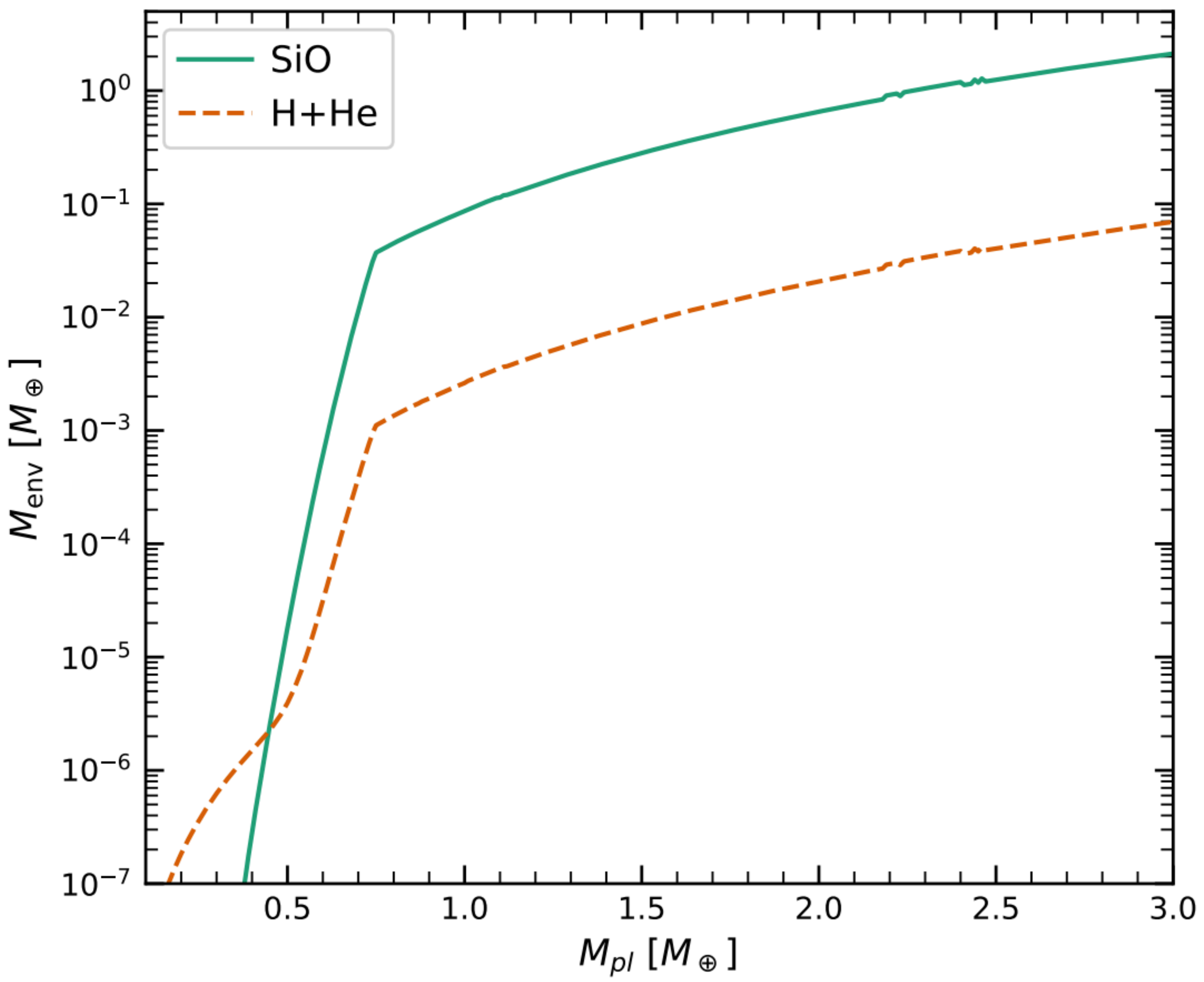
The interior evolution starting point

Initial conditions (planet formation)

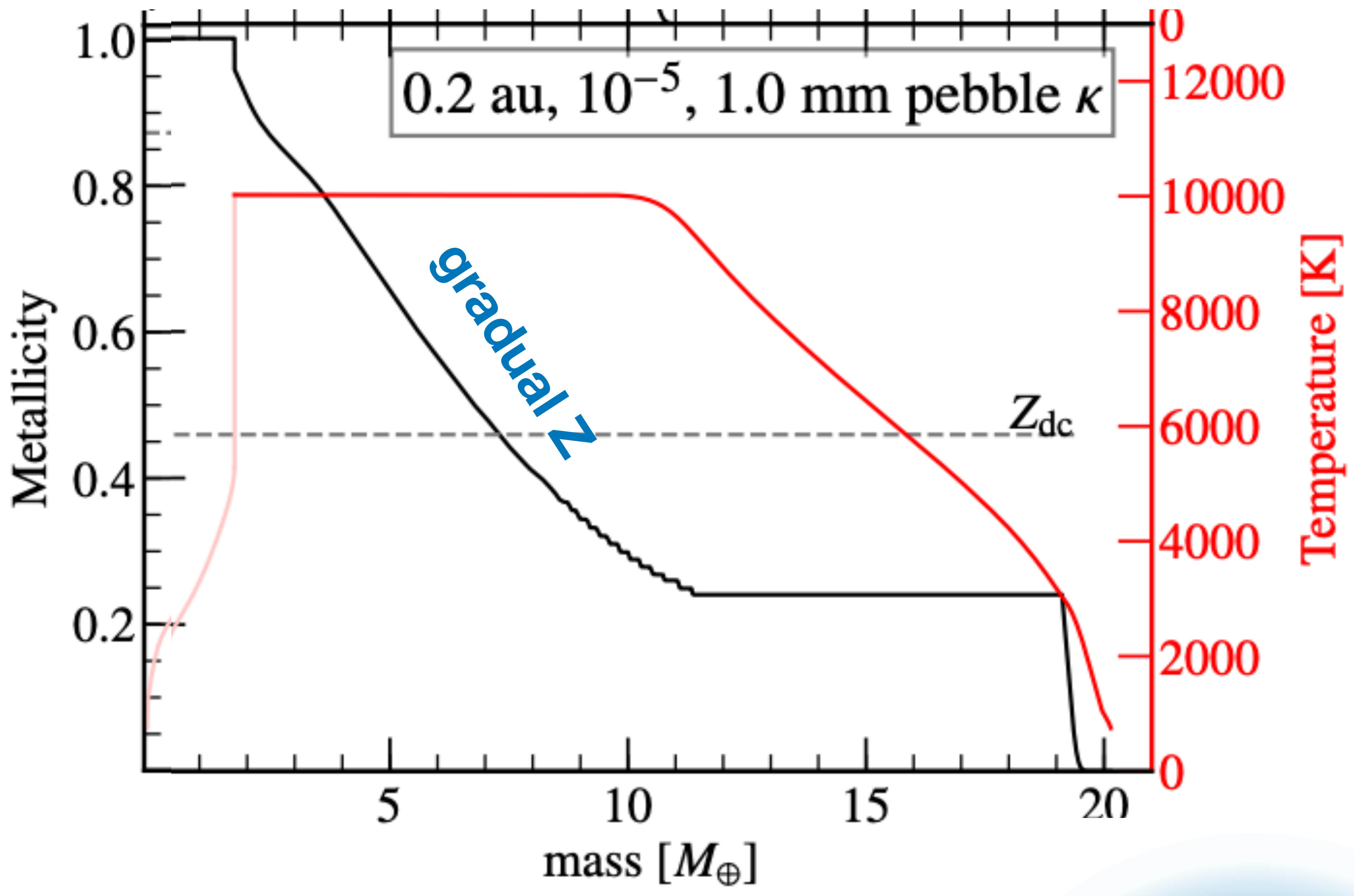


Brouwers et al. 2018

<u>Solid-gas interaction:</u>
Podolak et al. 1988
Mordasini et al. 2006
Iaroslavitz & Podolak 2007
Mordasini et al. 2015
Pinhas et al. 2016

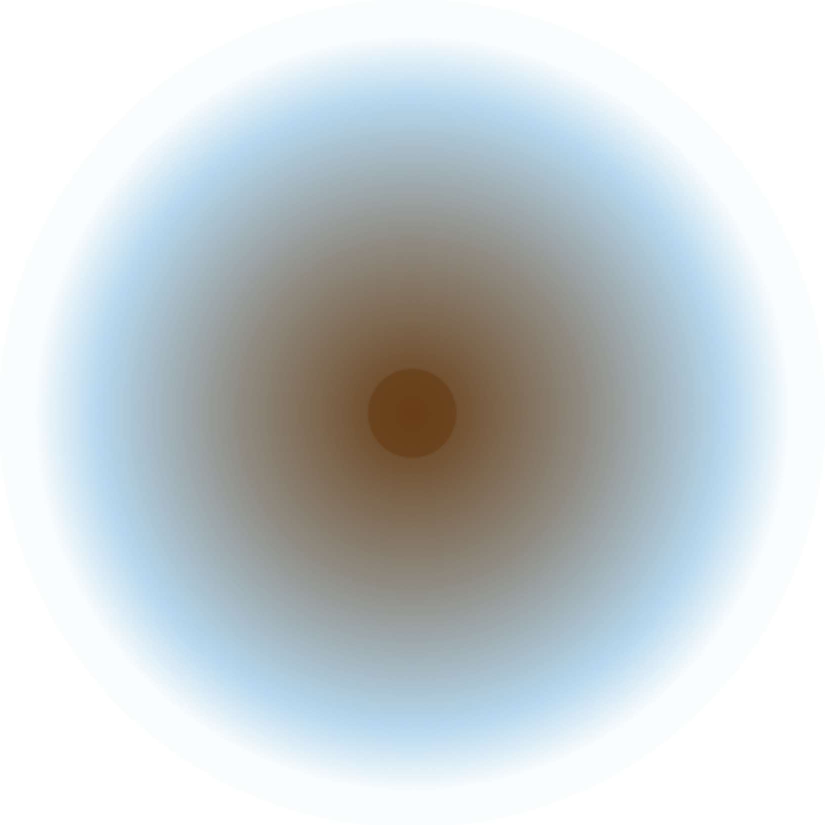


Steinmeyer & Johansen 2024



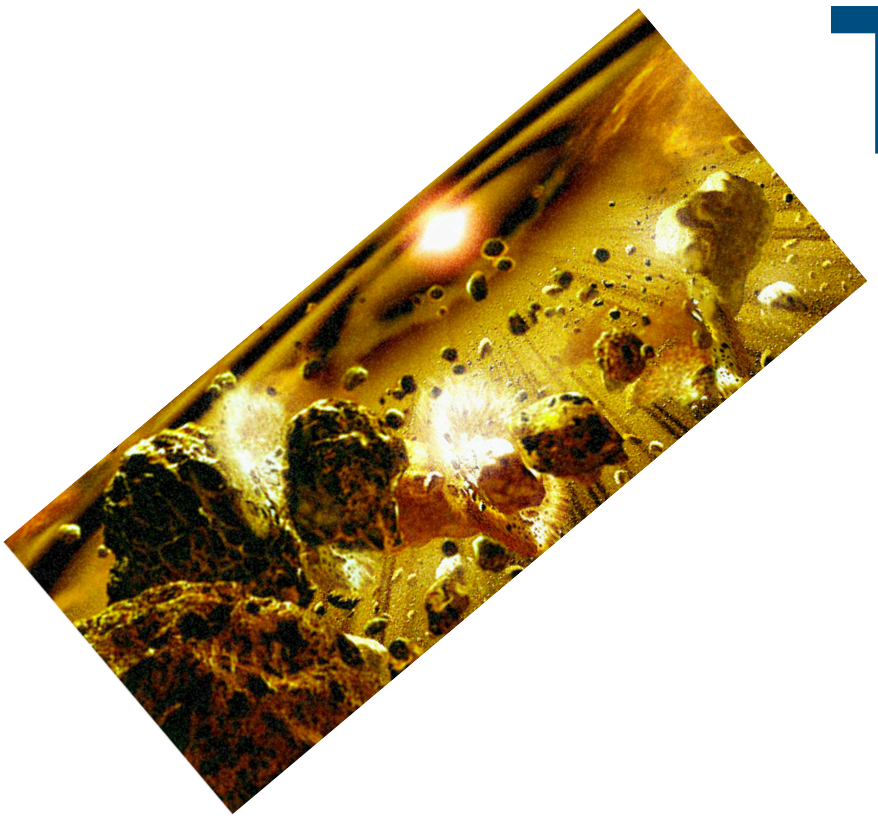
Ormel et al. 2021

Also:
Meisner et al. 2024

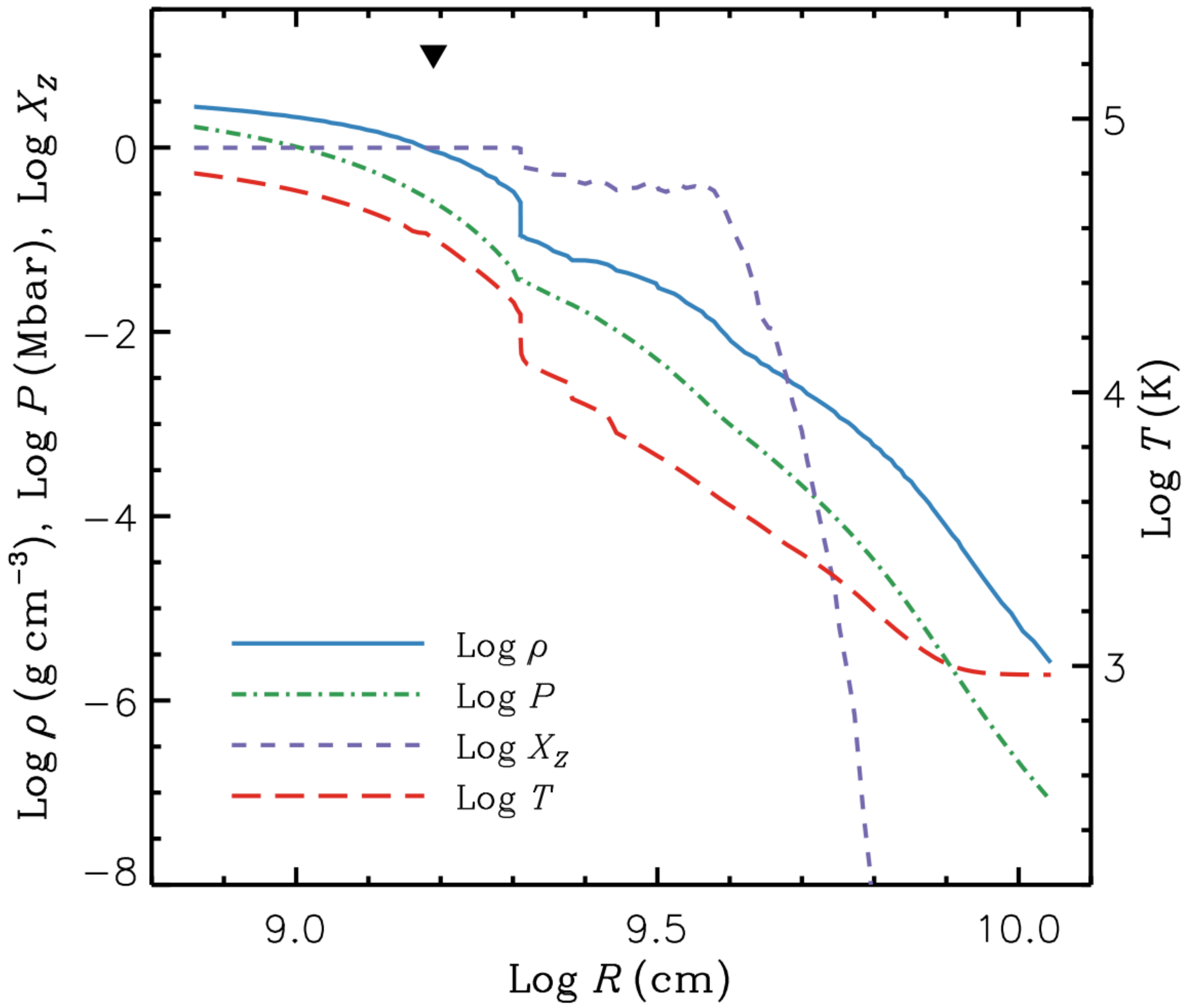


Ablation of accreted solids in the growing interior

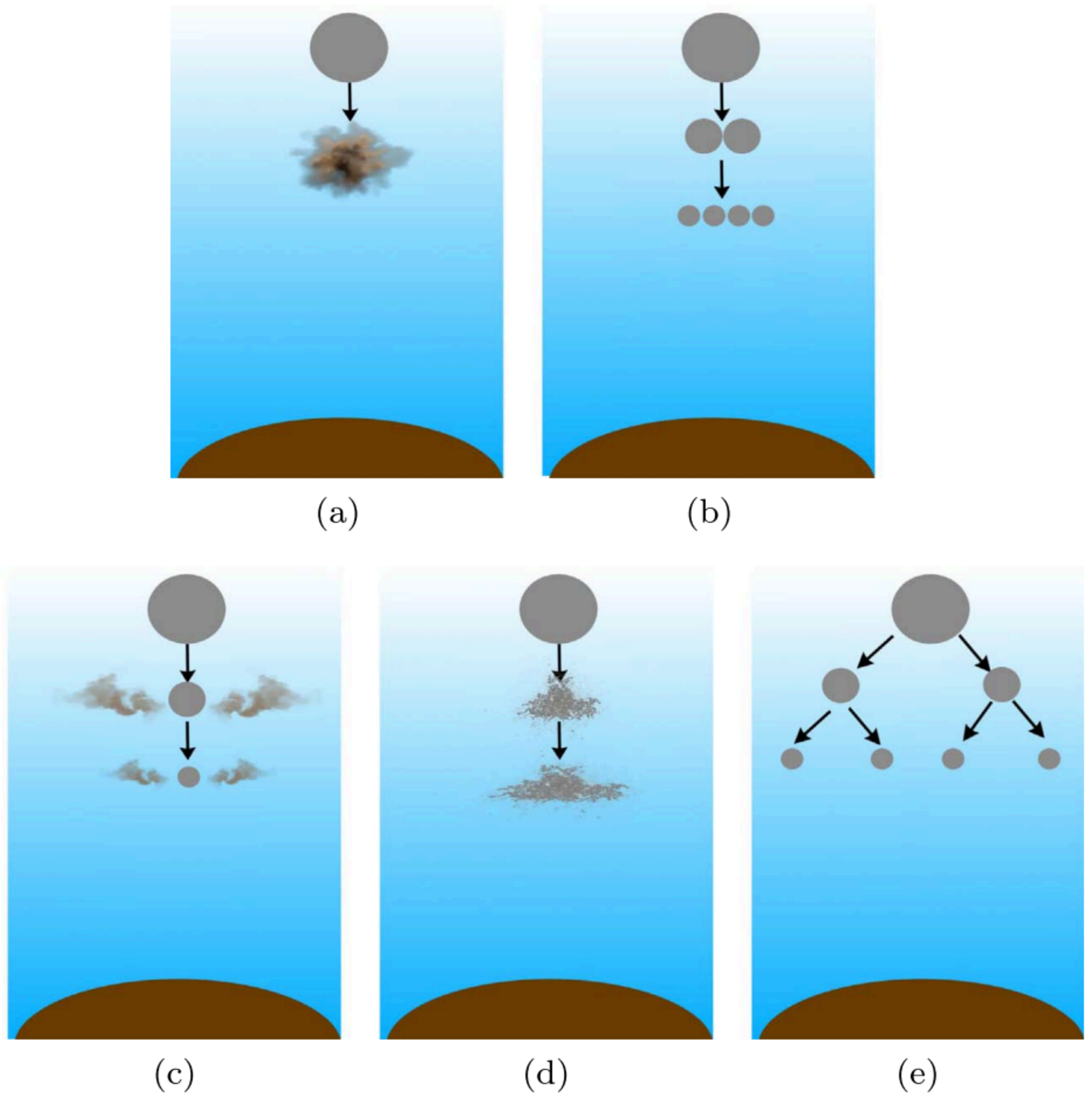
=> Polluted envelopes and composition gradients as natural outcomes of planet formation



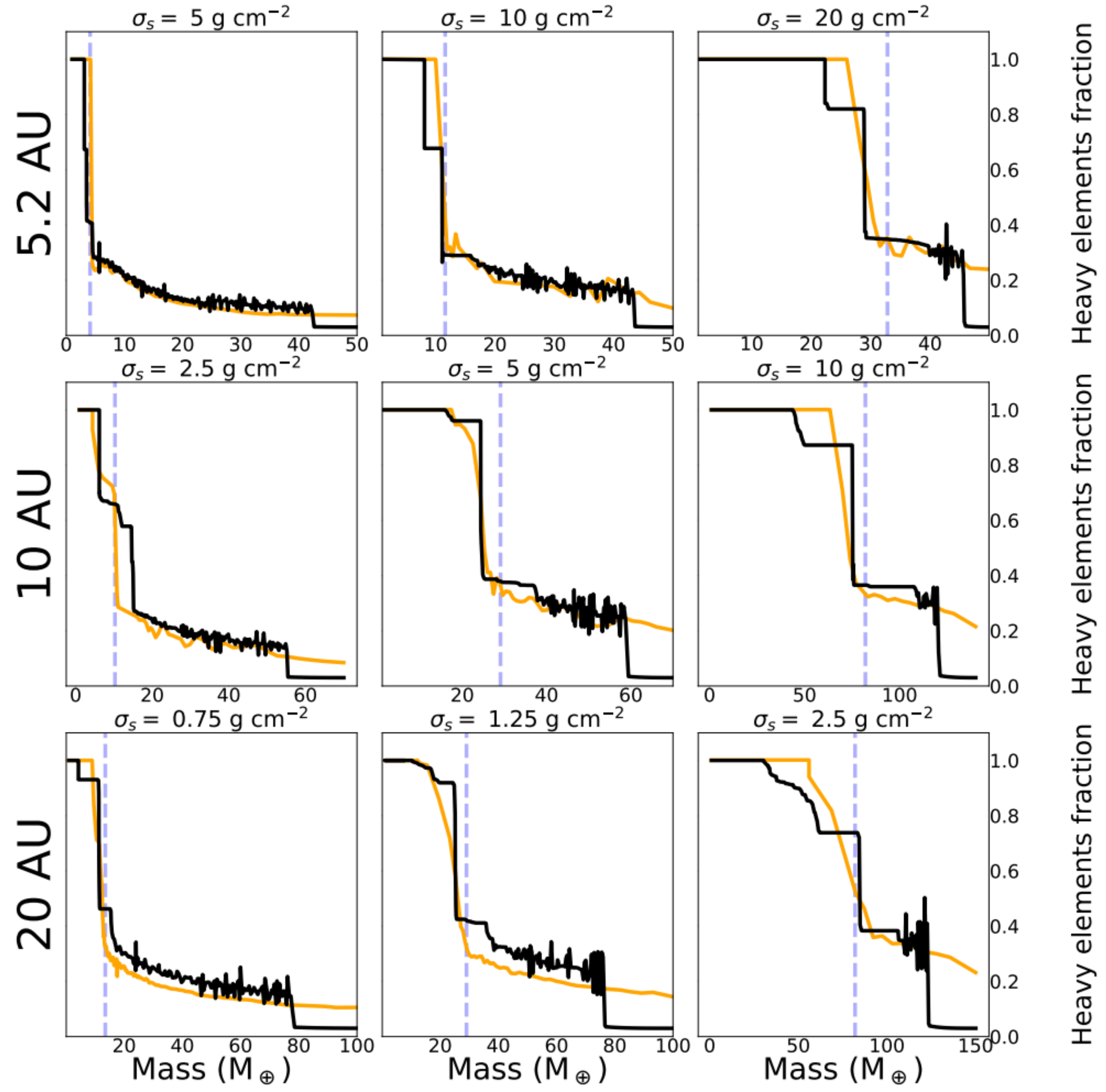
The interior evolution starting point
Initial conditions (planet formation)



Bodenheimer et al. 2018



Valletta & Helled 2019

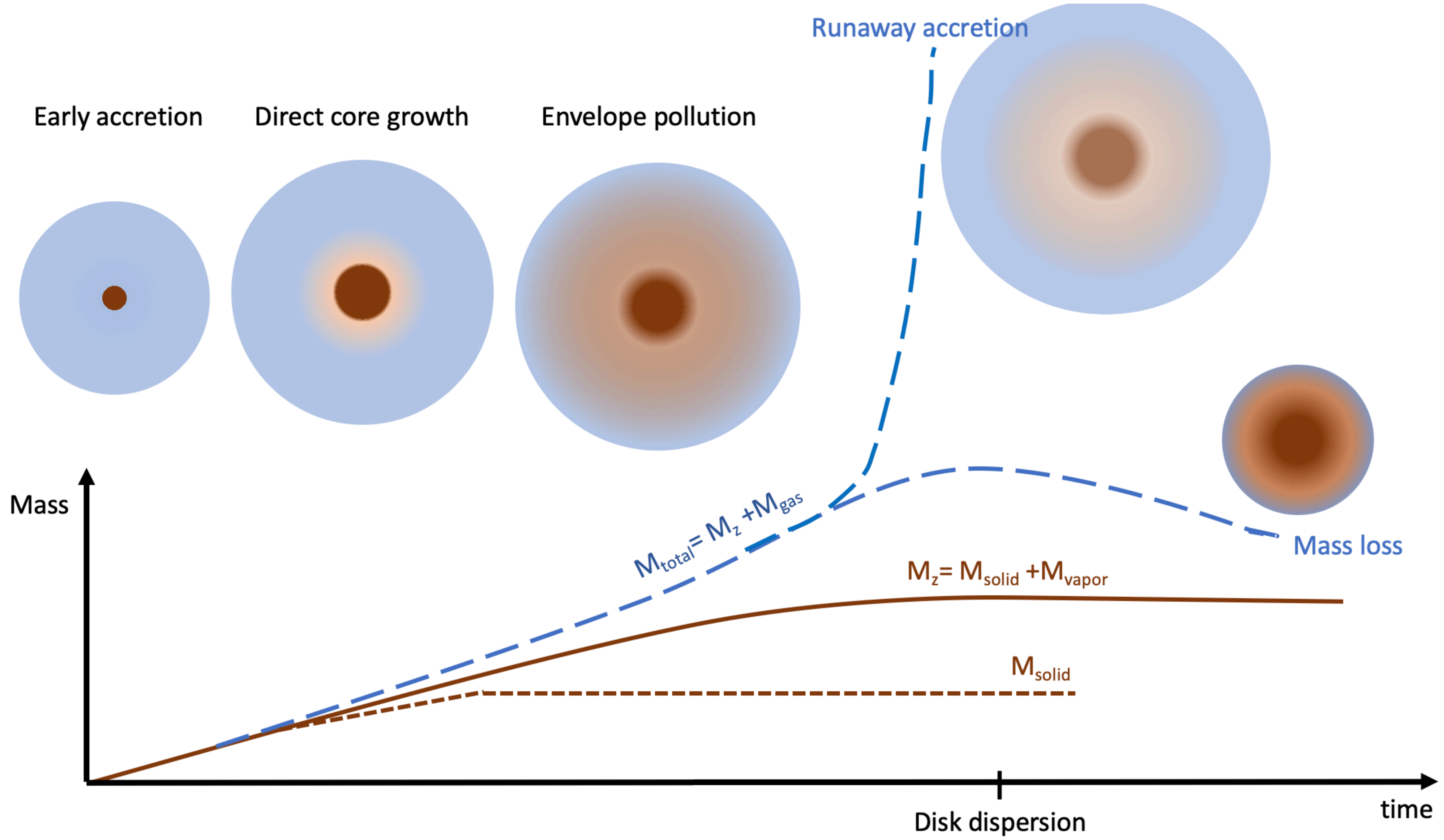


Valletta & Helled 2020

=> Polluted envelopes and composition gradients as natural outcomes of planet formation

The interior evolution starting point

Hot polluted envelopes



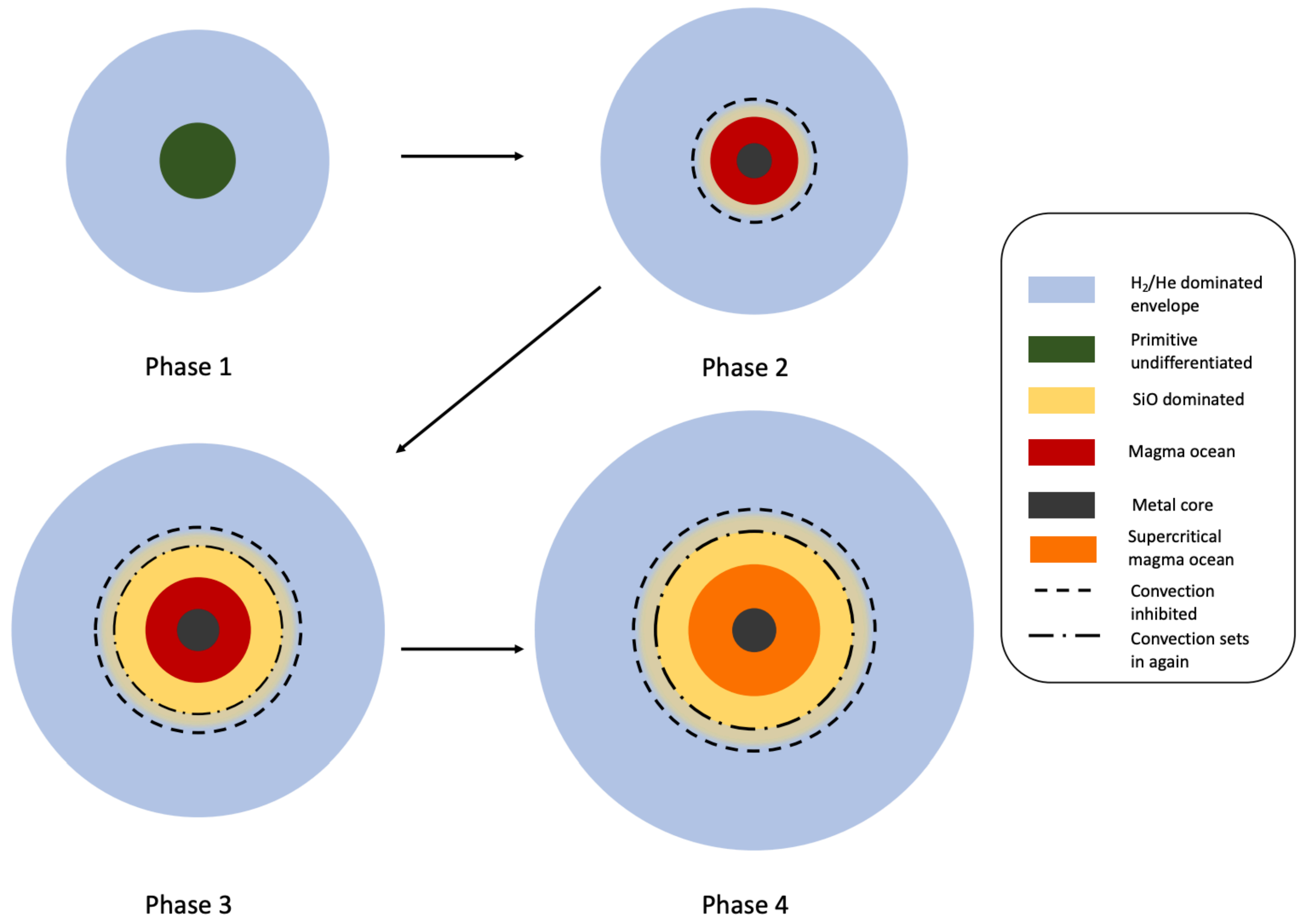
Drazkowska et al. 2023, PPVI

$$x\frac{3GM^2}{5R} = C_pTM$$

$$T_{max} \sim \frac{GM}{RC_p}$$

$$\sim 4.8 \times 10^4 \left(\frac{M}{M_\oplus}\right)\left(\frac{R_\oplus}{R}\right)\left(\frac{1KJ/kg/K}{C_p}\right)$$

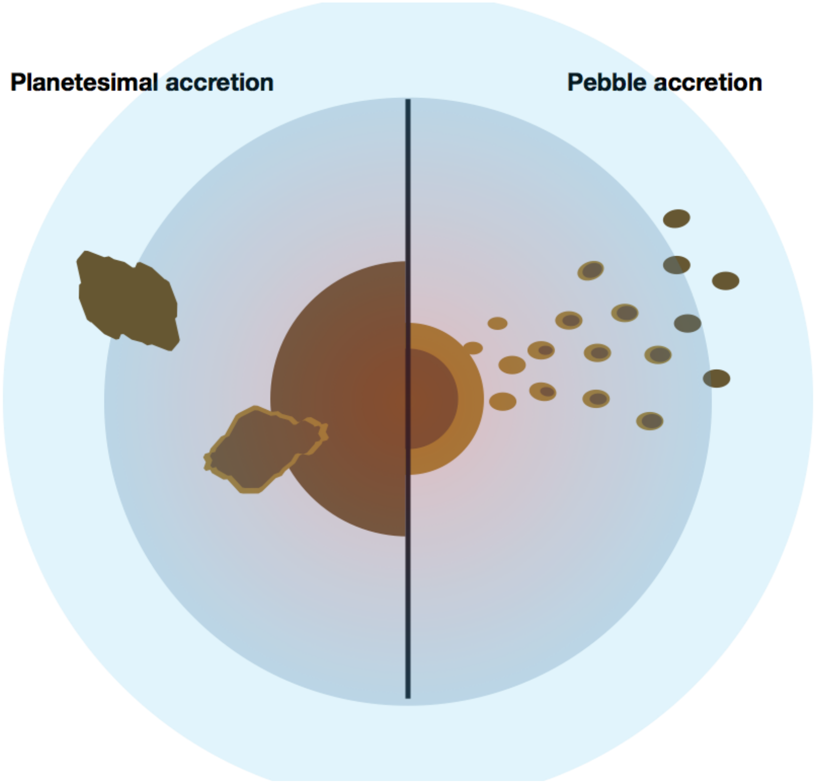
Lee et al. 2014, Ginzburg et al. 2016, Vazan et al. 2018, …



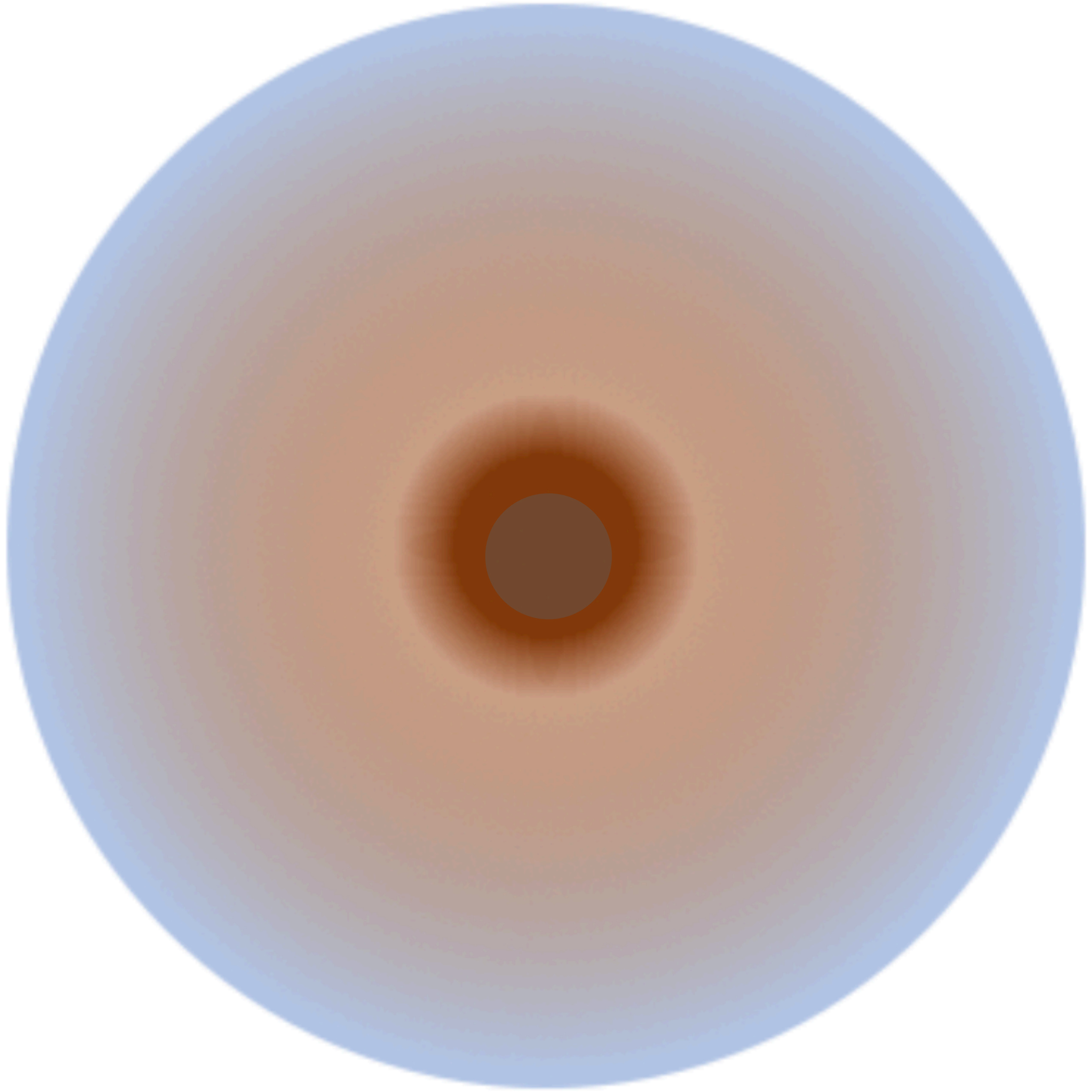
Steinmeyer & Johansen 2024

Early evolution scheme

Hot polluted envelopes



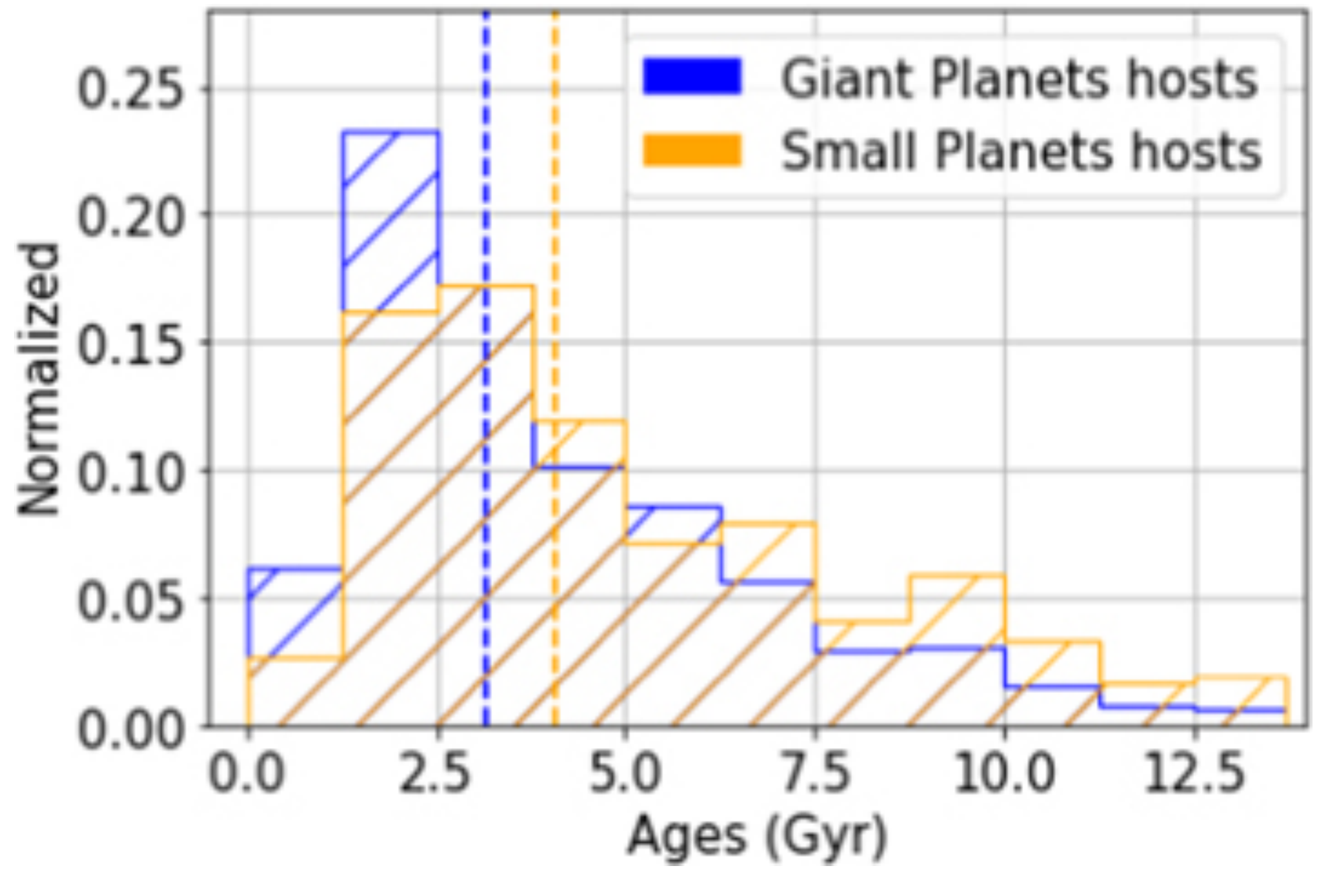
Myr



Gyr

?

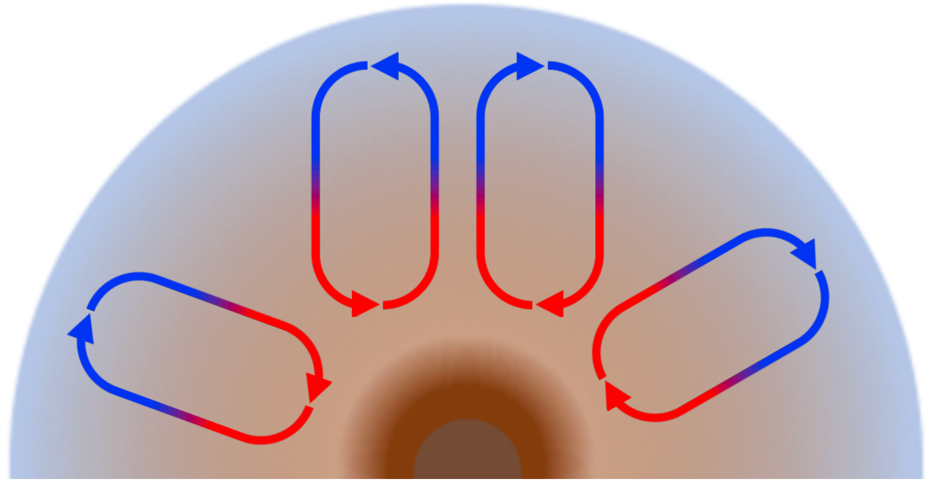
Swastik et al. 2023



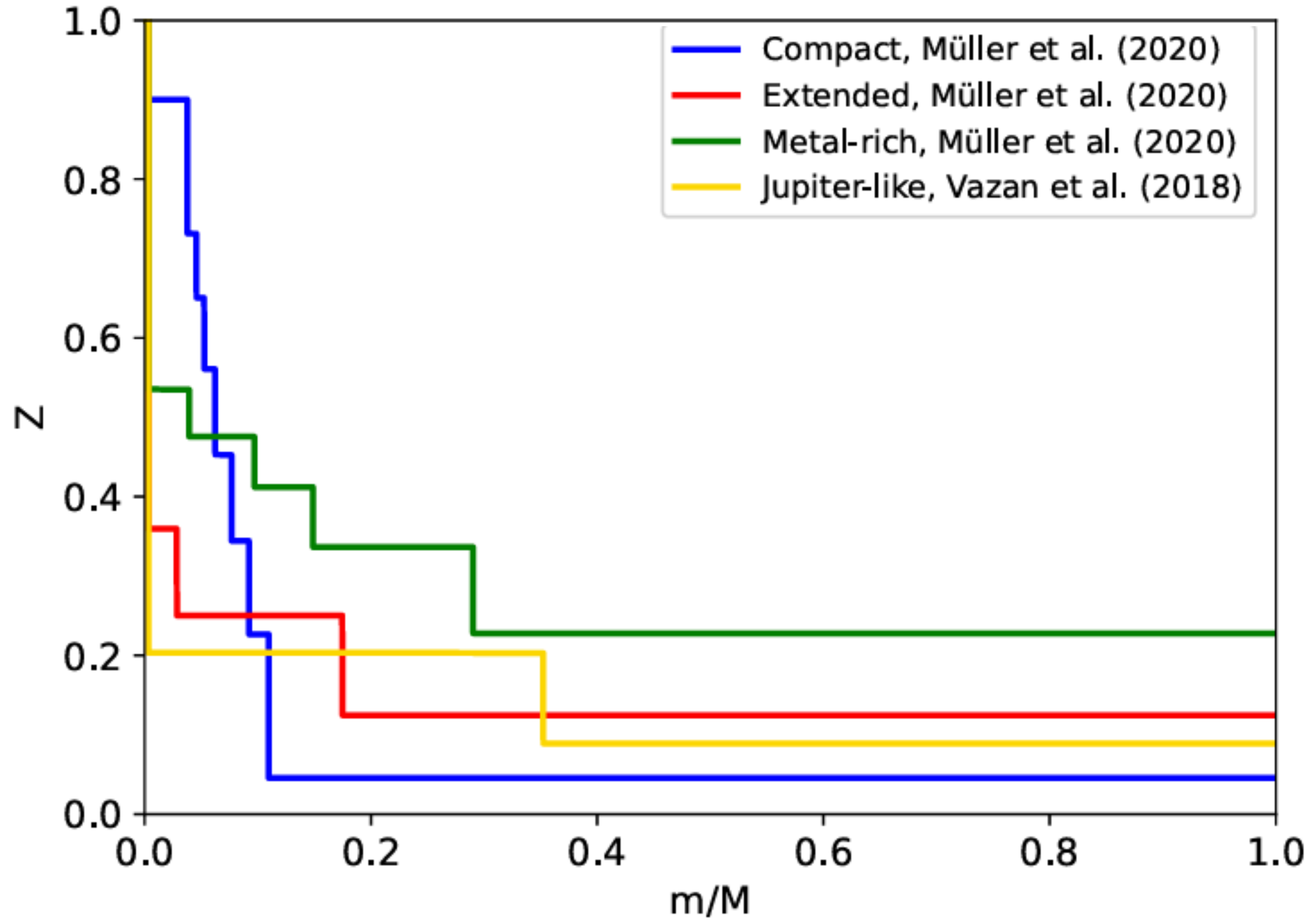
Most observed exoplanets are ~ Gyr old

Material transport

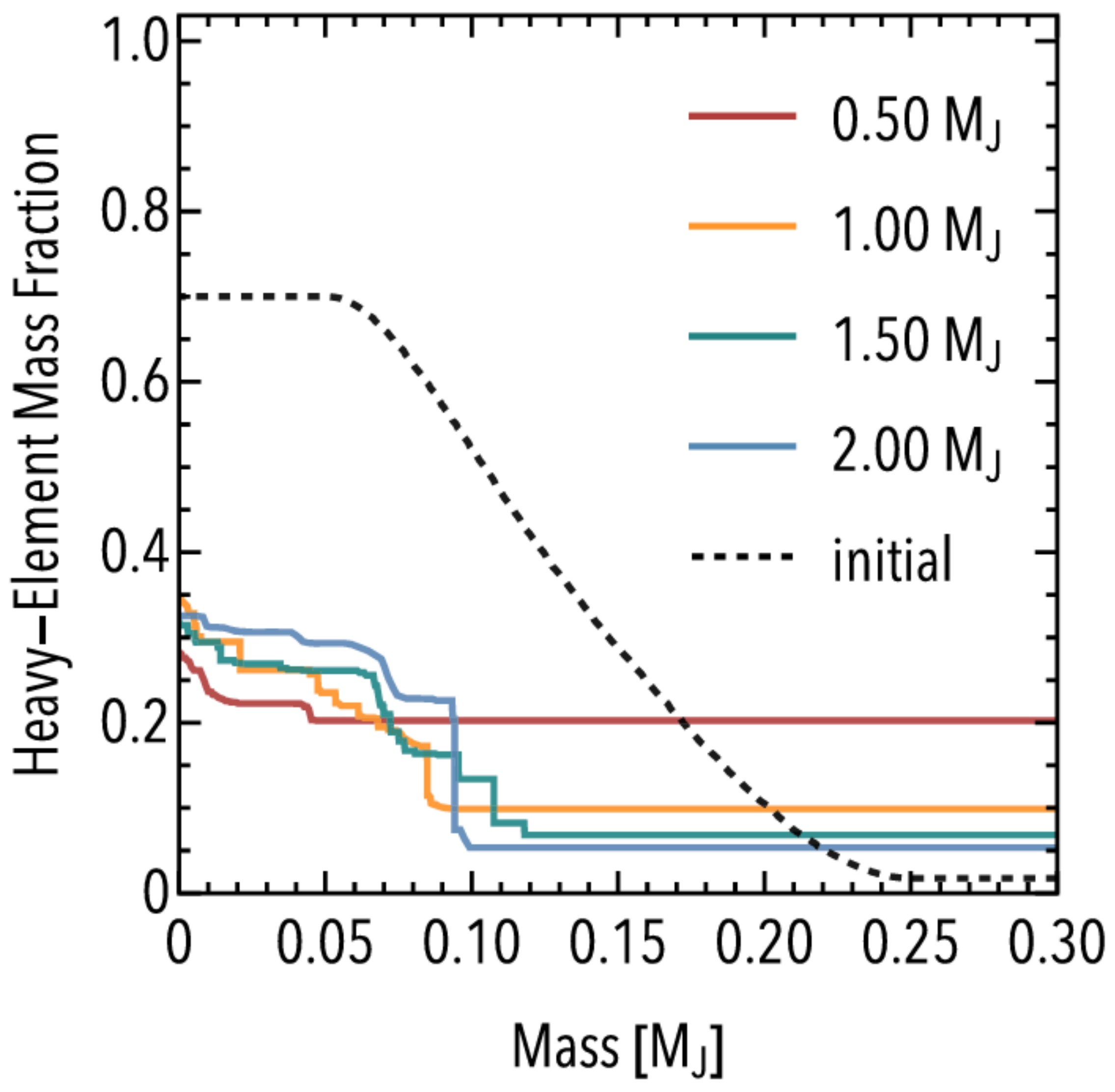
Physical evolution of planets that born with polluted envelopes



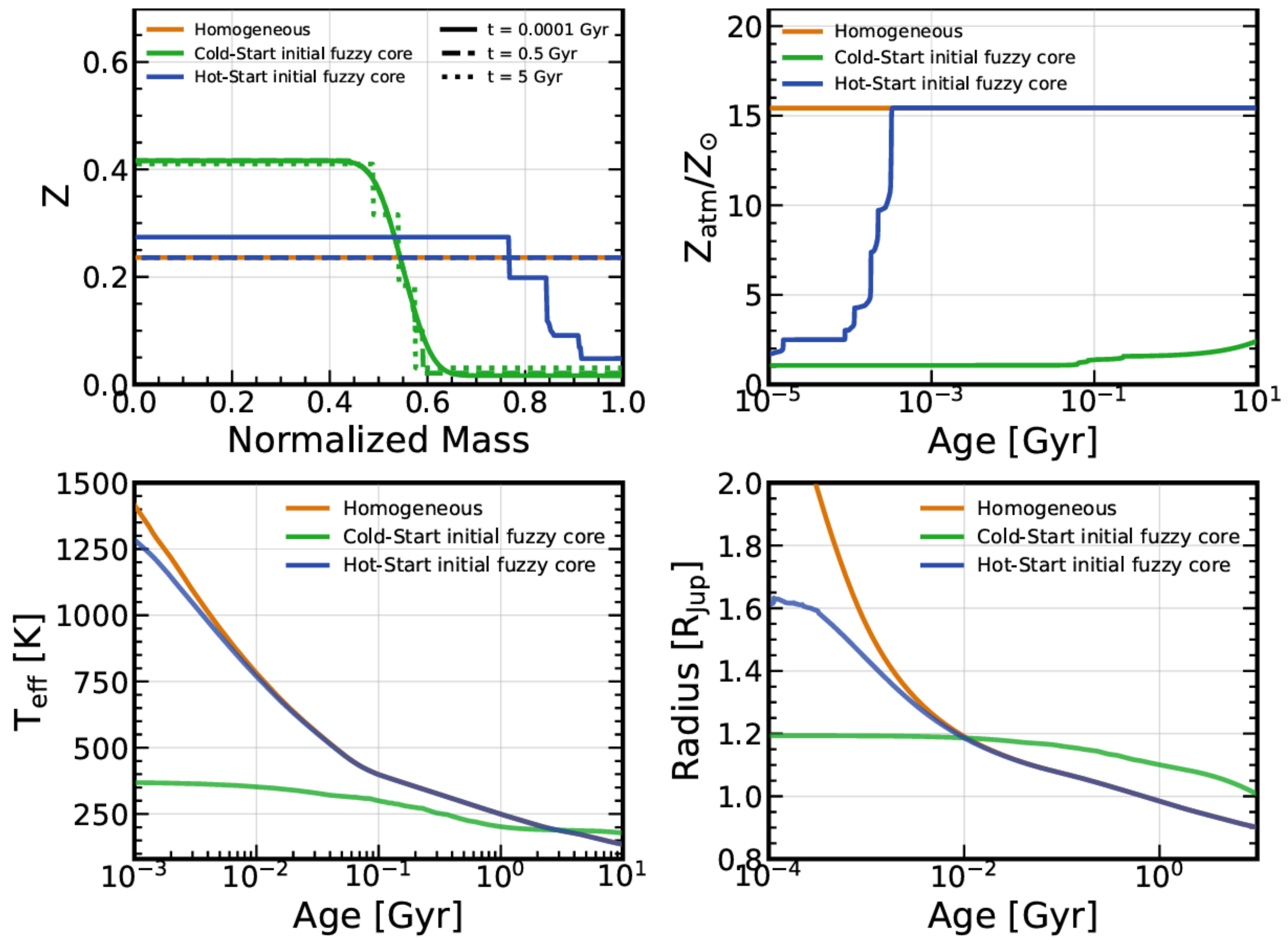
Convective-mixing (up)



Polman & Mordasini 2024



Knierim & Helled 2025



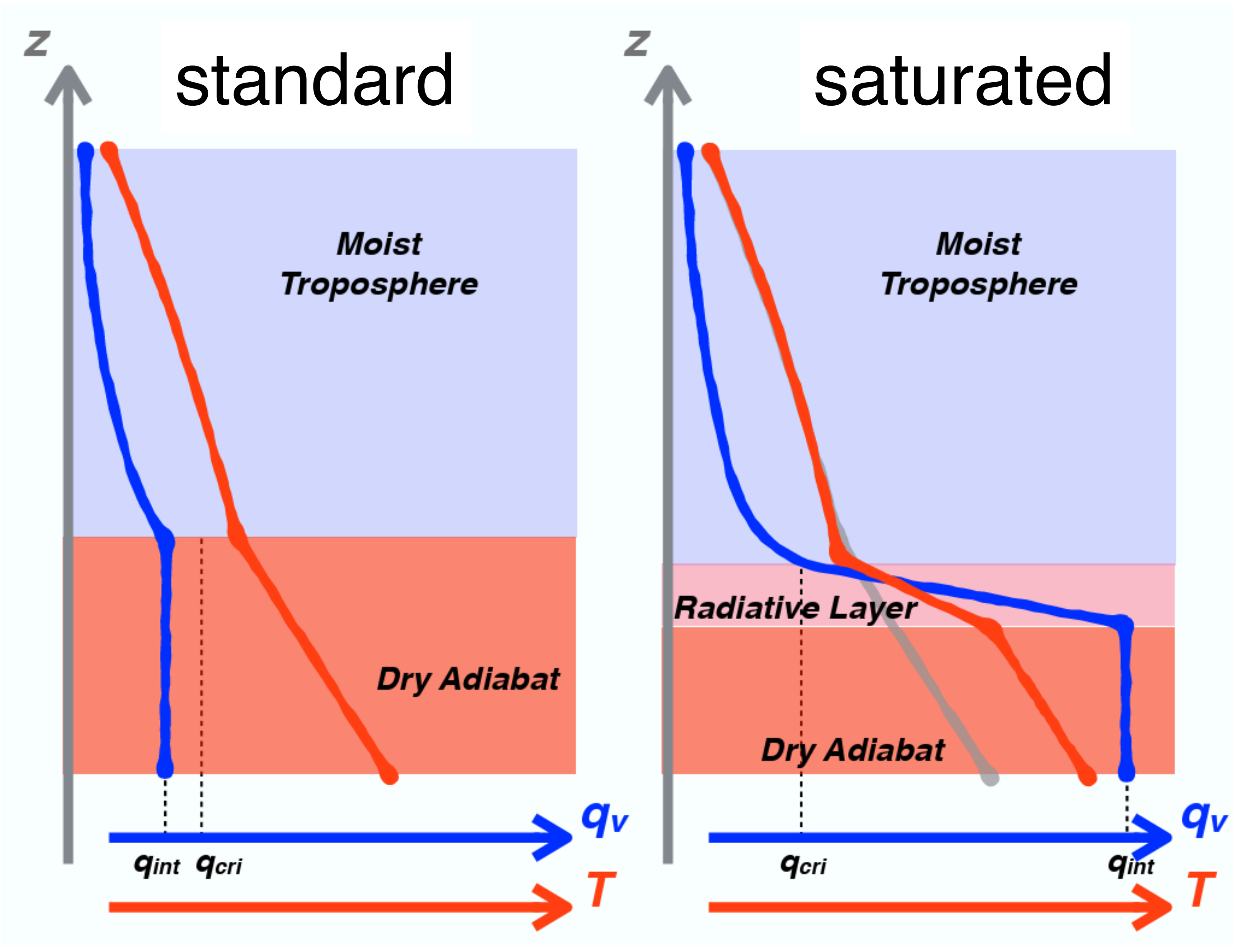
Sur et al. 2025

also: Vazan et al. 2015, 2016, 2018b

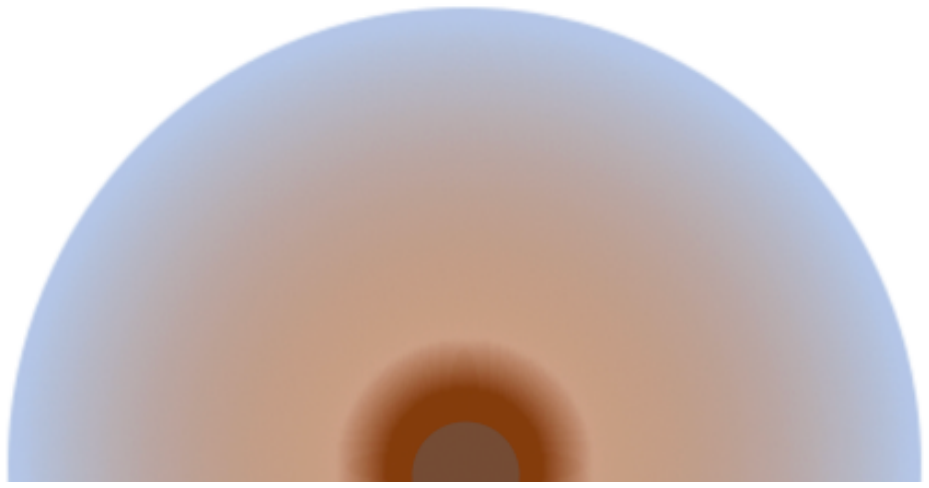
The stability of composition gradients in **unsaturated** interiors

Material transport

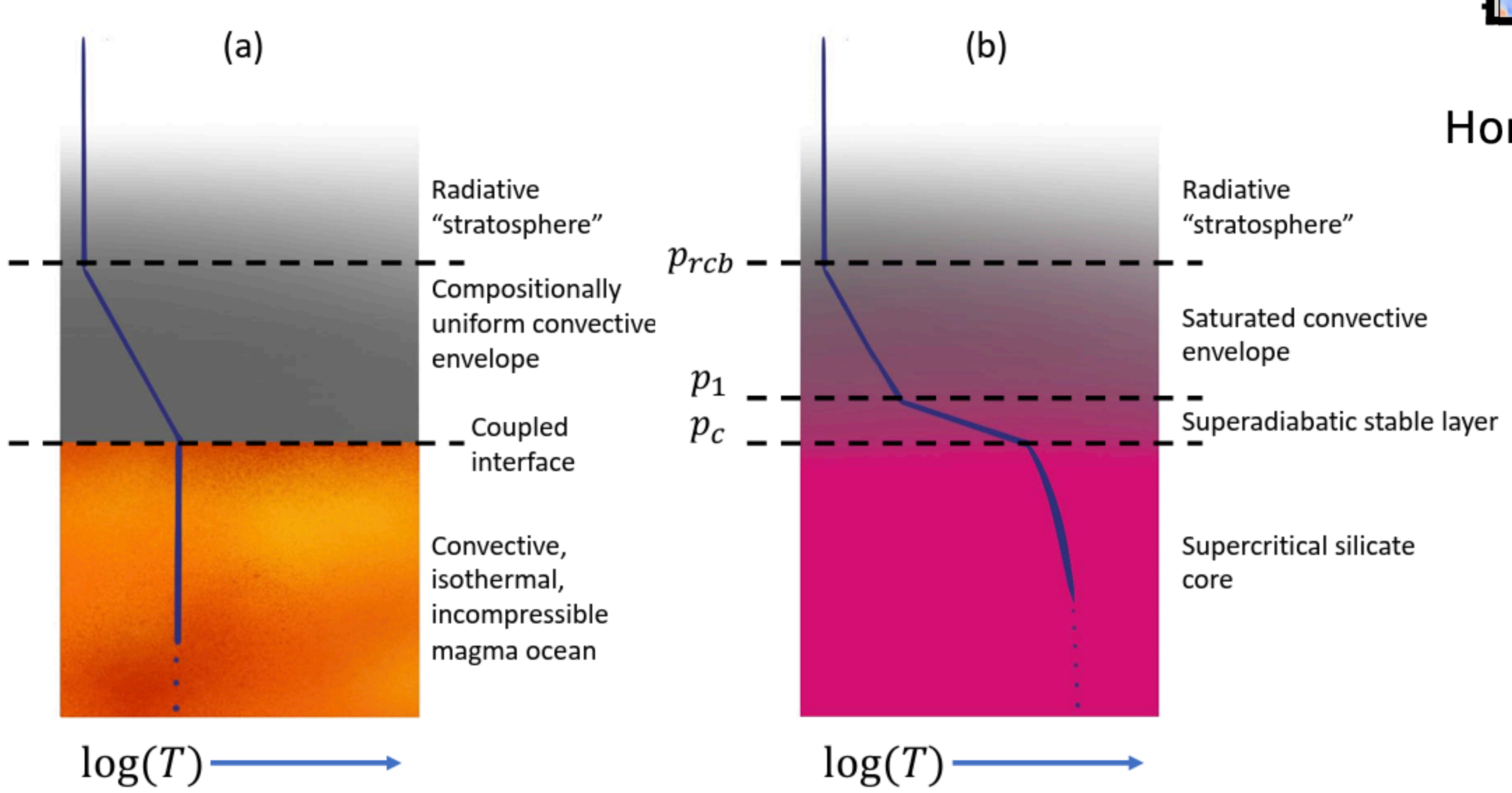
Physical evolution of planets that born with polluted envelopes



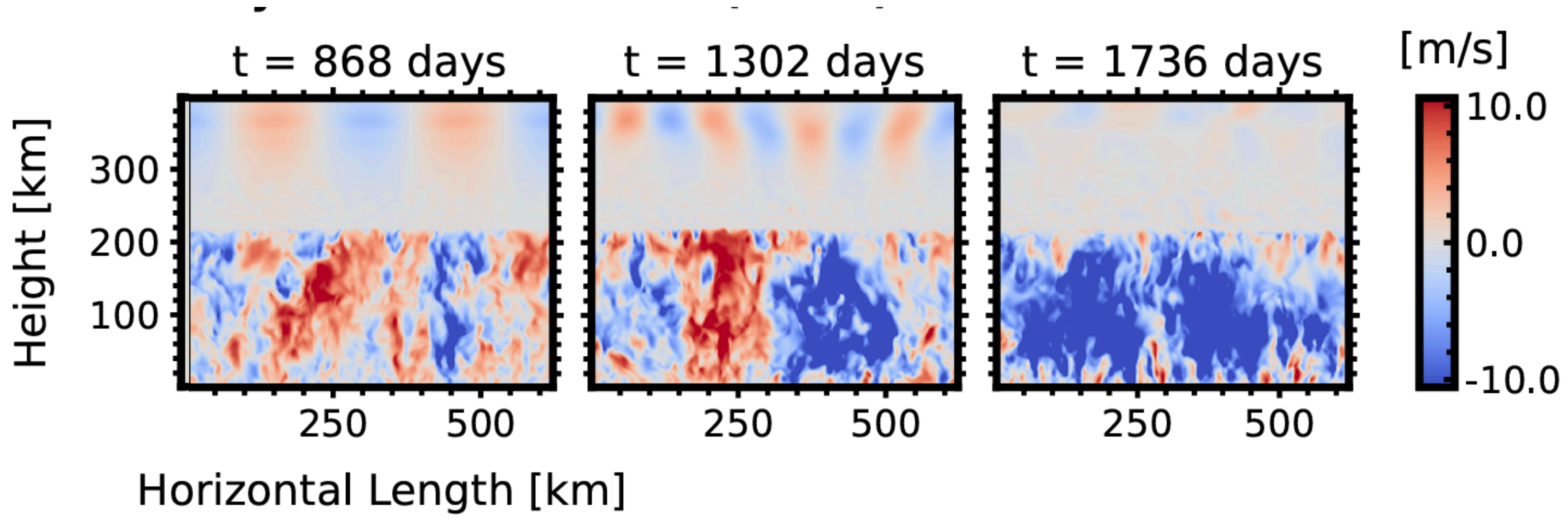
Leconte et al. 2017



Convection inhibition (static)



Markham et al. 2022



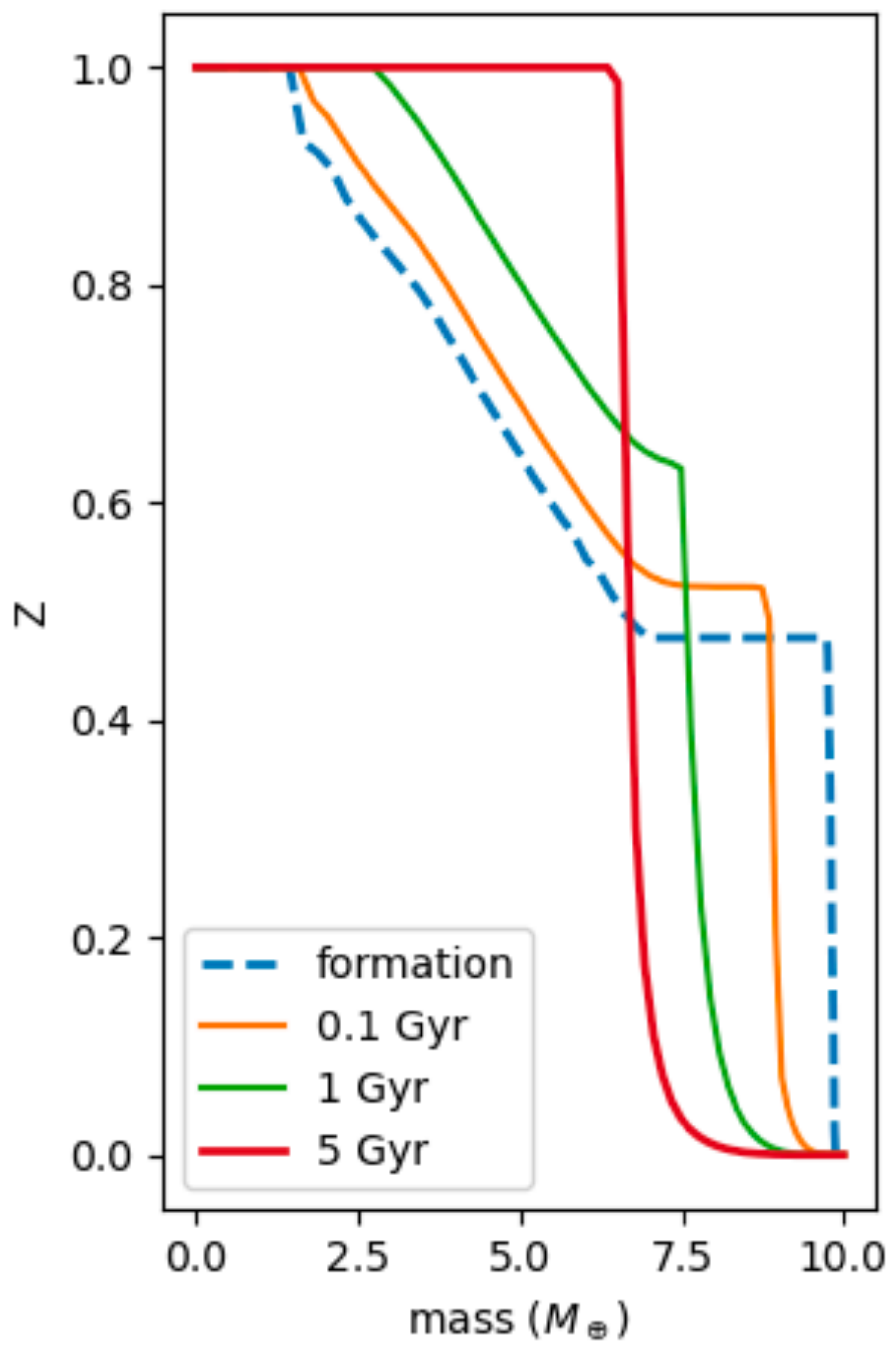
Habib & Pierrehumbert 2025

also: Guillot et al. 1995

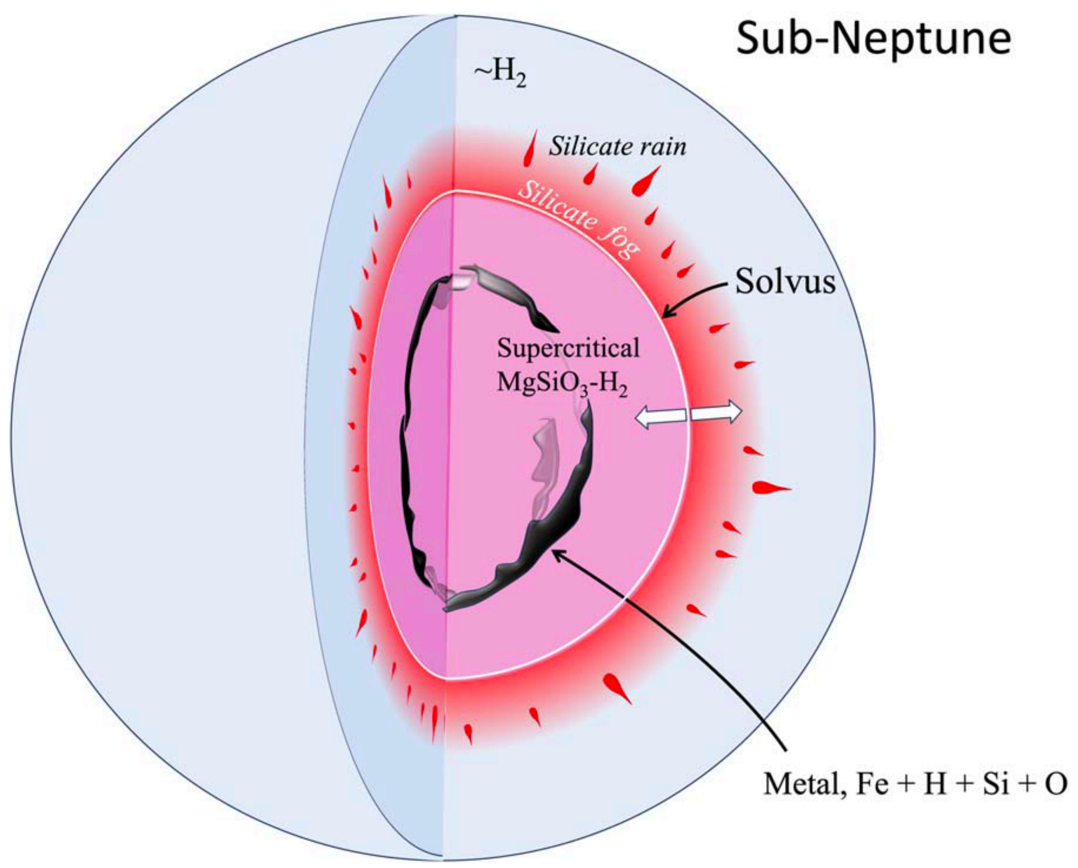
The stability of composition gradients in **saturated** interiors

Material transport

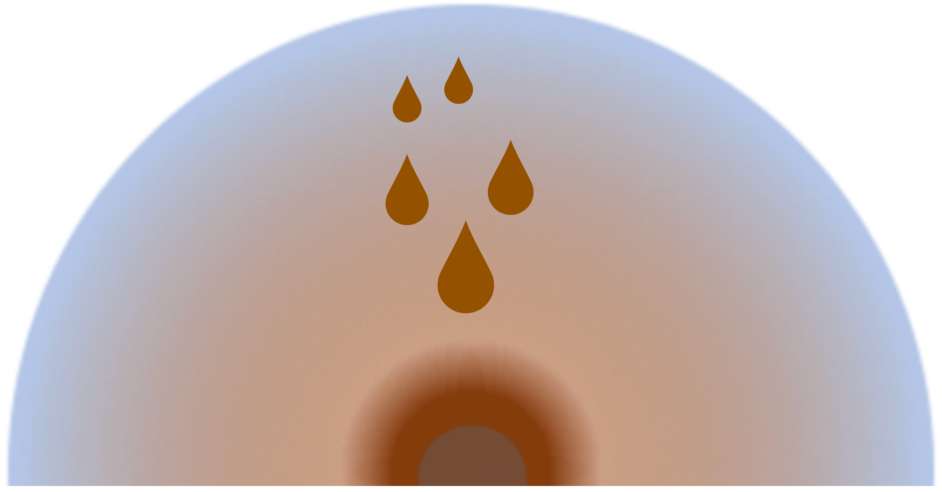
Physical evolution of planets that born with polluted envelopes



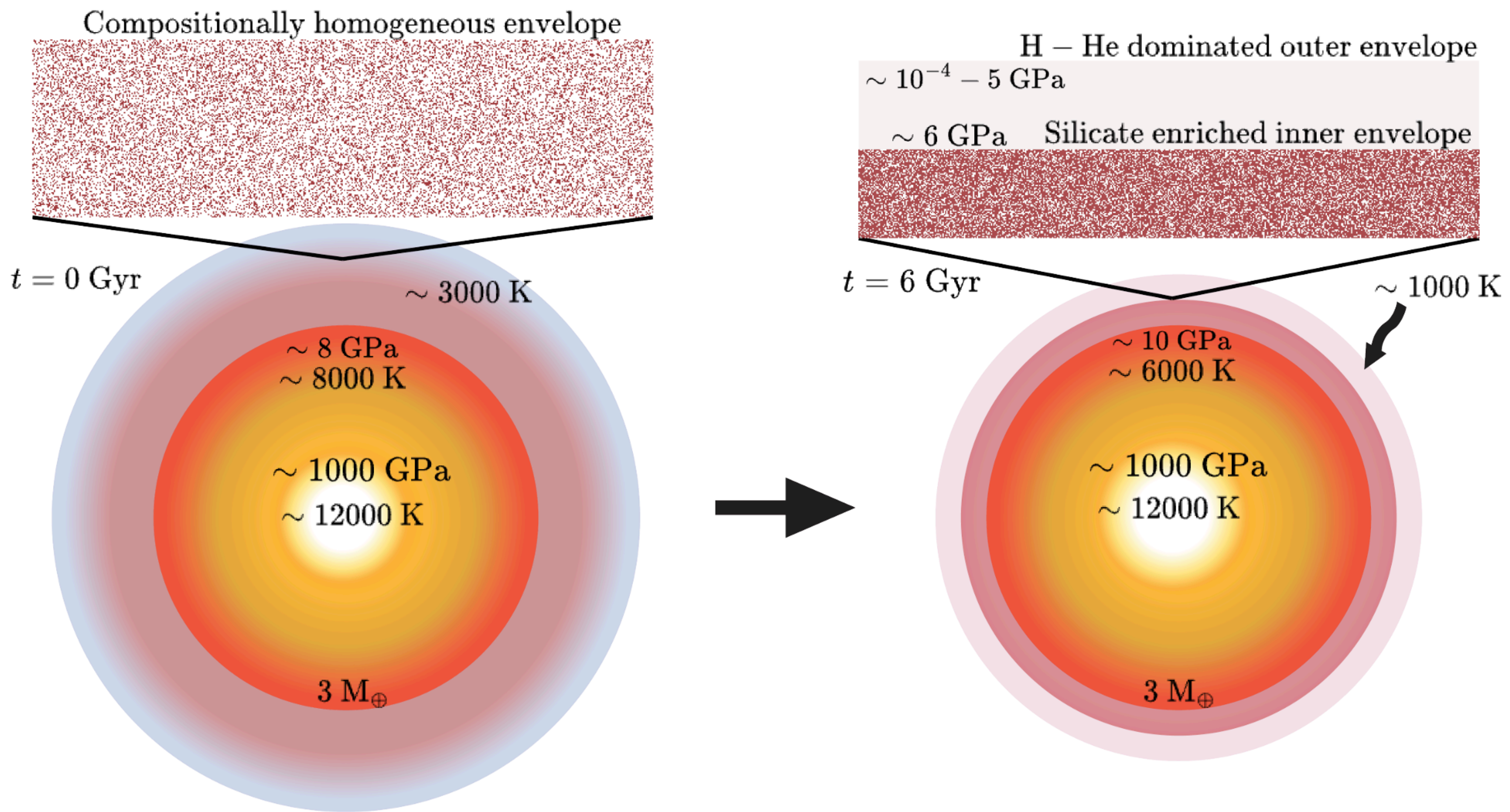
Vazan & Ormel 2023



Young et al. 2024



Rainout (down)

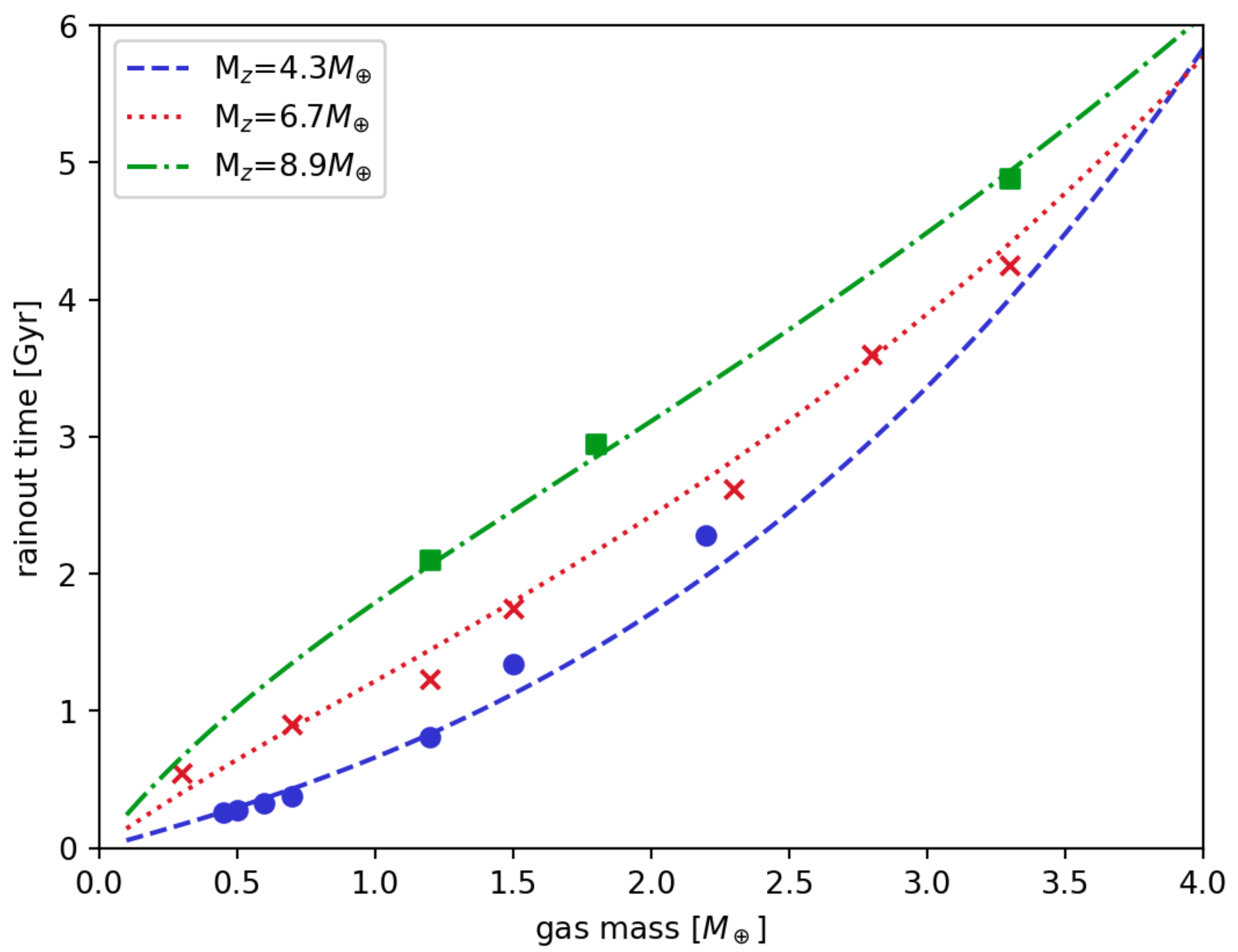


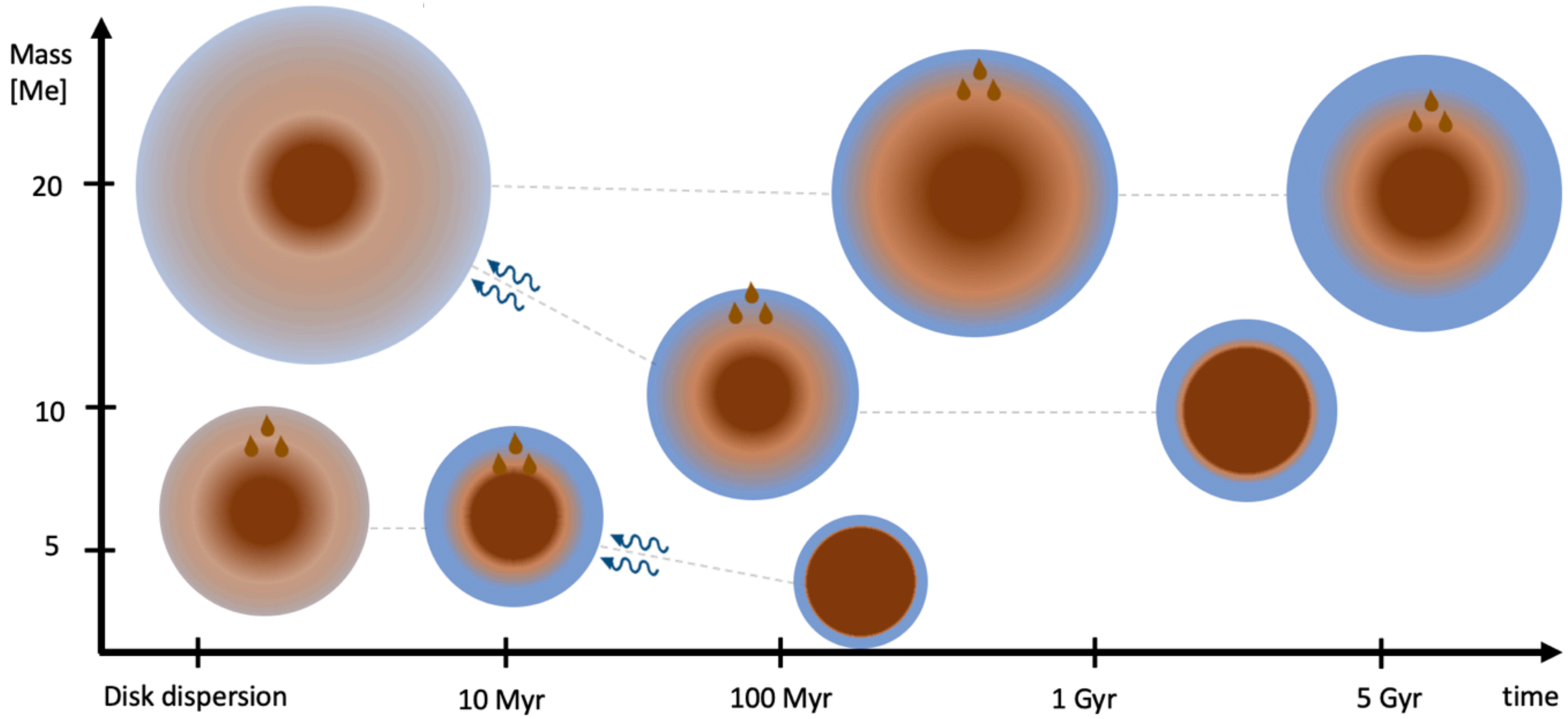
Tejada Arevalo et al. 2026

The erase of composition gradients in **oversaturated** interiors

Material transport

Silicate rainout in cooling envelopes of metal-rich planets



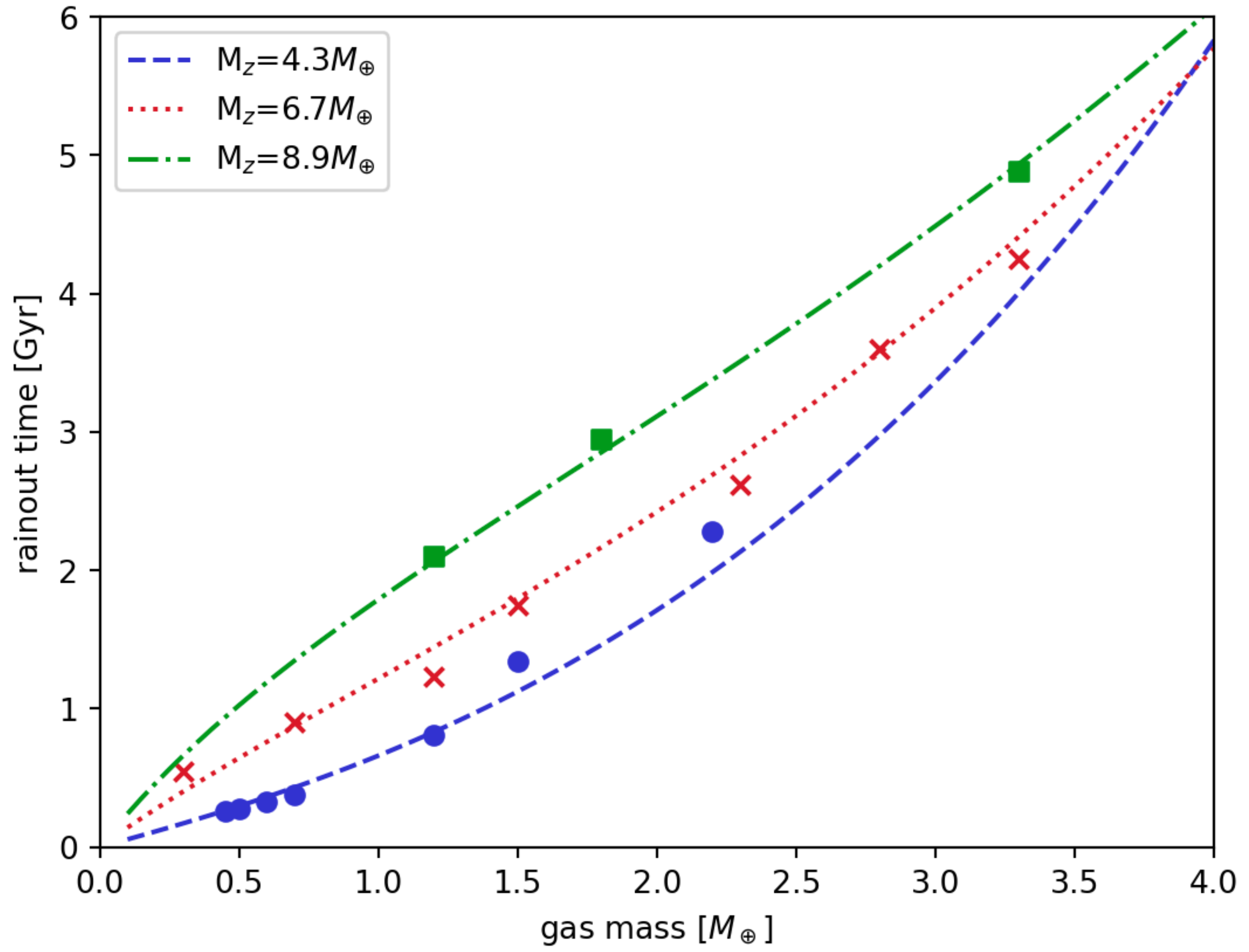


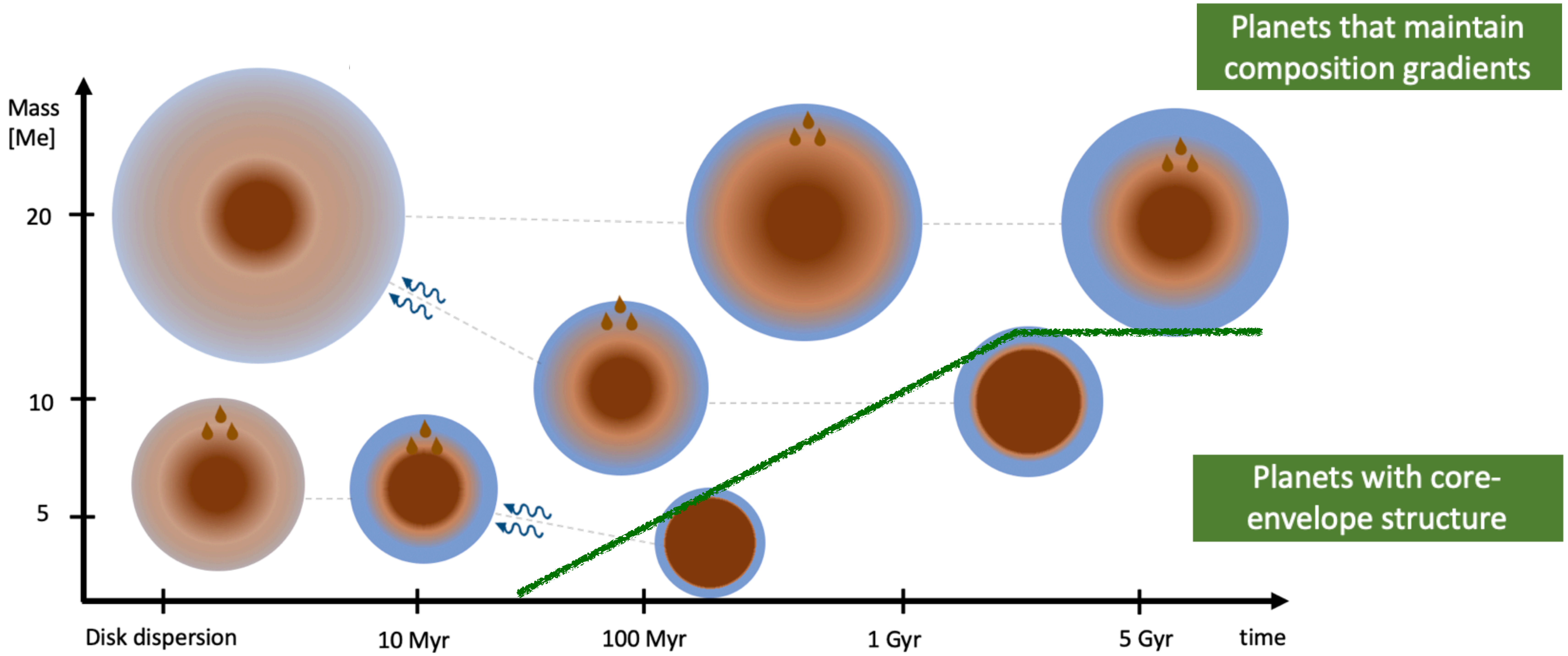
Vazan et al. 2024

Silicate rainout may split the population of planets, based on saturation in their cooling envelopes

Material transport

Silicate rainout in cooling envelopes of metal-rich planets





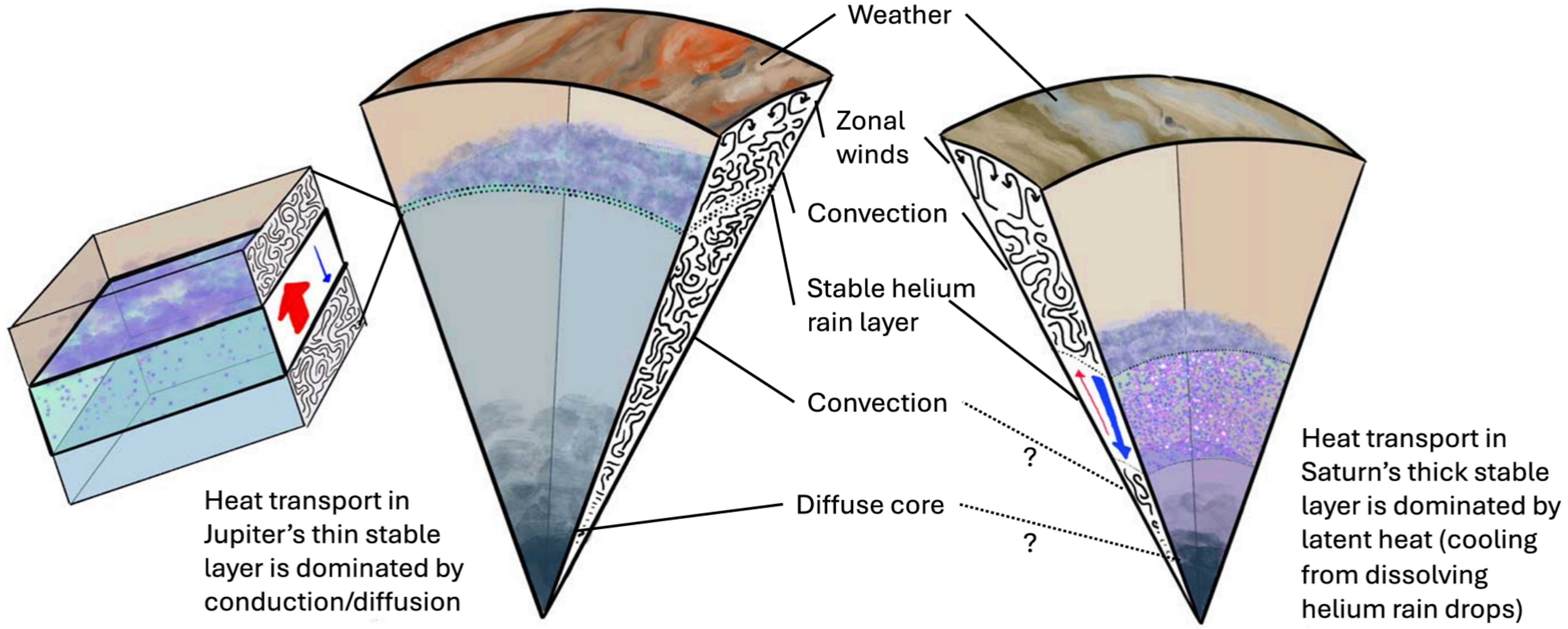
Vazan et al. 2024

Silicate rainout may split the population of planets, based on saturation in their cooling envelopes

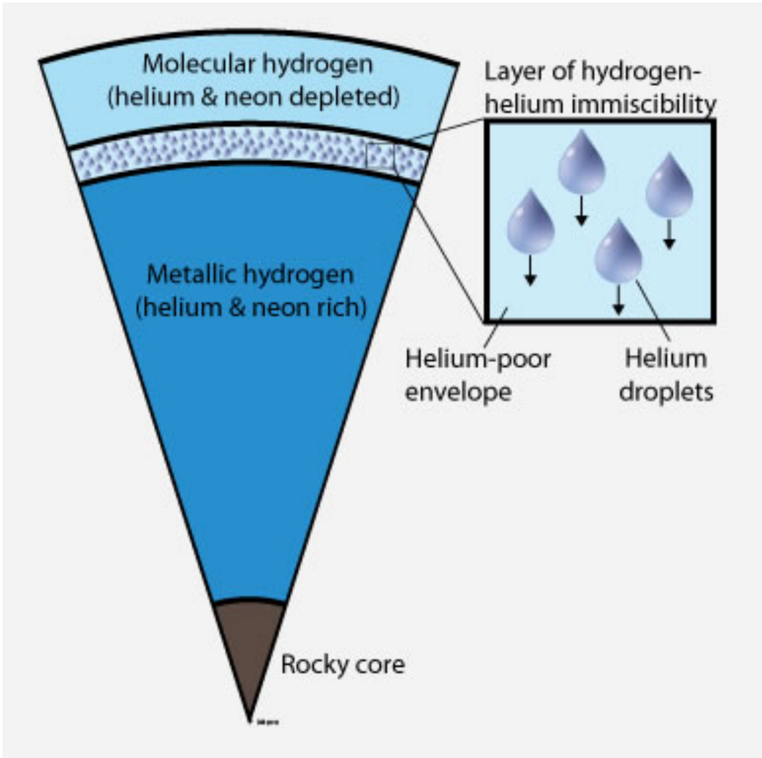
Material transport

Helium rain in cooling envelopes of giant planets

Stevenson & Salpeter 1977
Fortney & Hubbard 2003
Morales et al. 2013
Vazan et al. 2026
Schöttler & Redmer 2018
Mankovich & Fortney 2020
Militzer et al. 2022
Howard et al. 2024
Markham & Guillot 2024
Wang et al. 2026



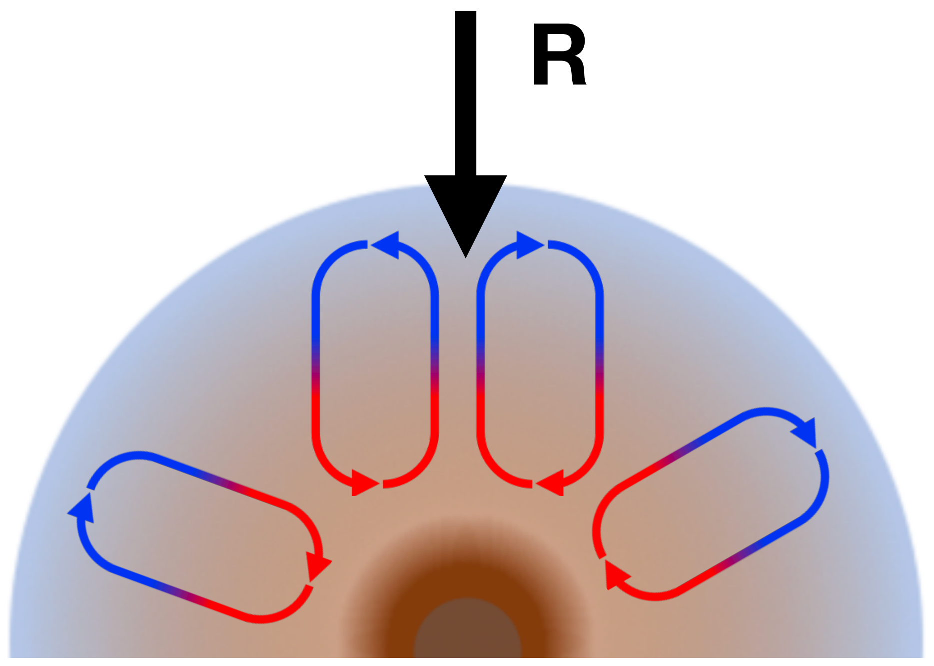
Markham & Guillot 2024



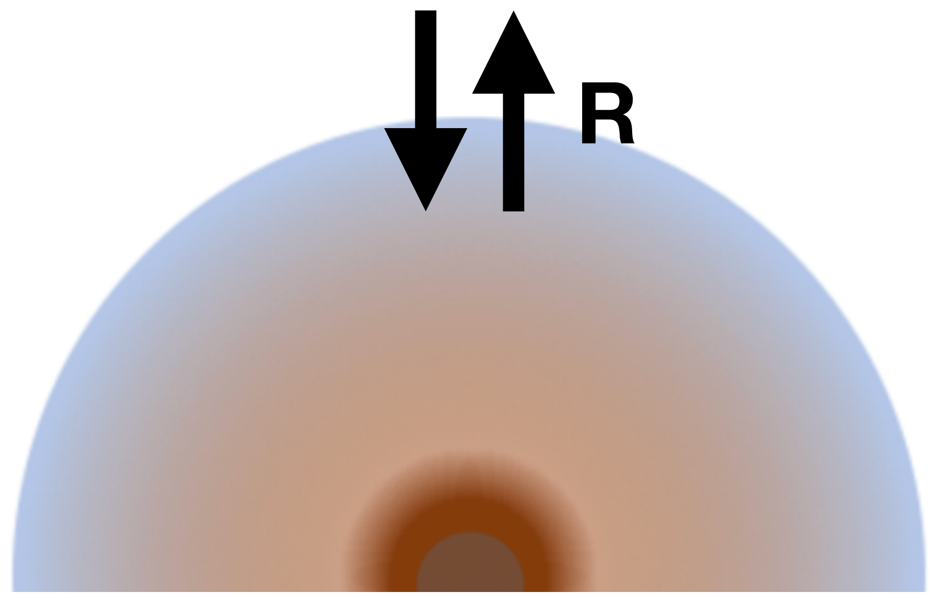
Hydrogen-Helium demixing (immiscibility) in gas giants lead to stably stratified helium layer at ~ 6000K, 100s GPa
Consistent with solar system Jupiter and Saturn, affect also magnetic fields

Material transport

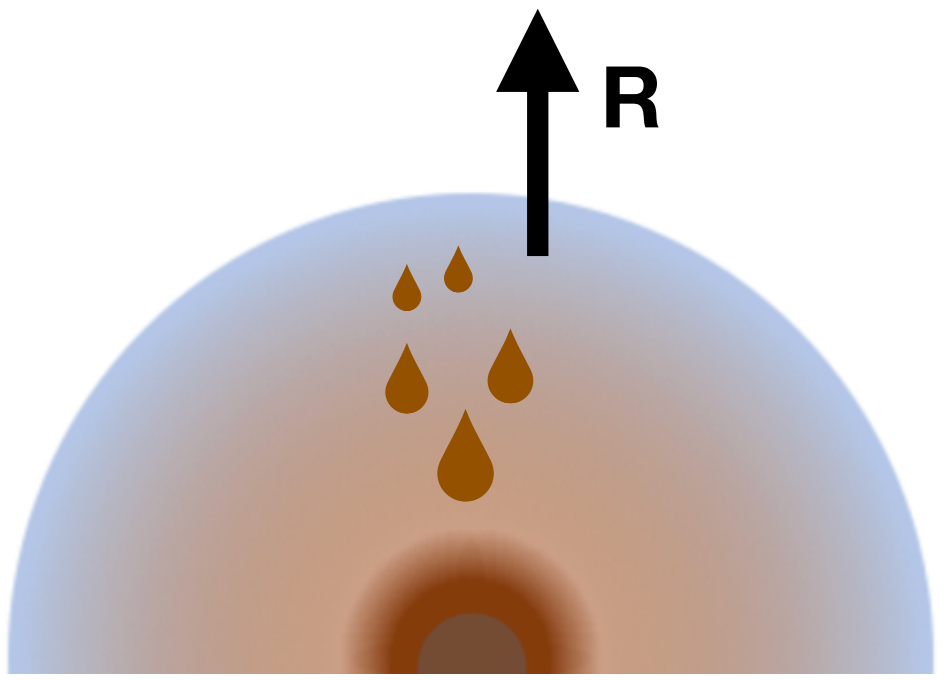
Impact on R(t)



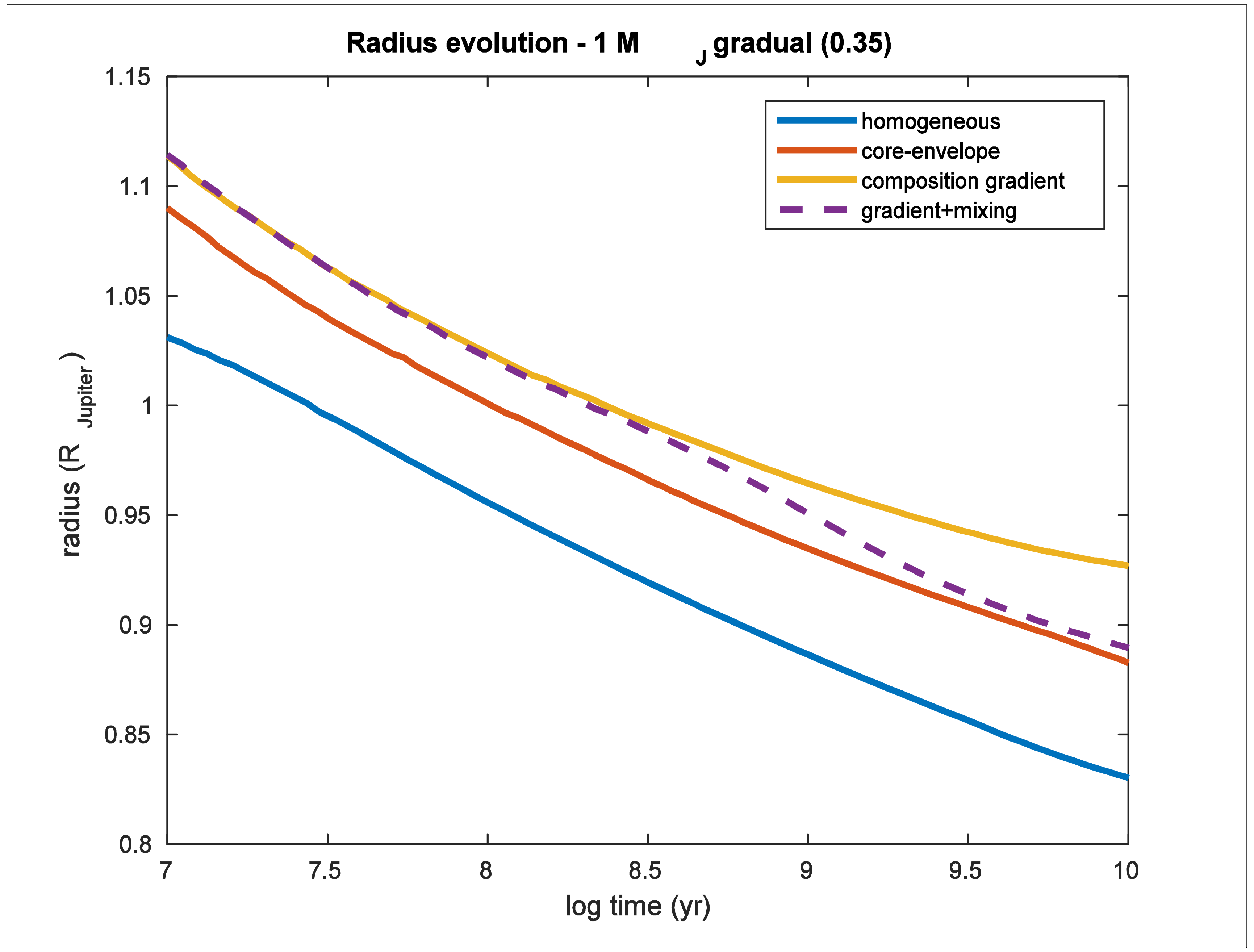
Convective-mixing (up)

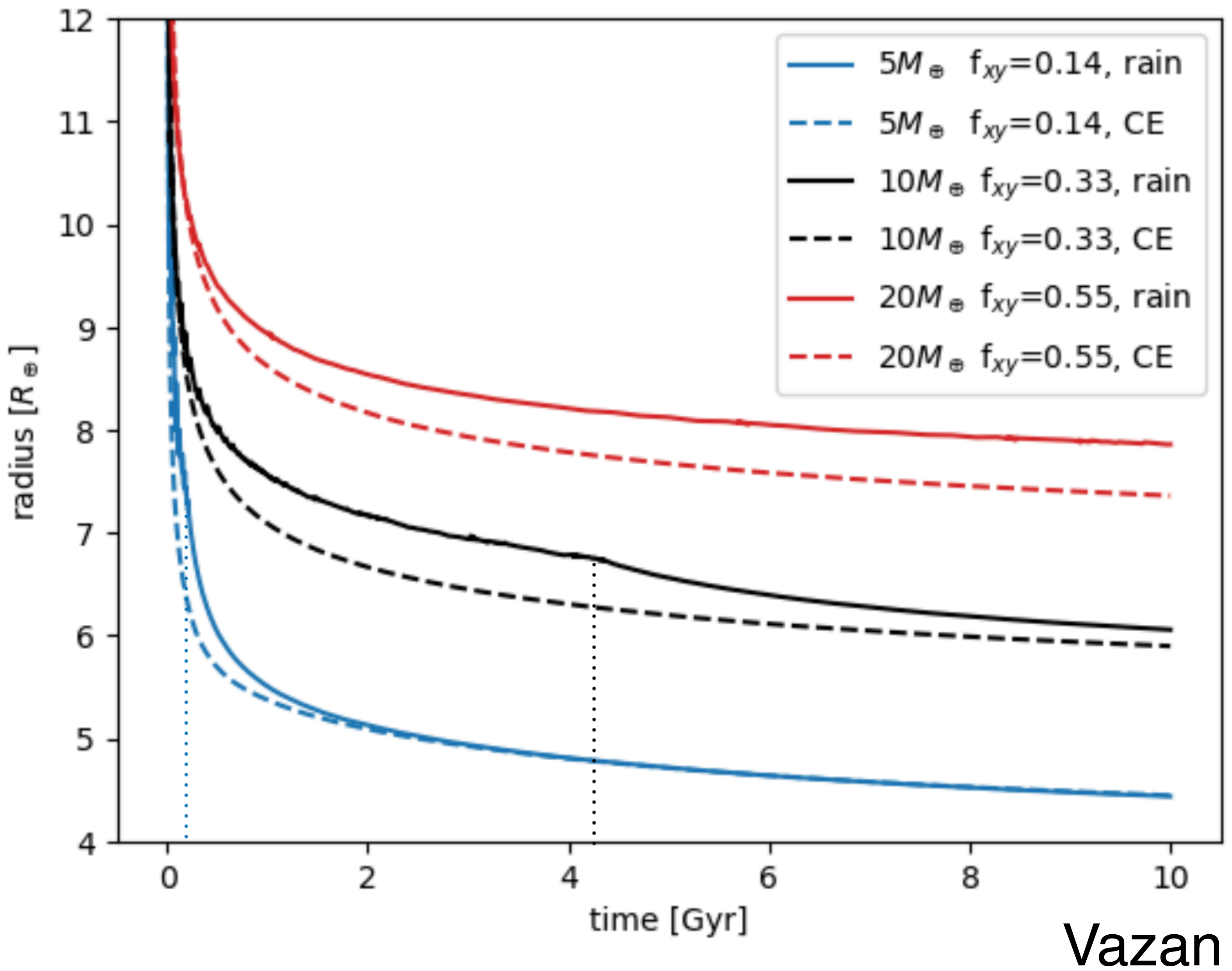


Convection inhibition (static)



Rainout (down)





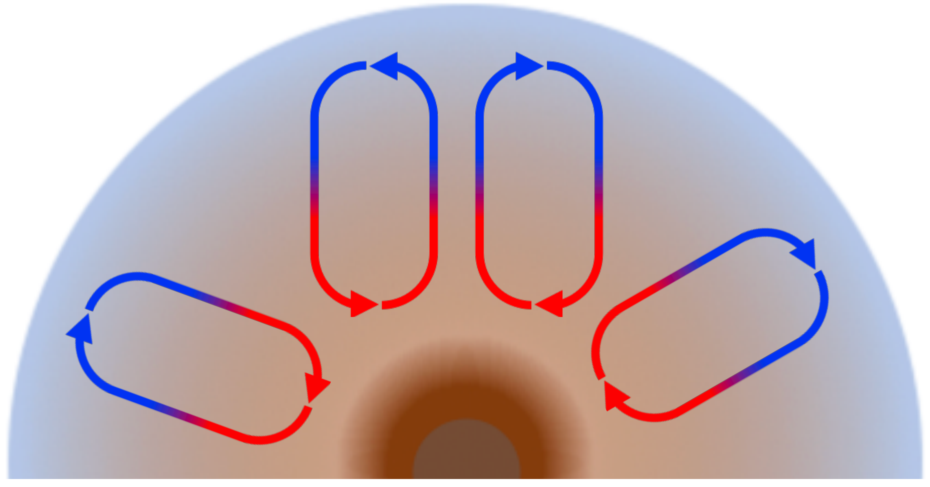
Vazan et al. 2024

<u>Energy release:</u>

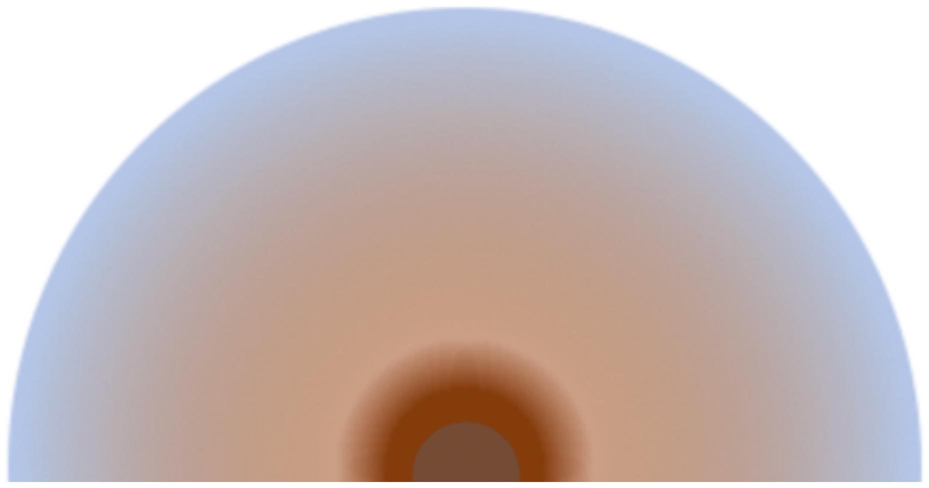
* Potential
* Latent heat
* Locked accretion

Material transport

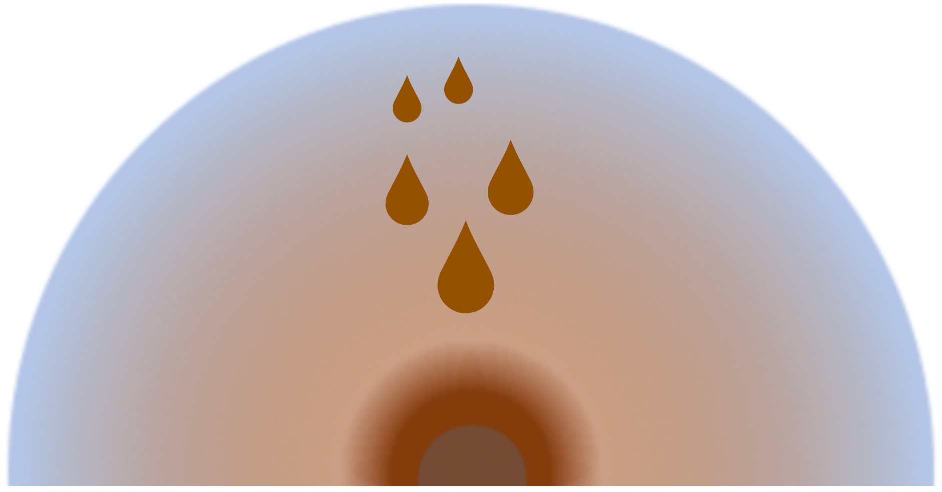
Chemical evolution of planets that born with polluted envelopes



Convective-mixing (up)



Convection inhibition (static)

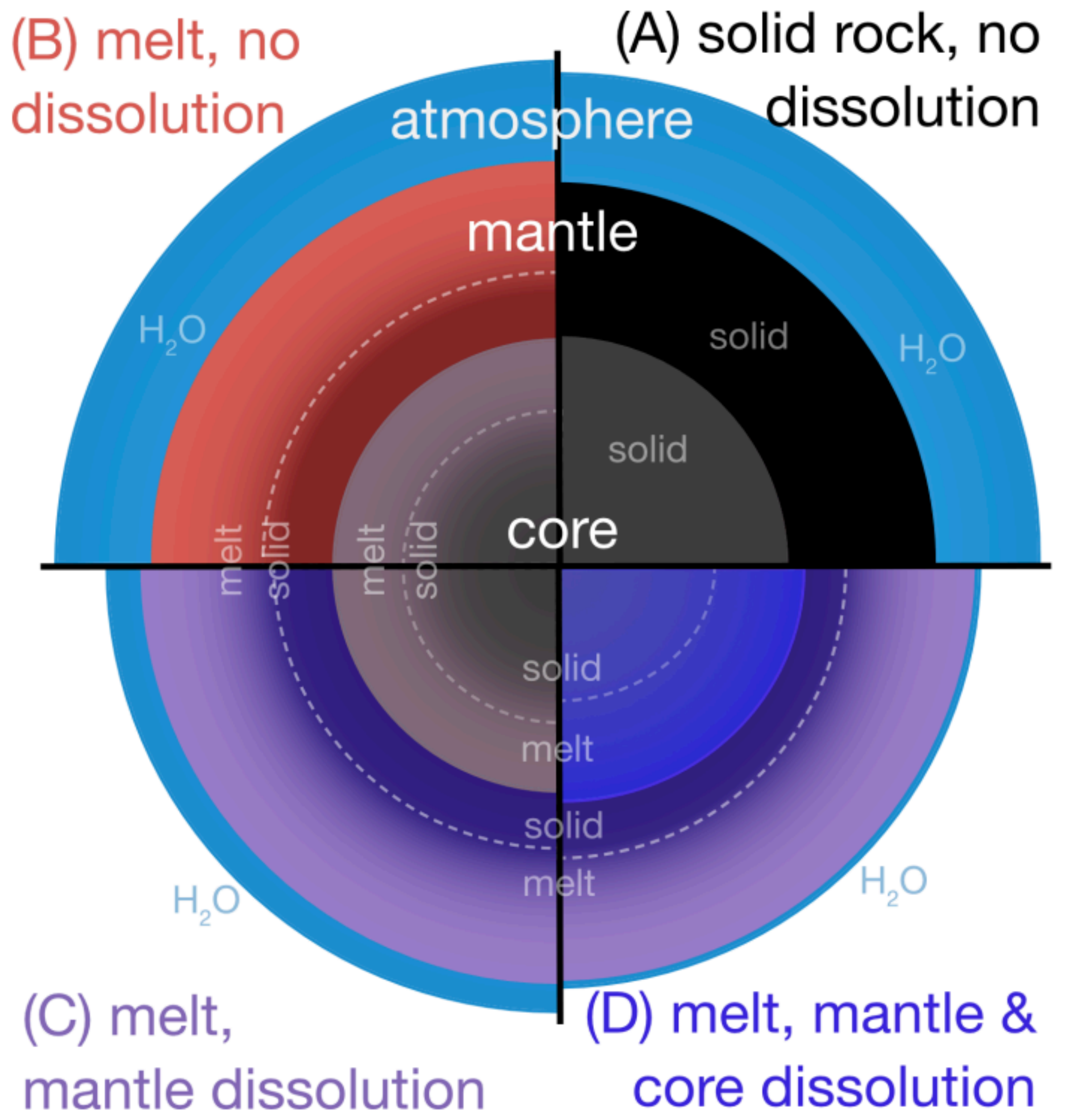


Rainout (down)

* Physical and chemical evolution are tightly linked
* Long-term composition distribution is an outcome of thermodynamics
* **Key processes: saturation and miscibility in mixtures (H-He, Silicate-H, water-H, …)**

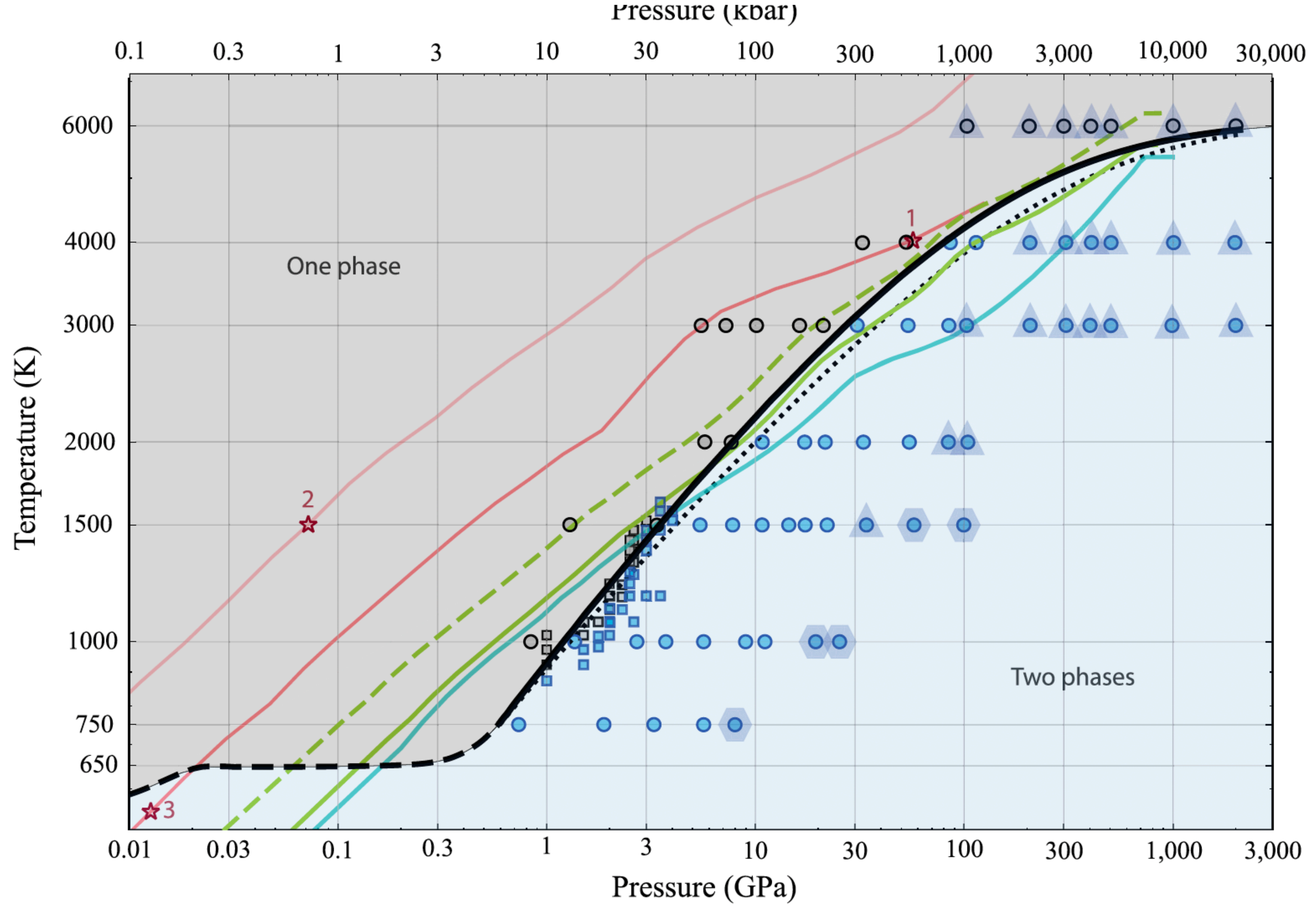
Material distribution

Miscibility of water

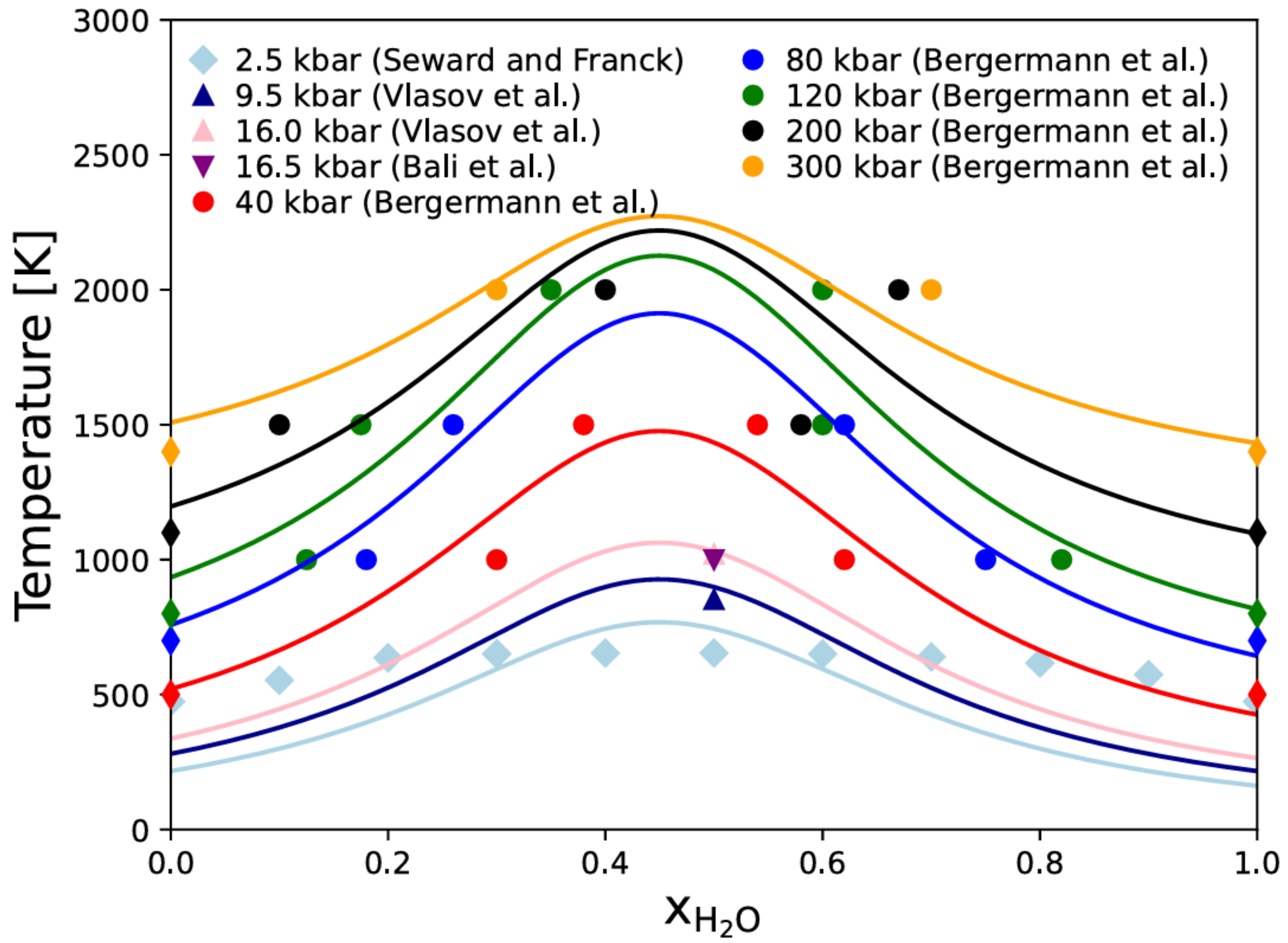


Luo et al. 2024

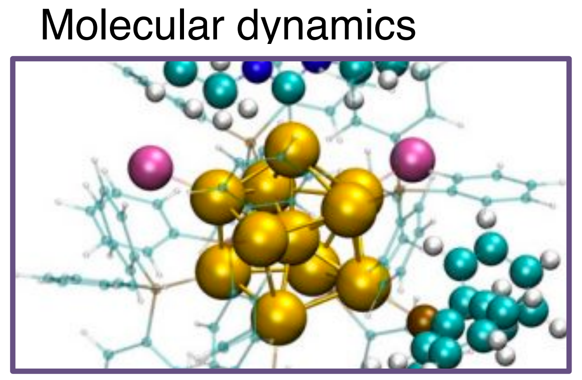
Dorn & Lichtenberg 2021

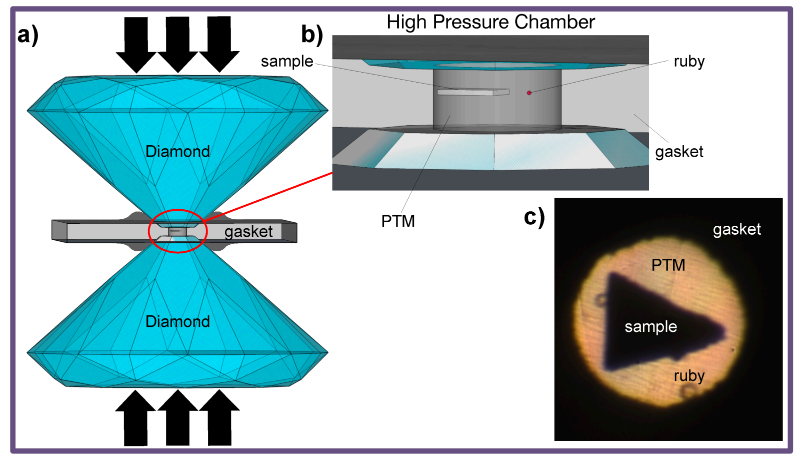


Gupta et al. 2025



Howe et al. 2025, Bergemann et al. 2024



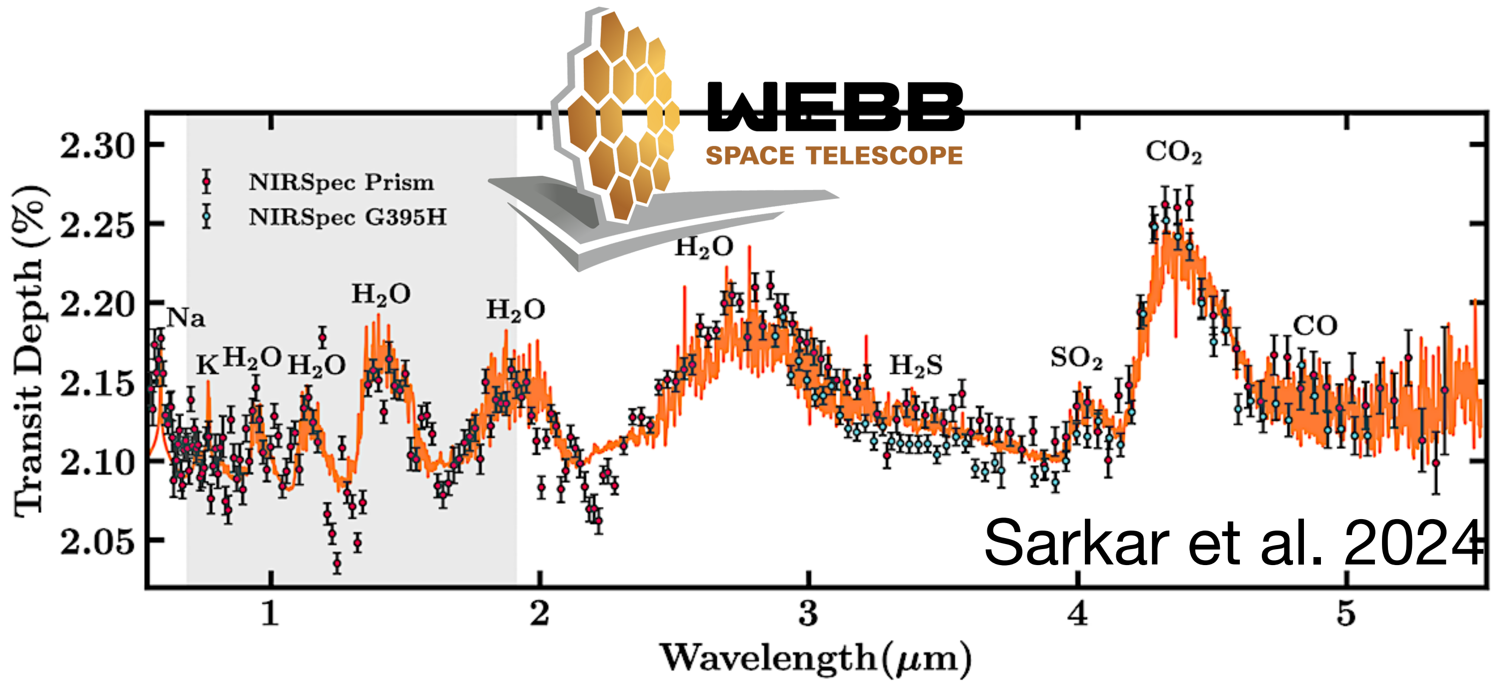


Water is mixed (miscible) in the iron core, rocky mantle, and hydrogen envelope

Knowledge gaps in thermodynamics and chemistry of mixtures at high pressure

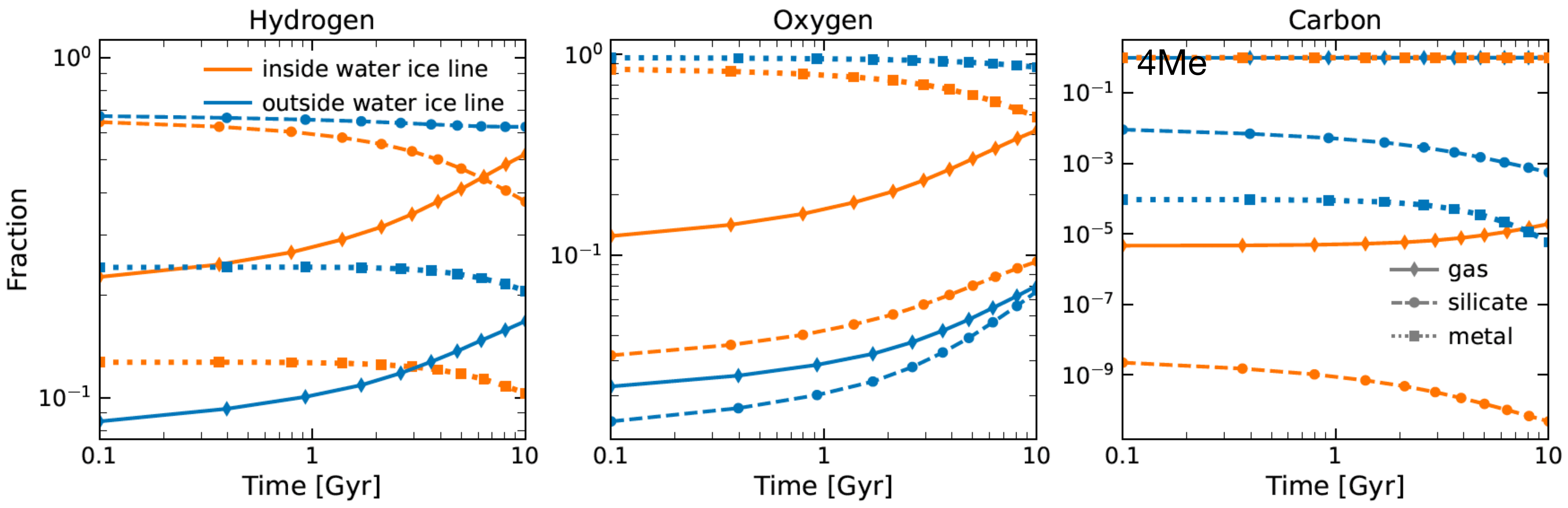
Material distribution

Light elements favour the deep interior and not the atmosphere

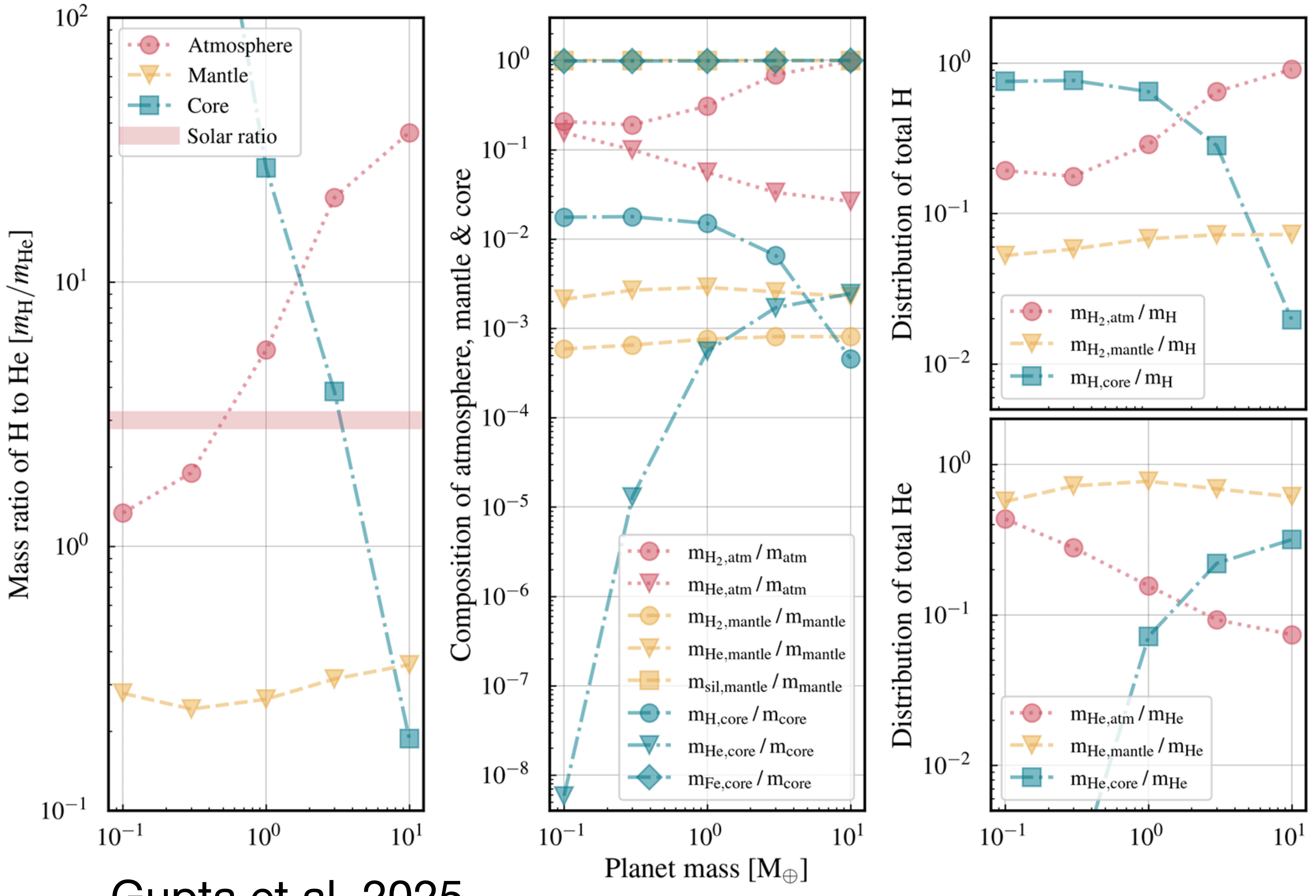


Sarkar et al. 2024

@ 2029



Steinmeyer et al. 2026



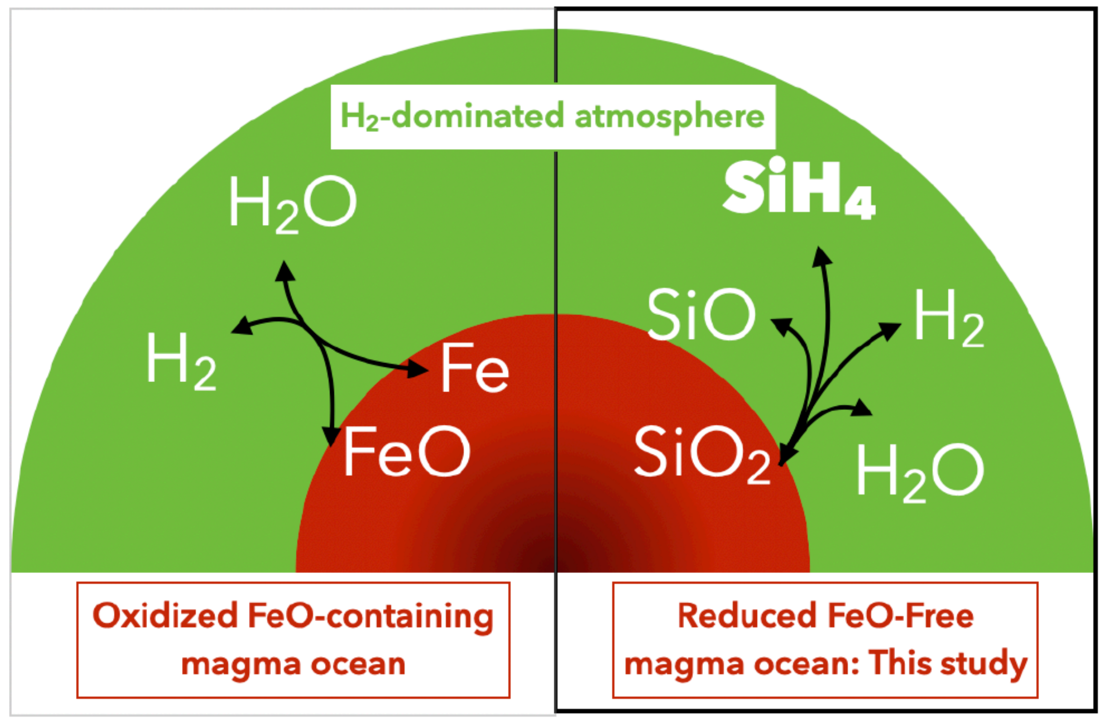
Gupta et al. 2025

* The majority of bulk volatile is in the interior, not in the atmosphere
* Elemental ratios depend on formation location

* The majority of H,He is in the interior, not atmosphere
* Abundances strongly depending on planet mass

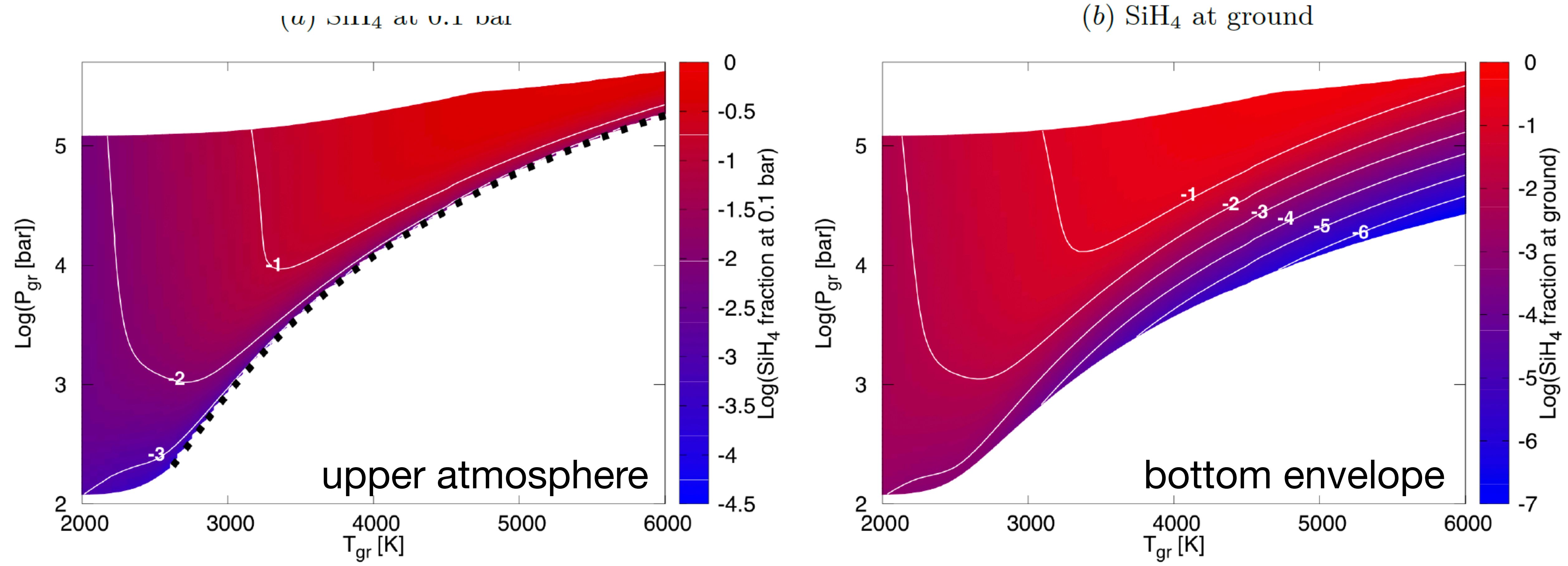
Evolving composition

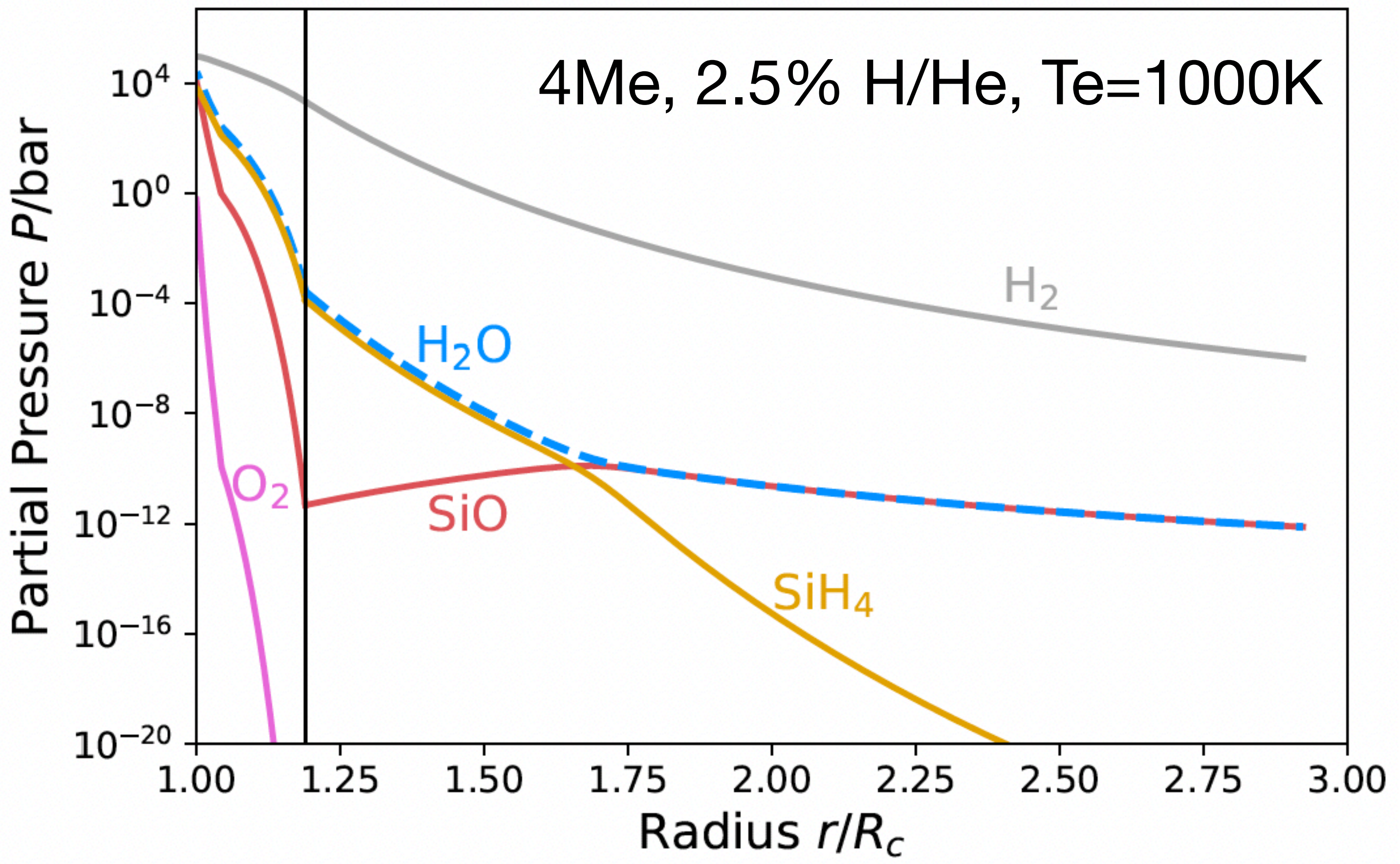
Volatile production in the interior



Ito et al. 2025

Ikoma & Genda 2006





Misener et al. 2023

also: Kite et al. 2019

Young et al. 2023

Small fraction of volatile (SiH4, H2O) can be produced by magma-hydrogen interactions, based on equilibrium chemistry

Evolving composition

Volatile production in the interior

With and without Fe involvement:

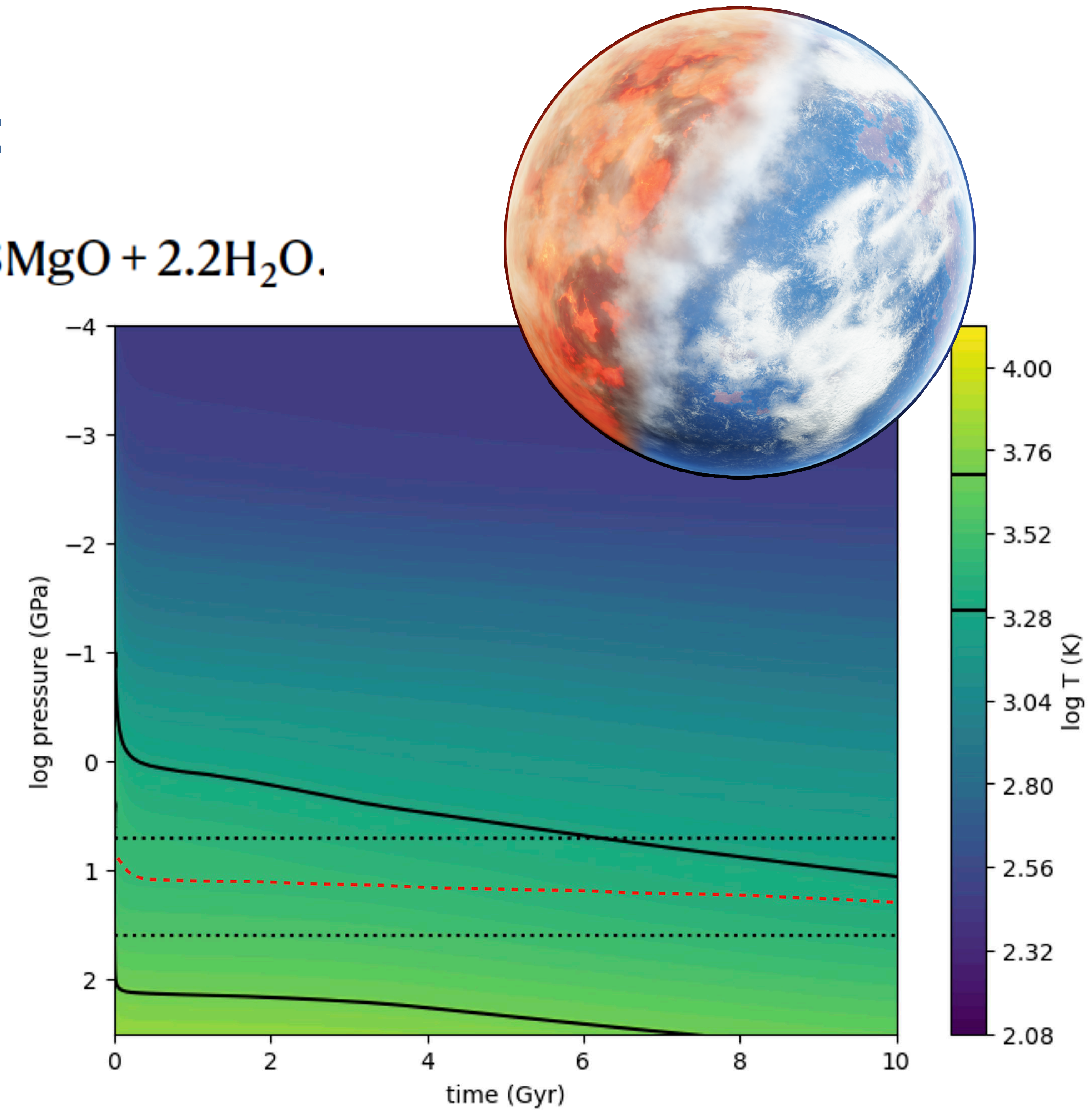
$$(Mg_{0.9}Fe_{0.1})_2SiO_4 + 0.8Fe + 2.2H_2 \rightarrow FeSi + 1.8MgO + 2.2H_2O.$$

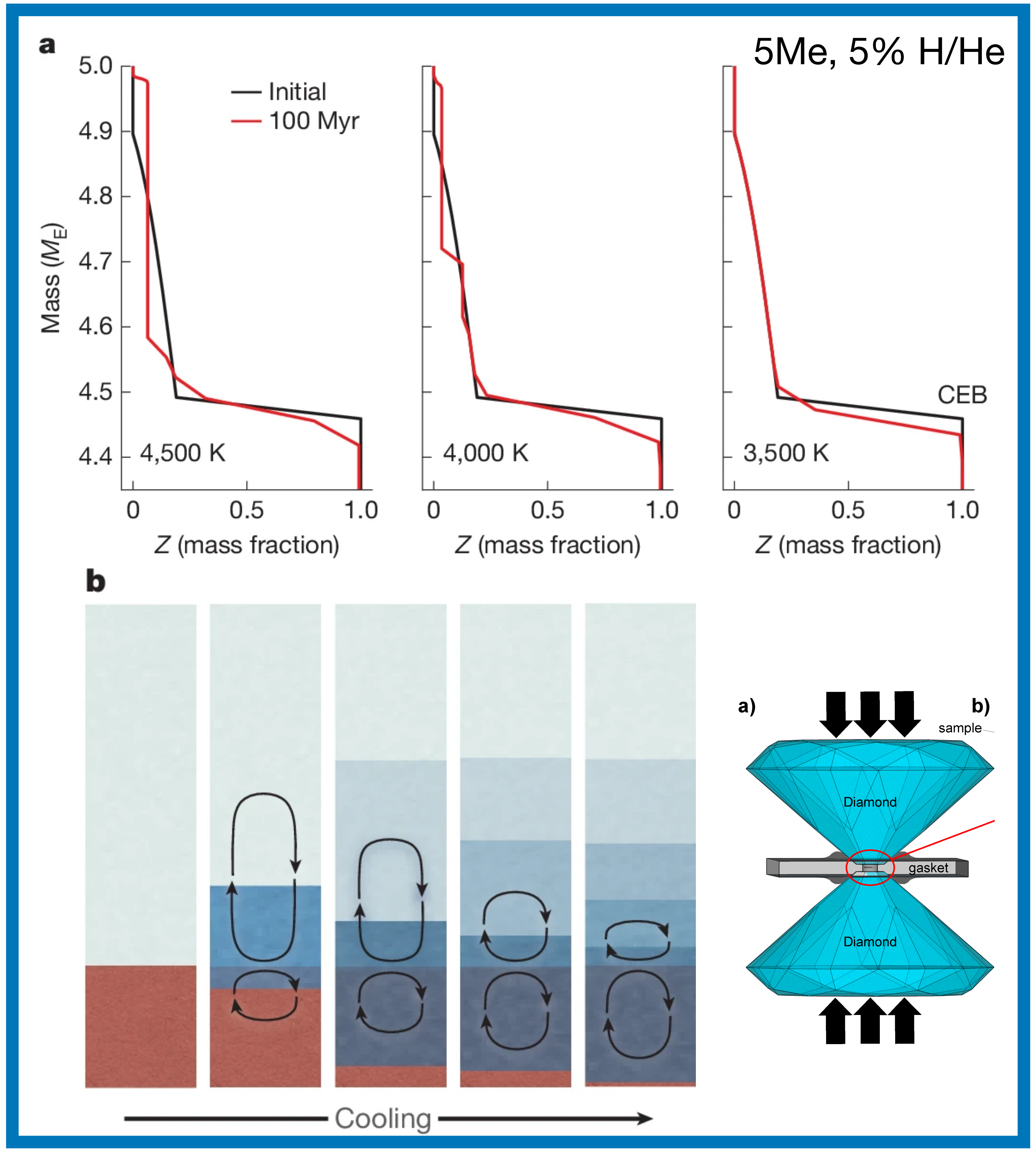
$$Mg_2SiO_4 + 4H_2 \rightarrow SiH_4 + 2MgO + 2H_2O.$$

Horn et al. 2025

$$FeO + H_2 = Fe + H_2O$$

Miozzi et al. 2025





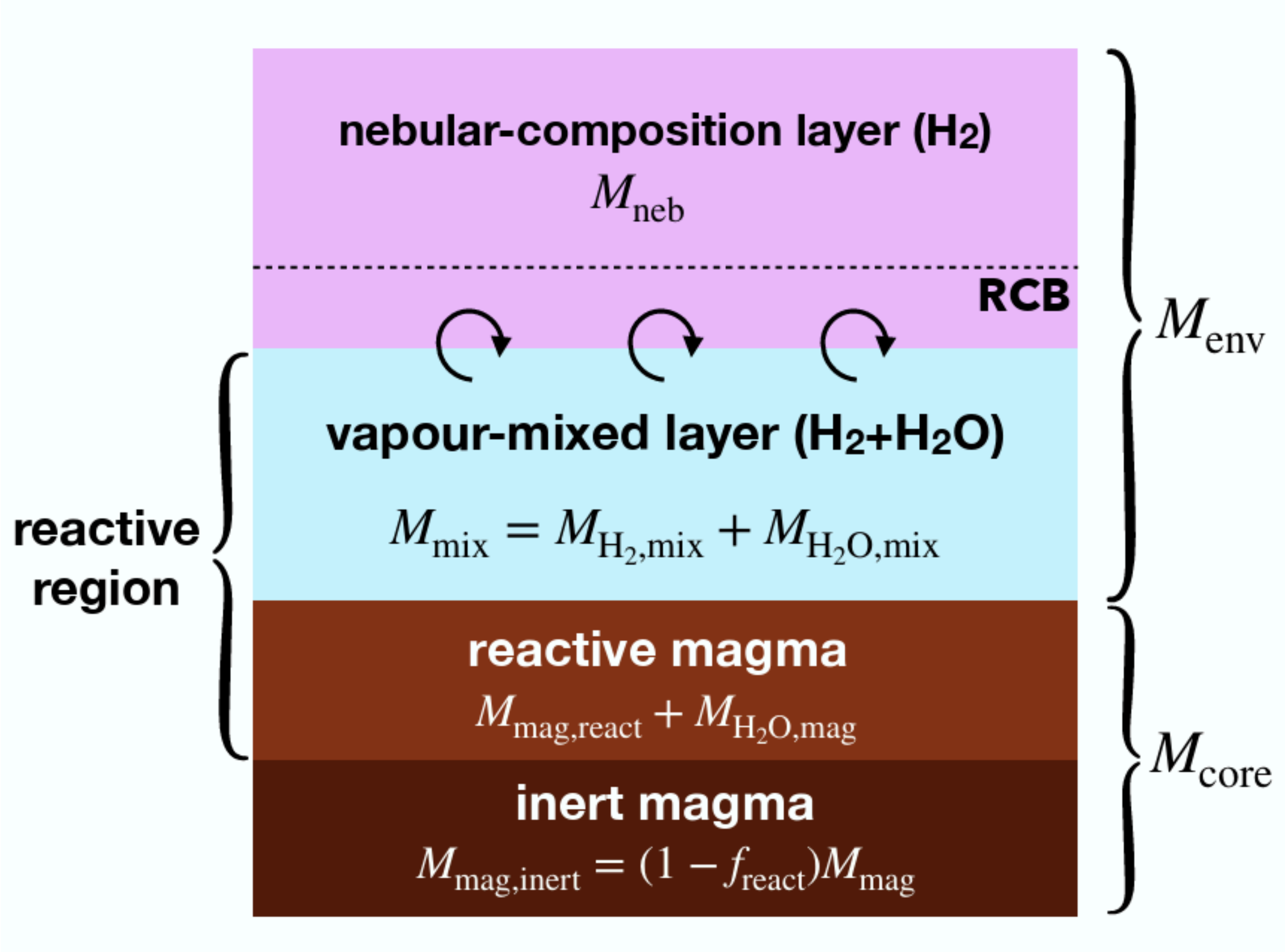
Horn, Vazan, et al. 2025, *Nature*

Water production found in lab is much more than the eq. chemistry levels

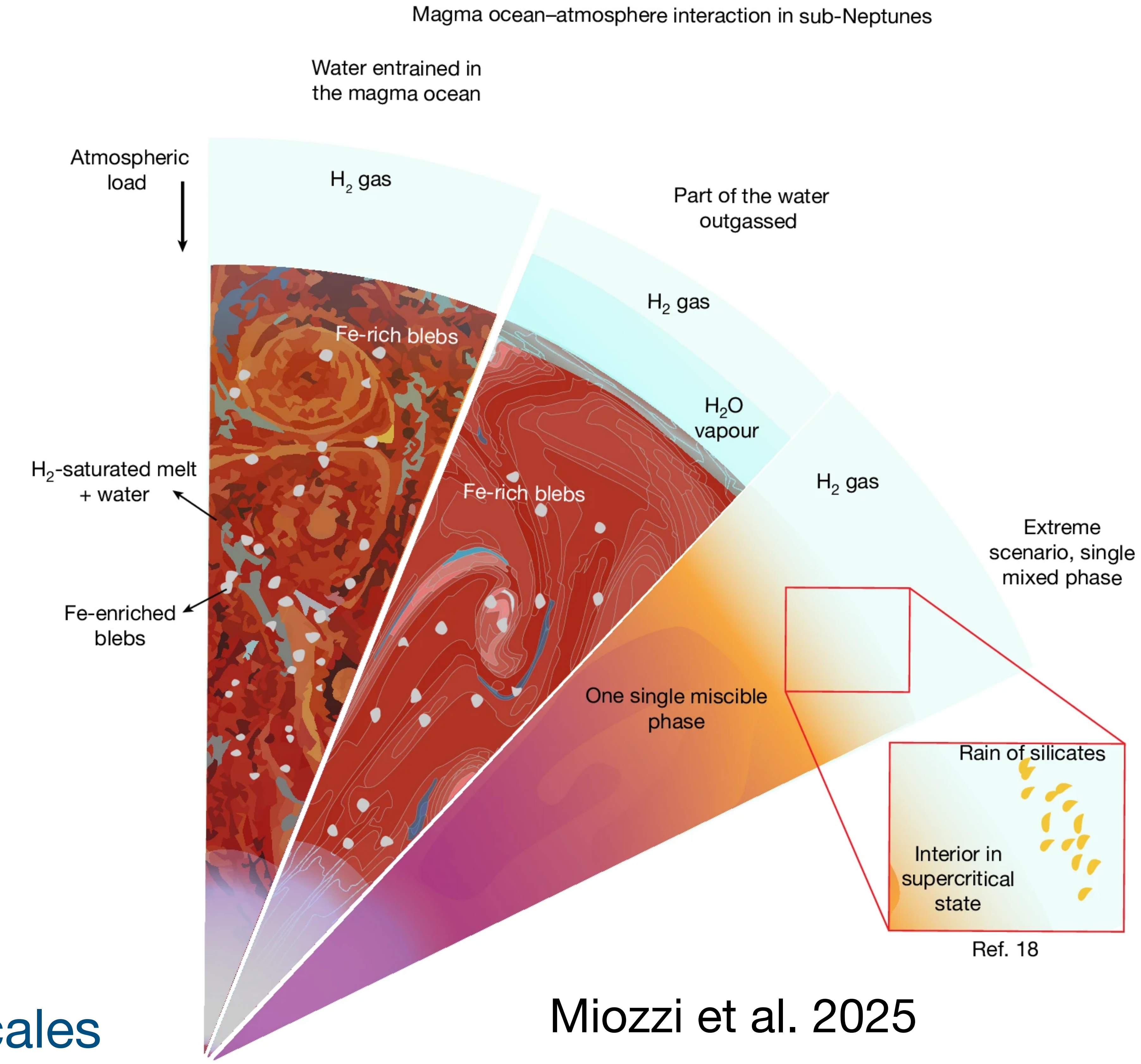
Convection near the core is not always suppressed by the Z gradients

Evolving composition

Work in progress



Kimura & Lichtenberg 2026



Miozzi et al. 2025

Efficiency of the products spread, and the H supply?

physical mixing (convection) and chemical mixing (miscibility) + timescales

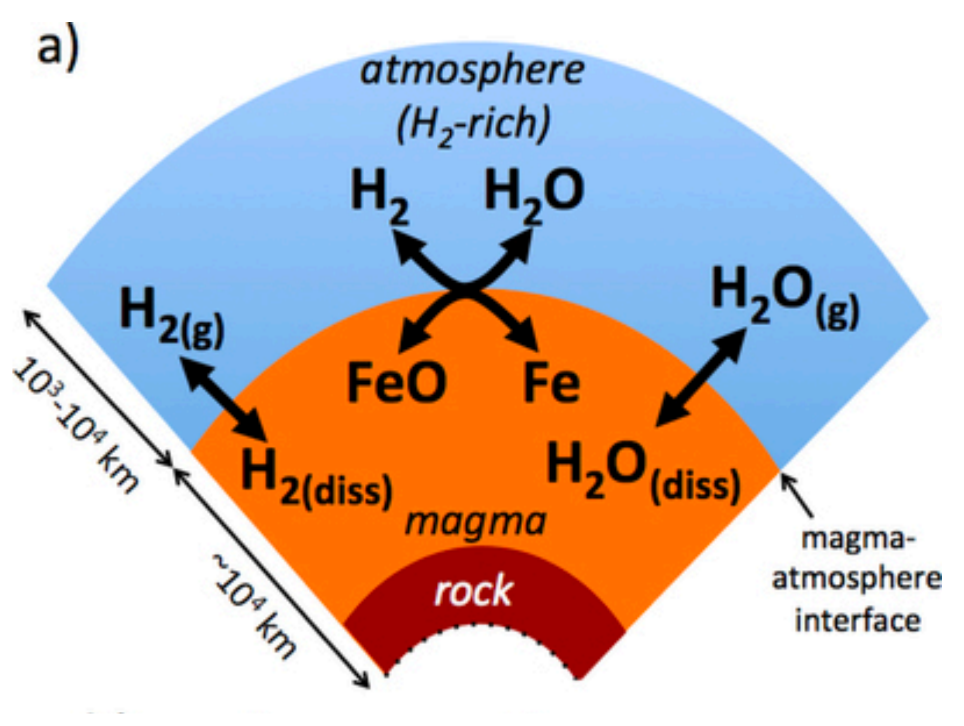
More modelling (and lab) work is needed - for what planetary types and conditions these processes are applicable?

Interior - atmosphere connection

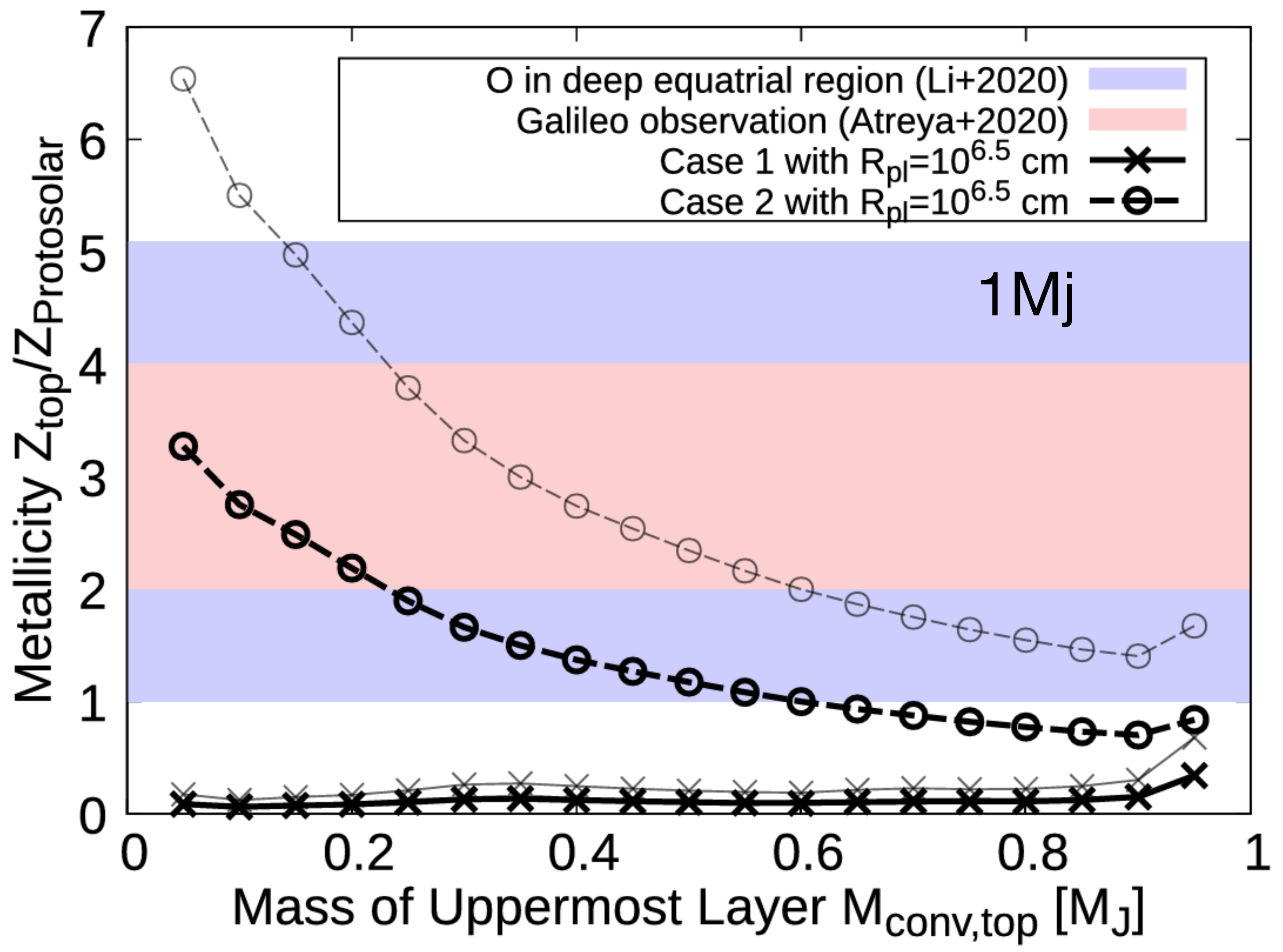
Loss / accretion of mass

Interior-wise, atmospheric composition is a mixture of leftovers:

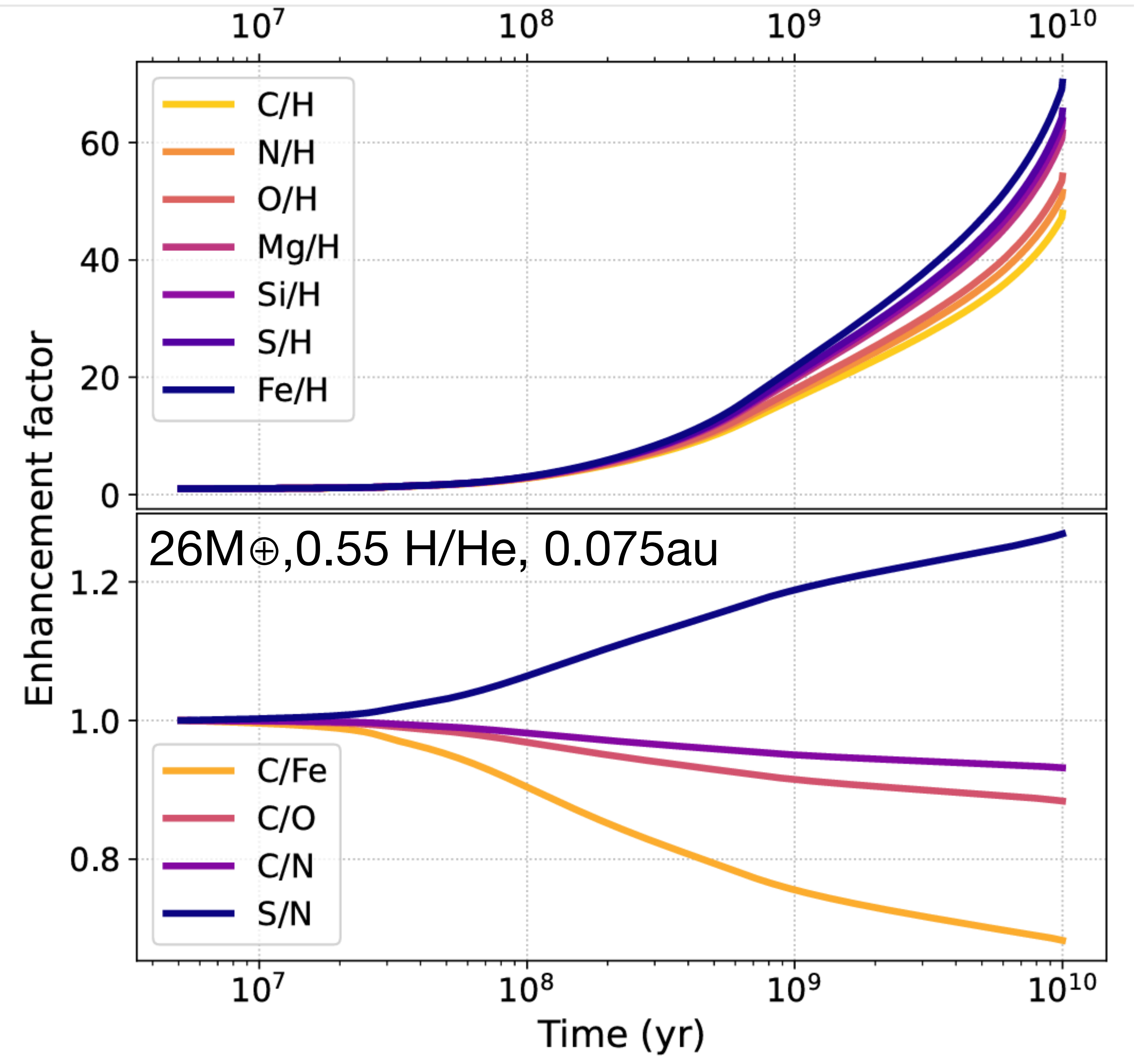
* from the gas disk (after mass loss)
* from solid ablation (formation or later impacts)
* from interior interactions (outgassing and production)



Kite et al. 2020



Shibata & Helled 2022



Louca & Miguel 2025

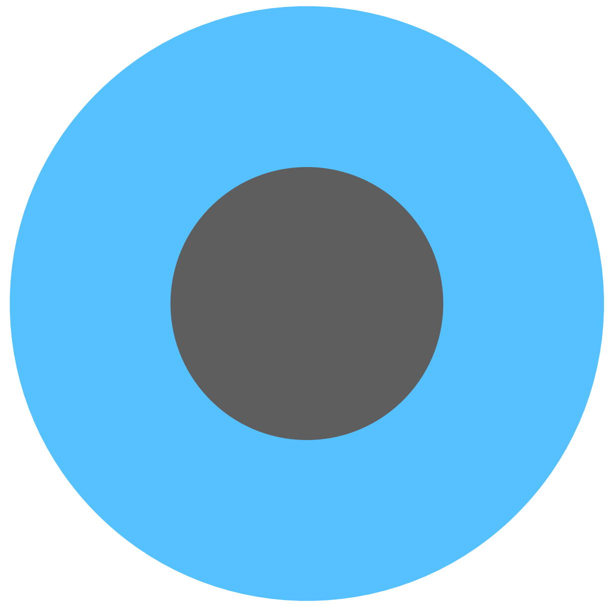
Multi-parameter problem…

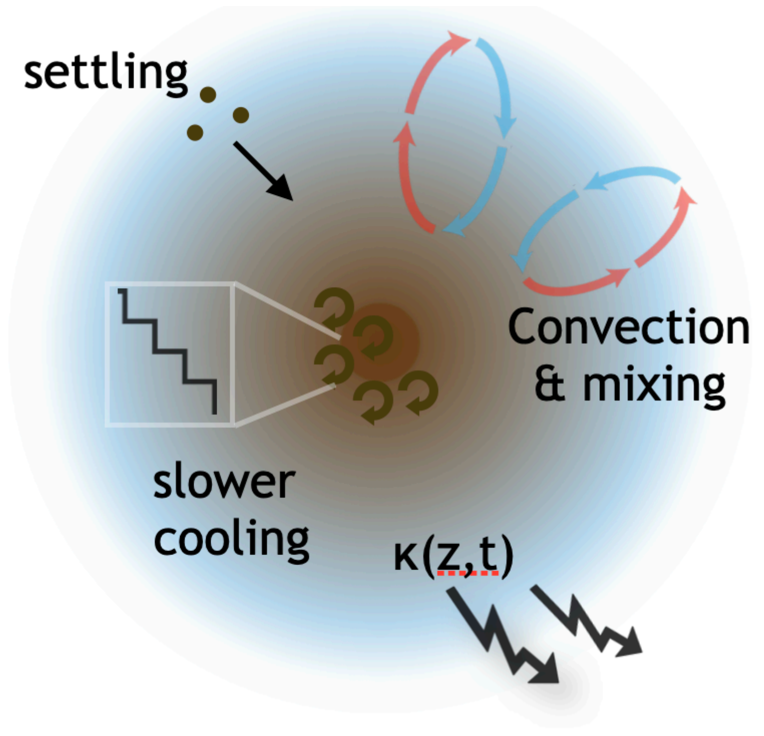
The evolution of planetary evolution

	First generation models	New generation models
cooling mechanism	convective interior + radiative top	chosen by conditions (P,T,X)
thermal bottleneck	outer boundary	everywhere, dynamic
interior structure	static structure	dynamic structure
composition	mostly constant	production
initial conditions	random, assumptions	planet formation
degrees of freedom	composition, EoS, opacity	many more

What we care about (and didn't before):

- planet formation - the initial conditions
- heat transport and structure instabilities
- composition mixtures and their thermal properties





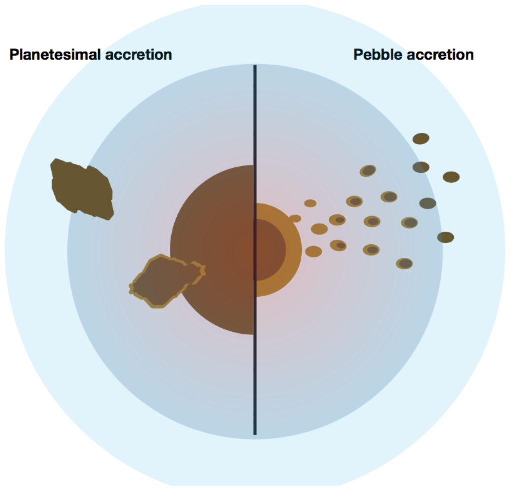
The future - active research

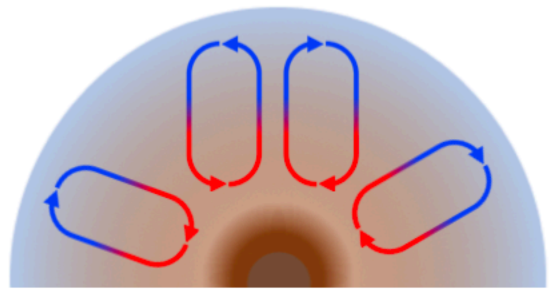
Evolving planetary interiors

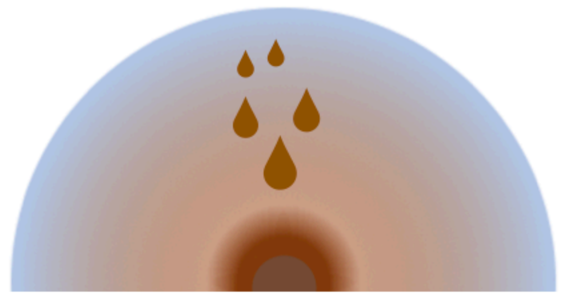
- Reducing degeneracies based on physics and chemistry :
    - Modelling mass transport is simplified (mixing-length 1D, saturation conditions, instantaneous settling, …)
    - Composition properties and in particular mixtures properties are missing
- **Accurate measurements in the R-M-Z_{env}-age parameter space (JWST, PLATO, ARIEL)**
- Characterise the main processes for different planetary types
    - giants: composition gradients stability?
    - sub-Neptunes w/ H,He: magma-H, rainout?
    - water worlds: where is the water?
    - terrestrial planets: atmosphere - interior

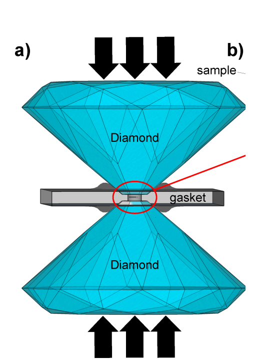
Planetary evolution in short

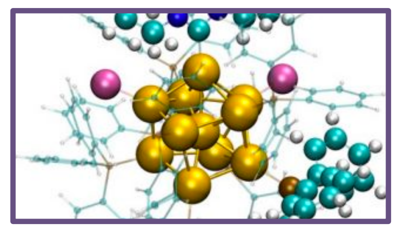
- **Interiors evolve thermally, structurally, and compositionally**
- Adiabatic models are a useful but limited approximation
- Observables are time-dependent properties
- **Interior structure reflects the evolutionary history, physically and chemically**
    - Material thermodynamics is key to determining the interior structure
    - Evolution comes in many flavours, depending on planetary type (conditions)
- Knowledge of material and mixture properties at high pressure is incomplete
- The physical processes which govern the evolution depends on the planetary type
- **Future:** coupled evolution models, mixture properties integration, age-related data

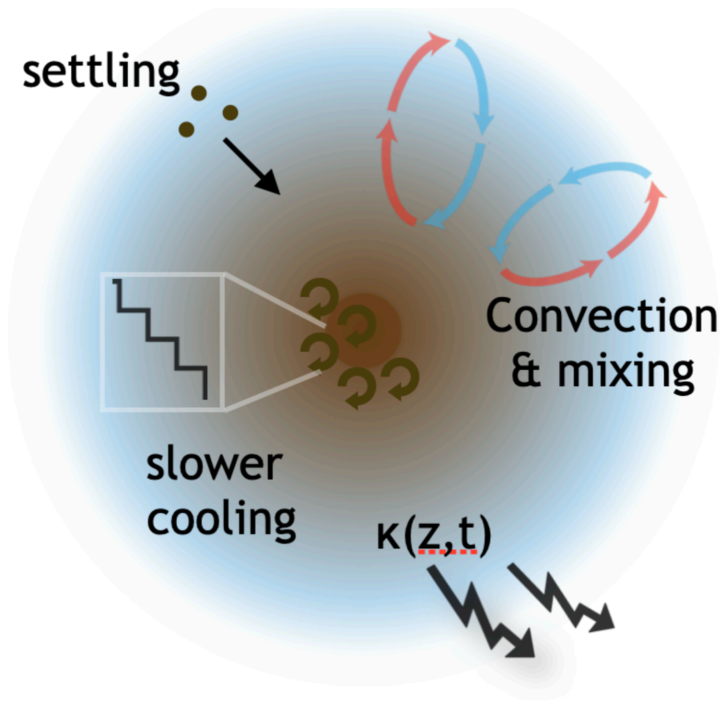






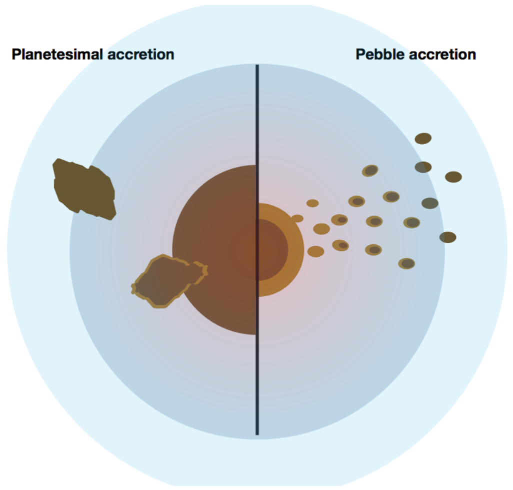


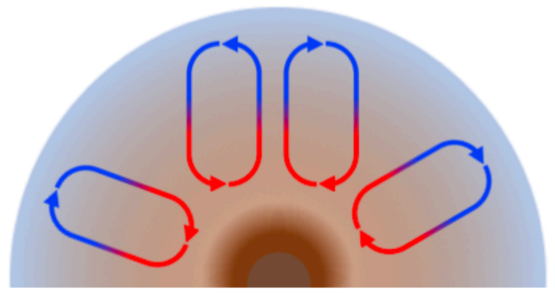


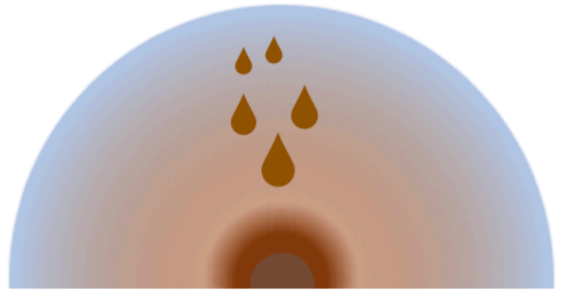


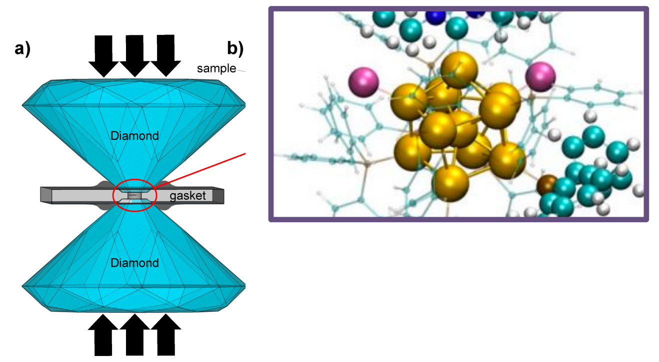
Planetary evolution in short

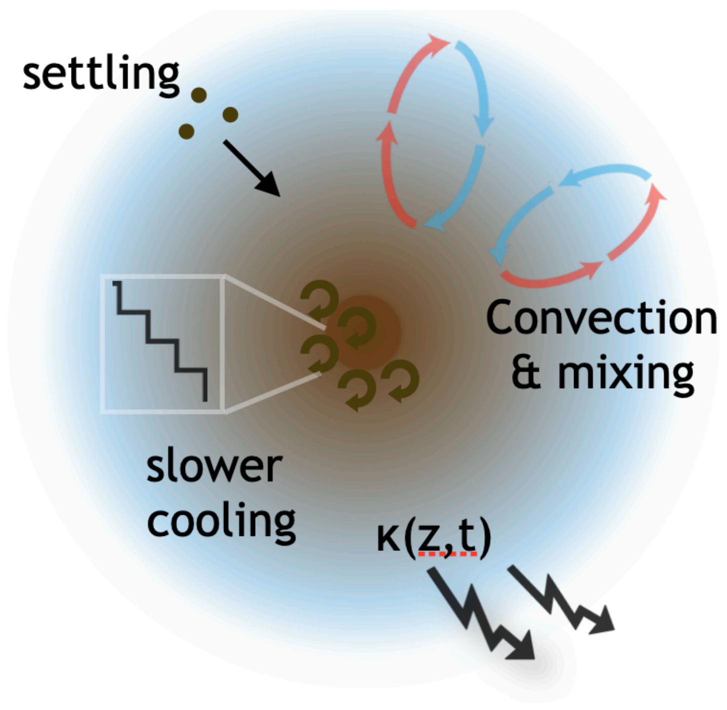
- **Interiors evolve thermally, structurally, and compositionally**
- Adiabatic models are a useful but limited approximation
- Observables are time-dependent properties
- **Interior structure reflects the evolutionary history, physically and chemically**
  - Material thermodynamics is key to determining the interior structure
  - Evolution comes in many flavours, depending on planetary type (conditions)
- Knowledge of material and mixture properties at high pressure is incomplete
- The physical processes which govern the evolution depends on the planetary type
- **Future:** coupled evolution models, mixture properties integration, age-related data











Thank you!

Backups

Abstract

From Formation to Observation: Thermal and Structural Evolution of Planetary Interiors

While static interior models provide valuable snapshots of planetary structure, planetary evolution determines how interiors and atmospheres change with time. In this review, I focus on the evolutionary processes that shape planetary interiors across different classes of planets, from gas giants and sub-Neptunes to super-Earths. I emphasize that planetary age is a key modelling parameter that is often treated implicitly, despite its strong influence on thermal state, interior structure, and observable properties. In particular, when evolution departs from adiabatic assumptions, formation conditions can influence planetary interiors over long timescales, such that the interior structure at a given age becomes an outcome of the evolutionary history rather than a prescribed input. I discuss why adiabatic interiors represent a convenient but limited approximation, and review physical mechanisms including composition gradients, phase transitions, saturation, and convection inhibition, that naturally lead to non-adiabatic evolution. Importantly, interior evolution is not purely thermal: structural and compositional changes modify density profiles, heat transport, and material exchange between interior layers over time. These processes affect observed properties such as radius, luminosity, and atmospheric abundances. I conclude by highlighting the implications of evolutionary modelling for interpreting observations and for upcoming missions targeting diverse planetary populations.

Composition as a dynamic link

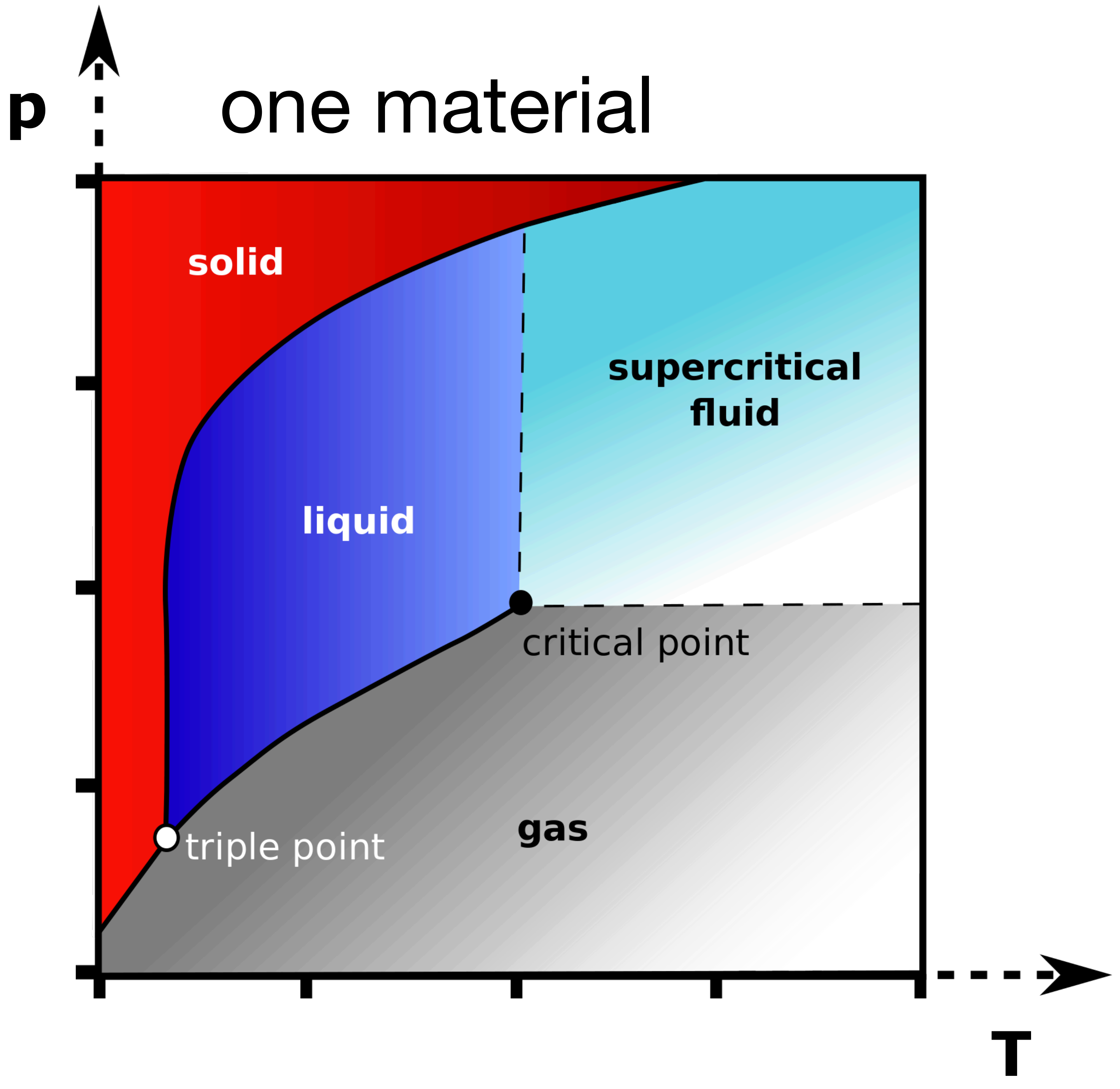
A lot is still missing…

The new planet formation scheme requires knowledge on mixtures at high pressure:

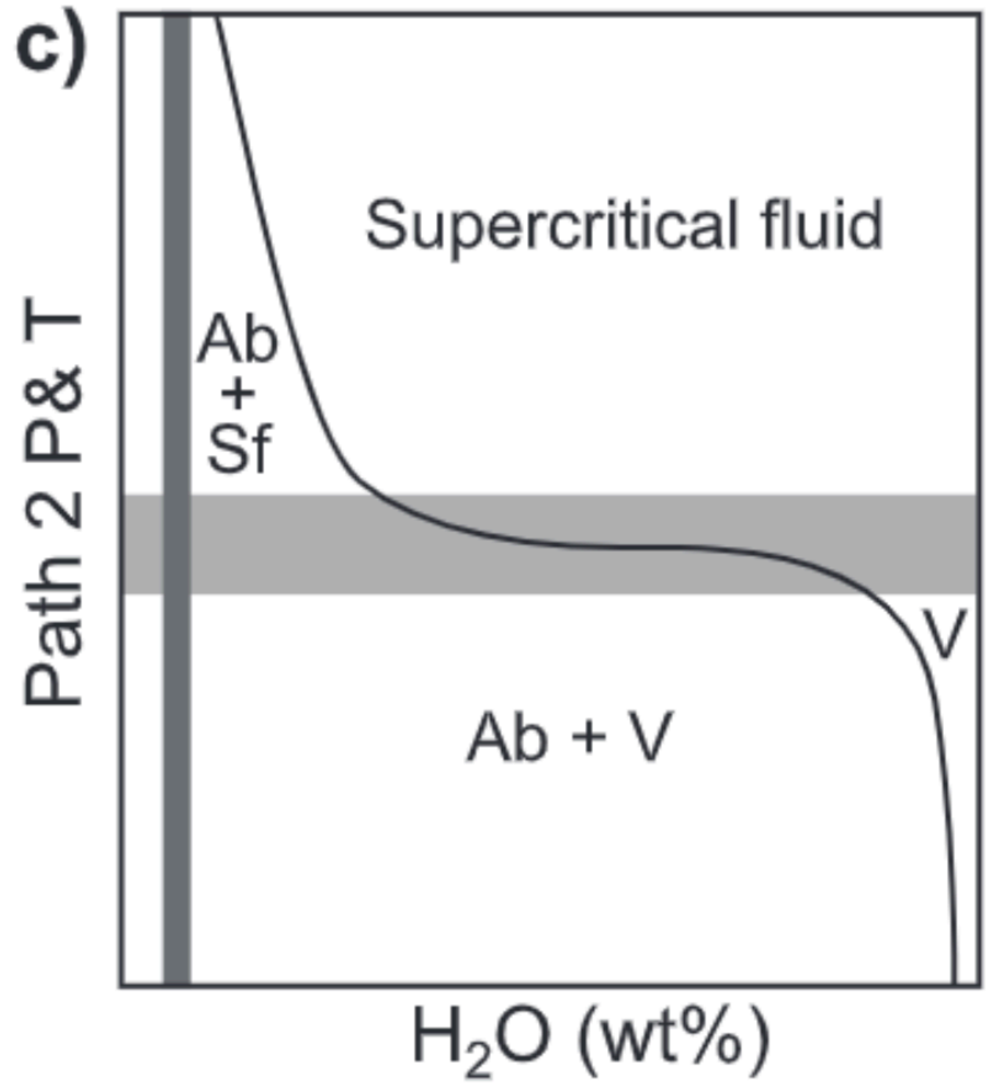
- Equation(s) of state + phase transitions
- Higher temperature data (10-10,000K)
- Material chemical interaction:
    - Miscibility of various species
    - Equilibrium chemistry
- Physical properties of mixtures:
    - Thermal conductivity
    - Electrical conductivity
    - Viscosity
    - …

Material interaction

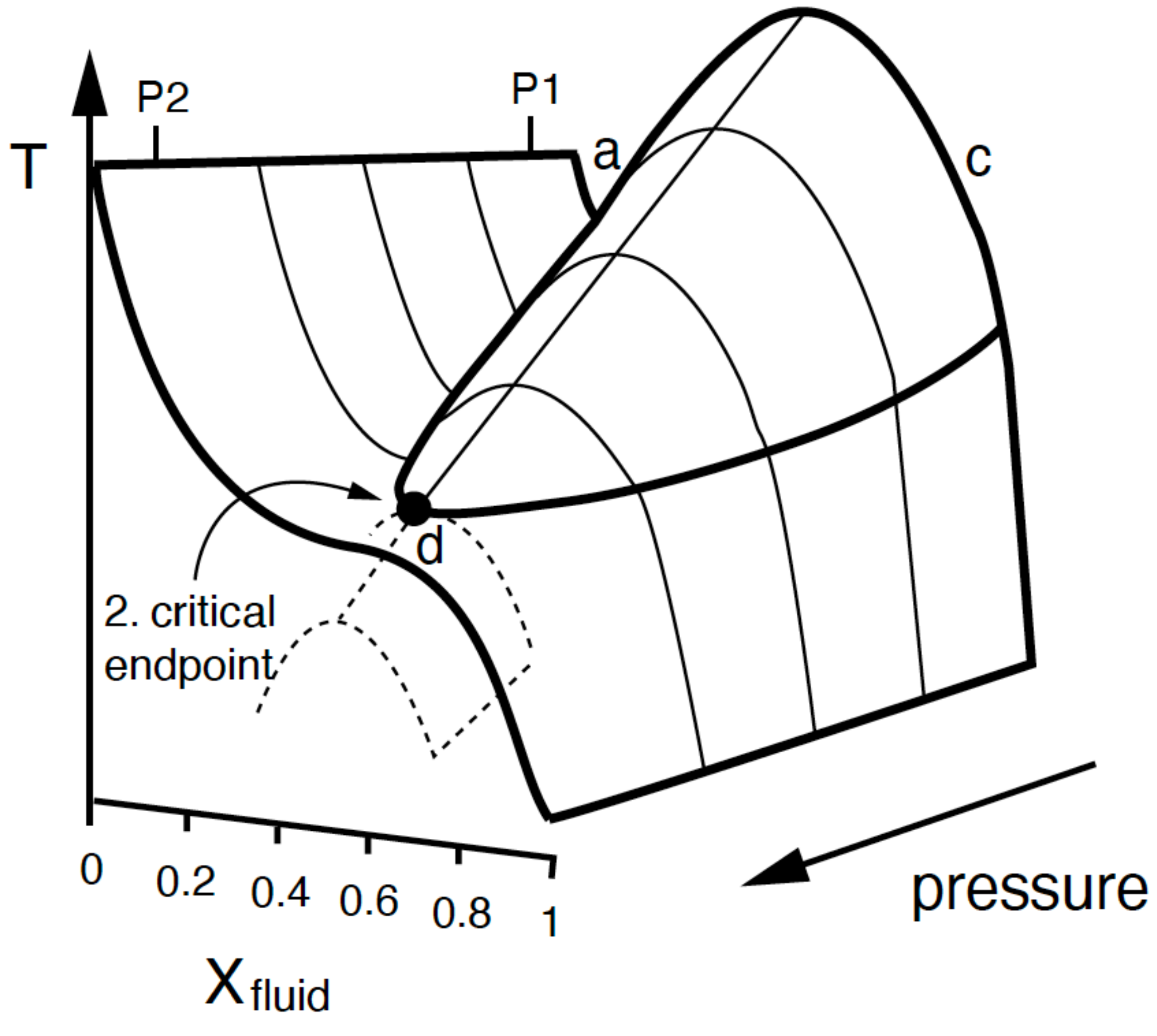
one material



mixture



Manning 2004



Stalder et al. 2000

<u>Critical point</u>

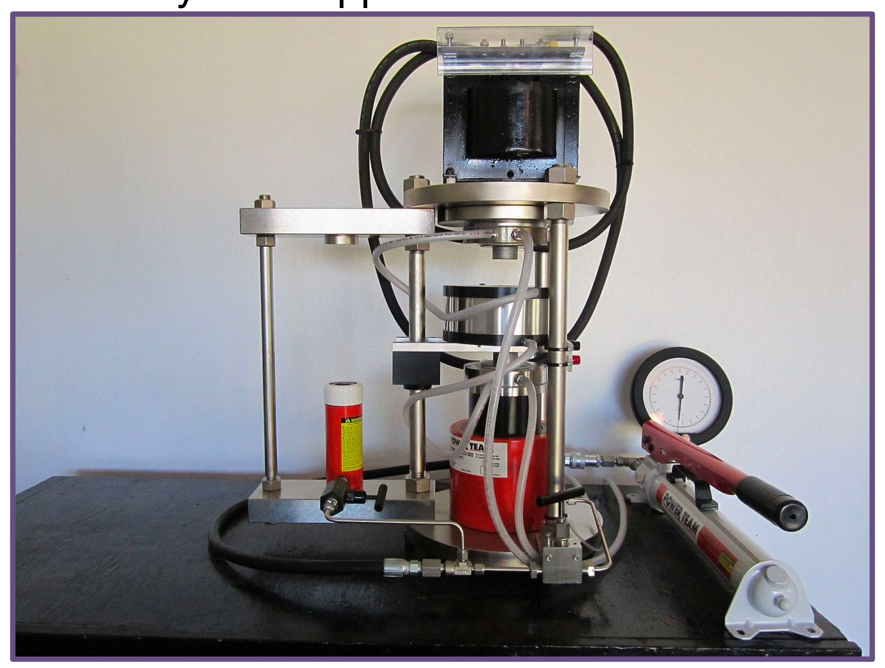
H_2O: 647K, 22MPa

SiO_2: ~5400K, 0.2 GPa

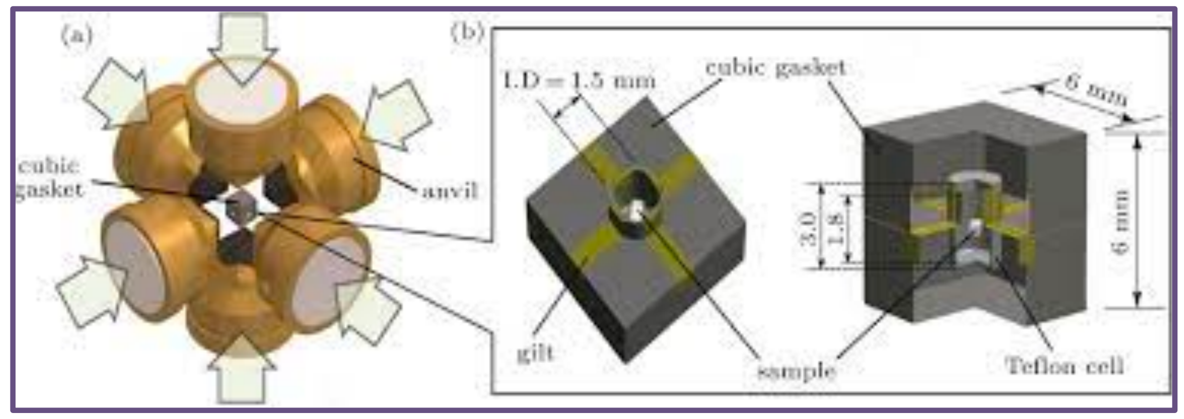
Iron: ~8500K, 0.5 GPa

Supercritical fluids are miscible in each other

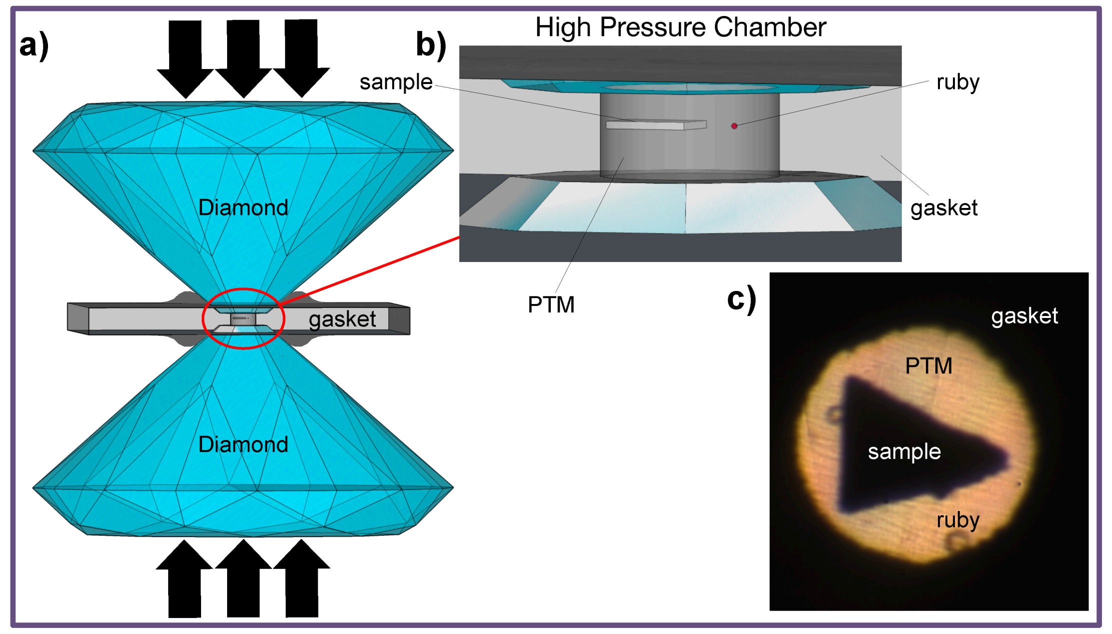
Piston-cylinder apparatus <10 GPa



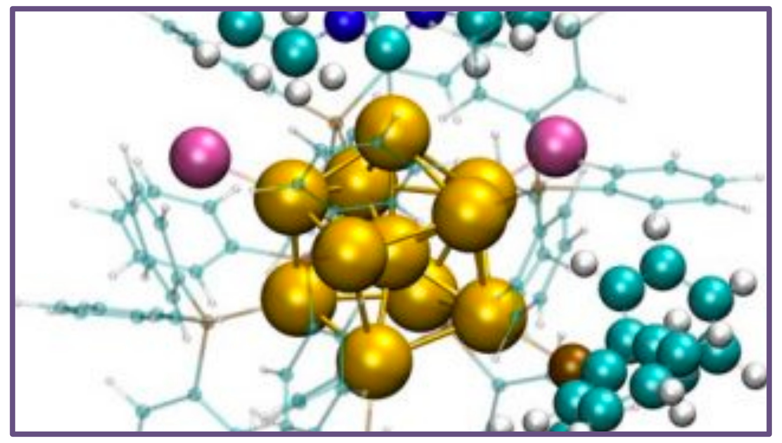
Multi anvil press 10s G



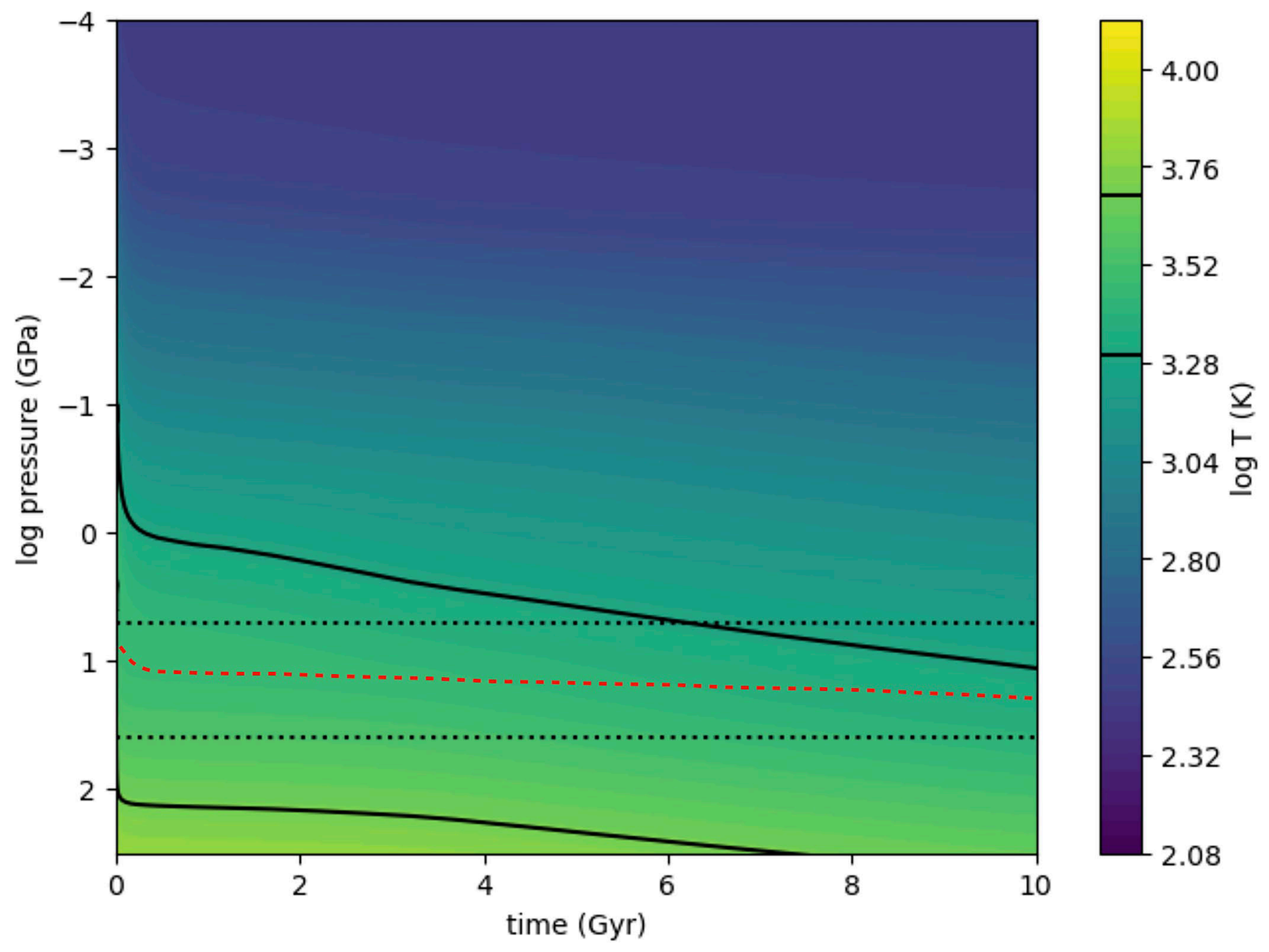
Diamond anvil cell 100s GPa

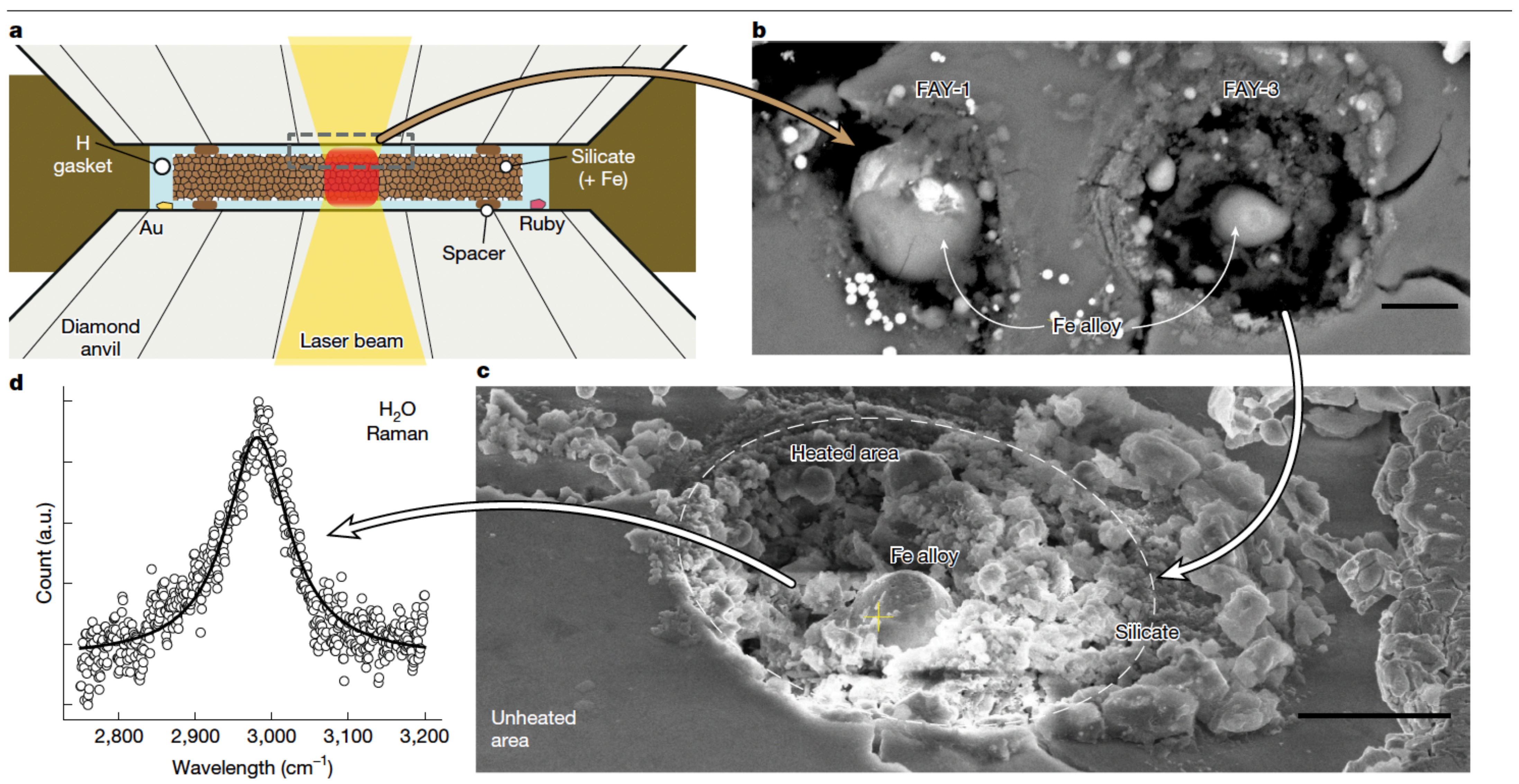


Molecular dynamics simulations



Horn et al. 2025





6-42 GPa, 2000-5000K (also Kim's)

Thermal evolution

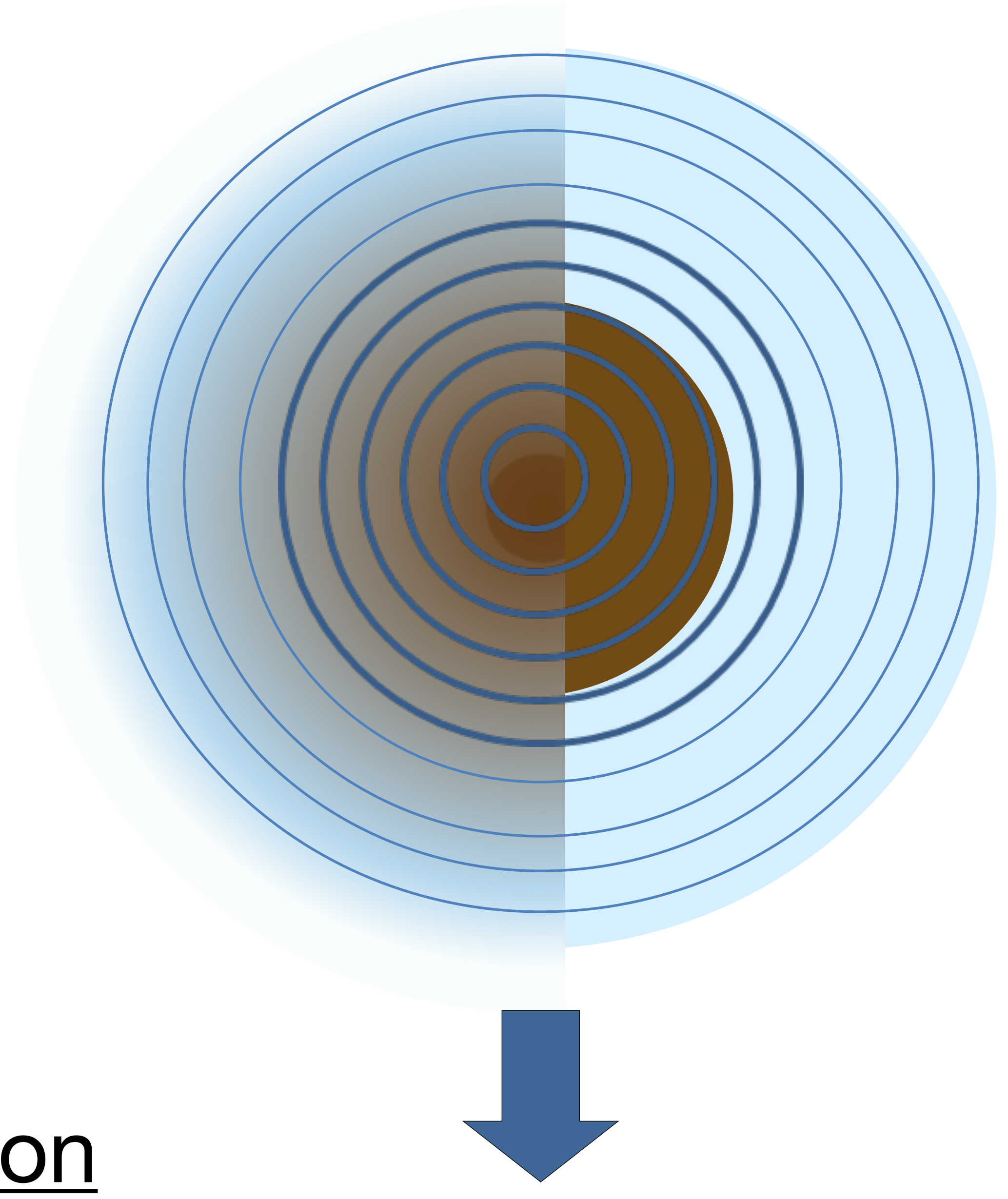
Model (Vazan et al. 2013,15,18c,22,24)

From formation to current stage:
interior thermal evolution

- Stellar evolution based (Kovetz et al. 2009)
- Mass loss / accretion scheme
- Stellar irradiation (grey)
- Tabular EoS for H, He, water, rock, iron
- Heat transport: convection, radiation, conduction
- Material transport: advection, rainout
- Self-consistent (adaptive Z) radiative opacity

$\nabla_R > \nabla_A + \nabla_{Ledoux}$ + Mixing Length Theory

$$L_{\rm core} = M_c \left(c_v \frac{dT_c}{dt} + \frac{E_{\rm radio}}{\tau_r} e^{(-t/\tau_r)} + \frac{E_{\rm solid}}{\Delta t} \delta\left(T - T_{\rm solid}\right) \right)$$



Radius
Temperature
Luminosity
Density
Pressure
Composition

$$\frac{\partial}{\partial m}\frac{4\pi}{3}r^3 = \frac{1}{\rho}$$

$$\frac{\partial p}{\partial m} = -\frac{Gm}{4\pi r^4}$$

$$\frac{\partial \ln T}{\partial m} = \nabla \frac{\partial \ln p}{\partial m}$$

$$\frac{\partial u}{\partial t} + p\frac{\partial}{\partial t}\frac{1}{\rho} = q - \frac{\partial L}{\partial m}$$

$$\frac{\partial Y_j}{\partial t} = R_j - \frac{\partial F_j}{\partial m}; \qquad F_j = -\sigma_j \frac{\partial Y_j}{\partial m}$$

Opacity: $$\frac{1}{\kappa} = \frac{1}{\kappa_{rad}} + \frac{1}{\kappa_{cond}}$$

EoS for a mixture: $$\frac{1}{\rho(P,T)} = \sum_{i=1}^{n} \frac{Xi}{\rho_{Xi}(P,T)}$$

Thermal evolution

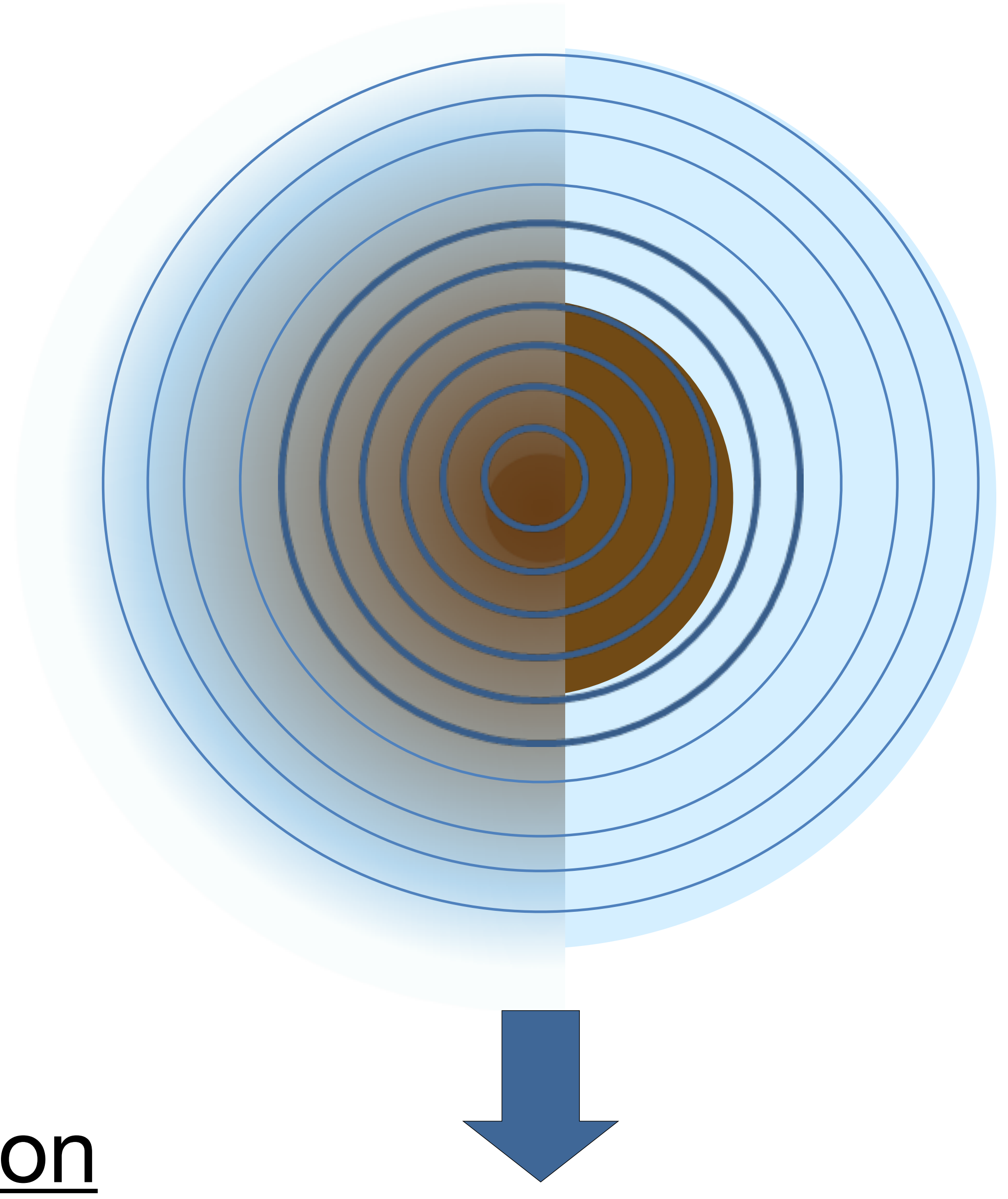
Model (Vazan et al. 2013,15,18c,22,24)

From formation to current stage:
interior thermal evolution

- Stellar evolution based (Kovetz et al. 2009)
- Mass loss / accretion scheme
- Stellar irradiation (grey)
- Tabular EoS for H, He, water, rock, iron
- Heat transport: convection, radiation, conduction
- Material transport: advection, rainout
- Self-consistent (adaptive Z) radiative opacity

$$\nabla_R > \nabla_A + \nabla_{Ledoux}$$ + Mixing Length Theory

$$L_{\rm core} = M_c \left(c_v \frac{dT_c}{dt} + \frac{E_{\rm radio}}{\tau_r} e^{(-t/\tau_r)} + \frac{E_{\rm solid}}{\Delta t} \delta \left(T - T_{\rm solid} \right) \right)$$



Radius
Temperature
Luminosity
Density
Pressure
Composition

$$\frac{\partial}{\partial m} \frac{4\pi}{3} r^3 = \frac{1}{\rho}$$

$$\frac{\partial p}{\partial m} = -\frac{Gm}{4\pi r^4}$$

$$\frac{\partial \ln T}{\partial m} = \nabla \frac{\partial \ln p}{\partial m}$$

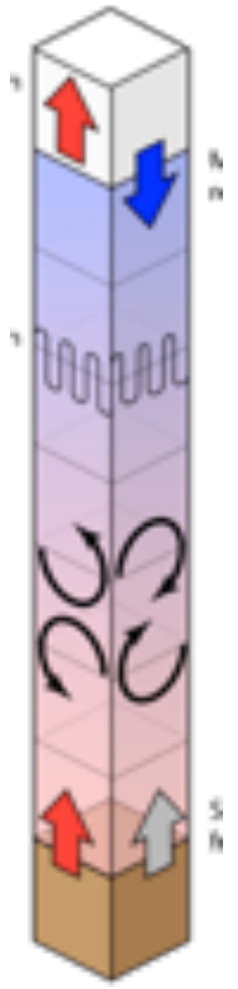
$$\frac{\partial u}{\partial t} + p \frac{\partial}{\partial t} \frac{1}{\rho} = q - \frac{\partial L}{\partial m}$$

$$\frac{\partial Y_j}{\partial t} = R_j - \frac{\partial F_j}{\partial m}; \qquad F_j = -\sigma_j \frac{\partial Y_j}{\partial m}$$

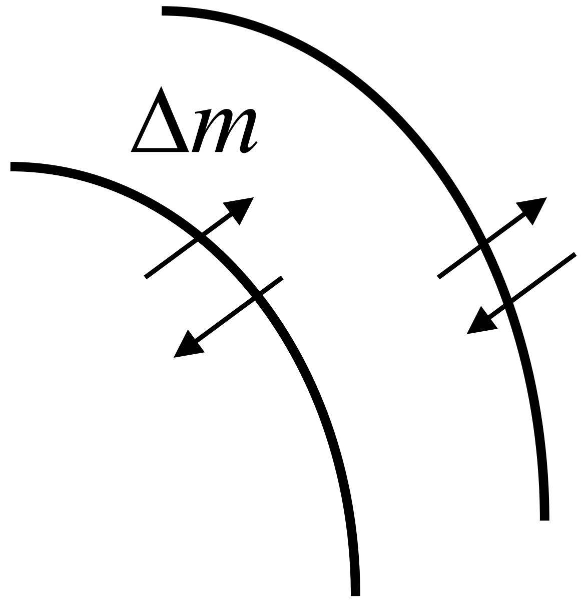
Opacity: $$\frac{1}{\kappa} = \frac{1}{\kappa_{rad}} + \frac{1}{\kappa_{cond}}$$

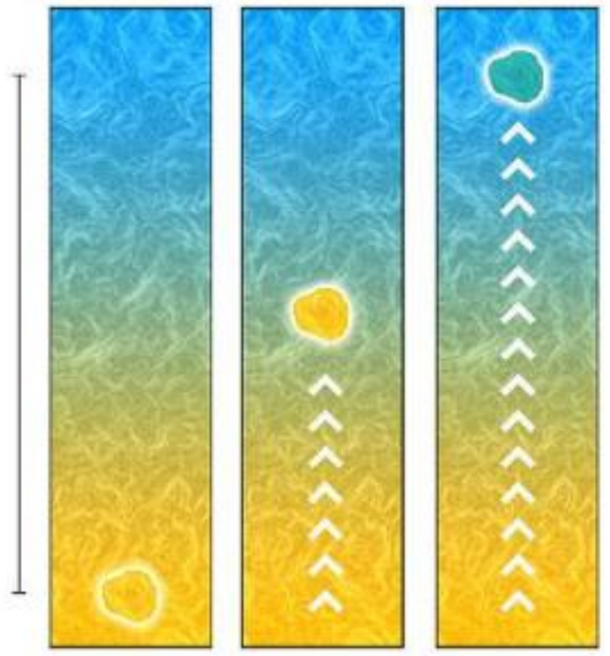
EoS for a mixture: $$\frac{1}{\rho(P,T)} = \sum_{i=1}^{n} \frac{Xi}{\rho_{Xi}(P,T)}$$

Convective – Diffusion



$$\frac{\partial Y_j}{\partial t} = R_j - \frac{\partial F_j}{\partial m}$$





Mixing Length Recipe

$$F_j = -\sigma_j \frac{\partial Y_j}{\partial m}$$

Heat transport

$$\frac{\partial \ln T}{\partial m} = \nabla \frac{\partial \ln p}{\partial m}$$

$$\nabla = \begin{cases} \nabla_R, & \nabla_R \le \nabla_A + \nabla_{Ledoux} \\ MLR, & \nabla_R > \nabla_A + \nabla_{Ledoux} \end{cases}$$

Convective diffusion coefficient

$$\sigma_j = \left(\frac{dm}{dr}\right)^2 D_c$$

The code regards convective mixing as a vertical diffusive process in a gas of density, mean velocity (supplied by MLR), and mean free path.

diffusion coefficient

$$D_c = \begin{cases} v_c l_c, & convective \\ 0, & radiative \end{cases} \quad \sum_i \rho_i v_i = 0$$

$$H_p \equiv \left(\frac{d \ln p}{dr}\right)^{-1} = \frac{p}{g\rho}$$

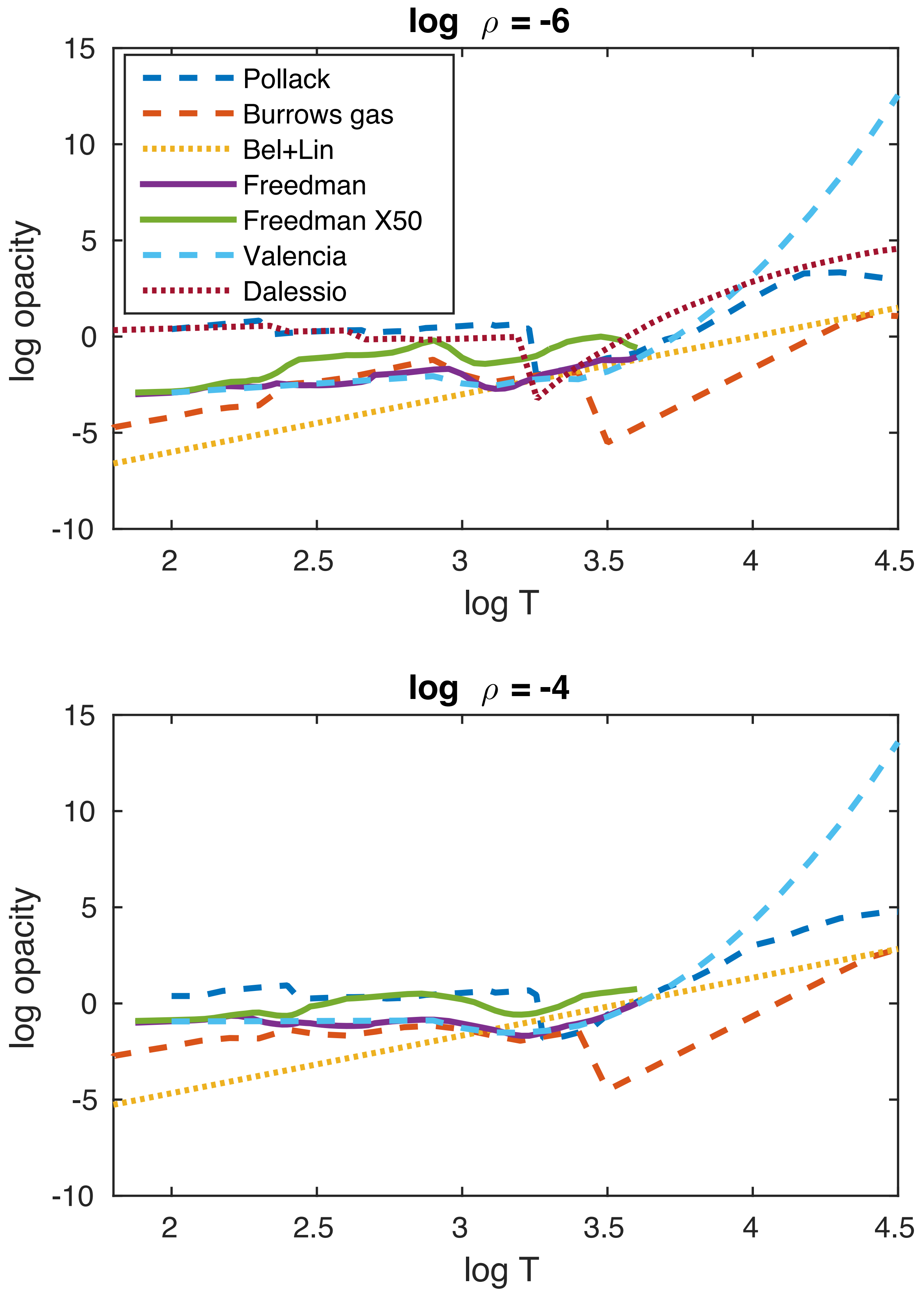
$$Q \equiv 1 - \left(\frac{\partial \ln \mu}{\partial \ln T}\right)_p$$

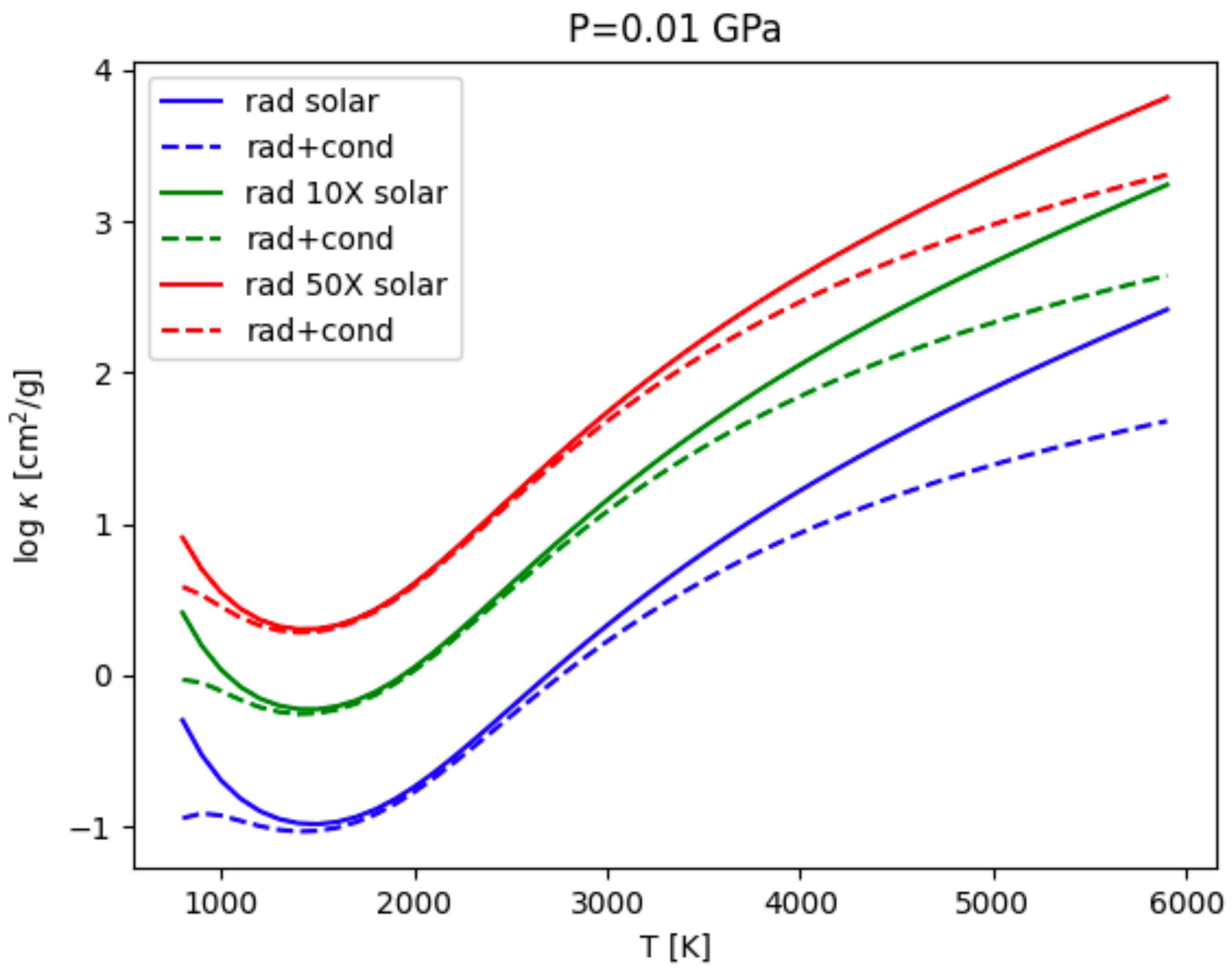
MLR
Mihalas 78

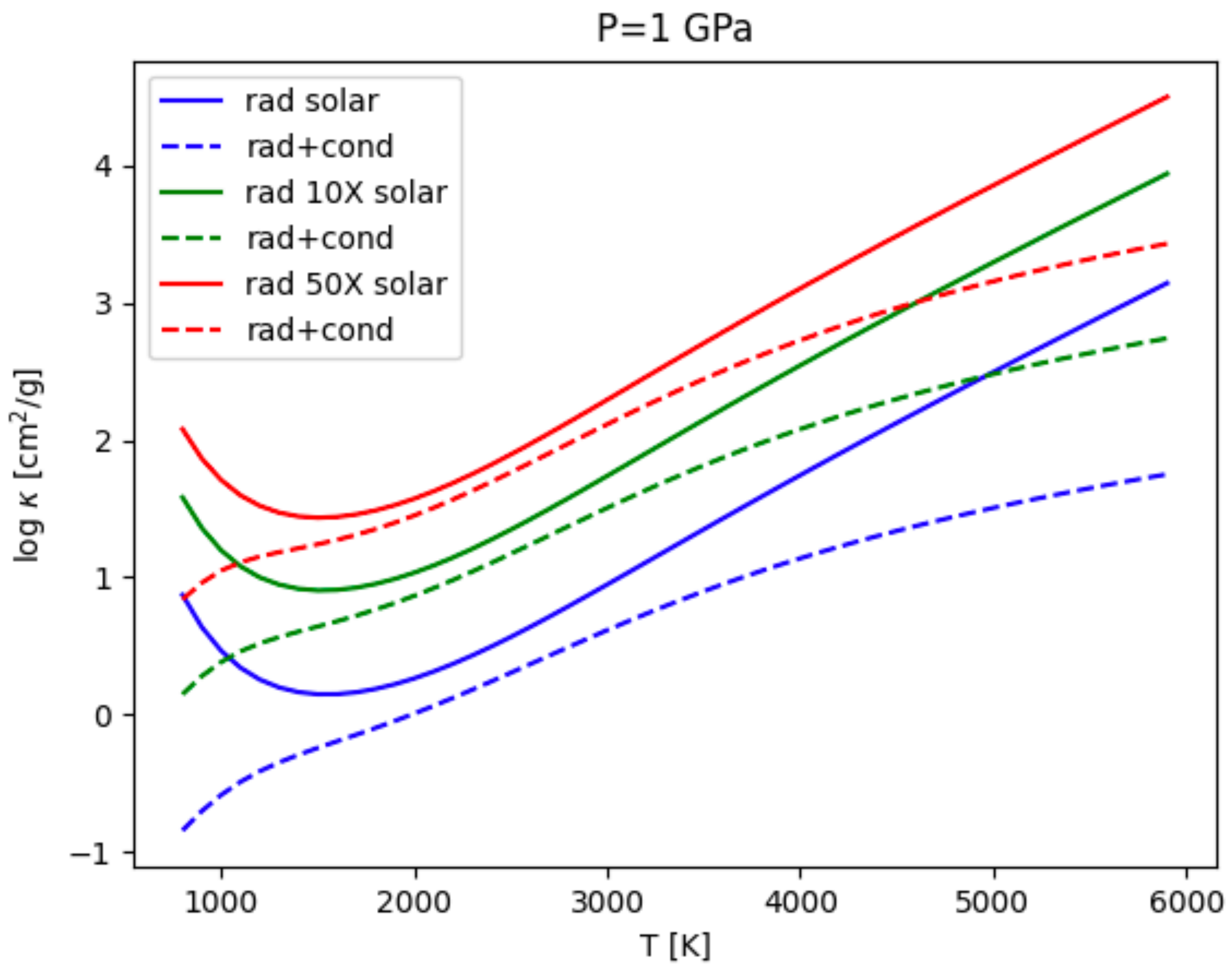
$$\left\{ \pi F_{conv} = \rho C_p v_c \delta T \sim \frac{1}{4\sqrt{2}} \rho C_p T \sqrt{g H_p Q} (\nabla - \nabla_E)^{3/2} \left(\frac{l_c}{H_p}\right)^2 \right.$$

Thermal and structural evolution depend on each other (self-consistent)

Radiative opacity calculations

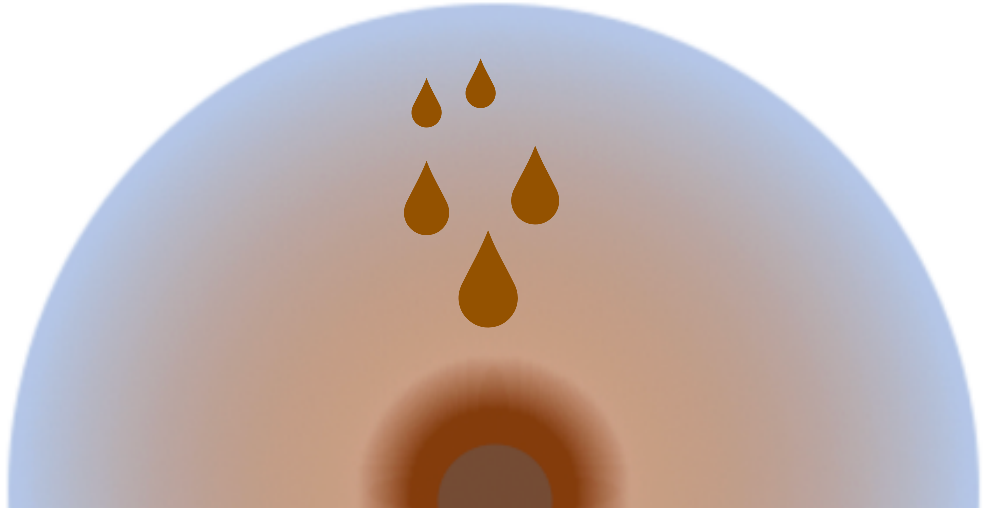




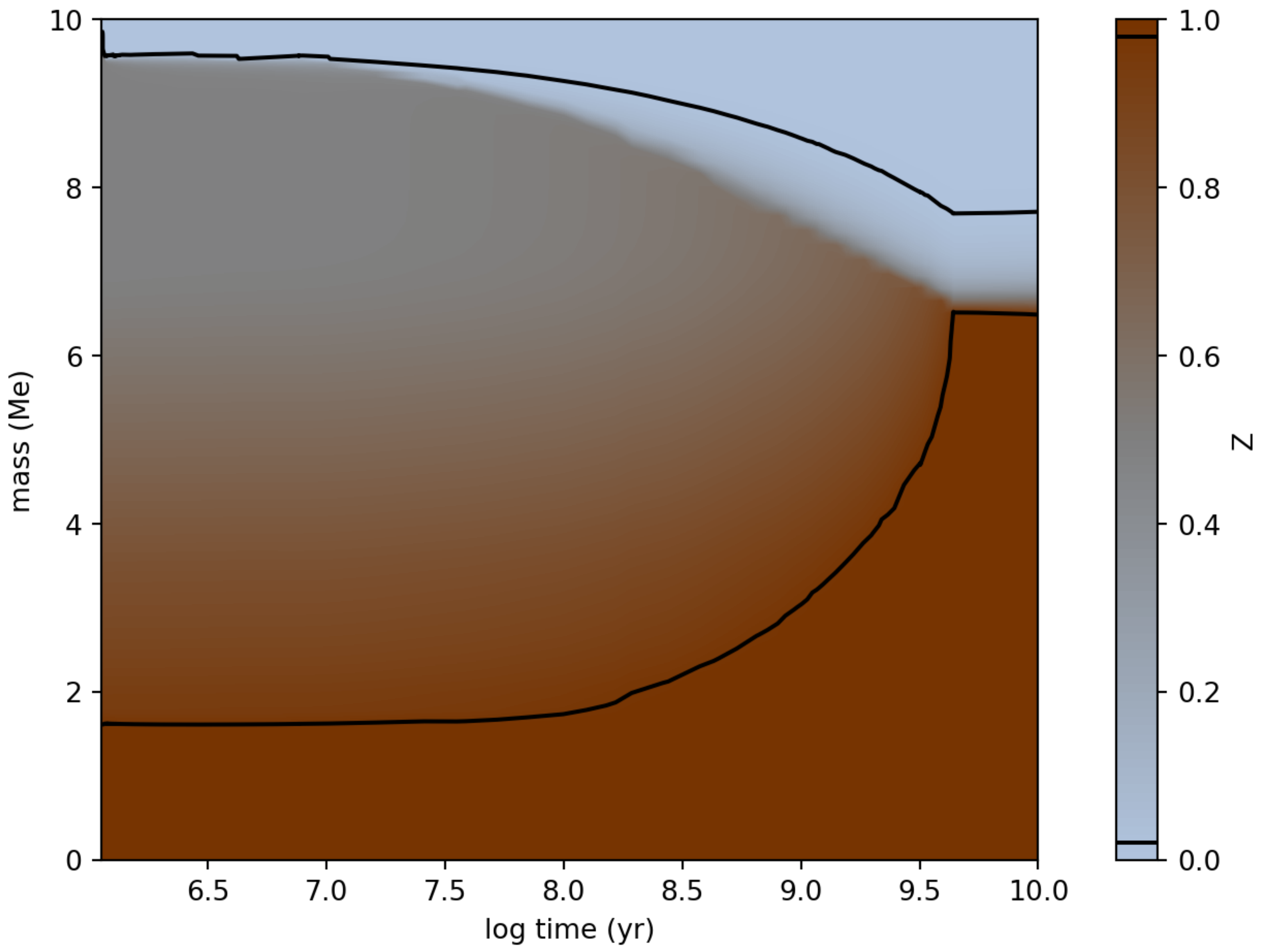


Interior evolution

Silicate rainout from cooling polluted envelopes



10 Earth masses

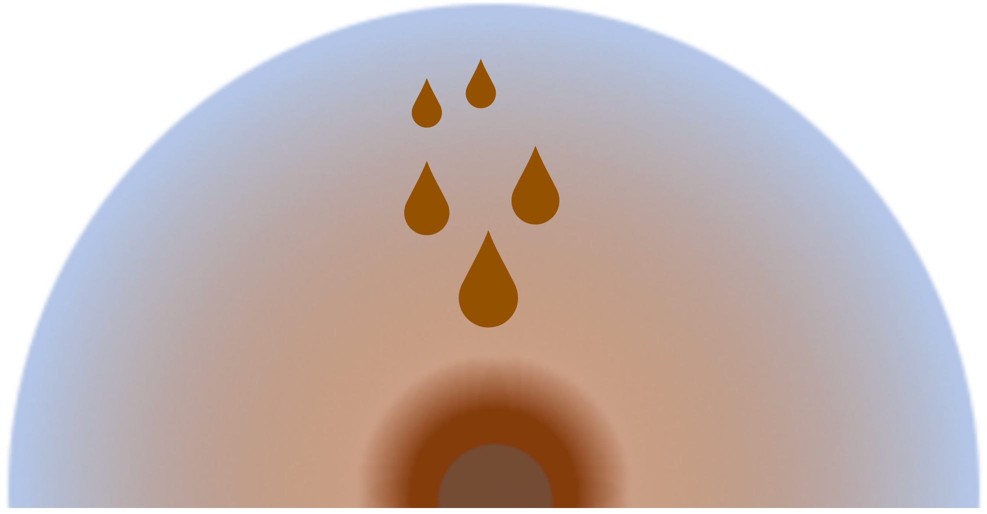


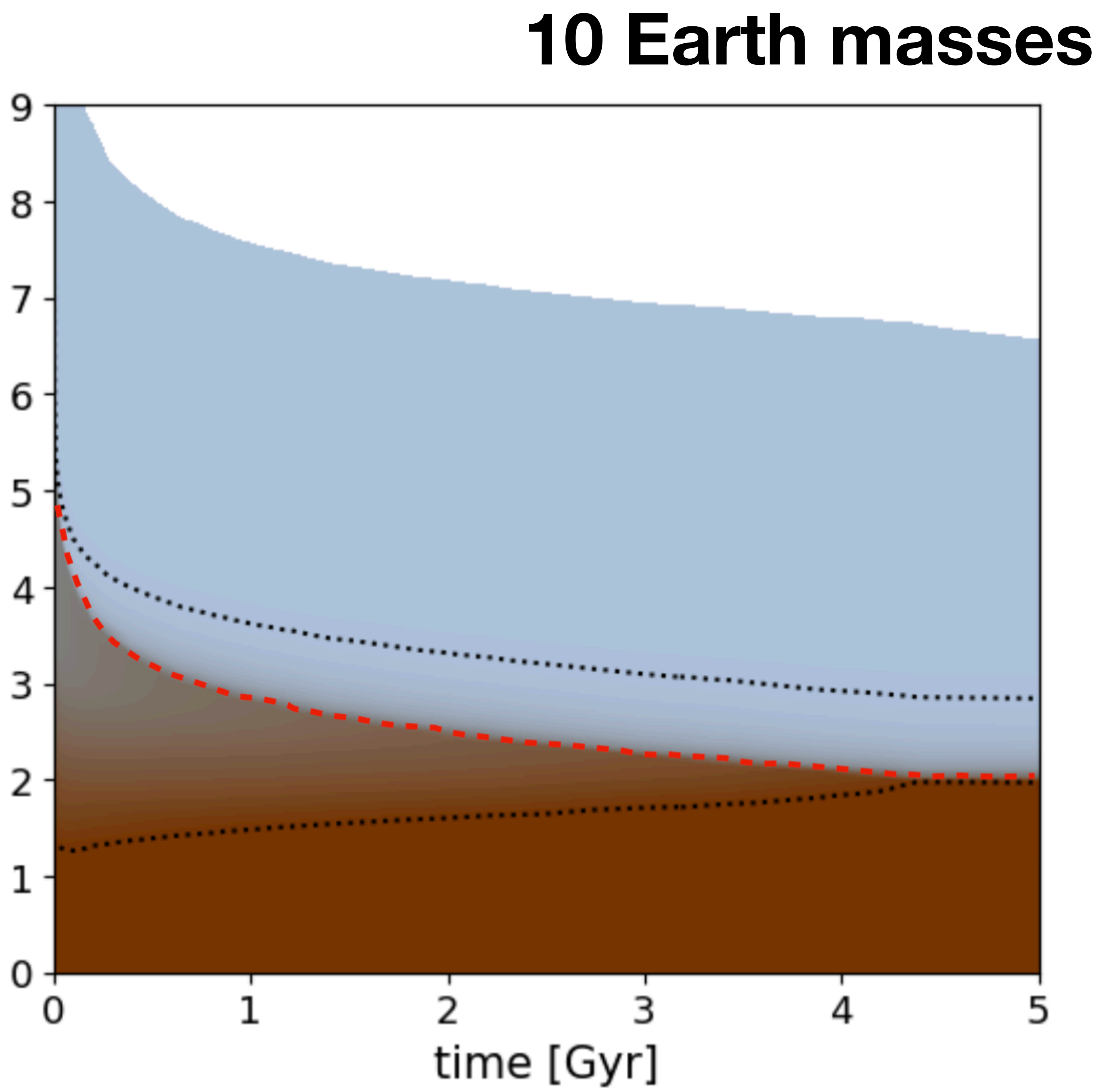
Vazan, Ormel, Brouwers 2024

Late growth of the rocky core in sub-Neptunes by silicate rainout is on ~ 1Gyr timescale

Interior evolution

Silicate rainout from cooling polluted envelopes



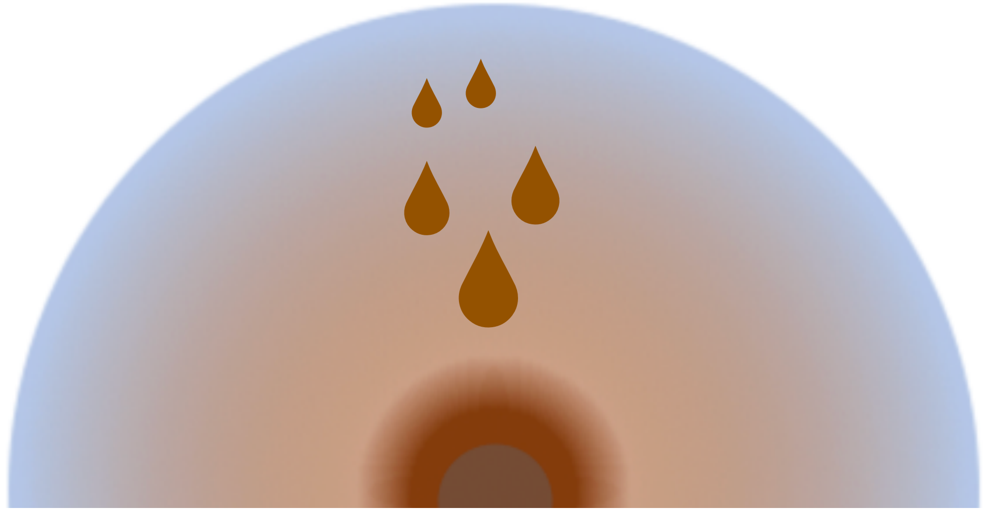


Vazan, Ormel, Brouwers 2024

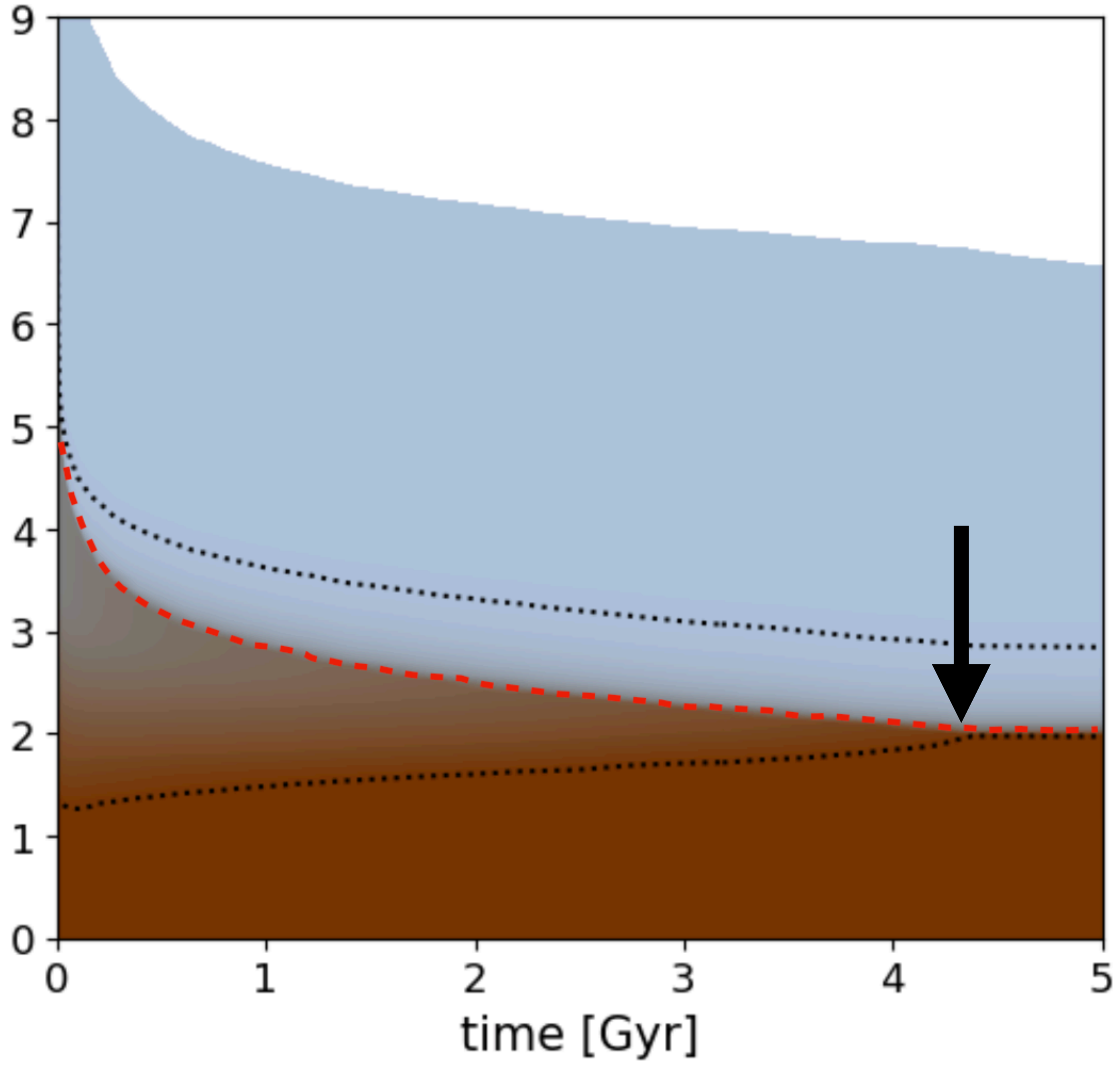
Late growth of the rocky core in sub-Neptunes by silicate rainout is on ~ 1Gyr timescale

Interior evolution

Silicate rainout from cooling polluted envelopes



10 Earth masses

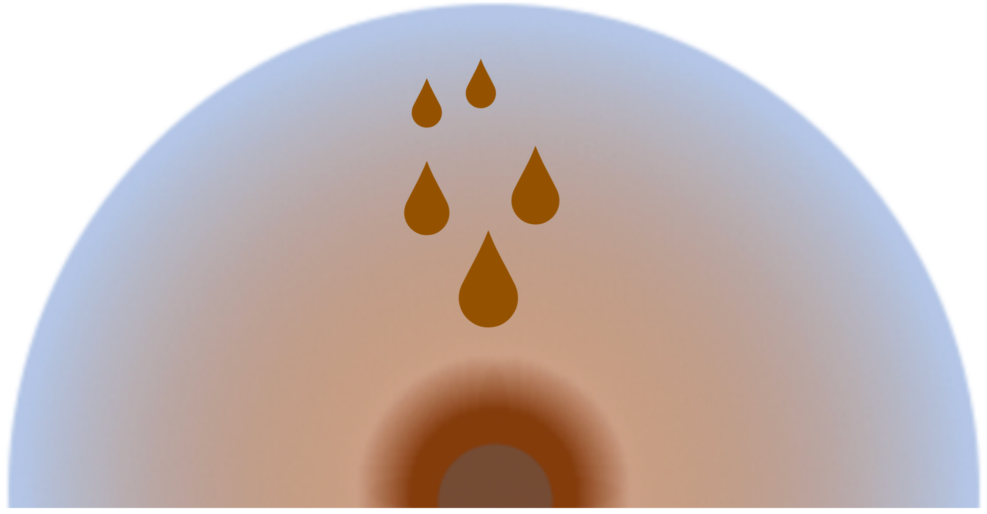


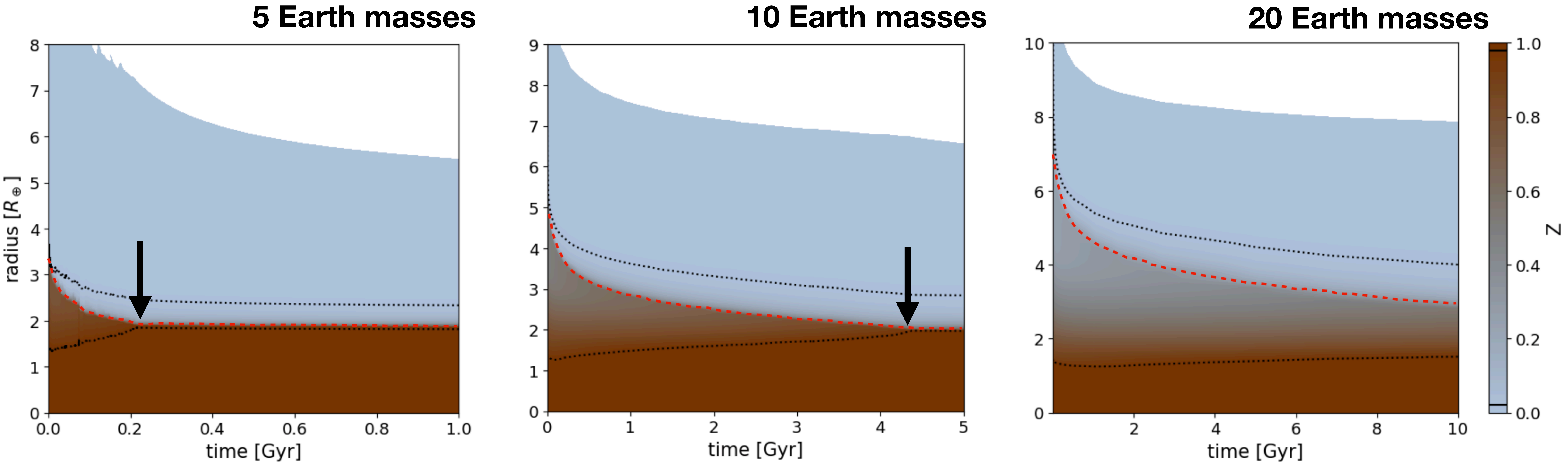
Vazan, Ormel, Brouwers 2024

Late growth of the rocky core in sub-Neptunes by silicate rainout is on ~ 1Gyr timescale

Interior evolution

Silicate rainout from cooling polluted envelopes





Vazan, Ormel, Brouwers 2024

Late growth of the rocky core in sub-Neptunes by silicate rainout is on ~ 1Gyr timescale

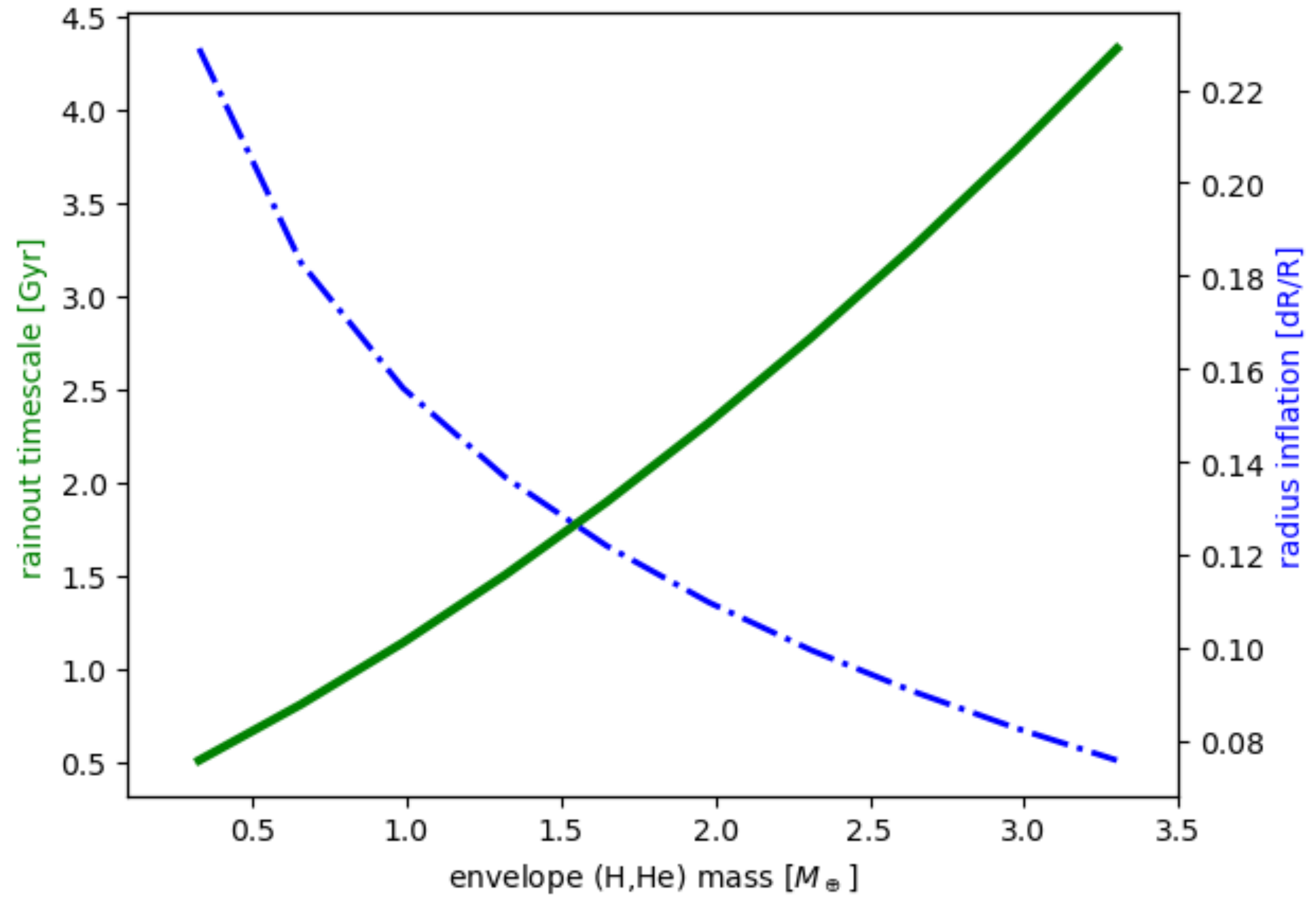
Rainout

mass = 7-12 Me, radius > 3.3Re

	Mass ($M_\oplus$)	Radius ($R_\oplus$)	Period (day)	Age (Gyr)	H,He standard	H,He w/ rainout
Kepler-36 c	7.13	3.6	16.2	6.9±0.372	7.8%	6%
Kepler-11 e	7.95	4.1	32	$8.5^{+1.1}_{-1.4}$	15%	11%
TOI-1136 d	7.95	4.53	12.5	0.7±0.1	13%	6.5%
TOI-1136 f	8.3	3.8	26.3	0.7±0.1	9%	4.5%
TOI-1422 b	8.9	3.88	13	$5.1^{+3.9}_{-3.1}$	10%	6%
KOI-142 b	9.54	3.37	10.9	$2.4^{+1.2}_{-0.77}$	7%	4%
K2-314 d	10.2	3.86	35.7	9±0.6	13%	10%
K2-19 c	10.8	4.76	11.9	8+	20%	14%
Kepler-79 b	10.9	3.4	13.5	$3.4^{+0.6}_{-0.91}$	6.6%	4.5%
Kepler-30 b	11.4	3.82	29.3	2±0.8	11%	6%

exoplanet.eu planets

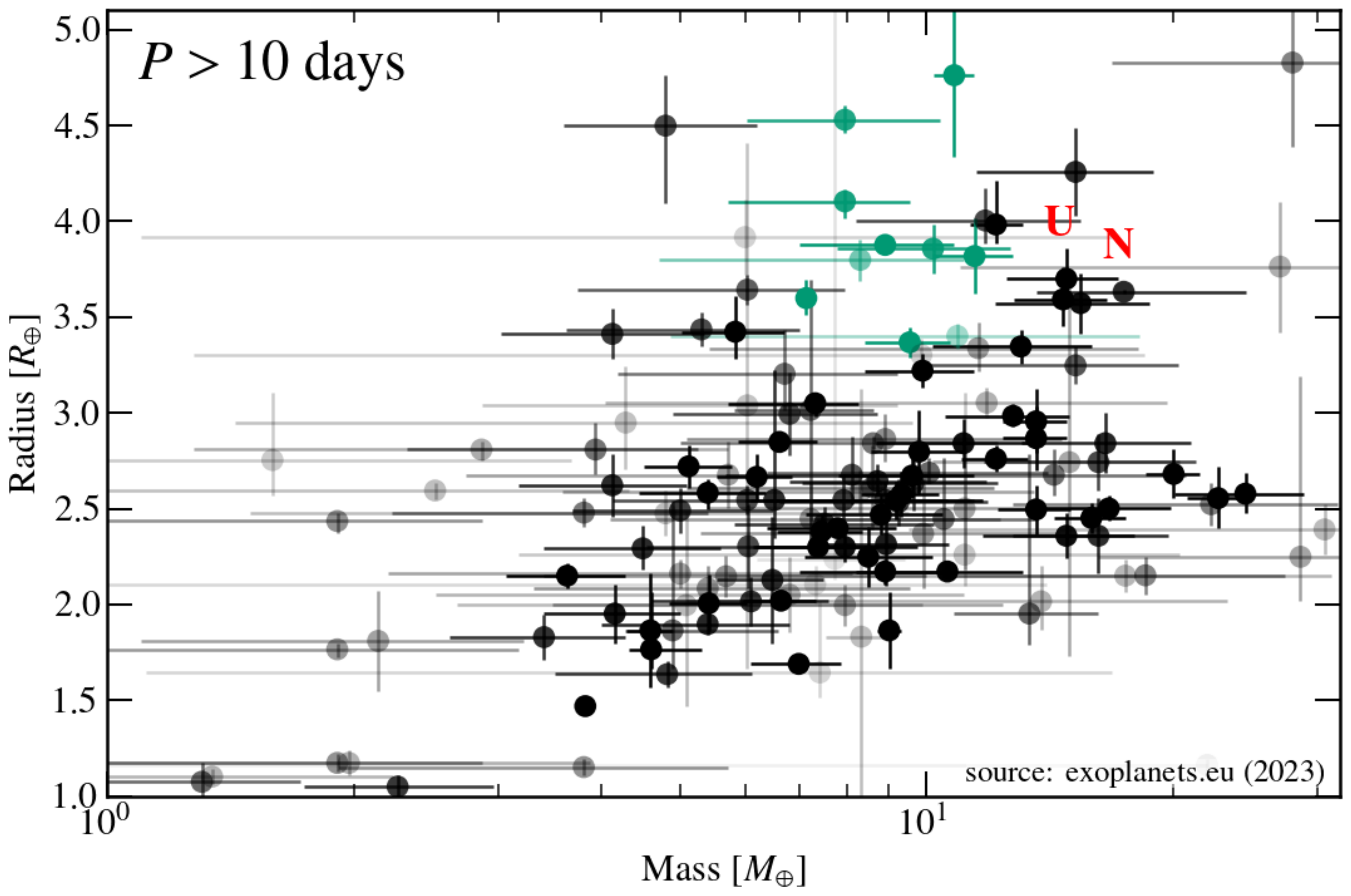
10Me rainout time vs. Menv



Future observations

Rainout affects observation interpretation

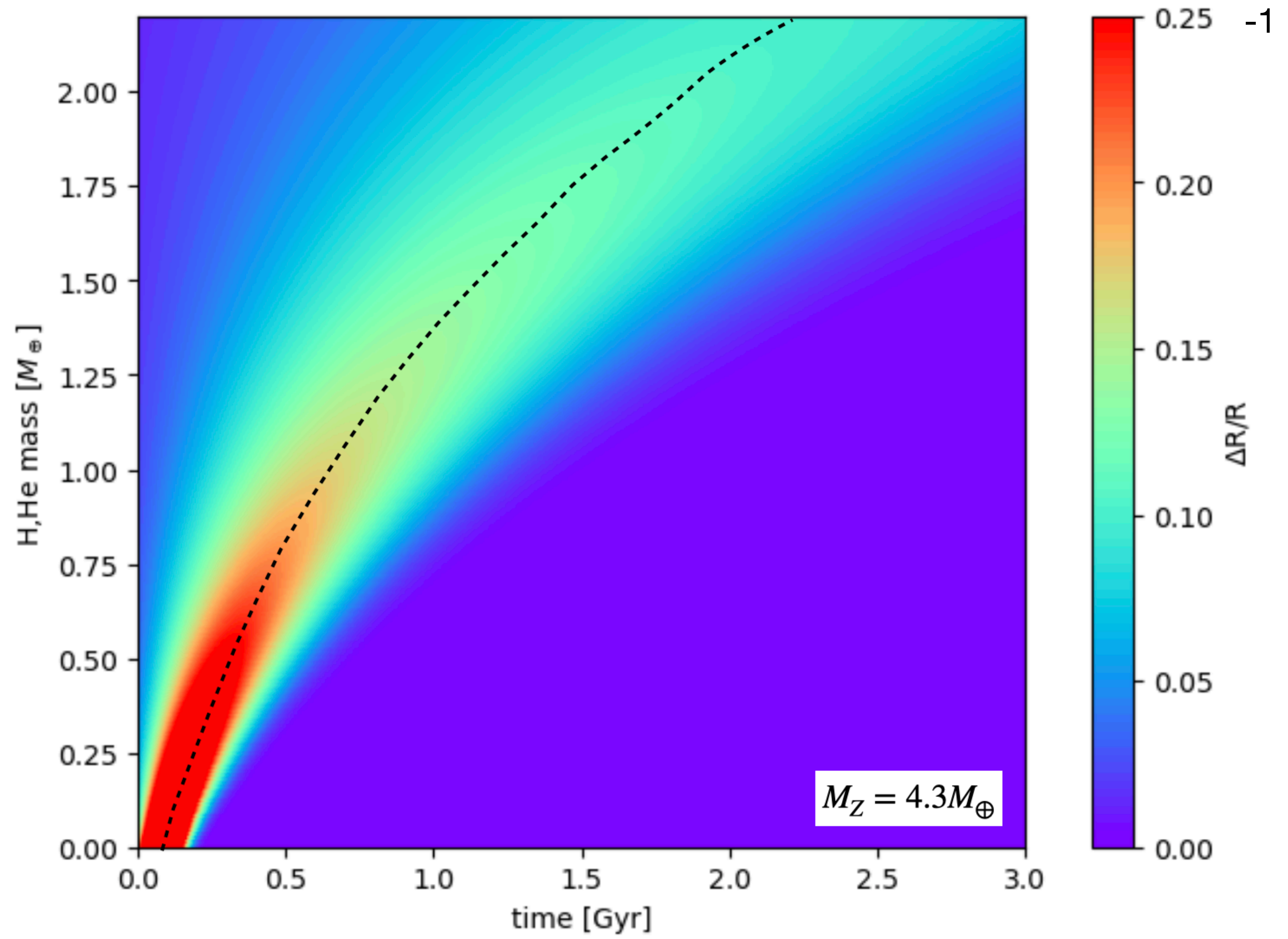
Mass-radius-age

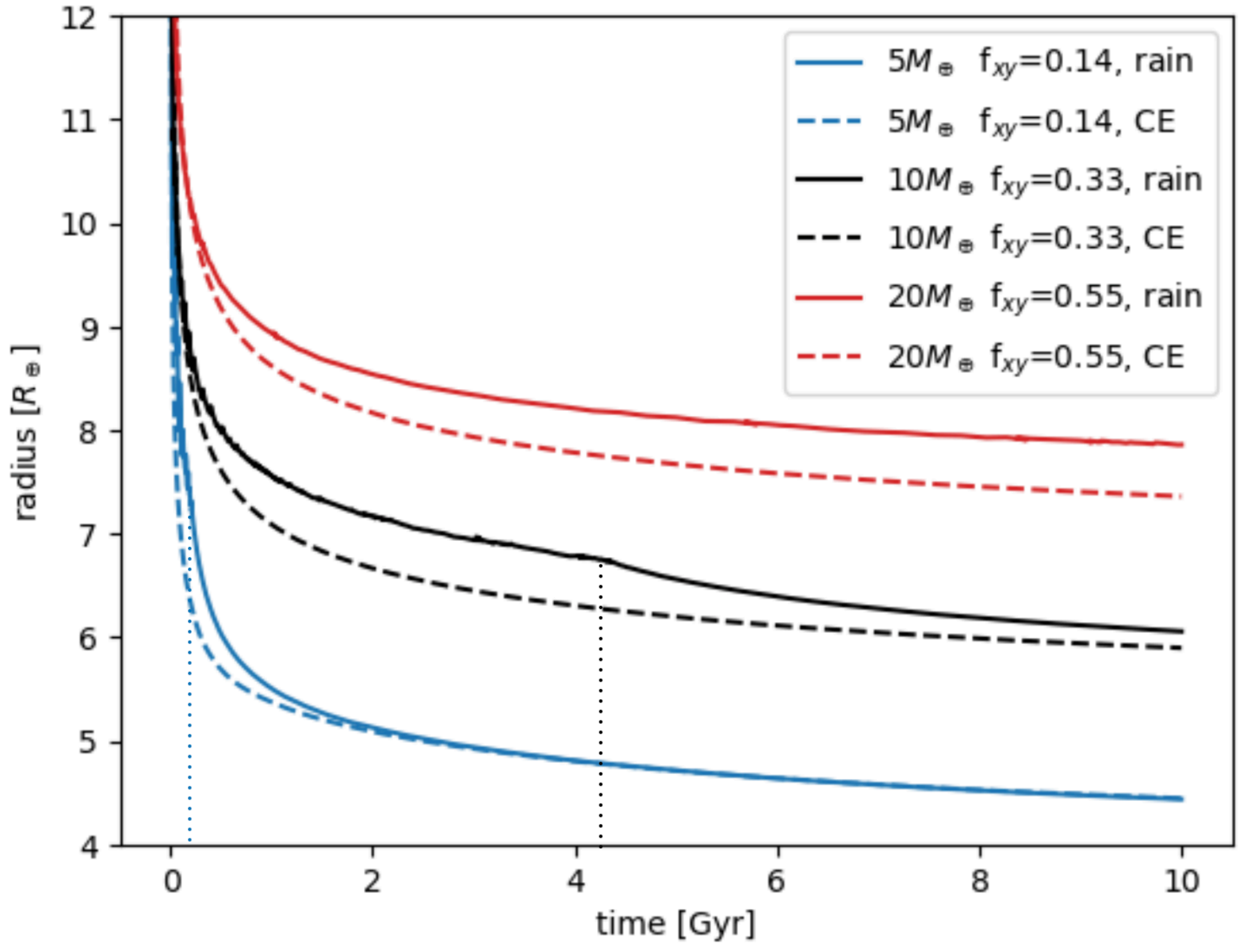


Vazan & Ormel 2023

H-He mass fraction is <u>overestimated</u> when using core-envelope models (during rainout)

Mass loss ~ R³





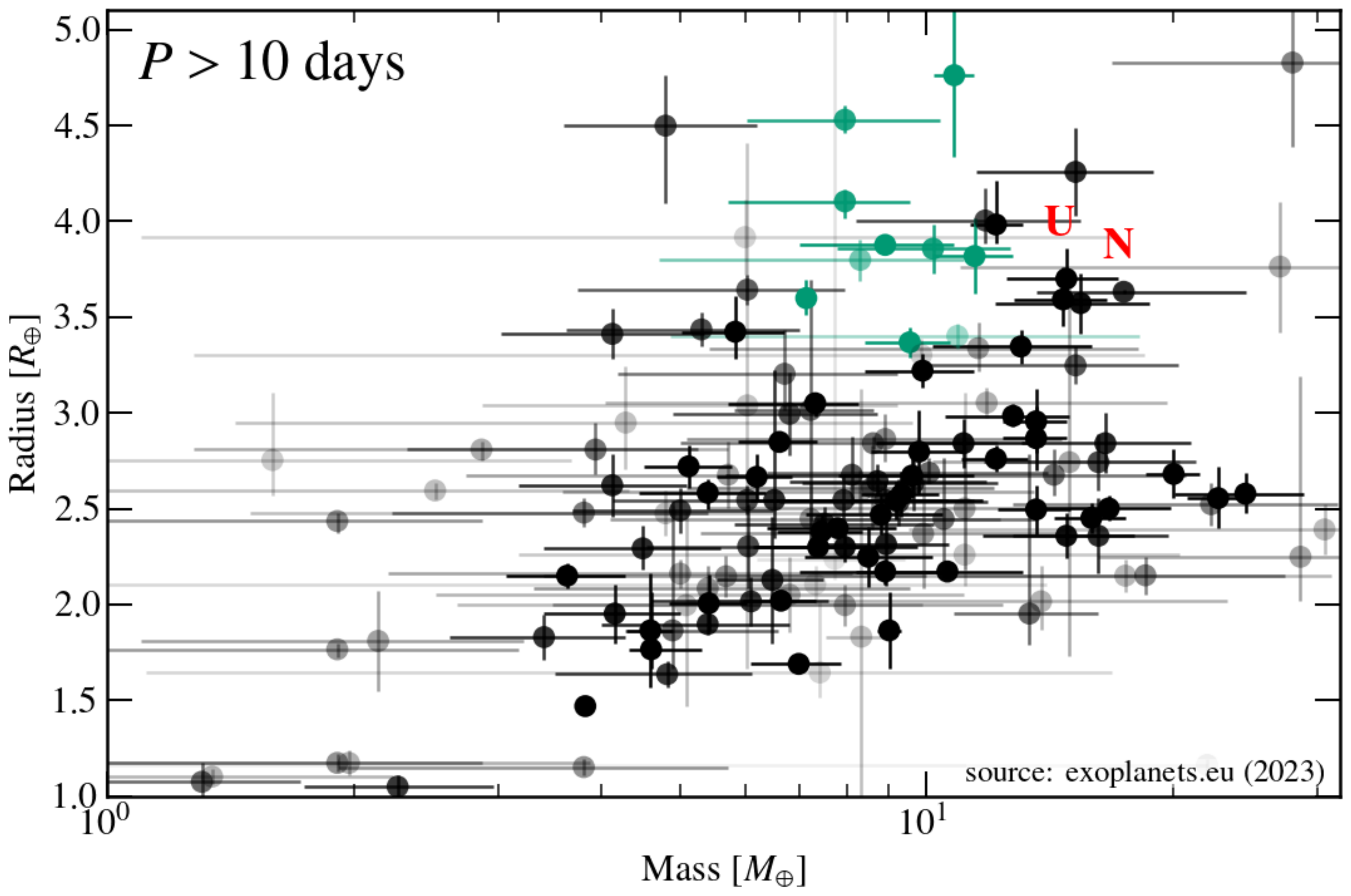
Vazan et al. 2024

Strong radius inflation at early stages => <u>enhanced mass loss</u> by photoevaporation

Future observations

Rainout affects observation interpretation

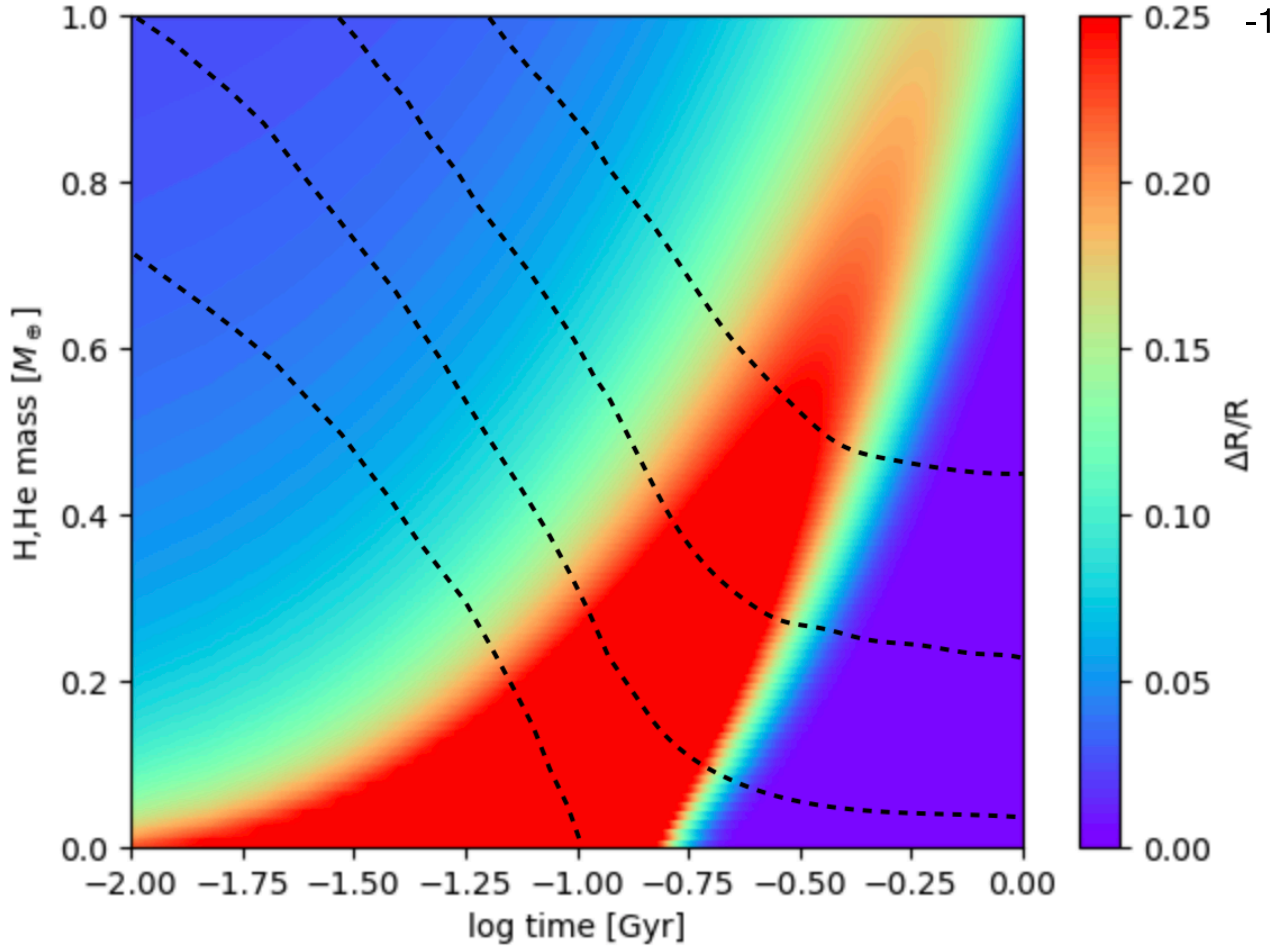
Mass-radius-age

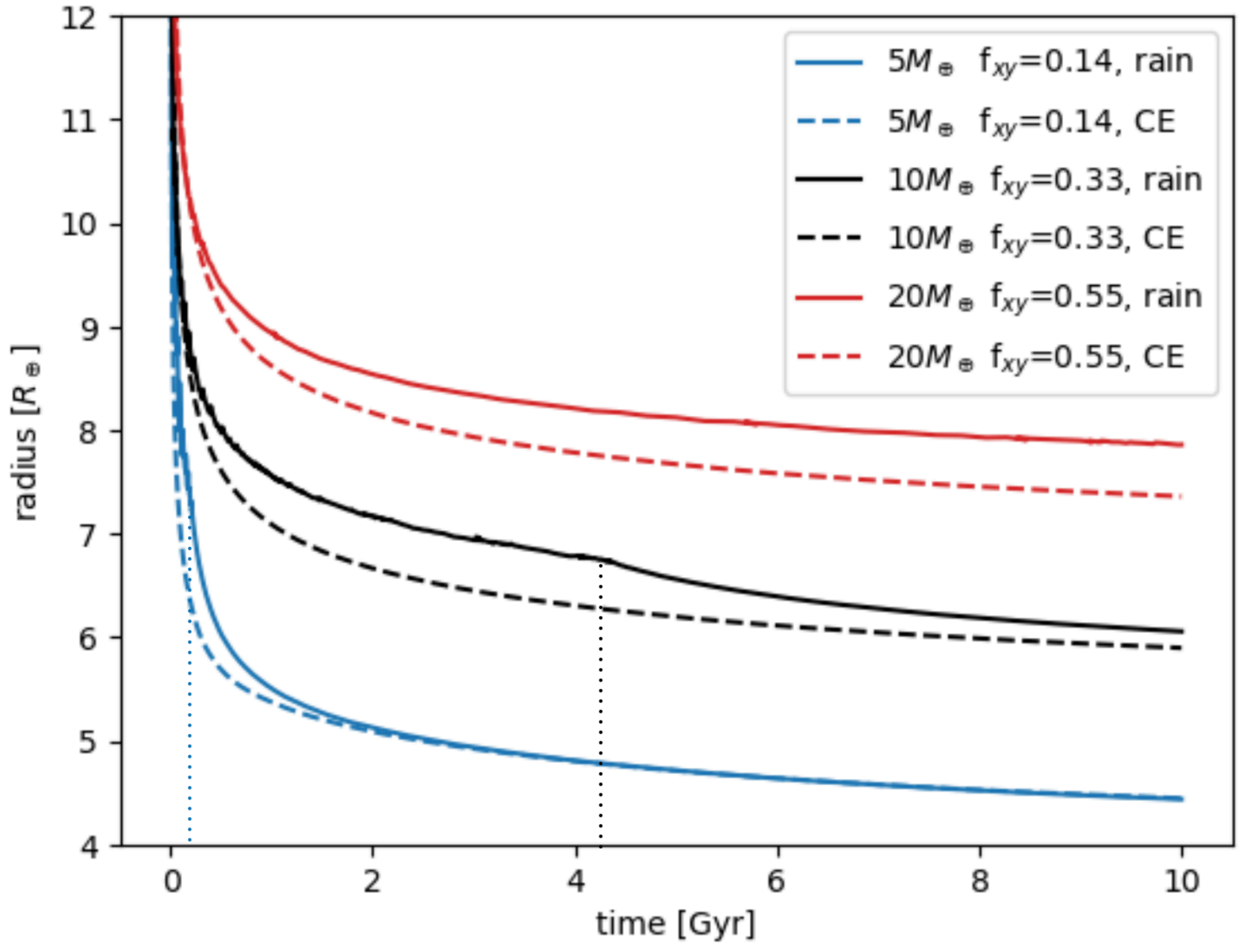


Vazan & Ormel 2023

H-He mass fraction is <u>overestimated</u> when using core-envelope models (during rainout)

Mass loss ~ R³





Vazan et al. 2024

Strong radius inflation at early stages => <u>enhanced mass loss</u> by photoevaporation