

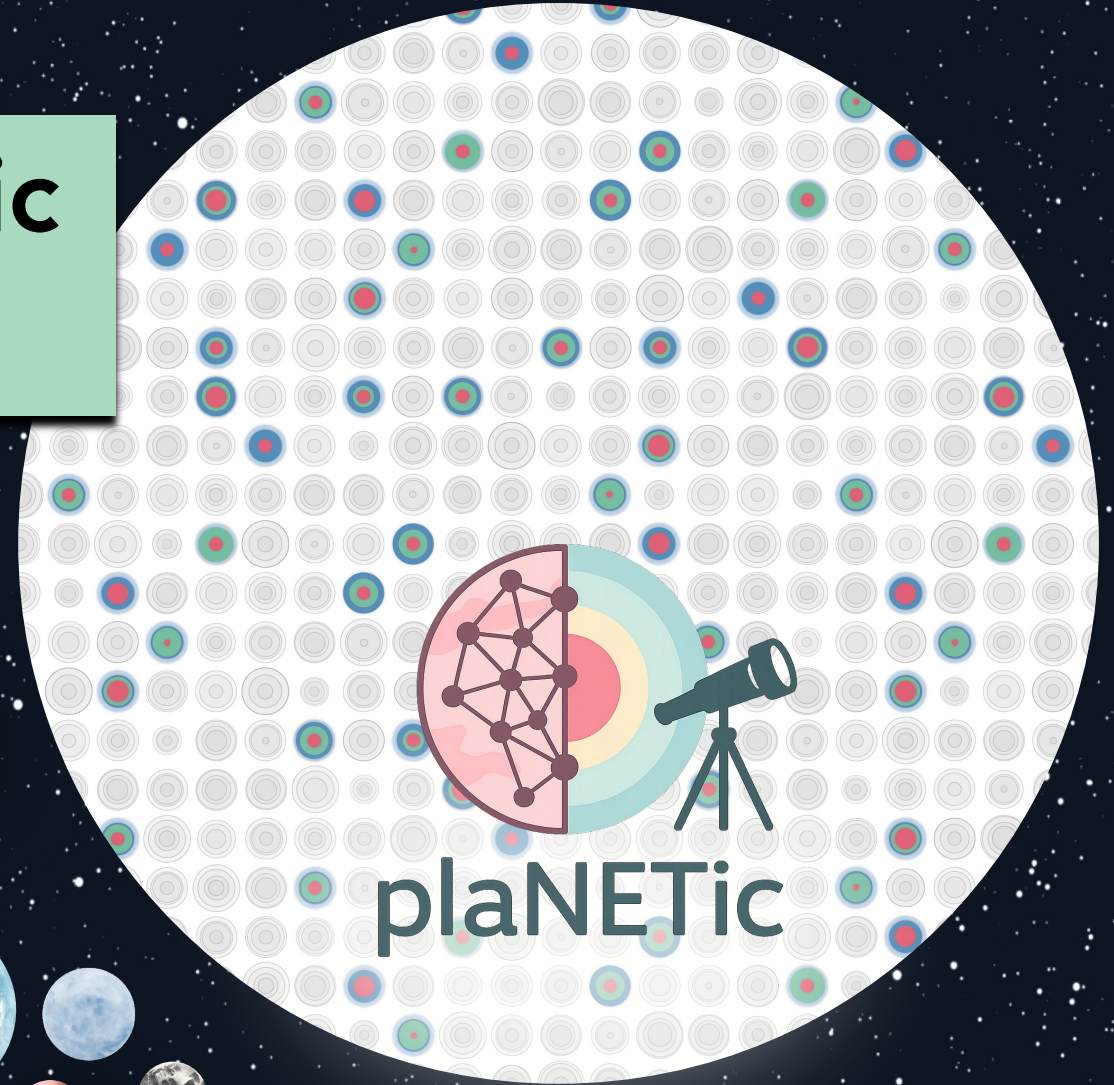
From BICEPS to plaNETic

Inferring the internal structure of observed super-Earths and sub-Neptunes

Jo Ann Egger

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Characterising the interiors of observed exoplanets



Observations:

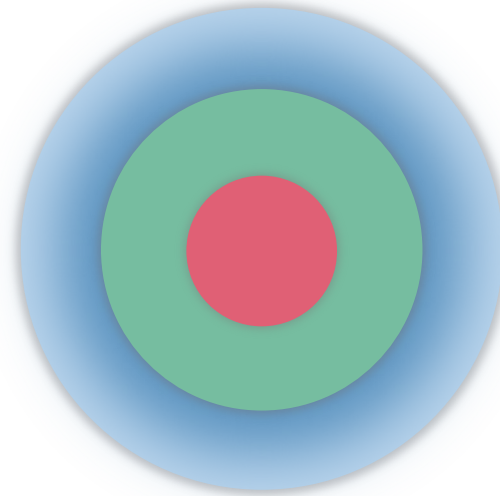
- Mass
- Radius
- Orbital period
- Host star properties

Characterising the interiors of observed exoplanets



Observations:

- Mass
- Radius
- Orbital period
- Host star properties



Composition and
internal structure

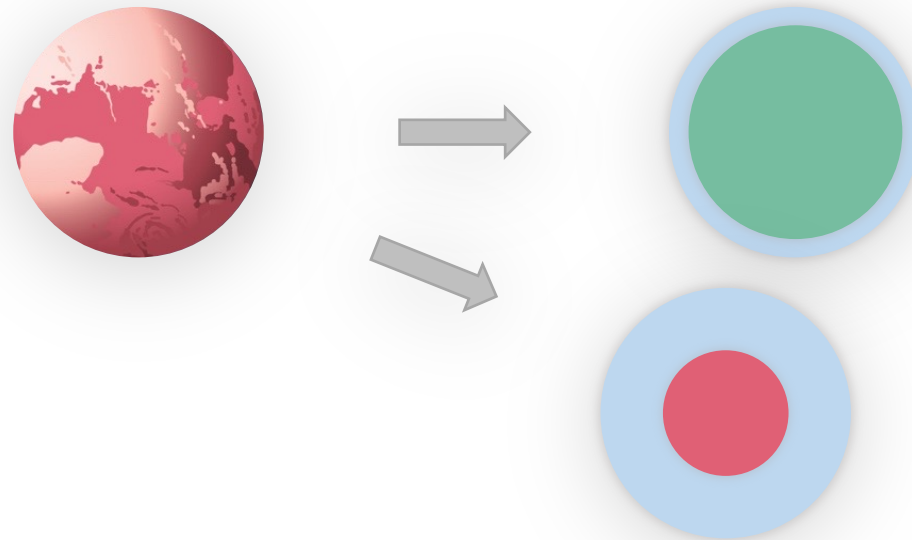
An inherent degeneracy in internal structure



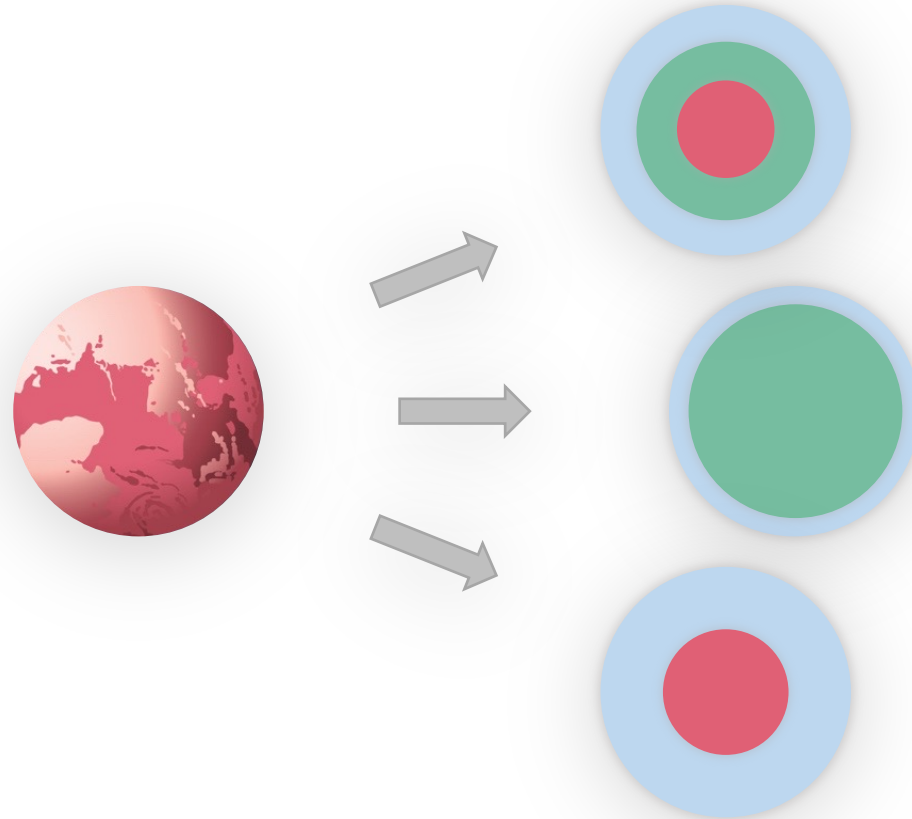
An inherent degeneracy in internal structure



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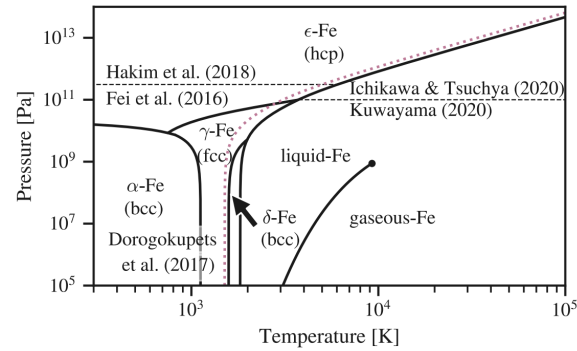
An inherent degeneracy in internal structure



The BICEPS planetary structure model (Haldemann et al. 2024)

Core layer

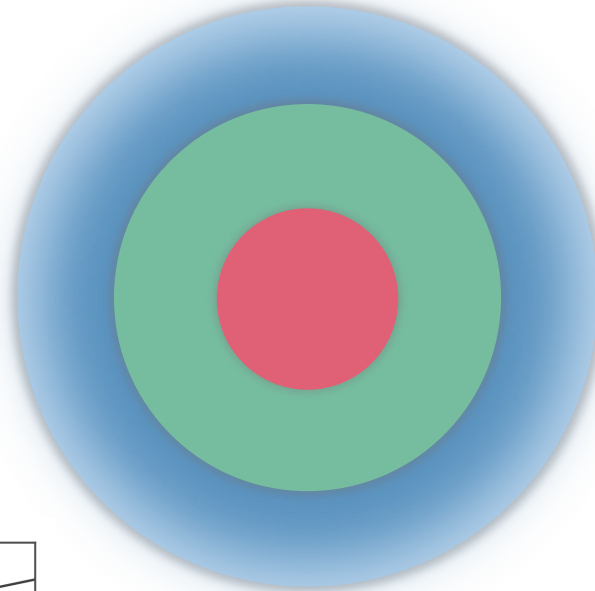
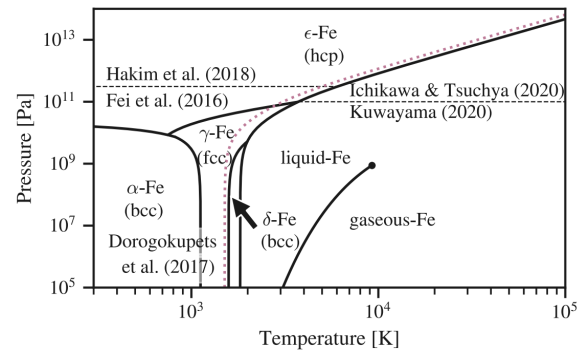
- Fe, diluted with up to 23.4% FeS
- Fully adiabatic



The BICEPS planetary structure model (Haldemann et al. 2024)

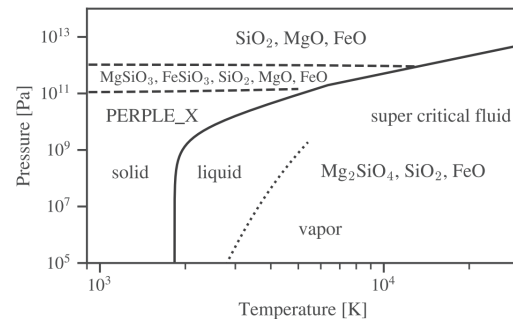
Core layer

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Mantle layer

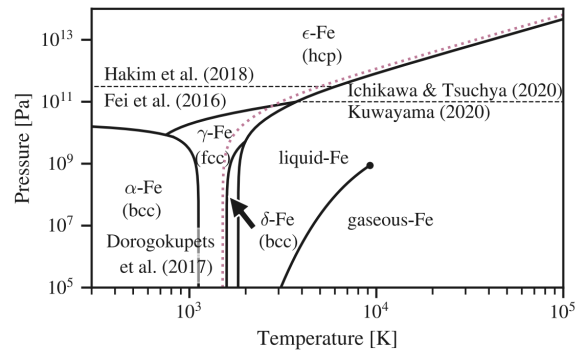
- Oxidised Si, Mg, Fe
- Fully adiabatic



The BICEPS planetary structure model (Haldemann et al. 2024)

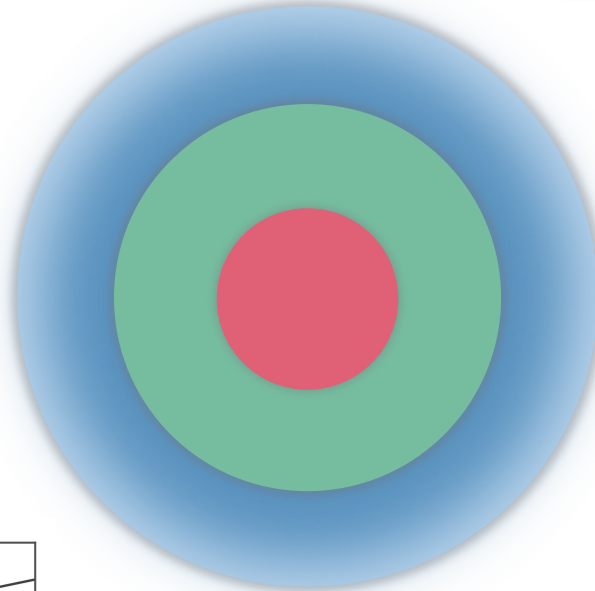
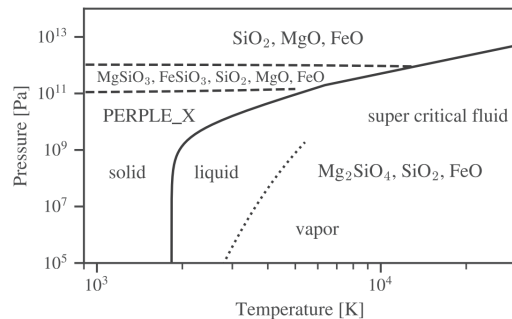
Core layer

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Mantle layer

- Oxidised Si, Mg, Fe
- Fully adiabatic



Volatile layer

- H, He, and H₂O, fully mixed
- SCvH EoS for H/He (Saumon et al. 1995), AQUA EoS for H₂O (Haldemann et al. 2020)
- Split into two sublayers (transition at 100 bar):

Irradiated outer atmosphere

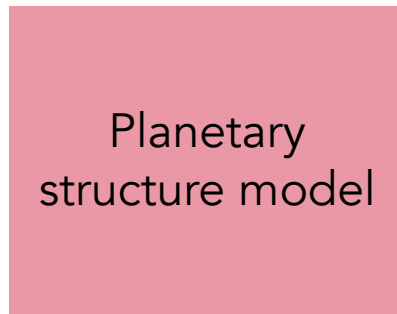
Temperature structure calculated using non-grey analytical model (Parmentier & Guillot 2014, Parmentier et al. 2015)

Non-irradiated envelope

Schwarzschild-Ledoux criterion used to determine if atmosphere is convective or radiative

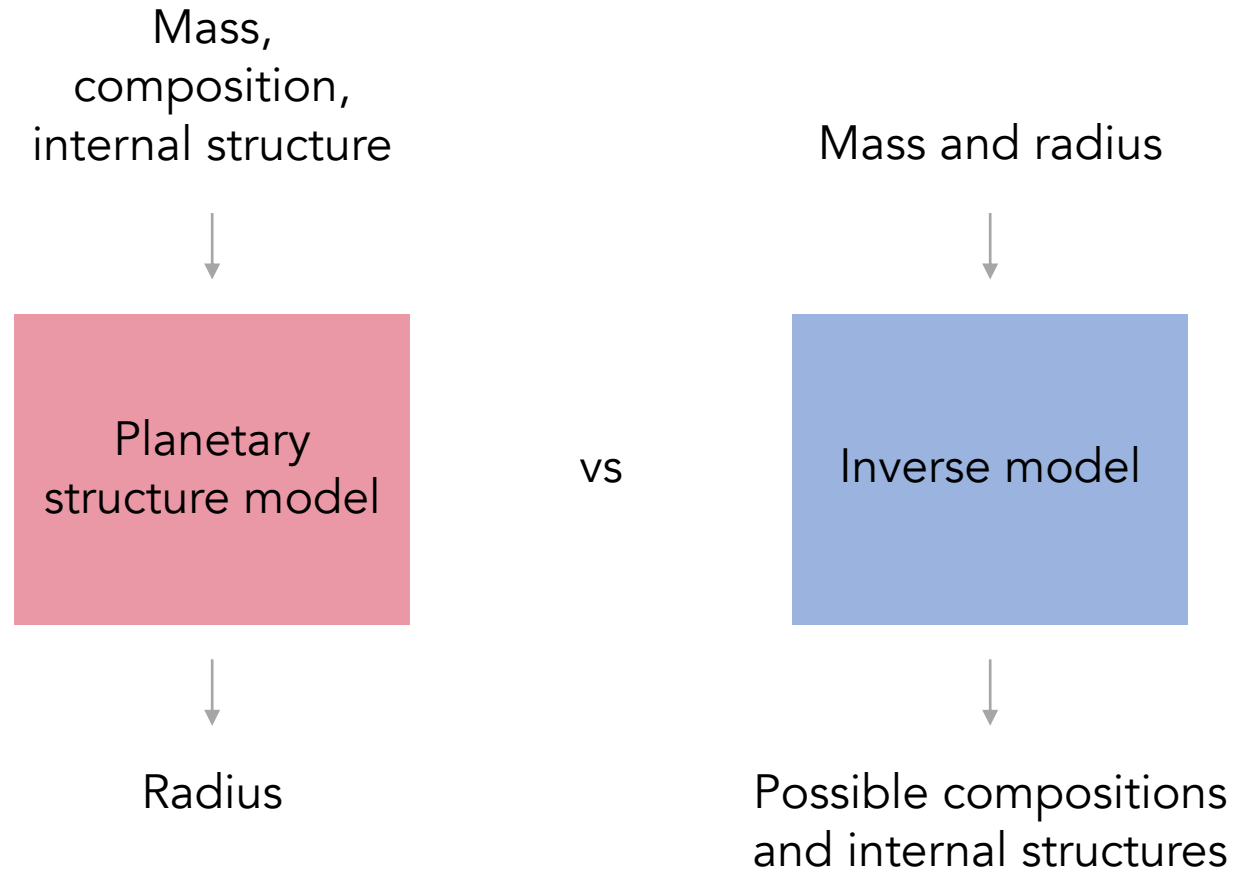
Characterising the interiors of observed exoplanets

Mass,
composition,
internal structure



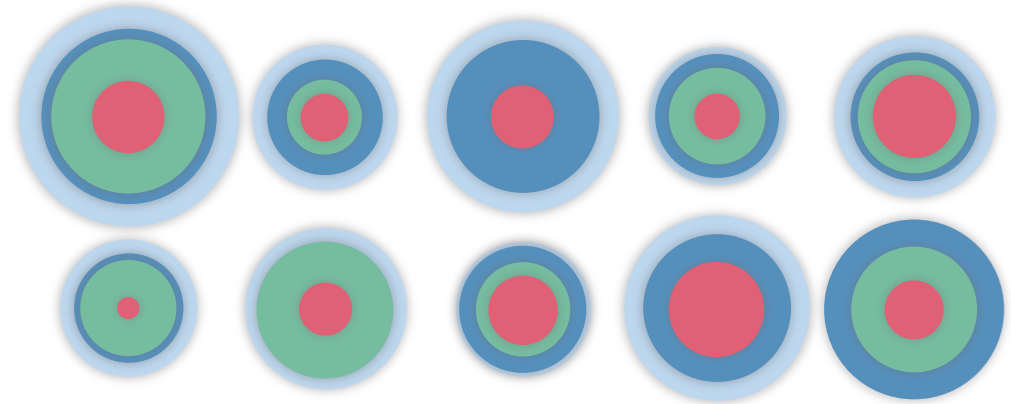
Radius

Characterising the interiors of observed exoplanets



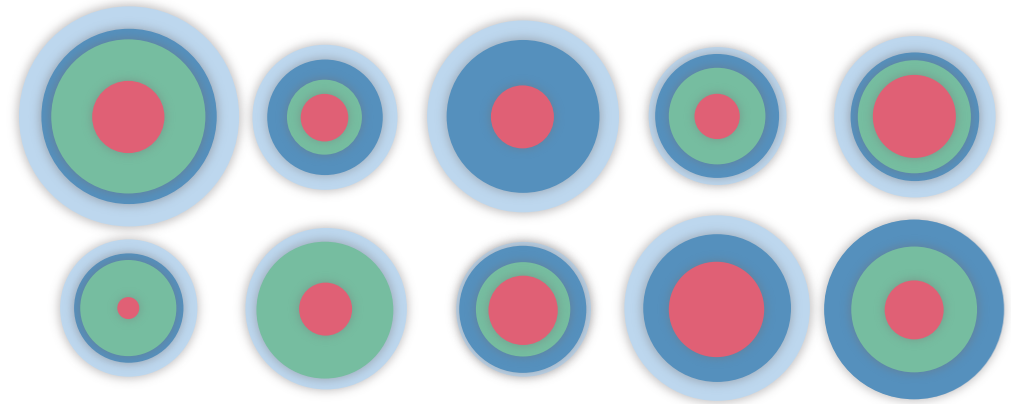
Characterising the interiors of observed exoplanets

1. Sample from all possible combinations of internal structure parameters



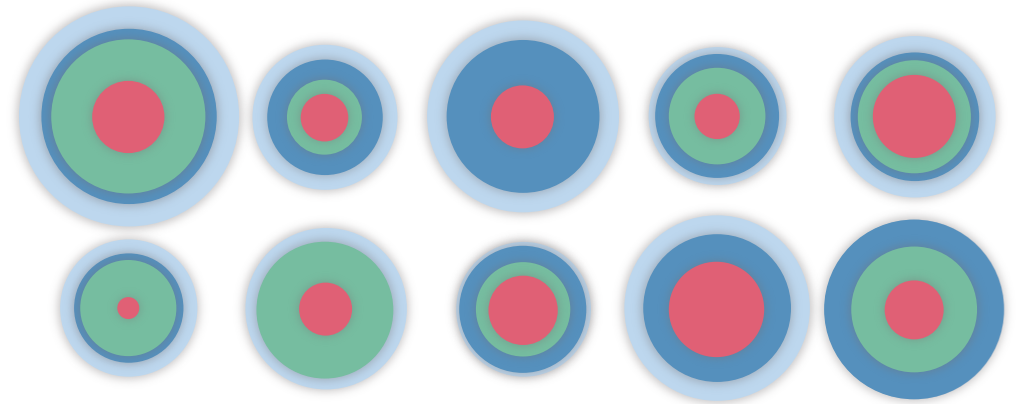
Characterising the interiors of observed exoplanets

1. Sample from all possible combinations of internal structure parameters
2. Use a **planetary structure model** to compute the radius of each structure



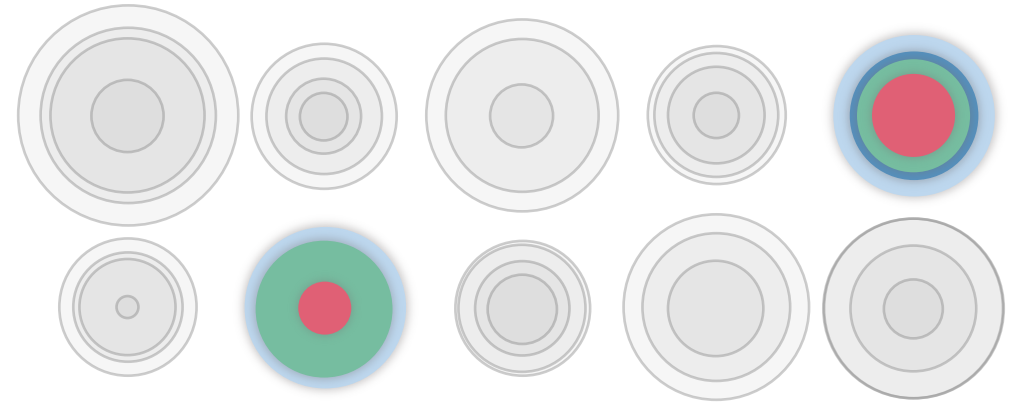
Characterising the interiors of observed exoplanets

1. Sample from all possible combinations of internal structure parameters
2. Use a **planetary structure model** to compute the radius of each structure
3. Select all structures that are compatible with the **observations**



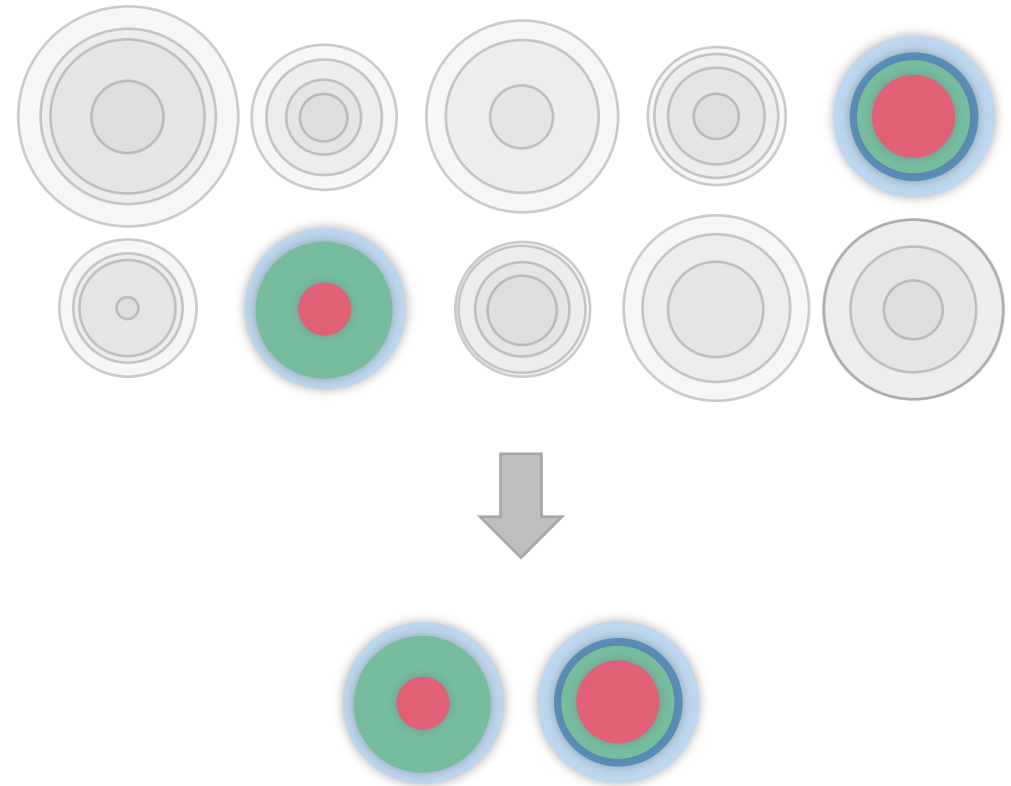
Characterising the interiors of observed exoplanets

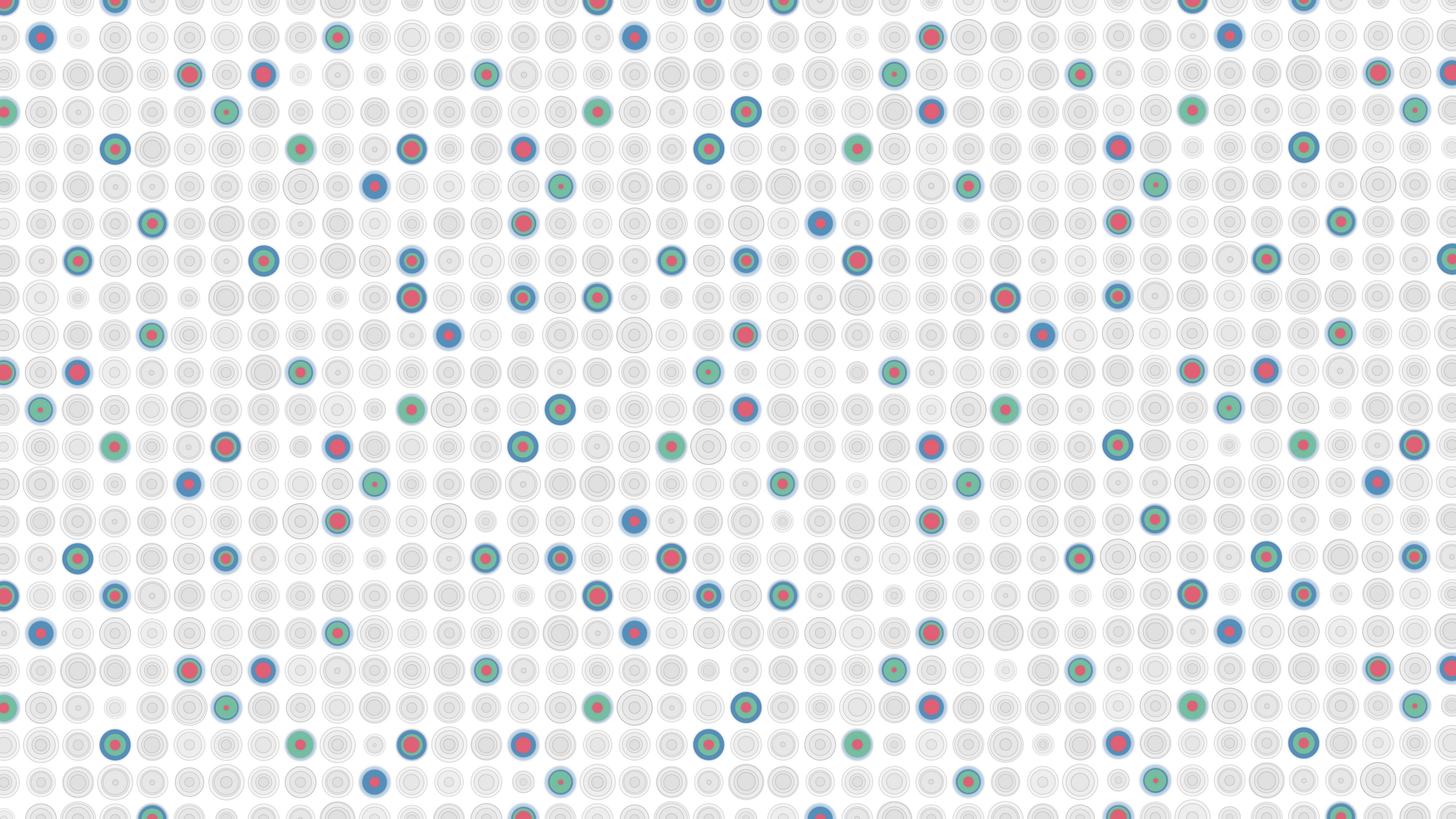
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Characterising the interiors of observed exoplanets

1. Sample from all possible combinations of internal structure parameters
2. Use a **planetary structure model** to compute the radius of each structure
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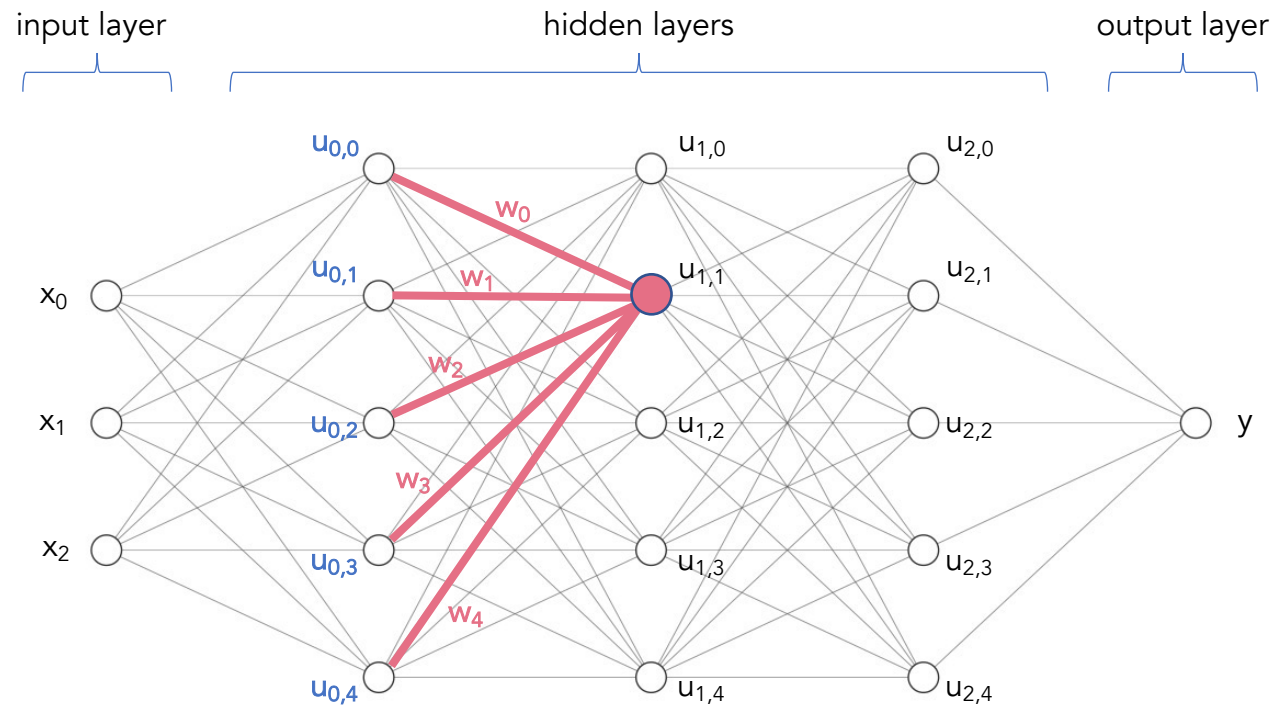
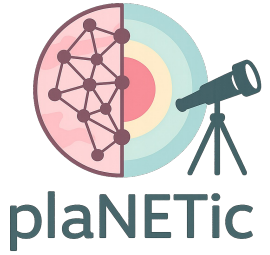


However...



Computation time of the
planetary structure model:
2-3 hours for 1000 structures

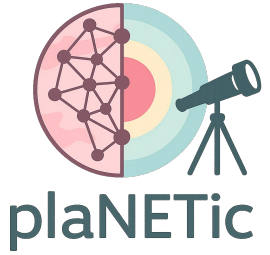
The plaNETic framework (Egger et al. 2024)



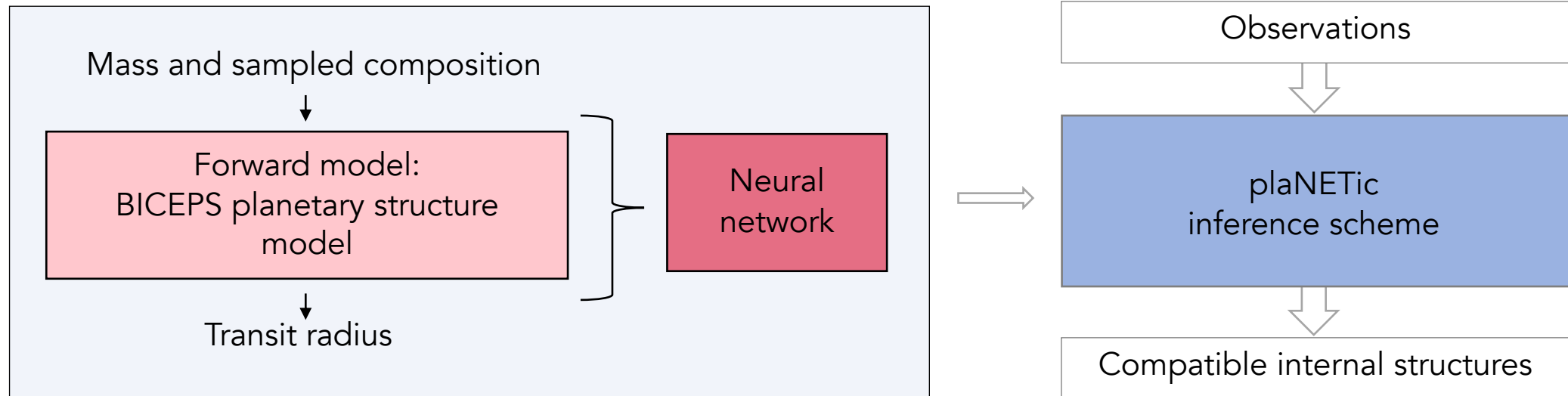
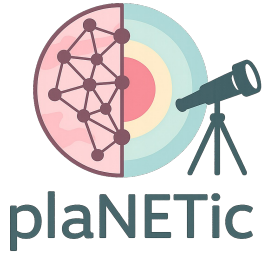
Train a **neural network** on data generated with the planetary structure model

⇒ fast surrogate model

The plaNETic framework (Egger et al. 2024)



The plaNETic framework (Egger et al. 2024)



Prior options

Water content of the planet

Option A



Water-rich

mass fractions of water, mantle and inner core:
uniform prior (simplex)

mass fraction of H/He:
log-uniform prior

Option B



Water-poor

mass fractions of mantle and inner core:
uniform prior

mass fraction of H/He:
log-uniform prior

mass fraction of water in the envelope:
normal prior ($0.50\% \pm 0.25\%$)

Prior options

Water content of the planet

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Water-poor

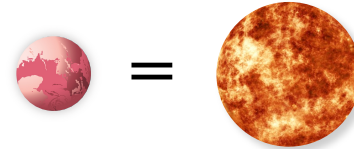
mass fractions of mantle and inner core:
uniform prior

mass fraction of H/He:
log-uniform prior

mass fraction of water in the envelope:
normal prior ($0.50\% \pm 0.25\%$)

Planetary Si/Mg/Fe ratios

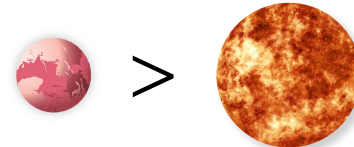
Option 1:



Stellar

(e.g. Thiabaud et al. 2015,
Pelletier et al. 2023)

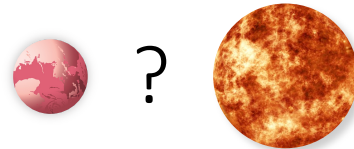
Option 2:



Fe-enriched

using the fit from Adibekyan+2021
(also e.g. Adibekyan+2024,
Plotnykov & Valencia 2020)

Option 3:

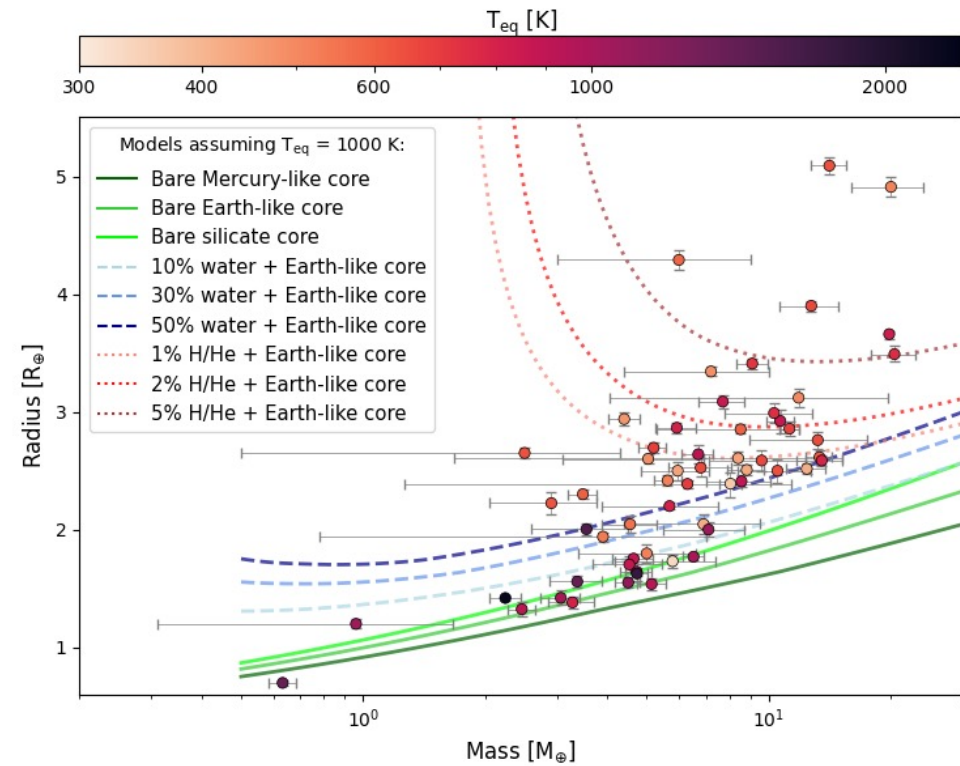


Independent from stellar values

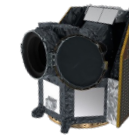
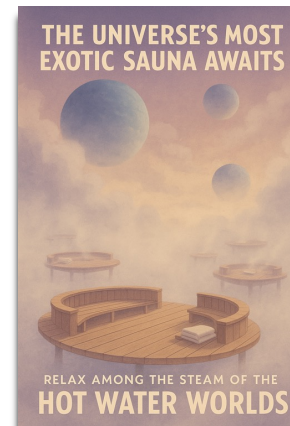
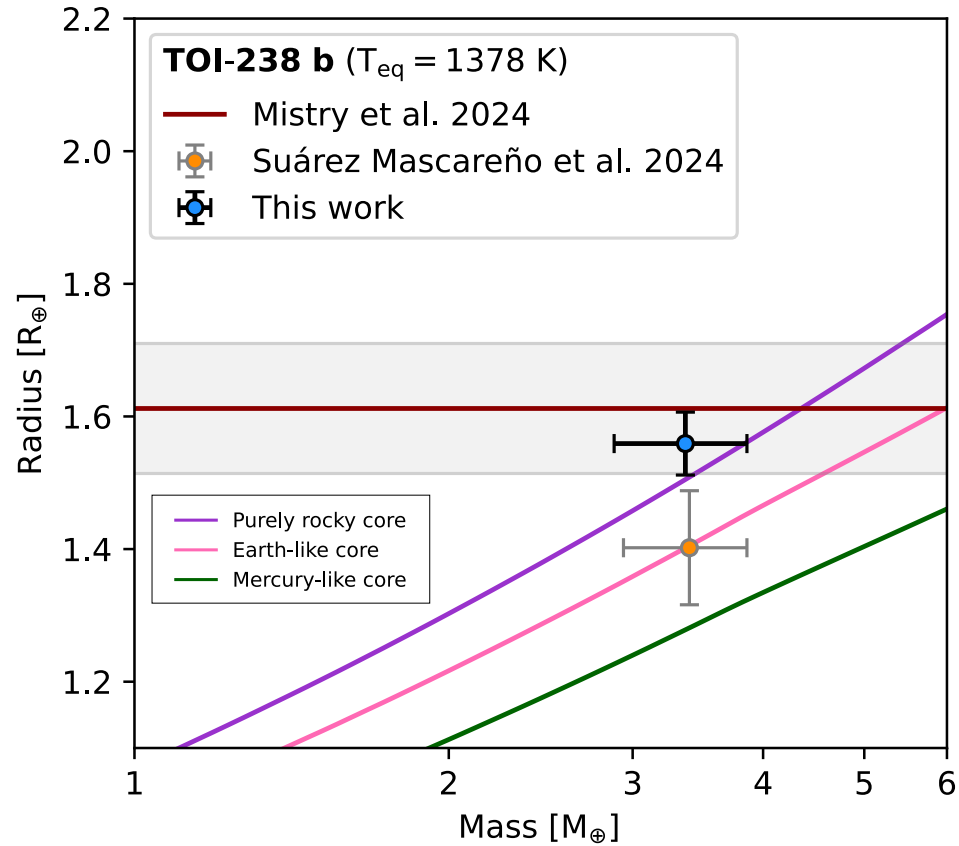
uniformly sampled

Application to observed exoplanets

The plaNETic framework has already been applied to ~100 observed exoplanets in more than 45 publications



The internal structure of TOI-238 b (Egger et al. 2025)

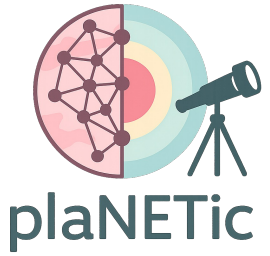


Axis 1 - Constraining the abundance of water in hot planets (HotWatermelon)

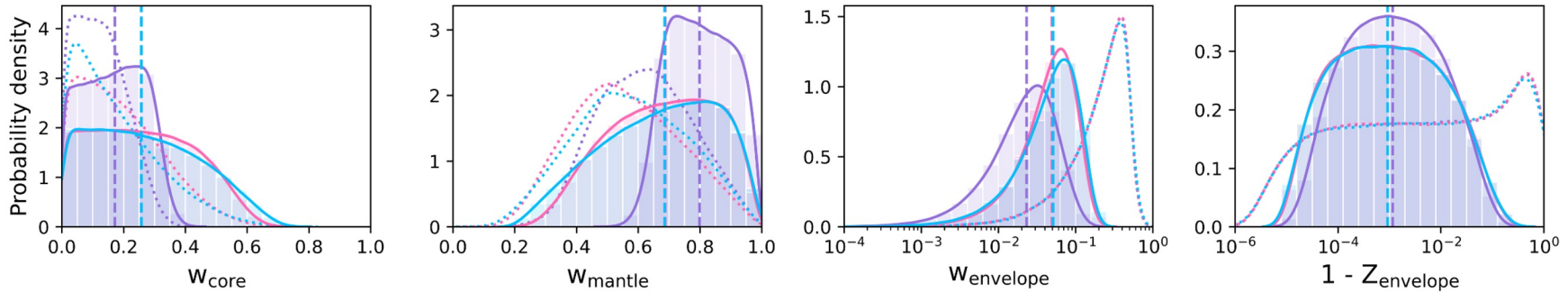
Willy BENZ
willy.benz@unibe.ch

Jo Ann Egger

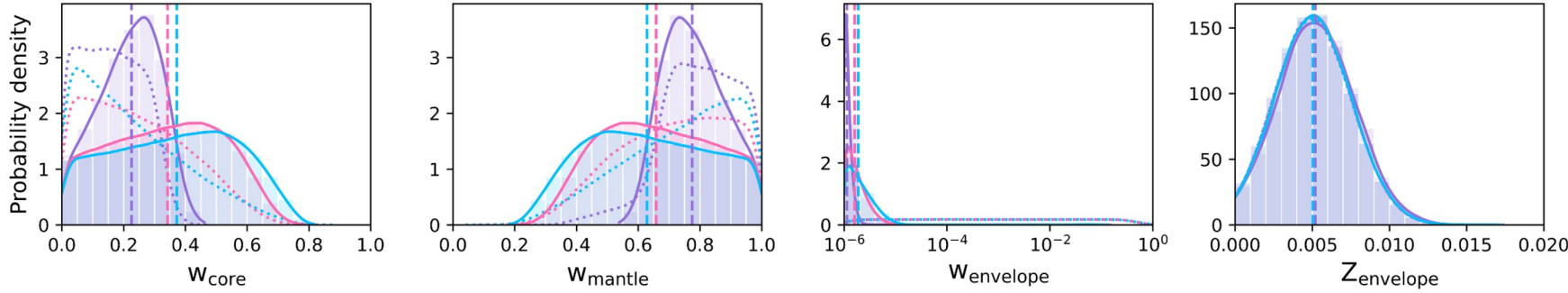
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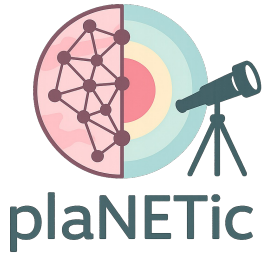
water-rich



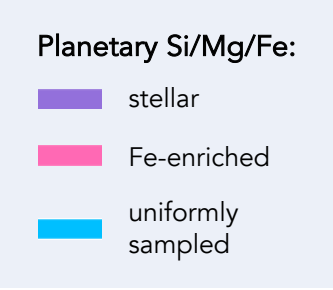
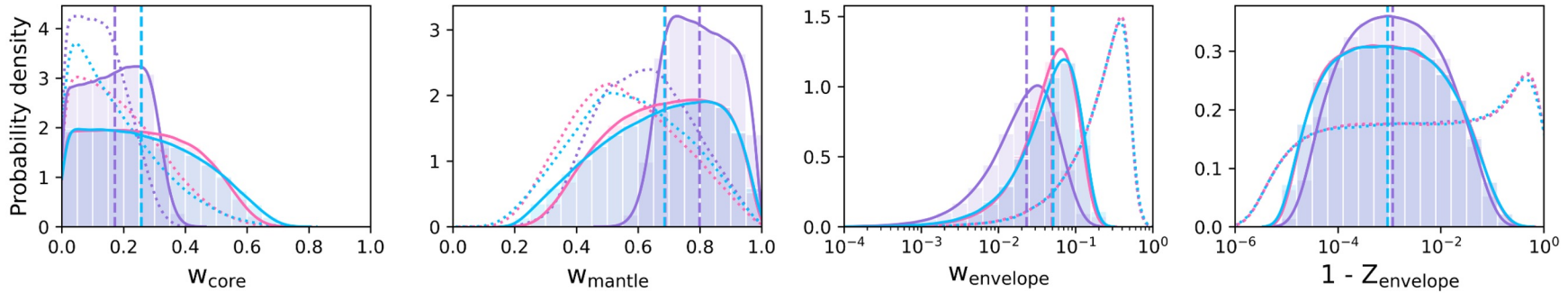
water-poor



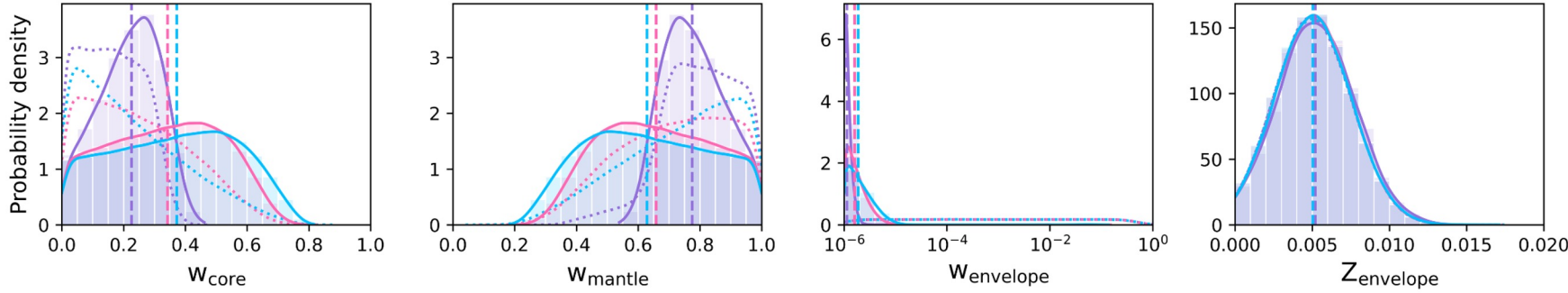
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water-rich



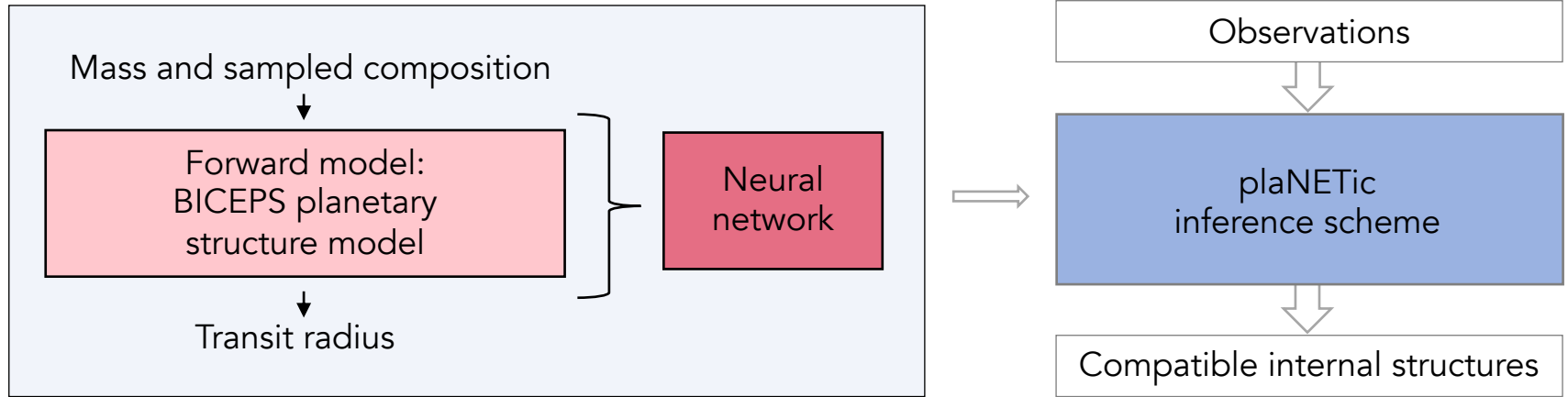
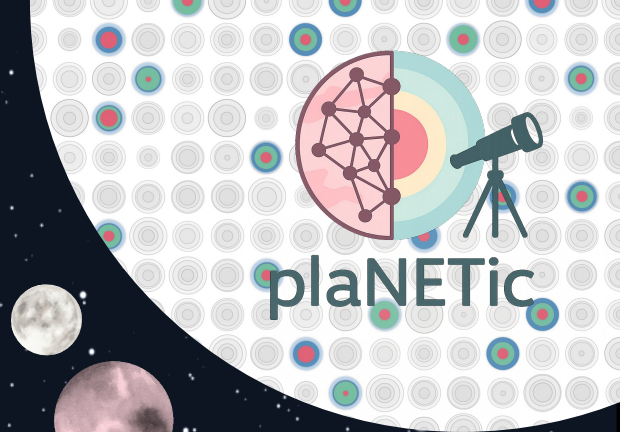
water-poor



A bare rocky core is not compatible with the planet's density!

The plaNETic framework

Inferring the interiors of super-Earths and sub-Neptunes using neural networks



The plaNETic
GitHub repository



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