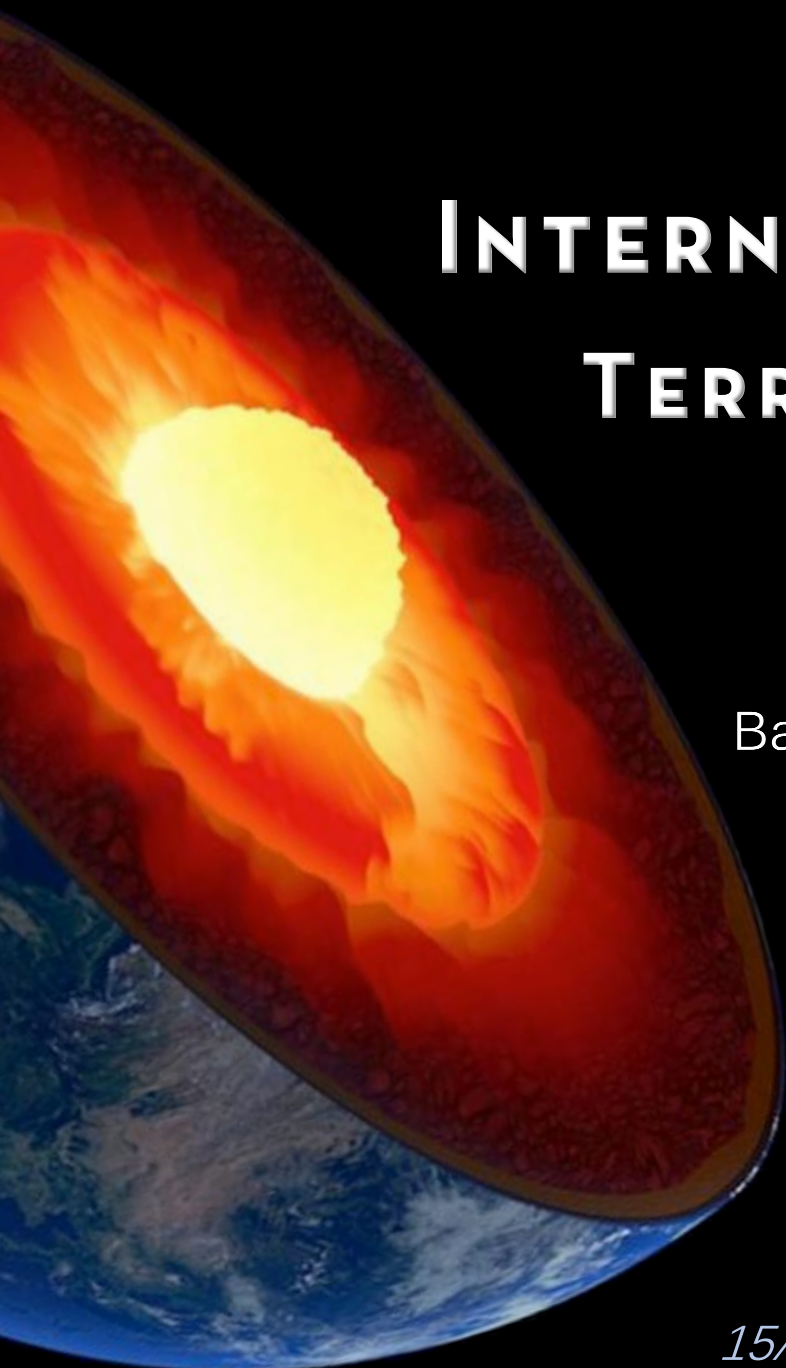


Internal Structure of Terrestrial Exoplanets

Bastien Brugger

Olivier Mousis

Magali Deleuil

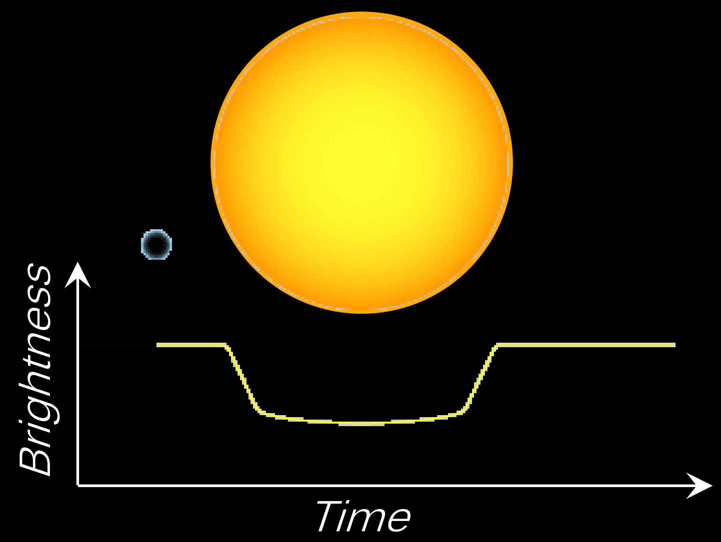
OHP
15/10/2018

Aix*Marseille université

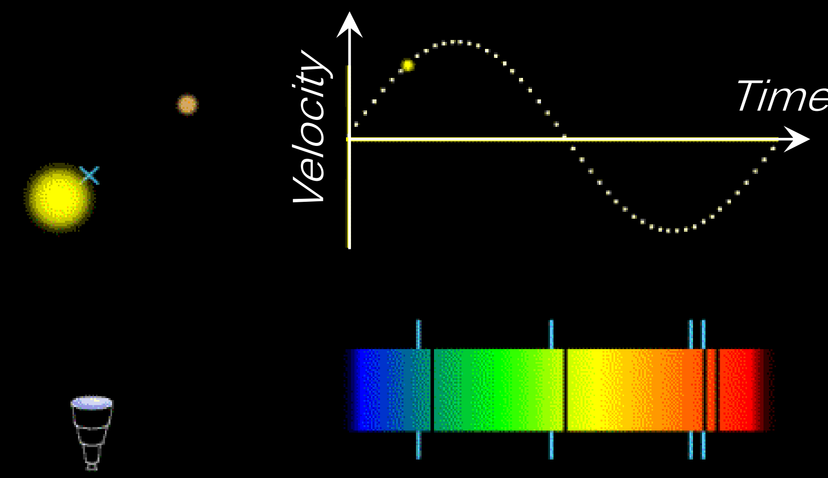
LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

Exoplanets Detection

Transit



Radial velocity



- More than 3700 **validated exoplanets**
- Mass and radius **known for ~17%**

Exoplanets draw a **continuous spectrum** in mass and radius, unlike in our solar system

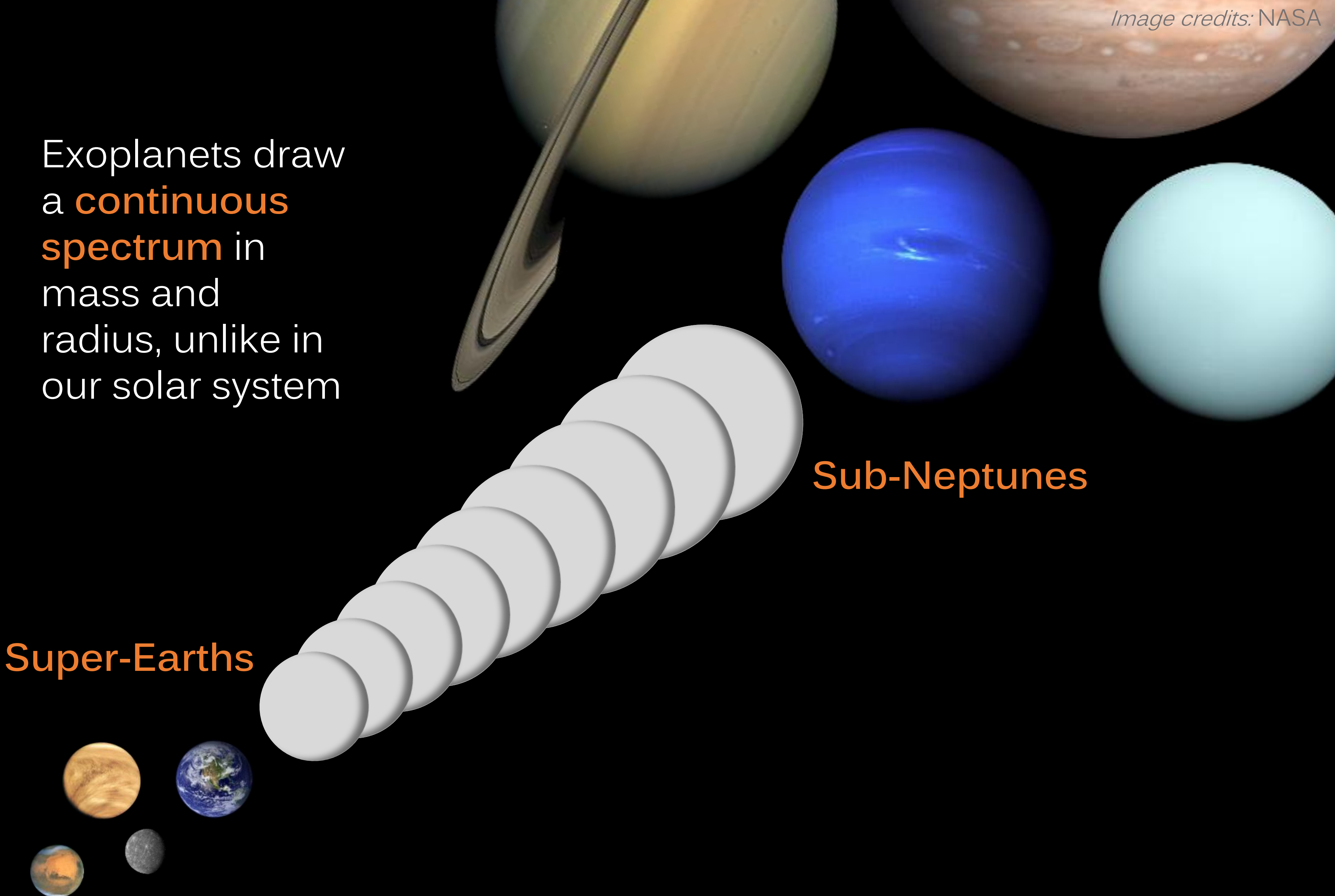


Image credits: NASA

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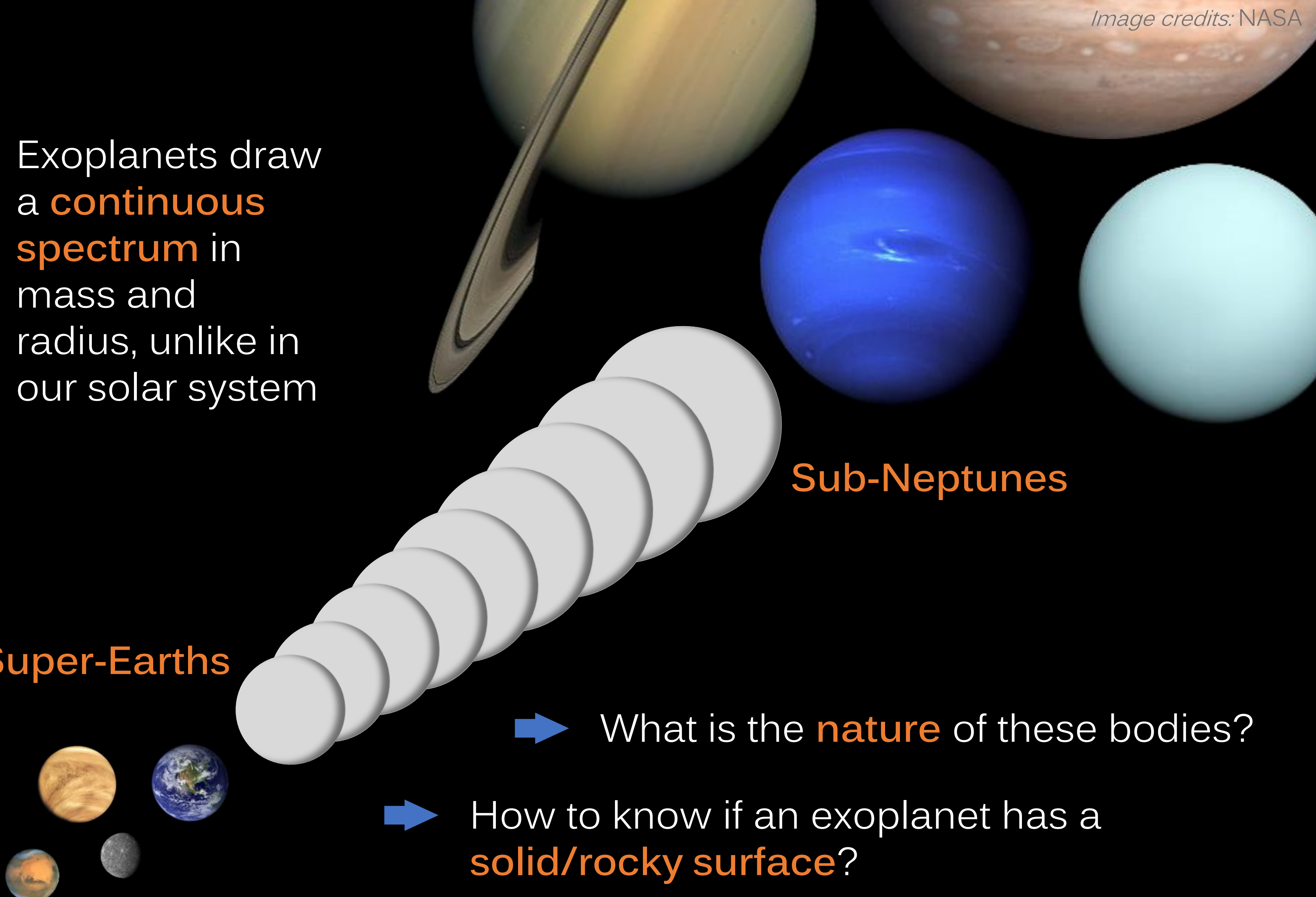
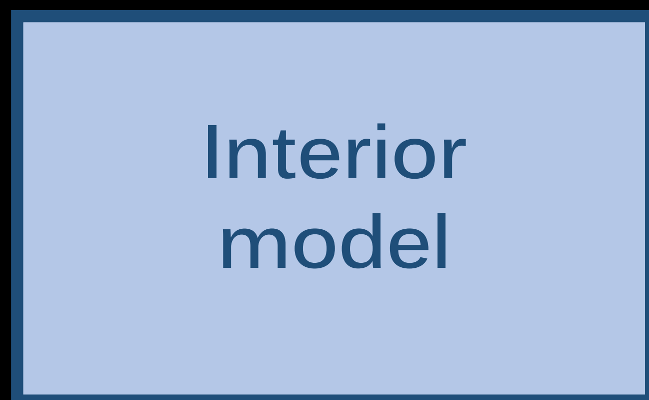


- What is the **nature** of these bodies?
- How to know if an exoplanet has a **solid/rocky surface**?
- Which planets are more suited for **habitability studies**?

Model that reproduces the **behavior** of planet-forming materials under conditions relevant to **planetary interiors**:



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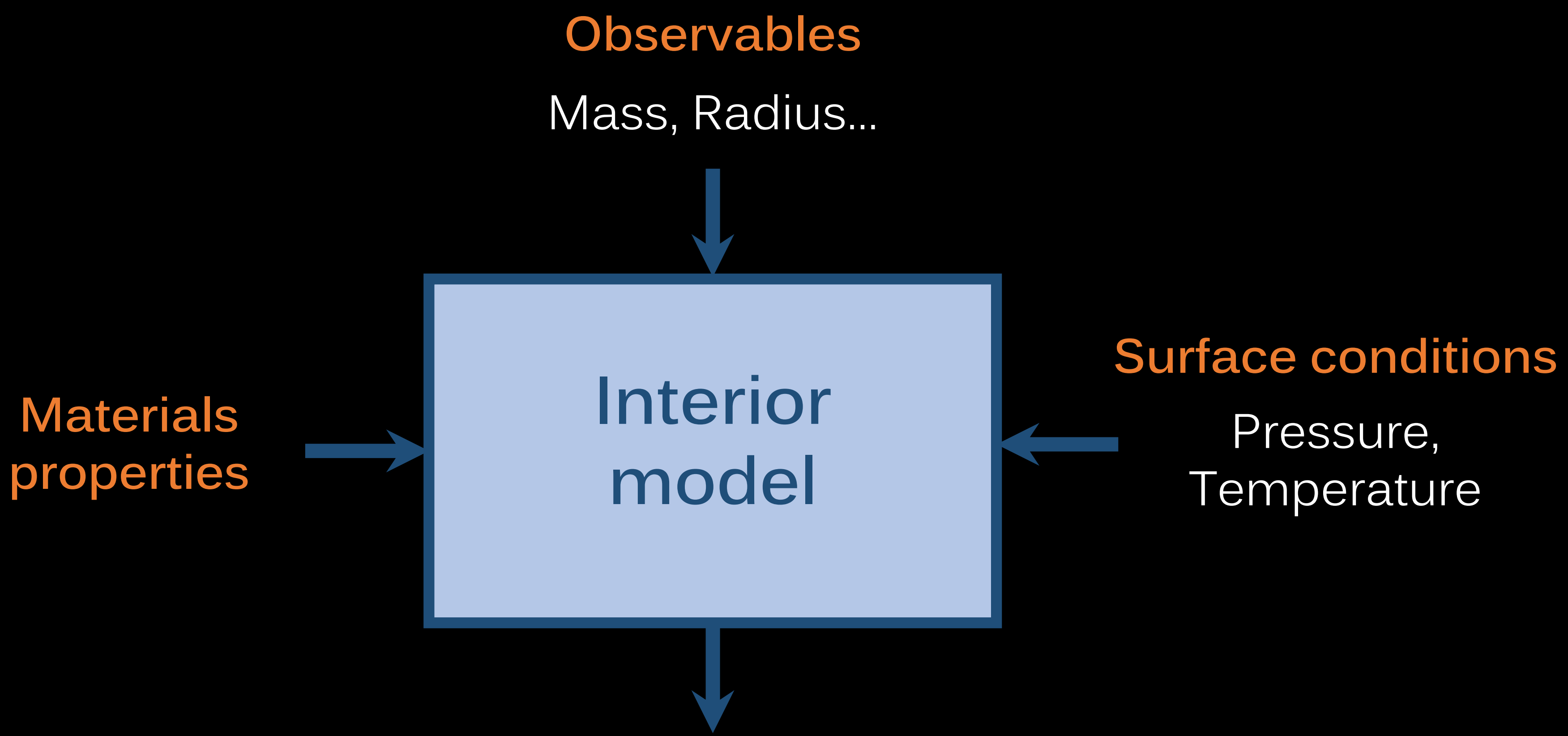


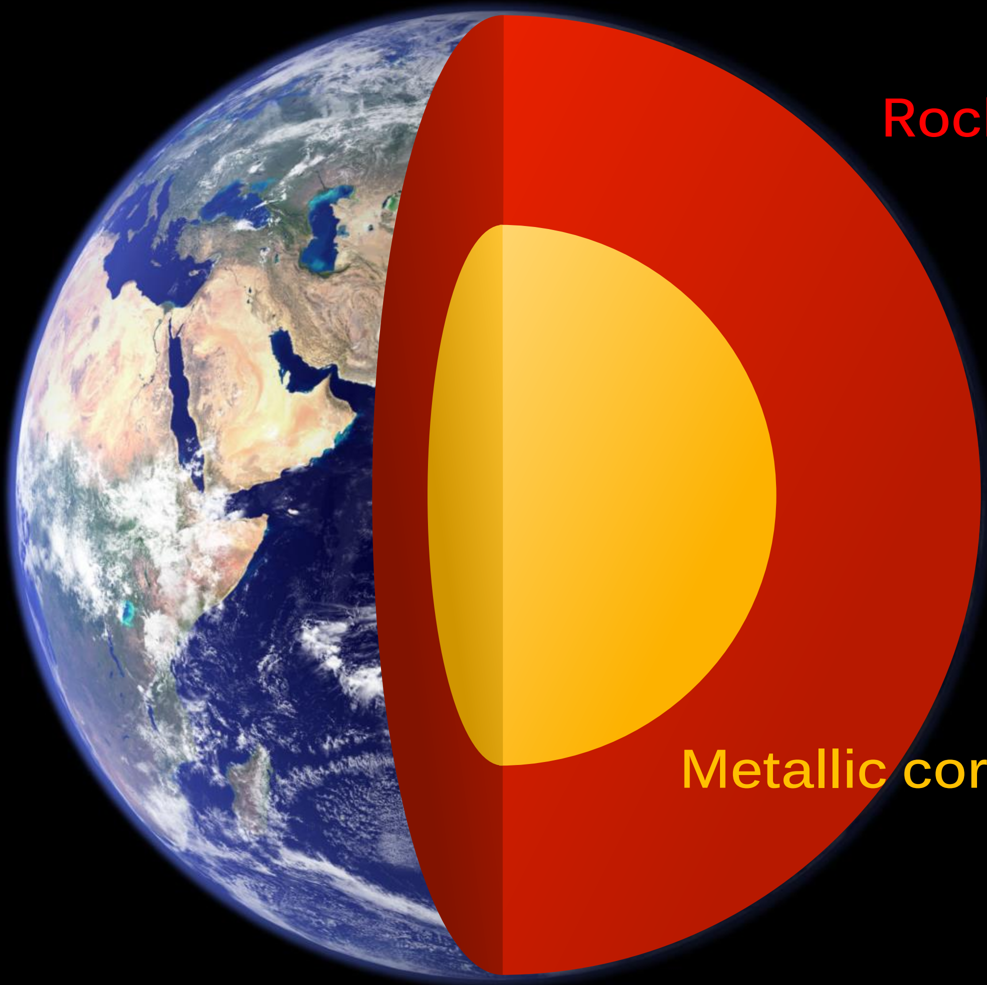
Internal structure & **bulk composition** of the planet

Gravity, pressure, temperature, density

Image credits: NASA

Interior of Earth

Interior of Earth



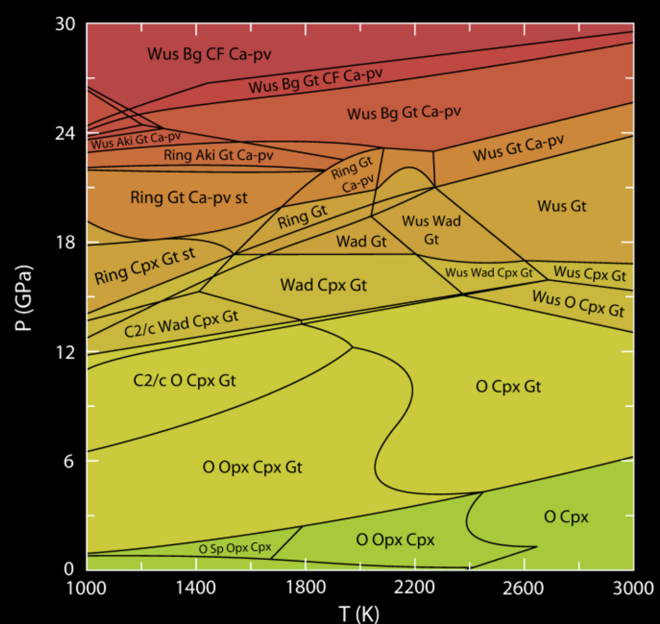
Interior model

Brugger et al. 2016, 2017

- Interior of **terrestrial planets**:
  - Metallic core *(liquid Fe-S-Si)*
  - Silicate mantle *(mineralogy from PerpleX)*

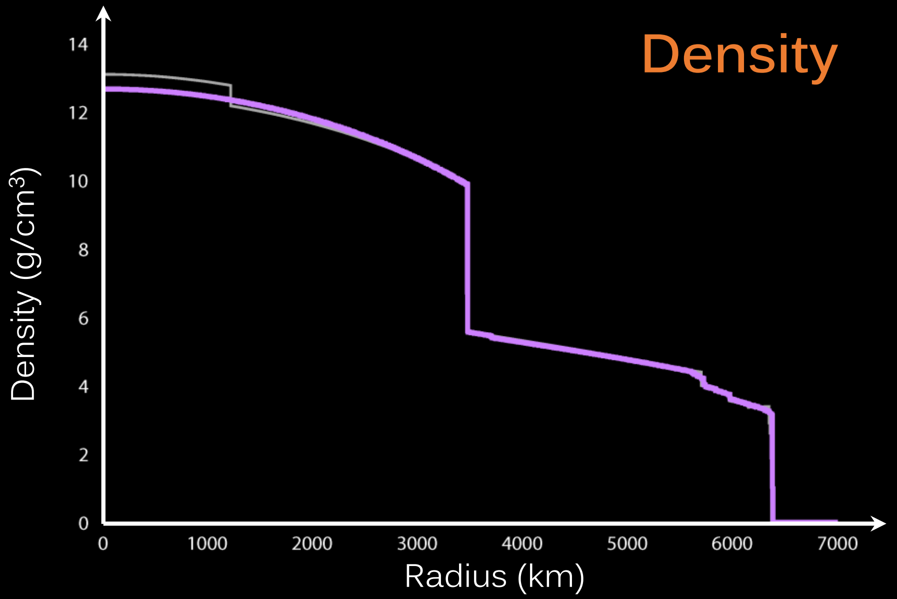
Mantle phase diagram

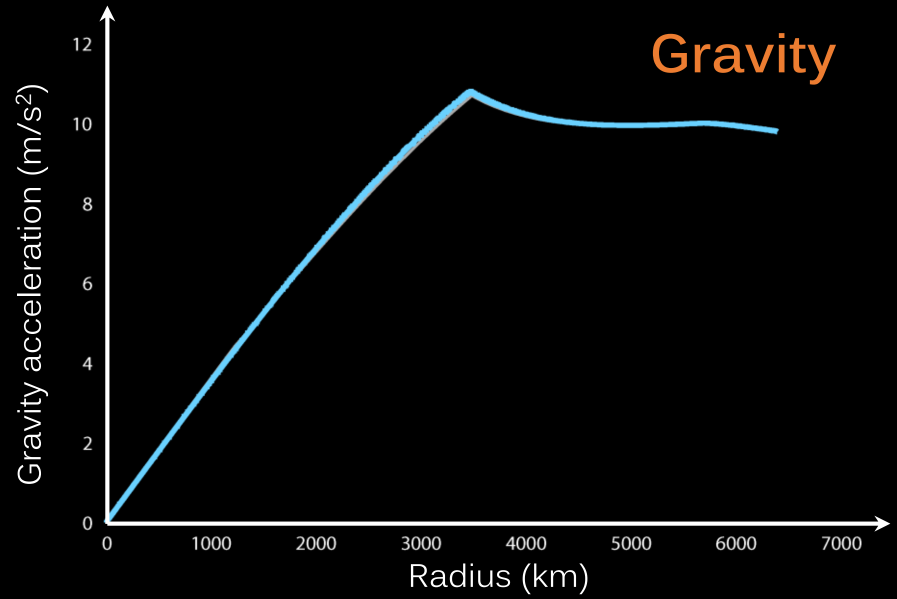
Pressure
Temperature

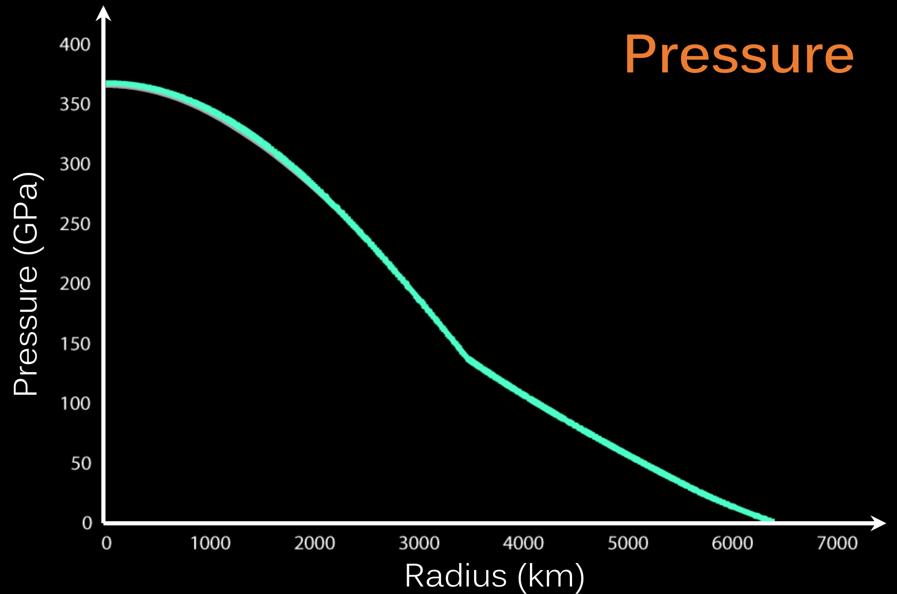


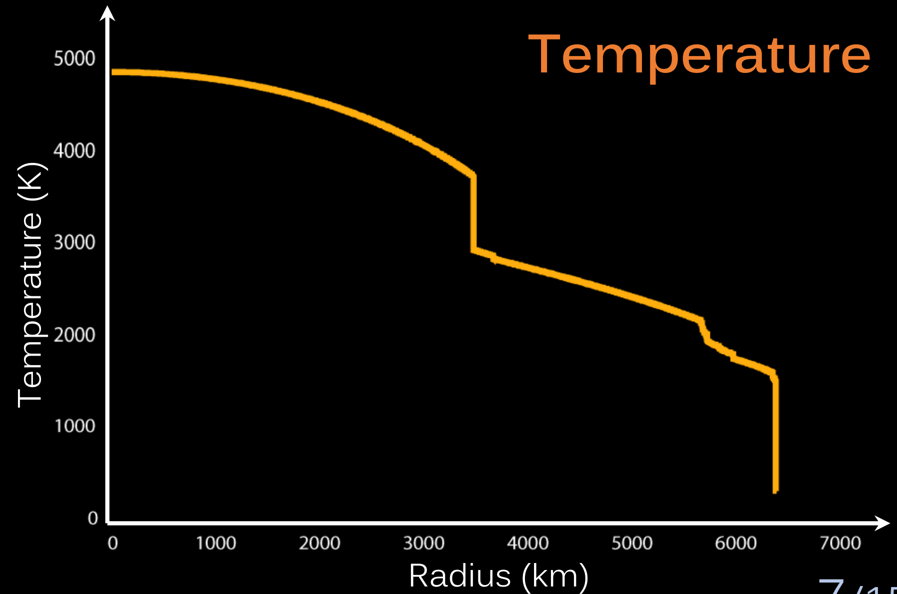
Material
properties

Reproducing the Earth









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Brugger et al. 2016, 2017

- Interior of **terrestrial planets**:
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- Theoretical case of **ocean planets** *(Léger et al. 2004)*:
  - Water envelope *(liquid and high-pressure ice)*

Interior model

Brugger et al. 2016, 2017

- Interior of **terrestrial planets**:
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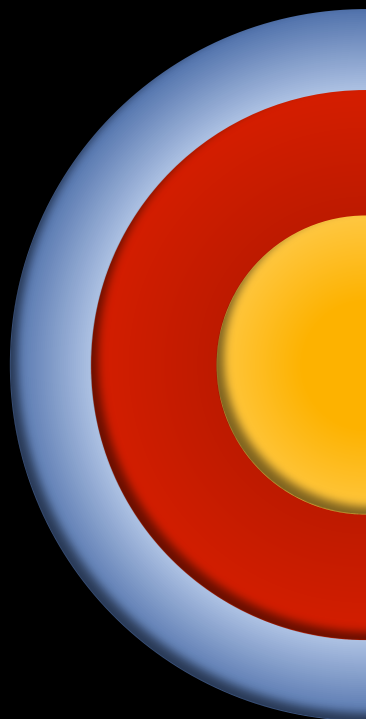
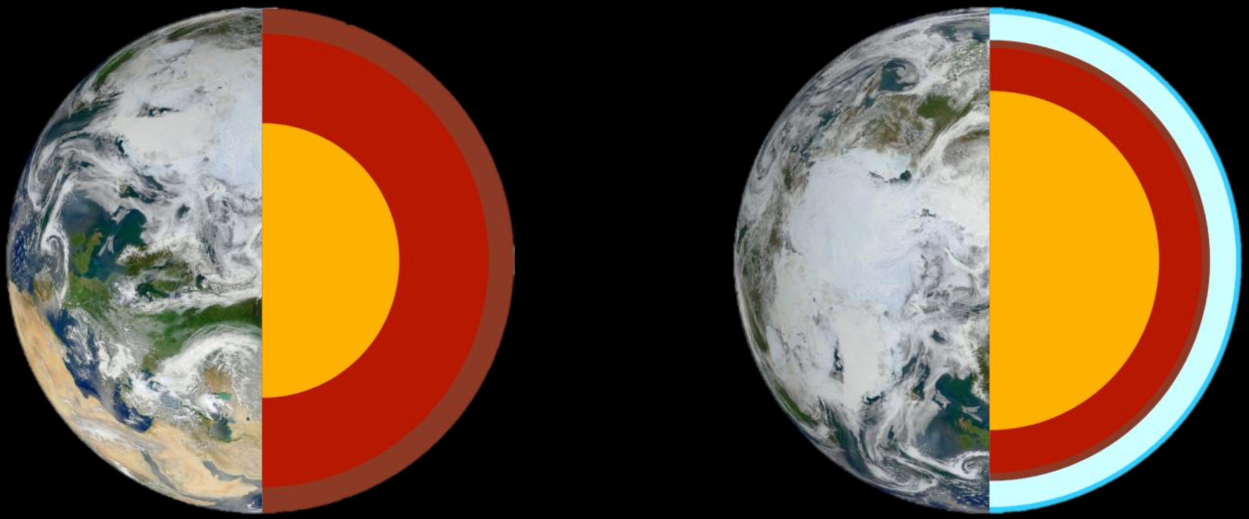
- Theoretical case of **ocean planets** *(Léger et al. 2004)*:
  - Water envelope *(liquid and high-pressure ice)*
- Previously unused equation of state *(Holzapfel 1991)*, allows to **correctly extrapolate** Earth data
- Monte-Carlo approach, adapts **planetary composition** to fundamental parameters

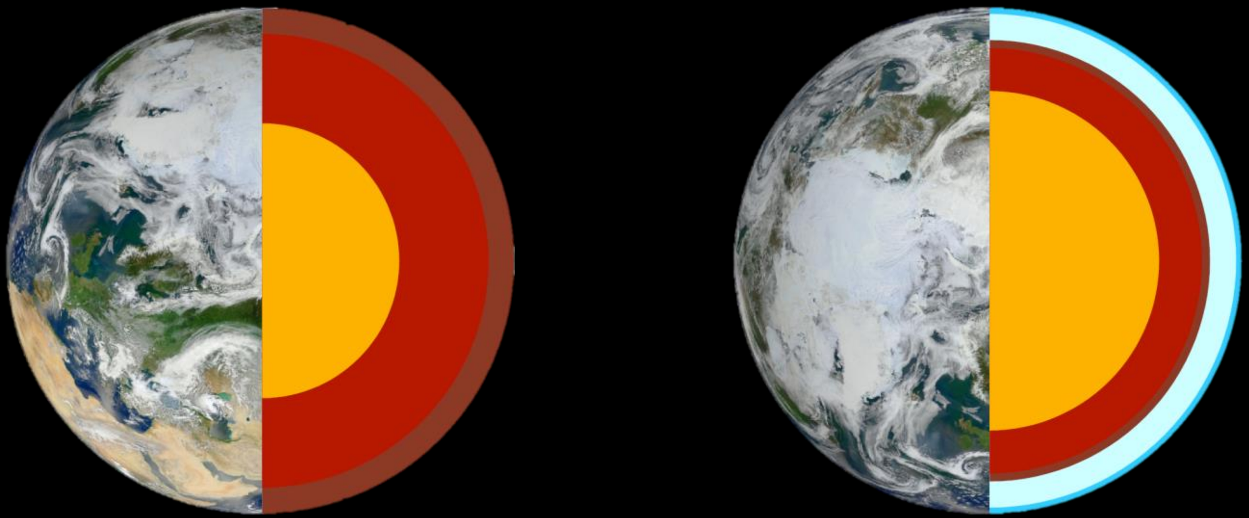


Degeneracy on Composition



Same mass, same radius

Degeneracy on Composition



Same mass, same radius

- Breaking the degeneracy requires an **additional parameter** *(Rogers & Seager 2010; Dorn et al. 2015, 2017)*
- **Stellar Fe/Si used as proxy** for planetary value, following assumption in the solar system *(e.g. Johnson et al. 2012)*
- Planetary Fe/Si fixes **core mass fraction** (CMF)

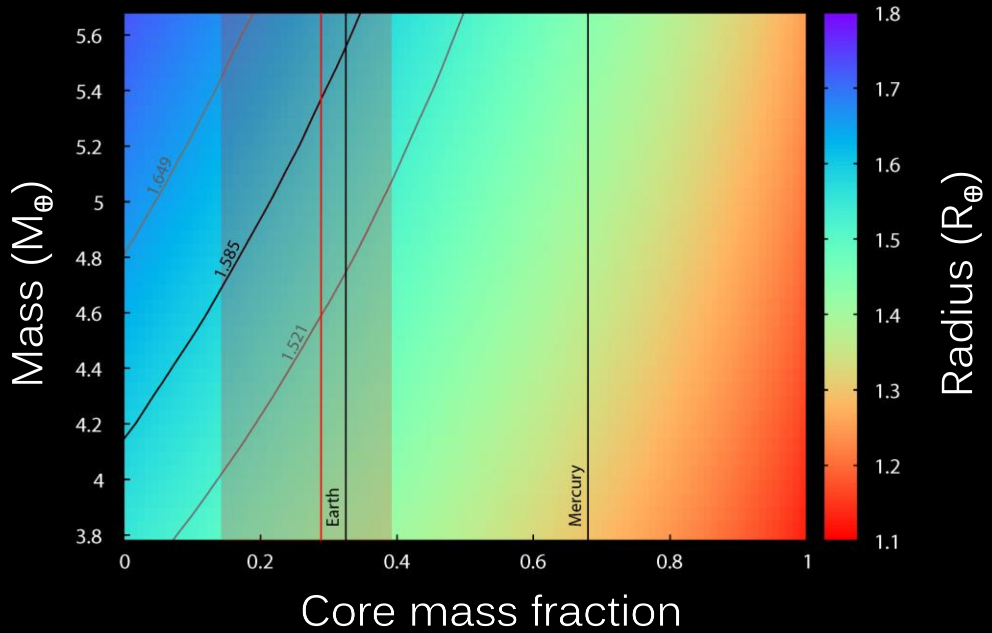
CoRoT-7b

The first **super-Earth** with measured mass & radius:

$M_P = 4.73 \pm 0.95\ M_{\oplus}$ — *Haywood et al. 2014*

$R_P = 1.585 \pm 0.064\ R_{\oplus}$ — *Barros et al. 2014*

As a dry terrestrial planet:



Brugger et al. 2017

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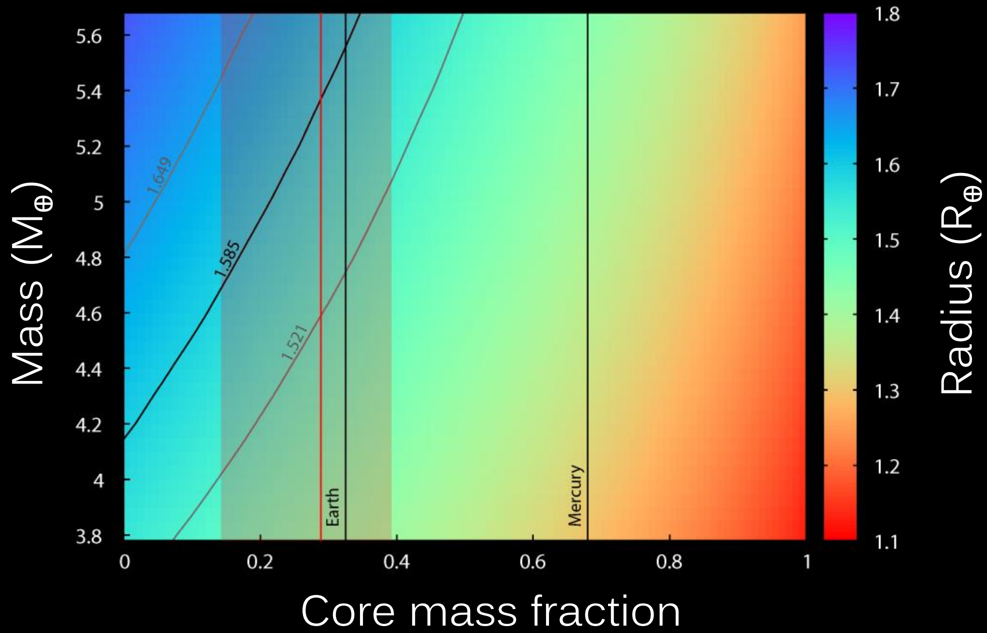

Brugger et al. 2017

Core mass fraction

- From fundamental parameters only:

  0 – 50 %

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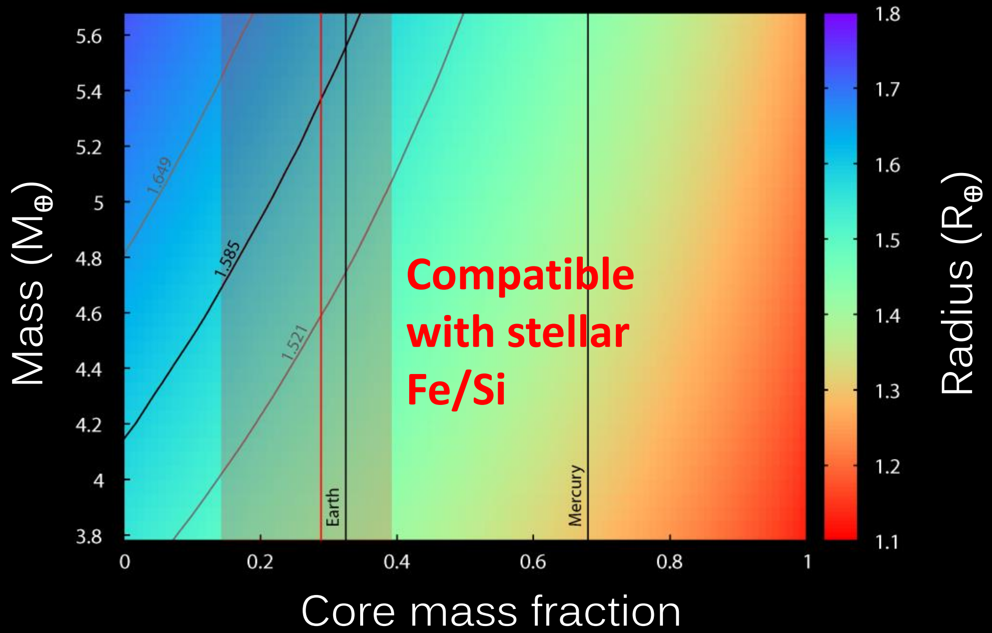


Brugger et al. 2017

Core mass fraction

- From fundamental parameters only:

  0 – 50 %

- Using stellar Fe/Si:

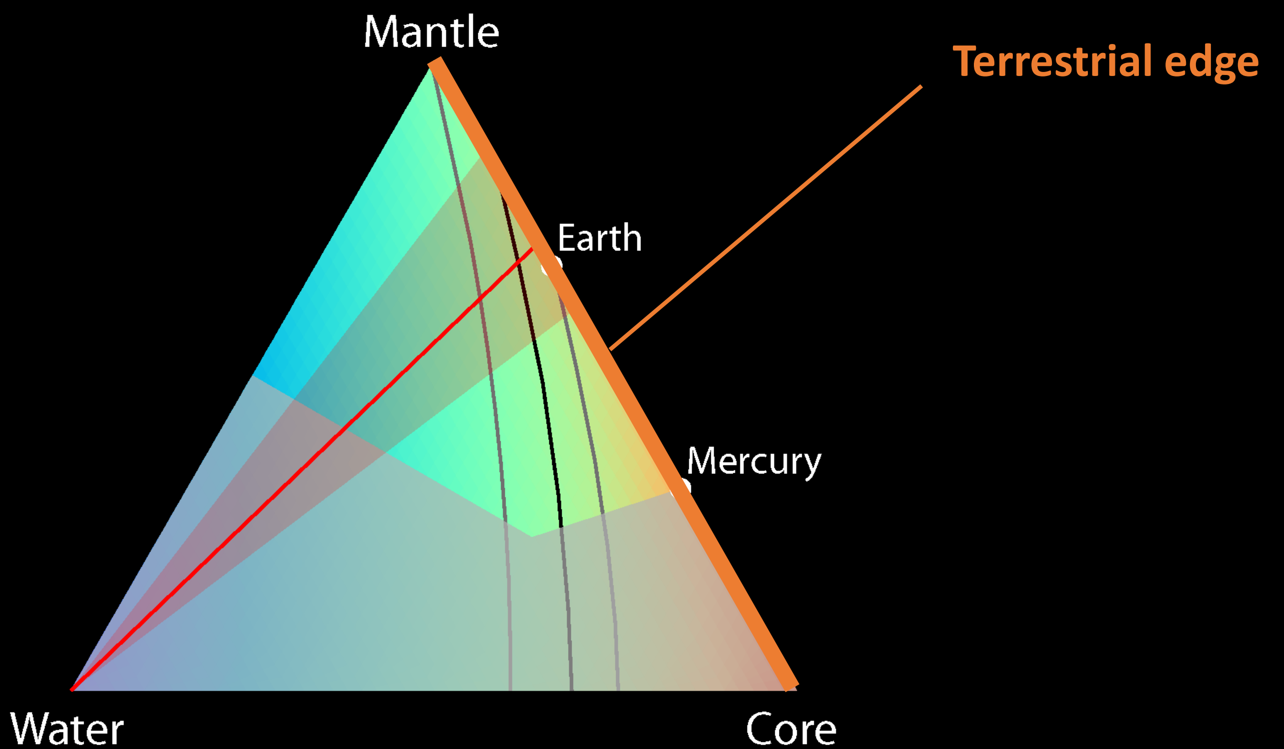
  13 – 37 %

➡ Terrestrial planets better characterized from stellar abundances

CoRoT-7b

Degenerate composition when considering the possibility that CoRoT-7b can also be an **ocean planet**:

Ternary diagram:



Brugger et al. 2017

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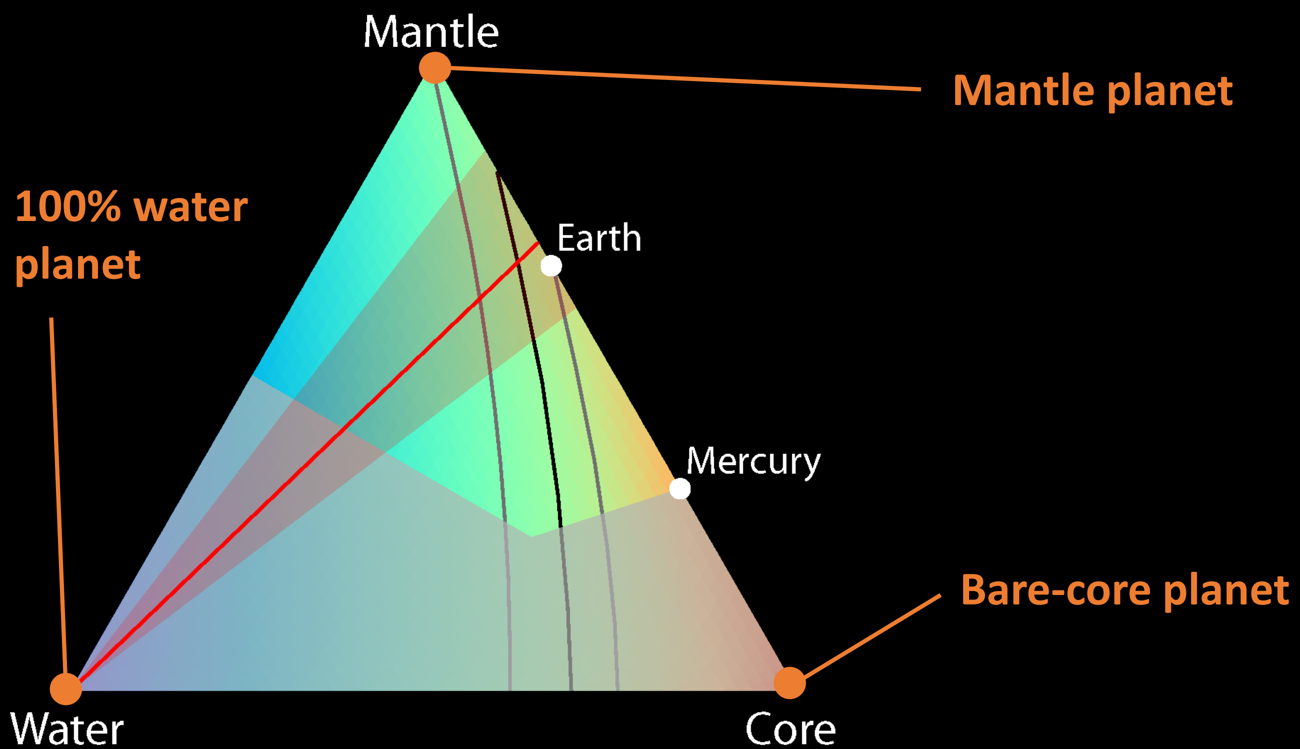

Brugger et al. 2017

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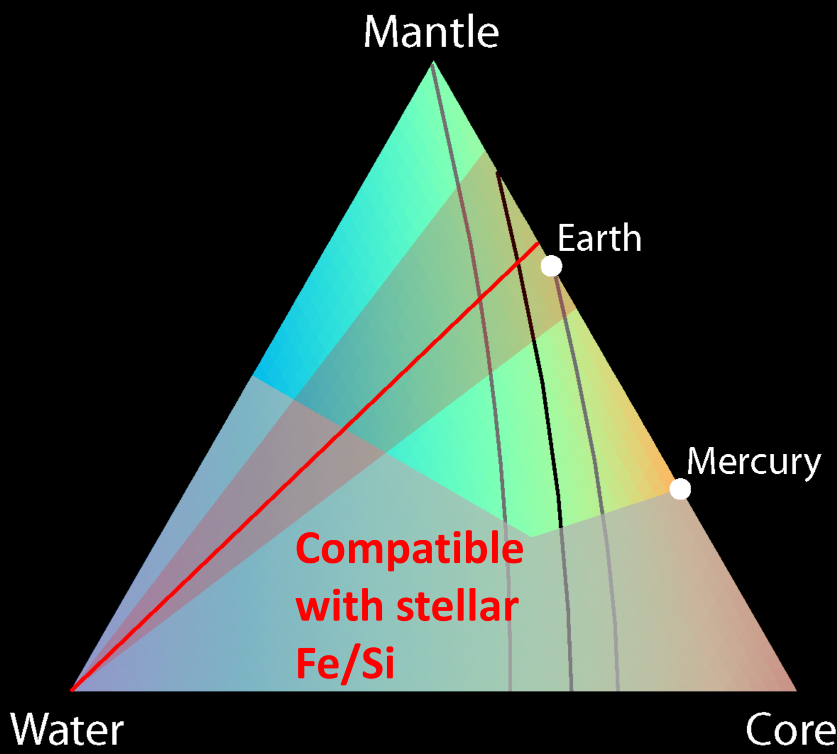


Brugger et al. 2017

- From fundamental parameters only:

CMF	0 – 65 %
WMF	0 – 50 %

- Using stellar Fe/Si:

CMF	13 – 37 %
WMF	0 – 31 %

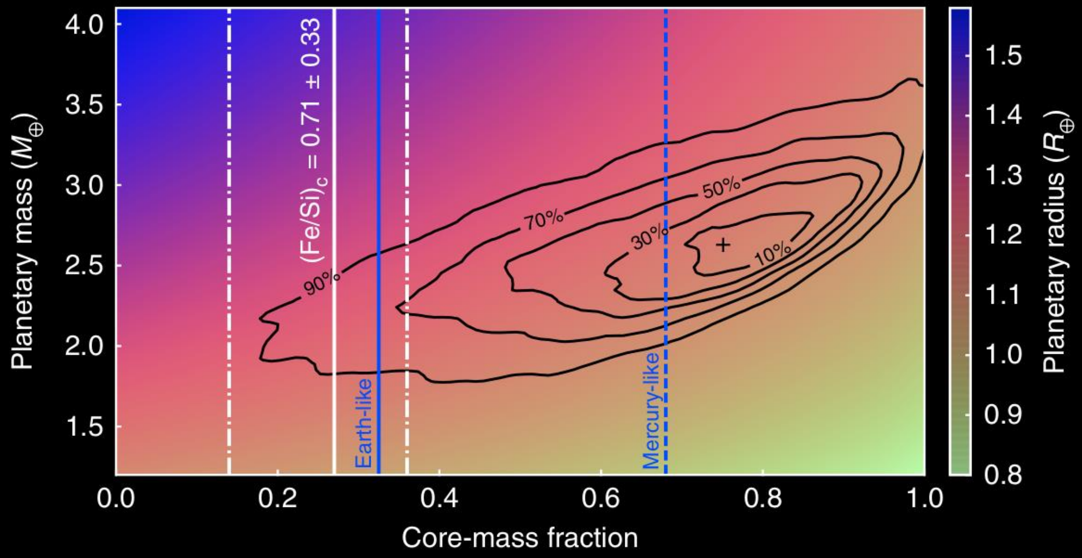
➡ Degeneracy reduced

K2-229b

Super-Earth with **high bulk density** of 8.9 ± 2.1 g/cm^3 *(Earth 5.5)*

➡ Fundamental parameters give a core mass fraction of **69^{+17}_{-25}%** *(Mercury ~70%)*

Mass & Radius vs composition:



Santerne, Brugger et al. 2018

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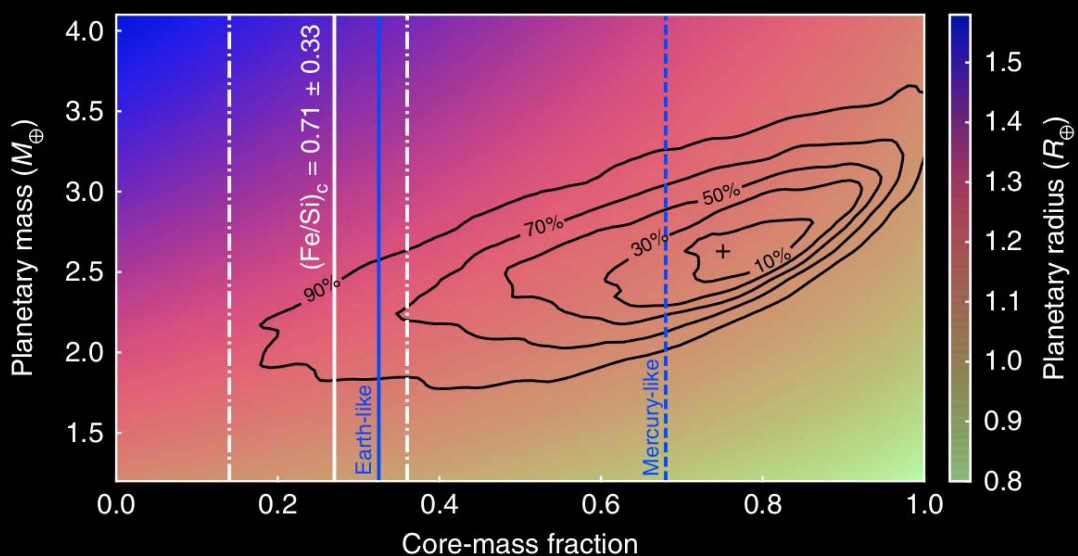


Santerne, Brugger et al. 2018

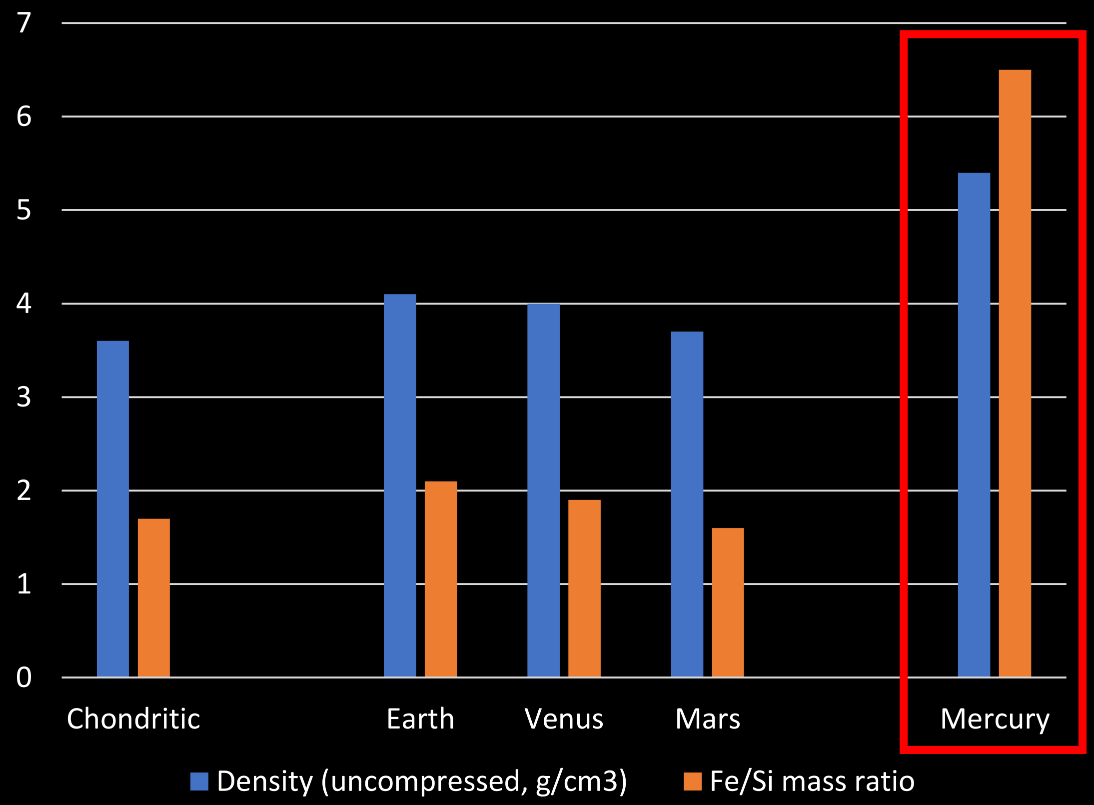
Stellar Fe/Si ratio gives a CMF of 27^{+9}_{-13}%

➡ **88% probability** that K2-229b has a composition differing from the stellar values

➡ **Discrepancy** between planetary and stellar composition, similar to the **case of Mercury** in the solar system

Peculiar Case of Mercury

Brugger et al. (sub)



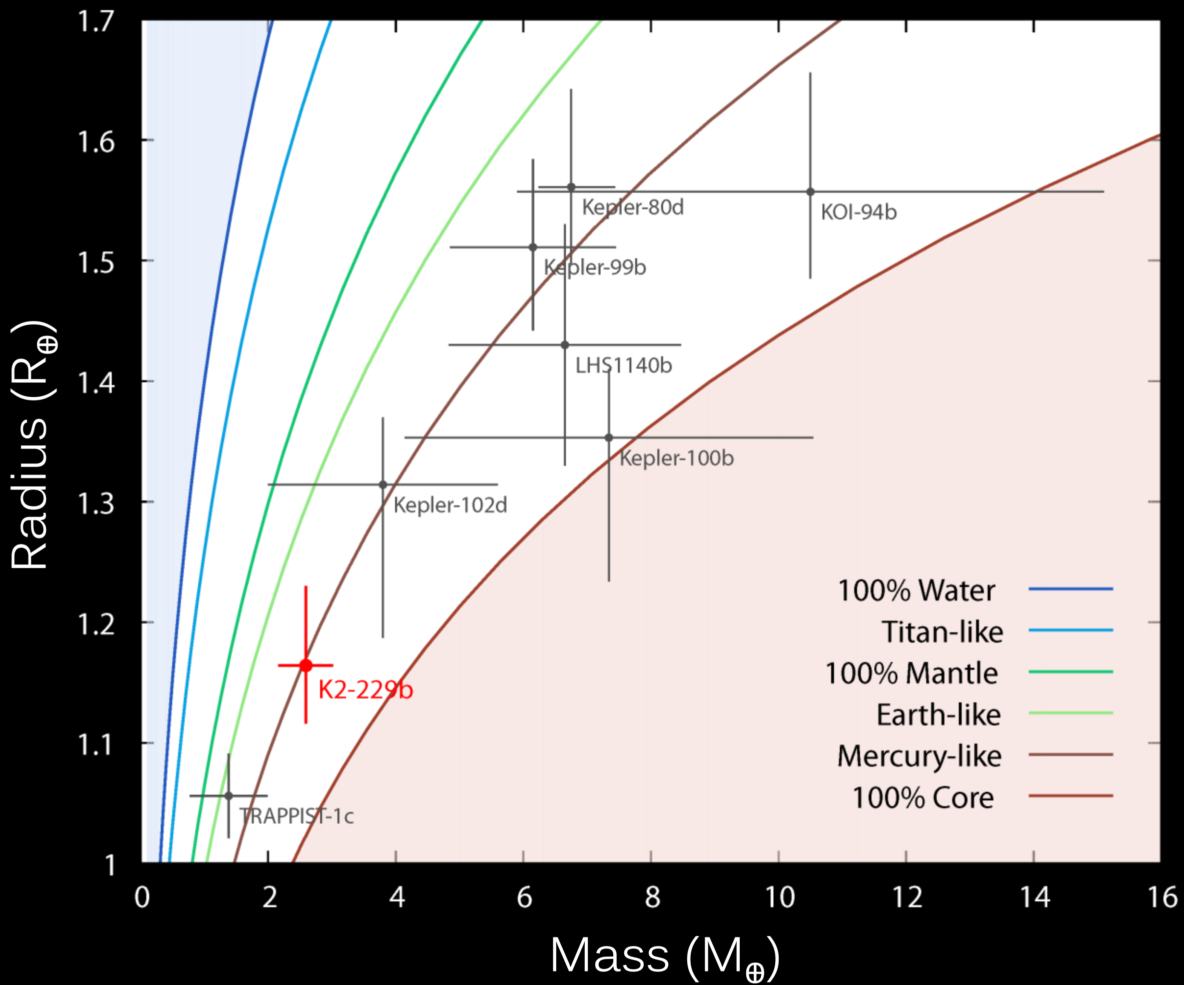
- High **uncompressed density**

  → Enriched in dense materials

- **Large Fe/Si ratio** compared to solar and chondritic values

→ **Origin** of this deviation still unclear

Super–Mercuries



- Several planets presenting **high bulk densities**, over large ranges of mass and radius
- Do they all have a composition **differing** from the stellar values?

➡ How **unique** is the case of Mercury?

Conclusions & Perspectives

- **Interior models** able to probe the nature and composition of detected exoplanets

  ➡ Help identify targets for further **habitability studies**

- Major challenge in interior characterization: existence of **degeneracy** due to lack of observables

  ➡ **Stellar abundances** shown to be important constraints in the characterization of both terrestrial and ocean planets

- Validity of the relation between stellar and planetary composition?

  ➡ **Family of super-Mercuries** can help decipher the potential discrepancies