Revisited relations for exoplanets mass-radius below 120 $M_{\oplus}$

Otegi et al. 2020

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2021/10/22

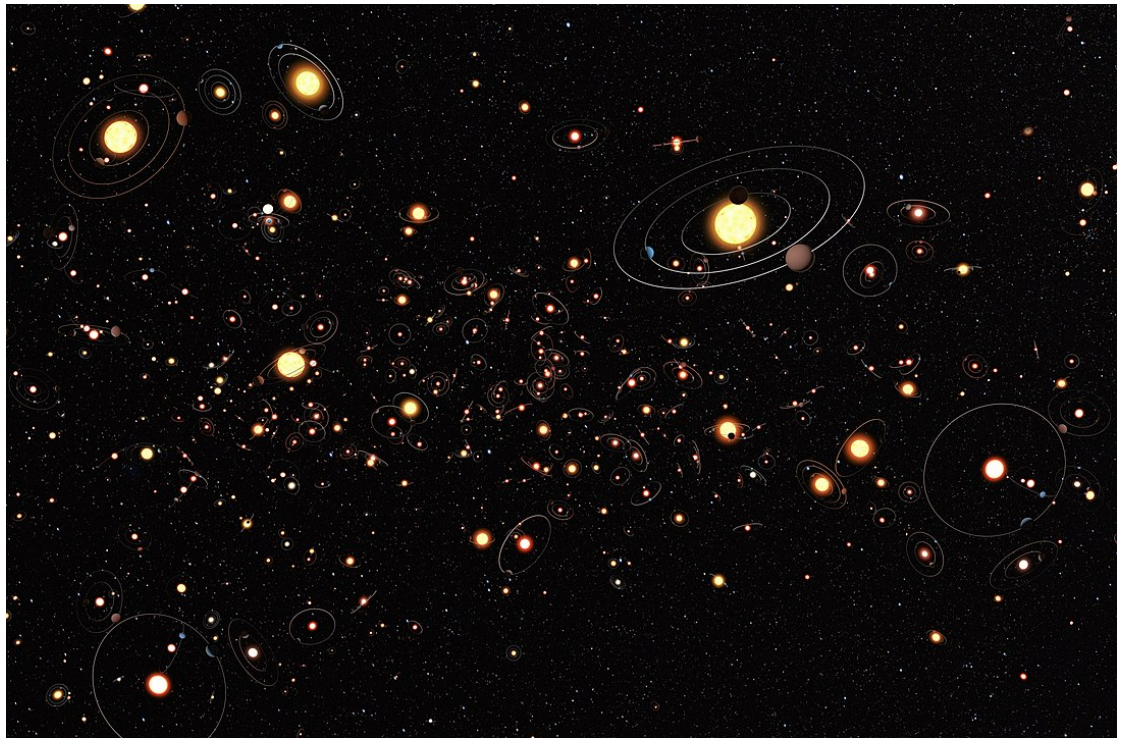
Outline

- An introduction to the exoplanets
  - Methods of detecting exoplanets
- Mass-radius (M-R) relations
  - Analysis of the M-R diagram
- Summary and my questions

Exoplanets

Exoplanets:

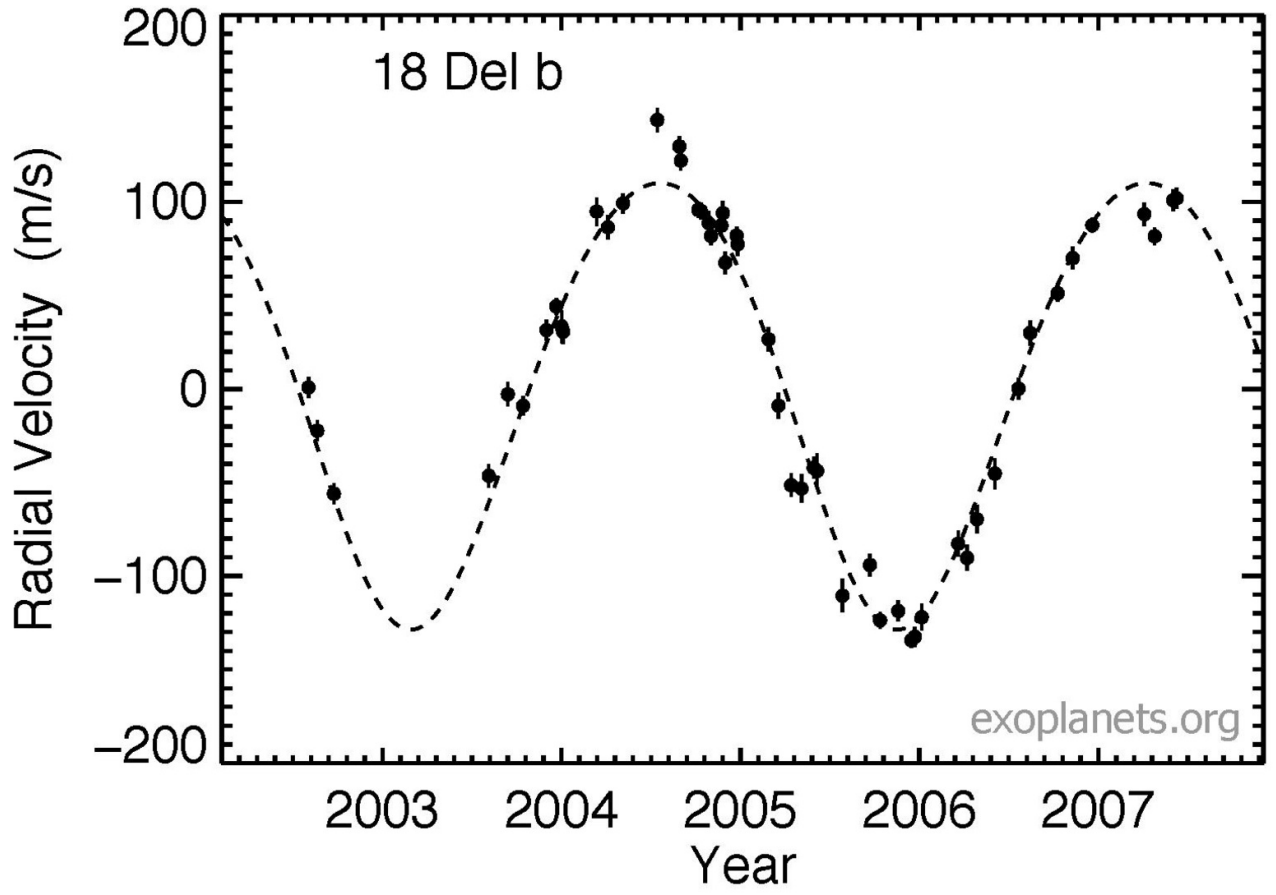
- The planets outside the Solar System
  - M below the limiting mass for thermonuclear fusion of deuterium ($\approx 13\ \mathrm{M}_{Jupiter}$)
  - orbit stars or stellar remnants
  - cleared its neighbouring region of planetesimals
  - ……



Artist's impression (not to scale) of how commonly planets orbit the stars in the Milky Way.

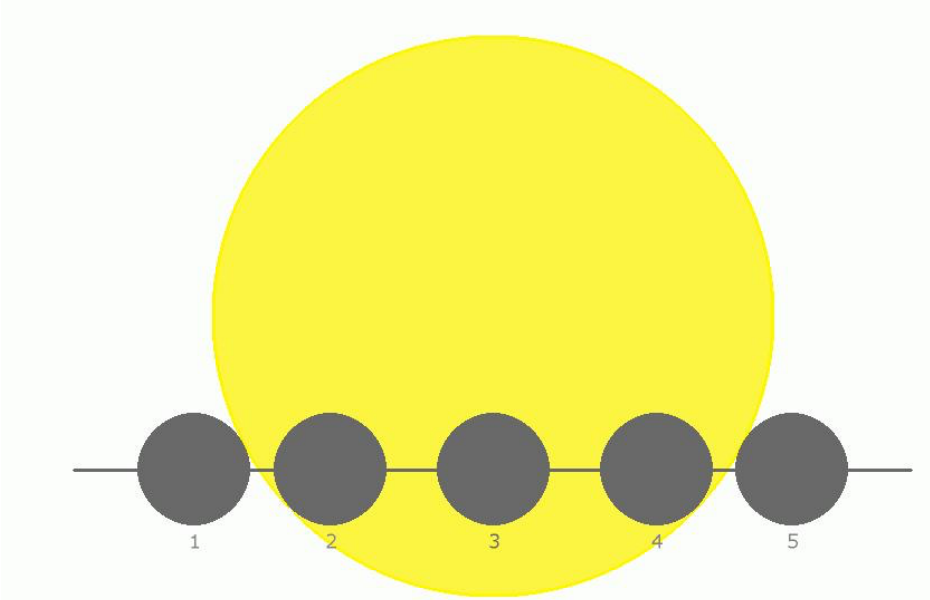
Methods of detecting exoplanets

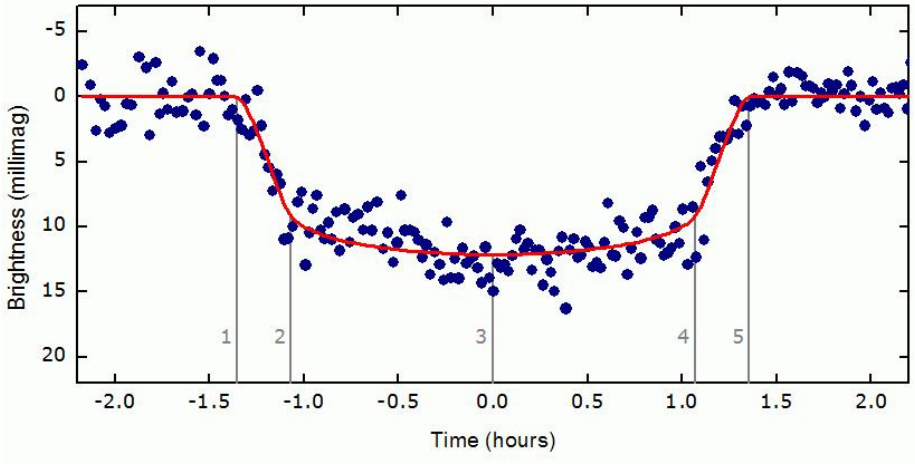
- Radial velocity (RV) method
  - A star with a planet will move in its own small orbit in response to the planet's gravity.



Methods of detecting exoplanets

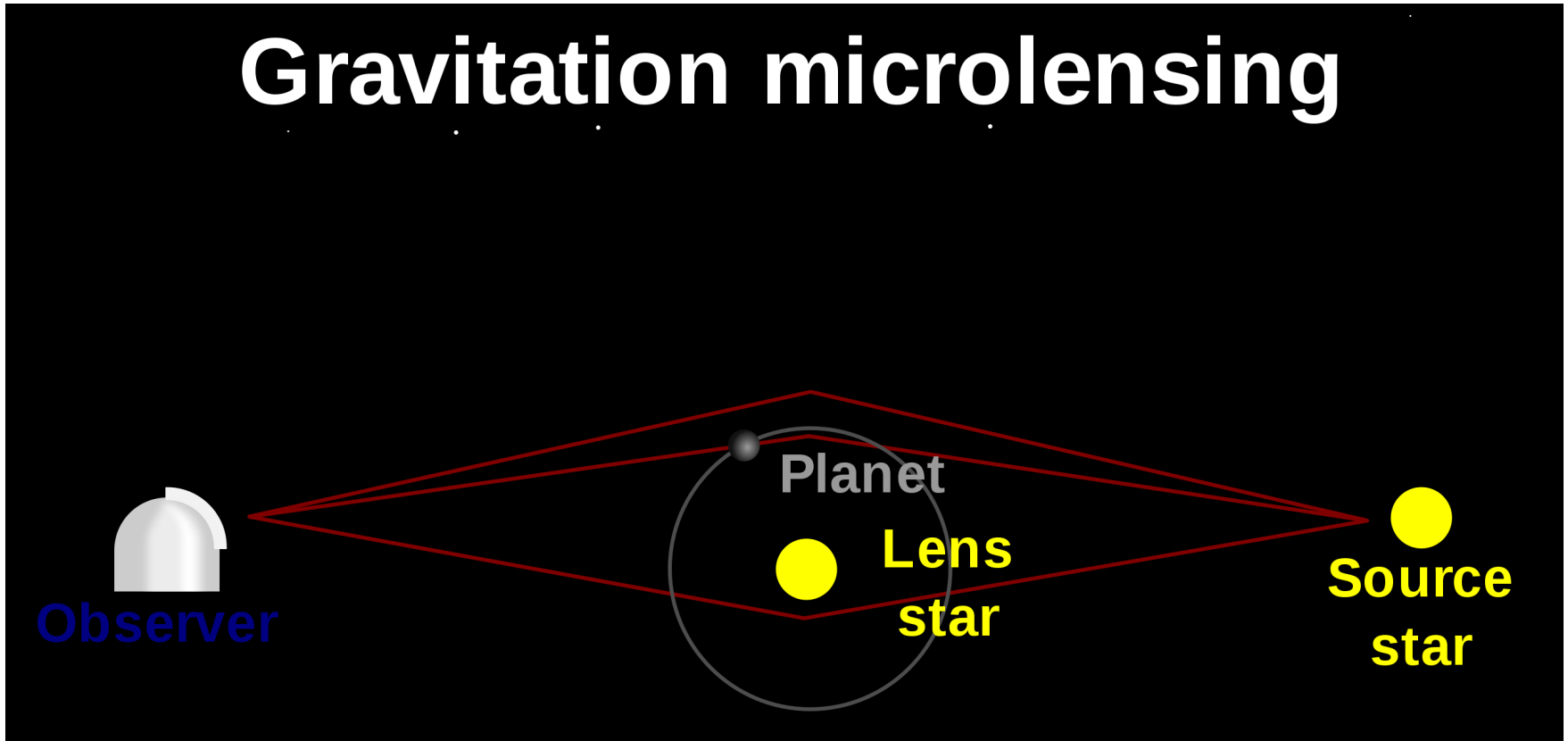
- The transit photometry
  - If a planet crosses (transits) in front of its parent star's disk, then the observed visual brightness of the star drops





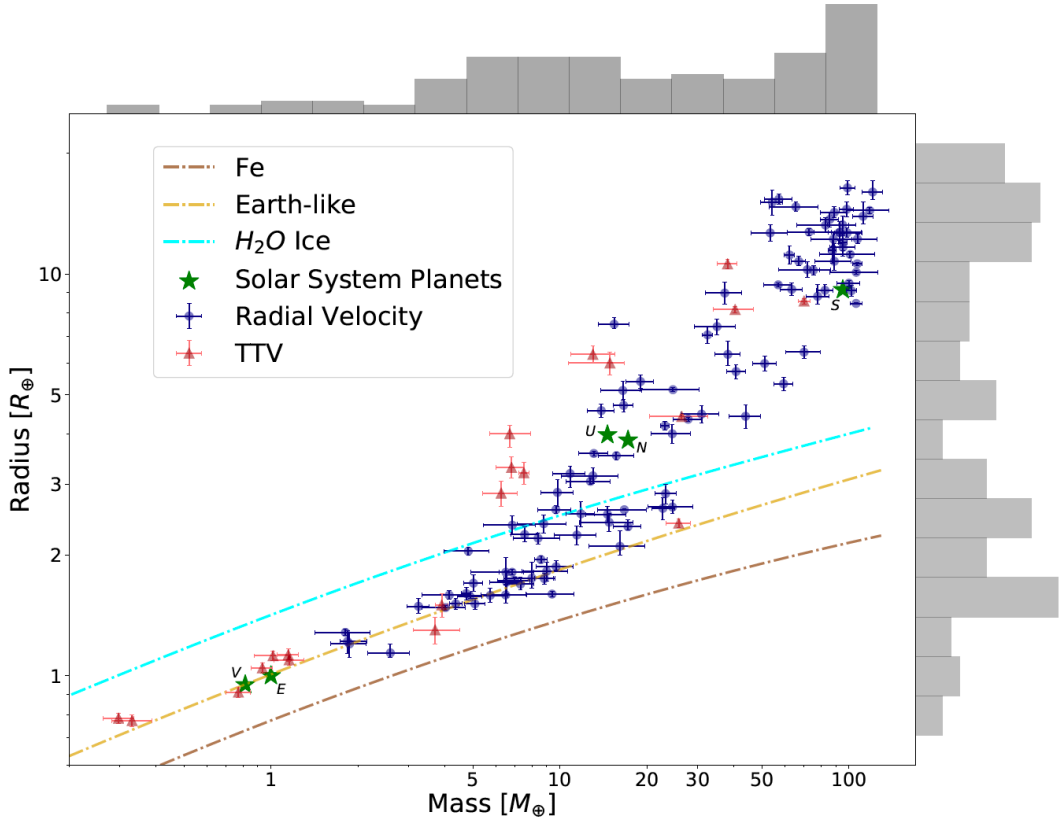
Methods of detecting exoplanets

- Microlensing
  - The planet's own gravitational field can make a detectable contribution to the lensing effect.



Mass-radius relations

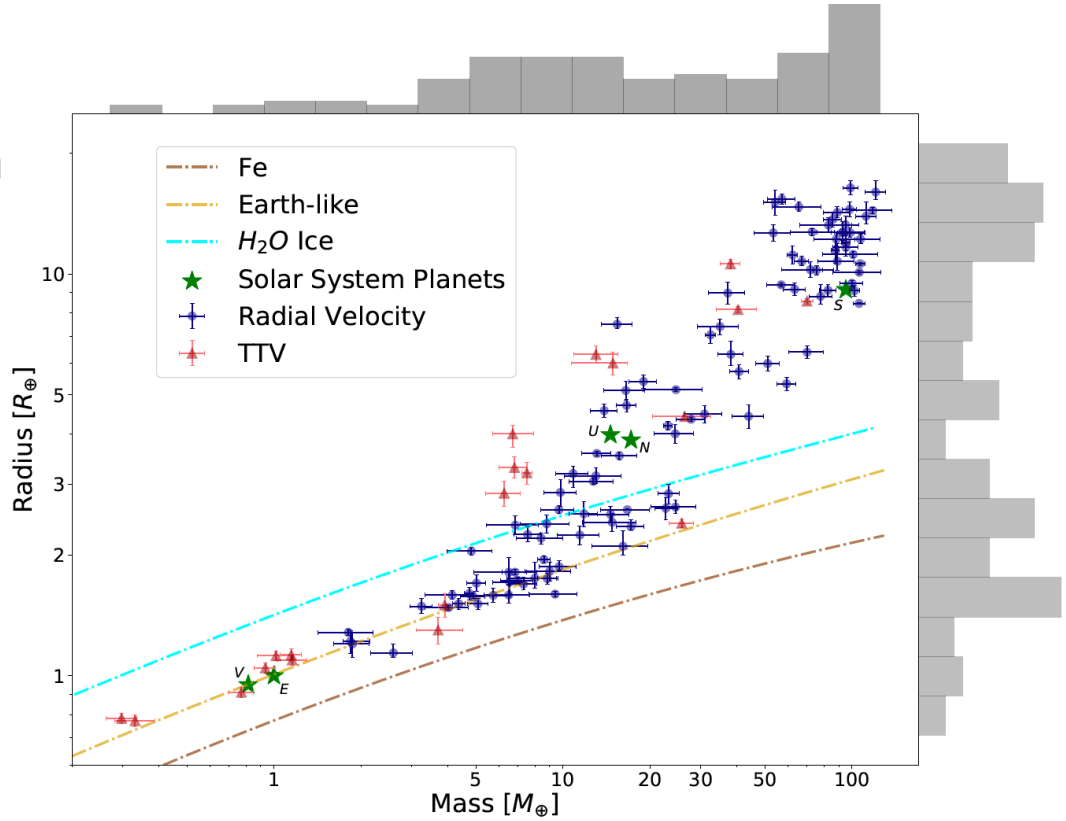
- To date, more than 4000 exoplanets have been discovered
- Knowledge of both the mass and radius
  - estimate the planetary bulk density
  - infer the possible compositions and internal structures



Revisited M-R diagram with relative uncertainties smaller than 25% for mass and smaller than 8% for radius (Otegi et al. 2020)

Mass-radius relations

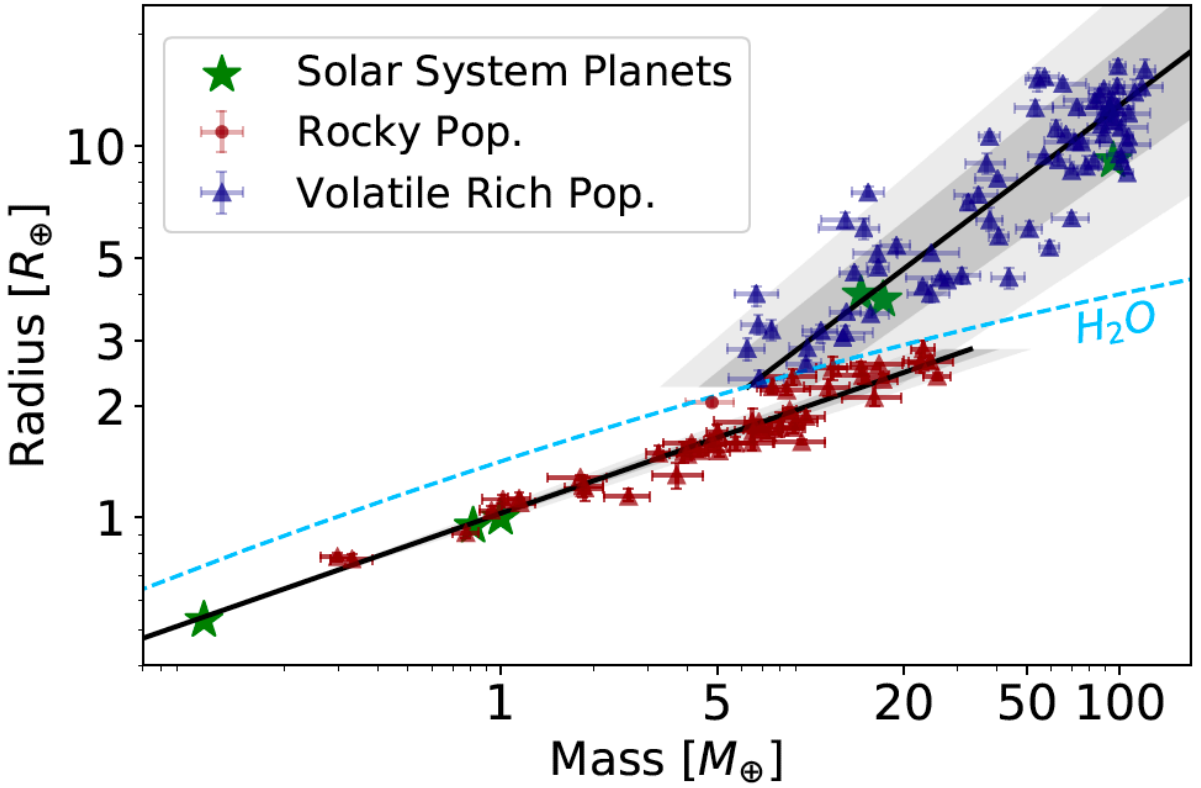
- Explore the demographic of exoplanets in a statistical sense
- Planet formation and evolution
  - The planetary mass function
  - primordial atmosphere mass
  - migration
  - atmospheric loss
  - …



Revisited M-R diagram with relative uncertainties smaller than 25% for mass and smaller than 8% for radius (Otegi et al. 2020)

Two distinct exoplanet populations

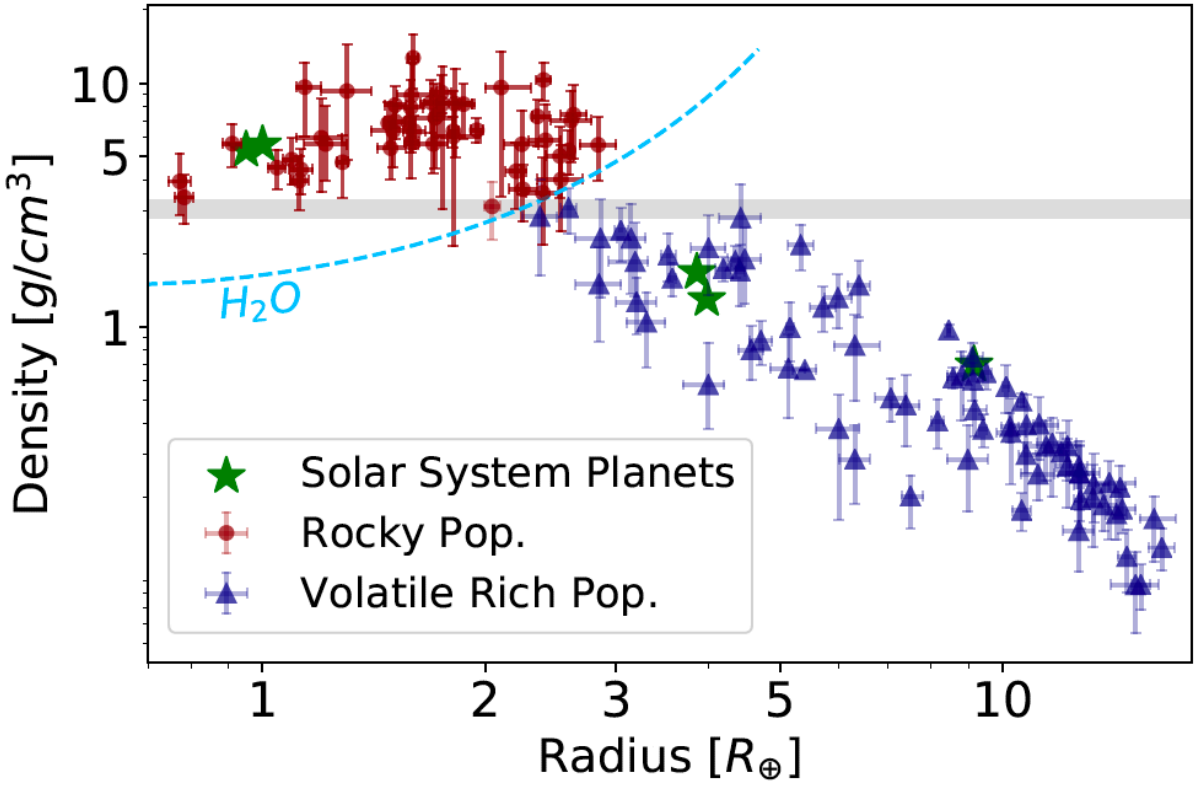
- Dashed line : The composition line of pure water
- Rocky populations' upper limit:
  - $25\ M_{\oplus}$ (giant planet formation models with pebble accretion)
- Volatile-rich populations lower limit (may):
  - $5\ M_{\oplus}$



M-R relations fitting rocky and volatile-rich populations (Otegi et al. 2020)

Two distinct exoplanet populations

- The pure-water composition curve is less arbitrary and is based on physical arguments



density against radius for the catalogue (Otegi et al. 2020)

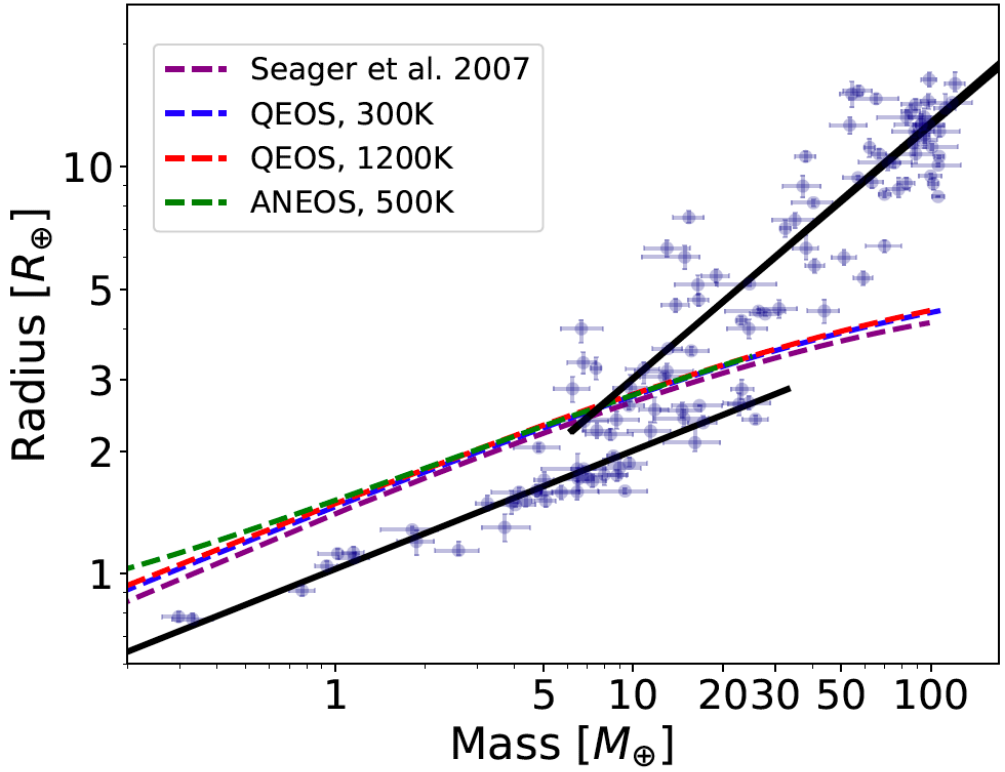
Mass-radius relations

- The composition line of pure-water depends on the EOS (Equation of State) used and the planetary temperature.

$$R = \begin{cases} (1.03 \pm 0.02)\, M^{(0.29\pm0.01)}, & \text{if } \rho > 3.3 \text{ g cm}^{-3} \\ (0.70 \pm 0.11)\, M^{(0.63\pm0.04)}, & \text{if } \rho < 3.3 \text{ g cm}^{-3}, \end{cases}$$

or

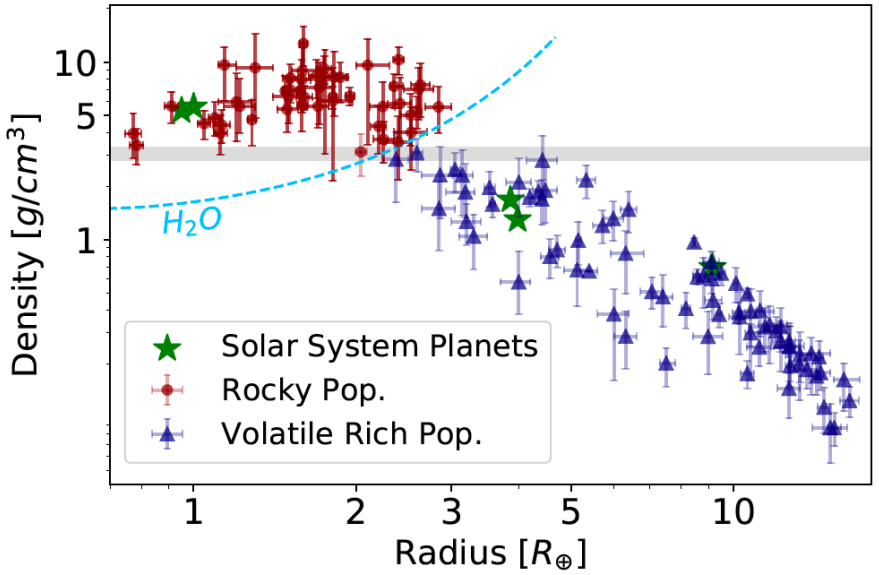
$$M = \begin{cases} (0.90 \pm 0.06)\, R^{(3.45\pm0.12)}, & \text{if } \rho > 3.3 \text{ g cm}^{-3} \\ (1.74 \pm 0.38)\, R^{(1.58\pm0.10)}, & \text{if } \rho < 3.3 \text{ g cm}^{-3}. \end{cases}$$

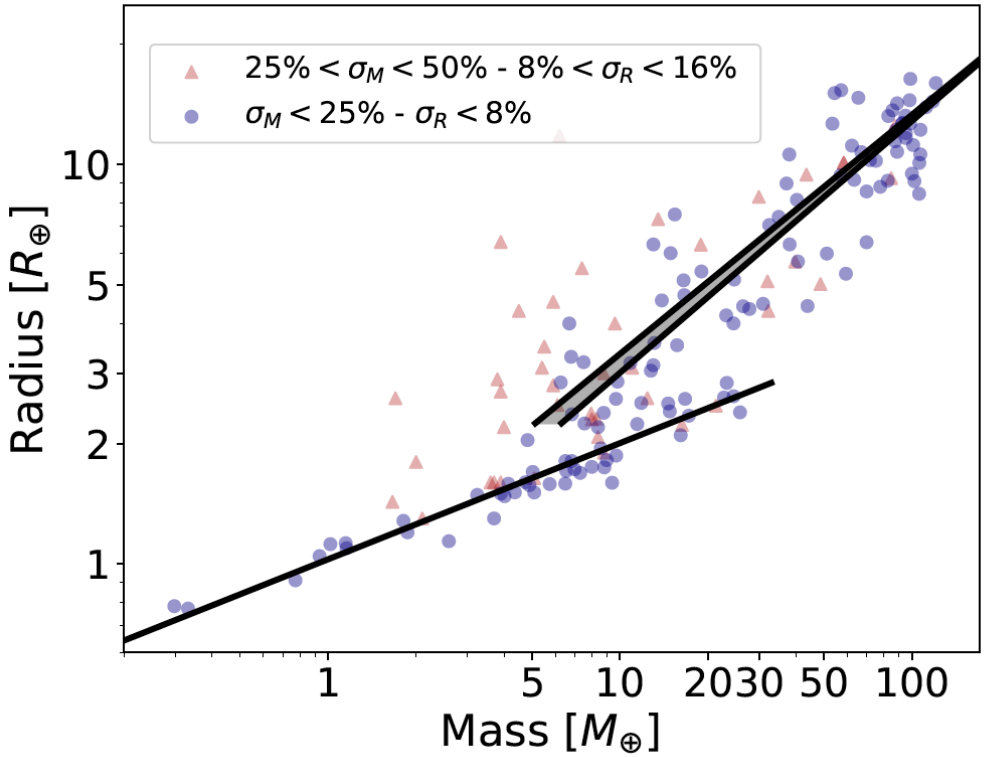


M-R diagram comparing obtained M-R relations when using different Equation of State (EOS) for water (Otegi et al. 2020)

Mass-radius relations

- Rocky population : density is nearly constant.
  - made of refractory materials
- volatile-rich populations: density scale with M^{-1}

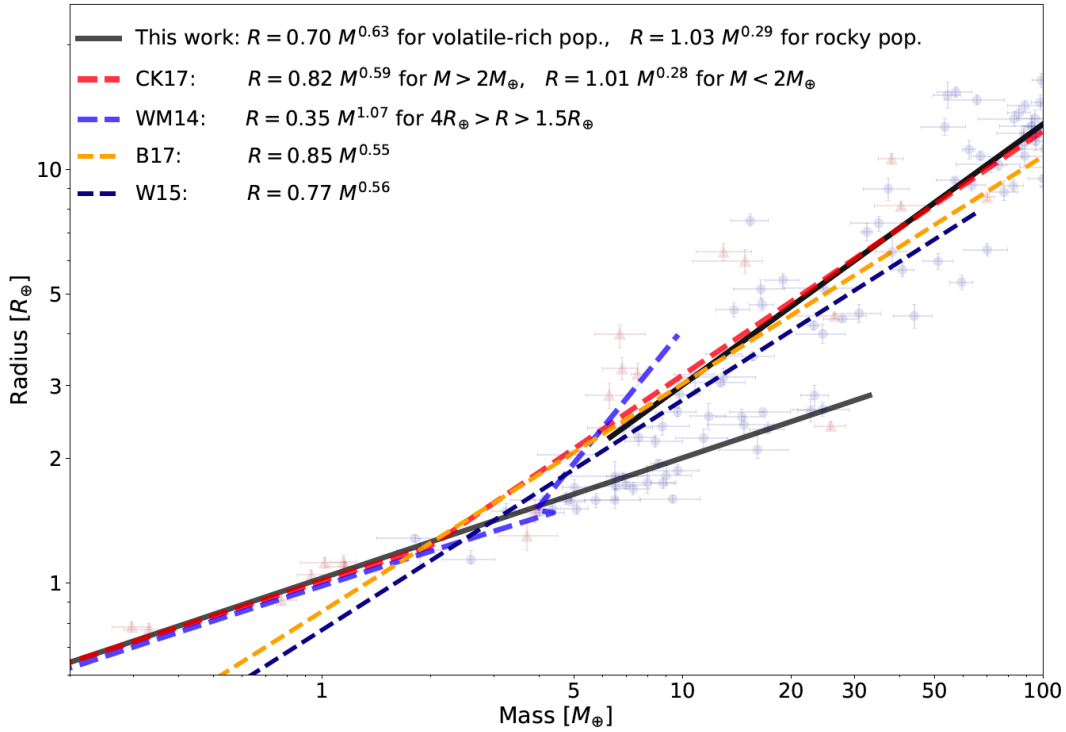




M-R diagram comparing obtained M-R relations when using different cuts for the mass and radius uncertainties (Otegi et al. 2020)

Comparison of the M-R relations

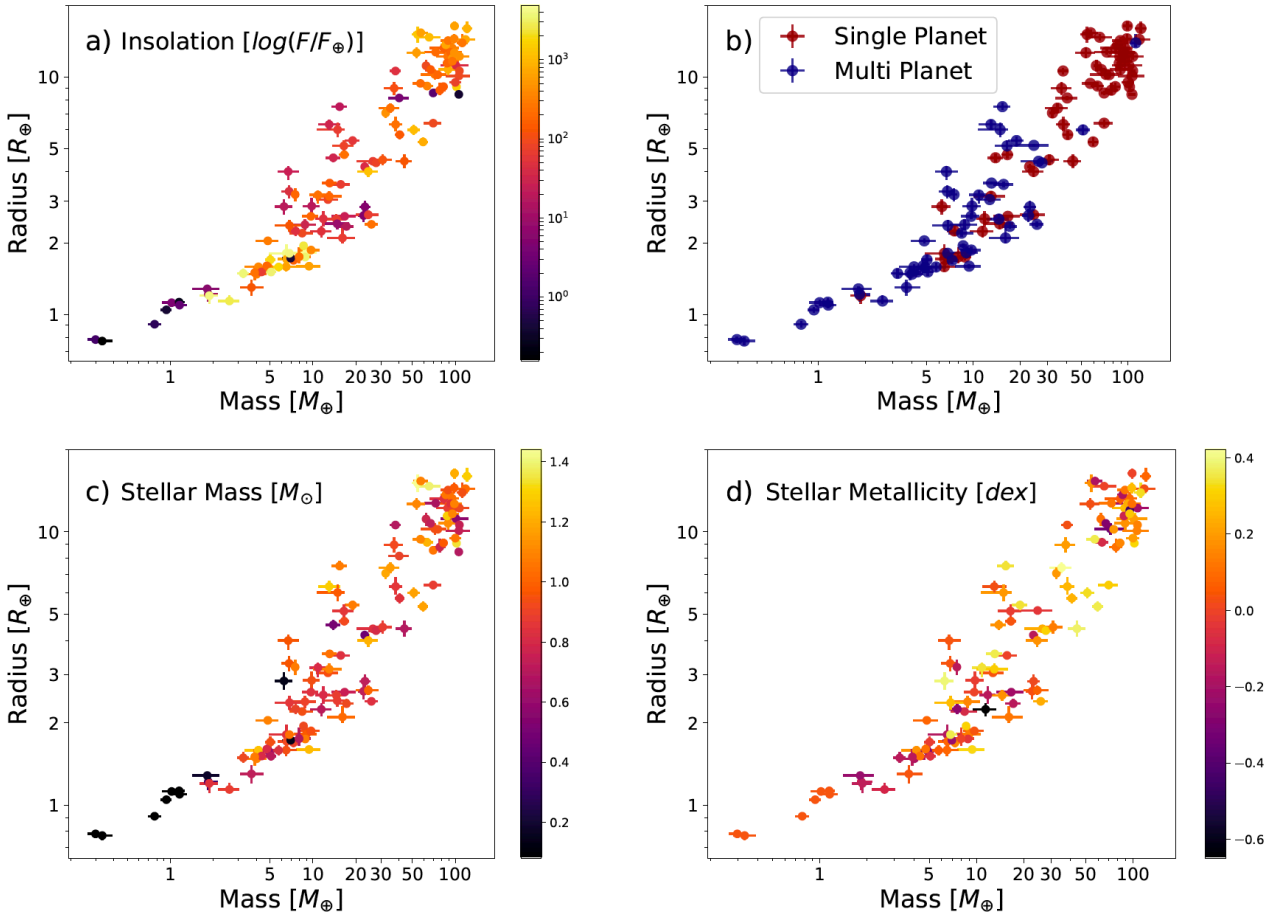
- Other articles usually only use one or not very suitable formula to describe the relations
- Focus on the transition from the rocky to the volatile-rich regime



Comparison of M-R relations in the literature with the one obtained from Otegi et al. 2020

Dependence on other parameters

- The dependence of M-R diagram with:
  - (a) insolation
  - (b) multiplicity
  - (c) stellar mass
  - (d) stellar metallicity



Summary

- Present an updated exoplanet catalogue and the resulting mass-radius (M-R) diagram shows two distinct populations
- Present new empirical M-R relations based on this catalogue and give some analysis
- Show the dependence on other parameters

Questions

- Why the volatile-rich exoplanet' density scale with M^{-1}?
- Is there a way to remove the degeneracy of planetary components ?
- How the single exoplanets and multi-planetary systems might affect the M-R relations?