University of Zurich[UZH]

PLATO Conference 2021

Synthetic Evolution Tracks of Giant Planets

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The importance of studying giant planets

Studying giant planet formation & evolution is a big piece of the puzzle of understanding planetary origins.

Composition

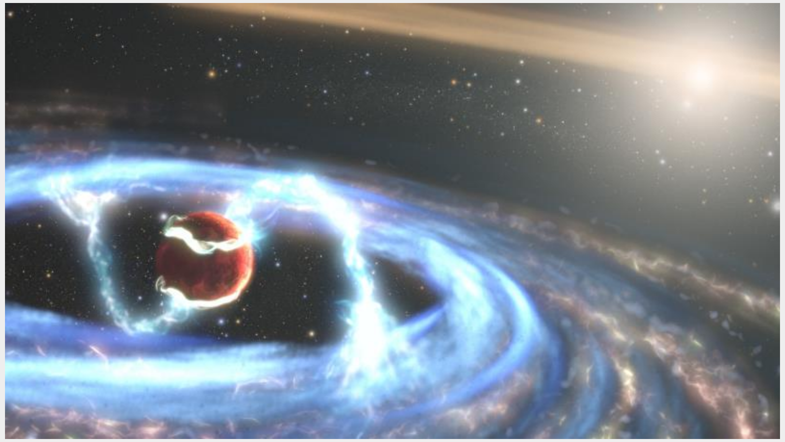
Since giant planets form in protoplanetary disks they can tell us something about the conditions at the time of their formation.

System architecture

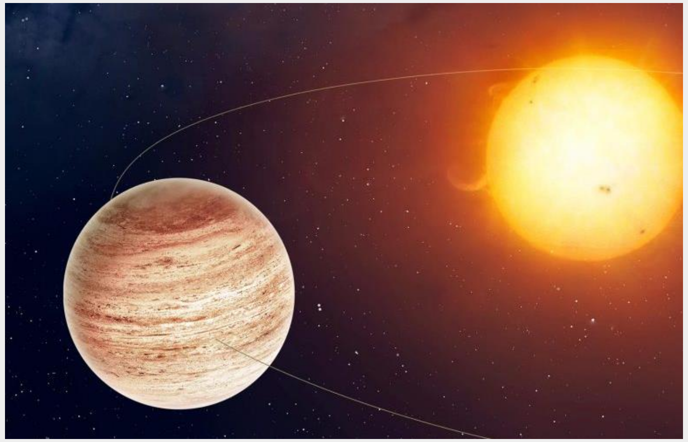
Since they are so massive, giant planets influence the final assembly of planetary systems.

Understanding Giant Planets: The Three Pillars

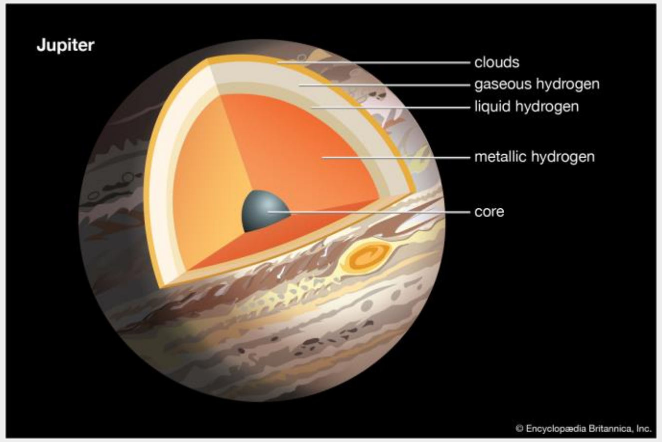
Formation



Evolution



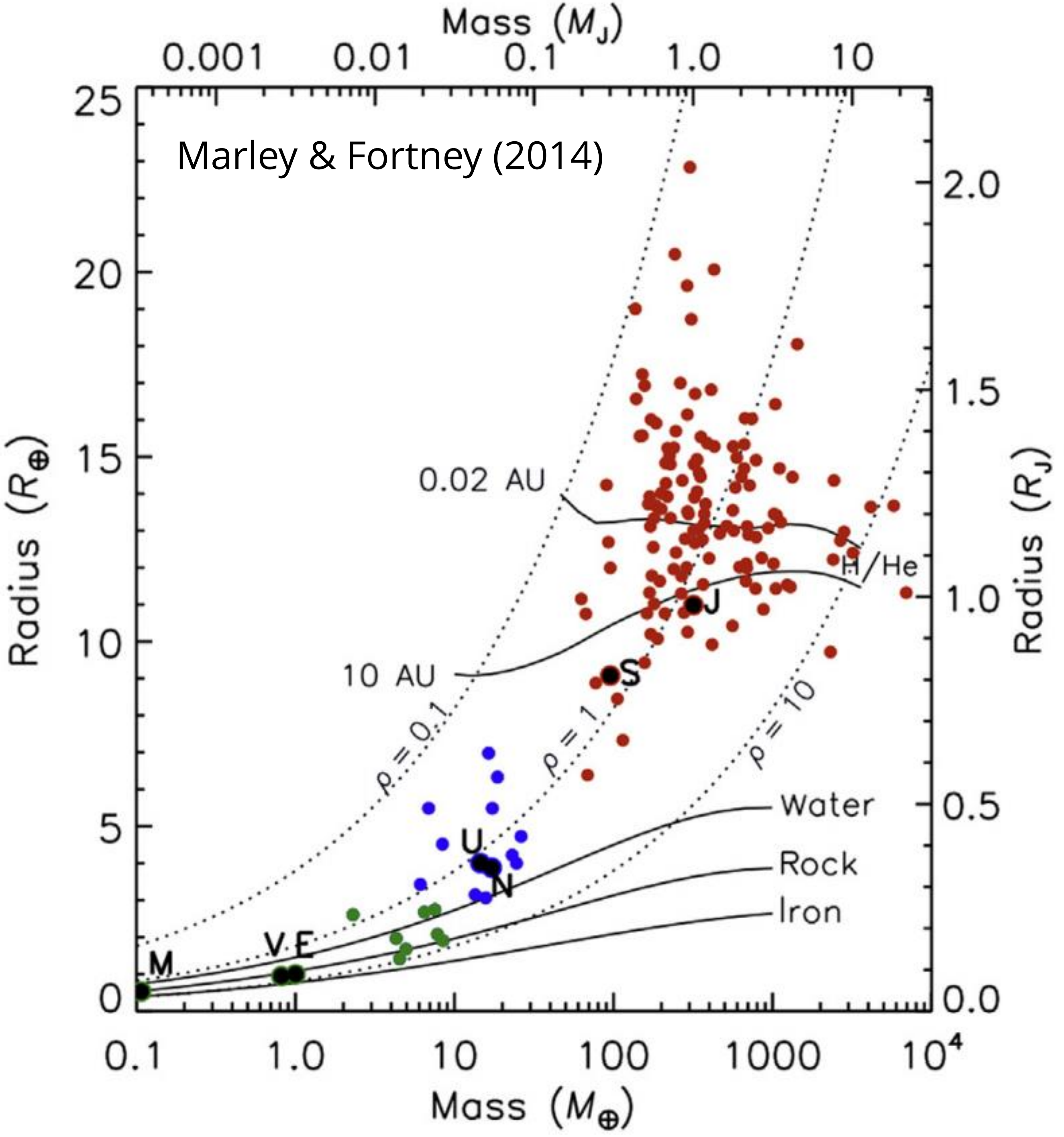
Internal Structure



Time

Giant Exoplanets

There is a large diversity of giant exoplanets in terms of their physical properties.



Composition of Giant Exoplanets

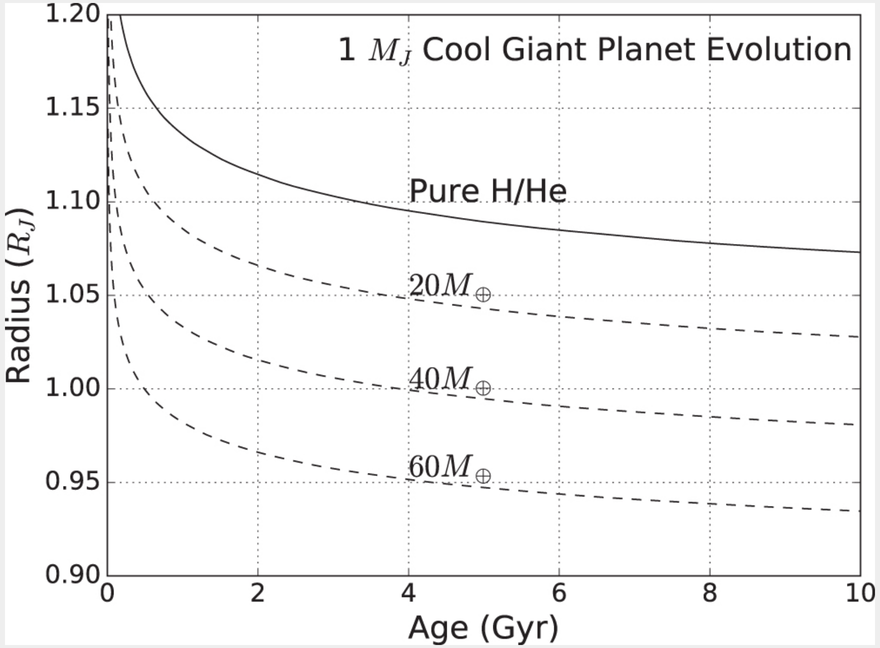
Heavy elements in giant planets:

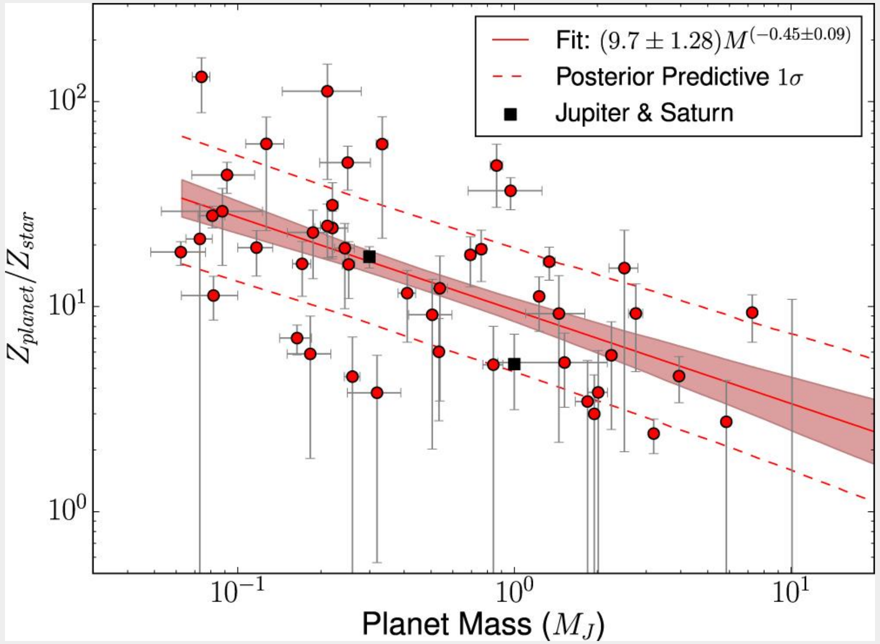
- Testbed for formation theory
- Influence on model predictions

How do we estimate the heavy-element mass?

- For a given planetary radius, mass and age (and stellar irradiation) find M_z such that: $R(M, M_Z, I_*, t) = R_{obs}$

Prediction of M_Z requires evolution models!





Thorngren et al. 2016

Synthetic Evolution Tracks of Giant Planets
(Müller & Helled 2021)

Giant planet evolution models play a crucial role in interpretating observations and constraining formation pathways; but simulations can be slow or difficult to perform.

Considering for example that future observations, will provide large numbers of observed planets and as well as atmospheric measurements this is a big limitation.

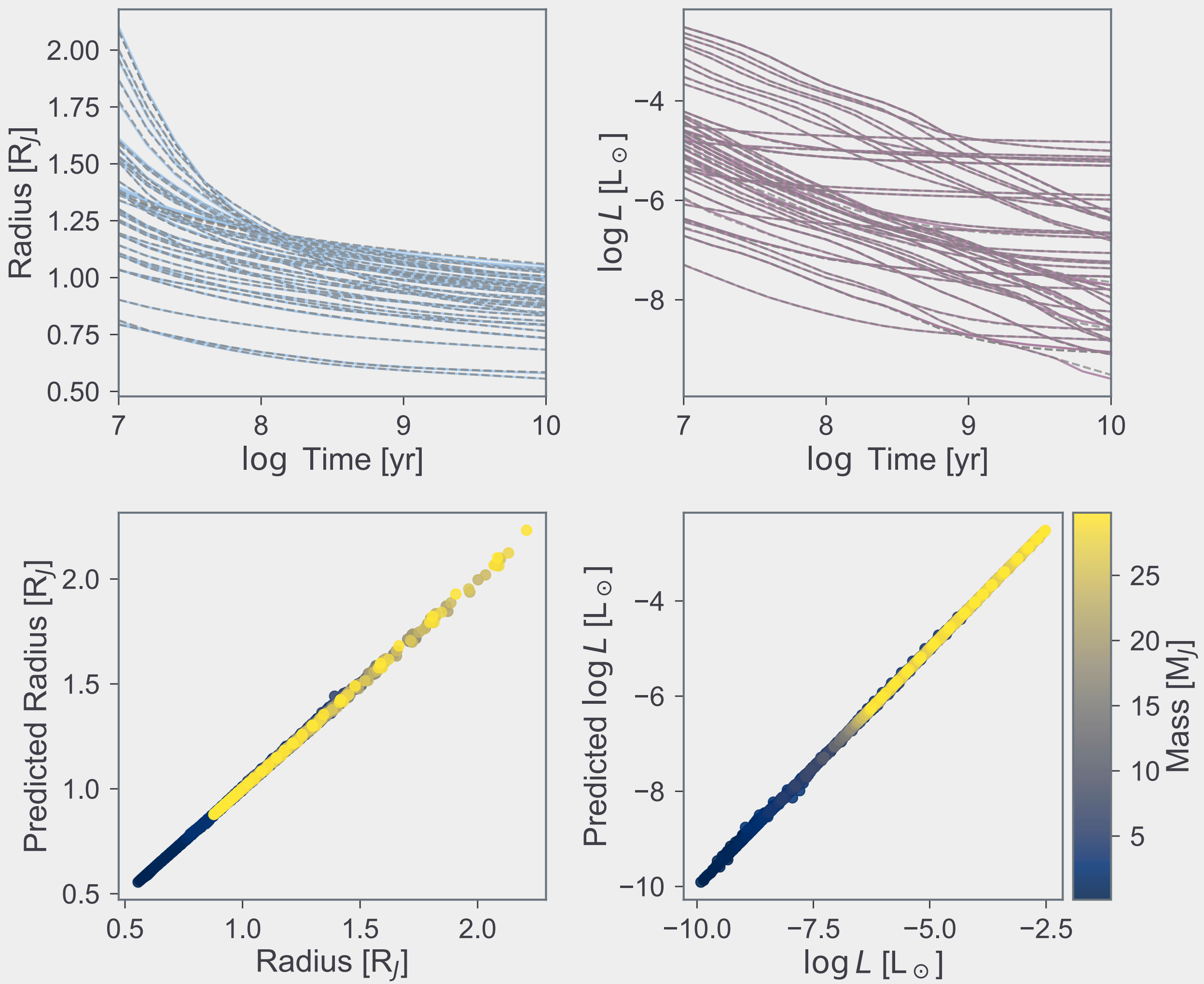
Is there an alternative?

planetsynth: A python module that generates giant planet cooling tracks

- Based on a large suite of evolution models calculated with MESA.
- The cooling tracks are generated by interpolation.
- Predict observables as a function of planetary mass, bulk & atmospheric metallicity and incident stellar irradiation.

Input: M, Z, Z_{env}, I_*

Output: $R(t), L(t), g(t)$



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planetsynth is accurate, *easy-to-use* and fast

```python
from planetsynth import PlanetSynth

logt = 9  # log(planetary age) in yrs
M = 0.4  # mass in Jupiter masses
Z = 0.2  # bulk heavy-element content (mass fraction)
Ze = 0.02  # atmospheric metallicity (mass fraction)
logF = 5  # log(incident stellar irradiation) in erg/s/cm2
planet_params = [M, Z, Ze, logF]

pls = PlanetSynth()
pls.predict(logt, planet_params)
```

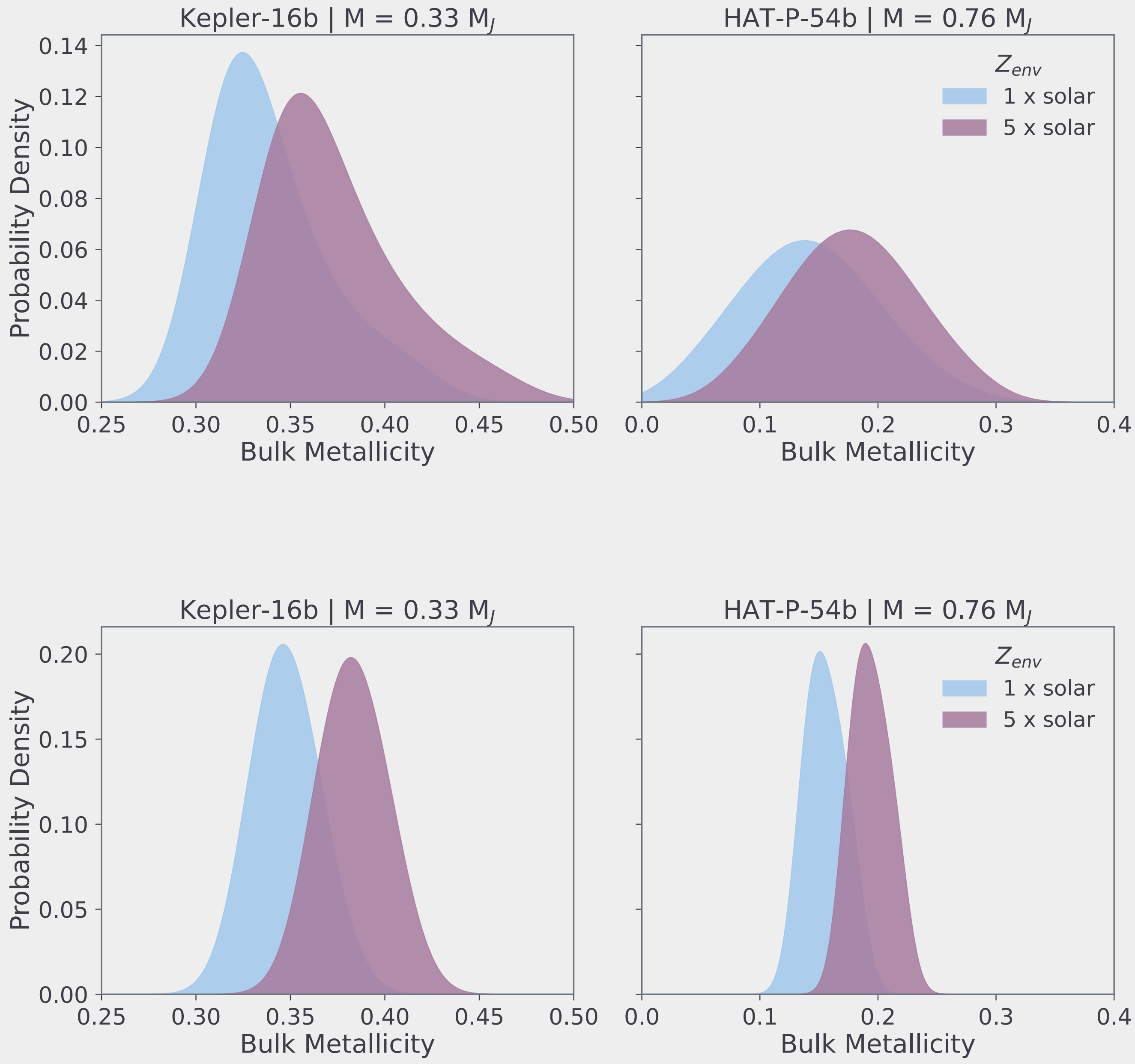
```python
import numpy as np
from planetsynth import PlanetSynth

num_samples = 1_000_000
M = np.random.uniform(0.3, 30, num_samples)
Z = np.random.uniform(0.012, 0.036, num_samples)
Ze = np.random.uniform(0, 0.012, num_samples)
logF = np.random.uniform(1, 7, num_samples)
planet_params = np.array([M, Z, Ze, logF]).T

pls = PlanetSynth()
%timeit pls.synthesize(planet_params)
```

```
9.41 s ± 94.4 ms per loop (mean ± std. dev. of 7 runs, 1 loop each)
```

Inferring Metallicities from Mass-Radius Measurements

- Top: Inferred metallicities based on actual measurements and their uncertainties
- Bottom: Inferred metallicities based on expected measurement uncertainties in the near future

Accounting for non-solar atmospheric metallicities is important with future observations.



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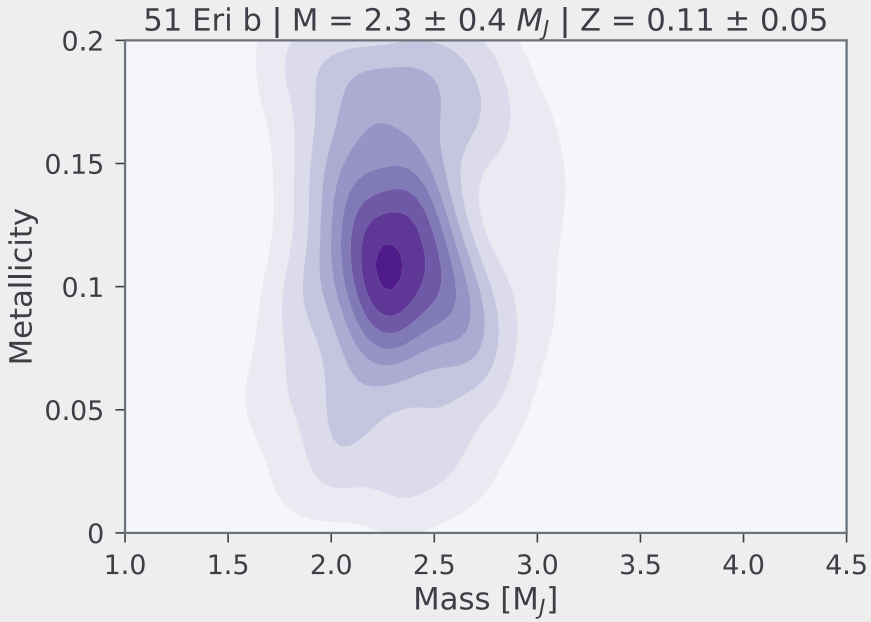
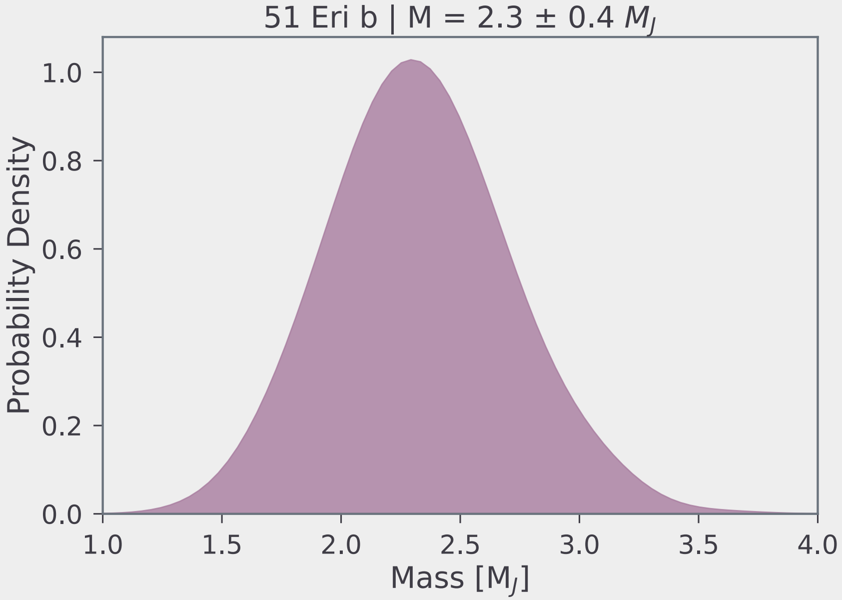
Inferring Metallicities from Luminosity Measurements

- Giant planets can be observed by detecting their thermal emissions (JWST)
- The mass is commonly inferred by using tables of mass-dependent evolution tracks (e.g., Baraffe et al. 2003)

Here:

- Use the observed luminosity of 51 Eri b to infer its mass and bulk metallicity with synthetic cooling tracks.
- Prediction: $M = 2.3 \pm 0.4\ M_J \mid Z = 0.11 \pm 0.05$
- Slightly higher than previous estimates of $\simeq 2\ M_J$ (Macintosh et al. 2015)





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Summary

Giant planet evolution models are an indispensable tool to connect observations and theory.

- *planetsynth* is a fast, accurate and easy-to-use alternative to evolution calculations, with many applications.
- It can be used to, for example, characterise giant planets from combined radial velocity & transit observations or direct imaging.

https://github.com/tiny-hippo/planetsynth