Atmosphere Origin For Exoplanet Sub-Neptunes

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Kangning Diao Nov. 12th 2021

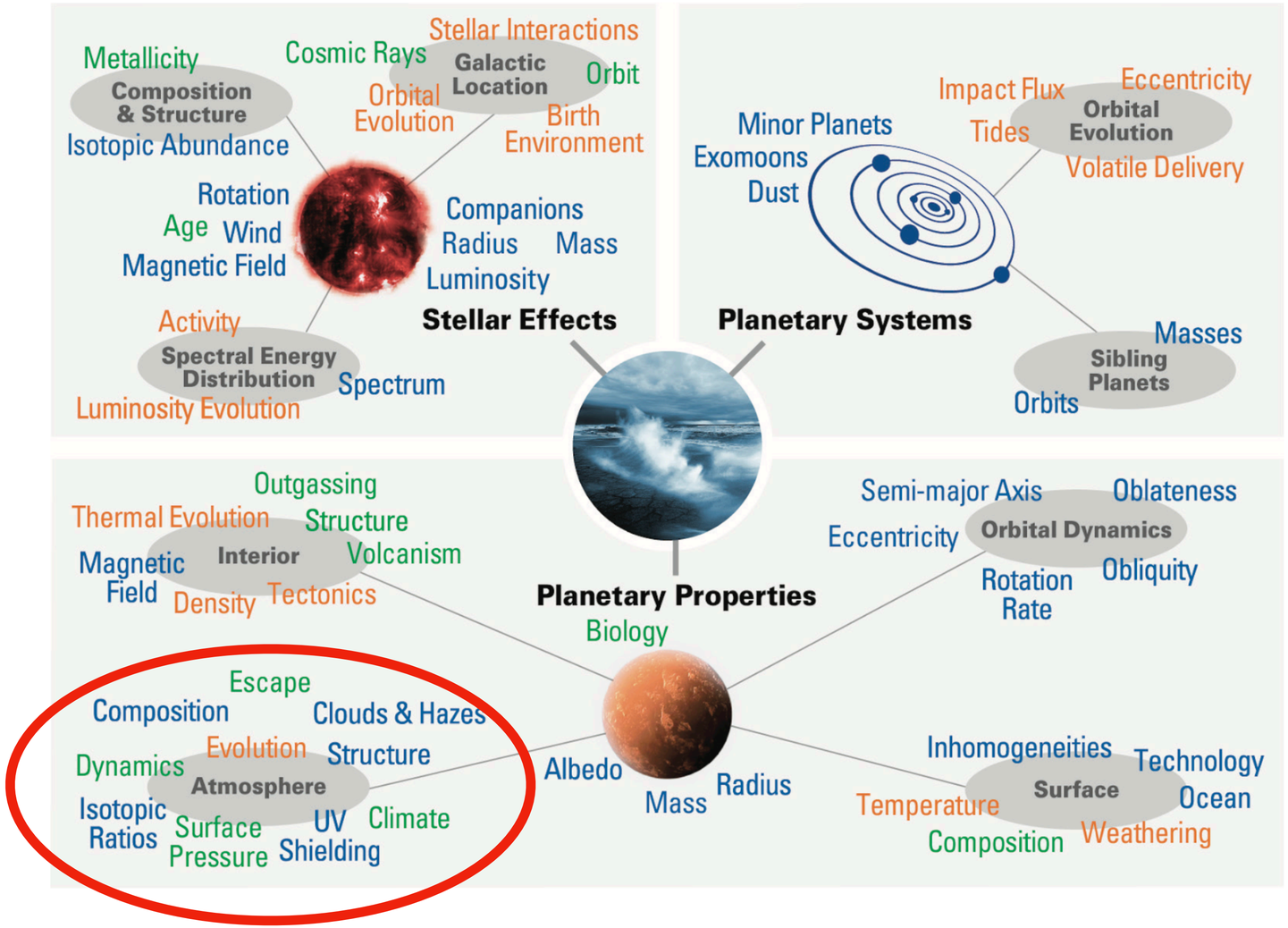
Background

Why atmosphere?

- Ultimate goal: find a habitat planet

- Constrain volatile delivery, planet formation…

Things that can influence the habitability

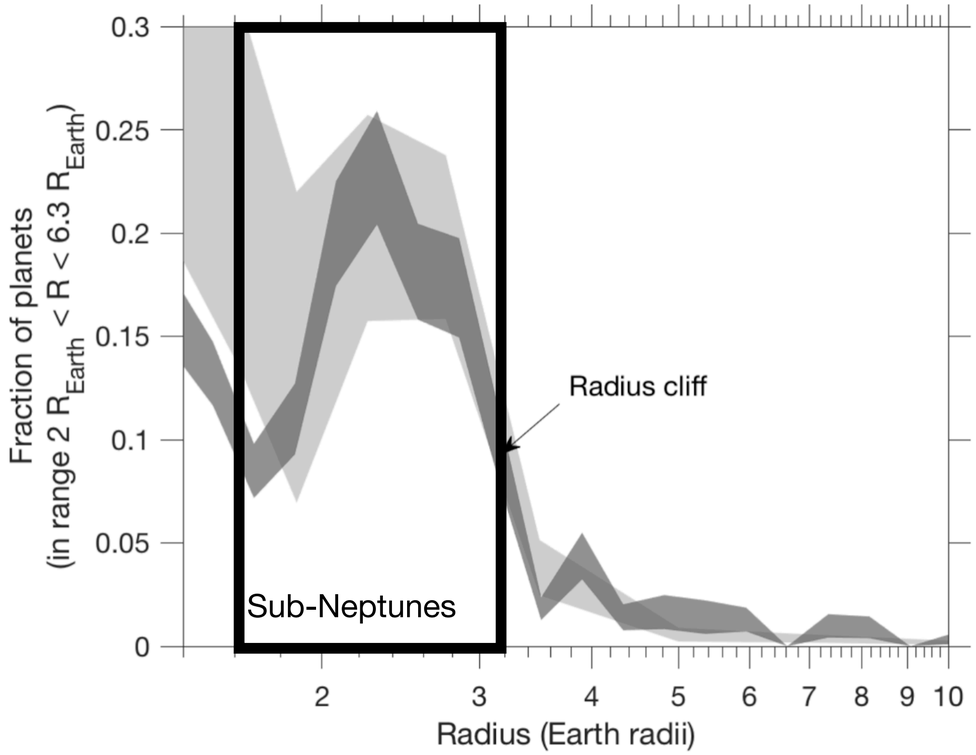


Background

Why sub-Neptune?

- $1.6 - 3.2 R_{\oplus}$, density $< 4 g/cm^3$

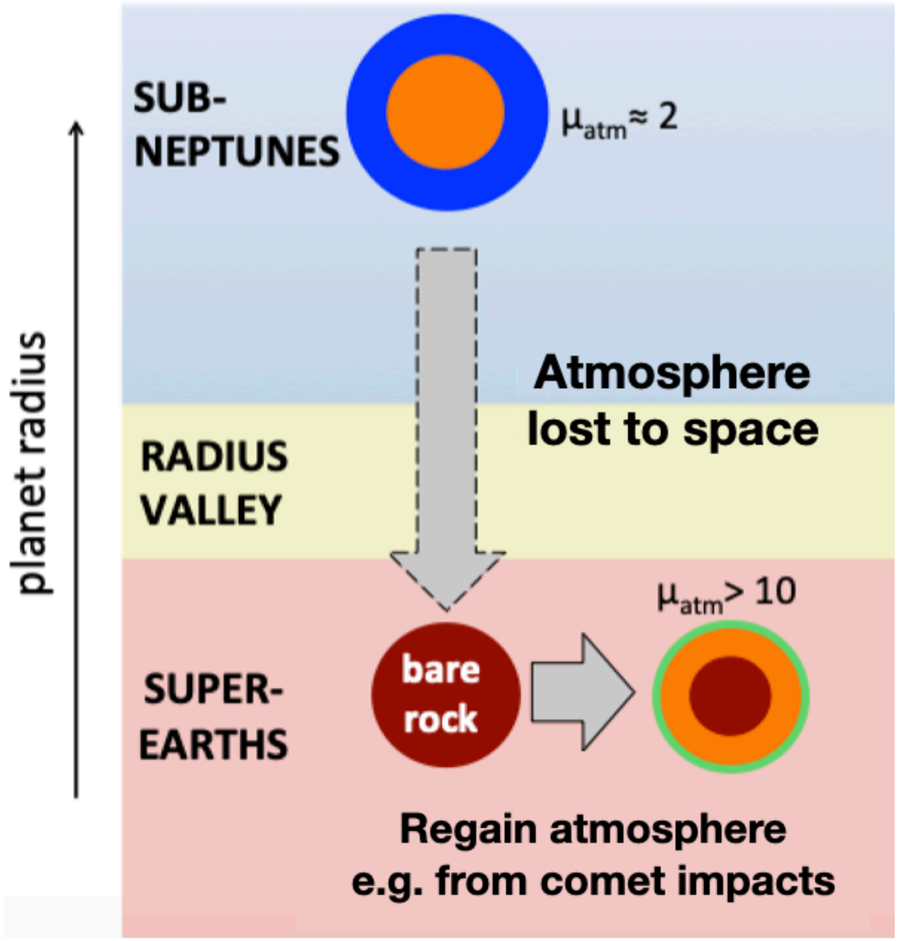
- They are abundant



Background

Why sub-Neptune?

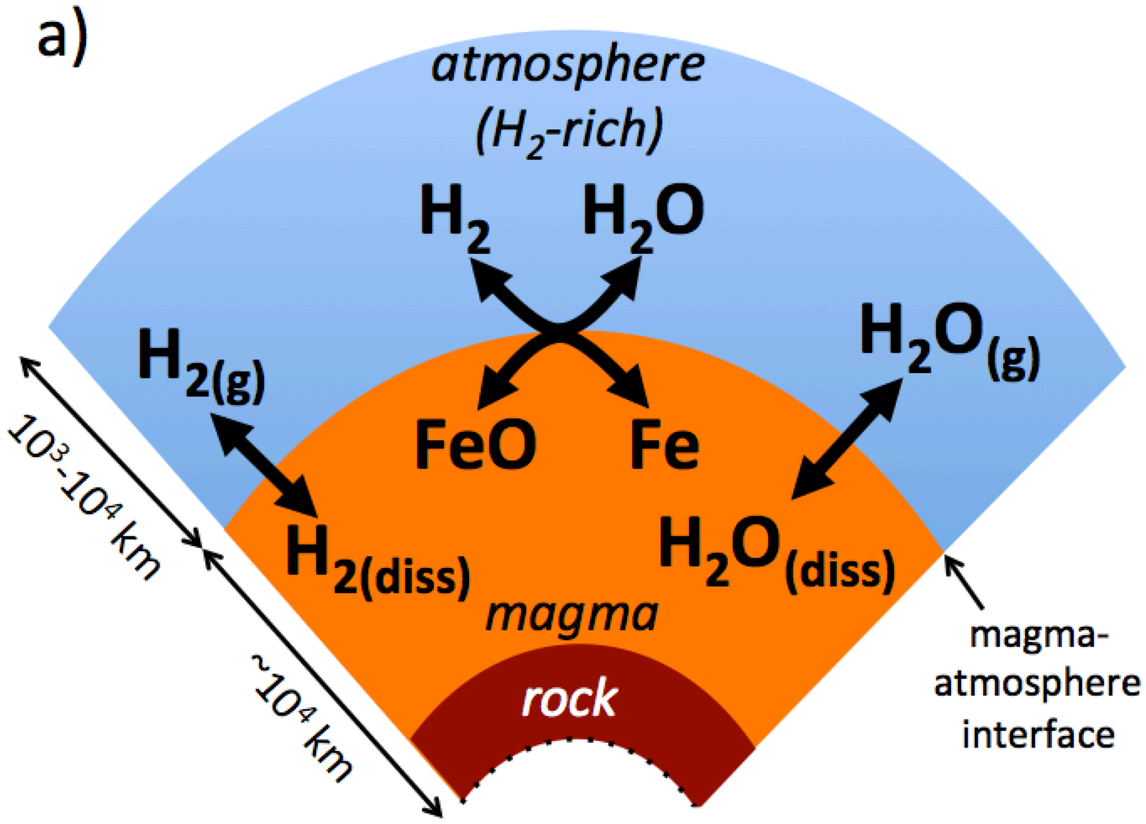
- $1.6 - 3.2 R_{\oplus}$, density $< 4 g/cm^3$
- They are abundant
- Super-Earth may come from them
- Observations towards their atmosphere is underway



Background

What do we already know?

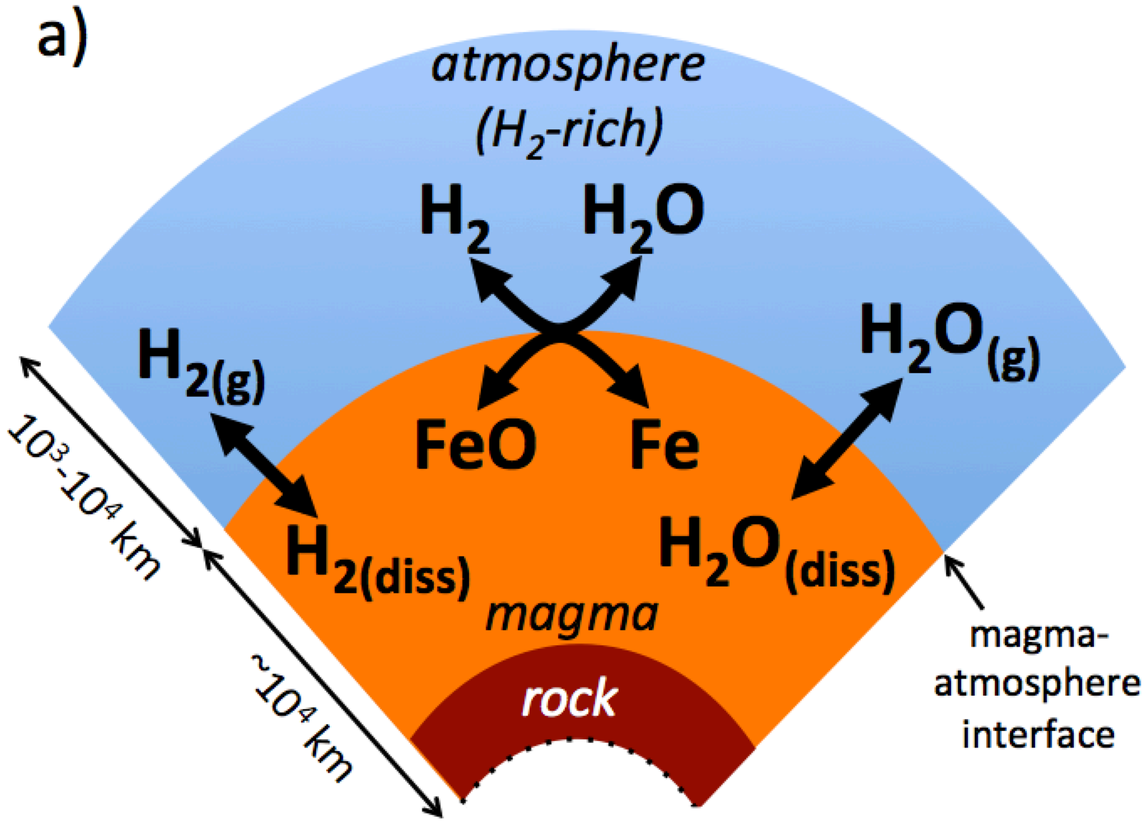
- Rock-Magma-Atmosphere
- The possible important physical and chemical reactions
- Previous work ignored the effect of these reactions on atmosphere



Methodology

Build up a model

- Contents:
  Mg, Fe, Si, O, H
- Reactions:
  Fe redox:
  $$\mathrm{Fe(liq) + H_2O(g) \Longleftrightarrow FeO(liq) + H_2(g)}$$
  Gas dissolution
- Environment:
  3000K
  At the interface
  Strong convection



Methodology

Model parameters

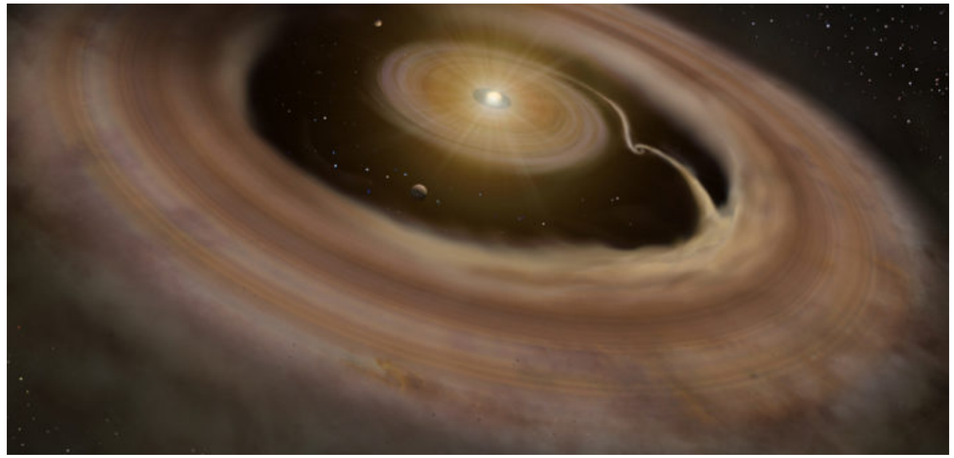
- Initial volatile: H_2,H_2O

  volatile: compounds that vaporize easier than water.

- Two ways are considered here:

  accreting nebula hydrogen
  come with external objects like comets

Accreting hydrogen



vs

External water

Methodology

Model parameters

- Magma content: mass weight of oxidized FeO and reduced Fe

$$Fe(liq) + H_2O(g) \Longleftarrow FeO(liq) + H_2(g)$$

Or

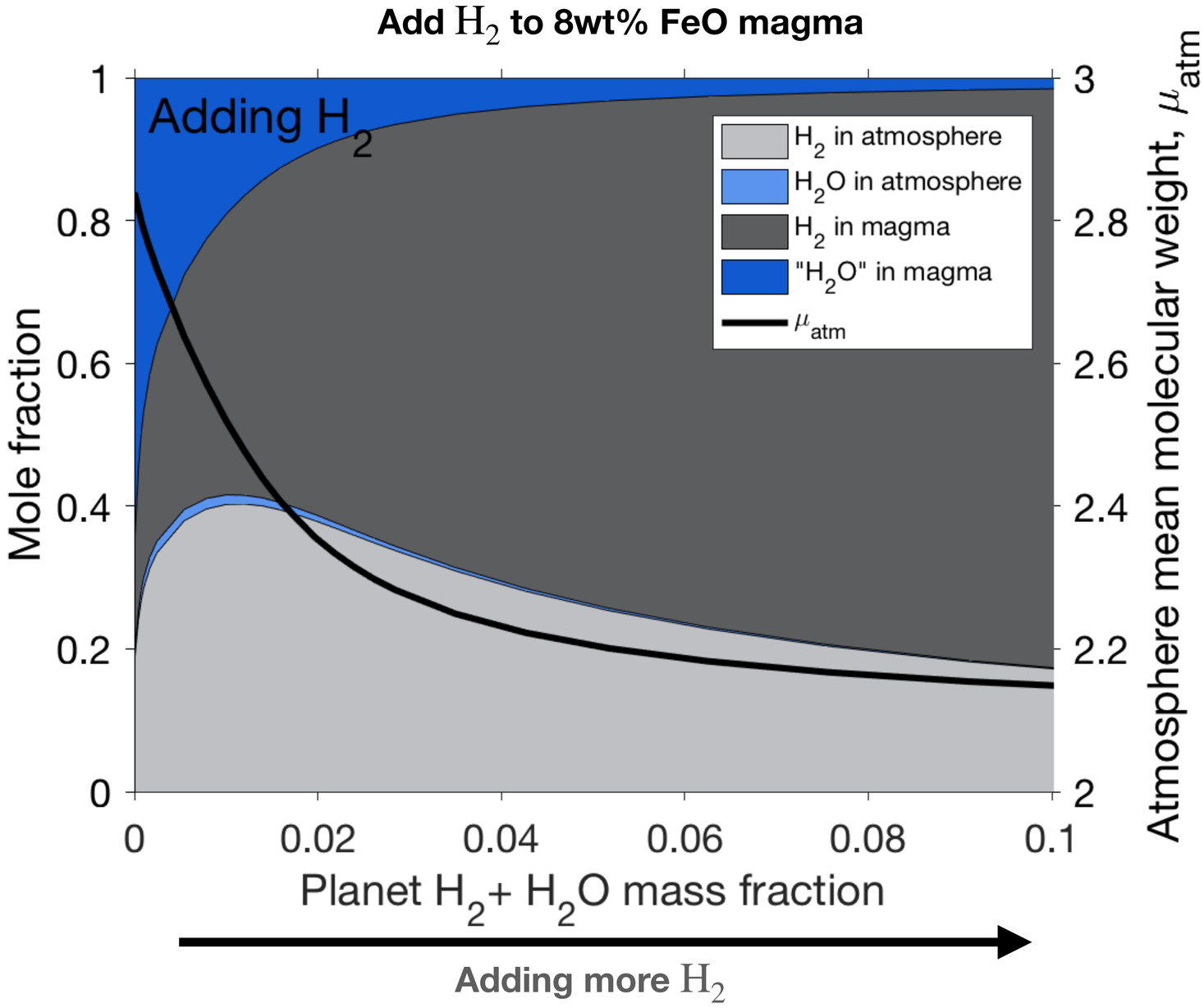
$$Fe(liq) + H_2O(g) \Longrightarrow FeO(liq) + H_2(g)$$

Results

Magma matters

- Most of gas are in the magma

- Redox reactions have a big impact

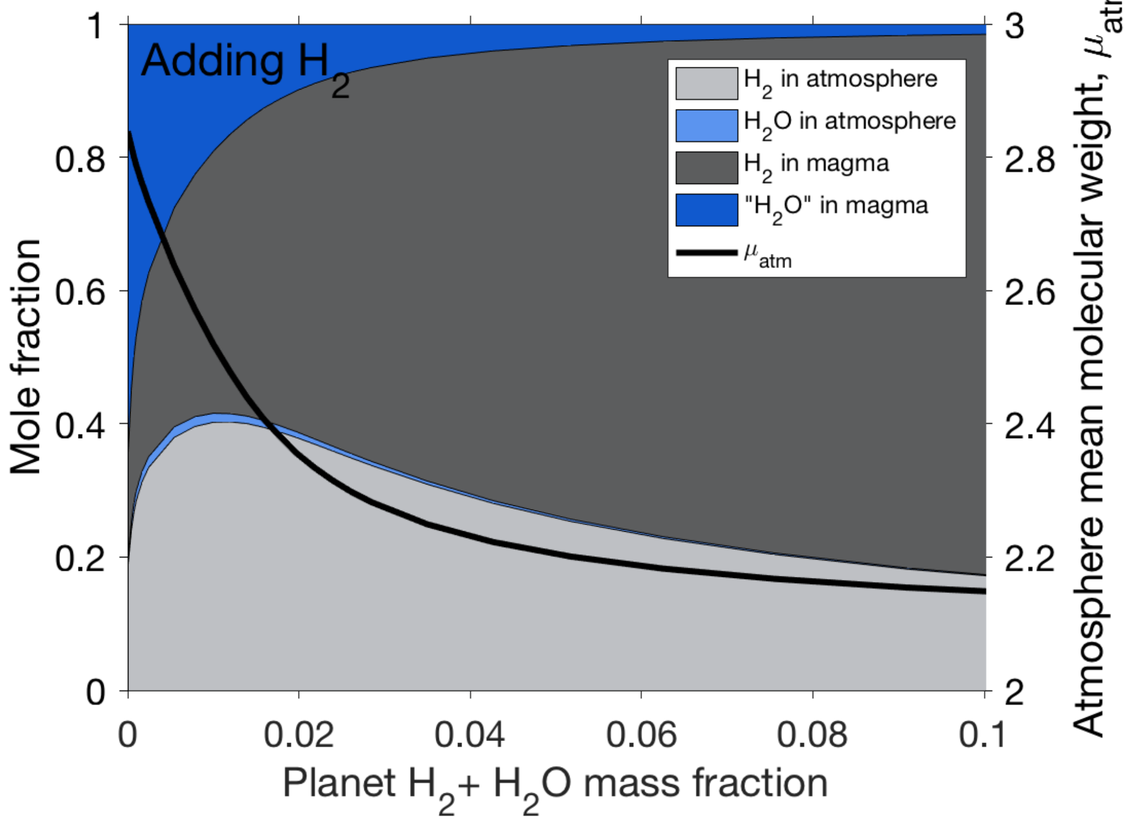


Results

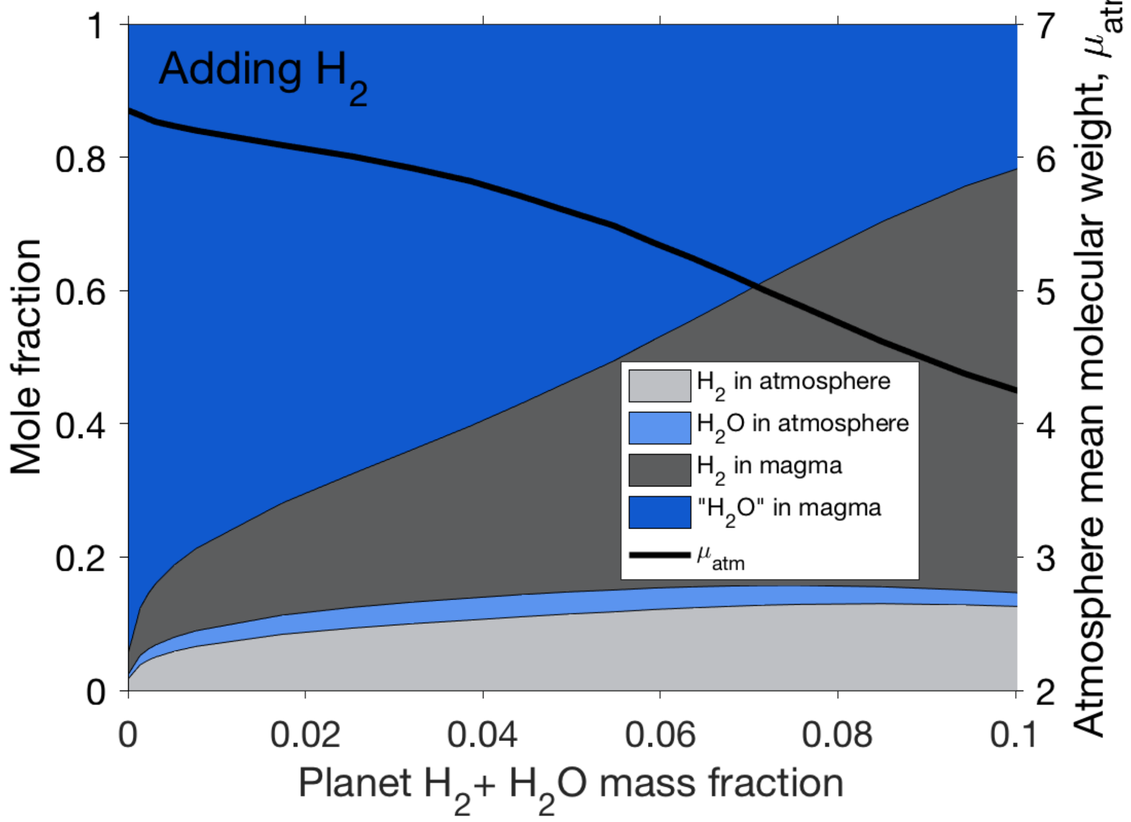
Magma matters

Redox matters!

Add H_2 to 8% FeO magma



Add H_2 to 49% FeO magma

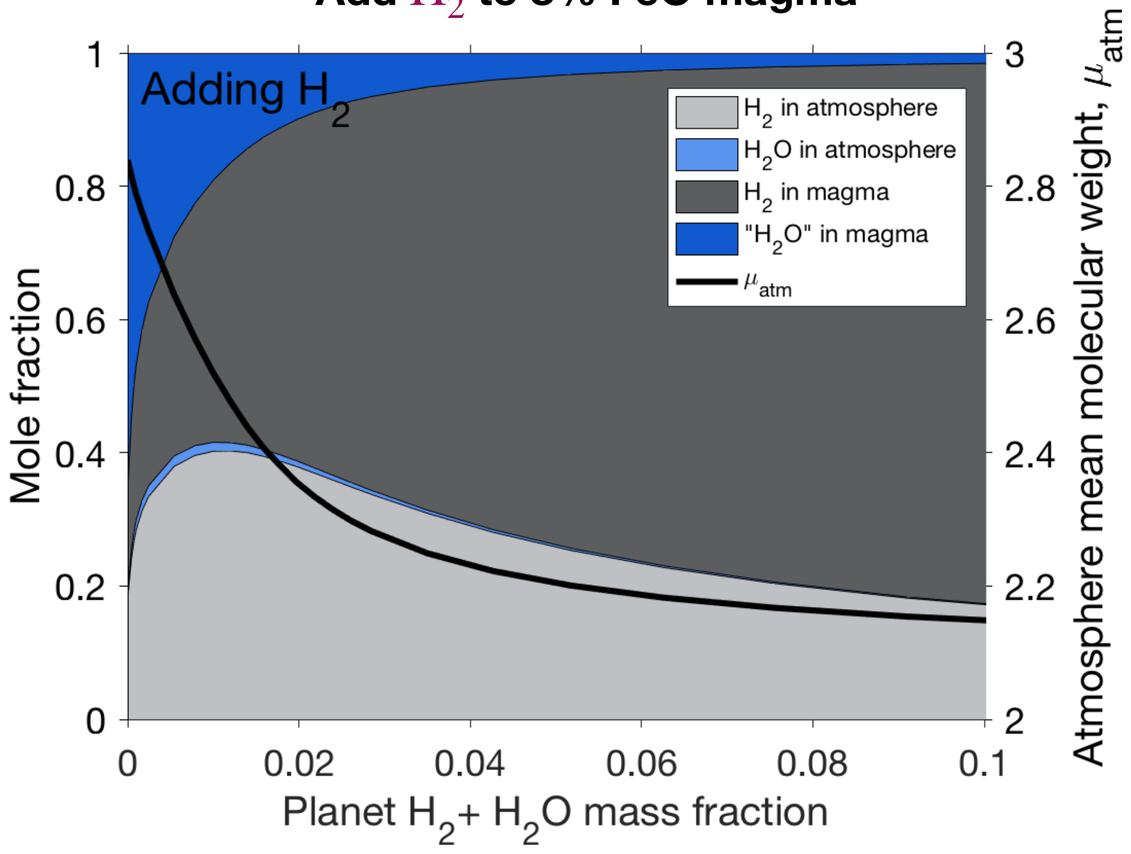


Results

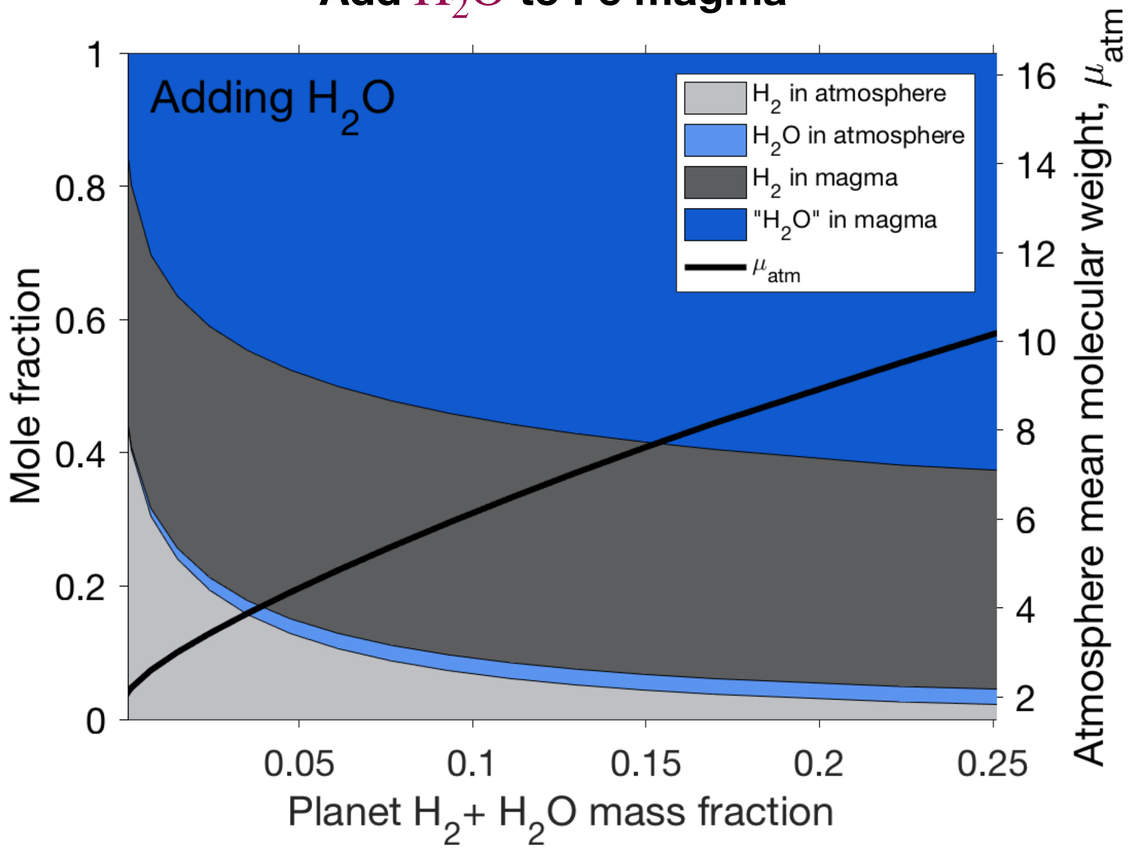
Magma matters

Initial volatile matters!

Add H_2 to 8% FeO magma



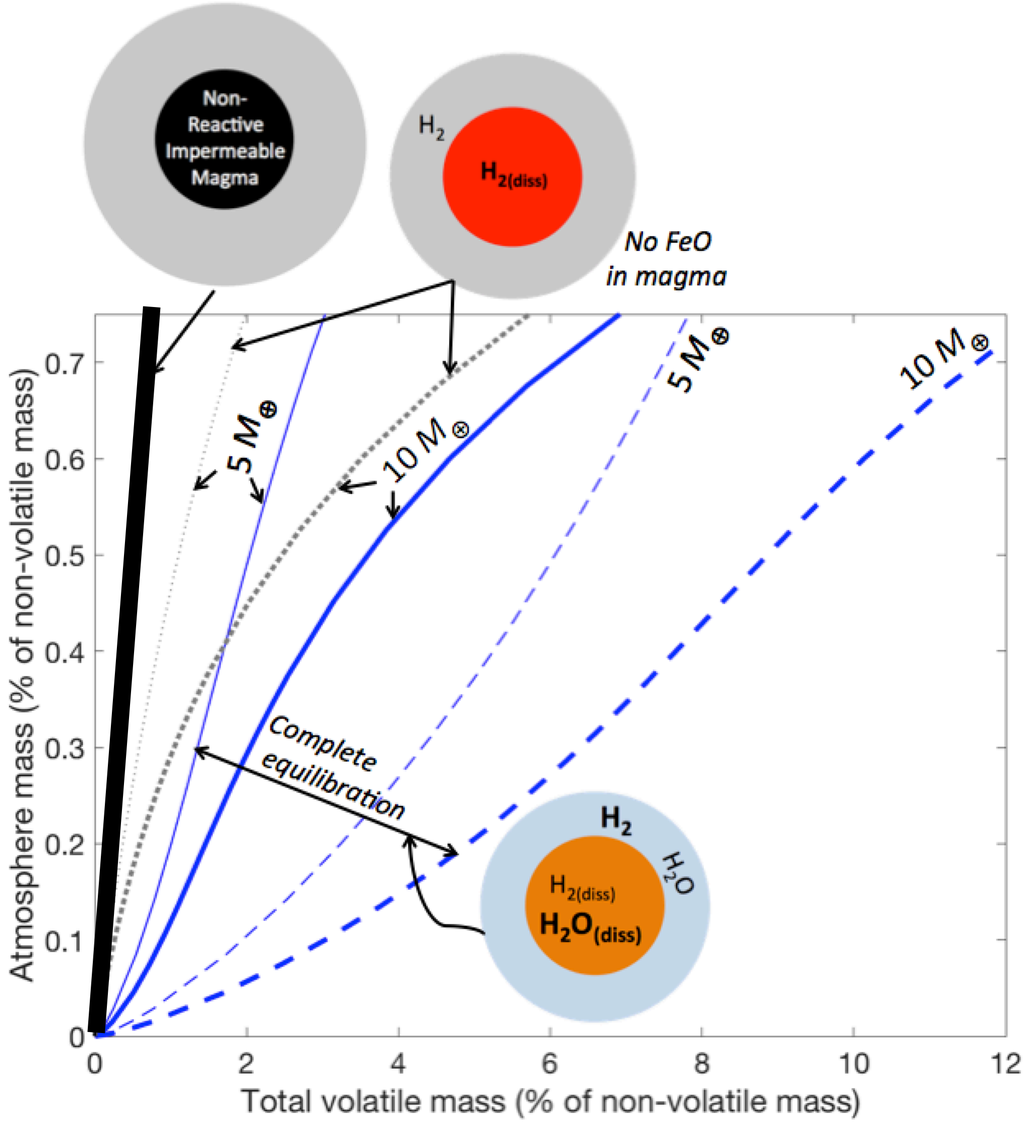
Add H_2O to Fe magma



Analysis

Volatile mass are variables

- Previous thought: Volatile mass can be derived from radius/atmosphere mass (Black line in the figure)



Analysis

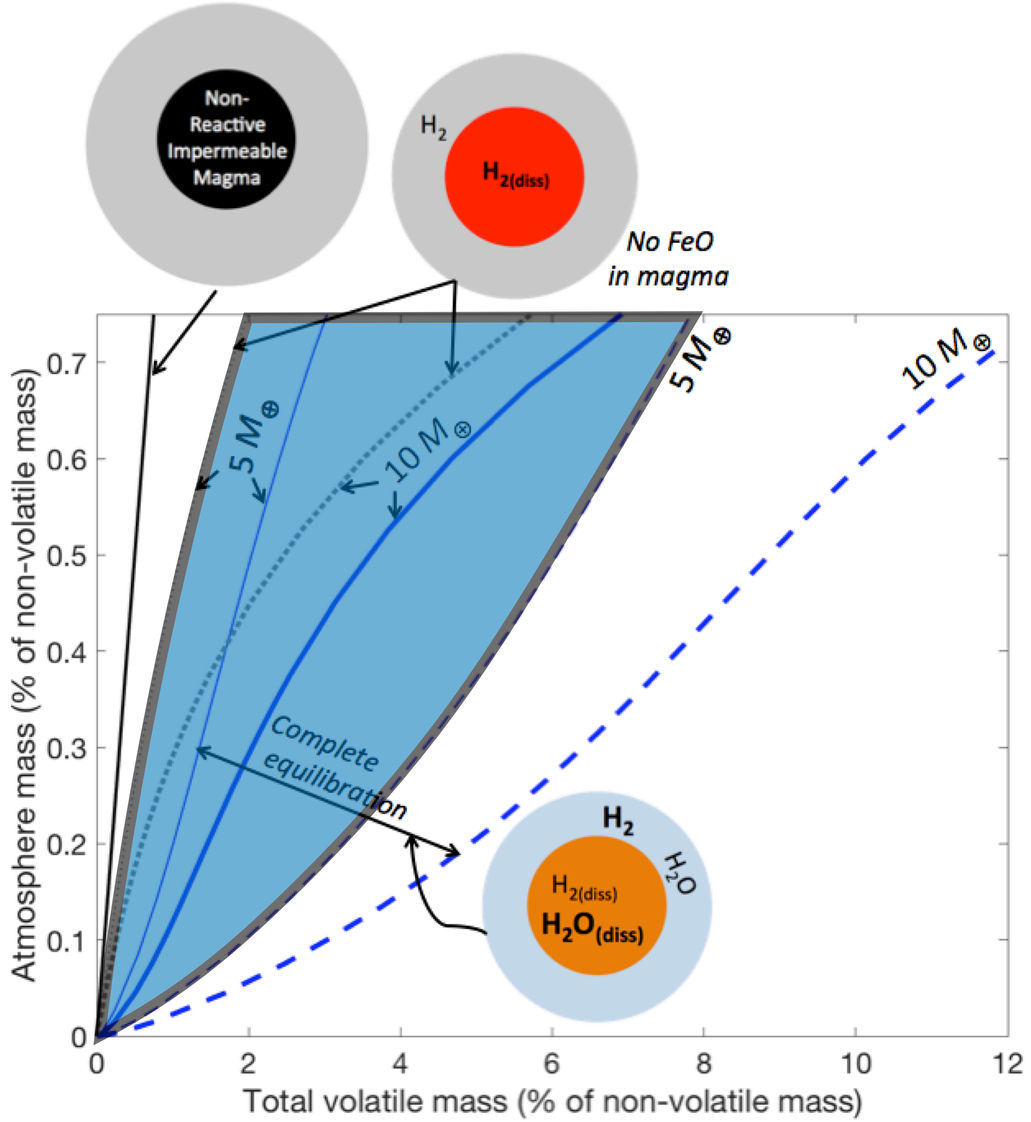
Volatile mass are variables

- Previous thought: Volatile mass can be derived from radius/atmosphere mass (Black line in the figure)

- This work:

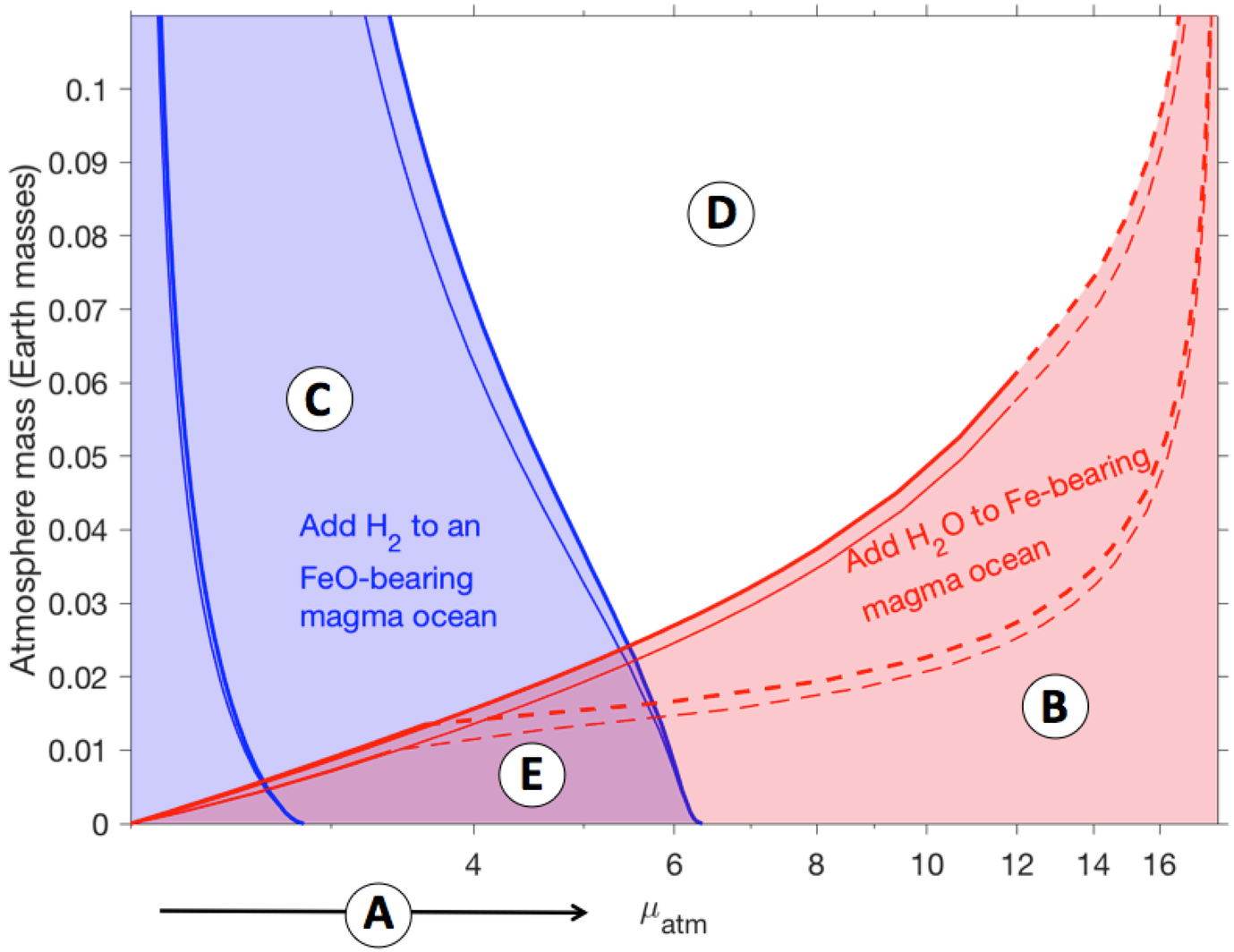
  More volatiles
  Big uncertainties

- The loss of atmosphere may be much harder



Analysis

Probe of atmosphere origin

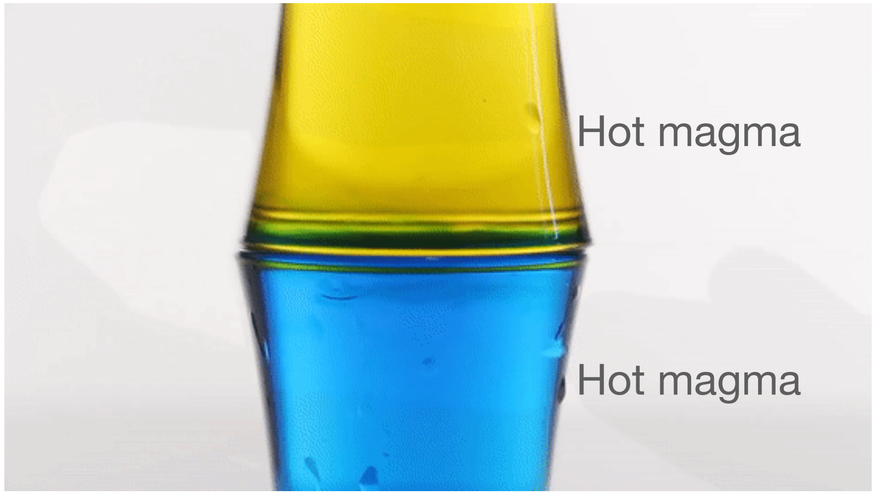


Analysis

How to test this theory?

- Previous thought: radius shrink with age

- This work: quicker shrink!



Cooling

Well-stirred magma leads to complete reaction

Conclusion

Or takehome massage

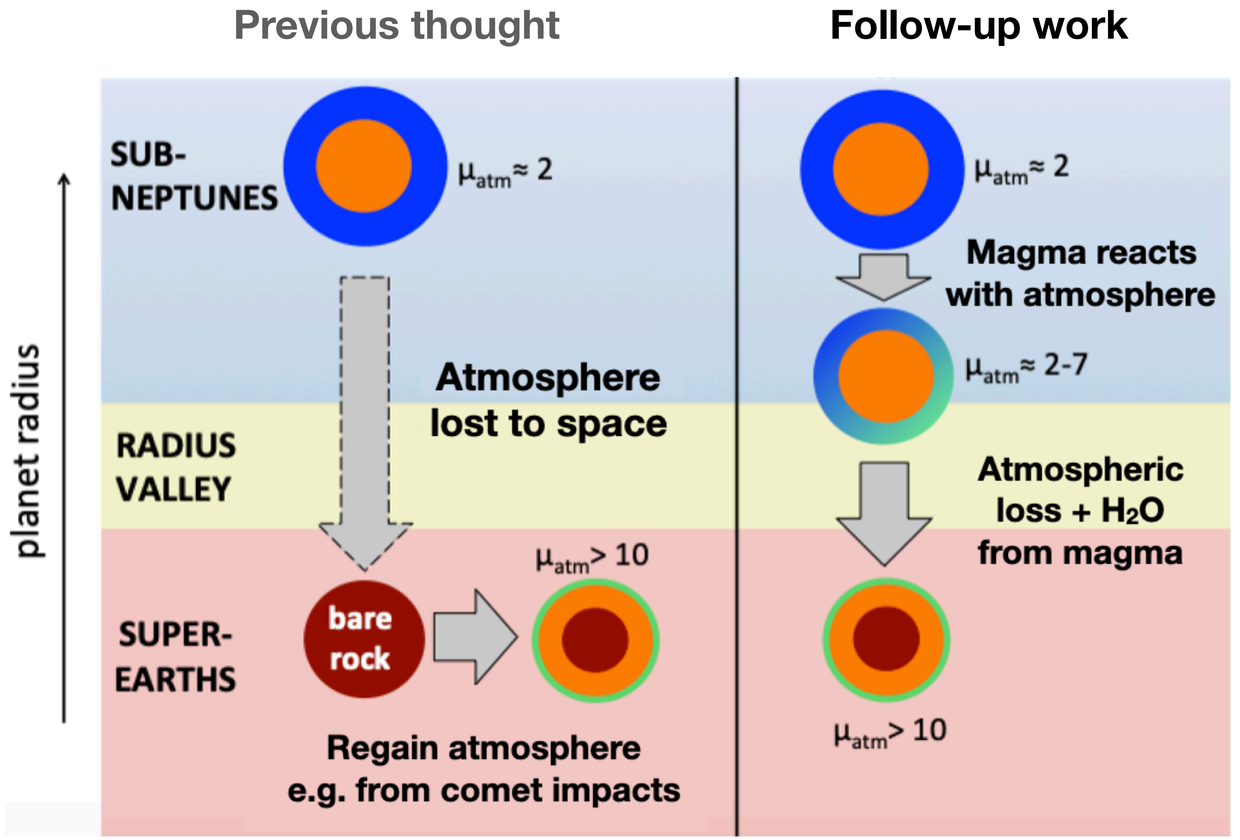
- Magma matters
- Observation of atmosphere can trace its origin
- Magma-atmosphere interaction can be tested

Possible Questions

- How to measure the mean molecular weight / atmosphere mass?
- Is there any observations of sub-Neptune atmosphere?
- Can initial volatiles be both water and hydrogen?

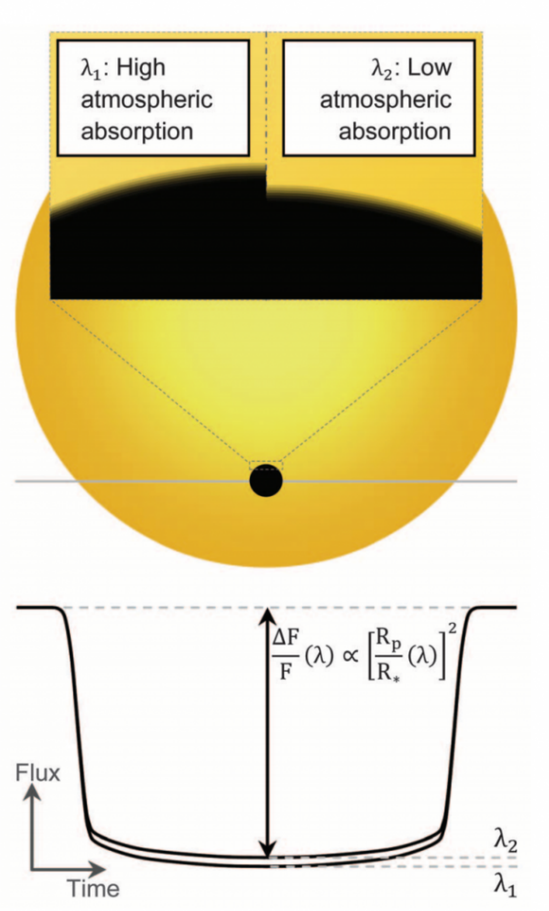
Discussion

- Too simplified
- Uncertainty of existing theory/ assumptions
- Reliability of chemical data



- Interesting follow-up: another way to form Super-earth

Observe the atmosphere



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