The effects of terrestrial exoplanet bulk composition on long-term planetary evolution

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Introduction

- Terrestrial planet composition affects **interior properties**, such as core size, mantle viscosity, and mantle melting behaviour.
- Bulk composition may therefore affect **volatile exchange** between interior and atmosphere, and may be profound to understanding atmospheric composition.
- Models of planet interior and interior-atmosphere interaction have not considered bulk interior composition so far. **First step**: constrain diversity in bulk planet compositions.
- **Stellar abundances**: significant compositional diversity in Solar neighbourhood.
- **Aim: Constrain range of bulk terrestrial exoplanet compositions based on stellar abundances.**

From stellar to planetary compositions

- Stellar abundances from **Hypatia catalogue**[1]
- Exoplanet compositions based on compositional (devolatilization) trend between Sun and Earth (fig. 1)[2]
- Apply trend to simulate hypothetical rocky exoplanets with the same formational history as Earth, around stars in Hypatia catalogue

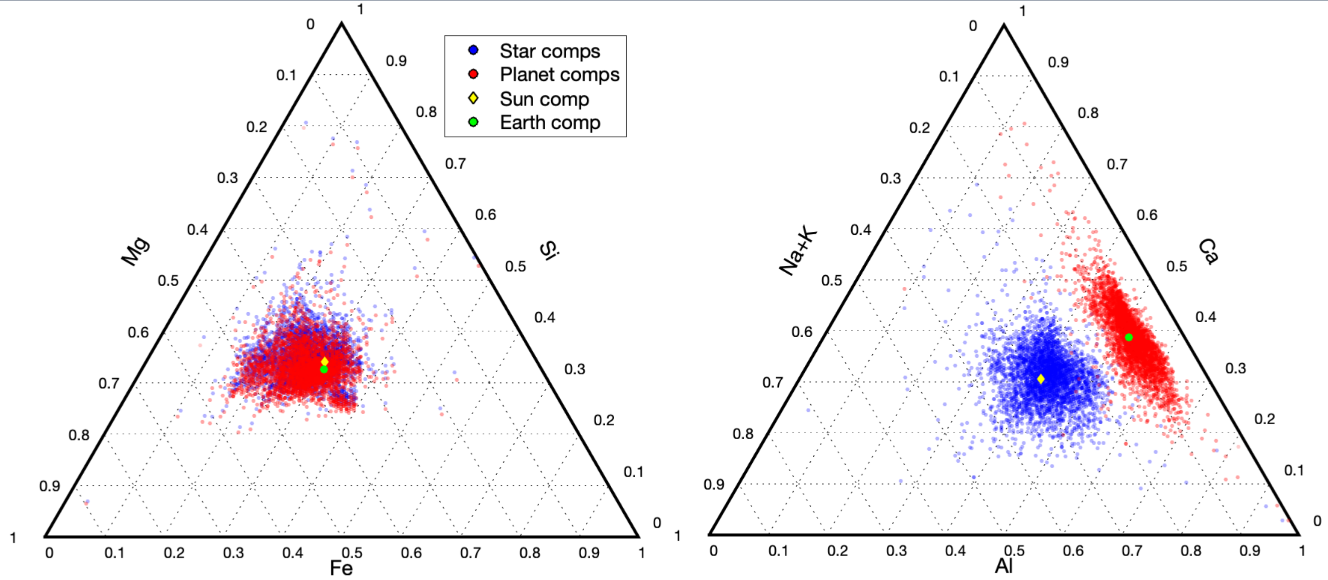


Figure 2: *Compositions of stars (blue) from the Hypatia catalog[1] and the corresponding planetary compositions, after applying the devolatilization trend[2].*

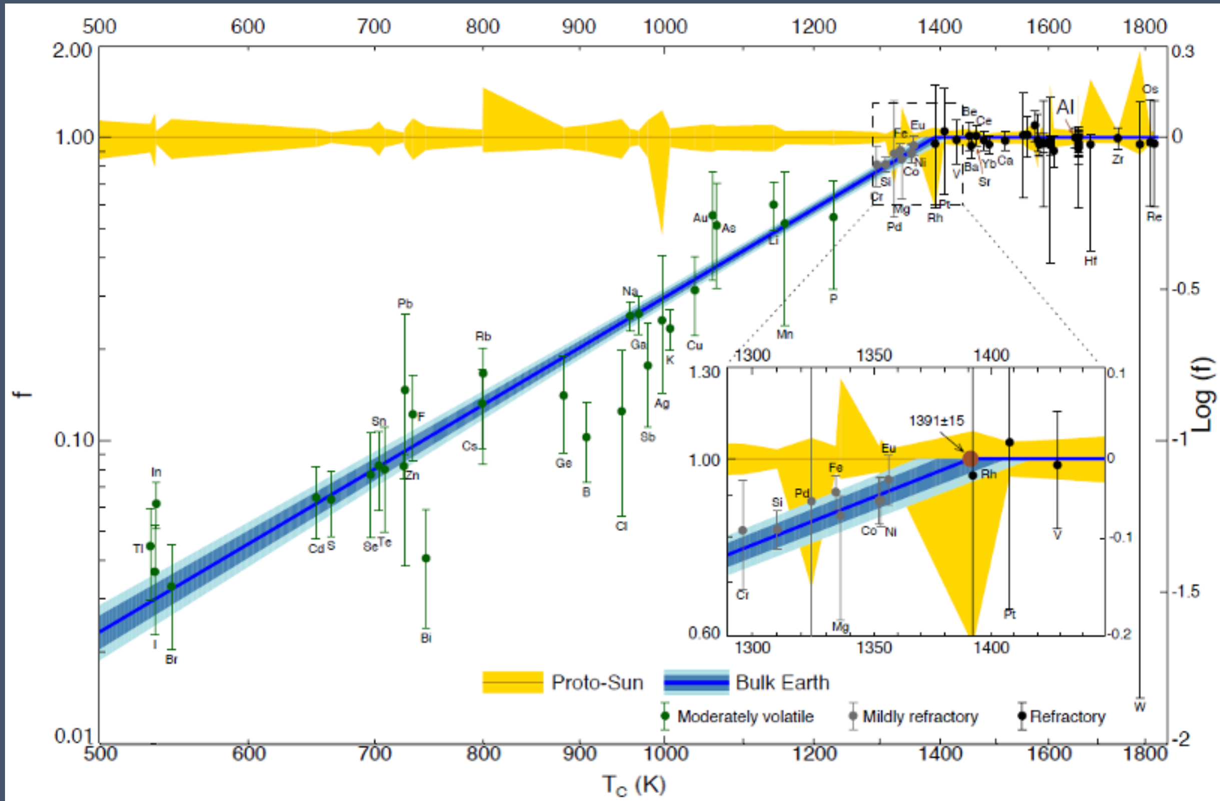


Figure 1: *Devolatilization trend[2]. The elemental abundance ratios between Earth and Sun, $f = X_{Earth}/X_{Sun}$, normalized to a very refractory element (Al), is plotted against the condensation temperature of each element[3]. It shows a trend of increasing depletion for more volatile elements.*

Planet compositions

Bulk compositions

- We consider elements O, Na, Mg, Al, Si, S, K, Ca, Fe, Ni.
- Core-mantle differentiation: 2 methods
  - *Similar oxygen fugacity as Earth[4]: same bulk Fe/FeO*
  - *Base oxygen on stellar oxygen abundances. Assume that most planets have a metallic core, and some iron in the mantle.*
  - *Combine them for more comprehensive method*
- Core composition[5]: Fe/Ni = 18±4; 6 wt% Si, 2wt% O, all S

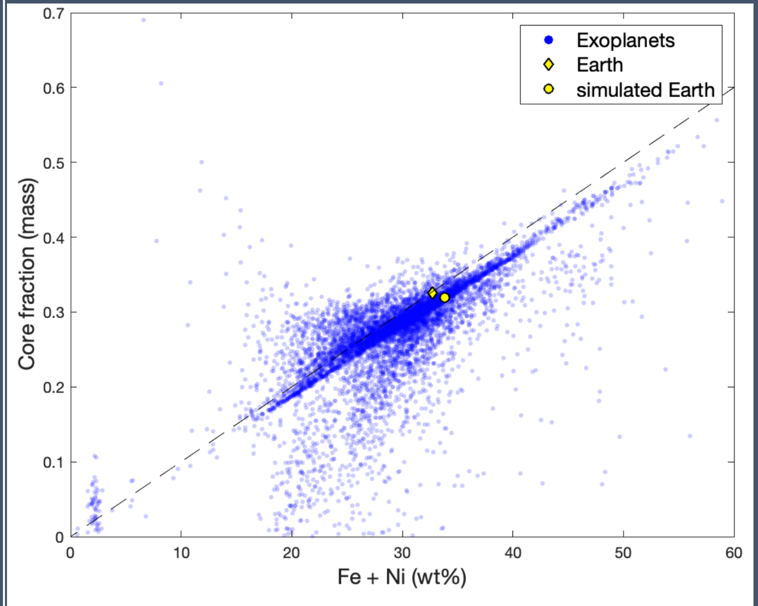


Figure 3: Core sizes (in mass fraction) of simulated planets, as a function of bulk planet Fe+Ni weight fraction. Dashed line is maximum core size of pure Fe+Ni core. Sizes are larger because of presence of O, Si, and S in core.

Mantle compositions

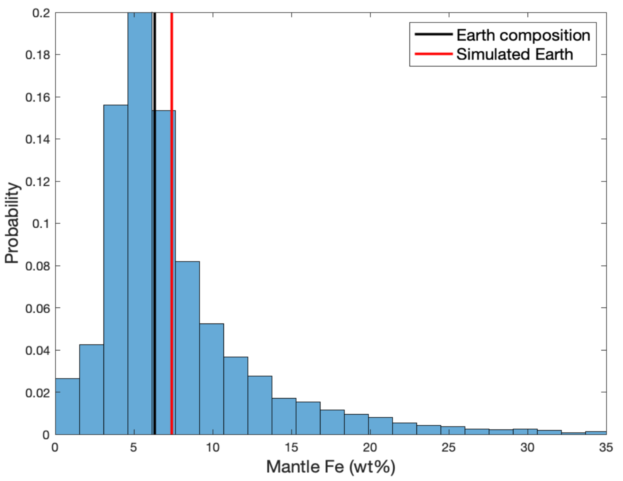
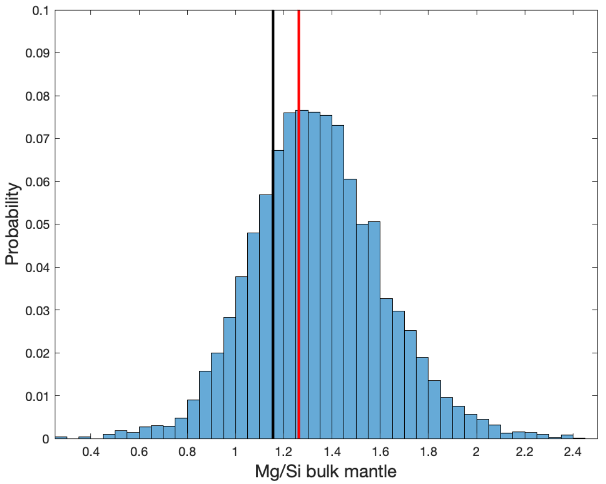
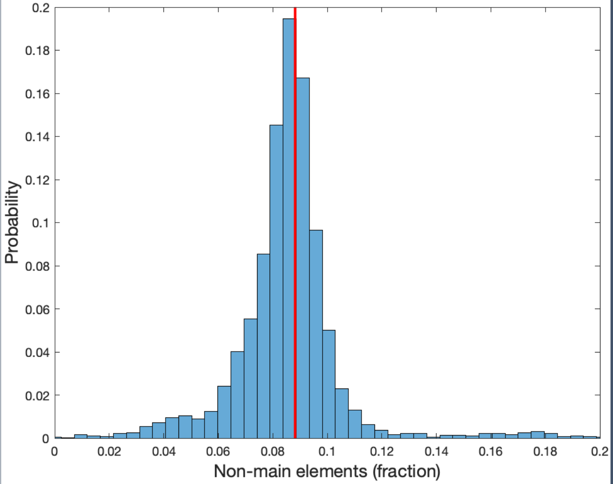


Figure 4: Mantle iron content (upper left), in wt%. Molar mantle Mg/Si-rations (lower left). Mantle fraction not consisting of the most common oxides; MgO, FeO, or SiO_2 (right). The values are shown for simulated Earth (red) and Earth data[5] (black), for comparison.





Discussion

- **Effects of composition:** Mantle Mg/Si is an important control on mantle viscosity[6], which controls thermal and dynamical evolution of the interior. Mantle Fe content affects melting behaviour of the mantle[7].

- **Formation:** We assume Earth-like formation. Focuses on habitable zone planets. Venus- or Mars-like formation changes devolatilization trend, changing volatile element abundances. Can be done with our methodology by changing trend.

- **Core size:** We present results here for a single core composition. While this is dependent on formational processes, it is not likely to change the range of mantle compositions significantly.

- **Interior modeling:** Previously, we studied compositional effects on terrestrial planet evolution for a simple compositional model, in a 1D setting[8]. We have now updated the compositional model, and will continue with 2D studies in the near future.

- **Compositional range:** We present the likely range of bulk terrestrial exoplanet compositions in the Solar neighbourhood, and recommend using these statistics for future research into compositional effects in terrestrial planets.

Take-home messages and references

- Earth is fairly typical.
- Mantle **iron content** usually lies between 5 and 10 wt%.
- Mantle **Mg/Si-ratios** usually lie between 1.0 and 1.7.
- Exoplanet mantles consist for >90% if **MgO, FeO, and SiO_2.**
- This compositional range will have important effects on **planetary interior properties**, and will be incorporated in future work on planet interior modelling.

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