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Compositional variations within the TRAPPIST-1 planets

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Since stars and their planetary accretion disks are formed by the collapse of the same interstellar dust cloud, the composition of a star can be used as a first estimate for the upper limit of the composition of the accretion disk. However, the stellar composition of TRAPPIST-1 has not yet been determined. We therefore derive elemental abundances for the main planet-forming elements from the stellar metallicity using large-scale astronomical surveys (GALAH and Hypatia).

We then apply a stoichiometric model extended from Bitsch & Battistini (2020) to obtain a first-order estimate on the compositional variation of planetary building material depending on the local temperature within an accretion disk. In this approach, the gas within the accretion disk is assumed to have achieved the state of chemical equilibrium before condensation, with the complete set of molecules preexisting in the gas. Consequently, the relative abundance of molecules can be calculated

stochiometrically and based on their condensation temperature (Lodders 2003).

We assume a fixed temperature profile within the accretion disk and do not consider planet migration to obtain a first prediction of compositional variability within the TRAPPIST-1 accretion disk. Our predicted composition of the planetary building blocks of the seven planets in the system is shown in Fig. 1. We obtain three different compositional clusters including dominantly dry (b,c,d), water-rich (e,f) and water- and ammonium-rich building blocks.

We then apply our interior-structure model (Noack et al. 2016) employing look-up tables created with Perple_X (Connolly 2009) for thermodynamic properties of the silicate mantles. We apply an Earth-like mantle iron number of 0.1 (i.e. a magnesium number of 0.9) for the silicate mantle, which leads to a predicted core-mass fraction of 25% for the three inner-most planets (Carone et al. in review). This core-mass fraction leads to planet radii matching the observed values from Agol et al. (2021) for all thre planets, which suggests, that our compositional model is able to correctly predict the planetary composition of the TRAPPIST-1 planets and that their composition was not strongly altered during accretion (by e.g. impact erosion).

For the outer planets of the system, the appearance of volatiles adds a degeneracy to our interior structure, since melting processes during planet accretion implies volatile losses. The final planetary composition is therefore expected to be considerably less volatile-rich than predicted here for the planetary building blocks. Assuming the same mantle-core composition as for the three inner-most planets, our model suggests that the outer planets should have a maximum water fraction below 20 wt-% to match their observed radii, which is in accordance with earlier studies, even though here we apply our TRAPPIST-1 adapted compositional model instead of an Earth-like mineralogy.