Composition and Seismic Properties of the Martian Interior:

A multi-stage model of core formation

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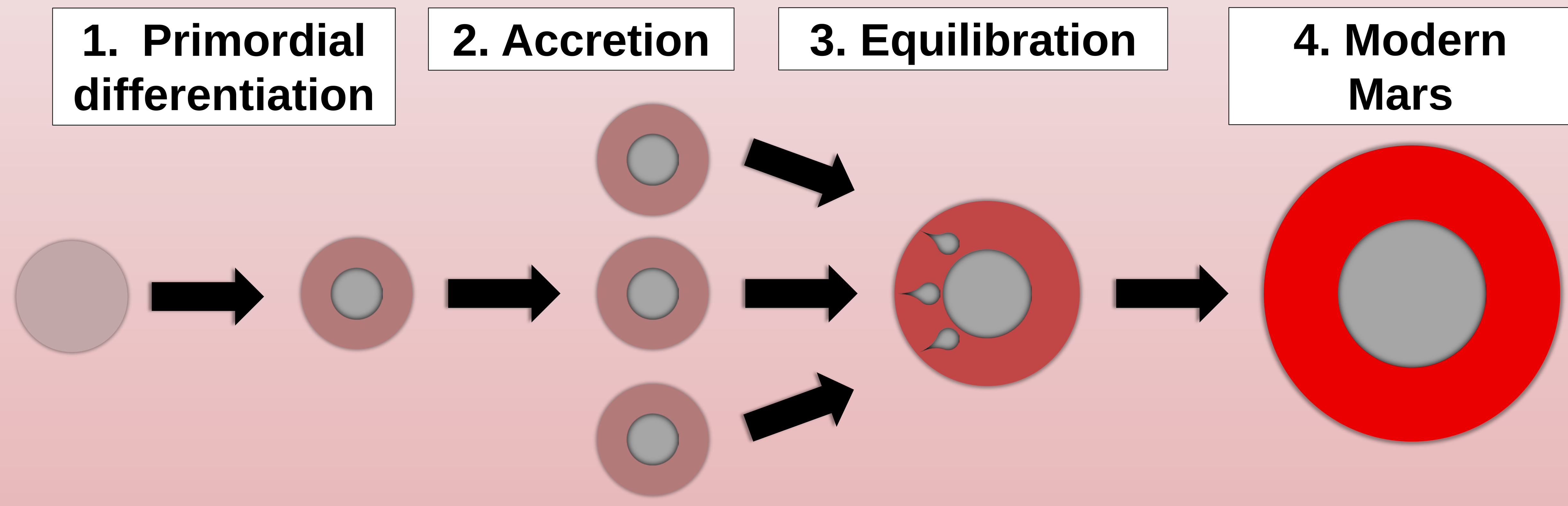
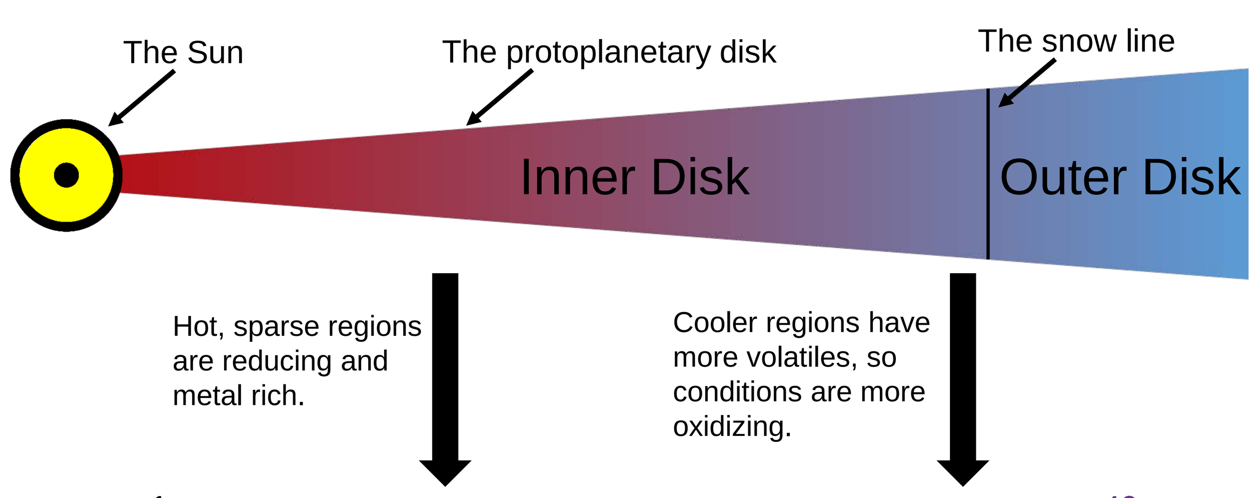


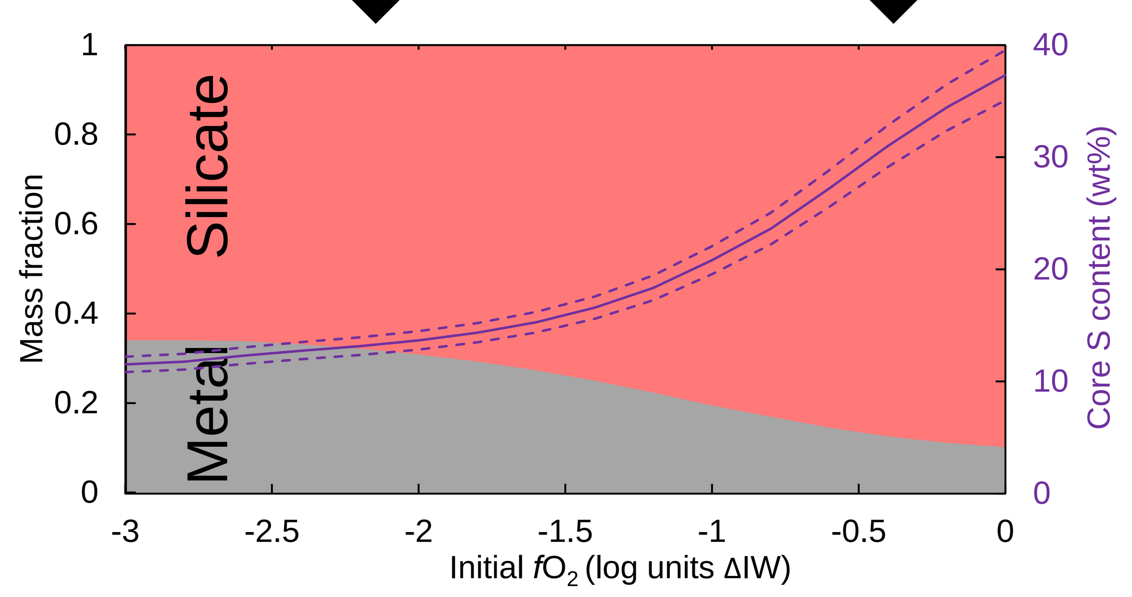
Introduction

- Terrestrial planets are made of silicate minerals and iron-rich metal.
- We can model planetary formation as partitioning between these two phases.
- This model accounts for geophysical and geochemical constraints, and quantifies the influence of **formational parameters** on the Martian core and mantle.

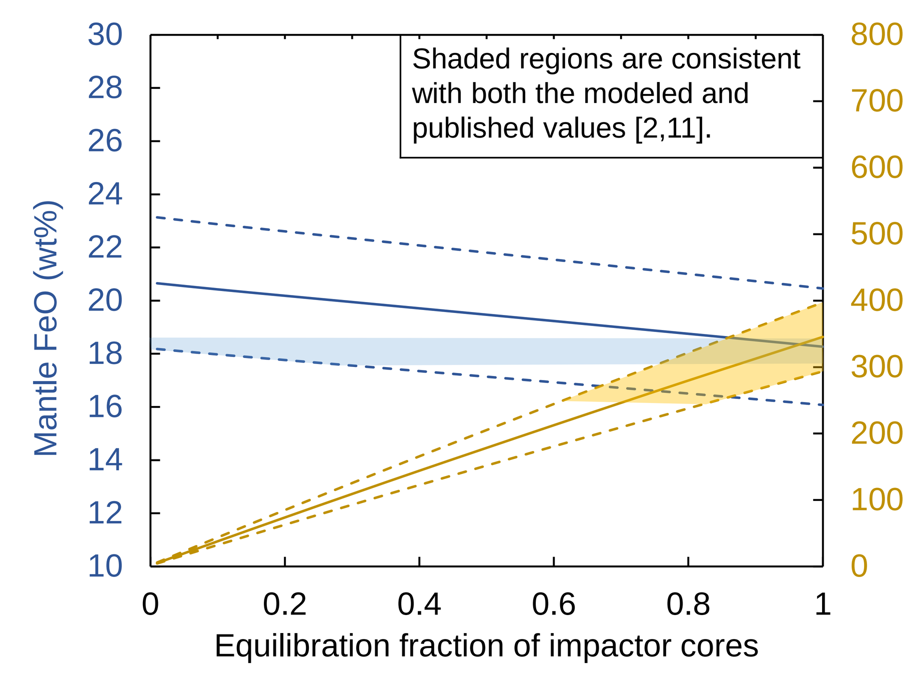
1. Small bodies are built and differentiated

- No single meteorite type matches the **bulk compositions** of the terrestrial planets [1]. Past studies have used various chondrite mixtures [2,3,4].
- We used CI material that was **partially depleted of volatile elements**.
- The **oxygen fugacity (fO_2)** of a body influences partitioning between the core and mantle.
- Martian rocks are rich in oxidized iron (FeO). This indicates a higher fO_2, which may be due to Mars' distance from the Sun [5].



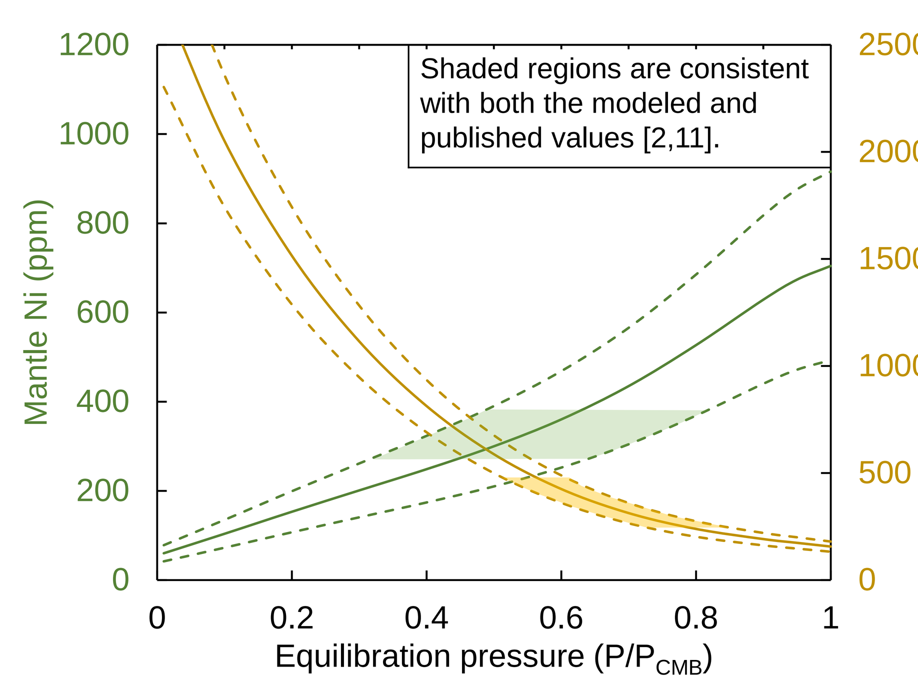


2. The small bodies accrete to proto-Mars



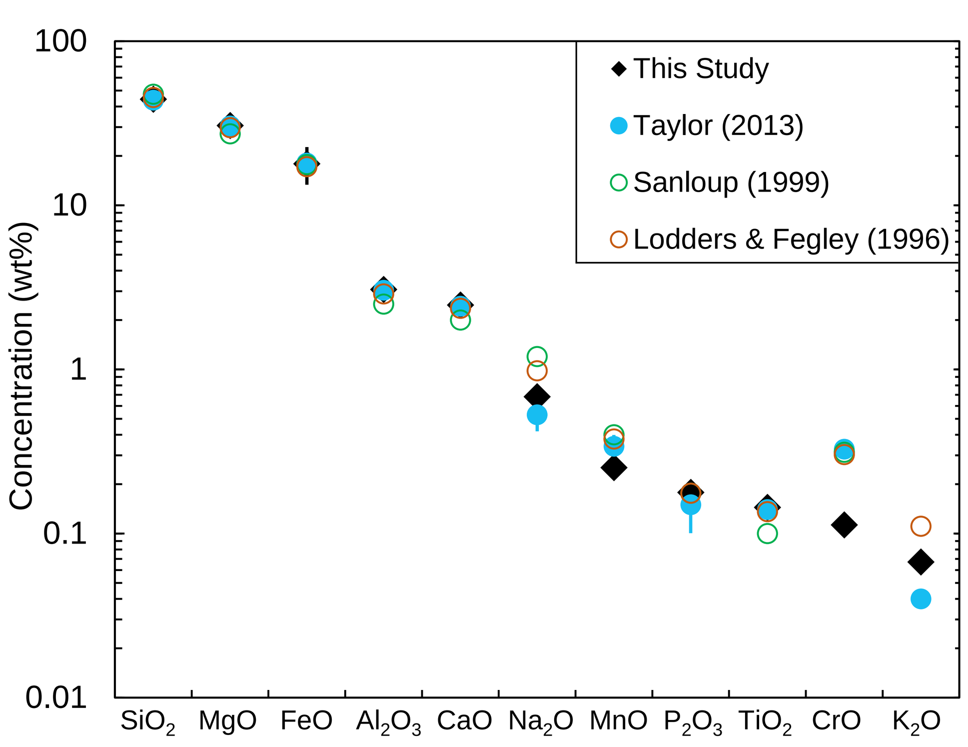
- We model accretion by adding small bodies to proto-Mars and equilibrating each one sequentially.
- The entire impactor may not always mix with the entire target [6], so we equilibrate a **fraction of the impactor core** with a **fraction of the target mantle**.
- We find that on average, >60% of impactor core material mixes and equilibrates with the target mantle.

3. The core and mantle equilibrate



- Partitioning is parametrized by high pressure/temperature metal-silicate partitioning experiments [7, 8, 9].
- Equilibration takes place at the liquidus temperature [10] and a **fraction of the CMB pressure** [6].
- We find an average equilibration depth of 50% – 80% of the CMB pressure.

4. The planet is done



Above: A comparison between compositions from our model and ones from meteorite data [2,3,4].

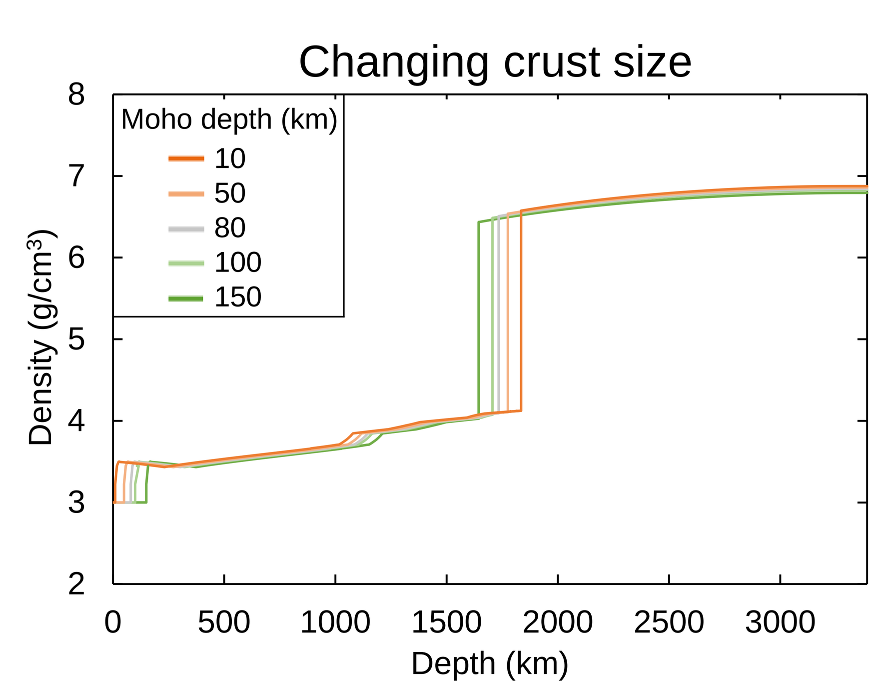
Right: The modeled composition that best matches Taylor (2013) [2]. This corresponds to an initial fO_2 of ΔIW = -1.2.

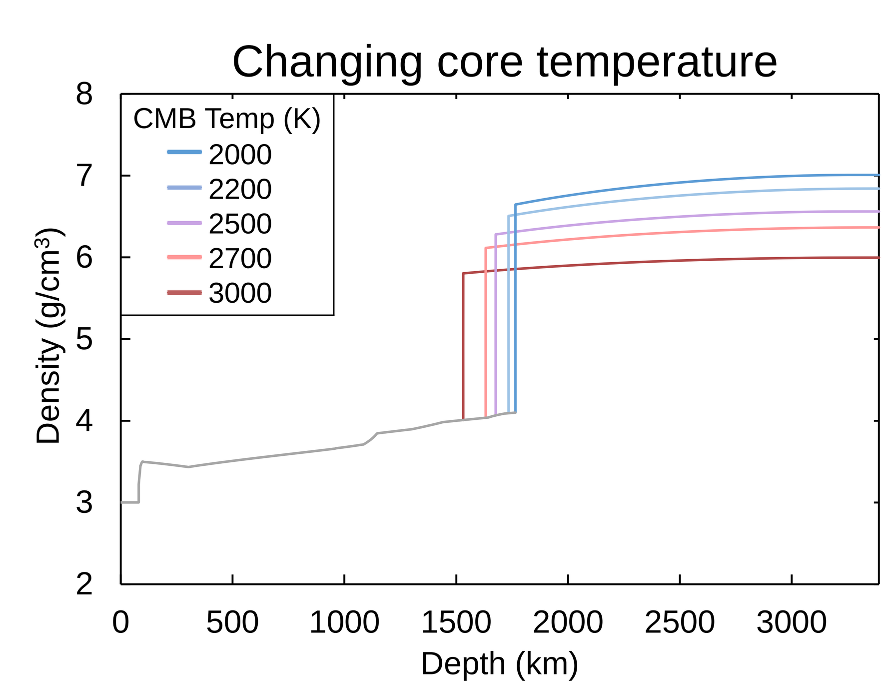
The Martian Composition

Mantle	wt %	(± 2σ)
SiO_2	44.3	2.31
MgO	30.7	1.60
FeO	17.9	4.25
Al_2O_3	3.08	0.160
CaO	2.43	0.129
Na_2O	0.68	0.036
S	0.067	0.020
Ni	0.041	0.025
Co	0.013	0.0060
W	7.5e-6	5.1e-6

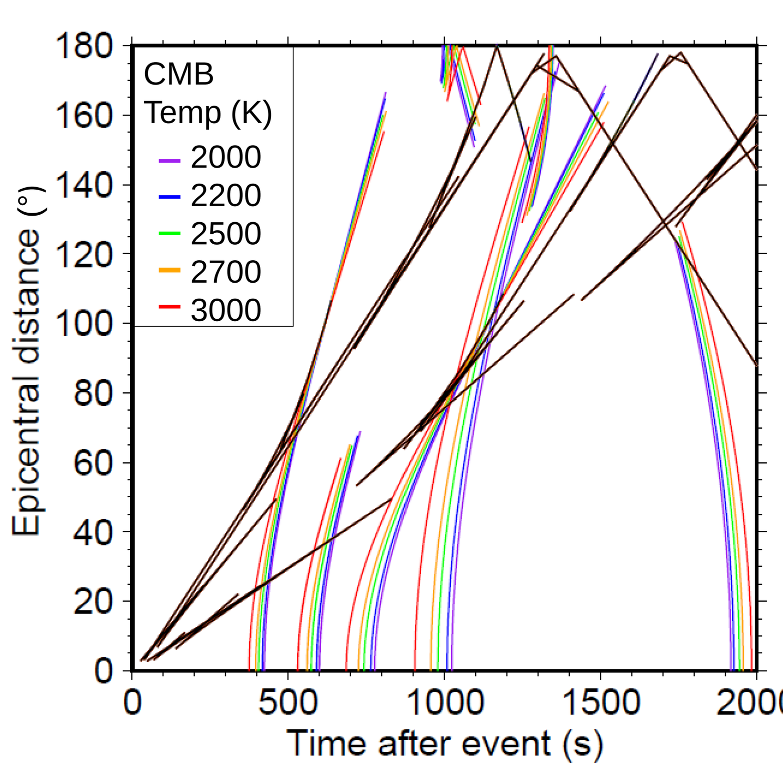
Core	wt %	(± 2σ)
Fe	74.2	2.75
S	18.2	2.28
Ni	7.00	0.820
O	0.34	0.19
Co	0.29	0.020
Si	8.1e-5	6.8e-5

- Each set of parameters corresponds to a single core radius; this allows us to predict Mars' internal structure.
- Sources of uncertainty include the thickness of the crust, the internal temperature, and the density of liquid Fe – S alloys at the relevant conditions.



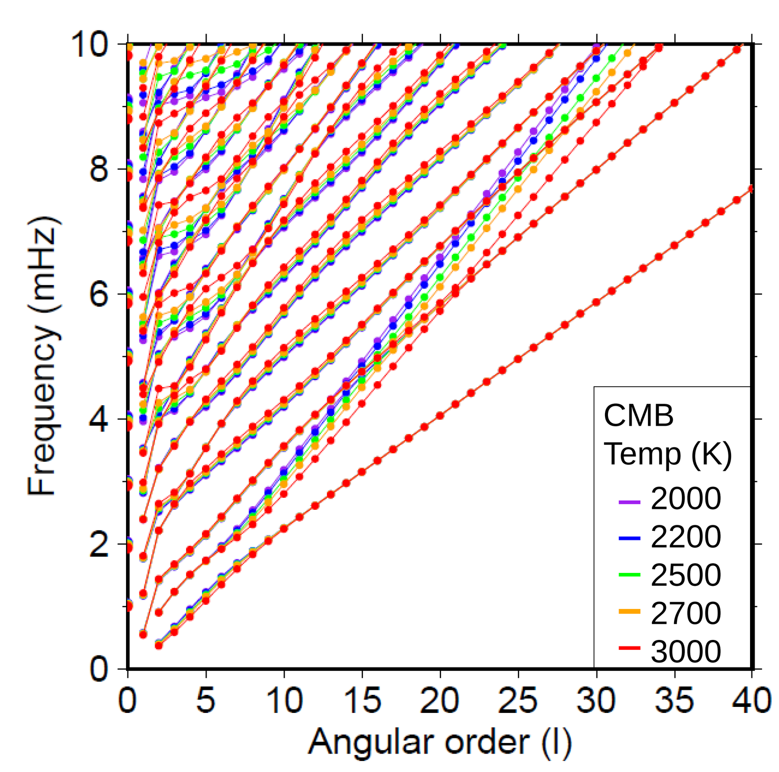


Above: The influence of two geophysical parameters on Mars' density profile. All of these are consistent with the observational constraints on the Martian core radius [12], but NASA InSight may help narrow down the range of acceptable parameters.



Left: Influence of core temperature on seismic phase arrival times. Phases in black do not interact with the core.

Right: Influence of core temperature on planetary normal modes. Most of these may not be observable by InSight [13], but a large enough marsquake might help distinguish between various models.



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