Implications of new elastic data about Fe-S alloys on the composition of the martian core and consequences

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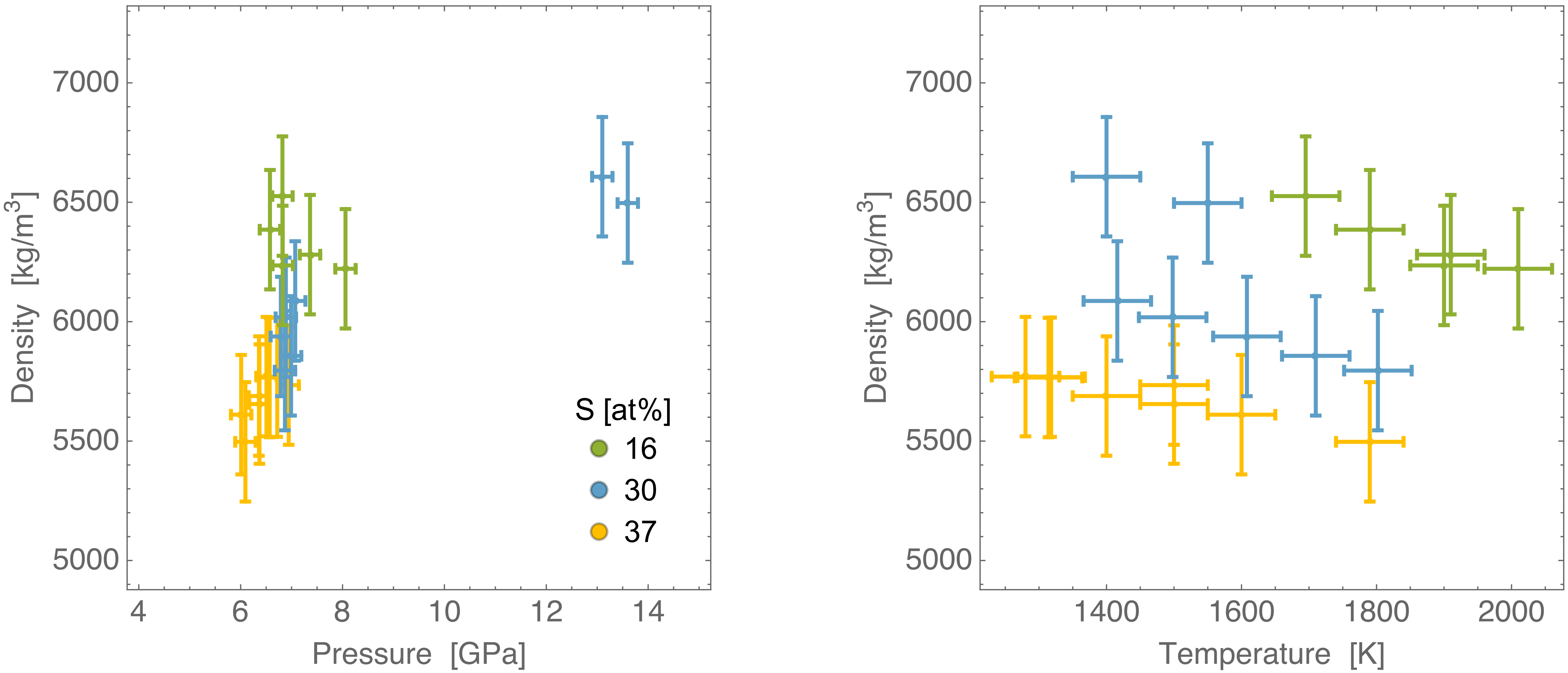
Scope

- compositional models based on geochemical investigations and formation hypothesizes favor sulfur as being the principal light element in the core of Mars
- S is siderophile at Mars' redox conditions and abundant enough in plausible precursor materials
- core S composition inferences deduced from geodesy data and interior modeling are in agreement with geochemical constraints ($xS \lesssim 21$wt%)
- but those results are not in agreement with new thermoelastic data about liquid Fe-S alloys

New Fe-S core model

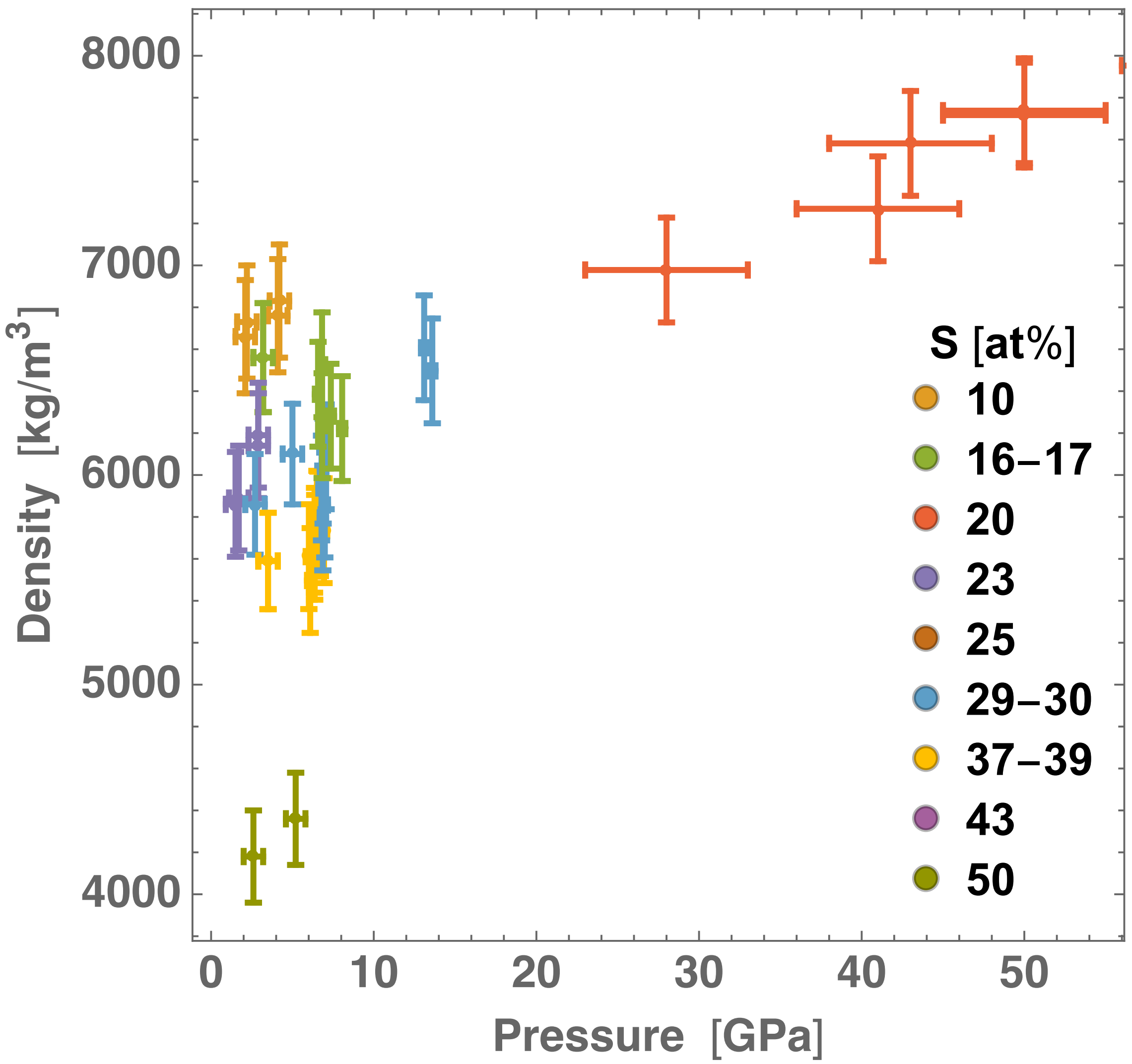
- old model
  - based on the equation of state of l-Fe10wt%S (Balog 2003) ($p_{lab} < p_{core}$) and assumed ideal mixing (volume conserving) between l-Fe and l-Fe10wt%S
- new model
  - based on new density and acoustic velocity data at several sulfur compositions
  - data acquired over a pressure range that comprises the pressure in the Martian core

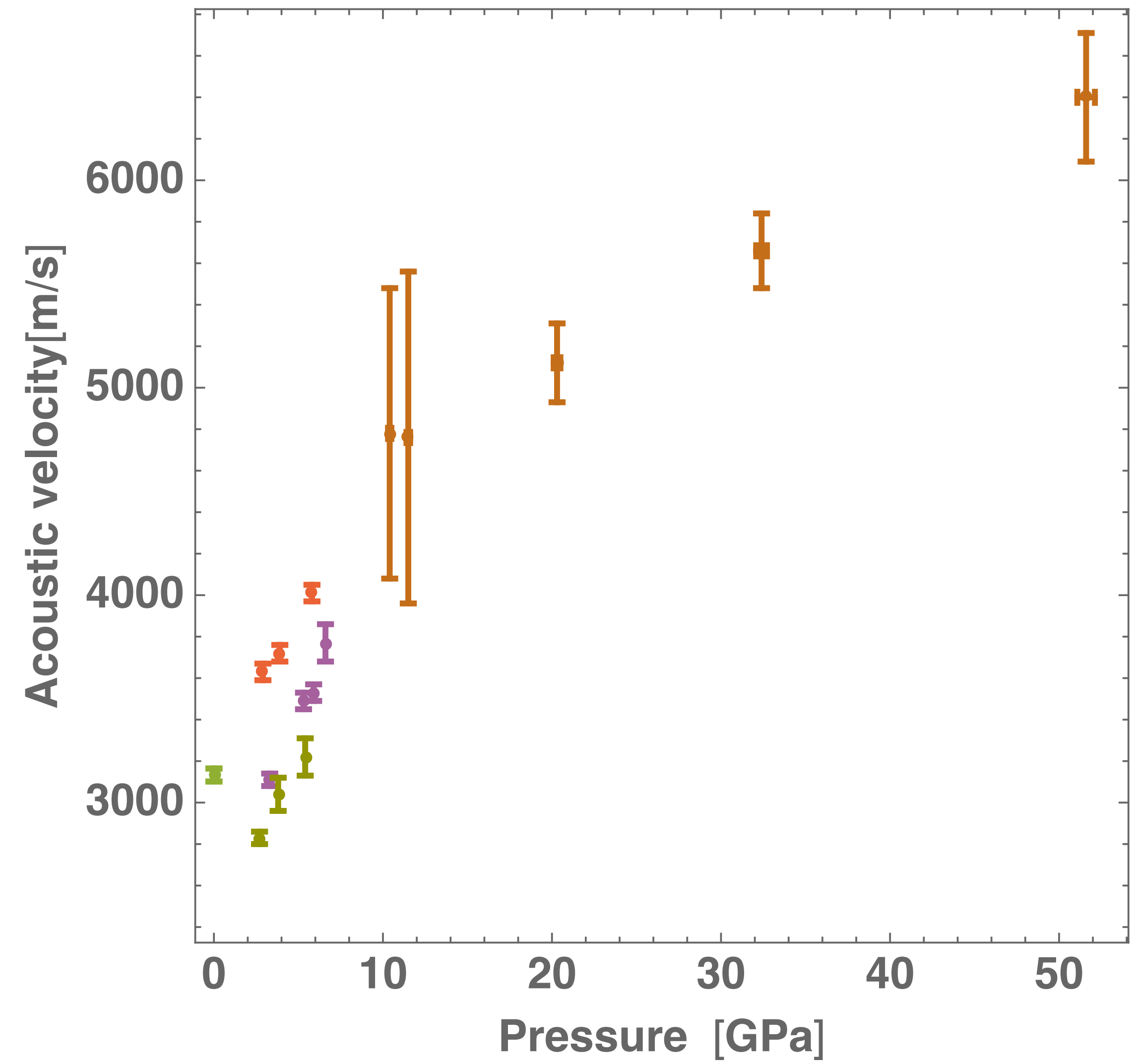
New density data of l-Fe-S from Daniele's group



below pressure of Martian core but very relevant for modeling the effect of S on thermoelastic properties of l-Fe-S alloys

Whole l-Fe-S data set

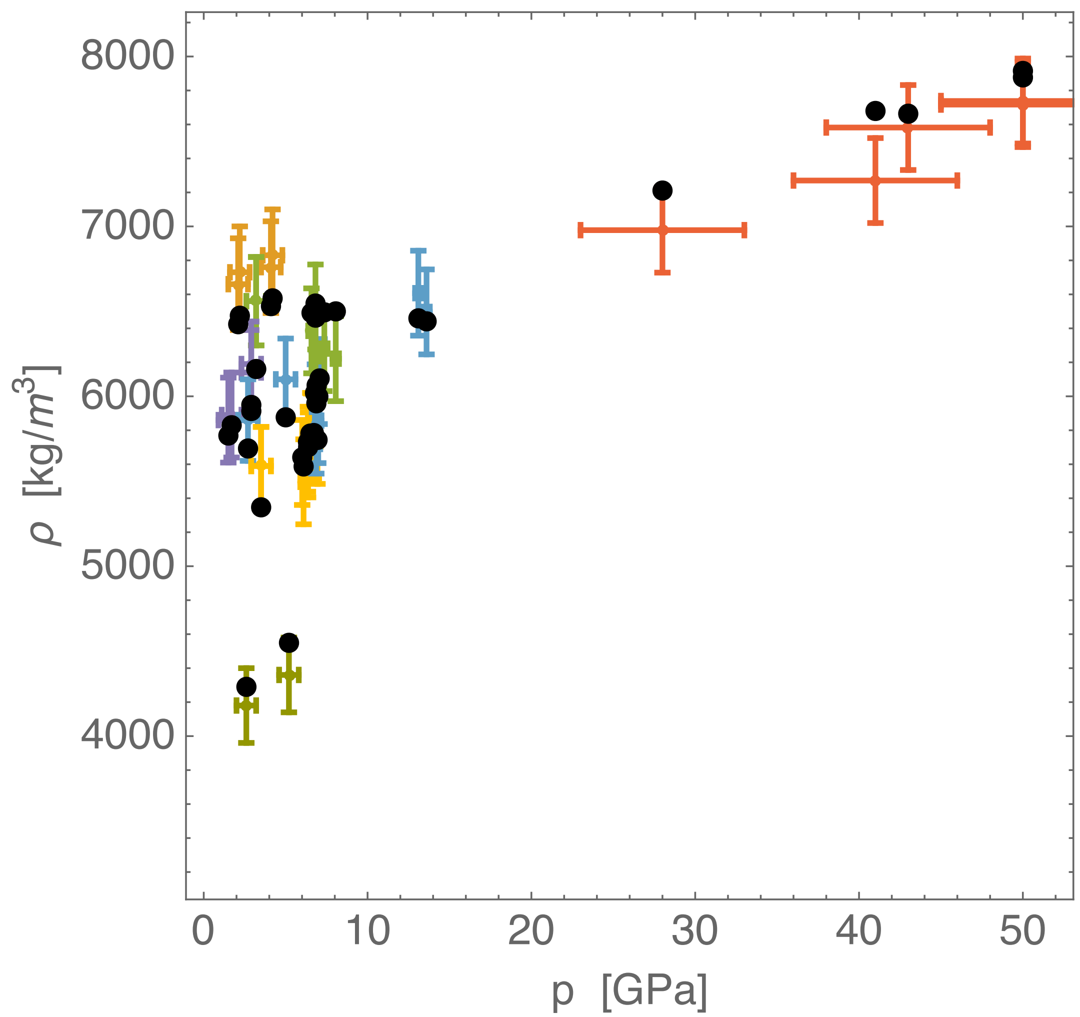


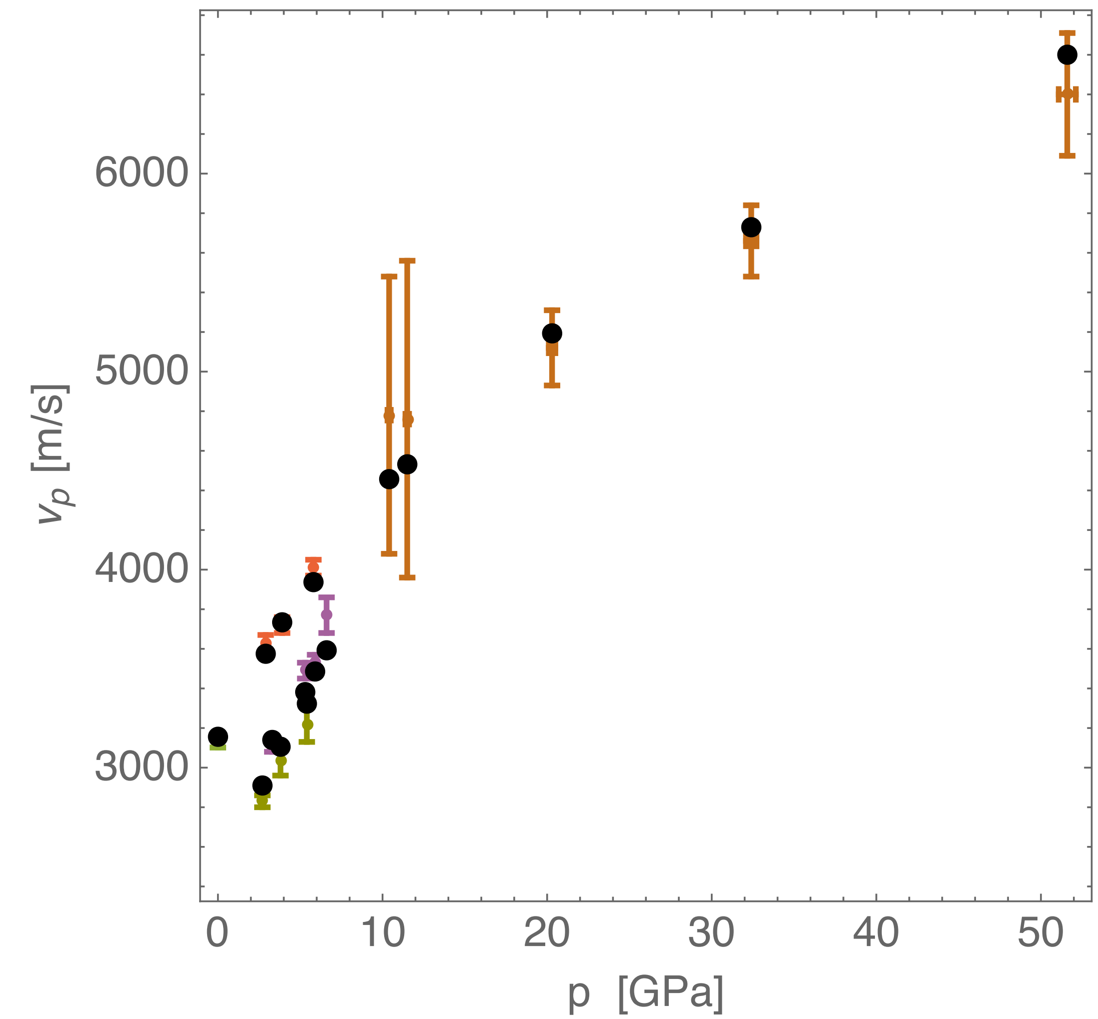


- **density**:
  Fe-(10-50)at%S (Morard 2018), Fe-(16,30,37)at%S (Antonangeli 201x), Fe5wt%Ni12wt%S (Morad et al. 2013)

- **acoustic velocity**:
  Fe(20,43,50)at%S (Nishida 2016), Fe18wt%Ni16wt%Si (Kawaguchi 2017)

Thermodynamic modeling and data fit





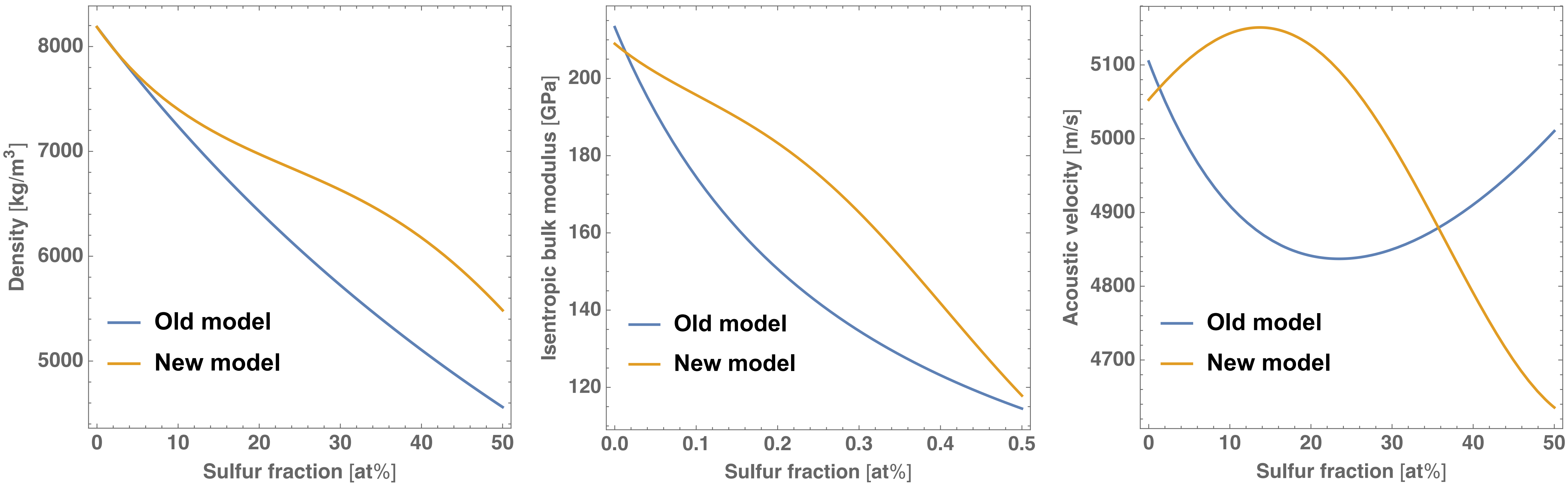
- both density and acoustic velocity data can be described accurately by a non-ideal solution model that has a pressure dependent excess volume

$$V(x_{FeS},p,T)=(1-x_{FeS})\ V_{Fe}(p,T)+x_{FeS}\ V_{FeS}(p,T)+V_{ex}(x_{FeS},p)$$

- parameters of equation of state of FeS end-member and excessive volume are estimated from the data

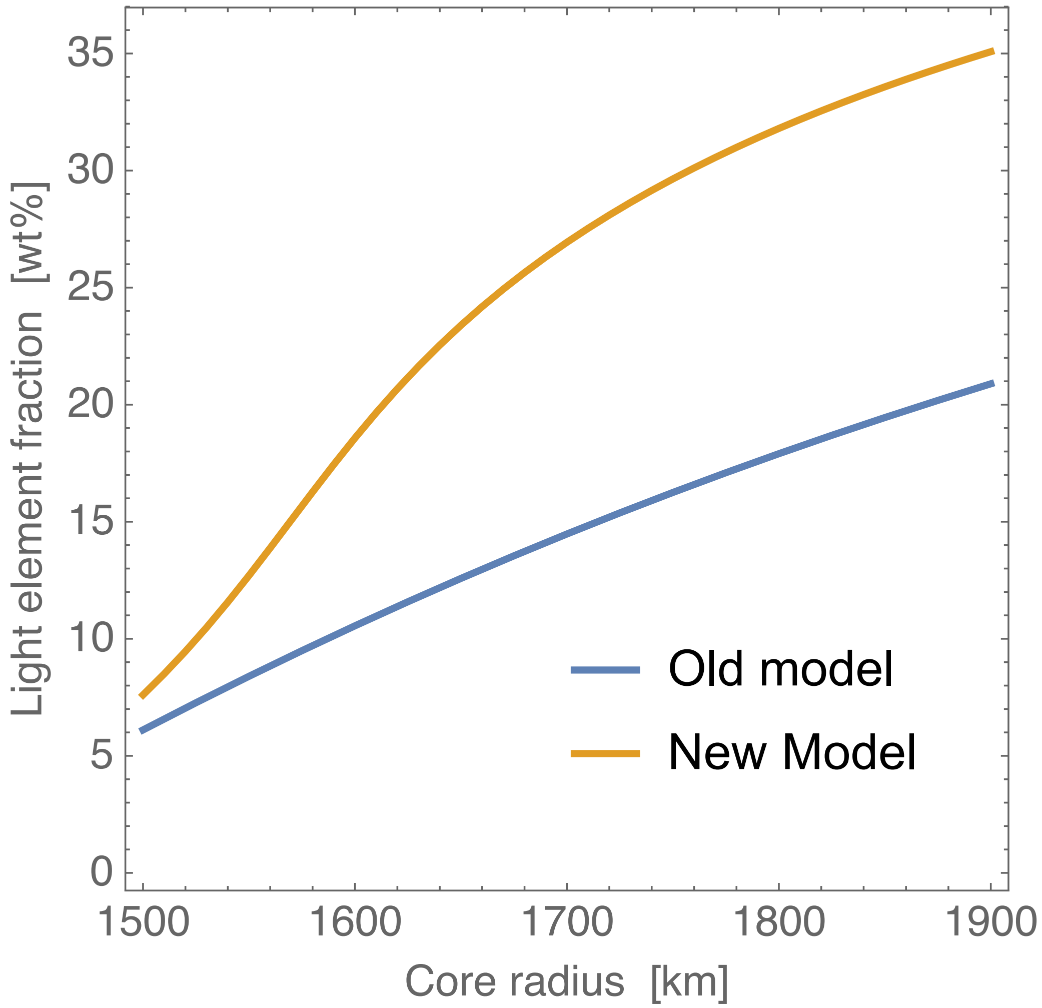
- l-Fe eos from Komabayashi 2014

Comparison with previous l-Fe-S model



⇒ non-ideal mixing behavior of S in l-Fe induces complex relation between S amount and elastic properties

Effect on Mars' core composition

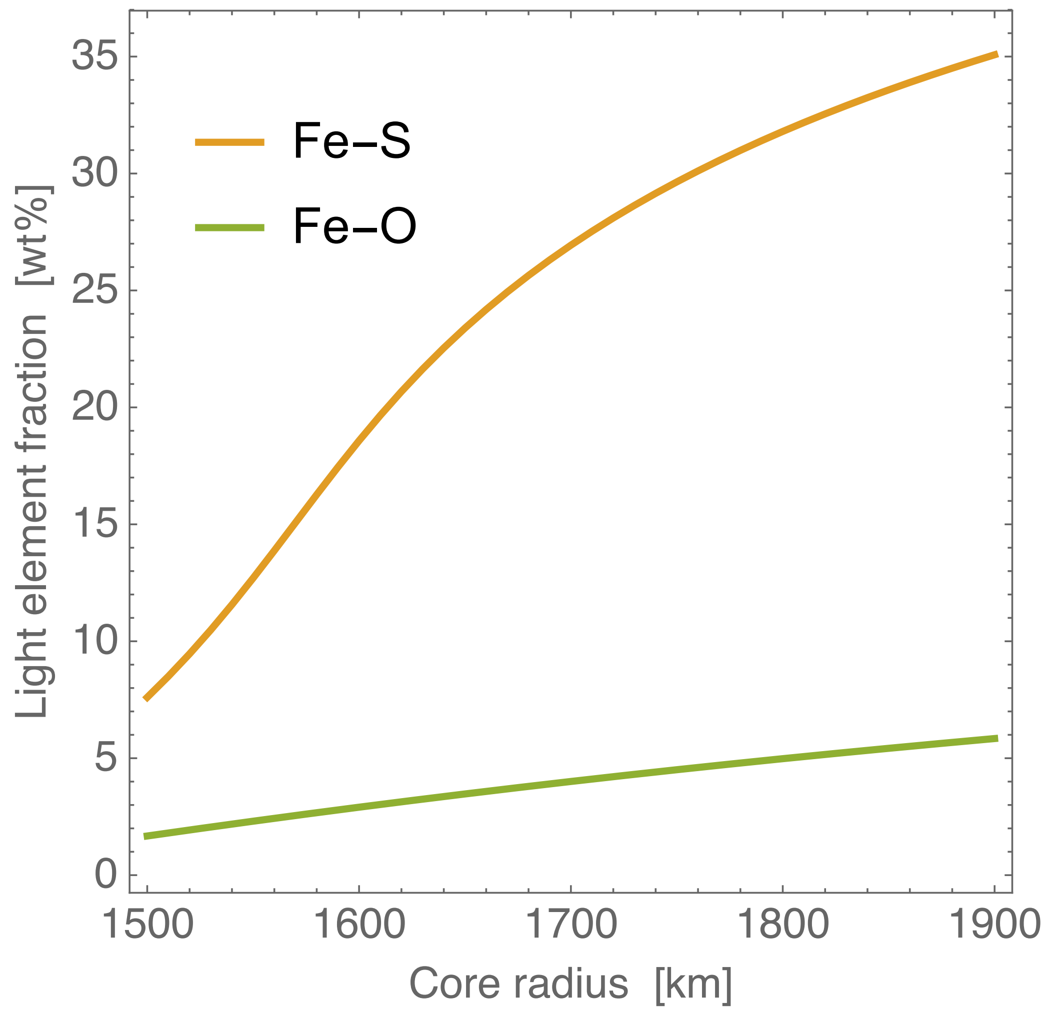


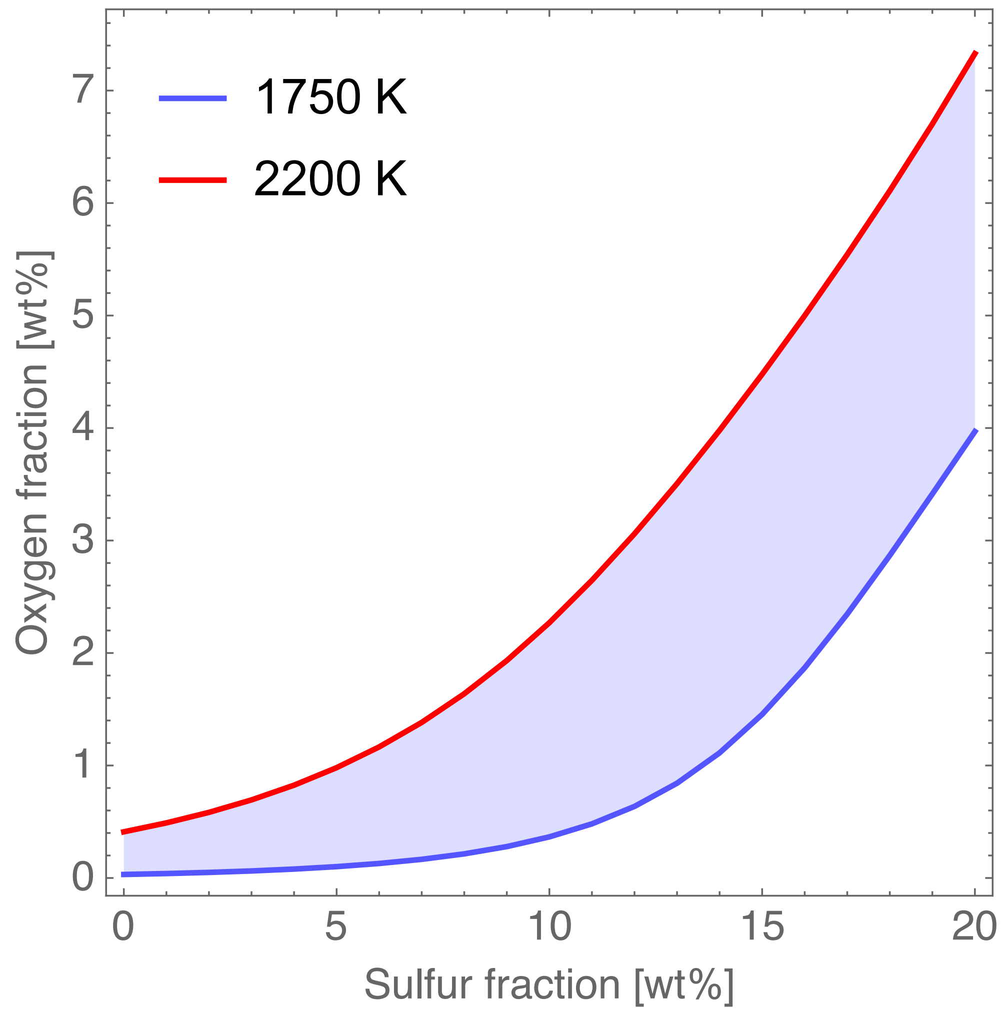
- models based on new elastic data require significant more S at a given core radius
- if the core is large ~1790km then xS~31wt% (old model ~17wt%S)
- in contradiction with compositional models (xS≲21wt%)

Secondary light elements

- geochemical composition models allow for ~4wt%O, ≲1.5wt%C, and few wt% of H or < few ppm (Tsuno 2018, Steenstra 2018, Clesi 2018, Malavergne 2019)
- unfavorable redox conditions exclude Si
- H requires water in the lower mantle (controversial?), partitioning data controversial, difficult to model because of missing eos of l-Fe-H
- the amount of C decreases with increasing S and preliminary results indicate that 1.5wt%C is not enough to decrease S amount to within geochemical constraints
- the amount of O that can dissolve in l-Fe increased with S and O is quite effective in reducing the density of l-Fe

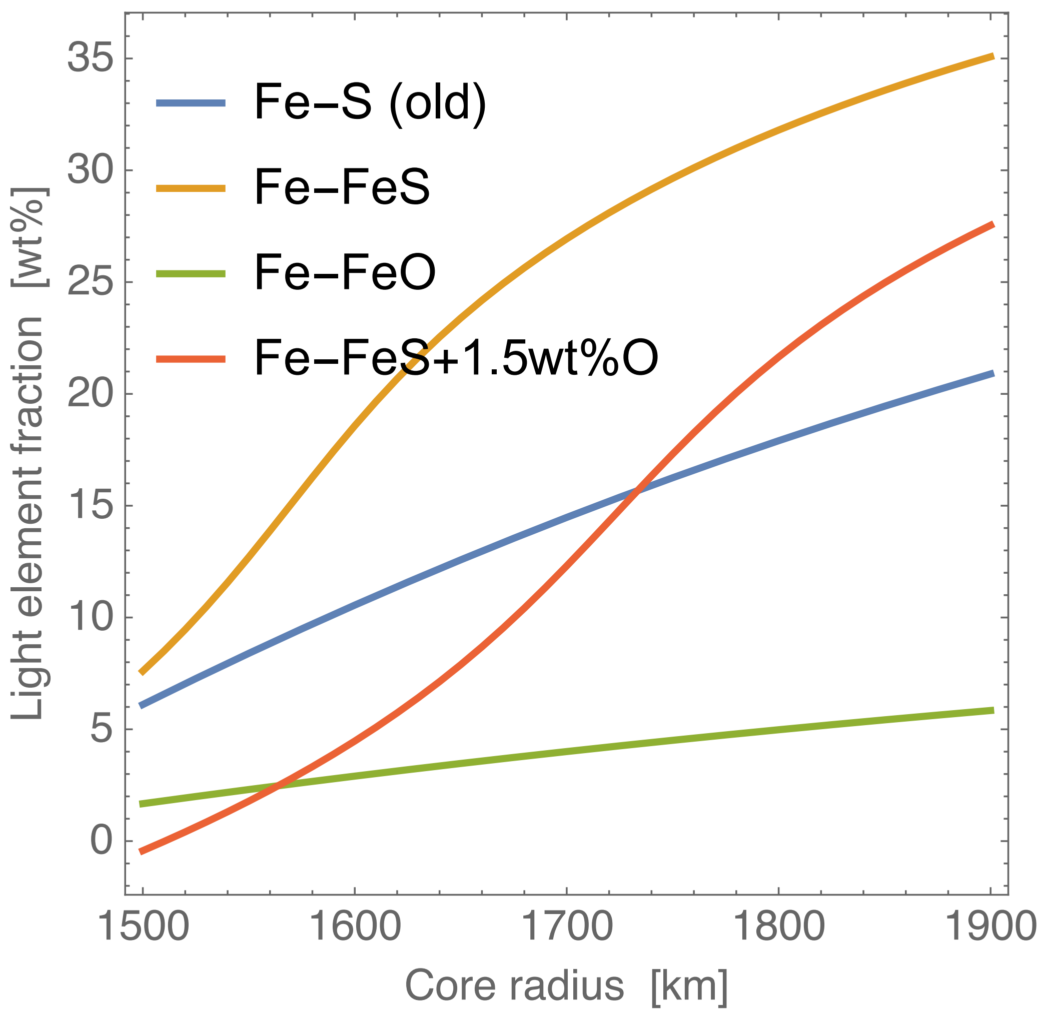
Core model with Fe-O

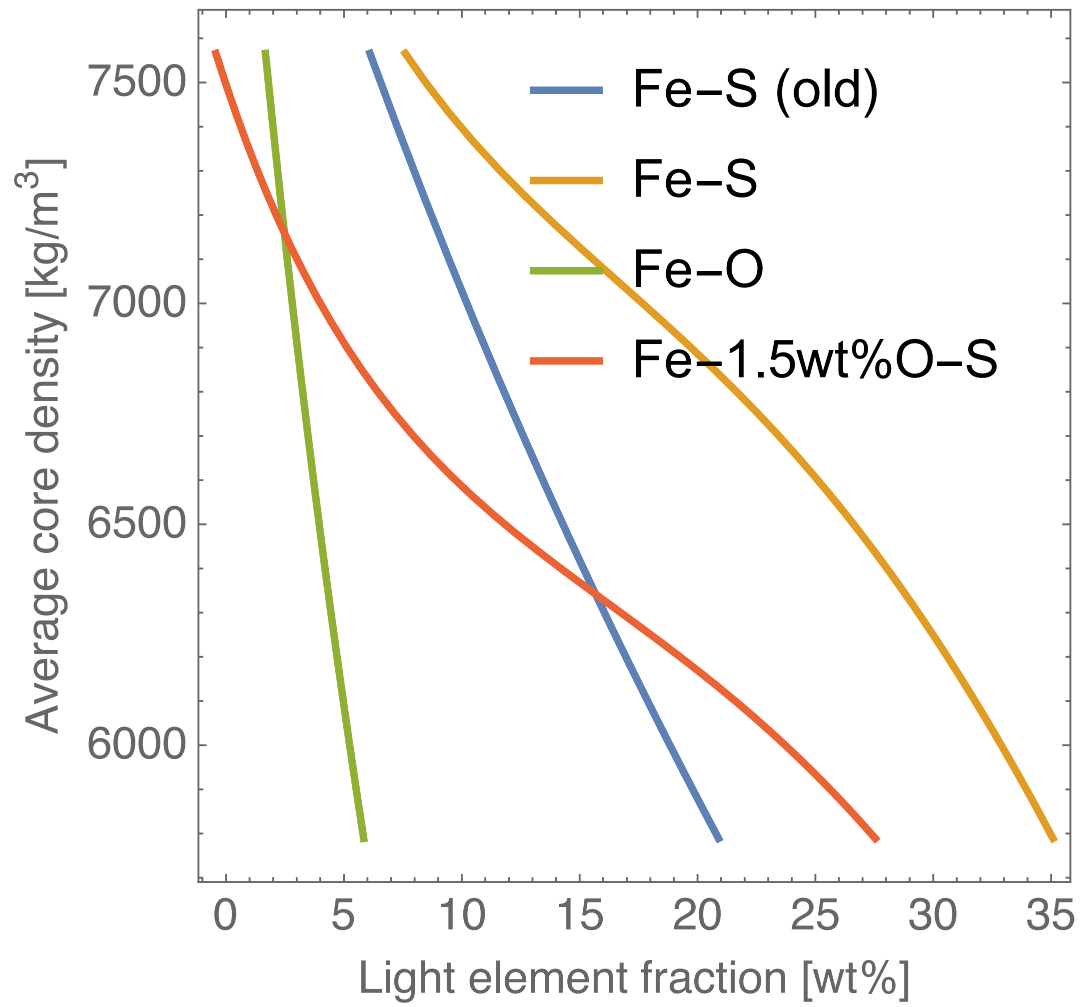




- O is very effective in decreasing the density of the core
- with 17wt% of S more than 2wt% of O can be dissolved in the core

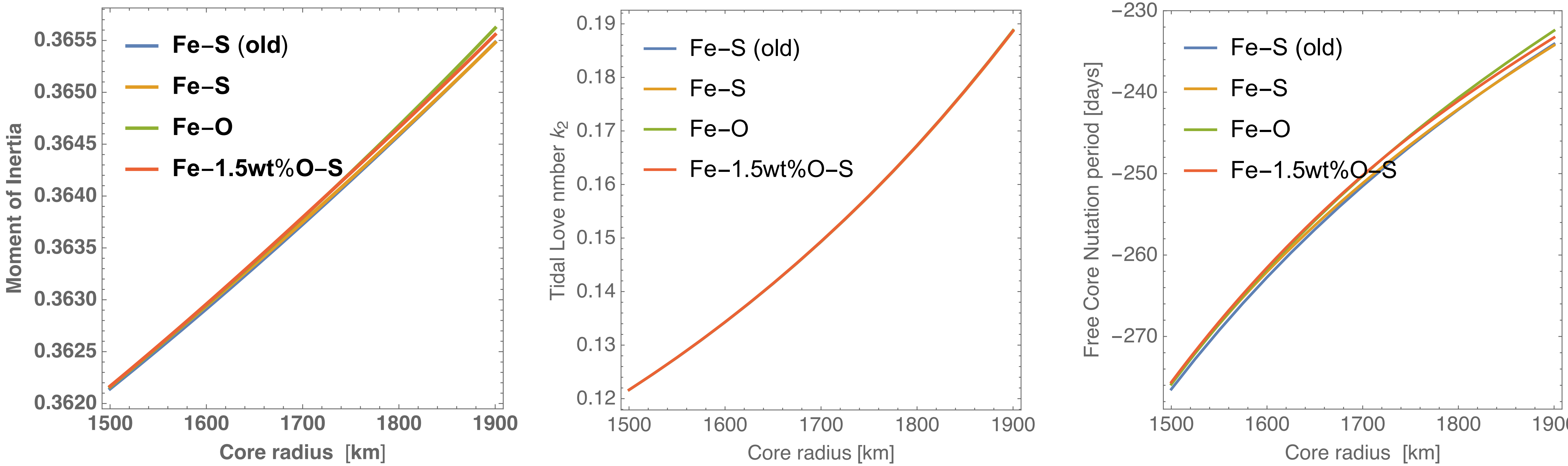
Core model with Fe-O-S





⇒ with ~1.5wt%O the amount of S required for a large core is in agreement with geochemical constraints

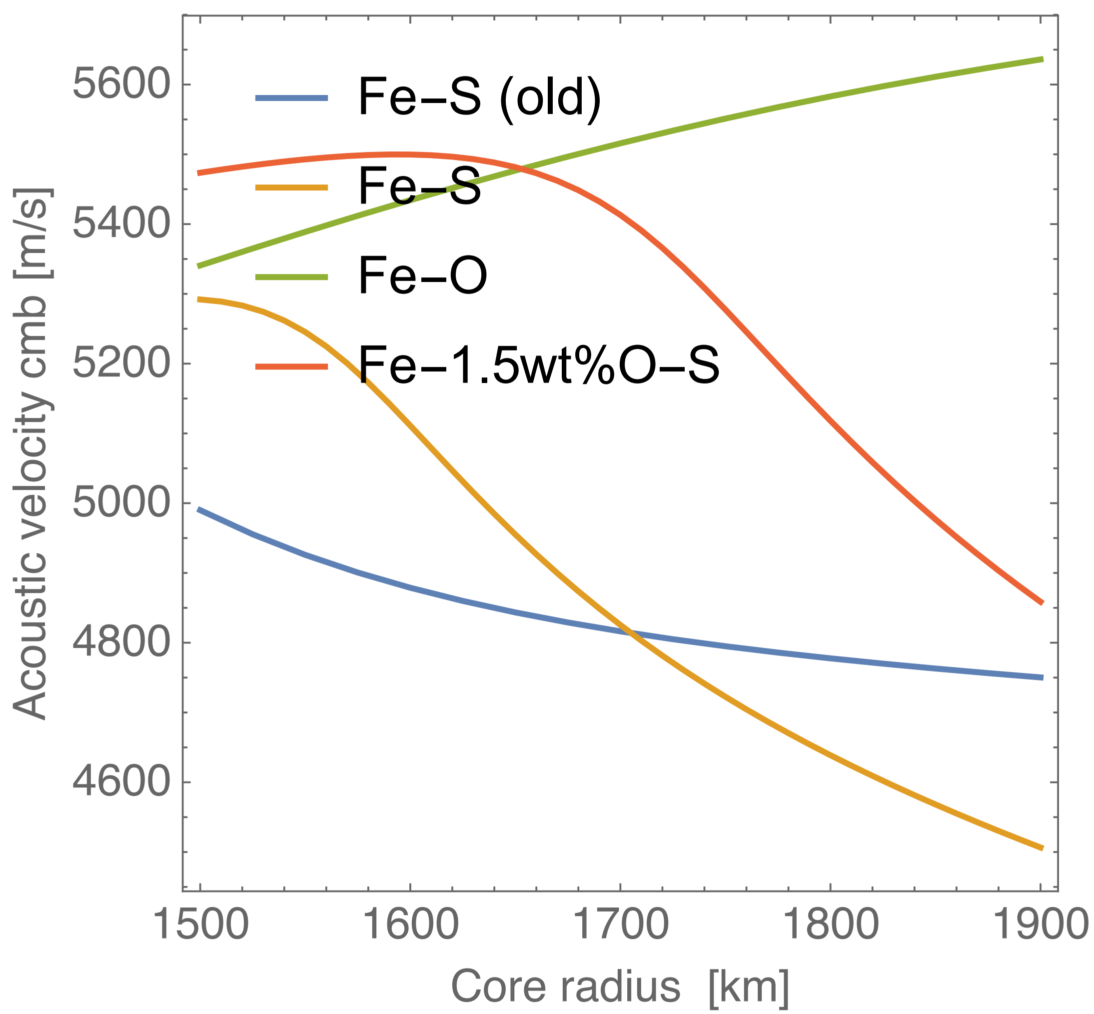
Effect on geodesy observables

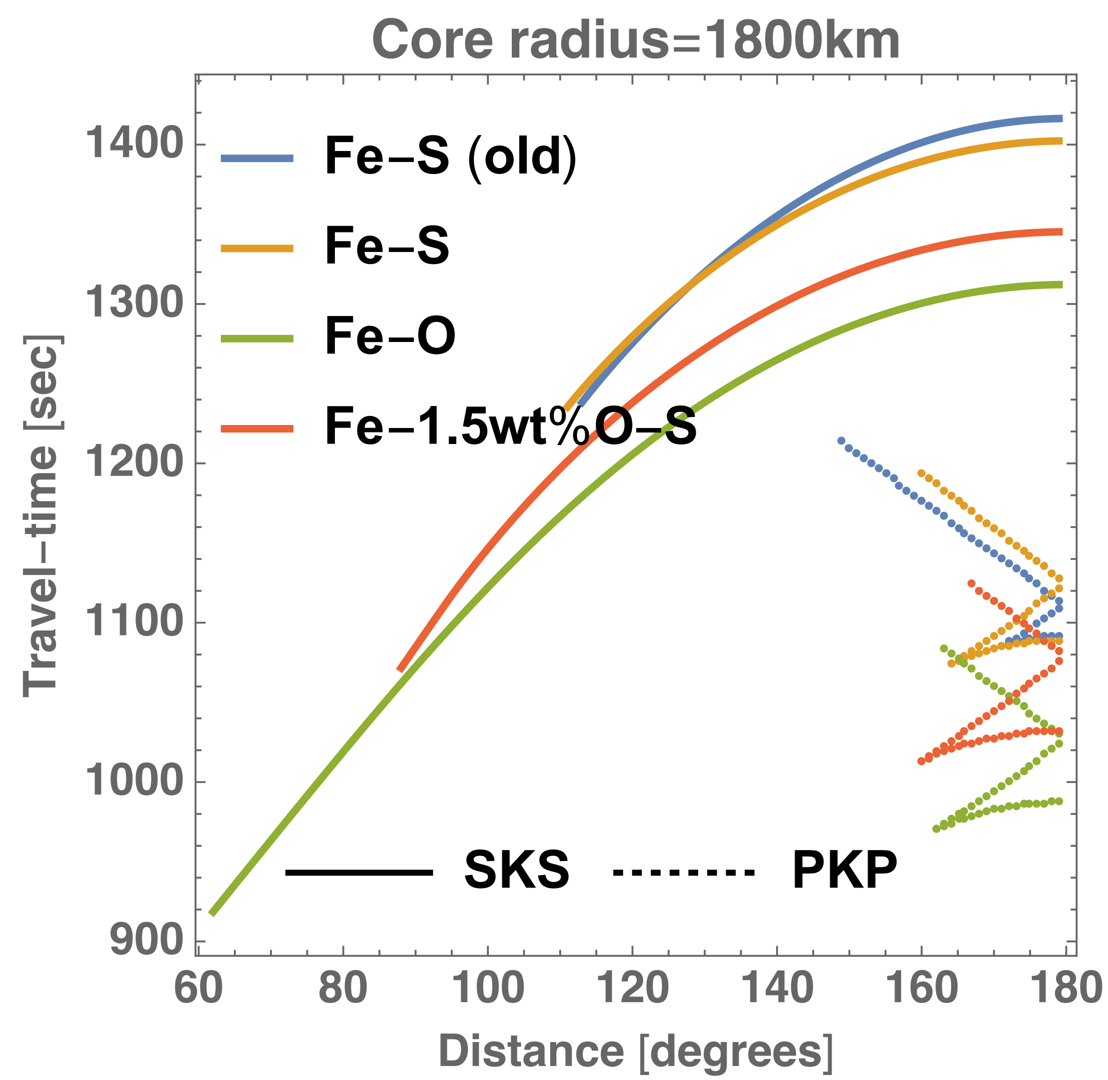


- moment of inertia, tidal Love number k_2, and nutation are almost not affected by core composition

  ⇒ core radius estimation from geodesy data are robust with respect to core composition

Effect on core acoustic velocity and travel-times





⇒ core composition has a significant effect on acoustic velocities and core seismic phases

Conclusions

- new elastic data about l-Fe-S alloys imply core S compositions that are at odds with geochemical constraints
- a few wt% of O are enough to reduce the amount of S in the core to values that agree with geochemical constraints
- geodesy observations are almost not affected by the core composition
- core composition significantly affects core seismic velocities