A precise knowledge of thermodynamic properties of the lunar core is of prime importance for the ongoing efforts to reanalyze Apollo seismic data, for the interpretation of results from GRAIL and future projects to send seismometers to the lunar surface, and for understanding the thermal evolution of the Moon. Here we present a new coherent thermodynamic model for Fe-S alloys to infer the composition and present-day temperature of the lunar core from recent geodesy data by assuming a mantle density distribution deduced from lunar seismic data. Additionally we study the effects of the two models on the thermal evolution of the core and evaluate the core’s capacity to generate a magnetic field.

### Constraints on the lunar core composition and thermal state from geophysical data and thermodynamic properties of liquid iron alloys

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#### Introduction

#### Data

- Liquidus of Fe (Anzelini et al., 2013)
- Iron-rich liquidus of Fe-S at 3 GPa, 6 GPa, and 10 GPa (Brett and Bell, 1969; Buono and Walker, 2011; Chen et al., 2008)
- Equations of state for solid fcc Fe and l-Fe (Komabayashi, 2014)
- Densities of liquid Fe-S alloys measured by X-Ray absorption (Moreard et al., 2015)
- Ambient pressure density of l-Fe (Kress, 2007) and ambient pressure sound velocity of l-Fe (Watson et al., 1997)
- Acoustic velocity data of liquid Fe-S alloys measured by ultrasonic pulse-echo method (Nash et al., 1997)

#### Thermodynamic model predictions

**Moon model**

- Interior structure models agree with the latest estimate of the average moment of inertia of the silicate shell (MOIs = 0.36312 ± 0.000212) (Williams et al., 2014)
- Based on the mantle density model of Weber et al. (2011)
- Core thermal evolution model based on Davies et al. (2015) and mantle evolution model based on Morshausen et al. (2011)
- Thermal conductivity depends on pressure, temperature, and sulfur concentration (Secco and Schloessin, 1989; Komijikawa et al., 2016)

**Thermal evolution**

Heat flux (left) and entropy (right) evolution until iron snow reaches the inner core boundary, for a model with 1.63% of sulfur an initial core-mantle boundary temperature of 2300K. The black dashed lines represent the heat and entropy transported along the adiabat at the core-mantle boundary. The total available power and entropy are shown by blue lines.

#### Conclusion

- Melting data and new elastic data about Fe-S alloys can be described with a non-ideal mixing model that has a pressure dependent excess volume
- To agree with the MOIs at 1 GPa the core-mantle boundary temperature cannot be below ~1400K and to avoid lower mantle melting it has to be below ~1910K
- Models without an inner core and without a whole snowing liquid core cannot be much colder than ~1825K and those models have less than ~4.3% of sulfur
- Models without an inner core having a marginal dynamo until about 3.56Gyr ago require core-mantle boundary temperatures significantly above the mantle solidus (C. 2500K)
- Models without an inner core cannot generate a dynamo in agreement with observations
- Models with an inner core can have mantle boundary temperatures below the mantle solidus 10Gyr after formation and agree with the timing of occurrence of the lunar dynamo, but the predicted magnetic fields have magnitudes that are significantly below what is expected to explain the lunar magnetic records (20-71-117 T) (Yous et al., 2017)

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