Outer Core Heat Flux in Small Terrestrial Bodies from Electrical Resistivity Measurements of Liquid Fe-8S-4.5Si at High Pressure

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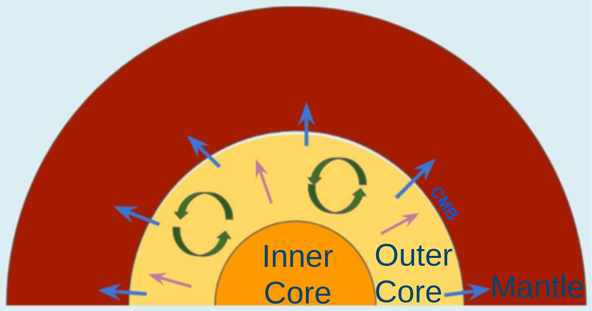
Introduction to Planetary Core Heat Flow

Due to internal dynamo action, the motion of liquid Fe alloys inside terrestrial cores may cause a planetary magnetic field to form. One energy source of this motion of Fe alloys is heat flow through the core. This study constrains adiabatic heat flow at the top of exoplanetary cores, with implications for thermal convection.

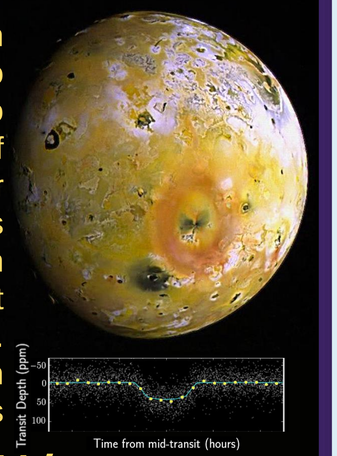


Total Heat Flow through CMB (Previous Models)
- Adiabatic Heat Flow in Core (This Study)
Convective Heat Flow in Core

Planetary Bodies of Interest

Io

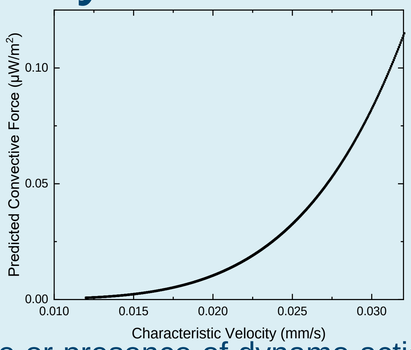
The innermost of the Galilean moons has been observed to possess an **Fe** core[1]. **S** is also thought to comprise the core of Io, in part due to its lower volatility at greater distances from the Sun[2]. Of the Galilean moons, Io has by far the largest expected bulk **Si** proportion[3]. While Ganymede possesses an intrinsic magnetic field, Io does not[4].



Kepler 444d

M = 0.6-6.0 x 10^{23} kg [5] and R = 3.3-3.5x10^{6} m [6]

Implications for the Fluid Velocity of the Ionian Core



Absence or presence of dynamo action in Io's core depends on the magnetic Reynolds number (Re_m)

$$Re_m \equiv UL\sigma\mu$$

U: Characteristic Fluid Velocity
L: Characteristic Length
μ: Magnetic Permeability
σ: Electrical Conductivity
Ω: Angular Velocity
H_T: Scale Height
ρ*: Density

$$F_{Conv} \approx U^2 \Omega H_T \rho^*$$ [7]

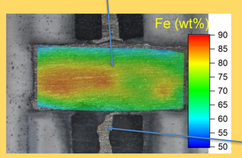
$$F_{Conv} \approx 3.3 U^2 H_T \rho^* / L$$ [8]

Io's lack of an intrinsic magnetic field may be attributable to a low characteristic velocity of a liquid core if the convective force at the top of the core is less than a few μW/m².

High Pressure Methods

Experiments on liquid Fe-8wt%S-4.5wt%Si (Fe-8S-4.5Si) at 2, 3, 4, or 5 GPa were carried out in a 1000-ton cubic anvil press.

EMPA Results*



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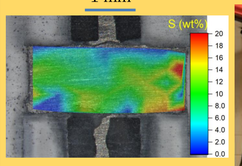
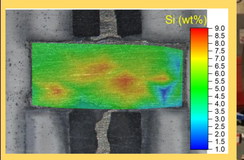
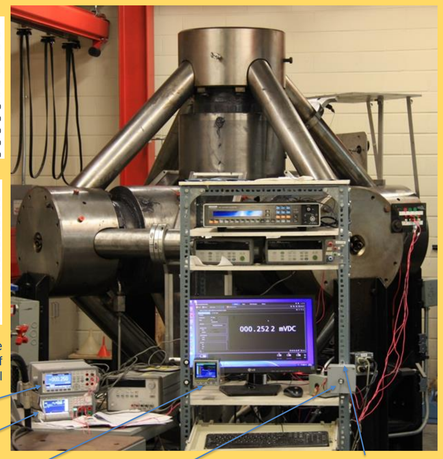
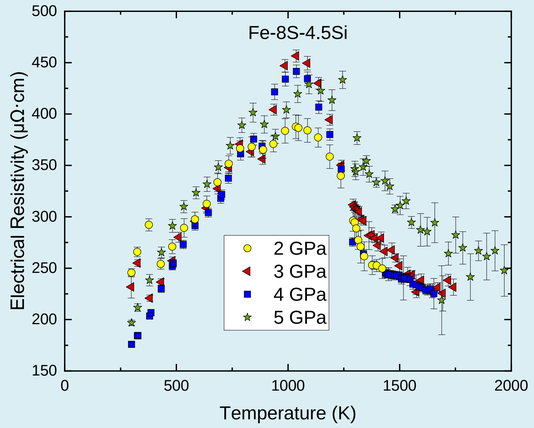


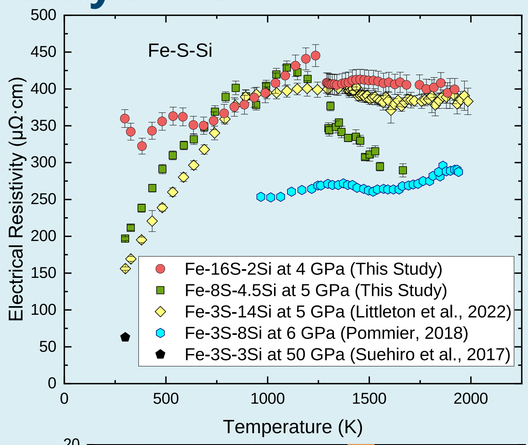


*Averages in Weight Percent of the Electron Microprobe Analysis of several points on a post-experimental sample



Electrical Resistivity Results



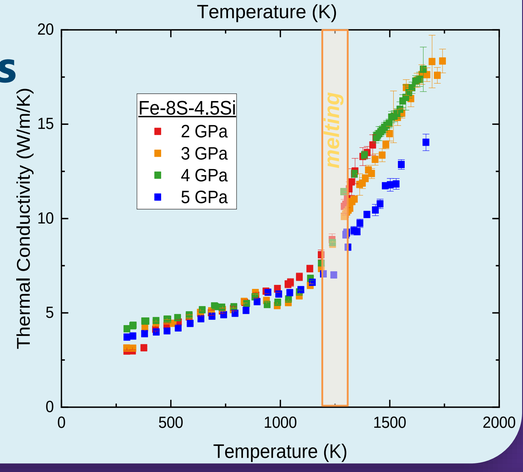


Thermal Conductivity Results

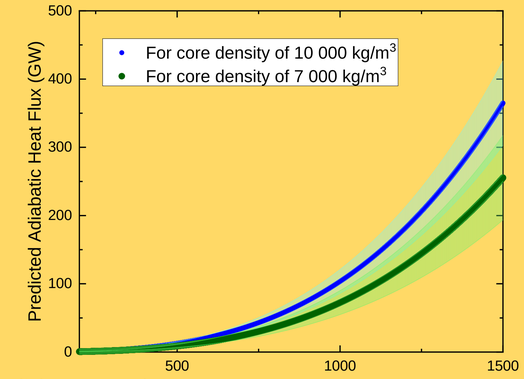
The Wiedemann-Franz Law approximates the thermal conductivity of Fe-8S-4.5Si at core temperatures and pressures:

κ: Thermal Conductivity
L: Lorenz Number
T: Temperature
ρ: Electrical Resistivity

$$\kappa = LT/\rho$$



Heat Flow through Fe-8S-4.5Si Planetary Cores



Q: Adiabatic Heat Flux
κ: Thermal Conductivity
α: Thermal Expansion
g: Gravitational Acceleration
T: Temperature
C_P: Heat Capacity
R: Radius of the Core

$$Q = 4\pi R^2 \kappa \nabla T$$

$$\nabla T = -\alpha g T / C_P$$

The adiabatic heat flux density for a sub-Earth exoplanet with an Fe-8S-4.5Si outer core and an Earth-like mantle is estimated as 500-800 GW.

Data References

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Text References

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