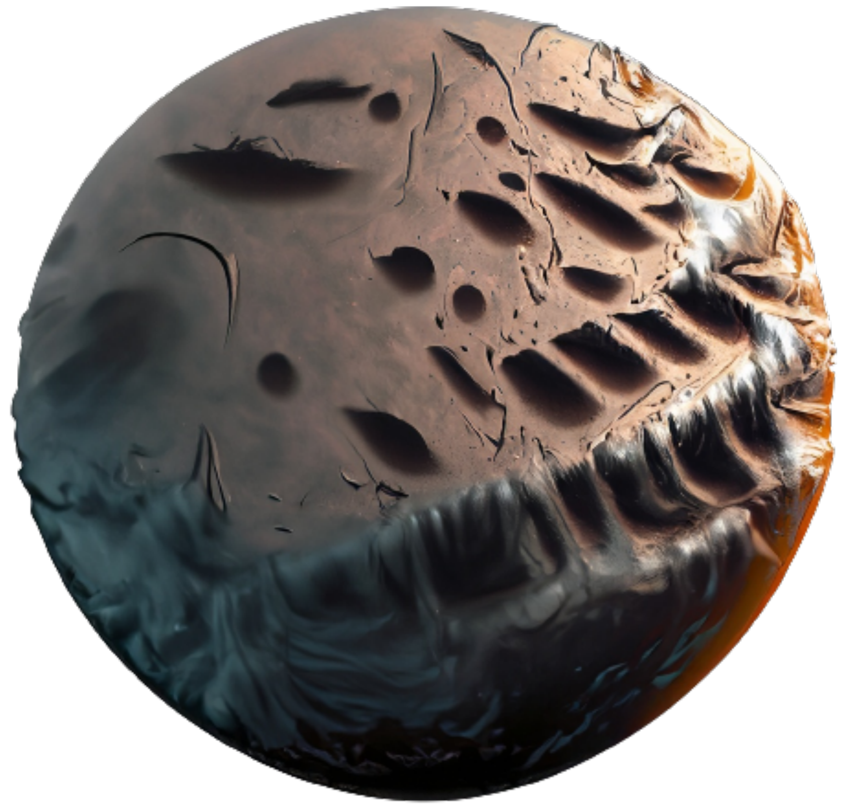
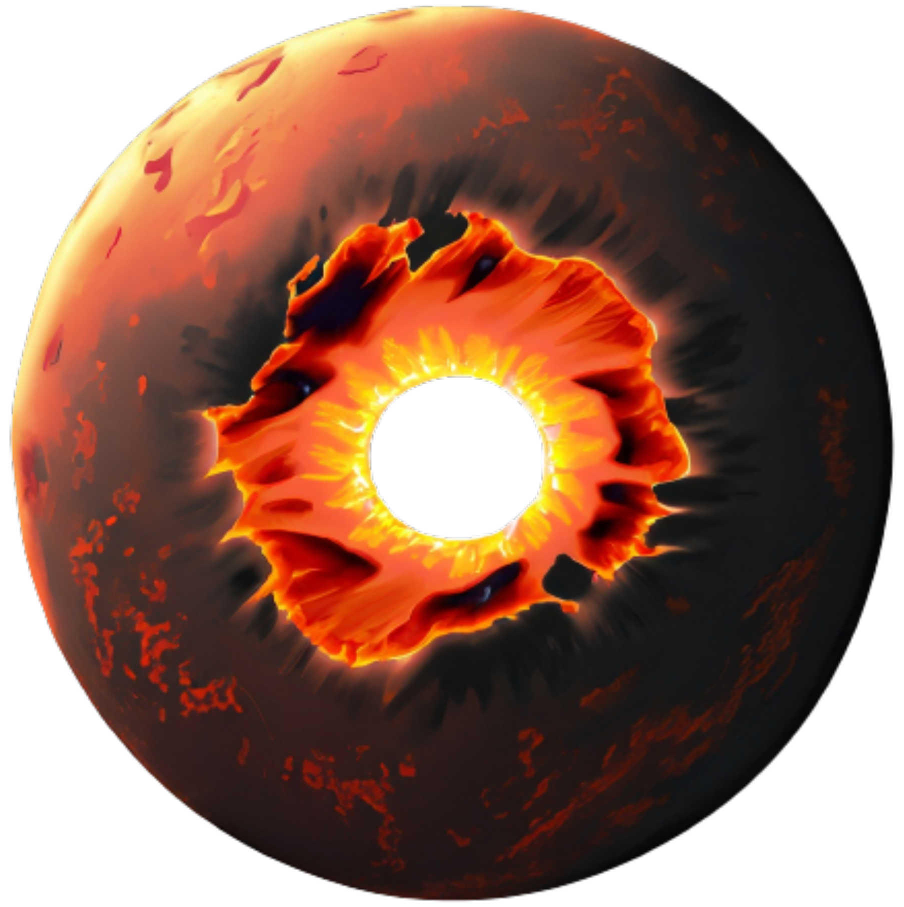
Differentiation in Fe-S and Fe-C Cores of Small Planetary Bodies

T. Rückriemen-Bez, C. Davies, S. Anders, S. Eckert, S. Greenwood, L. Huguet, M. Lasbleis, A. Pommier, A. Rivoldini, J. Wong





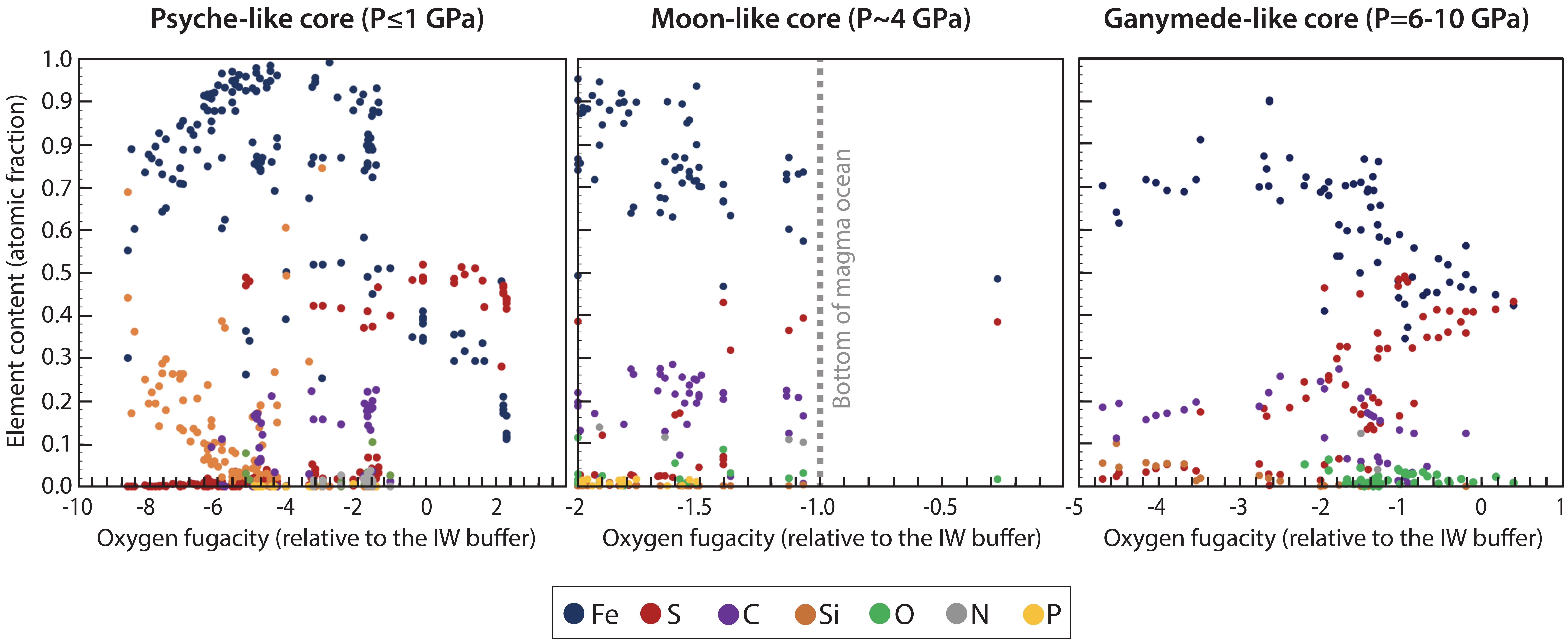
Credits: Adobe Firefly

ISSI Team

A New Non-Equilibrium Model Of “Iron Snow” In Planetary Cores

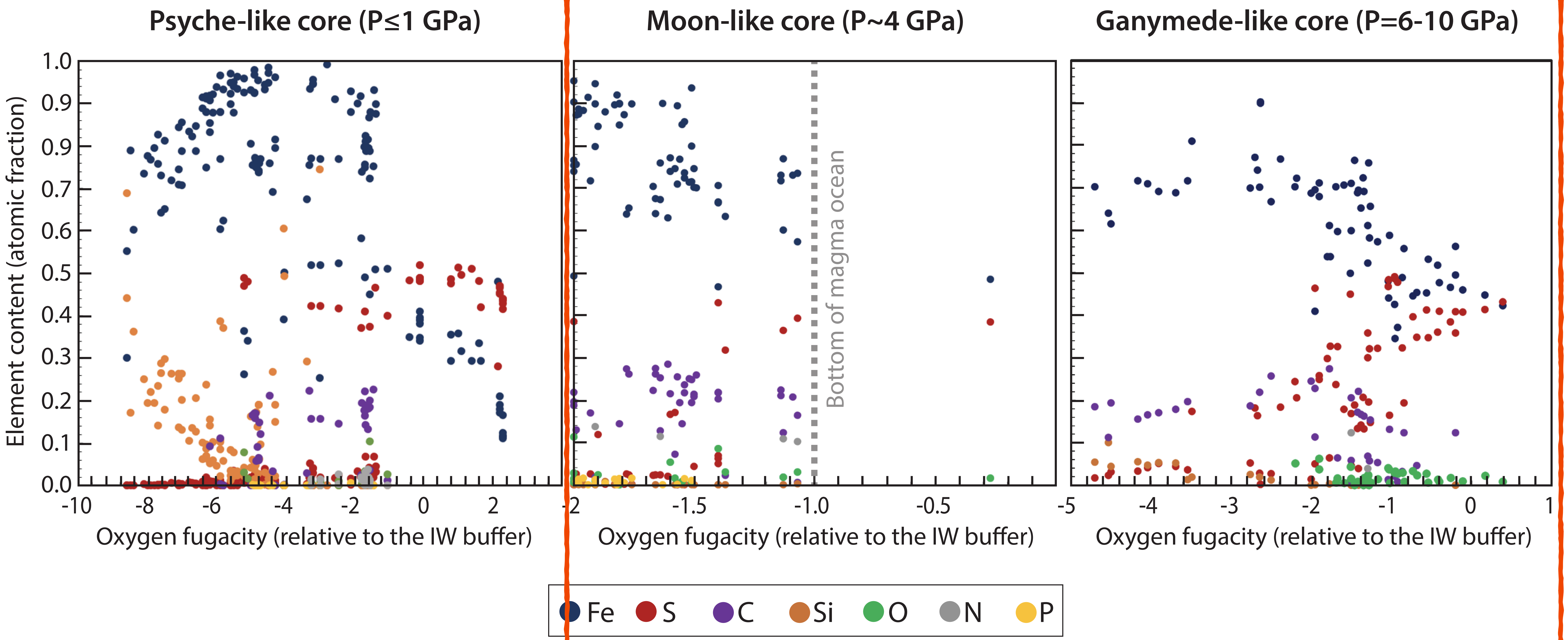
ISSI Bern Team Meeting April 2022

Light Elements in Low-Pressure Cores



- Fe-S, Fe-Si, Fe-C
- Fe-S, Fe-C
- Fe-S, Fe-C

Light Elements in Low-Pressure Cores



- Fe-S, Fe-Si, Fe-C
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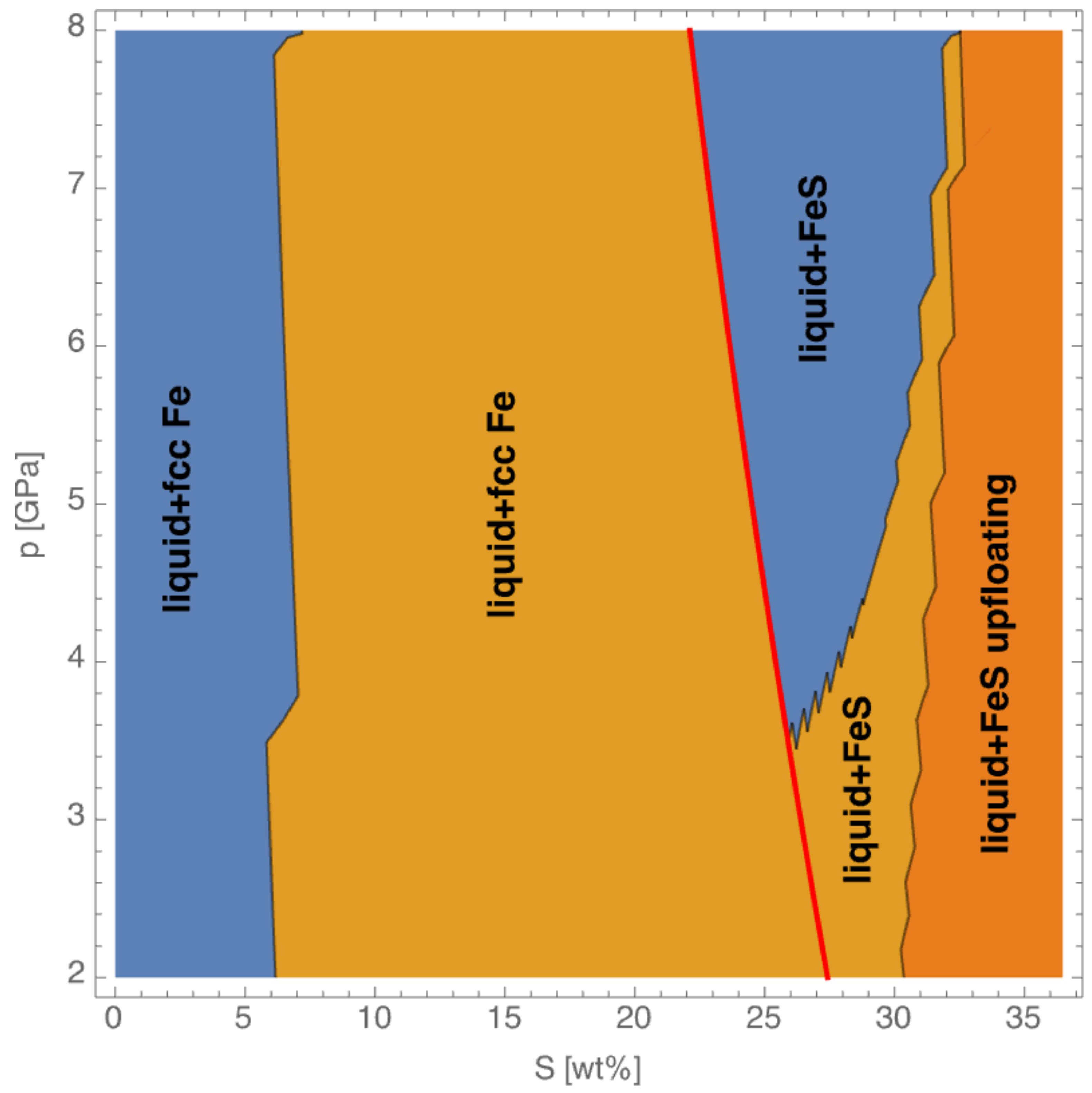
- Fe-S, Fe-C

Freezing Regimes

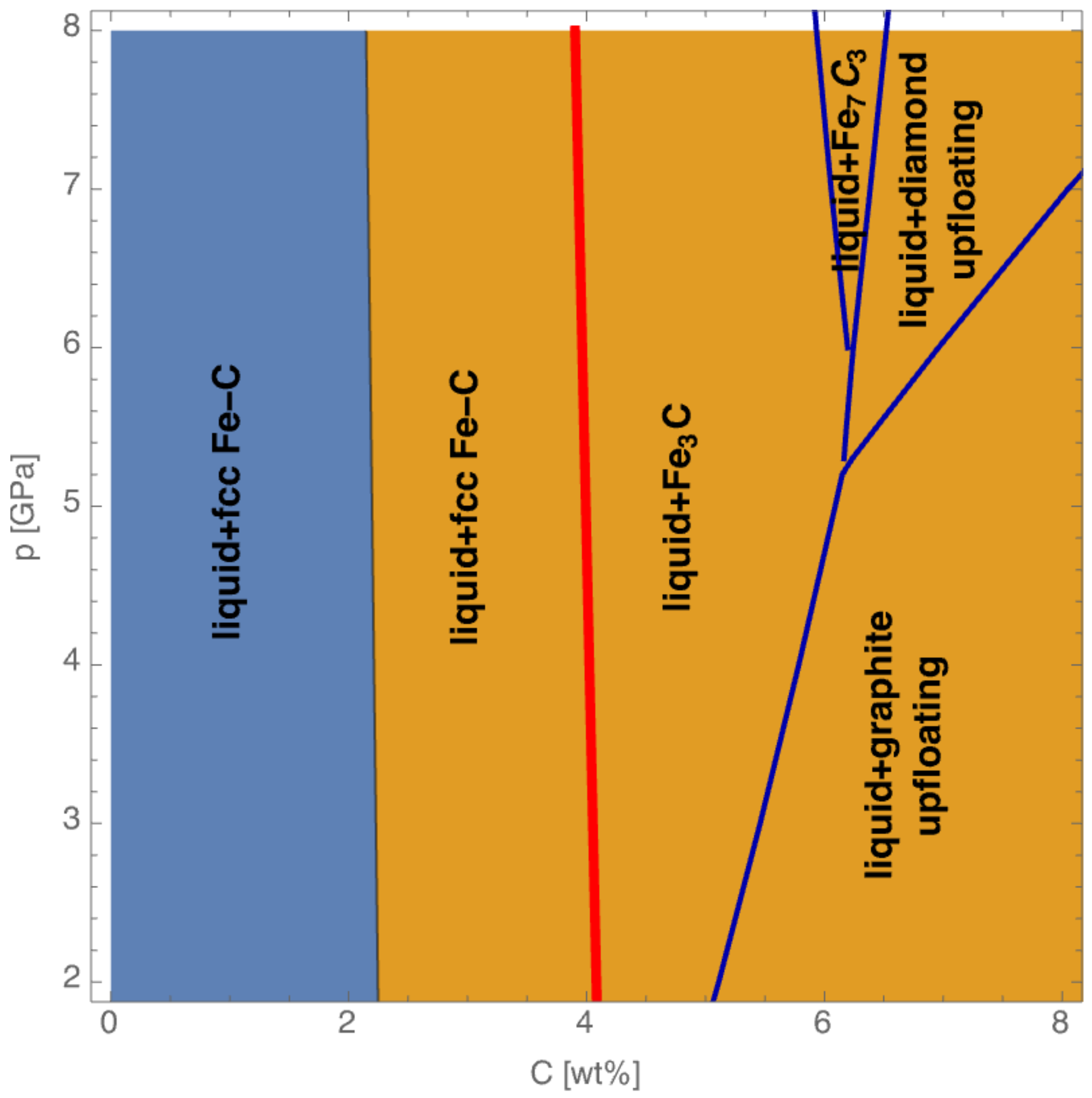
Fe-S



Bottom-up

Top—down

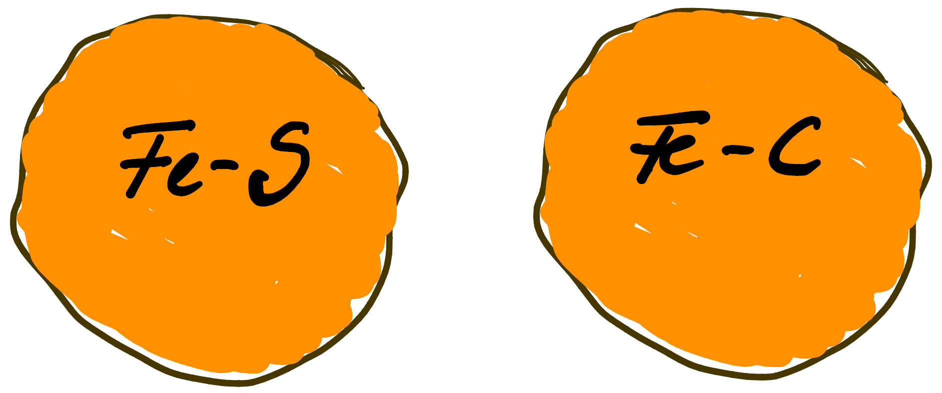
Fe-C



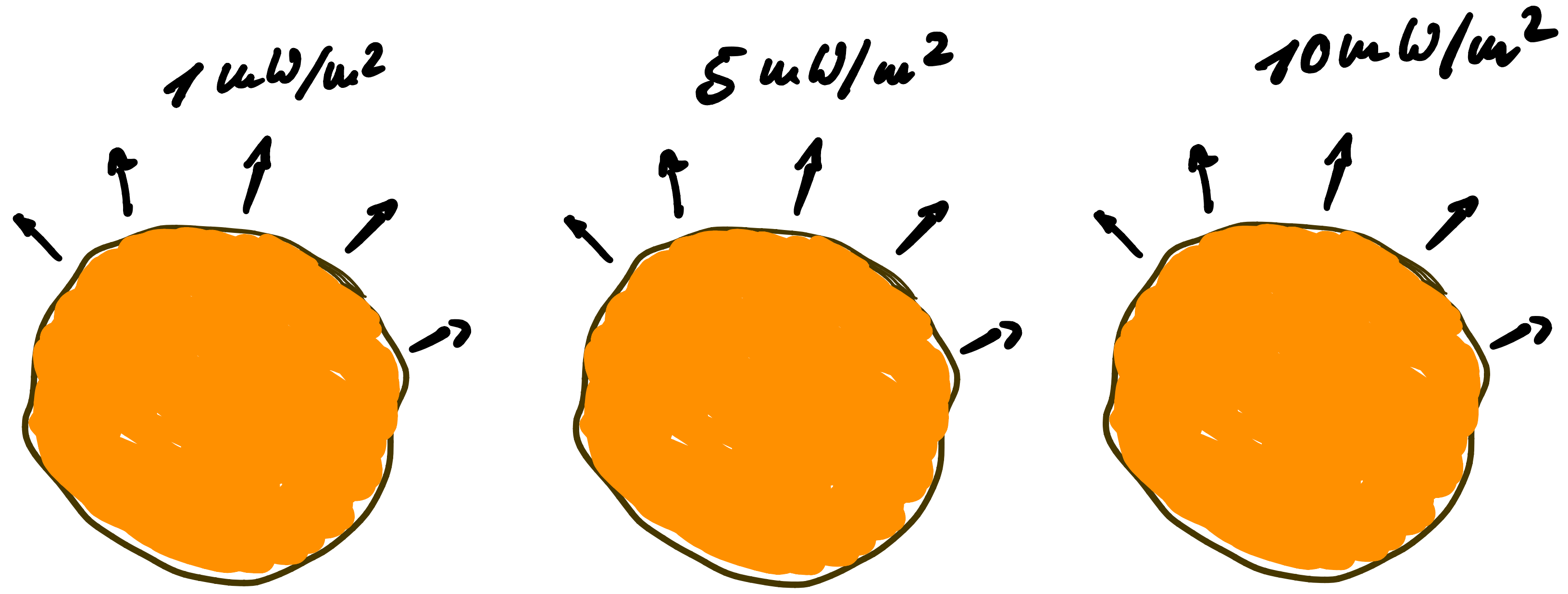
Model Parameters

1. Assuming cores of different sizes

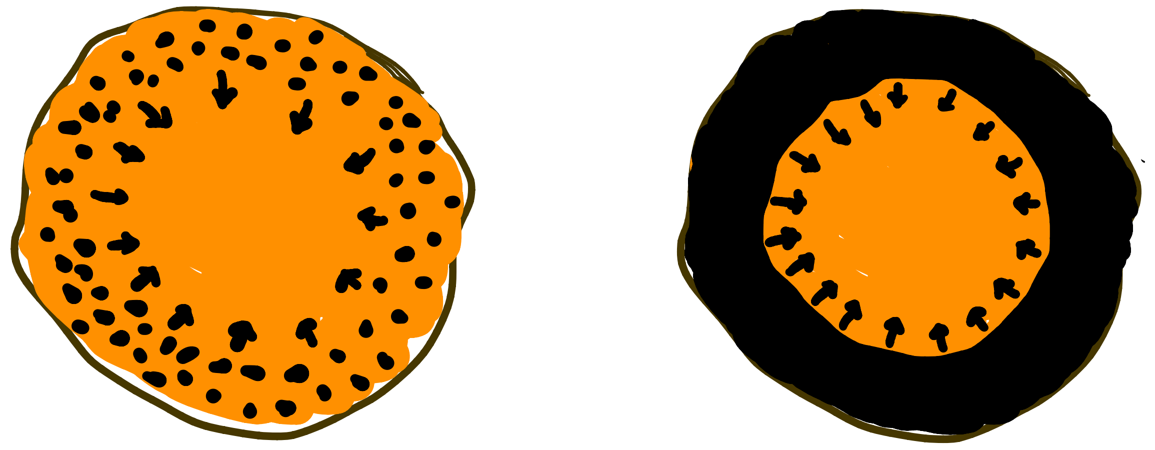
2. Assuming different compositions and self-consistent thermodynamic parameters



3. Prescribe heat flux at the CMB

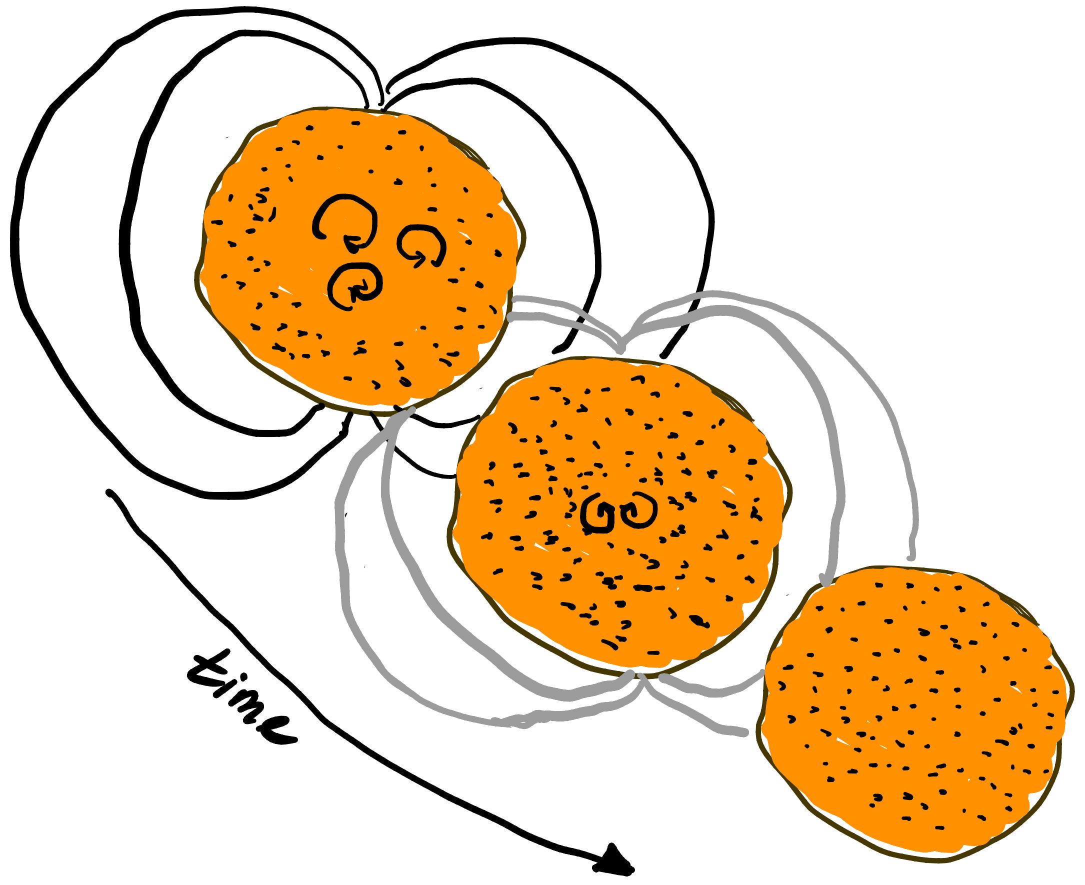


4. Plug these assumptions into core model



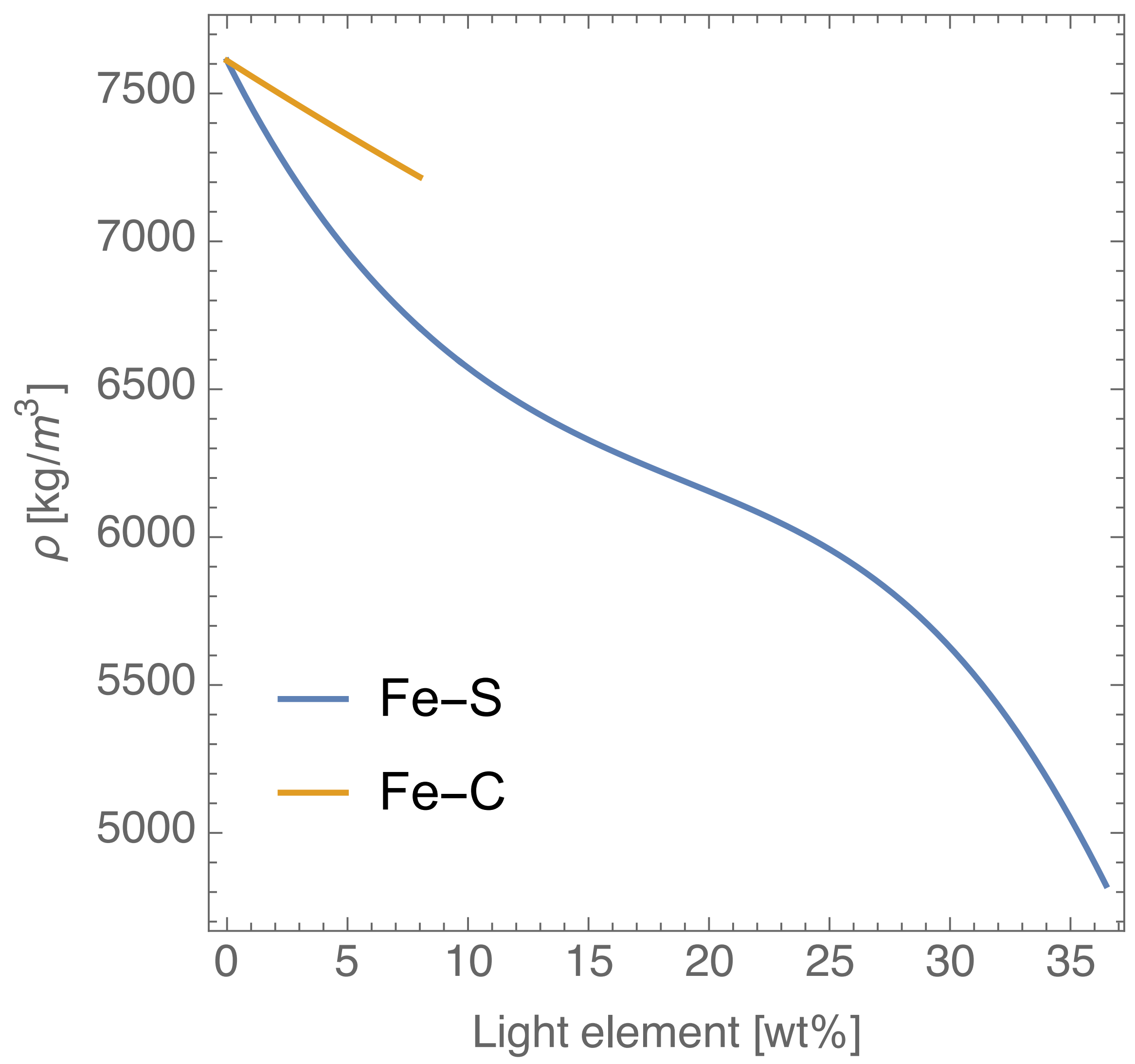
Rückriemen et al. 2015, 2018
Davies and Pommier 2018

Evolution of
- Structure
- Magnetic field strength

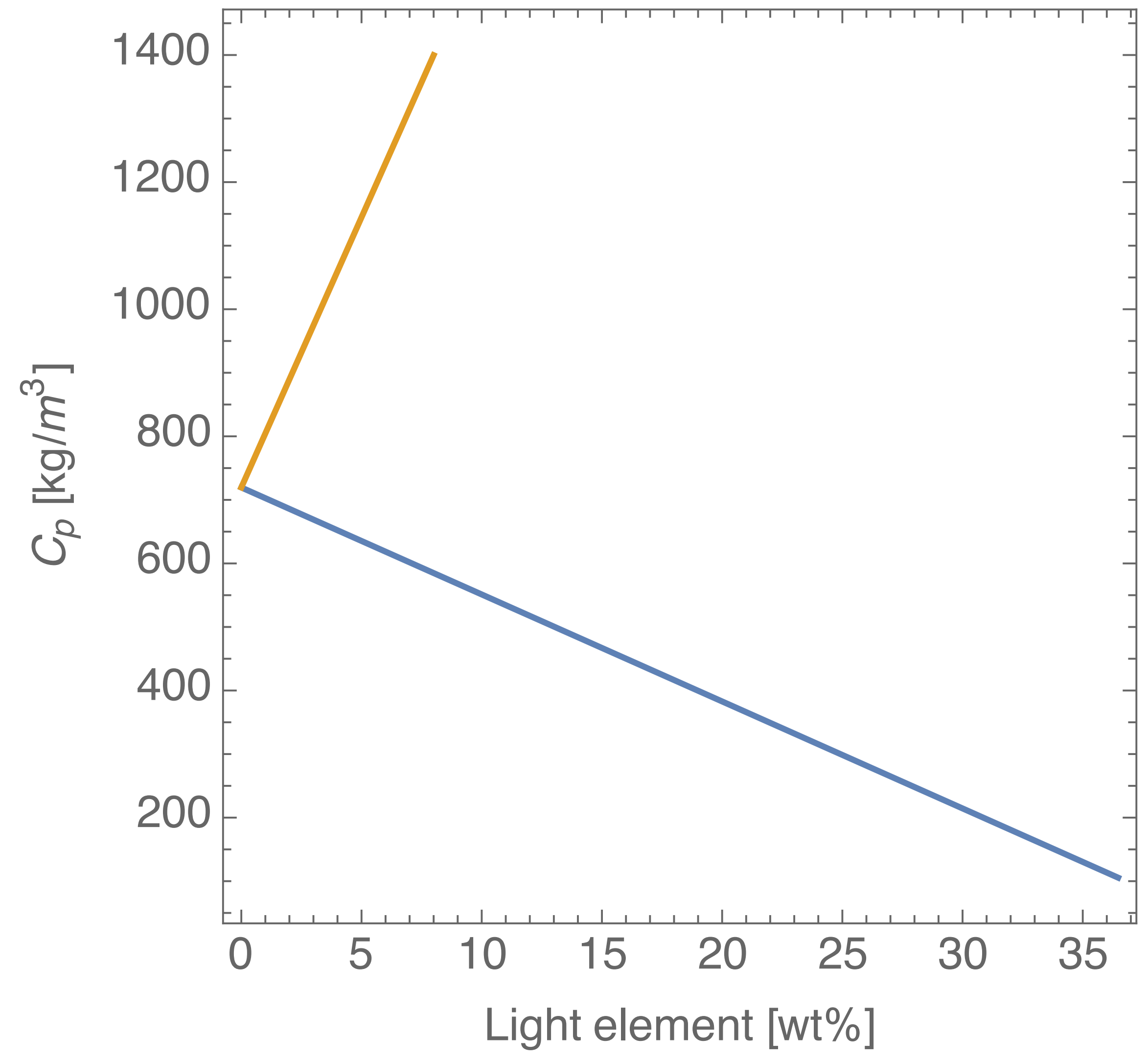


Thermodynamic Parameters

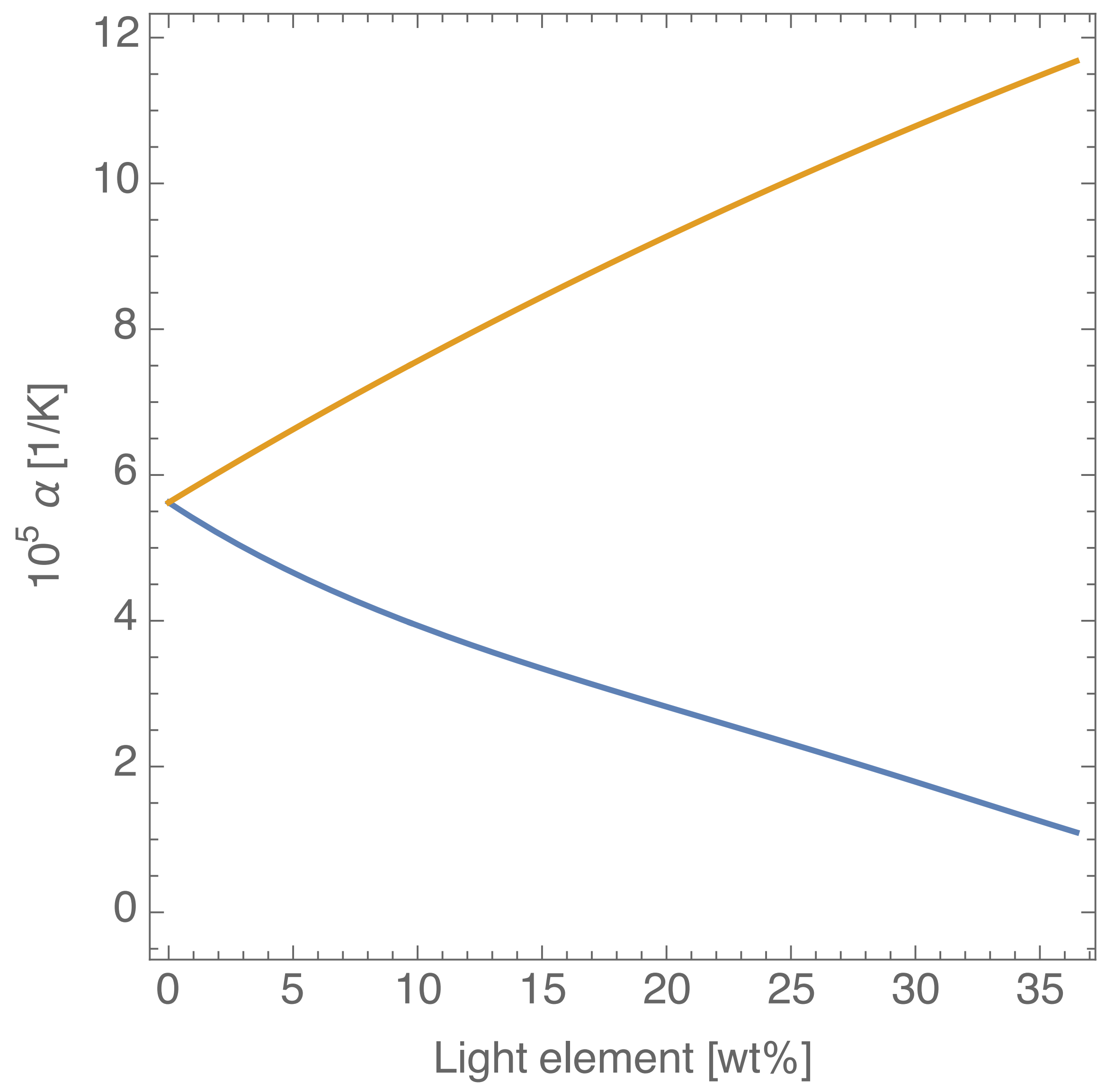
Density



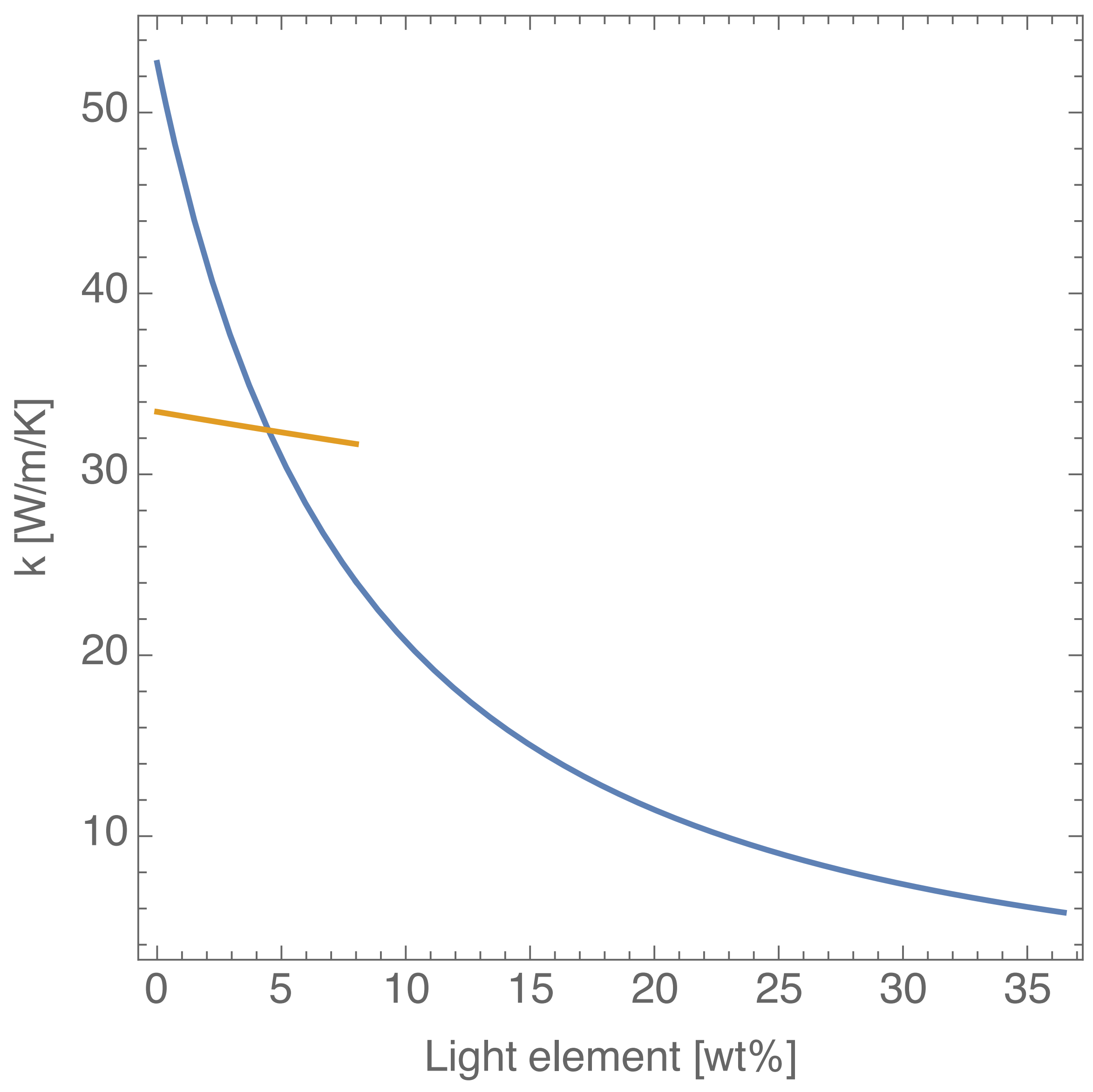
Heat Capacity



Thermal Expansivity

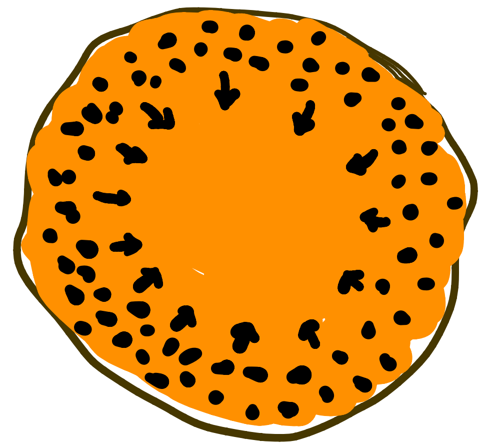


Thermal Conductivity



- Pressure, temperature, and concentration dependent
- For small (low-pressure) planetary bodies effect of concentration dominant

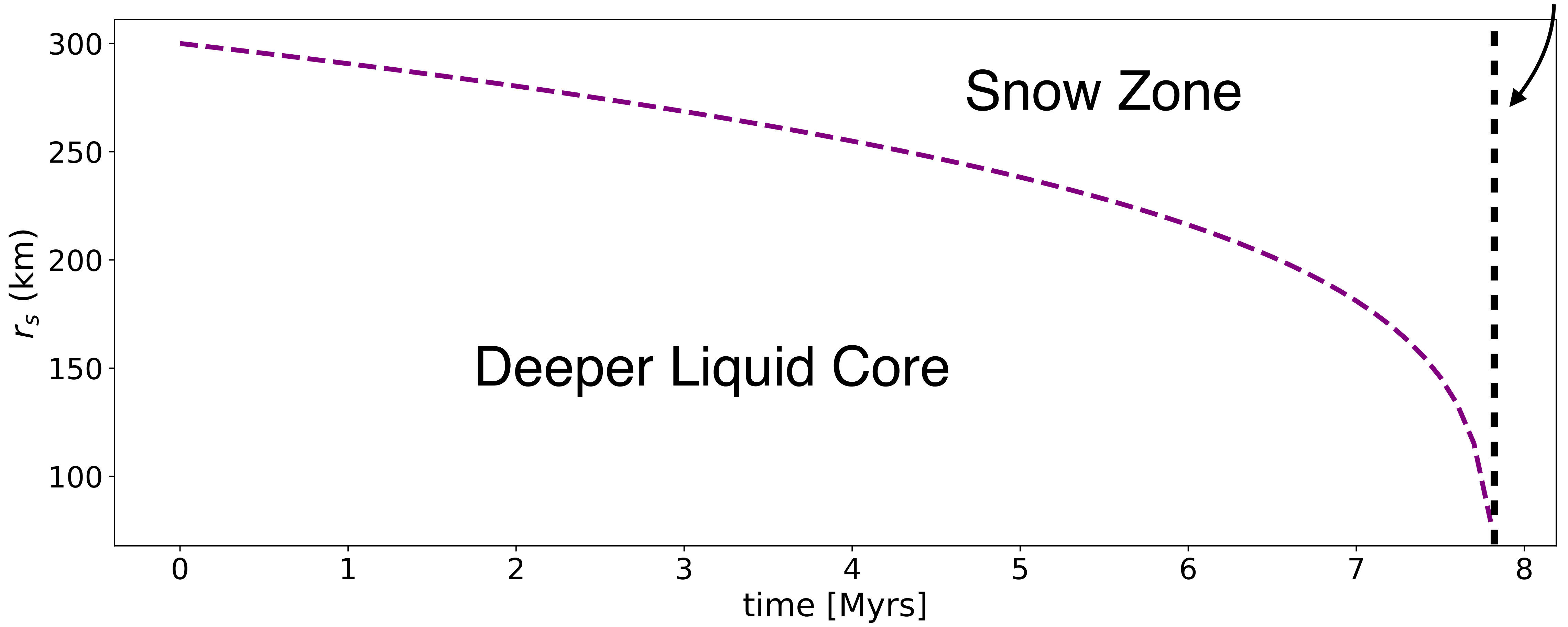
Snow in Fe-S Cores



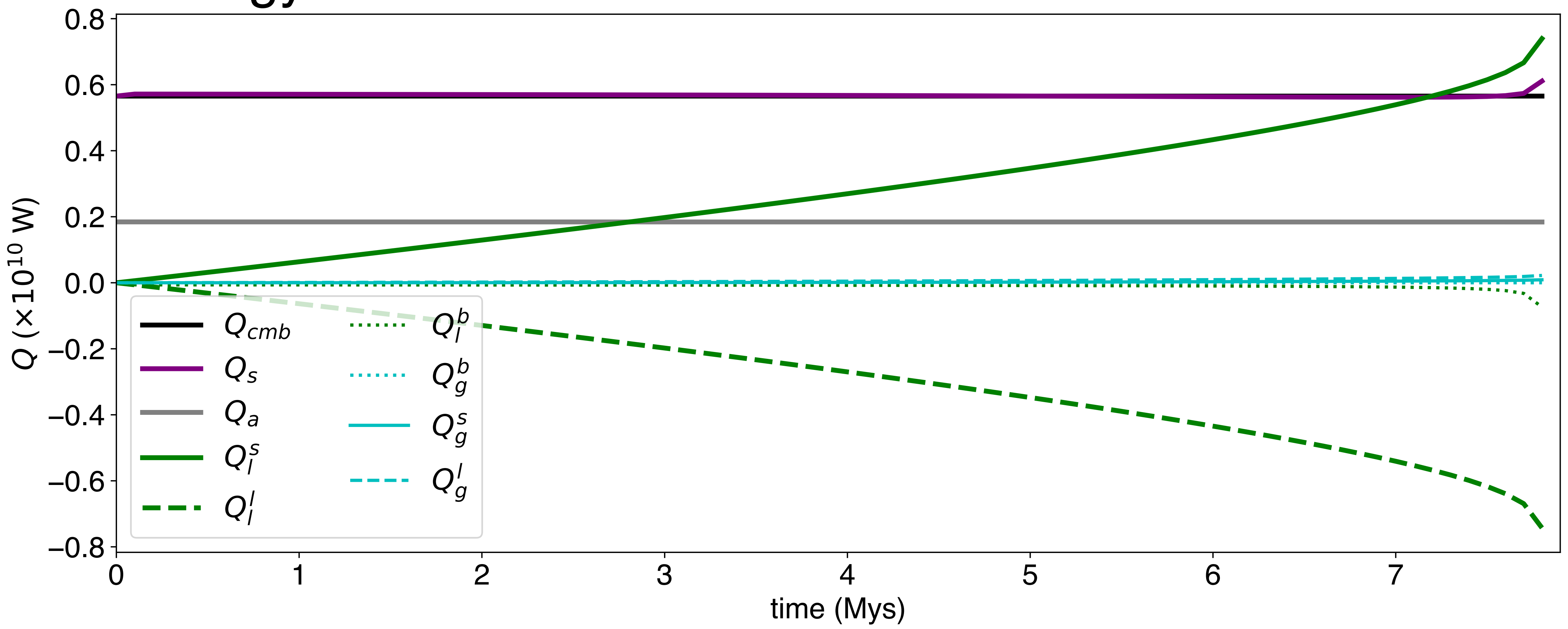
Snow Zone Evolution (x_S=10 wt.%, q_{cmb}= 5mW/m^2, R_c=300 km)

snow zone covers the entire core

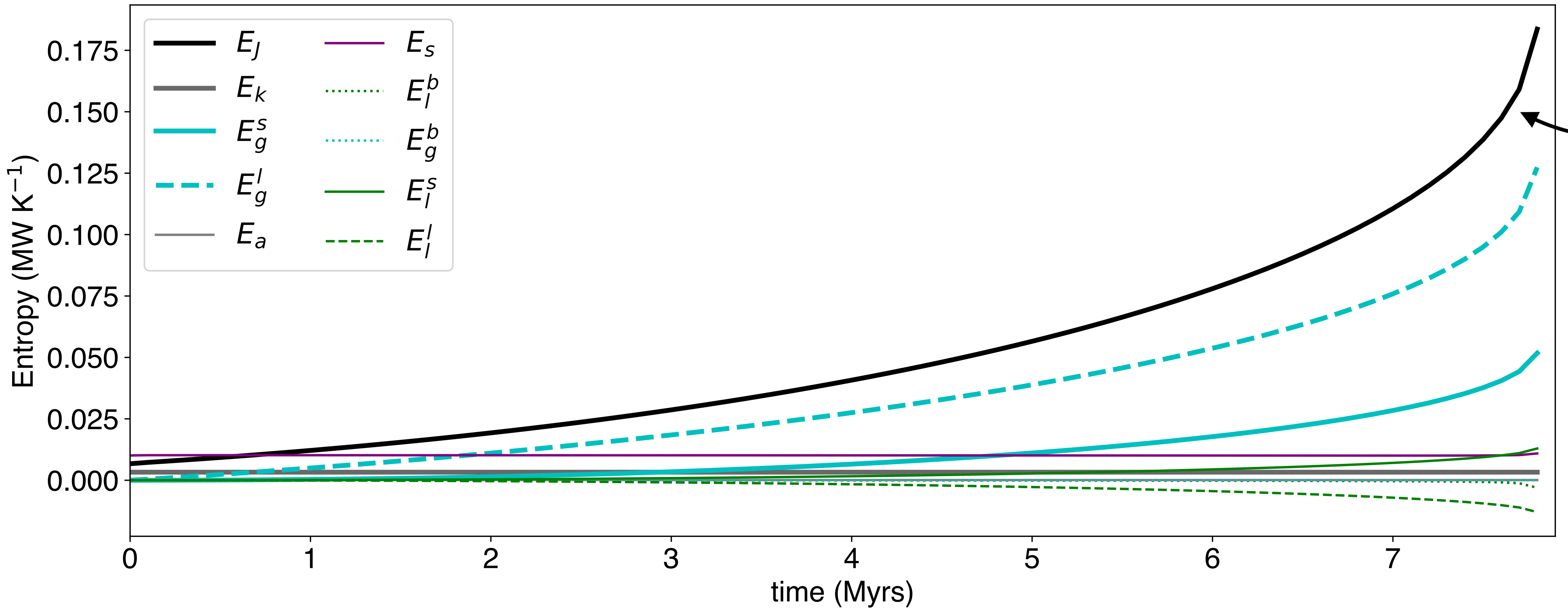
Snow Zone Growth



Energy Contributions

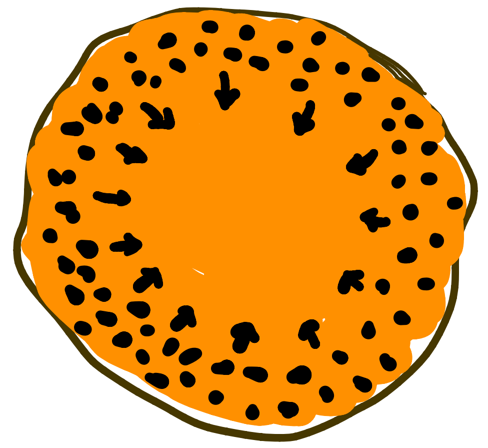


Entropy Contributions



total entropy above 0 for entire evolution (necessary for dynamo action)

Snow in Fe-S Cores



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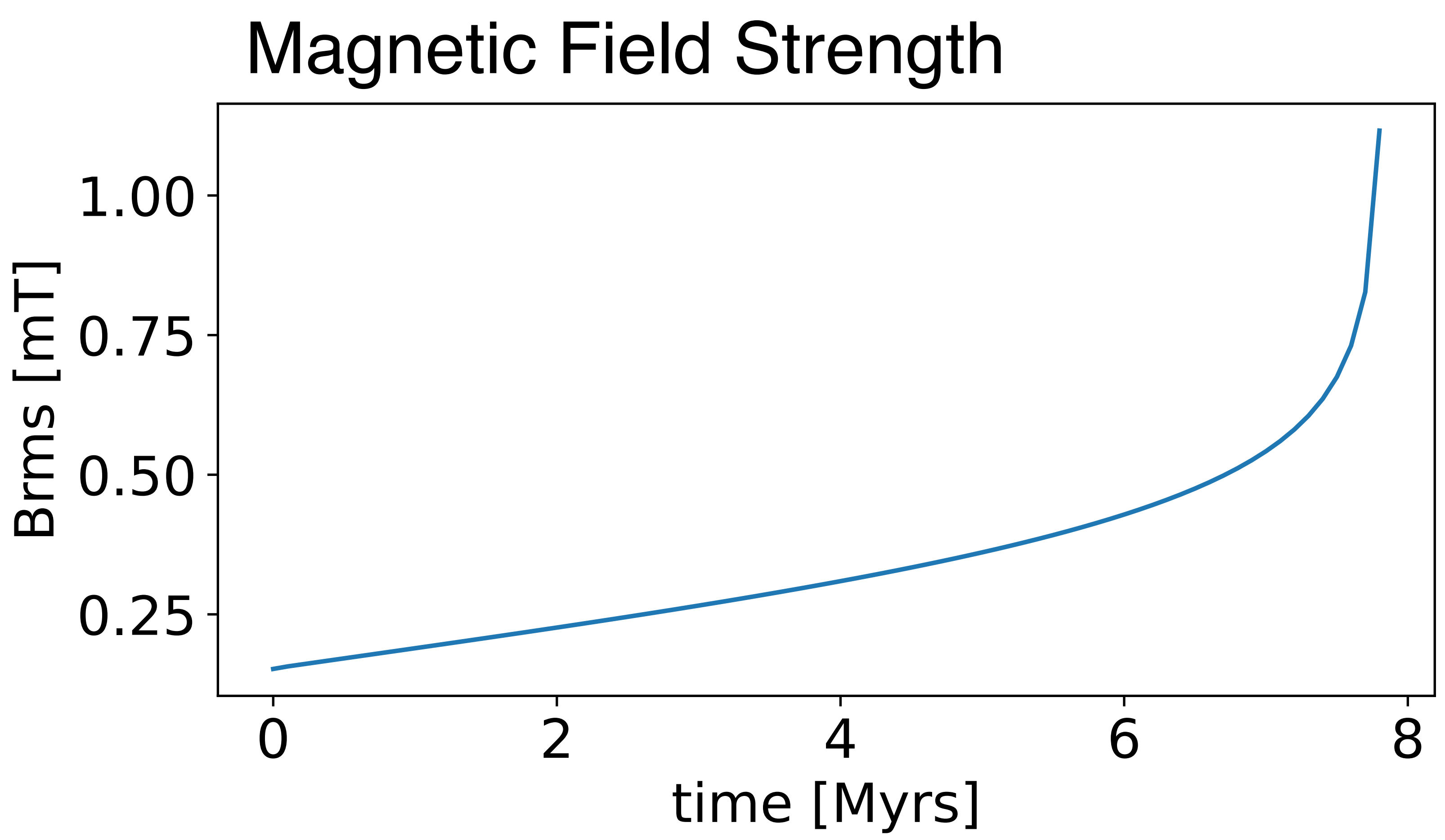
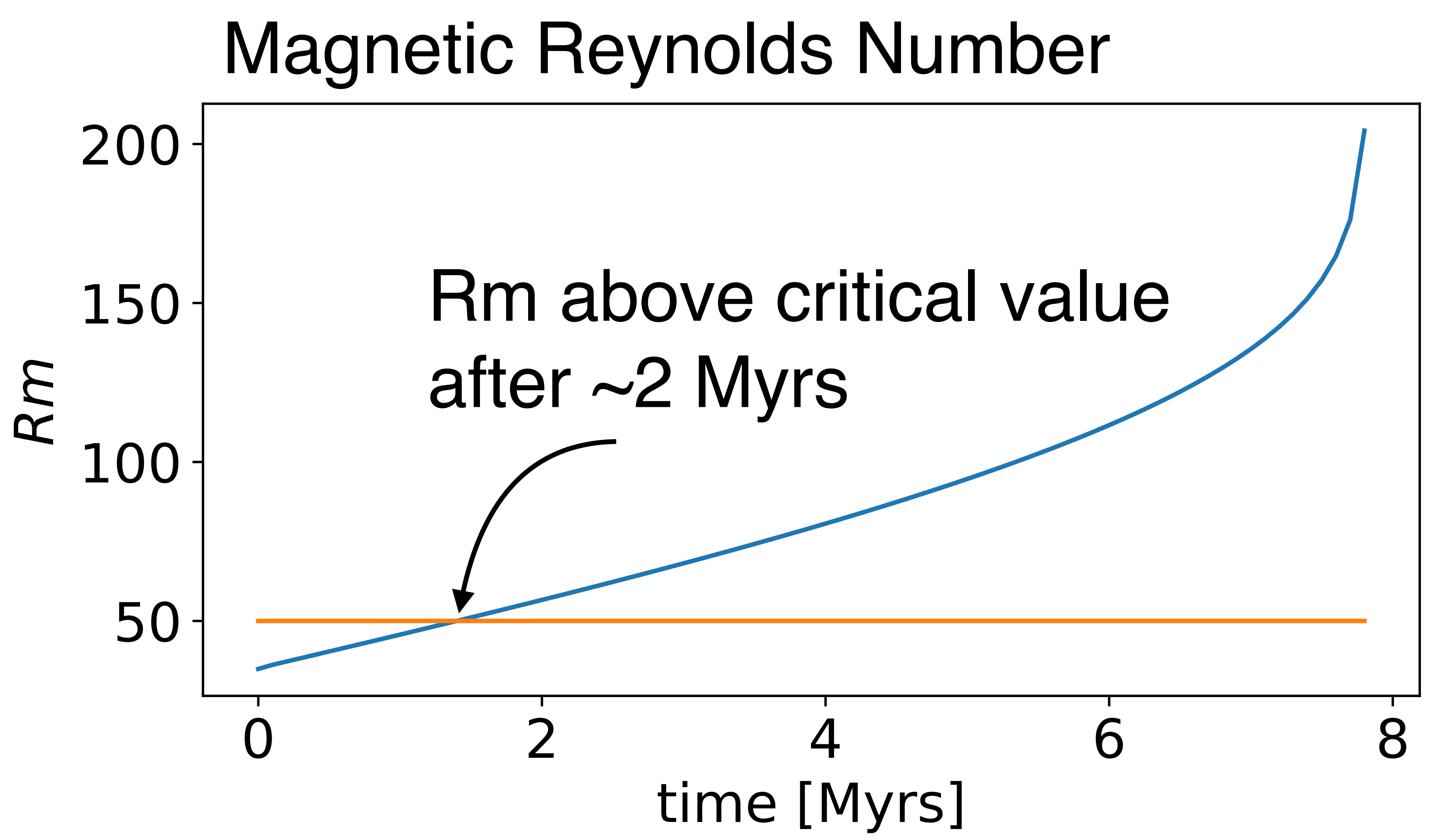
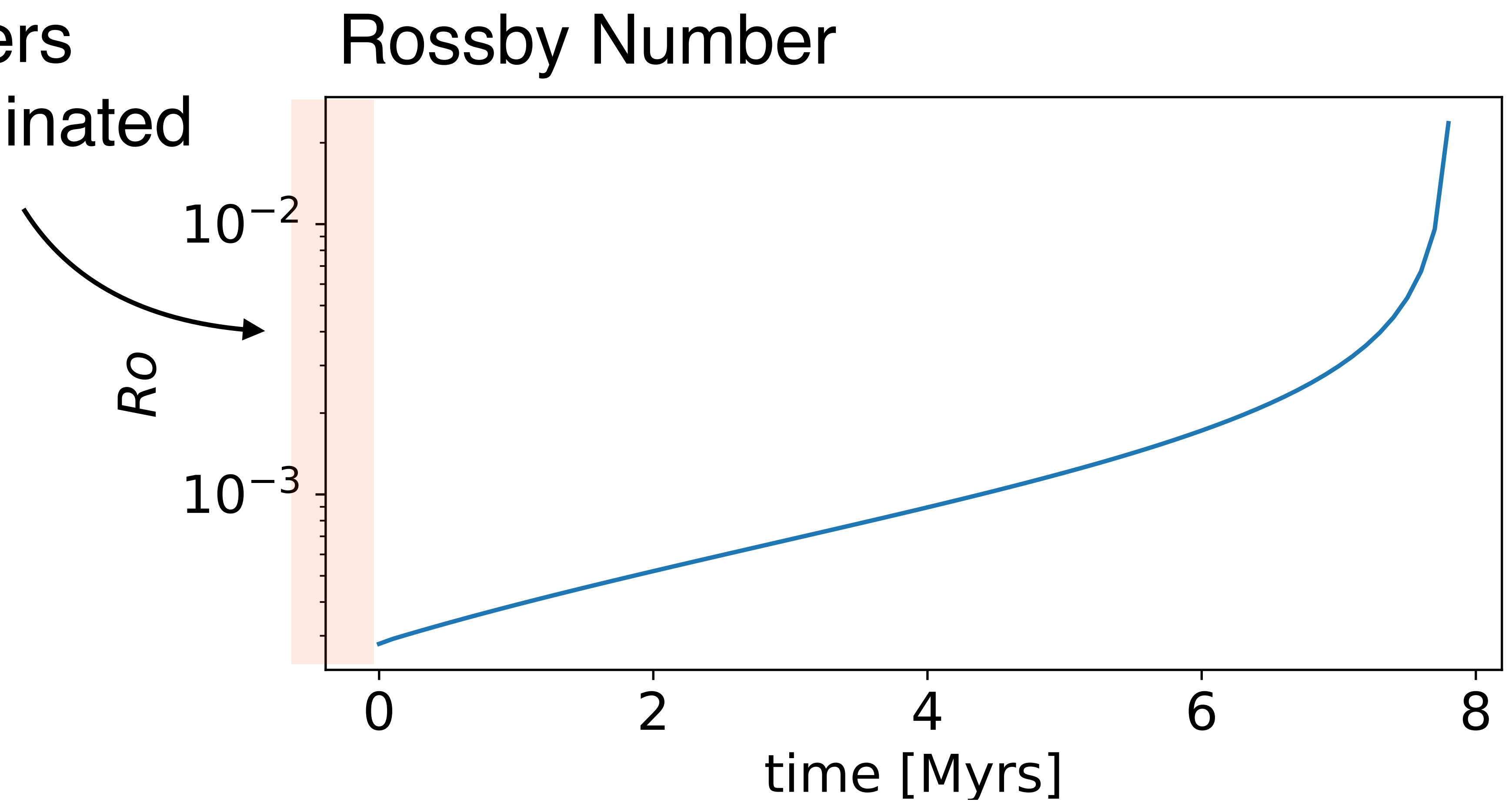
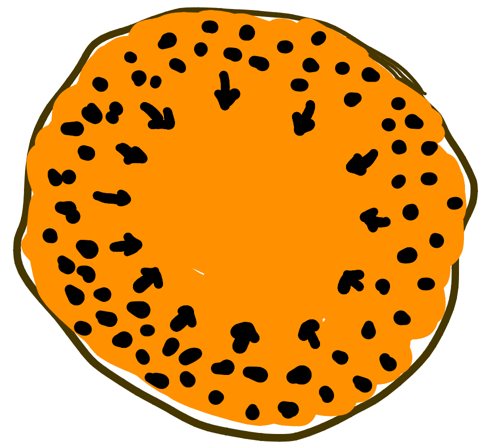




Small Rossby numbers indicate rotation dominated dynamics



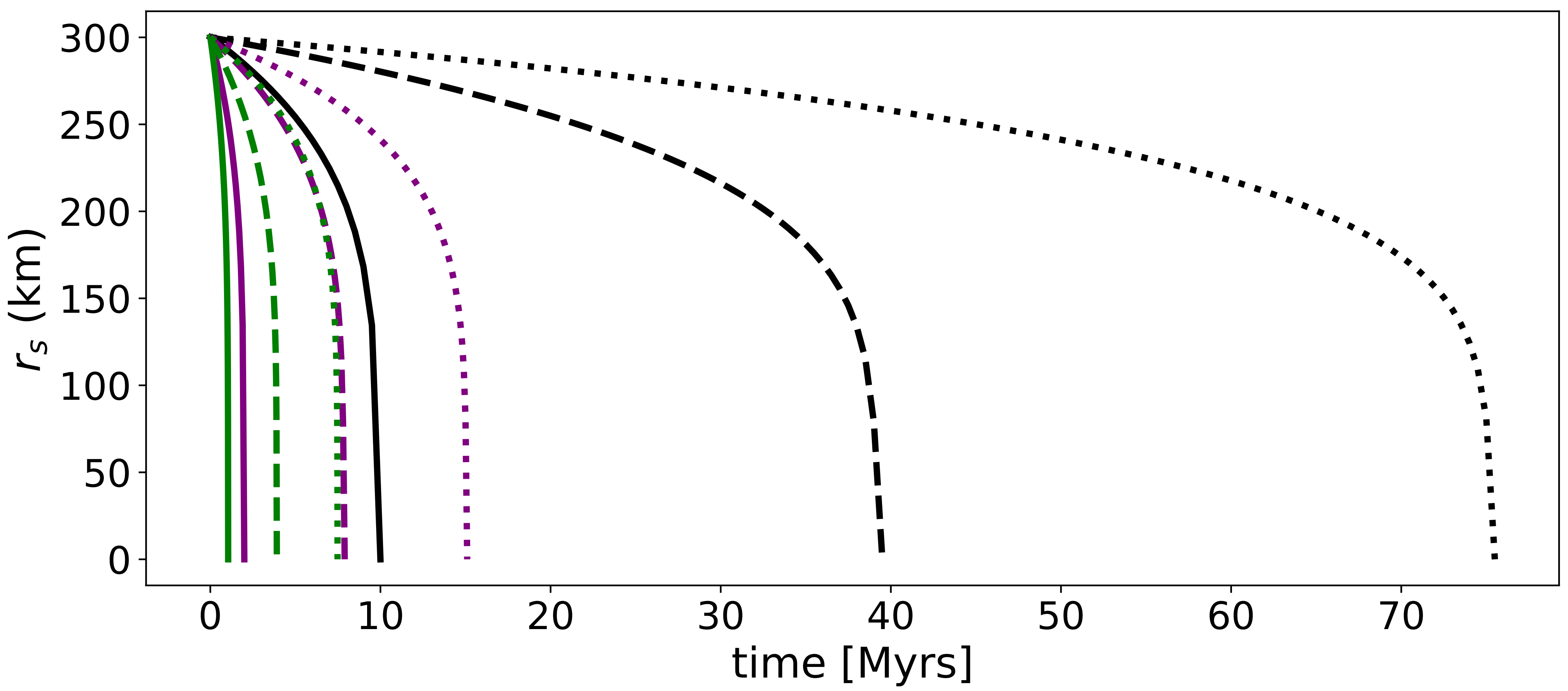


1mW/m² 5wt.%
5mW/m² 10wt.%
10mW/m² 15wt.%

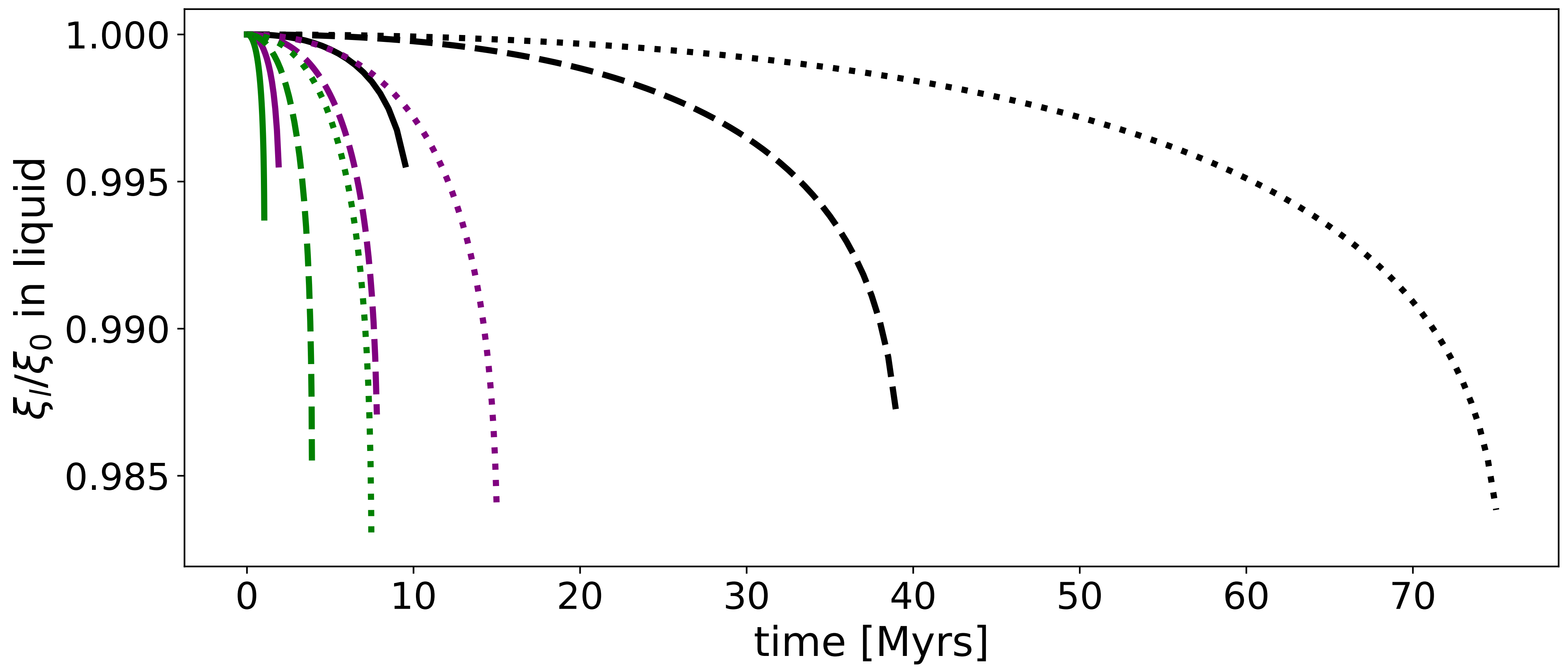
Snow in Fe-S Cores

Dependence on Sulfur Concentration and Heat Flux

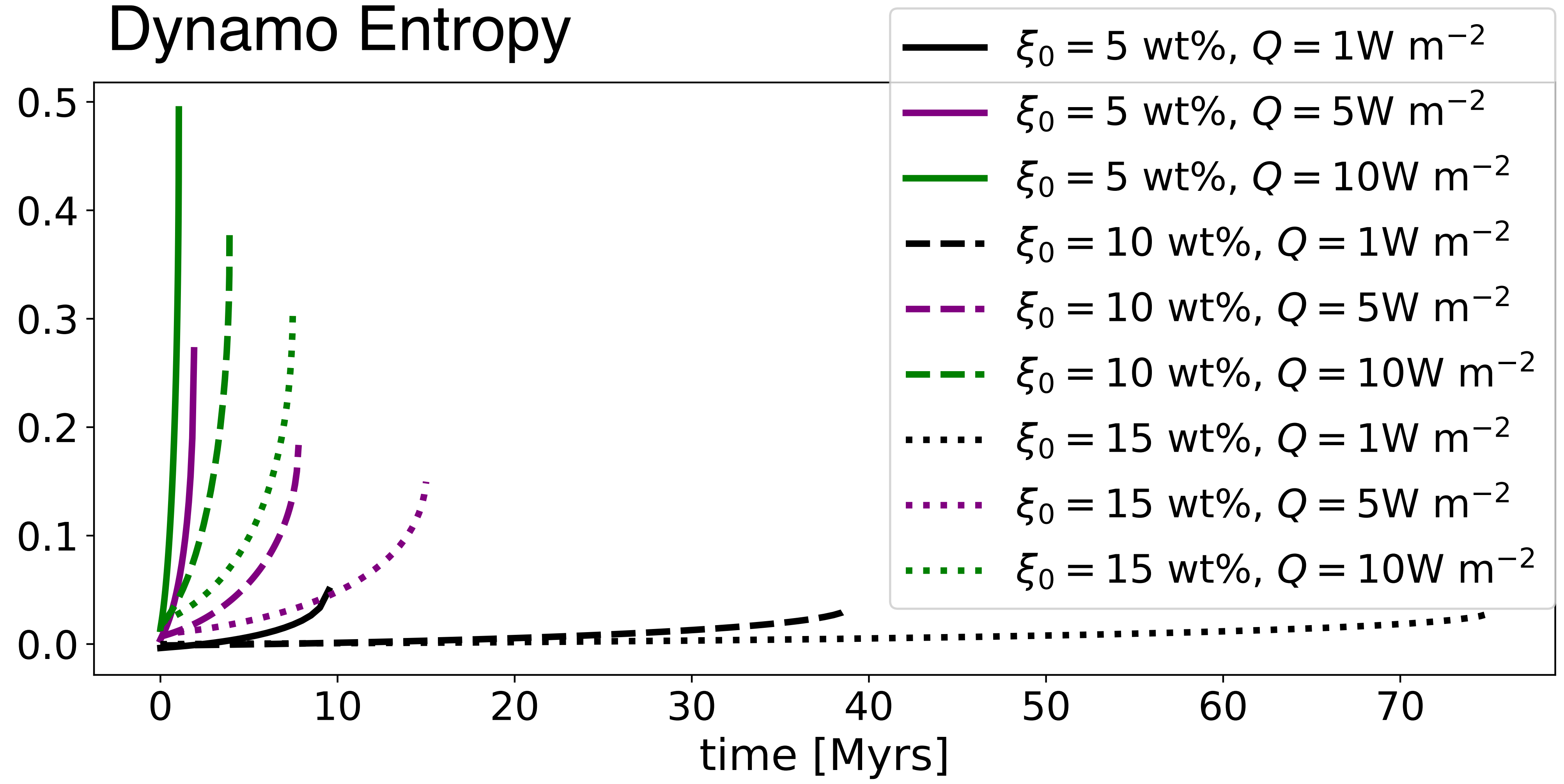
Snow Zone Growth



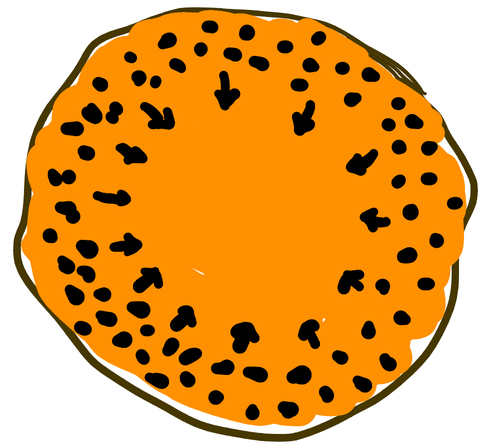
Sulfur Concentration Deeper Core



Dynamo Entropy



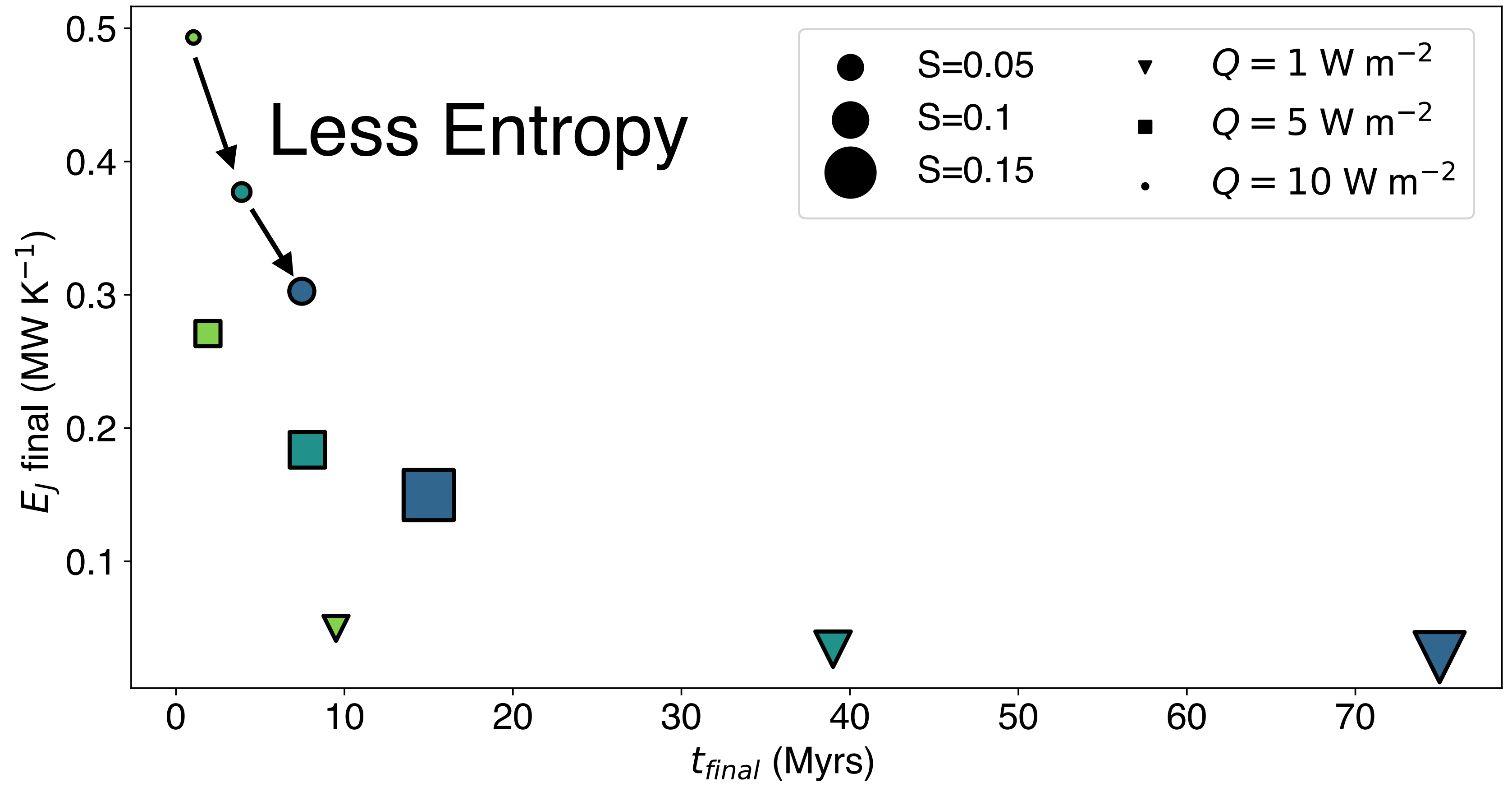
- Higher sulfur concentrations …
  - take longer to grow snow zone.
  - produce less entropy.
- Higher heat fluxes …
  - take less to grow snow zone.
  - produce more entropy.



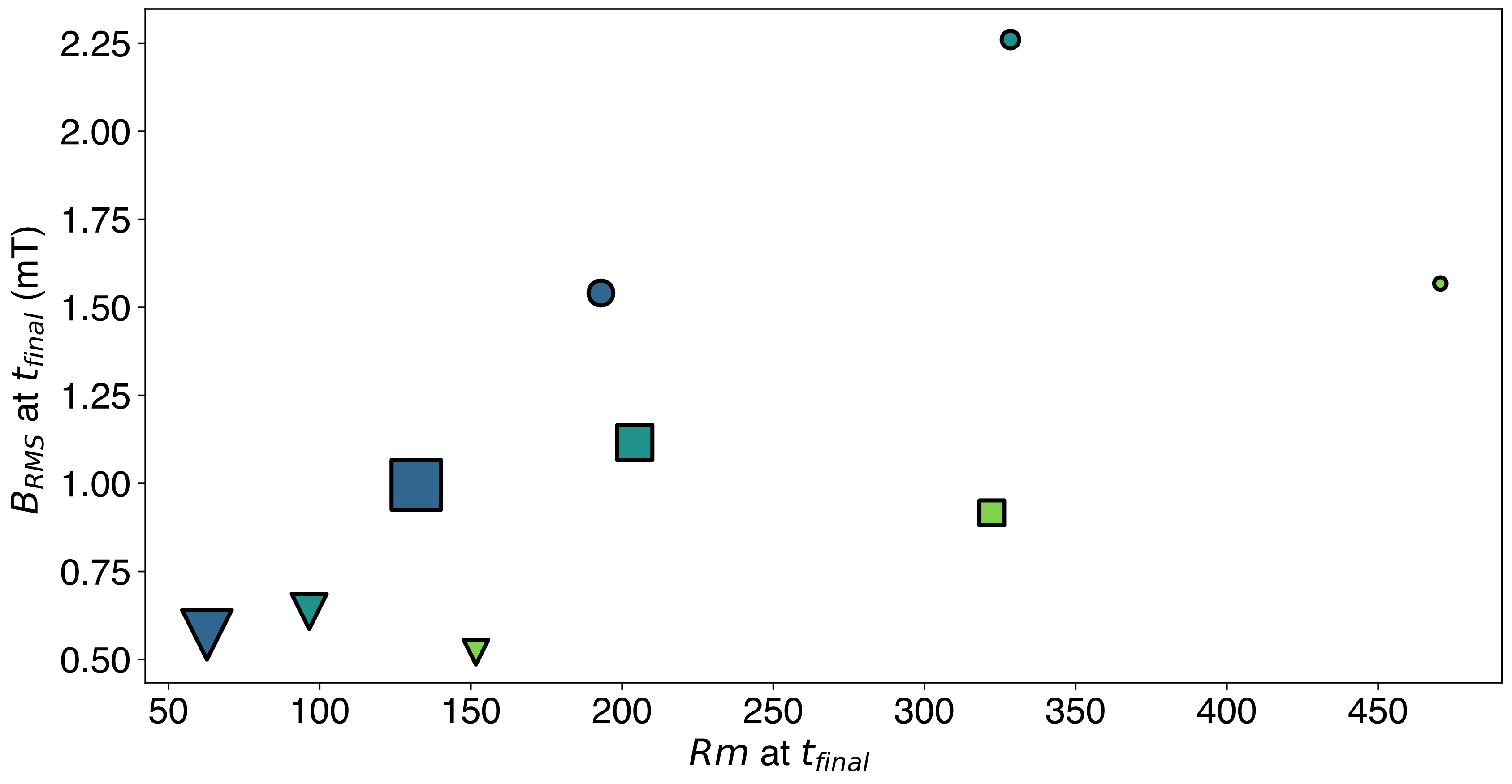
Snow in Fe-S Cores

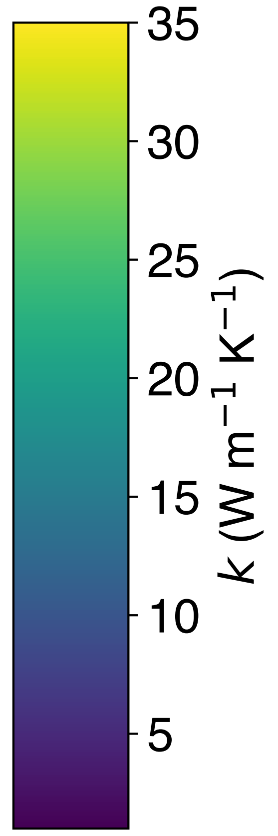
Dependence on Sulfur Concentration and Heat Flux

Dynamo Entropy vs Total Growth Time



B_{rms} vs Rm





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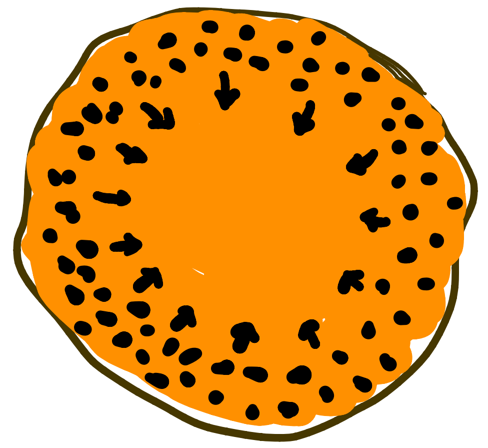
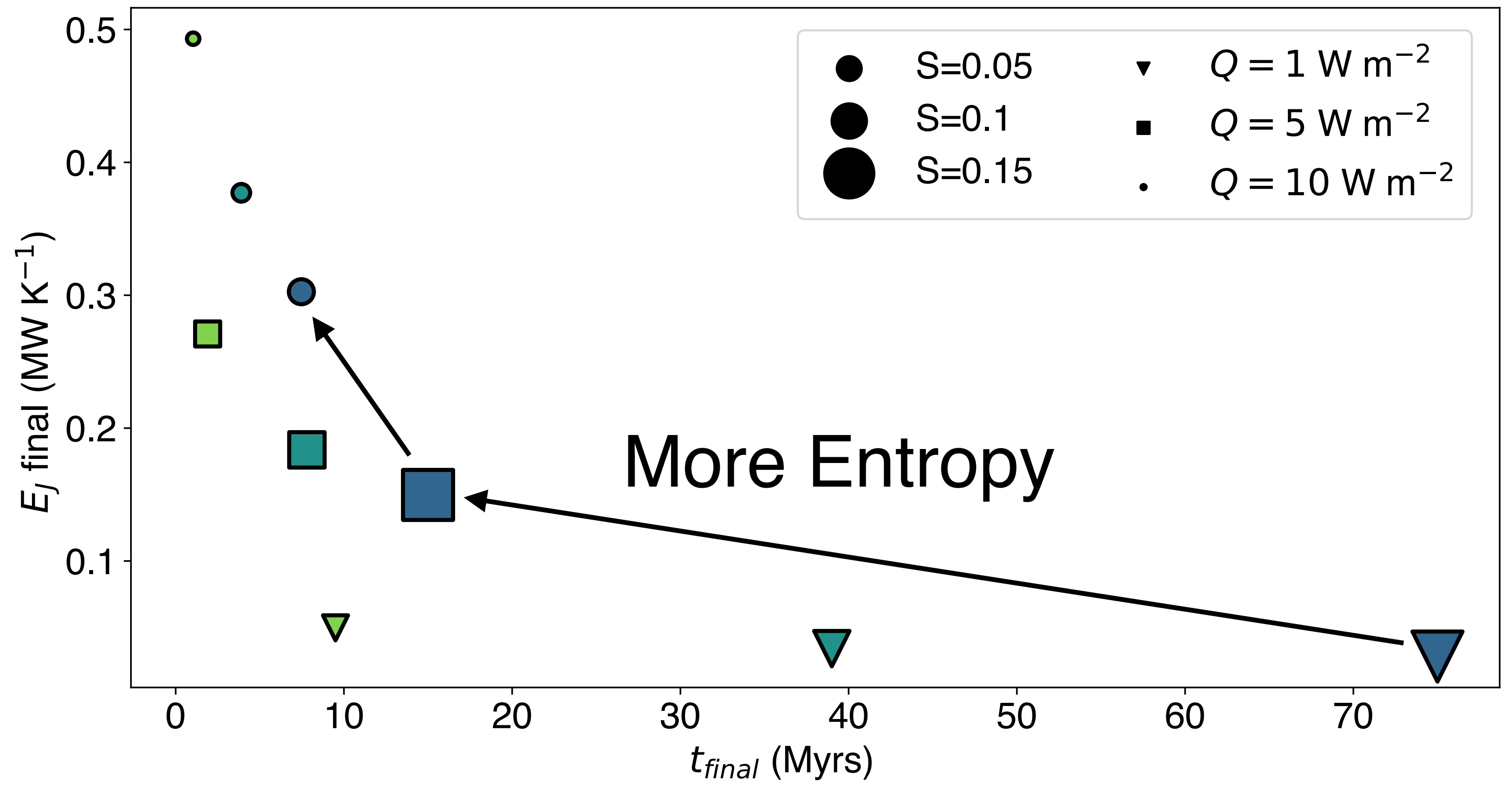
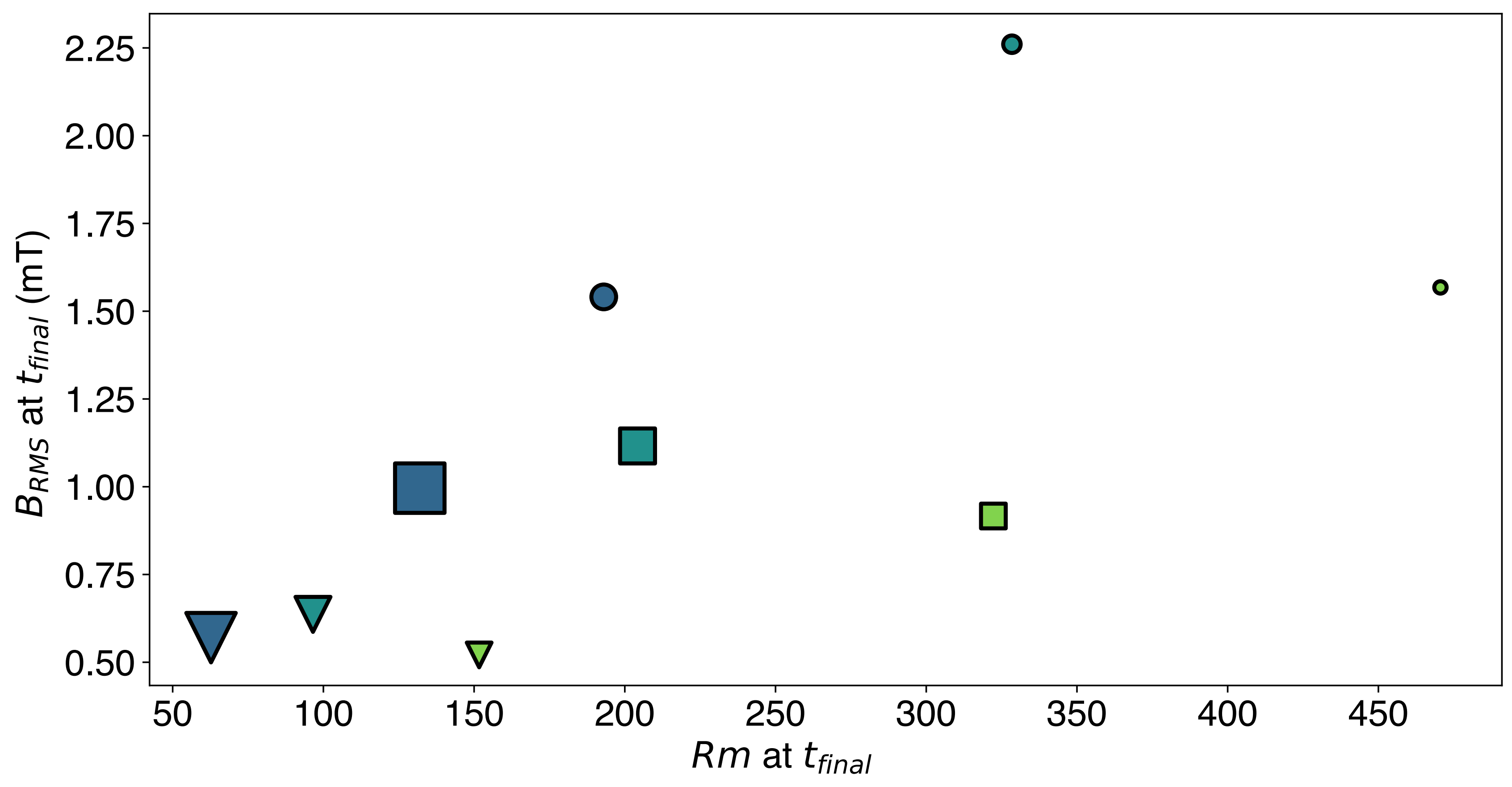


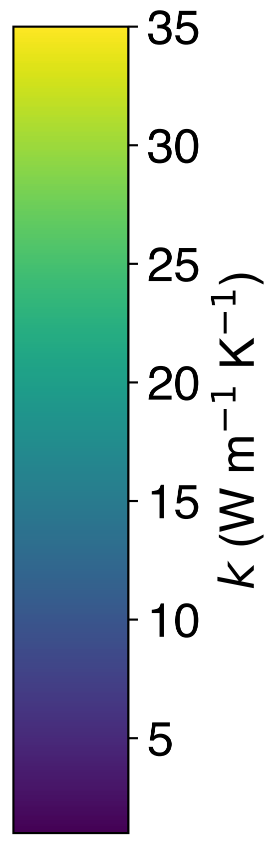
Dependence on Sulfur Concentration and Heat Flux

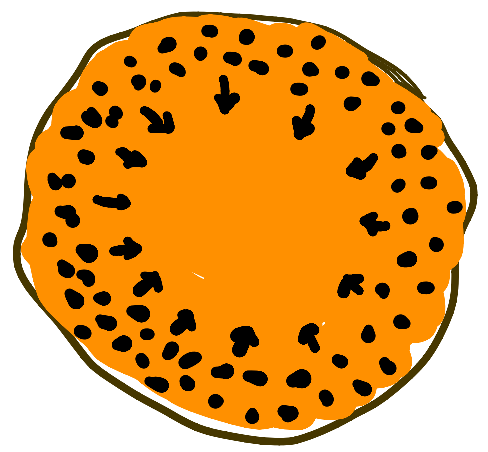
Dynamo Entropy vs Total Growth Time



B_{rms} vs Rm



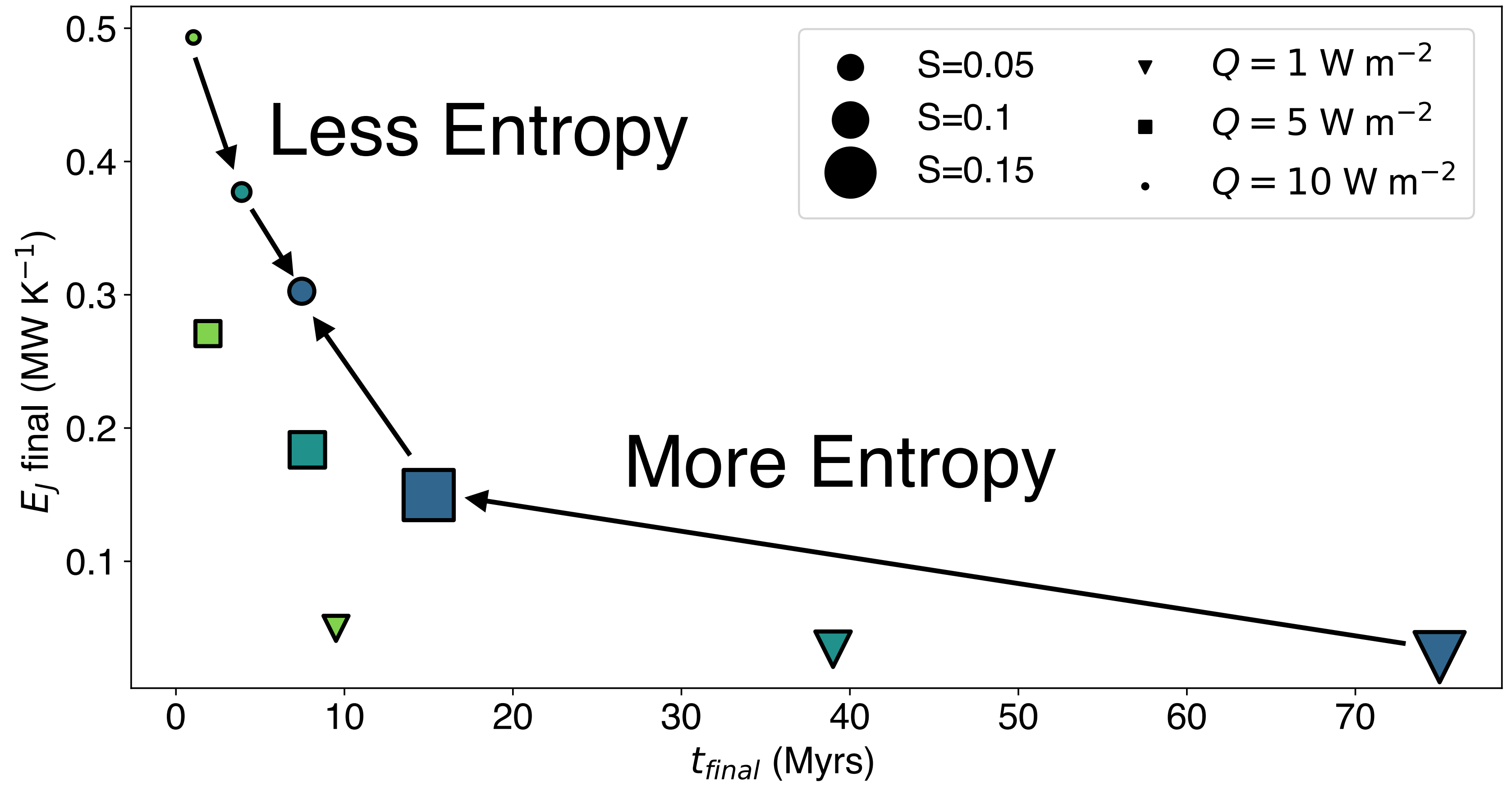




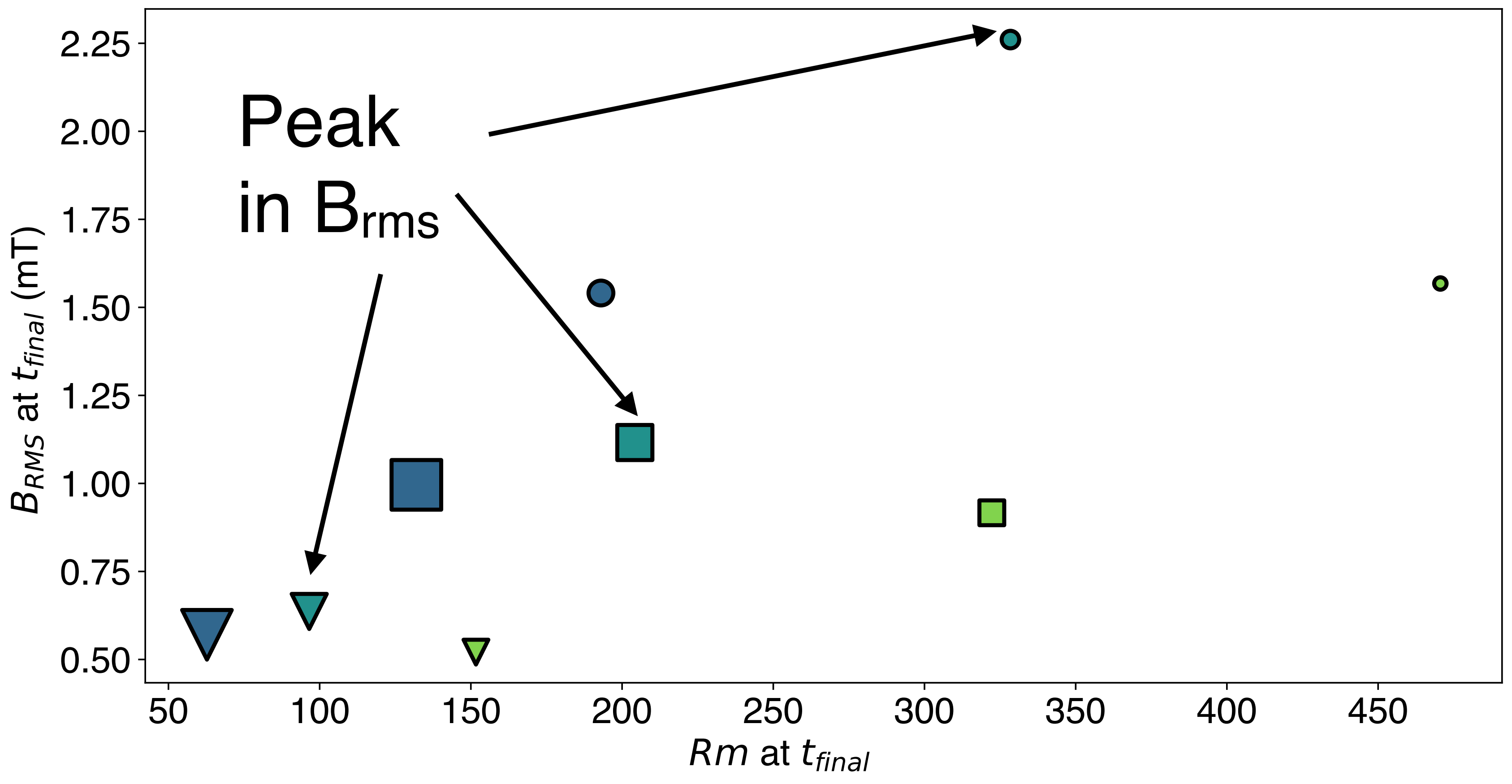
Snow in Fe-S Cores

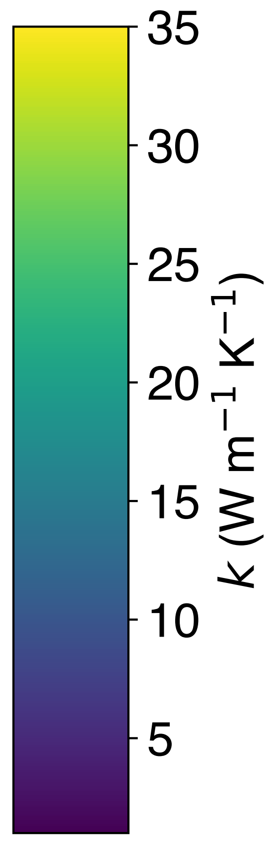
Dependence on Sulfur Concentration and Heat Flux

Dynamo Entropy vs Total Growth Time



B_{rms} vs Rm





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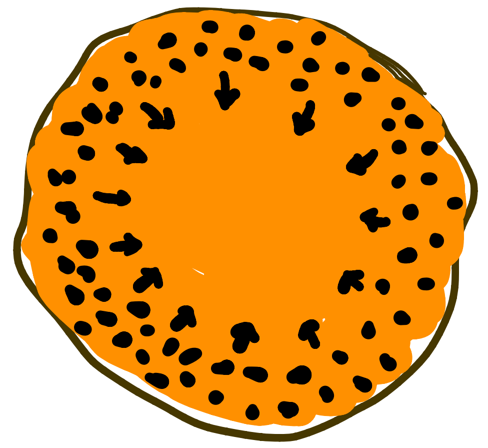
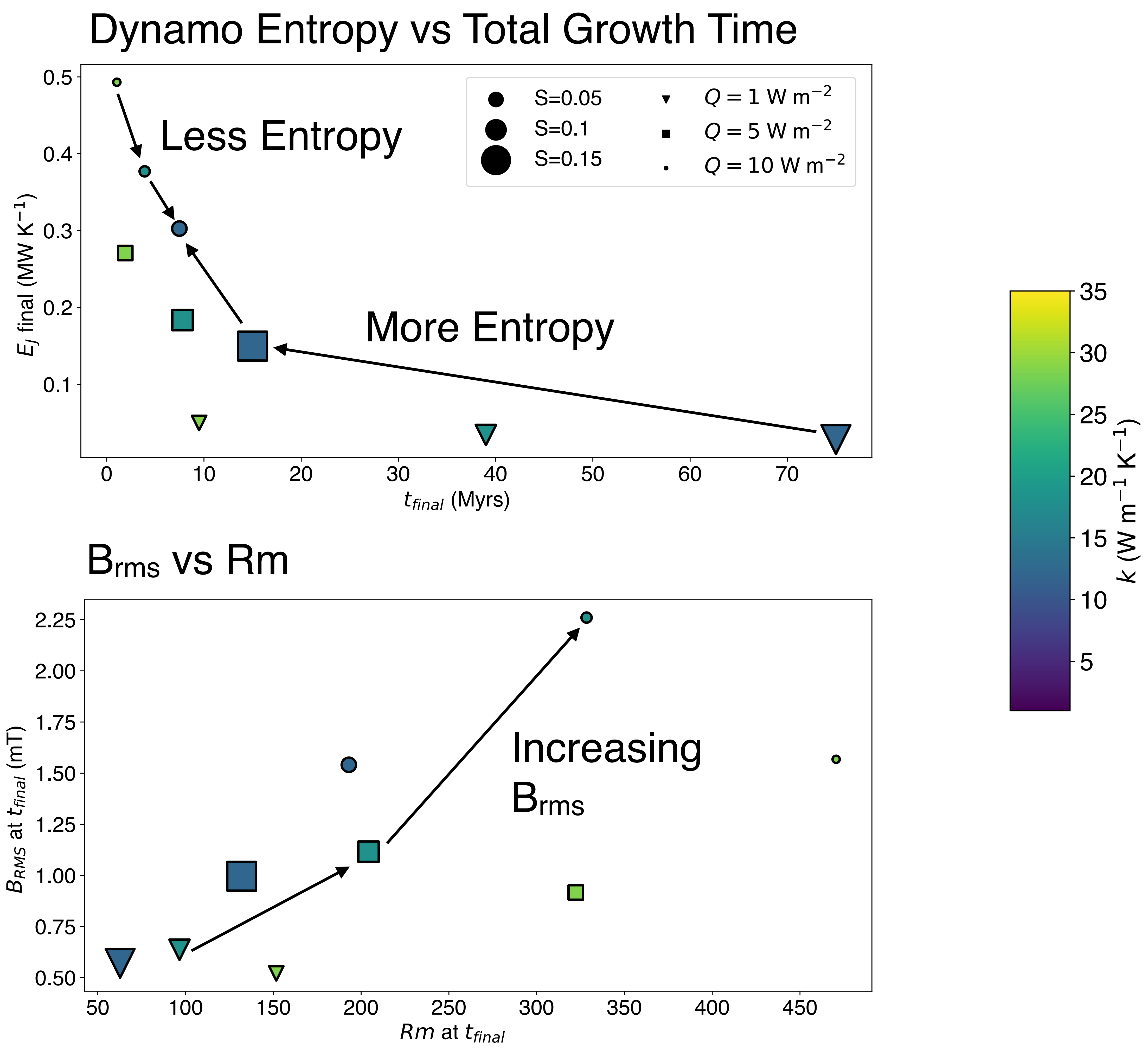


Dependence on Sulfur Concentration and Heat Flux



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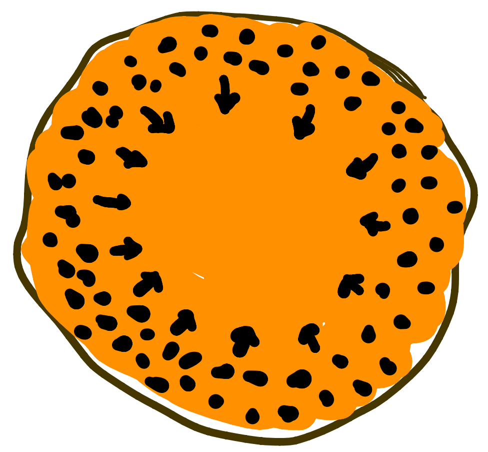
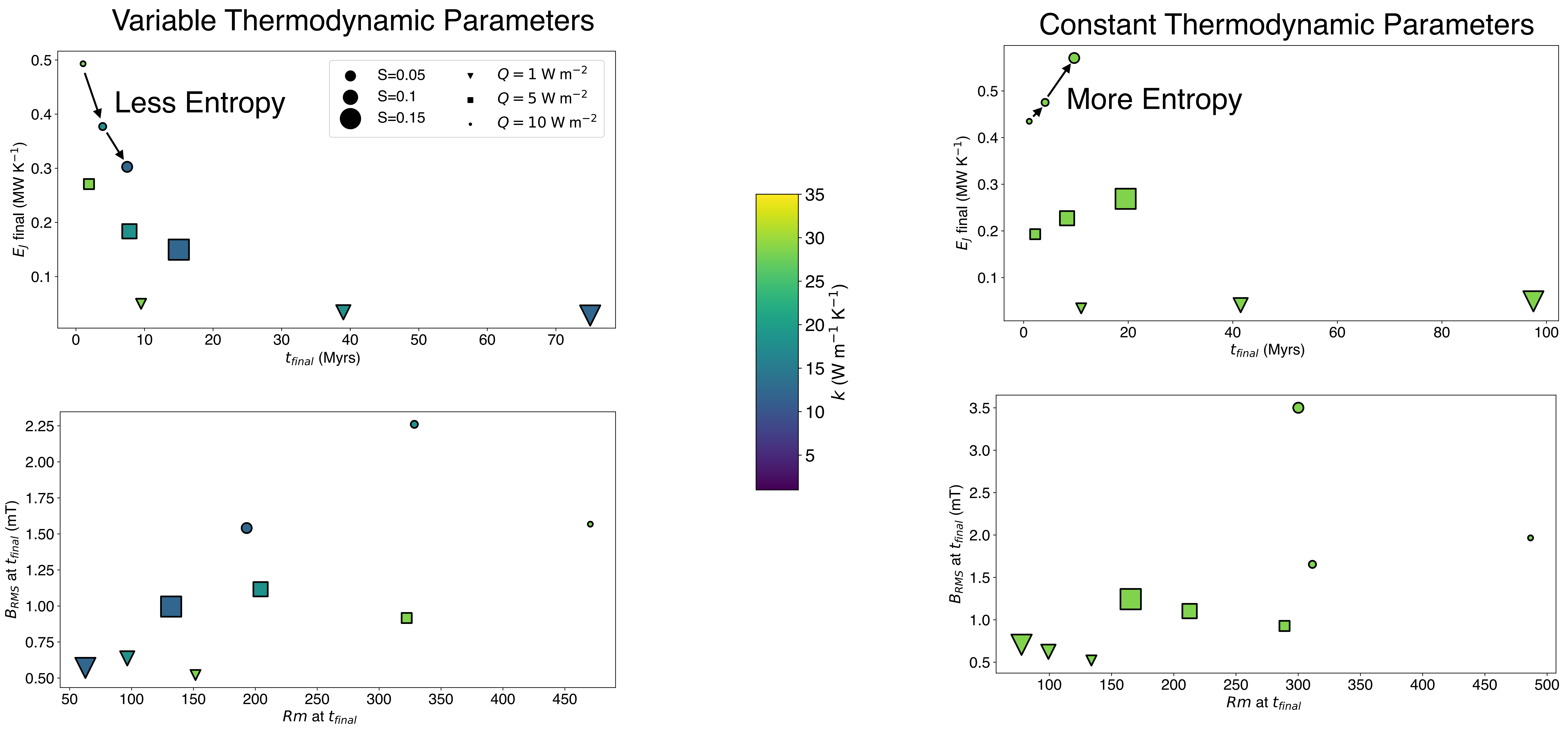
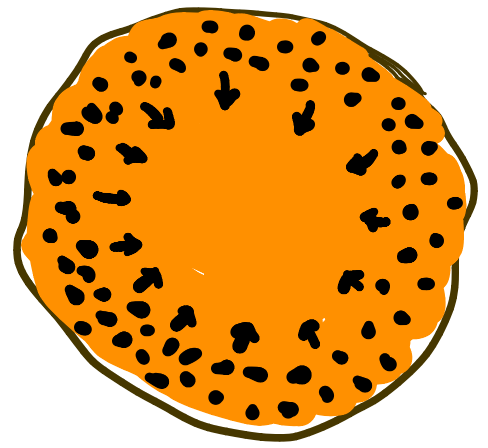


Comparison Variable vs. Constant Thermodynamic Parameters



Snow in Fe-S Cores



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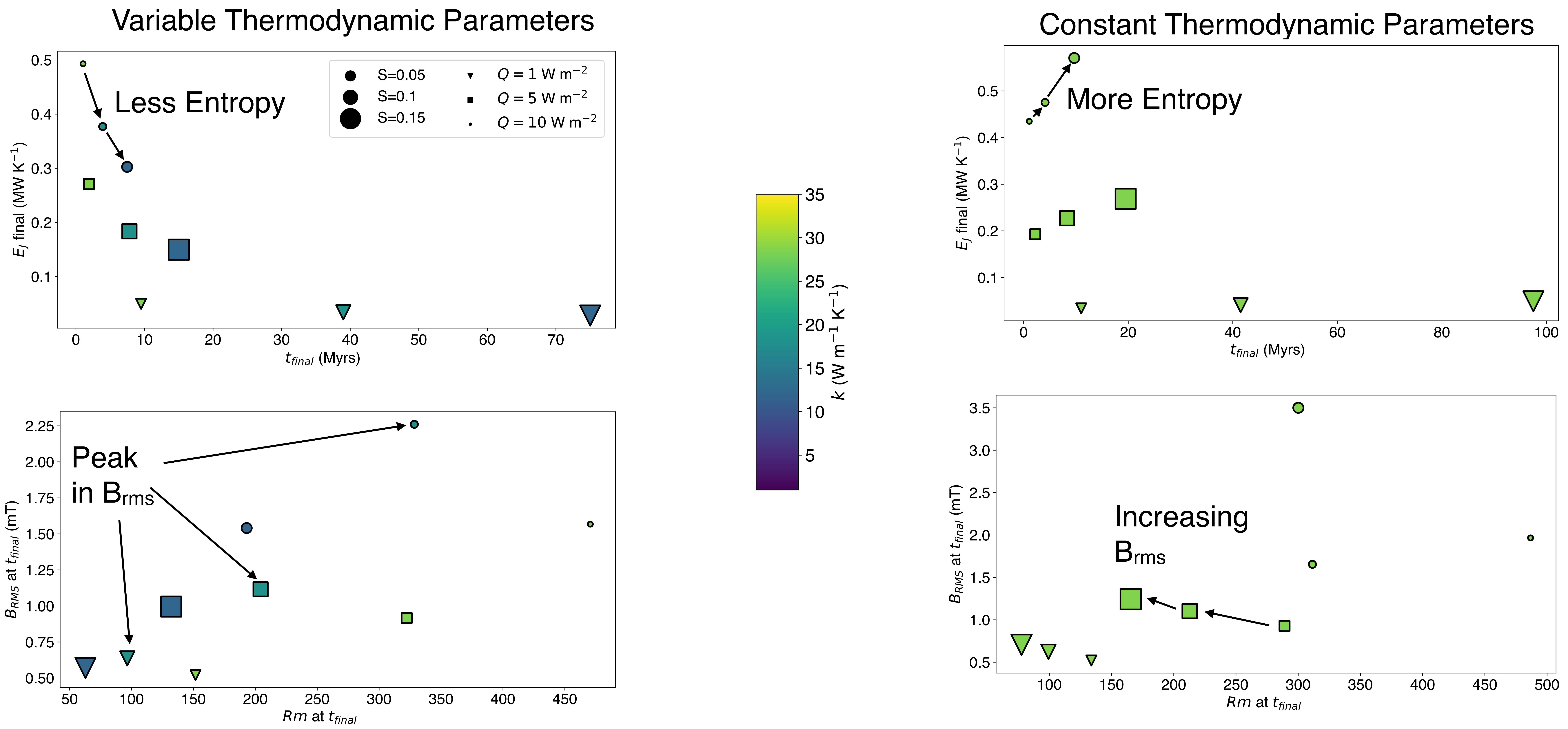
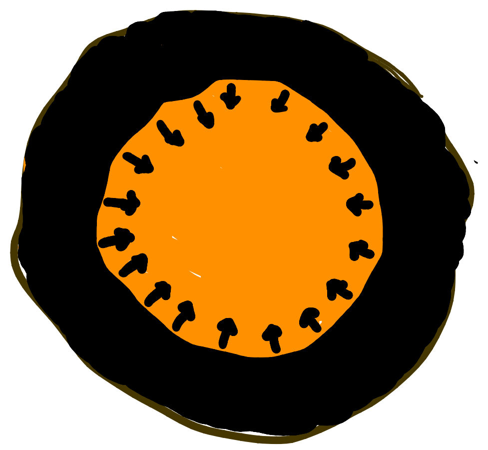
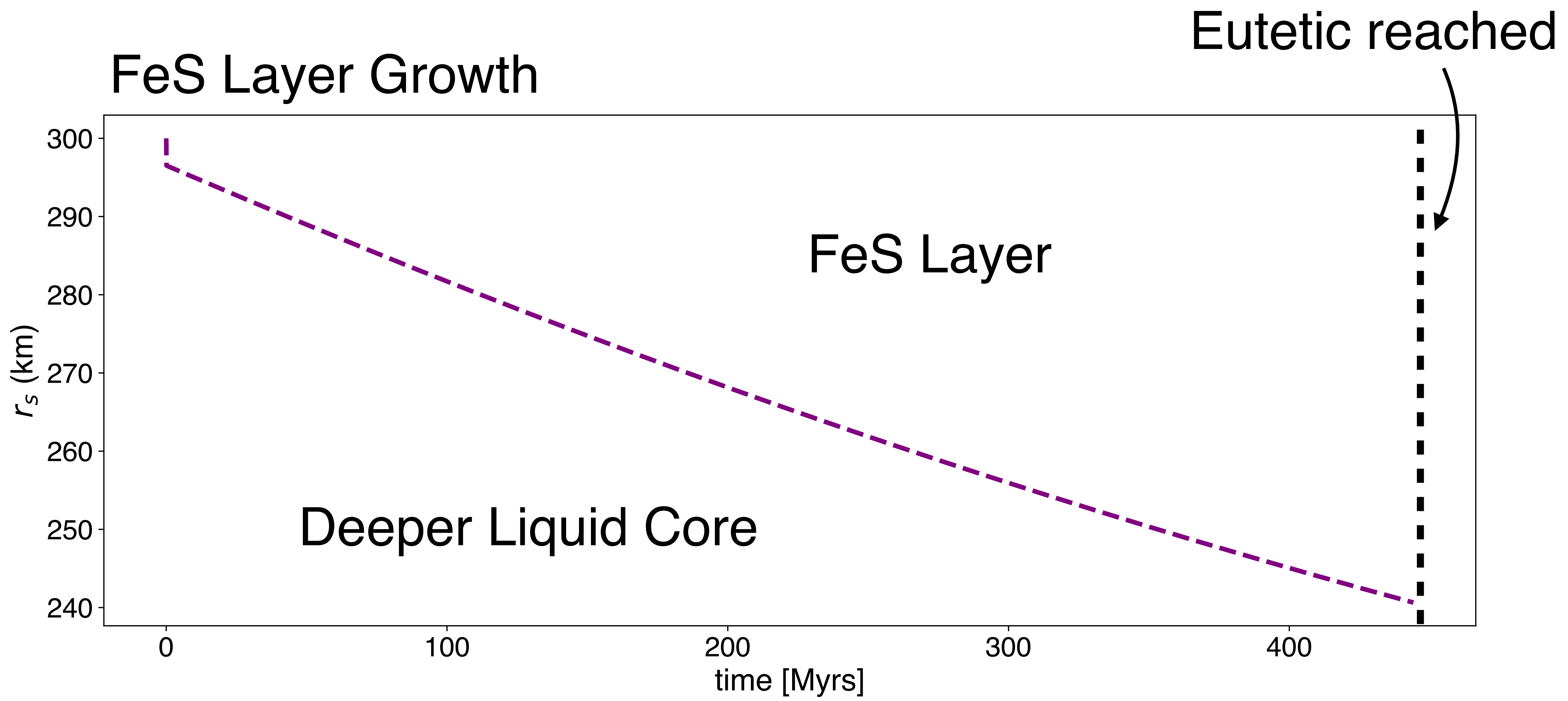
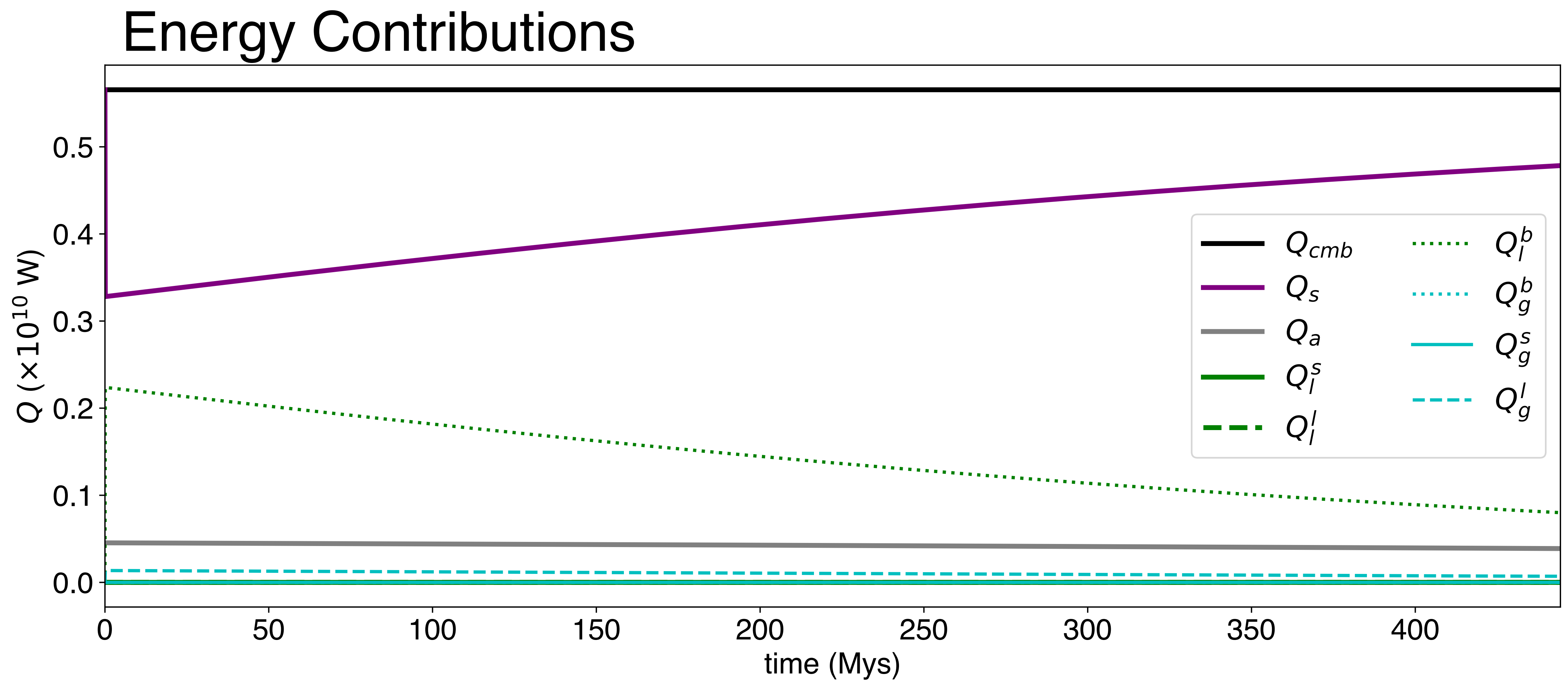


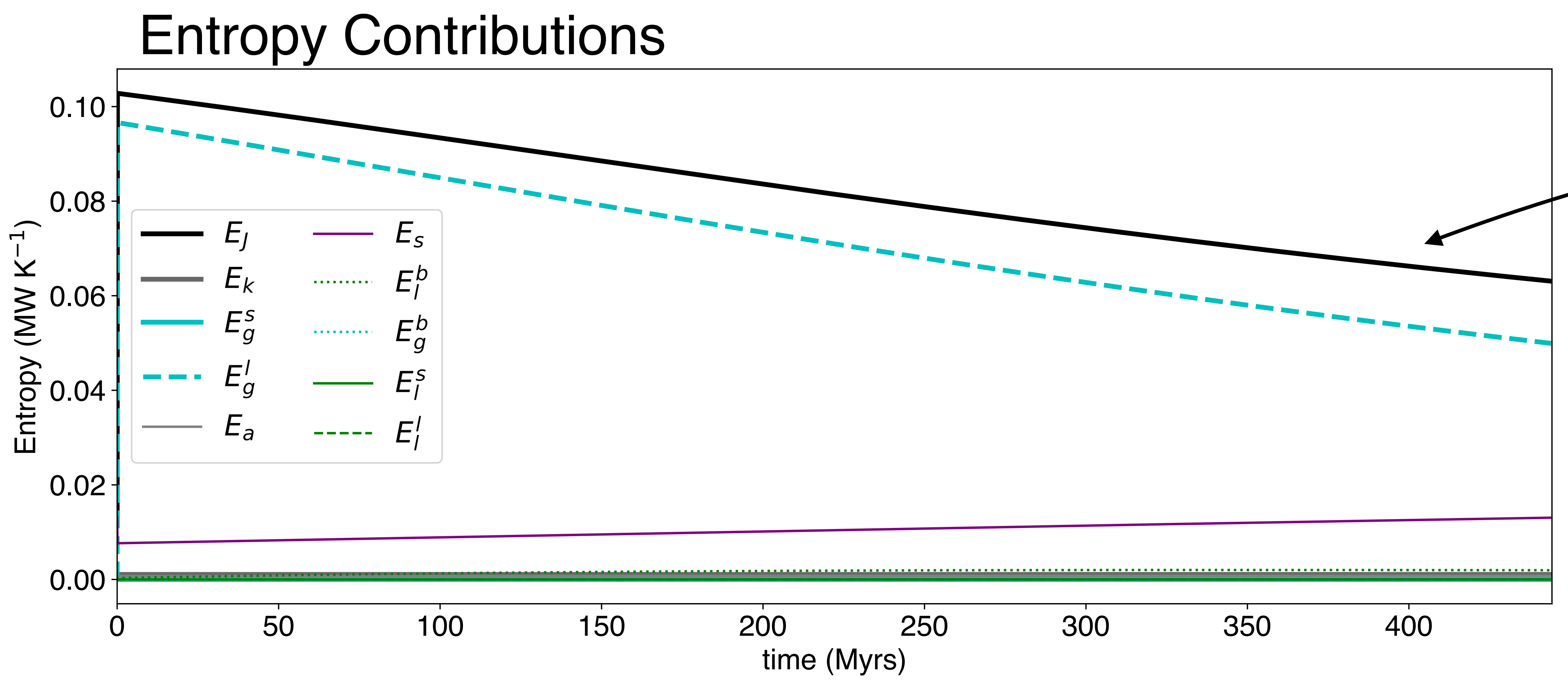
Flotation in Fe-S Cores



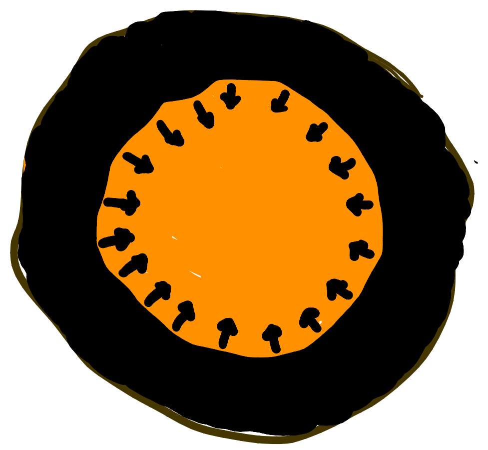
FeS Layer Evolution (x_S=30 wt.%, q_{cmb}= 5mW/m^2, R_c=300 km)







total entropy steadily declines



Flotation in Fe-S Cores

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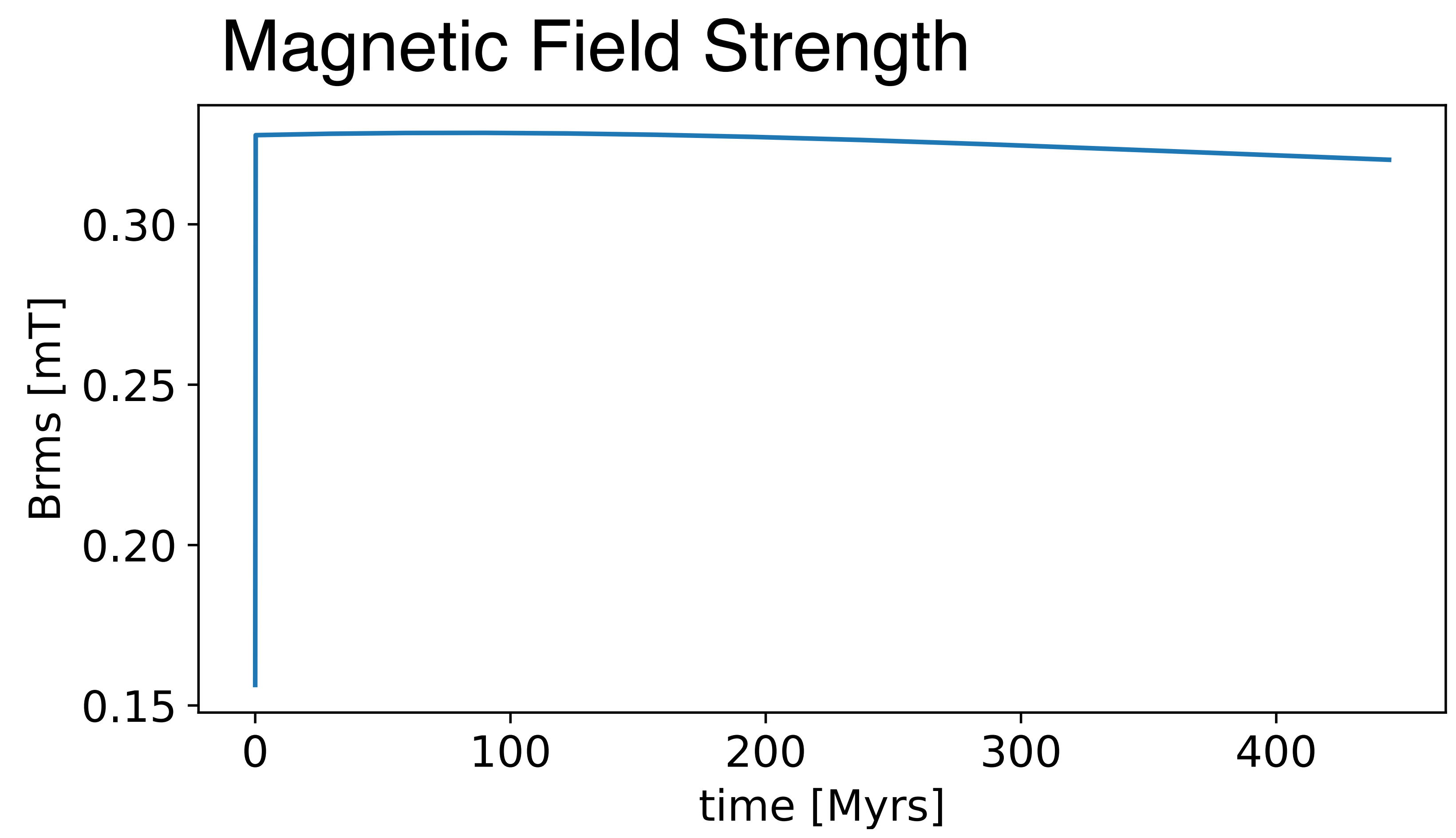
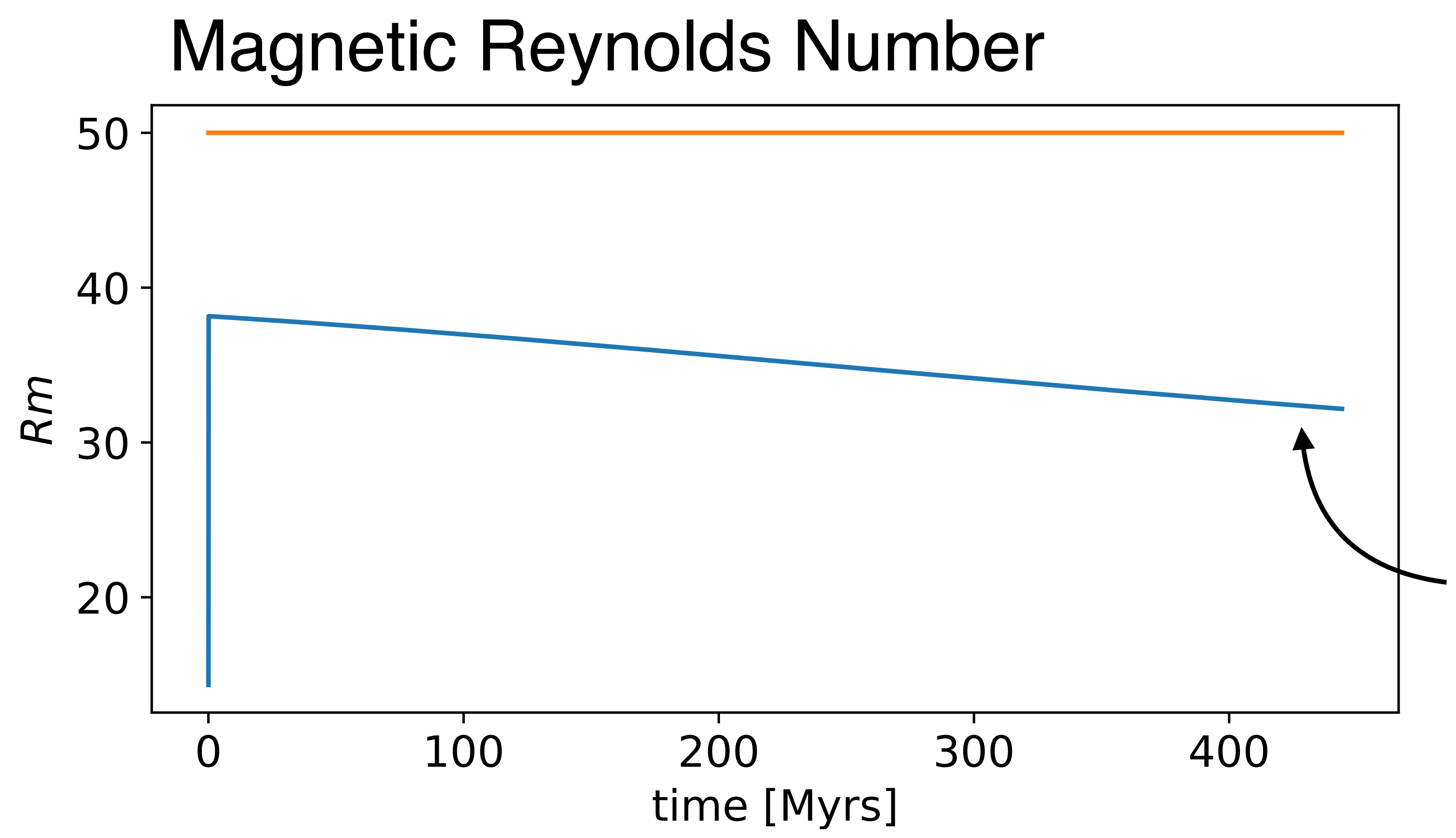
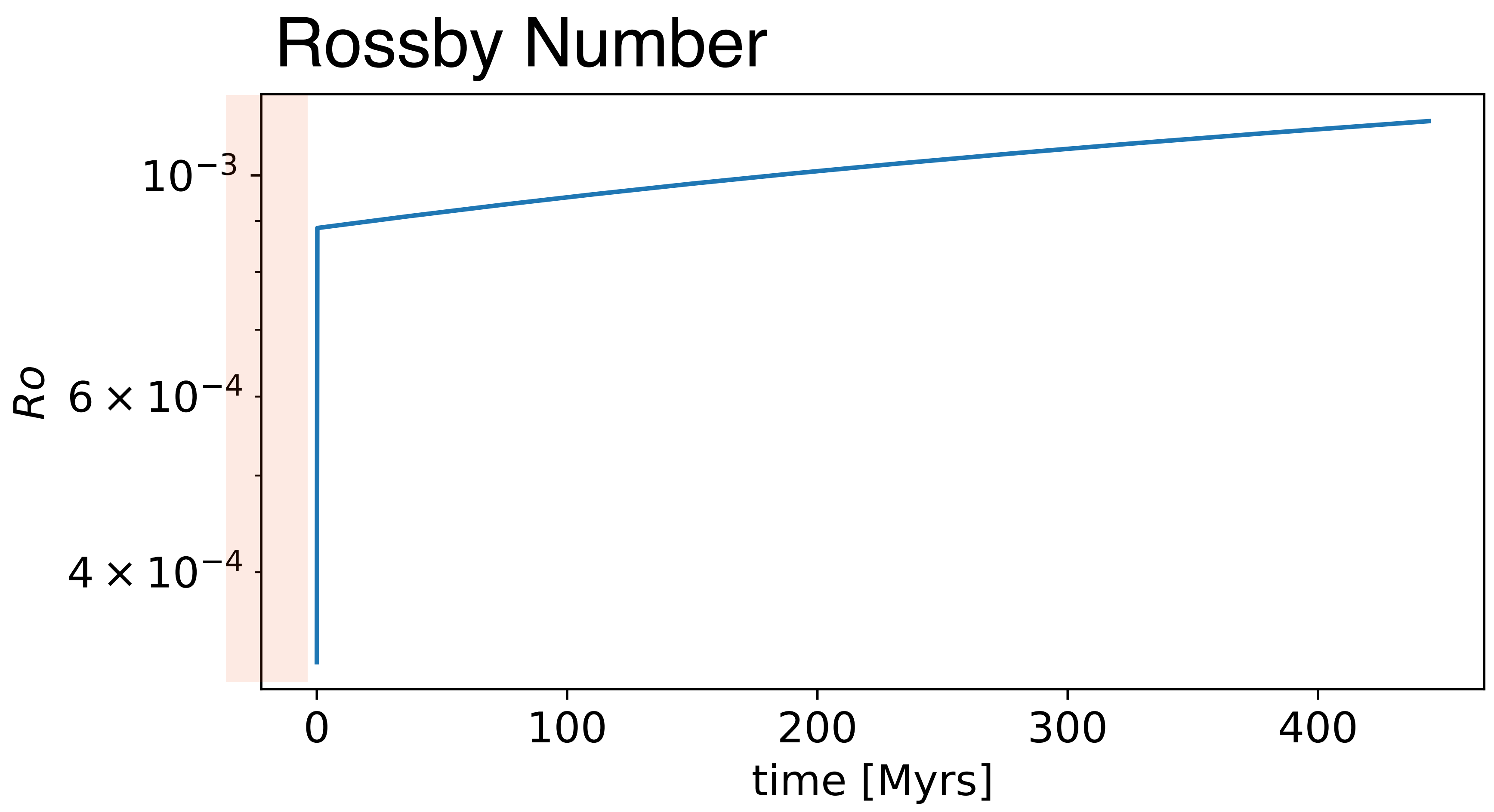




Never reaches critical Rm



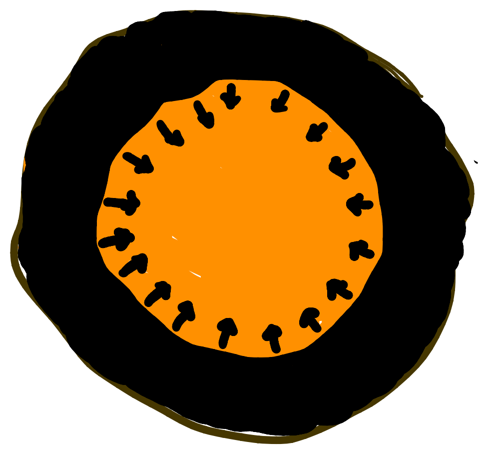
1mW/m² — 5wt.%

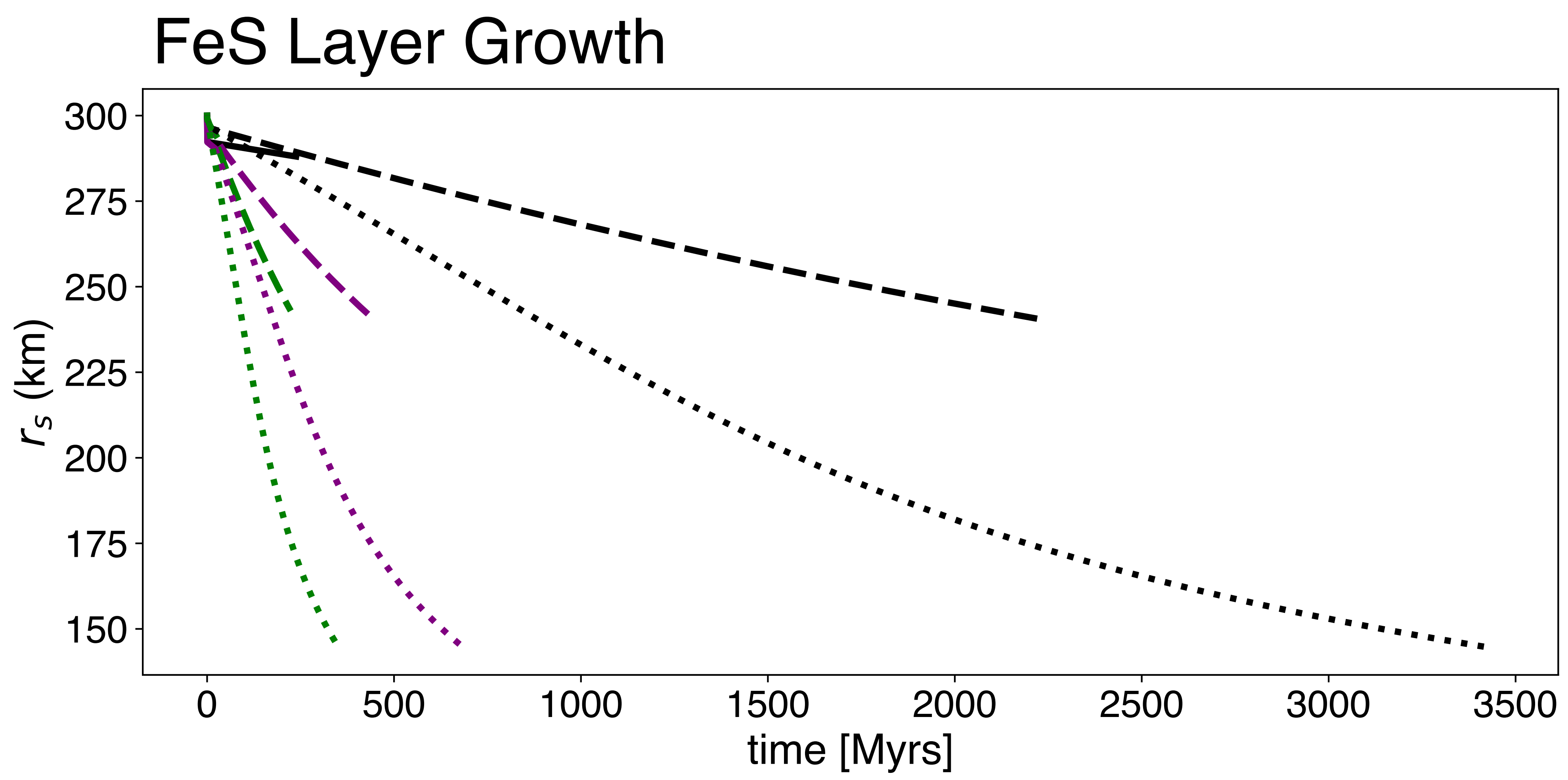
5mW/m² — 10wt.%

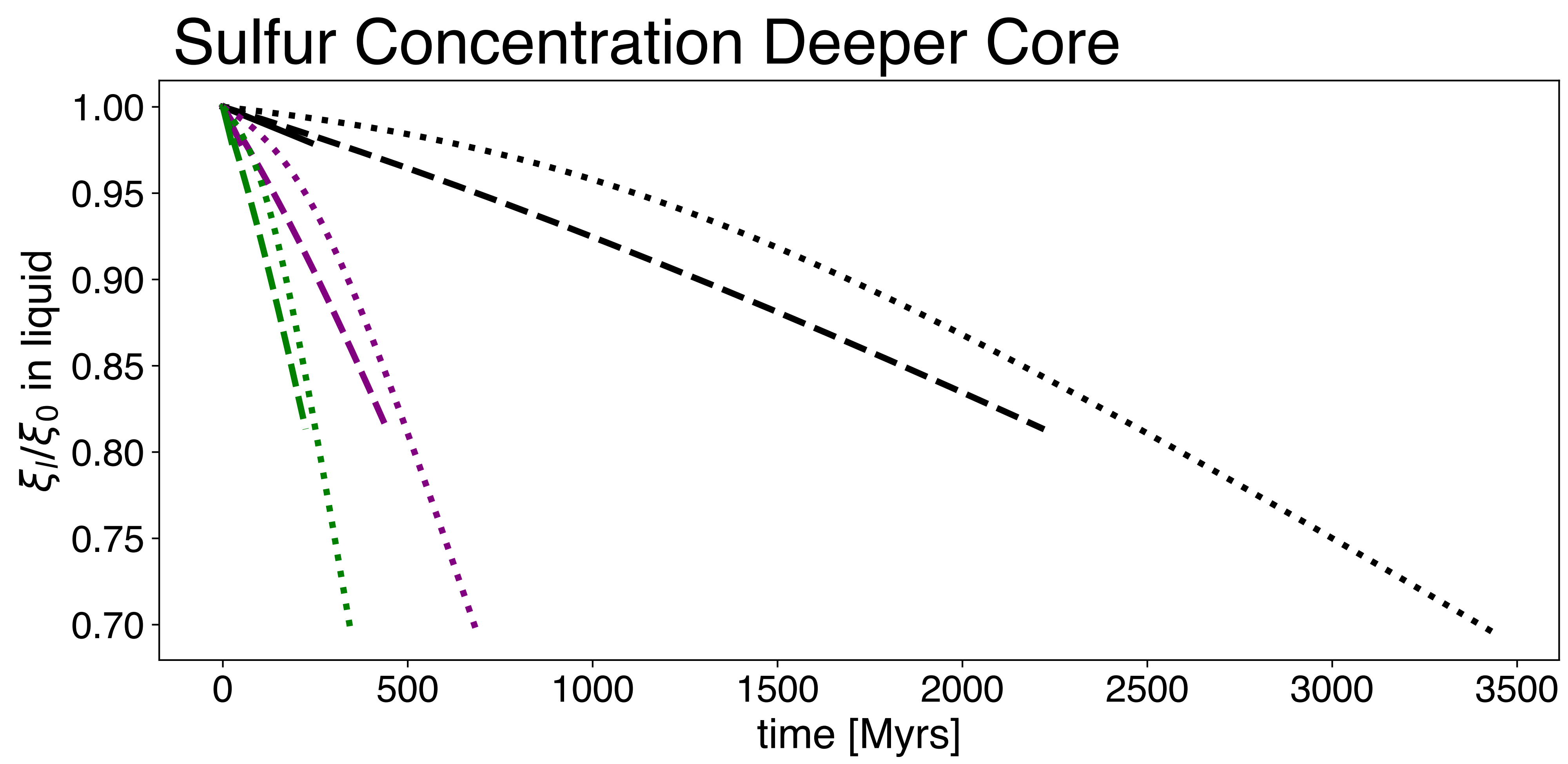
10mW/m² — 15wt.%

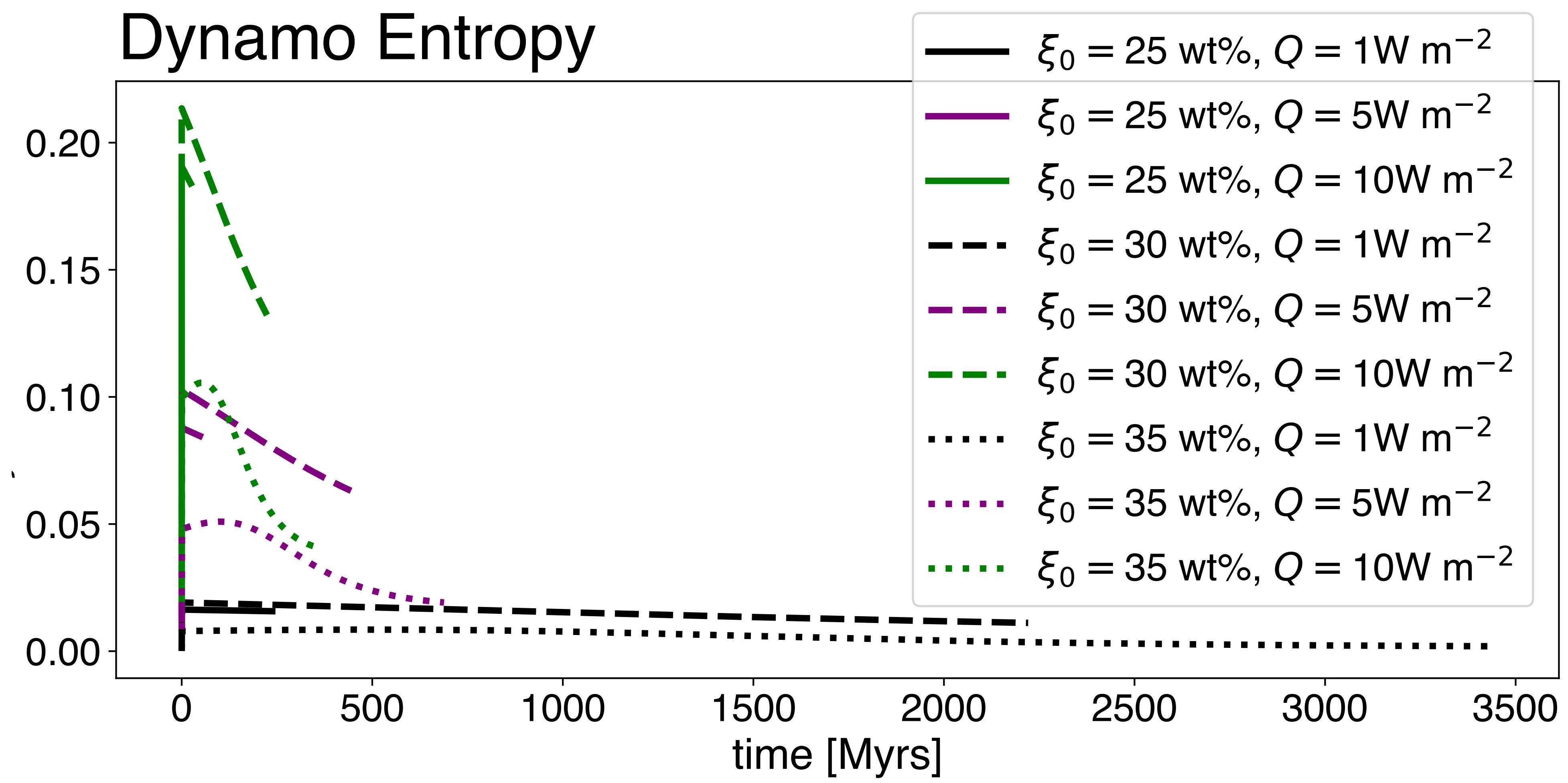
Flotation in Fe-S Cores

Dependence on Sulfur Concentration and Heat Flux



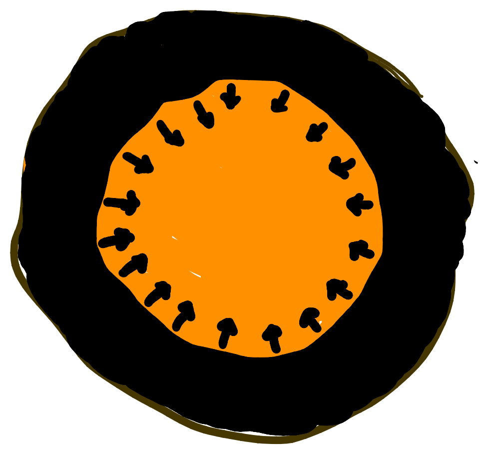






- Higher sulfur concentrations …
  - grow FeS layer more rapidly.
  - produce less entropy.
- Higher heat fluxes …
  - take less to grow FeS layer.
  - produce more entropy.

Flotation in Fe-S Cores



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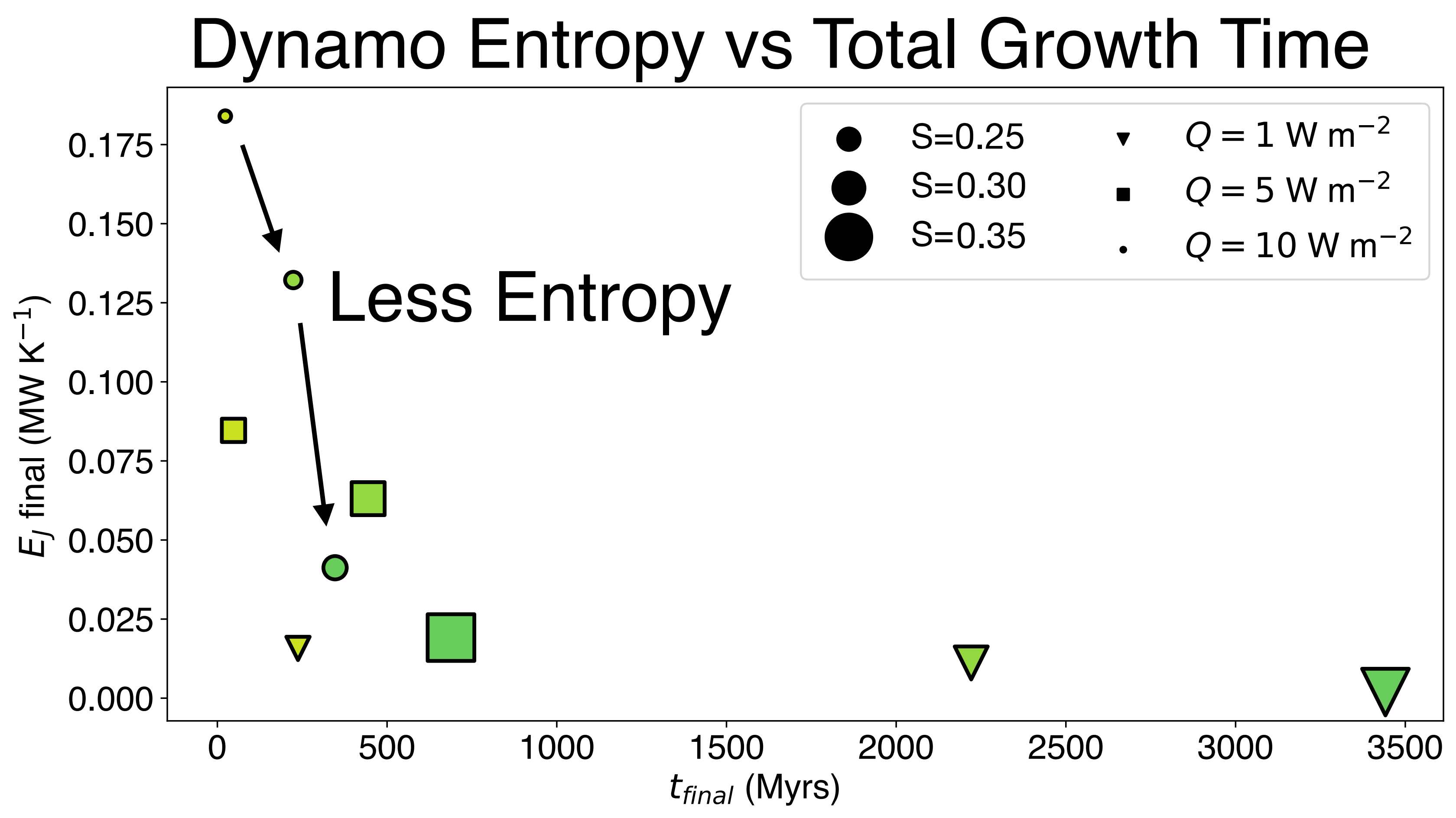

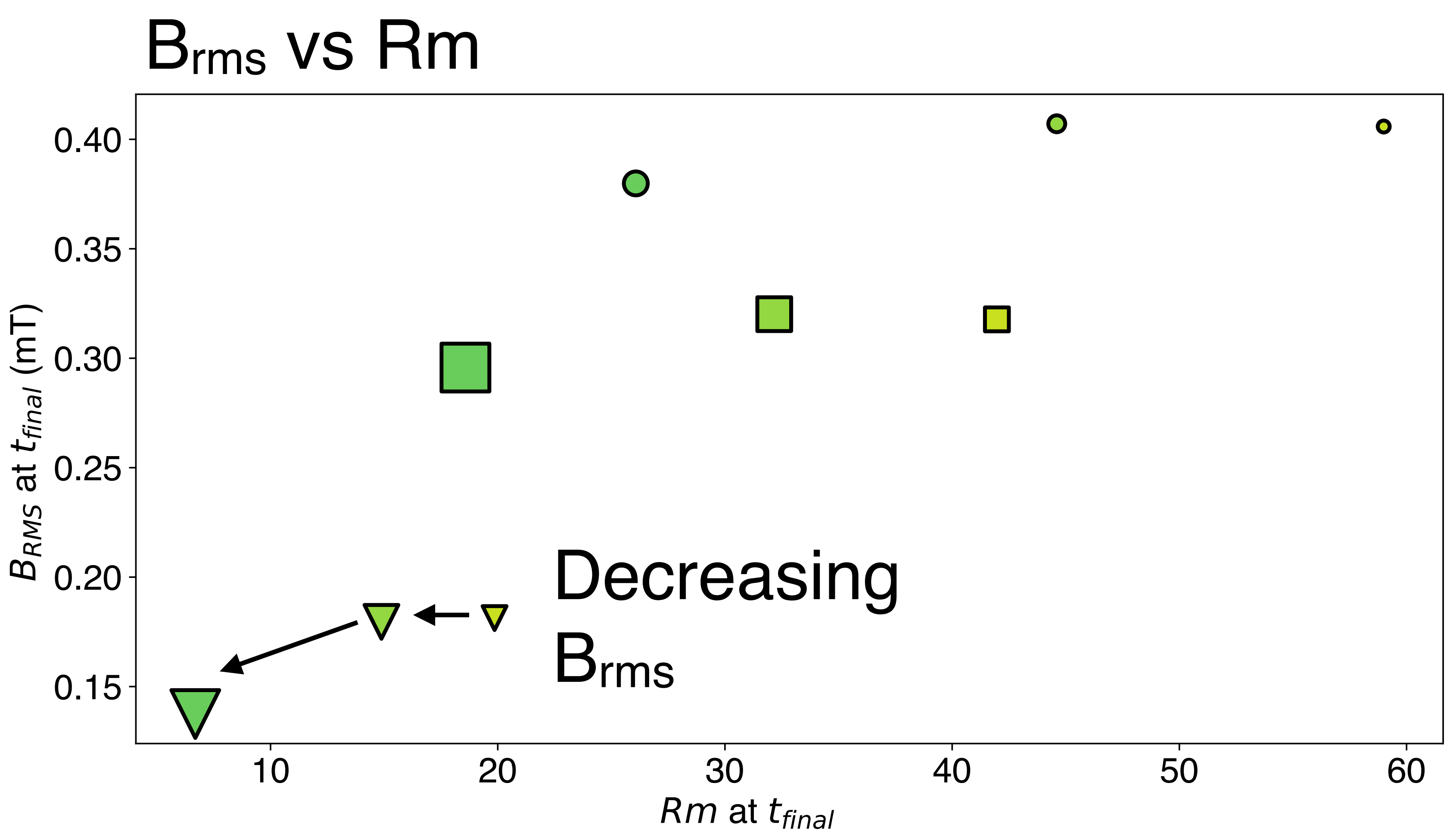

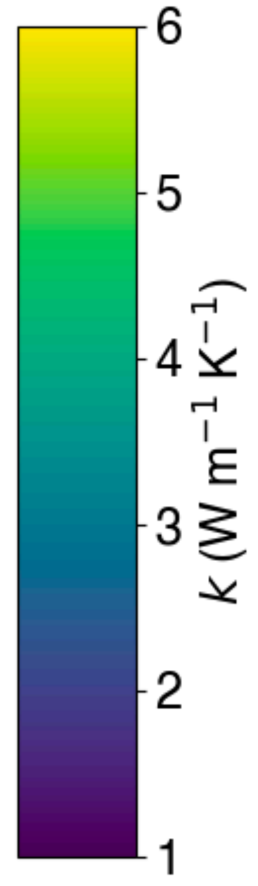

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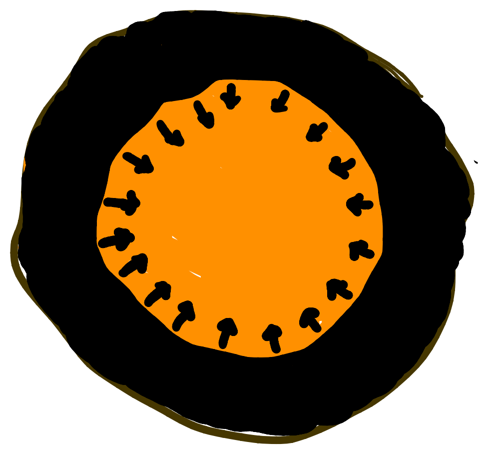

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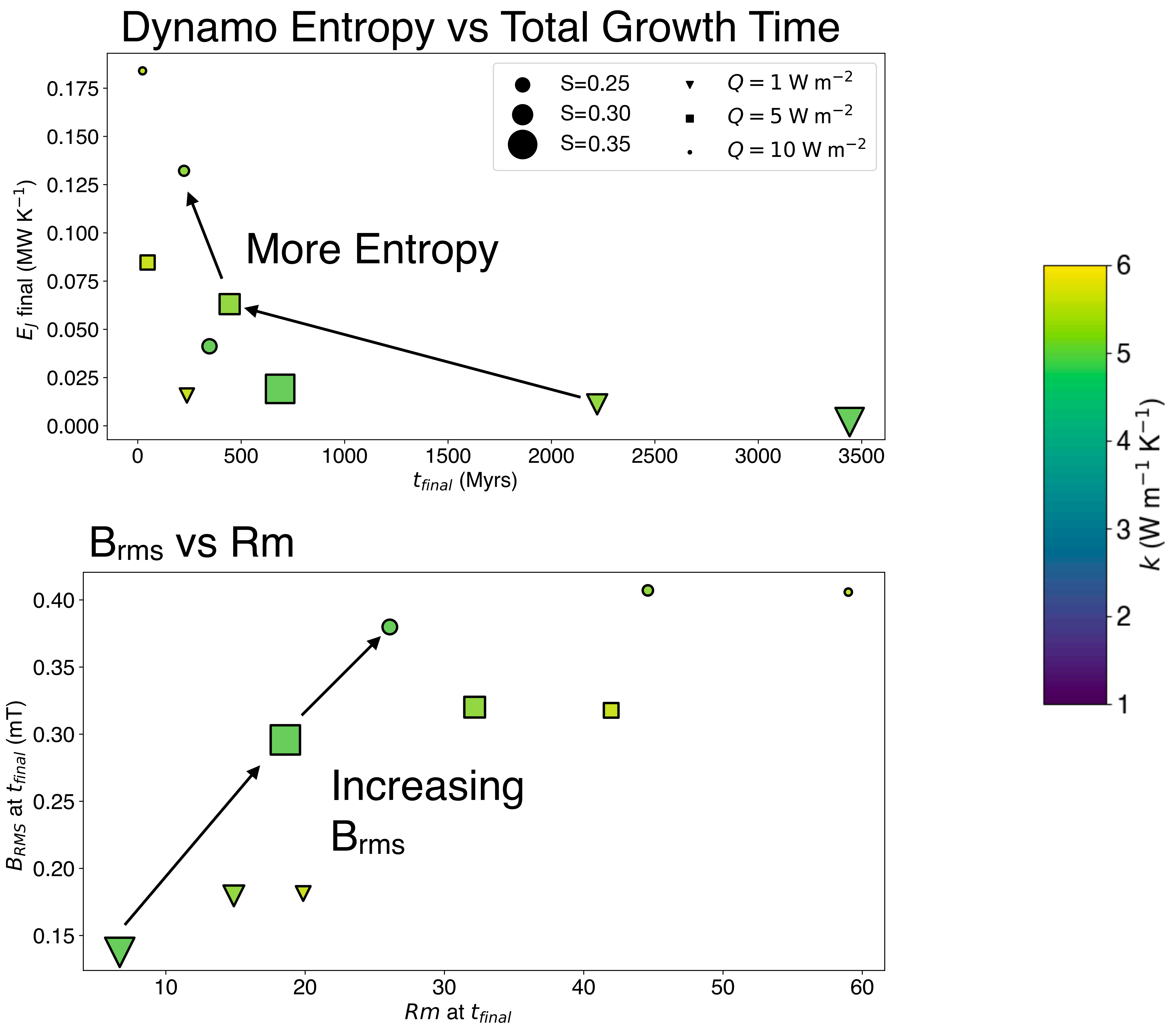

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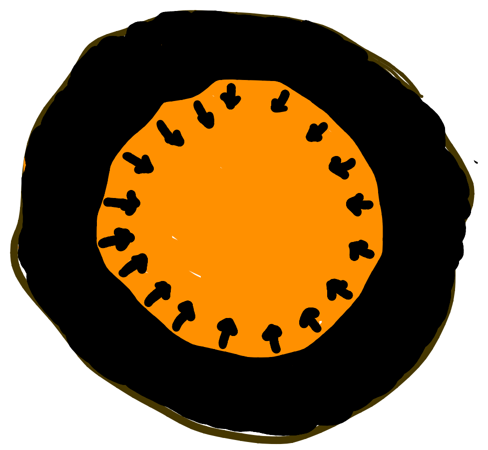

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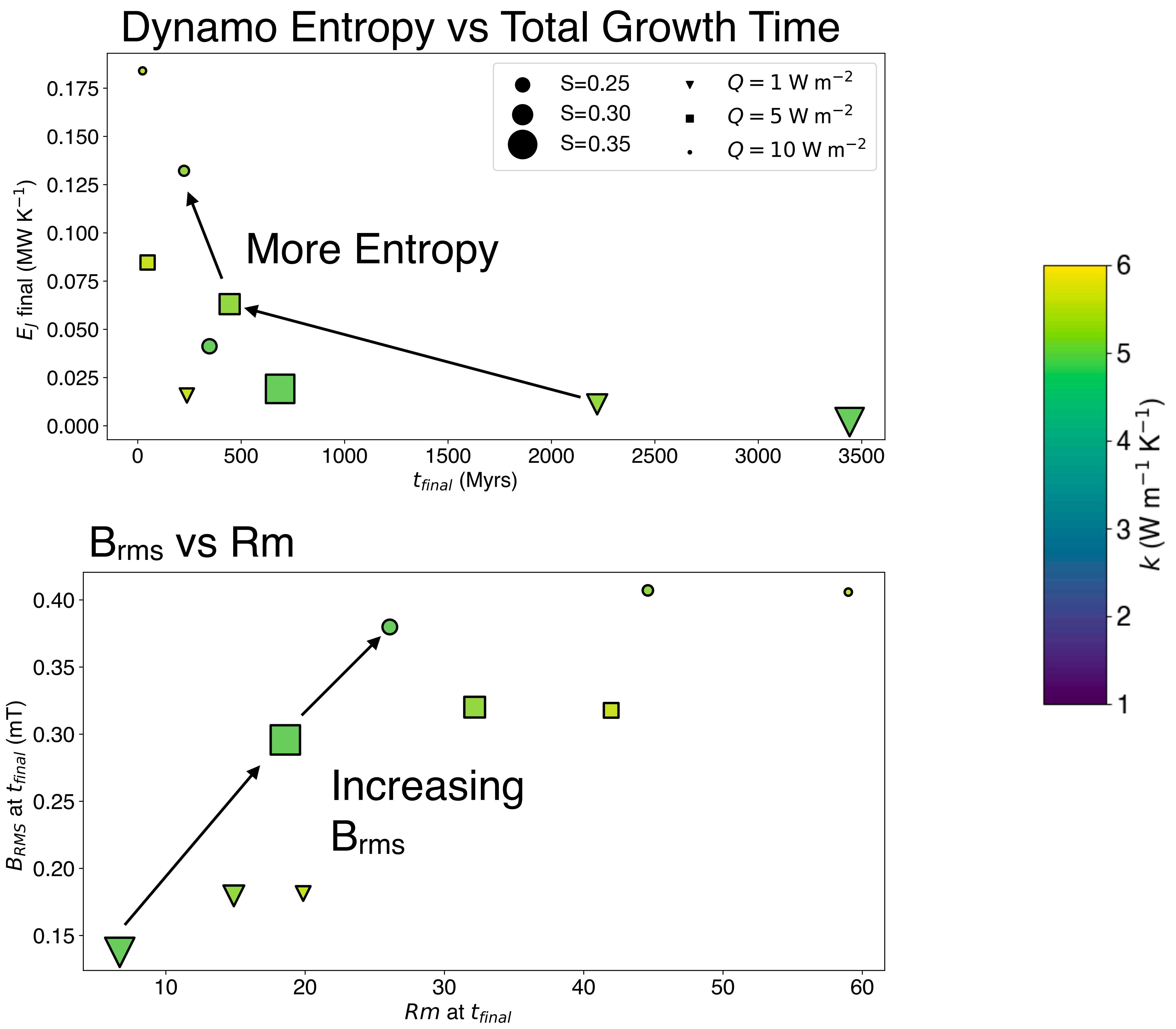


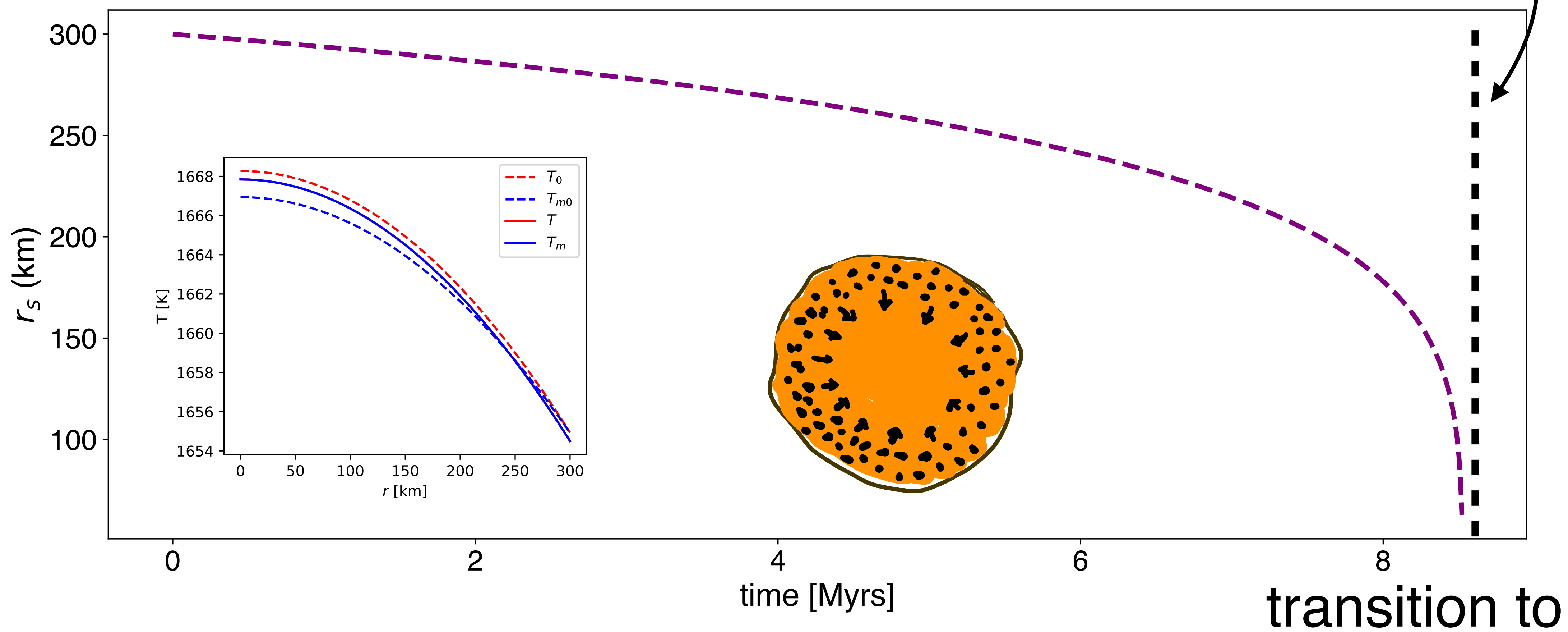
Coming soon
Runs with constant thermodynamic parameters

Fe-C Cores

q_{cmb}= 5mW/m^2, R_c=300 km

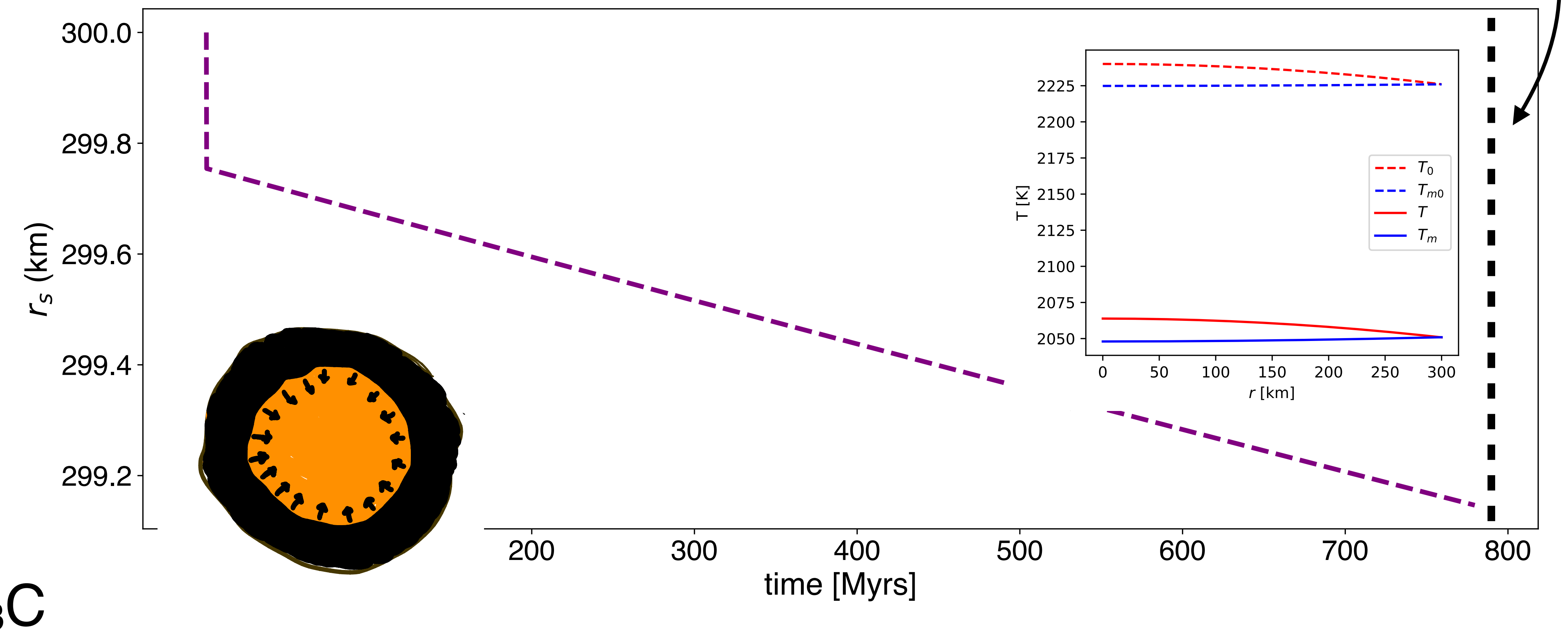
Iron Snow, x_s=3 wt.%

snow zone covers the entire core



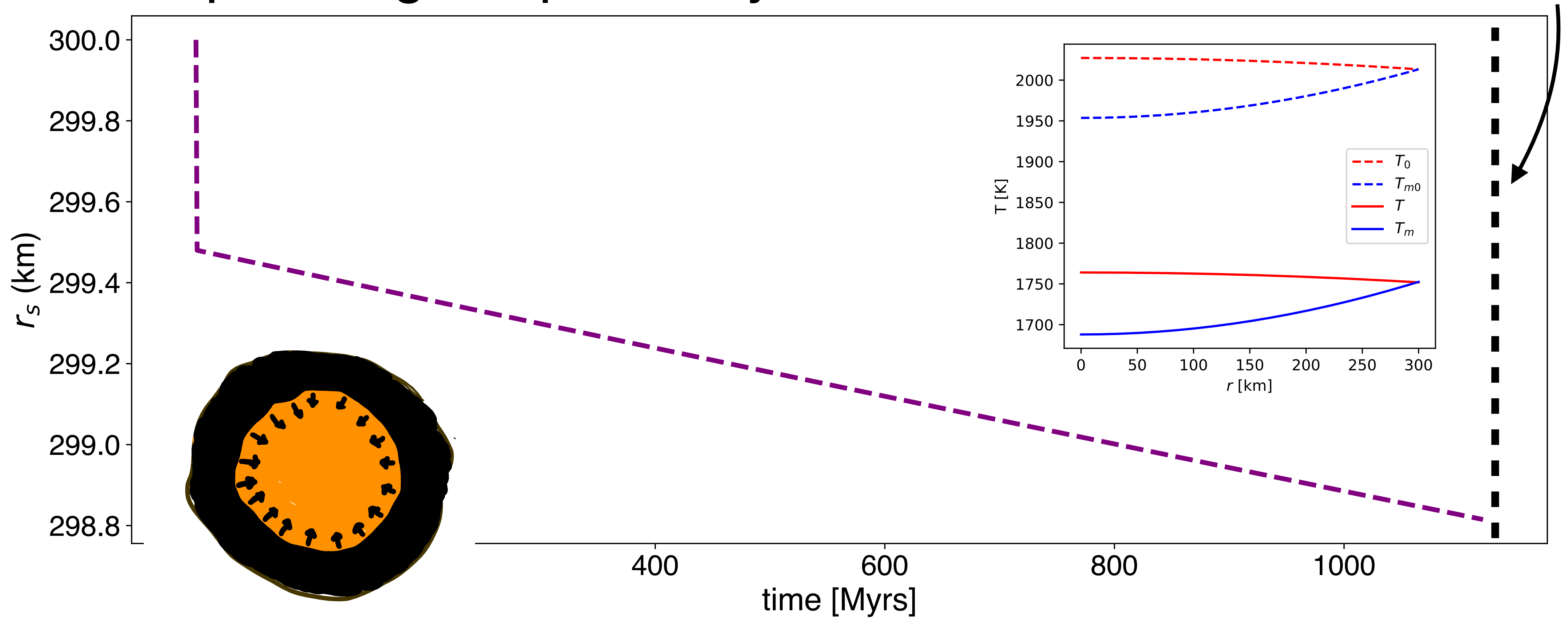
Upfloating Diamond Layer, x_s=8 wt.%

transition to Fe_7C_3 phase



Upfloating Graphite Layer, x_s=7 wt.%

transition to Fe_3C phase



- Iron snow in Fe-C core comparable to Fe-S system (partitioning must be included)
- Upfloating diamond and graphite layer grow very slowly
- Potential graphite layer is less dense than mantle material

Conclusion & Outlook

- At low pressures (~6 GPa) S and C might be dominant light elements in binary alloys (multicomponent mixtures are plausible too)

- Iron snow occurs for:
  - Fe-S: ~6-20 wt.%, Fe-C: ~2-4 wt.%
- Upfloating occurs for:
  - Fe-S: ~(25-30)–36 wt.%, Fe-C: ~6-min 8 wt.%

- Composition dependent thermodynamic parameters can change relation between entropy and light element content (sulfur) and therefore magnetic field strength

- Fe-C cores might produce carbon layers that are able to mix with the solid or liquid mantle

Session @ EGU 2024

Solid-Liquid Interactions in the Interiors of Terrestrial Planets and (Icy) Moons

PS1

Solid-Liquid Interactions in the Interiors of Terrestrial Planets and (Icy) Moons

The interactions between solid and liquid phases within the interiors of terrestrial planets and moons play a vital role in determining their evolutionary trajectories and dynamic behaviors. These interactions influence a variety of critical processes, such as the crystallization sequence of primordial magma oceans, the mechanisms driving global magnetic fields, the exchange of mass and energy between the core and mantle, and the origins of salts in oceans or ice layers of icy moons.

Recent research has unveiled the widespread occurrence of deep solid-liquid regions, manifesting at both the upper and lower boundaries of Earth's core, as well as within the cores of celestial bodies like Mars, Mercury, the Moon, and Ganymede. In a manner analogous to the intricate freezing behaviors observed in metal-rich cores, the crystallization of magma oceans has gained significant interest in recent years. This interest stems from its critical role in elucidating the composition of both primordial and secondary atmospheres. Yet, another crucial, albeit poorly understood, aspect of solid-liquid interactions pertains to the exchange of light elements between the rocky mantle and the metallic core, as well as the exchange of salts between the rocky mantle and water oceans or ice shells of icy moons.

This session aims to foster collaboration among various scientific communities to advance our understanding of these complex phenomena. We welcome submissions that encompass observational, experimental, theoretical, and computational approaches covering a wide array of topics, including (but not limited to) seismology, geodynamics, mineral physics, geochemistry, and geo/paleomagnetism.

Share: https://meetingorganizer.copernicus.org/EGU24/session/48096

Convener: Tina Rückriemen-Bez[ECS] | Co-conveners: Chris Davies, Attilio Rivoldini, Anne Pommier, Ludovic Huguet[ECS]

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- Fe-C cores might produce carbon crusts that are able to mix with the mantle