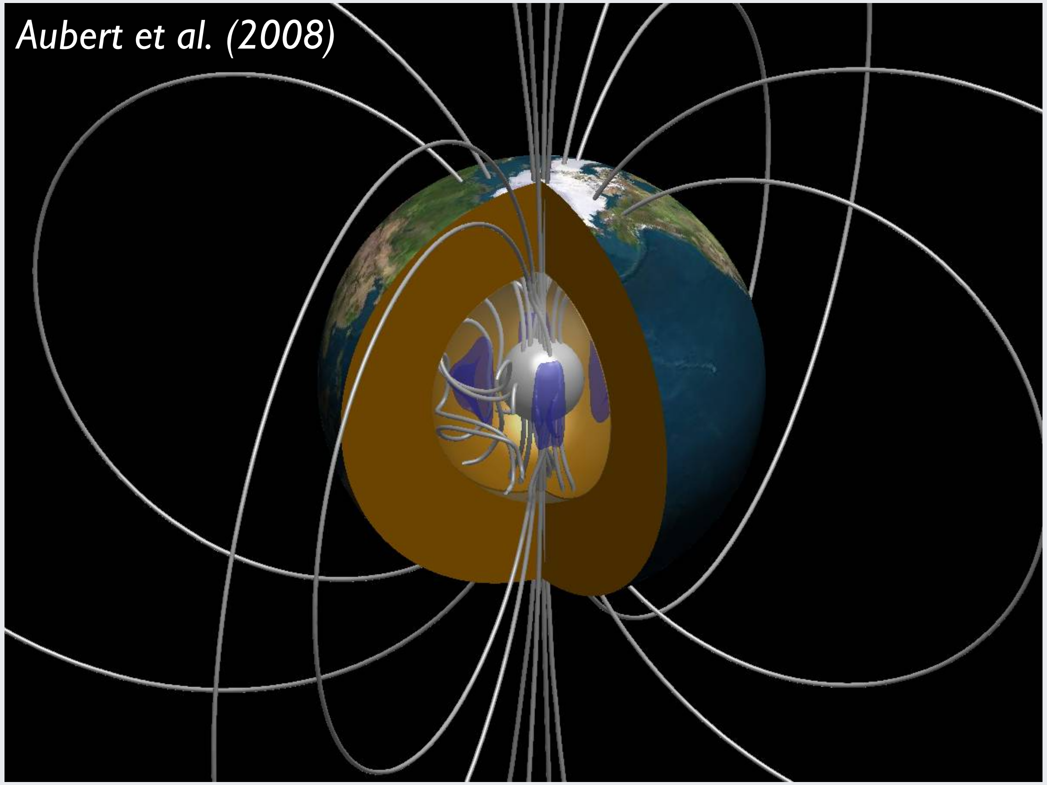
BIRTH OF THE GEODYNAMO

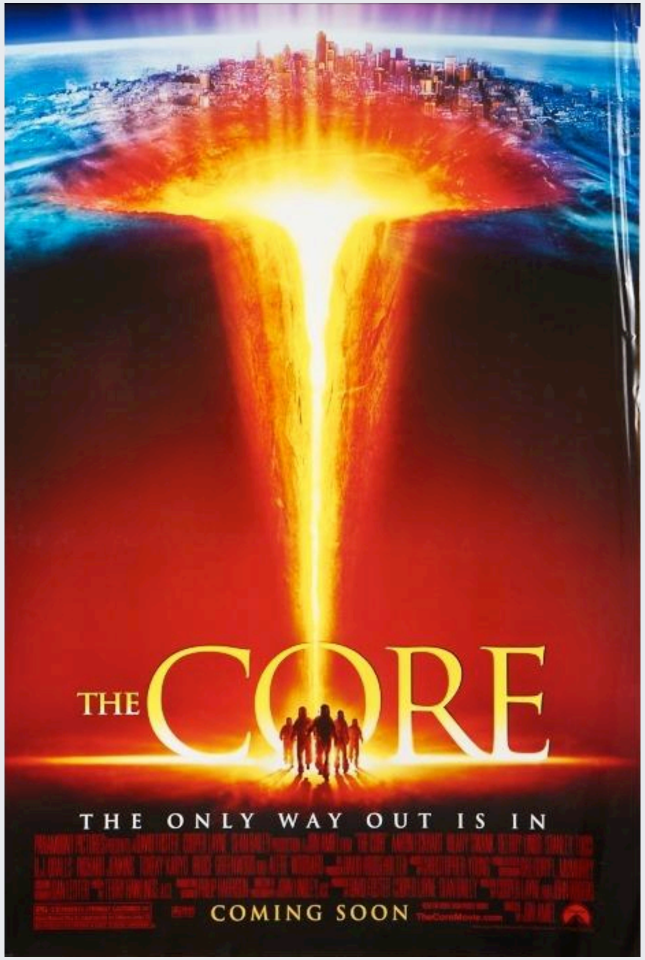


John Hernlund

University of California, Berkeley

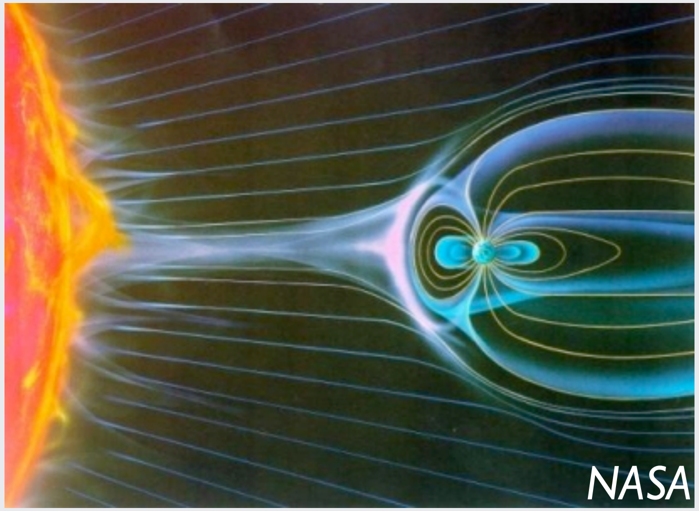
Earth-Life Science Institute

WHY IS IT IMPORTANT?

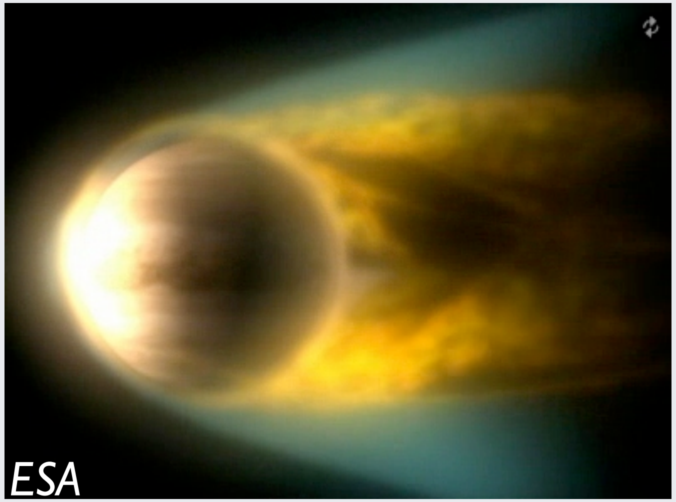


WHY IS IT REALLY IMPORTANT?

Earth

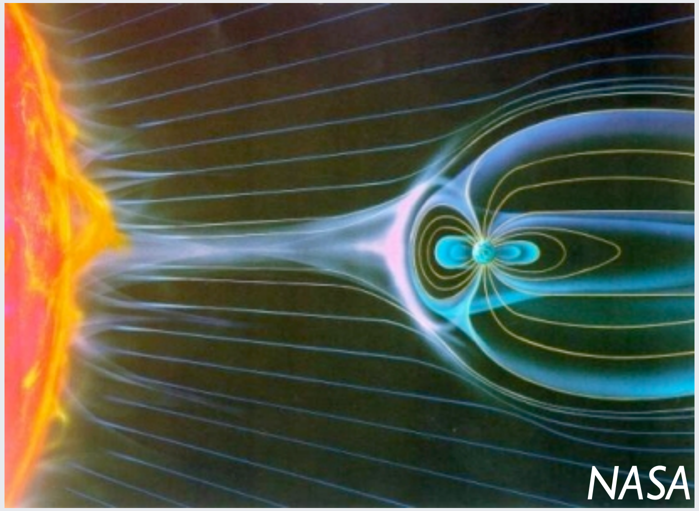


Venus/Mars

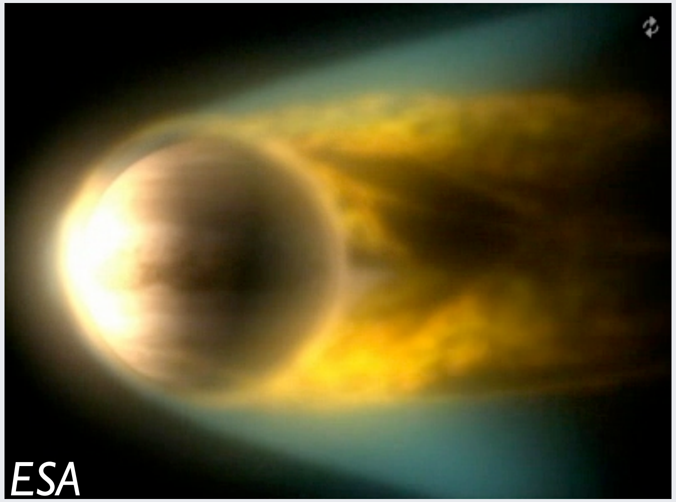


WHY IS IT REALLY IMPORTANT?

Present Earth



Early Earth?



See next talk by Peter Driscoll

AGE OF GEODYNAMO?

Many connections to other important issues…

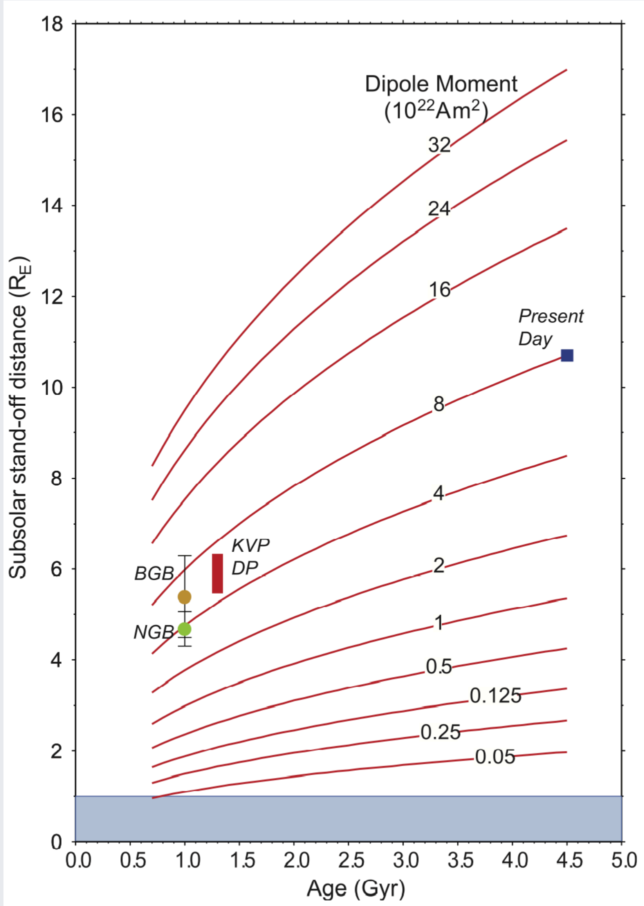
- Early atmosphere loss to entrainment in the solar wind?
- Trade-offs with accretion and core formation scenarios?
- Dependence upon geochemical reference models?
- Alternate dynamo mechanisms/buoyancy sources?
- Should we expect dynamos on other terrestrial planets?
- Etc.

EARLIEST PALEOMAGNETIC EVIDENCE

Geodynamo, Solar Wind, and Magnetopause 3.4 to 3.45 Billion Years Ago

John A. Tarduno,[1,2]* Rory D. Cottrell,[1] Michael K. Watkeys,[3] Axel Hofmann,[3] Pavel V. Doubrovine,[1,4] Eric E. Mamajek,[2] Dunji Liu,[5] David G. Sibeck,[6] Levi P. Neukirch,[2] Yoichi Usui[1,7]

Stellar wind standoff by a planetary magnetic field prevents atmospheric erosion and water loss. Although the early Earth retained its water and atmosphere, and thus evolved as a habitable planet, little is known about Earth's magnetic field strength during that time. We report paleointensity results from single silicate crystals bearing magnetic inclusions that record a geodynamo 3.4 to 3.45 billion years ago. The measured field strength is ~50 to 70% that of the present-day field. When combined with a greater Paleoarchean solar wind pressure, the paleofield strength data suggest steady-state magnetopause standoff distances of ≤5 Earth radii, similar to values observed during recent coronal mass ejection events. The data also suggest lower-latitude aurora and increases in polar cap area, as well as heating, expansion, and volatile loss from the exosphere that would have affected long-term atmospheric composition.



Was the early geodynamo weak, yielding a smaller magnetosphere?

EVIDENCE OF EARLY ABSENCE?

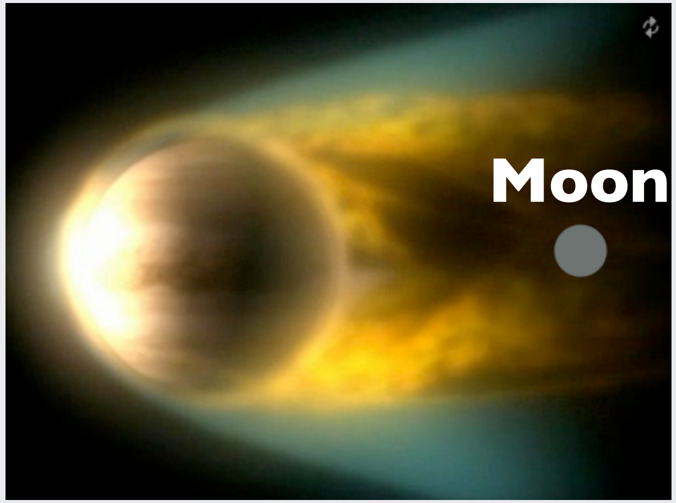
Vol 436|4 August 2005|**doi:10.1038/nature03929** nature

ARTICLES

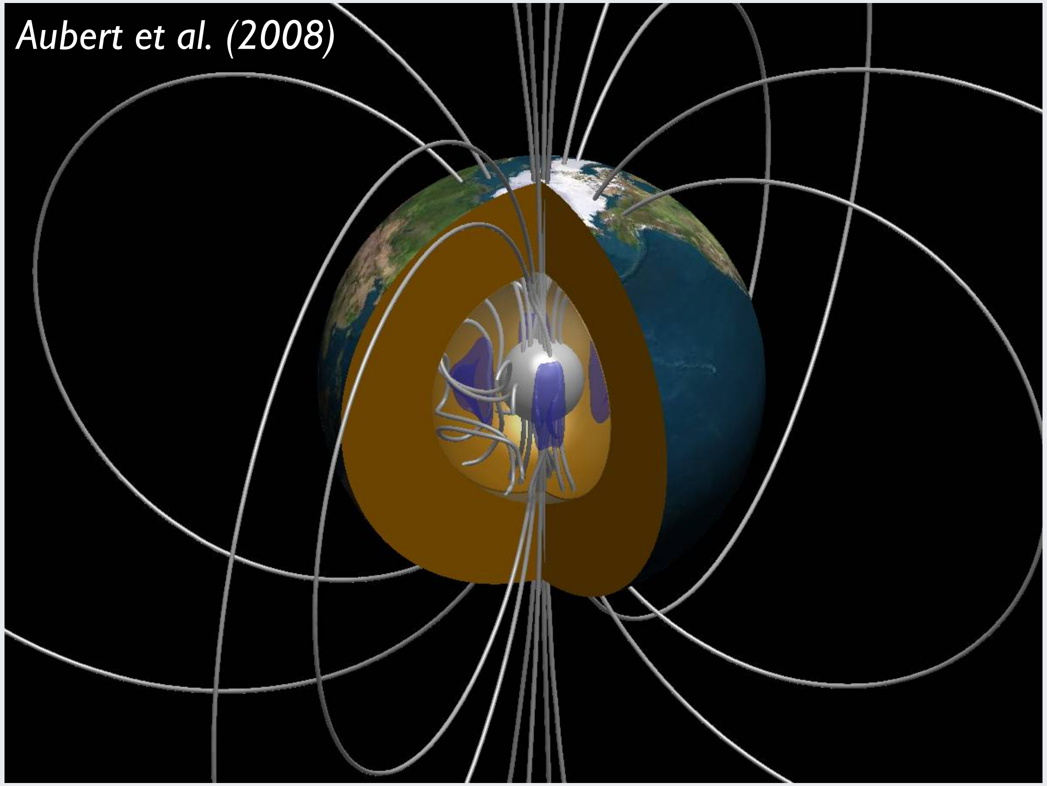
Terrestrial nitrogen and noble gases in lunar soils

M. Ozima[1], K. Seki[2], N. Terada[2]†, Y. N. Miura[3], F. A. Podosek[4] & H. Shinagawa[2]†

The nitrogen in lunar soils is correlated to the surface and therefore clearly implanted from outside. The straightforward interpretation is that the nitrogen is implanted by the solar wind, but this explanation has difficulties accounting for both the abundance of nitrogen and a variation of the order of 30 per cent in the $^{15}N/^{14}N$ ratio. Here we propose that most of the nitrogen and some of the other volatile elements in lunar soils may actually have come from the Earth's atmosphere rather than the solar wind. We infer that this hypothesis is quantitatively reasonable if the escape of atmospheric gases, and implantation into lunar soil grains, occurred at a time when the Earth had essentially no geomagnetic field. Thus, evidence preserved in lunar soils might be useful in constraining when the geomagnetic field first appeared. This hypothesis could be tested by examination of lunar farside soils, which should lack the terrestrial component.



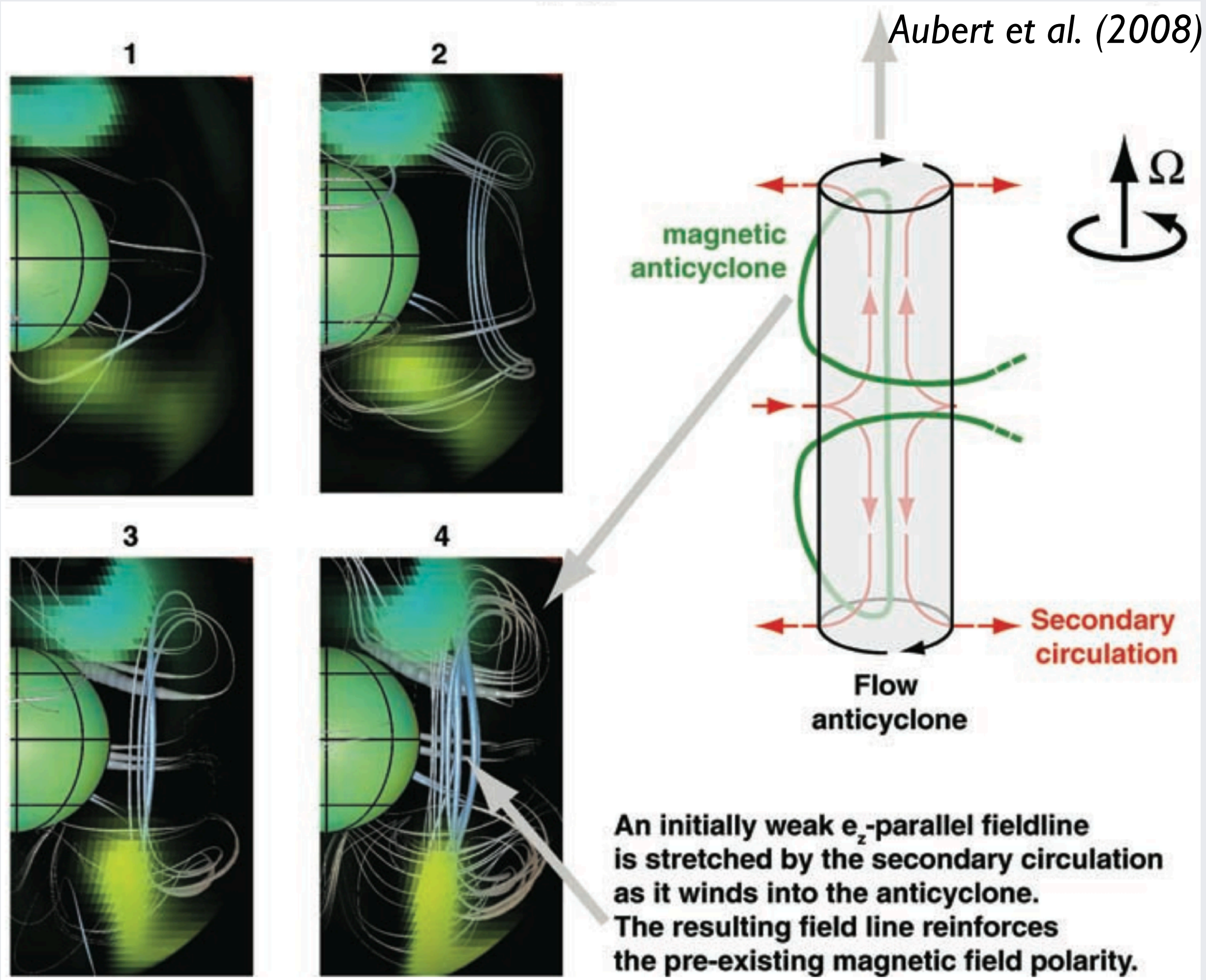
SOURCE OF THE GEODYNAMO



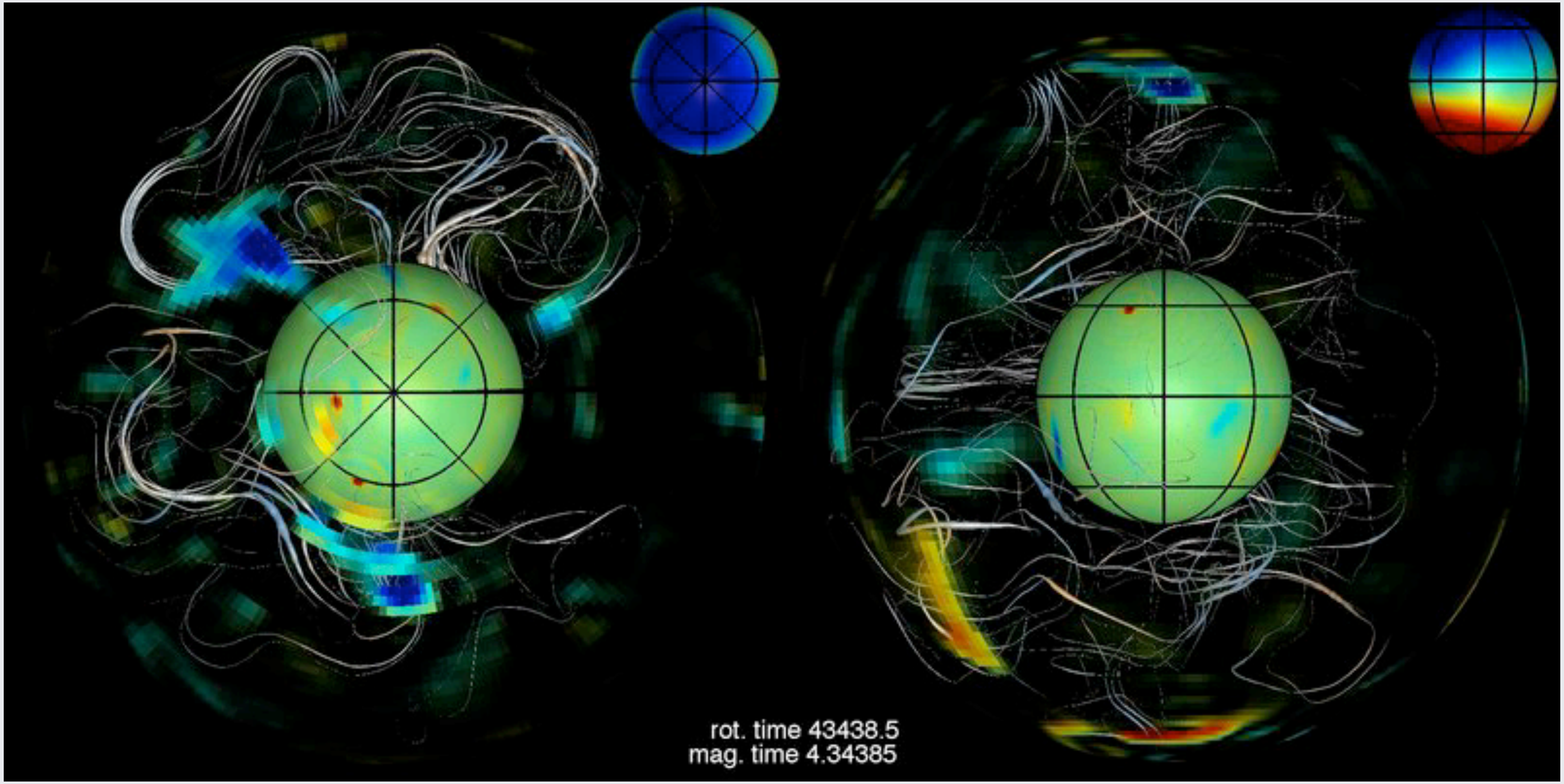
Convection in the liquid metal outer core

SOURCE OF THE GEODYNAMO

Aubert et al. (2008)



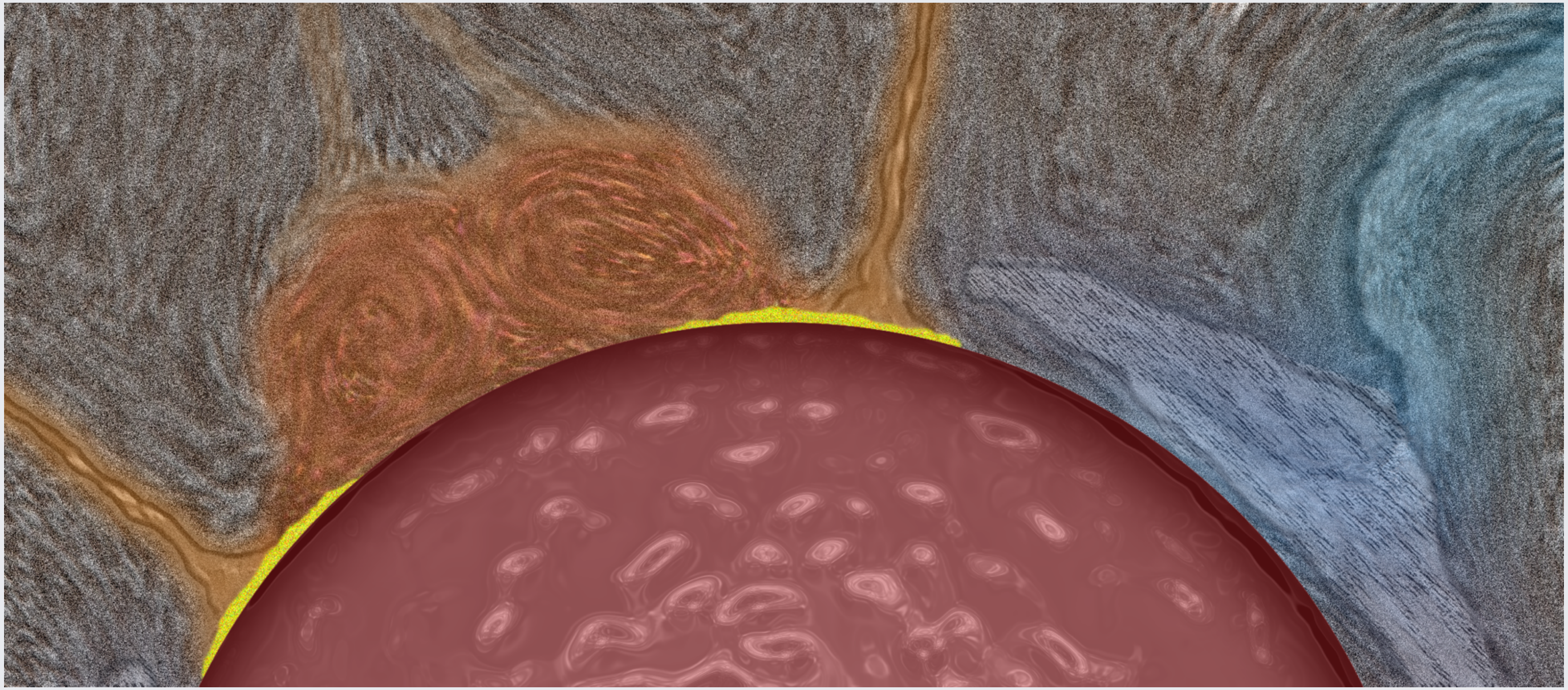
SOURCE OF THE GEODYNAMO



Aubert et al. (2008)

DRIVING FORCE FOR CORE CONVECTION?

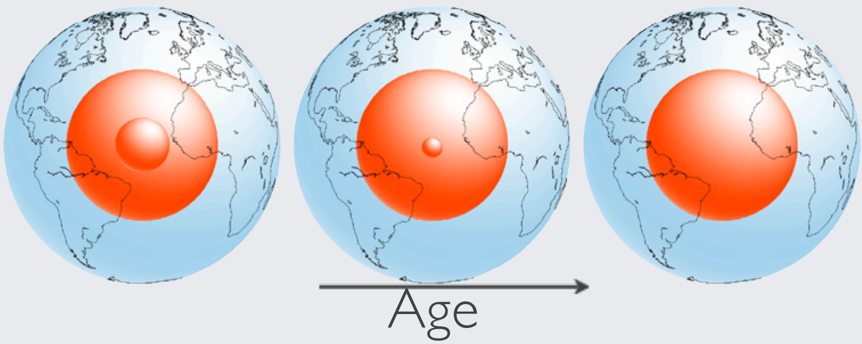
- <u>Thermal convection</u>: Top-cooling by the mantle, but must exceed conducted heat to avoid stratification.

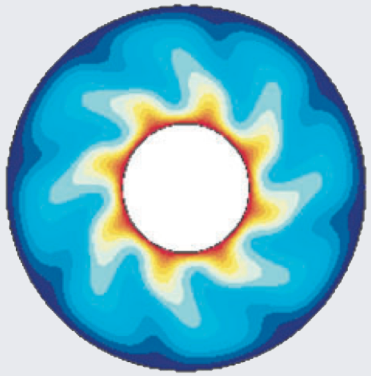


DRIVING FORCE FOR CORE CONVECTION?

- Thermal convection: Top-cooling by the mantle, but must exceed conducted heat to avoid stratification.

- Chemical convection: Release of light elements upon inner core crystallization...but inner core is only ~1 Ga in age.





DRIVING FORCE FOR CORE CONVECTION?

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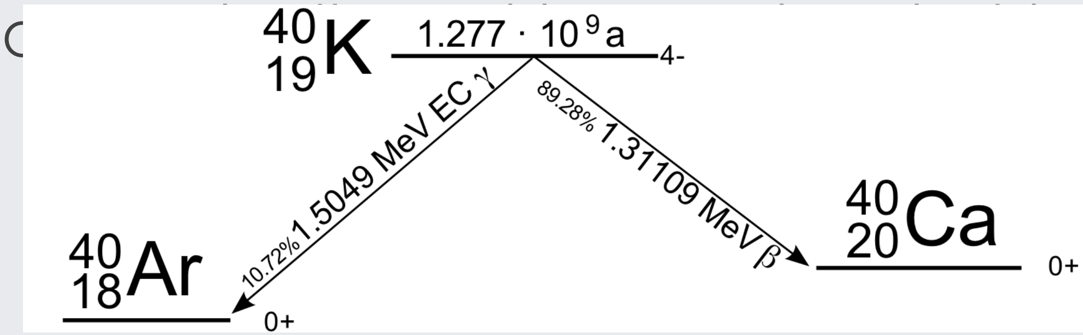
- Core Radioactivity: Potassium-40 may enter core, but inefficient and anyways no



udgets.

DRIVING FORCE FOR CORE CONVECTION?

- Thermal convection: Top-cooling by the mantle, but must exceed conducted heat to avoid stratification.

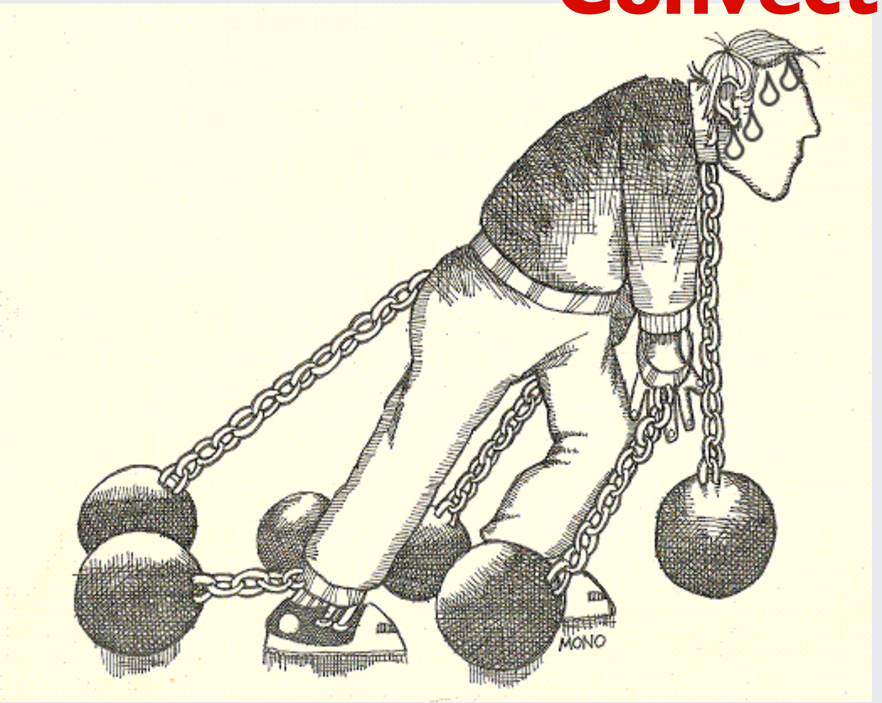
- Chemical convection: Release of light elements upon inner core crystallization...but inner core is only ~1 Ga in age.

- Core Radioactivity: Potassium-40 may enter core, but inefficient and anyways not much allowed by geochemical budgets.

- Exsolution: Cooling-induced saturation in some core alloys, but not yet well-documented by experimental evidence.

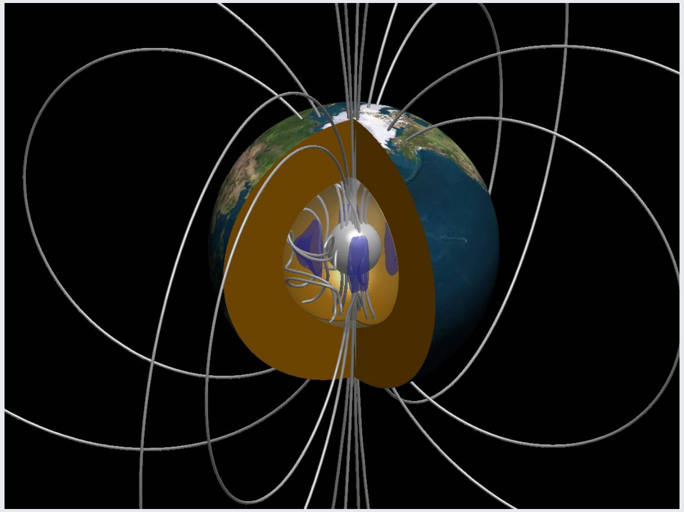
STRUGGLE FOR AN EARLY DYNAMO

Mantle Convection

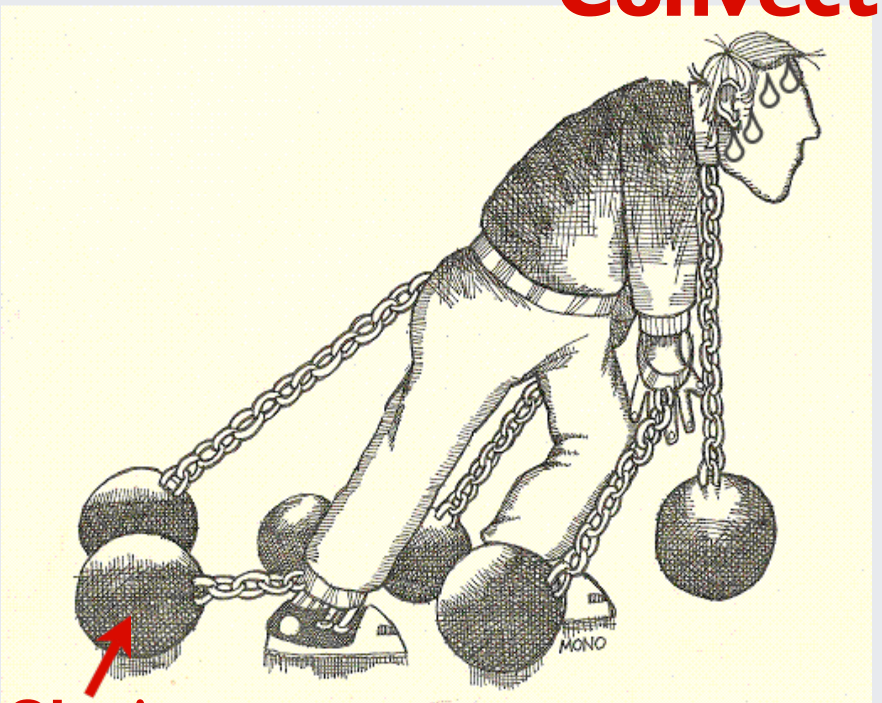


Cartoon by PD Lankovsky

Goal: Core Convection



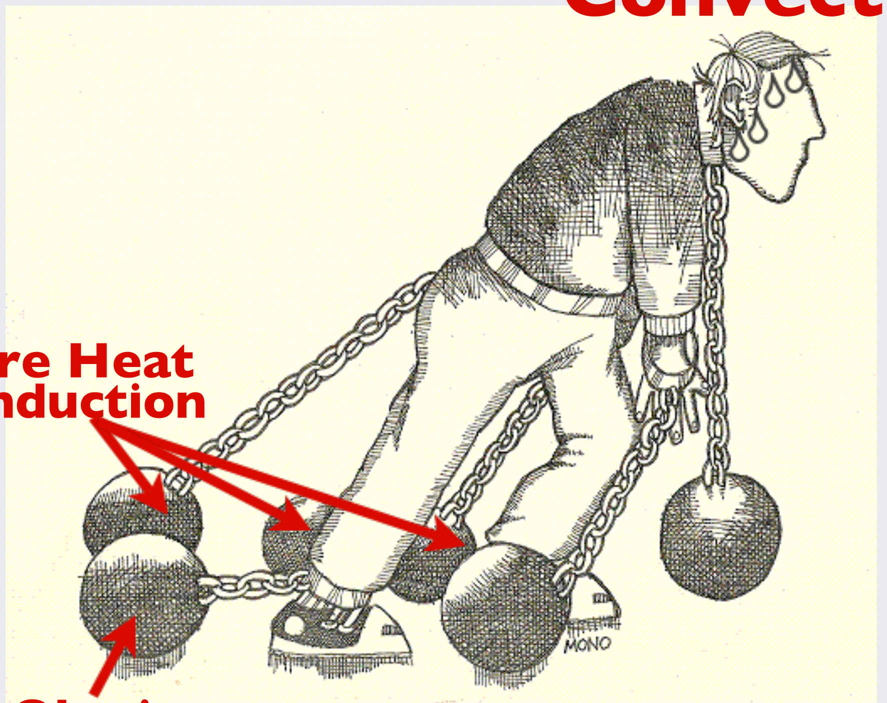
STRUGGLE FOR AN EARLY DYNAMO



$$\Phi = \left(\frac{\eta \bar{B}^2}{\mu L^2}\right) V$$

~0.1-1
TW

STRUGGLE FOR AN EARLY DYNAMO

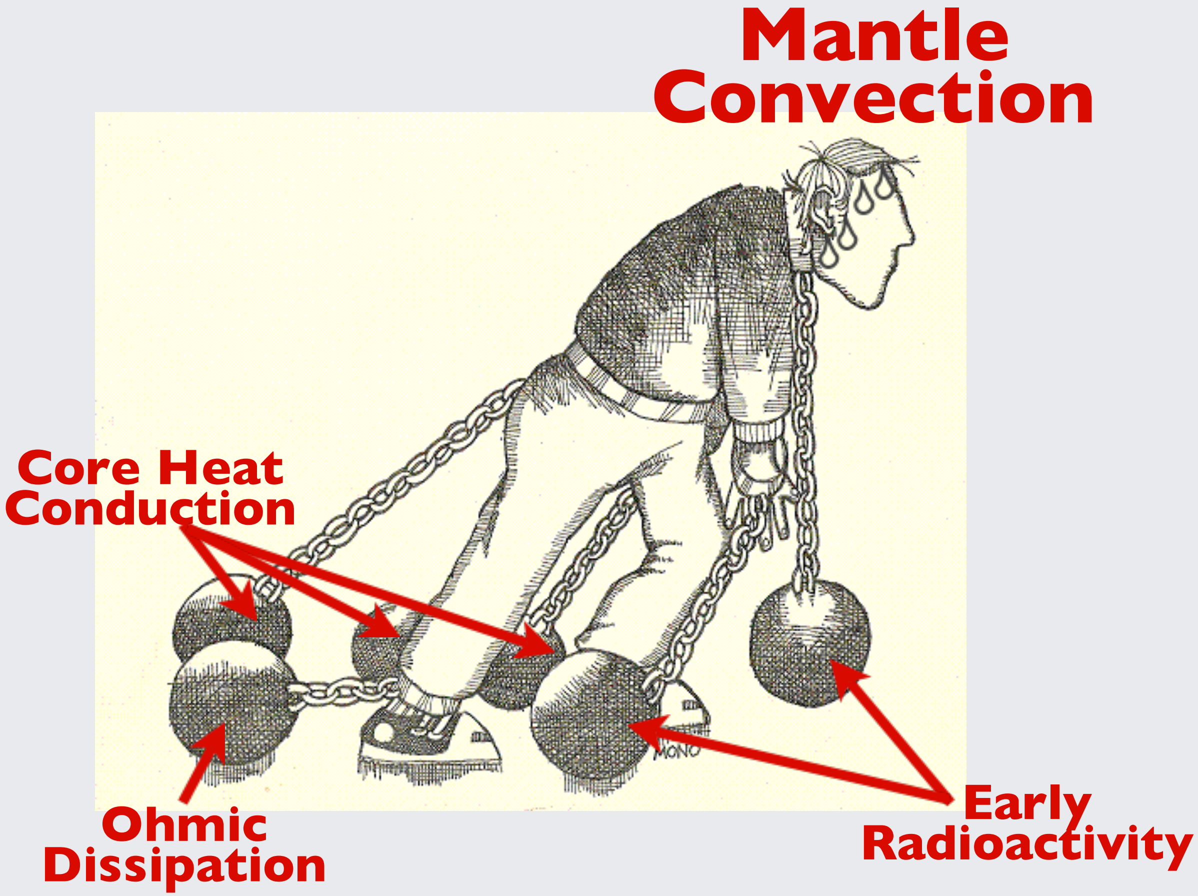


Core convection sets up an adiabatic gradient.

A large amount of heat is conducted down the adiabatic gradient because the core is metallic.

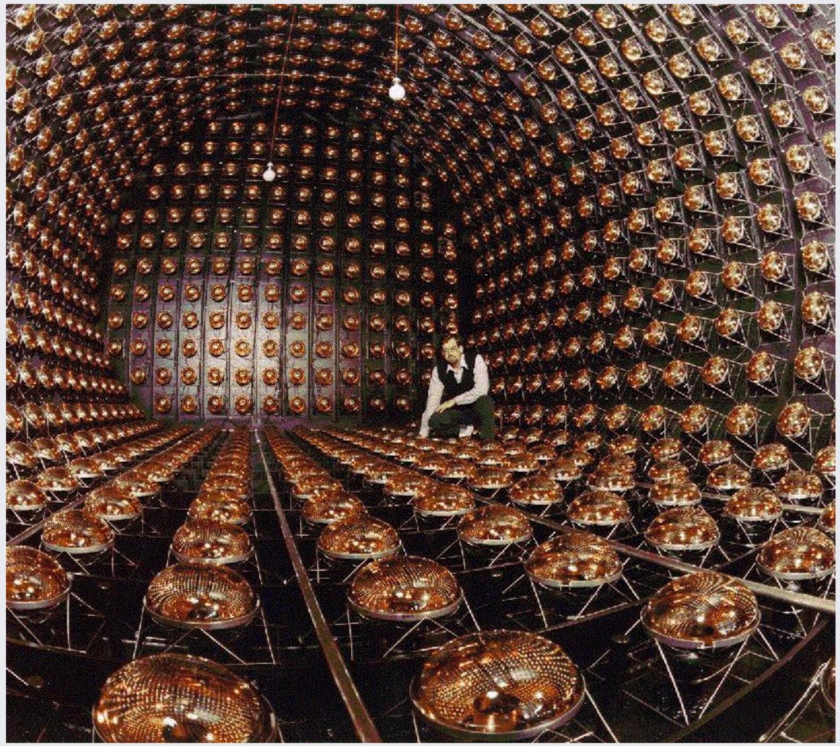
$$-k\frac{dT}{dr}A \quad \sim 5\text{-}13 \text{ TW}$$

STRUGGLE FOR AN EARLY DYNAMO



Present day: ~20TW

Early Earth: ~60-80TW



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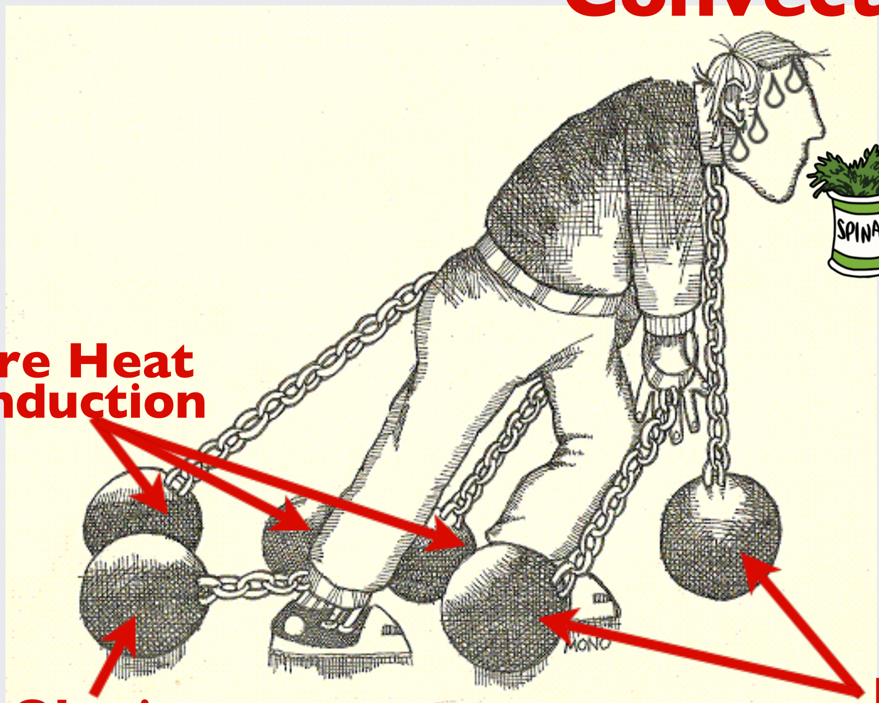

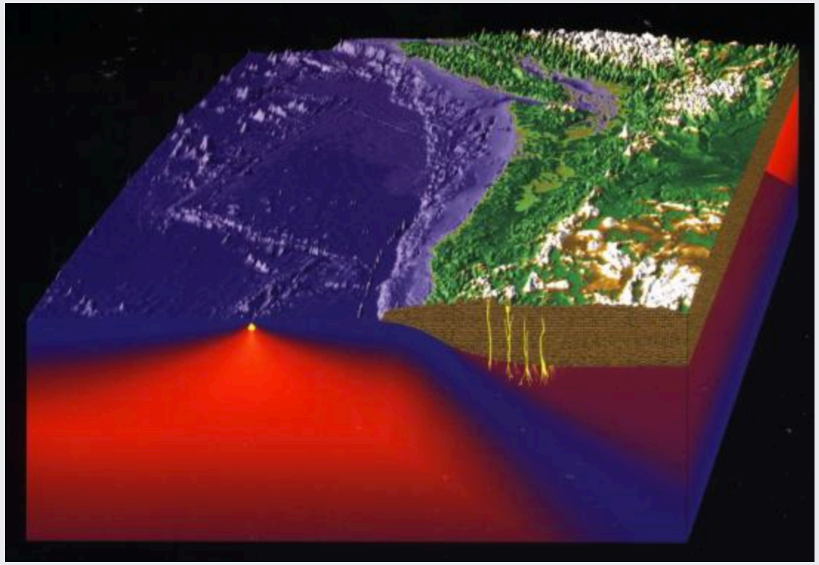

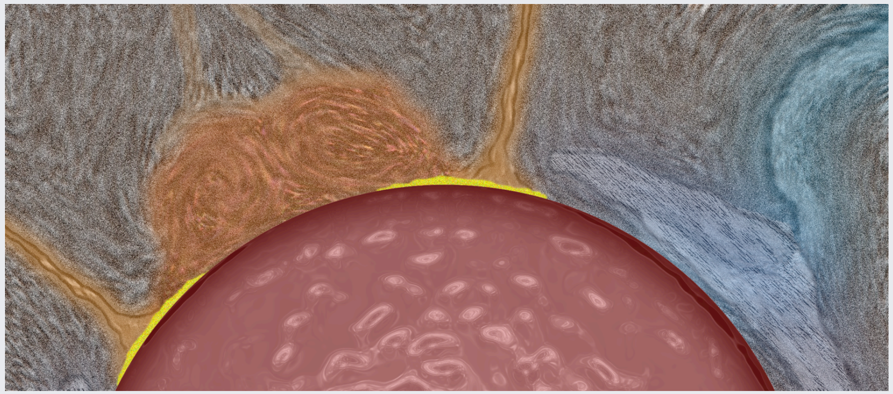

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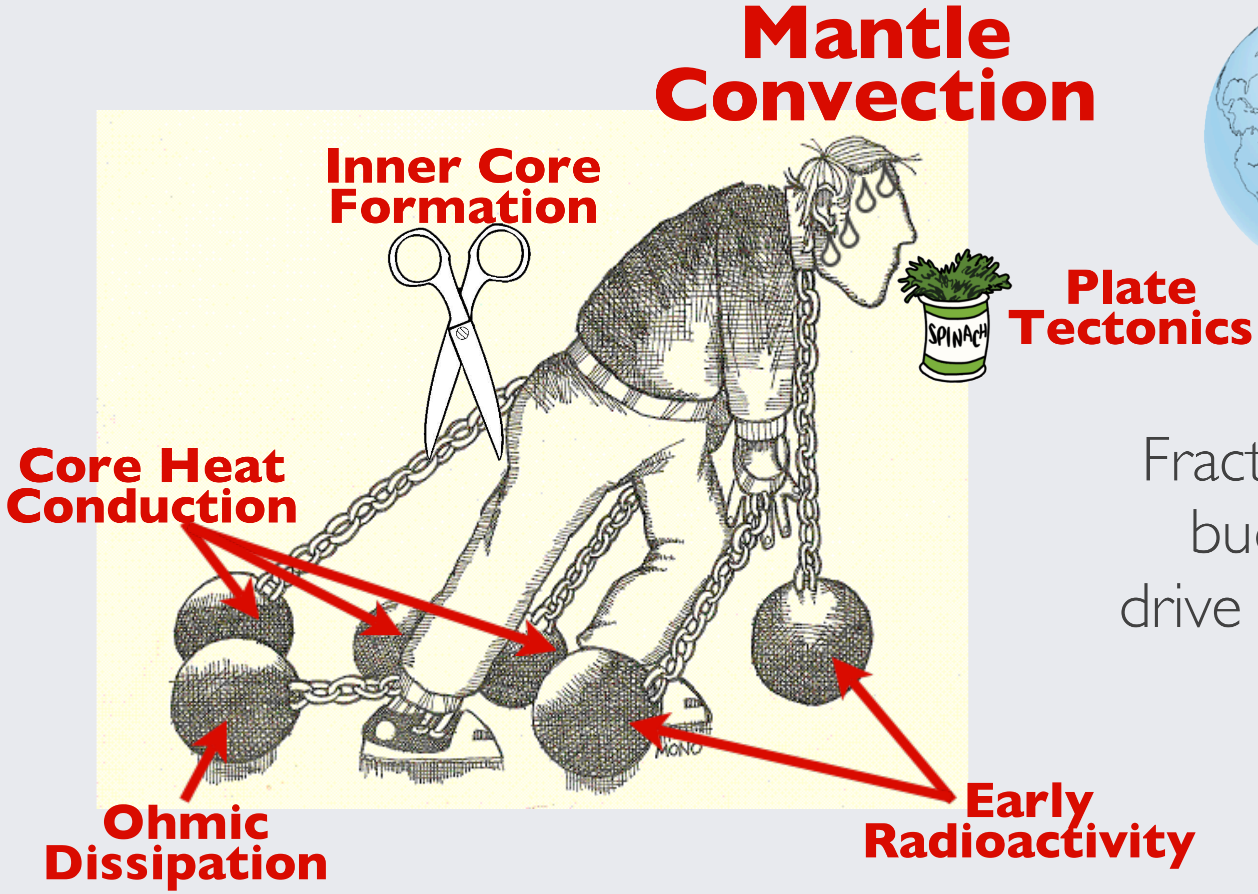
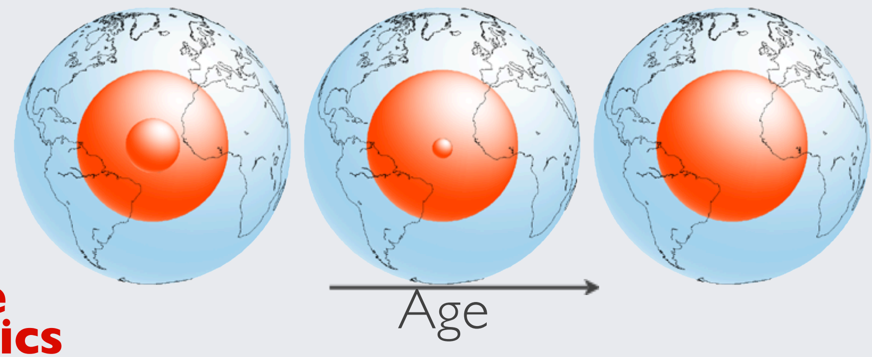
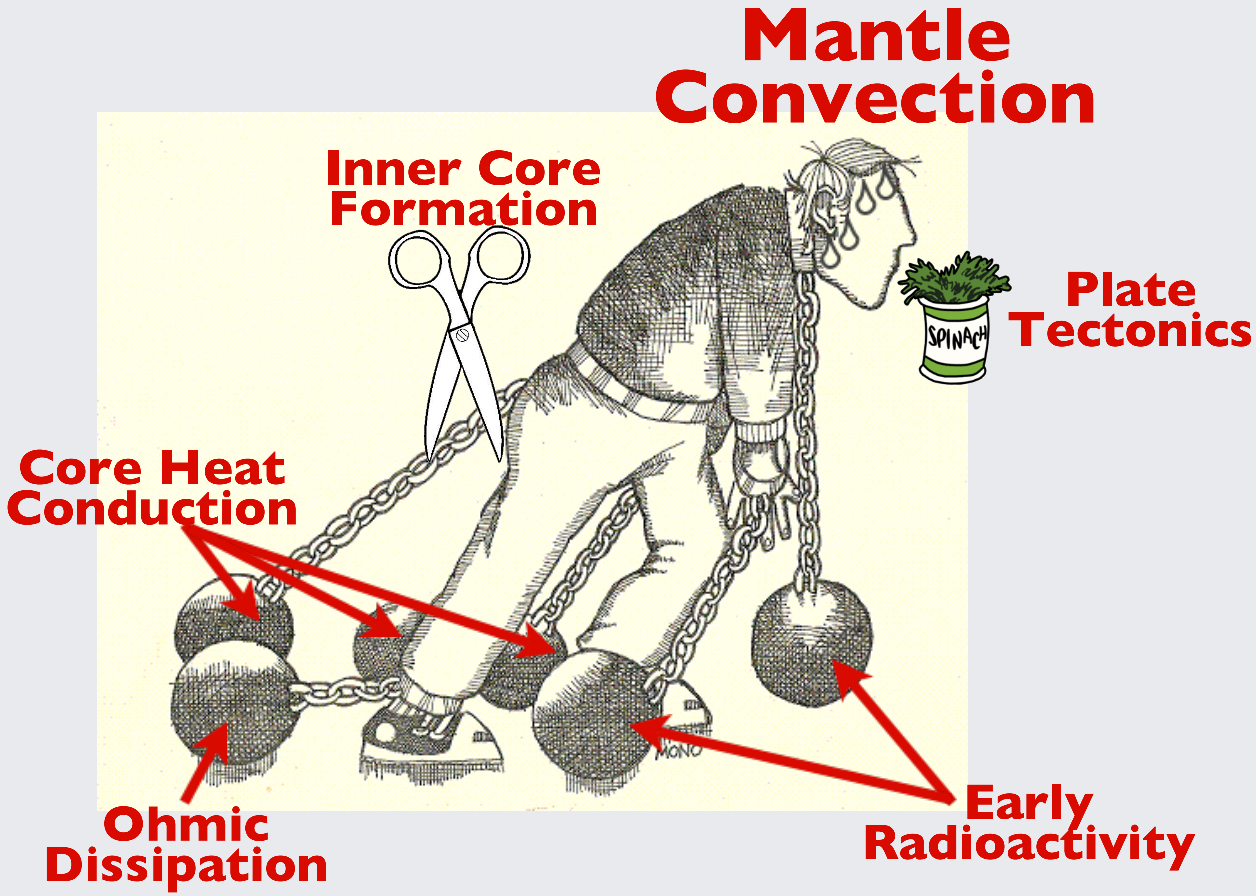
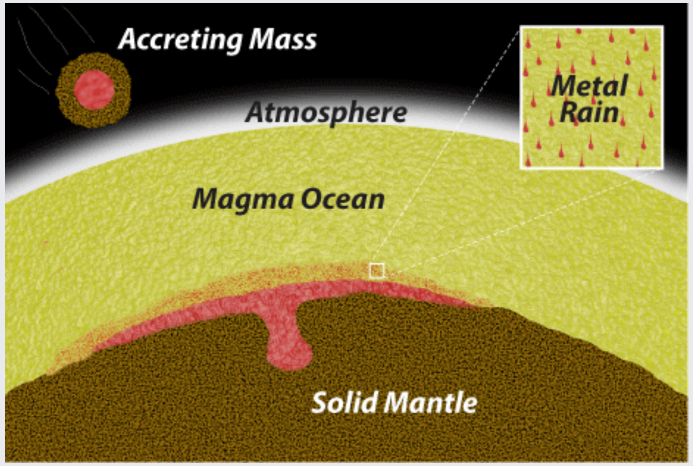




Fractional crystallization may release buoyant light elements that help drive convection ***and*** prevent thermal stratification

STRUGGLE FOR AN EARLY DYNAMO





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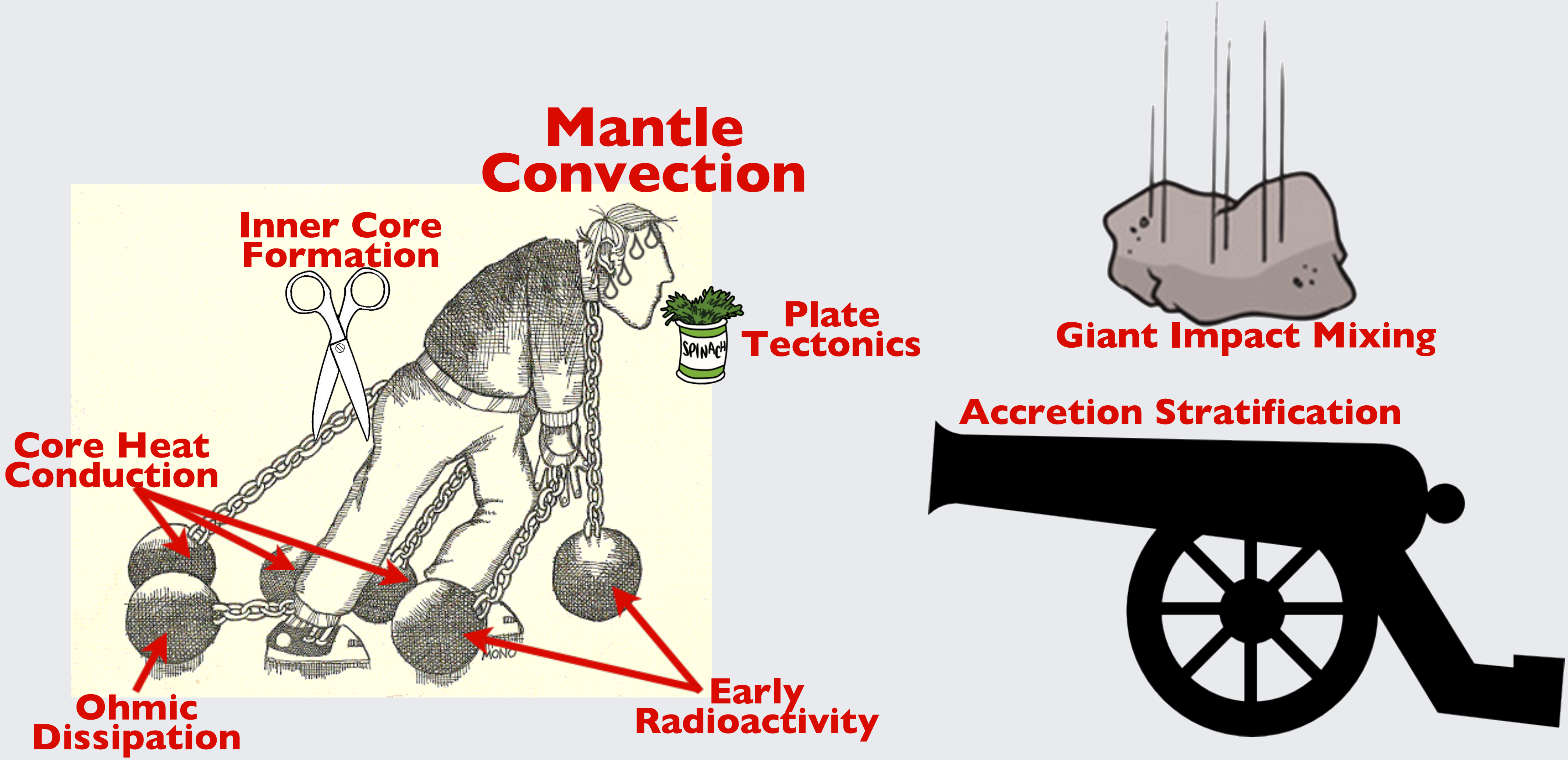

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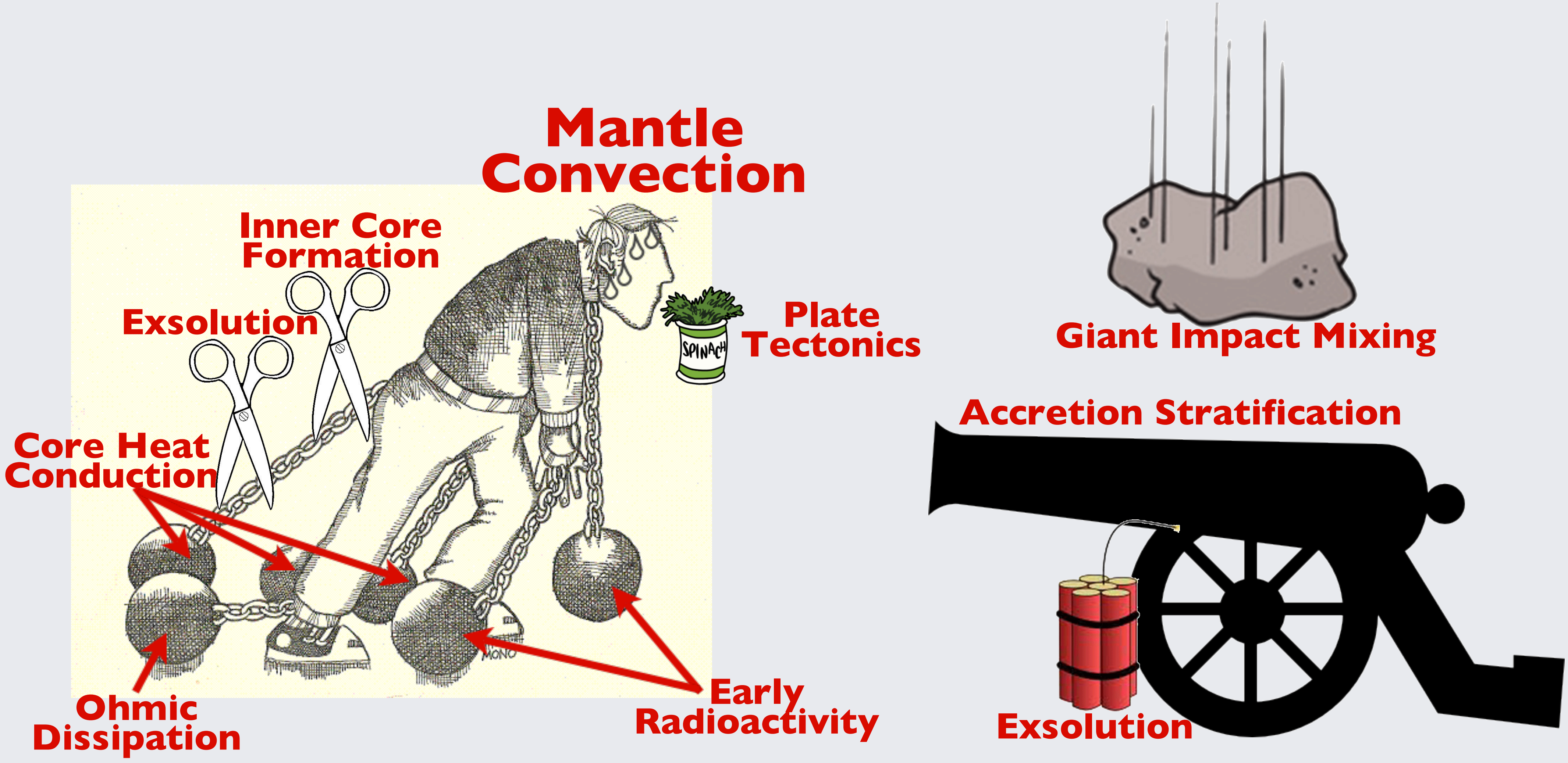
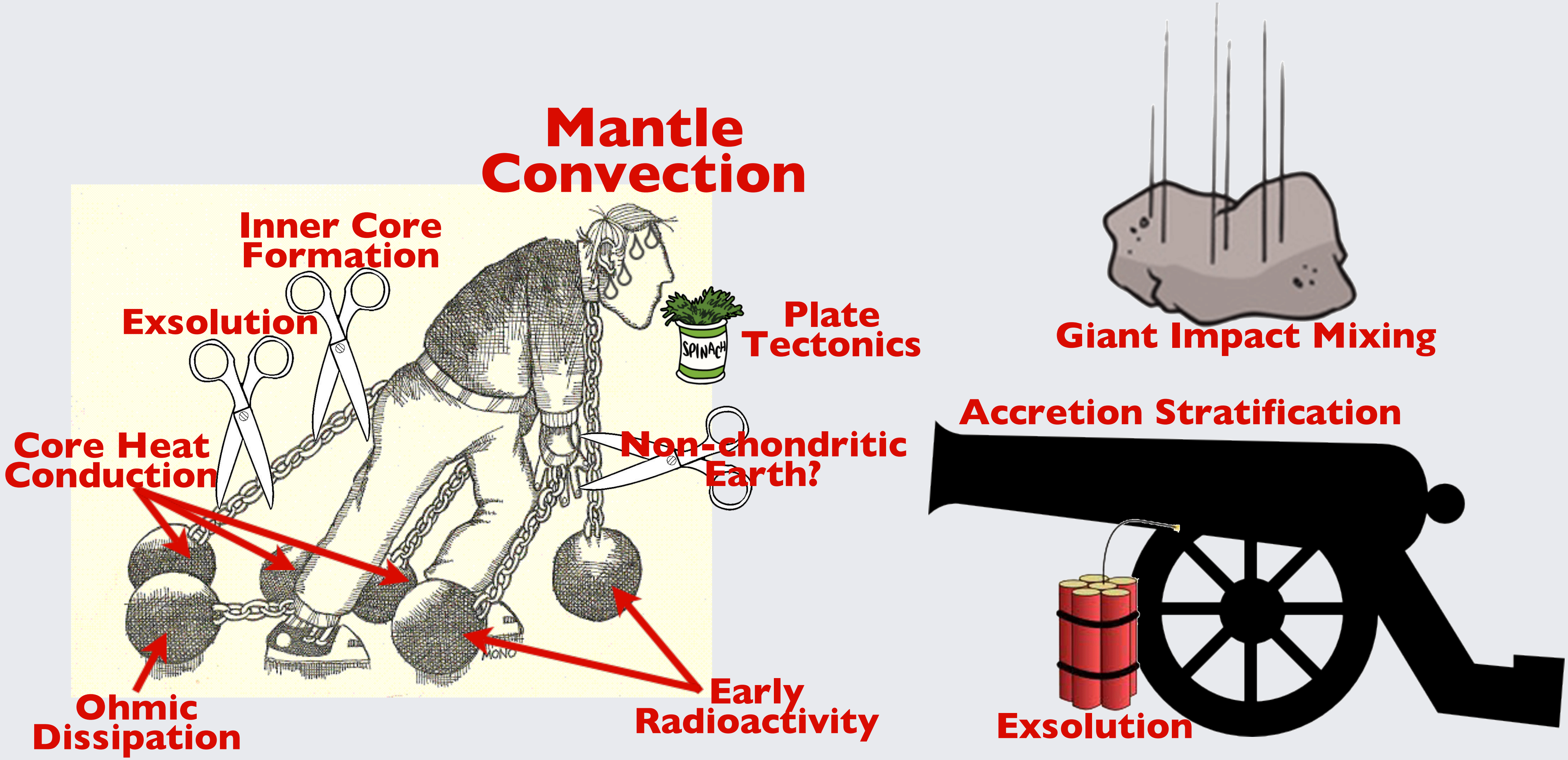
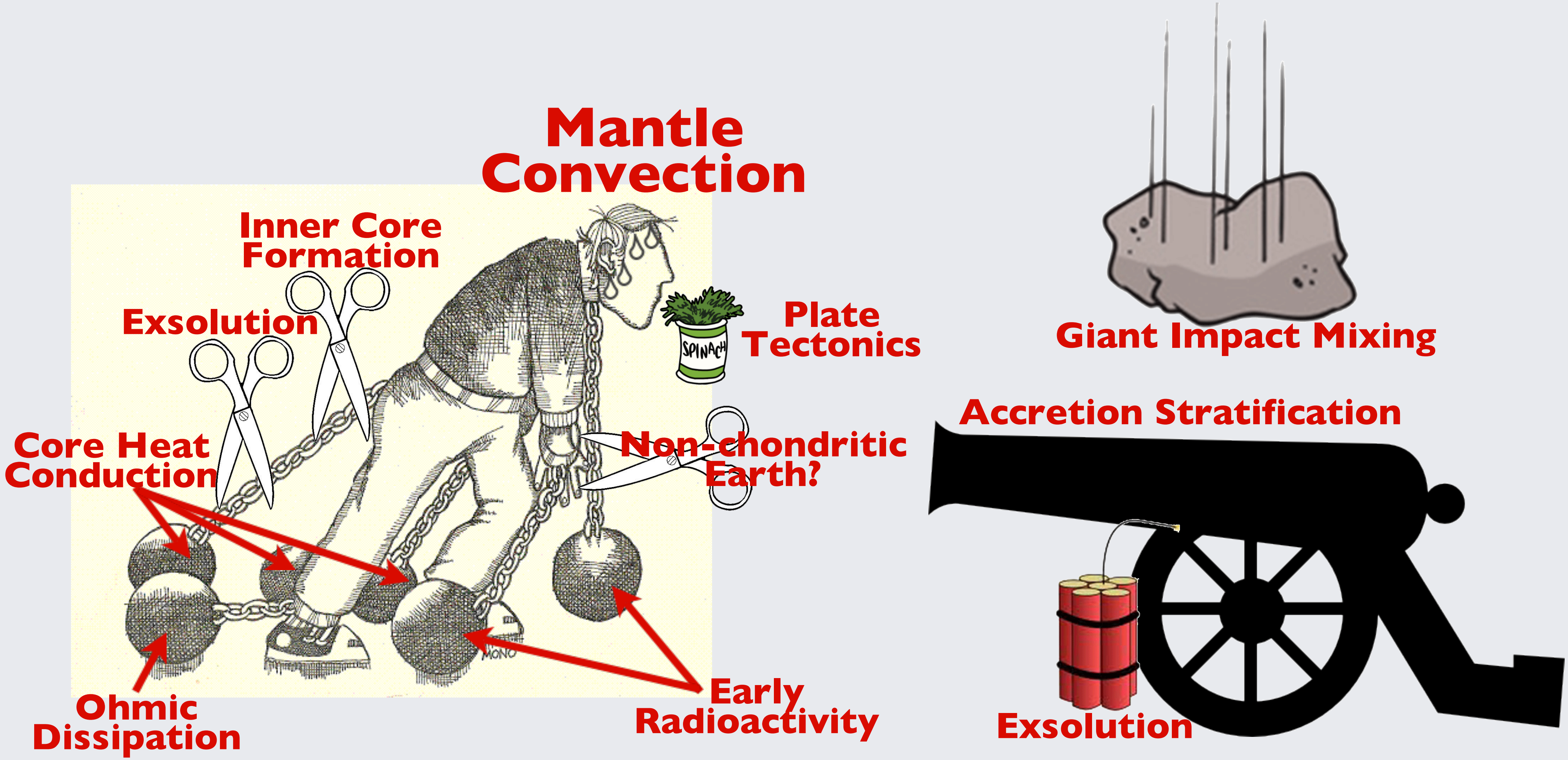


STRUGGLE FOR AN EARLY DYNAMO



SUMMARY


Mantle Convection
Inner Core Formation
Exsolution
Core Heat Conduction
Ohmic Dissipation
Plate Tectonics
SPINACH
Non-chondritic Earth?
Early Radioactivity
MONO
Giant Impact Mixing
Accretion Stratification
Exsolution

ELSI GEOPHYSICAL MODELING PLANS

- Formation and Evolution of the Early Atmosphere: Model the trade-offs with initial conditions, degassing, geomagnetic field history, to assess stability and suitability for life.

- Chemical Geodynamics in the Accreting Earth: Models of accretion and core formation, assess element partitioning, core chemistry, possibility for exsolution, and thermal evolution.

- Deep Earth-Deep Time Evolution: Models of deep Earth evolution to understand how present structures are related to ancient events and evolution scenarios, and test hypotheses.