Preserving ^{40}Ar from degassing: the influence of oceanic crust density and continental crust extraction

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I INTRODUCTION

- **^{40}Ar is produced by radioactive decay of ^{40}K**, one of the main Heat Producing Elements (HPEs) with a half-life of ~1.25 Gyr.
- **~50%** of the **^{40}Ar produced** is in the **atmosphere**.
- The remaining half, often referred as the "**missing argon**", is **trapped in the solid Earth** despite the highly incompatible and atmophile (low solubility in silicate melts) properties of Ar.
- Tucker *et al* [1] found that **early-formed oceanic crust** could be a good candidate as **holder of the missing Ar**, as it would concentrate substantial ^{40}K.
- **Preserving early recycled material is crucial** and parameters that influence buoyancy such as the intrinsic **density excess of oceanic crust** or the **amount of HPEs** are therefore **critical** to the Ar problem
- **We investigate the effect of the extraction of the continental crust and buoyancy number of slabs on the amount of degassed ^{40}Ar and its preservation within the convecting mantle**

II METHODS

- Using the **3D spherical** mantle convection code **TERRA** [2, 3], we produce **incompressible thermochemical** convection models with **temperature dependent viscosity** and **tracers** that hold isotopes including HPEs.
- **Differentiation** modifies **bulk composition** and **isotopic concentrations** with depth and composition dependent solidus [2].

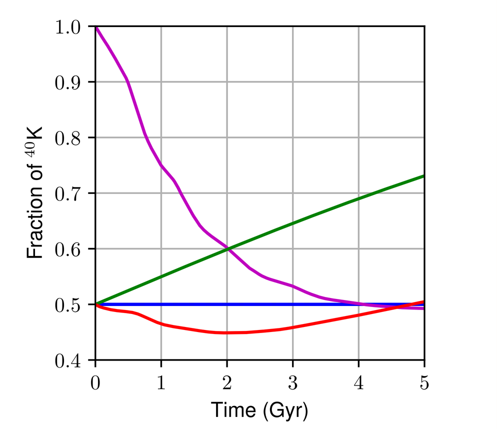

Figure 1: Fraction of total ^{40}K in the mantle

Models	Buoy 0	Buoy 0.3	Buoy 0.6	Buoy 1.2	Buoy 1.8	CC out	CC in	CC inout
Buoyancy Number	0	0.3	0.6	1.2	1.8	0.6		
Continental Crust Setting	Half of HPEs in CC, no exchanges with the mantle					Half of HPEs in CC, eroding CC	No initial CC, continuous extraction	Half of HPEs in CC, continuous erosion and extraction

III RESULTS

The Insulating effect of denser Oceanic Crust favours preservation of ^{40}Ar in the mantle

- Recycled Oceanic Crust can reside longer in the lowermost mantle because of its intrinsic density. **High Buoyancy number cases insulate the mantle** from receiving heat from the core (fig. 2)
- Because of insulation, **the upper mantle cools** and processing rates are lower (fig. 2B and 3 respectively)
- When the insulating layer accumulates too much heat, **it destabilizes, forming massive plumes** and causes massive **processing** and **outgassing events** (fig. 3 and 5A). However, the **total amount of processing remains lower**
- **Less processing overall favour preservation of both primitive and Early Enriched Material (EEM)** (fig. 7). Preserving both types of material is **key to preserve ^{40}Ar in the mantle** (fig. 5B)

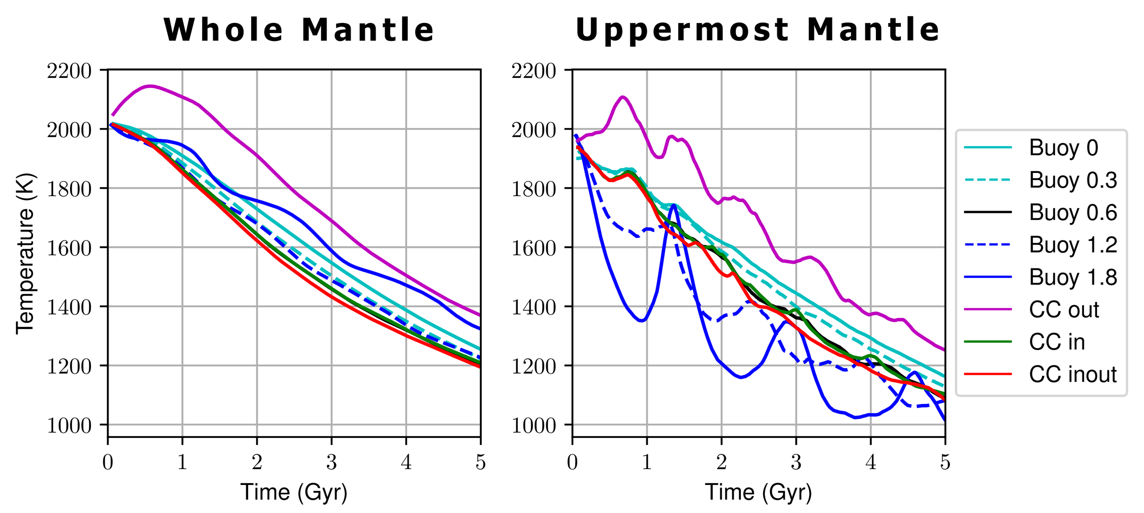

Figure 2: Average Temperature in function of time in the whole mantle (A) and the uppermost mantle (top 270 km) (B)

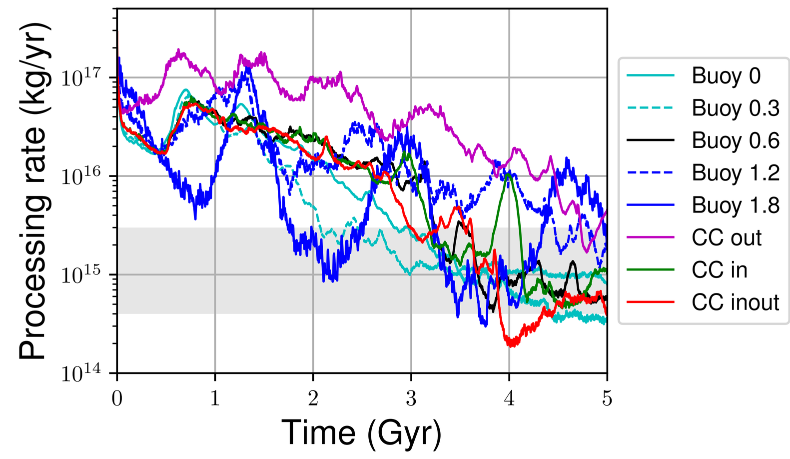

Figure 3: Processing rates in function of time. Shaded area represents the current estimate for Earth

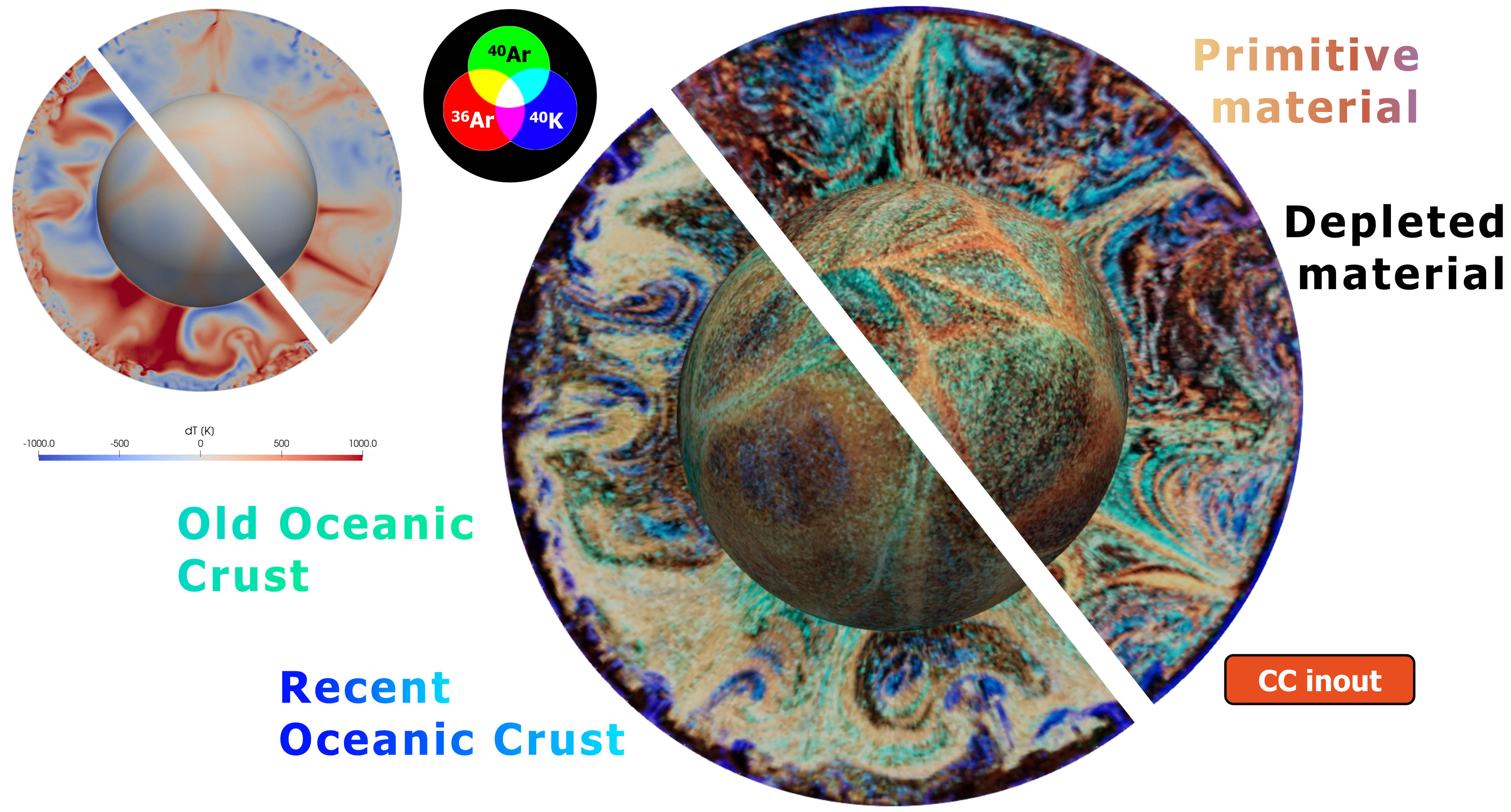

Figure 4: Visualizations of temperature difference (A) (compared to layer average) and color composite (B) (percentile ranks) at 1.5 Gyr.

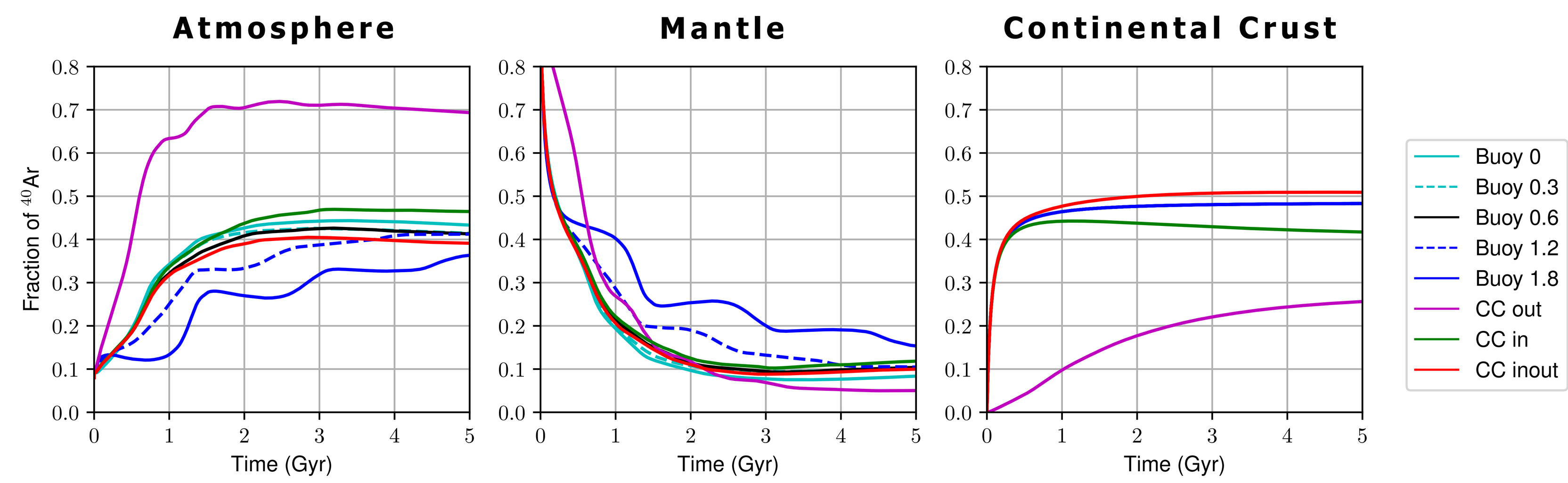

Figure 5: Fraction of total ^{40}Ar in the Atmosphere (A), Mantle (B) and Continental Crust (C) in function of time.

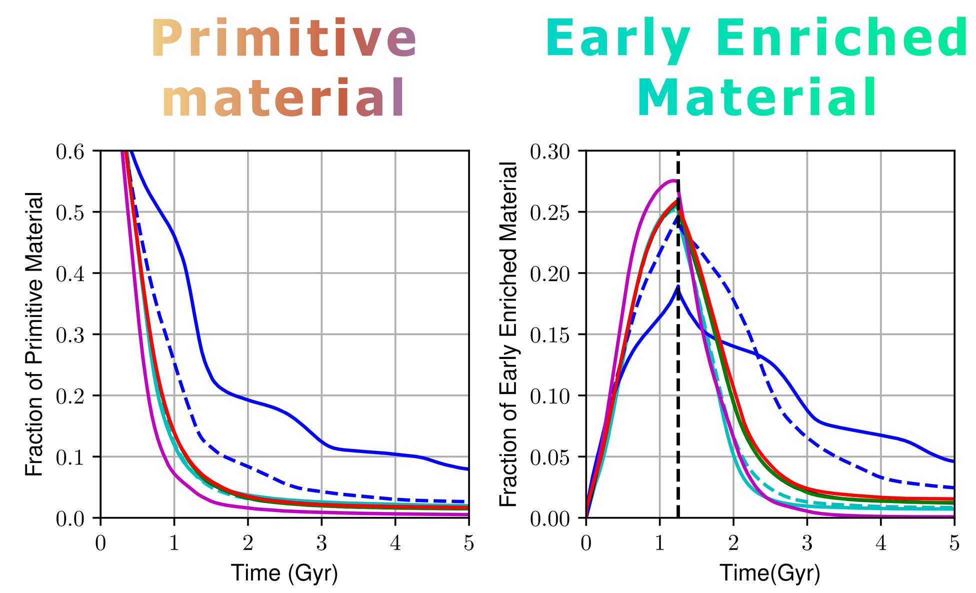

Figure 7: Preservation of Primitive (A) and Early Enriched material (B) in function of time.

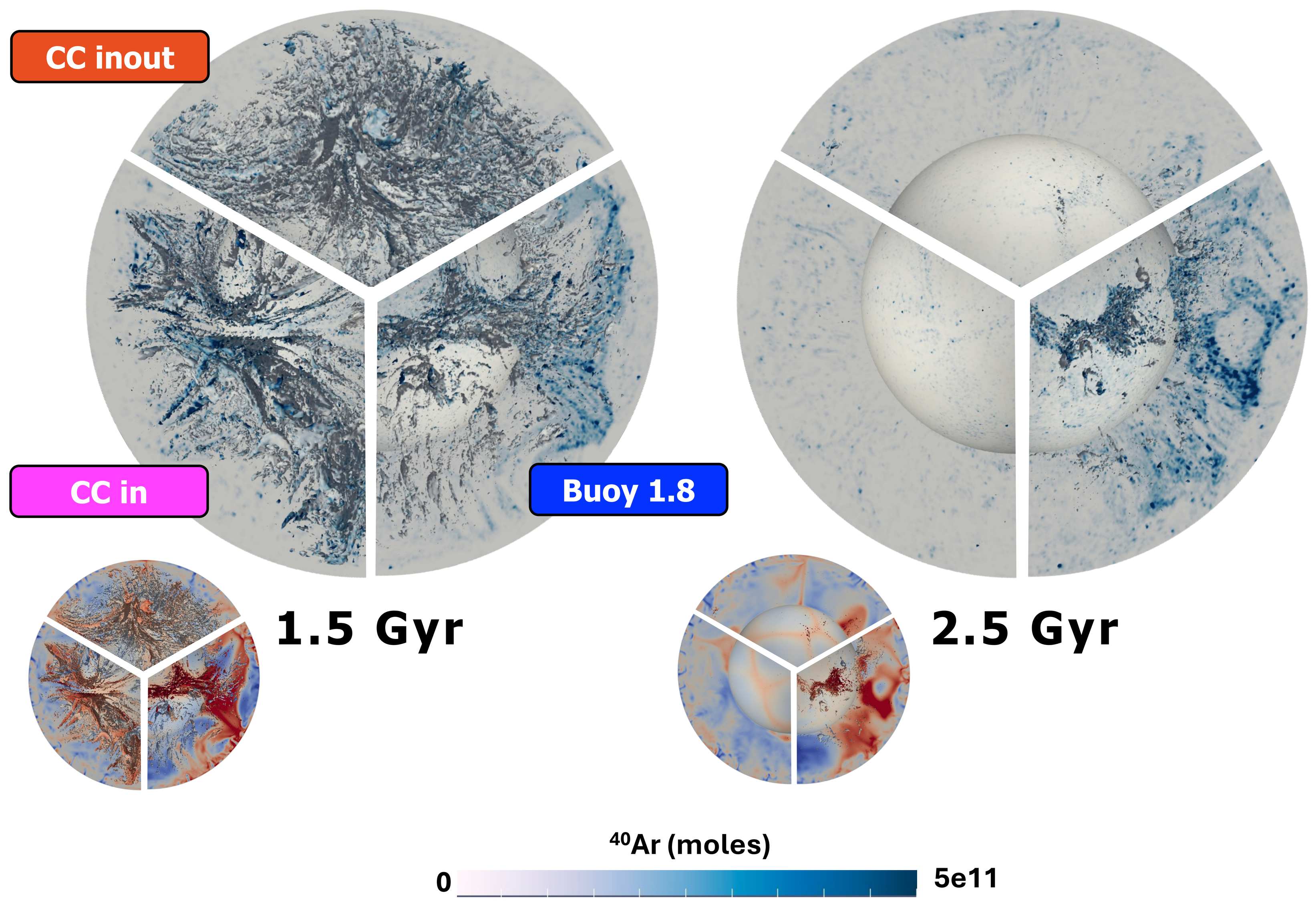

Figure 6: Visualizations of temperature difference and ^{40}Ar content (moles).

Early Enriched Material is a crucial ^{40}Ar reservoir

- **Early Enriched Material (EEM)** is produced by **melting within the first half-life of ^{40}K** (~1.2Gyr). It is old enriched mantle
- Increasing the Buoyancy number of enriched material results in **less, but better preserved, EEM** (fig. 6 and 7) (controlled by mantle temperature and processing rates, fig. 2and 3)
- **EEM, when intrinsically dense, reside deeper** in the lower mantle (fig. 6)
- **EEM can escape processing and degassing** even after being entrained by plumes (fig. 4 and 6)

Early Continental Crust extraction strongly enhances ^{40}Ar retention

- Heat Producing Elements (U, Th, K) are concentrated in the Continental Crust (CC) because of their incompatible nature. The amount of **HPEs in the convecting mantle controls temperature and processing rates** (fig. 2 and 3)
- **Early CC extraction results in greatest retention of ^{40}Ar** (~half less ^{40}Ar in the atmosphere than otherwise fig. 5A). Inversely, **no initial HPEs extraction leads to the most ^{40}Ar depletion** in the mantle (fig. 5B)
- **Removing HPEs form the mantle** (even temporarily) **favours preservation of ^{40}Ar in the Earth** (mantle+CC) as shown by case CC_inout (fig. 1 and 5)
- ^{40}Ar production becomes greater than ^{40}Ar outgassing ~half-way through the simulation in cases where B < 1.2 (fig. 5A)
- Our models show that the **CC stores substantial ^{40}Ar** (fig. 5C). It is probably overestimated because of our modelling assumptions. **Bender *et al* [4] showed that the CC was the main contributor to atmospheric ^{40}Ar.**

Interdisciplinary Perspectives on Mantle Formation, Structure, and Dynamics in the Earth and Other Planetary Bodies

Thursday, 12 December 2024
8:30-12:30

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