

The background of the slide is a rich, reddish-brown cosmic scene. It features a dense field of dust and small, bright stars. In the center, a larger, glowing planet or protoplanet is visible, surrounded by a ring of smaller, dark, rocky bodies. The overall atmosphere is one of a young, active star system.

Cosmochemical constraints on the composition of the Earth: the ^{142}Nd conundrum

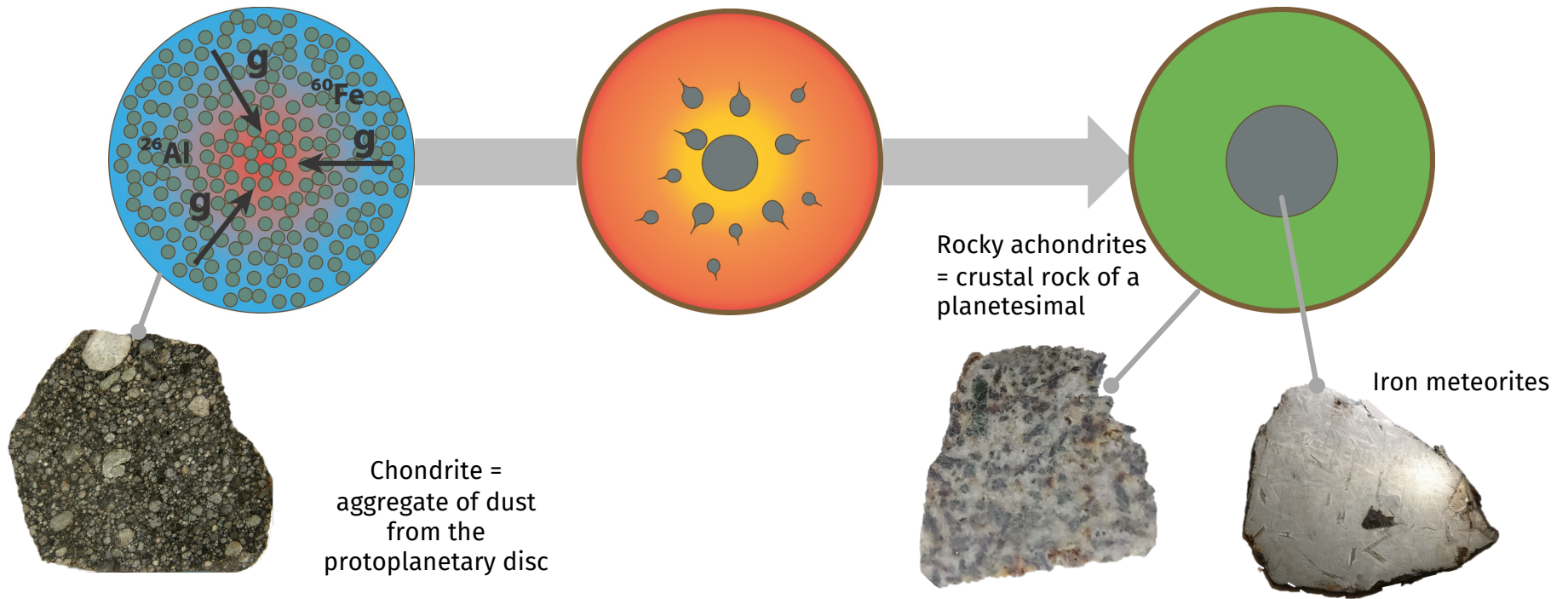
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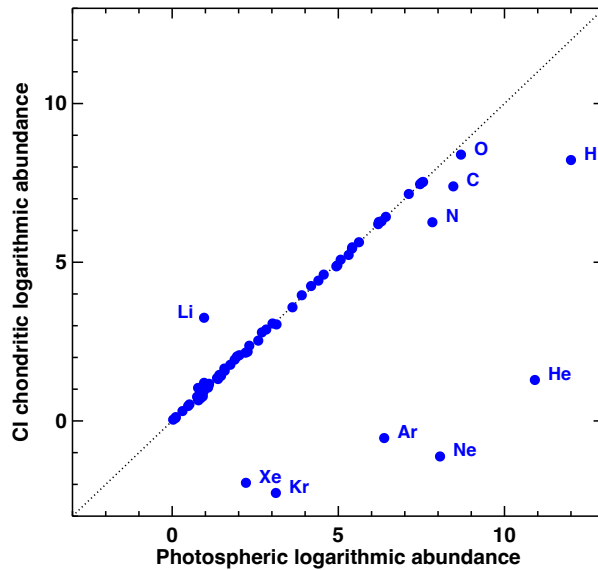
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Geoneutrino Geoscience – October 30th, 2025

Meteorites: witnesses of early Solar System evolution

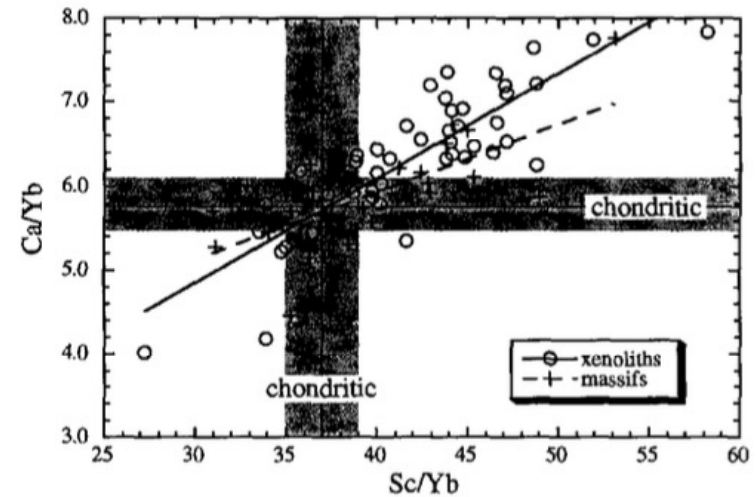


Primitive meteorites as building blocks of the Earth



Asplund et al. (2021)

Primitive meteorites (=chondrites) share a chemical composition similar to that of the Sun



McDonough and Sun (1995)

Refractory lithophile elements composition of samples from the Earth's mantle coincide with chondrites

Isotope cosmochemistry: forensics in the Solar System

PERIODIC TABLE OF ELEMENTS
Chemical Group Block

PubChem

1 H Hydrogen Nonmetal																	2 He Helium Noble Gas
3 Li Lithium Alkali Metal	4 Be Beryllium Alkaline Earth M.											5 B Boron Metalloid	6 C Carbon Nonmetal	7 N Nitrogen Nonmetal	8 O Oxygen Nonmetal	9 F Fluorine Halogen	10 Ne Neon Noble Gas
11 Na Sodium Alkali Metal	12 Mg Magnesium Alkaline Earth M.											13 Al Aluminum Post-Transition	14 Si Silicon Metalloid	15 P Phosphorus Nonmetal	16 S Sulfur Nonmetal	17 Cl Chlorine Halogen	18 Ar Argon Noble Gas
19 K Potassium Alkali Metal	20 Ca Calcium Alkaline Earth M.	21 Sc Scandium Transition Metal	22 Ti Titanium Transition Metal	23 V Vanadium Transition Metal	24 Cr Chromium Transition Metal	25 Mn Manganese Transition Metal	26 Fe Iron Transition Metal	27 Co Cobalt Transition Metal	28 Ni Nickel Transition Metal	29 Cu Copper Transition Metal	30 Zn Zinc Transition Metal	31 Ga Gallium Post-Transition	32 Ge Germanium Metalloid	33 As Arsenic Metalloid	34 Se Selenium Nonmetal	35 Br Bromine Halogen	36 Kr Krypton Noble Gas
37 Rb Rubidium Alkali Metal	38 Sr Strontium Alkaline Earth M.	39 Y Yttrium Transition Metal	40 Zr Zirconium Transition Metal	41 Nb Niobium Transition Metal	42 Mo Molybdenum Transition Metal	43 Tc Technetium Transition Metal	44 Ru Ruthenium Transition Metal	45 Rh Rhodium Transition Metal	46 Pd Palladium Transition Metal	47 Ag Silver Transition Metal	48 Cd Cadmium Transition Metal	49 In Indium Post-Transition	50 Sn Tin Post-Transition	51 Sb Antimony Metalloid	52 Te Tellurium Metalloid	53 I Iodine Halogen	54 Xe Xenon Noble Gas
55 Cs Cesium Alkali Metal	56 Ba Barium Alkaline Earth M.	72 Hf Hafnium Transition Metal	73 Ta Tantalum Transition Metal	74 W Tungsten Transition Metal	75 Re Rhenium Transition Metal	76 Os Osmium Transition Metal	77 Ir Iridium Transition Metal	78 Pt Platinum Transition Metal	79 Au Gold Transition Metal	80 Hg Mercury Transition Metal	81 Tl Thallium Post-Transition	82 Pb Lead Post-Transition	83 Bi Bismuth Post-Transition	84 Po Polonium Metalloid	85 At Astatine Halogen	86 Rn Radon Noble Gas	
87 Fr Francium Alkali Metal	88 Ra Radium Alkaline Earth M.	104 Rf Rutherfordium Transition Metal	105 Db Dubnium Transition Metal	106 Sg Seaborgium Transition Metal	107 Bh Bohrium Transition Metal	108 Hs Hassium Transition Metal	109 Mt Meitnerium Transition Metal	110 Ds Darmstadtium Transition Metal	111 Rg Roentgenium Transition Metal	112 Cn Copernicium Transition Metal	113 Nh Nihonium Post-Transition	114 Fl Flerovium Post-Transition	115 Mc Moscovium Post-Transition	116 Lv Livermorium Post-Transition	117 Ts Tennessine Halogen	118 Og Oganesson Noble Gas	
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		89 Ac Actinium Actinide	90 Th Thorium Actinide	91 Pa Protactinium Actinide	92 U Uranium Actinide	93 Np Neptunium Actinide	94 Pu Plutonium Actinide	95 Am Americium Actinide	96 Cm Curium Actinide	97 Bk Berkelium Actinide	98 Cf Californium Actinide	99 Es Einsteinium Actinide	100 Fm Fermium Actinide	101 Md Mendelevium Actinide	102 No Nobelium Actinide	103 Lr Lawrencium Actinide	

Atomic Number: 17
Name: Chlorine
Chemical Group Block: Halogen

Many elements, even more isotopes, different physicochemical properties
= a lot of information!

Isotope cosmochemistry: forensics in the Solar System

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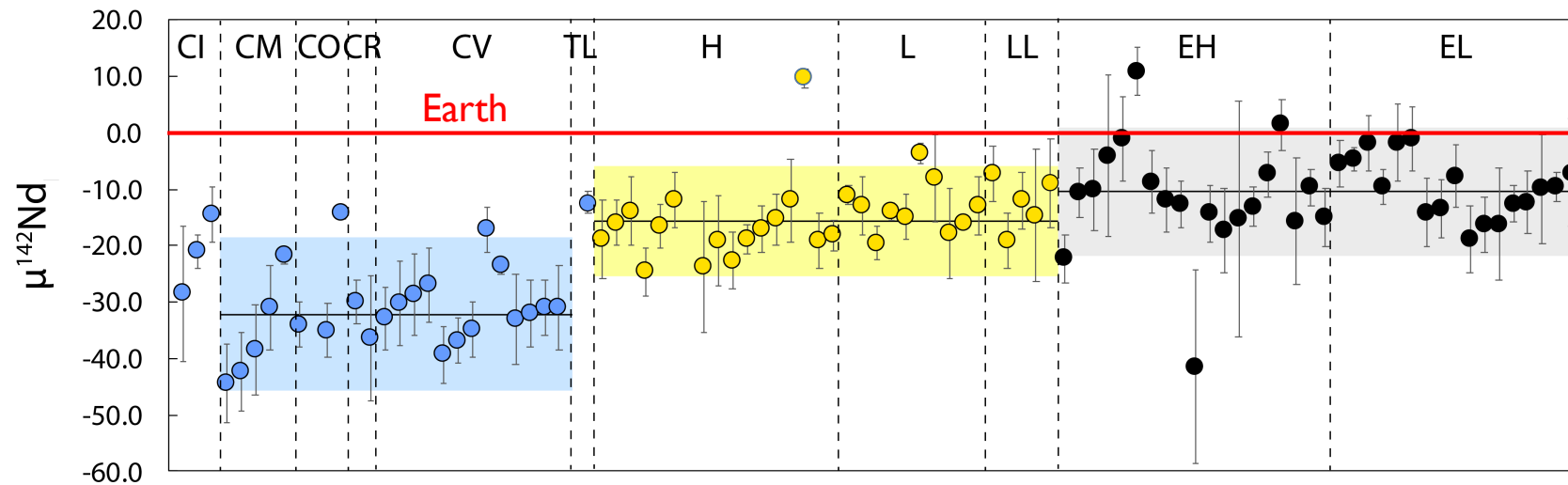
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The neodymium and samarium perspective



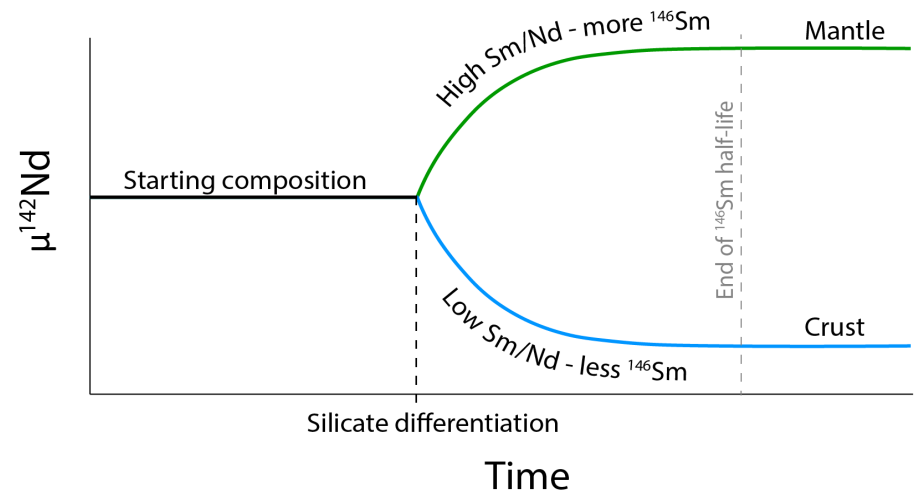
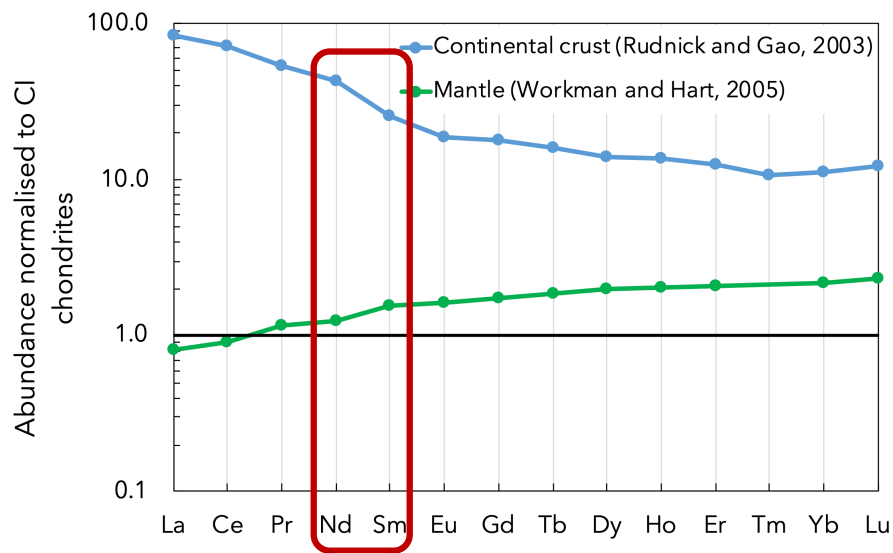
Earth displays an excess in ^{142}Nd compared to chondrites

$$\mu^{i\text{Nd}} = \left(\frac{{}^i\text{Nd}/{}^{144}\text{Nd}_{\text{sample}}}{{}^i\text{Nd}/{}^{144}\text{Nd}_{\text{standard}}} - 1 \right) \times 10^6$$

Origin of the ^{142}Nd excess in the Earth's mantle

① Radioactive decay?

Evidence for silicate differentiation from the extinct decay system ^{146}Sm - ^{142}Nd ($t_{1/2} = 92 \text{ Ma}$)



The **crust** is enriched in Nd relative to Sm compared to the **mantle** and leaves a **distinct ^{142}Nd signature**

Origin of the ^{142}Nd excess in the Earth's mantle

② Nucleosynthetic heterogeneity?

Nucleosynthetic anomalies are due to compositionally distinct dust in the protoplanetary disc

Nucleosynthetic anomalies act as genetic fingerprints – **source tracing for building blocks!**



Chili = presolar grain

Cream = large nebular reservoir

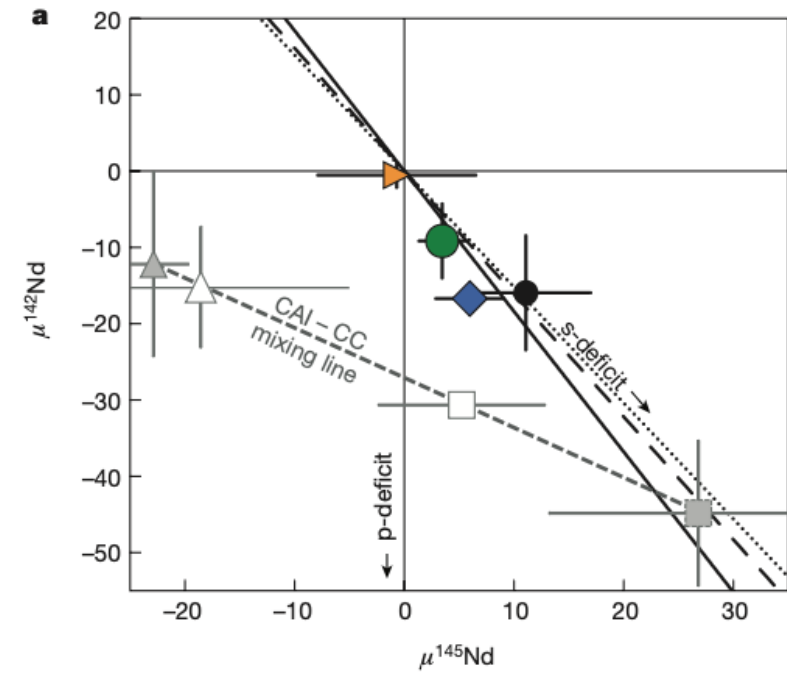
Bulk Solar System dust

Origin of the ^{142}Nd excess in the Earth's mantle

② Nucleosynthetic heterogeneity?

Evidence for nucleosynthetic variations for $\mu^{142}\text{Nd}$

Nucleosynthetic trends are not well characterised



Origin of the ^{142}Nd excess in the Earth's mantle

②

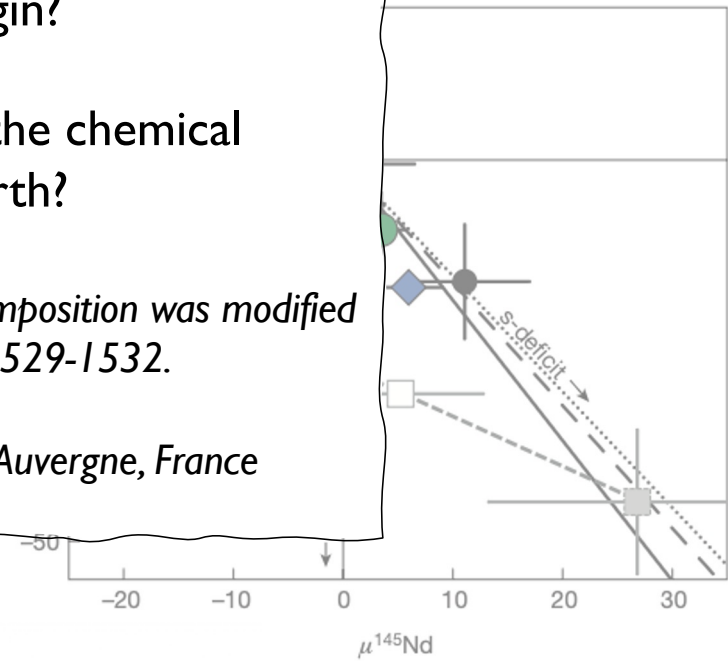
Nu

Is the excess of ^{142}Nd in Earth radiogenic or nucleosynthetic in origin?

What are the implications for the chemical composition of the Earth?

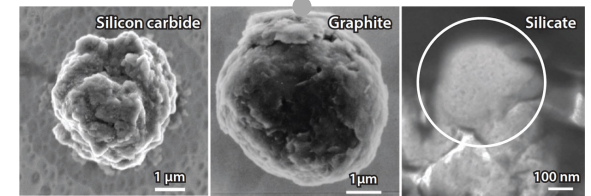
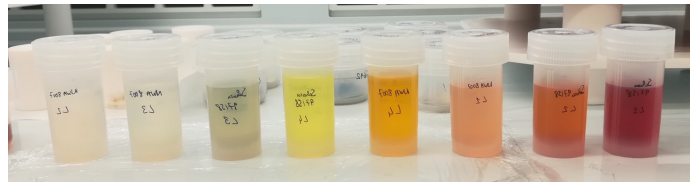
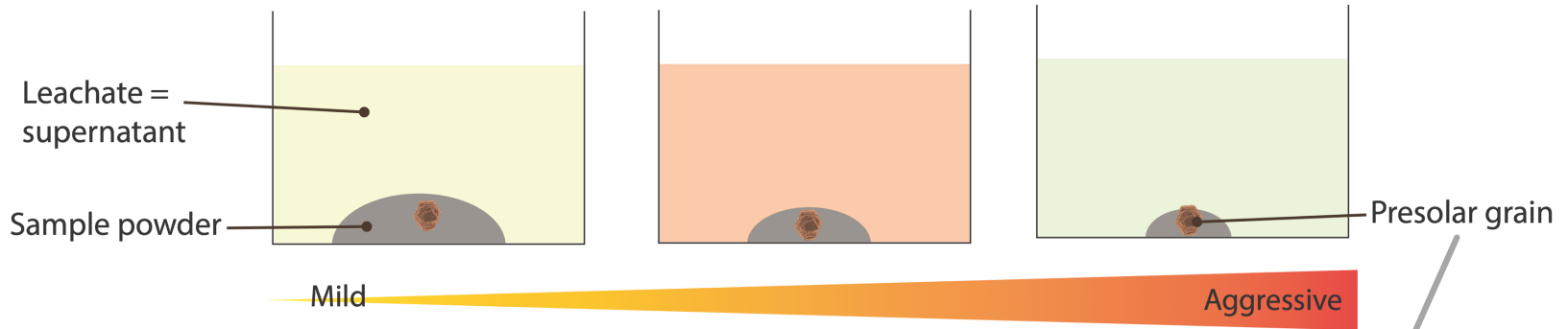
Frossard, Israel, Bouvier, Boyet, 2022. Earth's composition was modified by collisional erosion. Science 377, 1529-1532.

Study carried out in Université Clermont-Auvergne, France



Chemical separation of meteorite components

Stepwise dissolution (leaching) of primitive meteorites to isolate refractory presolar grains that carry highly anomalous nucleosynthetic compositions



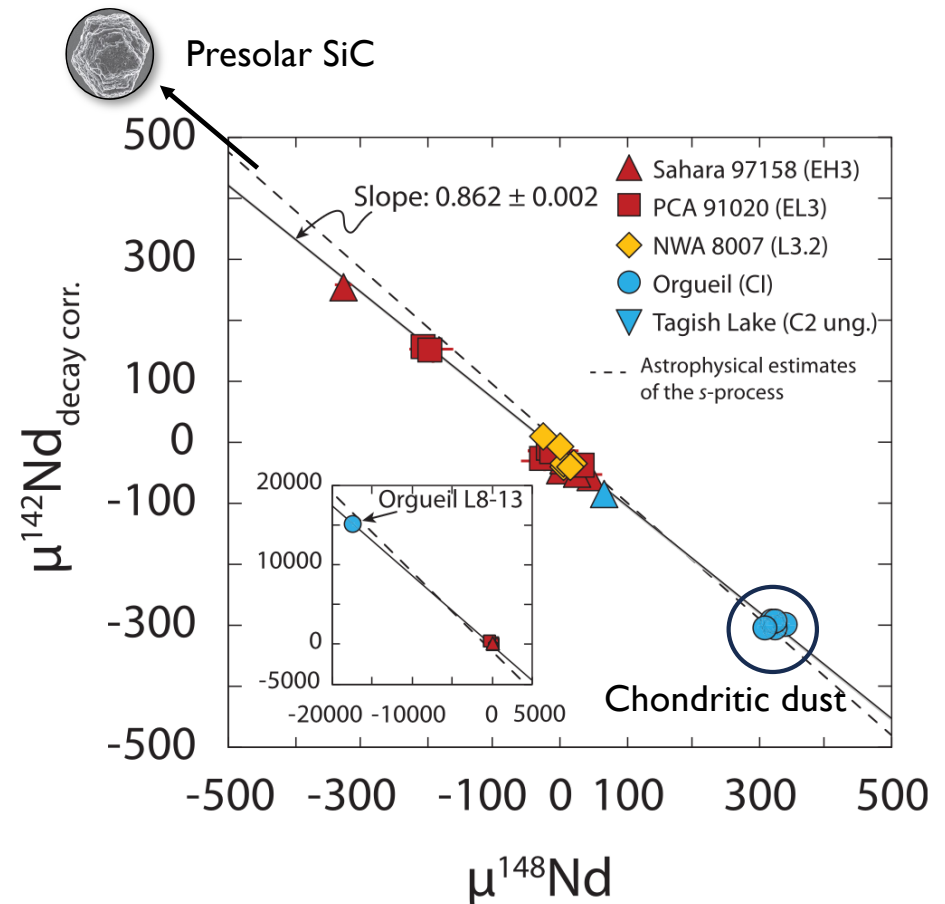
Nittler et al. (2016) Annual Rev. Astron. Astrophys.

Nucleosynthetic variations in leachates

Nd isotope composition of leachates are explained by mixing of:

“chondritic dust” + presolar SiC

Trend in Nd isotope composition of leachates defines precisely the nucleosynthetic variation in meteorites on ^{142}Nd



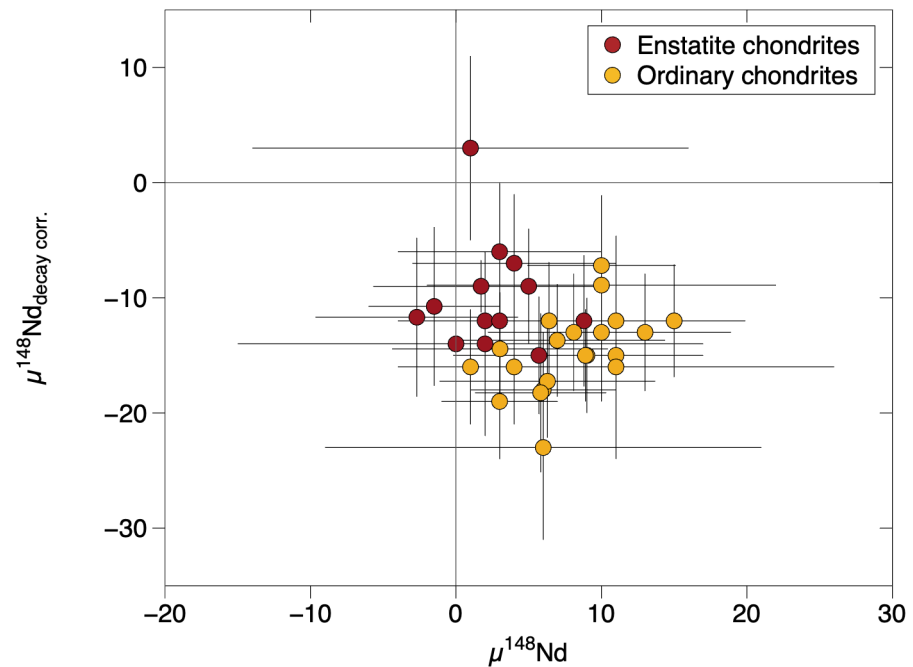
Radiogenic excesses in ^{142}Nd in differentiated bodies

Determining the theoretical composition of the Earth

$\mu^{142}\text{Nd}$ for $\mu^{148}\text{Nd} = 0$?

Several samples measured at high-precision for each chondrite group

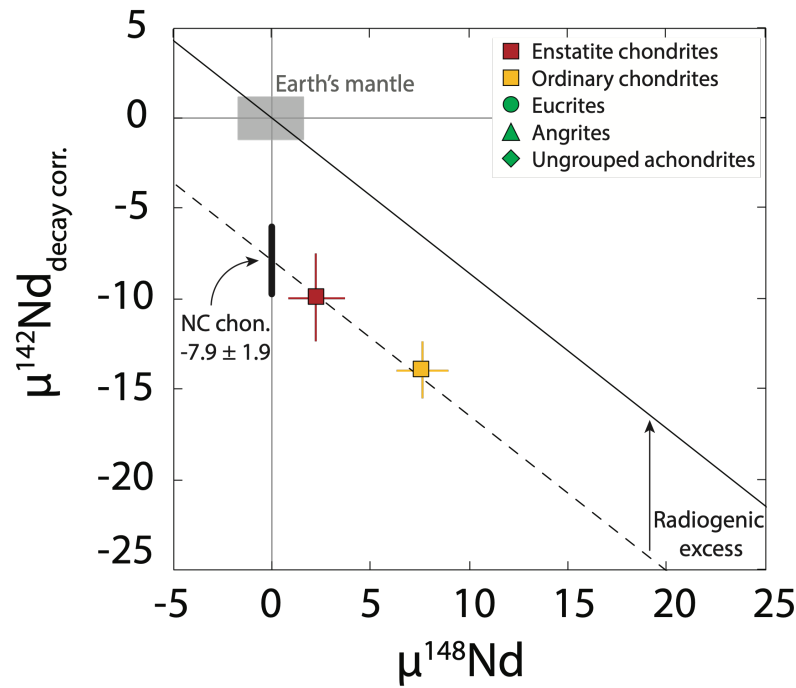
Statistics to constrain composition of chondrite groups!



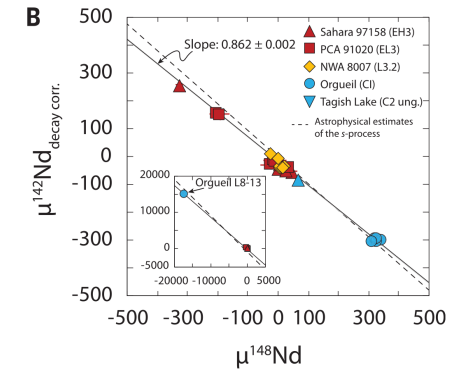
Data from: Burkhardt et al. (2016), Fukai and Yokoyama (2017, 2019), Saji et al. (2020), Render and Brennecka (2020), Frossard et al. (2021), Fang et al., (2022)

Radiogenic excesses in ^{142}Nd in differentiated bodies

② Nucleosynthetic and radiogenic



① Nucleosynthetic = source

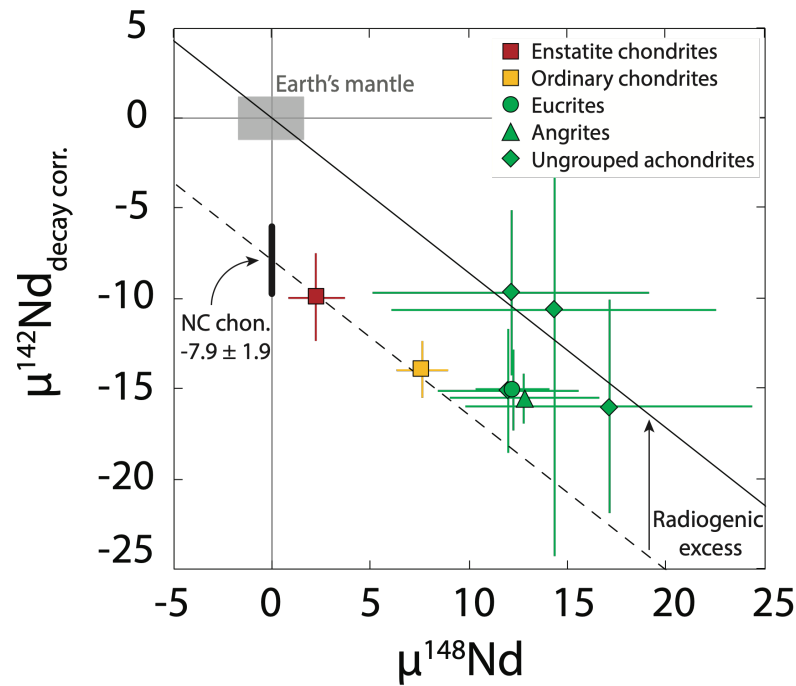


② Radiogenic excess in the Earth

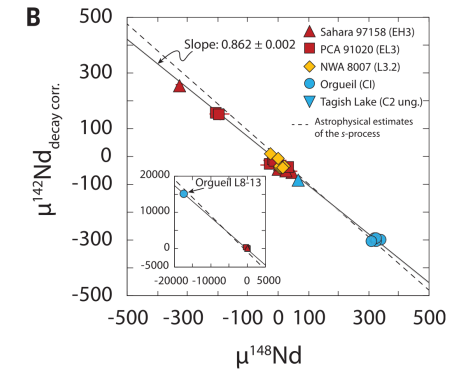
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Radiogenic excesses in ^{142}Nd in differentiated bodies

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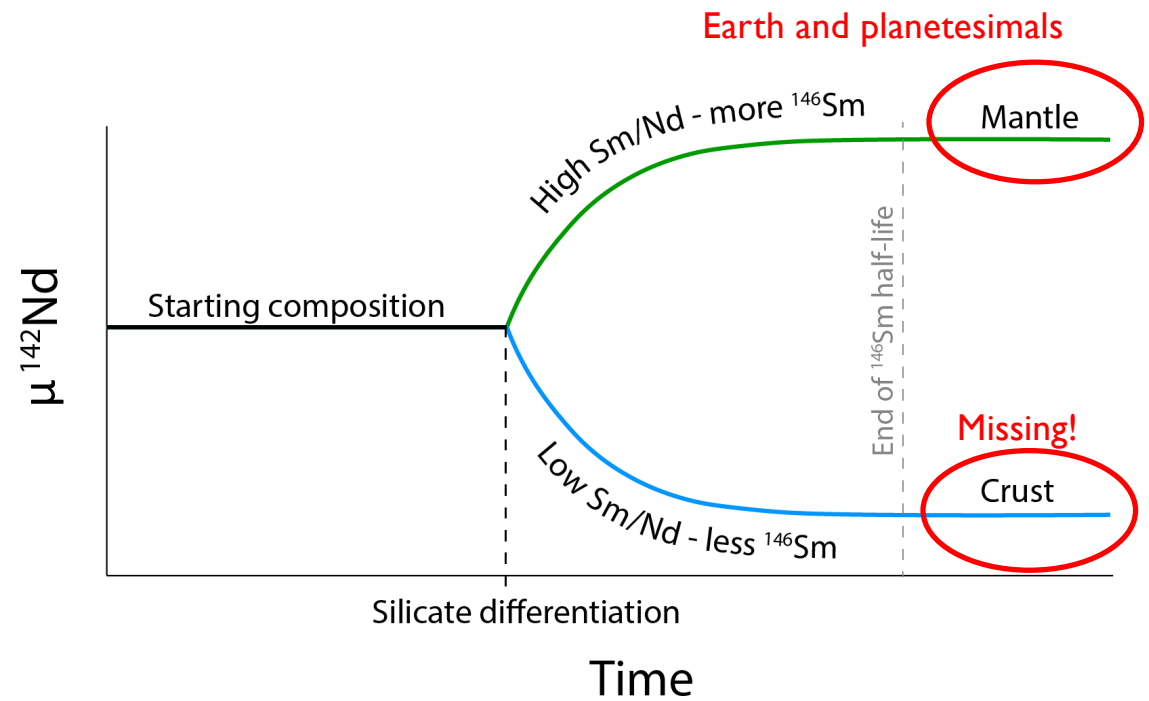
② Radiogenic excesses in the Earth and achondrites!

Data from: Burkhardt et al. (2016), Fukai and Yokoyama (2017, 2019), Saji et al. (2020), Render and Brennecka (2020), Frossard et al. (2021), Fang et al., (2022)

Radiogenic excesses in ^{142}Nd in differentiated bodies

The Earth and differentiated planetesimals display excesses in ^{142}Nd
→ Excesses of ^{146}Sm

Already experienced silicate differentiation in the first million years of the solar system!



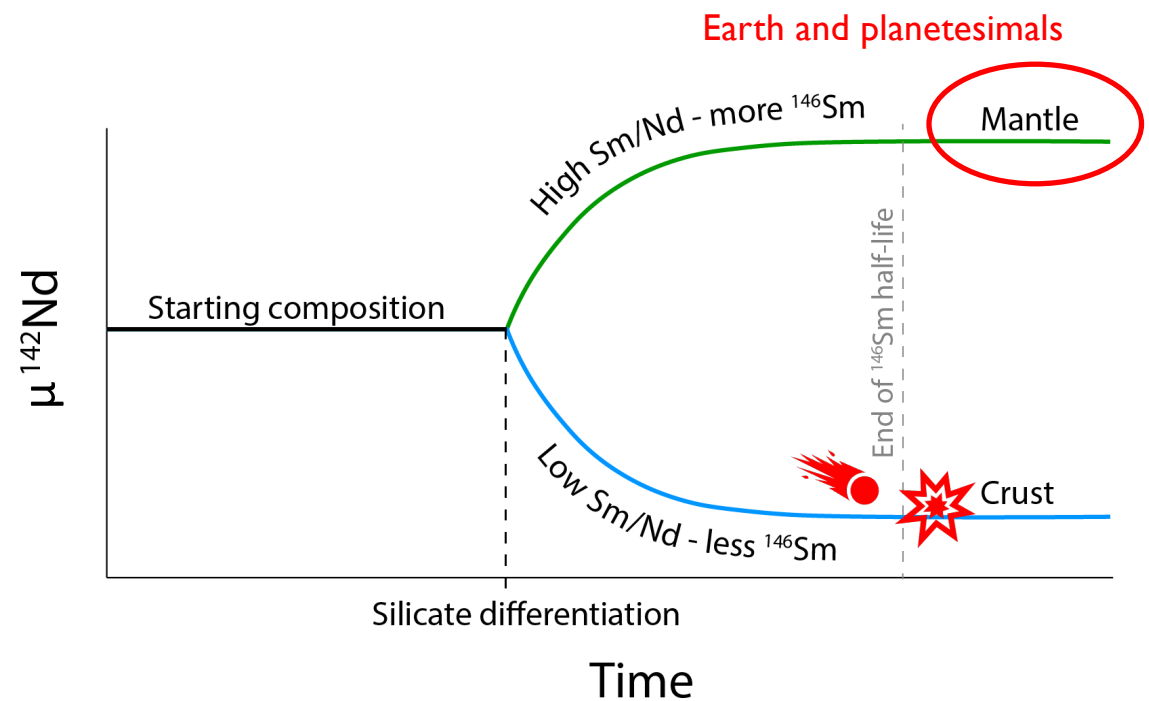
Where are the primordial crusts?

The Earth and differentiated planetesimals display excesses in ^{142}Nd
 → Excesses of ^{146}Sm



Already experienced silicate differentiation in the first million years of the solar system!

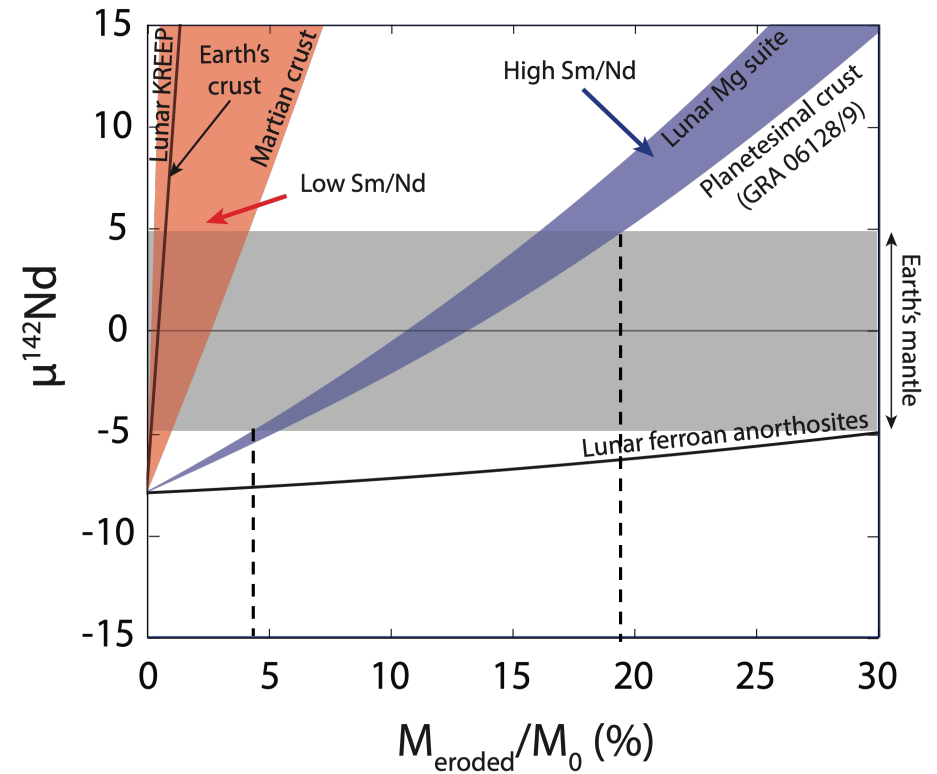
Several hypotheses:

- 🌐 Primordial crust is buried in the mantle
- 🌐 Planetesimals and Earth did not accrete from a chondritic composition
 See *Johnston et al. (2022) Nature*
- 🌐 **Primordial crust is lost during accretion**



Collisional erosion of primordial crusts

-  Most likely model considers a crust similar to basaltic rocks
 → 5 to 20 % lost
-  Results are consistent with numerical modelling of collisional erosion and planet formation theory (e.g. Bonsor et al., 2015, Icarus; Carter et al., 2018, EPSL; Allibert et al., 2021, Icarus)



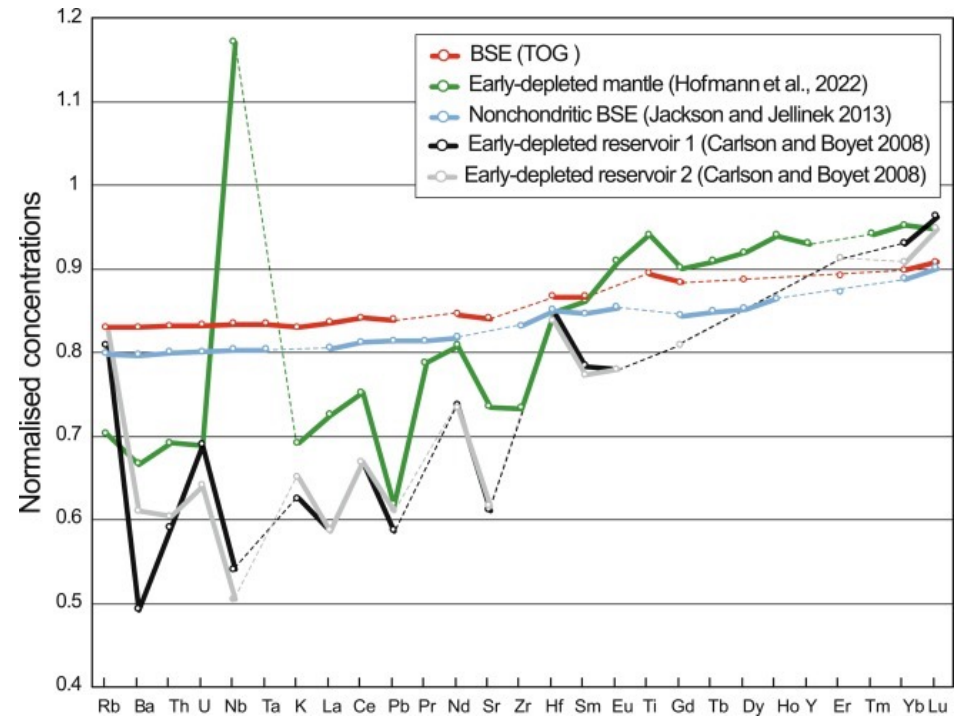
Composition of the bulk silicate Earth

Sm/Nd ratio is constrained by the ^{142}Nd results

Little information on the composition of primitive crusts of planetesimals

Boyet et al. (2025) ToG calculated the bulk silicate Earth to account for a Sm/Nd ratio of 0.2012:

Erosion of 17 % of a primitive crust produced by 5-10 % of partial melting



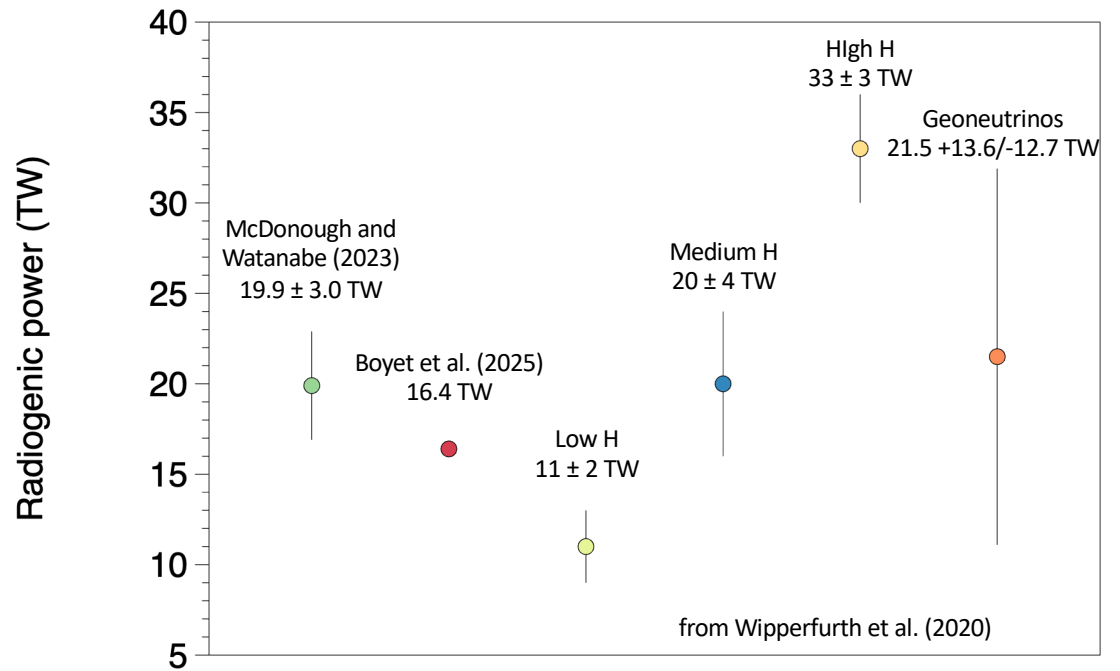
Boyet et al. (2025)

Radiogenic power of the bulk silicate Earth

Bulk silicate Earth model of Boyet et al. (2025) predicts 16.4 TW

Consistent within error with the geoneutrino estimates

Constraints from ^{142}Nd confirm the medium radiogenic heat flux scenario



Conclusions

- ① Sm–Nd systematic is a critical constraint on the composition of planetary bodies
- ② Earth and early planetesimals carry radiogenic excesses of ^{142}Nd
- ③ Collisional erosion is ubiquitous in the early Solar System and shaped the composition of planets
- ④ Radiogenic power of the bulk silicate Earth is lower than chondritic models
- ⑤ Combination of geoneutrino experiments with cosmochemical and geological observations is critical in constraining Earth's bulk composition