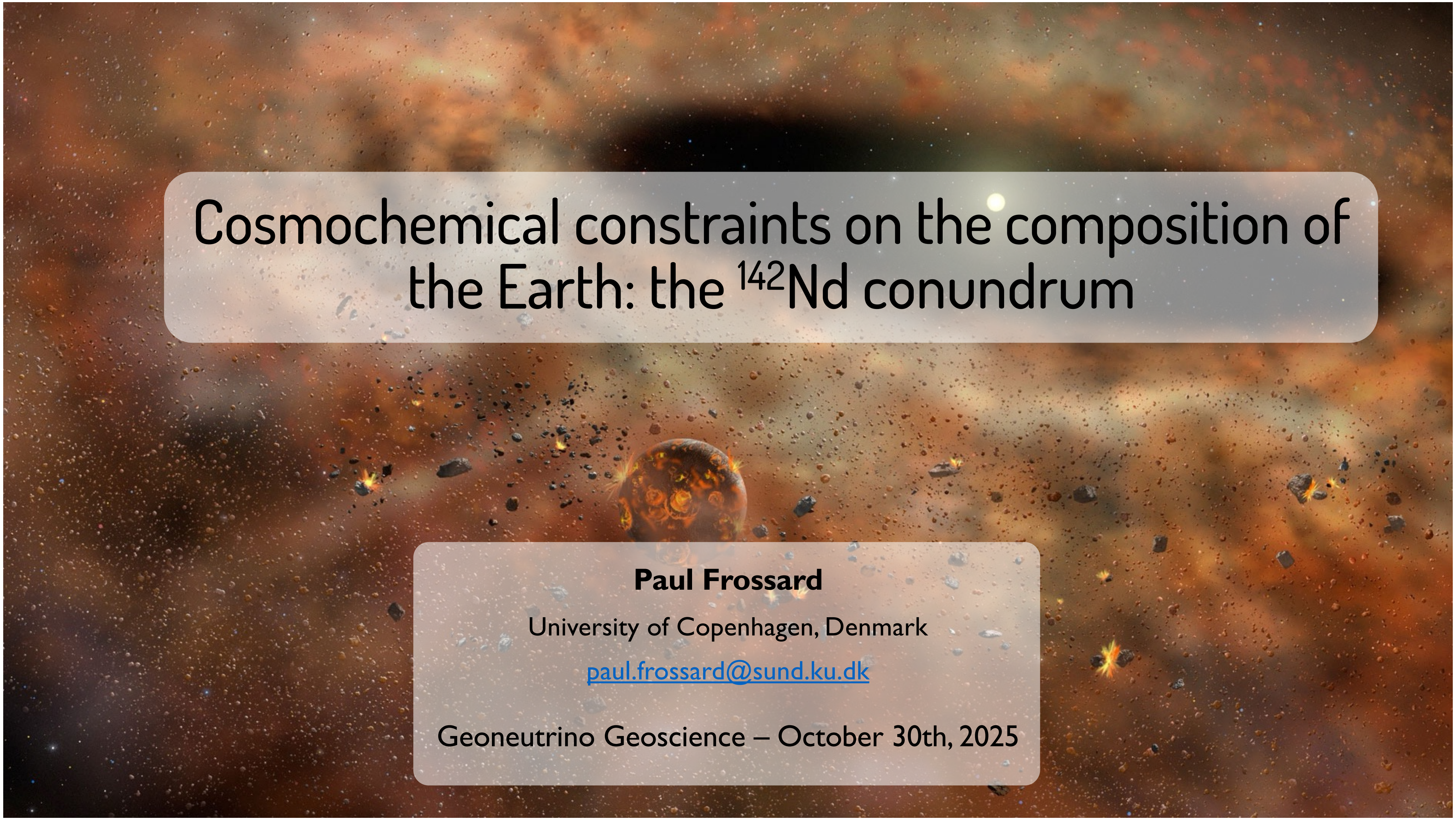

Cosmochemical constraints on the composition of the Earth: the ^{142}Nd conundrum

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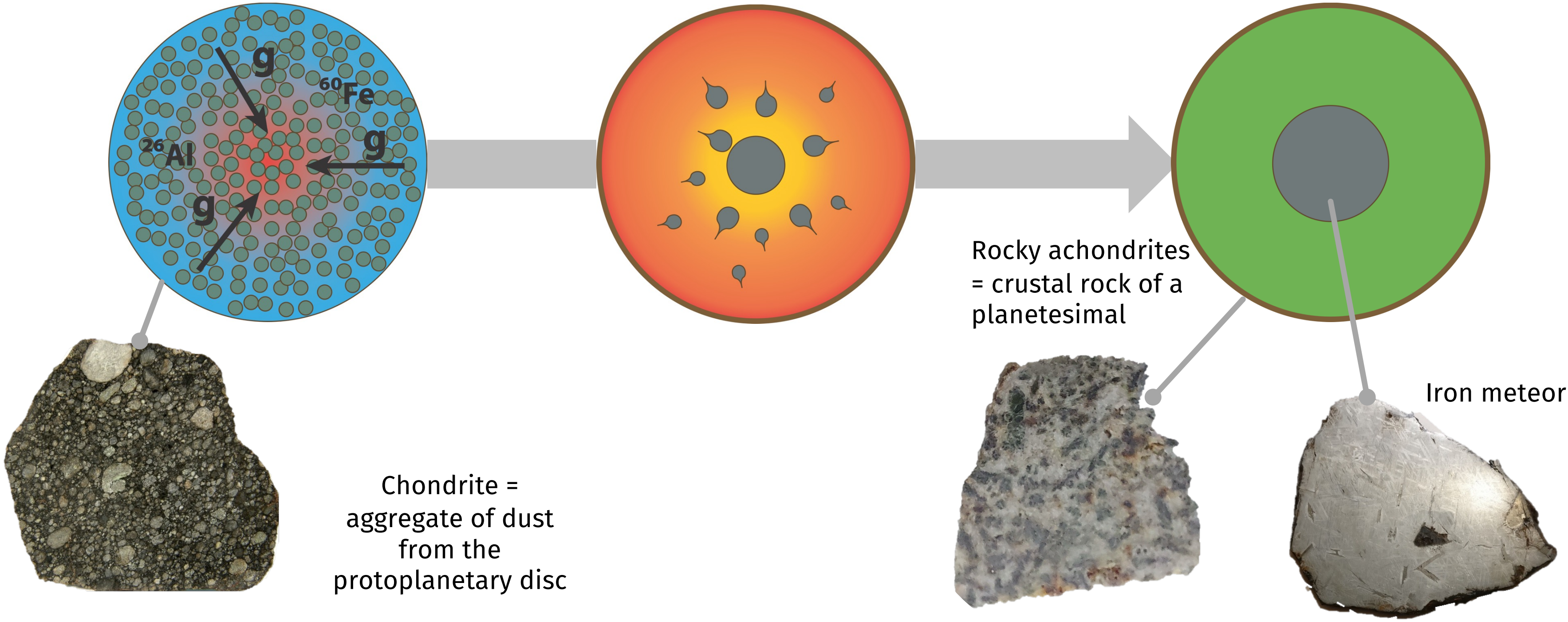
Meteorites: witnesses of early Solar System evolution

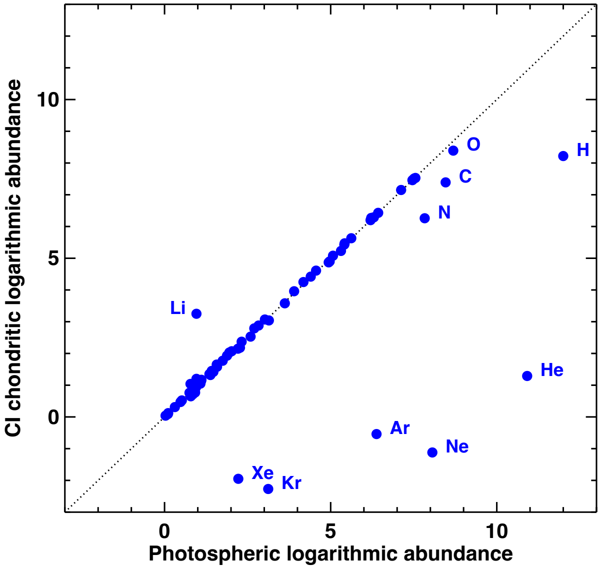


Chondrite =
aggregate of dust
from the
protoplanetary disc

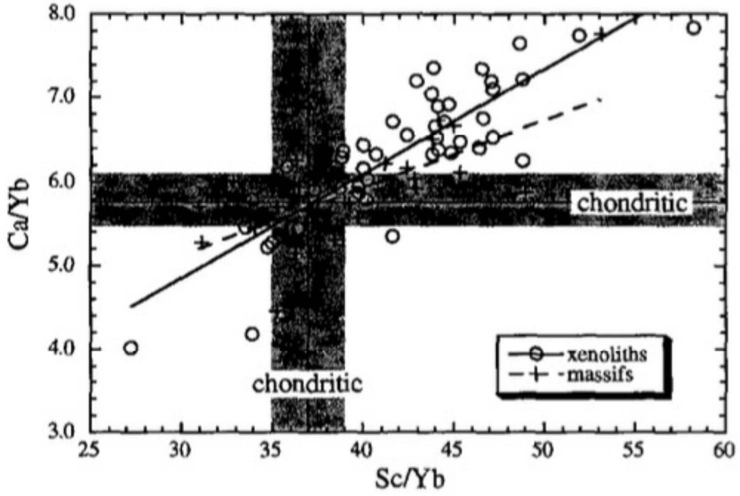
Rocky achondrites
= crustal rock of a
planetesimal

Iron meteorites

Primitive meteorites as building blocks of the Earth



Asplund et al. (2021)

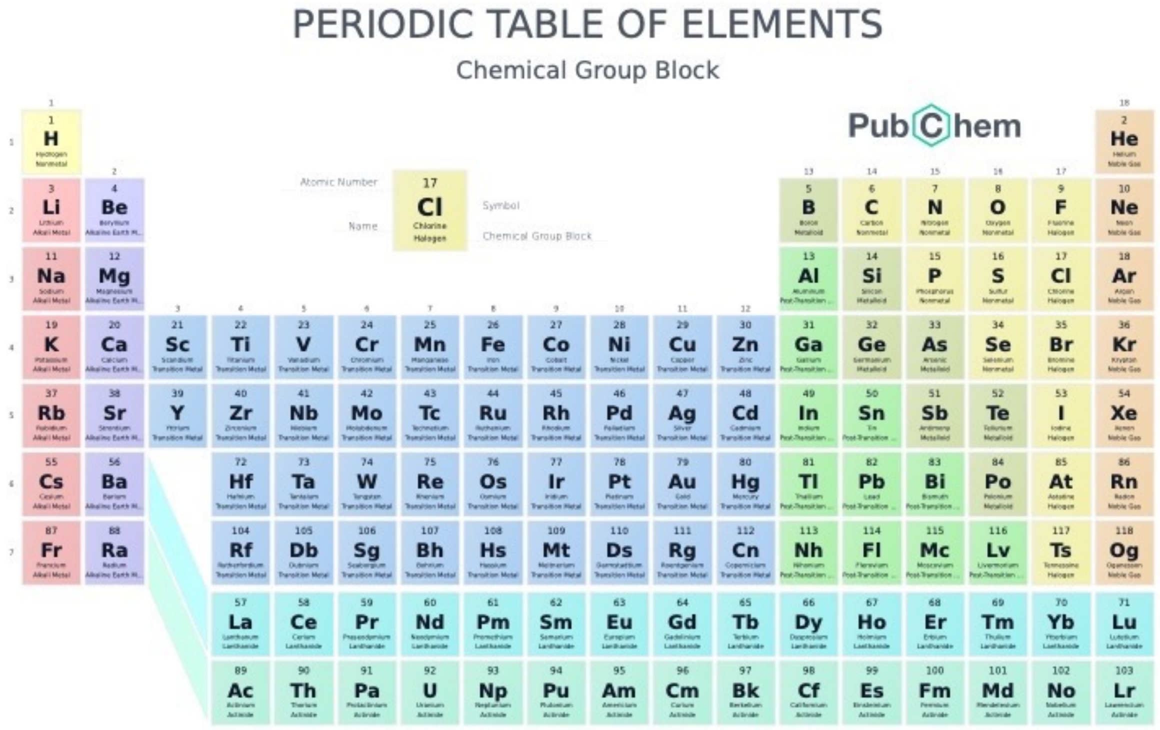


McDonough and Sun (1995)

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

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

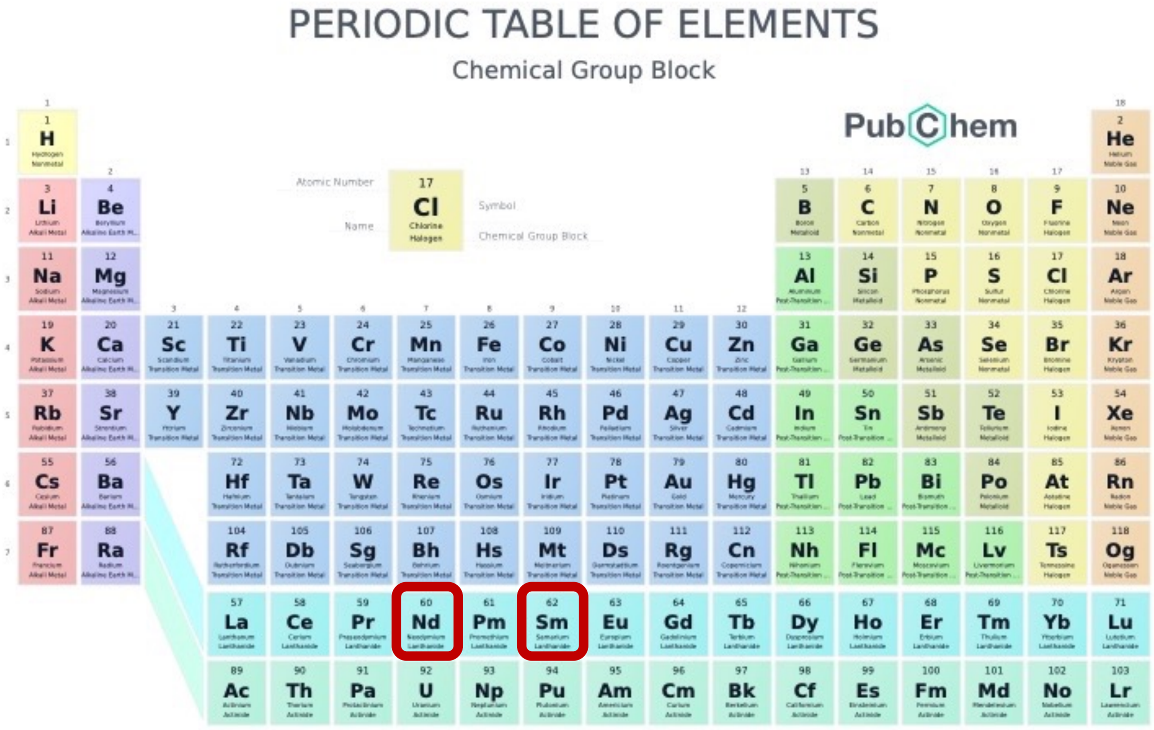
Chemical Group Block

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

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

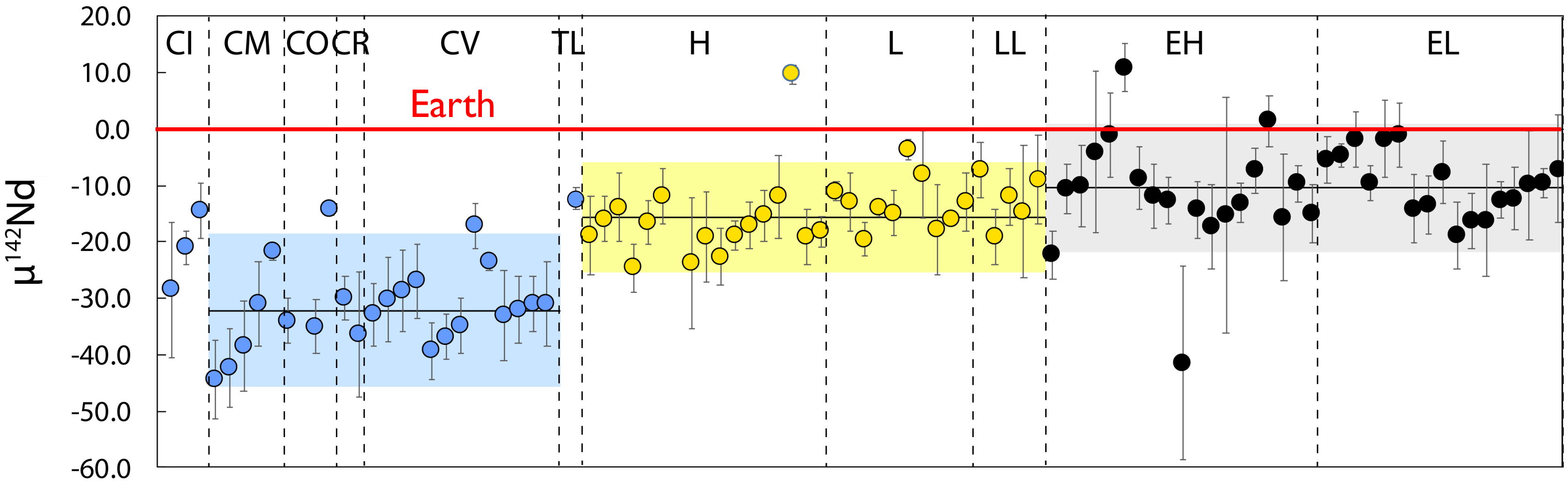
Introduction

Isotope cosmochemistry: forensics in the Solar System



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

The neodymium and samarium perspective



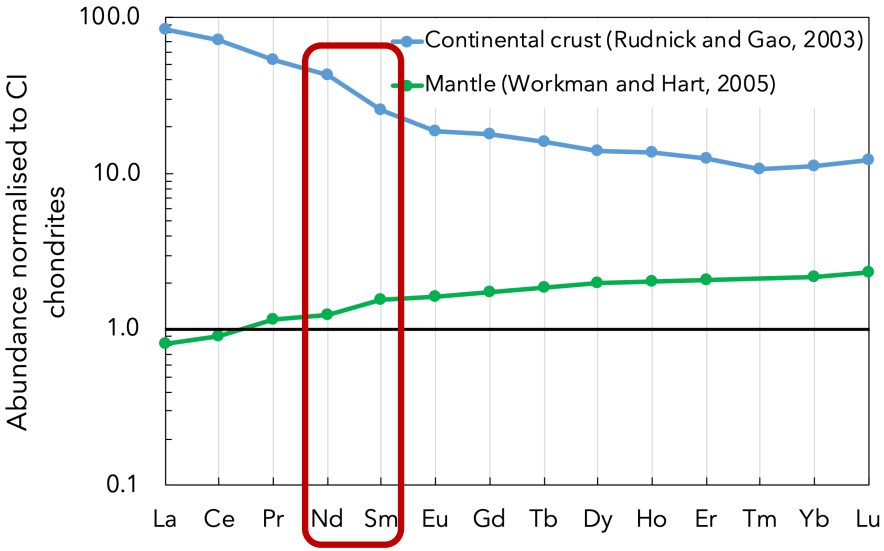
Earth displays an excess in ^{142}Nd compared to chondrites

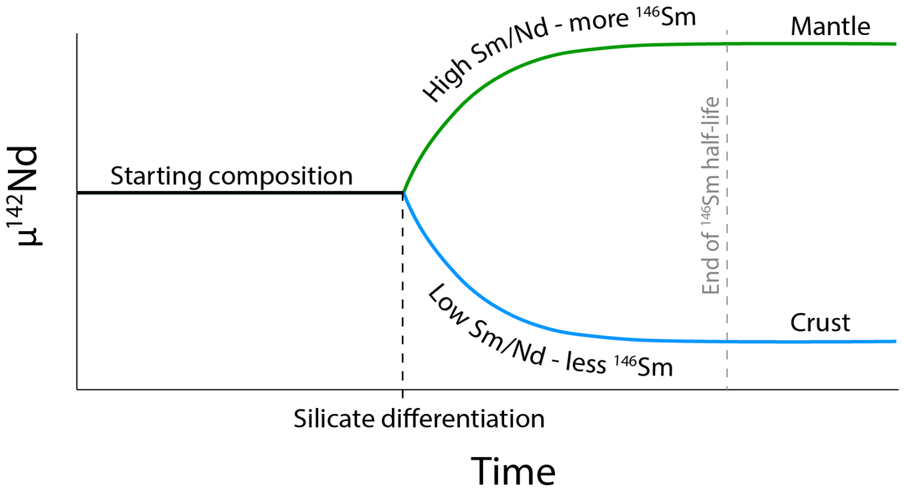
$$\mu\ {}^{i}Nd = \left(\frac{{}^{i}Nd/{}^{144}Nd_{sample}}{{}^{i}Nd/{}^{144}Nd_{standard}} - 1\right)\times 10^{6}$$

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 Ma)





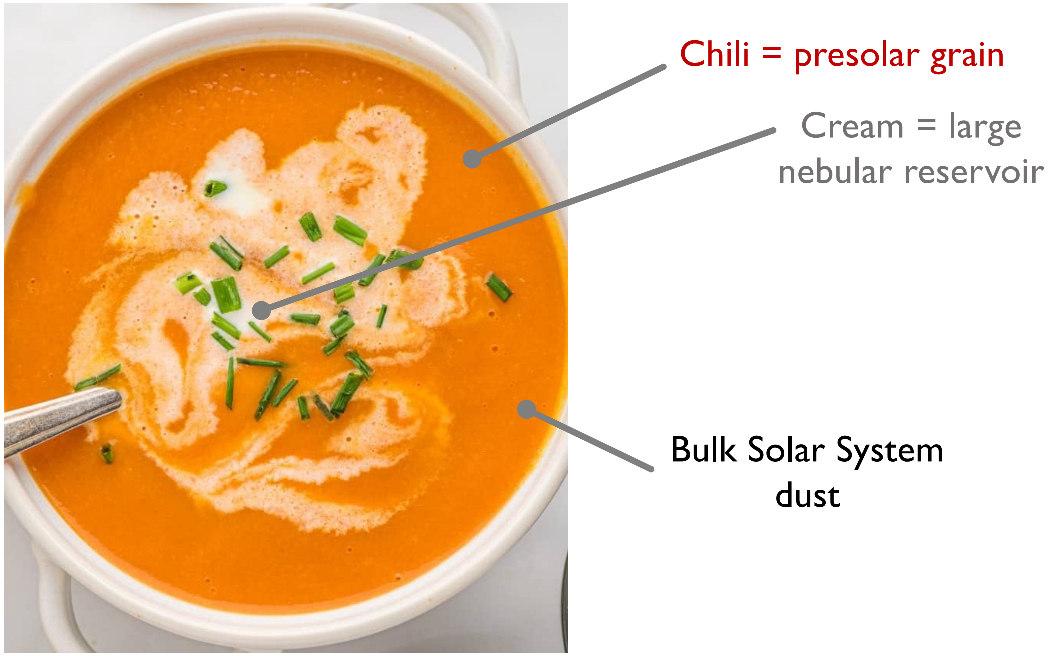
The **crust** is enriched in Nd relative to Sm compared to the **mantle** and leaves a **distinct ^{142}Nd signature**

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

② Nucleosynthetic heterogeneity?

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

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

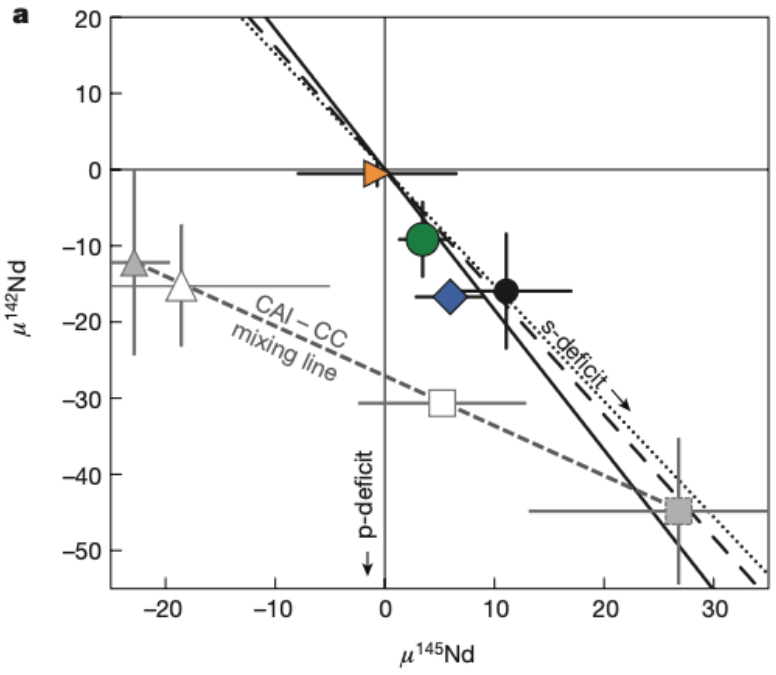


Origin of the ^{142}Nd excess in the Earth's mantle

② Nucleosynthetic heterogeneity?

Evidence for nucleosynthetic variations for μ^{142}Nd

Nucleosynthetic trends are not well characterised



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

② Nu

Evidence for

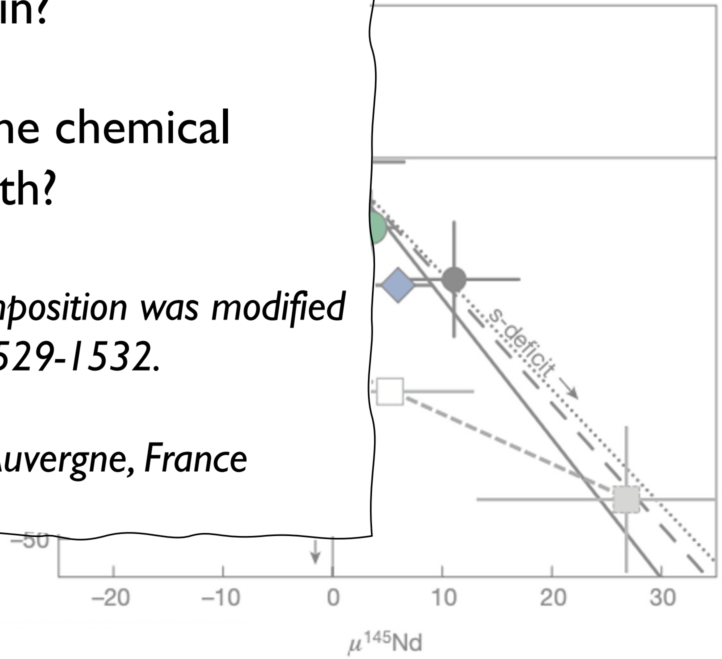
Nucleosynth

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



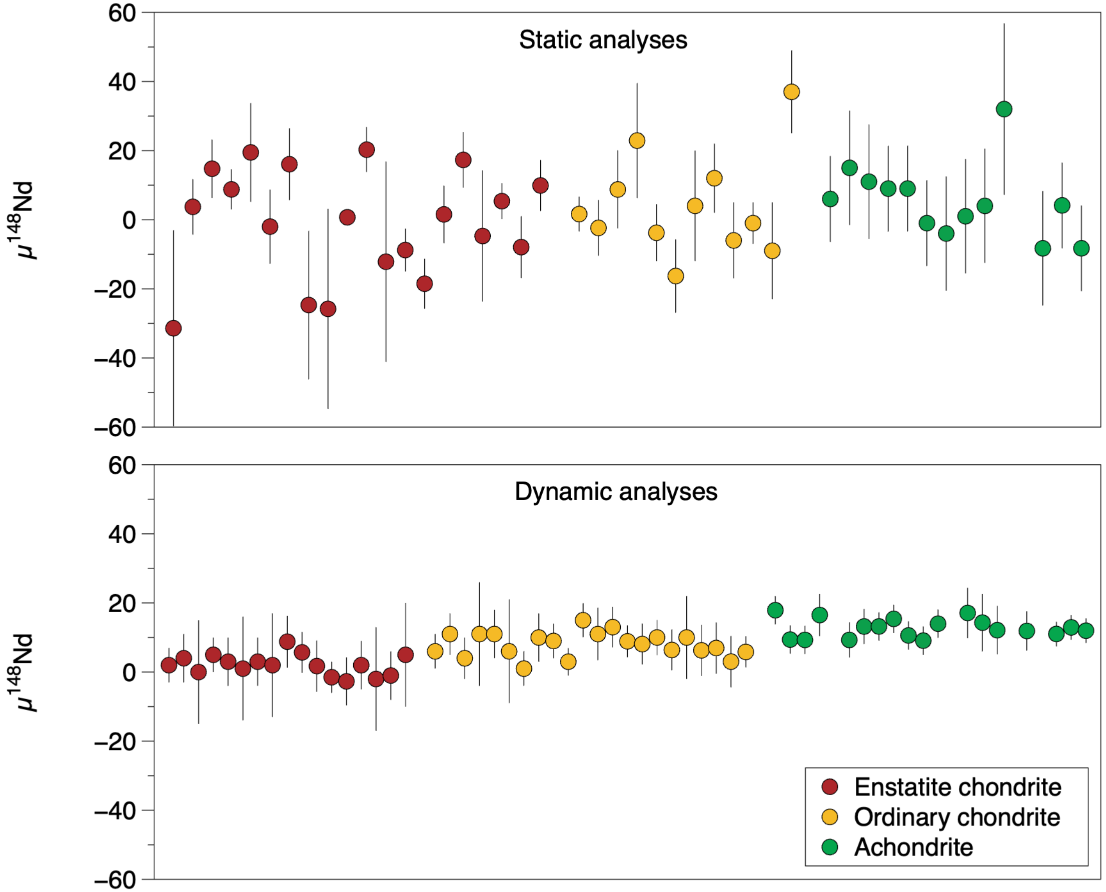
Methods

High-precision Nd isotope analysis

High-precision is required on **all** isotope ratios of Nd to constrain the origin of ^{142}Nd variations

New multidynamic method of analysis developed by Garçon et al. (2018) Chemical Geology

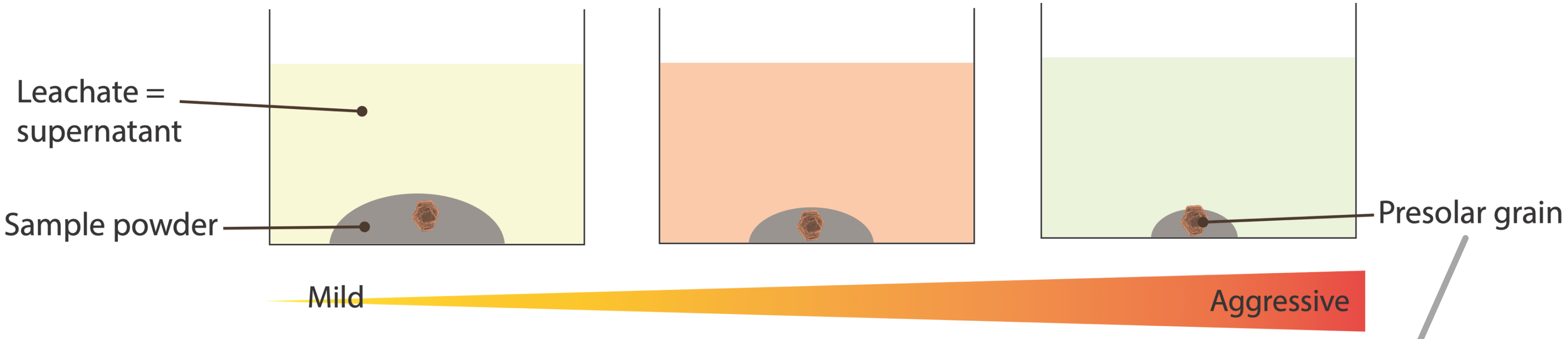
New data reveals variations not identifiable with older methods of analysis

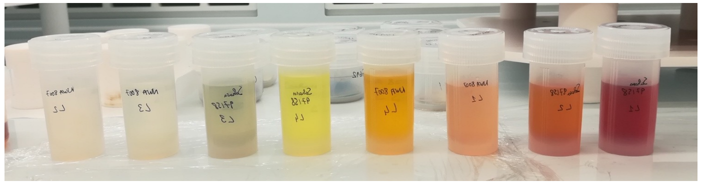


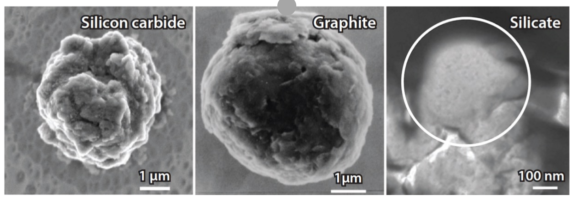
Methods

Chemical separation of meteorite components

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







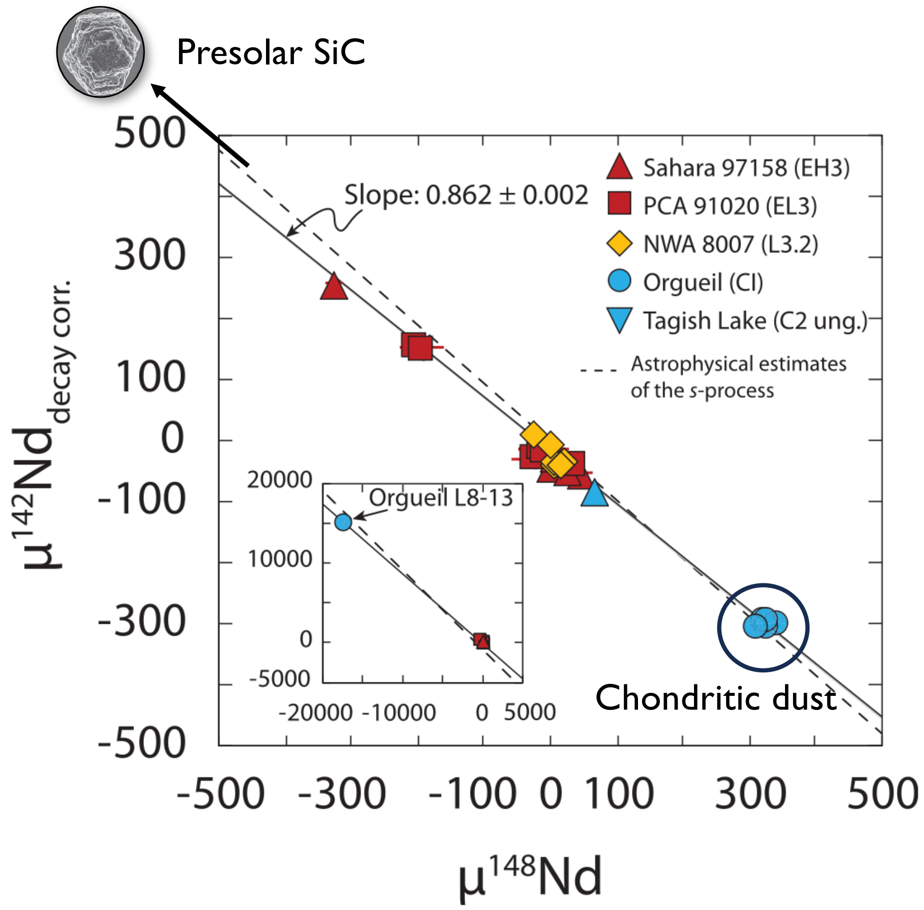
Nittler et al. (2016) Annual Rev. Astron. Astrophys.

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



Results

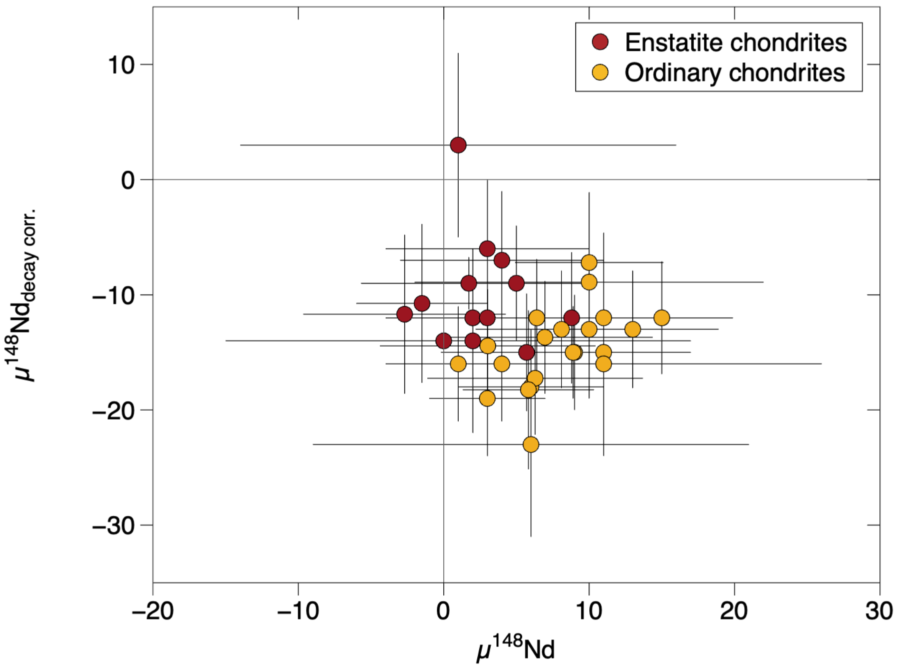
Radiogenic excesses in ^{142}Nd in differentiated bodies

Determining the theoretical composition of the Earth

μ^{142}Nd for μ^{148}Nd = 0 ?

Several samples measured at high-precision for each chondrite group

Statistics to constrain composition of chondrite groups!

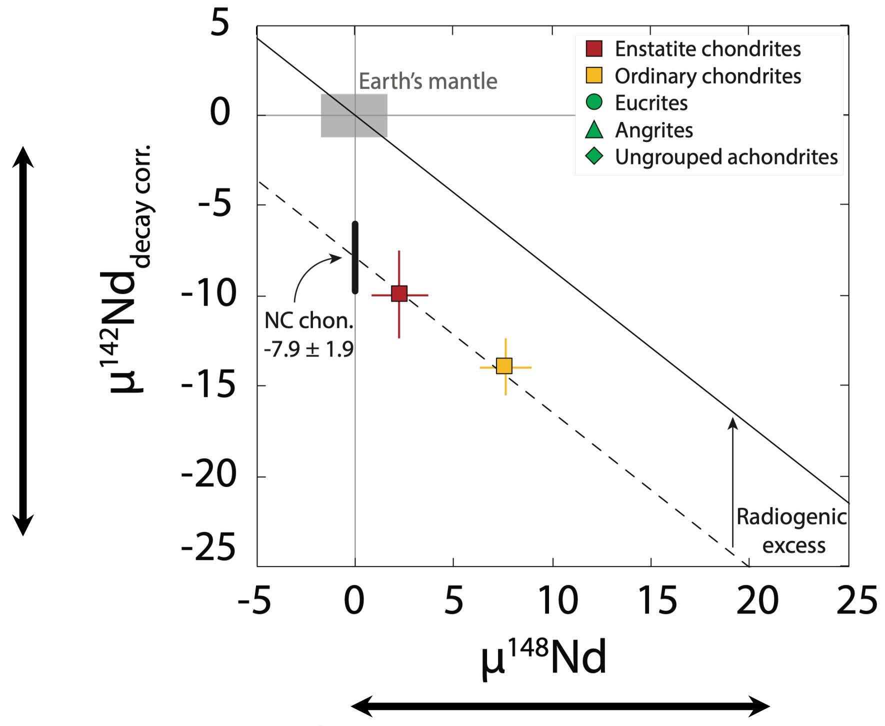


Data from: Burkhardt et al. (2016), Fukai and Yokoyama (2017, 2019), Saji et al. (2020), Render and Brennecka (2020), Frossard et al. (2021), Fang et al., (2022)

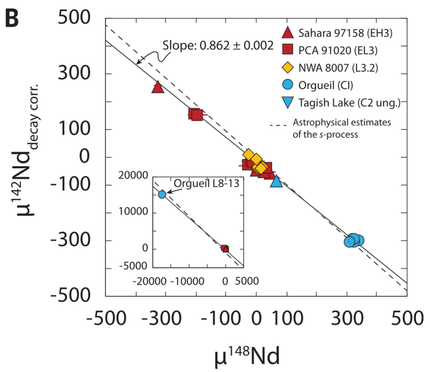
Origin of ^{142}Nd signatures

Radiogenic excesses in ^{142}Nd in differentiated bodies

② Nucleosynthetic and radiogenic



① Nucleosynthetic = source



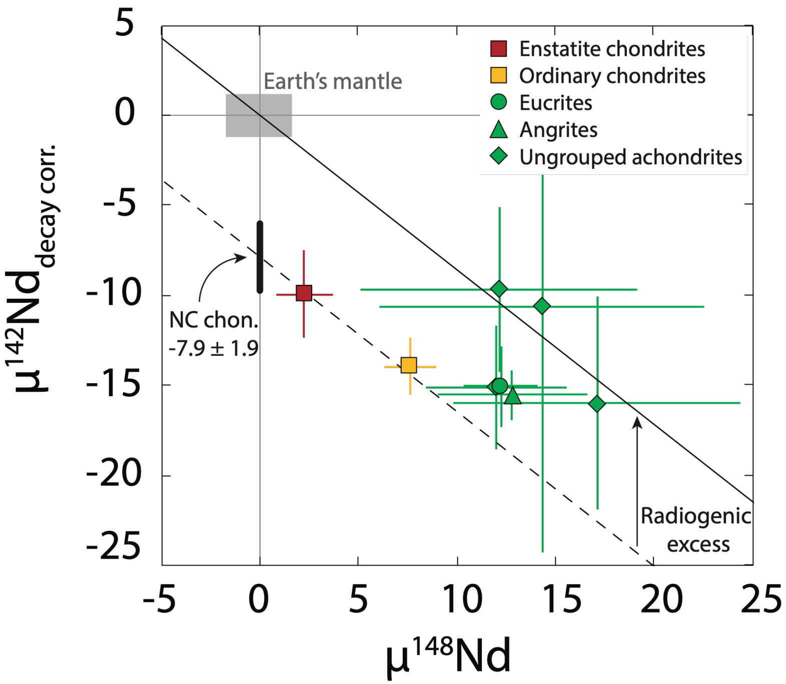
② Radiogenic excess in the Earth

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)

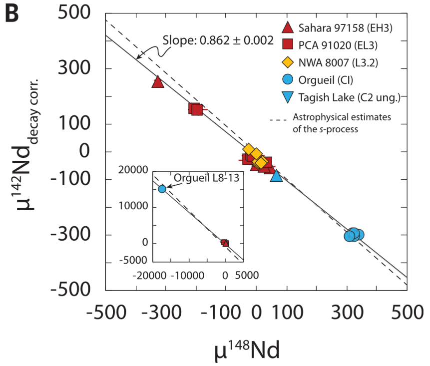
Origin of ^{142}Nd signatures

Radiogenic excesses in ^{142}Nd in differentiated bodies

② Nucleosynthetic and radiogenic



① Nucleosynthetic = source



② Radiogenic excesses in the Earth **and achondrites!**

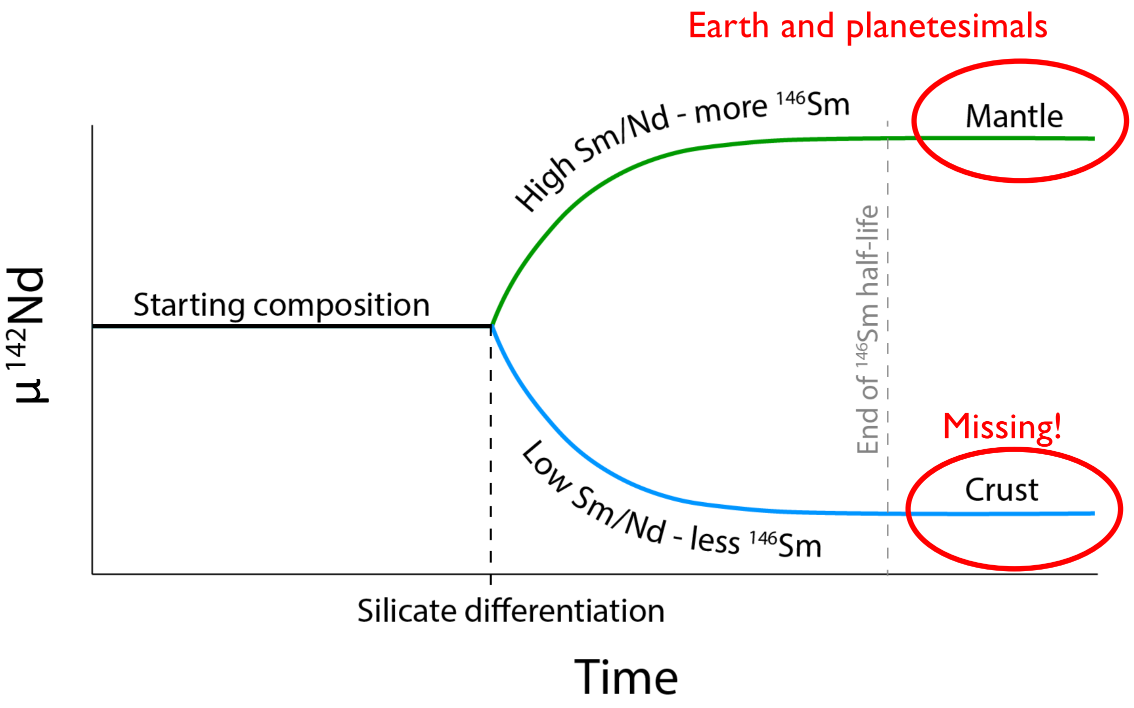
Data from: Burkhardt et al. (2016), Fukai and Yokoyama (2017, 2019), Saji et al. (2020), Render and Brennecka (2020), Frossard et al. (2021), Fang et al., (2022)

Collisional erosion model

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!



Collisional erosion model

Where are the primordial crusts?

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

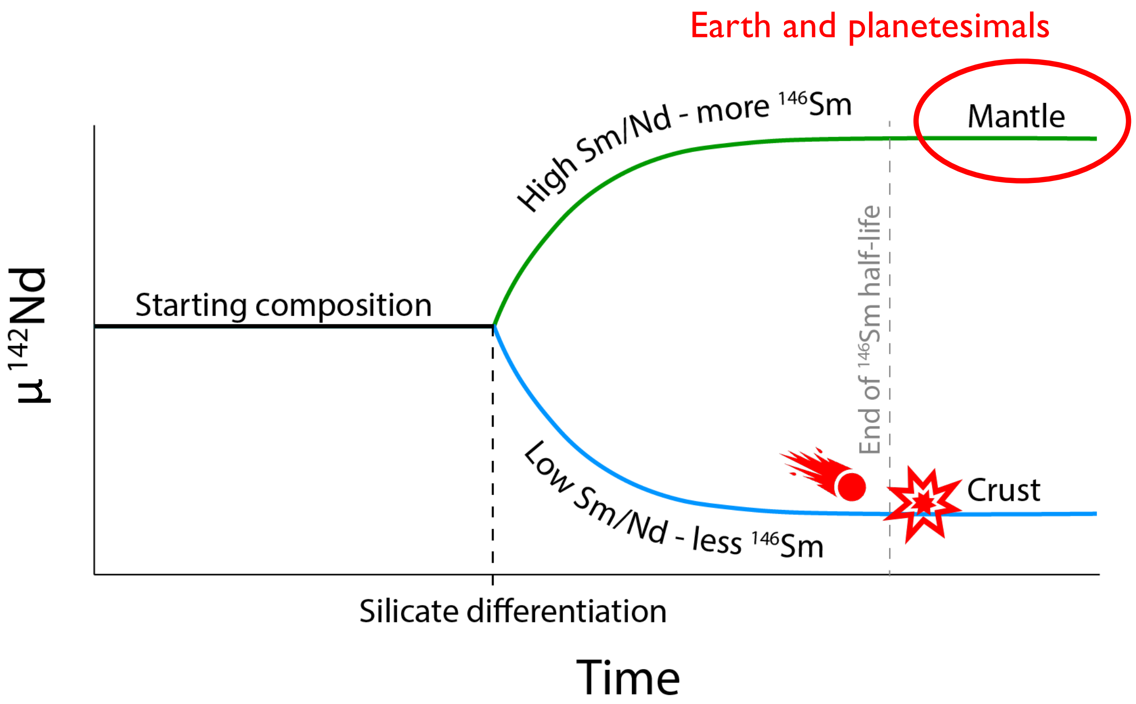
Already experienced silicate differentiation in the first million years of the solar system!

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**

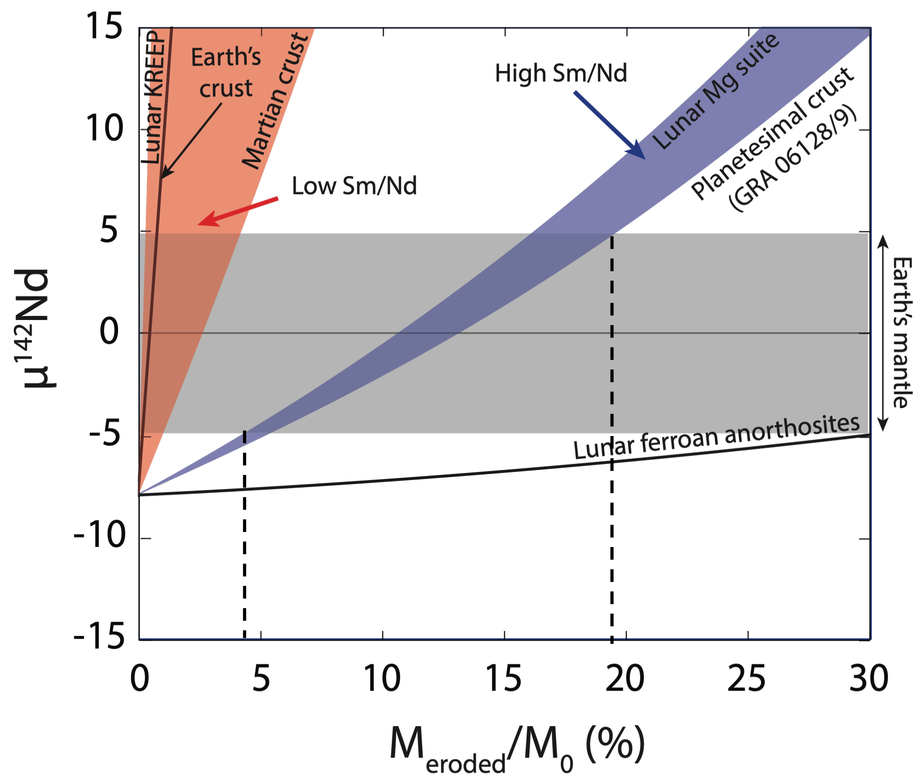


Collisional erosion model

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)



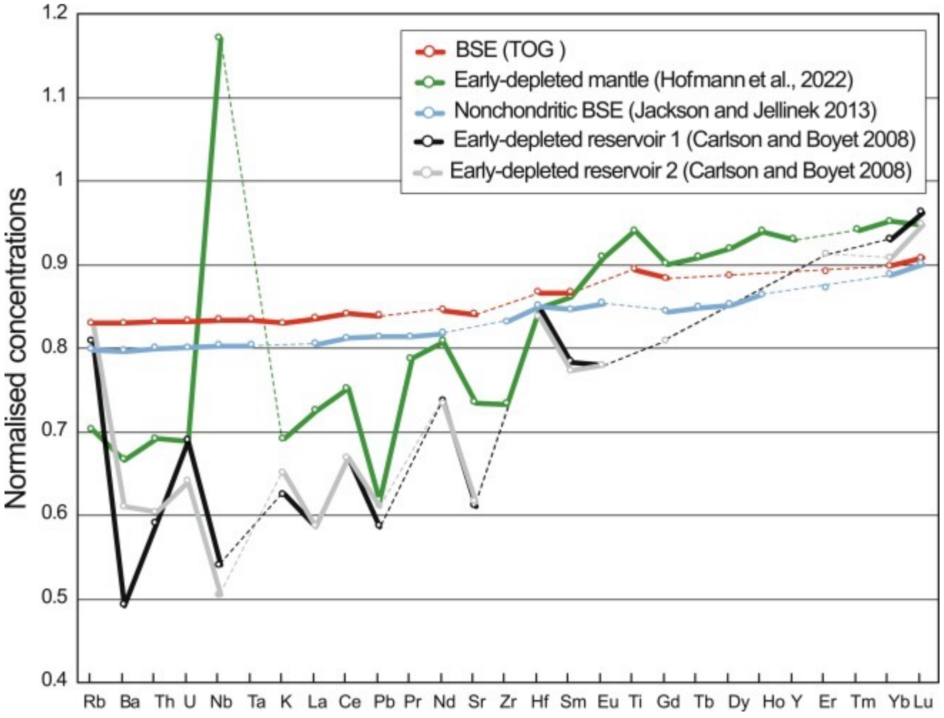
Composition of the bulk silicate Earth

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



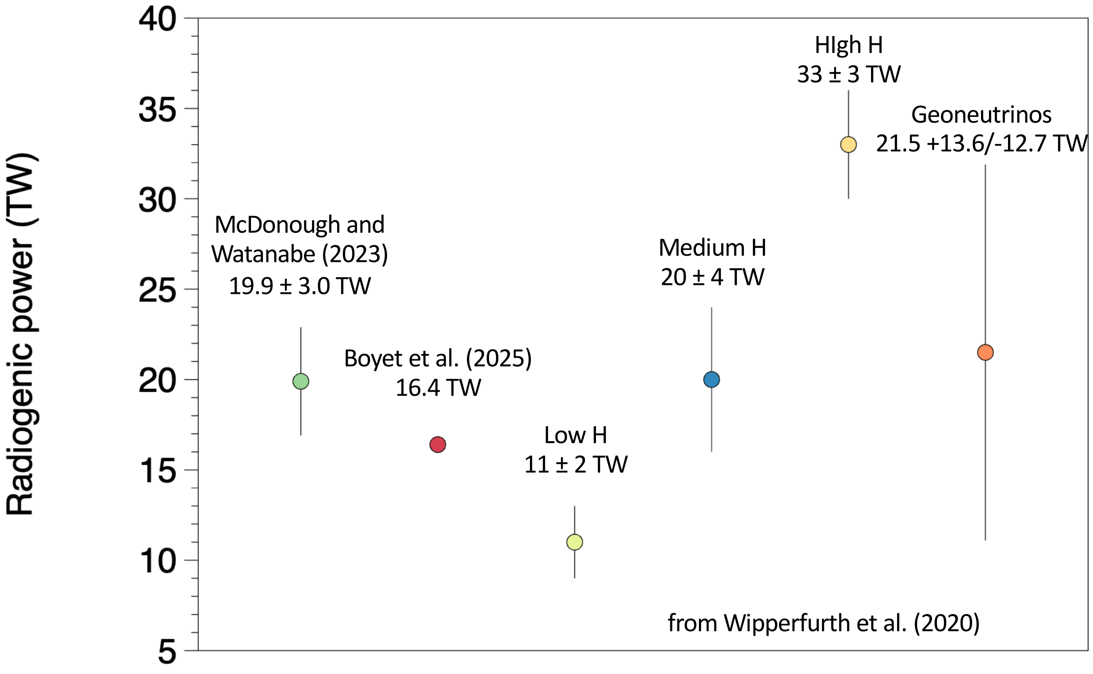
Boyet et al. (2025)

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



from Wipperfurth et al. (2020)

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