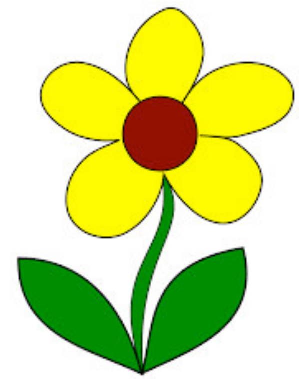
Radioactivity and Habitability



Maria Lugaro

Research Centre for Astronomy and Earth Sciences (CSFK), Hungarian Academy of Sciences (MTA), Budapest, Hungary

Monash Centre for Astrophysics (MoCA)

Monash University, Victoria, Australia

Ákos Kereszturi

Research Centre for Astronomy and Earth Sciences (CSFK), Hungarian Academy of Sciences (MTA), Budapest, Hungary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DANGER
RADIATION HAZARD

Many radioactive nuclei are of astrophysical interest, e.g.:

^{232}Th	^{238}U	^{146}Sm	^{182}Hf	^{60}Fe	^{26}Al
14 Gyr	4.5 Gyr	103 Myr	8.9 Myr	2.6 Myr	0.7 Myr

← half life ($T_{1/2}$)

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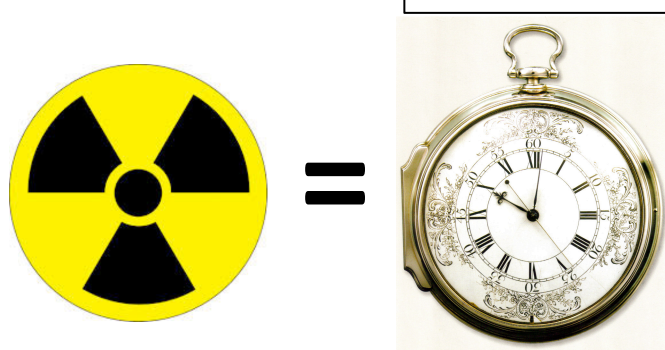
^{182}Hf → Allows us to date core-mantle differentiation



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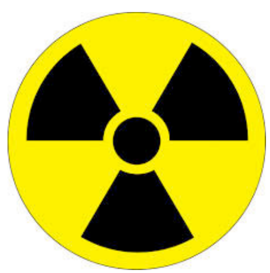 = 

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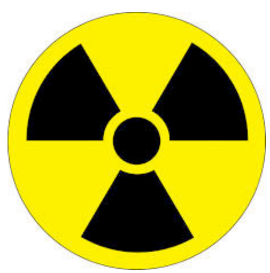

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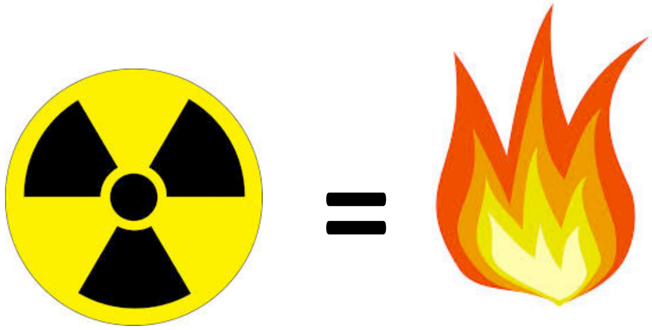
Because their decay can generate heat



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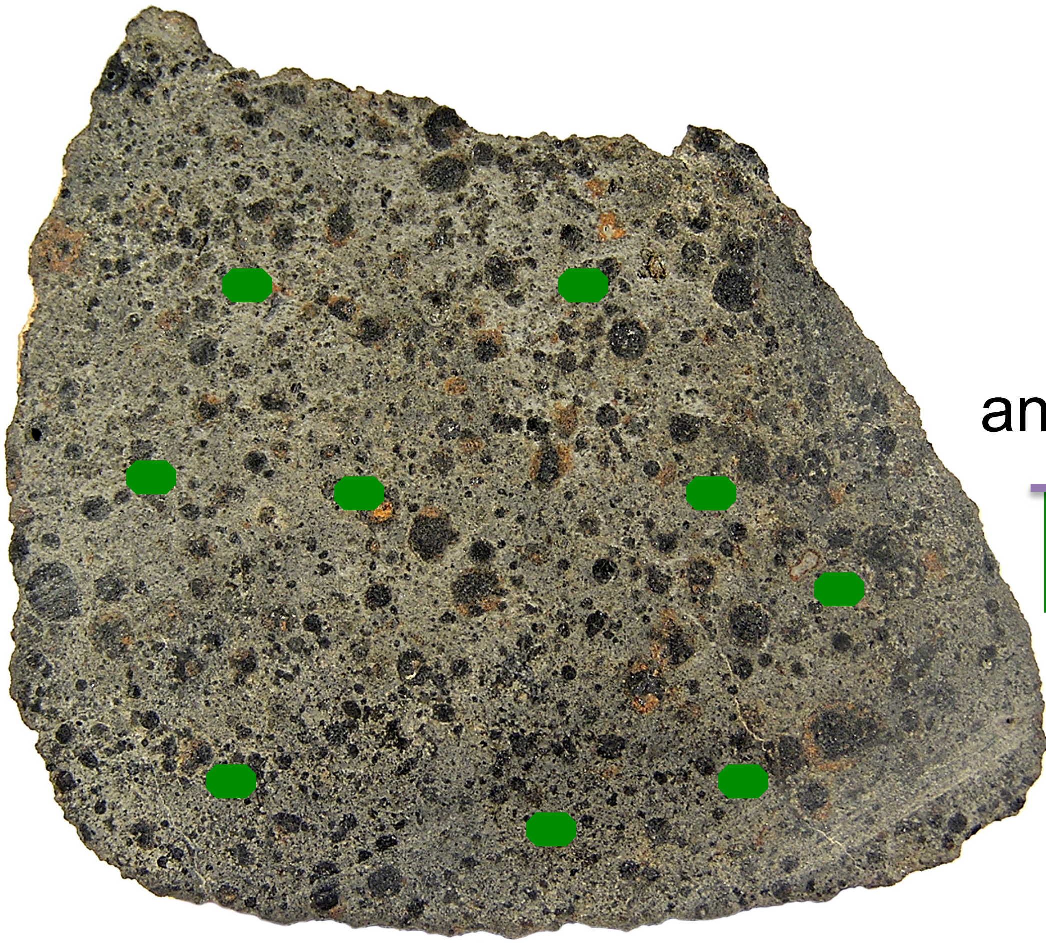

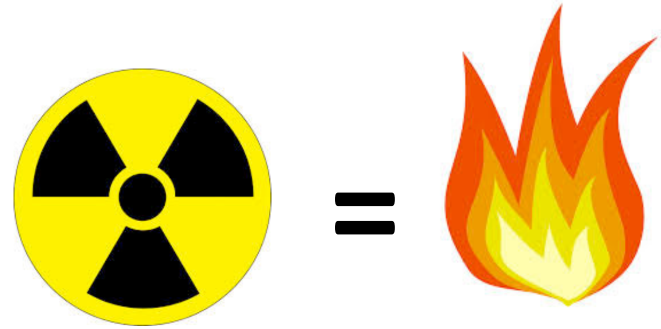

angular momentum

$J = 5$

^{26}Al

0.7 Myr

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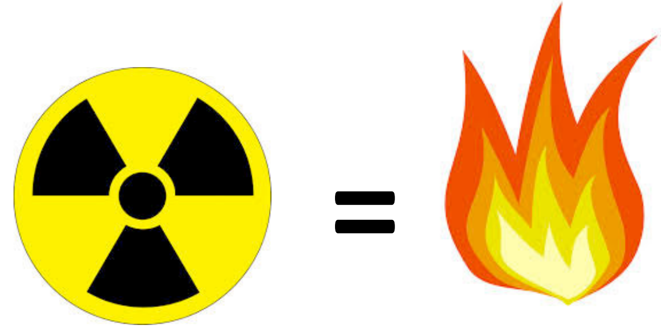

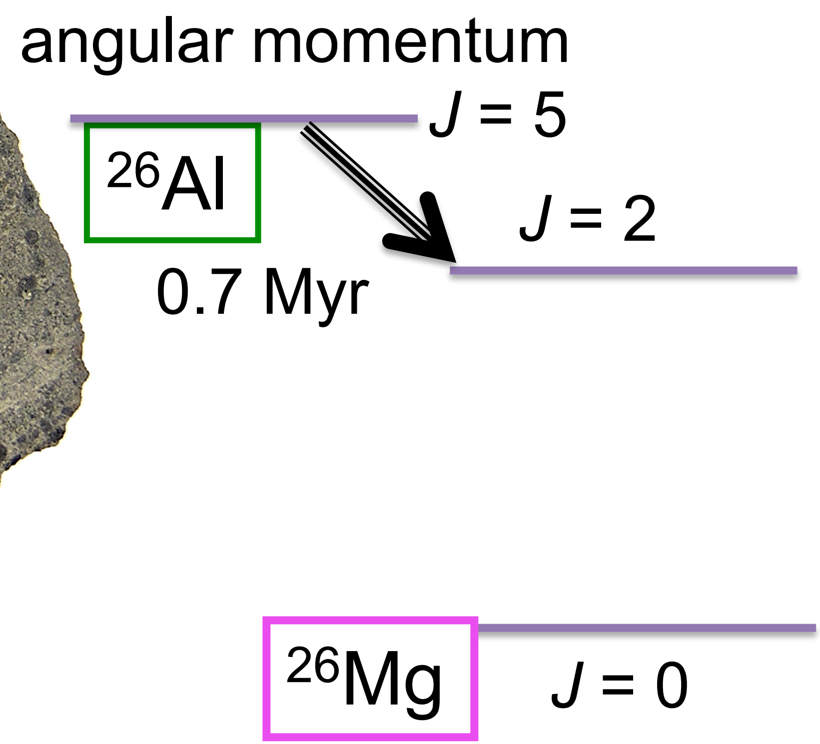

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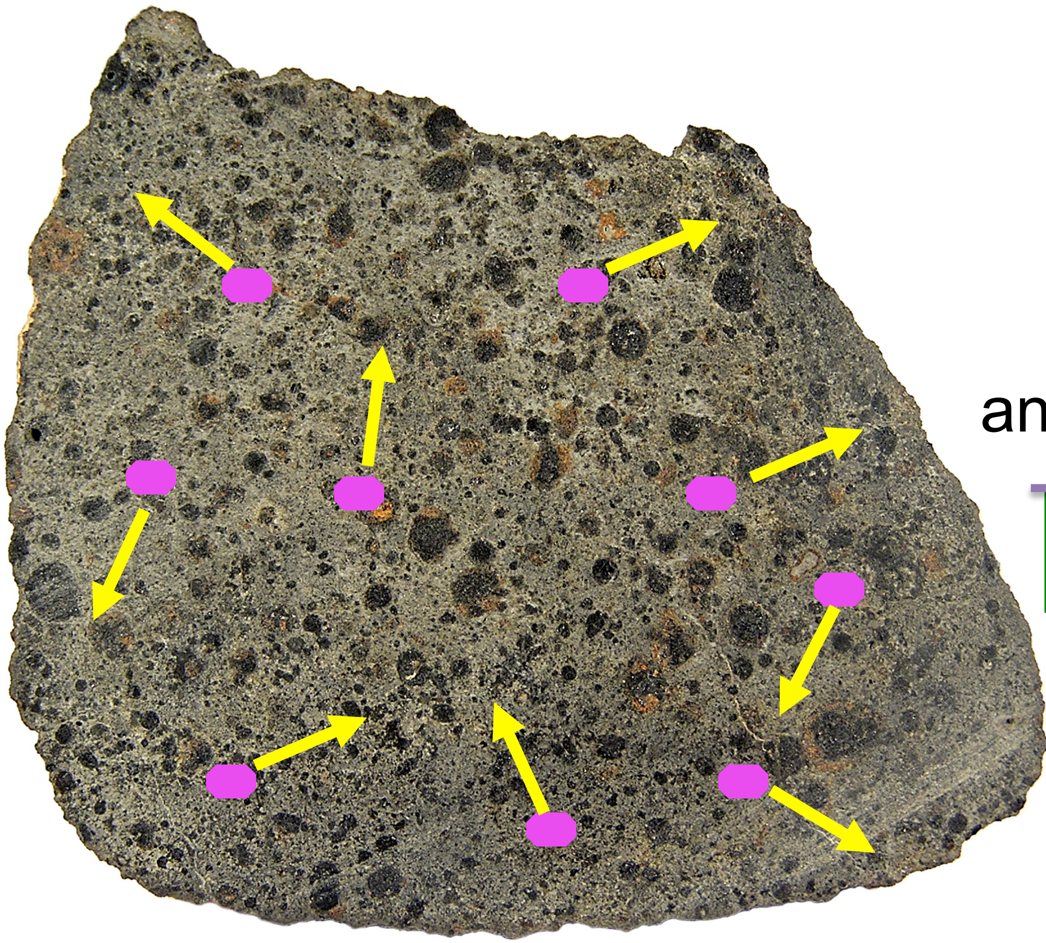

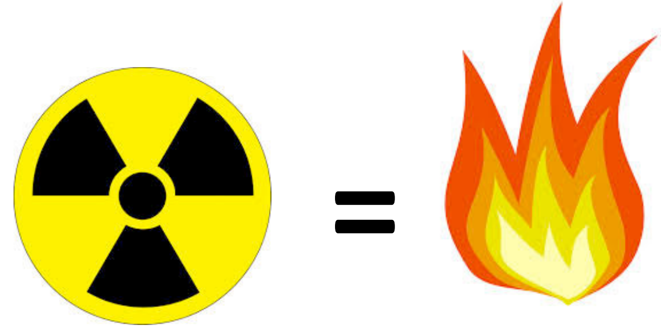

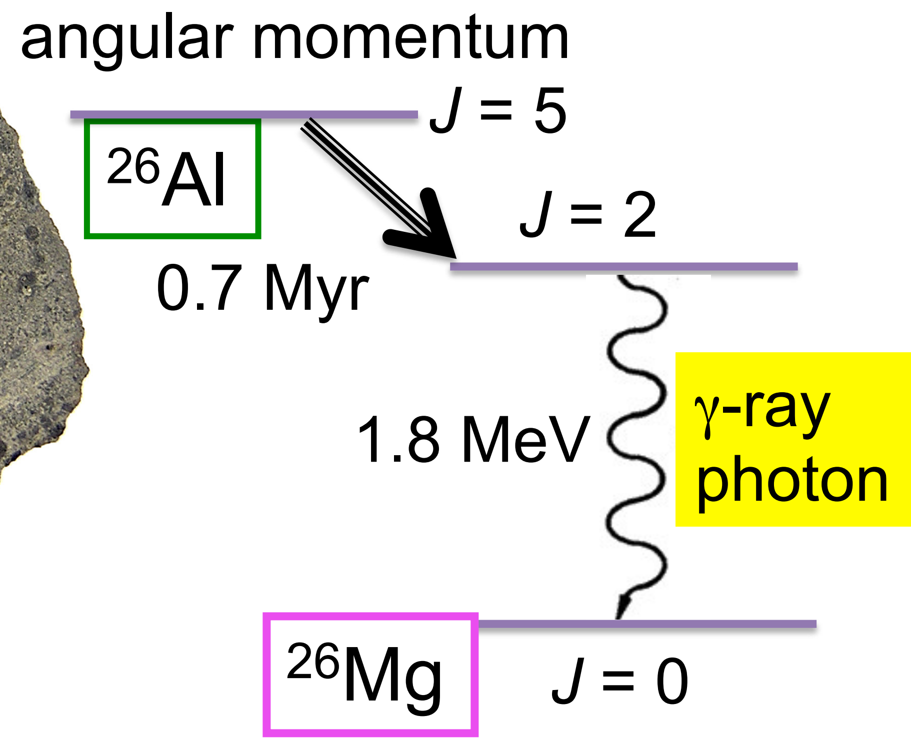

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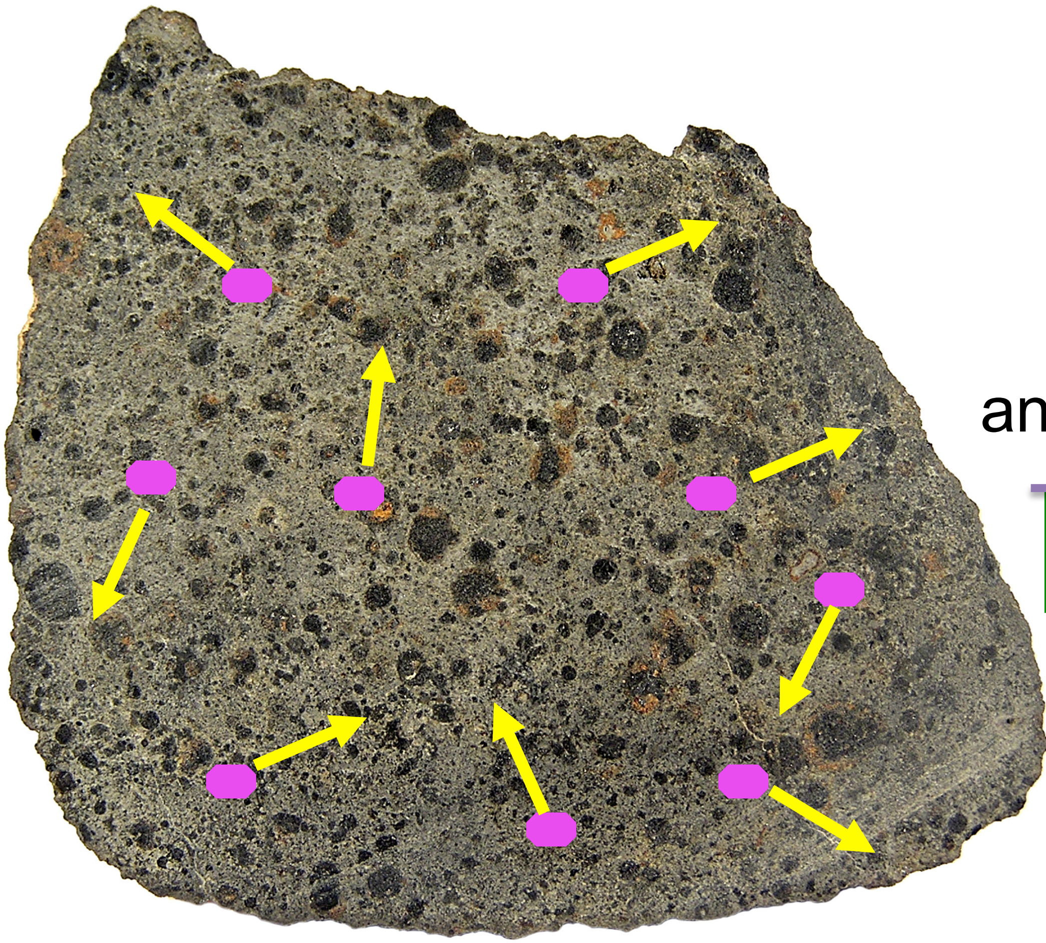
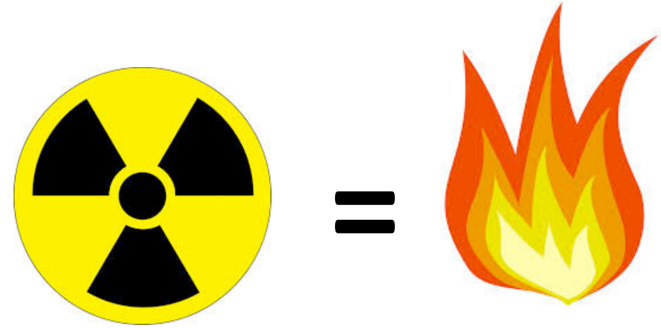
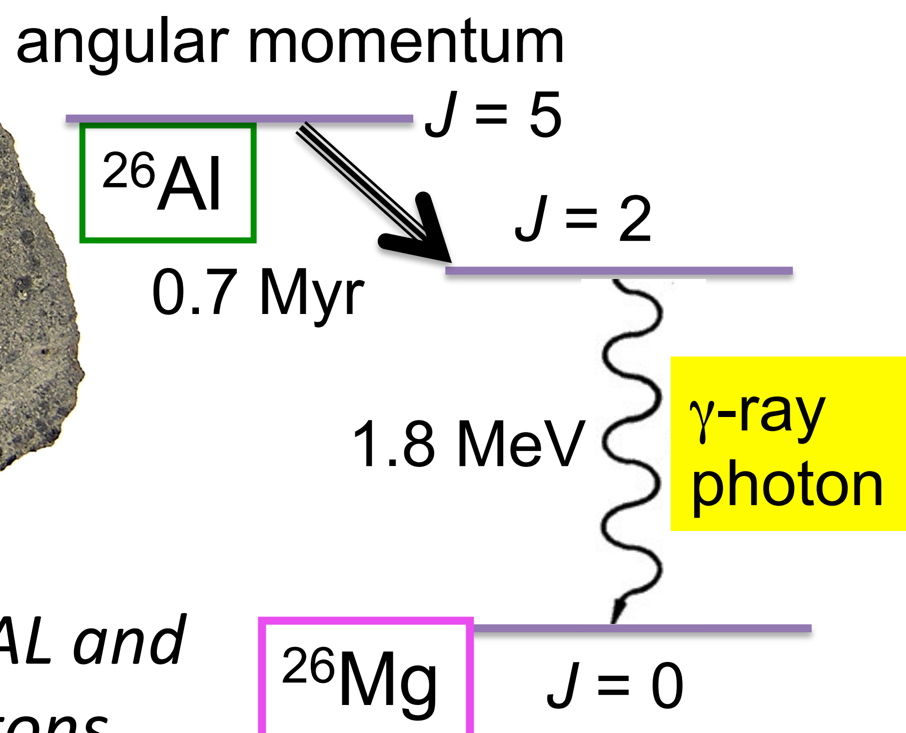




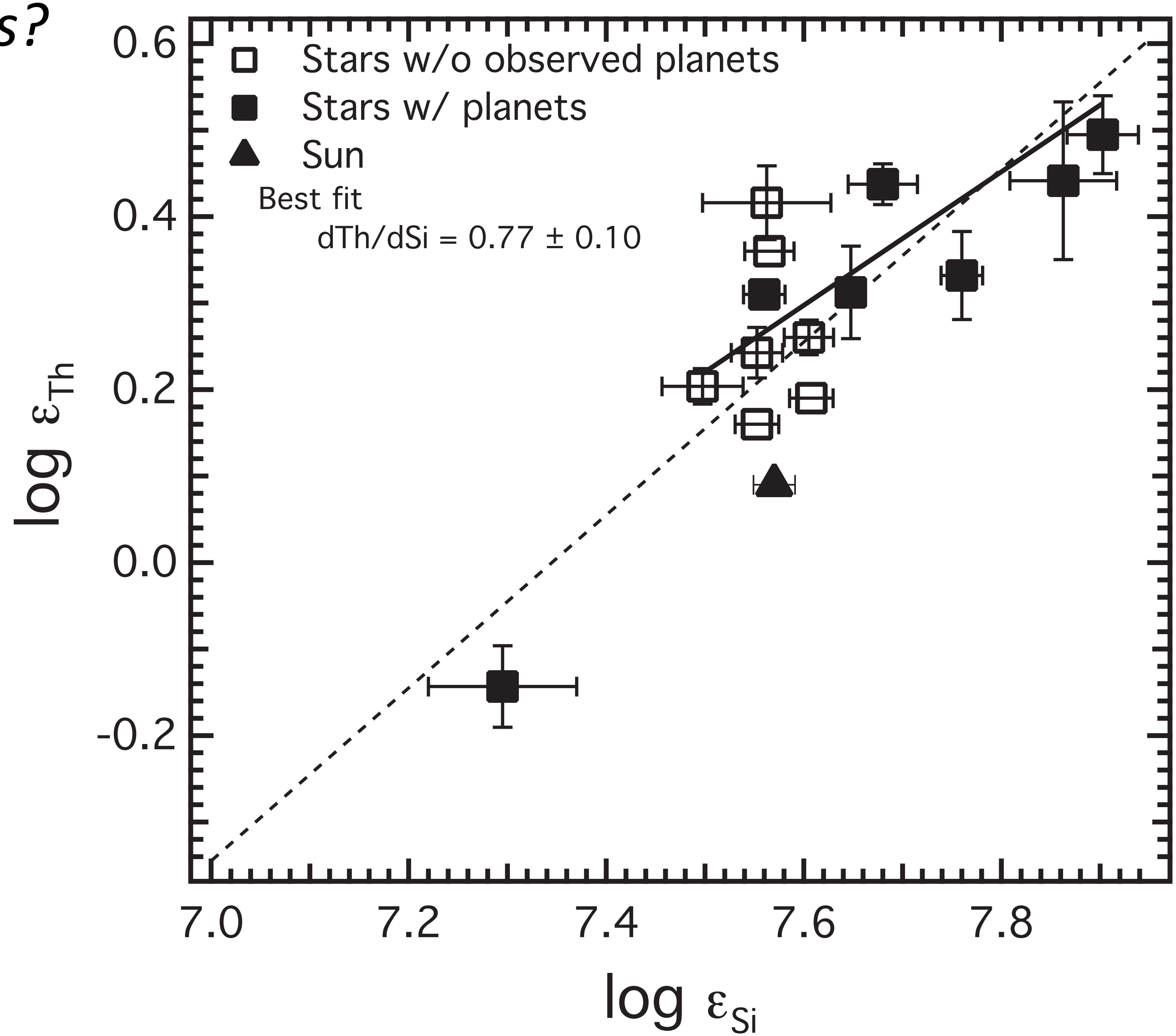


γ-ray satellites such as INTEGRAL and Compton observe these photons

^{232}Th
14 Gyr

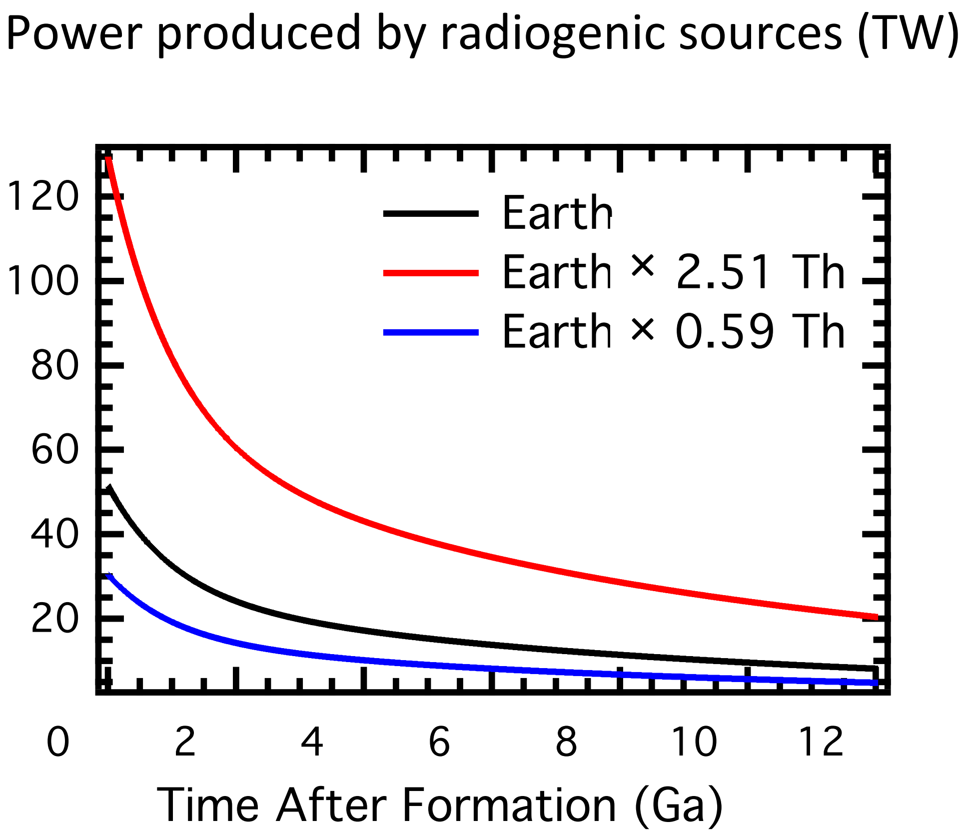
Th and U make up 30%–50% of the Earth's energy budget. *Would this be similar in other terrestrial planets?*

Unterborn et al. (2015) presented the first investigation of Th abundances in solar twins and analogues: They are up to 2.5 times higher than in the Sun



^{232}Th
14 Gyr

Unterborn et al. (2015) also presented a thermal model to evaluate the effect of different amount of Th in extrasolar terrestrial planets.

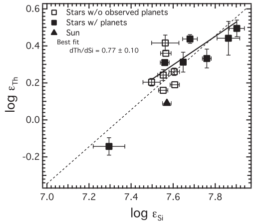


Planets with higher Th possess larger energy budgets.

- Mantle convection starts earlier
- Increased likelihood for carbon and water cycling between the surface crust and planetary interior,
- *broader range of planets which may support habitable surfaces*.

^{232}Th
14 Gyr

Why such a spread in Th?



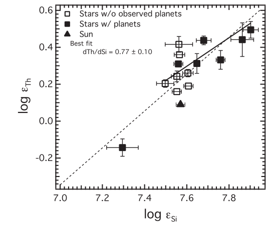
The cosmic origin of the actinides (atomic mass > 88, e.g. U, Th, Pu, Cm) is attributed to the *rapid* neutron-capture process (**the *r* process**).

Its astrophysical site is still debated but evidence is converging on **neutron star mergers**.

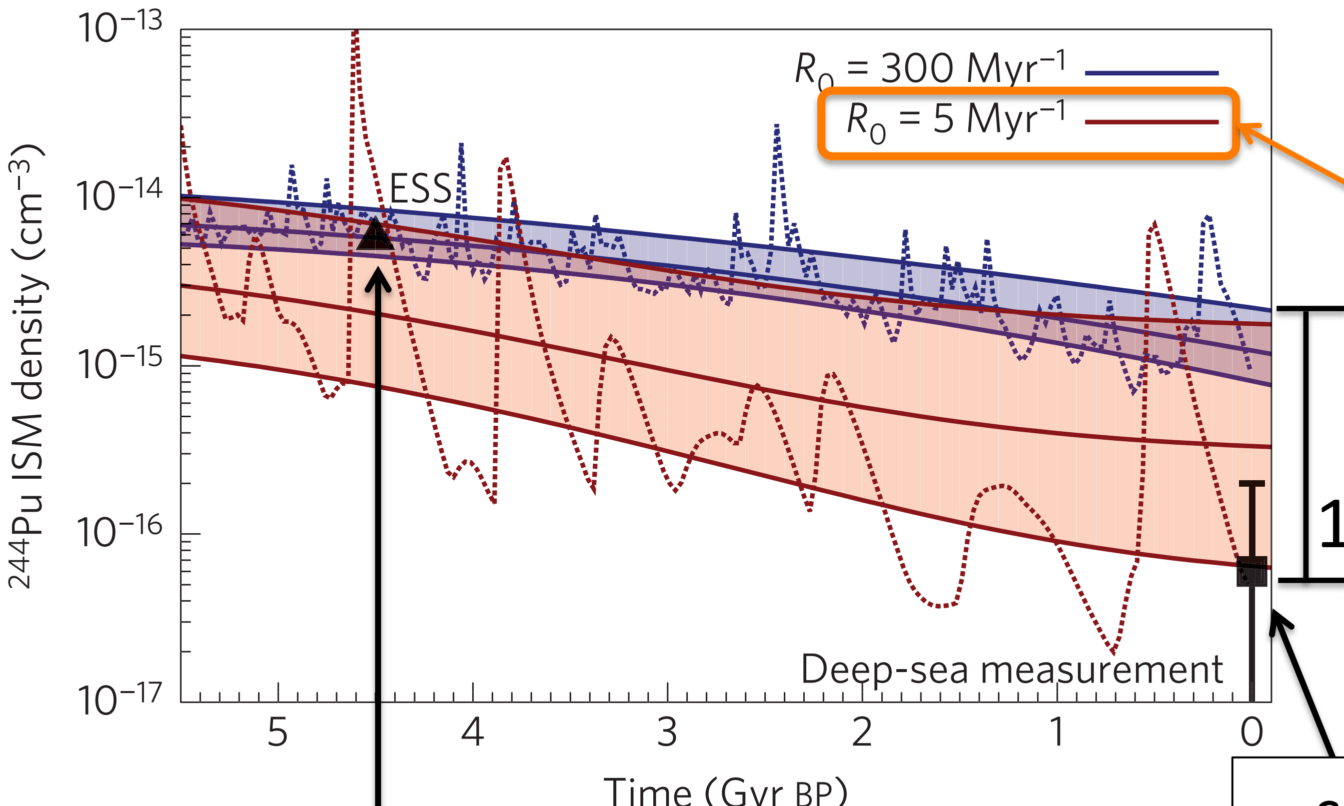
These are are **relatively rare events**, which means that we expect the distribution of their ejecta in the interstellar medium to be relatively inhomogeneous

^{232}Th
14 Gyr

Why such a spread in Th?



Hotekezaka et al. (2015) calculated the evolution of ^{244}Pu (80 Myr) in the interstellar medium with a Monte Carlo code



Galactic rate of short gamma-ray bursts from neutron star mergers

1σ fluctuations

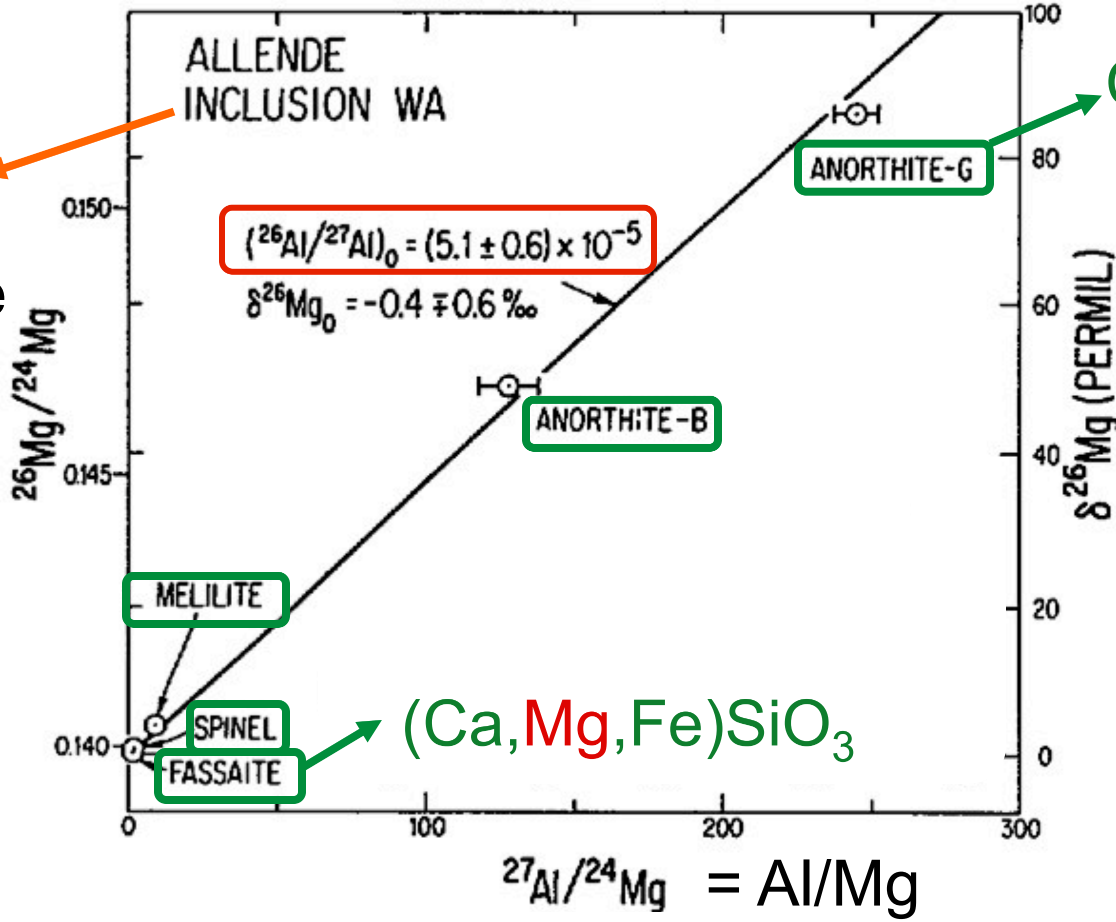
interstellar medium when the Sun formed from meteoritic measurements

current interstellar medium from deep-sea floor measurements

^{26}Al 0.7 Myr

From meteoritic analysis we can infer the abundance of ^{26}Al when the Sun was born

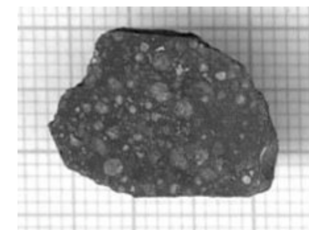
coarse-grained chondrule



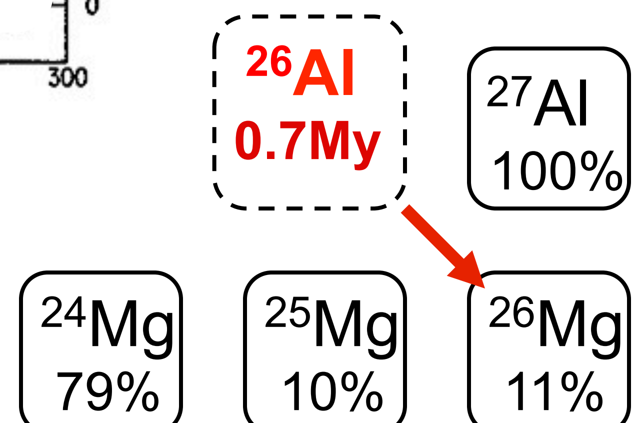
$CaAl_2Si_2O_8$

$(Ca,Mg,Fe)SiO_3$

including different mineral phases



Lee et al. 1977, ApJ, 211, L107



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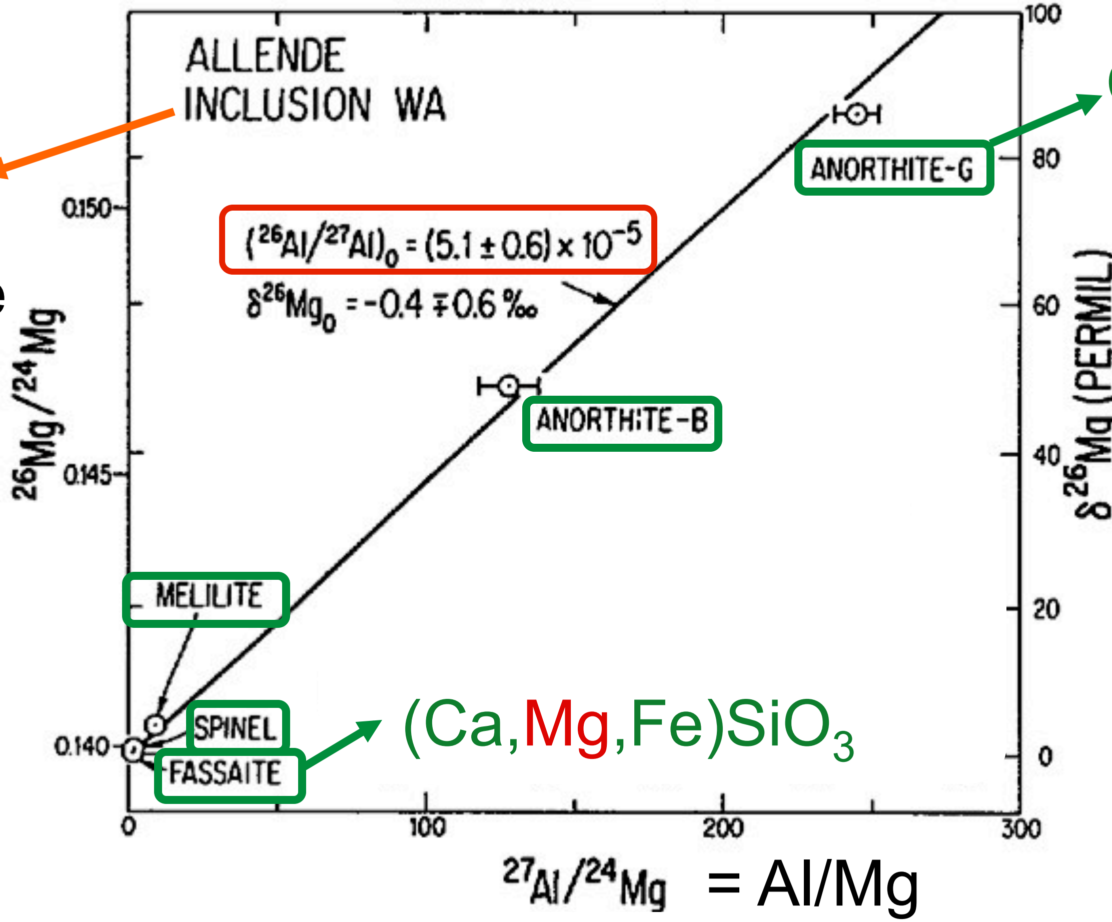

= Al/Mg

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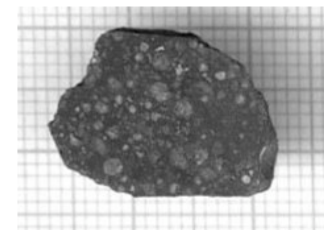


Lee et al. 1977, ApJ, 211, L107

^{26}Al 0.7My

^{27}Al 100%

^{24}Mg 79%

^{25}Mg 10%

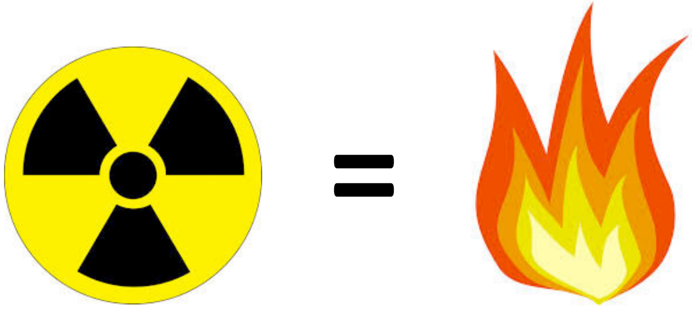
^{26}Mg 11%

*The origin of such high abundance of ^{26}Al at the Sun's birth has been **an ongoing mystery** for almost half a century!*

^{26}Al
0.7 Myr

Do other Solar Systems are also born with such high abundance of ^{26}Al?

1. Its radioactive decay provided **heat** inside early planetesimals that formed **within the first few Myr**
2. The heat led to differentiation and **melting of ice** even in small planetesimals beyond the snow line

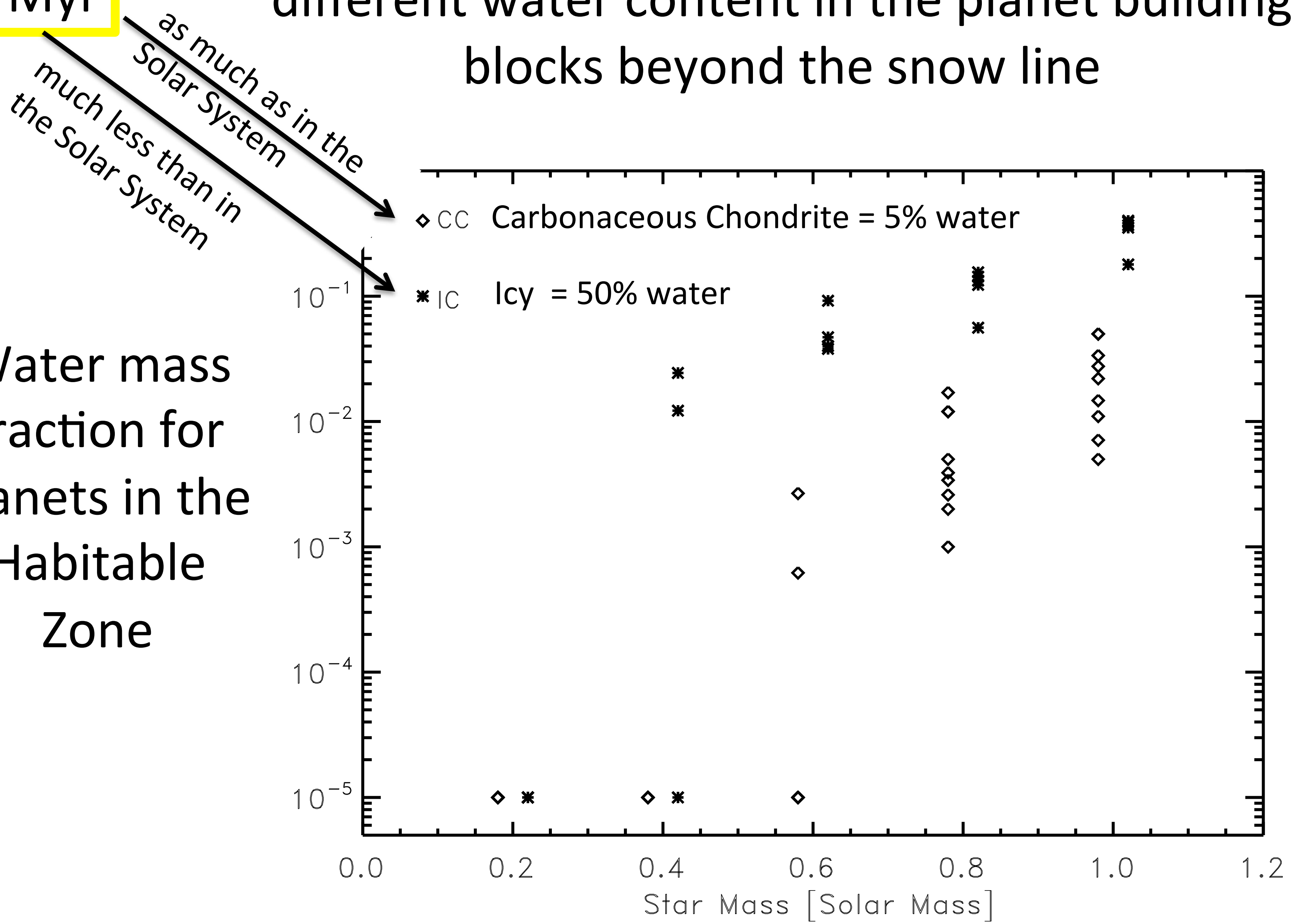


(Anthropic selection as an explanation for the presence of ^{26}Al in the ESS has also been proposed based on its implications on the existence of life on Earth, Gilmour & Middleton 2009).

^{26}Al
0.7 Myr

Ciesla et al. (2015) calculated the effect of different water content in the planet building blocks beyond the snow line

Water mass fraction for planets in the Habitable Zone



^{26}Al
0.7 Myr

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The presence of water determines **mineral diversity** and **modification of organic molecules**:

- serpentinization reactions, e.g., olivine weathering, which is exothermic and can initiate a new chemical heat source and further heating
- **possible** formation of clay minerals, clay surfaces -> catalysis for prebiotic chemistry (e.g. Franchi et al. 2003)
- **possible** change of primordial organic composition, possibility for organic synthesis

^{26}Al
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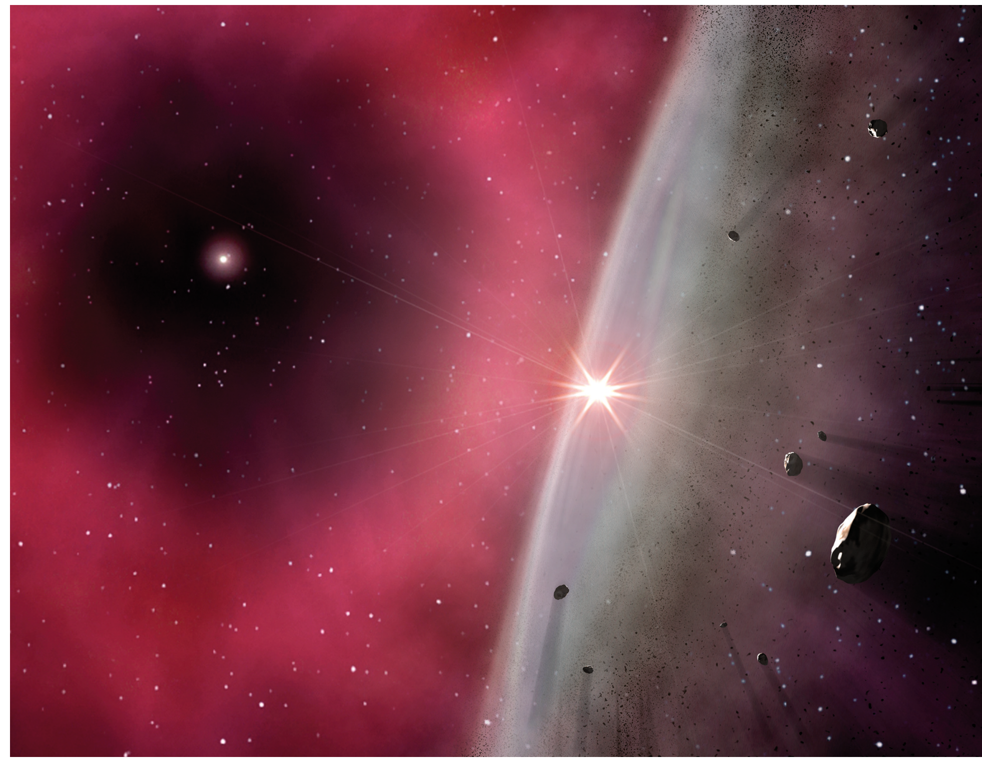
The *Local* scenario: a star died nearby the birth of the Sun



e.g., a nearby core-collapse supernova (e.g. Hester et al. 2004, Pan et al. 2012); the winds from a massive (> 30 $M_\odot$) star (e.g. Gounelle & Meynet 2012), etc.

Probability: <1% (e.g., Williams 2010)

Short timescales (a few Myr) star formation in a cluster requires the mass of the polluter > 40 $M_\odot$ (to live < 4 Myr). This requires the a very large cluster. In some models the distance from the stellar source to the Sun needs to be fine-tuned.

^{26}Al
0.7 Myr

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The *Global* scenario:
self-pollution of the giant molecular cloud where the Sun was born (Gaidos et al. 2009; Vasileiadis *et al*. 2013; Young 2014)

Probability: relatively common

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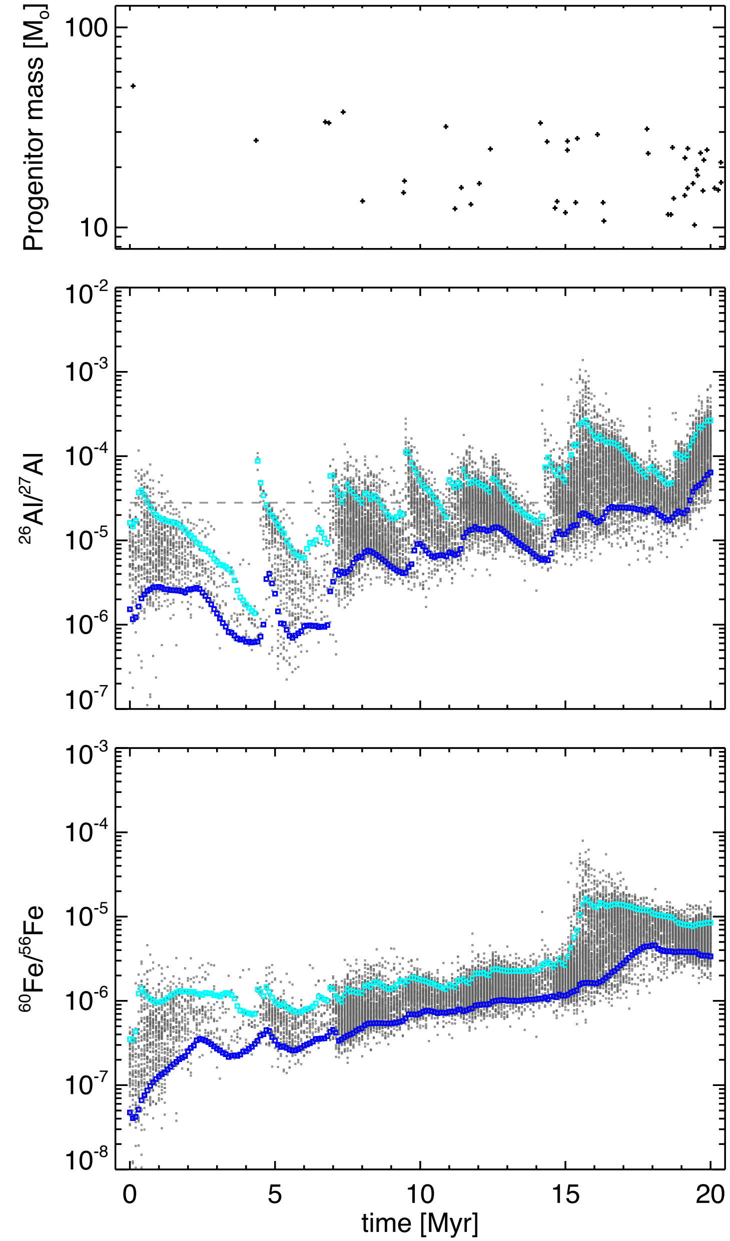
Probability: relatively common

Results from the multi-dimensional magnetohydrodynamics simulations of Vasileiadis *et al*. (2013)



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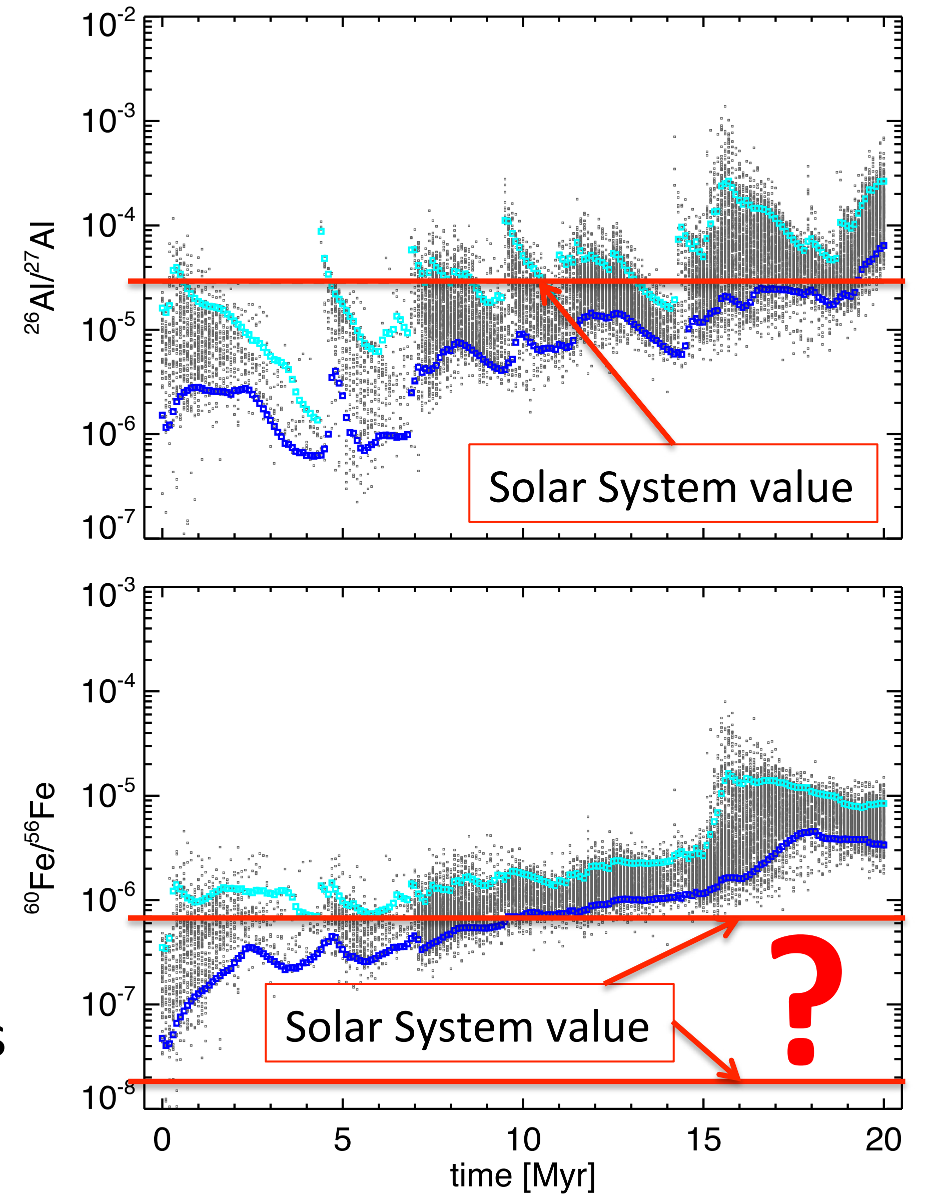

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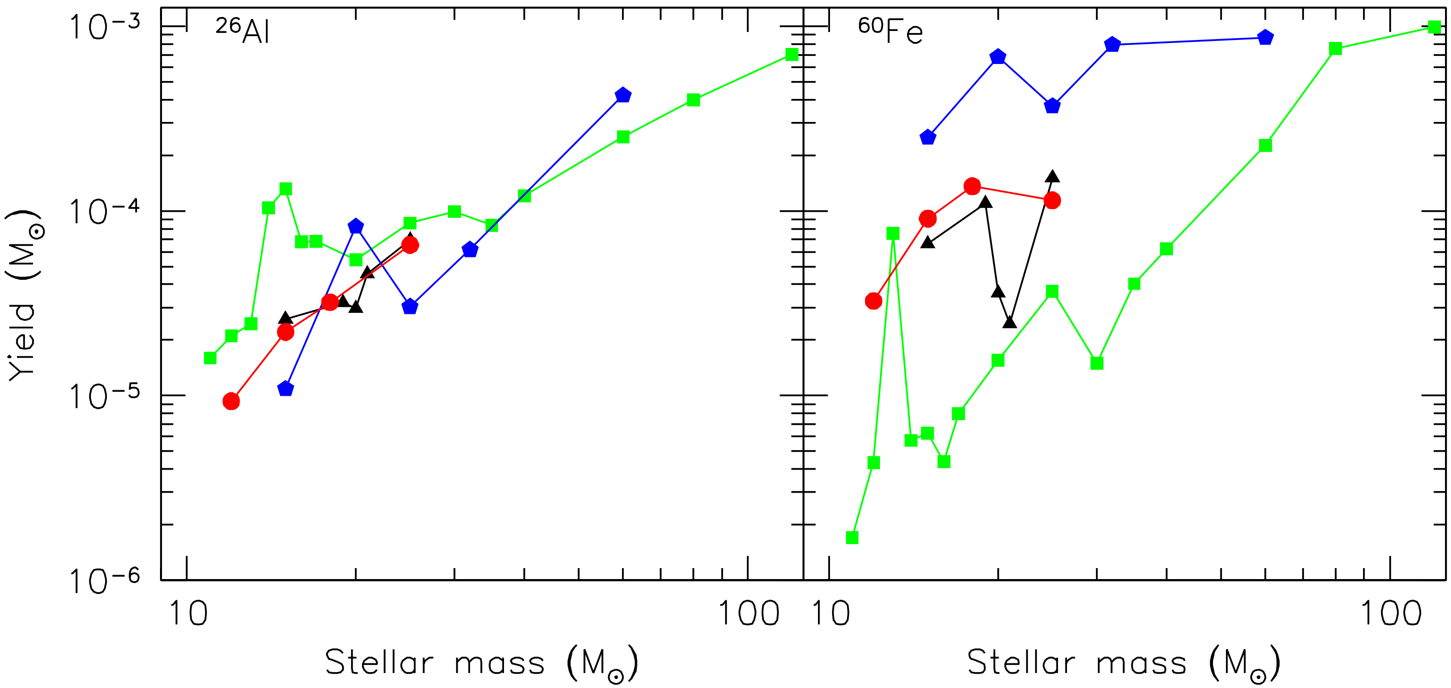

Rauscher et al. (2002)

Limongi & Chieffi (2006)

Pignatari et al. (2013)

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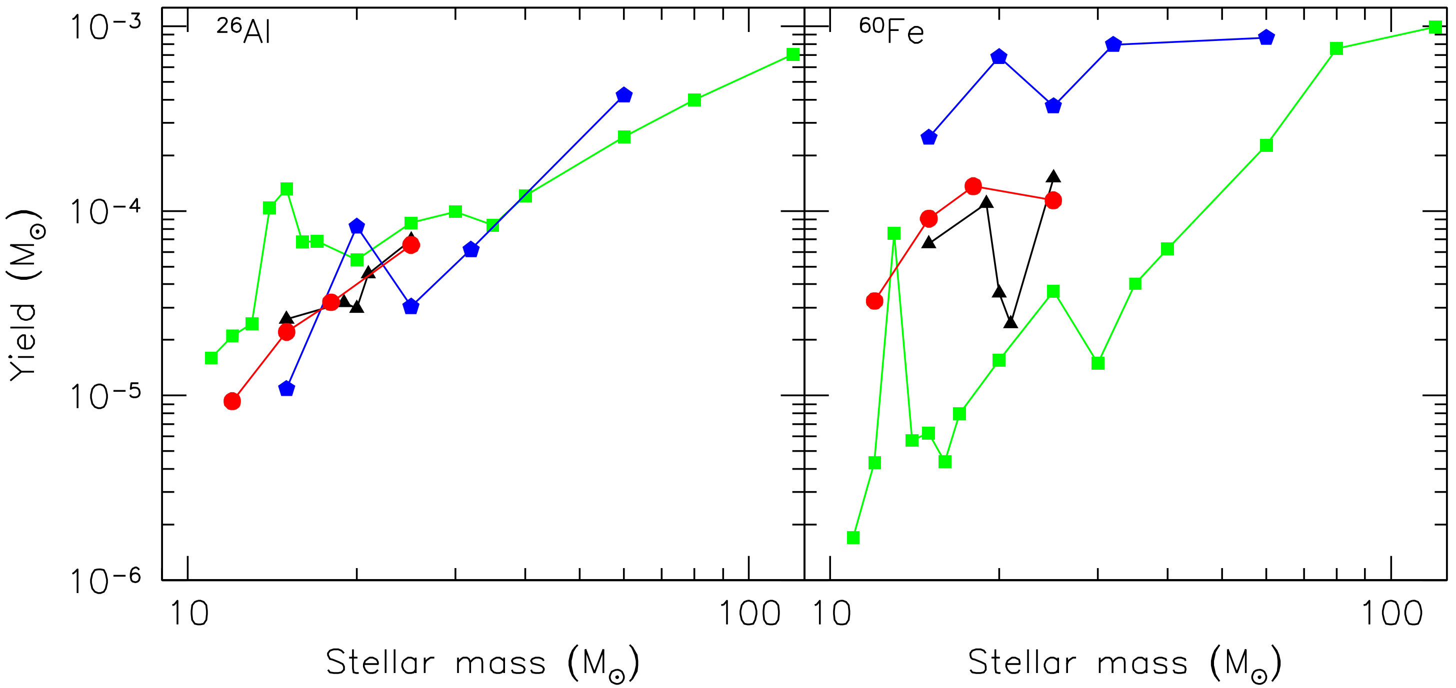

Rauscher et al. (2002)
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Lugaro, Heger et al. (2014)

However, stellar yields are far from been well constrained, which poses strong limitations on the accuracy of the present investigations of the Global scenario

Conclusions

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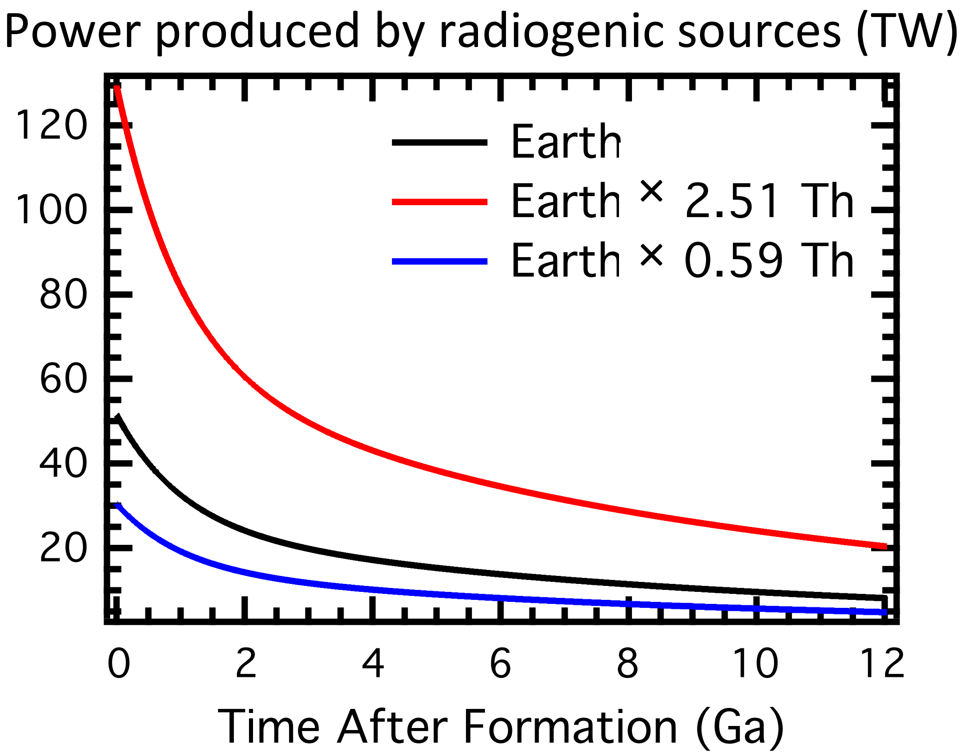
← half life ($T_{1/2}$)

The heat budget of extrasolar terrestrial planets seems to be typically higher than the Earth's

It affects chemistry and the amount of water in extrasolar terrestrial planets, but ***we do not know yet the possible ranges of its initial abundance***

Unterborn et al. (2015) also presented a simple thermal model to evaluate the effect of different amount of Th in extrasolar terrestrial planets.



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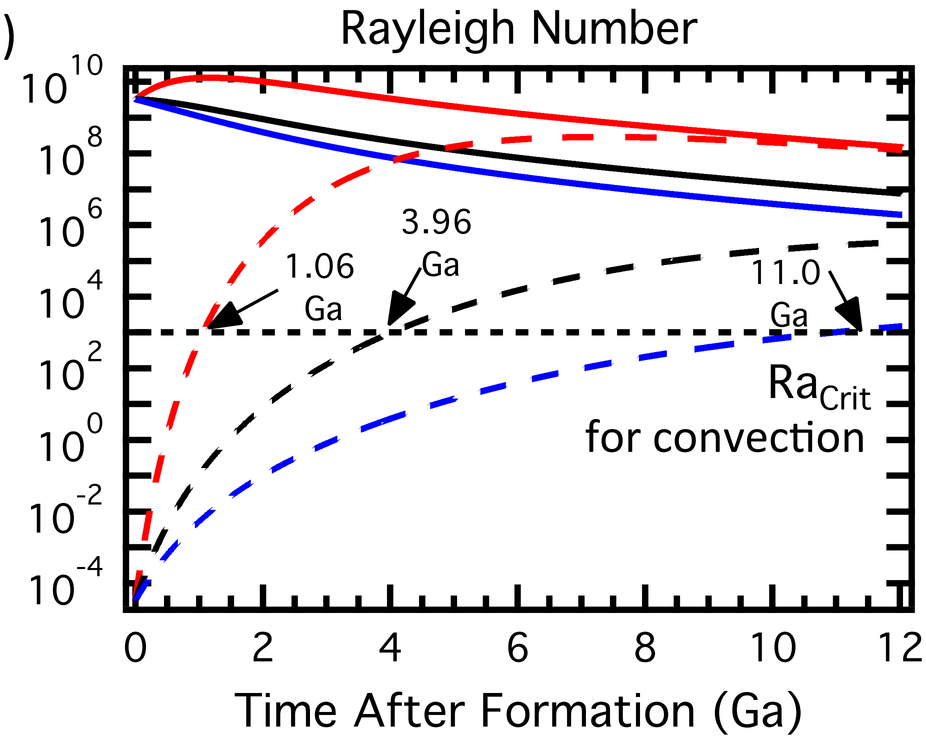

Mantle convection starts earlier