Constraining the Rapid Neutron-Capture Process with Meteoritic I-129 and Cm-247

"Meteorites remember the conditions of stellar explosions"

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RADIOSTAR erc

KONKOLY

Structure

- **Why I-129 and Cm-247 - GCE**
- Simulations of *r*-process nucleosynthesis

What are the SLR?

SLR: Short-lived radionuclides

$\tau \sim 0.1 – 100$ Myr

As their name says, they do not live long, so they are usually indicators of current nucleosynthesis. For example:

- Tc-99 ($\tau \sim 0.1$ Myr) was the first evidence of stellar nucleosynthesis observed by Merril in 1952
- Al-26 ($\tau \sim 1$ Myr) is believed to correlate with active stellar formation regions

Where are the SLR?

- **Where can we see SLR?**
  - **ɣ-rays (decay): Al-26, Fe-60 (Diehl+ 2021)**
  - **Deep-sea sediments: Fe-60, Pu-244 (Wallner+ 2015)**
  - **ESS meteoritic measurements: Al-26, I-129, Cm-247 (Dauphas & Chaussidon 2011)**

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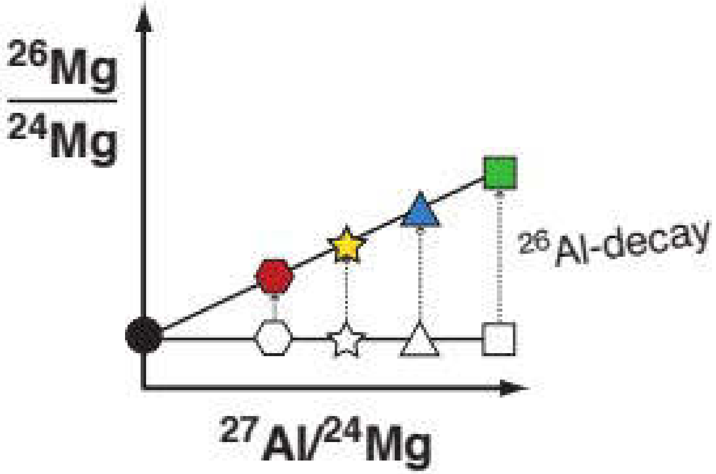
- Where can we see SLR?
  - ɣ-rays (decay): Al-26, Fe-60 (Diehl+ 2021)
  - Deep-sea sediments: Fe-60, Pu-244 (Wallner+ 2015)
  - ESS meteoritic measurements: Al-26, I-129, Cm-247 (Dauphas & Chaussidon 2011)

ESS meteoritic abundance

But wait a second, if SLR live < 100 Myr, how can we know the ESS abundances of 4.5 Gyr ago?

We can can observe the excess of the daughter nuclei in the ESS solids



Dauphas & Chaussidon 2011

ESS meteoritic abundance

We can obtain the ESS abundances for I-129 and Cm-247, and their ratio

Short-lived radionuclide	Half-life (Myr)	Reference nucleus	Half-life (Myr)	Early Solar System ratio
^{129}I	15.7 ± 0.8	^{127}I	stable	$(1.28 \pm 0.03) \times 10^{-4}$
^{247}Cm	15.6 ± 1.0	^{235}U	704 ± 2	$(5.6 \pm 0.3) \times 10^{-5}$
^{129}I	15.7 ± 0.8	^{247}Cm	15.6 ± 1.0	438 ± 184

GCE of SLR

Why are we interested in these two isotopes?

Short answer: Their mean lives are very similar (and short), so their ratio does not change much

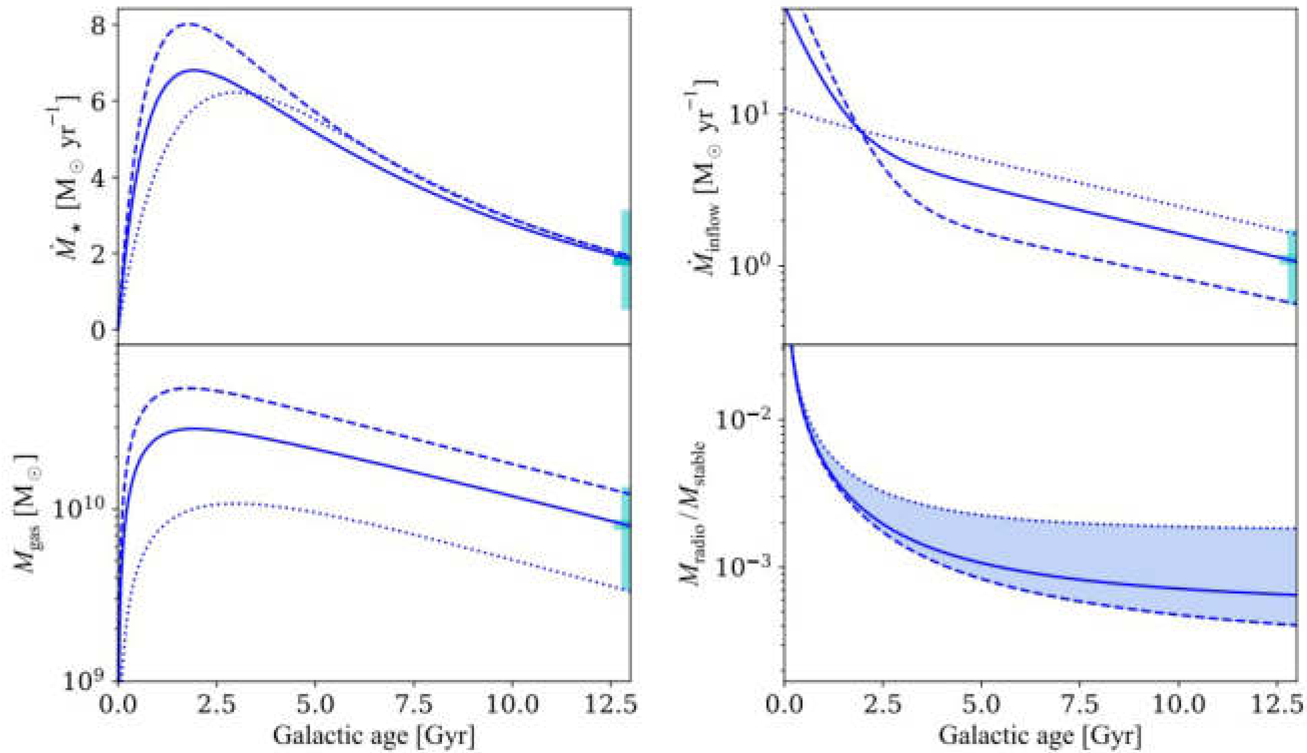
Longer answer: GCE uncertainties. An ESS SLR is measured in a ratio with a stable or long-lived reference. For example:

- Al-26/Al-27
- I-129/I-127
- Cm-247/U-235

Stable references carry GCE uncertainties

GCE of SLR

This is an example of the uncertainties for a SLR/Stable ratio in OMEGA+ for the Milky Way



Côté+ 2019

GCE of SLR

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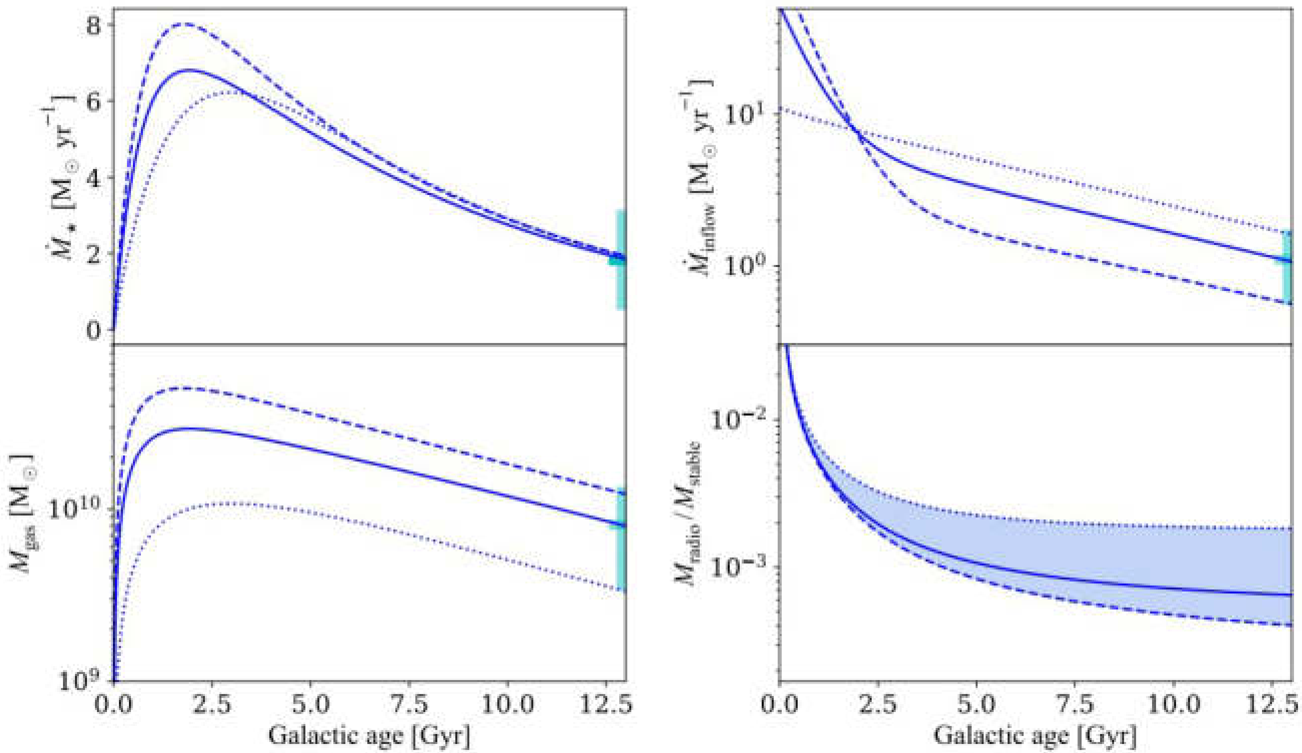


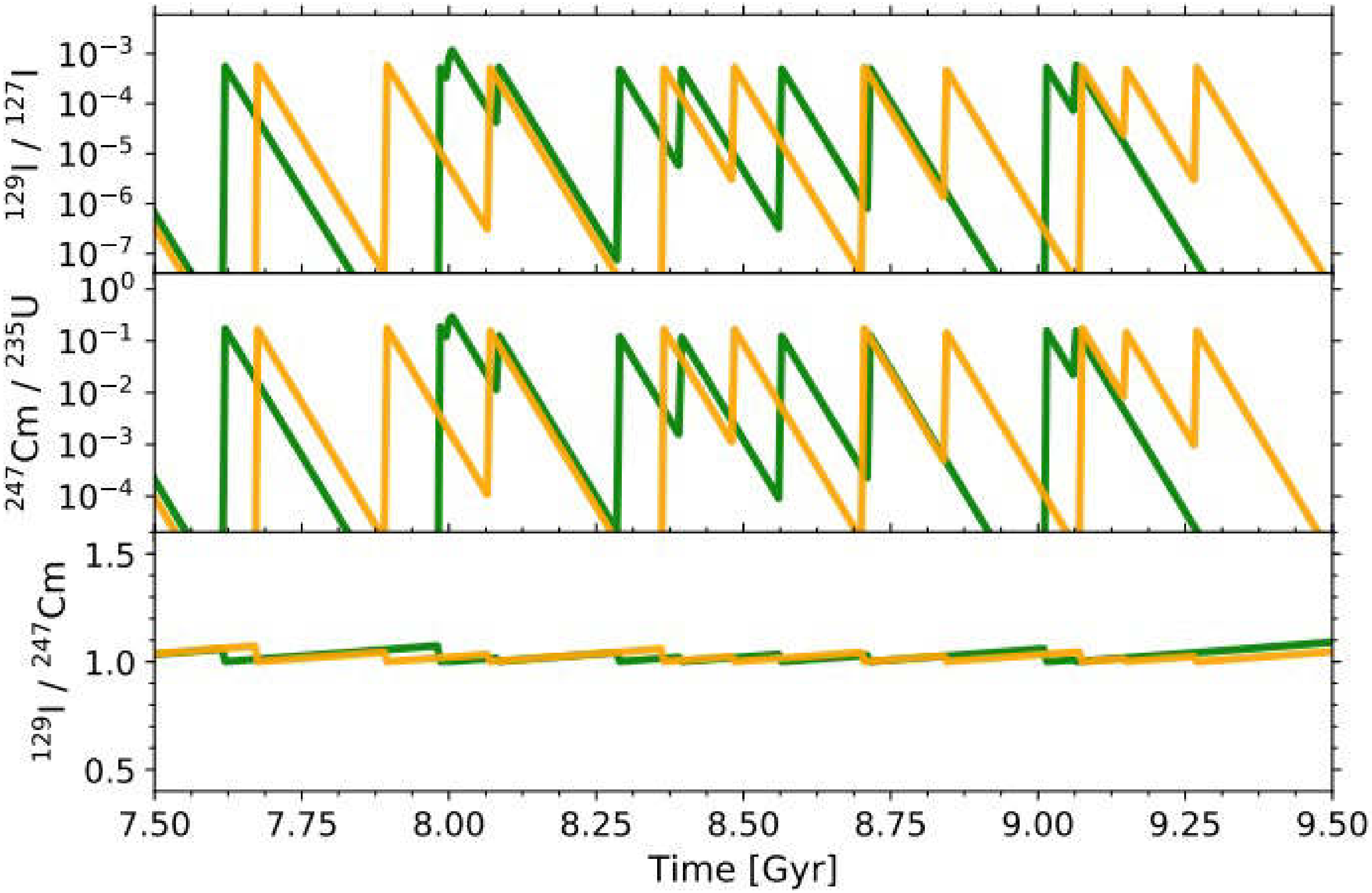
A factor of almost 4!

Côté+ 2019

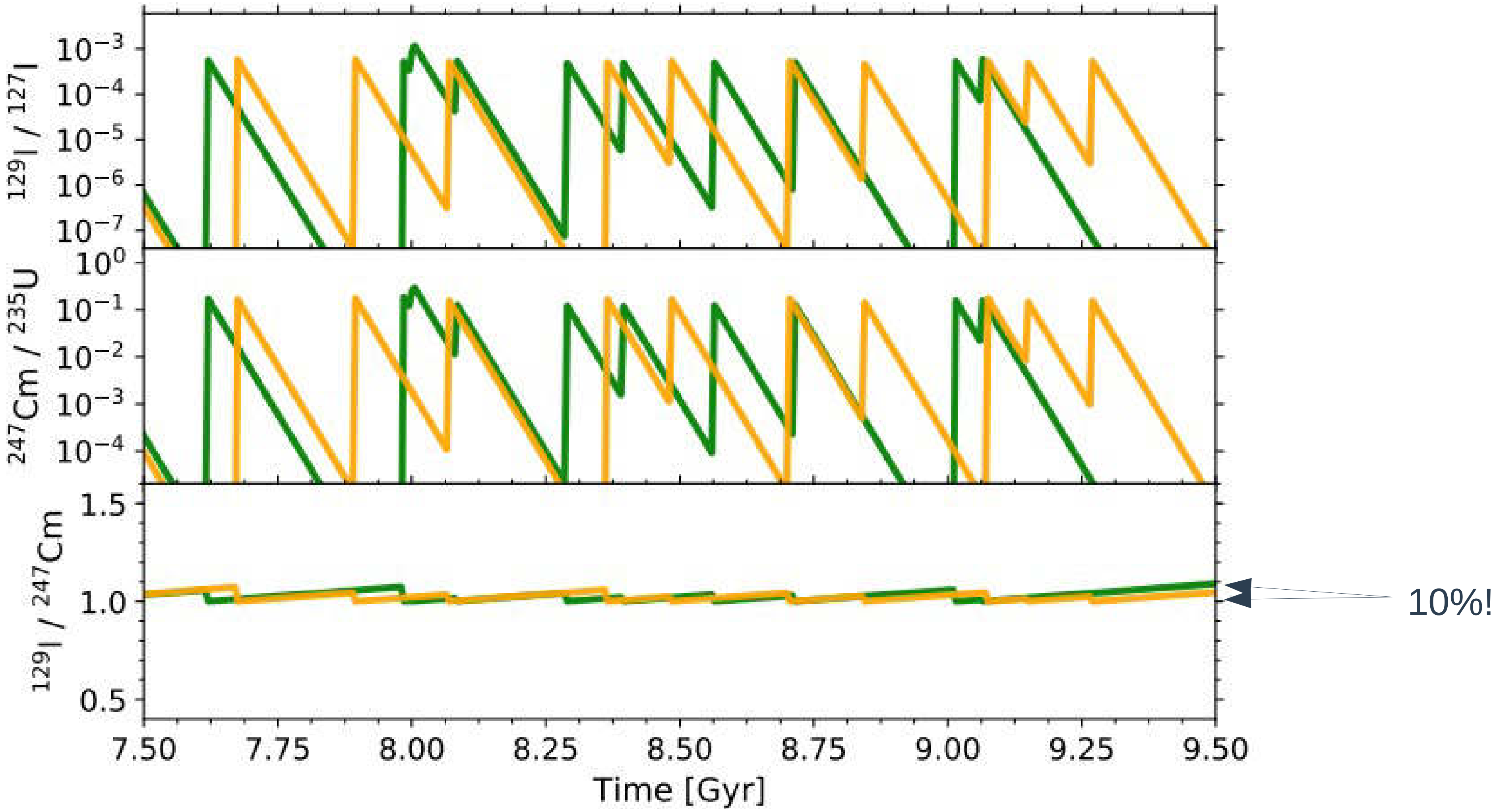
Ratio of SLR analysis

- What are the uncertainties of a ratio of SLR? When both SLR are created in the same events
- There are many different “regimes” depending on the mean-lives and the recurrence time for the event (Yagüe et al. submitted)
- We study I-129 and Cm-247, for which we know:
  - τ_{129} = 22.6 Myr
  - τ_{247} = 22.5 Myr
  - $\tau_{eq} = \tau_{129}\tau_{247}/(\tau_{247}-\tau_{129})$ = -5085 Myr
  - Average recurrence ~ 200 – 500 Myr

Ratio of SLR analysis



Ratio of SLR analysis



Ratio of SLR analysis

So the ratio is effectively "frozen" in time, but each time there is a new event, it arrives to a "clean slate", so it leaves only its imprint

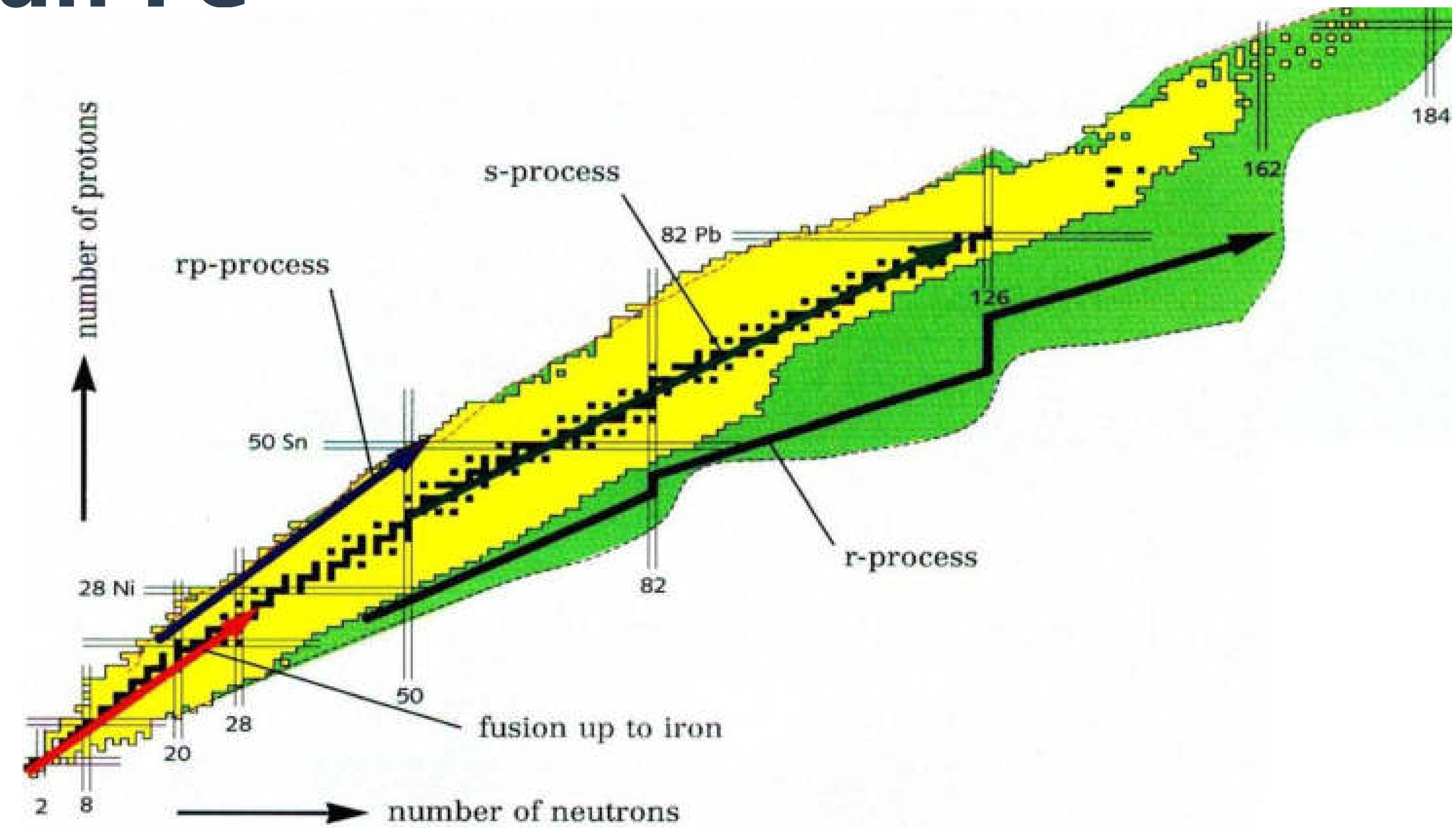
If we measure I-129/Cm-247, then it is the same it was at time of creation and it is not "mixed" with the ratios from previous events

Structure

- Why I-129 and Cm-247 - GCE
- **Simulations of *r*-process nucleosynthesis**

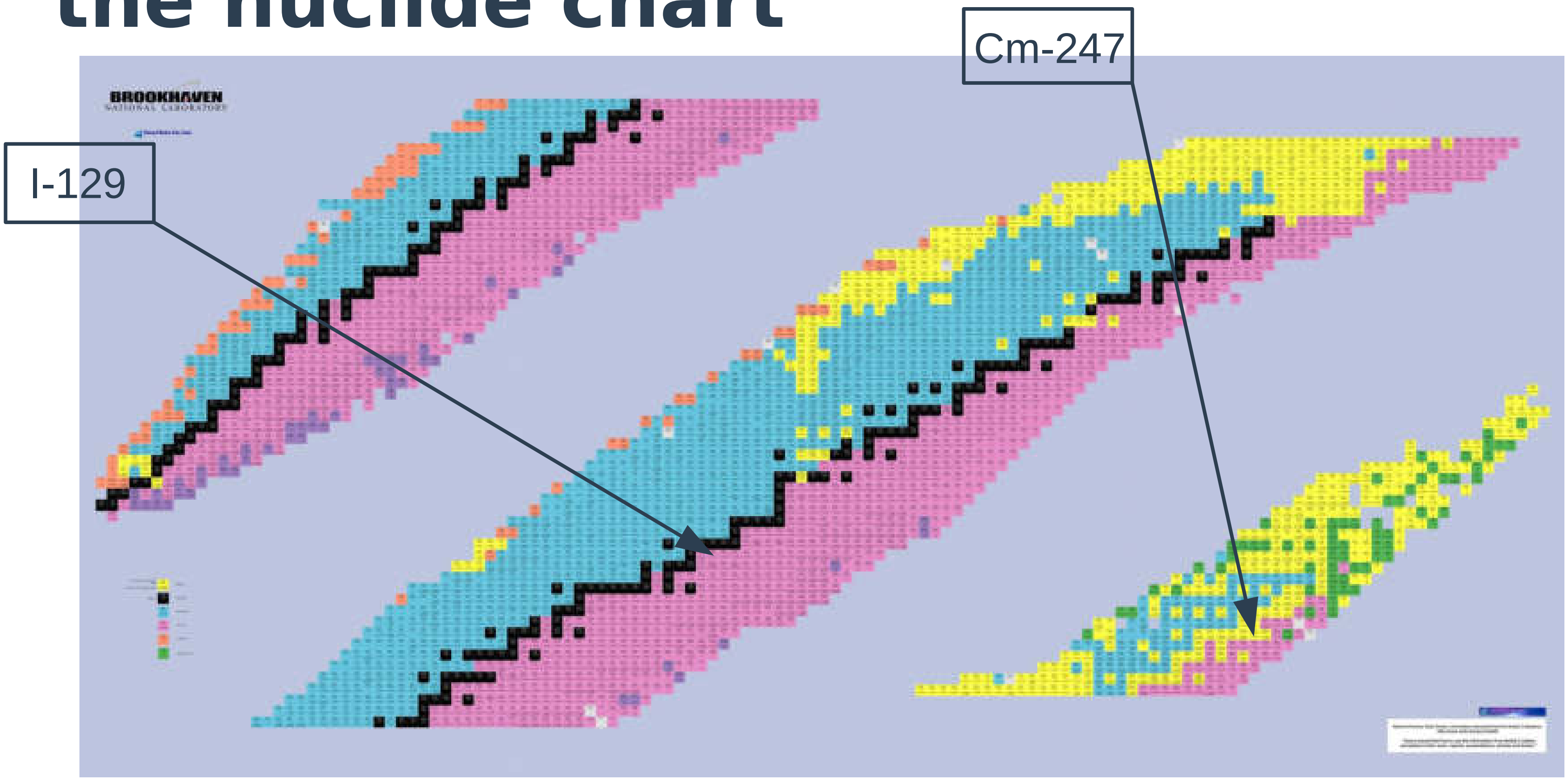
r-process nucleosynthesis

To make these elements, we need nucleosynthesis for species heavier than Fe



r-process nucleosynthesis

They are in very different places of the nuclide chart



National Nuclear Data Center, https://www.nndc.bnl.gov/

r-process nucleosynthesis

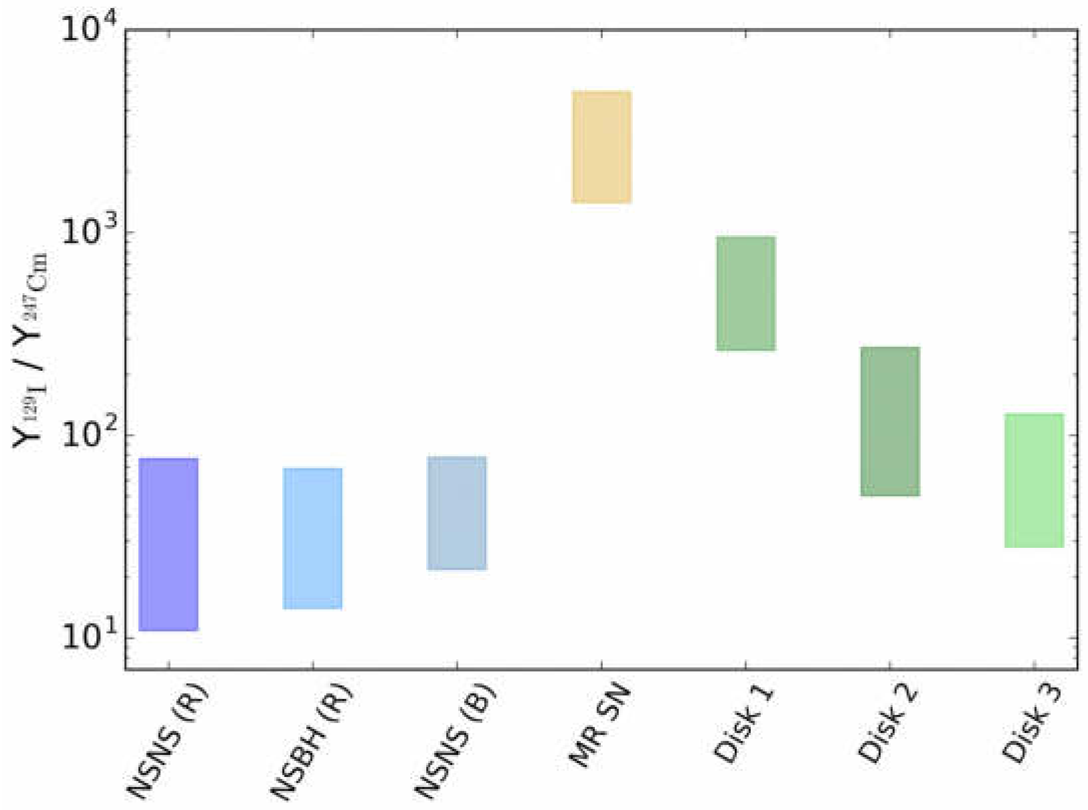
How much I-129 in proportion to Cm-247 is created depends roughly on the neutron-rich or -poor conditions

- **Neutron-poor conditions favour I-129 over Cm-247**

- **Neutron-rich conditions favour Cm-247 instead**

r-process nucleosynthesis

Different sites have different I-129/Cm-247 ratios



Now everything together

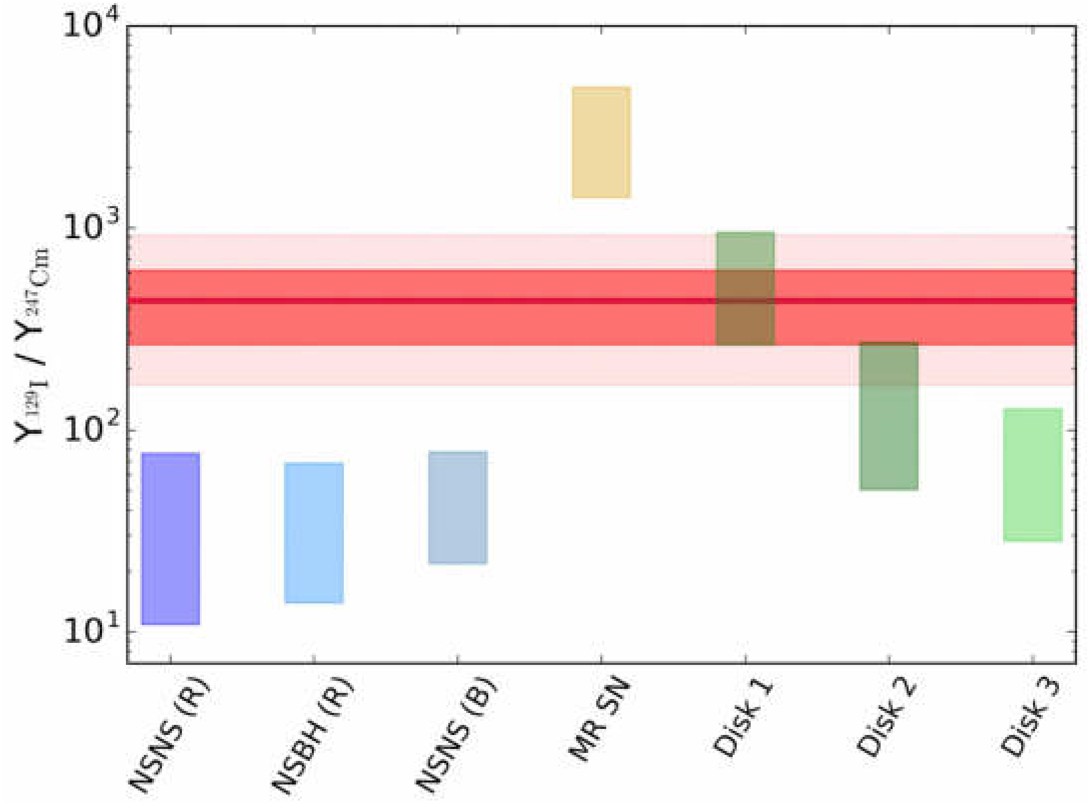
If we measure I-129/Cm-247, then it is the same it was at time of creation and it is not "mixed" with the ratios from previous events

Different sites have different ratios

We have the ESS abundances

Now everything together

We compare the ESS value to the simulations



Conclusions

- The I-129/Cm-247 SLR ratio sidesteps the GCE uncertainties and probes the last *r*-process event before the ESS
- The last *r*-process event before the ESS is compatible with a site with moderately neutron-rich conditions
- We can strengthen these results with more precise nuclear physics, ESS measurements and understanding of GCE