


The *RISE* of r-process in dwarf galaxies


mostly about [arXiv:2308.13702](#), but also [arXiv:2404.10067](#)

IAU Symposium 2024 – Paraty

November 2024

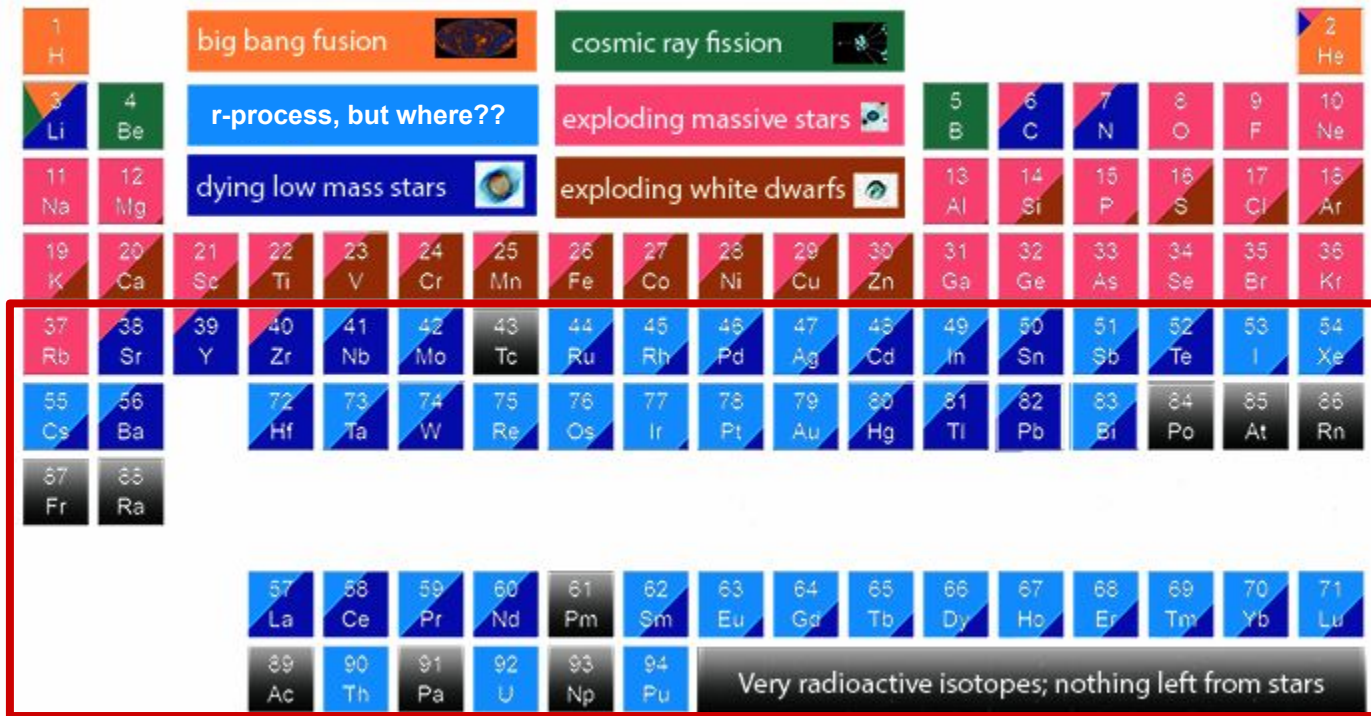
Guilherme Limberg – KICP postdoc fellow at UChicago

 guilherme.limberg@usp.br

 [@guilimberg](https://twitter.com/guilimberg)



All “metals” are formed in processes associated with stars. But what about the **heaviest elements**?

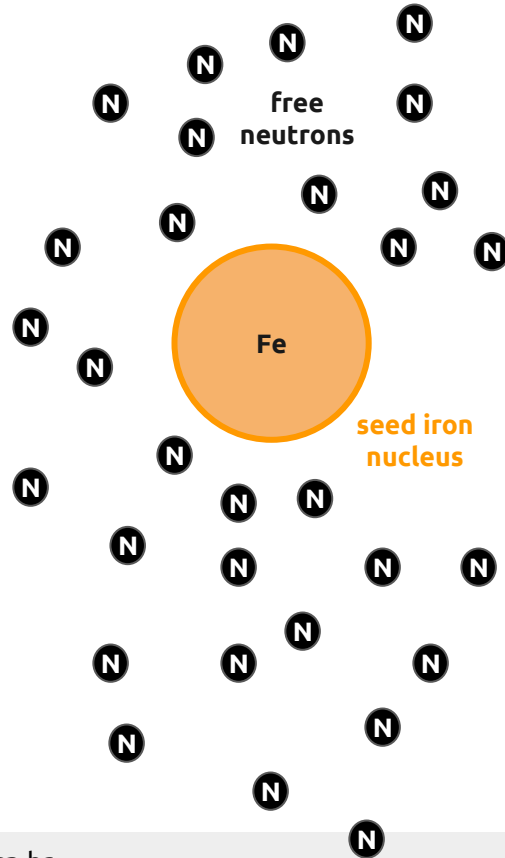


Graphic created by Jennifer Johnson
<http://www.astronomy.ohio-state.edu/~jaj/nucleo/>

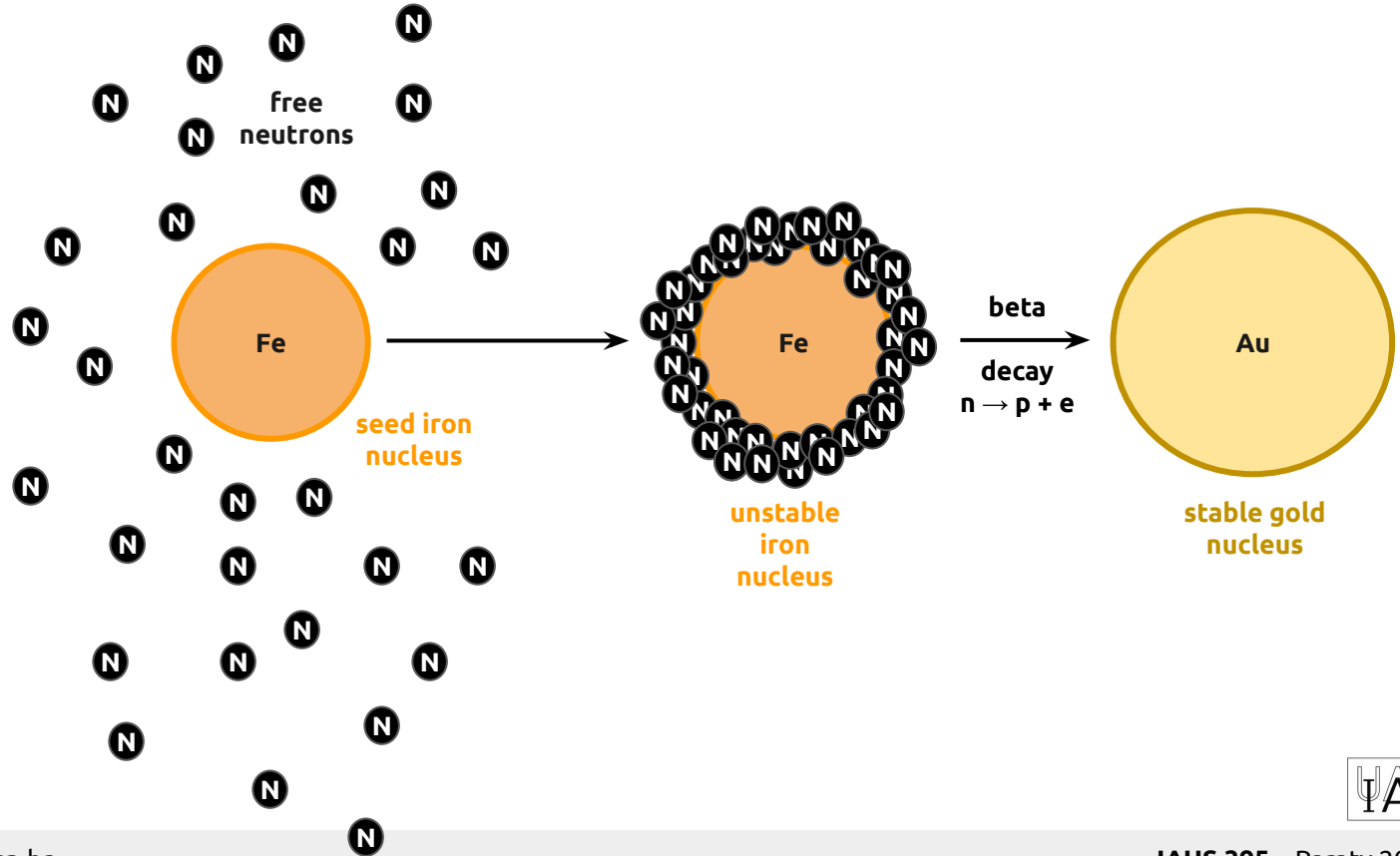
Astronomical Image Credits:
 ESA/NASA/AASNova



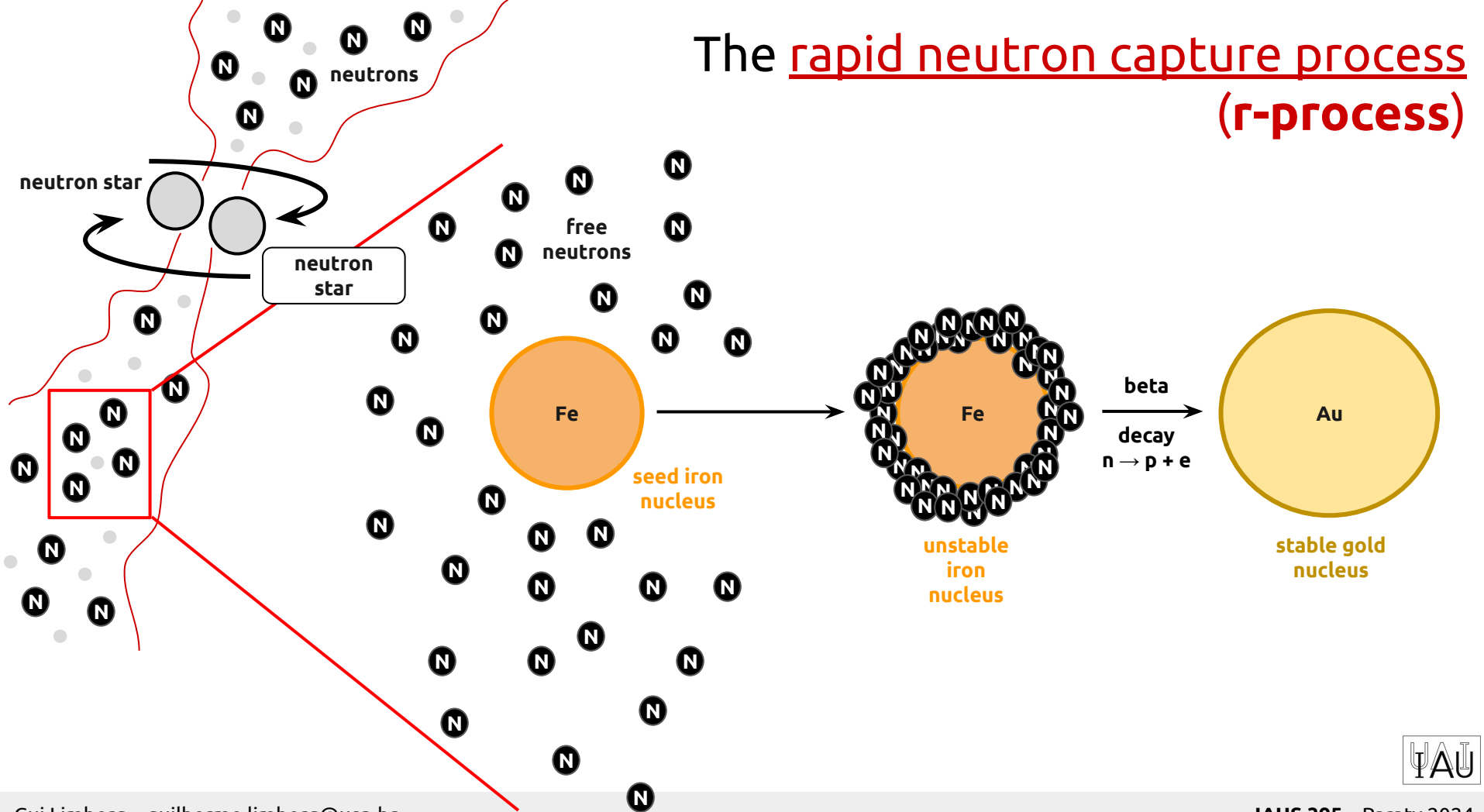
The rapid neutron capture process (**r-process**)



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Viable **r-process** site(s) are **rare** and **prolific!**

delayed

neutron star mergers and/or
neutron star + black hole

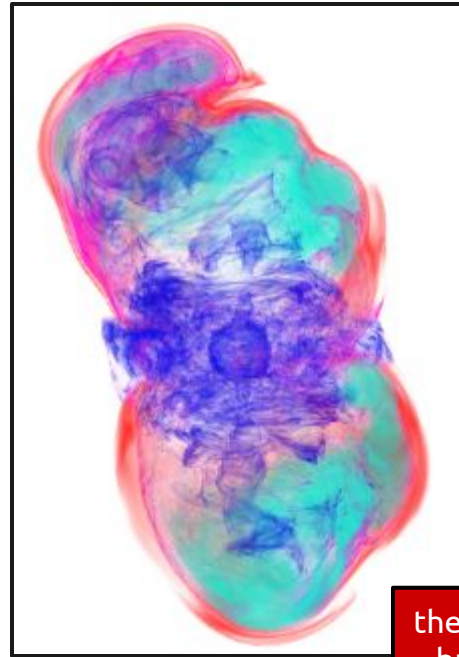


definitely happen and
make r-process!

credit: LIGO/VIRGO

prompt

exotic **rare kinds** of
core-collapse supernova
(e.g., magneto-rotational
and/or collapsars)

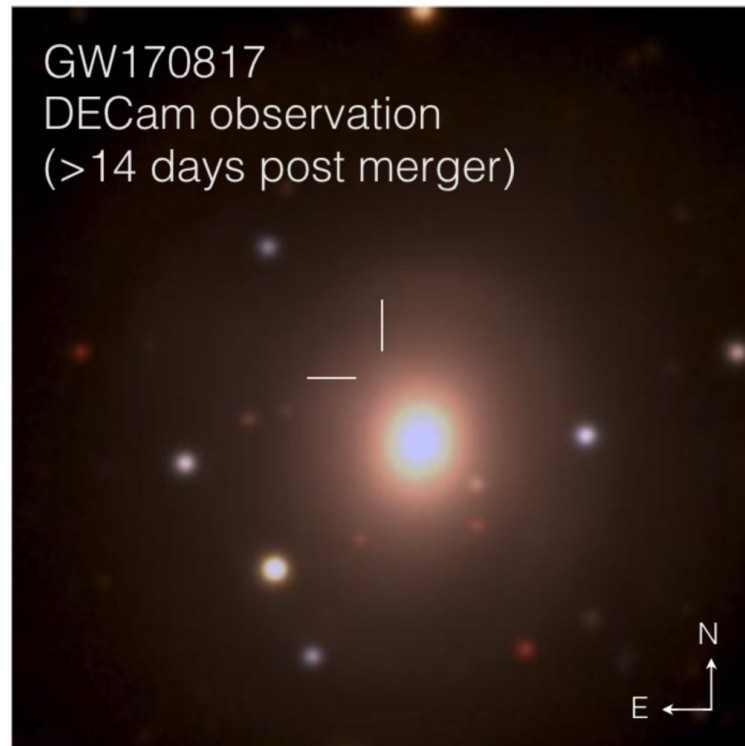
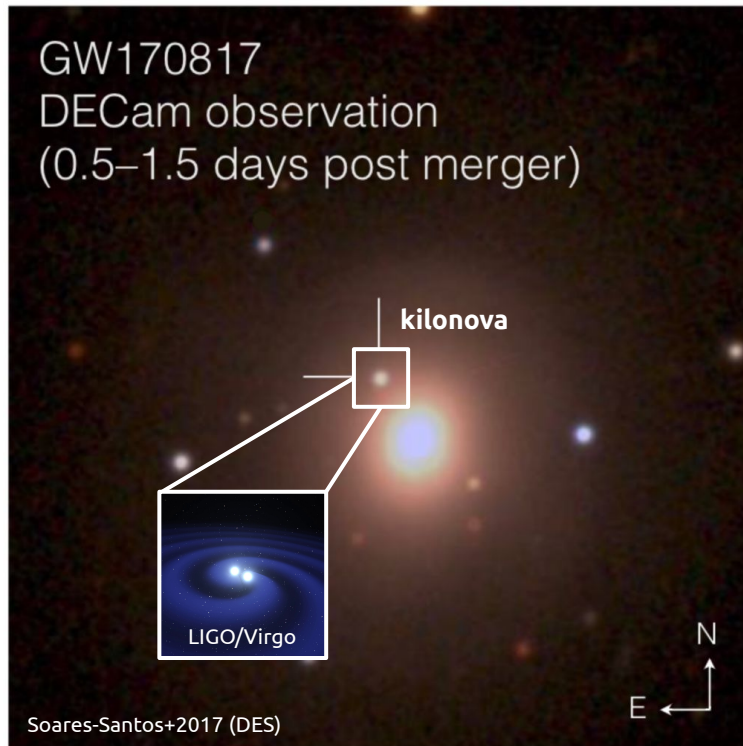


theoretically promising,
but no obs. evidence

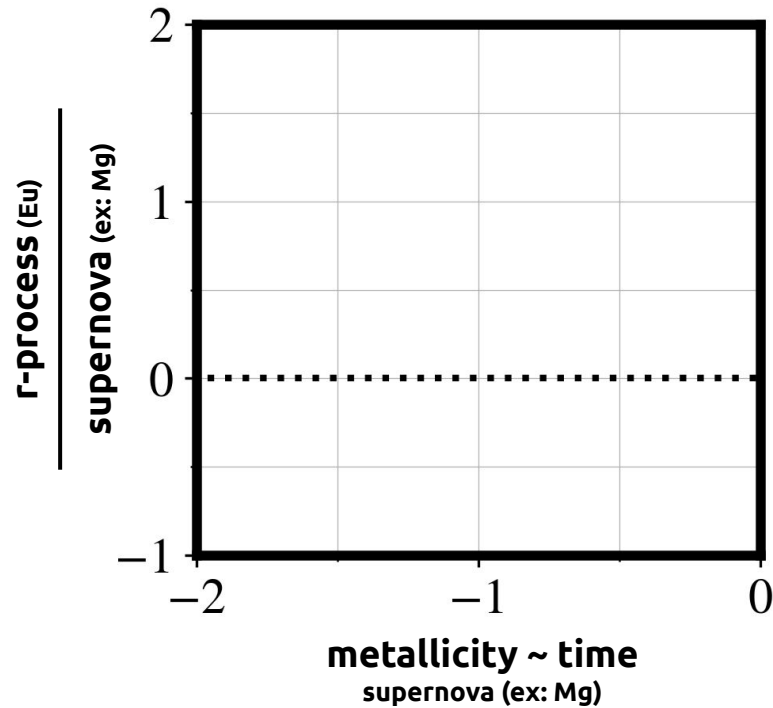
Mosta+2014



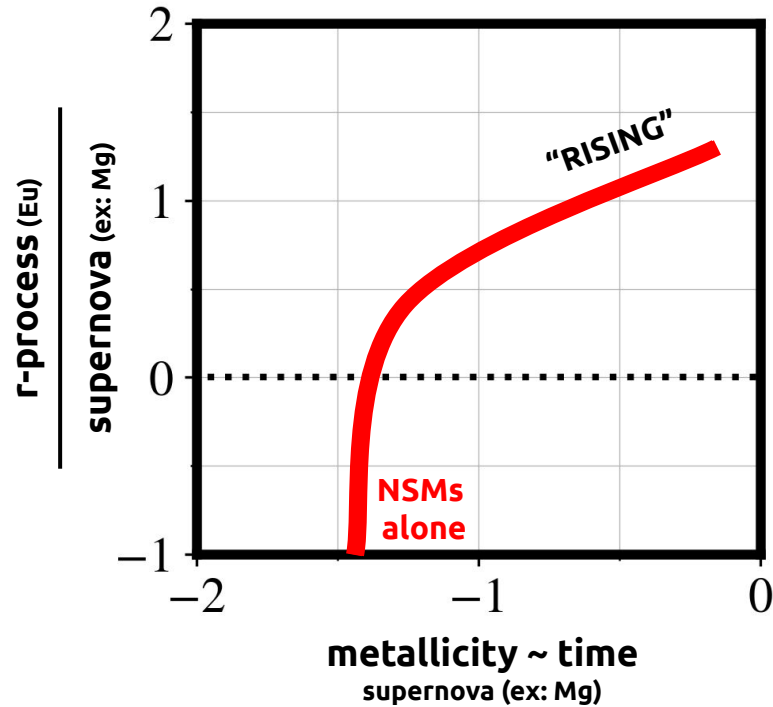
Multimessenger observations of GW170817 confirmed **neutron star mergers** as a site for **r-process**



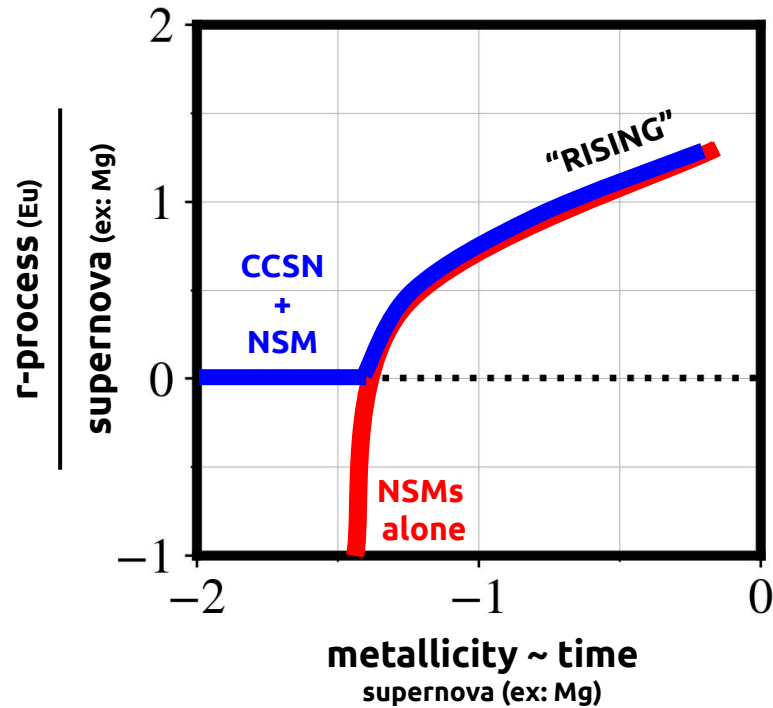
What should we expect for the chemical evolution of **r-process** in “**massive**” dwarf galaxies?



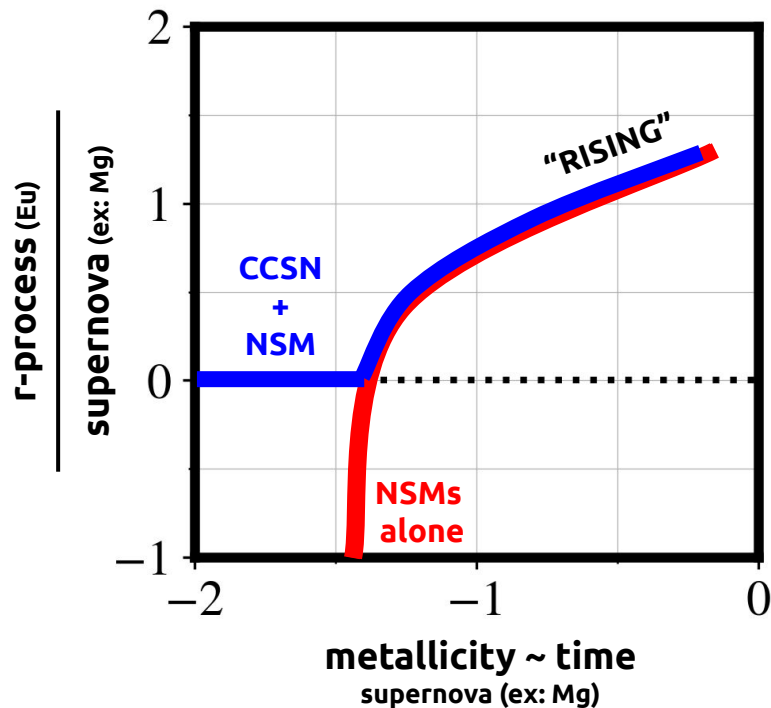
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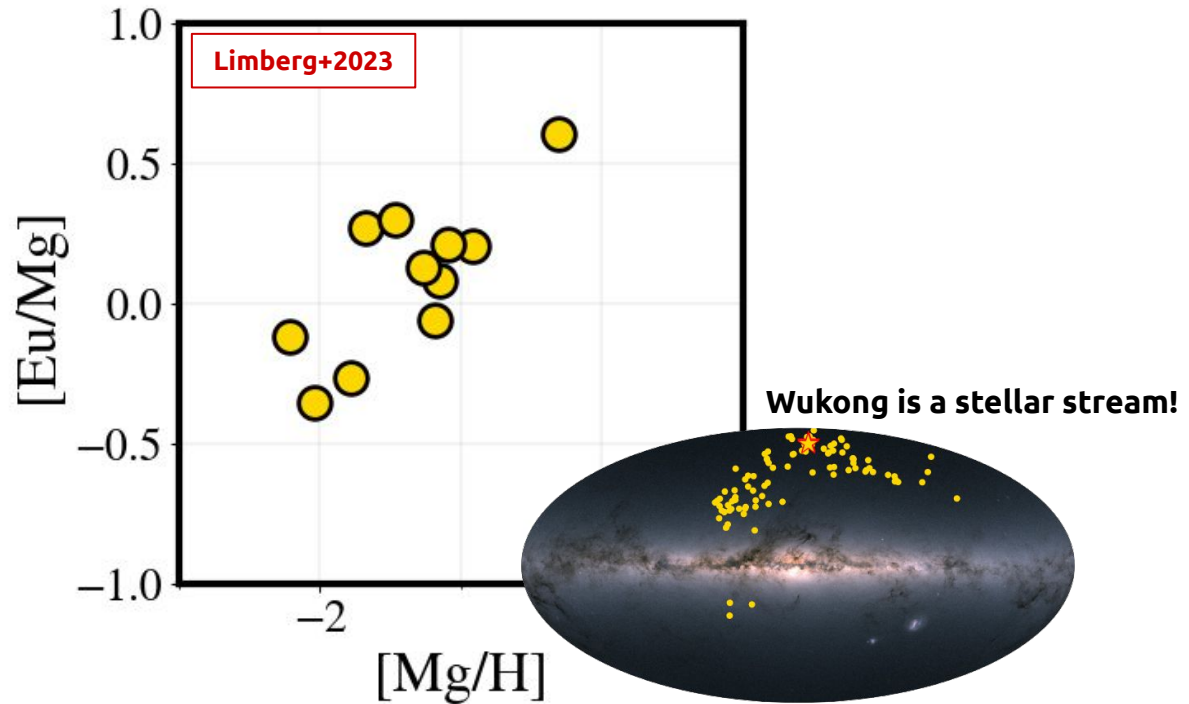


Why don't we just do it?

- high-res. spec.
- metal-poor
- real member
- cool ($T_{\text{eff}} < 5000\text{K}$)
- bright ($g < 18$)

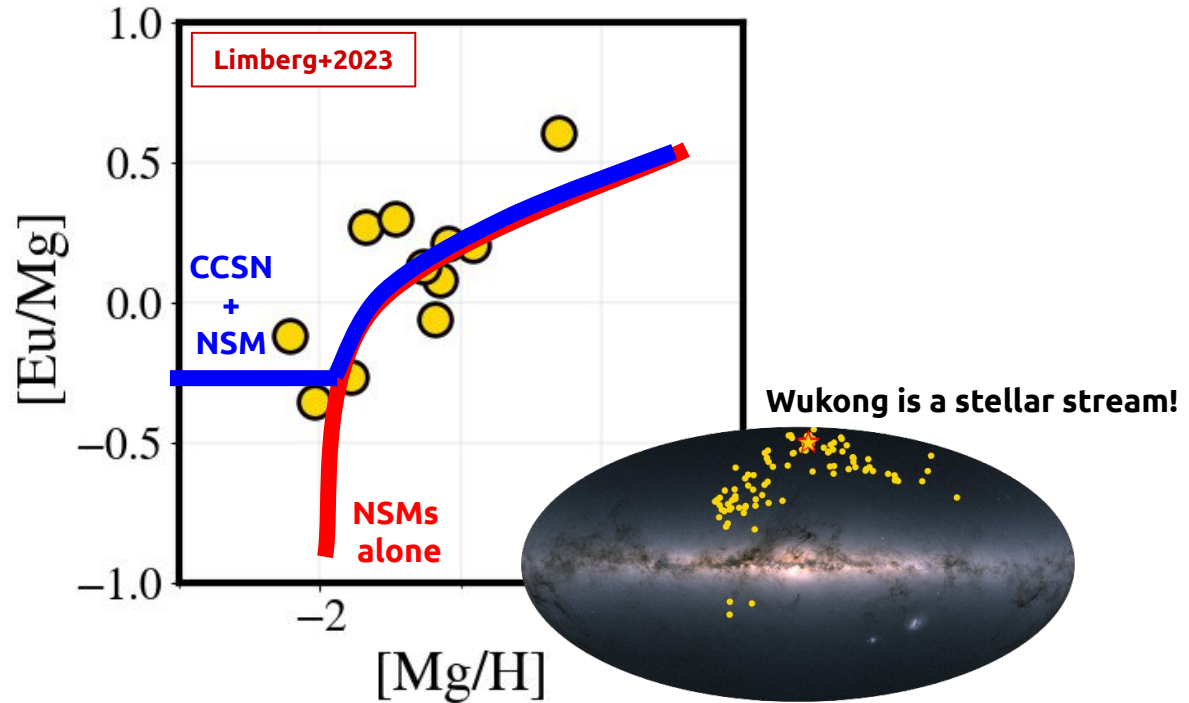
The first dwarf galaxy with **r-process** enrichment clearly from **delayed sources**

(presumably **neutron star mergers**)



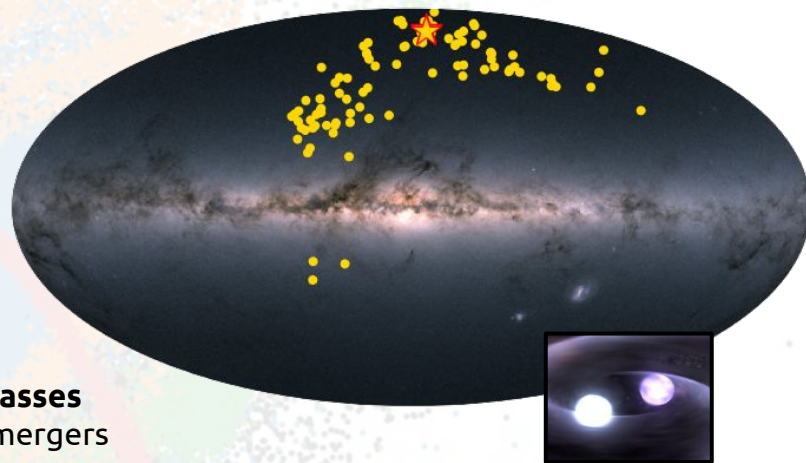
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Takeaway messages and **summary**

- **(G)alactic Archaeology to unveil the origin of chemical elements**
 - stars preserve the compositions of their natal gas clouds
- **Sources of r-process must be rare and prolific**
 - Delayed and prompt play their role, but what are they?
 - Delayed = neutron star mergers (GW170817) ✓
 - Prompt = core collapse or fast neutron star mergers?
- **Massive disrupted dwarfs: Wukong**
 - Delayed source(s) dominate r-process chemical evolution
- **The future: tackle this with other disrupted dwarfs of various masses**
 - We need to go very metal poor to disentangle neutron star mergers from core-collapse supernovae

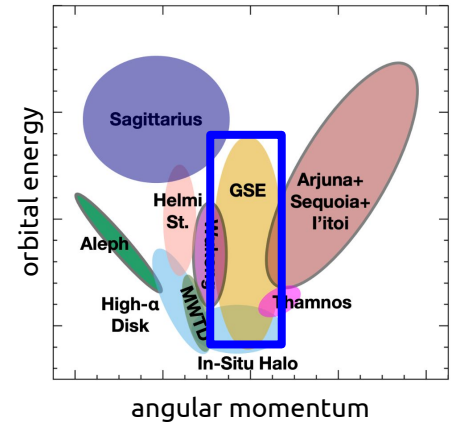
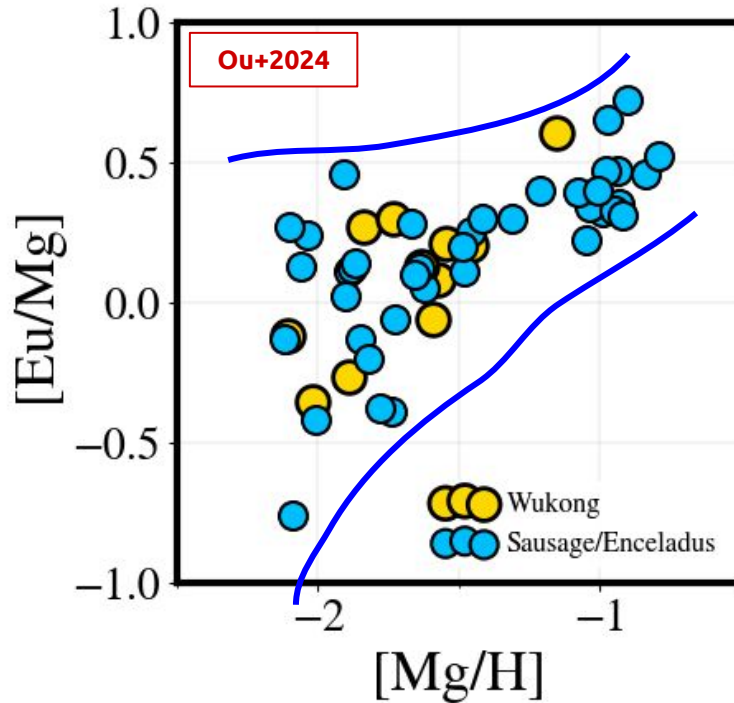


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 @guilimberg



The first dwarf galaxy with **r-process** enrichment clearly from **delayed sources**



Disrupted dwarfs to the rescue? The **Milky Way's halo** contains the debris of many accreted dwarfs

simulated halo* from Aquarius project



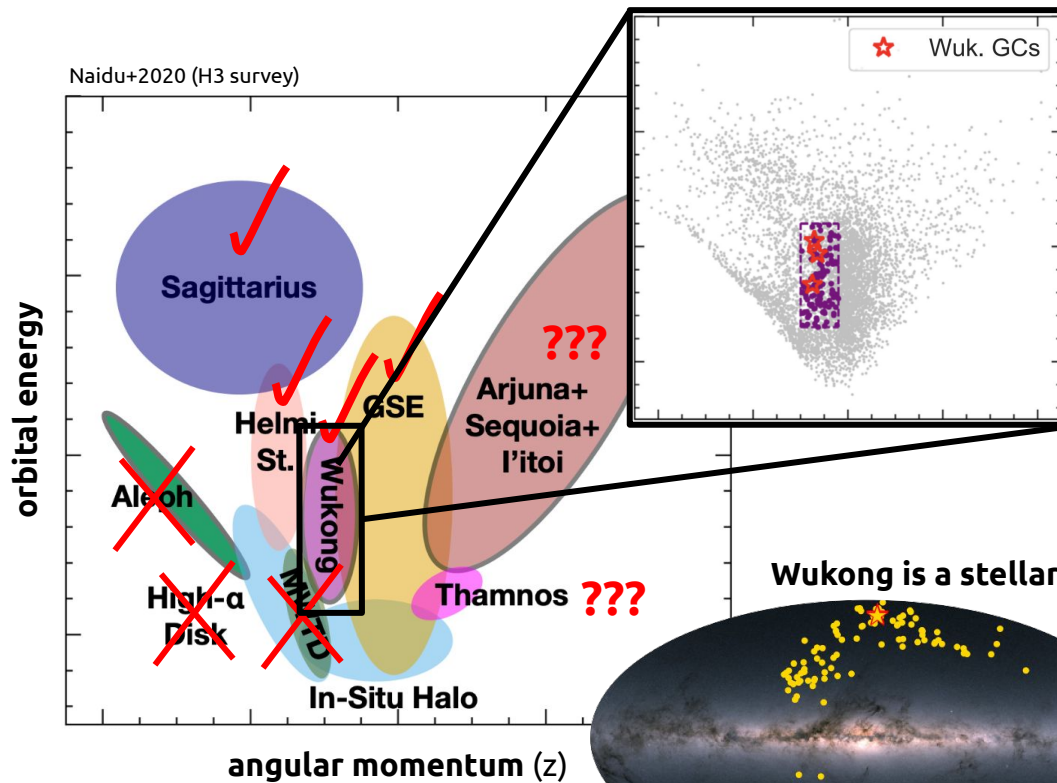
credit: Amina Helmi

Cooper+2010
Helmi+2011

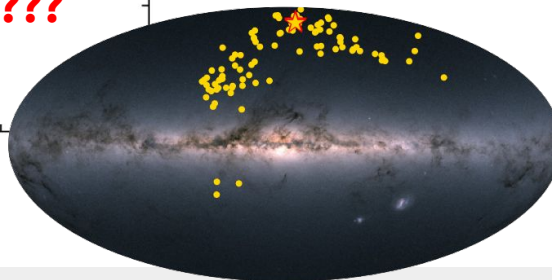


Gaia mission provides the astrometric information needed

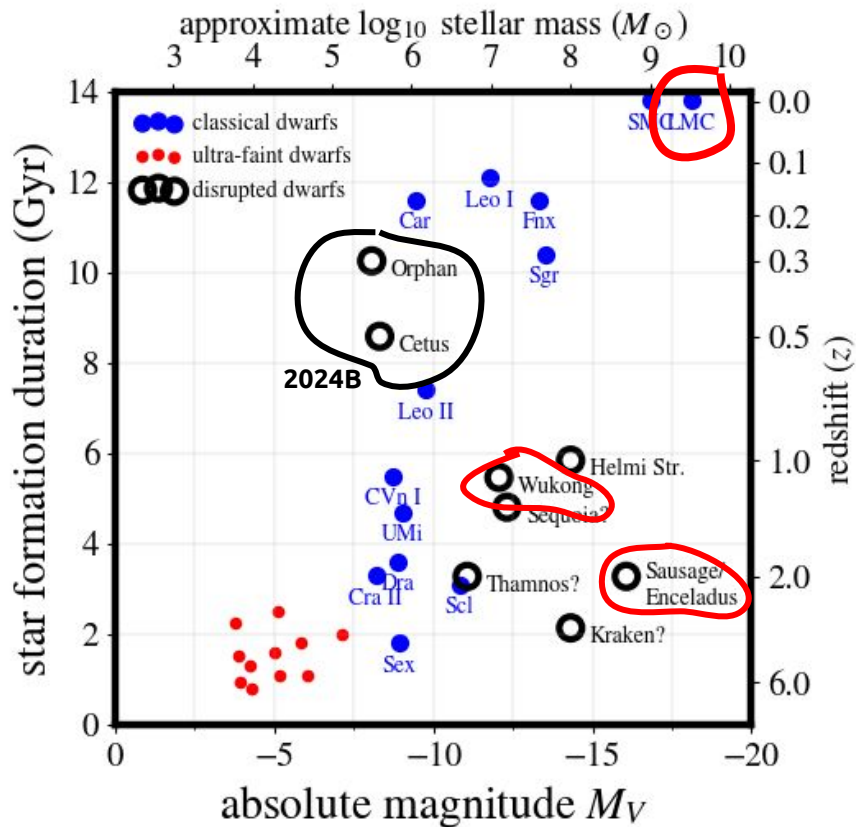
- accreted and real ✓
- do not know if real ???
- in situ (irrelevant) ✗



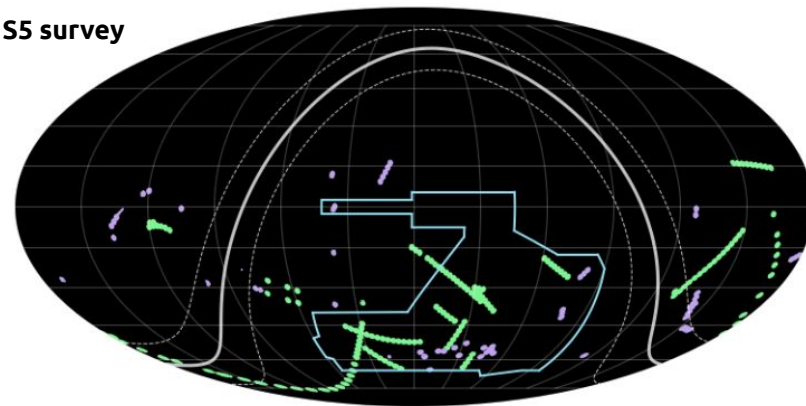
Wukong is a stellar stream!



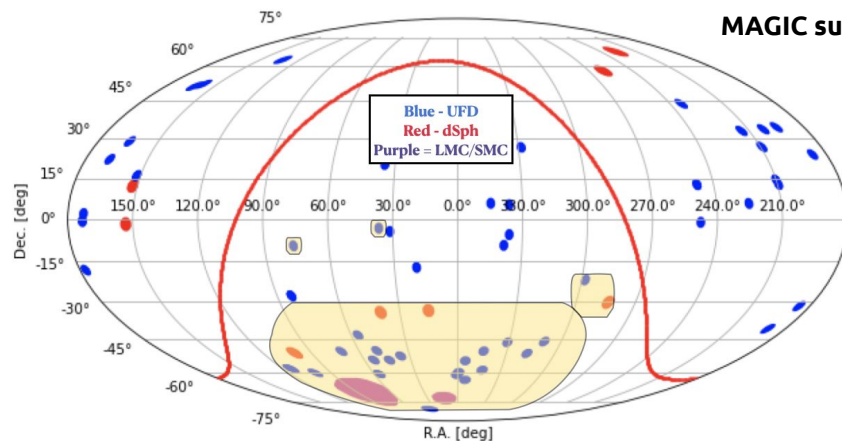
What should we do moving forward?



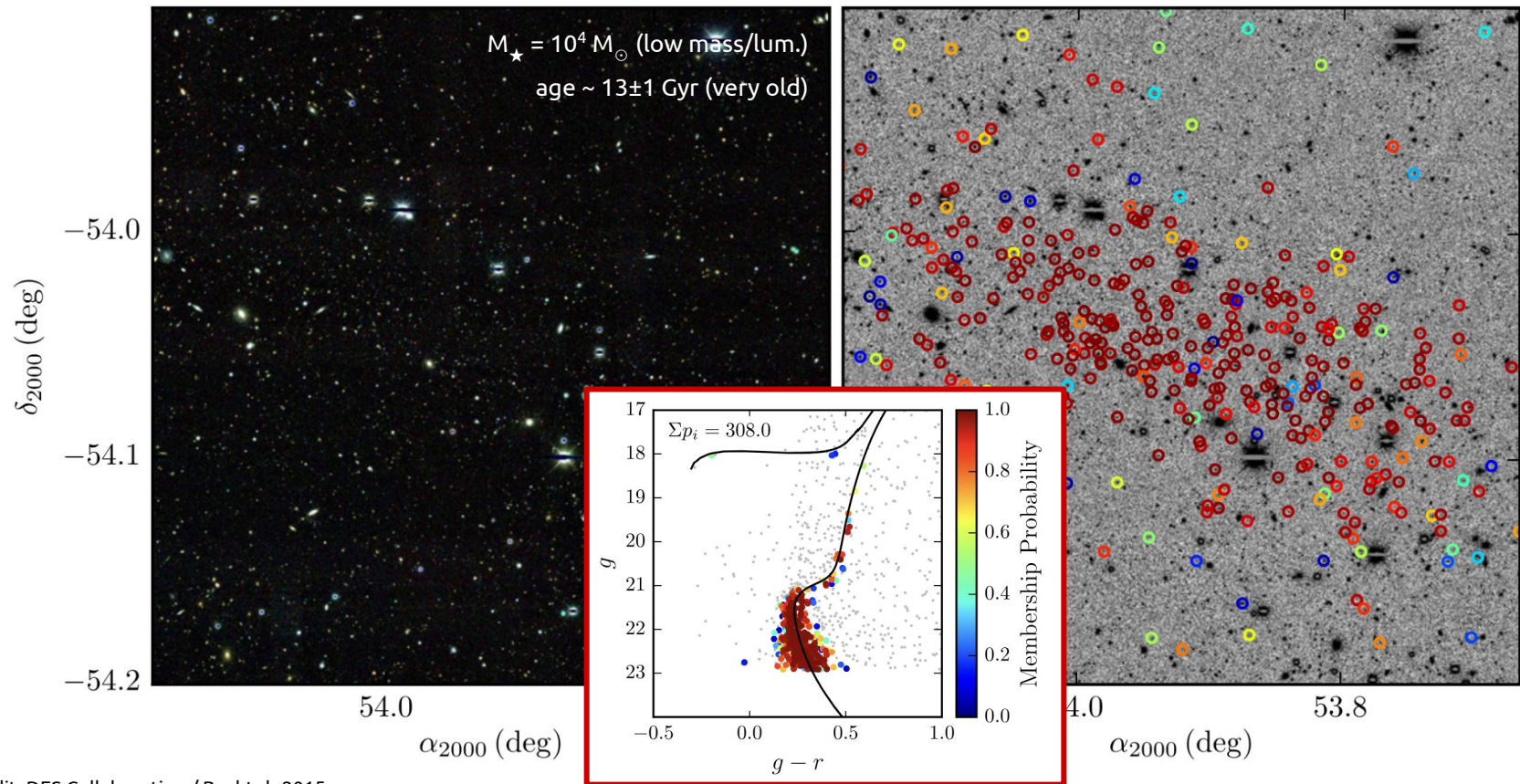
S5 survey



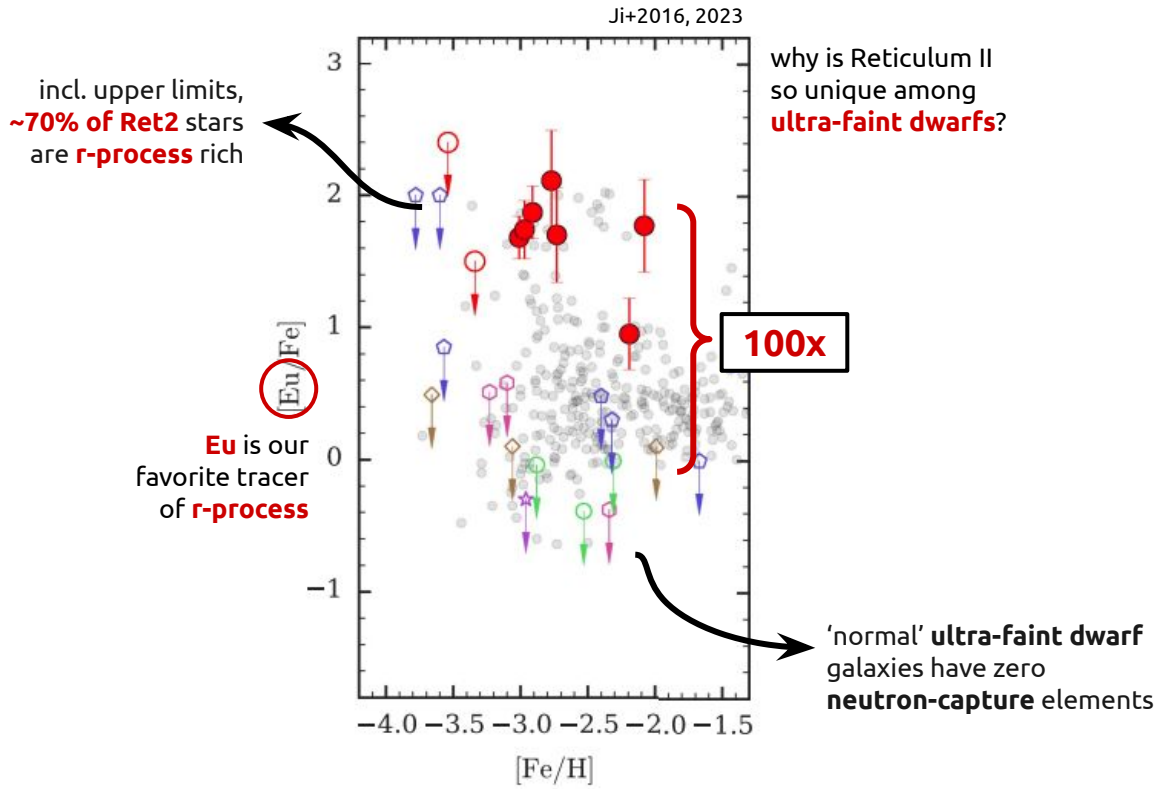
MAGIC survey



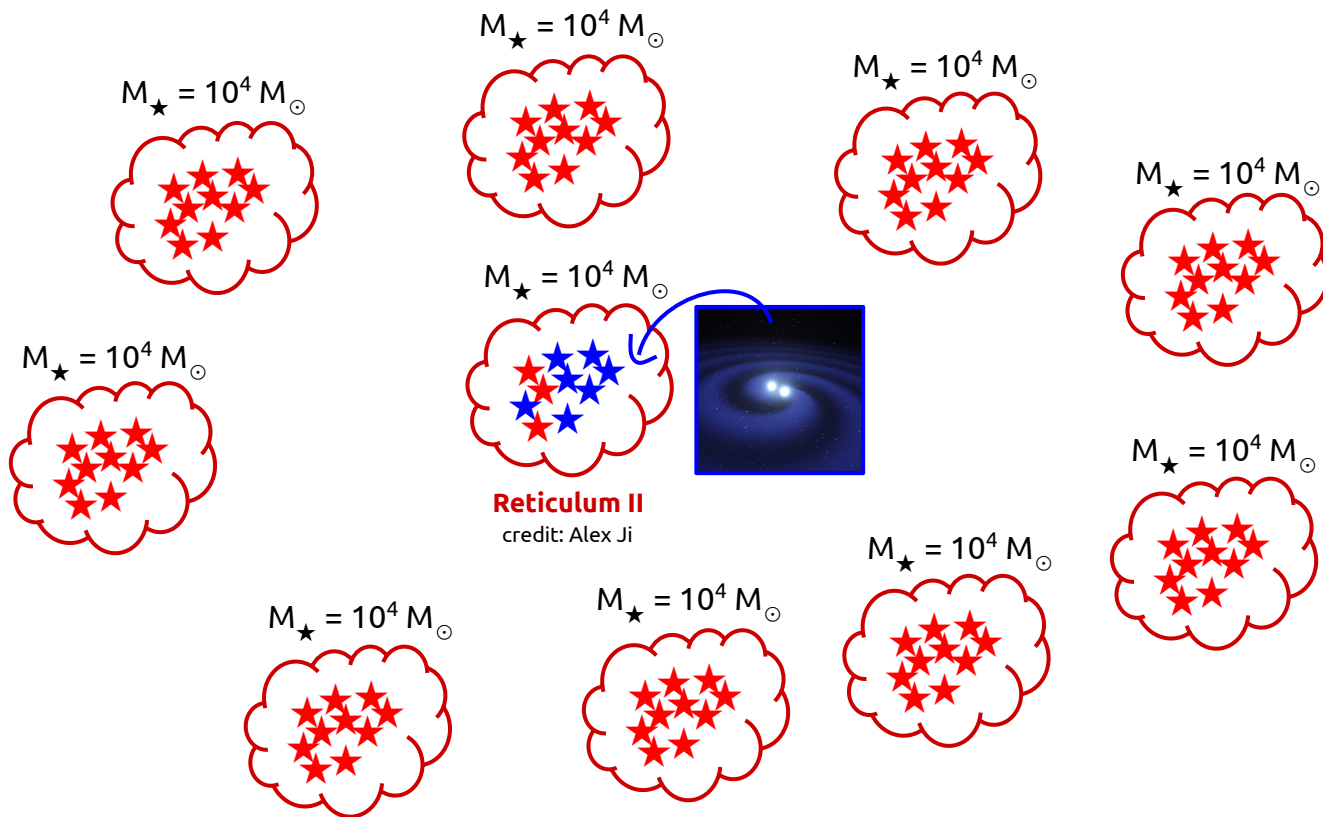
Ultra-faint dwarf **Reticulum II** was enriched in r-process by a single, rare, and prolific event...



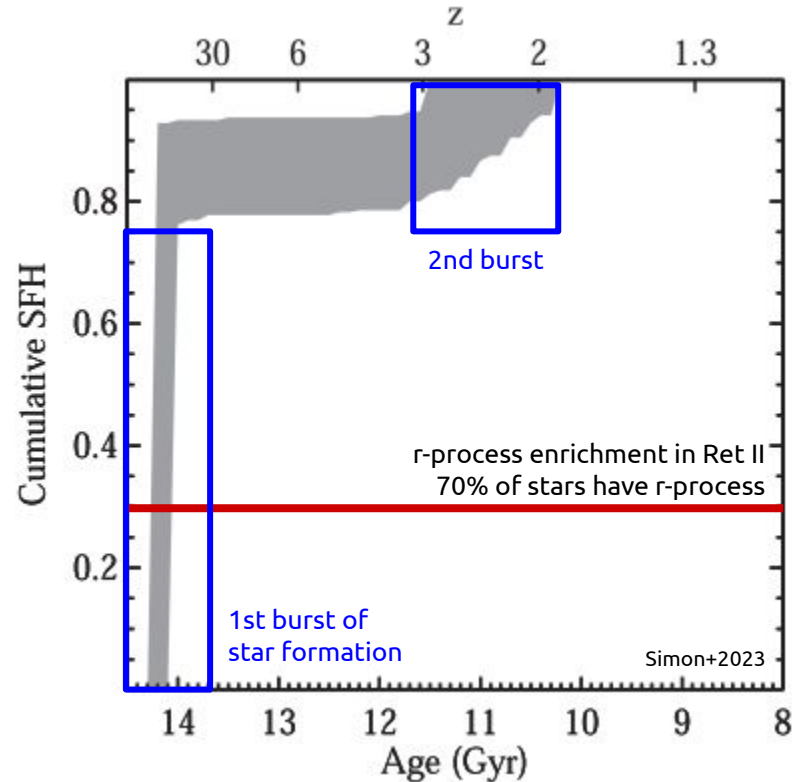
... and **Reticulum II** is immensely **r-process** rich. Why?

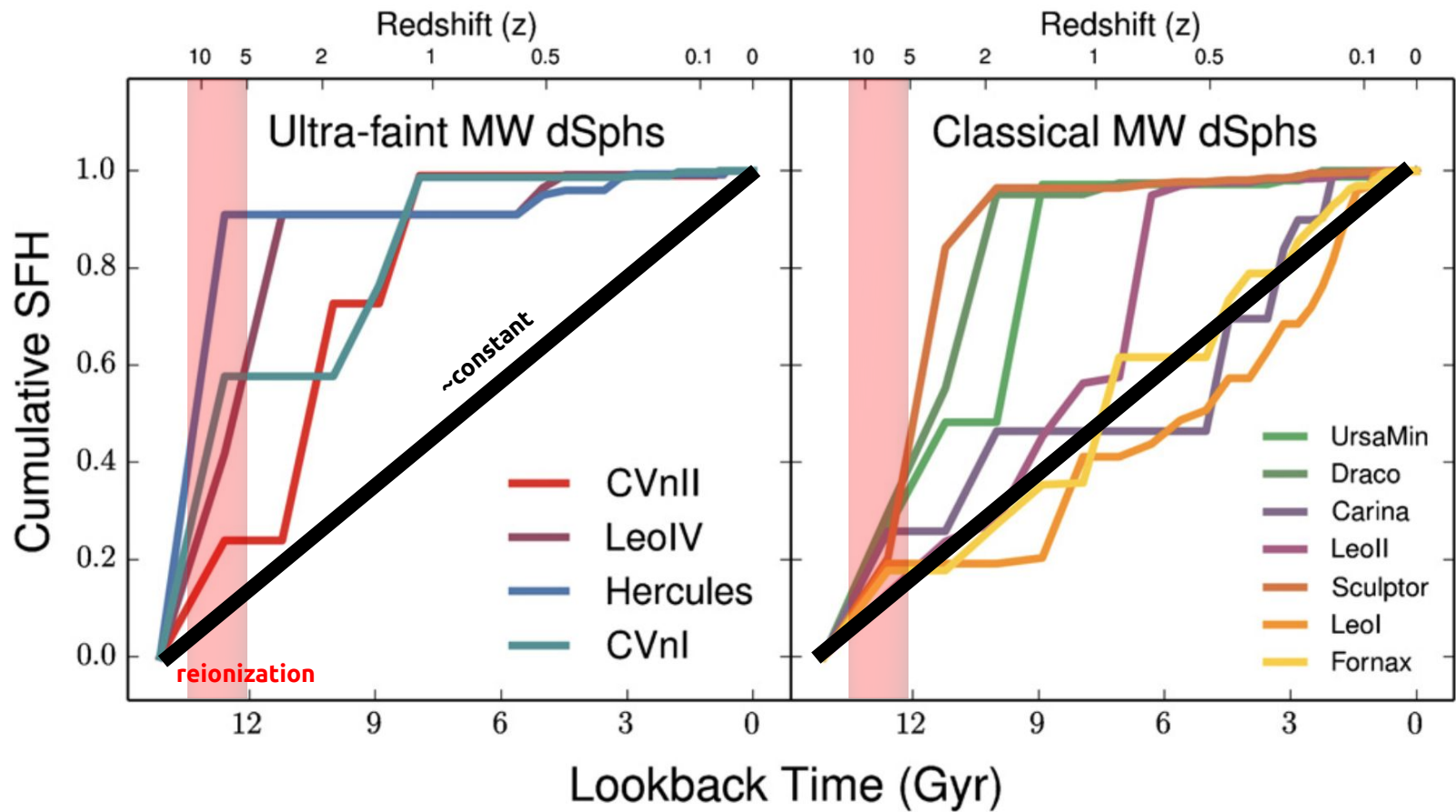


Reticulum II was perhaps just very (un)lucky



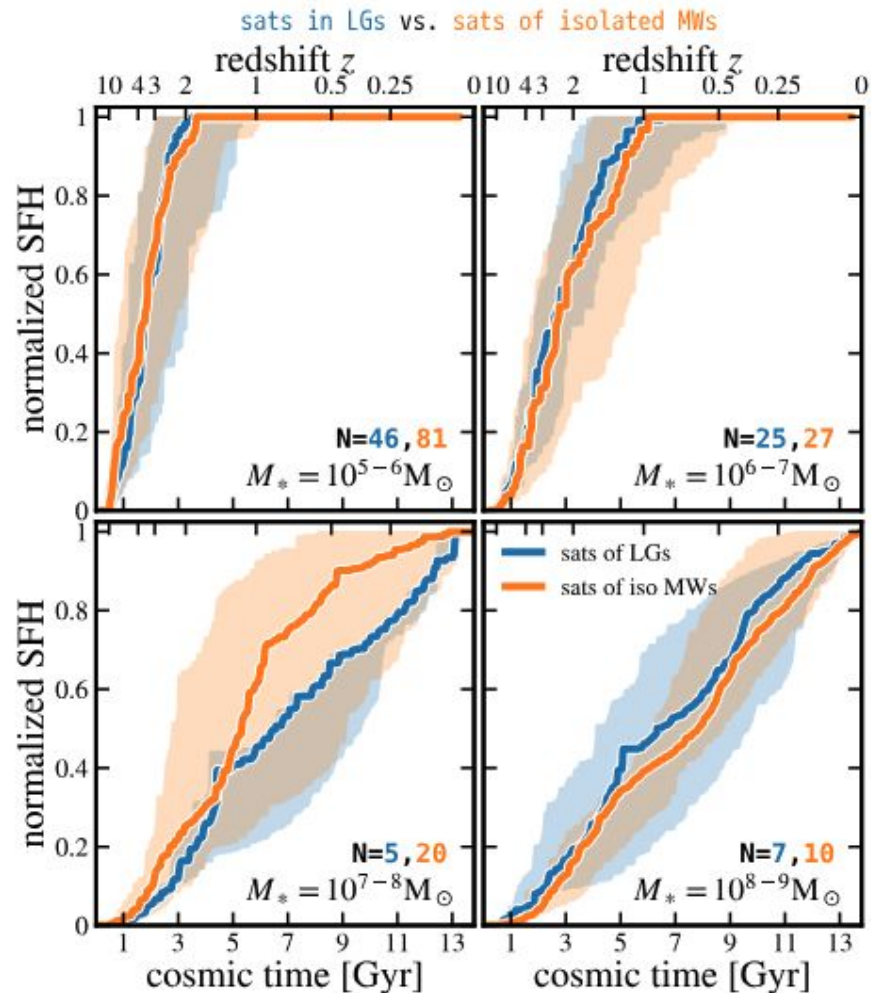
In **Reticulum II**, the r-process happened with a delay time of $\lesssim 500$ Myr





Weisz+2014





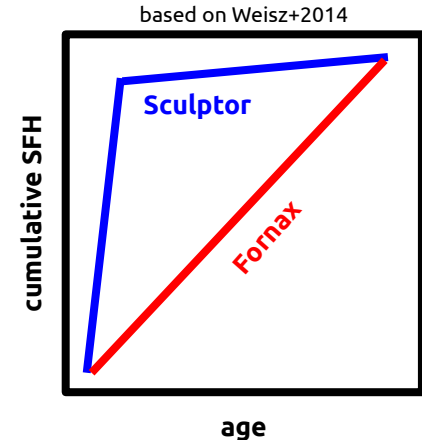
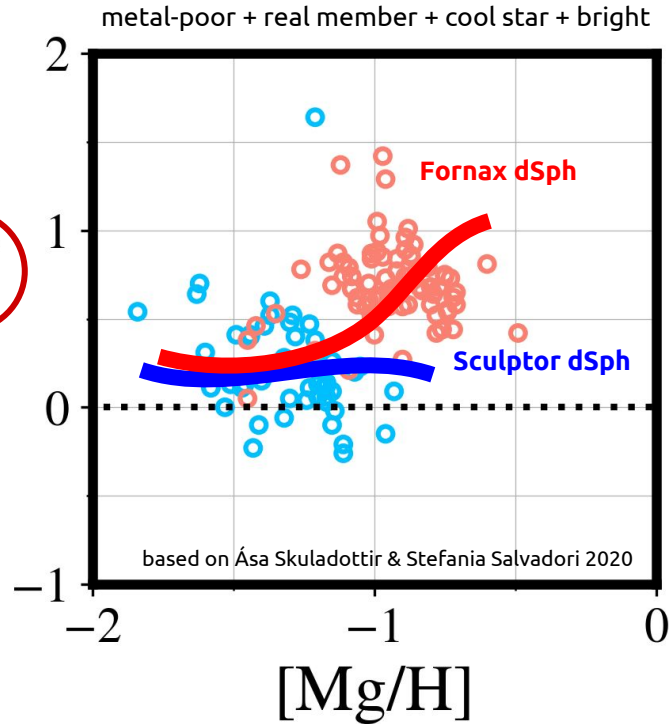
Garrison-Kimmel+2019 with FIRE simulations



In “massive” dwarf spheroidals, **r-process** appears to be **delayed** by several Gyr

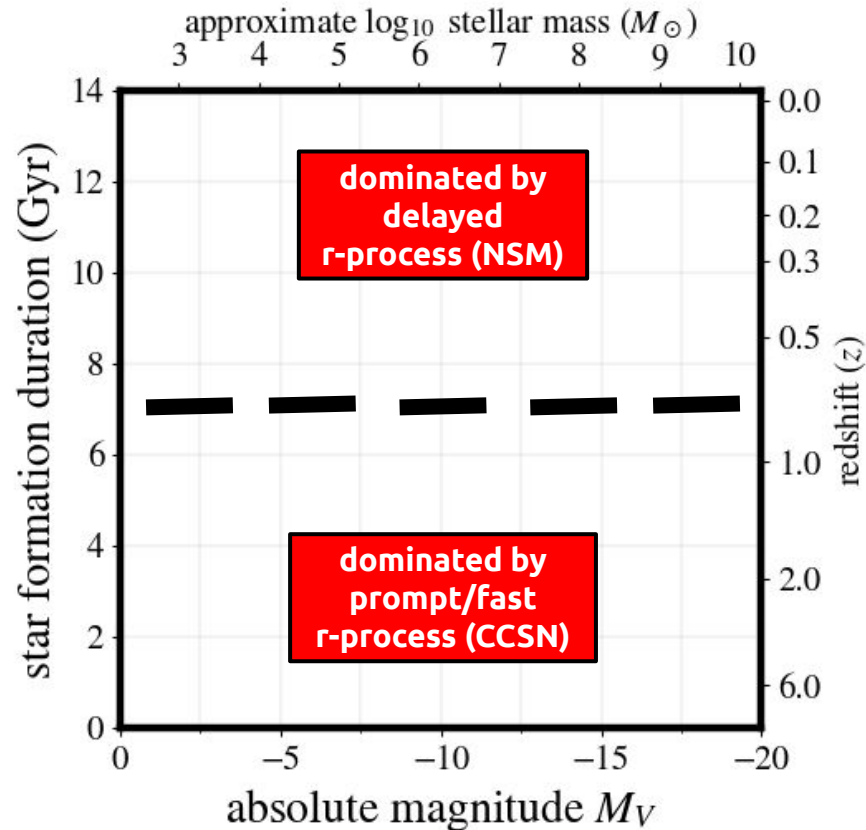
Mg is our favorite tracer of **core-collapse supernovae**

$[Eu/Mg]$

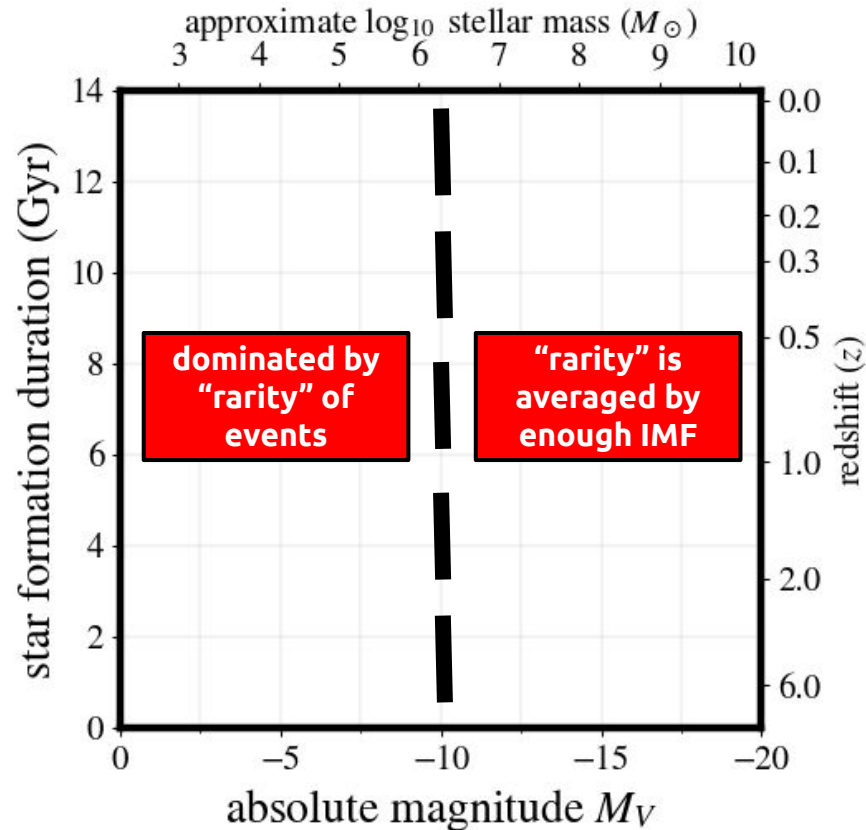


a proxy for “duration” of **star formation**

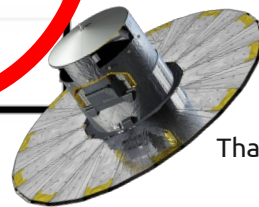
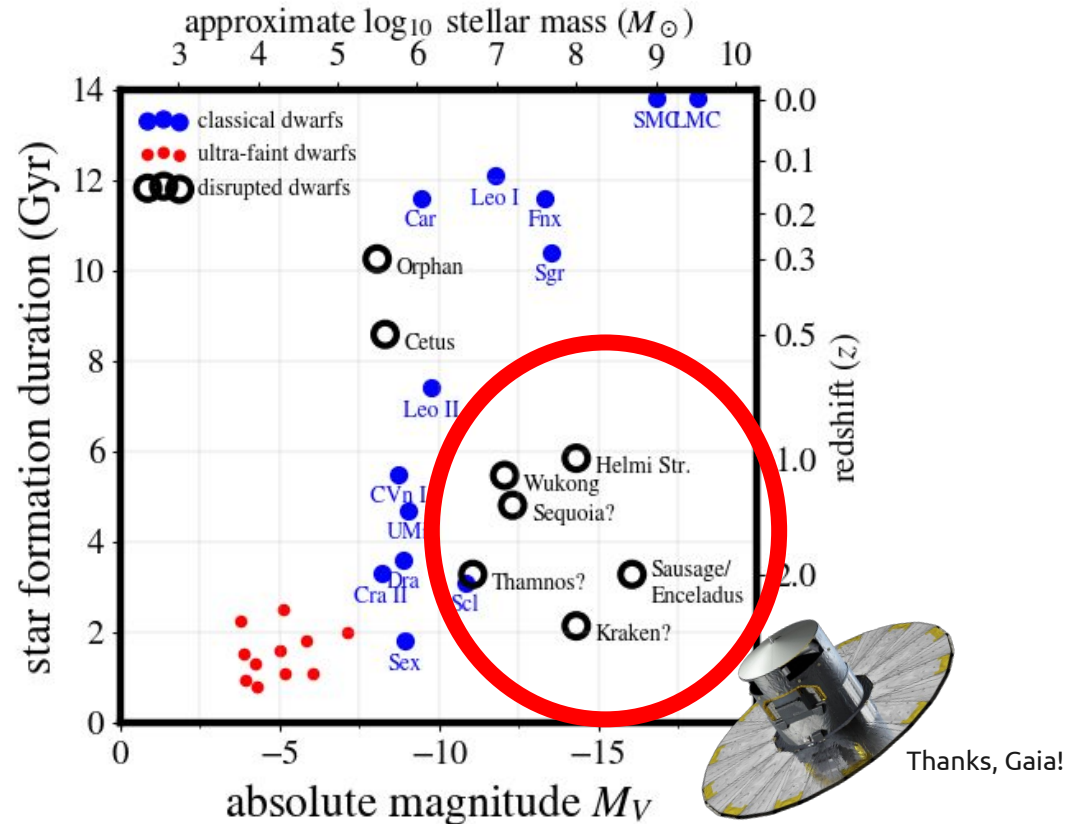
r-process enrichment in galaxies depends on star formation history and stellar mass



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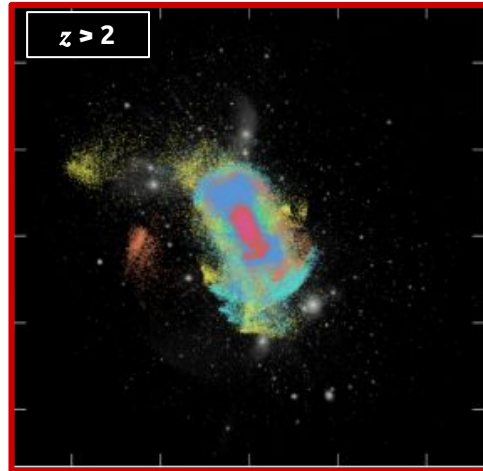
r-process enrichment in galaxies depends on star formation history and stellar mass



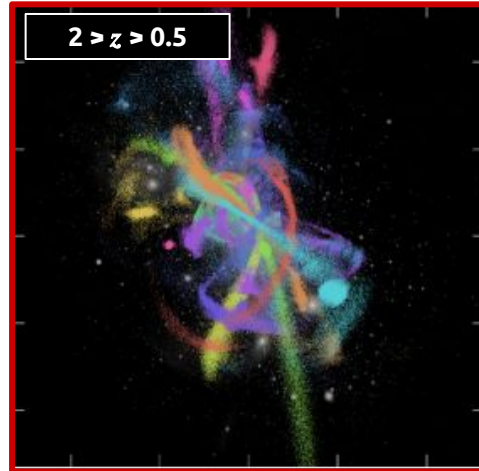
Thanks, Gaia!

... but, with time, **dwarf Milky Way satellites** get more and more disrupted

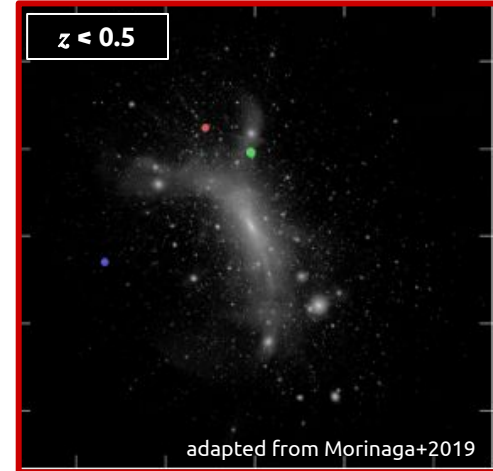
phase mixed



stellar stream



intact dwarf



past



$z = 0$



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