Where has all the r-process gone?

An Exploration of the Capacity for Swift GRB-KNe to Enrich their Hosts

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Center for Astrophysics
20 Years of Swift Conference
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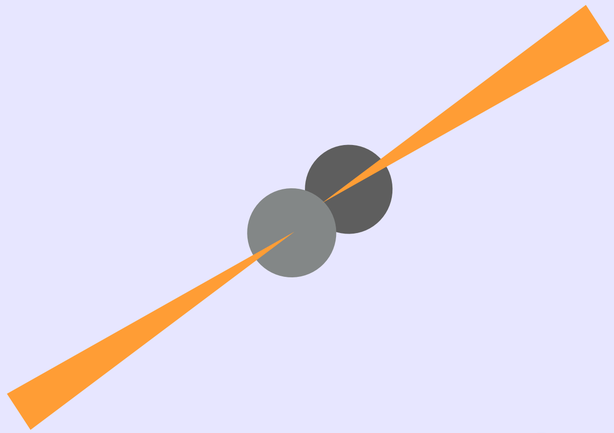
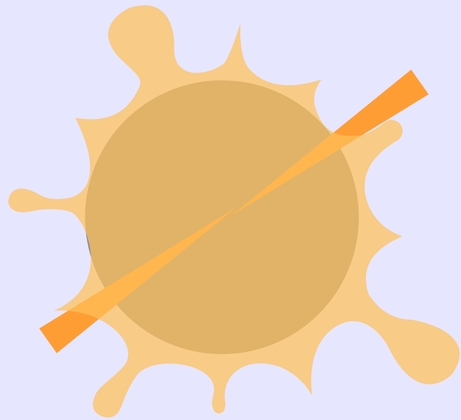
What are the astrophysical sites of r-process elements?



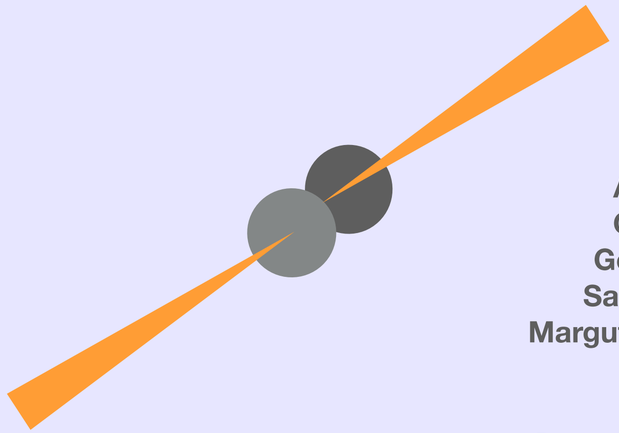
Neutron Star Mergers



Collapse of Massive Stars

What are the astrophysical sites of r-process elements?

Only confirmed source!



Abbott+ 2017,
Coulter+ 2017
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Margutti + Chornock 2021

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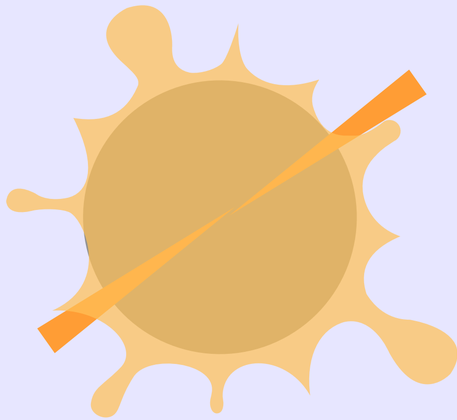

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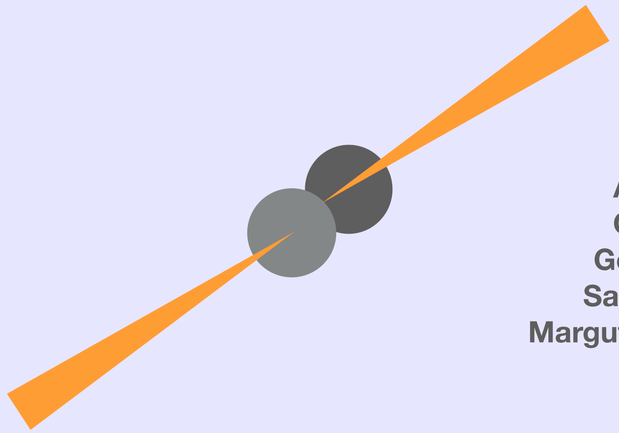

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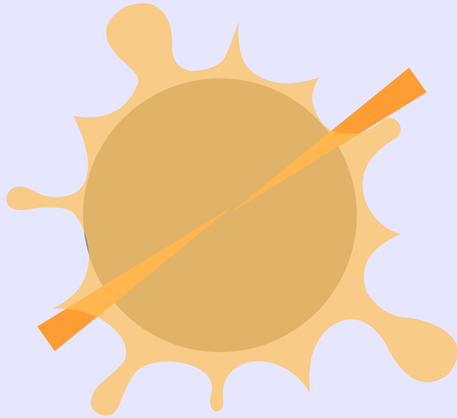
Neutron Star Mergers

Still no observational evidence

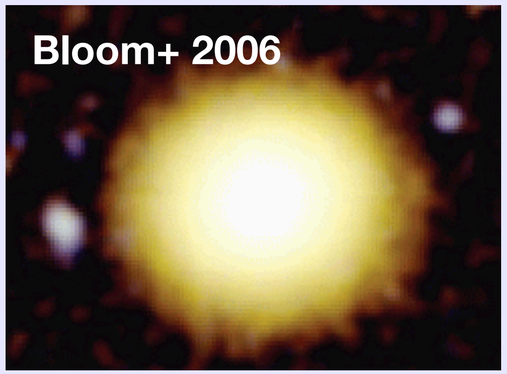


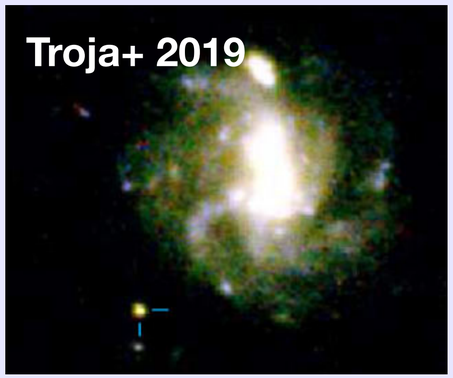
Siegel+ 2019
Blanchard+ 2023
Anand+ 2023
Rastinejad+ 2024

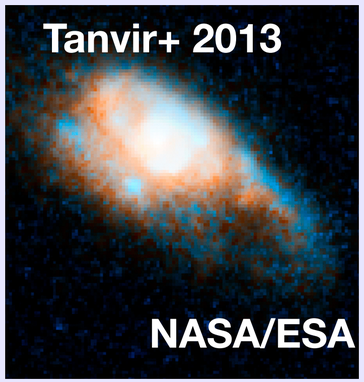
Collapse of Massive Stars

Neutron star mergers and collapsars have very different host environments!

NS mergers



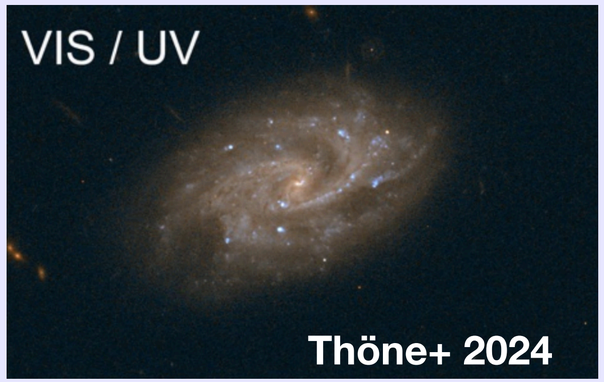




$\approx 10 - 200$ Myr minimum timescale

Belczynski+ 2010, Dominik+ 2012, O'Shaughnessy+ 2017, Zevin+ 2022, Nugent+ 2022, Mandhai+ 2022

CCSNe/Collapsars



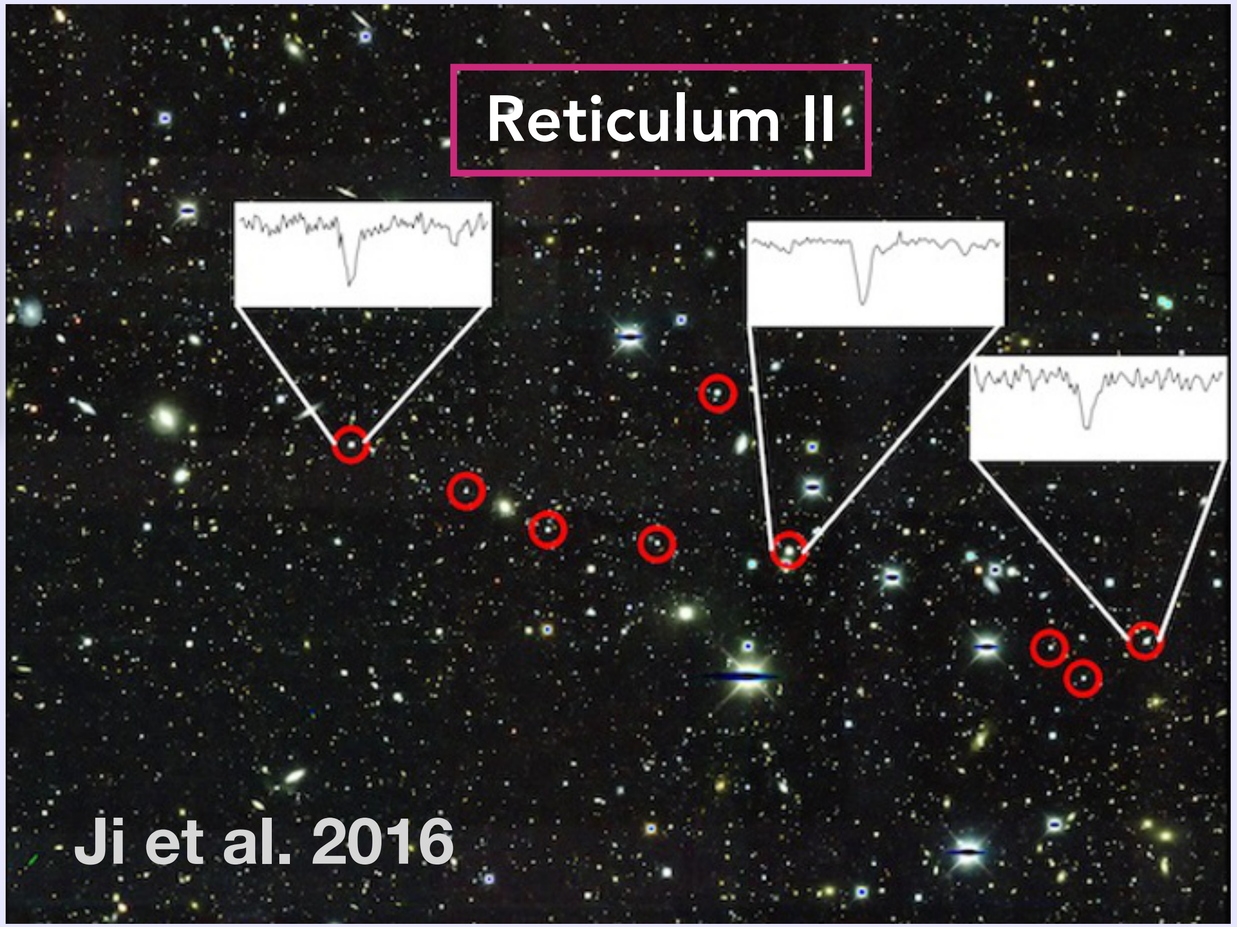
≈ 10 Myr timescale

Svensson+ 2010, Perley+ 2013, Vergani+ 2015, Wang & Dai 2014, Blanchard+ 2017, Niino+ 2017, Schulze+ 2021, Taggart & Perley 2021

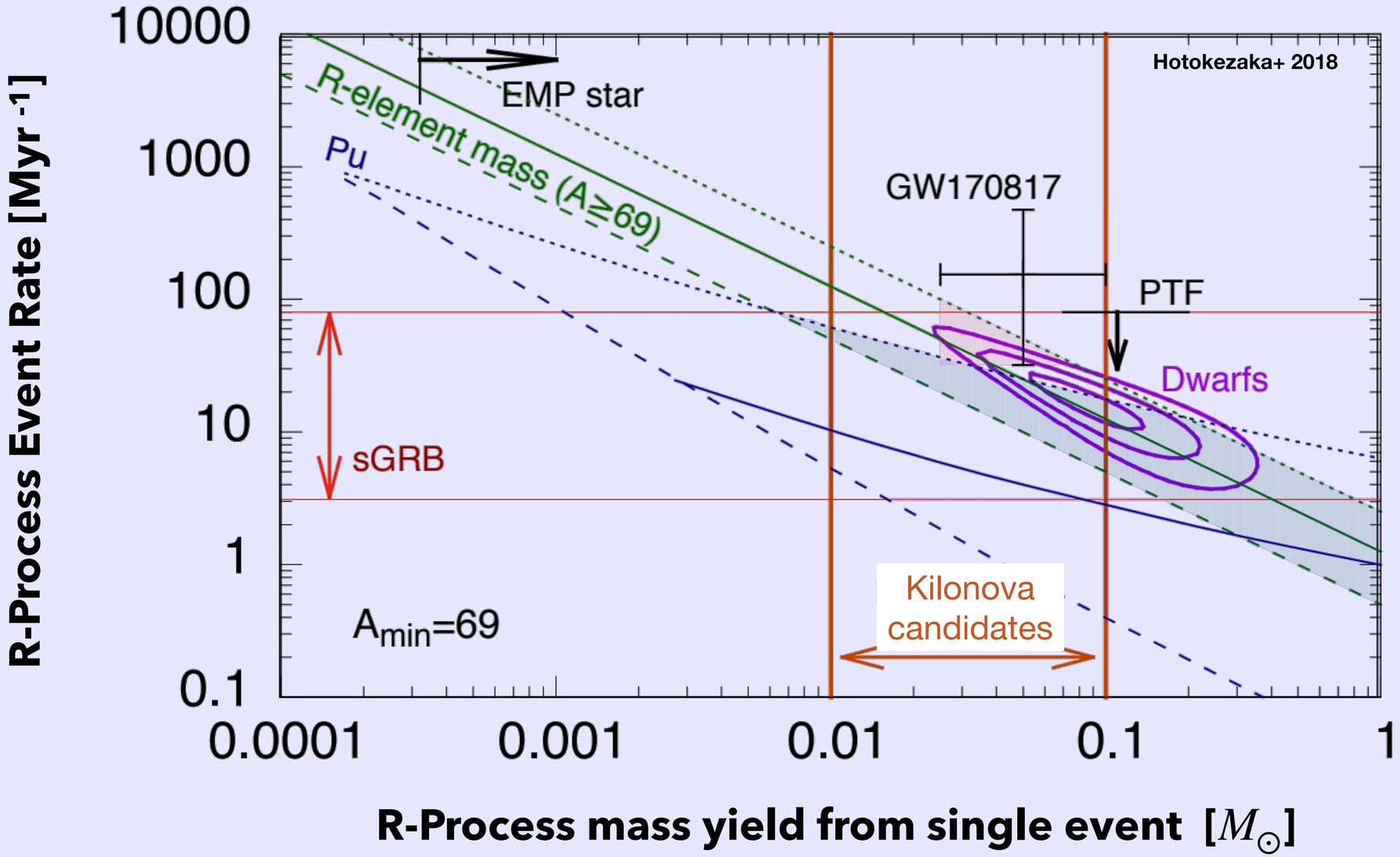
R-Process elements observed in the absence of transients

R-process elements have been discovered in a variety of Local Group dwarf galaxies and Galactic metal poor stars

Eichler+ 1980,
McWilliam+ 1995,
Shetrone+ 2001,
Ji+ 2016,
Duggan+ 2018,
Matsuno+ 2021,
Molero+ 2021,
Reggiano+ 2021,
Naidu+ 2022,
Limberg+ 2023



R-Process Event Rates and Yields



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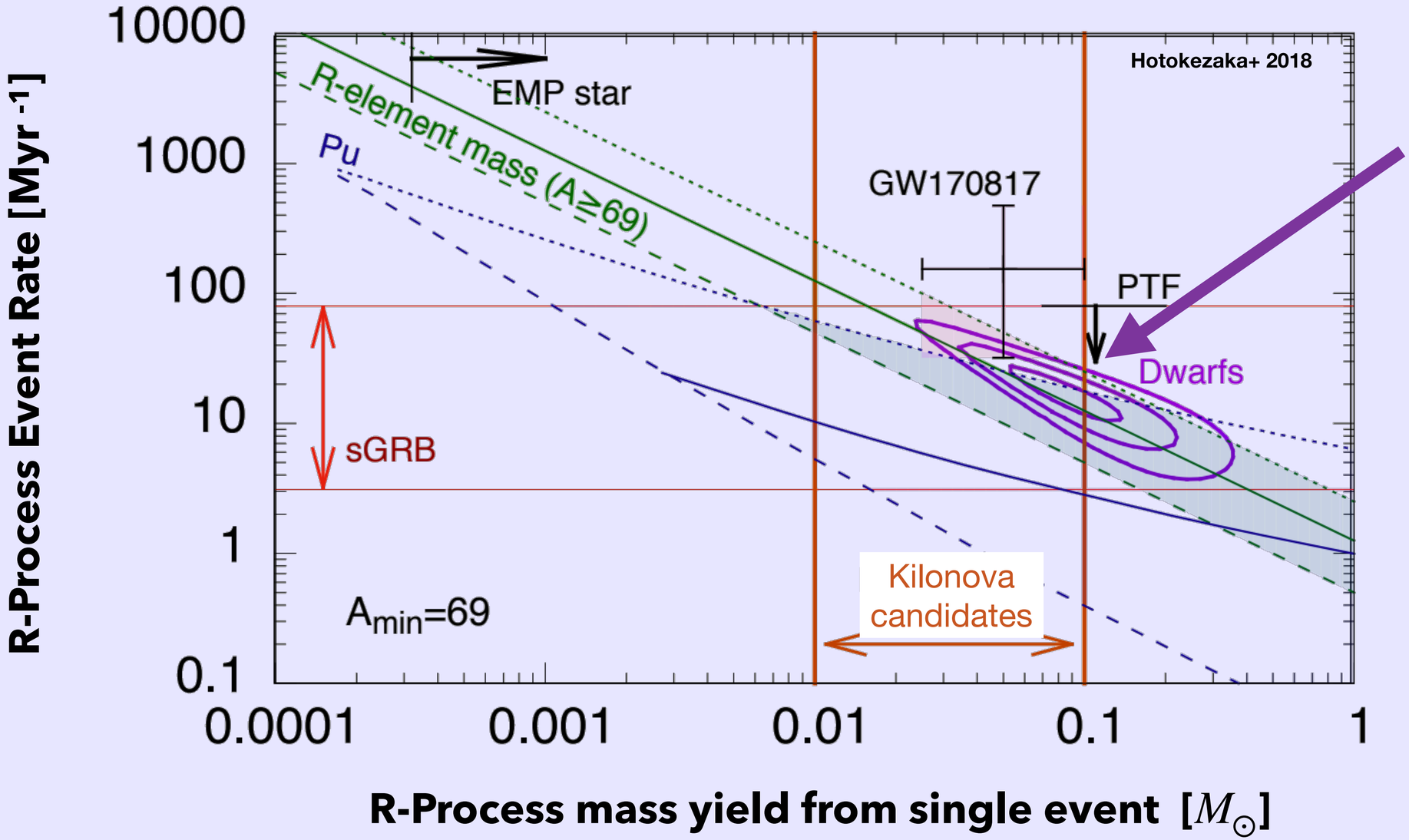
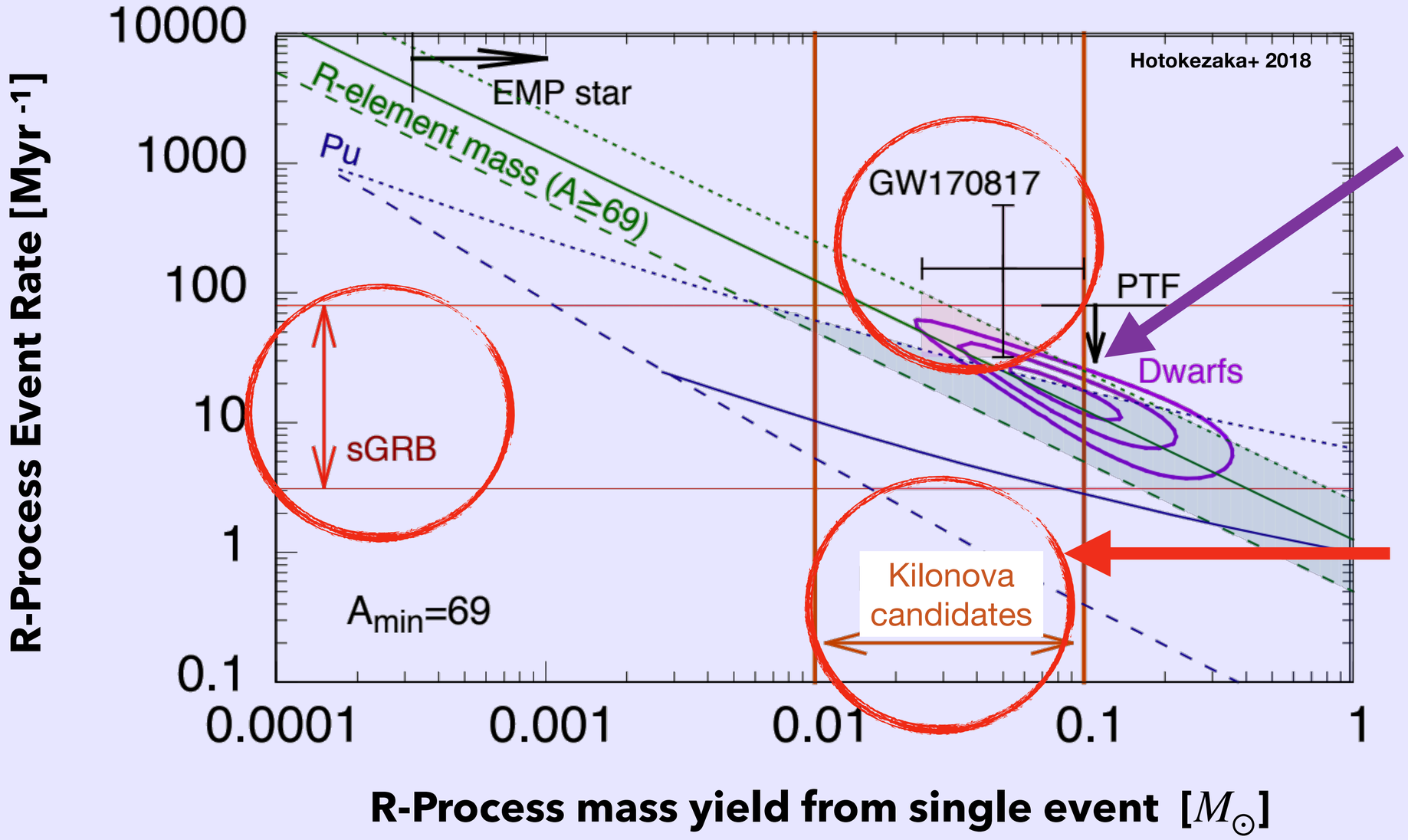


r-process mass estimated for a single event from dwarf galaxy stars and their event rates

R-Process Event Rates and Yields

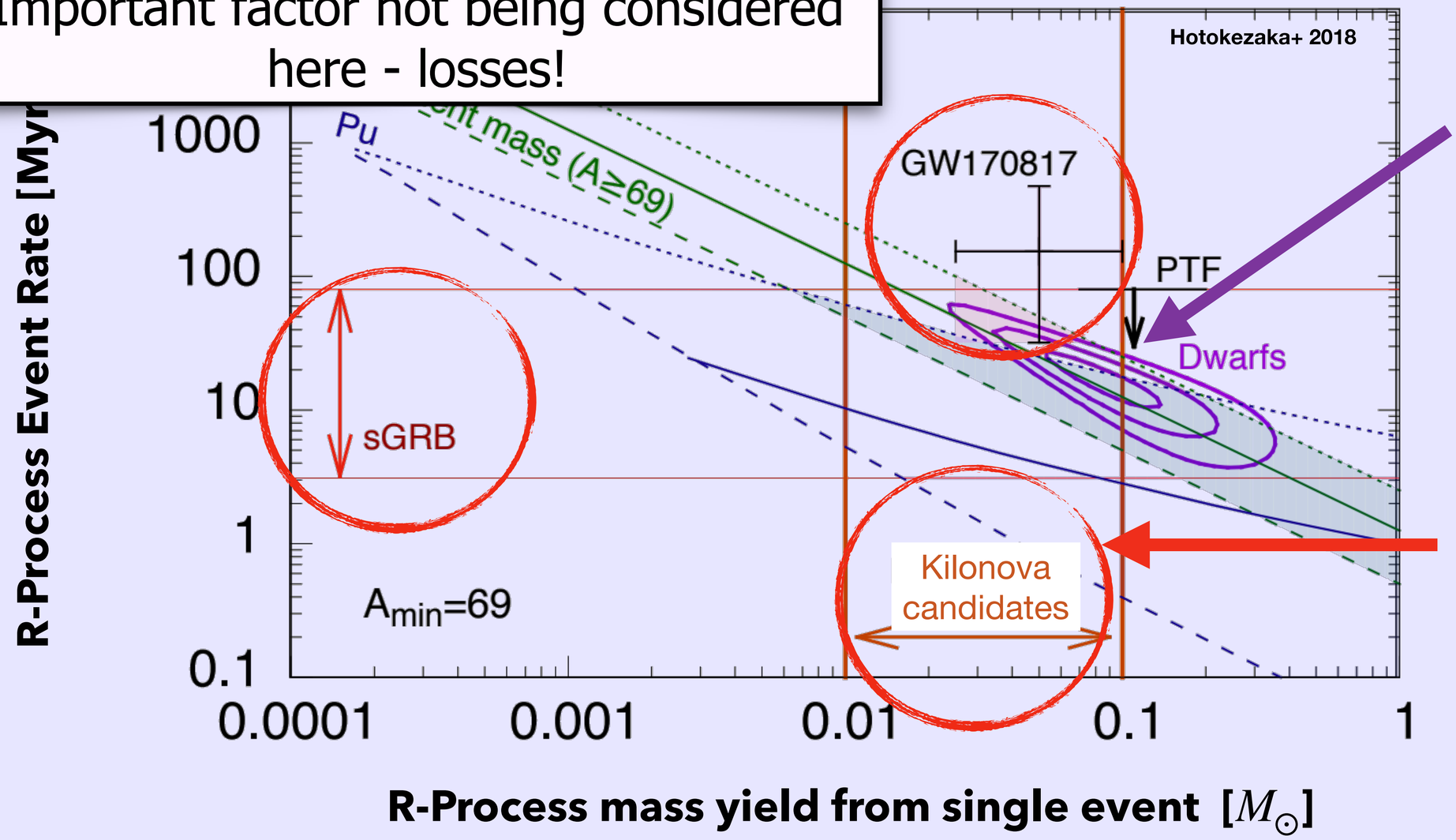


r-process mass estimated for a single event from dwarf galaxy stars and their event rates

match well with those of the observed NS merger population

R-Process Event Rates and Yields

Important factor not being considered here - losses!



r-process mass estimated for a single event from dwarf galaxy stars and their event rates

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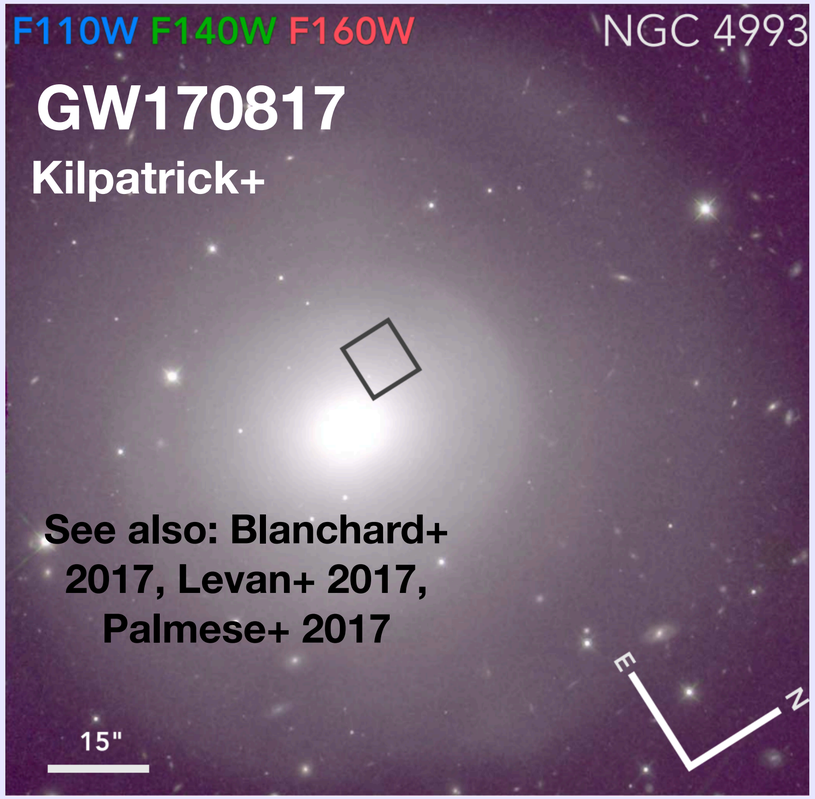
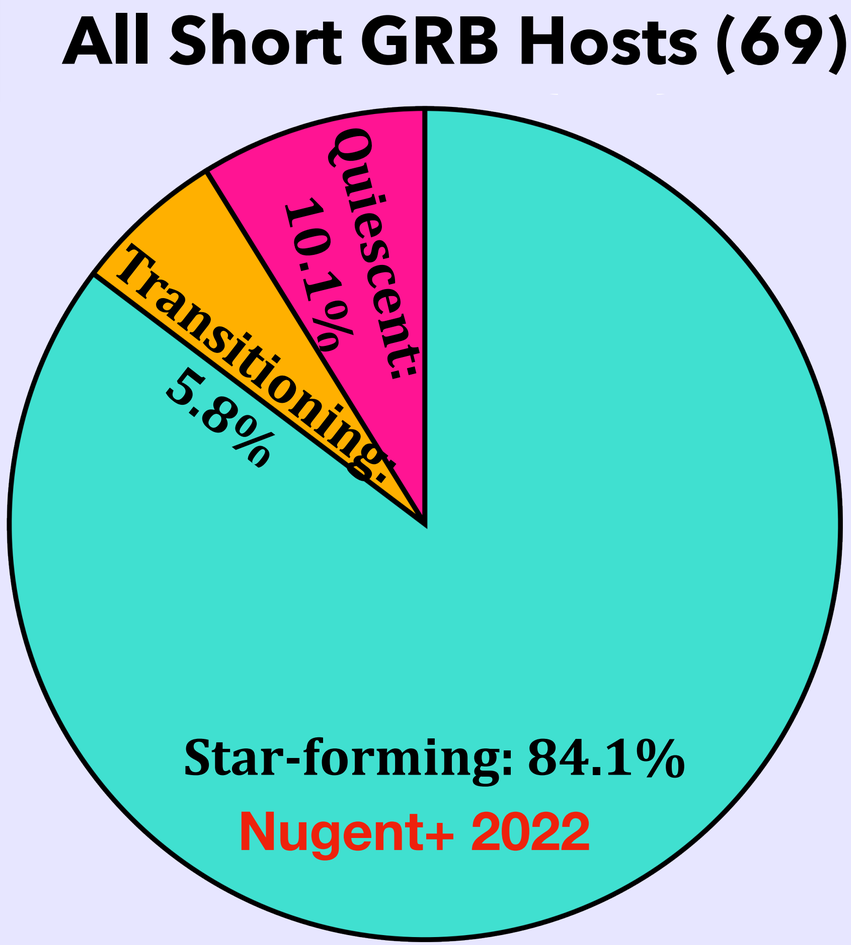
Why are losses important?

Neutron star mergers occur in galaxies with no ongoing star-formation!

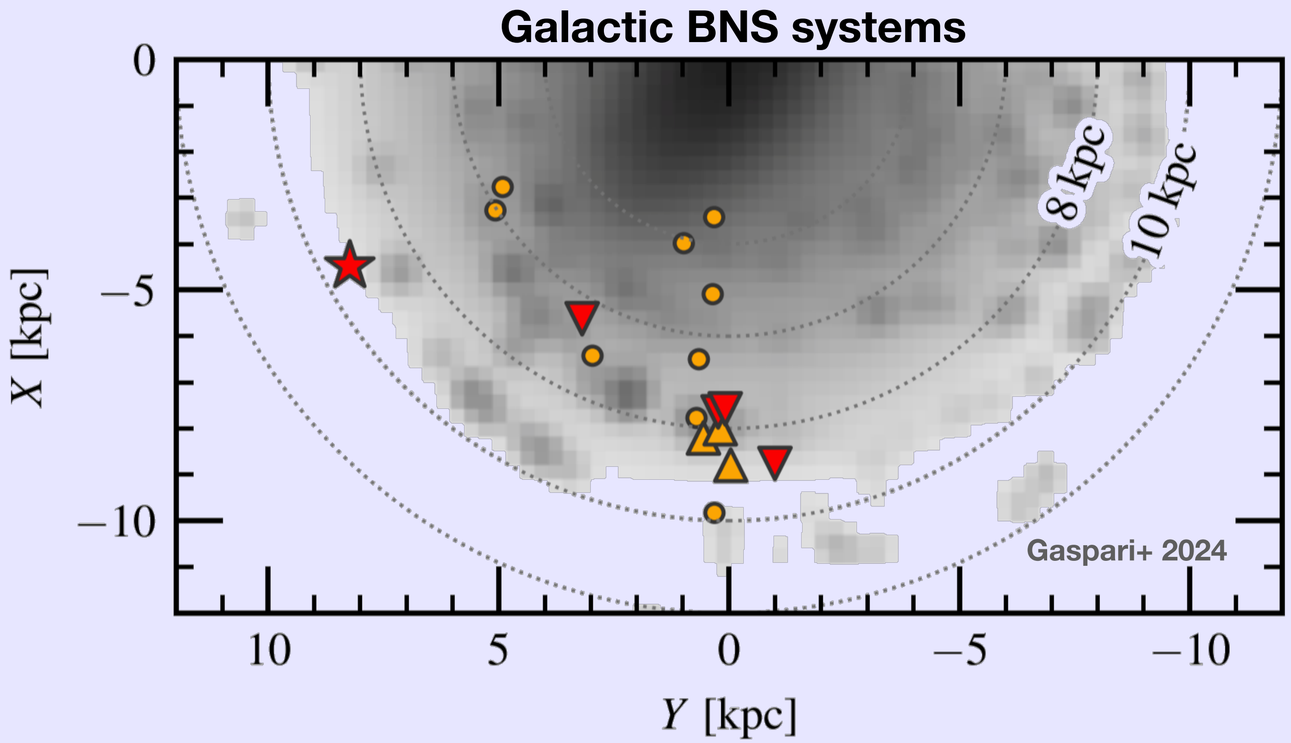


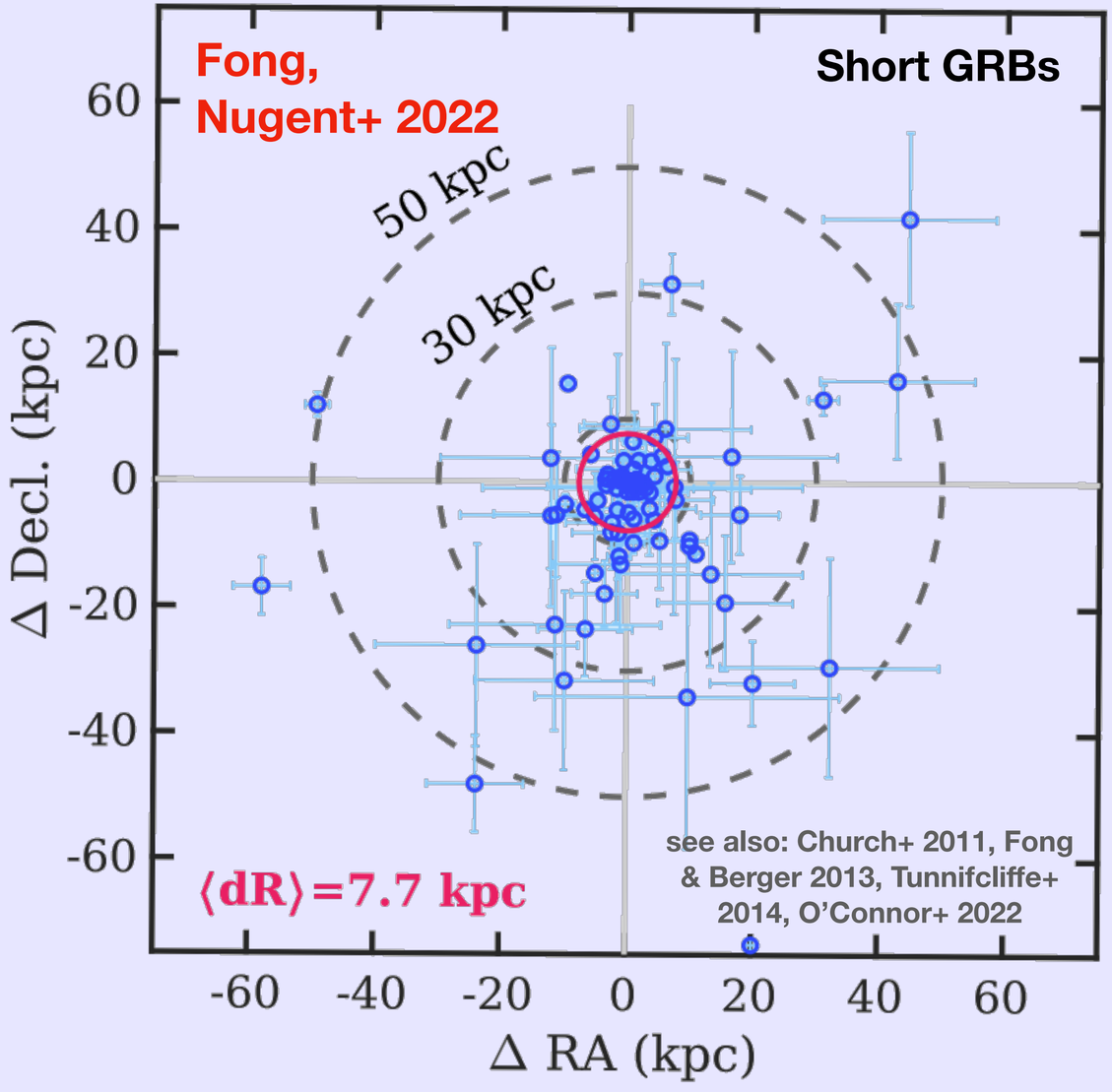


See also: Mandhai+ 2022, Chu+ 2022

Why are losses important?

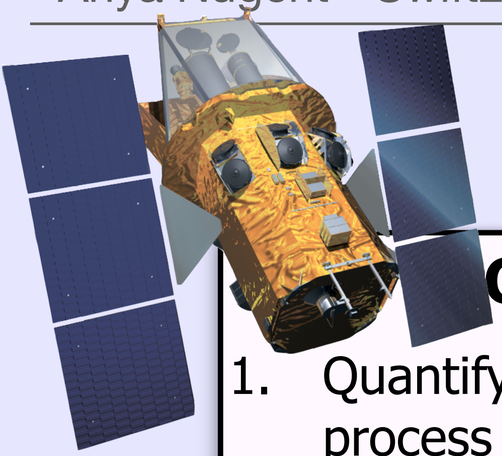
Neutron star mergers can be very offset from hosts - does this mean it takes a long time for their r-process to travel back?





Our goals:

1. Quantify the **timescale** for r-process to travel from NS merger location to star-forming gas
2. Determine the **fraction of stellar mass capable of being "enriched"** from a single NS merger event



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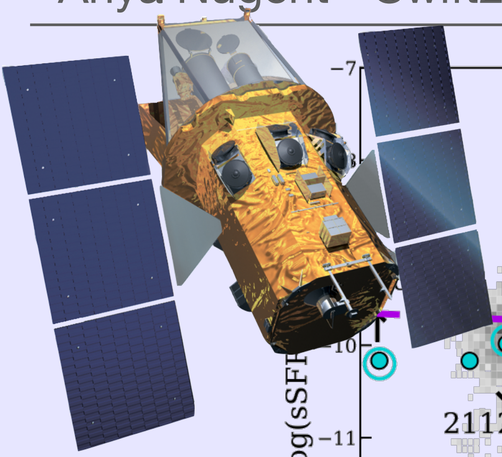
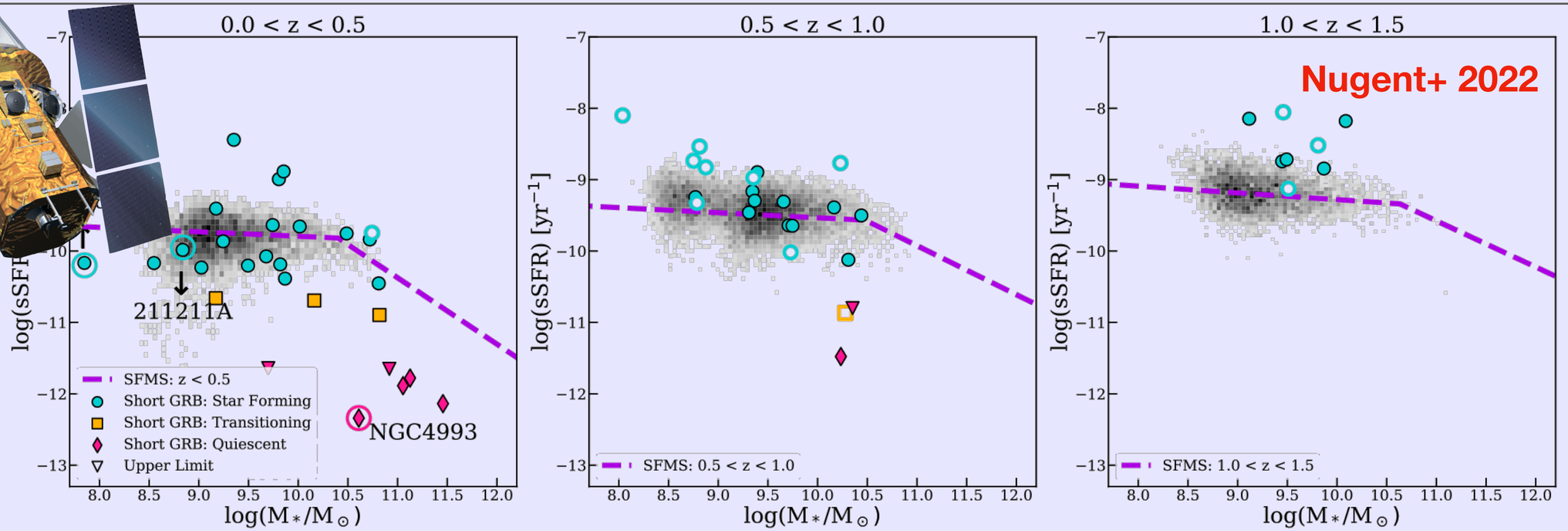
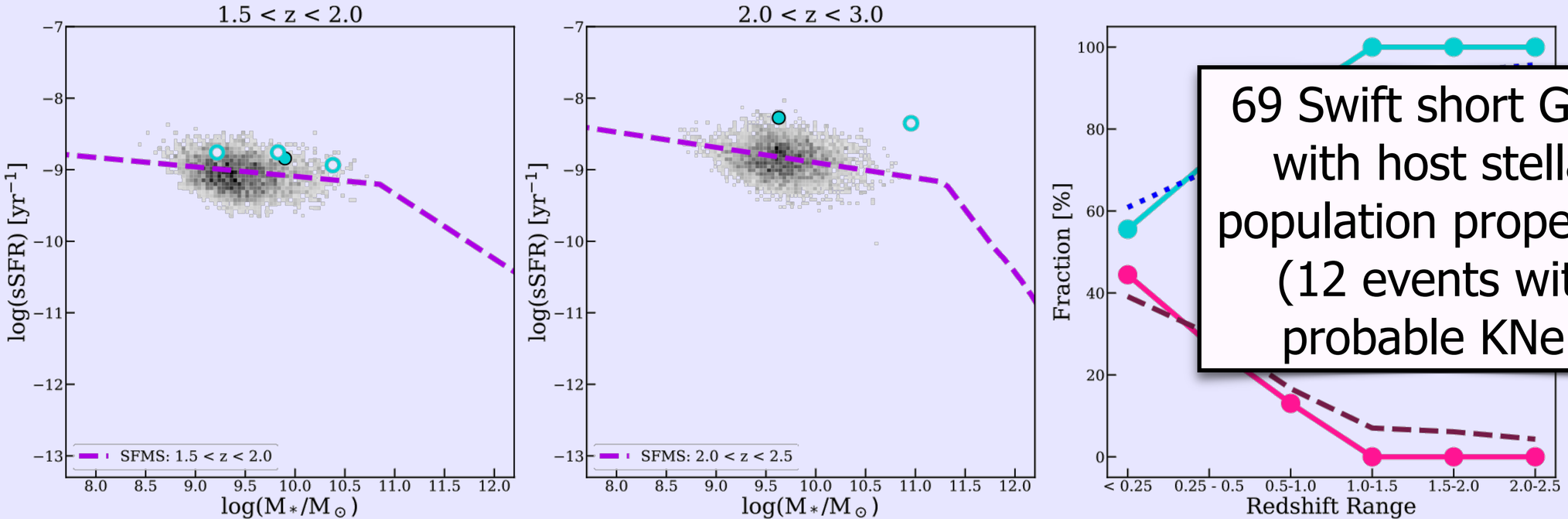




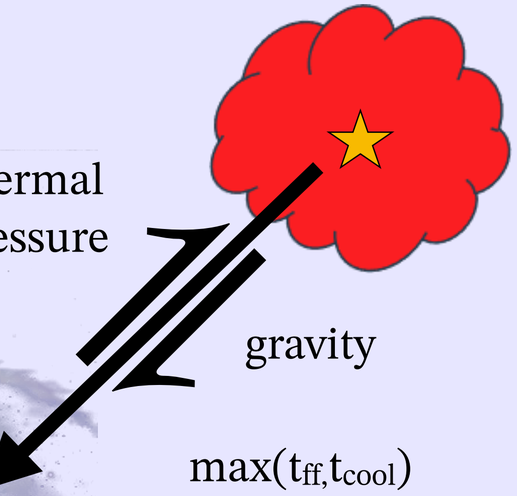


69 Swift short GRBs with host stellar population properties (12 events with probable KNe!)

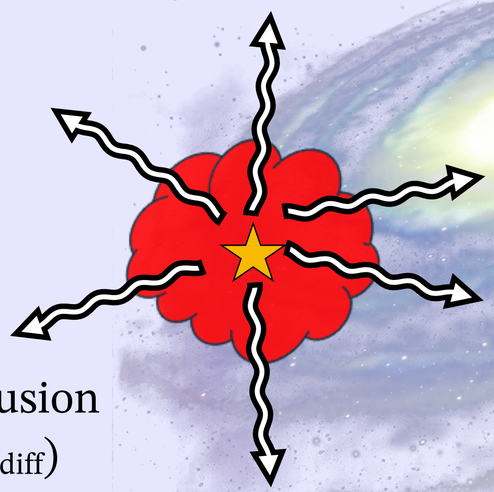
Quantifying the "Enrichment" Timescale

The enrichment timescale is the faster of either scenario

Scenario 1: Free-fall and Cooling

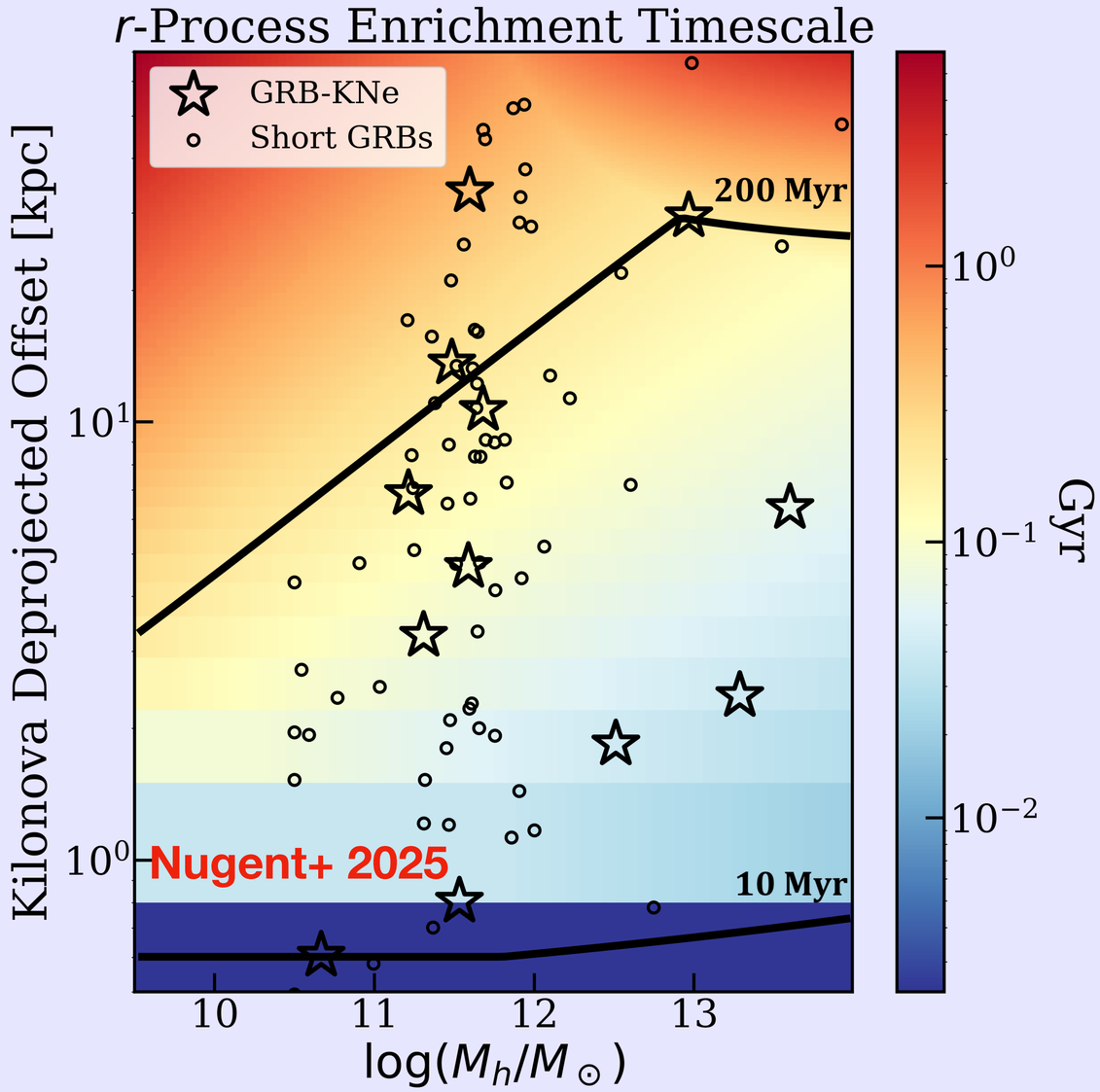


Scenario 2: Diffusive Transport



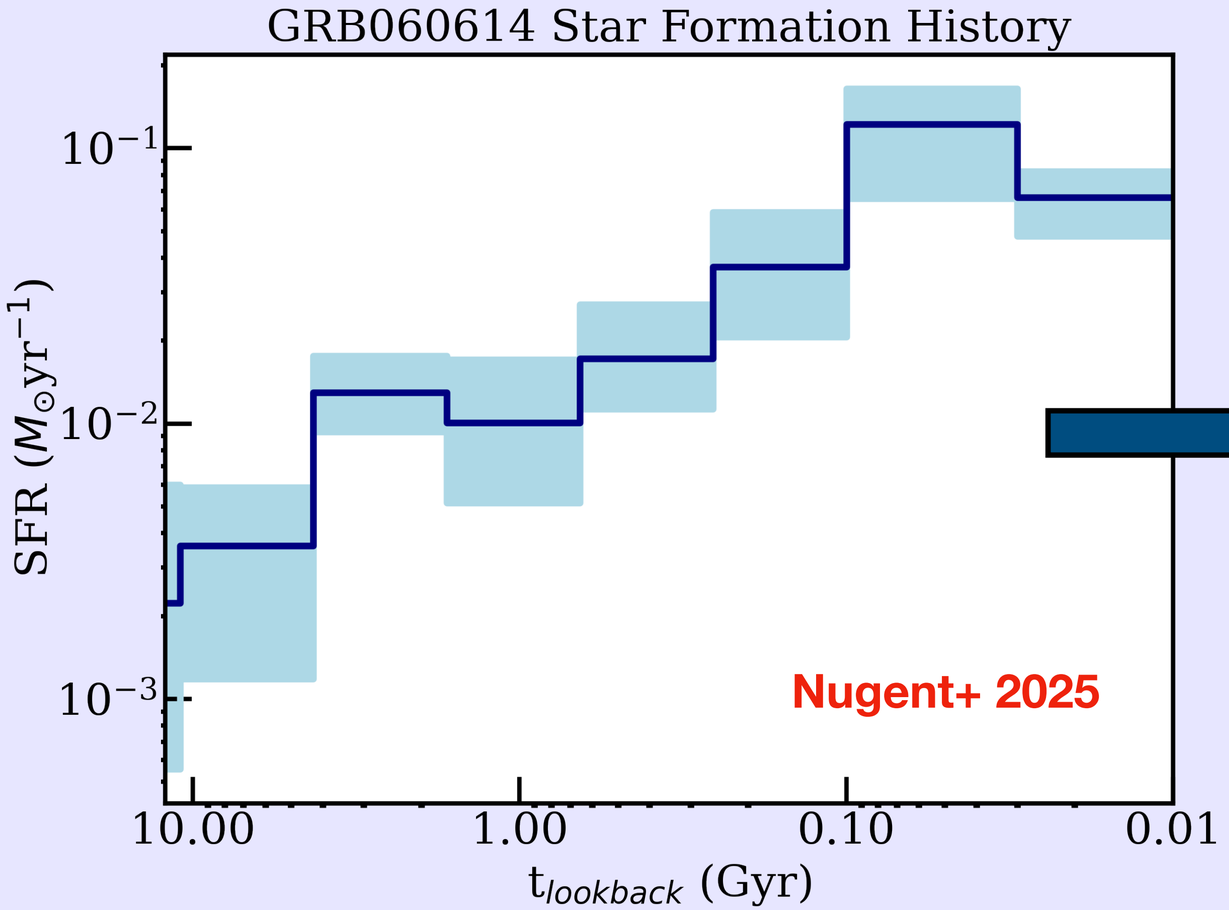
From Nugent+ 2025

Quantifying the "Enrichment" Timescale



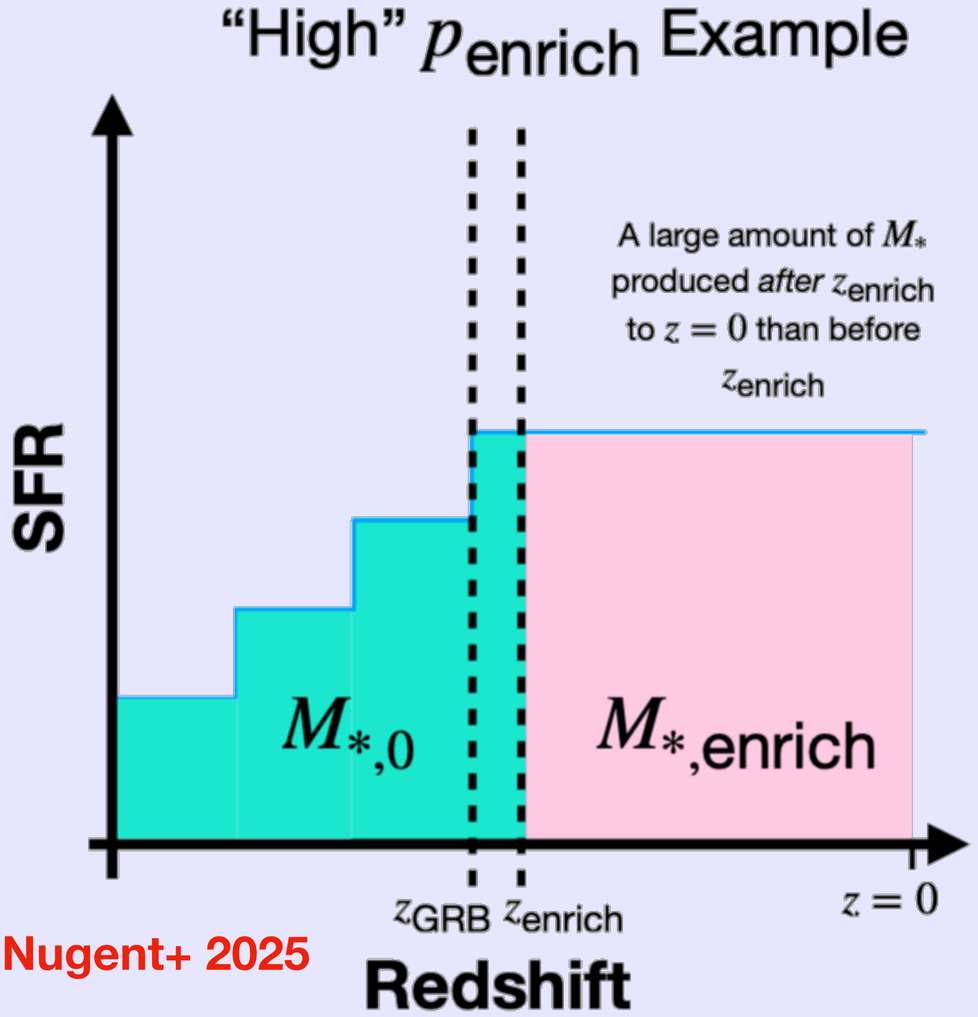
Enrichment timescales are NOT trivial! They are typically ~the minimum NS merger delay time

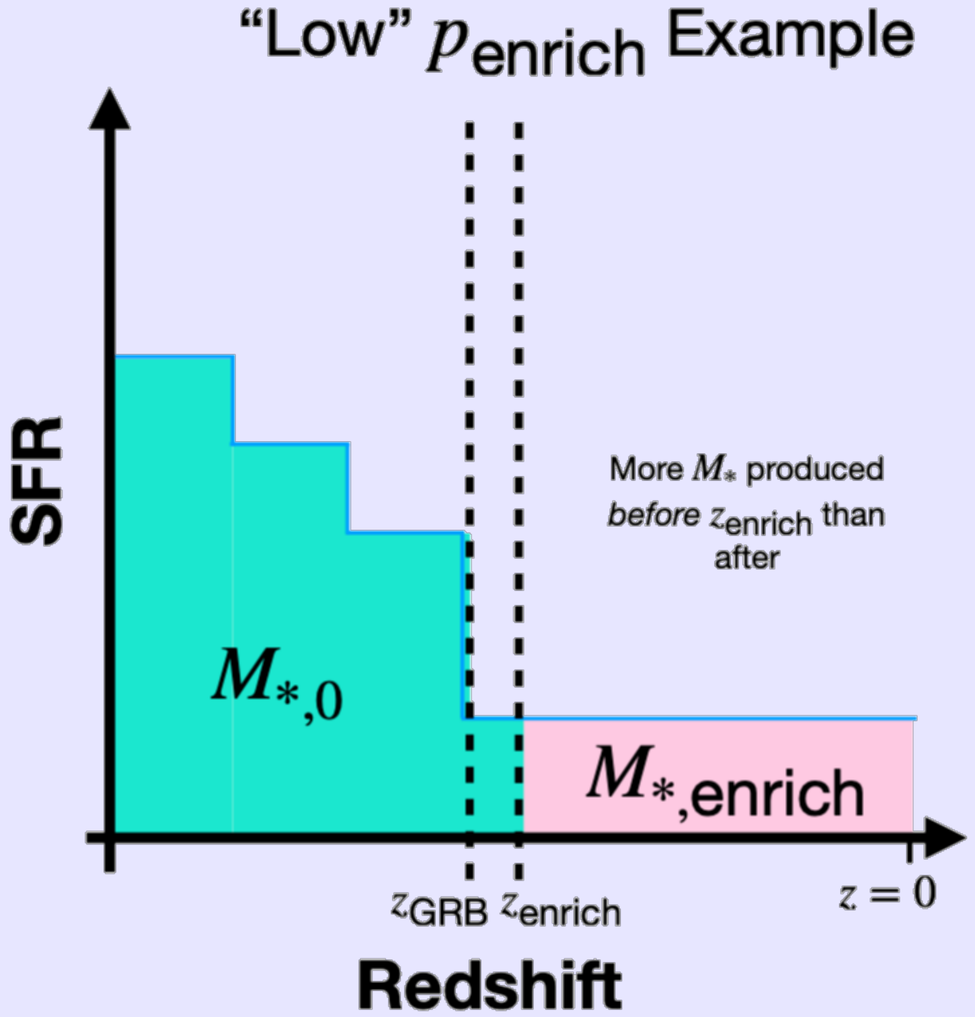
After r-process is incorporated into star-forming gas, what fraction of stellar mass in the host is enriched?



Evolve star formation history from z_{GRB} to $z = 0$ to determine amount of stellar mass in new stars

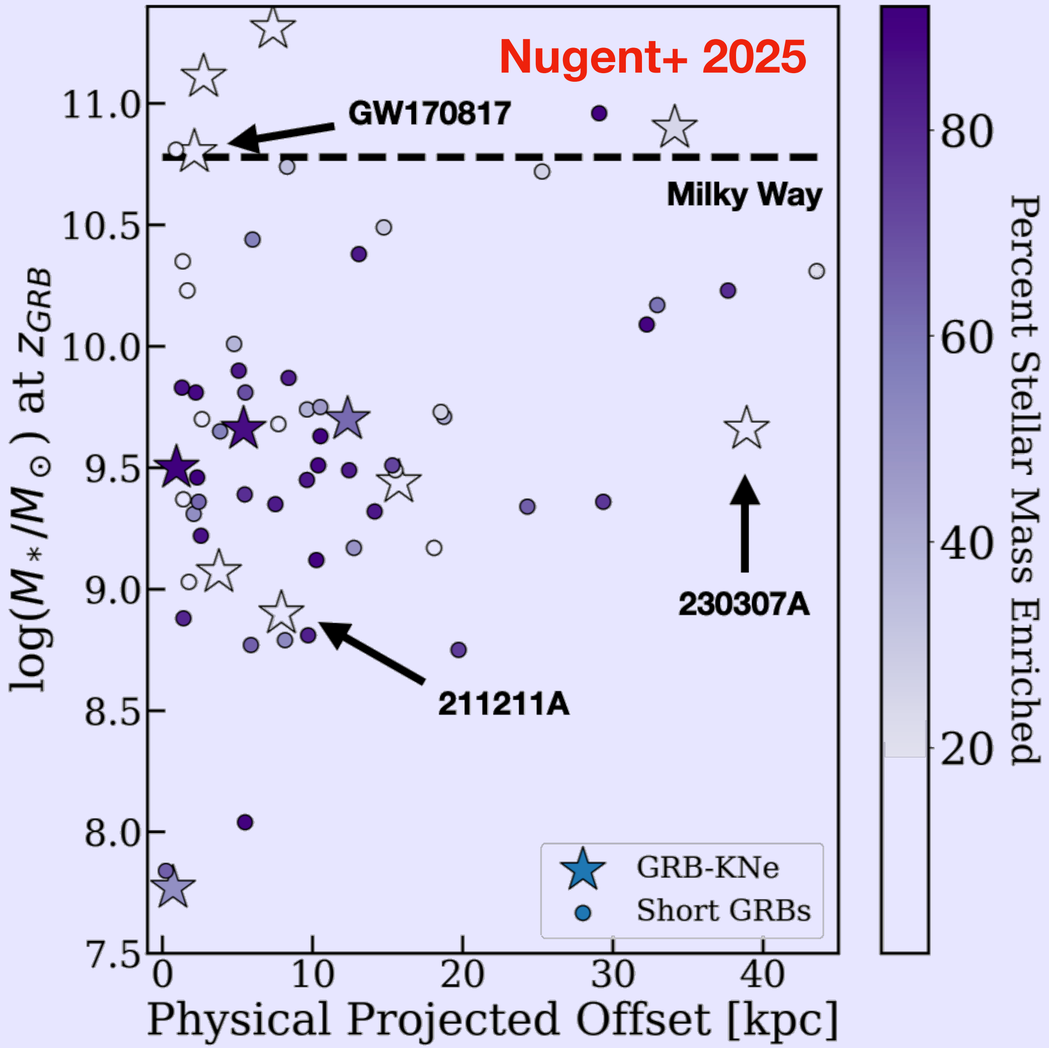
Quantifying the amount of enriched stellar mass from z_{GRB} to $z = 0$

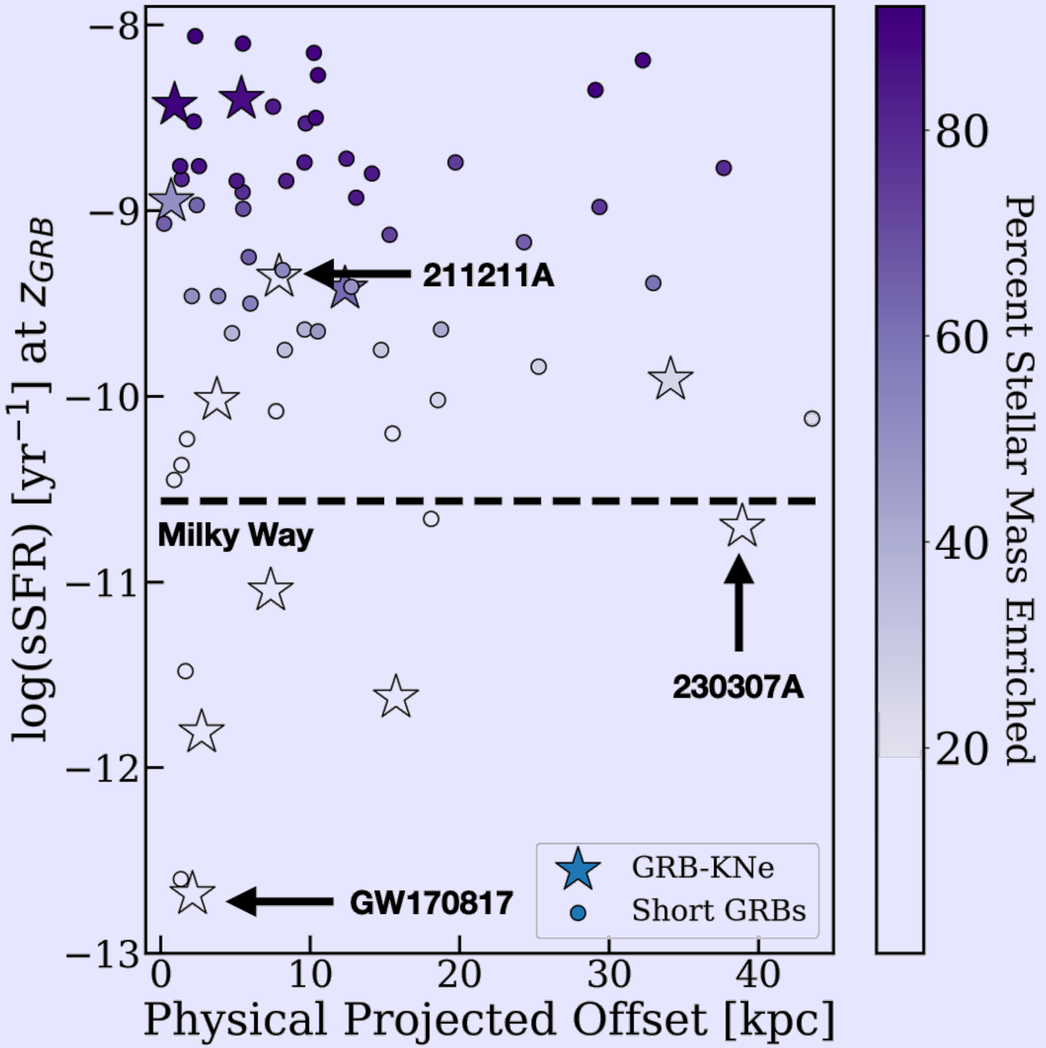




From Nugent+ 2025

What are the important factors that dictate the degree of enrichment?





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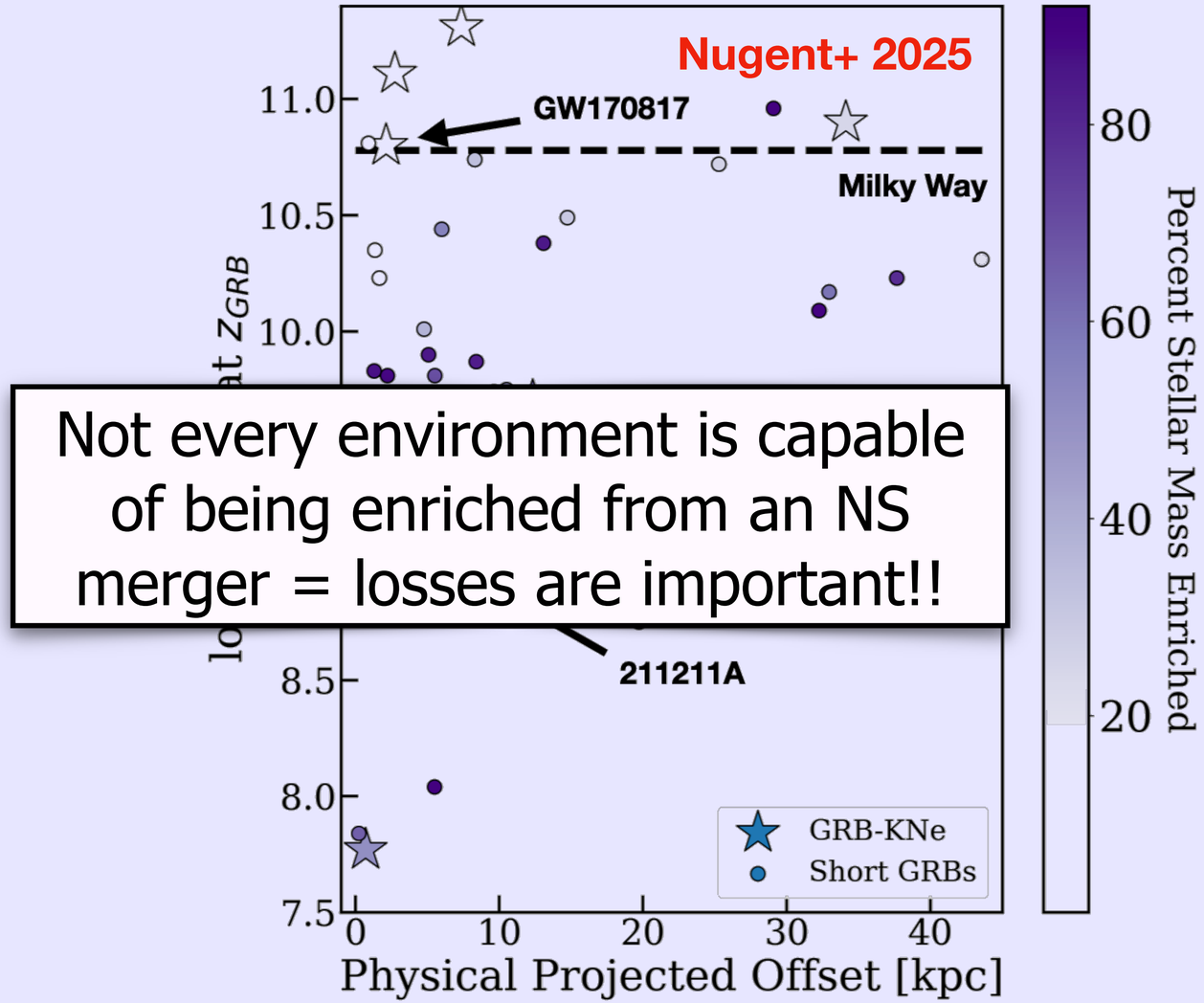
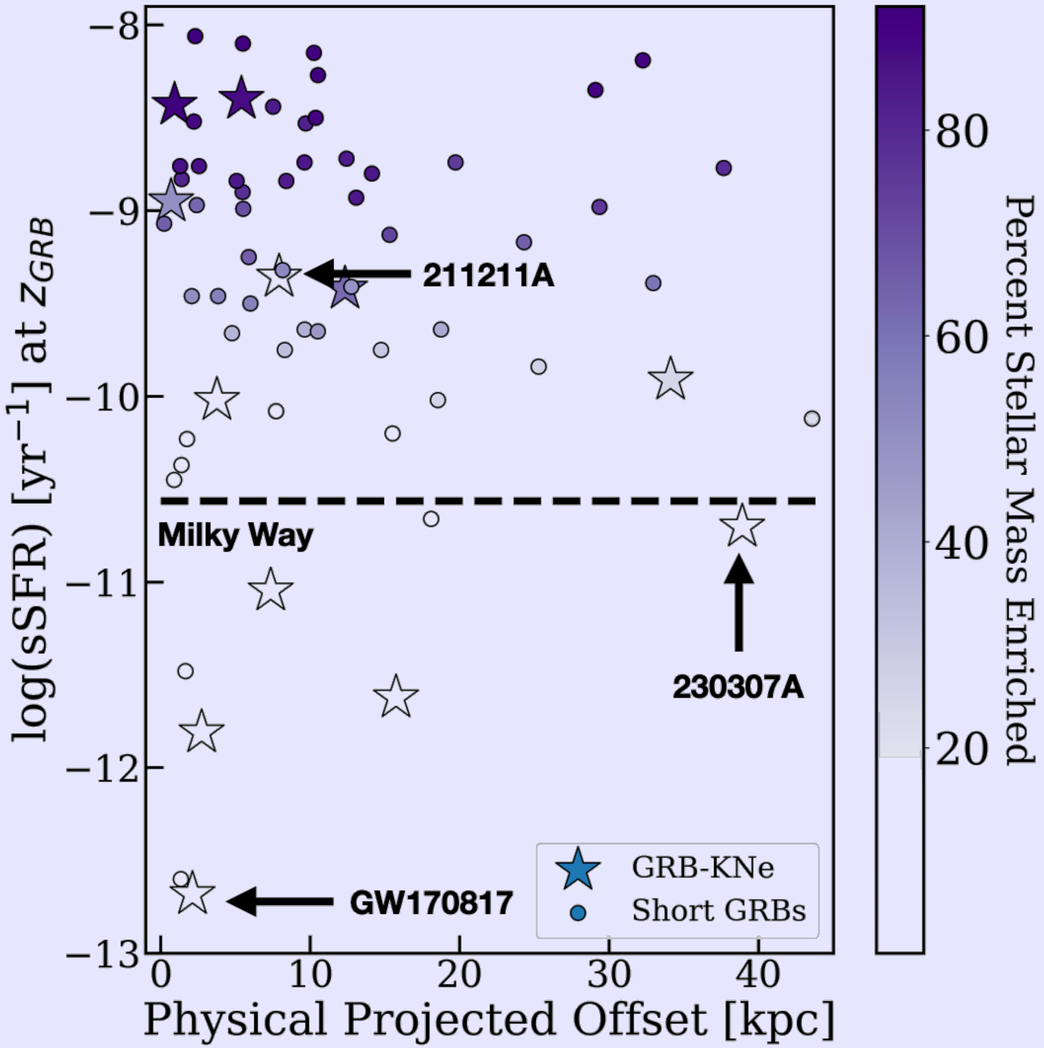


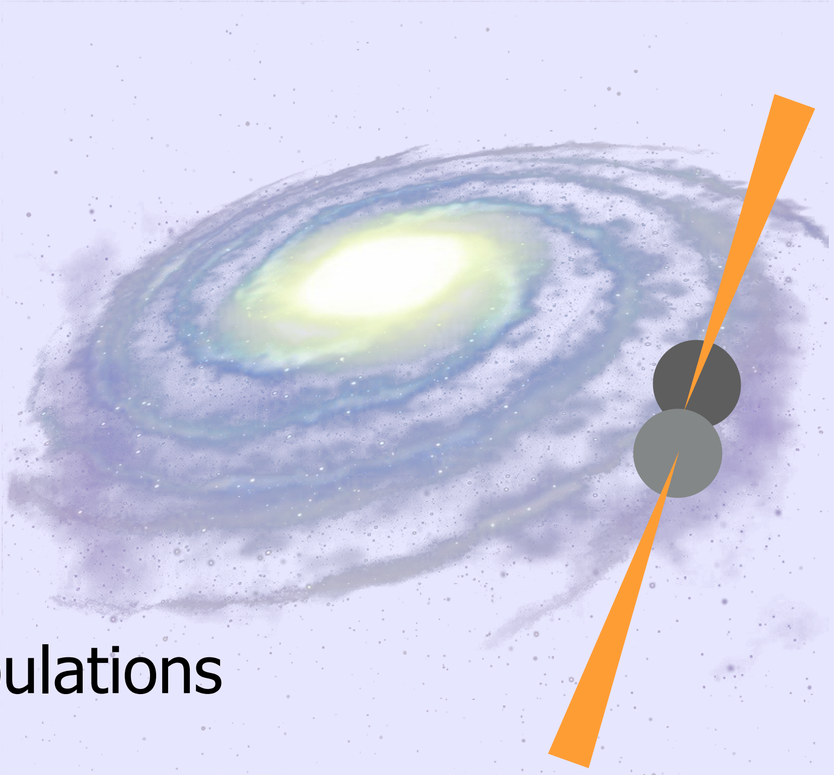
Not every environment is capable of being enriched from an NS merger = losses are important!!



Summary

Key conclusions:

1. Environments are not immediately enriched after NS merger
2. Capacity of environment to be enriched most strongly correlates with host sSFR
3. Some fraction of r-process is likely being lost to IGM/CGM

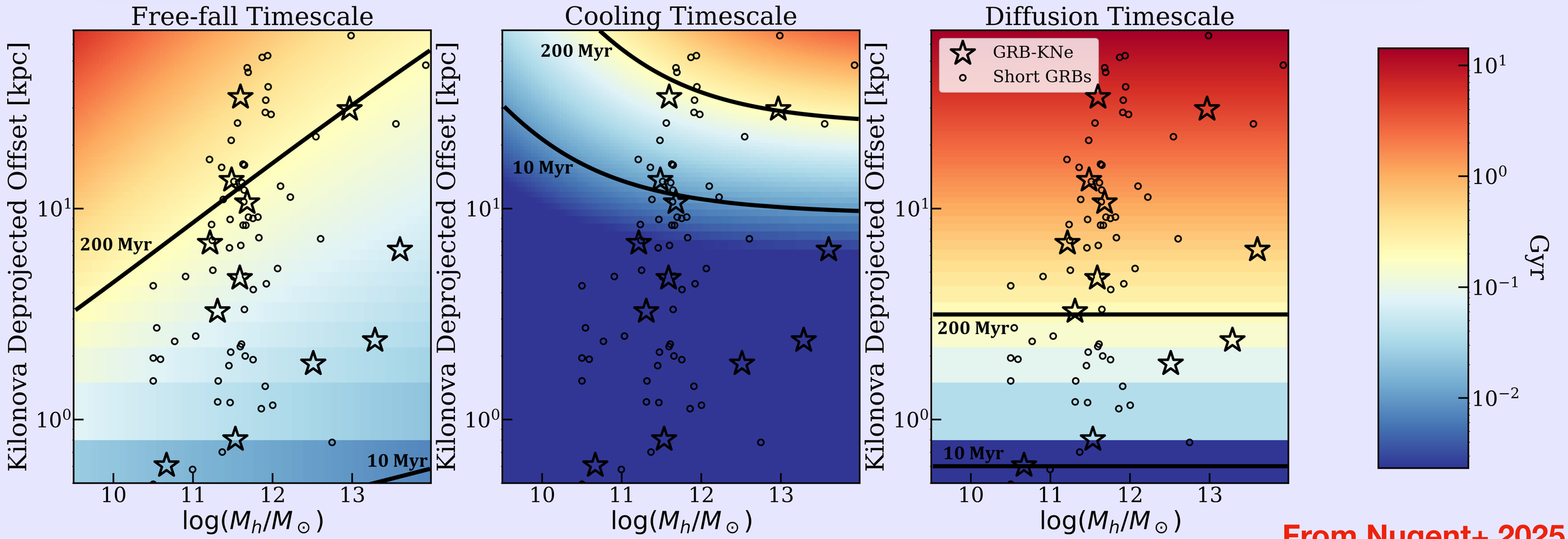


What to do next?

1. Continue to follow-up Swift GRBs to expand our populations of r-process sources
2. Use higher resolution simulations to understand true fraction of “lost” r-process from NS mergers and if NS mergers alone can explain Universe’s r-process enrichment

Quantifying the "Enrichment" Timescale

Most r-process will travel back on the free-fall timescale except at low offsets (diffusion) and high offsets from high-mass hosts (cooling)



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