Image credit: ESA/AASNova/Jennifer Johnson, NOIRLab / NSF / AURA / J. da Silva / Spaceengine, NASA/Goddard Space Flight Center

Inference of multi-channel r-process element enrichment in the Milky Way using neutron star merger observations

ApJ, 985, 154 (arXiv: 2402.03696)

Hsin-Yu Chen

Philippe Landry, Jocelyn S. Read, Daniel M. Siegel

TEXAS
The University of Texas at Austin

Nuclei in the Cosmos XVIII, June 2025

Are binary neutron star mergers the major production site for r-process elements?

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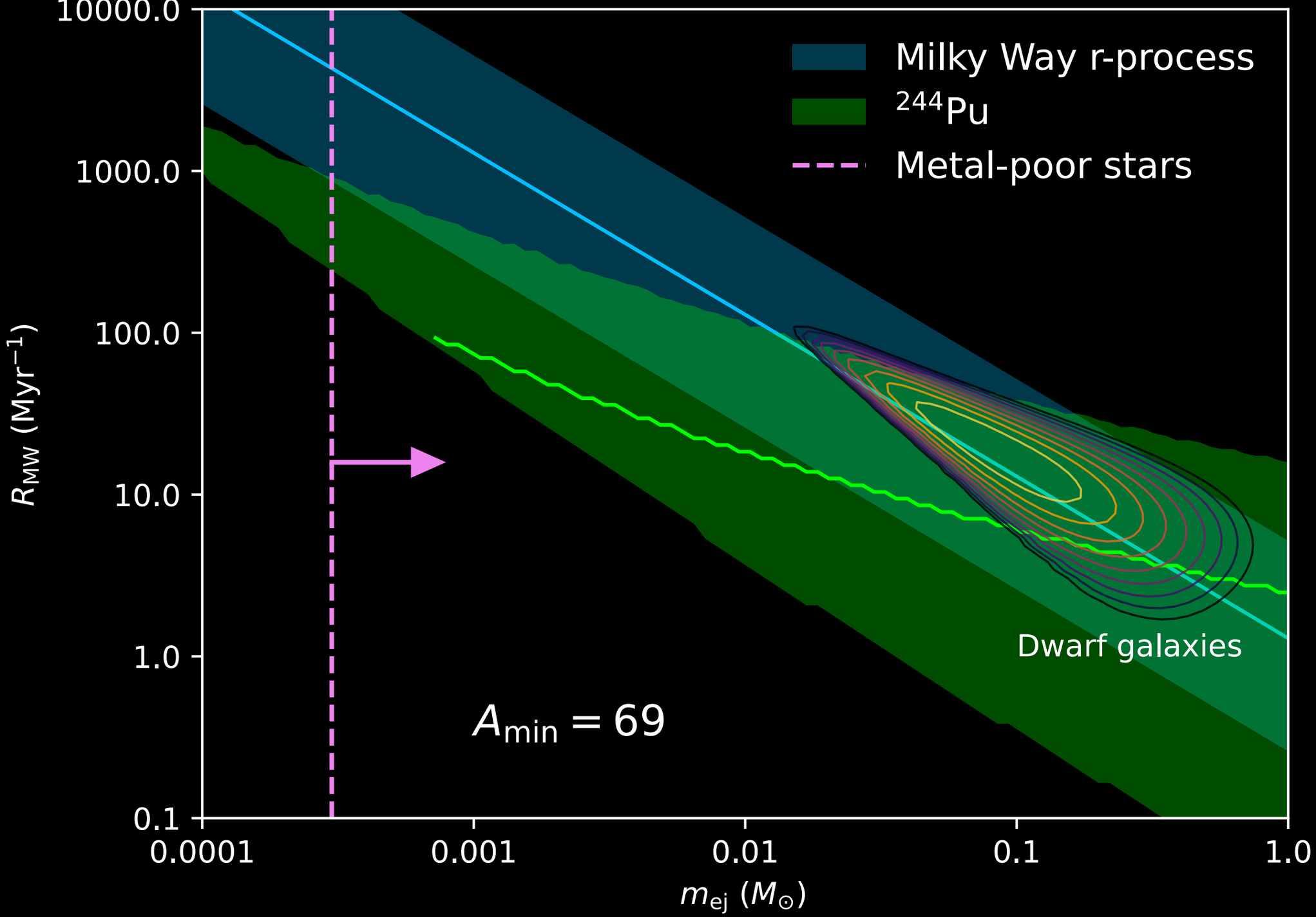
Are binary neutron star mergers the major production site for r-process elements?

They have to generate right amount of r-process elements with the right rate.

R-process element per event yield vs event rate

Adapted from Hotokezaka et al, Int. J.Mod. Phys. D (2018)



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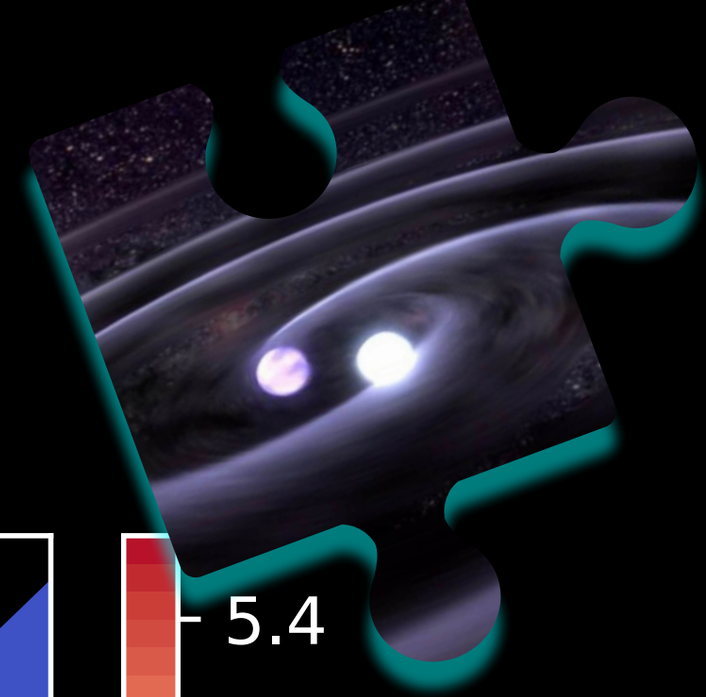
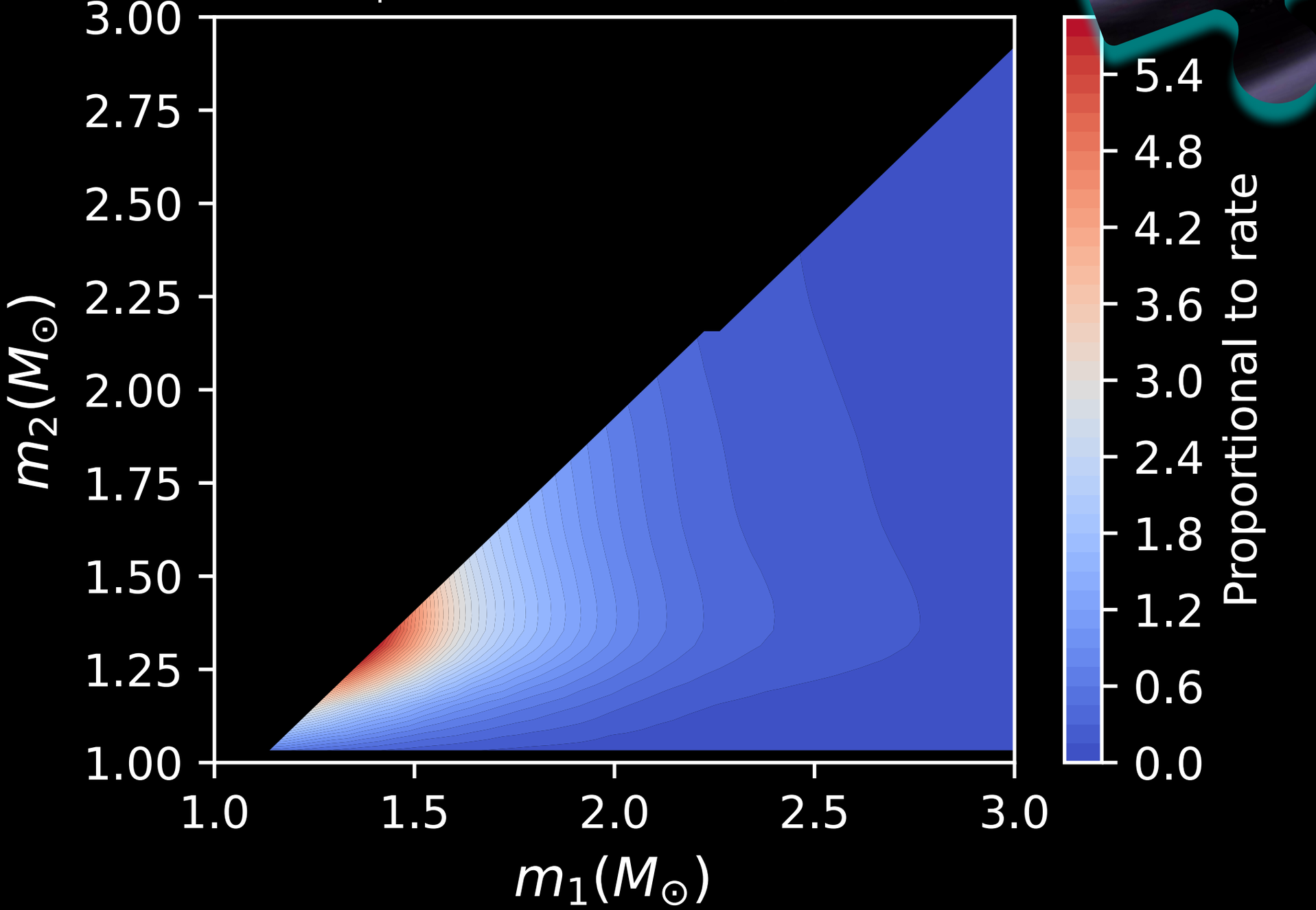
Gravitational-wave observations: merger rate as a function of mass



Adapted from LVK Collaboration, PRX (2023)



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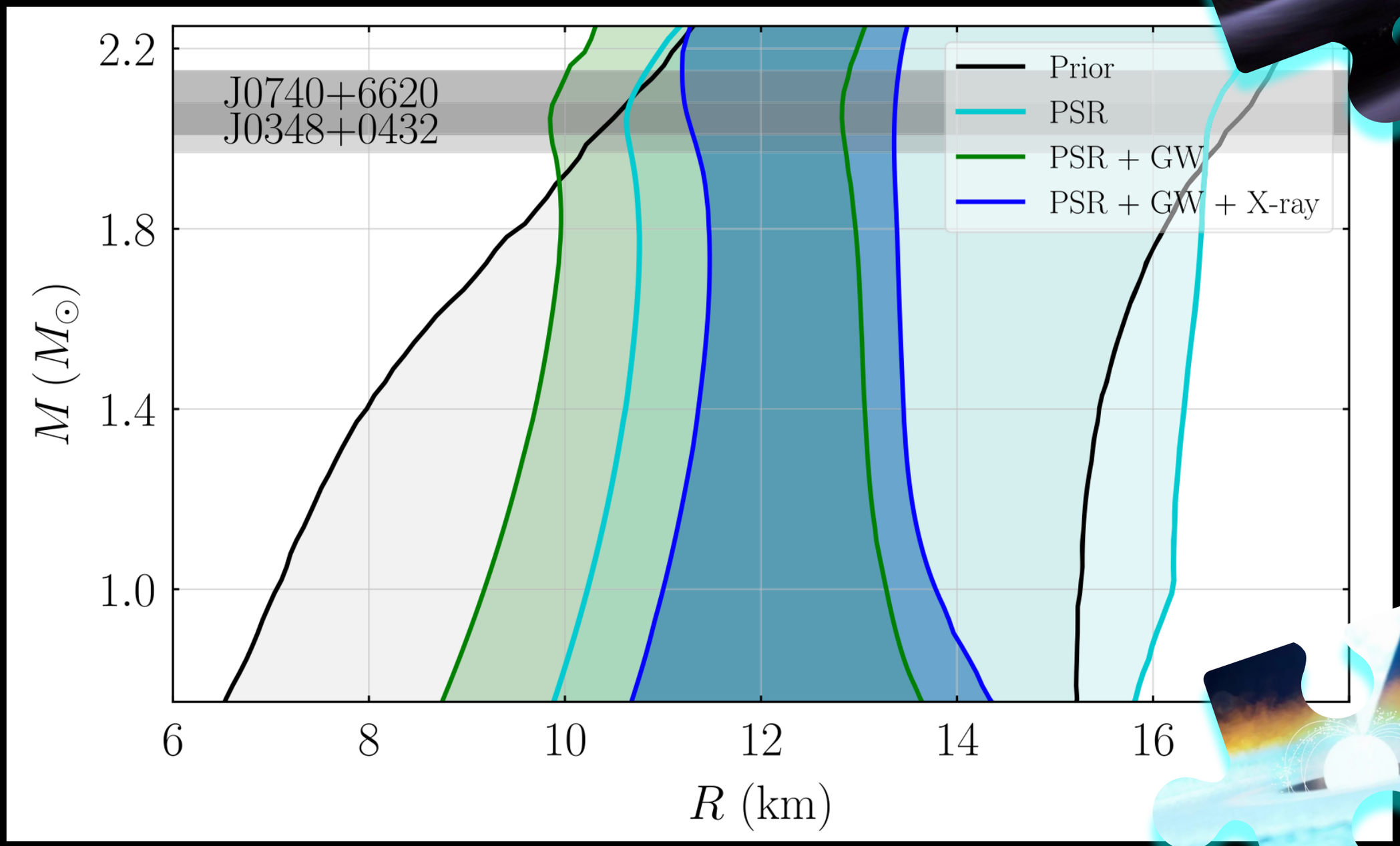
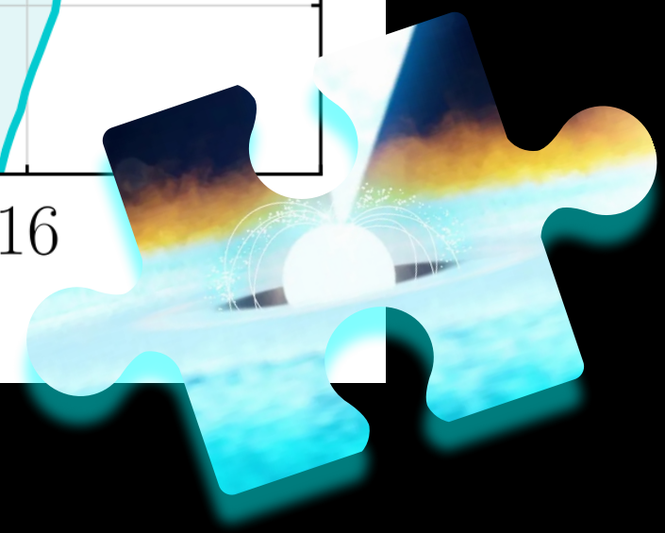
Gravitational-wave and pulsar observations: neutron star equation-of-state

Legred et al, PRD (2021)





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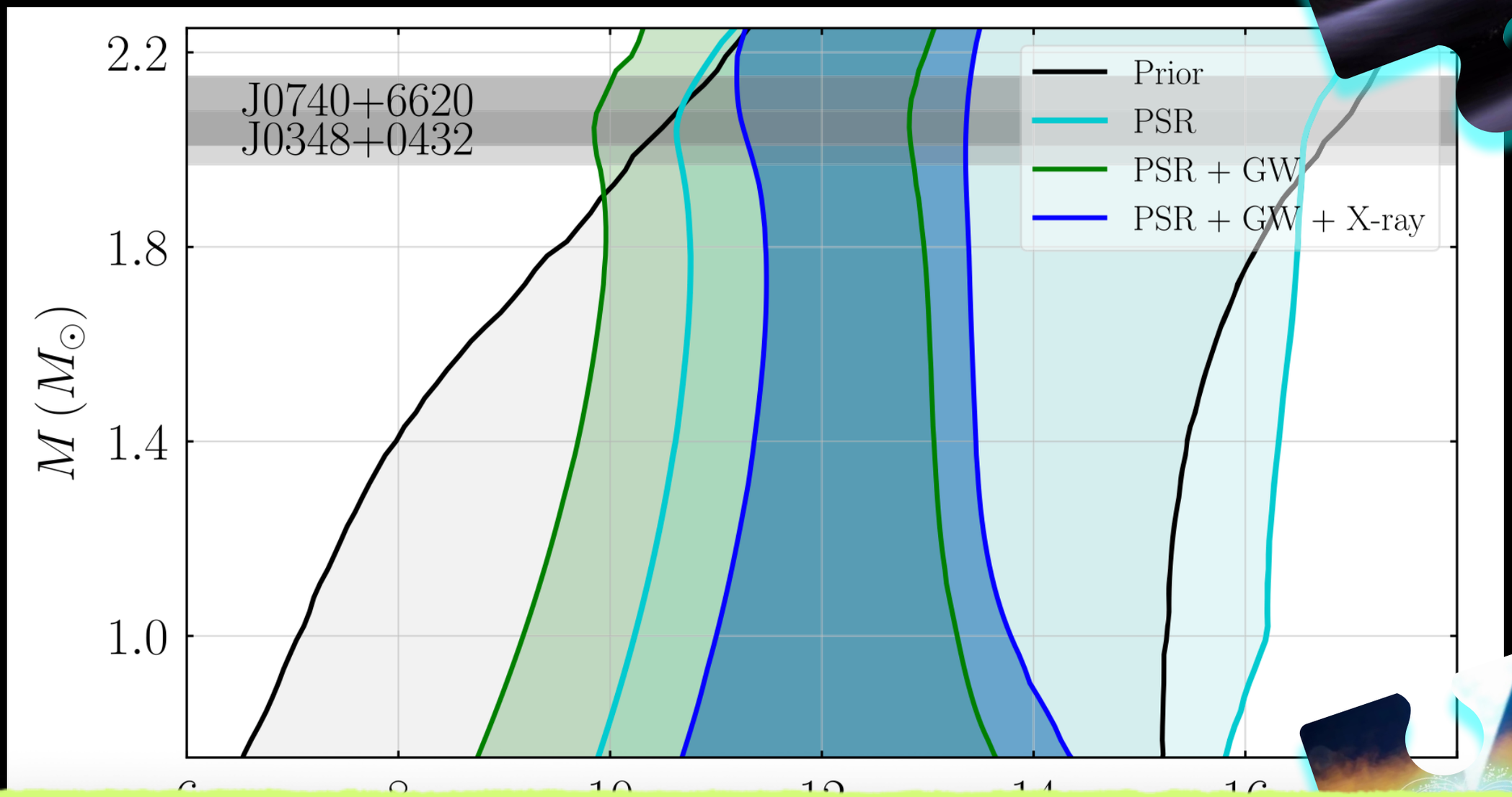
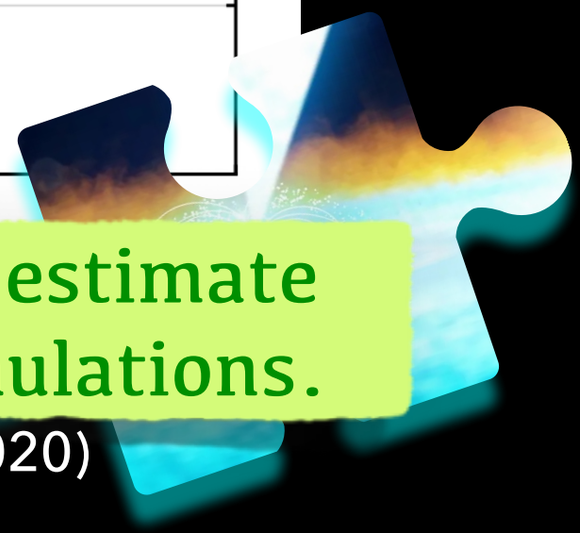
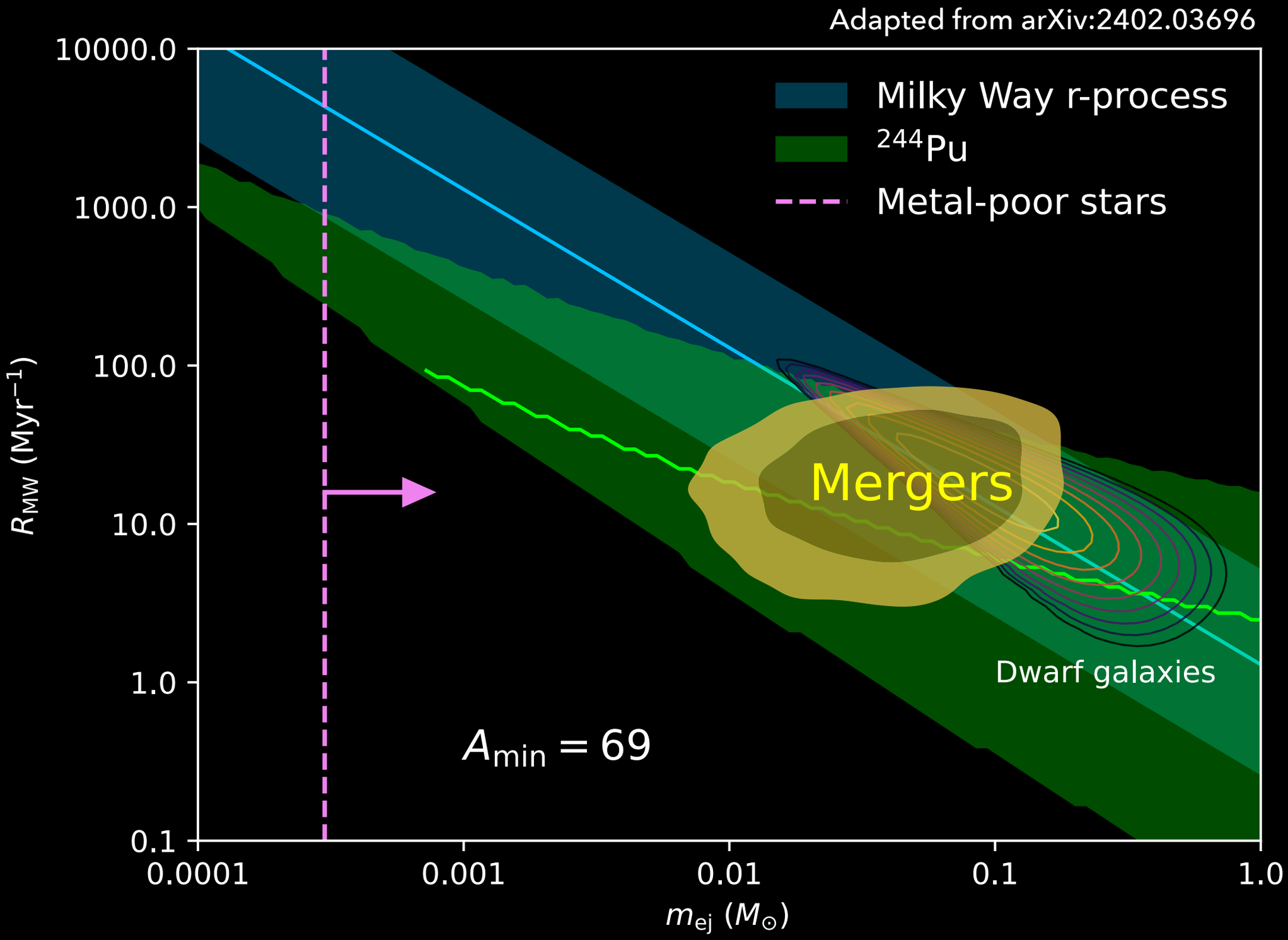


With mass and neutron star equation-of-state, we estimate the yield using semi-analytical fit to numerical simulations.

Kruger & Foucart, PRD (2020)



R-process element per event yield vs event rate



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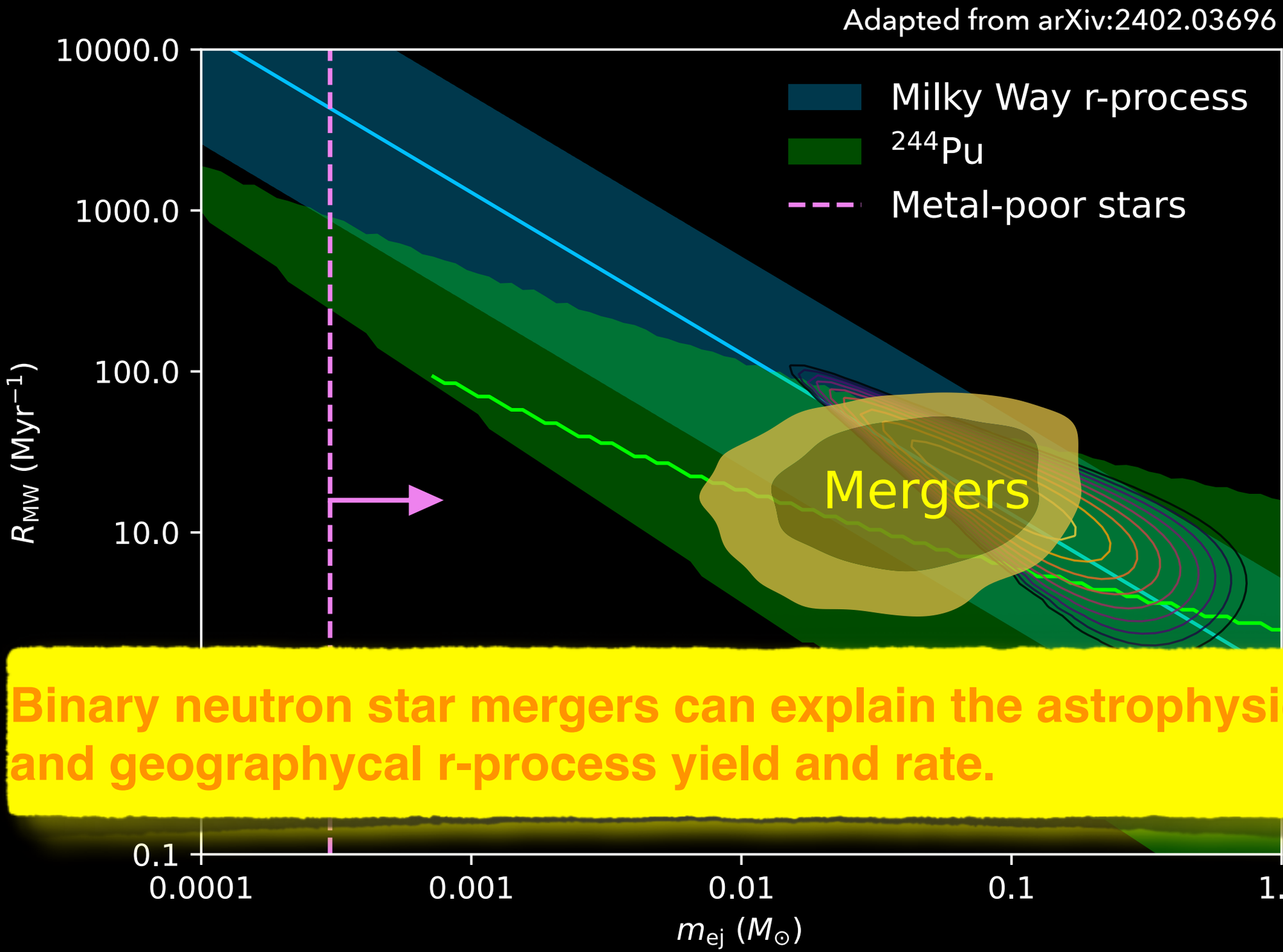
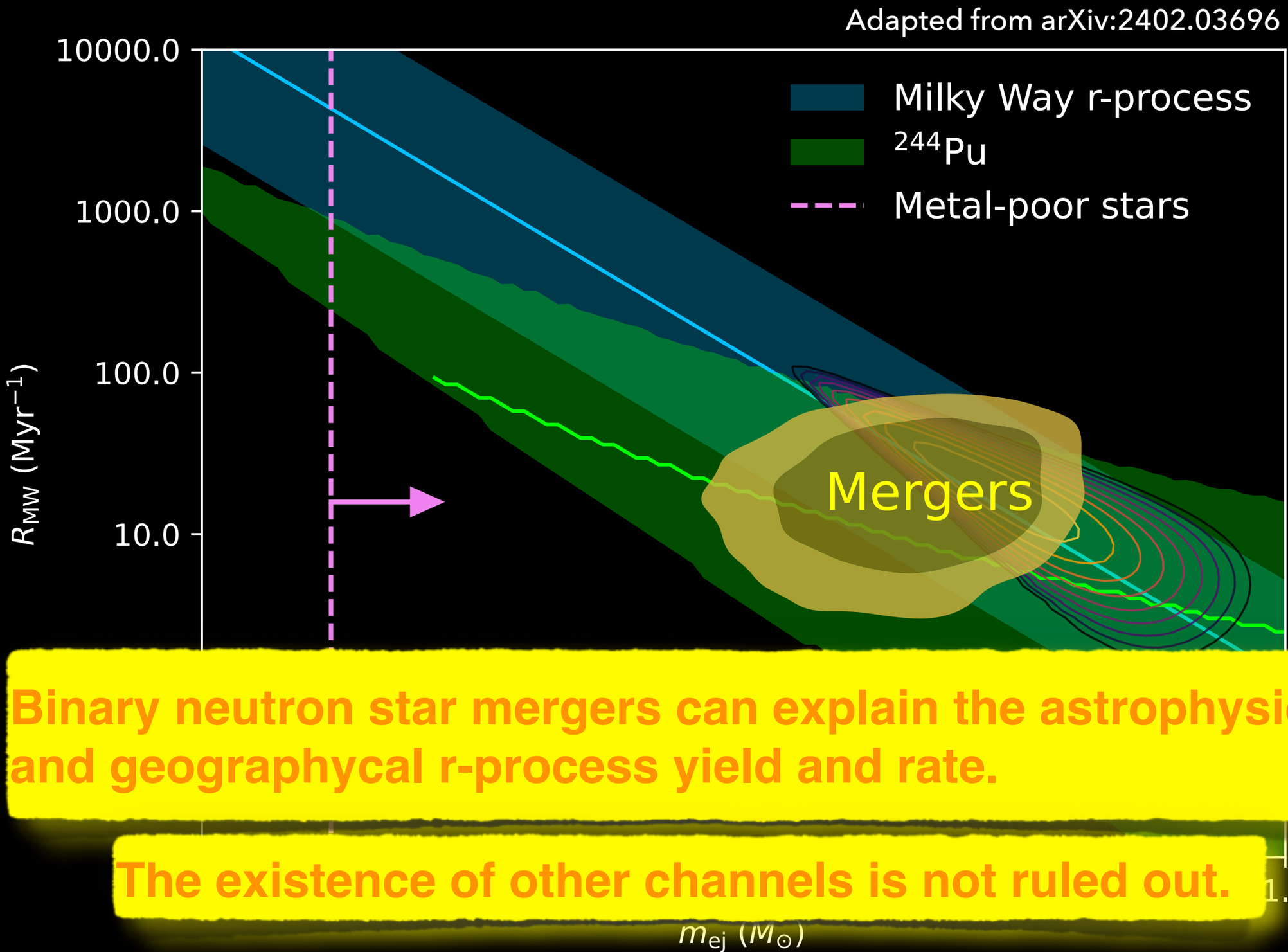
R-process element per event yield vs event rate



Binary neutron star mergers can explain the astrophysical and geographycal r-process yield and rate.

R-process element per event yield vs event rate



Binary neutron star mergers can explain the astrophysical and geographycal r-process yield and rate.

The existence of other channels is not ruled out.

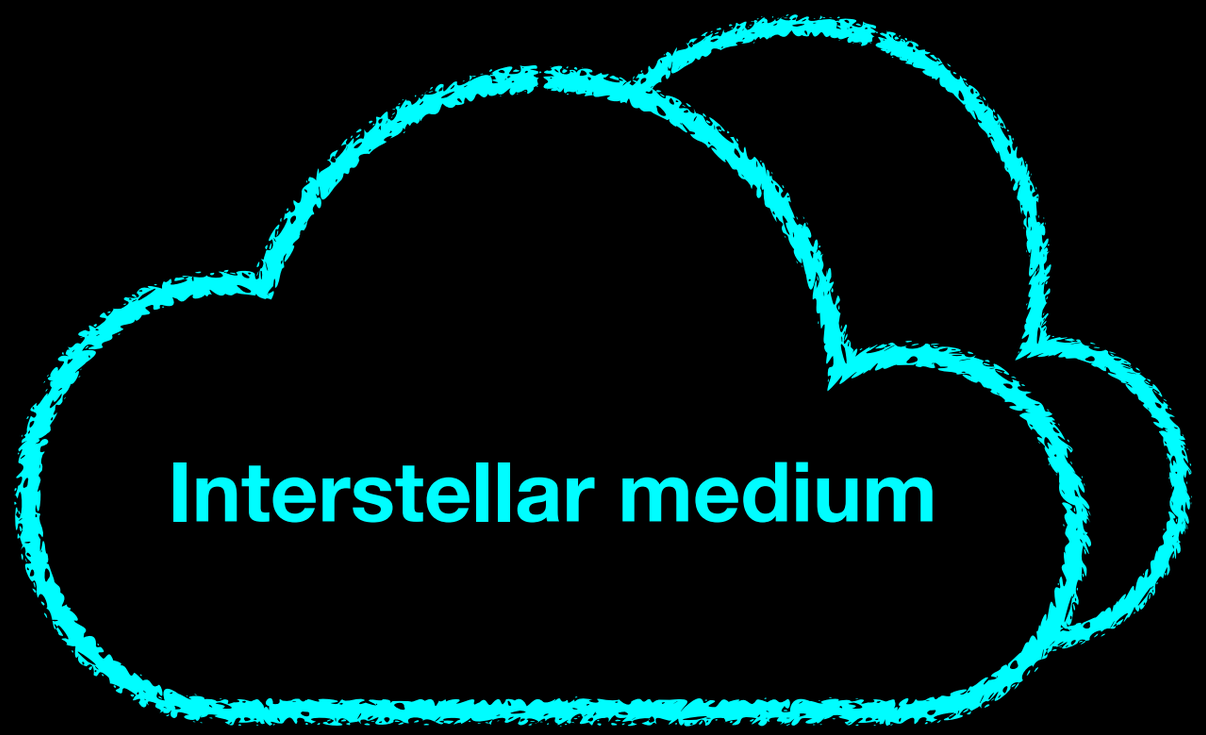
Are binary neutron star mergers the major production site for r-process elements?

They have to generate right amount of r-process elements with the right rate,

Are binary neutron star mergers the major production site for r-process elements?

They have to generate right amount of r-process elements with the right rate, and at the right time.

Tracer of r-process element production over time: Stellar metallicity

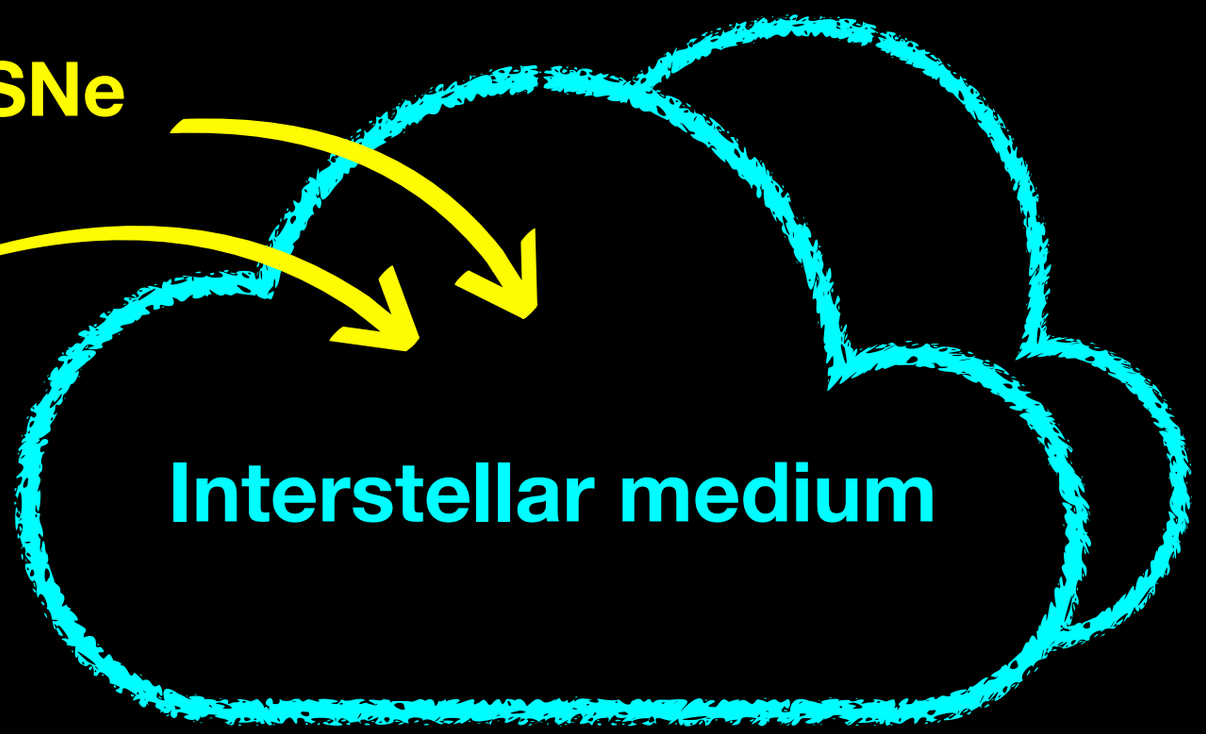


Tracer of r-process element production over time: Stellar metallicity

Iron

Core-collapsed SNe

Type Ia SNe



Tracer of r-process element production over time: Stellar metallicity

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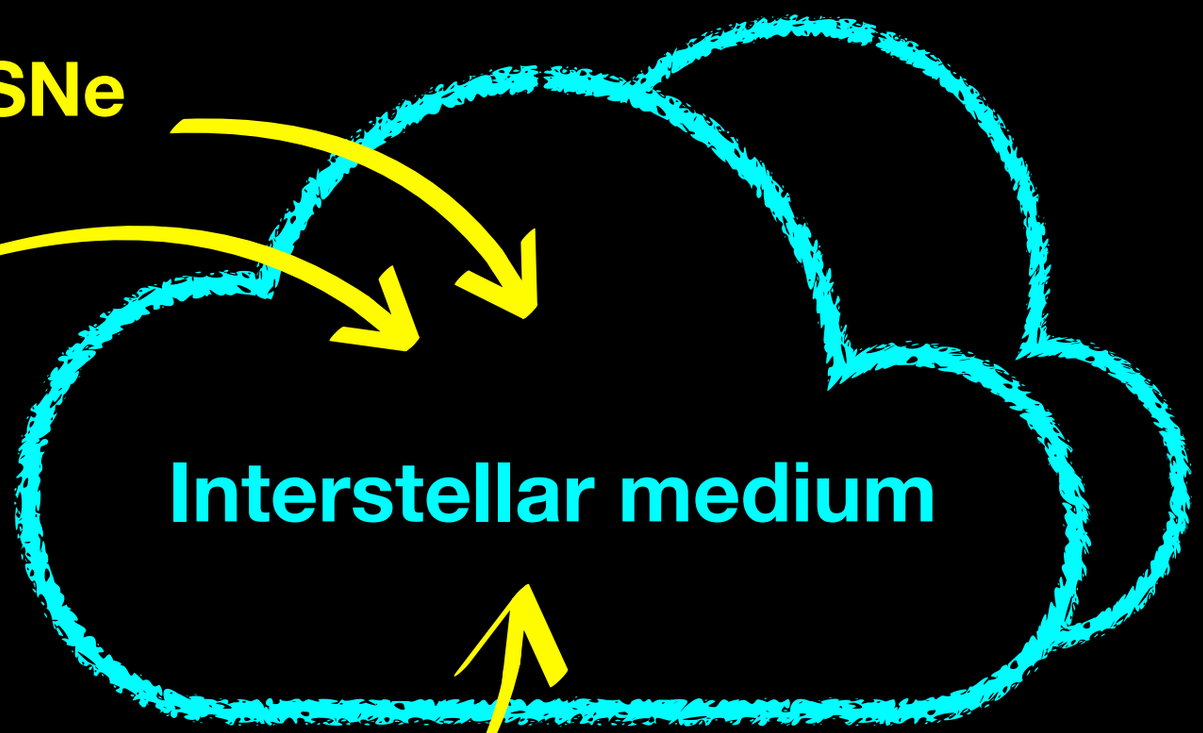


Europium

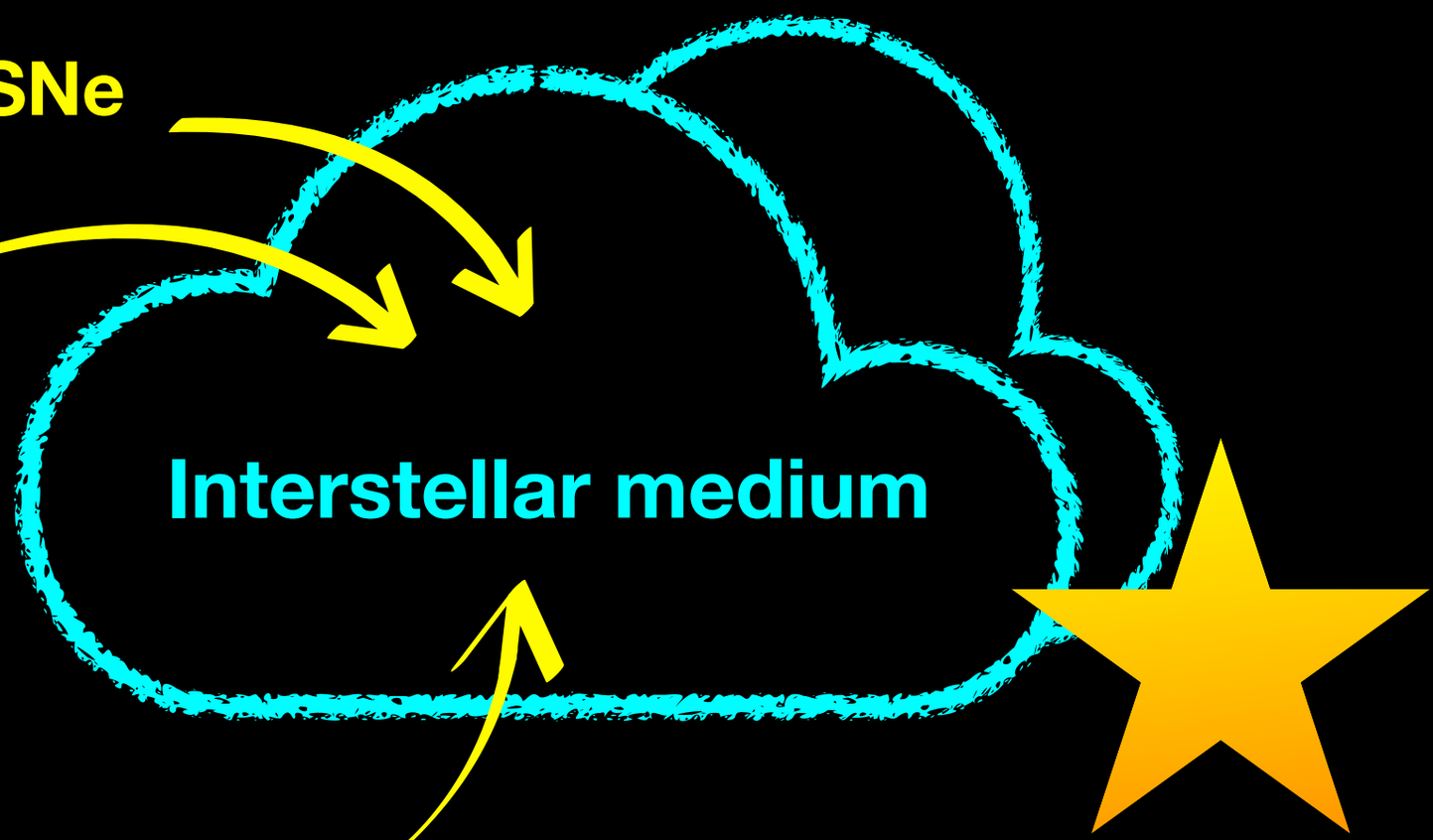
R-process production event

Tracer of r-process element production over time: Stellar metallicity

Iron

Core-collapsed SNe

Type Ia SNe

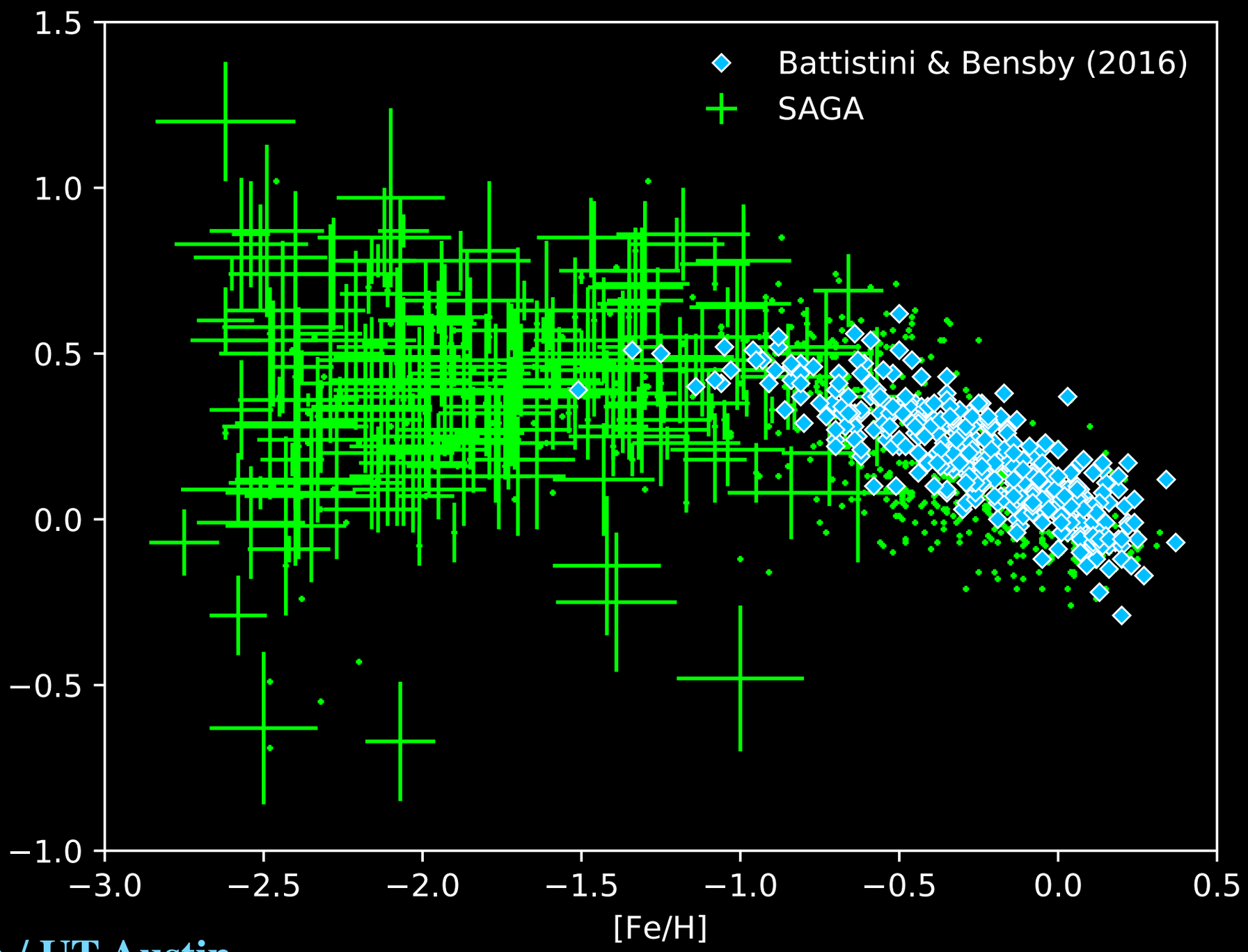


Europium

R-process production event

Tracer of r-process element production over time: Stellar metallicity

- Milky Way stellar chemical abundance observations



Tracer of r-process element production over time: Stellar metallicity

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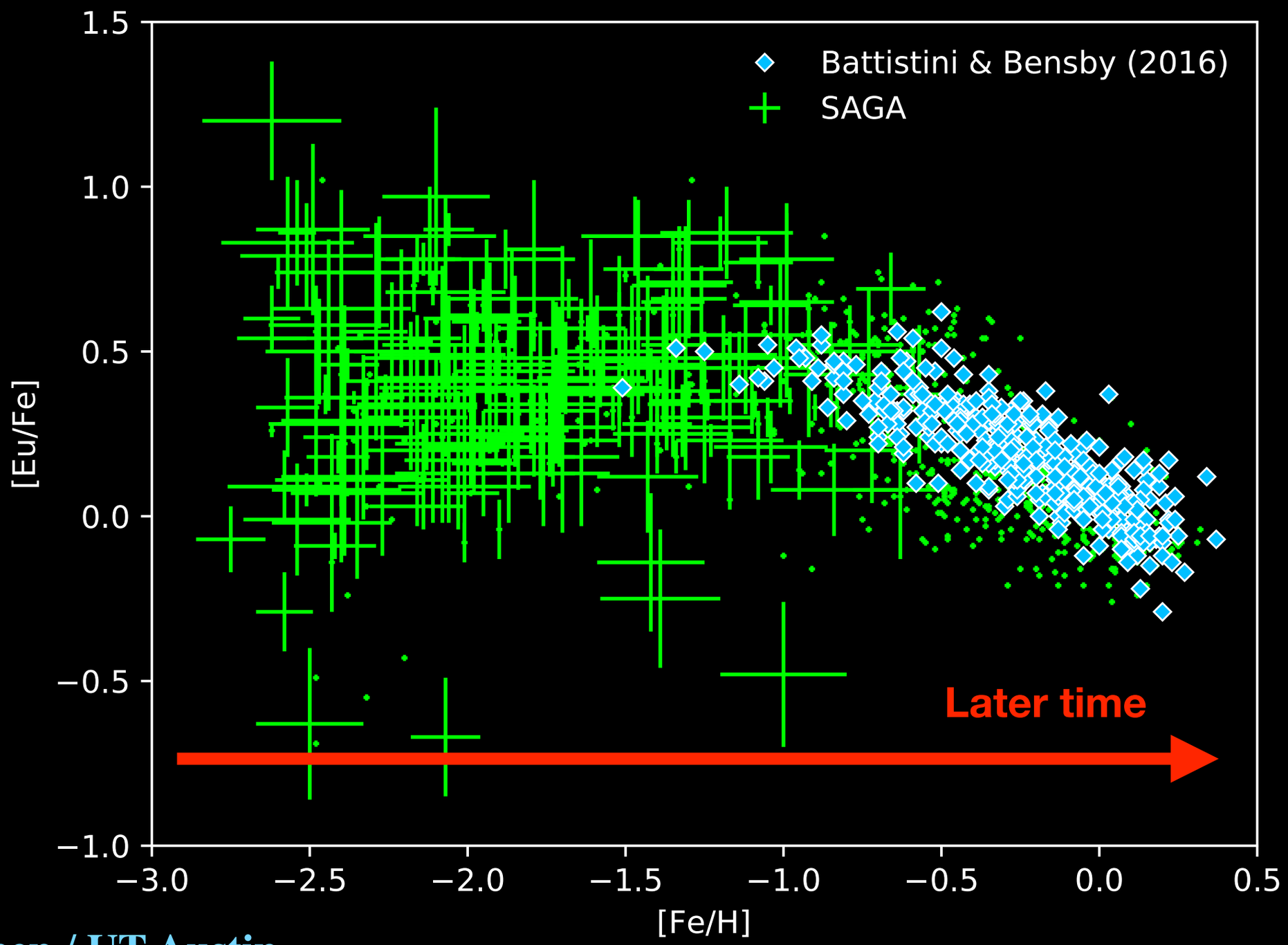

Tracer of r-process element production over time: Stellar metallicity

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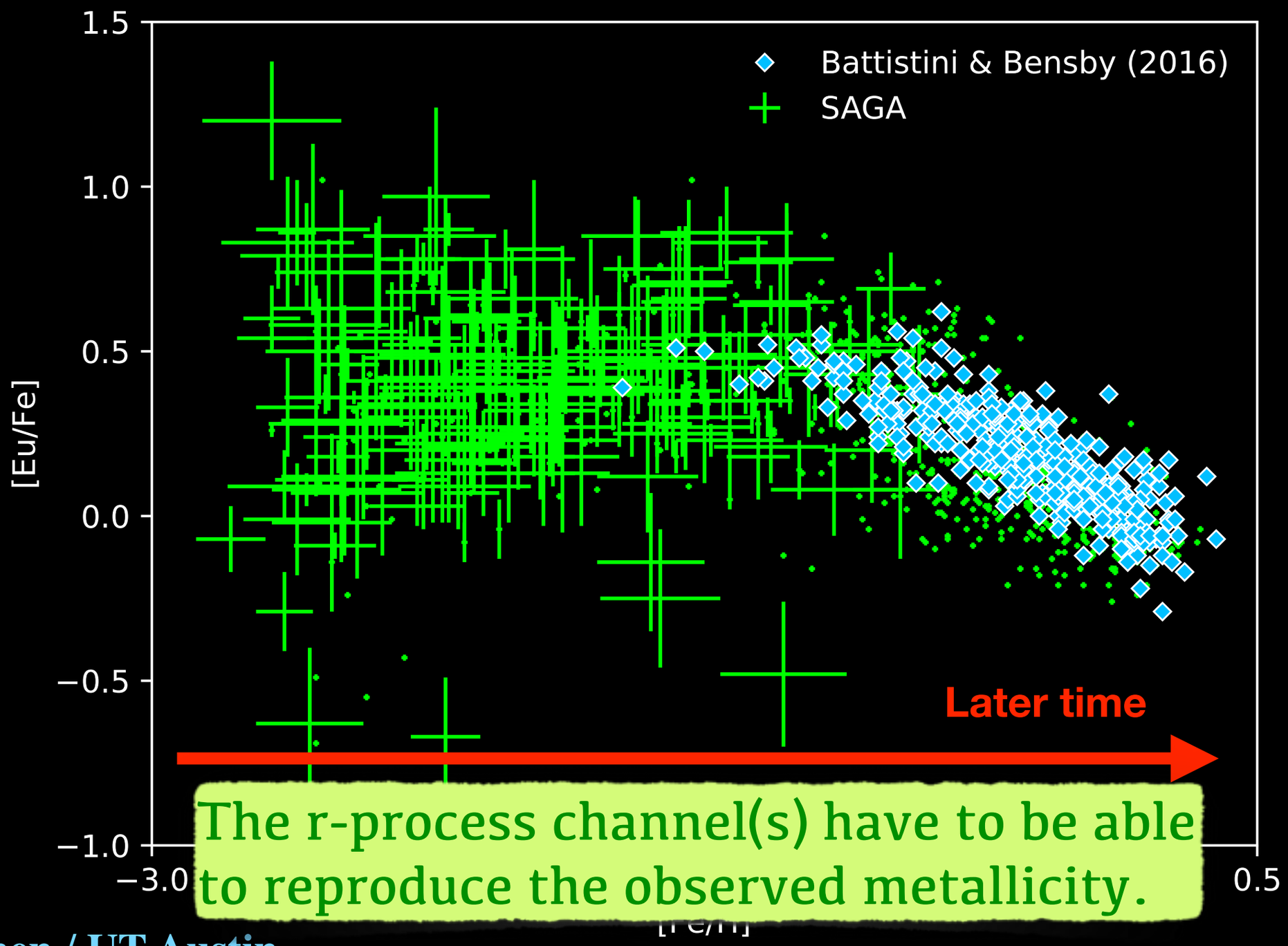
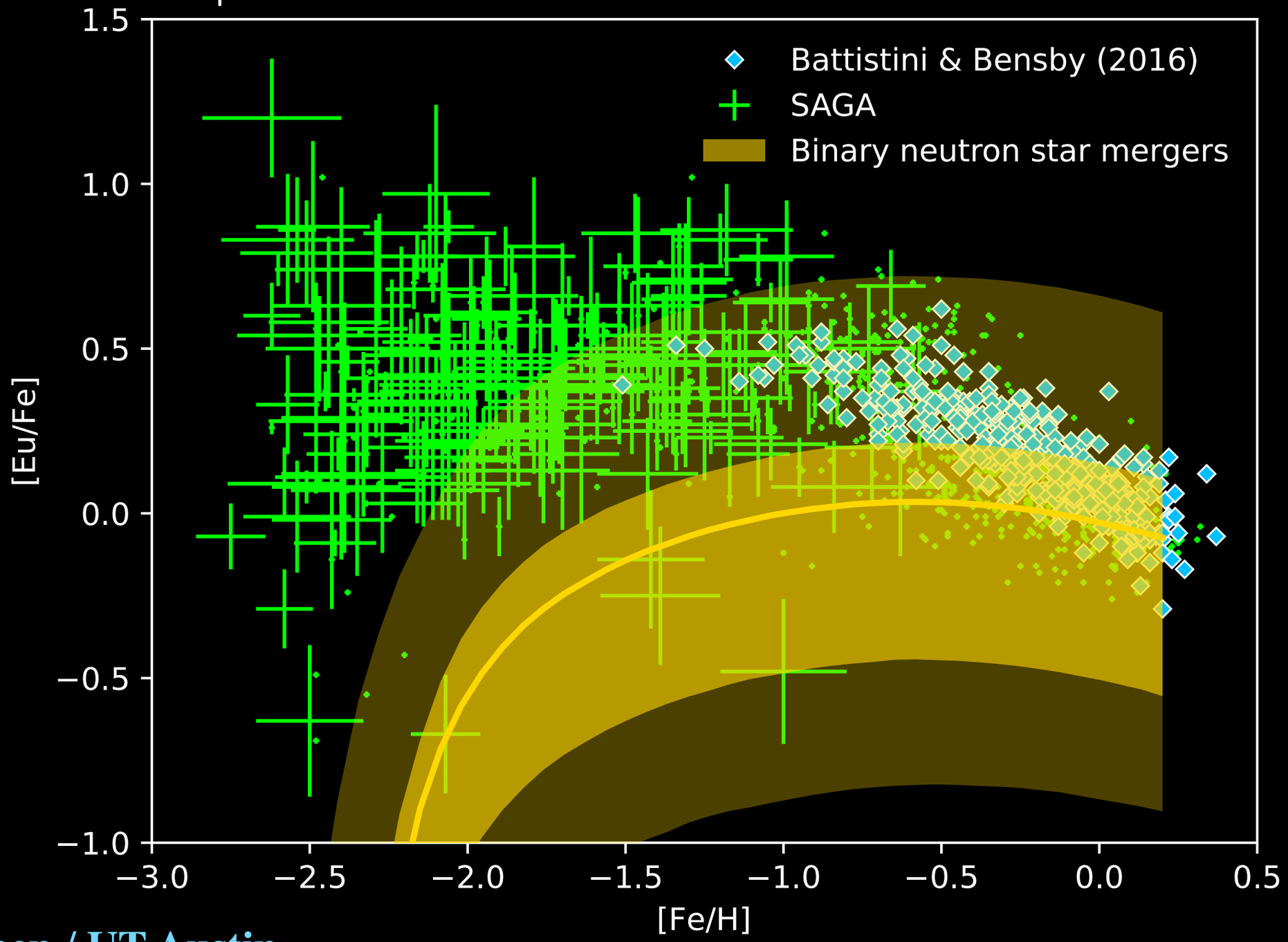


The r-process channel(s) have to be able to reproduce the observed metallicity.

Comparison to Galactic stellar metallicity observations

Adapted from arXiv:2402.03696



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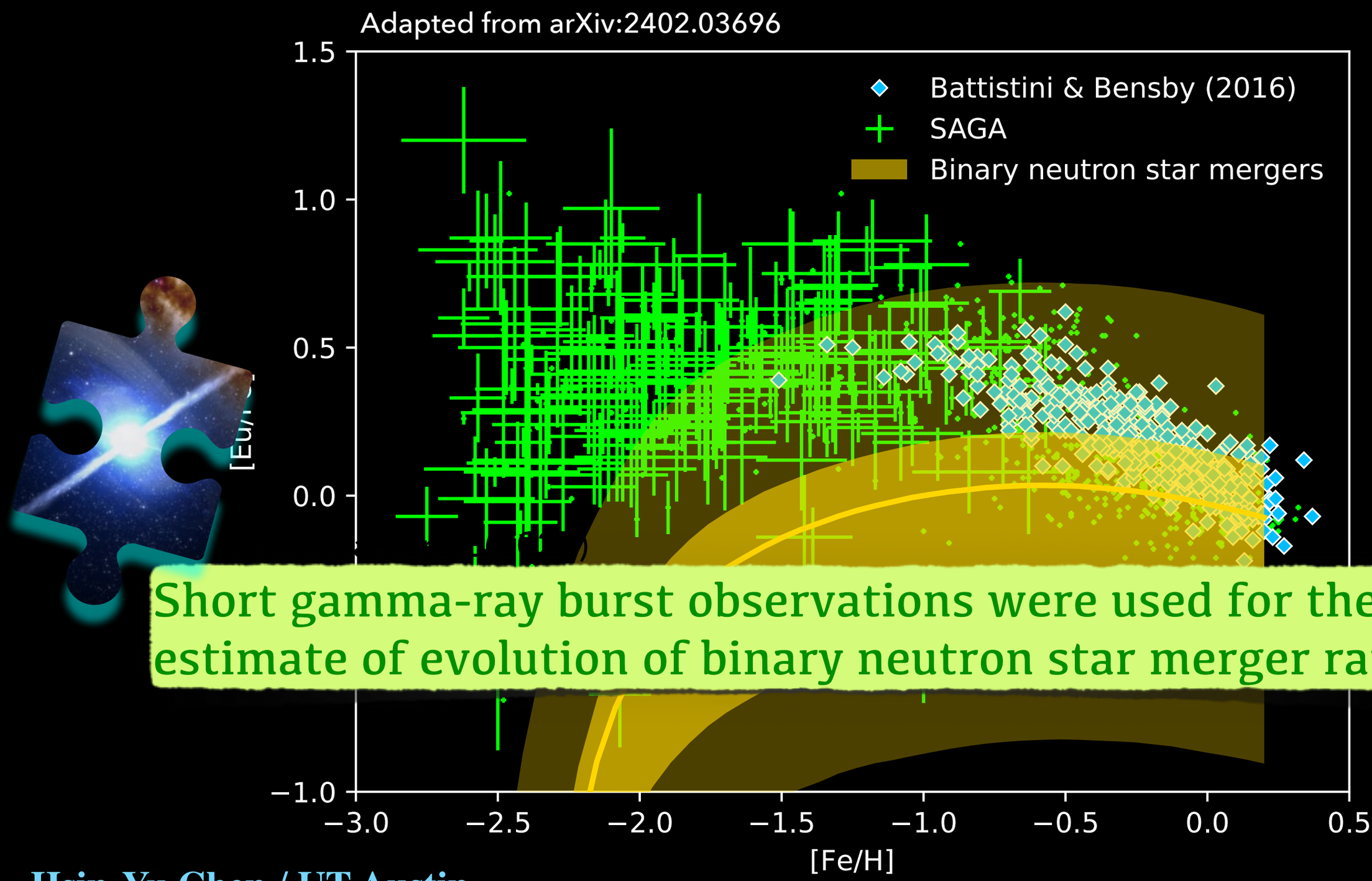
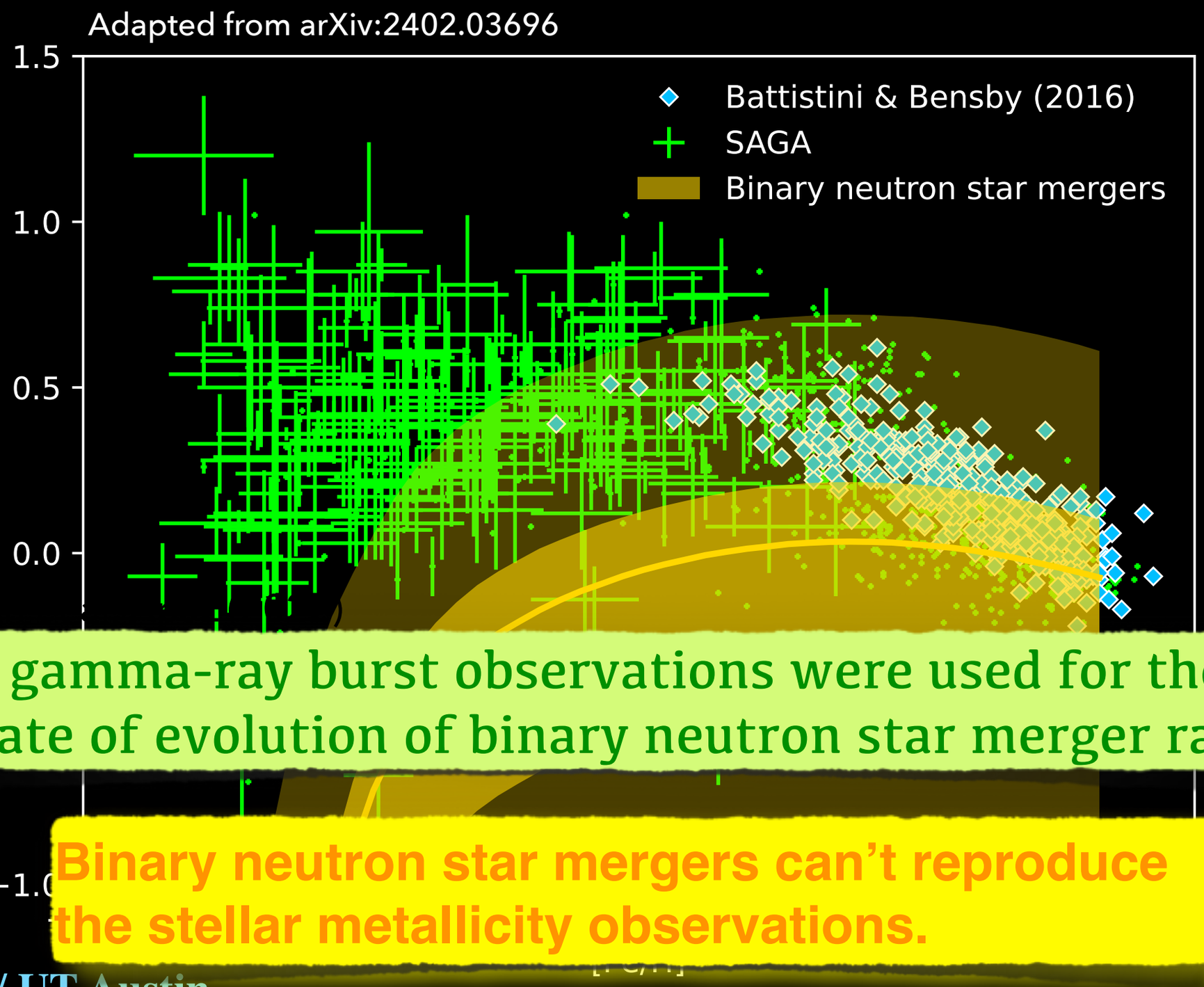
Comparison to Galactic stellar metallicity observations



Short gamma-ray burst observations were used for the estimate of evolution of binary neutron star merger rate.

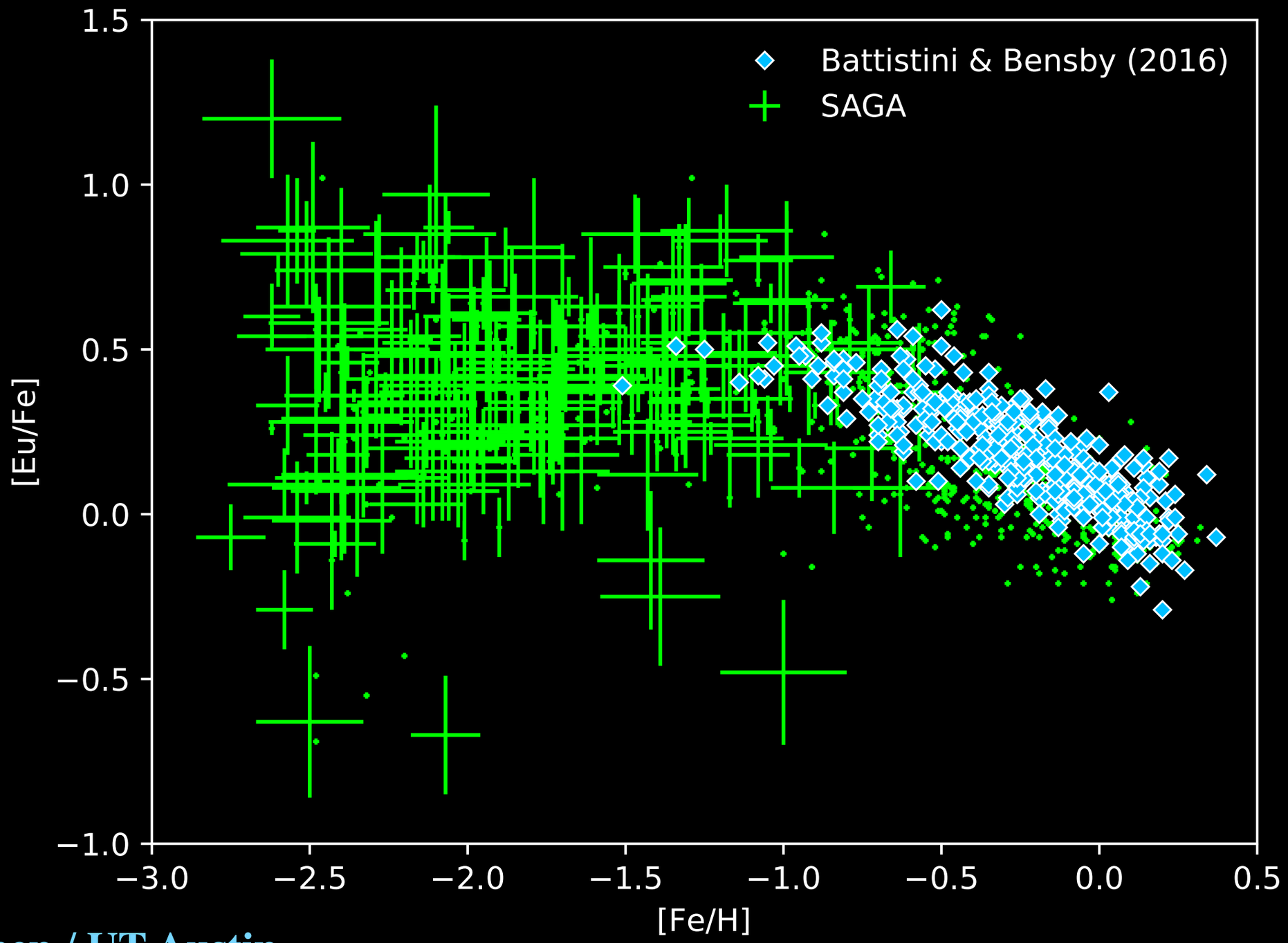
Comparison to Galactic stellar metallicity observations



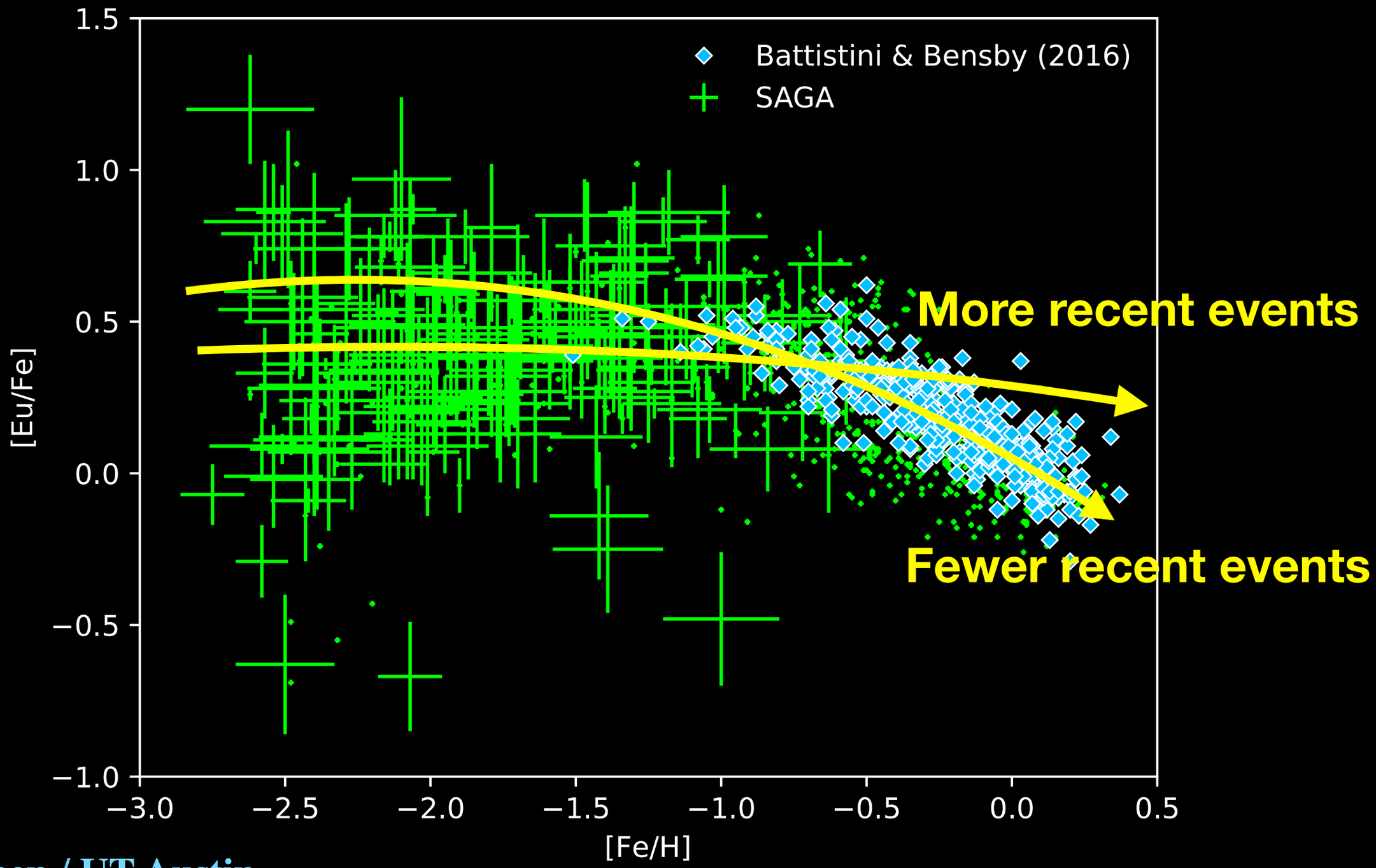
Short gamma-ray burst observations were used for the estimate of evolution of binary neutron star merger rate.

Binary neutron star mergers can't reproduce the stellar metallicity observations.

Comparison to Galactic stellar metallicity observations



Comparison to Galactic stellar metallicity observations



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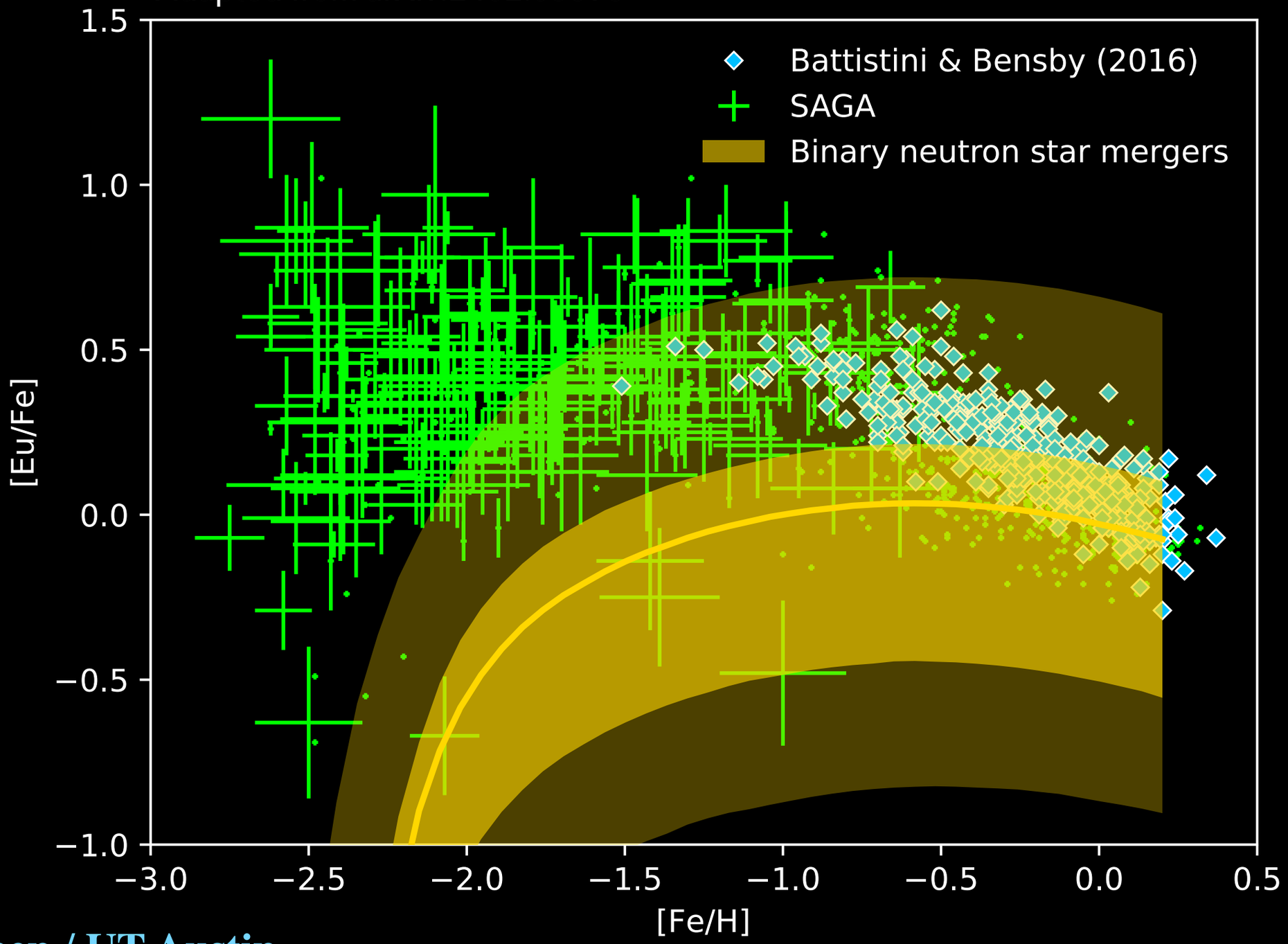

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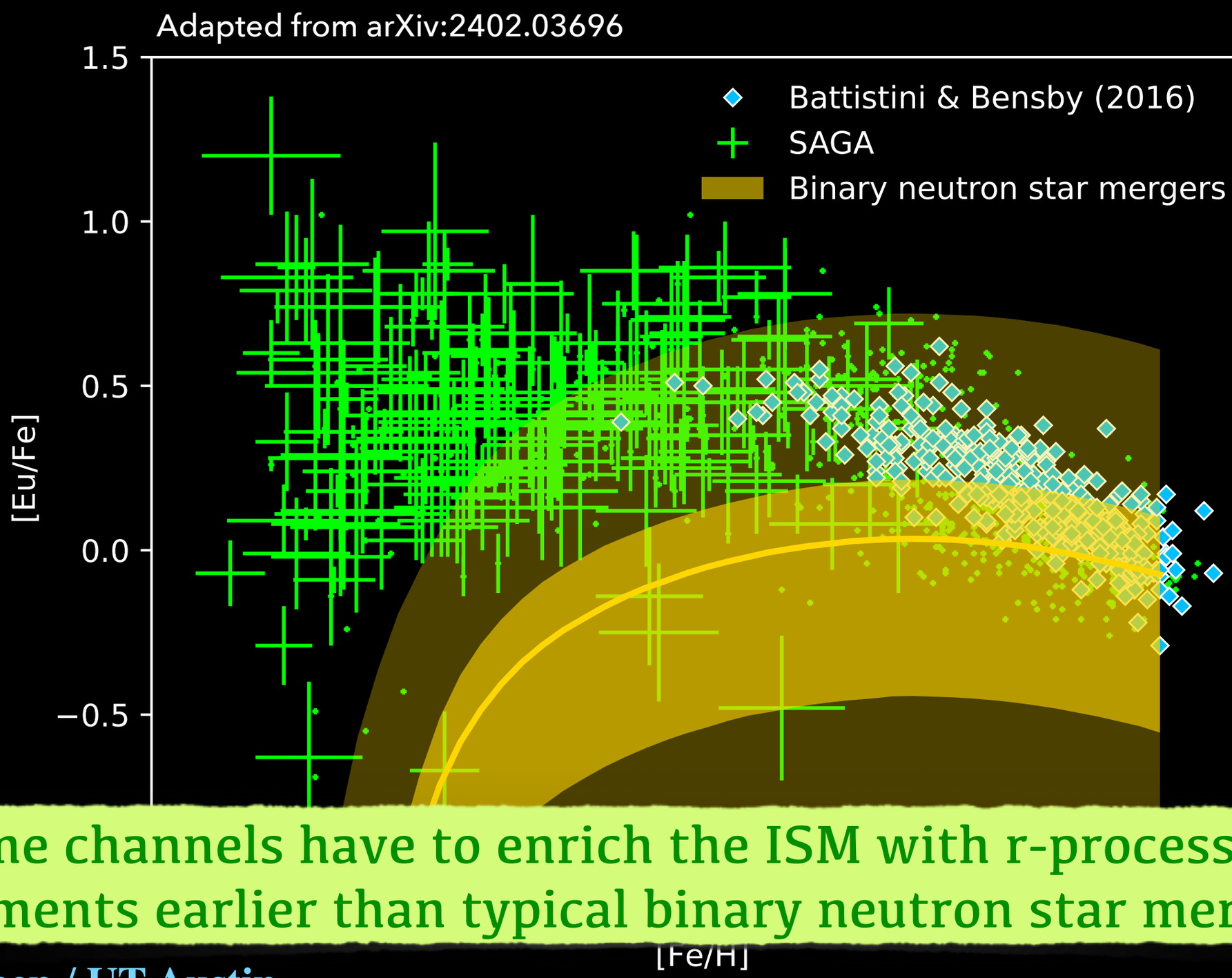
Comparison to Galactic stellar metallicity observations



Some channels have to enrich the ISM with r-process elements earlier than typical binary neutron star mergers.

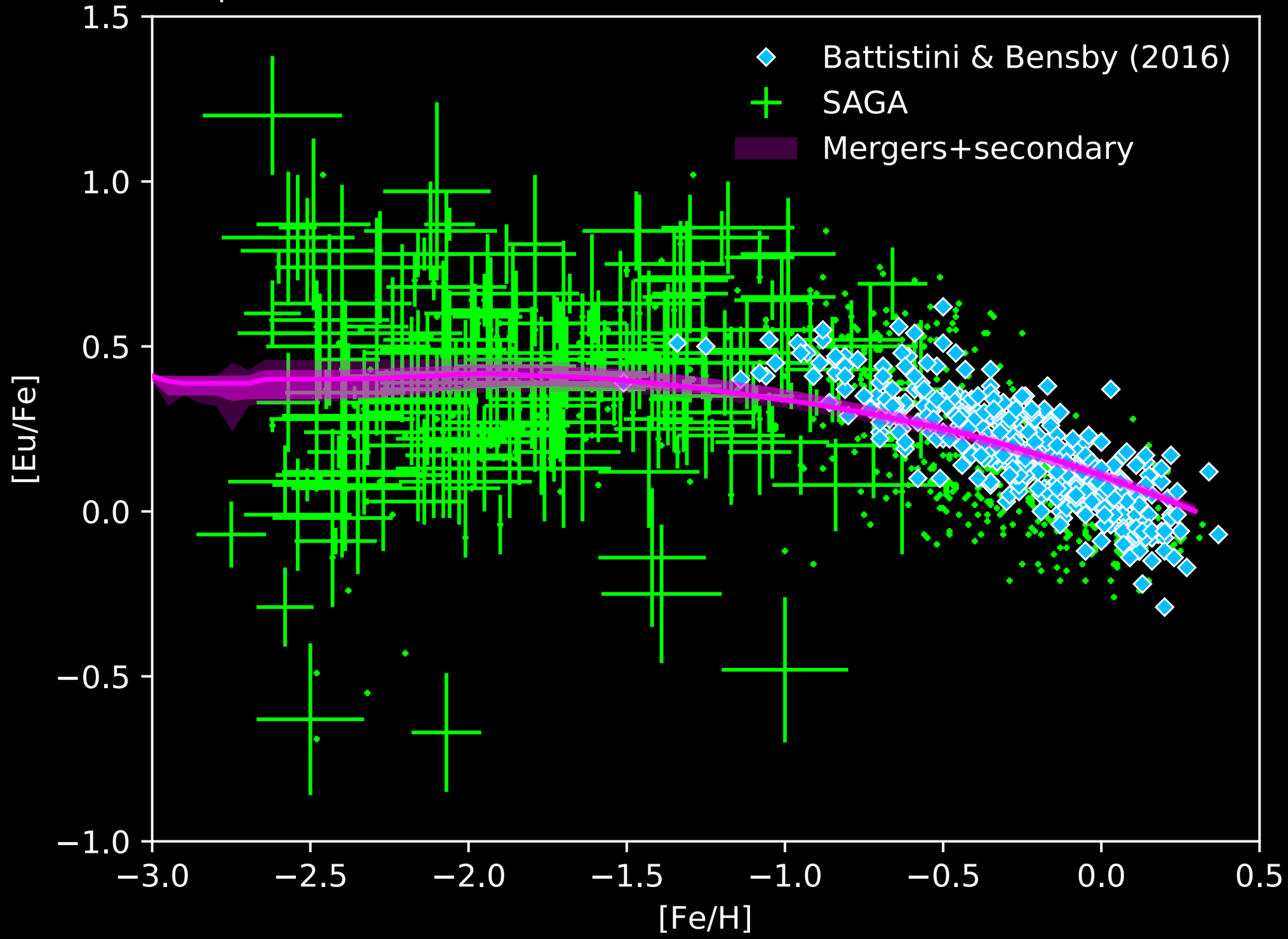
How early? How much r-process elements came from the additional channel(s)?

How early? How much r-process elements came from the additional channel(s)?

Bayesian framework to infer the contribution from the secondary channel.

Inference of the secondary channel

Adapted from arXiv:2402.03696



Inference of the secondary channel

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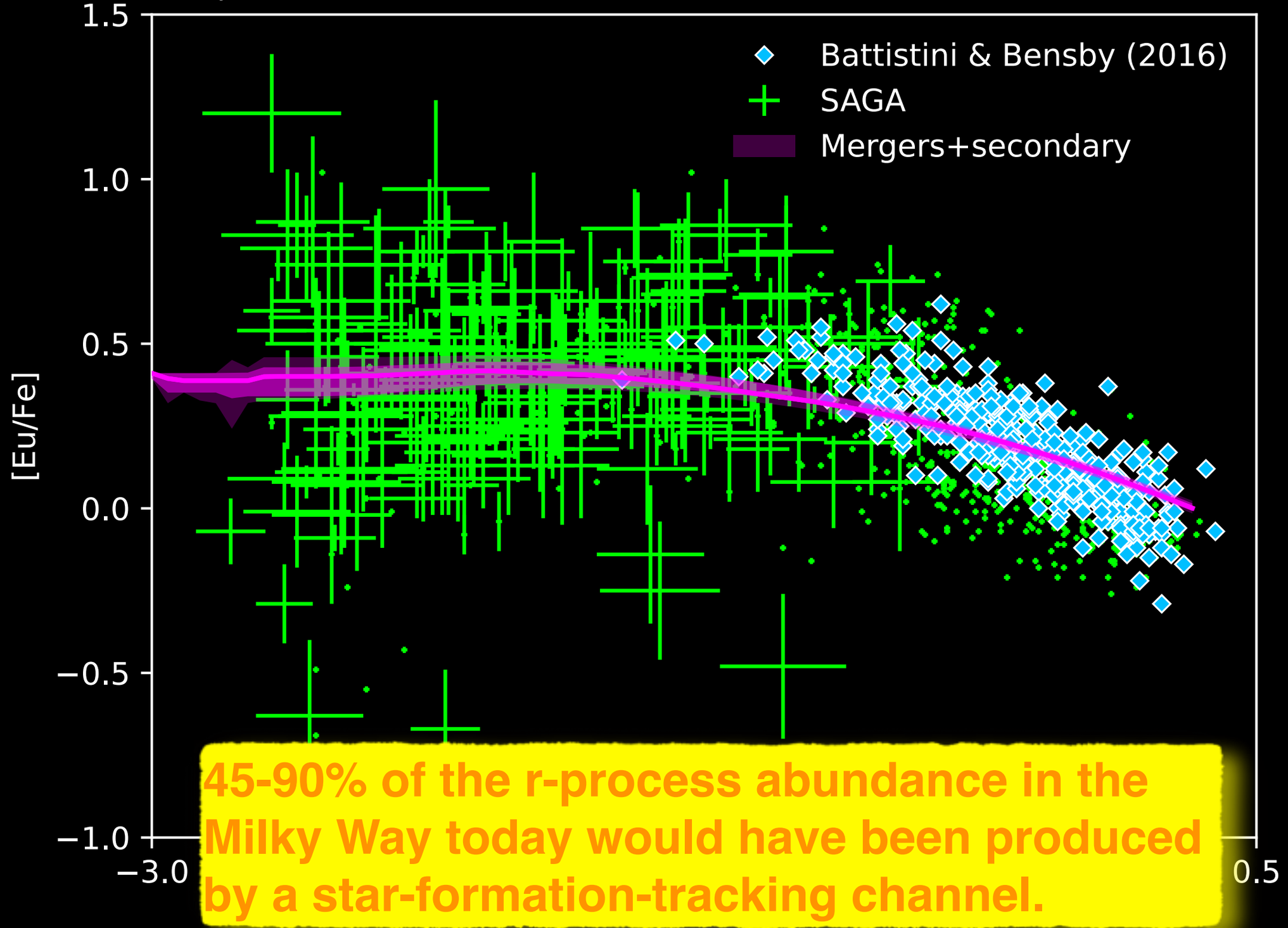

45-90% of the r-process abundance in the Milky Way today would have been produced by a star-formation-tracking channel.

Are binary neutron star mergers the major production site for r-process elements?

A star-formation-tracking channel have contributed to the same order-of-magnitude to the present-day r-process abundance in the Milky Way.

Are binary neutron star mergers the major production site for r-process elements?

Potential candidates for the secondary channels:
fast-merging binary neutron stars,
neutron star-black hole mergers,
collapsars, magnetar giant flares,
magnetohydrodynamic supernovae, ...

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Potential candidates for the secondary channels:
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Non-merger channel is needed.

Thank you!

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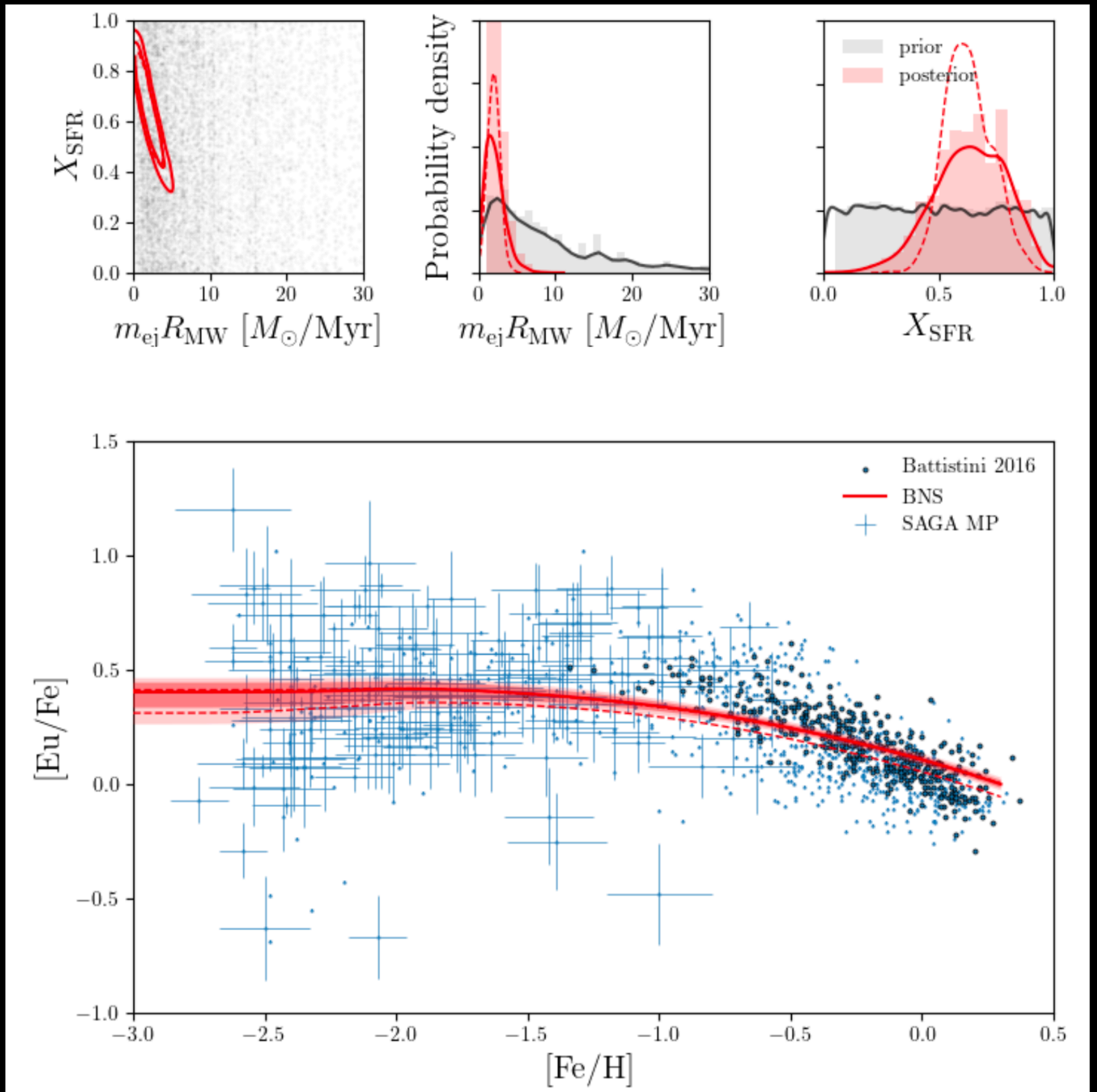
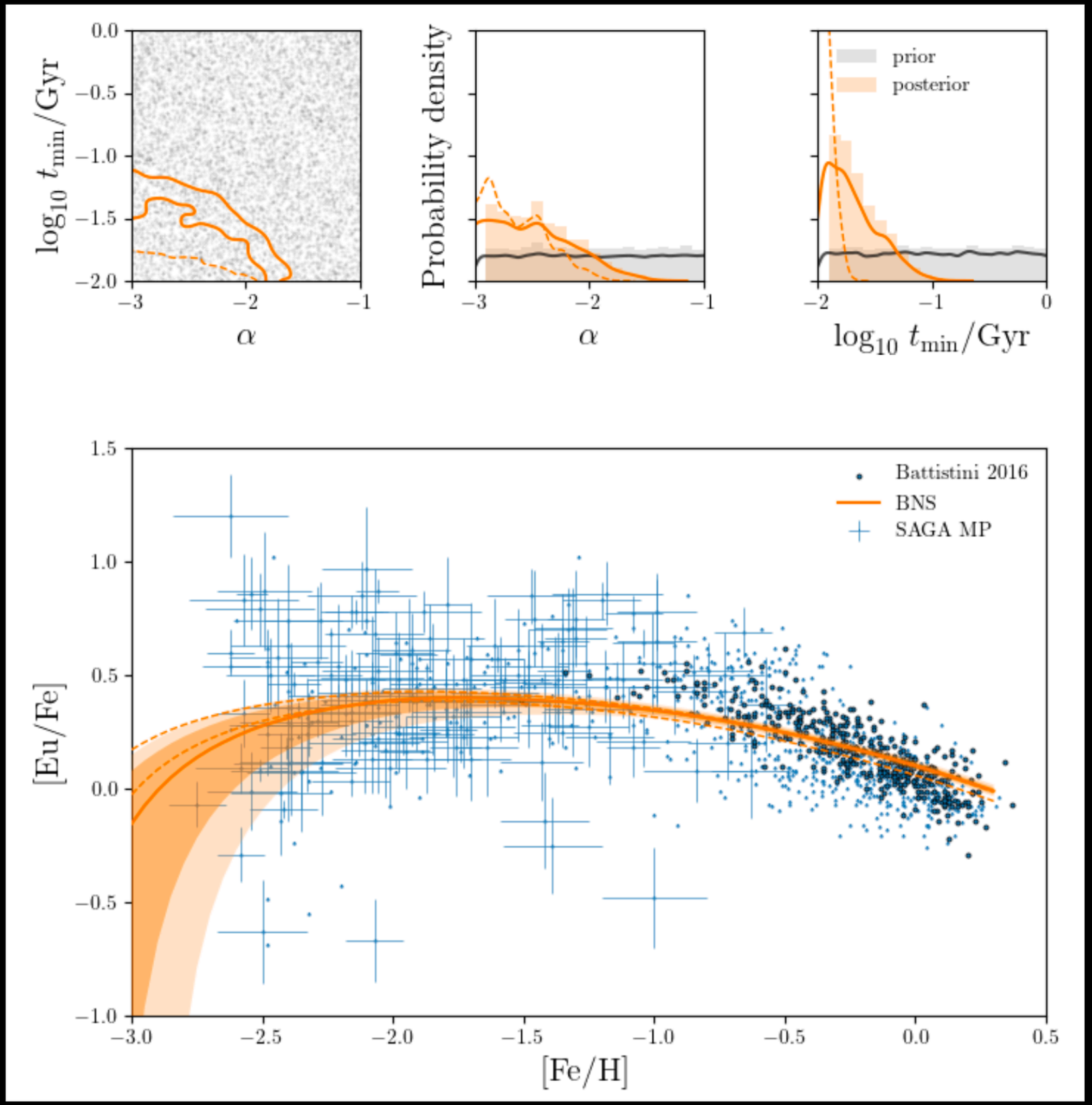
Inference of a second r-process site



What delay time would be enough?



Binary neutron star merger rate across the history

- Merger delay time distribution