Merger rates of binary neutron stars and r-process element abundances in the Milky Way

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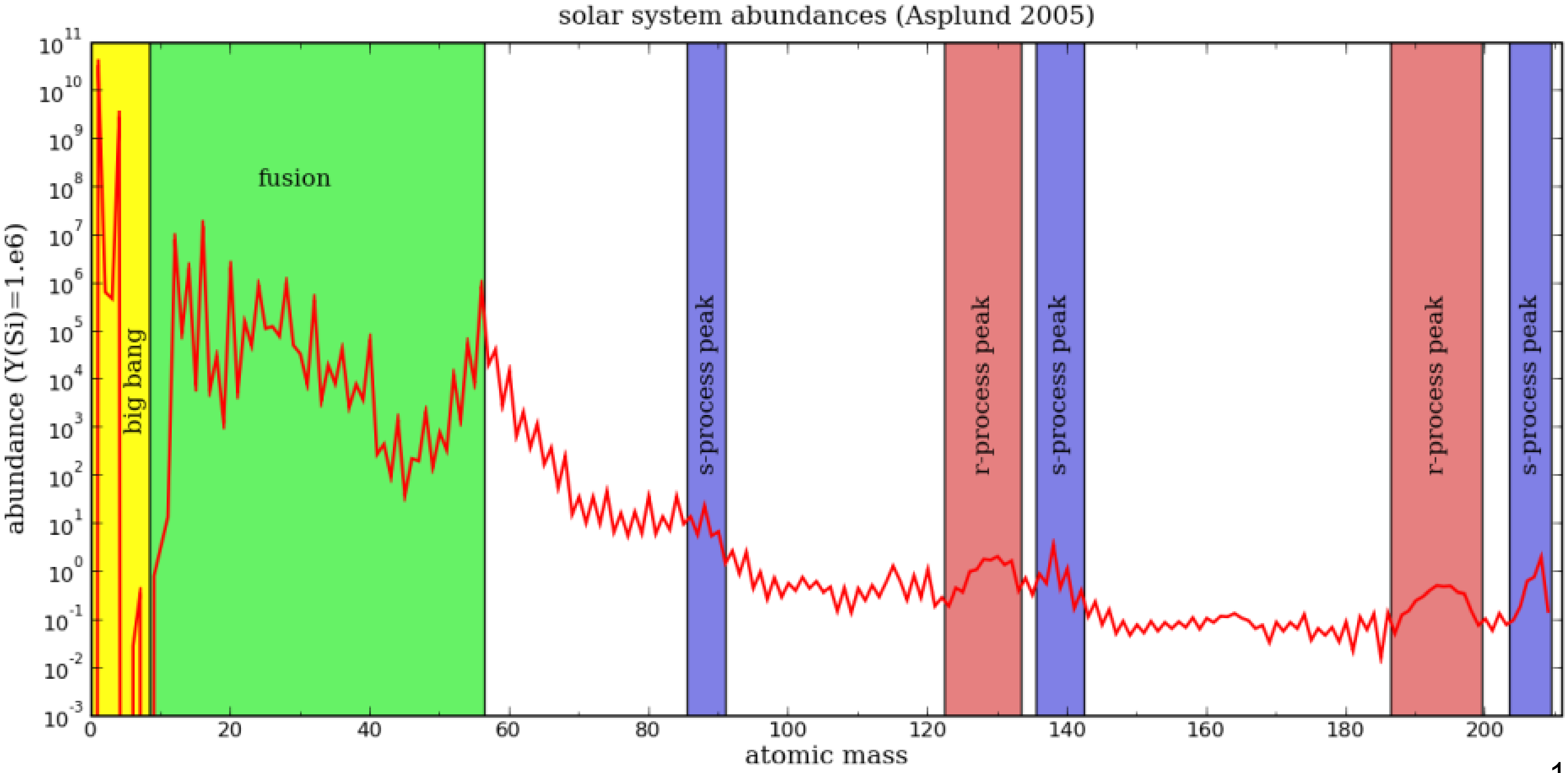
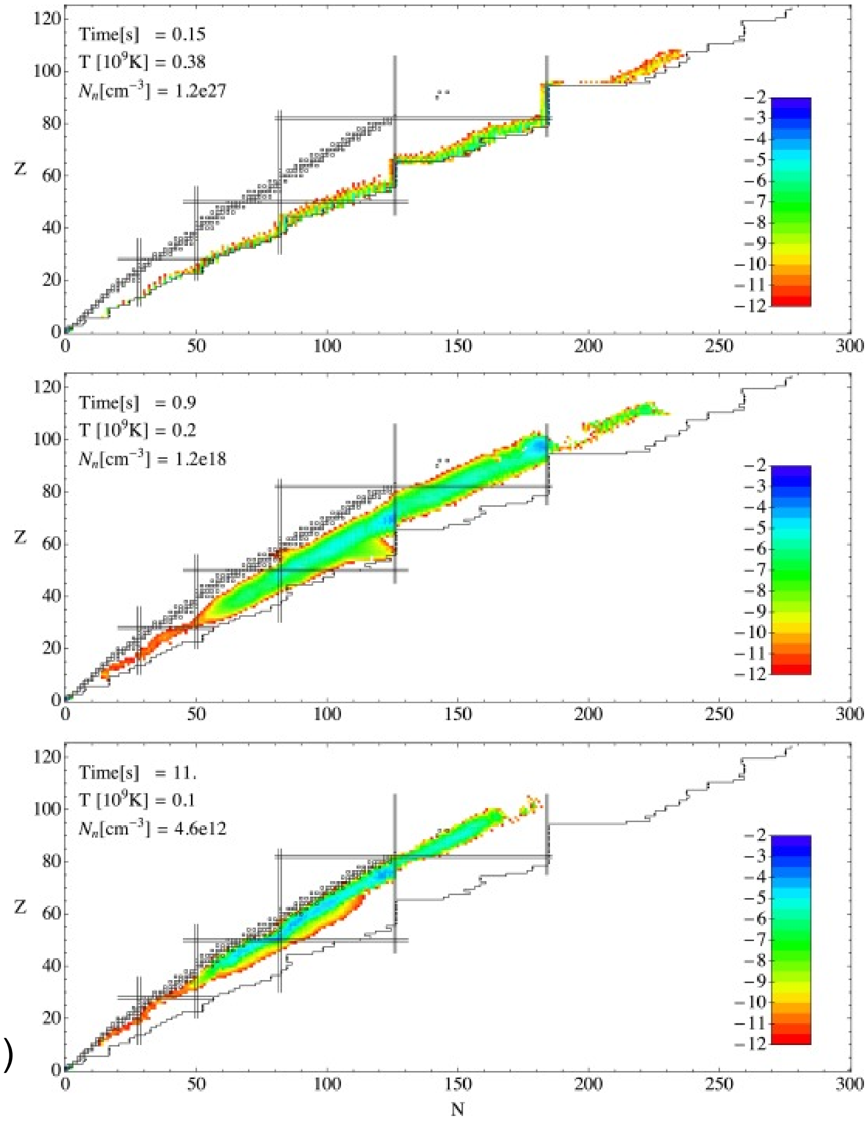
Assemblée générale du GdR OG, Lyon 11 Oct 2019

Intro: r-process elements



Intro: r-process elements

- High temperatures, densities: neutron capture faster than beta decay

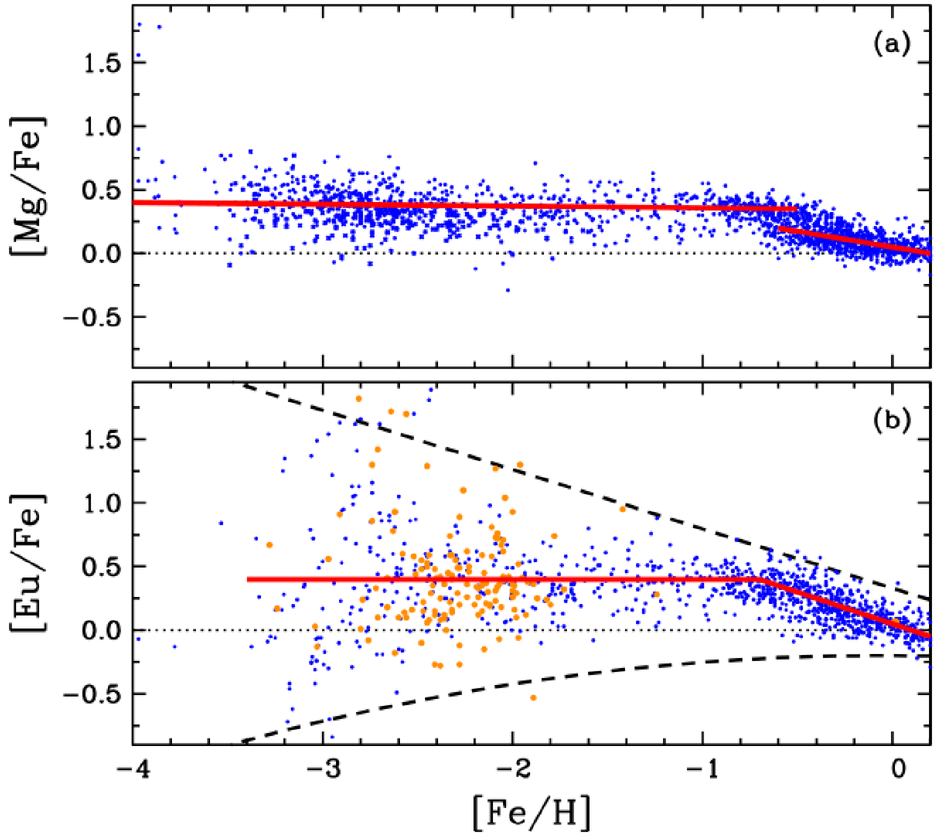


Goriely & Martinez Pinedo (2015)

r-process elements: observations

Cowan+2019

- Solar system
- **Metal-poor stars in the Milky Way**
- Dwarf galaxies (possibly building blocks of the Milky Way)



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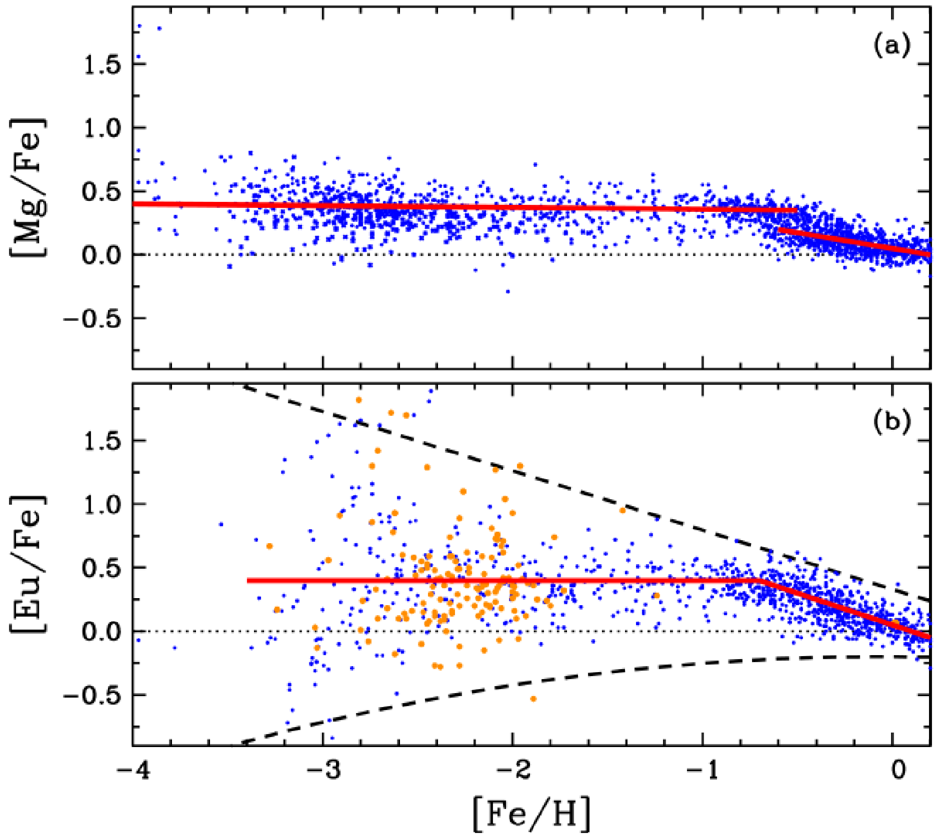

Large scatter in abundance → Rare events with high yields

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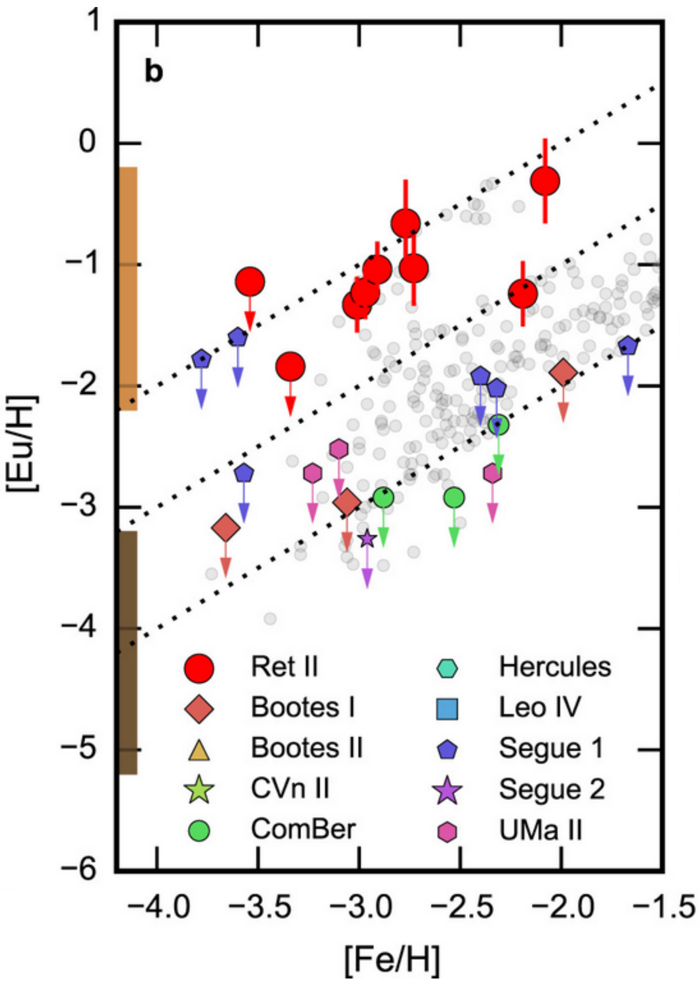
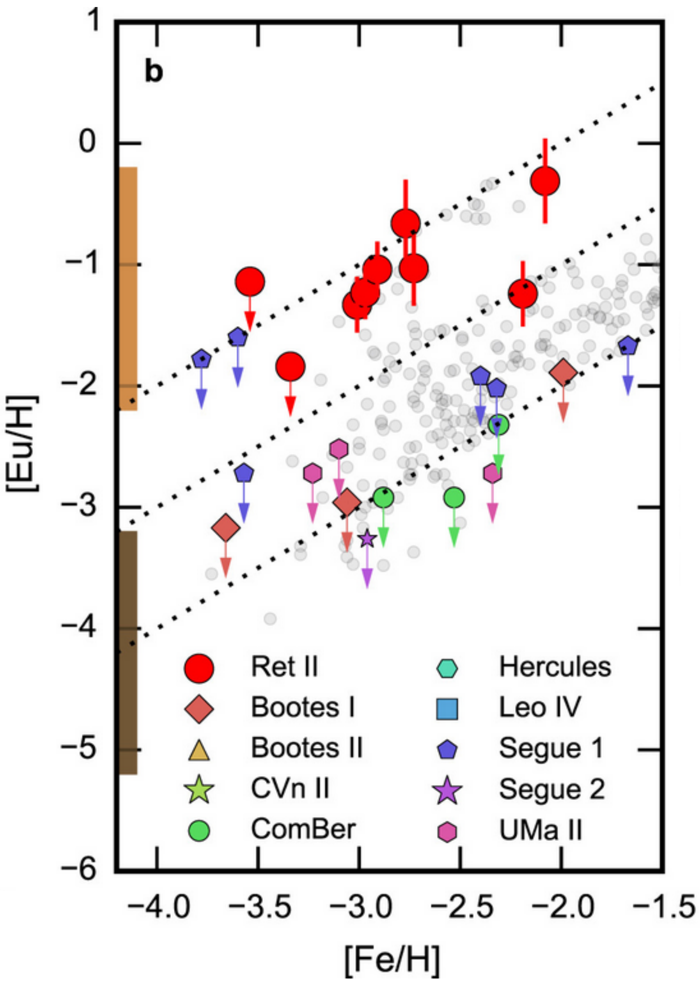


Ji+2016

r-process elements: observations

- Solar system
- Metal-poor stars in the Milky Way
- **Dwarf galaxies** (possibly building blocks of the Milky Way)
  - Can r-process material remain in the dwarf galaxy?



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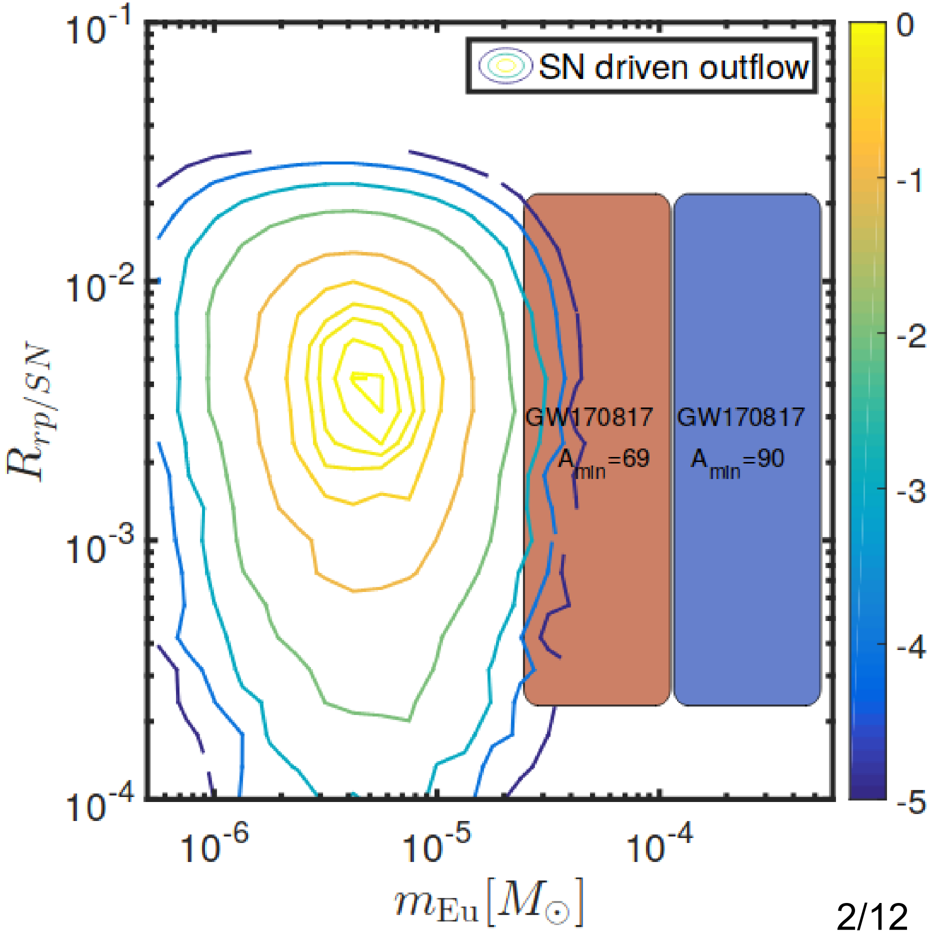

Beniamini, **ID,** Silk (2018)

Where to r-process elements form?

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  - Regular SNe

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- Core-collapse of massive stars
  - ~~Regular SNe~~
    - *Difficulties in reproducing the solar abundance pattern*
    - *Frequent events with low yields cannot explain the large scatter in [Eu/Fe] in metal-poor stars*

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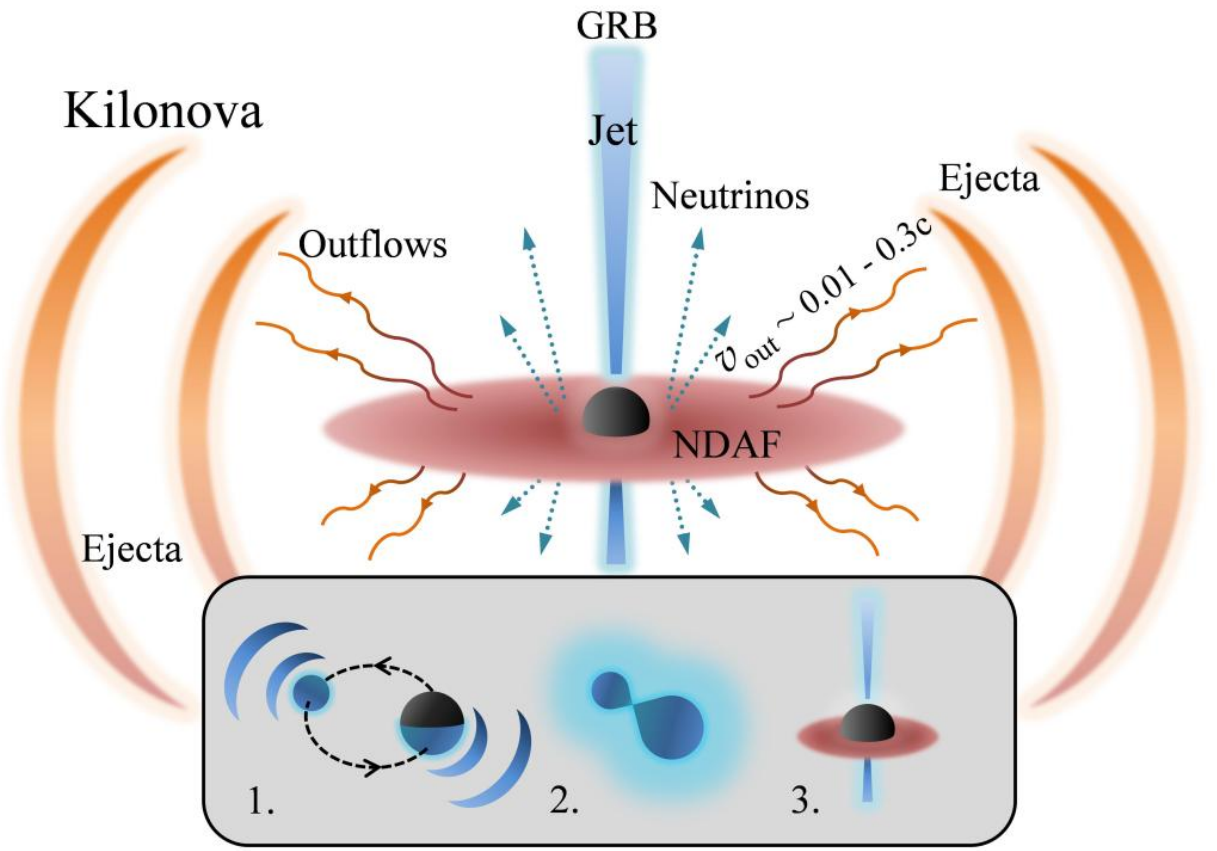
- *Must be rare events relative to regular core-collapse SNe*
- *Combination of ejecta mass and rates must explain the overall observed abundance*
- *Need to explain early enrichment (high [Eu/Fe] values at low metallicity)*

Where to r-process elements form? In BNS mergers !

- Neutron-rich high-density environment in the ejecta
- r-process elements form
- Radioactive decay of r-process elements heats the ejecta



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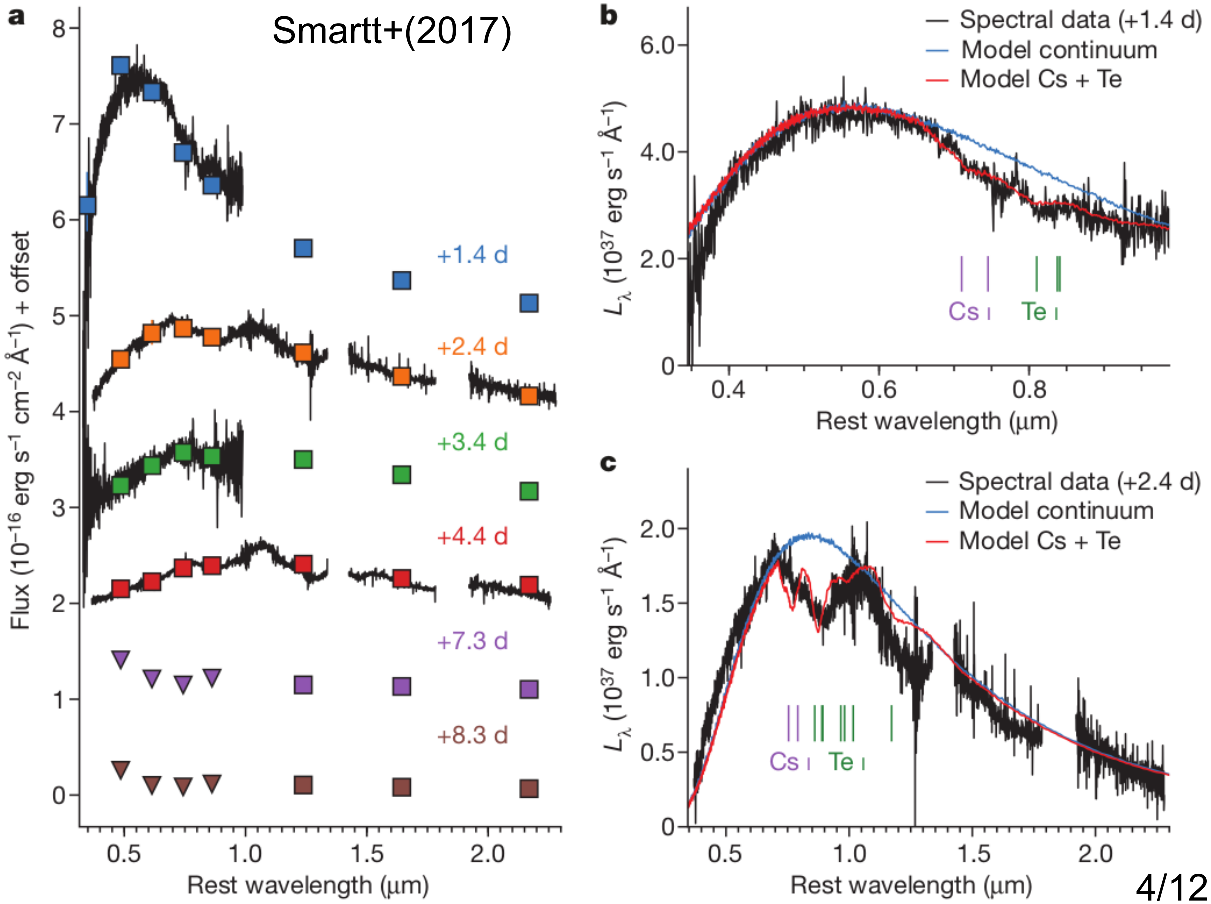
⇓

Kilonova

First GW+EM observation: GW170817 + AT 2017gfo



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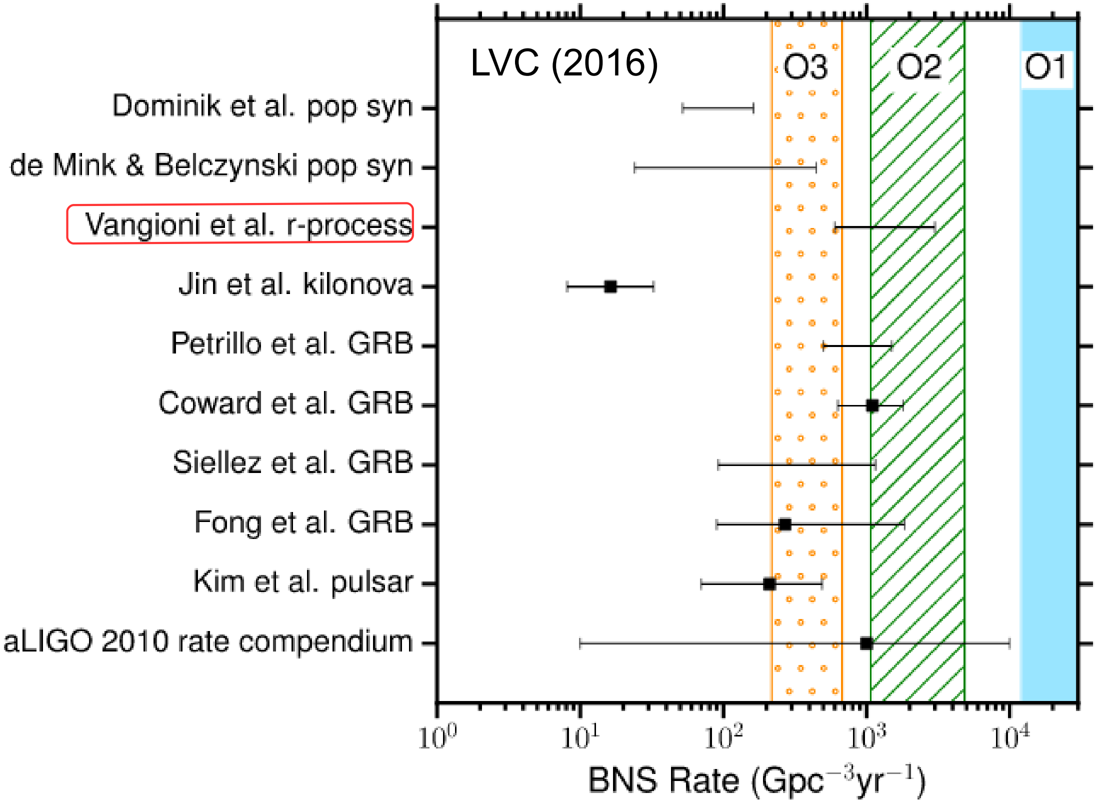
- Measure total mass of r-process elements in the interstellar medium
- Divide by the mass ejected by a single BNS merger
- Obtain the **rate** of BNS mergers



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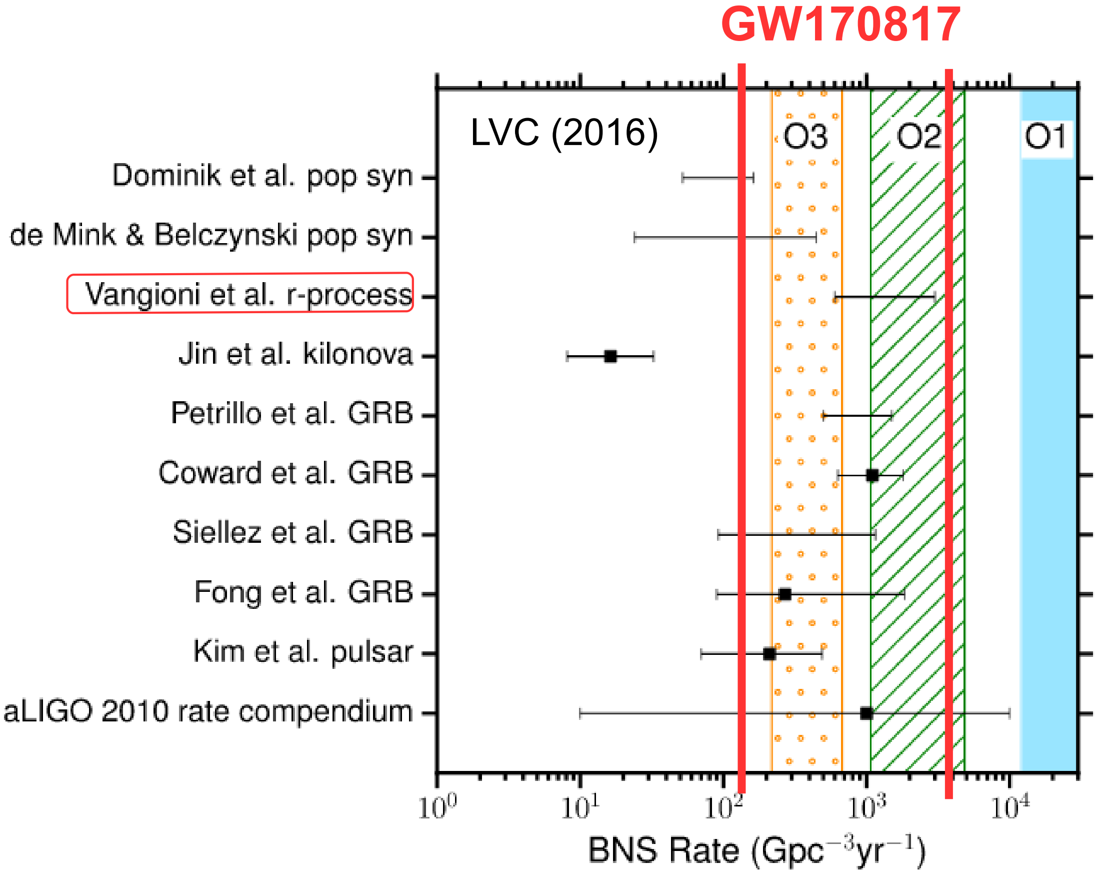
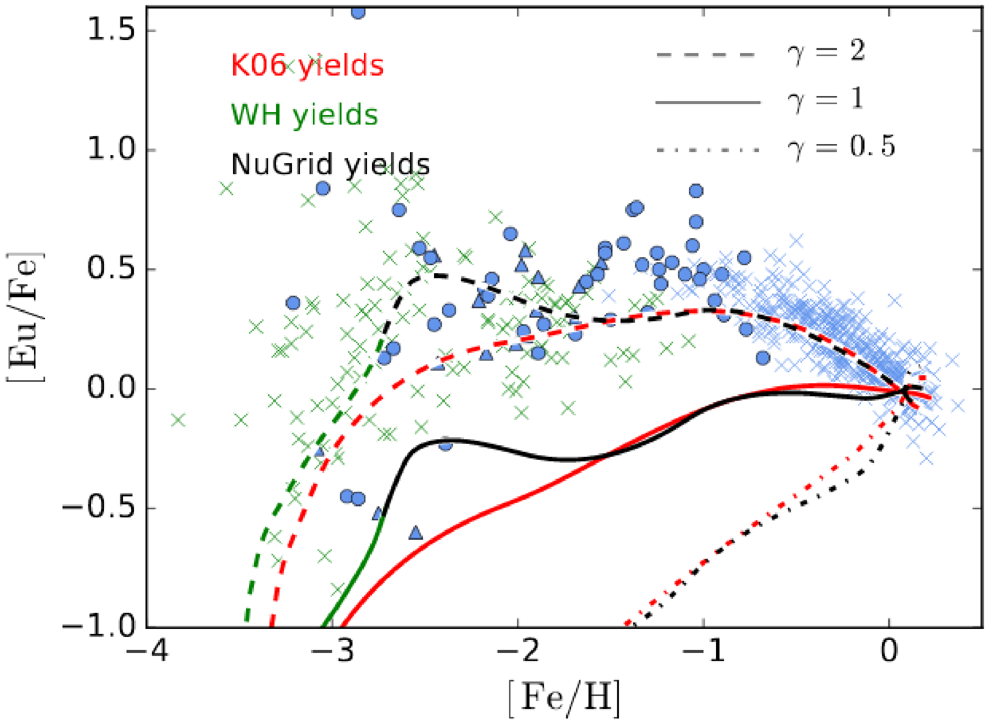


Where to r-process elements form? BNS vs. CCSN

- BNS mergers occur with a large time delay relative to star formation (evolution of the binary)
- Difficulties in explaining high [Eu/Fe] values in metal-poor stars if all of Eu is formed in BNS mergers

$$P(t) \sim t^{-\gamma}$$



Côté+(2017)

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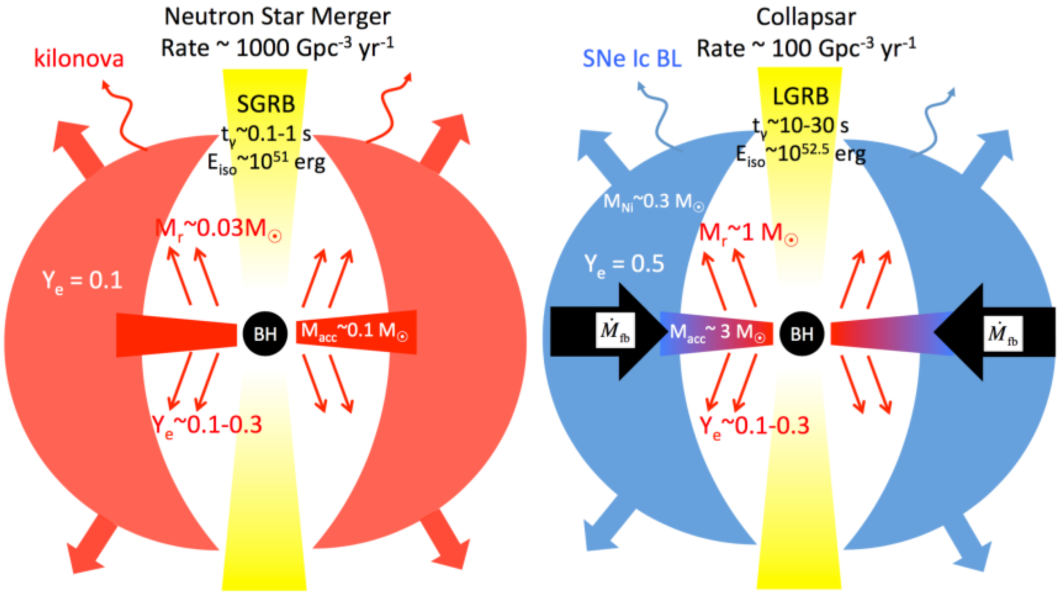

Siegel+ (2018)

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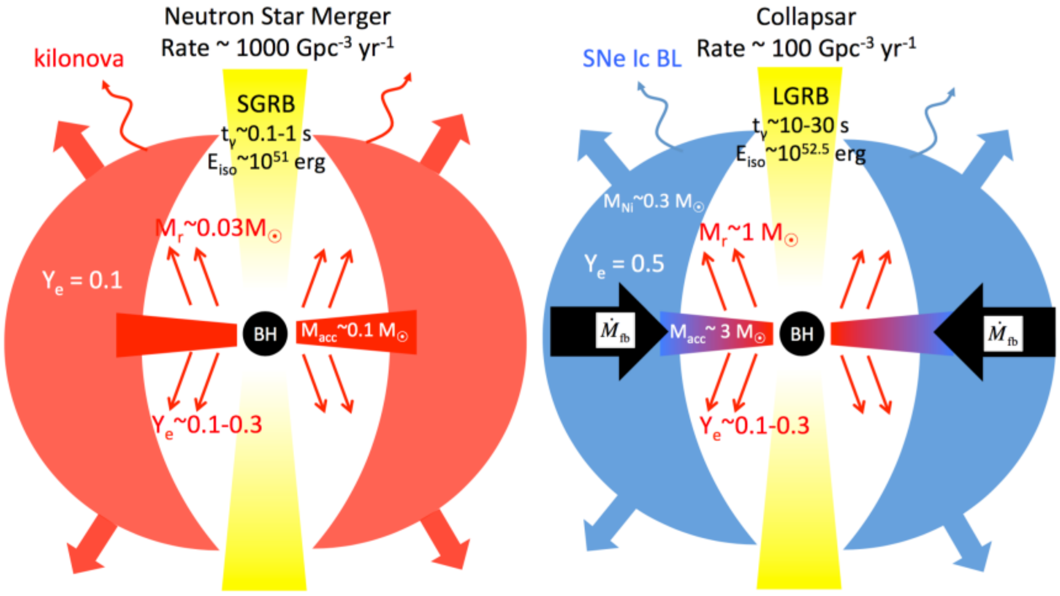

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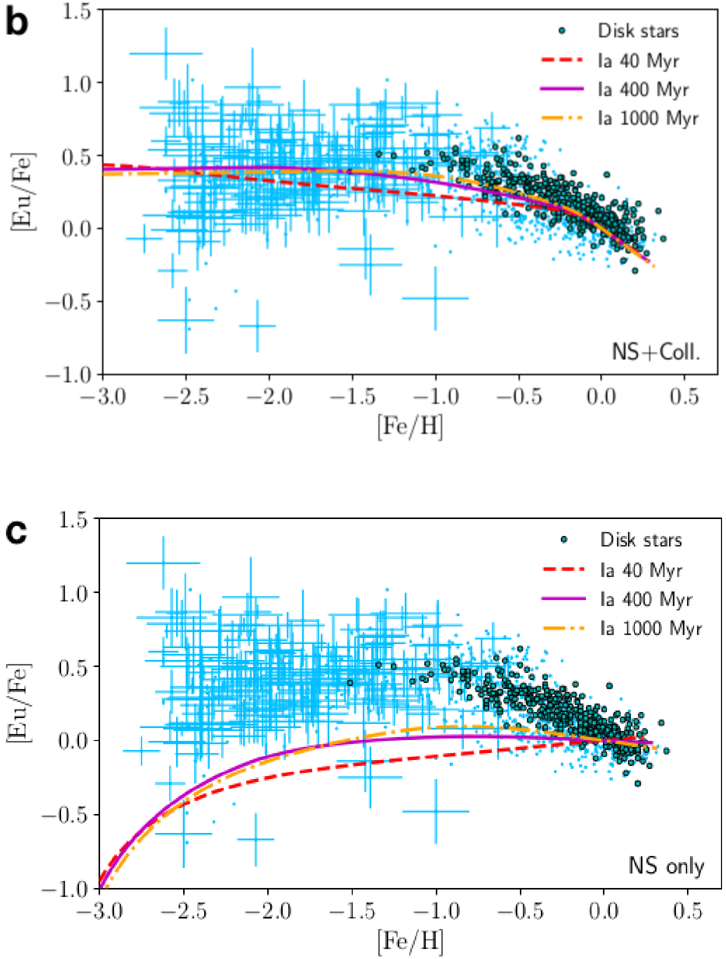
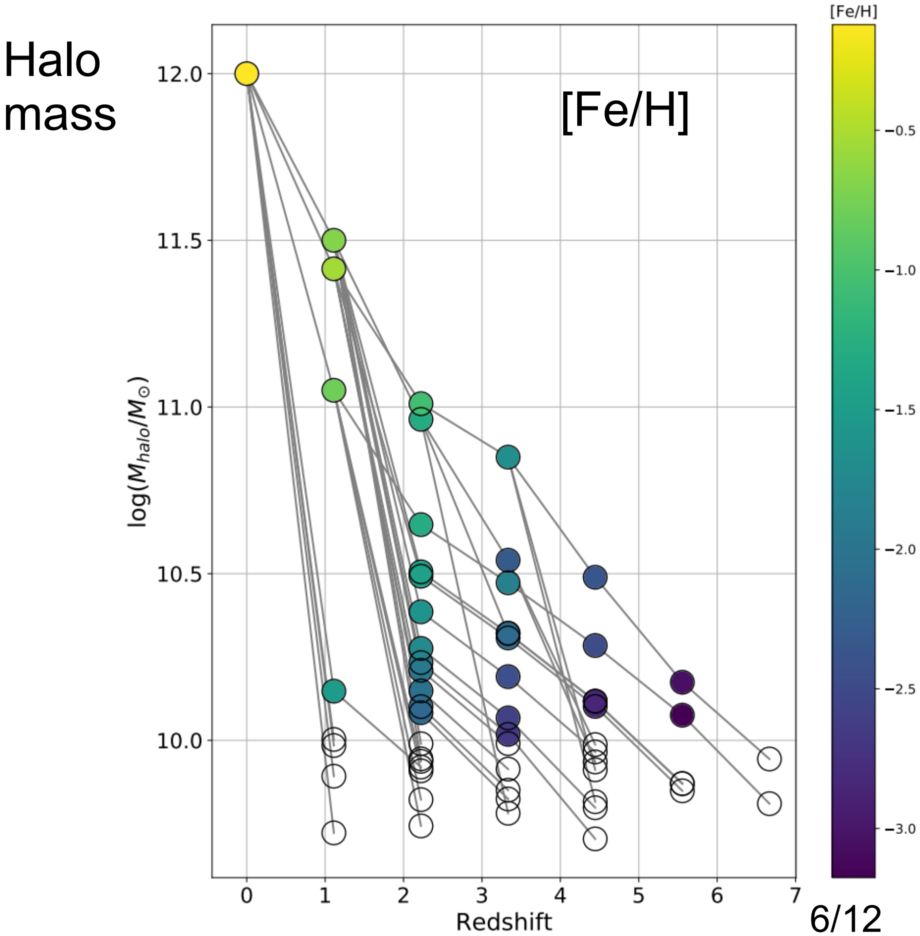


Siegel+ (2018)

Our study: Chemical evolution of a Milky-Way-like galaxy

- Semi-analytic model of structure formation
- Inflow of gas into DM halos
- Radiative cooling, K-S star formation law
- SN-powered winds
- Non-instantaneous recycling
- Chemical evolution (Daigne+2004,2006)
- r-process source: BNS mergers
  - 3×10^{-3} of all NSs are in binaries that merge within the age of the Universe
  - Each merger produces 2×10^{-4} M_{sun} in Eu



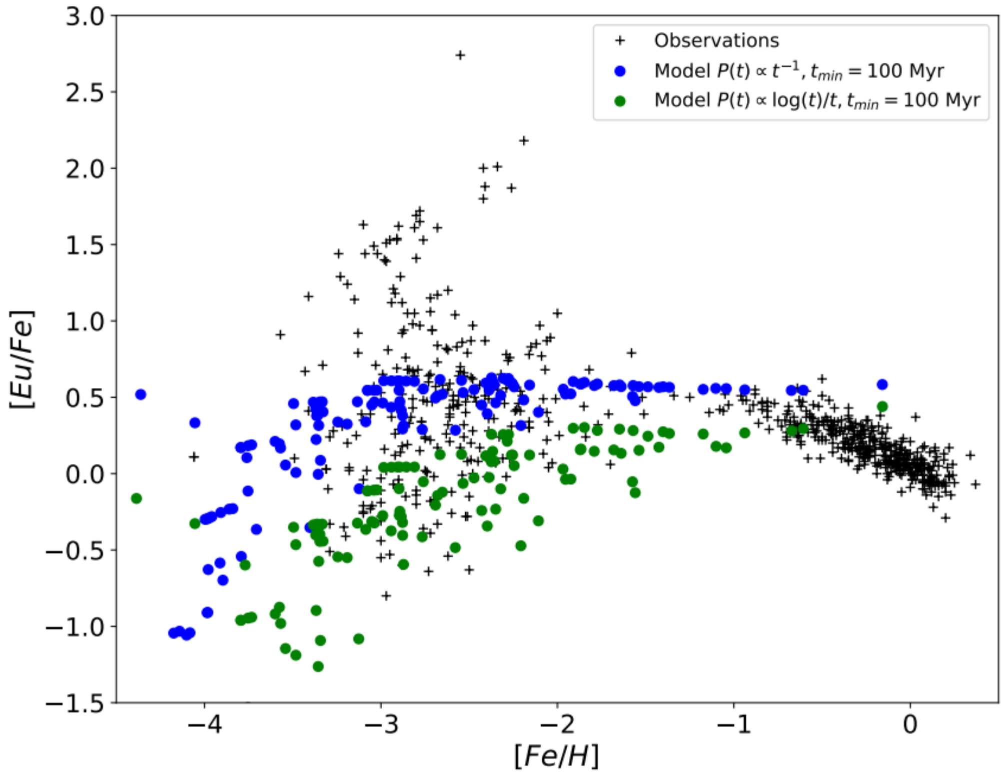
The effect of time delay distribution : functional form

Model A

$$P(t_{\mathrm{delay}}) = A t_{\mathrm{delay}}^{-1},\ t \in (t_{\min}, t_{\max})$$

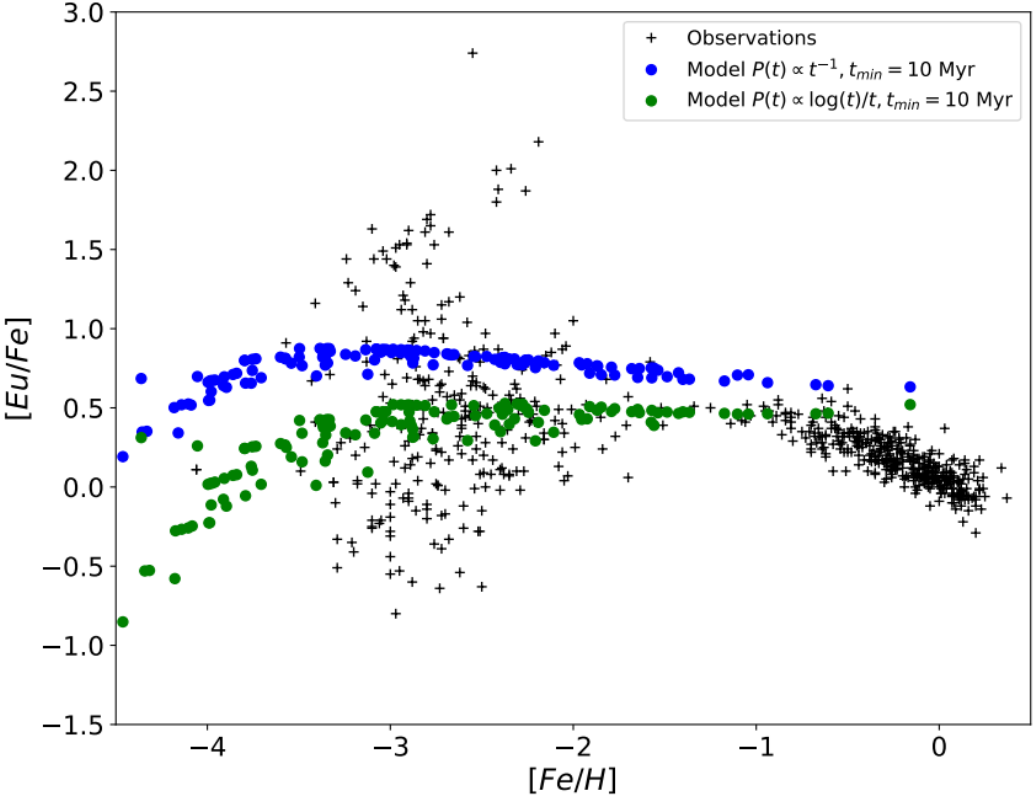
Model B

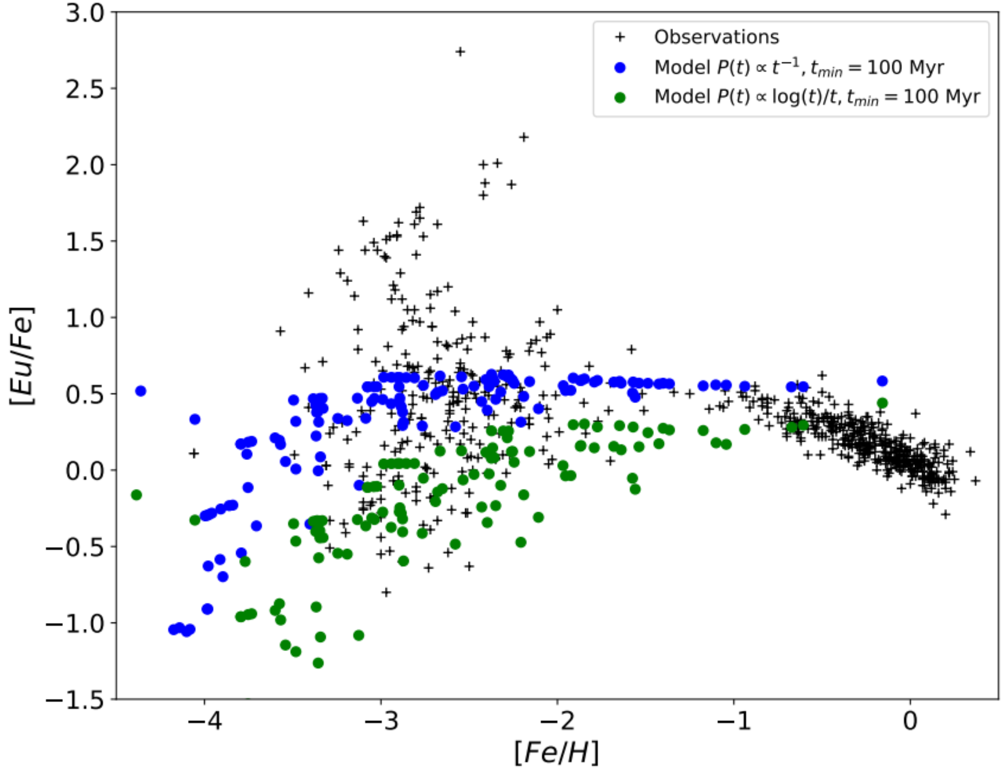
$$P(t_{\mathrm{delay}}) = A \frac{\log\left(t_{\mathrm{delay}}/t_{\min}\right)}{t_{\mathrm{delay}}},\ t \in (t_{\min}, t_{\max})$$



ID+ (in prep.)

The effect of time delay distribution : t_{min}





ID+ (in prep.)

The effect of time delay distribution : same mean delay

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Model B

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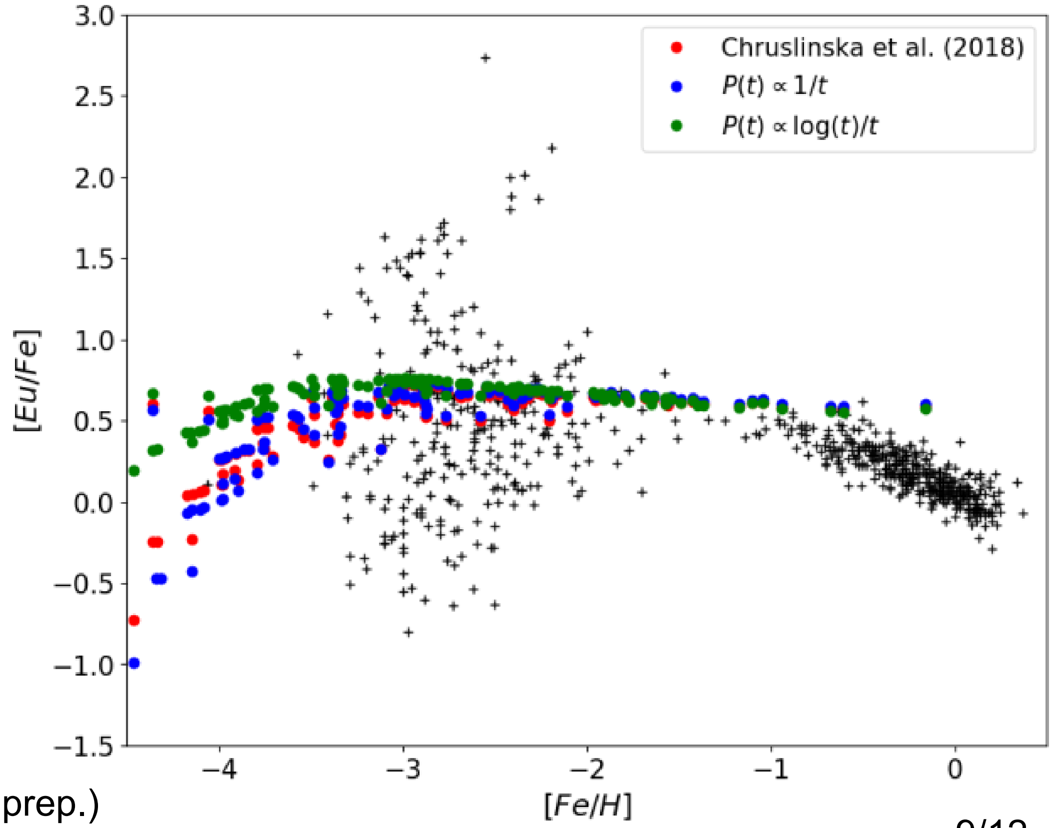
Model C

From population synthesis (Chruslinska+2018)



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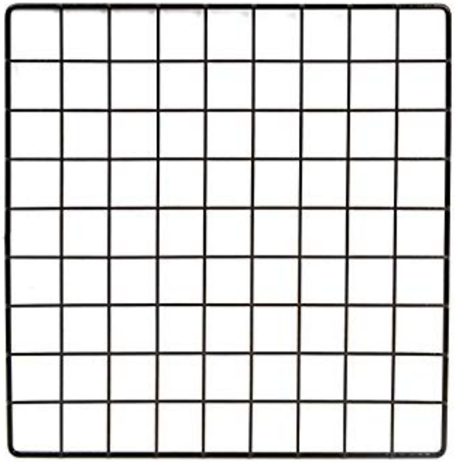
Inhomogeneous enrichment of the interstellar medium

- First implementation in a semi-analytic model (see e.g. van de Voort+2019 for numerical simulations)
- Assume r-process material is released into a small mass parcel $\sim 10^4$-10^5 M_{sun}
- BNS mergers and CCSN occur randomly in different parcels
- Mixing with the rest of the galaxy after a time t_{mixing}



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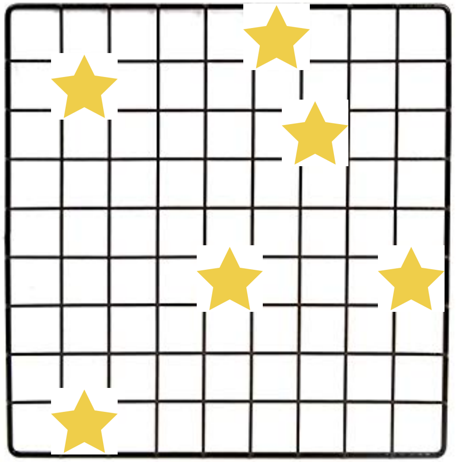

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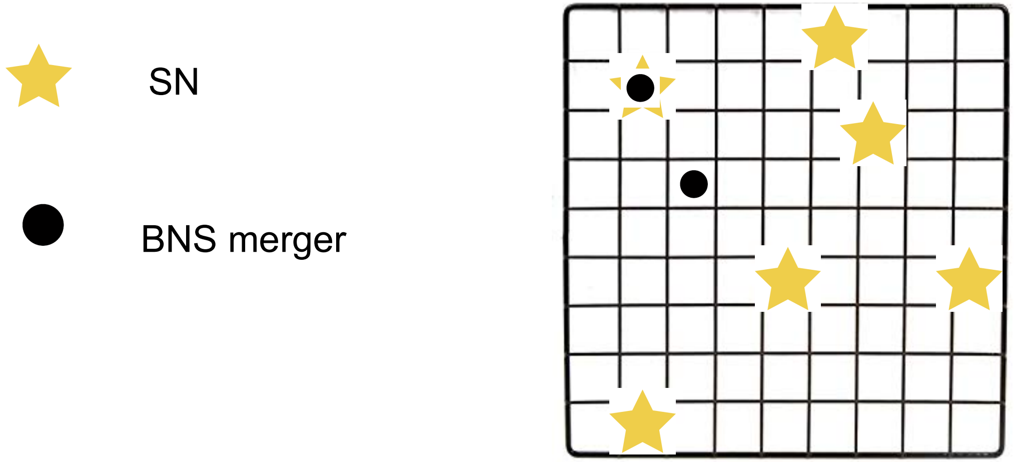
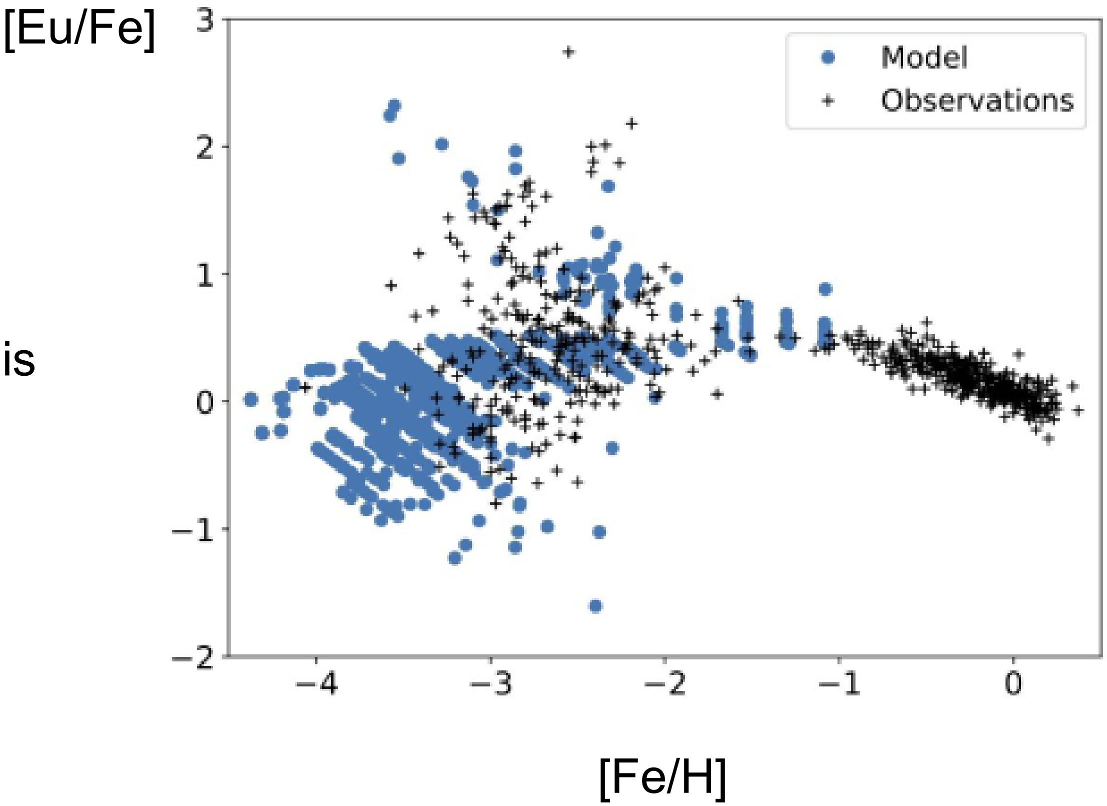


Inhomogeneous enrichment of the interstellar medium

- $M_{parcel} = 10^5\ M_{sun}$
- $t_{mixing} = 5$ Myr
- Both parameters influence the metallicity at which the dispersion is maximal



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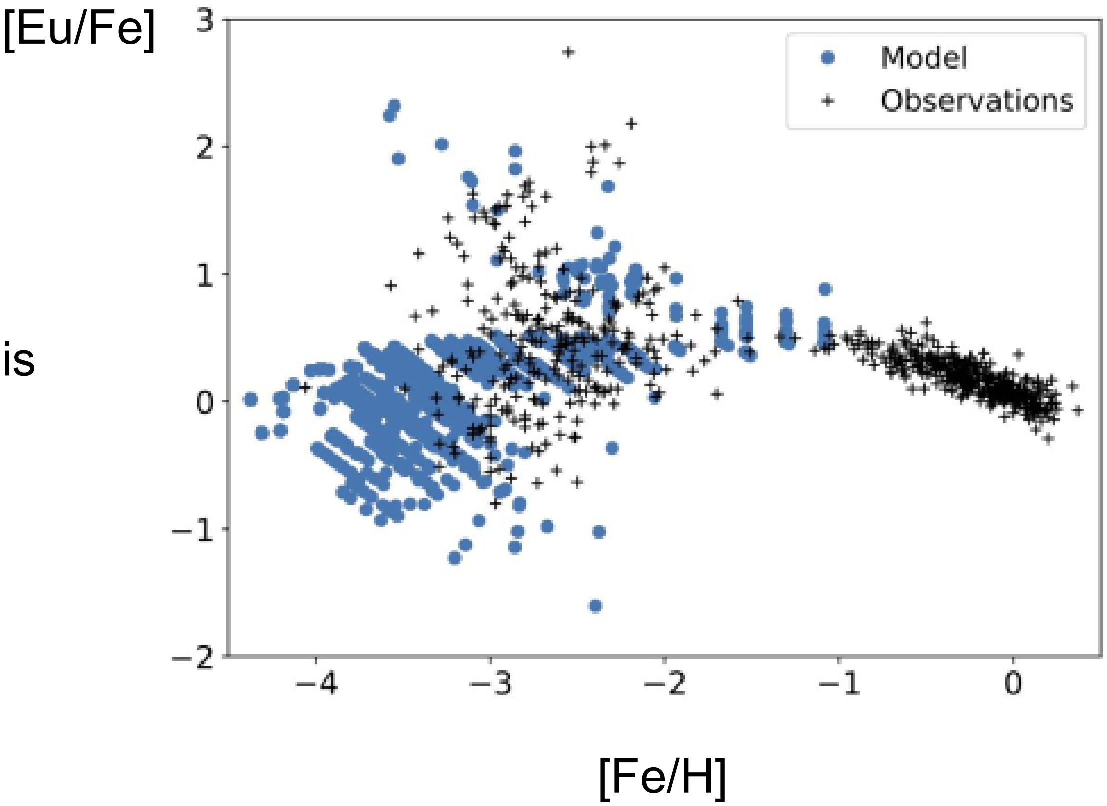
Work in progress !



Summary and future work

- *The dominant site of r-process element formation is still unknown!*
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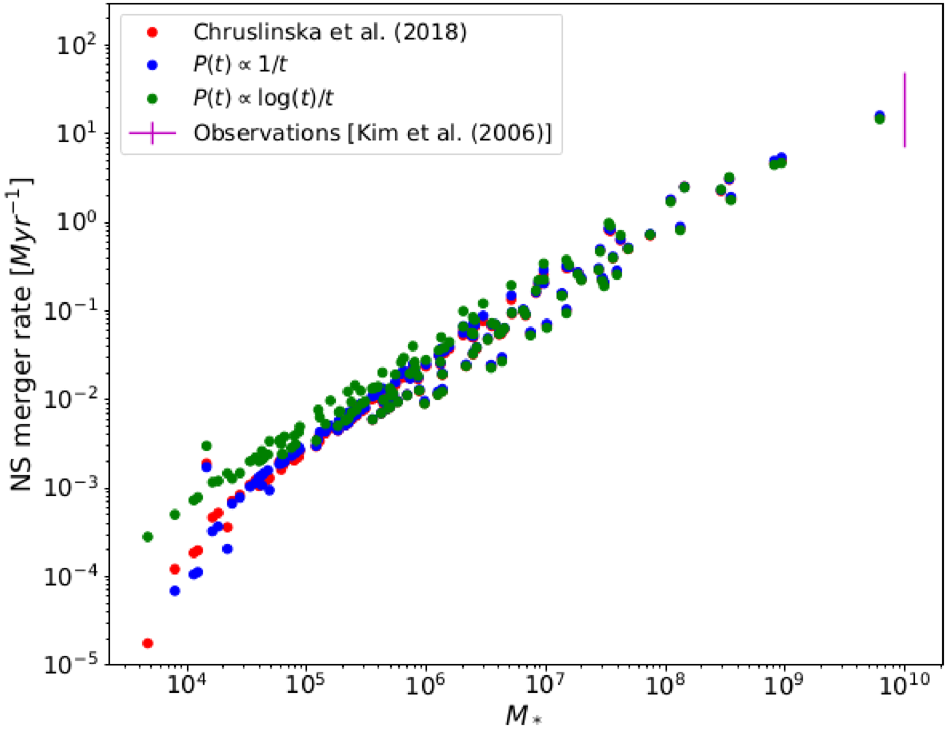
<u>Next steps:</u>

- Study inhomogeneous enrichment
  - Where did the merger happen?
- Include NS-BH mergers
- Include CCSN
- Extend to a galaxy population



r-process elements: observations

- **Solar system**
- Metal-poor stars in the Milky Way
- Dwarf spheroidal galaxies (possibly building blocks of the Milky Way)
- Ultra-faint dwarf galaxies