Neutron-capture elements in UFDs

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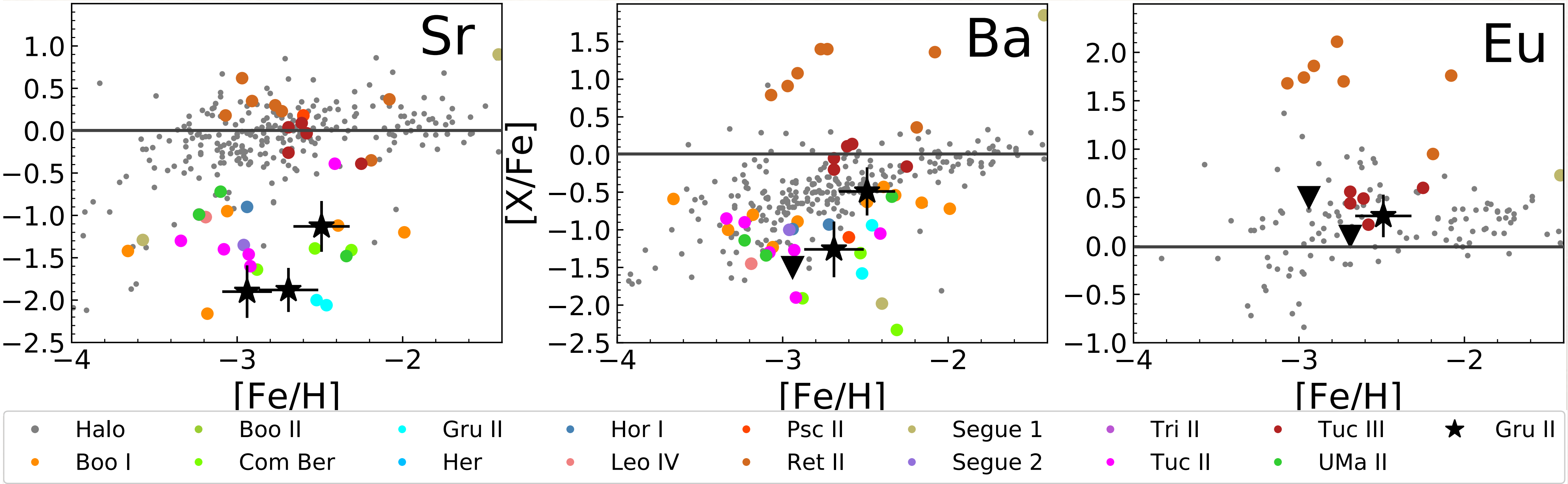
What are / Why UFDs?

- UFDs are small ($< 10^5$ Lsun) satellite galaxies.
- UFDs are old.
    - Good probe for high-z galaxy.
- Stochasticity: “0 or 1 r-process”.
- **Small but important !**


https://en.wikipedia.org/wiki/Local_Group

Neutron-capture elements in UFDs

s, r, “weak-s (?)”, “weak-r(?)”　　s, r　　r　　Hansen+20



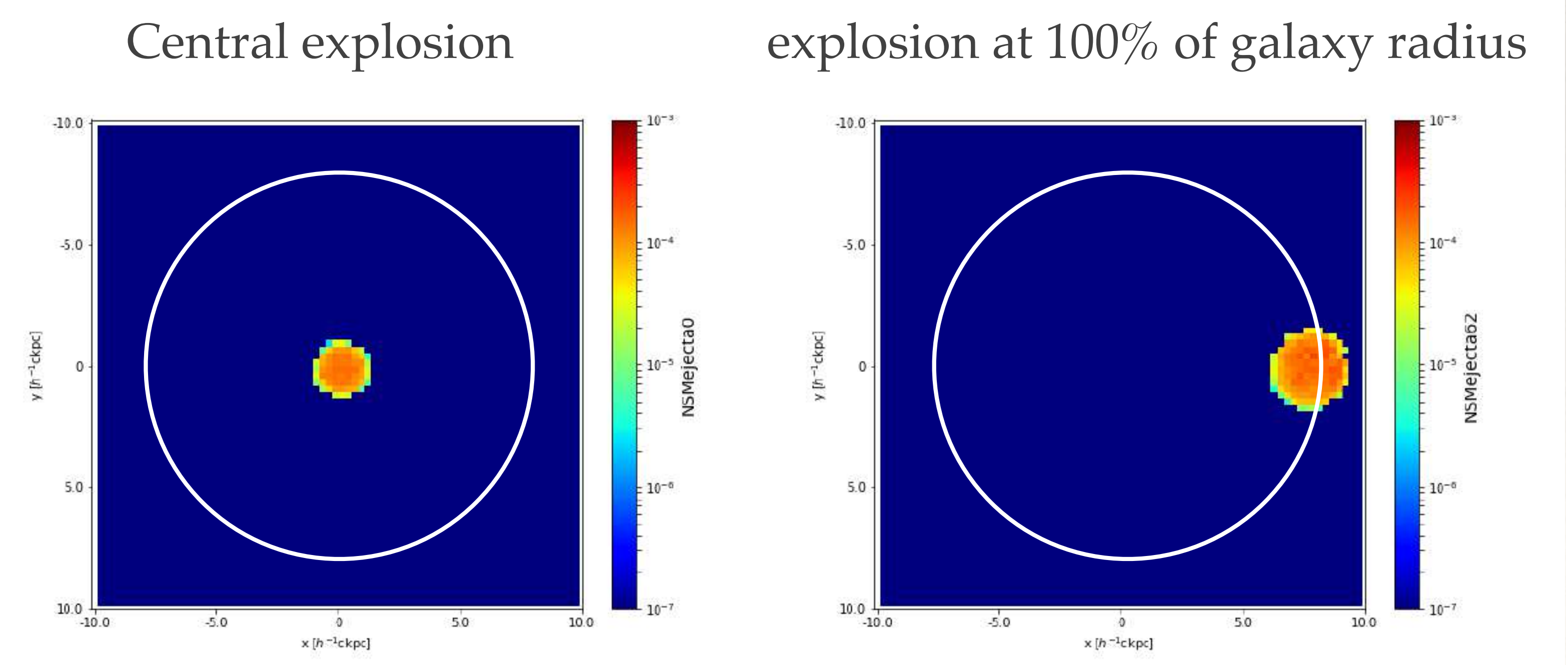
$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Sr, Ba: deficit. Eu: Not enough data.
- 3/16 UFD are enriched with Eu.
- **What are the origins of these elements?**

Method: simulation

- To investigate the effect of different explosion sites,
  - On each selected UFD progenitor,
  - (i) Pick up points on the spheres with various radii as “explosion points”.
  - (ii) “paint” cells around the “explosion points” with r-process elements to model NSM.



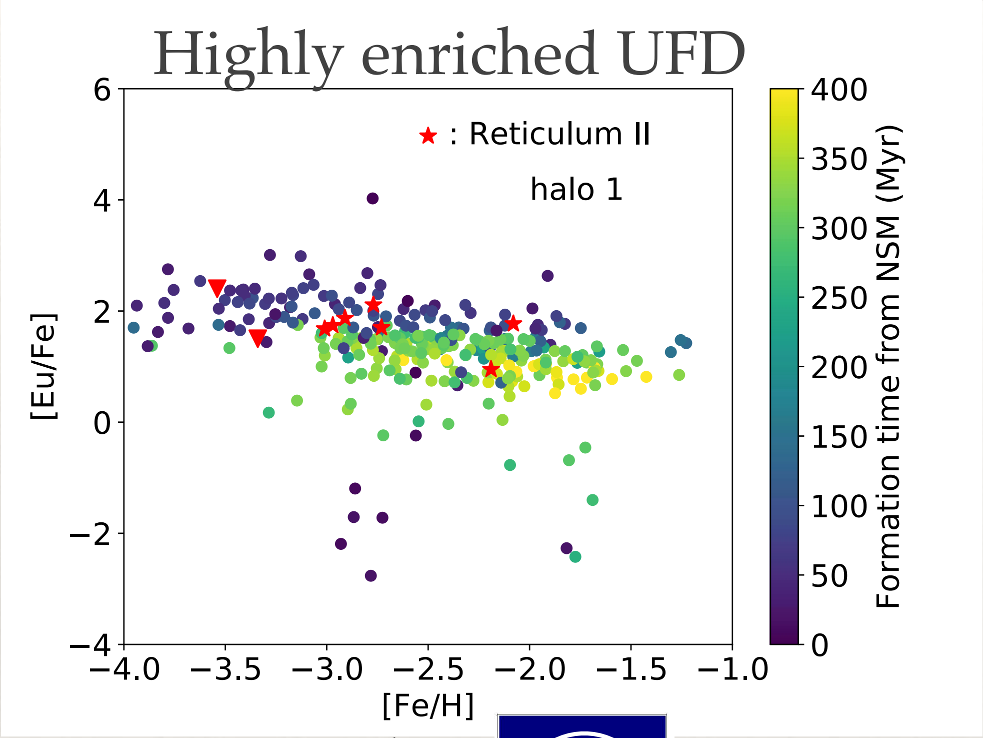
Central explosion

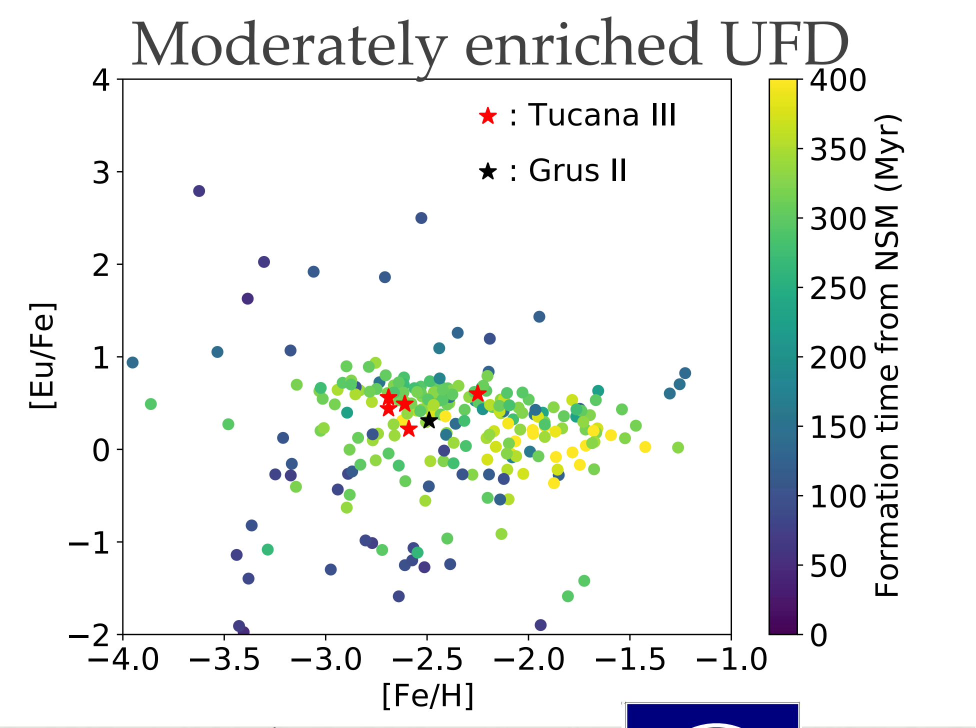
explosion at 100% of galaxy radius

r-process enrichment

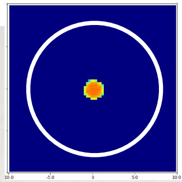
$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

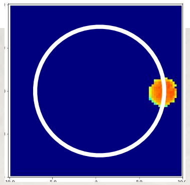

Highly enriched UFD


Moderately enriched UFD

Central explosion



explosion at 100% of radius



- Inside explosion is favored for highly enriched UFD (Ret II).
- Outside explosion is favored for Moderately enriched UFD (Tuc III, Gru II).

Discussion

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- The differences between NSM and rare CCSNe are:
  - Delay time <- Chemical evolution models
  - Travel distance before explosion <- <u>This work</u>

$$[\mathrm{Eu/H}] = \log_{10}\left[\frac{m_{Eu}}{m_H}\right]$$

⬅ travel distance

⬅ gas mass, similar between Ret II and Gru II

-> NSMs can make stars with a wide range of [Eu/H].

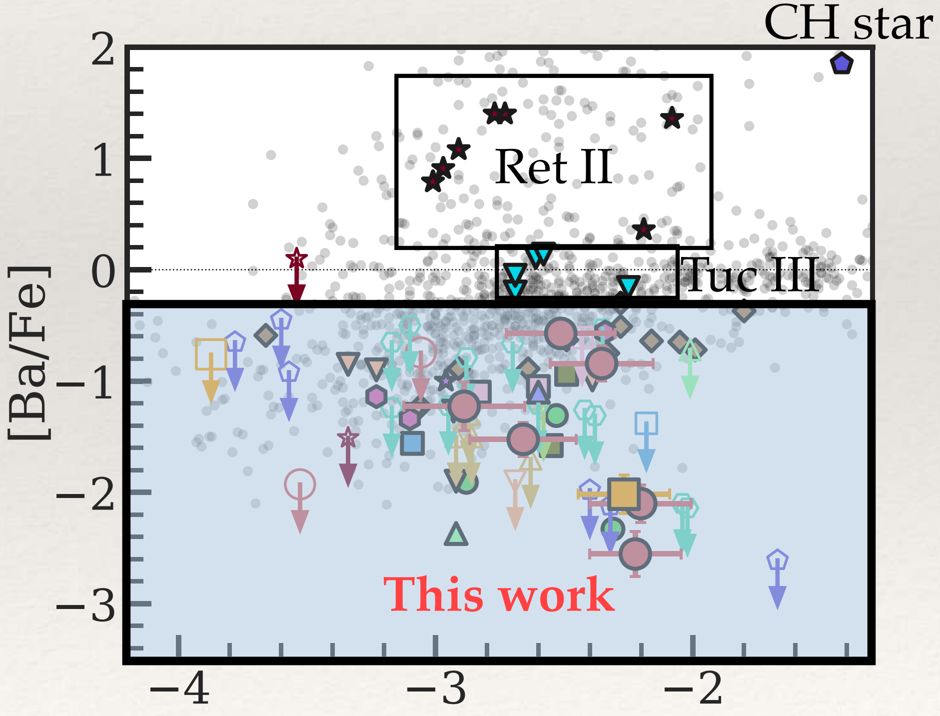
Ba in UFDs

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Stars with Eu detection have high [Ba/Fe]. Abundance is consistent with the “rare, prolific r-process event”.

Ret II, Tuc III, and Gru II have Eu-detected stars



Original figure: Ji+20

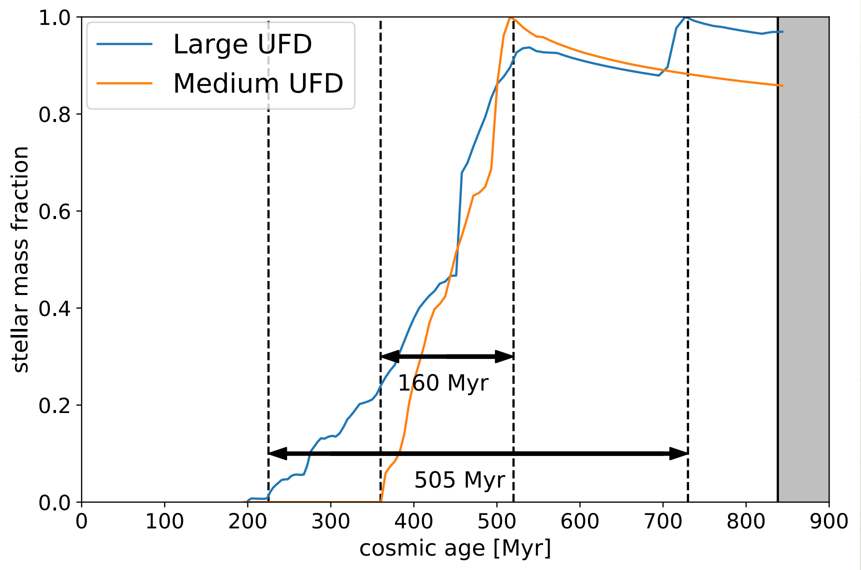
- **What is the origin of Ba in “no r-process” UFDs?**
    - Can AGB stars explain the Ba abundance?

Method

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Code: AREPO
- Yield: FRUITY database
- Star particle masses: 20Msun
- Up to z=6, two galaxy samples
- In addition to AGB stars, we test:
  - Rotating massive stars (RMSs), Ba and Sr
  - Electron-capture supernovae (ECSNe), Sr

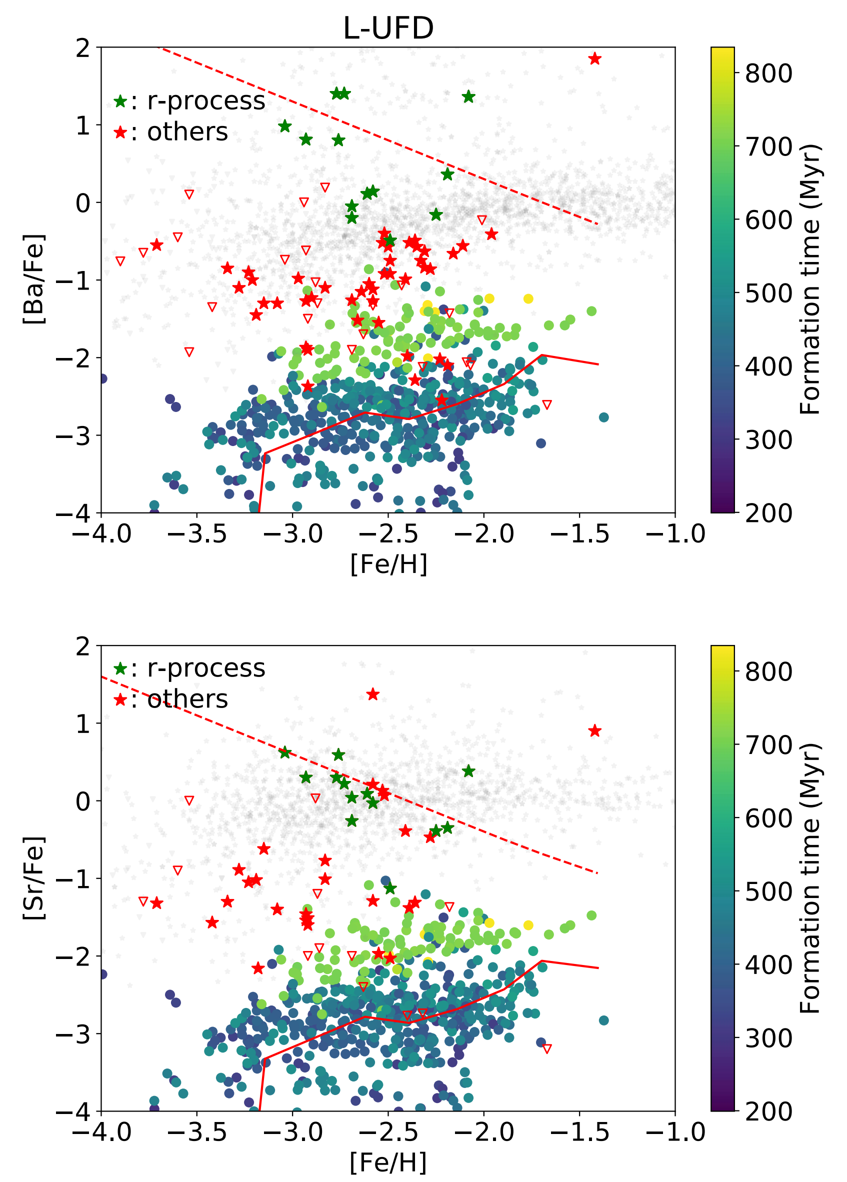


Results: AGB only

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- [Ba/Fe] is too low.
- **The standard model fails to reproduce the Ba abundance.**
- Possible solutions are…
    - Modify IMF (skipped).
    - Consider other channels for Ba production.

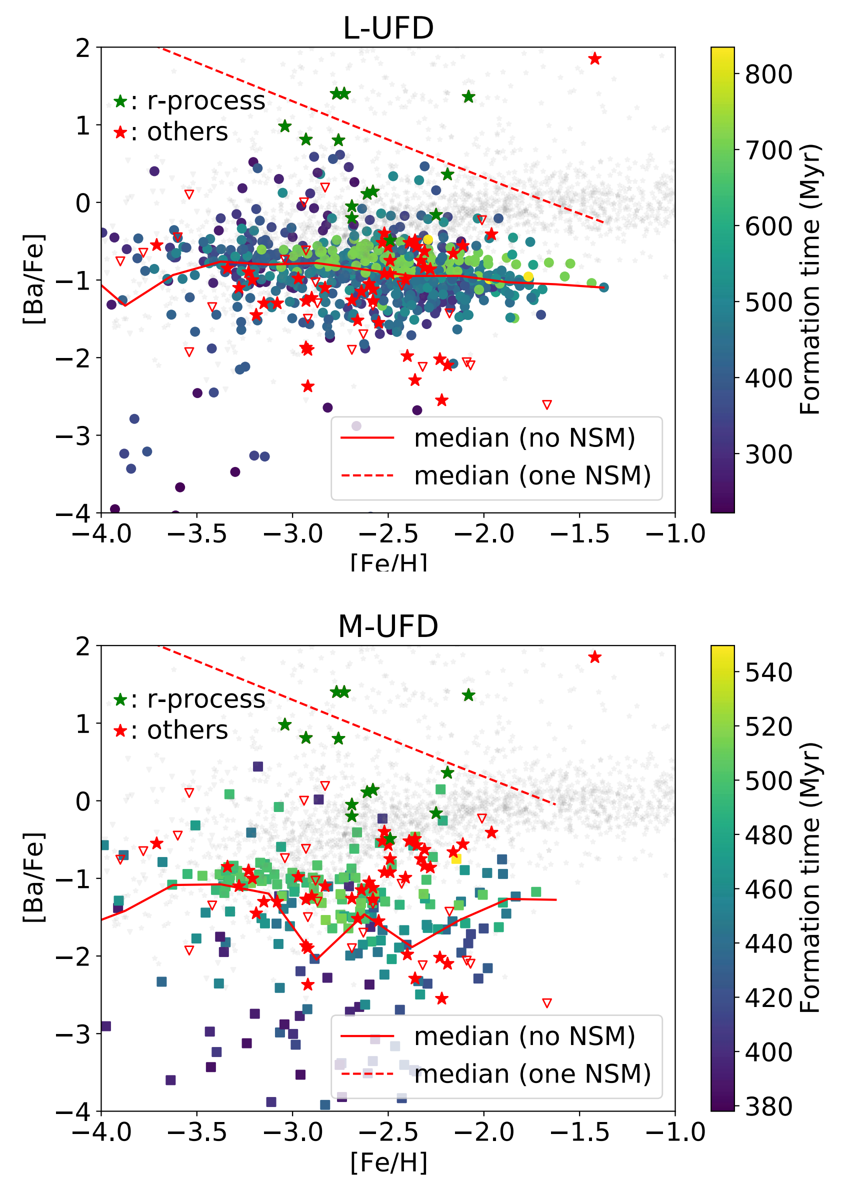


Results: rotating massive stars

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Yield: Limongi&Chieffi (2018)
- Rotation velocity distribution: Prantzos (2018)
- **The amount of Ba is appropriate.**
- Short star formation galaxy show large spread.
- Flat or decreasing [Ba/Fe] as [Fe/H] increase.

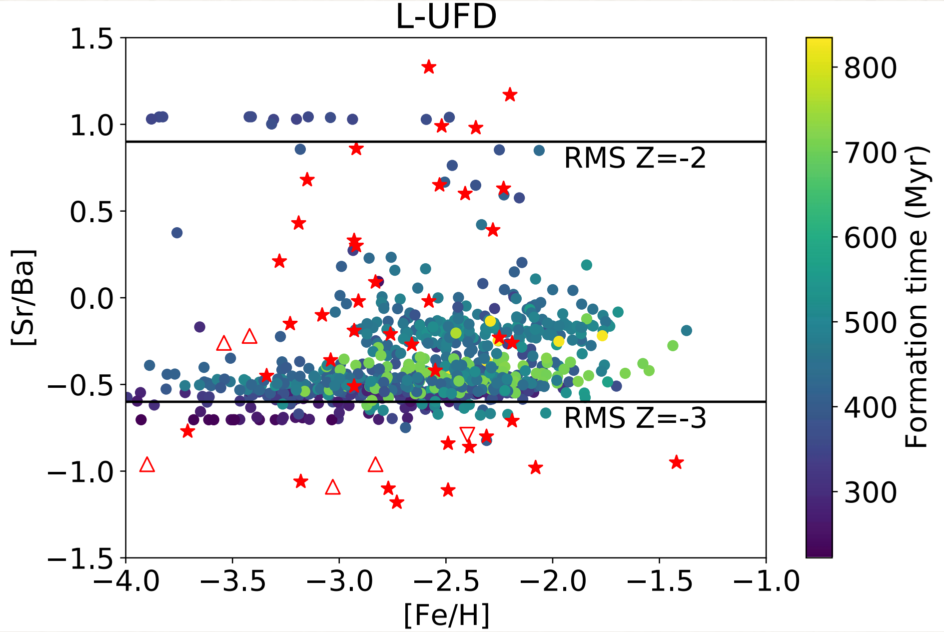


Results: rotating massive stars

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Tests for RMS:
  - Measurement of nitrogen
  - **[Sr/Ba] ratio**
- If RMS are dominant producers of neutron-capture elements, [Sr/Ba] would increase as metallicity.

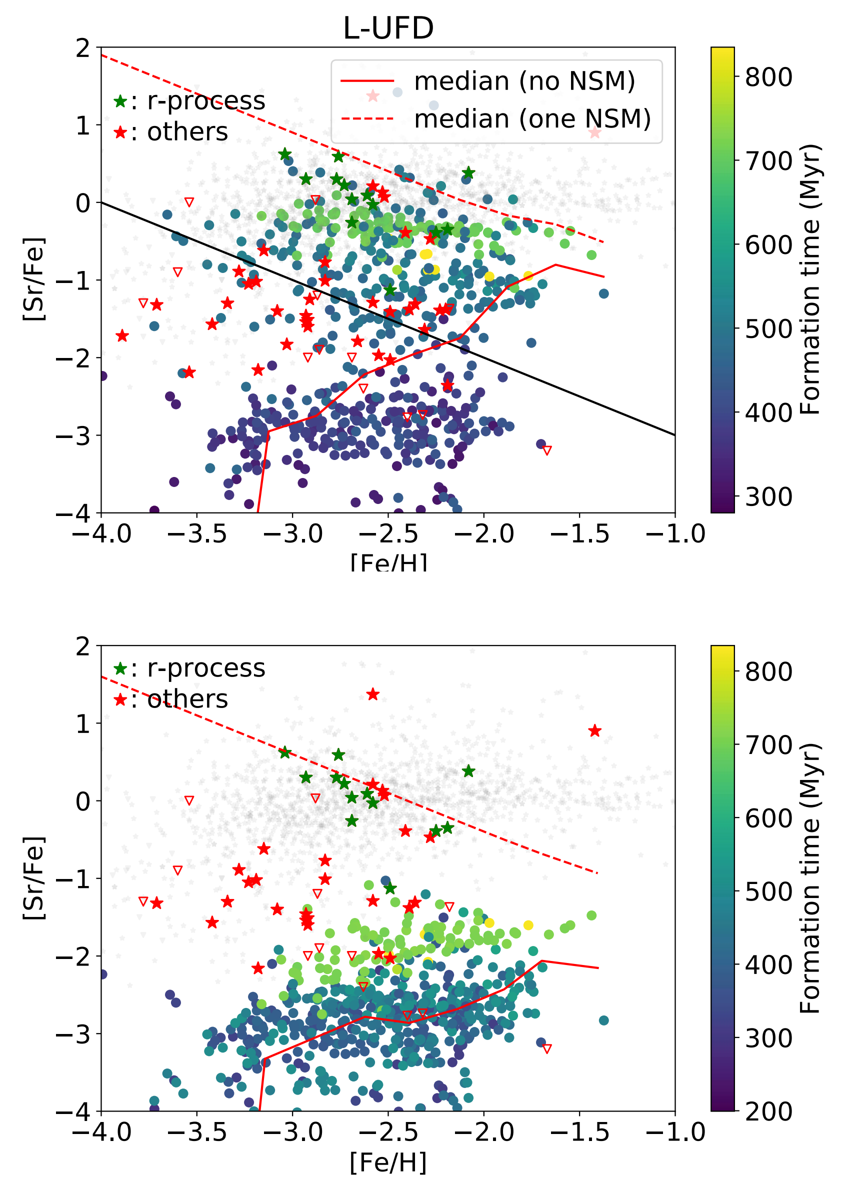


Results: ECSNe

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Yield: Wanajo (2018), 7.9×10^{-5} $M_\odot$ of Sr produced
- Assumed 2% of core-collapse SNe rate
- **One ECSN enriches the system to more than [Sr/H] > -4.0**



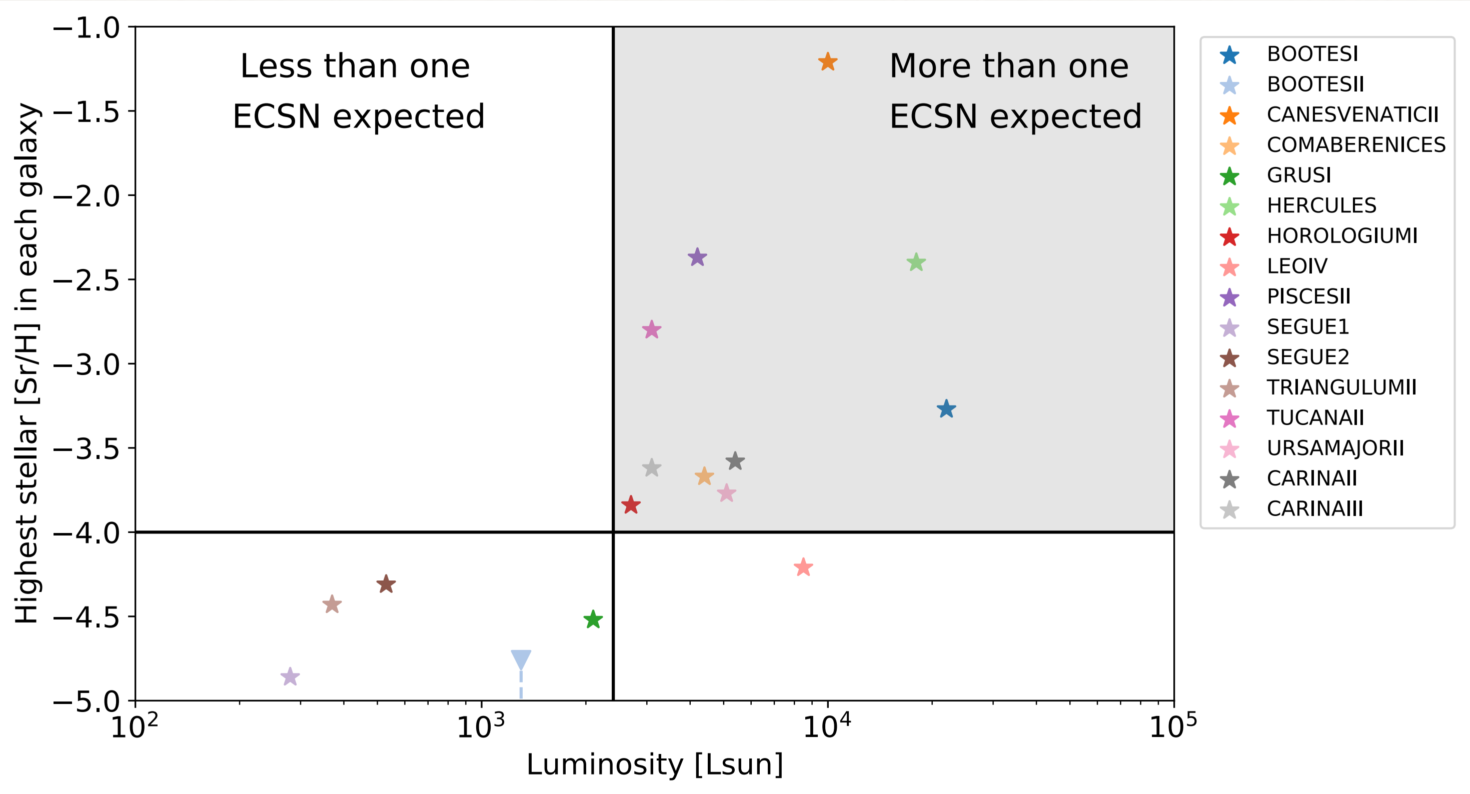
Part2: s-process (2021MNRAS.505.3755T)

Results: ECSNe

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Small UFDs have [Sr/H] < -4, **consistent with no ECSN**
- → (ECSN rate) < 1/5000 Msun, $\Delta M \lesssim 0.1\mathrm{M}_\odot$



Conclusion

$$[X/Y] = \log_{10}\left[\frac{N_X}{N_Y}\right] + C$$

Normalized to solar

- Eu: "NSM at the center" explains Ret II abundances, while "NSM at the outskirt" explains Tuc III and Gru II abundances.
- Ba: AGB contribution seems to be subdominant. Except for Eu-enhanced UFDs, maybe RMSs are the origins.
- Sr: Same as Ba, but also ECSNe can contribute. From the low values of [Sr/H] of UFDs, we can constrain the mass-range of ECSNe to be $\Delta M \lesssim 0.1 \mathrm{M}_{\odot}$.