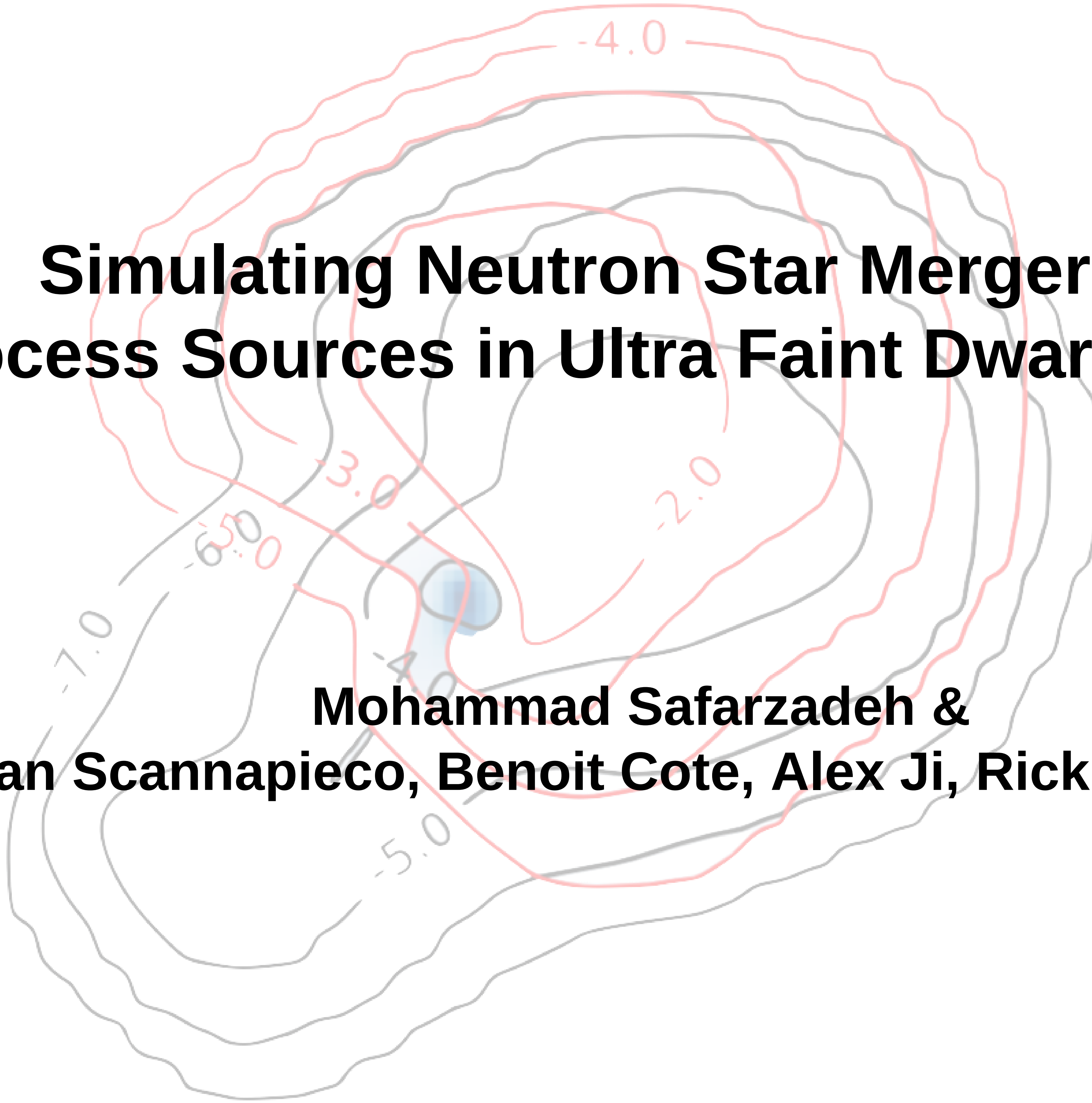
Simulating Neutron Star Mergers as *r*-process Sources in Ultra Faint Dwarf Galaxies



Mohammad Safarzadeh &
Evan Scannapieco, Benoit Cote, Alex Ji, Rick Sarmento

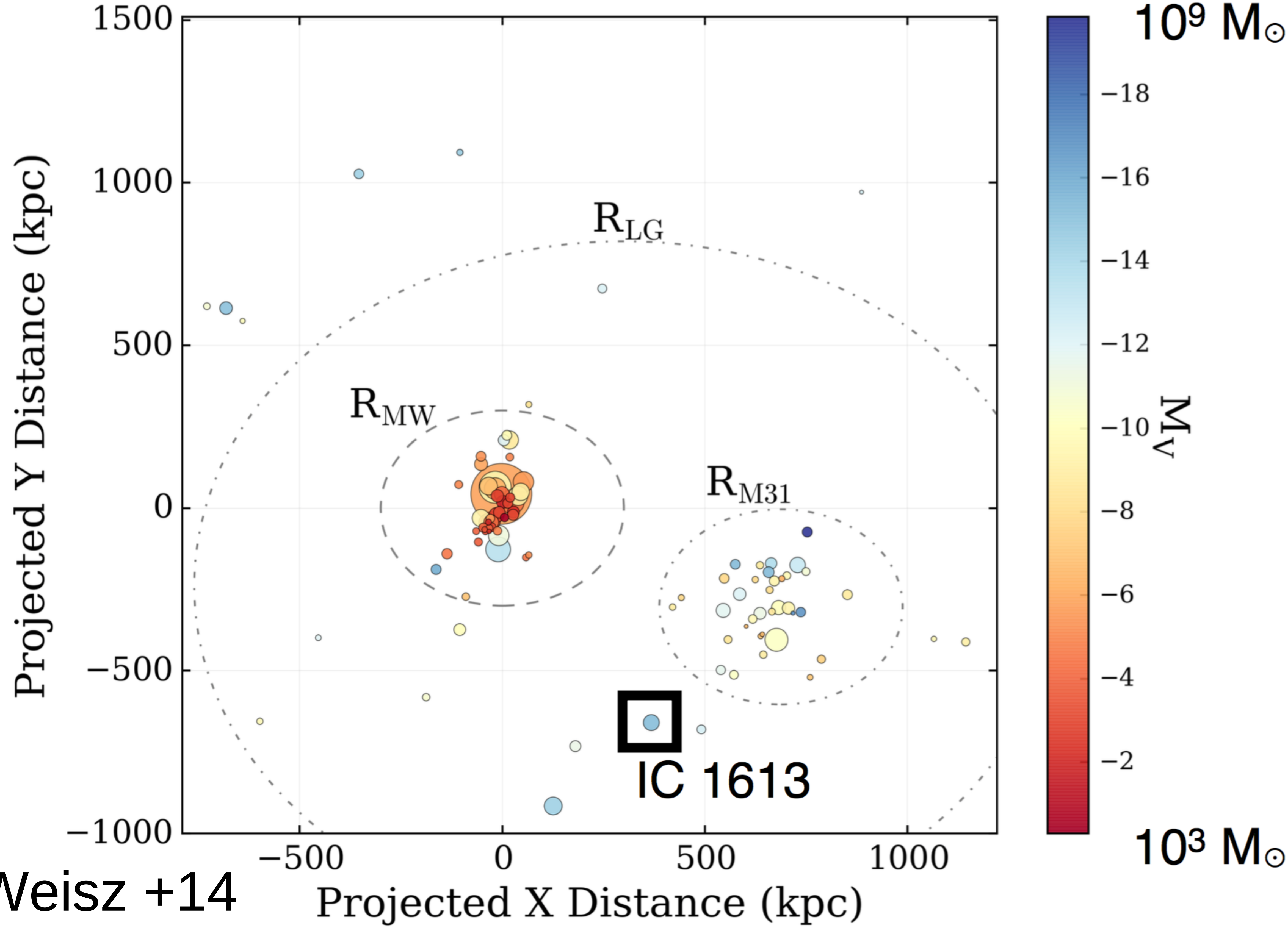
Arizona State University

INT workshop, Seattle, WA

Outline

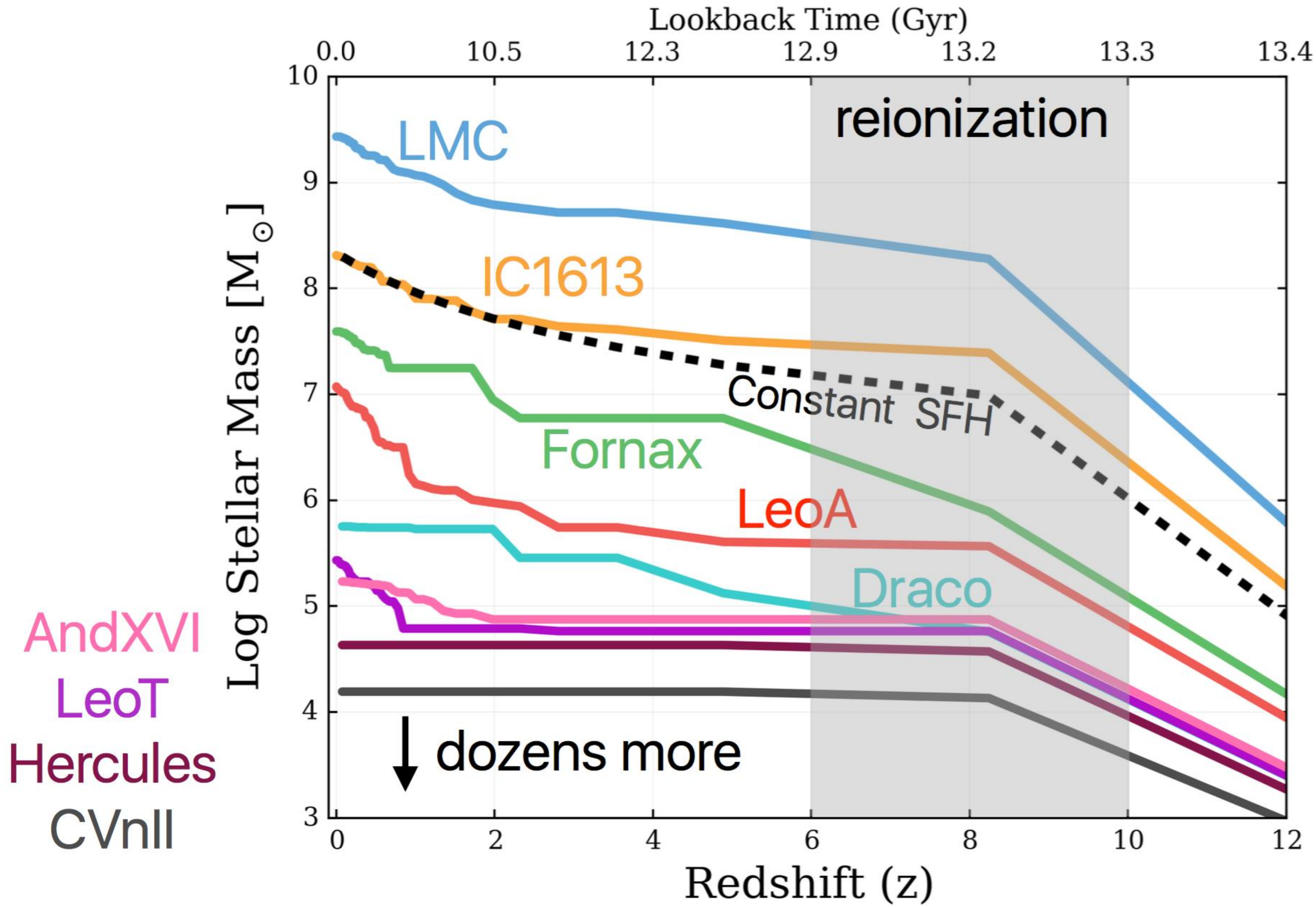
- **Observed *r*-process enrichment in an ultra faint dwarf galaxy.**
- **Zoom-in simulations of a local UFD with a single neutron star merger (NSM) event.**
- **Statistics of the *r*-process enriched stars as compared to the observations.**
- **Impact of natal kicks.**
- **Future work on MW ICs.**

Local Group Dwarf Galaxy Demographics

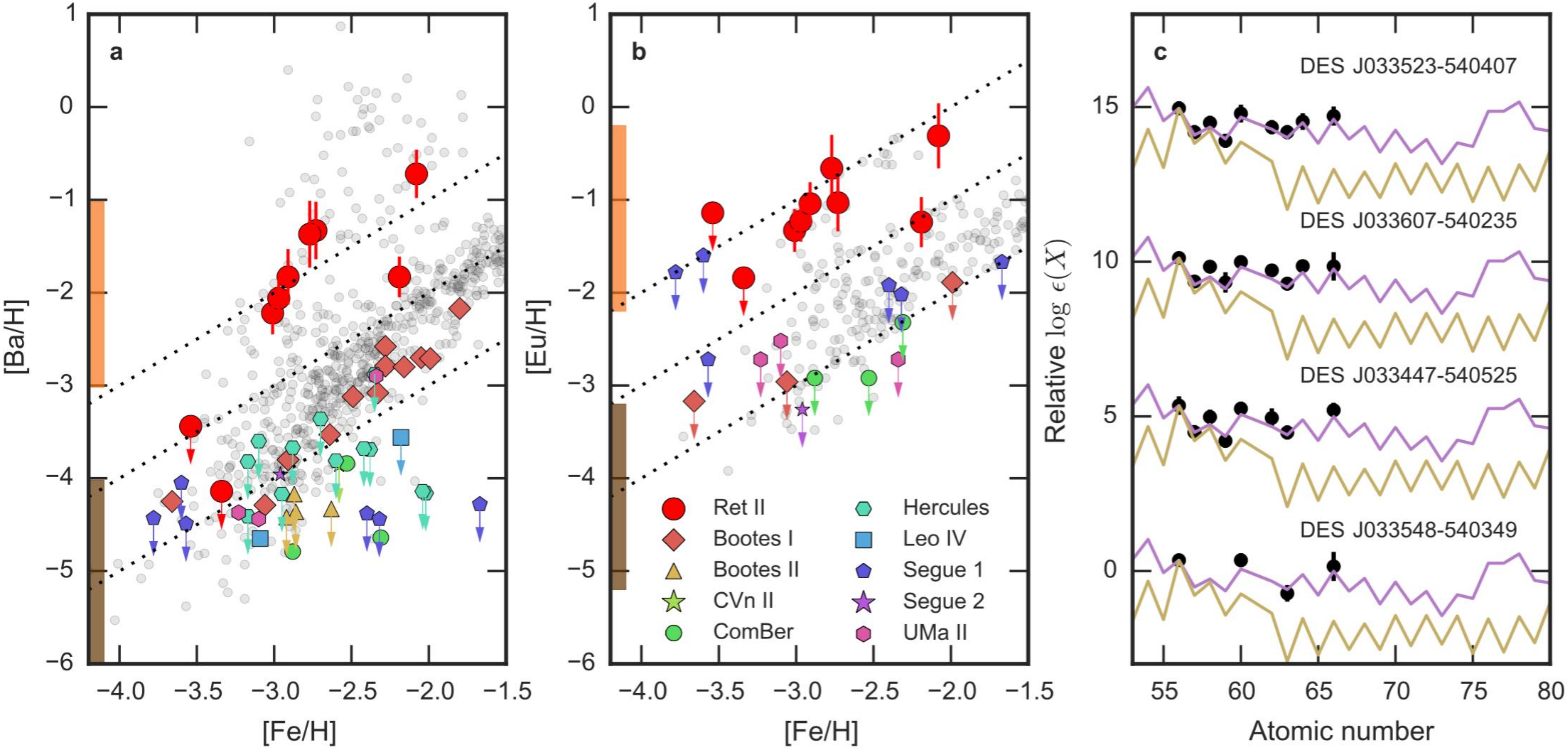


Weisz +14

Low-Mass Galaxies Across Cosmic Time



e.g., Weisz+ 2012, 2014a; Brown+ 2014; Skillman+ 2014



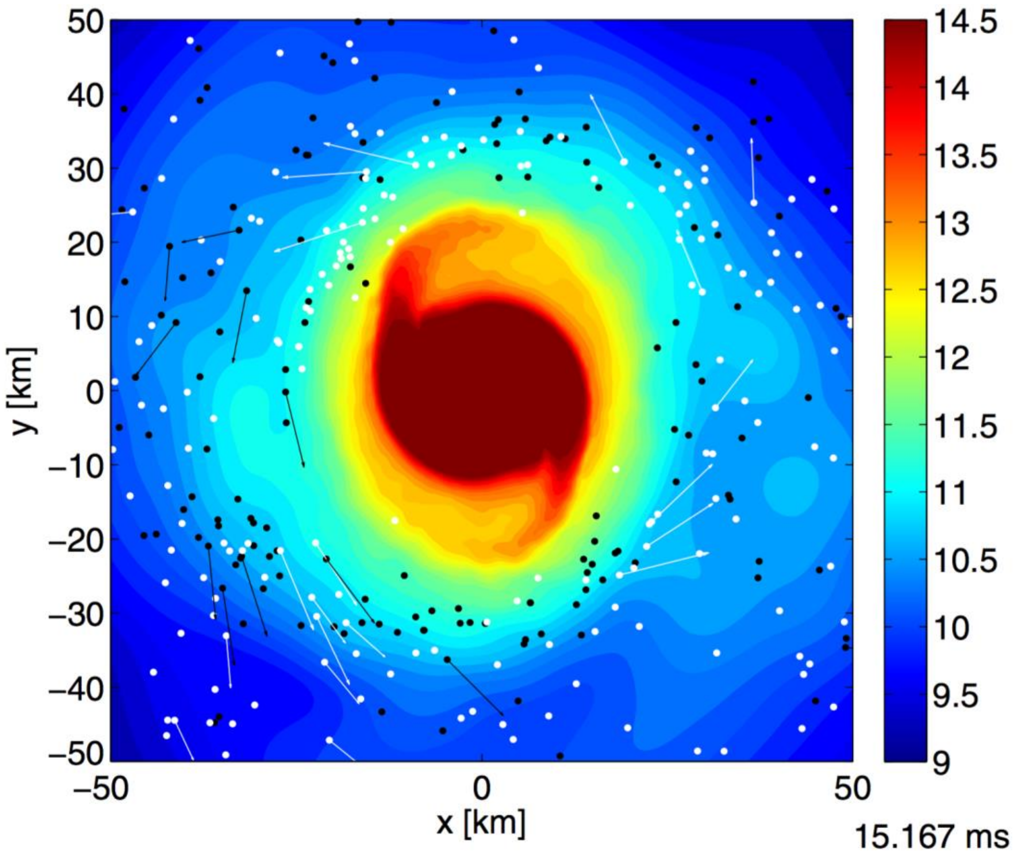
a
[Ba/H]
[Fe/H]
b
[Eu/H]
[Fe/H]
Ret II
Bootes I
Bootes II
CVn II
ComBer
Hercules
Leo IV
Segue 1
Segue 2
UMa II
c
DES J033523-540407
DES J033607-540235
DES J033447-540525
DES J033548-540349
Relative log ε(X)
Atomic number

What are the sites of *r*-process element production?

- **Core-collapse supernovae**
- **Neutron star mergers**
- **Others (magnetorotationally-driven supernovae, lone Neutron stars)**

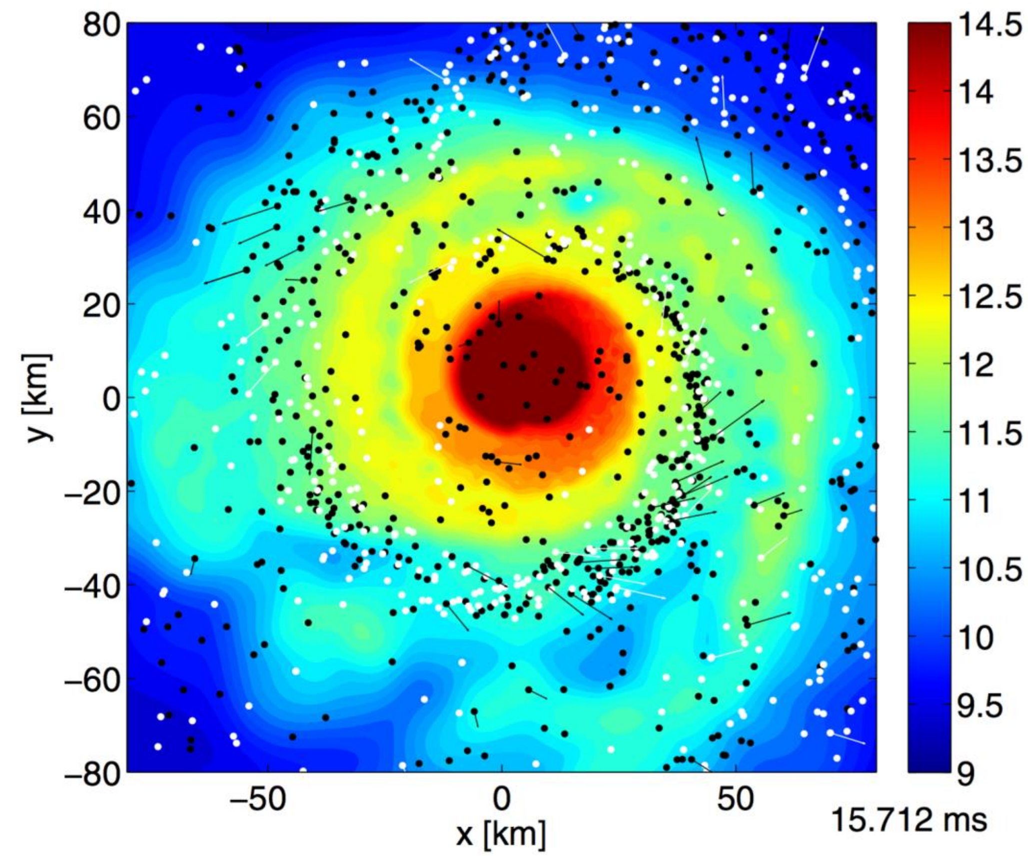
Neutron star mergers

- **Tidally unbound NS material in asymmetric NS mergers**
- **Large *r*-process yield (~$10^{-4.5}$ M_{sun} Eu per SN)**
- **1 NSM per ~1,000 SN**
- **Delay time for merger**



Symmetric merger final stage

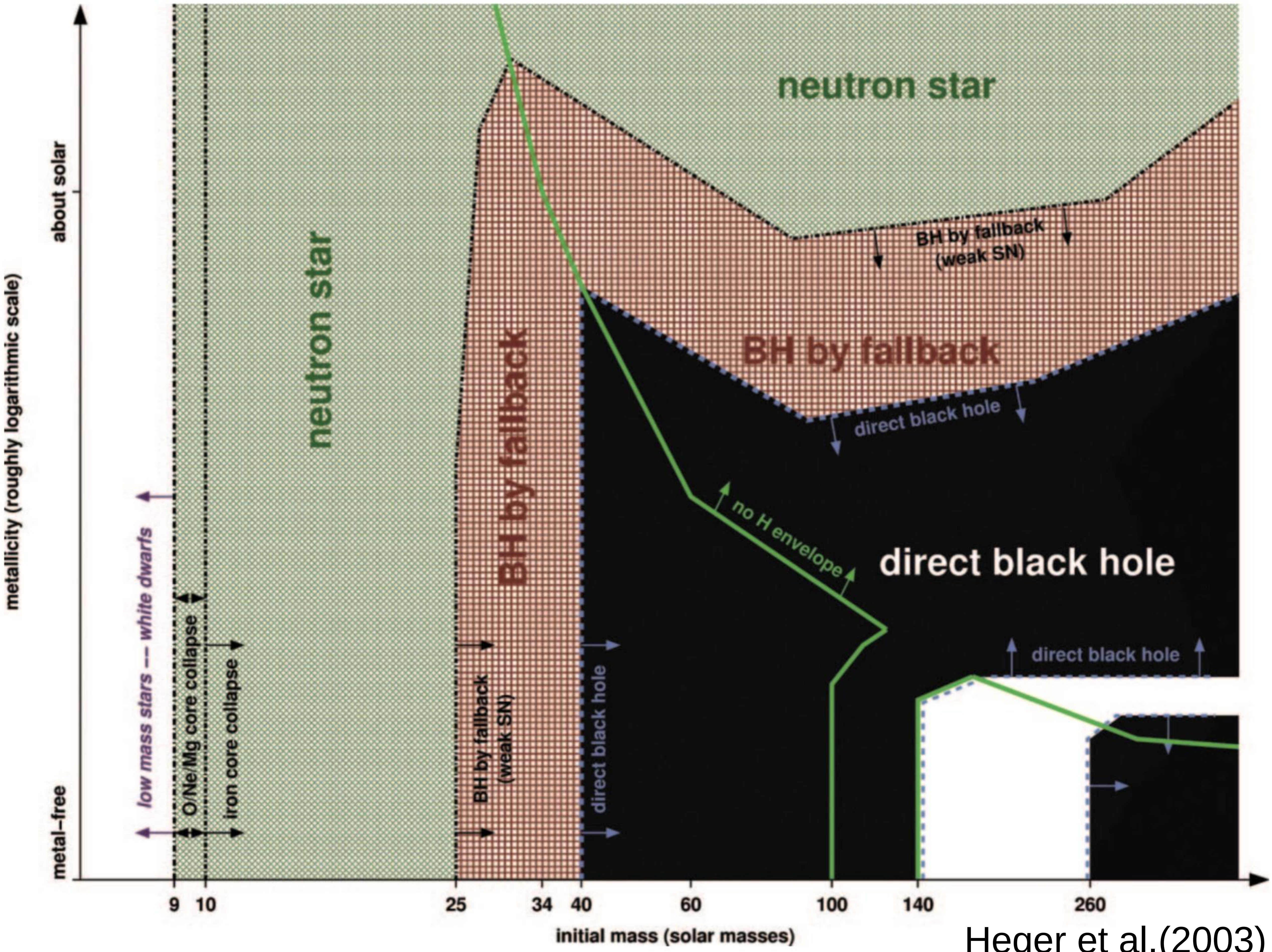
Asymmetric merger final stage



Bauswein et al. (2013)

Zoom-in simulation of a local UFD

- **We use the AMR code RAMSES for this purpose.**
- **The stellar particle mass in our simulation is ~50 M_{sun} to both resolve the stellar mass content of Ret II and be able to host a binary SNe II as a progenitor for a NSM event.**
- **We select two halo with mass ~ 10^8 M_{sun} at z~6.**
- **We simulate a single NSM event in the star formation history of both galaxies, and the SN IIs are modeled in a stochastic fashion.**



Heger et al.(2003)

Zoom-in simulation of a local UFD

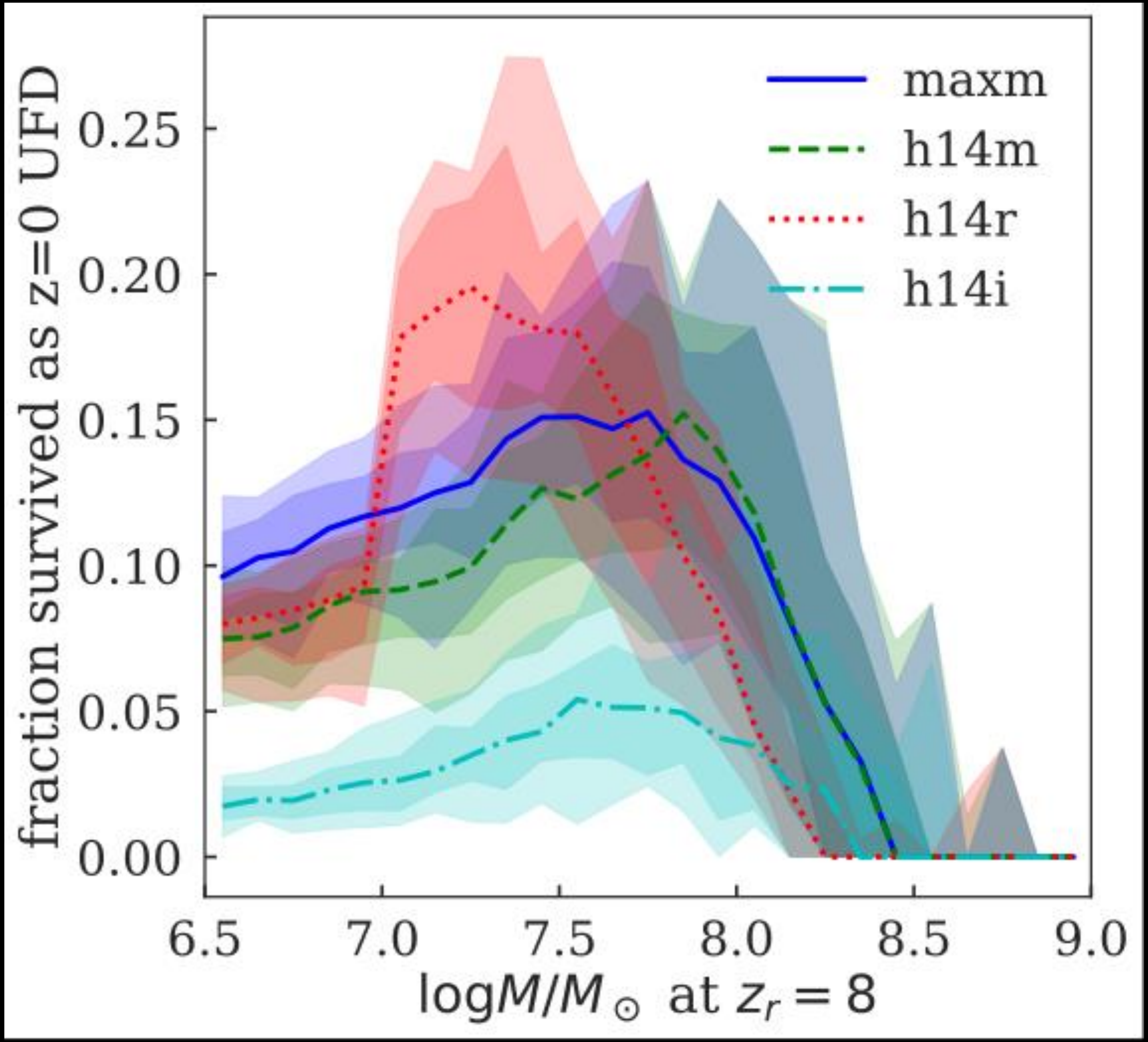
- **We use the AMR code RAMSES for this purpose.**

- **The stellar particle mass in our simulation is ~50 M_{sun} to both resolve the stellar mass content of Ret II and be able to host a binary SNe II as a progenitor for a NSM event.**

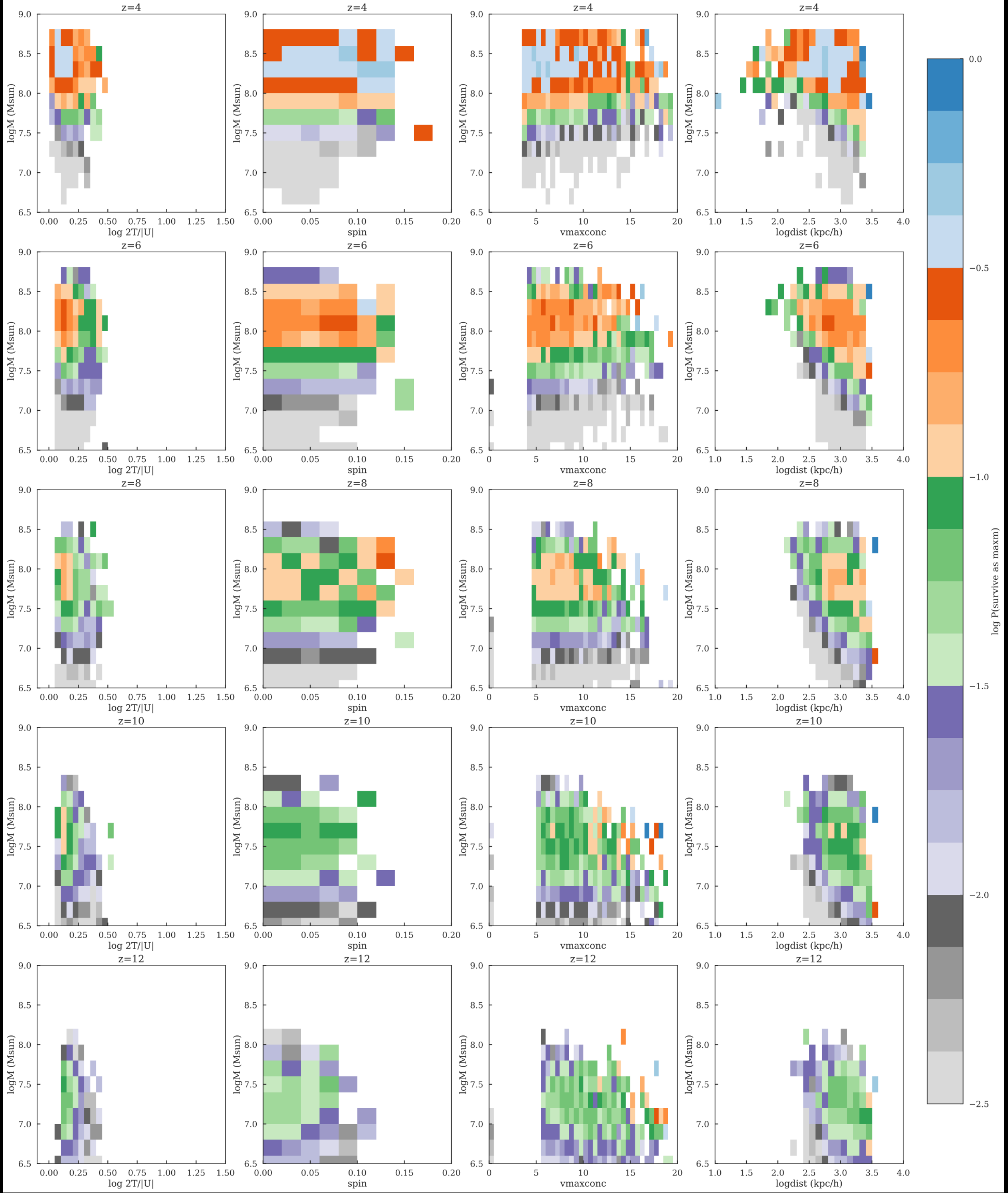
- **We select two halo with mass ~ 10^8 M_{sun} at z~6.**

- **We simulate a single NSM event in the star formation history of both galaxies, and the SN IIs are modeled in a stochastic fashion.**

Probability that a halo survives intact as a UFD.



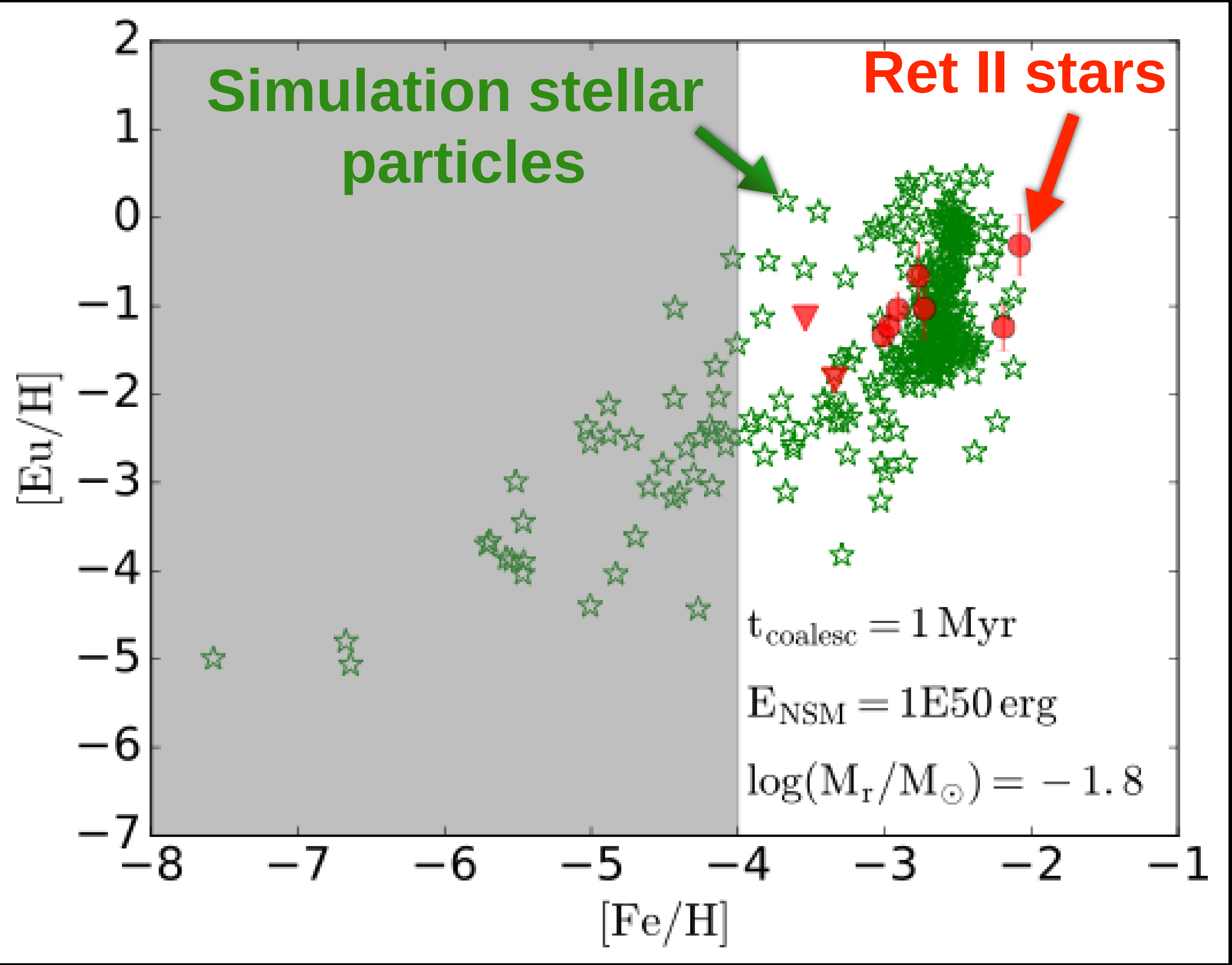
Safarzadeh & Ji (in prep)


z=4
z=6
z=8
z=10
z=12
logM (Msun)
log 2T/|U|
spin
vmaxconc
logdist (kpc/h)
log P(survive as maxm)

Simulation parameters

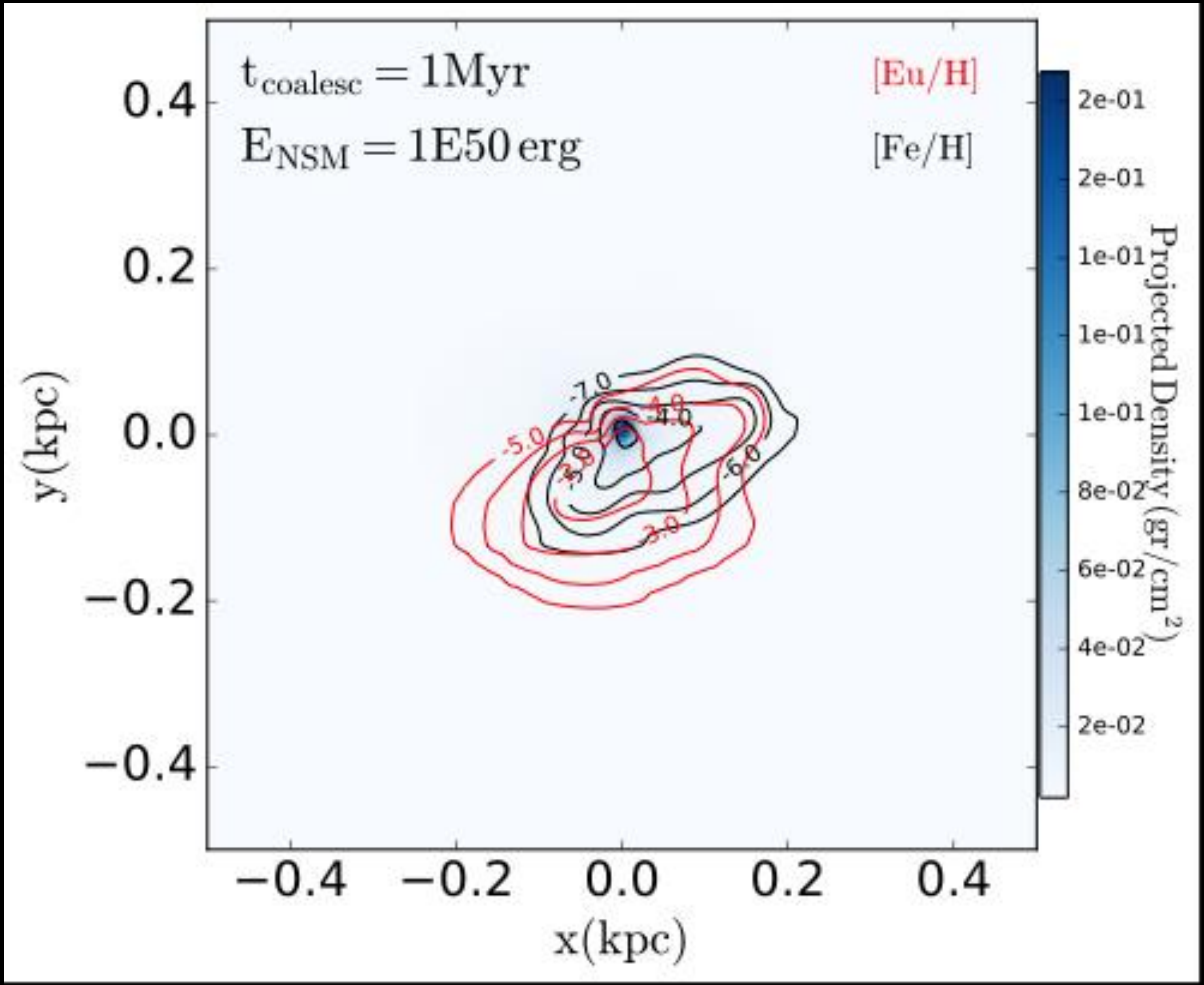
- **The energy of the NSM event is varied between 10^{50}-10^{51} erg.**
- **The timescale for coalescence is varied from 1 to 30 Myr.**
- **The mass of the *r*-process element is set to 10^{-3} M_{sun} and is modified in post-processing step.**

Comparing the results to Ret II

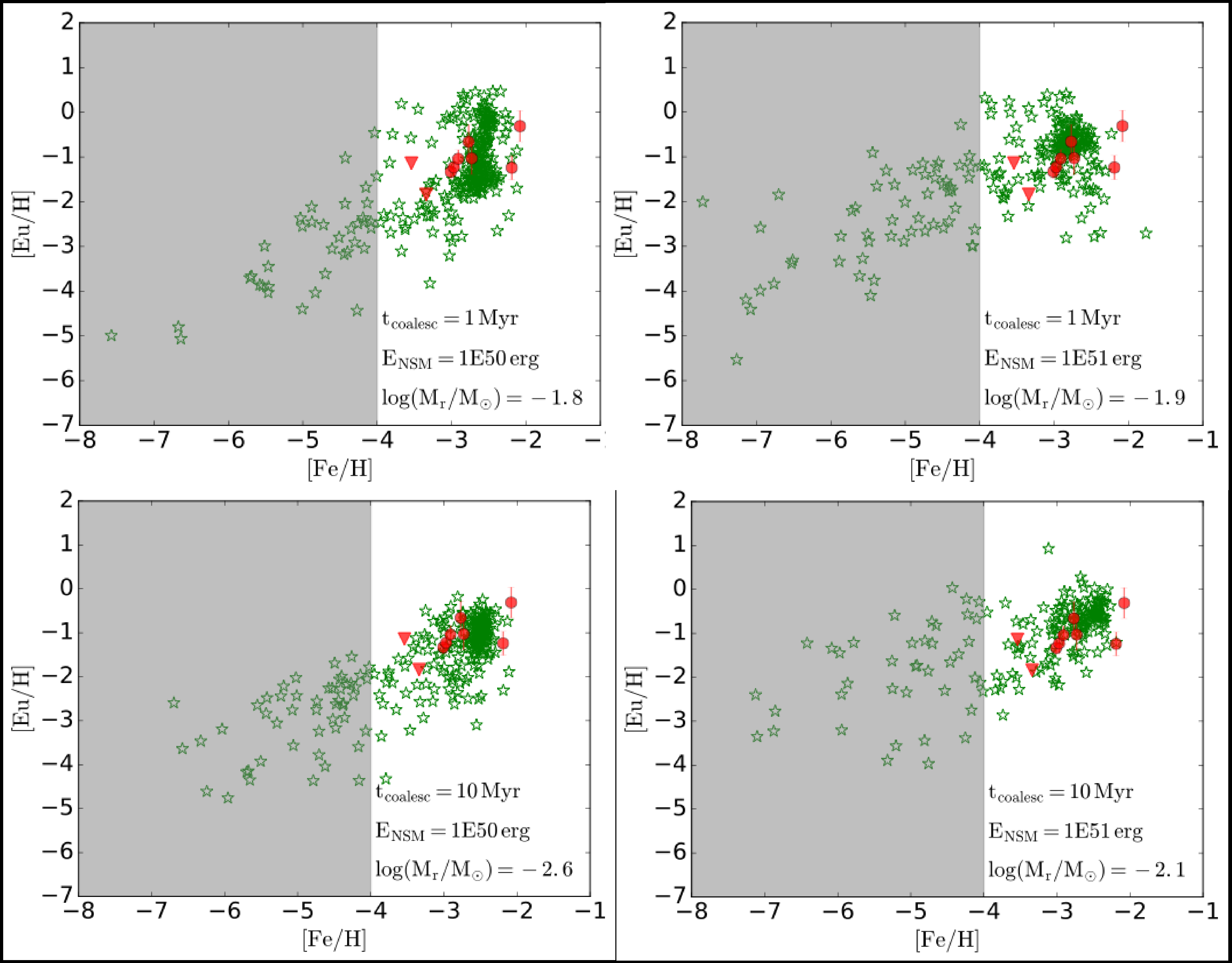


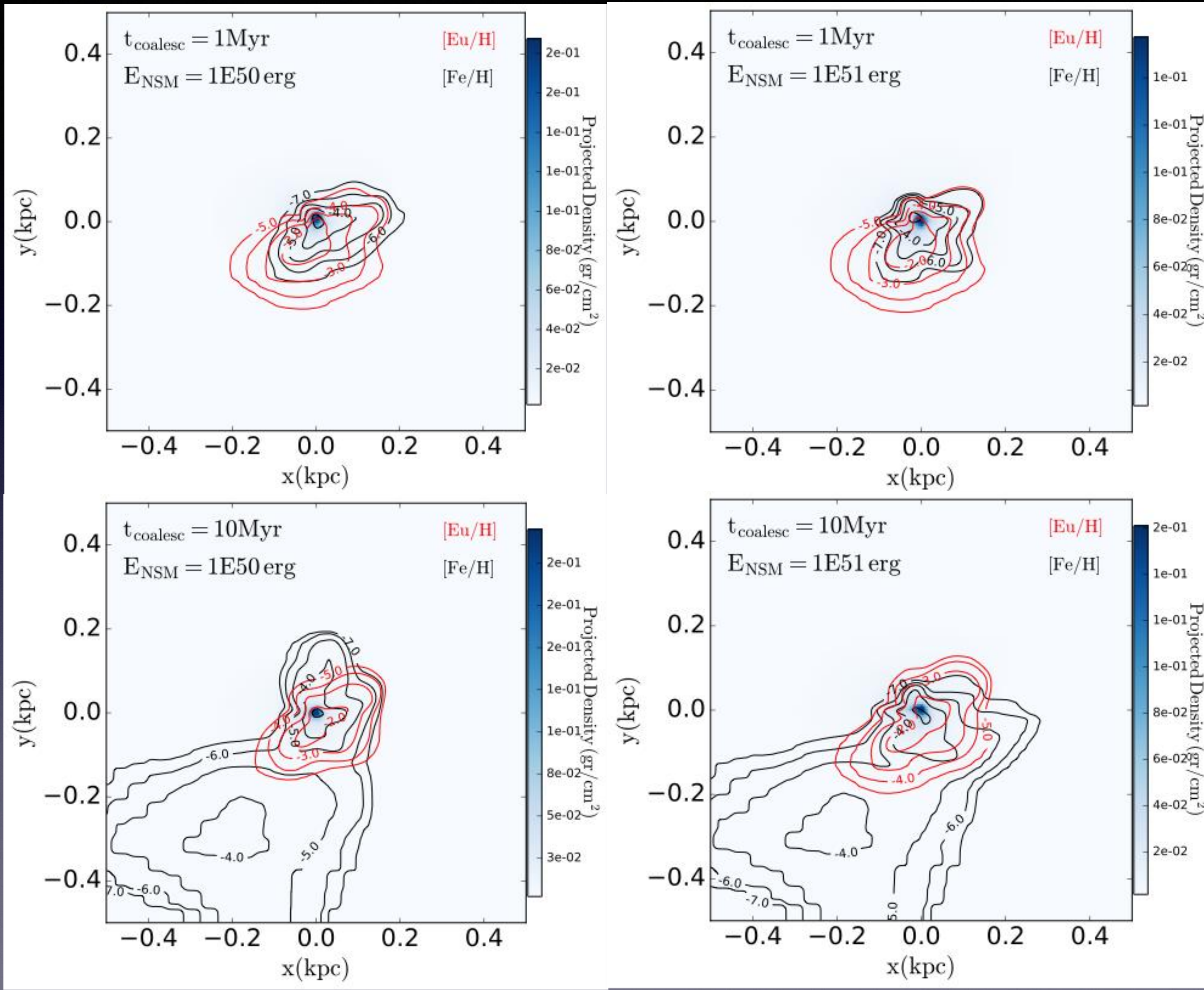
Safarzadeh & Scannapieco (2017)

Projected [Eu/H] vs. [Fe/H] for the gas



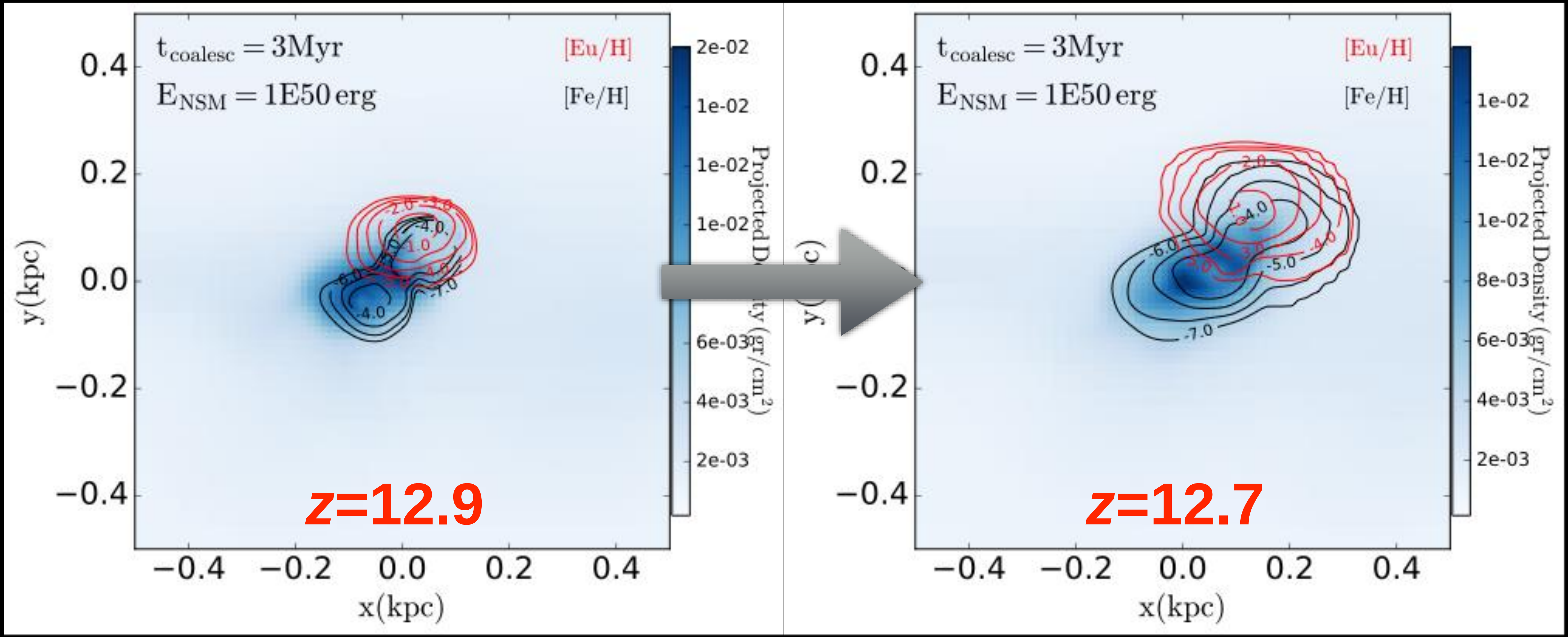
varying coalescence time scale and Explosion energy



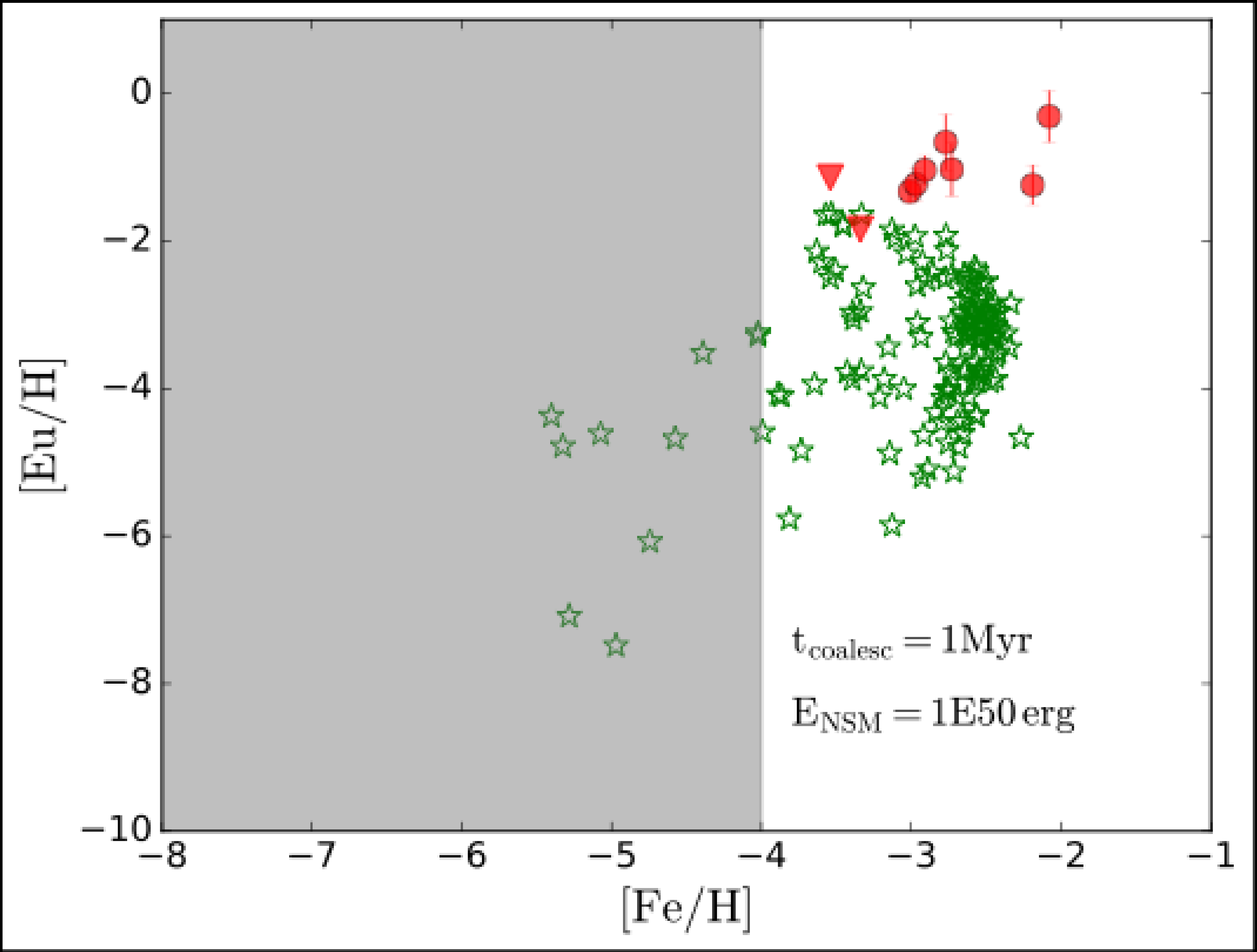


$t_{coalesc} = 1Myr$
$E_{NSM} = 1E50\,erg$
$t_{coalesc} = 1Myr$
$E_{NSM} = 1E51\,erg$
$t_{coalesc} = 10Myr$
$E_{NSM} = 1E50\,erg$
$t_{coalesc} = 10Myr$
$E_{NSM} = 1E51\,erg$
[Eu/H]
[Fe/H]
x(kpc)
y(kpc)
Projected Density (gr/cm^2)

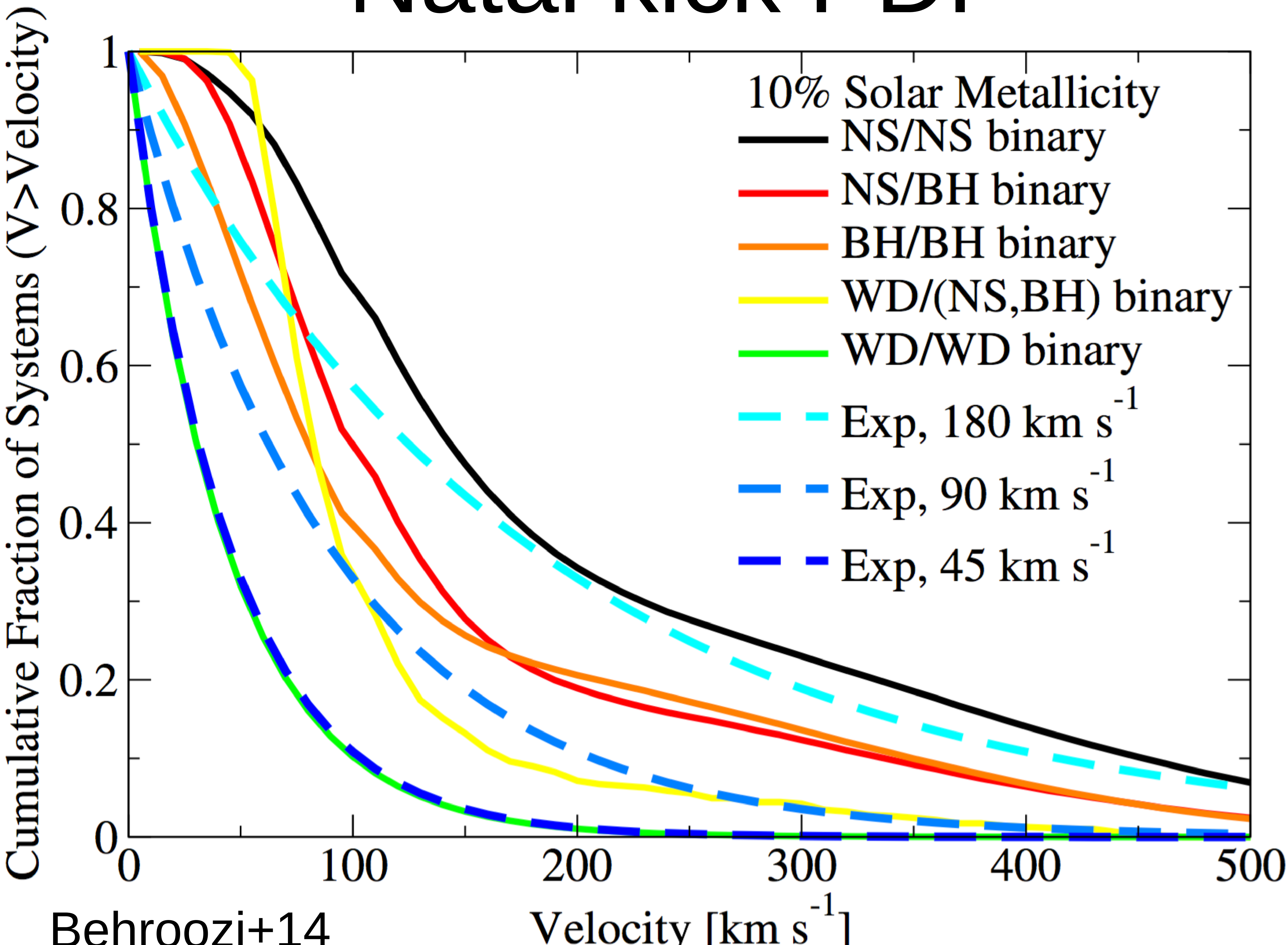
Off-center explosion



leads to low enrichment by r-process elements

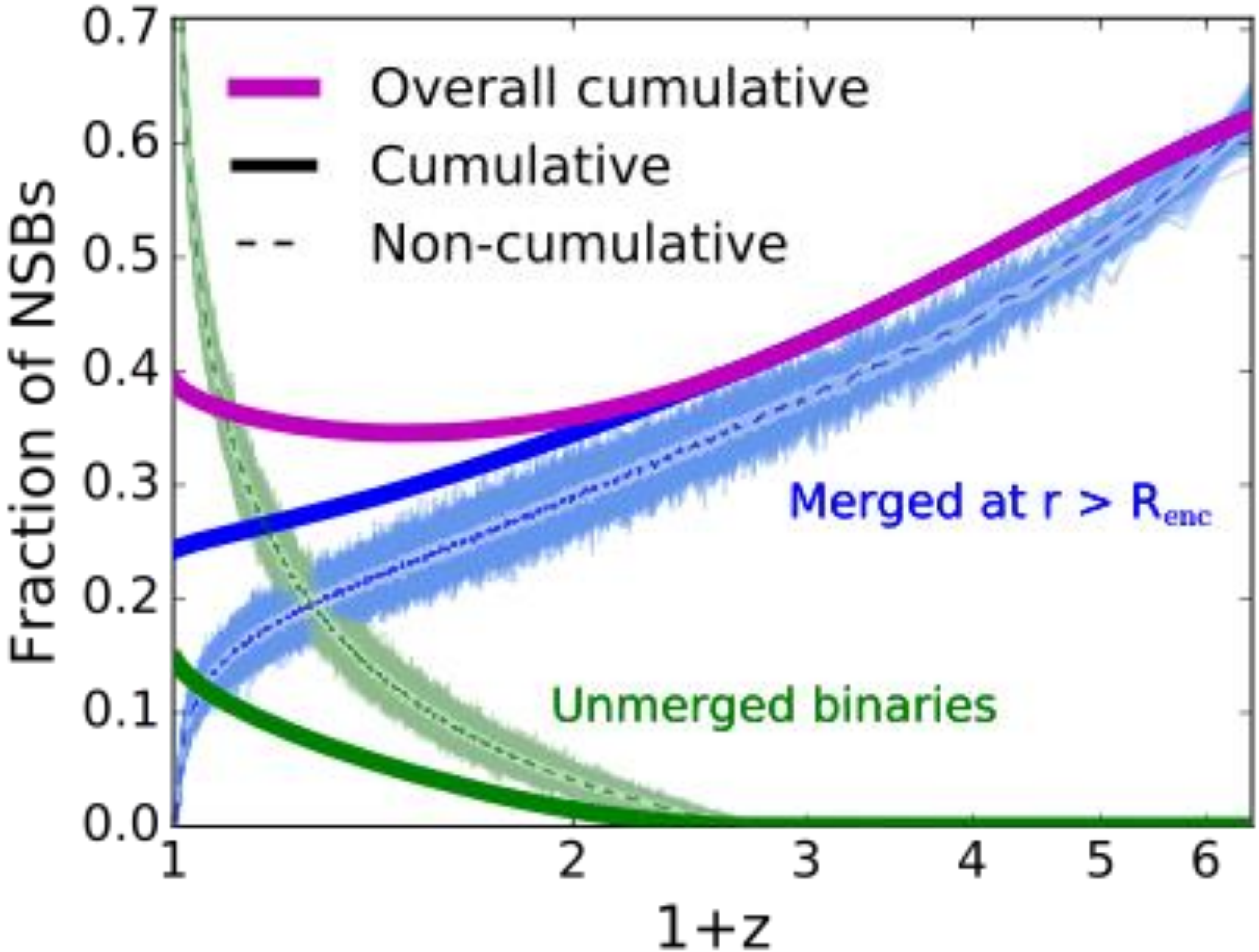


Natal kick PDF



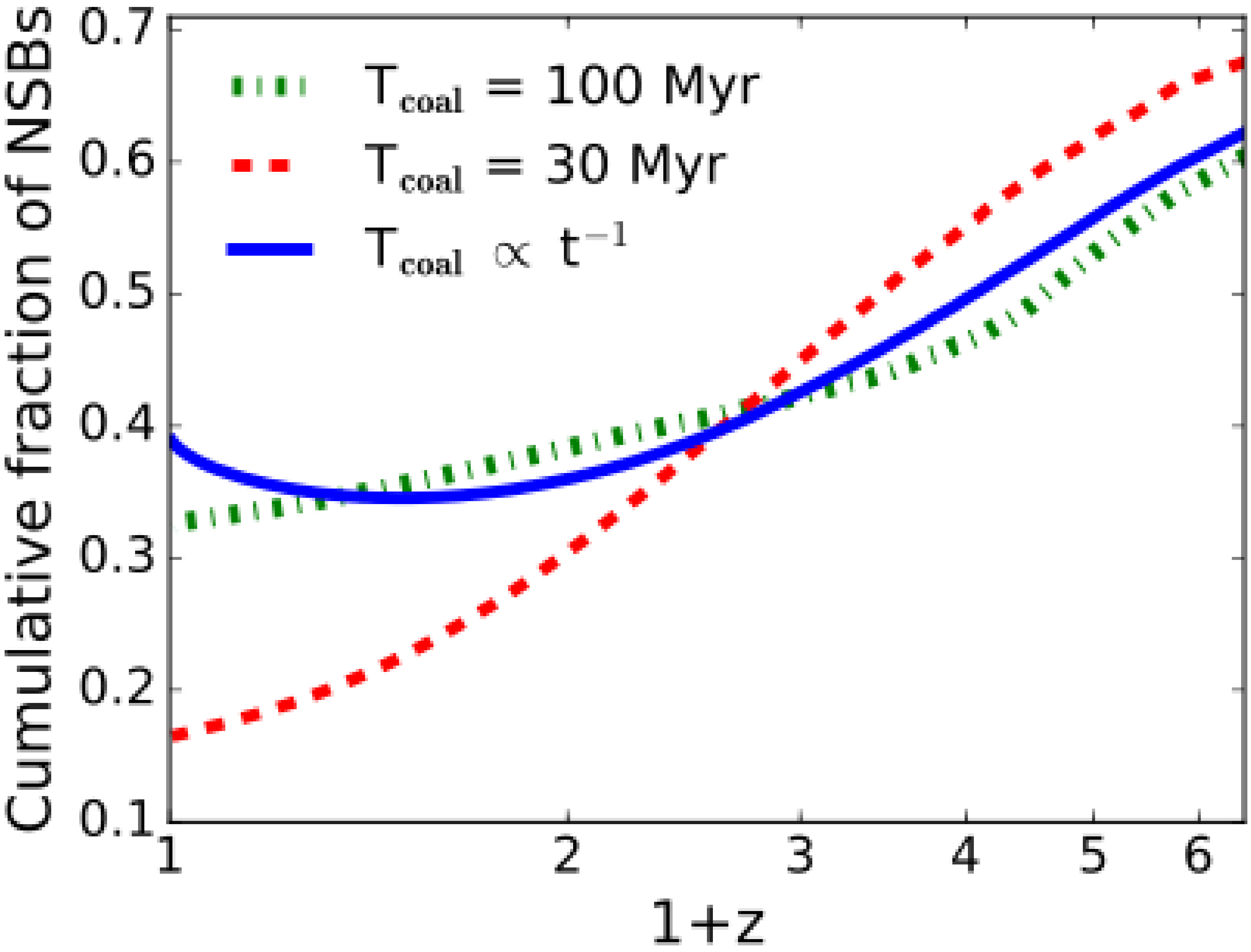
Behroozi+14

Impact of natal kicks on galactic *r*-process enrichment



Safarzadeh & Cote (2017)

Impact of natal kicks on galactic *r*-process enrichment



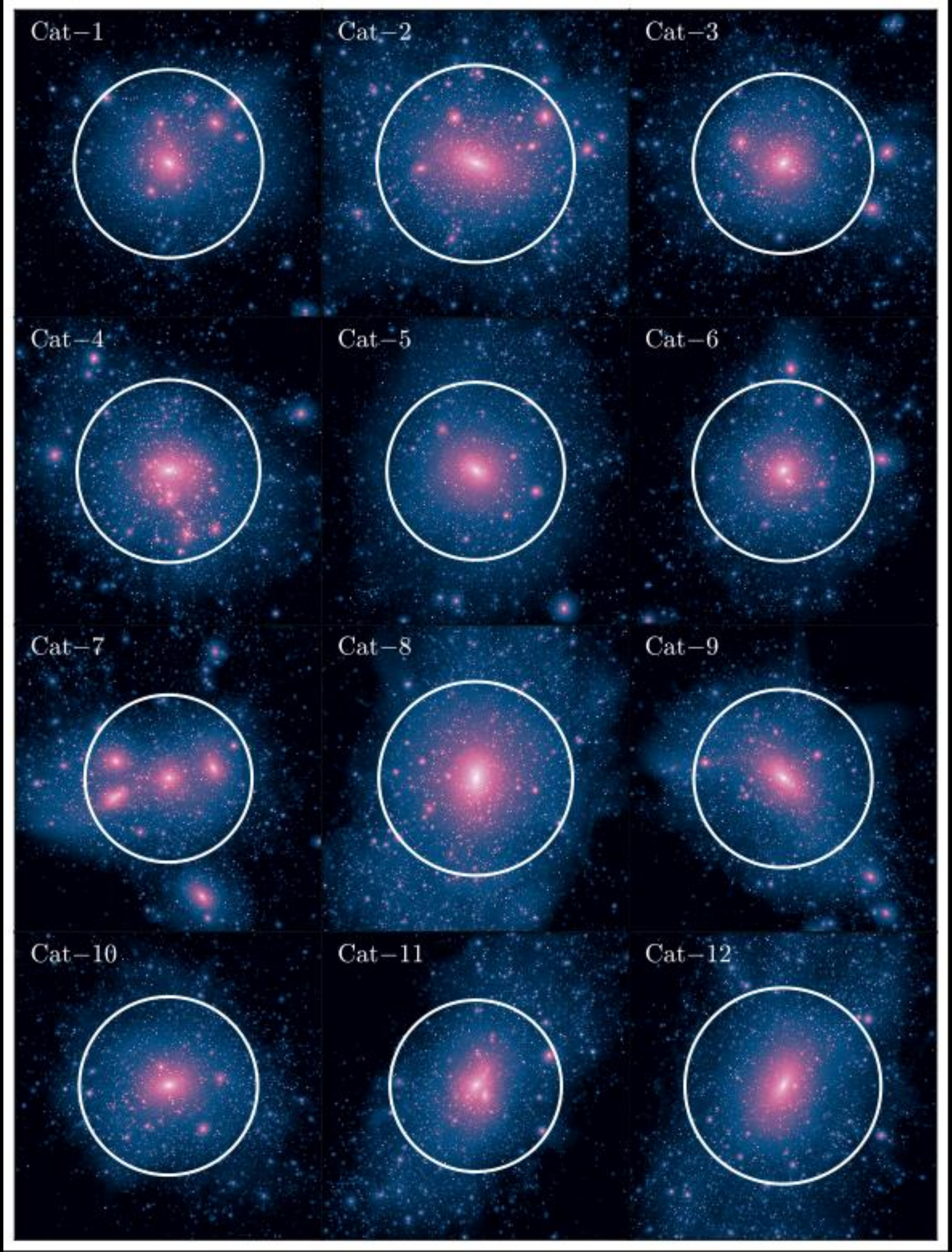
Safarzadeh & Cote (2017)

What is next?

Performing cosmological zoom simulation of *r*-process enrichment on MW type halos

Caterpillar Project

Griffen+16


Cat−1
Cat−2
Cat−3
Cat−4
Cat−5
Cat−6
Cat−7
Cat−8
Cat−9
Cat−10
Cat−11
Cat−12

Griffen+16

What is next?

- **Performing cosmological zoom simulation of *r*-process enrichment on MW type halo (Caterpillar project).**
- **Implement the Natal kicks when NSB candidates are born.**
- **Assign coalescence time to the NSBs when they are formed following a power law distribution.**

Summary

- **A single NSM event in star formation history of a UFD is compatible with Ret II observations.**
- **Ejection energy and coalescence time scale have minor impacts on the enrichment level.**
- ***r*-process enrichment efficiency is highly dependent on the location of NSM event, therefore natal kicks play a crucial role.**
- **About 40% of all NSBs formed do not contribute to the *r*-process enrichment of a MW type galaxy because of delay time distribution and Natal kicks.**
- **Next: Hydro-simulation with including NSBs on MW ICs.**