Enrichment of Heavy Elements in Local Group Galaxies

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Programs for Junior Scientists

First
Stars

Formation and Evolution of Galaxies

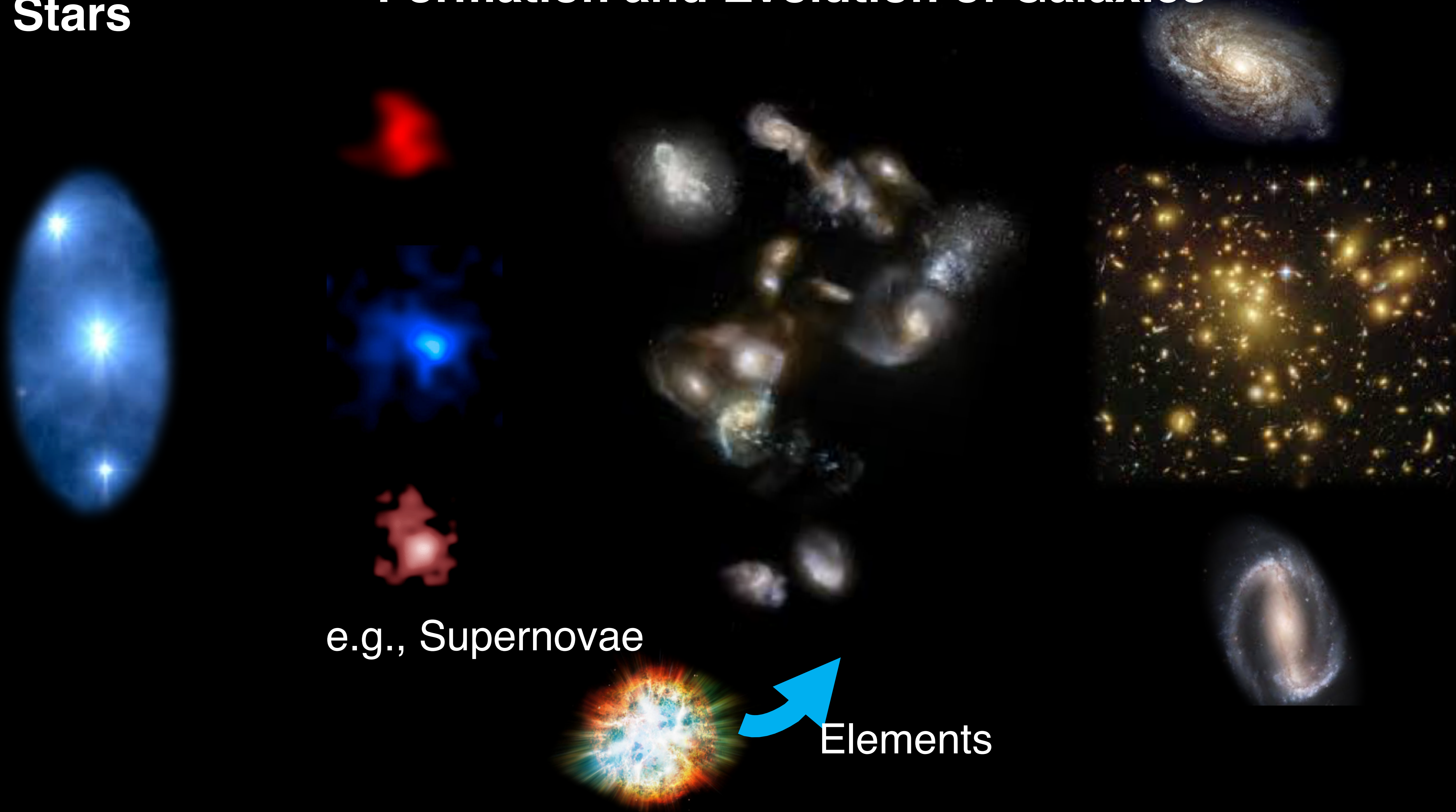
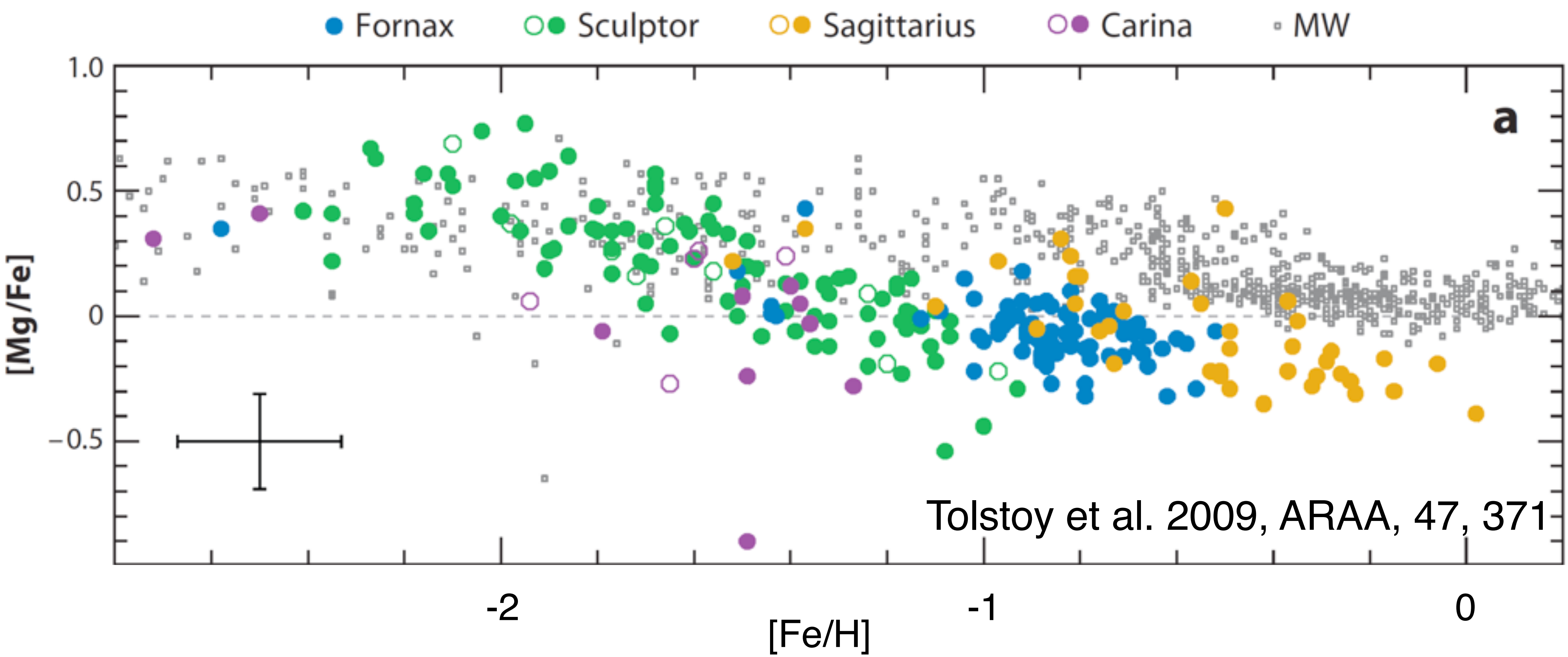


Image credits: NASA

Where are the astrophysical sites of heavy elements?

How abundances of heavy elements are related to galaxy evolution?

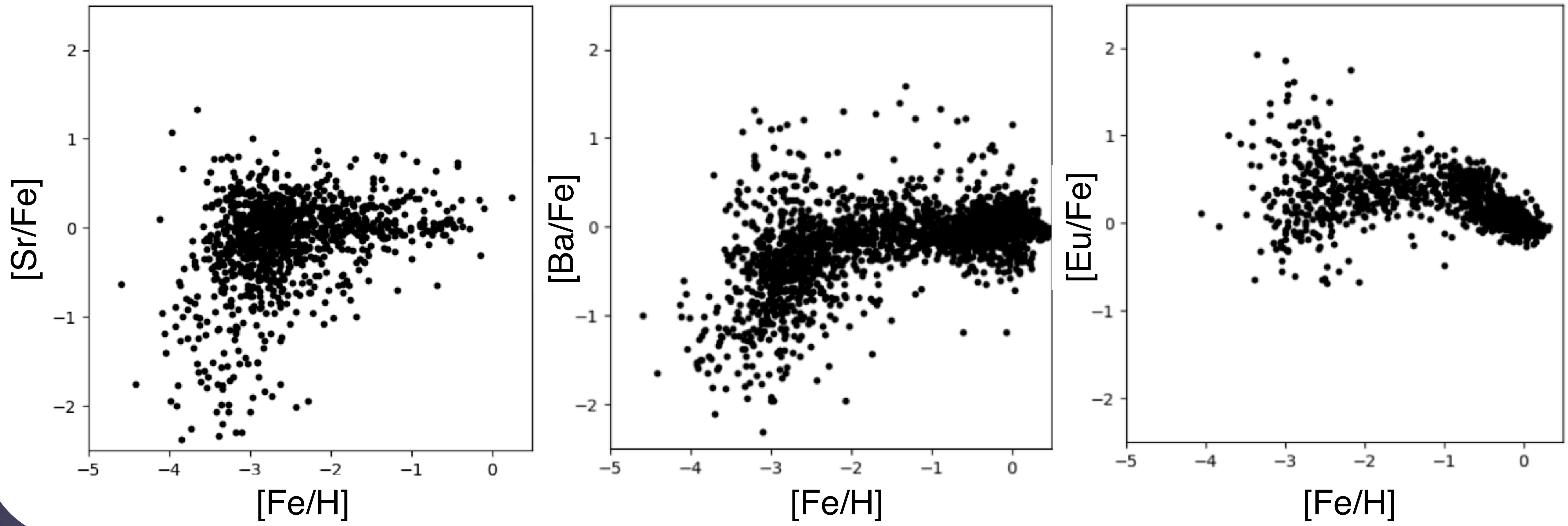
α-element abundances in the Local Group galaxies



α-element abundances can be an indicator for galactic chemical evolution

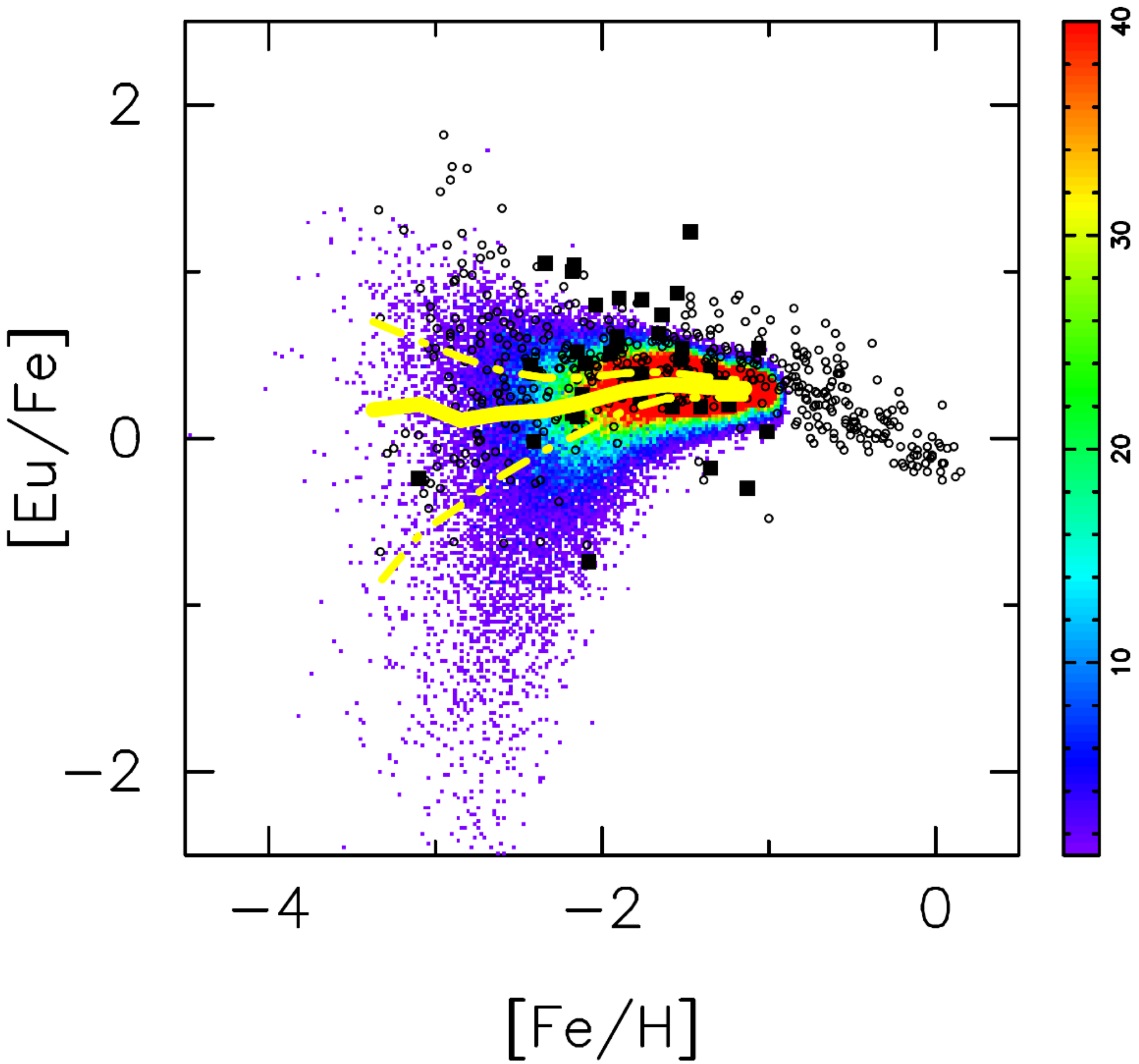
Observations of the neutron-capture elements

SAGA database (Suda et al. 2008; 2017)



Scatters of [Sr, Ba, Eu/Fe] at [Fe/H] < −2.5

Astrophysical sites of neutron-capture elements are not well understood.



Observation (SAGA database, Suda et al. 2008; 2017)

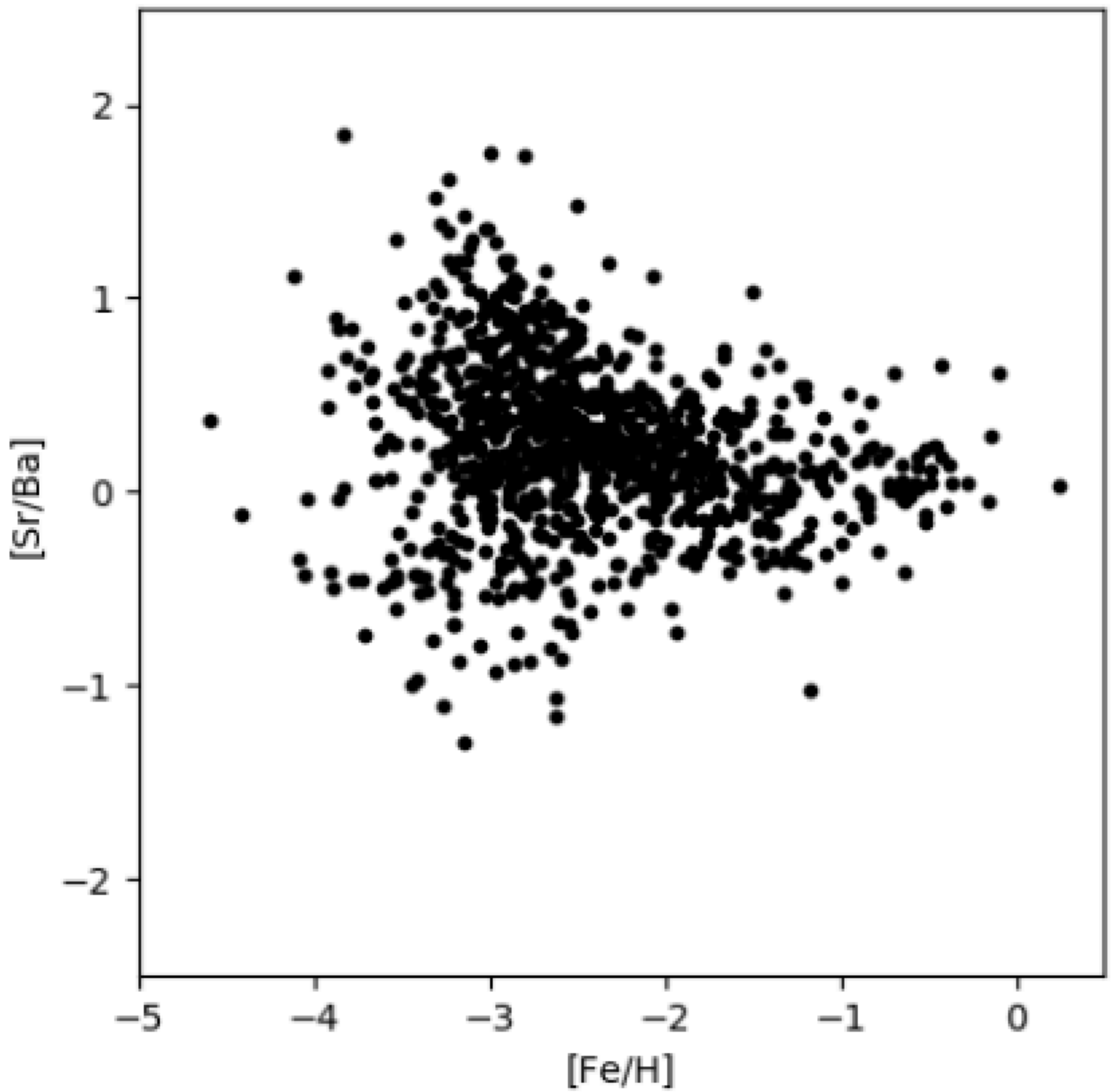
■ dSphs

○ Milky Way

Neutron star mergers can explain Eu abundances

Hirai et al. 2015, ApJ, 814, 41;
Hirai et al. 2017, MNRAS, 466, 2474;
Hirai 2019, Springer Theses

Ratios of light to heavy neutron-capture elements



SAGA database (Suda et al. 2008; 2017)

Astrophysical sites of **light neutron-capture elements** (e.g., Sr, Y, Zr) and **heavy neutron-capture elements** (e.g., Ba, Eu) **may be different**

Possible sites for light neutron-capture elements

Electron-capture supernovae (ECSNe)
(Supernovae with low mass progenitors)

Neutron star mergers (NSMs)

This study

Rotating massive stars

e.g.,
Chiappini et al. (2011), Nature, 472, 454;
Cescutti & Chiappini (2014), A&A, 565, A51;
Prantzos et al. (2018), MNRAS, 476, 3432

The role of each site is not clarified

Purpose of this study

Clarify the astrophysical sites of heavy elements

↓

Put heavy elements as an indicator for galaxy evolution

Method

N-body/SPH code ASURA (Saitoh et al. 2008; 2009)

- Star Formation
- Cooling and Heating Function (Cloudy, Ferland et al. 2013)
- Supernova Feedback
- Chemical Evolution (CELib, Saitoh 2017)
    - Core-Collapse Supernovae, Hypernovae (yield: Nomoto et al. 2013, mass range: 8-100 Msun)
    - **Electron-Capture Supernovae** (yield: Wanajo et al. 2018, mass range: Doherty et al. 2015)
    - **Neutron Star Mergers** (yield: Wanajo et al. 2014)
    - Type Ia Supernovae (yield: Seitenzahl et al. 2013)

Isolated dwarf spheroidal galaxy model

Gas and dark matter density profile：
pseudo-isothermal profile

(e.g., Revaz & Jablonka 2012, A&A, 538, A82)

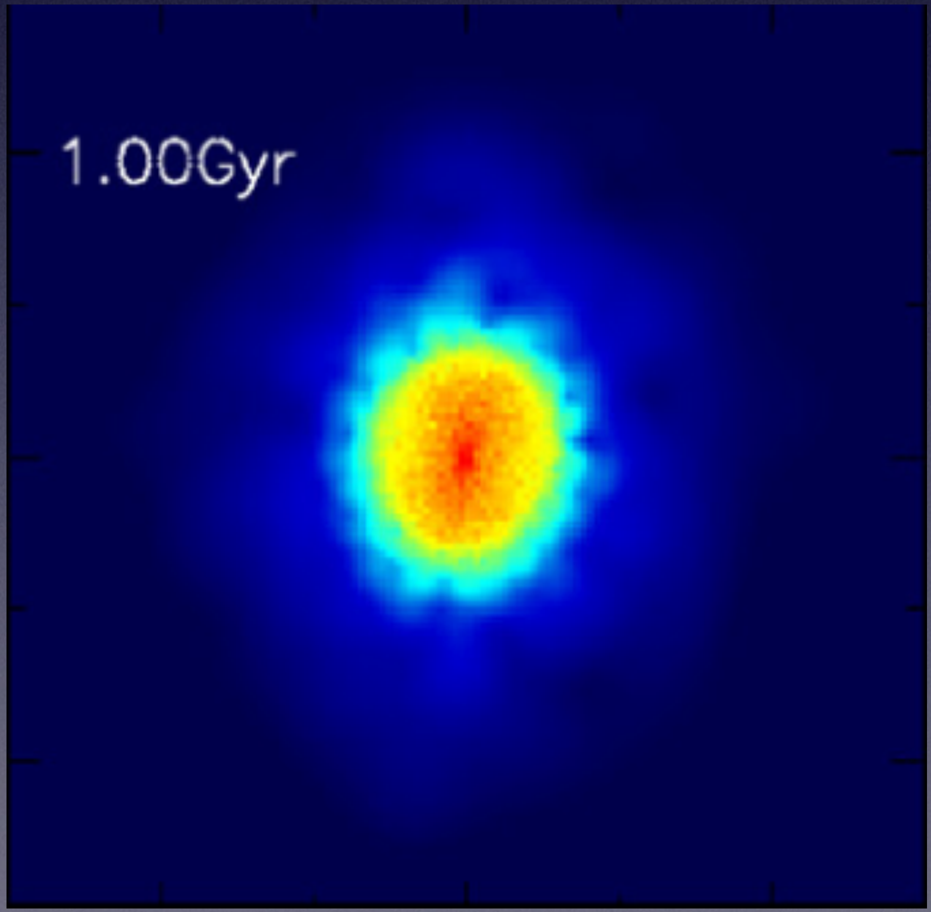
$$\rho_i(r) = \frac{\rho_{\mathrm{c,i}}}{1 + \left(\frac{r}{r_\mathrm{c}}\right)^2}$$

Total mass of the halo:
$7\times10^8\ M_\odot$

Final stellar mass of the galaxy:
$3\times10^6\ M_\odot$

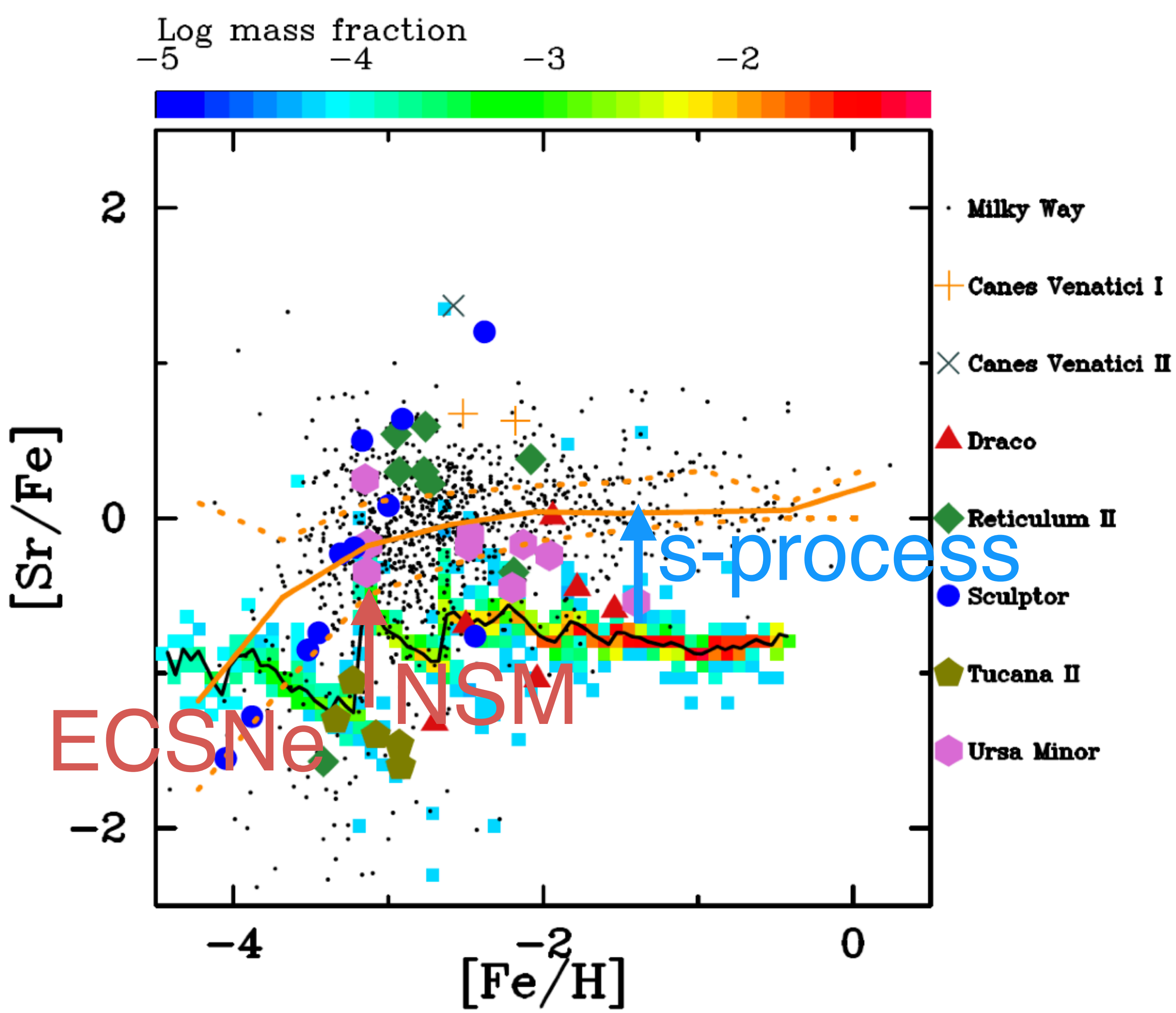
Total number of particles:
3×10^5

Gravitational softening length:
7.8 pc



Hirai et al. 2015, ApJ, 814, 41

Enrichment of Sr

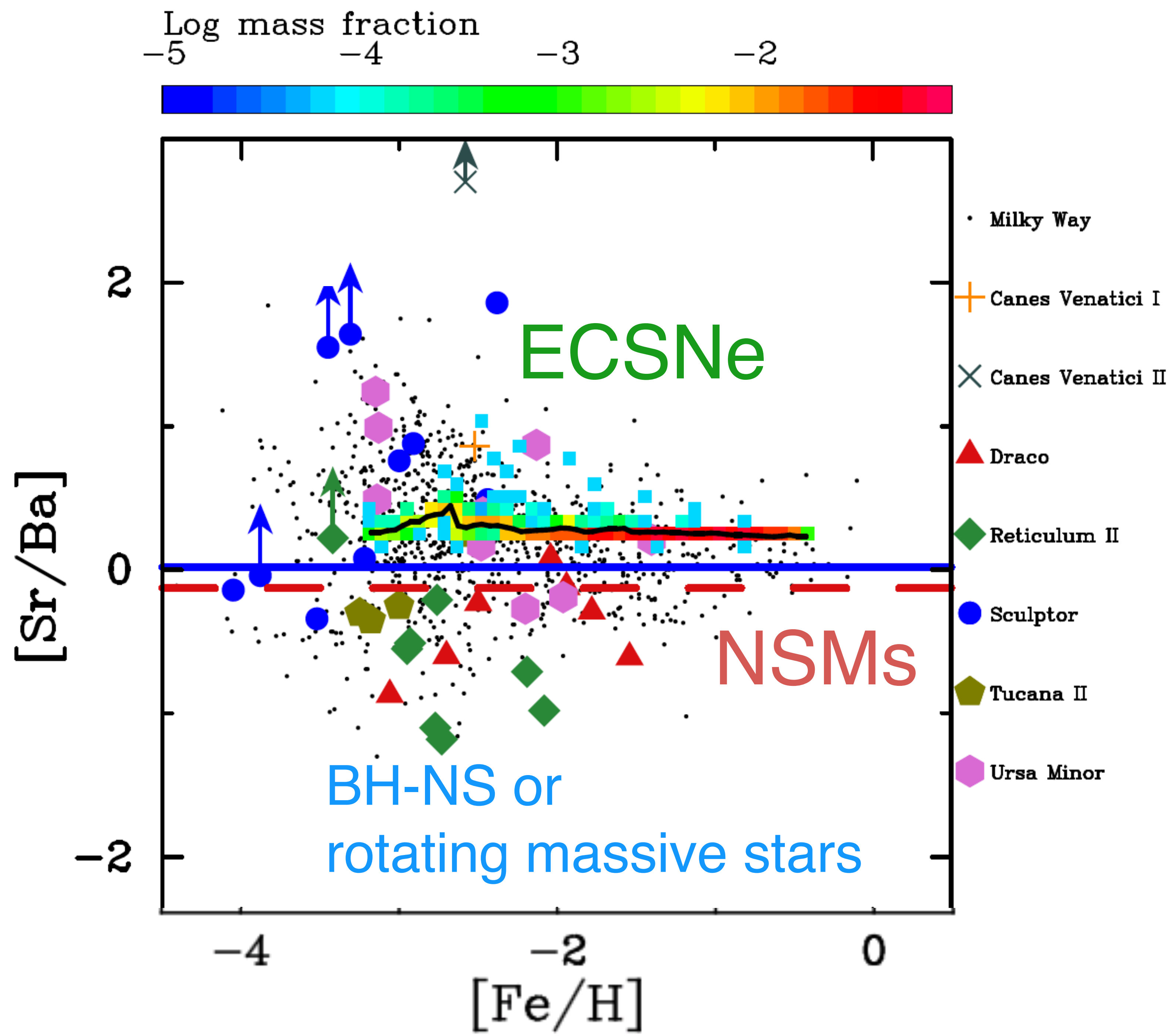


Hirai et al. (2019) ApJ submitted

Electron-Capture Supernovae + Neutron Star Mergers

- Main contributors on the enrichment of Sr at [Fe/H] < −2.5
- ~ 20 % of total mass of Sr is come from ECSNe and NSMs

[Sr/Ba] as a function of [Fe/H]



Hirai et al. (2019) ApJ submitted

Ejecta from ECSNe produce high [Sr/Ba] ratios

~ 2 % of stars has [Sr/Ba] > 1

Purpose of this study

Clarify the astrophysical sites of heavy elements

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Put heavy elements as an indicator for galaxy evolution


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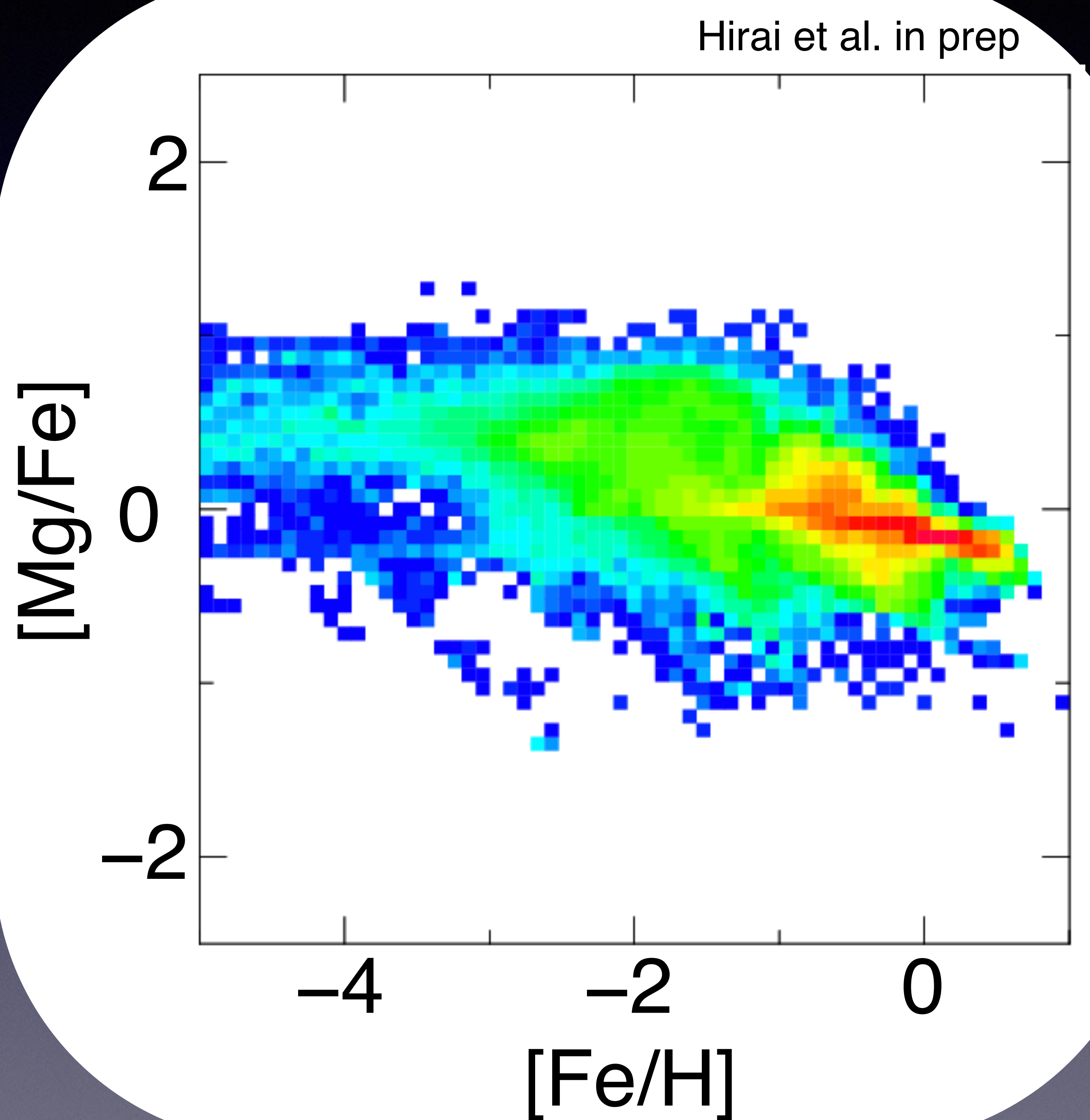
https://youtu.be/1qU_l9R6CU8

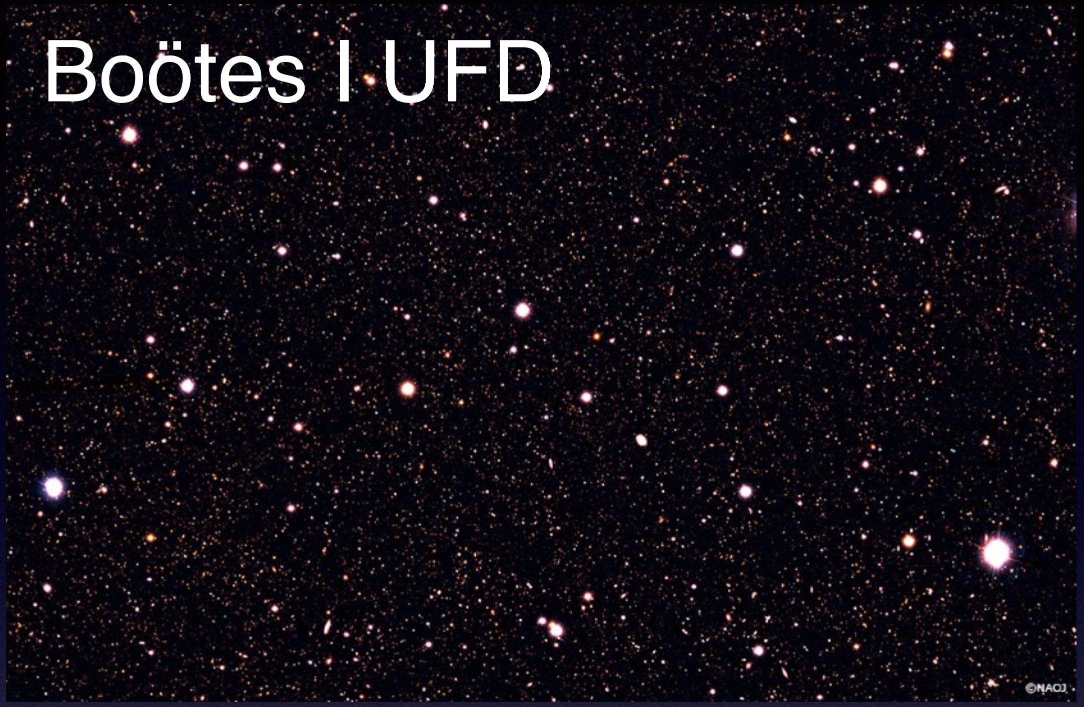
[α/Fe] vs. [Fe/H]



Mass resolution of our simulation (~10^3 M_{sun}) is enough to resolve satellite dwarf galaxies

Direct comparison with Subaru PFS data

Star-by-star simulation



CELib

Saitoh 2017, AJ, 153, 85

Star formation

Stellar mass, lifetime, yields, energy

ASURA

Hydrodynamics+*N*-body (Tree)

Saitoh et al. 2008, PASJ, 60, 667;
Saitoh et al. 2009, PASJ, 61, 481

Pos, Vel, Acc

Pos

BRIDGE

Direct *N*-body

Fujii et al. 2007, PASJ, 59, 1095

Simulations of galaxy formation resolving individual stars

Conclusions

- **Electron-capture supernovae (ECSNe) can be the main site of Sr at [Fe/H] < –3**
- **Neutron star mergers (NSMs) contribute to the enrichment of both light (e.g., Sr) and heavy (e.g., Eu) neutron-capture elements**
- **High-resolution cosmological zoom-in simulations will connect the abundances of heavy elements and evolutionary histories of galaxies**