S2-10-3

Constraints on the efficiency of metal mixing in galaxies through the chemical abundances of metal-poor stars

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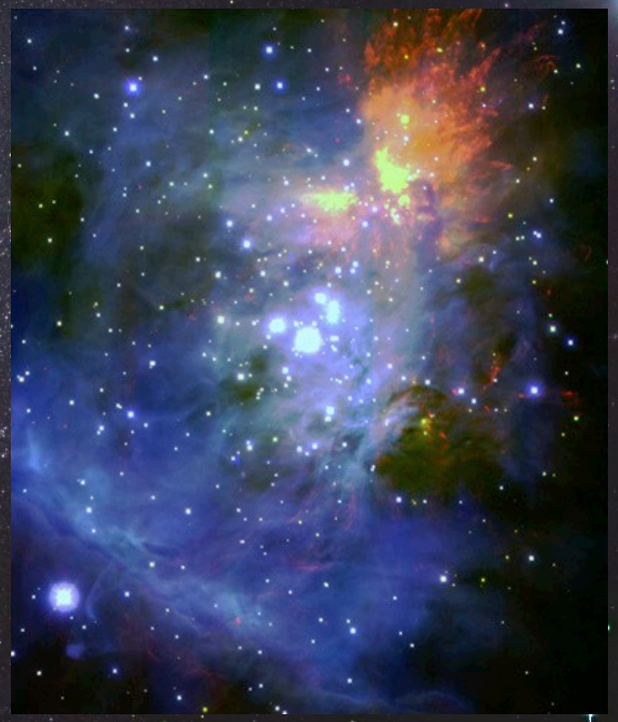
Hirai & Saitoh (2017), ApJL, 828, L23

Metal mixing

First Stars

Galactic Chemical Evolution

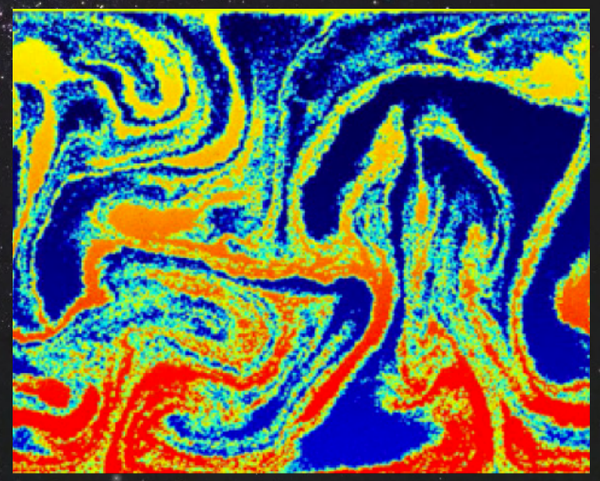
Star Formation



Supernovae

Dust formation

Interstellar Turbulence

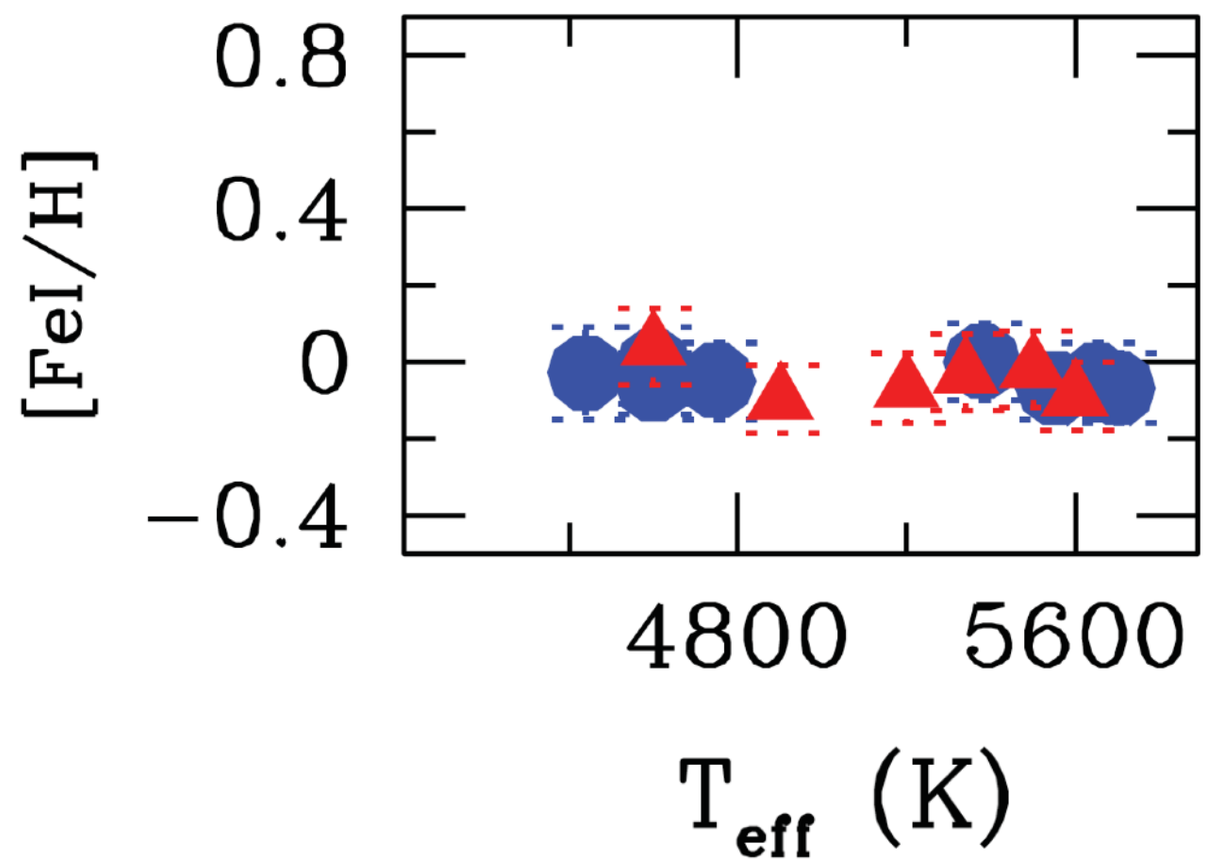


Signatures of metal mixing

Signatures of metal mixing

Metallicity distribution is homogeneous in open star clusters

De Silva (2013) MNRAS, 431, 1005

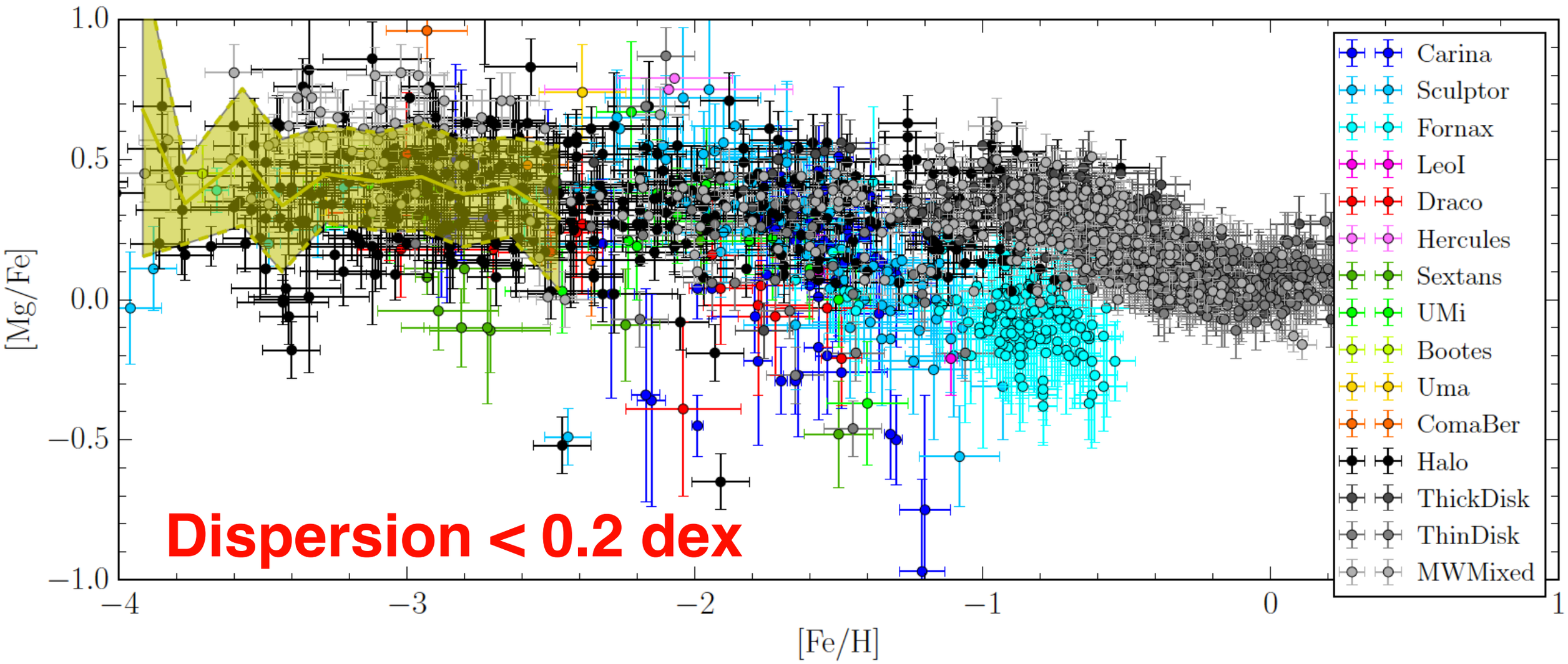


Metals are mixed by inter stellar turbulences

Efficiency of metal mixing is unknown

α-element abundances

Homogeneous in [Fe/H] < –3

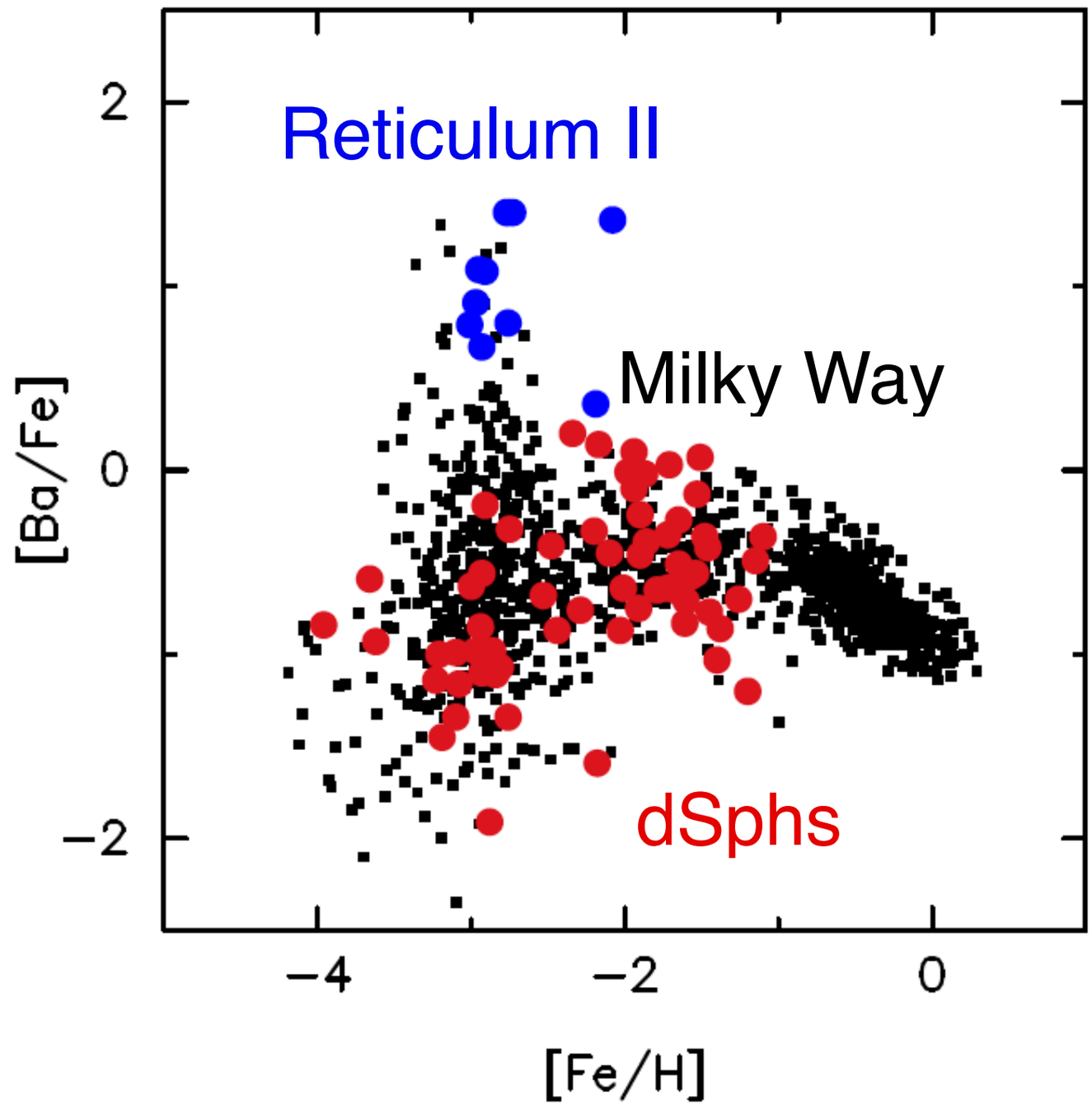


Revaz+16

Abundances of r-process elements

Lower abundances of r-process elements in dSphs than that of the Milky Way

This would constrain the efficiency of metal mixing

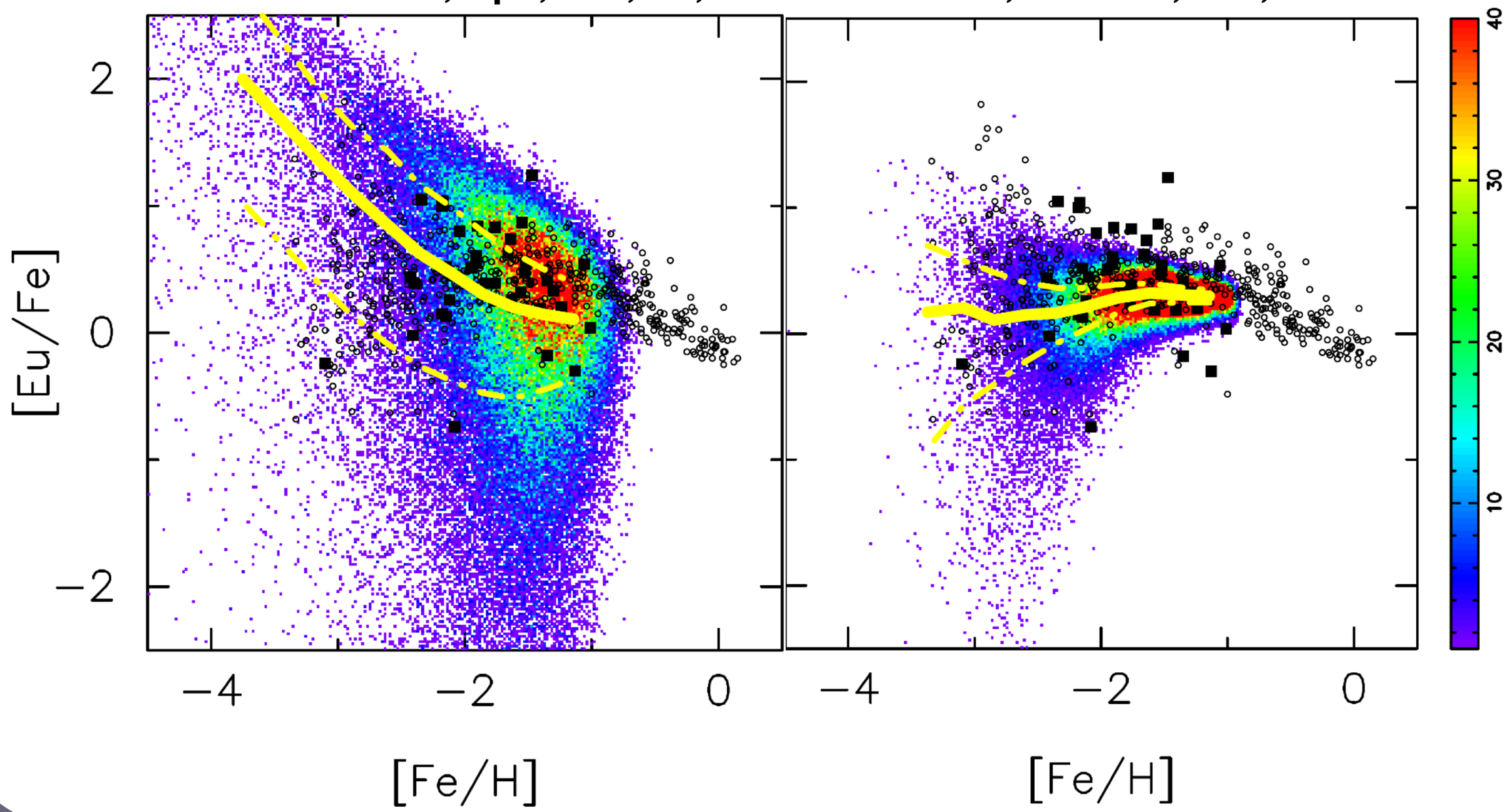


SAGA database (Suda et al. 2008; 2017)

Effects of metal mixing

Without mixing With mixing

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



Metal mixing significantly affects the r-process abundance

Purpose

Constrain the efficiency of metal mixing

Method

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

- Star Formation
- Cooling and Heating Function (Cloudy)
- Supernova Feedback
- Chemical Evolution
    - Fe, Mg：Supernovae
    - Ba：Neutron Star Mergers

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:
$7.0\times10^8\,M_\odot$

Final stellar mass:
$5.0\times10^6\,M_\odot$

Metal diffusion model

Diffuse elements (Z_i) in SPH particles through following equation:

$$\frac{\mathrm{d}Z_i}{\mathrm{d}t} = \nabla(D\nabla Z_i)$$

$$D = C_\mathrm{d}|S_{ij}|h^2$$

The metal diffusion parameters

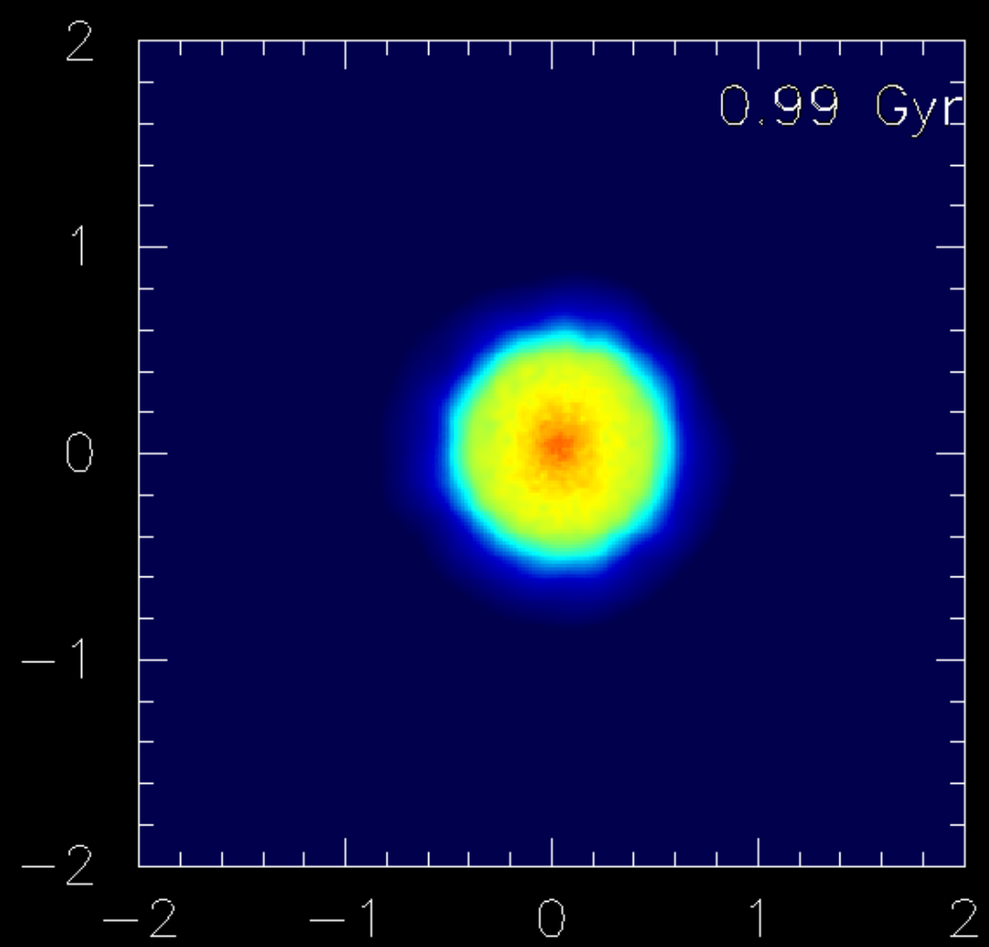
Trace-free shear tensor

Smoothing length

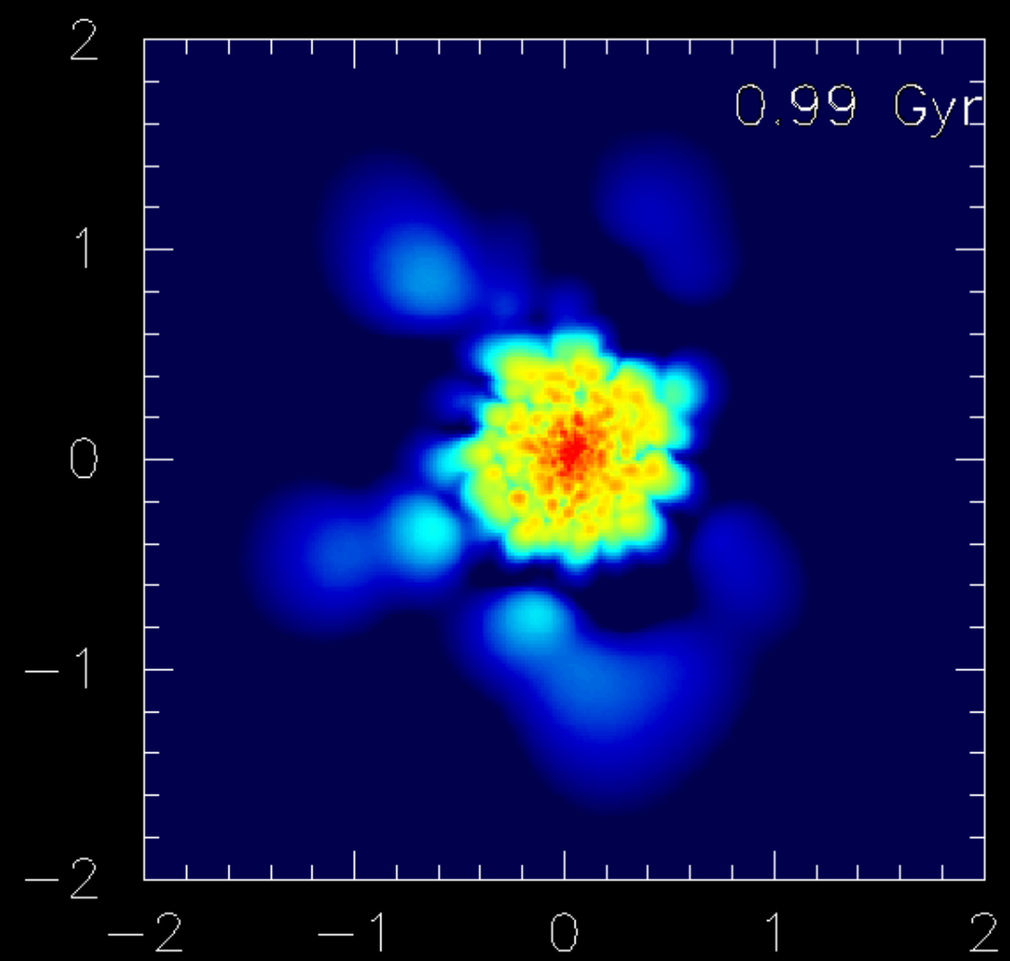
Smagorinsky63, Shen+10, Saitoh 17

With metal mixing

$C_d = 0.1$



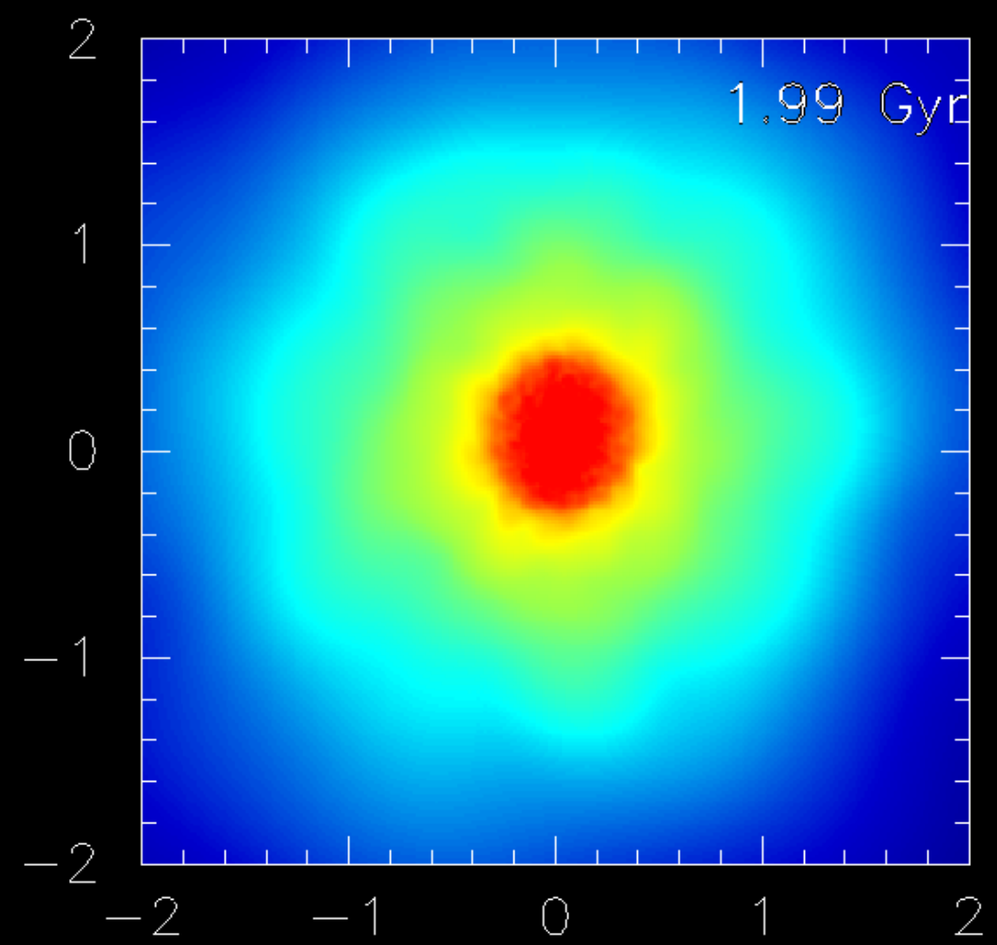
Without metal mixing



Spatial distribution of metallicity is highly inhomogeneous in the model without metal mixing

With metal mixing

$C_d = 0.1$



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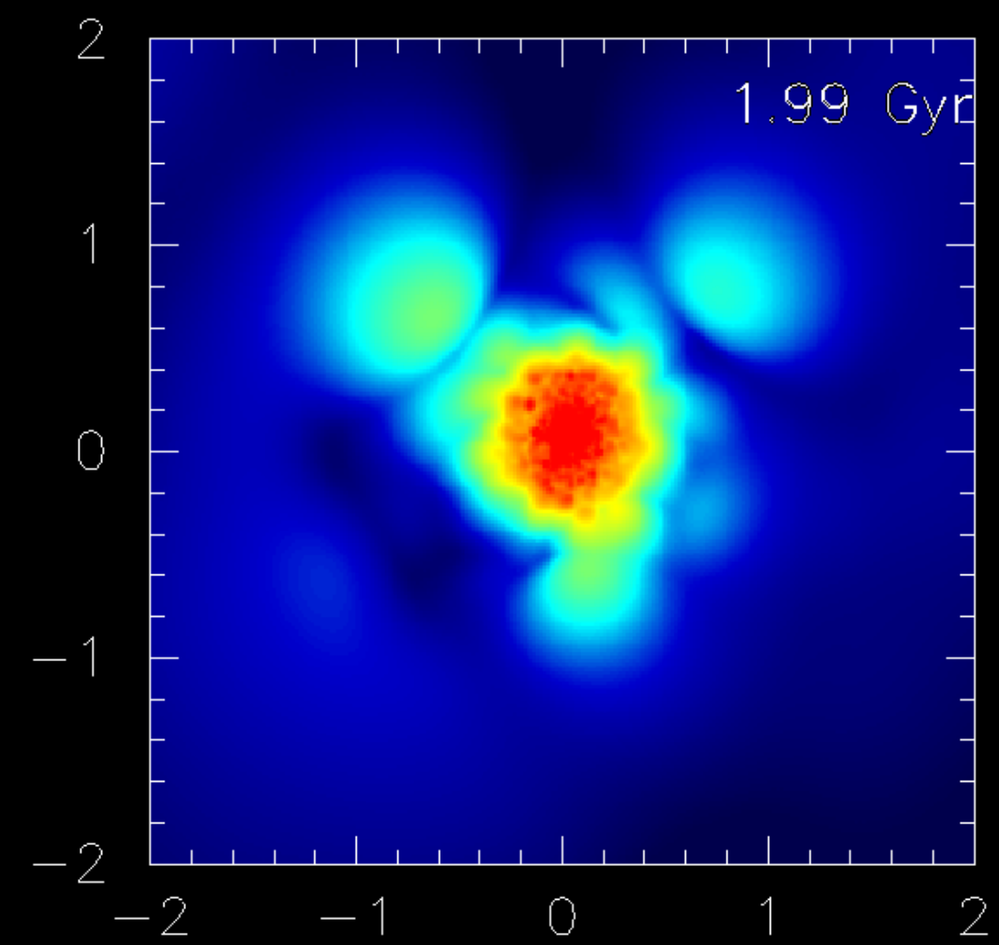

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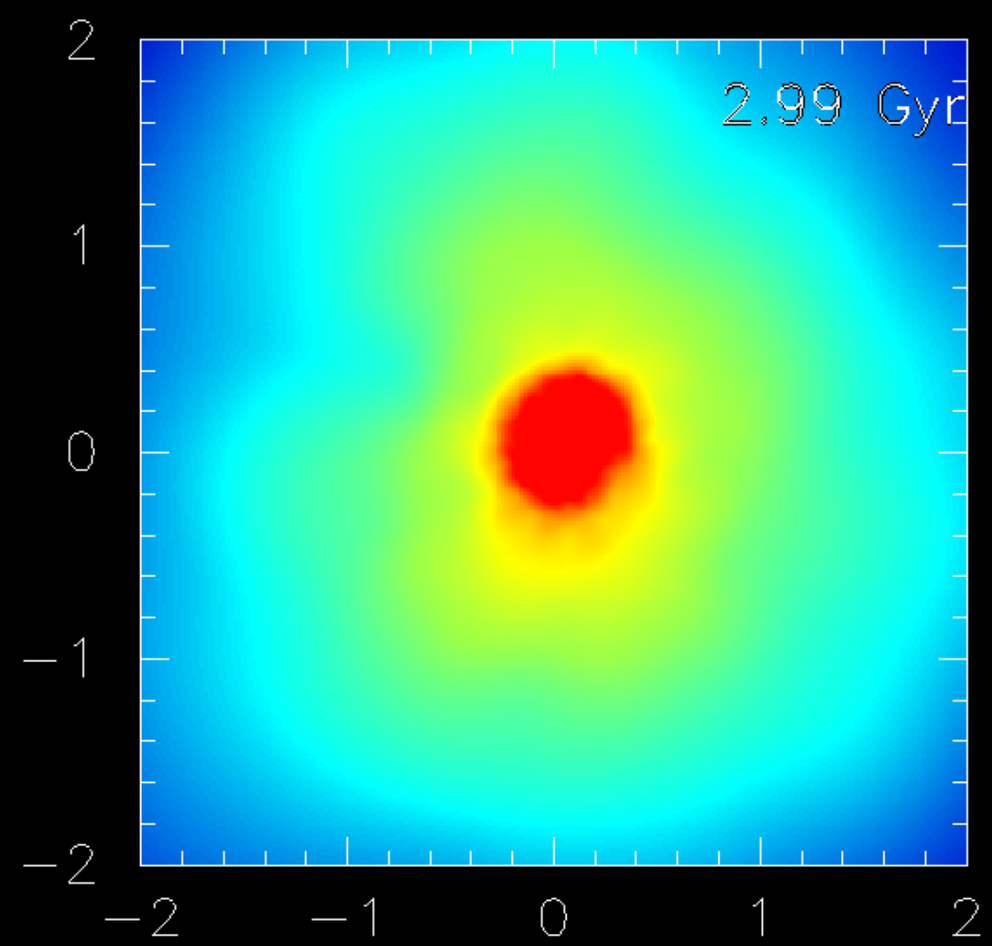
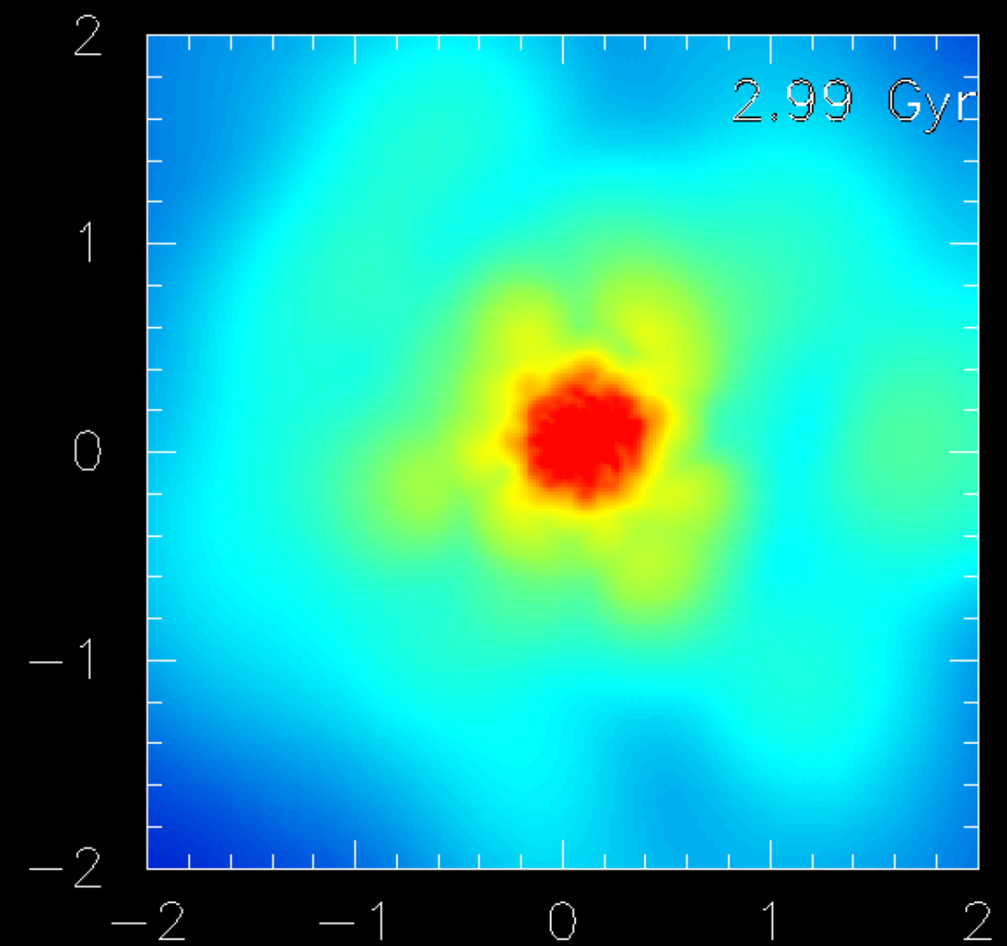
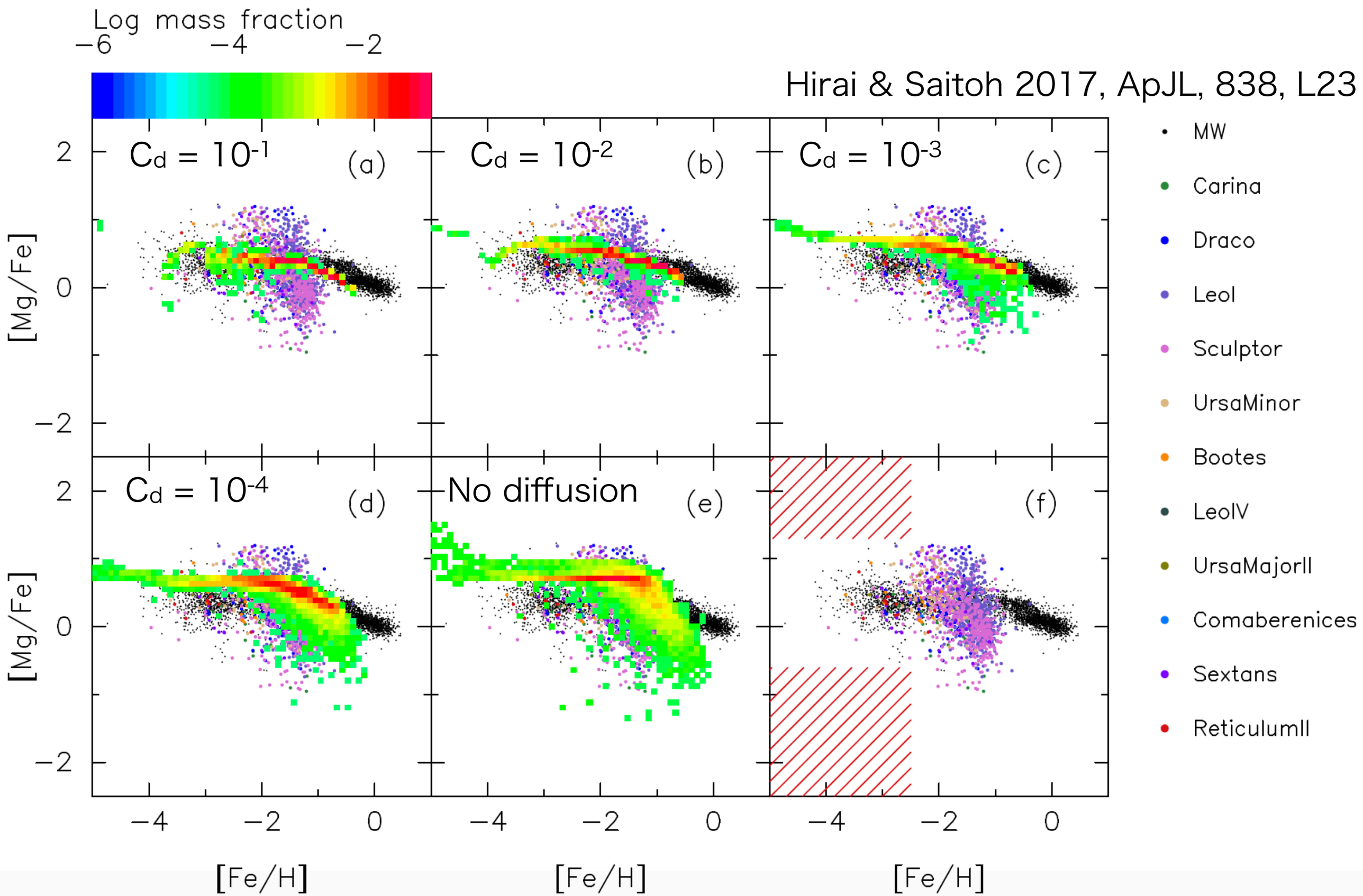


Without metal mixing

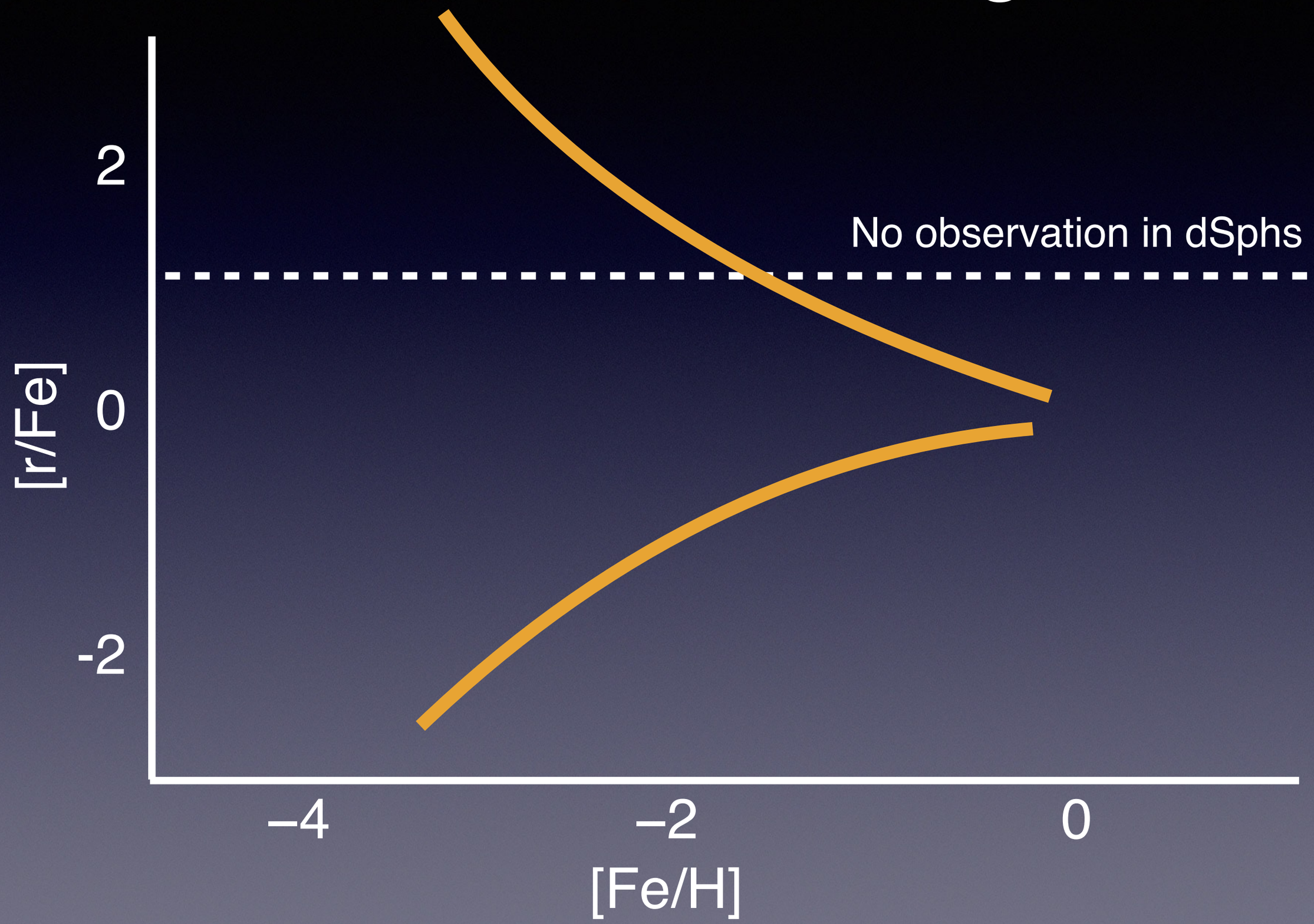


Spatial distribution of metallicity is highly inhomogeneous in the model without metal mixing

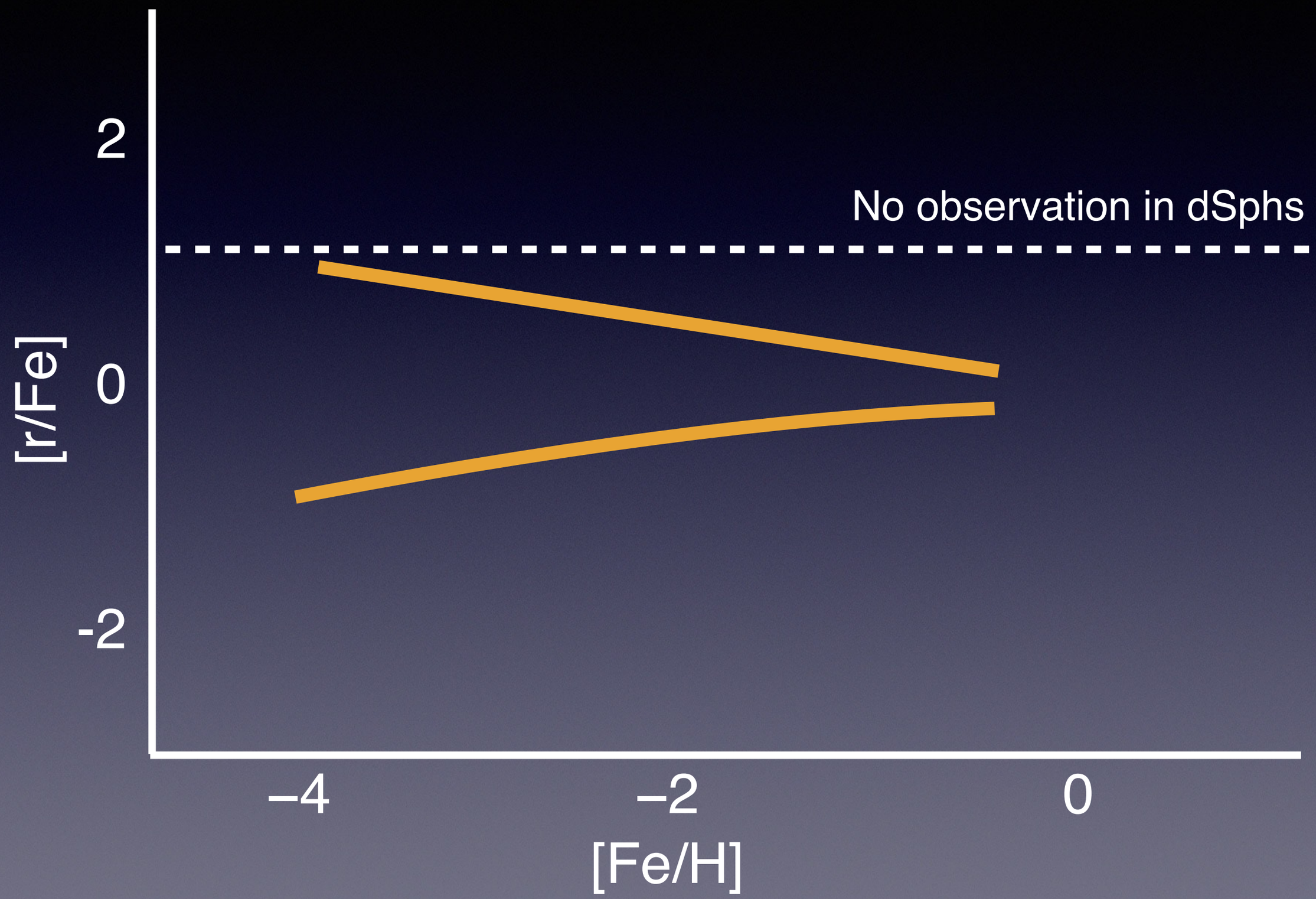
Cannot constrain the efficiency of metal mixing



Insufficient metal mixing

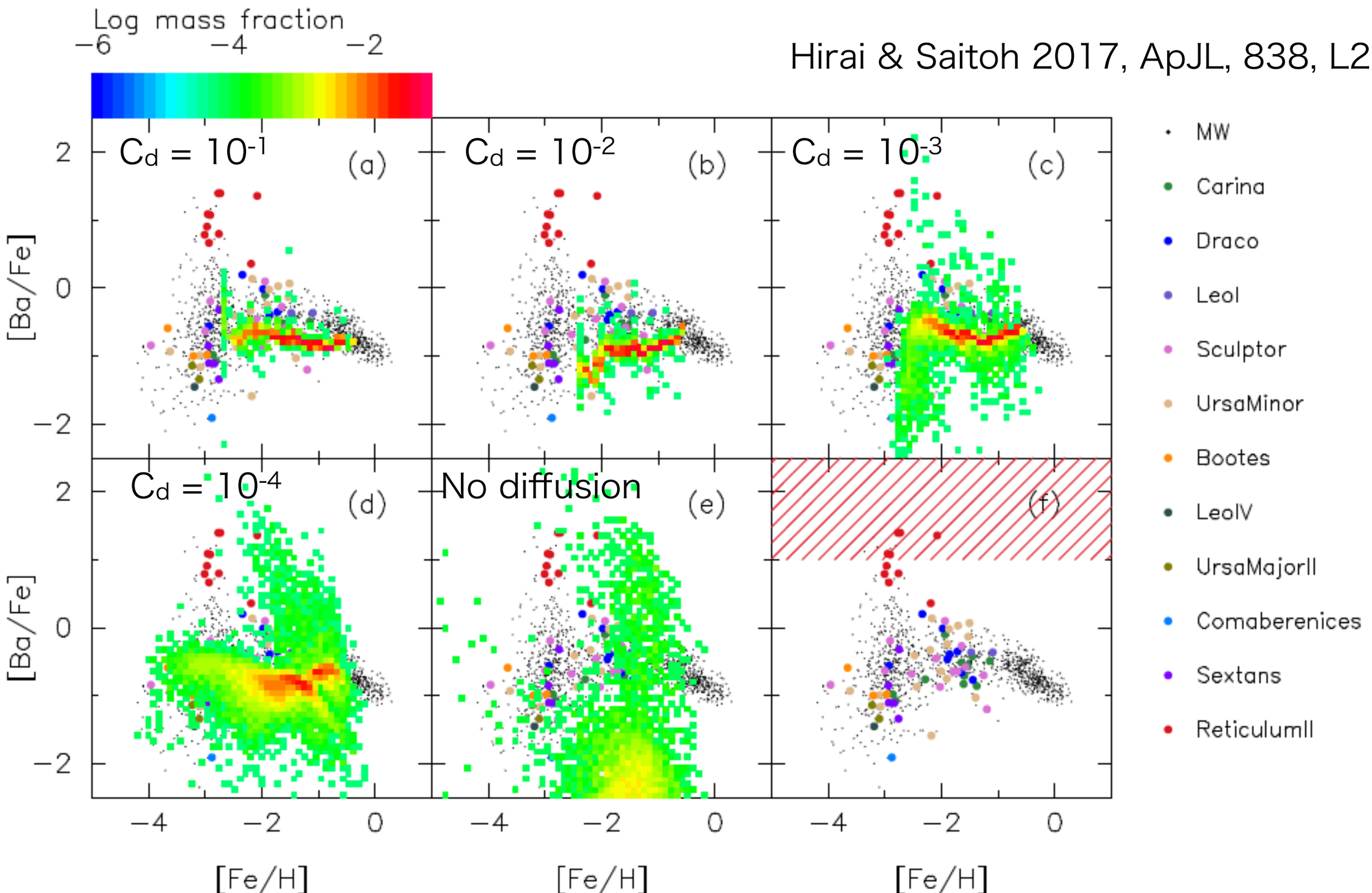


Efficient metal mixing



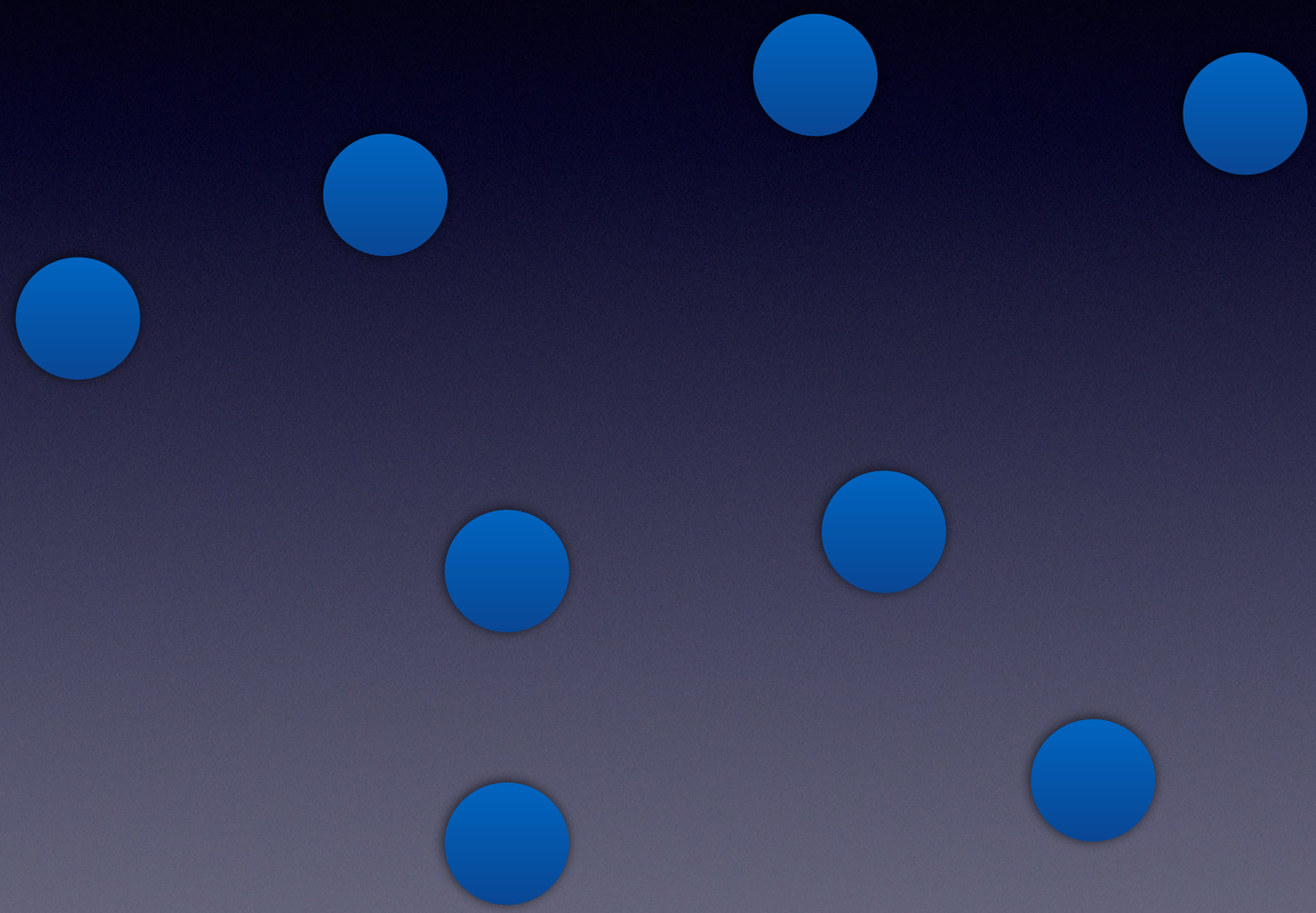
Efficiency of metal mixing: $C_d \gtrsim 0.01$

Hirai & Saitoh 2017, ApJL, 838, L23



Timescale of metal mixing

t_{mix}: Average time that the gas with [Ba/Fe] > 1 becomes [Ba/Fe] < 0



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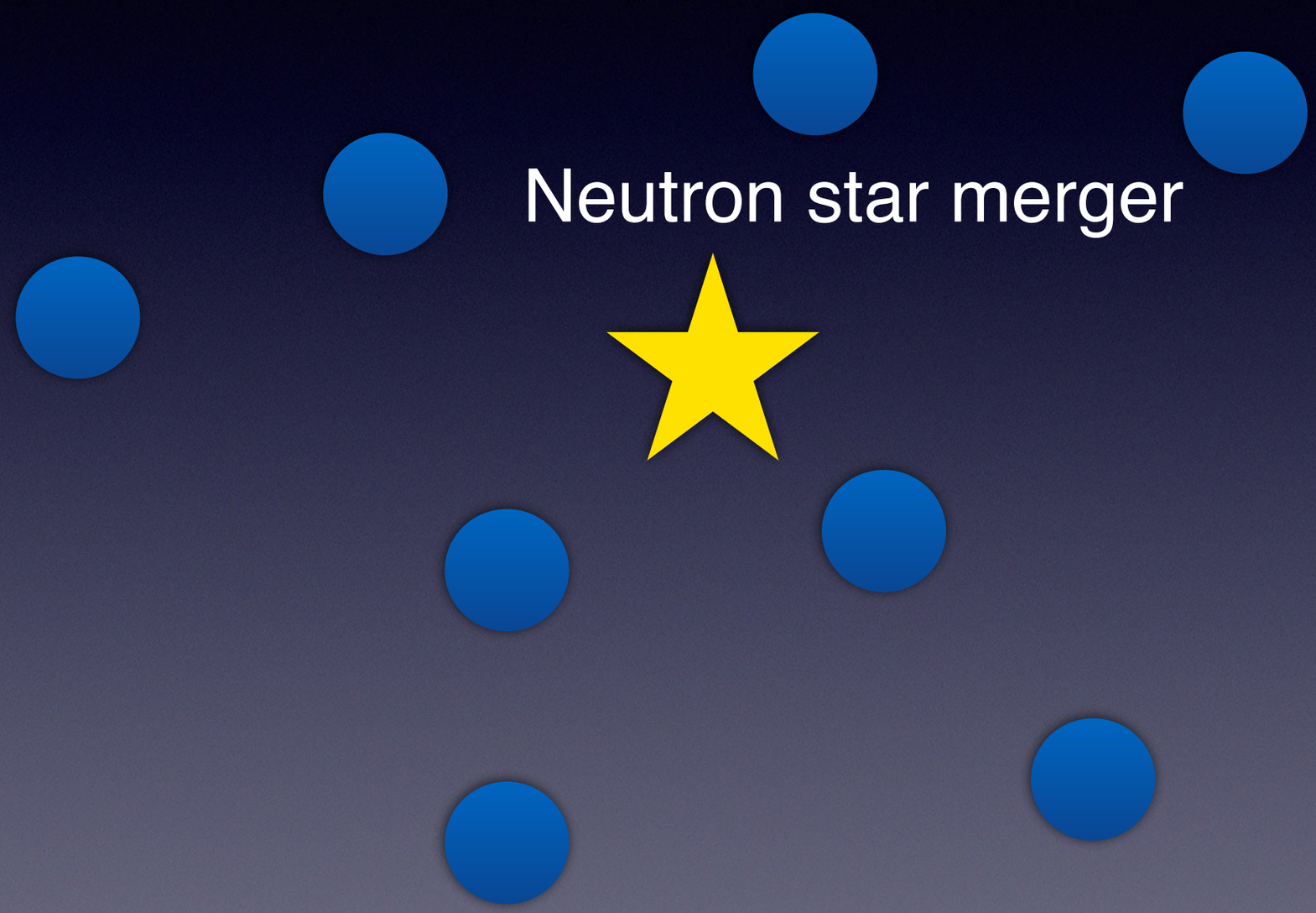

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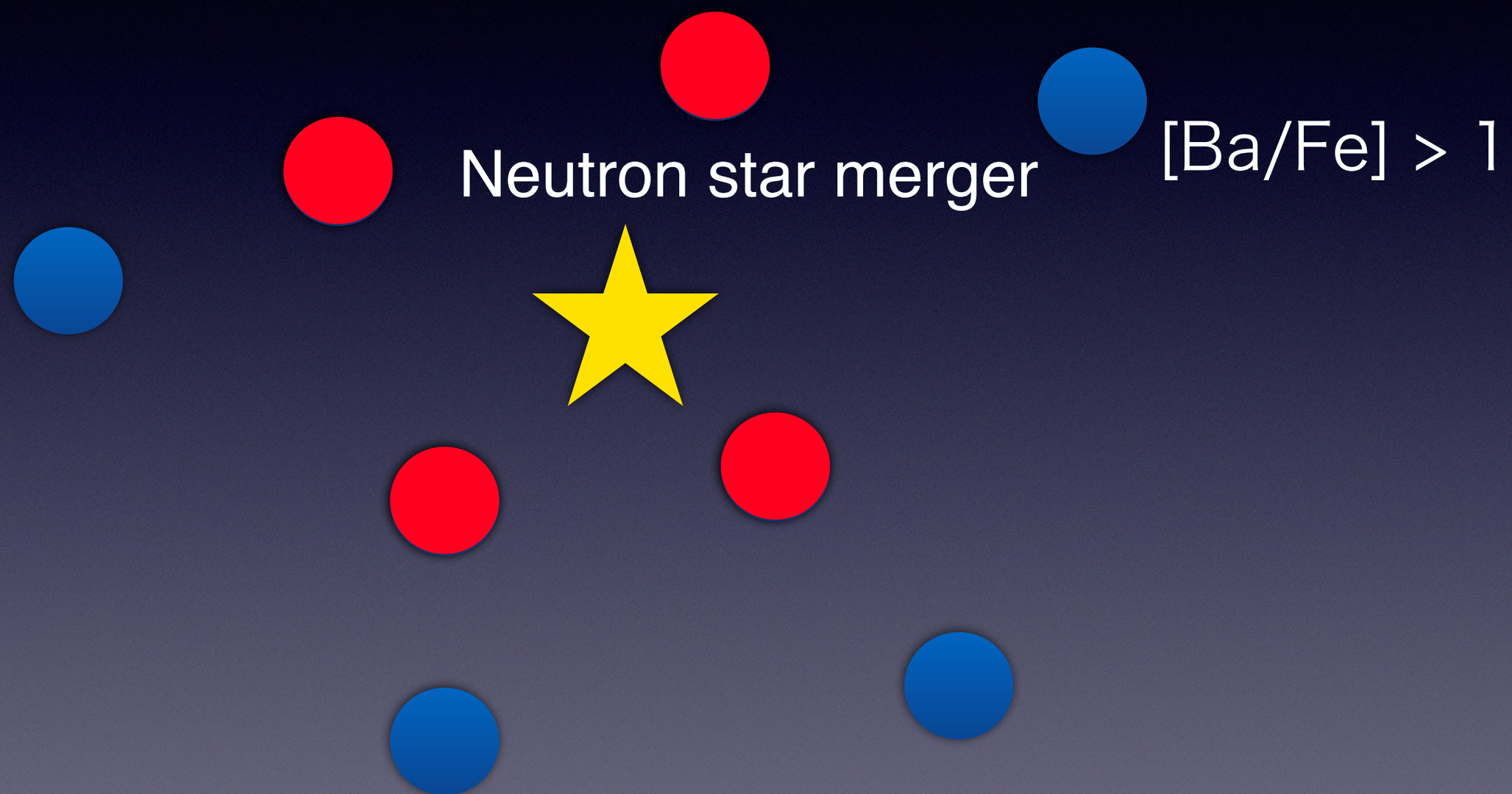

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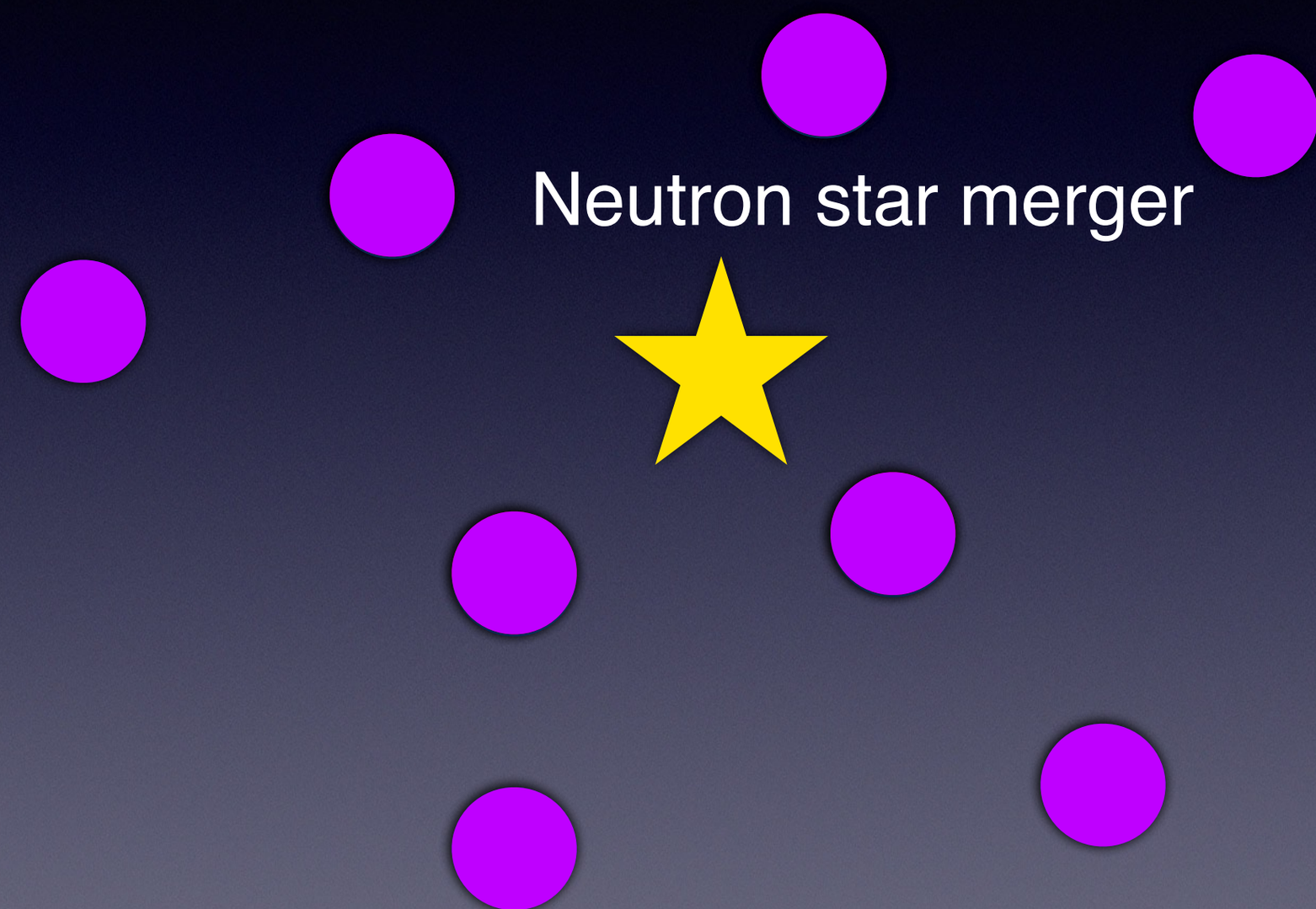

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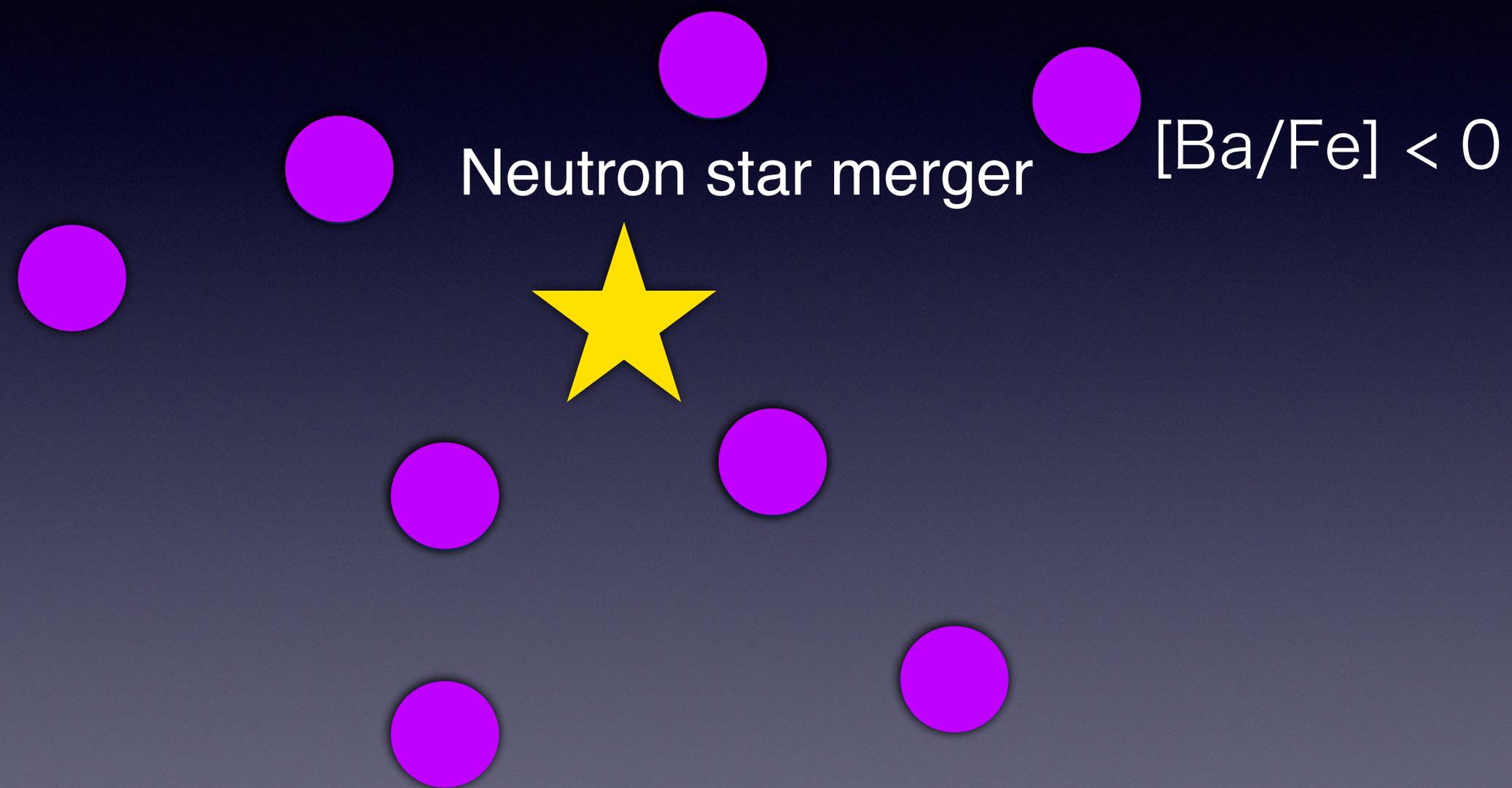

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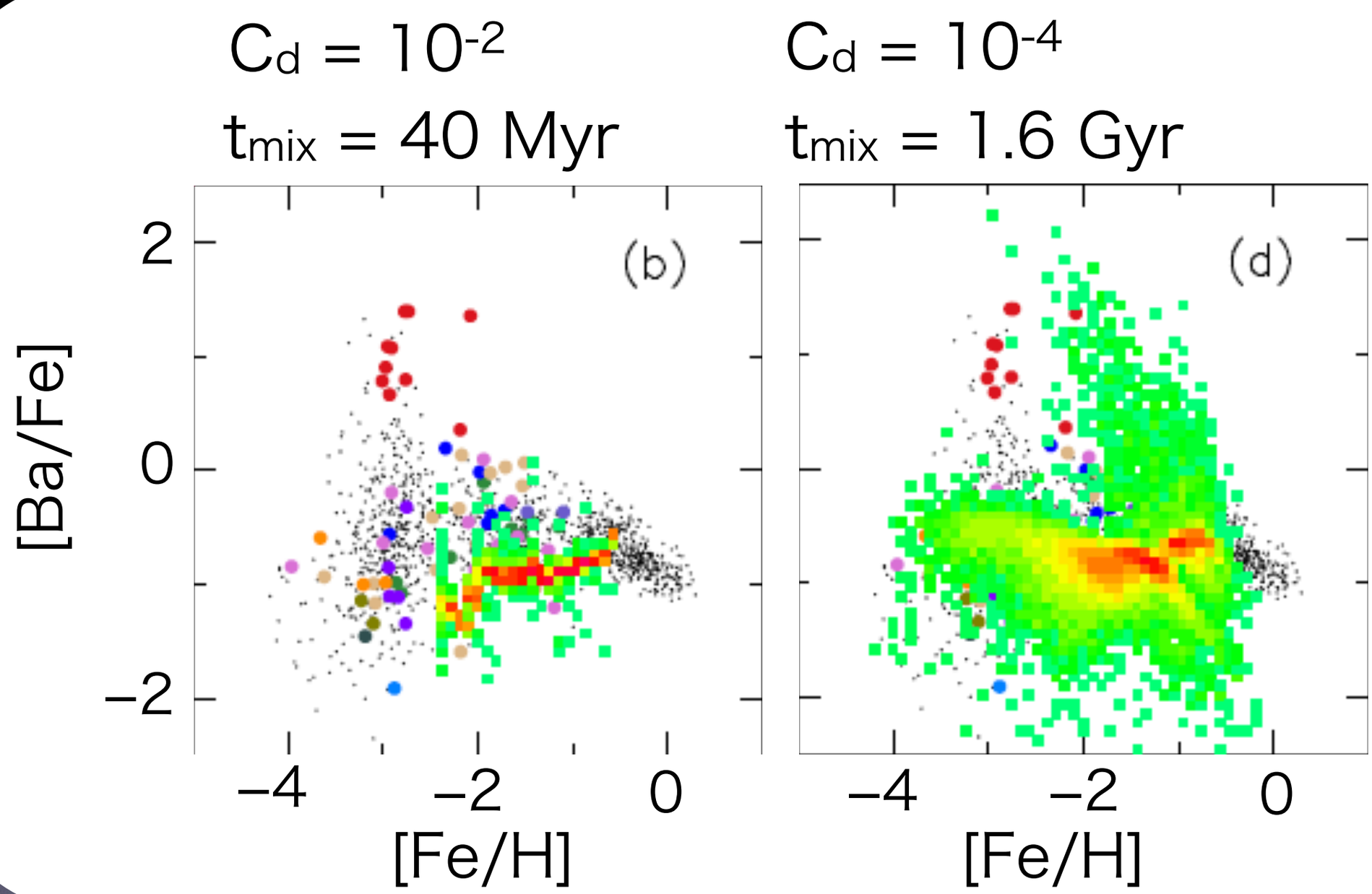


Can explain the observation if **$t_{mix} \lesssim$ 40 Myr**

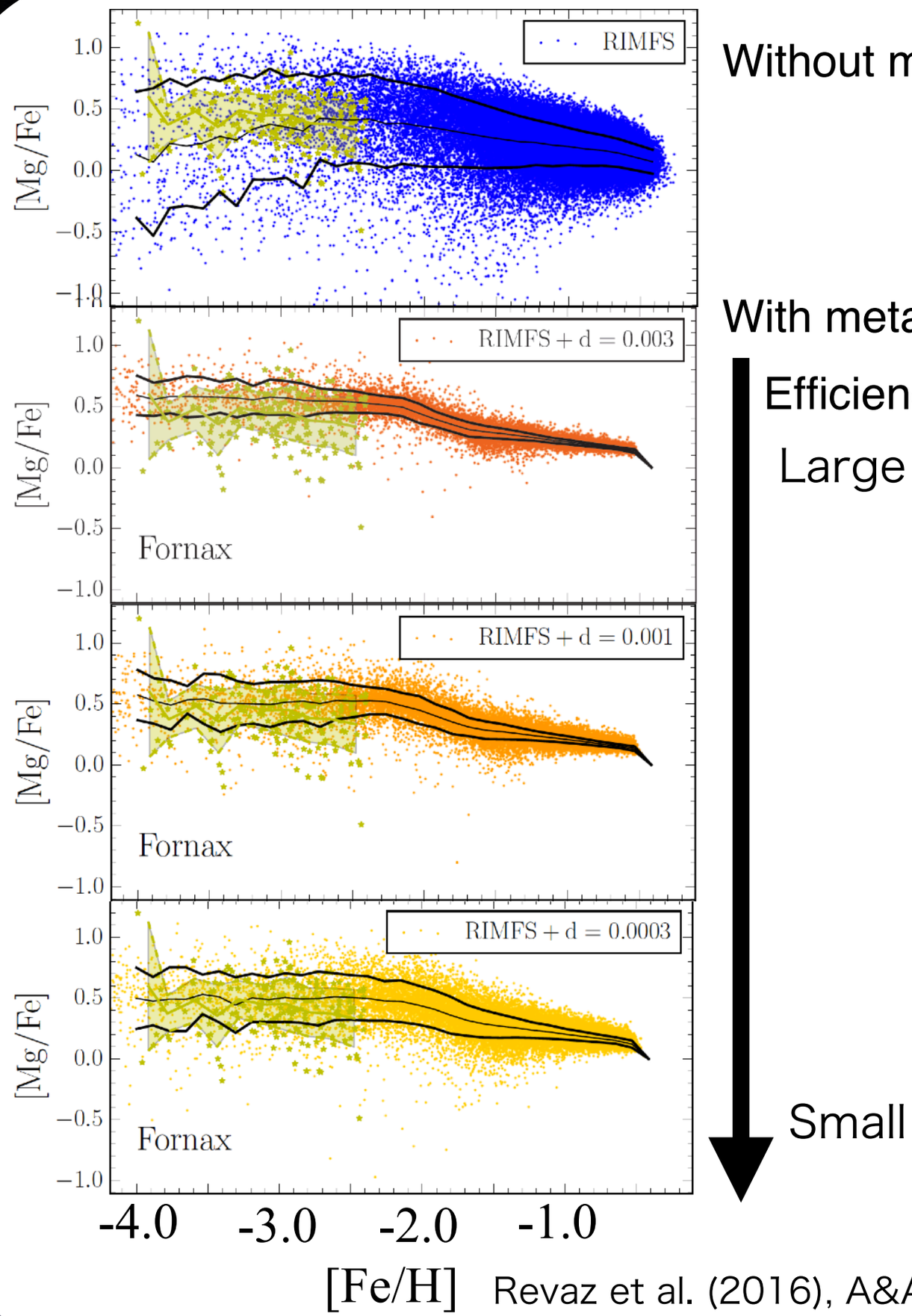
Dynamical times (~100 Myr) > t_{mix}

Conclusions

- **r-process abundances** in metal-poor stars would be a nice tracers to constrain the efficiency of metal mixing
- Timescale of metal mixing is less than **40 Myr**

Hirai & Saitoh 2017, ApJL, 838, L23

Appendix



Without metal mixing

With metal mixing

Efficiency

Large

Small

Revaz et al. (2016), A&A, 588, A21

Scatters of [Mg/Fe] in all models with metal mixing lie within the observational error

We cannot constrain the efficiency of metal mixing

r-process abundances in ultrafaint dwarf galaxy

Assumption：

- Ejected Ba is mixed in whole galaxy
- $M_{Ba} = 1.8 \times 10^{-4}\ M_{sun}$
- [Fe/H] = – 3

dSphs

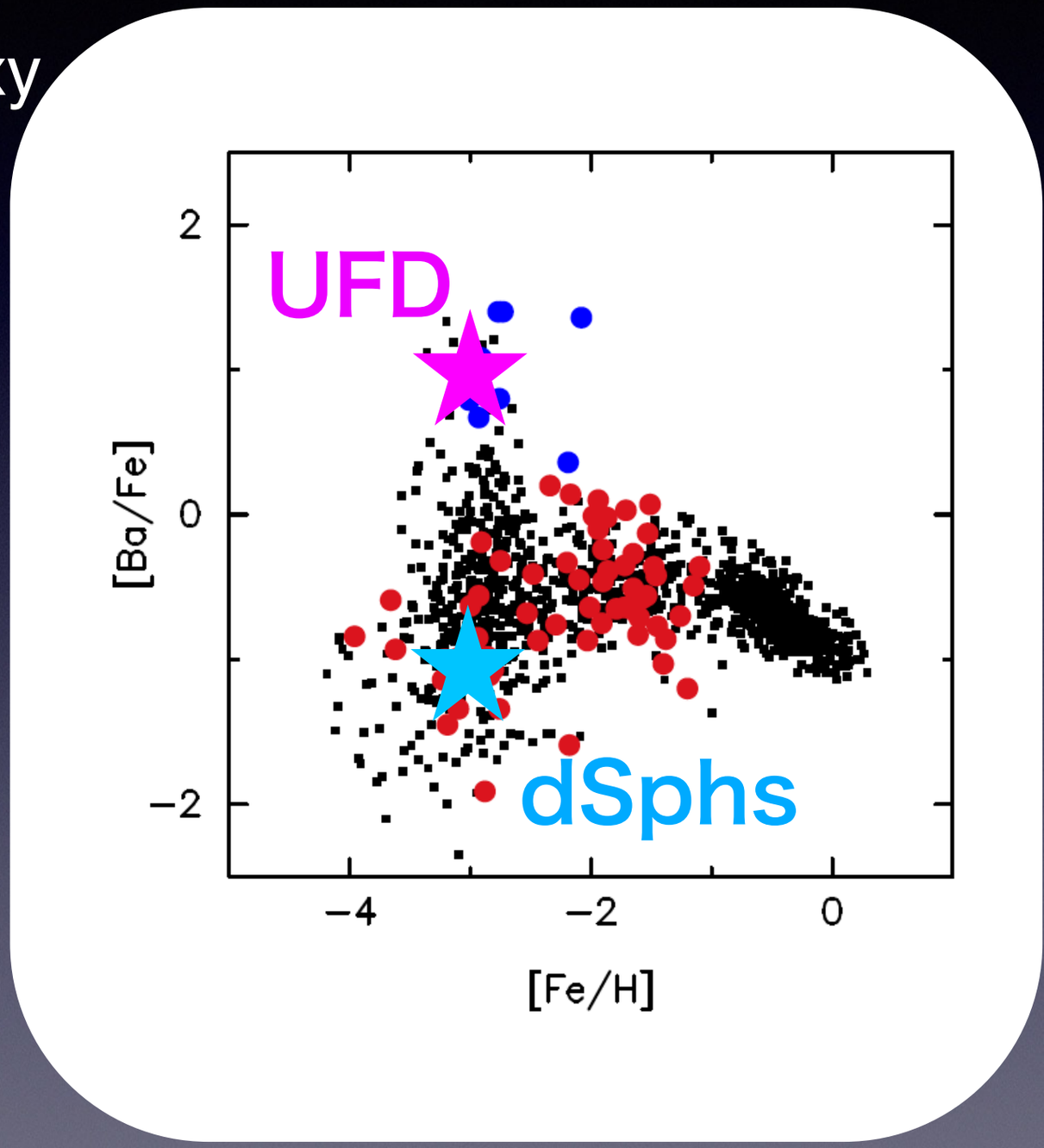
Initial gas mass ~ $10^8\ M_{sun}$

[Ba/Fe] = –1.0

UFD

Initial gas mass ~ $10^6\ M_{sun}$

[Ba/Fe] = 0.9



SAGA database (Suda et al. 2008; 2017), Ji et al. (2016)