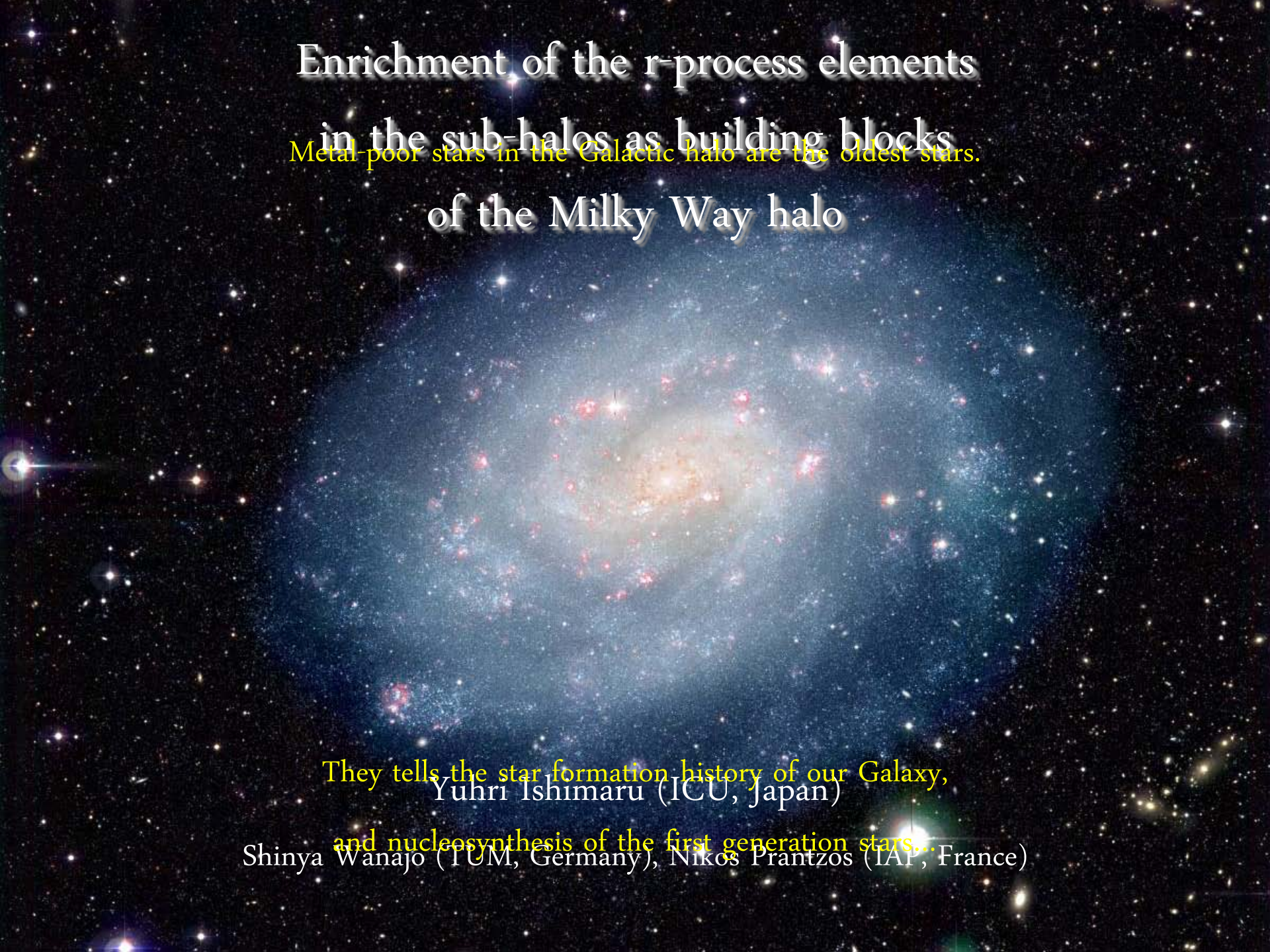
Enrichment of the r-process elements in the sub-halos as building blocks of the Milky Way halo



Metal-poor stars in the Galactic halo are the oldest stars.

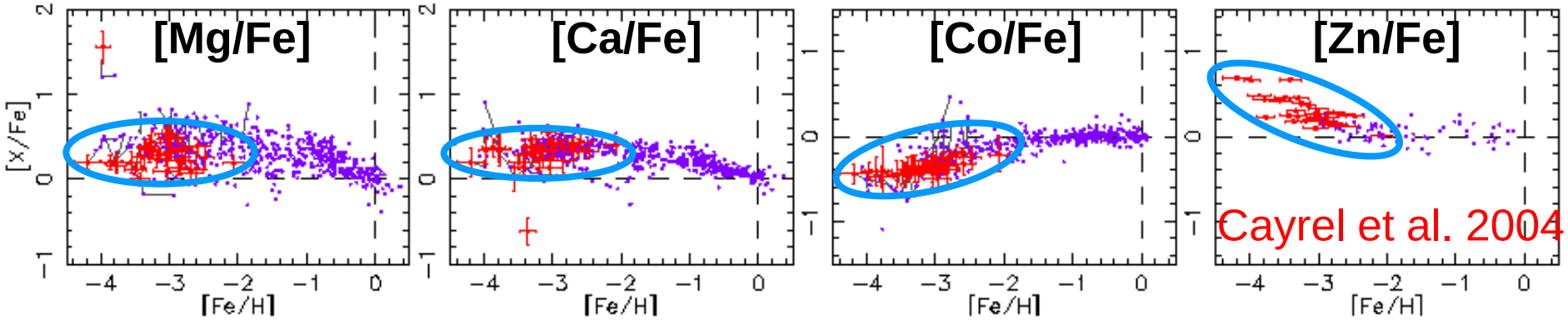
They tells the star formation history of our Galaxy,

and nucleosynthesis of the first generation stars...

Yuhri Ishimaru (ICU, Japan)

Shinya Wanajo (TUM, Germany), Nikos Prantzos (IAP, France)

Chemical Compositions of MPS

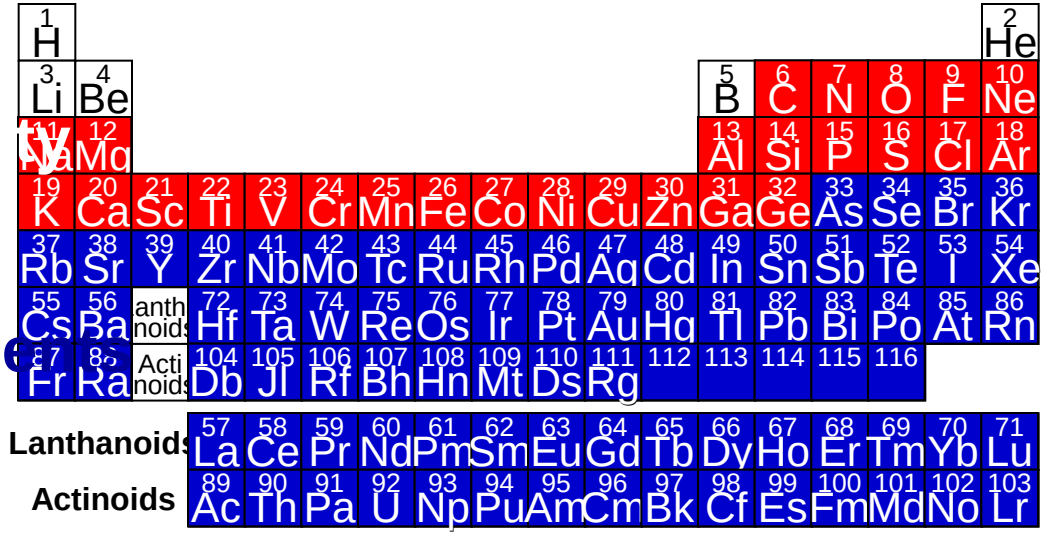


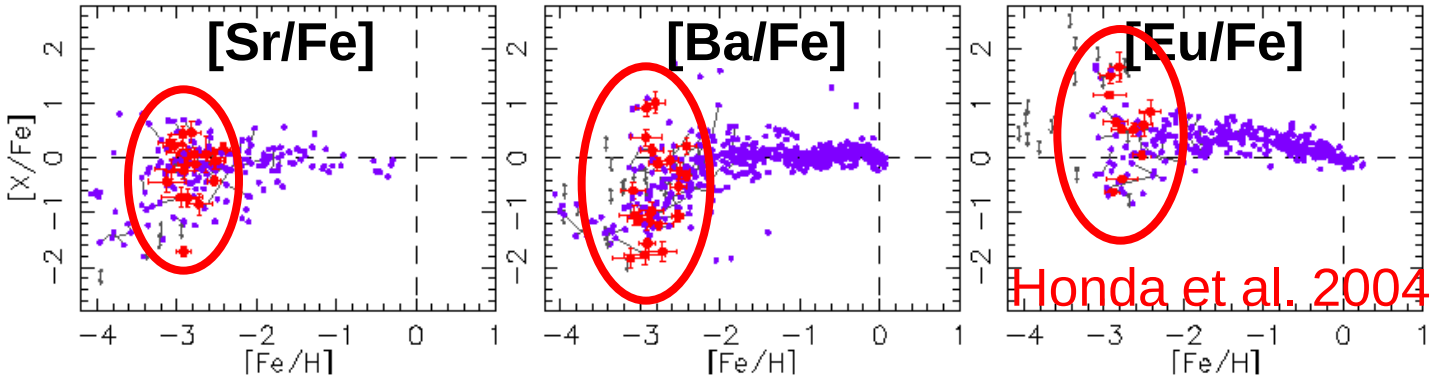
Small Scatters
＋ Trend with Metallic

α & Fe-peak elements

Neutron Capture Eleme

Huge Scatters





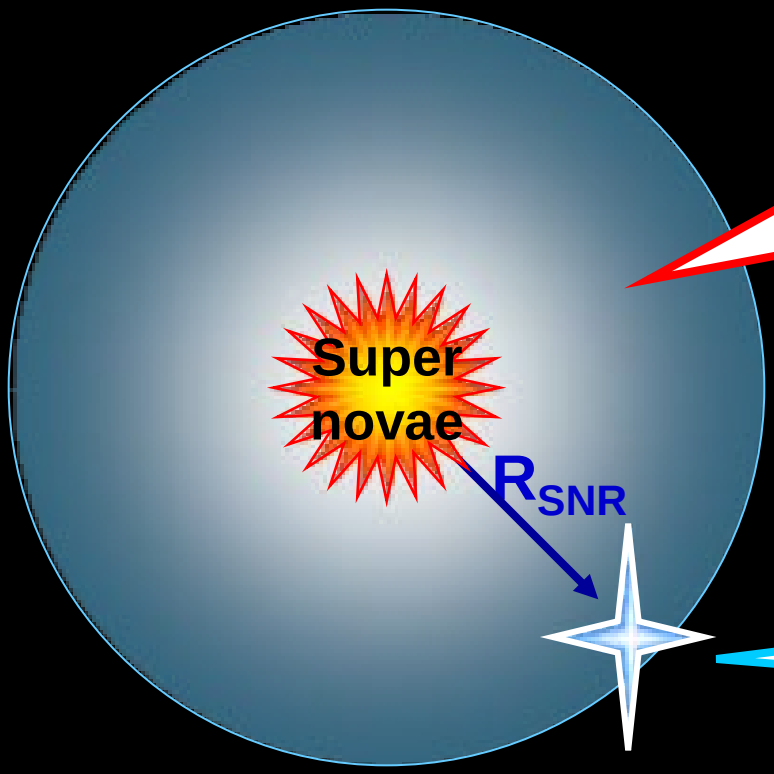
Why does [r/Fe] in MPS scatter?

One of possible explanation is ...

The ISM was not well-mixed!

And the r-process site is in specific SN II

Inhomogeneous Chemical Evolution



Supernova Remnant

The expansion radius is detemined by ISM density+metallicity, and **explosion energy** (Cioffi et al. 1988)

ISM

Standard One-zone chemical evolution is assumed

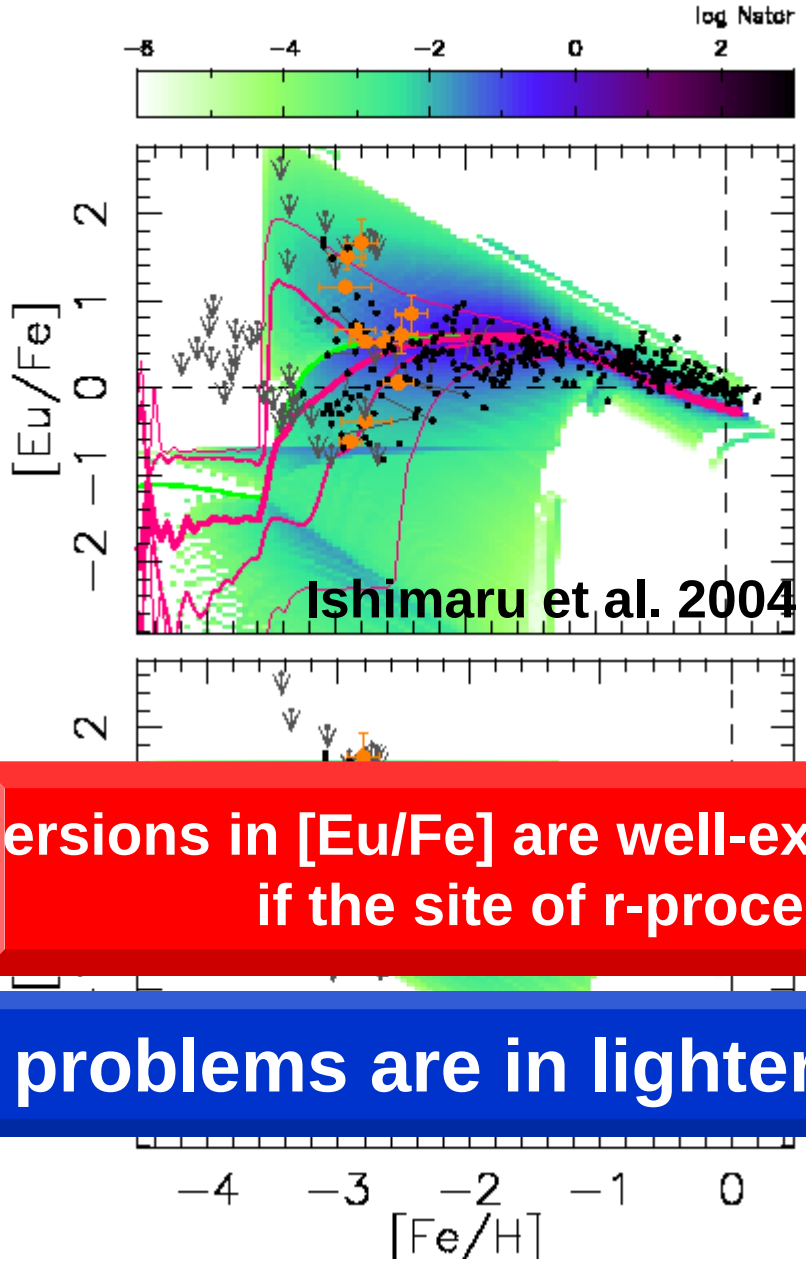
New Stars formed from mixed gas of ISM+SNR

Supernova Nucleosynthesis

SNe II: **Woosley & Weaver '95 (0~$Z_\odot$ stars),**
Chieffi & Limongi '04 (0~$Z_\odot$ stars),
Nomoto, Umeda, Tominaga '06 (0~$Z_\odot$ stars: SNe+HNe)

r-process: Yield is assumed to be constant among given stellar ma
for r-process site, and the absolute value is determined to SS v

Inhomogeneous Enrichment & Origin of Eu



If the site of r-process is in...

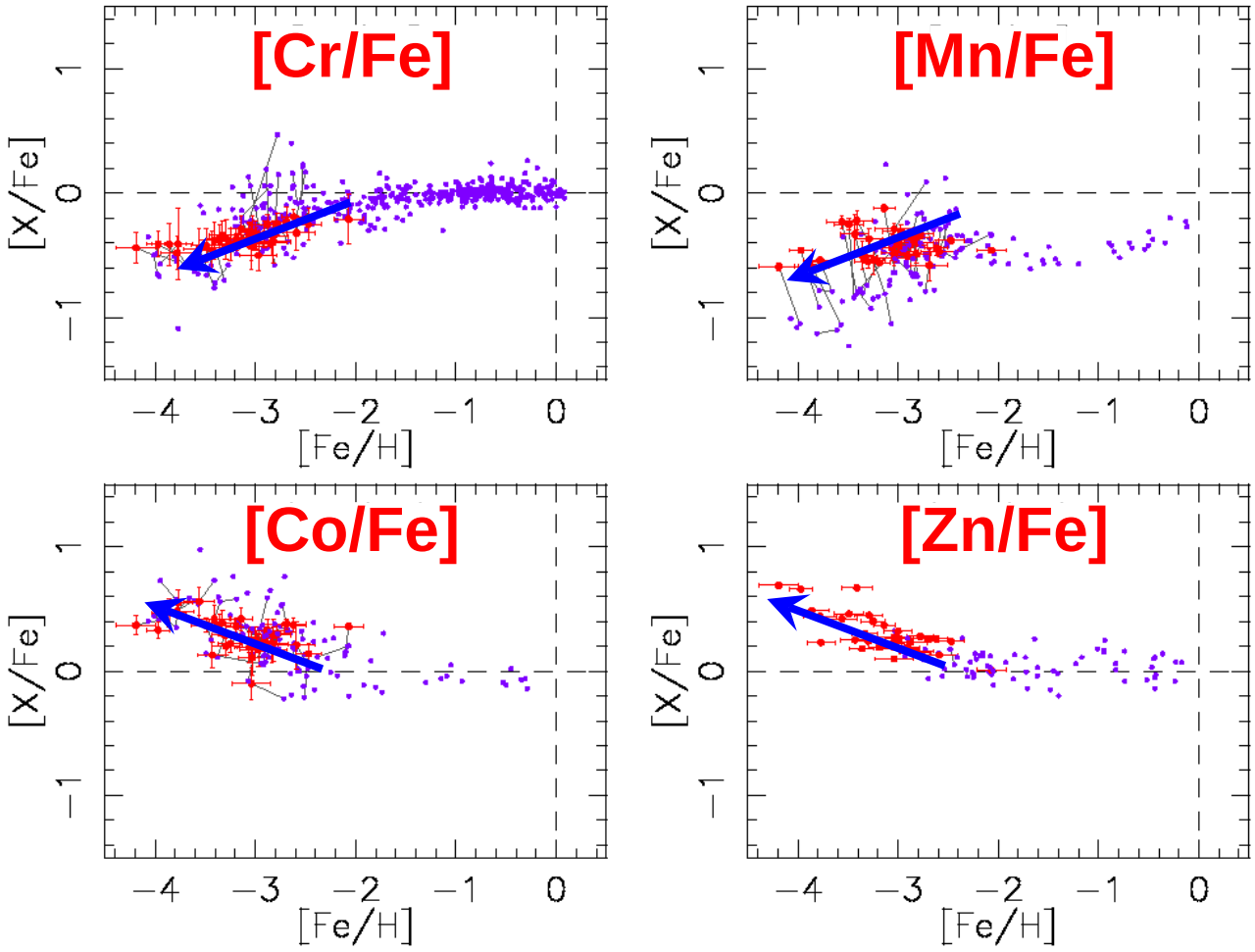
SN II of lower mass stars

(8-10$M_{\odot}$):

persions in [Eu/Fe] are well-explained by inhomogeneity of I
if the site of r-process in low mass SN II.

, problems are in lighter elements such as Fe-pe

Fe-peak Elements — Cr, Mn, Co, Zn



observations suggests clear trends with small dispersion

-peaks seem to suggest HOMOGENEOUS IS

Homogeneous ? or Inhomogeneous?

Why are dispersions in [r/Fe] huge,
while those for lighter elements are small?

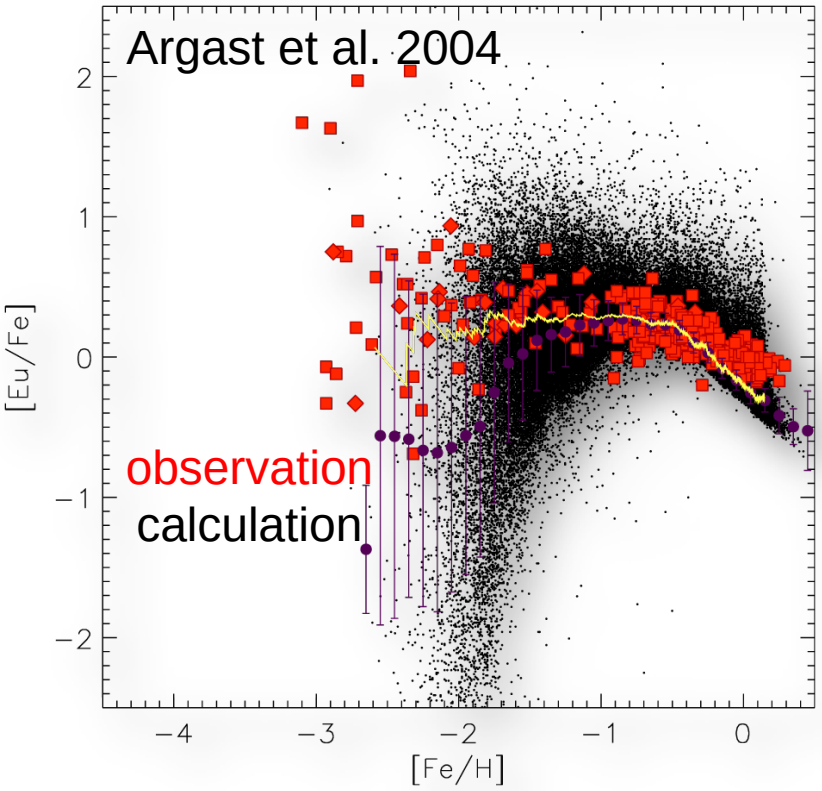
One possibility is

Hierarchical galaxy formation

+ Neutron star mergers

Neutron star mergers?

NSMs are one of the currently favored sites of r-process



➲ Previous chemical evolution studies seemed to contradict NSM:

Long lifietime (~ 100 Myr) and

low frequency (10^{-5} yr^{-1}) would lead to

the delayed appearance of r-elements and too larger scatter in the Galaxy

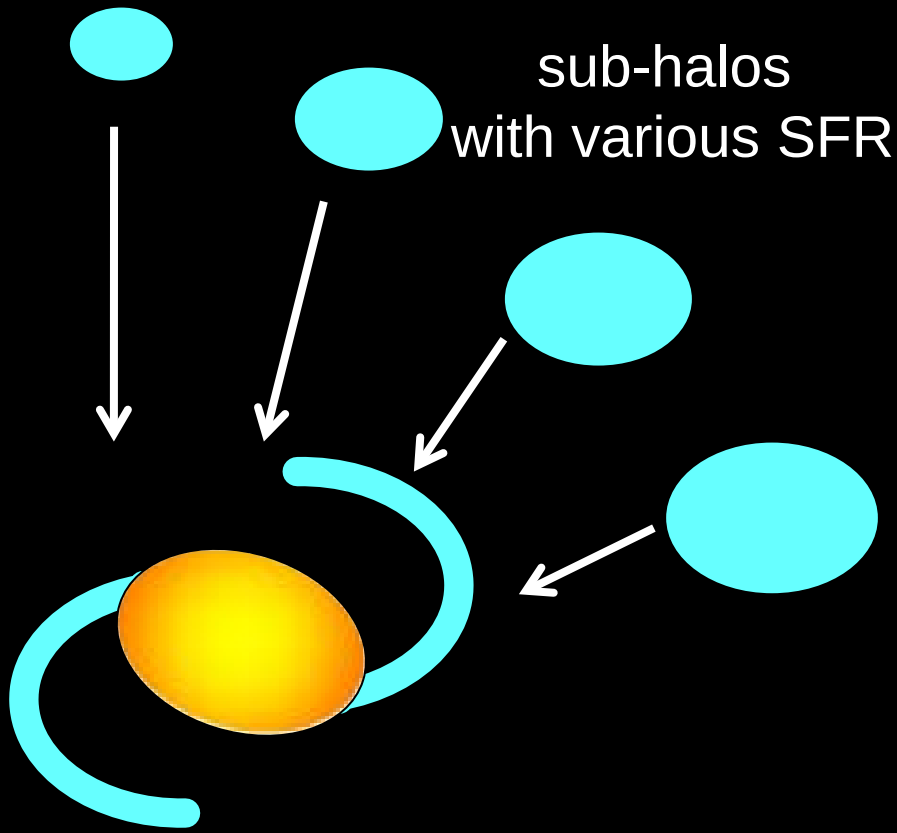
(Argast et al. 2004)

➲ BUT a hierarchical clustering model of sub-halos

do not exclude this possibility!!

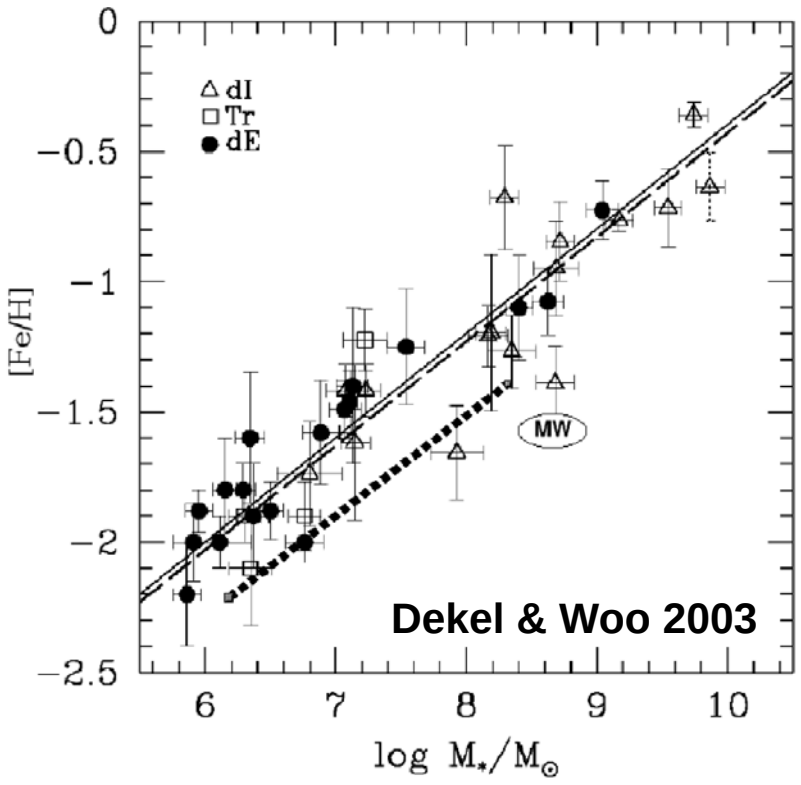
Galaxy formation via clusterings of sub-halos

According to the CDM model, our Galaxy may be formed from clusterings of sub-halos such as dwarf spheroidals (dSphs) in the local group.



Under this assumption, the halo is a collective of stars from various dSphs with different star formation histories!

Star formation history of sub-halos?



★ Observations of dwarf galaxies show:

Median stellar metallicity $[Fe/H]_0$

$\propto$ (total stellar mass M_*) $^{0.4}$

(Dekel & Woo 2003)

$\Rightarrow$ Massive dwarf galaxies have higher effective yield (y_{eff})

★ One of the most plausible formation scenarios of dwarf galaxies:

As stars are formed, the ISM is expelled because of its shallow grav. potential.

★ The Simple model of GCE suggests

y_{eff} is roughly inversely proportional to

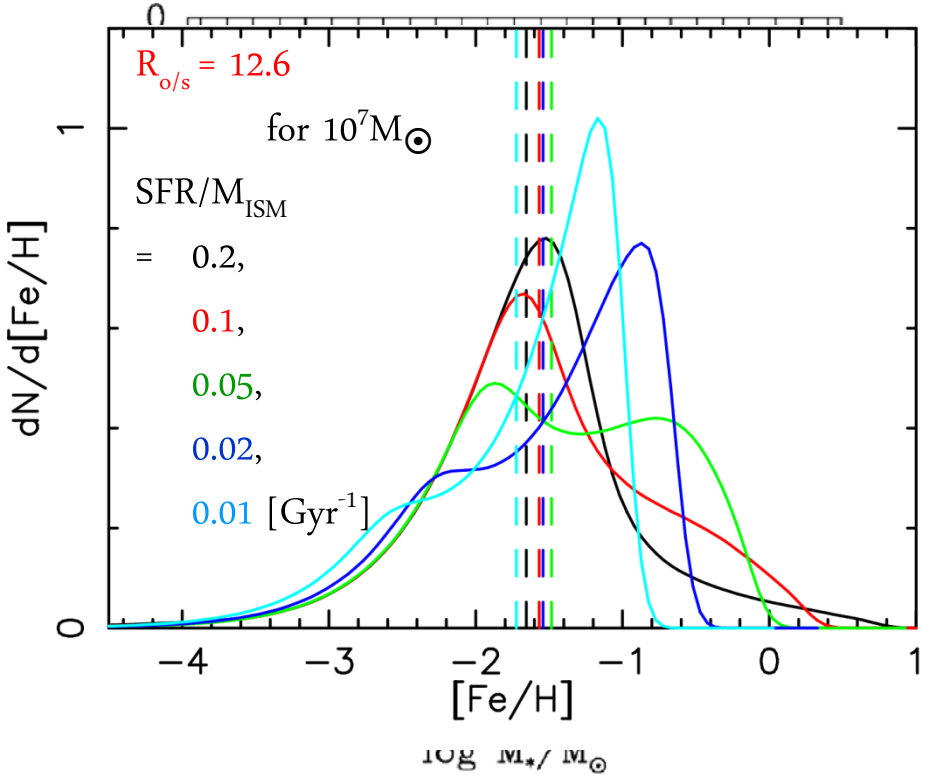
$R_{o/s} \equiv$ out flow / star formation rate

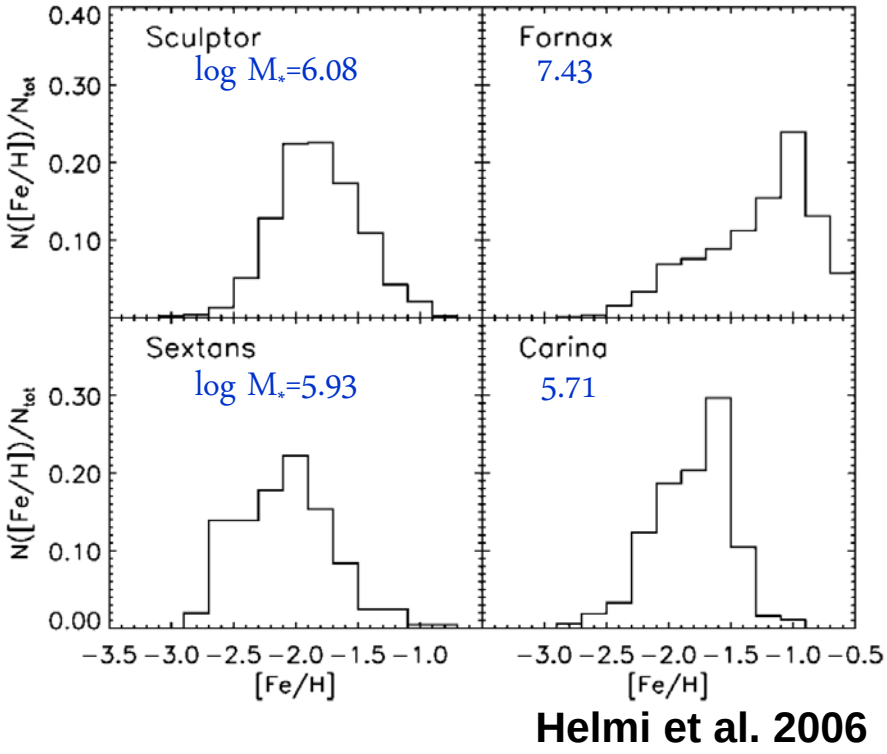
(Prantzos 2008)

Observed $[Fe/H]_0 - M_*$ relation suggests $R_{o/s} \propto (M_*)^{-0.4}$

Star formation history of sub-halos?

Observed $[Fe/H]_0 - M_*$ relation suggests $R_{o/s} \propto (M_*)^{-0.4}$





Helmi et al. 2006

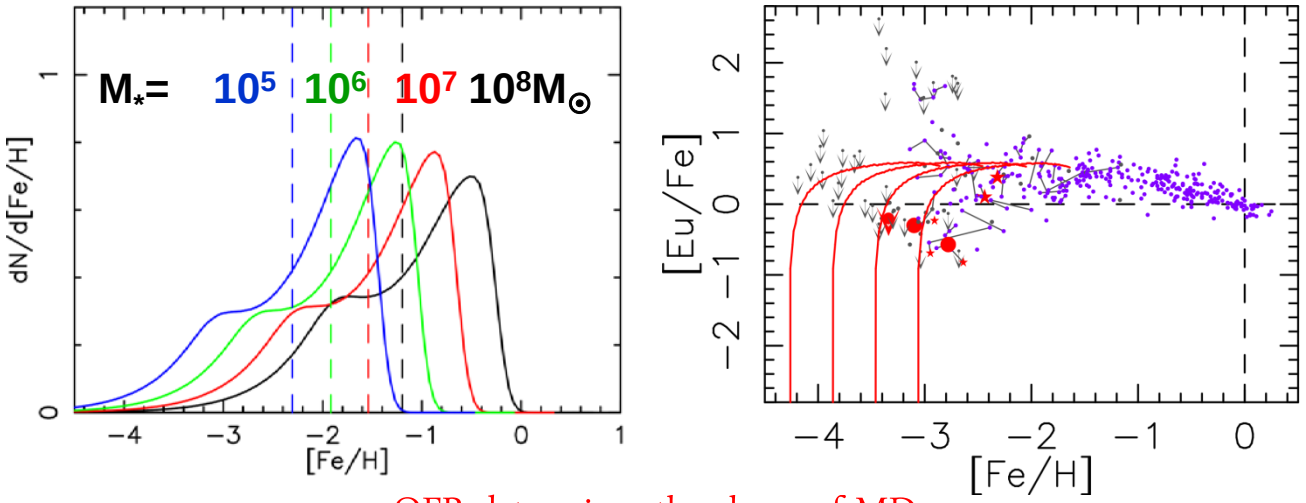
Actually, the shape MDs of dSphs are affected by both SN II and SNIa.

But the median [Fe/H] is almost constant for given $R_{o/s}$

In other words, SFR cannot be determined only by MD.

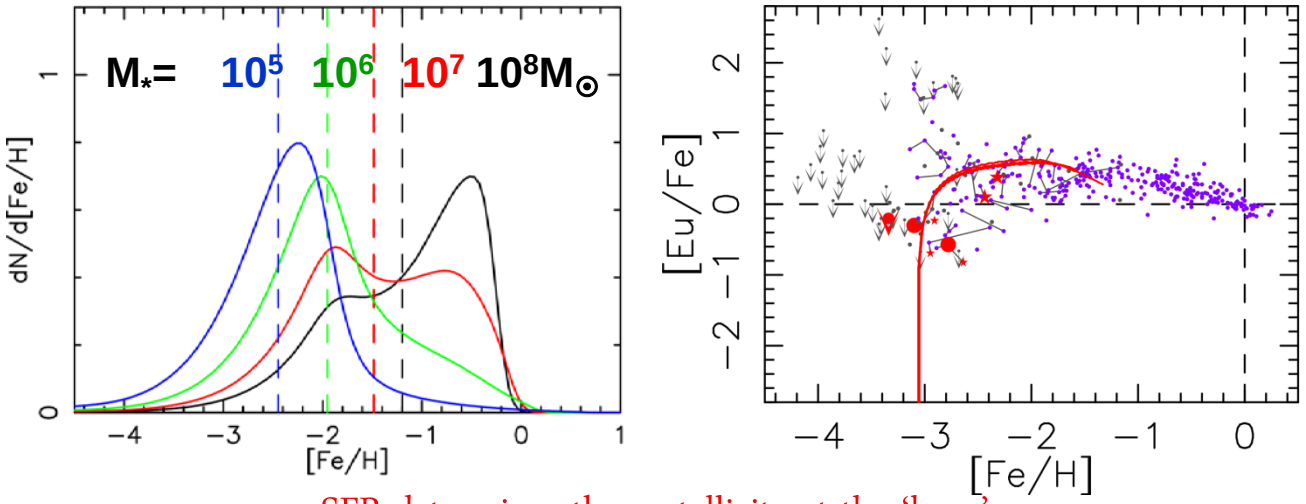
Combination of MD + [α/Fe]

i) Outflow rate: 0.1[Gyr^{-1}] (Constant) SFR: higher for massive dSphs



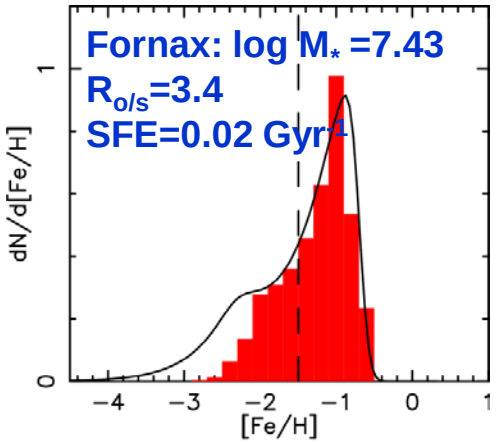
OFR determines the shape of MD

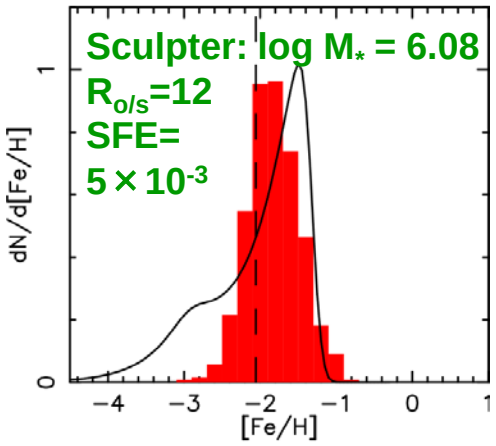
ii) Outflow rate: lower for massive dSphs SFR: 0.05 [Gyr^{-1}]Constant

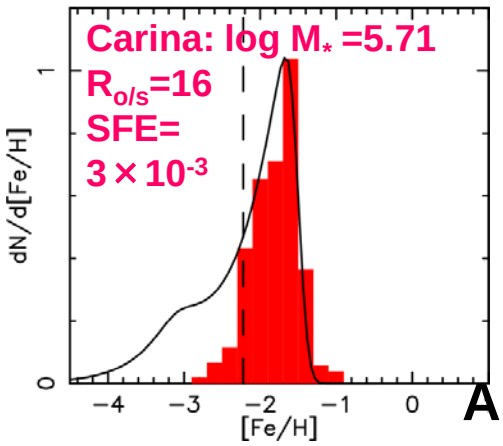


SFR determines the metallicity at the 'knee'

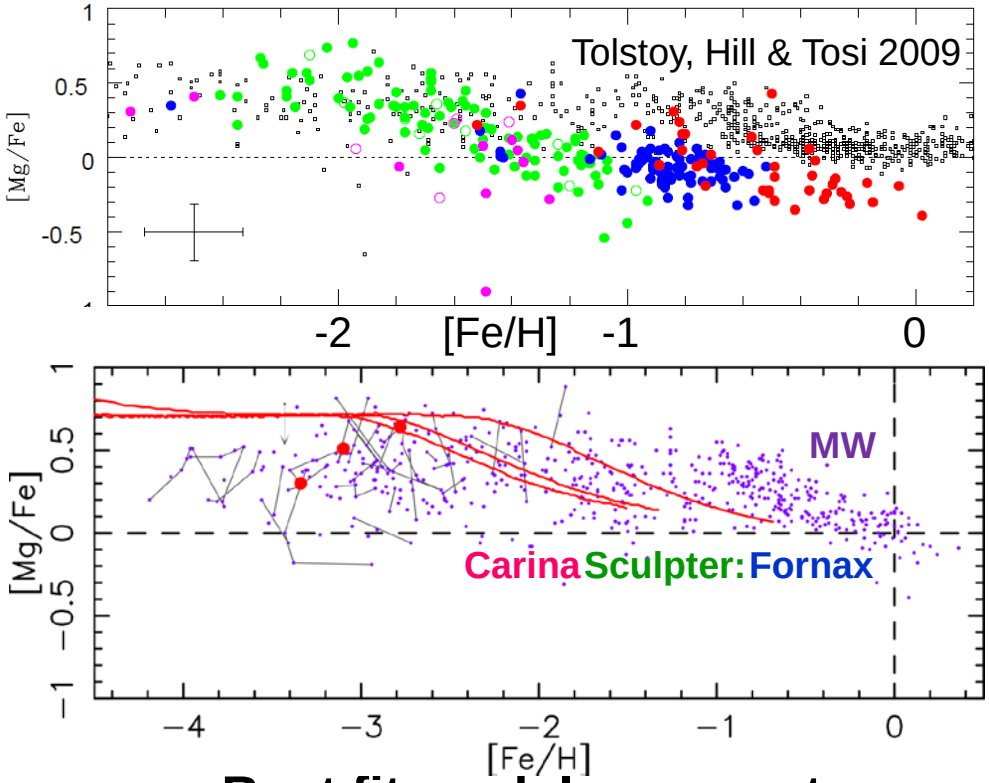
Star Formation History of dSphs from MD+[α/Fe]







Both MD and [α/Fe] data are available for 3 galaxies (Fornax, Sculpter, Carina)



Best fit models suggest:

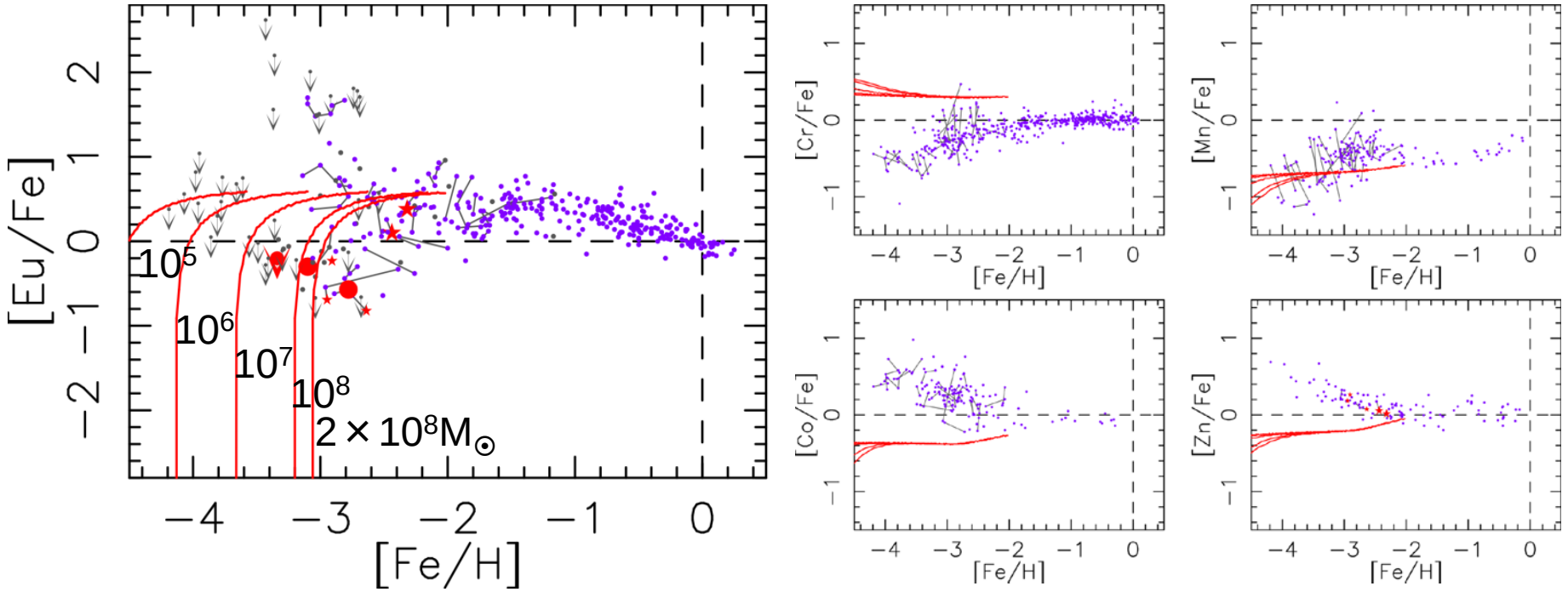
Ratio of outflow rate / SFR ∝ $(M_*)^{-0.4}$

Value of outflow rate ∝ log M_*

As a result, higher M_* dSphs have higher SFR

Clustering Model and Dispersions in [Eu/Fe]

sume 1) the Galactic halo is formed from clulsterings of dSphs of 10^5 – 2×1
with SFR & OFR determined from obs. data,
2) r-process site is in NSMs with lifetime of ~100 Myrs



If neutron star mergers are the r-process site,
Eu appears at lower metallicity in smaller sub-halos with lower SFR.
ring of sub-halos with various SFR can also explain large scatters in
even if their ISM is always well-mixed!

Conclusions

Observed scatters in [Eu/Fe] of metal-poor stars can be explained ,

if the halo is formed from monolithic collapse but **enriched inhomogeneous.**

or

if the halo is formed from **clusterings of sub-halos** with various star formation rates.

If so, the r-process site is in

Ne II of lower mass stars

Neutron star mergers