The very early days of the Sculptor dSph

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a DART work

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E. Tolstoy	University of Groningen, NL
K. Venn	University of Victoria, CA

too small to pretend

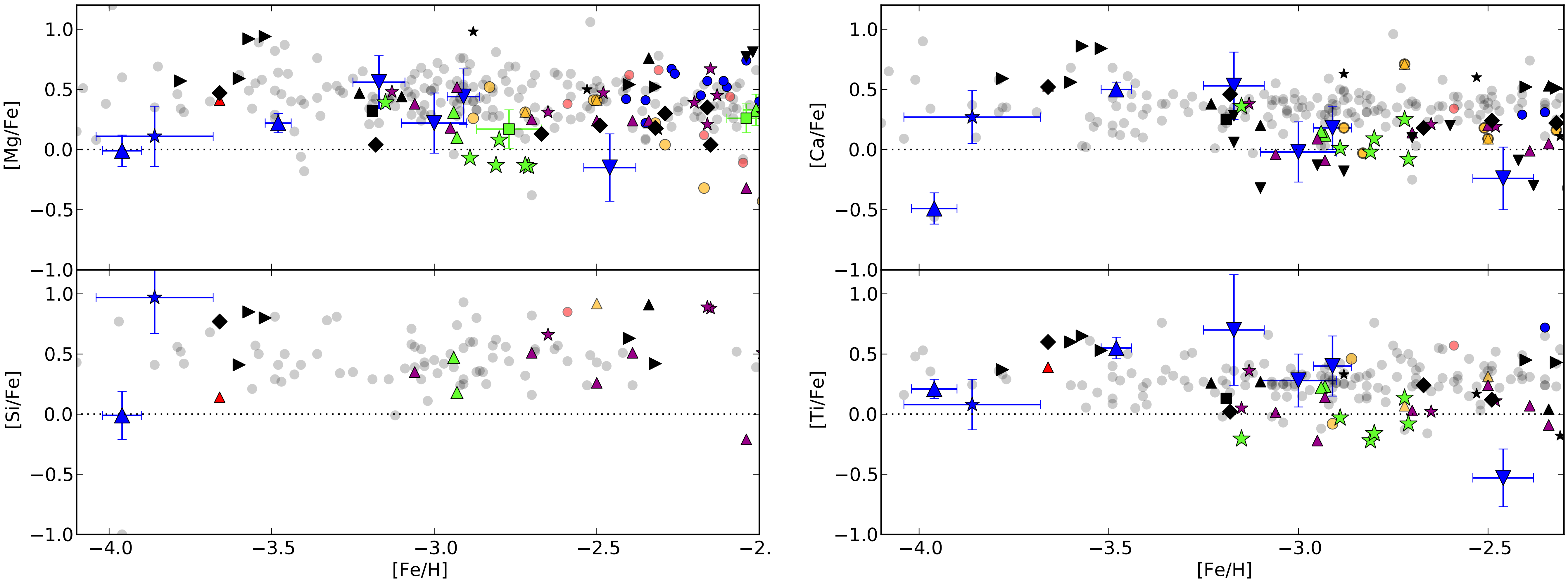
[Contrary to MW-like galaxies,
for which the large total mass galaxy softens the impact of uncertainties in the parameters driving the galaxy star formation history,
dwarf systems are very reactive]

How early ?

The EMP stars may **preserve** the abundance patterns synthesized by a **single or a few** supernovae (SNe), hence they can be used to **test** the supernova **explosion** and nucleosynthesis theories and to infer the **condition** of the first steps of **galaxy formation**.

How early ?

VERY metal-poor stars



Sculptor, Tolstoy, Hill, Tosi, 2009; Tafelmeyer 2010; Frebel et al., 2010; Starkenburg et al. 2013;

Sextans, Shetrone et al. 2001; Aoki et al. 2009; Tafelmeyer 2010

Fornax, Tafelmeyer et al 2010 Letarte et al. 2010

Carina, Shetrone et al. 2013; Koch et al. 2008; Venn et al. 2014; Lemasle et al. 2012

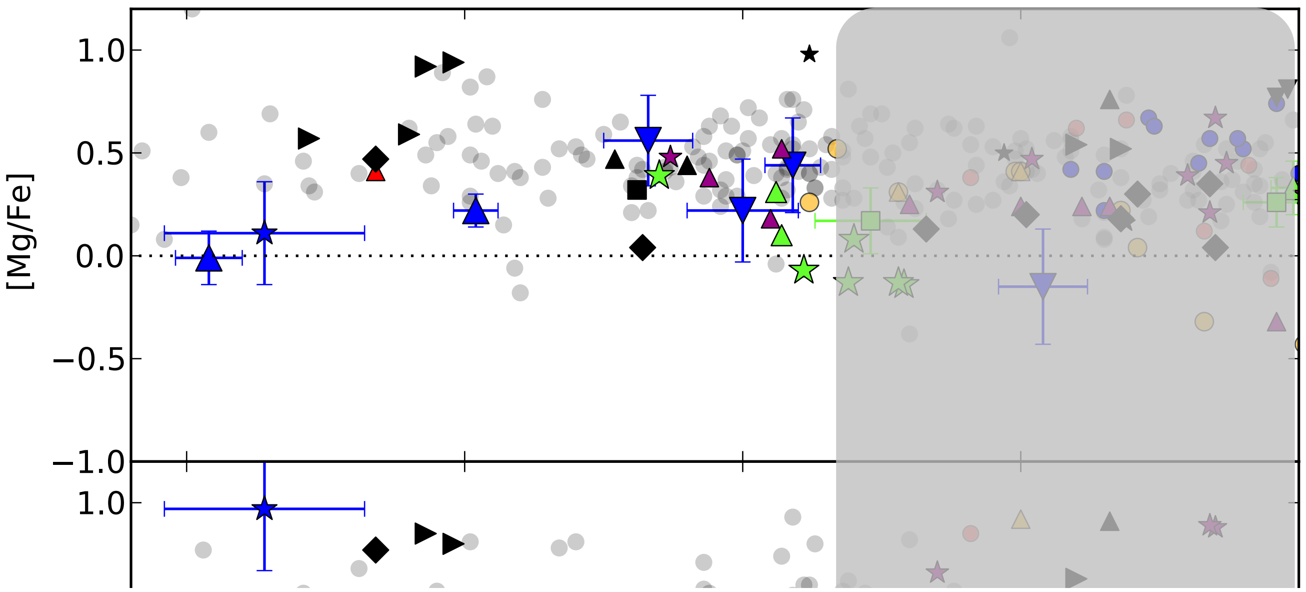
Leo IV Hercules UMa II Segue I Comber I Boötes — Koch et al 2008; Aden et al. 2011 Norris et al. 2010; Simon et al. 2010 Frebel et al. 2014

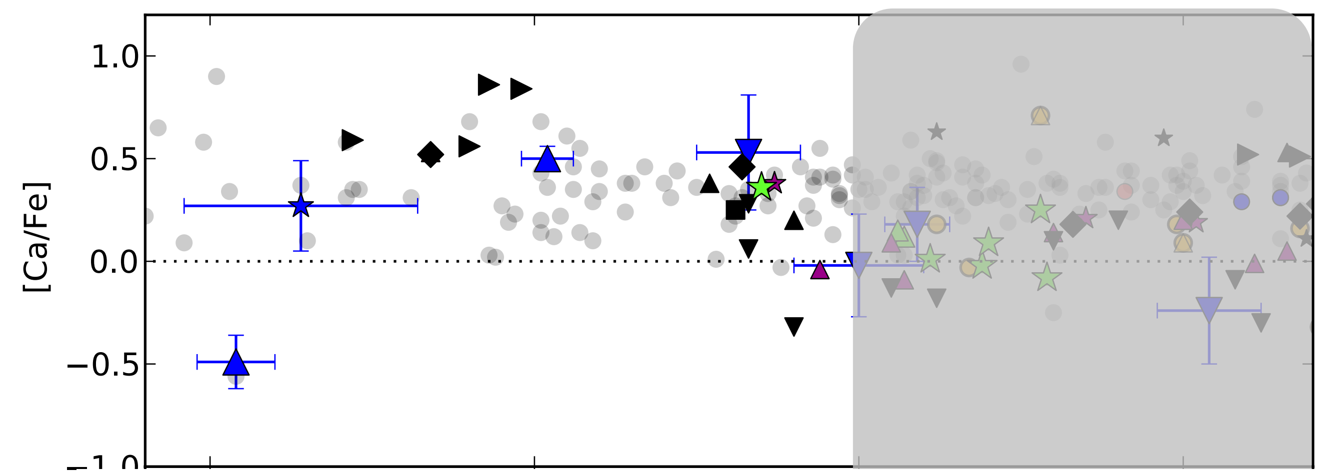
Draco & UMi Shetrone et al. 2001; Fulbright et al. 2004; Cohen & Huang 2009;2010; Sadakane et al. 2004;

MW Honda et al. 2004; Cayrel et al. 2004; Spite et al. 2005; Aoki et al. 2005; Cohen et al. 2013, 2006, 2004; Spite et al. 2006; Aoki et al. 2007; Lai et al. 2008; Yong et al. 2013; Ishigaki et al. 2013

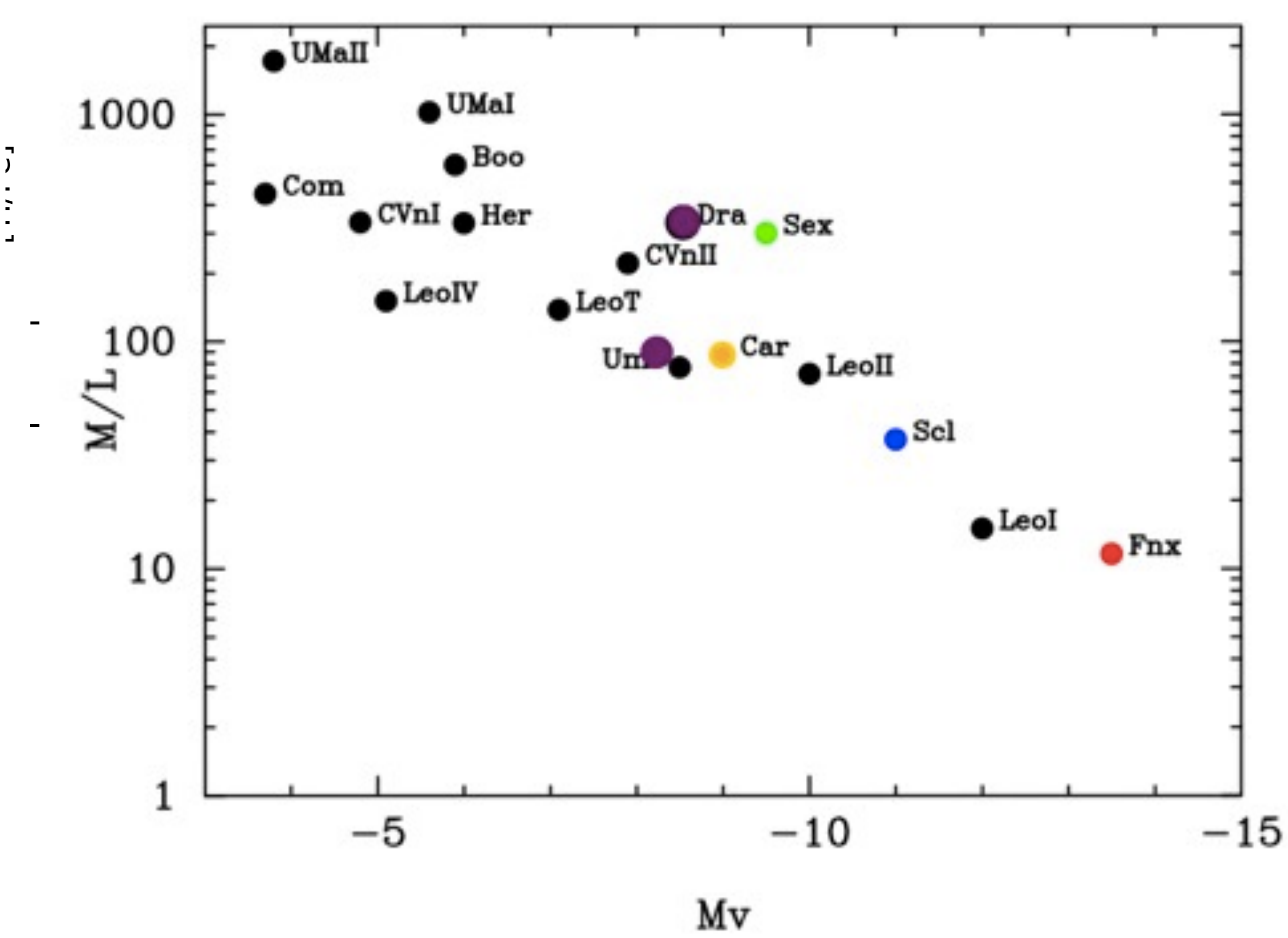
How early ?

EXTREMELY metal-poor stars





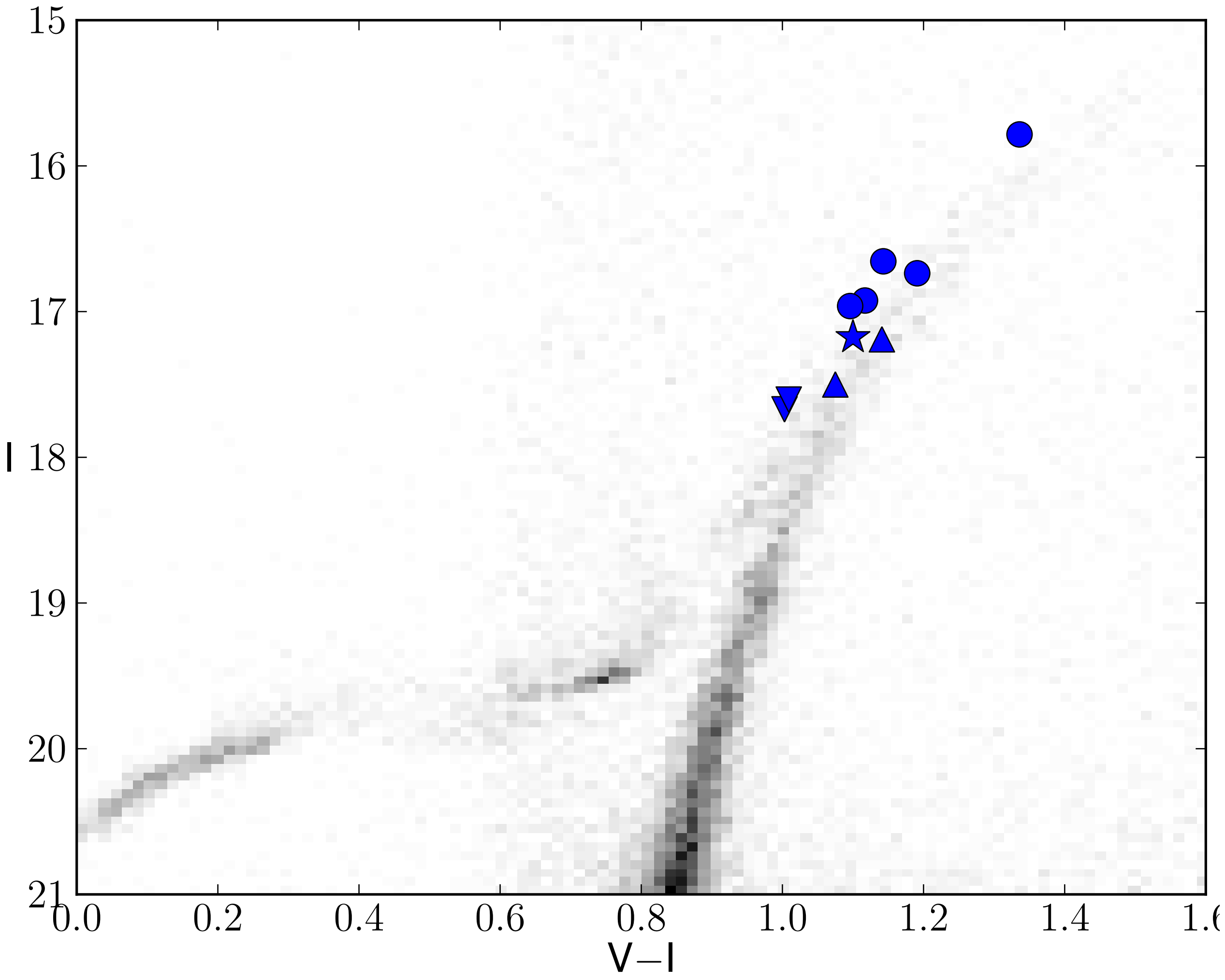
- At most 5 stars per galaxy, for nearly a factor 100 in M/L and 5 order of magnitude in L
- Mostly restricted to extremely short SFH systems

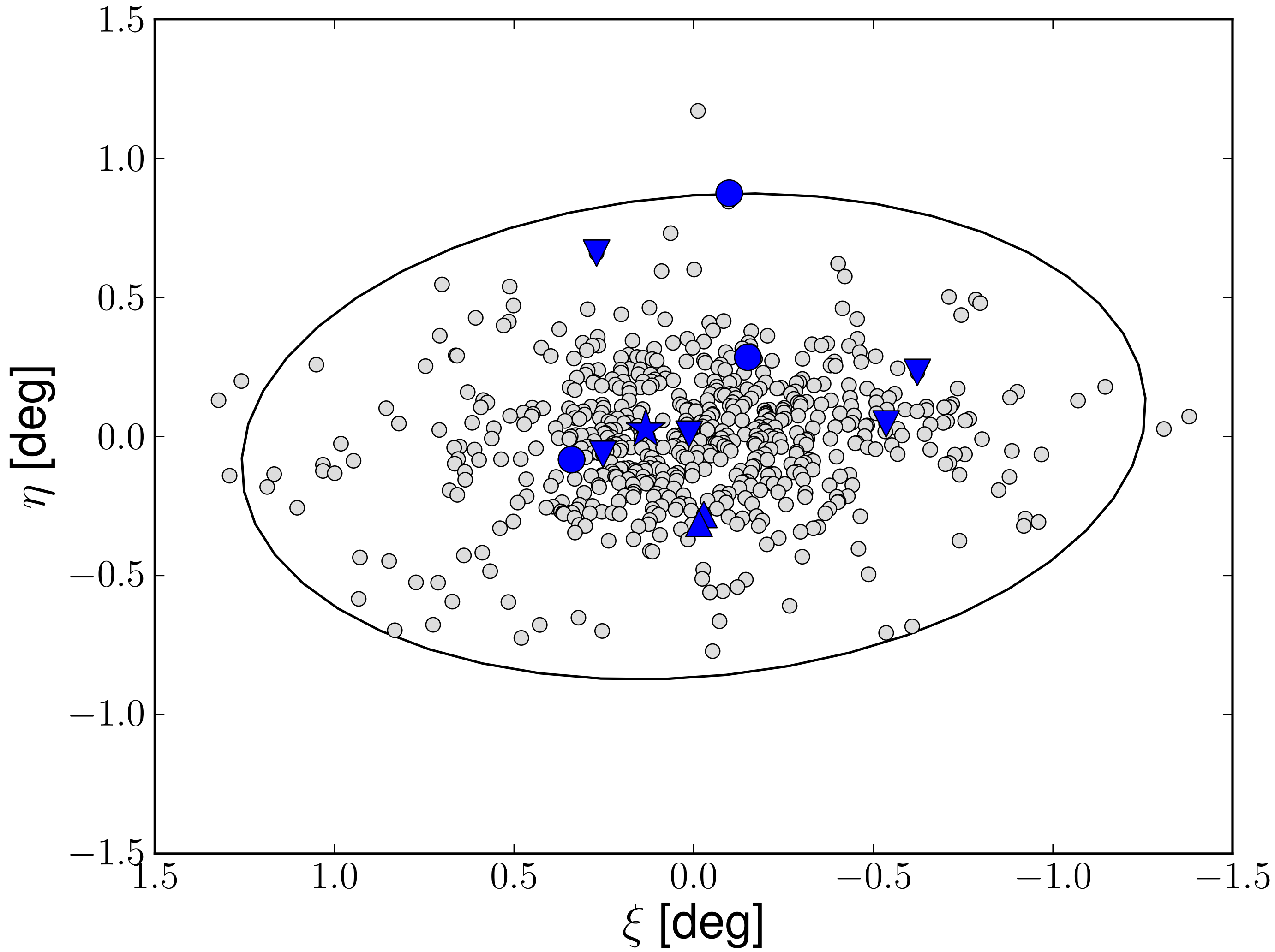


DART

Programmes running @ ESO
XSHOOTER & UVES
on «classical» dwarf EMPS

Sculptor





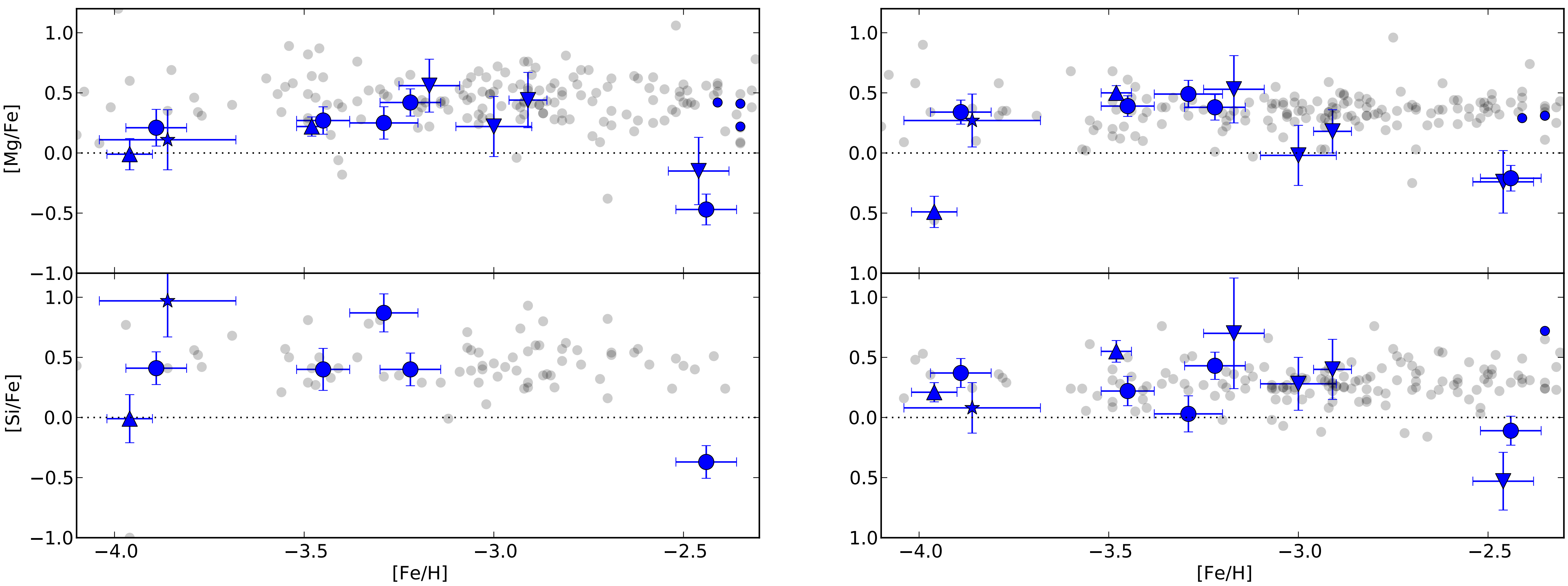
- ★ Frebel et al, 2010
- ▲ Tafelmeyer et al, 2010
- ▼ Starkenburg et al, 2013
- ● This study, Jablonka et al. 2014

Programme

FROM Low resolution	TO High resolution
CaT Battaglia et al. 2008 calibrated with Starkenburg et al. 2010 at $-4 < [Fe/H] < -2.5$	UVES @ ESO R=45000 3500 - 7000Å

- MARCS 1-D spherical atmosphere models (Gustafsson et al. 2008)
- Turbospectrum code (Alvarez & Plez 1998; Plez 2012),
- LTE ; continuum scattering in the source function
- Plane parallel transfer for the line computation

α-elements



★ Frebel et al, 2010

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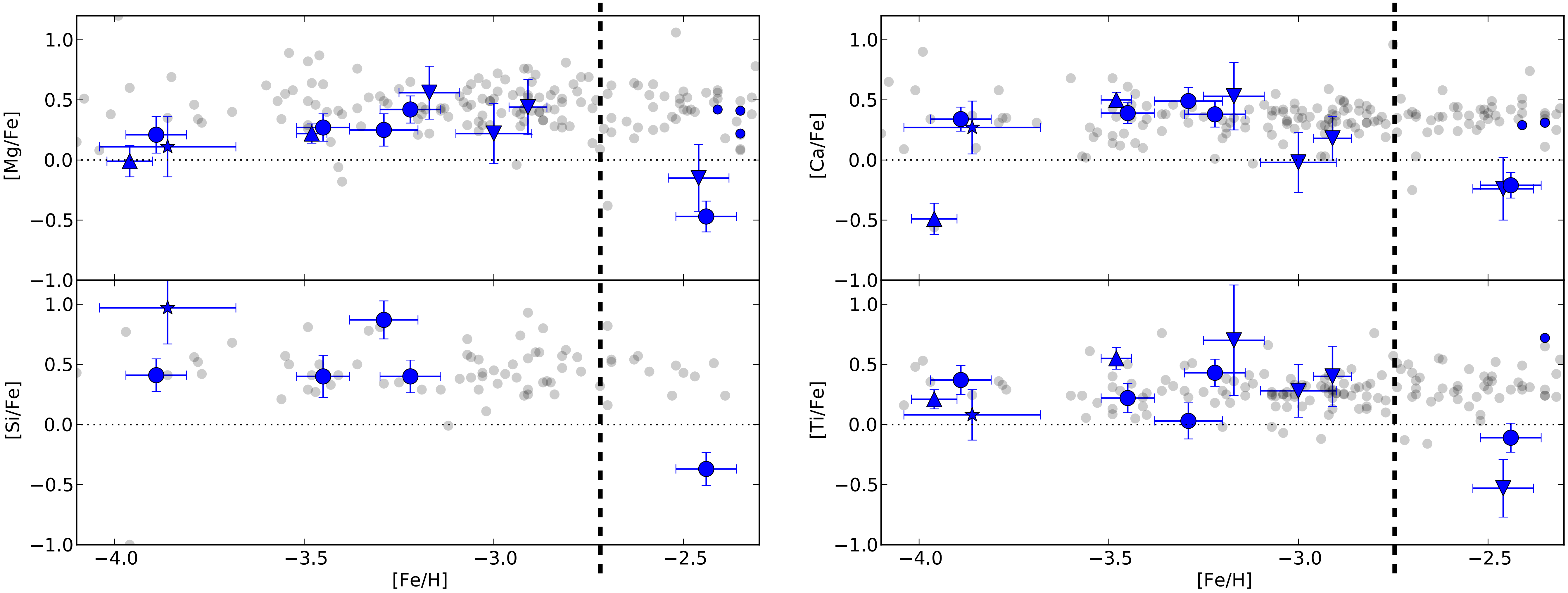
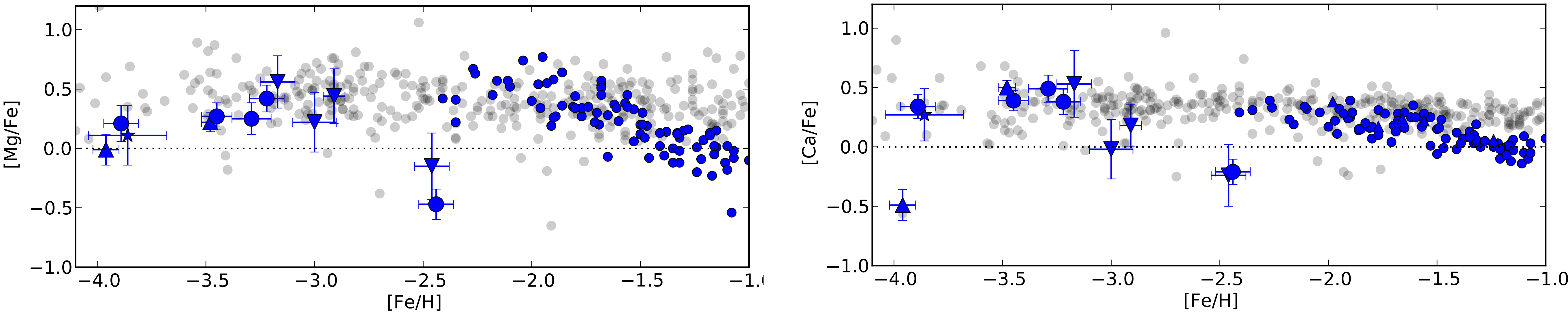
α-elements



- The existence of a plateau at low metallicity is fully confirmed
  ⇒ a sufficiently well sampled (classical) IMF

α-elements



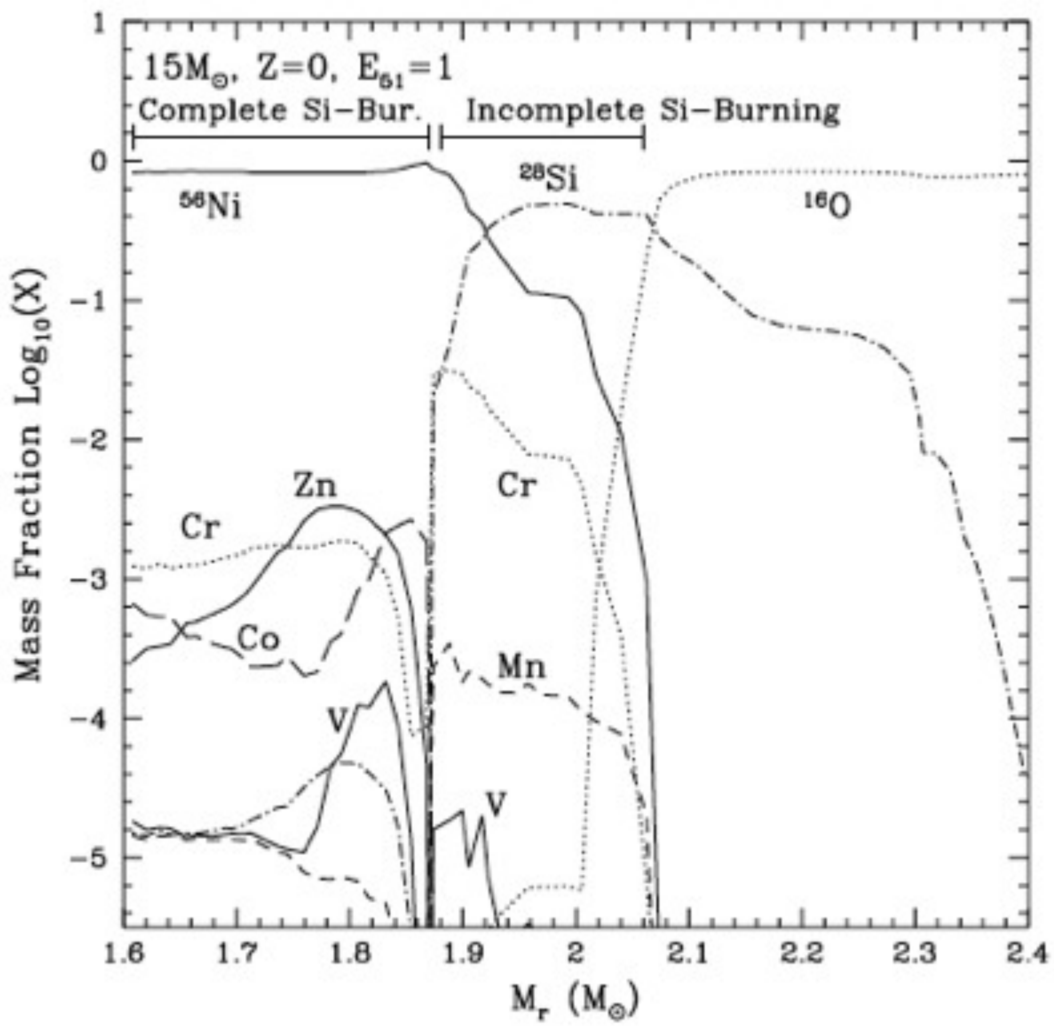
adding metal-rich pop ● Tolstoy, Hill, &Tosi et al. 2009

- A few outliers in an otherwise very homogeneous galaxy

Iron-Peak elements

Co, Zn complete explosive Si-burning

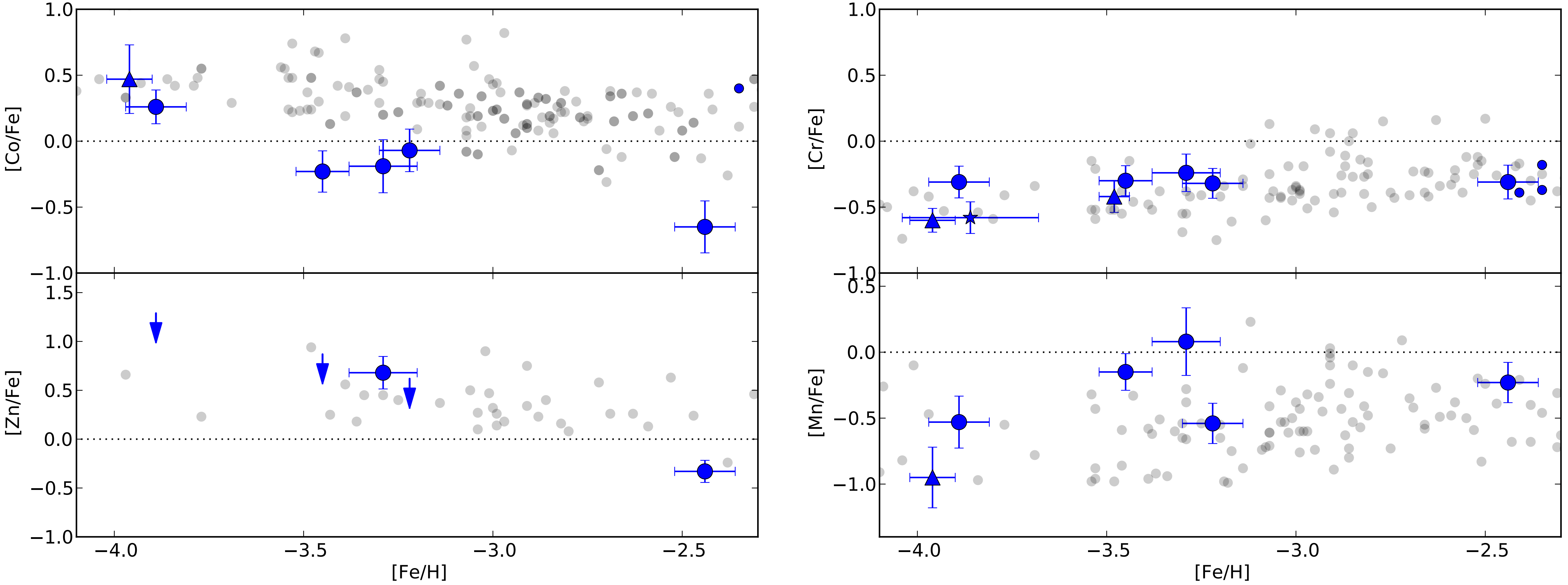
Cr, Mn incomplete explosive Si-burning



Nakamura et al. 1999;
Umeda & Nomoto 2002, 2005

- Nucleoythesis dependence on progenitor stellar mass (mass cut, explosion energy, fallback/mixing)
- The mass cut that divides the ejecta and the compact remnant is typically located somewhere close to the border of complete and incomplete Si-burning regions.
- Larger explosion energy forms a larger region of complete silicon burning
- For a deeper mass cut (i.e., smaller Mcut), [Co/Fe] is larger and [Mn/Fe] is smaller

Iron-Peak elements



•pockets of inhomogeneities, early in the evolution of Sculptor - IMF sampling

Neutron capture elements

rapid* neutron- capture process

makes

half of all elements heavier than iron

*~1s in a high-temperature environment by a very high flux of neutrons [> 10^{20} neutrons per cubic centimetre, at temperatures greater than 10^9 K] (Woosley & Janka 2005)

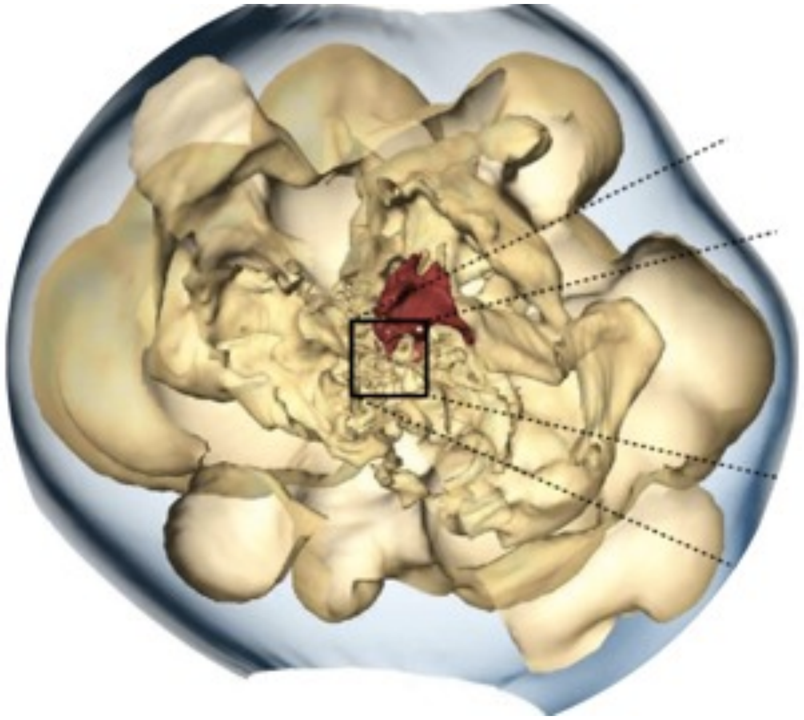
however

remains a long-standing mystery of nucleosynthesis

Neutron capture elements

rapid neutron- capture process makes half of all elements heavier than iron

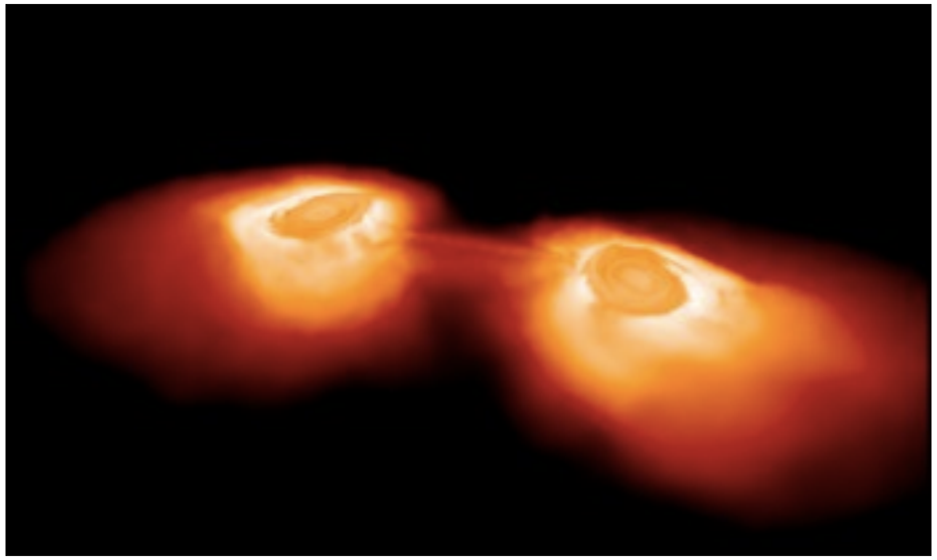
core-collapse supernovae (CCSNe; in particular proto-NS wind)



(Woosley & Janka 2005; Martinez-Pinedo et al. 2012; Roberts et al. 2012; Fischer et al. 2012; Wanajo et al. 2011; Wanajo 2013).

Including Winteler et al. 2012 (Magnetorotationally driven Supernovae)

compact binary mergers (CBMs) of double neutron star (NS–NS) and black hole–neutron star (BH–NS)



Lattimer & Schramm 1974; Symbalisty & Schramm 1982; Eichler et al. 1989; Meyer 1989; Freiburghaus et al. 1999 ; Rosswog et al. 2012; Bauswein et al. 2013; Korobkin et al. 2014

Neutron capture elements

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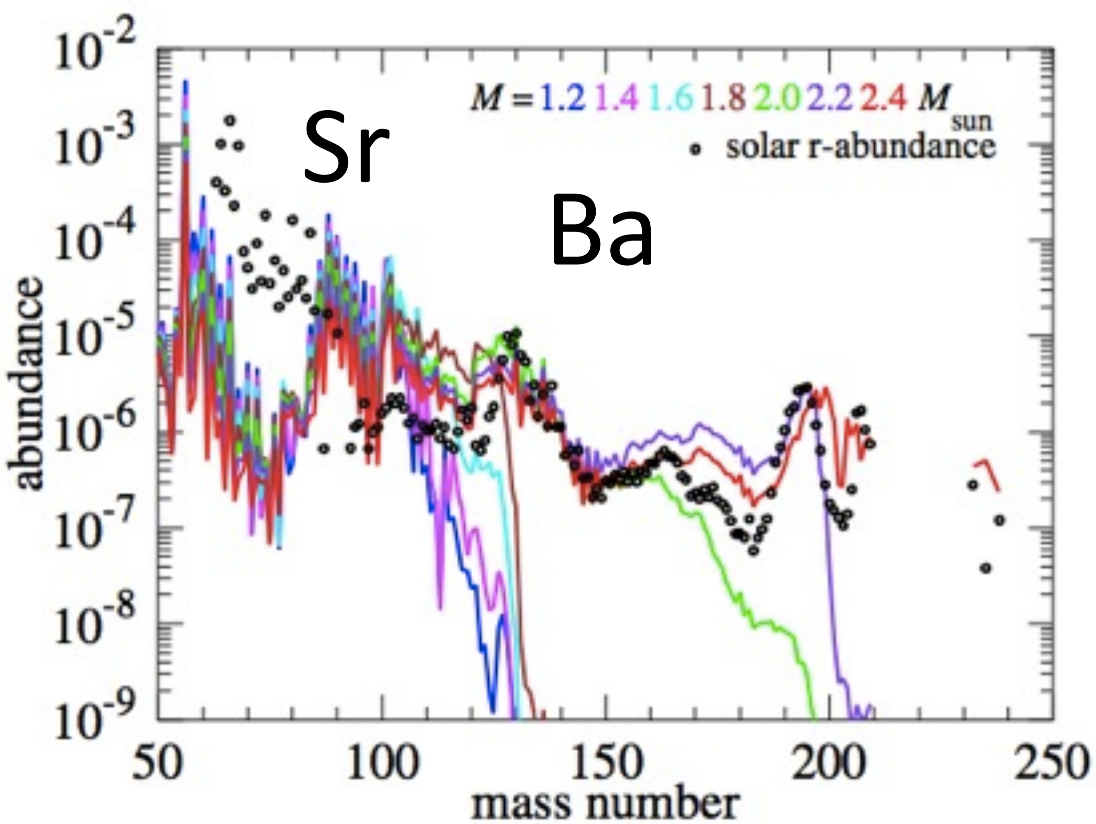

Wanajo 2013

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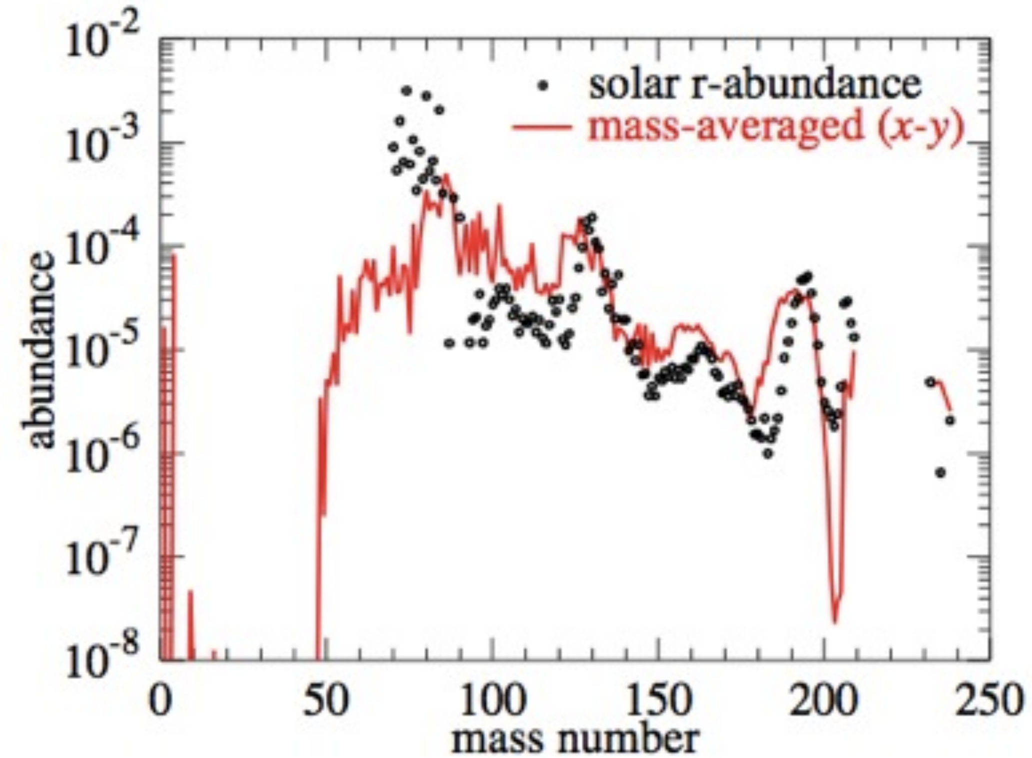
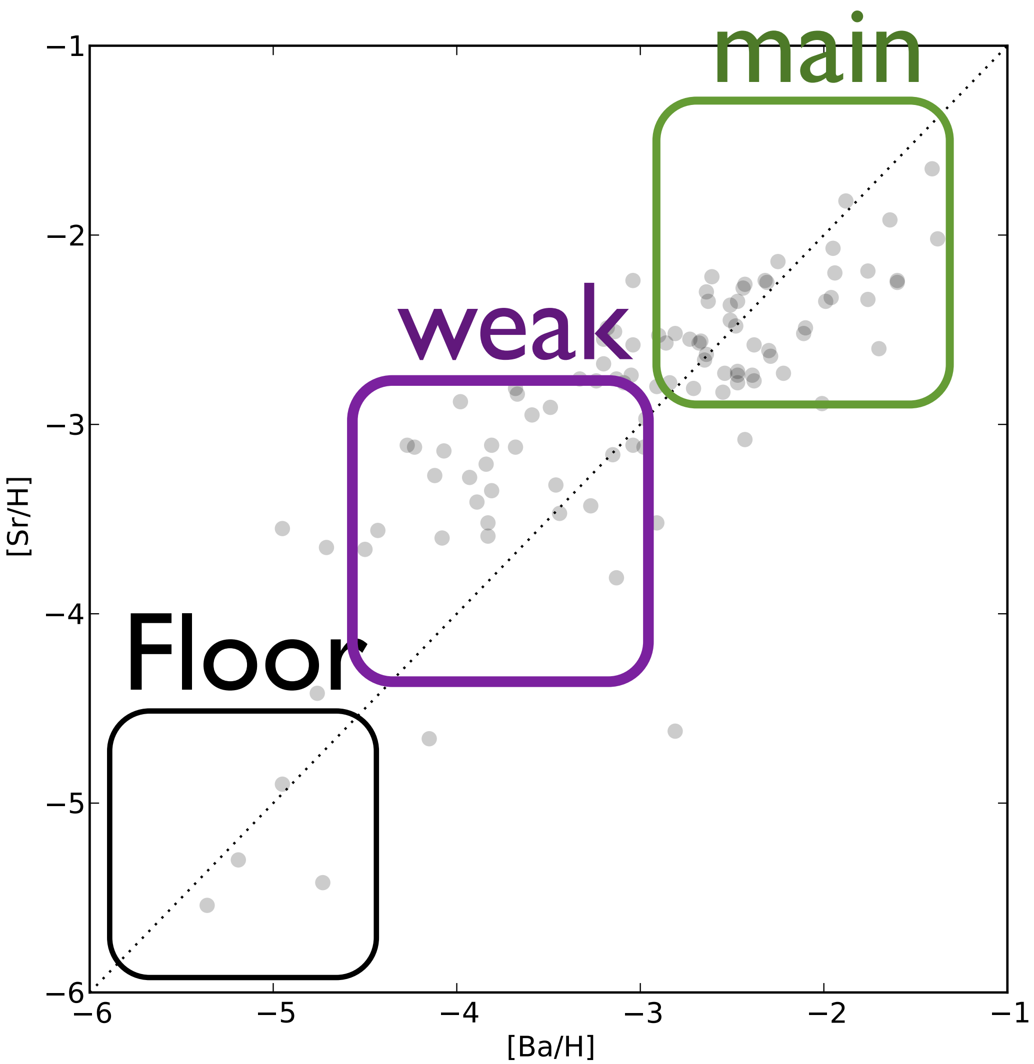
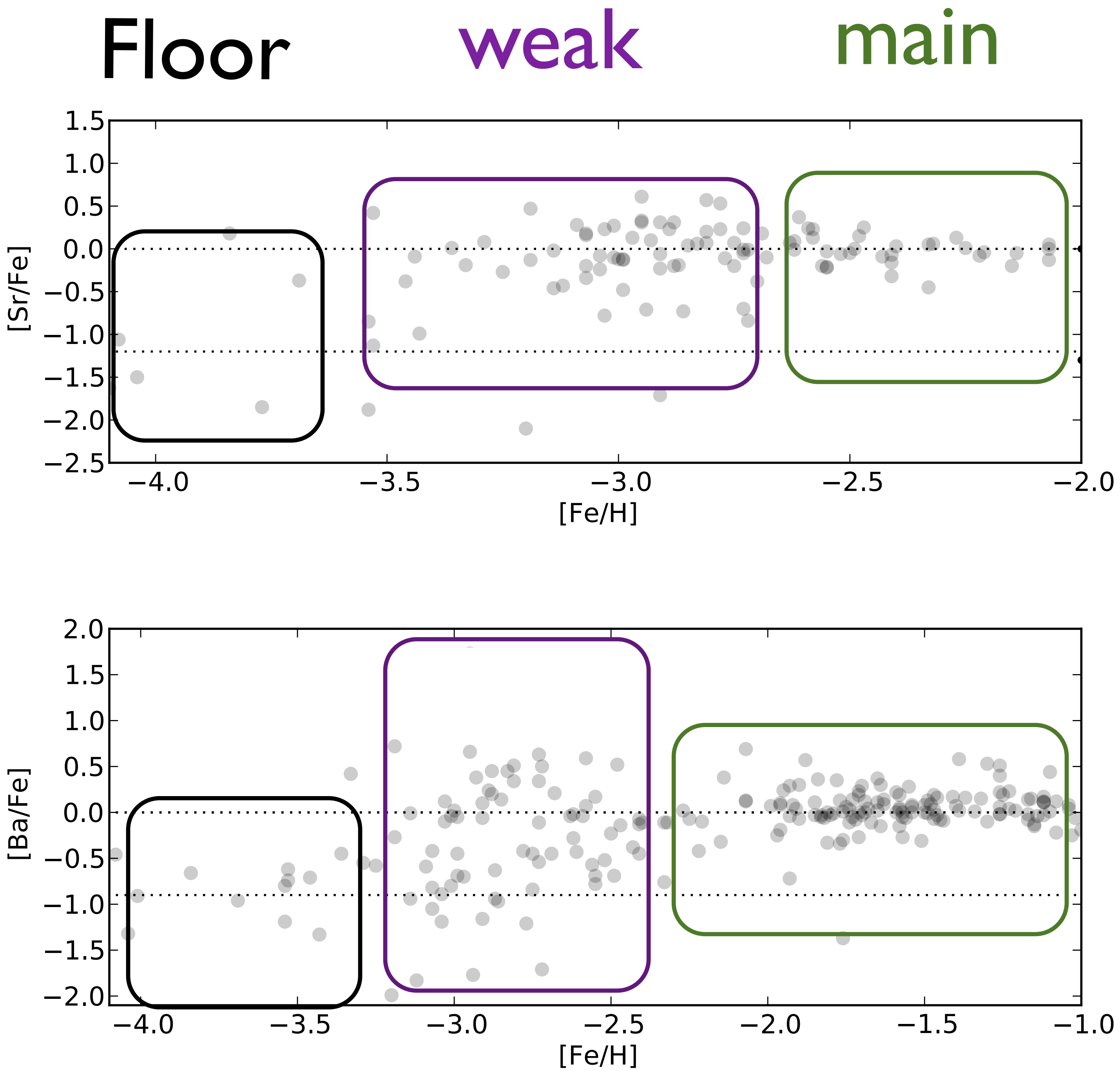


Wanajo et al. 2014

Neutron capture elements

Three different domains

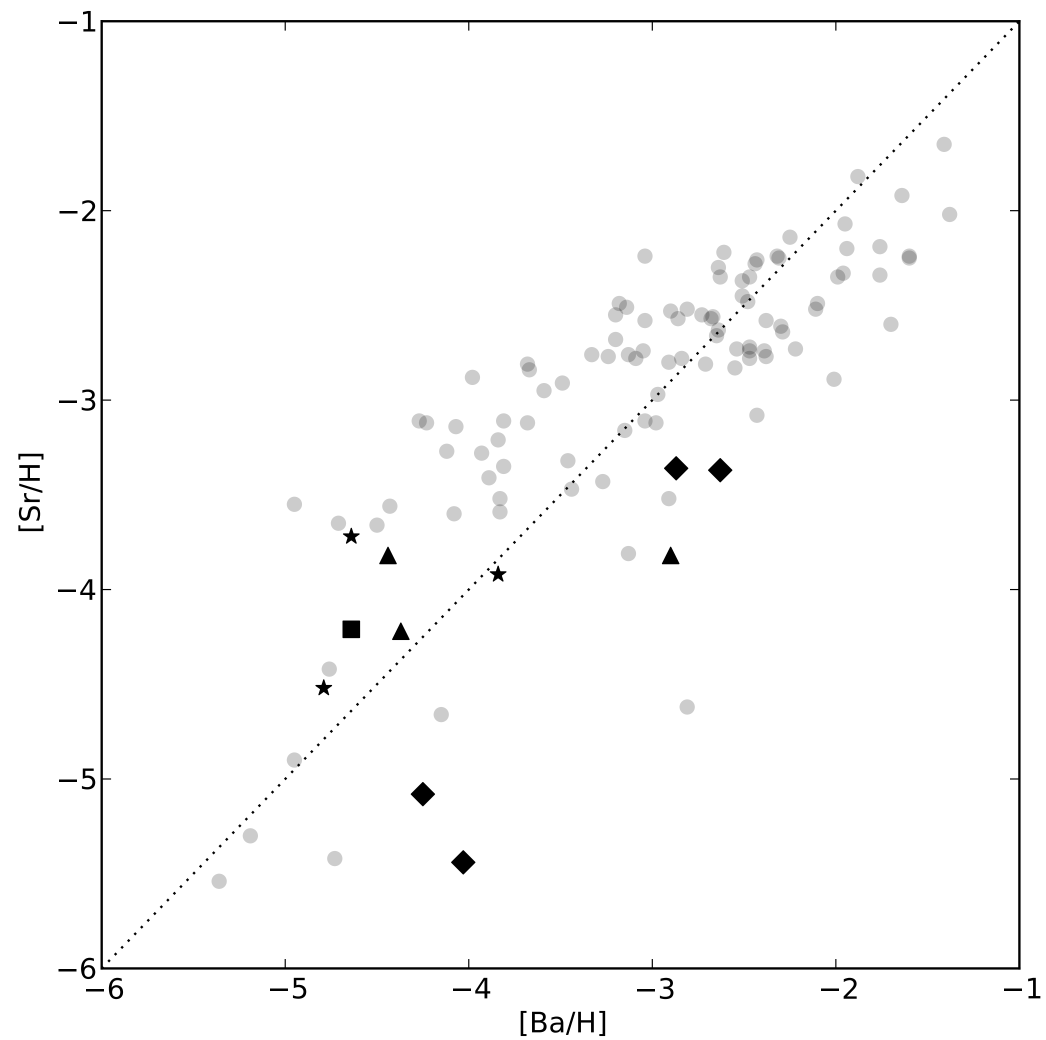


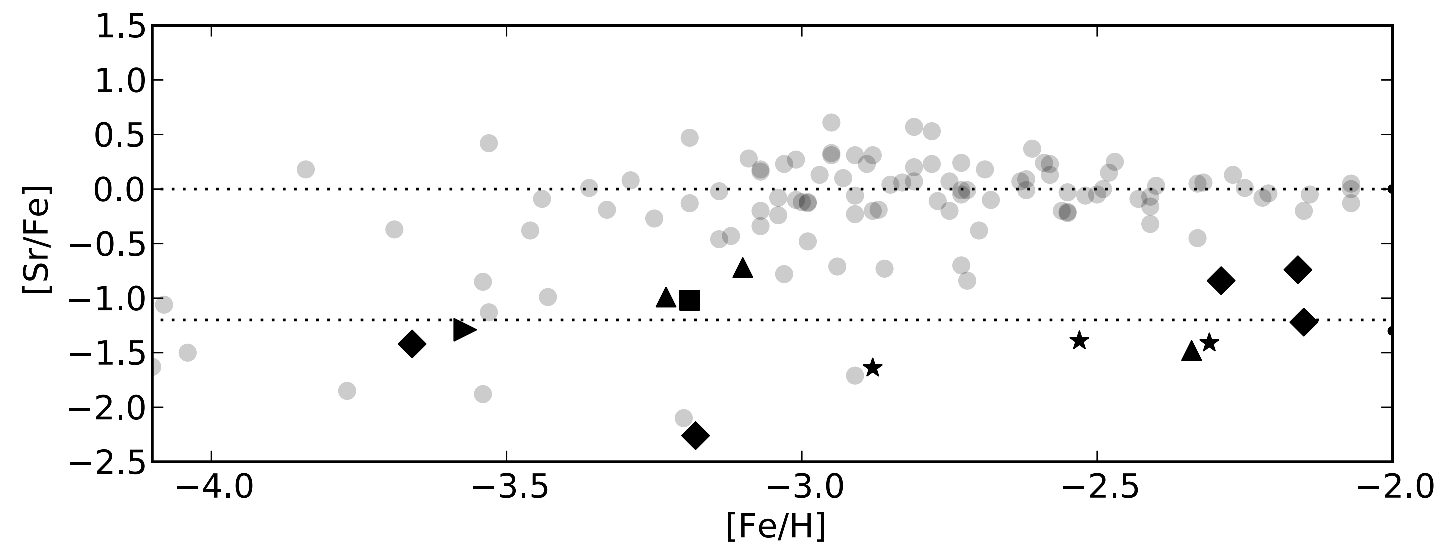


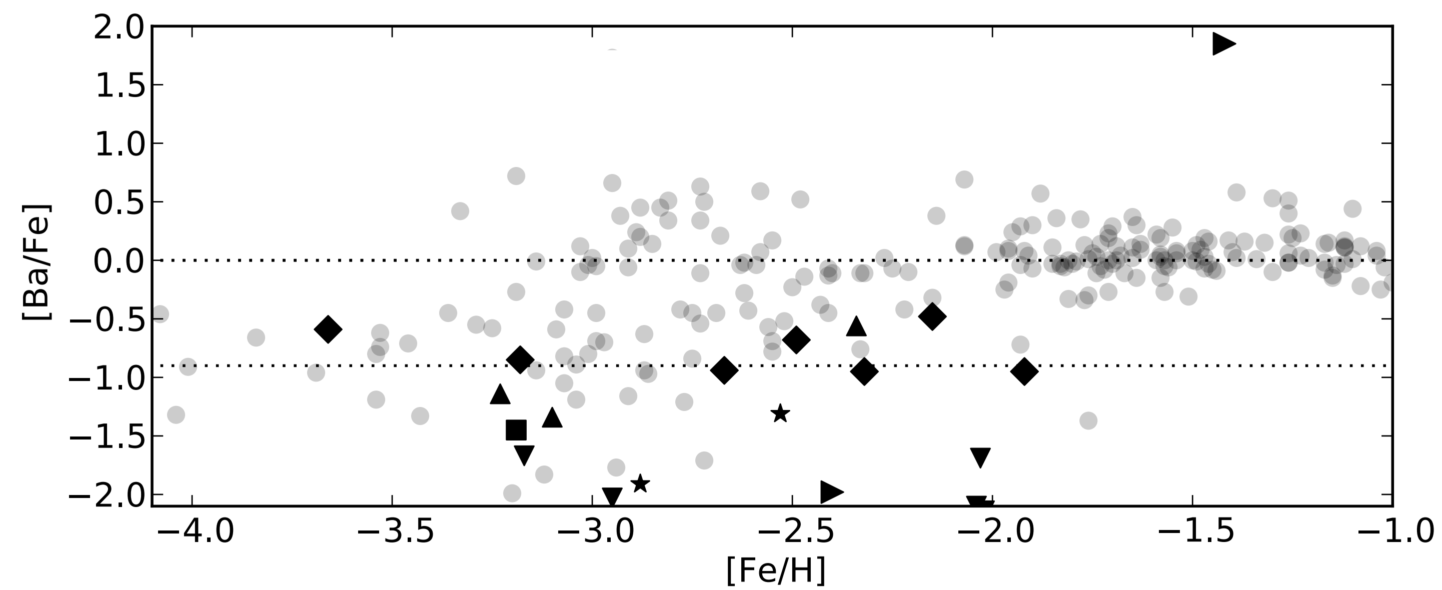
Neutron capture elements

The UFDs have low r-process enrichment

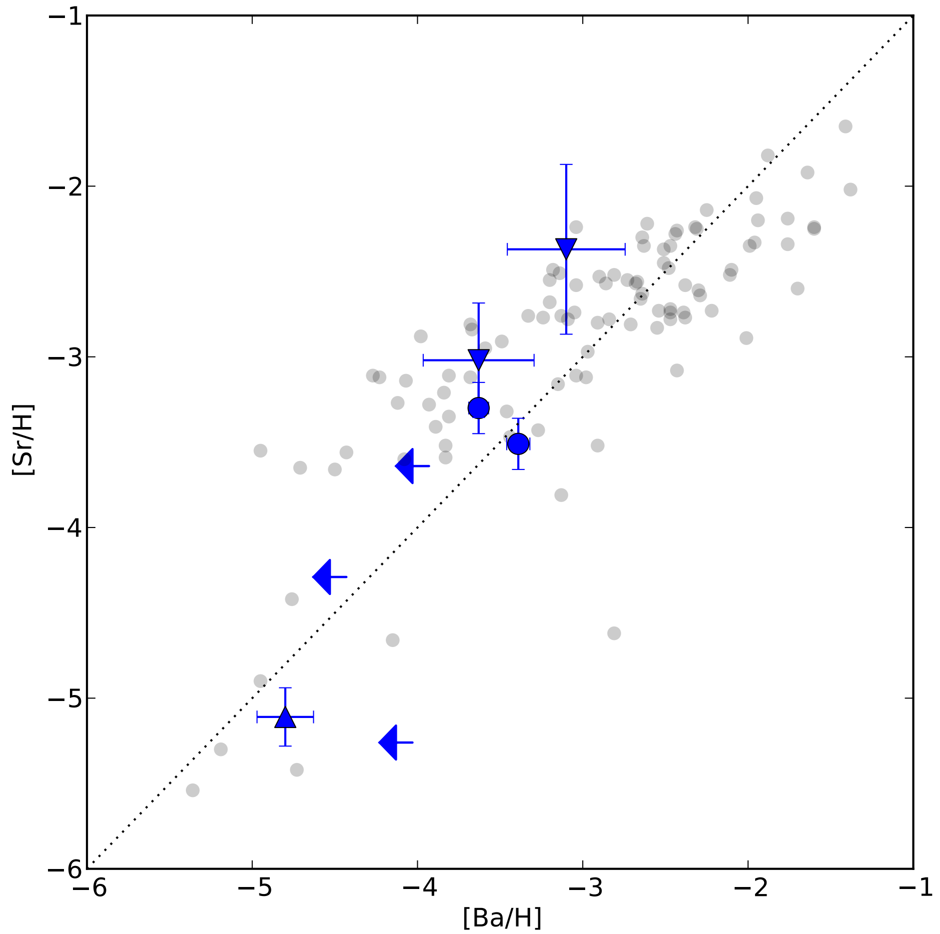
▶ Segue I ▼ Hercules ■ Leo IV ★ Comber I ▲ UMa II ◆ Boötes

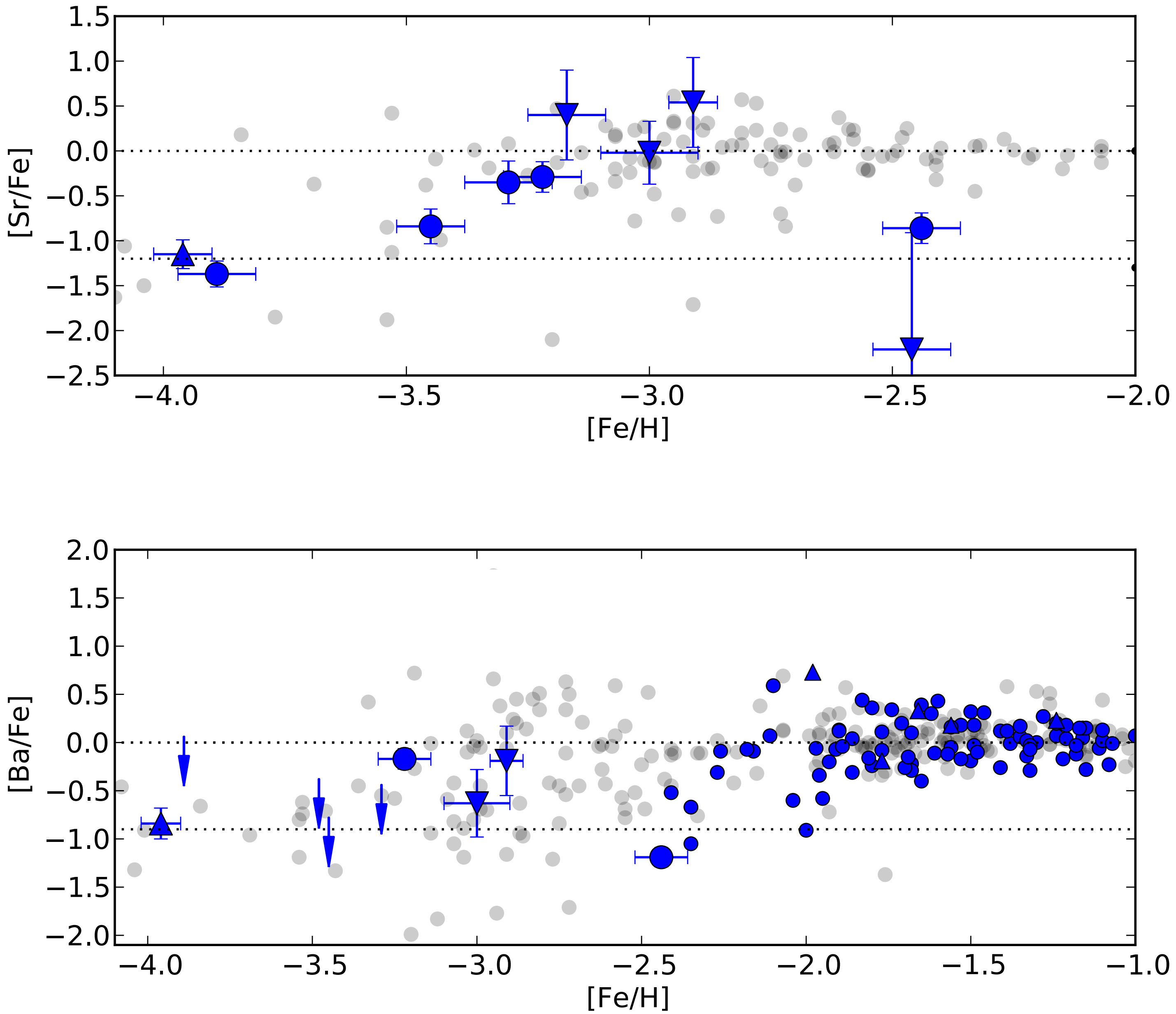




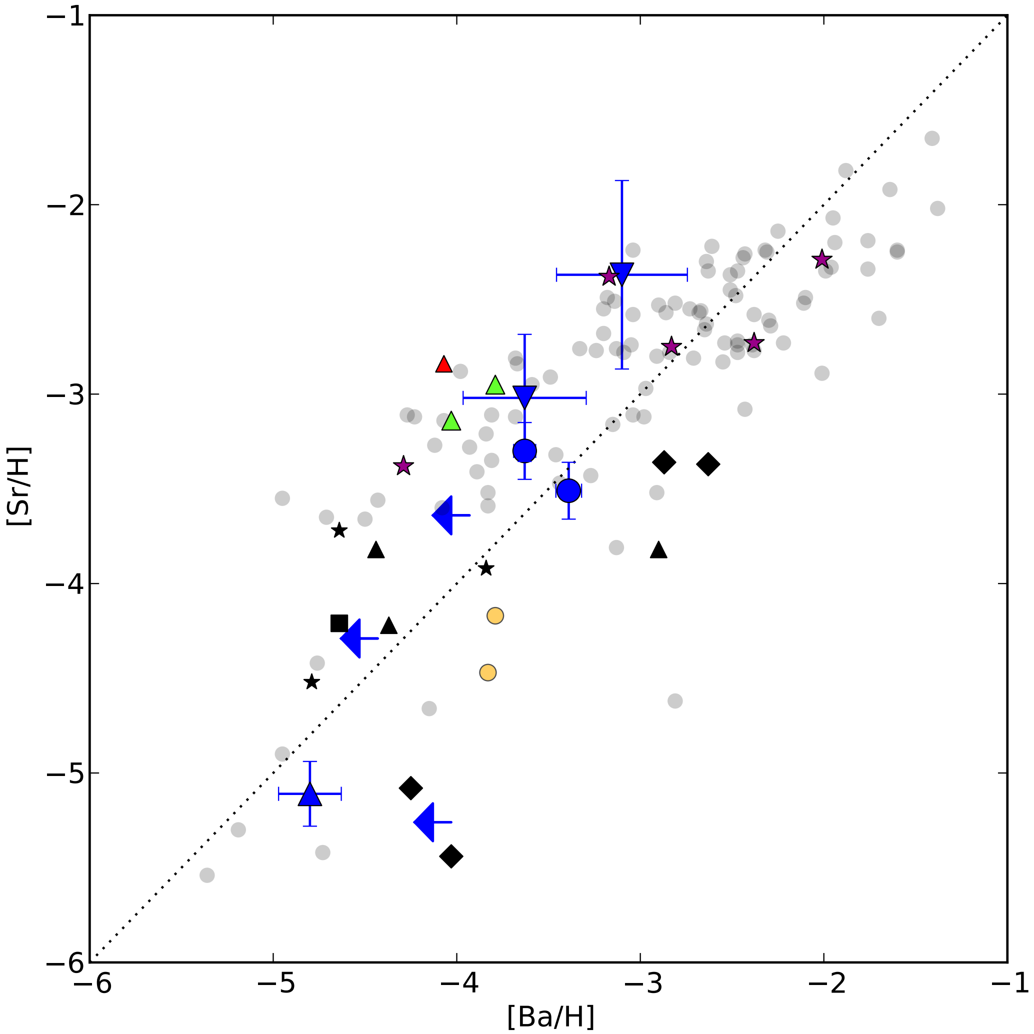


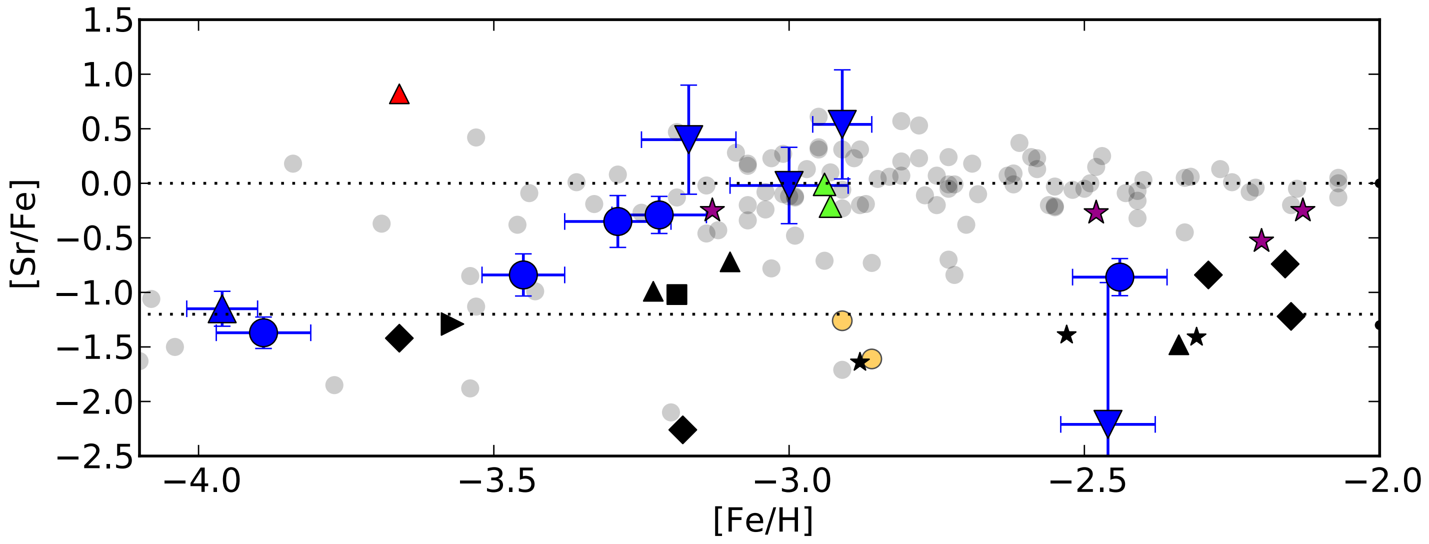
Neutron capture elements

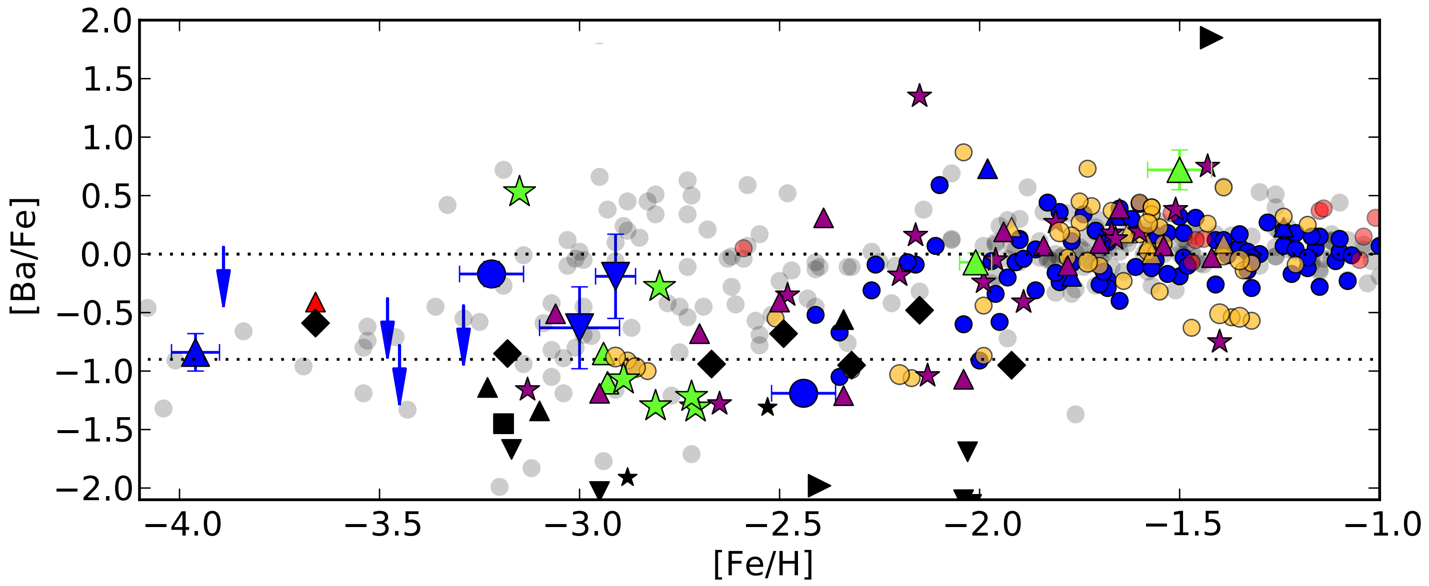




Neutron capture elements







Neutron capture elements

- Core collapse supernovae do explode and are capable of producing light r-process elements anyway

- Neutron star mergers are rare events /stellar mass

less than 4×10^{-15} events per year per solar mass inferred from observations for binary pulsars (Lorimer 2008)

an ultra-faint dSph galaxy with a stellar mass of about 10^4 $M_\odot$ is expected to have undergone $\ll 0.1$ events in its past, implying no enrichment of r-process elements - as noticed by Tsujimoto & Shigeyama (2014)

Neutron capture elements

- Favors a double and sequential origin of the r-process elements in galaxies

- Stress the importance of how the mass is a deciding agent in the evolution of the galaxies

- Constrain the epoch of mergers

Conclusions

- Elemental abundance patterns indicate very similar conditions of early star formation in galaxies

nevertheless

- Larger number of «outliers» in dSphs vs MW halo ?
- Very early in their evolution, galaxies follow distinct paths, according to their mass. This provides constrains to when and how much galaxies can merge.