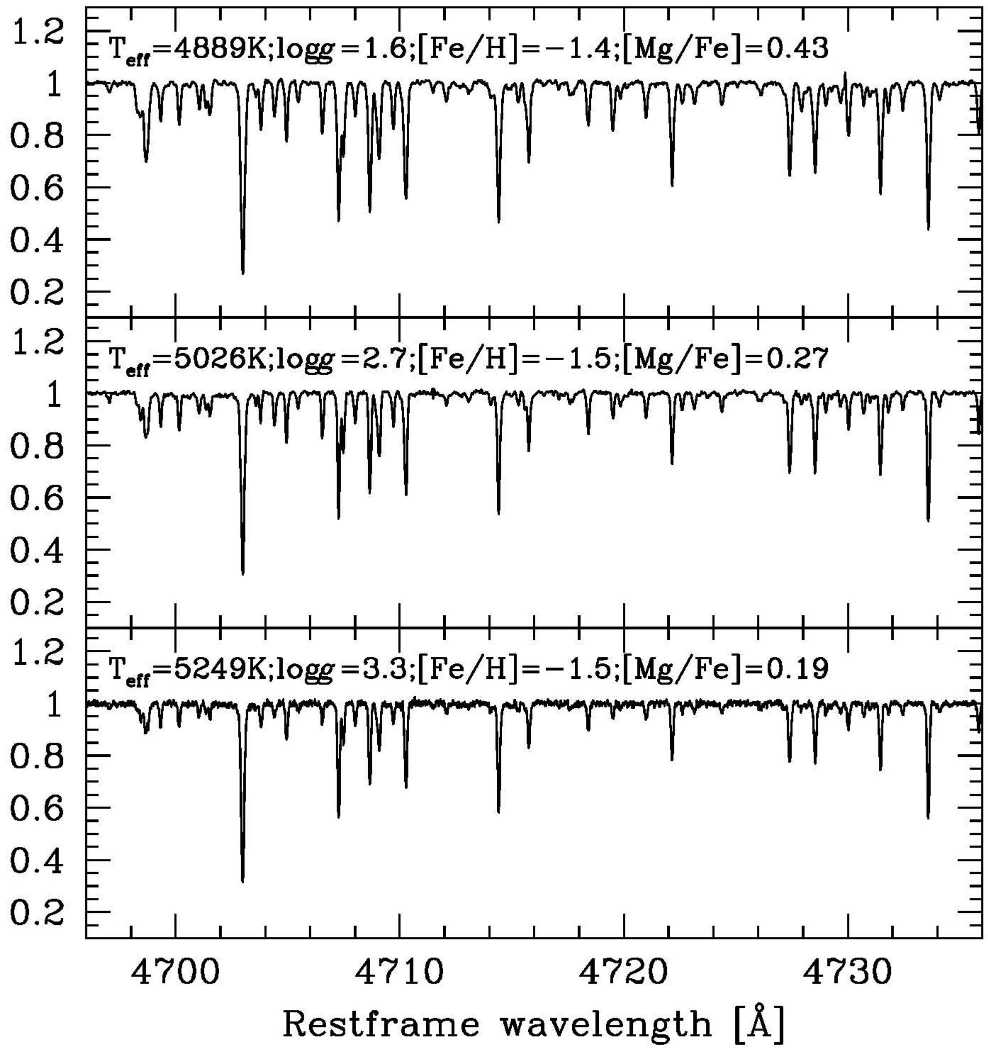
Chemical abundances of the Milky Way thick disk and stellar halo with Subaru/HDS



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Subaru Users Meeting

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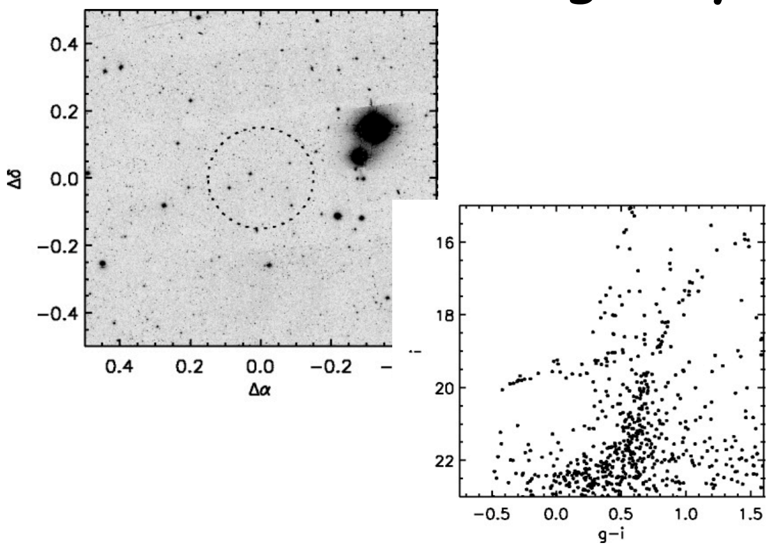
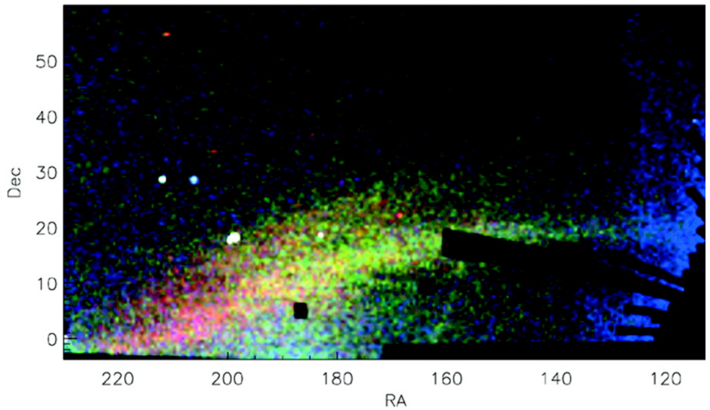
The Milky Way Galaxy
A laboratory of galaxy formation

- Cosmological simulation: formation of large galaxies via accretions of smaller-mass sub halos
  - How star formation begins, proceeds or suppressed within such sub halos?
  - How they have assembled to build up larger systems
- The local group is one of the best place to examine this issues by resolved stellar populations
- Recent surveys (e.g. 2MASS, SDSS, S-Cam) revealed important signatures

Ultra-faint dwarf galaxy



Stellar stream



Belokurov et al. 2006

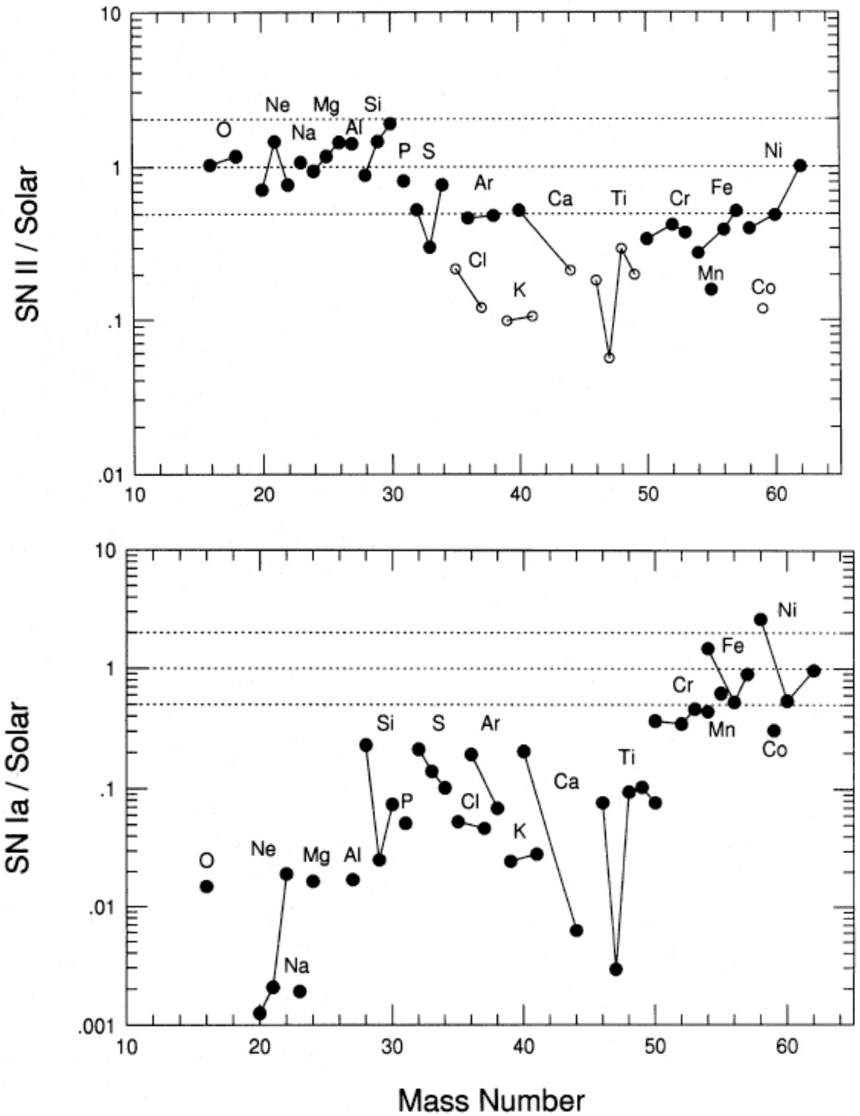
What chemical abundance tell us ?

- Elemental abundances are conserved in the surface of unevolved stars over long timescales (e.g. age > 10 Gyrs)
- Detailed chemical abundance patterns of metal-poor stars provide insights about past chemical enrichments at the star's birth place
- Formation sits for individual elements
  - Core regions of stars
  - Envelop of evolved stars (e.g. AGB phase)
  - Supernovae (Type II: massive stars, Type Ia: low-mass stars)

What kind of nucleosynthesis happen? how efficiently the enriched material mixed? How easily enriched material can escape from the system?

Formation sites of chemical elements

Tsujimoto et al. 1995



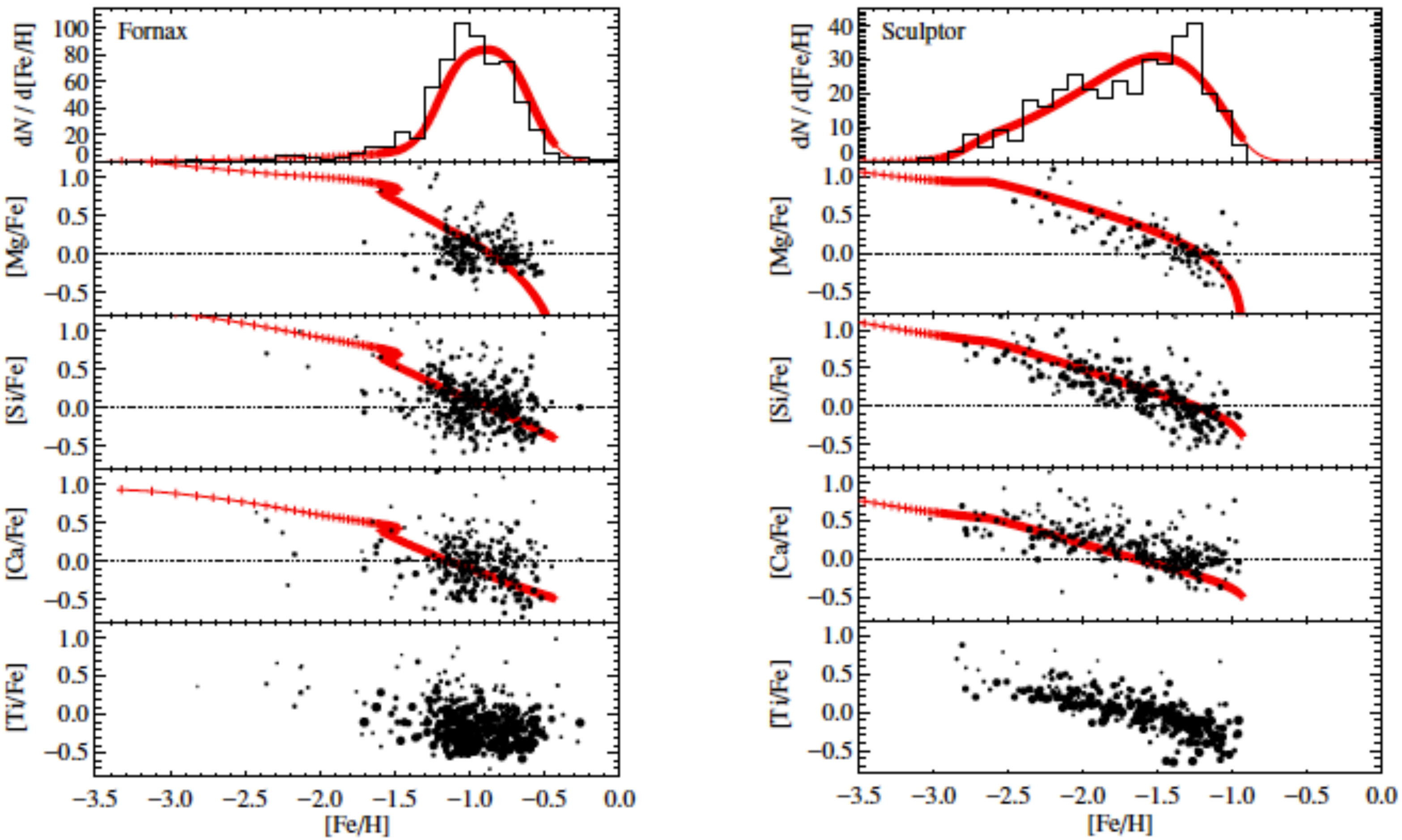
- α-elements (O, Mg, etc.)
  - Type II SNe ($\tau \approx 10^{6-7}$)
- Fe-peak elements (Fe, Ni, etc)
  - Type Ia SNe ($\tau \approx 10^{8-10}$)
- Neutron-capture elements
  - s-process: AGB stars
  - r-process: Type II Sne, neutron-star mergers, etc

Ratios of different elements (e.g. [Mg/Fe]):

Fractional contribution of different mechanisms (e.g. Type II / Ia SNe) to the system's past chemical evolution

Star formation history of dwarf galaxies
Fornax and Sculptor dSphs

Kirby et al. 2011



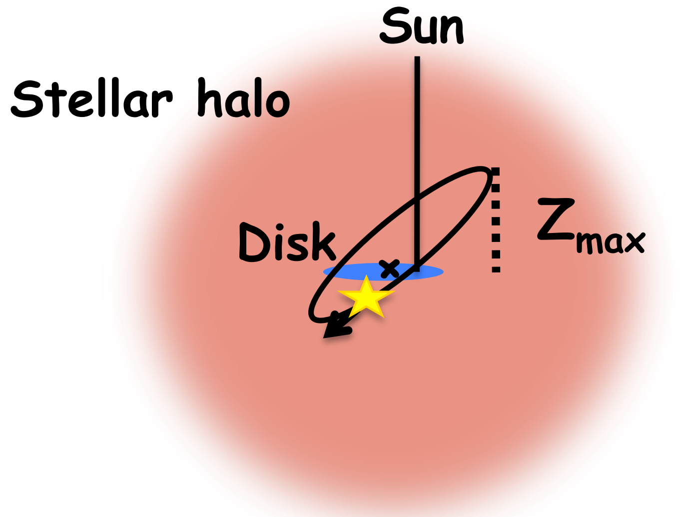
- Bursty and/or inhomogeneous SF
- Very rapid initial metal enrichment

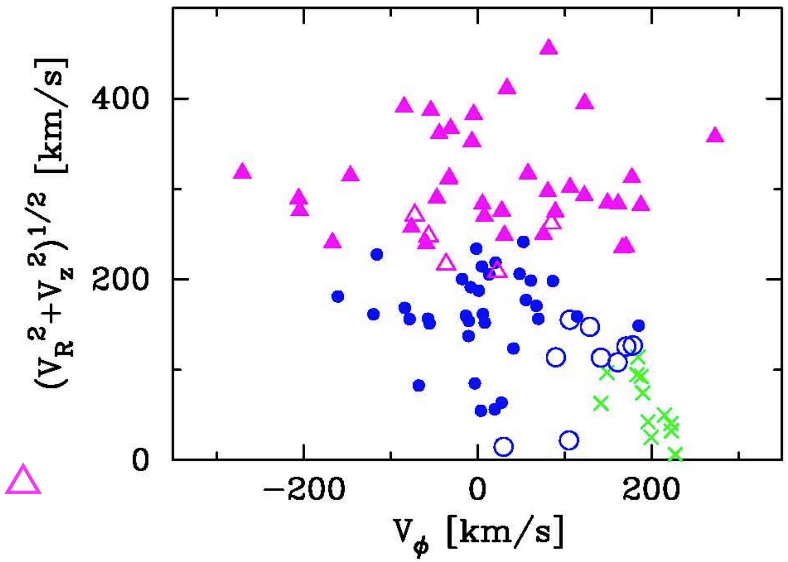
- Low star formation efficiency
- Low initial gas mass

Subaru/HDS study on chemical abundances of the thick disk and halo stars

- Sample: 97 metal-poor dwarfs and giants
  - Nearby (d<2 kpc). Bright stars (V<14)
  - Wide ranges of metallicity and orbital parameters
- Orbital parameters

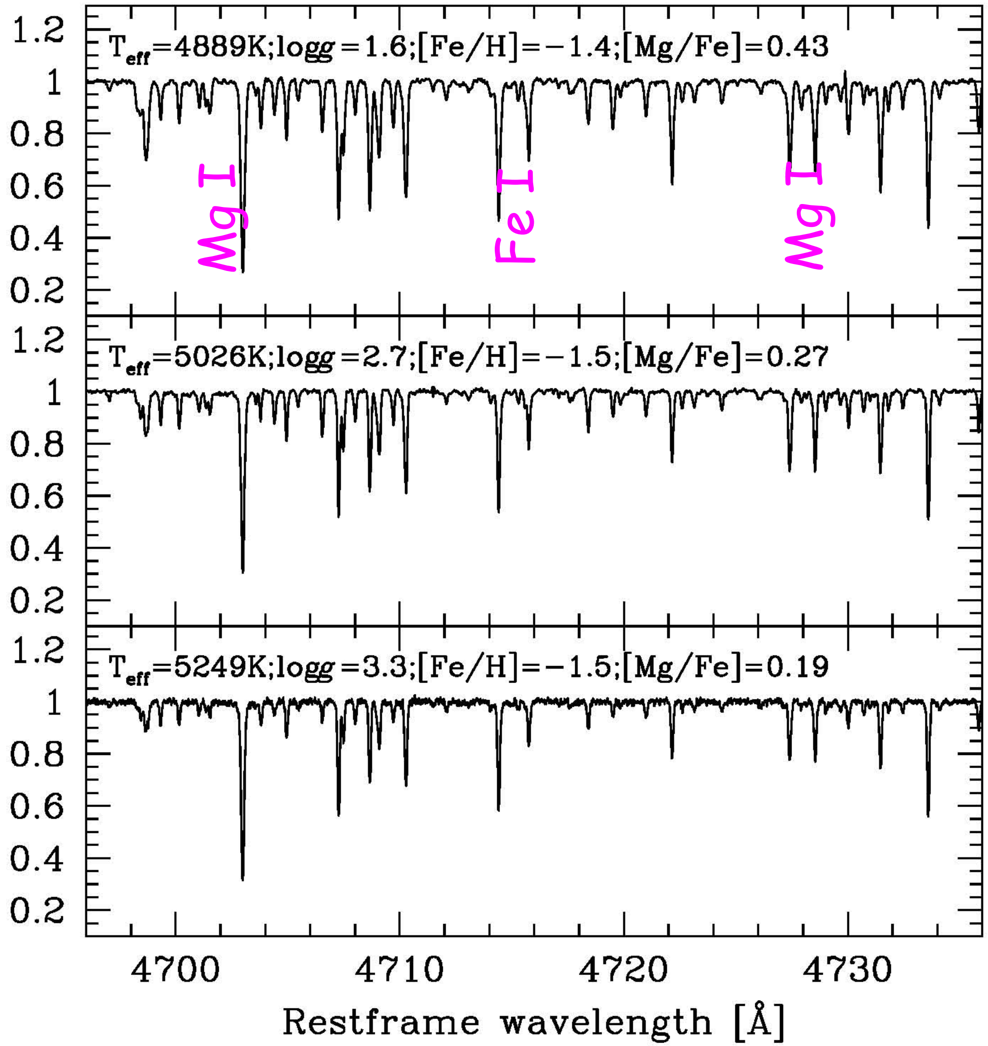
  Recalculated based on the latest proper motion, RV (from this work) and distances estimates (Chiba & Beers, 2000)
- Membership probability (P)
  - Thick disk (P_{TD}>0.9): 11 stars ×
  - Inner halo (P_{IH}>0.9): 35 stars •
  - Outer halo (P_{OH}>0.9): 37 stars ▲
  - ~15 stars with the intermediate kinematics ○, △





Observation and analysis

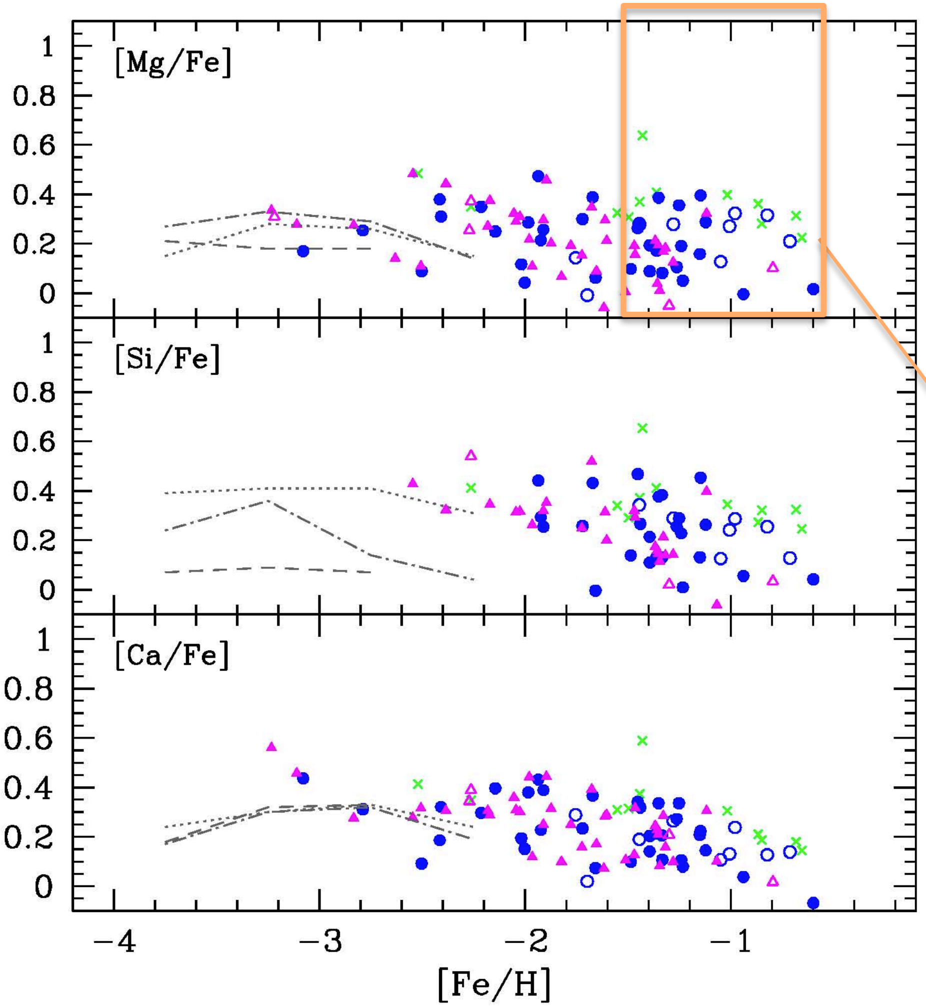
- Subaru/HDS observation during 2003-2010
  - Exp. time~ 300 – 3600 sec
  - 4000-6800 Å, R~50000
- Kurucz ("NEWODF") model atmosphere ([α/Fe]=0.4) + a 1-D LTE abundance analysis code (Aoki et al. 2009)
- T_{eff} from V-K color, logg from FeI/II ionization equilibrium, ξ from Fe I EWs



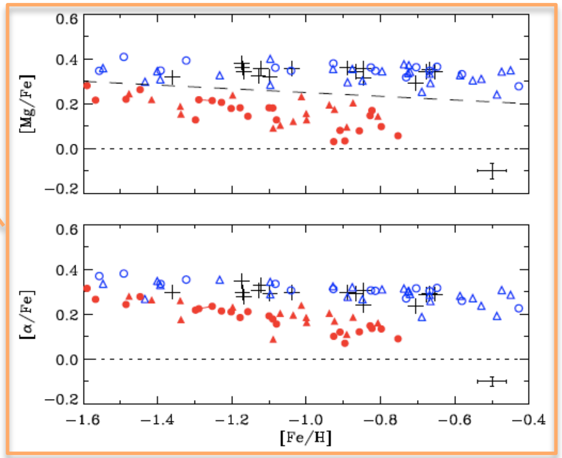
Mg, Si, Ca --- α elements

➔ Tracer of rapid chemical enrichments through Type II SNe of massive stars

x: Thick disk, •: Inner halo, ▲: Outer halo
○: thick/inner, △: inner/outer



- Thick disk stars:
  - High [α/Fe] ratio
  - Very small scatter (σ < 0.07 dex)
- The inner/outer halo stars:
  - Lower abundance ratios
  - Larger scatter (σ ≈ 0.13 dex)
  - Enhanced [α/Fe] for [Fe/H]<-1.5

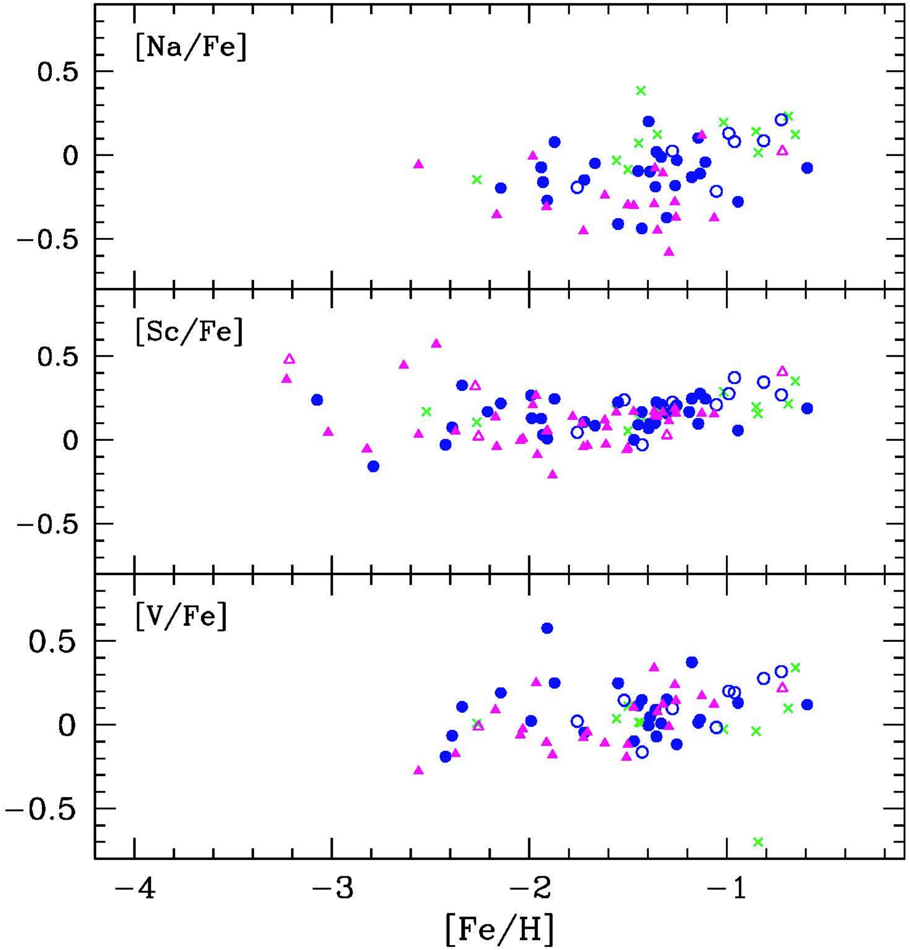


Nissen & Schuster 2010

Na, Sc and V --- odd-Z elements

➔ Na: hydrostatic carbon burning of massive stars, Sc and V: explosive burning of SNe

x: Thick disk, •: Inner halo, ▲: Outer halo
○: thick/inner, △: inner/outer



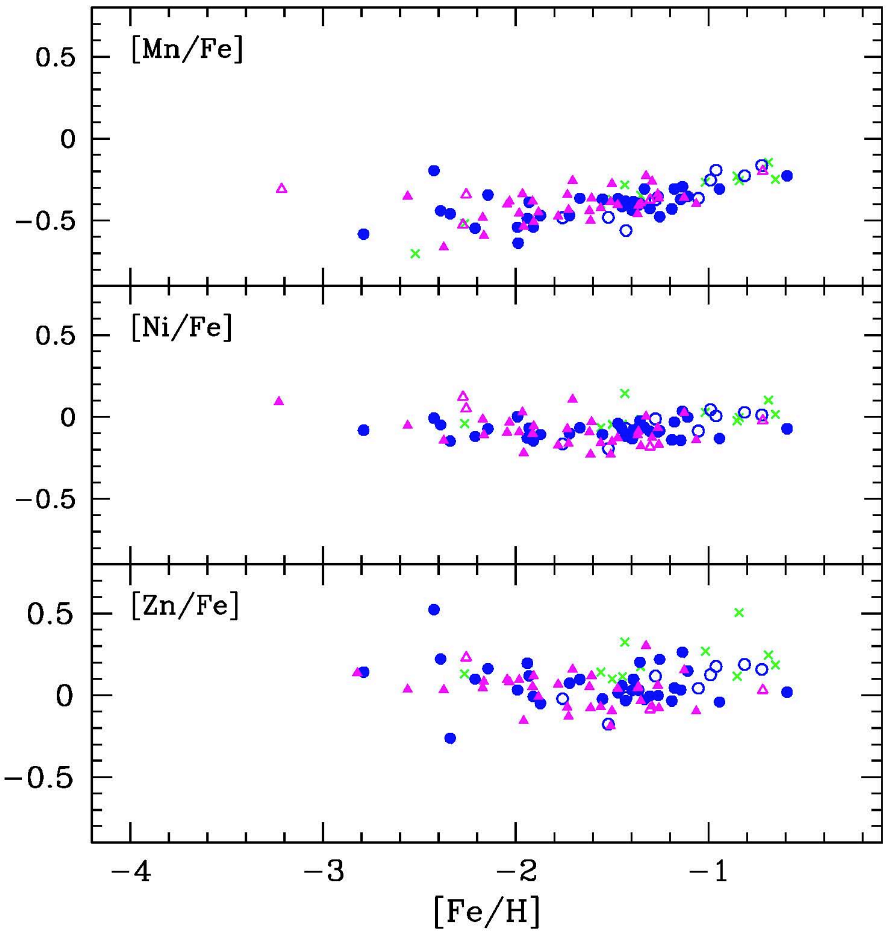
- Higher [Na/Fe] for the thick disk stars than the halo stars
- Increasing trend with [Fe/H]

Type II SNe
Different typical metallicity of the progenitor stars?

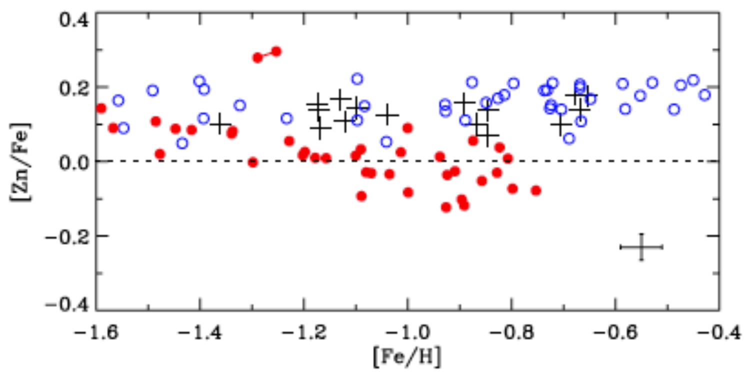
Mn, Ni, Zn --- Fe-peak elements

➔ Explosive burning in Type II/Ia SNe, depending on detailed conditions at SNe

x: Thick disk, •: Inner halo, ▲: Outer halo
○: thick/inner, △: inner/outer



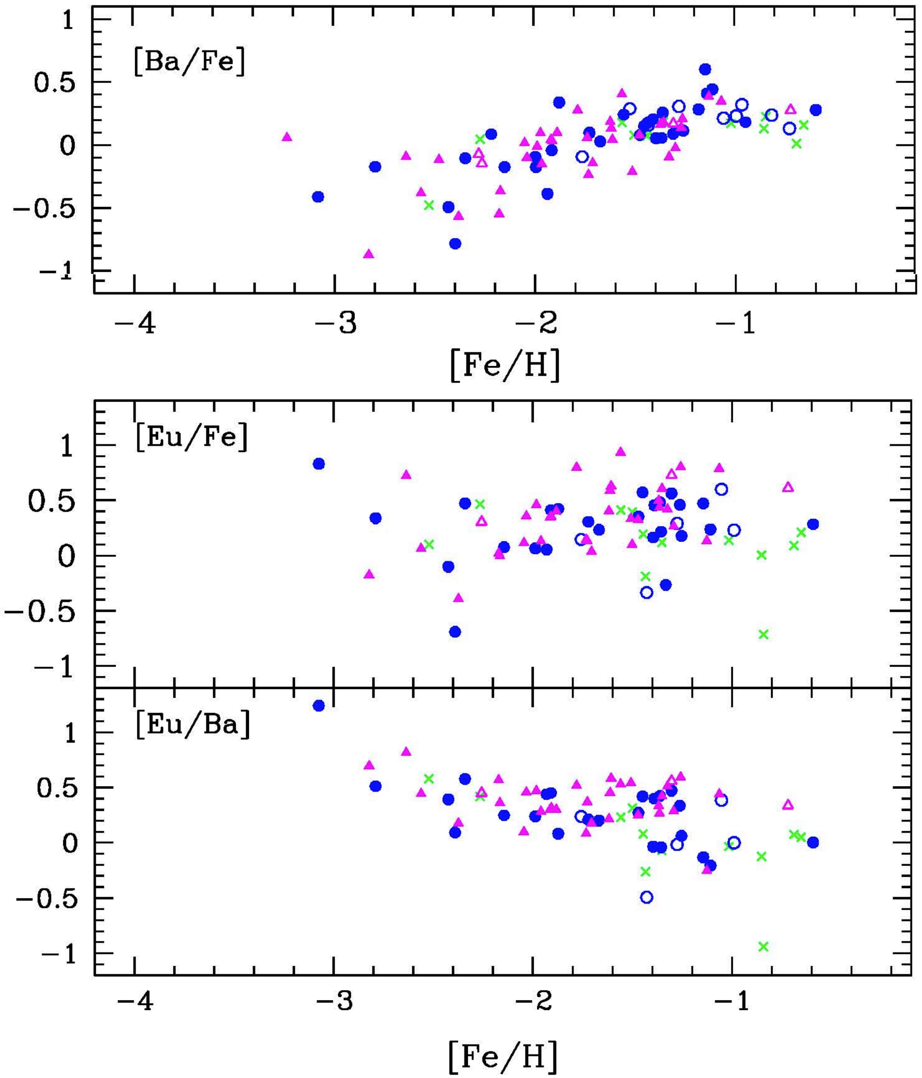
- Small scatter (e.g. Ni)
- The halo stars have lower [Zn/Fe] than the thick disk stars



Nissen & Schuster 2011

Ba and Eu --- Neutron-capture elements

➔ s-process: AGB stars, r-process: Type II SNe, neutron star mergers, etc.



- High [Eu/Fe] for the halo stars

→ If the Eu is synthesized with similar process as Mg, [Eu/Fe] would also show similarly low values

Implications

- Formation of the thick disk
  - Accretions of dwarf galaxies
  - Dynamical heating of pre-existing thin disk
  - Early gas-rich major merger

  High [α/Fe], [Na/Fe] and [Zn/Fe] for the thick disk stars: Rapid chemical enrichments primarily through Type II SNe
- Formation of the stellar halos
  - Rapid collapse of gaseous materials on to the central region of the MW
  - Formed within dwarf galaxies later accreted and disrupted

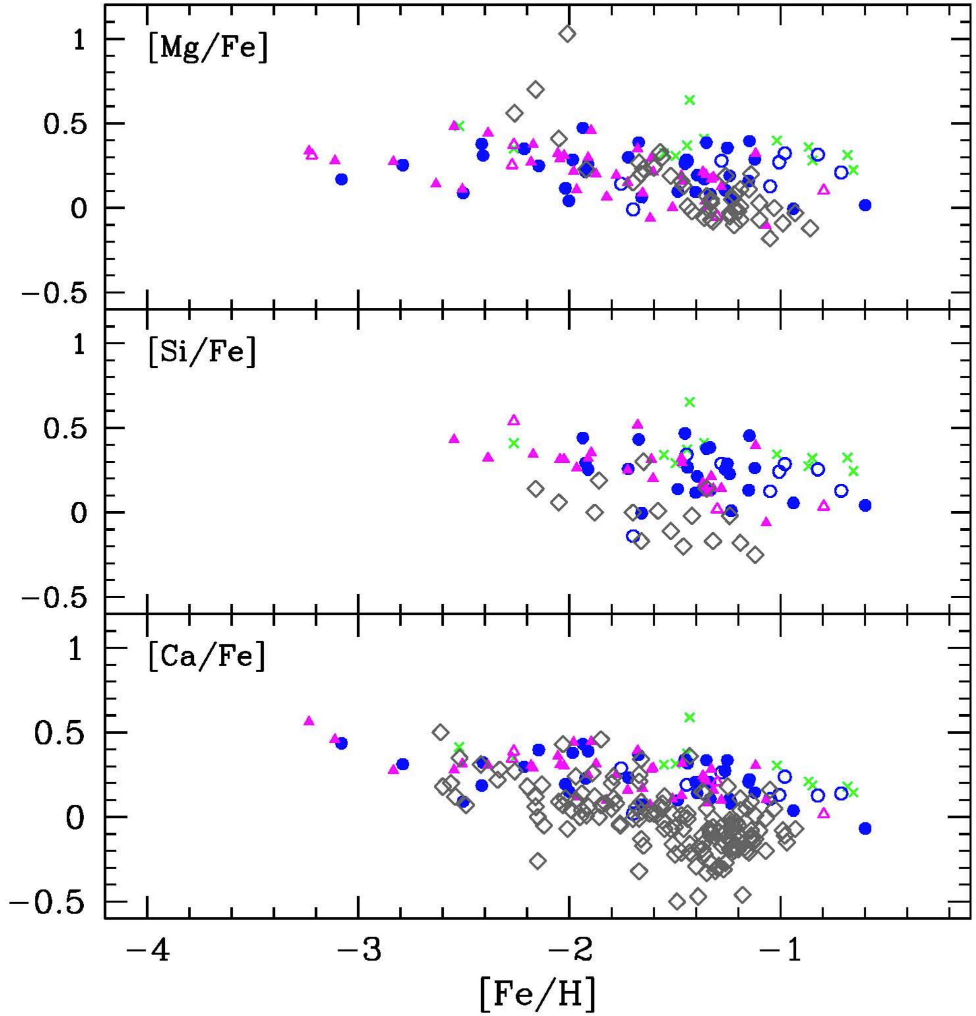
  Wide range of [α/Fe] and [Na/Fe] for the inner/outer halo stars: both of these scenarios may have contributed to the current stellar halo
- Origin of r-process elements
  - [Eu/Fe] of the halo stars do not show the trend seen in [Mg/Fe]

    → Difference in progenitor mass of the Type II SNe?

  Examination of detailed abundance patterns of neutron capture elements are now underway.

Comparison with dSphs

◇: Data of Sculptor dSphs from Kirby et al. 2010

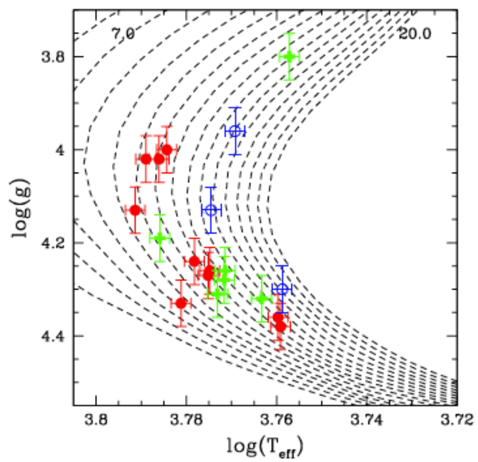


- Higher [α/Fe] than the Sculptor dSphs

Star formation of progenitors of the stellar halo have stopped much earlier than Sculptor

→ Large fraction of the halo stars have already accreted before ~ 10 Gyr

Age of halo stars are older than 10 Gyrs



Schuster et al. 2011

Future prospects: Go beyond the solar neighborhood

- Spatial/kinematical substructures are expected to be more abundant in the outer stellar halo
- Less contamination from the disk stars
- Photometric and astrometric data from the HSC and Gaia can be used to estimate star's atmospheric parameters (T_{eff}, log*g*) , kinematics and age → Full phase-space, abundance-space and age information will be available up to V <21.5 for a certain region of the sky