Europium abundances in the Milky Way thick disk and halo stars

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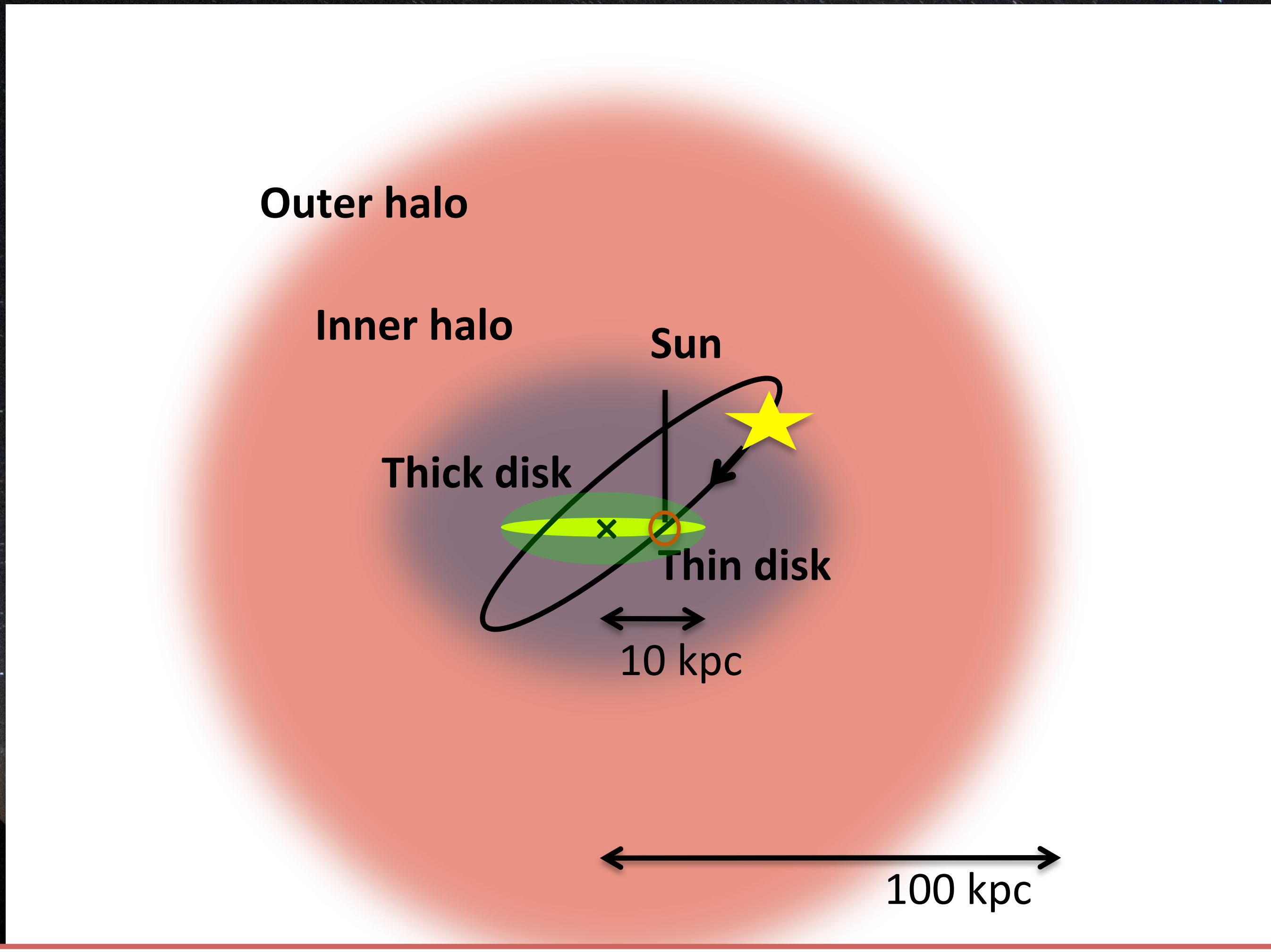
10th Russbach school on Nuclear Astrophysics

The major stellar components in the Milky Way



Whether stars belonging to the different Galactic components show different chemical abundances (α, Fe-peak and neutron-capture)?

This talk

- Whether Europium abundances are different or similar among the stars belonging to the three old MW components, thick disk, inner halo and outer halo
- Abundance analyses for a sample of 97 nearby metal-poor stars based on the high-resolution spectroscopic observation with Subaru/HDS
- *A hint that the [Eu/Fe] ratios between the kinematically defined thick disk and inner-/outer halo subsamples are systematically different*

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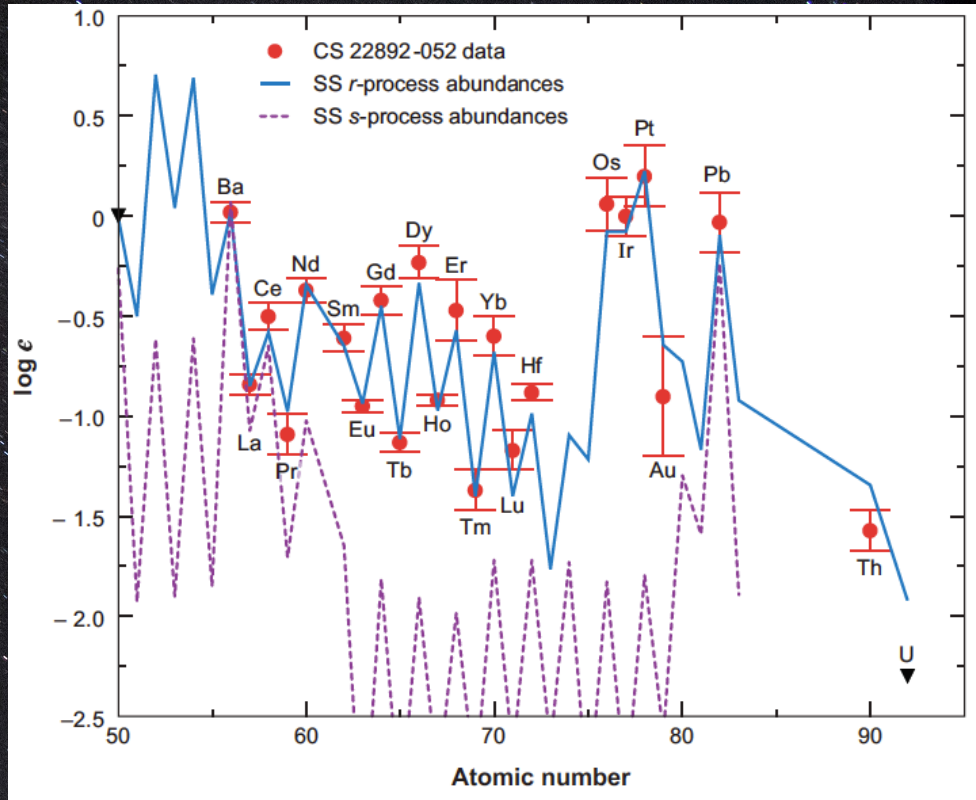
BACKGROUND

Eu: r-process element

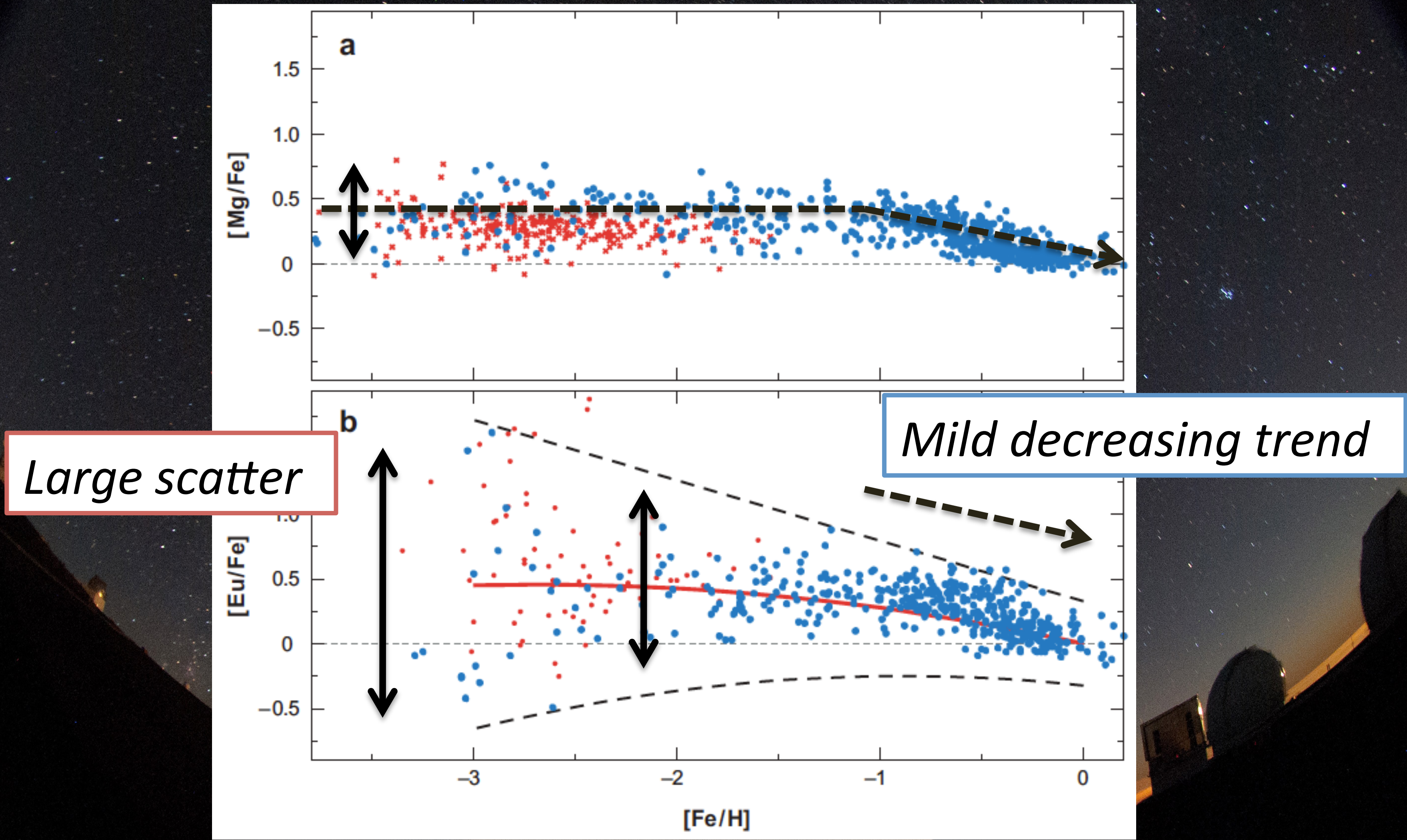
- Eu in solar-system material: >90% r-process origin
- Astrophysical sites for r-process: *unknown*
  - *Type II SNe of particular progenitor mass ranges*
  - *Neutron-star merger*
- The abundance pattern of r-process elements in r-rich stars: remarkably similar to that in the solar system



Roederer et al. 2008

A dominant astrophysical site for the r-process

Chemical evolution of Eu in the MW

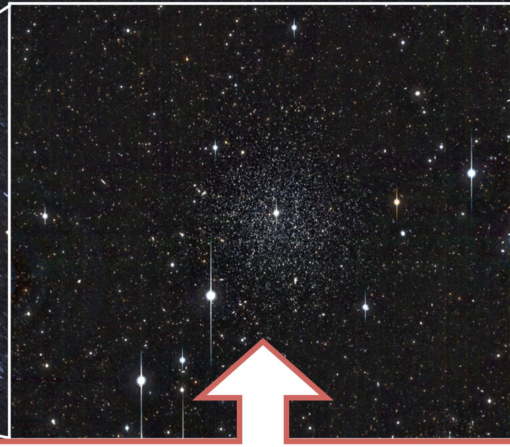


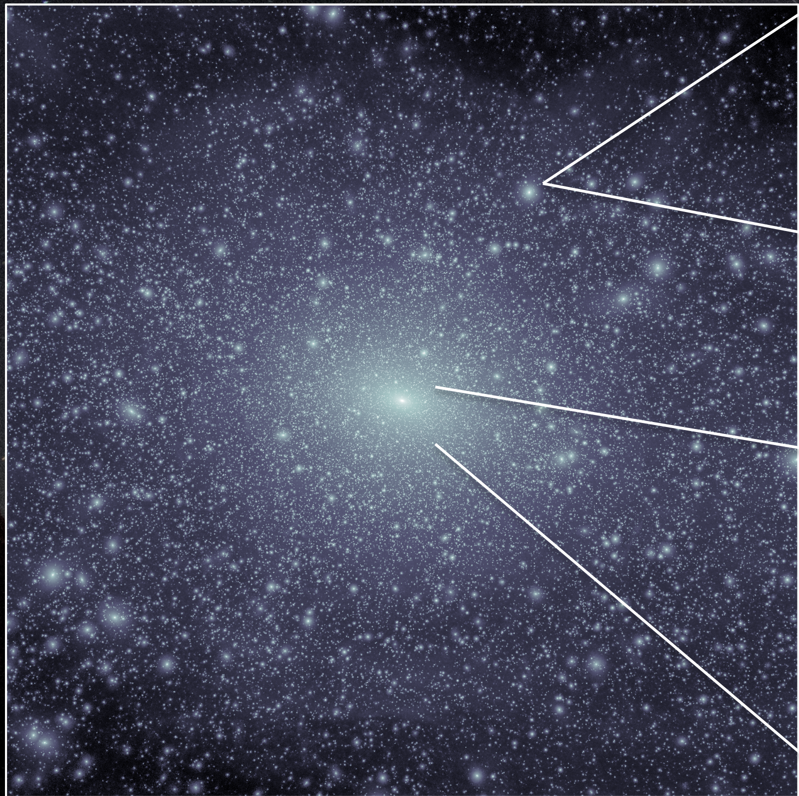
Sneden 2008

Chemical + dynamical evolution

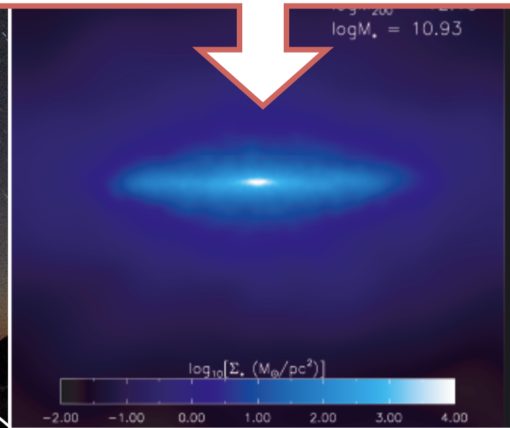
Formation of the thick disk and stellar halo

Leo II dwarf galaxy (credit:NAOJ)





Different chemical enrichment histories e.g. the number of Type Ia/ Type II SNe, efficiency of mixing, gravitational potential to retain SNe ejecta

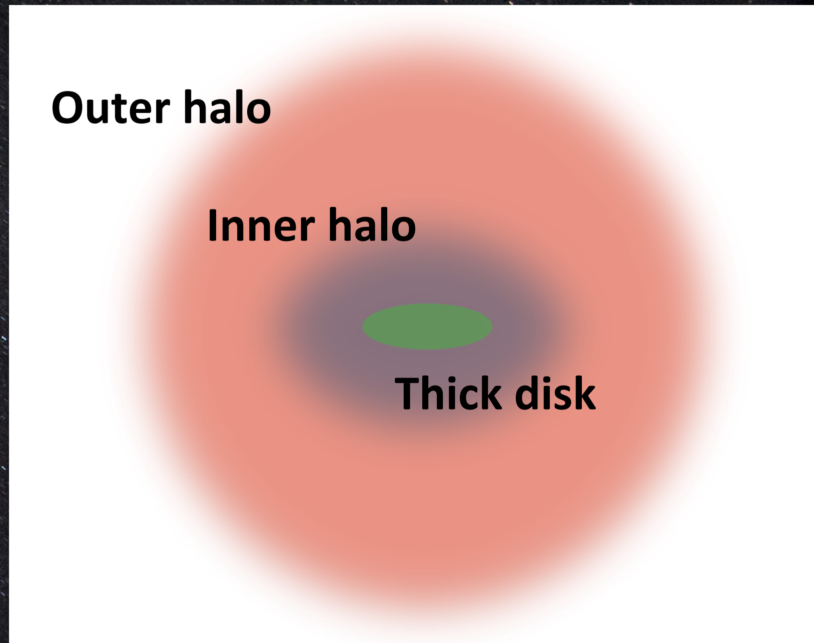


Cosmological simulation for the formation of a MW-sized galaxy (Diemand+08)

Simulation for a disk galaxy (Font+11)

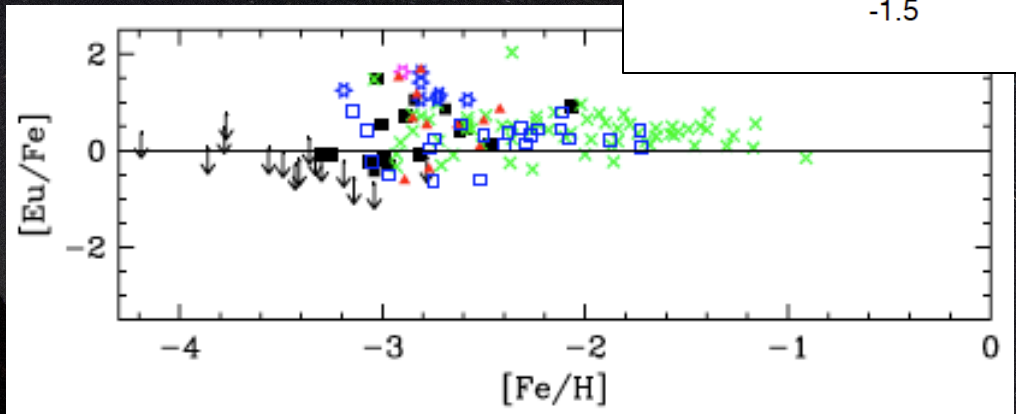
Observed properties of the thick disk and stellar halos

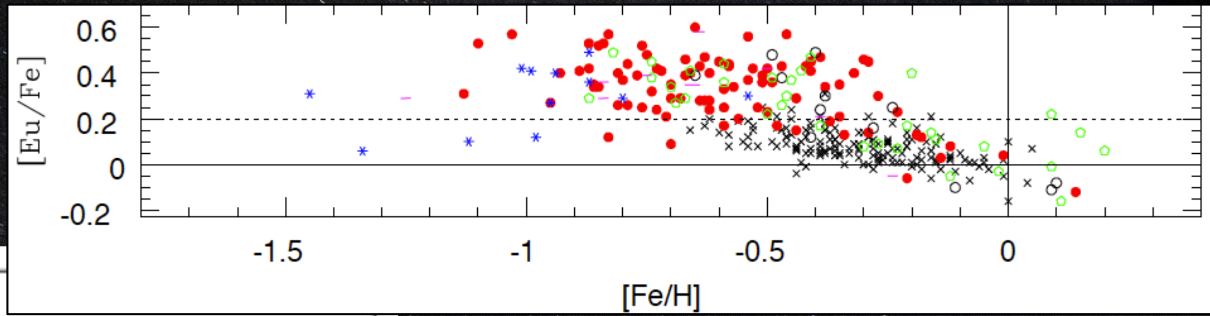
- Thick disk
  - scale height ~ 1 kpc
  - [Fe/H] ~ -1.6 dex
  - V_ϕ (rotational velocity around the Galaxy) ~ 180-190 km/s
- Stellar halo
  - Inner halo (r<10-25kpc)
    - flattened stellar density distribution
    - [Fe/H] ~ -1.6 dex
    - $\langle V_\phi \rangle \sim 0$ km/s
  - Outer halo (r>25kpc)
    - spherical stellar density distribution
    - [Fe/H] ~ -2.2 dex
    - $\langle V_\phi \rangle \leq 0$



Previous studies on [Eu/Fe] in metal-poor stars

Halo stars: Francois+07





Thick disk and halo stars: Reddy+06

<u>Motivation in this study</u>

- A homogeneous abundance analysis for a sample of kinematically different groups of stars (thick disk, inner halo and outer halo), *especially <u>for their overlapping metallicity range</u>*
- Whether the three subsamples show differences / similarities in chemical abundances, especially for outer halo stars having extreme kinematics

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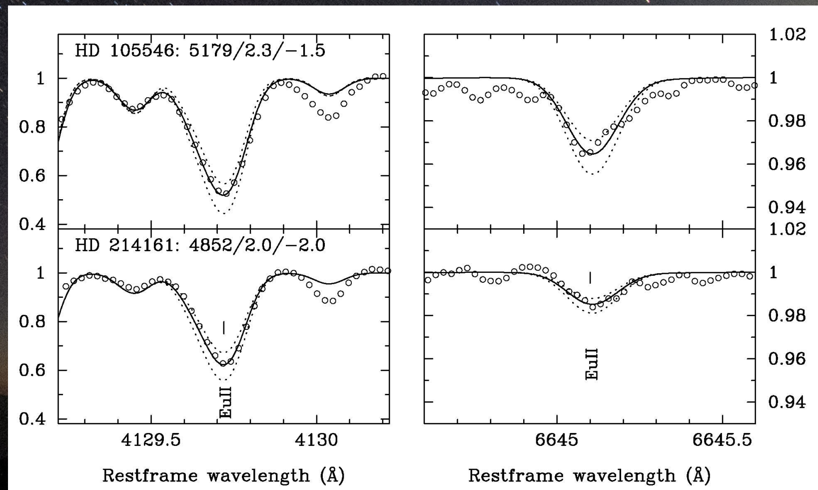
OBSERVATION AND ANALYSIS

Chemical abundances in the kinematically selected thick disk, inner halo and outer halo stars

- The sample: 97 metal-poor ([Fe/H]<-0.5) giant/main sequence stars
- with Subaru/High Dispersion Spectrograph during 2003-2010
- λ≈4000-6800 Å, R≈50000
- Data reduction with standard IRAF routines Kurucz ("NEWODF") model atmosphere ([α/Fe]=0.4) + a 1-D LTE abundance analysis code (Aoki et al. 2009)
- Na, α-elements, Fe-peak and neutron-capture elements

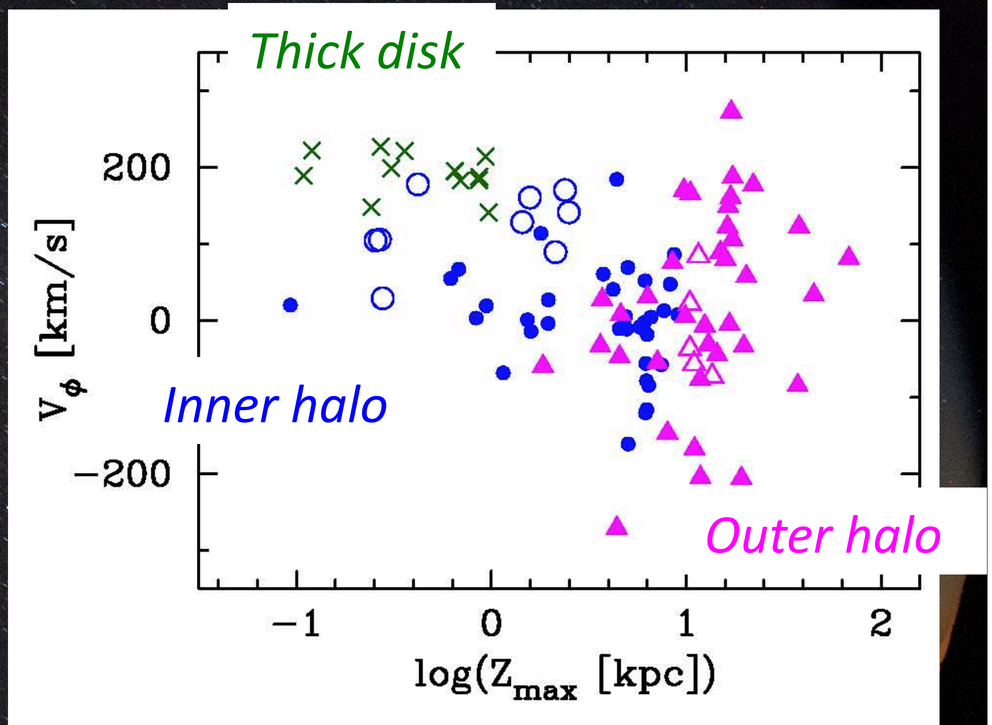
Subaru Telescope
- Mauna Kea, Hawaii
- Diameter 8.2m
- Altitude 4200m

Observed and synthesized spectra for the Eu II lines



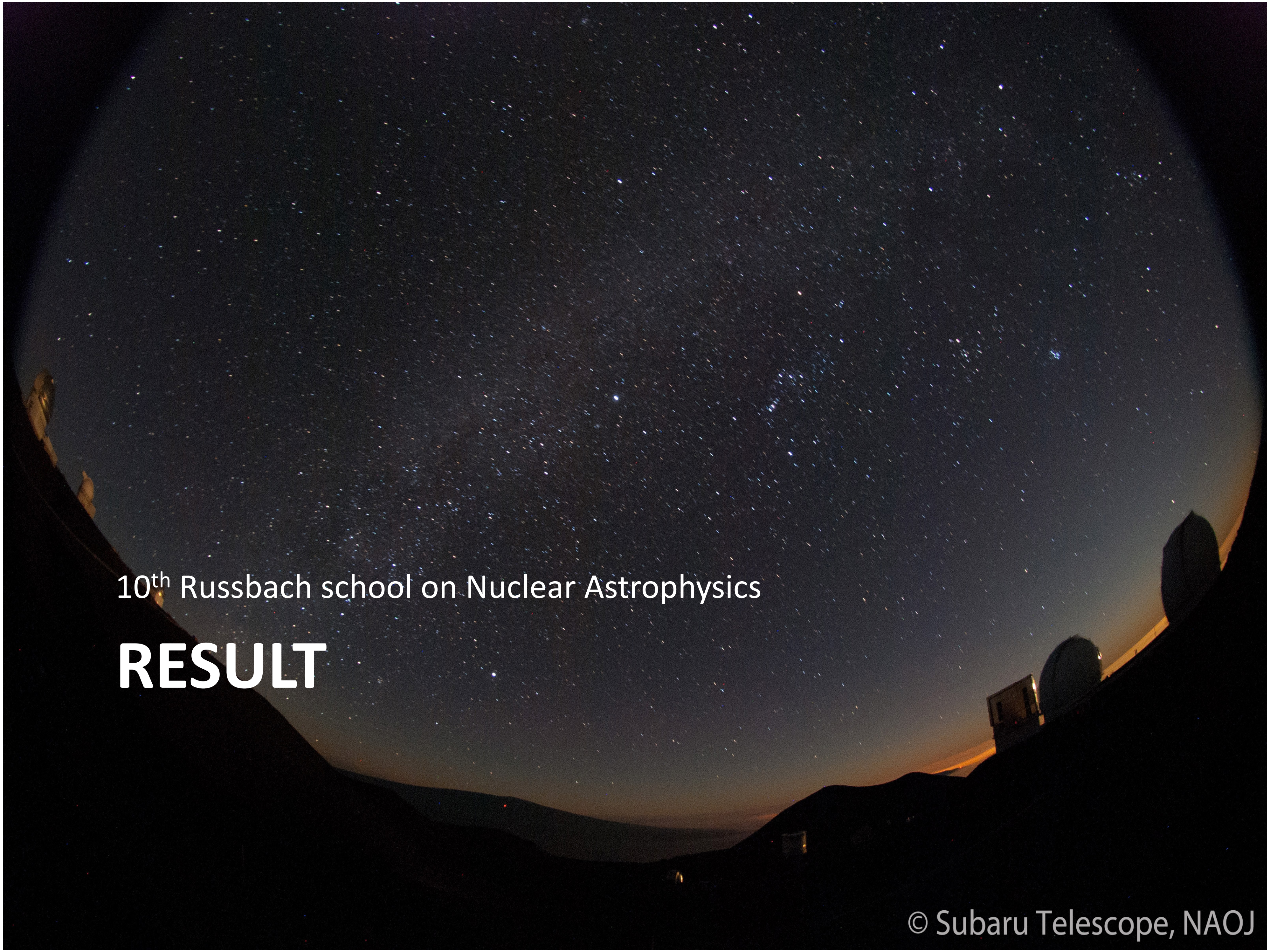
Kinematics of the sample

- Orbital parameters calculated based on the latest proper motion, radial velocities and distances by the method of Chiba & Beers (2000)
- Assignment of the membership: based on kinematics (V_R, V_ϕ, V_Z)
  Membership probability: P_{TD}, P_{IH}, P_{OH}
  - Thick disk (P_{TD}>0.9): 12 stars
  - Inner halo (P_{IH}>0.9): 34 stars
  - Outer halo (P_{OH}>0.9): 37 stars
  - ≈ 14 stars with the intermediate kinematics



MI, Chiba & Aoki 2012

V_ϕ: rotational velocity in the Galactic cylindrical coordinate
Z_{max}: maximum distance that a star can reach in its orbit above/below the Galactic plane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RESULT
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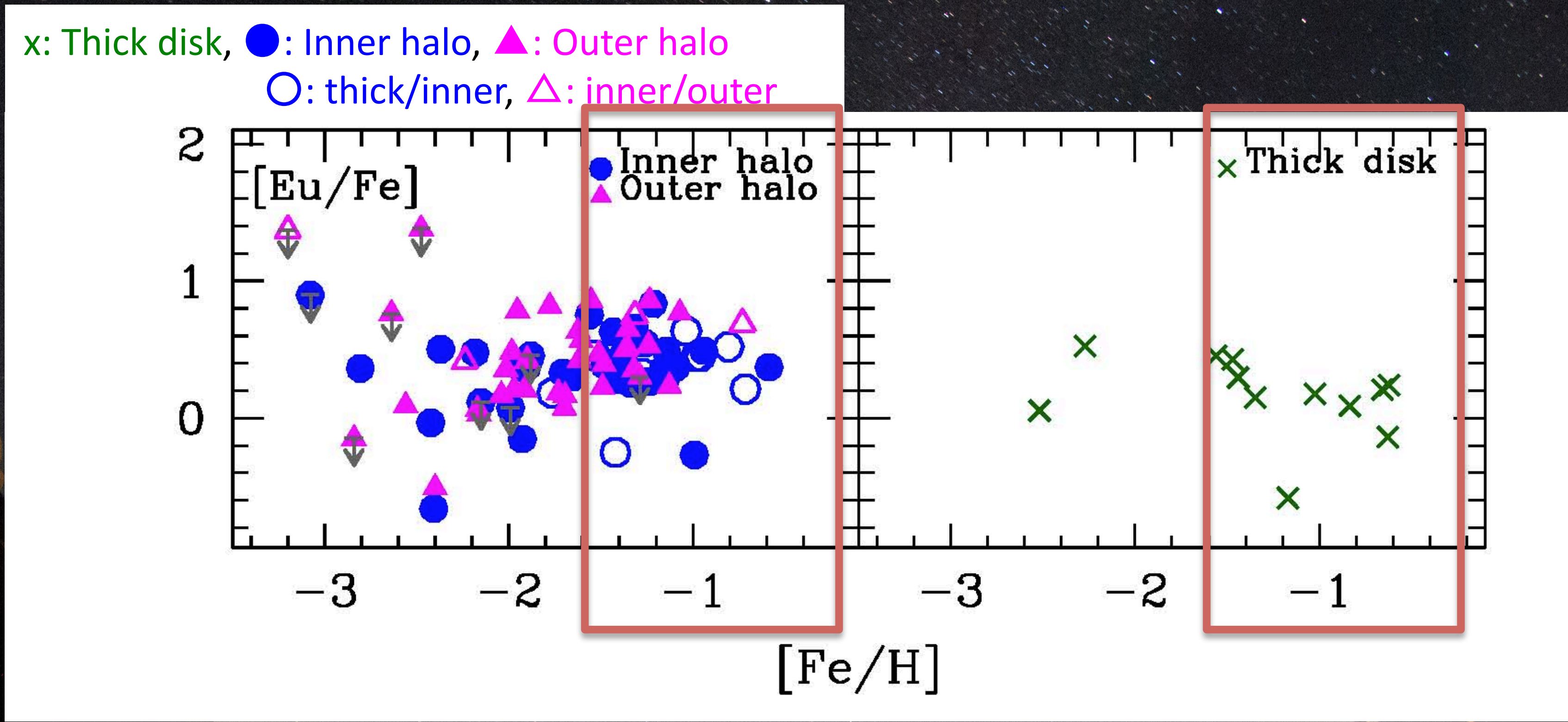
[Eu/Fe]



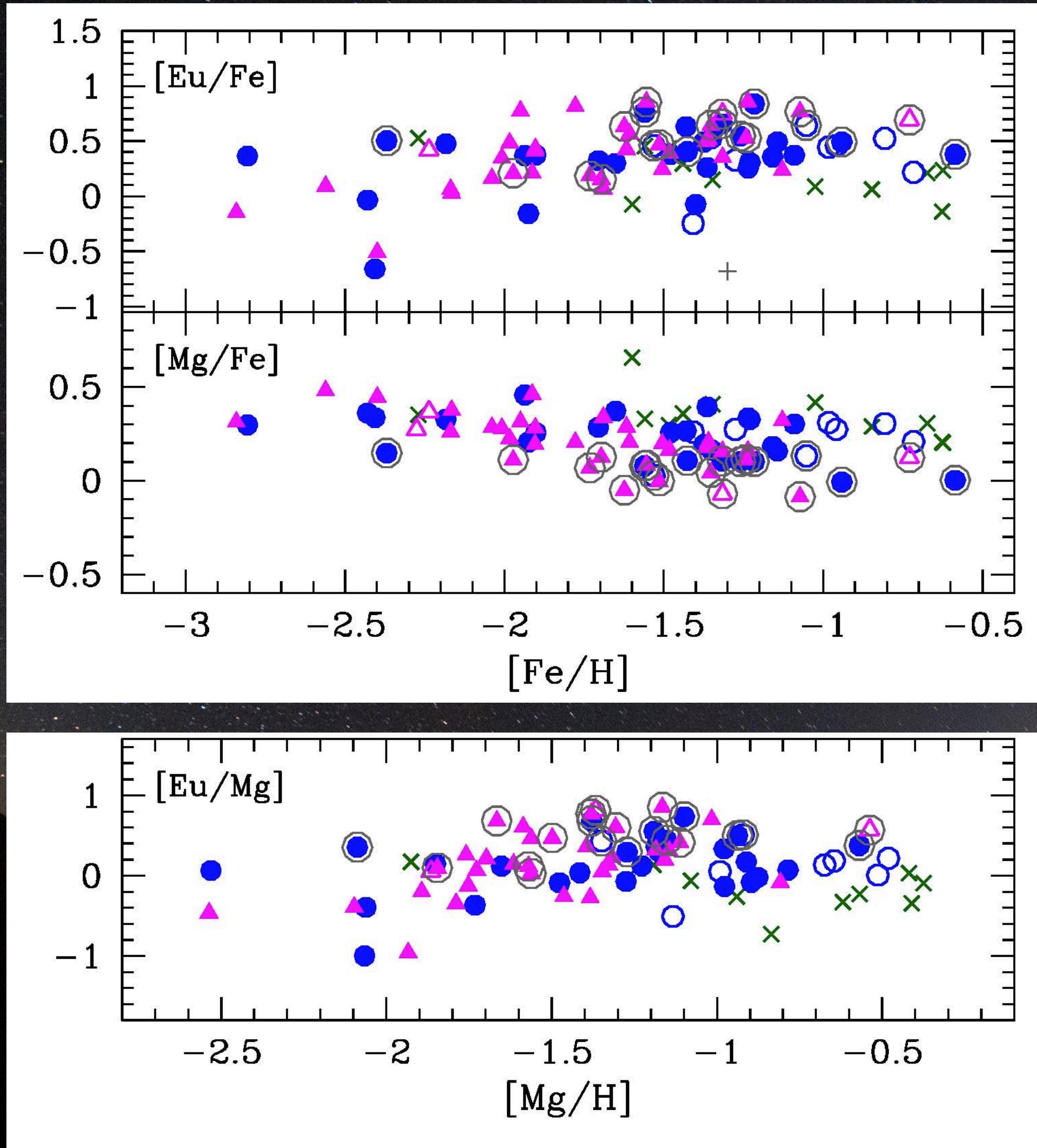
- [Fe/H]<-2.0: The thick disk, inner halo and outer halo subsamples show similar [Eu/Fe] abundance ratios
- *[Fe/H]>-2.0: The inner/outer halo subsamples show higher [Eu/Fe] ratios than the thick disk subsample*

Differences among the subsamples

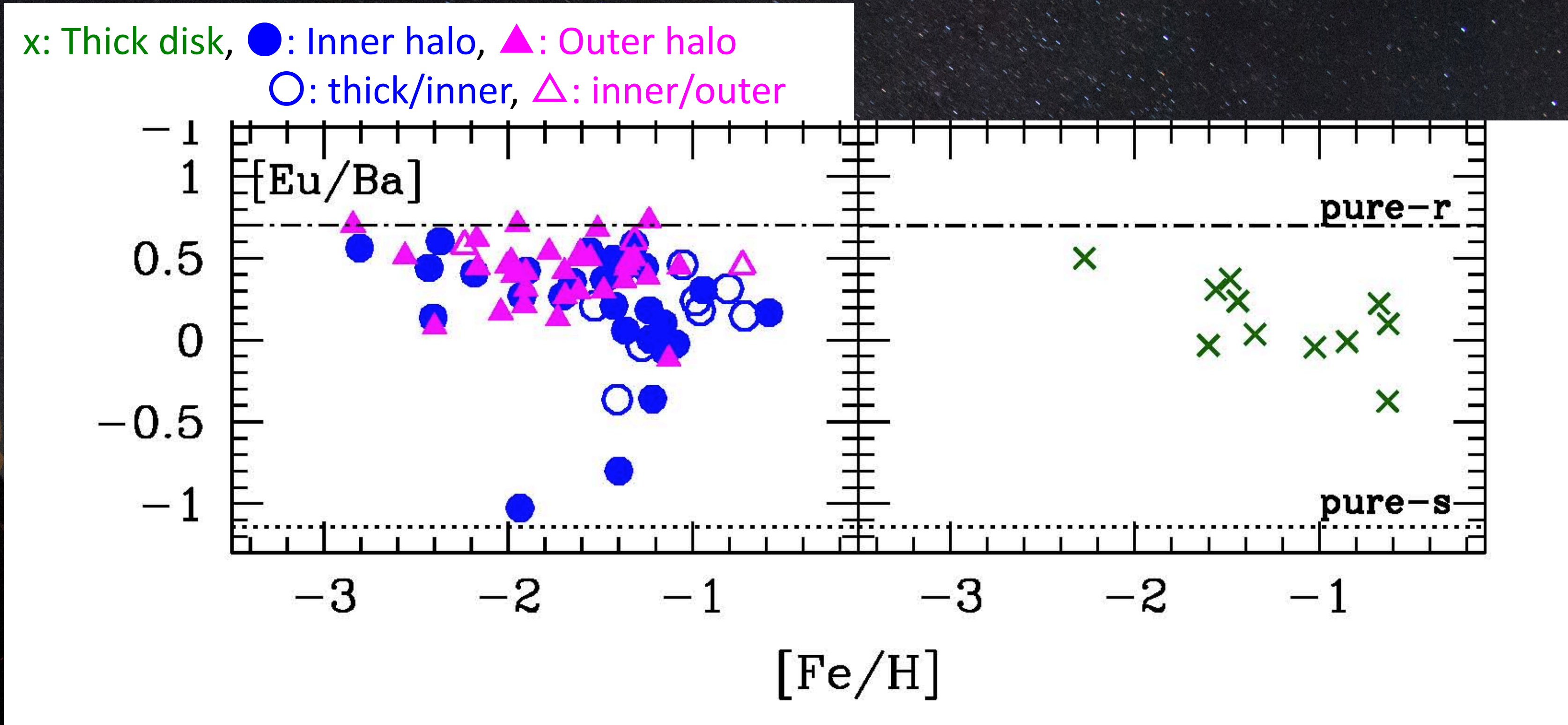
[Eu/Fe]@ [Fe/H]>-1.5

	All stars		Dwarf stars (T_{eff}>5000K, log$g$>3.5)	
	mean±σ/√N	N	mean±σ/√N	N
Thick disk	0.18±0.06	8	0.22±0.02	2
Inner halo	0.41±0.05	18	0.48±0.04	12
Outer halo	0.50±0.06	10	0.59±0.11	6

[Eu/Fe] vs. [Mg/Fe]



[Eu/Ba]



The thick disk stars show lower [Eu/Ba] ratios than the inner/outer halo stars

⇒ Relative contribution from s- and r-process on heavy element synthesis are different among these components

Implications and limitations

- The thick disk and inner/outer halo components show different abundances in [Eu/Fe] and some other elements (e.g. [Mg/Fe])

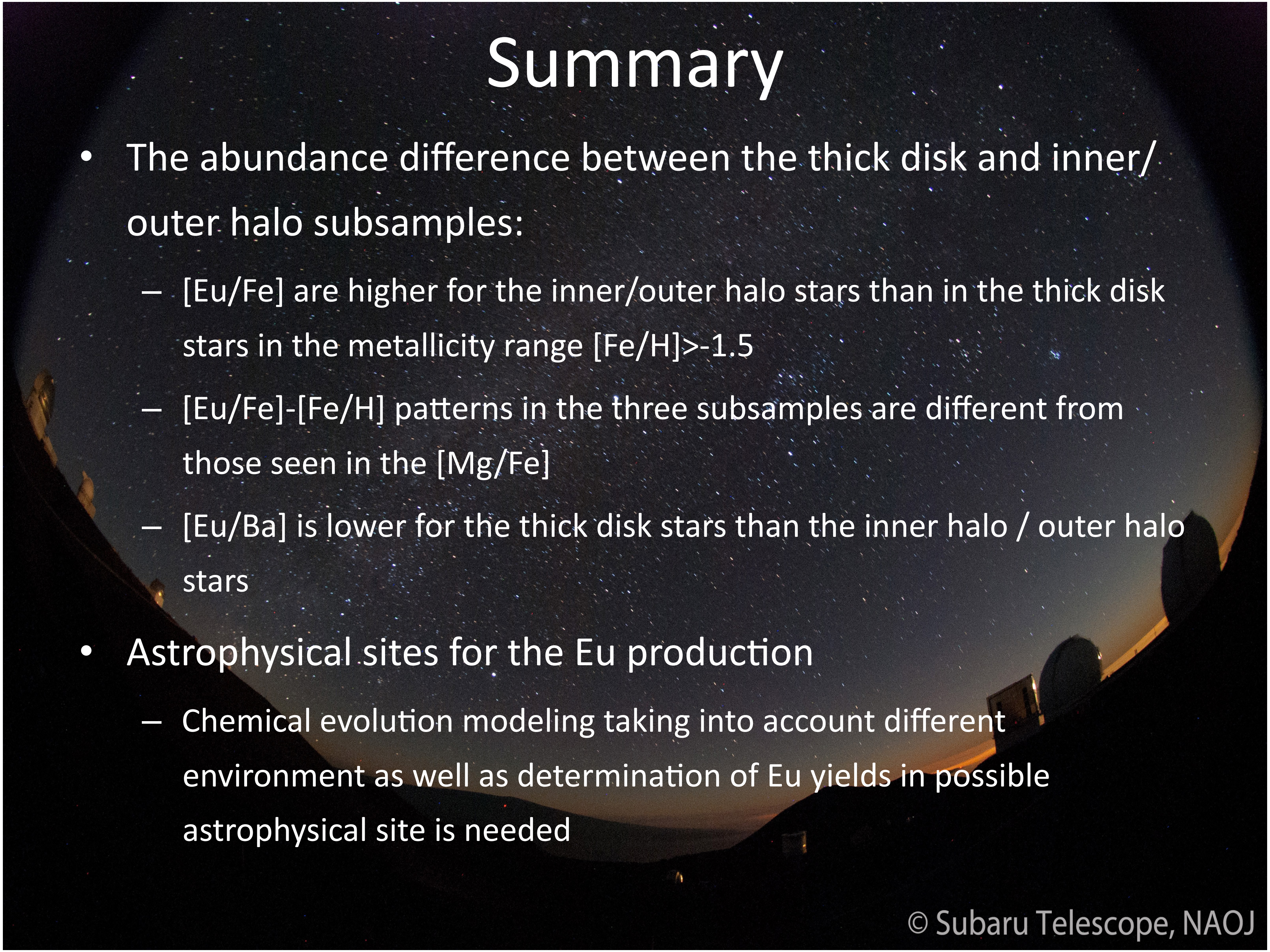
  ⇒ *These components experienced different chemical enrichment histories (e.g. relative contribution of Type II/Type Ia SNe, mixing of ejecta, gas infall or outflows)*

- Why [Eu/Fe] ratios are different between the thick disk and stellar halos?

  Difference in the behaviors of [Eu/Fe] and [Mg/Fe] as a function of [Fe/H]

  ⇒ *Dominant production site of Eu is different from that of Mg (e.g. Type II SNe of of different mass ranges)*

- A confirmation with a larger sample size is needed
- Interpretation depends on Eu yields in possible astrophysical sites
- Chemical evolution models for systems having various chemical enrichment histories



Summary

- The abundance difference between the thick disk and inner/outer halo subsamples:
  - [Eu/Fe] are higher for the inner/outer halo stars than in the thick disk stars in the metallicity range [Fe/H]>-1.5
  - [Eu/Fe]-[Fe/H] patterns in the three subsamples are different from those seen in the [Mg/Fe]
  - [Eu/Ba] is lower for the thick disk stars than the inner halo / outer halo stars
- Astrophysical sites for the Eu production
  - Chemical evolution modeling taking into account different environment as well as determination of Eu yields in possible astrophysical site is needed