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NIC-XI

A systematic study of Extremely Metal-Poor Stars with SDSS/Subaru

Sextans A galaxy
(Subaru Telescope)

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What can we learn from Extremely Metal-Poor (EMP) stars?

(1) Individual nucleosynthesis processes
(in early generations of stars)

(2) Constraints on low-mass star formation
at lowest metallicity

(3) Formation of the Milky Way halo

- Extremely Metal-Poor (EMP) stars: $[Fe/H]<-3$
- $[Fe/H]=\log(n[Fe]/n[H])-\log(n[Fe]/n[H])_{sun}$

What are required for observational studies of EMP stars?

•EMP stars are extremely rare around the solar system.

→wide-field & deep survey is required

•Spectral lines are weak (depending on temperature).

→high resolution spectroscopy is required.

Search for metal-poor stars by Sloan Digital Sky Survey (SDSS)

The 2.5m telescope at Apache Point Observatory

- SDSS spectroscopy:
  R~1800
  Covering 3900-9000A
  14<V<20
- Metallicity estimate from Ca II HK lines
- Standard stars in SDSS-I
- New surveys in SDSS-II (SEGUE)→240,000 stars

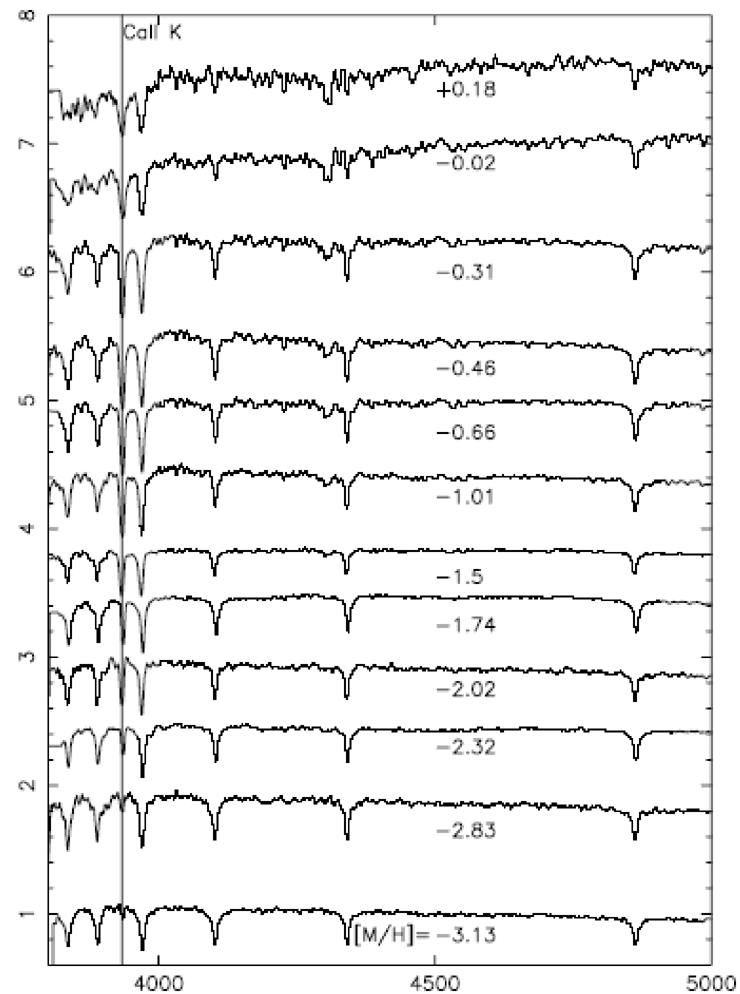
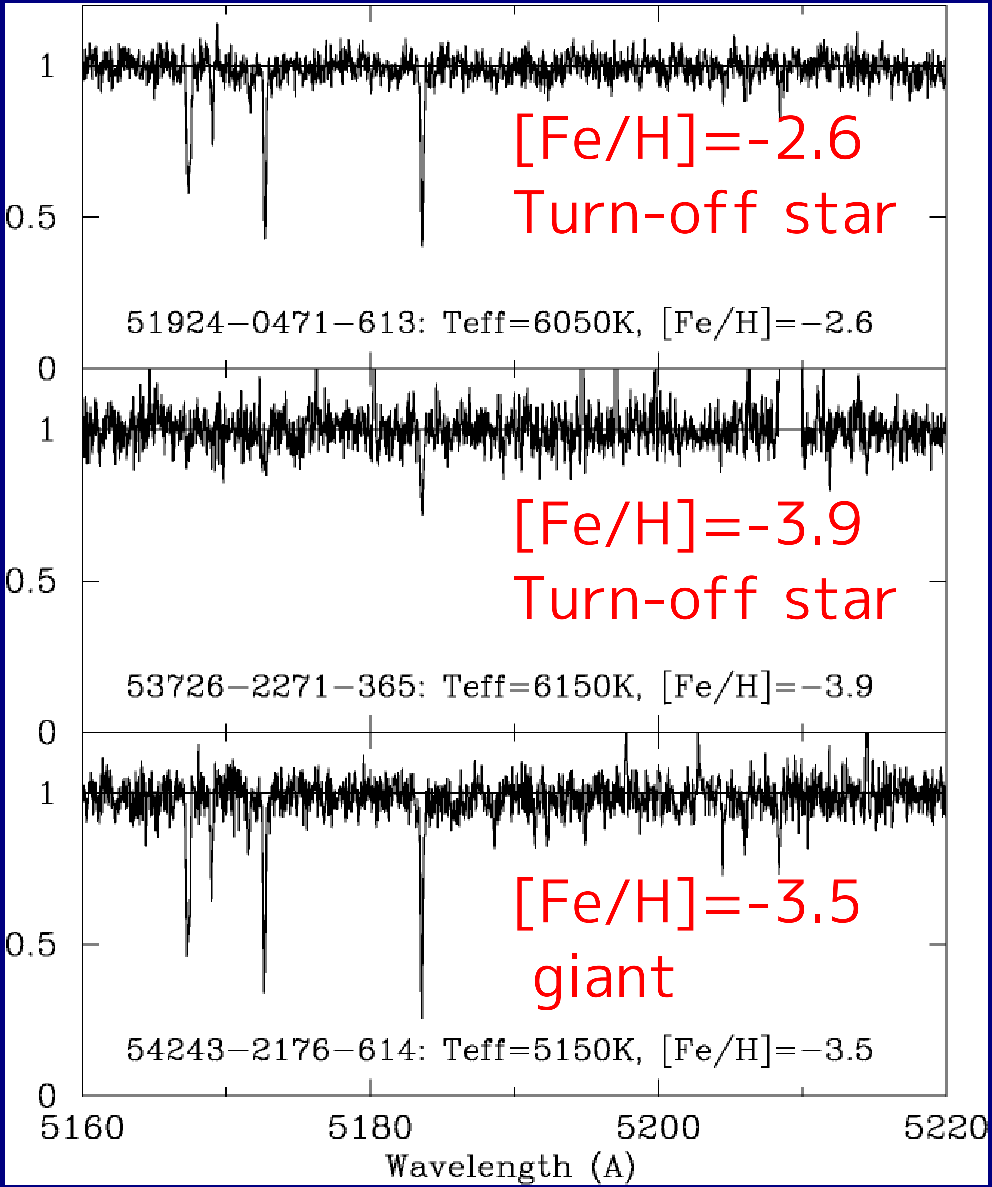


Figure 7. F star metal sequence—a set of SEGUE F stars, selected to show the range of metallicities sampled by the F subdwarf, F/G, spectrophotometric standard and reddening standard categories. All 13 stars have similar effective temperatures, near 6500 K, but the strength of the Ca K line at λ3933 indicates metallicities ranging from less than 0.001–1.5 times Solar.

High-resolution follow-up spectroscopy with Subaru/HDS

- R=30,000
- 4030-6800A
- S/N~25-30
- ~150 objects

Example: Mg triplet around 5170A →



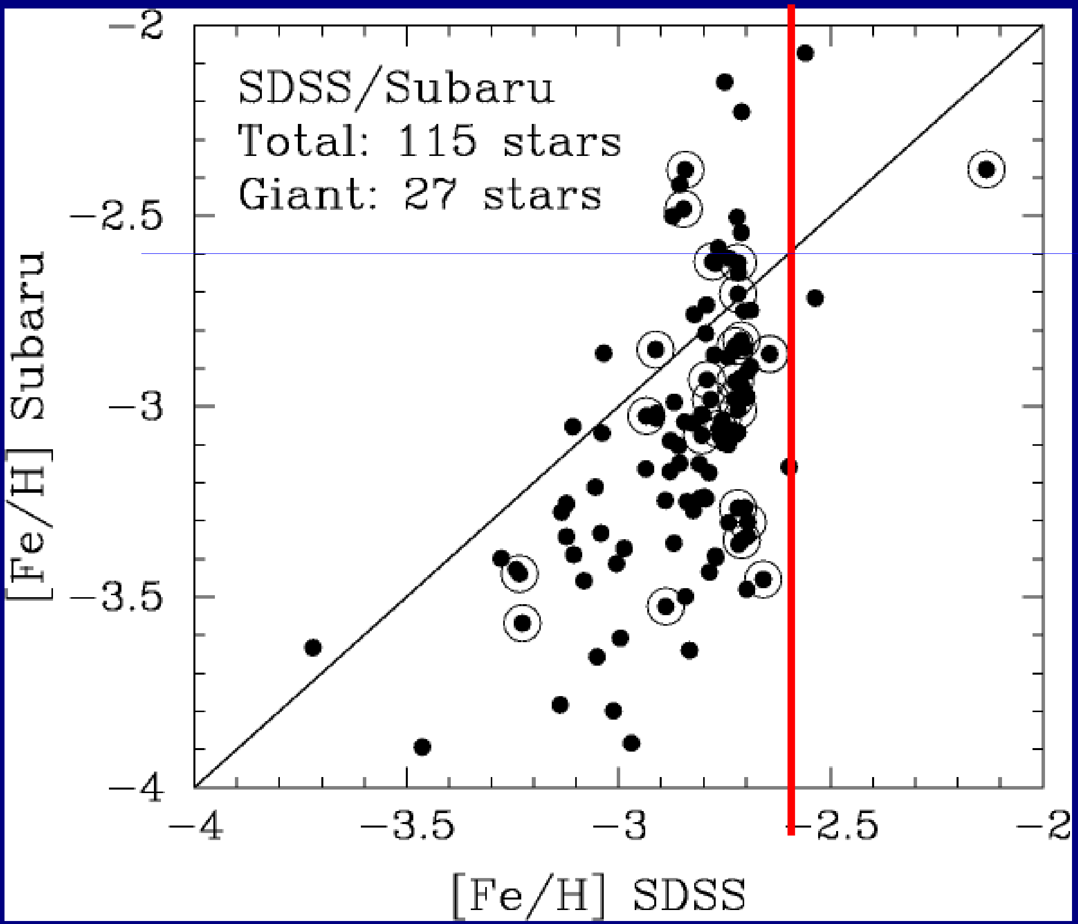
High S/N spectra with R=60,000 for ~15 selected stars have been obtained.

Metallicity ([Fe/H]) from Subaru spectra and comparison with SDSS estimates

- EMP stars are very efficiently selected from SDSS spectra

- High-res spectroscopy is required to accurately determine the metallicity for [Fe/H]<-3

- [Fe/H] estimates depend on Teff scale
  →a systematic error in the high-res estimate?



(estimates in 2008)

Subaru High resolution spectroscopy for EMP stars found by SDSS

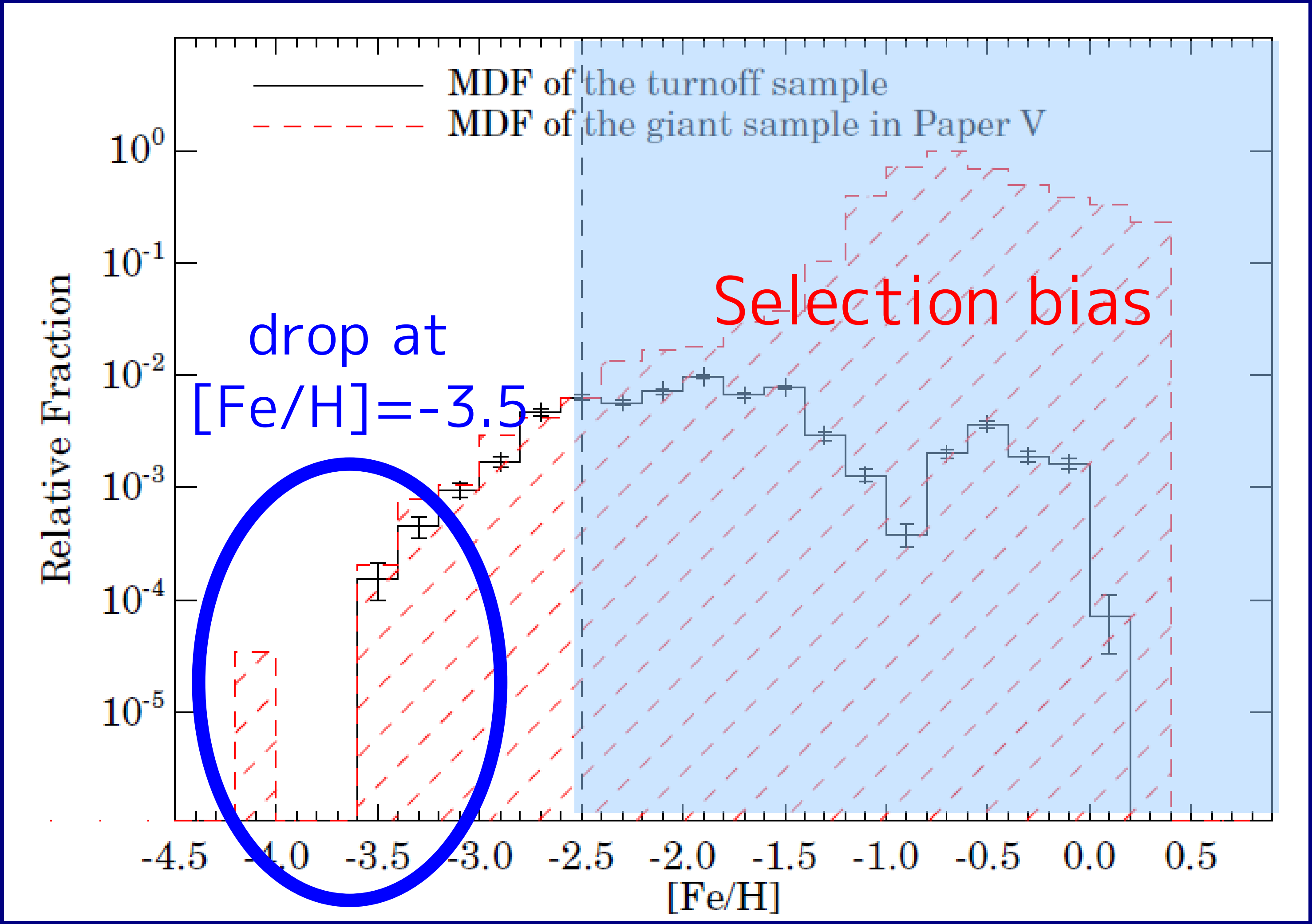
today's topics

- Metallicity distribution function (MDF) in the lowest metallicity range ([Fe/H]<-3)

- An r-process-enhanced cool main-sequence star with [Fe/H]=-3.4

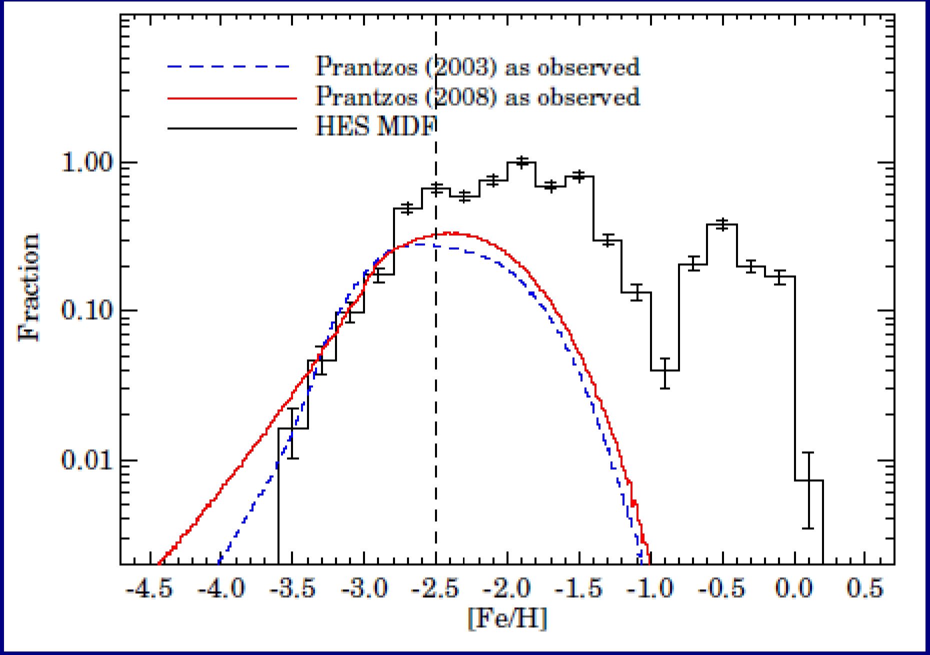
Metallicity Distribution Function (MDF) estimated from Hamburg/ESO survey + medium-resolution (R=2000) spectroscopy

Li et al. (2010)

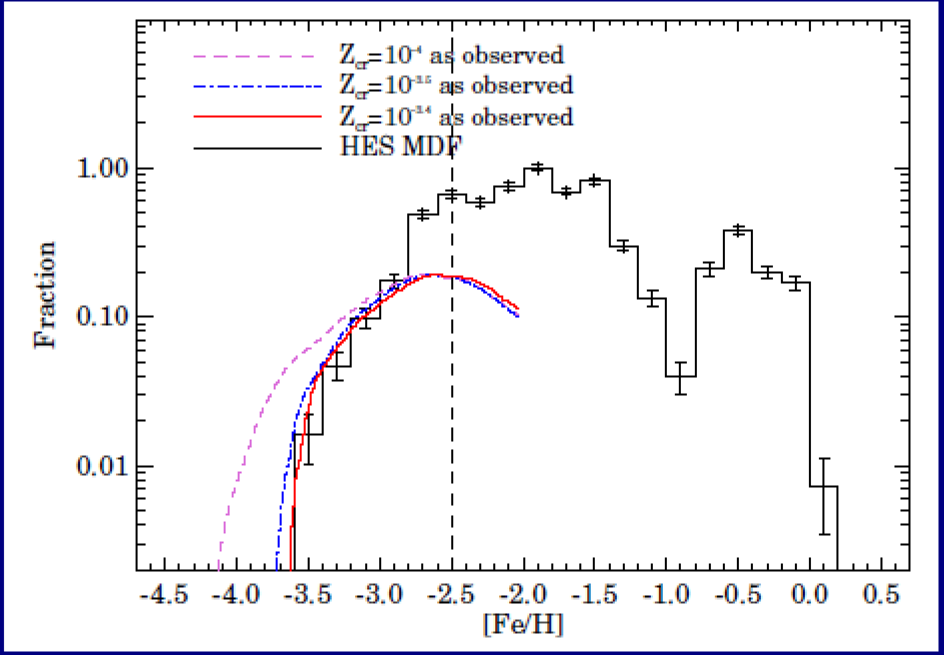


Comparisons with chemical evolution models

Comparison with models assuming gas infall or hierarchical merging scenario by Pranzos (2003, 2008)



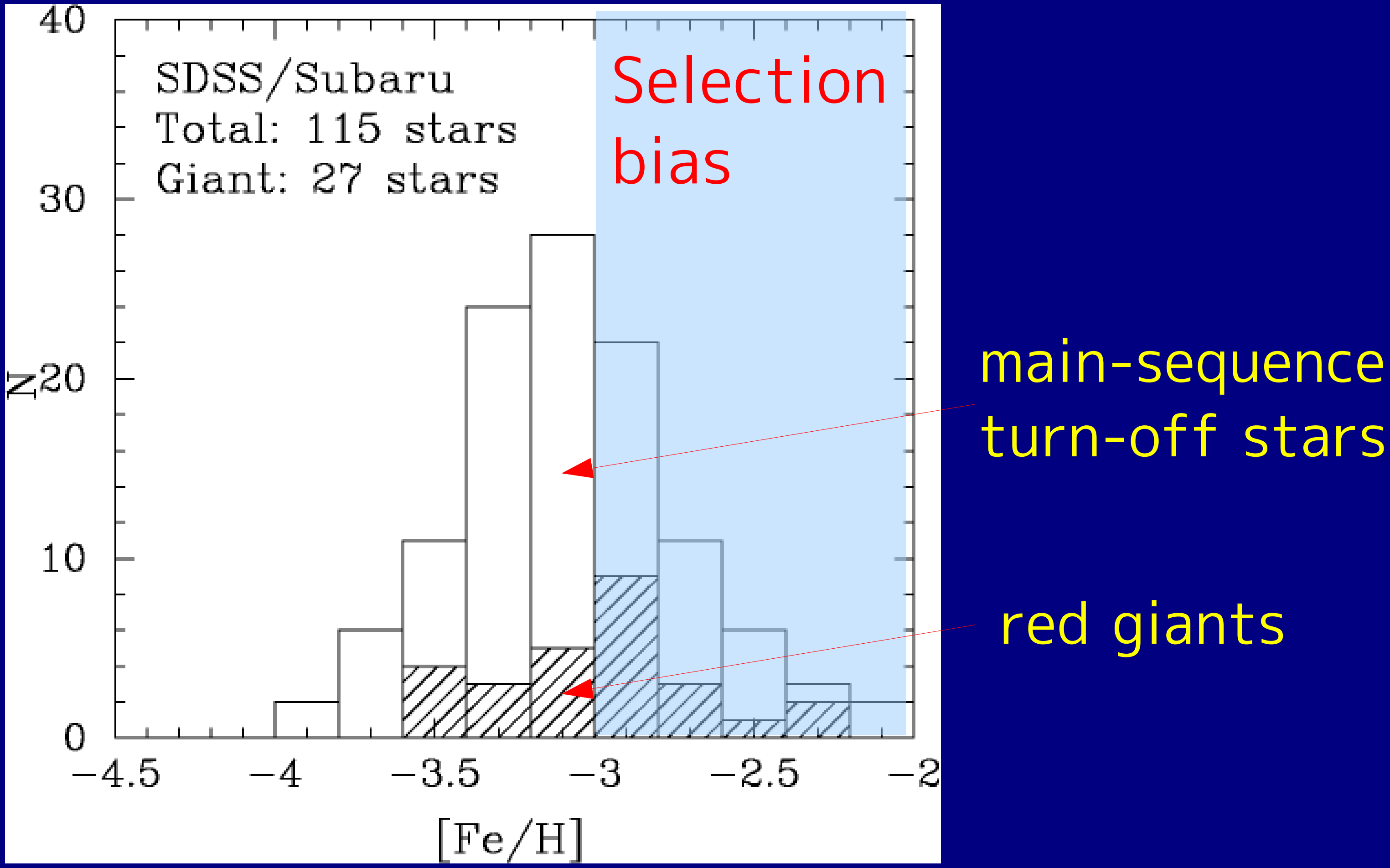
Comparisons with models assuming critical metallicity for low-mass star formation by Salvadori et al. (2007)



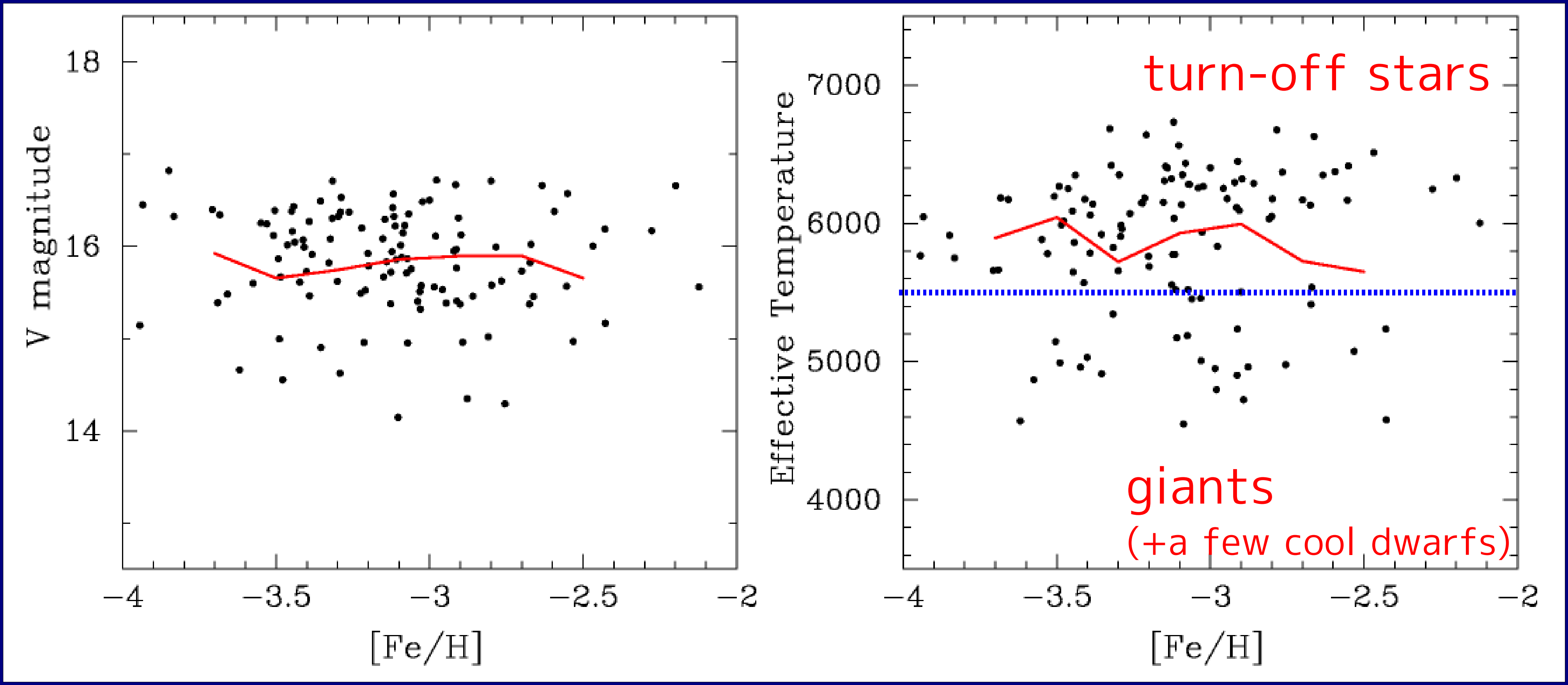
Li et al. (2010)

Metallicity distribution of the SDSS/Subaru sample

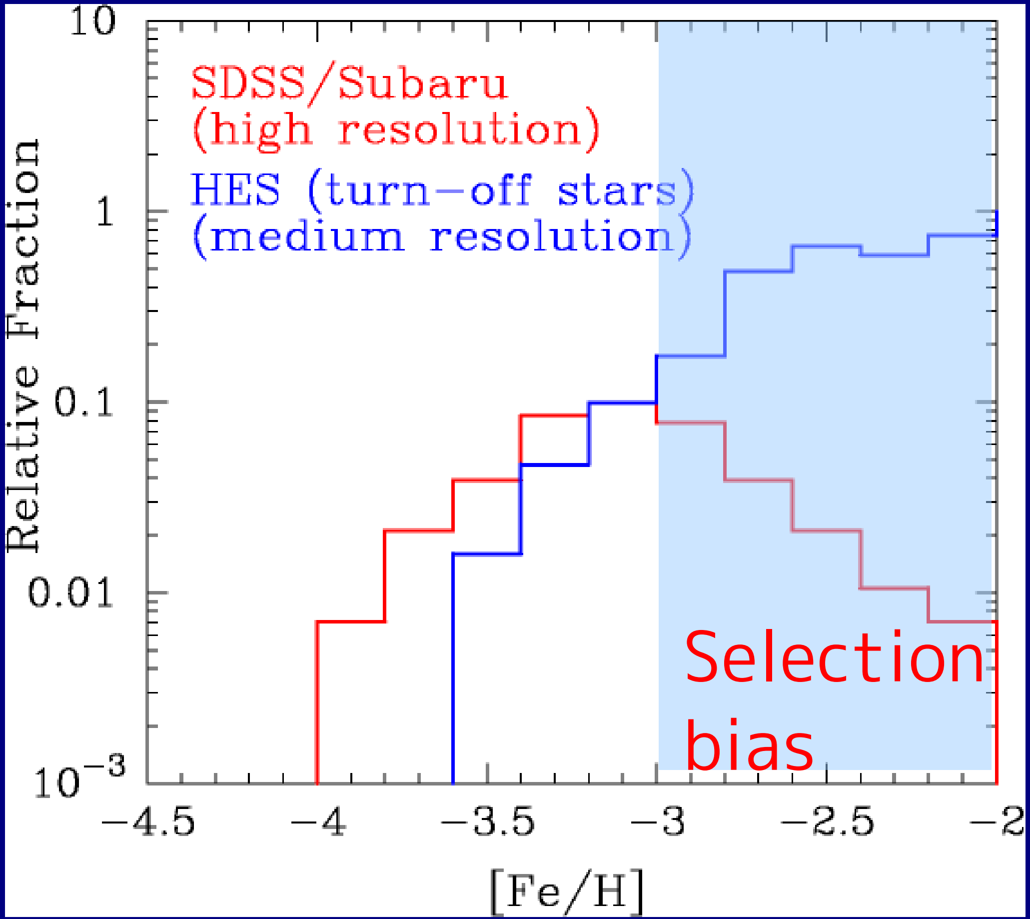
Metallicity is determined from Fe lines in high resolution spectra



Homogeneity of the sample:
No trend exists for V magnitude and temperature



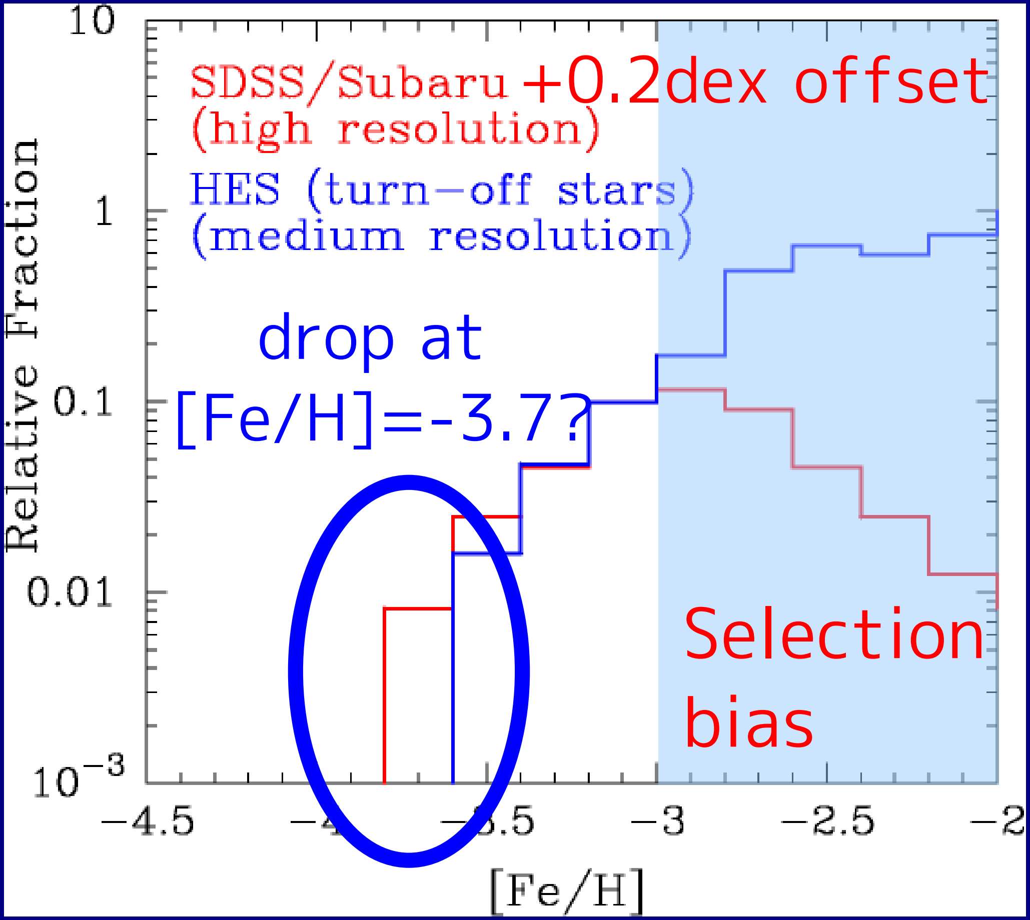
Comparison of the MDFs of the SDSS/Subaru sample with the HES result (Li et al. 2010)



Excess of [Fe/H]<-3.2 in our sample, or incompleteness of our sample at [Fe/H]=-3?

Comparison of the MDFs of the SDSS/Subaru sample with the HES result (Li et al. 2010)

A 0.2dex metallicity offset is assumed for our sample

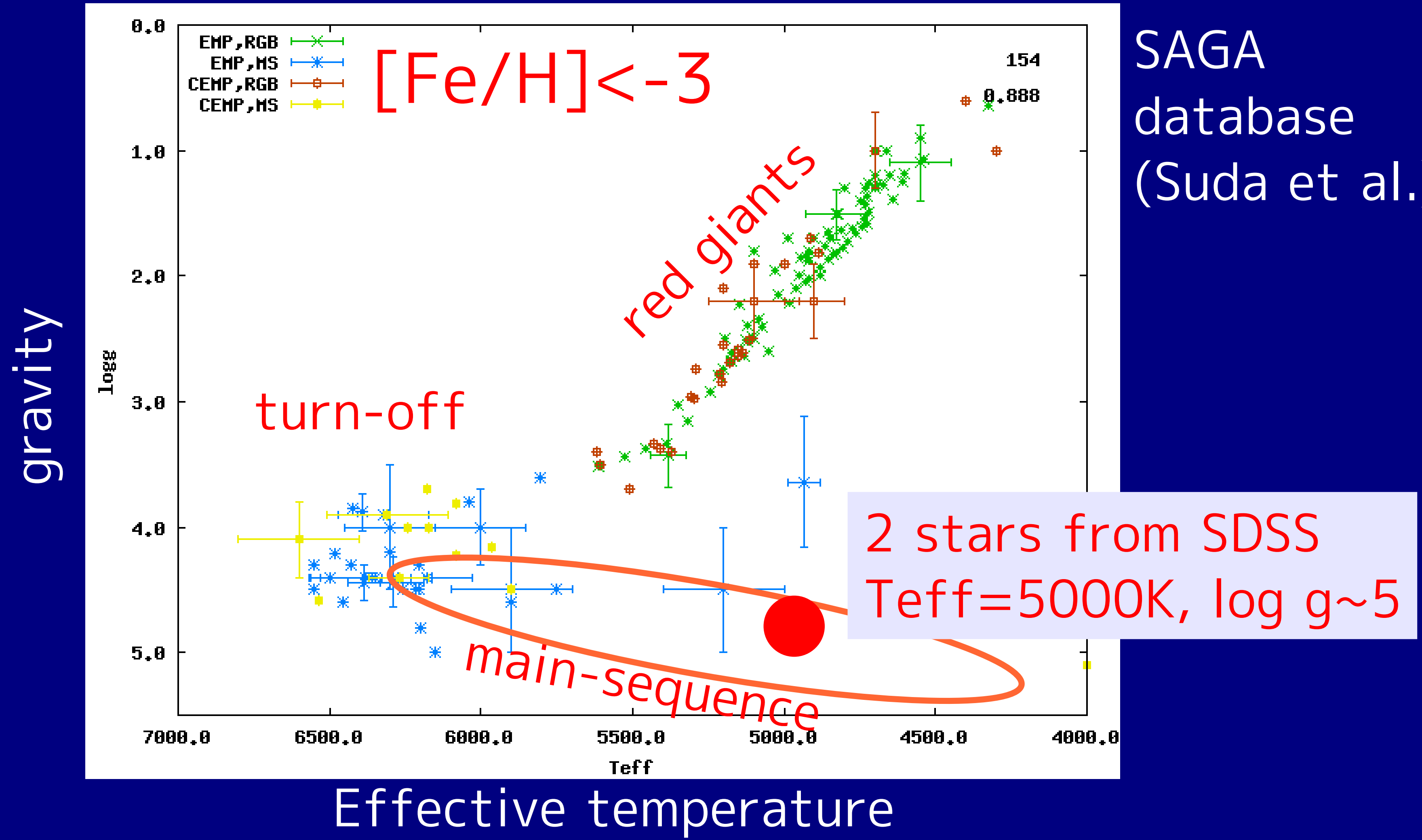


Metallicity Distribution Function estimated from the SDSS/Subaru sample for [Fe/H]<-3

- A good agreement with the HES estimates from medium resolution spectroscopy is found for [Fe/H]>-3.5 (after some corrections)
  →Further calibration is required between high-resolution and medium-resolution spectroscopy

- A drop of MDF is also suggested at [Fe/H]~-3.7, but that is not as sharp as found in HES estimates. The existence of stars with [Fe/H]<-3.5 in our sample will slightly modify the conclusions from the HES estimates.

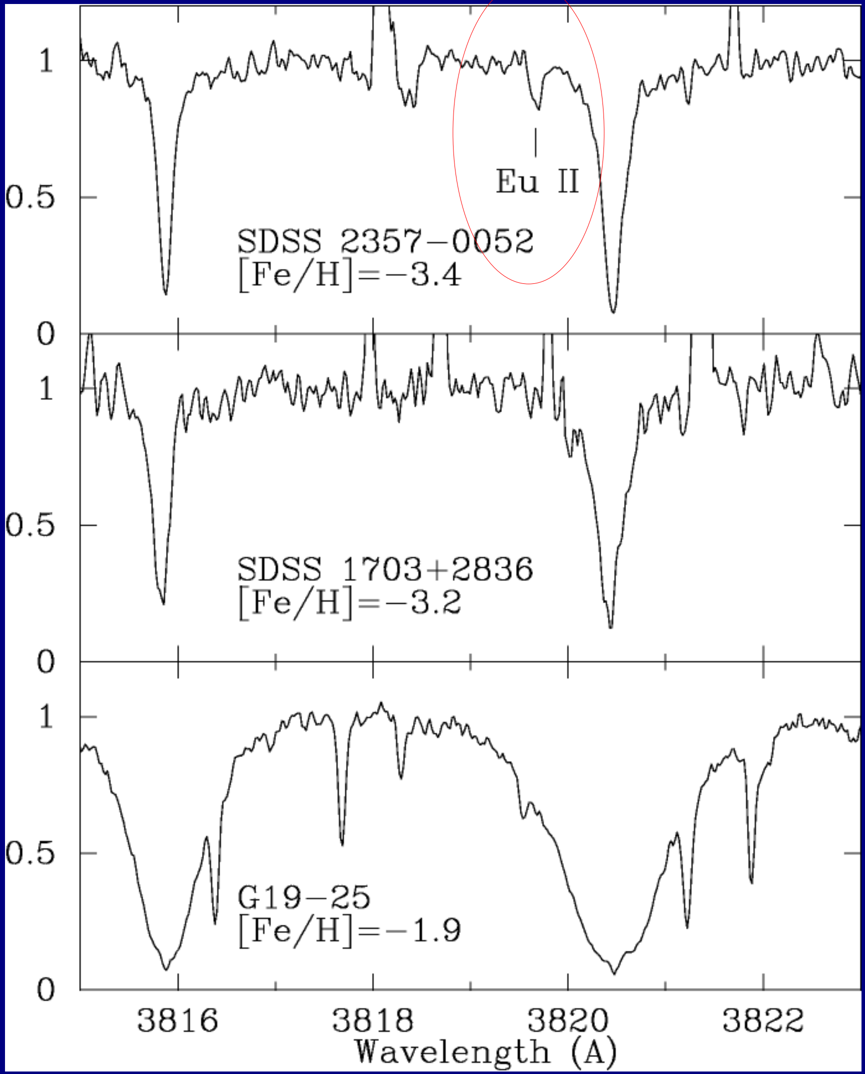
Discovery of a cool main-sequence star with [Fe/H]=-3.4 and large excesses of r-process elements

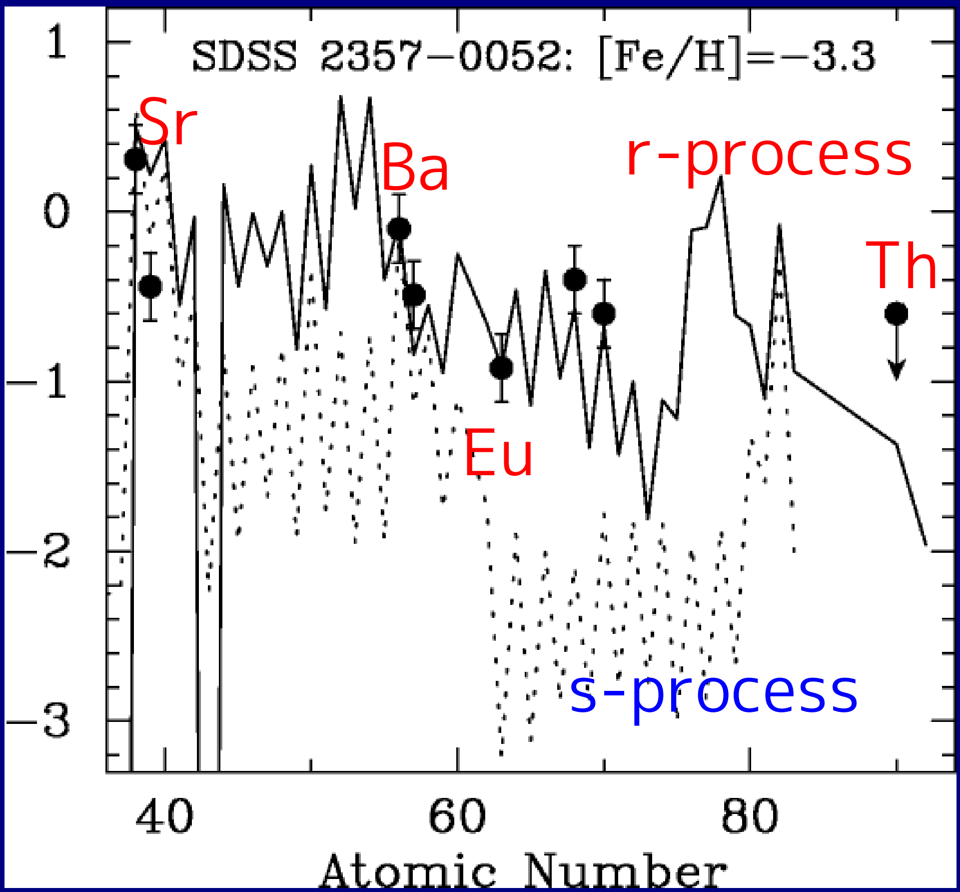


SAGA database (Suda et al.)

r-process enhancement in a cool main-sequence star with [Fe/H]=-3.4

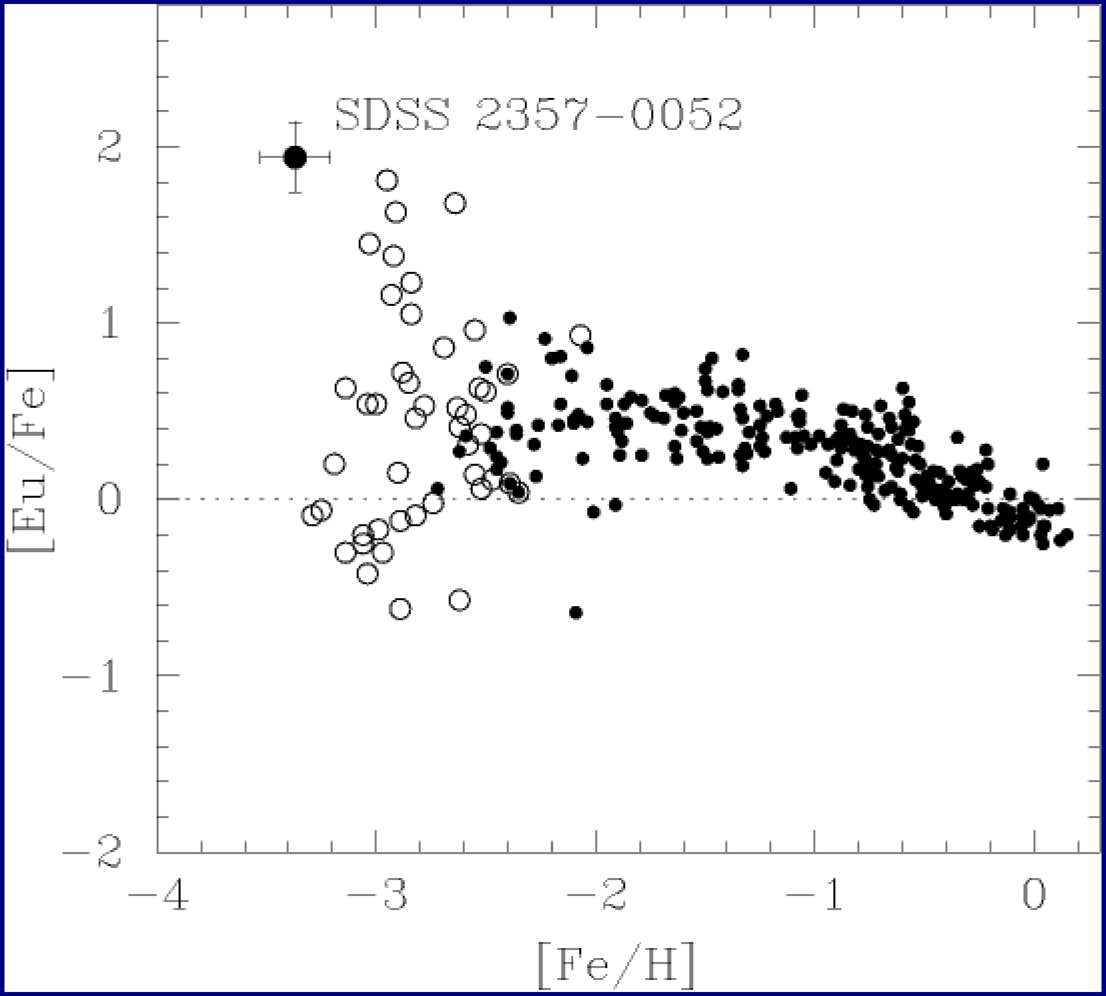
SDSS 2357-0052 has [Fe/H]=-3.4 and [Eu/Fe]=+1.9 with r-process abundance pattern





Aoki et al. (in prep.)

SDSS 2357-0052 has [Fe/H]=-3.4, the lowest metallicity among extremely r-enhanced stars



Discovery of a cool main-sequence star with [Fe/H]=-3.4 and large excesses of r-process elements

- r-process-enhanced ([Eu/Fe]>+1) stars have been found only at [Fe/H]~-3 by previous studies, but the metallicity range extends to [Fe/H]=-3.4.
  →constraints on the mass range of supernova progenitors related to r-process?

- There seems to be an upper bound of r-process-excesses of [Eu/H]~-1.5 ([Eu/Fe]=+1.5 at [Fe/H]=-3), suggesting the existence of limits in the pollution of interstellar matter by a single r-process event.

A systematic study of Extremely Metal-Poor Stars with SDSS/Subaru (summary)

High-resolution follow-up spectroscopy has been conducted for 150 candidates for EMP stars.

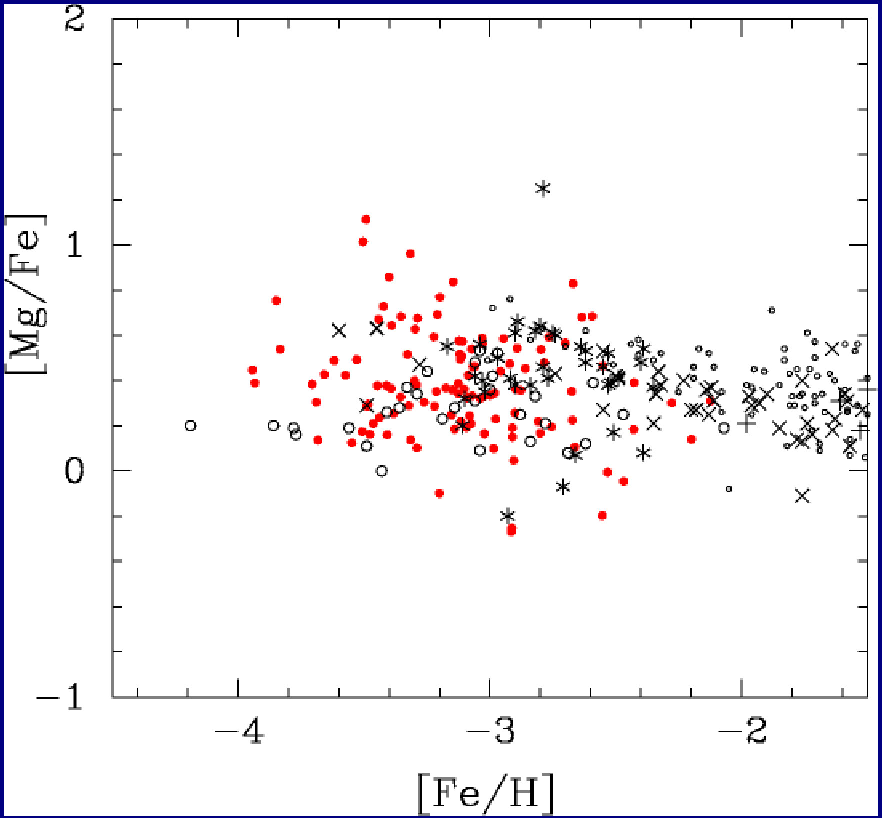
•A new estimates of metallicity distribution function is obtained for [Fe/H]<-3.

•Discovery of anr-process enhanced star at [Fe/H]=-3.4

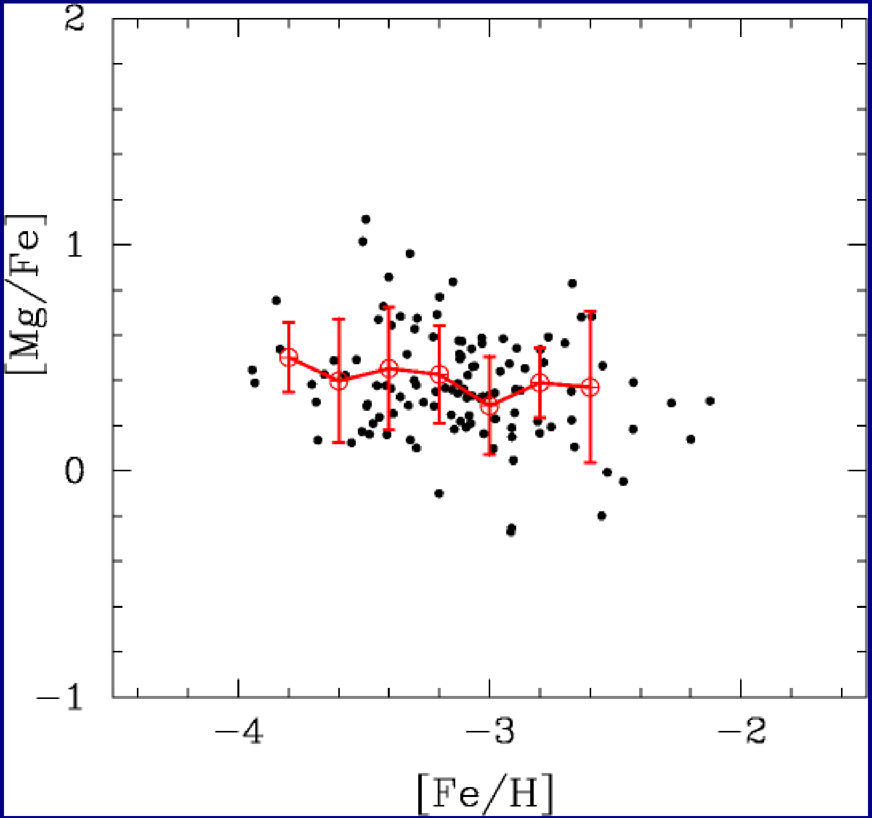
Further abundance studies for other elements (e.g. Mg, Ba etc.) for a large sample, and detailed abundance studies for several stars with [Fe/H]<-3.5 are ongoing.

Mg abundance ratios of SDSS/Subaru sample

comparisons with previous studies



average and standard deviation



Extremely Metal-Poor stars in the Milky Way halo found by SDSS/SEGUE

Chemical abundance studies of metal-poor stars:

- survey of metal-poor stars from (low- and) medium-resolution spectroscopy
  - e.g. HK survey (Beers et al. 1985)
  - Hamburg/ESO survey (Christlieb et al.)
  - SDSS/SEGUE (Yanny et al. 2009)

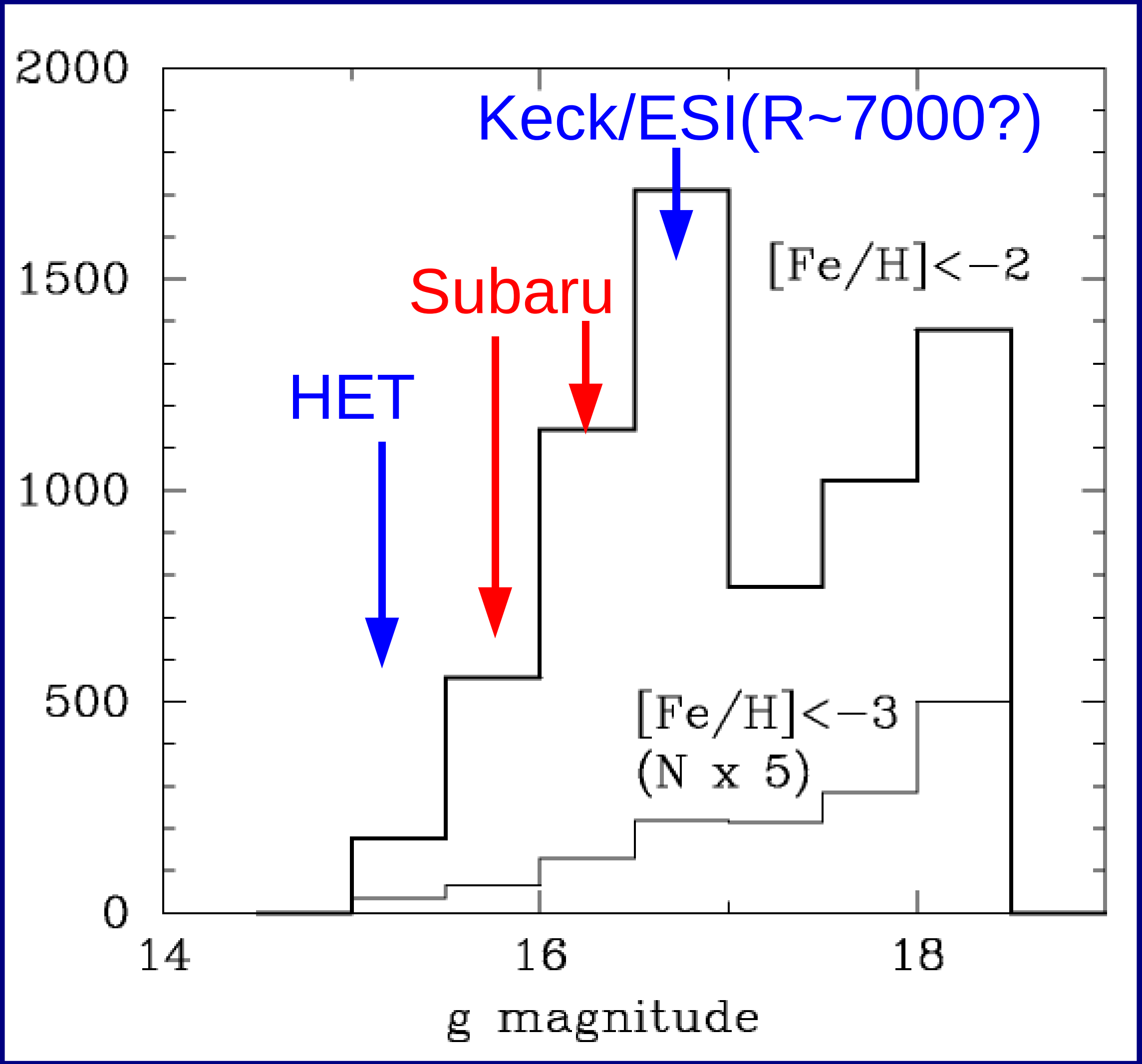
- high resolution spectroscopy of candidates for (extremely) metal-poor stars with large telescopes

Strategy of the program

Two steps of high-resolution spectroscopy with Subaru for SDSS/SEGUE obiects

(1)Moderate R & S/N

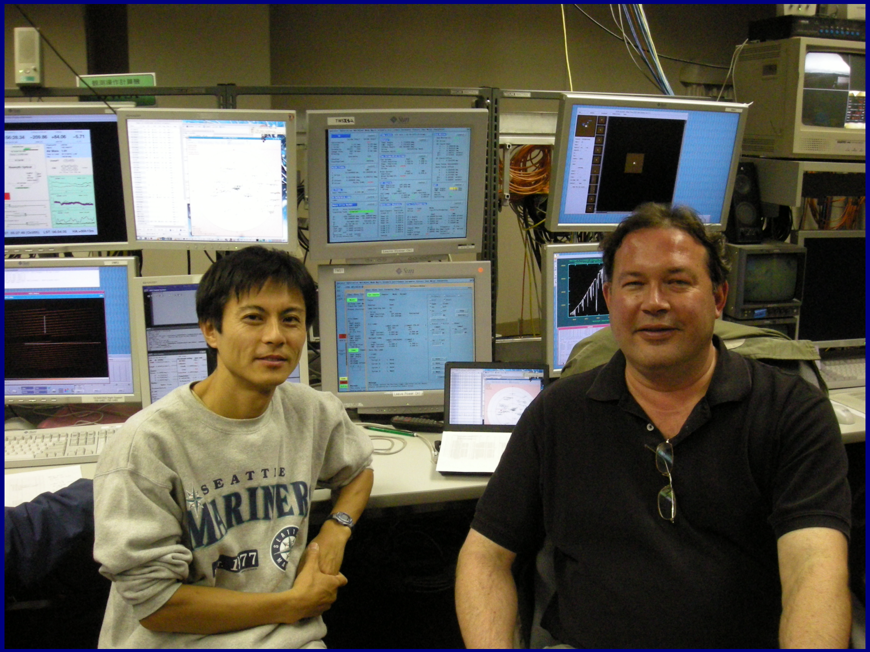
- R=30,000
- S/N~30
- ~150 objects
- →metallicity
  - C/Fe
  - α/Fe



(2)High R & S/N

- →detailed abundance pattern
- Li (turn-off stars)

Project team



- SDSS/SEGUE sample selection
  Calibration of SDSS analysis
  Beers, Sivarani, Carollo

- Moderate S/N survey:
  Aoki, Honda, Hidai

- High S/N study: Li abundances, neutron-capture elements, etc.: Honda, Ito, Aoki, others

- Collaborations with programs with other telescopes
  Frebel, Norris

- Interpretation : Fujimoto, Suda

Thirty Meter Telescope (TMT)

The construction site was decided to be Hawaii.
The first light is planed in 2018.