The metallicity distribution of Sr-enhanced metal-poor stars

Wako Aoki (NAOJ)
Satoshi Honda (Kyoto Univ.)
Timothy C. Beers (MSU)
Takuma Suda (NAOJ)

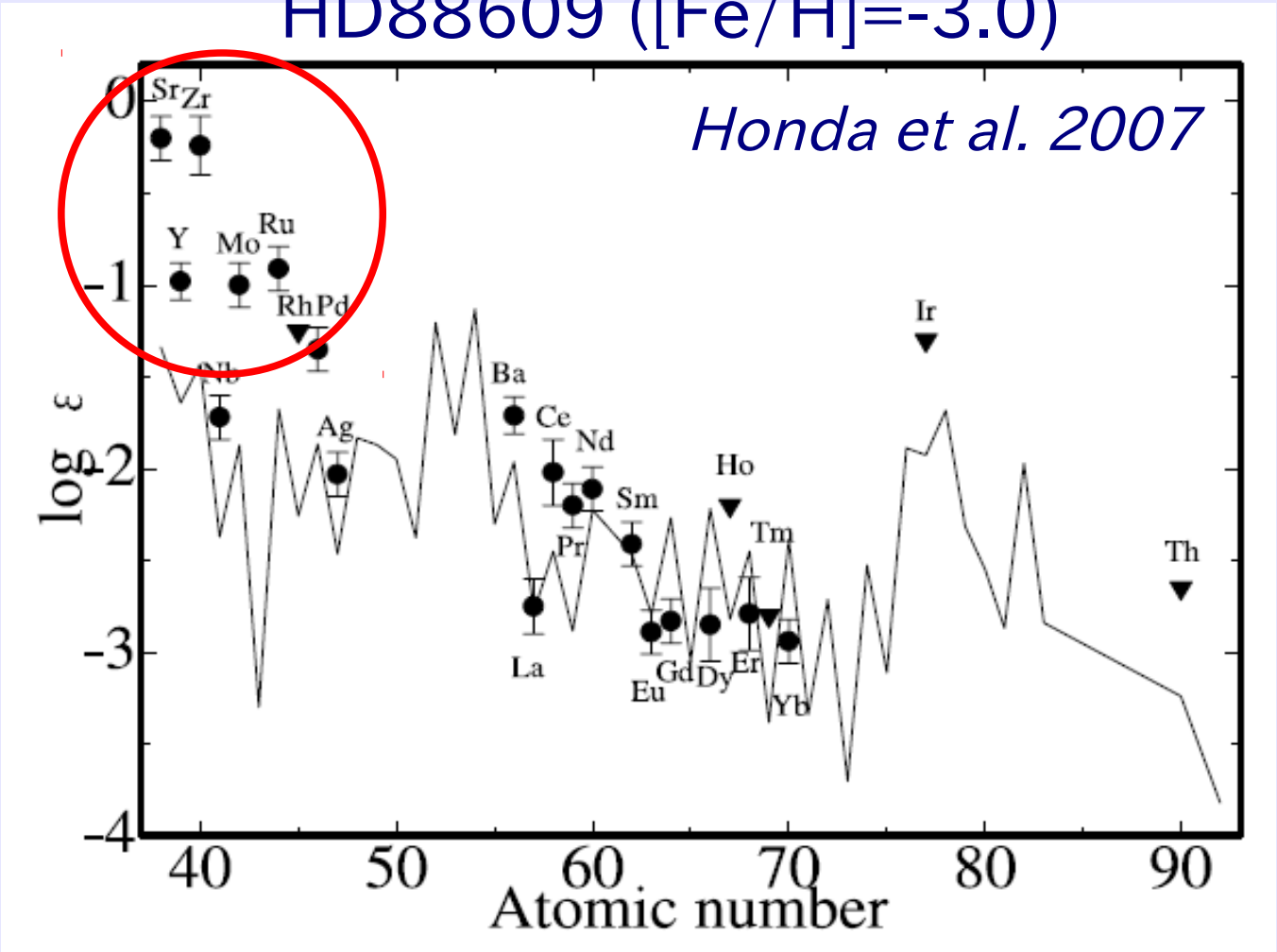
The metallicity distribution of Sr-enhanced metal-poor stars

- Overview: LEPP found in metal-poor stars
- Distribution of Sr and Ba abundances in metal-poor stars in SAGA database
- Sr-enhanced stars of a new sample:
  the nature of a Sr-enhanced star with [Fe/H]=-3.7

1. Overview

Abundance patterns produced by LEPP can be investigated from very metal-poor stars

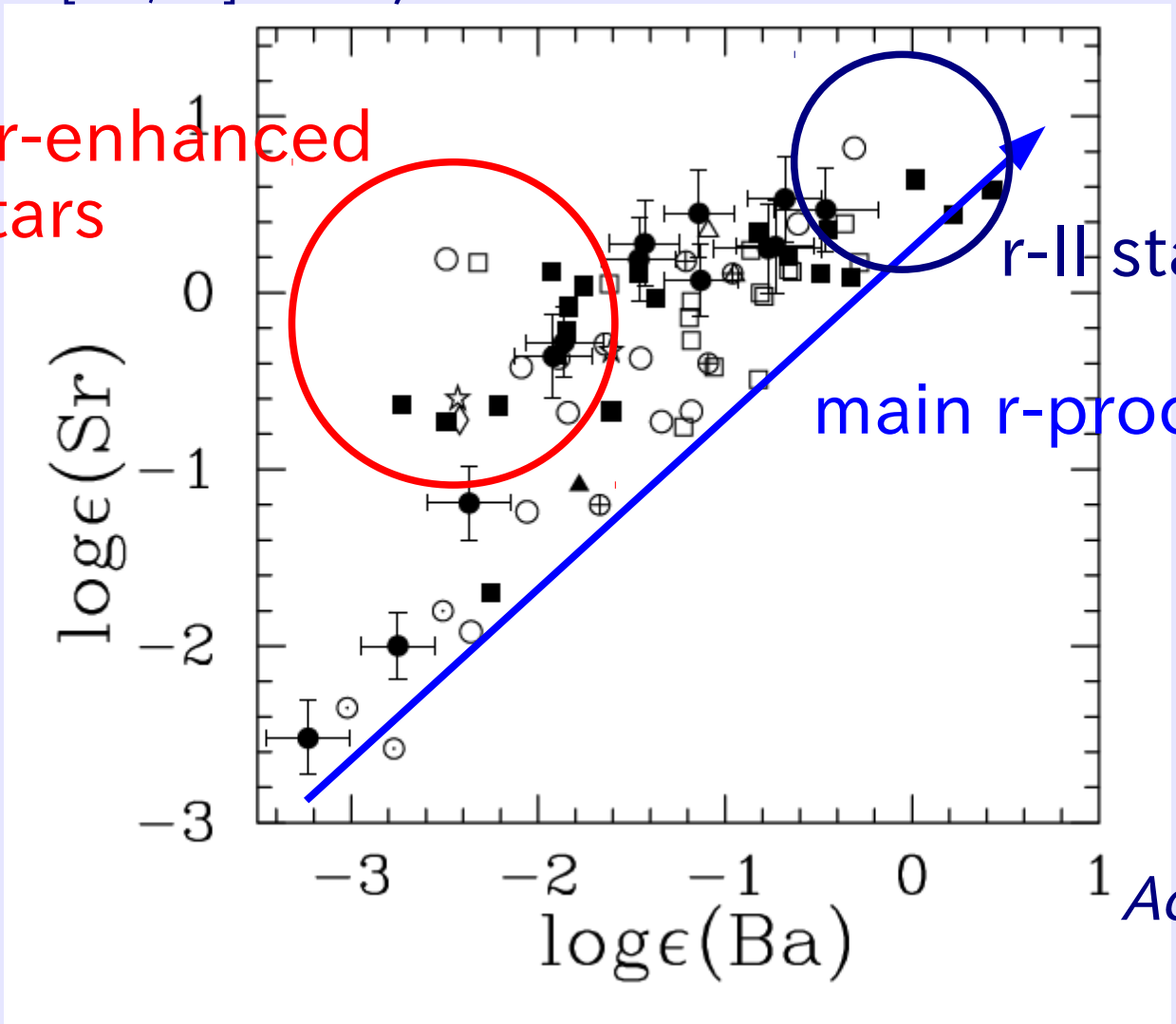
HD88609 ([Fe/H]=-3.0)



1. Overview

Signature of LEPP in very/extremely metal-poor stars

[Fe/H]<-2.5, carbon-rich stars are excluded

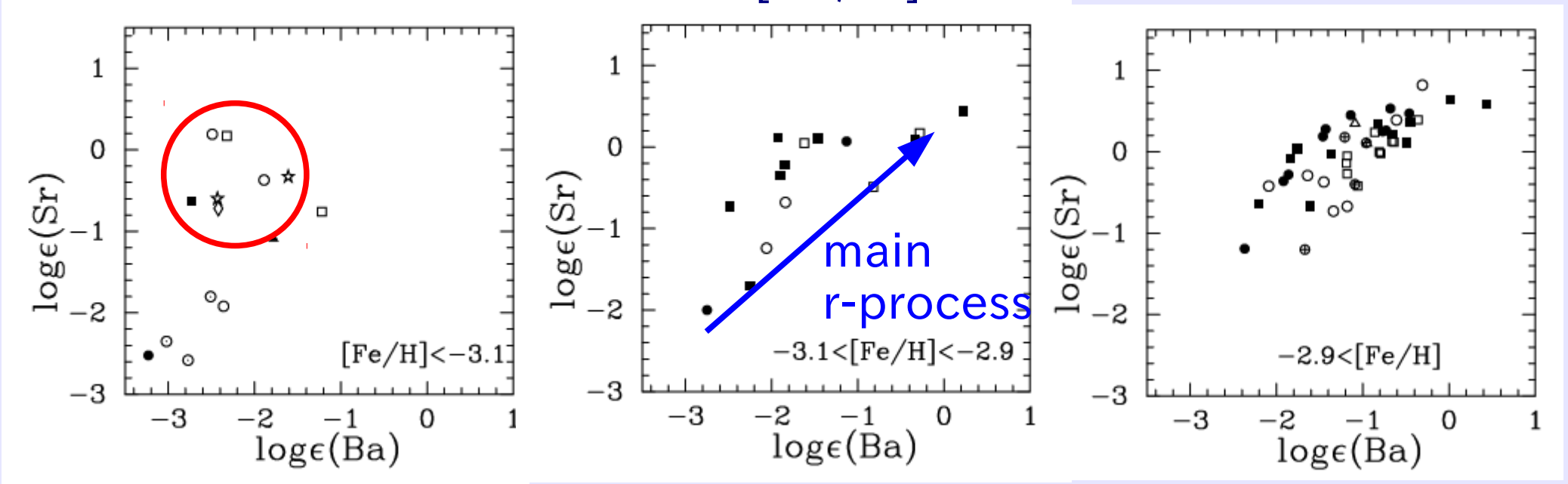


Aoki et al. 2005

1. Overview

LEPP has larger contributions at lower metallicity: contributions of main r-process become dominant in [Fe/H]≧-3

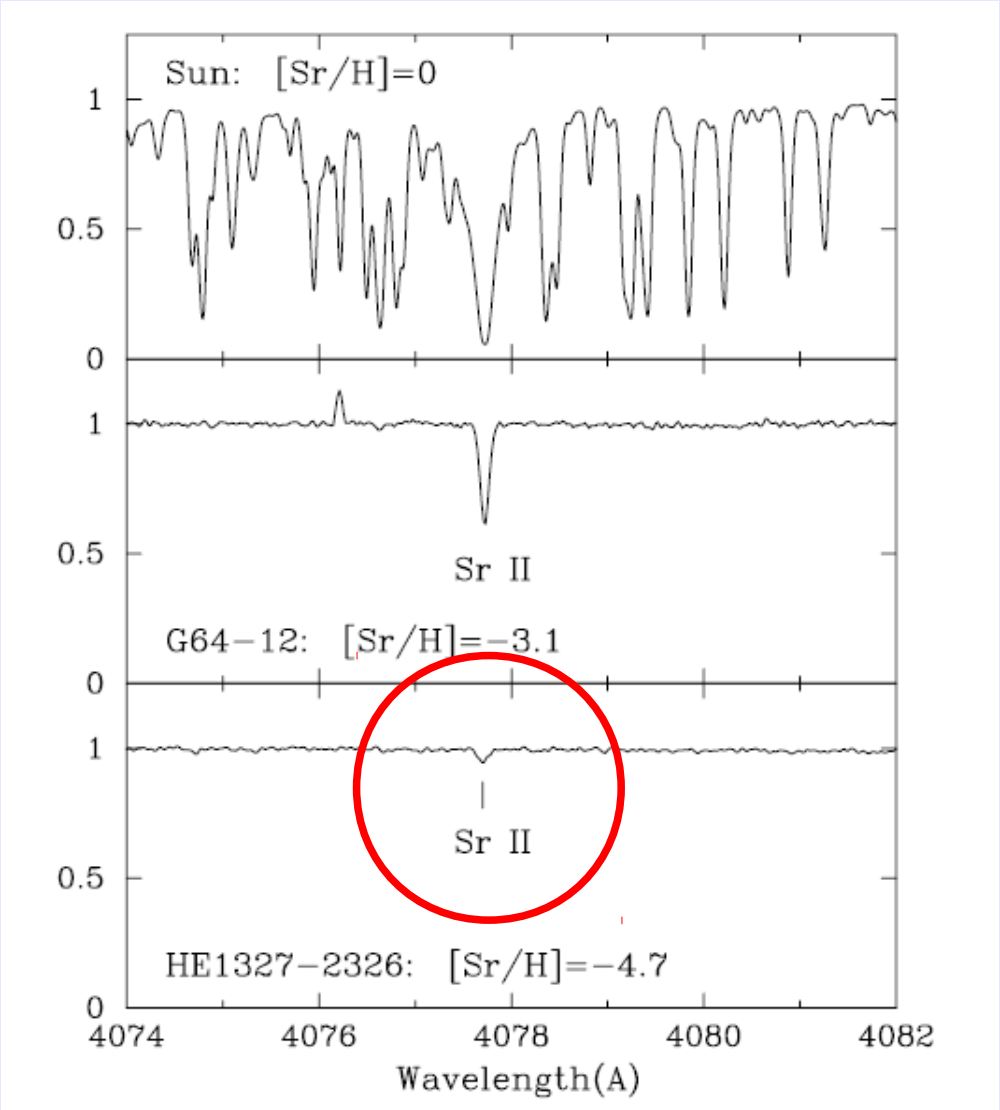
[Fe/H]<-3.1 -3.1<[Fe/H]<-2.9 -2.9<[Fe/H]



Aoki et al. 2005

1. Overview

The most iron-deficient star HE1327-2326: The most extreme case?



-[Fe/H]=-5.6
-[Sr/Fe]=+1.0
-Ba is not detected

However, this object is extremely carbon-enhanced ([C/Fe]>+3), and the total metallicity is not so low.

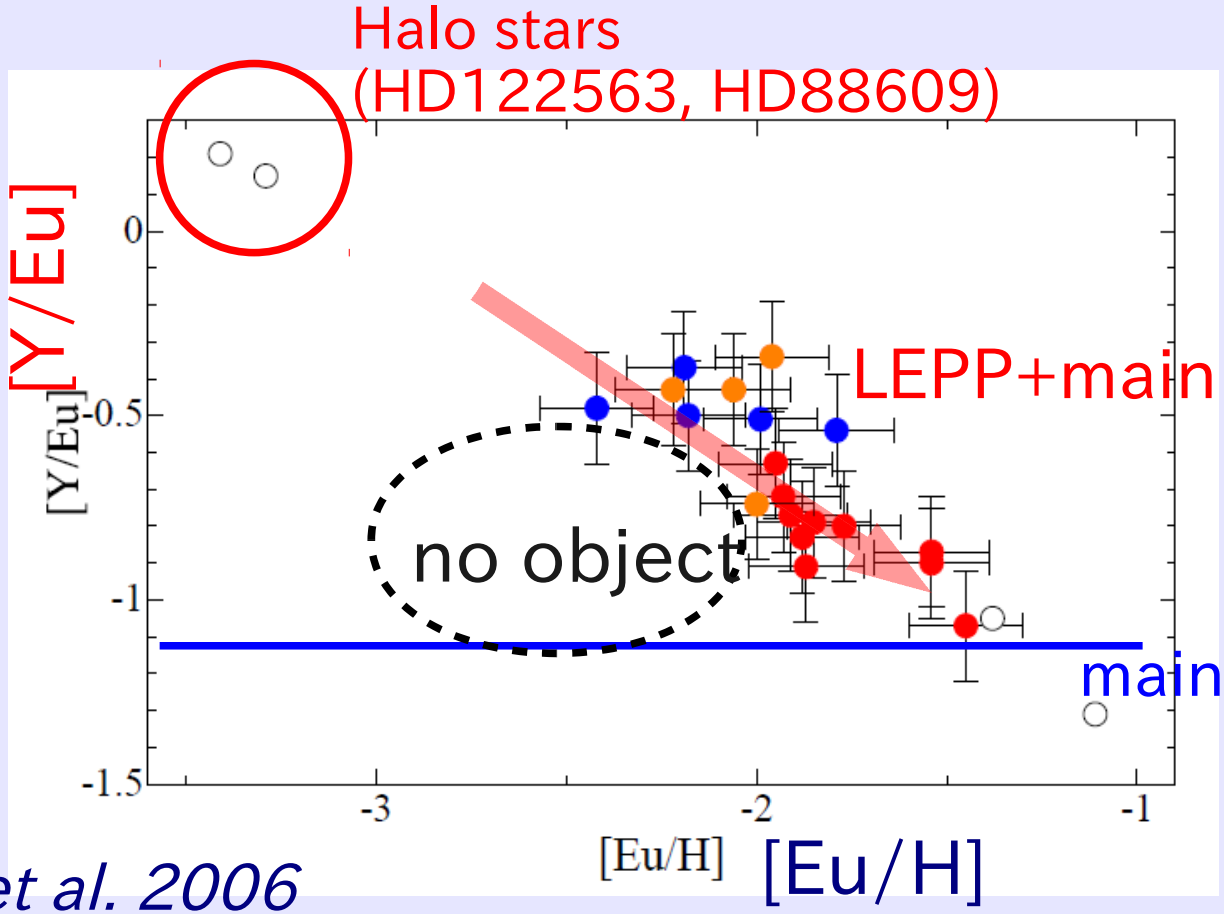
Frebel et al. 2005
Aoki et al. 2006

1. Overview

LEPP also appears in metal-poor globular clusters

M15●, M92●, M30●: [Fe/H]～-2.2

- Large scatter of contributions of main r-process.
- Contributions of LEPP



Otsuki et al. 2006
Honda et al. In prep.

1. Overview

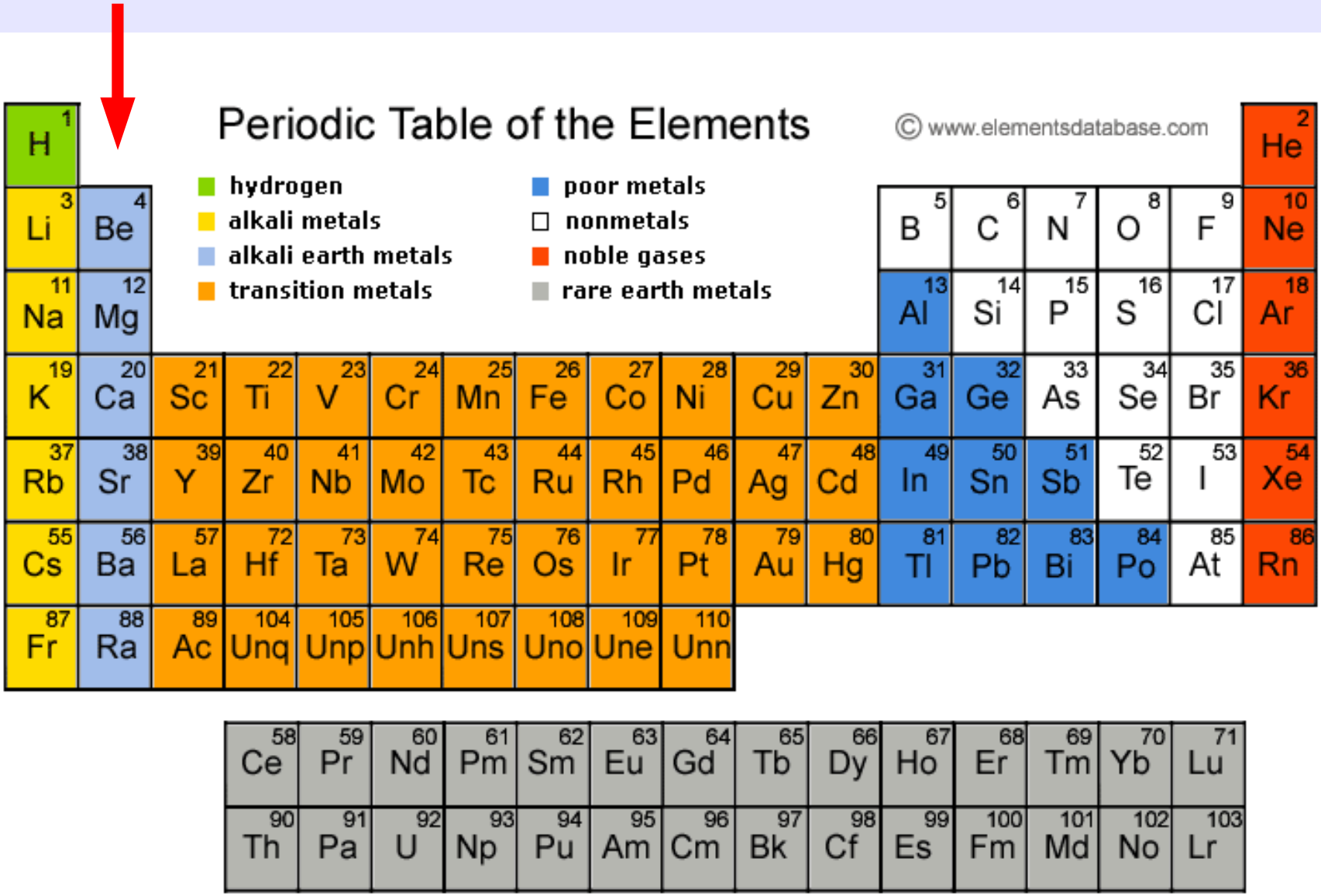
Sr-enhancement as an indicator of LEPP

- LEPP → enrichment of Sr, Y, Zr etc.

- Singly ionized Sr (as well as Ba) has strong resonance lines in the optical range
  → detectable even in extremely metal-poor stars

- Comparison with heavy n-capture elements is required
  → Ba is a useful indicator of (main) r-process (and s-process at low metallicity)

- Carbon-enhanced stars that also show excesses of main s-process elements are excluded from the sample.


Periodic Table of the Elements
© www.elementsdatabase.com
hydrogen
alkali metals
alkali earth metals
transition metals
poor metals
nonmetals
noble gases
rare earth metals
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
104 Unq
105 Unp
106 Unh
107 Uns
108 Uno
109 Une
110 Unn
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr

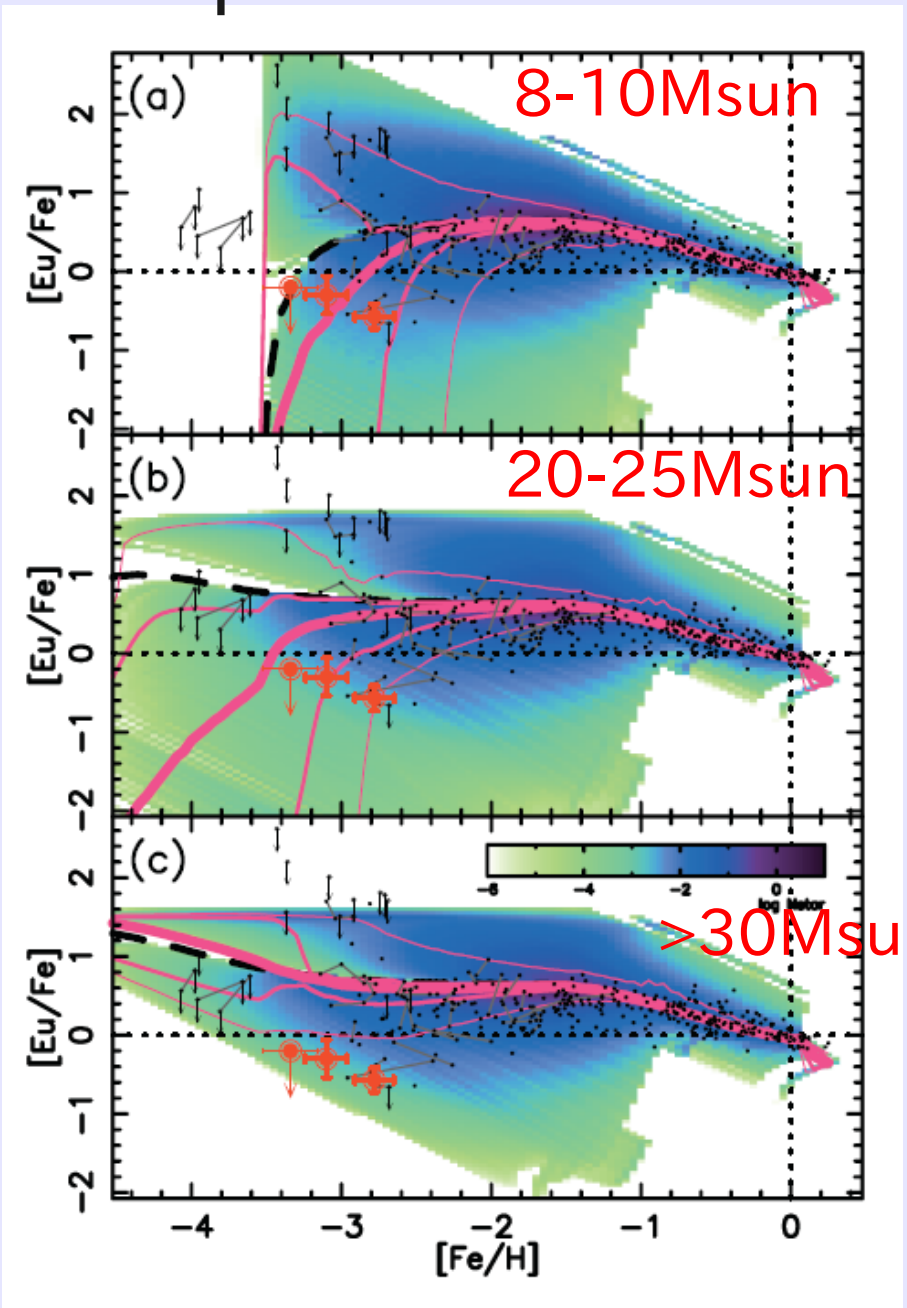
1. Overview

Metallicity dependence as a probe of the astrophysical sites

Metallicity dependence
→indirect estimate for mass of progenitors (model dependent)

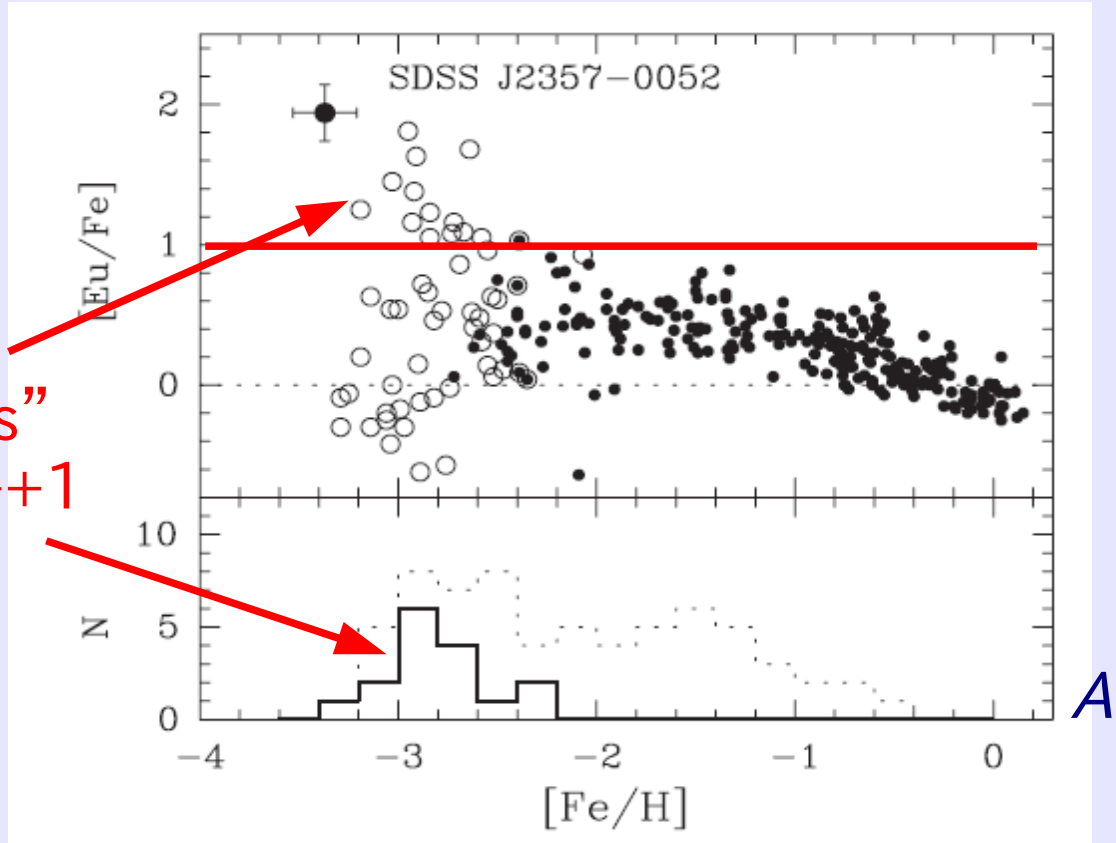
Example:
Trend and scatter of Eu abundances
→ less massive stars (8-10 Msun) are preferable as astrophysical sites of the main r-process.

Ishimaru et al. 2004



1. overview

Metallicity distribution of r-process-enahnced stars



“r-II stars”
[Eu/Fe]>+1

Aoki et al. 2010

Eu is the best indicator of the (main) r-process, but spectral lines are too weak in extremely metal-poor stars

1. Overview

Metallicity distribution of Sr-enhanced metal-poor stars

What should be done?

- Collecting Sr and Ba abundances for as many metal-poor stars as possible. (Homogeneous sample is preferable.)

- Defining Sr-enhanced metal-poor stars
  high Sr/Ba?, high Sr/Fe?

2. SAGA sample

Distribution of Sr and Ba abundances in metal-poor stars in SAGA database

- SAGA: a database of chemical abundances taken from publications (Suda et al. 2008)

- The sample is biased to lower metallicity:
  - complete collection for [Fe/H]<-2.5
  - almost complete (?) for [Fe/H]<-3 in the sample selection for observations

SAGA Database
(Stellar Abundances for Galactic Archaeology)

Public since June 2008

http://saga.sci.hokudai.ac.jp

http://www.astro.keele.ac.uk/saga

1. Collection of observed data

- ★ Taken from the literature on the abundance analyses of stars in our Galactic halo
- ★ Papers including stars with [Fe/H]<-2.5

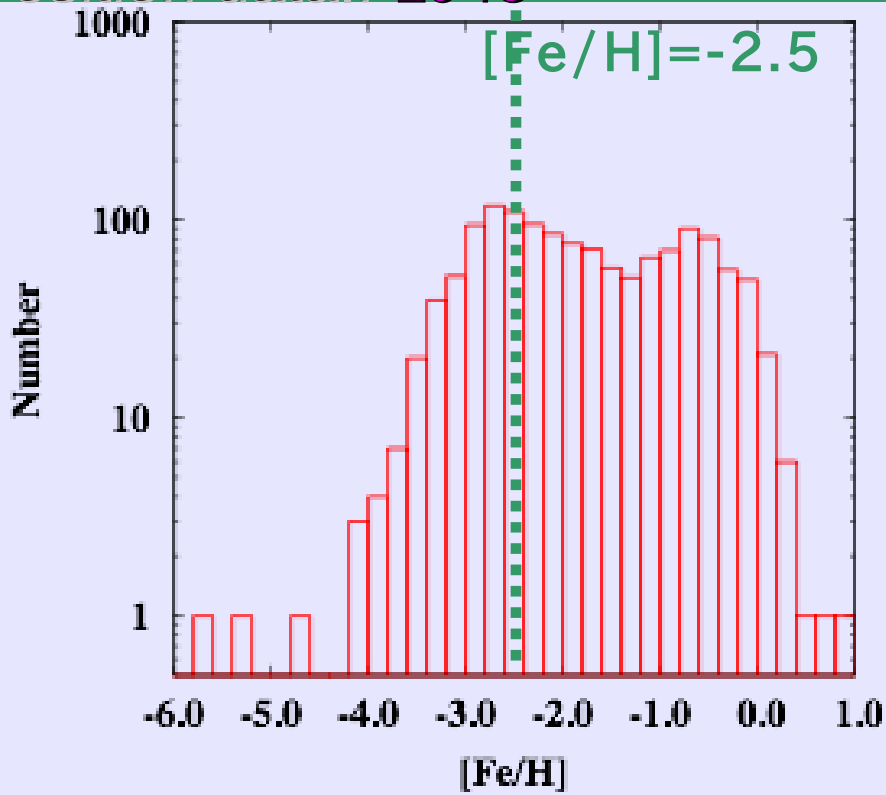
2. Compilation of adopted stellar parameters, derived abundances, etc.

- ★ Data Registration System can store the data through the web form.

3. Use of compiled data

- ★ Data retrieval system can search and plot the data for any combinations of quantities.

SAMPLE at September, 2011
Papers: 158 (covering since 2000)
Stars: 3444 (1385 unique stars)
Data
[X/H]: 23,775
V band mag.: 981
Position data.: 1045



Screen Snapshot of SAGA Database

[[start]]

Show pagesource | Old revisions | Recent changes | Search

Trace: » start

SAGA -Stellar Abundances for Galactic Archeology Database-

Public since June 24th, 2008 (go to UK mirror site)

- Retrieval - Last update of the retrieval system on **Mar. 16, 2010** and the database on **Mar. 16, 2010**.
  - Previous Version of Sep. 2, 2009 - updated retrieval system on Jan. 18, 2010 and database on Sep. 2, 2009
  - Previous Version of May 5, 2009 - updated retrieval system on Feb. 3, 2009 and database on May 5, 2009
  - Previous Version of Feb. 3, 2009 - updated retrieval system on Feb. 3, 2009 and database on Dec. 5, 2008
  - Previous Version of Nov. 20, 2008 - updated database, but retrieval without data rating and search with isotopic ratios
- Info-Information and News on update history (Data published in 2009 are available now!)
- Tutorial-Tutorial for the data retrieval system
- List of papers
- List of objects
- FeedBacks-Please give us any questions, comments, and suggestions on data and database - not created yet
- Links-Links to related institute

Data Retrieval subsystem with previous versions

News and Information

How to search the data

Links to the data of papers and objects

Please cite the following paper if you think that the SAGA database is helpful in writing your paper.

> **"The Stellar Abundances for Galactic Archeology (SAGA) Database - Compilation of the Characteristics of Known Extremely Metal-Poor Stars"**
>
> *T. Suda, Y. Katsuta, S. Yamada, T. Suwa, C. Ishizuka, Y. Komiya, K. Sorai, M. Aikawa, and M. Y. Fujimoto*, **PASJ**, 2008, vol.60, 1159-1171
>
> The paper is available at PASJ web site for free until the end of 2008 (probably still now).

Please contact saga-admin@astro1.sci.hokudai.ac.jp if you have any problems.

The SAGA database systems are maintained by Takuma Suda, Yutaka Katsuta, and Shimako Yamada.

License

Data Retrieval System for SAGA Database

SAGA Retrieval System

Last update of database: 2010-03-16 18:01:16

* not working
** Other options do not work.

Query

search | example | * | reset

Specify X and Y axis

Graph Options

Xaxis	Category	Li	[Fe/H]	From :	To :	Include	data with upper limit
Yaxis				From :	To :	Include	data with upper limit
Criterion +				From :	To :	Include	data with upper limit

Additional criteria

Range

Category: Category, log−e, [X/H], [X/Fe], Atmospheric Parameters, Photometric Parameters, Binary Parameters, Position and Velocity, Isotopic Ratio

Li: Li, Li I, Be, Be II, C, C I, CH, C2, N, CN, NH, O, O I, OH, F, F, Na, Na I, Mg, Mg I

ptional Criterion

Object:)107-5240", "CS", "0107"

Binarity: n To

Magnitude: Band : From mag

Resolution: < R <

graphical Criterion

Author: hor ex) "Lastname"

strict | forward agr vard agreement | fuzzy

Reference: ALL

Publication Year: From To

Retrieval Options

Display / Page	10
Order by**	Object
Output Option	single file
Histogram Option	Range (necessary for histgram)
Cross Search	cross papers

Output Option: separated files, single file, histgram

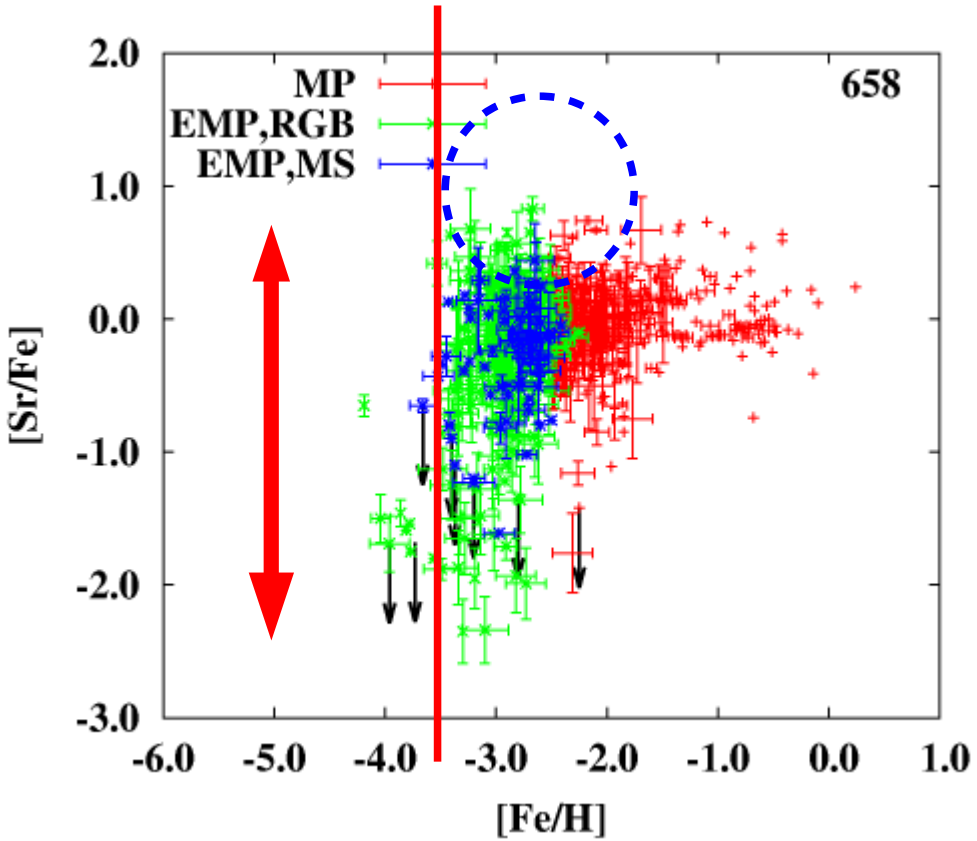
search | example | * | reset

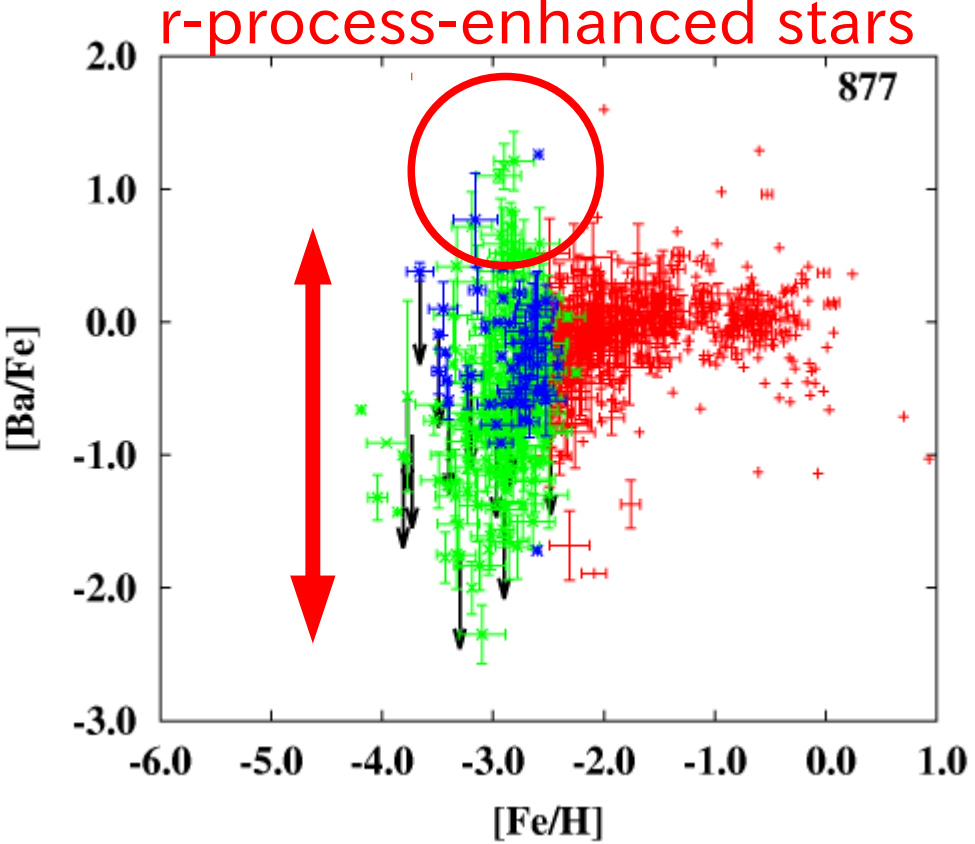
2. SAGA sample

Trend and scatter in abundance ratios of Sr and Ba from SAGA database

(Carbon-enhanced stars are excluded)

r-process-enhanced stars

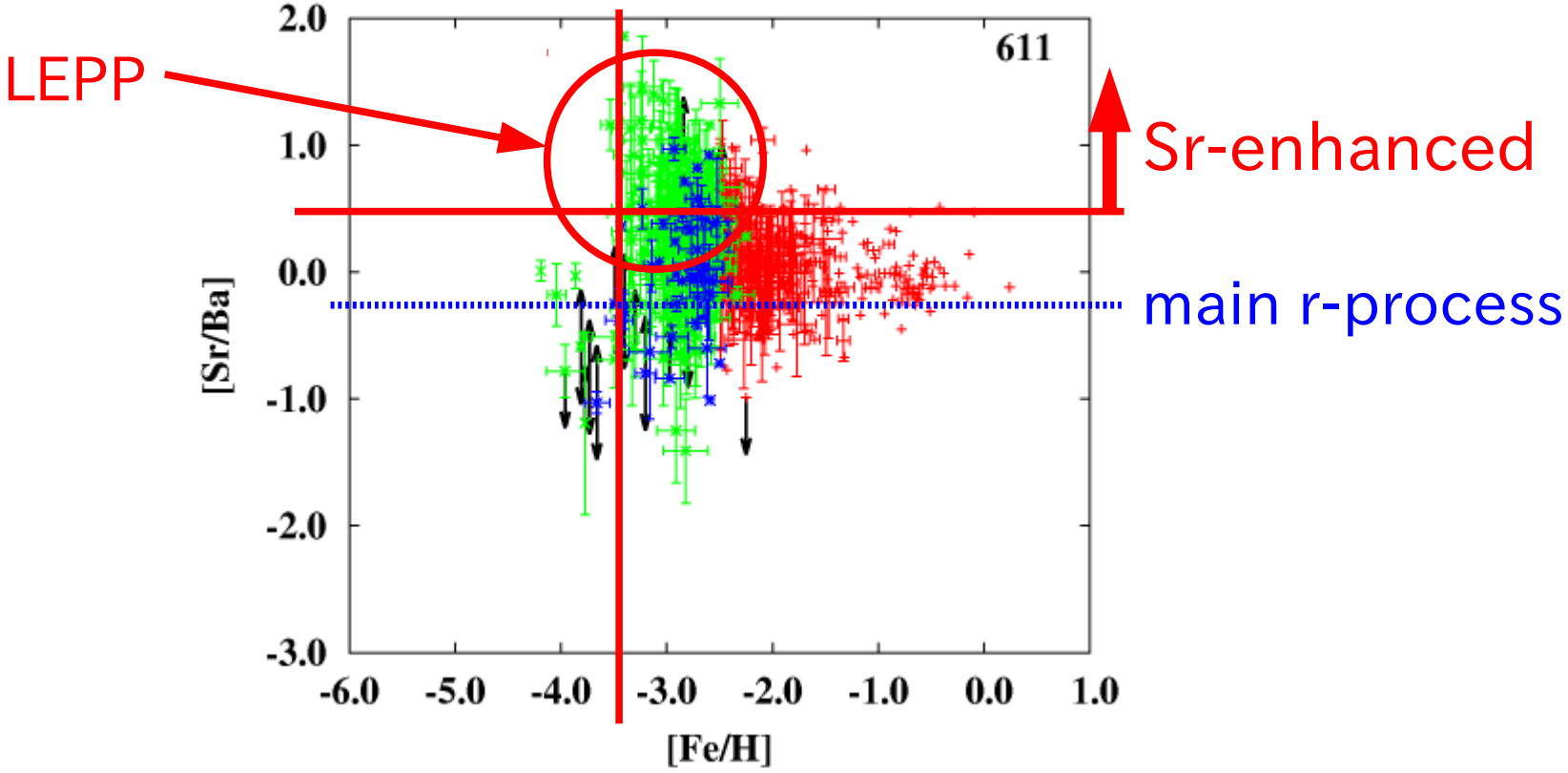




- Very large scatter in [Sr/Fe] and in [Ba/Fe] in [Fe/H]<-2.5.
- A group of stars show very high [Ba/Fe] at [Fe/H]=-3.. Such stars are not found in the [Sr/Fe] diagram.

2. SAGA sample

Trend and scatter in abundance ratios of Sr and Ba from SAGA database

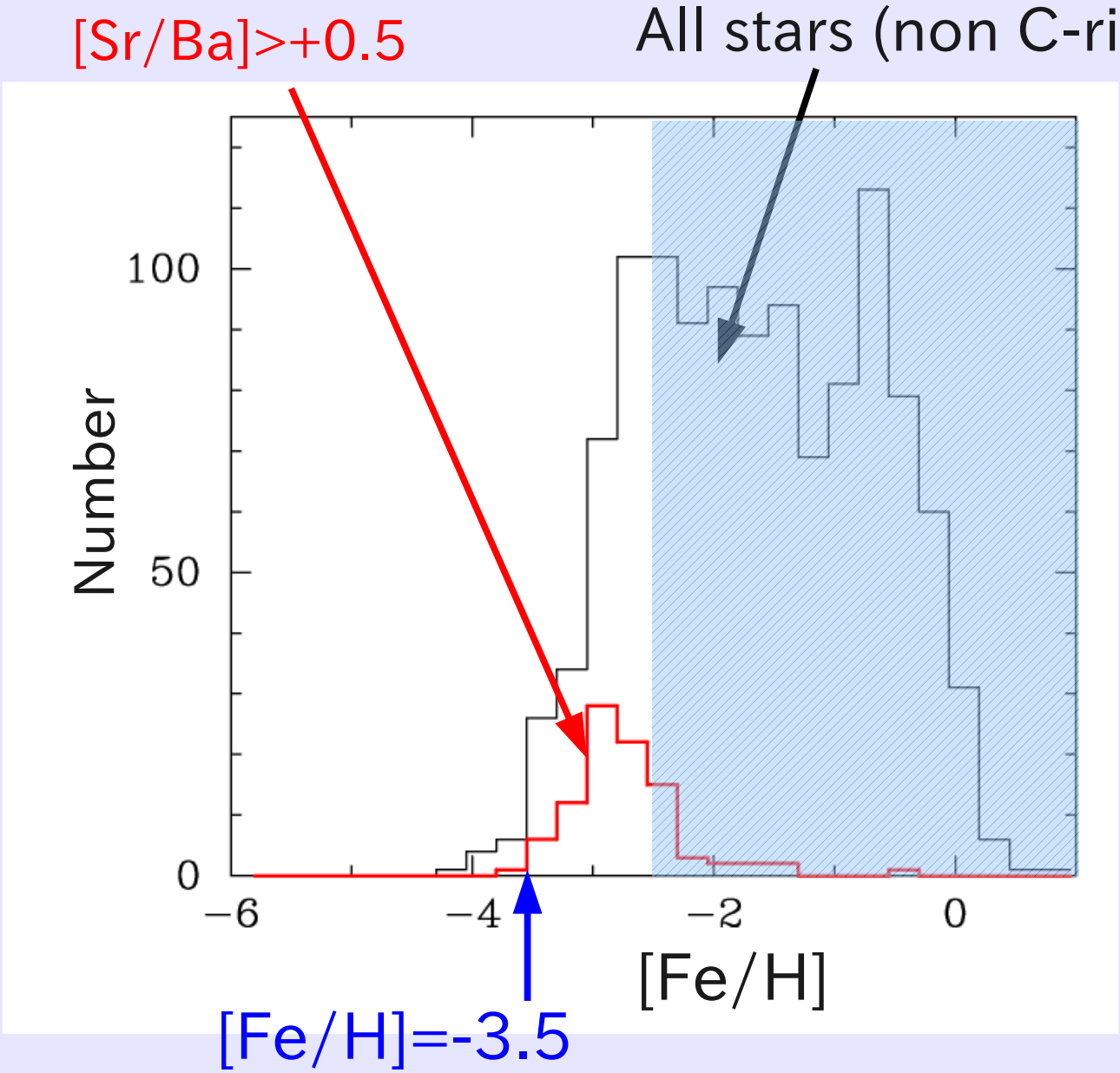


A tentative definition of Sr-enhanced stars:

[Sr/Ba]> +0.5 (→ SrEMP stars?)

2. SAGA sample

Metallicity distribution of Sr-enhanced stars



2. SAGA sample

Distributions of Sr and Ba abundances in metal-poor stars from the SAGA sample Summary

- Scatter in Sr/Ba (←LEPP/main r-process) increases with decreasing metallicity

- The fraction of Sr-enhanced stars ([Sr/Ba]>+0.5) is 30-40% at [Fe/H]～-3.0.

- No Sr-enhanced star is found in [Fe/H]<-3.5.
  (An exception is the C-rich hyper metal-poor star HE1327-2326.)

3. Sr-enhanced stars of new sample
SDSS/SEGUE stars followed-up with Subaru

- A Search for more EMP (extremely metal-poor) stars

- Homogeneous sample of EMP stars
  →Metallicity distribution
    Fraction of C-rich stars
    Fraction of binary systems
    ....

- Most objects are main-sequence turn-off stars
  →Sr and Ba are detectable in objects having relatively high abundances

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

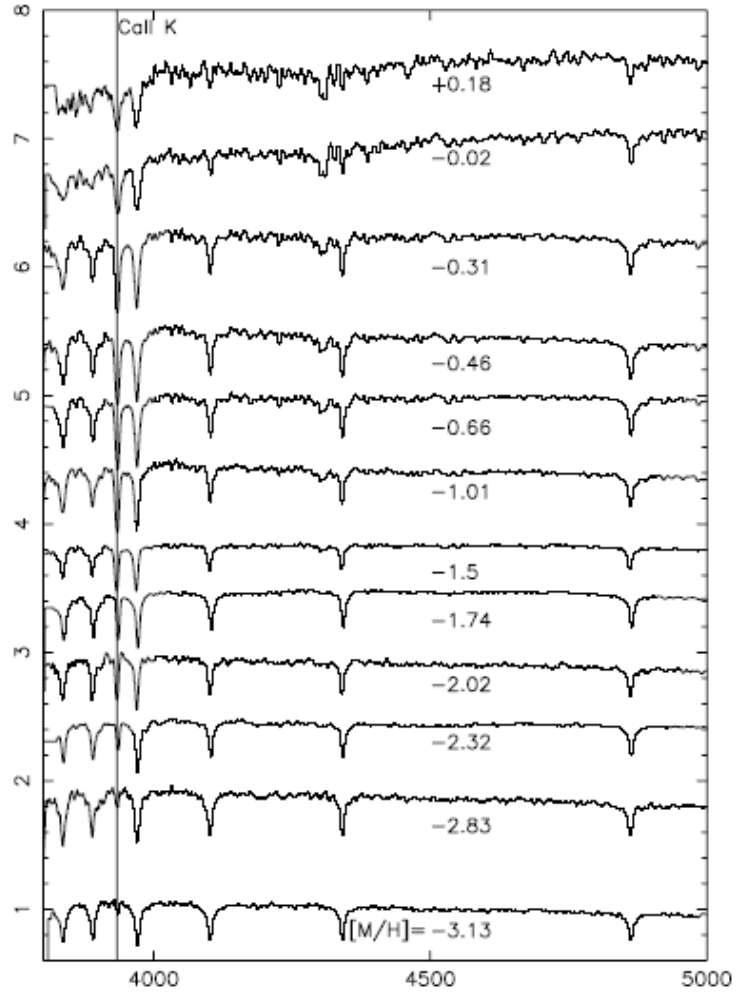


Figure 7. F star metal sequence—a set of SEGUE F stars, selected to show the range of metallicities sampled by the F subdwarf, F/G, spectrophotometric standard and reddening standard categories. All 13 stars have similar effective temperatures, near 6500 K, but the strength of the Ca K line at λ3933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

High-resolution follow-up spectroscopy with Subaru/HDS

"snap-shot spectroscopy"

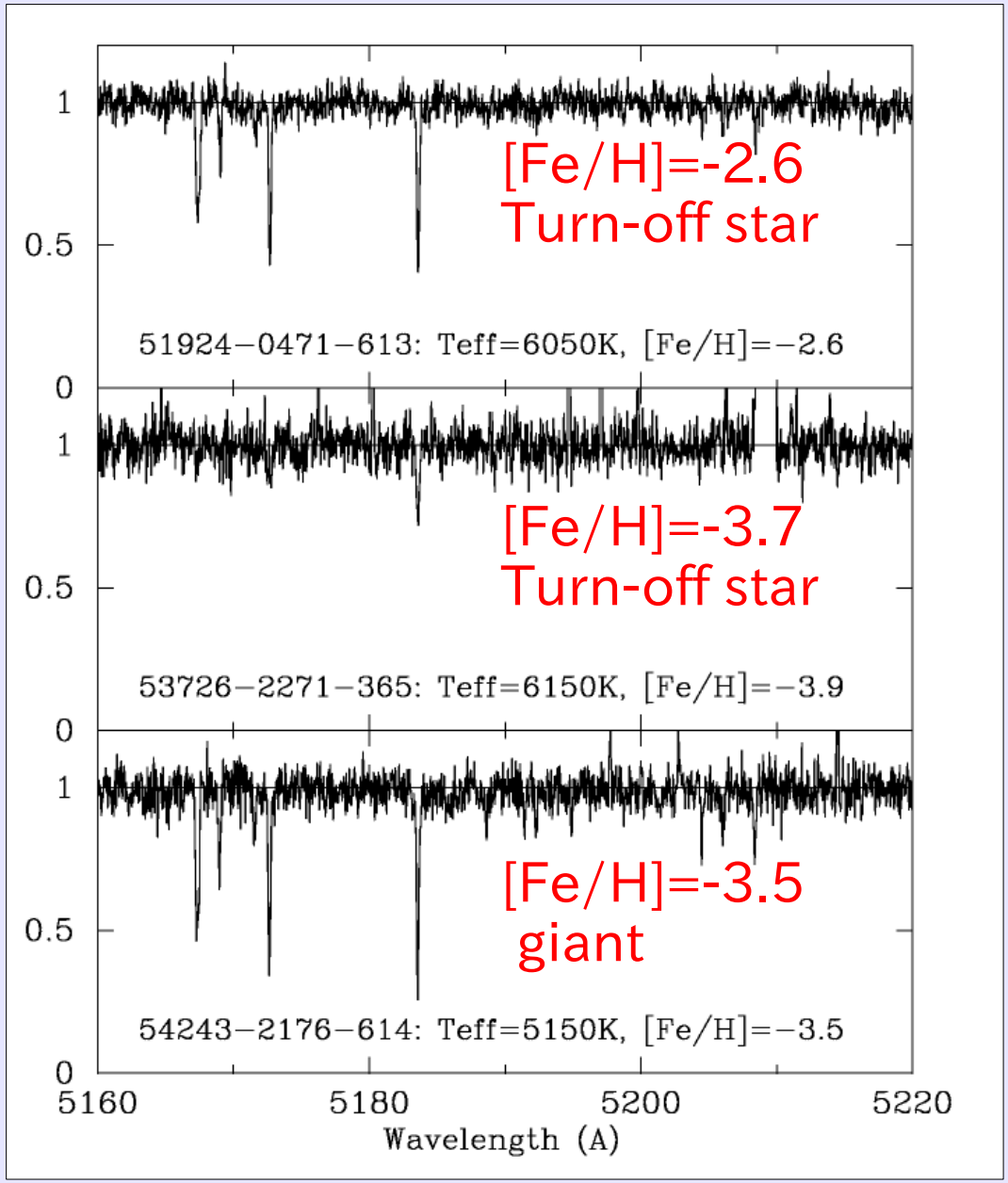
- R=30,000
- 4030-6800A
- S/N～25-30
- ～150 objects

Example: Mg triplet around 5170A →

"high S/N spectroscopy"

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

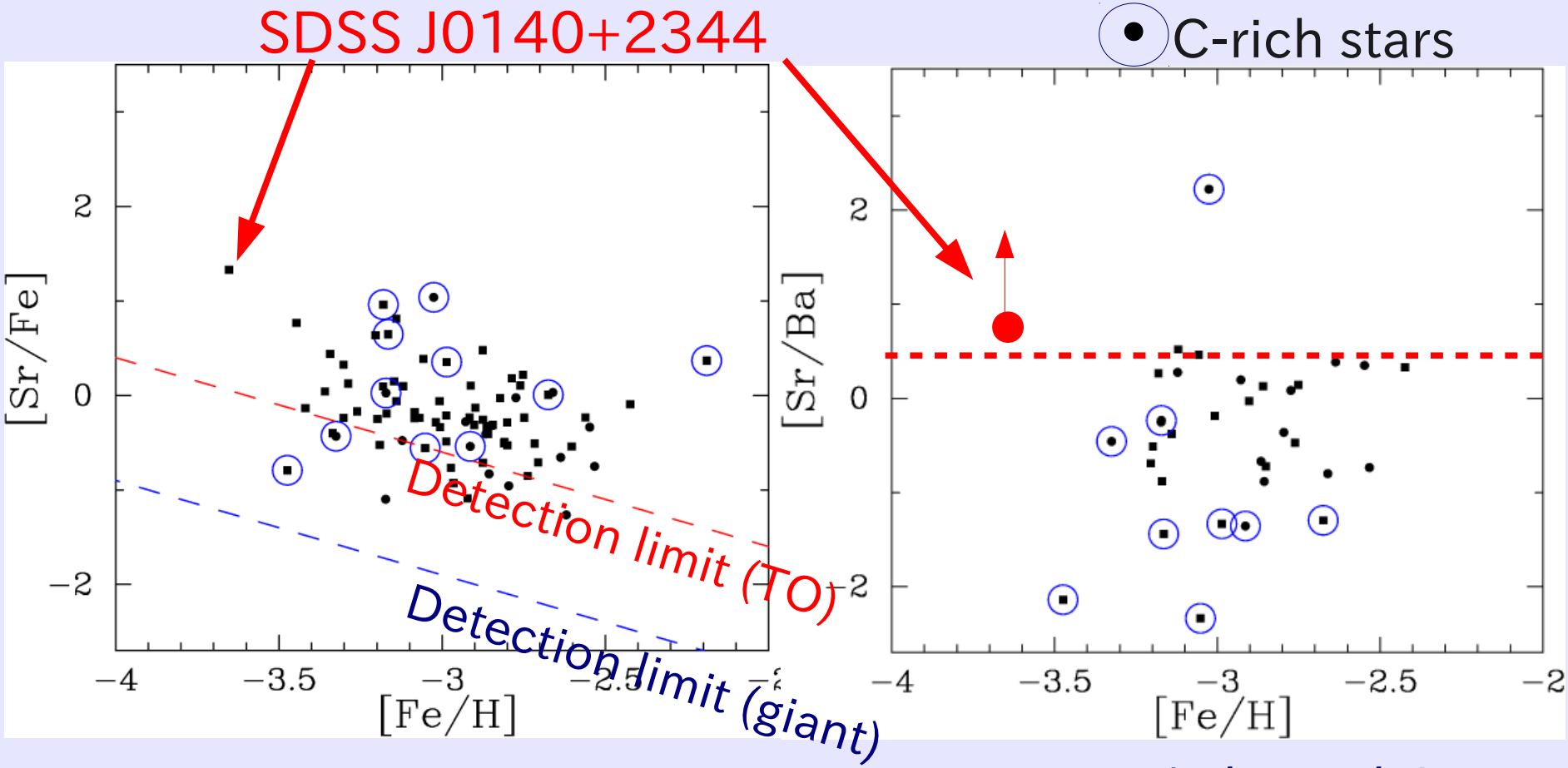
Aoki et al. In prep



3. SDSS sample

Resunts from snap-shot spectroscopy

- Not many Sr-enhanced stars are detected, because of the high detection limit of Ba.
- One object with [Fe/H]=-3.7 shows a large excess of Sr.

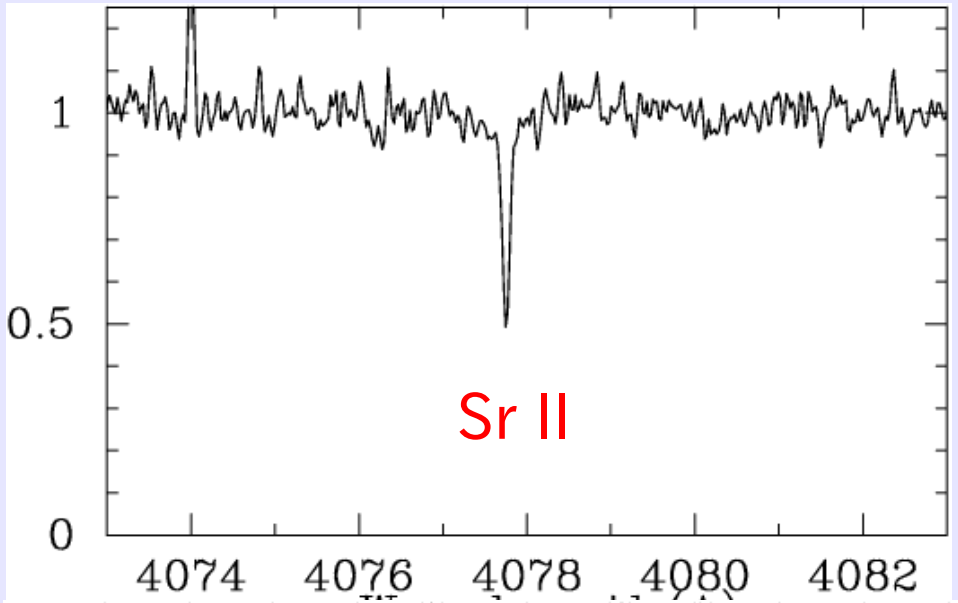


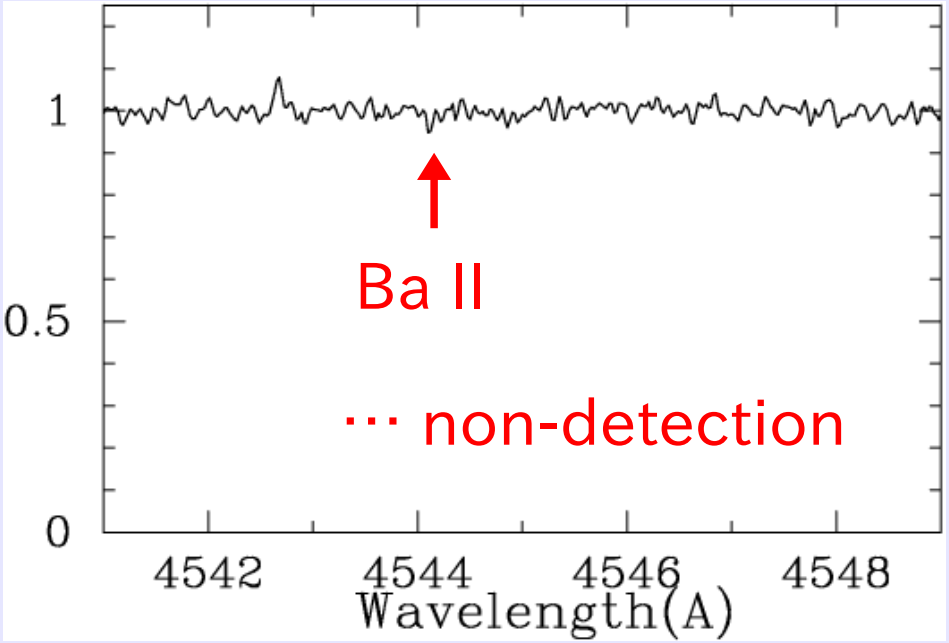
Aoki et al. In prep

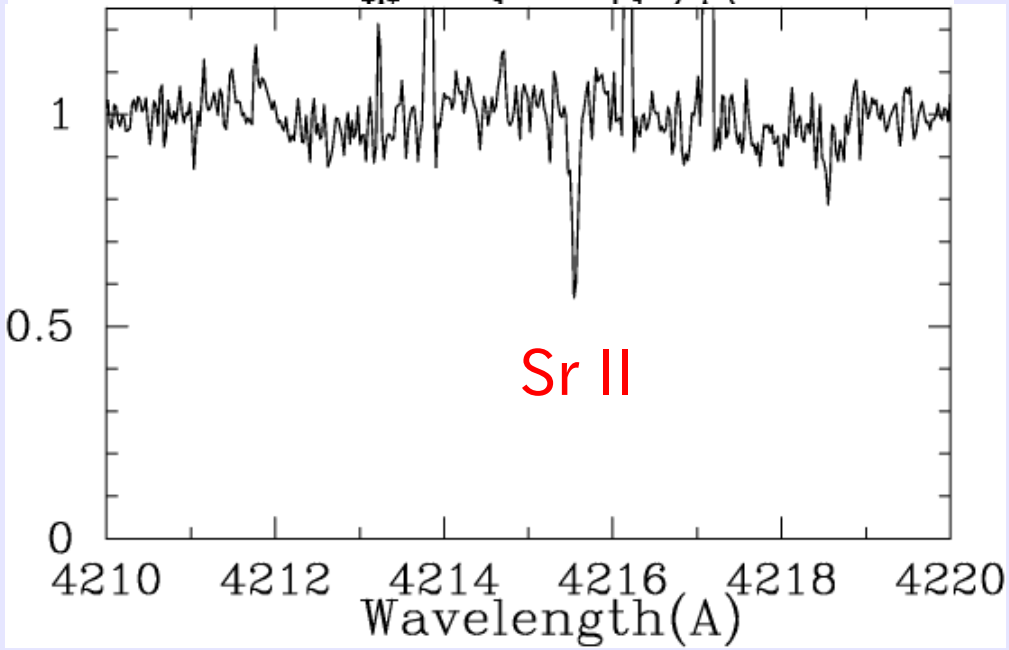
3. SDSS sample

The Sr-enhanced star with [Fe/H]=-3.7 SDSS 0140+2344

The high S/N spectrum obtained with the follow-up spectroscopy with Subaru confirms the Sr-excess and low Ba abundance.



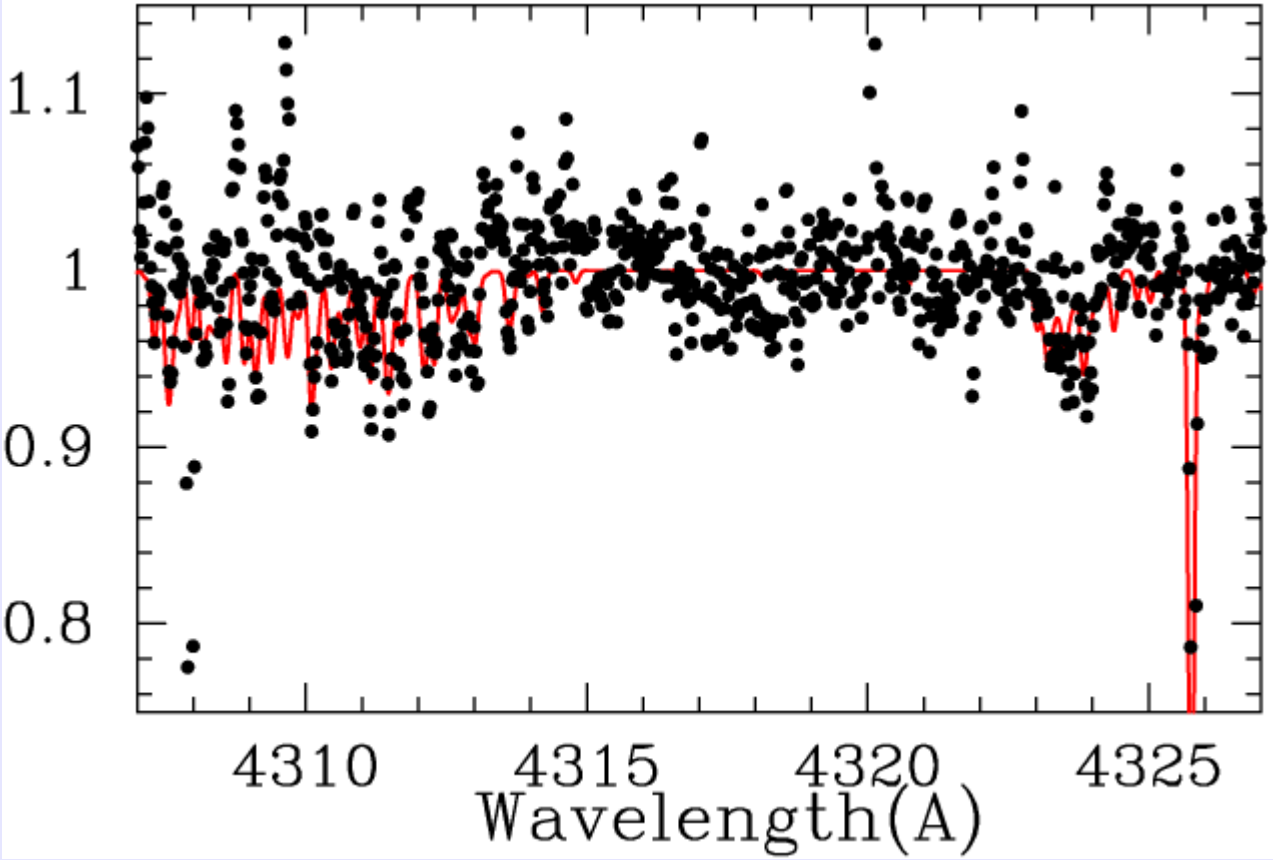




3. SDSS sample

The Sr-enhanced star with [Fe/H]=-3.7 SDSS 0140+2344

However, this object shows CH band feature:
→ [C/Fe]∼+1.8, a carbon-enhanced star with no Ba-excess!
→the total metallicity is not as low as [Fe/H]=-3.5 star with normal carbon abundance. (cf. HE1327-2326)



The metallicity distribution of Sr-enhanced metal-poor stars

Conclusions

- Sr-enhanced metal-poor stars appear in very/extremely metal-poor range.

- Sr-enhanced stars are found in lower metallicity ([Fe/H]<-3.0) than (main) r-process-enhanced stars
  →The progenitors (LEPP sites) are more massive?

- No Sr-enhanced star is found in [Fe/H]<-3.5 (except for C-rich stars). →"critical metallicity for LEPP"? Why?

- Sr-enhancement is also found in C-rich EMP/HMP stars (HE1327-2326, SDSS 0140+2344)
  →LEPP operated in their progenitors.