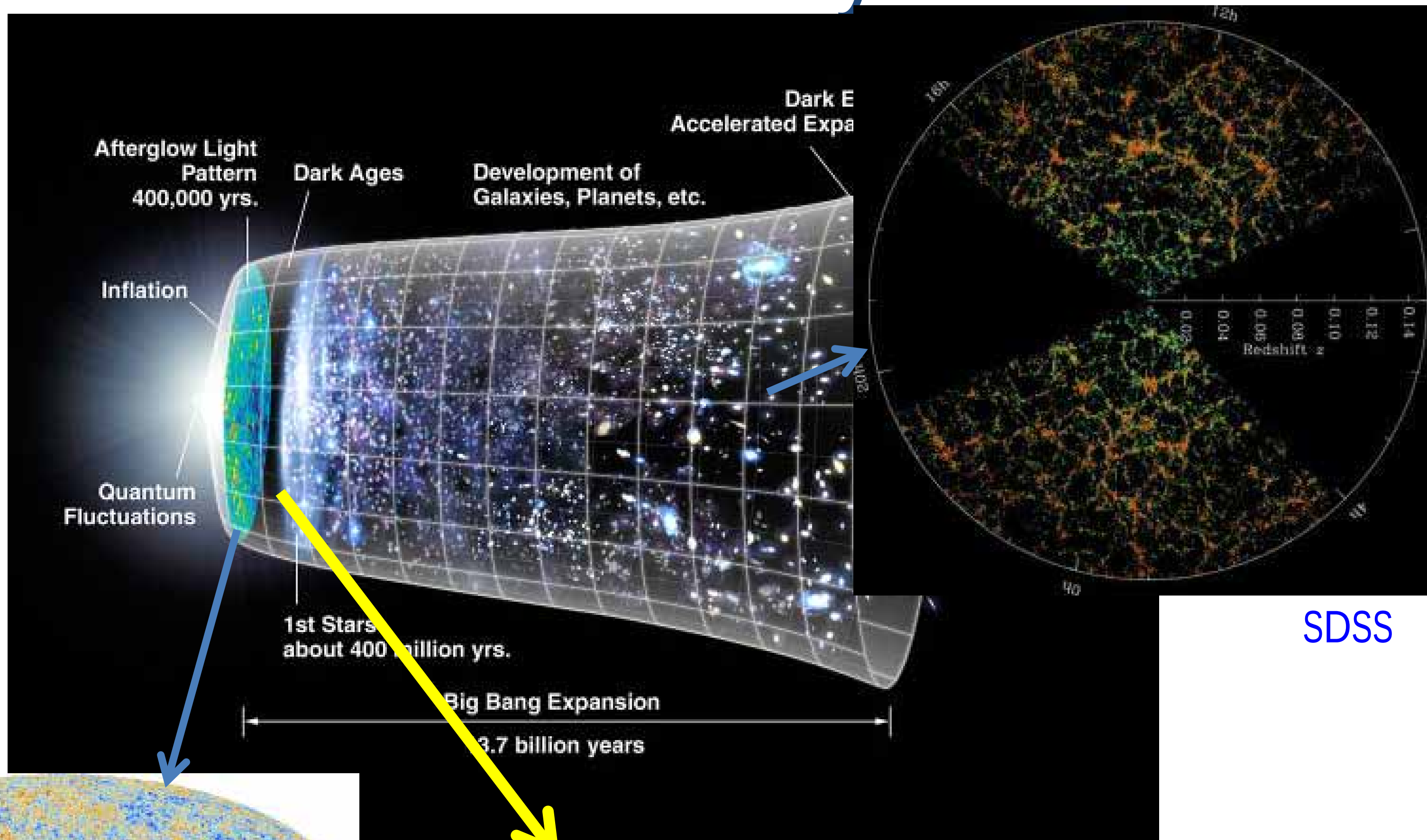
2014.8.25. Riken
Supernova/GRB

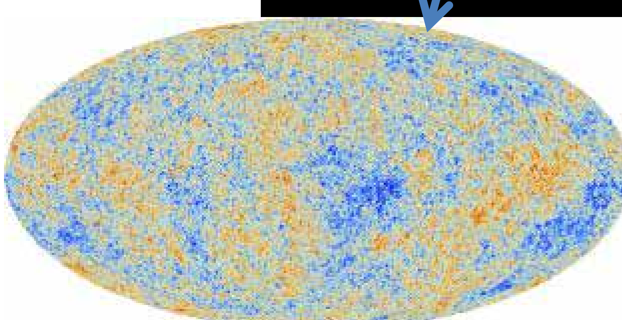
Metal-Poor Stars and Supernovae

National Astronomical Observatory of Japan
Wako Aoki

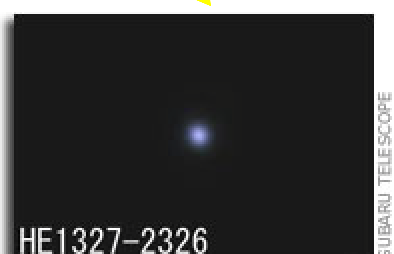
Structure formation and chemical enrichment in the early Universe



SDSS



Planck/ESA



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長寿命の小質量星なら現在まで生き残っている！

Early generation stars in the Milky Way
… old and metal-poor stars

Halo structure

球状星団

矮小銀河

What can we learn from early generation stars?

- Nucleosynthesis of individual stars and supernovae

➡ examination of nucleosynthesis models

- Nature of first-generation stars

  -no metal

  -mass distribution?

  -other characteristics (rotation, binarity, etc.)?

- Galaxy formation
  - From first-generation stars to early galaxies

Definition

- Chemical abundance：abundance ratio with respect to H

  log ε(X) or log A(X) = log(X/H) + 12

    ex. Fe/H=$10^{-4.5}$ → log ε(Fe)=7.5

  [X/Y] = log(X/Y)-log(X/Y)sun

    ex. [Fe/H]=-2.0 → 1/100 of the solar Fe/H ratio

- Metallicity： total abundance of heavy elements (elements heavier than boron)

  important for stellar structure and evolution

    sometimes presented as mass ratio

      ex. Solar metallicity = 0.02 (2%) or slightly lower

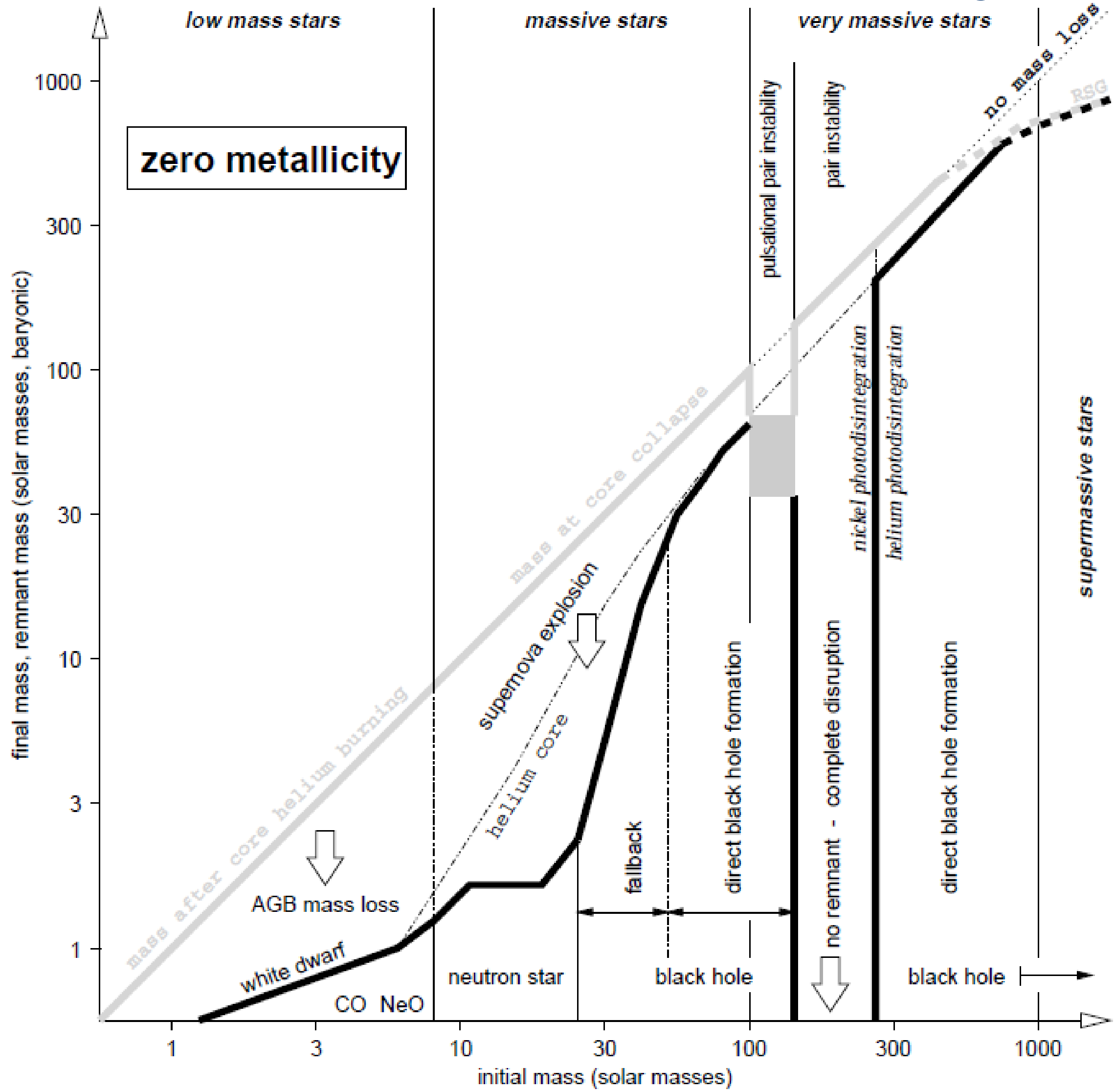
  usually represented by [Fe/H]

Mass distribution of first stars

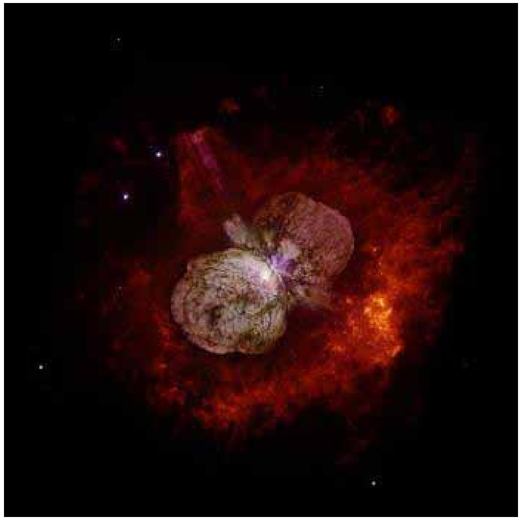
- Very-massive stars (>140 Msun)
  - formation is expected from clouds with zero metallicity
  - pair-instability supernovae or formation of black-hole
- Massive stars (8-140Msun)
  - dominant in first-generation stars?
  - core-collapse supernovas forming black holes or neutron stars
- Low-mass stars (<8Msun)
  - not formed from clouds with zero metallicity?
  - evolving to white dwarfs. Low-mass star with M<0.8Msun can be found in the current universe.

initial-final masses of primordial stars

Heger & Woosley (2002)



Candidates for very-massive stars in the current universe

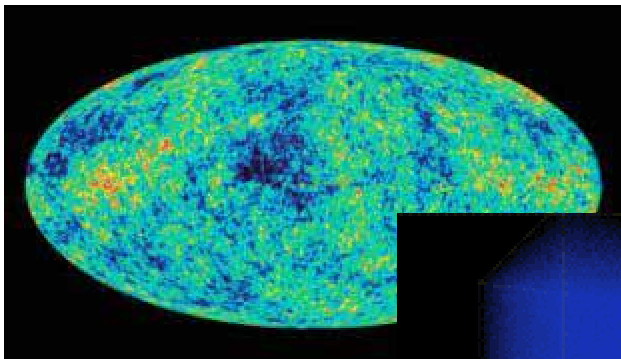


⇐イータ･カリーナ星
•現在の銀河系内で最大質量の星のひとつ
•放出物質が星雲をつくっている

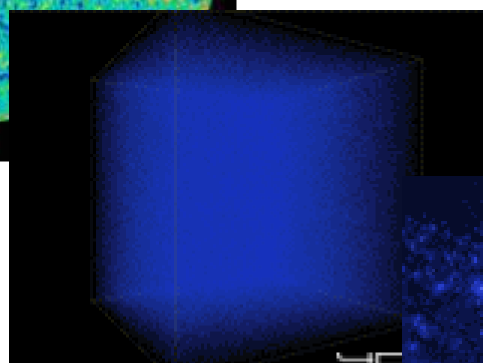
⇓マゼラン雲では150太陽質量以上
の星が次々誕生？

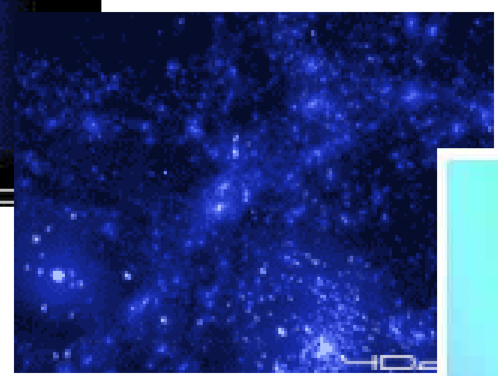
Numerical simulations of formation of first-generation stars

初期宇宙の物質分布

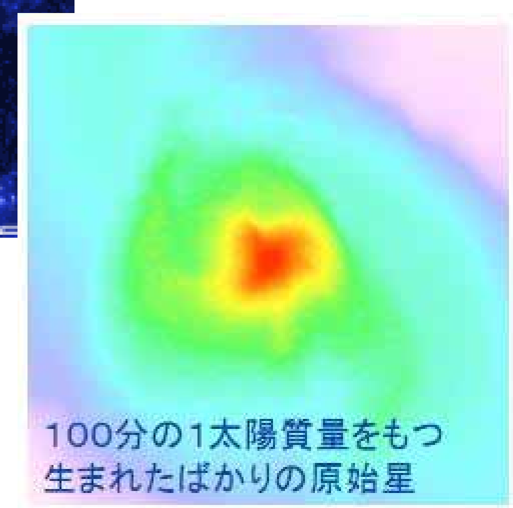


重力による構造の成長





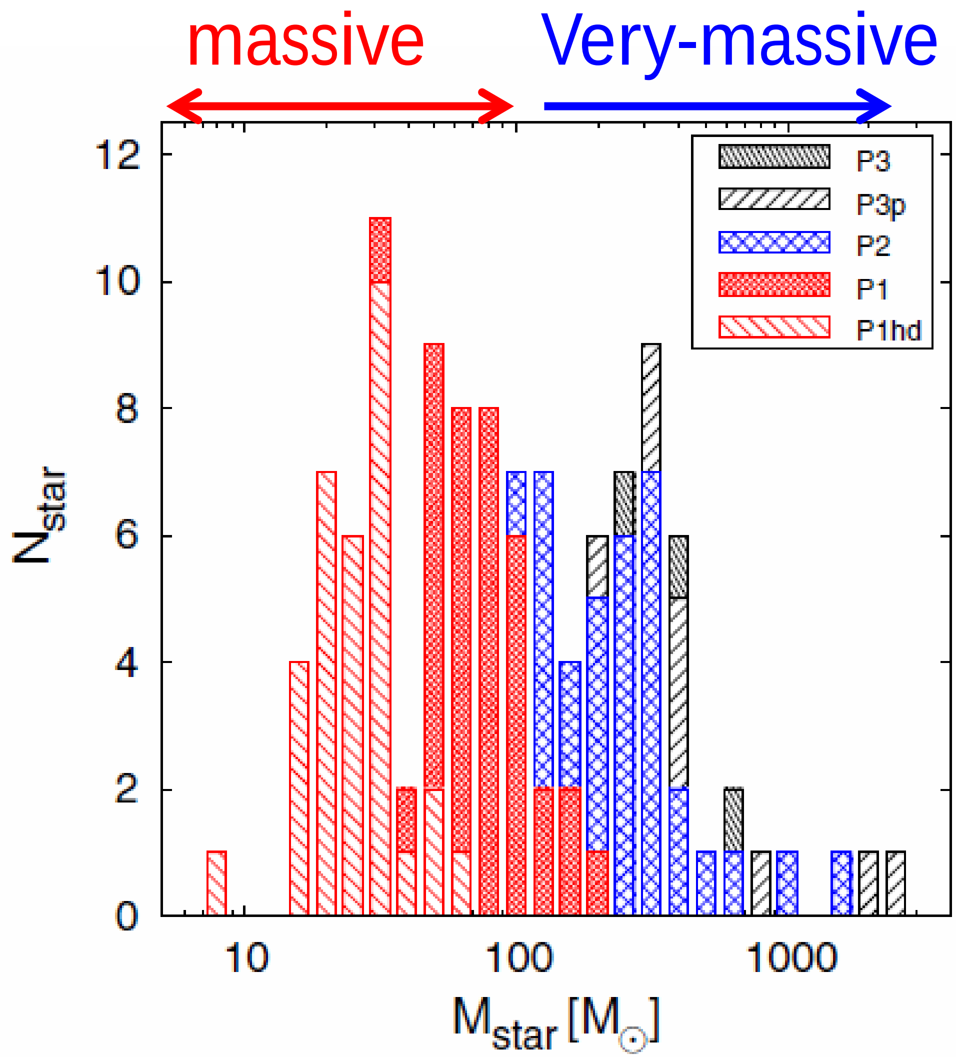
初代原始星の誕生



2〜3億年？

Mass distribution of first stars predicted by numerical simulations

Masses of first-generation stars
- Majority are massive stars
- some fraction of them are ver-massive

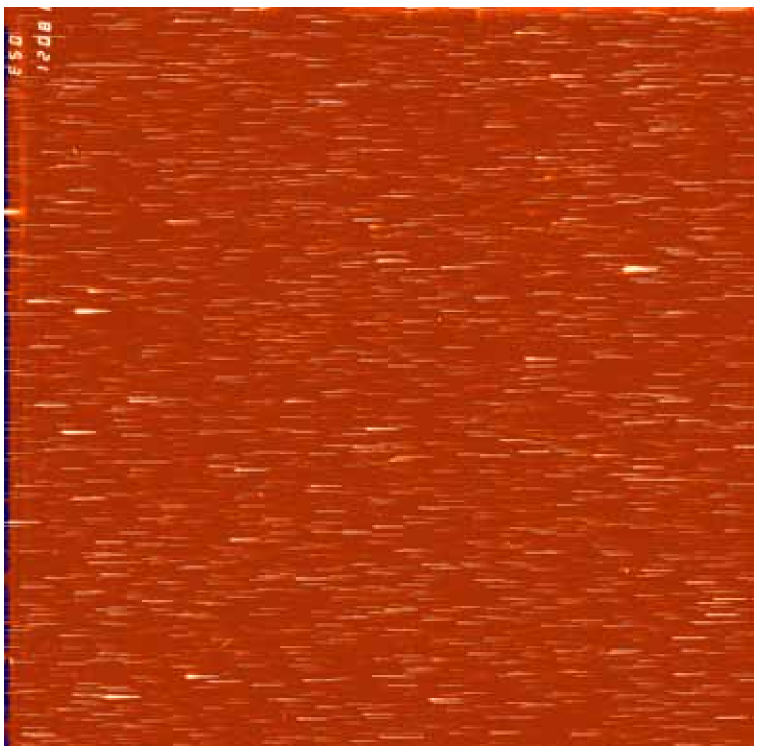


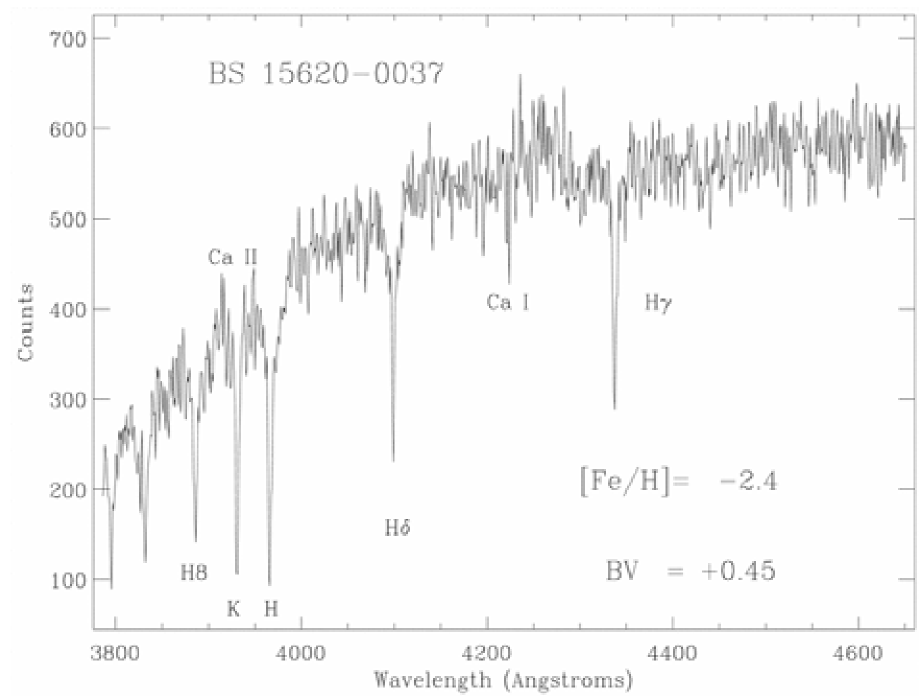
Hirano et al. (2014, Astrophys. J. 781, 60)

Searches for early generation stars (metal-poor stars) in the Milky Way

①wide-field spectroscopic survey

②follow-up medium resolution spectroscopy





Searches for metal-deficient stars

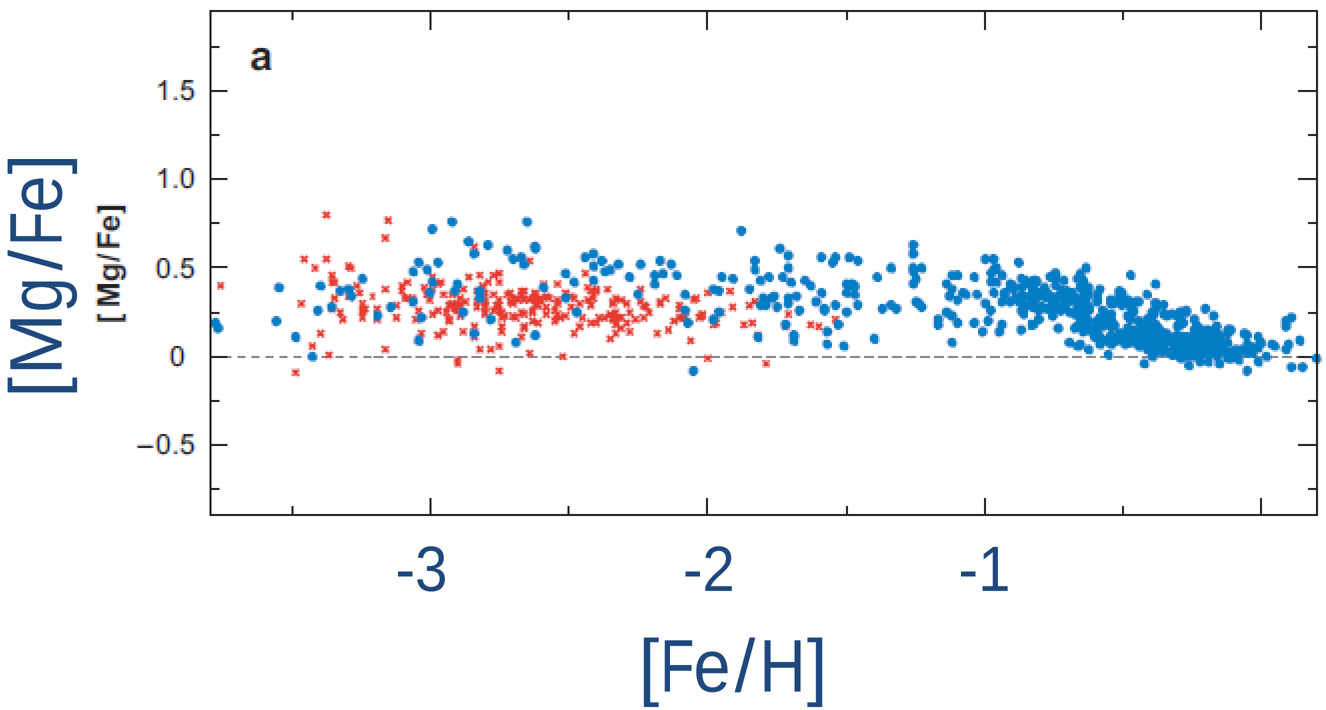
③follow-up high resolution spectroscopy to determine chemical composition

Subaru Telescope

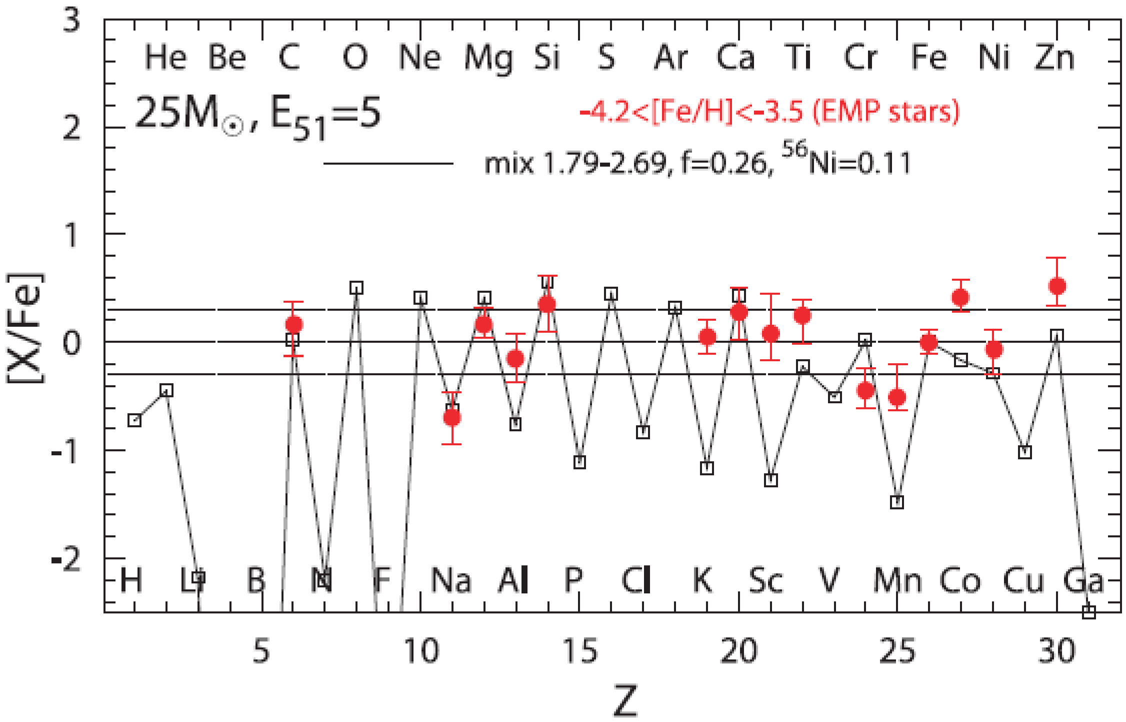
High Dispersion Spectrograph (HDS)

High S/N spectra obtained with large telescope are required for detection of weak absorption lines.

Extremely metal-poor stars with “normal” abundance pattern



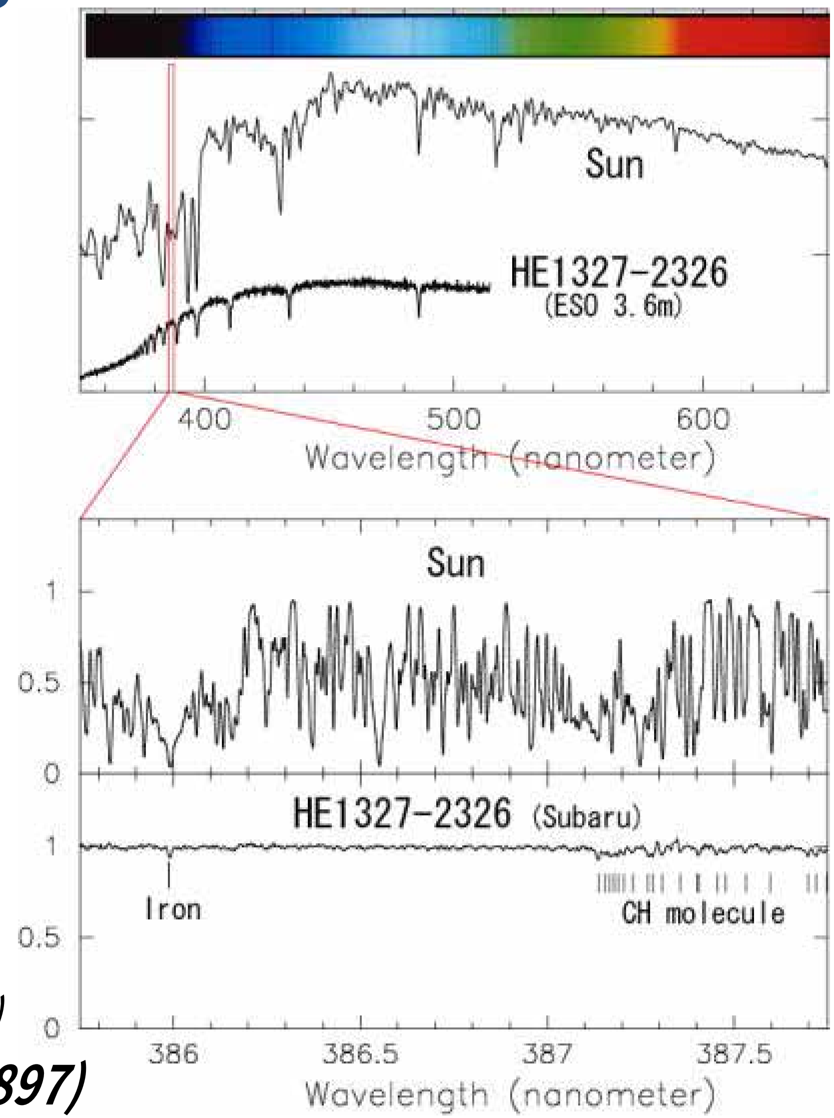
Extremely metal-poor stars with “normal” abundance pattern



Tominaga et al. (2007)

"Ultra/Hyper Metal-Poor" stars found in the past 10 years

HE1327-2326 ([Fe/H]=-5.4)

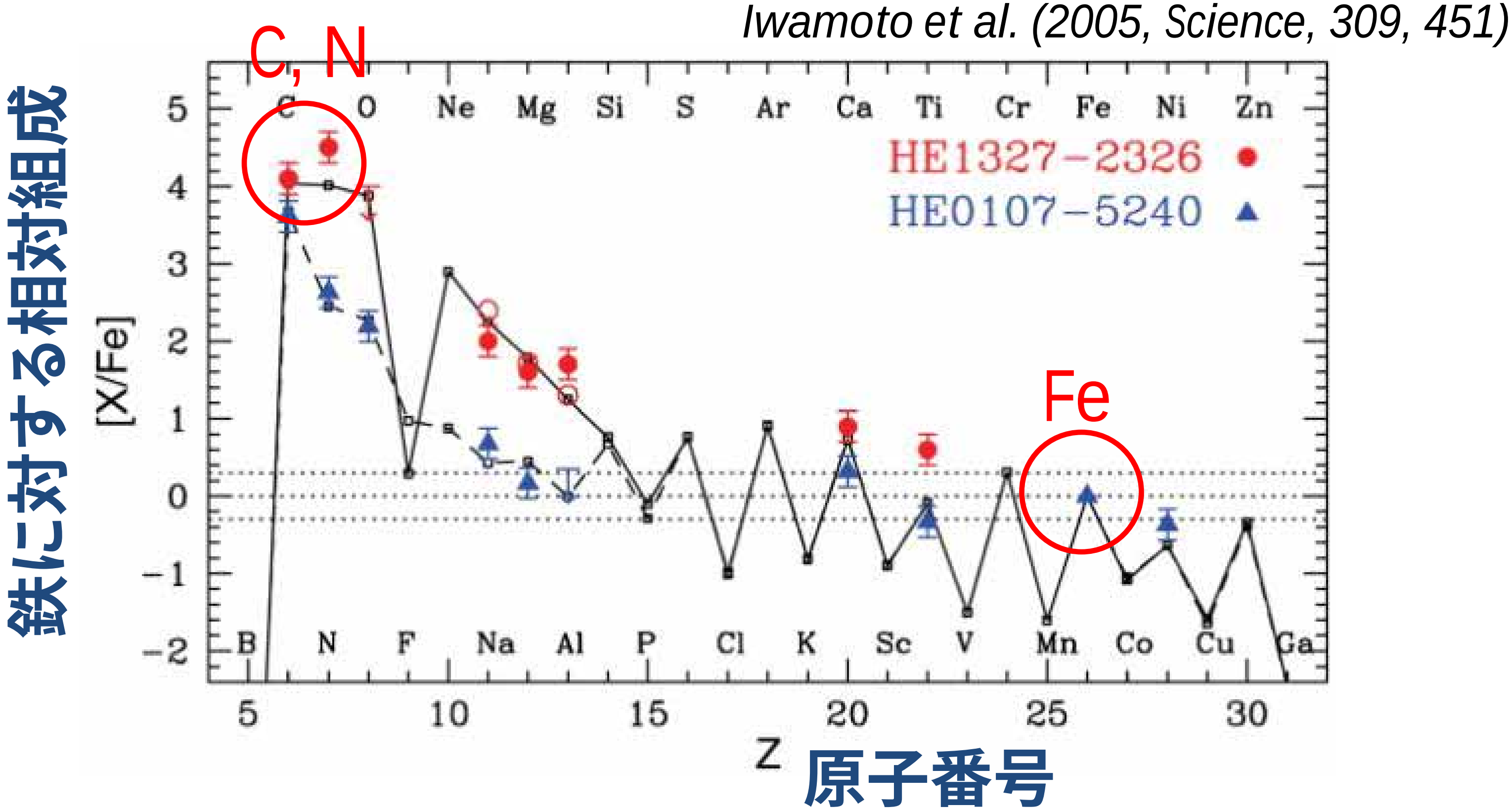


Frebel et al. (2005, Nature, 434, 871)
Aoki et al. (2006, Astrophys. J. 639, 897)

Chemical abundance patterns of “Hyper Metal-Poor” stars

- [Fe/H]=-5.4, [C, N/Fe]>〜+4
- Faint supernova origin?

Iwamoto et al. (2005, Science, 309, 451)

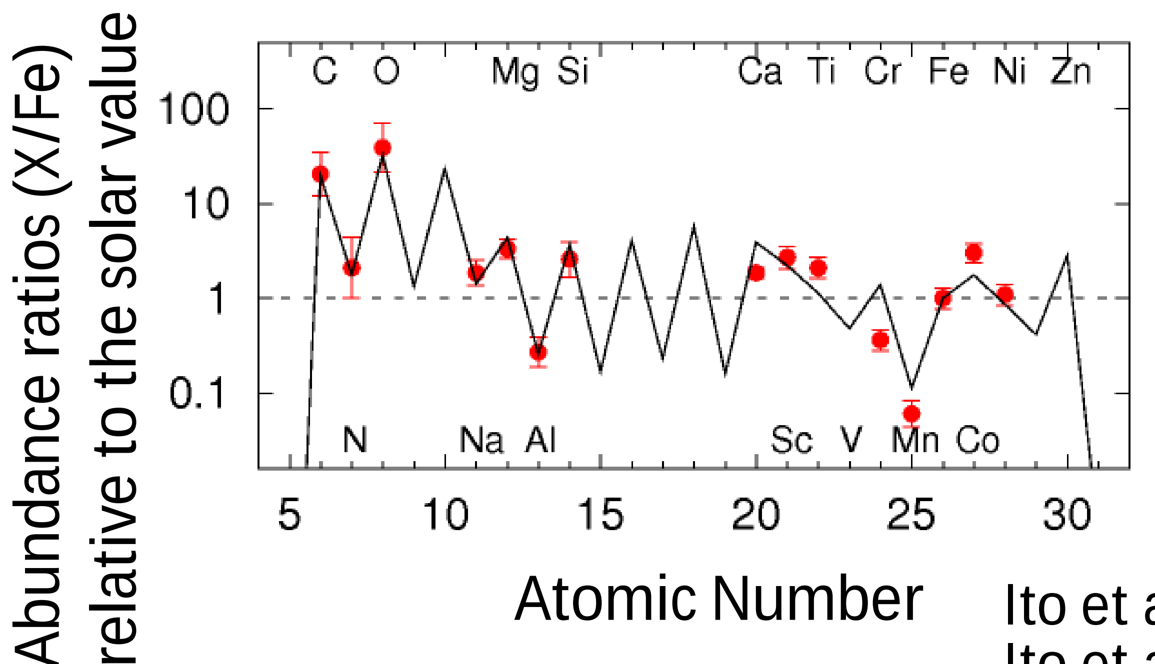


The carbon-enhanced star BD+44 493

Carbon-enhanced EMP star BD+44 493 ([Fe/H]=-3.7): another evidence for “faint supernovae”

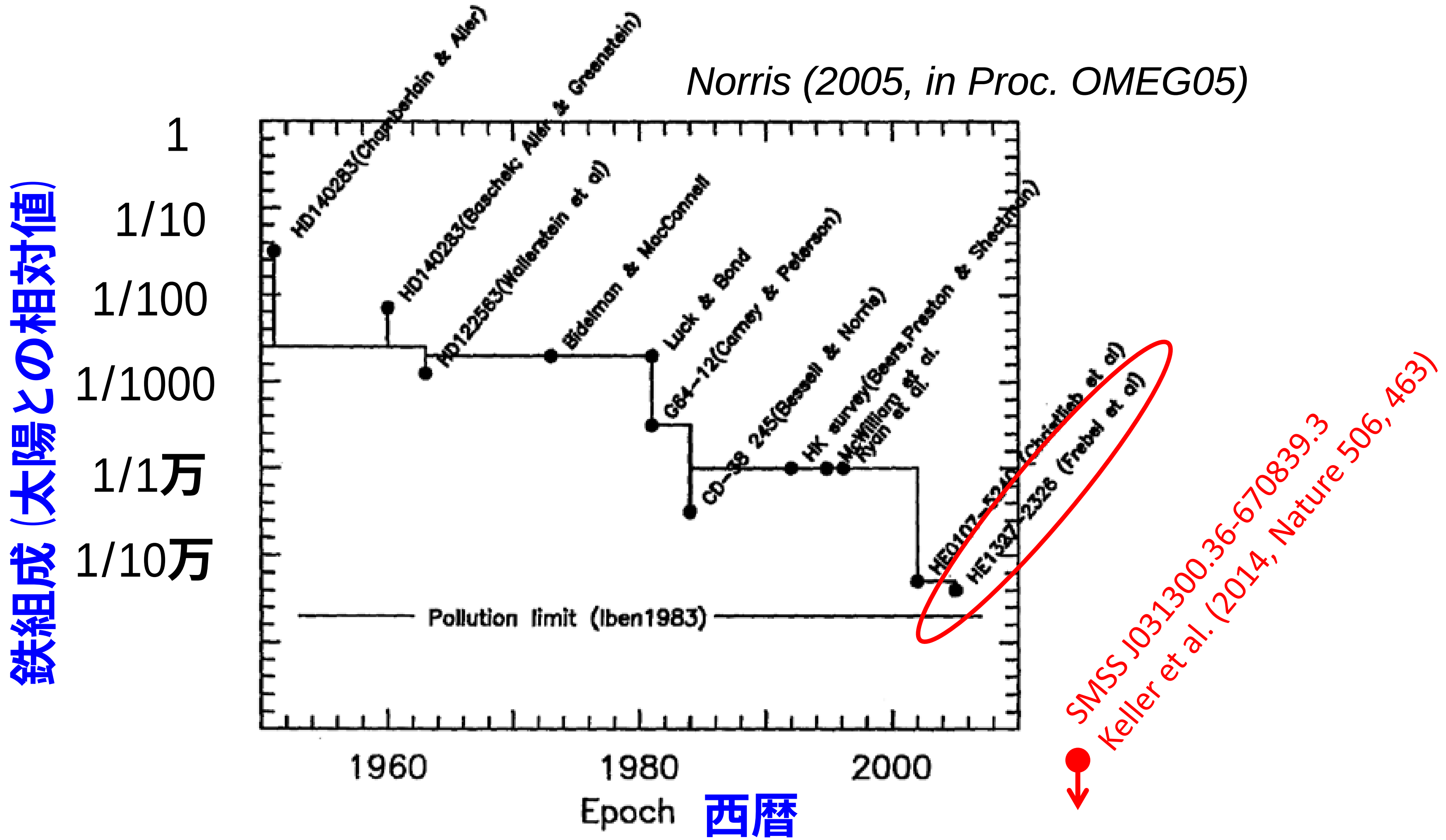
The normal Ba abundance, the high O/C, and the low N/C exclude the AGB and massive rotating stars as the progenitor

→ Faint supernova scenario is the remaining possibility.



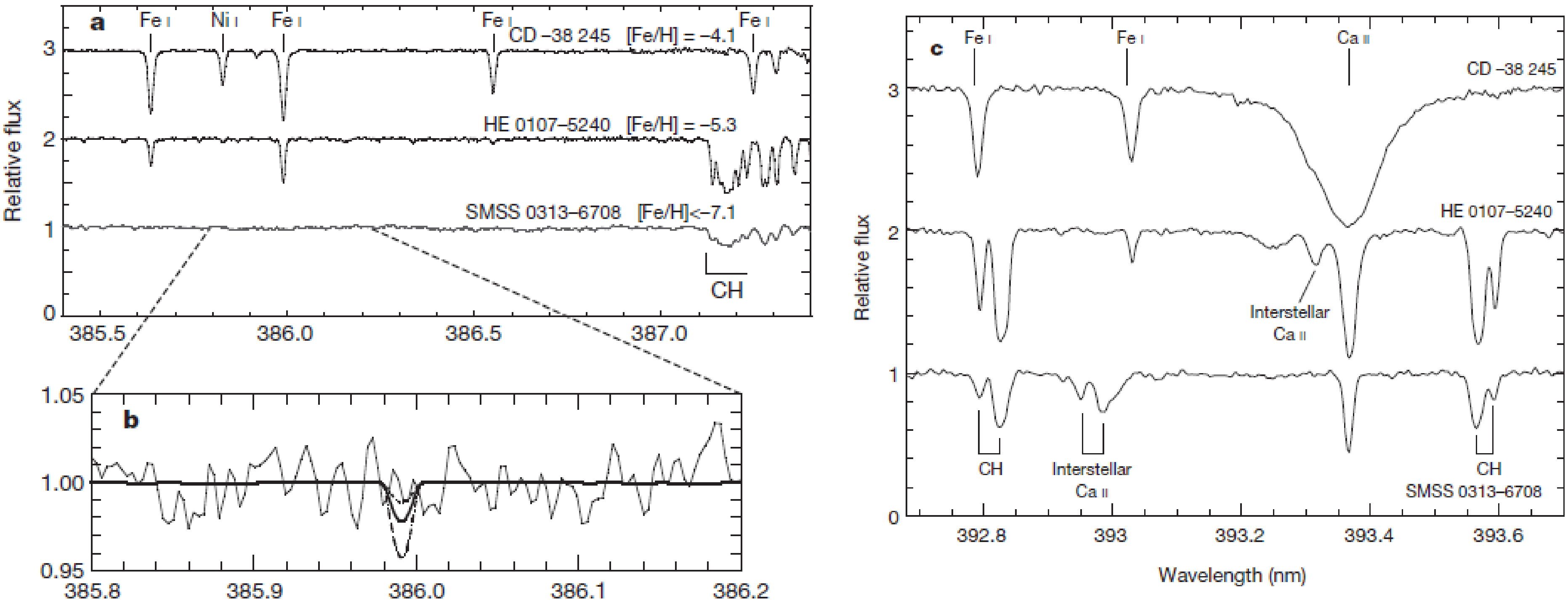
Ito et al. (2009, ApJL)
Ito et al. (in prep.)

Progress of searches for most metal-poor stars



SMSS 0313-6708 (Keller et al. 2014)

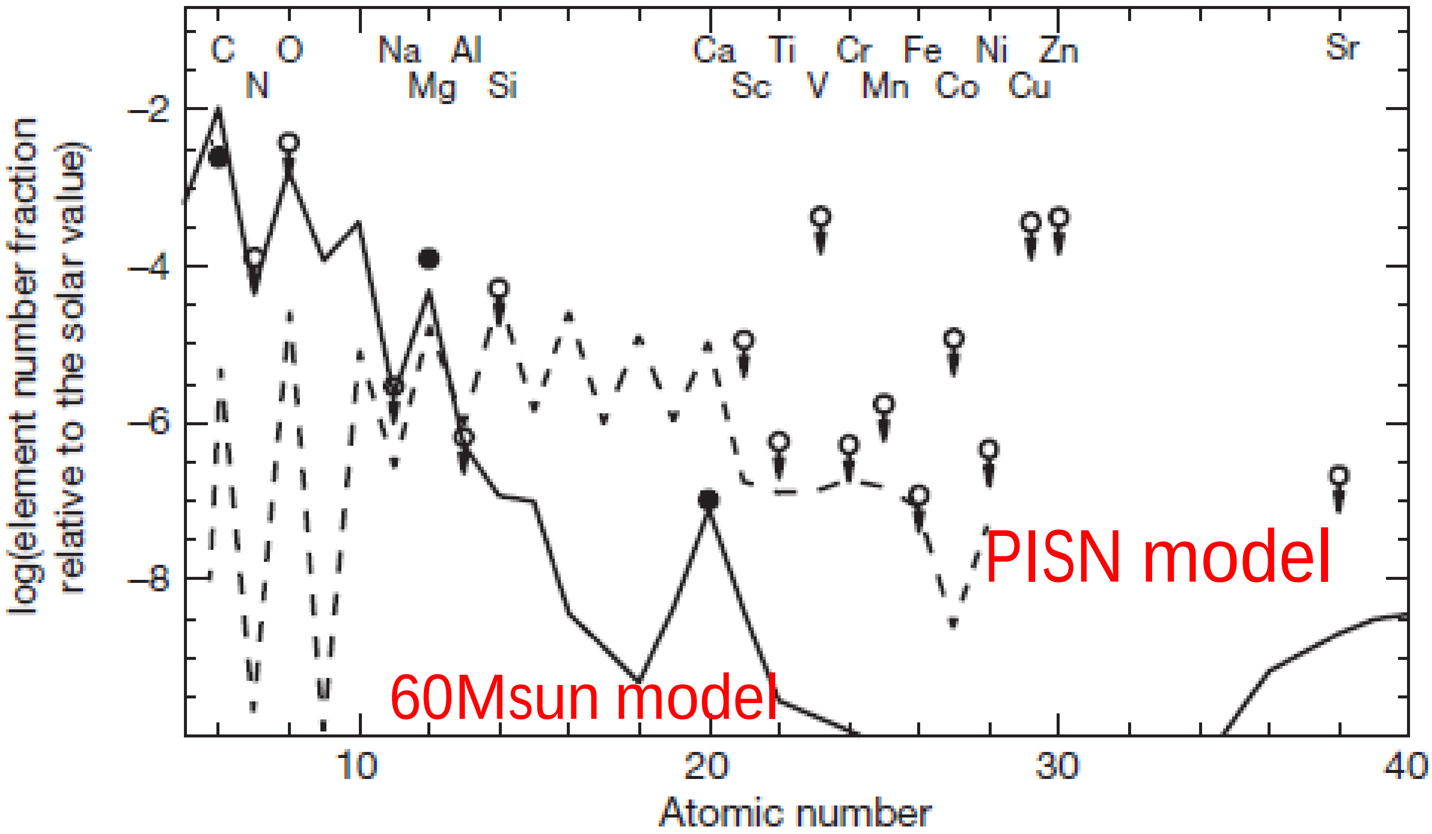
- [Fe/H]<-7
- red giant



Wavelength (A)

SMSS 0313-6708 (Keller et al.)

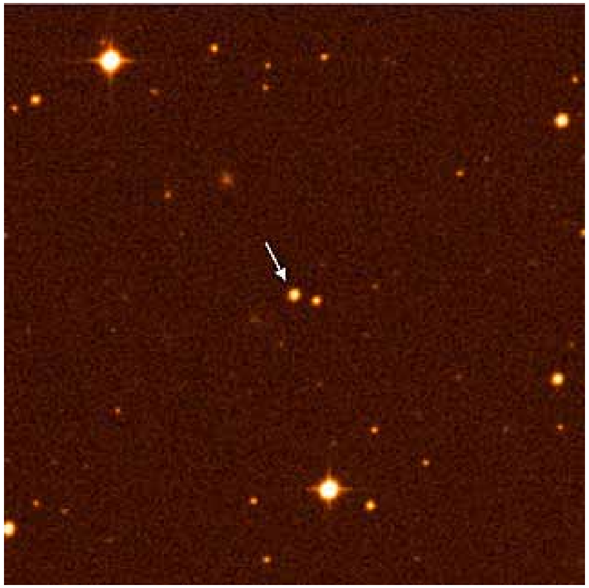
Abundance pattern is explained by a supernova from a 60 Msun star rather than PISN

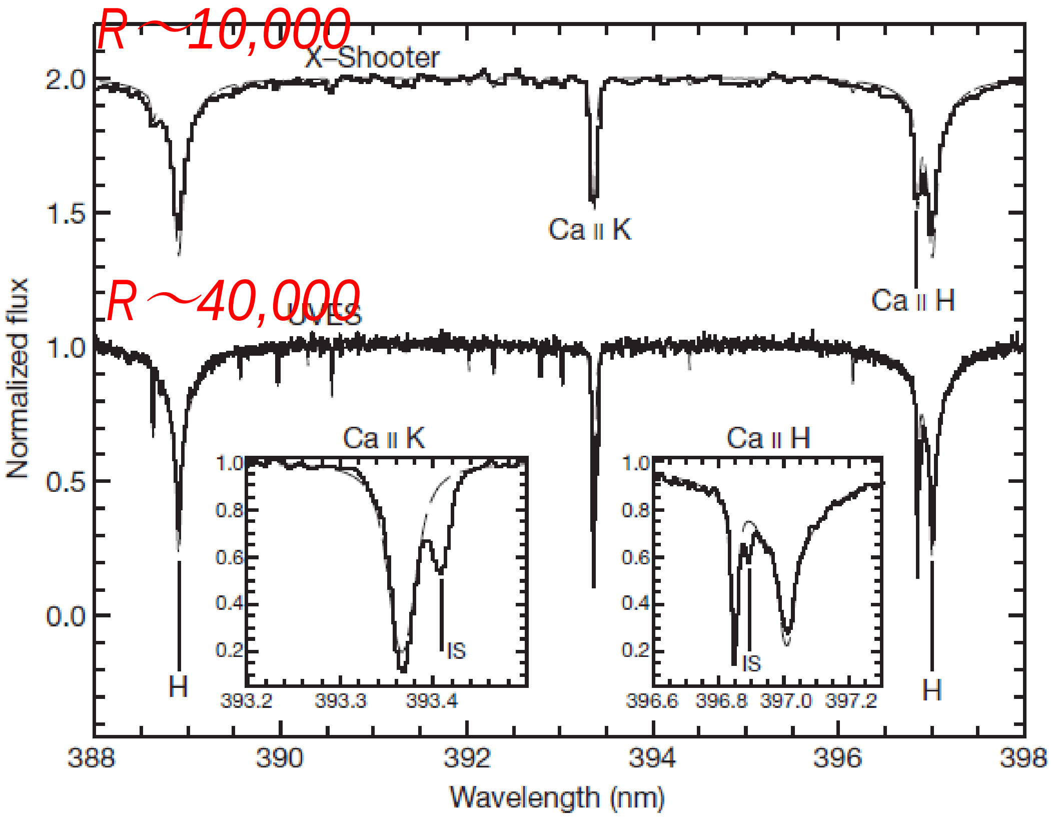


Discovery of the [Fe/H]～-5 star with normal C abundance SDSS J1029+1729

Caffau et al. (2011, 2012)

[Fe/H]=-4.7 (1D LTE analysis) → Ultra-Metal-Poor (UMP) star





No very-massive stars among first-generation stars?

Second-generation stars affected by first PISN might be metal-poor, rather than extremely metal-poor

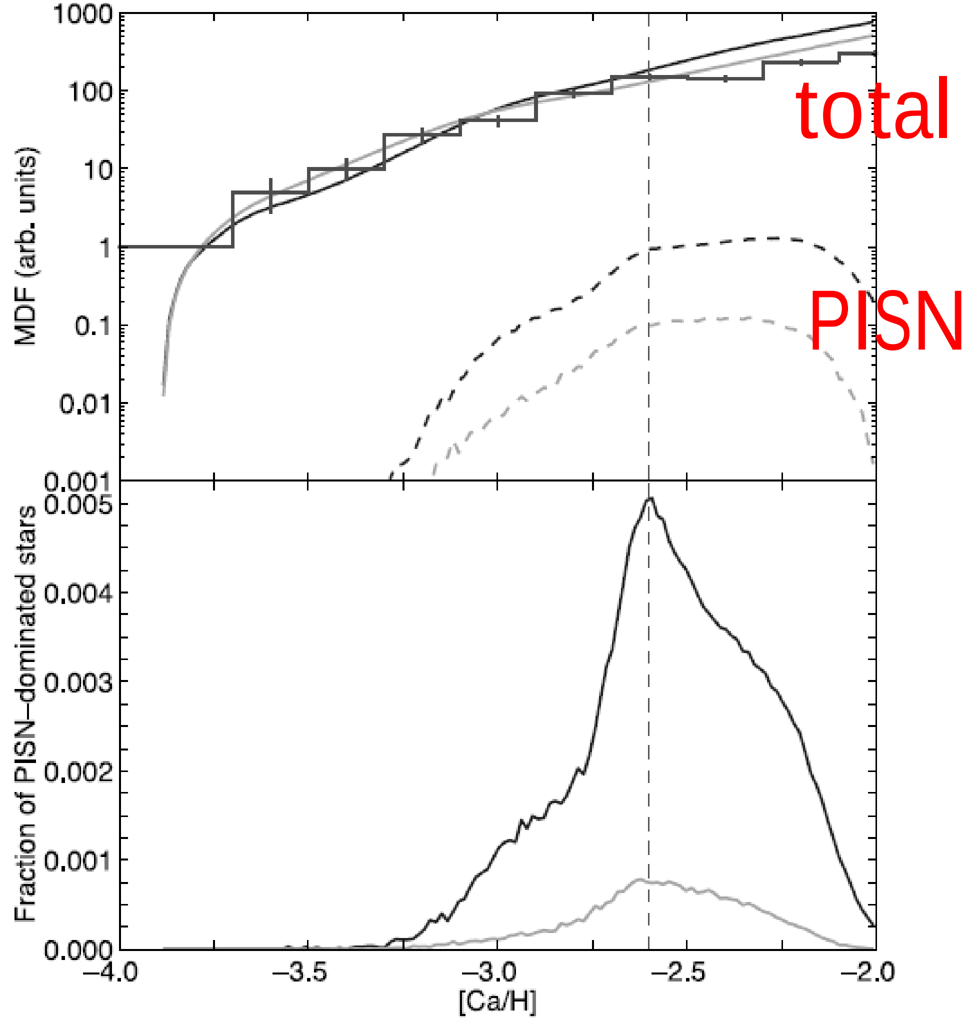
Karlsson et al. 2008, Astrophys. J. 679, 6)

"… **the evidence of very-massive stars and their explosions might only be found in moderate metal-poor stars**

→chemical abundance analysis for a large sample of metal-poor stars is required…

Metallicity distribution function of stars formed following PISN

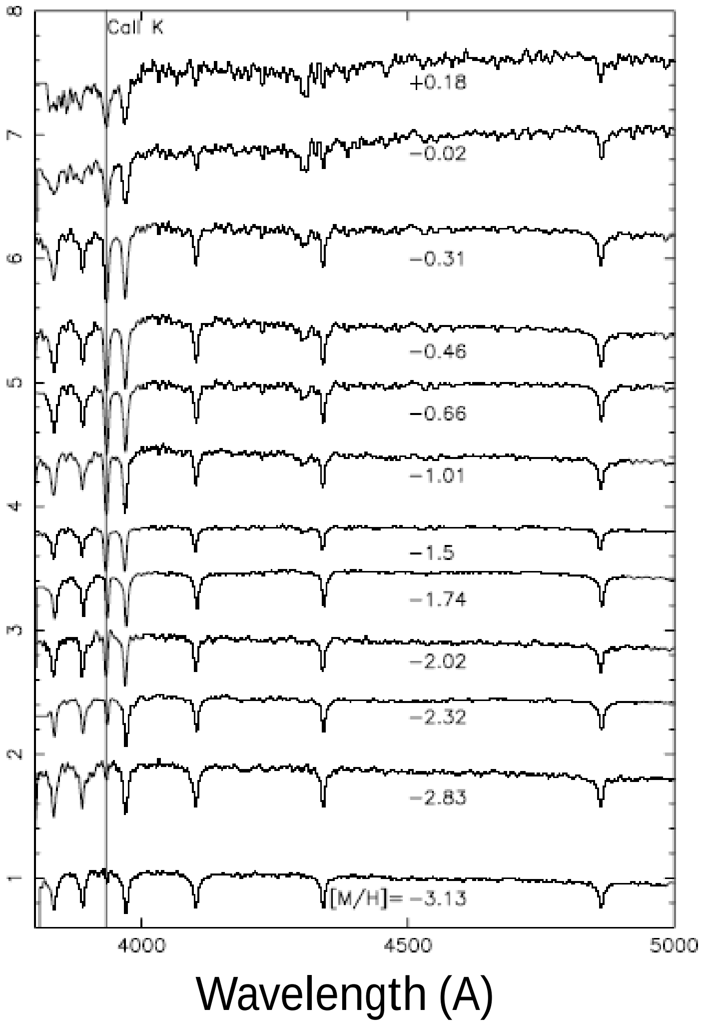
Karlsson et al. (2008)



Searches for very/extremely metal-poor stars in the Milky Way

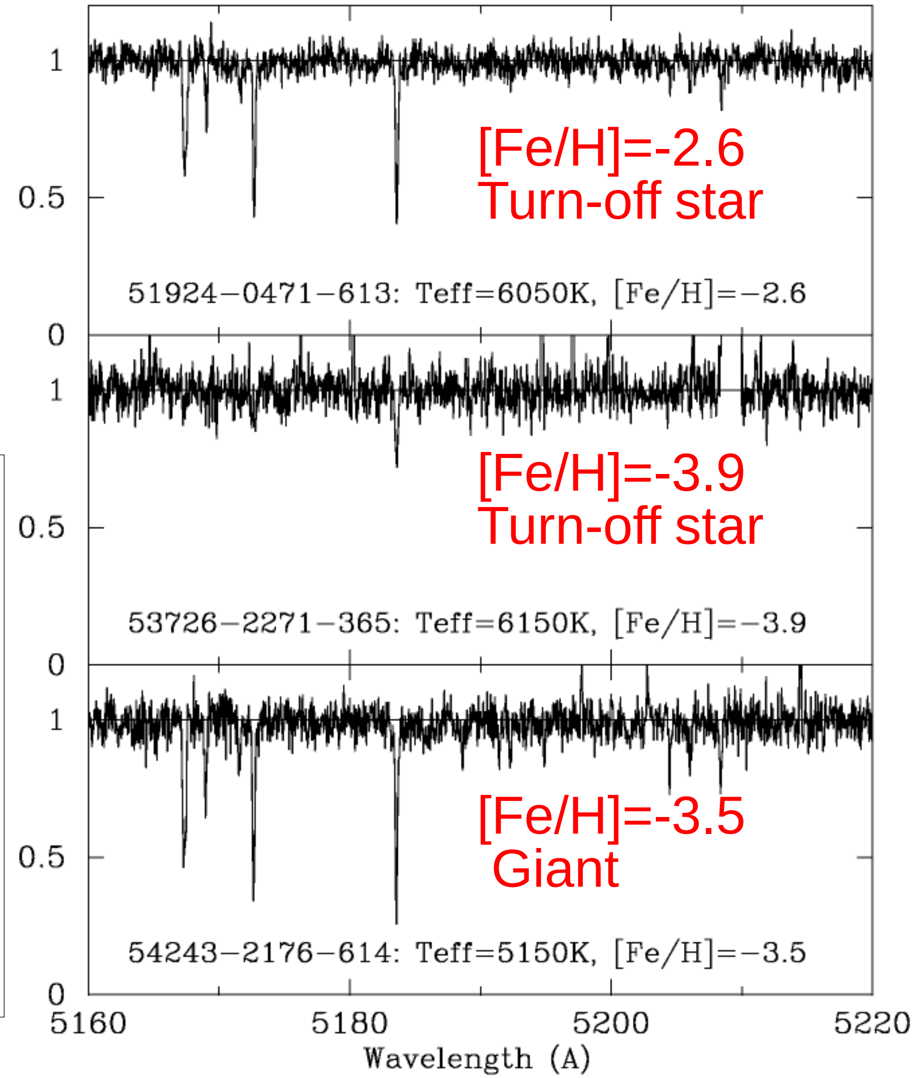
The 2.5m telescope at Apache Point Observatory

- Imaging/spectroscopic surveys
- Surveys of Galactic stars 240,000



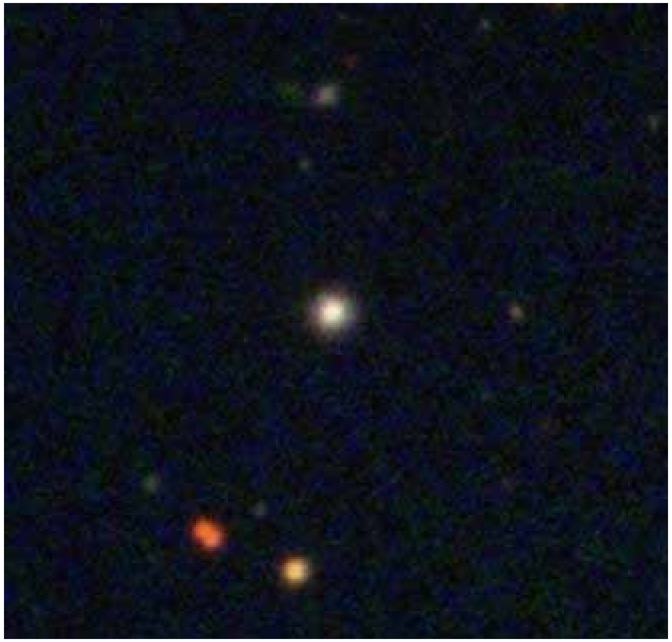
Follow-up high resolution spectroscopy with Subaru for selected SDSS objects

Follow-up spectroscopy with Subaru/HDS
 150 objects(2008-2009)
→chemical compositions of 137 very/extremely metal-poor stars（*Aoki et al. 2013, Astron. J. 145, 13*)



Discovery of a low-mass star with peculiar chemical composition

SDSS J001820.51-093939.2



Taken from SDSS

- [Fe/H]=-2.5
- Low C and Mg abundances
- A low-mass main-sequence star

Aoki et al. (2013, Astron. J. 145, 13)

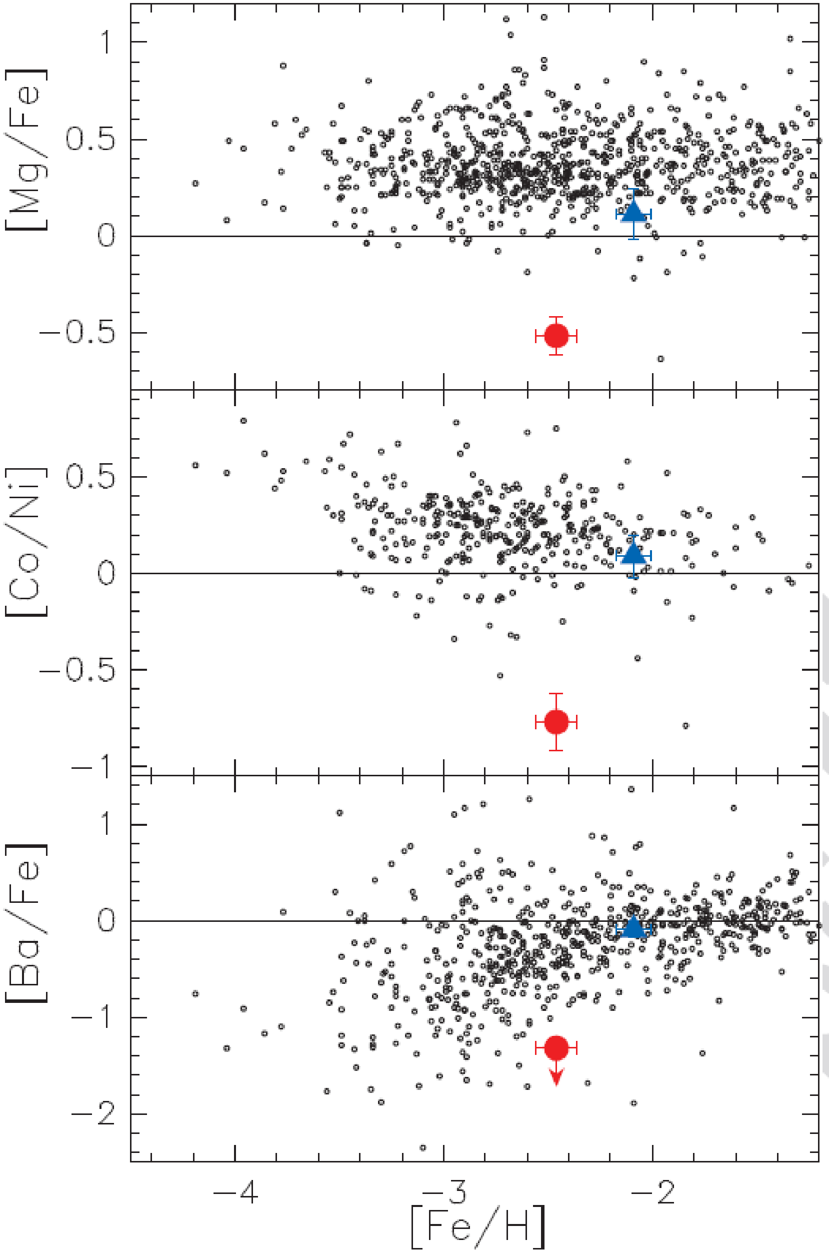
↓

Further follow-up spectroscopy with Subaru/HDS（August 2012）

Low abundances of alpha, odd, and neutron-capture elements of SDSS J0018-0939

Aoki, Tominaga, Beers, Honda, Lee (2014, Science)

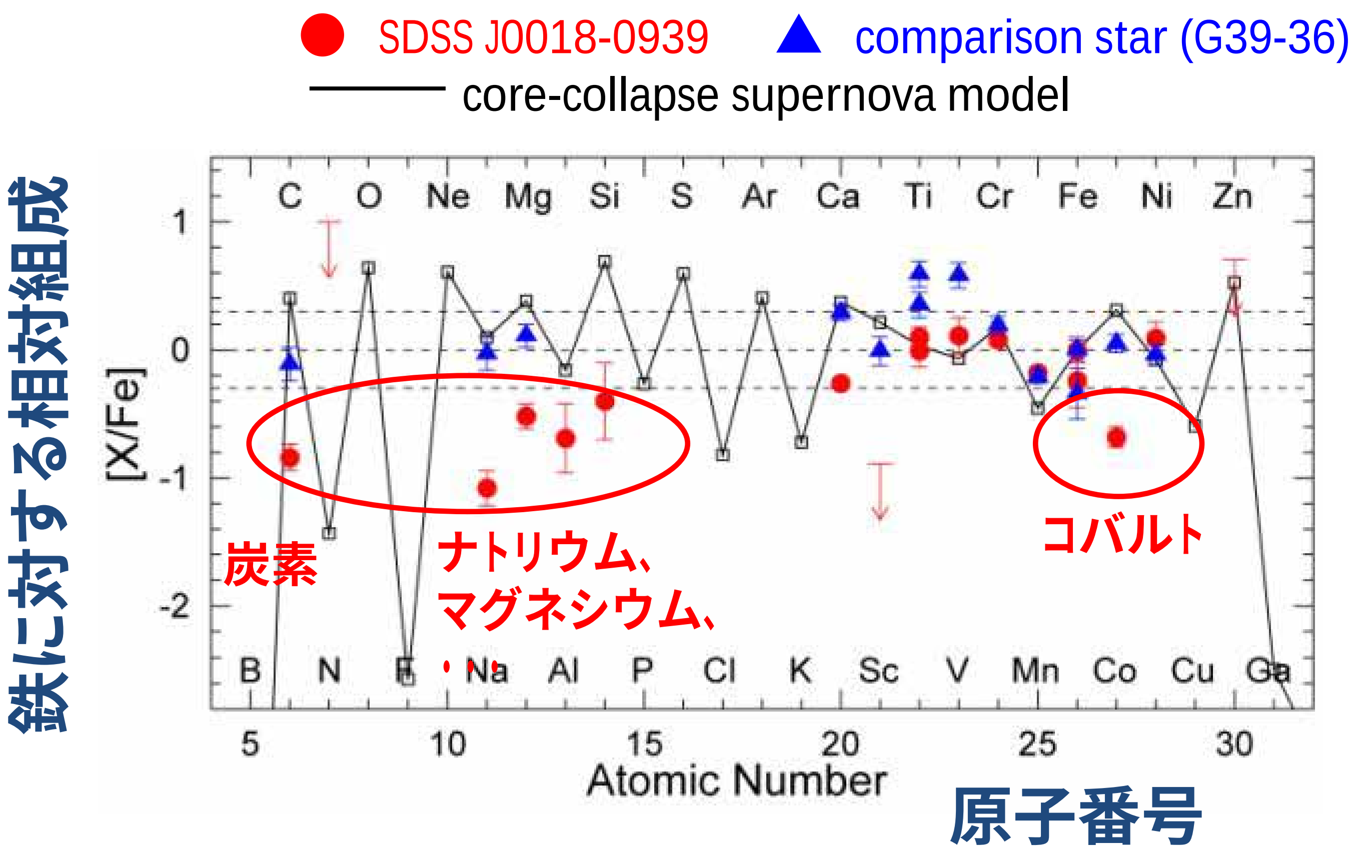
➡ excess of Fe?



SDSS J0018-0939 -- a low-mass star with a peculiar abundance pattern

The abundance pattern is not explained by normal core-collapse supernovae

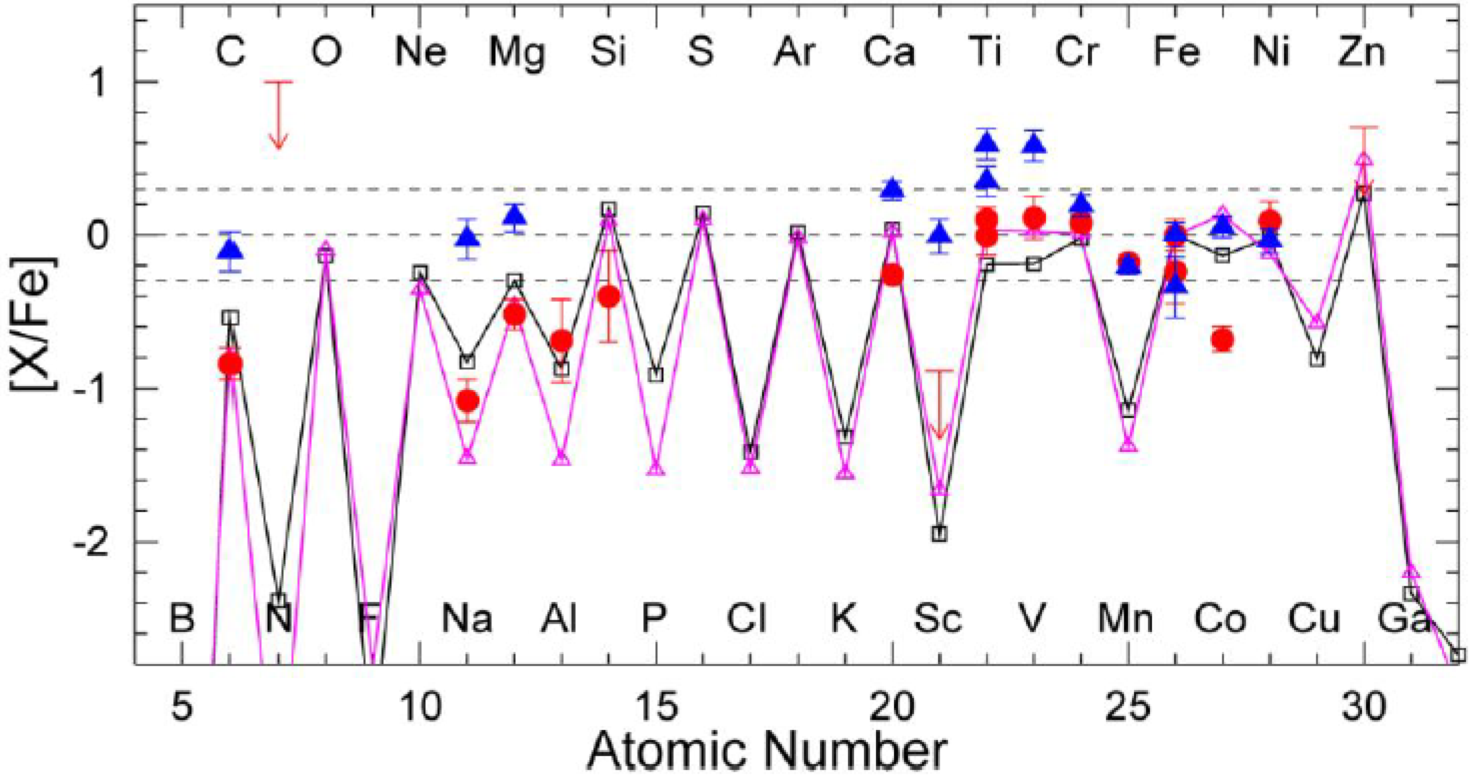
Aoki, Tominaga, Beers, Honda, Lee (2014)



SDSS J0018-0939 -- a low-mass star with a peculiar abundance pattern

The abundance pattern is not explained by variations of core-collapsed supernovae

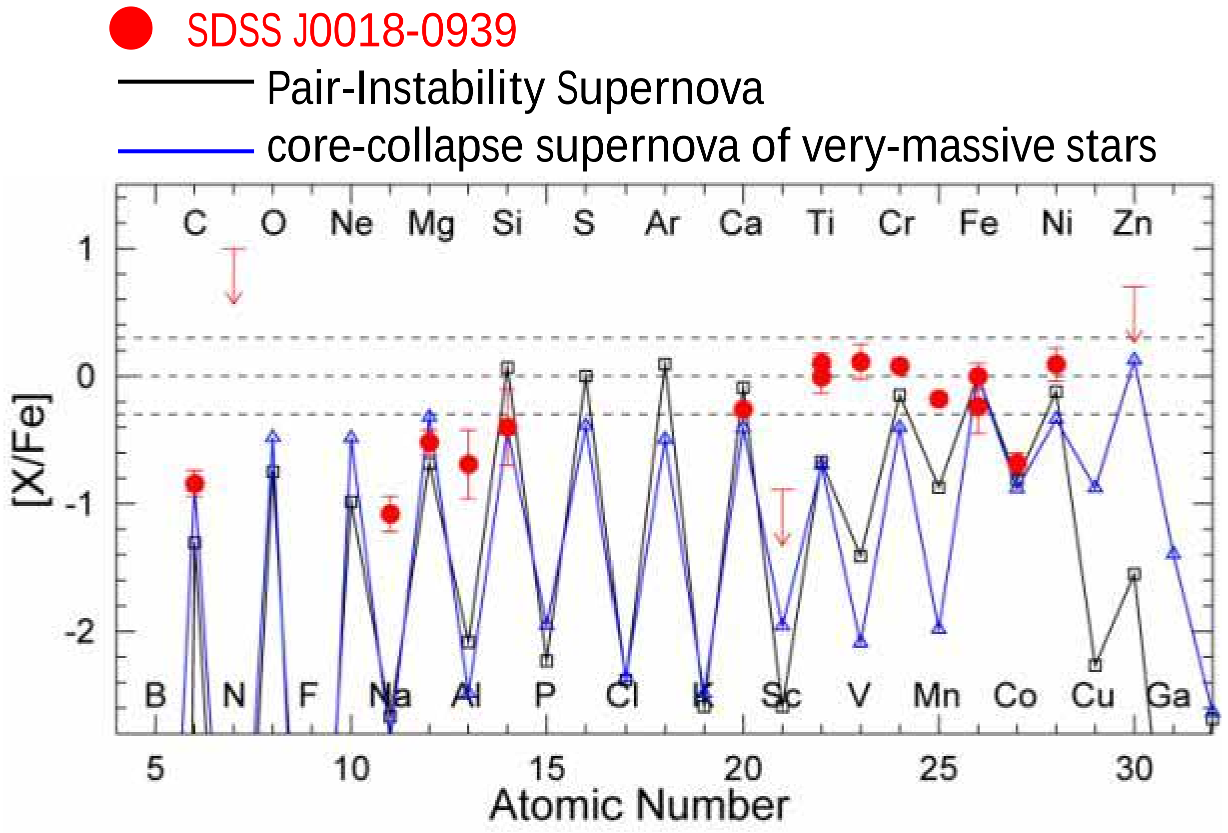
Comparison with higher explosion energy models



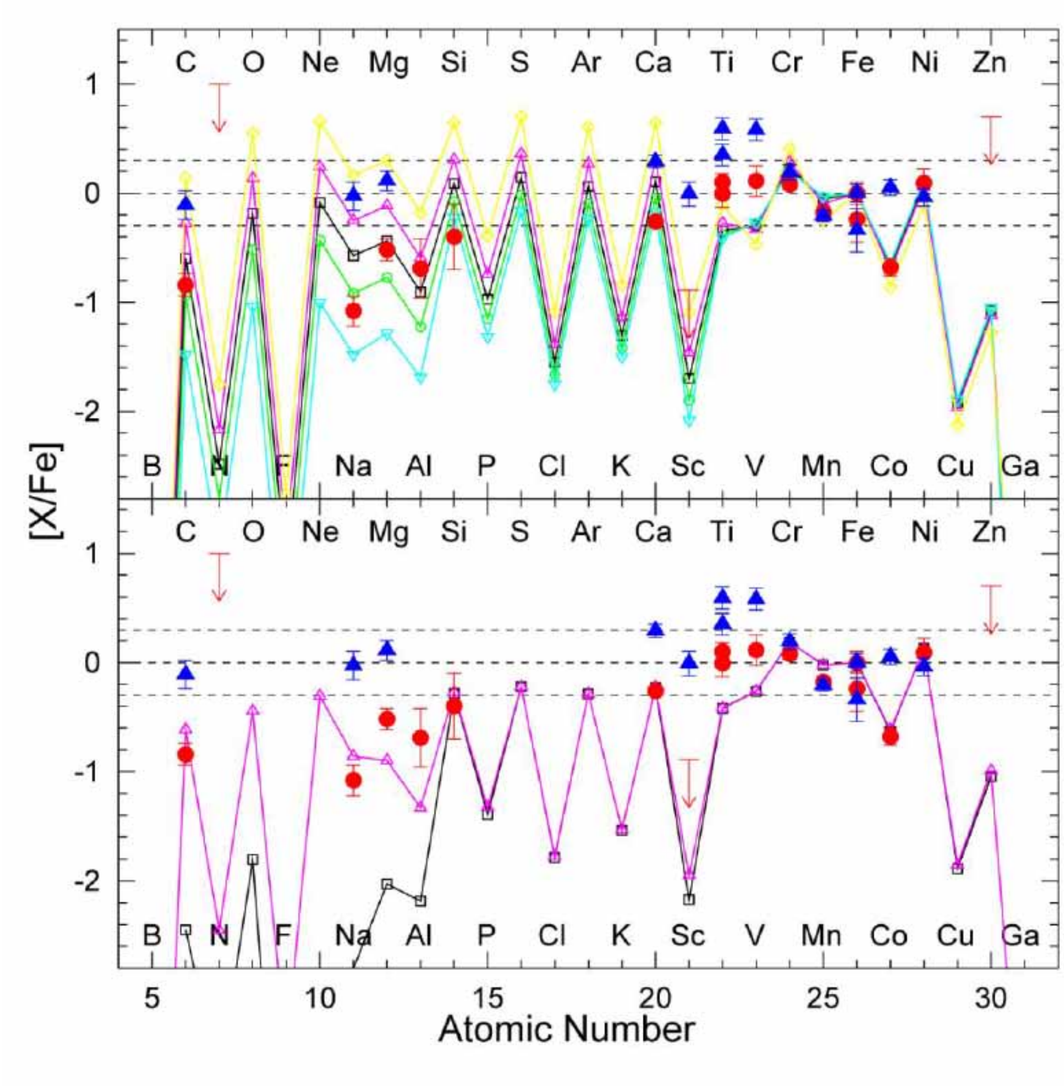
SDSS J0018-0939 -- a low-mass star with a peculiar abundance pattern

Aoki, Tominaga, Beers, Honda, Lee (2014)

Recording yields of a very-massive star?

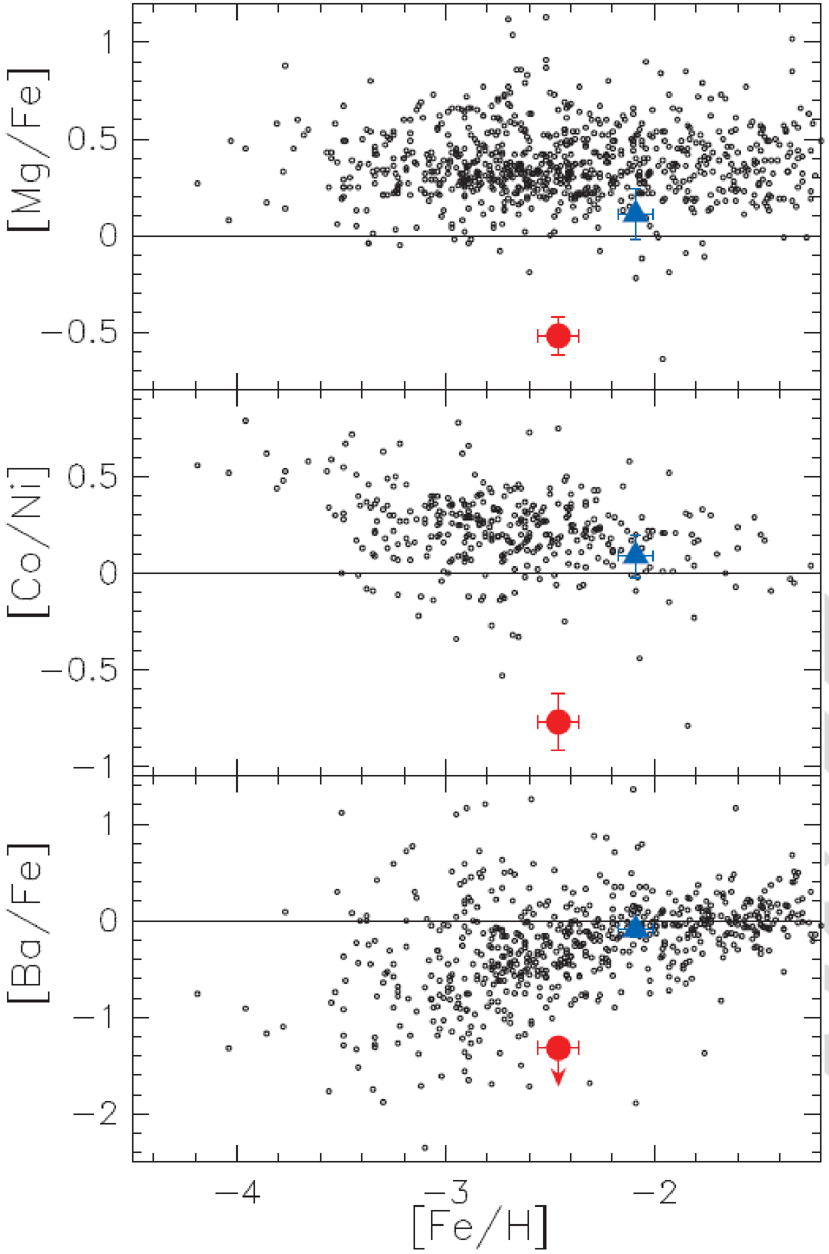


another possibility: Type Ia contamination?
… but a problem in time-scales



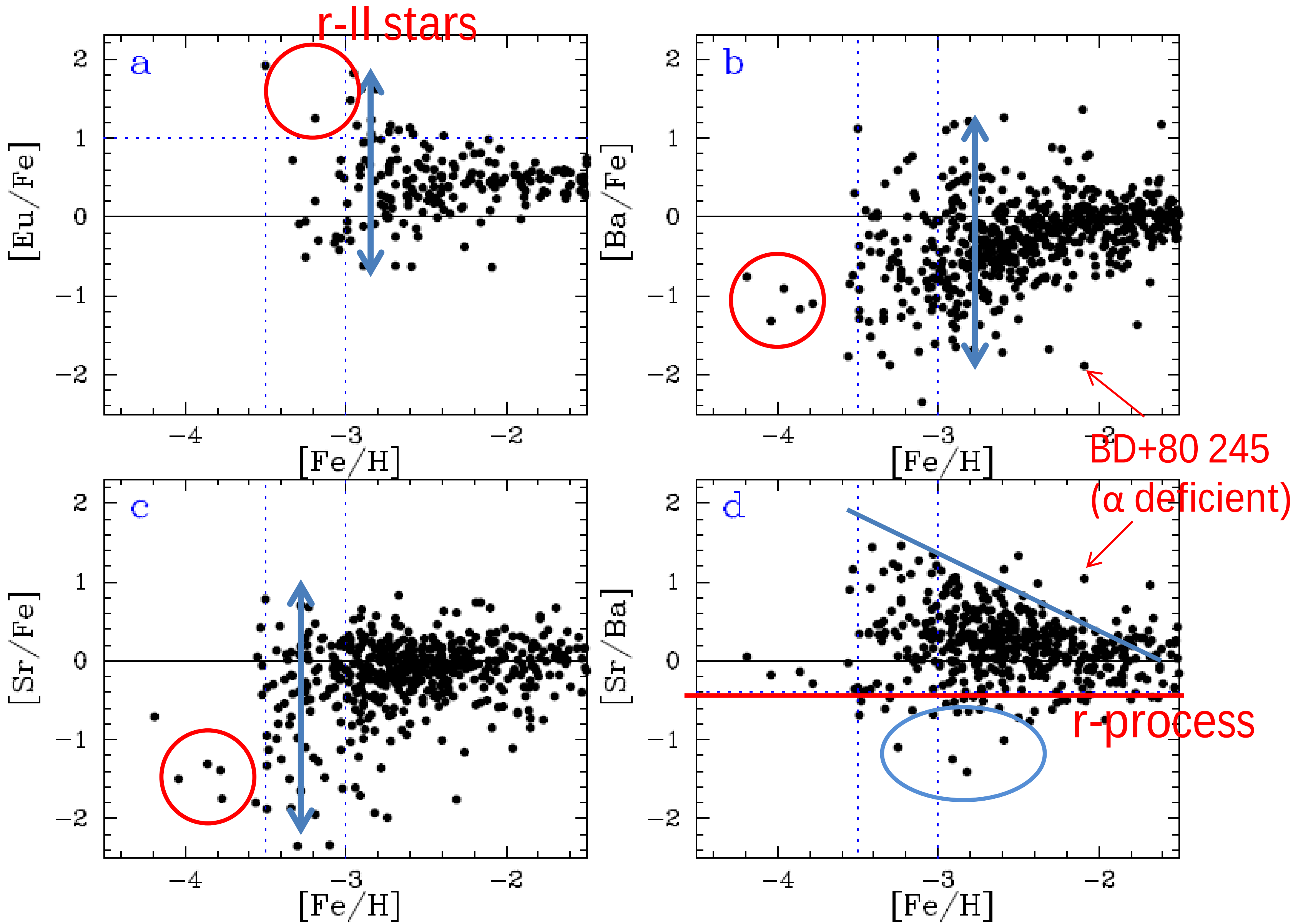
Neutron-capture elements in SDSS J0018-0939

Aoki, Tominaga, Beers, Honda, Lee (2014, Science)



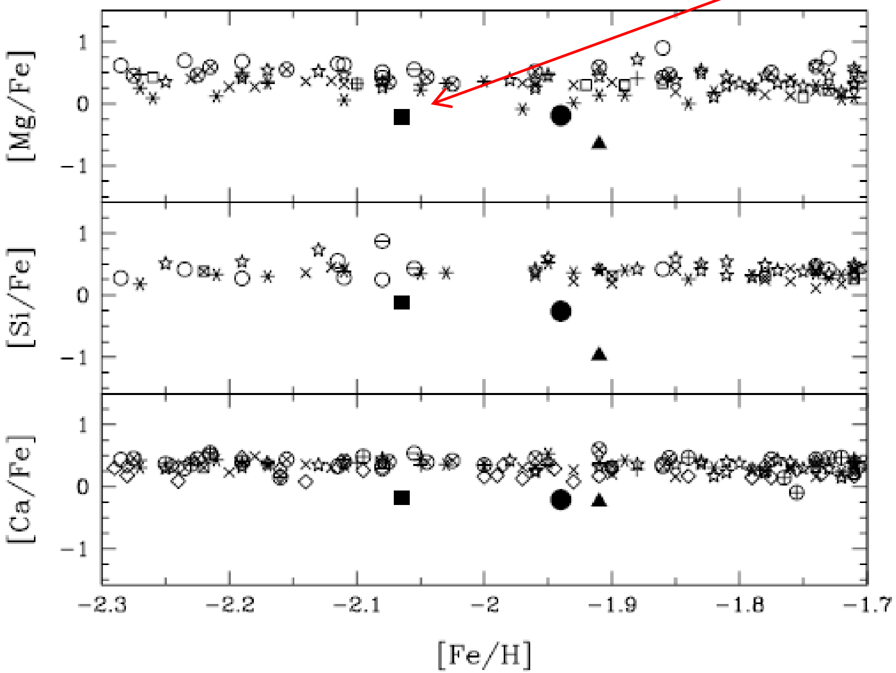
No detection of Sr and Ba

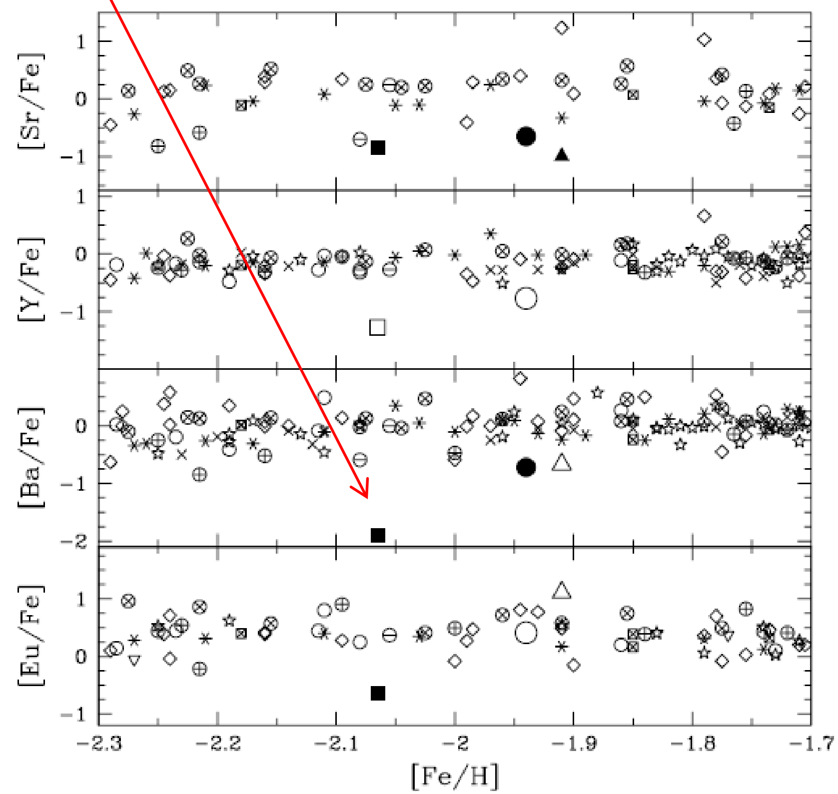
Sr and Ba (and Eu) abundance distributions



Another examples of “alpha-poor” metal-poor stars

BD+80 245





Next step: a larger survey of metal-poor star

- Further large surveys of metal-poor stars and follow-up program:
  LAMOST+Subaru
- Searches for metal-poor stars and chemical abundance measurements for dwarf galaxies
  Subaru＋TMT

LAMOST (中国、興隆)

矮小銀河
ろくぶんぎ座A

TMT完成予想図