Kyoto2009
19 May, 2009

First Generations of Stars and the Origins of Carbon-Enhancement in Metal-Poor Stars

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First generations of stars and the origins of carbon-enhancement in metal-poor stars

(1)Search for metal-poor stars and the discovery of the "Hyper metal-poor"(HMP) star ([Fe/H]<-5) HE1327-2326.

Large excesses of carbon with respect to Fe in HMP stars

→Constraints on nucelosynthesis by first generations of stars

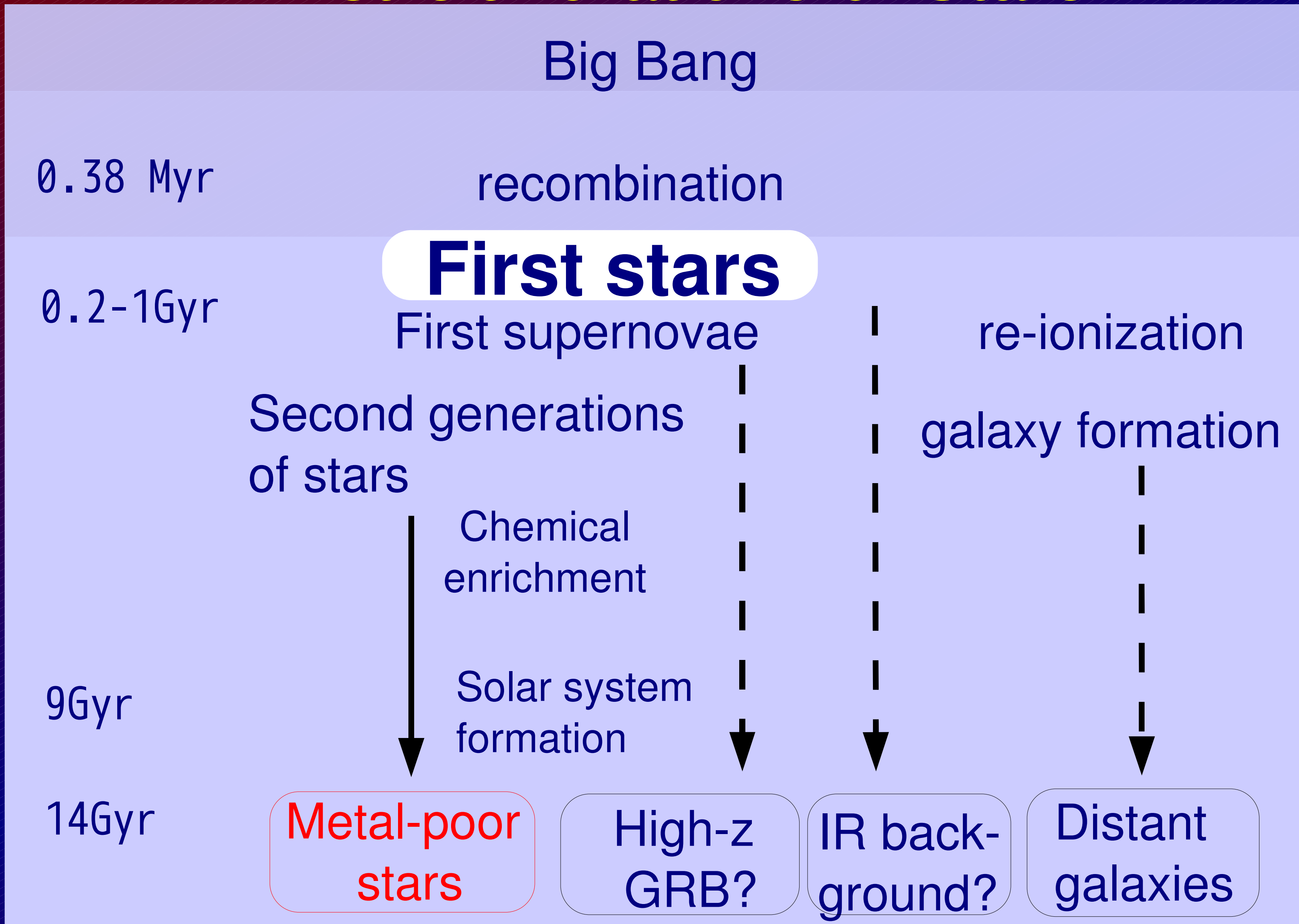
(2)Discoveries of many carbon-enhanced metal-poor stars Origin of their carbon-excesses

→Constraints on the progenitors of HMP stars

(3)Current observing program on metal-poor stars with Subaru and future prospect with WFMOS and TMT

Subaru Telescope High Dispersion Spectrograph (HDS)

Observational Approaches of First Generations of Stars



What can we know from stars with the lowest metallicity?

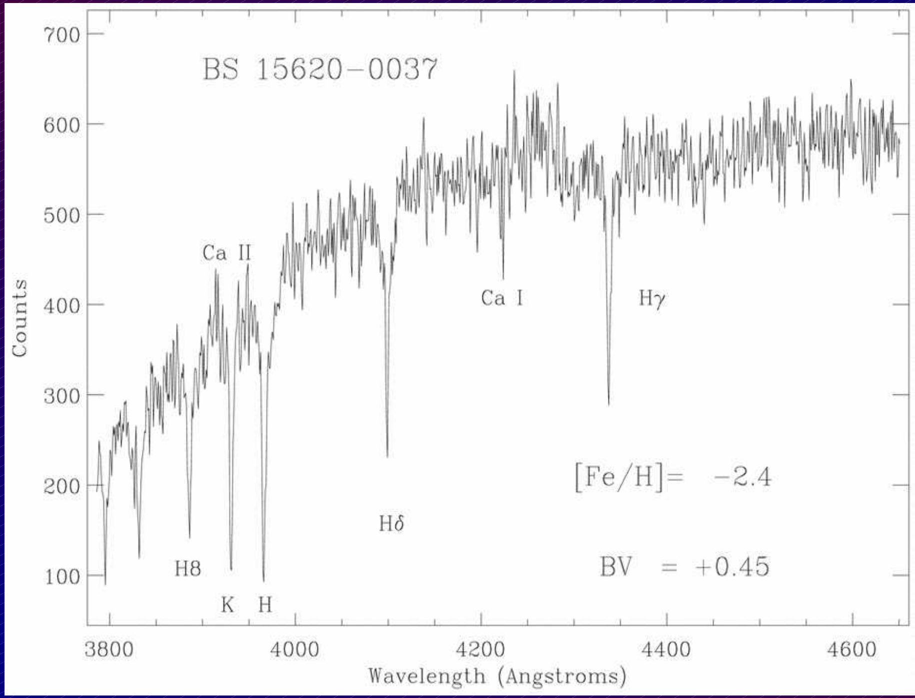
- Nucleosynthesis products by first generation (metal-free) stars:
  - -Evolution of massive stars and supernova explosion
  - -Intermediate-mass stars in binary systems

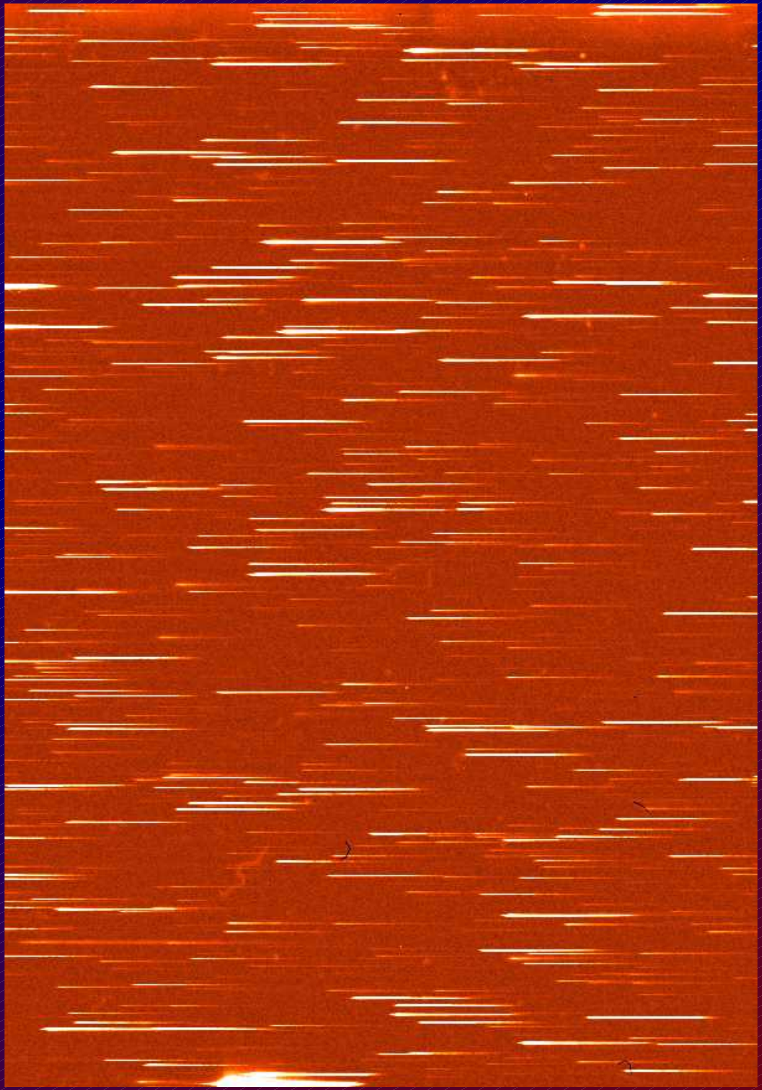
↓

- Mass distribution of first stars
  - -Super massive (M>100Msun) stars that exploded as pair-instability supernovae?←Constraints from nucleosynthesis products
  - -Low-mass star formation from metal-free clouds?

Search for Metal-Deficient Stars

1) Low-resolution spectroscopy with objective prism
2) Medium resolution spectroscopy for selected candidates ↓





e.g., Beers et al. 1992

Progresses of surveys

cf. *Beers & Christlieb (2005, ARAA)*

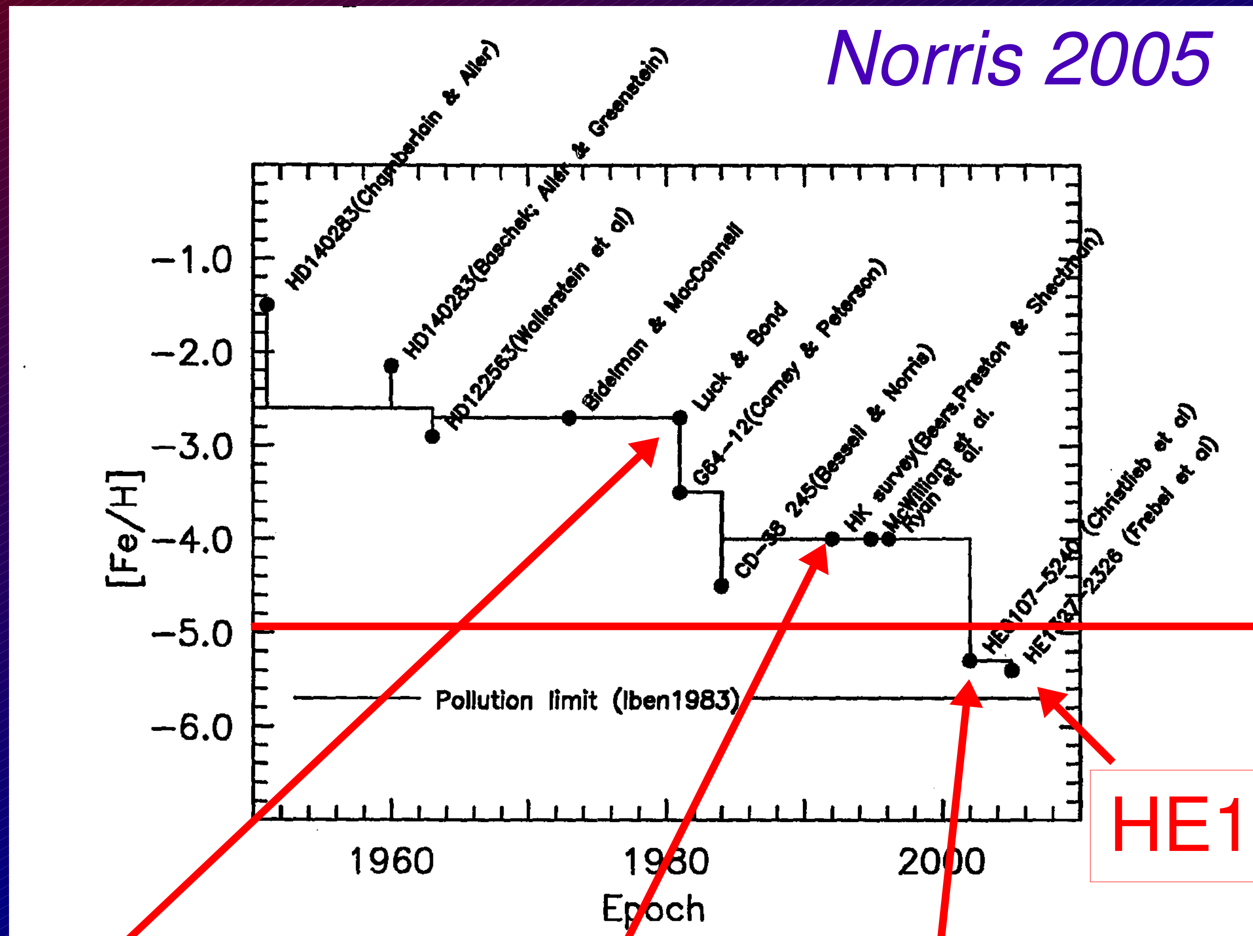
- HK survey (1980s~)
  Beers et al. 1985, 1992, etc.
  → BS12345-678, CS23456-789 ...

- Hamburg/ESO survey (1990s~)
  stellar content: *Christlieb et al. 2001* etc.
  → HE1234-5601

- SDSS/SEGUE (2006~)

Search for the most metal(iron)-deficient stars in the Galaxy

[Fe/H]=
log(n[Fe]/n[H]) - log(n[Fe]/n[H])sun



Hyper Metal-Poor (HMP) stars

HE1327-2326

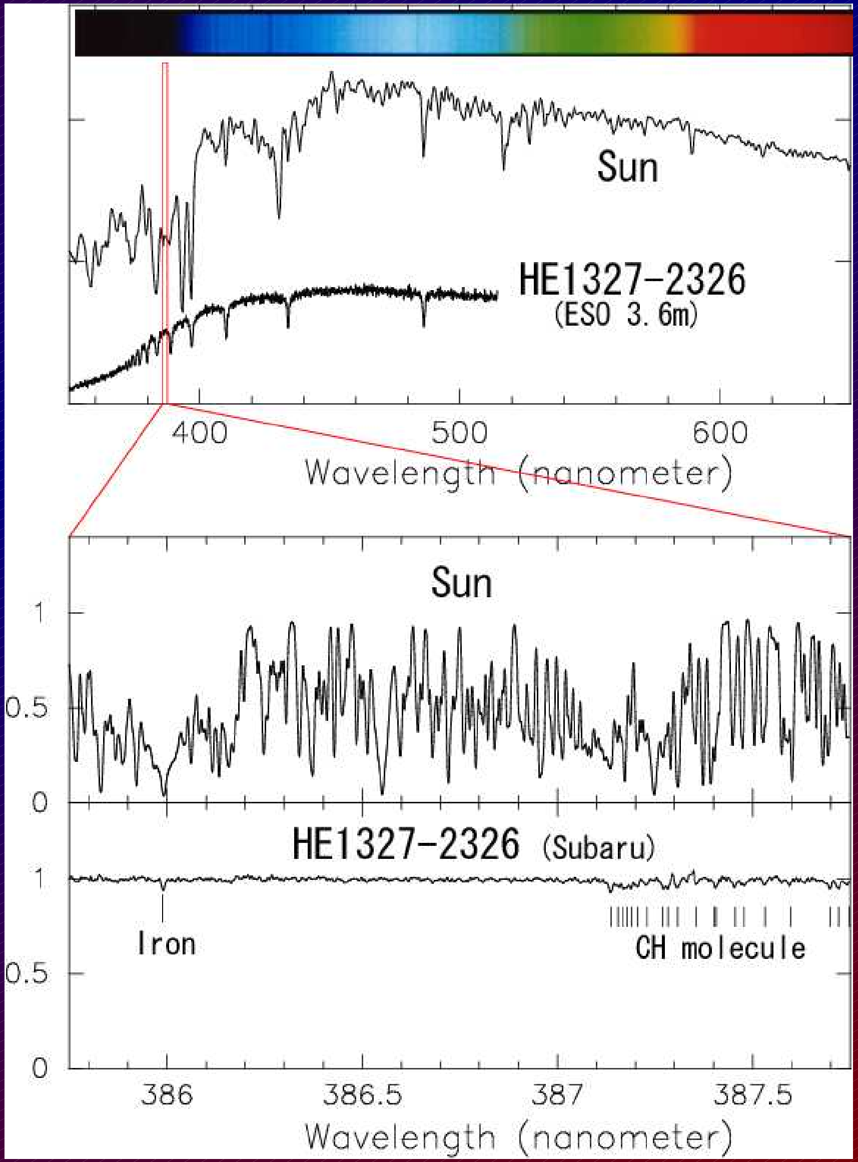
Bond (1981)
"Where is Population III"

HK survey

Discovery of HE0107-5240
([Fe/H]=-5.3)

Discovery of HE1327-2326, the most iron-deficient star to date

Frebel, Aoki, Christlieb et al. (2005)

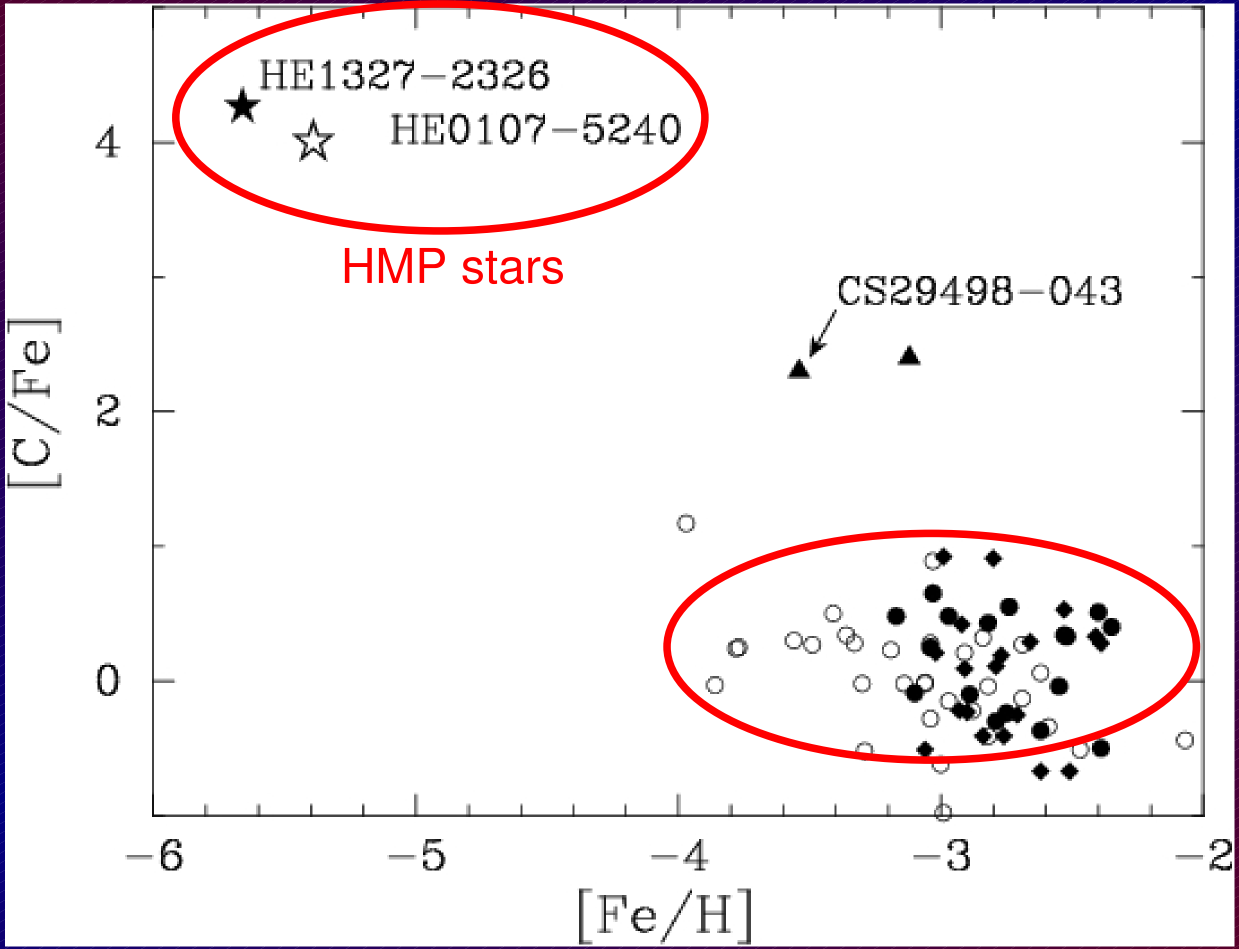


- Medium resolution spectra
- High resolution spectra
  very weak Fe lines
  → [Fe/H]=-5.4
  detection of CH molecular bands
  → excess of carbon

Iron-Deficient & Carbon-Enhanced Stars

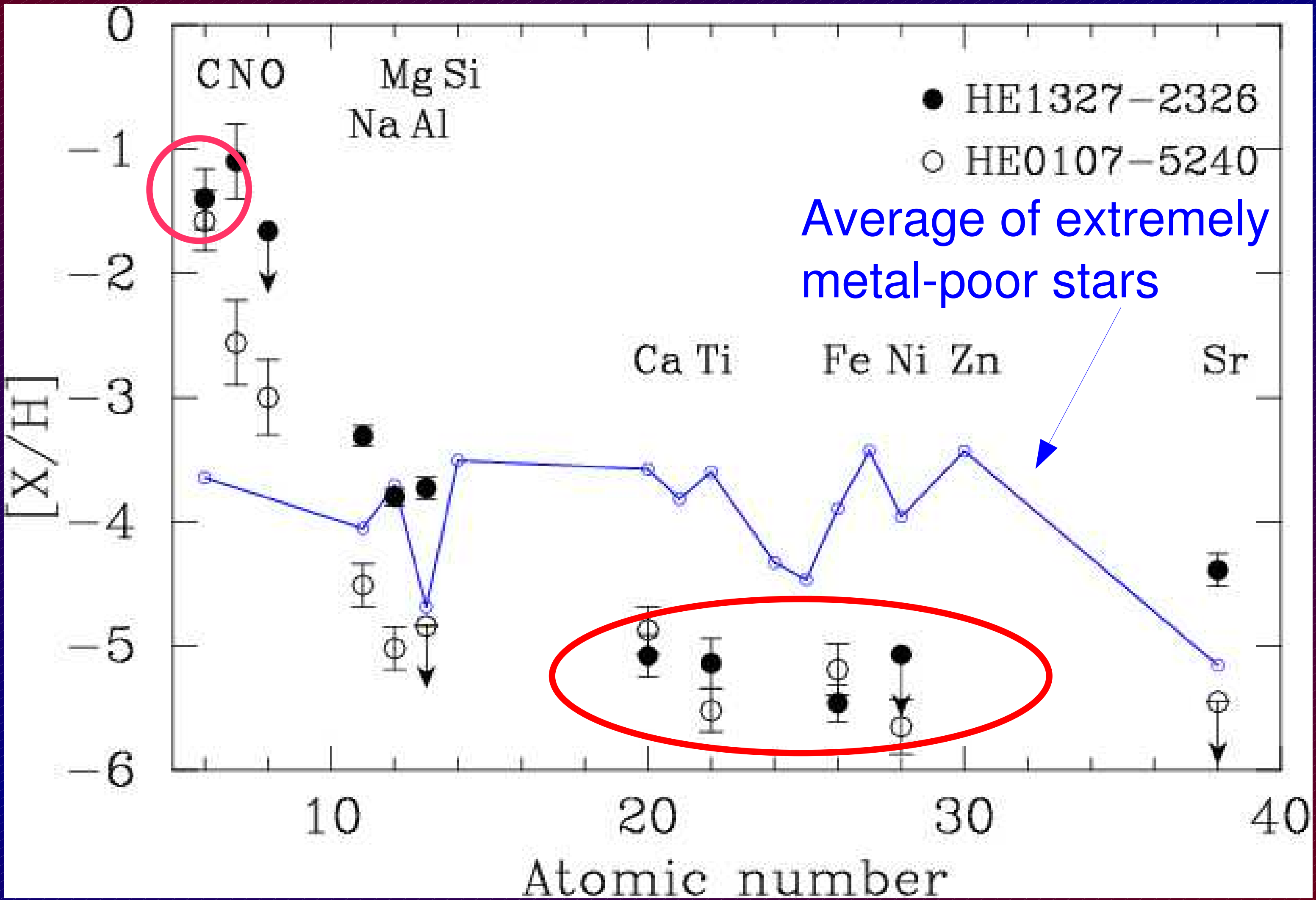
HE1327 and HE0107 have very high C/Fe ([C/Fe]~+4)

→A common origin of the peculiar abundance pattern



Aoki et al. 2006

Elemental Abundance Patterns of Stars with [Fe/H]<-5



Aoki et al. 2006

Implications of the discoveries of HMP and their chemical composition

- Two stars (including HE1327-2326) have been found in [Fe/H]<-5, which is much lower than the previously suggested metallicity limit for low-mass star formation.

- However, the two HMP stars show large excesses of carbon with respect to Fe.
There seems to still exist a limit in [Metal/H] for low-mass star formation (e.g. Frebel et al. 2007).

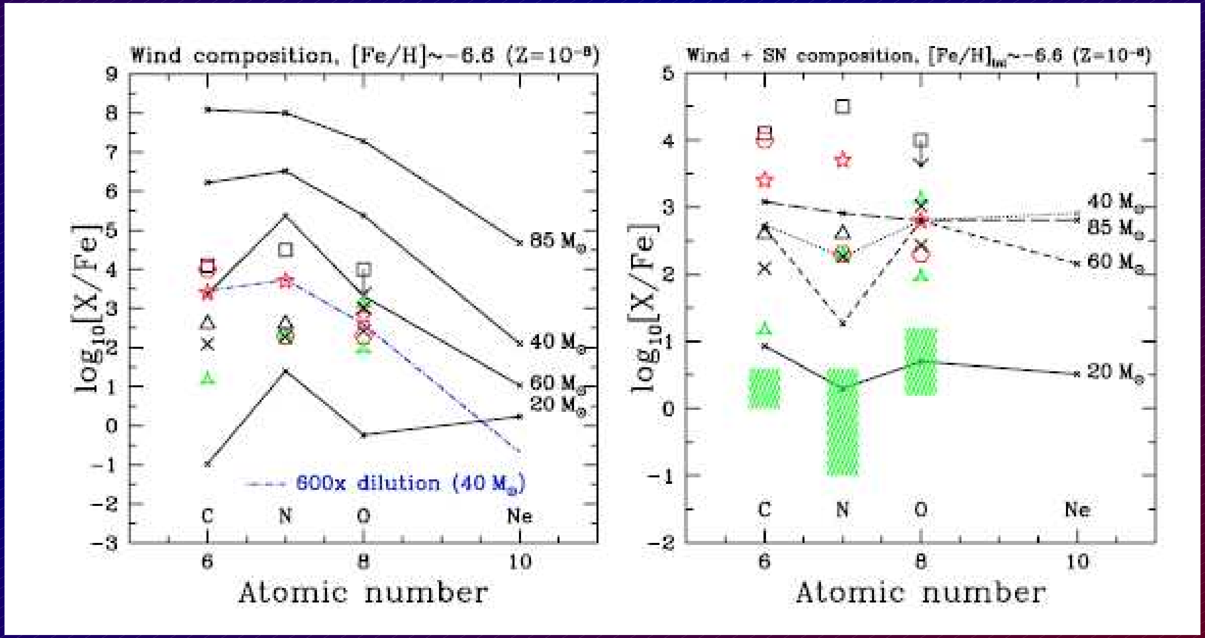
- The large carbon-excesses are the key to understanding the progenitors of HMP stars, which are likely the first generations of stars.

Scenarios proposed for explaining the low Fe and high C abundances

Scenario 1. Mass-loss (wind) from rotating massive stars

Surface of (originally) zero-metal massive stars can be enriched in CNO by mixing if they are rapidly rotating. Significant amount of CNO are provided by their stellar wind. (e.g. Meynet et al. 2006)

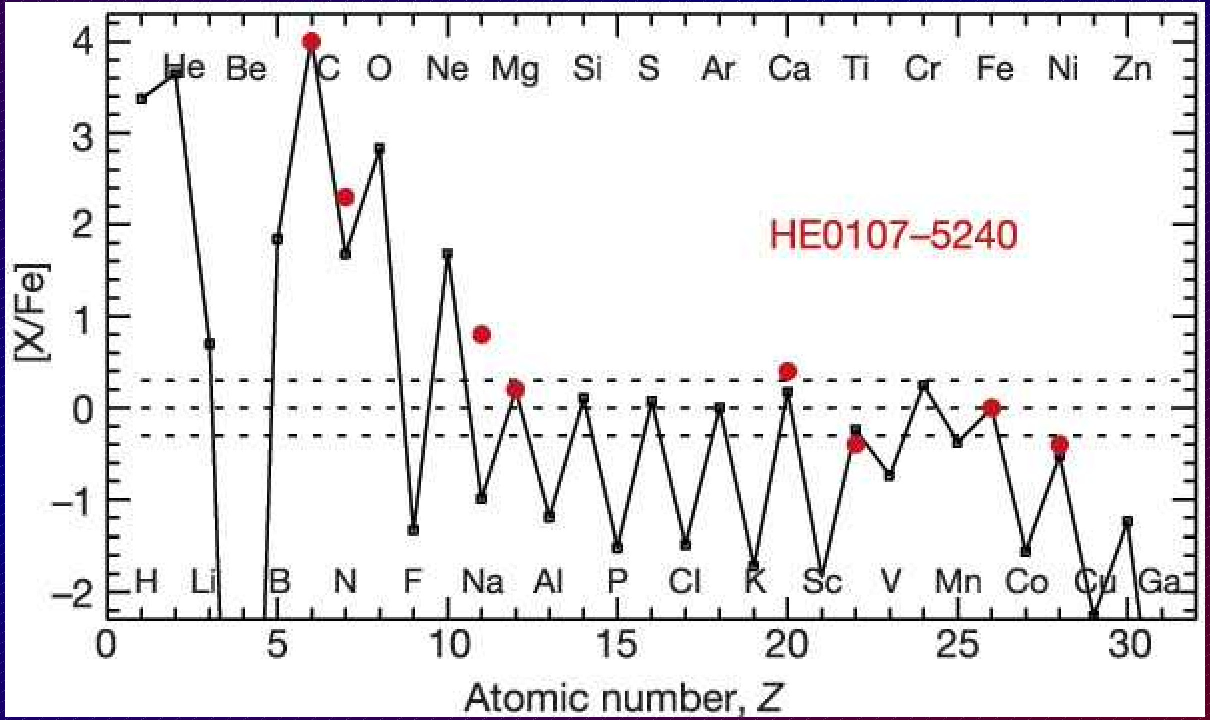
Wind   Wind + supernove



Hirshi (2007)

Senario 2. Faint supernovae

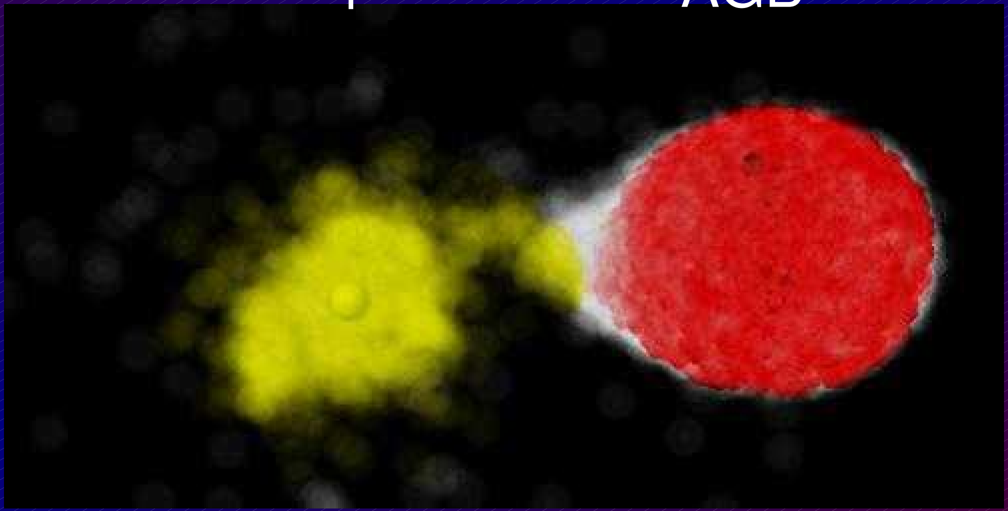
High C/Fe and O/Fe ratios can be produced by significant mixing and fall-back in supernova explosions by producing little Fe. Such phenomena are expected in non-spherical explosions. Small ejection of Fe makes the supernova faint. (e.g. Umeda & Nomoto 2003)



Umeda & Nomoto 2003

Scenario 3. AGB stars in binary systems

Carbon-rich material is produced by evolved intermediate-mass stars (AGB stars). That can be transferred to companion low-mass stars if they form a binary system. (e.g. Suda et al. 2004)



(From RSPA web page)

Candidates of the origins of Carbon excesses in HMP stars are

- -rotating massive stars?
- -faint supernovae?
- -AGB stars in binary systems?

We cannot conclude which is the best scenario for the progenitors of HMP stars. More searches for stars with [Fe/H]<-5 are required.

Some constraints are obtained from the studies of Carbon-Enhanced Metal-Poor stars.

Carbon-Enhanced Metal-Poor (CEMP) stars as constraints on progenitors of HMP stars

- Carbon-enhanced stars in the Galactic halo are known as the spectral class CH stars (Keenan 1942).

- A number of carbon-enhanced stars were identified by the HK survey (e.g. Beers et al. 1992)

- The fraction of CEMP is estimated to be 10-25% in [Fe/H]<-2.

Beers et al. (1992)

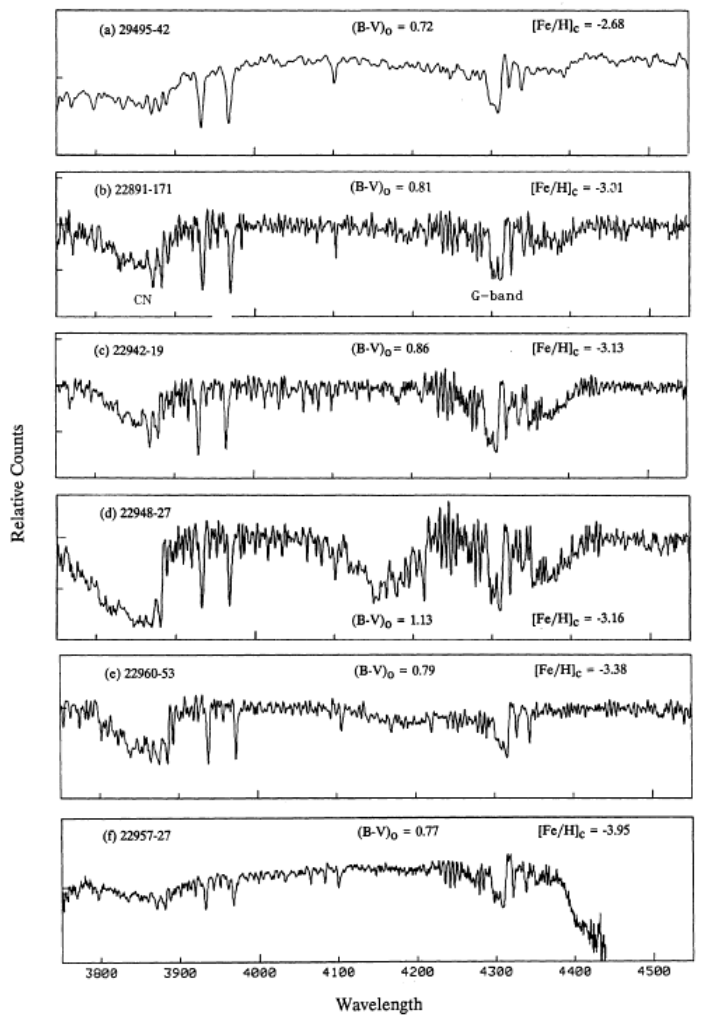


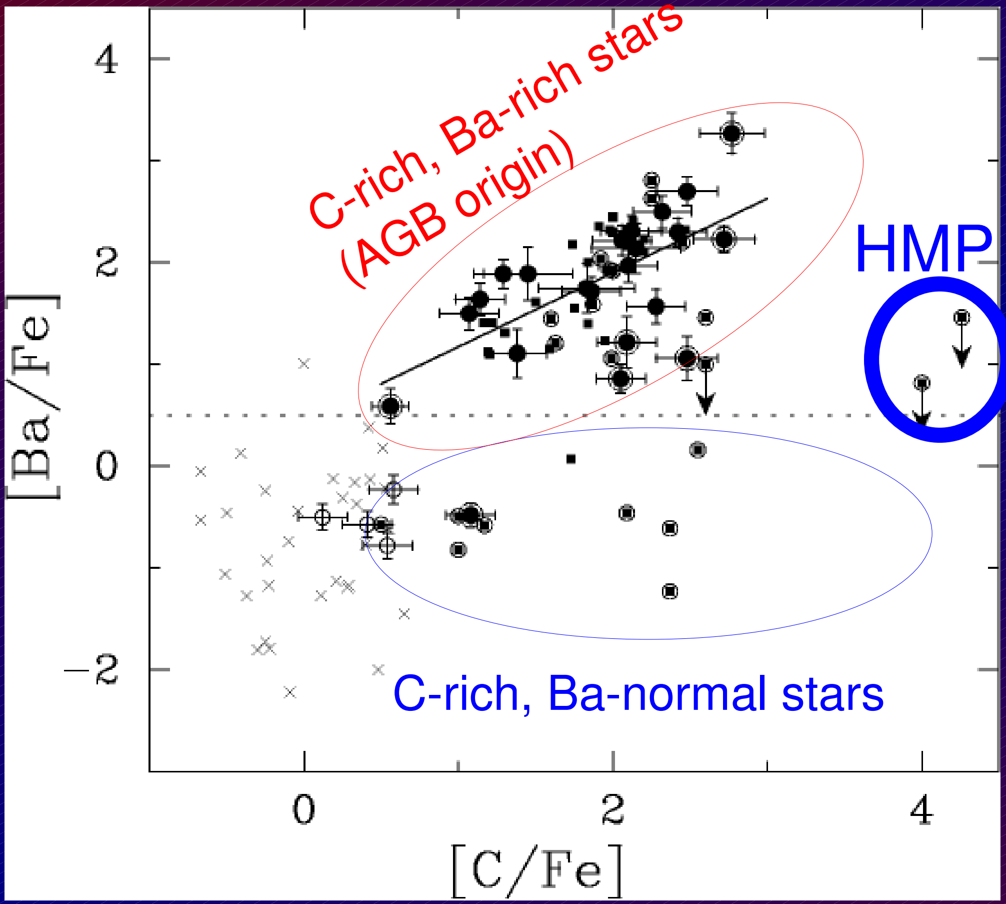
FIG. 13. Type examples of stars in the present sample with moderate to strong CN bandheads at λ3883 Å and/or λ4215 Å, and anomalously large CH (*G*-band) λ4300 Å features. All spectra have been smoothed with a Gaussian of breadth 2.5 Å, and flattened with a boxcar smooth.

Why are these objects carbon-rich?

•Heavy (s-process) elements *enhanced* stars:
Most of C-enhanced stars also show excesses of s-process elements (e.g. Ba). The carbon would be enriched by nucleosynthesis in AGB stars (and binary mass transfer).

•Heavy elements *normal* stars:
There are C-rich stars whose Ba abundances are low. Origins of carbon in these objects are not well understood.

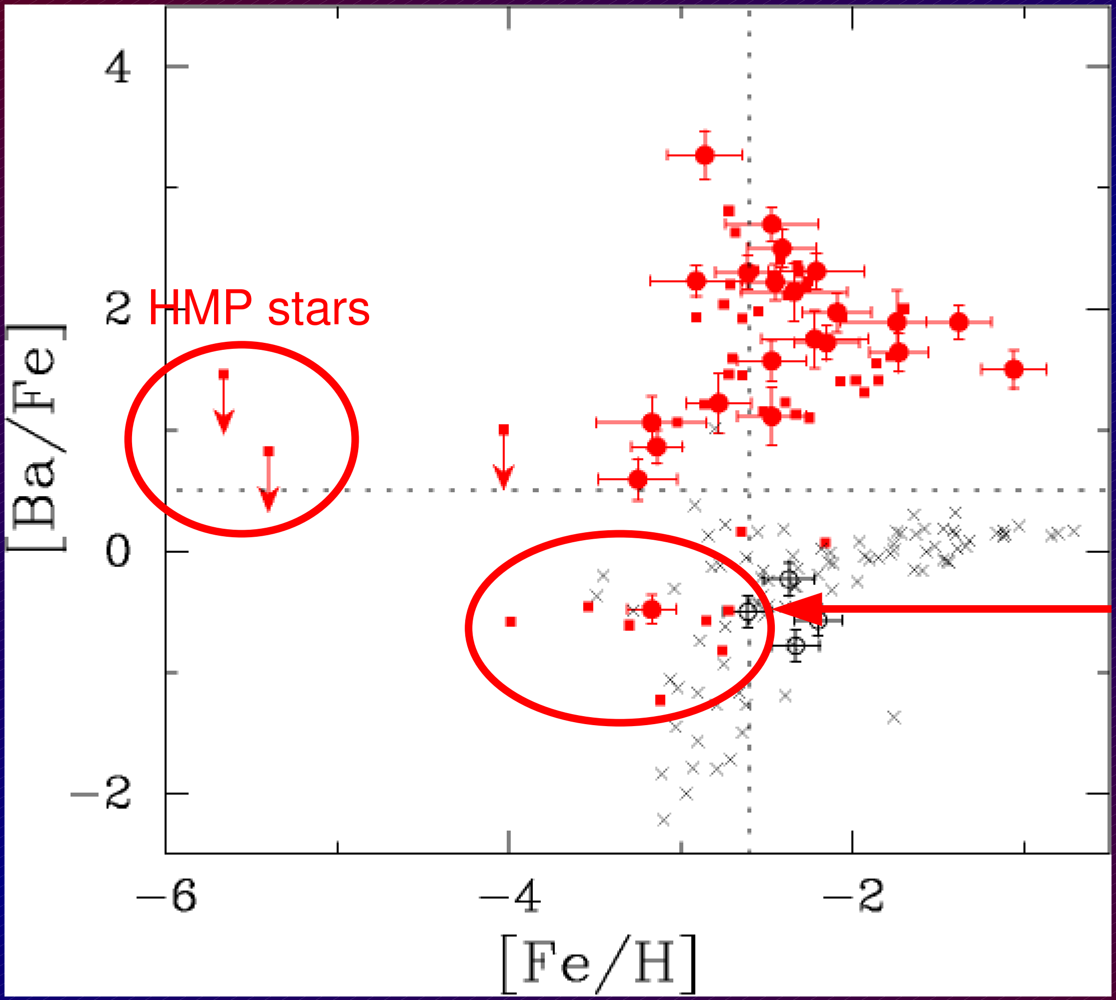
Correlation between carbon and Ba (=s-process) abundances



•A majority (~75%) of C-enhanced stars show excesses of Ba (and a correlation between C and Ba abundances).

•Ba abundances of others are low (normal)... the reason for C excess is not fully understood.

Neutron-capture element Ba: Connection between Ba-normal stars and HMP stars



C-rich stars with normal Ba are extremely metal-poor!

Aoki et al. 2007

Classification of Carbon-Enhanced Metal-Poor stars

C-rich stars
([C/Fe]>+0.7)

(~80%) Ba-rich — Binarity is confirmed for at least some of them.

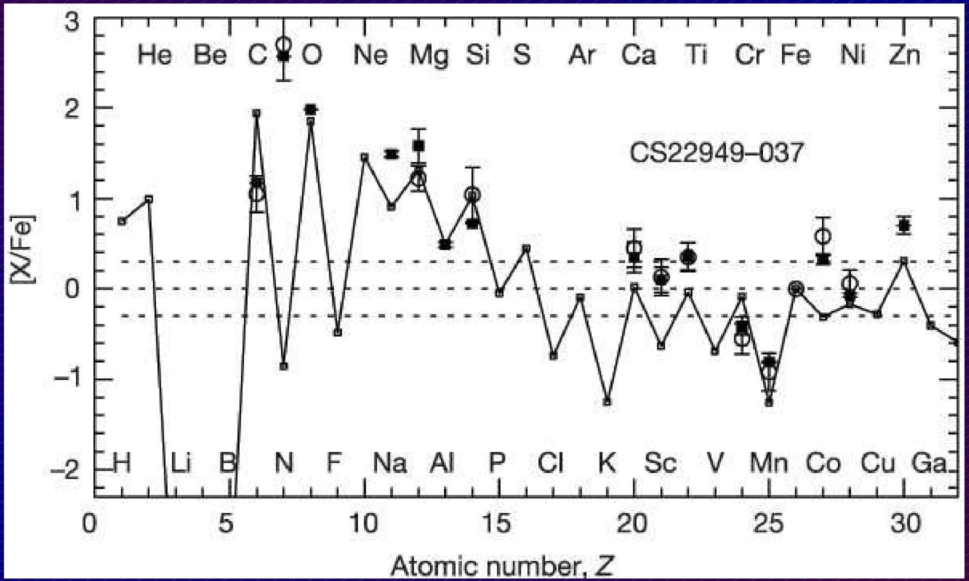
Origin of carbon is believed to be AGB stars (+ mass transfer across binary systems)

(~20%) Ba-normal — Evident in extremely low metallicity range ([Fe/H]<-2.5)

Connection with HMP stars?

Origins of C-excess in Ba-normal CEMP stars: Evidence for core-collapse (faint) supernovae

- Two stars with [Fe/H]<-3.5 show large excesses of alpha elements
→ Nucleosynthesis by core-collapse supernovae (faint supernovae) is suggested.



Umeda & Nomoto 2003

- Discovery of the very bright CEMP star BD+44 493 ([Fe/H]=-3.7)
The normal Ba abundance, the high O/C, and the low N/C exclude the AGB and massive rotating stars as the progenitors
→ Faint supernova scenario is the remaining possibility.
(H. Ito et al. in this session)

Summary and Conclusion

• Surveys of metal-poor stars in the past decade have discovered two "Hyper Metal-Poor" ([Fe/H]<-5) Stars. They show large excesses of carbon with respect to Fe, a key to understanding their progenitors.

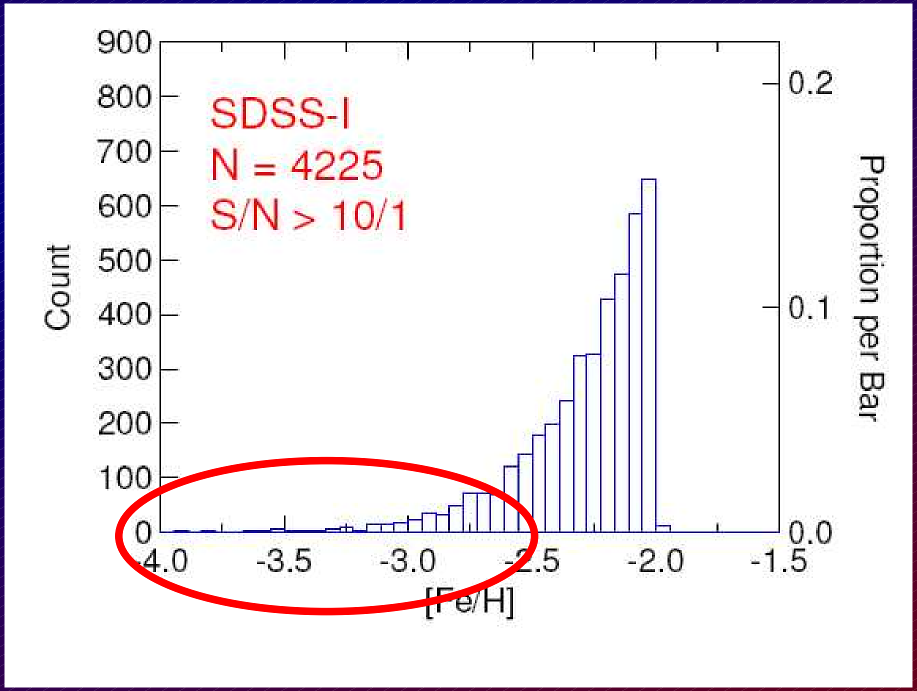
• Our systematic studies for Carbon-Enhanced Metal-Poor (CEMP) stars revealed that a majority of them also show large excesses of the heavy element Ba, signature of AGB nucleosynthesis.

• Some other CEMP stars in the lowest metallicity range suggest the contributions of "faint supernovae" at very low metallicity. This provides a constraint on the progenitors of HMP stars.

Ongoing program: stellar chemical abundance studies for SDSS sample

SDSS provides a huge sample of candidate metal-poor stars
→Subaru follow-up program in 2008-2009

- metallicity distribution
- carbon excesses
- Li processes
- neutron-capture ...



Future prospects: multi-object spectroscopy

A disadvantage of the current Subaru:
Lack of instruments for wide-field, multi-object, medium/high resolution spectroscopy

Example: VLT/FLAMES

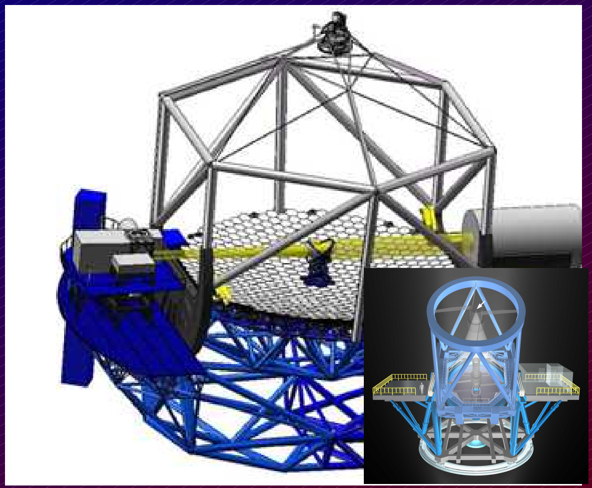
the multi-object, intermediate and high resolution spectrograph

WFMOS-like instrument will have a large impact on the studies of stars at the earliest stage of the Galaxy.

More future ....: High resolution follow-up spectroscopy for stars discovered with Subaru

Spectroscopic capability of the Thirty Meter Telescope

→ Detailed studies of outer halo, bulge, dwarf galaxies, etc.



(from TMT and Subaru)