Carbon-Enhanced Metal-Poor stars studied with LAMOST and Subaru

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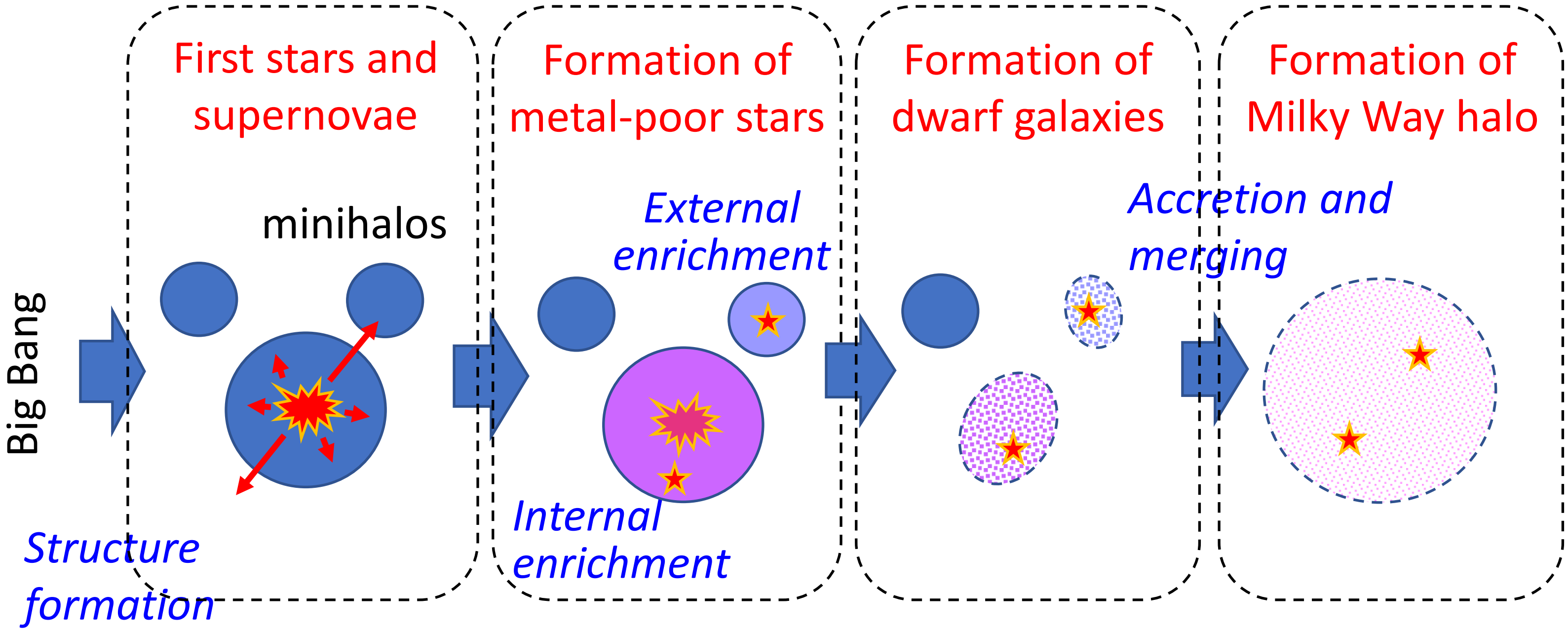
Li et al. (in prep)

Aoki et al. (2018, PASJ), Zhang et al. (2019, PASJ)

Carbon-Enhanced Metal-Poor stars studied with LAMOST and Subaru: summary

- About 400 very metal-poor stars ([Fe/H]<-2) have been found and investigated with LAMOST and Subaru/HDS. (Li et al., P14 in this meeting)
- About 15% of them are carbon-enhanced stars (CEMP). The frequency is higher in main-sequence turn-off stars than giants, reflecting the evolutionary effect, in particular dilution of carbon accreted from companion AGB stars for some CEMP stars (CEMP-s).
- Detailed abundance patterns of both light and heavy elements for extreme objects provide useful constraints on mass of the progenitors (AGB stars and a sort of supernovae) that produce carbon-rich material.

Large sample of metal-poor stars are useful for studying process from first stars to low-mass stars



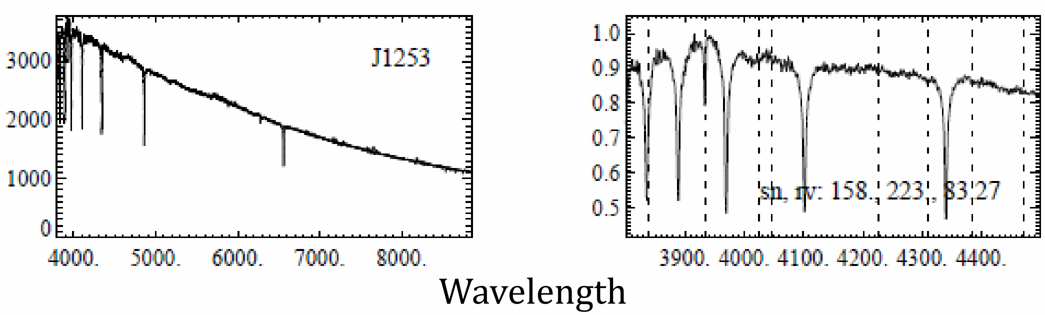
Chemical abundances of extremely metal-poor stars
→ Nucleosynthesis of first stars/supernovae
→ Masses of progenitor stars

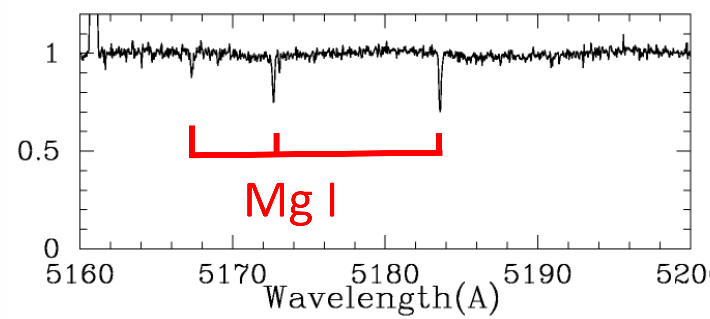
Studies of metal-poor stars with LAMOST and Subaru

Japan(JSPS)-China(CAS) joint program:
<u>2016-2018:</u> Exploring the early chemical evolution of the Milky Way with LAMOST and Subaru

<u>2019-2021:</u> Origins of the Milky Way halo structure explored with LAMOST and Subaru

Subaru intensive program S16A-119I (2016-2017):
LAMOST/Subaru study for 500 very metal-poor stars

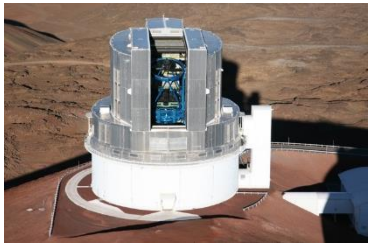




Sample and results

- 7 million spectra for Milky Way stars have been obtained with the LAMOST regular survey (LAMOST-I).

- High resolution spectra with Subaru/HDS have been obtained for >400 metal-poor stars.(Aoki et al., in prep.)



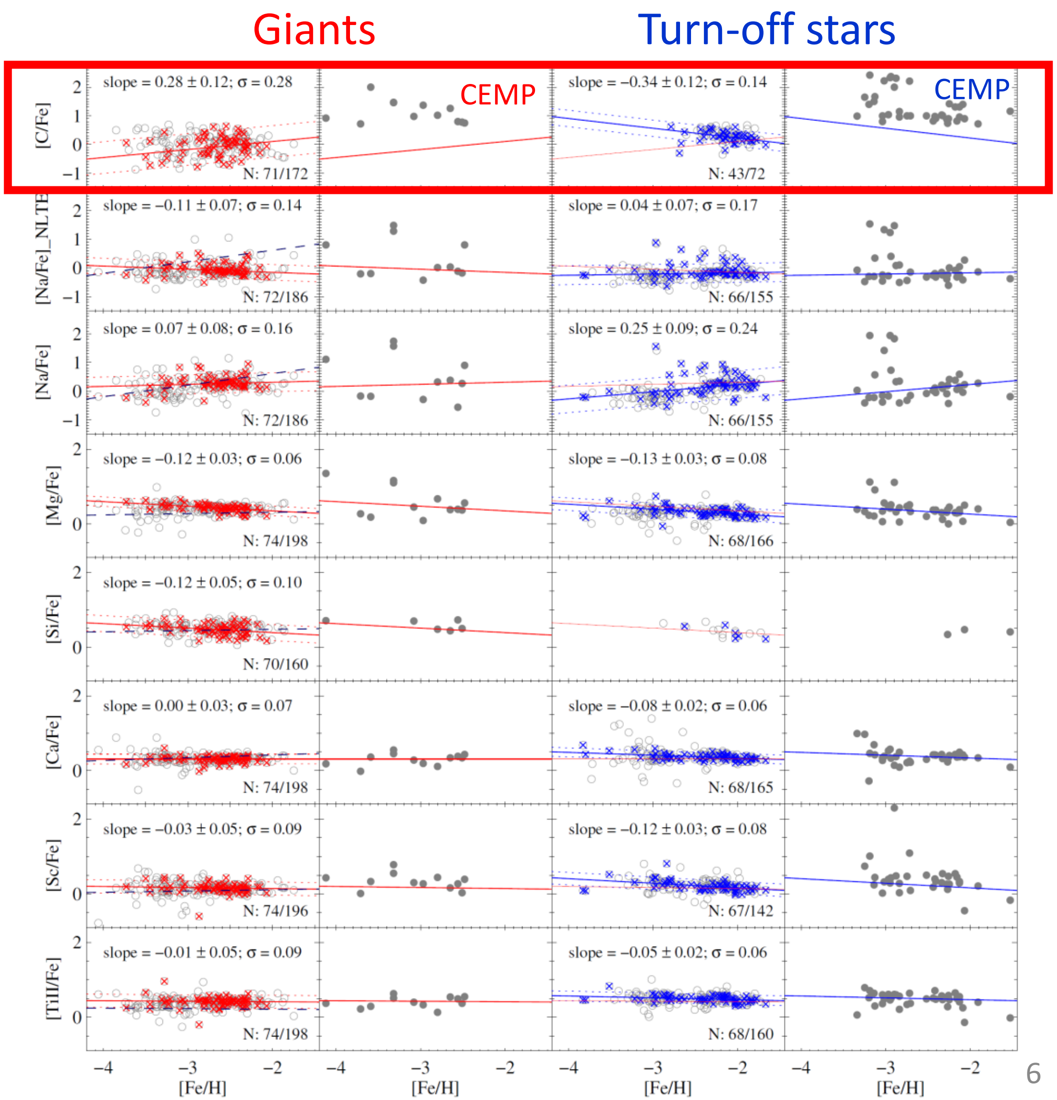
- Abundance of >20 elements are measured by standard analysis with model atmospheres (Li et al. in prep. Poster P14 in this meeting)
- Other studies:

  Xing et al. (P32)

  Zhao et al. (P33)

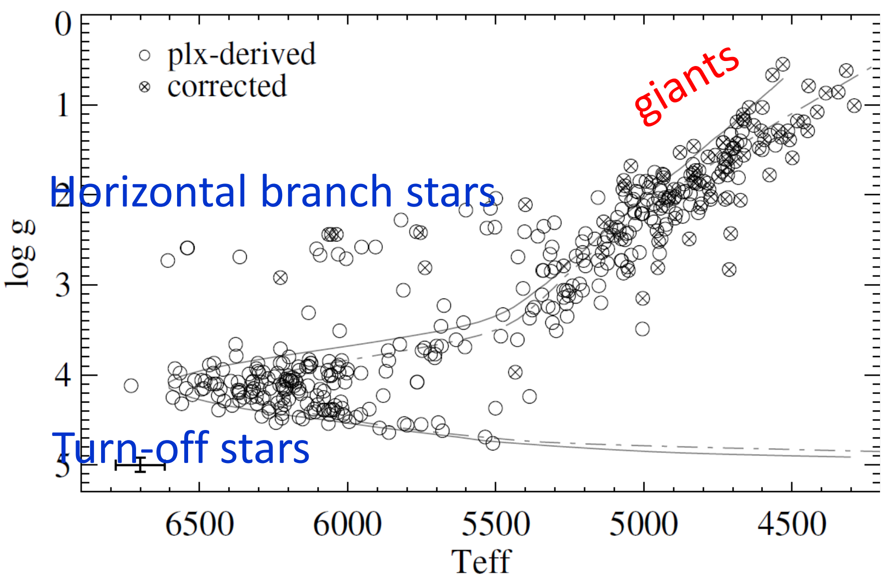
Abundance distributions measured from the Subaru/HDS spectra

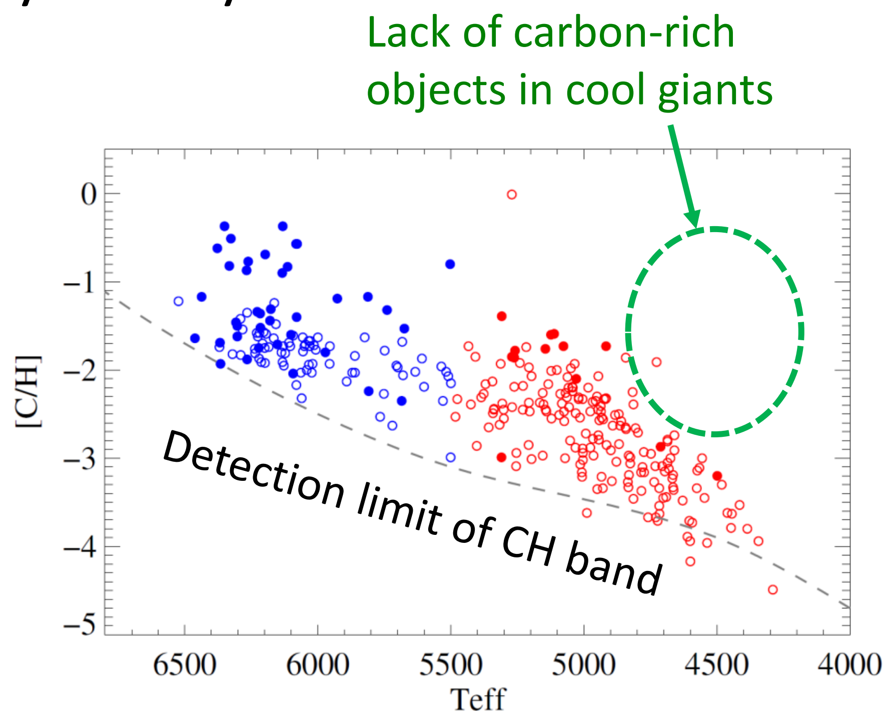
- Abundance trends as a function of metallicity are studied for carbon-normal stars.
- Abundance ratios of CEMP are compared to abundance trends.
- Warm stars (turn-off stars) and cool stars (red giants) are studied separately.



Detection limit of CH band: possible bias in C abundance measurements in warm stars

CH molecular bands are not detected in warm stars unless C is enhanced, where as lack of C-rich stars in cool giants suggests extra-mixing of matter affected by CNO cycle.

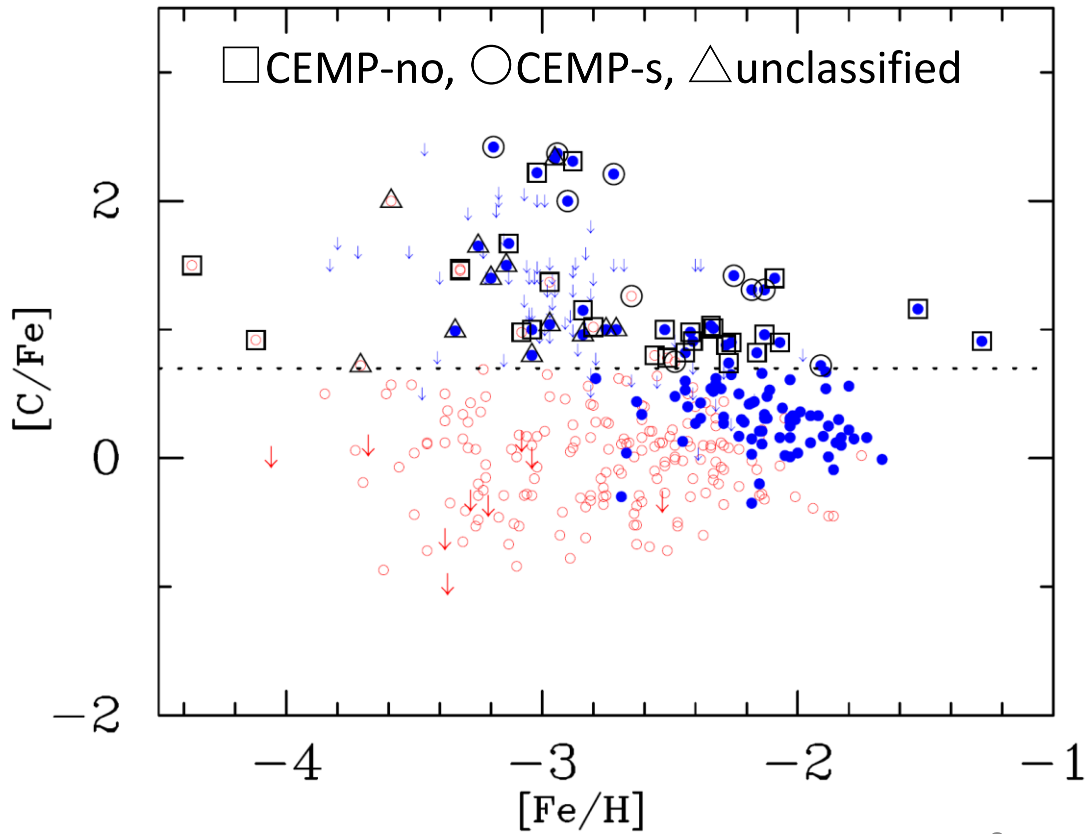




C abundance distribution: [C/Fe]

[C/Fe] distribution is wide reflecting depletion in giants and enhancements for some objects. Frequency of CEMP is 7% in giants and >20% in turn-off stars.

- Carbon-enhanced stars: [C/Fe] > 0.7 (in this work)
- CEMP-s (s-process-enhanced by mass accretion from AGB stars)
- CEMP-no stars are not well separated from C-normal stars.



C abundance distribution: C/H ratio

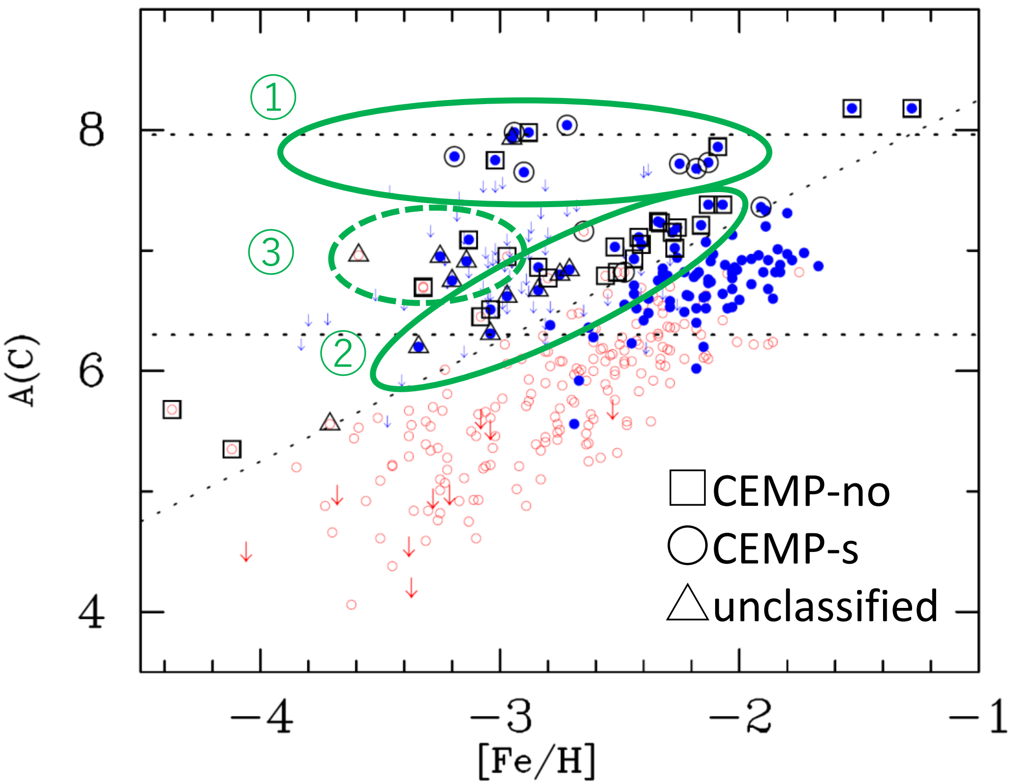
C/H (*A*(C)) distribution is different between CEMP-s and CEMP-no stars as found by previous studies (e.g., Yoon et al. 2016)

① Group I: Large C-excess is found in CEMP-s stars.

② Group II: C-excess of most of CEMP-no is moderate.

③ Group III: some CEMP-no with extremely low metallicity shows relativel high A(C) → It is not clear in our sample.

$A(\mathrm{C})=\log(N_C/N_H)+12$; $A(\mathrm{C})_{\odot} = 8.45$



Detailed abundance patterns of extreme objects: mass estimates for progenitors

- **Detailed abundance patterns are determined for extreme CEMP stars, constraining the progenitor masses**

- **LAMOST J2217+2104: ultra metal-poor CEMP-no star. The progenitor mass is about 20-25$_{\odot}$ and its explosion (→p.11)**

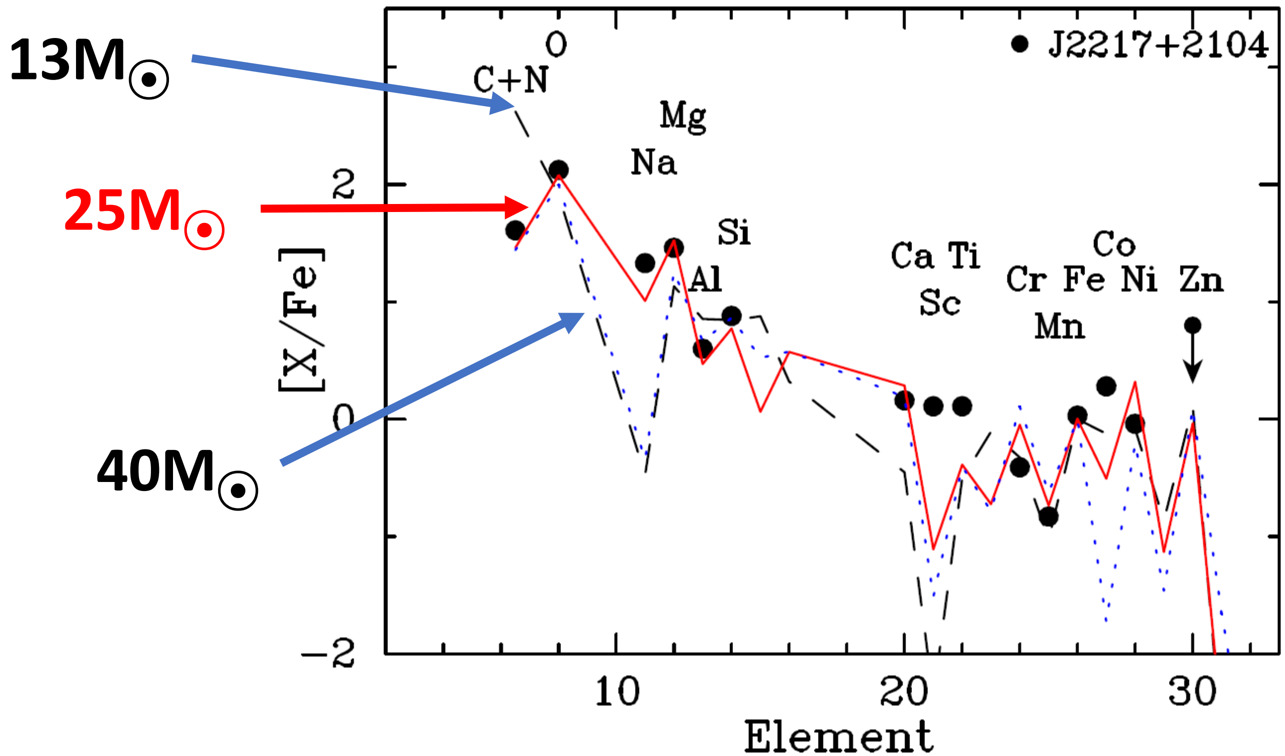
- **LAMOST J0119-0120: CEMP-s star showing the largest excess of s-process elements → 1.4$M_{\odot}$ AGB star as the progenitor (→p.12)**

CEMP-no star LAMOST J2217+2104: Comparison with supernova models

The abundance pattern is well reproduced by a supernova model for a 25M$_\odot$ first star (Ishigaki et al. 2018)

- The (C+N)/O and Na/Mg ratios are sensitive to the progenitor mass.
- The cause for excesses of C, Mg, and Si would not be the progenitor mass, but other natures (e.g. spin, binarity)

Aoki et al. (2018, PASJ)



LAMOST J0119-0121: CEMP-s star showing largest excess of s-process elements

Direct comparison of AGB models (e.g. Bisterzo et al. 2010)

- Abundance pattern of neutron-capture elements (Sr-Ba-Pb) are reproduced by models of s-process for low metallicity
- Na and Mg abundances are useful to constrain AGB mass.

  →1.4M$_\odot$ model AGB star

Zhang et al. (2019, APSJ)