Mass estimates for early generation stars from detailed abundance patterns of Carbon-Enhanced Metal-Poor Stars

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

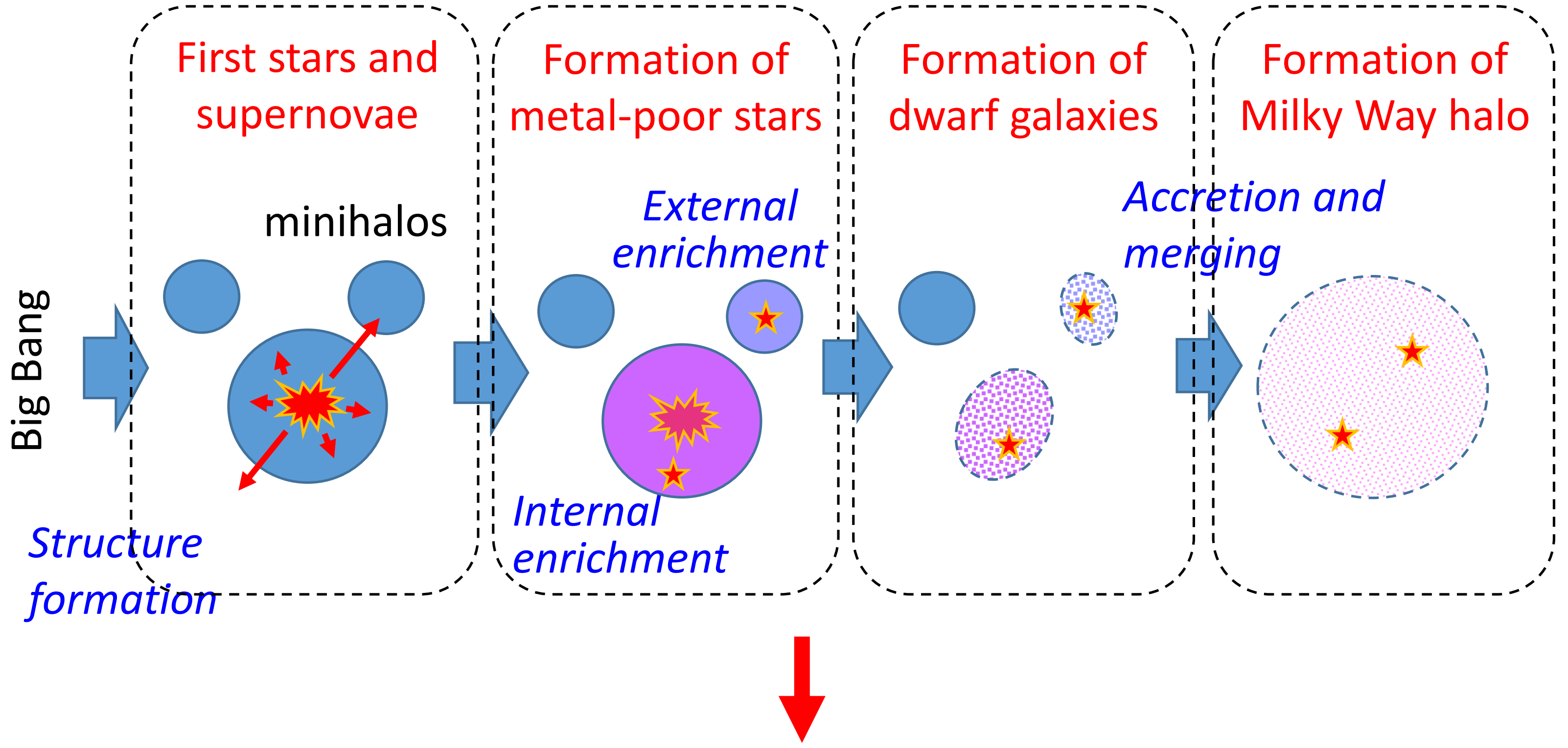
Outline

- Detailed abundances of metal-poor stars as an indicator of progenitor mass
- Two classes of CEMP stars: CEMP-no and CEMP-s
- Extreme CEMP stars studied with LAMOST & Subaru

  -LAMOST J2217+2104: a CEMP-no star with excesses of Mg and Si, constraining nucleosynthesis of first generation supernovae

  -LAMOST J0119-0120, an extreme CEMP-s: direct record of AGB nucleosynthesis at low metallicity

From first stars to metal-poor stars found in the current Milky Way



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

CEMP=Carbon Enhanced Metal-Poor 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.

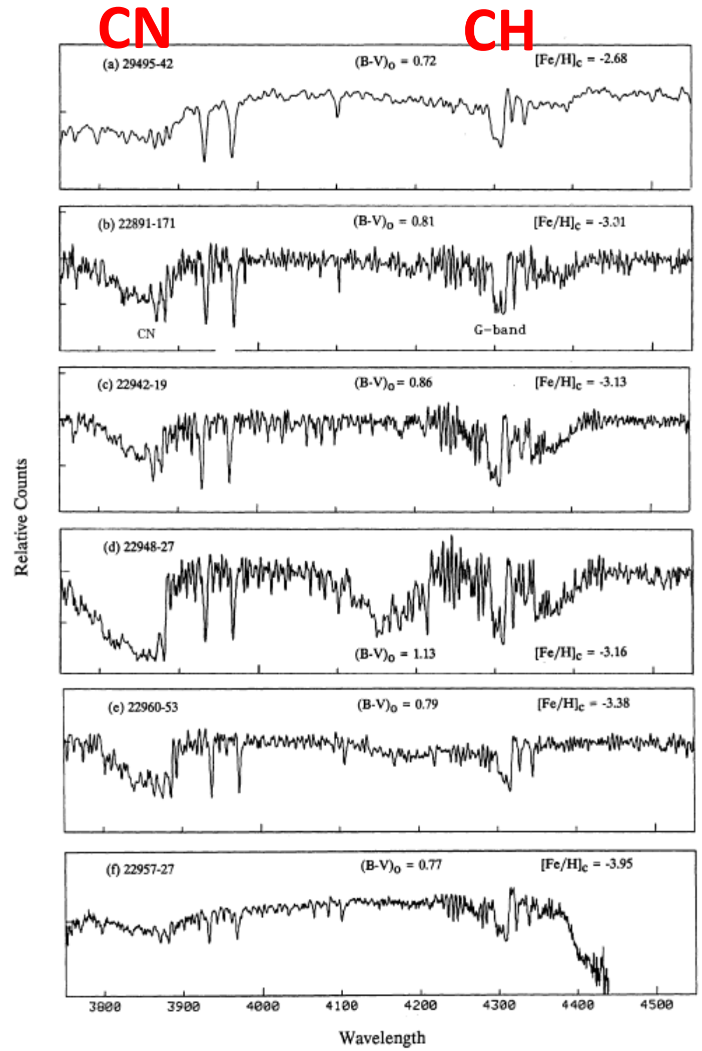


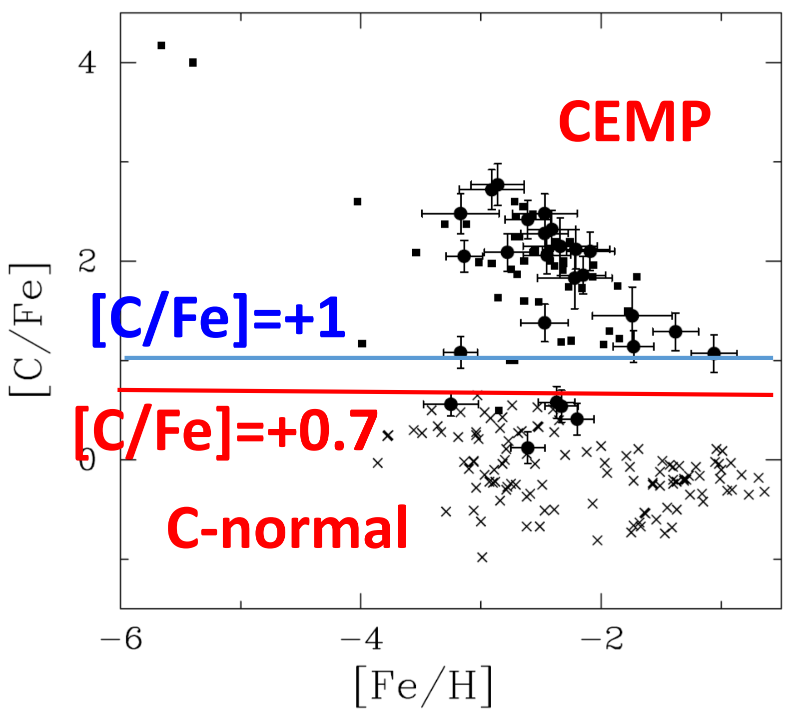
FIG. 13. Type examples of stars in the present sample with moderate to strong CN bandheads at λ3883 Å and/or λ4215 Å, and anomalously large CH (*G*-band) λ4300 Å features. All spectra have been smoothed with a Gaussian of breadth 2.5 Å, and flattened with a boxcar smooth.

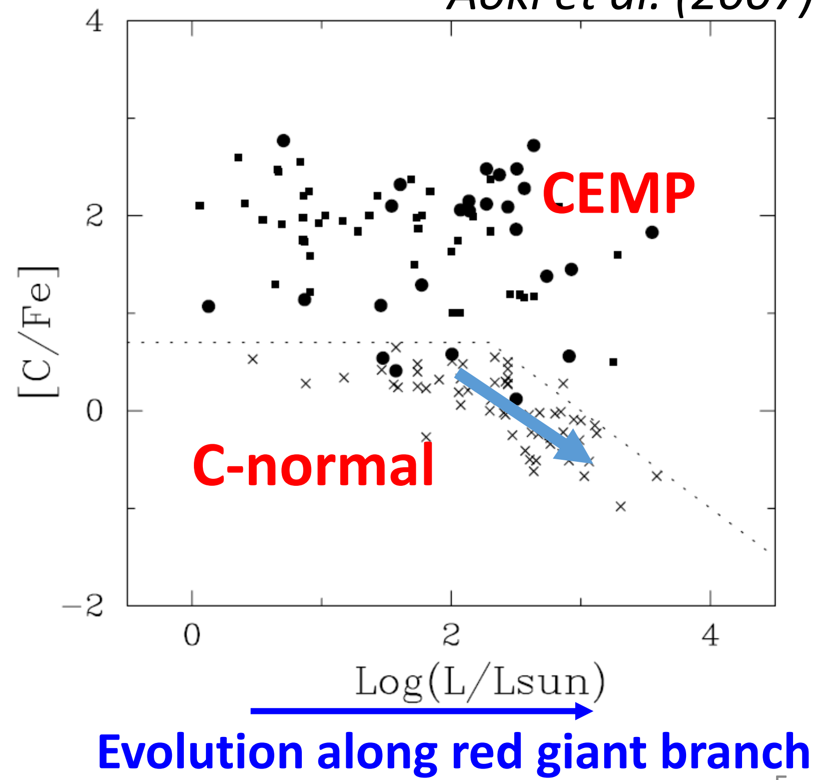
Beers et al. (1992)

CEMP definition

- CEMP stars are well separated from C-normal stars in general, but CEMP-no stars could be affected by the definition
- Highly evolved red giants might be affected by CNO cycle
- See more detailed discussion by Norris & Yong (2019)

Aoki et al. (2007)

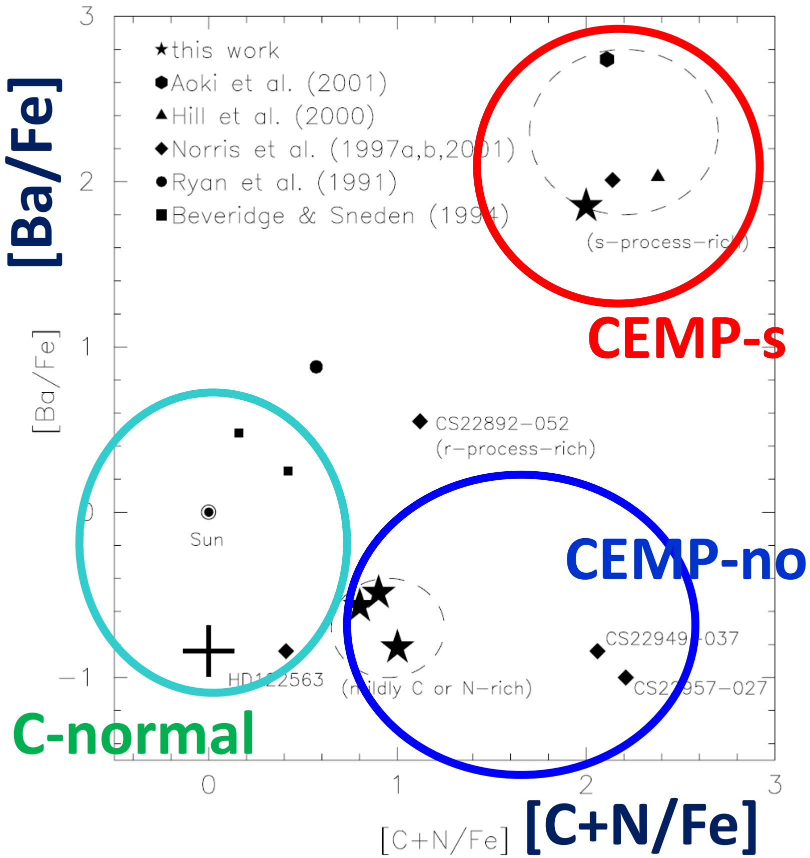




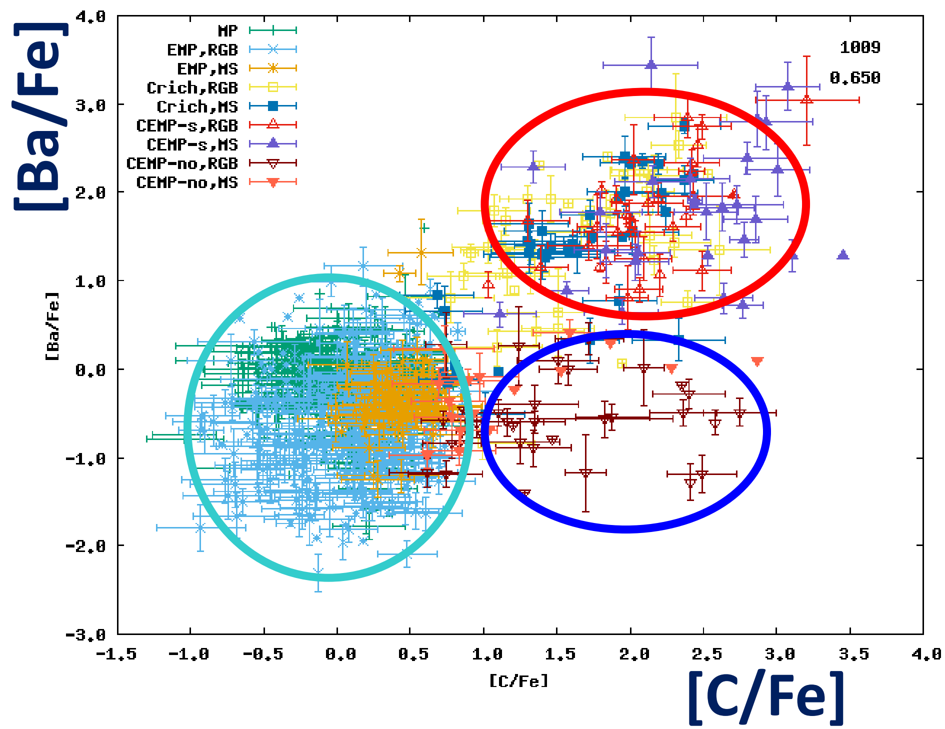
CEMP classification

CEMP-s : Ba-rich stars (due to s-process)
CEMP-no : Ba-normal stars

Aoki et al. (2002)

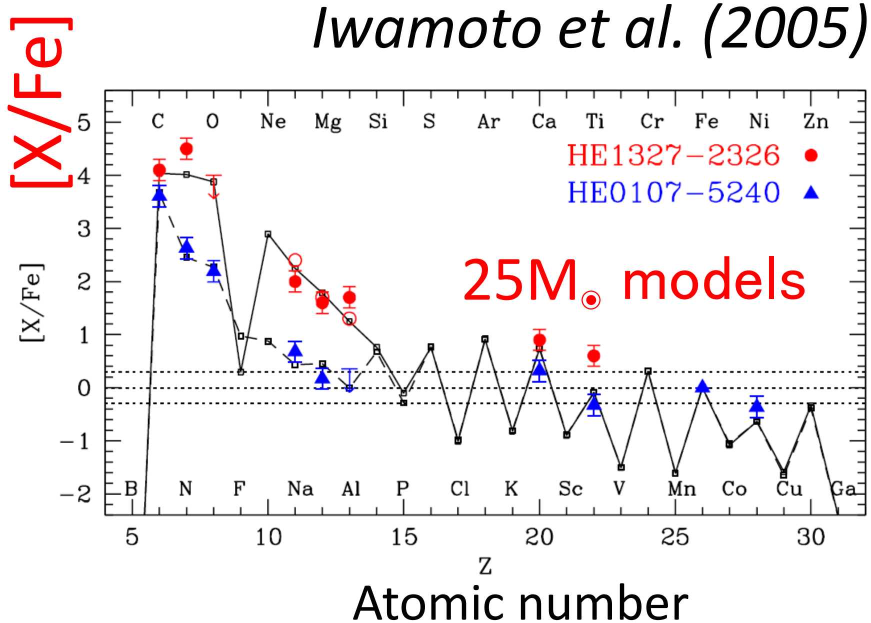


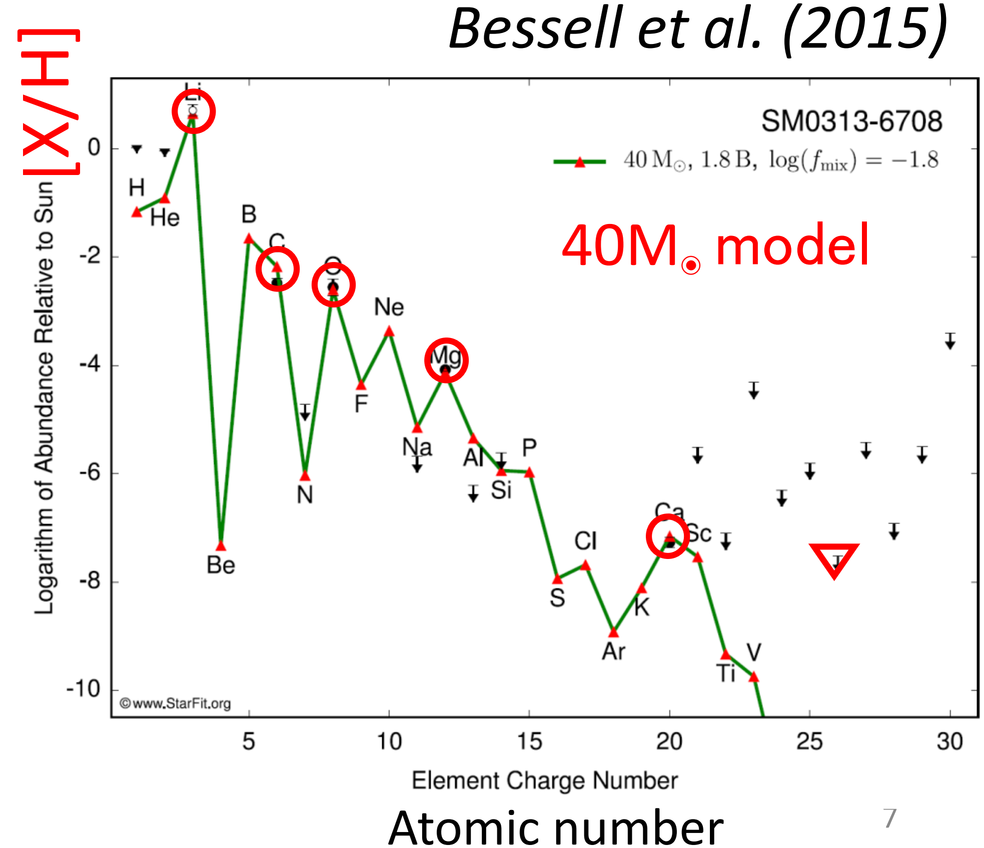
SAGA database (Suda et al. 2017)



“Hyper metal-poor” stars as extreme cases of CEMP-no

HE0107-5240 [Fe/H]=-5.4, [C/Fe]=+4.0, [Ba/Fe]<+0.8 (Christlieb et al. 2002)
HE1327-2326 [Fe/H]=-5.6, [C/Fe]=+4.3, [Ba/Fe]<+1.5 (Frebel et al. 2005)
SMSS 0313-6708 [Fe/H]<-7, [C/Fe]>+4.7 (Keller et al. 2014)



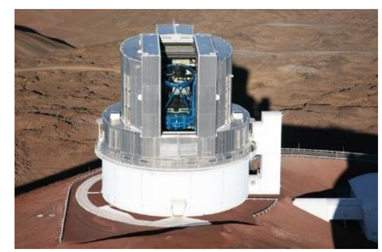


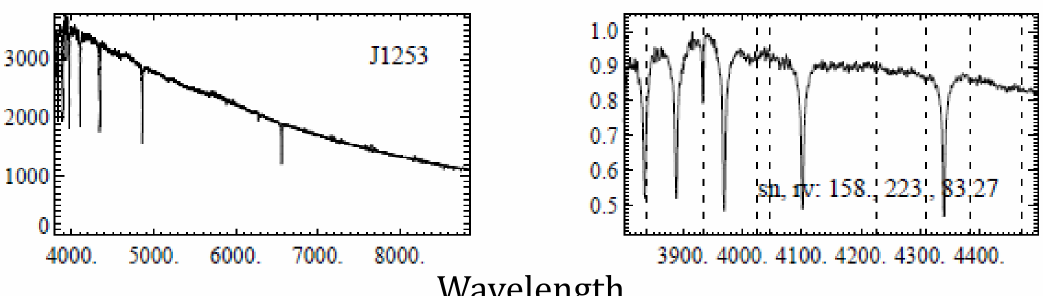
Japan(JSPS)-China(CAS) joint program:

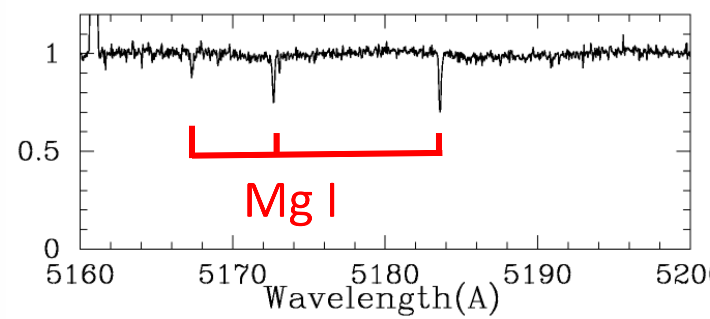
2016-2018: Exploring the early chemical evolution of the Milky Way with LAMOST and Subaru

2019-2021: 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

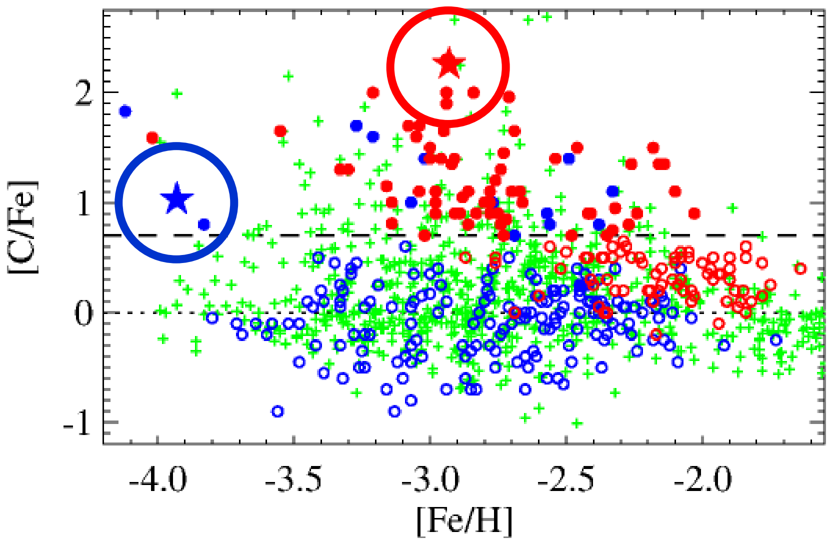


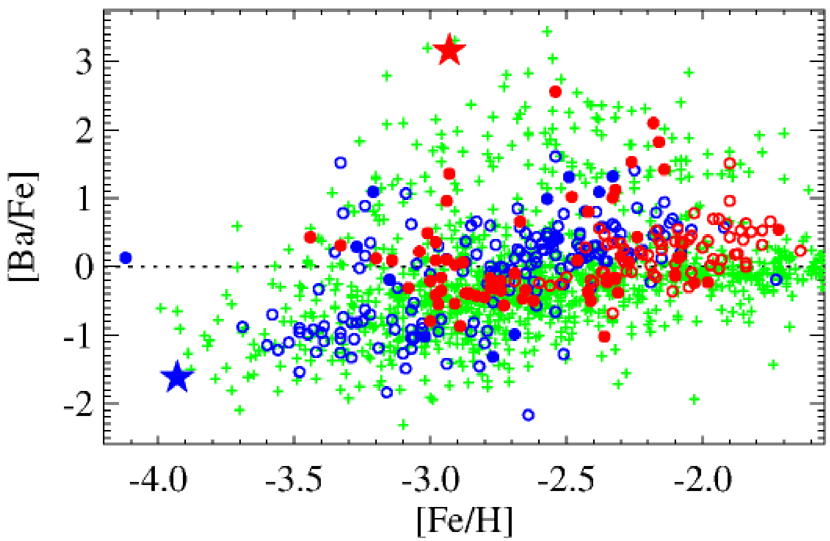


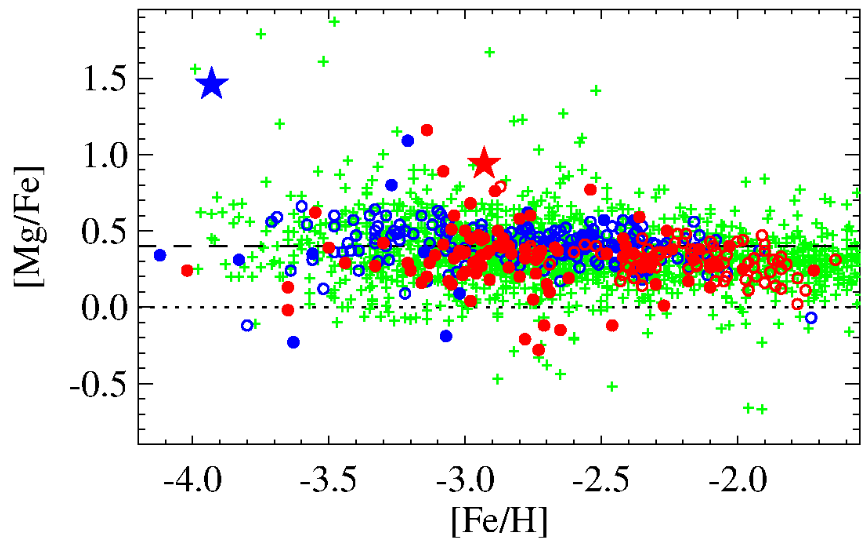


Most Extreme CEMP-no and CEMP-s stars found with LAMOST/Subaru

- LAMOST J2217+2104:CEMP-no
- LAMOST J0119-0120: CEMP-s



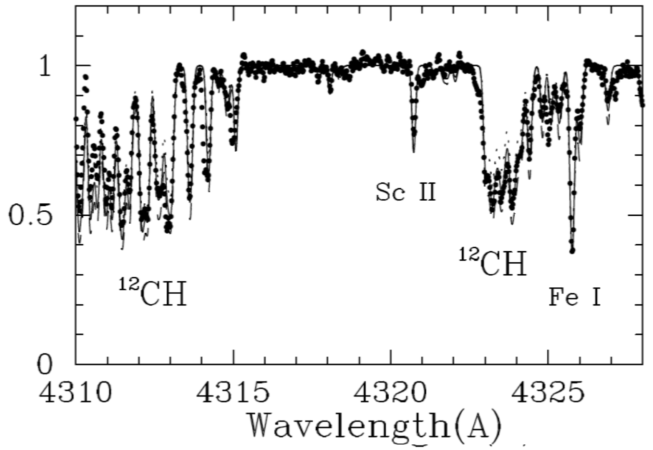


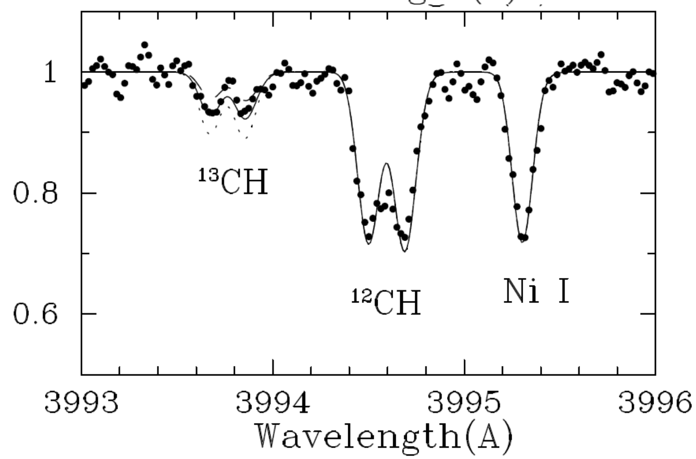


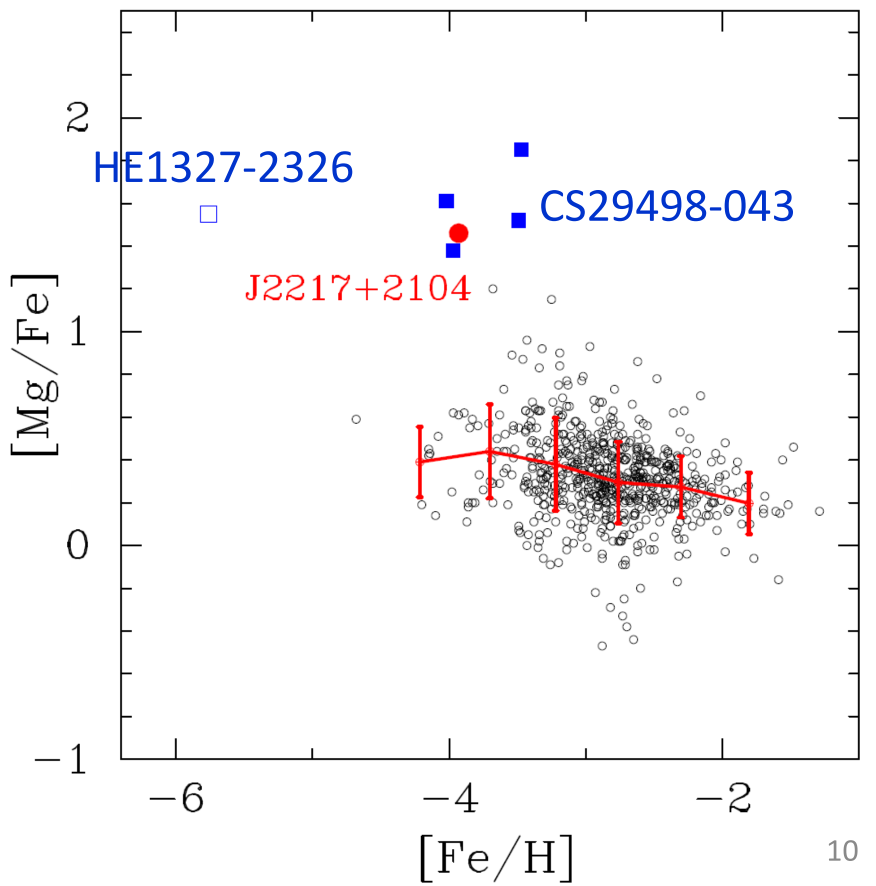
CEMP-no star LAMOST J2217+2104

- [Fe/H]=-4.0, [C/Fe]=+1.5, [Mg/Fe]=+1.4
- High [Mg/Fe] →nucleosynthesis of core-collapse supernovae
- The progenitors would be a unique sort of massive first stars

Aoki et al. (2018)





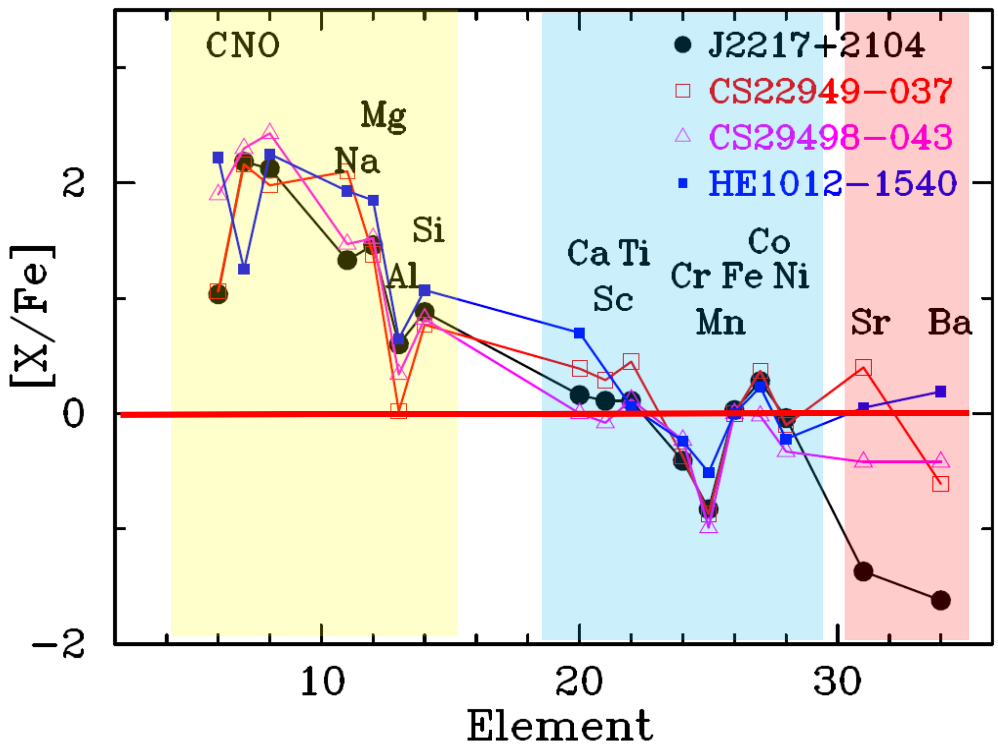


Abundance pattern of CEMP-no stars with Mg and Si excess

The four stars in this class have very similar abundance patterns

- Excesses are found for C-Si, no excess in Ca-Ni
- C/N ratios show scatter, but (C+N)/O ratios are similar
- Neutron-capture elements show scatter

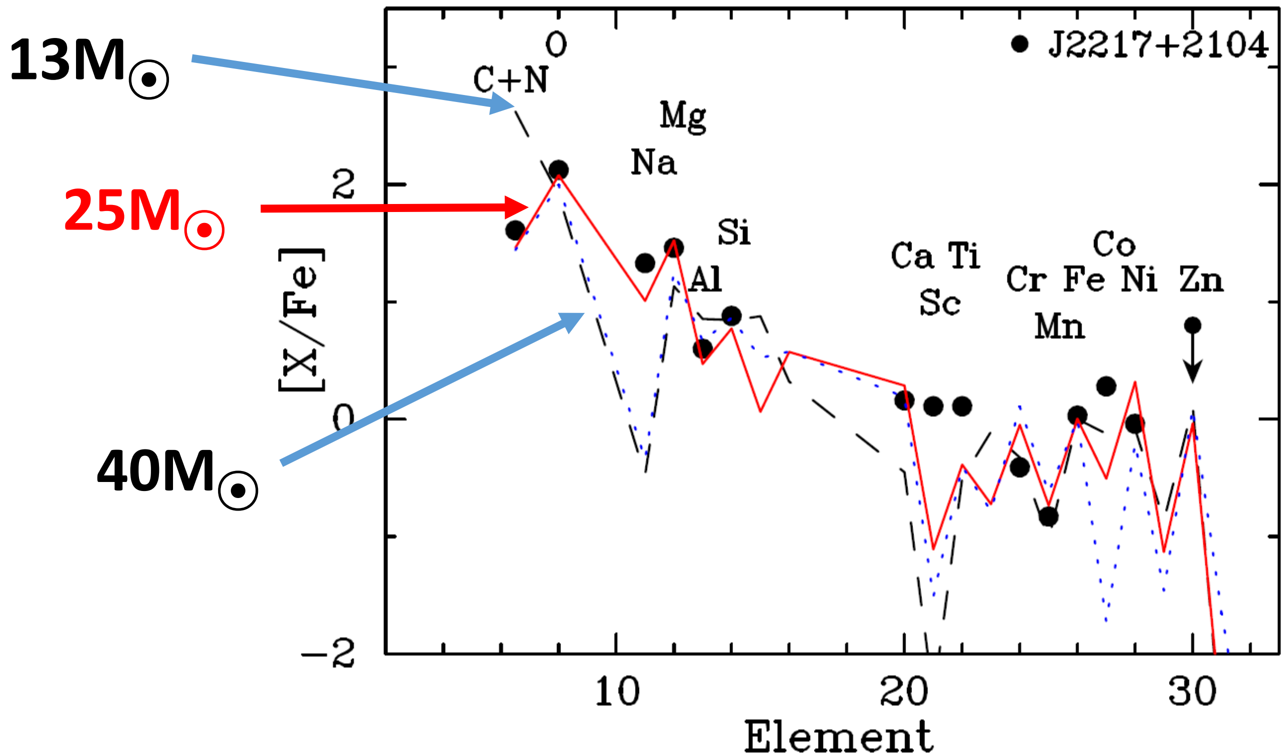
Aoki et al. (2018)



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

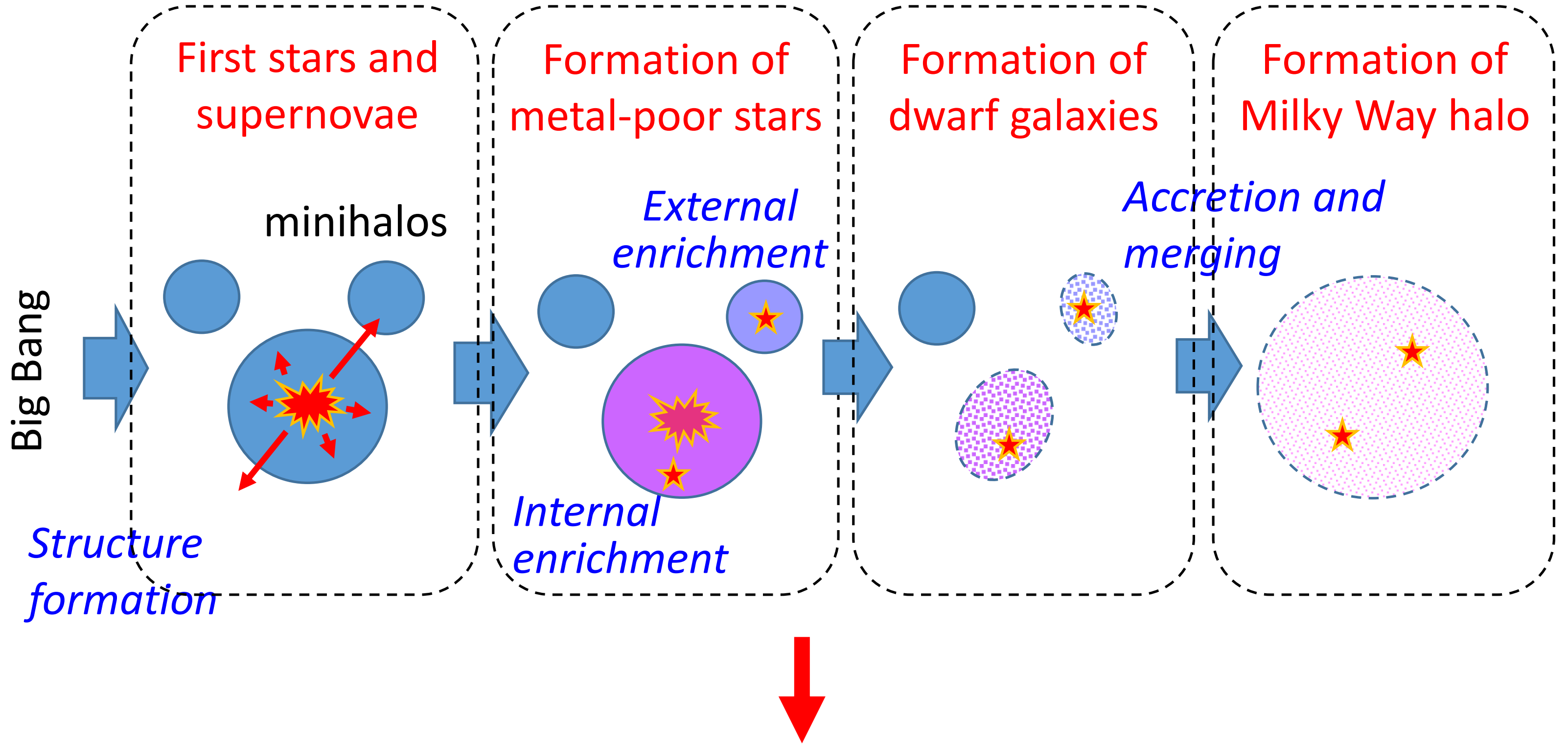
The abundance pattern is well reproduced by a supernova model for a 25M$_\odot$ first star (Ishigaki et al. 2018)

- 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)

From first stars to metal-poor stars found in the current Milky Way



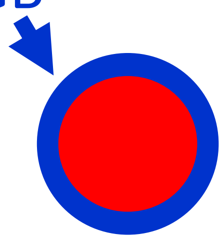
Chemical abundances of metal-poor stars in *binary systems*
→ Nucleosynthesis of former primary stars (in AGB phase)
→ Masses of progenitor (AGB) stars

CEMP-s stars

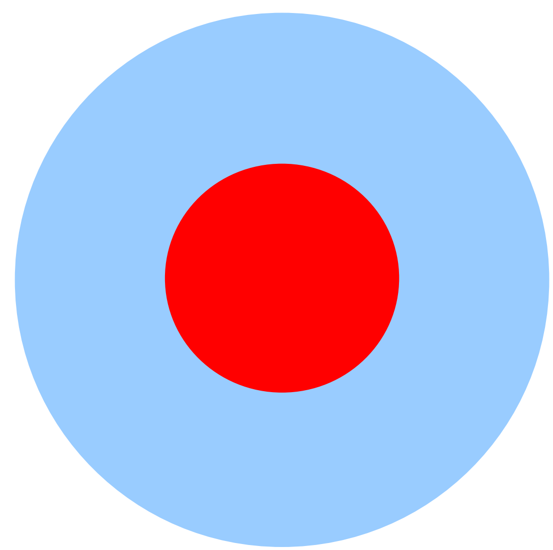
- C-rich material should be accreted from the companion AGB star.
- The accreted material could be dominated at the surface of main-sequence stars with very thin convective layer.

Main-sequence: thin convective layer (~$0.01M_\star$)

Mass accretion from AGB



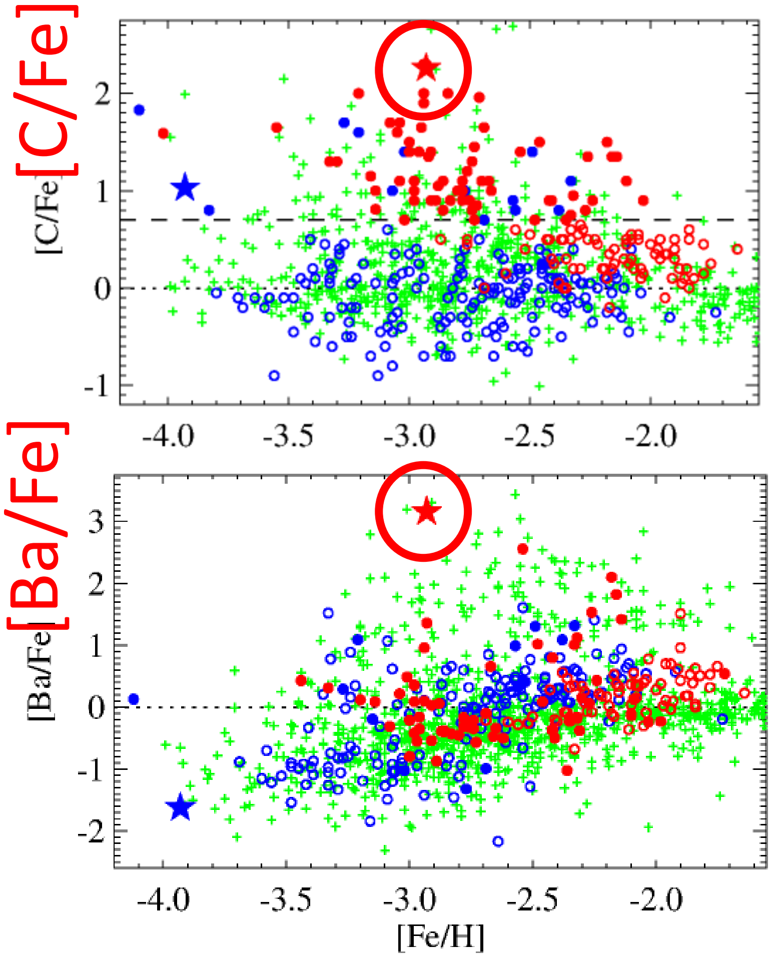
Red giant: thick convective layer (~$0.2M_\star$)
→Accreted material is diluted

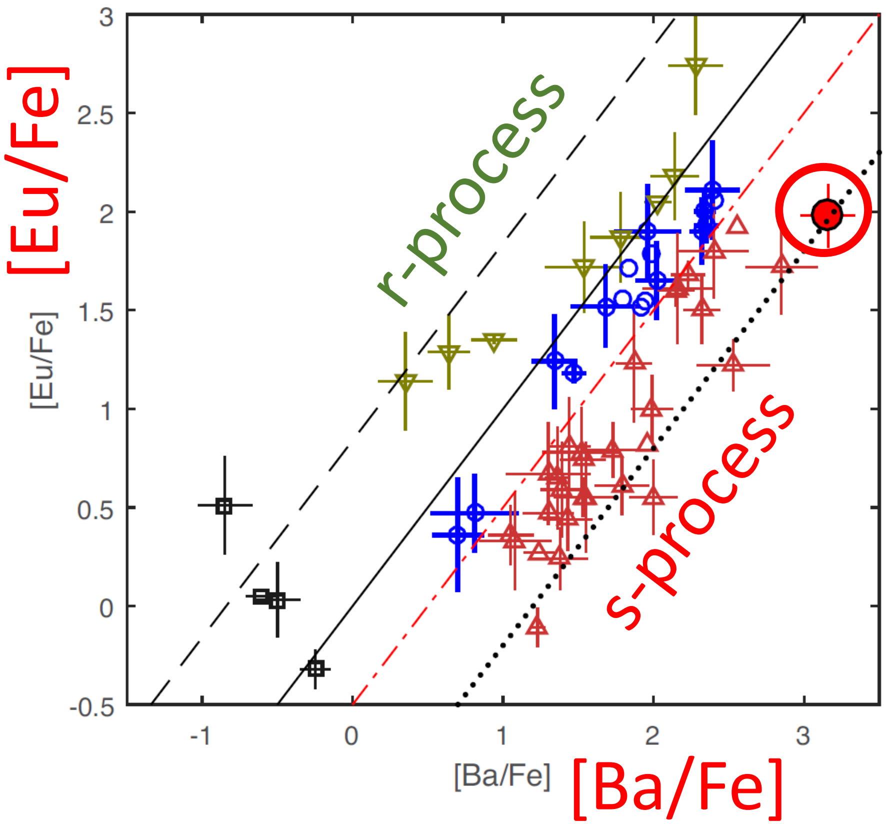


LAMOST J0119-0121: the most extreme CEMP-s star

- [Fe/H]=-2.9, [C/Fe]=+2.3, [Ba/Fe]=+3.2
  The Ba/Eu ratio is explained by the s-process
- The surface could be well covered by material transferred from the companion AGB star.

Zhang et al. (2019)





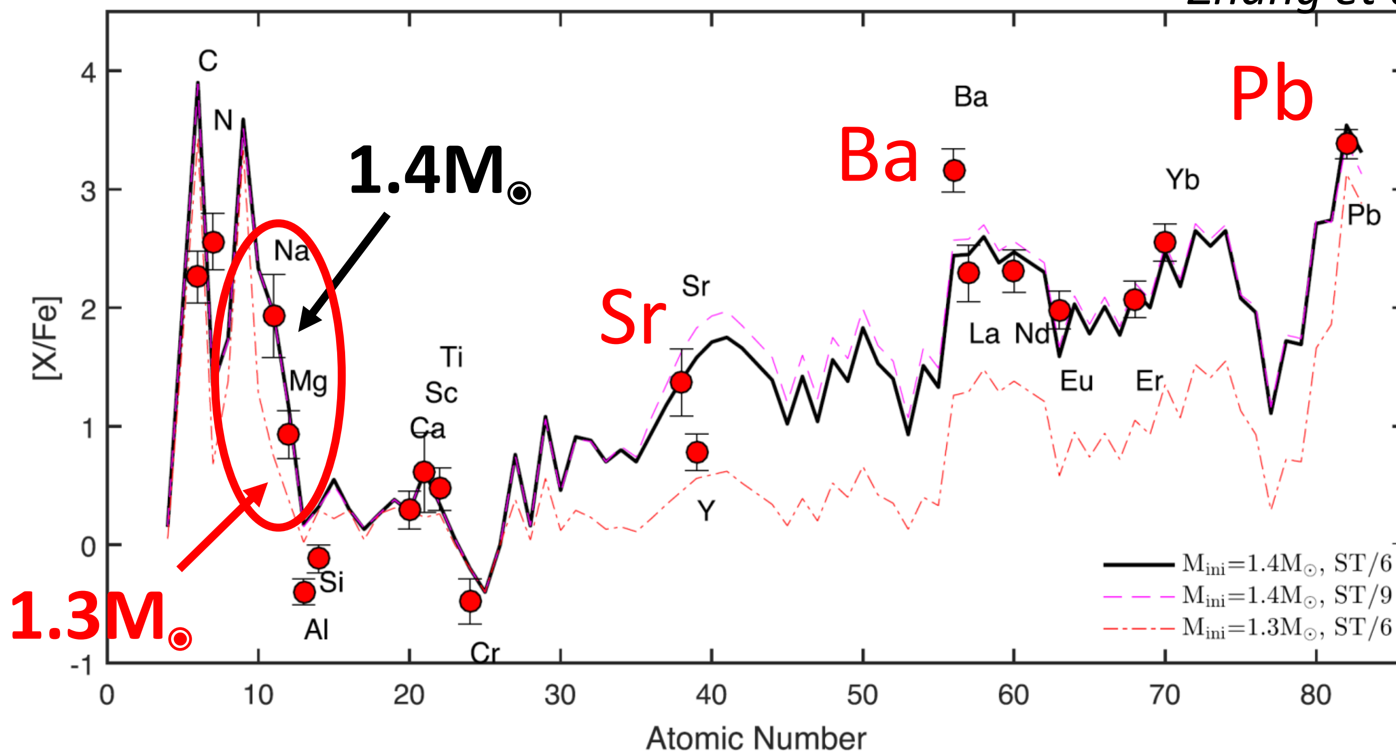
LAMOST J0119-0121: comparison with AGB nucleosynthesis models

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)

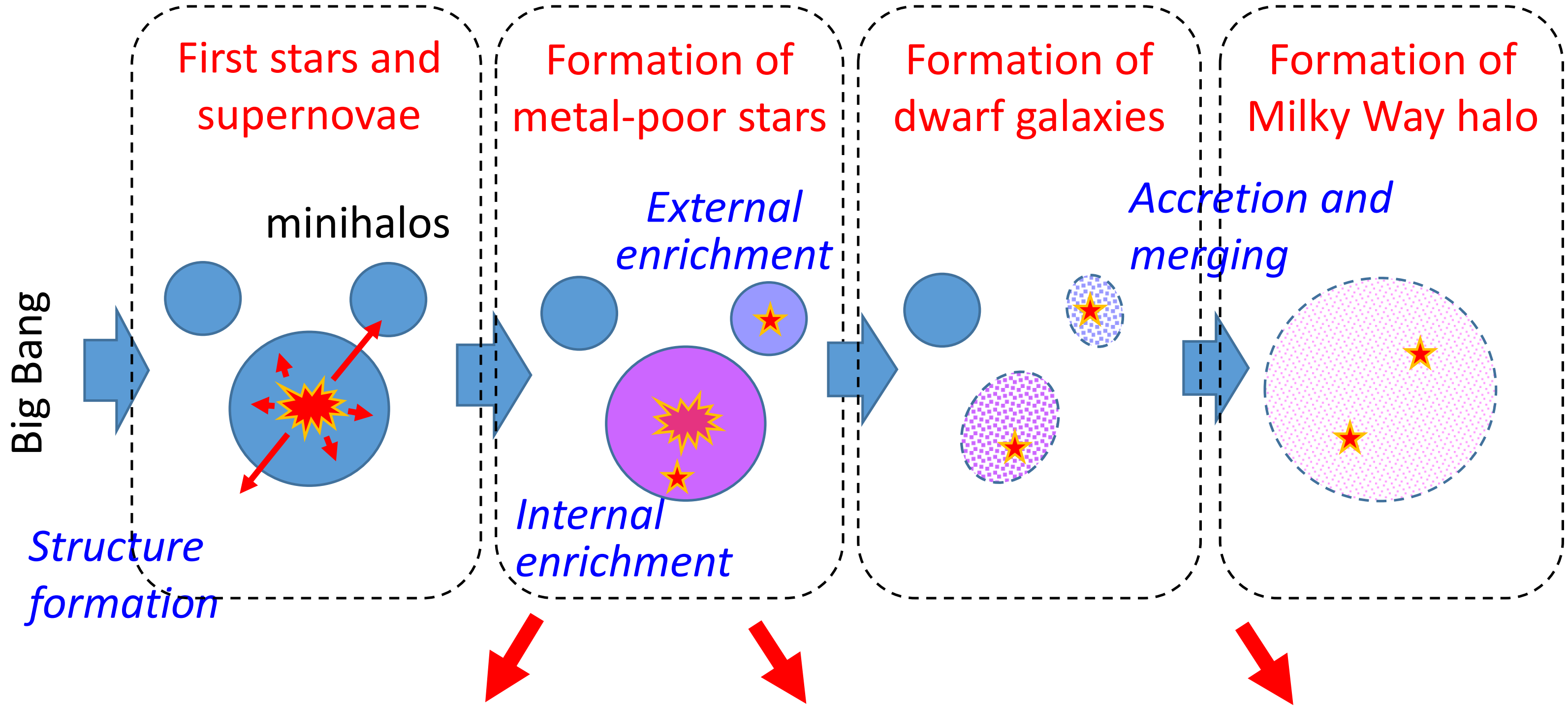


Mass estimates for early generation stars from detailed abundance patterns of Carbon-Enhanced Metal-Poor Stars

- Detailed abundance patterns are determined for extreme CEMP stars, constraining the progenitor masses
  - -LAMOST J2217+2104 (CEMP-no): $25M_{\odot}$ first generation supernova
  - -LAMOST J0119-0120 (CEMP-s): $1.4M_{\odot}$ AGB star

- For extending the study to larger sample, further understanding of low-mass star formation and evolution after the enrichment of first generation stars is necessary.

From first stars to metal-poor stars found in the current Milky Way



First stars & supernovae

Low-mass star formation in minihalos and their evolution

Galaxy formation with merging & accretion