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
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)*
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).
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)

Iwamoto et al. (2005)

Bessell et al. (2015)
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

- $[\text{Fe/H}]=-4.0$, $[\text{C/Fe}]=+1.5$, $[\text{Mg/Fe}]=+1.4$
- High $[\text{Mg/Fe}] \rightarrow$ 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 25$M_\odot$ 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★)

Mass accretion from AGB

Red giant: thick convective layer (~0.2M★)

→ Accreted material is diluted
LAMOST J0119-0121: the most extreme CEMP-s star

- $[\text{Fe/H}]=-2.9$, $[\text{C/Fe}]=+2.3$, $[\text{Ba/Fe}]=+3.2$
  - 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)

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\text{[C/Fe]} \quad \text{[Ba/Fe]} \quad \text{[Eu/Fe]} 
\]

\[ 
\text{[Ba/Fe]} \quad \text{[Fe/H]} 
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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.

→ 1.4$M_\odot$ 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☉ first generation supernova
  - LAMOST J0119-0120 (CEMP-s): 1.4M☉ 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 and supernovae
- Formation of metal-poor stars
- Formation of dwarf galaxies
- Formation of Milky Way halo

First stars & supernovae

Low-mass star formation in minihalos and their evolution

Galaxy formation with merging & accretion