Observations of CEMP stars. II.

CEMP-no stars

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![Graph showing normalized flux over wavelength range]
CEMP-no stars

• Definition and classification
• Observational features
  • Metallicity and C abundance distribution
  • Binarity
  • Li abundances
  • Abundance patterns
  • Neutron-capture elements
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

*Beers & Christlieb (2005, ARAA)*

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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.

**Aoki et al. (2007)**

- CEMP\textsuperscript{\text{-}normal}

**Evolution along red giant branch**

**Placco et al. (2014)**

- [C/Fe] plot with observed and corrected values.

**Evolution along red giant branch**
CEMP frequency increases with decreasing metallicity

Placco et al. (2014)

\[ \text{[C/Fe]} > +0.5 \]
\[ \text{[C/Fe]} > +0.7 \]
\[ \text{[C/Fe]} > +1.0 \]
# CEMP classification

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CS22957-027: A carbon-enhanced star with no excess of neutron-capture elements

$[\text{Fe/H}]=-3.38$, $[\text{C/Fe}]=+2.2$, $[\text{Ba/Fe}]=-0.97$, $[\text{Sr/Fe}]=-0.56$

Norris et al. (1997)

EXTREMELY METAL-POOR STARS. THE CARBON-RICH, NEUTRON CAPTURE ELEMENT–POOR OBJECT CS 22957–027

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Bonifacio et al. (1998)

CS 22957-027: a carbon-rich extremely-metal-poor star*

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CEMP classification

**CEMP-s**: Ba-rich stars (due to s-process)

**CEMP-no**: Ba-normal stars

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**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
HE1327-2326  [Fe/H]=−5.6, [C/Fe]=+4.3, [Ba/Fe]<+1.5

Aoki et al. (2007)
New definition of CEMP-no

\[[\text{Ba/Fe}] < +1.0 \text{ (or 0.0)} \text{ for } [\text{C/Fe}] < +2.0\]
\[[\text{Ba/Fe}] < [\text{C/Fe}] -1.0 \text{ (or -2.0)} \text{ for } [\text{C/Fe}] > +2.0\]

Matsuno et al. (2017)
Observational features

1. Metallicity and C abundance distribution
2. Binarity
3. Li abundances
4. Abundance patterns
5. Neutron-capture elements
CEMP-no stars (1)
Metallicity and C abundance distribution

CEMP-s: found in $[\text{Fe/H}] > -3$, having high $[\text{C/H}]$
CEMP-no: mostly found in $[\text{Fe/H}] < -2.5$, having moderate $[\text{C/H}]$

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Aoki et al. (2007)
CEMP-no stars (1)
Metallicity and C abundance distribution

Jinmi et al. (2017)
CEMP-no stars (2) binarity

No signature of high binary frequency

Hansen et al. (2016)

10,000 days!
CEMP-no stars (3) Li in warm stars

- CEMP-no stars with $-4 < [\text{Fe/H}] < -3$ have *normal* Li abundance
  cf. Li in CEMP-s stars is depleted
- Li in Ultra/Hyper metal-poor stars (only two!) is depleted

*Matsuno et al. (2017)*

![Graph showing Li abundance vs. metallicity for CEMP-no and CEMP-s stars](image)
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.

[Fe/H] = -3.7, [C/H] ~ [O/H] ~ -2.5

The CEMP-no stars (4) abundance pattern

The carbon-enhanced star BD+44 493

Ito et al. (2009) Ito et al. (2013)
CEMP-no stars (4) abundance pattern
“CEMP-α”

Large excess of C,N,O. and alpha elements with [Fe/H]~ -4
... “iron deficient”  (Tsujimoto & Shigeyama 2003, Umeda & Nomoto 2003)

CS22949-037 ([Fe/H]= -4.0)
Depagne et al. (2002)
CS29498-043 ([Fe/H]= -3.5)
Aoki et al. (2002)
Exploring the early chemical evolution of the Milky Way with LAMOST and Subaru

LAMOST  $R=1800$  

Subaru  $R=45000$

Mg I

Wavelength (Å)

[Na/Fe]  [Mg/Fe]  [Ca/Fe]  [Sc/Fe]

[Ti/Fe]  [Cr/Fe]  [Mn/Fe]  [Co/Fe]

[Ni/Fe]  [Zn/Fe]  [Sr/Fe]  [Ba/Fe]
CEMP-no stars (4) abundance pattern
“CEMP-α”

- Very similar pattern between C and Ni
- Scatter in neutron-capture elements

Aoki et al. (in prep)
CEMP-no stars (5) neutron-capture elements: “CEMP-r stars”

How many CEMP-r stars do we know?

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

- CS22892-052
  - Sneden et al. (1996)
- CS22945-017
  - Roederer et al. (2014)
- BS16929-005?
  - Allen et al. (2012); but Lai et al. (2008) report lower Eu upper limit
- BS16543-097?
  - Allen et al. (2012); but Honda et al. (2004) and Aoki et al. (2005) report normal C abundance
- CS31070-093?
  - Allen et al. (2012)
  - CEMP-r/s star?
Classification and origins of CEMP stars

• CEMP-s and CEMP-r/s stars:
  s-process, high binary frequency, Li depletion
  → mass transfer from AGB stars in binary systems

• CEMP-no stars:
  Common feature with C-normal stars: binary frequency, Li, heavy neutron-capture elements, etc.
  a small fraction of CEMP-no stars show excess of alpha elements ... similar to some Hyper Metal-Poor stars?
  → Faint supernovae, and other origins?