Origin of CEMP-no morphology in the Milky Way halo
(A holistic approach)

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Collaboration with
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Univ., China)
Nucleosynthetic origin of CEMP-no Stars
Halo CEMP Morphology – A(C)-[Fe/H]

- Distinct 3 CEMP groups
  - Group I: CEMP-s (majority) CEMP-no (~13%)
  - Group II: CEMP-no
    strong correlation of A(C)-[Fe/H]
  - Group III: CEMP-no
    no correlation of A(C)-[Fe/H]

Halo CEMP Morphology – $A$(Na, Mg)-$[\text{Fe/H}]$

Group II CEMP-no  
★BD+44 493

Group III CEMP-no  
★HE 1327-2326

Origin of Group I CEMP-no

- GI CEMP-no and G III have a higher binary fraction than G2 \(\rightarrow\) mass transfer?

- But G I CEMP-no and G III CEMP-no have similar A(Ba) and lower Ba (\(>\sim 4\) dex) from G I CEMP-s

→ Perhaps different nucleosynthetic origin from the rest of CEMP-no stars

→ multiple Faint SNe or spinstars contribution – favorable?
Host galactic environments of CEMP-no Stars (Accretion origin)
Another Perspective

A(X), [X/H]

X : nucleosynthesis
H : Galactic formation / star formation / metal-mixing

Reflecting the dilution of stellar yields due to mixing with pristine interstellar medium
(Galactic/ natal environments)
CEMP groups of the dwarf galaxies


Yoon, Beers, Tian, & Whitten (2019)
Accretion origin

- **Distinct 3 CEMP groups**
  - **Group II: CEMP-no**
    - Strong correlation of A(C) - [Fe/H]
    - Formed in more massive dwarf galaxies (classical dSph-like galaxies)
  - **Group III: CEMP-no**
    - No correlation of A(C) - [Fe/H]
    - Formed in least massive dwarf galaxies (ultra-faint dwarf (UFD)-like galaxies)
  - **Group I: CEMP-s (majority)**
    - CEMP-no (~13%)
Yoon, Beers, Tian, & Whitten (2019)

Accretion origin

- Distinct 3 CEMP groups
  - Group I: CEMP-s (majority)
  - CEMP-no (~13%)

Based on the morphological Connection between the halo CEMP-no Group I and 3 and dwarf galaxy Group3,

Halo Group I CEMP-no stars could have the same origin with the Group III CEMP-no stars
Origin of Group I CEMP-no

Yoon, Beers, Tian, & Whitten (2019)
CEMP Fractions

<table>
<thead>
<tr>
<th></th>
<th>UFDs</th>
<th>dSphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;[\text{Fe}/\text{H}]&gt;$</td>
<td>-2.69</td>
<td>-1.88</td>
</tr>
<tr>
<td>$&lt;\text{A(C)}&gt;$</td>
<td>6.33</td>
<td>6.49</td>
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<tr>
<td>CEMP frequency</td>
<td>~28%</td>
<td>~3%</td>
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</tbody>
</table>

See e.g., Salvadori+15

Data: literature data, SAGA database

Yoon, Beers, Whitten, & Tian(2019)
Kinematic origin of CEMP Stars
Kinematical Analyses

- Higher fraction of **prograde** stars among **CEMP-no** stars (G1, G2 and G3)

- G3 + G1 **CEMP-no** stars share similar $V_\phi$ range $\to$ **similar** kinematic origin

- G3 + G1 **CEMP-no** may have **different origin** from the most of **G2 CEMP-no** stars

NMP ~ 500 stars
CEMP ~ 180 stars

$V_\phi$ = 0
Kinematical Analyses

- **CEMP-s** stars and some of the **G2 CEMP-no** stars have the plume feature → Gaia Enceladus/Sausage event.

- Also, there are stars with **prograde** motion among **G2 CEMP-no** and **G3** → **minor accretion**.

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NMP ~ 500 stars  
CEMP ~ 180 stars
Inclination angle vs. Eccentricity

0 = prograde in-plane, 90 = polar orbit, 180 = retrograde in-plane

- G3 CEMP-no is different from the rest of them
- Three (\(\nu\) Polar ~ another merger?) different preferred orbits among others
- Carbon-normal (NMP) share some orbits with G2 CEMP-no, however, G2 has more stars close to polar orbit
- Retrograde NMP have very eccentric orbit, while G2 retrograde stars rather low eccentricity.
- G2 CEMP-no retrograde share the same region of CEMP-s retrograde
Future Work

• Detailed abundance analysis of G I CEMP-no and Carbon-normal stars

• Theoretical modeling needed to explain the origin of G I/G3 CEMP-no

• Look for signature of binary mass transfer

• More CEMP stars from the dwarf galaxies

• Further understanding of kinematical analysis (is there clear separation among carbon-normal if G 2 does not exist?)

• CEMP stellar pipeline for very cool stars
CEMP-no morphology

- multiple nucleosynthetic pathways for CEMP-no stars
- star forming and galactic environment
- possible accretion origin
- Mass of host galaxies is important for CEMP formation/fraction.
- Kinematic origin -- each class of stars have complex accretion history
  - CEMP-no stars have preferentially prograde motion.
  - A substantial fraction of CEMP-no stars have polar orbits indicates another merger event?

- Thank you!
# Impact of masses of galactic environment

## Table 1. Characteristics of Group II and Group III CEMP-no Stars

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group II</th>
<th>Group III</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical signatures</td>
<td></td>
<td></td>
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<tr>
<td>A(C)-[Fe/II] correlation</td>
<td>yes</td>
<td>no &amp; higher A(C)</td>
<td>(1), (2)</td>
</tr>
<tr>
<td>A(C)-A(Na, Mg) correlation</td>
<td>yes</td>
<td>no &amp; lower A(Na,Mg)</td>
<td>(1)</td>
</tr>
<tr>
<td>A(C)-A(Ba) correlation</td>
<td>yes</td>
<td>no &amp; lower A(Ba)</td>
<td>(2)</td>
</tr>
</tbody>
</table>

| Galactic environment        |                                |                                                        |            |
| Galaxy type                 | dSphs (& UFDs)                 | UFDs                                                  | (2)        |
| Galaxy total mass           | $\sim 10^9 M_\odot$           | $\sim 10^6 M_\odot$                                   | (3), (4), (5), (6) |
| Star-formation history      | prolonged (chemically evolved) | truncated (stochastic, inhomogeneous)                 | (6), (7)   |

| Star-forming environment    |                                |                                                        |            |
| Progenitor SN               | normal CCSNe                  | faint SNe                                             | (8)        |
| Gas cooling agents          | silicate grains                | carbon grains                                          | (8)        |
| Dominant Pop. contribution  | Pop. II                       | Pop. III                                              | (9), (10), (11) |
| Number of progenitors       | multiple (multi-enrichment)    | single (mono-enrichment)                              | (12)       |
| Natal-gas enrichment        | internal pollution (self-enrichment) | external & internal pollution                         | (13), (14), (15) |


Yoon, Beers, Tian, & Whitten (2019)
Origin of ubiquitous Ba abundance

- **r-process** production events via NSM, collapsar, magneto-driven supernovae

- **weak-s process** in rapidly rotating massive stars

- **Existence of AGB stars with** $[\text{Fe/H}]<-3.0$ that produce little if any s-process elements. → r-process might not be the only producers for Ba

- Require theoretical understanding of this phenomenon
Archetypal fitting to CEMP groups

3 archetypes of parameters representing CEMP groups.


Devin Whitten