The Nature of First-Generation Stars as Revealed by Ultra Metal-Poor ([Fe/H] < -4.0) Stars

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Abstract

Ultra Metal-Poor (UMP, [Fe/H] < -4.0) stars hold the key to understanding the nucleosynthesis processes associated with first-generation stars in the Universe. However, only about two dozen UMP stars have been discovered to date. In an effort to search for additional such stars, we selected UMP candidates from low-resolution spectra from the Sloan Digital Sky Survey, and carried out high-resolution spectroscopic follow-up with Gemini/GRACES. In this study, we present preliminary results of elemental abundances derived for UMP candidates, and investigate their possible progenitors by comparing measured abundance patterns with yields predicted by that various supernovae models. Our results can be used to provide stringent constraints on the nature of the first generation of stars, which the likely progenitors of the UMP objects.

Sample Selection

• Data selection
  - UMP candidates were selected from the low-resolution SDSS spectra. We used the metallicity estimate based on the Ca II K in the SEGUE Stellar Parameter Pipeline (SSPP; Lee et al. 2008), which is the most sensitivity metallicity indicator for extremely low-metallicity stars.
  - The selection criteria are as follows.
    - [Fe/H] < -3.5 measured from Ca II K line
    - 4500 < T_\text{eff} < 6500K, 15.5 < g < 16.5

Stellar Parameters

Table 1. Derivation of stellar parameters by fitting spectral features

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>T_\text{eff}</th>
<th>\log g</th>
<th>[Fe/H]</th>
<th>Ca/Fe</th>
<th>Cr/Fe</th>
<th>Mg/Fe</th>
<th>Na/Fe</th>
<th>TID/Fe</th>
<th>[C/Fe]</th>
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<tbody>
<tr>
<td>1</td>
<td>SDSS 3214-5486-429</td>
<td>5496</td>
<td>3.08</td>
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<td>0.76</td>
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<tr>
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<td>0.76</td>
<td>0.52</td>
<td>0.08</td>
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<td>0.77</td>
<td>1.33</td>
</tr>
<tr>
<td>4</td>
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<td>1.02</td>
<td>1.02</td>
<td>1.02</td>
</tr>
<tr>
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- We first performed spectral fit to the grid of synthetic spectra to derive effective temperature, surface gravity, and metallicity, which are used to generate a starting model atmosphere for chemical abundance analysis.
- Figure 1 shows the best-matching synthetic spectrum by the spectral fitting technique for our reference star, SDSS 3214. Table 1 lists parameters derived from the spectral fitting.
- Since our sample consists of turn-off stars, we assumed 1.0 km/s of micro turbulence velocity.

Chemical Abundances

Table 2. Elemental abundances for our program stars

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>[Fe/H]</th>
<th>[Ba/Fe]</th>
<th>[Ca/Fe]</th>
<th>[Cr/Fe]</th>
<th>[Mg/Fe]</th>
<th>[Na/Fe]</th>
<th>[TID/Fe]</th>
<th>[C/Fe]</th>
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<td>1.33</td>
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<tr>
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<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
<td>0.97</td>
<td></td>
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- We used SPECTRE to measure equivalent widths, and derived stellar parameters (T_\text{eff}, \log g, [Fe/H]) and chemical abundances using MOOG (Sneden 1973).
- Table 2 lists preliminary results of abundance analysis of our UMP stars.
- C was not detected directly. So [C/Fe] is an estimate from the SSPP.

Results

• Comparison with Abundance Trends

We compared the chemical abundances of our UMP stars with those of other metal-poor stars. Figure 2 is [X/Fe] vs [Fe/H] for α, iron-peak, and s-process elements of the objects. Na and Mg are similar to other stars in the same metallicity. On the other hand, Ca and Cr are relatively lower, while Ti is lower than other UMP stars.
- Mass range of UMP progenitors

Figure 3 shows the abundance pattern as a function of atomic number. The red symbol indicates the predicted yield from supernova model with specific condition listed at the top of each panel, while the black symbol is our measurement.
- Even though there is small number of elements measured in our sample, we were able to find best-matching model with specific mass. The progenitor of our sample is in the mass range of 10 ~ 20 M_☉.
- This result may indicate that the masses of Pop III stars were not that high as thought previously.

Summary and Conclusions

- We derived elemental abundances for our UMP candidates, and identified most of our candidates as UMP stars.
- Two of the UMP stars have low Ba abundances, indicating that they are CEMP-no stars. Other stars for which Ba was not measured would have weak Ba absorption line. Therefore, these can also be assumed to be CEMP-no.
- We investigated the possible progenitor mass of our UMP stars by comparing measured abundance patterns with yields predicted by that various supernovae models.
- We have estimated the mass progenitor range of 10 ~ 20 M_☉, which is in the similar range as in the previous study (10 ~ 40 M_☉, by Placco et al. 2016).
- Our result implies that masses of Pop III stars may have a lighter component with masses between 10 ~ 40 M_☉.

References

Asplund, M., Grevesse, N., Sauval, A. J. & Scott, P. 2009, ARAA, 47, 481

http://starfit.org

Figure 2

Figure 3