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

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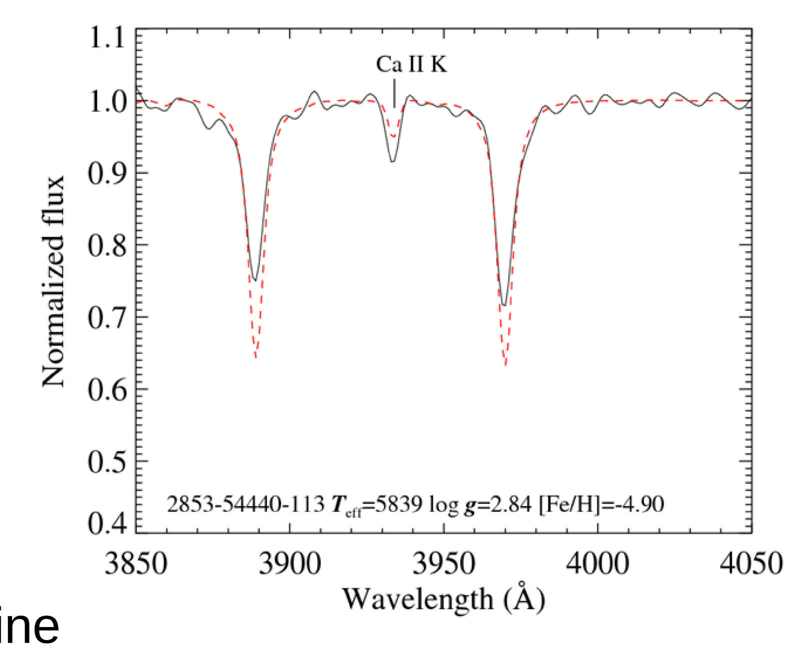
Abstract

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.

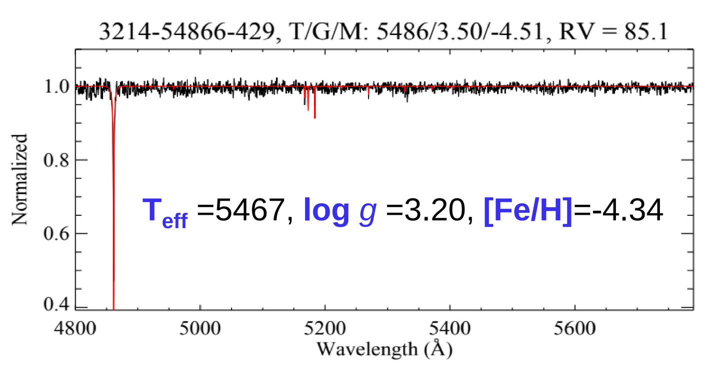


- The selection criteria are as follows.
  - [Fe/H] < -3.5 measured from Ca Ⅱ K line
  - 4500 < T_{eff} < 6500K, 15.5 < g < 16.5

Stellar Parameters

▼ **Table 1.** Derivation of stellar parameters by fitting spectral features

Ultra Metal-poor Stars					
Spectral fitting of Ultra Metal-poor Stars					
ID	Name	T_{eff}	Log g	Metallicity	Micro turbulence
1	SDSS 3214-54866-429	5486	3.50	- 4.51	1.0
2	SDSS 1650-53174-492	5548	3.96	- 4.00	1.0
3	SDSS 2901-54652-464	5762	3.50	- 4.03	1.0
4	SDSS 3264-54889-032	5275	3.21	- 3.94	1.0
5	SDSS 6377-56245-0382	5684	3.5	- 4.24	1.0



▲ **Figure 1.** Reference star : SDSS 3214
· T_{eff} =5467, log g=3.20, [Fe/H]=-4.34 (Placco et al.2015)

- 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.
- **Figure1** shows the best-matching synthetic spectrum by the spectral fitting technique for our reference star, SDSS 3214. **Table 1** lists the parameters derived from the spectral fitting.
- Since our sample consists of turn-off star, we assumed 1.0 km/s of micro turbulence velocity.

Chemical Abundances

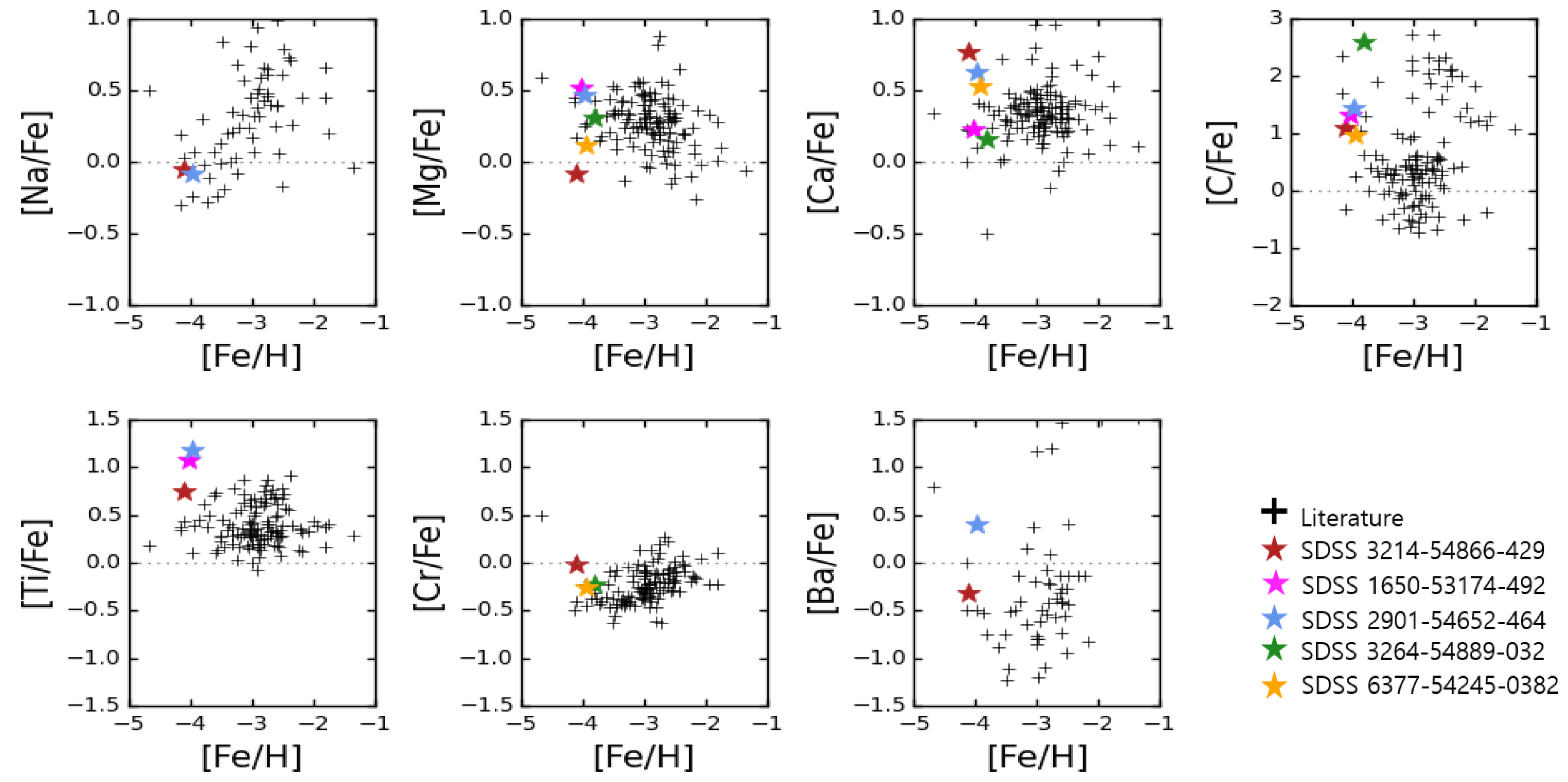
▼ **Table 2.** Elemental abundances for our program stars

Measured abundances of Ultra Metal-poor Stars										
ID	Name	[Fe/H]	[Ba/Fe]	[Ca/Fe]	[Cr/Fe]	[Mg/Fe]	[Na/Fe]	[Ti Ⅰ/Fe]	[Ti Ⅱ/Fe]	[C/Fe]*
1	SDSS 3214-54866-429	-4.09	-0.22	0.76	-0.02	-0.06	-0.04	0.75	···	1.10
2	SDSS 1650-53174-492	-4.03	···	0.23	···	0.52	···	1.08	0.77	1.33
3	SDSS 2901-54652-464	-3.97	0.41	0.63	···	0.47	-0.08	1.19	···	1.46
4	SDSS 3264-54889-032	-3.82	···	0.16	-0.23	0.31	···	···	···	2.61
5	SDSS 6377-56245-0382	-3.94	···	0.53	-0.25	0.12	···	···	···	0.97

- We used SPECTRE to measure equivalent widths, and derived stellar parameters (T_{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



▲ **Figure 2.** [Fe/H] vs [X/Fe] for UMP candidates, compared to literature data, which come from Yong et al. (2013) and Hansen et al. (2014)

- **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 larger, while Ti is lower than other UMP stars.
- Ba is measured for two stars, and it is relatively lower, indicating that they are CEMP-no stars as expected. Because other stars for which Ba was not measured would have weak Ba absorption lines, these can be regarded as CEMP-no stars as well.

• Mass range of UMP progenitors

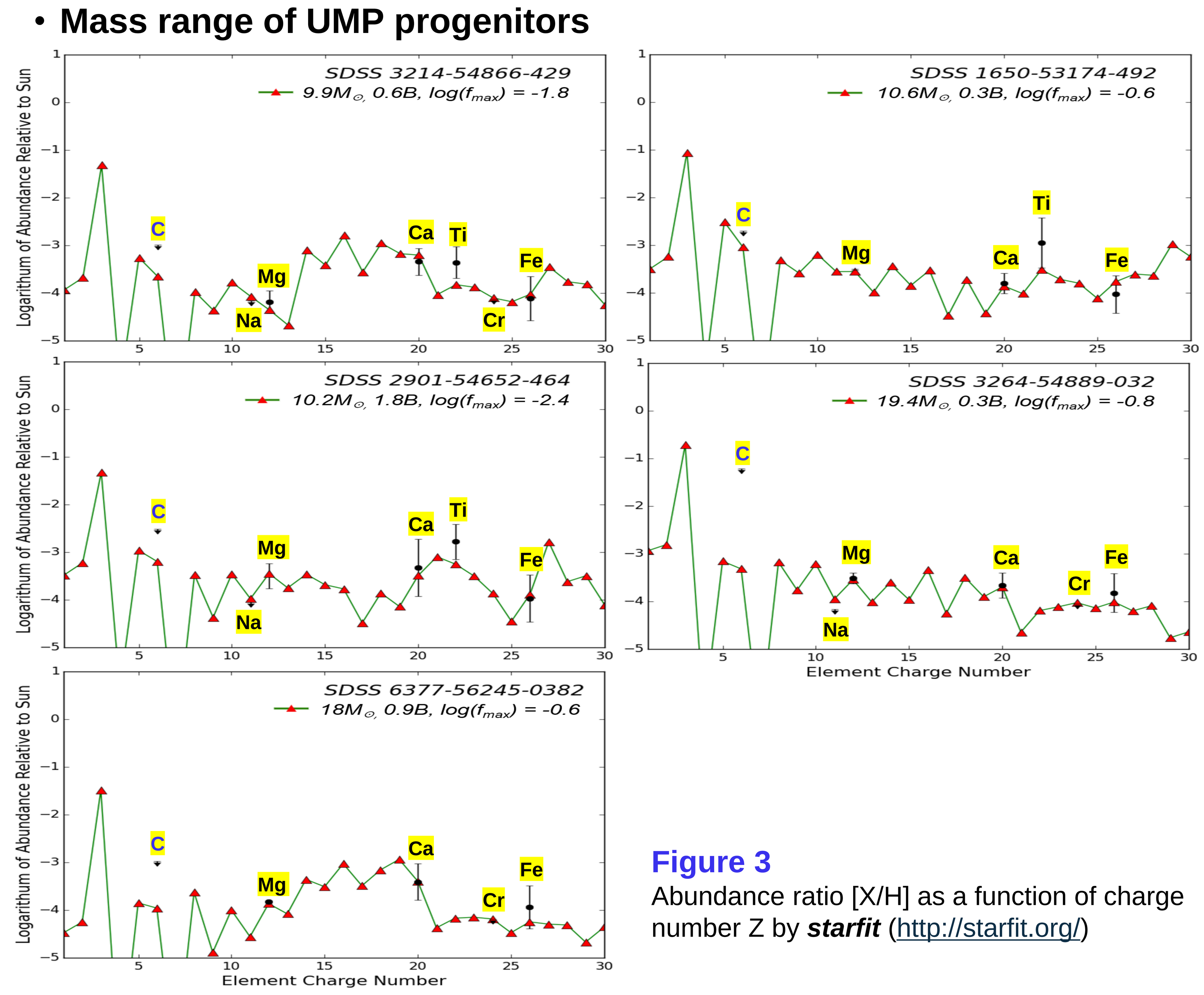


Figure 3
Abundance ratio [X/H] as a function of charge number Z by ***starfit*** (http://starfit.org/)

- **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 big 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 $M_{\odot}$.
- This range is similar to the previous estimates of about 10 ~ 40 $M_{\odot}$.(e.g., Placco et al. 2016)
- 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 lines. 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 of progenitor range is 10 ~ 20 $M_{\odot}$, which is in the similar range as in the previous study (10 ~ 40 $M_{\odot}$ by Placco et al. 2016)
- Our result implies that masses of Pop III stars may have a lighter component with masses between 10 ~ 40 $M_{\odot}$.

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