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The Chemical Composition of HE 1305+0132: A Carbon-Enhanced Metal-Poor Star with Enhanced Fluorine

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The abundances of Fe, C, N, and Ba have been derived for the Carbon-Enhanced Metal-Poor star HE 1305+0132. The C and N abundances are typical of CEMP stars. The Ba abundance, derived for the first time for HE 1305+0132, is found to be enhanced relative to Fe, placing this star in the CEMP-s group. Combined with a previously derived highly enhanced abundance of F, the chemical composition of HE 1305+0132 strongly suggests that it has been polluted via mass transfer by a more evolved companion as it passed through its asymptotic giant branch phase.

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1. Introduction

Carbon-enhanced metal-poor (CEMP) stars constitute a large fraction of stars in the Galactic halo [1]. It has been shown that the incidence of CEMP stars increases at decreasing metallicities [2], suggesting that the nucleosynthetic pathways leading to these interesting objects was highly efficient in the early Galaxy.

CEMP fall into two general classes, those that have enhancements of *s*-process elements (CEMP-s), such as Ba, and those that do not show such enhancements (CEMP-no). The source of the chemical abundance pattern of CEMP-s stars is thought to be a mass-transfer event from a now evolved higher mass companion during its asymptotic giant branch (AGB) phase, the predominant nucleosynthetic site of the *s*-process. CEMP-no stars are believed to have formed from clouds that had been previously enriched by a prior generation of massive stars. Meynet, Ekström, & Maeder [3] provided the theoretical basis for an observational abundance analysis that could potentially distinguish between and constrain the two hypotheses proffered for the nucleosynthetic origins of CEMP stars. They showed that low-metallicity AGB stars may have been prodigious producers of ^{19}F while more massive stars most likely were not.

Motivated by the results of Meynet et al., we carried out a ^{19}F abundance analysis of the CEMP star HE 1305+0132 and found this star to have an abundance of [F/Fe] $= +2.90$ [4]. This highly super-solar ^{19}F abundance is reminiscent of the high [F/Fe] ratio predicted by Meynet et al. to be present in the envelope of an AGB star, suggesting that HE 1305+0132 has been polluted by an AGB companion. Here we present the preliminary results of an abundance analysis of a high-resolution spectrum of HE 1305+0132. Abundances of Fe, C, N, and Ba are presented and discussed in terms of the nucleosynthetic history of HE 1305+0132.

2. Data Analysis

High-quality echelle spectra of HE 1305+0132 were obtained with the High Resolution Spectrograph and 9.2-m Hobby-Eberly Telescope (HET) located at the McDonald Observatory. The spectra have a nominal resolution of $R = \lambda/\Delta\lambda = 60,000$, and eight individual spectra obtained on four different nights were coadded to achieve a final spectrum with a signal-to-noise (S/N) ratio of $\mathrm{S/N} \approx 75$ near the C_2 band head at 5635 Å.

The abundances of Fe, C, N, and Ba have been derived assuming local-thermodynamic equilibrium (LTE) using the stellar line analysis package MOOG [5]. The adopted stellar parameters are from our previous work on the ^{19}F abundance of HE 1305+0132 and are $T_{\mathrm{eff}} = 4262 \pm 100$ K, $\log g = 0.80 \pm 0.30$ (cgs), microturbulent velocity $\xi = 2.00$ kms^{-1}, and $[\mathrm{Fe/H}] = -2.50$ [4]. We also use the CNO-enhanced model stellar atmosphere from our previous study. The model was generated using the ATLAS12 1-dimensional stellar atmosphere code [6], and along with the stellar parameters listed above, it is characterized by CNO abundances of $[\mathrm{C/Fe}] = +2.20$, $[\mathrm{N/Fe}] = +1.60$, and $[\mathrm{O/Fe}] = +0.50$. It has been shown that the temperature and pressure profiles of CNO-enhanced model atmospheres differ from those with scaled-solar abundances, and that these differences can affect abundance derivations of some elements, particularly those based on molecular lines [7]. Thus, the use of CNO-enhanced model atmospheres in abundance analyses of CEMP stars is crucial if accurate results are to be obtained.

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Species	$A(\mathrm{m})$	[m/H]	[m/Fe]
Fe	5.53 ± 0.14	-1.92	···
C	8.16 ± 0.07	-0.23	+1.69
N	7.39 ± 0.16	-0.39	+1.53
Ba	1.11 ± 0.33	-1.06	+0.86

Table 1: Abundances

The abundances of Fe and N have been derived by an equivalent width analysis. Heavy molecular absorption, particularly from CN, permeates the HE 1305+0132 spectrum, making it difficult to identify clean unblended lines of any species. Despite a broad wavelength coverage (4300 – 7800 Å), only 23 Fe I and three Fe II lines were found to be presumably unblended and suitable for measurement. Nitrogen abundances have been derived by measuring the equivalent widths of 55 supposedly clean lines of the CN red system. For consistency, N abundances have been determined from the CN lines by adopting the C abundance derived from our HET/HRS spectrum, as described below.

Spectral synthesis has been used to derive the abundances of C and Ba. We employ the $\lambda 4737$ and $\lambda 5635$ band heads of the C_2 Swan system in order to estimate the C abundance. The fits of the synthetic spectra to the observed C_2 features are quite satisfactory and are shown in Figure 1. Barium abundances have been derived by analysis of two Ba II lines, one at 5853.7 Å and one at 6141.7 Å. As shown in Figure 2, the synthetic fit to the $\lambda 5853$ line does not reproduce well the absorption in the wings of the feature, presumably due to an incomplete linelist. The core of the line, however, is well fit. The synthesis of the $\lambda 6141$ line is excellent, and along with the observed spectrum, it is also shown in Figure 2.

3. Results & Discussion

The abundance results are summarized in Table 1. The Fe abundance based on the analysis of Fe I lines is $A(\mathrm{Fe\,I}) = \log N(\mathrm{Fe\,I}) = 5.63 \pm 0.20$ (standard deviation), and that from Fe II lines is $A(\mathrm{Fe\,II}) = 5.43 \pm 0.17$. Abundances derived from the Fe II lines are sensitive to the adopted $\log g$, and often in high-resolution spectroscopic abundance analyses, stellar $\log g$ values are set by forcing ionization balance of Fe, *i.e.*, requiring Fe I and Fe II-based abundances to be the same. We are unable to perform such an analysis here because of the dearth of Fe II lines. Nonetheless, the Fe I and Fe II-based abundances are in decent agreement, suggesting our adopted $\log g$ is not grossly in error.

Averaging the mean Fe I and Fe II abundances gives $A(\mathrm{Fe}) = 5.53$ with a standard deviation of $\sigma = 0.14$ dex. Adopting the solar abundances of Asplund, Grevesse, & Sauval [8] gives a relative abundance of $[\mathrm{Fe/H}] = -1.92$ for HE 1305+0132. This is about 0.50 dex higher than the Fe abundance derived from an analysis of a medium resolution spectrum of HE 1305+0132 in our previous study [4], and it is also about equal to the quoted uncertainty in that previously derived value. While the Fe abundance presented here is in statistical agreement with that from Schuler

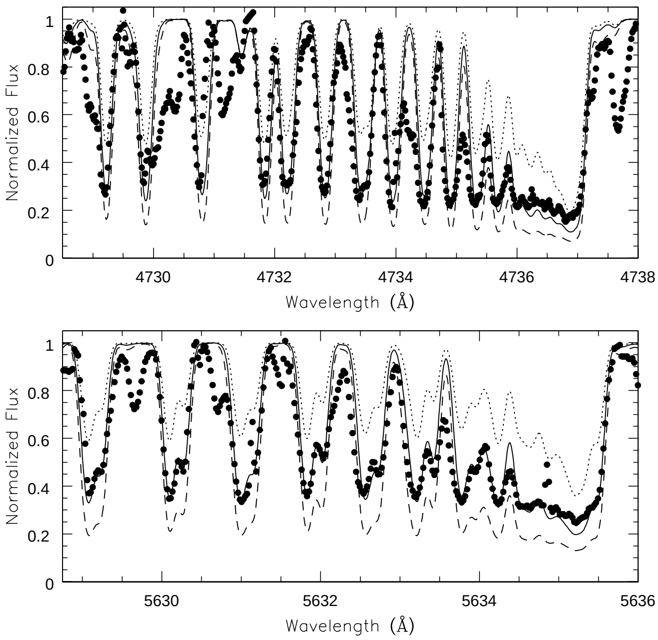

Figure 1: Synthetic fits to the λ4736 and λ5635 C_2 band heads. Along with the best fit syntheses, synthetic spectra representing $\pm$0.25 dex of the best fit abundance are also shown.

et al. [4], the large difference was not expected, and an attempt to understand the nature of the discrepancy is ongoing.

The C abundances derived from the λ4737 and λ5635 C_2 band heads- $A(\mathrm{C}) = 8.11$ and $A(\mathrm{C}) = 8.21$, respectively- are in good concordance and have a mean value of $A(\mathrm{C}) = 8.16 \pm 0.07$, corresponding to an abundance relative to Fe of $[\mathrm{C/Fe}] = +1.69$. The absolute abundance of $A(\mathrm{C}) = 8.16$ is 0.41 dex lower than the one found in our previous study, which was based on the analysis of a single C_2 feature in the near-IR *K* band at 2.3332 μm. Adopting the mean C abundance derived from the C_2 band heads, analysis of 55 lines of the CN red system results in a mean N abundance of $A(\mathrm{N}) = 7.39 \pm 0.16$ or $[\mathrm{N/Fe}] = +1.53$. Similar to the case for Fe, the N abundance presented here is in agreement within uncertainties with the value reported in Schuler et al. [4].

The Ba abundances derived from the 5853.7 Å and 6141.7 Å lines exhibit a sizable spread of 0.47 dex and have a mean abundance of $A(\mathrm{Ba}) = 1.11 \pm 0.33$. As noted above, the wings of the λ5854 Ba II line are not well fit by our synthetic spectrum, resulting in lower confidence in the associated abundance. While additional Ba II lines that can be used for this analysis are being investigated, the mean relative abundance of the two lines studied here is $[\mathrm{Ba/Fe}] = +0.86$, indicating that HE 1305+0132 is indeed enhanced in *s*-process elements.

We have presented the preliminary results of an Fe, C, N, and Ba abundance analysis of the F-enhanced CEMP star HE 1305+0132. The C and N abundances are typical of CEMP stars [9], and the enhanced Ba abundance, presented here for the first time for HE 1305+0132, places this star in the CEMP-s group. The enhanced Ba and F abundances strongly suggests that HE 1305+0132 has been polluted by an evolved companion during its AGB phase via a mass-transfer

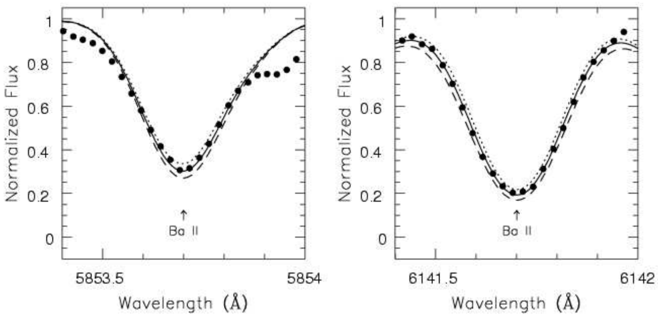

Figure 2: Synthetic fits to the $\lambda 5853$ and $\lambda 6142$ Ba II lines. The best fit syntheses, corresponding to abundances of $A(\mathrm{Ba}) = 0.87$ for $\lambda 5853$ and $A(\mathrm{Ba}) = 1.34$ for $\lambda 6142$, are shown along with syntheses characterized by ± 0.25 dex of the best fit abundance.

event. The abundances presented here, along with the F abundance of Schuler et al. [4], should provide stringent constraints for models of AGB star nucleosynthesis at low metallicities and mass transfer to secondary companions, such as those of Lugaro et al. [10].

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