Carbon Abundances of Three Carbon-Enhanced Metal-Poor Stars from High-Resolution Gemini-S/bHROS Spectra of the λ8727 [C I] Forbidden Line‡

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INTRODUCTION

Carbon-Enhanced Metal-Poor (CEMP) stars constitute a significant fraction of stars in the Galactic halo, and their frequency increases with declining [Fe/H] abundances. The three stars known to have [Fe/H] < -4.0 are all carbon-enhanced. The large number of CEMP stars relative to C-normal stars in the halo implies that the nucleosynthetic pathway(s) leading to CEMP stars is highly efficient at low metallicities and that it played an important role in the chemical evolution of the early Galaxy.

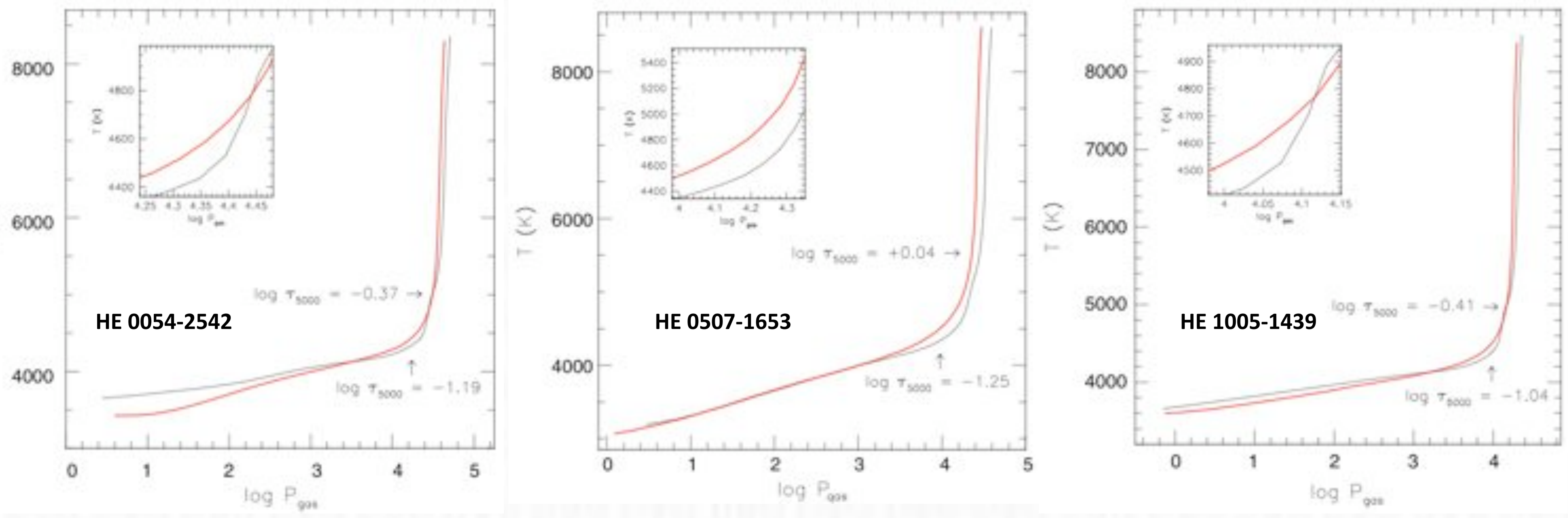
The derivation of accurate C abundances of CEMP stars is critical to their proper characterization and subsequently to the correct interpretation of their role in the nucleosynthetic history of the Galaxy. Carbon abundances of CEMP stars are primarily derived from high-resolution spectra of CH and C_2 features, lines that are expected to be highly sensitive to photospheric temperature inhomogeneities, the so-called 3D effects.

Here we present the results of our investigation into the accuracy of molecular line-based C abundances of CEMP stars by analyzing the λ8727 forbidden [C I] line in high-resolution Gemini-S/bHROS spectra of three CEMP stars. The λ8727 [C I] line is known to be insensitive to NLTE effects and to be a highly accurate C abundance indicator.

STELLAR MODELS

We chose three CEMP stars from the recent literature as targets for our study. The stars and the adopted stellar parameters are listed in the table below. The stellar parameters are taken from Aoki et al. (2002, ApJ, 580, 1149) and Aoki et al. (2007, ApJ, 655, 492).

The structure of a stellar photosphere is dependent in part on the star's chemical composition due to the contribution of metals to the continuous opacity. In addition to a handful of other metals, C is a significant contributor to the continuous opacity, and consequently, the temperature and pressure stratification of CEMP star photospheres is expected to differ from that of "C-normal" stars, as demonstrated in the figures below. In light of this, we have used C-enhanced model atmospheres constructed with the ATLAS12 LTE stellar atmosphere code of R.L. Kurucz (1996, IAU Symp. 176, 523) for our analysis. As noted in the table below, the models include enhancements in N and O, as well.

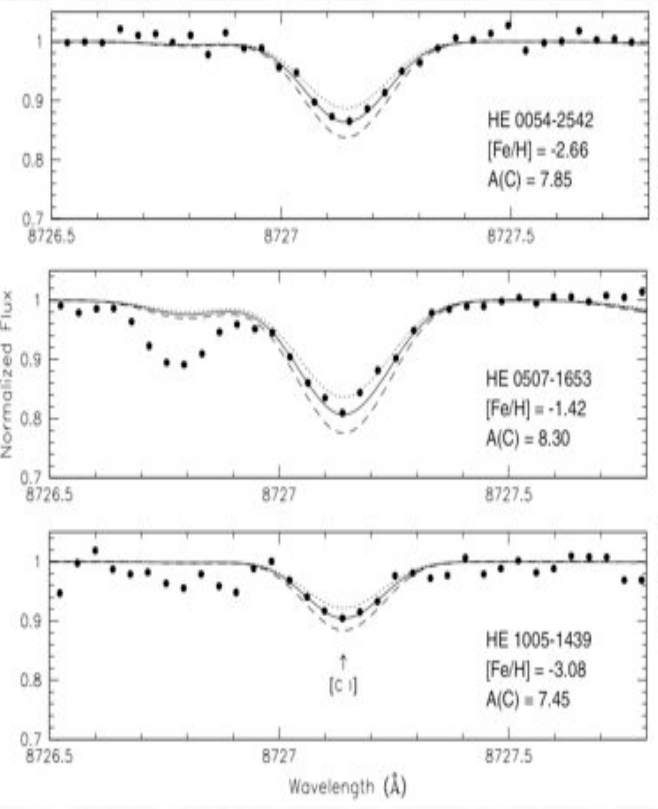


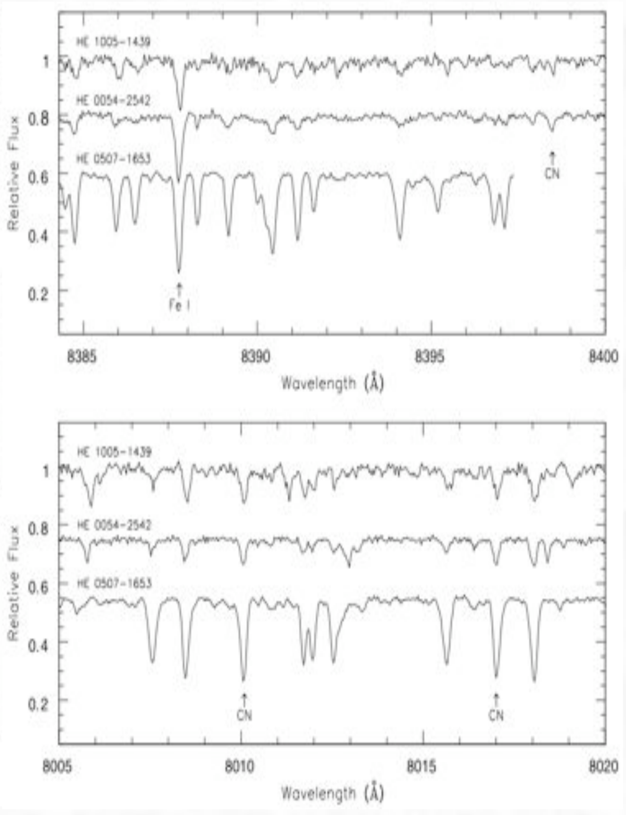
Temperature vs. the logarithm of the gas pressure of the one-dimensional LTE C-enhanced ATLAS12 (red) and solar-scaled ATLAS9 (black) model atmospheres. The insets show the relations in the line-forming regions of the spectral features analyzed in our study, as marked by the upper and lower optical depths in the main panels. It is clearly seen that, in general, the C-enhanced models are hotter than the C-normal models in the line forming regions.

Star	Adopted Stellar Parameters						Abundance Results				
	T_{eff} (K)	log g (cgs)	ξ (km s^{-1})	[Fe/H]	[C/Fe]	[N/Fe]	[Fe/H]	[C/Fe]	Δ[C/Fe]*	[N/Fe]	[K/Fe]
HE 0054-2542	5000	2.40	2.00	-2.64	+2.00	+0.80	-2.66±0.08	+2.12±0.14	+0.12	+1.24±0.35	+0.61±0.11
HE 0507-1653	5000	2.40	2.00	-1.38	+1.30	+0.80	-1.42±0.15	+1.33±0.20	+0.03	+1.20±0.34	+0.74±0.24
HE 1005-1439	5000	1.90	2.00	-3.17	+2.50	+1.80	-3.08±0.13	+2.14±0.17	-0.36	+2.27±0.35	+0.50±0.15

ANALYSIS & RESULTS

We have used the LTE stellar line analysis code MOOG (Sneden 1973, ApJ, 184, 839) for the abundance analysis. The [C I] abundances have been derived using the spectral synthesis method. Our linelist includes the [C I] oscillator strength from Allende Prieto et al. (2002, ApJ, 573, L137; log *gf* = -8.136), an atomic linelist from VALD (Piskunov et al. 1995, A&AS, 112, 525), and the molecular line data from Gustafsson et al. (1999, A&A, 342, 426). Fe, N, and K abundances have also been derived via an equivalent width analysis. The N abundances were determined by analyzing CN lines while adopting the [C I]-based C abundance.



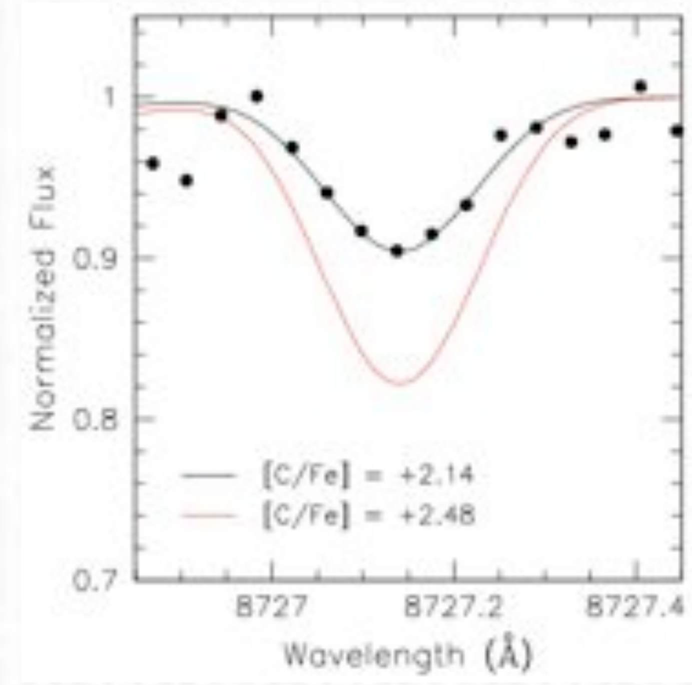


Left: Gemini-S/bHROS spectra of the [C I] line (filled circles). The spectra are characterized by a resolution of R = $\lambda/\Delta\lambda$ = 75,000 and S/N ratios of 114, 149, and 65 for HE 0054-2542, HE 0507-1653, and HE 1005-1439, respectively. The best fit synthetic spectrum is given as the solid line and corresponds to the C abundance given in each panel. The broken lines represent ±0.10 dex the best-fit abundance.

Right: Gemini-S/bHROS spectra of the λ8010 and λ8390 spectral regions. Some of the Fe and CN lines used in the analysis are marked.

CONCLUSIONS

1) The [C I]-based abundances of HE 0054-2542 and HE 0507-1653 are in good agreement with the previously published molecular line-based values. ***On the contrary, the [C I]-based abundance of HE 1005-1439- the most Fe-poor star in our sample- is 0.36 dex lower than the molecular line-based value.*** The figure to the right shows synthetic fits to the bHROS spectrum of HE 1005-1439 assuming the [C I] (black) and molecular line-based (red) abundances.



2) ***We have carried out 3D calculations of the [C I] line formation and have found that the predicted corrections are modest, suggesting that the difference between the [C I] and molecular line-based values is due primarily to more severe 3D effects on the molecular lines.*** These results are in concert with predictions that 3D corrections for molecular lines become more significant toward lower metallicities, although more data are needed to verify and quantify this effect.

3) Our [Fe/H] abundances are in good agreement with published values.

4) Our [N/Fe] abundances are systematically higher than published values by at least 0.40 dex. Previously derived N abundances for these and the majority of all CEMP stars are based on analyses of the CN blue system. ***Our result, along with evidence found in the literature, suggests that analyses of the CN blues system underestimate the N abundances of metal-poor stars.***

5) Our [K/Fe] abundances fall squarely within the scatter of LTE abundances observed among C-normal metal-poor stars. K abundances are generally derived from the λ7699 K I resonance line, which is known to be highly sensitive to NLTE effects. The effects, however, are not expected to vary with metallicity, and thus the concordance in the K abundances of CEMP and C-normal stars should be real.

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