BD+44°493: A NINTH MAGNITUDE MESSENGER FROM THE EARLY UNIVERSE;
CARBON ENHANCED AND BERYLLIUM POOR*

HIROKO ITO1,2, WAKO AOKI1,2, SATOSHI HONDA3, AND TIMOTHY C. BEERS4
1 Department of Astronomical Science, School of Physical Sciences, The Graduate University of Advanced Studies (SOKENDAI), 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan; hiroko.ito@nao.ac.jp
2 National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo 181-8588, Japan; aoki.wako@nao.ac.jp
3 Gunma Astronomical Observatory, 8680-86 Nakayama, Takayama, Agatsuma, Gunma 377-0702, Japan; honda@astron.pref.gunma.jp
4 Department of Physics & Astrophysics, Center for the Study of Cosmic Evolution, and Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, MI 48824-1116, USA; beers@pa.msu.edu

Received 2009 March 19; accepted 2009 April 30; published 2009 May 21

ABSTRACT

We present a one-dimensional LTE chemical abundance analysis of the very bright (V = 9.1) carbon-enhanced metal-poor (CEMP) star BD+44°493, based on high-resolution, high signal-to-noise spectra obtained with Subaru/HDS. The star is shown to be a subgiant with an extremely low iron abundance ([Fe/H] = −3.7), while it is rich in C ([C/Fe] = +1.3) and O ([O/Fe] = +1.6). Although astronomers have been searching for extremely metal-poor stars for decades, this is the first star found with [Fe/H] < −3.5 and an apparent magnitude V < 12. Based on its low abundances of neutron-capture elements (e.g., [Ba/Fe] = −0.59), BD+44°493 is classified as a “CEMP-no” star. Its abundance pattern implies that a first-generation faint supernova is the most likely origin of its carbon excess, while scenarios related to mass loss from rapidly rotating massive stars or mass transfer from an asymptotic giant branch companion star are not favored. From a high-quality spectrum in the near-UV region, we set an very low upper limit on this star’s beryllium abundance ([Be] = −2.0), which indicates that the decreasing trend of Be abundances with lower [Fe/H] still holds at [Fe/H] < −3.5. This is the first attempt to measure a Be abundance for a CEMP star, and demonstrates that high C and O abundances do not necessarily imply high Be abundances.

Key words: Galaxy: abundances – stars: abundances – stars: individual (BD+44° 493) – stars: Population II

1. INTRODUCTION

Chemical abundance analyses of metal-poor stars based on high-resolution spectroscopy play an important role in our understanding of the chemical evolution of the early universe (e.g., Beers & Christlieb 2005) because their atmospheres preserve (in most cases) the chemical composition of the gas from which they formed. In particular, the nucleosynthesis signatures from the first generations of (likely massive) stars are believed to be recorded by lower-mass stars at the lowest observed metallicity. However, the number of extremely metal-poor stars having [Fe/H] < −3.5 known to date is quite small (∼15), and the chemical-enrichment processes that were in operation at such low metallicity are still unclear.

Surveys for metal-poor stars over the past few decades have shown that a large fraction of metal-poor stars exhibit enhancements of carbon. Such stars are often referred to as carbon-enhanced metal-poor (CEMP) stars. In particular, all three ultra metal-poor ([Fe/H] < −4) stars discovered so far exhibit strong C excesses. Several sources that could produce a significant amount of carbon in the early universe have been suggested to account for these observations. For example, mass transfer from an asymptotic giant branch (AGB) companion is proposed to explain the so-called “CEMP-s” stars, which have excesses of s-process elements as well as carbon. However, some CEMP stars, in particular for [Fe/H] < −2.6 (Aoki et al. 2007), are not rich in s-process elements (“CEMP-no”). Among the handful of CEMP stars with [Fe/H] < −3.5 studied to date, none exhibits a clear excess of the s-process elements. One must therefore consider other scenarios where the C excess at extremely low metallicity may have been produced by previous generations of stars, e.g., mass loss from rapidly rotating massive stars (Meynet et al. 2006) or the ejecta of so-called “faint” supernovae (Umeda & Nomoto 2005). In order to distinguish between these, and other possible scenarios, measured abundances of N and O, as well as for the heavy neutron-capture elements, are required.

In this Letter, we present a one-dimensional LTE abundance analysis of the extremely metal-poor ([Fe/H]= −3.7) CEMP star BD+44°493. Anthony-Twarog & Twarog (1994) reported the metallicity of this object to be [Fe/H]= −2.71, based on uvby photometry, while Carney et al. (2003) pointed out that a synthetic spectrum with lower metallicity produced a better fit to the spectrum they used to measure its radial velocity. Our analysis reveals the presence of strong CH bands, which might lead to the overestimate of this star’s iron abundance, and that the lower metallicity speculation by Carney et al. (2003) is indeed correct. BD+44°493, with apparent magnitude V = 9.1, is quite remarkable in that it has the lowest iron abundance of any star with V < 12 found to date, and is by far the brightest extremely low metallicity star among all objects that have reported [Fe/H] based on high-resolution spectroscopy (according to the SAGA database; Suda et al. 2008).

Thanks to its brightness, our high signal-to-noise ratio (S/N) UV spectrum also allows inspection of the strength of the Be II lines at 3130 Å for BD+44°493, permitting measurement of a meaningful upper limit for beryllium at the lowest metallicity yet achieved. In the past decade, observations have revealed a clear linear correlation between stellar Be abundances and metallicity (e.g., Boesgaard et al. 1999). This result was at first surprising, because standard cosmic-ray spallation processes, in which high-energy protons and α-particles accelerated by supernovae impact interstellar CNO, predicted a quadratic correlation (“secondary” process). The observations indicated

* Based on data collected at the Subaru Telescope, which is operated by the National Astronomical Observatory of Japan.
the need for a “primary” process, in which accelerated CNO nuclei impinge on interstellar protons and $\alpha$-particles (e.g., Yoshii et al. 1997). Such a primary process is expected to be especially important in the early universe, due to the lack of large amounts of interstellar CNO. The mechanism to accelerate CNO nuclei is still uncertain, but superbubbles (e.g., Parizot & Drury 1999) and type Ic supernovae (e.g., Nakamura & Shigeyama 2004) have been suggested as possibilities. Our analysis of Be for BD+44°493 provides new insight for the origin of Be in the early universe, as well as a constraint on models that predict a low-metallicity plateau of Be abundances, including the Inhomogeneous Big Bang Nucleosynthesis (IBBN) scenario (Orito et al. 1997).

2. OBSERVATIONS

High-resolution spectroscopy of BD+44°493 was carried out on 2008 October 5 with HDS (Noguchi et al. 2002) on the Subaru Telescope for three grating settings, covering 3100–9350 Å with a resolving power of $R \sim 90,000$ (no on-chip binning). The exposure time for the UV observation is 120 minutes, while those for the other settings used are 15 minutes. In order to obtain a spectrum over 3900–3950 Å, which fell in the CCD gap in the October run, an additional exposure of 5 minutes was made with the same instrument on 2008 November 15, with a resolving power of $R \sim 60,000$ and $2 \times 2$ on-chip binning.

Data reduction was performed with the IRAF5 echelle package. The S/N per pixel achieved was $\sim 100/1$ at 3100 Å, $\sim 400/1$ at 4500 Å, and $\sim 250/1$ at 5000 Å. The spectrum covering the range 3400–6800 Å, where the S/N is the highest and many atomic lines exist, is used for the abundance analysis for most elements. We use the UV spectrum ($\sim 3400$Å) to measure the Be lines and the molecular features of NH and OH. Equivalent widths are measured by fitting Gaussian profiles to isolated atomic lines. For blended lines and molecular features, the spectrum synthesis technique is employed.

3. ABUNDANCE ANALYSIS

We adopt the effective temperature $T_{\text{eff}}$ of 5510 K determined by Carney et al. (2003), who used the color-$T_{\text{eff}}$ relations derived by Alonso et al. (1999) based on the infrared flux method. Although they adopted a higher metallicity of $[\text{Fe/H}] = -2.7$ in the calculation, the results hardly change even if a lower metallicity is assumed. The surface gravity is obtained from the LTE ionization equilibrium between Fe i and Fe ii, and the microturbulent velocity is determined from 107 Fe i lines by demanding that no trend of Fe abundances with equivalent widths is found. For this analysis, as well as for the following measurements of elemental abundances, a one-dimensional LTE abundance analysis was performed using the grid of ATLAS9 NEWODF model atmospheres (Kurucz 1993; Castelli & Kurucz 2003). The results are $\log g = 3.7$ and $v_t = 1.3$ km s$^{-1}$; the derived metallicity is $[\text{Fe/H}] = -3.68$. The non-LTE (NLTE) effect on Fe i is estimated to be 0.1–0.3 dex by previous studies (e.g., Asplund 2005). NLTE effects on determinations of abundances and stellar parameters will be discussed separately (H. Ito et al. 2009, in preparation). For elements for which no line is detected, we estimate upper limits based on the 3$\sigma$ error of equivalent width measurement, employing the formula given in Norris et al. (2001). The derived abundances and uncertainties are listed in Table 1.

![Figure 1](image_url)

Figure 1. Observed spectrum (dots) and synthetic spectra (lines) for the CH band at 4312 Å. Assumed abundances are $[\text{C/Fe}] = +1.16$ (blue line), +1.36 (red line), and +1.56 (green line).

| $X$ | Ion | $N_{\text{lines}}^a$ | $\log \epsilon(X)$ | $[\text{X/Fe}]^b$ | Random error | Total error |
|-----|-----|---------------------|---------------------|-------------------|--------------|-------------|
| Li  | 1   | Syn                 | 1.04                | ...               | 0.03         | 0.09        |
| Be  | 2   | Syn                 | $< -2.0$            | ...               | ...          | ...         |
| C   | CH  | Syn                 | 6.02                | +1.31             | 0.10         | 0.23        |
| N   | NH  | Syn                 | 4.42                | +0.32             | 0.25         | 0.32        |
| O   | OH  | Syn                 | 6.57                | +1.59             | 0.15         | 0.26        |
| Na  | 1   | 2                   | 2.76                | +0.27             | 0.09         | 0.13        |
| Mg  | 1   | 7                   | 4.37                | +0.52             | 0.04         | 0.10        |
| Al  | 1   | 3961 Å              | 2.12                | $-0.57$           | 0.13         | 0.16        |
| Si  | 1   | 3905 Å              | 4.24                | +0.41             | 0.13         | 0.19        |
| Ca  | 1   | 9                   | 2.90                | +0.27             | 0.02         | 0.06        |
| Sc  | 2   | 6                   | $-0.20$             | +0.43             | 0.04         | 0.12        |
| Ti  | 1   | 5                   | 1.54                | +0.32             | 0.02         | 0.11        |
| Ti  | 2   | 13                  | 1.53                | +0.31             | 0.01         | 0.11        |
| V   | 1   | 4379 Å              | $<-1.00$            | $<-0.42$          | ...          | ...         |
| Cr  | 1   | 6                   | 1.52                | $<-0.44$          | 0.04         | 0.11        |
| Mn  | 1   | 2                   | 0.59                | $<-1.22$          | 0.09         | 0.14        |
| Fe  | 1   | 107                 | 3.77                | $<-3.68$          | 0.01         | 0.11        |
| Fe  | 2   | 7                   | 3.77                | $<-3.68$          | 0.03         | 0.11        |
| Co  | 1   | 6                   | 1.72                | +0.48             | 0.02         | 0.10        |
| Ni  | 1   | 5                   | 2.59                | +0.04             | 0.03         | 0.11        |
| Zn  | 1   | 4722 Å              | $<-1.29$            | $<-0.37$          | ...          | ...         |
| Sr  | 2   | 2                   | $<-1.02$            | $<-0.26$          | 0.09         | 0.15        |
| Y   | 2   | 3774 Å              | $<-1.81$            | $<-0.34$          | 0.13         | 0.17        |
| Zr  | 2   | 4149 Å              | $<-1.31$            | $<-0.22$          | ...          | ...         |
| Ba  | 2   | 2                   | $<-2.10$            | $<-0.59$          | 0.09         | 0.15        |
| Eu  | 2   | 3819 Å              | $<-3.03$            | $<-0.13$          | ...          | ...         |
| Pb  | 1   | 4057 Å              | $<-0.27$            | $<-1.41$          | ...          | ...         |

Notes:

$^a$ “Syn” indicates the use of spectrum synthesis. In the case that the number of lines used is one, as well as for upper limits, the wavelength of the line is given.

$^b$ Solar abundances were taken from Asplund et al. (2005). For iron $[\text{Fe/H}]$ is given.

---

5 IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.
using the spectrum synthesis approach. The derived abundance, 
Frebel et al. 2007). The $\alpha$-elements Mg, Si, Ca, and Ti are 
enhanced by $\sim 0.3$–0.5 dex with respect to Fe, as found in most 
metal-poor stars of the halo.

No excess of neutron-capture elements is found. Note that the 
measurements (or upper limits) for Sr, Zr, and Y are all sub-
solar. The Ba abundance ([Ba/Fe] = –0.59) is derived from 
the Ba $\text{II}$ resonance lines at 4554 Å and 4934 Å, including the 
effect of hyperfine splitting using the line list of McWilliam 
(1998) (assuming the isotope ratios of the $r$-process component 
of solar-system material). We only have an upper limit available 
for Eu, which is quite low as well ([Eu/Fe] < +0.13).

Random errors arising from the measurements of atomic lines 
are estimated to be $\sigma N^{-1/2}$, where $\sigma$ is the standard deviation of 
the individual derived abundances and $N$ is the number of 
lines used in the analysis. When the number of lines is smaller 
than five, we use the $\sigma$ of Fe $\text{I}$ instead. For molecular features, 
abundance variations from different features and continuum 
placement are taken into account to estimate random errors. In 
order to examine how stellar parameters affect abundances, we 
performed an abundance analysis after changing each stellar 
parameter by its uncertainty ($\Delta T_{\text{eff}} = 100$ K, $\Delta \log g = 0.3$ dex, $\Delta v_t = 0.3$ km s$^{-1}$). The root-sum-square of all the 
error sources is adopted as the total error of log $\epsilon(X)$.

4. DISCUSSION

From its overabundance of C ([C/Fe] > +1) and low Ba 
abundance ([Ba/Fe] < +0.5), BD$+44^\circ$493 is classified as a 
“CEMP-no” star, according to the nomenclature of Beers & 
Christlieb (2005). The abundance pattern of BD$+44^\circ$493 is very 
similar to that of HE 1300+0157, which is a CEMP-no subgiant 
with [Fe/H] = −3.9 (Frebel et al. 2007), whose [C/Fe] and 
[O/Fe] are comparable with those of BD$+44^\circ$493. The bright-
ness of BD$+44^\circ$493 enables us to measure the abundances of N, 
Sr, Y, and Ba, which were not determined for HE 1300+0157. 
We can also set stronger upper limits for Zn, Pb, and so on. 
We now discuss the origin of the C excess in BD$+44^\circ$493 and 
implications of the very low Be upper limit.

4.1. The Origin of the Carbon Excess

Since BD$+44^\circ$493 is an unevolved subgiant, self-enrichment 
of carbon by dredge-up of the products of the helium core flash 
is clearly excluded.

For many CEMP stars, mass transfer from a companion 
AGB star is proposed as one of the causes of C enrichment, 
and such a model has had great success in explaining CEMP-
s objects. However, the observations of BD$+44^\circ$493 do not 
support this scenario. The first problem, which is common 
for CEMP-no objects, is that the neutron-capture elements that 
are expected to be enhanced by an AGB companion are not 
overabundant in this star. Cohen et al. (2006) suggested that 
the normal Ba abundances of CEMP-no stars can be explained 
by the high neutron-to-seed nuclei ratio in the $s$-process that 
occurred in the AGB companion, resulting in little Ba excess 
but a large Pb enhancement. Under this hypothesis, the Pb 
abundance predicted by them is log $\epsilon$(Pb) = 1.5 at [Fe/H] = 
−3.5, which is much higher than our measured Pb upper limit 
for BD$+44^\circ$493 (log $\epsilon$(Pb) < −0.27). Komiyama et al. (2007) 
discussed the possibility that a relatively high-mass companion

\[ A(\text{Be}) < -2.18 \]

\[ \Delta \log g = 0.3 \text{ dex}, \Delta v_t = 0.3 \text{ km s}^{-1} \]

\[ \Delta T_{\text{eff}} = 100 \text{ K}, \Delta \log g = 0.3 \text{ dex} \]

\[ \Delta v_t = 0.3 \text{ km s}^{-1} \]

\[ \sigma N^{-1/2} \]

\[ \sigma \text{ of Fe } \text{I} \]

\[ \text{root-sum-square of all the error sources} \]

\[ \text{total error of log } \epsilon(X) \]

\[ \text{CEMP-no} \]

\[ \text{CEMP-no star} \]

\[ \text{normal Ba abundances of CEMP-no stars} \]

\[ \text{high neutron-to-seed nuclei ratio} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{overabundant in this star} \]

\[ \text{expected to be enhanced} \]

\[ \text{mass transfer} \]

\[ \text{normal Ba abundances of CEMP-no stars} \]

\[ \text{high neutron-to-seed nuclei ratio} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]

\[ \text{mass transfer} \]

\[ \text{dredge-up of the products of the helium core flash} \]

\[ \text{CEMP-no objects} \]

\[ \text{AGB companion} \]
AGB star \((M > 3.5 \, M_\odot)\) produces little \(s\)-process elements due to inefficient radiative \(^{13}\text{C}\) burning. Since a high-mass AGB star converts \(\text{C}\) into \(\text{N}\) via hot-bottom burning, the low \(\text{N}\) abundance of \(\text{BD+44}\) \(^{19}\text{~493}\) allows only a narrow range of mass. Another constraint is the low \(\text{C}/\text{O}\) ratio \((\text{C}/\text{O} < 1)\) found for \(\text{BD+44}\) \(^{19}\text{~493}\), which cannot be explained by the AGB nucleosynthesis scenario \((\text{Nishimura et al. 2009})\). Moreover, radial velocity monitoring from 1984 to 1997 did not find any characteristic binarity signature \((\text{Carney et al. 2003})\). The radial velocities measured by our data \((\sim 150 \, \text{km} \, \text{s}^{-1} \, \text{both} \, \text{2008 in} \, \text{October} \, \text{and} \, \text{November})\) agree with those in \text{Carney et al. (2003)}). Our conclusion is that the binary mass-transfer scenario is excluded as the origin of the \(\text{C}\) excess in \(\text{BD+44}\) \(^{19}\text{~493}\).

Another scenario is that the \(\text{C}\) enhancement occurs prior to the formation of \((\text{at least some})\) CEMP stars due to the predicted mass loss from rapidly rotating massive stars with very low metallicity. \text{Meynet et al. (2006)} explored models of rapidly rotating \(60 \, M_\odot\) stars with metallicities \(Z = 10^{-8}\) and \(10^{-7}\), and found that stronger internal mixing increases the total metallicity at the stellar surface significantly, leading to a large mass loss. The ejecta are highly enriched in \(\text{N}\) elements, which are products of the \(\alpha\) reactions and the CNO cycle. In particular, the \(\text{N}\) excess is predicted to be quite large due to operation of the CNO cycle in the H-burning shell. However, the low observed \(\text{N}\) abundance of \(\text{BD+44}\) \(^{19}\text{~493}\) is not explained by this scenario.

A remaining possibility is element production by the so-called faint supernovae associated with the first generations of stars, which experience extensive matter mixing and fallback during their explosions \((\text{Umeda & Nomoto 2003, 2005; Tominaga et al. 2007b})\). Such a process is realized in relativistic jet-induced supernovae with low-energy deposition rates \((\text{Tominaga et al. 2007a})\). The small amount of ejected \(^{56}\text{Ni}\) results in the faintness of the supernova, and high \(\text{[C/Fe]}\) and \(\text{[O/Fe]}\) ratios are predicted in the ejected material. This model can reproduce the observed abundance pattern of the CEMP star HE 1300+0157 \((\text{N. Tominaga et al. 2009, in preparation})\), which is very similar to that of \(\text{BD+44}\) \(^{19}\text{~493}\). The abundances of elements that are newly determined for \(\text{BD+44}\) \(^{19}\text{~493}\) (e.g., \(\text{N}\)) are also compatible with this model. The low \(\text{[N/C]}\) in \(\text{BD+44}\) \(^{19}\text{~493}\) indicates that the mixing between the \(\text{He}\) convective shell and \(\text{H-rich envelope during pre-supernova evolution is not significant} \) \((\text{Iwamoto et al. 2005})\). Thus, a faint supernova is the most promising candidate for the origin of the \(\text{C}\) excess in \(\text{BD+44}\) \(^{19}\text{~493}\).

### 4.2. Implications of the Low Beryllium Abundance

Figure 4 shows the Be abundance upper limit for \(\text{BD+44}\) \(^{19}\text{~493}\) in the \(\text{A(Be)}\) versus \([\text{Fe/H}]\) plane, along with the results of previous studies. Our result is consistent with a linear trend with this model. The low \(\text{[N/C]}\) converts \(\text{C}\) into \(\text{N}\) via hot-bottom burning, the low \(\text{N}\) abundance of \(\text{BD+44}\) \(^{19}\text{~493}\) is not significant \((\text{Iwamoto et al. 2005})\). Thus, a faint supernova is the most promising candidate for the origin of the \(\text{C}\) excess in \(\text{BD+44}\) \(^{19}\text{~493}\).

Our analysis is the first attempt to measure a Be abundance for a CEMP star. Since Be is produced via the spallation of CNO nuclei, their abundances, especially \(\text{O}\) abundances, have been expected to correlate with Be abundances. However, our low Be upper limit shows that the high \(\text{C}\) and \(\text{O}\) abundances in \(\text{BD+44}\) \(^{19}\text{~493}\) are irrelevant to its Be abundance. Moreover, the origin of the \(\text{C}\) excess in CEMP-no stars like \(\text{BD+44}\) \(^{19}\text{~493}\), which we have argued is most likely due to faint supernovae, is unlikely to be a significant source of high-energy CNO nuclei that participate in the primary process associated with Be production.

W.A. is supported by a Grant-in-Aid for Science Research from JSPS (grant 18104003). T.C.B. acknowledges partial funding of this work from grants PHY 02-16783 and PHY 08-22648: Physics Frontier Center/Joint Institute for Nuclear Astrophysics (JINA), awarded by the U.S. National Science Foundation.

## REFERENCES

Alonso, A., Arribas, S., & Martínez-Roger, C. 1999, A&A, 140, 261

Anthony-Twarog, B. J., & Twarog, B. A. 1994, AJ, 107, 1577

Aoki, W., Beers, T. C., Christlieb, N., Norris, J. E., Ryan, S. G., & Tsangarides, S. 2007, ApJ, 655, 492

Aoki, W., Ryan, S. G., Norris, J. E., Beers, T. C., Ando, H., & Tsangarides, S. 2002, ApJ, 580, 1149

Aoki, W., et al. 2006, ApJ, 639, 897

Asplund, M. 2005, ARA&A, 43, 481

Asplund, M., Grevesse, N., & Sauval, A. J. 2005, in ASP Conf. Ser. 336, Cosmic Abundances as Records of Stellar Evolution and Nucleosynthesis, ed. T. G. Barnes III & F. N. Bash (San Francisco, CA: ASP), 25

Beers, T. C., & Christlieb, N. 2005, ARA&A, 43, 531

Boesgaard, A. M., Deliyannis, C. P., King, J. R., Ryan, S. G., Vogt, S. S., & Beers, T. C. 1999, AJ, 117, 1549

Boesgaard, A. M., & Novicki, M. C. 2006, ApJ, 641, 1122

Carney, B. W., Latham, D. W., Stefaniak, R. P., Laird, J. B., & Morse, J. A. 2003, AJ, 125, 293

Castelli, F., & Kurucz, R. L. 2003, in IAU Symp. 210, Modelling of Stellar Atmospheres, ed. N. Piskunov, W. W. Weiss, & D. F. Gray (San Francisco, CA: ASP), 20P

Cohen, J. G., et al. 2006, AJ, 132, 137

Frebel, A., Christlieb, N., Norris, J. E., Aoki, W., & Asplund, M. 2006, ApJ, 638, L17
