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Abundances of α-elements in the ultra-metal-poor giants CS29498-043 and CS22949-037

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Abstract. We discuss abundances of α-elements in the ultra-metal-poor giants CS29498-043 and CS22949-037. The abundance of oxygen has been derived from measurements of the oxygen triplet at 7771–5 Å in high resolution and high S/N ratio near-IR spectra obtained with KeckI/HIRES. A detailed non-LTE analysis of Fe lines has been carried to provide more reliable stellar parameters. A non-LTE analysis of O and Mg allowed us to demonstrate the failure of standard 1D atmospheric models to describe the physical conditions in the line-forming regions of our targets.

Key words. Galactic Chemical Evolution–Halo stars–Population III

1. Introduction

The most metal-poor stars in our Galaxy contain the material ejected from the first generation supernova. Oxygen is a key element in this scheme and may help to distinguish between different enrichment scenarios.

The current situation with abundance trends of various α-elements is very confusing. Observations of Stephens & Boesgaard (2002) clearly demonstrate that the [α/Fe] ratios for Ca, Si, Ti and Mg do not a show a *plateau* at [Fe/H] < -1. The results obtained by Idiart & Thevenin (1999) and Stephens & Boesgaard (2002) cannot be called "consistent" with the analysis presented recently by Carretta et al. (2002). The situation with oxygen is far from being resolved (Israelian, García López & Rebolo 1998; Israelian et al. 2001; Nissen et al. 2002; Takeda 2003), while a new debate over the sulphur abundance in metal-poor stars has already emerged (Israelian & Rebolo 2001; Takada-Hidai et al. 2002; Nissen et al. 2003). It is possible that the volatile element S shows a monotonically increasing trend similar to that observed for oxygen (see Fig. 1). These and many other studies clearly show that [α/Fe] $>$ 0 for the great majority of metal-poor stars in the Galaxy. However, it is hard to speak of any "trend" when the abundance ratios of different authors disagree by more than 0.3–0.4 dex. There are many aspects to this serious problem, and we shall not discuss it further here. Consideration of very metal-poor stars with [Fe/H] < -3 gives rise to even more enigmas into this field.

McWilliam et al. (1995) were the first to carry out a detailed spectroscopic analysis of CS22949-037 and to confirm that the star is very metal-poor with α-element excess. Furthermore, Depagne et al. (2002) found a

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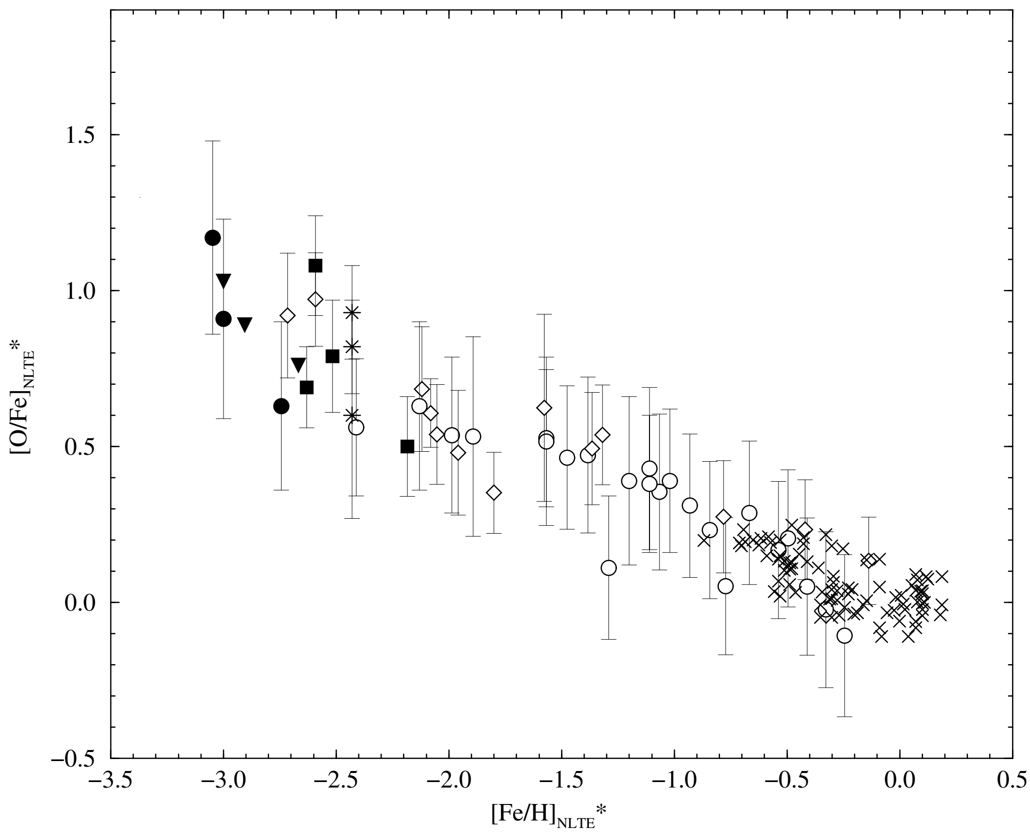

Fig. 1. Oxygen abundances in unevolved metal-poor stars (from Israelian et al. 2001).

large excess of oxygen ([O/Fe] = +2.0) and sodium ([Na/Fe] = +2.1) in this star. Zero-heavy-element supernovae models with fall-back have been invoked in order to interpret the elemental abundance ratios in this star. More recently, Aoki et al. (2002) have discovered another ultra-metal-poor giant, CS29498-043, with a very high abundance excess of [Mg/Fe] = 1.81. Both CS22949-037 and CS29498-043 exhibit a large overabundance of N and C. It is possible that the surface of these stars has been polluted by enriched material, either dredged from the stars' inner core or transferred from a companion star. The abundances of α-elements in these stars could be used to discriminate in favour one of these hypotheses or to confirm a pristine origin. The detailed comparison of elemental abundances may provide important constraints on the properties of the first supernova progenitors.

2. Observations

The observations of the two giants were performed in 2002 October at the Keck I using the high-resolution spectrograph HIRES and the TEK 2048 × 2048 pixel CCD. A 1.1 arcsec entrance slit provided a resolving power ~60 000. A red wavelength setting was used to observe oxygen triplet lines at 7771–5 Å. The average signal-to-noise ratio near the triplet was close to 100.

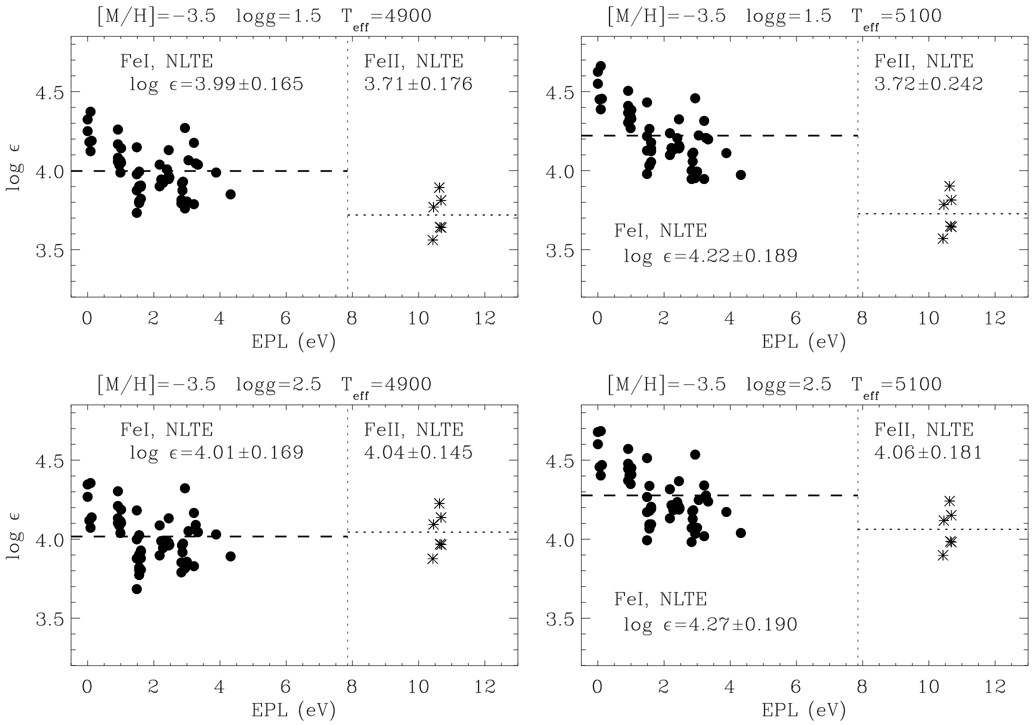

Fig. 2. CS22949-037: non-LTE analysis of Fe for a small atmospheric grid.

3. Analysis

The spectra of these ultra-metal-poor giants were analysed using the atmospheric models of Kurucz (1992). Next, the equivalent widths of 60 (CS29498-043) and 26 (CS22949-037) Fe lines were taken from the articles of Aoki et al. (2002) and Depagne et al. (2002), respectively, in order to derive the stellar parameters. Non-LTE analysis of Fe was carried out with the code NATAJA (Shchukina & Trujillo Bueno 2001), and the atmospheric parameters were derived using the same method as in Israelian et al. (2001). NLTE computations of the oxygen and magnesium atoms were carried out using the updated 23 level (oxygen) and 24 level (magnesium) model atoms described by Shchukina (1987) and Carlson, Rutten & Shchukina (1992), respectively.

Figures 2 and 3 show our computations for a small grid of the atmospheric models for CS22949-037 and CS29498-043. The final stellar parameters are $T_{\rm eff}$=4900 K, $\log g$ = 2.5 and [Fe/H]= −3.5 for CS22949-037 and $T_{\rm eff}$ = 4300 K, $\log g$ = 1.5 and [Fe/H] = −3.5 for CS29498-043. Thus, the gravities obtained by us are about 1 dex larger than those reported by Aoki et al. (2002) and Depagne et al. (2002).

We have detected all three lines of the oxygen triplet in CS22949-037 and CS29498-043 (Fig. 4). The NLTE corrections ($\Delta\epsilon = \epsilon(\mathrm{NLTE}) - \epsilon(\mathrm{LTE})$) to the oxygen abundance derived from the triplet were 0.18 (CS29498-043) and 0.22 (CS22949-037). Our NLTE oxygen abundances yield very high ratios: [O/Fe] = 3.2 and [O/Fe] = 3.12 in CS22949-037 and CS29498-043, respectively. Assuming for CS22949-037 our stellar parameters and the equivalent width measurement by Depagne et al. (2002) for the forbidden line, we find [O/Fe] = 2. This large difference cannot be explained by the NLTE abundance correction for the triplet and/or by a noise/telluric correction for the forbidden line. In fact, one needs a forbid-

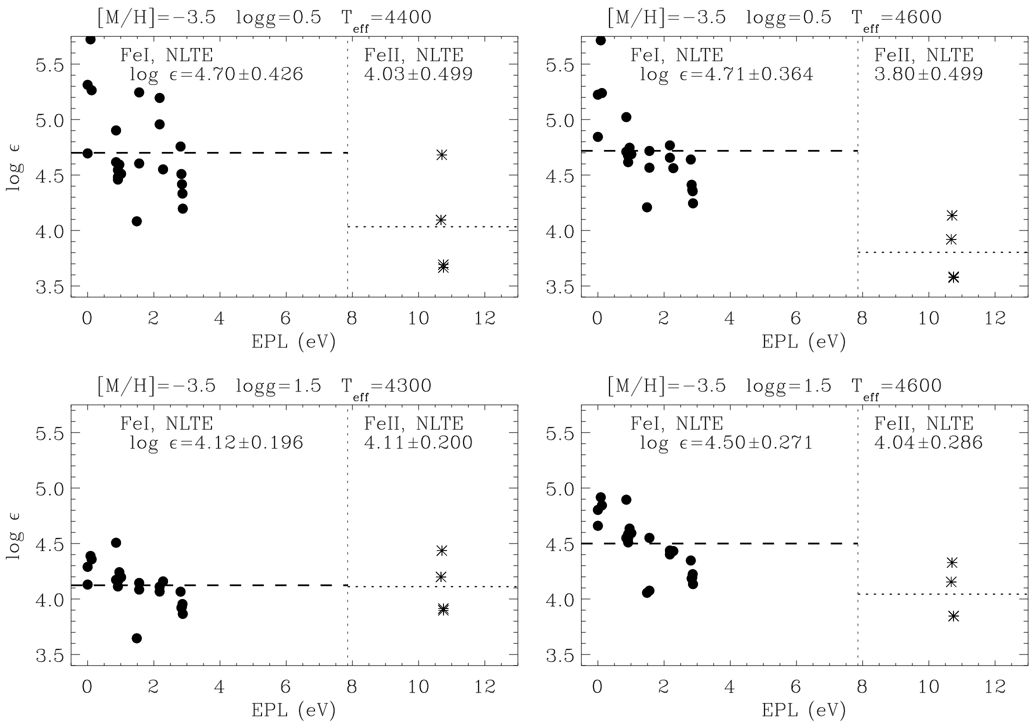

Fig. 3. CS29498-043: non-LTE analysis of Fe for a small atmospheric grid.

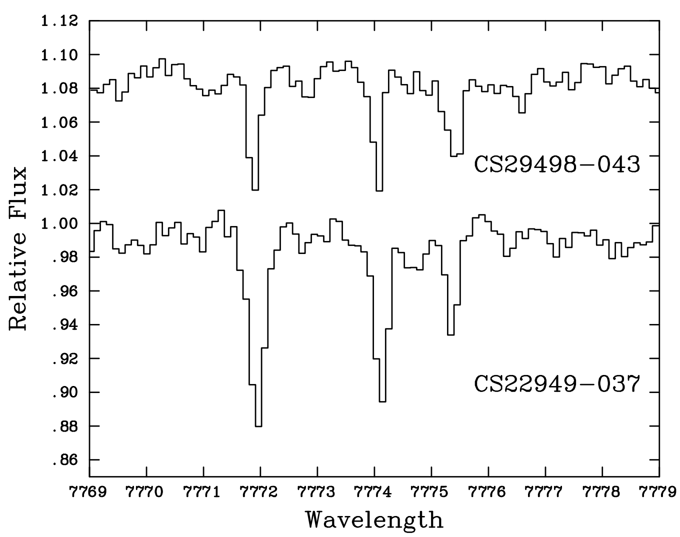

Fig. 4. The oxygen triplet in two ultra-metal-poor giants.

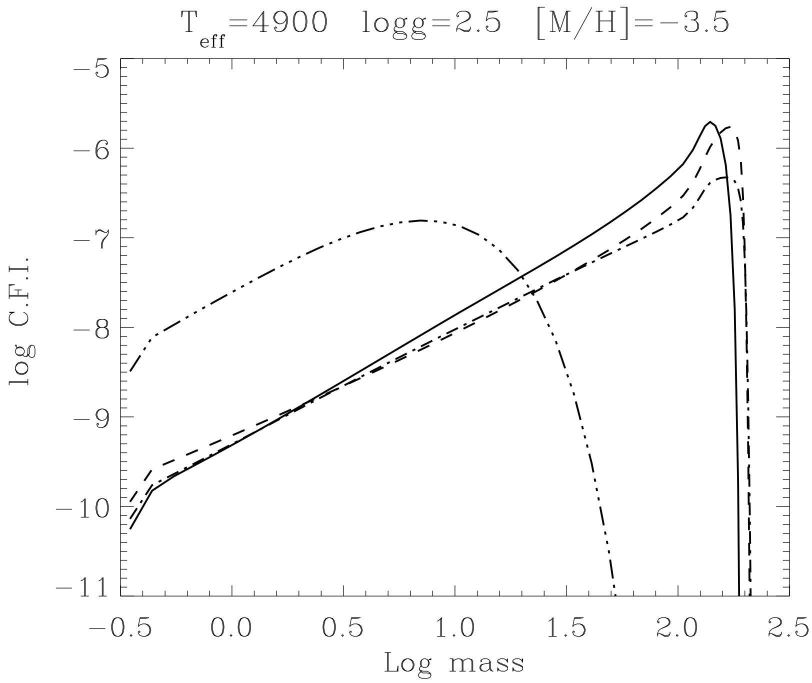

Fig. 5. The intensity contribution function for the oxygen 6300 Å (dashed), 7771–5 Å (solid), MgI 5183 Å (dashed three dots) and MgI 4571 Å (dashed–dotted) lines in CS22949-037.

den line with EW ~ 50 mÅ to provide [O/Fe] = 3.2, which is clearly ruled out by observations. While the forbidden line was not measured in CS29498-043, our computations for this line predict [O/Fe] = 1.1 if the triplet provides [O/Fe] = 3.12.

Non-LTE abundance analysis of Mg reveals an interesting behaviour. The abundance of Mg in CS29498-043 was derived from three lines: 4571, 5172 and 5183 Å using the equivalent width measurements from Aoki et al. (2002). These lines provide very different abundances, just like in case of the oxygen atom. In CS29498-043 we derived from MgI 4571 Å line [Mg/Fe] = 1.626 with small non-LTE correction of ~0.18 dex while MgI lines at 5172 and 5183 Å provided a mean [Mg/Fe] = 1.08. The difference between the 4571 and 5172 + 5183 Å is larger in the non-LTE than in the LTE case. The mean abundance from the three lines is 1.26, which of course makes no sense given the huge discrepancy between the 4571 and 5172 + 5183 Å lines. In this situation one cannot state what the real Mg abundance is in this star. As for CS22949-037, there are six MgI lines available in the article of Deapgne et al. (2002). From the five lines listed in Depagne et al. (2002) we obtained [Mg/Fe] = 1.016, while the strongest 4571 Å line again gives a much larger abundance of [Mg/Fe] = 1.81.

Abundances of other α-elements were derived using the new set of stellar parameters obtained from a non-LTE analysis of Fe lines and the equivalent widths provided in the papers of Aoki et al. (2002) and Depagne et al. (2002). For CS29498-043 we obtained [Ca/Fe] = 0.13, [Si/Fe] = 0.63 and [Ti/Fe] = 0.2, and for CS22949-037 we obtained [Si/Fe]=0.16, [Ca/Fe]= −0.01 and [Ti/Fe] = 0.15. Apparently the abundances of Ca and Ti are not enhanced with respect to Fe.

4. Discussion

Our analysis suggests that the gravities of metal-poor giants derived from the LTE Fe analysis are underestimated because non-LTE effects are neglected. The xygen abundance in CS22949-037 derived from the triplet and the forbidden line differ by more than 1 dex. This difference cannot be explained by non-LTE effects or uncertainties in the stellar parameters. Other mechanisms must be invoked in order to explain this puzzle. It is interesting that the oxygen forbidden line at 6300 Å and the near-IR triplet are formed in the same layers deep in the atmosphere (Fig 5). However, our figure also shows that the MgI line at 4571 Å is formed in the deep layers of the atmosphere. This suggests that one needs a different atmospheric structure in order to achieve consistency for O and Mg. It is clear that standard 1D models are unreliable for ultra-metal-poor giants.

The fact that the atmospheres of these stars do not contain large amounts of Ca and Ti suggests that supernovae with fallbacks (which form massive black holes) explain the observed abundance patterns. It has been suggested that the bulk of light r-nuclei (with A < 130) appear to have different sources from those for heavy r-nuclei (Wasserburg, Busso & Gallino 1996). The meteoritic data require at least two distinct types of SN r-process events: the high-frequency events, *H*, producing heavy nuclei with A > 130, including ^{182}Hf, and the low-frequency *L* events producing light nuclei with A > 130, including ^{129}I. The r-process production in the SN environments associated with the *H* and *L* events has been discussed in some detail by Qian, Vogel & Wasserburg (1998). The abundance analysis of CS22949-037 and CS29498-043 may directly test the speculation by Qian et al. (1998) that *H* events are associated with supernovae producing black holes, whereas *L* events are associated with supernovae producing neutron stars. However, first of all we need to be sure that the atmospheric models employed in this and similar studies provide consistent abundances.

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