NLTE determination of the Calcium abundance in Extremely Metal-Poor stars

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I- Introduction

In the frame of the ESO Large Program "First Stars" 52 Extremely Metal-Poor Stars "EMP stars" have been observed with the high resolution spectrograph UVES at the VLT.
In this sample 9 turnoff stars and 22 giants have [Fe/H]<-3.
These stars are the witnesses of the early Galaxy. The metals contained in their atmosphere have been formed by the first supernovae.
The aim of this work was to find the chemical composition of the matter in the early Galaxy, to deduce the characteristics of the first supernovae and to constrain the nucleosynthetic processes. The analysis of the stars has been made with the LTE hypothesis and the main results of this analysis have been published in Cayrel et al. (2004) and Bonifacio et al. (2009).
However we have shown that the derivation of accurate element abundances requires that NLTE effects be taken into account (e.g. Andrievsky et al. , 2010, 2011, Spite et al. 2011).
We present here an attempt to determine the Ca abundance from NLTE computations.

II- Atmospheric Parameters

The adopted values of the atmospheric parameters of the stars were discussed in detail in Cayrel et al. (2004) and Bonifacio et al. (2007).
The temperatures were deduced from the color indices, and also, for the turnoff stars, from the profile of the Hα wings.
The gravity was derived from the ionization equilibrium of iron and titanium (under the LTE hypothesis).

III- NLTE Abundance of Calcium

In our sample of very metal poor stars about 15 Ca I lines and 2 Ca II lines (the 3933Å and 8662Å lines) can be measured.
The NLTE profiles of these lines were computed using a modified version of the MULTI code (Carlsson et al., 1986) described by Korotin et al. (1999).

Our model atom contains 70 levels of Ca I , 38 levels of Ca II, and the ground level of Ca III. The fine structure was taken into account for the levels 3d2D and 4p2P* of Ca II. The ionization cross-sections come from TOPBASE. Collisional rates between the ground level and the ten lower levels of Ca I are based on detailed results available from the R-matrix calculations of Samson & Berrington (2001). For Ca II collisional rates have been found in Meléndez et al. (2007).
Collisions with hydrogen atoms were taken into consideration using the Steenbock & Holweger (1984) formula with a correction coefficient obtained by fitting the synthetic and the observed profiles of the Ca lines the Sun and in some reference stars (Procyon, HD122563 and ν Indi). This correction factor was found to be 0.1, in good agreement with Mashonkina et al. (2007).

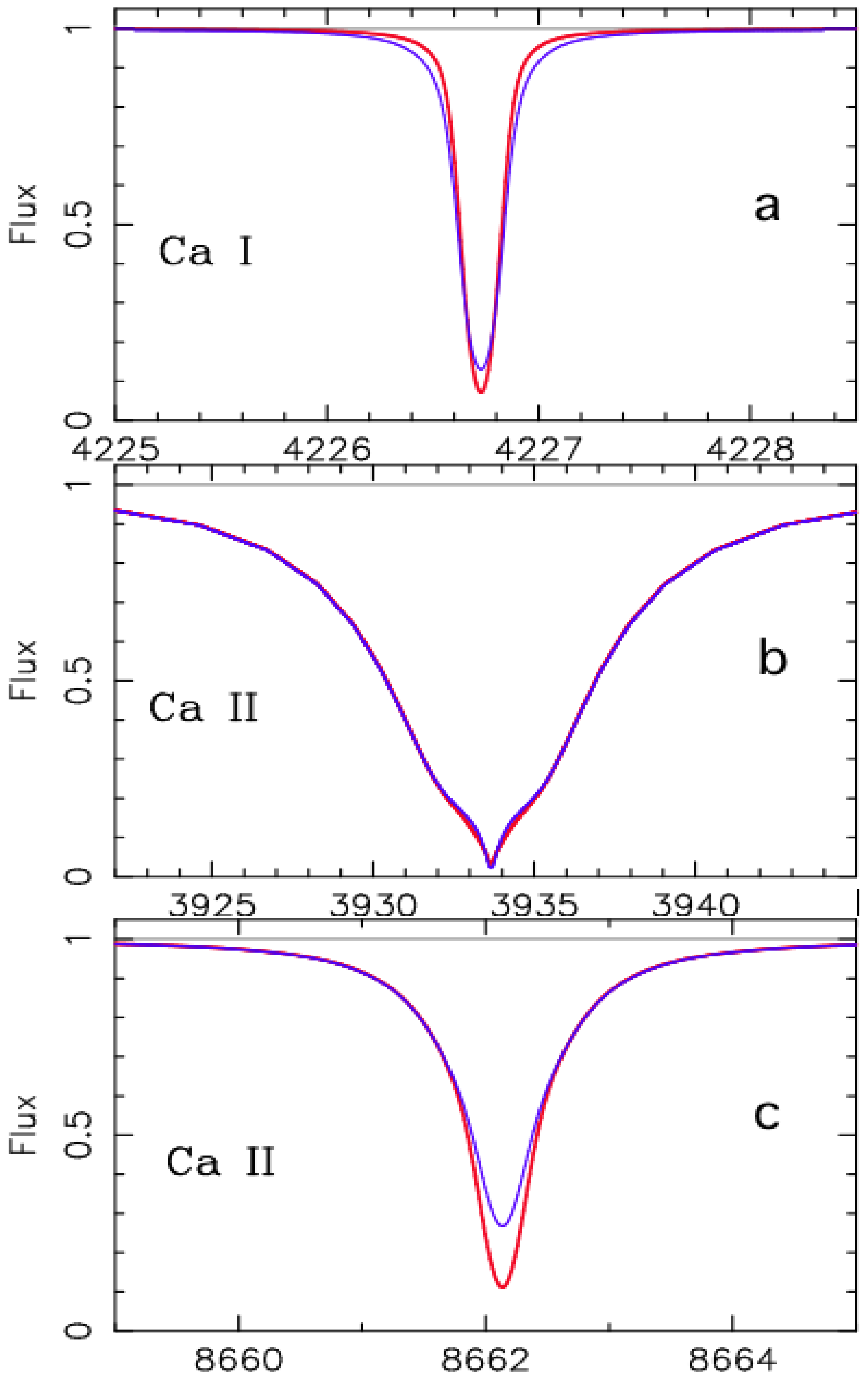

Fig.1 Profiles of three Ca lines computed for a giant star with [Fe/H]≈-3 with **LTE (blue)** and **NLTE (red)** hypotheses.
a) The profile of the resonance line of Ca I is affected by NLTE effects. The NLTE profile is narrower even in the wings.
b) The K Ca II line is practically not affected by NLTE.
c) The NLTE correction is important for the strong IR CaII line, but the wings are not affected and a reliable calcium abundance can be deduced from these wings.

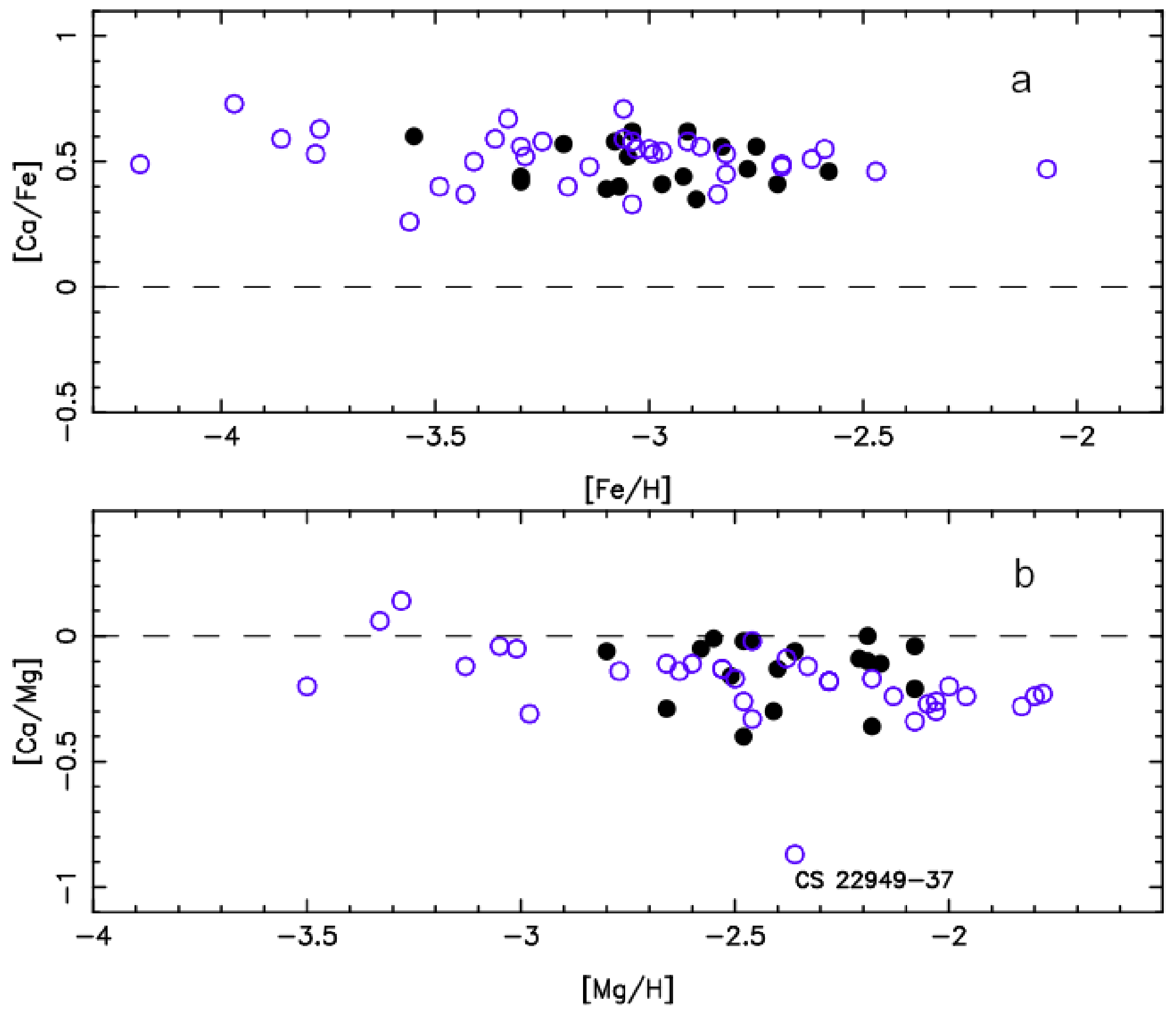

Fig.2 a) [Ca/Fe] vs. [Fe/H] and,
b) [Ca/Mg] vs. [Mg/H] at very low metallicity.
Black dots, dwarfs, open symbols, giants
The calcium abundance of CS22949-37 is normal but it is Mg-rich and also C-rich, N-rich and O-rich (Depagne et al. 2002).

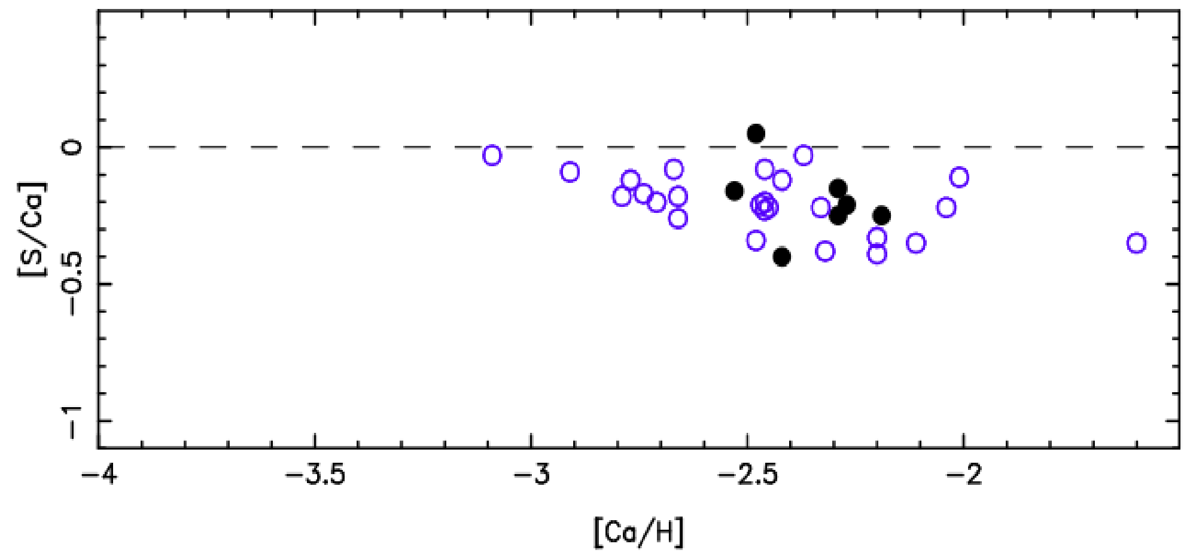

Fig.3 [S/Ca] vs. [Ca/H]. Symbols like in Fig.2

At low metallicity the influence of the NLTE is very complex and depends on the line considered. In **Fig. 1** we present the LTE and NLTE profiles of the 4227Å line (Ca I) and the 3934Å (Ca II K) and 8662Å lines of Ca II for a giant with [Fe/H] ~ –3.

IV-Results and Conclusion

The calcium abundance has been derived from about 15 CaI lines. In **Fig.2a and 2b** we present the variation of [Ca/Fe] vs. [Fe/H] and of [Ca/Mg] vs. [Mg/H] for our sample of extremely metal-poor stars. (NLTE Mg abundance from Andrievsky et al., 2010)

-In both cases there is a **very good agreement between dwarfs and giants**.

-In Fig 2b it seems that there is a slight increase of [Ca/Mg] at very low metallicity but this trend is not significant (owing to the larger error on [Ca/Fe] and [Ca/Mg] at very low metallicity.)

-Unexpectedly, the **scatter of [Ca/Mg] is a little larger than the scatter of [Ca/Fe]** although Ca and Mg are "α elements" supposed to be formed in similar processes (unlike Fe).

-In the early Galaxy:
[Ca/Fe] ≈ +0.5 ±0.1 dex
[Ca/Mg] ≈ –0.15 ±0.1 dex

In **Fig 3** we present [S/Ca] vs. [Ca/H].
S is also an "α element", its NLTE abundance has been taken from Spite et al. (2011).

The correlation between the sulfur and the calcium abundance is very good, **the spread of [S/Ca] is small, smaller than the spread of [S/Mg]** (see Spite et al. 2011).

This suggests that the production processes of S and Ca are more closely linked than the productions of S and Mg.

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