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Non-solar Abundance Ratio Effects in Lick Spectral Indices of Individual Stars

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Abstract

We aim at the evaluation of the influence of non-solar scaled abundance ratios on absorption features measured by Lick indices both from new observations and theoretical point of view. We will illustrate our approach to the problem via the analysis of a selected sample of G-type stars characterized by recent and well-determined chemical composition from high-resolution spectra. Synthetic Lick indices computed with scaled solar abundances and with the proper chemical mixture are presented and compared with prediction both from theoretical computations and empirical fitting functions.

1.1 Introduction

Information on abundance patterns of α-elements is looked for in the Galaxy and in external galaxies to get insight into possible formation and chemical evolution scenarios and to check theoretical model predictions. Particular interest is devoted to establish the trend of α-element abundance with respect to iron, as it will shed light on the role of different sources of chemical enrichment in various epochs of the Galaxy lifetime. Ideally high spectral resolution observations are best suited for deriving accurate and detailed abundance determinations, but are available only for a very limited number of stars in external galaxies so that, in general, estimates of chemical abundance are derived by using different tools. A widely applied one is the analysis of prominent features in low/medium resolution spectra in the form of spectral features, as defined for instance by the UCO/Lick researchers (Worthey et al. 1994, and references therein). We took advantage of the ability of Lick/IDS spectral indices of carrying information about stellar chemical composition for selecting candidate α-enhanced G-type star. We present here our approach which is based on the comparison of synthetic and observed indices in the Lick system.

1.2 The Grids of Synthetic Indices

We synthesized the twenty-one Lick/IDS optical absorption features (among them 19 particularly relevant for G type stars), defined in Worthey et al. (1994), following the prescriptions given in Worthey web site.

These new synthetic Lick indices were computed from a set of 220 spectra synthesized

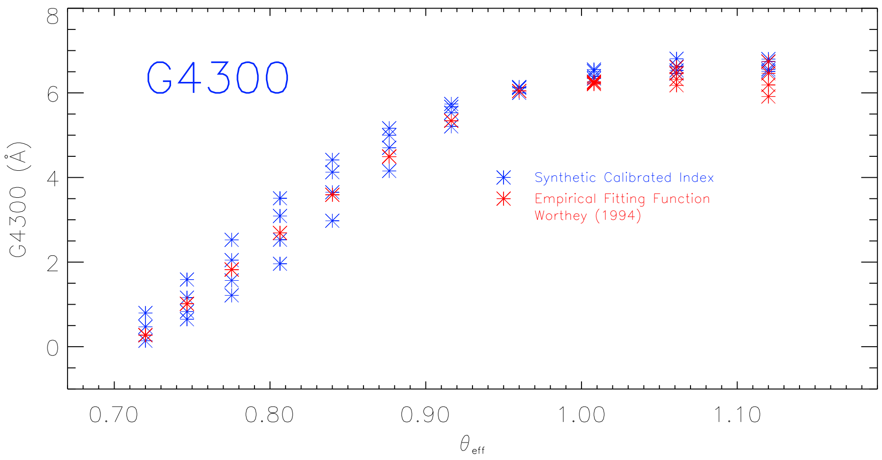

Fig. 1.1. The SSA synthetic calibrated values of the G4300 index (blue) and the ones computed by using the empirical fitting function (red) by Worthey et al. (1994) are plotted against inverse effective temperature. Synthetic values are given at each θ_{eff} for log g = 2.0, 3.0, 4.0, 5.0 dex, and [M/H] = 0.0 dex

with Spectrum 2.48 code* (Gray & Corbally 1994, and Gray, 2001) with the following characteristics: $\Delta\lambda = 0.05$ Å, rotational velocity of 0 km s^{-1} and microturbulent velocity $\xi = 2$ km s^{-1} in the wavelength range 4000 – 6500 Å. The starting stellar atmosphere models are from the completely new collection by Castelli & Kurucz (2003) computed with updated Opacity Distribution Functions. The models are selected in the following ranges of parameters:

- Effective temperature from 4500 to 7000 K at a step of 250 K;
- Surface gravity from 2.0 to 5.0 dex at a step of 1.0 dex.

Two different assumptions on chemical composition lead to two different grids of models and synthetic spectra. The first one (SSA grid) refers to Solar Scaled Abundances at overall metallicities [M/H]=-1.0, -0.5, 0.0. The second one (NSSA grid) refers to Non-Solar Scaled Abundances with enhanced α over iron ratios, i.e. ([Fe/H]=-1.0, [α/Fe]=+0.4) and ([Fe/H] = –0.5, [α/Fe]=+0.4). The α elements considered here are O, Ne, Mg, Si, S, Ar, Ca, and Ti.

It is worth stressing that the problem of non solar abundance ratios is, for the first time, treated in a fully consistent way by adopting new opacity distribution functions and models ad-hoc computed to take into account the α-element enhancement.

After degradation of the synthetic spectra to the resolution of Lick/IDS original ones, the computed indices were measured and transformed into the standard system by using 32 stars present in the catalogs by Worthey et al. (1994) and by Thevenin (1998).

1.3 Comparison of Theoretical Grid Predictions with Observations

A check of the validity of our calibrated grids can be appreciate by looking at Fig. 1.1 where the case of the G4300 index is illustrated. The synthetic calibrated index

* http://www.phys.appstate.edu/spectrum/spectrum.html

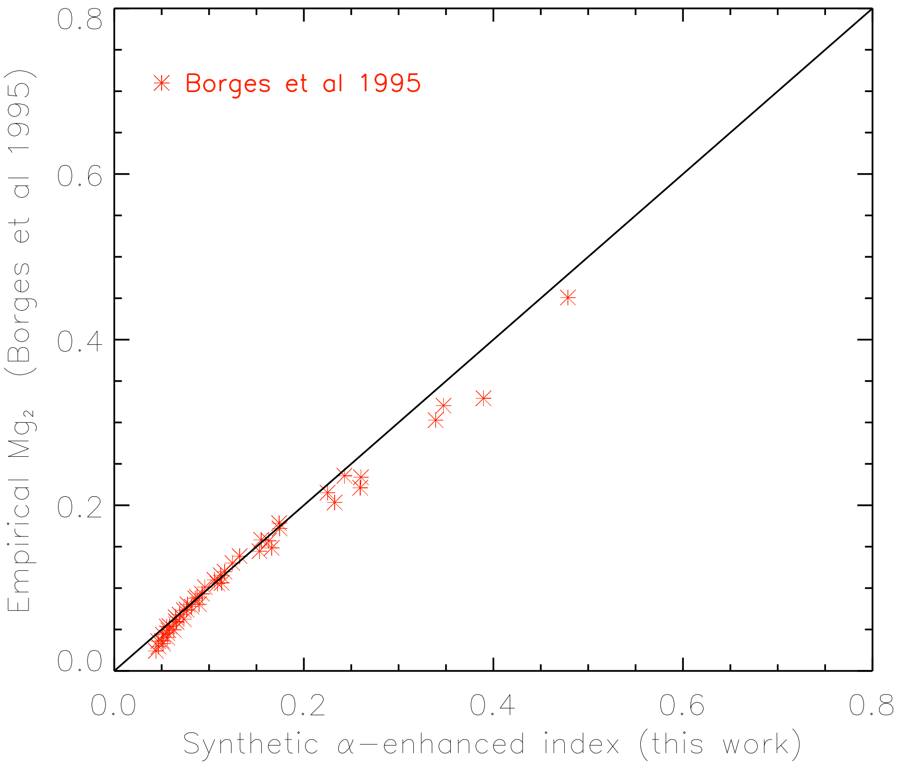

Fig. 1.2. The predicted Mg_2 values from empirical fitting function by Borges et al. (1995), computed with [α/Fe] = +0.4 dex, are compared with NSSA synthetic indices at each T_{eff} for log g = 2.0, 3.0, 4.0 dex, and [M/H] = -1.0 and -0.5 dex

values are reported as functions of inverse effective temperature and compared with the values computed by using the empirical fitting function by Worthey et al. (1994). Note that at low temperatures ($T_{\rm eff} < 5160$ K) the fitting function does not distinguish different gravity values thus only one point is plotted at each $\theta_{\rm eff}$ while four different synthetic values exist. The same kind of overall consistency of synthetic and empirical fitting function values is achieved also for the other spectral features.

We remind that Worthey fitting functions were derived by using a sample of stars with different atmospheric parameters ($T_{\rm eff}$, log g, [Fe/H]), but without detailed information about [α/Fe]. In Fig. 1.2 we take explicitly into account the role of [α/Fe] on one of the most referenced Lick indices, say Mg_2. We use the fitting function predictions derived from Borges et al. (1995), which have explicit dependence on [α/Fe], adopting [α/Fe]=+0.4 in order to compare with our NSSA grid. The synthetic and the empirically derived Mg_2 values agree quite well with the only exception of those at $T_{eff} = 4500$ K. At the lowest temperature in our grid the synthetic values are larger than the empirical ones by about 0.04 dex. We

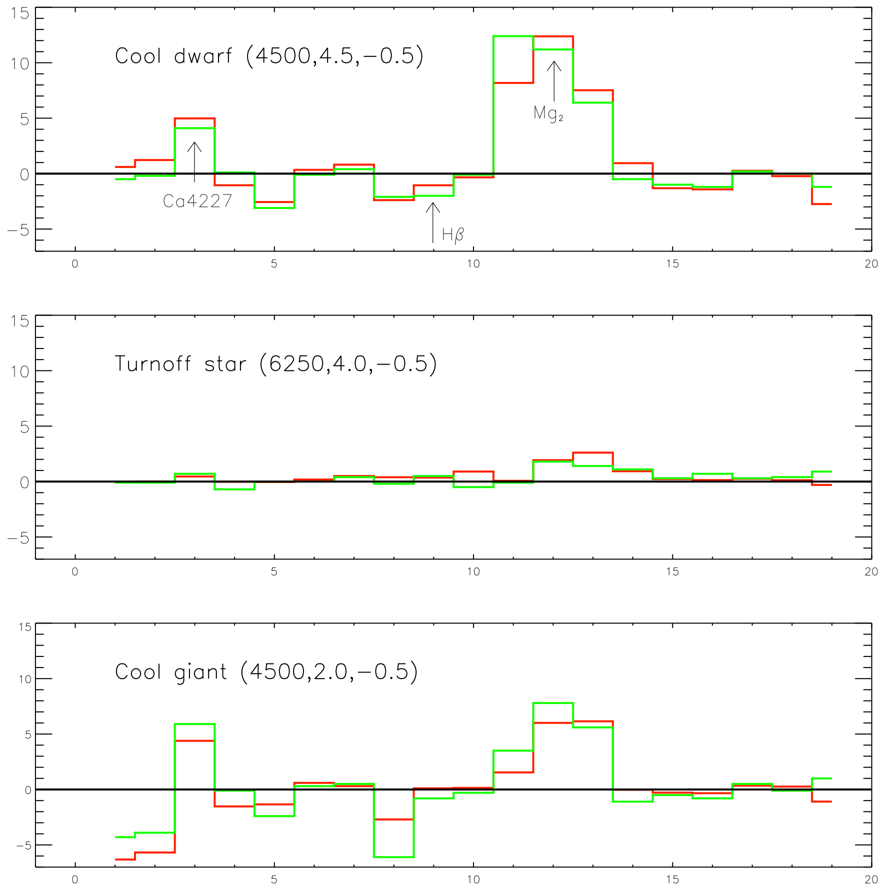

Fig. 1.3. The differences between NSSA and SSA index values for three representative cases: red line - this paper; green line - TB95, see text

attribute this discrepancy to incompleteness of the molecular line lists in the computation of synthetic spectra which is more severe at the lowest temperature.

The different responses of Lick/IDS indices to α-element enhancement in different stars are shown in Fig. 1.3. We computed the differences between NSSA and SSA indices in units of the (observed) standard errors (Worthey et al. 1994) for three cases like those in Tripicco & Bell (1995, TB95): i.e. synthetic spectra representative of a cool dwarf, of a turnoff star, and of a cool giant. Figure 1.3 shows also differences from TB95 computed by adding the data in columns 6, 7, 9, 11, and 13 in their Tables 4, 5, and 6 to mimic an overall [α/Fe]=+0.3 dex. As can be seen, there is a qualitative good agreement between our results and those by TB95. We recall that TB95 data are derived for [M/H]=0.0 and a single element enhancement in turn, while we used [M/H]=-0.5 and an overall [α/Fe]=+0.4. Thus, Fig. 1.3 seems to indicate that the effect of α-element enhancement is similar at 0.0 and -0.5 overall metallicities. We notice that the indices more sensitive to the α-element enhancement are

Mg_1, Mg_2, Mg b, and Ca4227. We notice that Hβ is not very sensitive as also found by Houdashelt et al. (2002).

The amount of the NSSA-SSA differences depends on the different values of the atmospheric parameters (T_{eff}, log g, and [Fe/H]), therefore, to single out stars with α enhancement chemical composition on the basis of the observed indices, it is mandatory to disentangle the signature of α enhancement from the effects due to the other parameters. An analysis of the possible (index,index) diagrams put in evidence several pairs of indices which permit us to identify well separated loci representative of SSA and NSSA points irrespectively of effective temperatures, surface gravities and iron abundance. As an example, the pair Ca4227 and Na D is shown in Fig. 1.4. The potentiality of such a diagram to identify α enhanced candidate stars is demonstrated by comparing theoretical predictions with data in Worthey et al. (1994). Figures 1.5 and 1.6 show the comparison for two different subsets of stars selected according to their [Fe/H] values given in Taylor (1998 and 2003). As can be seen, the two subsets distribute differently in the two figures: most of the quasi-solar stars ($-0.25 <$[Fe/H]$< +0.25$) fall over the locus of SSA indices (dashed area) while the opposite happens for the mildly metal-poor stars which mostly fall close to the α enhanced locus (lower continuous curve). This fact can be taken as a qualitative proof of the validity of the proposed diagram to separate SSA and NSSA stars. Furthermore, a quantitative confirmation is given by the index values of stars whose [α/Fe] ratios are well known from high resolution spectral analysis* (see Fig.s 1.5 and 1.6 for some examples).

1.4 Conclusions

The usefulness of Lick/IDS indices to study the enhanced α over iron ratios is confirmed. New synthetic indices have been computed for both SSA and NSSA stellar atmospheres and an example of pair of indices suitable to single out α enhancement candidate stars is shown.

Computation of more extended grids of theoretical indices, i.e. in larger T_{eff}, log g, and [Fe/H] ranges, is in progress.

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* Abundance ratios from literature were scaled to the [Fe/H] values by Taylor (1998 and 2003)

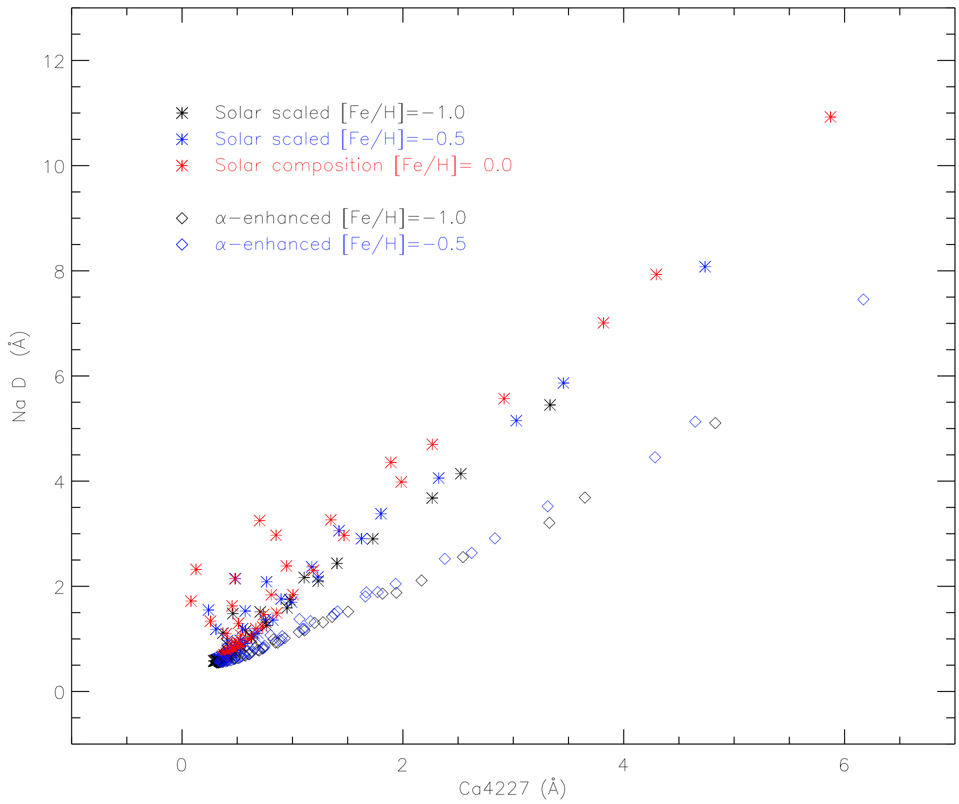

Fig. 1.4. The Na D versus Ca4227 diagram

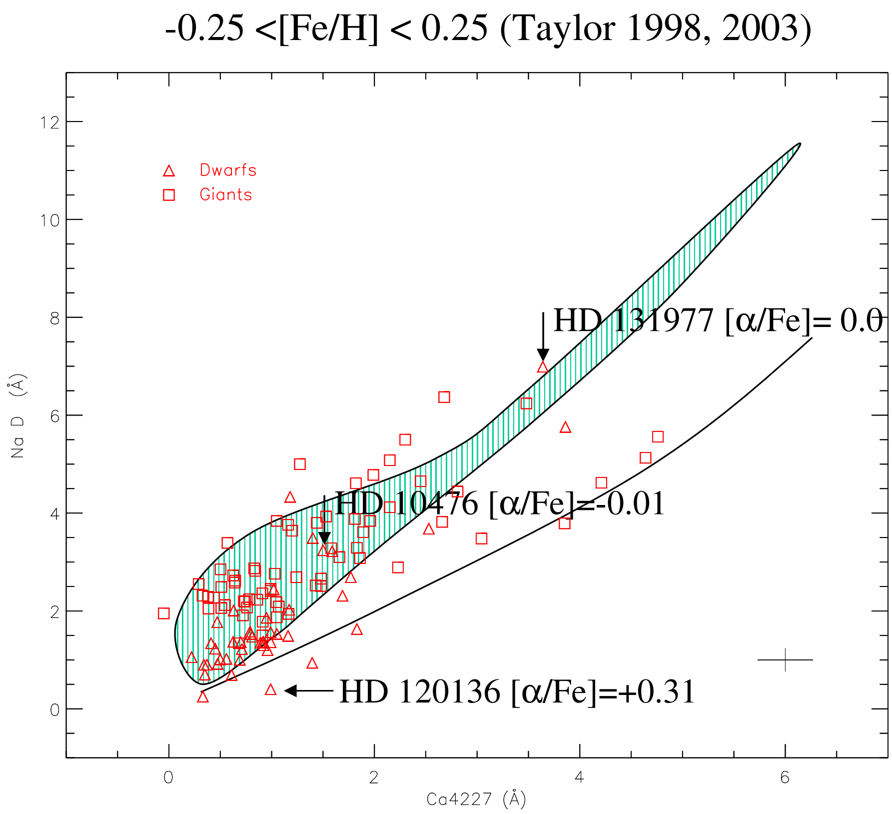

Fig. 1.5. The locii of Na D versus Ca4227 NSSA (lower continuous curve) and SSA (dashed area) with quasi-solar stars from Worthey et al. (1994) superimposed (red symbols). Three representative stars with α-element abundances from high resolution spectral analysis (Thevenin, 1998, and Thorén & Feltzing, 2000) are indicated

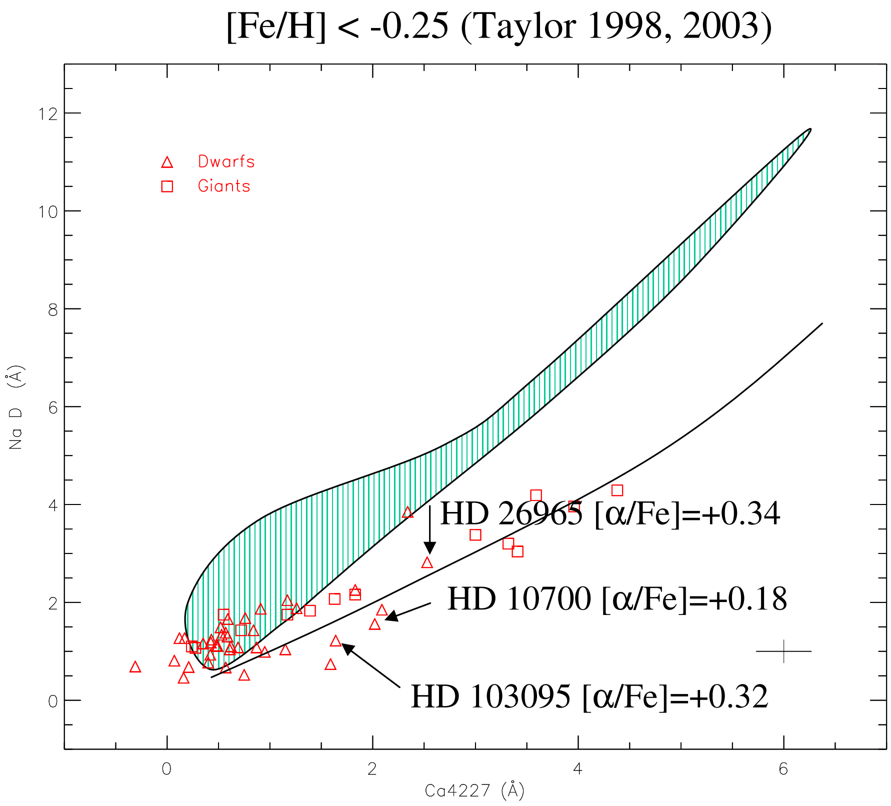

Fig. 1.6. The locii of Na D versus Ca4227 NSSA (lower continuous curve) and SSA (dashed area) with mildly metal-poor stars from Worthey et al. (1994) superimposed (red symbols). Three representative stars with α-element abundances from high resolution spectral analysis (Thevenin, 1998) are indicated