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The solar photospheric abundance of europium

Results from CO5BOLD 3D hydrodynamical model atmospheres

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ABSTRACT

Context. Europium is an almost pure *r*-process element, which may be useful as a reference in nucleocosmochronology.
Aims. Determine the photospheric solar abundance using CO5BOLD 3D hydrodynamical model atmospheres.
Methods. Disc-centre and integrated-flux observed solar spectra are used. The europium abundance is derived using equivalent-width measurements. As a reference, one-dimensional model atmospheres are in addition used.
Results. The europium photospheric solar abundance (0.52 ± 0.02) agrees with previous determinations. We determine the photospheric isotopic fraction of ^{151}Eu to be $49\% \pm 2.3\%$ using the intensity spectra, and $50\% \pm 2.3\%$ using the flux spectra. This compares well to the meteoritic isotopic fraction 47.8%. We explore 3D corrections for dwarfs and sub-giants in the temperature range ~5000 K to ~6500 K and solar and 1/10-solar metallicities and find them to be negligible for all models investigated.
Conclusions. Our photospheric Eu abundance agrees well with previous determinations based on 1D models. This is in line with our conclusion that 3D effects for this element are negligible in the case of the Sun.

Key words. Sun: abundances – stars: abundances – hydrodynamics

1. Introduction

Europium ($Z = 63$) is formed by neutron captures on to *seed*-nuclei. In a seminal paper by Burbidge et al. (1957), it was assigned both to the *s*-process (slow neutron capture) and to the *r*-process (rapid neutron capture). According to current understanding about *r*-process nucleosynthesis, europium is an almost *pure* *r*-process element. About 95–97% of the Eu in the solar system is produced by the *r*-process (Arlandini et al. 1999; Burris et al. 2000). See the introduction in the paper by Mashonkina & Gehren (2000) on the significance of the Eu/Ba ratio for assessing the relative contributions of the *r*-process and *s*-process.

The trend of the [Eu/Fe] abundance ratio as a function of [Fe/H] in the Milky Way stars, both halo and disk, appear to follow a similar behaviour to the [α/Fe] ratio, which has an enhanced value in metal-poor stars and a decrease for [Fe/H] > −1 dex down to solar values. Measurements of this abundance ratio in extra-galactic stars highlight a decoupling between [Eu/Fe] and [α/Fe] ratios, with over-solar [Eu/Fe] at high metallicity and solar or sub-solar [α/Fe] values, as observed in Sagittarius (Bonifacio et al. 2000), in the Small Magellanic Cloud (Hill 1997), and the Large Magellanic Cloud (Hill et al. 1995).

The ratio of the two *r*-process elements Eu/Th[1] is potentially an interesting chronometer, provided that the production ratio of

the two nuclei can be predicted reliably theoretically (see Cowan & Sneden 2004, for an extensive review of the *r*-process).

In this paper we reconsider the Eu solar abundance in the light of the recent progress of the 3-dimensional (hereafter 3D) model atmosphere computations, measuring the solar abundance both with 1-dimensional (1D) and 3D models in order to assess the impact of this new generation of models on the solar Eu abundance.

The Eu solar abundance reported in the compilation of Grevesse & Sauval (1998) is $A(\mathrm{Eu}) = 0.51 \pm 0.08$[2] and $A(\mathrm{Eu}) = 0.55 \pm 0.02$ dex, from the solar photosphere and from meteorites, respectively. The analysis of Lawler et al. (2001) yields $A(\mathrm{Eu}) = 0.52 \pm 0.01$ dex, adopting new atomic data for the Eu lines and taking into account the hyperfine structure of the lines employed.

2. Solar europium chemical analysis

2.1. Theoretical tools

We derive the solar Eu photospheric abundance using 3D model atmospheres computed using the CO^{5}BOLD code (COnservative COde for the COmputation of COmpressible COnvection in a BOx of L Dimensions with $L = 2, 3$) (Freytag et al. 2002; Wedemeyer et al. 2004) and we compare our results to 1D model results. CO^{5}BOLD solves the coupled non-linear equations of compressible hydrodynamics including

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[1] The isotope ^{232}Th is radioactive with a half-life of 14.05 Gyr.

[2] We adopt the spectroscopic notation $A(\mathrm{X}) = \log(N(\mathrm{X})/N(\mathrm{H})) + 12$.

non-local frequency-dependent radiation transport for a small volume located at the stellar surface (for technical issues, see the on-line manual available at http://www.astro.uu.se/~bf/co5bold/index.html). The atmospheric-flow field is sampled in equal temporal intervals each of which we call a "snapshot". In total, 25 snapshots were selected from a CO⁵BOLD simulation to represent the solar photosphere.

As references, we also adopted several 1D solar models:

– the 1D solar model computed by F. Castelli[3] using the ATLAS9 code, adopts the solar abundances of Asplund et al. (2005), an T_{eff} = 5777 K, $\log g$ = 4.4377, and microturbulence velocity of 1 km s^{-1};
– the semi-empirical solar atmosphere model derived by Holweger & Müller (1974);
– a solar 1D atmospheric model obtained using the temporal and horizontal average of the 3D structure over surfaces of equal Rosseland optical depth. The comparison between the 3D CO⁵BOLD model and this kind of *average* 3D model, allows us to estimate the influence of the fluctuations, around the mean stratification, on the line formation process;
– a solar 1D atmospheric model computed using a Lagrangian hydrodynamical code LHD (see Caffau & Ludwig 2007), which includes the same opacities and equation-of-state adopted by the CO⁵BOLD 3D code. LHD code treats convection using the standard mixing-length theory (MLT) in the formulation given by Mihalas (1978). The use of this kind of models allows us to compare these 1D models directly with the 3D CO⁵BOLD models, which erases the systematics due to different physical assumptions.

The spectral synthesis from ATLAS and HM models are performed using the SYNTHE code (Kurucz 1993, 2005) in its Linux version (Sbordone et al. 2004; Sbordone 2005). For CO⁵BOLD and LHD models, the Linfor3D[4] code is used.

2.2. Observational material

The present study is based on two sets of high-resolution, high signal-to-noise ratio spectra of solar-flux and disc-centre intensity:

– *Solar Flux* – We adopted the solar-flux spectra of Neckel & Labs (1984) and of Kurucz (2005)[5].
– *Solar Intensity* – As centre-disc solar-intensity spectra, we used the intensity of Neckel & Labs (1984) and that of Delbouille et al. (1973)[6].

We selected 5 Eu II optical spectral lines from the list of Lawler et al. (2001). It is worth noting that not all of these solar spectra are useful to measure the selected features. In the following, we describe briefly the single Eu II features used in this analysis and the corresponding adopted solar spectrum:

– 412.972 nm – strong Eu II line, with a weak blending on the blue side; this feature exhibits the same shape in all adopted solar spectra, without telluric contamination;

Table 1. Atomic data for the europium lines considered in this work.

Wavelength (nm)	$\log gf$	E.P. (eV)
412.972	0.22	0.000
604.951	–0.80	1.278
664.510	0.12	1.379
707.709	–0.72	1.249
721.756	–0.35	1.229

– 604.951 nm – clean feature without particular difficulties, it is not blended or contaminated by nearby lines to cause problems in the placement of the continuum;
– 664.519 nm – this is one of the strongest optical transitions and is commonly used to infer the Eu II abundance. In all four of the solar observed spectra we consider this line results not blended with telluric features. This feature has a blending in its red wing, due to the presence of the weak features of Cr I and Si I;
– 707.709 nm – this weak line shows an H_2O telluric-line contamination on its red side and only in the Delbouille spectrum does this blending seems to be less severe;
– 721.756 nm – this line is measurable only in the Delbouille spectrum; the other solar spectra show a strong blending of this feature with a H_2O telluric-line, which is completely absent in the Delbouille spectrum.

2.3. Chemical analysis

2.3.1. Analysis

The chemical analysis of the selected Eu II features was performed adopting the atomic parameters for the Eu II lines by Lawler et al. (2001) and is summarised in Table 1. The Eu II spectral lines display significant hyperfine structures. We include in the line list, hyperfine structure and isotopic splitting, using the meteoritic isotopic ratio[7] and the hyperfine constants A and B measured by Lawler et al. (2001). The calculation of the hyperfine structure was completed using the code LINESTRUC, described by Wahlgren (2005). All the hyperfine components for each Eu II feature, computed without the assumption of a specific isotopic ratio, are available in Table 4. We did not take into account possible NLTE effects, which are different between intensity and flux spectra and could explain the small positive difference between intensity and flux abundances. Mashonkina (2000) analysed the NLTE effects for the resonance Eu II line at 421.9 nm in solar-like stars, finding a NLTE correction of ~0.04 dex.

The solar Eu abundance was derived from the curve of growth of each line calculated using Linfor3D, adopting a meteoritic isotopic ratio. The equivalent width (*EW*) of the Eu II lines was measured using a Gaussian fit with the IRAF task SPLOT, for its deblending option. The 3D models include only the Eu II lines, without the contribution of possible blending features. The choice to infer the abundance using the *EW* measurement was made because of the inefficiency of the line-profile fitting with a 3D grid, due to the lack of the weak-blending components in the 3D synthetic spectra. This is caused by the inability of the current version of Linfor3D to handle a large number of lines. In Table 2, we provide our results for both

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Table 2. Solar europium abundances from the adopted observed spectra. Column (1) indicates the solar spectrum used: KF: Kurucz flux, NF: Neckel flux, NI: Neckel intensity, DI: Delbouille intensity. Column (2) is the wavelength of the observed lines. Column (3) is the Equivalent Width. Columns (4) and (5) are Eu abundance from the CO^5BOLD models and the corresponding uncertainty due to the error of the Equivalent Width. Columns (6)−(9) are the results from the 1D chemical analysis by adopting two solar models (HM: Holweger & Müller (1974). FC: ATLAS9 solar model by Fiorella Castelli). Finally, Cols. (10) and (11) are the 3D corrections.

Spec	Wave	EW	3D CO^5BOLD	σ_{EW}	1D HM	$N(^{151}Eu)/N(Eu_{tot})$ HM	1D FC	$N(^{151}Eu)/N(Eu_{tot})$ FC	3D-$1D_{LHD}$	3D-$\langle 3D \rangle$
	nm	(pm)	(dex)	(dex)	(dex)		(dex)		(dex)	(dex)
KF	412.972	5.620	0.509	0.045	0.535	0.54	0.526	0.51	−0.013	−0.030
NF	412.972	5.652	0.513	0.045	0.527	0.49	0.513	0.48	−0.014	−0.030
NI	412.972	5.026	0.537	0.050	0.533	0.51	0.537	0.49	0.014	0.006
DI	412.972	5.045	0.540	0.050	0.545	0.53	0.541	0.51	0.015	0.006
KF	604.951	0.063	0.504	0.030	0.528	–	0.539	–	0.013	0.002
NF	604.951	0.061	0.490	0.030	0.519	–	0.492	–	0.014	0.003
NI	604.951	0.051	0.480	0.035	0.532	–	0.487	–	0.023	0.013
DI	604.951	0.057	0.529	0.035	0.537	–	0.521	–	0.022	0.012
KF	664.519	0.436	0.511	0.020	0.540	0.52	0.520	0.51	0.011	0.000
NF	664.519	0.432	0.507	0.020	0.531	0.49	0.520	0.47	0.011	0.000
NI	664.519	0.400	0.530	0.026	0.506	0.46	0.518	0.47	0.020	0.010
DI	664.519	0.384	0.514	0.021	0.504	0.50	0.504	0.49	0.020	0.011
DI	707.709	0.082	0.526	0.032	0.480	–	0.472	–	0.025	0.012
DI	721.756	0.220	0.564	0.031	0.508	–	0.513	–	0.026	0.013

1D and 3D models, the 3D correction defined by Caffau & Ludwig (2007) as $A(X)_{3D} - A(X)_{1D_{LHD}}$, and the difference between 3D and $\langle 3D \rangle$ models. We report also the error (σ_{EW}) in the Eu abundance due to the uncertainty in the EW measurement, which we estimated by performing EW measurements using different continuum placements and deblending assumptions, for each line: typically this is ~0.02−0.03 dex, with only the Eu II line at 412.972 nm showing an error in the abundance of ~0.05 dex, probably due to the blending on the blue side of the spectrum.

To place solar 3D correction results in a wider context, we computed 3D corrections of the 664.5 nm Eu II line for flux spectra in F and G-type atmospheric stellar models. We explored a parameter grid including T_{eff} between 4980 and 6460 K, $\log g = 3.5, 4.0, 4.5$ and [M/H] = 0.0, −1.0. The Eu abundance is scaled with respect to the metallicity of the model, according to the solar ratio. The reference solar Eu abundance is 0.52. The results are listed in Table 3. The majority of the 3D corrections (3D-$1D_{LHD}$) are negligible, and the largest is just 0.011 dex. The 3D correction related to the average temperature profile (3D-$\langle 3D \rangle$) is in the range 0.01−0.02 dex for all models and it is larger than the complete 3D correction.

As an additional check to test the consistency of our results, we performed a *classical* 1D analysis on these 5 features. This step is necessary to compare the results obtained by the LHD models and the 1D models, which are usually used in the chemical analysis. To compute the abundance, we used line-profile fitting and employed the line list from the Kurucz database, updated including the atomic parameters for the Eu II lines. This was completed using a code (Caffau et al. 2005) that performs a linear interpolation in a synthetic-spectra grid with the Eu abundance as a free-fitting parameter: the final best-fit was derived using numerical χ^2 minimisation, using MINUIT (James 1998). Even the line-shift and the continuum-placement can be a free parameter to optimise the fit. Only for two strong features, namely 412.9 and 664.5 nm, we adopted a different version of this code, which include as free-fitting parameters both the Eu abundance and the fraction of the Eu isotope ^{151}Eu with respect to the total abundance, $\log(N(^{151}Eu)/N(Eu_{tot}))$.

Table 3. The CO^5BOLD models considered in this work (excluding the solar model) for the Eu II spectral line at 664.519 nm: the table reports the atmospheric parameters ($T_{eff}/\log g$/[M/H]) for each model, the EW measurement, and the corresponding 3D-$1D_{LHD}$ and 3D-$\langle 3D \rangle$ corrections.

Model parameters ($T_{eff}/ \log g$ / [M/H])	EW (pm)	3D-$1D_{LHD}$ (dex)	3D-$\langle 3D \rangle$ (dex)
5430/3.5/0.0	1.070	−0.001	0.007
5480/3.5/−1.0	0.190	0.007	0.019
5930/4.0/0.0	0.670	0.004	0.008
5850/4.0/−1.0	0.110	0.009	0.023
4980/4.5/0.0	0.400	0.000	0.009
5060/4.5/−1.0	0.073	−0.003	0.009
5870/4.5/0.0	0.430	0.006	0.015
5929/4.5/−1.0	0.066	0.011	0.021
6230/4.5/0.0	0.400	0.009	0.017
6240/4.5/−1.0	0.058	0.008	0.017
6460/4.5/0.0	0.370	0.008	0.015
6460/4.5/−1.0	0.051	0.001	0.013

3. Results and discussion

The main results of this analysis are:

1. The 3D analysis, based on different high-resolution high signal-to-noise solar spectra and by using the CO^5BOLD model, provided a mean Eu photospheric abundance of $A(Eu) = 0.506$ dex with a standard deviation $\sigma = 0.008$ for the flux spectra, using the first three spectral features, and $A(Eu) = 0.527$ with $\sigma = 0.024$ for the intensity spectra at the disk-centre, using all the five lines. As a final value of Eu solar photospheric abundance we recommend $A(Eu) = 0.518$ dex ($\sigma = 0.024$). This value comes from the average of all measurements, both flux and intensity, since they are very close, and is consistent with the previous 1D determinations.

2. The difference 3D-$\langle 3D \rangle$ allows us to estimate the 3D corrections due to the horizontal temperature fluctuations, a component which was not taken into account in the classical 1D models. This correction is negligible for all of the lines considered, with an average value of −0.009 dex ($\sigma = 0.016$)

Table 4. Linelist for the five selected Eu II transitions: $\log gf$, excitation potential and corresponding isotope for each hyperfine component are reported.

Wavelength (nm)	$\log gf$	E.P. (eV)	Isotope	Wavelength (nm)	$\log gf$	E.P. (eV)	Isotope	Wavelength (nm)	$\log gf$	E.P. (eV)	Isotope
412.9627	−1.34	0.000	151	604.9532	−2.36	1.278	151	664.5149	−1.22	1.379	151
412.9623	−1.81	0.000	151	604.9531	−2.83	1.278	151	664.5142	−2.13	1.379	151
412.9649	−1.81	0.000	151	604.9529	−2.83	1.278	151	664.5133	−3.55	1.379	151
412.9645	−1.28	0.000	151	604.9528	−2.30	1.278	151	664.5136	−1.14	1.379	151
412.9640	−1.62	0.000	151	604.9526	−2.64	1.278	151	664.5127	−1.94	1.379	151
412.9676	−1.62	0.000	151	604.9524	−2.64	1.278	151	664.5116	−3.38	1.379	151
412.9671	−1.15	0.000	151	604.9522	−2.17	1.278	151	664.5120	−1.06	1.379	151
412.9665	−1.56	0.000	151	604.9519	−2.58	1.278	151	664.5108	−1.88	1.379	151
412.9710	−1.56	0.000	151	604.9516	−2.58	1.278	151	664.5094	−3.45	1.379	151
412.9704	−1.00	0.000	151	604.9514	−2.02	1.278	151	664.5101	−0.97	1.379	151
412.9698	−1.59	0.000	151	604.9510	−2.62	1.278	151	664.5087	−1.93	1.379	151
412.9753	−1.59	0.000	151	604.9506	−2.62	1.278	151	664.5070	−3.77	1.379	151
412.9746	−0.85	0.000	151	604.9502	−1.87	1.278	151	664.5079	−0.89	1.379	151
412.9739	−1.78	0.000	151	604.9496	−2.80	1.278	151	664.5062	−2.12	1.379	151
412.9803	−1.78	0.000	151	604.9492	−2.80	1.278	151	664.5056	−0.82	1.379	151
412.9796	−0.70	0.000	151	604.9486	−1.72	1.278	151	664.5123	−1.22	1.379	153
412.9681	−1.34	0.000	153	604.9514	−2.36	1.278	153	664.5121	−2.13	1.379	153
412.9678	−1.81	0.000	153	604.9515	−2.83	1.278	153	664.5118	−3.55	1.379	153
412.9690	−1.81	0.000	153	604.9514	−2.83	1.278	153	664.5115	−1.14	1.379	153
412.9688	−1.28	0.000	153	604.9515	−2.30	1.278	153	664.5112	−1.94	1.379	153
412.9684	−1.62	0.000	153	604.9515	−2.64	1.278	153	664.5107	−3.38	1.379	153
412.9701	−1.62	0.000	153	604.9515	−2.64	1.278	153	664.5106	−1.06	1.379	153
412.9698	−1.15	0.000	153	604.9515	−2.17	1.278	153	664.5101	−1.88	1.379	153
412.9694	−1.56	0.000	153	604.9515	−2.58	1.278	153	664.5095	−3.45	1.379	153
412.9715	−1.56	0.000	153	604.9514	−2.58	1.278	153	664.5097	−0.97	1.379	153
412.9712	−1.00	0.000	153	604.9513	−2.02	1.278	153	664.5090	−1.93	1.379	153
412.9709	−1.59	0.000	153	604.9511	−2.62	1.278	153	664.5081	−3.77	1.379	153
412.9733	−1.59	0.000	153	604.9510	−2.62	1.278	153	664.5088	−0.89	1.379	153
412.9731	−0.85	0.000	153	604.9508	−1.87	1.278	153	664.5079	−2.12	1.379	153
412.9730	−1.78	0.000	153	604.9503	−2.80	1.278	153	664.5081	−0.82	1.379	153
412.9756	−1.78	0.000	153	604.9500	−2.80	1.278	153				
412.9755	−0.70	0.000	153	604.9496	−1.72	1.278	153				

Wavelength (nm)	$\log gf$	E.P. (eV)	Isotope	Wavelength (nm)	$\log gf$	E.P. (eV)	Isotope	Wavelength (nm)	$\log gf$	E.P. (eV)	Isotope
707.7169	−2.34	1.249	151	721.7564	−2.08	1.229	151				
707.7164	−2.64	1.249	151	721.7573	−2.18	1.229	151				
707.7154	−2.17	1.249	151	721.7549	−2.63	1.229	151				
707.7156	−3.60	1.249	151	721.7559	−1.92	1.229	151				
707.7144	−2.46	1.249	151	721.7574	−1.81	1.229	151				
707.7132	−2.00	1.249	151	721.7534	−2.59	1.229	151				
707.7134	−3.49	1.249	151	721.7550	−1.83	1.229	151				
707.7120	−2.40	1.249	151	721.7570	−1.56	1.229	151				
707.7104	−1.86	1.249	151	721.7517	−2.74	1.229	151				
707.7104	−3.60	1.249	151	721.7537	−1.84	1.229	151				
707.7086	−2.44	1.249	151	721.7564	−1.36	1.229	151				
707.7066	−1.73	1.249	151	721.7496	−3.10	1.229	151				
707.7063	−3.94	1.249	151	721.7523	−2.01	1.229	151				
707.7045	−2.62	1.249	151	721.7554	−1.20	1.229	151				
707.7024	−1.61	1.249	151	721.7605	−2.08	1.229	153				
707.7125	−2.34	1.249	153	721.7602	−2.18	1.229	153				
707.7125	−2.64	1.249	153	721.7602	−2.63	1.229	153				
707.7116	−2.17	1.249	153	721.7598	−1.92	1.229	153				
707.7125	−3.60	1.249	153	721.7594	−1.81	1.229	153				
707.7115	−2.46	1.249	153	721.7590	−2.59	1.229	153				
707.7106	−2.00	1.249	153	721.7586	−1.83	1.229	153				
707.7112	−3.49	1.249	153	721.7578	−1.56	1.229	153				
707.7104	−2.40	1.249	153	721.7572	−2.74	1.229	153				
707.7093	−1.86	1.249	153	721.7564	−1.84	1.229	153				
707.7095	−3.60	1.249	153	721.7553	−1.36	1.229	153				
707.7086	−2.44	1.249	153	721.7543	−3.10	1.229	153				
707.7078	−1.73	1.249	153	721.7531	−2.01	1.229	153				
707.7071	−3.94	1.249	153	721.7514	−1.20	1.229	153				
707.7063	−2.62	1.249	153								
707.7060	−1.61	1.249	153								

and 0.010 dex (σ = 0.003) for flux and intensity, respectively. This difference between the two solar data-sets was already observed in a previous 3D analysis for sulphur (Caffau et al. 2005) and phosphorus (Caffau & Ludwig 2007), and can be attributed to the different atmospheric layers where intensity and flux spectra originate: the centre disc intensity spectra arise from deeper layers, where the temperature fluctuations are more pronounced.

3. The difference 3D-1D$_{LHD}$ allows us to compare 3D and 1D models that use the same physical assumptions, such as equation of state and opacities, and provides a *3D correction*. These values are close to zero both in flux and intensity, with an average difference of 0.004 dex (σ = 0.013) and 0.021 dex (σ = 0.004) respectively. The 3D-1D$_{LHD}$ corrections appear to be systematically higher than the 3D-$\langle$3D$\rangle$ corrections with a difference of about 0.010 dex.

4. Finally, as consistency check, we performed a classical 1D analysis, using the Holweger & Müller (1974) and ATLAS models. We derived a mean photospheric abundance for europium of A(Eu) = 0.515 dex (σ = 0.022) and 0.523 dex (σ = 0.014) for disc-centre intensity and flux, respectively, in good agreement with the previous values of Anders & Grevesse (1989) of 0.51 dex and Lawler et al. (2001) of 0.52 dex. The isotopic ratio (N(^{151}Eu)/N(Eu$_{tot}$)) computed using the two strongest Eu lines agrees well with the meteoritic ratio: 0.49 (σ = 0.023) and 0.50 (σ = 0.023) for intensity and flux, respectively.

There is no way to know a priori if 3D effects are important for any given line. A detailed calculation has to be done in each case. Solar abundances are widely used as a reference and their implication goes beyond pure chemical composition, but touches fields such as helioseismology and solar-neutrino production. The low solar abundances measured by Asplund et al. (2005) have put some strain on our understanding of both. As suggested by Bahcall et al. (2005), different measurements of solar abundances, obtained using different observed spectra and different solar models, allow a better estimation of the systematic uncertainties. In the case of Eu, we conclude that the 3D effects are negligible in the Sun and solar-like stars. The scenario is very coherent, when we consider 3D of the non-solar models. 3D corrections are negligible for both solar and slightly metal-poor models. This is in line with the findings discussed by Steffen & Holweger (2002), which investigated granulation corrections in the Sun for several elements. Although Eu is not included in this study, we can compare our results for Eu with their findings for Sr. These two elements show very similar line-formation properties for spectral lines with similar excitation potential and oscillator strength. Also for Sr, the corrections are negligible, typically between −0.02 and +0.02. Therefore, for Eu, as for S (Caffau et al. 2007a) and P (Caffau et al. 2007b) we conclude that the use of 3D models does not imply a substantial downward revision of the solar abundances with respect to that deduced using 1D models.

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