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Abundances of Mn, Co and Eu in a sample of 20 F–G disk stars: the influence of hyperfine structure splitting⋆,⋆⋆

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ABSTRACT

We present Mn, Co and Eu abundances for a sample of 20 disk F and G dwarfs and subgiants with metallicities in the range $-0.8 \leq$ [Fe/H] $\leq +0.3$. We investigate the influence of hyperfine structure (HFS) on the derived abundances of Mn and Co by using HFS data from different sources in the literature, as well as calculated HFS from interaction factors *A* and *B*. Eu abundances were obtained from spectral synthesis of one Eu II line that takes into account HFS from a series of recent laboratory measurements. For the lines analysed in this study, we find that for manganese, the differences between abundances obtained with different HFSs are no greater than 0.10 dex. Our cobalt abundances are even less sensitive to the choice of HFS than Mn, presenting a 0.07 dex maximum difference between determinations with different HFSs. However, the cobalt HFS data from different sources are significantly different. Our abundance results for Mn offer an independent confirmation of literature results, favouring type Ia supernovae as the main nucleosynthesis site of Mn production, in contrast to trends of Mn versus metallicity previously reported in the literature. For Co, we obtain [Co/Fe] ~ 0.0 in the range $-0.3 <$ [Fe/H] $< +0.3$ and [Co/Fe] rising to a level of +0.2 when [Fe/H] decreases from -0.3 to -0.8, in disagreement with recent results in the literature. The observed discrepancies may be attributed to the lack of HFS in the works we used for comparison. Our results for Eu are in accordance with low-mass type II supernovae being the main site of the *r*-process nucleosynthesis.

Key words. stars: abundances – atomic data

1. Introduction

Accurate stellar abundance determinations are fundamental for numerous astrophysical studies, like those of Galactic and stellar structure, evolution and nucleosynthesis. In order to study the behavior of certain elements like Mn, Co and Eu with metallicity, it is crucial to consider hyperfine structure (HFS) splitting in the calculations using strong lines, because otherwise the computed abundances are bound to be erroneous. Moreover, abundance results computed adopting HFSs from different sources can produce trends with metallicity that are significantly different, as shown, for example, by Prochaska & McWilliam (2000, PM00).

PM00 investigated the importance of HFS on abundance determinations of Mn and Sc. In their study, they find that an incorrect treatment for HFS can lead to abundances that are significantly in error. For Mn, in particular, they discuss the results of Nissen et al. (2000, NCSZ00), who used the HFS components published by Steffen (1985, S85) which, in turn, are based on the work of Biehl (1976). PM00 pointed out that S85 grouped together nearby HFS components and applied old, inaccurate splitting constants, and that such simplifications introduce significant errors in the obtained Mn abundances, producing spurious abundance trends with metallicity.

The purpose of this work is to investigate the behavior of Mn, Co and Eu from a sample of 20 F–G dwarfs and subgiants with metallicities typical of the Galactic disk (in the range $-0.8 \leq$ [Fe/H] $\leq +0.3$), focusing on the evaluation of the influence of HFS in the abundance determinations and abundance trends. Concerning the latter, the main questions that we seek to answer 1) how large are the differences between abundances obtained using HFS components from different sources? and 2) how large are the inaccuracies introduced when simplifications like the grouping together of close-by components are used? In order to accomplish this goal, two sets of Mn and Co abundances were calculated for our sample: one with the HFS data from S85, and another with HFS data from Kurucz's website (http://kurucz.harvard.edu/linelists.html,

⋆ Based on observations collected at the European Southern Observatory, La Silla, Chile, under the ESO programs and the ESO-Observatório Nacional, Brazil, agreement.

⋆⋆ Full Table 2 and Table 3, which contain line-by-line Mn and Co abundances (respectively), are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/441/1149 hereafter referred to as KLL). For the Co I lines, two additional sets of calculations were also obtained: one without HFS and one using HFSs calculated by us with interaction factors A and B taken from the literature (A and B are the magnetic dipole and electric quadrupole coupling constants, respectively). In addition, Eu abundances for the sample stars (from del Peloso et al. 2005) which were derived adopting HFSs calculated with interaction factors from the literature, in a similar manner as for Co I lines, will be discussed and compared to abundance results from the literature.

2. Sample selection, observations, data reduction and atmospheric parameter determination

The detailed description of sample selection, observations, data reduction and atmospheric parameter determination is given in del Peloso et al. (2005); in what follows, we provide only a brief overview of these topics.

The sample was originally selected to determine the age of the Galactic thin disk through Th/Eu nucleocosmochronology. It is composed of 20 dwarfs and subgiants of F5 to G8 MK spectral types with $-0.8 \leq$ [Fe/H] $\leq +0.3$, located less than 40 pc away.

All objects were observed with the Fiber-fed Extended Range Optical Spectrograph (FEROS; Kaufer et al. 1999) coupled to the 1.52 m European Southern Observatory (ESO) telescope, as a part of the ESO-Observatório Nacional, Brazil, agreement. The obtained spectra have high nominal resolving power (R = 48 000), signal-to-noise ratio ($S/N \geq 300$ in the visible) and coverage (3500 Å to 9200 Å spread over 39 echelle orders). Additional observations, centered around the Eu II line at 4129.72 Å, were carried out with the Coudé Échelle Spectrograph (CES) fiber-fed by ESO's Coudé Auxiliary Telescope (CAT). The obtained spectra have high nominal resolving power (R = 50 000) and signal-to-noise ratio ($S/N \sim 300$); coverage is 18 Å.

A set of homogeneous, self-consistent atmospheric parameters was determined for the sample stars. Effective temperatures were determined from photometric calibrations and Hα profile fitting; surface gravities were obtained from $T_{\rm eff}$, stellar masses and luminosities; microturbulence velocities and metallicities were obtained from detailed, differential spectroscopic analysis, relative to the Sun, using equivalent widths (*EW*s) of Fe I and Fe II lines.

3. Abundance determinations

3.1. Manganese and cobalt

Mn and Co abundances were determined using *EW*s of 6 Mn I and 8 Co I lines measured in FEROS spectra. As mentioned above, two sets of abundance calculations for Mn and Co were obtained, with HFS data from S85 and KLL. For the Co I lines, two additional sets were also obtained, without HFS and with HFS calculated with Casimir's equation (Casimir 1963):

$$W_F = W_J + \frac{AK}{2} + \frac{3BK(K+1) - 4I(I+1)J(J+1)}{8I(2I-1)J(2J-1)},$$

where W_F is the energy of the hyperfine level, W_J is the energy of the fine-structure level of quantum number J, I is the nuclear spin, K is defined as

$$K = F(F+1) - I(I+1) - J(J+1),$$

and F is the quantum number associated with the total angular momentum of the atom,

$$F = I + J; I + J - 1; \ldots ; |I - J|.$$

HFS transitions are governed by the following selection rules: $\Delta F = 0; \pm1$, but not $F = 0 \leftrightarrow F' = 0$.

The energies of the fine-structure levels were taken from Pickering & Thorne (1996), and the A and B constants from Guthöhrlein & Keller (1990) and Pickering (1996). Intensities of the components were obtained by distributing the total $\log gf$ values according to the relative weights tabulated in 1933 by White & Eliason (Condon & Shortley 1967). The Co HFSs derived are presented in Table 1. Solar $\log gf$ values were used for all Mn and Co lines. These were determined by forcing the abundances obtained with solar spectra to match those from Grevesse & Sauval (1998) ($\log \varepsilon$(Mn) = 5.39 and $\log \varepsilon$(Co) = 4.92).

The adopted metallicities ([Fe/H]) were taken from del Peloso et al. (2005). Table 2 presents a sample of the [Mn/H] results on a line-by-line basis. Its complete content, composed of the abundances of all measured lines, for all sample stars, obtained with all HFS sources employed, is only available in electronic form at the CDS. Column 1 lists the HD number of the object. Subsequent columns present the [Mn/H] abundance ratios. Table 3, which contains the line-by-line [Co/H] abundance ratios, is formatted in this same manner and is also only available electronically at the CDS.

3.2. Europium

Eu abundances were taken from del Peloso et al. (2005). They were obtained from spectral synthesis of the Eu II line at 4129.72 Å. HFS was calculated by us in exactly the same way as for Co, using data from Becker et al. (1993), Möller et al. (1993), Villemoes & Wang (1994), and Broström et al. (1995). Isotope shift was taken into account, using data from Broström et al. (1995) and the solar abundance isotopic ratio $\varepsilon(^{151}\mathrm{Eu})/\varepsilon(^{153}\mathrm{Eu}) = 1.00 \pm 0.29$ (Lawler et al. 2001). The complete HFSs obtained for both Eu isotopes are presented in Table 4.

We kept the $\log gf$ value fixed at the laboratory value provided by Komarovskii (1991) and derived a solar abundance using solar spectrum. Abundances for the sample stars were obtained relative to this solar value.

4. Abundance results obtained with HFS from different sources

4.1. Manganese

Of the 6 Mn I lines used in this study, 4 of them (5399.479 Å, 5413.684 Å, 5420.350 Å, and 5432.548 Å) have HFS data available from both S85 and KLL. Note that KLL assembles

Table 1. HFSs of all Co I lines calculated in this study.

4749.612 Å		5212.691 Å		5280.629 Å		5301.047 Å	
λ (Å)	*W* (%)	λ (Å)	*W* (%)	λ (Å)	*W* (%)	λ (Å)	*W* (%)
4749.616	19.850	5212.595	1.732	5280.562	0.256	5301.014	4.517
4749.634	16.321	5212.622	2.842	5280.569	2.088	5301.023	22.584
4749.650	13.266	5212.646	3.409	5280.586	0.426	5301.032	6.836
4749.665	10.635	5212.653	20.168	5280.591	3.386	5301.040	11.529
4749.678	8.370	5212.668	3.513	5280.606	0.533	5301.046	7.393
4749.684	1.408	5212.673	14.745	5280.608	21.318	5301.049	4.517
4749.691	6.498	5212.687	3.145	5280.609	4.025	5301.054	4.517
4749.694	2.343	5212.691	10.487	5280.623	0.533	5301.058	6.365
4749.702	4.940	5212.704	2.498	5280.625	20.773	5301.062	6.836
4749.703	2.817	5212.705	7.255	5280.637	4.007	5301.064	0.859
4749.710	2.916	5212.717	4.917	5280.638	12.786	5301.068	4.016
4749.712	3.748	5212.726	3.347	5280.647	2.876	5301.071	7.438
4749.716	2.702	5212.732	1.732	5280.649	9.500	5301.076	2.212
4749.721	2.161	5212.733	2.442	5280.653	1.831	5301.077	6.365
4749.724	1.330	5212.738	2.359	5280.656	6.804	5301.080	4.016
4749.743	0.139	5212.742	2.842	5280.661	6.155		
4749.746	0.218	5212.749	3.409	5280.662	2.702		
4749.747	0.119	5212.754	3.513				
4749.748	0.218	5212.755	2.498				
		5212.756	3.145				

5342.708 Å		5454.572 Å		5647.234 Å		6188.996 Å	
λ (Å)	*W* (%)	λ (Å)	*W* (%)	λ (Å)	*W* (%)	λ (Å)	*W* (%)
5342.699	6.071	5454.551	2.003	5647.212	31.657	6188.925	4.517
5342.700	10.870	5454.553	3.941	5647.225	19.296	6188.938	22.584
5342.702	13.099	5454.555	4.061	5647.237	10.034	6188.968	6.836
5342.705	15.676	5454.557	3.662	5647.243	7.473	6188.979	11.529
5342.707	1.136	5454.560	2.888	5647.248	3.643	6188.991	4.517
5342.708	18.545	5454.568	2.727	5647.251	10.826	6189.002	7.393
5342.710	1.876	5454.569	8.388	5647.258	1.139	6189.012	4.517
5342.712	21.839	5454.571	12.124	5647.264	7.319	6189.023	6.836
5342.713	2.335	5454.572	17.047	5647.269	1.013	6189.030	6.365
5342.718	2.531	5454.575	23.316	5647.272	2.719	6189.038	0.859
5342.719	0.065	5454.577	2.888	5647.274	4.881	6189.048	7.393
5342.722	2.400	5454.580	3.662			6189.052	4.016
5342.724	0.109	5454.583	4.061			6189.057	0.045
5342.728	1.964	5454.587	3.941			6189.064	6.365
5342.731	0.131	5454.592	3.286			6189.069	2.212
5342.734	1.178	5454.597	2.003			6189.075	4.016
5342.738	0.109						
5342.745	0.065						

Note: "*W*" stands for weight.

data from multiple sources; for the Mn I lines studied here, they come from Martin et al. (1988) and Kurucz (1990). For these 4 lines, the structures of S85, although simplified by the grouping together of close-by components, are very similar to those from KLL. We note, however, that the HFSs for the three Mn I lines used in the studies of NCSZ00 and PM00 (6013.513 Å, 6016.673 Å, and 6021.819 Å) are, on the other hand, quite different in S85 and KLL. The differences in the HFSs offer an explanation for the fact that our abundances obtained with HFS from S85 do not match those

Table 2. A sample of the [Mn/H] abundance ratios, line-by-line. Abundances are presented for all HFS sources, for all measured lines. The complete content of this table is only available in electronic form at the CDS, along with a similar table for [Co/H] abundance ratios. For a description of the columns, see text (Sect. 3.1).

HD	4739.113 Å	5394.670 Å	···	5432.538 Å	
	martin	martin		steffen	martin
2151	−0.08	−0.12	···	−0.14	−0.13
9562	+0.22	+0.10	···	+0.12	+0.12
⋮	⋮	⋮	⋮	⋮	⋮
199 288	−0.75	−0.78	···	−0.79	−0.78
203 608	−0.75	−0.72	···	–	–

Note: Column labels indicate the source of the HFS: martin – Martin et al. (1988); steffen – Steffen (1985); kurucz – Kurucz (1990).

Table 4. HFSs of the Eu II line.

λ_{151}(Å)	λ_{153}(Å)	W
4129.615	4129.695	0.923
4129.618	4129.698	2.792
4129.632	4129.702	1.462
4129.636	4129.705	3.170
4129.640	4129.708	0.922
4129.657	4129.712	1.664
4129.662	4129.715	4.285
4129.667	4129.719	1.462
4129.690	4129.727	1.531
4129.696	4129.730	6.053
4129.702	4129.733	1.663
4129.731	4129.747	0.993
4129.738	4129.748	8.590
4129.744	4129.751	1.531
4129.788	4129.773	11.966
4129.795	4129.774	0.993

Note: λ_{151} and λ_{153} are the central wavelengths of components for ^{151}Eu and ^{153}Eu, respectively. "W" stands for the weight of each component and each isotope.

from NCSZ00, although taken from the same reference. This is because, while the HFSs from S85 for the six Mn I lines used by us appear to have been accurately calculated, those for the three lines used in NCSZ00 appear to contain important deviations when compared to KLL.

In Fig. 1 we show the differences between average [Mn/H] abundance ratios obtained for our sample with the two adopted HFSs, from S85 and KLL. The abundances are very similar at roughly solar metallicities and down to roughly [Fe/H] = −0.2, but the differences are larger at lower metallicities, reaching a maximum value of 0.10 dex. This dependance of the abundance differences with metallicity (although reaching only the modest level of 0.10 dex) would create a spurious trend in the run of Mn abundance with metallicity that is only due to the choice of HFS.

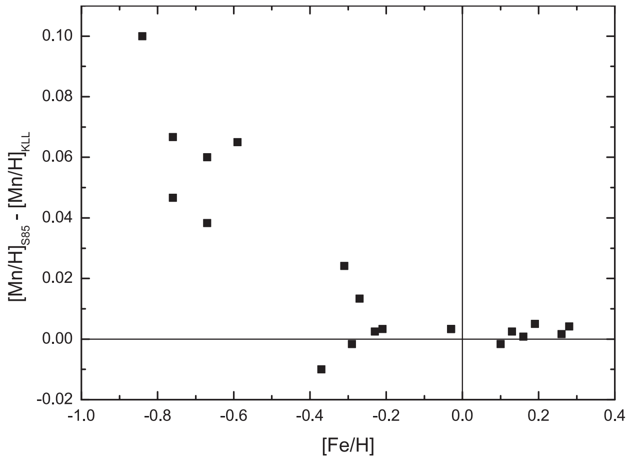

Fig. 1. Diagram displaying the difference between average [Mn/H] abundance ratios obtained with the HFSs from S85 and KLL, for our sample stars.

4.2. Cobalt

Of the 8 Co I lines studied here, 5 have HFS data available from both S85 and KLL (4749.662 Å, 5212.691 Å, 5342.708 Å, 5454.572 Å, and 5647.234 Å). In Fig. 2 we compare these HFSs with those calculated in this study. Note that we have employed newer, more accurate laboratory values for the A and B interaction factors, and our calculations are thus expected to be more reliable than the previous ones. It can be seen that there is not good agreement between the three HFS sets. This constitutes further evidence of the very heterogeneous character of the S85 and KLL databases: while the HFSs of some of the lines contained in those works have been very well calculated (like the Mn I line near 5400 Å – see Sect. 4.1), some present very strong inconsistencies. For the other 3 Co I lines, two of them, at 5280.629 Å and 5301.047 Å, have HFSs from KLL that disagree strongly with our calculations. However, for the Co line at 6188.996 Å there is good agreement between our calculations and those from KLL. This offers yet another indication of the heterogeneity of KLL: even coming from one single source (Fuhr et al. 1988), there are data with different levels of accuracy.

A [Co/Fe] vs. [Fe/H] diagram containing our four sets of abundance results, obtained without HFS and with the HFS data from S85, KLL, and our own HFS calculations, is presented in Fig. 3. It is clear that the Co abundances are not very sensitive to the inclusion of HFS: the difference between determinations carried out with and without HFS is at most 0.10 dex. This small influence of the HFS on the derived abundances is a consequence of the small EWs of the Co I lines in our sample stars – $\overline{EW(\mathrm{Co\,I})}$ = (23 ± 15) mÅ, even if we find quite pronounced differences in the HFS, as discussed above. For cooler stars, with stronger Co I lines, the effect of HFS would be considerably more pronounced. The differences in the average abundances obtained with HFS from different sources are small, being at most 0.07 dex.

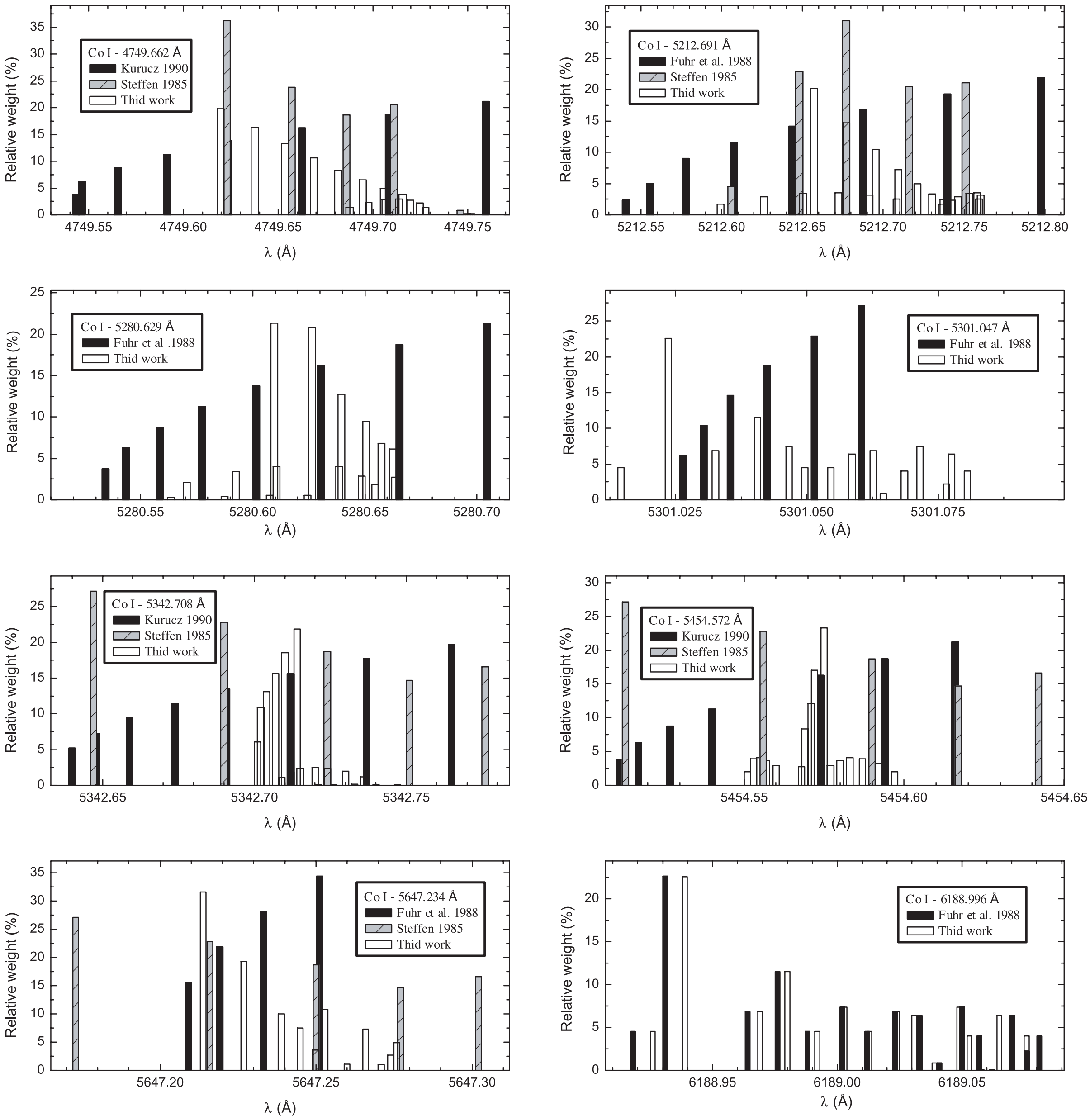

Fig. 2. HFSs of Co I lines from KLL, S85, and our own calculations. Note the dissimilarity of the structures (with the exception of the line at 6188.996 Å).

5. Abundance trends and comparisons with results from the literature

5.1. Manganese

In Fig. 4 we present a [Mn/Fe] vs. [Fe/H] diagram which compares our derived manganese abundances (from the HFS data in S85 and KLL) with the abundances obtained in the studies of NCSZ00 and PM00, both of which include HFS in their abundance calculations; NCSZ00 adopted HFS from S85, while PM00 used KLL. Inspection of this figure indicates the [Mn/Fe] abundances derived in this study overlap well with the results from PM00, but not with NCSZ00. NCSZ00 Mn abundances typically fall below all other abundance results. This apparent inconsistency can be explained by inhomogeneities in the database of S85: the HFSs of the Mn I lines used here (near 5400 Å) seem to have been accurately calculated, agreeing well with the HFSs from KLL, while those employed by NCSZ00 (near 6000 Å) seem to present important discrepancies. As noted before, HFSs for different lines, although from the same source, can have quite different levels of reliability.

The origin of Mn has been associated with its production in SN Ia or SN II, with the yields in SN II being strongly metallicity dependant. The Mn results from PM00, which were obtained from a sample of 119 F and G main-sequence stars from the thin disk, thick disk, and the halo, indicated that SN Ia's are the preferred source for Mn mainly because the run of [Mn/Fe] versus [Fe/H] showed a discontinuity at roughly −0.7 in [Fe/H]; this metallicity represents the transition between the thin disk and the thick dick/ halo. The overlap of our derived Mn abundances with those from PM00 would support the idea

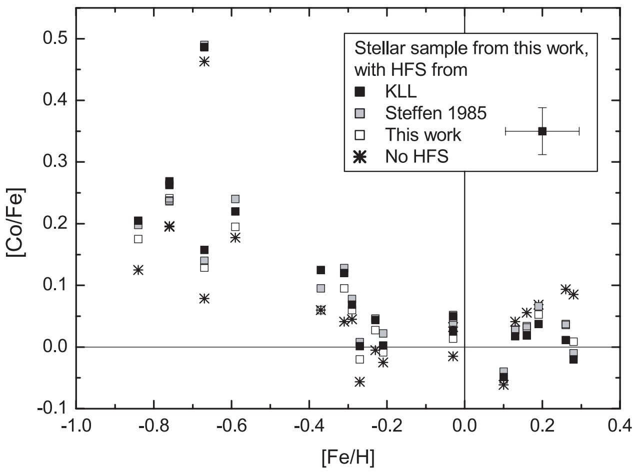

Fig. 3. [Co/Fe] vs. [Fe/H] diagram displaying our sample star results obtained without HFS and with three different sources of HFS (our own calculations; S85 and the Kurucz website, i.e., Kurucz 1990; and Fuhr et al. 1988). There is good agreement among all results, which indicates the small influence of HFS on Co abundance determinations. An average error bar is shown inside the legend box.

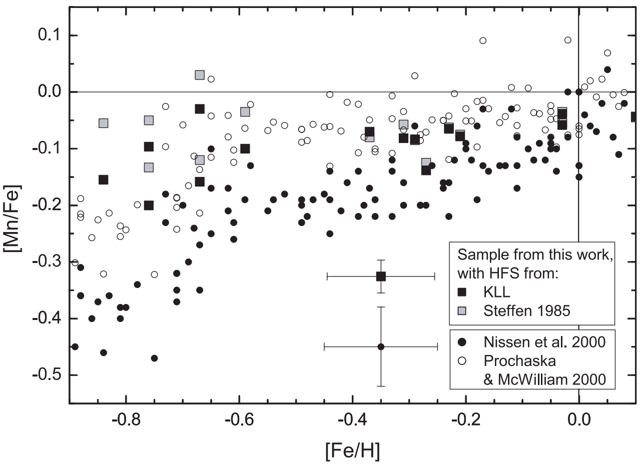

Fig. 4. [Mn/Fe] vs. [Fe/H] diagram displaying our sample star results obtained with two different sources of HFS – S85 and KLL. Also displayed are the objects from NCSZ00 and PM00. Both our sets of results agree well with PM00, for [Fe/H] $\gtrsim -0.5$. For the more metal-poor objects, a good match is obtained between our results using KLL HFS and PM00, whereas our results using S85 HFS tend to lie above PM00. Average error bars are displayed for our data (large, full square) and for those of NCSZ00 and PM00 (small, full circle).

that SN Ia are effective Mn producers, with no need to invoke production from metallicity dependant yields in SN II.

5.2. Cobalt

It is interesting to compare the cobalt abundance trends indicated by our data with the results from other studies in the literature that have analysed larger samples of stars. This is shown in Fig. 5, where we plot the [Co/Fe] abundances from the study of Reddy et al. 2003 (RTLAP03, top panel) and Allende Prieto et al. 2004 (APBLC04, bottom panel). The cobalt results from

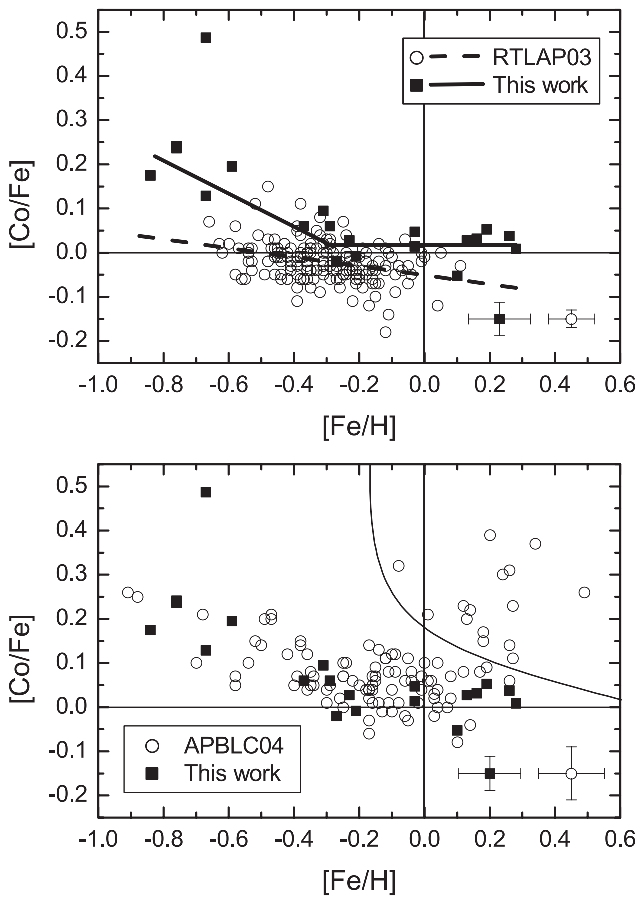

Fig. 5. Comparison of our [Co/Fe] results with results from the literature. *Upper panel*: RTLAP03. Average trends are shown as a thick, solid line for our data and a thick, dashed line for RTLAP03. *Lower panel*: APBLC03. A solid, curved line separates the objects that agree well with ours from those that do not. In both panels, average error bars are shown in the lower right corner.

this study in the figure are those obtained with our HFS calculations.

Inspection of the top panel of Fig. 5 indicates that the abundances obtained from our sample are roughly coincident with the upper envelope of the RTLAP03 distribution (for metallicities roughly between solar and −0.4). As indicated by the lower metallicity stars in our sample and by the thick line depicted in the figure, our Co abundances seem to exhibit a flat behaviour with nearly-solar values ($\overline{\text{[Co/Fe]}} = +0.02 \pm 0.03$) for stars with [Fe/H] ≥ -0.30, but increase linearly for the more metal-poor objects, reaching [Co/Fe] = +0.22 at [Fe/H] = −0.80. We note that RTLAP03 did not include HFS in their Co abundance calculations and that they used *EW*s of three lines, only one of which (at 5342 Å) was used in this study. Also, it seems that RTLAP03 tend to find [Co/Fe] lower than the solar value for stars around solar metallicities.

APBLC04 determined their Co abundances from *EW*s of six lines, three of which (at 5212 Å, 5280 Å, and 6188 Å) were also analysed here. They did not employ HFSs. Their abundance pattern is very similar to ours, with the same flattening for objects with [Fe/H] ≥ -0.30 and the same increase for more metal-poor objects. One major difference, however, is evident (although we have a much lower number of stars in our sample): APBLC04 data exhibit a strong increase in the [Co/Fe] abundance ratios for the objects with metallicities higher than the Sun, with a large abundance dispersion. This behaviour has also been reported by Feltzing & Gustafsson (1998) and Bodaghee et al. (2003). The discrepancy may be explained by the lack of HFS in their analyses. Note that the large majority of the stars with [Fe/H] > +0.1 in APBLC04 have $T_{\rm eff}$ ∼ 5000 K, resulting in stronger Co lines. For this reason, the lack of HFS would lead to an incorrect increase in the Co abundances of metal-rich objects. The authors of stellar abundance analyses often take into account the HFS of elements like Mn, Eu and Ba, but usually neglect Co HFS, leading to erroneous conclusions. We hope that, by virtue of the results presented here, future studies will always include Co HFS in their abundance determinations.

Comparing Figs. 3 to 4 we can see that the behavior of Co with metallicity is clearly distinct from that of Mn. The origin of cobalt, however, again involves production from both SN II and SN Ia, with the relative contributions still uncertain. [Co/Fe] rises from roughly solar metallicity to ∼+0.2, with a behaviour that is reminiscent of an alpha-element.

5.3. Europium

In Fig. 6 we compare our [Eu/Fe] abundance ratios to results from four other works: Mashonkina & Gehren (2000, MG00) and Mashonkina & Gehren (2001, MG01) – upper panel; Woolf et al. (1995, WTL95) and Koch & Edvardsson (2002, KE02) – lower panel. Such a comparison is also of interest because it can ultimately provide us with some additional check on our HFS calculations.

MG00 and MG01 obtained Eu abundances for samples of halo and disk stars, taking into account a non-local thermodynamical equilibrium (NLTE) line formation. For comparison with our results, we have retained only the disk stars with metallicities [Fe/H] ≥ −1.00 and with accurate determinations of Eu abundances (i.e., those not marked by ":" in their tables). HFSs were calculated by the authors using data from Becker et al. (1993) and Broström et al. (1995), as we did, but they simplified the adopted structure by grouping close-by components together, like S85. Spectral synthesis was employed to analyse the same line we used. Our results agree well with theirs for stars with [Fe/H] ≥ −0.50, but are lower for the more metal-poor objects.

The Eu abundances from WTL95 and KE02 were determined by spectral synthesis using the same line we used, following a procedure identical to ours. The HFS used by WTL95 was taken from Krebs & Winkler (1960), who group close-by components together, arriving at a total of 6 components per Eu isotope. KE02 calculated their own HFS based on data taken from Broström et al. (1995), also used here, retaining the complete, detailed structure (16 components per isotope). NLTE effects are minimal, because they are partially canceled out in the differential analysis (as also happens in our work). KE02 merged their database with that from WTL95 by means of a simple linear conversion, obtained by

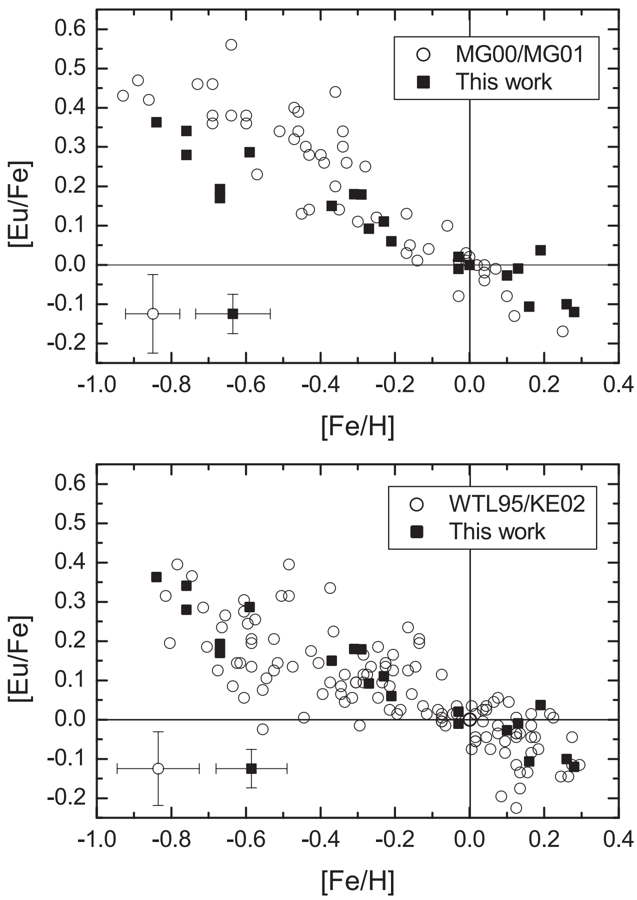

Fig. 6. Comparison of our [Eu/Fe] results with the literature. *Upper panel*: MG00/MG01. *Lower panel*: WTL95/KE02. The average error bars from these works are displayed in the lower left corners of both panels.

intercomparison. Our abundances show a behaviour very similar to that of WLT95/KE02, but with considerably lower scatter, as evident in the lower panel of Fig. 6. Concerning the origin of Eu we refer the reader to the thorough discussion of WTL95, where they conclude that low-mass type II supernovae are favoured as the main *r*-process site (97% of all Eu is produced by the *r*-process, according to Burris et al. 2000).

6. Conclusions

We present Mn, Co and Eu abundances for a sample of 20 disk dwarfs and subgiants of F5 to G8 MK spectral types with −0.8 ≤ [Fe/H] ≤ +0.3. Our abundance trends for Mn with metallicity are found to confirm the abundance results from Prochaska & McWilliam (2000), although both studies used different sets of Mn I lines in the analyses, so this represents an independent confirmation of the trend obtained in their study, which favours type Ia supernovae as the main astrophysical site of Mn nucleosynthesis. In particular, our Mn results are in disagreement with the trends previously found by Nissen et al. (2000), due to uncertainties in the HFS adopted in their study. For Co, our results are in good agreement with the trends with metallicity delineated by Allende Prieto et al. (2004) for objects with [Fe/H] < 0.0, but significant discrepancy is found for those with higher-than-solar metallicity. The increase in Co abundances and high dispersion found by APBLC04 for the latter objects has been previously reported by Feltzing & Gustafsson (1998) and Bodaghee et al. (2003). We believe this behaviour may be attributed to the lack of HFS in their analyses. A comparison of our Co results with those by Reddy et al. (2003) indicates that our Co abundances fall mostly in the upper envelope of their distribution, for metallicities lower than solar. The underabundance of their results may also be connected to the lack of HFS in their analysis. Our Eu trend with [Fe/H] was found to be in excellent agreement with other studies in the literature (particularly with Woolf et al. 1995; and Koch & Edvardsson 2002).

In order to investigate the influence of HFS on the Mn and Co abundances derived from our sample lines, we conducted calculations with different HFSs from the literature, as well as with HFSs calculated by us. For Mn, we find that for the four Mn I lines around 5400 Å, the approximate HFS calculations of S85 lead to nearly the same Mn abundances as obtained with HFS from KLL. There are, however, large differences in the Mn abundances calculated from the Mn I lines around 6000 Å, as pointed out by Prochaska & McWilliam (2000). The Co abundances in this study (which were obtained from weak lines) are weakly sensitive to HFS, presenting a 0.10 dex maximum difference between determinations with and without HFS; they also are weakly dependent on some details of the HFS calculations, such as small variations between the selected A and B interaction factors and grouping of close-by components. However, it is important to note that the HFSs from different sources differ significantly and the differences vary in magnitude for different Co I lines. These inconsistencies in the HFS data for different lines reported here would suggest that great care has to be taken when considering the abundance of certain elements that require HFS calculations.

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