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Research Note

Abundances of a sample of A and F-type dwarf members of the Ursa Major Group⋆,⋆⋆

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ABSTRACT

Abundances of 11 chemical elements have been determined for 10 F and 12 A dwarfs ("normal" and chemically peculiar) bona-fide and probable members of the Ursa Major Group (age about 500 Myr). The abundances were determined in a uniform manner using a model atmosphere analysis by minimising the chi-square of grids of synthetic spectra to observed high resolution high S/N ($R \simeq 25\,000$ and $R \simeq 70\,000$) spectra obtained in three narrow spectral regions centered around 5075 Å, 5525 Å and 6160 Å. Specifically, Takeda's (1995) semi-automated procedure was used to derive the abundances of C, O, Na, Mg, Si, Ca, Sc, Fe, Ni, Y, and Ba, the projected rotational velocity $v_{\rm e} \sin i$ and the microturbulent velocity for each star analysed. In graphs [X/H] versus $T_{\rm eff}$, the A stars exhibit larger star-to-star variations in [Fe/H], [Ni/H], and [Si/H] than the F dwarfs do. The abundance of nickel is the only one that appears to be correlated with that of iron.

Key words. stars: abundances – stars: rotation – open clusters and associations: individual: Ursa Major Group

1. Introduction

Abundance determinations in A and F dwarfs in open clusters or in moving groups of known properties aim at elucidating the mechanisms of mixing at play in the interiors of main-sequence stars. In a previous paper (Varenne & Monier 1999), abundance determinations were presented for 19 A and 29 F dwarfs in the Hyades. The motivation of this Research Note is to report on new abundance determinations of 11 chemical elements in 12 A and 10 F bona-fide or possible members of a moving group, the Ursa Major group (age about 500 Myr i.e. slightly younger than the Hyades). Five of these stars are members of its nucleus. The chemical composition of field and open cluster A dwarfs is still poorly known, and high resolution high signal to noise observations of these fairly bright objects are needed. The spectroscopy presented here is part of an ongoing program aiming at observing A and F dwarfs in galactic open clusters of various ages in order to set constraints on self-consistent models of the interiors of these objects, including various hydrodynamic and particle transport processes (Monier & Richard 2005).

The kinematics of the Ursa Major Group has been thoroughly studied by Roman (1949) who highlighted the existence of a central nucleus, the other members of the moving group being spread out over a large fraction of the sky. She collected a list of 365 putative members and a second tighter list of 135 probable members based only on kinematical grounds. Eggen (1960, 1983) later produced membership lists for the "Sirius Group" and the Sirius moving supercluster which contains the UMa group. Ages for the UMa group have been estimated from its H-R diagram and theoretical models by Levato & Abt (1978) who found 3×10^8 yr. Giannuzzi (1979) proposed an age of 2.7×10^8 yr from a careful study of eclipsing binaries, while Palous & Hauck (1986) derived an age of $4.9(\pm 1.3) \times 10^8$ yr in their study of A stars of the group. Soderblom & Mayor (1993) readdressed the membership of the stars listed in Roman (1949) and Eggen (1960) using compilations of new radial velocities, new astrometric data, and new spectroscopic observations, in particular chromospheric emission. They could thus restrict the membership list to 37 probable bona-fide members and 6 possible members. More recently, King et al. (2003, refered to as K2003 in what follows) have also revisited UMa membership using *Hipparcos* parallaxes, new accurate radial velocities, new Ca II H and K measurements, updated photometry (in particular for the resolved close binaries), and abundance estimates from the literature. They produced a final "clean list" based on kinematic

⋆ Based on spectroscopic observations performed at the Observatoire de Haute-Provence (France).
⋆⋆ Table 2 is only available in electronic form at http://www.edpsciences.org

Table 1. List of the observed A and F dwarfs: 6 are confirmed members of the UMa moving group and 16 are probable/possible members in King et al. (2003). Spectral types are from Gray & Garrison (1987, 1989a,b) or from SIMBAD.

HR	HD	Type	m_V	$T_{\rm eff}$ (K)	$\log g$	$v_{\rm e} \sin i$ ($\rm km\,s^{-1}$)	ξ_t ($\rm km\,s^{-1}$)	Membership	Comments
235[†]	4813	F7IV-V	5.17	6229	4.43	6	1.0	?	
330	6763	F0III-IV	5.51	6922	4.00	85	1.9	?	
534	11257	F2V	5.92	7005	4.05	17	2.3	?	
3998	88355A	F7V	6.43	6596	4.32	19	1.5	?	binary
4141	91480	F1V/F1V	5.16	7018	4.30	39	2.0	Y	nucleus
	111456	F5V	5.84	6417	4.59	37	1.5	Y	nucleus
	113139	F5V	4.93	6927	4.20	103	1.5	Y	nucleus
5830	139798	F2V	5.76	6782	4.23	68	3.8	?	
	151044	F8V	6.48	6298	4.61	8.4	0.9	?	
7451	184960	F7V	5.71	6392	4.30	9.8	1.4	Y?	
68	1404	A2V/A2V	4.51	8948	3.99	125	3.0	?	
290	6116A	A5m	5.95	8073	3.93	34	5.0	?	binary
378	7804	A3V	5.13	8731	3.78	124	4.0	Y	
599	12471A	A2V	5.50	9299	3.76	121	3.0	?	binary
2763	56537A	A3V/A4IV	3.58	8482	3.91	156	4.0	?	SB
	95418	A1 V	2.35	9600	3.83	46	2.5	Y	nucleus
	116657	A1m	3.86	8425	4.40	61	3.5	Y	nucleus
7781	193592A	A2V	5.76	8274	4.18	27	4.5	?	binary
8291	206538A	A2V	6.07	8792	3.60	165	3.0	?	binary
8407	209515A	A0IV	5.57	10 073	3.74	64	2.5	?	
8709	216627	A3V/A3IV-V	3.27	8657	3.56	81	3.6	Y?	
8984	222603	A7V/A6IV	4.49	7964	4.03	56	5.1	?	

and photometric criteria, which contain 31 assured members, all quoted as "Y" in their Table 5 (among which are 12 A stars and 5 F stars). The adjustment of isochrones to the final UMa members shows that the age of the UMa group is 500±100 Myr, i.e. 200 Myr older than previous estimates.

The abundances of lithium, berylium, boron of several F dwarfs in the UMa group have been extensively studied by Boesgaard and her collaborators (see Boesgaard et al. 1988; Soderblom et al. 1993; Boesgaard et al. 2003; and Boesgaard 2004). The iron and carbon content of several F dwarfs in the UMa group have also been determined by Boesgaard et al. (1988), Boesgaard (1989) and Friel & Boesgaard (1990), who found that iron and carbon are slightly deficient in this moving group. The mean iron abundance is $[\mathrm{Fe/H}] = -0.082 \pm 0.021$ and the mean carbon abundance is $[\mathrm{C/H}] = -0.12 \pm 0.05$ (Friel & Boesgaard 1990).

2. Program stars, observations, and data reduction

The selection criteria of stars, the observational procedure, and data reduction are the same as in Varenne & Monier (1999). We observed 5 A and F dwarfs members of the nucleus of the UMa stream (quoted as "Y" in K2003) rotating at $v_{\rm e} \sin i \leq 120\ \mathrm{km\,s^{-1}}$, plus 1 confirmed member of the stream and 16 probable (quoted as "Y?" in K2003) and possible (quoted as "?" in K2003) members. In addition, Procyon was observed as control star for the abundance analysis. These observations were carried out with the AURELIE spectrometer (Gillet et al. 1994) placed at the coudé focus of the 152 cm telescope at Observatoire de Haute Provence. Fundamental data for the programme stars are collected in Table 1. The star identifications (HR and HD numbers) appear in Cols. 1 and 2, the spectral types retrieved from Gray & Garrison (1987, 1989a,b) or else from SIMBAD in Col. 3, and the apparent magnitudes, m_V in Col. 4. Columns 5 to 8 display the effective temperatures, surface gravities, rotational velocities, and microturbulent velocities as derived in our analysis (see Sect. 3.). The membership status and comments appear in Cols. 9 and 10. Six stars are binaries or belong to multiple systems and one is a spectroscopic binary. Inspection of the Catalogue of Components of Double and Multiple stars (CCDM, Dommanget et al. 1995) reveals that the companions of HD 6116A, HD 12471A, HD 206538A and HD 209515A are all much fainter than the primary stars and distant enough from them so that their spectra cannot have contributed to the spectra observed. The companions of HD 88355A and HD 6116A are only about 1 mag fainter and may have been close enough to the primary stars to contribute light to the spectra. Their spectral type being unknown, no correction for the light of the companion was attempted. Abundances were derived for HD 88355A, HD 6116A, and the spectroscopic binary HD 56537, but they may be erroneous.

Three spectral regions centered on $\lambda 6160$ Å (region 1), $\lambda 5080$ Å (region 2) and $\lambda 5530$ Å (region 3) were observed as they include several lines with accurate oscillator strengths for the chemical elements we study. Regions 1 and 2 are those observed by Edvardsson et al. (1993) in their spectroscopic survey of F dwarfs in the galactic disk. For the brightest stars ($V \leq 6$), grating 5 working at its second order (for region 1) and grating 1 (for region 2) yielded resolving powers equal to 60 000 and 65 000, respectively. For the faintest stars ($V > 6$), grating 7 was used resulting in resolving powers of 36 000 and 28 000 (for regions 1 and 2, respectively). In region 3, all stars were observed with grating 7 (R = 31 000) except for Procyon. According to the V magnitude and weather conditions, exposure times between a few minutes to 90 min were necessary to secure signal to noise ratios ranging from 200 (around $m_V = 6.0$) to 500 (around $m_V = 2.0$). The high S/N ratios are required to locate the stellar continuum accurately. The MIDAS software was used to reduce all spectra following the standard procedure (offset removal, division by the flat field, wavelength calibration). The spectra of the narrow lined stars were used to locate continuum windows through which cubic splines were interpolated. Careful inspection of the spectra of the few fast rotators indicates that some of these windows can still be used, and convolution of the synthetic spectra by the appropriate rotational profiles confirms this. All spectra were then rectified to their continua.

3. Chemical abundance analysis

3.1. Method and input data

The effective temperatures ($T_{\rm eff}$) and surface gravities ($\log g$) of the stars were determined using Napiwotzki's (1992) UVBYBETA calibration of the Strömgren photomery indices *uvby* in term of $T_{\rm eff}$ and $\log g$. The errors on $T_{\rm eff}$ and $\log g$ are estimated to be ±125 K and ±0.2 dex, respectively. Model atmospheres were then calculated using Kurucz's ATLAS9 code, assuming a plane parallel geometry, a gas in hydrostatic and radiative equilibrium, and LTE. Calculations were carried out with a depth independent microturbulence of 2.0 km s^{-1} and a solar metallicity taken from Grevesse & Noels (1993). For stars with $T_{\rm eff} \leq 9000$ K, convection was taken into account in the model computations with a mixing-length ratio equal to 1.25.

The line opacity calculation uses the 58 million line list compiled by Kurucz (Kurucz 1992a,b).

The line lists and atomic parameters used to calculate the synthetic spectra are given in Table 3 of Varenne & Monier (1999). Abundances for 11 chemical elements were derived by adjusting synthetic spectra to the observed normalized spectra and minimizing the chisquare of the models to the observations. Spectrum synthesis is the only method applicable to the fastest rotators. Specifically, synthetic spectra were computed assuming LTE using Takeda's (1995) iterative procedure (see Takeda 1995; and Varenne & Monier 1999, for a description).

The procedure outputs the abundance of elements of interest, the microturbulence (ξ_t) constant with depth, the apparent rotational velocity, and the wavelength shift relative to the laboratory frame. The lines studied here are weak lines which are essentially formed deep in the atmosphere where LTE should prevail. They are well suited for abundance determinations.

In practice, complete convergence was reached for each star after 2 sets of 5 iterations, i.e. 10 calculations. As suggested by Takeda (1995), we first fixed the $v_{\rm e} \sin i$ value (taken from Uesugi & Fukuda 1982, for F dwarfs; or from Abt & Morrell 1995, for A dwarfs) and the microturbulence (derived from Nissen's 1981, fit for F-type stars and set equal to 3 km s^{-1} for the A stars) for iterations 1 to 5. For the 5 remaining iterations, $v_{\rm e} \sin i$ and ξ were left as free parameters using abundances determined in the first step of the procedure.

3.2. Results and uncertainties

Takeda's procedure was first checked on Procyon, whose atmospheric parameters and abundances are fairly well known (Steffen 1985). The derived $v_{\rm e} \sin i$ and ξ_t and the abundances agree well with those determined by Steffen. The differences $\Delta[\frac{\rm X}{\rm H}] = [\frac{\rm X}{\rm H}]_{\rm this\ study} - [\frac{\rm X}{\rm H}]_{\rm other}$ are less than 0.1 dex for 8 out of 11 elements and less than 0.15 dex for the 3 remaining (C , Y, and Ba). The abundances for the 22 UMa group stars relative to the Sun ($[\frac{\rm X}{\rm H}] = \log(\frac{\rm X}{\rm H})_\star - \log(\frac{\rm X}{\rm H})_\odot$) are collected in Table 2 together with a mean value and a standard deviation.

The main sources of uncertainties for the abundances stem from those on the effective temperatures, surface gravities, microturbulent velocities, oscillator strengths, and apparent rotational velocities which are assumed to be independent. For the fastest rotators, the placement of the continuum is less secure and induces an additional error on the abundances. Table 5 in Varenne & Monier (1999) lists, for each chemical element and for 8 stars of different effective temperatures, typical uncertainties on the abundances, caused by representative uncertainties on $T_{\rm eff}$, $\log g$, and ξ_t only. The actual errors on the abundances are higher , probably around 0.30–0.40 dex, as they must include the uncertainty caused by the oscillator strengths and that on the rotational velocity. Only 2 lines, BaII λ6141.713 Å and ScII λ5526.790 Å, were found to be sensitive to the microturbulent velocity.

4. Discussion and conclusion

The iron and carbon abundances of a few F stars studied here (HR 235, HR 330, HR 534, HR 5830, HR 7451, and HD 151044) have been determined by Boesgaard (1989) and Friel & Boesgaard (1990) from a model atmosphere analysis of equivalent widths (see Boesgaard & Tripicco 1986). Comparison of our determinations to theirs reveals differences that are always smaller than 0.10 dex which is less than the actual errors on [Fe/H] and [C/H]. This seems satisfactory considering that we did not use exactly the same effective temperatures for these stars as FB90 nor the same model atmospheres and method of analysis.

The chemical pattern found for the A and F dwarfs of the UMa group resembles that found in the Hyades (Varenne & Monier 1999). In graphs where [X/H] is displayed versus $T_{\rm eff}$, in particular for iron, nickel, and silicon, the A dwarfs display abundances which are more scattered around the mean value for the group than the F stars do, the mean abundance being only calculated from the F dwarfs. This is readily seen in Fig. 1 which displays the iron abundance for the 22 stars analysed. The mean iron abundance for the F dwarfs is found to be −0.06 ± 0.10 dex in very good agreement with Boesgaard (1989) (−0.08 ± 0.02 dex). The A dwarfs thus exhibit larger star-to-star variations in [Fe/H], [Ni/H], and [Si/H] than the F dwarfs. Even when HD 88355A, HD 193592A, and HD 56537A (for which contamination by the light of a nearby companion might have occured) are removed, the scatter of the

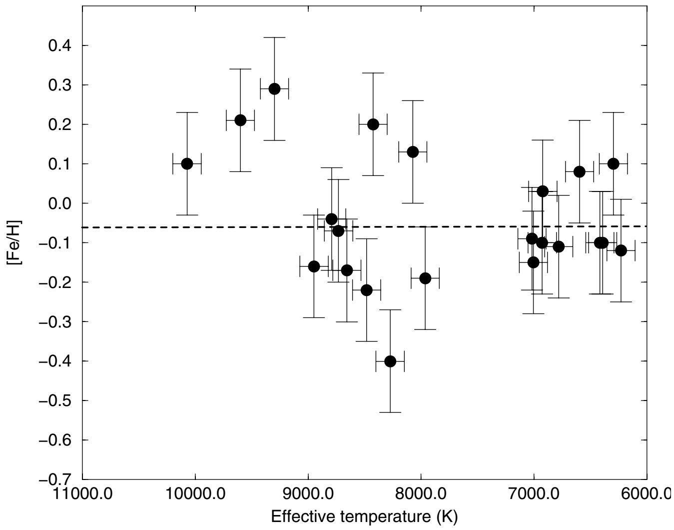

Fig. 1. [Fe/H] versus $T_{\rm eff}$ for the 22 stars analysed. The dashed line represents the mean [Fe/H] for the F dwarfs.

A dwarfs remains larger than that of the F dwarfs. The two Am stars analysed, HD 6116A and HD 116657, display characteristic deficiencies in calcium and scandium, and enrichments in heavy elements (iron, nickel and baryum). They are also markedly deficient in oxygen. Some of the normal A stars have overabundances in Ni, Y and Ba. No convincing trend of the abundances [X/H] versus $v_{\rm e} \sin i$ was found. The abundance of nickel appears to be correlated to that of iron (correlation coefficient = 0.88), but [Si/H] and [Na/H] do not. The [Ni/H] versus [Fe/H] correlation is only slightly improved when HD 88355A, HD 193592A and HD 56537A are removed. A correlation of [Ni/H] with [Fe/H] was also found by Hill (1995) in his study of a few field A dwarfs.

The most recent evolutionary models of A and F stars (Richer et al. 2000; Richard et al. 2001; Michaud 2005) include the effects of atomic diffusion for all species with Z less than 30. The predicted abundance patterns ([X/H] versus Z) succeed in reproducing the overall shape of the observed abundance pattern (i.e. underabundances for the lightest elements C, N and O and overabundances for the iron-peak elements). For the iron-peak elements, the predicted surface abundances are commonly 3 times larger than the ones derived from spectroscopy. Turbulent transport was added to counteract diffusion and improve the agreement with the abundances derived from spectroscopy. Although models for the age of the UMa group have not yet been published, the found C and O underabundances in this analysis do indicate that these two elements seem to indeed be underabundant in the atmospheres of A and F dwarfs aged 500 Myr. However the predicted overabundances in Fe and heavier elements are actually seen only in a few stars suggesting that competing processes must counteract radiative diffusion in at least a number of the stars analysed here.

The spectroscopy of a much larger number of stars in the UMa group is obviously necessary in order to address the abundance pattern of the F and A dwarfs in this moving group. Abundance determinations for more chemical elements are also necessary to set stronger constraints on evolutionary models including transport processes.

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Table 2. Abundances ($[X/H] = \log(X/H)_\star - \log(X/H)_\odot$) for the A and F dwarfs of the UMa moving group.

HD	SpT	C I	O I	Na I	Mg I	Si I	Ca I	Sc II	Fe I	Ni I	Y II	Ba II
4813	F7IV–V		−0.40	−0.19	−0.32	−0.15	−0.04	−0.28	−0.12	−0.12		0.30
6763	F0III–IV		0.03	0.39	0.08	−0.11	0.09	0.13	+0.03	+0.02		0.51
11257	F2V	−0.40	−0.42	−0.36	−0.31	−0.42	−0.31	−0.31	−0.15	−0.17	−0.28	−0.14
88355	F7V	+0.18	−0.55	−0.10		−0.03	−0.02		+0.08	+0.09	−0.10	0.06
91480	F1V/F1V	0.00	−0.16	−0.21	0.13	−0.10	−0.14	0.02	−0.09	−0.16	−0.05	0.12
111456	F5V		0.00	−0.27		−0.09	−0.10		−0.10	−0.11		+ 0.07
113139	F5V		0.00	−0.27		−0.10	−0.10		−0.10	−0.11		+ 0.07
139798	F2V		0.00	−0.20		−0.38	−0.51		−0.11	−0.12		−0.66
151044	F8V		−0.35	0.00		0.00	0.07		0.10	0.13		0.26
184960	F7V		−0.35	−0.12		−0.05	0.01		−0.10	−0.09		0.15
$\langle[X/H]\rangle$		−0.07	−0.27	−0.09	−0.10	−0.15	−0.10	−0.11	−0.06	−0.06	−0.14	0.07
σ		±0.16	±0.20	±0.22	±0.24	±0.16	±0.22	±0.22	±0.10	±0.23	±0.12	±0.35
1404	A2V/A2V		−0.10		−0.11	0.27	−0.22	−0.01	−0.16			0.03
6116	A5m		−0.57	0.34		−0.07	−0.62	−0.47	+0.13	0.46		0.43
7804	A3V		−0.29		−0.11	0.31	−0.01	0.05	−0.07			0.05
12471	A2V		−0.23		0.24	0.78	0.09	0.17	0.29			0.69
56537	A3V/A4IV		0.00	0.15	0.00		0.04	0.11	−0.22	−0.09		−0.08
95418	A1V	−0.20	+0.35		−0.11		−0.10	−0.24	+0.21	+0.60	+0.72	+1.12
116657	A1m		−0.47	0.24		+0.07	−0.53	−0.56	+0.20	0.36		0.54
193592	A2V		−0.12	0.08		−0.26	−0.48		−0.40	−0.27		−0.49
206538	A2V		−0.03		−0.12	0.11	0.12	−0.07	−0.04			
209515	A0IV		−0.77				0.32		0.10			−0.68
216627	A3V/A3IV-V		−0.39		−0.39	−0.29	−0.01	0.05	−0.17			0.07
222603	A7V/A6IV	−0.10	−0.25	0.01	−0.33	−0.12	−0.15	−0.11	−0.19	−0.10	0.07	−0.12
$\langle[X/H]\rangle$		−0.15	−0.24	0.16	−0.12	0.09	−0.13	−0.11	−0.03	−0.16	0.40	0.14
σ		±0.07	±0.25	±0.26	±0.26	±0.24	±0.26	±0.25	±0.21	±0.23	±0.28	±0.40