

UVES observations of the Canis Major overdensity[★]

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Abstract. We present the first detailed chemical abundances for three giant stars which are candidate members of the Canis Major overdensity, obtained by using FLAMES-UVES at VLT. The stars, in the background of the open cluster NGC 2477, have radial velocities compatible with a membership to this structure. However, due to Galactic disc contamination, radial velocity by itself is unable to firmly establish membership. The metallicities span the range $-0.5 \lesssim [\text{Fe}/\text{H}] \lesssim +0.1$. Assuming that at least one of the three stars is indeed a member of CMa implies that this structure has undergone a high level of chemical processing, comparable to that of the Galactic disc. The most metal-rich star of the sample, EIS 6631, displays several abundance ratios which are remarkably different from those of Galactic stars: $[\alpha/\text{Fe}] \sim -0.2$, $[\text{Cu}/\text{Fe}] \sim +0.25$, $[\text{La}/\text{Fe}] \sim +0.6$, $[\text{Ce}/\text{Fe}] \sim +0.8$ and $[\text{Nd}/\text{Fe}] \sim +0.6$. These ratios make it likely that this star was formed in an external galaxy.

Key words. stars: abundances – stars: atmospheres – galaxies: abundances – galaxies: evolution – galaxies: dwarf

1. Introduction

In the framework of the hierarchical merging scenario for the galaxy formation, dwarf galaxies play the role of “building blocks” of the larger structures like the Milky Way (MW). Nevertheless, the *present day* dwarf galaxies in the Local Group (LG) appear to be somewhat undesirable building blocks: their chemistry is significantly different from the one found both in the MW Disc and Halo systems (Venn et al. 2004). This is not surprising, since a long evolution took place, after the main merging phase, in the “survived” dwarf galaxies (Lanfranchi & Matteucci 2003). Nevertheless, merging events are still taking place in the MW, as testified by the discovery in the Halo of the stream related to the Sagittarius dwarf Spheroidal galaxy (Sgr dSph, see Ibata et al. 2001; Majewski et al. 2003). The Sgr dSph itself displays a peculiar chemical composition (Bonifacio et al. 2000a, 2004), leading to think that chemically peculiar subpopulations, traces of past or ongoing merging events, should be identifiable in the Galactic Disc or Halo.

Recently Martin et al. (2004a) claimed the discovery of the core of a tidally disrupted dwarf galaxy, still recognizable as an overdensity in the external Galactic disc in Canis Major (Canis Major Overdensity or CMa from now on). In a subsequent paper (Bellazzini et al. 2004) they recognized the same population also in the background of the Galactic open cluster NGC 2477 at $\approx 13^\circ$ from the CMa centre.

[★] Based on observations obtained in the ESO Director’s Discretionary Time program 272-B.5017.

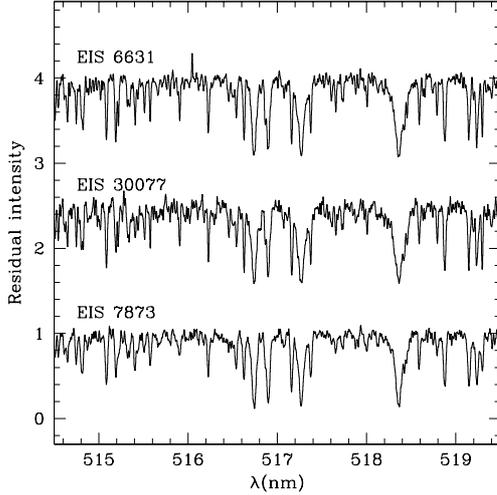
The authors situate the structure at about 7 kpc from the Sun and about 16 kpc from the Galactic Centre, and estimate a mass of about $10^7 M_\odot$, which would make it the nearest known external galaxy. They also associate it to the ring-like structure known as Monoceros Ring (Newberg et al. 2002), Ring (Ibata et al. 2003) or GASS (Galactic Anticentre Stellar Structure, see Crane et al. 2003 and Frinchaboy et al. 2004). Bellazzini et al. (2004) also inferred a possible connection with some Galactic globular clusters, among others NGC 2808. Shortly afterwards, Momany et al. (2004) questioned the effective existence and size of CMa, claiming that the anomaly could be explained, to a large extent, by properly taking into account the Galactic disc warp, which is maximum in the CMa direction. Bellazzini et al. (2004) examined and rejected this hypothesis, and so did Martin et al. (2004b), deriving for the centre of the structure a radial velocity of 109 km s^{-1} , with a low velocity dispersion of 13 km s^{-1} , both difficult to reconcile with the dynamics of the local disc.

2. Data reduction and analysis

Shortly after the announcement of the discovery of CMa, we obtained Director’s Discretionary Time (DDT) at VLT-FLAMES with the aim of probing the dynamics and chemical composition of the newly discovered structure. Bellazzini et al. (2004) detected the CMa population in the background of NGC 2477 using the EIS pre-FLAMES photometry and astrometry of Momany et al. (2001) which is publicly available. We therefore observed this field selecting in the EIS

Table 1. Photometry and physical parameters for the three stars.

Star	α (J2000.0) hms	δ ° ' "	V mag	$(V - I)_0$ mag	T_{eff} K	$\log g$ cgs	[Fe/H] dex	ξ km s ⁻¹	V_{rad} km s ⁻¹
EIS 6631	07 51 36.2	-38 31 10	16.35	0.75	5367	3.5	+0.15	1.80	135.4
EIS 7873	07 52 37.1	-38 28 01	16.26	0.89	4990	2.3	-0.42	1.80	111.1
EIS 30077	07 51 41.0	-38 38 39	16.51	0.89	4994	2.8	-0.04	1.45	97.0

**Fig. 1.** Spectra of the three most probable CMa stars, in the region of the Mg b triplet. [Fe/H], $\log(g)$ and T_{eff} all increase from bottom to top. The spectra are normalized to one, stars 30077 and 6631 are shifted vertically for display purposes (continuum is at 2.5 for 30077 and at 4 for 6631).

photometry Red Giant/Clump stars possible CMa members. Observations were performed between January and March 2004 and consisted of 4×3045 s exposures, using the HR09 setting for GIRAFFE fibers, and the UVES setting centred at 580 nm.

In this letter we describe the detailed chemical analysis of 3 of the 7 UVES stars obtained with FLAMES; the analysis of the stars observed with GIRAFFE has been described briefly in Zaggia et al. (2004) and will be the object of a separate paper. The four spectra of each star have been corrected to heliocentric radial velocity and then coadded. Due to the very low S/N ratio, they have been convolved with a 5 km s^{-1} FWHM Gaussian, degrading the resolution to about 33 000, reaching a S/N of about 40 per pixel at 580 nm. By combining our UVES and GIRAFFE radial velocity measurements with those of Martin et al. (2004b) in the direction of CMa centre, those of Yanny et al. (2003) for the Monoceros Ring and data for open and globular clusters, we show in Zaggia et al. (2004) that, assuming all these objects belong to the same structure, its motion is consistent with an object in circular motion at the distance of 15 kpc from the Galactic Centre, and circular velocity of 220 km s^{-1} . This result is not very different from that derived by Frinchaboy et al. (2004) who prefer a distance of 18 kpc. In the observed field CMa member stars are thus expected to have radial velocities $>100 \text{ km s}^{-1}$. This led us to exclude from our sample two stars (EIS 4383 and EIS 31581) which showed near-to-zero radial velocities. $E(V - I)$ color excesses

Table 2. Abundance ratios for the three stars. [X/Fe I] is used for neutral elements, [X/Fe II] for ionized species, and [Fe/H] for Fe I and Fe II. Errors are 1σ intervals, “ n ” is the number of lines used.

	EIS 6631		EIS 7873		EIS 30077	
	[X/Fe]	n	[X/Fe]	n	[X/Fe]	n
Na I	0.18 ± 0.18	4	0.18 ± 0.10	3	-0.10 ± 0.15	4
Mg I	-0.49 ± 0.11	3	-0.18 ± 0.23	3	-0.01 ± 0.15	4
Al I	-0.21 ± 0.14	2	-0.14 ± 0.13	2	-0.24 ± 0.14	2
Si I	-0.21 ± 0.14	4	0.10 ± 0.11	4	-0.27 ± 0.16	4
Ca I	-0.22 ± 0.16	11	0.02 ± 0.16	9	-0.08 ± 0.18	7
Sc II	-0.03	1	-0.28 ± 0.14	2	-0.20 ± 0.20	2
Ti I	0.18 ± 0.16	7	-0.02 ± 0.14	5	0.13 ± 0.16	7
V I	0.33 ± 0.19	3	0.31 ± 0.12	2	0.49 ± 0.14	2
Mn I	-0.02	1	-0.12	1	0.12	1
Fe I	0.15 ± 0.11	20	-0.42 ± 0.10	15	-0.04 ± 0.13	21
Fe II	0.12 ± 0.17	13	-0.37 ± 0.13	8	-0.07 ± 0.08	8
Co I	0.25 ± 0.21	2	-0.17	2	0.06 ± 0.13	2
Ni I	0.02 ± 0.18	15	-0.09 ± 0.19	13	-0.21 ± 0.15	11
Cu I	0.25	1			0.23	1
Y II	0.19 ± 0.21	3	-0.15 ± 0.13	2	-0.61 ± 0.13	3
Ba II	0.21	1	0.37	1	0.07	1
La II	0.61 ± 0.24	2	0.26 ± 0.14	2	0.67 ± 0.10	2
Ce II	0.78 ± 0.25	3	0.16	1	0.21 ± 0.09	2
Nd II	0.59 ± 0.20	2	-0.01 ± 0.18	3	0.36 ± 0.13	4
Eu II	0.21	1	0.20	1	0.10	1

were derived from Schlegel et al. (1998) maps, as corrected by Bonifacio et al. (2000b). Effective temperatures were derived from the Alonso et al. (1999) calibration for giant stars. The abundance analysis was performed in a traditional manner by using our Linux porting of the ATLAS, WIDTH and SYNTH codes (see Kurucz 1993 and Sbordone et al. 2004). We noticed that, at variance with the other two stars, the lines of EIS 7873 appear to be somewhat broader than the instrumental resolution. We derived the final gravity by forcing Fe I – Fe II ionization equilibrium. In this phase, two more stars (EIS 2812 and EIS 5429) proved to be dwarfs ($\log g > 4.0$), and thus incompatible with a heliocentric distance of the order of 7 kpc. The coordinates, photometry and atmospheric parameters for the three remaining stars are detailed in Table 1, which provides also heliocentric radial velocities.

Synthetic spectra were computed with SYNTH to derive the elemental abundance, taking into account HFS splitting for Co I, Cu I, Eu II.

The atomic data and lines used are essentially the ones used in Bonifacio et al. (2000a), the line list for iron and α elements has been expanded, and new $\log(gf)$ used for Mg I (Gratton et al. 2003), Ca I (Smith & Raggett 1981), La II (Lawler et al. 2001) Nd II (Den Hartog et al. 2003) and Eu II (Lawler et al. 2001a). The equivalent widths and atomic data used are available on request. Derived abundances are listed in Table 2.

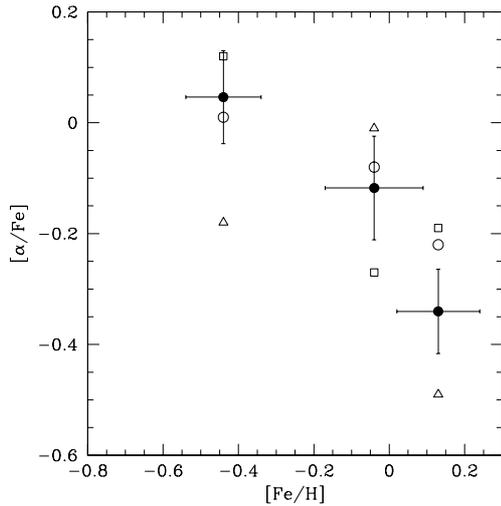


Fig. 2. Alpha elements abundances for the three sample stars, plotted against $[\text{Fe}/\text{H}]$. Triangles are Mg I, squares Si I, and open circles are Ca I. Error bars for single elements removed for clarity. Filled circles with error bars represent *weighted* means of Mg, Si, and Ca. Increasing in metallicity from left we have EIS 7873, 30077 and 6631.

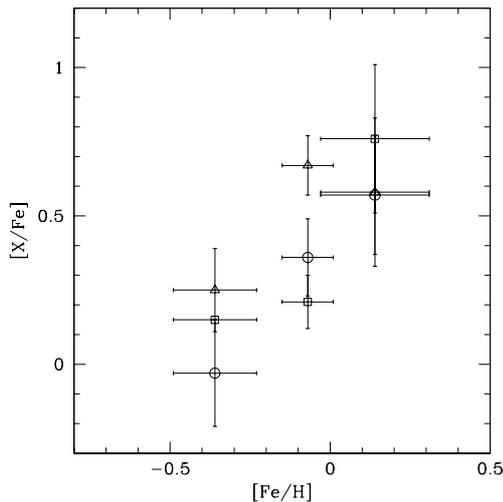


Fig. 3. Abundances for n-capture elements La (triangles), Ce (squares) and Nd (circles) plotted against metallicity.

3. Discussion and conclusions

The three stars appear to be rather metal rich, ranging between $-0.5 \lesssim [\text{Fe}/\text{H}] \lesssim +0.1$. The abundances of α elements are shown in Fig. 2 and those of n-capture elements in Fig. 3. In order to see whether the chemical abundances of these three stars show any differences from Galactic stars let us compare with the large sample compiled by Venn et al. (2004). This catalogue contains also a probability of each star to belong to the Halo, Thick disc or Thin disc. We selected only stars for which the population membership probability exceeds 85%. The mean values and dispersion for some significant abundance ratios are given in Table 3. From this comparison we may see that star EIS 7873 appears to be undistinguishable from Galactic stars of similar metallicity. In this regime the three components are very similar, differing from each other by not more than 1σ . EIS 30077 and EIS 6631,

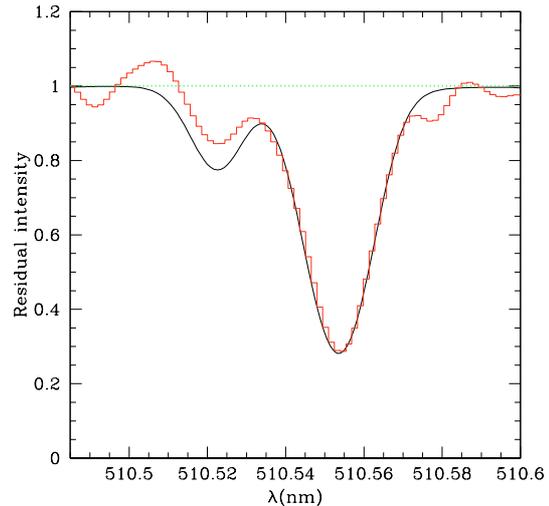


Fig. 4. Synthesis for the Cu I 510.5 nm line in EIS 6631 (thick line) with superimposed the observed spectrum. Hyperfine splitting is taken into account, $[\text{Cu}/\text{Fe}] = +0.25$ in the synthesis.

Table 3. Abundance ratios in different Galactic components.

	(1)	(2)	(3)	(4)	(5)
N	16	11	35	31	4
$[\alpha/\text{Fe}]$	0.14	0.06	0.06	0.02	0.08
$[\alpha/\text{Fe}]_\sigma$	0.09	0.03	0.04	0.03	0.05
$[\text{Na}/\text{Fe}]$	0.06	0.03	0.05	0.00	–
$[\text{Na}/\text{Fe}]_\sigma$	0.04	0.08	0.04	0.07	–
$[\text{Y}/\text{Fe}]$	0.00 ^a	-0.11 ^b	0.11 ^c	0.04	-0.06
$[\text{Y}/\text{Fe}]_\sigma$	0.24	0.14	0.58	0.10	0.03

(1) Thick disc $-0.5 \leq [\text{Fe}/\text{H}] < -0.2$.

(2) Thick disc $-0.2 \leq [\text{Fe}/\text{H}]$.

(3) Thin disc $-0.5 \leq [\text{Fe}/\text{H}] < -0.2$.

(4) Thin disc $-0.2 \leq [\text{Fe}/\text{H}]$.

(5) Halo $-0.5 \leq [\text{Fe}/\text{H}]$.

^a 8 stars; ^b 5 stars; ^c 28 stars.

instead, display a significant underenhancement of α elements (except for Ti) and a significant enhancement over the solar values of La, Ce and Nd. Unfortunately there is very little data available on these elements for Galactic stars in this metallicity regime. The situation is better for Y, for this element EIS 6631 shows $[\text{Y}/\text{Fe}] \approx 0$, while EIS 30077 shows a strong deficiency $[\text{Y}/\text{Fe}] \approx -0.6$; note that also Galactic stars display a large scatter in Y abundances. EIS 6631 and EIS 30077 display another remarkable abundance anomaly: a significant overabundance of Cu ($[\text{Cu}/\text{Fe}] \approx +0.25$). This abundance is based on a single line, shown in Fig. 4 for EIS 6631. The line appears clean and the fitting straightforward, although all the usual *caveats* on speculating on an abundance derived from a single line apply. Galactic stars in the high metallicity regime show $[\text{Cu}/\text{Fe}] \sim 0$ (Bihain et al. 2004). Moreover, this resemblance strengthens the hypothesis that these two stars have a common origin.

It is also interesting to compare these abundances with those of Local Group dwarf galaxies. Among these the only one which has a population as metal-rich as our stars is Sagittarius (Bonifacio et al. 2004, and references therein). Sagittarius is

characterized by a low $[\alpha/\text{Fe}]$ and in this respect it is similar to EIS 30077 and EIS 6631. This characteristic is shared by other dwarf spheroidal galaxies in the LG (Shetrone 2004; Venn et al. 2004), which are more metal-poor than Sgr. This feature is generally interpreted as due to a low star formation rate in these galaxies. Therefore the $[\alpha/\text{Fe}]$ ratios support the notion that EIS 30077 and EIS 6631 have not been formed in the Galaxy but rather in a LG dwarf spheroidal. Another “signature” of Sgr is a rather strong overabundance in heavy neutron capture elements La, Ce, Nd and Eu; EIS 30077 and EIS 6631 seem to behave in the same way. On the other hand Sgr displays low $[\text{Na}/\text{Fe}]$, $[\text{Ni}/\text{Fe}]$, $[\text{Mn}/\text{Fe}]$ and $[\text{Cu}/\text{Fe}]$ ratios (Bonifacio et al. 2000a; McWilliam et al. 2003) while we find solar ratios for our stars (except for Cu).

Field contamination may constitute a significant issue. By comparing the derived heliocentric velocity distribution of our GIRAFFE target stars to Galactic models we found that contamination by disc stars is present at any radial velocity (Zaggia et al. 2004), thus radial velocity, by itself, does not ensure membership to the structure. We need both radial velocity and metallicity to isolate possible CMa members. Our estimate for the mean heliocentric V_{rad} of CMa in the background of NGC 2477 is of about 132.0 km s^{-1} with a velocity dispersion of $\approx 12.0 \text{ km s}^{-1}$ for a sample of ≈ 20 stars. The resolution of our GIRAFFE spectra is $\sim 18 \text{ km s}^{-1}$, which allows us to measure radial velocities with an internal accuracy of the order of 1 km s^{-1} . While all three the stars in Table 1 have a radial velocity within 3σ of this, only EIS 6631 falls inside the 1σ boundary. EIS 6631, our “best candidate”, appears also to be the most α -poor and the most enhanced in n-capture elements.

Using the data compiled by Venn et al. (2004) we find that negative $[\alpha/\text{Fe}]$ ratios are observed in only three disc stars at such high metallicities, the most α -poor being HR 7126 with $[\alpha/\text{Fe}] = -0.08$. Thus the underenhancement of EIS 6631 seems to be rather unique and constitutes a fairly strong case for an extragalactic origin. Also the significant Cu overabundance in this star, taken at face value, suggests an extra-galactic origin.

The conclusions that may be drawn from our observations are not very compelling. EIS 7873 appears to be undistinguishable from Galactic stars. For EIS 30077 and EIS 6631 there are some clues for an extra-galactic origin, and these are stronger for EIS 6631, the most metal-rich star of the sample. This is surprising, since CMa is a highly “degraded” structure, at variance with the Sgr dSph, most of the (hypothetical) galaxy has already dissolved, and its gas content, whatever it may have been, has likely mixed with that of the MW. Colours and metallicity of EIS 6631 imply a young age (about 2 Gy according to isochrones). It should then have formed from gas in which possible chemical signatures may have been already diluted. If EIS 6631 actually belongs to an external galaxy, its high metallicity requires that the mass of this galaxy should be as large as that of Sgr ($M \geq 10^9 M_{\odot}$ Ibata et al. 1997), or larger. This is consistent with the high end of the mass estimate of the Ring by Ibata et al. (2003) ($2 \times 10^8 M_{\odot} \leq M \leq 10^9$). Larger samples are required in order to shed more light on the origin and nature of the CMa overdensity.

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