Abundances in Sagittarius: present state and perspectives for the use of VLT

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Abstract. Sagittarius, the nearest external galaxy, will be amenable to detailed abundance studies with VLT and other 8m class telescopes. Such data, in conjunction with the similar data of our own galaxy, will allow a deeper understanding of chemical evolution. Our study conducted with NTT shows the presence of metal-rich stars with radial velocities compatible with Sagittarius membership and of stars as metal-poor as $[\text{Fe}/\text{H}] = -1.5$. In this talk I shall address the way in which VLT instruments will allow to clarify this intricate situation.

1 Introduction

The Sagittarius dwarf galaxy discovered \cite{4, 5} as a comoving group ($V_{\text{hel}} \approx 140\text{km/s}$) with a velocity dispersion as small as 2$\text{km/s}$, is the nearest external galaxy and will be amenable to detailed abundance studies with VLT and other 8m class telescopes. These shall be important for two distinct reasons: on the one hand, we shall be able to study chemical evolution in an environment different from our Galaxy; on the other hand, if Sagittarius shows any chemical signature, this should allow us to identify Sagittarius debris, currently populating the Galactic Halo.

The colour-magnitude diagram of Sgr shows a wide Red Giant Branch (RGB), which is interpreted as evidence of a spread in metallicity of Sgr. Marconi et al \cite{9} conclude that the RGB of Sgr lies between that of 47 Tuc ($[\text{Fe}/\text{H}] = -0.71$) and M2 ($[\text{Fe}/\text{H}] = -1.58$). In the following I shall describe the work done with the ESO NTT to determine spectroscopic metallicities of giants in Sgr and shall address the potentiality of VLT on this issue.

2 NTT Observations

We selected, from the Marconi et al \cite{9} sample, stars on the RGB which ought to display the spread in metallicity present in Sgr. We used the ESO NTT telescope with the EMMI instrument in Multi Object Spectroscopy (MOS) mode. The dispersing element was grism $\#5$ providing a resolution of about 1500. We have obtained spectra for a total of 57 objects in field Sgr1 of \cite{9} on June 19th 1996. In addition, we obtained long slit spectra of one of the stars observed with the MOS and of star HD 190287 on September 18th 1998.

Of the 57 stars observed 23 matched the criterion $100 \text{km/s} \leq V_{\text{hel}} \leq 180 \text{km/s}$, which we adopted, to ascribe membership to Sagittarius. For
Fig. 1. Metallicity distribution for 22 radial velocity members of Sgr

these 23 stars the average radial velocity is 136 \( \pm 18 \) kms\(^{-1}\), in good agreement with previous determinations; the r.m.s. is dominated by the error in the measure of the radial velocity and not by the velocity dispersion of Sgr.

3 Abundance estimates from low resolution spectra

Our approach has been to define spectral indices which measure some prominent spectral features which may be used for abundance estimates. We defined six spectral indices, two of which measure the Mg I b triplet and the remaining four measure essentially iron and iron-peak elements. The location of the indices may be found in Fig.1 of reference\(^\[10\]\). The indices are all measured with respect to a common pseudo-continuum, defined by six quasi-continuum windows. The aim is to be able to determine both \([\text{Fe/H}]\) and \([\text{Mg/Fe}]\).

We computed the values of the indices for a small grid of synthetic spectra \((T=4750 \, \text{K}, \, 5000 \, \text{K}, \, 5250 \, \text{K}; \, \log g = 2.50 \, [\text{Fe/H}] = -1.5, -1.0, -0.5, 0.0, +0.5; \, \xi = 2\text{km}^{-1}\)\) computed with the SYNTHE code\(^\[7\]\). The spectra were broadened with a gaussian profile of 210 kms\(^{-1}\) to match the resolution of the observed spectra. The input model-atmospheres were computed with version 9 of the ATLAS code\(^\[7\]\) switching off the overshooting option. Models with \([\text{Fe/H}]= -1.5 \) and \(-1.0 \) were computed using \(\alpha\)-enhanced opacity distribution functions. For each star the temperature was determined from the \((V-I)_0\) colour\(^\[9\]\) through the calibration of\(^\[1\]\). Strictly speaking this calibration is valid only for dwarf stars, however the \(V-I\) colour has only a weak dependence on gravity, especially in the colour range we are interested in. We excluded from analysis SgrM 172 \((V-I = 1.81)\), because it is much
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cooler than all the other stars. The metallicity was determined from the four iron-sensitive indices by interpolating in the table of computed indices.

3.1 Zero-Points

We made the same analysis for the Sun using the solar atlas, degraded at the same resolution as our grism spectra, as an observed spectrum and a small grid of synthetic spectra appropriate for the Sun \((T=5777, \log g = 4.44, [\text{Fe/H}] = -0.5, 0.0, +0.5)\). The difference between these derived metallicities and the meteoritic iron abundance, is small (around 0.1–0.2 dex). On the assumption that these differences reflect inadequacies of our atomic data and model atmosphere and that the systematics is the same for the Sun and for our program stars, we treated these as zero-point shifts.

3.2 Cross-checks

We determined the metallicity of the Sun from a twilight spectrum taken with the MOS. The deduced [\text{Fe/H}] was \(-0.32, -0.04, -0.01, +0.10\) for the four indices respectively. These are not 0.00 because of the noise in the observed spectrum. One of the indices (F1) yields an abundance considerably different from the others. To obtain the final metallicity we decided to use a central estimate, defined as the mean of the two central values, which is akin to the median and more robust than the mean. In this case the central estimate is [\text{Fe/H}] = -0.02, in good agreement with the expected value of 0.00.

Our program stars are considerably cooler and more luminous than the Sun. We analysed the spectrum of the cool metal-poor giant HD 190287 ([\text{Fe/H}] = -1.34, \text{Teff} = 5300), taken with EMMI, grism # 5 and a long-slit. We obtain [\text{Fe/H}] = -1.52, -1.22, -1.23, -1.37, for the four indices, which yields a central estimate [\text{Fe/H}] = -1.30.

We compared a spectrum of one of our program stars (SgrM 139) through the EMMI long-slit with its MOS spectrum. The derived metallicities were the same ([\text{Fe/H}]_{\text{MOS}} = -0.05 ; [\text{Fe/H}]_{\text{LS}} = +0.02) and also the radial velocities were consistent within errors \((v_{\text{MOS}} = +147\text{km}^{-1} ; v_{\text{LS}} = +124\text{km}^{-1})\).

3.3 Error estimates

In order to estimate the random errors in our metallicity estimates we used a Montecarlo simulation. We took a synthetic spectrum \((\text{Teff} = 5000K \ [\text{Fe/H}] = -0.5)\) to which we added Poisson noise so that S/N = 10 (i.e. the S/N of our spectra) and estimated the metallicity from this noisy spectrum. The mean of 10000 realizations was < [\text{Fe/H}] >= -0.56 and the standard deviation was 0.25 dex, we take this as our estimate of the random error.

In addition one should consider the errors arising from uncertainties in the atmospheric parameters. The largest error comes from the microturbulent
velocity. At this resolution we are forced to rely only on strong lines which are very sensitive to microturbulence. The value of $\xi$ must be assumed since there is no way to fix it from the spectrum. The associated error is larger for the more metal-rich stars, if the microturbulence is $1 \text{km s}^{-1}$ the metallicities increase by $\Delta([\text{Fe/H}]) = 0.24 \times [\text{Fe/H}] + 0.38$. A change in effective temperature by 150 K brings about a change of 0.2 dex in metallicity as does a change of surface gravity by 0.5 dex.

### 3.4 Previous results and future work

Preliminary results of this work have been already presented [10, 2]. There are two main differences with the results presented here. The first is that here we use pre-tabulated synthetic indices rather than iteratively performing spectrum synthesis for each star and each index. The second is that in the present work the indices are measured with respect to the pseudo-continuum, rather than with respect to an estimate of the true continuum, obtained by iteratively re-normalizing the observed spectrum using the current estimate of the best-matching synthetic spectrum, as done previously. The re-normalization procedure was abandoned because we realized that it is strongly dependent on the initial metallicity estimate. In fact it tends to relax the observed spectrum onto the first guess. Differences on the order of 0.2 dex are obtained from the same observed spectrum but initial metallicity guesses differing by 0.5 dex. Our present results are in agreement with our previous estimates at the level of 0.1 dex except for the two most metal-poor stars (Sgr M 124 and Sgr M 115) for which we find a metallicity which is 0.32 and 0.41 dex lower.

We have so far not determined $[\text{Mg/Fe}]$ because the indices M1 and M2 depend on both $[\text{Mg/H}]$ and $[\text{Fe/H}]$. Our grid of synthetic spectra includes only “standard” values of $[\text{Mg/Fe}]$ (0.0 down to $[\text{Fe/H}] = -0.5$ and +0.4 below). On the other hand, our preliminary results suggest different $[\text{Mg/Fe}]$ ratios, especially for $-0.5 < [\text{Fe/H}] < 0.0$. On the contrary the F indices are essentially independent of the abundance of $\alpha$ elements. Determining $[\text{Mg/Fe}]$ is still possible, once $[\text{Fe/H}]$ is fixed through the F indices, but requires a grid of synthetic spectra computed for a range of $[\text{Mg/Fe}]$ values or direct spectrum synthesis on a star by star basis. This shall be the object of our future work.

### 4 Results on Sagittarius

The metallicity distribution of our 22 candidate Sagittarius members is shown in Figure 1. The peak at metallicity +0.5 reflects our choice to avoid extrapolation at metallicities higher than our most metal-rich grid point; when a star showed indices indicative of higher metallicity we assigned to it the value +0.5.
The distribution appears to be distinctly tri-modal: there is a metal-rich population whose mean metallicity is yet undefined and there are two metal-poor populations which peak around $-1.2$ and $-0.5$ respectively. The existence of the two metal-poor populations is in substantial agreement with previous findings\cite{9}. The presence of a metal-rich population is something new and unexpected. It is not yet clear whether the metal-rich stars belong to Sagittarius or are Bulge interlopers, although in the latter case their number is uncomfortably large and may require a revision of our understanding of Bulge kinematics. An independent study based on Keck High-Res spectra\cite{11}, finds that 2 out of 7 stars, with radial velocity compatible with Sagittarius membership, are in fact metal-rich. Yet another photometric survey\cite{3} suggests the possible existence of a RGB sequence considerably more metal-rich than 47 Tuc.

Although we are at an early stage to draw definitive conclusions, circumstantial evidence is arising for a metal-rich population in Sagittarius. This does not fit with our present understanding of chemical evolution of dwarf spheroidals, however we should keep an open mind and stick to the observations.

5 Perspectives for the use of VLT

VLT will quite likely play a fundamental role in the study of Local Group Galaxies and Sagittarius in particular. With UVES it shall be possible to do a detailed line by line analysis for stars along the RGB to below the Horizontal Branch ($V_{HB} \approx 18.2$). The Turn-off $21 \leq V \leq 21.5$ will still be out of reach of UVES though.

New perspectives are opened by FORS. The resolution shall be at most $1/2$ of that used by us at NTT, however the indices we have defined measure such strong features that they will be usable even at this lower resolution, as shown by simulations we carried out. Moreover the MOS slitlets of FORS have sharp edges and it will be possible to flux-calibrate the spectra, thus allowing to measure spectral indices in absolute flux. This will recover all the information contained the continuum. The spectral coverage (350 - 590 nm) will allow to use the Ca II H and K lines and probably other iron-related indices in the range 400 - 500 nm. Finally with VLT+FORS a S/N of about 100 can be reached in one hour for stars of $V \approx 18.5$, with this S/N our Monte-carlo simulations predict the random error in metallicity determinations to be around 0.02 dex.

The use of a 3m class telescope, such as NTT, for preliminary observations aimed at the determination of radial velocities has proved to be too time-consuming to be worth the effort. FORS will be able to provide good quality spectra from which radial velocities, metallicities and key abundance ratios, such as [Mg/Fe] and [Ca/Fe], can be determined.
The real killer in the studies of Local Group galaxies shall be Giraffe fed by 130 fibres in MEDUSA mode. The highest resolution achieved by Giraffe (15000) is high enough to perform a classical line by line analysis. However the number of spectra we shall get (several hundreds per night) will preclude the use of this approach. We will have to find new ways to estimate abundances from these spectra which will be able to cope with the data flow provided by Flames+Giraffe.

One possibility is suggested by our low-resolution experience: define spectral indices that can be related to abundances of particular elements and tabulate their value from synthetic spectra. The estimation of an abundance requires then only an interpolation in an appropriate table.

Different indices will be appropriate for different temperature and luminosity regimes. Now is the time to investigate both theoretically and observationally which features will provide useful indices. For example some indices may be defined to measure essentially strong iron lines others essentially weak iron lines, the balance of the two will allow to determine microturbulence.

The index approach is not the only possibility. Other very promising techniques such as autocorrelation and cross-correlation should be investigated. A whole range of methods could complement each other to extract information from the spectra, however if any particular star seems deserving of special attention, all the spectra will be nicely archived and one can go back and do the good old line by line analysis.

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