A&A 436, L9–L12 (2005)
DOI: 10.1051/0004-6361:200500110


Astronomy & Astrophysics

Letter to the Editor

# Sulphur abundances in Terzan 7*

E. Caffau[1], P. Bonifacio[2], R. Faraggiana[3], and L. Sbordone[4,5]

[1] Liceo L. e S.P.P. S. Pietro al Natisone, Annesso al Convitto Nazionale "Paolo Diacono", Piazzale Chiarottini 8, Cividale del Friuli (Udine), Italy
e-mail: elcaffau@libero.it
[2] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Trieste, via Tiepolo 11, 34131 Trieste, Italy
e-mail: bonifaci@ts.astro.it
[3] Dipartimento di Astronomia, Università degli Studi di Trieste, Italy
e-mail: faraggiana@ts.astro.it
[4] ESO European Southern Observatory – Alonso de Cordova 3107 Vitacura, Santiago, Chile
[5] Universitá di Roma 2 "Tor Vergata" – via della Ricerca Scientifica, Rome, Italy
e-mail: sbordone@mporzio.astro.it

Received 1 March 2005 / Accepted 19 April 2005

**Abstract.** We present here the first measurements of sulphur abundances in extragalactic stars. We make use of high resolution spectra, obtained with UVES at the ESO 8.2 m Kueyen telescope, of three giants of the Globular Cluster Terzan 7, which belongs to the Sagittarius dwarf galaxy. We measure the sulphur abundances using the lines of S I multiplet 1. The S/Fe ratios for all three stars are nearly solar, thus considerably lower than what is found in Galactic stars of comparable iron content ([Fe/H] $\sim -0.50$). This finding is in keeping with the abundances of other $\alpha$-chain elements in this cluster and in Sagittarius and other dSphs in general. These low $\alpha$-chain elements to iron ratios suggest that Sagittarius and its Globular Clusters have experienced a low or bursting star-formation rate. Our sulphur abundances imply $\langle \log(\mathrm{S/O}) \rangle = -1.61$ which is comparable to what is found in many H II regions of similar oxygen content, and is slightly lower than the solar value ($\log(\mathrm{S/O})_{\odot} = -1.51$). These are also the first measurements of sulphur abundances in a Globular Cluster, thus a direct comparison of Terzan 7 and Galactic Globular Clusters is not possible yet. However our analysis suggests that the lines of S I multiplet 1 should be measurable for other Globular Clusters at least down to a metallicity $\sim -1.5$.

**Key words.** nucleosynthesis – stars: abundances – globular clusters: individual: Terzan 7 – galaxies: abundances – galaxies: dwarf – galaxies: individual Sgr dSph

## 1. Introduction

The $\alpha$-chain elements (i.e. all the even elements from oxygen to titanium) may be produced in stars during carbon-burning, oxygen-burning and neon-burning phases, both in central burning and convective shell burning, as well as in explosive burning phases (Limongi & Chieffi 2003). It is only the massive stars, which end their lives as type II SNe, which undergo these phases and have a means to eject their nucleosynthesis products in the interstellar medium. Thus the $\alpha$-chain elements are a good tracer of the nucleosynthesis of the short lived massive stars. On the other hand Fe and other iron-peak elements are produced both in type II SNe and in type Ia SNe, which may explode over longer time-scales (Tinsley 1979; Kobayashi et al. 1998). For this reason the ratios $\alpha$/Fe (where $\alpha$ is any of the $\alpha$-chain elements) are sensitive diagnostics which may give us information on the time scales for the evolution of a galaxy and on the star formation rate, although their interpretation is not always straightforward (see Kobayashi et al. 1998, and references therein). Among the $\alpha$-chain elements sulphur is not often studied in stars because there are few suitable lines, at variance with the neighbouring elements Si and Ca which are more easily measured. Sulphur is instead more easily measured in the interstellar medium, both in the warm ISM, through absorption lines (Savage & Sembach 1996, and references therein) and in H II regions through emission lines (Garnett 1989; Torres-Peimbert et al. 1989). This makes sulphur an element which is readily measured in external galaxies in which one of its gaseous phases is measurable, i.e. Damped Ly $\alpha$ galaxies (DLAs, Centurión et al. 2000) and Blue Compact Galaxies (BCGs, Garnett 1989; Izotov & Thuan 1999). With respect to other easily accessible $\alpha$ elements, such as Si or Mg, sulphur has the advantage that it is not depleted onto dust grains (Savage & Sembach 1996); thus its abundance in the gas phase equals the total abundance.

This situation makes it highly desirable to have a direct comparison with sulphur abundances measured in stars, either

* Based on data obtained in ESO programme 65.L-0481.

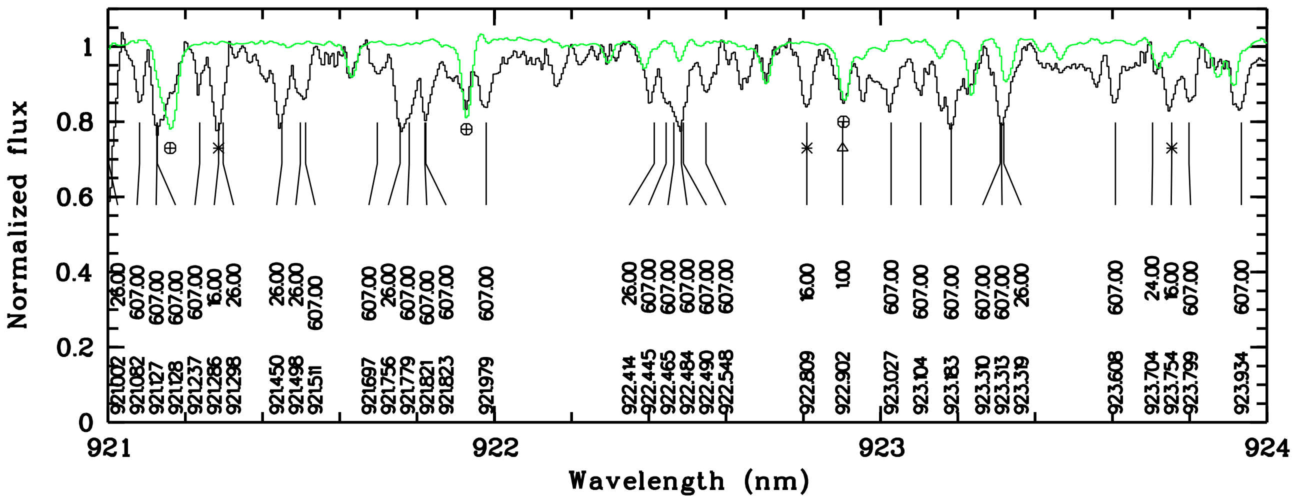


**Fig. 1.** The spectrum of star # 1282 (black line) and the spectrum of the B star HD 68761 ($v \sin i$ = 350 km s$^{-1}$) (grey line), which has been used to remove the telluric lines. The three most prominent telluric features have been marked with a crossed circle. The three sulfur lines (marked by asterisks), as well as the other stellar lines, with central residual intensity less than 0.8 have been identified. Also the position of Paschen $\zeta$ has been identified (and marked by a triangle), although its predicted central residual intensity is 0.9665; note that, due to the radial velocity of Terzan 7 this coincides with the telluric line at 923.48 nm.

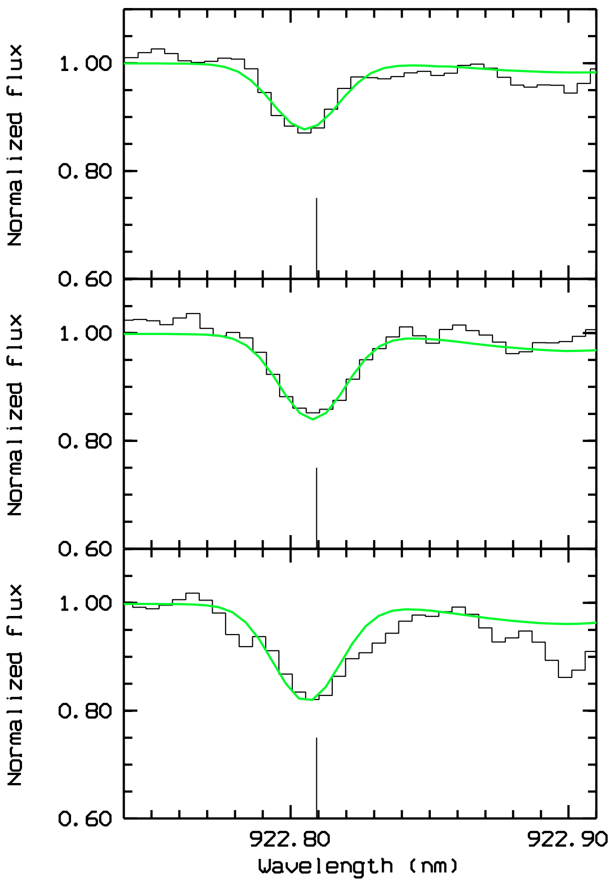


**Fig. 2.** Fit of the 922.8 nm line of the three stars, from top to bottom are stars # 1665, # 1282 and # 1708. This line is not contaminated by telluric lines in any of the stars.

**Table 1.** Atmospheric parameters and S abundances.

| Star | | $T_{\rm eff}$ | log $g$ | $\xi$ | [Fe/H] | [S/H] | [S/Fe] |
|---|---|---|---|---|---|---|---|
| | | | cgs | km s$^{-1}$ | dex | dex | dex |
| 1665 | S16 | 3945 | 0.8 | 1.55 | –0.51 | –0.59 | –0.08 |
| 1282 | S34 | 4203 | 1.3 | 1.60 | –0.54 | –0.59 | –0.05 |
| 1708 | S35 | 4231 | 1.2 | 1.70 | –0.56 | –0.62 | –0.01 |

in the Milky Way or in gas-poor galaxies, such as dwarf spheroidals, for which stellar measurements are the main, or only source of abundances. Although it could be argued that other $\alpha$-chain elements such as Ca or Si could be used as proxies, there are some theoretical predictions that not all $\alpha$-chain elements should vary in lockstep (Lanfranchi & Matteucci 2003, and references therein), as well as some observational hints (Venn et al. 2004). Clearly, accurate observations of several $\alpha$-chain elements are needed to decide if this is the case or not. For these reasons the additional effort to measure sulphur in stellar spectra is justified.

Terzan 7 (Terzan 1968) is a Globular Cluster associated with the Sgr (dSph) system. Its low stellar concentration allowed to obtain accurate photometry into the central region; from these data the young age and the metallicity have been estimated (Buonanno et al. 1995). However it appeared soon that the metallicity determined photometrically (lower than [Fe/H] = −0.74, Buonanno et al. 1995) is in clear disagreement with that obtained spectroscopically from Ca II triplet lines ([Fe/H] = −0.36 ± 0.11 Da Costa & Armandroff 1995). The metallicity derived from high resolution spectra of giant stars is [Fe/H] = −0.61 according to Tautvaišienė et al. (2004) and [Fe/H] = −0.59 according to Sbordone et al. (2005), both obtained from spectra observed with UVES.

Both Tautvaišienė et al. (2004) and Sbordone et al. (2005) found that the abundance of $\alpha$-chain elements, notably Ca, Si and Mg, implies $\alpha$ to iron ratios which are *lower* than the ratios observed in Galactic stars of comparable metallicity. It is thus quite interesting to investigate whether sulphur behaves like the other $\alpha$-chain elements. We stress that these are the first

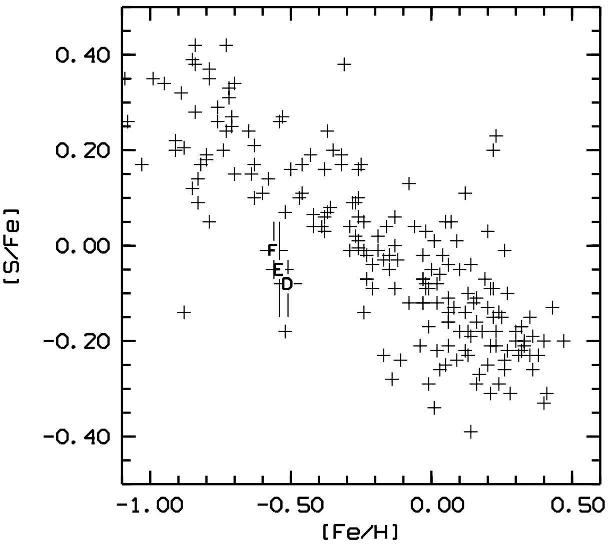


**Fig. 3.** [S/Fe] versus [Fe/H] for Galactic stars of the compilation of Caffau et al. (2005) (crosses) and Terzan 7; each star is denoted by a letter: # 1665 is D, # 1282 is E and # 1708 is F.

measurements of S in a Globular Cluster. The usually studied $\alpha$ elements are: O, Si, Ca and Ti.

## 2. Data analysis and results

Our sample consists of three giant stars of Terzan 7 observed with UVES at the 8.2 m Kueyen ESO telescope which have already been analyzed by Tautvaišienė et al. (2004) and Sbordone et al. (2005). UVES has been used with dichroic # 2, for the present work we used only the data of the upper CCD in the red arm. The resolution is $R \sim 43\,000$. We determine the sulphur abundance using line profile fitting in the region from 921 nm to 924 nm (see Fig. 1), which covers the three lines of the S I multiplet 1, the signal to noise ratio in this region is ~50 for all three stars. We use a $\chi^2$ minimization code as we did for sulphur determination for Galatic stars (see Caffau et al. 2005). Telluric lines were subtracted making use of the spectrum of a fast rotator, suitably scaled. In all three stars one sulphur line (922.8 nm) was not blended with telluric lines and this allowed to check the success of the telluric subtraction procedure. The 921.2 nm line has very near a telluric line, while the 923.8 nm line was contaminated.

With respect to the Galatic stars which we analyzed (Caffau et al. 2005), these Terzan 7 stars are cooler and of lower gravity, so that some weak CN molecular lines are present. Of the three sulphur lines only the 923.8 nm is blended with a CN feature, however for all three the presence of these CN lines affects the position of the continuum. Therefore at first we fitted the CN features in the region between 921.2 nm and 922.8 nm, in order to fix the CN abundance, then we fitted S lines. Fits to the 922.8 nm line in the three stars are shown in Fig. 2. We do not report here the adopted abundances of C and N because we are not sure of the quality of the oscillator strengths we are using. The abundances of C and N in these stars will be the object of future work, making use also of the blue spectra available. For the stars we adopted the atmospheric parameters and metallicities derived by Sbordone et al. (2005), these are reported in Table 1 together with the derived sulphur abundances, the star numbers refer to the Buonanno et al. (1995) catalogue, the names used by Tautvaišienė et al. (2004) are also provided. The difference in S abundance derived from the three different lines is ≤0.06 dex in all cases. The model atmospheres were the same used by Sbordone et al. (2005), the effective temperatures were derived from the $B-V$ colour and have an uncertainity of the order of 100 K. The model atmosphere for star # 1665 was computed with ATLAS 12 and custom abundances, while for the other two stars ATLAS 9 with solar-scaled Opacity Distribution Functions for $\xi = 1$ km s$^{-1}$ was used. The synthetic spectra were computed using the SYNTHE suite (Kurucz 1993) in its Linux version (Sbordone et al. 2004). The oscillator strengths of the S I lines were taken from Wiese et al. (1969).

To estimate the errors in the sulphur abundances we resorted to a Monte Carlo simulation. Since all the stars have similar atmospheric parameters and signal to noise ratios, we performed the simulation only for star # 1282, and take these error estimates as representative also for the other stars. A Monte Carlo set is obtained by injecting noise into a synthetic spectrum so that $S/N = 50$, all sets comprised 10 000 events. The input synthetic spectrum had $T_{\rm eff} = 4203$ K, $\log g = 1.30$, $\xi = 1.60$ km s$^{-1}$ [Fe/H] = −0.54, [S/Fe] = −0.05. The simulated spectrum is fitted as though it were an observed spectrum and the standard deviation from the mean fitted abundance is taken as error estimate. The synthetic spectra used in the fitting have either equal $T_{\rm eff}$, log $g$ and $\xi$ as the input spectrum, in order to estimate the random error due to the noise in the data, or different parameters ($T_{\rm eff}$, log $g$, $\xi$, [Fe/H]) to estimate the joint effect of systematic errors in the parameters and noise in the data.

From these simulations we derive a random error of 0.04 dex. A change of metallicity of 0.2 dex results in a change of about 0.10 dex in the mean S abundance (+0.10 for an increase of 0.20 in [Fe/H]; –0.06 for a decrease of 0.20 in [Fe/H]). A change in log $g$ of ±0.5 dex results in a change of ±0.18 dex in sulphur abundance. A change in $T_{\rm eff}$ of ±100 K results in a change in sulphur abundance of ∓0.18 dex (note the change in sign).

## 3. Discussion

With respect to Galactic stars of comparable metallicity, the three Terzan 7 stars which we analyzed are clearly deficient in S. In Fig. 3 are shown the [S/Fe] ratios versus [Fe/H] for the stars of the compilation of Caffau et al. (2005), and each of our Terzan 7 stars is identified with a letter. Virtually all Galactic stars, of metallicity comparable to Terzan 7, have higher [S/Fe] ratios. We note a few Galactic stars with low [S/Fe] ratios, which could be accreted by the Galaxy, however their Galactic orbits do not appear to be distinctive (Caffau et al. 2005). Our main conclusion is that sulphur appears to track the other $\alpha$ elements. Moreover, since for the other $\alpha$ elements, Terzan 7 seems to be undistinguishable from the Sgr field stars of similar metallicity, one may expect the same to hold for sulphur: a prediction which may be verified with



Article published by EDP Sciences and available at http://www.edpsciences.org/aa or http://dx.doi.org/10.1051/0004-6361:200500110

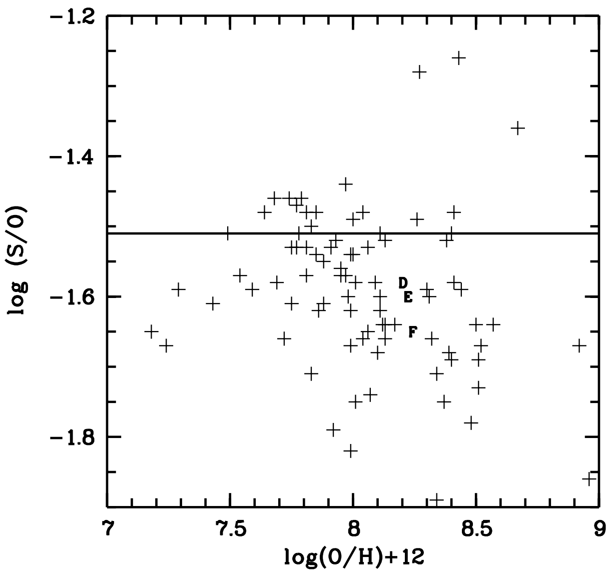


**Fig. 4.** Comparison of the S/O ratio in the stars of Terzan 7 (each star is designated by a letter as in Fig. 3) and in H II regions, both Galactic and extragalactic (crosses), the latter data are from Garnett (1989) and Izotov & Thuan (1999). The solid line represents the solar value: $A(\mathrm{S})_\odot = 7.21$ Lodders (2003) and $A(\mathrm{O})_\odot = 8.7$ Asplund et al. (2004, from MARCS 1D models).

observations of Sgr field stars. This conclusion relies on the accuracy of our effective temperatures, if these were systematically higher by 100–150 K the [S/Fe] ratios in Terzan 7 would become similar to those of Galactic stars. The good agreement between our colour temperatures and the excitation temperatures of Tautvaišiené et al. (2004) suggests that such a systematic shift is unlikely. The [S/Fe] ratios found by us seem to strengthen the similarity of Sagittarius with DLA galaxies, which had been already asserted on the basis of other $\alpha$ elements (Bonifacio et al. 2004).

Our results may also be directly compared with those of Garnett (1989) and Izotov & Thuan (1999) who concluded that in BCGs the S/O ratio is constant, independent of the metallicity. This has been taken as evidence that in such galaxies the initial mass function (IMF) does not vary with time and that the same massive stars are responsible both for the production of oxygen and sulphur. The oxygen abundances in our stars have been measured by Sbordone (2005) and the S/O ratios are shown in Fig. 4 compared to the values in H II regions, both Galactic and extragalactic, from Garnett (1989) and Izotov & Thuan (1999). The solar value is shown as a horizontal line. The stars in Terzan 7 occupy a position which is populated by many H II regions, slightly below the solar S/O ratio. From Fig. 4 we note a rather large scatter, which might be due to observational errors, however it is intriguing that most galaxies (and Galactic H II regions) show S/O ratios which are *below* the solar value. Note that in the previous work on S abundances in H II regions this fact was not apparent because the value $A(\mathrm{O})_\odot = 8.93$ for the solar oxygen abundance, from Anders & Grevesse (1989), was adopted. Instead we have adopted the determination of Asplund et al. (2004, using MARCS 1D models). The quality of the data does not allow to claim that IMF variations actually exist. However new and more accurate observations of S/O ratios, both in stars and H II regions should be able to address this point. The success of our measurement of S in Terzan 7 suggests that the lines of multiplet 1 should be measurable, at least down to $[\mathrm{S/H}] \sim -1.5$, for stars in Globular Clusters and Local Group galaxies.

## References


Anders, E., & Grevesse, N. 1989, Geochim. Cosmochim. Acta, 53, 197
Asplund, M., Grevesse, N., Sauval, A. J., Allende Prieto, C., & Kiselman, D. 2004, A&A, 417, 751
Bonifacio, P., Sbordone, L., Marconi, G., Pasquini, L., & Hill, V. 2004, A&A, 414, 503
Buonanno, R., Corsi, C. E., Pulone, L., et al. 1995, AJ, 109, 663
Caffau, E., Bonifacio, P., Faraggiana, R., et al. 2005, A&A, submitted
Centurión, M., Bonifacio, P., Molaro, P., & Vladilo, G. 2000, ApJ, 536, 540
Da Costa, G. S., & Armandroff, T. E. 1995, AJ, 109, 2533
Garnett, D. R. 1989, ApJ, 345, 282
Izotov, Y. I., & Thuan, T. X. 1999, ApJ, 511, 639
Kobayashi, C., Tsujimoto, T., Nomoto, K., Hachisu, I., & Kato, M. 1998, ApJ, 503, L155
Kurucz, R. L., 1993, CDROM 13, 18, http://kurucz.harvard.edu/
Lanfranchi, G.A., & Matteucci, F. 2003, MNRAS, 345, 71
Limongi, M., & Chieffi, A. 2003, MSAIS, 3, 58
Lodders, K. 2003, ApJ, 591, 1220
Savage, B. D., & Sembach, K. R. 1996, ARA&A, 34, 279
Sbordone, L. 2005, Ph.D. Thesis, Universitá di Tor Vergata
Sbordone, L., Bonifacio, P., Castelli, F., & Kurucz, R. L. 2004, MSAIS, 5, 93
Sbordone, L., Bonifacio, P., Marconi, G., Buonanno, R., & Zaggia, S. 2005, A&A, in press
Tautvaišiené, G., Wallerstein, G., Geisler, D., Gonzales, G., & Charbonnel, C. 2004, AJ, 127, 373
Terzan, A. 1968, C. R. Acad. Sci. Ser. B1, 267, 1245
Tinsley, B. M. 1979, ApJ, 229, 1046
Torres-Peimbert, S., Peimbert, M., & Fierro, J. 1989, ApJ, 345, 186
Venn, K. A., Irwin, M., Shetrone, M. D., et al. 2004, AJ, 128, 1177
Wiese, W. L., Smith, M. W., & Miles, B. M. 1969, NSRDS-NBS, Washington, DC: US Department of Commerce, National Bureau of Standards


Article published by EDP Sciences and available at http://www.edpsciences.org/aa or http://dx.doi.org/10.1051/0004-6361:200500110