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Is sulphur a typical α element?

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Abstract. Observationally, the galactic chemical evolution of sulphur shows a complex pattern. Some studies find no correlation between [S/Fe] and [Fe/H] at halo metallcities, which is typical for α-elements, others find [S/Fe] increasing towards lower metallicities, and still others find a combination of the two. Each scenario has different implications for the Galactic chemical evolution of sulphur. Here, we briefly summarise our results (Jönsson et al., 2011; Matrozis et al., 2013) from investigations where we derive stellar sulphur abundances from the [S I] λ1082 nm line, a atomic transition which hardly shows any departures from local thermodynamic equilibrium, or *LTE*. Our results argue for a chemical evolution of sulphur that is typical for α-elements, contrary to some previous studies that have found high sulphur abundances ([S/Fe] $\gtrsim 0.6$) for stars with $-2.5 <$ [Fe/H] < -1.

Key words. Stars: abundances – Stars: atmospheres – Stars: Population II – Infrared: stars

1. Introduction

Sulphur is one of the α elements, along with Mg, Si, Ca, and Ti, and as such an important diagnostics for the star-formation rate, the distribution of stellar masses in the early stages of the Galaxy, and for testing models of Galactic chemical evolution.

A problem with determining its abundance in stars is the paucity of useful spectral lines. Only recently, several investigations have been made, using the near-IR part of stellar spectra, where several diagnostics lie. We have, for example, explored several of these in a series of investigations, see for example, Ryde & Lambert (2004); Korn & Ryde (2005); Ryde (2006); Jönsson et al. (2011); Matrozis et al. (2013). The different trends found in recent studies have led to an on-going discussion of the origin and chemical evolution of sulphur, but also of the reason for different observed trends.

Different investigations have thus found different trends for the galactic chemical evolution of sulphur in the halo, here meaning metallicities [Fe/H] < -1. Some find a scattered trend (Caffau et al., 2005), a zig-zag trend (Takeda & Takada-Hidai, 2011), and a flat trend (Spite et al., 2011). This has great implications for Galactic chemical evolution models and in turn models for SNe yields and star-formation rate. The flat trend can be explained within the framework of explosive nucleosynthesis in type II SNe, while the others cannot. It has been suggested that the disagreement between different investigations of sulphur abundances in halo stars might be due to problems with the diagnostics used, that a new production source of sulphur might be needed in the early Universe, like hypernovae, or that

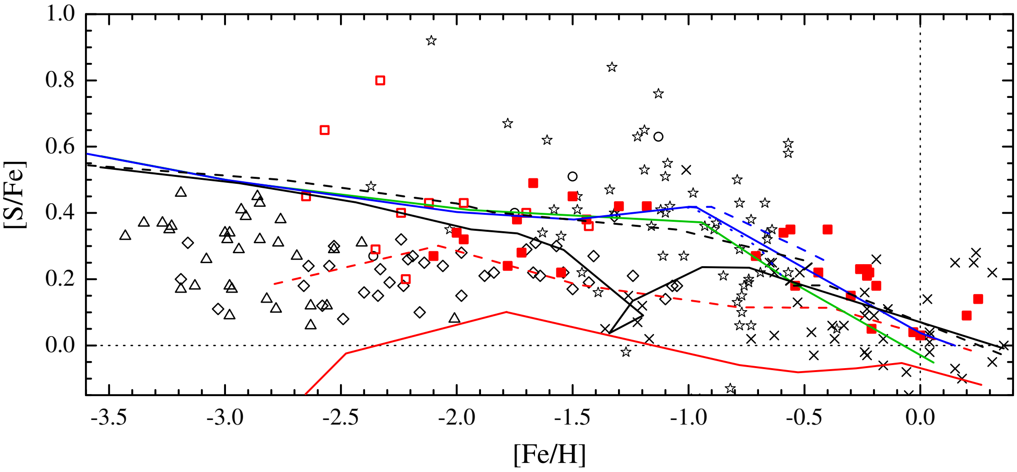

Fig. 1. This figure, which is taken from Matrozis et al. (2013), shows our results with solid and open red squares, in addition to the data from Takada-Hidai et al. (2002, crosses), Caffau et al. (2005, stars), Nissen et al. (2007, rhombi), Caffau et al. (2010, circles), and Spite et al. (2011, upward-pointing triangles). We also show a few relevant comparisons with theoretical models of Galactic chemical evolution, see the text for details. (Reproduced with permission from Astronomy & Astrophysics,©ESO)

the deposition of supernova ejecta into the interstellar medium is time-delayed.

Here, we summarise our two recent investigation of the Galactic chemical evolution of sulphur, based on the forbidden [S I] line at 1082 nm observed with VLT/CRIRES, NOT, and Gemini South telescopes, all providing high-resolution, near-infrared spectra of the [SI] line (Jönsson et al., 2011; Matrozis et al., 2013). Similar to the widely used 630 nm [O I] lines, this line has large virtues, most important of which is that it is formed in LTE, but also that it has a small temperature dependence. We use 1D LTE MARCS model atmospheres when synthesising the spectra.

2. Discussion

The forbidden [S I] line at 1082 nm, particlularly in our high-resolution CRIRES spectra, is detectable and useful down to [Fe/H] = −2.5 and gets stronger for cool giants. We have also shown that it is free from known atomic and molecular blends.

In Jönsson et al. (2011), we analysed both the [S I] line at 1082 nm and the S I triplet around 1045 nm. Since the former is not sensitive to non-LTE effects, we can empirically test the existing non-LTE corrections for the triplet. Our abundances deduced from the [S I] line and the non-LTE corrected values deduced from the 1045 nm triplet shown good agreement, see Jönsson et al. (2011). Thus, the non-LTE corrections available for the 1045 nm triplet (Takada-Hidai et al., 2005) seem to perform well for our halo giants using 1D models. When considering effects of convective inhomogeneities in the stellar atmospheres, it might be argued that they perform worse. It is, however, expected that non-LTE corrections fully incorporating convective inhomogeneities would be different than the 1D non-LTE corrections used. This needs further study with the coupling between 3D and non-LTE done self-consistently.

In Matrozis et al. (2013) we analysed the [SI] line in 39 stars for which we homogeneously determined the stellar parameters in order to minimize the systematic uncertainties. Our new abundance results, that include the ones from the Jönsson et al. analysis, are in reasonable agreement with predications of contemporary models of Galactic chemical evolution, in which sulphur is mainly synthesised in massive stars by oxygen burning. The best agreement is found with the Kobayashi et al. (2011) models shown in blue in Figure 1.

The red solid line in this figure correspond to the Timmes et al. (1995) nominal model and the red dashed one shows the model where the iron yields are reduced by a factor of two. The green line is the prediction of Kobayashi et al. (2006) for the solar neighbourhood. The dotted, solid and dashed blue lines correspond to halo, solar neighbourhood, and thick disk models of Kobayashi et al. (2011), respectively. The solid and dashed black lines correspond to the Brusadin et al. (2013) double-infall model with and without outflow, respectively.

3. Conclusions

In both our recent studies we corroborate the flat trend in the [S/Fe] vs. [Fe/H] plot for halo stars found in some previous works (Nissen et al. 2007, and Spite et al. 2011) and we do not find any high [S/Fe] values found in other works (Caffau et al. 2005, 2010 and Takeda et al. 2011). The high sulphur abundances found in some other studies, still needs an interpretation and understanding in a galactic chemical evolution context.

Due to its LTE formation and small 3D corrections, the [SI] line is an advantageous sulphur diagnostic when observable. The [S I] line is a valuable diagnostic of sulphur abundances in cool giants down to [Fe/H] $\simeq -2.5$. Our results ([S/Fe]) agree reasonably well with predictions of contemporary models of Galactic chemical evolution. In these models sulphur is predominantly created in massive stars by oxygen burning and is ejected into the interstellar medium during Type II supernovae explosions.

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References

Brusadin, G., Matteucci, F., & Romano, D. 2013, A&A, 554, A135
Caffau, E., Bonifacio, P., Faraggiana, R., et al. 2005, A&A, 441, 533
Caffau, E., Sbordone, L., Ludwig, H. G., Bonifacio, P., & Spite, M. 2010, Astron. Nachr., 331, 725
Jönsson, H., Ryde, N., Nissen, P. E., et al. 2011, A&A, 530, A144
Kobayashi, C., Umeda, H., Nomoto, K., Tominaga, N., & Ohkubo, T. 2006, ApJ, 653, 1145
Kobayashi, C., Karakas, A. I., & Umeda, H. 2011, MNRAS, 414, 3231
Korn, A. J. & Ryde, N. 2005, A&A, 443, 1029
Matrozis, E., Ryde, N., & Dupree, A. K. 2013, A&A, 559, A115
Nissen, P. E., Akerman, C., Asplund, M., et al. 2007, A&A, 469, 319
Ryde, N. 2006, A&A, 455, L13
Ryde, N. & Lambert, D. L. 2004, A&A, 415, 559
Spite, M., Caffau, E., Andrievsky, S. M., et al. 2011, A&A, 528, A9
Takada-Hidai, M., Saito, Y.-J., Takeda, Y., et al. 2005, PASJ, 57, 347
Takada-Hidai, M., Takeda, Y., Sato, S., et al. 2002, ApJ, 573, 614
Takeda, Y. & Takada-Hidai, M. 2011, PASJ, 63, 537
Timmes, F. X., Woosley, S. E., & Weaver, T. A. 1995, ApJS, 98, 617