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Chemical abundances in QSO host galaxies and environments

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Abstract. We determined C, N and α-element relative abundances in the gas surrounding six QSOs at an average redshift of $< z > \simeq 2.4$, by studying six narrow associated absorption systems in UVES high-resolution spectra. We found five systems with a metallicity (measured by C/H) consistent or above the solar value. There is a possible correlation (anticorrelation) between [N/C] ([Si/C]) and [C/H] of the studied associated systems, and [N/C] ≥ 0 when [C/H] ≥ 0. We have compared these observational results with the predictions of a model simulating the joint evolution of QSOs and their spheroidal hosts. The agreement turns out to be very good, in particular for the case envisaging massive haloes and high star-formation rates. Narrow associated absorption systems prove to be powerful tracers of the chemical abundances in gas belonging to high redshift spheroidal galaxies. The outflow of this same gas, triggered by the QSO feedback, is probably going to contribute to the early enrichment of the surrounding intergalactic medium.

Key words. galaxies: abundances - galaxies: active - galaxies: elliptical and lenticular, cD - galaxies: evolution - QSOs: absorption lines

1. Introduction

Observations of the population of early-type galaxies up to redshift $z \sim 1$ seem to imply a high uniformity and synchronization in the galaxy formation process. The color evolution with redshift is consistent with the passive evolution of an old stellar population formed at $z \geq 2-3$ (see e.g. Bernardi et al. 1998; Worthey, Faber & González 1992). Recently, several pieces of evidence have been collected indicating a strong connection between early-type galaxies and AGN (see e.g. Kormendy & Gebhardt 2001), in particular, all massive early-type galaxies could have shone as QSOs in a specific phase of their life.

In this work, we address the star formation history and the evolution of massive early-type galaxies at high redshifts by measuring in a reliable way the metallicity and the chemical abundances of gas belonging to host galaxies and environments of QSOs.

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2. Results

Up to now the main approach to study the chemical abundances in QSO environments

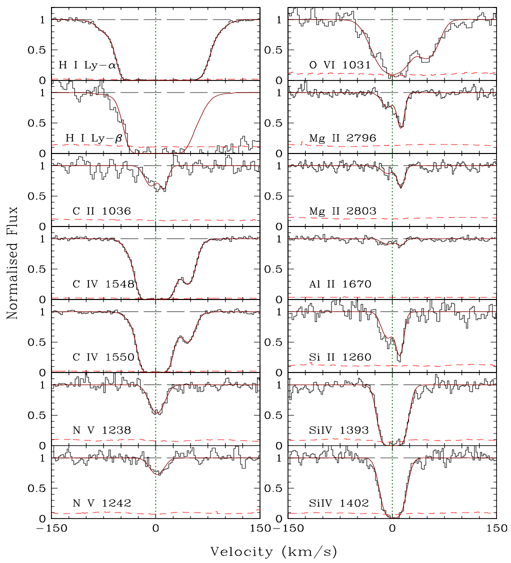

Fig. 1. Ionic transition lines observed at redshift $z_{\rm abs} = 2.122$ (marked by the vertical dotted line) in the spectrum of QSO UM681 ($z_{\rm em} = 2.1219$). The result of the best fitting for the analysed absorptions is overplotted on the spectrum. The short-dashed line represents the noise

has been the analysis of broad emission lines (BELs) observed in their spectra. Metallicities determined from BELs are consistent with solar or slightly supersolar values without a significant evolution in redshift (see e.g. Hamann & Ferland 1999). Other elemental abundances are very difficult to measure, in particular determinations of the ratio α/Fe are very uncertain.

Narrow absorption systems lying within 5000 km s^{-1} from a QSO emission redshift (the so-called "associated absorption lines", AALs) are complementary probes of the physical status of QSO-elliptical systems with respect to BELs. In general, they can be due to gas belonging to the interstellar medium of the galaxy, outflowing under the effect of the QSO or re-infalling on the QSO itself. Furthermore, it is more straightforward to derive chemical abundances from absorption lines than from emission lines. We need only to determine and apply the proper ionisation corrections to convert the measured ionic column densities into relative abundances.

We selected six associated absorption systems (Fig. 1 shows one of the studied systems) and determined the abundances of C, N and α-elements in the gas they originate from. We used high resolution, high signal-to-noise spectra of $2 < z < 3$ QSOs obtained with the UVES spectrograph at the 2nd unit of the VLT telescope (ESO, Chile) and applied a procedure based on the photoionisation code Cloudy (Ferland 2003) to compute the chemical abundances starting from the measured column densities (for more details refer to D'Odorico et al. 2004). The results of our calculations are summarised in Fig. 2 where errors on the abundance ratios are due mainly to the uncertainties in the column density determinations.

Only one among the six studied systems has a metallicity significantly lower than solar, $Z \sim 1/6\ Z_{\odot}$. The other 5 systems show values comparable or larger than solar. We confirmed the supersolar N/C abundance ratio in those systems with $Z \gtrsim Z_{\odot}$, as already found in other AALs (see Hamann & Ferland 1999, for a review). On the other hand, in our AALs we measured enhanced α-element/C abundance ratios at variance with the tentative detection of supersolar Fe/Mg abundance ratios in broad emission line regions but in agreement with abundances measured in elliptical galaxies. This suggests that we are sampling regions where SNe Ia did not yet have the time to enrich the gaseous medium, implying that the bulk of star formation started less than ~ 1 Gyr before.

3. Comparison with model predictions

We compared the present results on abundances with theoretical predictions based on a physical model for the co-evolution of QSO and host galaxy systems (Romano et al. 2002; Granato et al. 2004). In order to illustrate the effects of the star-formation rate (SFR) history on abundances, we considered two cases for the gas distribution inside the virialized dark

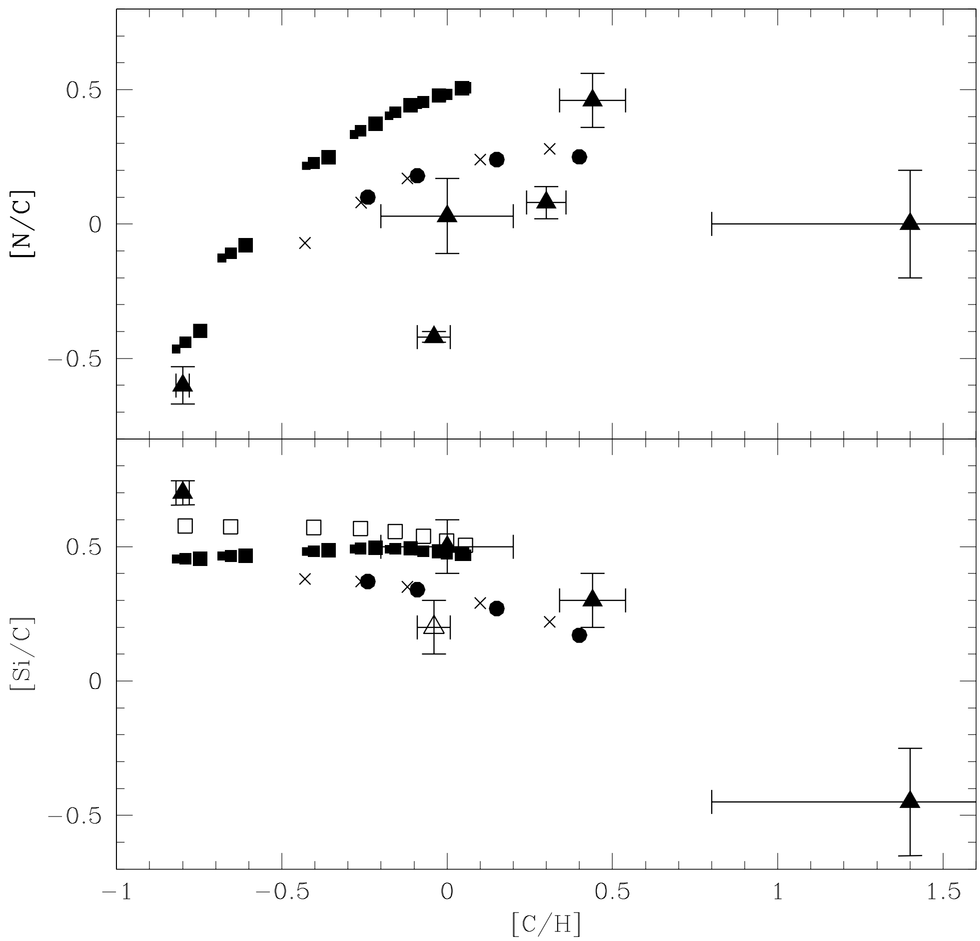

Fig. 2. [N/C] and [Si/C] abundance ratios vs. [C/H] obtained for the analysed associated absorption systems and for the considered chemical evolution model. Solid triangles with error bars are our data. The empty triangle in the bottom panel is an [O/C] abundance ratio used instead of [Si/C]. *Upper panel:* solid dots are the predictions of case B based on Granato et al. (2004) for a DM halo mass of 3×10^{13} $M_{\odot}$, $z_{QSO} = 2.1$ and $z_{vir} = 2.4$, 2.5, 2.7 and 3 in order of increasing [C/H] abundance. The crosses are the predictions for a DM mass of 5×10^{13} $M_{\odot}$, $z_{QSO} = 2.55$ and $z_{vir} = 2.8$, 2.9, 3, 3.2, 3.5. Solid squares are the results of case A based on Romano et al. (2002) for a DM halo of $M_{halo} = 1.37 \times 10^{13}$ $M_{\odot}$. Increasing sizes represent virialization redshifts $z_{vir} = 2.5, 3$ and 4, the different groups of squares are the abundances at time-steps of 0.1 Gyrs from z_{vir} to z_{QSO}. *Lower panel:* Solid dots, crosses and solid squares are the same as above. Empty squares represent the predictions by Romano et al. (2002) for the abundance of [O/C] starting at $z_{vir} = 3$

matter (DM) halo. The first one, case A, assumes that the gas closely follows the DM profile with no clumpiness, while in the second case, B, we assumed that after virilization on the average the gas follows the DM profile, but we introduced a clumping factor. As expected, in case A it is difficult to get a rapid star formation in DM haloes with $M_{\rm halo} \geq 1.5 \times 10^{13}$ $M_{\odot}$ before the QSO shines (see Fig. 10 in Romano et al. 2002), while in case B we can form stars very rapidly even in larger haloes (see Granato et al. 2004).

As is shown in Fig. 2, the differences between the predictions of case A and B are small. They are mostly due to the higher SFR that can be attained in case B before the QSO shining, due to the clumping factor that shortens the cooling time of the gas. It should be noticed also that this is a single-zone model, i.e. the results are averaged over the whole physical dimension of the galaxy, while a metallicity gradient is observed in elliptical galaxies.

In conclusion, the high level of chemical enrichment and the α-enhancement observed in the QSO environments indicates that the massive elliptical galaxies hosting QSOs must have formed the bulk of their stellar population on short time-scales at high redshifts.

In order to obtain a deeper insight in the evolution of QSO host-galaxies and environments it is essential to enlarge the data sample. In particular, obtaining high signal-to-noise spectra in the UV to reliably measure the doubly-ionised lines of C and N and increasing the redshift range especially at large values. Indeed, the five $z \sim 4$ AALs analised up to now (Savaglio et al. 1997) seem to indicate a slightly lower average metallicity, [C/H] ~ -0.5, than for the bulk of the sample at redshift $z \sim 2 - 2.5$. More data will be fundamental to verify the observed correlations and to constrain the predictions of theoretical models.

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