Chemical abundances in the young galaxy at z=2.309 towards PHL 957

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ABSTRACT
We present high-resolution UES spectra of the quasar PHL 957 obtained for studying the foreground Damped Lyα galaxy at z=2.309. Measurements of absorption lines lead to accurate abundance determinations of Fe, S and N which complement measurements of Zn, Cr and Ni already available for this system. We find [Fe/H]=−2.0 ± 0.1, [S/H]=−1.54 ± 0.6 and [N/H]=−2.76 ± 0.7. The ratio [Fe/Zn]=−0.44 provides evidence that ≈ 74% of iron and ≈ 28% of zinc are locked into dust grains with a dust-to-gas ratio of ≈ 3% of the Galactic one. The total iron content in both gas and dust in the DLA system is [Fe/H]=−1.4. This confirms a rather low metallicity in the galaxy, which is in the early stages of its chemical evolution. The detection of SII allows us to measure the SII/ZnII ratio, which is a unique diagnostic tool for tracing back its chemical history, since it is not affected by the presence of dust. Surprisingly, the resulting relative abundance is [S/Zn]=0.0 ± 0.1, at variance with the overabundance found in the Galactic halo stars with similar metallicity. We emphasize that the [S/Zn] ratio is solar in all the three DLA absorbers with extant data. Upper limits are also found for Mn, Mg, O and P and, once the dust depletion is accounted for, we obtain [Mg/Fe]<+0.2, [O/Fe]<0.4, [Mn/Fe]<+0.0 and [P/Fe]<−0.7. The [α/Fe] values do not support a Galactic halo-like abundances implying that the chemical evolution of this young galaxy is not reproducing our own Galaxy’s evolution.

Key words: Stars: abundances – Stars: Population II – Galaxy: halo – Cosmology: observations

1 INTRODUCTION

Abundances in QSO absorption systems offer a unique opportunity to probe both chemical and dust evolution of galaxies at high redshifts. Among the variety of the QSO absorbers the most useful for abundance determinations are the Damped Lyα (DLA) systems, since they provide very accurate absolute measurements for the ion species dominant in the HI gas. The interest in the damped Lyα galaxies is amplified by the suggestion that they are the likely progenitors of the present day spiral galaxies (Wolfe et al. 1986). Research on chemical abundances in DLA systems was pioneered by Black, Chaffee & Foltz (1987) and Meyer & York (1987). The subject has been recently reviewed by Lauroesch et al. (1996), to which we refer for detailed references. Recently a wealth of new data has been presented by Lu et al. (1996) and Pettini et al. (1997). The metallicities in the DLA absorbers are found between −2.5 < [Fe/H] < −0.5, and largely overlap those found in the Galactic halo or in globular cluster stars ([Fe/H]≈ log([Fe/H]⊙)−log([Fe/H]⊙)).

The very early stages of the chemical evolution of protogalaxies are expected to be dominated by Type II supernovae products because their lifetimes are much shorter than those of SNIa. Type II SNe nucleosynthesis is characterized by an enhancement of α elements over the iron-peak elements, as observed in the halo stars of the Galaxy, while the cumulative effects of both types of supernovae essentially yield solar ratios. In the Galaxy the transition occurs at a metallicity of [Fe/H]≈ −1.0 corresponding to a few Gyrs after Galaxy formation. If Damped Lyα are following a similar chemical evolution we should find a halo-like pattern in high redshift systems (or [Fe/H] < −1.0) and a smooth transition towards solar composition at low redshift (or [Fe/H] ≥ −1.0). Several claims state that the relative abundances of DLA systems are consistent with the halo pattern (Wolfe et al. 1994, Lu et al. 1996), while a change in the relative abundances at low redshift may have been observed for the first time in the candidate DLA system at zabs=0.558 towards PKS 0118-272 (Vladilo et al. 1997). However, DLA abundances are measured in diffuse interstellar gas and the intrinsic abundances are underestimated if some of the atoms are removed away from the gas phase and locked in dust grains. For instance, Si is generally found overabundant with respect to Fe in DLA absorbers, with [Si/Fe] ≈ 0.4, but Si and Fe are differentially depleted from gas to dust in our Galaxy and are consistent with the observed DLA overabundance. Probably dust is present as shown by the reddening of QSO with damped systems (Pei, Fall & Betchold, 1991) and by the observed [Zn/Cr] overabundance in DLA systems (Pettini et al. 1997). Therefore the real chemical pattern in the high redshift absorbers is not yet firmly established.

In this paper we present new observations of the
z=2.309 damped system towards PHL 957 (V=16.6) with $z_{em} = 2.681$. The system has been studied by Meyer & Roth (1990), Pettini, Boksenberg & Hunstead (1990), Wolfe et al. (1994), and abundances have been derived for Cr, Zn, Ni. Here we provide measurements for additional species such as S, Fe, N and limits for O, Mn, P and Mg. It is shown that the relative ratios do not conform to a simple scaling of a Galactic halo pattern in whatever way modified by dust.

2 OBSERVATIONS

The data we present are based on observations obtained with the Utrecht Echelle Spectrograph (Walker & Diego 1985) at the Nasmyth focus of the 4.2 William Herschel Telescope at the Observatorio del Roque de los Muchachos on La Palma island. Two sets of three spectra of 1 hour each were obtained in September and in December 1996, using a Tektronix CCD with 1024x1024, 24μm square pixels for a total integration of $\approx 22000$ s. The seeing was of $\approx 2$ arcsec in both observing runs. The slit width was set to $2.2$ arcsec giving a 4 pixel projected slit onto the detector that was binned by two pixels along the dispersion. The resolving power measured from the emission lines of the thorium-argon lamp frames is $R = \lambda/\Delta \lambda = 27000$ or $\Delta v \sim 11.1$ km s$^{-1}$ at all wavelengths. We used the 31.6 grooves/mm grating which provides a wavelength coverage of $\lambda\lambda 3657-4617$ Å allowing the search for the resonance transitions of FeII $\lambda\lambda 1125.448, 1127.098, 1133.665, 1143.226, 1144.938, 1260.533$ Å PII $\lambda\lambda 1152.818, 1197.184, 1199.391$ Å MgII $\lambda\lambda 1239.925, 1240.395$ Å SII $\lambda\lambda 1250.584, 1253.811, 1259.519$ Å OI $\lambda\lambda 1302.168, 1355.598$ Å NI $\lambda\lambda 1134.980, 1134.415, 1134.165$ Å at the redshift of $z = 2.309$. The two sets of spectra were reduced separately and then combined together using weights according to their S/N. Cosmic ray removal, sky subtraction, optimal order extraction and wavelength calibration were performed using the ECHELLE context in MIDAS. The rms scatter in the wavelength calibration was $0.7$ km s$^{-1}$. The two sets of data were normalized using a spline to connect smoothly the regions free from Ly $\alpha$ clouds. The final S/N is about 15 in correspondence of the SII lines and between 8 and 11 for all the other lines.

2.1 Column densities

In Figs 1 and 2 we show the identified transitions of FeII and SII together with the spectral ranges of the resonance transitions of MnII, MgII and PII. In the figure the zero of the Doppler velocity scale corresponds to $z = 2.30907$. A component at $v \sim 35$ km s$^{-1}$ or $z = 2.30946$ is also detected in the stronger transitions of SII 1254 Å and FeII 1144 Å. Wolfe et al. (1994) with $\Delta v \sim 8$ km s$^{-1}$ resolution spectra of PHL957 revealed an asymmetric profile of the $v = 0$ km s$^{-1}$ main component, suggesting the presence of an additional component at $v \sim 8$ km s$^{-1}$.

Column densities and b values were derived by a $\chi^2$ minimization of Voigt profiles convolved with the instrumental point spread function by using the FITLYMAN routine in MIDAS (Fontana & Ballester 1995). Atomic parameters were taken from Morton (1991) with the exception of the MgII $\lambda\lambda 1240$ Å doublet, for which the oscillator strengths were taken from Sofia, Cardelli & Savage (1994). The results of the fits are reported in Table 1 and shown in Figs 1 and 2 as a continuous line. The effect of the double structure of the main component on the column densities of FeII and SII is negligible. In fact, using a two cloud model the fit of FeII and SII lines gives a total column density which is within 0.01 dex of the one-cloud model for both elements.

3 DISCUSSION

The elemental abundances or limits for the absorber at z=2.309 towards PHL 957 are reported in Table 1. The adopted hydrogen column density is $N(HII) = (2.5 \pm 0.25) \times 10^{22}$ (Pettini, Boksenberg & Hunstead 1990) and the solar abundances are from Anders & Grevesse (1989) except for Fe taken from Hannaford et al. (1992).

The iron abundance in the absorber is $[Fe/H]=-1.99$, and when combined with the zinc value of $[Zn/H]=-1.55$ derived by Wolfe et al. (1994), we obtain $[Fe/Zn]=-0.44$. In halo stars zinc tracks closely iron and is almost undepleted in the Galactic interstellar medium. The current interpretation for the Fe underabundance relative to Zn is that the missing iron is tied up in dust grains. An estimation of the
that the intrinsic ratio between Fe and Zn is solar and scaling down the Galactic relative fraction of atoms of Fe and Zn in dust grains to get the observed [Fe/Zn]=−0.44, we infer a depletion of −0.58 dex for Fe and −0.14 dex for Zn in the DLA system towards PHL 957. This means that ≈ 74% of Fe and ≈ 28% of Zn in PHL 957 is locked up in grains as opposed to the nearly total ≈ 94% of Fe and the 35% of Zn in the Galaxy. For the other refractory elements Mg and Mn for which we present limits the predicted depletions are −0.48 dex and −0.51 dex starting from a Galactic depletion of −0.82 dex and −0.92 dex respectively (Savage & Sembach 1996). Strictly speaking the depletions of Mg and Mn depend on the intrinsic abundances in DLA absorbers. If Mg is overabundant the depletion factor is smaller and if Mn is underabundant the depletion is larger of what inferred here which holds for solar relative composition (Vladilo 1998).

For the elements S, N, P, and O we assume null depletion as it is observed in the Galaxy. The depletion factors and the abundances relative to Fe and corrected for dust contributions (≡ [X/Fe]c) are reported in the last two columns of Table 1. These show that there is a considerable reduced grain condensation in the Damped system, although it is not negligible. If we consider the grain contribution the metallicities of the DLA system is [Fe/H]=−1.41, only slightly higher than that deduced by the observed [Zn/H]=−1.55 ought to the small correction for depletion of Zn. This metallicity confirms previous indications that the absorption system arises in a galaxy at an early stage of its chemical evolution. With this value for the metallicity the dust-to-gas ratio amounts to about 3% of that of the Galaxy. This value is in agreement with the values obtained by means of the [Cr/Zn] argument for this and other DLA absorbers by Pettini et al. (1997).

Of particular importance is the comparison between α and iron peak elements. In DLA systems the relative abundances of Si and Fe are often found to be consistent with a halo-like pattern. Lu et al. (1996) found an average value of <Si/Fe >=+0.36±0.11 from a compilation of 12 measurements. However, Si and Fe are differentially depleted from gas to dust. The average value of Galactic interstellar clouds is [Si/Fe]=+0.66±0.26 (Lu et al. 1995). The observed enhancement of Si versus Fe in the DLA systems would reflect the overabundances of α elements with respect to the iron-peak elements only in absence of dust. Since DLA systems contain some amount of dust, as shown by the reddening of QSO with DLA absorbers in their spectra (Pei, Fall & Bechtold 1991), a moderate enhancement of Si over Fe cannot be regarded as a clear evidence of a halo-like pattern.

It has been pointed out that the ratio between SII and ZnII is probably the best diagnostic tool available for revealing the relative contributions from the different types of supernovae since S is mainly a product of type II SN, while Zn of type Ia SN. This because both elements show little affinity with dust and their ratio is also safe against possible contributions to the column densities from III regions along the line of sight, since they essentially cancel out each other in the ratio (Molaro, Matteucci & Vladilo 1995, Lauroesch et al. 1996). Combining the Zn determination of Wolfe et al (1994) with our determination for S we obtain [S/Zn]=0.01, or [S/Zn]c=−0.13 when corrected for the small Zn depletion, a result which is at variance with the value [S/Fe]≈0.5 observed in halo stars (Weeler, Sneden & Truran 1989). In spite of the very low metallicity of...
the gas in this galaxy, the ratios of two elements believed not to be significantly affected by dust depletion are strictly solar. Only few determinations for S and Zn are present in literature. Meyer & Roth (1990) found [S/Zn] = −0.1 in the DLA system at z = 2.8 towards QSO PKS 0528-250, and this number is confirmed by the new Keck measurements by Lu et al. (1996). By combining the column density published by Kulkarni et al. (1995) we obtain [S/Zn] = +0.1 in the z=1.775 absorber in QSO 1331+170. For these two cases a possible mild depletion of Zn in dust grains has not been considered, and the ratios may even slightly decrease. Thus in all systems with extant data for S and Zn their ratio is found far from what observed in the Galactic halo stars.

The observed limit for the α element Mg is [Mg/Zn] ≤ −0.18 that becomes [Mg/Fe] ≤ +0.16 when the Mg depletion is applied. This value is not consistent with the typical overabundance of Mg observed in the halo stars.

Oxygen abundance is not known since the OI 1302.1685 Å line is strongly saturated and contaminated. By using the non-detection of the much fainter OI 1355.5977 line we obtain [O/H] ≤ −0.8 which is consistent but somewhat less stringent than the [O/H] ≤ −0.97 derived by Wolfe et al. (1994) at 3σ level. The limit by Wolfe implies [O/Fe] < +0.44 and this is only marginally consistent with the O enhancement of 0.5 < [O/H]<1 observed in the halo stars.

The upper limit for Mn yields a ratio of [Mn/Fe] c < +0.04. The limit is consistent with the moderate deficiency of < [Mn/Fe] c > = −0.32 ±0.16 observed by Lu et al. (1996) in about 7 DLA absorbers. The limit for the non-refractory phosphorus is the first for a DLA absorber and gives [P/Fe] c < −0.68. This matches the expectations for an odd-light element but the lack of P observations in metal poor stars prevents tighter considerations.

In our system we find [N/Fe] c = −1.35. Nitrogen is believed to be mostly a product of secondary nucleosynthesis, but a primary component can be obtained when the seed nuclei are produced in earlier helium burning stages of the same star. Nitrogen is essentially a non refractory element and dust problems are avoided but the complex nucleosynthetic origin prevents a straightforward interpretation. The nitrogen underabundance we find is significantly lower than that of halo dwarfs (Wheeler, Sneden & Truran 1989), in line with the limit at [N/Fe] c < -0.8 for the absorber at z=2.27936 towards 2348-147 (Pettini et al. 1995), but at variance with the [N/Fe] c ≃ −0.39 found in the absorber at z=3.390 towards QSO 0000-2619 (Molaro et al. 1996). The measurements show that a real dispersion in the nitrogen abundances is probably present among the DLAs, and we defer the discussion to a subsequent paper where we present other N observations in DLA systems (Centurión et al. 1997).

In summary, we find that all the α over iron ratios [S/Fe] c ≃ −0.13, [O/Fe] c < +0.44 and [Mg/Fe] c < +0.16 are far from the typical value of the halo. Assuming that the Zn and Fe track each other closely these results do not strongly rely on the depletion corrections we have applied, which have some intrinsic uncertainty related to the unknown dust properties of these young galaxies. The observed ratios suggest that the star formation history of this high redshift galaxy is different from that of the Milky Way. Other anomalous ratios have been observed in two other DLA absorbers with solar S/Zn and in the DLA system at z=3.390 towards QSO 000-2619 where N has been found at rather high levels (Molaro et al. 1996). A project to extend S observation to other DLA systems is currently in progress.

Alternative chemical evolution models for explaining approximately solar-like ratios for α over iron-peak elements at very low absolute abundances have been discussed in Molaro et al. (1995, 1996) and at length in Matteucci, Molaro & Vladilo (1997). These models adopt bursts of star formation and/or selective galactic winds and are able to produce scenarios in which Type I SNe and AGB yields are dominant. Such models appear suitable to interpret anomalous abundances such those found in the z=2.309 DLA absorber towards PHL 957. If chemical patterns different from the Galactic halo should be found either common or frequent among the Damped Lyα galaxies, through future observations there would be important implications for disclosing the nature of the galaxies which are responsible for the DLA systems. The present observations show that at least few DLA absorbers do not conform to the notion that they are the progenitors of the present day spiral galaxies.

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