Constraints on Chemical Evolution Models from QSOALS Abundances

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1 Introduction

Models of the formation and early chemical evolution of our Galaxy are guided and constrained by our knowledge of abundances in globular cluster stars and halo field stars. The abundance patterns identified in halo and disk stars should be discernible in absorption lines of gas clouds in forming galaxies which are accidentally lying in front of background QSO's. Conversely, the ensemble of QSO absorption line systems (QSOALS) at each redshift may suggest a detailed model for the formation of our Galaxy that is testable using abundance patterns in halo stars.

2 Galactic Abundances

Over the past decade, high signal-to-noise ratio, spectroscopic studies of Population II stars have provided strong evidence that the oldest and most extremely metal deficient halo stars in our Galaxy are characterized by elemental abundance patterns which differ substantially from those characteristic of Solar System matter (Wheeler, Sneden, and Truran 1989, Gratton and Sneden 1991). In halo stars, it is found that oxygen and the other even-Z, alpha particle nuclei (neon, magnesium, silicon, sulphur, argon, calcium, and perhaps titanium), are enriched relative to iron and the other even-Z, iron peak nuclei (chromium, nickel, and zinc) by approximately a factor of 3, when $[Fe/H] \lesssim -1.0$. Aluminum, an odd-Z nucleus, is underabundant relative to the even-Z alpha particle nuclei for $[Fe/H] \lesssim -1.0$. While the even-Z iron peak nuclei (nickel, chromium, and zinc) have essentially solar abundance ratios compared to iron in metal-poor stars, Mn and Cu (both odd-Z nuclei) are relatively underabundant. These trends can be understood as a consequence of early formation of the bulk of the α nuclei in type II SNe, with the later buildup of the Fe-group by type I SNe (Wheeler, Sneden, and Truran 1989, Lauroesch *et al.* 1992).

Abundance determinations in Galactic gas clouds have shown that in the ISM there is selective depletion of some elements into dust grains. A review of elemental abundances in the ISM and of the inferred composition of interstellar dust is given by Jenkins (1987). It is important to note that S and Zn show little or no depletion, while Si and Mn are depleted by $\gtrsim 0.5$ dex, and Al, Fe, Ni, and Cr are depleted by $\gtrsim 1$ dex.

3 QSO Absorption Line Systems

Absorption lines appear in spectra of QSO's at $z_{abs} \lesssim z_{em}$. York *et al.* (1991) list ~900 absorption systems out to a redshift of z~4.5. Such absorption line systems, when studied at high redshifts, might be expected to show abundances similar to those in halo stars, as the halo stars are thought to represent the first low mass stars formed from Galactic interstellar clouds. Based upon depletion patterns in the local ISM, one should expect that abundances for S and Zn should be straightforward to interpret as indicators of overall metallicity if dust in QSOALS is like local interstellar dust, whereas the total abundances of other elements may be harder to determine depending on how much dust is present. However, by comparing specific gas-phase abundance ratios and assuming that dust depletion occurs in a similar manner to that in the local ISM, it is possible to set constraints on dust formation (Meyer, Welty, and York 1989). Additional constraints on the amount of dust depletion have been placed by Pei, Fall, and Bechtold (1991), who estimated that the typical dust-to-gas ratios in damped Ly-α sytems are 5%-20% of that in the Milky Way.

A number of studies of the heavy-element absorption line systems have found evidence that the metallicity in these systems is decreasing with increasing redshift. The number density of C IV absorption systems per unit z, M(z), decreases with increasing redshift, and the mean C IV doublet ratio systematically increases with increasing redshift (Sargent, Boksenberg, and Steidel 1988, Steidel 1990, York *et al.* 1991). In contrast the number of Lyman-limit systems per unit z is increasing (Steidel 1990, and references therein). Searches for C IV absorption in known Ly-α systems have found additional C IV absorption (Meyer and York 1987, Lu 1991). The number density of Si II, Si IV, and Fe II absorbers has also been found to decline with increasing redshift (York *et al.* 1991, Lauroesch *et al.* 1992), implying that the decline in density of systems is not due to an evolving radiation field.

Recent abundance determinations from high resolution and/or high signal-to-noise observations have been published for ~10 absorption systems at z~2. It is evident, at least for this sample, that typically [Fe/H]$\simeq$-2, and that nc species, including S and Zn, have abundances in excess of $\frac{1}{8}$ solar (Lauroesch *et al* 1992). Refractory elements such as Fe, Cr, and Ni are down by less than a a factor of 5 compared to Zn in QSO absorbers, whereas in the Galactic ISM they are depleted by factors of ~20-100. If dust is similar at all redshifts, the refractory elements are relatively more depleted today than in the available sample at z~2.

Is the gas in QSO absorbers the same type of gas from which the Milky Way halo stars formed? The gas is similar to halo stars in having low metallicities, however in only a few cases have abundances been measured for a number of species with different nucleosynthetic origins. In addition, for some systems, some abundances are derived from saturated lines, and may be underestimates. Finally, it is worth noting that these results are generally without any ionization correction, although the the corrections required appear small in some systems (Meyer, Welty, and York 1989). It remains to be seen whether any anomalies in relative abundances can be discerned and separated from dust depletion effects in a larger sample of absorbers. However, from the limited data available at present there are some suggestive results. The z_{abs}=2.140 system in 0528-250 shows Mn underabundant with respect to Cr and Ni (Meyer, Welty, and York 1989), Cr and Ni being among the more heavily depleted species in the local ISM. This is similar to the halo stars where Mn is underabundant compared to the even-Z iron peak nuclei, and suggests that type II SNe are the dominant source of the metals. The z_{abs}=1.766 system in 1331+170 (York *et al.* 1992) has a metallicity of $\sim \frac{1}{10}$ solar, but Si, S, and Mn appear to be in essentially solar ratios when compared to the Cr, Fe, Ni, and Zn. This may be a result of significant early type I SNe activity, which would explain the high Fe-group abundances and the high relative abundance of Mn.

4 Conclusions

Studies of abundances in QSO absorption line systems, determining the distribution of abundances at each redshift, should allow detailed modelling of the history of chemical evolution in the universe. Patterns in the relative abundances in the absorber systems can be used as probes of the history of chemical evolution in these systems, and can be compared both to the patterns observed in the Galactic halo and to chemical evolution models. If a large sample of relative abundance measurements can be made for a number of systems in different redshift intervals, it may be found that there are systems where the chemical evolution occurs in a manner quite different than in the Galactic disk and halo. This topic has been discussed in detail by Lauroesch *et al.* (1992). A program of high resolution measurements of a number of QSO lines-of-sight has begun using the 4-meter telscope at Kitt Peak National Observatory by J. T. Lauroesch, D. G. York, and R. F. Green.

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