Dust, Metals and Diffuse Interstellar Bands in Damped Lyman Alpha Systems

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Although damped Lyman alpha (DLA) systems are usually considered metal-poor, it has been suggested that this could be due to observational bias against metal-enriched absorbers. I review recent surveys to quantify the particular issue of dust obscuration bias and demonstrate that there is currently no compelling observational evidence to support a widespread effect due to extinction. On the other hand, a small sub-set of DLAs may be metal-rich and I review some recent observations of these metal-rich absorbers and the detection of diffuse interstellar bands in one DLA at $z \sim 0.5$.

1. Introduction

At this conference on the metal-rich universe, a talk on damped Lyman alpha (DLA) systems may seem misplaced, since there is now a considerable literature on these absorption selected galaxies that describes them as metal-poor (e.g. Pettini 2004 and references therein). Faced with the almost universally sub-solar abundances of DLAs over all redshifts (the average metallicity of DLAs is $\sim 1/30 Z_\odot$ at $z \sim 3$ and $\sim 1/10 Z_\odot$ and $z \sim 1$), questions have been raised concerning DLA selection techniques. For example, are we missing a large fraction of metal-rich DLAs due to dust obscuration bias (Ostriker & Heisler 1984)? Or are the bulk of the metals in absorbers below the canonical DLA column density threshold (Péroux et al. 2006)? In this contribution, I review the latest observations on the possibility of selection bias and discuss whether DLAs can ever be considered as metal-rich.

2. Are DLA Abundances Biased Due to Dust Obscuration?

DLA identification relies on a bright background QSO on whose continuum the strong Lyman $\alpha$ and metal line species can imprint their absorption signature. If an intervening galaxy is rich in dust and metals, the very background QSO on which we rely will appear fainter and redder and may ‘drop out’ of traditional quasar surveys. This idea has been around for more than 20 years (Ostriker & Heisler 1984; Fall & Pei 1993) and it has been suggested that extinction bias may ‘hide’ more than 70% of gas at high redshift. Four pieces of observational support are often cited for the dust bias scenario 1) only mild redshift evolution in DLA metallicities, 2) low metallicities compared with emission line galaxies at similar redshifts, 3) steeper continuum slopes in QSOs with DLAs compared to those without (Pei, Fall & Bechtold 1991) and 4) an anti-correlation between N(HI) and metallicity (Prantzos & Boissier 2000, see Figure 1).

In order to quantify the impact of dust bias, two surveys based on radio-selected QSOs have now been completed. Together, the Complete Optical and Radio Absorption Line System (CORALS; Ellison et al. 2001) and the UCSD survey (Jorgenson et al. 2006) cover a redshift path $\Delta z \sim 100$ for 119 radio-selected QSOs with very deep (and, in the case of CORALS, complete) optical follow-up. Neither survey finds an excess of absorbers either at high or low (Ellison et al. 2004) redshift and the neutral gas content is in good
Figure 1. Metallicities from optically selected DLA surveys (open points) and from the radio-selected CORALS survey (filled points). The dashed line shows the ‘dust filter’ of Prantzos & Boissier (2000), although this is inconsistent with limits on DLA reddening (Ellison, Hall & Lira 2005). Figure adapted from Akerman et al. (2005).

agreement (within a factor of 2) with optical samples, see Figure 2. More importantly for the present discussion, Akerman et al (2005) have shown that the metallicities of DLAs in the CORALS sample are not significantly higher than optically selected samples and do not populate the parameter space at high N(HI) and high metallicity (Figure 1). However, since metallicities are usually weighted by the rare high N(HI) absorbers, a larger sample is required in order to make this result robust.

So, how do we explain the the observational ‘evidence’ in support of dust bias? A number of recent papers point to the idea that although DLAs maybe reservoirs rich in atomic gas, they do not generally flag the location of the bulk of star-formation and, therefore, metals (e.g. Wolfe & Chen 2006). Indeed, emission line spectroscopy of $z \sim 0.5$ galaxies causing absorption line systems typically have solar abundances (Ellison, Kewley & Mallen-Ornelas 2005). Such observations indicate that high abundances can be found in absorption selected galaxies, although they may be confined to smaller regions than the cross-section of DLA-producing gas. The cause of the anti-correlation between N(HI) and metallicity is still under debate. However, Ellison, Hall & Lira (2005) have argued that the very low values of reddening that are now being determined for DLAs may soon make dust obscuration an unviable explanation. An alternative explanation may be that sightlines that pass through high column density, high metallicity gas, are simply rare. Simulations support this idea (e.g. Johansson & Efstathiou 2006), showing that the cross-section for such gas at $z \sim 3$ is small. Finally, concerning the reddening of QSO continua, this may simply have been a case of a difficult measurement combined with small number statistics. Fitting continua to $\sim 1500$ SDSS spectra, Murphy & Liske (2004) have found reddening to be very low: E(B−V) < 0.02 and a similarly low value has been found by Ellison,
Figure 2. Mass density of neutral gas in DLAs from SDSS (points shown as a function of redshift) and radio-selected surveys (cross). Figure adapted from Jorgenson et al. (2006).

Hall & Lira (2005) in CORALS QSOs, E(B–V) < 0.04 based on optical-to-IR colours. Therefore, regardless of concerns about the modest sample size of radio-selected QSO surveys such as UCSD and CORALS, there is no compelling observational evidence to invoke a dust bias. Combined with this revised observational view of dust obscuration, it is interesting to note that theory is also re-assessing the effect of extinction. For example, Trenti & Stiavelli (2006) estimate the total gas density in DLAs to be underestimated by only ~15% in optical surveys.

3. Are All DLAs Low Metallicity?

Although the majority of DLAs are metal and dust poor, this is not to say that a small fraction of absorbers do not exhibit more extreme properties. These extreme cases open the door to some innovative analyses, permitting detection of unusual species and even shedding light on the galaxy’s physical properties.

3.1. Diffuse Interstellar Bands

Diffuse interstellar bands (DIB) are common in the spectra of reddened stars in the Milky Way. Although numerous (there are now over 100 different known bands), the identification of the DIB carriers is one of the oldest outstanding mysteries in astronomical spectroscopy. Amongst the potential candidates are polycyclic aromatic hydrocarbons and long carbon chains. DIBs have been detected in only a handful of extra-galactic sightlines, including the LMC and SMC (see Snow 2001 for a review) and in one case, the broad 4428 Å feature in a z ~ 0.5 DLA (Junkkarinen et al 2004). Since the strength of some DIB lines, such as the 5780 Å feature, correlate with N(HI) in the Galaxy (Herbig...
Figure 3. A search for DIBs in DLAs; only one detection of the 5780 Å DIB has been made (York et al. 2006). In general the 5780 Å DIB is weaker for its N(HI) by up to a factor of 10 compared with Galactic sightlines, but is consistent with strengths in the Magellanic Clouds. In contrast, all sightlines show a similar dependence on E(B−V). Figure adapted from York et al. (2006).

selecting high column density DLAs may allow us to detect DIBs in high redshift galaxies. We have been undertaking such a search (Lawton et al. in preparation) and summarise our findings in Figure 3. In only one case do we detect DIB absorption: in the z ∼ 0.5 DLA towards AO 0235+164 (York et al. 2006) where we detect both the 5780 Å and the 5705 Å DIB. From this detection and upper limits from 4 other DLAs, we find that the 5780 Å line strengths in DLAs are weaker, by up to a factor of 10, for their N(HI) than Galactic sightlines. Similar deficiencies are seen in Magellanic sightlines, suggesting that DIB strength likely depends on metallicity and local physical properties as well as N(HI). On the other hand, the 5780 and 5705 Å DIBs have similar equivalent width ratios in the z ∼ 0.5 DLA and the Galaxy, possible evidence that these two bands originate from a similar character. Surprisingly, we do not detect the 6284 Å DIB which is usually much stronger than the 5780 Å line which we do detect. This indicates that the physical conditions in the DLA are different to the bulk of Galactic and Magellanic sightlines that have been studied. The only known sightline with similarly weak 6284 Å absorption is towards the sightline Sk 143, located in the SMC wing. Finally, in contrast to the trends with N(HI), Galactic, Magellanic and DLA sightlines show a similar trend of E(B−V) with DIB strength. Since DLAs generally have low E(B−V) (Ellison, Hall & Lira 2005) this implies that DIBs are unlikely to be commonly detected in these absorbers.

3.2. Metal-Strong DLAs in the SDSS

Herbert-Fort et al. (2006) have recently identified a sample of ‘metal-strong’ absorbers from the SDSS, characterised by strong heavy element absorption that is clearly detected even in low resolution SDSS spectra. These metal-strong DLAs comprise ∼ 5% of the total population. In some cases, the very strong metal lines are a symptom of high N(HI). In other cases, the metallicity is truly high compared with known DLAs. Although relatively rare, the statistical power of Sloan is expected to reveal several hundred metal-
strong DLAs. Follow-up observations with high resolution spectrographs will yield data for a myriad of applications, including the search for rarely detected atomic transitions, molecular species and the study of isotopic ratios.

In closing, it is interesting to note that although the definition of ‘metal-rich’ at this conference has been somewhat subjective, with the exception of AGN (see e.g. Max Pettini’s contribution to these proceedings) we rarely find metallicities above $2Z_{\odot}$ in either individual stars, HII regions or in galaxies. However, a handful of very super-solar abundances (up to $5Z_{\odot}$) have been recently reported for QSO absorbers just below the traditional DLA column density criterion of $N$(HI) $\geq 2 \times 10^{20}$ cm$^{-2}$ (Péroux et al 2006; Prochaska et al. 2006). The surprisingly high metallicities in these absorbers leads to a volley of new questions: How have these absorbers become so metal-rich at early times? What are their low redshift analogues? And what is the implication for the cosmic metals budget?

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