ON THE ANALYSIS OF DLA KINEMATICS

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Abstract

We discuss two mistreatments of damped Ly\textsc{a} (DLA) kinematic analysis that were first performed by Haehnelt, Steinmetz, & Rauch (1998; hereafter HSR98) and have recently been repeated by Hong et al. (2010; astro-ph/1008.4242v1; hereafter H10). Each mistreatment led to the improper excising of simulated absorption profiles. Specifically, their analyses are strictly biased against DLA sightlines that have low HI column density $N_{\text{HI}} \lesssim 10^{20.5}$ cm\textsuperscript{-2}, very high $N_{\text{HI}}$ values, and (for all $N_{\text{HI}}$) sightlines with low $\Delta v$ ($< 30$ km s\textsuperscript{-1} for HSR98; $< 20$ – 30 km s\textsuperscript{-1} for H10). None of these biases exist in the observational analysis. We suspect these mistreatments compromise the results that followed. Hopefully this posting will prevent their repetition in the future.

Subject headings: galaxies: evolution — intergalactic medium — quasars: absorption lines

1. Introduction

In 1997, we first measured the kinematic characteristics of a small sample ($N = 17$) of damped Ly\textsc{a} systems (DLAs) as a means to assess the dynamical motions of high $z$ galaxies [Prochaska & Wolfe 1997; hereafter PW97]. We compared these data against simplistic models of protogalaxies (e.g. rotating disks, infalling gas clumps) and favored a thick ($h \gtrsim 1$ kpc) disk scenario with rotation speeds $v_{c} \approx 200$ km s\textsuperscript{-1}. Furthermore, we ruled out standard CDM scenarios that considered DLAs as rotating disks (e.g. Kauffmann 1996). These conclusions hold today.

The following year, Haehnelt et al. (1998, hereafter HSR98) published a competing model within the CDM framework that described DLAs a merging protogalactic clumps. Their hybrid analysis combined results from a small set of ‘zoom-in’ numerical simulations with a Press-Schechter treatment of the dark matter (DM) halo mass function, and a heuristic assumption for the DM halo dependence of DLA gas cross-section. HSR98 concluded that this model could reproduce the DLA kinematics provided that low mass DM halos ($v_{c} < 30$ km s\textsuperscript{-1}) [Check: could be 50] did not host DLAs (see Barnes & Haehnelt 2000, for a modern update of this model).

Many other models have since been proposed with a range of success (e.g. Nulsen et al. 1998; Maller et al. 2001; Schaye 2001; Razoumov et al. 2008; Pontzen et al. 2008). Most recently, Hong et al. (2010, hereafter H10) proposed that galactic-scale winds are an essential ingredient to explaining DLA kinematics. In reviewing this paper, we noted two treatments of the simulated spectra that depart from the prescription applied to the DLA observations (as detailed in PW97). To our surprise, we discovered that these mistreatments were first introduced by HSR98. We expect that H10 simply repeated the HSR98 analysis without realizing the errors. As H10 themselves demonstrate, these have important consequences for the results derived from the simulations. With this posting, we wish to highlight these issues in the hopes of preventing their further propagation.

2. The Depth Criterion

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Because the H I Lyman series of DLAs is highly saturated, we cannot assess the gas kinematics with neutral hydrogen. Instead, DLA kinematics have been assessed using low-ion, metal-line transitions (e.g. Si II 1808). To minimize the effects of line-saturation and statistical noise in the spectra, we imposed a criterion on the depth of the transition that is analyzed:

$$0.1 \leq \min \left( \frac{I}{I_c} \right) \leq 0.6$$ \hspace{1cm} (1)

where $I$ is the observed intensity and $I_c$ is the continuum of the quasar local to the transition. This criterion precludes lines that are heavily saturated (i.e. $I/I_c < 0.1$) also weak profiles to focus the analysis on the bulk of the gas while maintaining a good S/N ratio (see PW97 for more details). Conveniently, nature provides enough UV transitions at $\lambda < 2000\AA$ such that we have always identified at least one low-ion transition for analysis in every DLA observed, no matter its HI column density and metallicity. Furthermore, the low-ion transitions very precisely trace one another (Figure 1, Prochaska 2003 see also) such that all lines satisfying this criterion have nearly identical kinematic characteristics. To emphasize, no DLA has been precluded from kinematic analysis because of this criterion. Indeed, the original PW97 analysis relied on transitions with a wide range of $\lambda f$ values (e.g. Fe II 1608, Si II 1808).

HSR98 generated metal-line absorption profiles from their numerical simulations (i) by assuming the H I gas had a metallicity $[\text{Si/H}] = -1$ everywhere and (ii) by adopting the atomic data for the Si II 1808 transition. These authors then only considered profiles \textit{“satisfying the criterion in equation (1).”}. In other words, the Si II 1808 profiles that violated this criterion were excised from the analysis. In fact, this likely includes nearly all of the profiles that they presented in their Figures 3-6 as representative of their analysis. H10 followed the same steps as HSR98 and thereby excised 30 – 60% of the profiles from analysis.

It is impossible for us to precisely predict the implications of this mistreatment, but there are some obvious biases. Figure 2 shows the Si II 1808 profile for a DLA at the H I column density threshold $N_{\text{HI}} = 10^{20.3}\text{ cm}^{-2}$ with metallicity $[\text{Si/H}] = -1$, and a single component with Doppler parameter $b = 8 \text{ km s}^{-1}$. We also indicate the depth criterion expressed in Equation (1). In this mistreatment of this criterion, the sightline would have been excised from kinematic analysis. In a proper treatment, one would identify another, strong transition (e.g. Si II 1526, Fe II 1608) to perform the analysis. In short, the mistreatment biases analysis against sightlines with low $N_{\text{HI}}$ value. Figure 2 also shows that sightlines with very large $N_{\text{HI}}$ value may produce saturated profiles that also violate the depth criterion. Therefore, this mistreatment also biases the results against sightlines with very high $N_{\text{HI}}$. Of course, nature provides many more low $N_{\text{HI}}$ sightlines than high $N_{\text{HI}}$ sightlines such that the overall bias is against the former. The effects kinematically are more difficult to predict.

### 3. A $\Delta v$ Threshold

The other mistreatment of the simulated profiles by HSR98 was: \textit{“For the discussion of velocity widths a minimum threshold of $\Delta v > 30 \text{ km s}^{-1}$ was imposed on both the observed and simulated velocity widths to avoid incompleteness effects.”}. Observationally, one has never imposed such a cut. There is no equivalent to the magnitude limit in absorption line studies, especially for kinematic analysis.\textit{\footnotemark} Every DLA known that has been observed at even moderate S/N and spectral resolution shows several low-ion, metal transitions. Indeed, this has established the so-called ‘floor’ in metallicity at $\approx 1/1000$ solar for DLAs (Prochaska et al. 2003, Penprase et al. 2010).

Imposing a $\Delta v < 30 \text{ km s}^{-1}$ threshold actually has a minor effect on the DLA observations because so few systems exhibit such low $\Delta v$ values (see Wolfe et al. 2003 for the latest compilation). In contrast, models may produce a preponderance of systems with small $\Delta v$ values. Adopting a $\Delta v$ threshold, therefore, can greatly affect the results when one compares the model predictions against the observations. Indeed, the KS probability of the favored wind model in H10 decreases from 39% (fine agreement) to 2.8% (nearly ruled out) as they reduced the threshold from 30 km s$^{-1}$ to 20 km s$^{-1}$. It is quite possible that their model would be ruled out at $> 99\%$ c.l. if no threshold were imposed (i.e. the proper treatment). We can only speculate on the implications for HSR98. It seems likely that the primary result from their analysis of the numerical simulations, that $\Delta v \sim 0.6v_c$, would be greatly diminished (e.g. examine their Figure 10a). Presumably, this could be tested in the ‘no wind’ models of DLAs.

\footnotetext{It has been oft debated that a limit exists for metallicity measurements owing to dust obscuration by the DLA of the background quasar. This would almost certainly bias one against sightlines with large velocity width, not small.}
4. CONCLUDING REMARKS

Before concluding, we (sheepishly) apologize for not having identified these issues previously. We also fully acknowledge that the many successes of CDM will not be overturned by simple mistreatments of DLA kinematic analysis. Nevertheless, the results appear to remain a challenge to modern theories of galaxy formation. Hopefully the tension that lies between the observations and theoretical prediction will reveal key aspects of ISM physics and feedback in the early universe.

JXP and AMW are supported by NSF grant (AST-0709235). JXP acknowledges the hospitality of UC San Diego and CASS where he is spending a sabbatical.

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