Feedback and the metallicity evolution of DLAs

P.H. Johansson & G. Efstathiou

Institute of Astronomy, Cambridge, UK
phjohans@ast.cam.ac.uk

Introduction

Damped Lyman α systems (DLAs) are defined as quasar absorption systems with a column density of $N_H \geq 2 \times 10^{20}\mathrm{cm}^{-2}$ and they dominate the neutral hydrogen content of the universe up to $z \geq 4$. Since their discovery studies of DLAs have also helped to reveal the chemical enrichment history of the universe in neutral gas. Initial measurements of the metallicity of DLAs at $z \sim 2$ revealed subsolar metallicities with a considerable scatter from system to system. Further observations established that the global mean cross-section (N_H) weighted metallicity of DLAs was $\log(Z/Z_\odot) \approx -1$ with minimal evolution in the redshift range $z \sim 1-3.5$. At lower redshift ($z < 1$) the situation is more uncertain due to a small sample of DLAs, but some recent measurements seem to indicate that the evolution of metallicity in DLAs remains mild. Observations also revealed that the cosmological mass density of hydrogen gas measured from the DLA population has remained constant at a value of $\log\Omega_{DLA} \approx -3$ from $z \approx 5$ to $z \approx 0.5$.

Here we present semi-analytic modelling of DLAs including a realistic and detailed supernova feedback mechanism. Our model calculations produce both a mild evolution of the metallicity content in DLAs and the cosmological mass density of hydrogen in DLAs, in accordance with the observations.

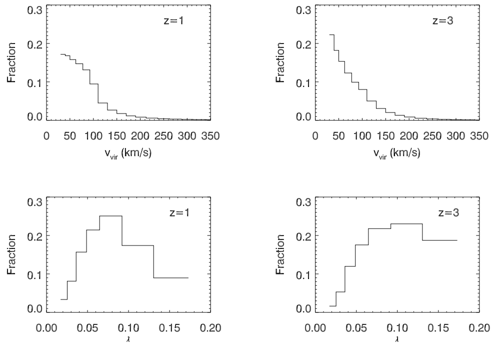

Fig. 2: The top panel shows the distribution of the DLA cross-section as a function of $v_{\rm vir}$ and the lower panel as a function of the dimensionless spin parameter λ.

The feedback model

We use the Efstathiou (2000) model of supernova feedback to evolve a grid of galaxy models with varying virial velocities and spin parameters. All models are started at $z = 7$.

The model incorporates infall of cooling gas from a halo, and outflow of hot gas from a multiphase medium. The star formation rate is determined by balancing the energy dissipated in collisions between cold gas clouds with that supplied by supernovae. Hot gas is created by thermal evaporation of cold gas clouds in supernova remnants.

The feedback model is fixed by two free parameters. The parameter ϕ_κ quantifies the effectiveness of classical thermal conductivity of the cold clouds and effectively sets the strength of the feedback. We adopt a reasonable value of $\phi_\kappa = 0.1$, although models with stronger ($\phi_\kappa = 1.0$) and weaker ($\phi_\kappa = 0.01$) feedback are also run. The second parameter ϵ_c governs the star formation rate and is calibrated using the Milky Way. Chemical evolution is included in the model using a instantaneous recycling approximation and we adopt a yield of $p = 0.02$.

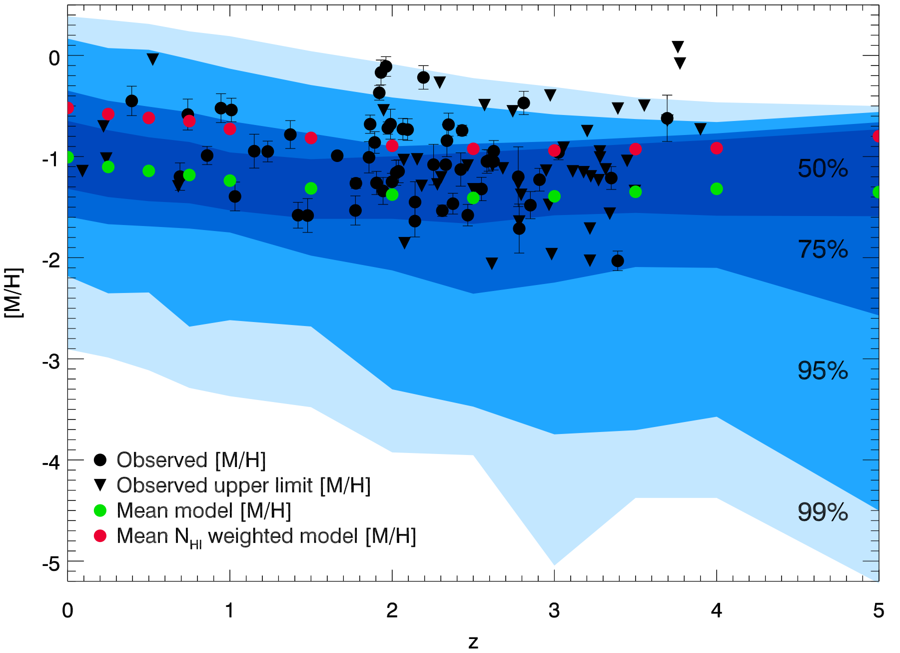

Fig. 1: The redshift evolution of DLA metallicity for our normal feedback model ($\phi = 0.1$) overplotted with observations from Akerman et al. (2005); Kulkarni et al. (2005) and references therein. The coloured contours show the fractions of the unweighted metallicities of DLAs predicted by the model.

Results

The evolution of metallicity with redshift of DLAs using our standard feedback model is compared with observations in Fig 1. Both the evolution of the mean metallicity and the weighted mean metallicity is very flat until $z = 2$ followed by a mild increase until $z = 0$. The feedback description produces a strong initial starburst and a rapid buildup of metallicity already at high ($z = 5$) redshifts. After this initial burst star formation proceeds in quiescent mode with a slow buildup of the galactic disc. The quiescent mode of star formation together with feedback that expels enriched gas keeps the mean metallicity at an almost constant subsolar level until $z = 2$. This is followed by a mild increase in the metallicity from $z = 2$ to $z = 0$ due to an increasing contribution to the DLA cross-section from lower λ and higher $v_{\rm vir}$ discs with higher metallicities (see Fig. 2).

Making the feedback stronger ($\phi_\kappa = 1.0$) decreases the overall metallicities by 0.1-0.3 dex while the weaker feedback ($\phi_\kappa = 0.01$) increases the metallicities by a similar amount. We estimated the effect of dust obscuration using the simple Prantzos & Bossier (2000) method, obscured DLAs have $[\mathrm{Zn/H}] + \log \mathrm{N_{HI}} > 21$. We found the obscuration correction to be small with an overall increase of the metallicity by only ~ 0.1 dex.

In Fig 3. the evolution of Ω_{HI} as a function of redshift is shown together with observational measurements. We reproduce the weak evolution of the neutral hydrogen mass density and find resonable agreement with observations at both high and low redshift.

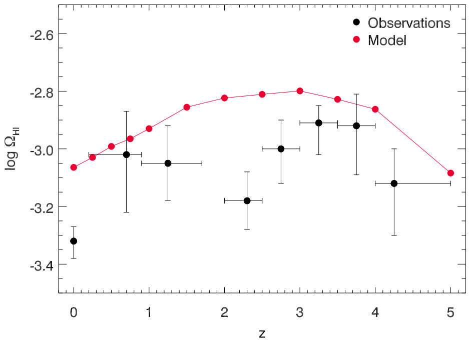

Fig. 3: The plot shows the evolution of the neutral hydrogen mass density in DLAs overplotted with observations. The $z = 0$ point is from Zwaan et al. (2005), the two points around $z = 1$ are from Rao et al. (2005) and the five points at high redshift are from Prochaska & Herbert-Fort (2004).

Summary

We present here semianalytic modelling of DLAs including a detailed treatment of supernova feedback. Our modelling predicts a very flat evolution of both the metallicity of DLAs and the neutral mass density in DLAs as a function of redshift. Varying the strength of feedback changes the overall metallicities by 0.1-0.3 dex but the mild evolution with redshift remains.

We argue that the evolution of the DLA metallicity and Ω_{HI} as a function of redshift is more likely to tell us about infall and feedback than the cosmic star formation history.

References

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