# The impact of different feedback processes on the Lyα emission and the circumgalactic medium of high redshift galaxies

## ABSTRACT

This poster shows results from different works which explore the effect of feedback processes on the galaxies and the intergalactic medium at high redshift.

Firstly, I present the paper Tescari et al. (2011, MNRAS, 411, 826) on the cosmic evolution of the triply ionized Carbon (CIV) in high-resolution hydrodynamic simulations, where we investigate the properties of CIV in the intergalactic medium using a set of high-resolution and large box-size cosmological simulations of a ΛCDM model.

Then, I present 3D resonant radiative transfer simulations of the spatial and spectral diffusion of the Lyα radiation from a central source in the host galaxies of high column density absorption systems at z~3: Barnes, Haehnelt, Tescari and Viel (2011, MNRAS in press). The radiative transfer simulations are based on a suite of cosmological galaxy formation simulations which reproduce a wide range of observed properties of Damped Lyα absorption systems (Tescari et al. 2009, MNRAS, 397, 411).

## SIMULATIONS

**Codes:**

➔ A modification of the Lagrangian SPH code ***GADGET-2*** (Springel 2005) with a self-consistent implementation of the metal enrichment mechanism (Tornatore et al. 2007).

➔ The Eulerian AMR code ***RAMSES*** (Teyssier 2002).

Simulations were run in parallel on different Supercomputers:

- in Cambridge (UK): HPC and COSMOS
- at CINECA (Bologna, Italy): BCX and SP6
- CCRT machines in Bruyères-le-Châtel (Paris, France): Titane, Platine, Mercure

**Feedback models:**

### GALACTIC WINDS

Energy-Driven Winds model Springel & Hernquist (2003):

$$\frac{1}{2}\dot{M}_w v_w^2 = \chi \epsilon_{SN} \dot{M}_\star$$

$$\dot{M}_w = \eta \dot{M}_\star$$

$\eta$ is kept fixed to the value 2.

Original model where the velocity of the wind $v_w$ is constant. We tested Strong Winds (SW) of 600 km s$^{-1}$ and Weak Winds (WW) of 100 km s$^{-1}$.

Momentum-Driven Winds model Oppenheimer & Davé (2006, 2008):

$$\dot{M}_W V_\infty \approx \dot{P}_*$$

$$V_\infty \sim \sigma,$$

$$v_{wind} = 3\sigma\sqrt{f_L - 1};$$

$$\eta = \frac{\sigma_0}{\sigma}.$$

The velocity of the wind scales as the galaxy velocity dispersion $\sigma$. This model (MDW) is more physically motivated.

### GAS ACCRETION ON TO BHs

AGN feedback model, Springel et al. (2005), Fabjan et al. (2009):

$$\dot{M}_{BH} = \min\left(\dot{M}_B, \dot{M}_{Edd}\right)$$

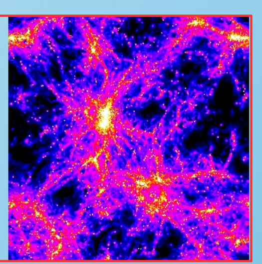
$$\dot{E}_{feed} = \epsilon_f \epsilon_r \dot{M}_{BH} c^2$$

$$\epsilon_r = 0.1$$

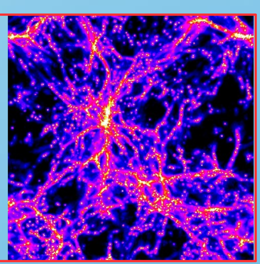
$$\epsilon_f \sim 0.05$$

The AGN feedback is powered by gas accretion on to super-massive black holes. A fraction $\epsilon_f$ of the radiated energy is thermally coupled to the surrounding gas.

SW Box gas density map



WW Box gas density map

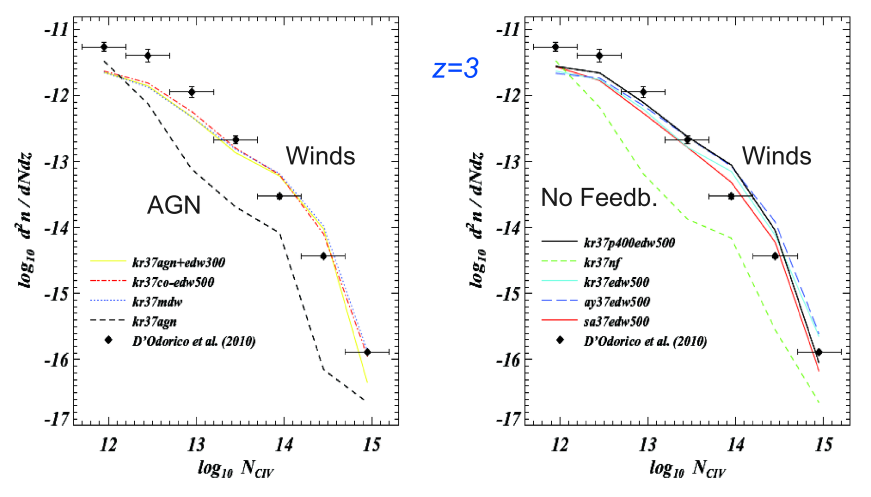


We also run a simulation with galactic winds hydrodynamically coupled to the surrounding gas and a simulation in which the energy-driven galactic winds were combined with the AGN feedback. Furthermore, our results were compared to a run in which galactic feedback were not present and we also explored different initial stellar mass functions.

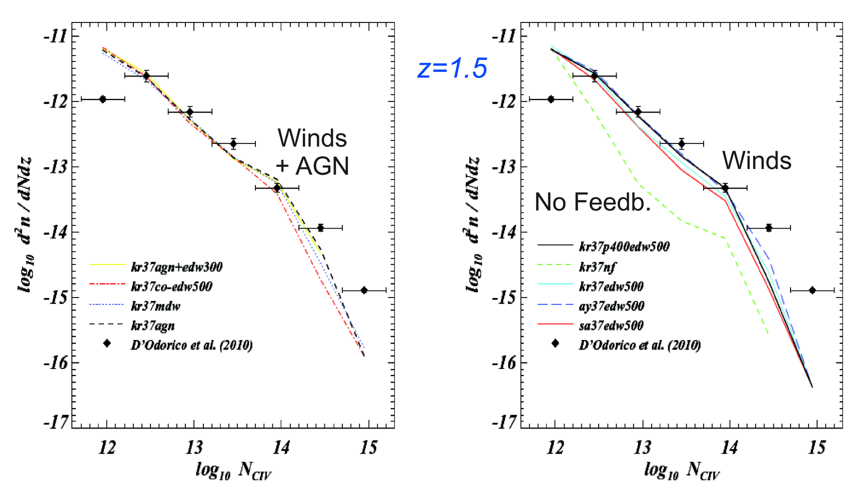
## CIV EVOLUTION

CIV Column Density Distribution Function (CDDF) evolution with z

For the CIV CDDF, we considered systems of lines formed by groups of components with relative separation smaller than $dv_{min}$ = 50 km s$^{-1}$.

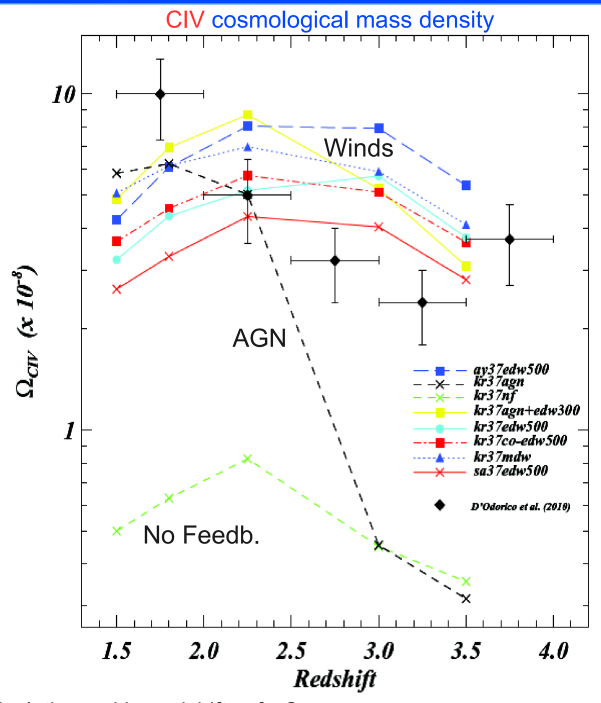



C IV CDDF at $z = 3$. Left-hand panel: part I. Right-hand panel: part II. Data from D'Odorico et al. (2010).



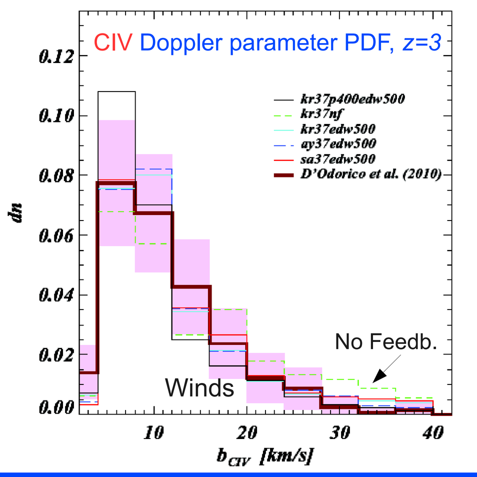

redshift $z = 1.5$.

CIV cosmological mass density

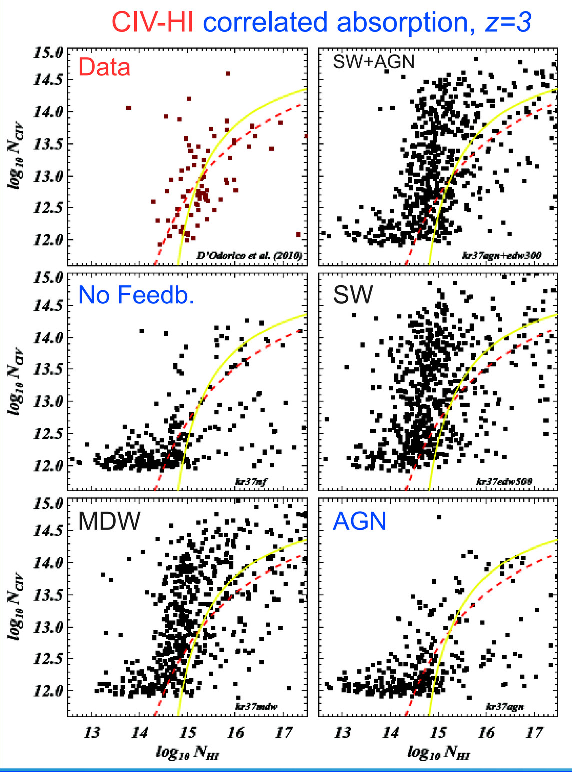



Evolution with redshift of $\Omega_{CIV}$ calculated considering the CDDF of the CIV absorption lines:

$$\Omega_{C\,IV}(z) = \frac{H_0 m_{C\,IV}}{c\rho_{crit}} \frac{\sum_i N_i(C\,IV)}{\Delta X},$$




From all these plots: galactic winds feedback starts to be active at high redshift. Moving to lower redshift, also the AGN feedback becomes effective and actually stronger than the galactic winds. The No Feedback simulation, on the other hand, fails in reproducing the observational data.




## CIV CONCLUSIONS

✔ The different statistics of CIV are strongly affected by feedback. All the simulations except for the No Feedback run and the AGN run (this latter only at high redshift) agree with the CIV column density distribution function (CDDF).

✔ Evolution with redshift of the CIV cosmological mass density: in the redshift range $z$ = 2.5 – 3.5, our "wind" simulations reproduce the observed $\Omega_{CIV}(z)$ evolution, even if with a slightly overestimation, and they perfectly reproduce the observational data around redshift $z$ = 2.25 ± 0.25. At lower redshift we found a decreasing trend at variance with the increasing trend shown by the observational data. In the AGN case the trend is nearly constant at low redshift and in better agreement with data.

✔ At all redshift considered, the CIV Doppler parameter distribution is in good agreement with the observational data. The No Feedback and AGN feedback simulations (the latter only at high redshift) result in distributions shifted towards higher $b_{CIV}$ than the observed ones.

✔ We explored the correlated CIV-HI absorption, considering systems of lines in which CIV and HI are physically dependent. At the two redshift considered both our reference runs and the observational data of D'Odorico et al. (2010) roughly follow the fit proposed by Kim et al. (2010), even if the simulations show a slightly steeper trend in the range log $N_{HI}$ (cm$^{-2}$) < 16.

✔ Galactic winds feedback starts to be active at high redshift, but moving to lower redshift, also the AGN feedback becomes effective.

✔ Feedback appears to be a crucial physical ingredient in order to reproduce statistics of metal absorption lines.

✔ Momentum-driven wind simulation reproduces best all the different quantities explored in this work.

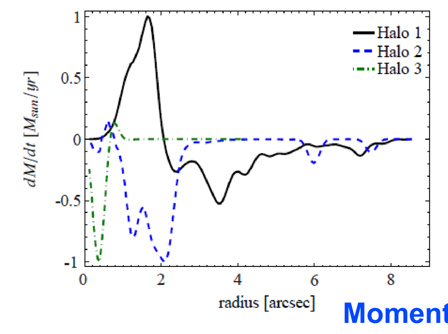
## Lyα EMISSION

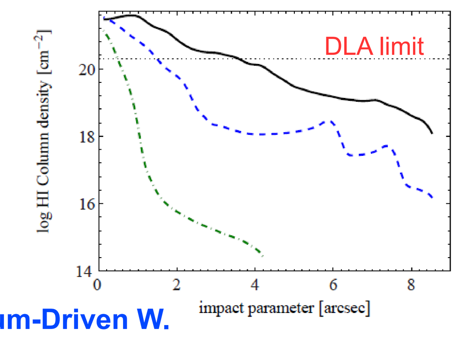
Lyα = resonant transition in hydrogen ➝ $\tau_0$ very large ➝ photons undergo many scatterings ➝ diffusion both in frequency and space. We have selected three representative haloes at $z$=3 from simulations with different galactic wind feedback prescriptions: Strong and Weak energy-driven Winds (SW and WW), Momentum-Driven Winds (MDW) and a simulation with No Wind (NW).

| Halo ID | Wind Model | Mass ($M_\odot$) | Mass HI ($M_\odot$) | Virial Velocity (km s$^{-1}$) | Virial Radius (kpc) | Virial Radius (arcsec) | Lyα Luminosity ($\times10^{40}$ erg s$^{-1}$) |
|---|---|---|---|---|---|---|---|
| 1 | momentum (MDW) | 7.70×10$^{11}$ | 2.03×10$^{10}$ | 206.7 | 77.5 | 9.8 | 882.7 |
| | strong (SW) | 7.24×10$^{11}$ | 1.38×10$^{10}$ | 202.5 | 76.0 | 9.6 | 830.9 |
| | weak (WW) | 8.15×10$^{11}$ | 2.80×10$^{10}$ | 210.7 | 79.0 | 10.0 | 935.3 |
| | none (NW) | 8.12×10$^{11}$ | 2.00×10$^{10}$ | 210.4 | 78.9 | 10.0 | 931.5 |
| 2 | MDW | 1.54×10$^{11}$ | 3.36×10$^{9}$ | 120.9 | 45.3 | 5.8 | 176.5 |
| | SW | 1.40×10$^{11}$ | 1.07×10$^{9}$ | 117.2 | 43.9 | 5.6 | 160.8 |
| | WW | 1.70×10$^{11}$ | 6.22×10$^{9}$ | 125.0 | 46.9 | 5.9 | 195.1 |
| | NW | 1.65×10$^{11}$ | 4.76×10$^{9}$ | 123.7 | 46.4 | 5.9 | 189.3 |
| 3 | MDW | 1.46×10$^{10}$ | 2.74×10$^{8}$ | 55.1 | 20.7 | 2.6 | 16.7 |
| | SW | 1.36×10$^{10}$ | 1.30×10$^{8}$ | 53.8 | 20.2 | 2.6 | 15.6 |
| | WW | 1.58×10$^{10}$ | 8.10×10$^{8}$ | 56.6 | 21.2 | 2.7 | 18.2 |
| | NW | 1.57×10$^{10}$ | 9.12×10$^{8}$ | 56.5 | 21.2 | 2.7 | 18.1 |

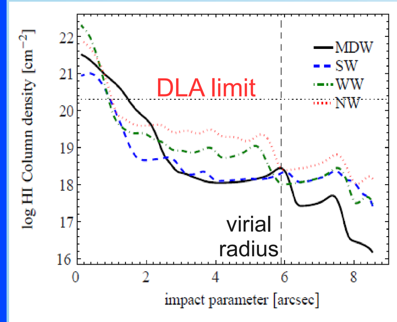
Ref. — Central Source

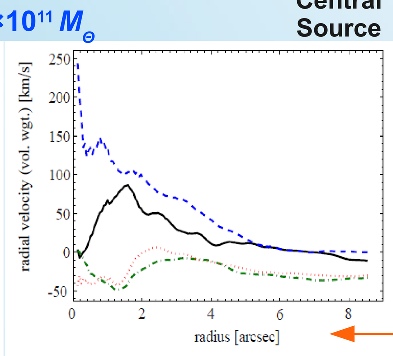
**HALO 2: Mass ≈ 1.5×10$^{11}$ $M_\odot$**

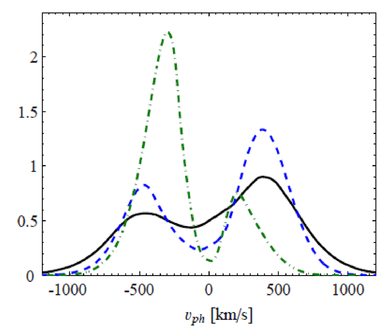


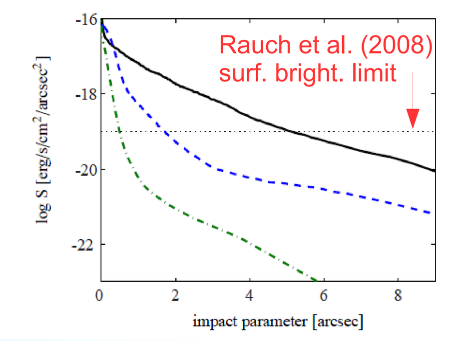




Momentum-Driven W.



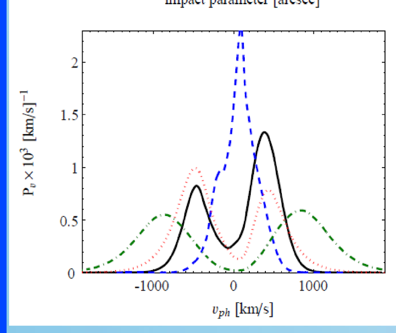



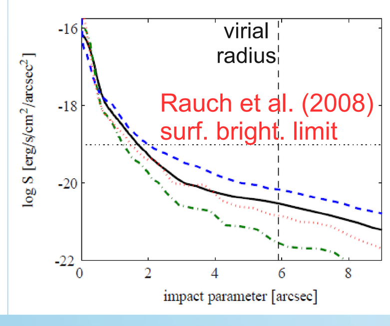



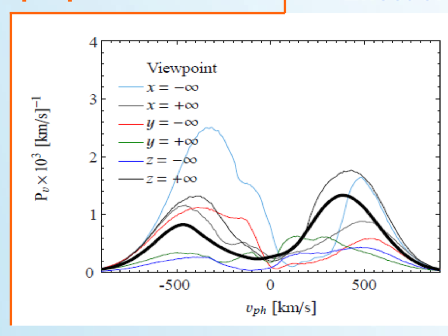


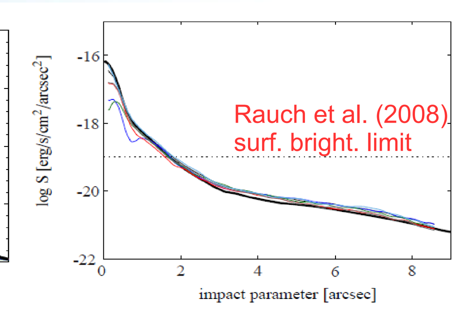

Angularly-averaged properties

Effect of the viewing angle: HALO 2 & MDW

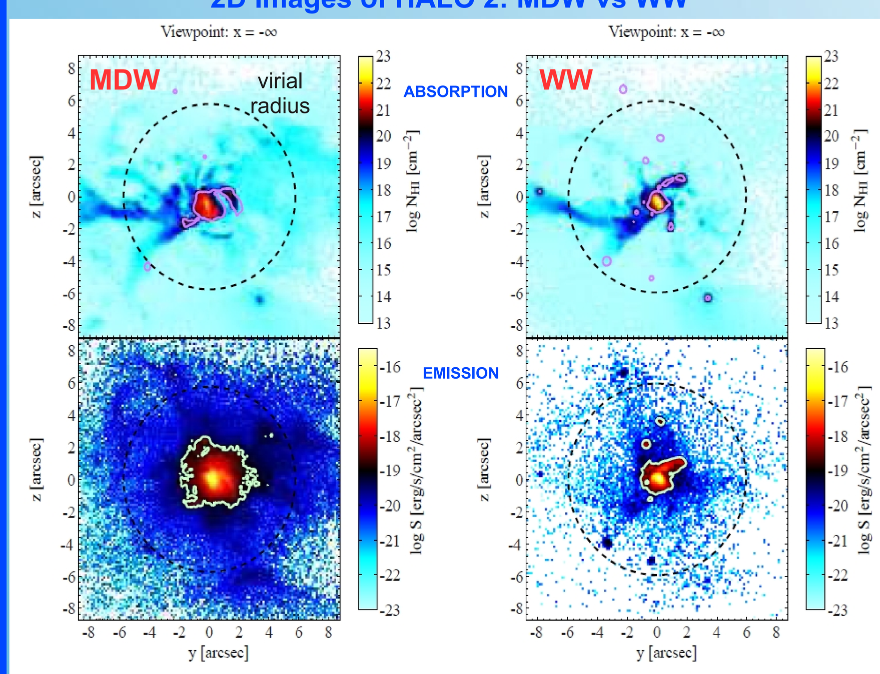




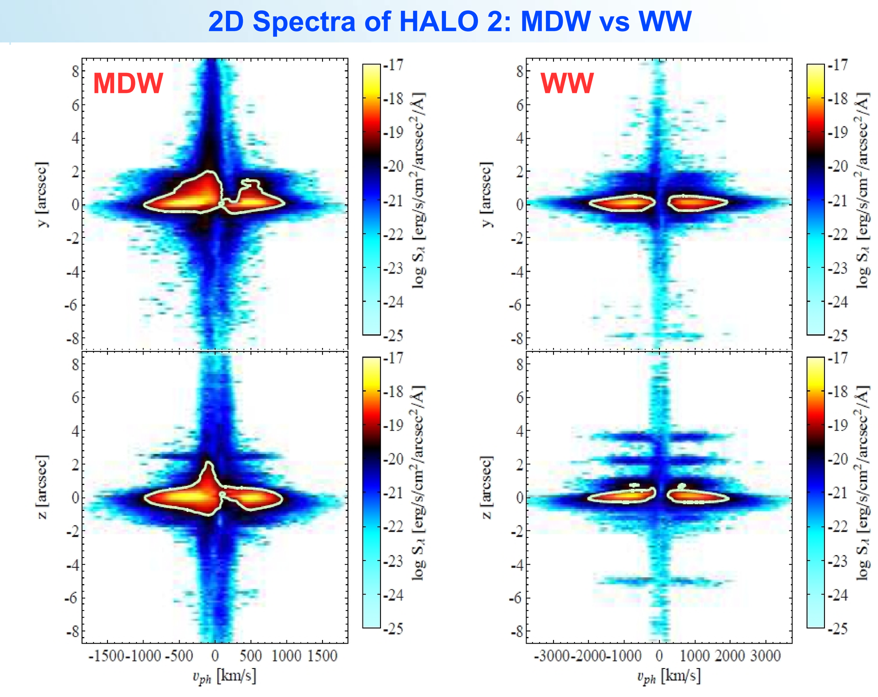




**2D Images of HALO 2: MDW vs WW**




**2D Spectra of HALO 2: MDW vs WW**




**Conclusions:**

✔ The haloes contain a mixture of inflowing and outflowing gas. As a result, the angularly-averaged spectrum typically shows two peaks, with the relative strength of the red (blue) peak being a reflection of the relative contribution of outflow (inflow). The separation of the two peaks is mainly governed by the central HI column density.

✔ The different wind implementations lead to significantly different central HI column densities as well as different radial motions of the gas, which are reflected in different spectral shapes of the Lyα emission.

✔ Lyα emission region is larger and smoother than the cross-section for damped absorption ($N_{HI}$ > 2 x 10$^{20}$ cm$^{-2}$). Lyα photons escaping at large radii illuminate regions of protogalaxies that would be probed by absorption line spectra with column dens. down to $N_{HI}$ ~ 10$^{18}$ cm$^{-2}$.

✔ The 2D spectra show considerable variety for the same halo viewed from different angles. A typical line profile is double-peaked with one of the peaks dominating. The separation of the peaks decreases with increasing distance from the central, dense regions of the halo.

✔ The dependence of the spectra on the viewing angle is very striking ➝ orientation effect.

✔ The angularly-averaged surface brightness profile is most sensitive to the column density of the gas at the centre of the haloes which in turn is very sensitive to the feedback from galactic winds. The more efficient feedback implementations result in reduced column densities at the centre and therefore reduced diffusion in frequency space and narrower spectral profiles.

✔ For the Momentum-Driven Wind model our simulated emitters show encouraging agreement with the properties of the Rauch et al. (2008) emitters and thus further corroborate the suggestion that these are the long-sought host population of DLAs.

**Future work:**

So far, we focused on galactic haloes extracted from cosmological simulations. Now, we want to simulate single (interacting) galaxies: study the effect of merger on the star formation rate.



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MARIE CURIE ACTIONS

SEVENTH FRAMEWORK PROGRAMME

## PUBLICATIONS


*Damped Lyman α systems in high-resolution hydrodynamical simulations*, E. Tescari, M. Viel, L. Tornatore and S. Borgani, 2009, MNRAS, 397, 411;

*Cosmic evolution of the CIV in high-resolution hydrodynamic simulations*, E. Tescari, M. Viel, V. D'Odorico, S. Cristiani, F. Calura, S. Borgani and L. Tornatore, 2011, MNRAS, 411, 826;

*Galactic winds and extended Lyα emission from the host galaxies of high column density QSO absorption systems*, L. A. Barnes, M. G. Haehnelt, E. Tescari and M. Viel, 2011, arXiv: 1101.3319, MNRAS in press.


## PEOPLE INVOLVED

Romain Teyssier, Matteo Viel, Stefano Borgani, Luke A. Barnes, Martin G. Haehnelt, Luca Tornatore, Francesco Calura, Valentina D'Odorico, Stefano Cristiani.