SF2A 2009
M. Heydari-Malayeri, C. Reylé and R. Samadi (eds)

LYMAN-ALPHA RADIATION TRANSFER IN SIMULATED GALAXIES : VARIATION OF LYA ESCAPE FRACTION, SPECTRA, AND IMAGES WITH VIEWING ANGLE, FOR DIFFERENT GALAXY FORMATION SCENARIOS

Verhamme, A.[1,2], Dubois, Y.[1], Slyz, A.[1] and Devriendt, J.[1]

Abstract. We present our first results from a study of Lyman-alpha (hereafter Lyα) radiation transfer calculations in a simulated dwarf galaxy ($M_{halo} = 10^{10}$ $M_{\odot}$) isolated in its dark matter halo. For two different galaxy formation senarios, we discuss the variation of the Lyα spectra, images and escape fractions with the line of sight. In the case of star-formation with supernova feedback, the Lyα emergent spectra are different edge-on and face-on, whereas they are identical in all directions in the simulation without supernova feedback. In particular, the Lyα beam is collimated along the rotation axis in the case with feedback, leading to double the Lyα equivalent width compared to the intrinsic emission. The Lyα escape fraction depends more strongly on the assumptions concerning the star formation (feedback or not), than on the different lines of sight for one given simulation.

1 Introduction

One of the most efficient methods to discover distant galaxies has been so far the "narrow band" imaging technique, selecting galaxies with a very bright emission line falling onto the detector, followed by spectroscopic confirmations that this line is indeed Lyα at high redshift. However, because of complex radiation transfer effects in this resonant line, the escape of the Lyα radiation from star-forming galaxies is not ubiquitous : there are exemples of galaxies at low redshift presenting a very strong burst of star-formation, but Lyα in absorption (Kunth et al. 1998; Atek et al. 2008); and at high redshift, 25% of the star-forming galaxies detected by the "Lyman break" technique (Steidel et al. 1996) also present a Lyα spectrum in absorption. The physical parameters which govern Lyα escape from starbursting galaxies is still unclear. Is it a question of orientation? As seems to be observed at $z \sim 0.3$ (Mallery et al. 2009), face-on galaxies might show more Lyα emission than galaxies seen edge-on. How does the geometry and the kinematics of the interstellar gas influence the ability of Lyα to escape, and in what proportion (Verhamme et al. 2006,2008)? Is there a mass sequence? Massive galaxies might have a mean Lyα escape fraction lower than less massive ones, given their stronger gravitational potential well, and higher dust content (Laursen et al. 2009). Is there a time sequence? with successive Lyα-loud and Lyα-quiet phases, as proposed by several semi-analytic models trying to reproduce observed Lyα luminosity functions (Nagamine et al. 2008; Mori et al. 2009; Dayal et al. 2009). Carrying out detailed Lyα radiation transfer on the various redshifts outputs of high resolution hydrodynamical simulations allows us to test these assumptions.

2 Description of the simulations

Simulations of galaxy formation were run using the Adaptive Mesh Refinement code called RAMSES (Teyssier 2002), allowing to describe the evolution of a gas component in presence of massive particles. It solves the Euler equations using a second order Godunov scheme. The gravitational potential given by the Poisson equation for a self-gravitating gas is added as a source term in the momentum equation. Initial conditions are generated as in Dubois & Teyssier (2008). Dark matter is a static gravitational potential (any back reaction of the baryons

[1] Oxford Astrophysics, Denys Wilkinson Building, Keble Road, OX1 3RH Oxford, UK
[2] Observatoire de Genève, Université de Genève, 51 chemin des Maillettes, CH-1290 Versoix, Switzerland

on the dark matter distribution is neglected) with a spherical NFW (Navarro, Frenk & White 1996) profile. The gas is distributed with the same profile assuming a baryon fraction $f_b = 0.15$ and an hydrostatic equilibrium to compute its temperature distribution. Radiative losses are accounted for a monoatomic primordial H/He abundance as given by the cooling function of Sutherland & Dopita 1993. We also account for a metal cooling function given by the abondancy of a mean (but not necessarily homogenous) metal component in the gas, that could enhance the cooling rate down to the minimum temperature floor T_0. No UV heating background source term is taken into account. In order to mimic the observational law (Kennicutt 1998), star formation process is computed in a heuristic way following a simple Schmidt law. We ensure that no more than 90% of the gas in the cell is depleted in one time step. The complex multiphase ISM is simulated by a polytropic equation of state (EOS) (Springel & Hernquist 2003). The supernovae feedback is treated using the same recipe than in Dubois & Teyssier (2009) : each supernovae inflates a bubble within which we deposit the energy in a full kinetic form.

We ran two sets of simulations. In the first case, the temperature floor is set to $T_0 = 300$ K and the supernovae feedback is turned off. As a consequence, the galaxy disk is thin (0.1 kpc) and starformation takes place in clumpy dense cores, the halo gas is symetrically infalling onto the disk. We call this run GALAXYCLUMPS. In the second case, the temperature floor is set to $T_0 = 10^4$ K and the supernovae feedback is turned on. The galaxy disk is thick (1 kpc) and starformation takes place homogeneously. A bipolar galactic wind develops from the disk into the halo after 2 Gyrs. This run is called GALAXYWIND.

To compute the Lyα radiation transfer in the snapshots described above, we use MCLya (Verhamme et al. 2006). This 3D Monte Carlo code includes the treatment of interstellar dust (and Deuterium). The Lyα emissivity is assumed to be located around the youngest stars of the simulations (< 200 Myrs), and proportional to the stellar mass in each emitting cell. We derive Lyα spectra, images and escape fraction along any given line of sight.

3 Results of the Lyα radiation transfer

First, we tested the effect of inclination for one given configuration: the Lyα escape fraction is indeed higher when the galaxy is seen face-on rather than edge-on for GALAXYWIND, even if the relative difference is only a factor of two. We expected a big difference: strong winds escape the galaxy along the rotation axis,whereas the gas remains neutral and almost static in the perpendicular direction. The emergent Lyα spectral shape is also very different along different lines of sight, as expected. In particular, double-peaked profiles are observed when the galaxy is seen edge-on, signature of mostly static gas along the line of sight. On the contrary, an interesting effect is seen face-on: the Lyα beam can be collimated by tunnels of ionised gas, ending with twice as more photons emerging in the direction along the rotation axis than the number of photons originaly produced in this direction (see Fig. 1).

Then, by varing the quantity of energy injected in the surrounding gas when a star dies and explodes, we investigated the influence of the supernova feedback efficiency on Lyα escape fraction, spectral shape and image (see Fig. 2). Supernova feedback efficiency has an influence on the kinematics of the interstellar gas. Indeed, the global Lyα escape is two times higher in the simulation with supernova feedback, GALAXYWIND, than in the simulation without, GALAXYCLUMPS.

Furthermore, we studied the effect of the floor of the cooling function. This influences the clumpiness of the interstellar gas, and allows us to test the effects of the interstellar medium geometry on the Lyα line. However, no straightforward conclusion could be derived from our calculations so far, as we were confronted to a numerical issue: a lack of resolution in the McLya code may erase the clumpiness effect, making the emergent spectra from GALAXYCLUMPS being the same in all directions. A new version of MCLya working on Adaptive Mesh Refinement grids in under developpement, to carry out the Lyα radiation transfer using all the detailed information contained in the hydrodynamical simulations.

Finally, radiation transfer calculations will be performed in isolated galaxies with different halo masses, to test the influence of mass on the Lyα escape fraction.

4 Perspectives

We will then test the influence of the environment on the Lyα escape from distant galaxies. Instead of considering a single galaxy isolated in its dark mater halo, we will perform Lyα radiation transfer in very-high resolution resimulations of a forming galaxy, embedded in its cosmological environment: filled with cooling flows, and undergoing mergers. This step needs the technical improvement described above, as well as the addition of another Lyα emission process: Lyα production by gravitational cooling of pristine gas onto the galaxy. Among other results, we are particularly interested in testing what "Lyα signature" cold flows imprint, as they have recently been proposed as an explanation for the mysterious observed Lyα-blobs (Dekel et al. 2009; Dijkstra et al. 2009).

The final step of this collaboration will be to post-process a cosmological volume, using these data to pin down the statistics, compute the spatial, physical and spectral properties of the sources, compare them to existing data up to $z = 5 - 6$ and make predictions for Lyα Emitters number counts for future instruments (especially MUSE and JWST).

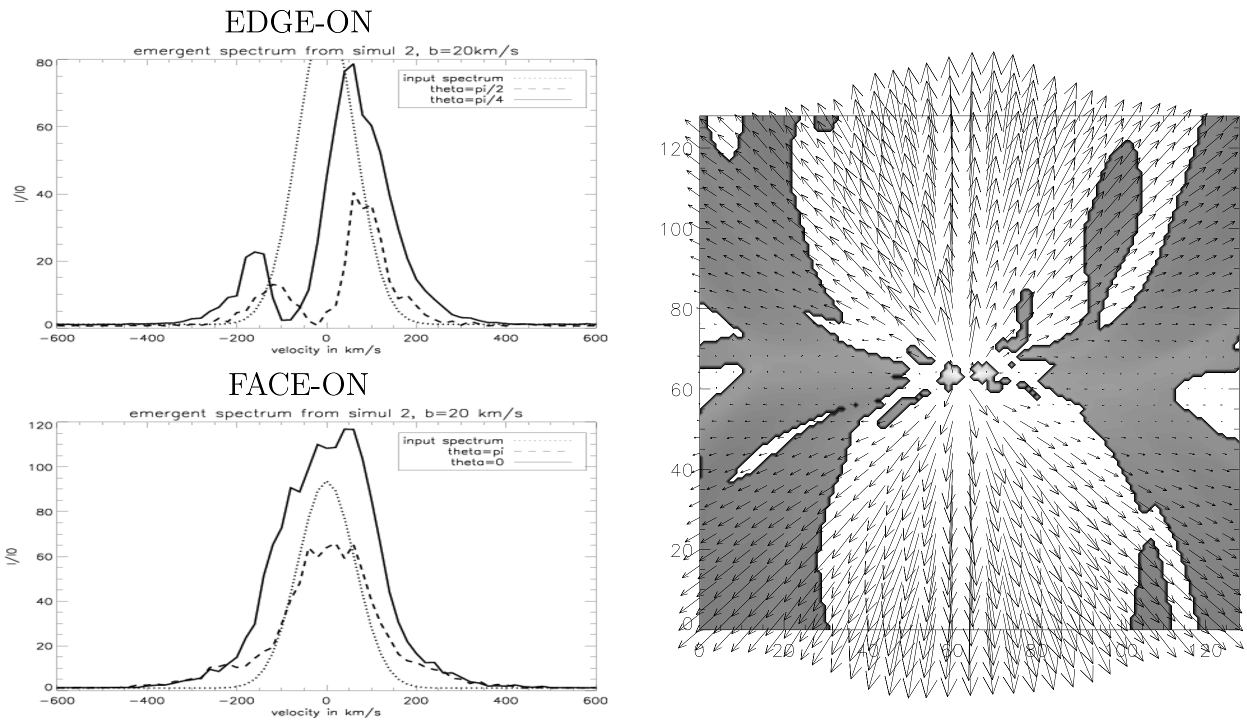

Fig. 1. Left: Emergent spectra from the galaxy along different lines of sight, for GALAXYWIND. Top panel: the emergent spectrum along the rotation axis (solid line) is boosted compared to the input spectrum (dotted line), the Lyα beam has been collimated by the neutral gas tunnel. Lower panel: the emergent spectrum along the x axis is double-peaked (solid line), with the red peak slightly higher than the blue peak, meaning that the gas is almost static in this direction. Looking at this galaxy in a direction $\theta = pi/4$, the emergent spectrum is double-peaked (dashed line), but shifted compared to the spectrum along x axis. In particular, the minimum is reached at the abscissa ~ -100 km/s, which means that most of the gas in this direction is expanding at this velocity. **Right:** Snapshot of the galaxy in which McLya was processed. In grey scale is the density distribution of the neutral gas. The velocity field is overlayed.

References

Atek, H., Schaerer, D., Kunth, D. 2009, A&A, 502, 791

Dayal, P., Ferrara, A., Saro, A., et al. 2009, MNRASsubmitted, astroph/0907.0337

Dekel, A., Birnboim, Y., Engel, G., et al. 2009, Nature, 457, 451

Dijkstra, M., Loeb, A. 2009, MNRASsubmitted, astroph/0902.2999

Dubois, Y., & Teyssier, R. 2009, A&Asubmitted, astroph/0908.3862

Dubois, Y., & Teyssier, R. 2008, A&A, 477, 79

Kennicutt, R. 1998, ApJ, 498, 541

Kunth, D., Mas-Hesse, J.M., Terlevich, E. et al. 1998, A&A, 334, 11

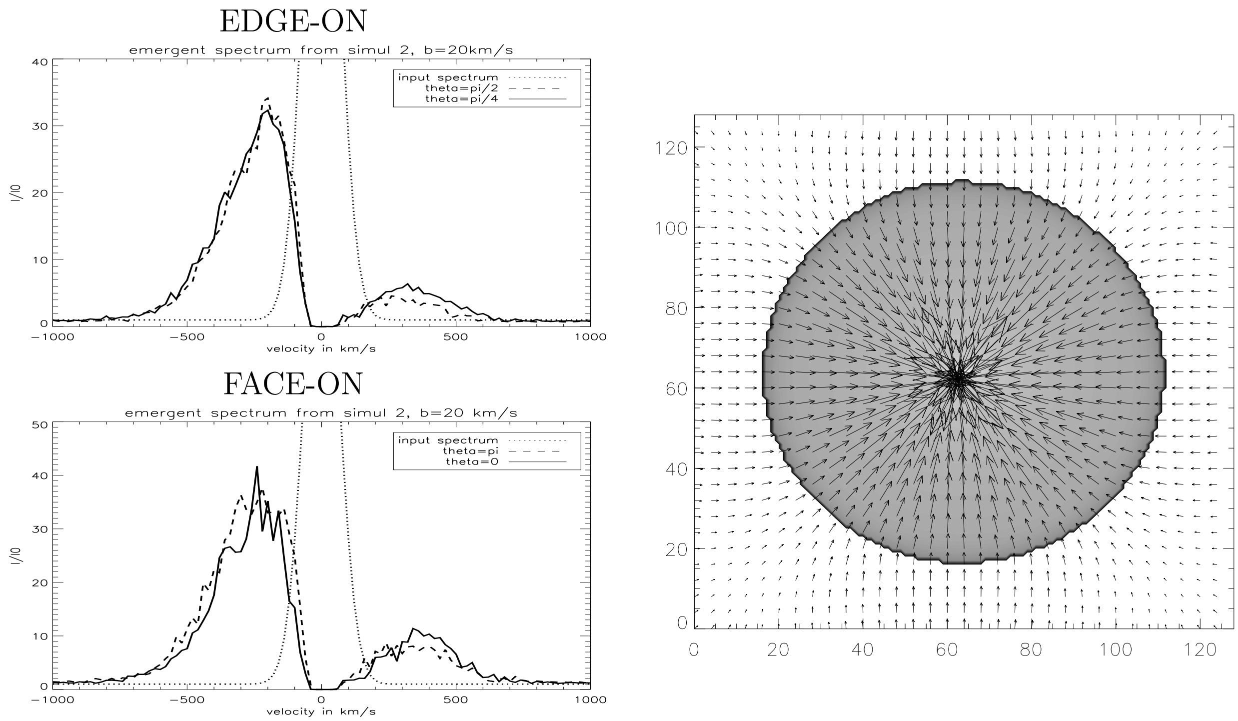

Fig. 2. Left: Emergent spectra from the galaxy along different lines of sight, for GALAXYCLUMPS. All emergent spectra show a similar shape : an asymetric blue peak, as expected for Lyα radiation transfer through an infalling halo. **Right:** Snapshot of the galaxy in which McLya was processed. In grey scale is the density distribution of the neutral gas. The velocity field is overlayed.

Laursen, P., Sommer-Larsen, J., Andersen, A. 2009, ApJ, submitted, astroph/0907.2698

Mallery, R., et al. 2009, ApJ, in prep

Mori, M., & Umemura, M. 2007, Astrophysics and Space Science, Volume 311, Issue 1-3, pp. 111-115

Nagamine, K., Ouchi, M., Springel, V., et al. 2008, astroph/0802.0228

Navarro, J., Frenk, C., White, S. 1996, ApJ, 462, 563

Springel, V., & Hernquist, L. 2003, MNRAS, 339, 289

Steidel, C., Giavalisco, M., Pettini, M., et al. 1996, ApJ, 462, 17

Sutherland, R., & Dopita, M. 1993, ApJS, 88, 253

Teyssier, R. 2002, A&A, 385, 337

Verhamme, A., Schaerer, D., Atek, H., et al. 2008, A&A, 491, 89

Verhamme, A., Schaerer, D., Maselli, A. 2006, A&A, 460, 397