Fluorescent Lyα emission from the IGM at z=3: theoretical model and observations

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Abstract

We combine a high-resolution hydro-simulation of the ΛCDM cosmology with two radiative transfer schemes (for continuum and line radiation) to predict the properties, spectra and spatial distribution of fluorescent Lyα emission at z=3. We focus on line radiation produced by recombinations in the dense intergalactic medium ionized by UV photons. In particular, we consider both a uniform background and the case where gas clouds are illuminated by a nearby quasar. We find that the emission from optically thick regions is substantially less than predicted from the widely used static, plane-parallel model. We make also prediction about the expected number density of fluorescent sources in function of the impinging ionizing flux.

Using the results and the predictions of our model we carried out a blind survey for fluorescent emitters around the z=3.1 QSO [HB89]0420-388. Preliminary results show the presence of - at least - 6 fluorescent candidates. Their emission and spatial distribution can give fundamental information about the physics of the intergalactic medium and quasar emission.

Theoretical model: hydro-simulation + UV and Ly-α radiative transfer

The Velocity Effect

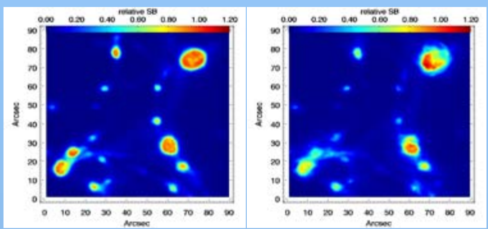


Fig. 1- Simulated Images (band width = 90Å) of fluorescent Lyα emission at z=3 for static gas clouds (left) and accounting for the gas velocity field (right). The intergalactic medium is ionized by a diffuse background only ("boost factor" b=0).

The color code gives the fluorescent SB in units of: $SB_{HM} = 3.67\times10^{-20}$ ergs cm^{-2} s^{-1} arcsec^{-2}

The plane-parallel model suggests that self-shielded (isotropically - illuminated) objects should shine with a constant surface brightness of SB_{HM} (given by the impinging ionizing rate times the fraction of the recombinations yielding a Lyα photon; Gould & Weinberg 1996, GW96). In a static simulation (where the gas velocity has been artificially set to zero) the SB of self-shielded objects closely matches the predictions of the plane-parallel model (top-left panel in Fig. 2).

When the gas velocity field is taken into account (top-right panel in Fig.2) the SB distribution of optically thick regions is broader and it is slightly shifted to fainter fluxes (to nearly 75% of the value predicted by GW96). In this case the spectral energy distributions (showed in Fig.3) are no longer symmetric (central panels) as they were in the static case (left panels).

In fact, particular configura-tions of the velocity and density fields are able to strongly suppress one of the wings of the Lyα line and significantly lower the observed SB of the self-shielded objects.

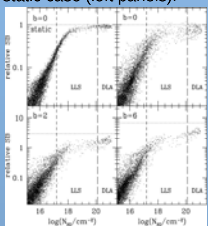


Fig. 2 - SB–N_{HI} relation for the lines of sight of 4 different simulations. Predictions of the static plane-parallel model are plotted with a dotted line.

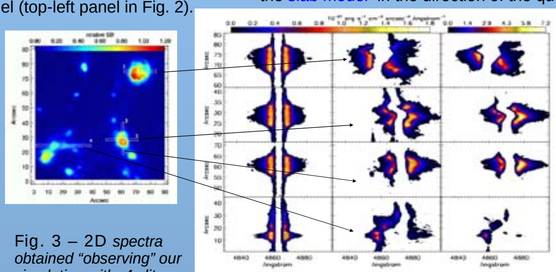


Fig. 3 – 2D spectra obtained "observing" our simulation with 4 slit spectrographs (positioned as shown in the left image). Different columns refer to different simulations. From left to right: diffuse background and static gas, diffuse background and realistic gas velocities, diffuse background plus quasar with boost factor b=6.

Quasar + Diffuse Background: the Geometric Effect

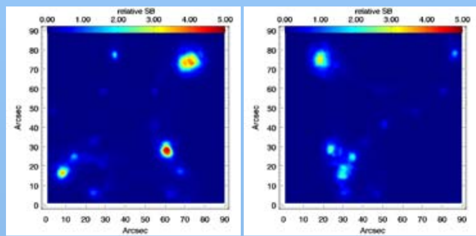


Fig. 4 – Simulated Images (band width = 90Å) of fluorescent Lyα emission at z=3. In this case, the ionizing flux from a quasar (with boost factor b=6) has been superimposed to the UV background. The image on the left (right) is obtained by observing our simulation from a line of sight parallel (perpendicular) to the direction of quasar illumination.

For anisotropic illumination and in the presence of a strong ionizing flux, the thickness of the shielding layer is comparable to the size of the gas cloud. In this case, the angular distribution of the emerging radiation is very different than in the plane-parallel approximation. For instance, close to a quasar, a cloud emits much less (more than a factor 2, see Fig.5) than predicted by the slab model in the direction of the quasar and much more in the other directions.

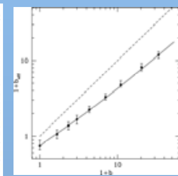


Fig. 5 - Lyα SB of optically thick clouds (expressed in terms of an "effective boost factor") obtained varing the impinging quasar ionizing flux. Solid line represents the best-fitting relation: $1+b_{eff}=0.74+0.50b^{0.89}$

Predictions of the static, plane-parallel model are plotted with a dashed line.

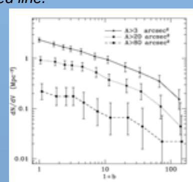


Fig. 6 – Physical number density of expected fluorescent sources (with sizes indicatated by the labels) in function of the impinging quasar ionizing flux, expressed in terms of the boost factor b.

Observation run at VLT: blind search around the z=3.1 QSO [HB89]0420-388

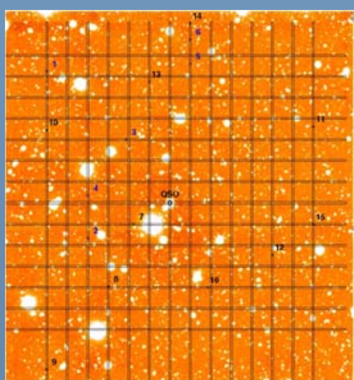
Observations were taken during four visitor mode nights on the VLT-Antu on November 28-30 and December 1, 2005. We used the MXU mode of FORS2 to build a ``multi-slit plus narrow-band filter'' configuration composed of 14 parallel slits (6'.8x2'') and separated by 25'' (see Fig.7). The configuration was also rotated by 90 deg to increase the sampled volume. Two different narrow band filters were used to cover a larger redshift range around the quasar.

Filter OIII/3000+51 was used for both the slit configurations (0 and 90 deg rotation), instead we used filter OIII+50 for just one configuration (0 deg rotation) for time reasons. For our setup the central wavelength of the filters OIII+50 and OIII/3000+51 is, respectively 4490Å and 5050Å with a FWHM of 57Å and 59Å, corresponding to a total redshift range z=3.081-3.177 for Ly-α. Using the results of our theoretical model and given the volume and the sensitivity limits of the survey, we were expecting to detect between 3 and 7 fluorescent Ly-alpha clouds.

Preliminary results:

- 6 fluorescent candidates (S/N>5, labeled from #1 to #6 in Figs.7 and 8, solid circles in Fig.9) without any continuum counterpart in a 2-hour integration time V-band image (at S/N>1 and in a circle of radius R<3'' around the expected position).

- 10 fluorescent candidates (S/N>5, labeled from #7 to #16 in Figs. 7 and 8, open circles in Fig.9) with possible low S/N continuum counterpart (1<S/N<2) or with a close detected source in the V-band image w.r.t the expected candidate position (3"<R<5").



- Fig. 7 – V-band image of the field around the selected quasar. The slits configuration and the corresponding positions of the candidates recovered in the spectra are superimposed to the image.

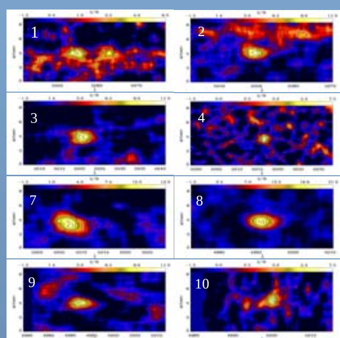


Fig. 8 – 2D-spectra (in S/N units) of 8 detected sources selected from the 16 candidates. Notice the double peaked emission (with a separation between the peaks of ~8Å, observer frame) of #1 and, marginally, of #10.

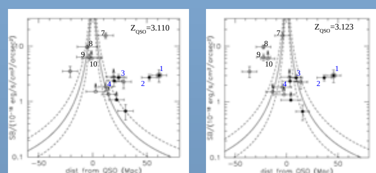


Fig. 9 – SB vs. (comoving) distance from the QSO for the 16 fluorescent candidates. Two QSO redshifts are considered.The SB is calculated from the peak flux emission using the slit width (2") as a size in one spatial dimension. See text for the meaning of the used symbols and labels. The continuum line represent the predicted SB-distance relation for fluorescent emission from our theoretical model, assuming the ionizing flux from the QSO (L_{QSO} =9.61x10^{31} erg/s/Hz) is constant in time and isotropic. The dashed lines represent the case in wich the extrapolated UV flux of the QSO is twice (upper line) or half (lower line) the value of L_{QSO}. Notice that, because of the large distance from the QSO, candidates #1 (double peaked) and #2 - if fluorescent – are emitting as a result of the ionizing flux received from the QSO with a time-delay of ~10^{8} years.

Conclusions

Our detailed numerical treatment improves upon previous work which was either based on rather crude approximations for the transfer of resonantly scattered radiation (Hogan & Weynmann 1987; GW96) or on highly symmetric semi-analytical models for the gas distribution (Zheng & Miralda-Escudé 2002). We find that simple models (e.g. GW96) tend to overpredict the Lyα flux emitted from optically thick clouds. In fact, we identified two effects (due to a realistic velocity field and to the complex geometric structure of the clouds) that reduce the fluorescent Lyα flux and modify the spectral energy distribution.

Using the predictions of our model we carried out a blind search around the z=3.1 QSO [HB89]0420-388. As a preliminary result, we found 6 fluorescent candidates without any continuum counterpart and 10 candidates with low S/N counterpart or with a close continuum source. One of them clearly shows the presence of two peaks with a separation similar to the theoretical expectation (~8Å). In most of the cases, as shown in the theoretical model, just one of the peak is clearly detected. The emission properties and the spatial distribution of the fluorescent clouds can give fundamental information about QSO properties (in particular, the angular distribution and time evolution of the emission) and about the physics of the intergalactic medium.

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