Study of Re-ionization using Lyman-alpha Emitters

Akila Jeeson Daniel
Benedetta Ciardi
MPA, Garching

Abstract:

It was proposed by Haiman and Spaans (1999) that a class of high-redshift galaxies, Lyman-alpha emitters [LAEs] can be used to constrain the neutral hydrogen fraction in the Universe. LAEs can be unambiguously detected using the Lyman break and the strength, width and asymmetry of the observed Lyman-alpha line. Lyman-alpha photons are highly sensitive to even small amounts of neutral hydrogen (e.g. neutral fraction of 10^{-4}) in the Inter Galactic Medium [IGM] (Miralda-Escude 1998). Therefore, the observed luminosity function at different redshifts can be used to constrain the re-ionization history (Malhothra & Rhodes 2004). In addition to this method, the Lyman-alpha line profile (eg. Santos 2004; Haiman & Cen 2004) give constraints on the neutral fraction in the IGM. Also, clustering properties of sources (McQuinn et al. 2007) can shed light on the re-ionization stage.

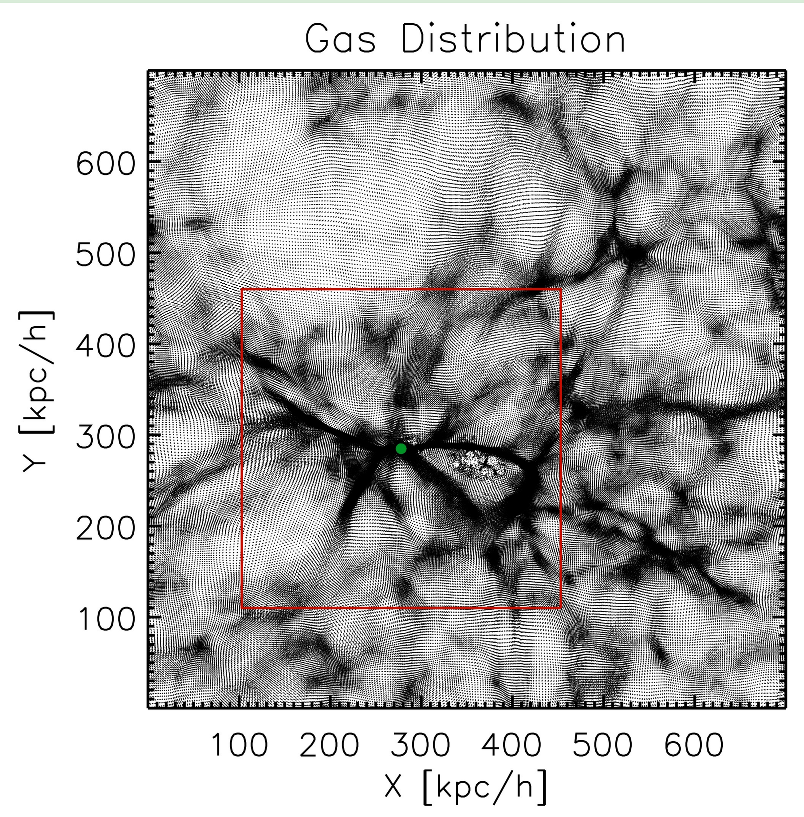
But to constrain the re-ionization history, we need to compare observations to models which include structure formation along with its radiative, chemical and mechanical feedback effects. We plan to simulate LAEs in a cosmological set up and compare it to observations. This poster shows the method and the work in progress.

Method:

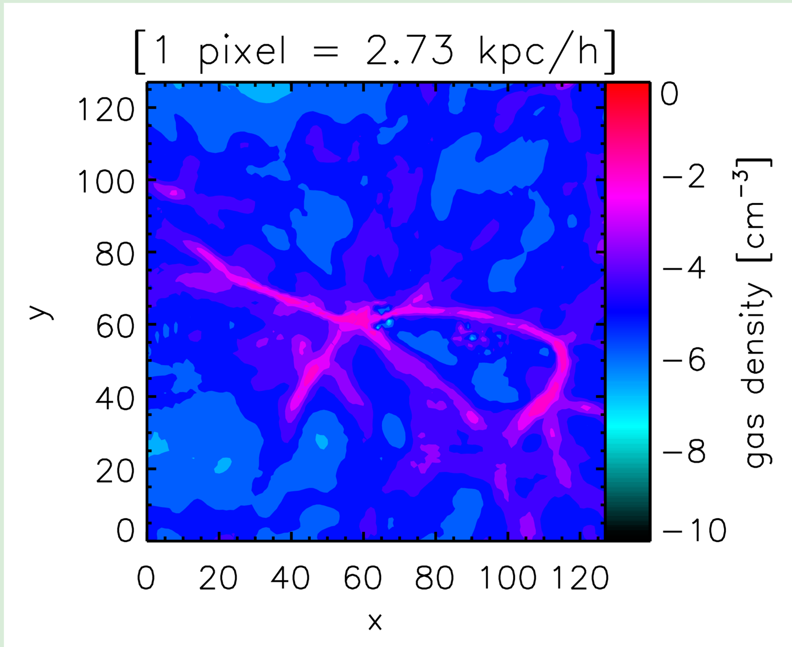
Take cosmological simulations (Gadget simulations; Maio et al.,2007, 2008 & 2009) at high redshift (z=6-12) with primordial and metal chemistry, star formation and supernova feedback included. Extract density, temperature, ionization structure, velocity profile and source properties like stellar mass & metallicity from the simulation box and run radiative transfer using CRASHα (Pierleoni et al., 2009). The source luminosity is calculated using STARBURST99 (Leitherer et al., 1999; Vazquez & Leitherer,2005) . Repeat this for all sources in the simulation box to get a statistically significant sample. Compare the luminosity functions and line profiles to observations.

Simulations (Maio et al.,2007, 2008 & 2009):

The cosmological simulations used in this work are Gadget simulations with primordial (H, D, He, H2 and HD) and metal cooling included. The initial mass functions (IMF) changes from Larson to Salpeter at the critical metallicity ($Z \sim 10^{-4}$). Supernova feedback is also included in the simulations. Source properties like centre-of mass, gas mass, metallicity, stellar mass, etc. are extracted using the FoF method. For a CRASHα input, density, temperature, ionization structure and velocities need to be gridded. This is done for the entire simulation box and then the input files are made by extracting the values for a cube around the source.



Here is an example of the simulation output. On the left is a slice though the snapshot at redshift 11 where the gas particles are plotted in black. The slice is taken such that the centre of mass of the largest source (plotted in green) in the box is seen. The snapshot is gridded and a cube around the source (shown in red) is extracted for CRASHα input. The source has a stellar mass of ~ 3 x 10^3 M_{sun} and a metallicity of about 10^{-4}. On the right is a slice through the gridded density structure around the object which will become an input for CRASHα.

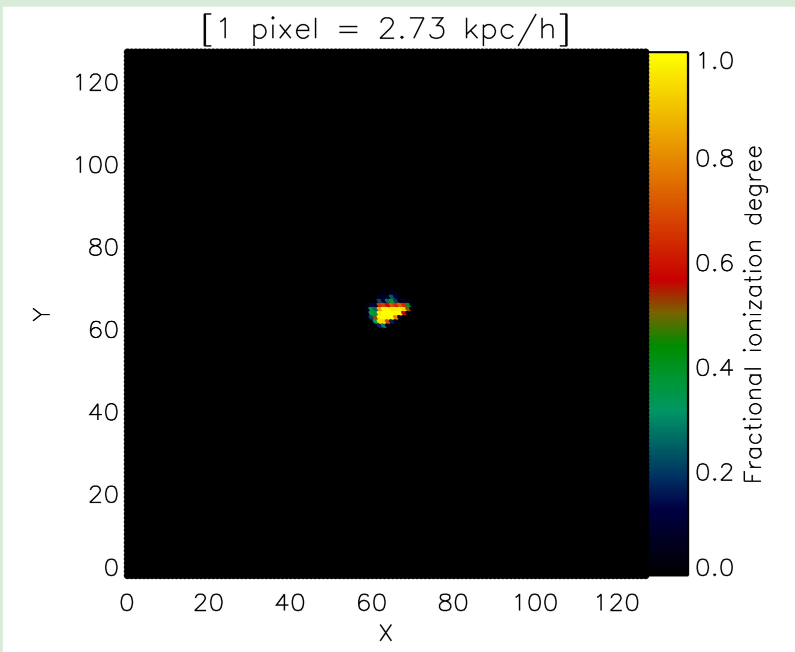


Starburst99 (Leitherer et al., 1999; Vazquez & Leitherer,2005):

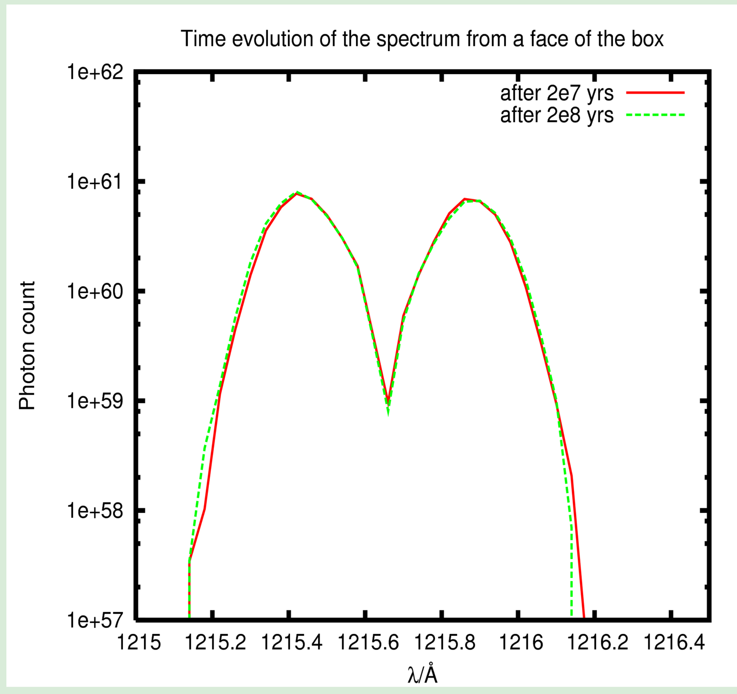
Starburst99 is a population synthesis code which uses a specific IMF, metallicity and stellar tracks (for our example, we use Salpeter IMF, Z = 4 x 10^{-4} and Padova standard tracks) to produce the total stellar spectrum at desired time intervals. Source properties obtained from the simulations are used to make the spectrum. Ionizing photon rate and stellar Lyman-alpha photon rates can be calculated from the spectrum which are then used as input.

CRASHα (Pierleoni et al., 2009):

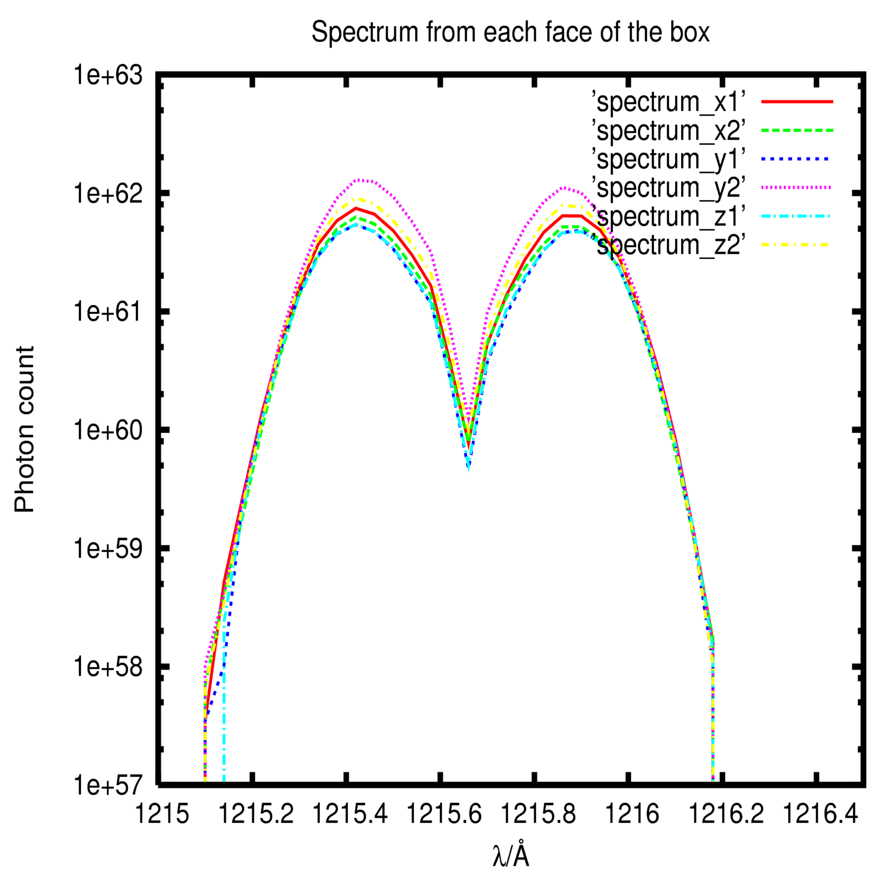
CRASHα is a 3D grid based radiative transfer code for cosmological simulations with the parallel propagation of Lyman-alpha and ionizing photons using ray-tracing and Monte-Carlo techniques. Ionizing photons are propagated through a static H/He density field which changes the temperature and ionization state of the gas in each cell. Lyman-alpha photons are propogated through this evolving medium also taking into account the velocity of the gas in each cell. Dust density is implemented as a fraction of the gas density and the absorption is calculated from the Lyman-alpha optical depth.



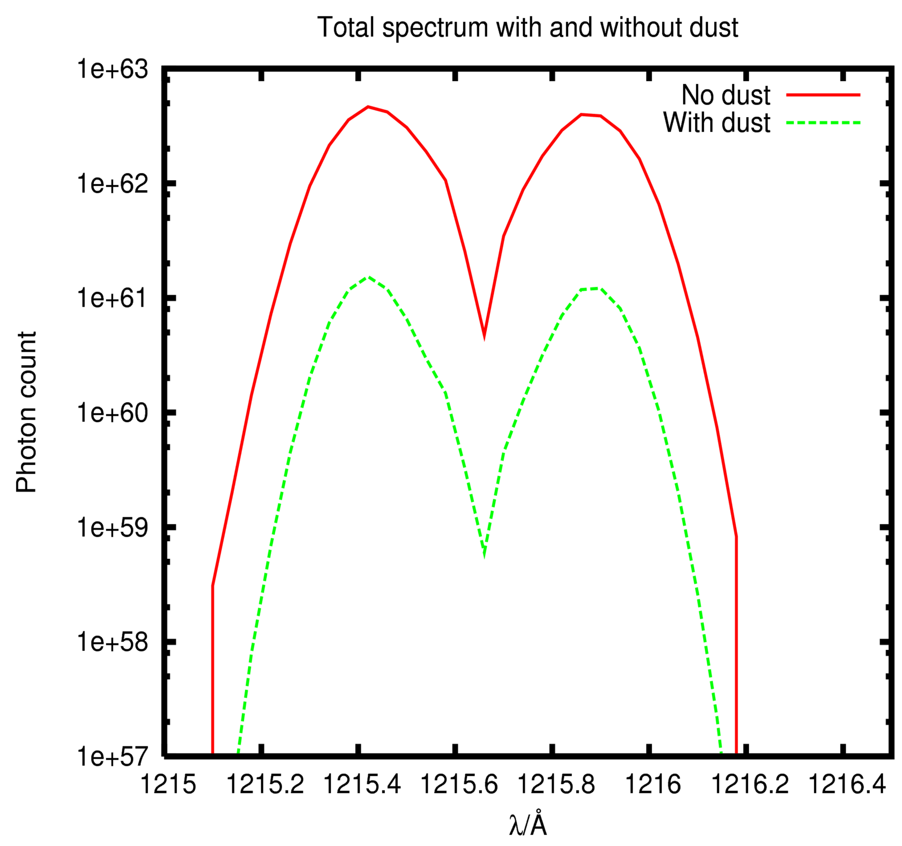
Here are the outputs of CRASHα from a test run with the input shown above. For this test, we use a Salpeter IMF and an ionizing photon escape fraction of 10%. We run the simulation for 2 x 10^8 years. The ionization structure at the end of the simulation is shown on the left. The spectrum of the Lyman-alpha photons escaping from a side of the box is shown on the right. There does not seem to be a significant time evolution in the spectrum.

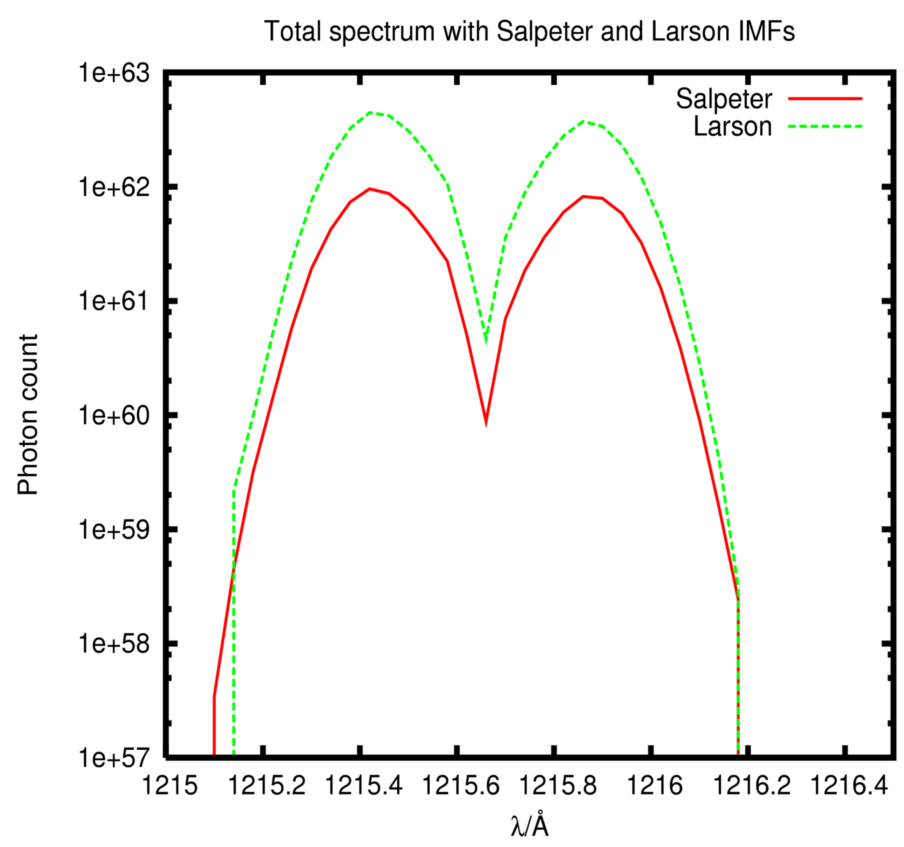


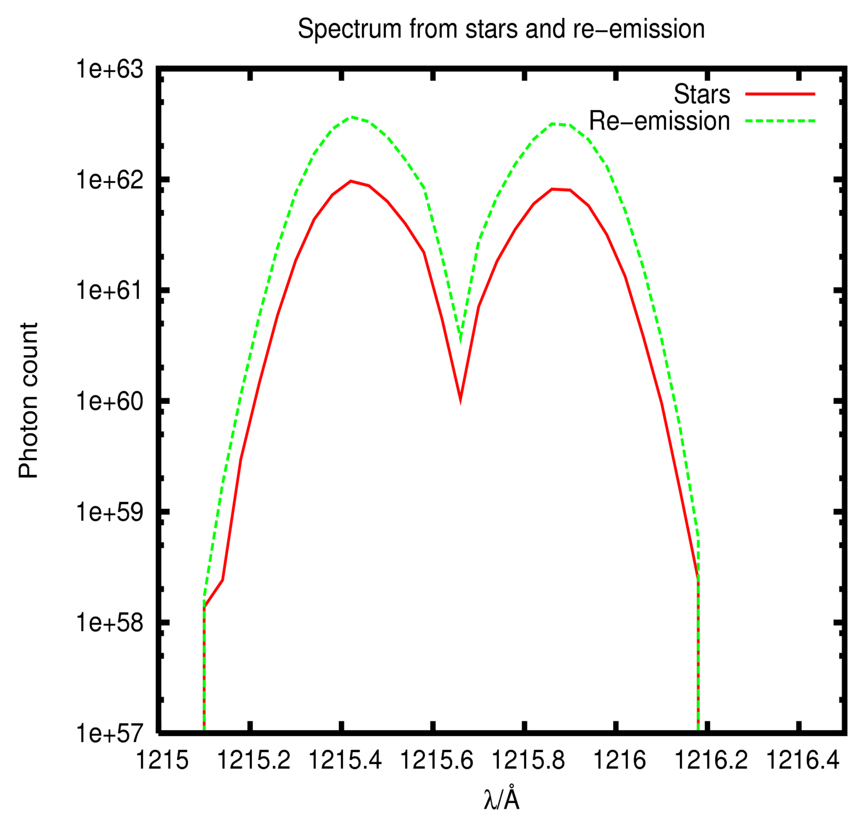
Test examples



Effect of environment on the escaping Lyman-alpha spectrum. Plotted on top is the spectra of all the Lyman-alpha photons escaping from each side of the simulation box. On the right, we can see the effect of dust on the spectra. Plotted are all the photons escaping from the box.







The top plot shows the spectra of Lyman-alpha photons produced by the stars and those formed by re-emission in the gas. This shows that re-emission is an important source of Lyman-alpha photons in these galaxies. On the left, we study the effect of the IMF on the escaping Lyman-alpha spectrum. Here we have used simulations without re-emission taken into account.

Future Outlook:

- We would like to remind you that this is work in progress and the plots shown are tests. The plan is to run CRASHα for all objects in a simulation box and do a statistical analysis of source properties for each set of parameters.
- Planned examples of parameter study : Halo properties, environment, clustering, effects of IMF, redshift, feedback, chemistry, dust, IGM inhomogeneities, escape fraction.

akila@mpa-garching.mpg.de