PRIORITY: PRedicting galaxies InflOws' emission at low RedshIft wiTh cloudY

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The Big Question

By which mechanisms do galaxies obtain the gas they need to fuel star formation?
Emission spectroscopy offers a new perspective to provide critical spatio-spectral information with a possible complete 2- or 3-D mapping of faint diffuse Lyα HI emission of the CGM.

Introduction

- Perhaps the most basic process of galaxy evolution, flows of gas into galaxies, remains poorly constrained
- The key seems to lie in our lack of understanding of the very sensitive interface between galaxies and IGM where these exchanges happen: the *circumgalactic medium* (CGM)

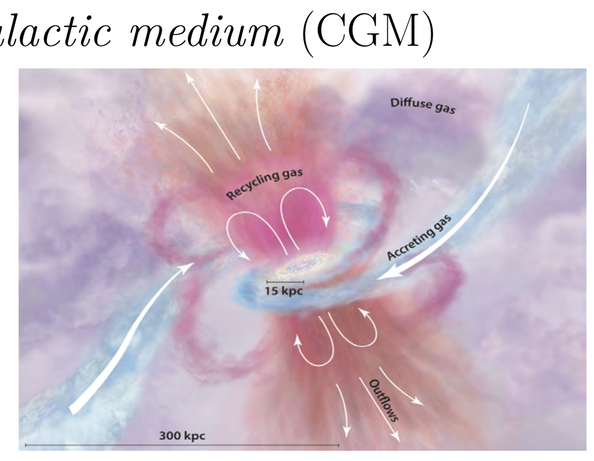

Figure 1: Gas dynamics in galaxies: The CGM, not well constrained is roughly defined as the gas surrounding galaxies at 10 to 300 kpc. It encompasses all gas in transition.

- Absorption spectroscopy gives important insights about CGM but lacks in giving spatial information

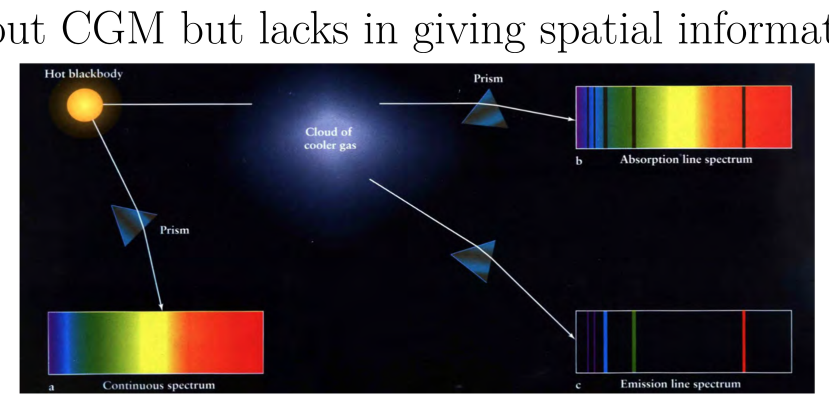

Figure 2: Absorption spectroscopy principle (key role in the discovery of CGM in 1971 by Lynds)

- Emission spectroscopy of strong emission lines such as Lyα (1216Å) overcomes this limitation but also comes with disadvantages (very low surface brightness, need space instrument for low z galaxies)
- FIREBall-2, a path-finding balloon borne UV spectrograph (MOS) aiming to detect the CGM in emission via specific spectral lines (Lya, CIV, OVI) for z<1, is designed to deal with these drawbacks

Parameter	Value
Design	1m moving siderostat,F/2.5 paraboloid
λ, z range	$199-213$nm, $z\sim0.7$
Resolution	$R_\lambda\sim2000$, $R_x\sim5$'
FOV	11*37arcmin^2
Detector	Delta dopped emCCD

Table 1: Instrument's characteristics

- A parametric simulation of the instrument's optic behaviour has been implemented at LAM[1]
- We present here a *Cloudy*[8] based emission model that, coupled to a cosmological simulation and post-processed by the FIREBall instrument model will simultaneously adress the following goalds:
  1. Study CGM emission and the technological requirements to detect/resolve it
  2. Prepare future data analysis for the upcoming flight of FIREBall-2 (Sept 2018)
  3. Help the calibration of the instrument

Emission model

Cosmological RAMSES 'zoom' simulation

The emission model is applied to 100Mpc hydro-simulation gathering the following characteristics:

- SF and SNae feedback with 'on-the -fly' *self-shieding*
- Zoom in on massive $10^{13}M_\odot$ halo: from 100Mpc to a new box of 13.92Mpc
- AMR simulation with a best resolution of $\sim380pc/h$ and $8.7\cdot10^5M_\odot/h$ for DM particles
- Ramses adopt a UV background with a 0% f_{esc} from galaxies below the Lyman limit

Cloudy based Emission model

- **3 contributions**: Photo-ionization from UV cosmological background (HM01), collisional ionization from gravitational collapse and feedback, scattering of Lya photons emitted by OB stars of the host galaxies and escaping the ISM[4] which is then redistributed following neutral hydrogen density and weighted by its inverse squared distance to the center of the galaxy
- The 2 first contribution are taken into account with *cloudy*, generating 2D Lyα emissivity maps (ρ,T) with PyCloudy[7] using respectively an incident radiation field and a coronal model.
- **2 types of cells** (using cut 2 from [4]): normal gas, self shielded gas which is protected from photo-ionization and will then only be ionized by collisional heating.

The estimation of intrinsic $Ly\alpha$ and ionizaing photons escaping the ISM are respectively performed using:

$$L^{Gal}_{Ly\alpha}[erg/s]=f^{Ly\alpha}_{esc}\cdot10^{42}\cdot SFR[M_\circ/yr] \quad (1)$$

The addition of the ionizing photons emitted be the host galaxy is also investigated with Cloudy. The spectra is calculating using Bruzual 2003 model and the luminosity is set assuming a Kroupa IMF model:

$$L^{Gal}_{Ionizing\gamma}[erg/s]=f^{Ion\gamma}_{esc}\cdot2\cdot10^{45}\cdot SFR[M_\circ/yr] \quad (2)$$

- Ionizing photons from the host galaxy generate a substential part of the total Lyα emission in the CGM up to several tens of kpc from center
- This emission depends on the gas $T°$. The gas is totally transparent to this spectra when higher than $\sim3\cdot10^4K$ and fully colisionally ionized.

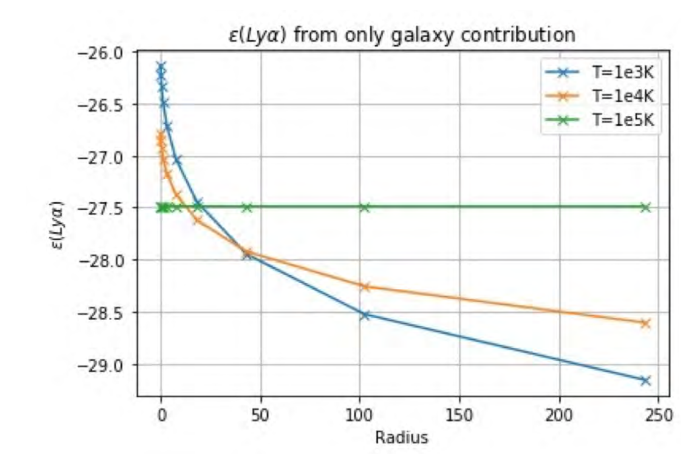

Figure 3: Lyα emission due to ionizing flux from the 100$[M_\circ/yr]$ host galaxy. A kroupa IMF is assumed with a 10% $f^{Ion\gamma}_{esc}$

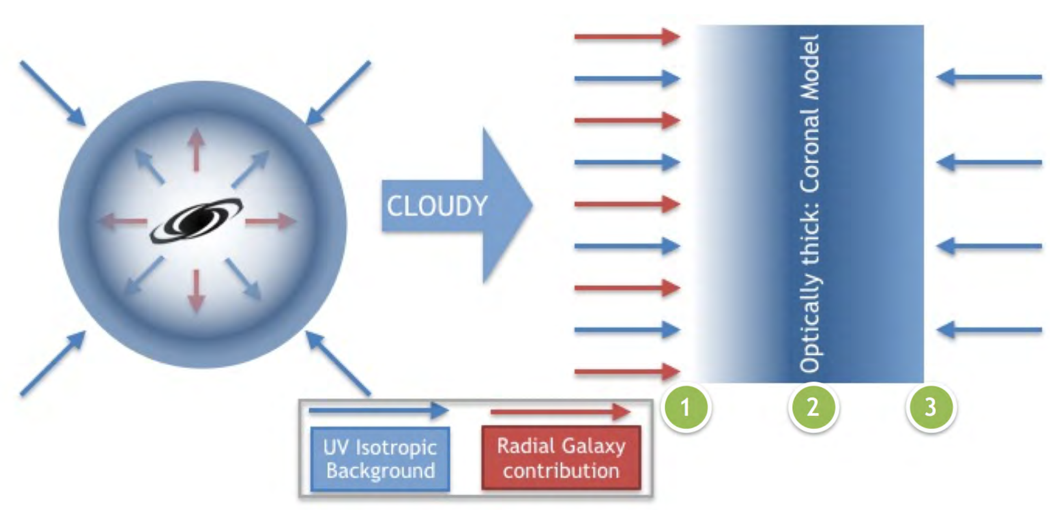

Figure 4: Representation of 3 possible *Cloudy* models to take into account the PIE (UVB &/or SED$_{gal}$) and CIE contributions

In order to take into account this contribution we should run several *Cloudy* models to simulate the difference between the radial galactic contribution and the isotropic UV background contribution (see Figure 4). Lyα emissivities respectively du to Photo or/and Collisional ionization are then attributed to each simulation's cells (Figure 5).

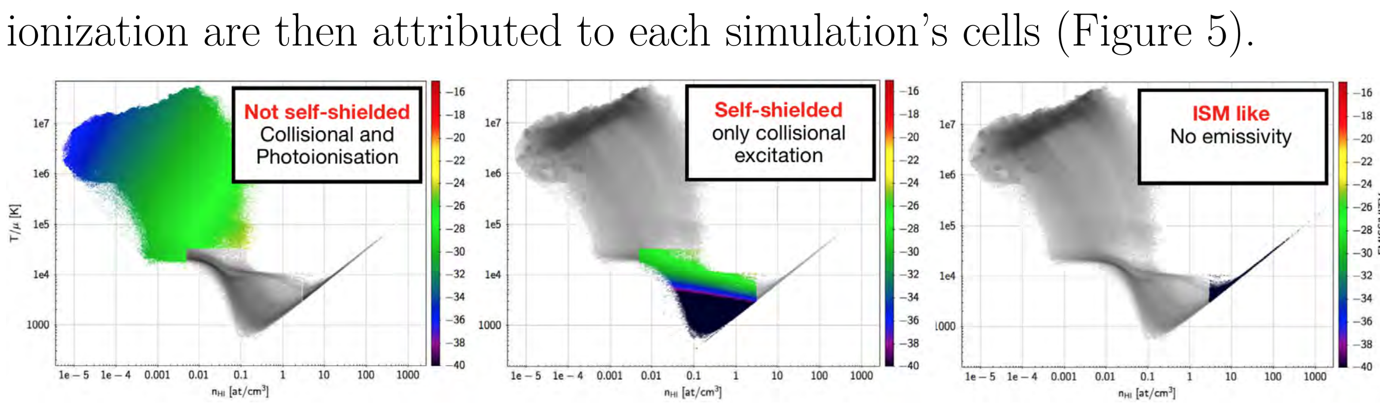

Figure 5: Emissivity of the three different types of gas cell superposed to the phase diagram of the main halo

The 3-D Lyα luminosity most massive halo ($3.3\cdot10^{42}$erg/s) $L(\alpha_x,\alpha_y,\lambda)$ is then processed by the FIREBall-2 calibrated instrument model.

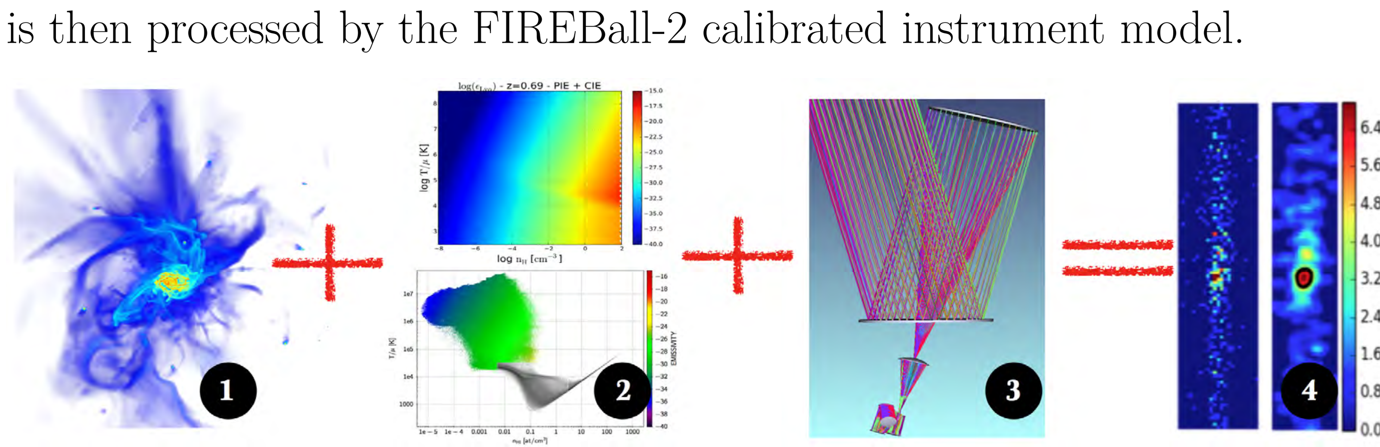

Figure 6: (1) represents a galaxy from the zoom simulation, (2) the CLOUDY emission table projected on the galaxy's phase diagram, (3) the ZEMAX instrument model and (4) the SNR obtained from the end to end simulation

The Great Connection

The end to end analysis, composed of a zoom-cosmological simulation coupled to an emission model processed by the instrument's model predicts that the CGM should be detectable by FIREBall-2's instrument.

Main Results

Validation of the model is difficult considering the lack of low-z observations. Moving to higher redshifts (z = 4[6] and z = 2.3[5]), the model agrees well with observational data provided we use a lower Lyα escape fraction than is usually inferred from observations

SNR calculator implementation

Defining the Lyα line as the signal, we use the following basic estimator and divide it by the associated noise:

$$\widehat{S_{CGM}}=S_{Tot}-\widehat{CONT}-\widehat{DC}-\widehat{SKY}$$

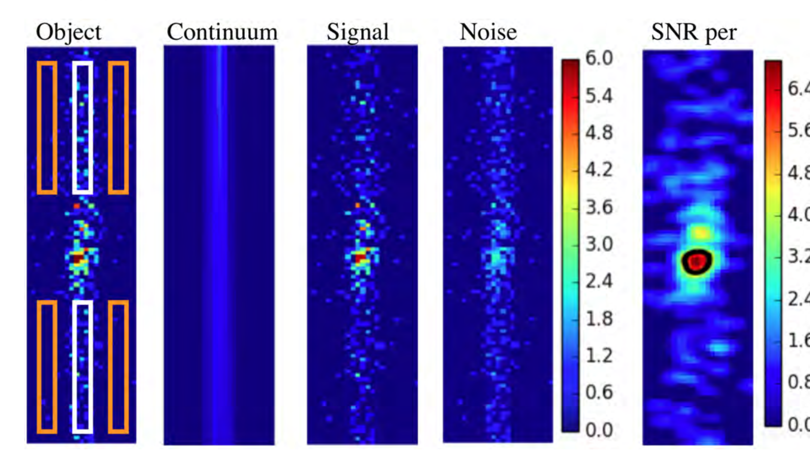

Figure 7: Electronic density map derived from the instrument model for the Poisson realized 1-hour exposure observation of the Lyα emission, with fesc(Lyα) =1%, from the main halo at z = 0.67 (Predicted emisison: $L_{Ly\alpha}=3.3\cdot10^{42}ergs/s$). Orange and white parts are extracted and interpolated to estimate the continuum of the host galaxy and the sky contributions in order to substract it from the total signal.

- Lya line detection for 1-hour exposure and 1% f_{esc}, resolving spectral profile for 1% f_{esc} but unable to resolve spatially the source due to the relatively low angular resolution of the instrument
- Detection of CIV or OVI unlikely to happen. Need for more exposure time (>7h) and important stacking
- Ionization from nearby QSO should allow easier detection (not tested here)

Conclusions

- This model shows that the instrument should provide critical spatio- spectral information about the intergalactic medium surrounding $z\sim0.7$ galaxies that is currently missing in our search for gas dynamics in the CGM. Both simulations and observations at higher redshifts suggest that the faint emission of the intergalactic medium (IGM) and filamentary structure remains beyond the capabilities of short-duration exposure potential like FIREBall-2 but the CGM spatial extension might be resolved for very bright objects.
- 2018 flight target selection: 4 scientific masks ($\sim$ 70 targets each prioritized on bright galaxies), $t_{exp}=2h$ for each, $\sim$ 10 QSOs in total
- It encourages the development of important UV projects such as ISTOS which would enable high exposure times (>10^6s).

References

[1] Mege P. et al, Proc.SPIE, vol. 9601, Issue 2, 2015, pp. 9601 - 9601 - 39
[2] Quiret S., PhD thesis, 2016
[3] Tessier R., Astronomy and Astrophysics, vol. 385, 2002, pp. 337–364.
[4] Franck S. et al, Monthly Notices of the Royal Astronomical Society, vol. 420, Issue 1, 2012.
[5] momose R. et al, Monthly Notices of the Royal Astronomical Society, vol. 442, 2014
[6] Wisotzki et al., Astronomy and Astrophysics, vol. 587, 2016
[7] Morisset, C., pyCloudy, Astrophysics Source Code Library, 2013
[8] Ferland, G. J et Al., pyCloudy, Revista Mexicana de Astronomia y Astrofisica, 2017

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