Mapping cosmic HI from the Reionization epoch to z~3 through the IGM Lyα emission

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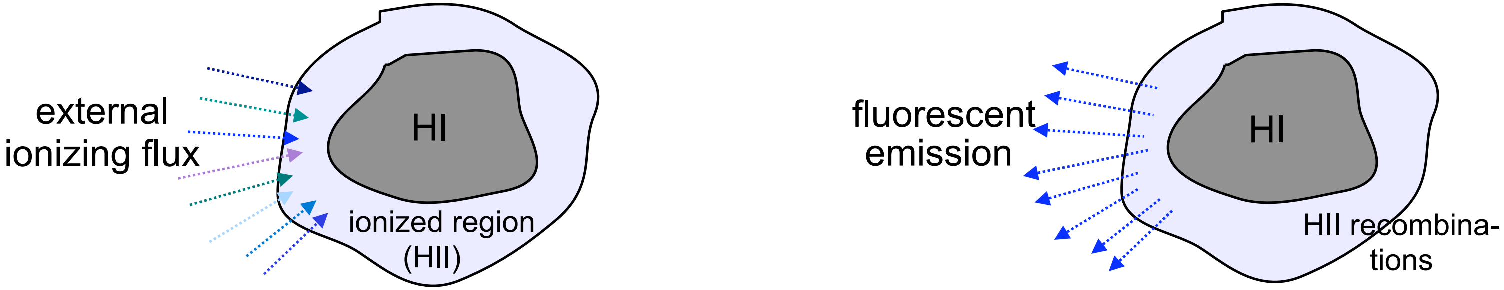
Outline

- HI clouds imaging at z~3 via Fluorescent Lyα emission
  - basic idea
  - theoretical models
  - observing the clouds around the z=3.1 QSO428-388

- Mapping the HI distribution during Reionization
  - basic idea
  - theoretical models
  - results and detectability

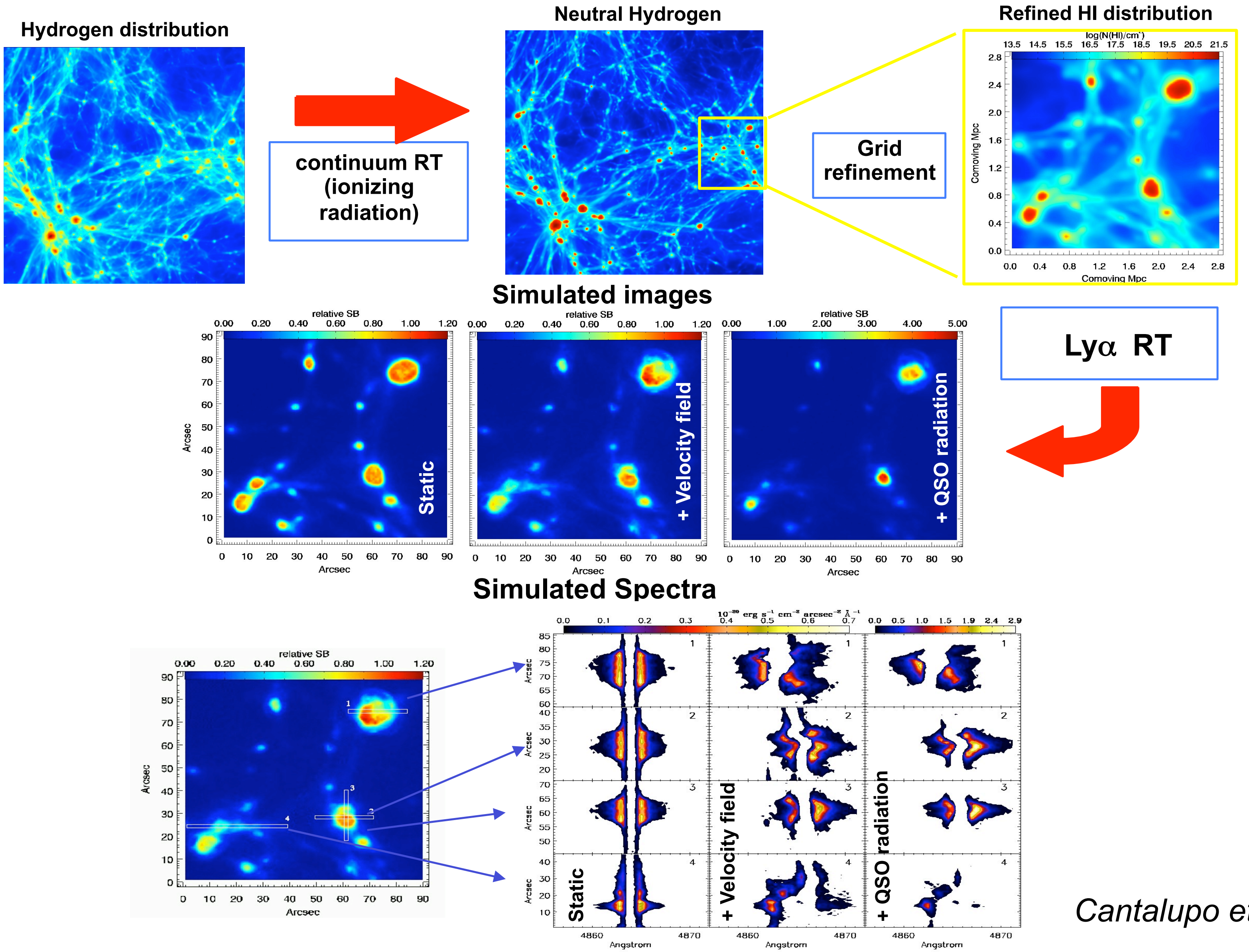
Fluorescent Lyα emission at z~3: basic idea and motivations

- Self-shielded HI clouds re-emit a significant fraction of the impinging ionizing flux in Lyα (via HII recombinations) (*Hogan & Weymann 1987;Gould & Weinberg 1996; Cantalupo et al. 2005*).



- Advantages w.r.t absorption systems in QSO spectra:
  - 2D information
  - Lya SB is proportional to the external ionizing flux, therefore:
    - we can measure the UV background
    - knowing the ionizing flux (e.g., from a QSO) we can exclude clouds with internal star-formation
    - if the source is a QSO: we can get the QSO age and angular shape of the emission

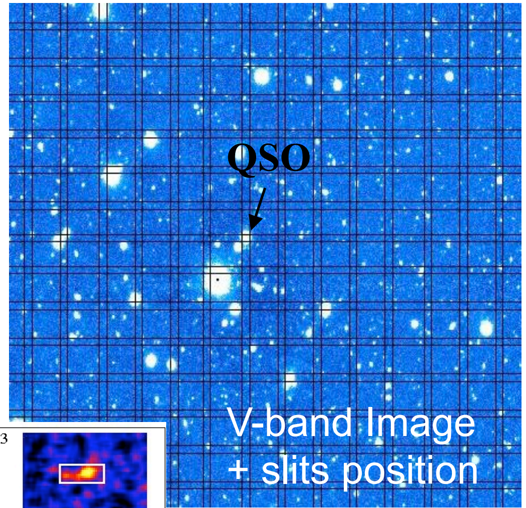
Theoretical Models of fluorescent Ly-α emission at z=3



Cantalupo et al. 2005

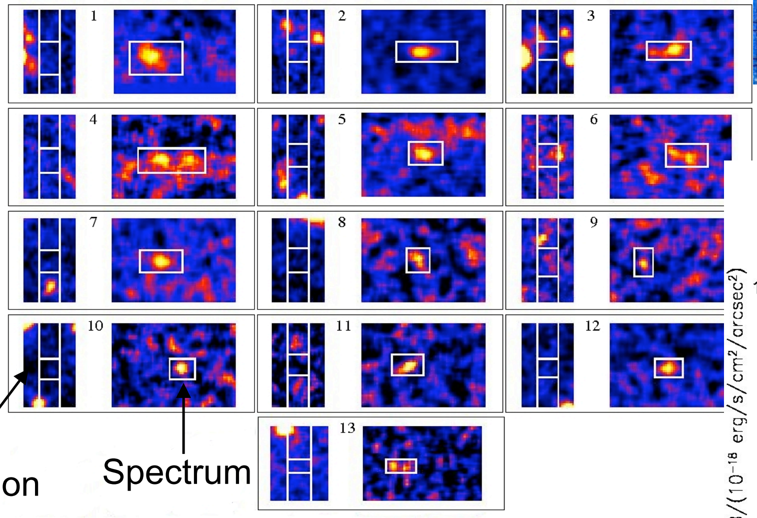
Detecting Fluorescent Lyα emission around the z=3.1 QSO 0428-388

- 4 nights @ VLT
- Blind search with "multislit+filter tecnique"
- detected 13 line-emission without continuum counterparts (at 2sigma in 2-hrs V-band image)

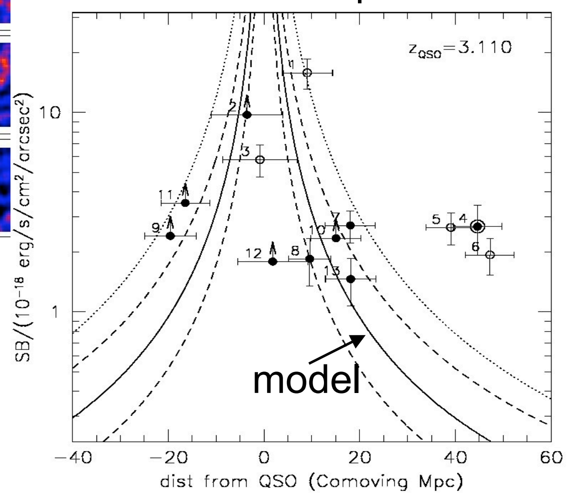


- Best constraints for fluorescent emission:
  - High EWs (lower limits)
  - SB-distance relation

- Secondary constraints:
  - Line and SB profiles
  - Number densities



SB-distance plot



- Some of them are plausibly fluorescent. Further studies are needed

Cantalupo et al. 2007, ApJ, 657, 135

How to map the "bulk" of intergalactic hydrogen with Lyα emission?

- HII recombination rate is too slow to detect low density gas *(Hogan & Weymann 1987; Baltz, Gnedin & Silk 1998)*.
- Fluorescent emission maps only overdense regions.

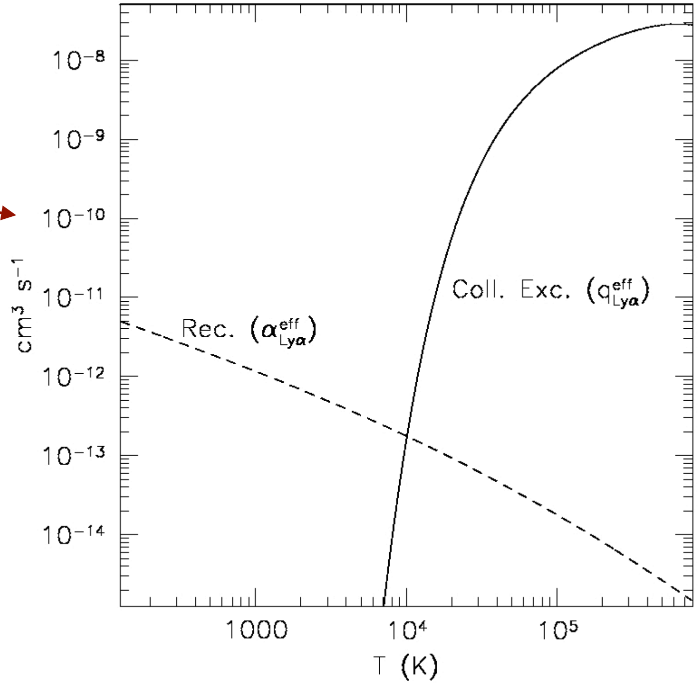
- A more efficient mechanism than HII recombination to produce Lyα photons: HI collisional excitation (CE) by energetic electrons.

emissivity *recombinations* *coll. excitations*

$$\frac{4\pi j_{\mathrm{Ly}\alpha}}{h\nu_{\mathrm{Ly}\alpha}} = n_{\mathrm{e}} n_{\mathrm{p}}\ \alpha^{\mathrm{eff}}_{\mathrm{Ly}\alpha}(T) + n_{\mathrm{e}} n_{\mathrm{HI}}\, q^{\mathrm{eff}}_{\mathrm{Ly}\alpha}(T)$$

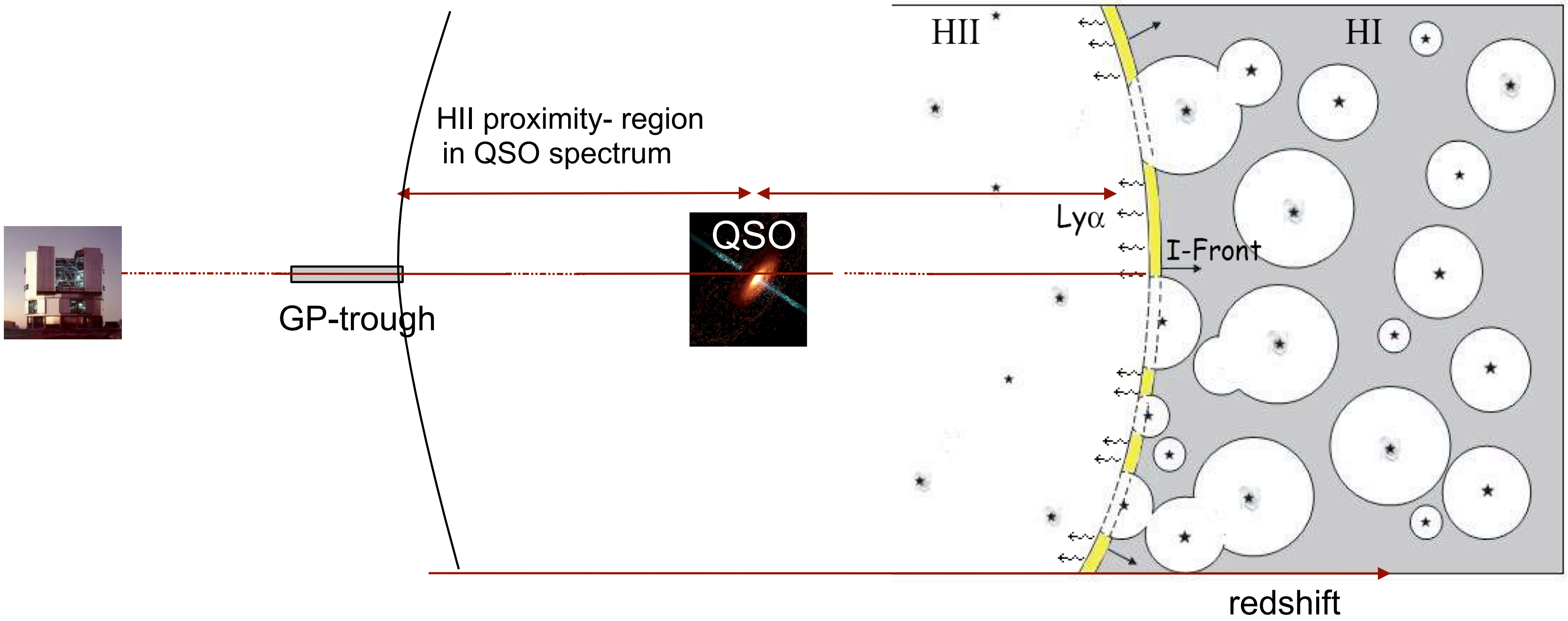
- CE dominates the Lyα emissivity where:
  - neutral fraction (x_{HI}) is ~ 0.5
  - High temperatures: T>10^4 K

Typical conditions of QSO Ionization-Fronts



Cantalupo et al. 2008, ApJ, 672, 48

Mapping HI through the I-Fronts of the highest-z QSOs



- basic idea:

as the I-Front cross the IGM, Lyα photons are produced whitin the neutral patches via collisional excitations

- The Lyα emission gives a "tomography" of the neutral hydrogen at the I-Front position ($j_{Ly\alpha} \sim x_{HI}^2$)
- From the I-Front position we also get:
  - additional information on the average neutral fraction around the QSO
  - constraints on the QSO age and on the emission shape

Cantalupo et al. 2008, ApJ, 672, 48

Modelling the Lyα signal

- New (continuum) RT:
  - time-dependent, temperature-dependent, full 3D ray-tracing
  - AMR structure to resolve (and to follow) I-Fronts as they expand
  - including He and all relevants heating/cooling processes

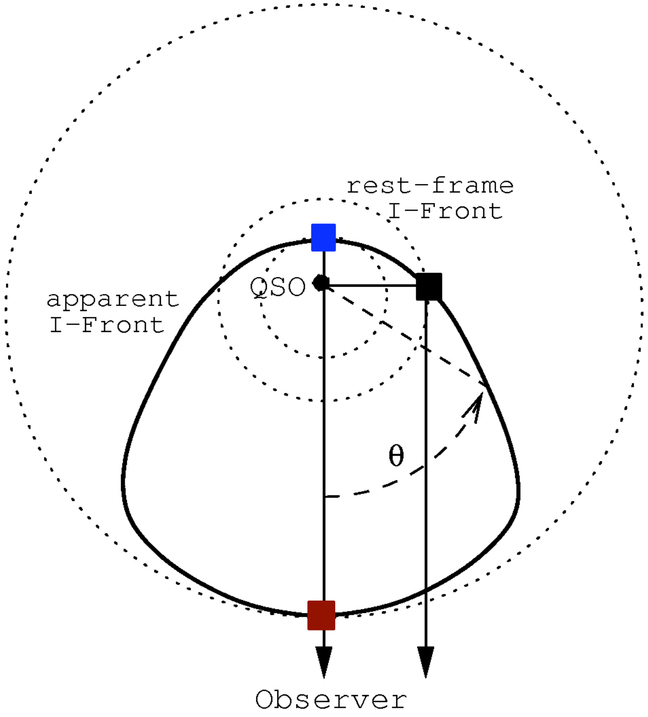
- New Lya RT:
  - multi-grids structure from continuum RT
  - multi-temperature medium

In the present study we approximate the computational domain with an uniform density (cosmologically-expanding) IGM surrounding a single source.

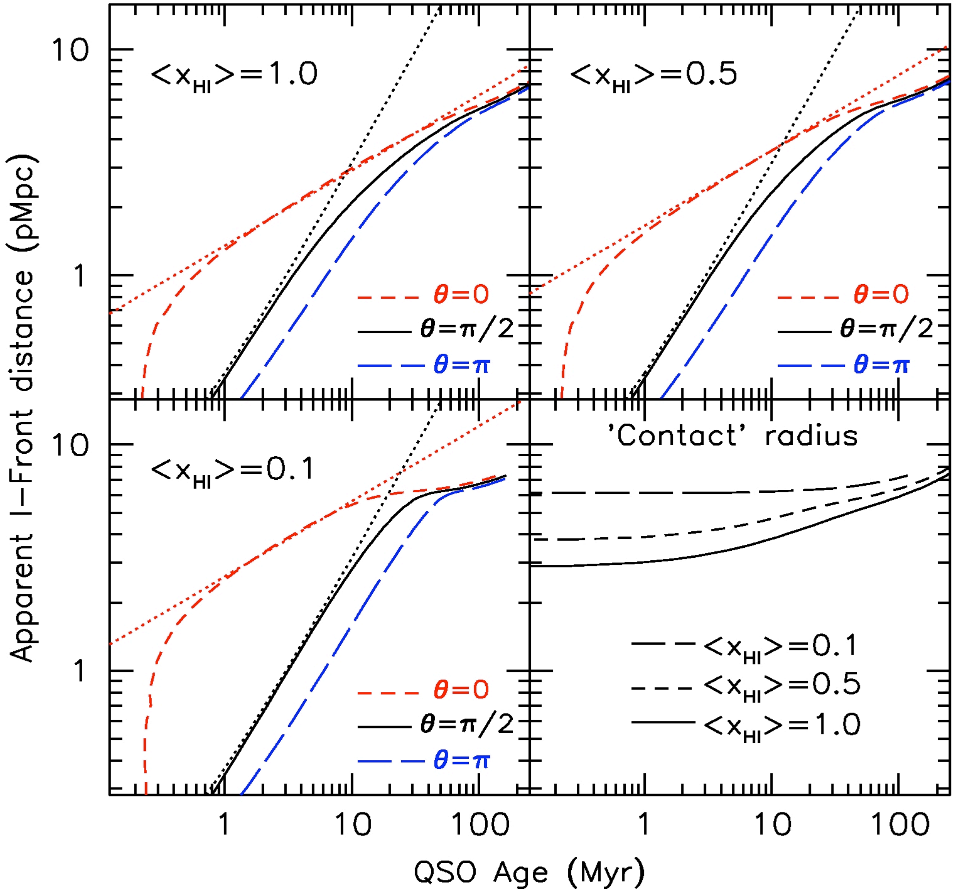
Cantalupo et al. 2008, ApJ, 672, 48

The apparent (angular) shape of QSO I-Fronts

- We include relativistic and light-travel effects following the analytical works of *Yu 2005* and *Shapiro et al. 2006.*



RT results

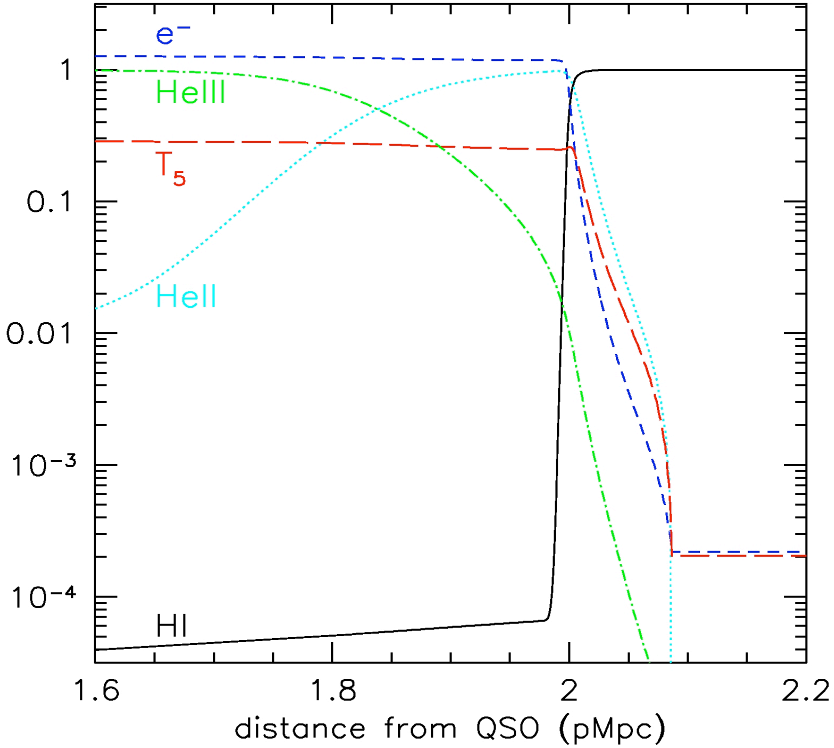


- Simulation parameters:
  - IGM: z_{IN}=6.5 ; $\langle\delta\rangle$=0 ; C=30
  - QSO: $N_{ion}=10^{57}\ s^{-1}$; α=-1.7

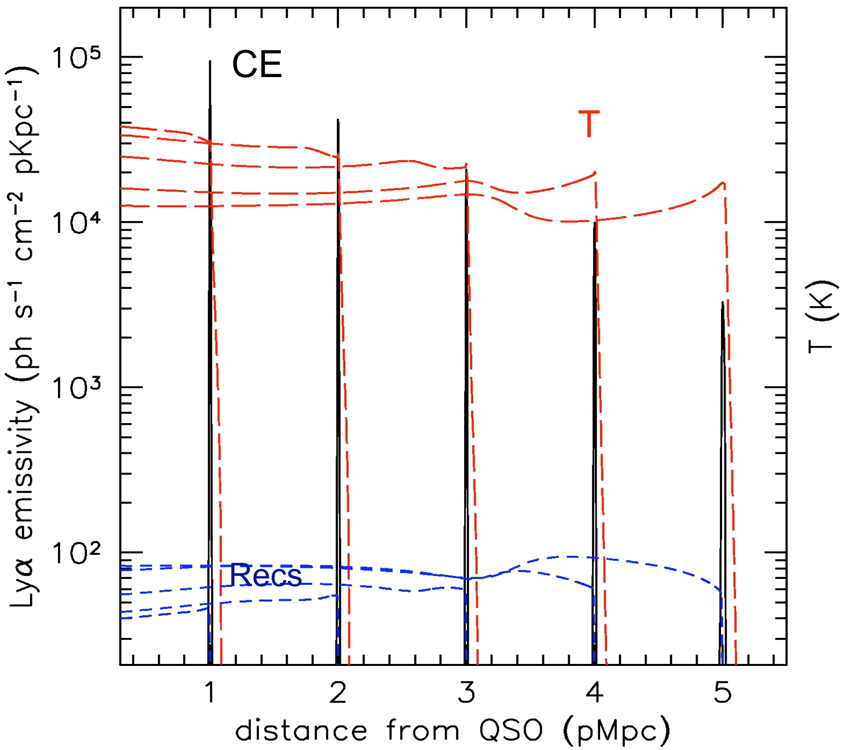
Cantalupo et al. 2008, ApJ, 672, 48

Results: I-front profiles and Lyα emissivity

I-front density and temperature profiles (t~10Myr)



Lyα emissivities (5 different expansion epochs)

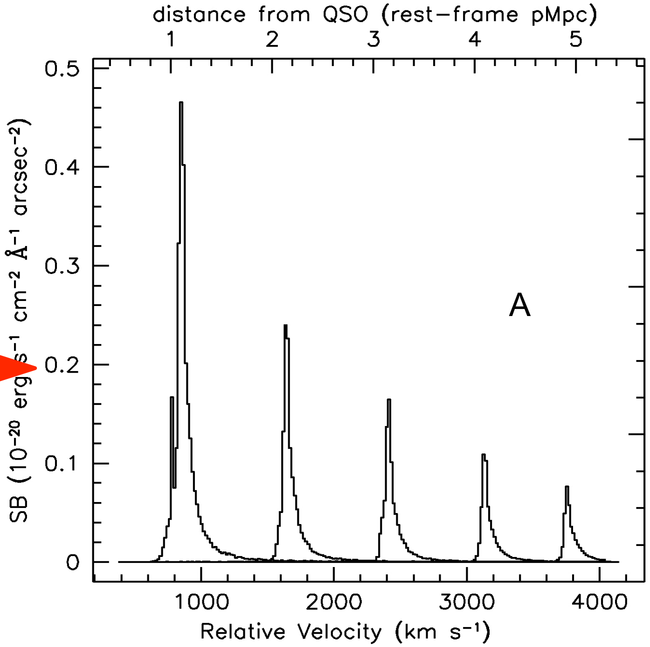


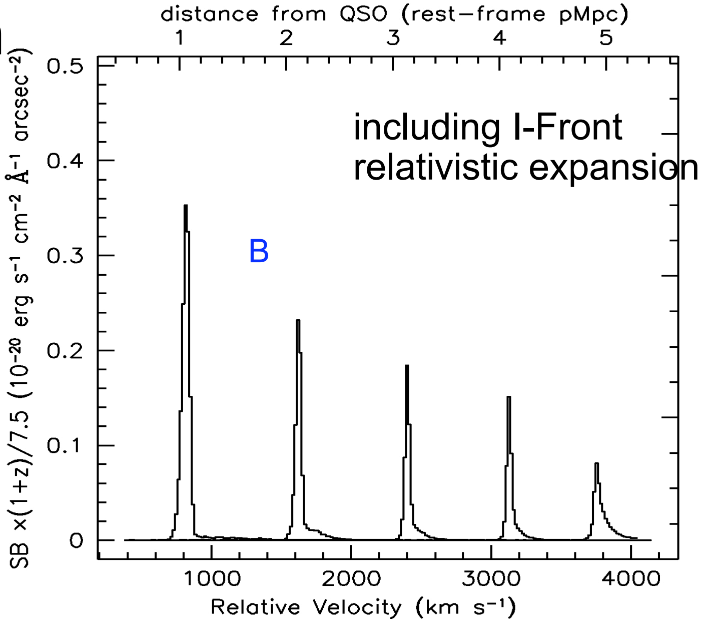
- Simulation parameters:
  - IGM: z_{IN}=6.5 ; C=30
    x_{IN}=1 ; δ=0
  - QSO: $N_{ion}=10^{57}\ s^{-1}$; α=-1.7

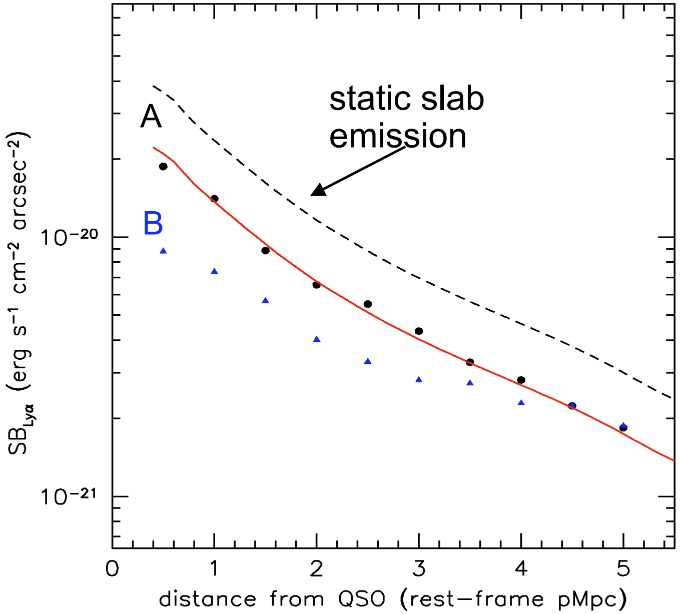
Cantalupo et al. 2008, ApJ, 672, 48

Results: line shape and SB evolution

Lyα RT





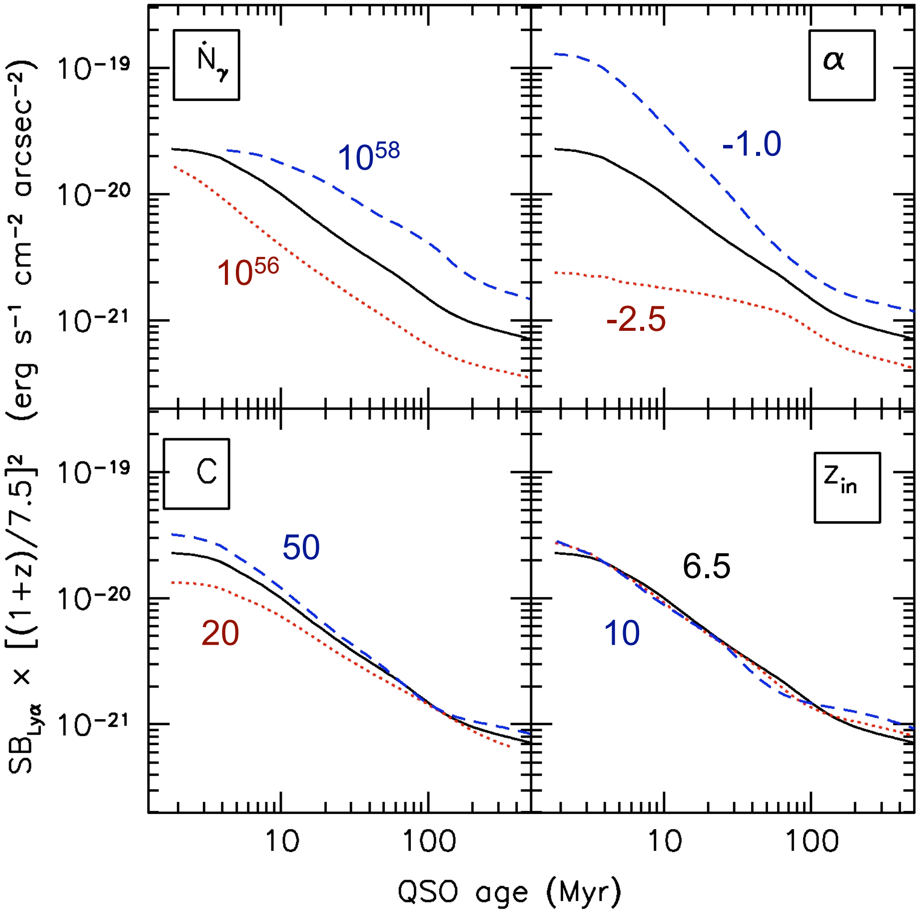


Single line emission (red peak)

Blue peak scattered by residual HI in the QSO bubble

HI in front of the bubble has a negligible effect on the observed emission

Results: exploring a larger parameter space



Lya SB from a fully neutral and at mean density patch of IGM crossed by the I-Front

- $SB_{Ly\alpha}$ ~ 10^{-20} erg/s/cm^2/arcsec^2 for a large range in QSO properties and expected lifetimes

$$SB_{\mathrm{Ly}\alpha} \sim 10^{-20} \cdot x_{\mathrm{HI}}^2 (1+\delta)^{1/2} \cdot \left[\frac{t_{\mathrm{Q}}}{10\mathrm{Myr}}\right]^{-1} \times \left[\frac{\dot{N}_\gamma}{10^{57}\mathrm{s}^{-1}}\right]^{1/3} \left[\frac{1+z}{7.5}\right]^{-2} \mathrm{erg\ s^{-1} cm^{-2} arcsec^{-2}}$$

Cantalupo et al. 2008, ApJ, 672, 48

Is it detectable?

- ~ 3 orders of magnitude below sky-background (better for JWST)
- but: Line and extended emission (hundreds of arcmin^2!)

Possible detection strategy: long-slit (or multi-slit) spectroscopy + integration over the slit lenght.

- neutral patch of IGM with few arcminutes scales may be already detected
- from the ground with current facilities.
- good redshift dependence, good for (future) z>6.5 QSOs.
- first possible goal: detecting I-front position around known QSOs

  (already gives us constraints on average HI fraction and QSO age)
- for the future (e.g., JWST): HI tomography below arcmin scales

Summary

- Fluorescent Lyα emission is able to map the HI self-shielded clouds in the high-z IGM before substantial star-formation takes place. Moreover, it can gives the age and emission properties of high-z QSOs.

- We presented a new method to directly map the HI during Reionization through the Lyα emission from QSOs I-Fronts.

- Applications:

    - HI "tomography" at the emitting I-Front position

    - Constraining the size and shape of QSO HII regions

- Detectability: neutral (mean density) IGM patches can be detected with current facilities if they extend over few arcmins scales. Otherwise, constraint on the QSO HII region size can be obtained if the mean neutral fraction is greater than 0.1.