Lyα emission from the high-redshift Intergalactic Medium

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Outline

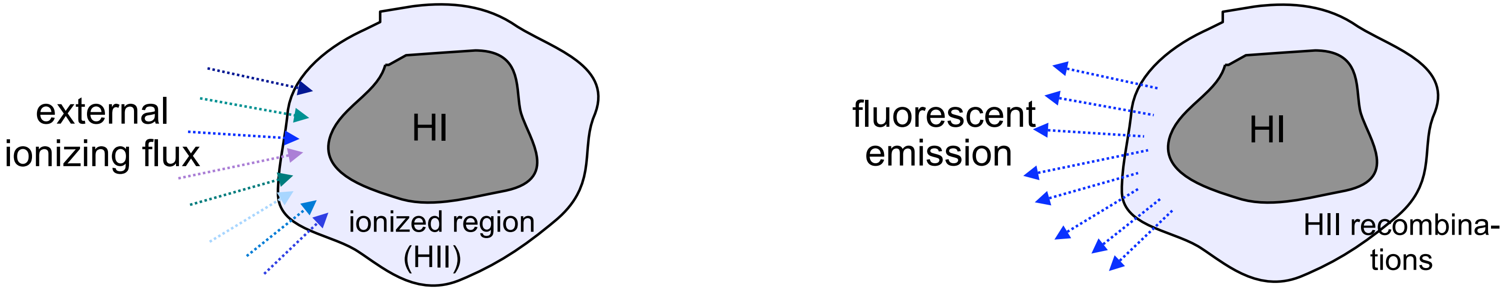
- Brief introduction and motivations

- Detecting the Intergalactic Medium (IGM) at z~3 with fluorescent Lyα emission:
  - theoretical models
  - observational results

- Mapping HI during the Epoch of Reionization (EoR) with the Lyα emission from QSO I-fronts
  - basic idea
  - recent numerical results
  - movies, movies, movies
  - detectability

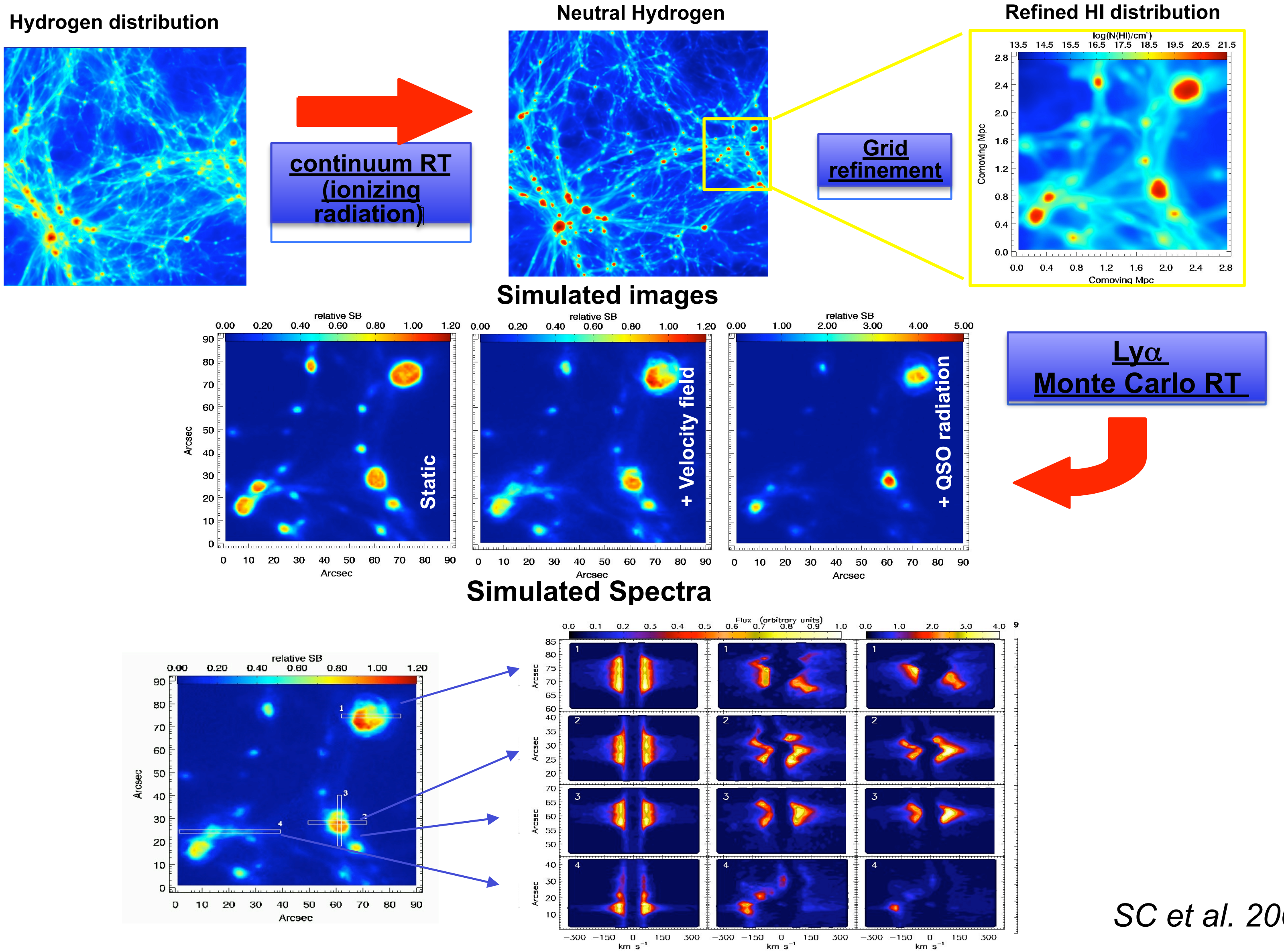
Fluorescent Lyα emission at z~3: basic idea and motivations

- 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*).



- Advantages w.r.t absorption studies with QSO spectra:
  - 2D information
  - Lyα 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

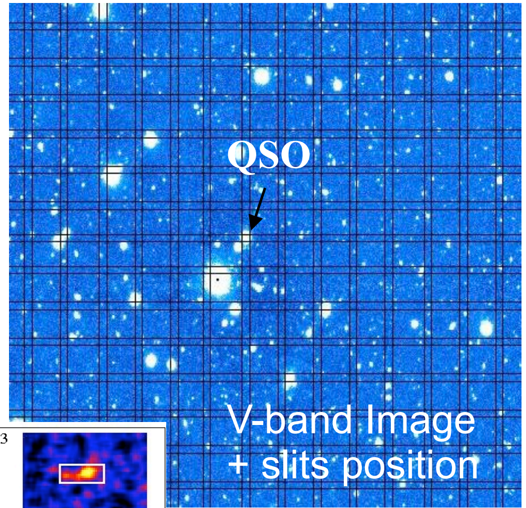
Theoretical Models of fluorescent Lyα emission at z=3



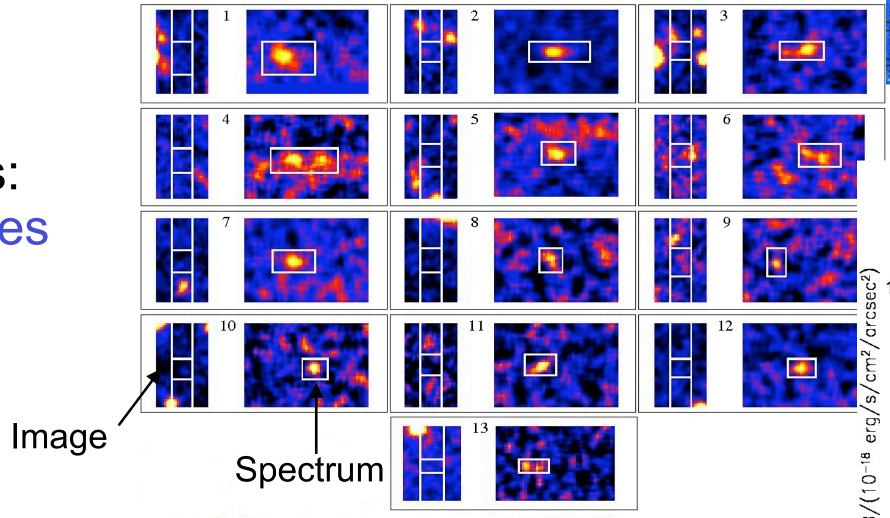
SC et al. 2005

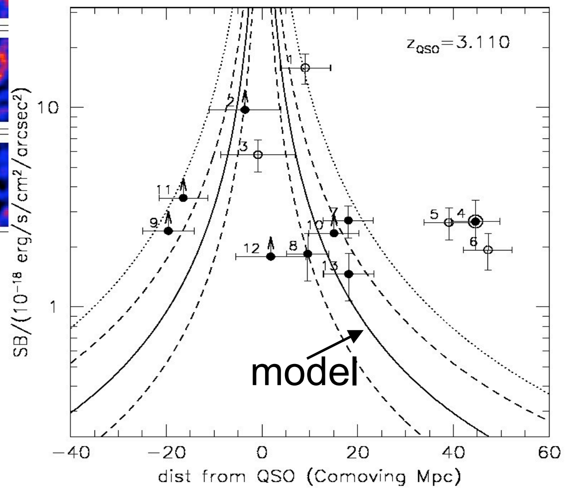
Detecting Fluorescent Lyα emission around the z=3.1 QSO 0428-388

- 4 nights @ VLT
- Blind search with multislit+filter tecnique
- detected 13 line-emission without detectable continuum in deep V band image



- Best constraints for fluorescent emission:
  - High EWs
  - SB-distance
- Secondary constraints:
  - Line and SB profiles
  - Number densities

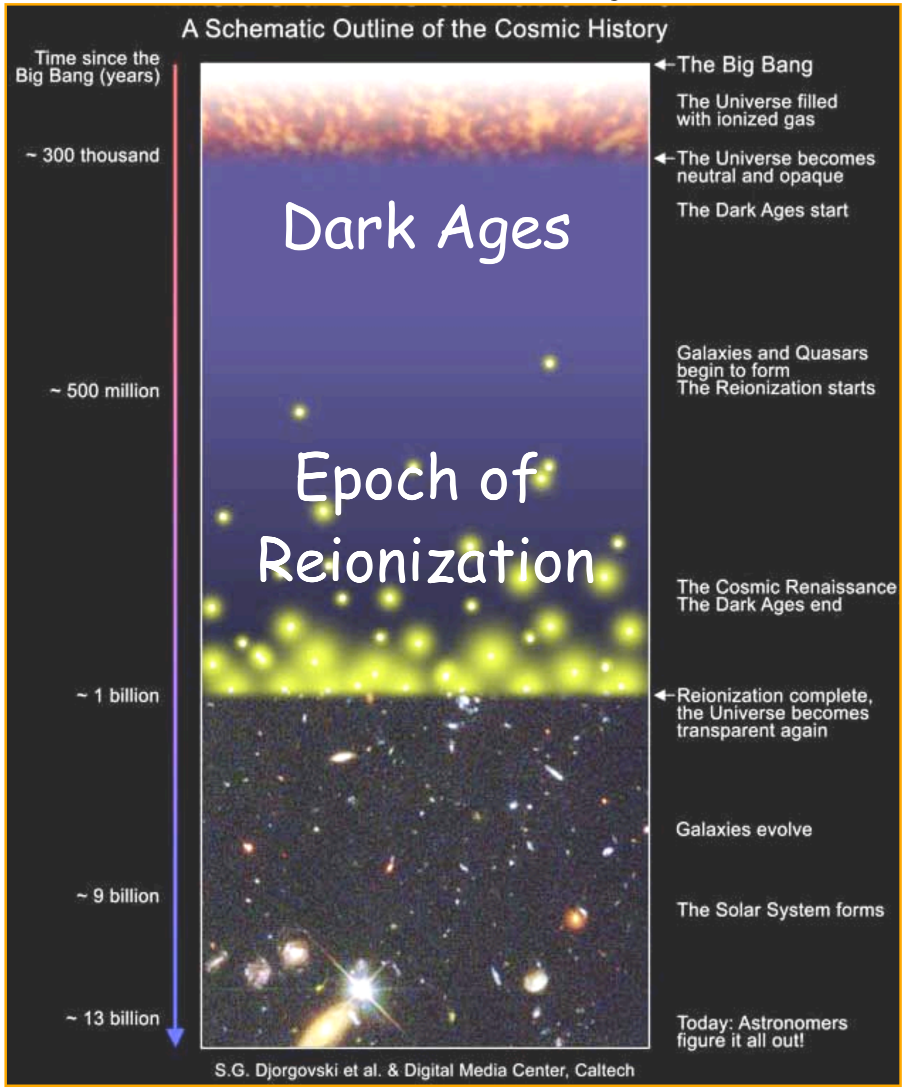




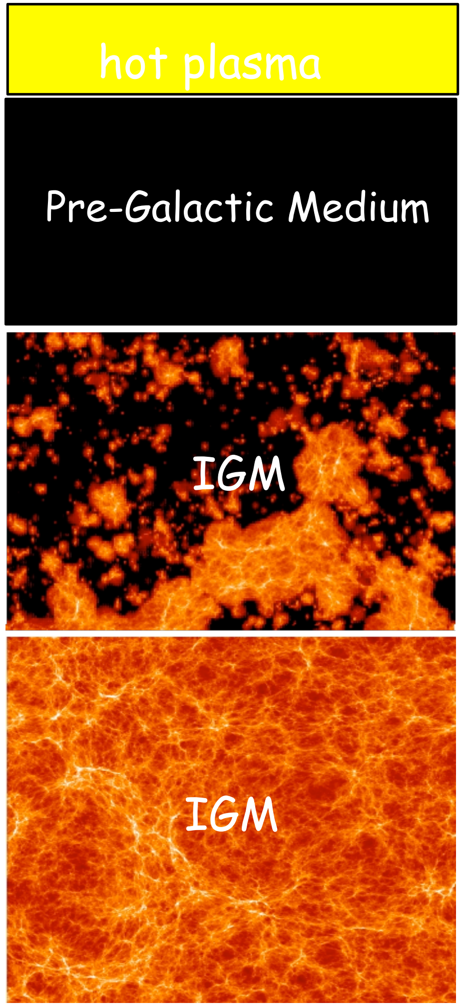
- At least half of them are plausibly fluorescent

SC, Lilly & Porciani 2007

cosmic history



cosmic hydrogen history



ionized

mostly neutral

partially ionized

mostly ionized

Images: Trac & Cen 2006

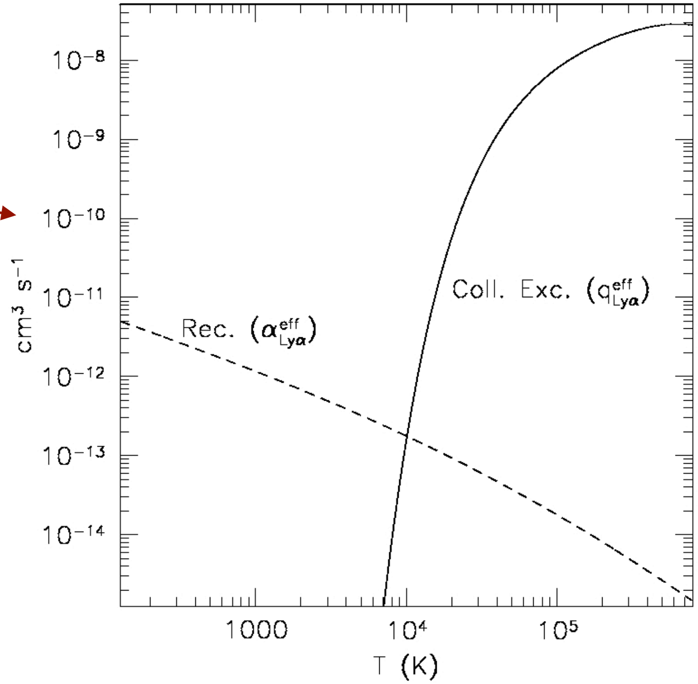
How to map the "bulk" of intergalactic hydrogen during EoR with Lyα emission?

- 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*

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

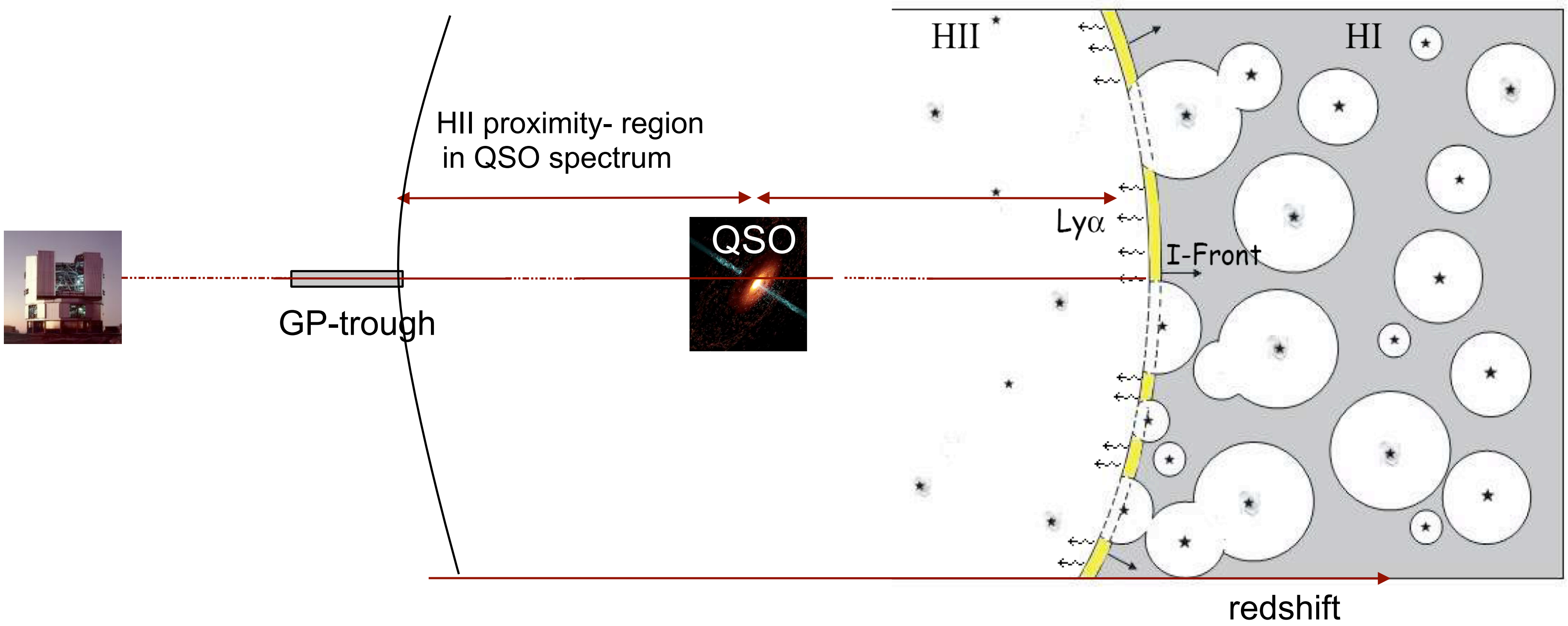


SC, Porciani & Lilly 2008

- 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

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



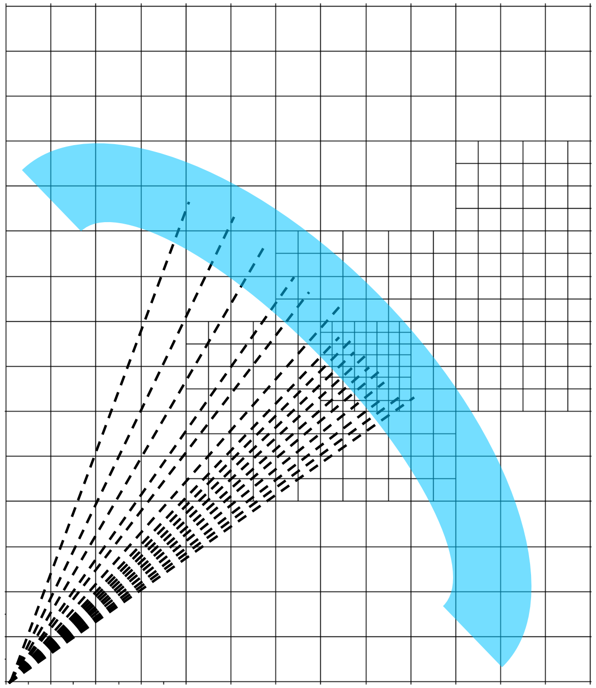
- basic idea:
as the I-Front cross the IGM, Lyα photons are produced within the neutral patches via collisional excitations

  - 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

SC, Porciani & Lilly 2008

A new AMR radiative transfer: StART

- Based on a new algorithm that tells you:
  - solid angle of each cell as seen by any point
  - how to draw rays with correct solid angle distribution within each cell



⇨ Cell-by-Cell approach (cell-by-cell MonteCarlo)

- We are free to choose the number of rays (depositing photons) per cell (e.g., set by convergence).

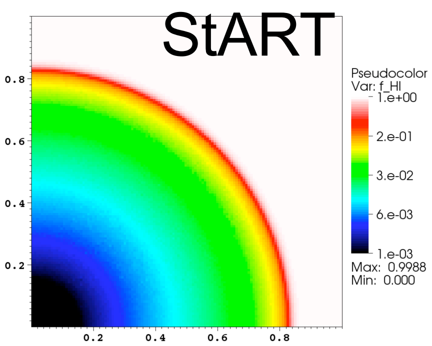
- Adaptive to the physical/grid properties: efforts concentrate where needed (i.e., for cells within the I-front). It scales like $O(N_{front})$.

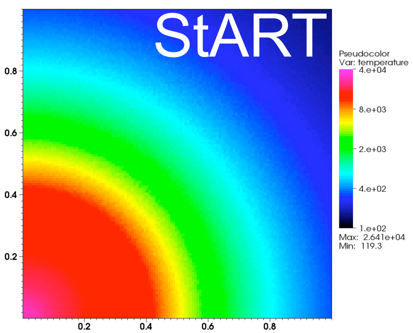
⇨ Adaptive Mesh Refinement on the I-front

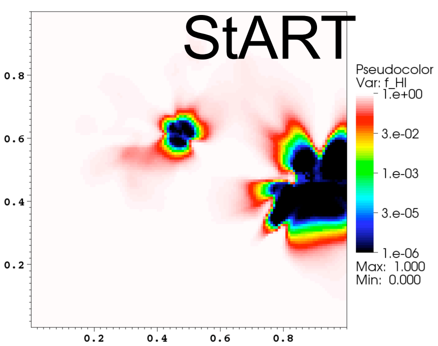
SC & Porciani 2009, TBS

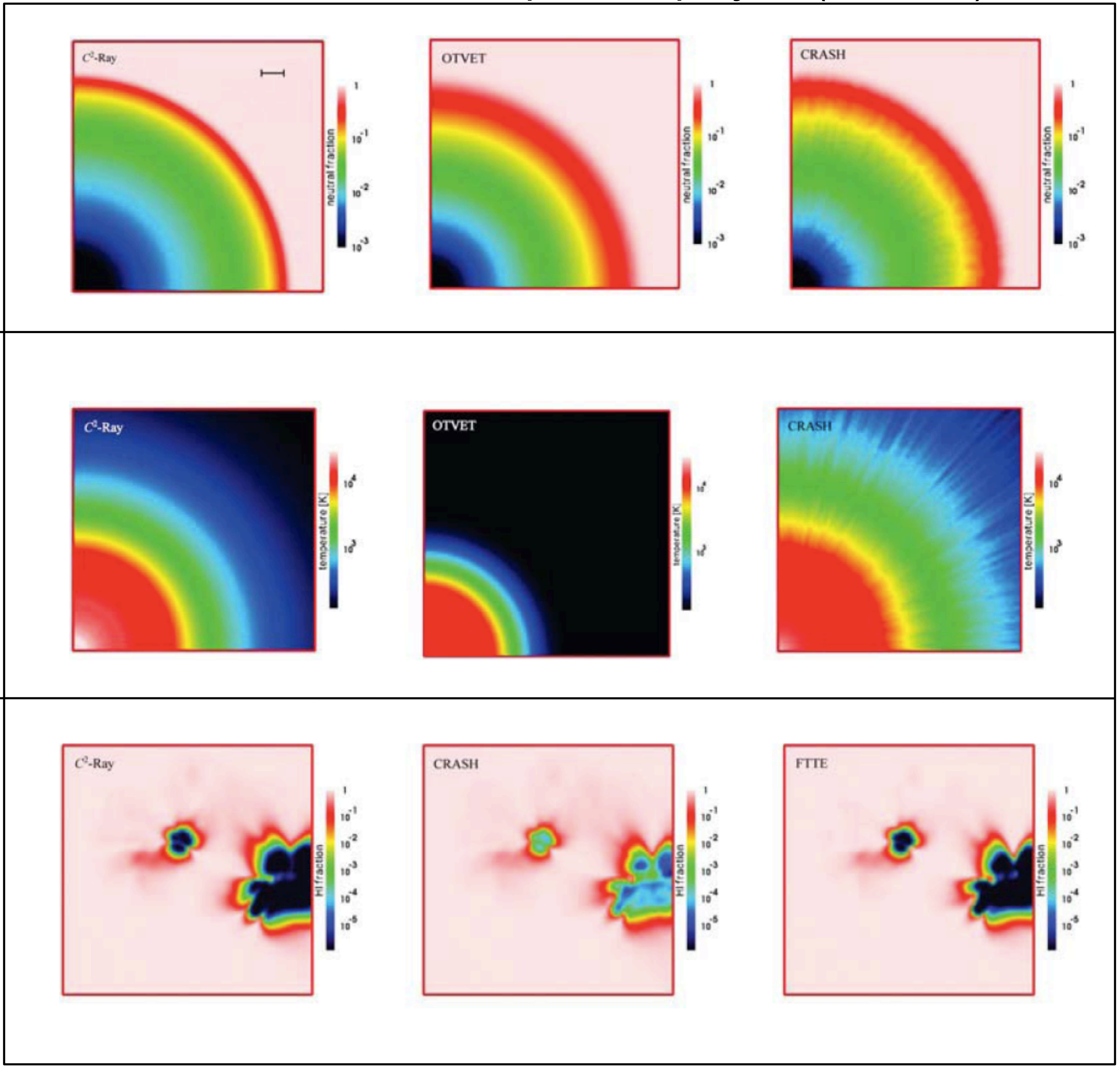
Tests (uniform grid):

from the Code comparison project (Iliev+06):

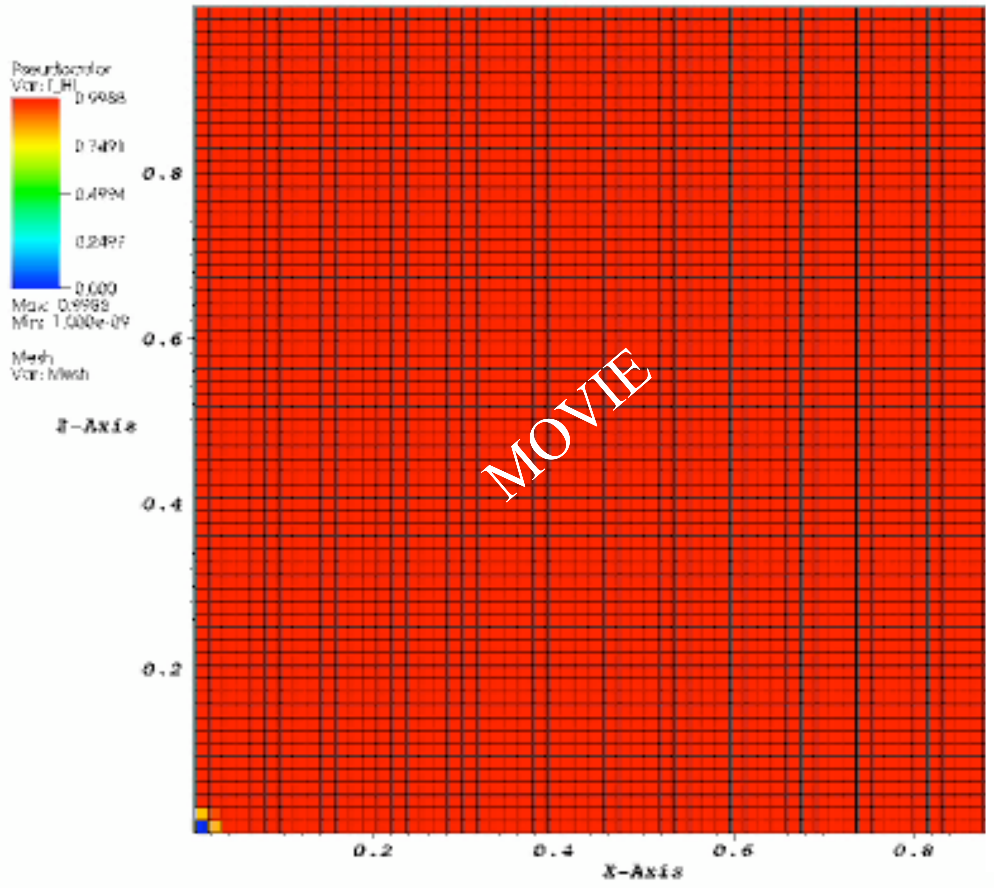


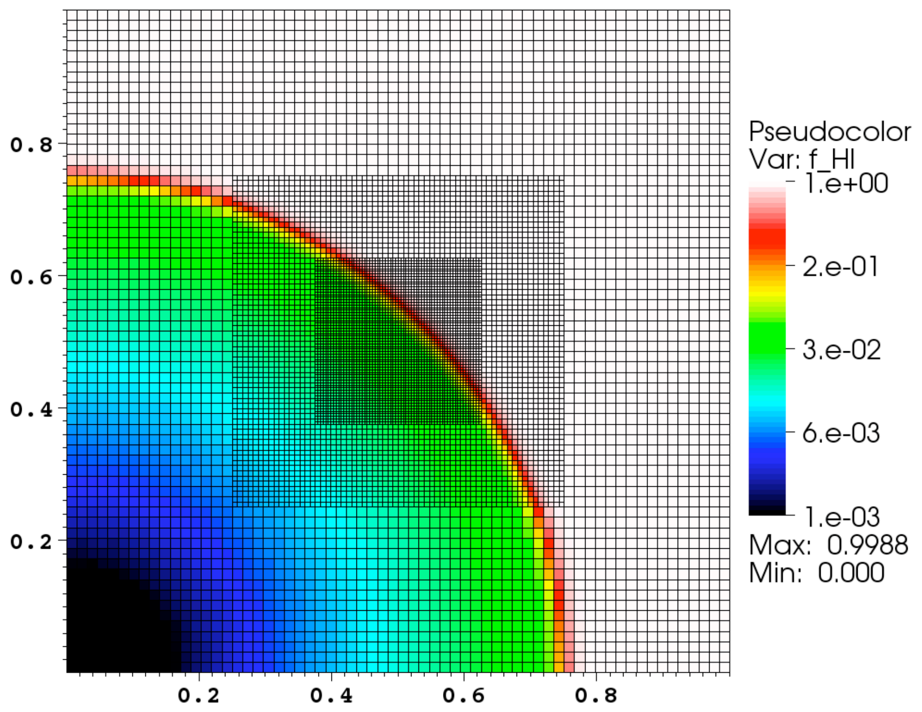






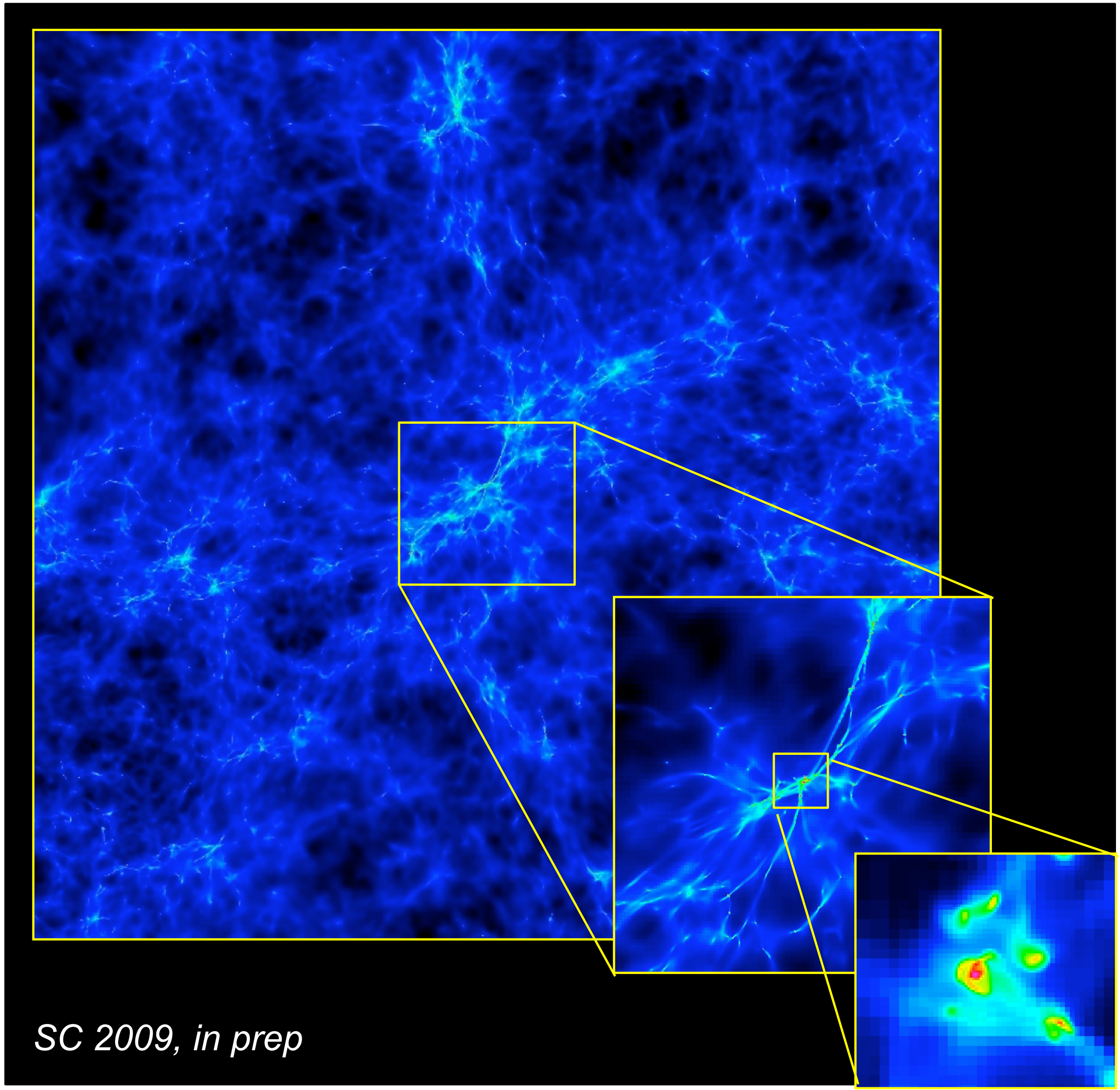
Multi-grids and I-front AMR:





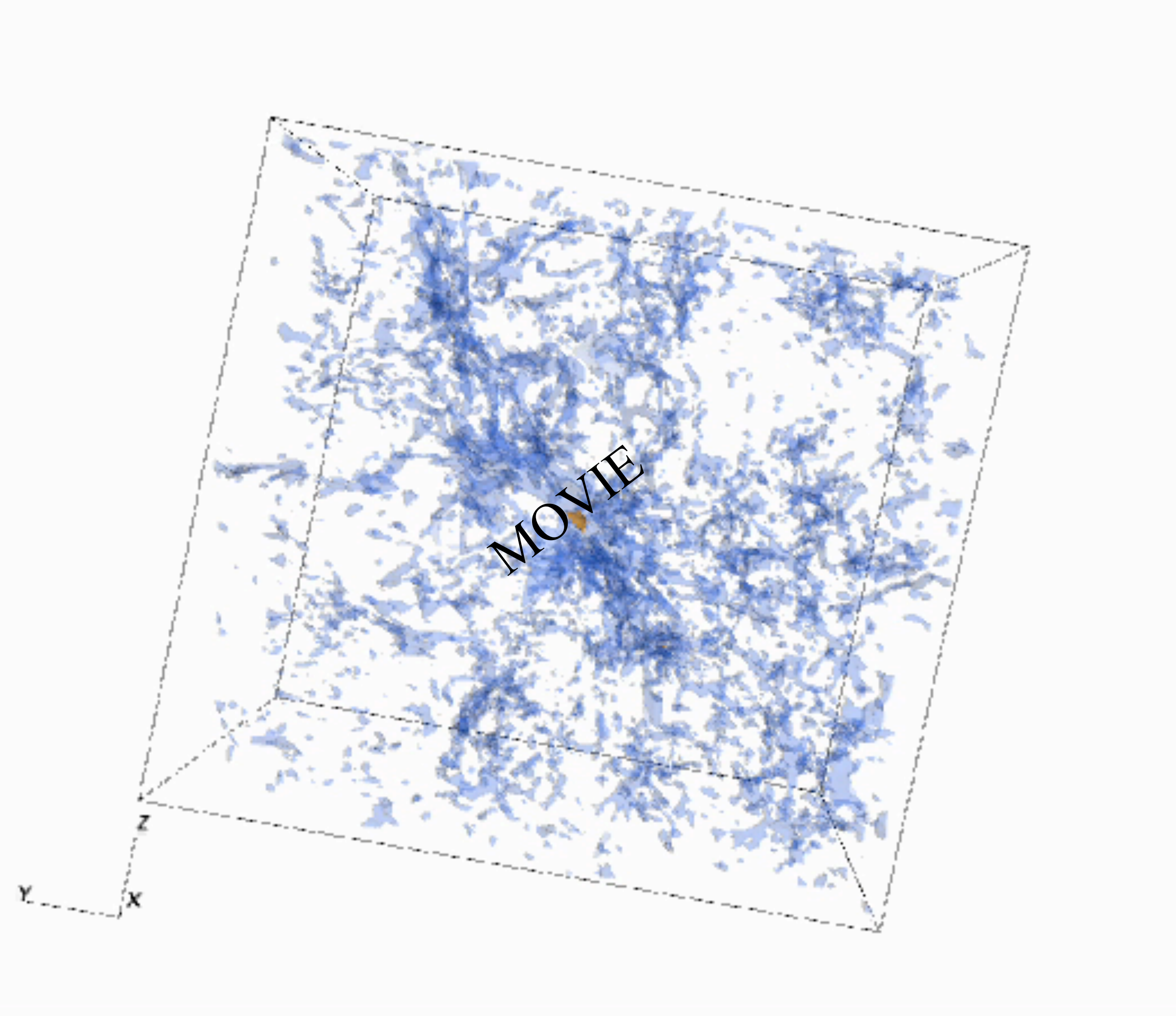
Simulating the near-zone of a bright QSO during the EoR

- Series of 200 Mpc zoomed initial condition boxes. AMR hydro-runs performed with RAMSES.
- Selected halo: $5 \times 10^{12}\, M_{\odot}$ (z=6.5)
- High resolution region of 100 Mpc, 512^3 base grid + 5 levels of refinement (effective physical resolution of ~800pc).

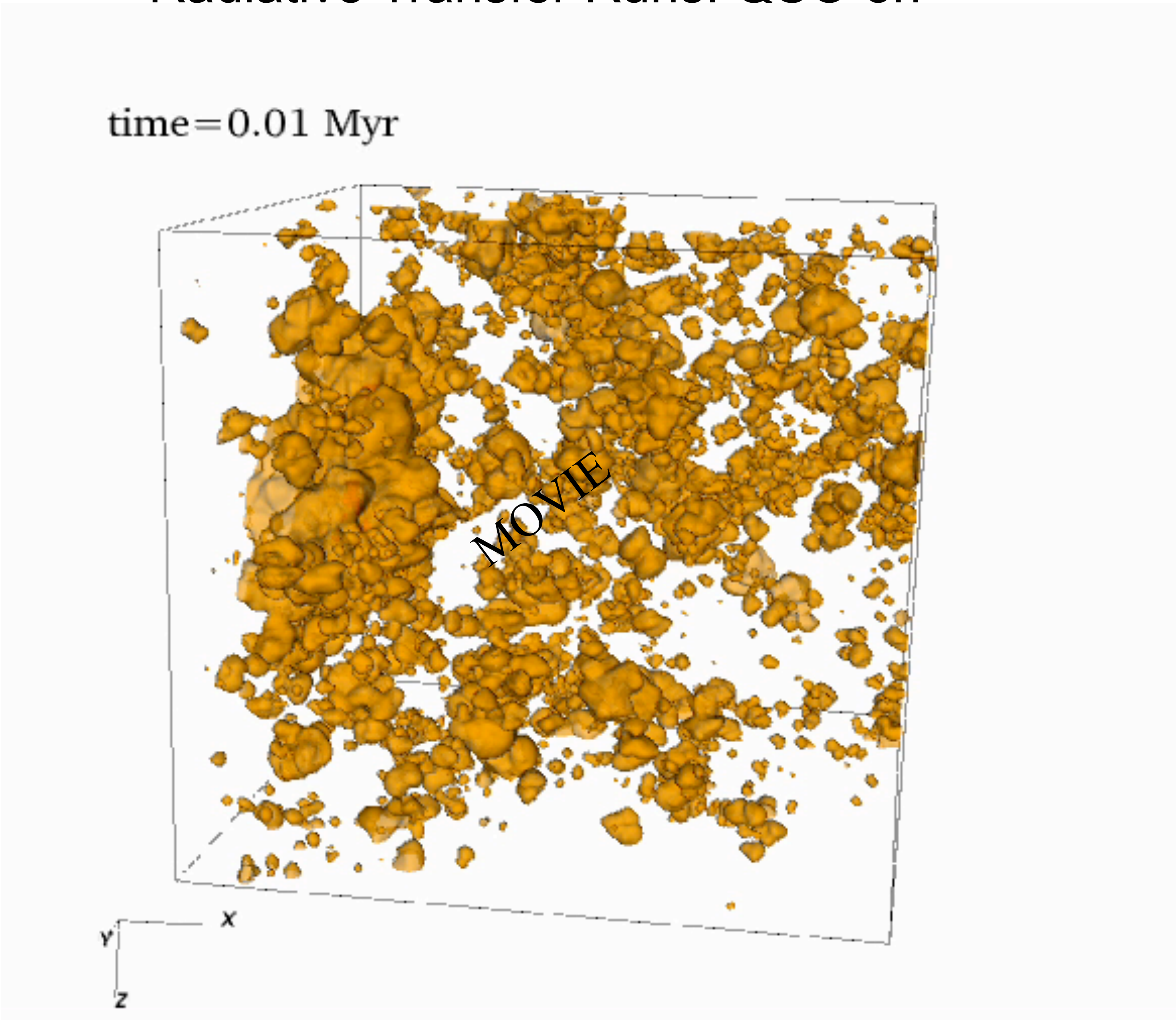


Radiative Transfer Runs: before the QSO turns on

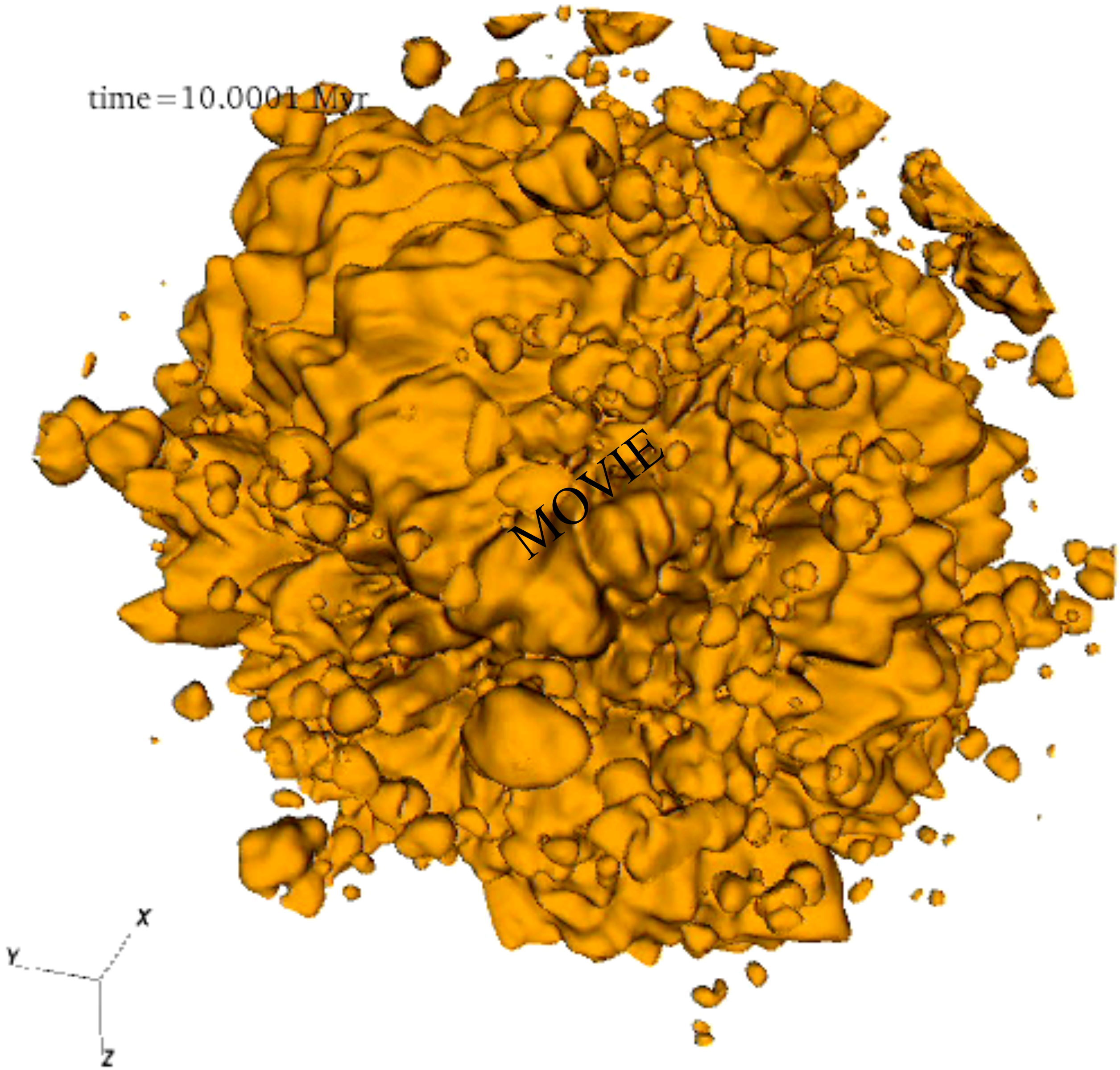
- Performed on an extracted region of size 50 Mpc.
- 256^3 base grid + 5 levels of refinement (effective physical resolution: ~800pc).
- + 3 additional levels on I-fronts
- ~10^4 sources (>10^9 $M_\odot$), PopII spectrum + QSO.
- Including Helium, 70 frequency bins (logarithmically spaced) from 13.6eV to 1keV.
- Including finite light-speed.



Radiative Transfer Runs: QSO on

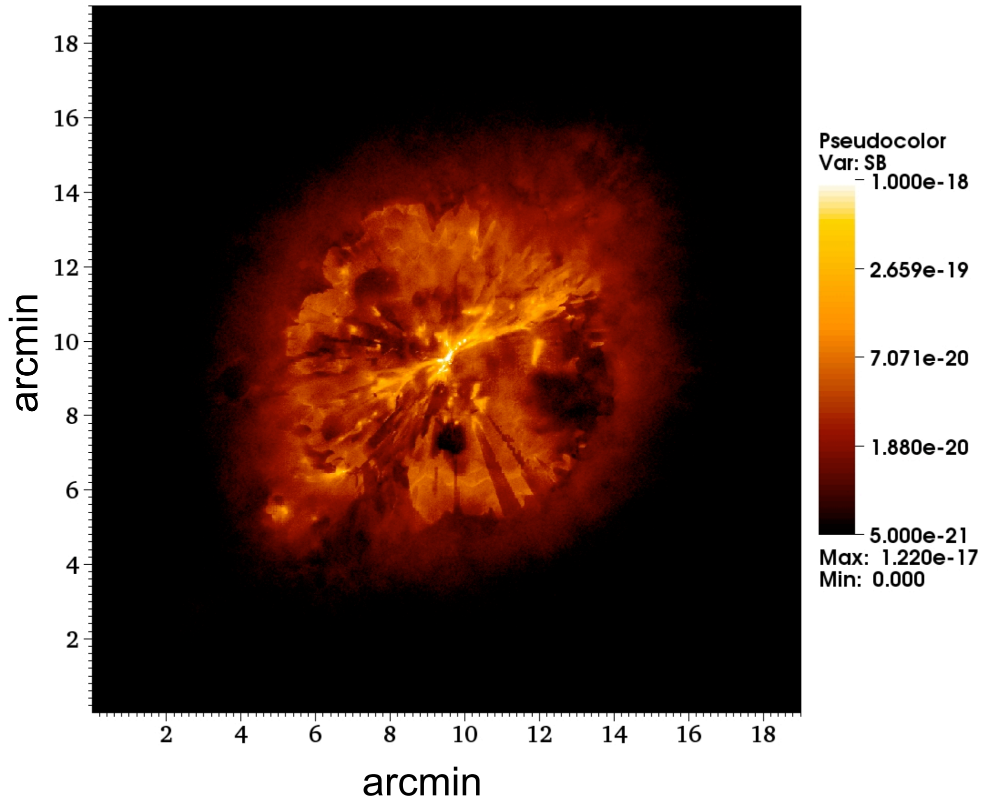


A look inside a QSO bubble

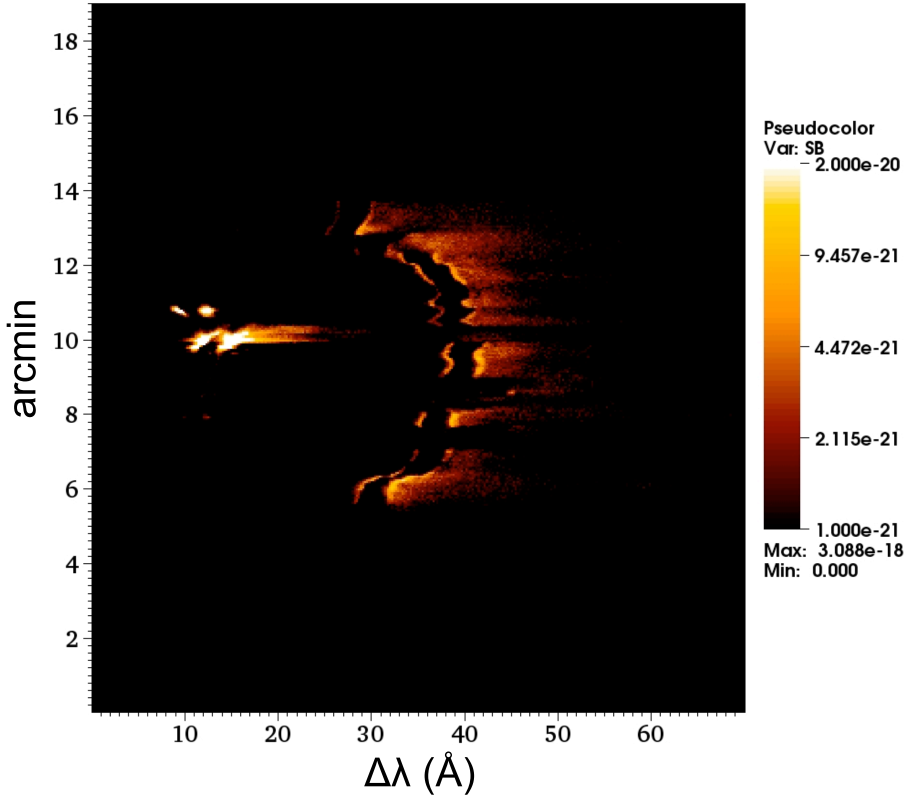


Lyα RT (preliminary) results:

Narrow Band Image



2D-spectrum



SC 2009, in prep

Is it detectable?

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

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

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

- 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 (Pan-STARRS)

with 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.

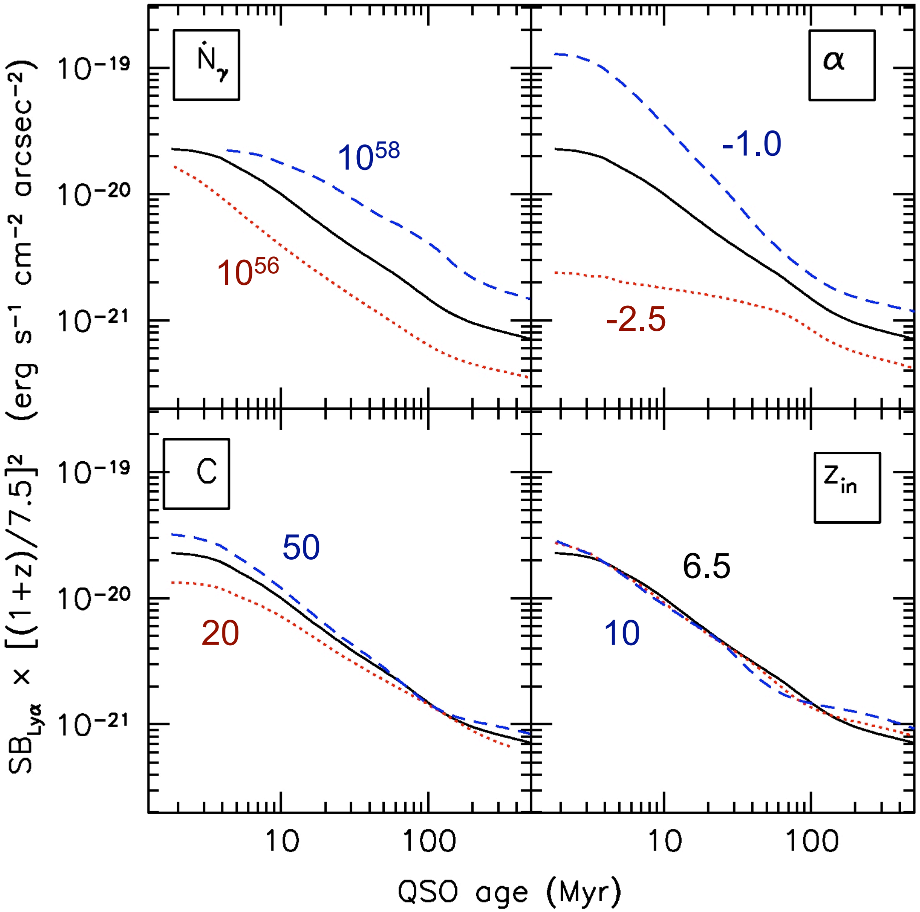
- Applications:

    - 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.

Results: exploring a larger parameter space



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

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

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

Cantalupo, Porciani & Lilly 2008