The bright Lyα side of 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
  - radiative transfer model
  - recent numerical results
  - detectability

- Bonus track: local photoionization flux, gas cooling and galaxy formation

Why to study the IGM?

The followings are just few reasons:

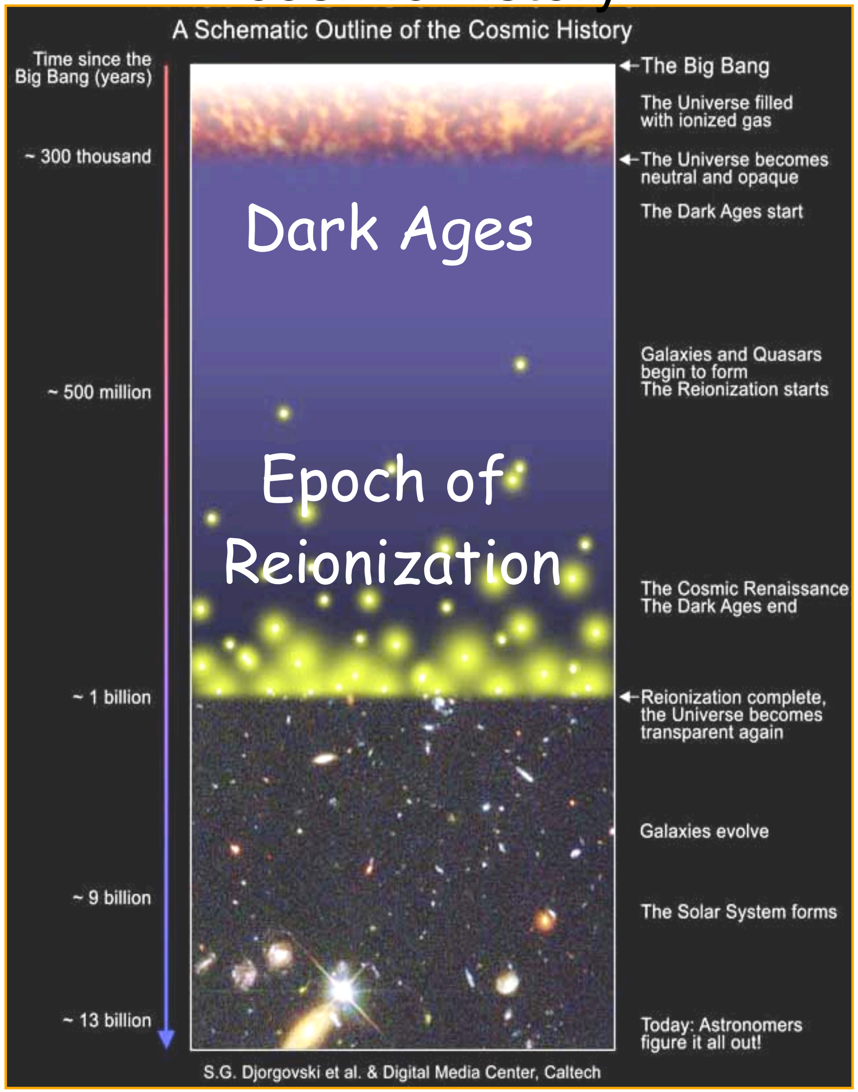
- it is where most of the baryons are

- trace well the Large Scale Structure of the Universe

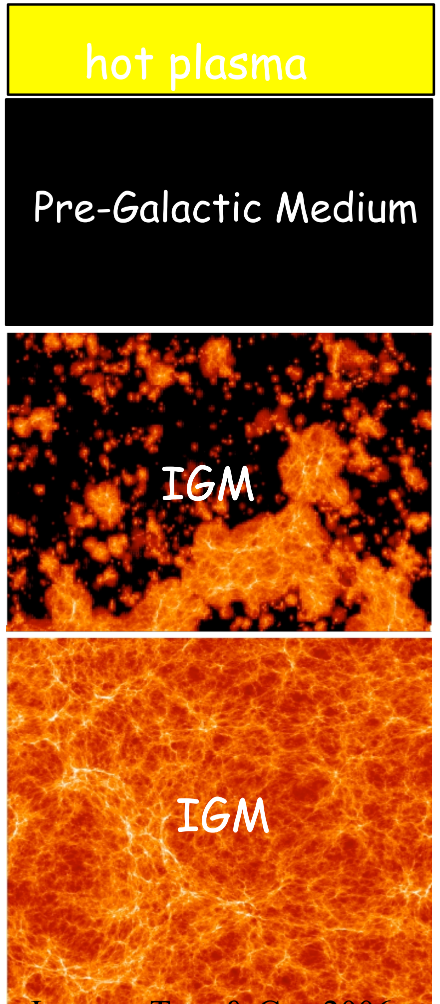
- closely connected to the first steps of galaxy formation but easier to model/understand (less unconstrained physical processes)

What do we know about the IGM?

cosmic history



cosmic hydrogen history



ionized

mostly neutral

partially ionized

mostly ionized

Images: Trac & Cen 2006

Classical approach to study the IGM: in absorption

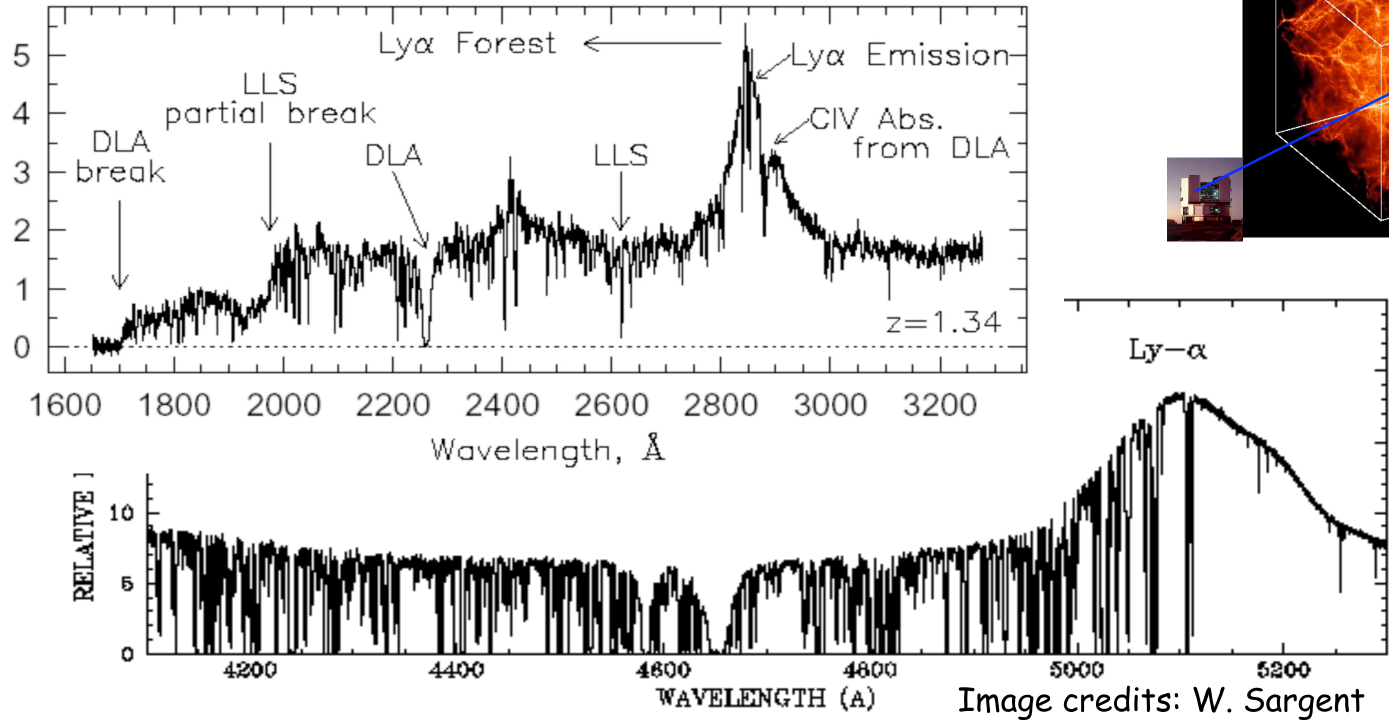
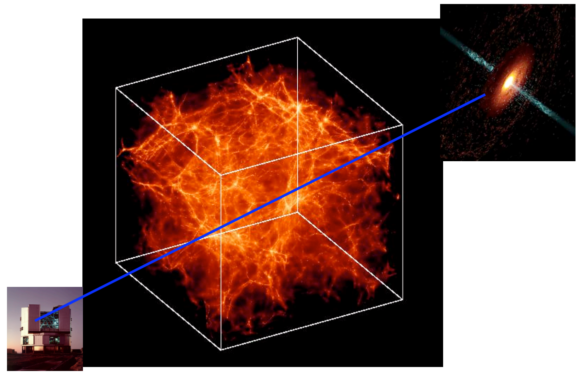


Image credits: W. Sargent



- powerful tool to map also the low-density (ionized) gas and to constrain cosmology
- However: only 1D information on denser (mostly neutral?) HI clouds (e.g., LLSs)

What we would like (still) to know about the post-Reionization IGM:

where is the neutral IGM?

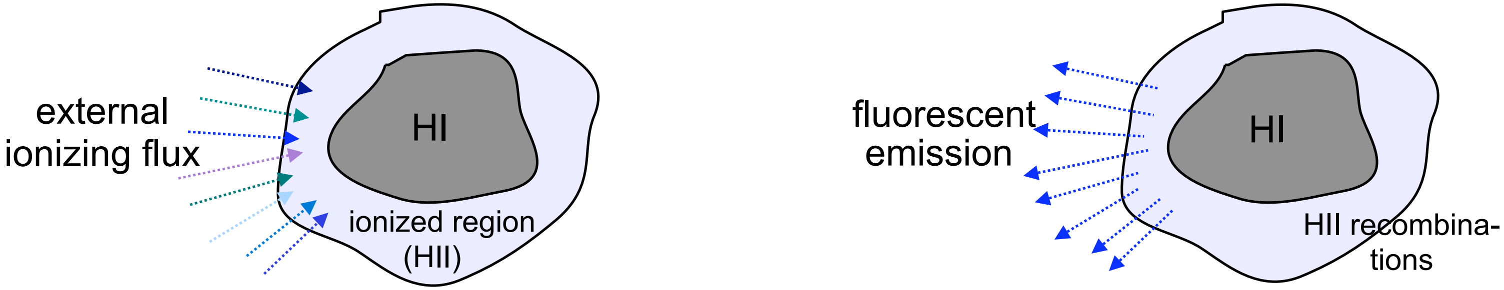
i.e., what is the nature of the LLSs (and DLAs)?

do they exist HI clouds in the IGM without significant star-formation (proto-galactic clouds or “dark galaxies”)?

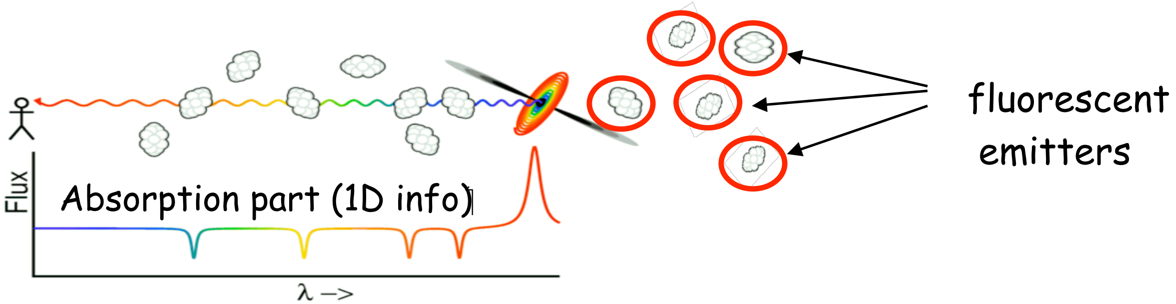
How the galaxies get their gas from the IGM (cold/hot, streams/smooth, etc.)?

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*).



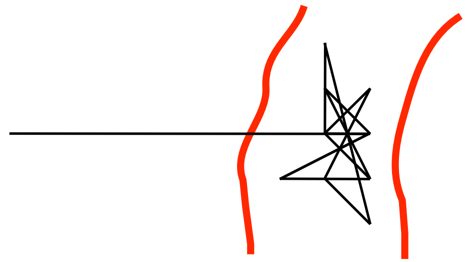
- Advantages:



  - 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

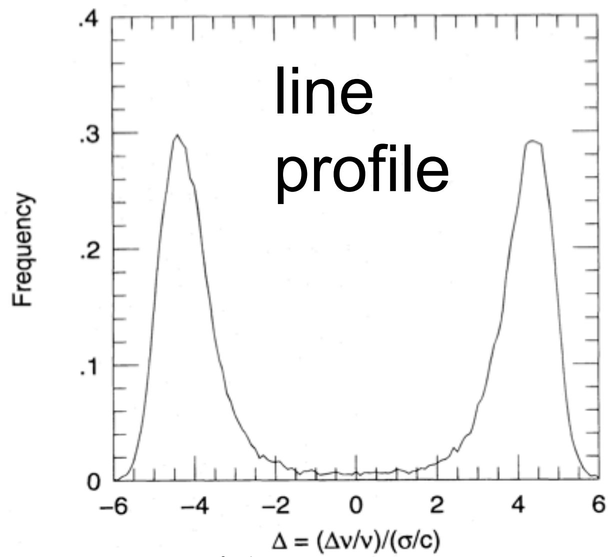
How to model fluorescent Lya emission?

high optical depth (to escape the medium) ~ 10^4-10^5
"random walk" in space and frequency
→ Monte Carlo techniques



early works based on:
- homogeneous slab approximation (e.g., Gould & Weinberg 1996) or isothermal sphere (Zheng & Miralda-Escude' 2002)
- static or rotating cloud
- uniform (external) illumination

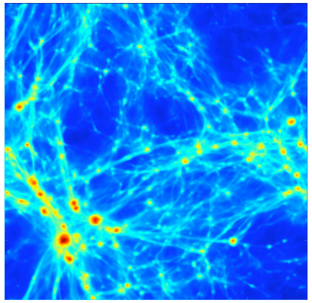
main results:
- uniform Lya SB (~60% of impinging ionizing flux)
- double peaked line profile



Gould & Weinberg 1996

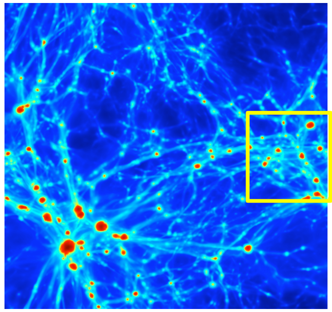
Our approach:

Hydrogen distribution



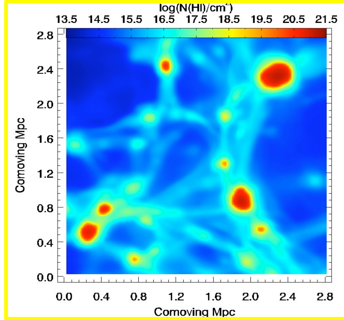
continuum RT (ionizing radiation)

Neutral Hydrogen

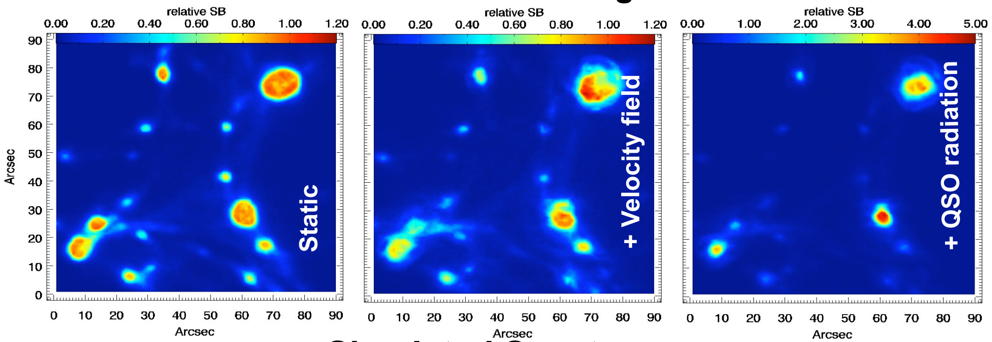


Grid refinement

Refined HI distribution

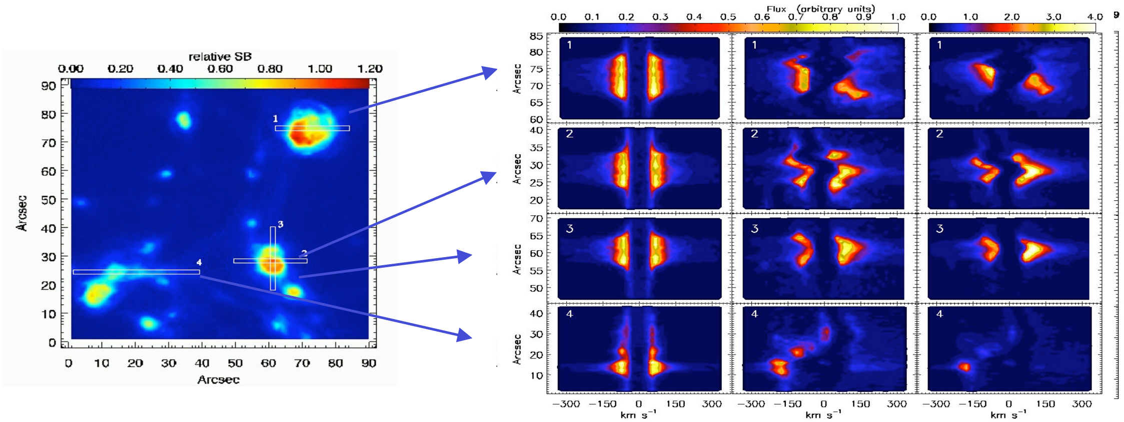


Simulated images



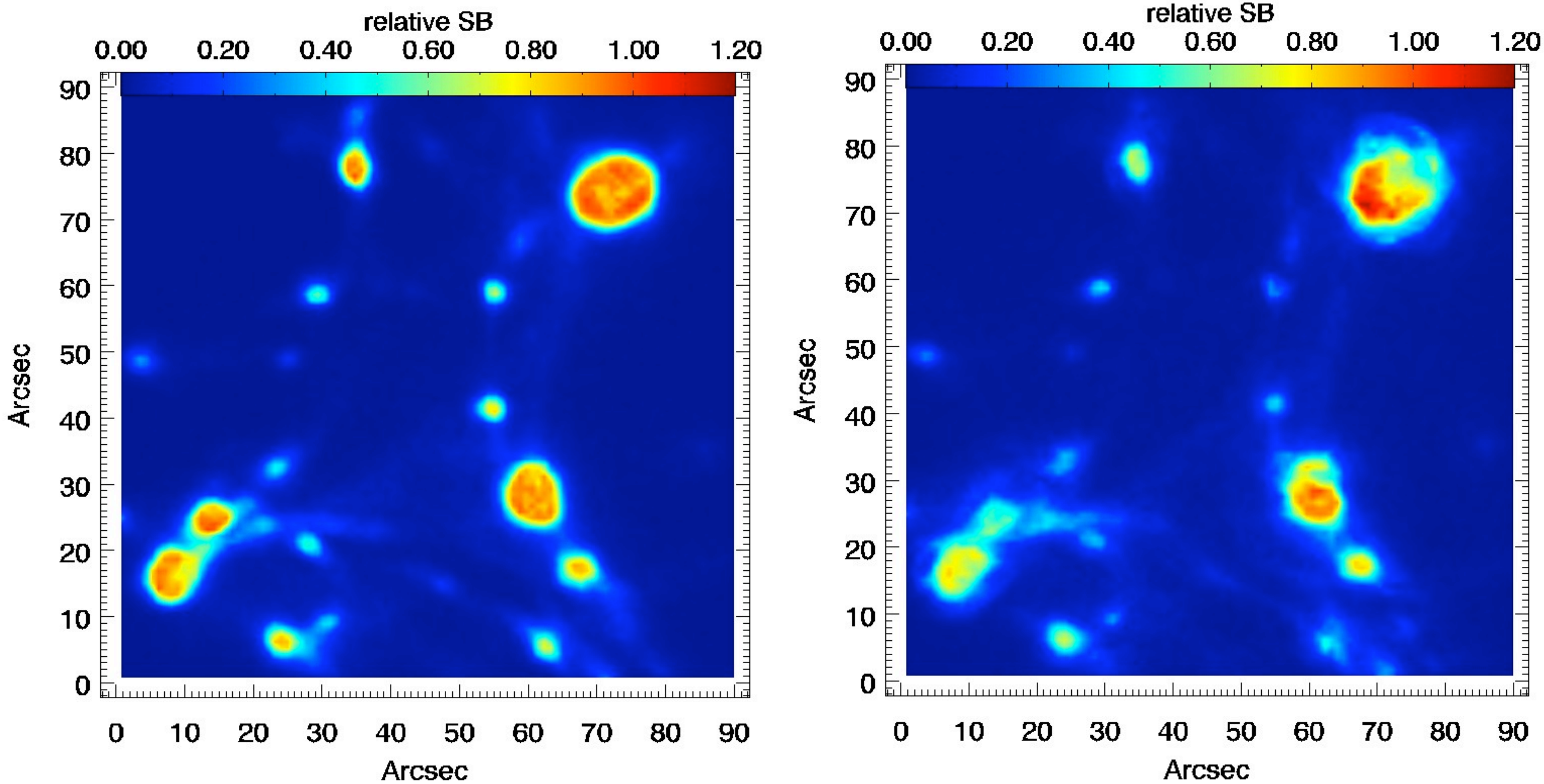
Lyα Monte Carlo RT

Simulated Spectra



SC, Porciani, Lilly & Miniati 2005

Results: Lyα images and the effect of the gas velocity field

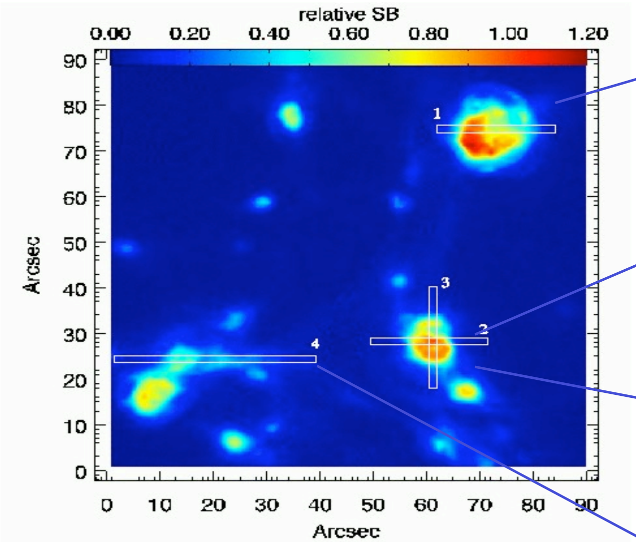


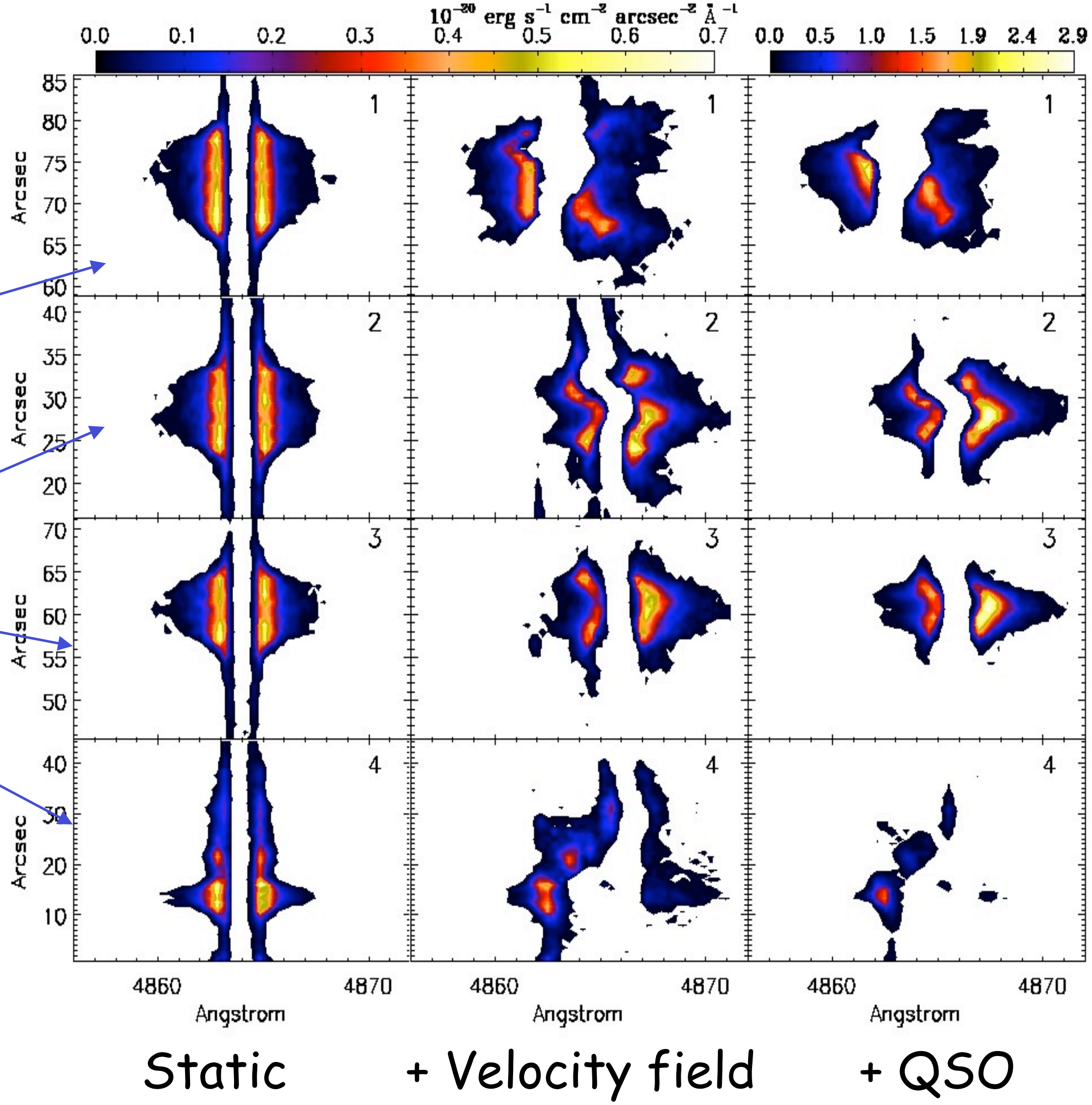
Static Case

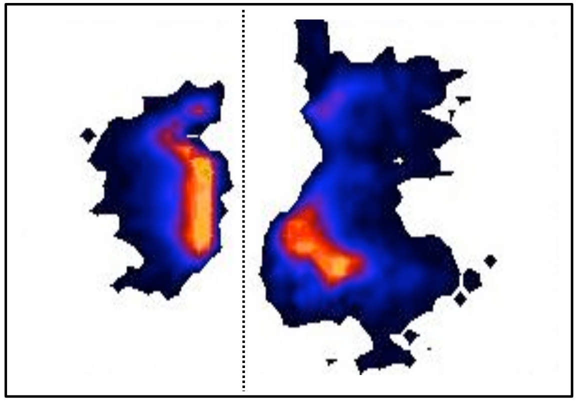
Including velocity field

Surface-Brightness relative to: $SB_{HM} = 3.67 \times 10^{-20}$ ergs cm^{-2} s^{-1} arcsec^{-2}

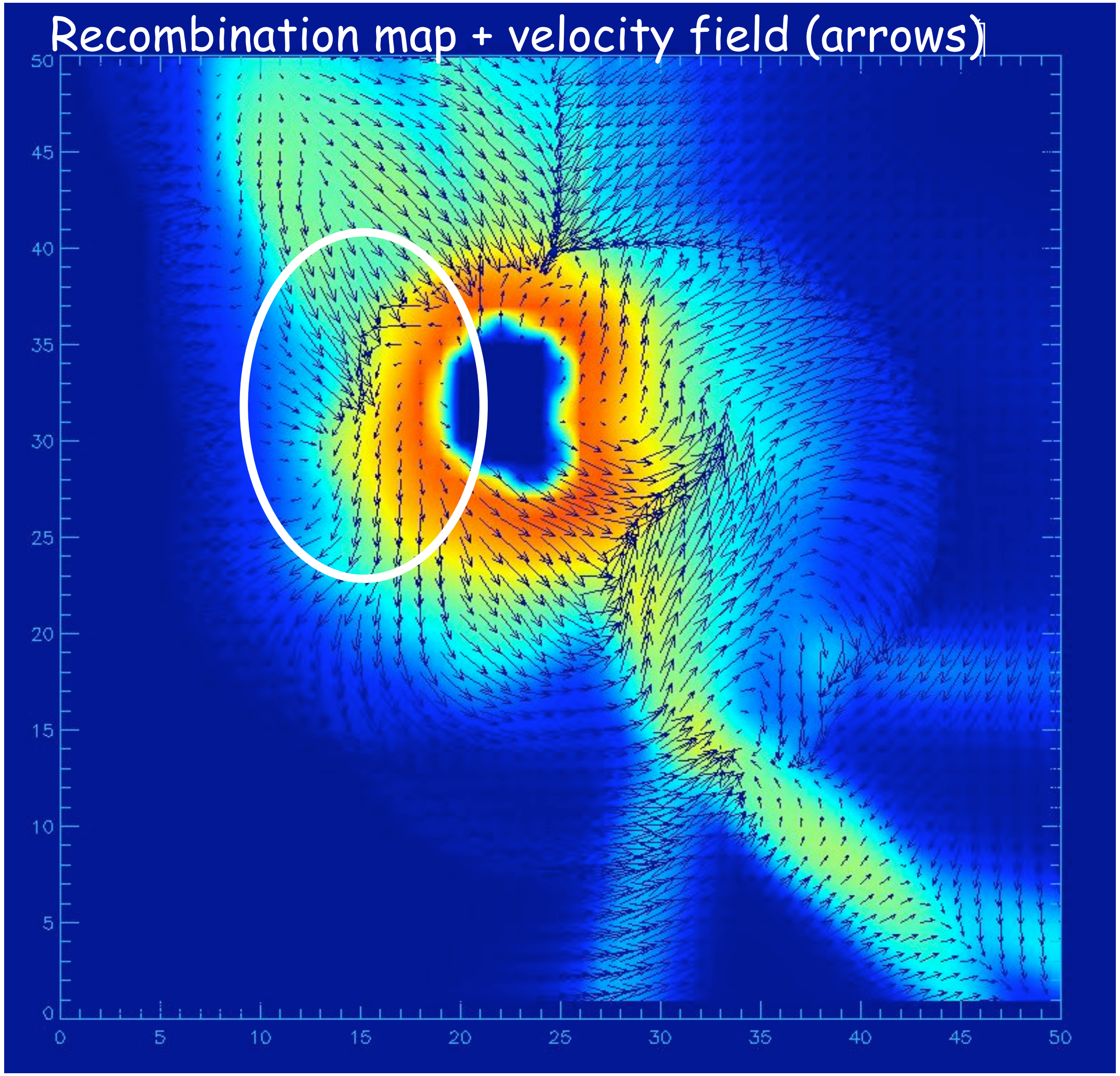
Results: 2D spectra



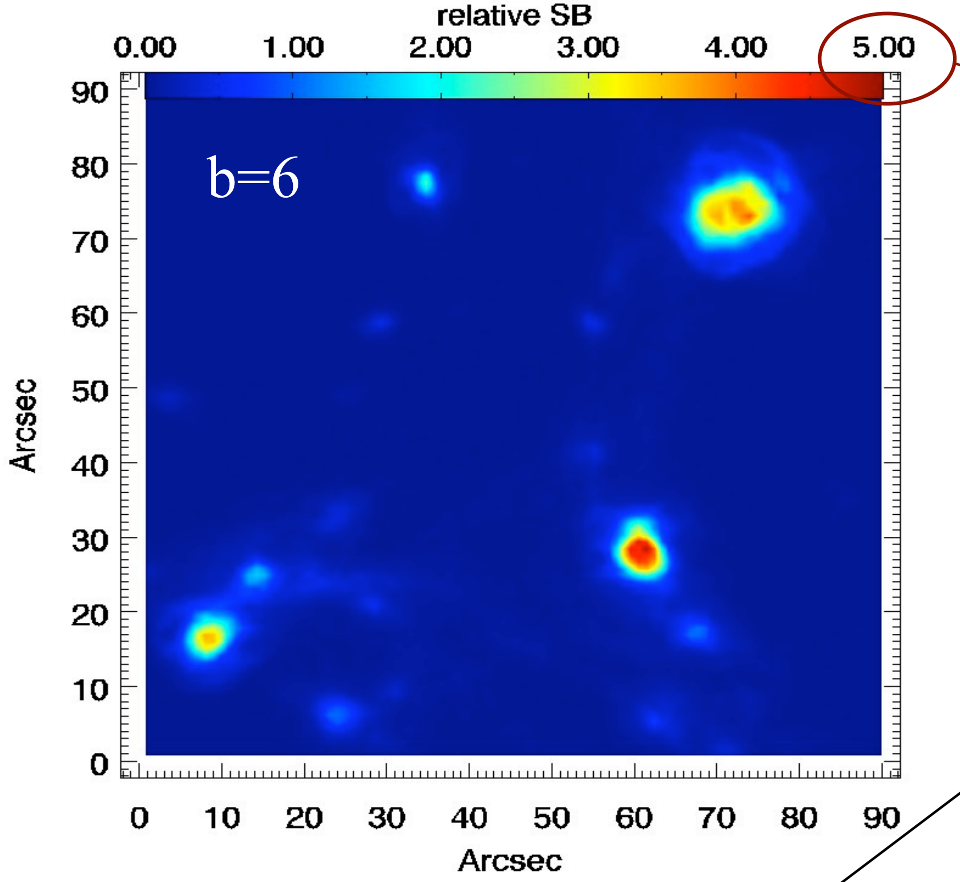




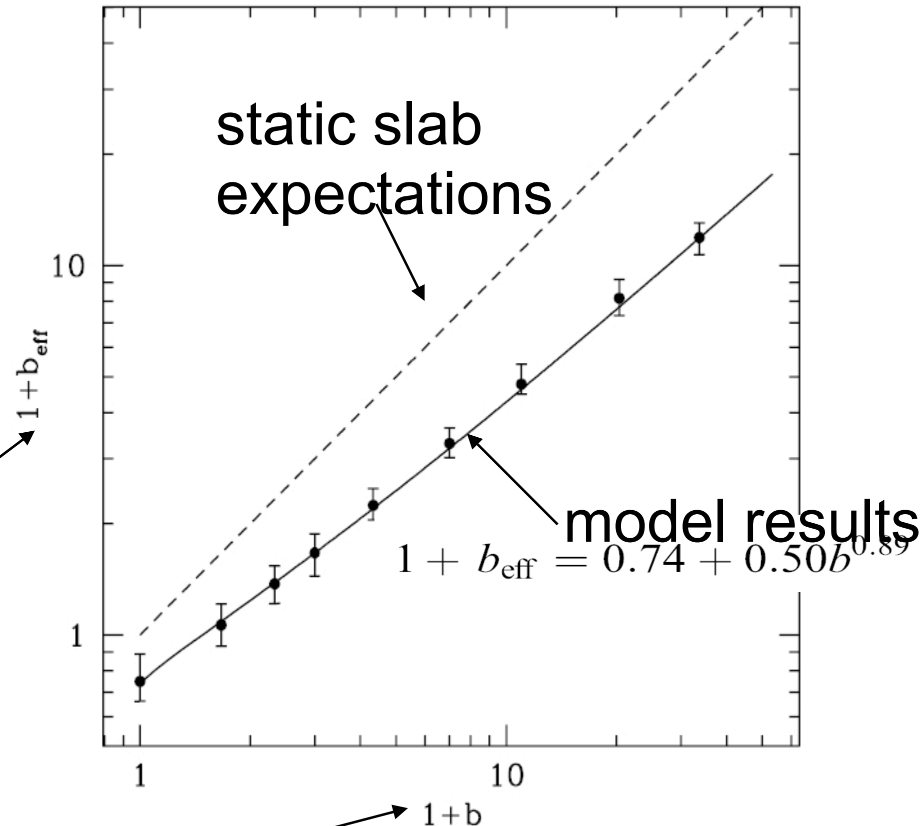
wavelenght


Recombination map + velocity field (arrows)
Slit coordinate
depth

Adding the QSO flux: the “geometrical” effect



1+b=7 expected!



effective “boost factor” from the observed SB

$$SB_{\|} = (1 + b_{\rm eff}) SB_{\rm HM}.$$

input “boost factor” from QSO

Is it detectable?

fluorescence from cosmic UV-background below the limit for current facilities.

BUT using a QSO for boosting fluorescence should make the first detection possible.

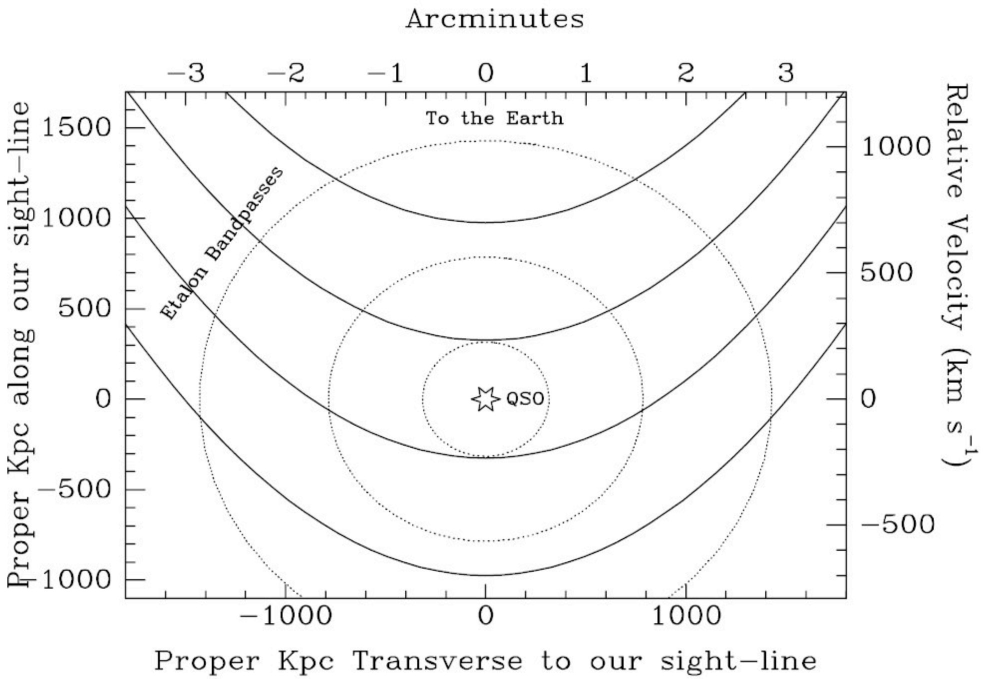
Let's look at all the attempts to detect this emission so far…

First attempt: Tunable-Filter search around a QSO at z=2.17
Francis and Bland-Hawthorn 2004

expectation based on slab model (6 clouds with 100 arcsec^2)

result: null detection

result consistent with our model (expected 0.3 clouds in the survey volume).



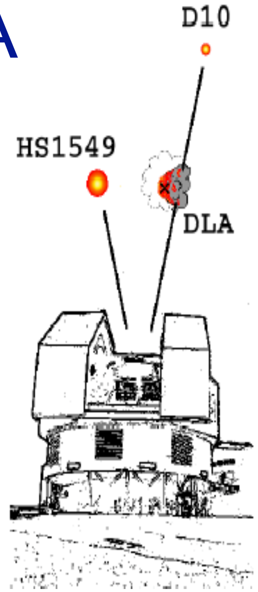
main reasons: too small volume, expected size and number density decrease in proximity of the QSO.

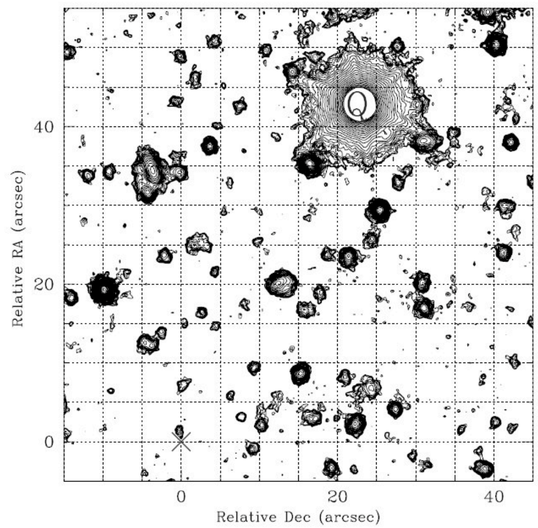
Possible fluorescence from a DLA (Adelberger et al. 2006)

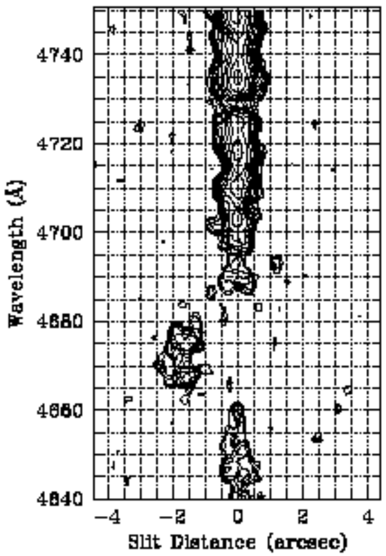
serendip. discovered: double peaked line profile, SB consistent with fluorescence (?)

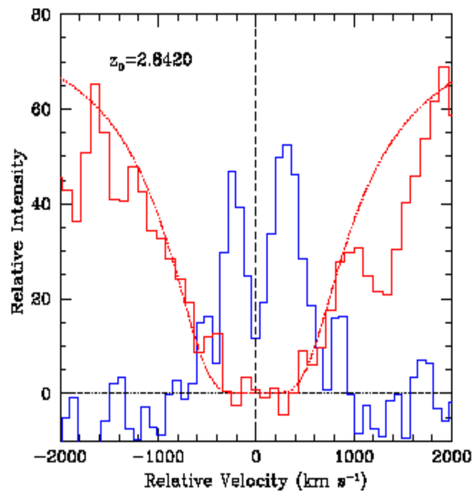
problems: continuum detected (in G and R band, ~26 mag), metal lines, very close to the QSO (unrealistic size to be self-shielded)

most likely there is star formation inside. Ly-alpha galaxy?



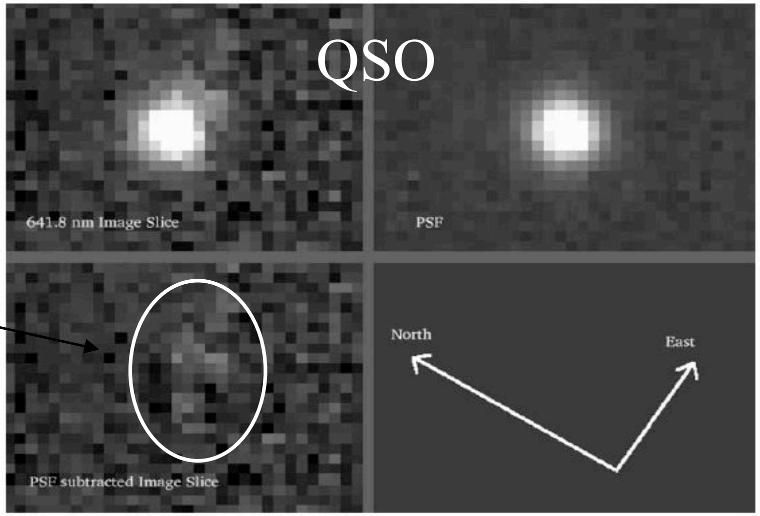




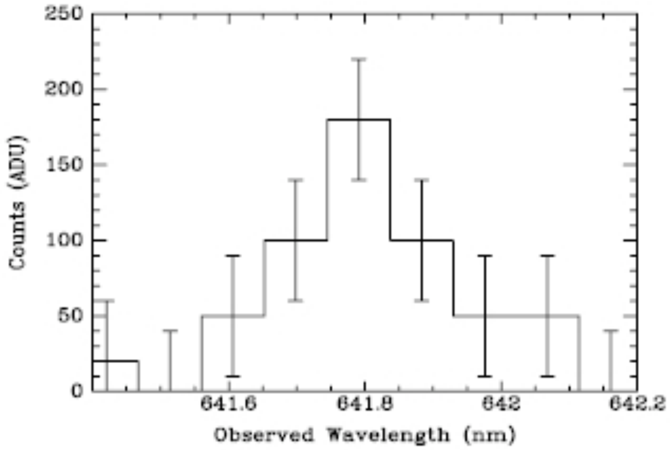


Integral-field spectroscopy search around a QSO at z~4
Francis & McDonnel 2006

detection of 1 Ly-alpha emission around the QSO (?)



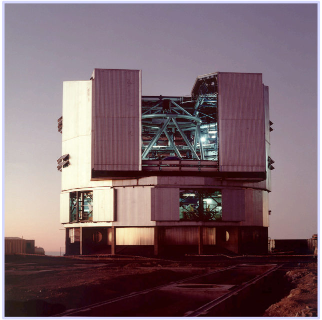
problems: just 50Kpc from QSO (physically connected?)
no constraints on SB or EW (because of QSO subtraction)



technique limitation: very small volume sampled.

Our approach: blind search with multislit+filter technique

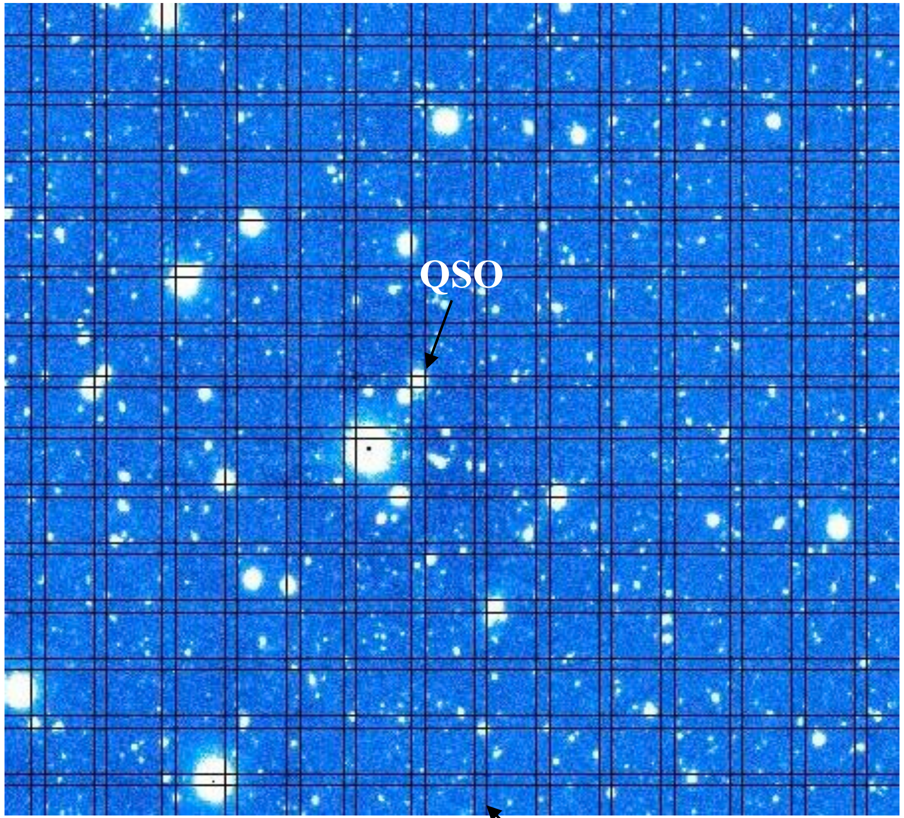
4 Nights @ VLT-FORS2



Target: z=3.1 QSO 0420-388
(brightest QSO in FORS2 narrow filters)

14 slits (2”x7’)

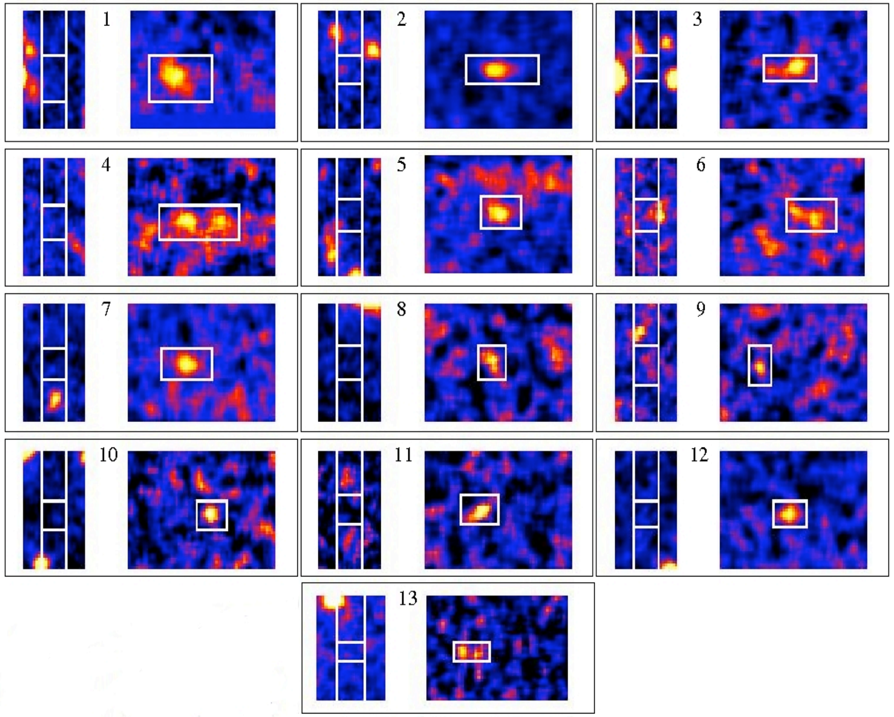
2 filters + 2 mask rotations
+ 1 deep V-band image



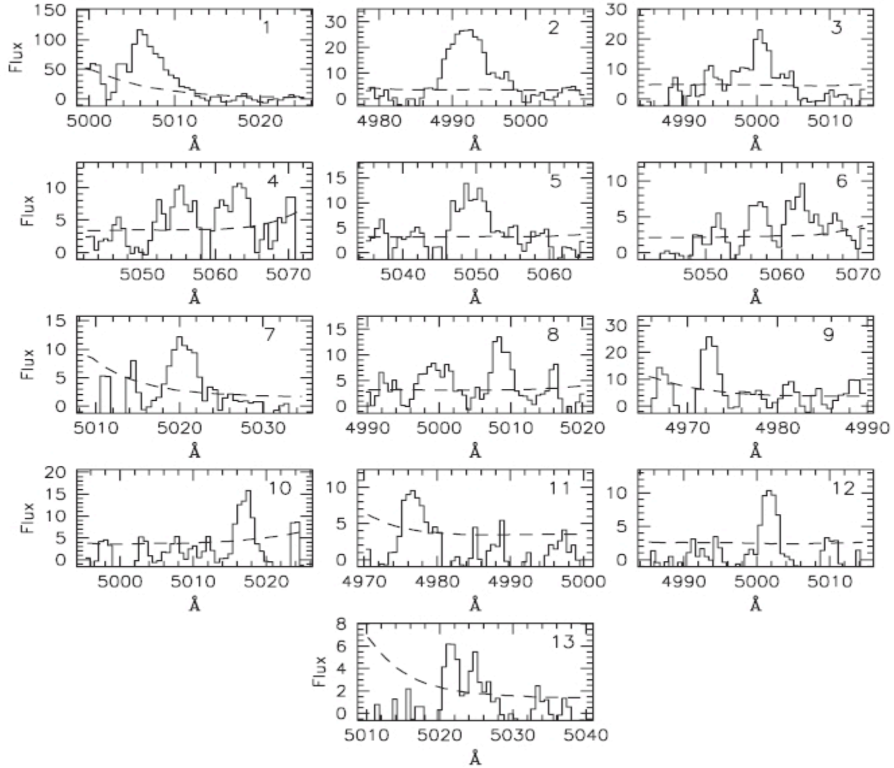
(sparsely) sampled volume=14000 comoving Mpc^3
expected #: ~7-10 fluorescent emitters

SC, Lilly & Porciani 2007

Results: 13 Lyα candidates detected

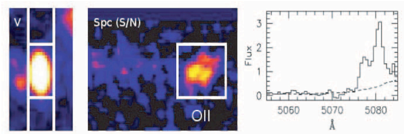


slit positions (V image) and 2D spectra



1D spectra

+ 2 OII interlopers (z~0.7), e.g.:



Are they fluorescent or galaxies?

primary constraints:
- equivalent width (EW)
- SB – distance relation

secondary constraints:
- line profile
- number density

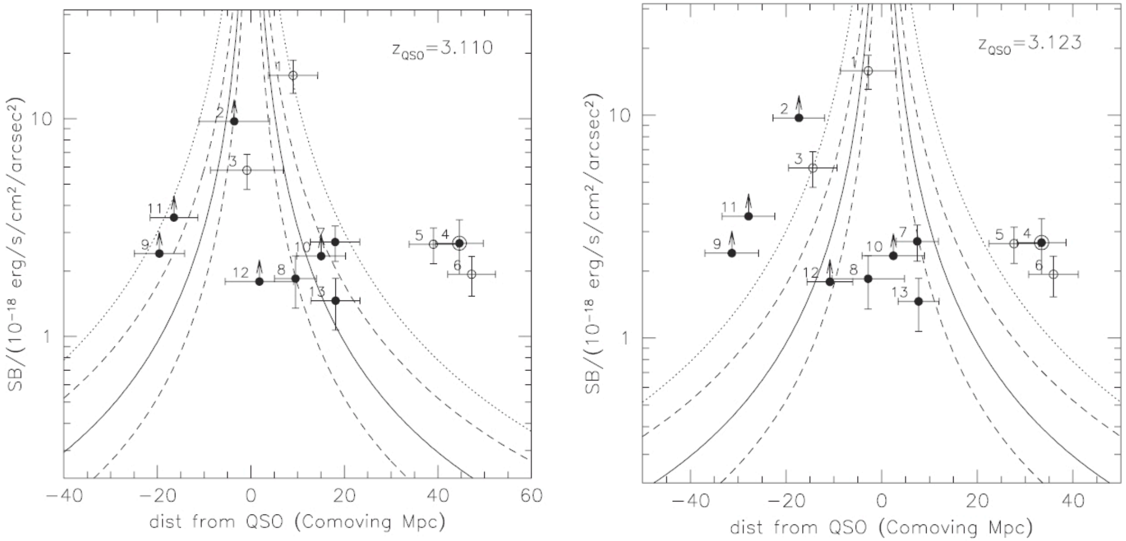
they all indicate that
about half of them
are plausibly fluorescent

further studies
(e.g., increasing EW constraint)
are needed...

TABLE 3
SPECTROPHOTOMETRIC PROPERTIES OF THE Lyα CANDIDATES

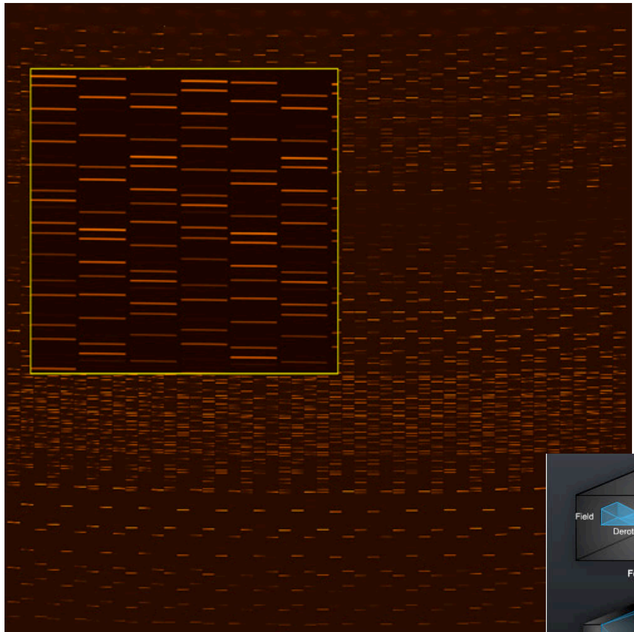
OBJECT NUMBER	$F_{\rm line} \pm 1\ \sigma$ (10^{-18} ergs s^{-1} cm^{-2})	$f_V \pm 1\ \sigma$ (10^{-20} ergs s^{-1} cm^{-2} Å^{-1})	EW$_0$ (Å)	SB (10^{-18} ergs s^{-1} cm^{-2} arcsec^{-2})	FLUORESCENT?[a] EW	FLUORESCENT?[a] EP	FLUORESCENT?[a] SB
1	58.27 ± 6.67	6.55 ± 5.90	$\gtrsim$370	15.81 ± 2.73	+		+
2	18.81 ± 1.20	3.43 ± 3.69	>150	$\gtrsim$9.72	+		+[b]
3	12.98 ± 1.35	16.70 ± 3.32	16^{+6}_{-4}	5.80 ± 1.06	–		+
4	11.33 ± 1.41	1.46 ± 4.43	>65	2.68 ± 0.78	+	+	–
5	7.30 ± 0.81	4.76 ± 4.06	$\gtrsim$36	2.65 ± 0.49			–
6	6.36 ± 0.68	8.86 ± 4.06	15^{+17}_{-5}	1.93 ± 0.40	–		–
7	5.31 ± 0.82	0.86 ± 4.06	>30	2.71 ± 0.50			+
8	4.70 ± 0.67	0.59 ± 4.43	>24	1.84 ± 0.49			+
9	4.21 ± 1.16	0.65 ± 5.17	>18	$\gtrsim$2.40			–
10	4.06 ± 1.01	−5.65 ± 3.69	>25	$\gtrsim$2.34			+
11	3.49 ± 1.05	−1.98 ± 3.69	>21	$\gtrsim$3.52			–
12	2.65 ± 0.56	3.17 ± 3.32	>18	$\gtrsim$1.79			+
13	2.62 ± 0.45	2.34 ± 2.58	>23 (>70)[c]	1.46 ± 0.39		+	+
Previous Fluorescent Lyα Candidates in the Literature							
AA1[d]	21.0 ± 5.0		72^{+20}_{-20}	110.00 ± 26.00	–	+	
FD1[e]	$\gtrsim$15.0		>19				

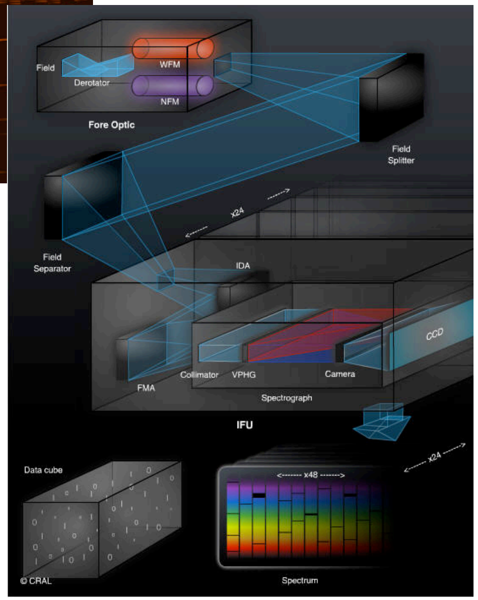
[a] In view of the indicators discussed in § 2 (where EP = emission-line profile).
[b] If $z_{\rm QSO} = 3.110$.
[c] If the line is O II at $z = 0.36$.
[d] Adelberger et al. (2006); candidate at $z = 2.842$.
[e] Francis & McDonnell (2006); candidate at $z = 4.279$.

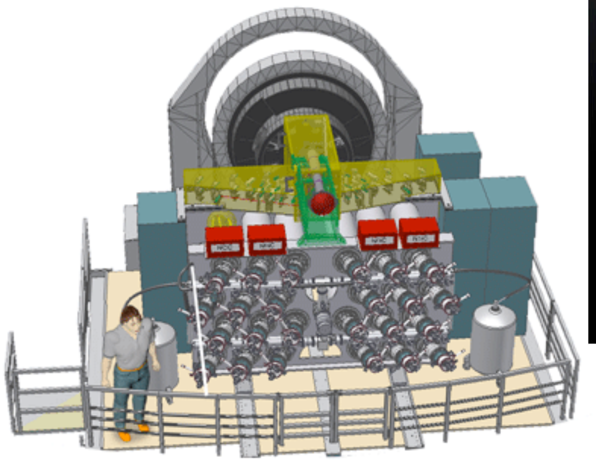


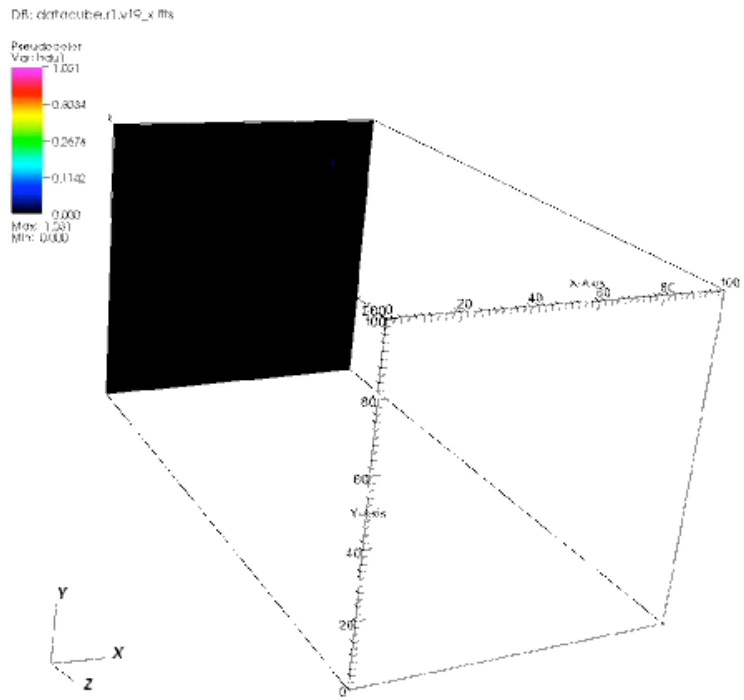
Next future (2012): MUSE (Multi-Unit Spectroscopic Explorer) @ VLT

- 1’x1’ Integral Field Unit
- 24 modules, 3750 spectra each (!)
- range: 4800-9200 Å (z~3-6.5 for Lyα)
- Adaptive Optics

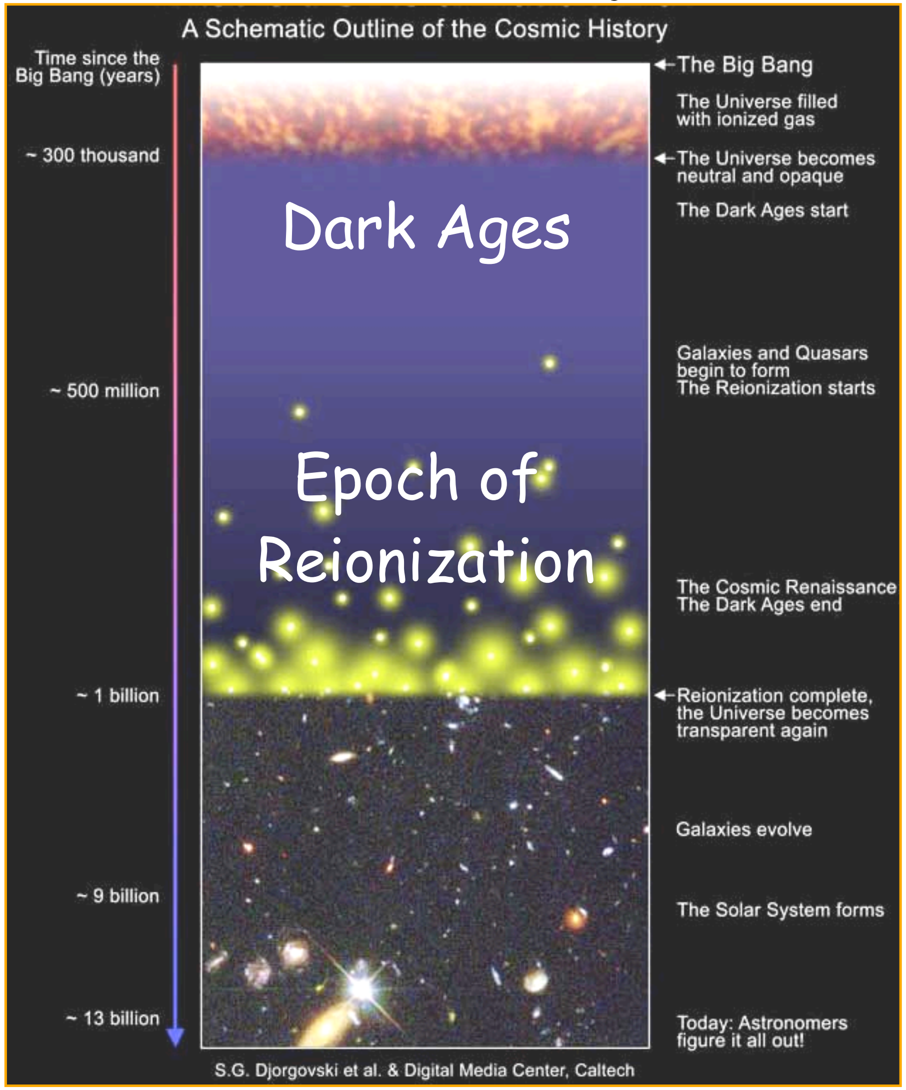




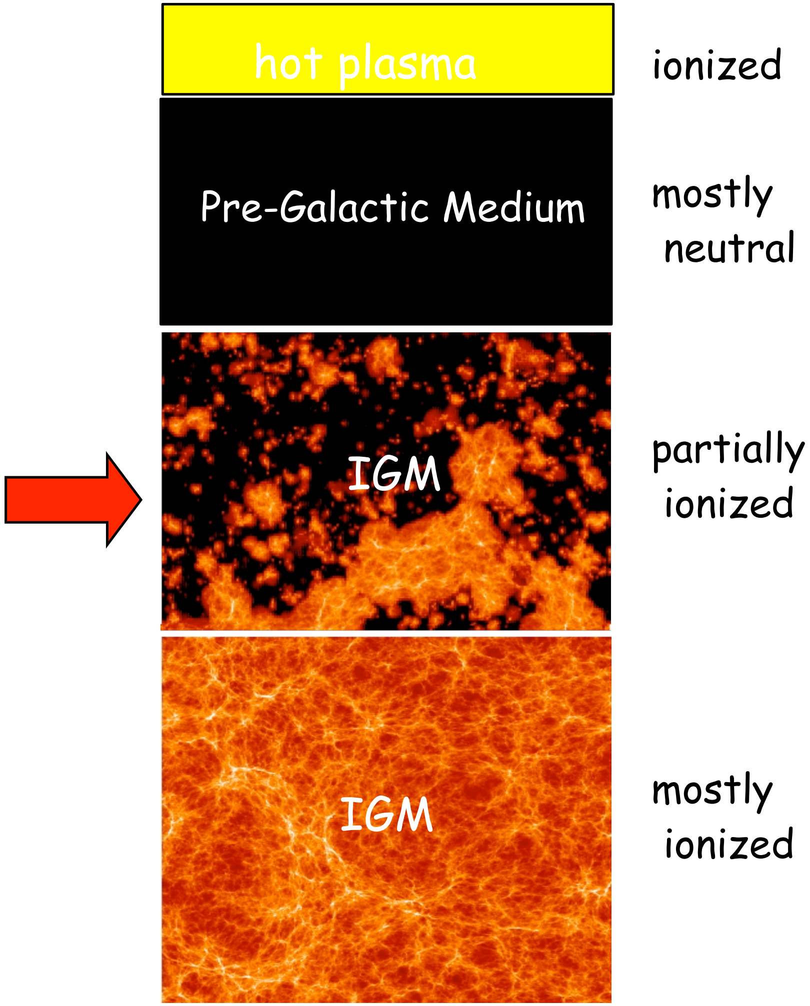




cosmic history



cosmic hydrogen history



Images: Trac & Cen 2006

Reionization F.A.Q.

- Q1: When did happened?

- Q2: How? (i.e., who did the job?)

- Q3: Should we really care about Q1 and Q2?

Yes, if you are also interested in:

-> the physics of the (post-EoR) Intergalactic Medium

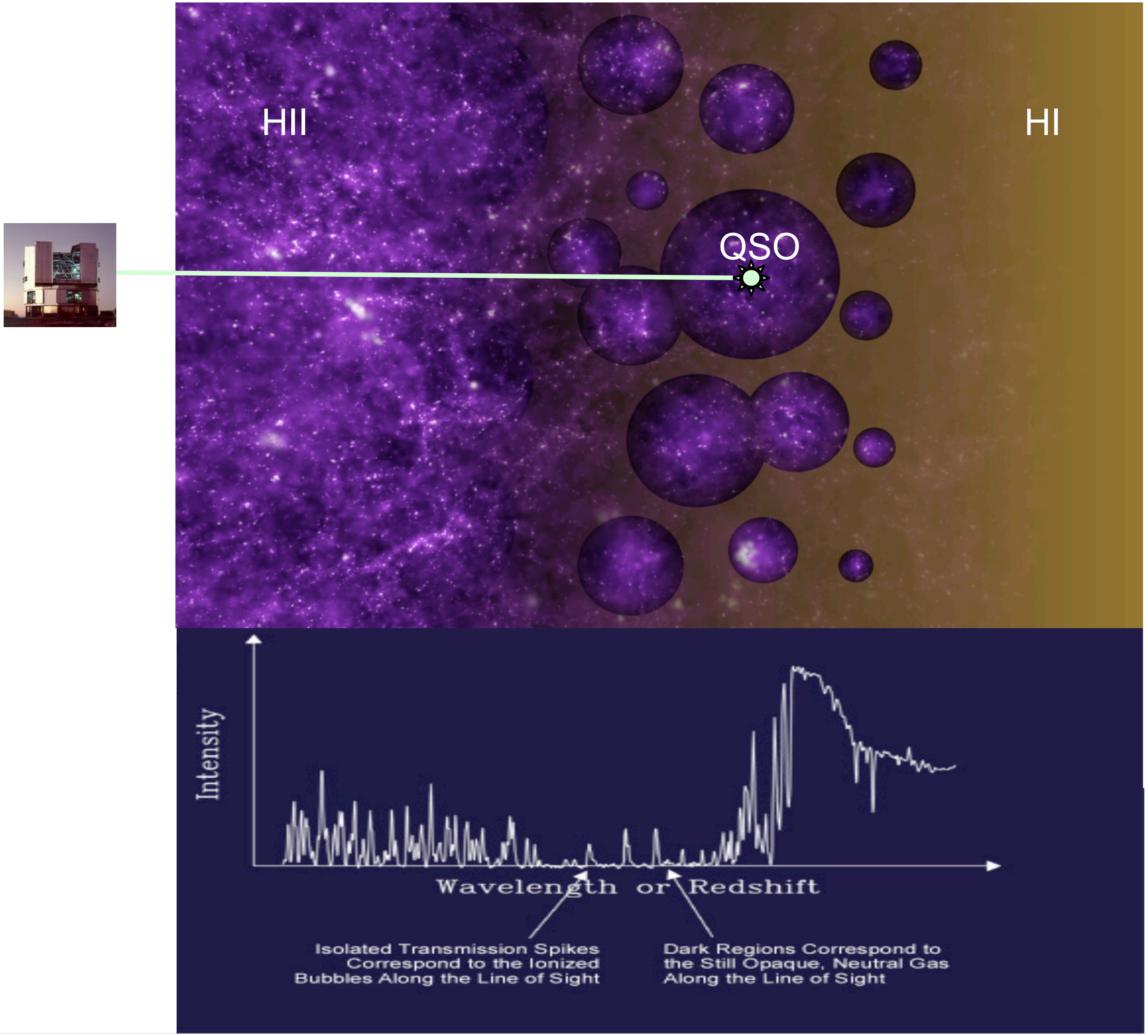
-> understanding (the first steps of) the galaxy-formation process

-> measuring cosmological parameters (e.g., with CMB large-scale polarization or galaxy power-spectrum)

-> answer to fundamental questions

-> finding new questions

Constraints (1): high-redshift quasars (Gunn-Peterson effect)



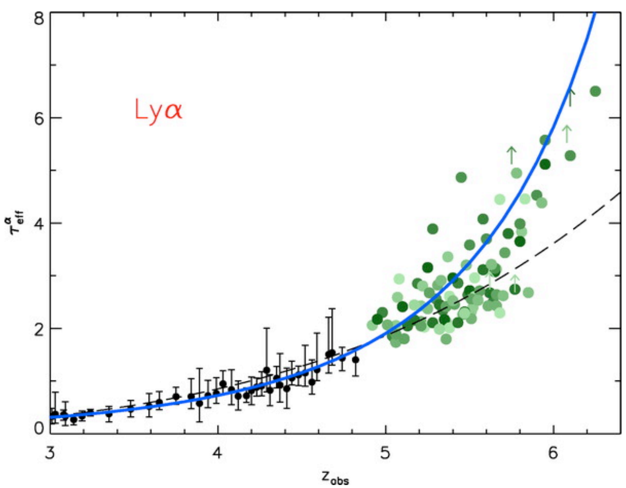
Constraints (1): high-redshift quasars (Gunn-Peterson effect)

$$t_{GP} \approx 6\text{x}10^5 x_{HI} \left(\frac{1+z}{10} \right)^{3/2}$$

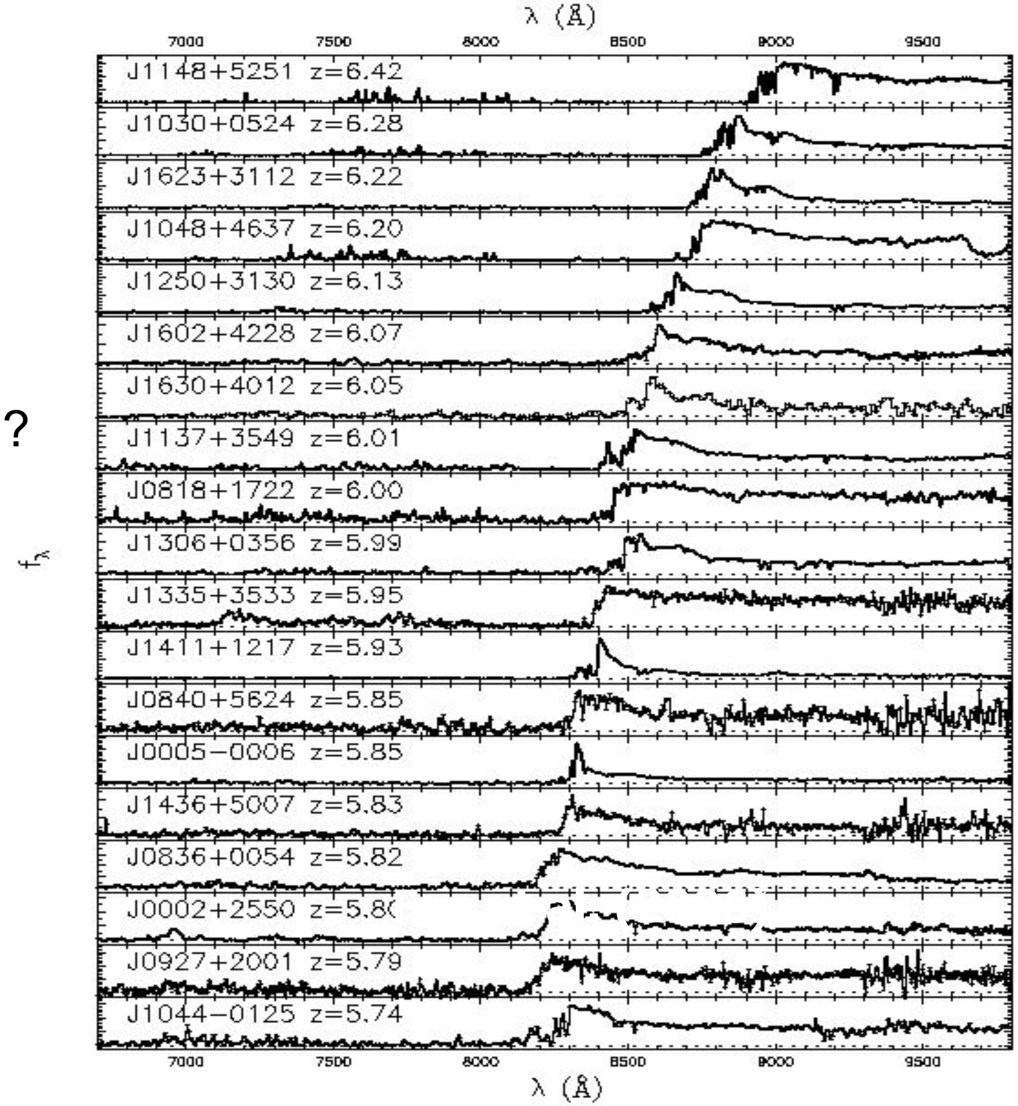
main limitation:

- Saturates already at very low neutral fractions (0.0001)

probing only the END of reionization?



Becker et. al 2007



Fan et. al 2006

Constraints (2): HII region size in QSO spectra

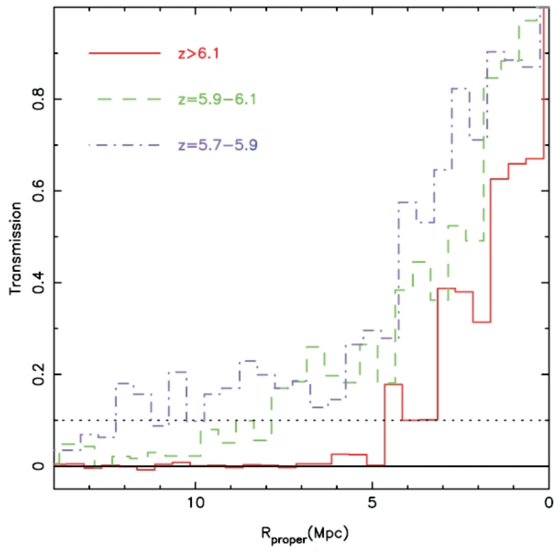
bubble size related to mean HI fraction (f_HI):

$$R_s = 8.0 f_{\mathrm{H\,I}}^{-1/3} \left(\dot{N}_Q / 6.5 \times 10^{57}\ \mathrm{s}^{-1}\right)^{1/3} \left(t_Q / 2 \times 10^7\ \mathrm{yr}\right)^{1/3} \times \left[(1+z_Q)/7\right]^{-1}\ \text{proper Mpc.}$$

for t<<t_rec

(Haiman 2002)

... but we need (also) the QSO age to constrain f_HI.

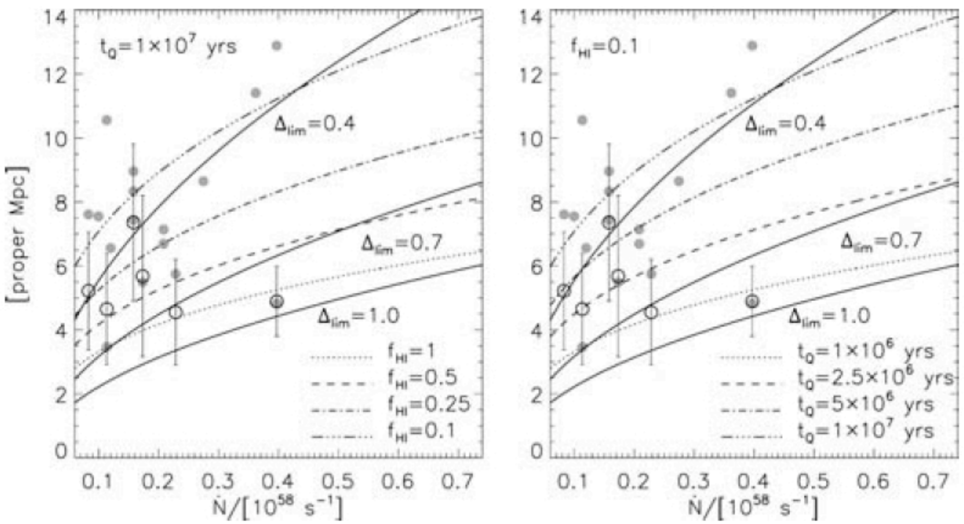


Fan et al. 2006

Again: hint for rapid redshift evolution,

but no clear values for the HI fraction

(see e.g., White+ 2003; Whythe+ 2005; Yu & Lu 2005; Bolton & Haehnelt 2007; Maselli+2007)



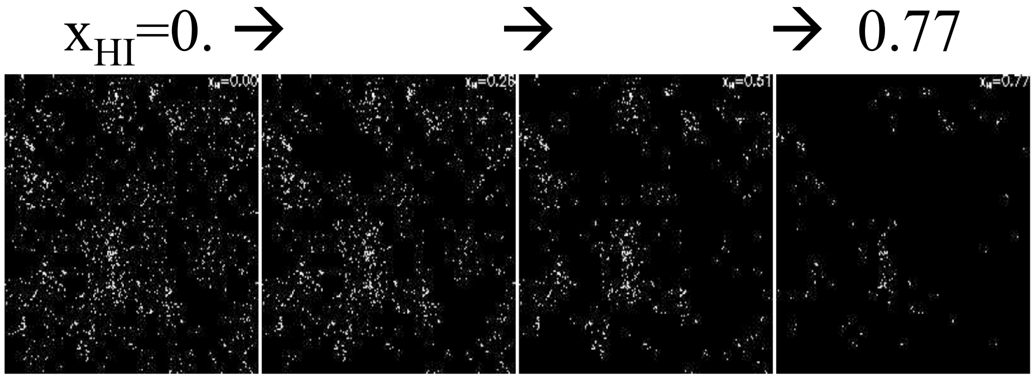
from Bolton & Haehnelt 2007

Constraints (3): Lyα galaxies (LF and clustering evolution)

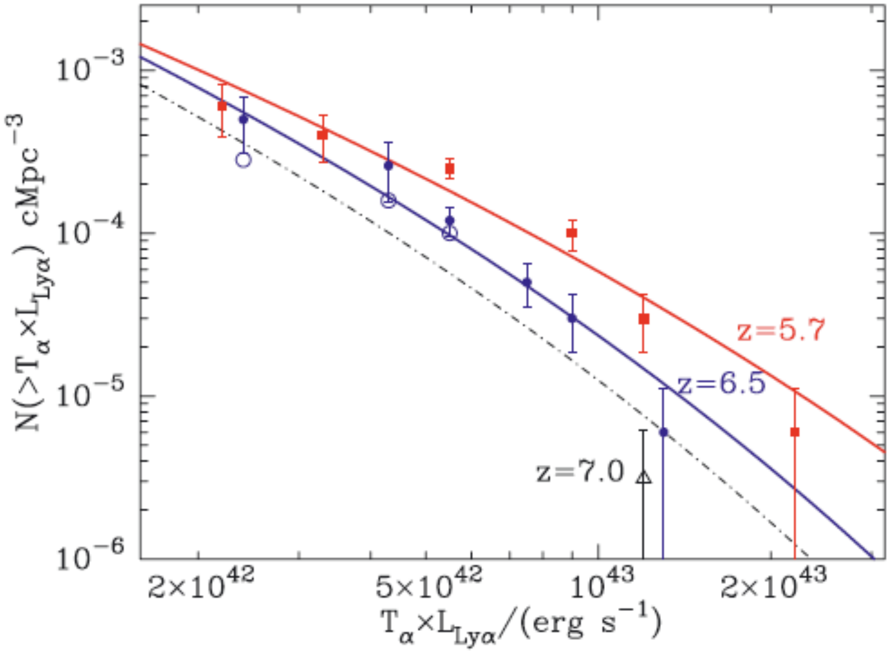
Basic idea:
IGM trasmission changes Lyα galaxies Luminosity Function (Miralda-Escude' 1998) and clustering (McQuinn+ 2007).

Observational results:
Rapid evolution of the LF for z>6 (e.g., Kashikawa+06, Ouchi+08).
Reionization detected? NO clear answer: LF evolution can also be explained by mass function evolution only (Dijkstra+07, see also Mesinger & Furlanetto 2008)

Other challenges:
-> these observables also depends on intrinsic (unknown so far) properties of the sources (e.g., dust; see Dayal+09).
-> clustering analysis requires huge sample (unrealistic for planned near future facilities?).



Mesinger & Furlanetto 2008



Dijkstra et al. 2007

Constraints (4): CMB polarization

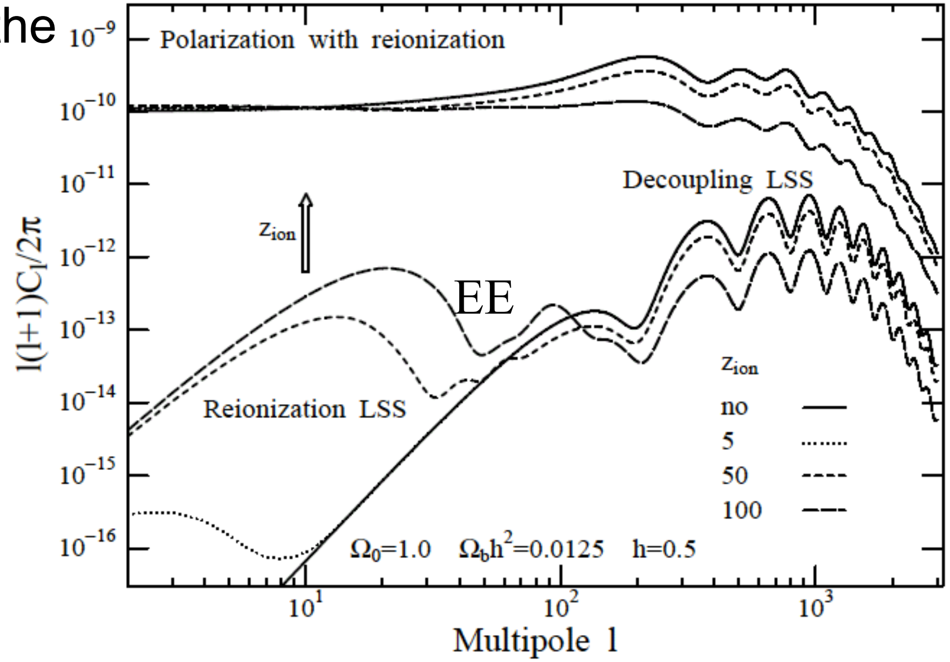
- CMB polarization is generated by electron scattering => the amplitude depends on the Thomson optical depth:

$$\tau(z) = \sigma_T n_{e0} \int_0^z dz' \frac{cdt}{dz'} x_e(z')(1+z')^3$$

which is related to the electron column density:

$$N_e = \tau / \sigma_T = 1.5 \times 10^{23} (\tau / 0.1)\ \mathrm{cm}^{-2}$$

Peak position : $l_{peak} \sim 2(s_0 - s_{ri})/(s_{ri}-s_D) \sim 2(z_r)^{1/2}$
Peak height: $1 - \exp(-\tau_r)$



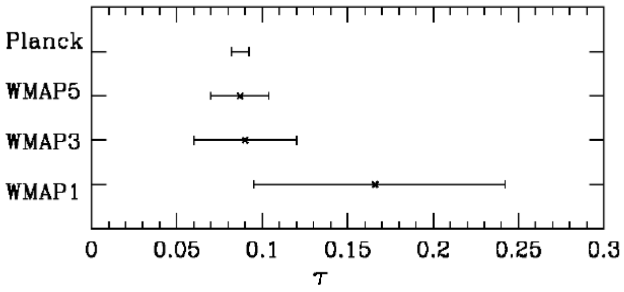
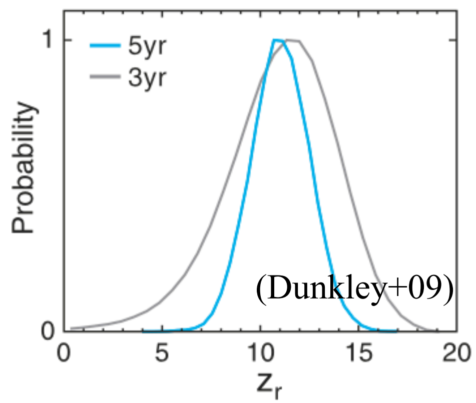


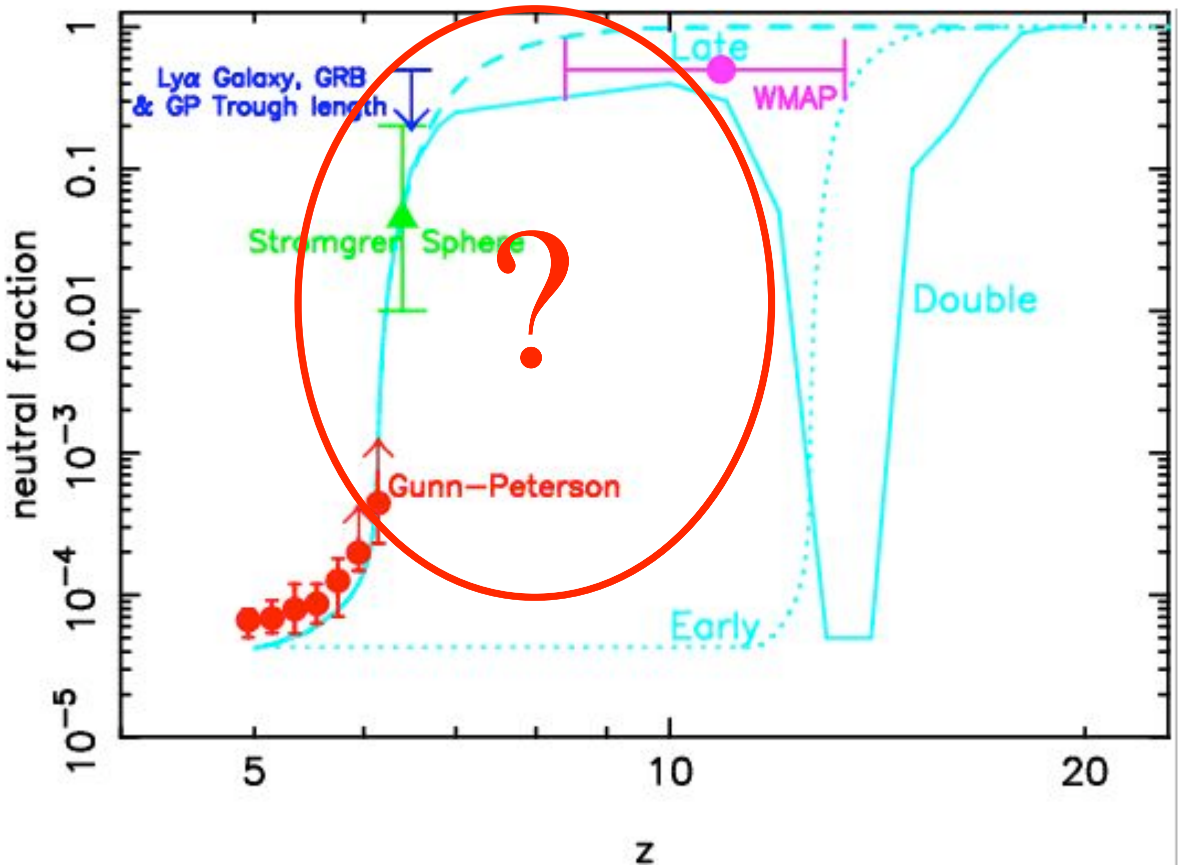
Figure 1. Evolution of WMAP $1-\sigma$ constraints on the optical depth τ_{CMB} and, for comparison, the predicted error for Planck.

BUT: Integrated value. To recover z_r we need to "assume" a reionization history.



A partial list of other constraints:

Lyα damping wings,
IGM temperature at 2<z<5,
Gamma-Ray-Bursts,
...
(Mesinger & Haiman 2004, Theuns+02, Hui & Haiman 2003, Totani+06, …)



Conclusion:
to date, reionization is still a big question mark.

The future is in 21-cm?

expected signal:

$$T_b \approx 23 x_{HI}(1+\delta)\left(\frac{1+z}{10}\right)^{1/2}\left(\frac{T_S - T_{bkg}}{T_S}\right) \mathrm{mK}$$

(at least ~ 4 orders of magnitude smaller than background)

next future: power-spectrum analysis (LOFAR-2010?)

next-next future: direct HI "tomography" (SKA-2020??)

Challenges:
- terrestrial interference
- ionospheric "seeing"
- foregrounds
- instrumental issues

see e.g., Furlanetto+06 and Meiksin 2009 for a review.

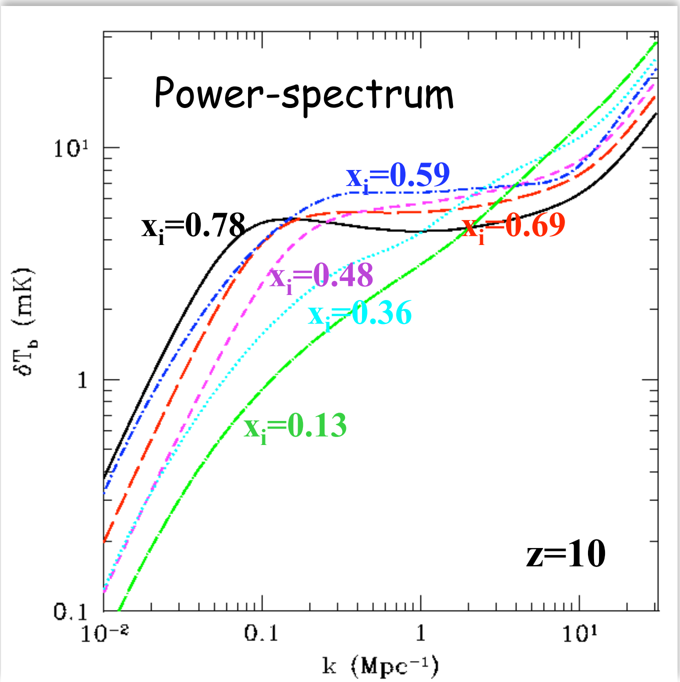
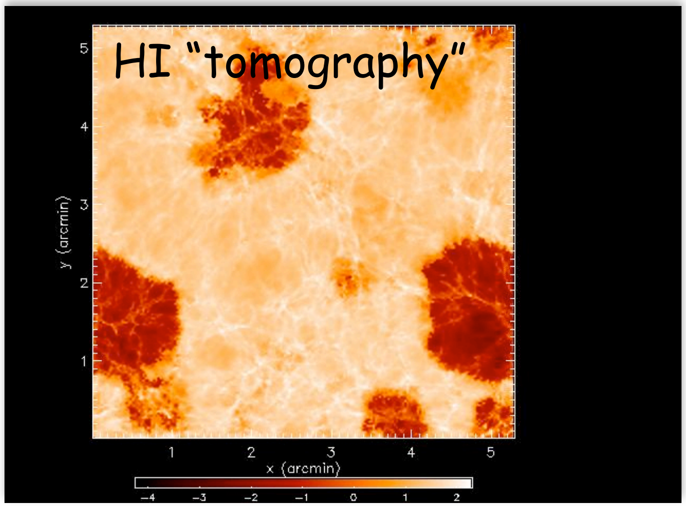
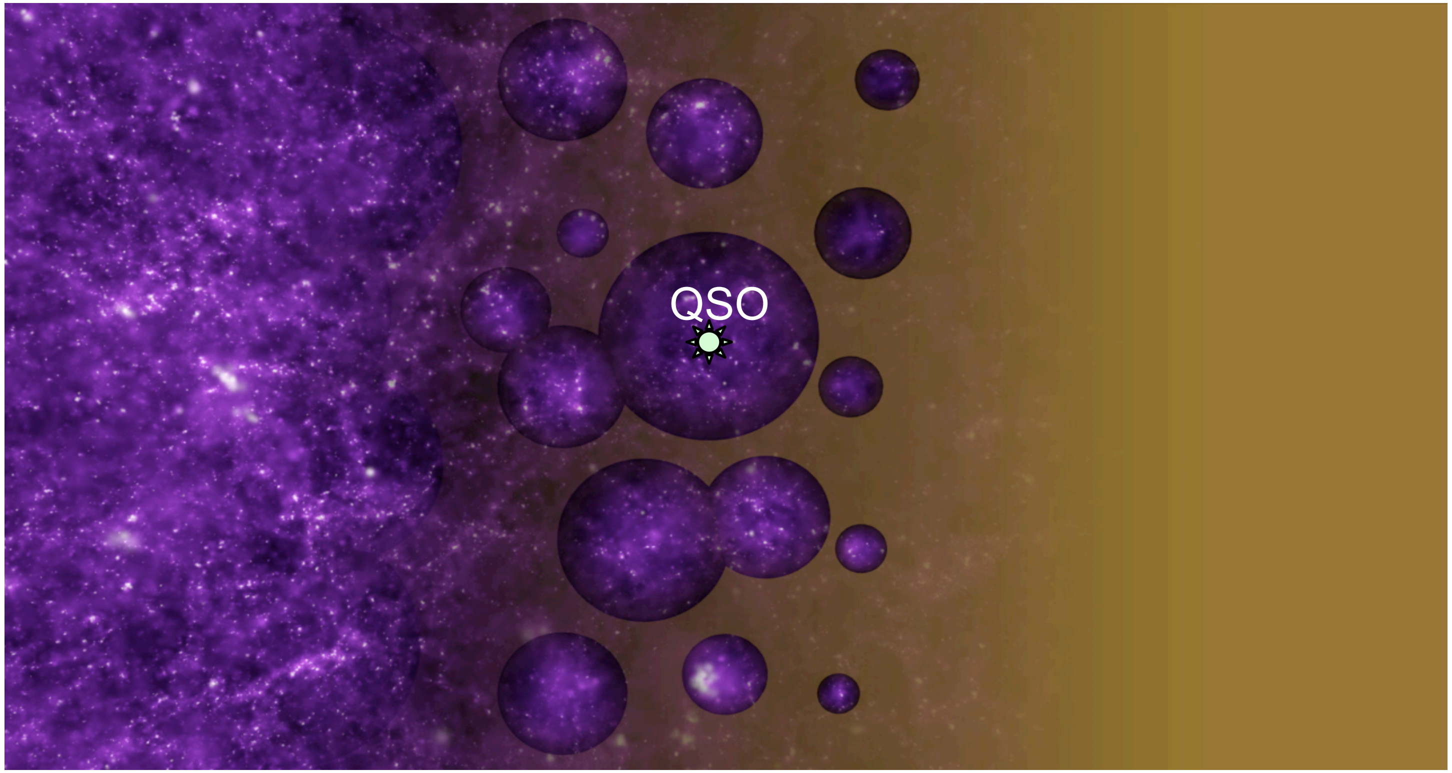


image credits: S. Furlanetto



Alternative (or complementary) approach?

let's try to look the
IGM in Lyα *emission*...



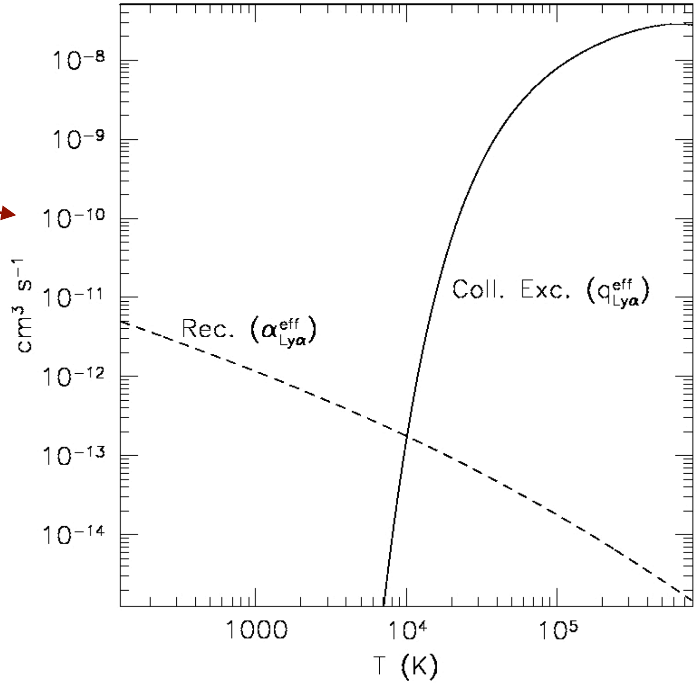
How to map the "bulk" of intergalactic hydrogen during EoR with Lyα emission?

- 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*

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

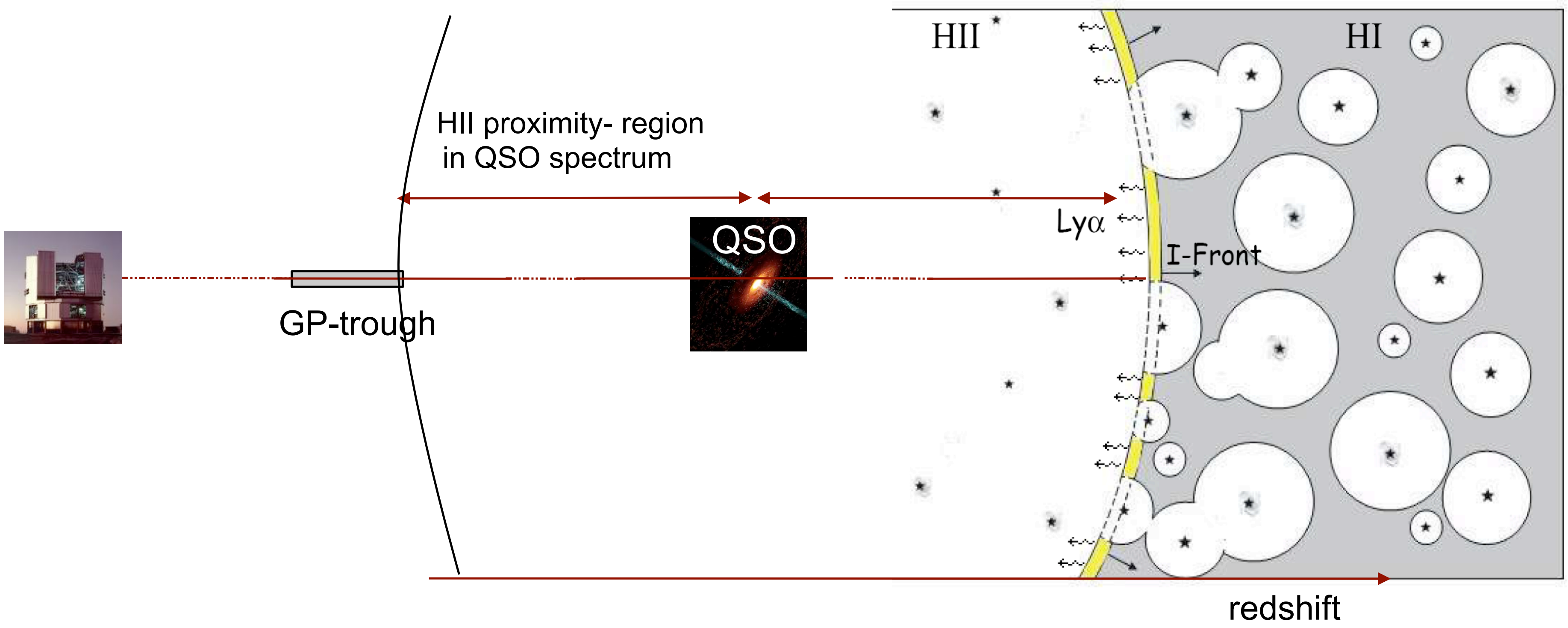


SC, Porciani & Lilly 2008

- 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:

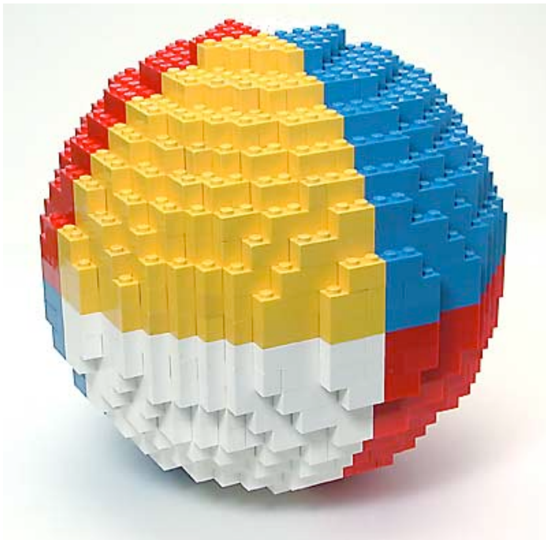
as the I-Front cross the IGM, Lyα photons are produced within the neutral patches via collisional excitations

- 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

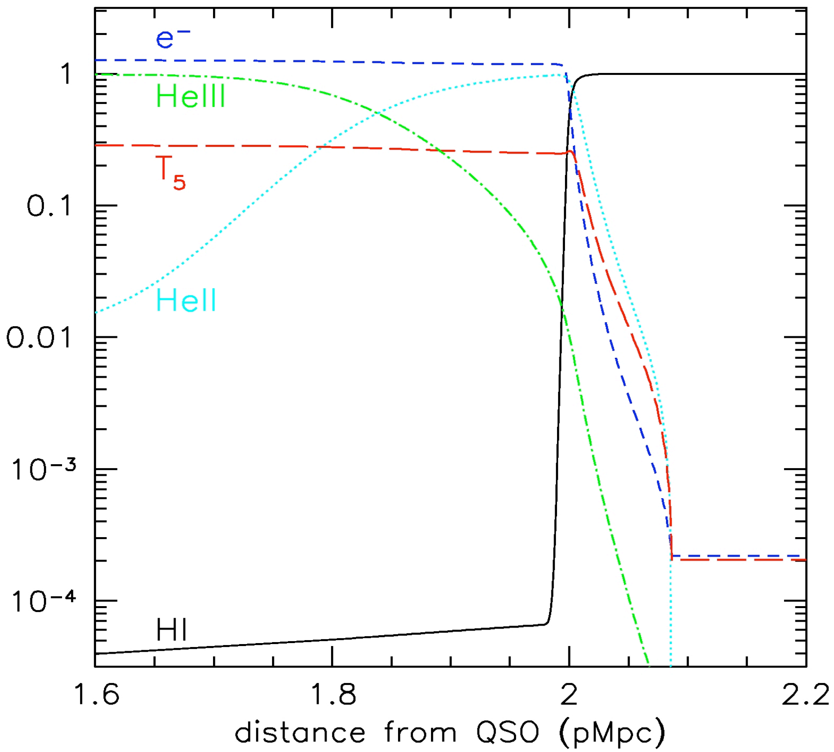
OK… but how bright is this signal?

Let's start with a simple spherical model - a QSO surrounded by an uniform IGM - including continuum and Lyα RT (time-dependent, temperature-dependent, Helium, etc.).

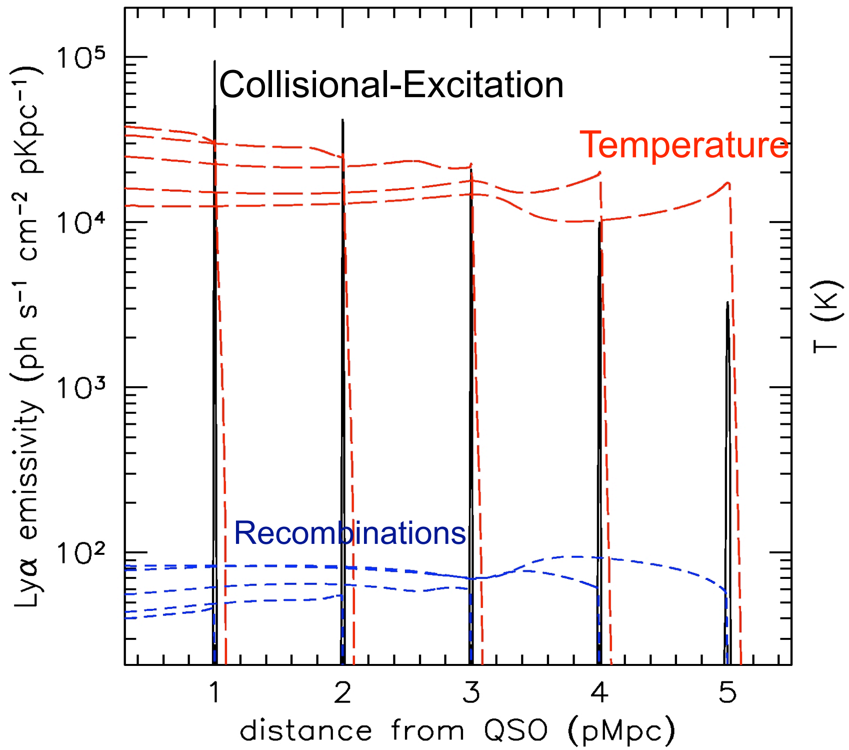


Results: I-front profiles and Lyα emissivity

Example:
I-front density and temperature profiles at t~10Myr



Lyα emissivities (5 different expansion epochs)

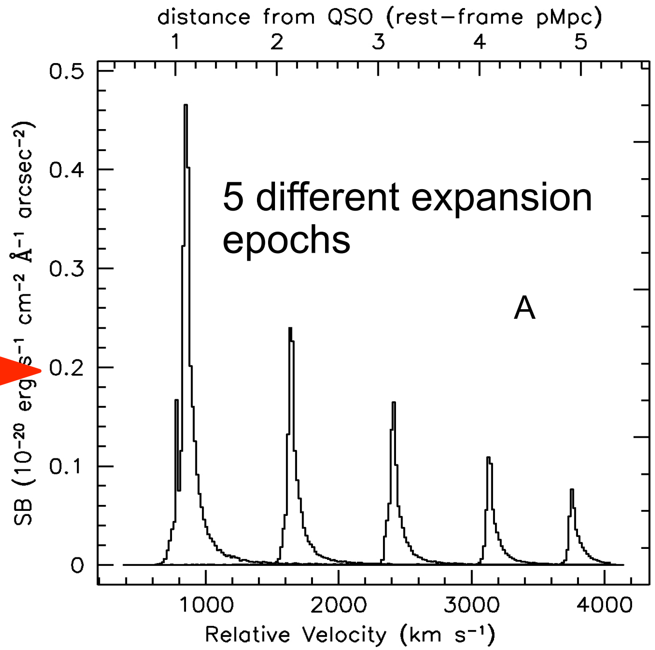


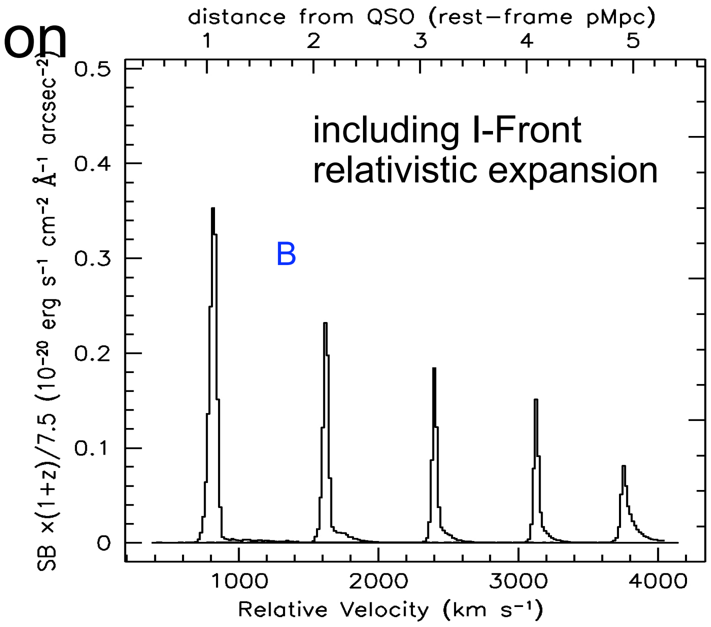
- Simulation parameters:
  - IGM: z_{IN}=6.5 ; C=35
    x_{IN}=1 ; δ=0
  - QSO: $N_{ion}=10^{57}\ s^{-1}$; α=-1.7

SC, Porciani & Lilly 2008

Predicted line shape and SB evolution

UV+Lyα RT

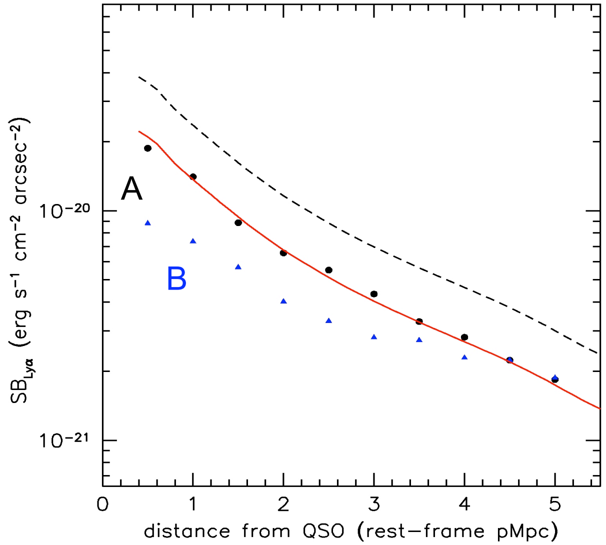




Single line emission (red peak)

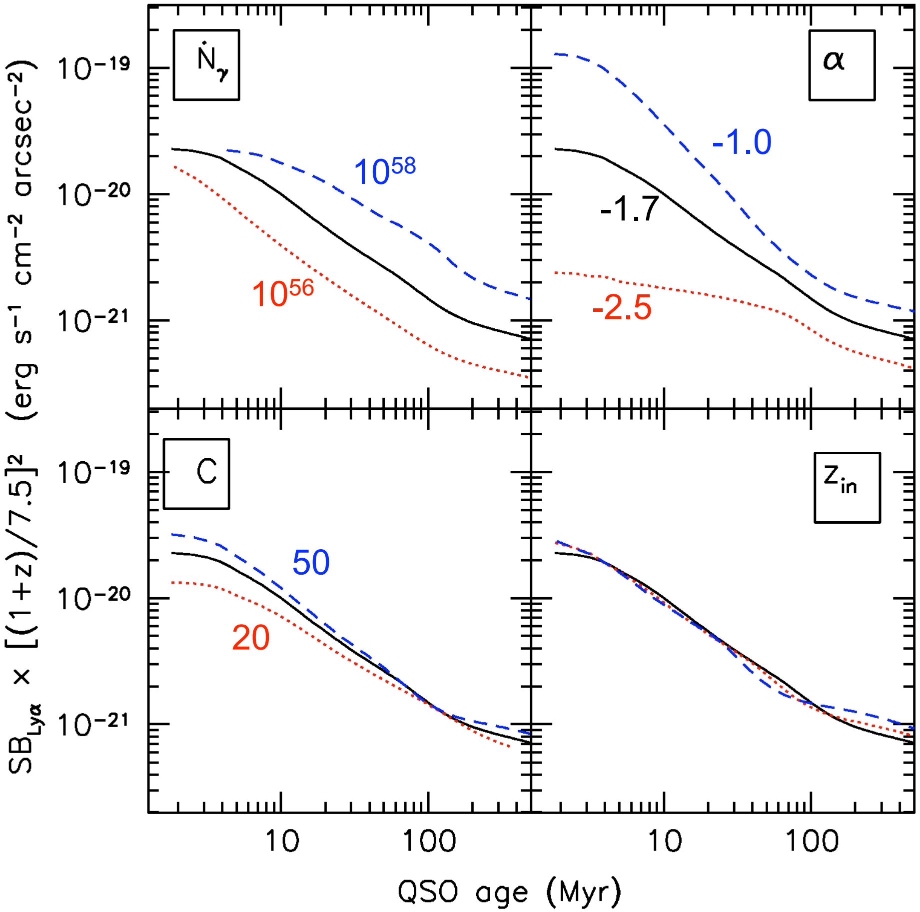
Blue peak scattered by residual HI in the QSO bubble.

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



SC, Porciani & Lilly 2008

Expected Surface Brightness for a large parameter space



Lya SB from a fully neutral patch of IGM, at mean density, 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

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

(for α=-1.7)

SC, Porciani & Lilly 2008

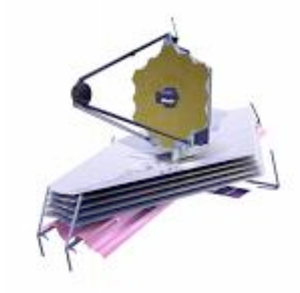
Is it detectable?

- ~ 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 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



But, we should try first to better understand the expected signal…

Towards a more realistic modeling: basic questions

What is the effect of density dishomogeneities?

What is the effect of other (galactic) sources?

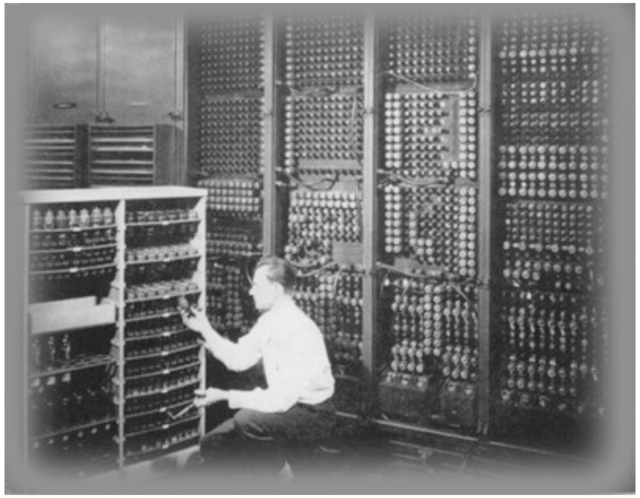
Bright QSO are rare objects and should live in overdense environment. How does this change the expected signal?

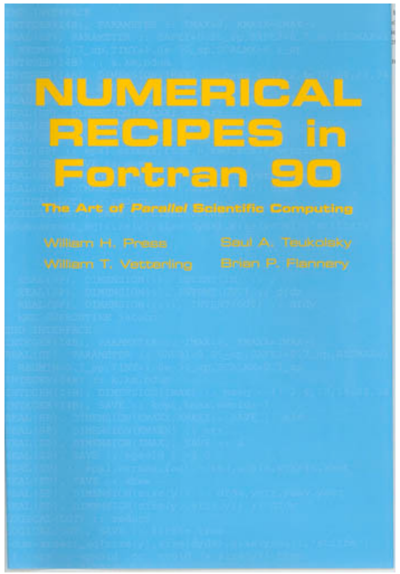
To answer we need: numerical models that follows large volumes (~100Mpc) and, at the same time, resolve the Ionization-fronts (~10Kpc)

→ SOLUTION: Adaptive Mesh Refinement

“Numerical” digression:

building a new adaptive RT method for AMR simulations



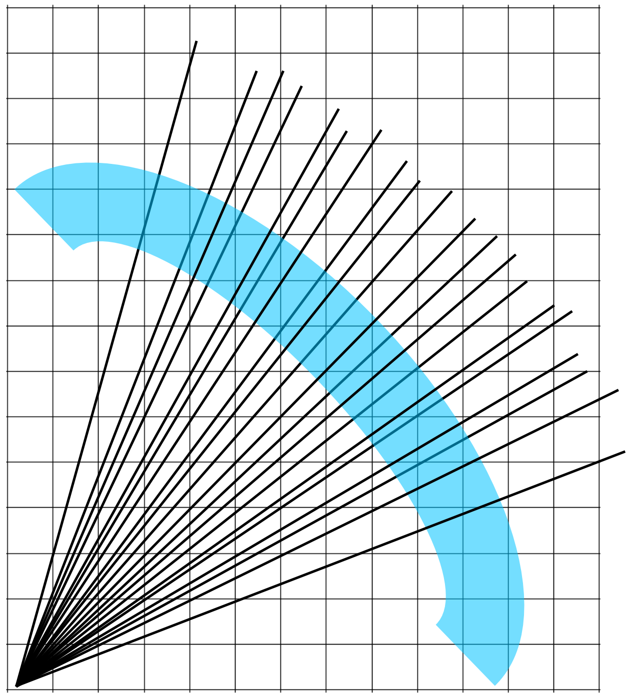


Propagating rays in a grid: "classical" Monte Carlo RT method

- Monte Carlo (MC) sampling of the solid angle (uniform rays or Healpix). Photons deposited while rays propagate through the grid.

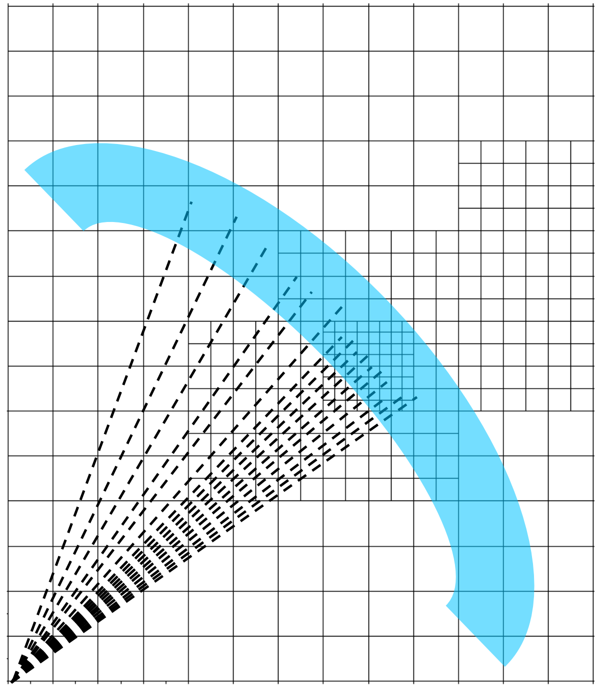
- Algorithm scales with angular resolution (not optimal with multi-meshes; but see also: adaptive ray-splitting).

- Convergence depends on few cells (within the I-front), but *all* the cells have to be sampled (solid-angle constraint).



Propagating rays in multi-grids: "RADAMESH"

- 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 (or cell-by-cell MC)

- We are now 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 $O(N_{front})$.

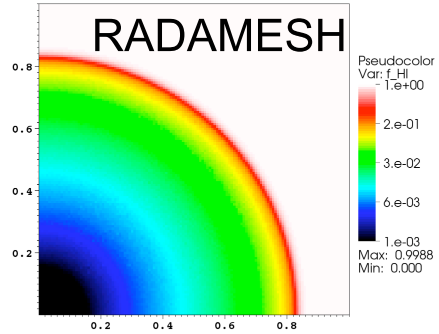
- Adaptive Mesh Refinement on the I-front.

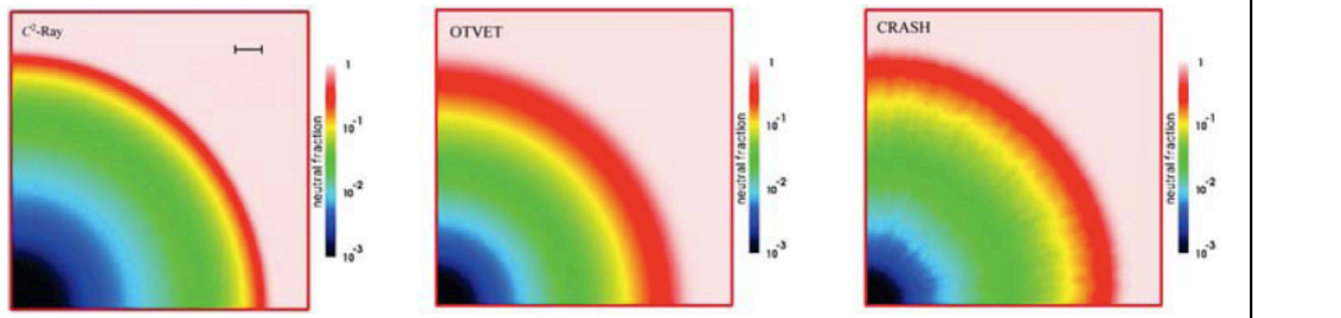
SC & Porciani 2010, in press

Tests (uniform grid):

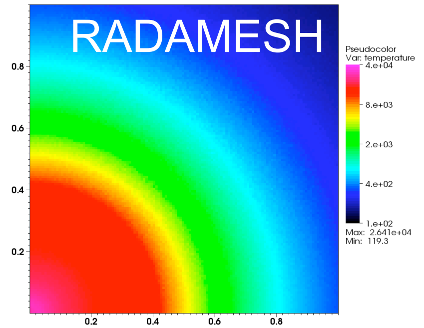
from the Code comparison project (Iliev+06):

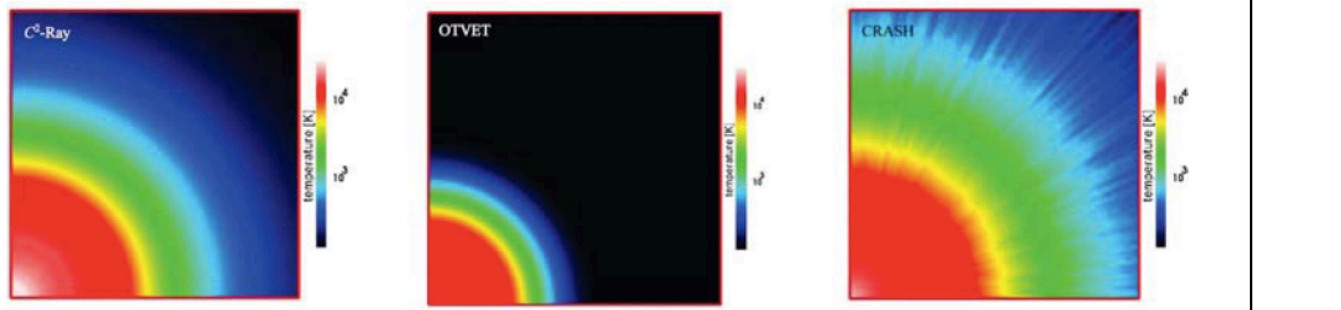
HI fraction



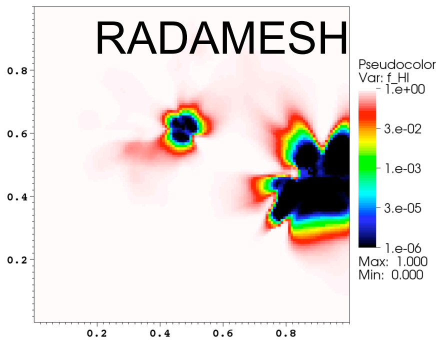


Temperature

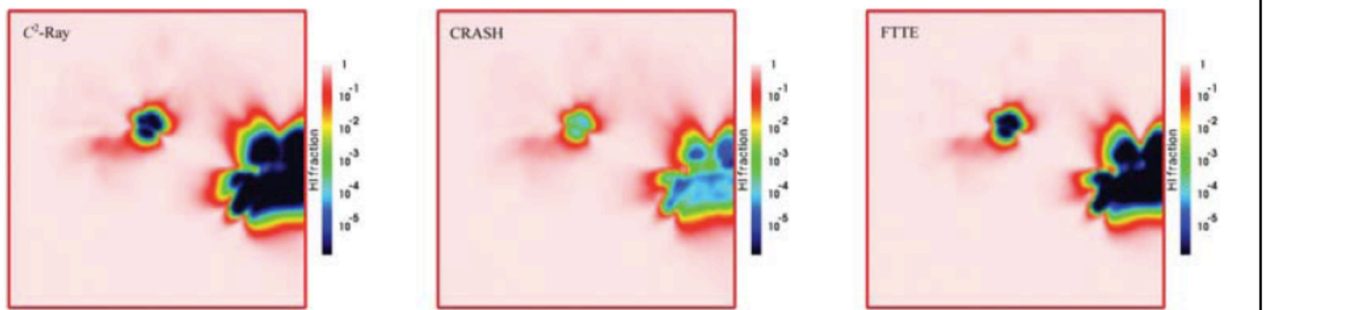




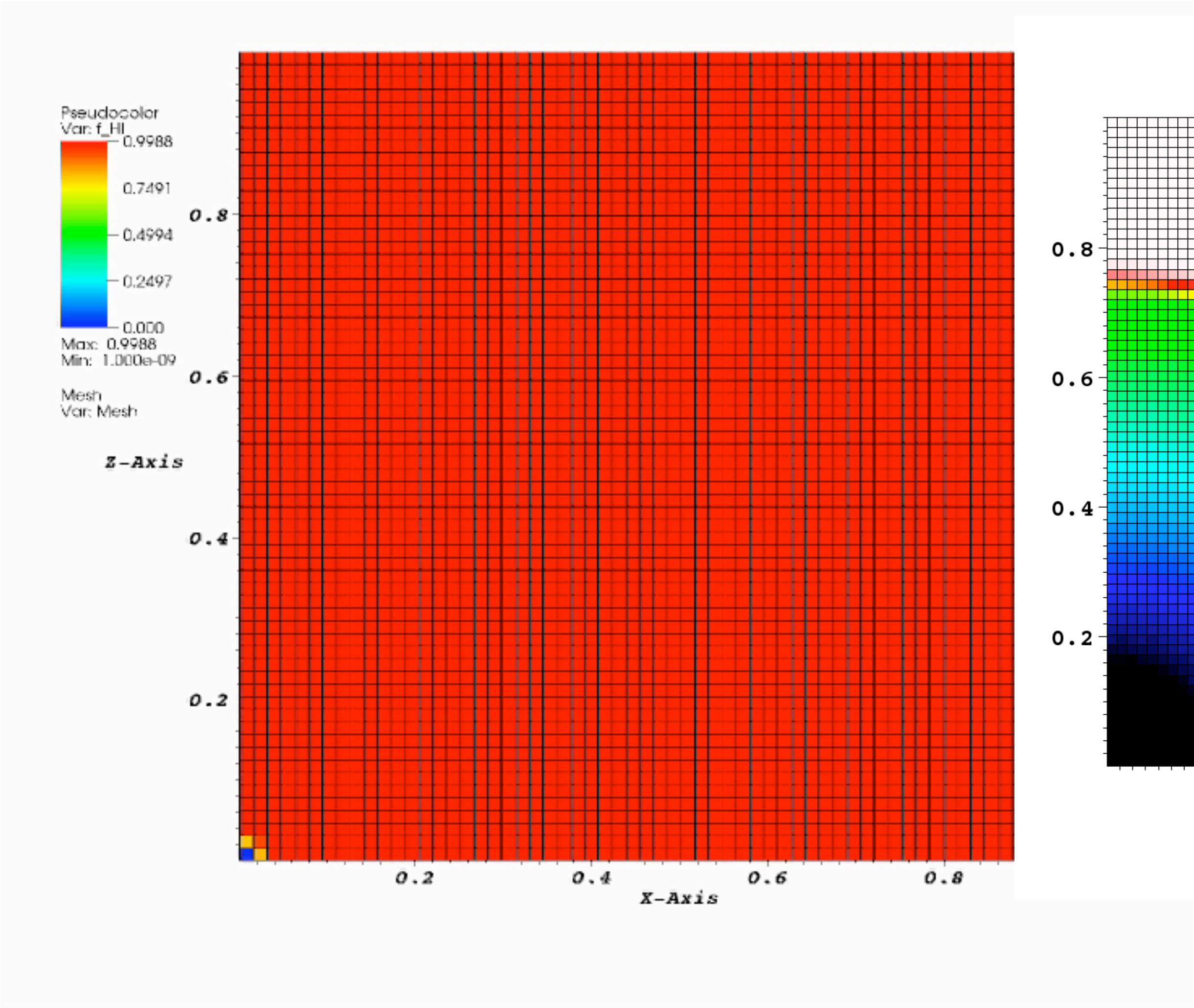
Multi-sources

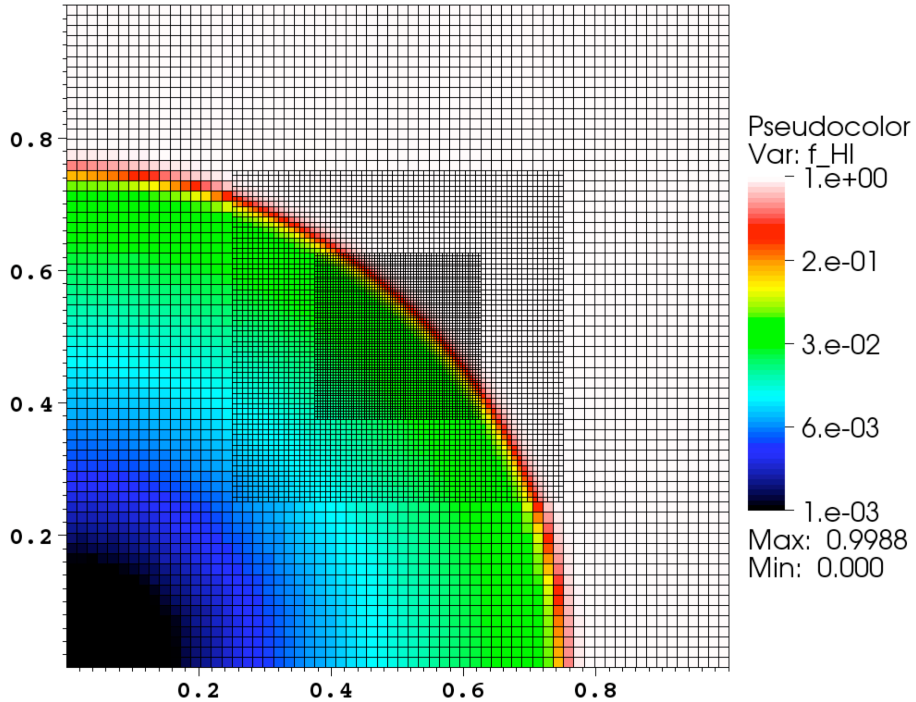


SC & Porciani 2010



Multi-grids and I-front AMR:





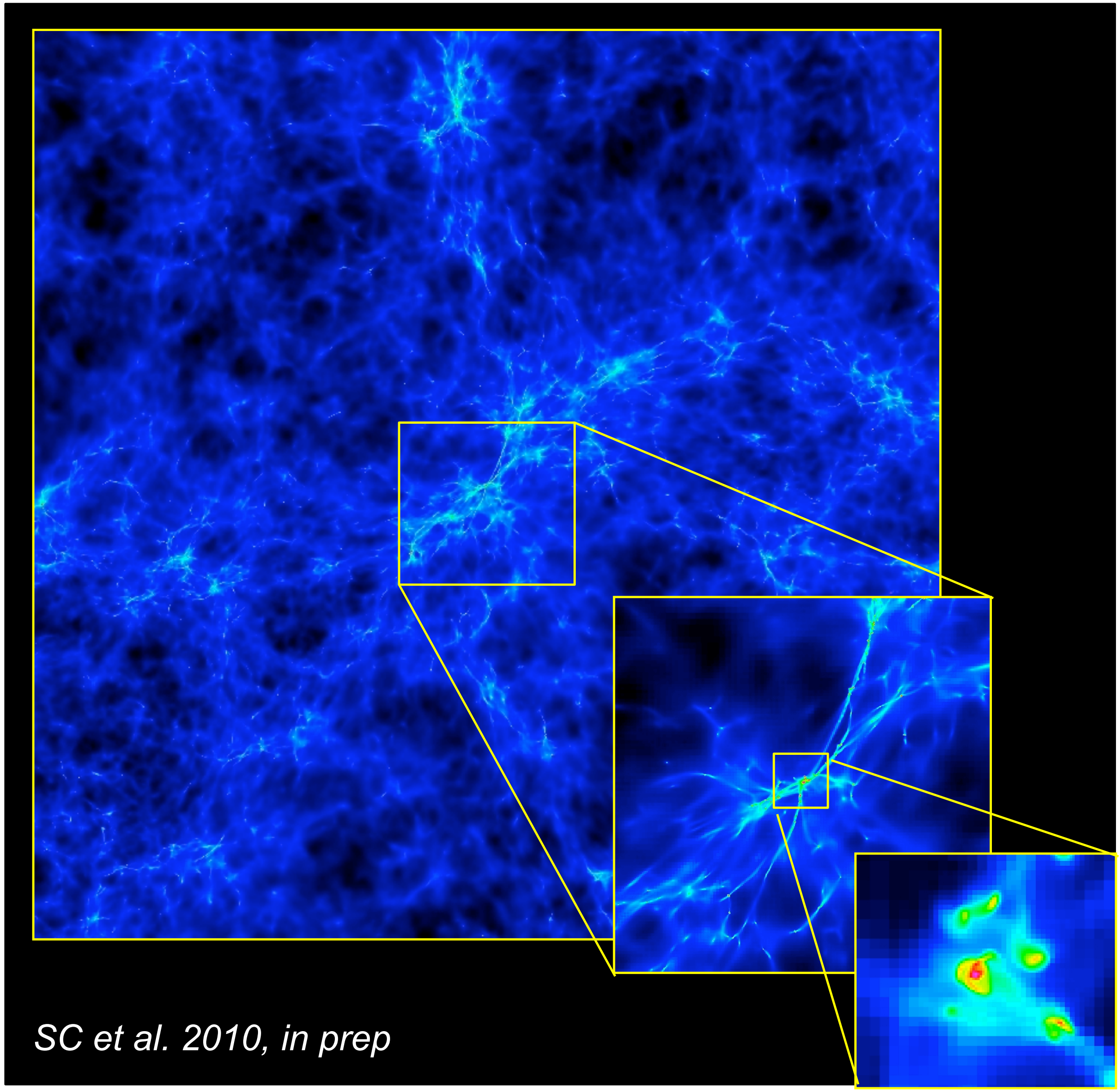
SC & Porciani 2010

We have now the “right” tool…

Let’s improve our previous simple model with the help of large, high-resolution AMR hydro-simulations

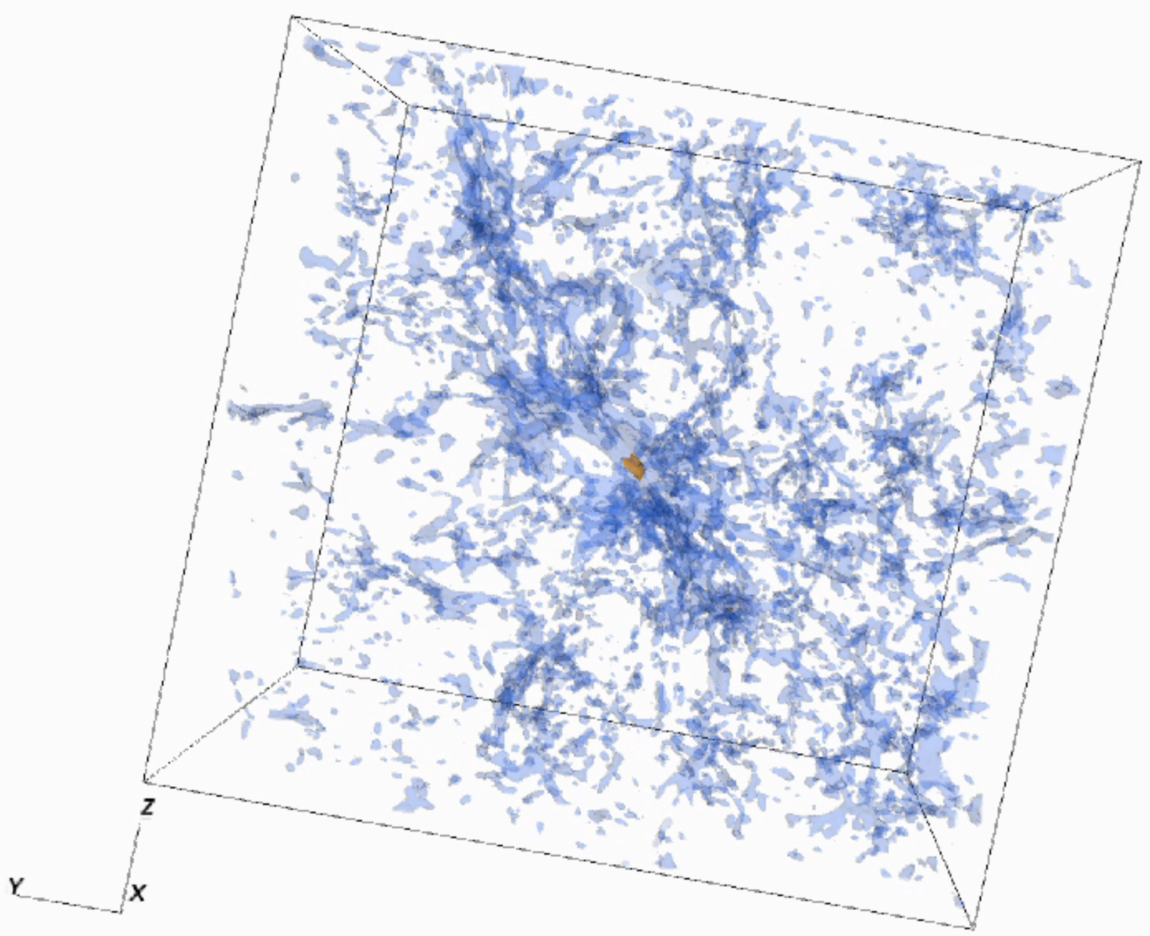
Simulating the near-zone of a bright QSO during the EoR

- 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).

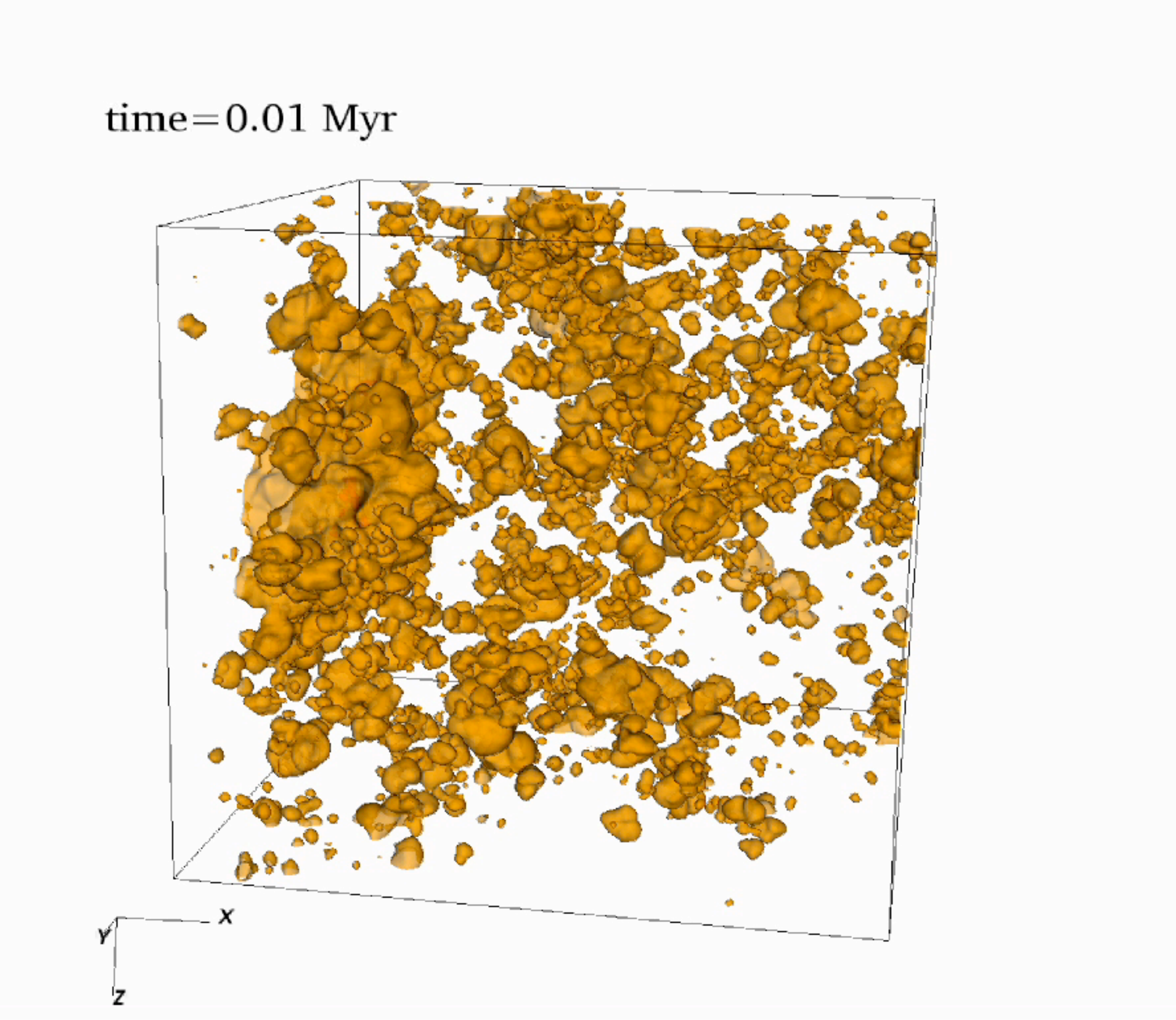


Radiative Transfer Runs: before the QSO turns on

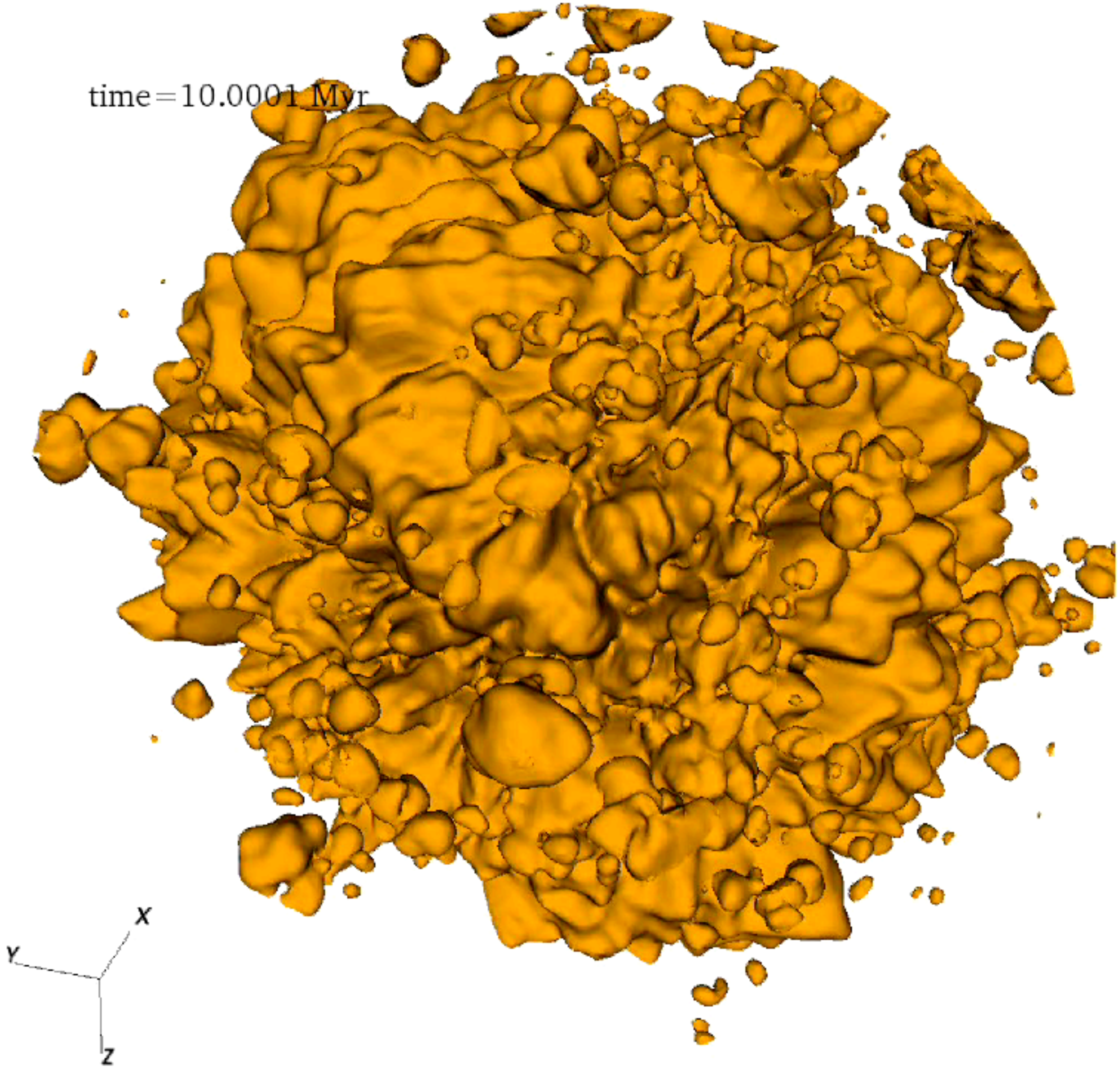
- Performed on an extracted region of size 50 Mpc.
- 256^3 base grid + 5 levels of refinement (effective physical resolution: ~800pc).
- + 3 additional levels on I-fronts
- ~10^4 sources (>10^9 $M_\odot$), PopII spectrum + QSO.
- Including Helium, 70 frequency bins (logarithmically spaced) from 13.6eV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



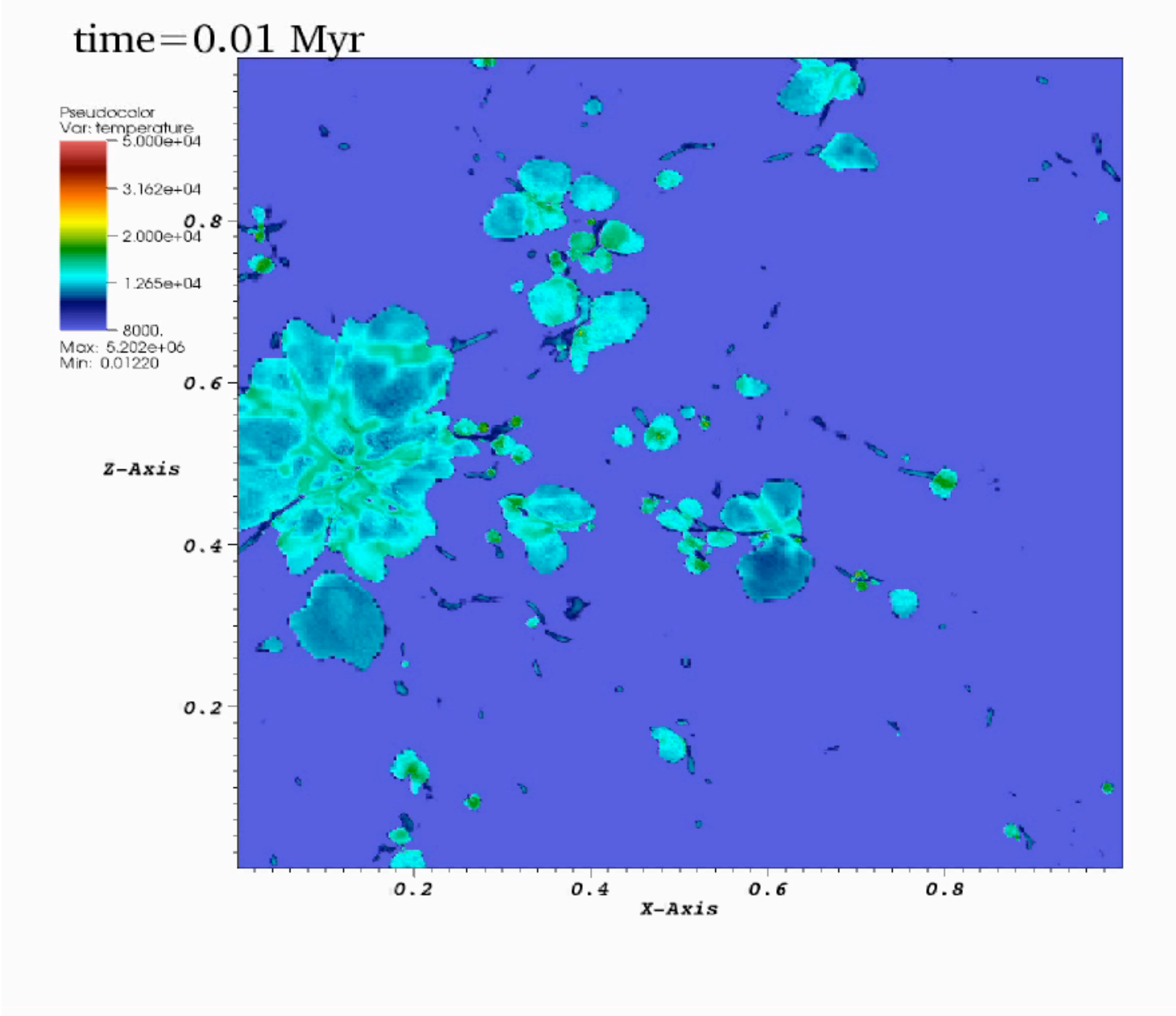
Radiative Transfer Runs: QSO on



A look inside a QSO bubble



The temperature evolution within the near-zone: a thin slice



The temperature within the near-zone: phase diagram

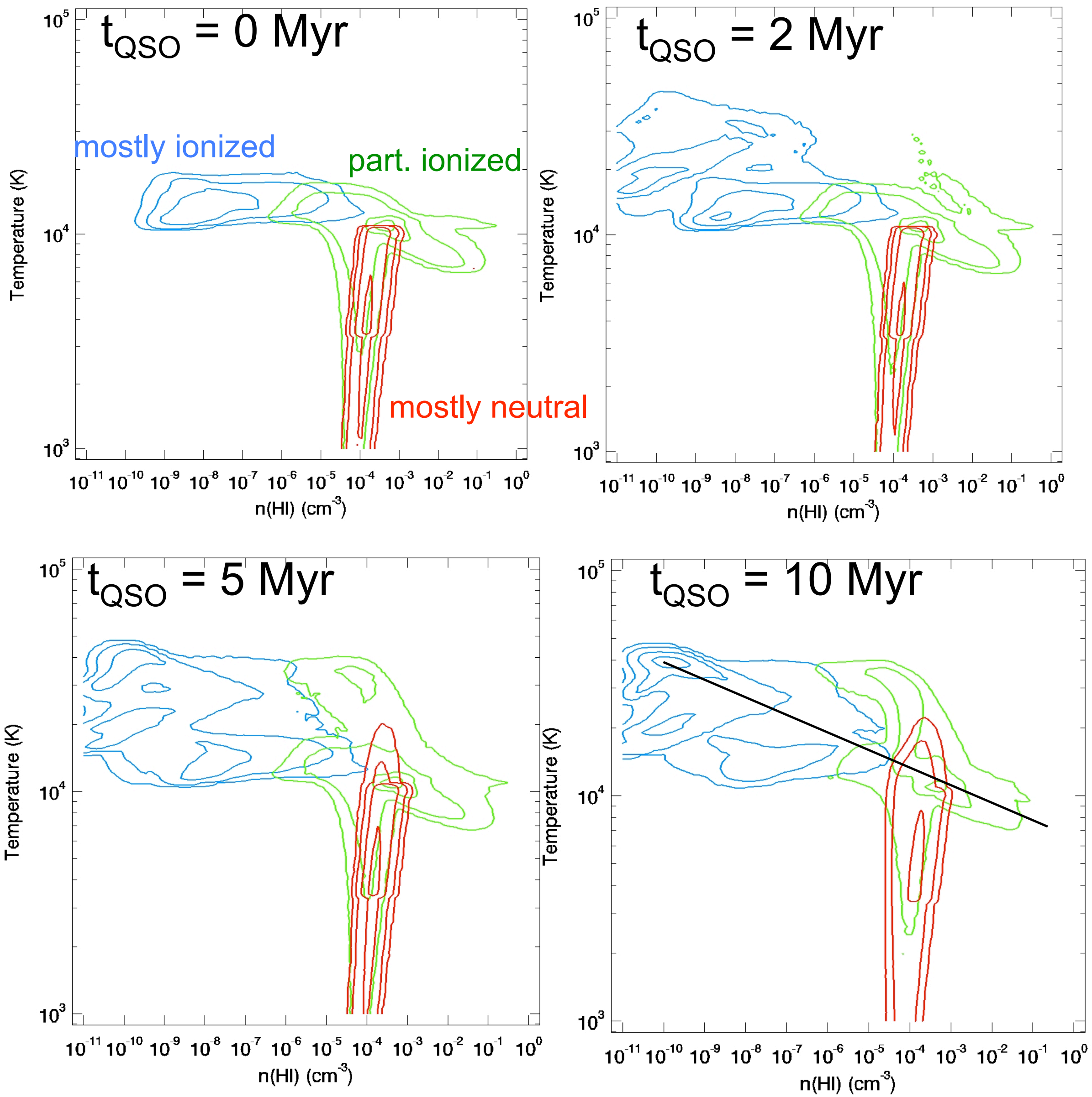
As expected (see e.g., Tittley & Meiksin07): bimodal temperature distribution within the qso near-zone:

- Hot regions: H+HeI+HeII ionized by the QSO

- Warm regions: H+HeI ionized by local sources. HeII ionized by the QSO

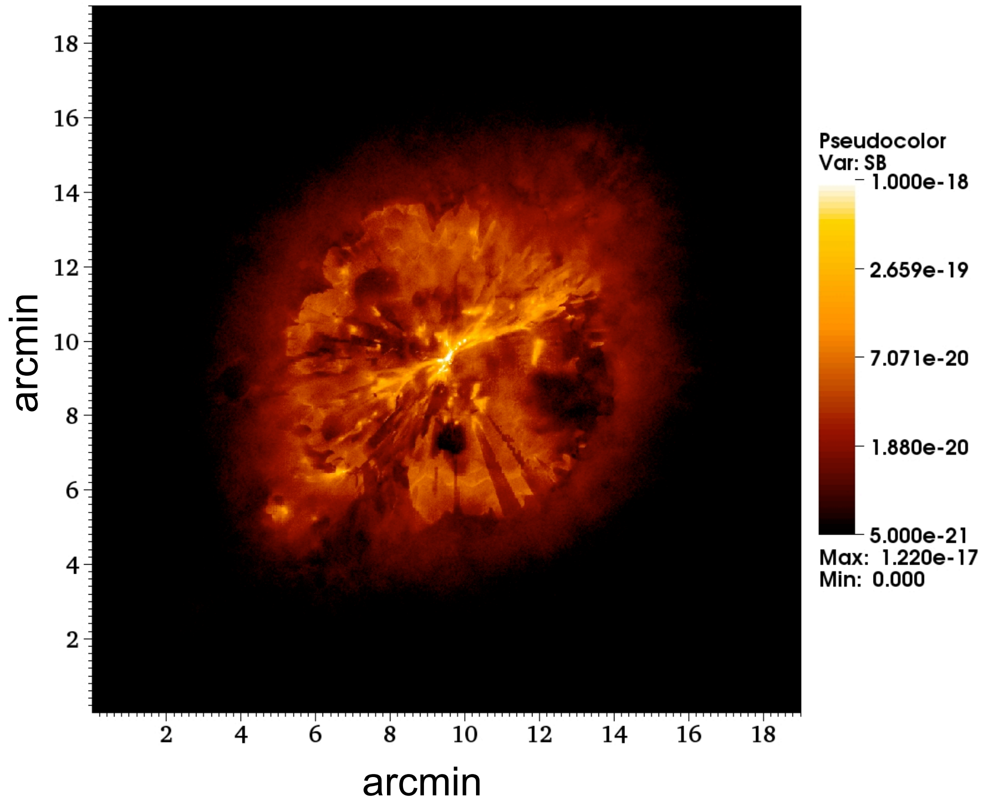
For a given spectrum, overall temperatures are mostly determined by cooling processes within the I-front.

SC et al. 2010, in prep

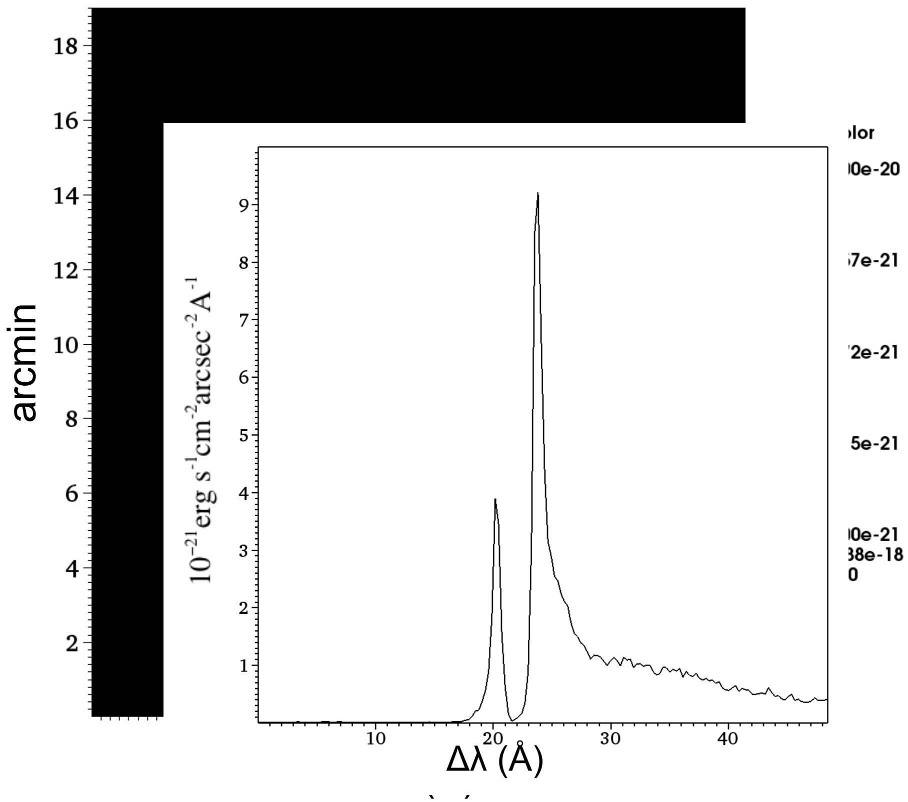


Lyα RT (preliminary) results:

Narrow Band Image



2D-spectrum



SC et al. 2010, in prep

Summary

- We discussed Fluorescent Lyα emission as a way to detect HI self-shielded clouds in the high-z IGM before substantial star-formation takes place. We shown theoretical models and first observational results: 13 fluorescent candidates surrounding a bright QSO at z=3.

- 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

- We calculated the observed properties of this emission simulating the near zone of high-z QSO during the EoR with hydro-simulation and a new adaptive Radiative Transfer code (RADAMESH).

- 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.

BONUS TRACK

Local photo-ionization flux, gas cooling
and galaxy formation

SC, 2010, MNRAS, 403, L16

Evolution of the observed Star Formation Rates (SFR)

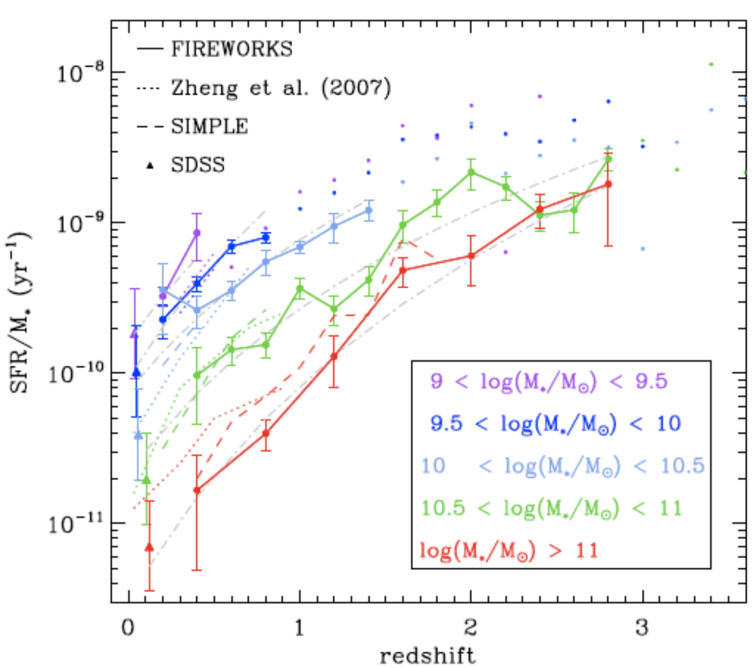


Figure 2. sSFR vs. redshift in different mass bins. Filled, connected circles are the FIREWORKS results, dots show where mass incompleteness starts to play a role. The error bars represent bootstrap errors. The dashed and dotted lines represent results from Damen et al. (2009) and Zheng et al. (2007), respectively. SDSS data were used to include a local data point (triangles). Linear fits to the FIREWORKS results are displayed using gray dash-dotted lines. The fits show that the SSFR increases with z at a rate that appears independent of mass.

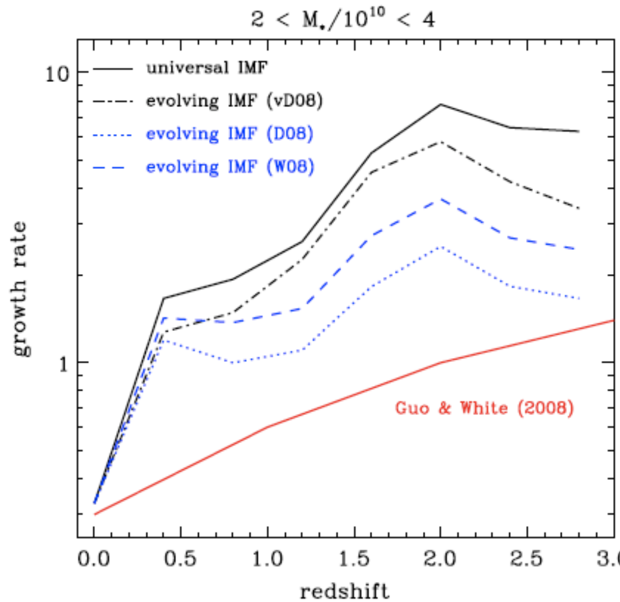


Figure 5. Dimensionless growth rate as a function of redshift for galaxies with masses ranging from $2 \times 10^{10}\ M_\odot$ to $4 \times 10^{10}\ M_\odot$. The black solid line shows the FIREWORKS result when a Kroupa (2001) IMF is applied. The dash-dotted lines, dashed, and dotted lines show the FIREWORKS growth rate based on an evolving IMF, according to the parameterization of van Dokkum (2008, vD08), Davé (2008, D08), and Wilkins et al. (2008, W08), respectively. The corrected values based on the IMFs of D08 and W08 (in blue) are lower limits, since they do not include the effect an evolving IMF has on the stellar mass. Introducing a time-dependent IMF decreases the discrepancy between the observations and the simulated results from Guo & White (2008; red solid line), but it does not completely resolve it. In particular, the steep increase in observed growth rate at low redshift ($z = 0$–1) is still evident.

Damen et al. 2009

How to obtain the steep decline at low z?

Two possibilities: 1) remove the gas from the galaxy (SN feedback)
2) reduce/stop cooling gas accretion from halo

Solution (1): requires to fix unconstrained physical parameters (winds, mass loading factor, etc.) and fine tuning. Not able to explain a large range of observations (e.g., sSFR-M_*, see Bouche'+10).

Solution (2): cooling gas accretion is governed by "simple" atomic physics, ions abundances and gas temperature.

➡ basic idea (Efstathiou 1992): every process that is able to change cooling ions abundances is able to change cooling gas accretion.
e.g., UV background suppresses H+He cooling and thus the formation of low mass haloes with T_vir<few times 10^4 K.

What about a "local" photo-ionization background and the cooling in more massive haloes (also due to metal cooling)?

The observed relation between Star Formation activity and Soft X-ray emission: some examples

Strickland+04

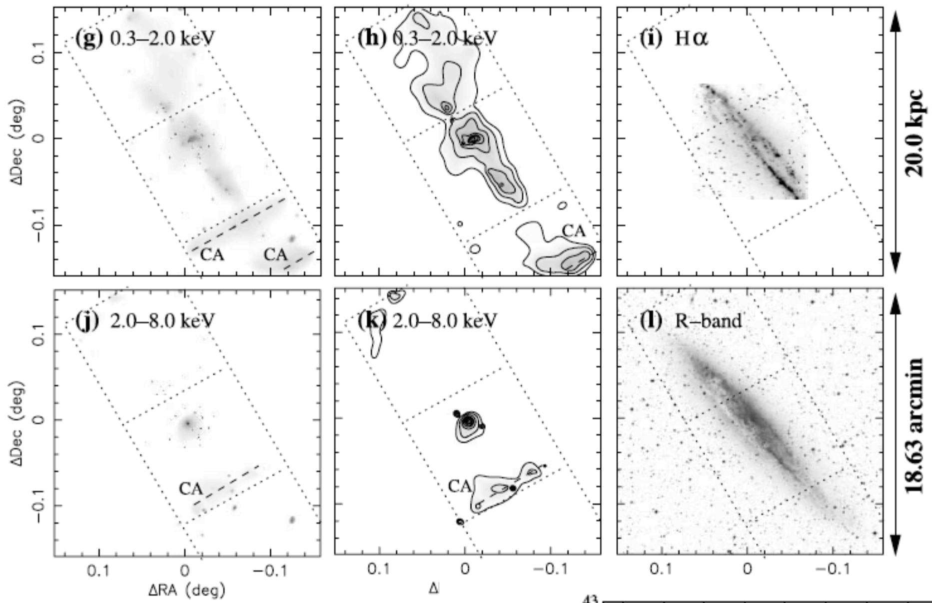
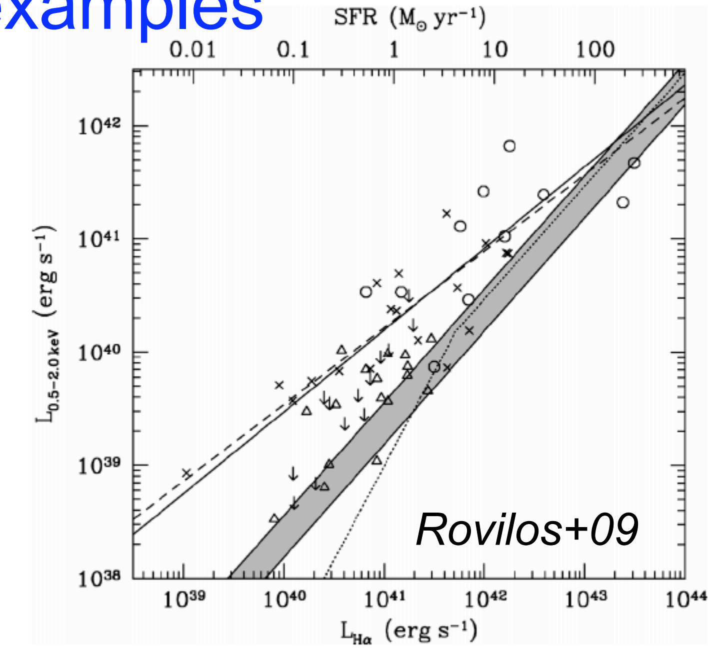


FIG. 9.—*Chandra* X-ray and optical images of NGC 4945. The meaning c
described in Fig. 2.



Mas-Hesse+07

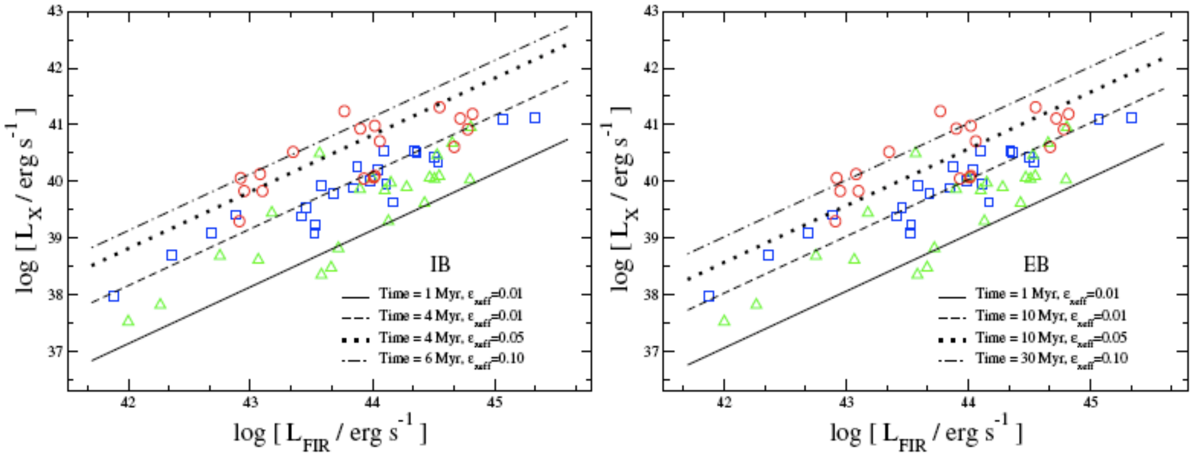
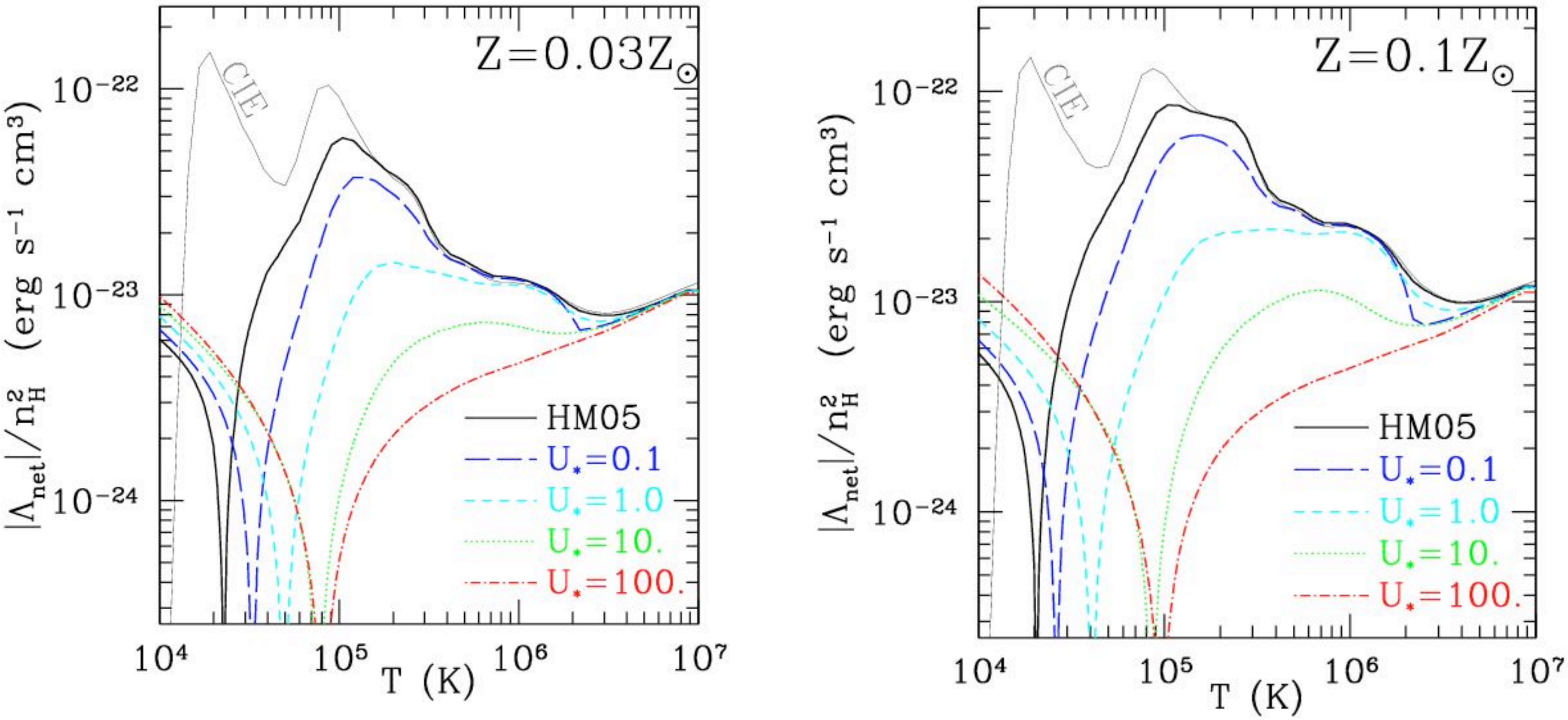


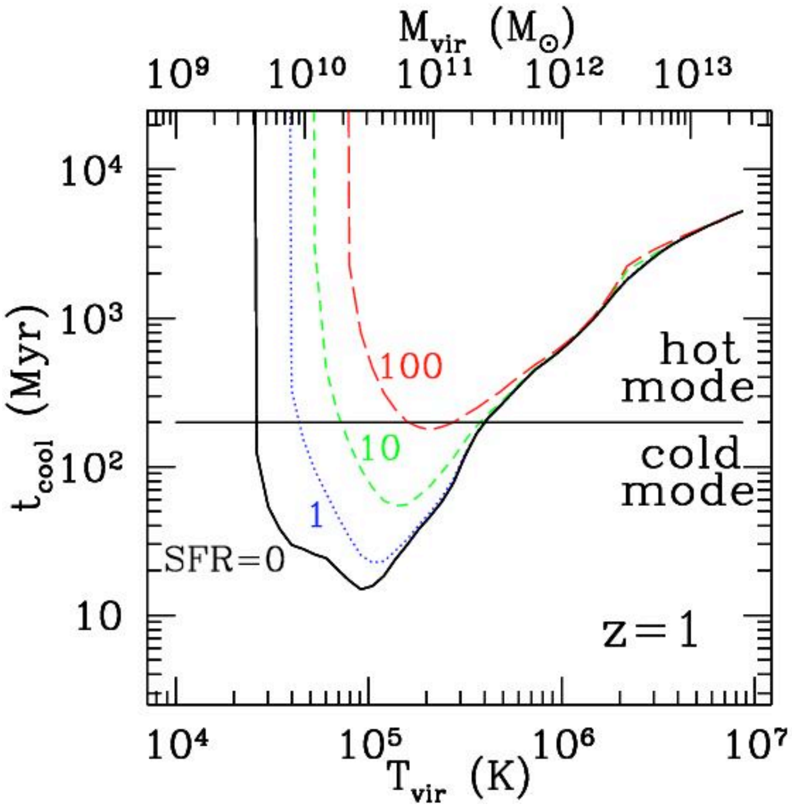
Fig. 6. L_{softX} vs. L_{FIR} for the RCS03 (squares), TUL06 (triangles) and ROSA07 (circles) samples. In the *left panel* we have overplotted the correlation lines corresponding to the L_{softX}/L_{FIR} ratios predicted by IB models for different ages and ϵ_{xeff} values. The *right panel* shows the corresponding predictions for EB models.

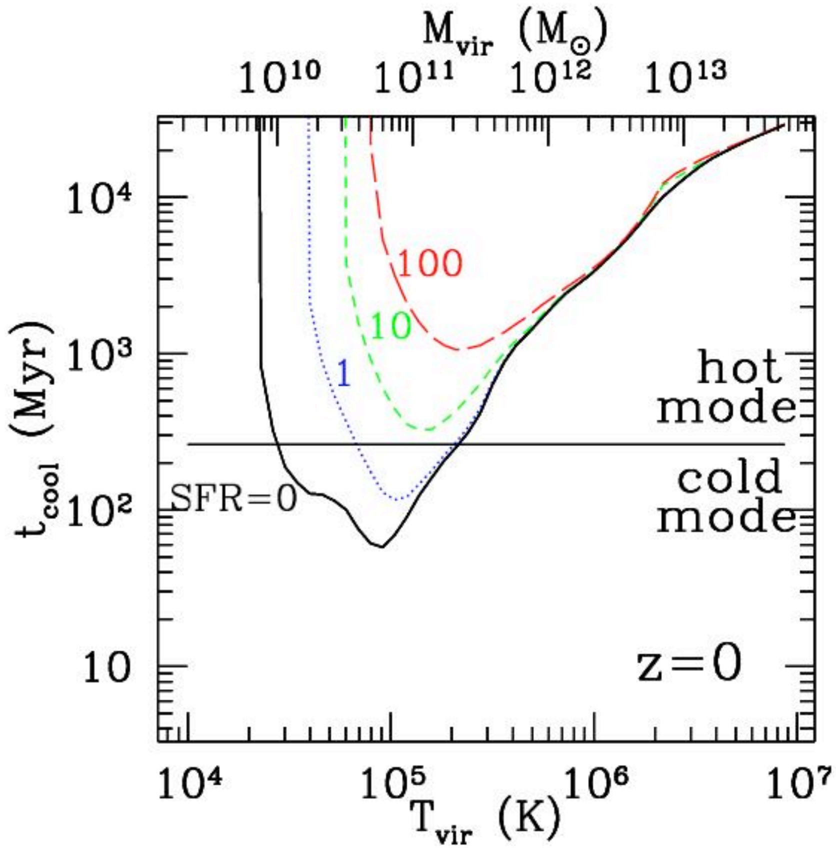
Effect on the Cooling rate of circum-galactic gas (CLOUDY models)



SC 2010

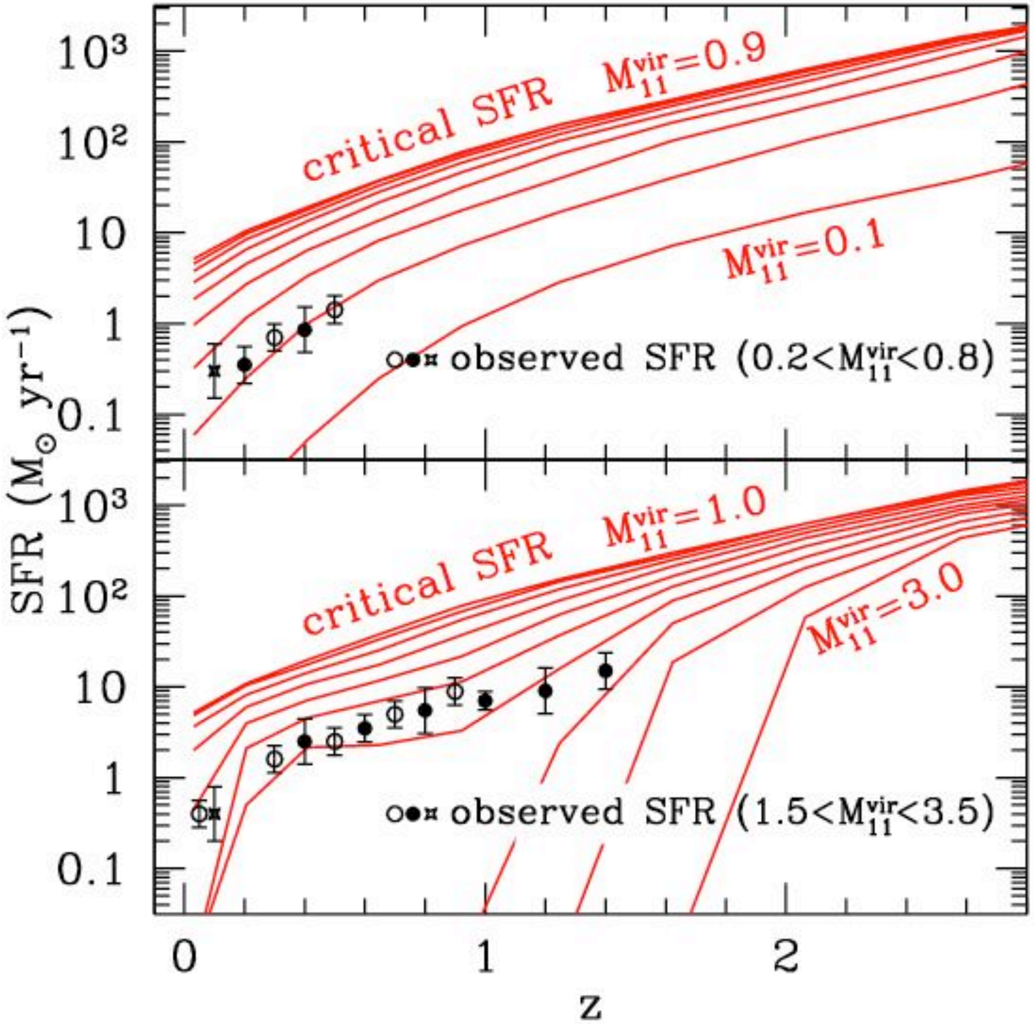
Effect on the Cooling time: hot-mode/cold-mode transition



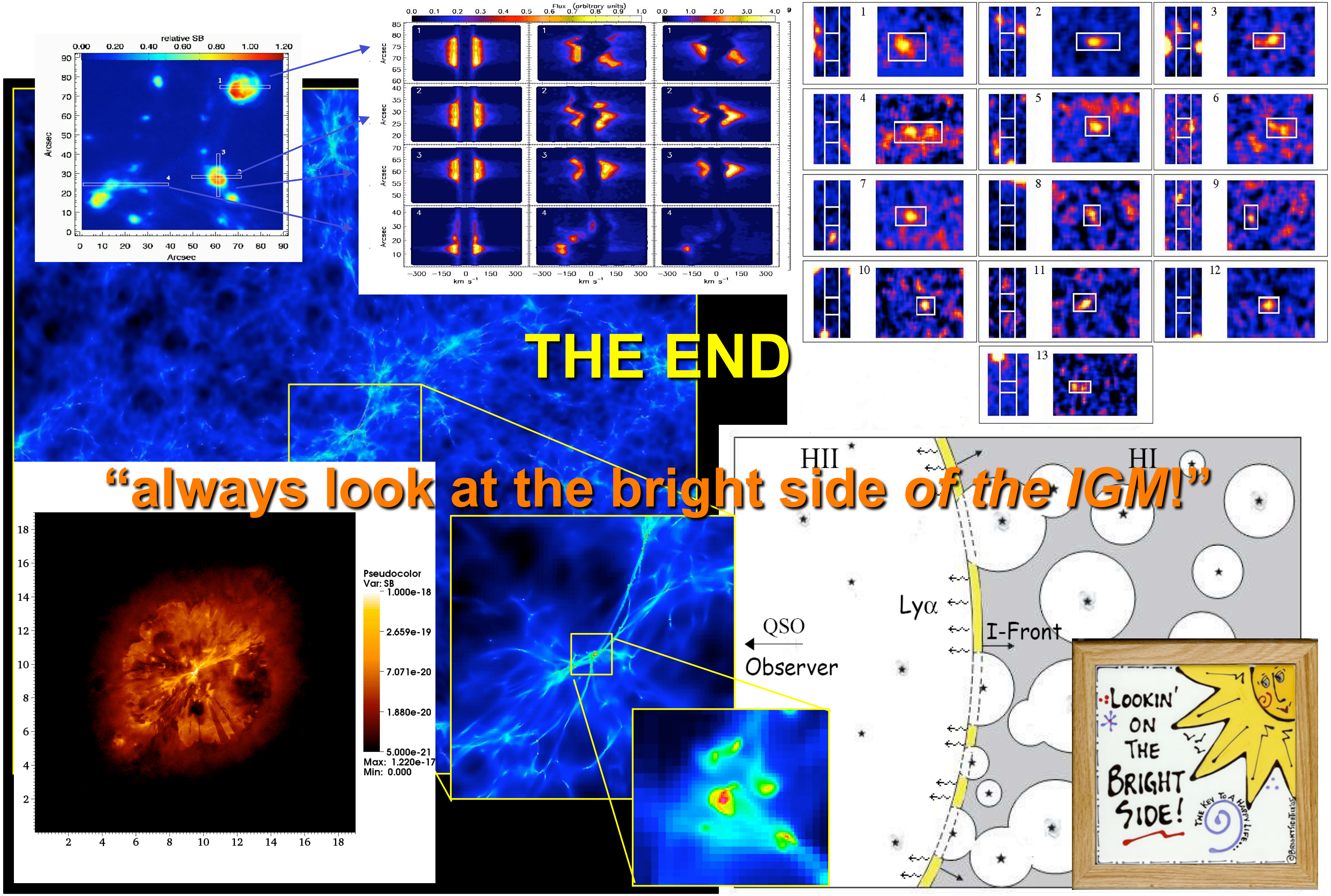


SC 2010

Implications on the evolution of the SFR



SC 2010


THE END
"always look at the bright side of the IGM!"
relative SB
Arcsec
Flux (arbitrary units)
km s⁻¹
Pseudocolor
Var: SB
1.000e-18
2.659e-19
7.071e-20
1.880e-20
5.000e-21
Max: 1.220e-17
Min: 0.000
HII
HI
Lyα
I-Front
QSO
Observer
LOOKIN' ON THE BRIGHT SIDE!
THE KEY TO A HAPPY LIFE...