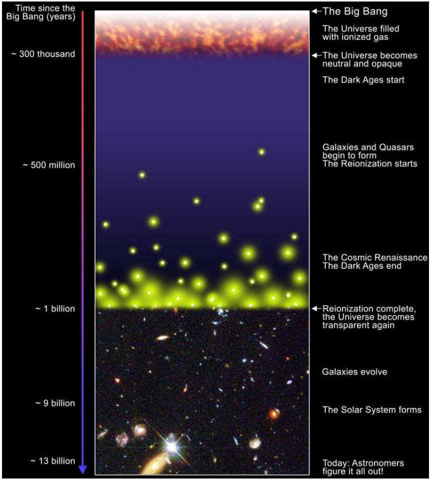
# Reionization and environments of high redshift QSOs

**Girish Kulkarni**

Harish-Chandra Research Institute, Allahabad

Cosmological Reionization – February 18, 2009

# Motivation




- Study reionization in overdense regions at high redshift.
- Biased regions have more sources but also more recombinations and enhanced radiative feedback.
- Number of objects seen in these regions promises to be an independent probe of reionization.

(Image: George Djorgovski)

# Outline

1. Reionization Model: intergalactic medium (IGM), sources and sinks, peculiarities.

2. Reionization in Quasar Environments: assigning mass to quasars, biased reionization, effect on observations.

# Model for Reionization

- We remain interested in semi-analytic models of thermal and ionization history because full numerical simulations are expensive and have resolution limits.

  'It is better to be vaguely right than exactly wrong.' (Carveth Read, 1908.)

- Our model treats IGM as an evolving two-phase medium with sources and sinks of radiation.

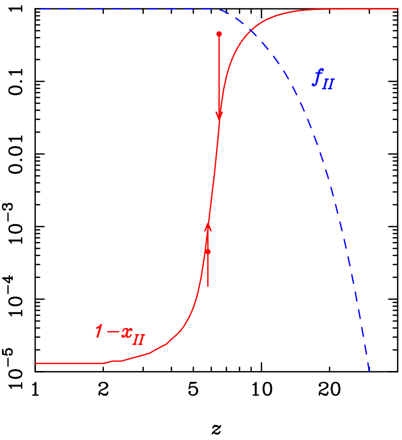
  This model does not assume (1) local absorption of radiation and (2) photoionization equilibrium.

- This model includes (1) gravitational collapse and virialization, (2) non-equilibrium atomic (and molecular) physics of hydrogen, (2) heating and ionization by UV photons, (3) cooling, (4) star formation, (5) clumping, and (7) feedback.

- This model *neglects* (1) spatial inhomogeneities, (2) frequency evolution of spectra, and (3) helium, dust, etc.

- Once background cosmology and power spectrum are fixed, our model has only one free parameter, related to star formation efficiency ("$f_*$"), and photon generation ("$N_\gamma f_{\rm esc}$").

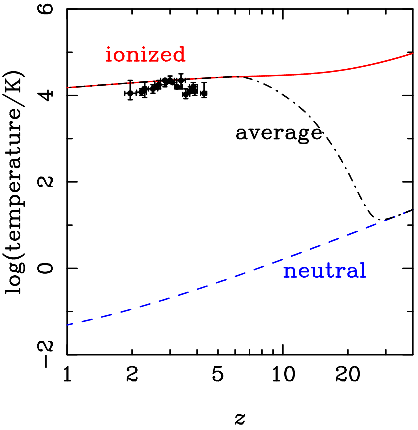
  We fix this parameter by calibrating with observations.




The volume filling factor $f_{\rm II}$ monotonically increases and goes to unity by $z \approx 6$.

Volume-averaged neutral hydrogen fraction $x_{\rm II}$ is consistent with observations (Fan et al. 2006, Kashikawa et al. 2006).

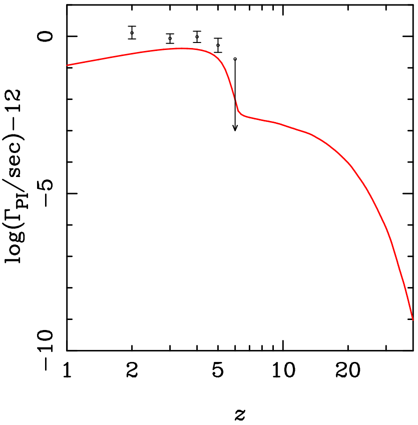
$\tau = 0.087$ here (Dunkley et al. 2009).




Temperature of the neutral fraction is primarily driven by adiabatic expansion.

Photoheating and several cooling mechanisms are accounted for while evolving ionized fraction temperature.

Average IGM temperature settles down to few times $10^4$ K (Schaye et al. 2000).

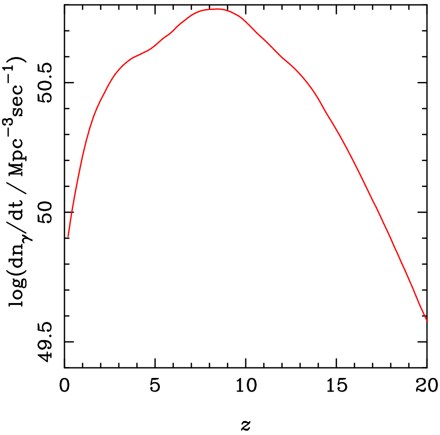



Photoionization rate $\Gamma_{\rm PI}$ is roughly consistent with observations (Bolton and Haehnelt 2007).

Assumption of homogeneity a problem here.

This is the average photoionization rate given by

$$\Gamma_{\rm PI} = 4\pi \int_{\nu_0}^{\infty} J_\nu \sigma(\nu) \frac{d\nu}{h_{\rm P}\nu}.$$




The mean ionizing photon emissivity is roughly consistent with what is expected (Bolton and Haehnelt 2007).

Emissivity shows a bump: sign of feedback.

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REIONIZATION OF THE INHOMOGENEOUS UNIVERSE

JORDI MIRALDA-ESCUDÉ,[1,2,3] MARTIN HAEHNELT,[4,5] AND MARTIN J. REES[4]
jordi@llull.physics.upenn.edu, haehnelt@mpa-garching.mpg.de, mjr@ast.cam.ac.uk
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- One way of implementing inhomogeneities in this model is by formulating it in terms of ionized mass fraction and using results from simulations (Miralda-Escudé et al. 2000, Pawlik et al. 2009).

(Currently working on this!)

# Application to quasar fields

- One application of this model is high-redshift quasar fields.
- Quasars form preferentially in high mass haloes ($\approx 10^{12} - 10^{14}$ M$_\odot$).

  They will thus reside in highly biased regions, and average reionization history may not be applicable.

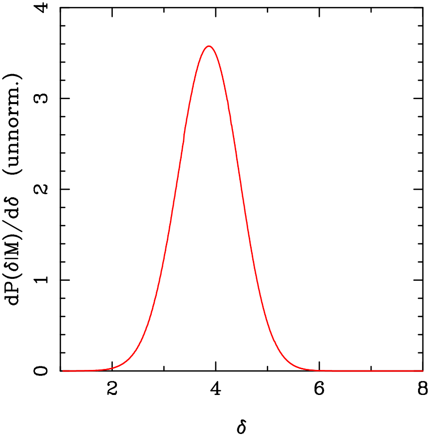
  The idea is to thus solve our reionization model in the high-density neighbourhood of a quasar.
- We ask: what is the peculiar signature of reionization history in quasar environments?

- Consider the SDSS quasar $J1048 + 4637$ with $z \simeq 6.2$ and $i$-band magnitude 22.38.

  Suppose we observe a square field of 11.3 arcmin$^2$ centered on this quasar. (Corresponds to observations presented by Kim et al. 2009.)

- We use a model due to Croton (2009) that uses the empirical $m_{\rm BH}$-$\sigma$ relation to assign a dark matter halo mass to the quasar, given its luminosity: gives a mass of $4.4 \times 10^{12}$ M$_\odot$ for our quasar.

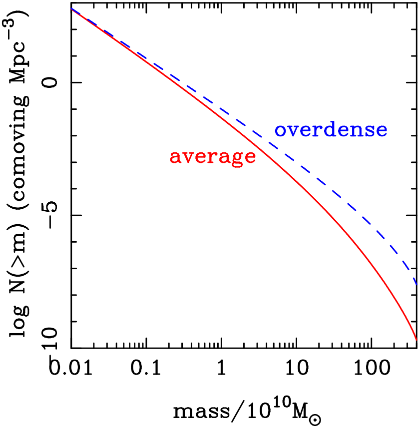
  We then use excursion set theory to find the value of $\delta$ at the comoving Lagrangian scale corresponding to the observed region's size.




A region of size 3.36 arcmin corresponds to 1.15 Mpc at z = 6.2. But this is an Eulerian distance.

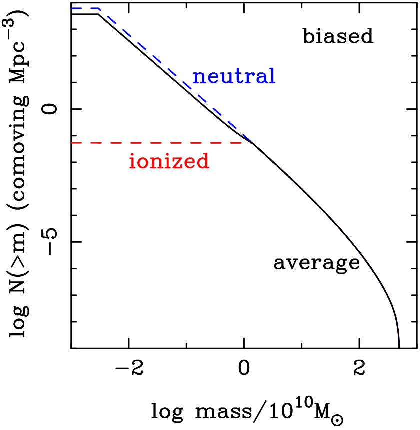
The mapping from Eulerian coordinates to Lagrangian ones is not one-to-one.

We thus get a probability distribution of overdensities given that the region contains a halo of mass $4.4 \times 10^{12}$ $M_{\odot}$.



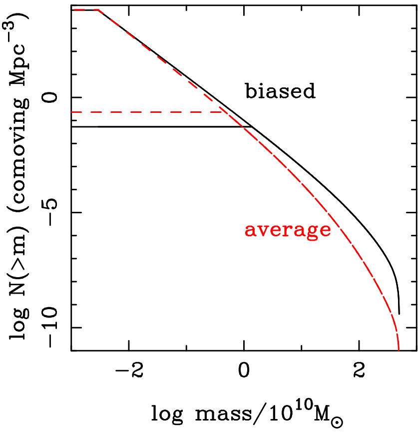

We now use the prescription of Mo and White (1996) to calculate the source term of our model, now limited to the quasar field.

This prescription incorporates the fact that haloes in the intermediate mass range will be overabundant in the overdense region (“bias”).




Feedback produces a “knee” in the average cumulative mass function.

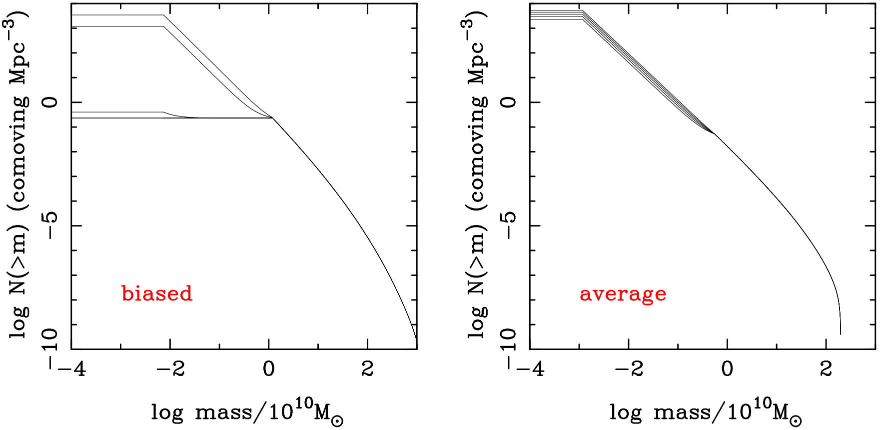
This feature depends on reionization history — a potential probe.




What is so special about biased regions?

(1) The difference in mass thresholds is larger in biased regions?

(2) At higher redshift, highly biased quasar environments become better probe.




This effect will be redshift dependent.

# Summary

- Large variation can be seen in the comoving number density ('luminosity function') of objects in biased regions at high redshift due to radiative feedback.

- This is a potentially observable probe that could discriminate between different reionization histories.

- Predictions will change after better calibration. But cannot do that without inhomogeneities.