Quasar environments as a probe of Reionization

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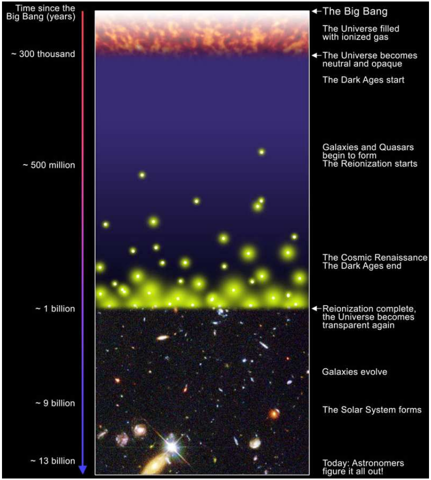
Motivation



- Cosmic reionization receiving attention.
- Really a study of small scale structure. Need theory, observables and analytical methods.
- Here, we look at a semi-analytical model of reionization.
- We study reionization in quasar environments and try to construct an observable.

(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.

  Semi-analytic models also help understand results of simulations.

- Our model is based on Chiu and Ostriker (2000) and treats IGM as an evolving two-phase medium with sources and sinks of radiation.

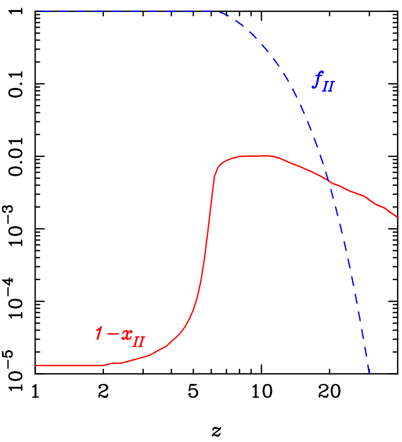
  This model does not assume (1) local absorption of radiation and (2) photoionization equilibrium.

- 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 two free parameters: star formation efficiency (“f_*”), and photon generation (“$N_\gamma f_{\rm esc}$”).

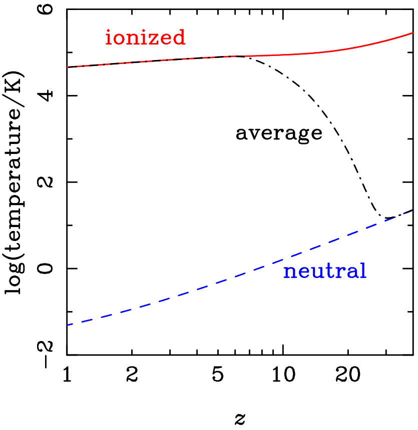
  We fix these parameters by calibrating with observations.



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

The ionized hydrogen fraction x_{II} *inside ionized regions* initially shows a decrease.

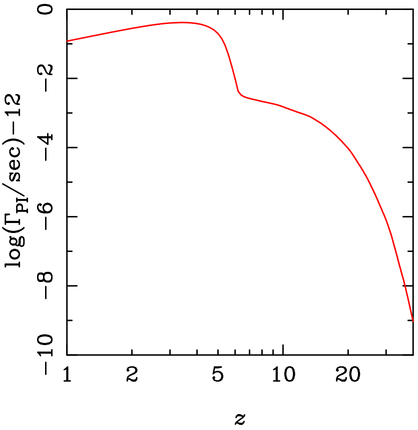
Neutral hydrogen fraction $1 - x_{\text{II}}$ then settles to a value of $\approx 10^{-5}$, consistent with absorption spectra observations.



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

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

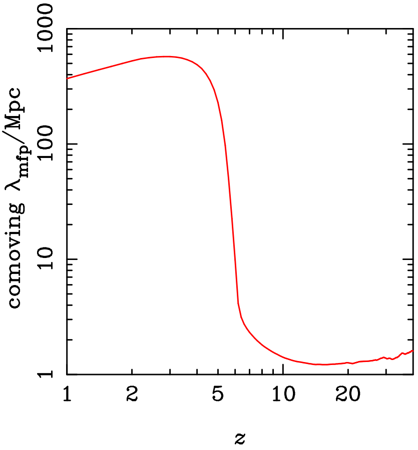
Average IGM temperature settles down to few times 10^4 K.



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

This is the average photoionization rate given by

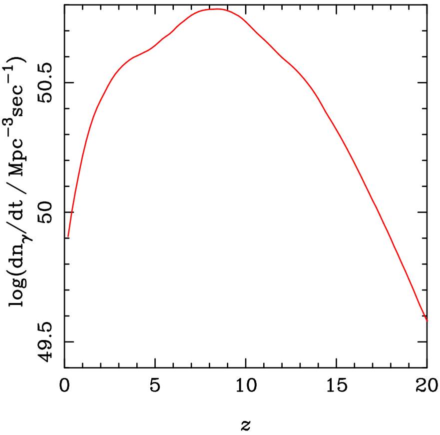
$$\Gamma_{\rm PI} = 4\pi \int_{\nu_0}^{\infty} J_\nu \sigma(\nu) \frac{d\nu}{h_{\rm P}\nu}.$$



We calculate the comoving mean free path of ionizing photons as ‘flux/emissivity.’

Mean free path grows rapidly near the end of reionization. But growth faster than what is expected from simulations.

Reflects the fact that inhomogeneities have not been taken into account.



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

Emissivity shows a bump: sign of feedback.

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.

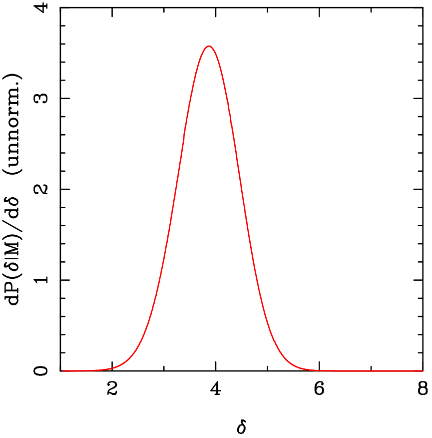
  The idea is to thus solve our reionization model in the high-density neighbourhood of a quasar.
- We ask: what is the peculiar signature of reionization history in quasar environments?

- 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 $m_{\rm BH}$-σ relation to assign a dark matter halo mass to the quasar, given its luminosity: gives a mass of 4.4×10^{12} M$_\odot$ for our quasar.

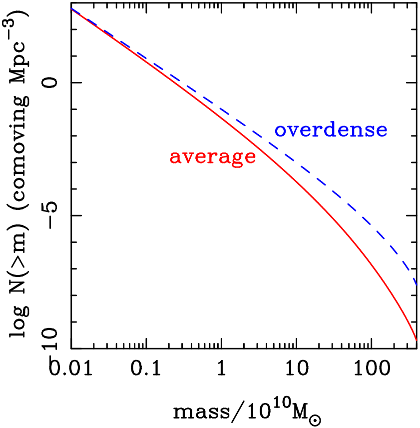
  We then use excursion set theory to find the value of δ at the comoving Lagrangian scale corresponding to the observed region's size.



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

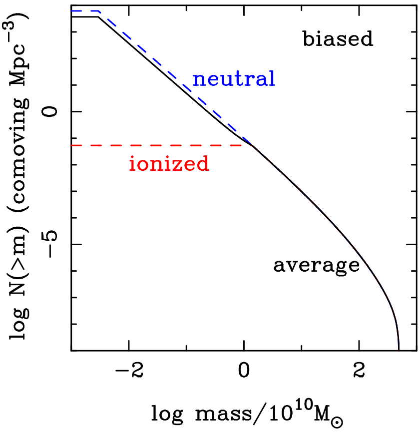
The mapping from Eulerian coordinates to Lagrangian ones is not one-to-one.

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



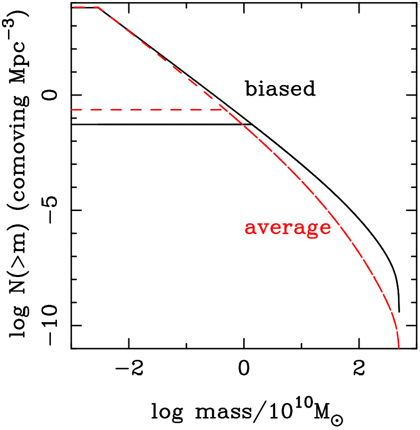
We now use the prescription of Mo and White (1996) to calculate the source term of our model, now limited to the quasar field.

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.

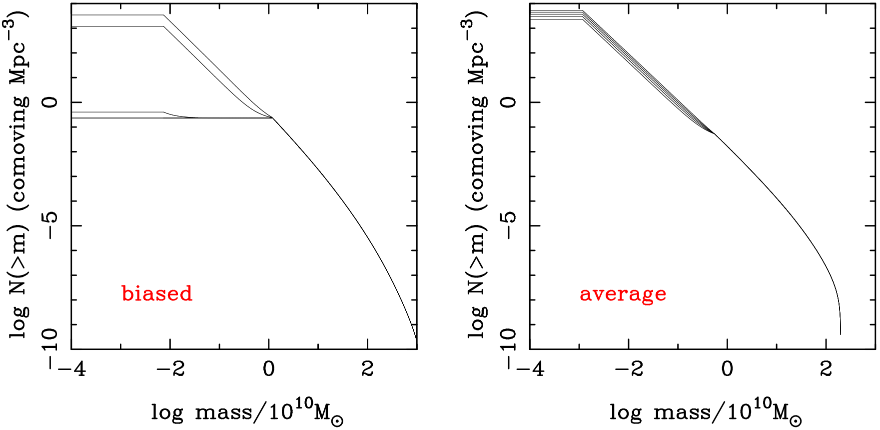
This feature depends on reionization history — a potential probe.



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

- Feedback affects object counts in quasar fields.
- This is a potential probe of reionization history.
- Sensitivity of the probe will be redshift dependent. Currently working on this.