Reionization Simulation for LOFAR

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Outline

- Motivation: Simulating observation
- The unknowns: Source properties, z,….
- Radiative Transport: 1D simulations & results
- N-body coupled with RT: Semi-Analytical approach
- Following signal path through

Simulating Observations

- Primary reason: Testing signal extraction algorithms (talk by Panos Labropoulos)
- Study influence of foregrounds (talk by Vibor Jelic)
- Understanding the effect of the ionosphere
- Feedback to the calibration team

Unknowns: The not so clear

- Power spectrum:

  Stars : blackbody type

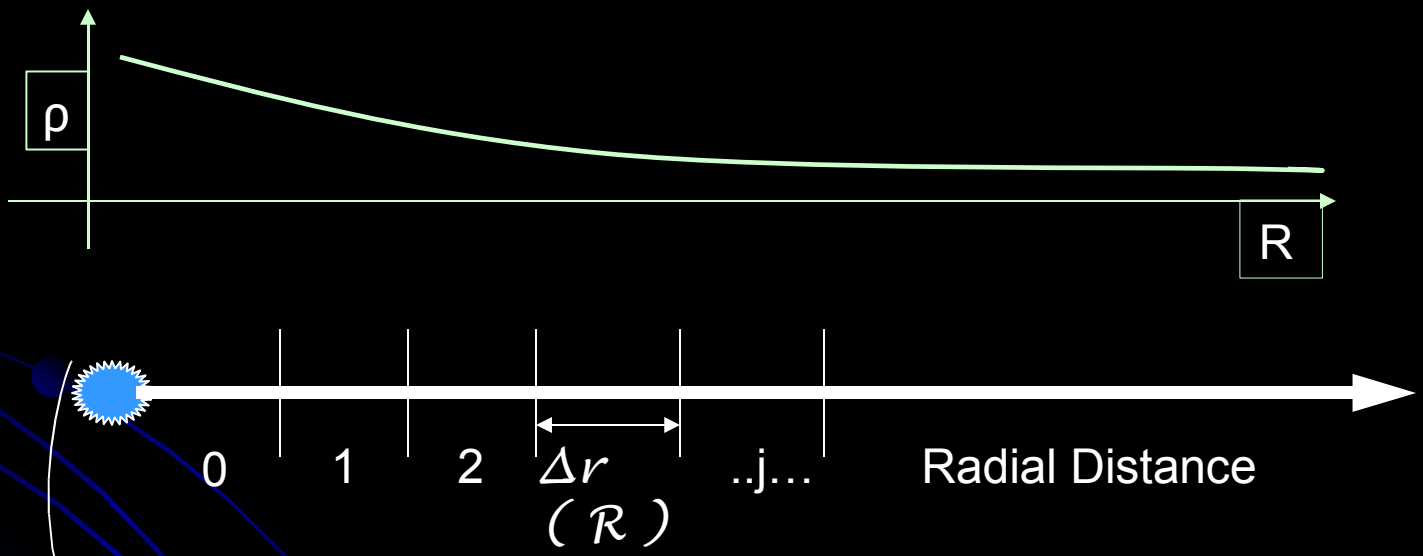
  Quasars: power-law sources (index ?)

- Redshifts of Turn-ON/birth
- Clustering properties, dust, photon escape fraction
- Other complex feedback processes

Implies we need **MANY** and **LARGE** simulations

Radiative Transport – 1D

- Returns 3 species fraction and temperatures (kinetic, spin, brightness) as function of radius



Source characteristics : total energy and distribution

Radiative Transport – 1D

$$\frac{\mathrm{d}}{\mathrm{d}t}\left[\frac{n(\mathrm{H\,II})}{n_{\mathrm{H}}}\right] = \frac{R_{1c}\,n(\mathrm{H\,I})}{n_{\mathrm{H}}} - \frac{\alpha_{2,\mathrm{H\,II}}\,n_{\mathrm{e}}^2}{n_{\mathrm{H}}}$$

$$R_{2c} = \gamma_{2c} + \beta_{2,\mathrm{H\,I}}\,n_{\mathrm{e}} + \int_{\varepsilon_{2,\mathrm{H\,I}}} c\sigma_{2\mathrm{f},\mathrm{H\,I}}\,n_\gamma(\varepsilon_\gamma)\,\mathrm{d}\varepsilon_\gamma,$$

Hydrogen

$$\frac{\mathrm{d}}{\mathrm{d}t}\left[\frac{n(\mathrm{He\,II})}{n_{\mathrm{He}}}\right] = \frac{n(\mathrm{He\,I})}{n_{\mathrm{He}}}\int_{\varepsilon_{\mathrm{He\,I}}} \mathrm{d}\varepsilon_\gamma \sigma_{\mathrm{bf},\mathrm{He\,I}} c n_\gamma(\varepsilon_\gamma)$$

Ionizing spectrum

$$+\beta_{\mathrm{He\,I}} n_{\mathrm{e}} \frac{n(\mathrm{He\,I})}{n_{\mathrm{He}}} - \beta_{\mathrm{He\,II}} n_{\mathrm{e}} \frac{n(\mathrm{He\,II})}{n_{\mathrm{He}}}$$

Collisional ionization

Helium-II

$$-\alpha_{\mathrm{He\,II}} n_{\mathrm{e}} \frac{n(\mathrm{He\,II})}{n_{\mathrm{He}}} + \alpha_{\mathrm{He\,III}} n_{\mathrm{e}} \frac{n(\mathrm{He\,III})}{n_{\mathrm{He}}}$$

Recombination ionization

$$-\xi_{\mathrm{He\,II}} n_{\mathrm{e}} \frac{n(\mathrm{He\,II})}{n_{\mathrm{He}}},$$

Recombination

$$\frac{\mathrm{d}}{\mathrm{d}t}\left[\frac{n(\mathrm{He\,III})}{n_{\mathrm{He}}}\right] = \frac{n(\mathrm{He\,II})}{n_{\mathrm{He}}}\int_{\varepsilon_{\mathrm{He\,II}}} \mathrm{d}\varepsilon_\gamma \sigma_{\mathrm{bf},\mathrm{He\,II}} c n_\gamma(\varepsilon_\gamma)$$

Dielectronic Recombination

Helium-III

$$+\beta_{\mathrm{He\,II}} n_{\mathrm{e}} \frac{n(\mathrm{He\,II})}{n_{\mathrm{He}}} - \alpha_{\mathrm{He\,III}} n_{\mathrm{e}} \frac{n(\mathrm{He\,III})}{n_{\mathrm{He}}}$$

Fukugita & Kawasaki 1994

Temperature Evolution

HEATING **COOLING**

$$\frac{3}{2}\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{kT_e n_B}{\mu}\right) = \sum_{i=\mathrm{H\,I},\mathrm{He\,I},\mathrm{He\,II}} n(i)\,c\int(\varepsilon_\gamma-\varepsilon_i)\,n_\gamma\sigma_{\mathrm{bf},i}\,\mathrm{d}\varepsilon_\gamma$$

$$-\sum_{i=\mathrm{H\,I},\mathrm{He\,I},\mathrm{He\,II}}\zeta_i n_e n(i)$$

$$-\sum_{i=\mathrm{H\,II},\mathrm{He\,II},\mathrm{He\,III}}\eta_i n_e n(i)$$

$$-\omega_{\mathrm{He\,II}} n_e n(\mathrm{He\,III})$$

$$-\sum_{i=\mathrm{H\,I},\mathrm{He\,I},\mathrm{He\,II}}\psi_i n_e n(i)$$

$$-\lambda_c$$

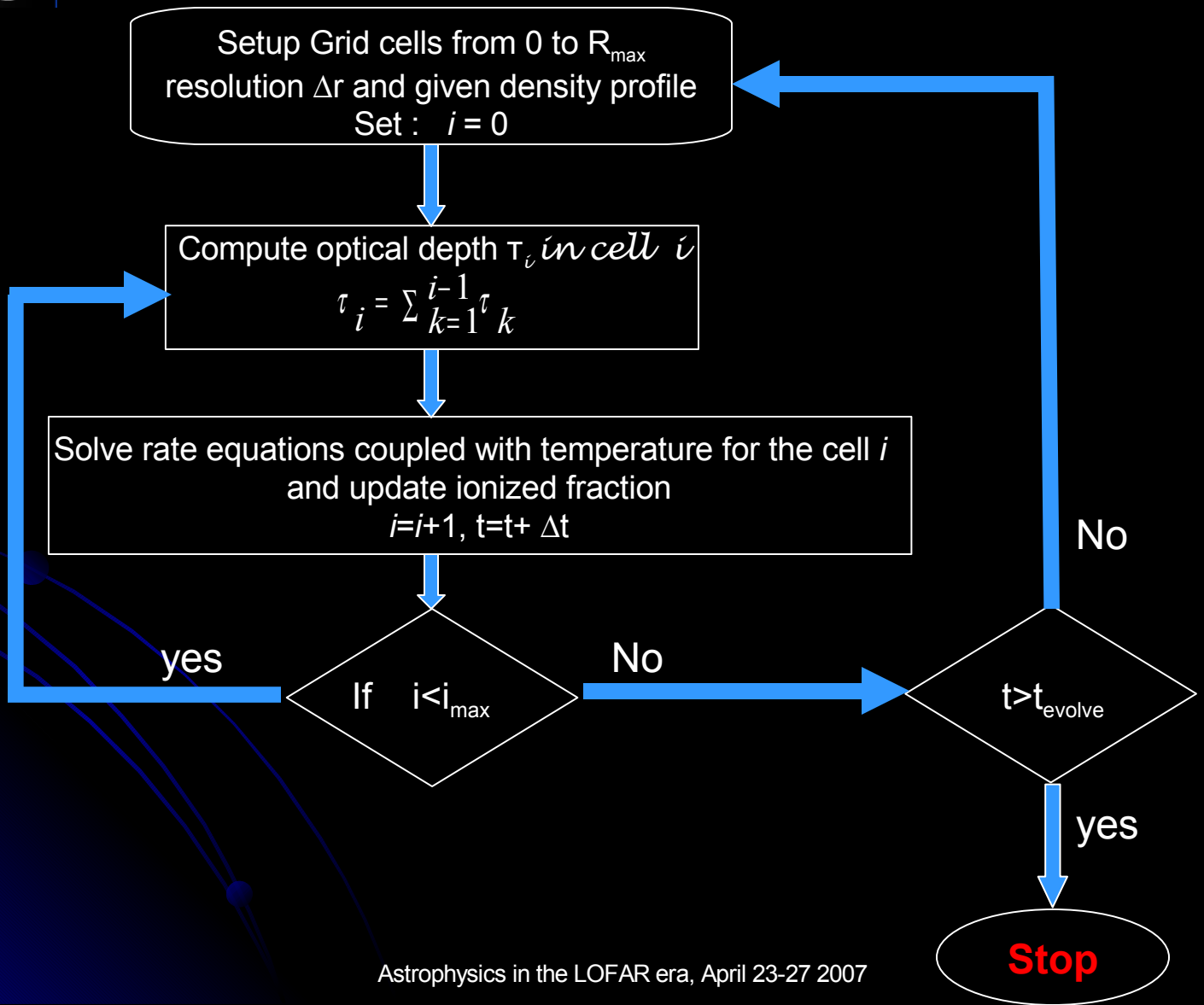
$$-\theta_{\mathrm{ff}}[n(\mathrm{H\,II})+n(\mathrm{He\,II})+4n(\mathrm{He\,III})]\,n_e$$

$$-\frac{15}{2}\frac{\dot{a}}{a}\left(\frac{kT_e n_B}{\mu}\right),$$

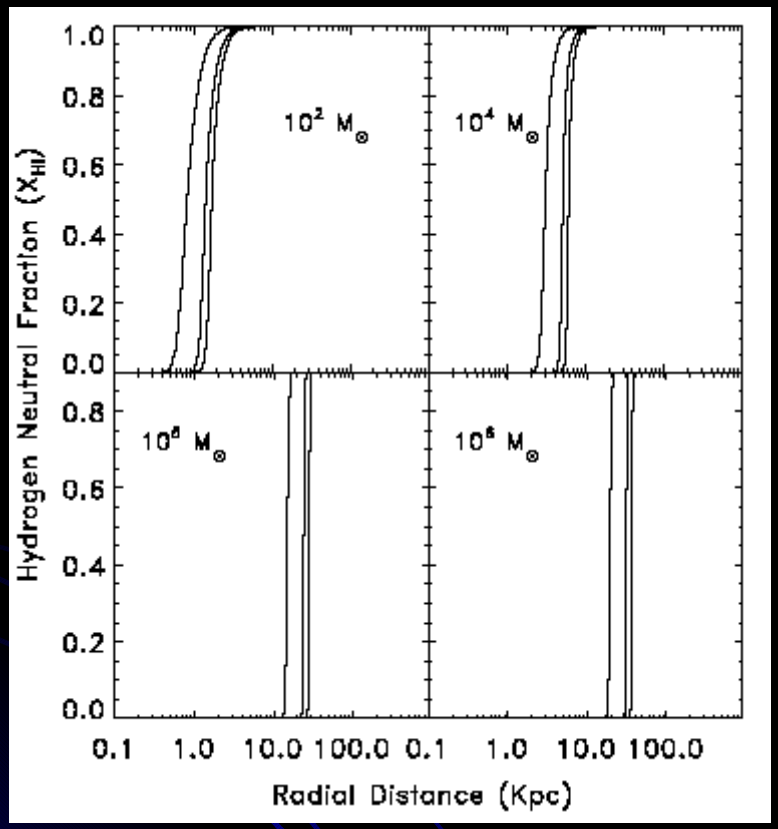
- Secondary heating
- Collisional-ionization
- recombination
- Dielectronic-recombination
- Collisional-excitation
- Compton
- Free-free
- Hubble cooling

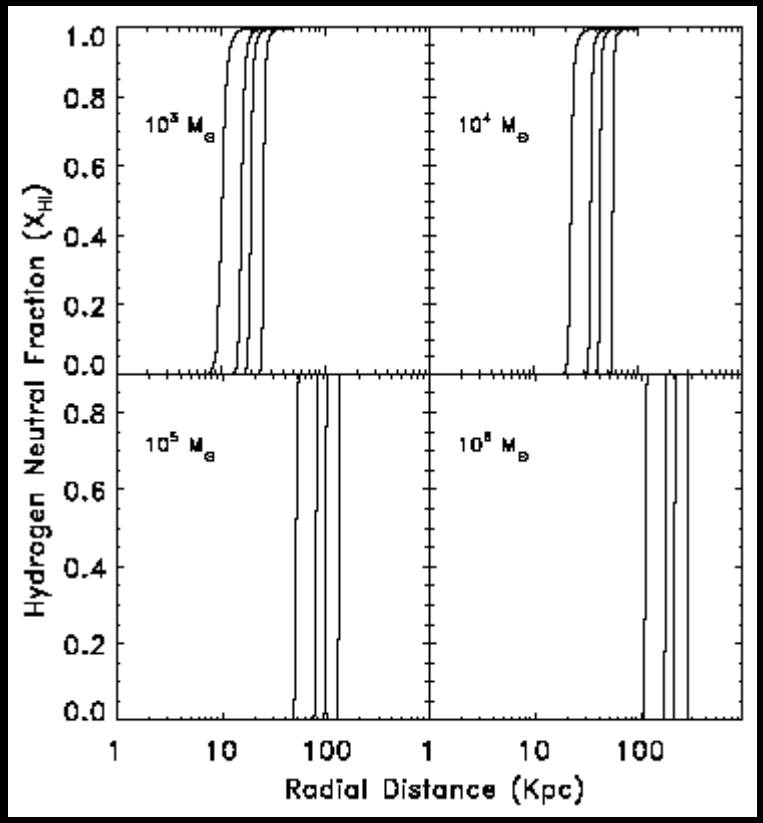
Fukugita & Kawasaki 1994

Radiative Transport: Algorithm



Some Results: ionized sphere

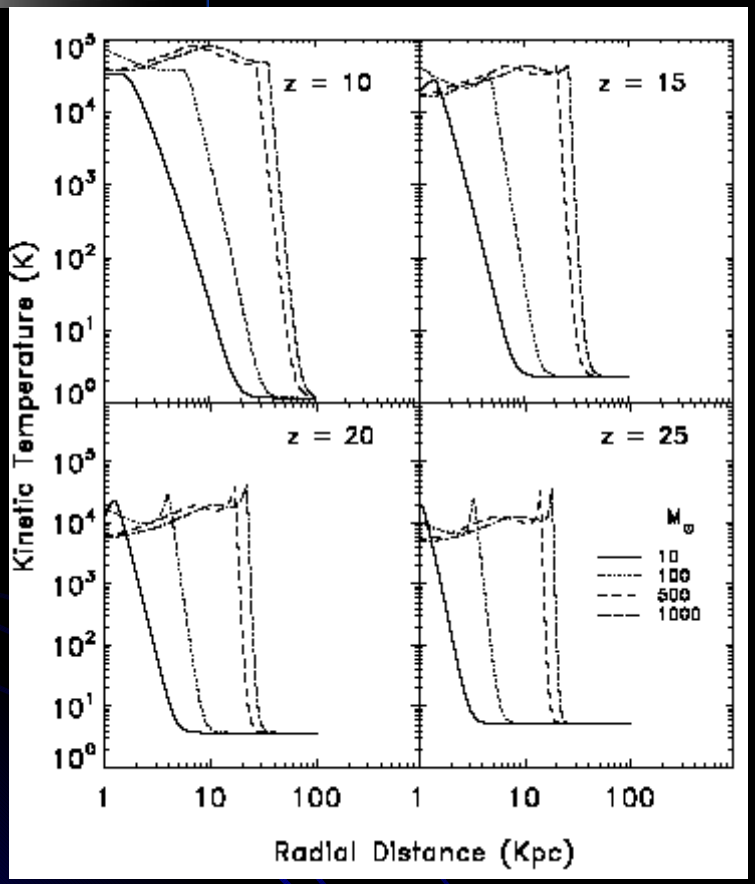


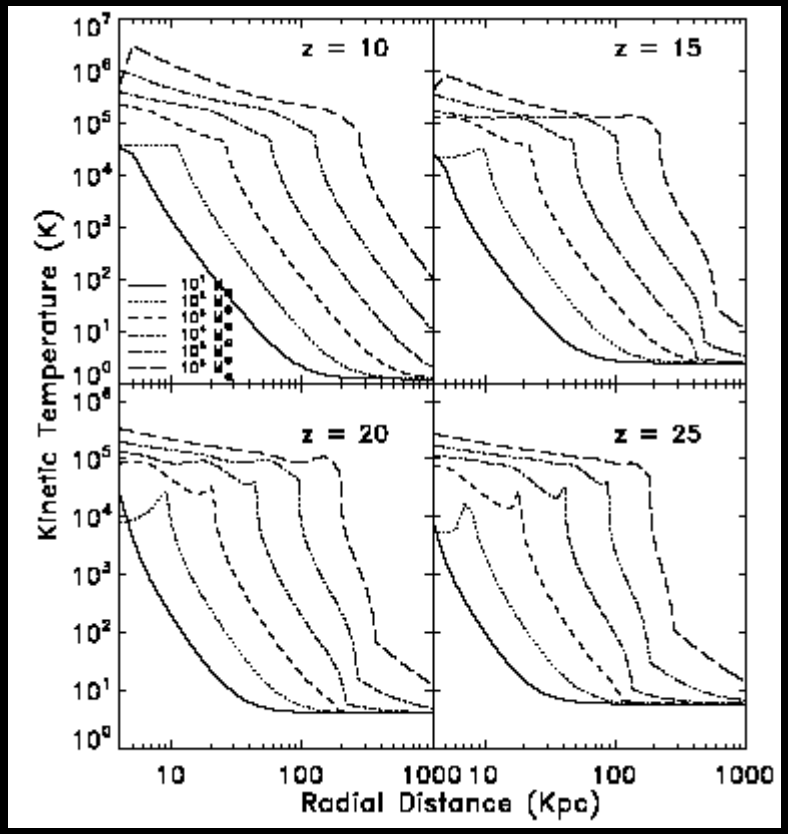


Stars: Blackbody spectrum

Mini-quasars: power-law (α=1)

Some Results: heating

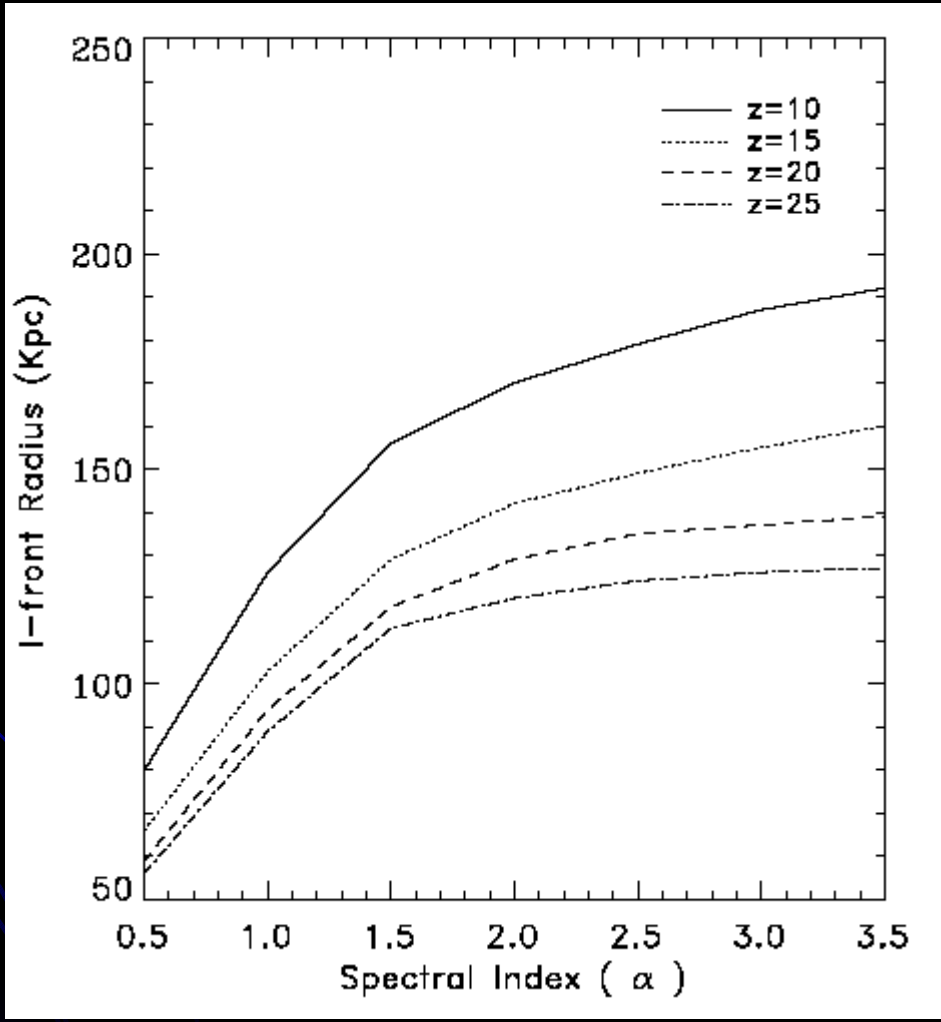




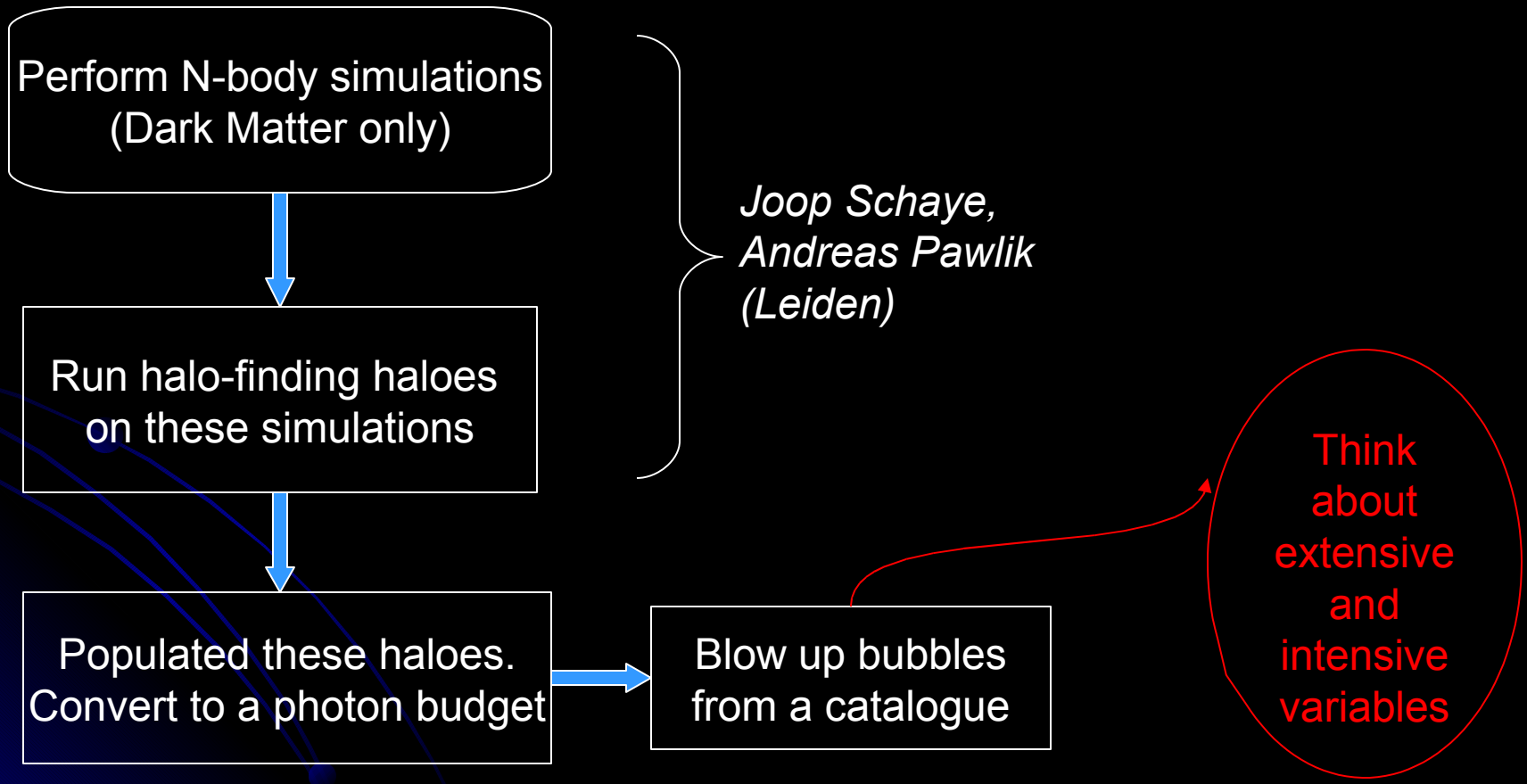
Stars: Blackbody spectrum

Mini-quasars: power-law (α=1)

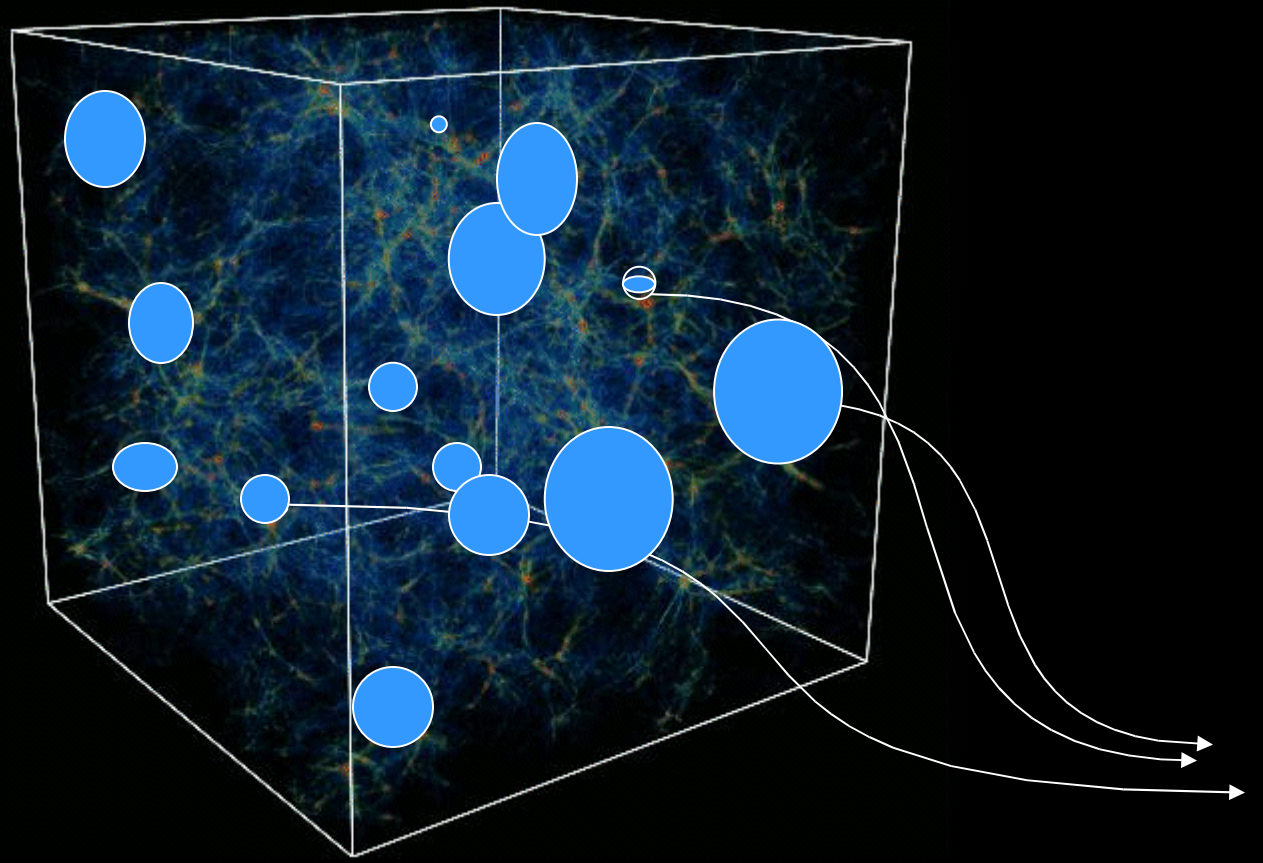
Some Results: Dependence of I-front on spectral index



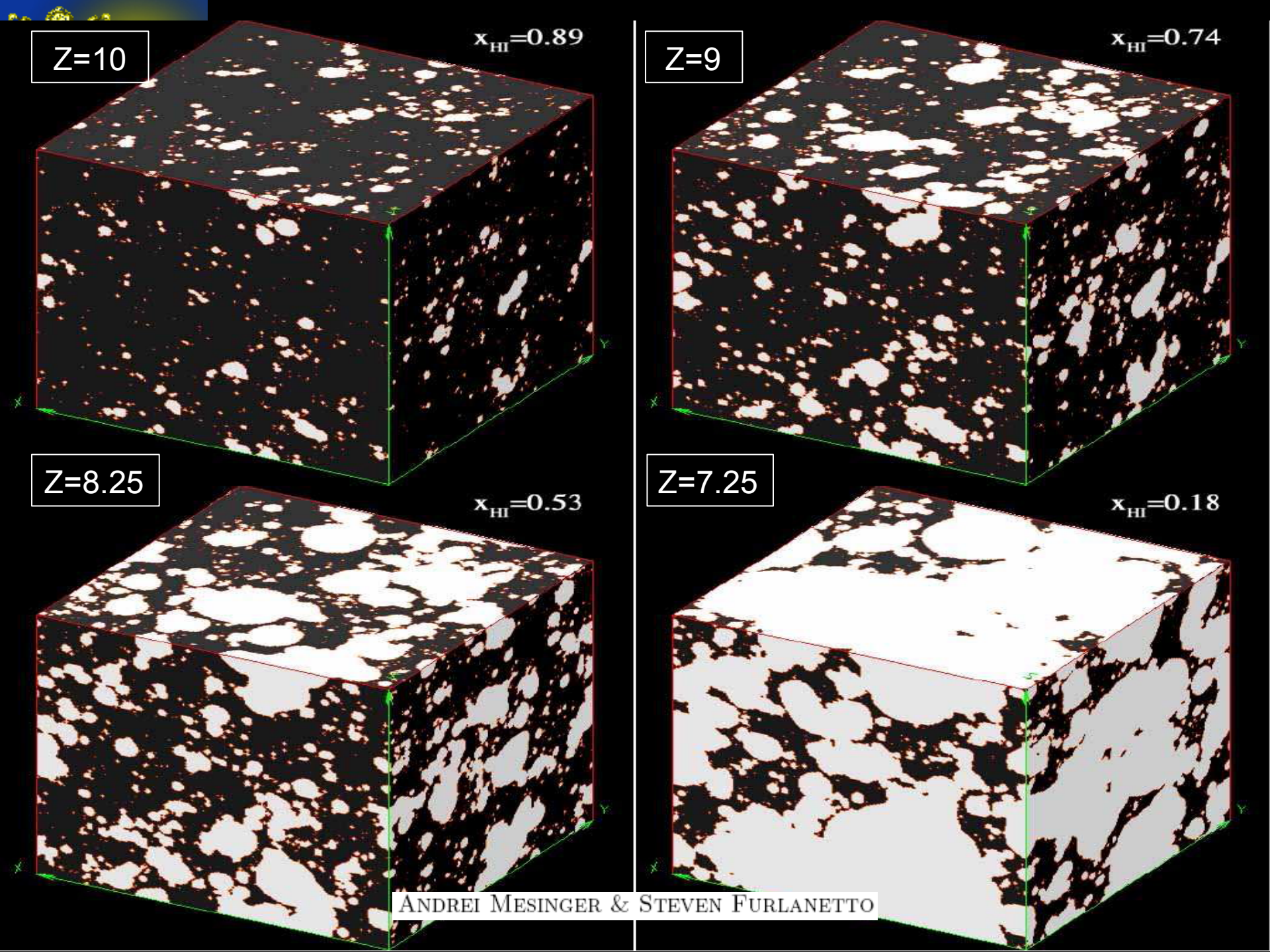
Coupling with N-body semi-analytically



Semi-Analytics: 2



Identify the haloes


Z=10
x_{HI}=0.89
Z=9
x_{HI}=0.74
Z=8.25
x_{HI}=0.53
Z=7.25
x_{HI}=0.18
Andrei Mesinger & Steven Furlanetto

The Skeleton of the PIPELINE is in place.
What is left is to add some meat!!