Probing the End of Reionization via QSO H_{II} Regions

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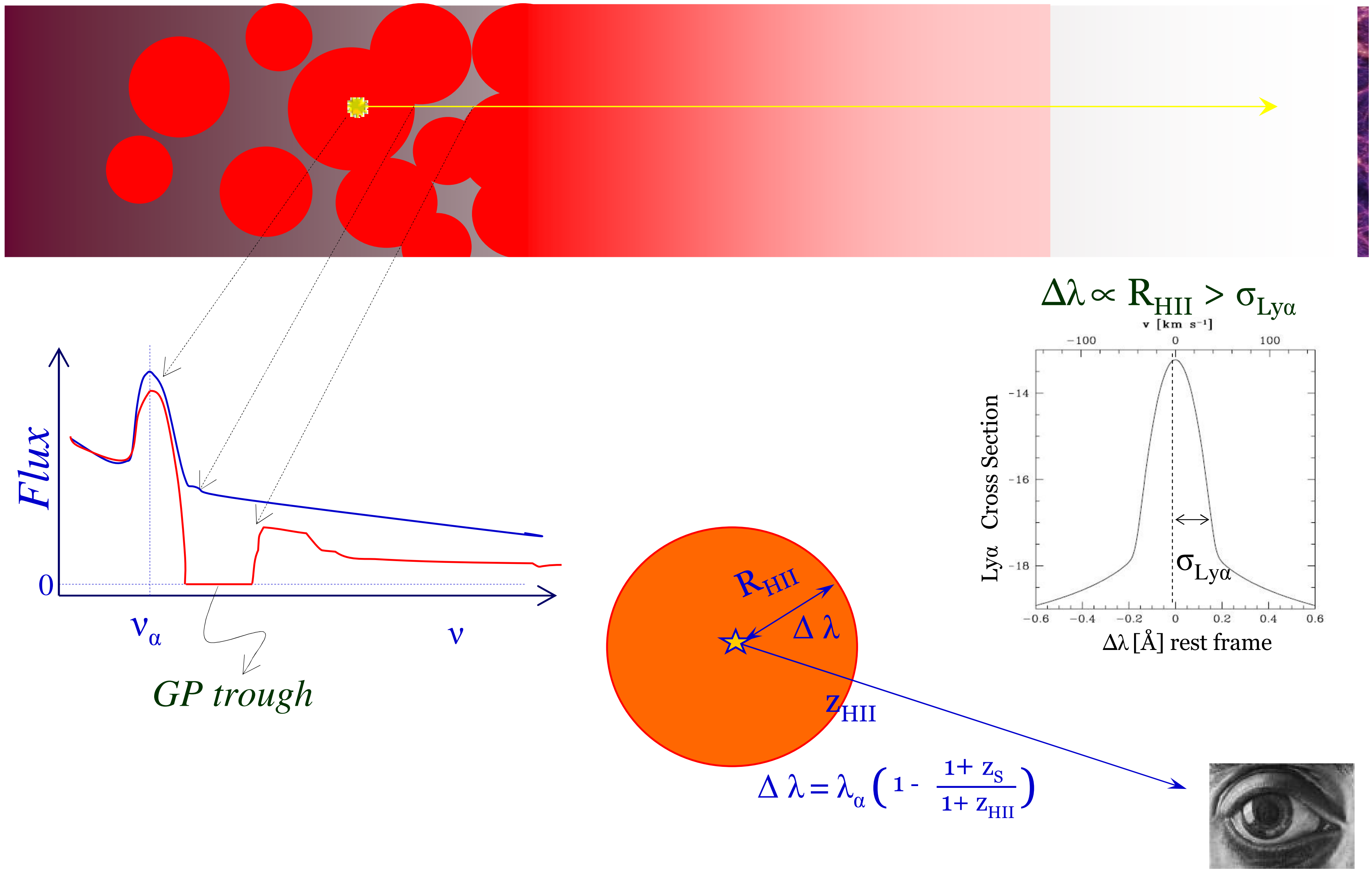
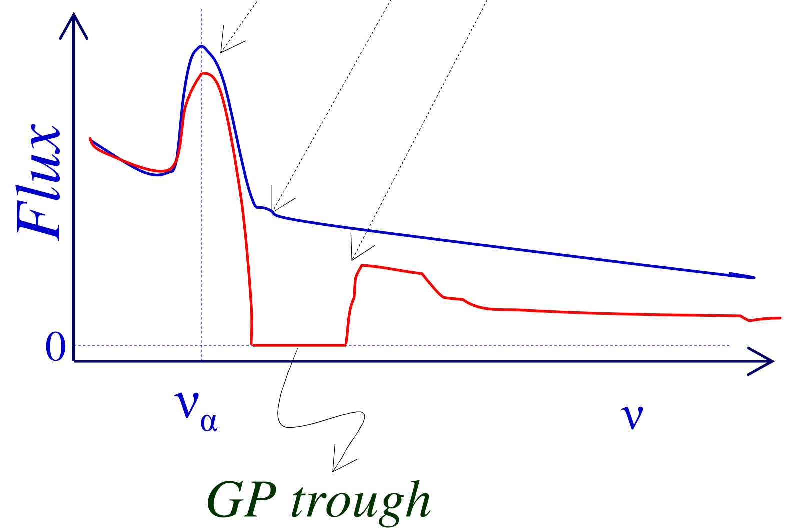
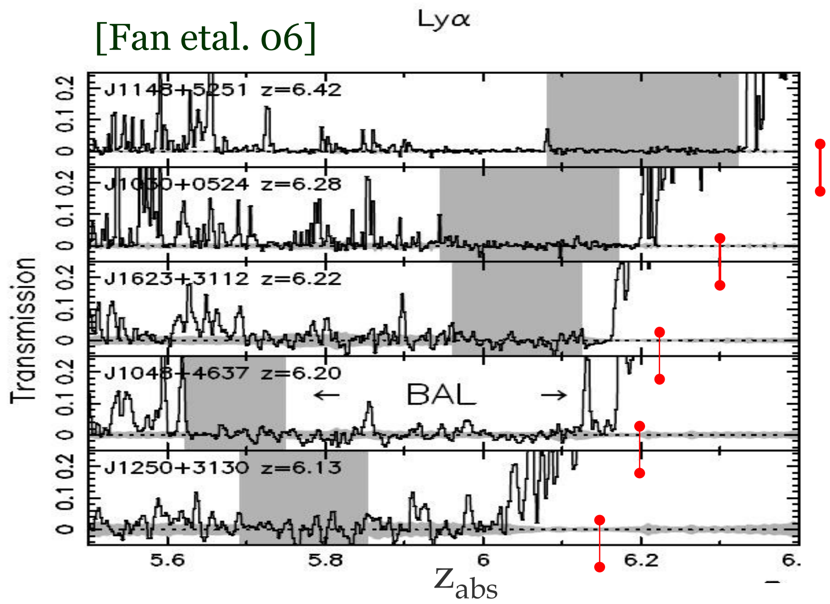
H_{II} Region Signature in High-z QSO Spectra

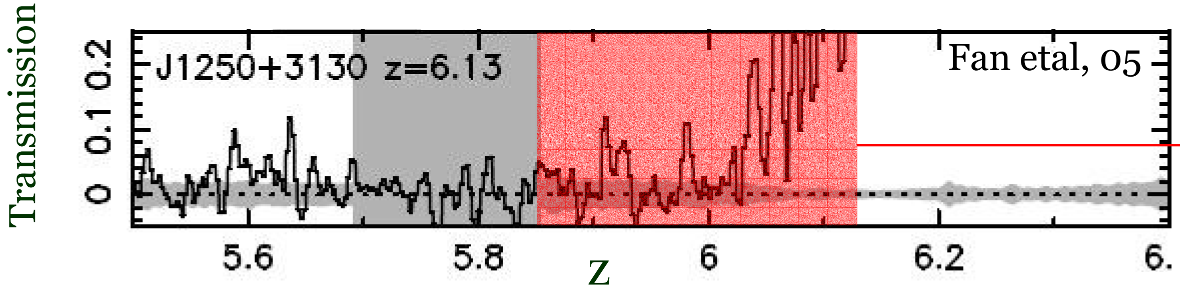


H_{II} Region Signature in High-z QSO Spectra





Constraining the IGM Ionization State



$\Delta z \Rightarrow R_{HII}$

(i) $R_{HII} \approx \left(\frac{3\, \dot{N}_\gamma\, t_Q}{4\, \pi\, n\, x_{HI}} \right)^{1/3} \Rightarrow x_{HI} \propto R_{HII}^{-3}\, \dot{N}_\gamma\, t_Q$

Wyithe & Loeb 04
Wyithe, Loeb & Carilli 04
Fan etal. 06; Yu & Lu 04

(ii) Observed vs Simulated Spectra (x_{HI})

Mesinger & Haiman 04, 06
Bolton & Heanhelt 07
AM etal. 07

Problems & Uncertanties

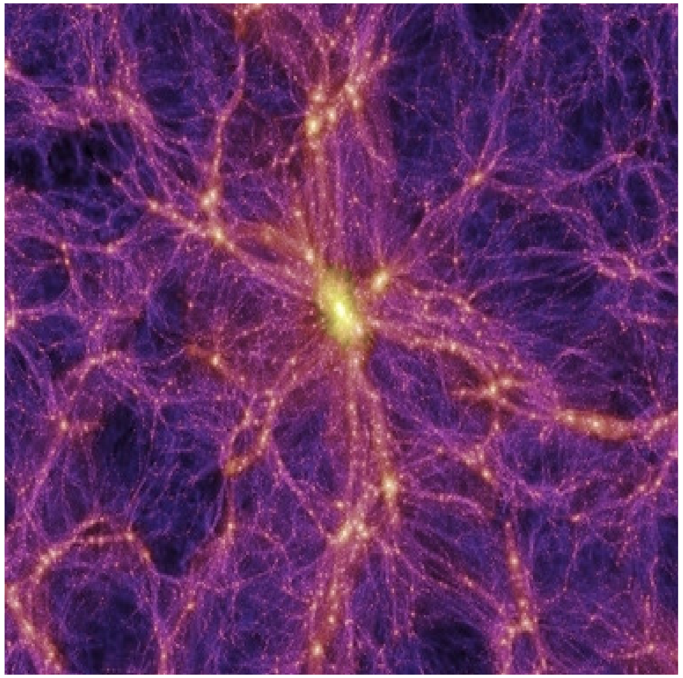
- ✓ t_Q , $\dot{N}_\gamma$ unknown
- ✓ QSOs live in highly biased environment
- ✓ Fluctuations in the ionizing background
- ✓ RT effects: $H_I + He_I + He_{II}$ opacity
- ✓ Fluctuations in the opacity along different LOS

Alvarez etal. 07
Lidz etal. 07

Numerical Simulations

GADGET 2

z ~ 6.1



⟵ $L_{box} = 142\ h^{-1}$ Mpc ⟶

$M_{halo} = 2.9 \times 10^{12}\ h^{-1}\ M_{\odot}$

Radiative Transfer Simulations

$t_Q = 10^6 \div 10^7$ yr

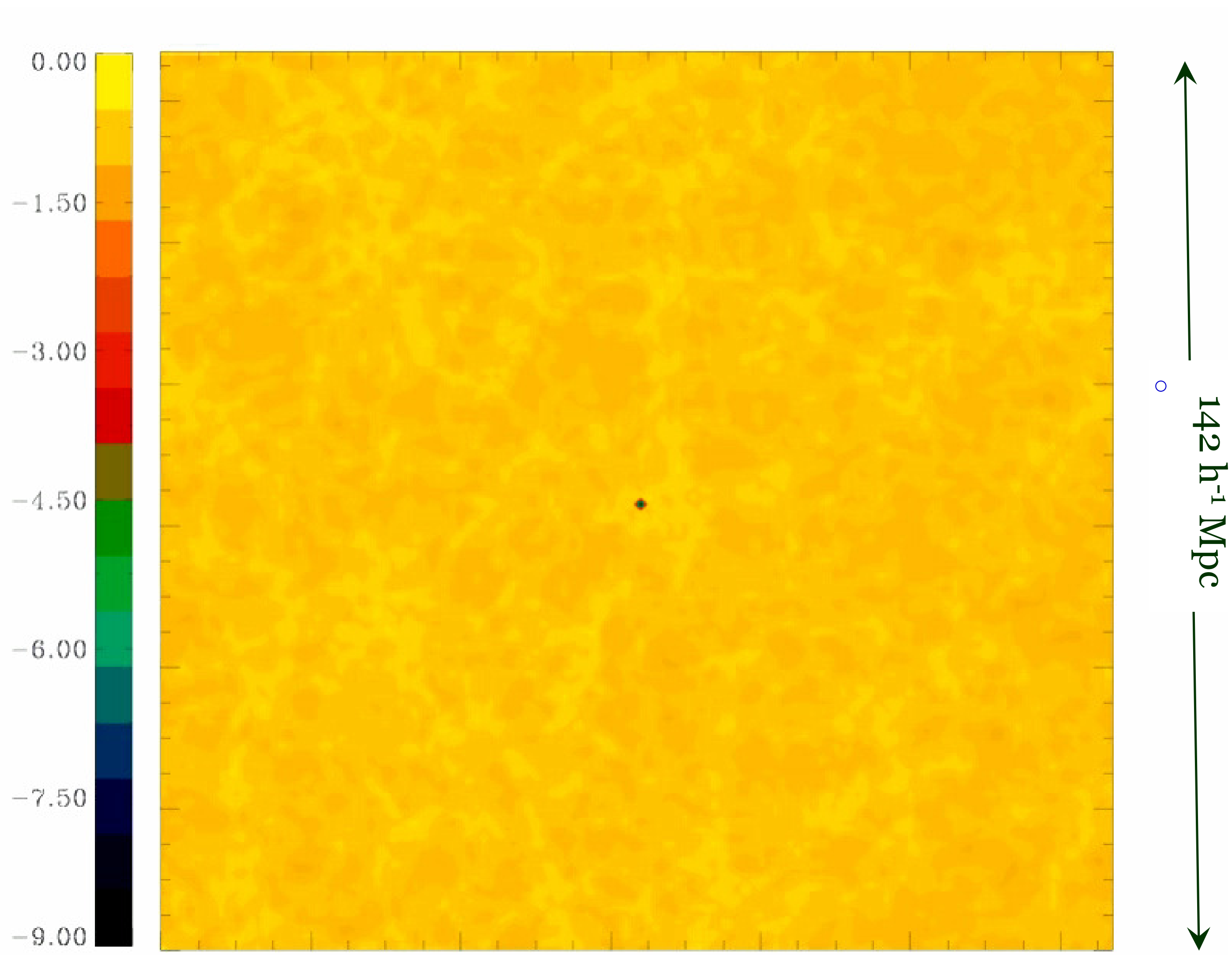
$N_\gamma = 5.2 \times 10^{56} \div 2 \times 10^{57}\ s^{-1}$

$< x_{HI} > = 1 \div 10^{-4}$

H & He

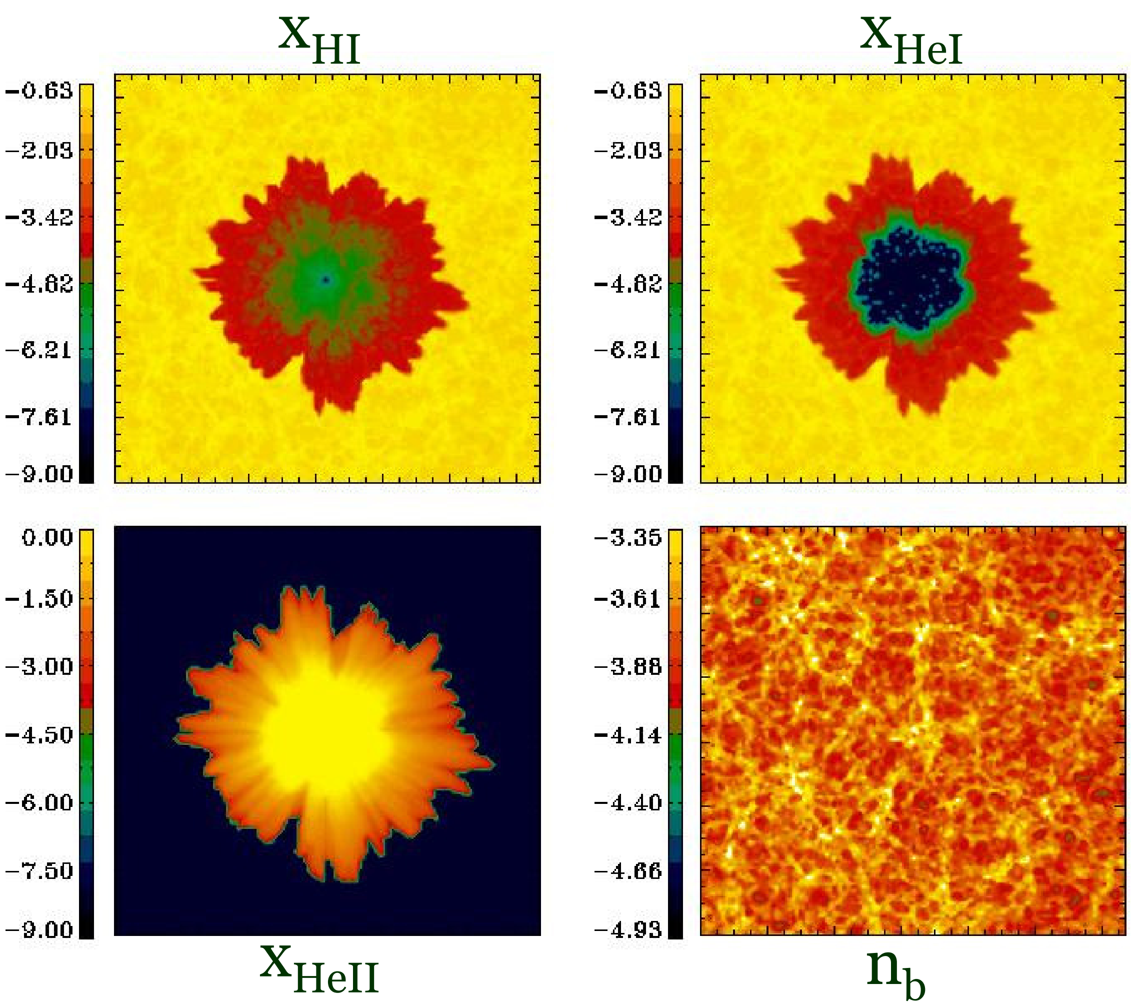
Temperature Evolution

x_{HI} Map



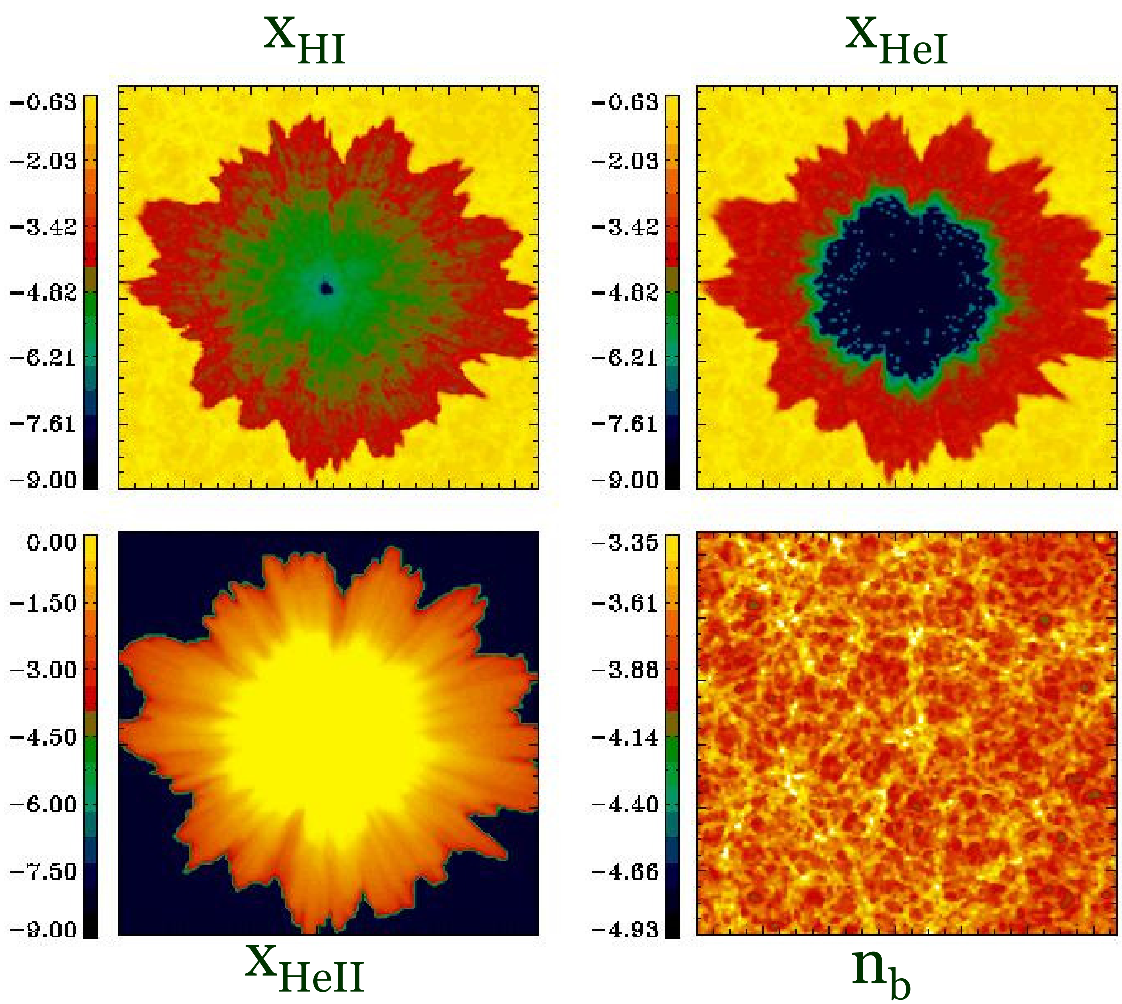
$t_Q = 2 \times 10^7$ yr, $N_\gamma = 5.2 \times 10^{56}\ s^{-1}$, $< x_{HI} > = 0.1$

The Shape of QSOs H_{II} Regions



- ✓ Uneven Ionization Fronts
- ✓ Non Spherical H_{II} Regions
- ✓ The Ionization Front is stopped by overdense filaments

$t_Q = 10^7$ yr, $N_\gamma = 5.2 \times 10^{56}\,s^{-1}$, $< x_{HI} > = 0.1$

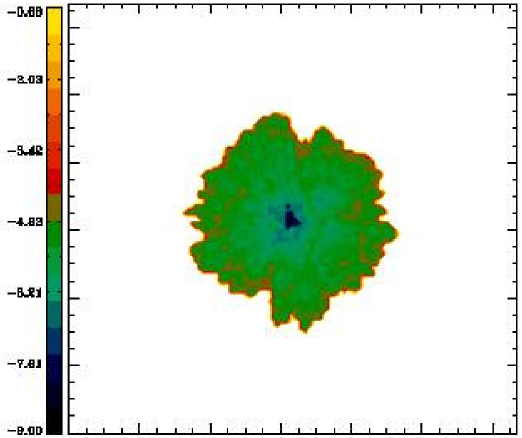


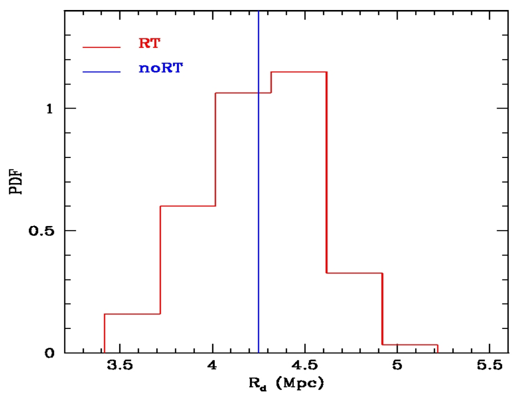
- ✓ Uneven Ionization Fronts
- ✓ Non Spherical H_{II} Regions
- ✓ The Ionization Front is stopped by overdense filaments
- ✓ Asymmetry becomes more evident at higher $\dot{N}_\gamma$

$t_Q = 10^7$ yr, $\dot{N}_\gamma = 2 \times 10^{57}\,s^{-1}$, $< x_{HI} > = 0.1$

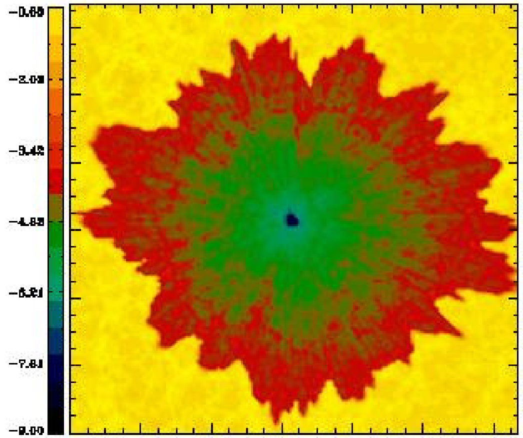
Asymmetry Dependence on x_{HI}

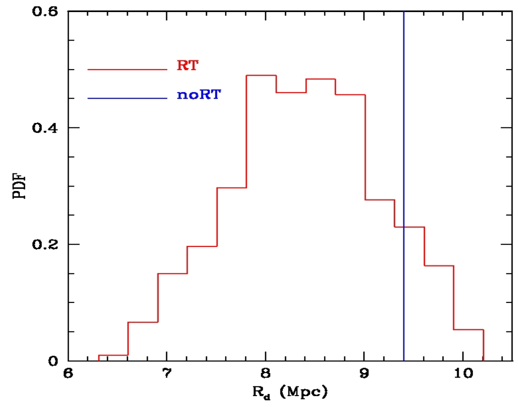
$\langle x_{HI} \rangle = 1$



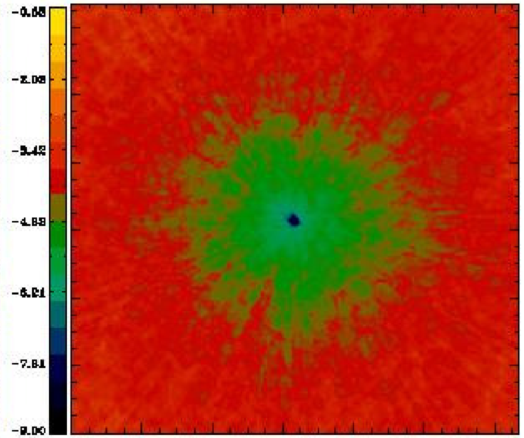


$\langle x_{HI} \rangle = 0.1$



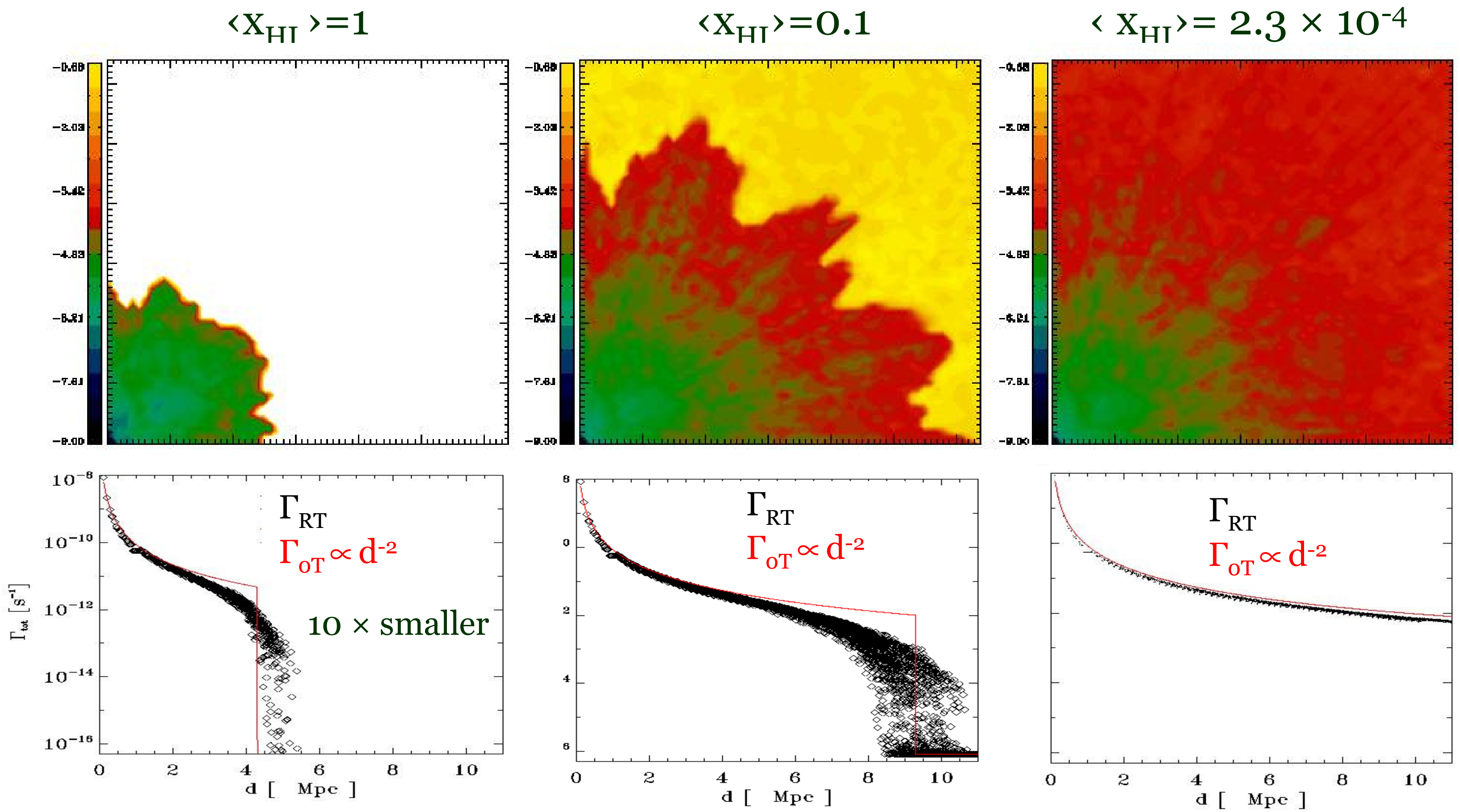


$\langle x_{HI} \rangle = 2.3 \times 10^{-4}$



$t_Q = 10^7$ yr, $N_\gamma = 2 \times 10^{57}$ s^{-1}

RT Effects on the Photoionization Rate



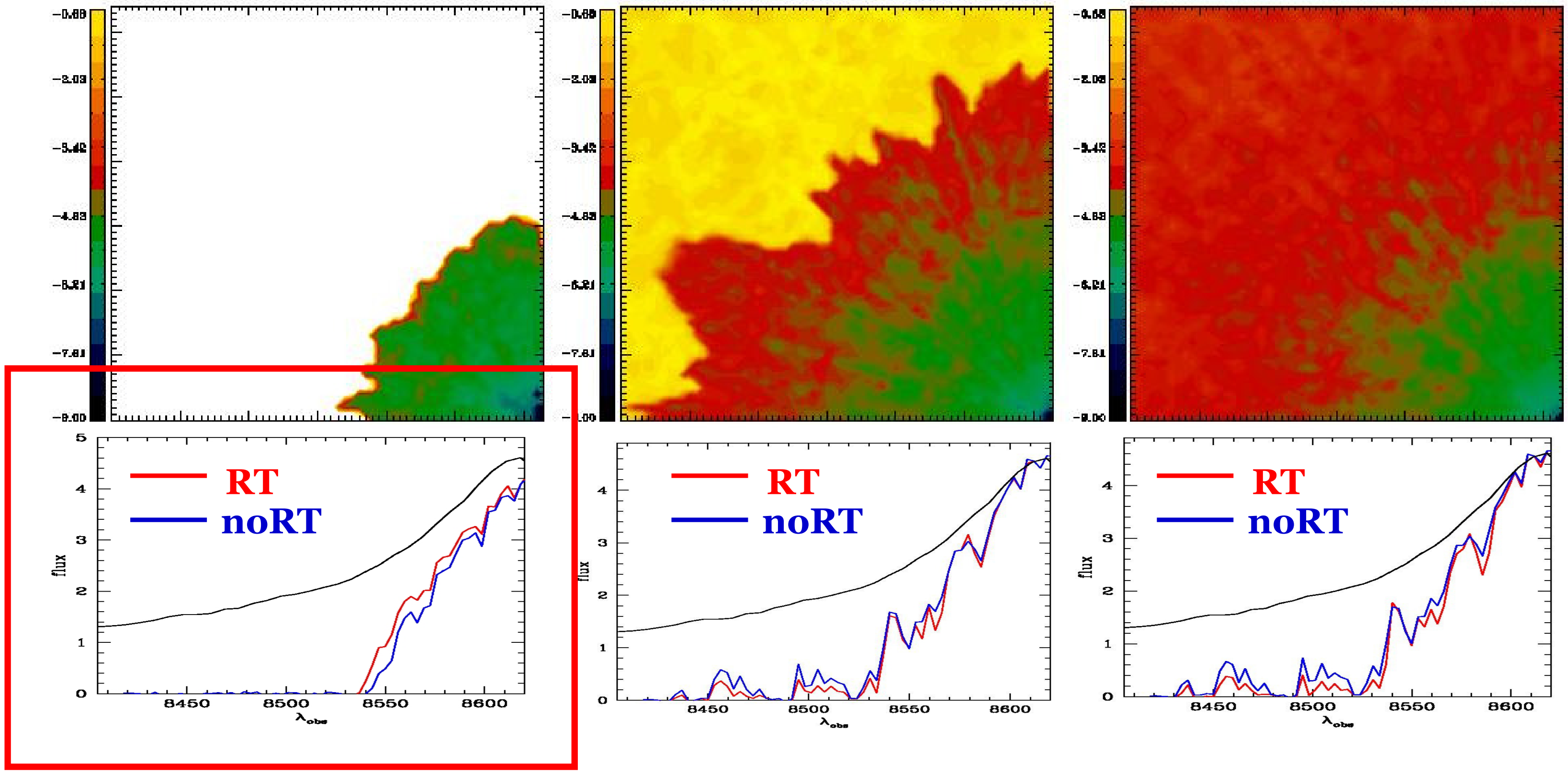
The photoionization rate falls faster than $1/d^2$

- $\Gamma(d) < \Gamma_o/(4\pi d^2)$
- $\delta\Gamma(d)$ increases with distance ie. with decreasing x_{HI}

$t_Q = 10^7$ yr, $N_\gamma = 2 \times 10^{57}\,s^{-1}$

RT Effects on the Lyα Transmitted Flux

$\langle x_{HI} \rangle = 1$ $\langle x_{HI} \rangle = 0.1$ $\langle x_{HI} \rangle = 2.3 \times 10^{-4}$



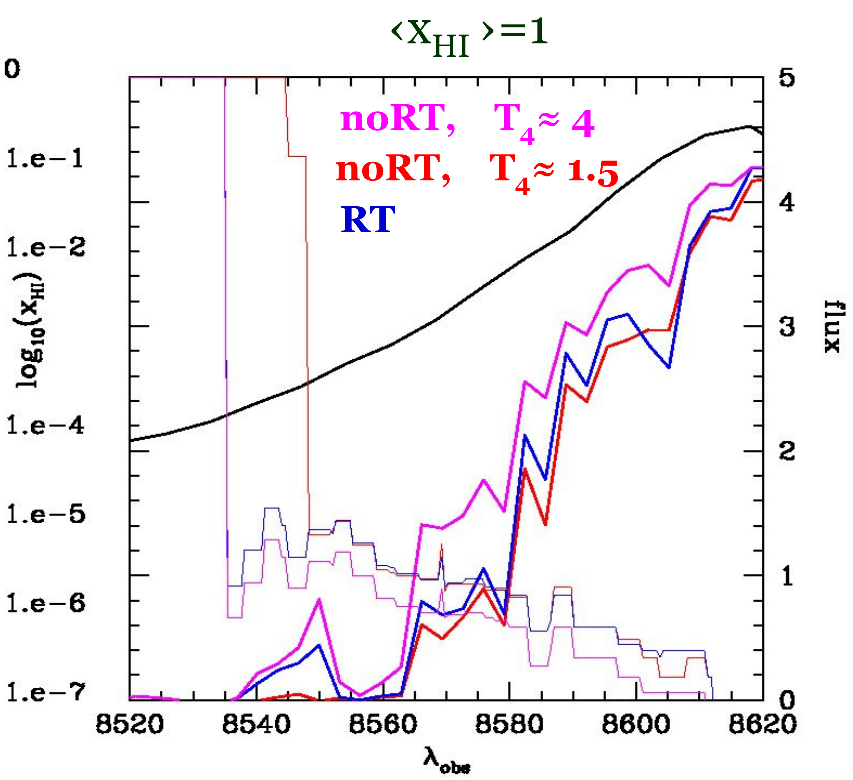
- Neglecting RT effects slightly overestimates the transmitted flux

$t_Q = 10^7$ yr, $N_\gamma = 2 \times 10^{57} s^{-1}$

Temperature Effects on the Transmitted Flux

- Temperature of a fully ionized H/He gas
  QSO-like hard spectrum source
  $T \approx 5 \times 10^4$ K

- Collisional ionizations become important and affect the transmitted flux significantly

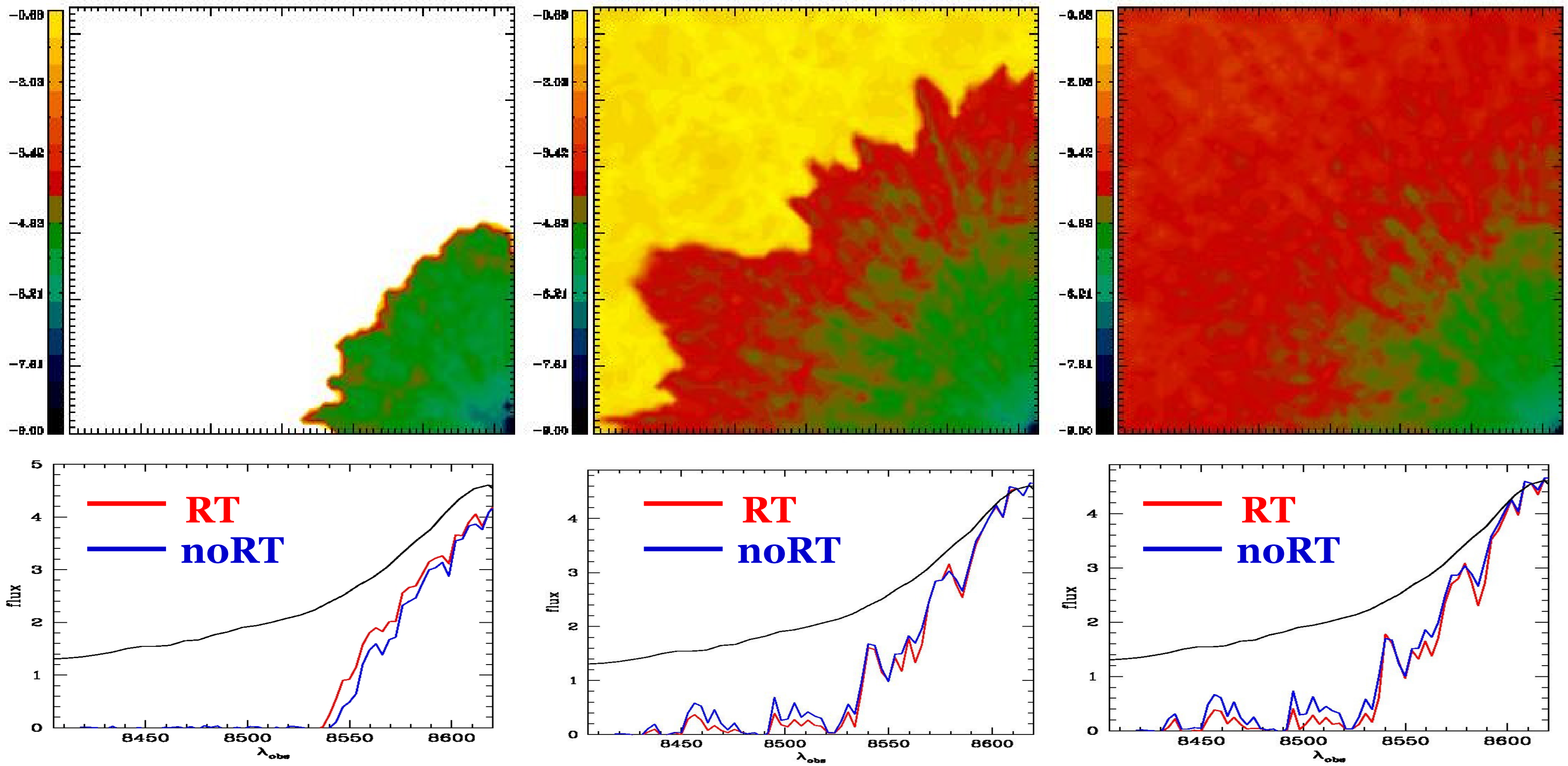


- Collisional ionizations must be included in the models

- Temperature evolution is crucial

RT Effects on the Transmitted Flux

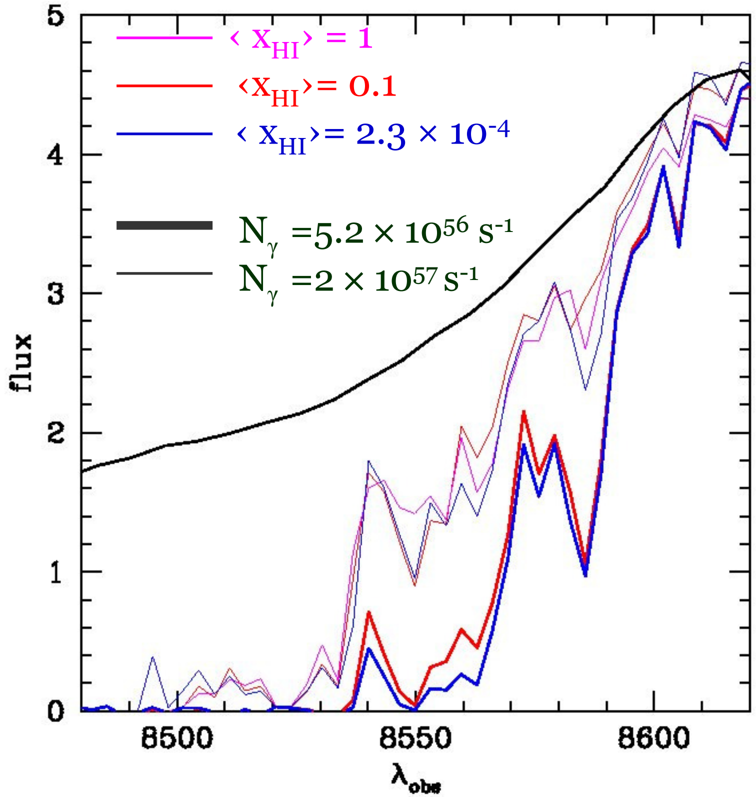
$\langle x_{HI} \rangle = 1$ | $\langle x_{HI} \rangle = 0.1$ | $\langle x_{HI} \rangle = 2.3 \times 10^{-4}$



- Neglecting RT effects slightly over estimate the transmitted flux
- $\Delta\lambda_{trans}$ virtually independent of $\langle x_{HI} \rangle$ (Bolton & Haehnelt, 07)
- $F(\lambda)$ profile almost independent on $\langle x_{HI} \rangle$

$t_Q = 10^7$ yr, $N_\gamma = 2 \times 10^{57} s^{-1}$

Hints on the QSO Ionizing Luminosity



- Inner profile completely independent on x_{HI}
- Inner profile significantly sensitive to N_γ

The spectral signature of the H_{II} region can be used to determine the quasar ionizing luminosity

Summary & Conclusions

Radiative Transfer Effects

- Asymmetries in the H_{II} region shape increase with decreasing x_{HI}
- Suppression of the QSO photo-rate slightly reduces the transmitted flux

Absorption Spectra Analysis

- ➢ The IGM ionization state cannot be constrained neither by the size of the H_{II} regions nor by the profile of the transmitted flux
- ➢ The profile of the transmitted flux can be used to infer the QSO luminosity