Constraints From High-Redshift Absorption Spectra

Andrei Mesinger

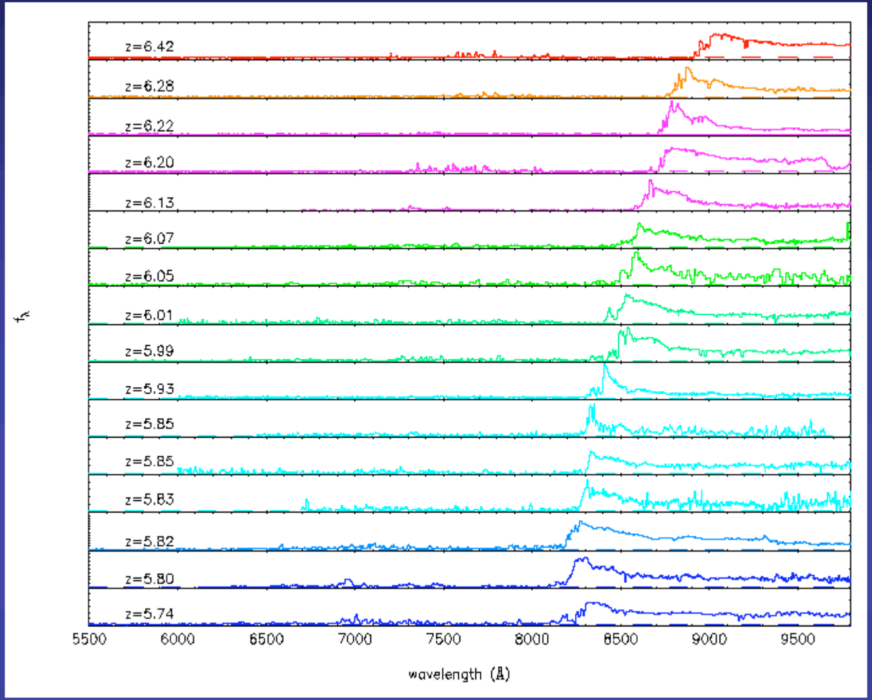
Yale University

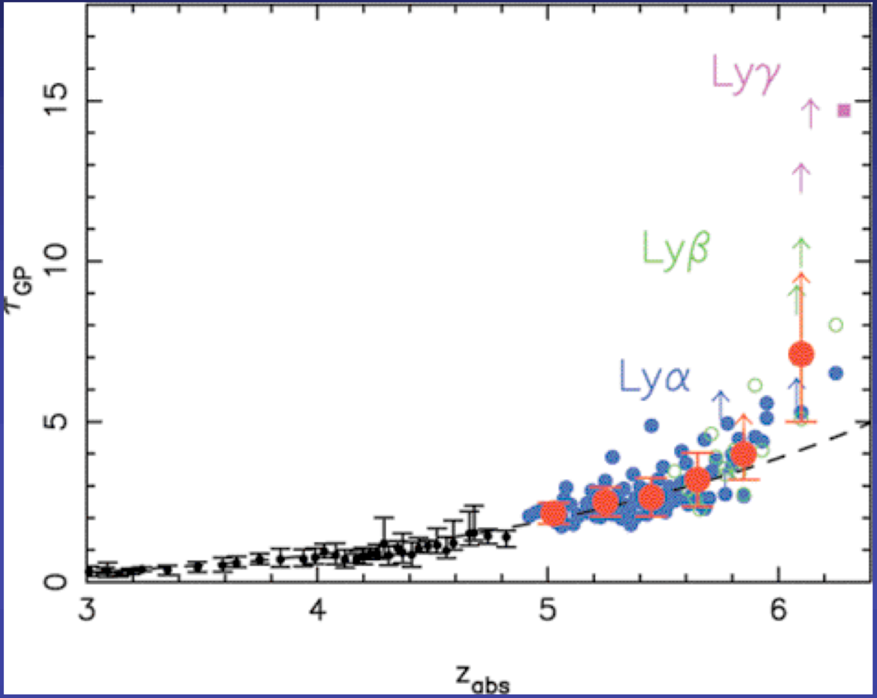
Collaborators: Zoltán Haiman, Steven Furlanetto

SDSS QSOs

Fan et al. (2006)

reionization ends at z ~ 6 ?



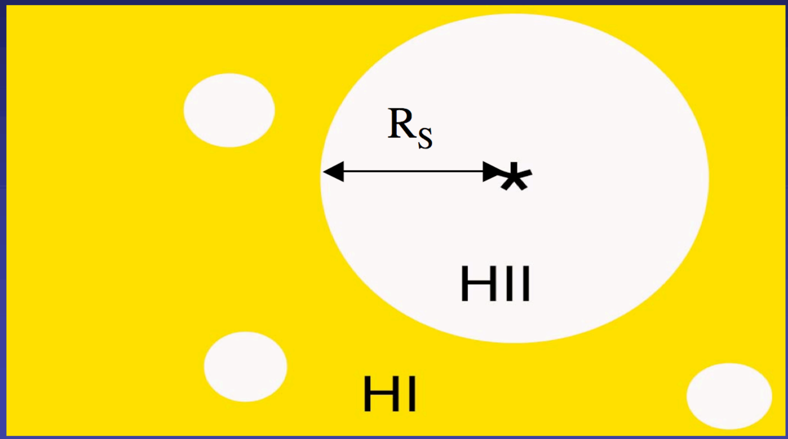


$x_{HI}(z{\sim}6) \geq 10^{-3}$

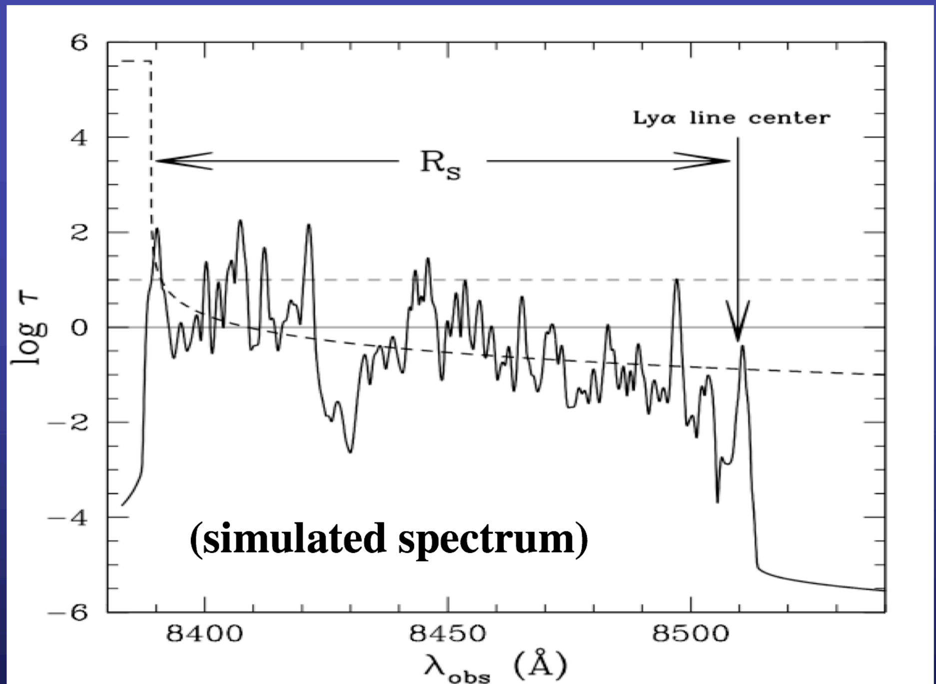
Caution:

- averaging over the density field to get x_{HI} is not accurate; $\langle x_{HI} \rangle \propto \langle \tau \rangle \neq -\ln \langle e^{-\tau} \rangle$
- conversion to $\tau_{Ly\alpha}$ from β and γ even more uncertain
- large scatter between lines of sight

Cosmological HII Regions



e.g. Cen & Haiman (2000);
Madau & Rees (2000)



Two contributions to the Lyα optical depth,

$\tau_\alpha = \tau_R + \tau_D$

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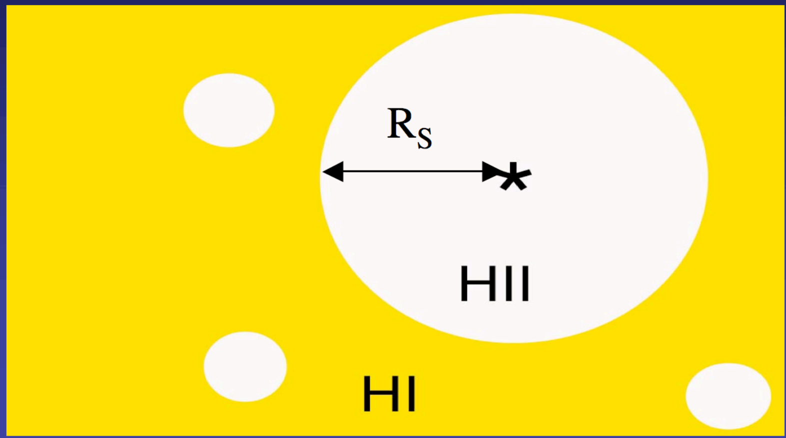

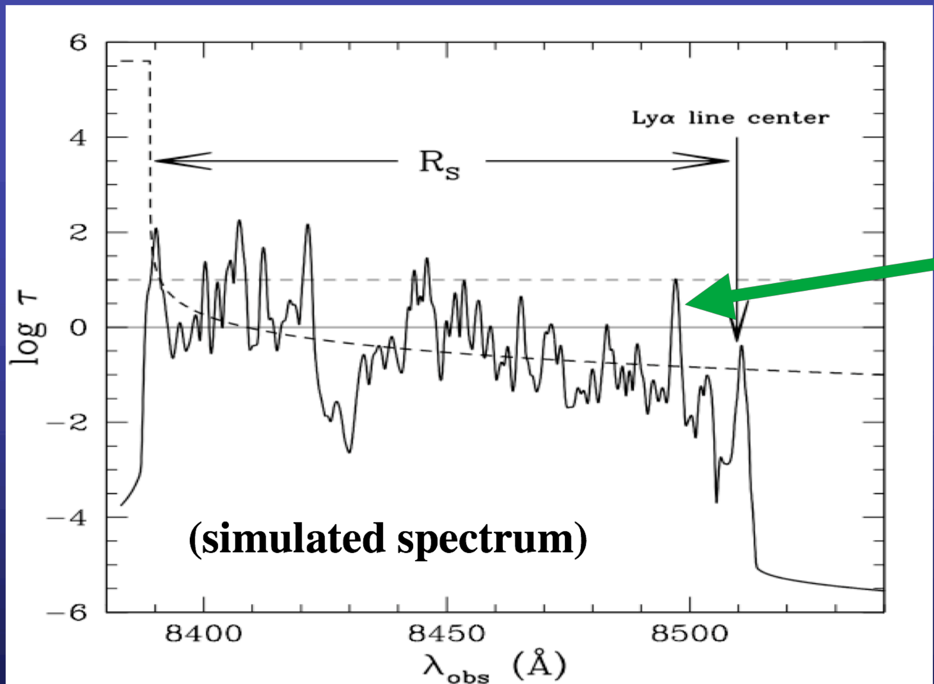

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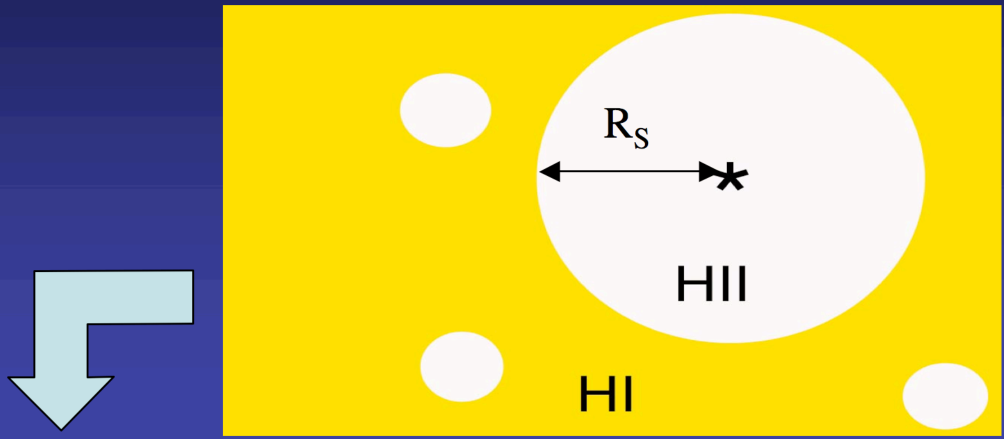
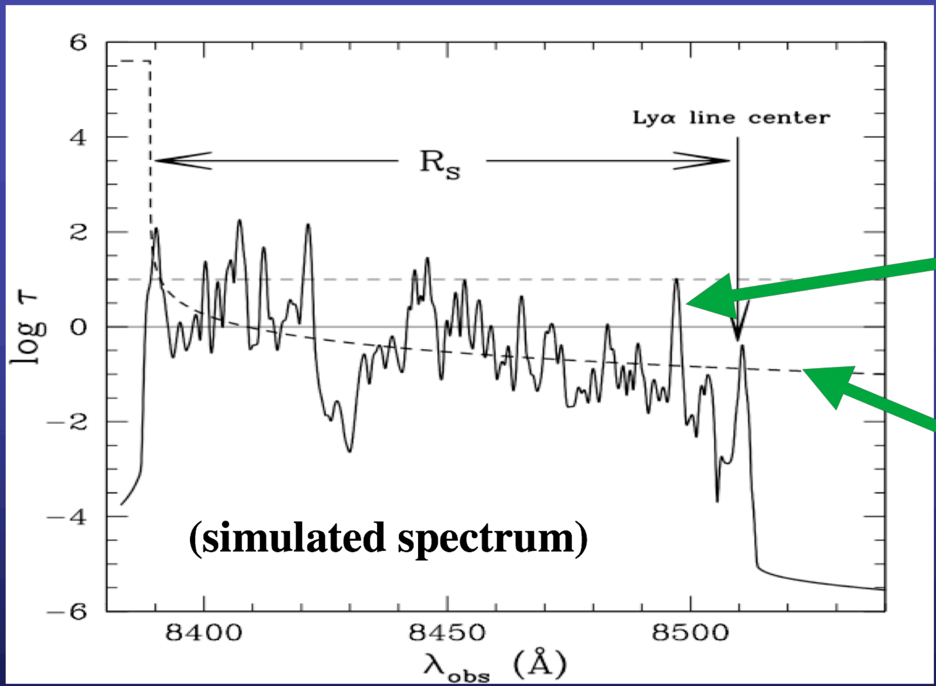




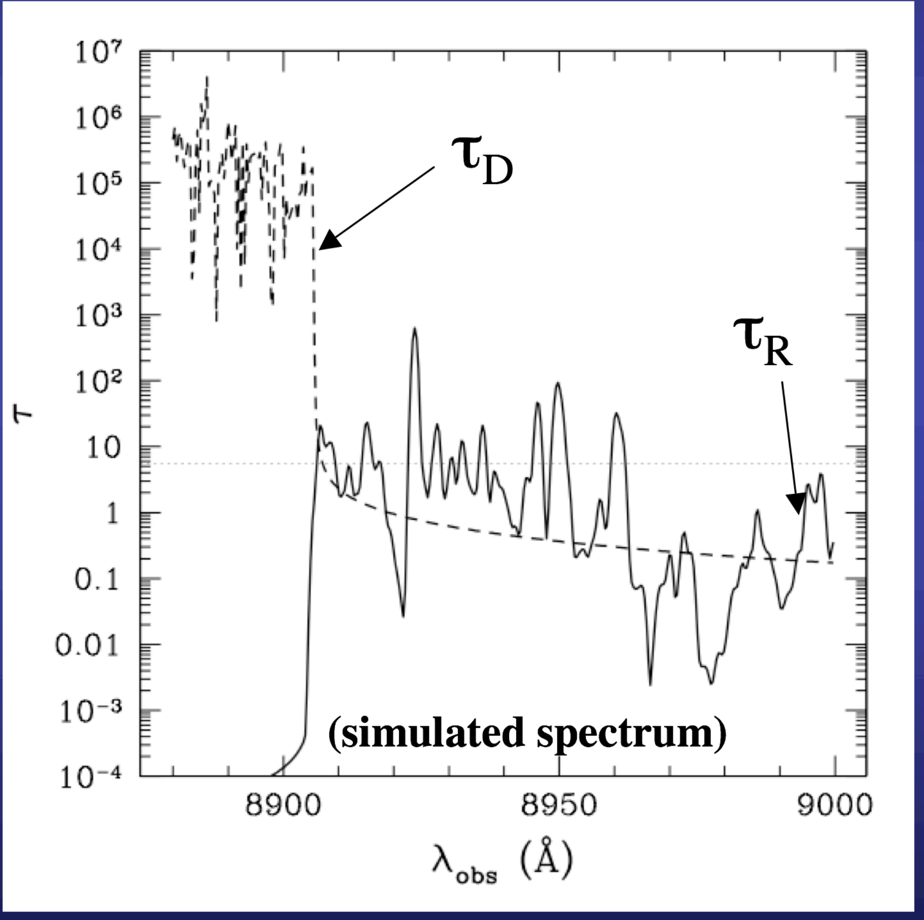
Two contributions to the Lyα optical depth,
$\tau_\alpha = \tau_R + \tau_D$

τ_R - resonance optical depth
(not sensitive to x_{HI} or R_S)

τ_D - damping wing optical depth
(very sensitive to x_{HI} and R_S)

Creating Simulated Spectra

Model spectra using LOSs from hydro simulation (Cen et al. 2003)



Free Parameters:

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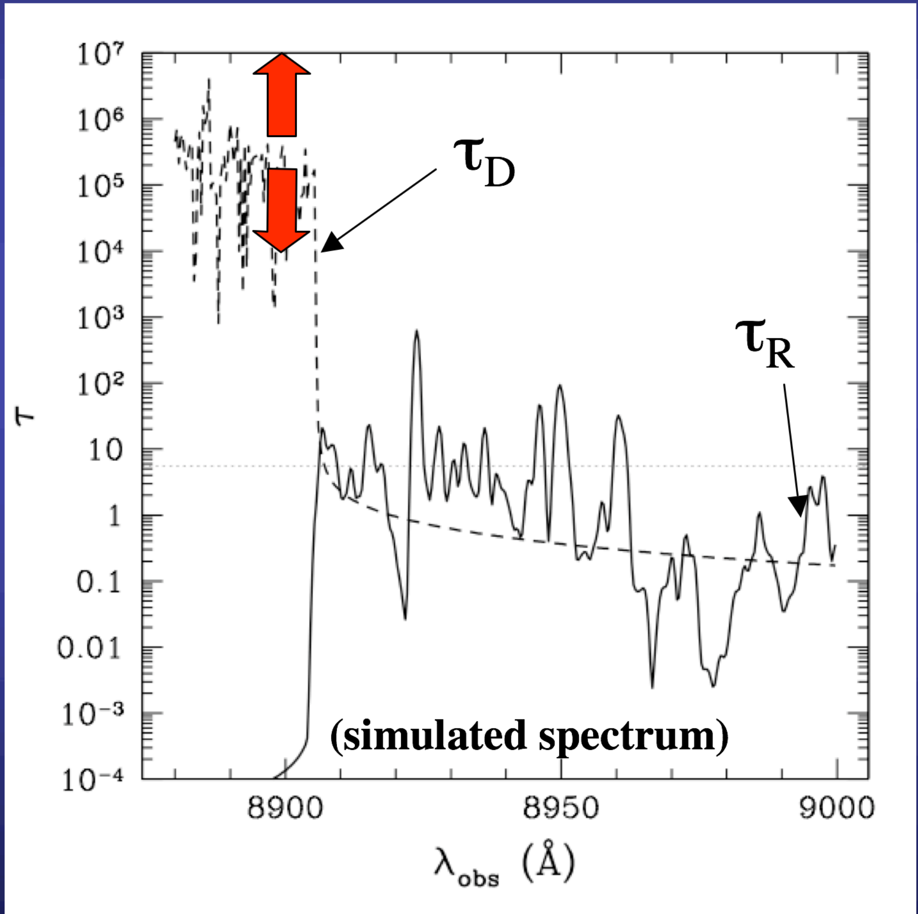

Free Parameters:

- IGM neutral fraction, x_{HI}

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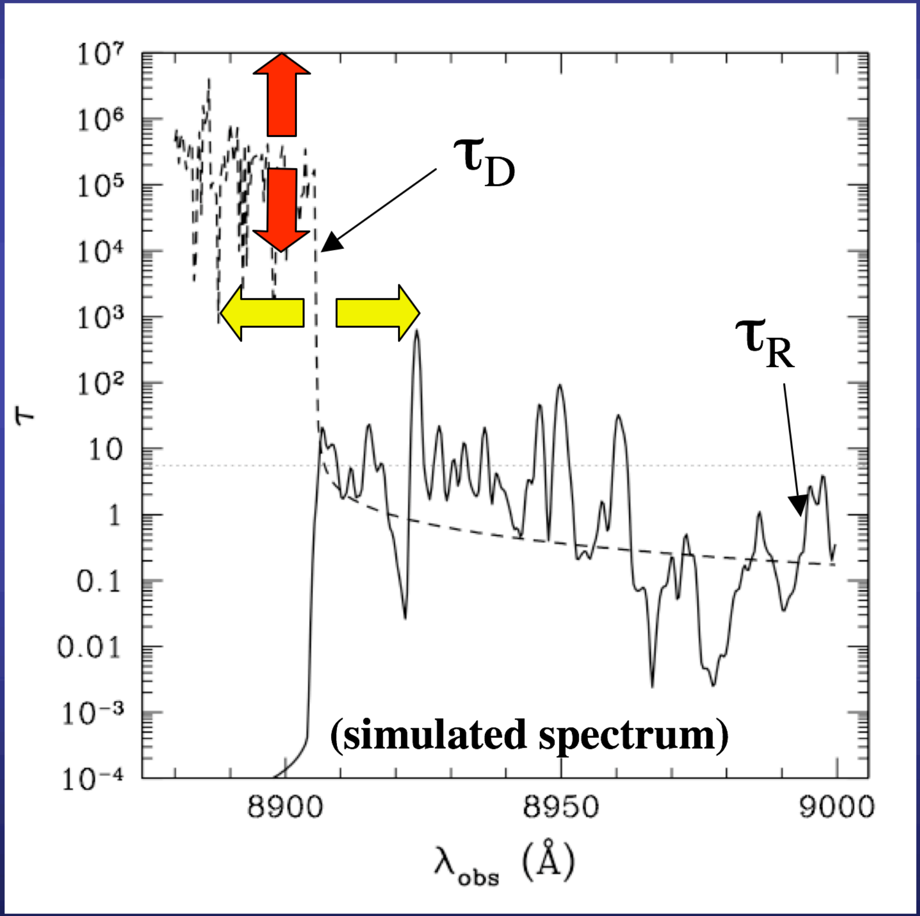

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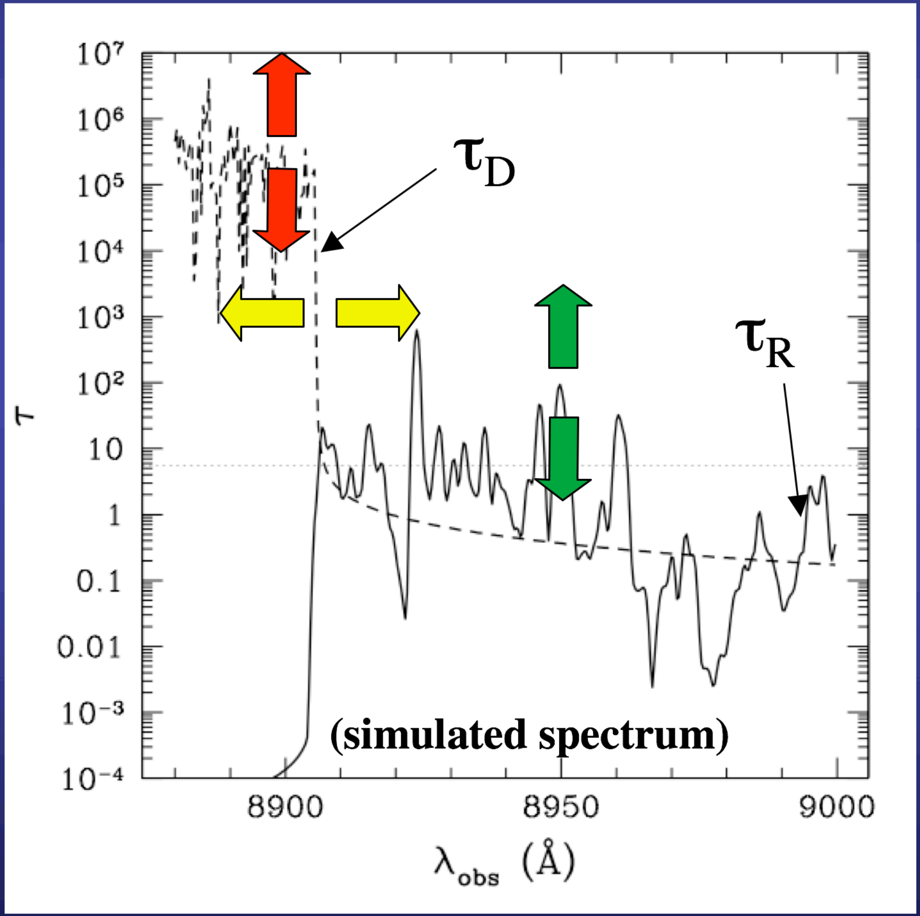

Free Parameters:

- IGM neutral fraction, x_{HI}
- Strömgren sphere radius, R_S
- QSO's ionizing luminosity, L_ν

Important to keep parameters free and treat each spectrum independently

Caution:

Mesinger & Haiman 2004, 2007 (damping wing)

$\neq$

"near-zone" or "proximity-zone" size constraints on x_{HI}

⇑

of dubious reliability (Mesinger & Haiman 2004; Bolton & Haehnelt 2007; Maselli et al. 2007; Lidz et al. 2007)

Procedure

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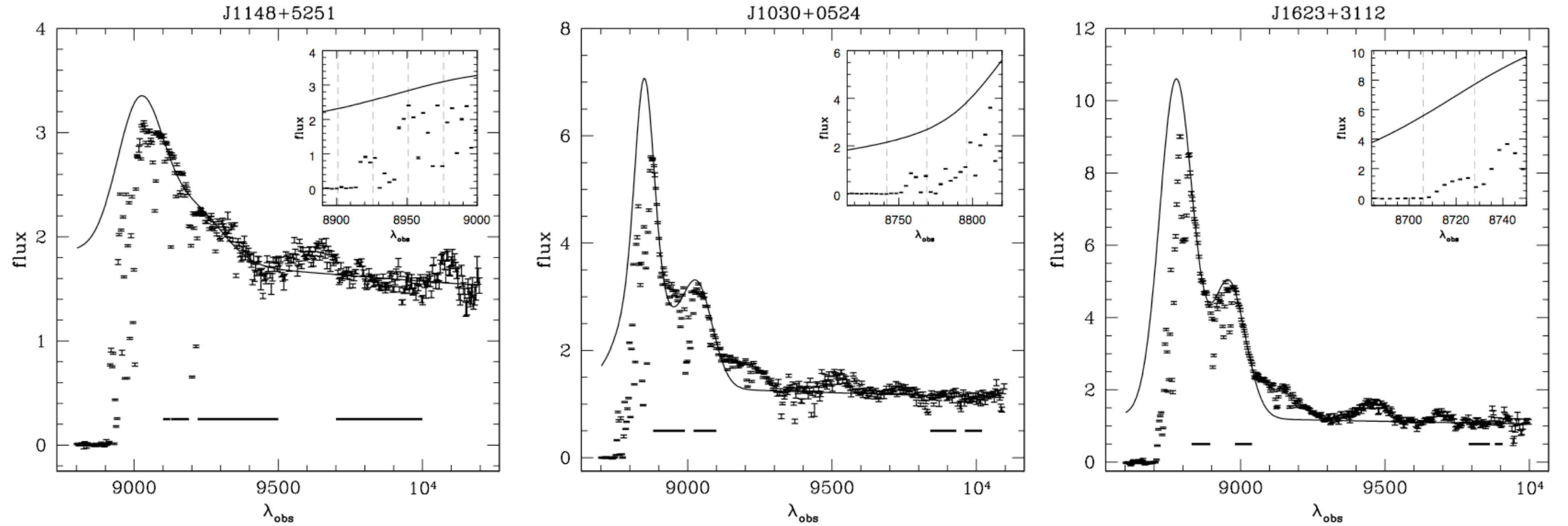
- Fit each quasar's intrinsic emission using clean spectral regions in the Keck ESI observed spectra redward of the Lyα line center
- Using the Kolmogorov-Smirnov test, statistically compare the cumulative probability distributions of simulated and observed optical depths in several spectral bins, blueward of the Lyα line center (very similar to an independent analysis by Rollinde et al. 2005; also similar to a cruder version in Mesinger et al. 2004)

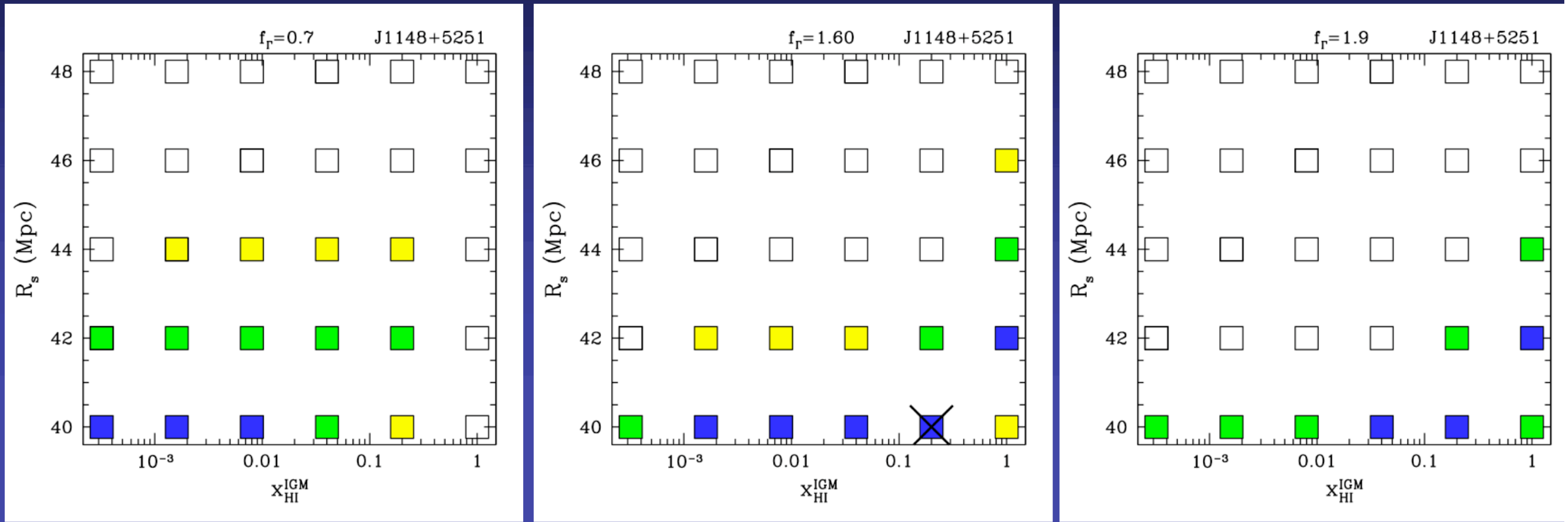
Fitting QSO Intrinsic Emission

Mesinger & Haiman (2007)



double Gaussian for Lyα + single Gaussian for Nv + power law continuum

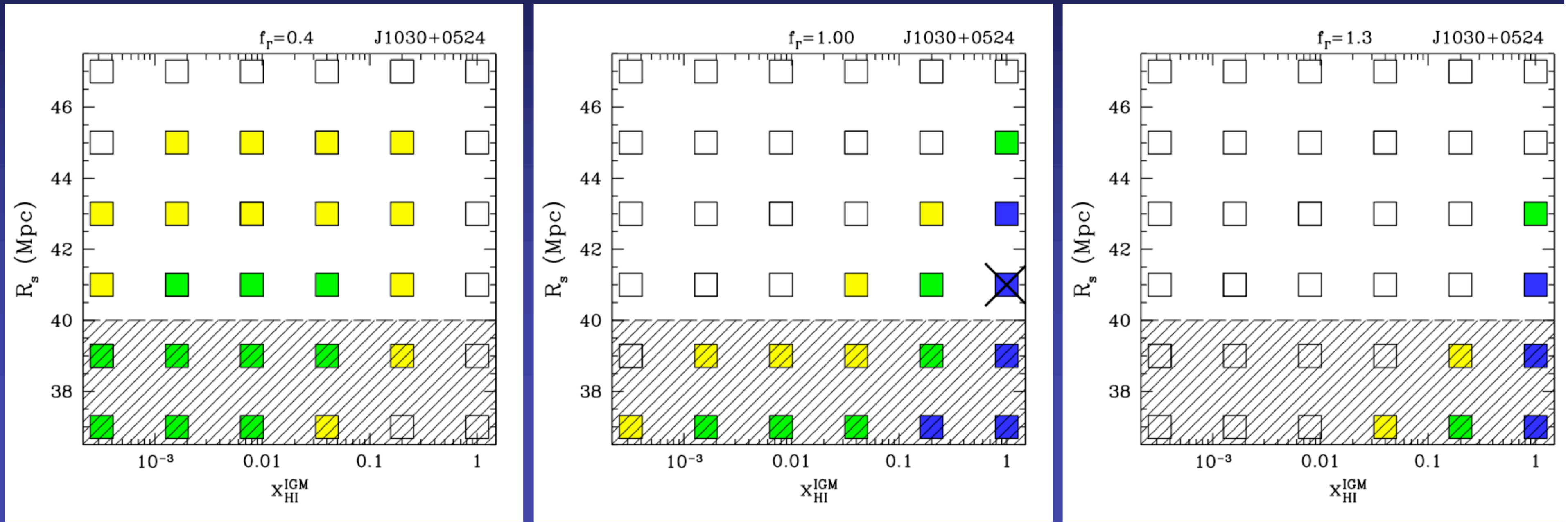
J1148+5251, z = 6.42



Peak likelihood of 3% occurs at $(R_S, x_{HI}, N_{ph}) = (40\text{ Mpc}, 0.16, 2.1\text{x}10^{57}\text{s}^{-1})$

- $40\text{ Mpc} \leq R_S \leq 42\text{ Mpc}$
- $x_{HI} \leq 1$
- $0.9\text{x}10^{57}\text{s}^{-1} \leq N_{ph} \leq 2.5\text{x}10^{57}\text{s}^{-1}$

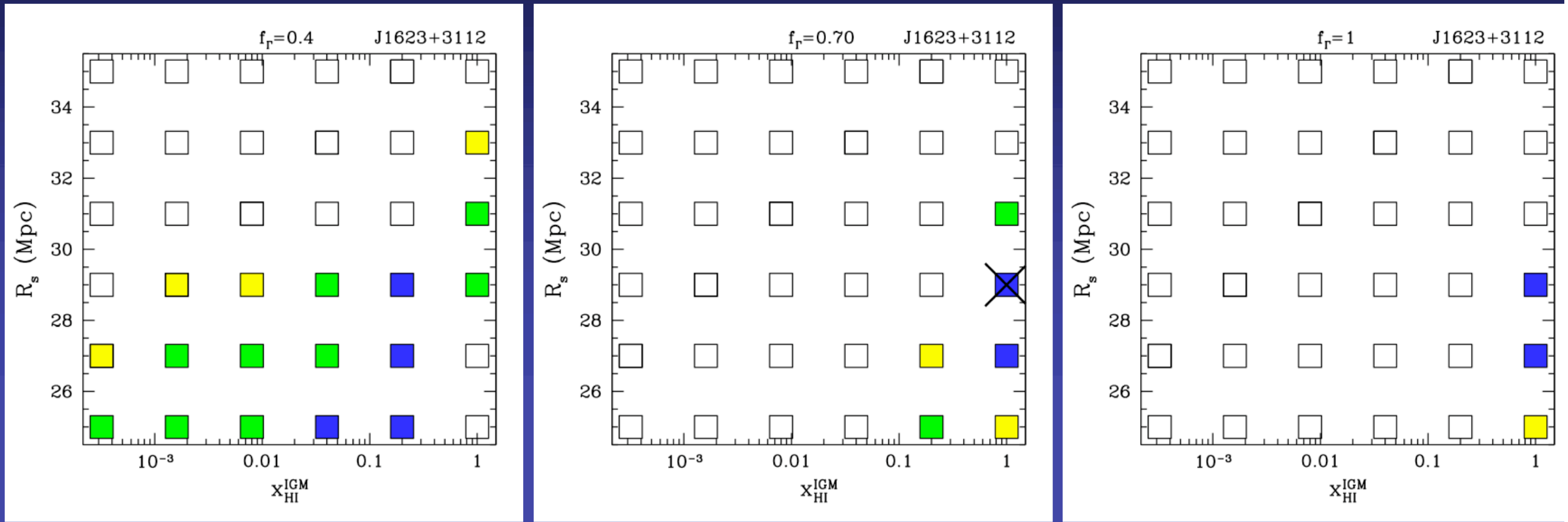
J1030+0524, z = 6.28



Peak likelihood of 34% occurs at (R_S, x_{HI}, N_{ph}) = (41 Mpc, 1.0, $1.3\text{x}10^{57}s^{-1}$)

- 41 Mpc ≤ R_S ≤ 45 Mpc
- 0.033 ≤ x_{HI}
- $0.9\text{x}10^{57}s^{-1}$ ≤ N_{ph} ≤ $1.7\text{x}10^{57}s^{-1}$

J1623+3112, z = 6.22



Peak likelihood of 39% occurs at $(R_S, x_{HI}, N_{ph}) = (29\text{ Mpc}, 1.0, 0.9\text{x}10^{57}\text{s}^{-1})$

- $25\text{ Mpc} \leq R_S \leq 29\text{ Mpc}$
- $0.033 \leq x_{HI}$
- $0.5\text{x}10^{57}\text{s}^{-1} \leq N_{ph} \leq 1.7\text{x}10^{57}\text{s}^{-1}$

Sanity Checks
(not meant to be taken too seriously)

- Isocontours behave as expected

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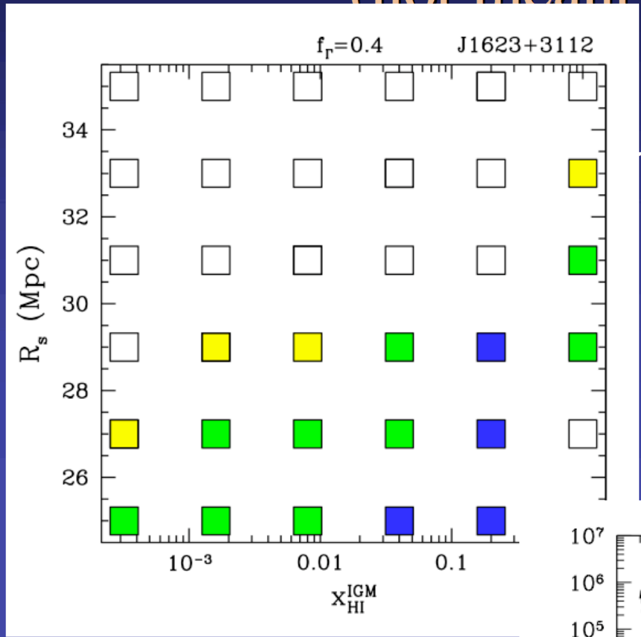

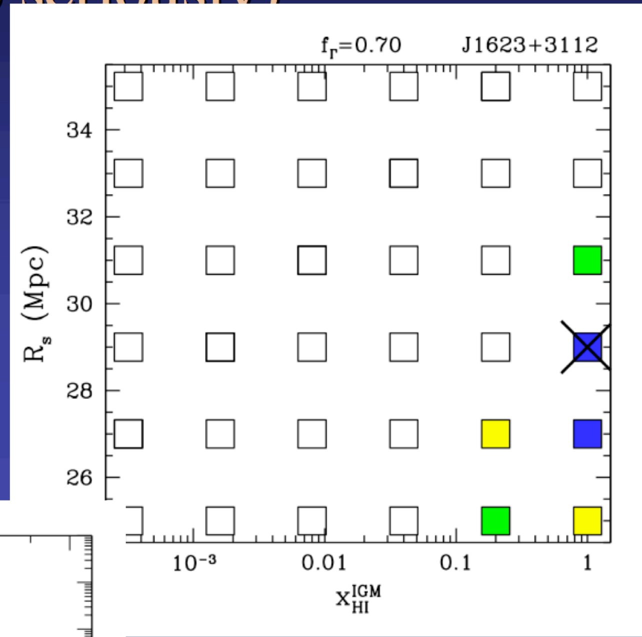

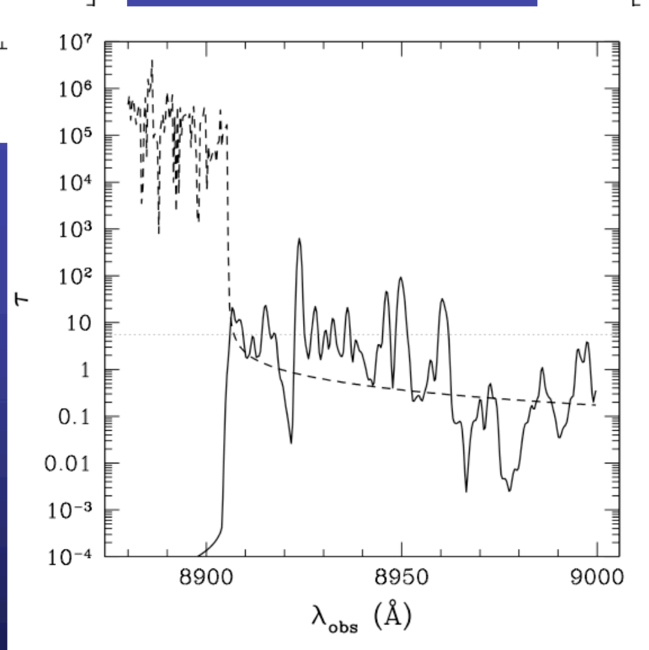

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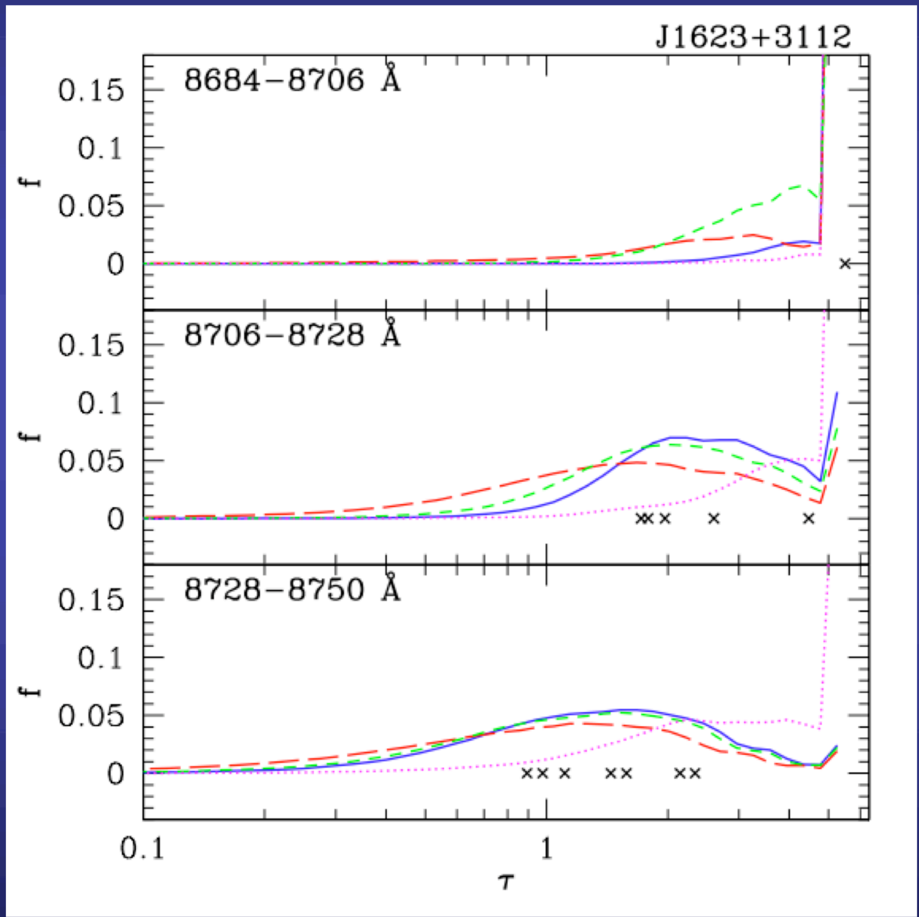
- Our results on x_{HI} agree in relative terms with estimates obtained from GP troughs (Fan et al. 2006)
- The maxim likelihood values of N_{ph} match the relative strengths of the QSO continua redward of Lyα
- In terms of peak likelihood values, the quasar with the smallest HII region also has the highest value of x_{HI} and smallest value of N_{ph}

Constraints come from…



τ

$(R_S, x_{HI}, N_{ph}) =$

	(29 Mpc, 1.0, 0.9x10^{57}s^{-1})
	(29 Mpc, 0.033, 0.9x10^{57}s^{-1})
	(33 Mpc, 1.0, 0.9x10^{57}s^{-1})
	(29 Mpc, 1.0, 0.13x10^{57}s^{-1})

- Although some models perform well in one or two bins, only the blue curve does well in all bins.
- Data doesn't show evidence for a low-τ tail, as would be expected in models with small x_{HI}.

Transition slide

Improvements in the interpretation of high-z spectra should take advantage of improved modeling (density and velocity biases, realistic ionization topology, etc.)

The major difficulty lies in the enormous dynamical range required…

Even with modest halo resolution (Springel & Hernquist 2003) of tens of dark matter particles per halo, current simulations are limited to box sizes of ≤ tens of Mpc --> not enough to model highly-non linear processes such as reionization!

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Enter "pseudo"-simulations…
Fast! (e.g. PTHalos and Pinocchio model halo fields)

Procedure

Halo fields

(updated form of the independently developed "peak-patch" formalism of Bond & Myers 1996

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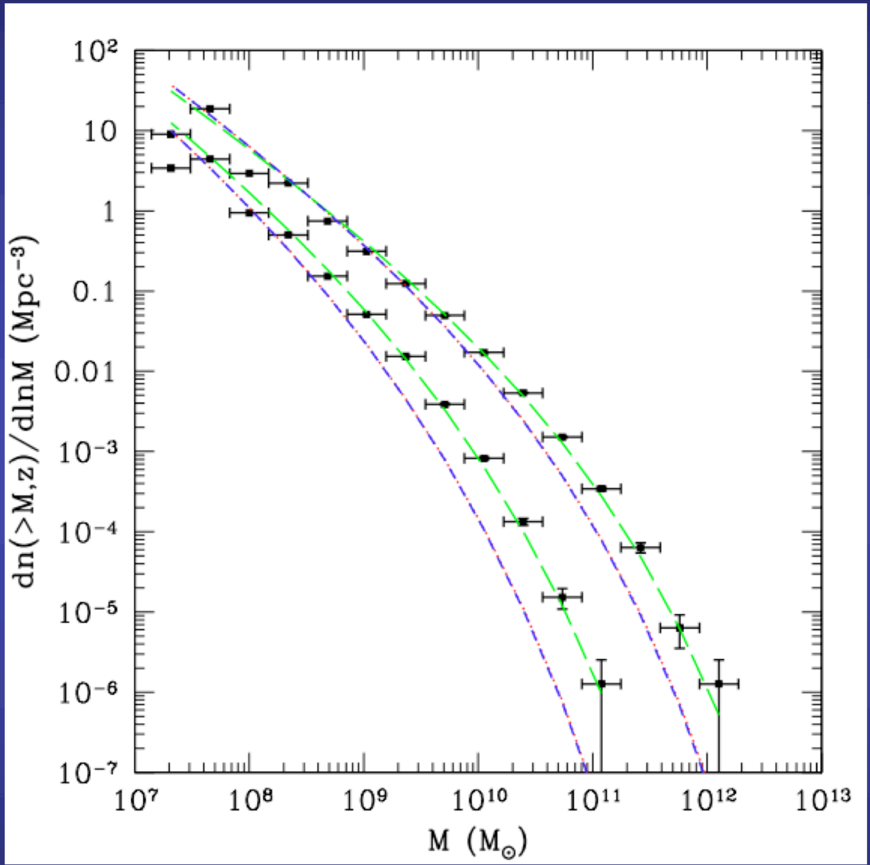
3. adjust halo locations using linear-order displacements (Zel'Dovich 1970)

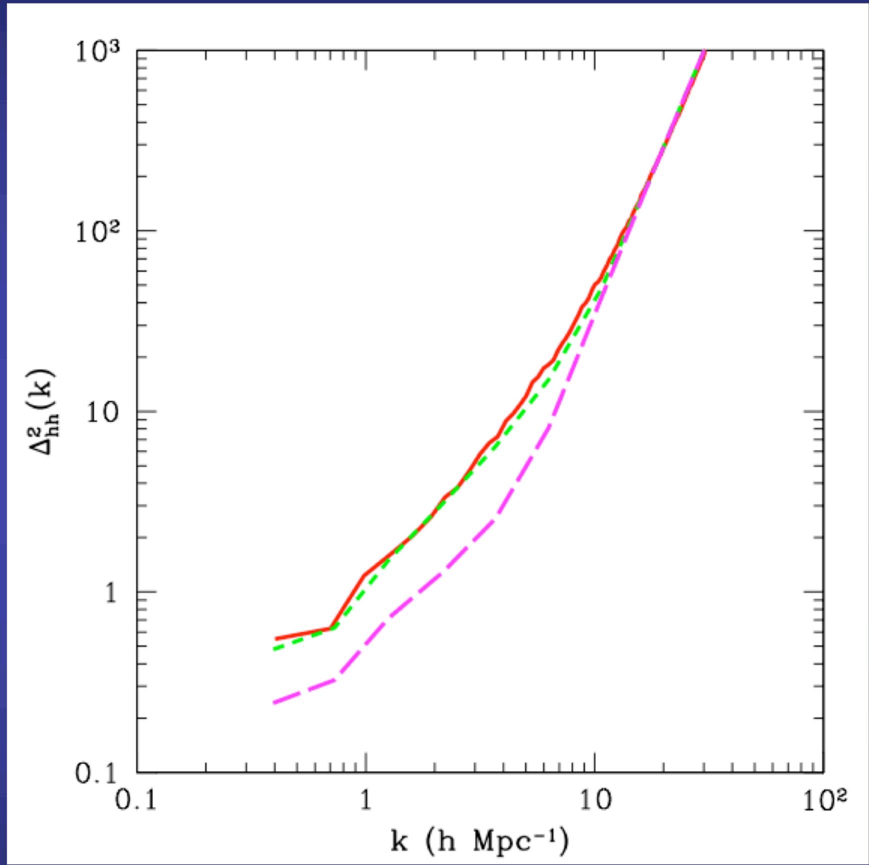
Ionization fields

4. perturb linear density field using linear-order displacements (Zel'Dovich 1970)
5. filter ionized regions from the halo and perturbed density fields using excursion-set formalism (e.g. Furlanetto et al. 2004)

Halo Filtering

Mesinger & Furlanetto (2007)





z=8.7 N-body halo field from McQuinn et al. (2006)

Halo Filtering

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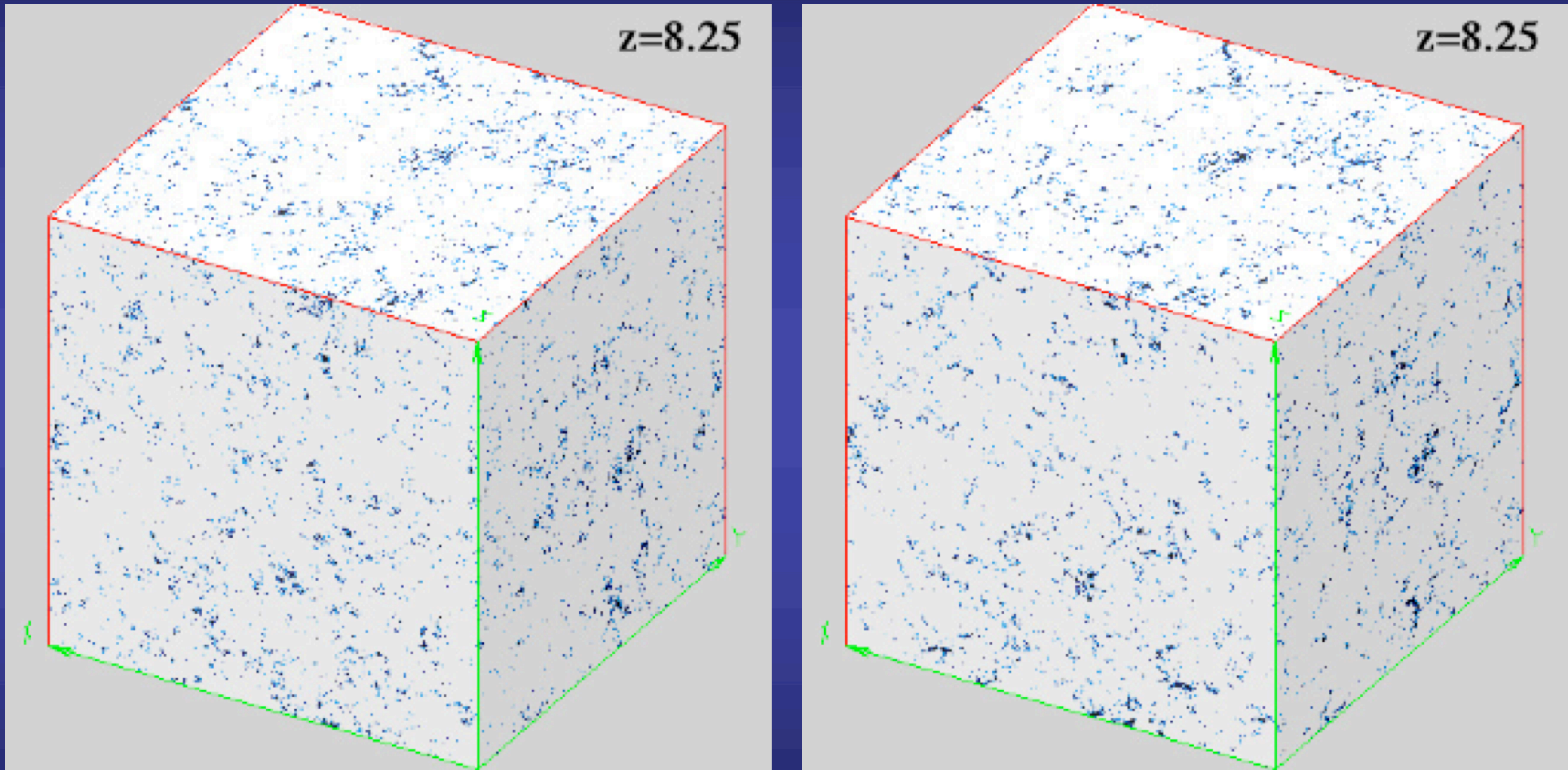
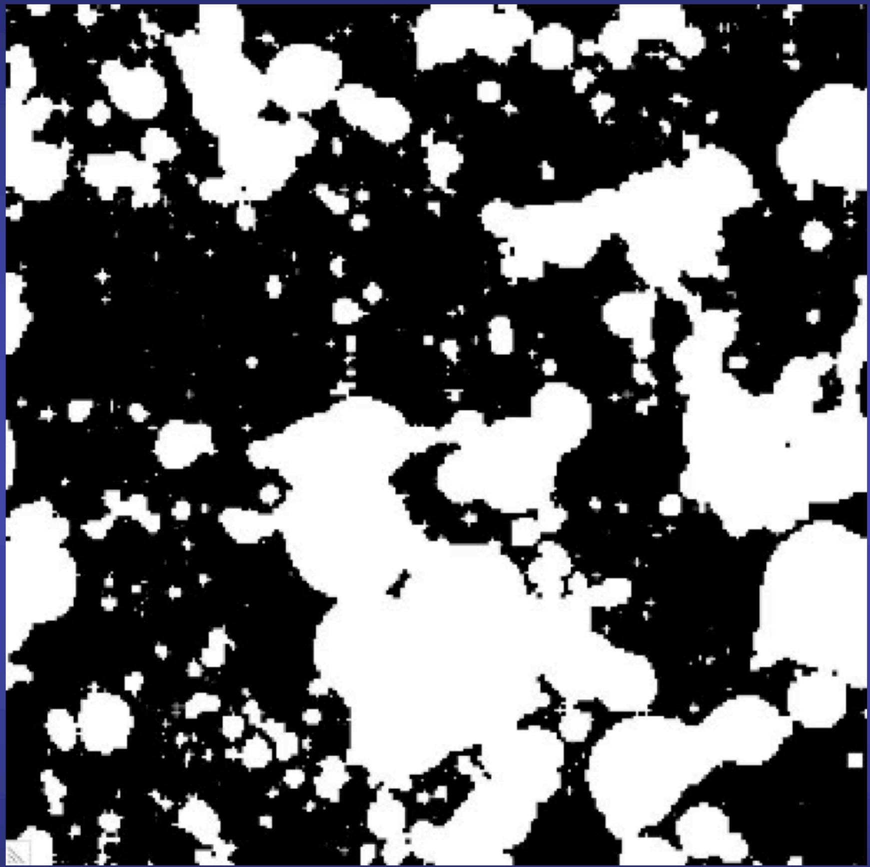
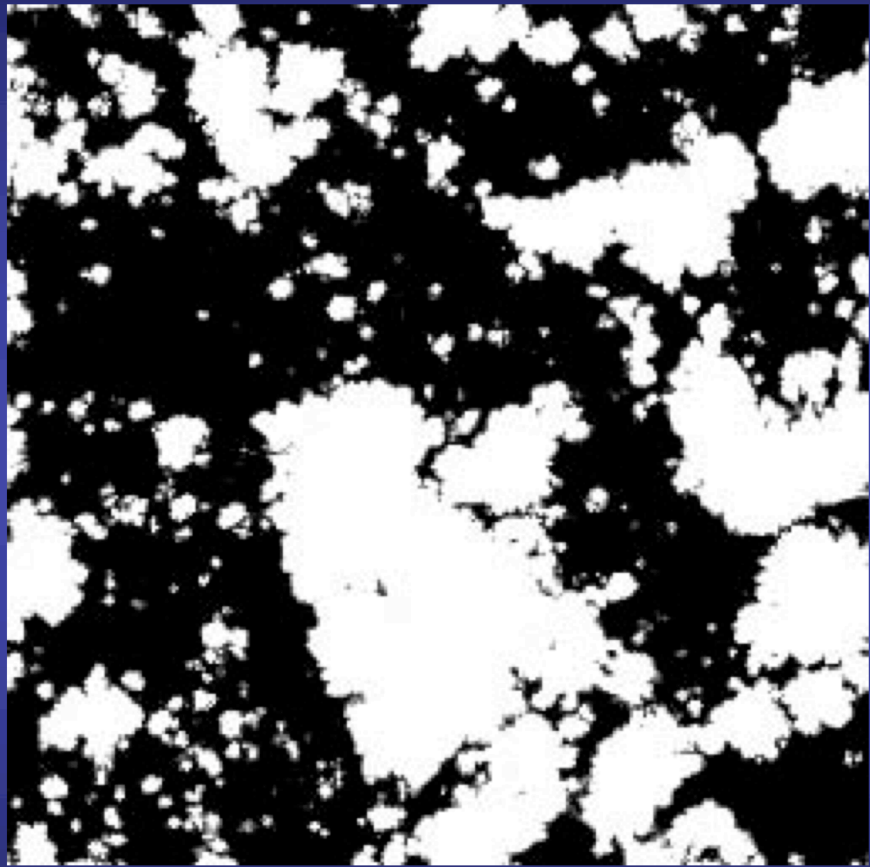


without adjusting halo locations | with adjusting halo locations

HII Bubble Filtering

Mesinger & Furlanetto (2007)

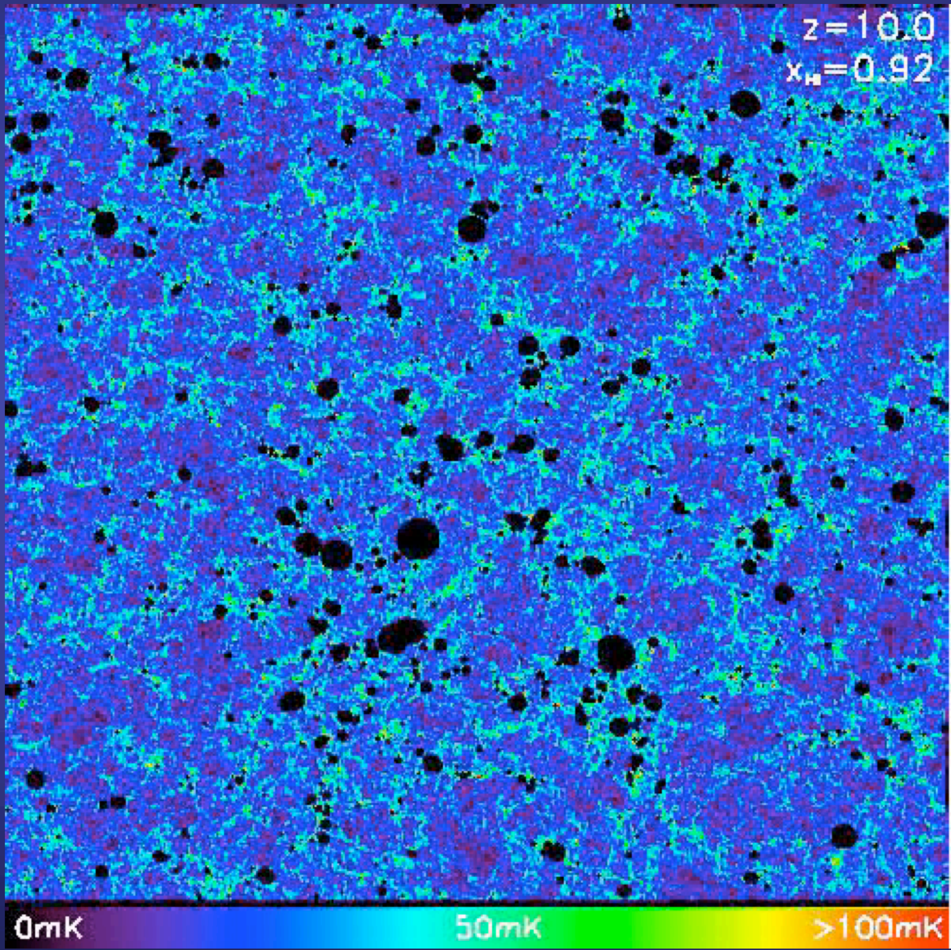


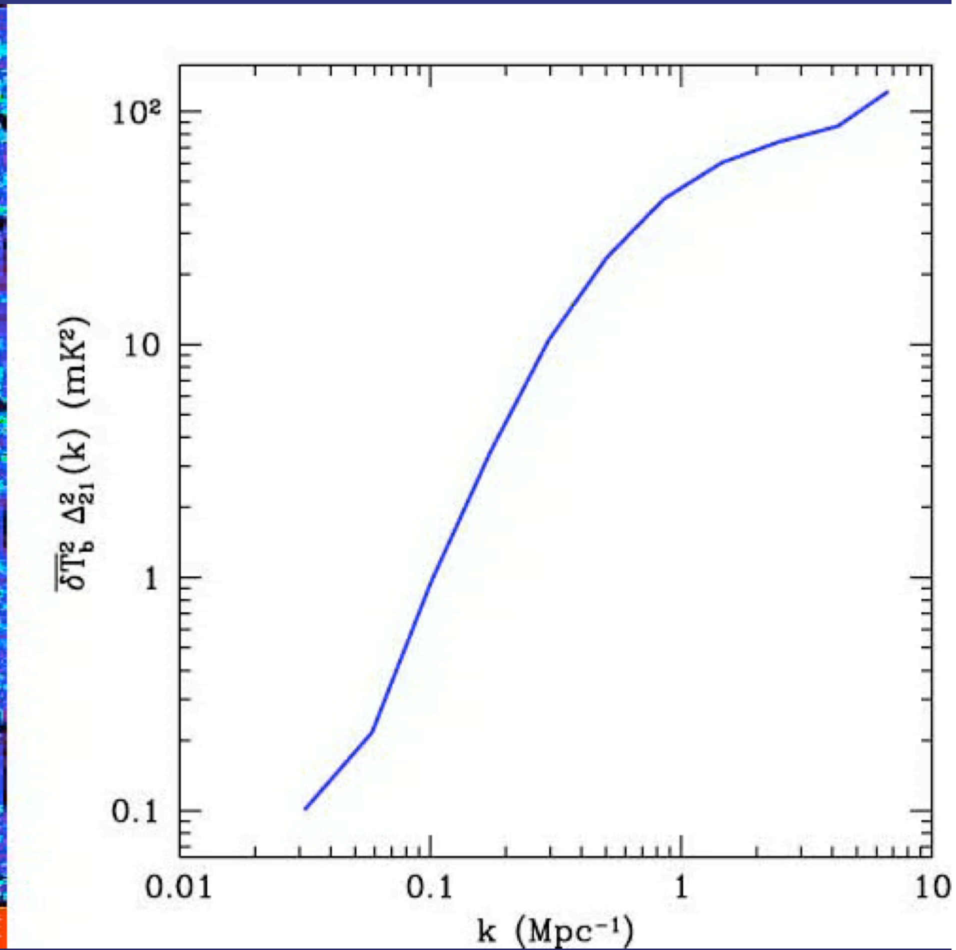


RT ionization field from
Zahn et al. (2007)

Cool PR Movie

available at http://pantheon.yale.edu/~am834/Sim





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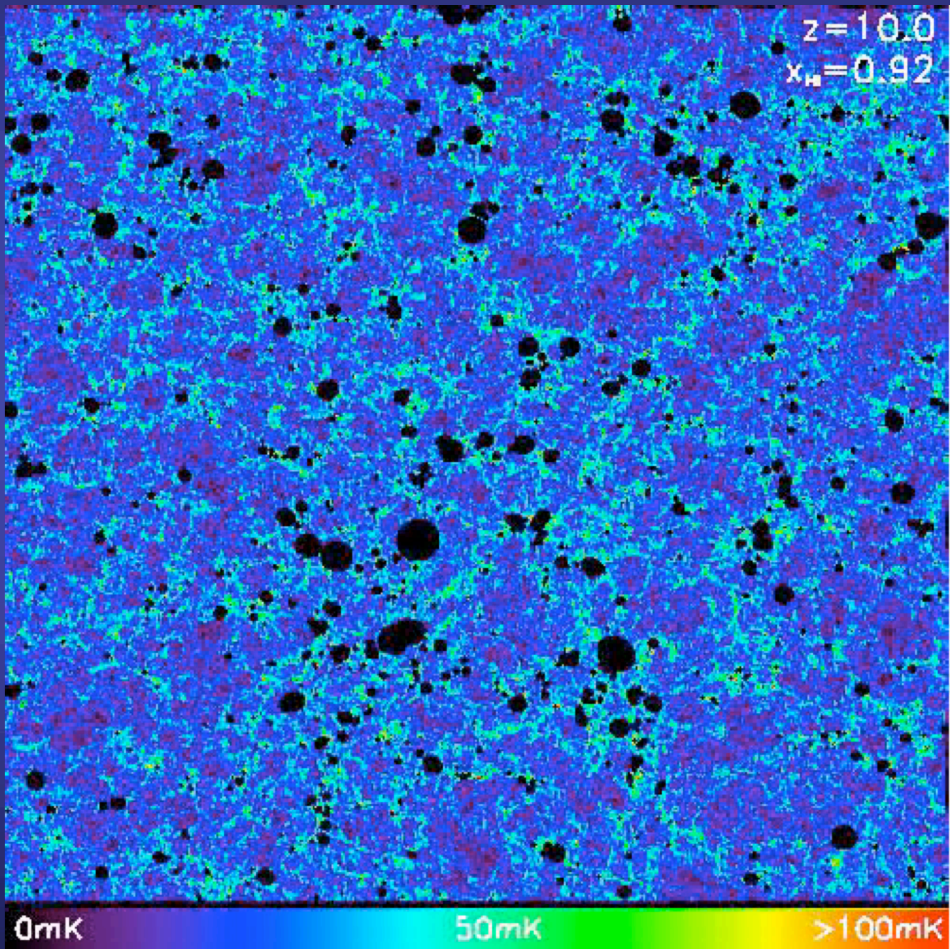

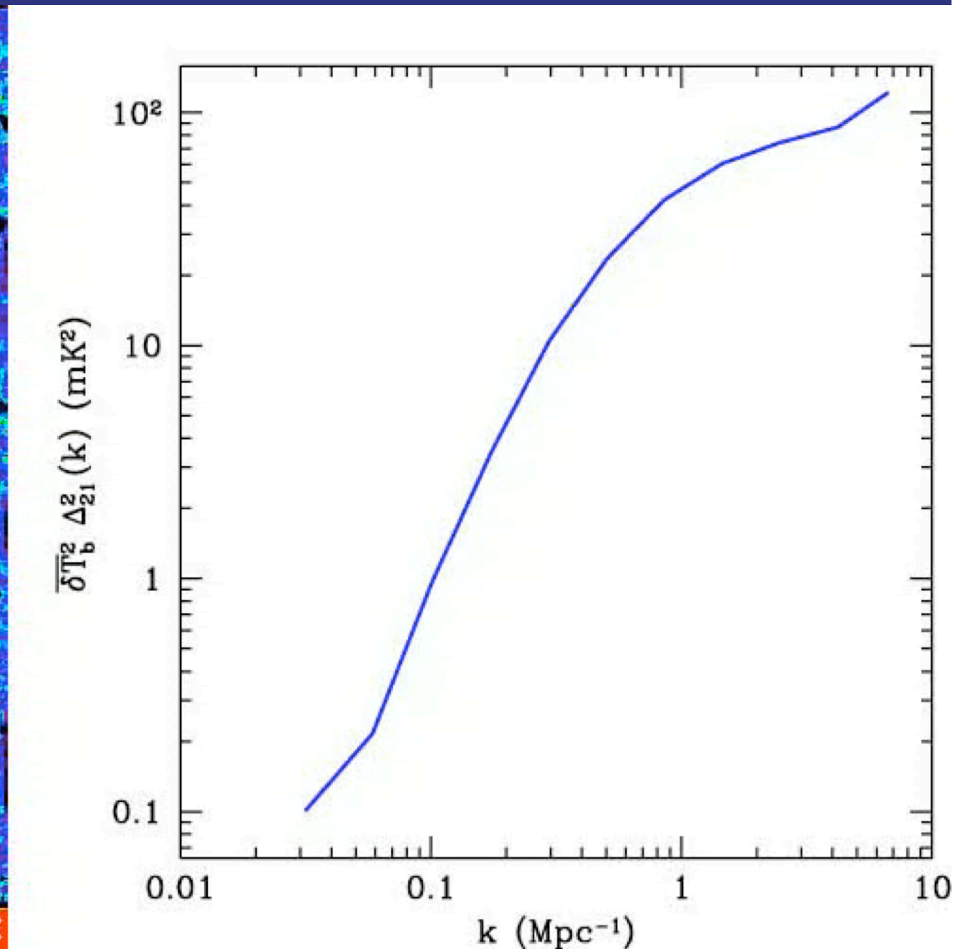

Conclusions

- Modeling of Lyα absorption statistics of QSO HII regions can be a promising tool to extract relevant parameters
  - J1148+5251: 40 Mpc $\leq R_S \leq$ 42 Mpc; $x_{HI} \leq 1$; $0.9\times10^{57}s^{-1} \leq N_{ph} \leq 2.5\times10^{57}s^{-1}$
  - J1030+0524: 41 Mpc $\leq R_S \leq$ 45 Mpc; $0.033 \leq x_{HI}$; $0.9\times10^{57}s^{-1} \leq N_{ph} \leq 1.7\times10^{57}s^{-1}$
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- Our semi-numeric simulation can be a very useful scientific tool:
  - density and velocity biases, ionization topology, but also radiative and chemical feedback, LAE studies, deterministic merger trees, training ground for bubble detection algorithms and other 21-cm software, allows for quick parameter variance…
  - Fairly easy to fold-in smaller scale physics calibrated from numerical simulations.

The End

Kraj

La Fine

Vége

Le Fin

Einde

Hasof

Vanakkam

끝