Lyα Galaxies as a Probe of the High-z Universe

Mark Dijkstra

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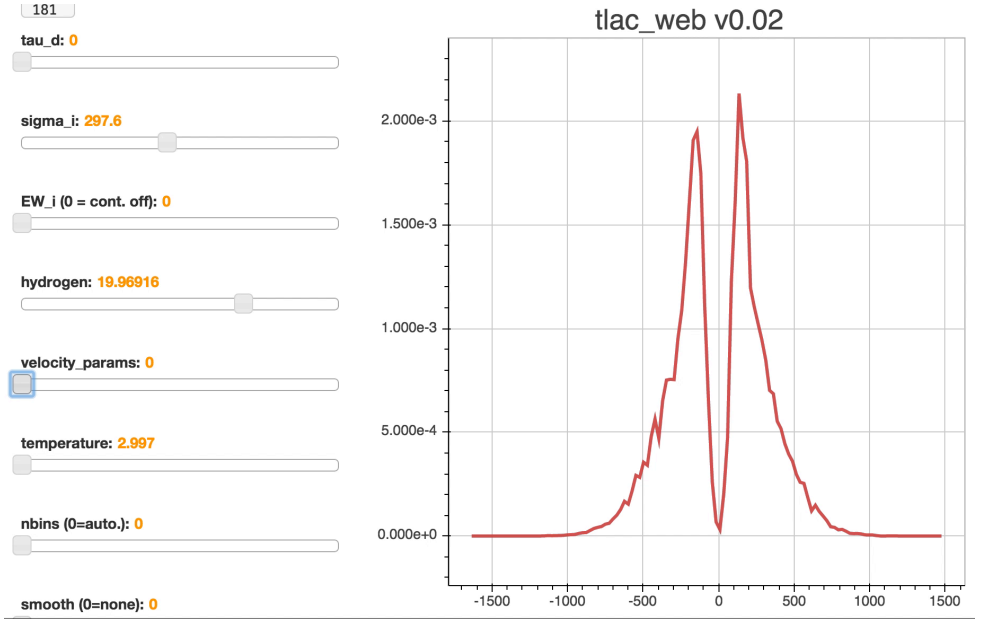
Credit: Andrew Chung (MPA)

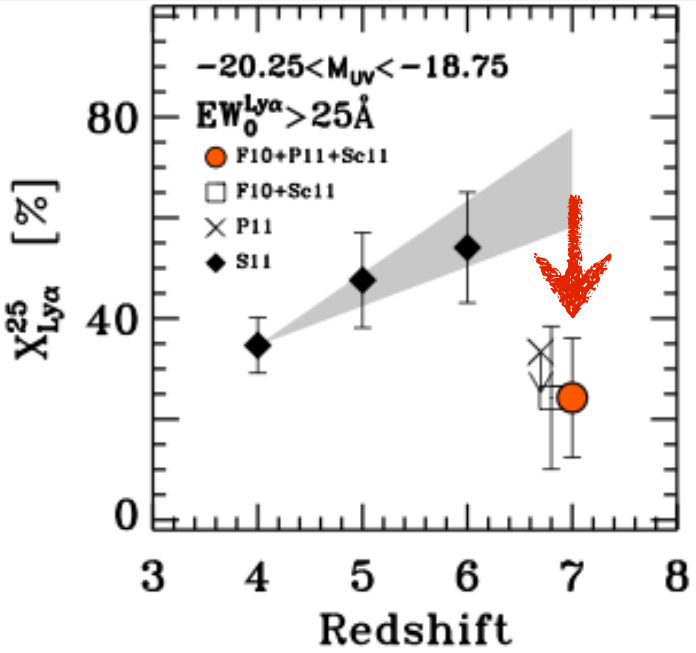


Credit: Max Gronke (Oslo)

The Suppressed Lyα flux from galaxies at z>6

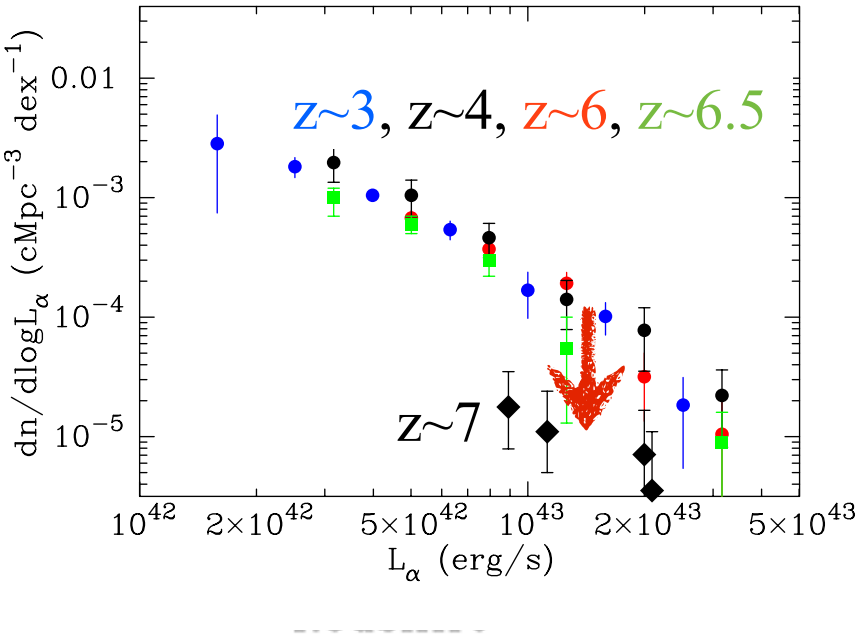
`Lyα fraction'

Stark et al., Pentericci et al. Ono et al., Tilvi et al.



LAE Luminosity function

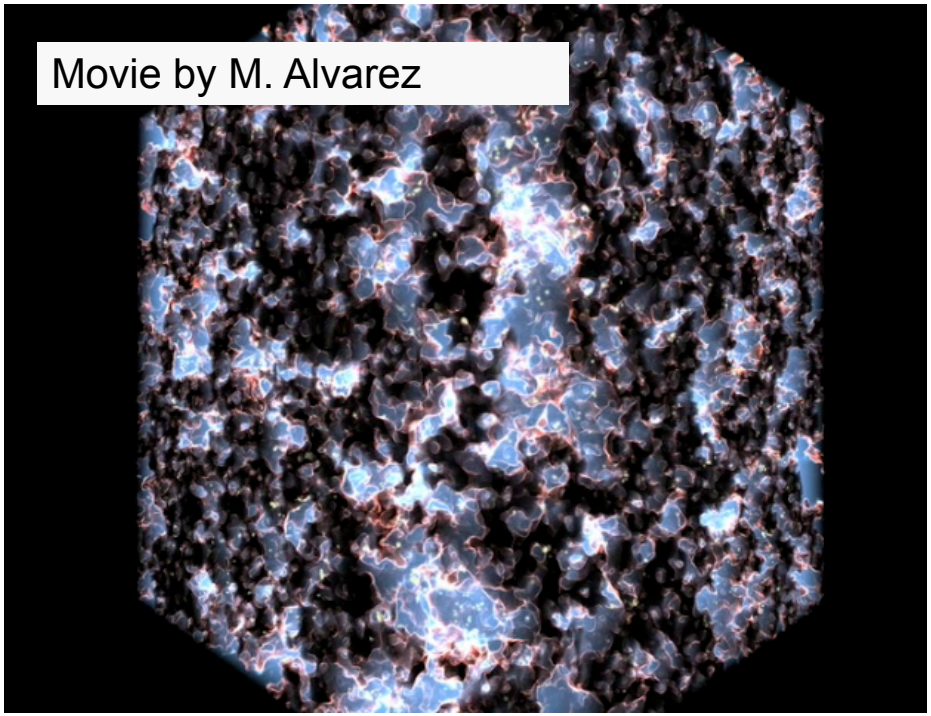
Kashikawa et al., Ota et al. Ouchi et al.

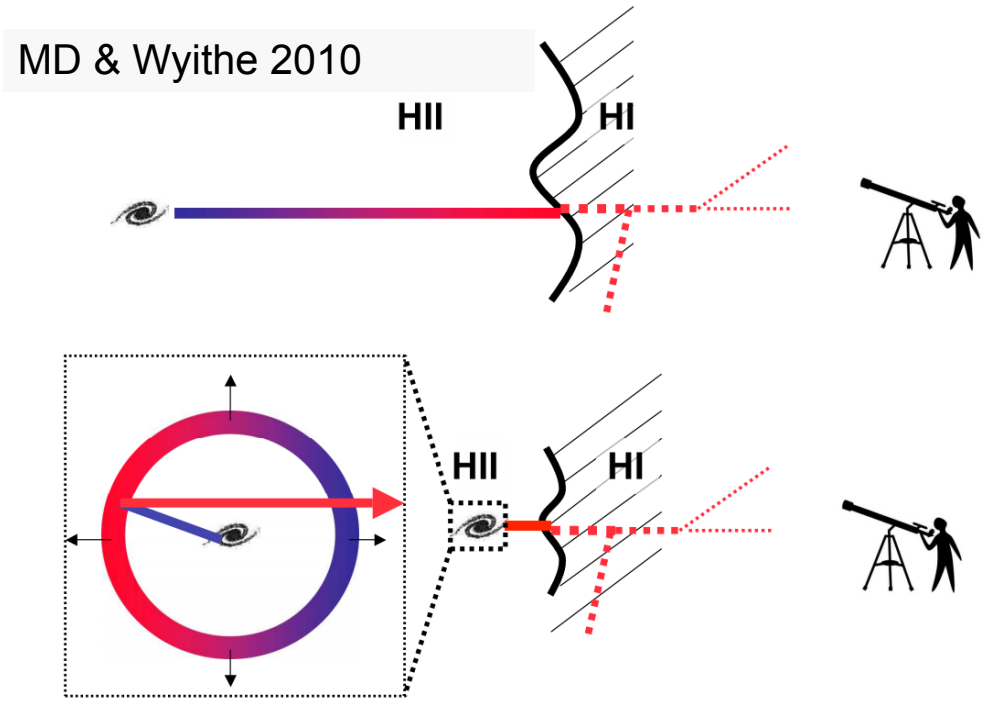


Reduced Lyα flux at z > 6 is apparent in both continuum and line selected galaxies, and evolution is *quantitatively consistent* (MD & Wyithe 2012, MD et al. 2014).

The Visibility of Lyα Emitting Galaxies during Reionization

The *inhomogeneous* nature of reionization, and the presence of large bubbles promote the visibility of Lyα emitting galaxies during reionization.

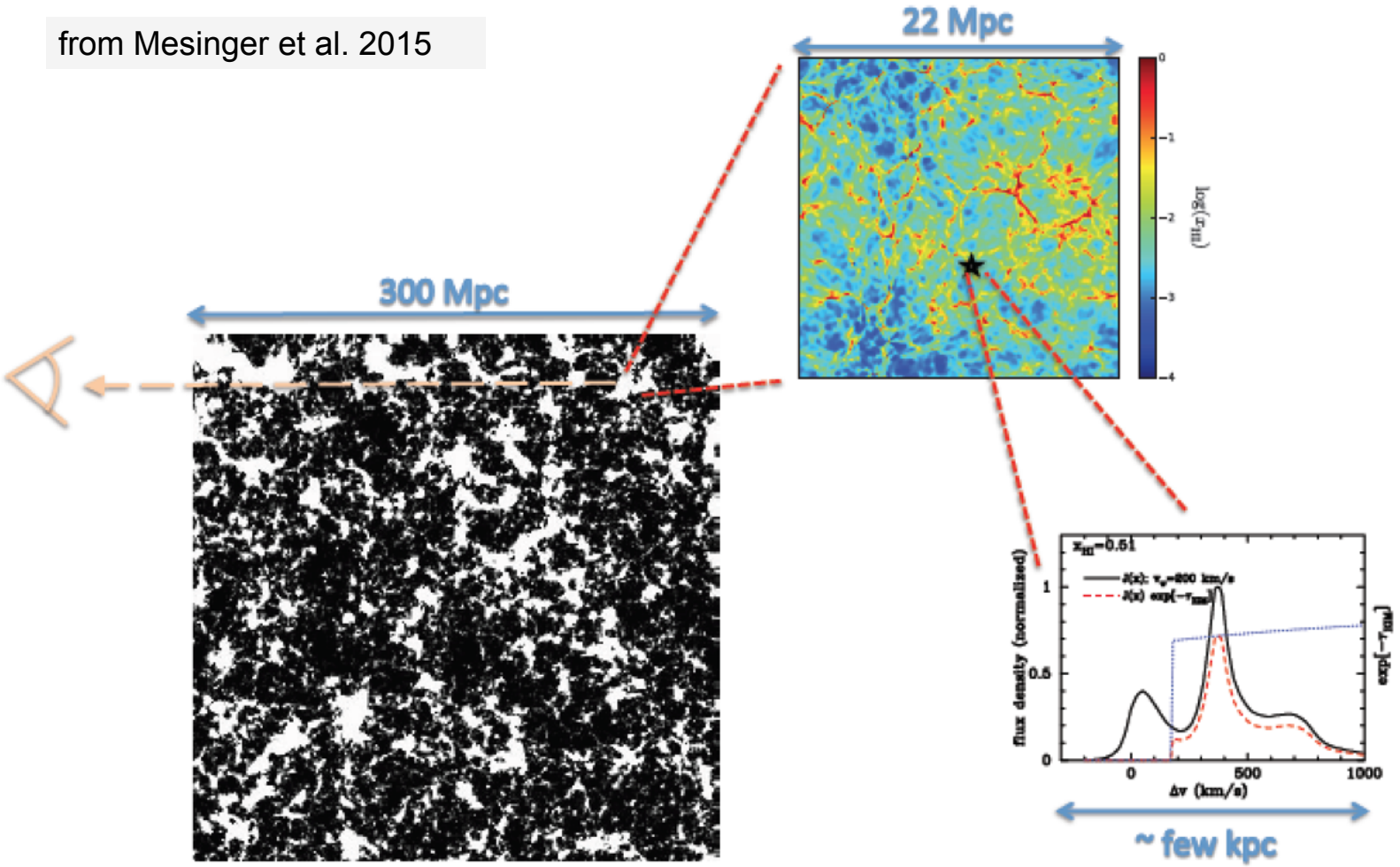




The impact of reionization on the visibility of the Lyα flux should be subtle.

Modelling the Impact of Reionization on Lyα Visibility

from Mesinger et al. 2015



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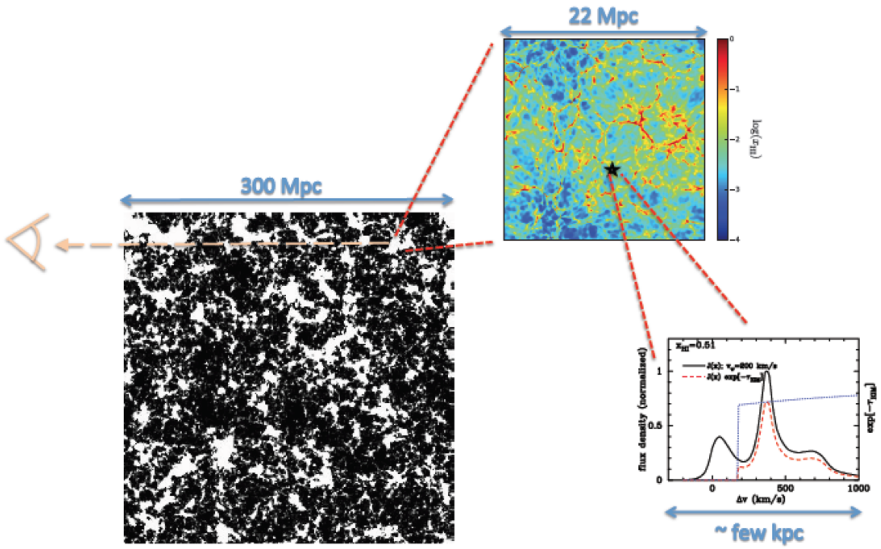

Multi-scale approach

$$\mathrm{IGM-Transmitted\ fraction} = \int d\nu_{\rm e}\ L(\nu_{\rm e})\exp[-\tau_{\rm Ly\alpha}(\nu_{\rm e})]$$

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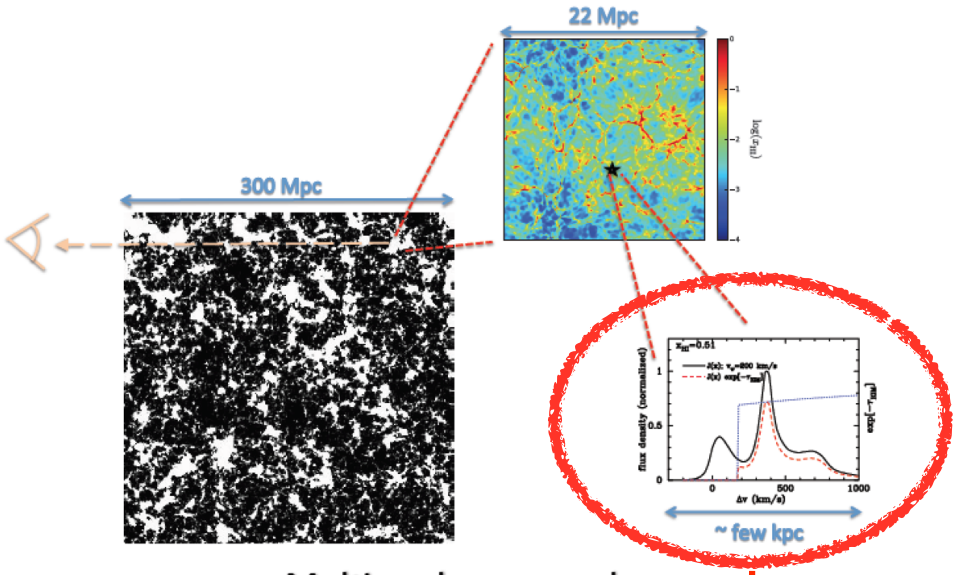

Multi-scale approach

interstellar RT:
dust, gas kinematics,...

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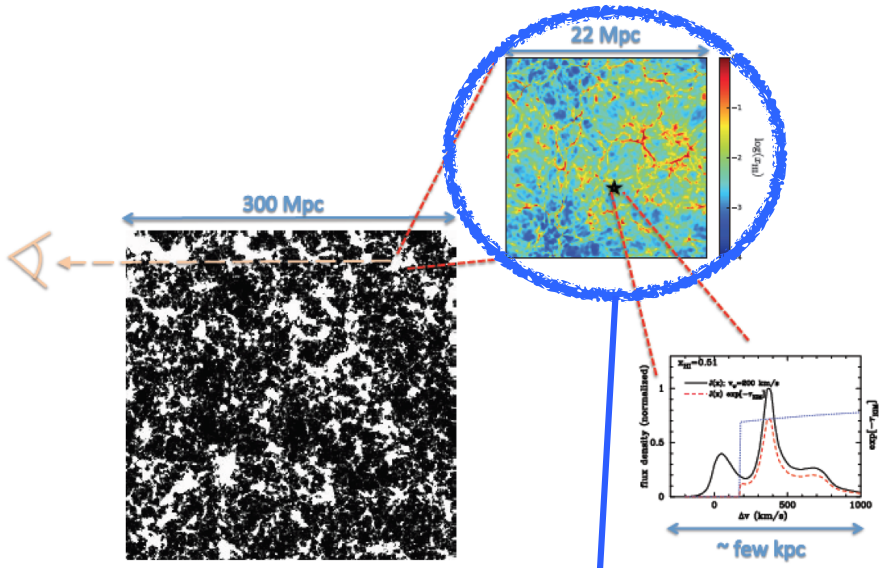

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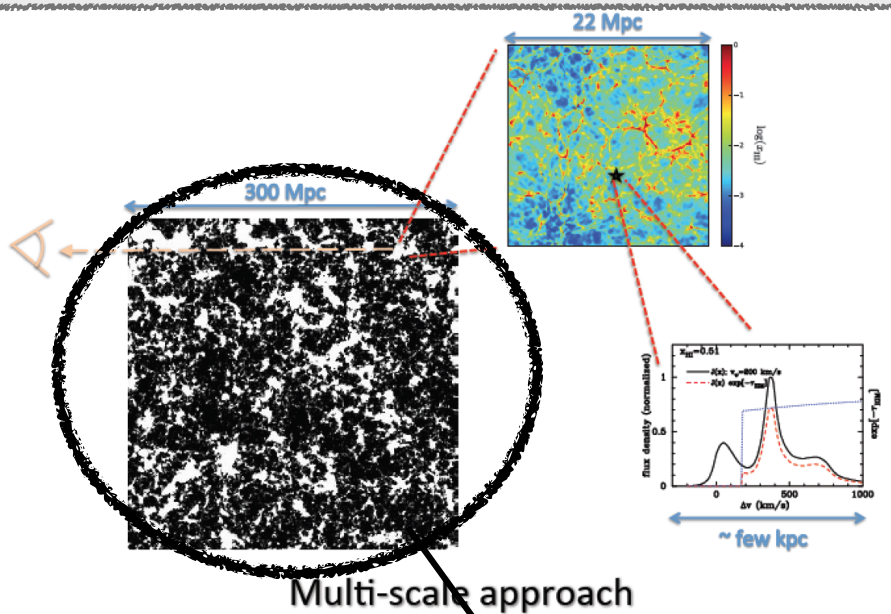
$$\tau_{\rm Ly\alpha}(\nu_{\rm e}) = \tau_{\rm HII}(\nu_{\rm e}) + \tau_{\rm D}(\nu_{\rm e})$$

self-shielding absorbers inside ionized bubbles (see e.g. Bolton & Haehnelt 2013), or residual HI in ionised IGM. (This component could give rise to Lyα halos)

Modelling the Impact of Reionization on Lyα Visibility



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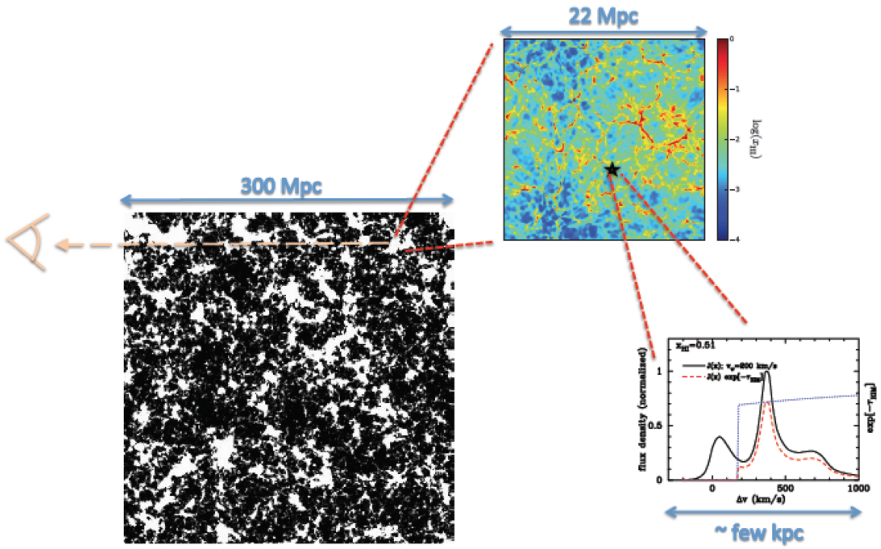
Diffuse neutral intergalactic gas. → unique to EoR!

Modelling the Impact of Reionization on Lyα Visibility



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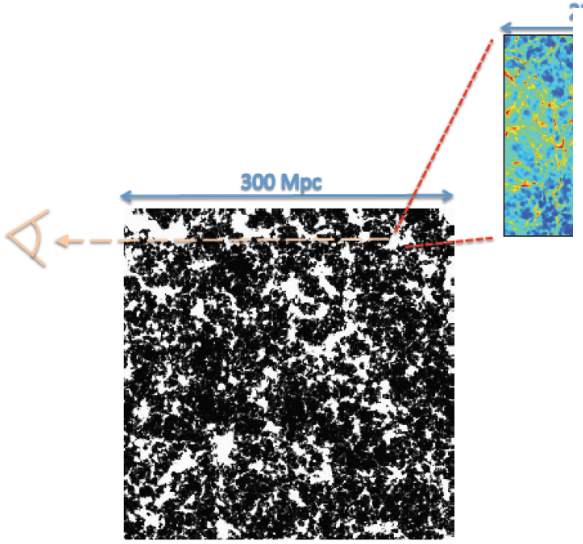
Recent theoretical efforts have focussed on improving various aspects of this problem [MD et al. 2011, Jensen et al. 2013 (`bubble'), Bolton & Haehnelt 2013 (`web'), MD et al. 2014 (LyC evolution), Mesinger et al. 2015, Choudhury et al. 2015 ('w. velocity shift'), Kakiichi et al. 2016 (`web-bubble')].

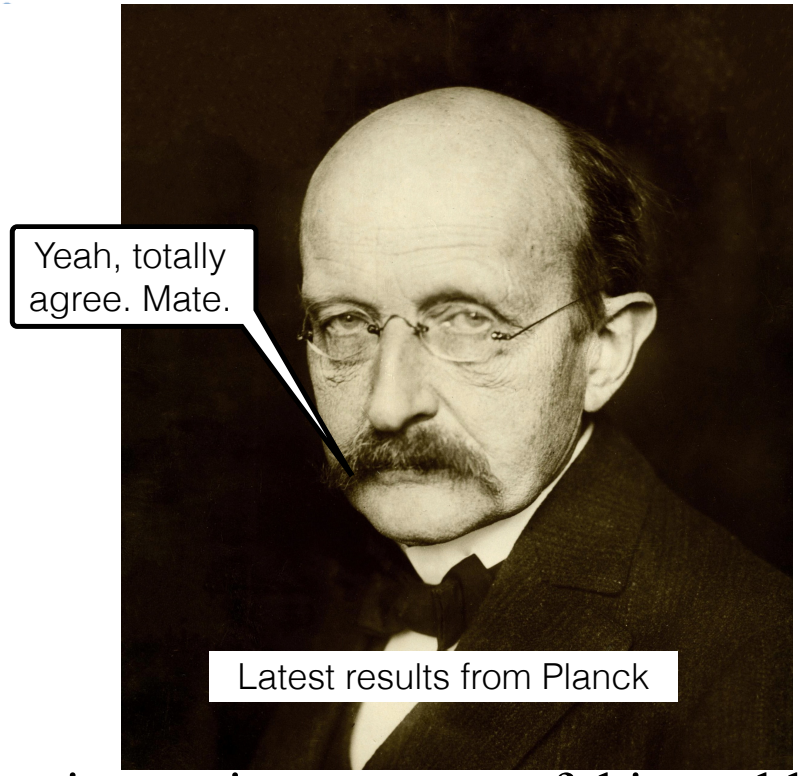
Has proven difficult to avoid concluding that Universe at z~7 had $x_{\rm HI}(z\sim7) > 0.2$-0.3, with preferred values of $x_{\rm HI}(z\sim7)\sim0.4$-$0.5$. *Also see talk by B. Greig.*

Modelling the Impact of Reionization on Lyα Visibility



Multi-scale appro

$$\text{IGM} - \text{Transmitted fraction} = \int$$



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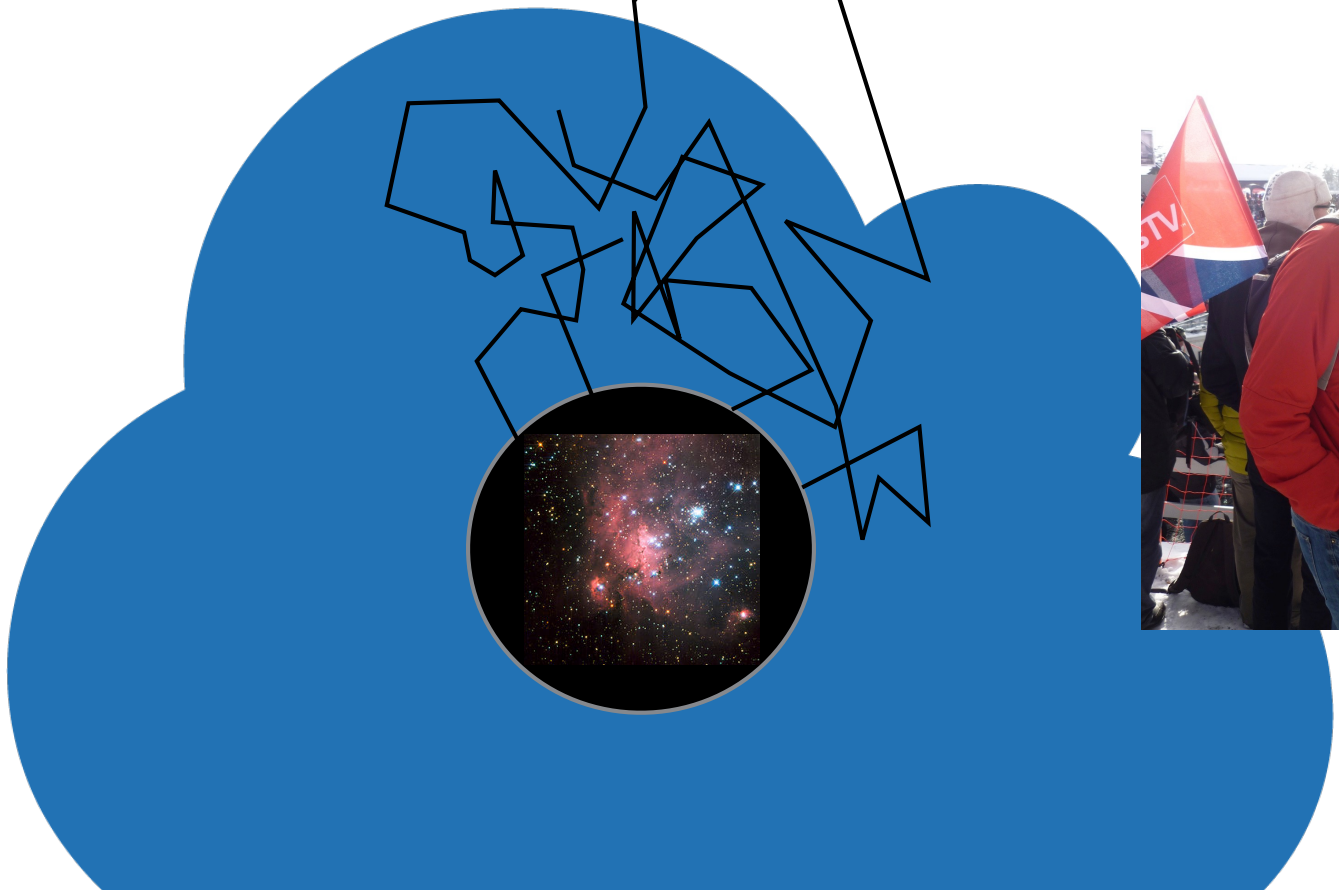
The Lyα-LyC Connection

Based on Dijkstra & Gronke, arXiv:1604.08208 and Gronke & Dijkstra 2016



Claim: The transport of Lyα photons is affected by whether the ISM permits the escape of ionising (LyC) photons.

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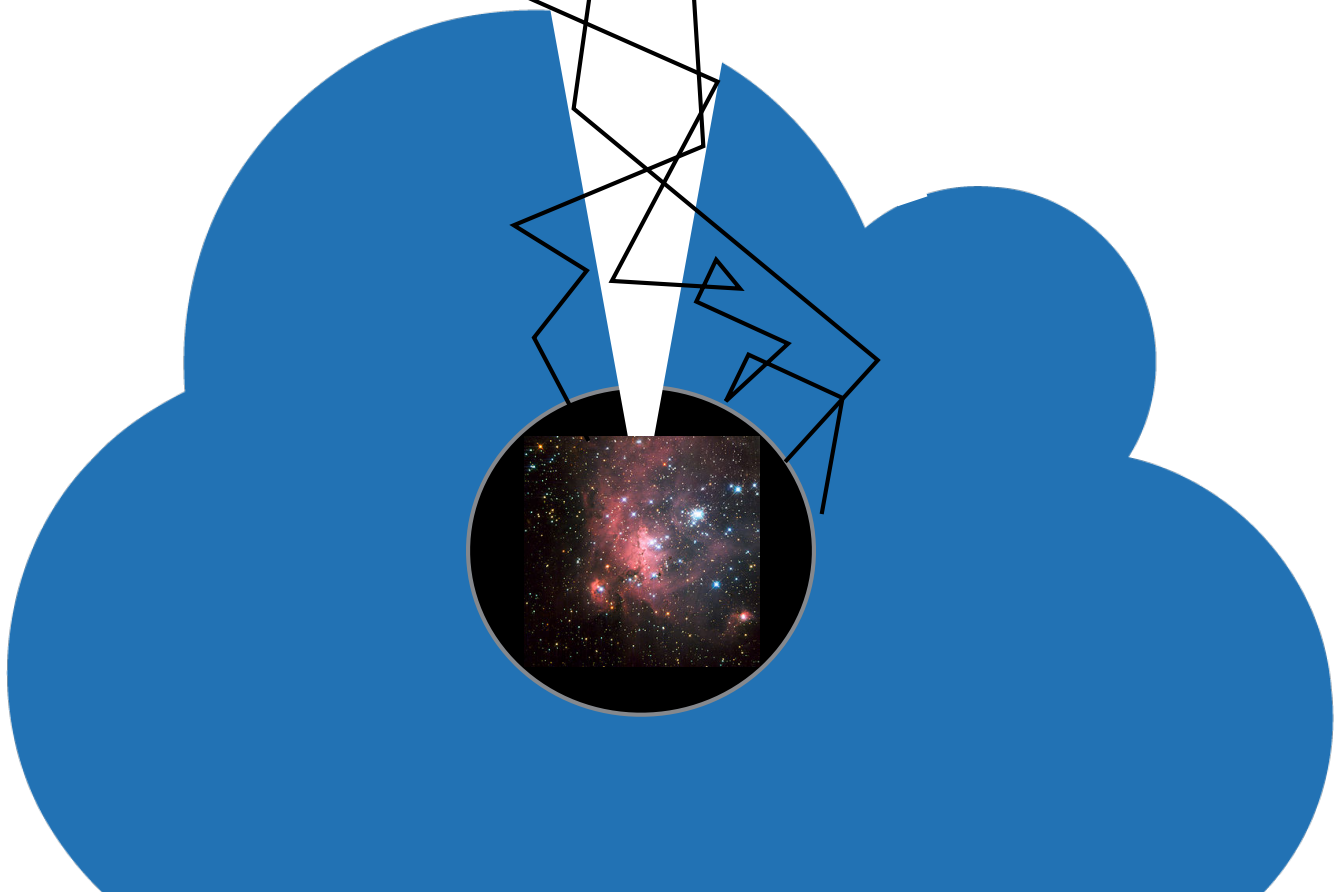

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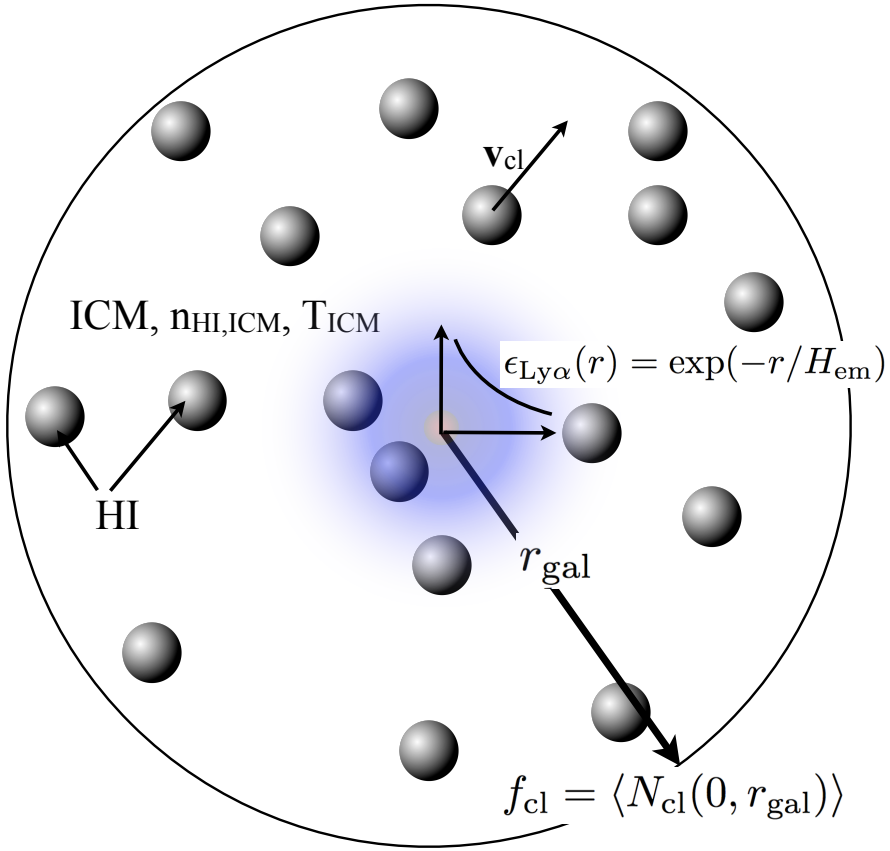
The Lyα-LyC Connection

Compare Lyα and LyC escape fractions in ~ 2500 simplified models of the multi-phase ISM spanning a wide range of physical parameters (Gronke & Dijkstra 2016).



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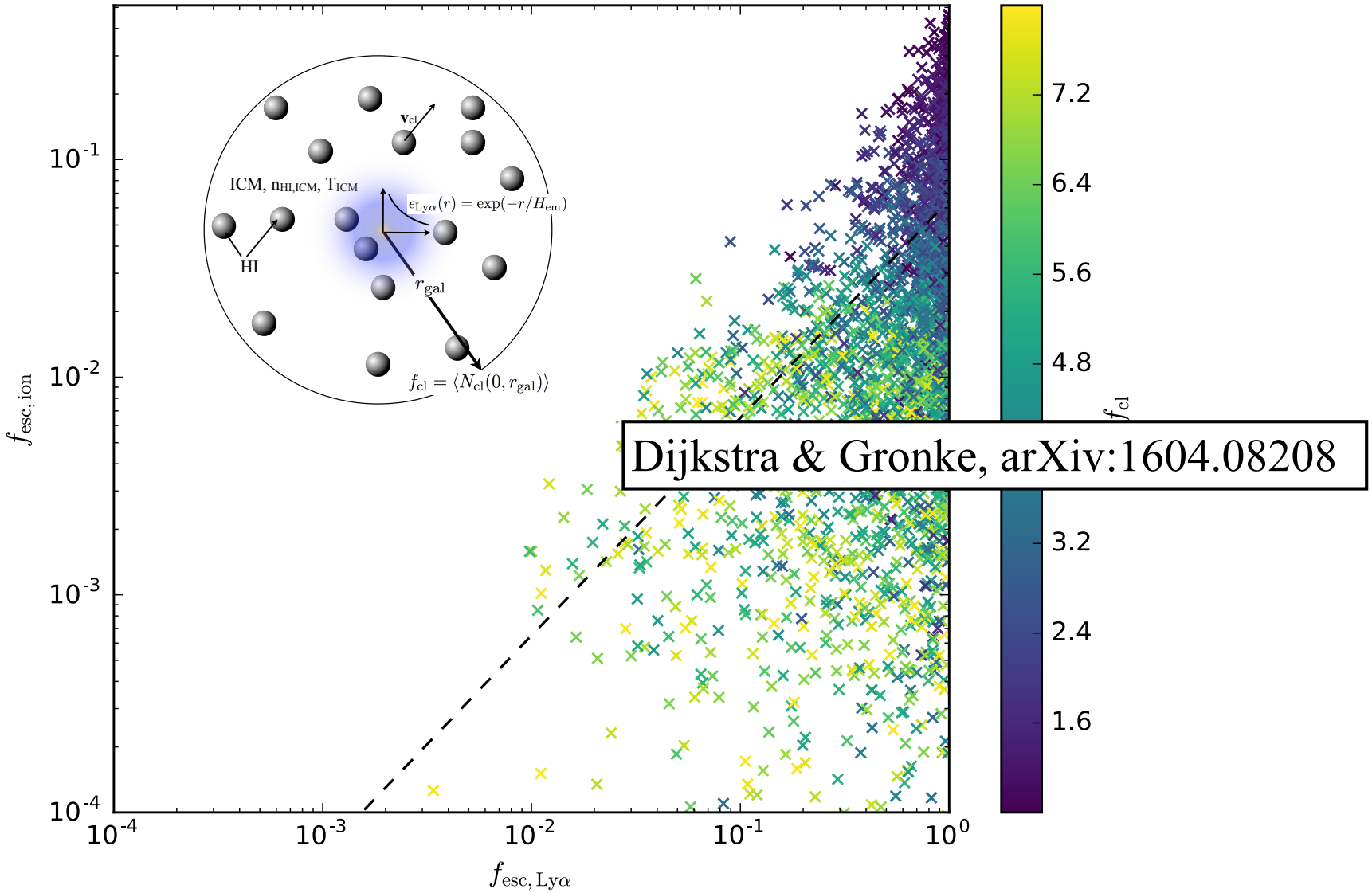
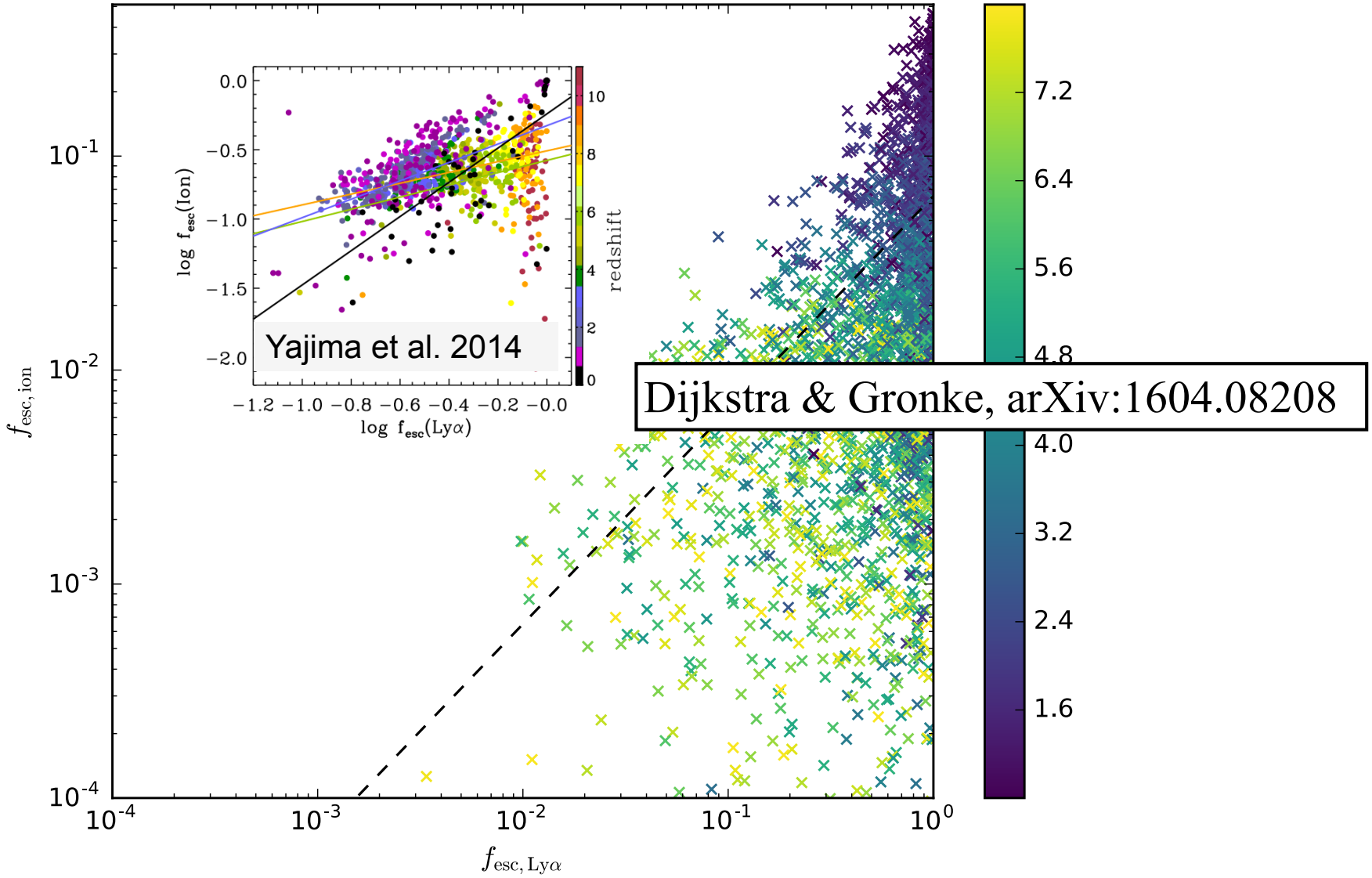


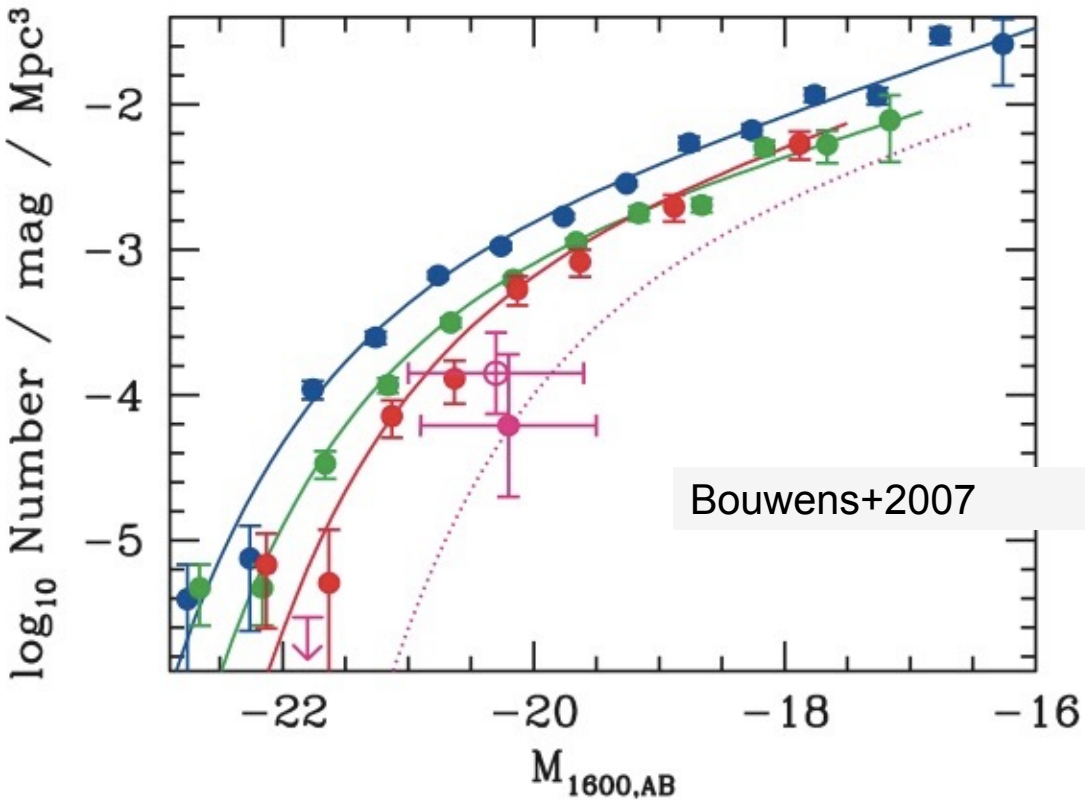
Dijkstra & Gronke, arXiv:1604.08208

Lyα escape correlates with LyC statistically.

The Lyα-LyC Connection



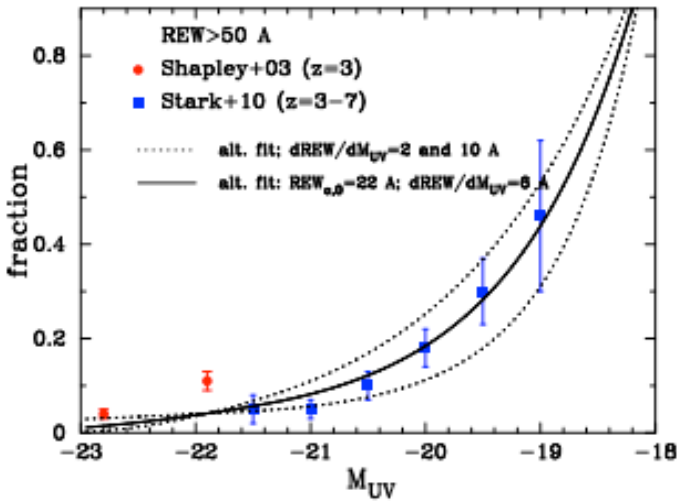
The Relevance of the Lyα-LyC Connection



Bouwens+2007

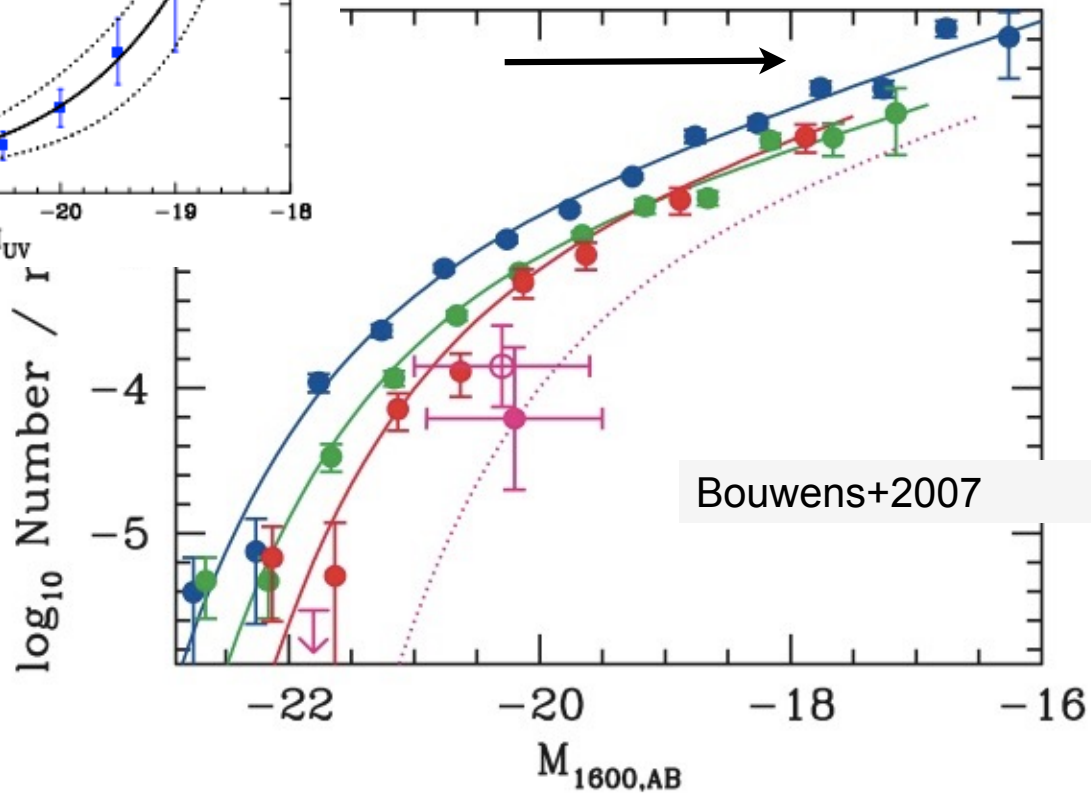
The Relevance of the Lyα-LyC Connection

Gronke et al. 2015



UV-faint galaxies tend to be brigher in Lyα

Lyα escapes more easily from UV-faint galaxies.



Bouwens+2007

The Lyα-LyC connection implies that UV-faint galaxies contribute more to the ionising photon budget than implied by the faint end slope of the UV-LF!

Point 1-2.

The reduced Lyα flux from galaxies at z ~7 is because reionization is still well underway, and possible at its midpoint.

Exciting for future surveys! (Especially because we still are likely not optimally using data on Lyα emitting galaxies)

Escape of LyC photons *requires* low N_{HI}-paths. Lyα escape is *facilitated* by these paths.

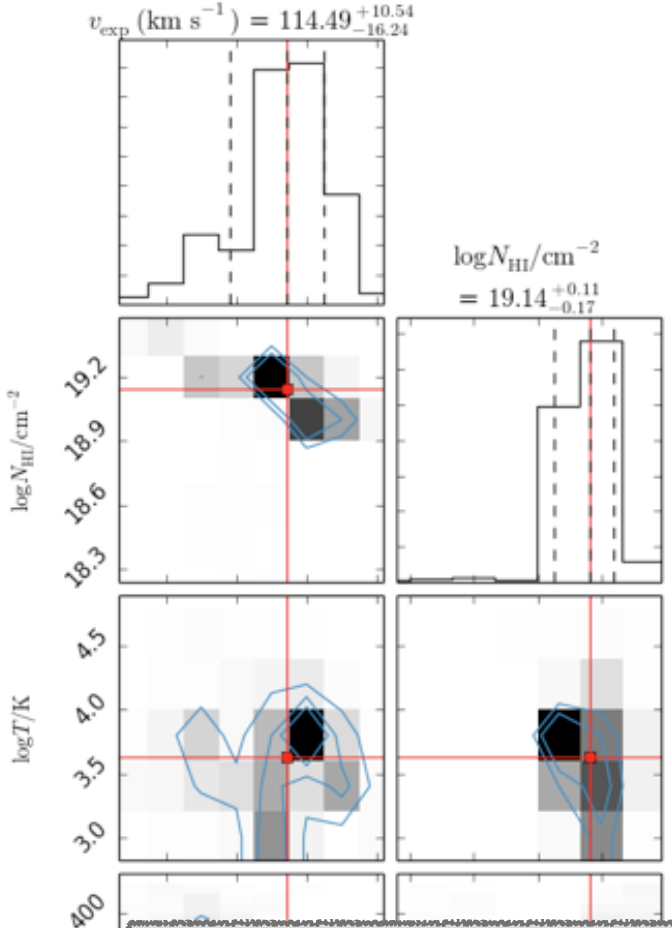
The Lyα-LyC connection implies that UV-faint galaxies contribute more to the ionising photon budget than implied by the faint end slope of the UV-LF.

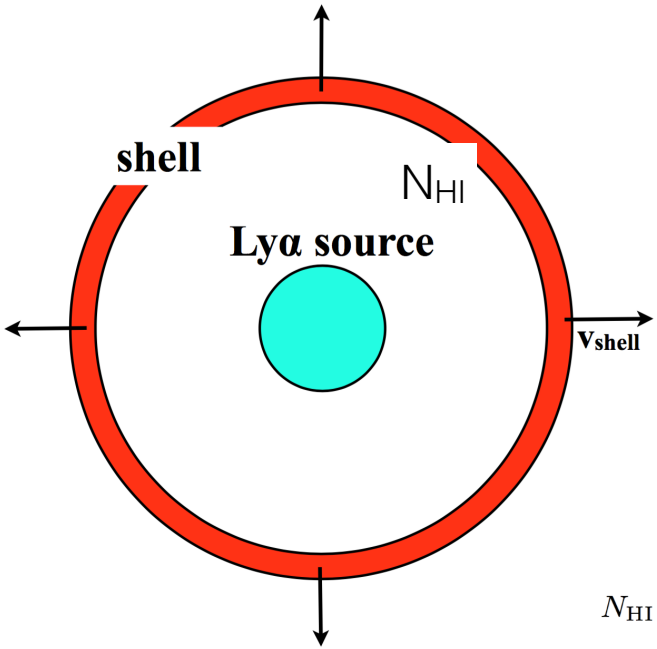
$$f_{\rm esc} = f_{\rm esc}(z, M_{\rm UV}, ...).$$

Beyond Statistical Constraints: Interpreting Lyα Spectra

Fitting procedure in Gronke, et al, 2015

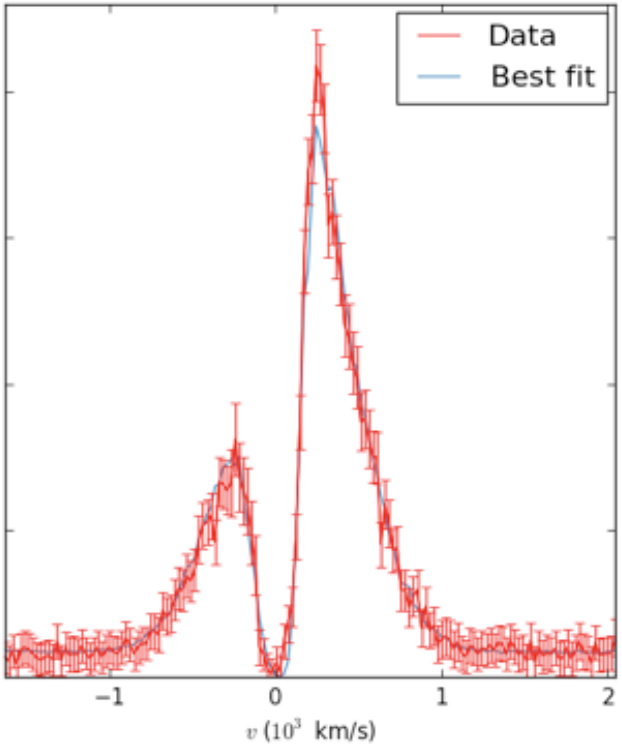
Data: Huan Yang et al. 2016





$N_{\rm HI}$,

z=0.2: green pea galaxy

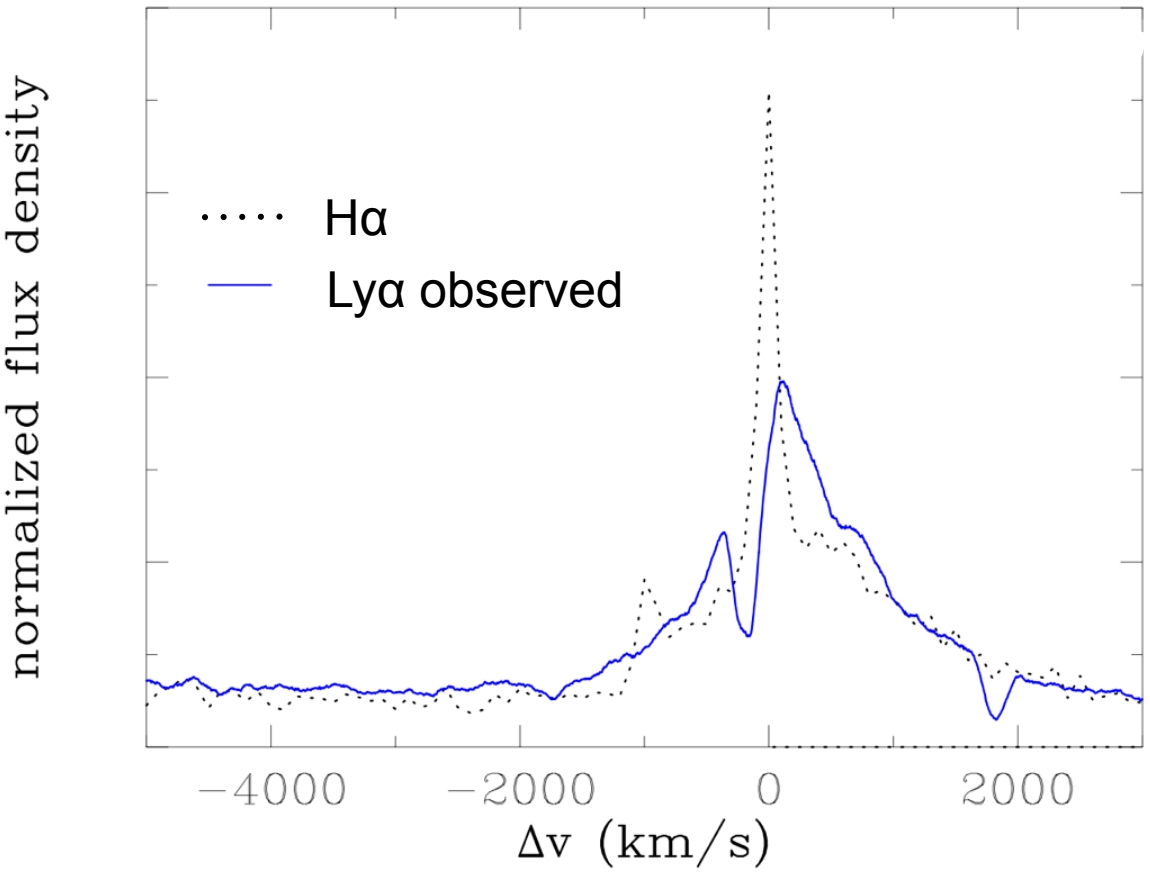


It is unclear what physical information is encoded in shell model parameters (see Gronke & Dijkstra 2016.)

Beyond Statistical Constraints: Interpreting Lyα Spectra

Martin, MD, et al. 2015

Lyα from a local ULIRG



Beyond Statistical Constraints: Interpreting Lyα Spectra

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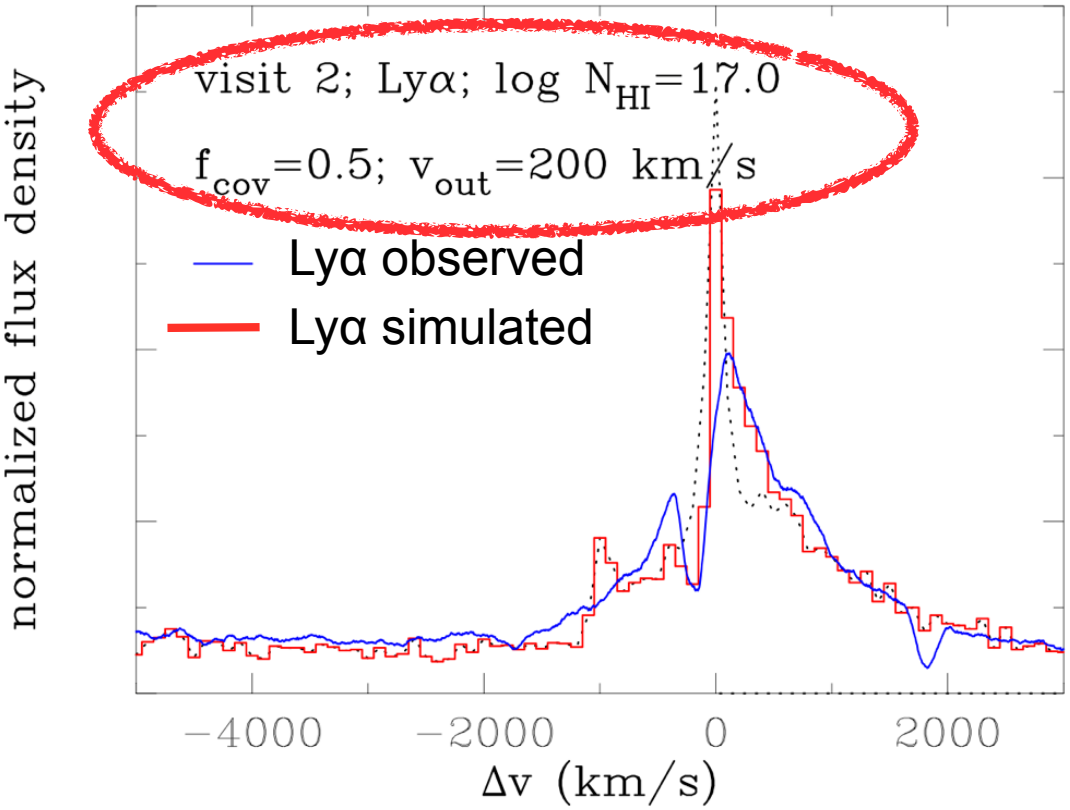
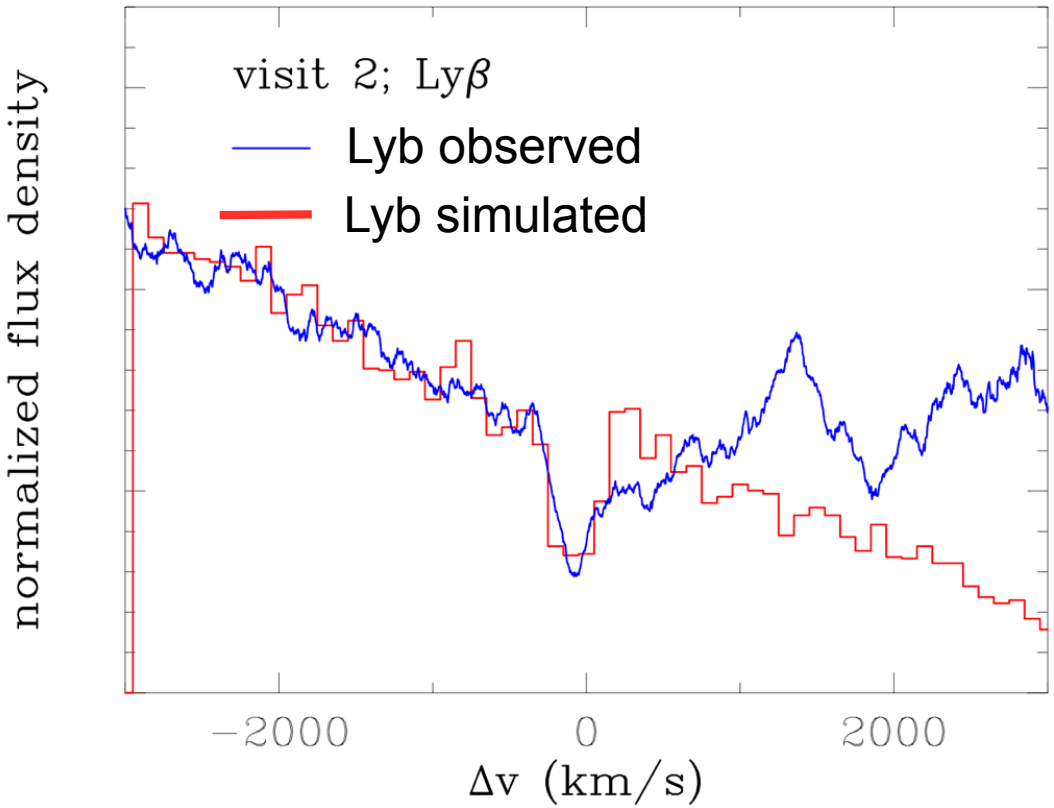


Low HI column density + `empty' holes: allows escape of ionizing photons.

Beyond Statistical Constraints: Interpreting Lyα Spectra

Martin, MD, et al. 2015



In certain individual cases, it is already possible to place physically meaningful constraints.

Lyα Galaxies as a Probe of the High-z Universe

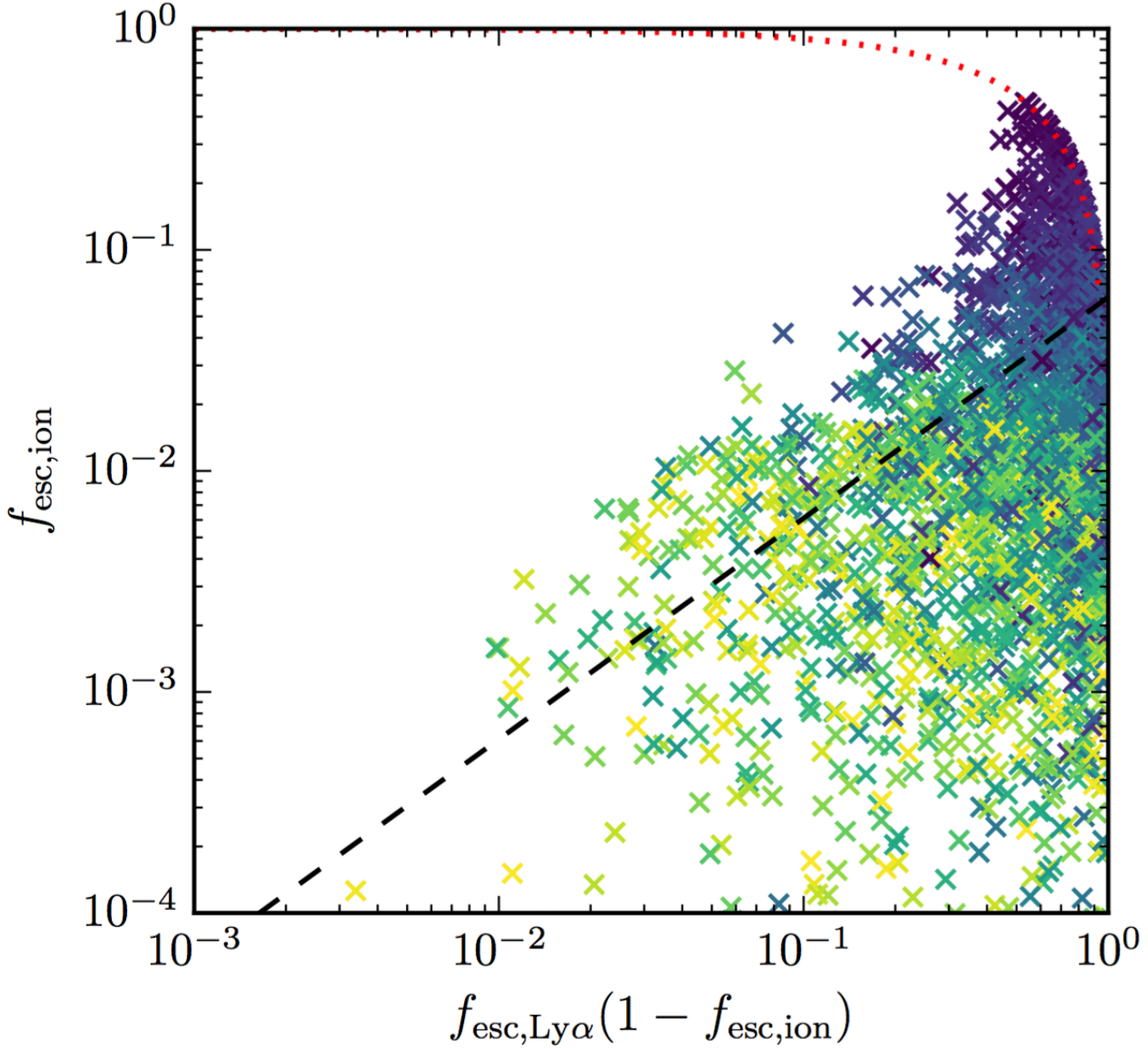
Conclusions

- Lyα emitting galaxies at z>6 provide an excellent measure of the `global' ionisation state of the Universe.

- The Lyα-LyC connection implies f_{esc}(LyC) increases towards lower UV-luminosities:

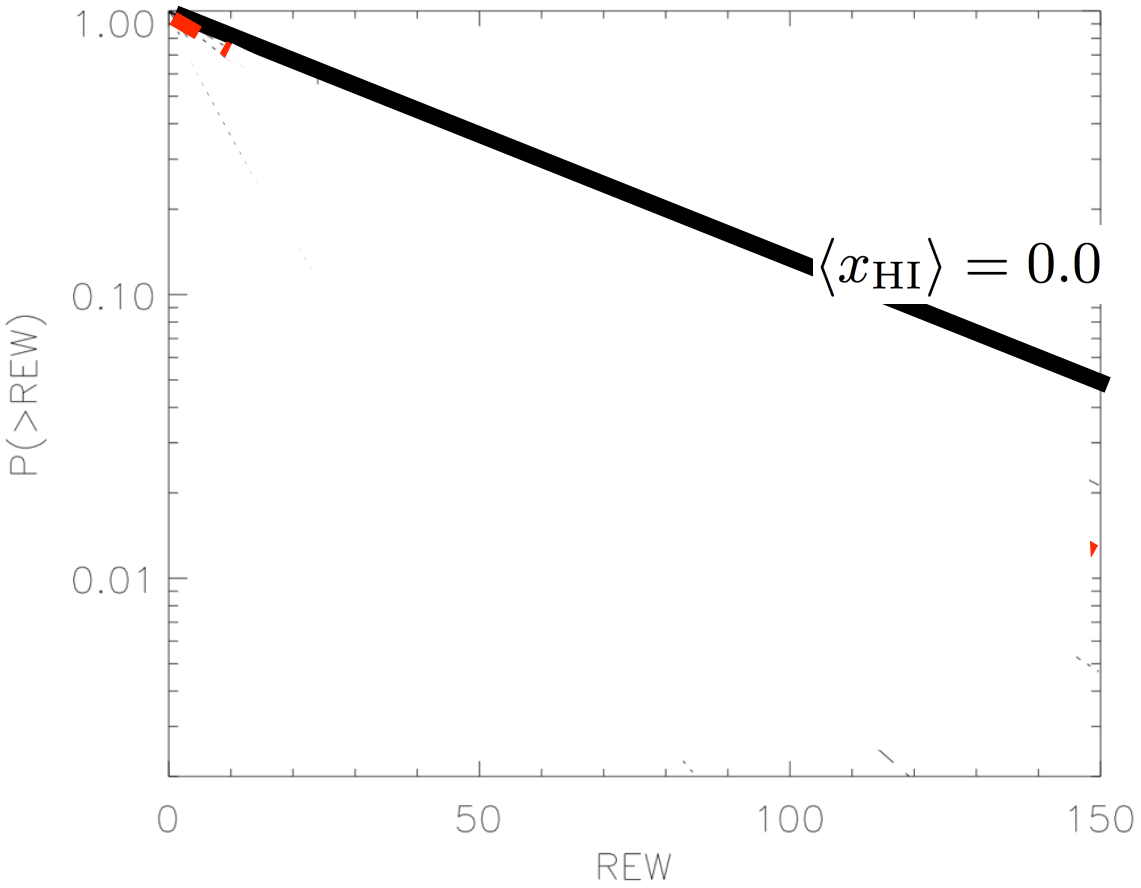
  UV-faint galaxies contribute *more* to cosmic reionization than implied by the faint end slope of the UV-LF.

- Next: going beyond a statistical use of Lyα emitting galaxies, and try and extract physical properties of the ISM of galaxies based on Lyα spectra.


10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$f_{\rm esc,ion}$
10^{-3}
10^{-2}
10^{-1}
10^0
$f_{\rm esc,Ly\alpha}(1 - f_{\rm esc,ion})$

Current Constraints on Reionization

Focus on the Lyα EW-PDF (slightly more general than Lyα fraction)



Assume small scale RT processes do not evolve from z=6-7, the EW-PDF for x_{HI}=0 is given by that observed at z~6.

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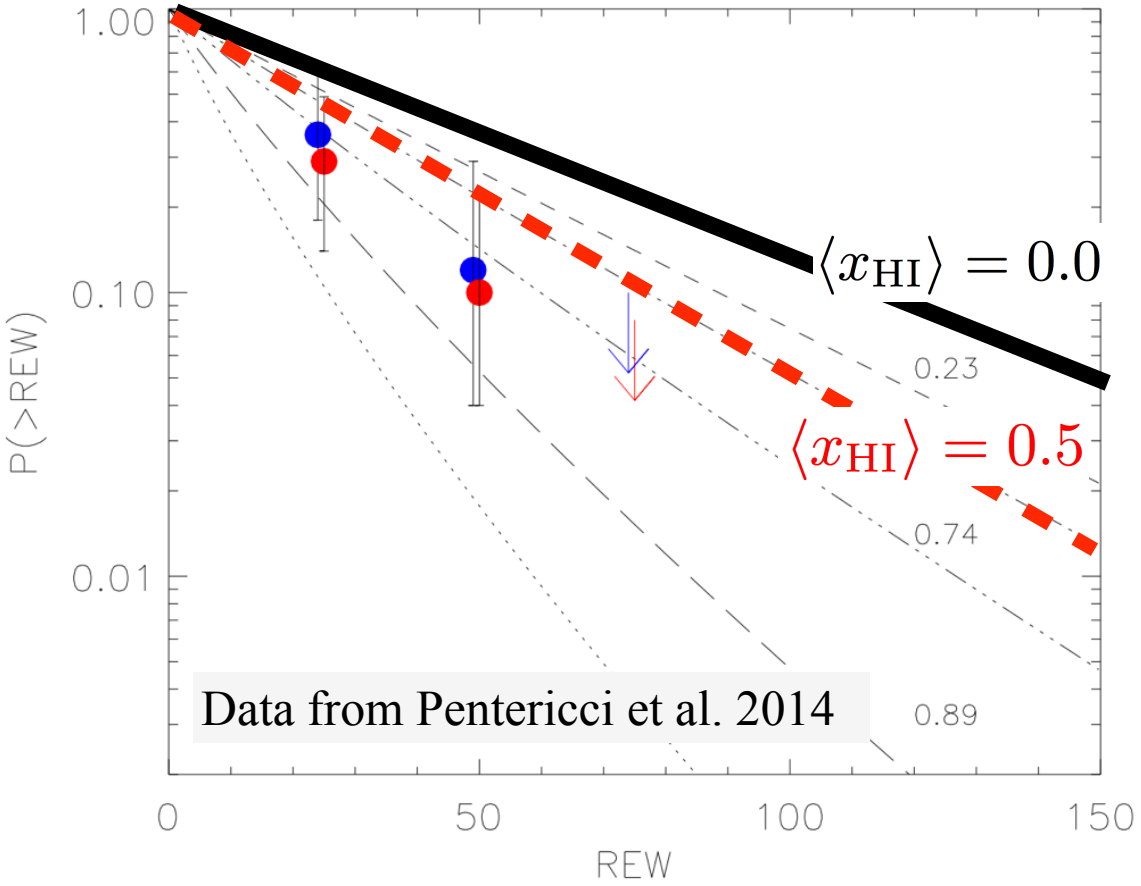

MD. 2011, Jensen et al. 2013, Mesinger et al. 2015, Choudhury et al. 2015, Kakiichi et al. 2015, arXiv:1510.05467