Bridging the Gap Between Clumpy Outflows and Shell Models: Towards an Improved Understanding of Lyα Radiative Transfer

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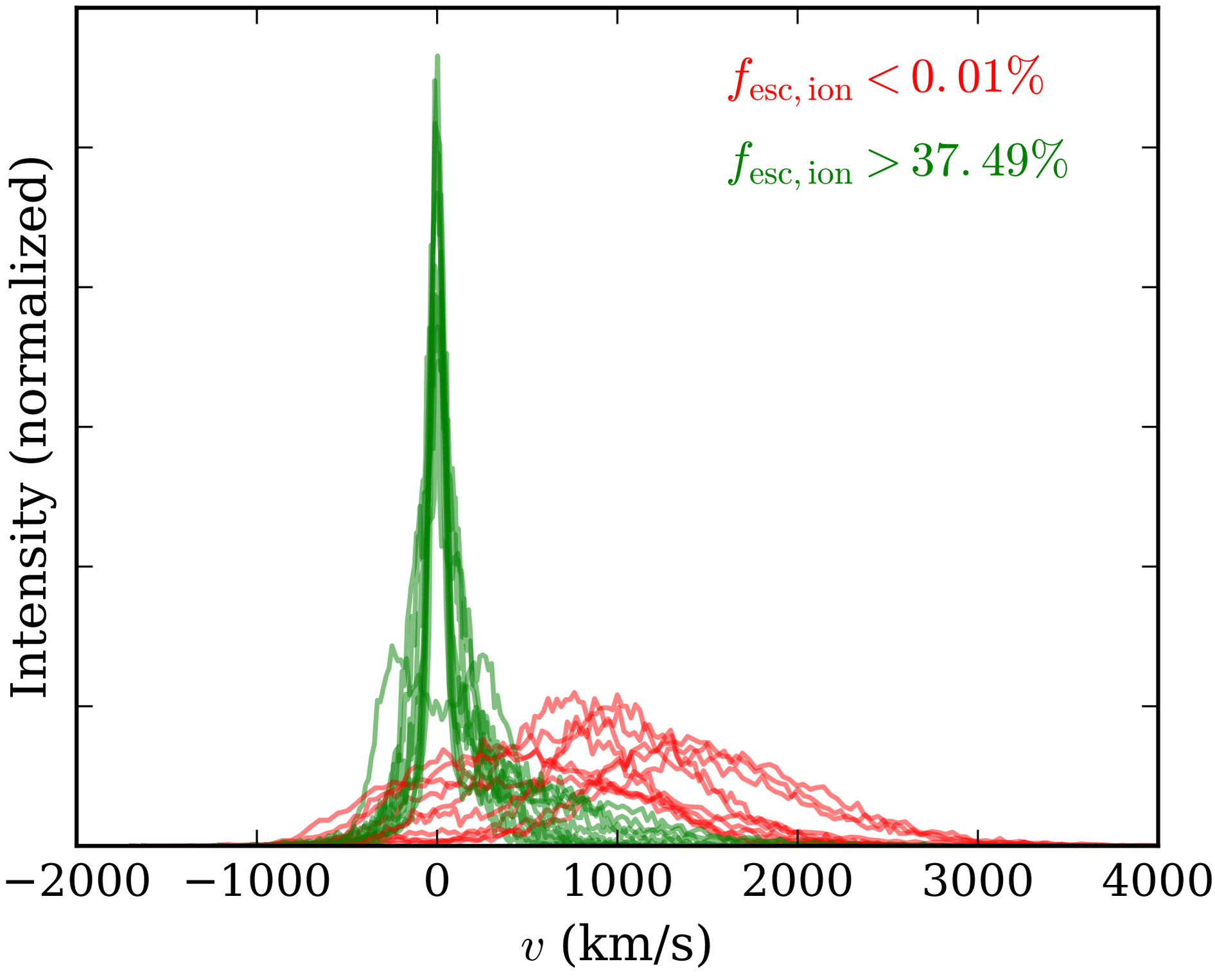
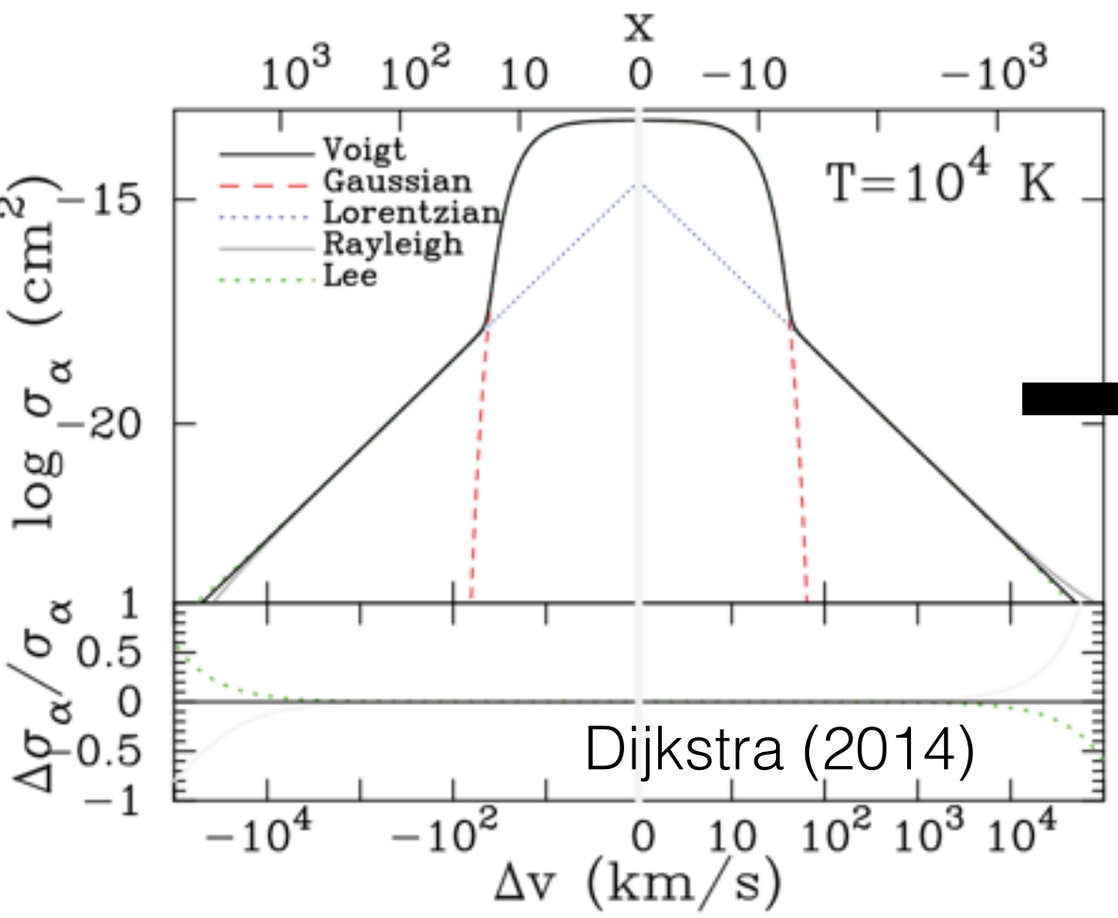
…as seen in the previous talk…

Lyα spectra and $f_{esc,ion}$

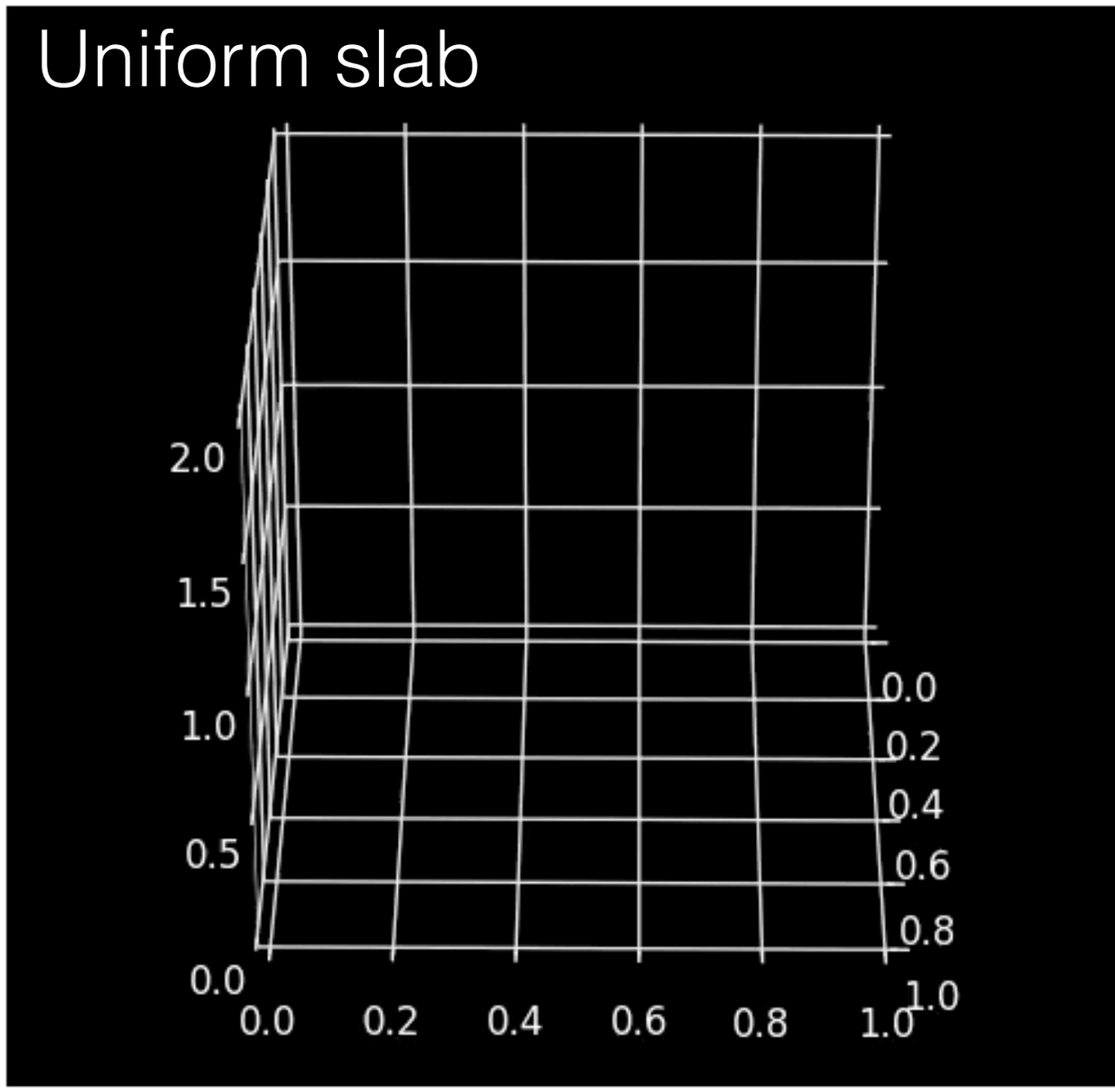


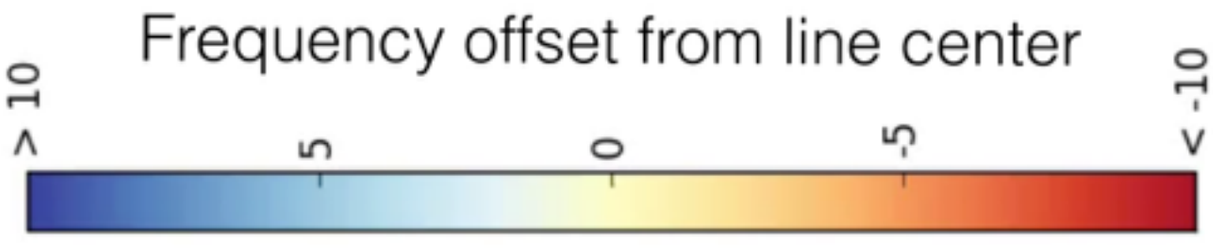
The need for a sub-grid model

Lya scattering cross section



Dijkstra (2014)

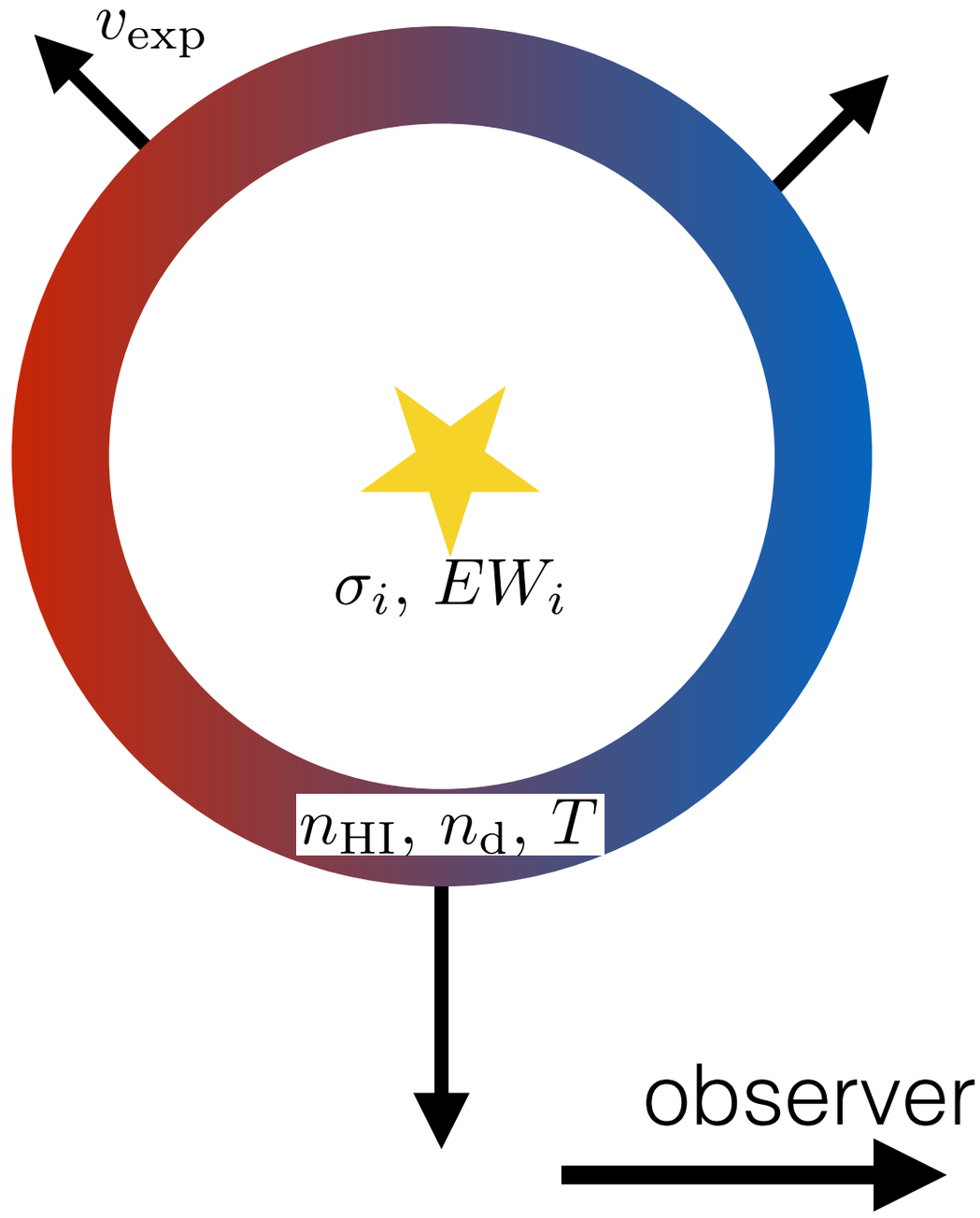




Ahn et al. (2004)
Verhamme et al. (2008)
Schaerer et al. (2011)
…

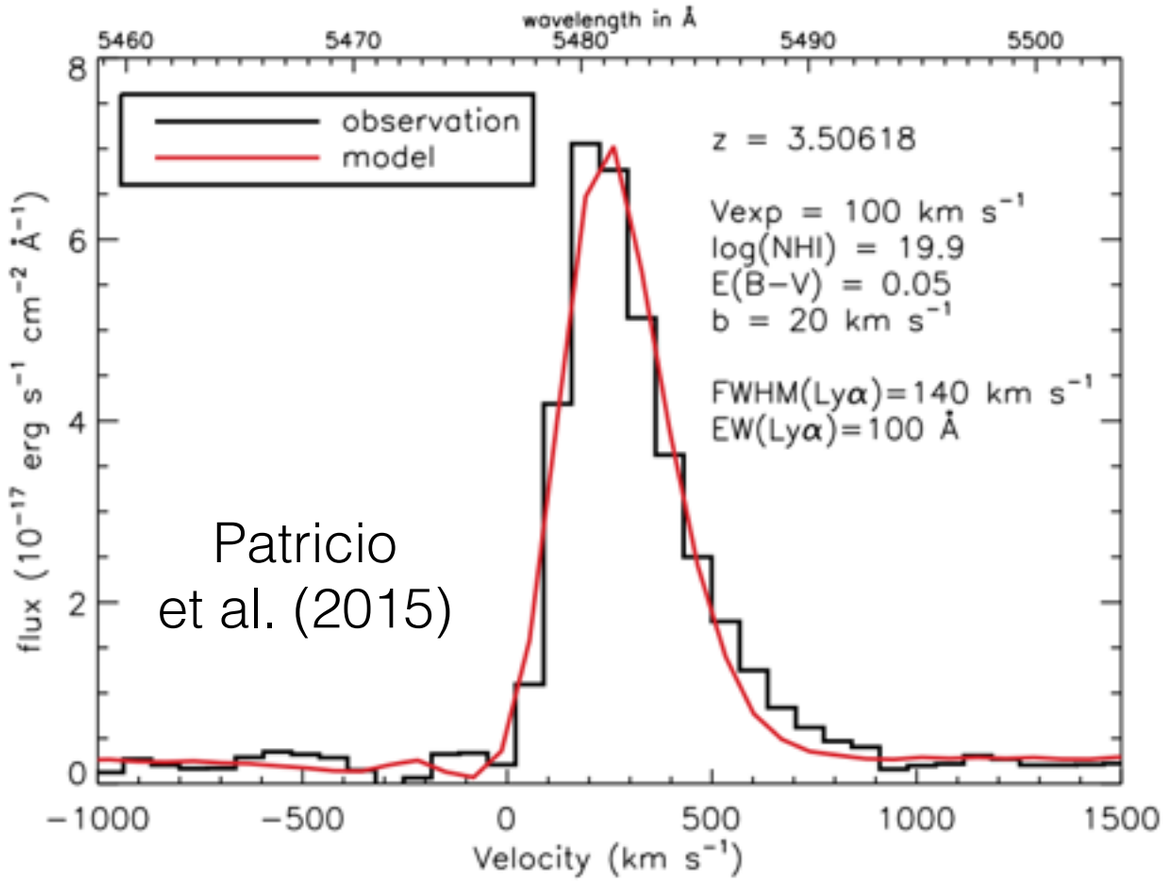
The “shell-model”

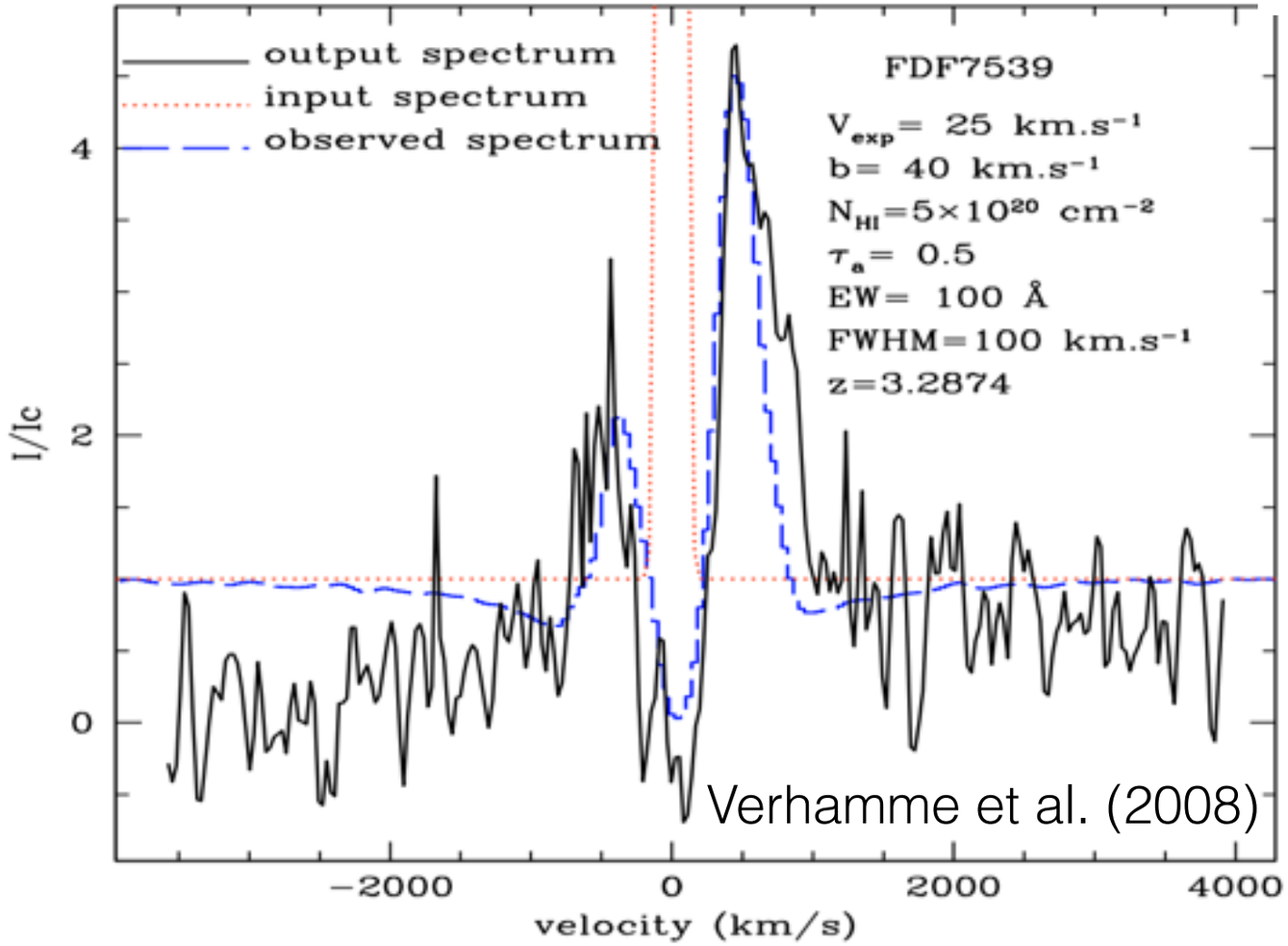
- 6 parameters:
  - Emission parameters σ_i, EW_i
  - Outflow velocity $v_{\rm exp}$
  - Shell-content $n_{\rm HI}$, $n_{\rm d}$, T

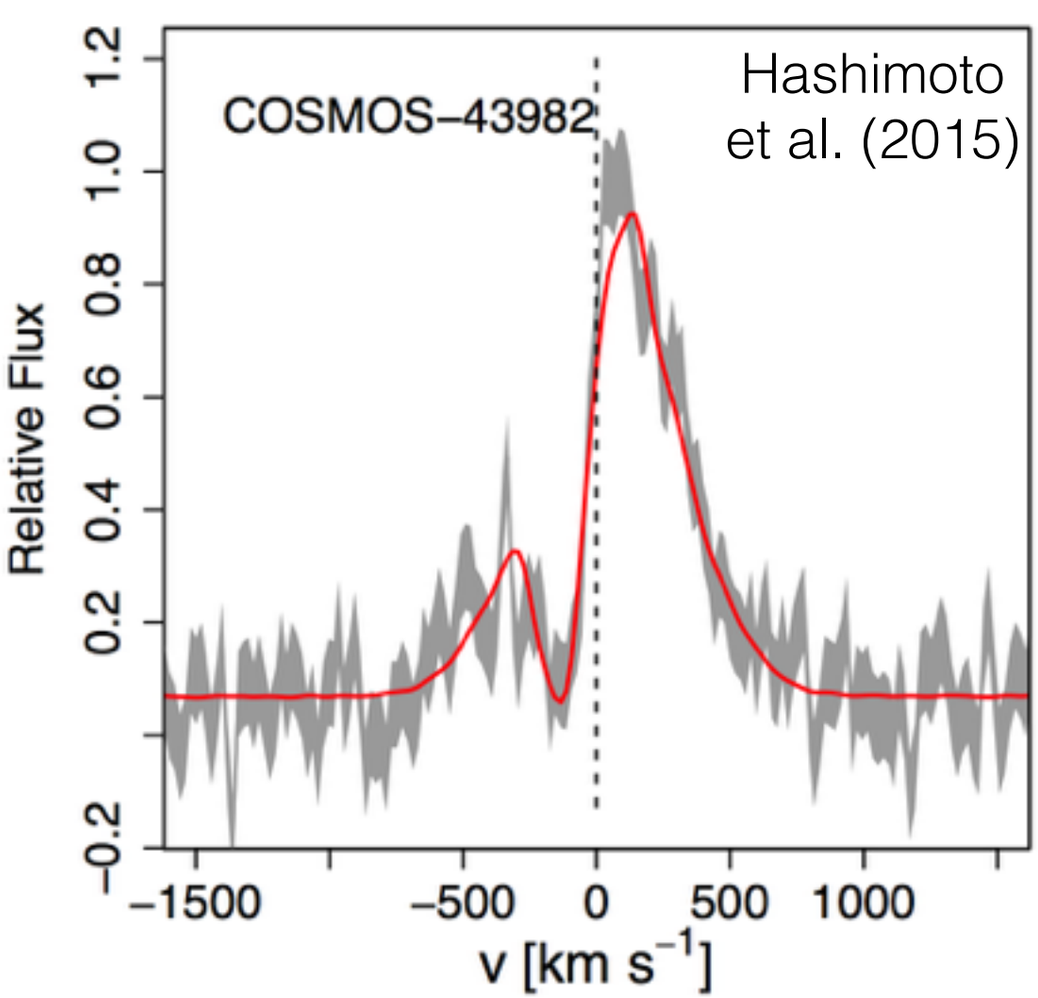


“Shell-model” fitting

(some examples)

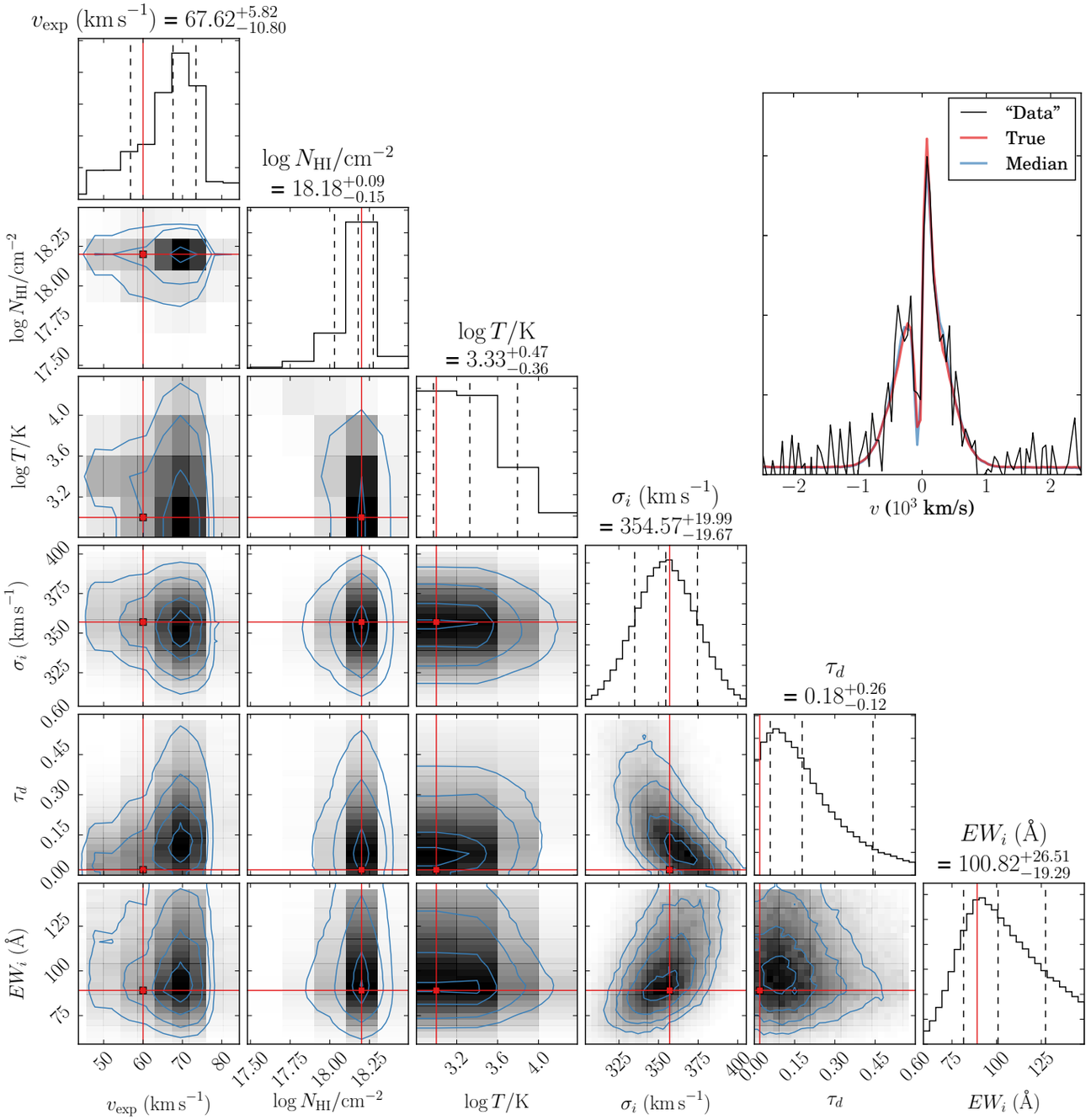






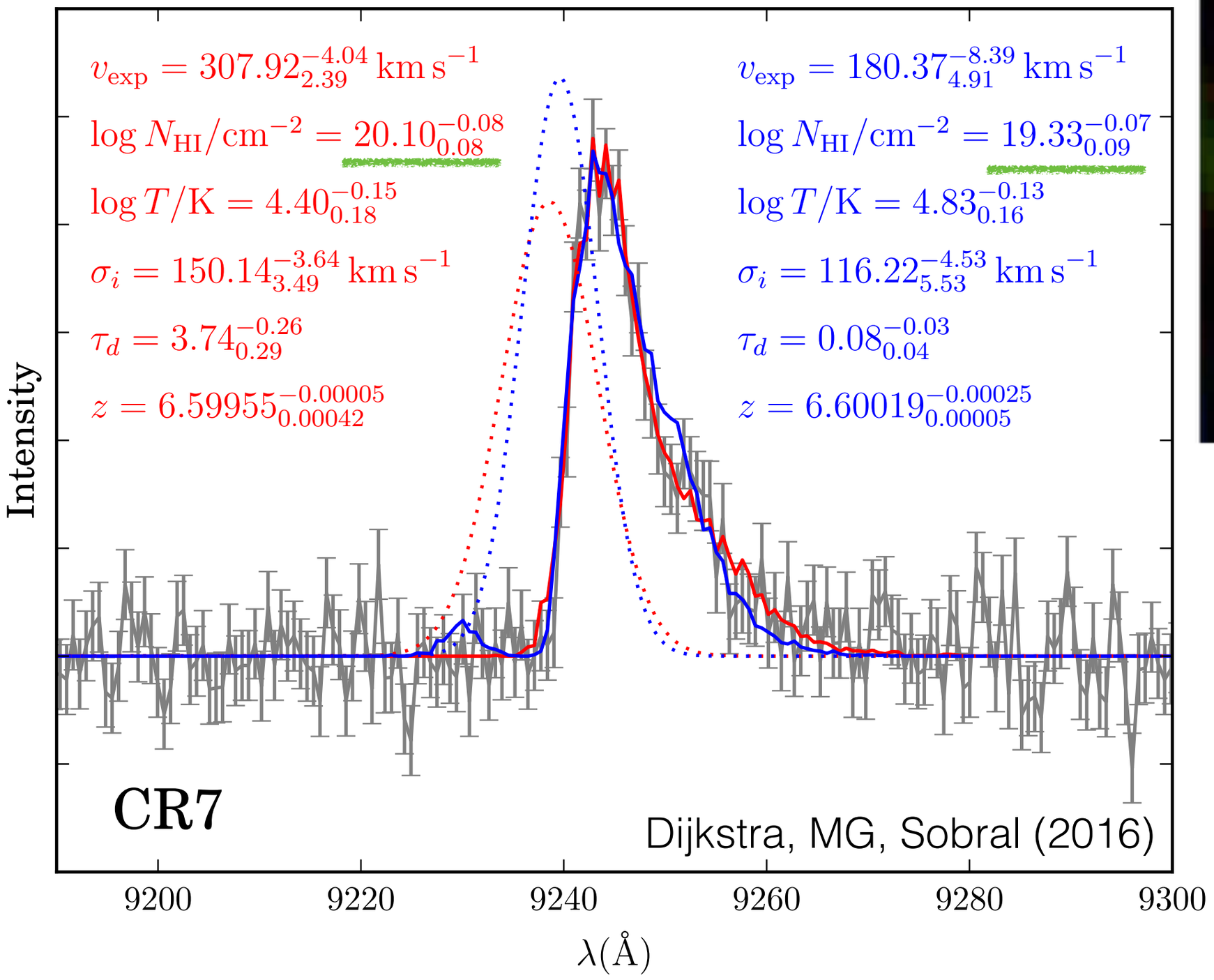
Our fitting pipeline

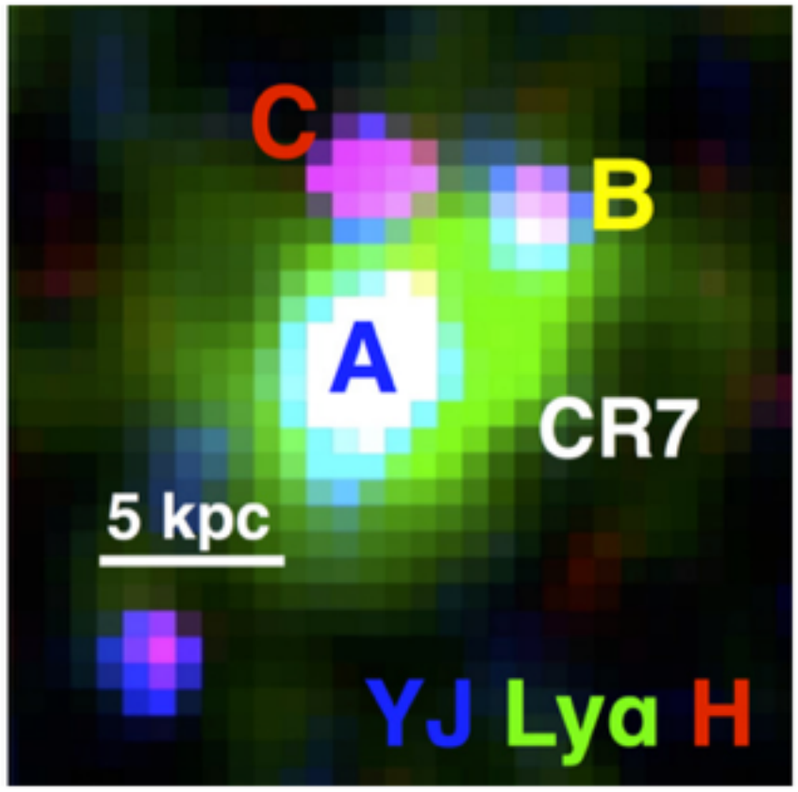
- 3 out of 6 parameters as through weighting of photons
- 10,800 discrete models with 170,000 photon packages each
- Interactive online tool to access the spectra http://bit.ly/man-alpha
- Possible to do a full likelihood analysis



MG, Bull, Dijkstra (2015)

Fitting “CR7”



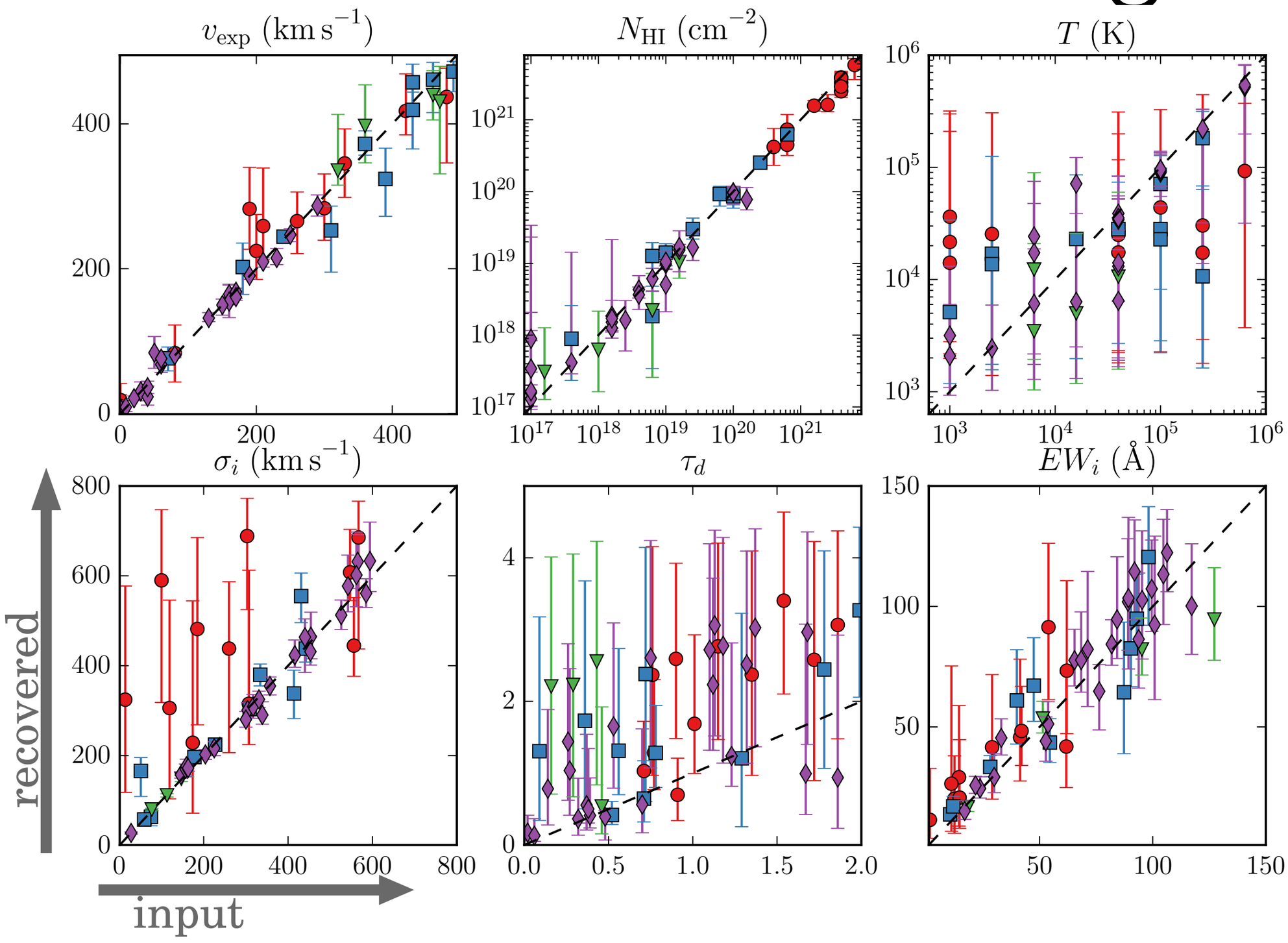


Sobral et al. (2015)

$N_{HI} \sim 10^{19}$-10^{20}cm^2

differs from initial stage of DCBH formation with $N_{HI} \gtrsim 10^{21}$cm^2

Can we trust shell-model fitting?



absorption

P-Cygni

single peak

double peak

MG, Bull, Dijkstra (2015)

Clumpy interstellar-medium

A THEORY OF THE INTERSTELLAR MEDIUM: THREE COMPONENTS REGULATED BY SUPERNOVA EXPLOSIONS IN AN INHOMOGENEOUS SUBSTRATE

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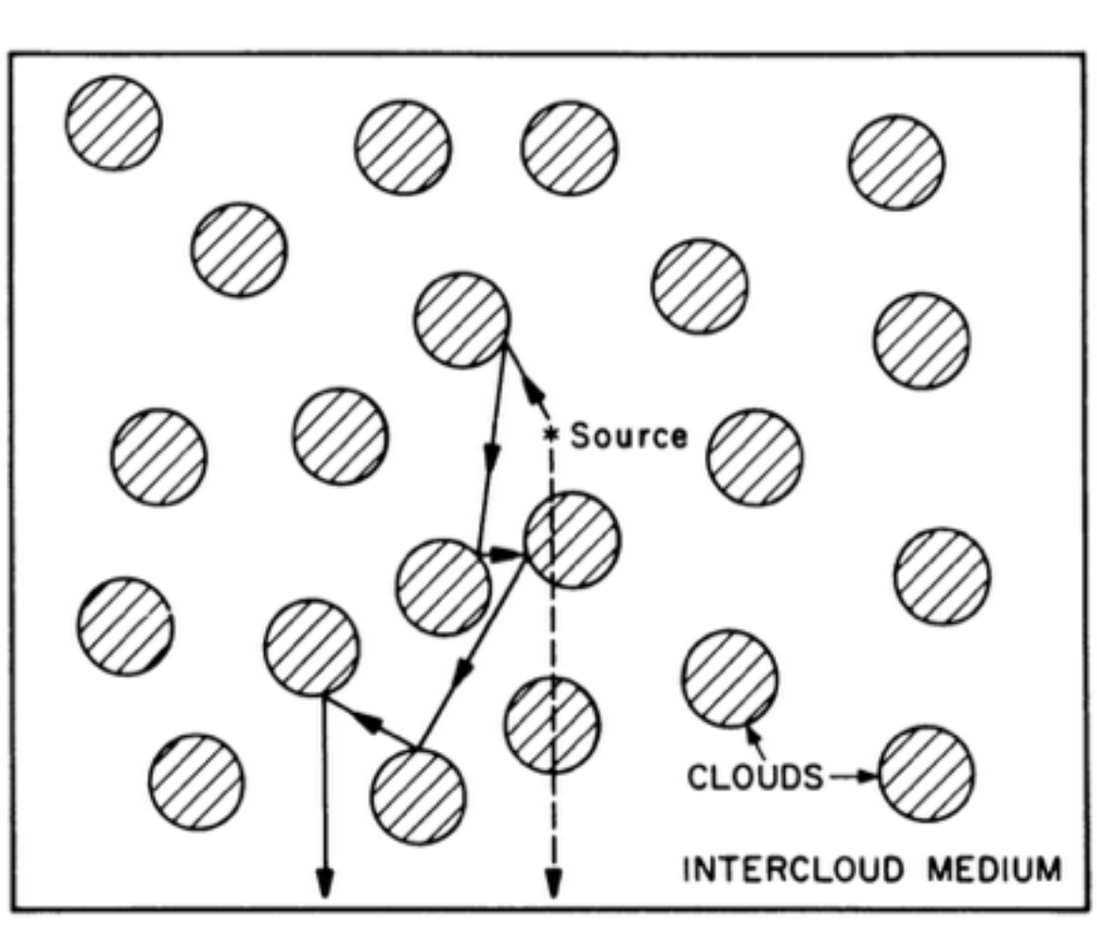

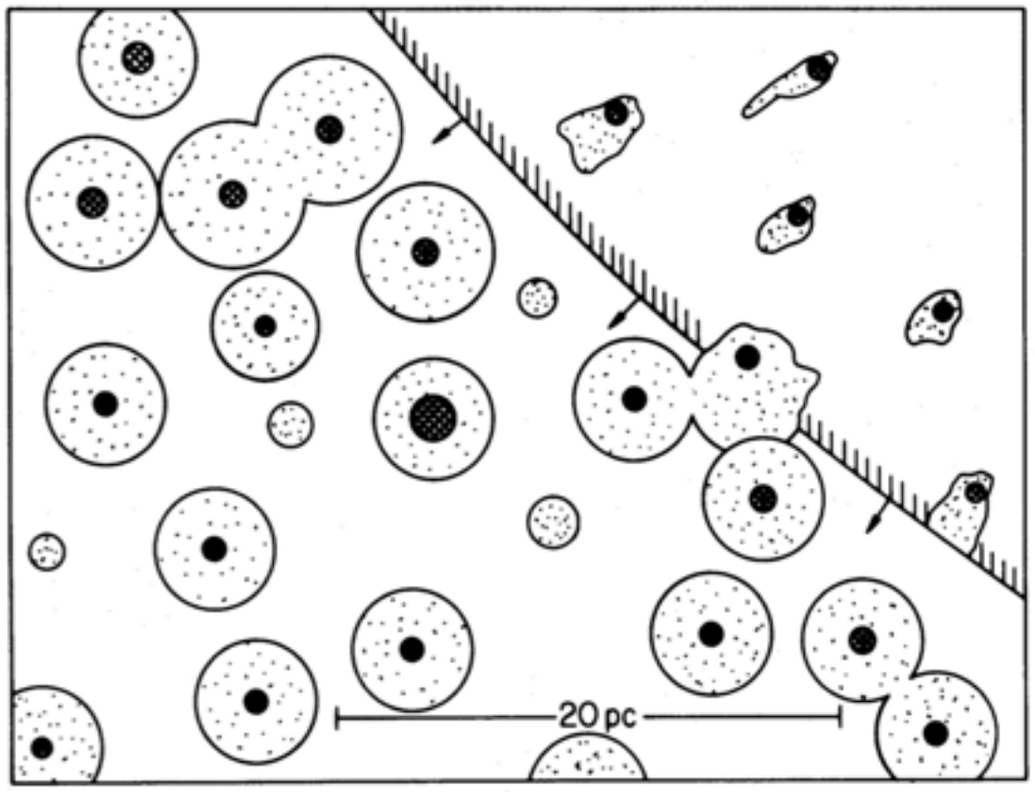

A CLOSE UP VIEW

THE ESCAPE OF LYMAN-ALPHA RADIATION FROM A MULTIPHASE INTERSTELLAR MEDIUM

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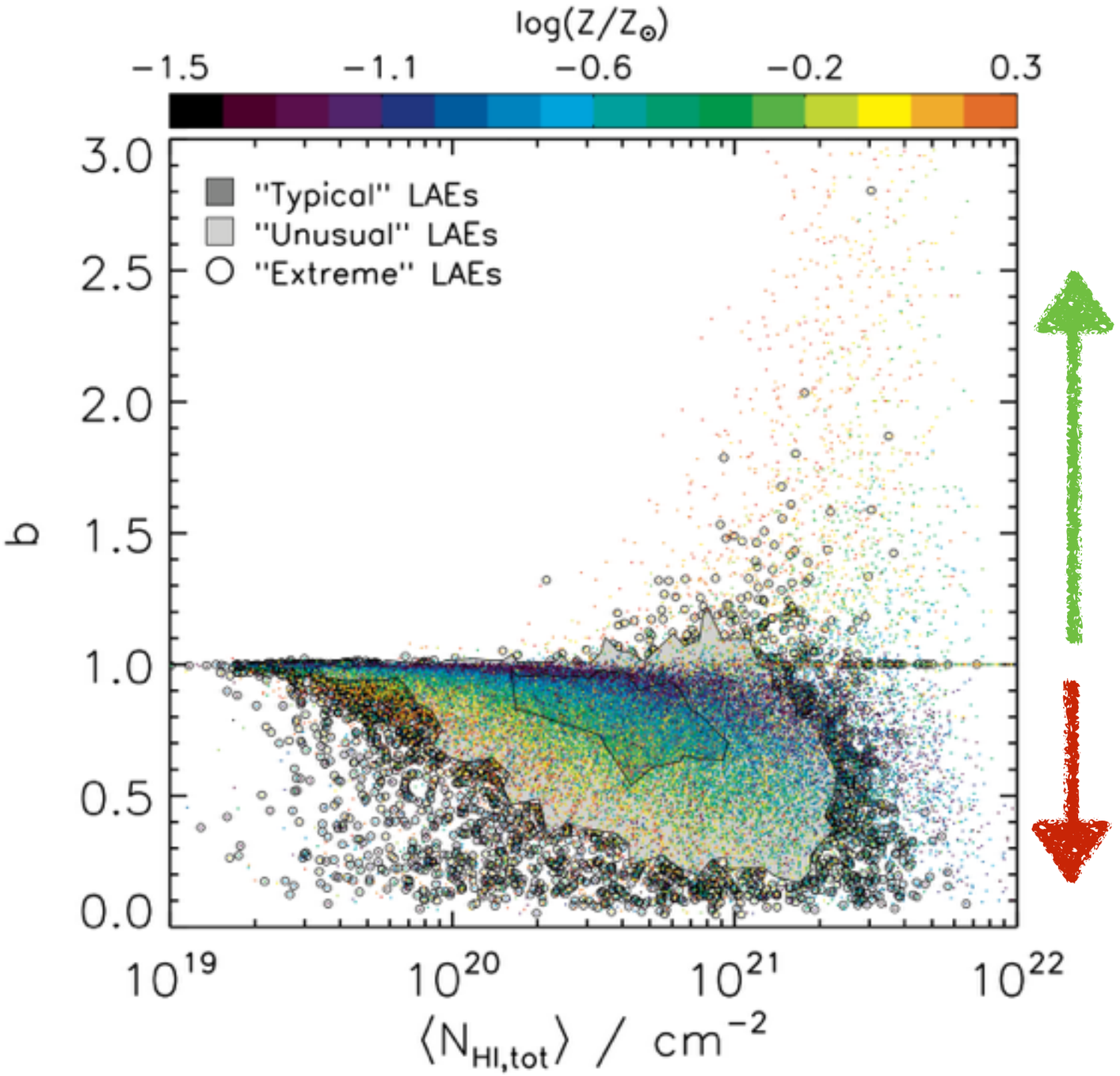
The Neufeld effect



(angle averaged) boost parameter

$$b = \frac{f_{\mathrm{esc,Ly}\alpha}}{f_{\mathrm{esc,UV}}}$$

EW boost

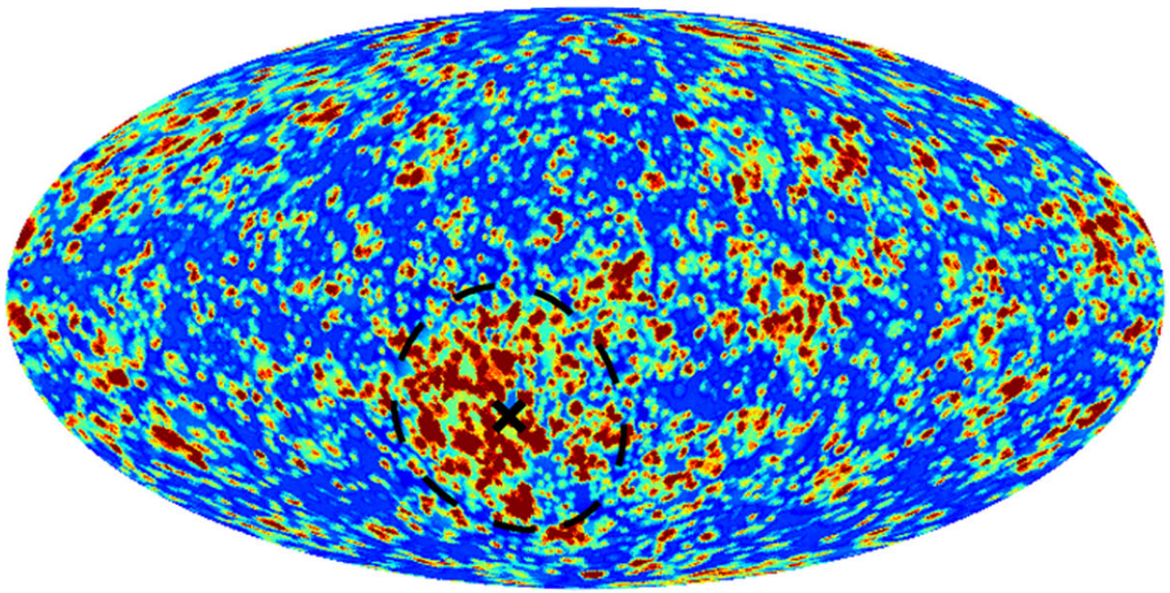
no EW boost

Laursen et al. (2013)

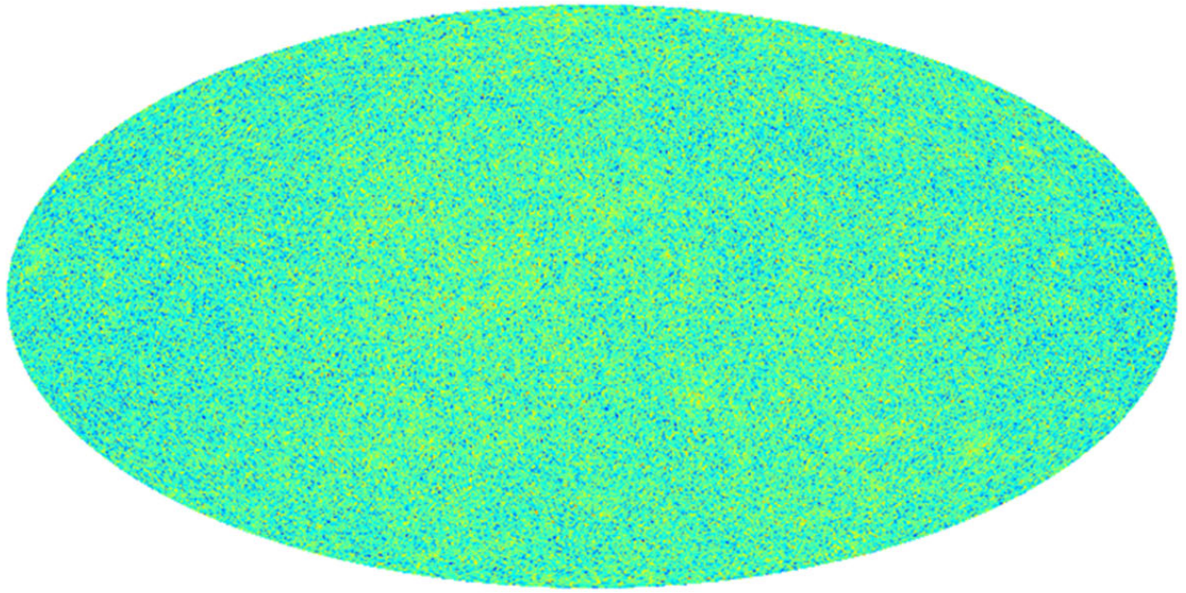
MG & Dijkstra (2014)

Directional dependent Neufeld effect

“Extreme” model



“Realistic” model



Possible but rare!

MG & Dijkstra (2016)
on the arXiv today!

Spectra of multiphase models

hot inter-clump medium (ICM)

$n_{\rm HI} \lesssim 10^{-6}{\rm cm}^{-3}$

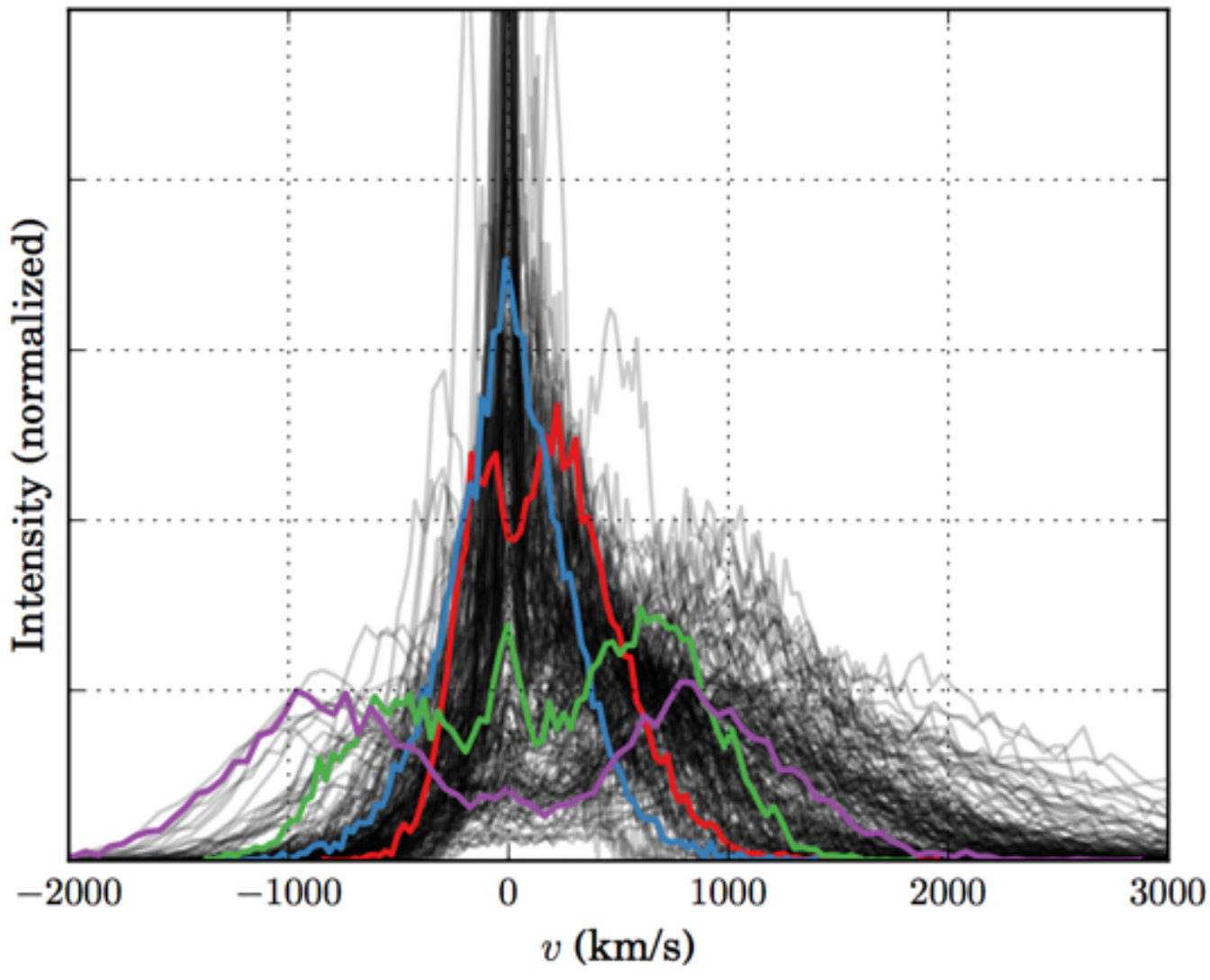
$T \sim 10^6{\rm K}$

cold, dense clumps

$n_{\rm HI} \sim 1\,{\rm cm}^{-3}$

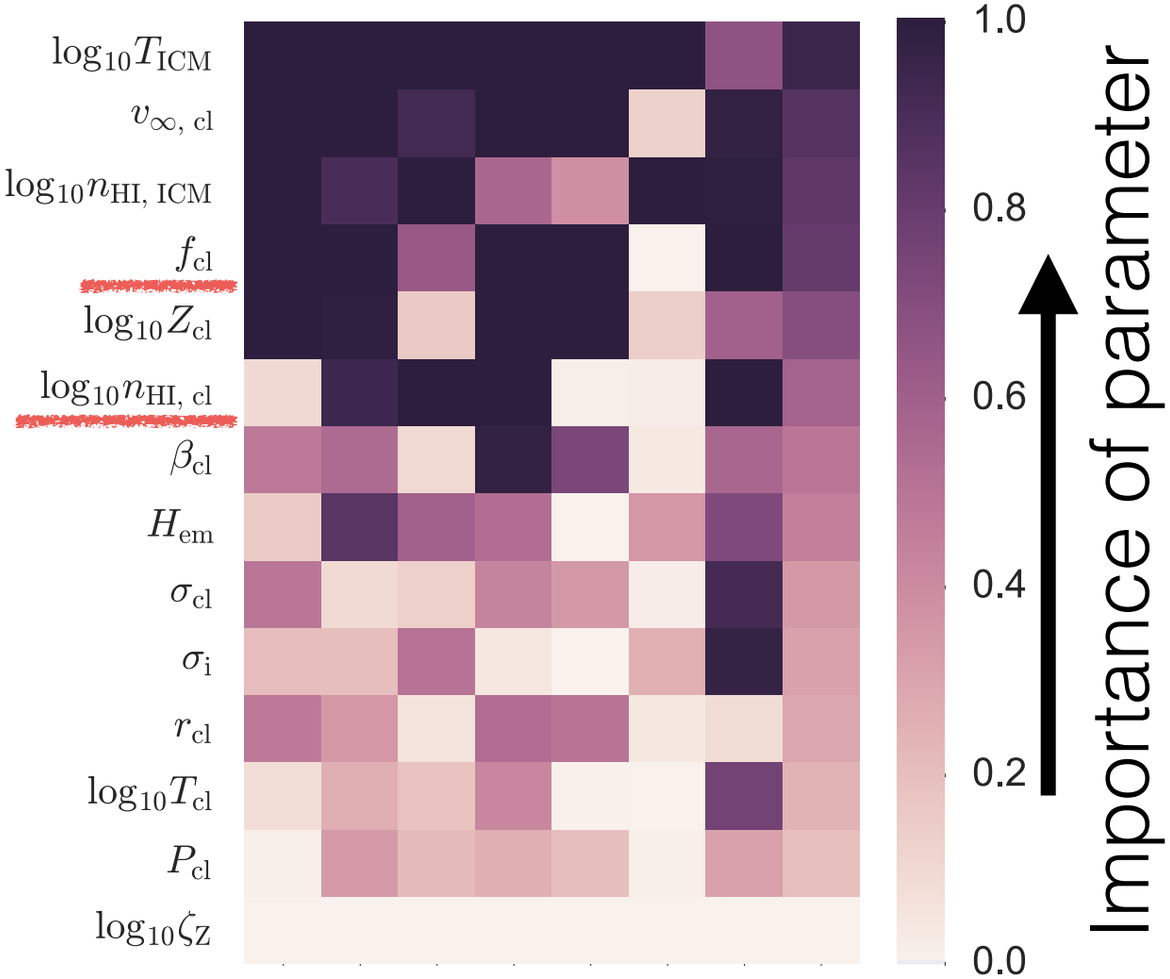
$T \sim 10^4\,{\rm K}$

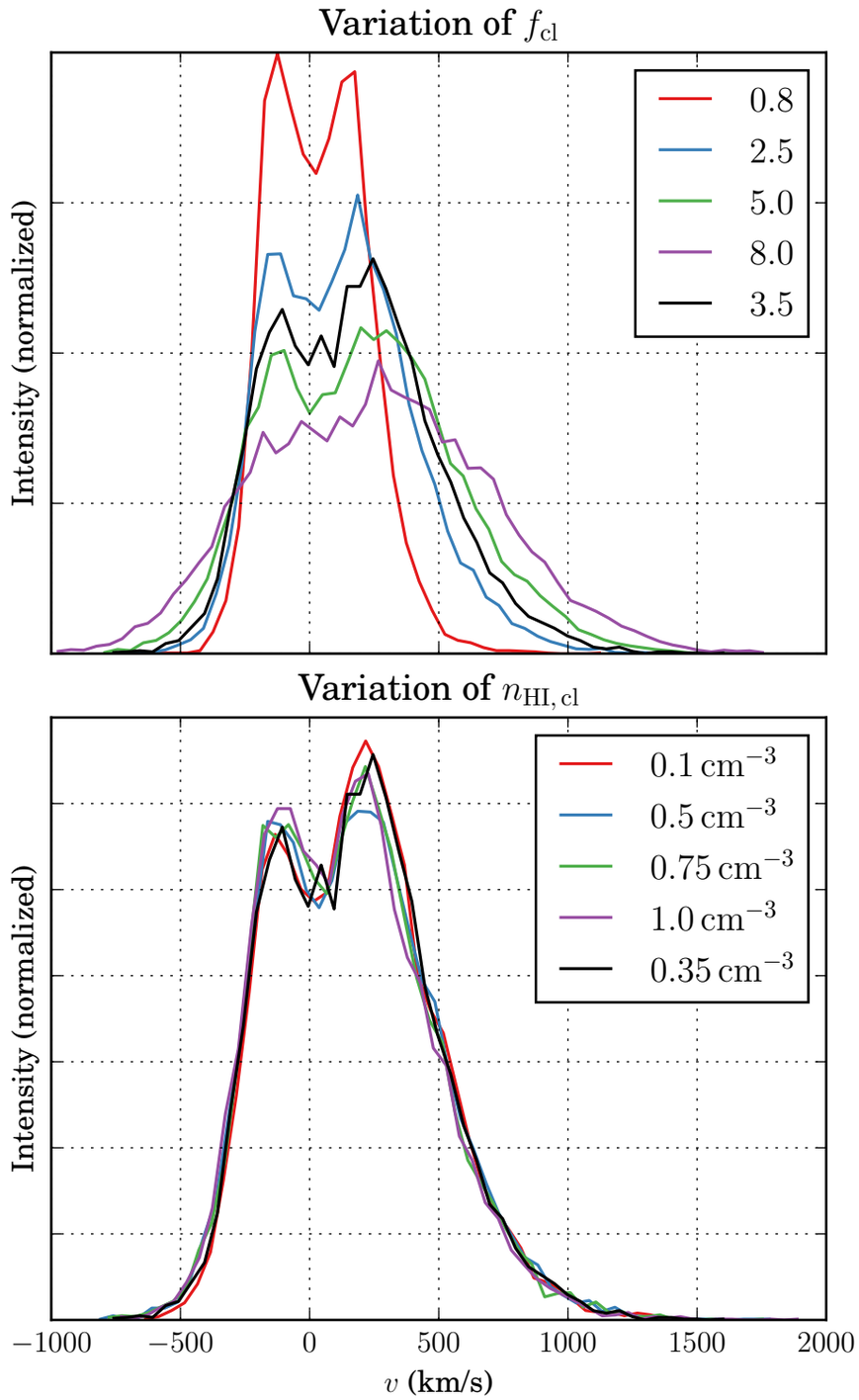
$v \sim 100\,{\rm km\,s}^{-1}$



MG & Dijkstra (2016)

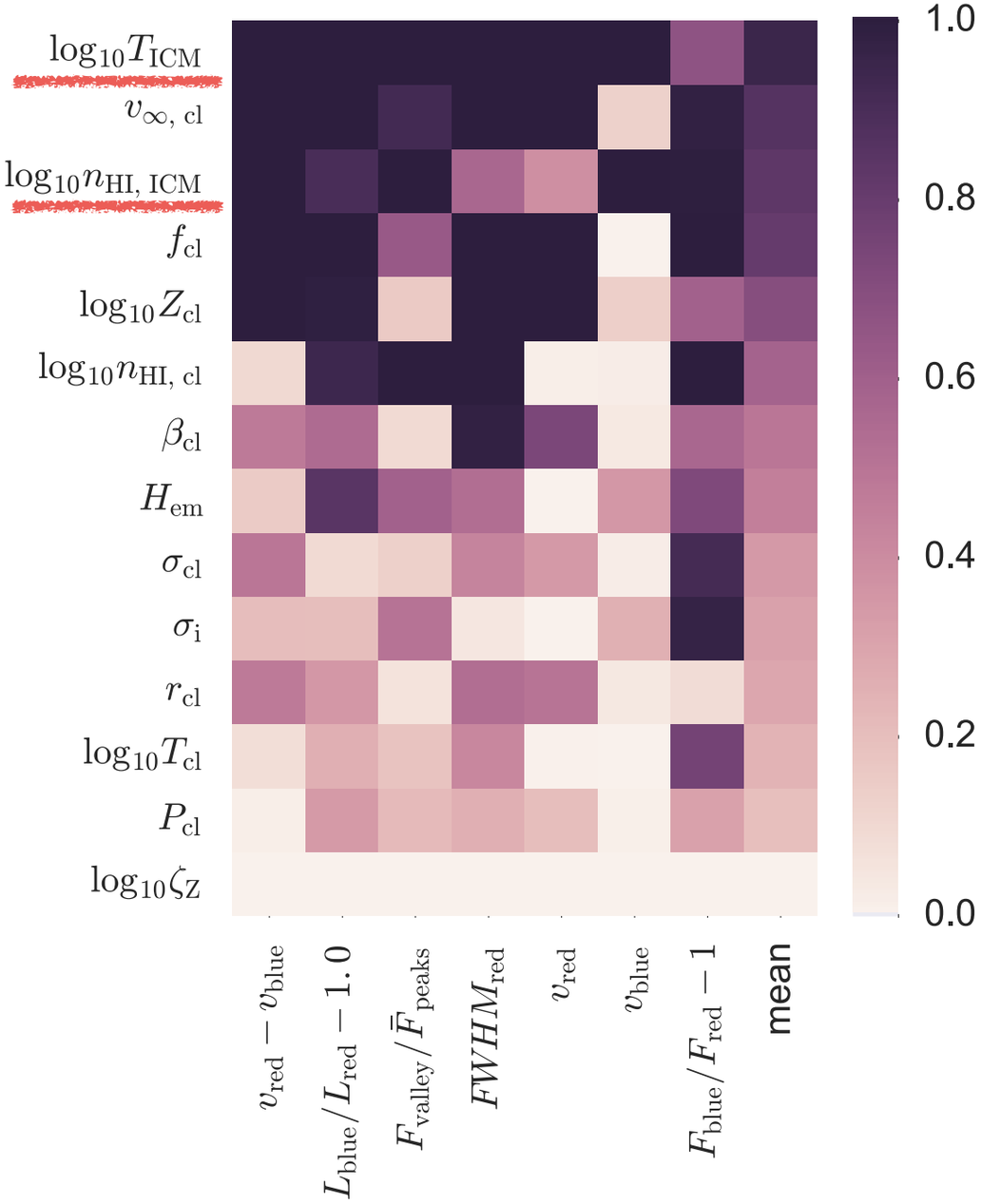
Sensitivity of spectral shapes to multiphase medium

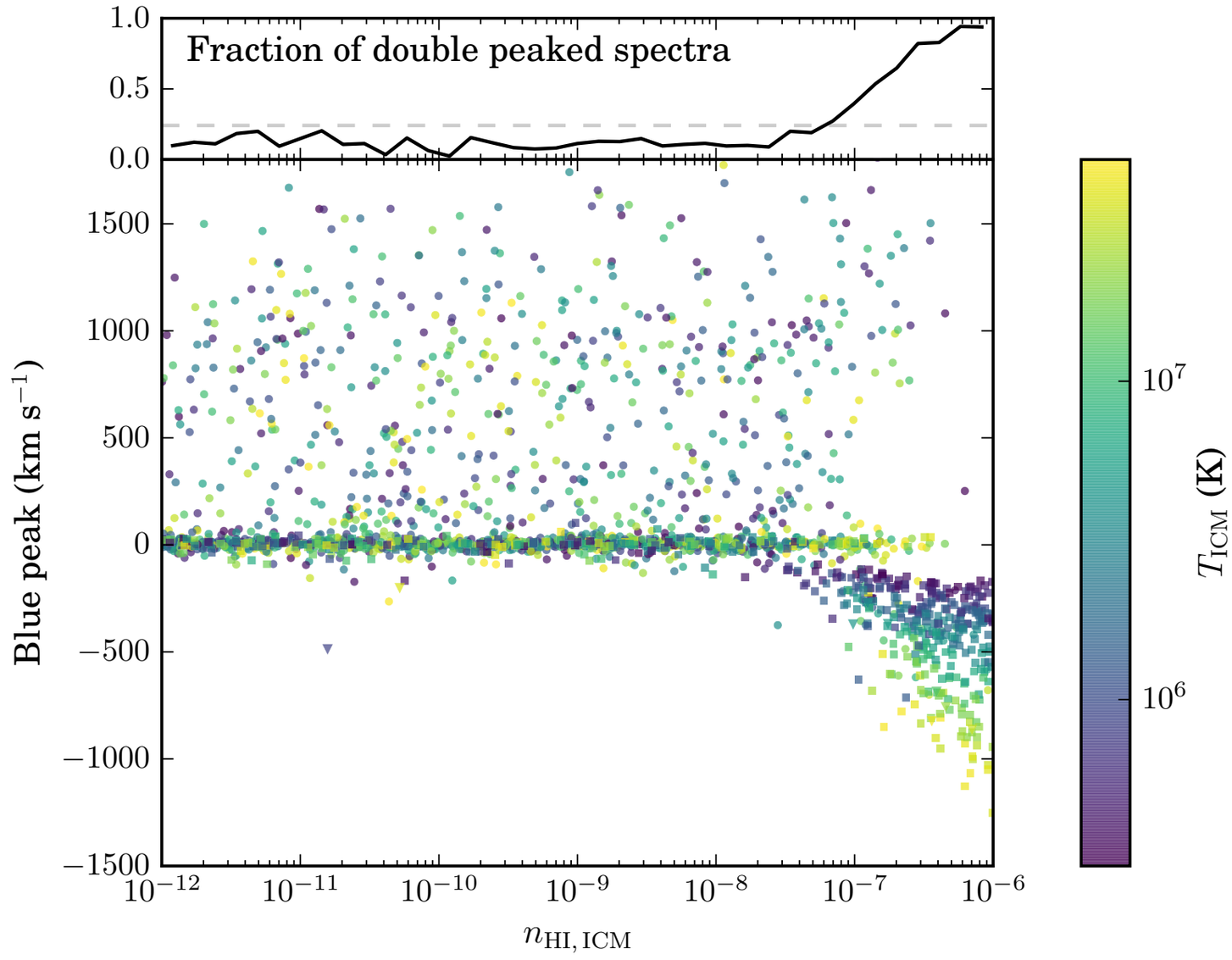




MG & Dijkstra (2016)

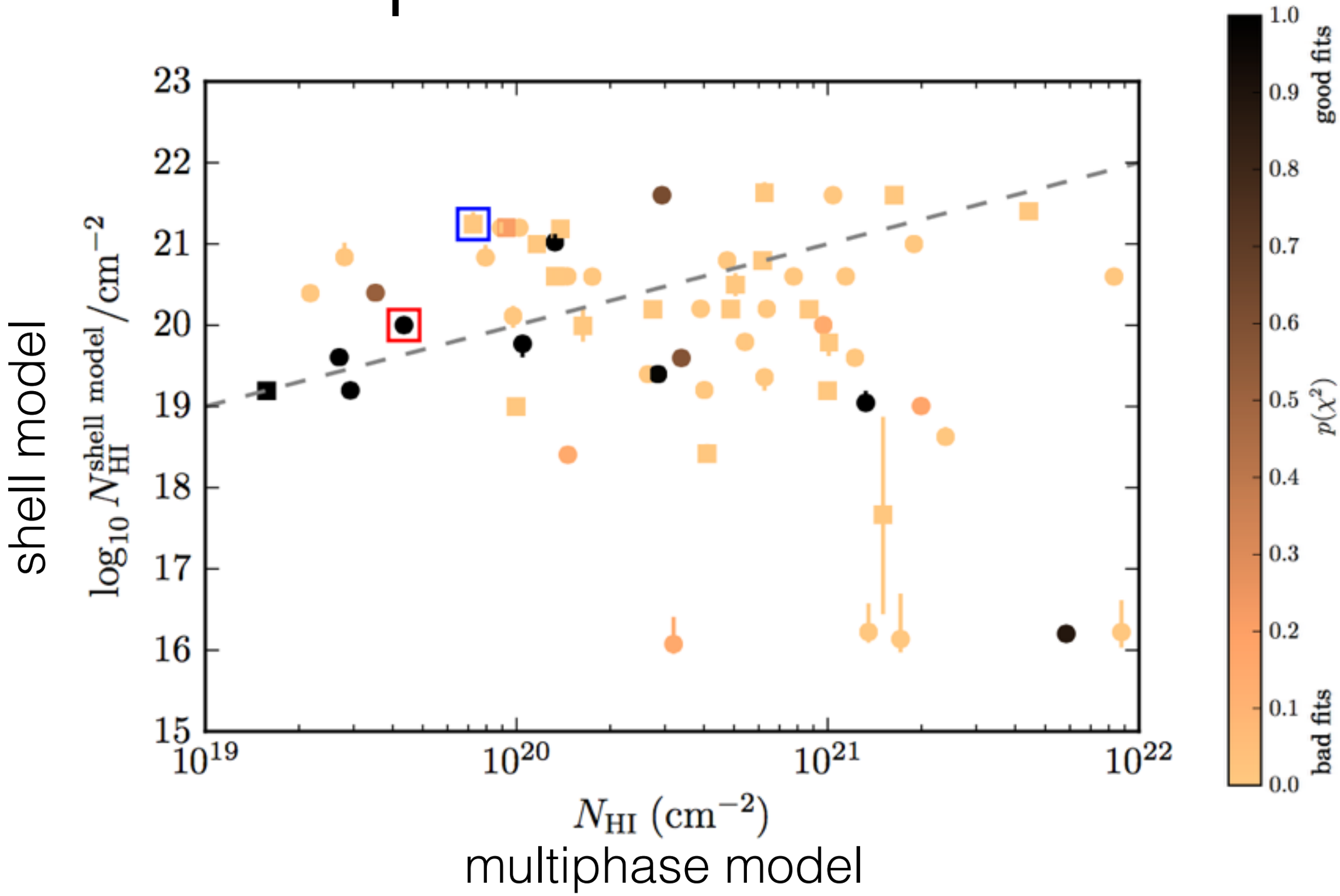
The inter-clump medium matters!





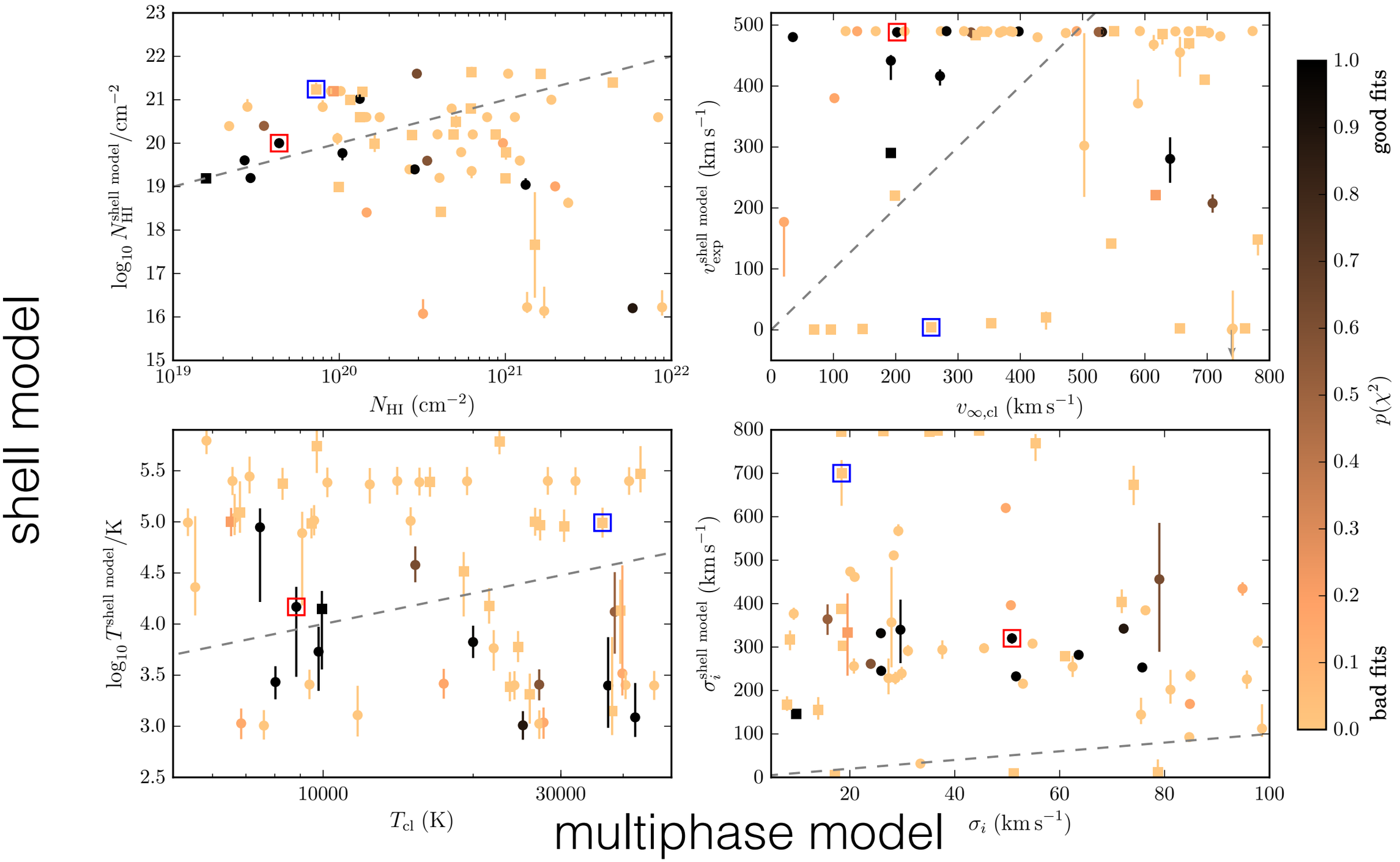
MG & Dijkstra (2016)

Shell model versus multiphase models



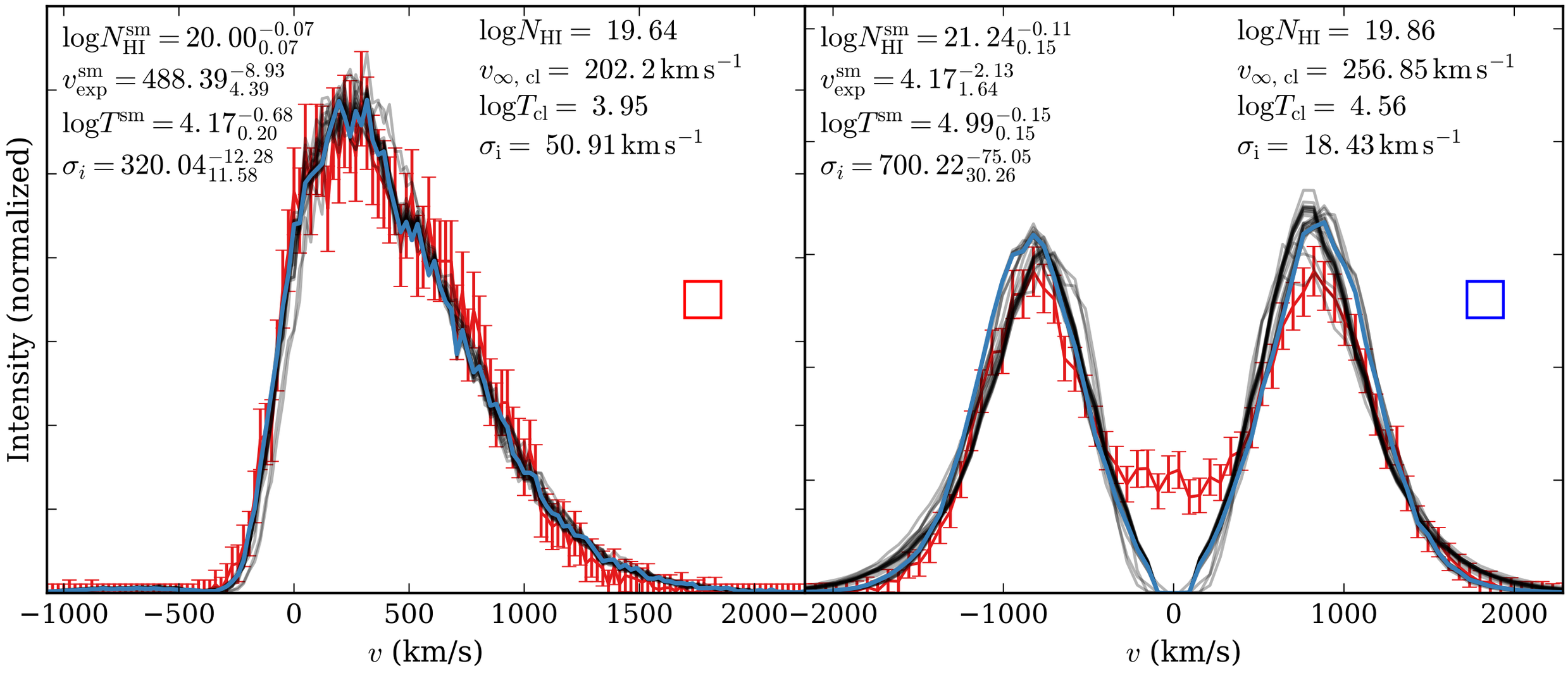
MG & Dijkstra (2016)

Shell model versus multiphase models



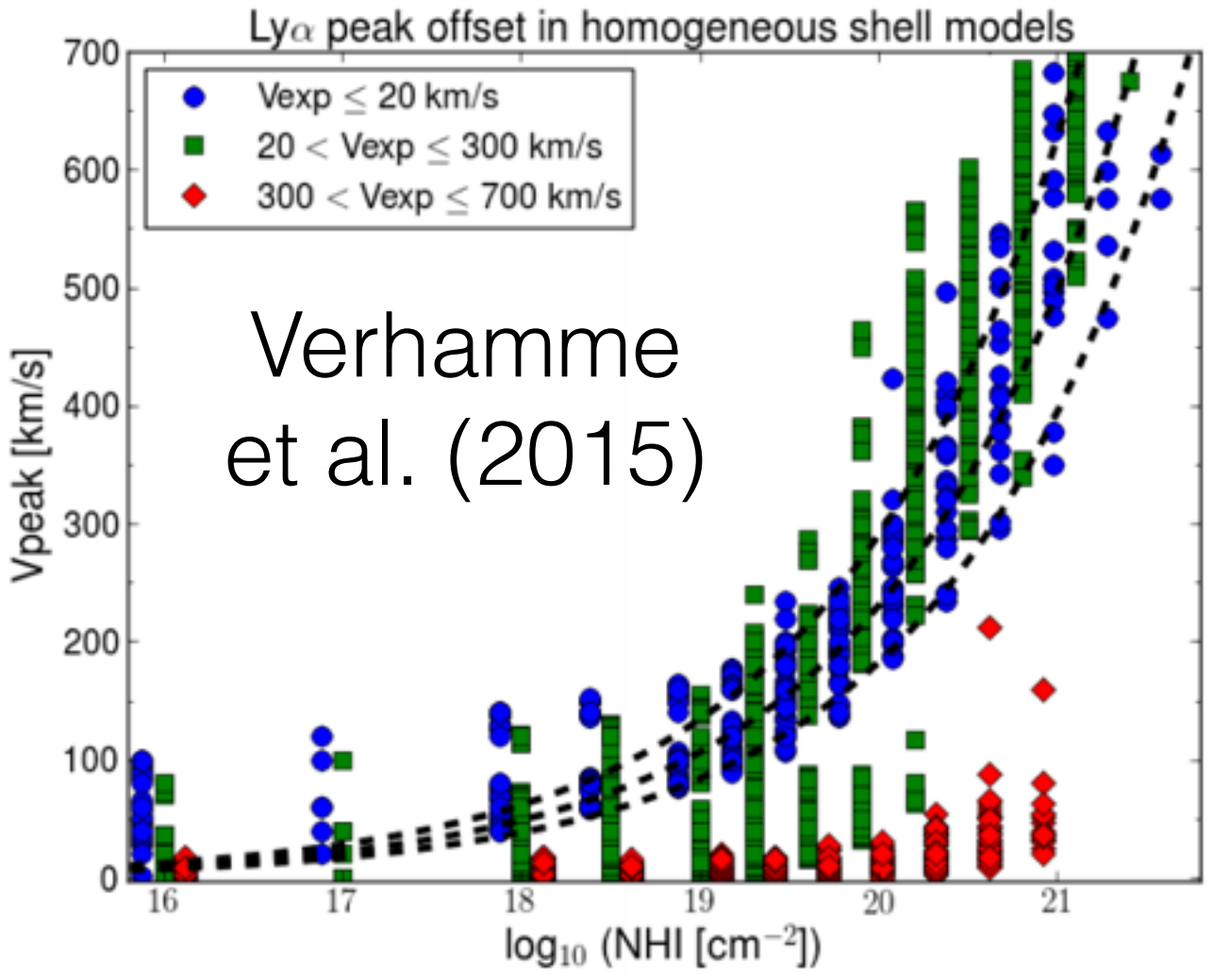
MG & Dijkstra (2016)

Two example spectra



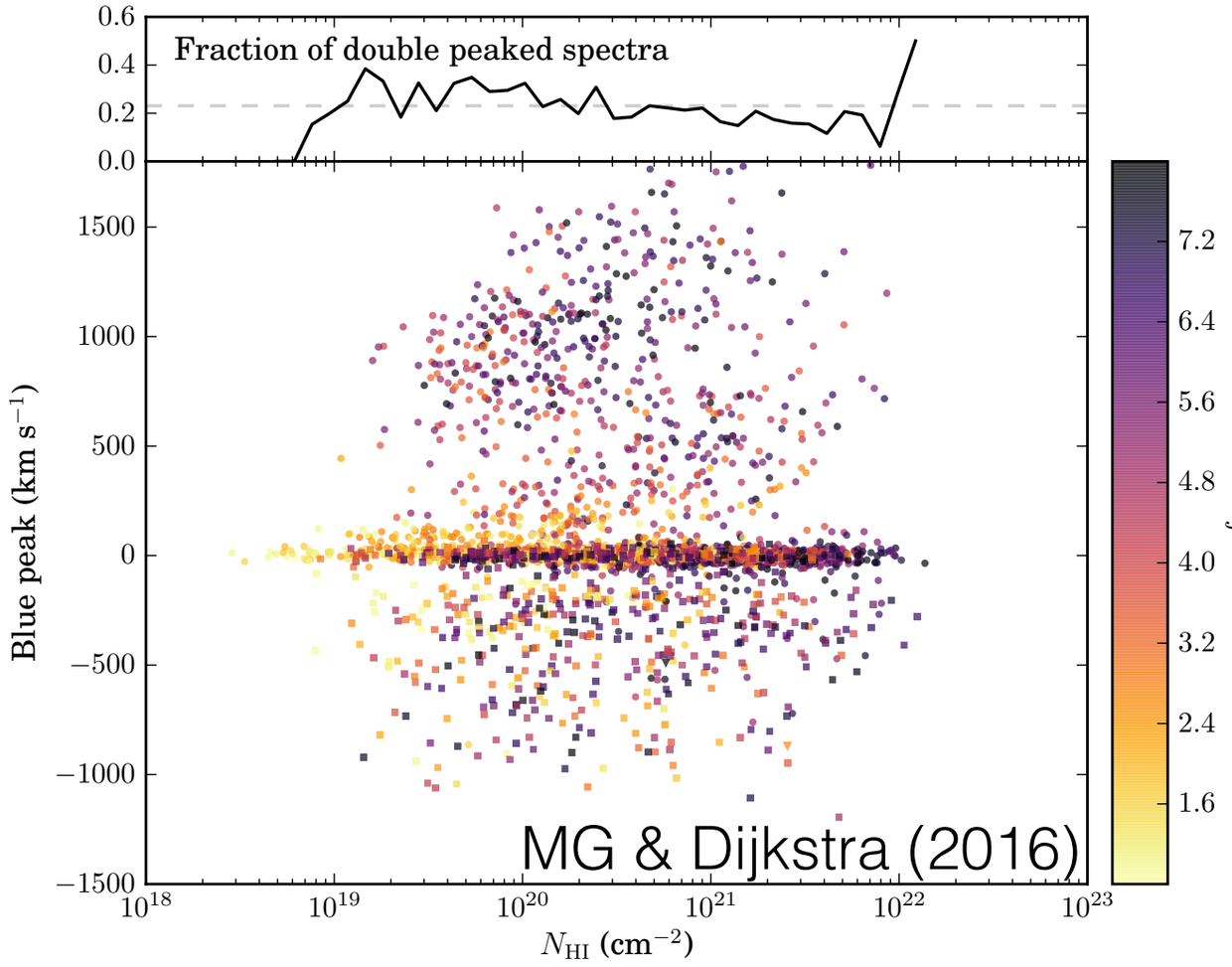
Peak offset vs column density

Shell-model



$$N_{\rm HI} = N_{\rm HI,shell}$$

Multiphase model



$$N_{\rm HI} \approx N_{\rm HI,clumps}$$

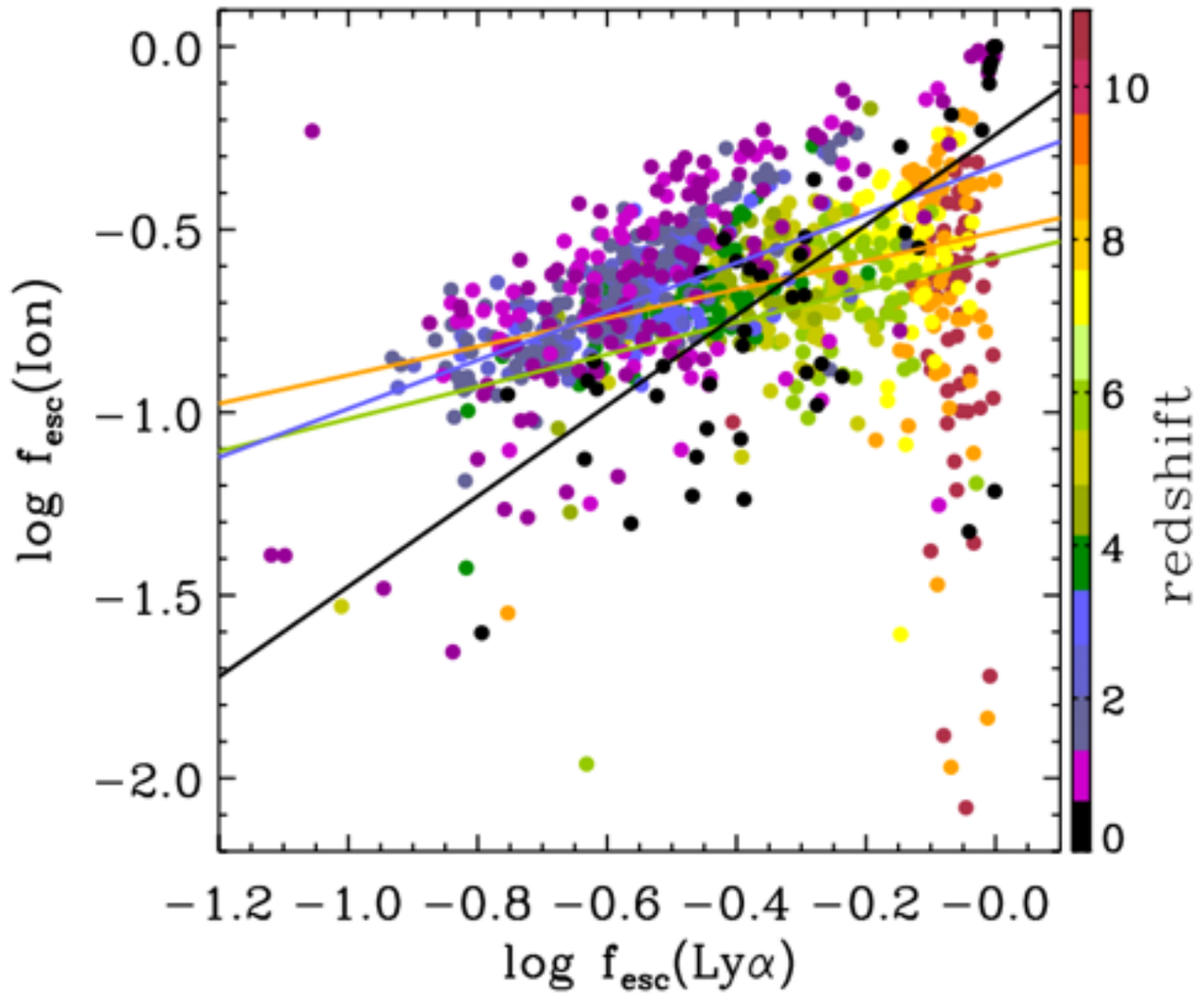
Lyα radiative transfer in clumpy outflows

- “Neufeld” effect unlikely to play a major role
- Clumpy outflows yield a wide variety of spectra
- Important parameters: covering factor & inter-clump medium
- Shell-model…

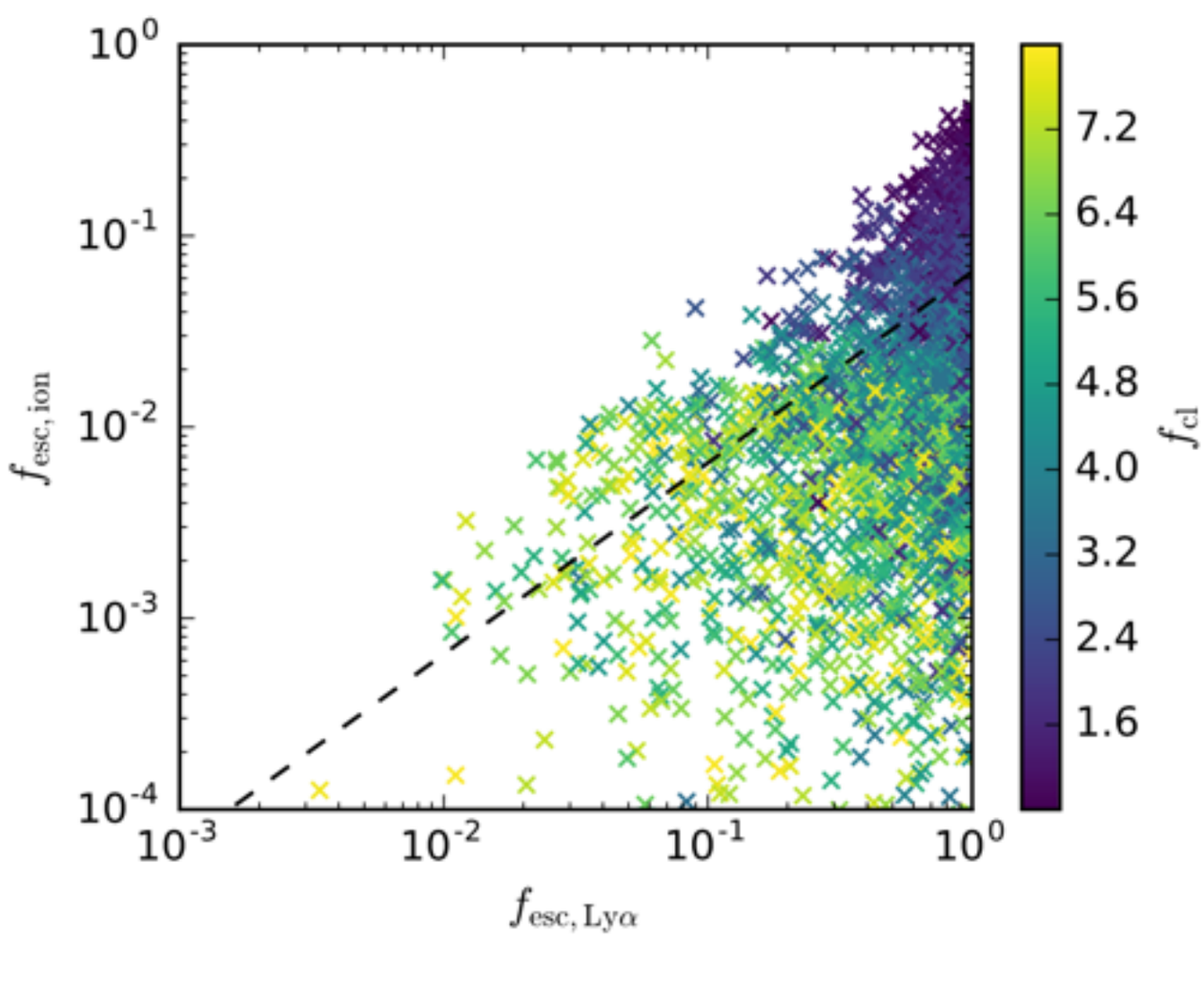
  …can reproduce only few spectra

  …parameters do not match clumpy model

$f_{esc,ion}$ vs $f_{esc,\ Lya}$



Yajima et al. (2014)

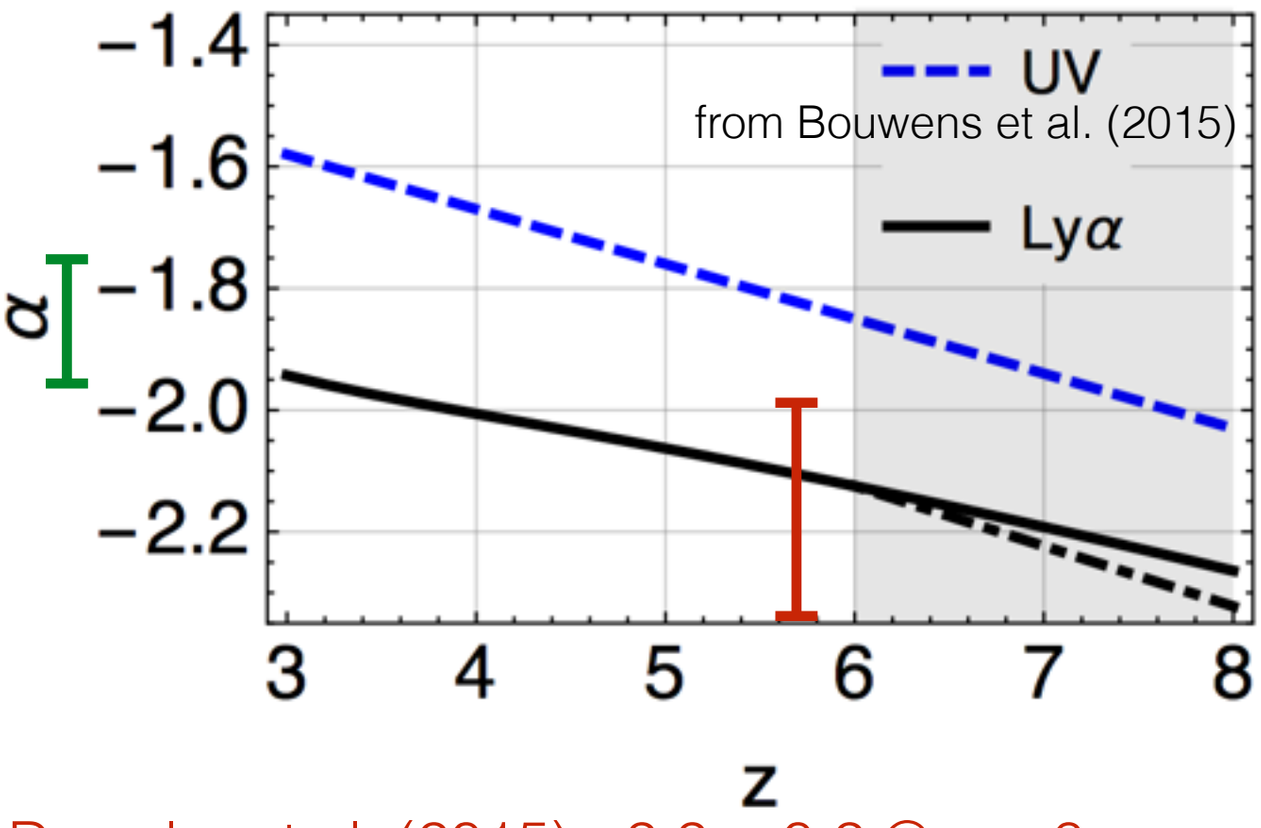


Dijkstra & MG
(Friday on the arXiv)

Implications for reionization

Faint-end slope of Lyα luminosity function

MG, Dijkstra, Trenti, Wyithe (2015)



$$\phi_{\rm LAE}(L_\alpha)\mathrm{d}L_\alpha = \mathrm{d}L_\alpha F \int_{M_{\rm UV,min}}^{M_{\rm U}} \mathrm{d}M_{\rm UV}\, \phi(M_{\rm UV}) P(L_\alpha|M_{\rm UV})$$

Dressler et al. (2015): -2.2 ± 0.2 @ z ~ 6

Konno et al. (2016): -1.75 ± 0.1 @ z ~ 2

Implications for reionization

Faint-end slope of Lyα luminosity function

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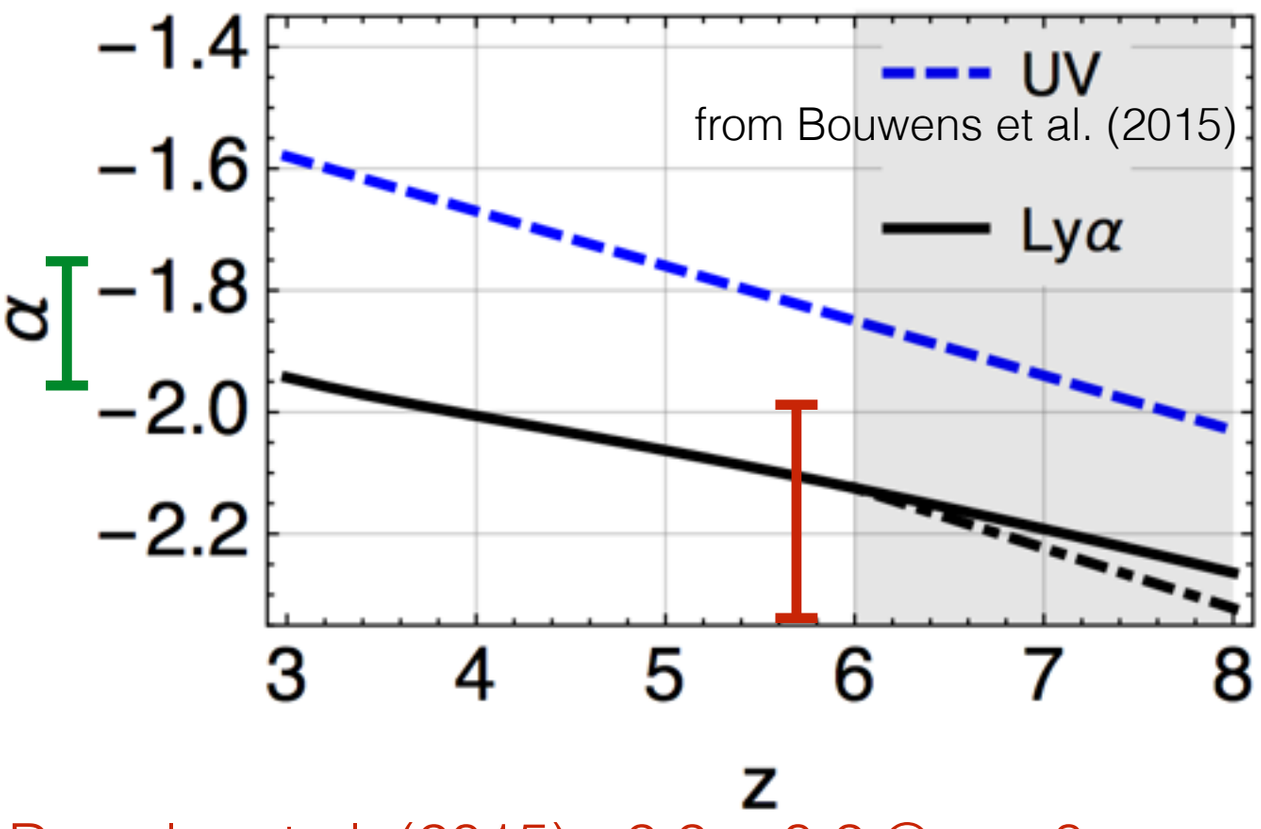

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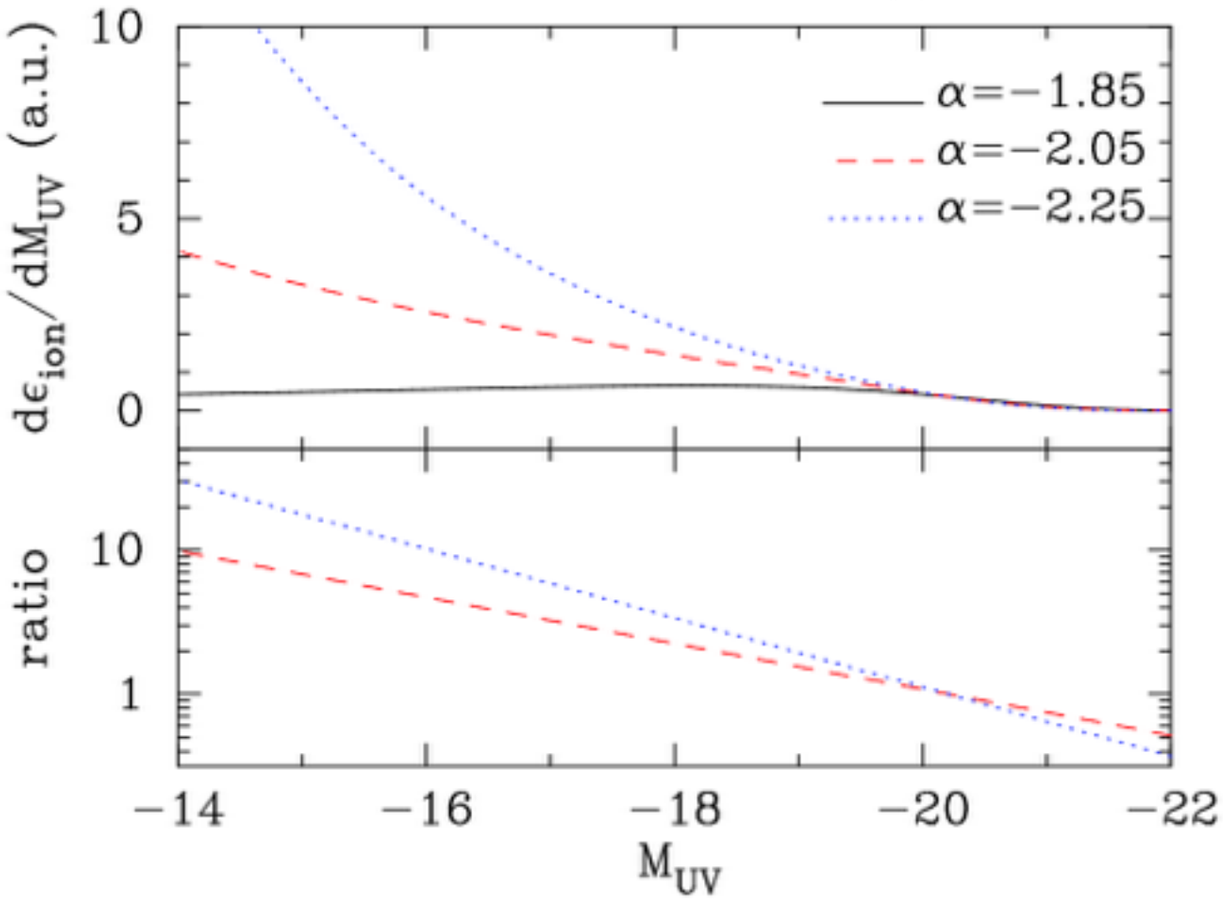
Effect of steeper faint-end slope of LyC LF

Dijkstra & MG (Friday)



Clumpy Outflows and Shell Models in Lyα radiative transfer

- Successful but puzzling “shell-model”

fits observed spectra remarkable well
meaning of fitting parameters unclear

- Tension between shell- & multiphase models

different spectral shapes
mismatch of physical parameters

- Hints that UV faint galaxies reionized the Universe

correlation between escape fractions
steepening of the Lyα faint-end slope