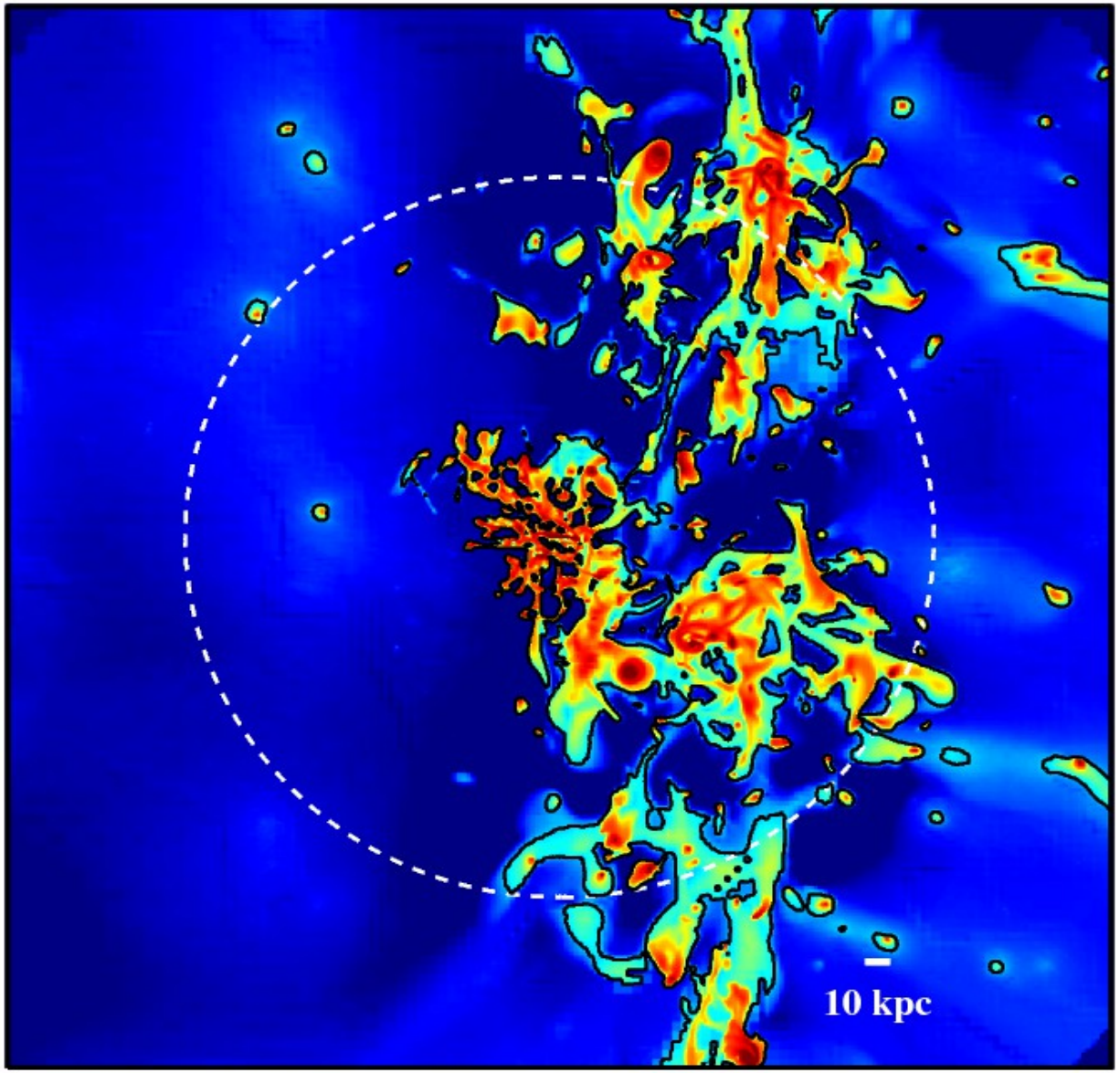
Lyman limit systems and the circumgalactic medium at z~2-3



Michele Fumagalli
Hubble Fellow
Carnegie Observatories
Princeton University

with

Joe Hennawi, John O'Meara, Xavier Prochaska, Daniel Kasen, Daniel Ceverino, Avishai Dekel, Joel Primack, Gabor Worseck

(arXiv:1308.1669, arXiv:1308.1101)

August 2013

Outline

Lyman limit systems and the circumgalactic medium

A prediction of simulations and a useful observational tool

Optically-thick hydrogen in massive galaxies

Comparing simulations and observations

Moving forward: the LLS auto-correlation function

A new experiment to rapidly advance our knowledge on the CGM

…if there is time...

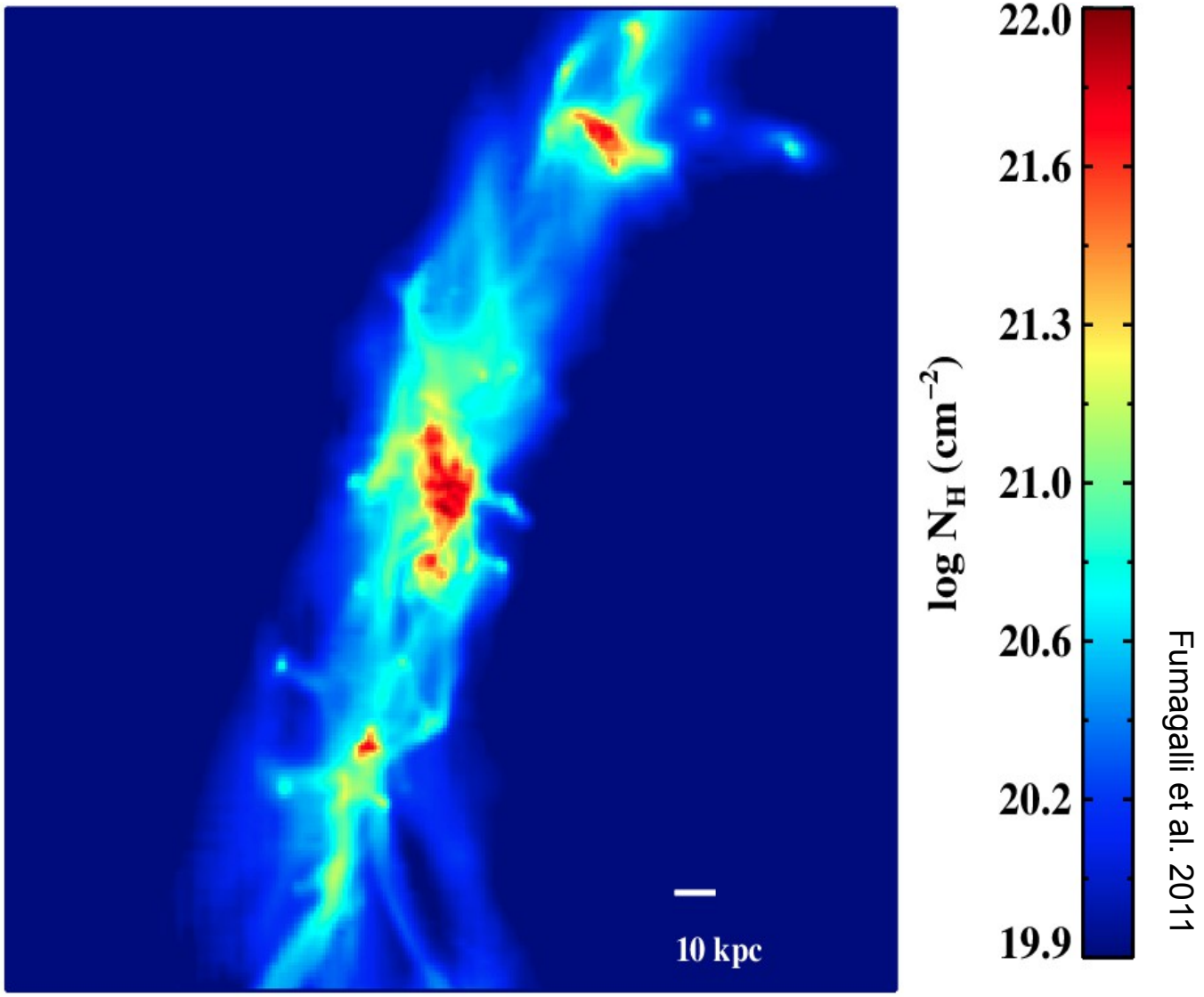
Learning from Lyman limit system surveys

Probing the CGM in a more statistical fashion

Lyman limit systems and the circumgalactic medium

The link between LLSs and the CGM

Simulations consistently predict the presence of optically thick hydrogen in the surroundings of high-redshift galaxies



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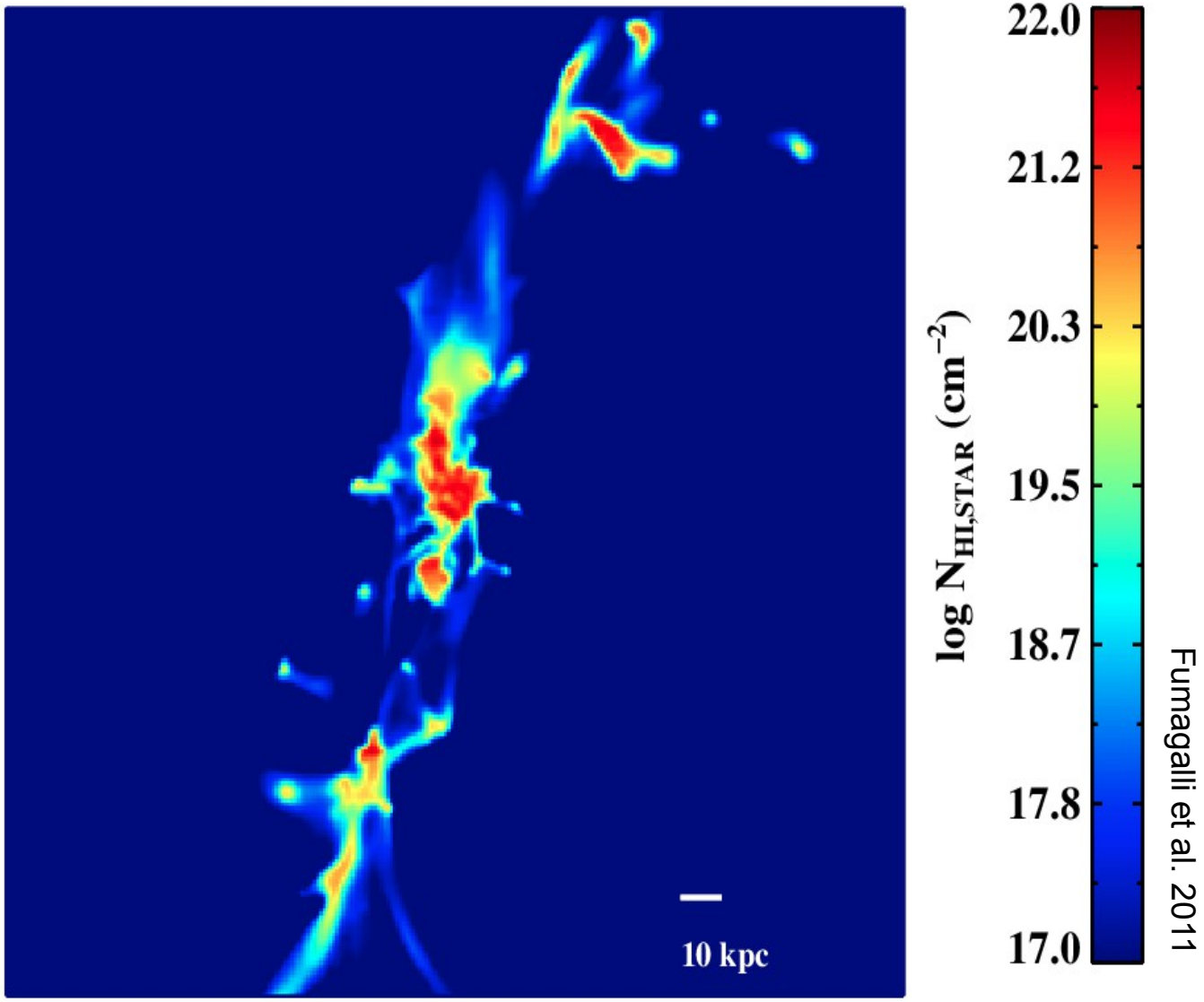

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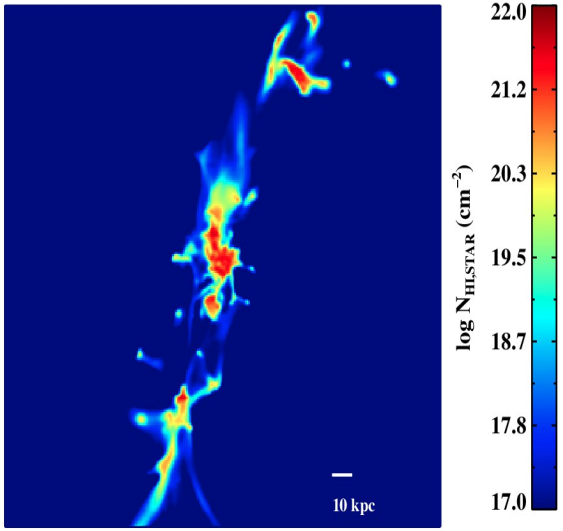
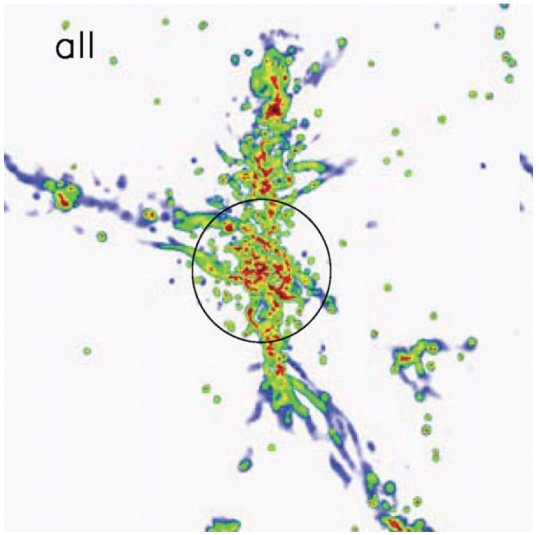
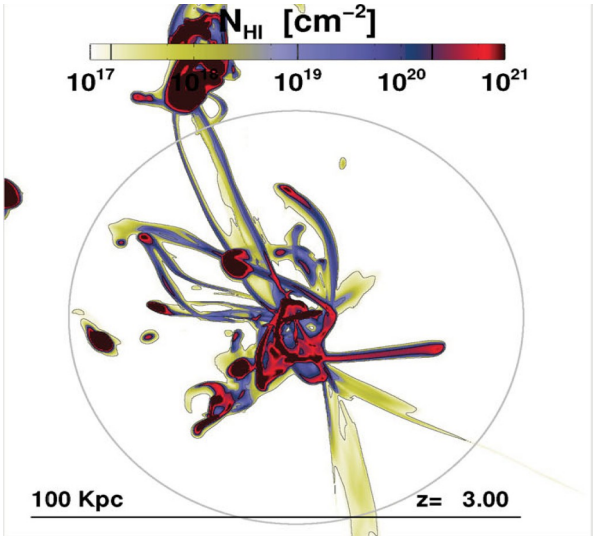


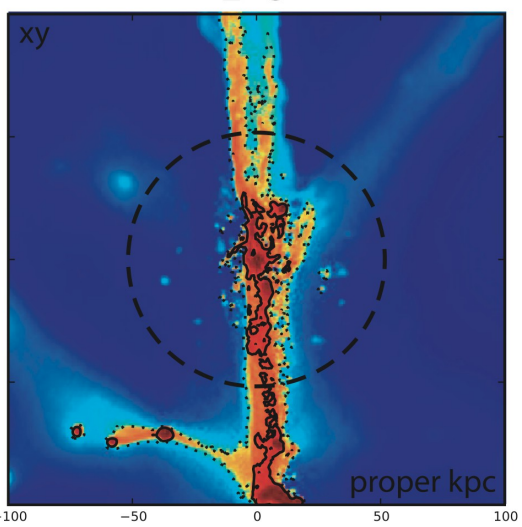
Fumagalli et al. 2011



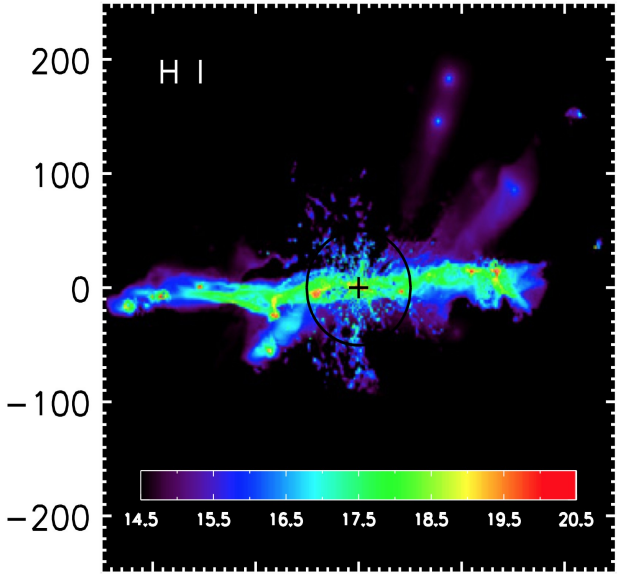
van de Voort et al. 2012



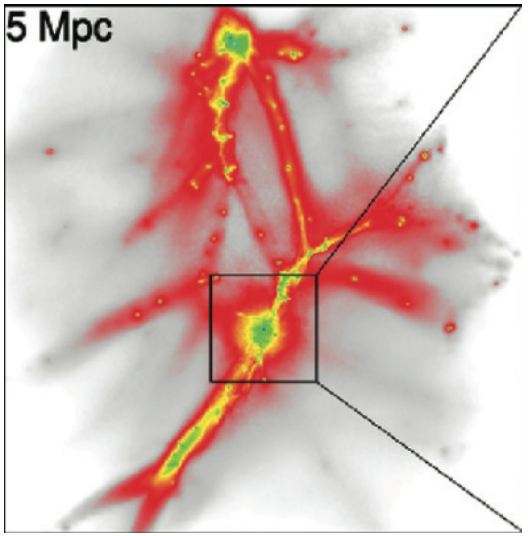
Rosdahl et al. 2012



Faucher-Giguère et al. 2011



Shen et al. 2013

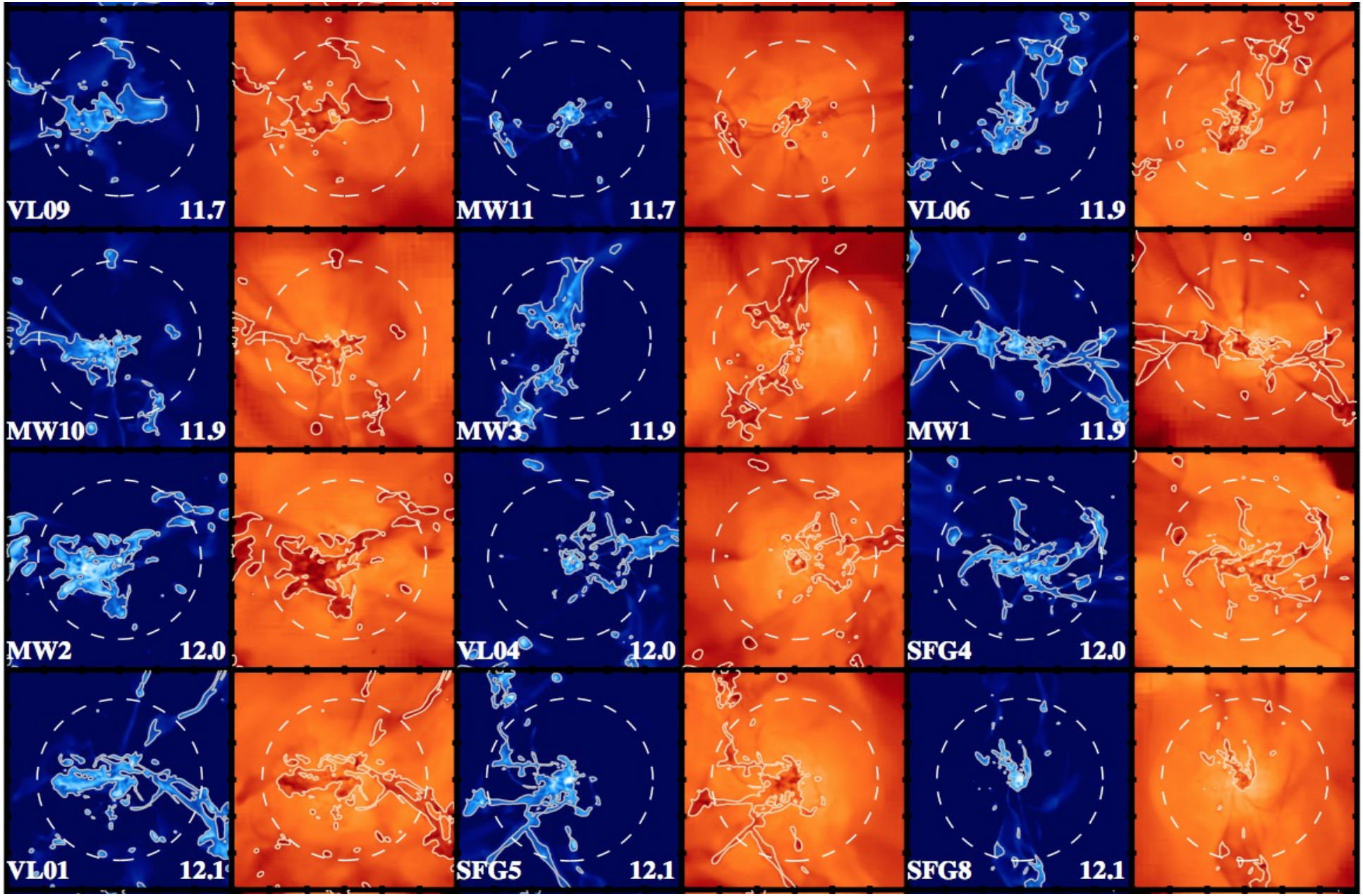


Stewart et al. 2011

Optically-thick hydrogen in massive galaxies

The covering fraction of optically thick gas

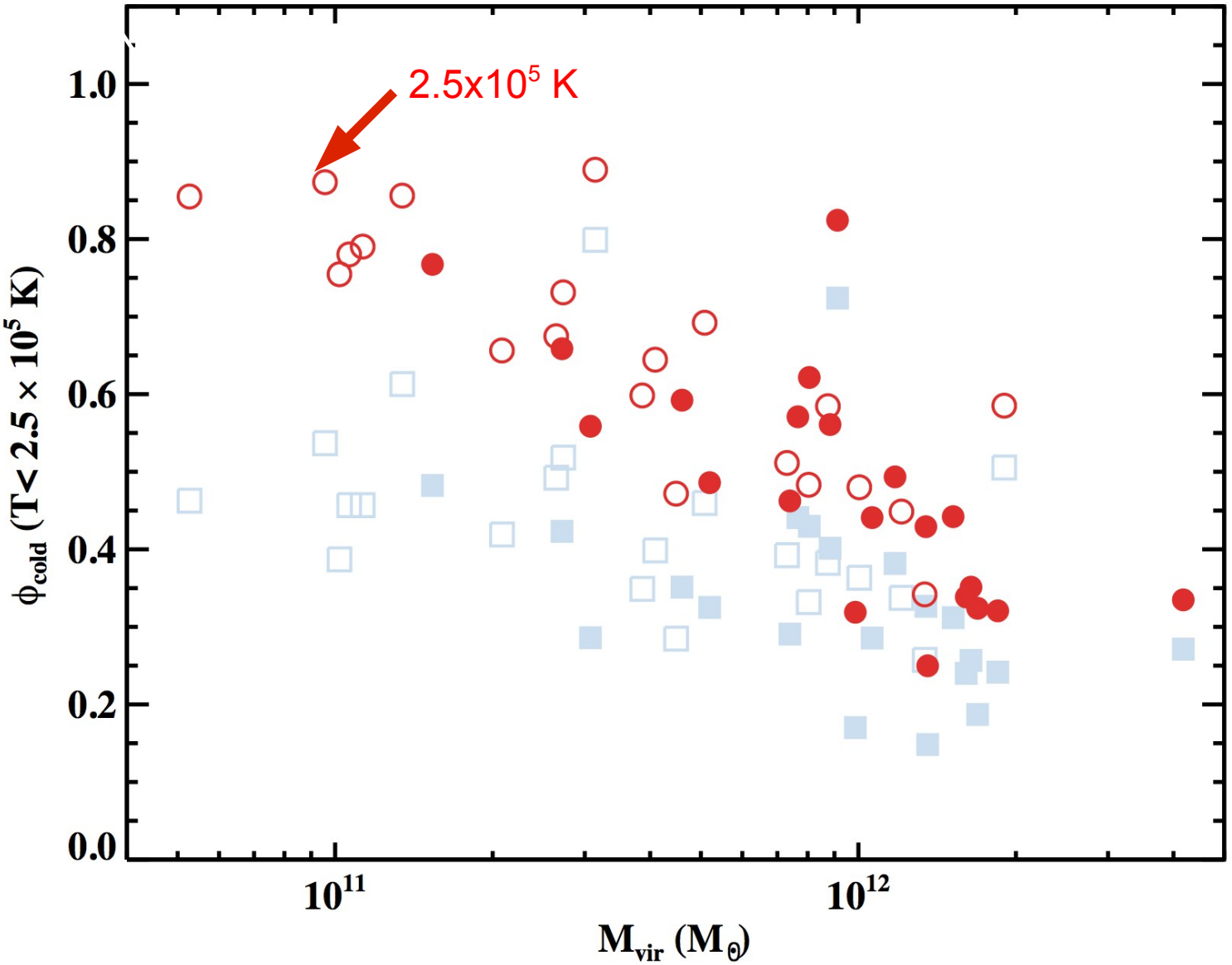
We investigate the hydrogen distribution in 21 simulations at z~2 and z~3



Fumagalli et al. 2013b

The covering fraction of optically thick gas

Simulations predict a low, mass-independent covering fraction of optically thick gas between z~2-3



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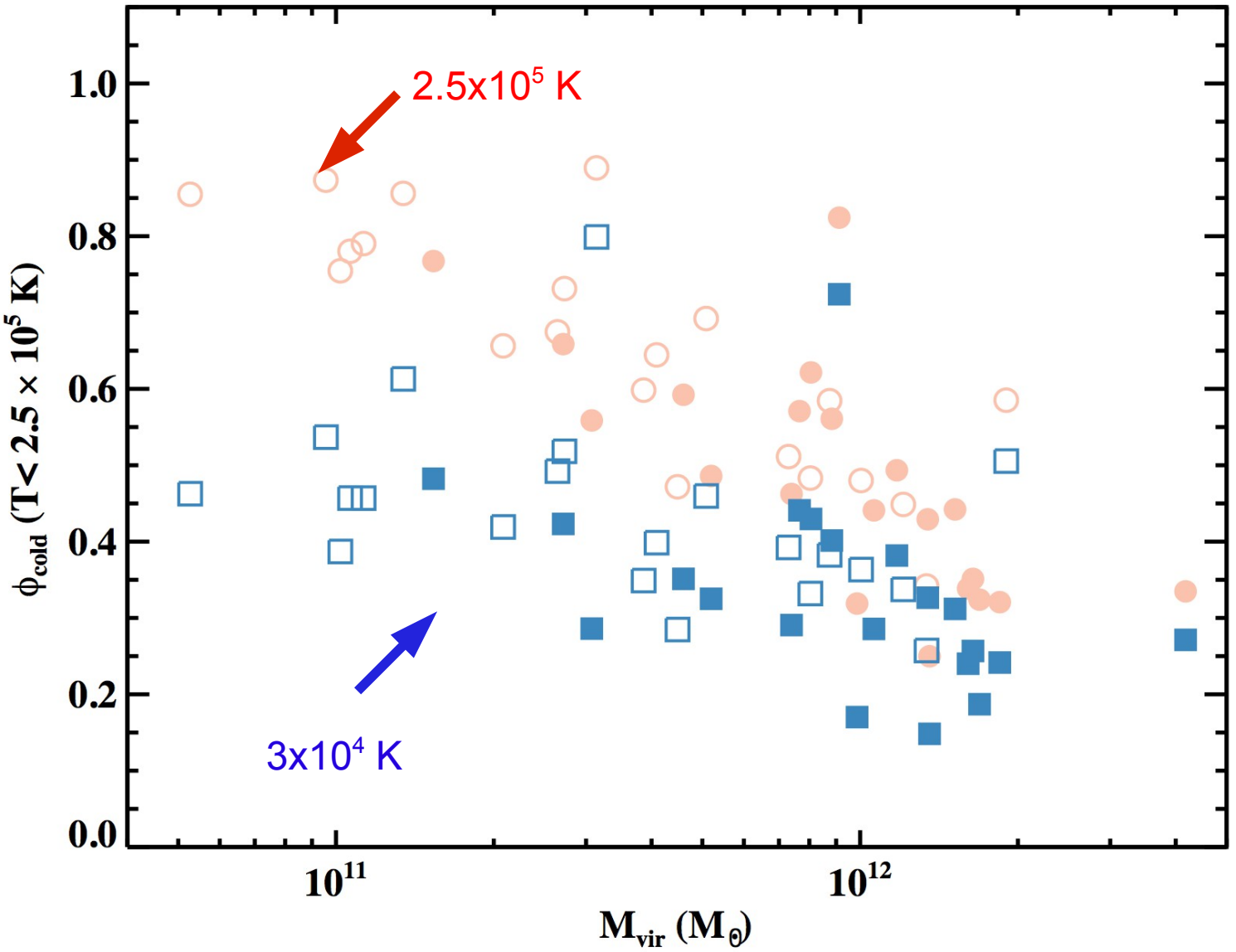

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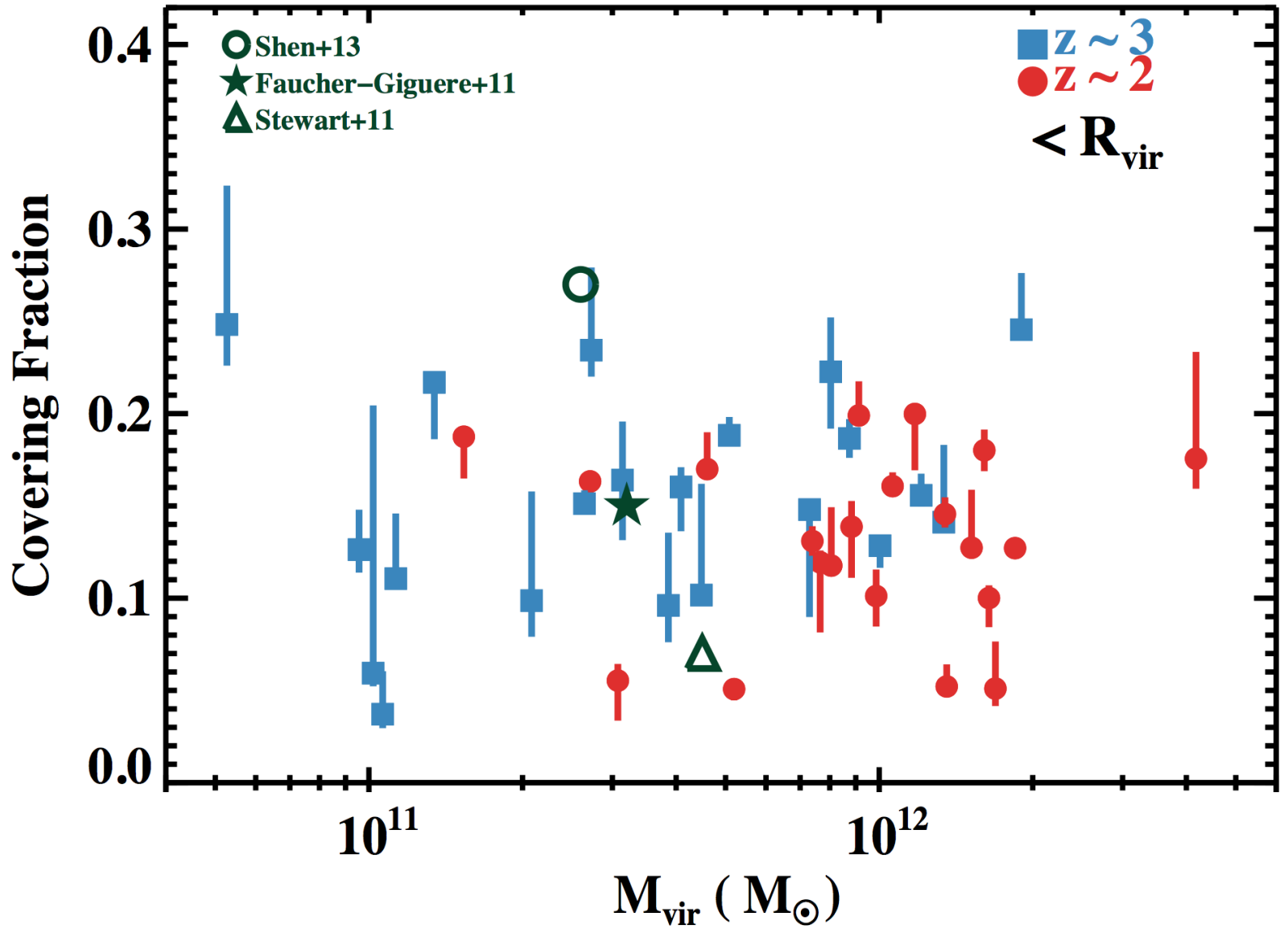
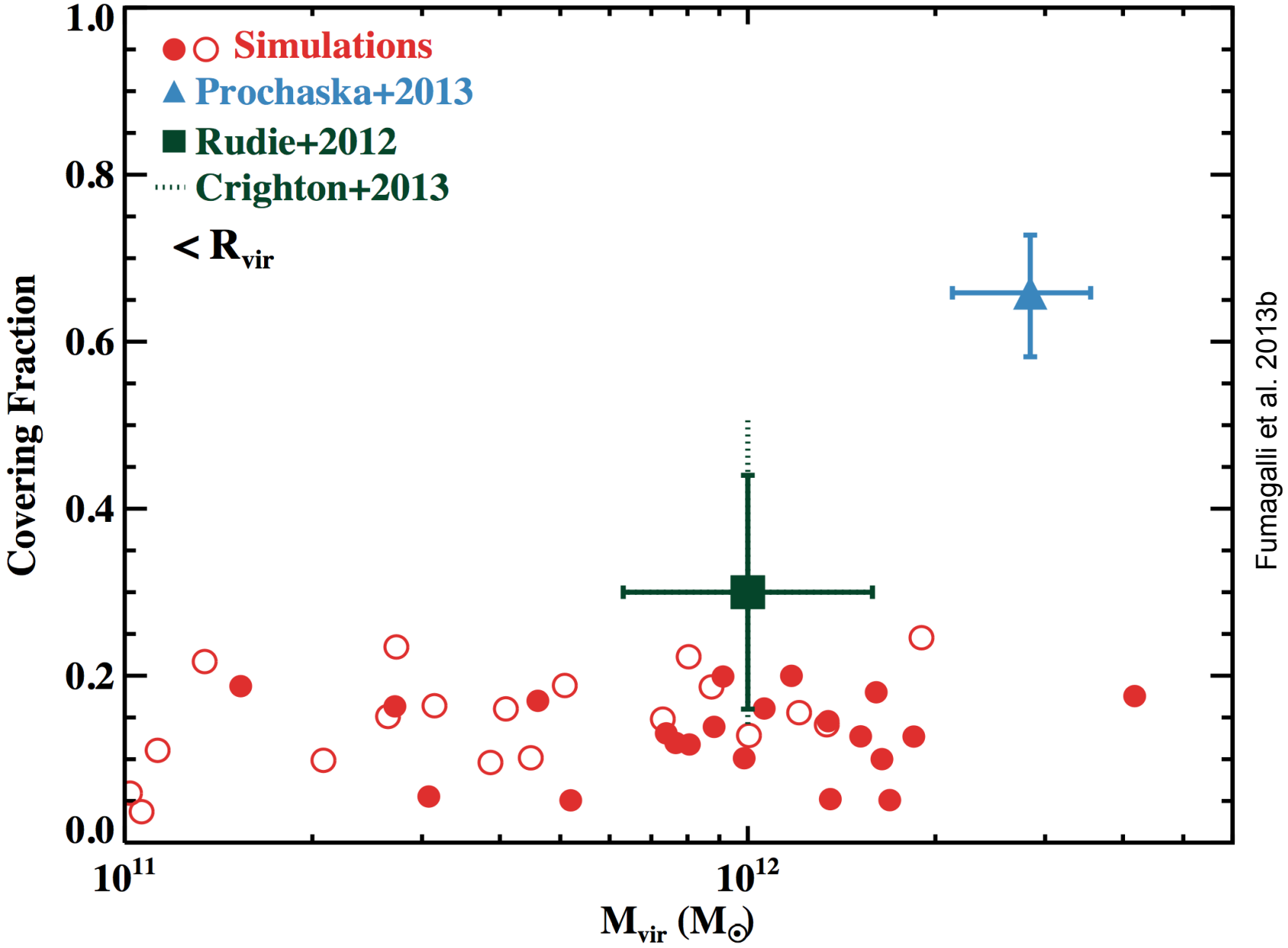


Fumagalli et al. 2013b

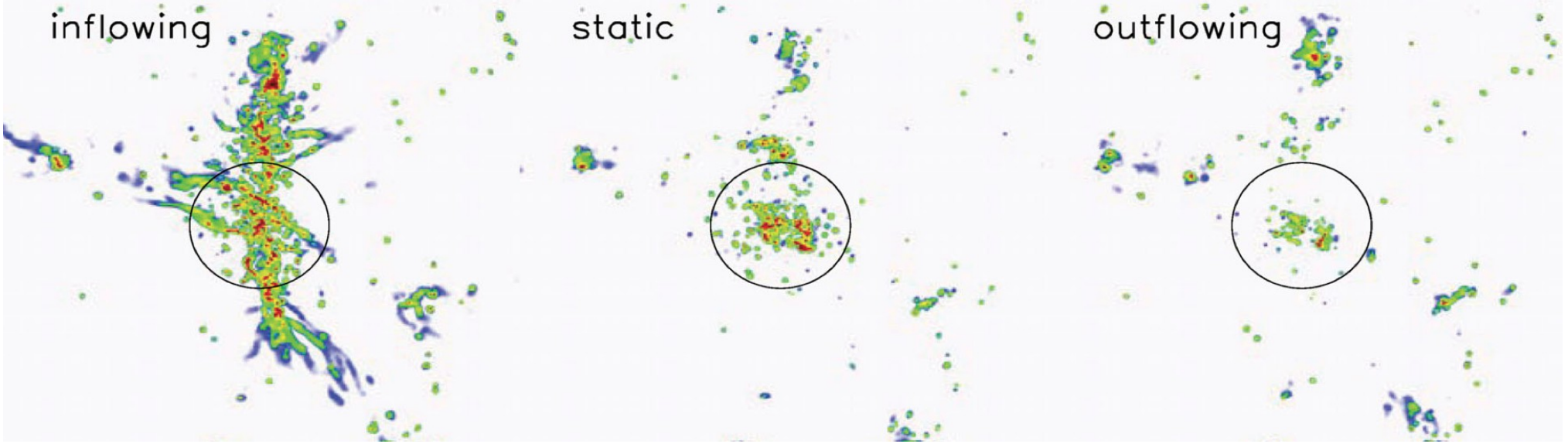
The covering fraction of optically thick gas

Simulations underestimate the covering fraction around massive halos



Does feedback matter?

The majority of the cross section is in inflowing gas. So, maybe not.



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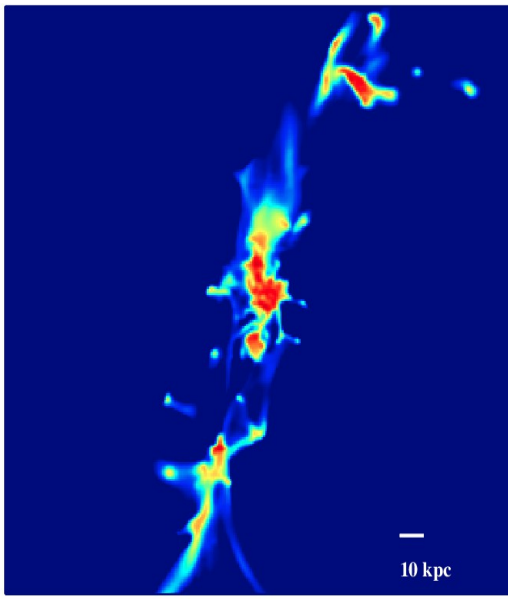
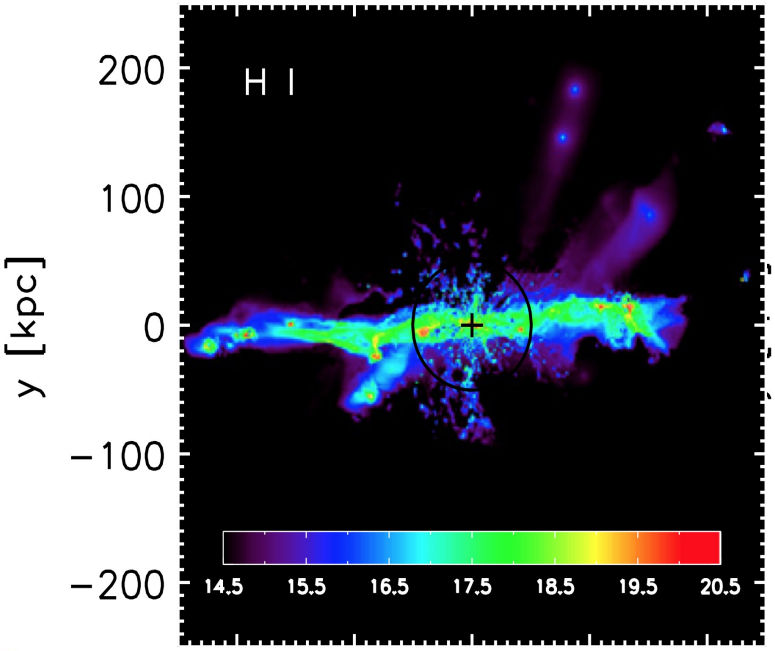
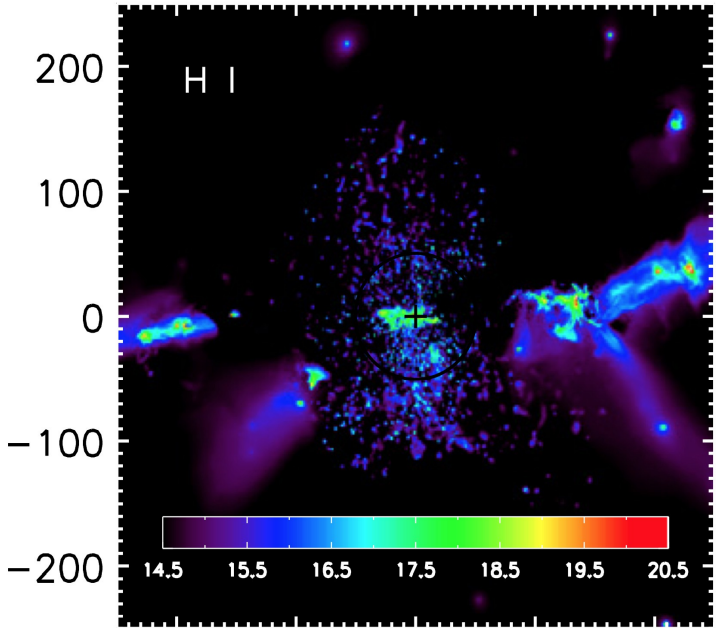






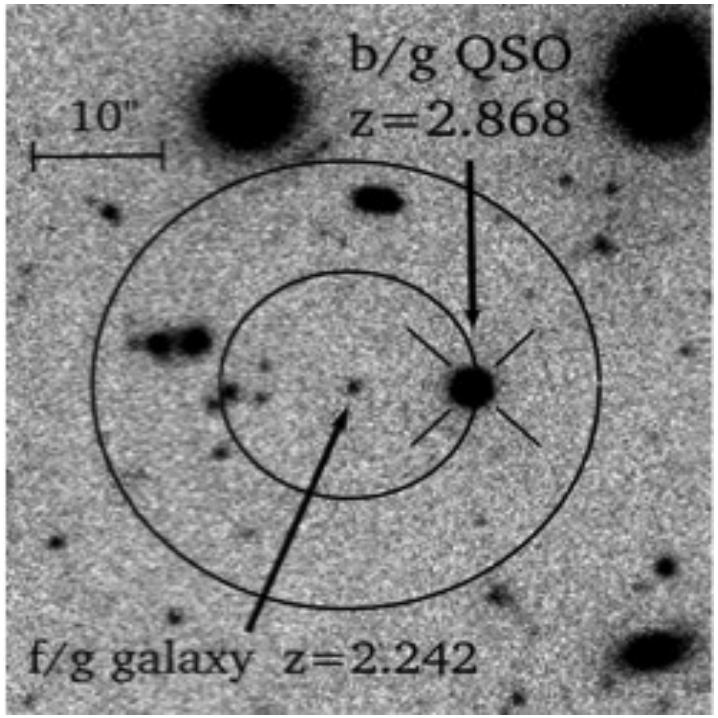
Shen et al. 2013

Moving forward:
The LLS auto-correlation function

Samples of galaxy-quasar pairs

Observations of galaxy-quasar pairs offer a perfect experimental setup to test some of these predictions, but large samples are hard to get.

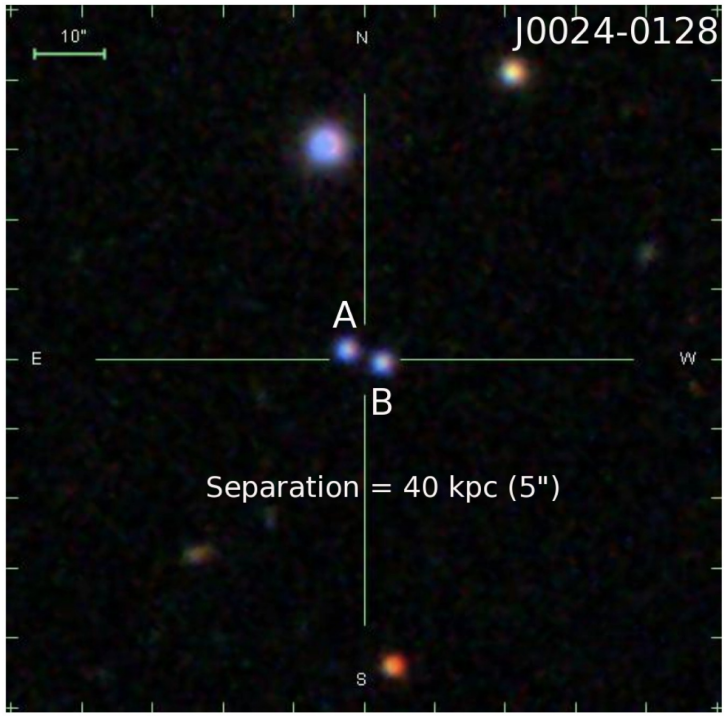
LBG – quasar pairs



Crighton+2013

Rudie+ 2012:
Keck Baryonic Structure Survey
Crighton+;Bielby+:
VLT-LBG survey

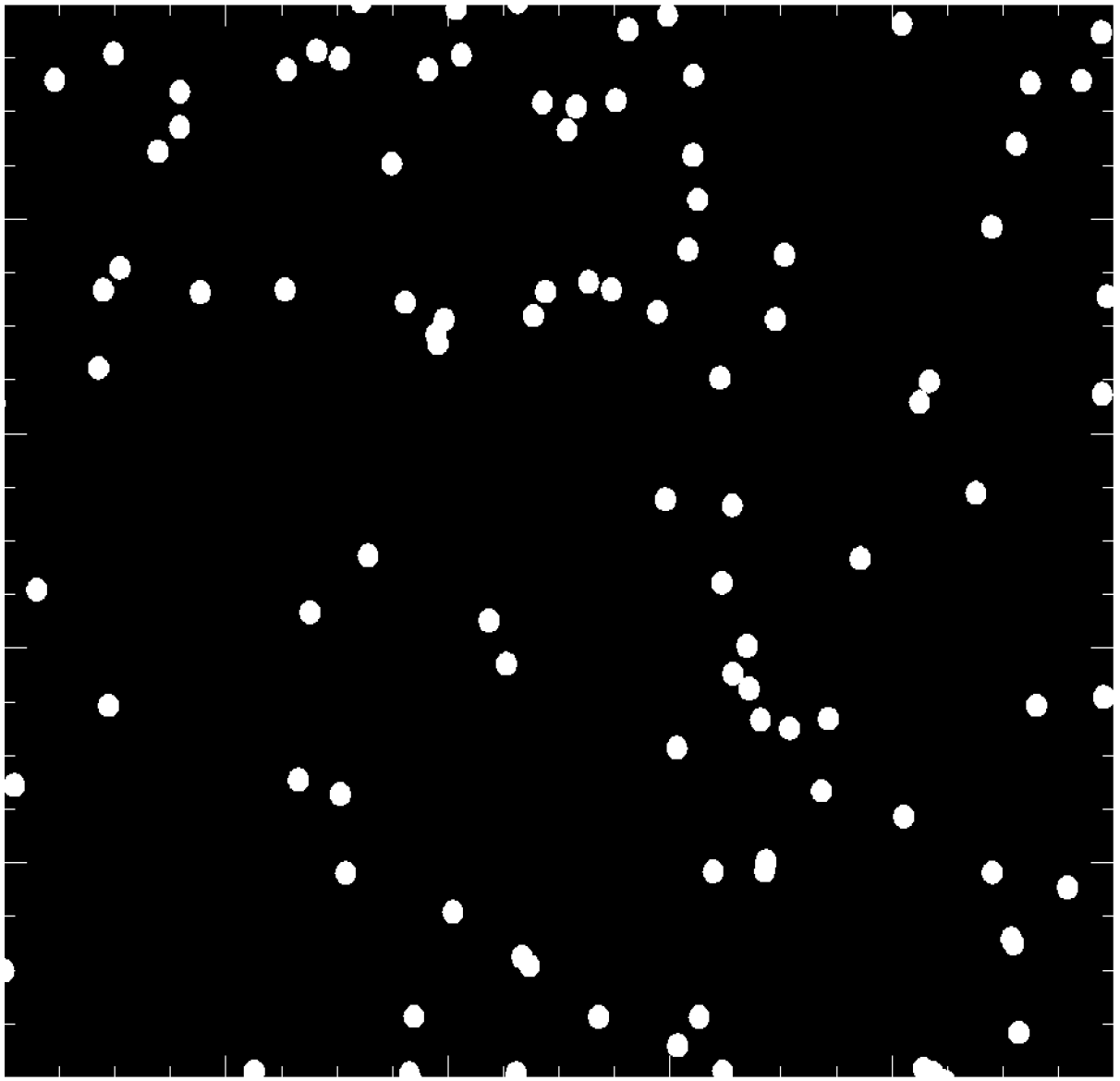
quasar – quasar pairs



Hennawi&Prochaska et al.:
Quasars Probing Quasars I. - VI.

Galaxy – LLS correlation function

The covering fraction of optically-thick gas can be recast in terms of the galaxy-LLS cross-correlation function



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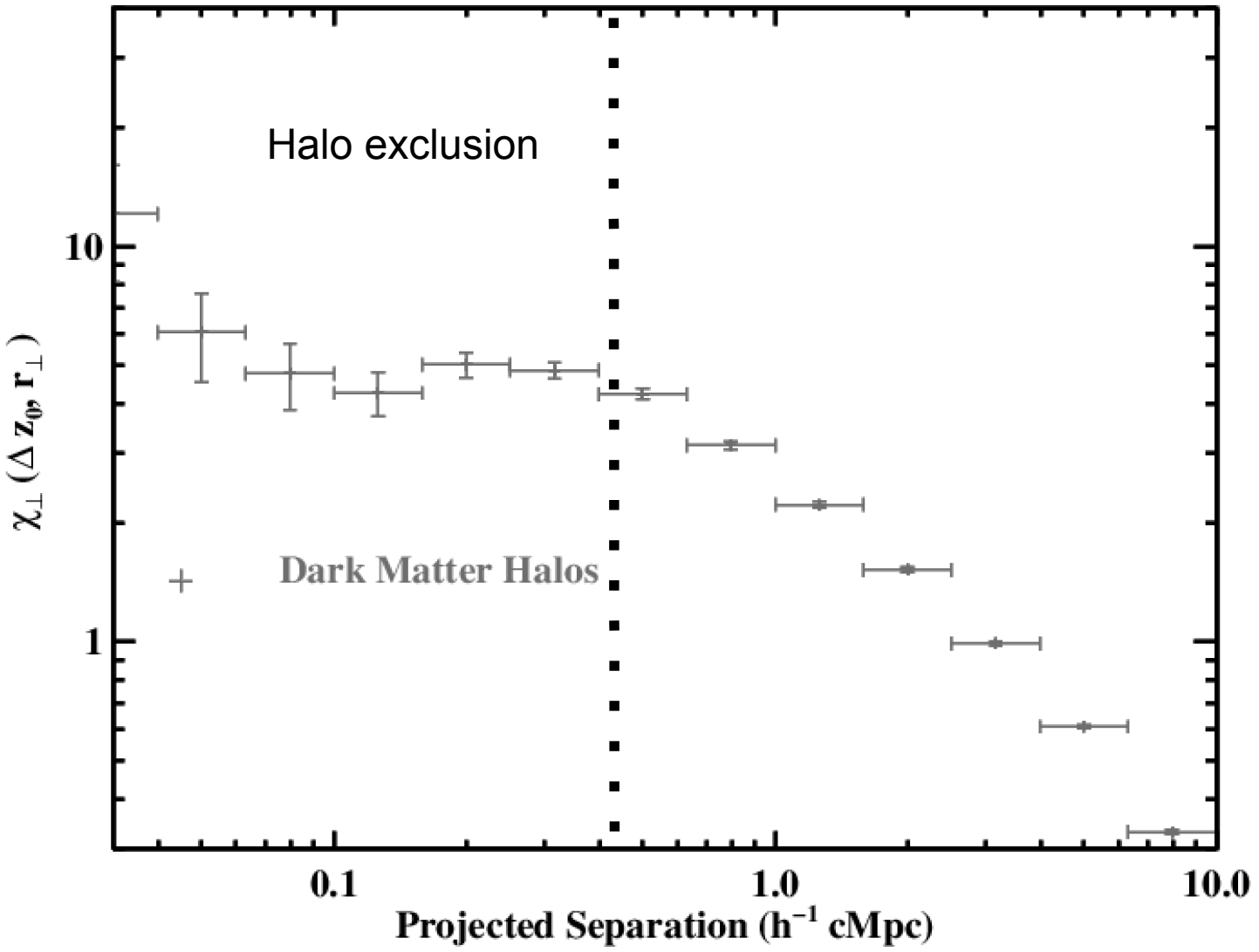

Fumagalli et al. 2013b

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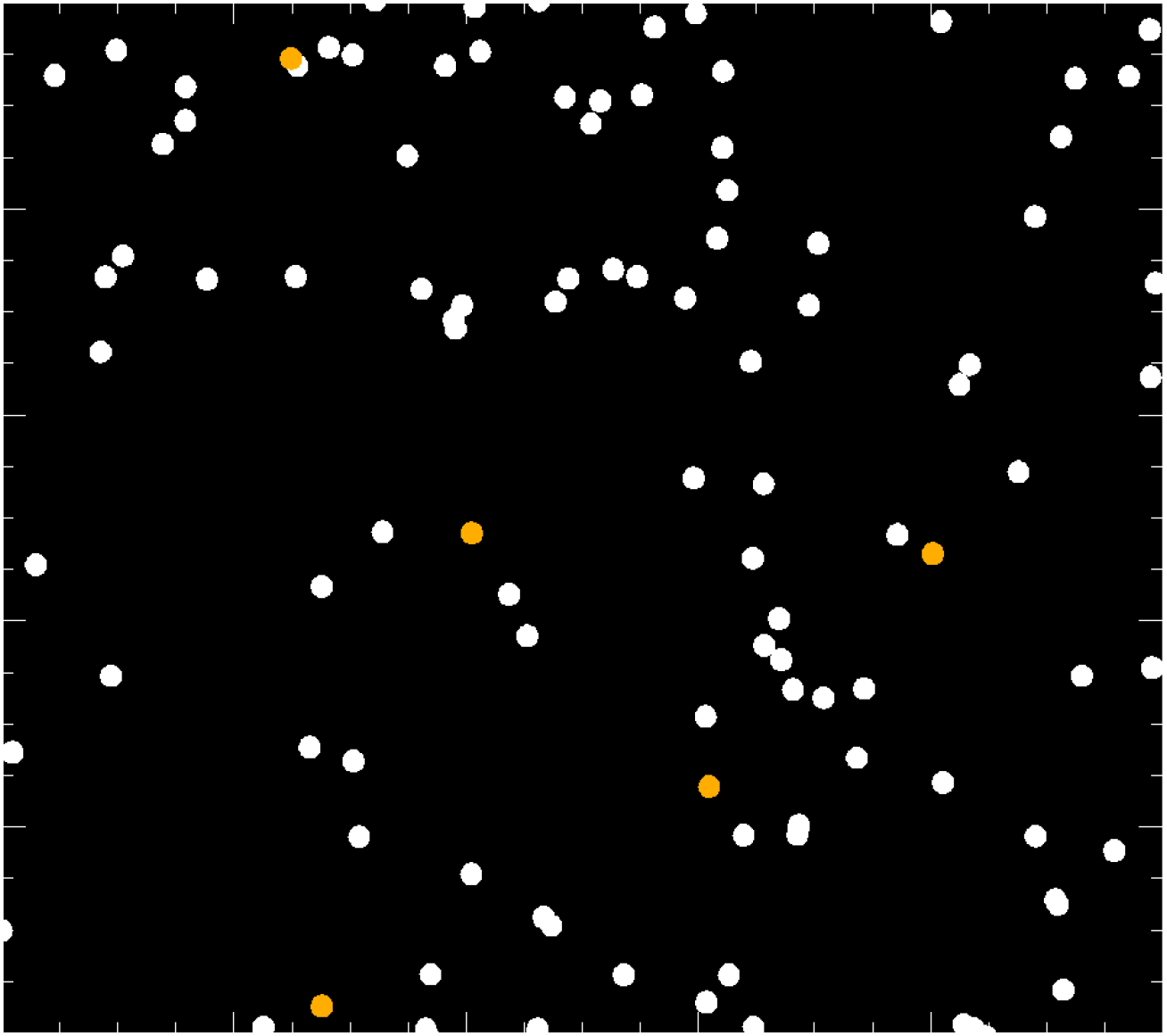

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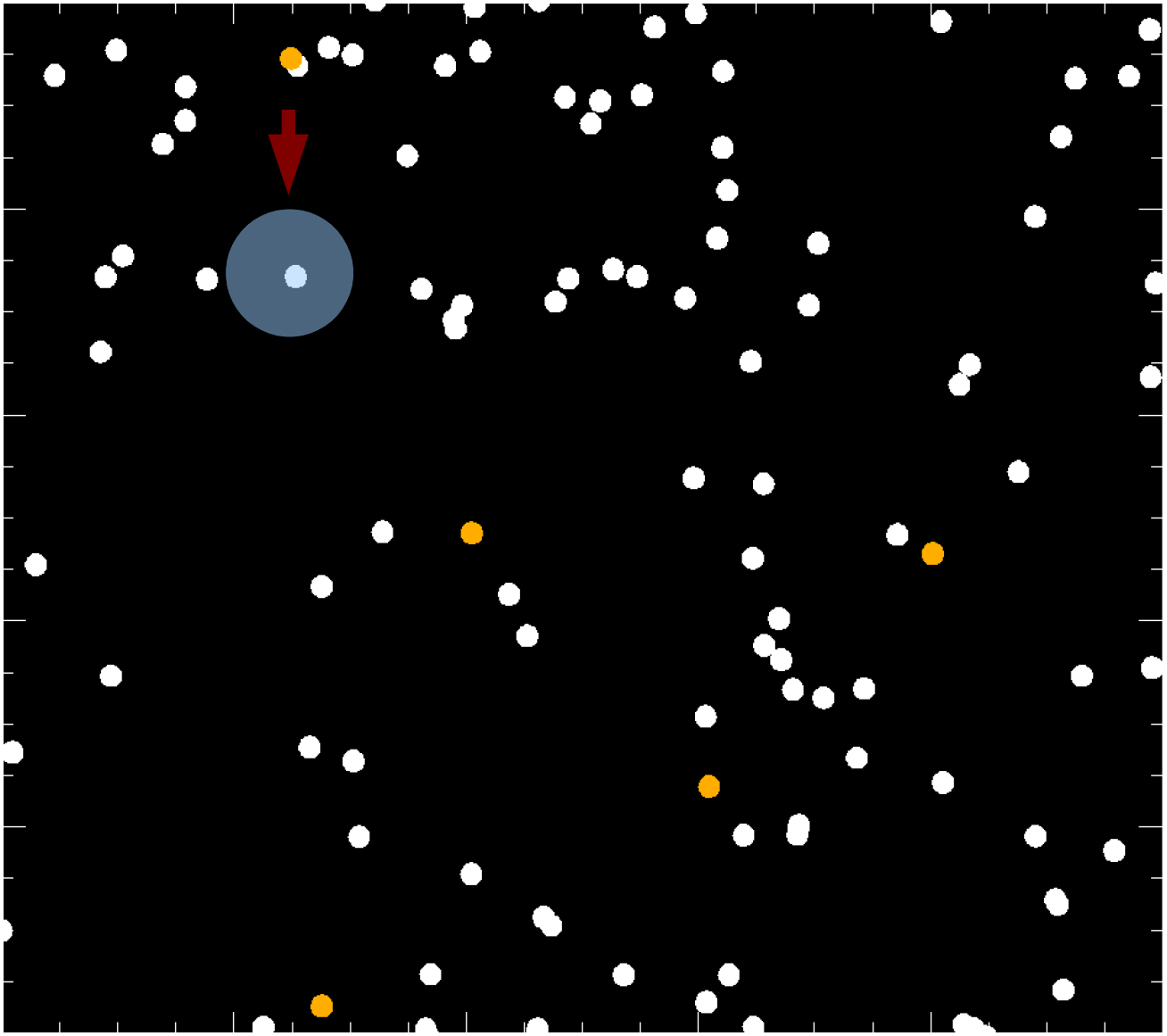

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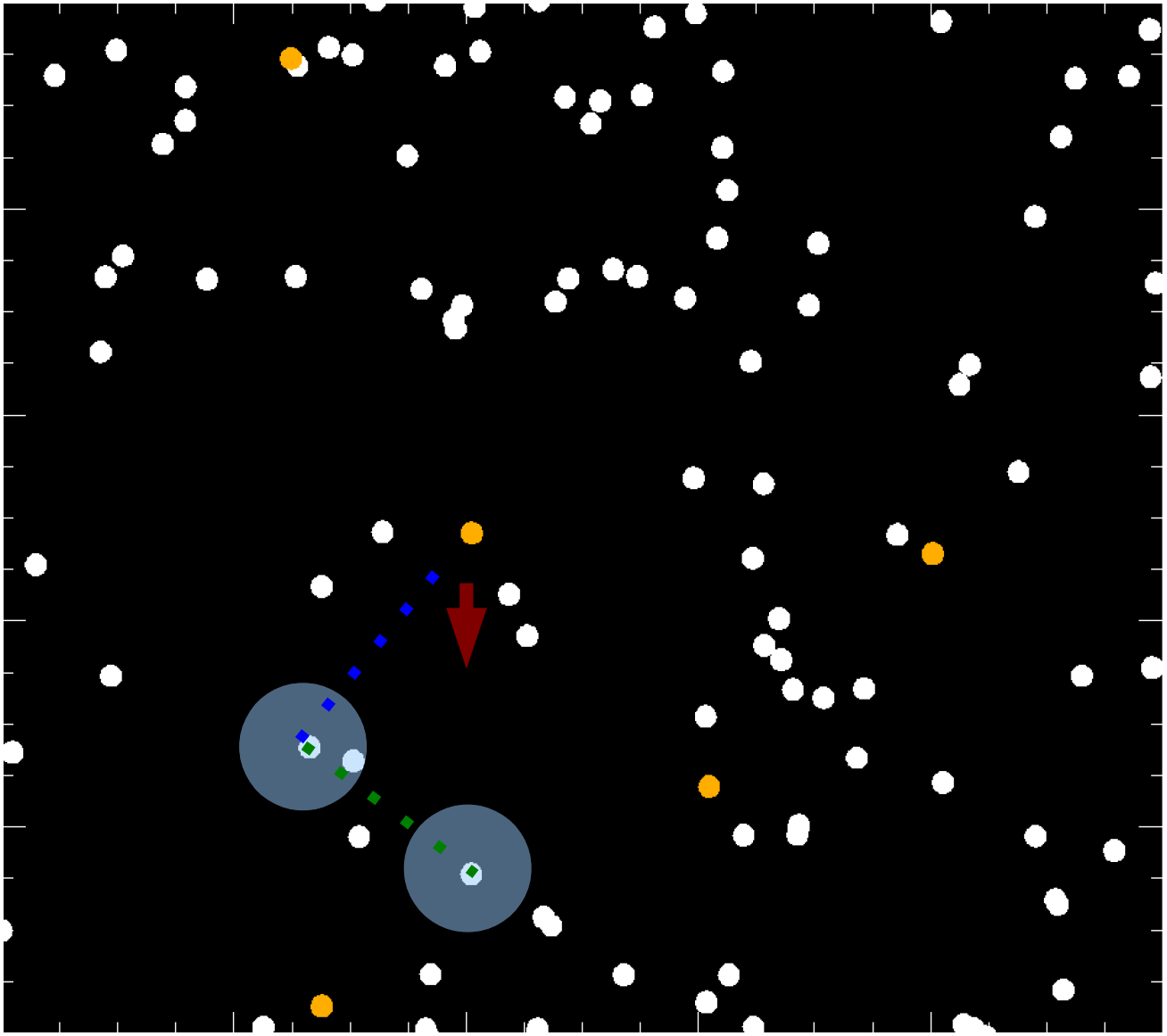

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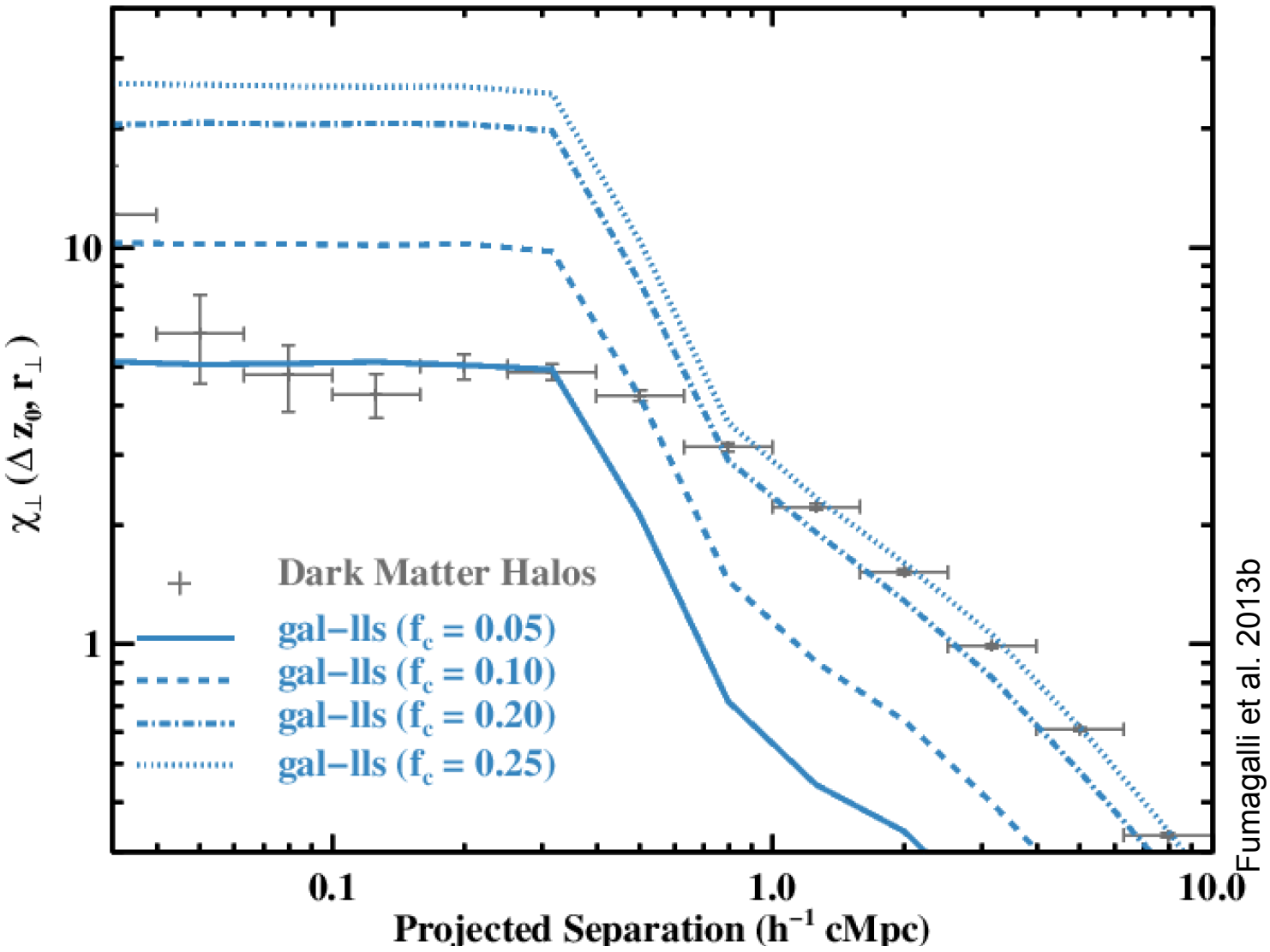
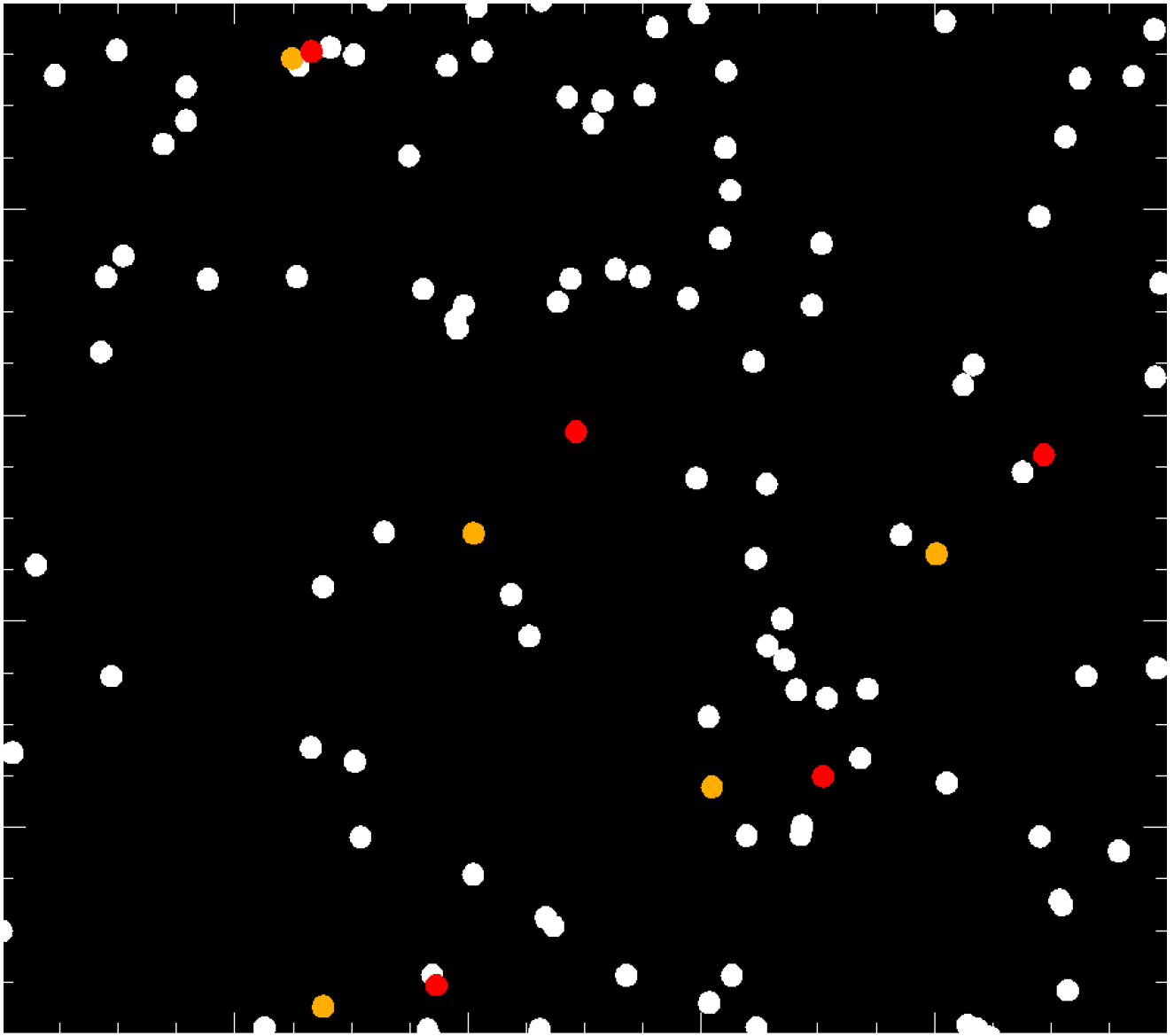


LLS auto-correlation function

If LLSs arise from galaxies, the LLS autocorrelation function is equivalent to the galaxy-LLS correlation function



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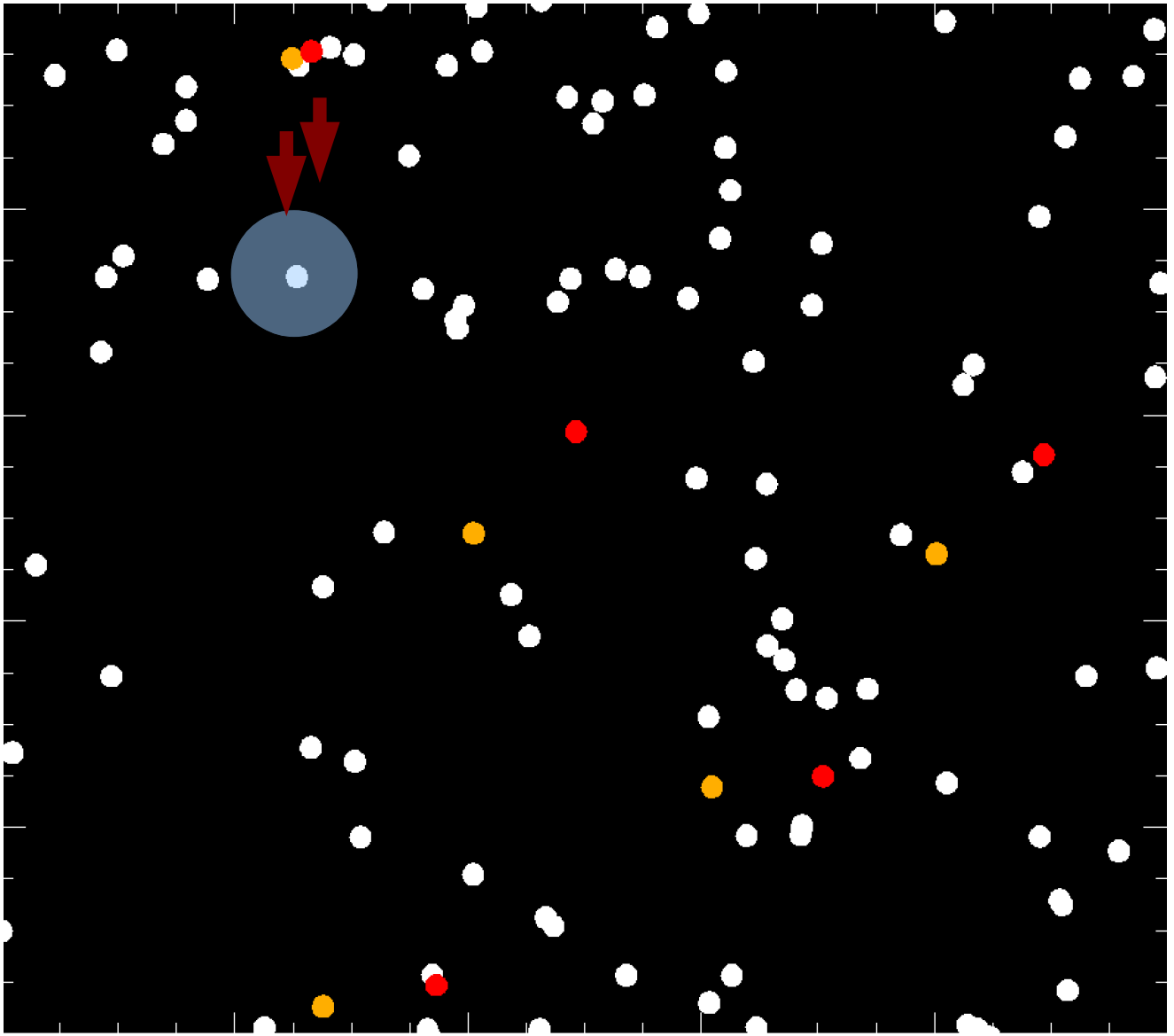

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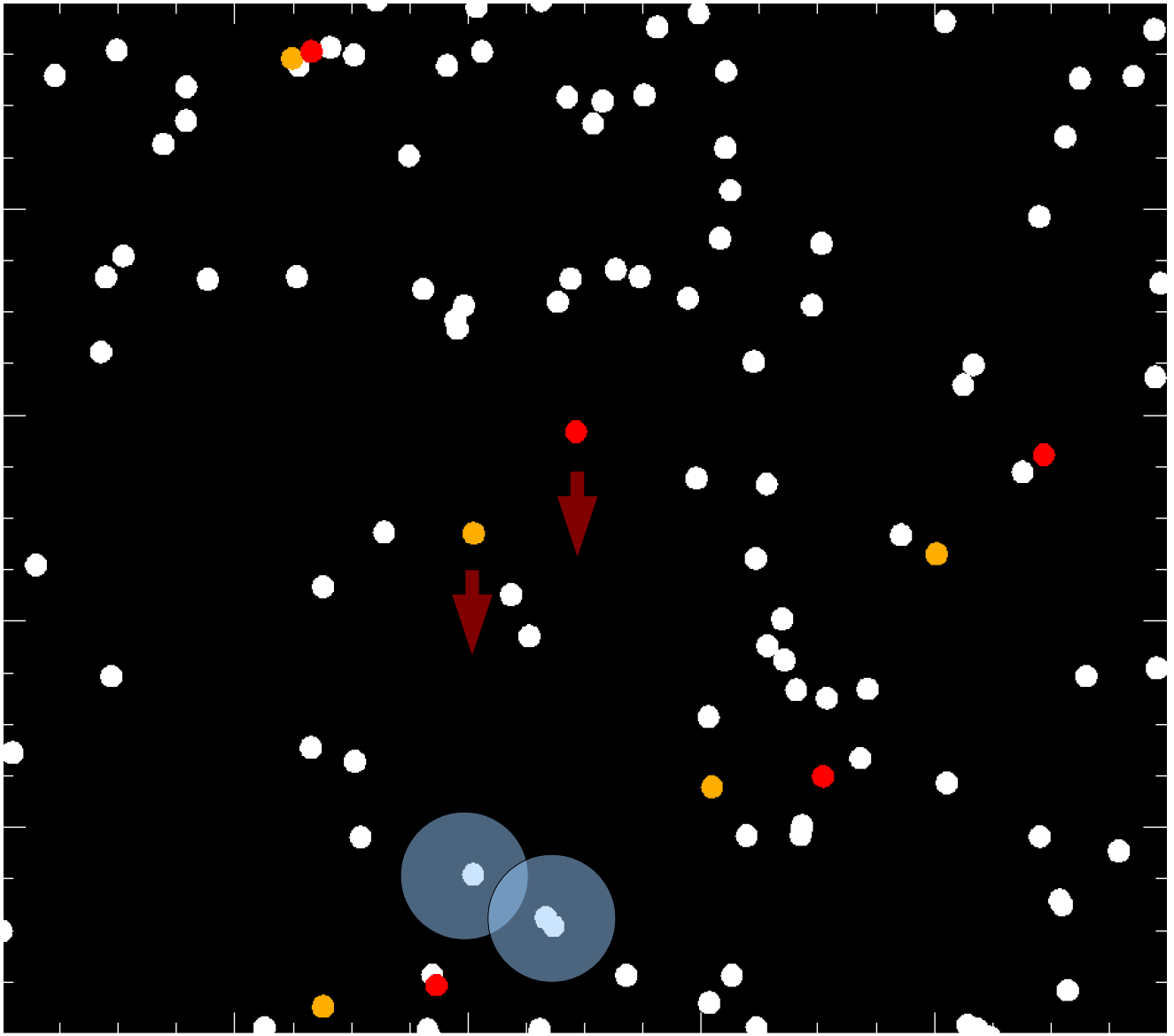

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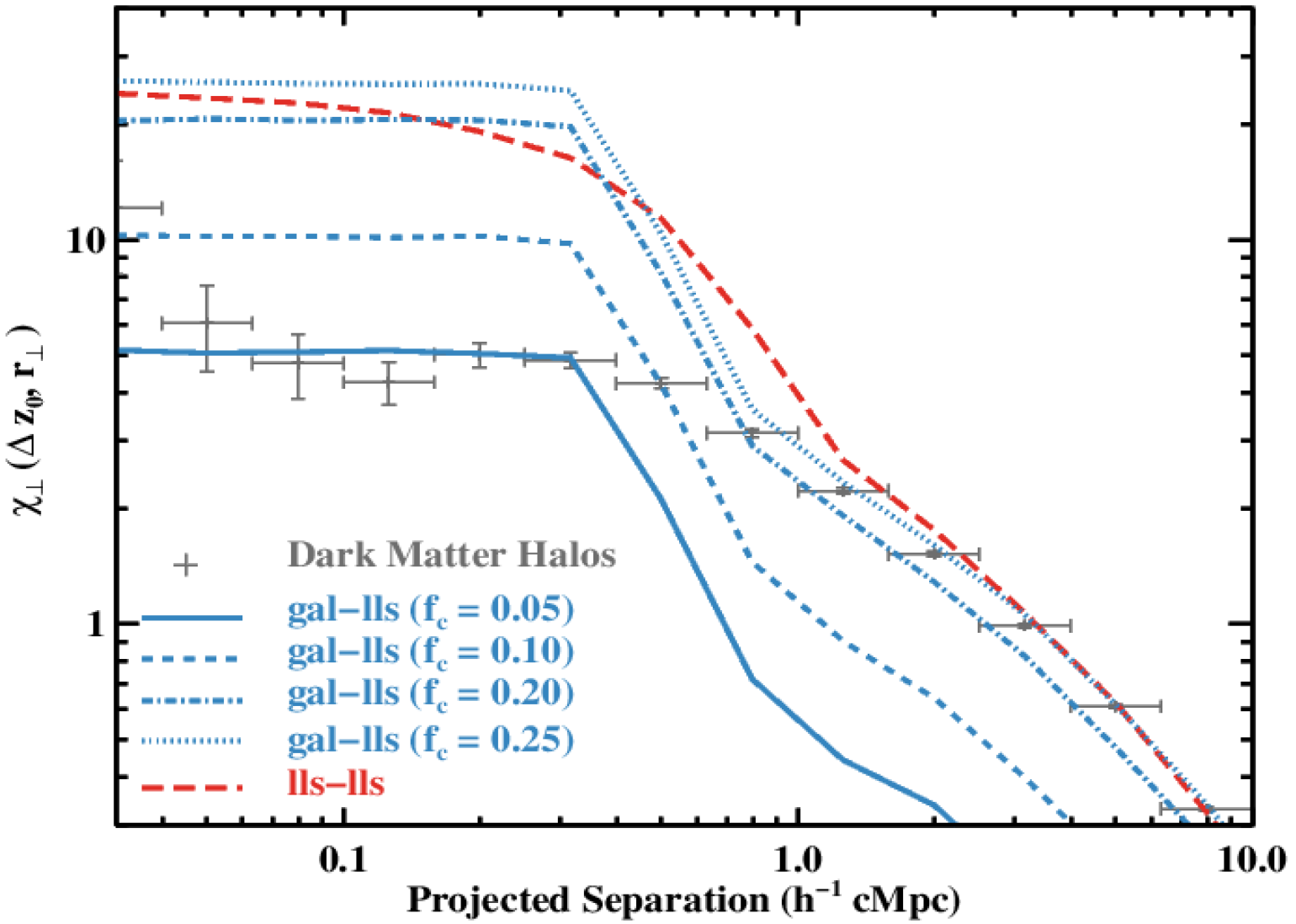
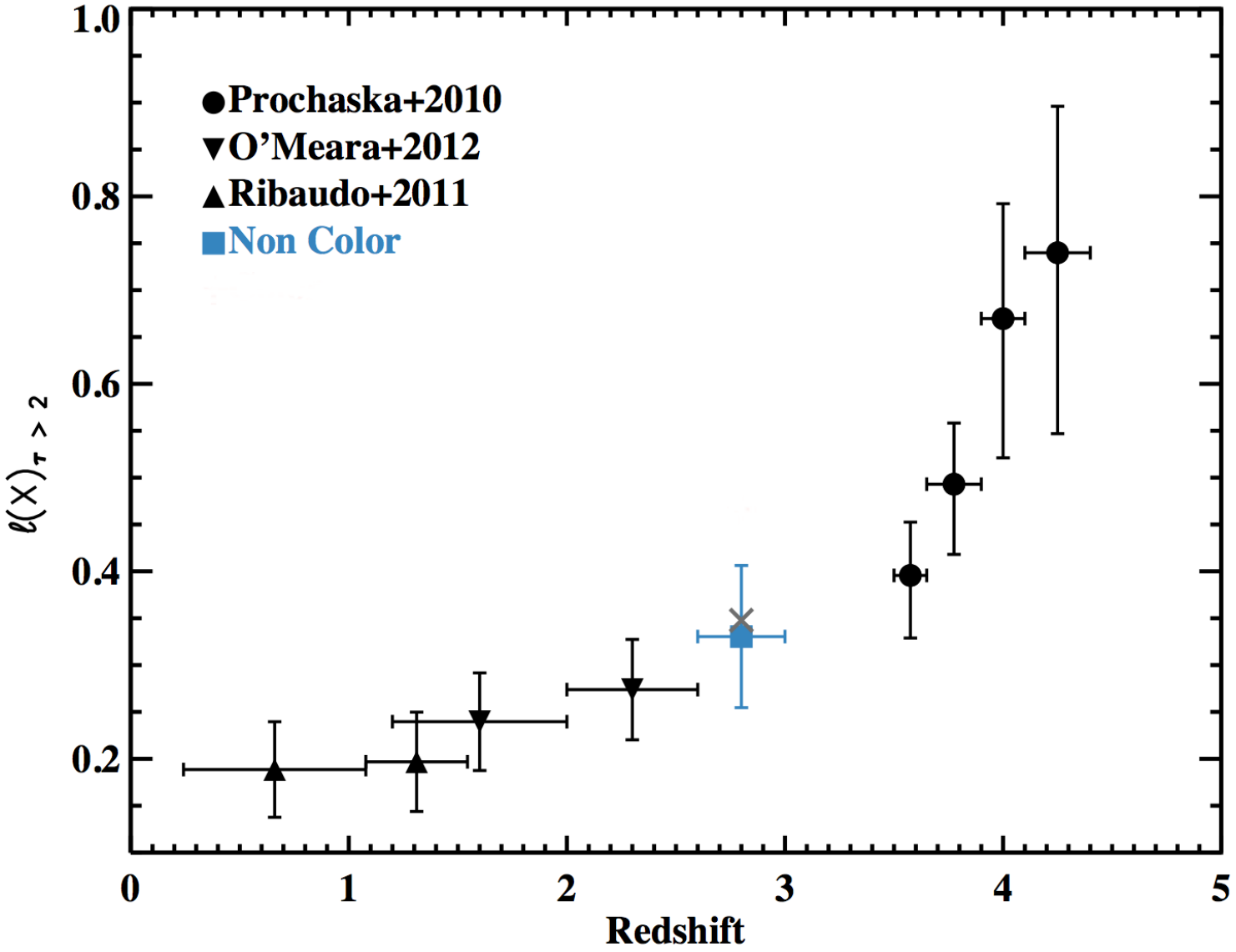


Fumagalli et al. 2013b

Learning form LLS surveys

Statistically connecting LLSs and galaxies

Modern LLS surveys are mapping the number of optically-thick absorbers across ~1 dex of cosmic evolution



Fumagalli et al. 2013a

Statistically connecting LLSs and galaxies

Simple models for the CGM can be constructed to describe the observed redshift evolution of LLSs

$$\ell(X) = \frac{4c\pi}{H_0} \int_{\log M_{\rm low}}^{\log M_{\rm up}} R_{\rm vir}^2(M_{\rm vir}, z) f_{\rm c}(M_{\rm vir}, z) \frac{dn_{\rm gal}}{d\log M_{\rm vir}}(M_{\rm vir}, z) d\log M_{\rm vir}$$

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