

Black holes in the cosmic web:

The big picture of AGN and large-scale structure

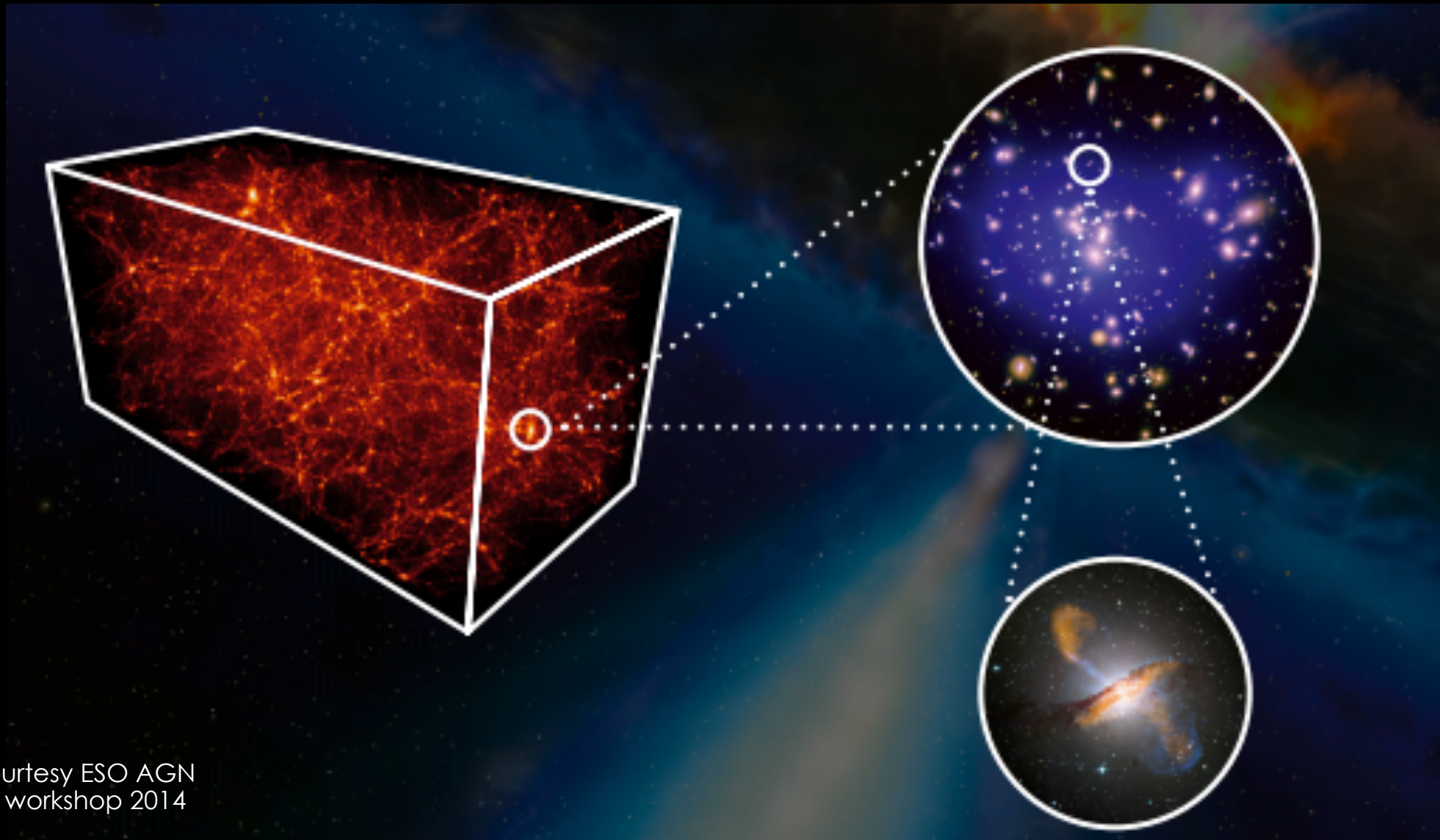


Image courtesy ESO AGN
clustering workshop 2014

Ryan C. Hickox



Dartmouth

Hot Spots in the XMM Sky
Mykonos
15 June 2016

And now for something different...



AGN research at Dartmouth



Dartmouth



PhD students:



Mackenzie Jones



Chris Carroll



McKinley Brumback



Vivyan Yan

Undergrads:

Nicky Golini, Meg Lane, Parker Gardner, Raphael Hviding, Ana Colon, Emily Golitzin

Postdocs:



Mike DiPompeo



Lauranne Lanz
(starting fall 2016)



Former members:

Francesca Civano (Yale/CfA), Kevin Hainline (Steward JWST/NIRCam team), Chien-Ting Chen (Penn State)



Sloan Digital Sky Survey

Miguel A Aragon (JHU), Mark Subbarao (Adler P.), Alex Szalay (JHU)

A galaxy



A quasar

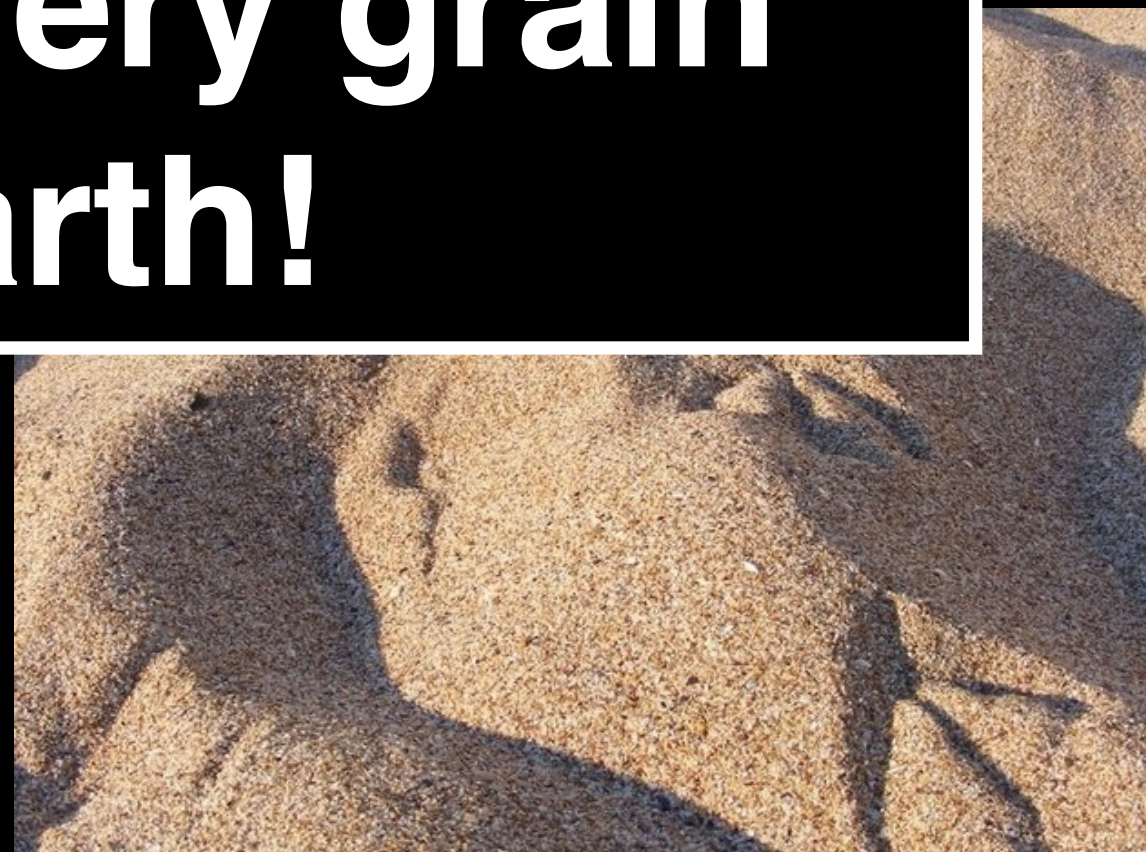




**10 hydrogen bombs per
second for every grain
of sand on Earth!**

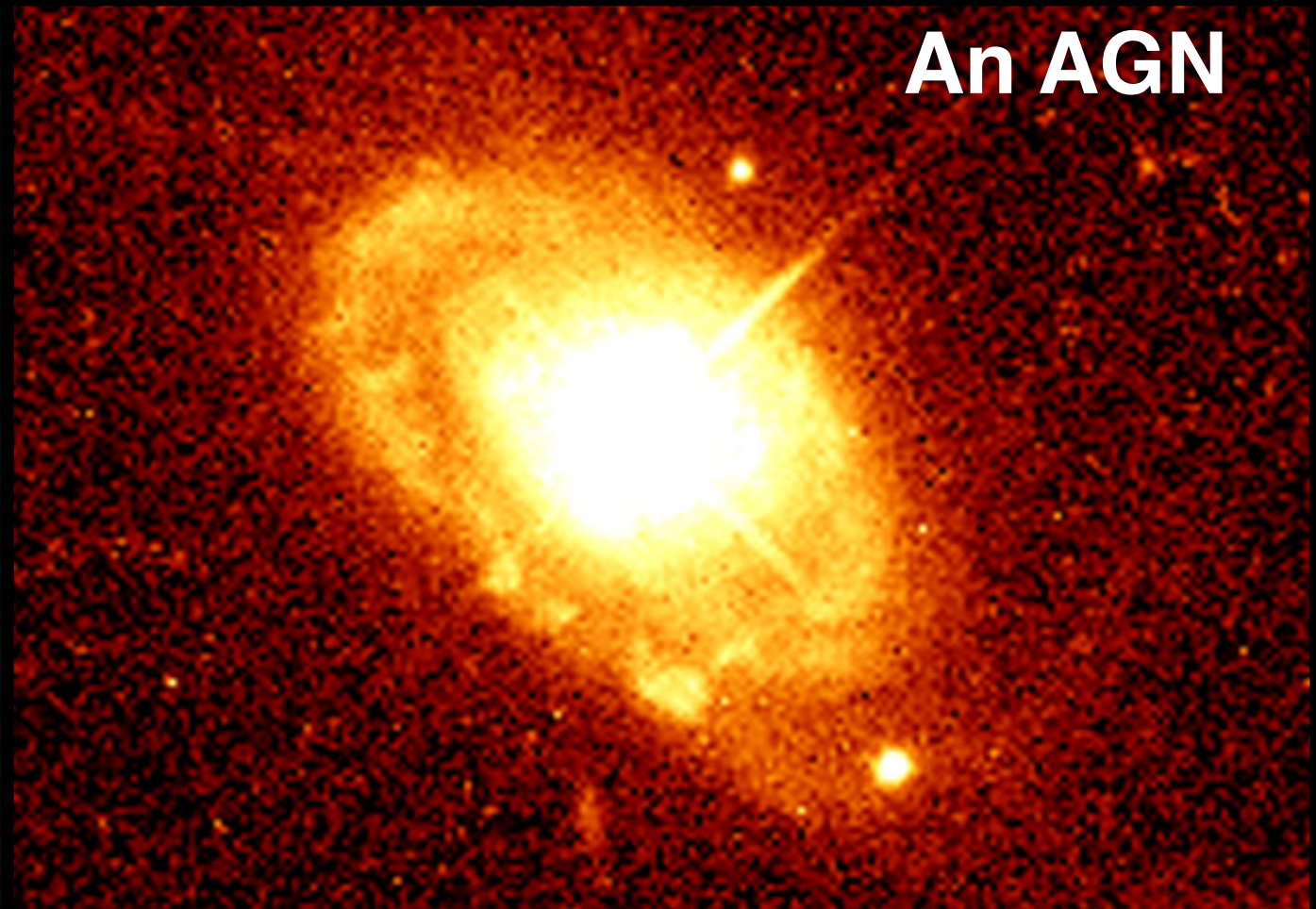
**A hydrogen bomb produces
 10^{24} erg of energy**

**There are 10^{22} grains of
sand on Earth**



A photograph of a galaxy, likely a spiral galaxy, showing a bright central bulge and a diffuse, glowing disk of stars and gas. The background is dark with scattered stars.

A galaxy

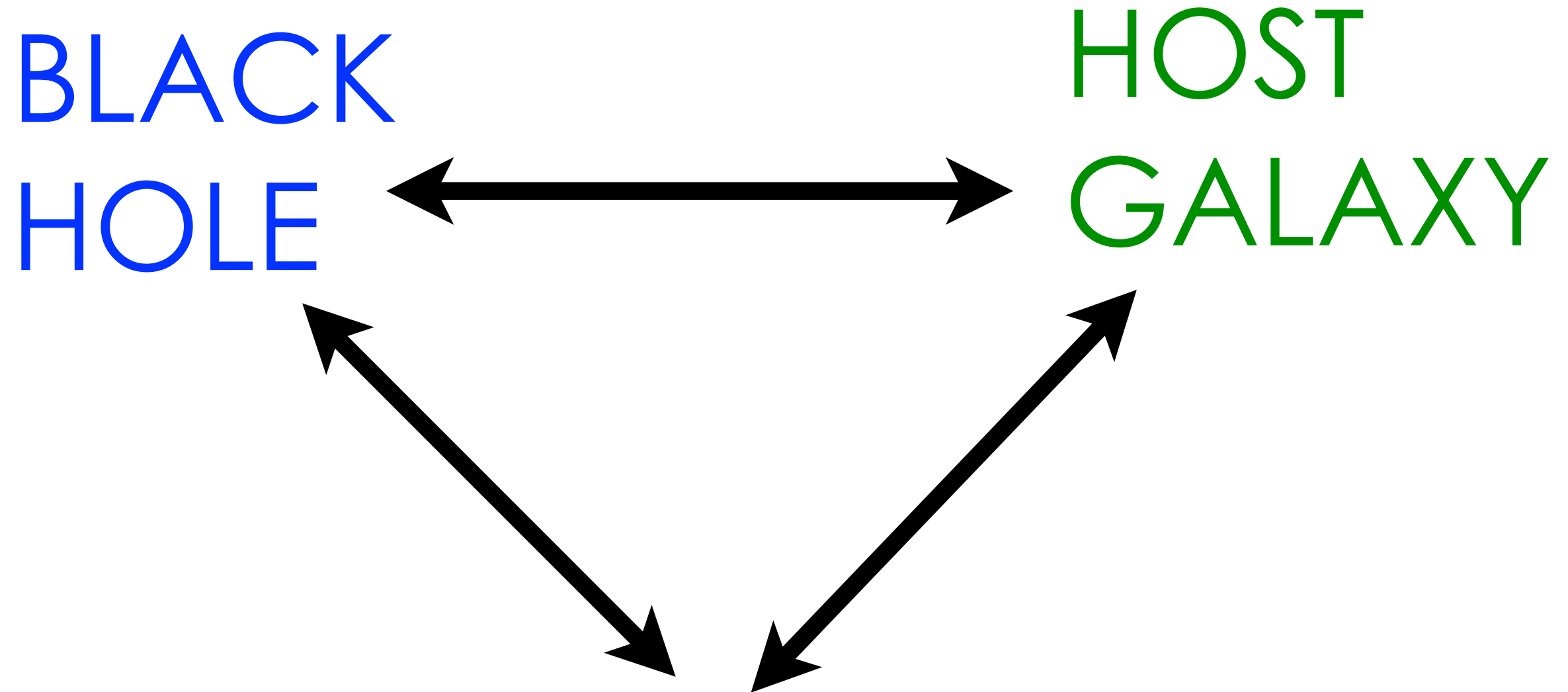
A photograph of an Active Galactic Nucleus (AGN), showing a bright, intense, yellowish-white central region surrounded by a glowing, orange-red disk. The background is dark with scattered stars.

An AGN

The big question:

How is black hole growth connected to the growth of galaxies and large-scale structures?

Why study AGN clustering?

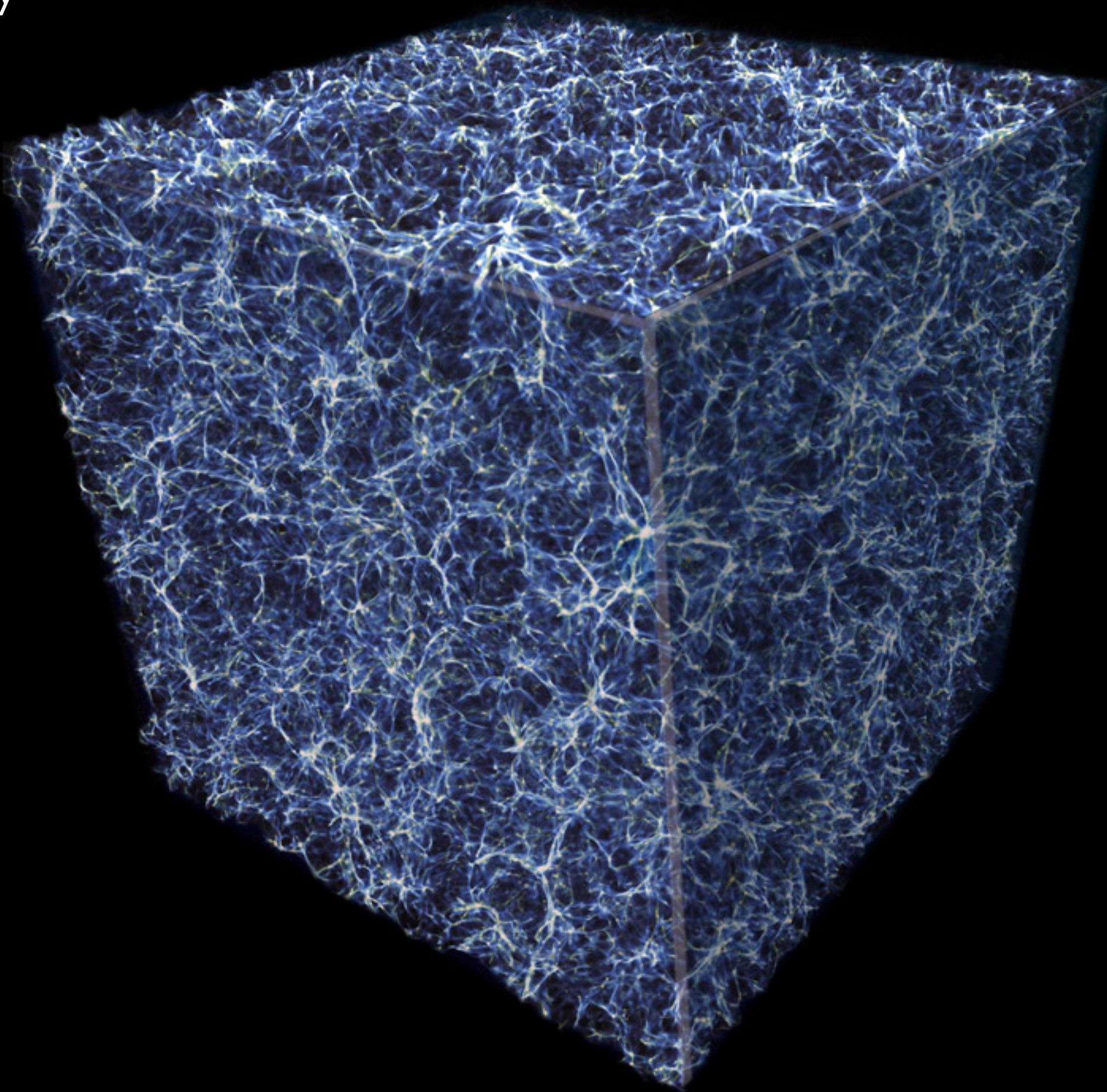


DARK MATTER HALO

Measure **halo mass** via clustering

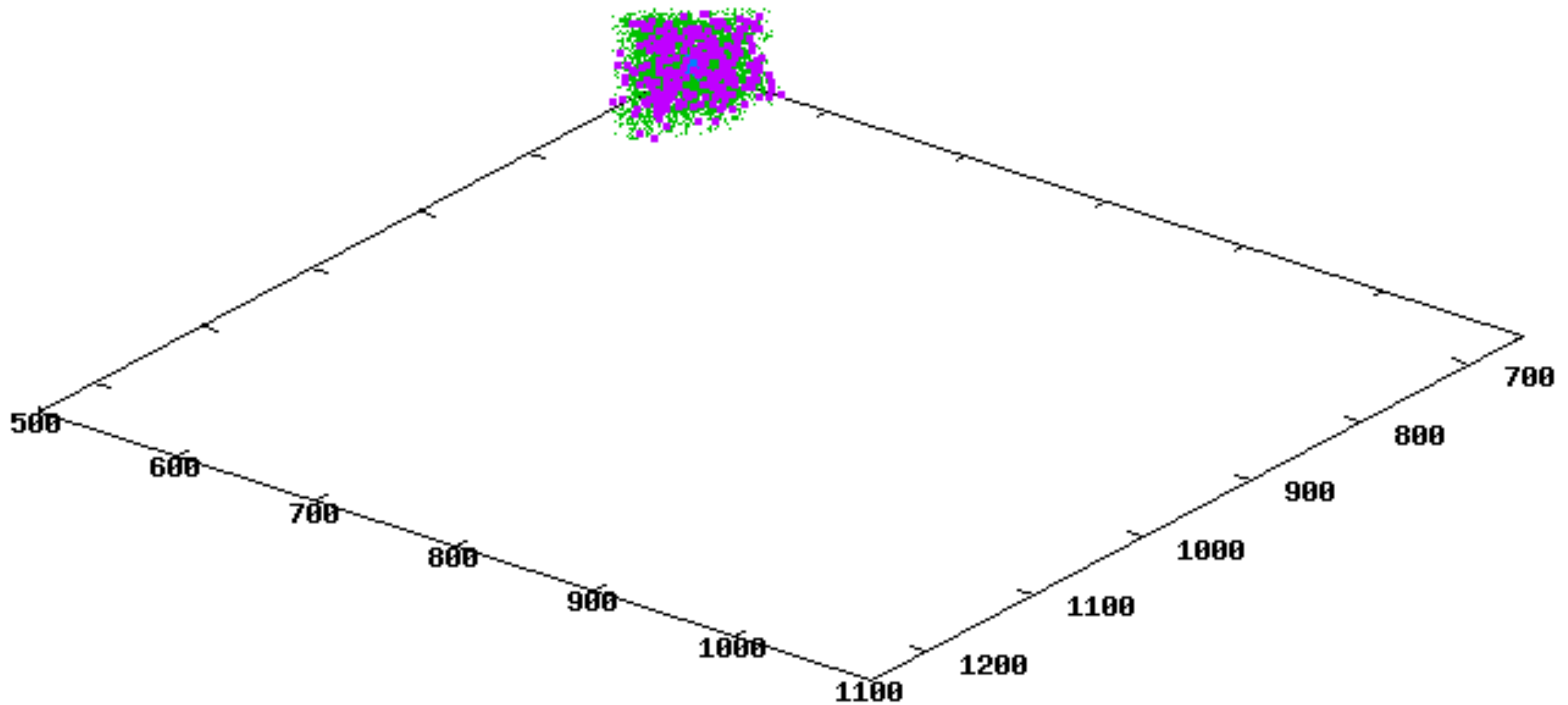
Learn about **cosmological evolution**

Theory



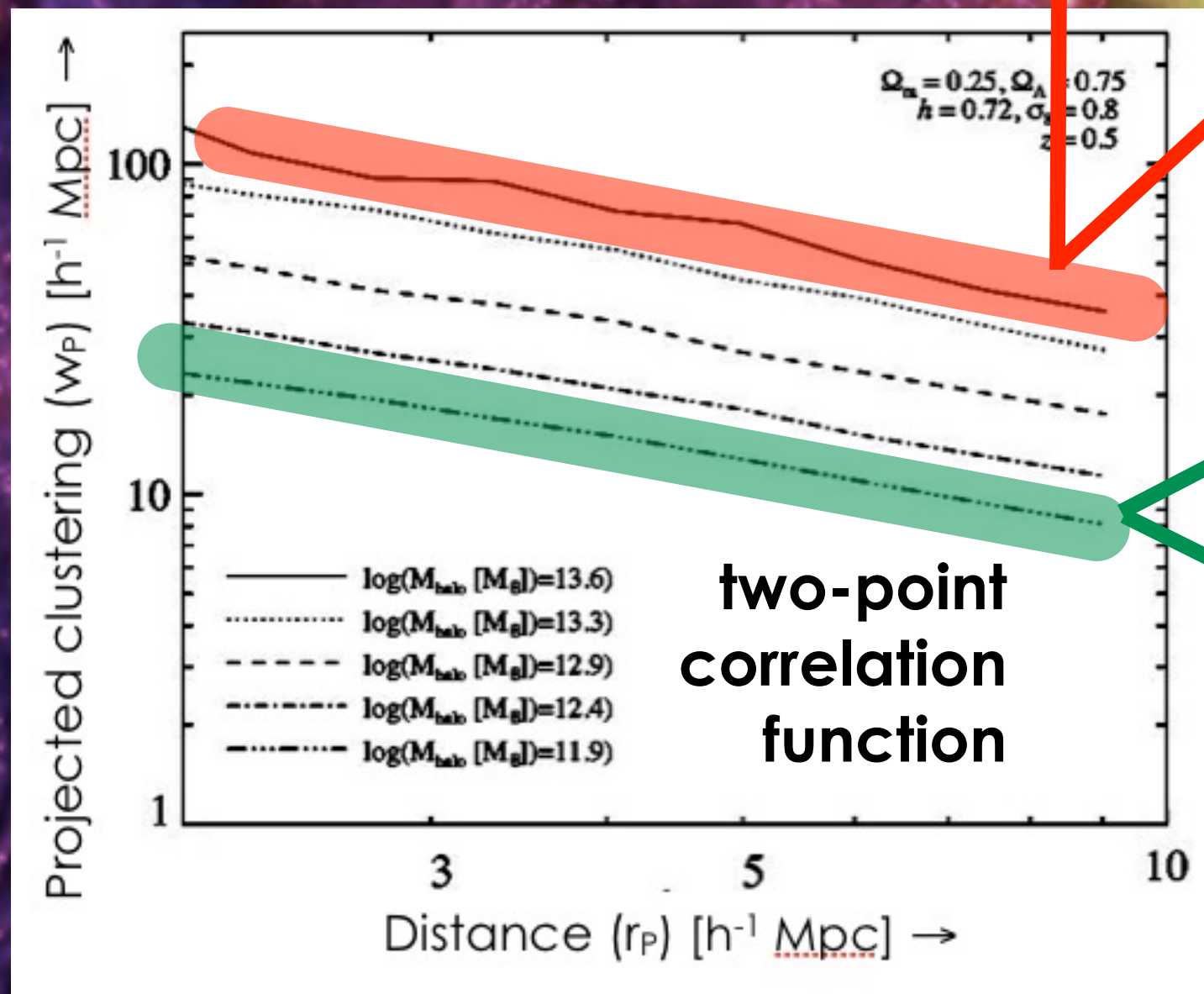
Observation

- galaxies
- X-ray AGN

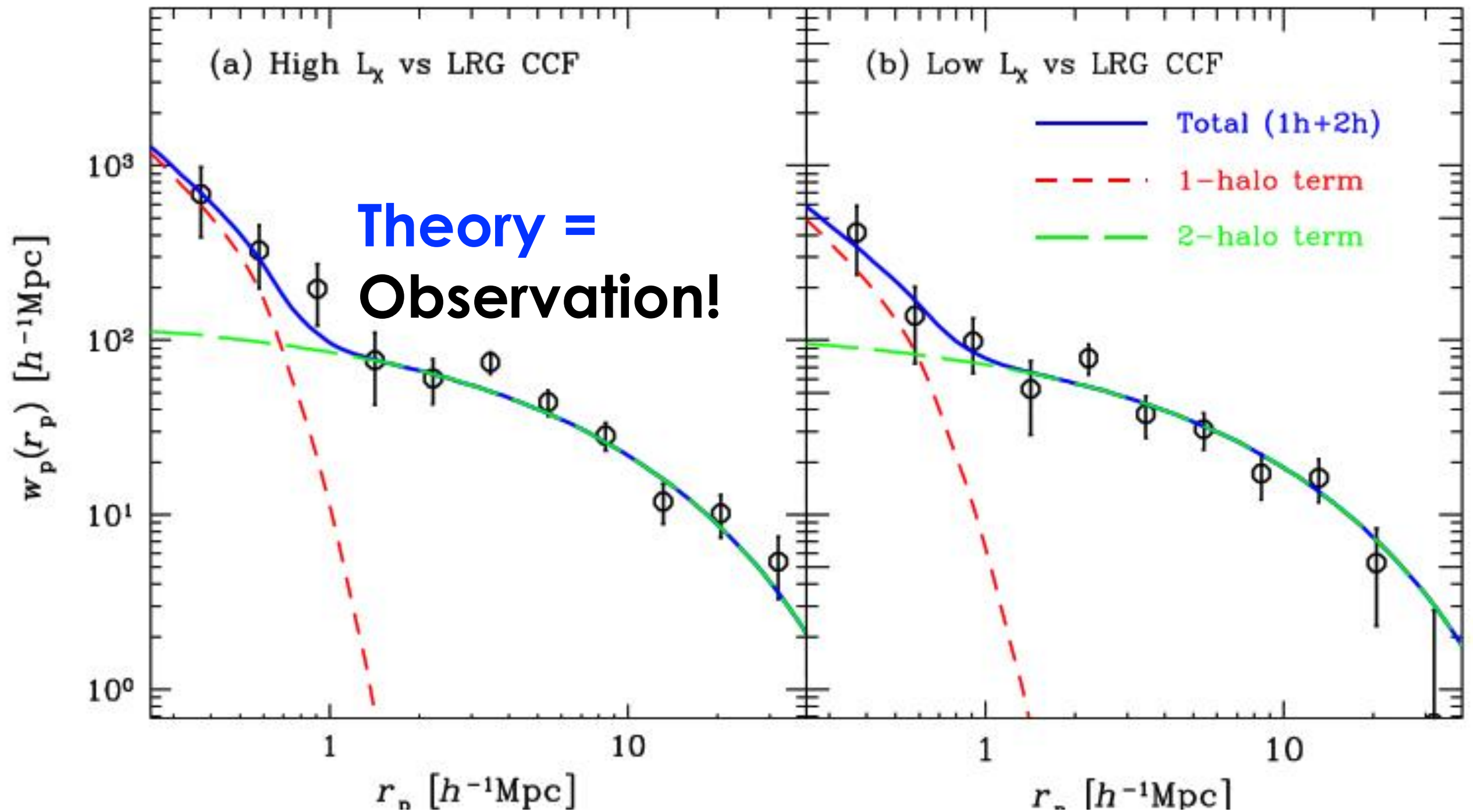


Clustering tells us how AGN populate dark matter halos

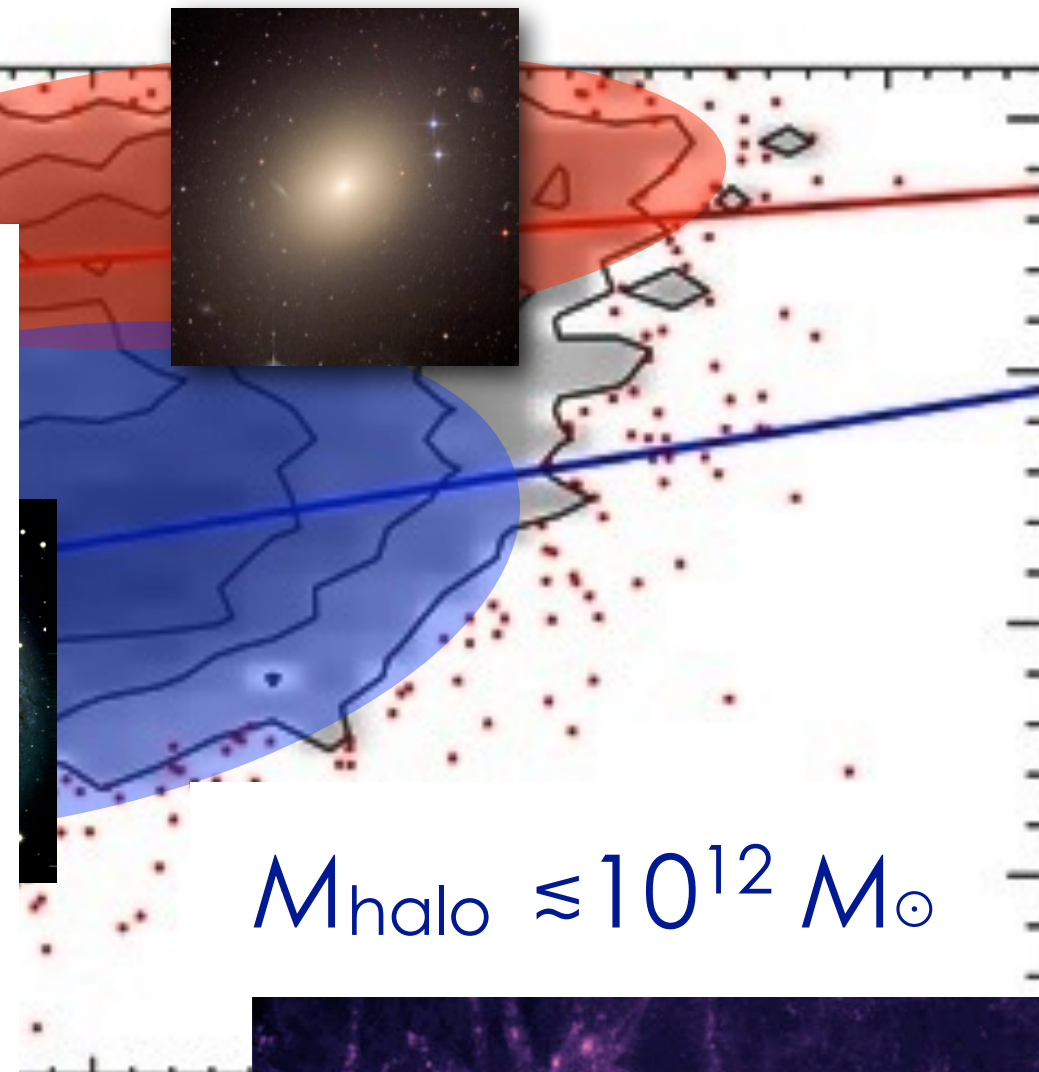
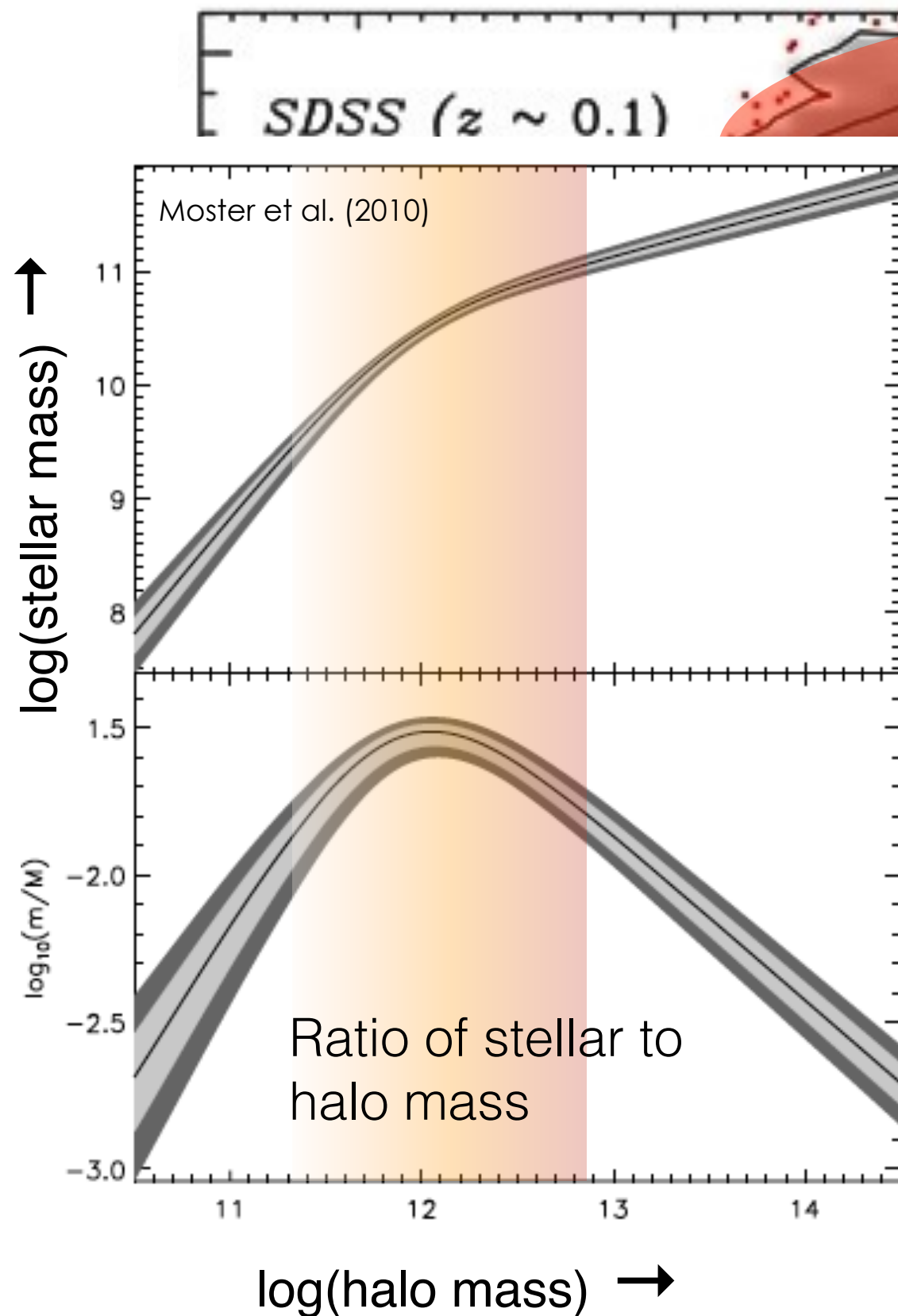
31.25 Mpc/h



This is **amazing**



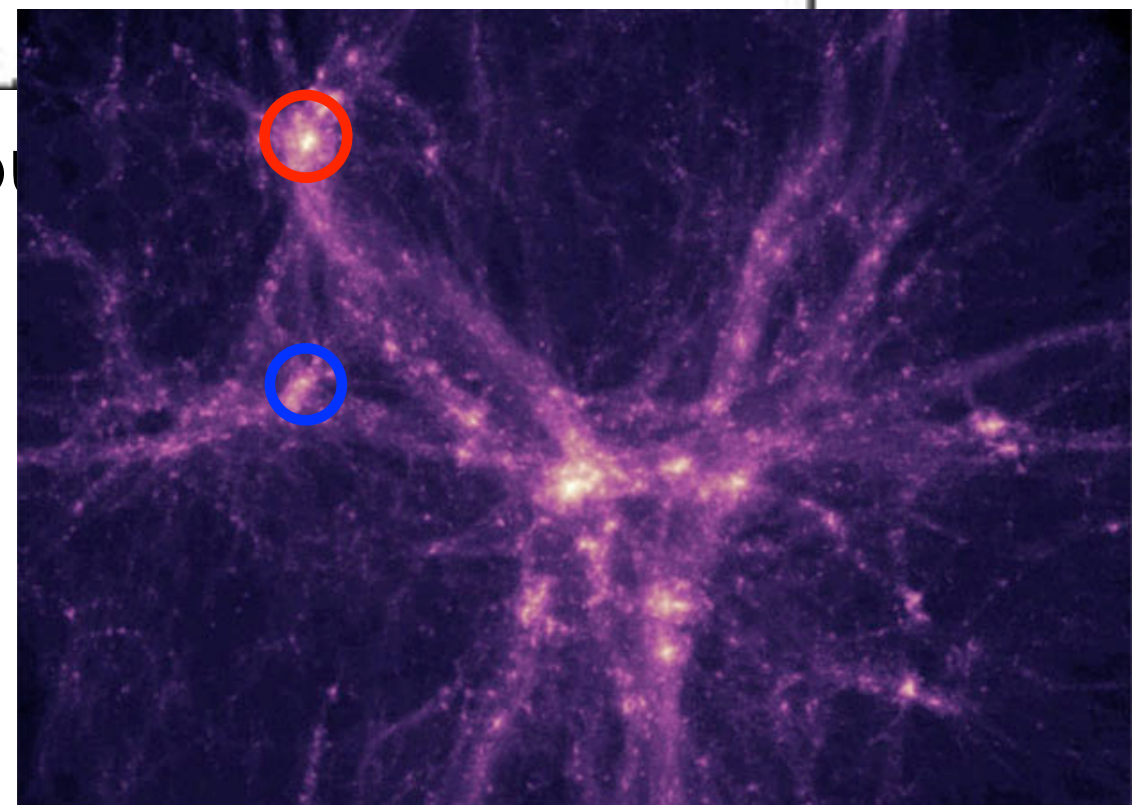
Some context: Galaxies and halos $M_{\text{halo}} \sim 10^{13} M_{\odot}$



More star formation →

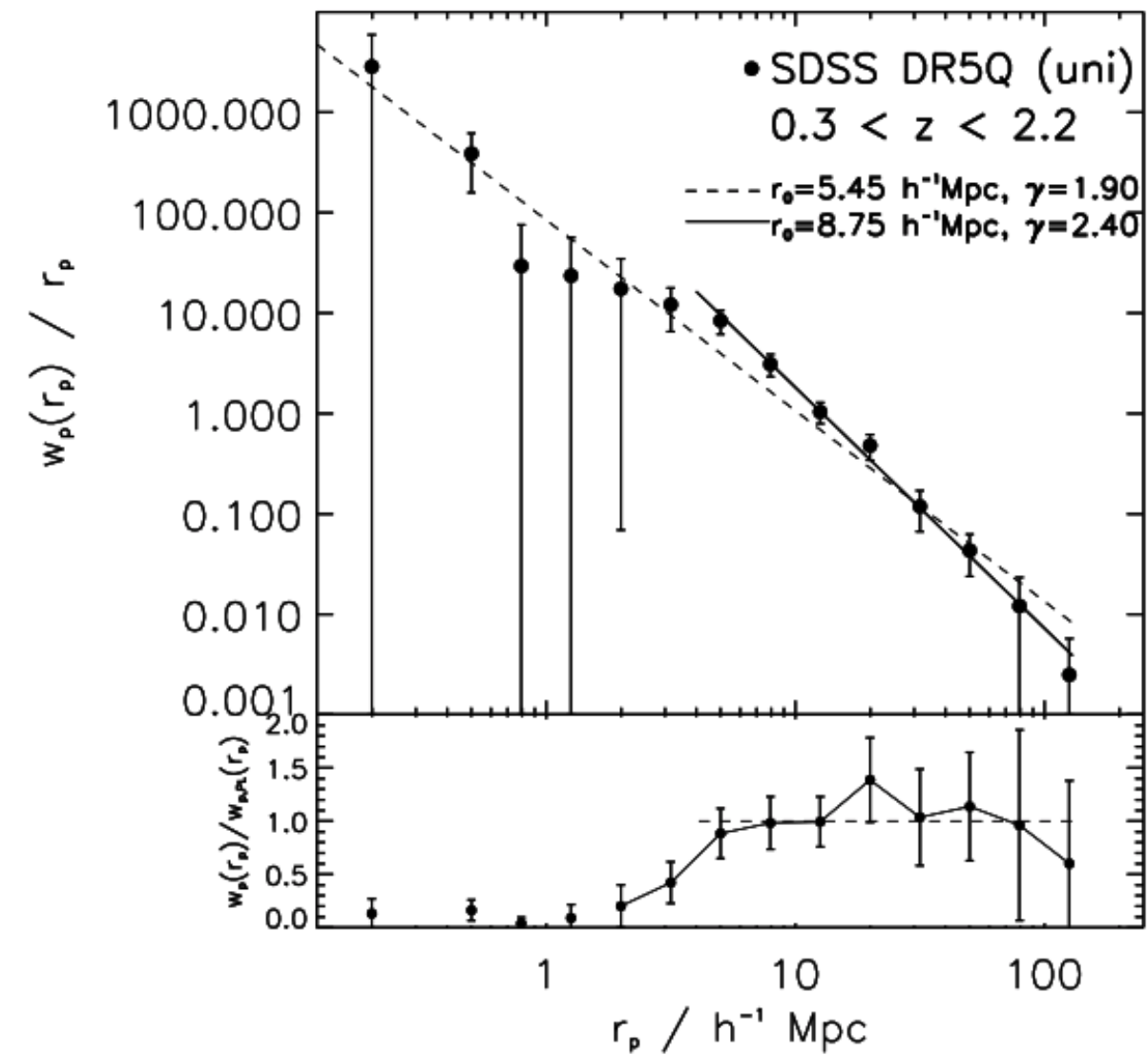
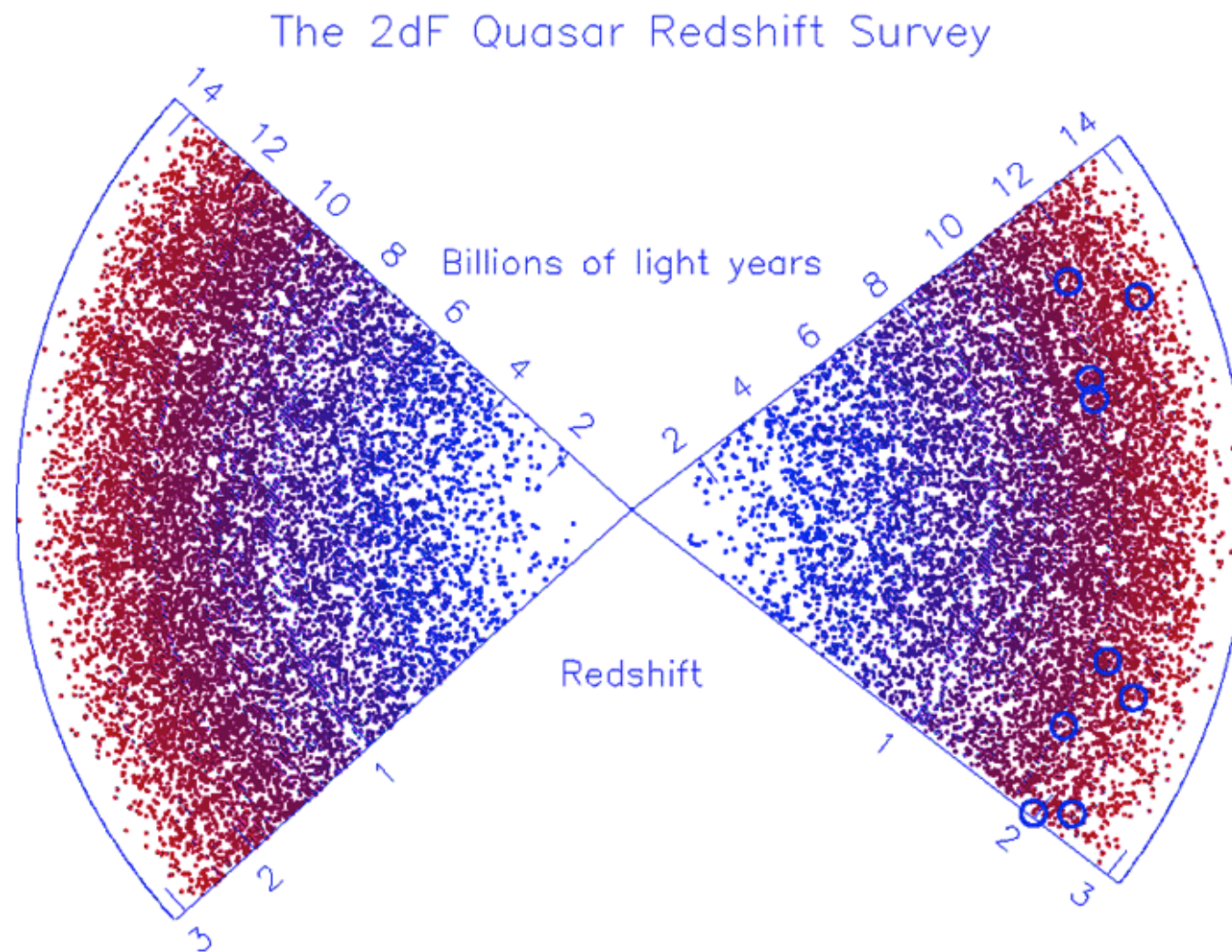
$M_{\text{halo}} \lesssim 10^{12} M_{\odot}$

minor



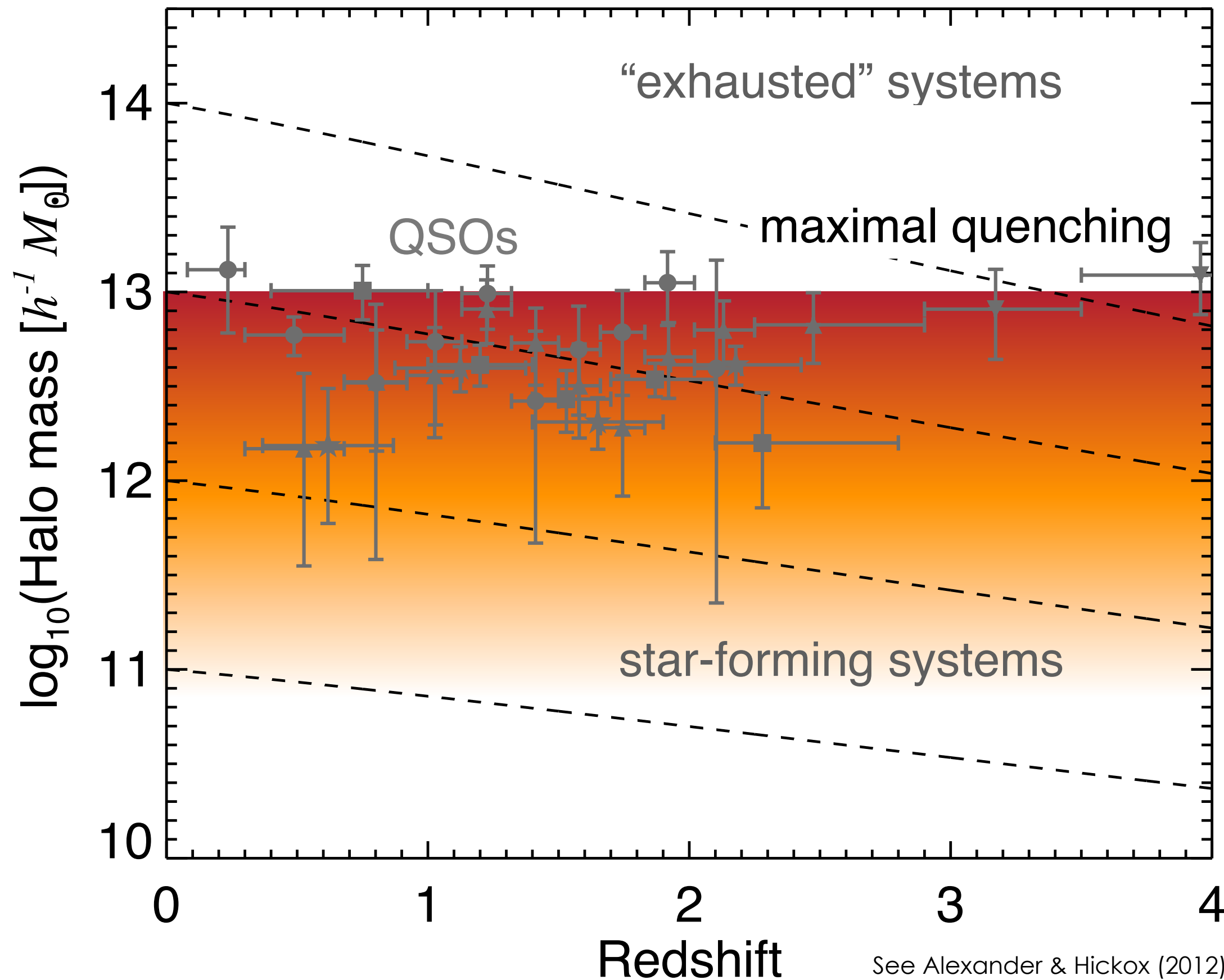
Star formation is most efficient in $\sim 10^{12} M_{\odot}$ halos

The simplest AGN clustering measurements: **Optical quasars**



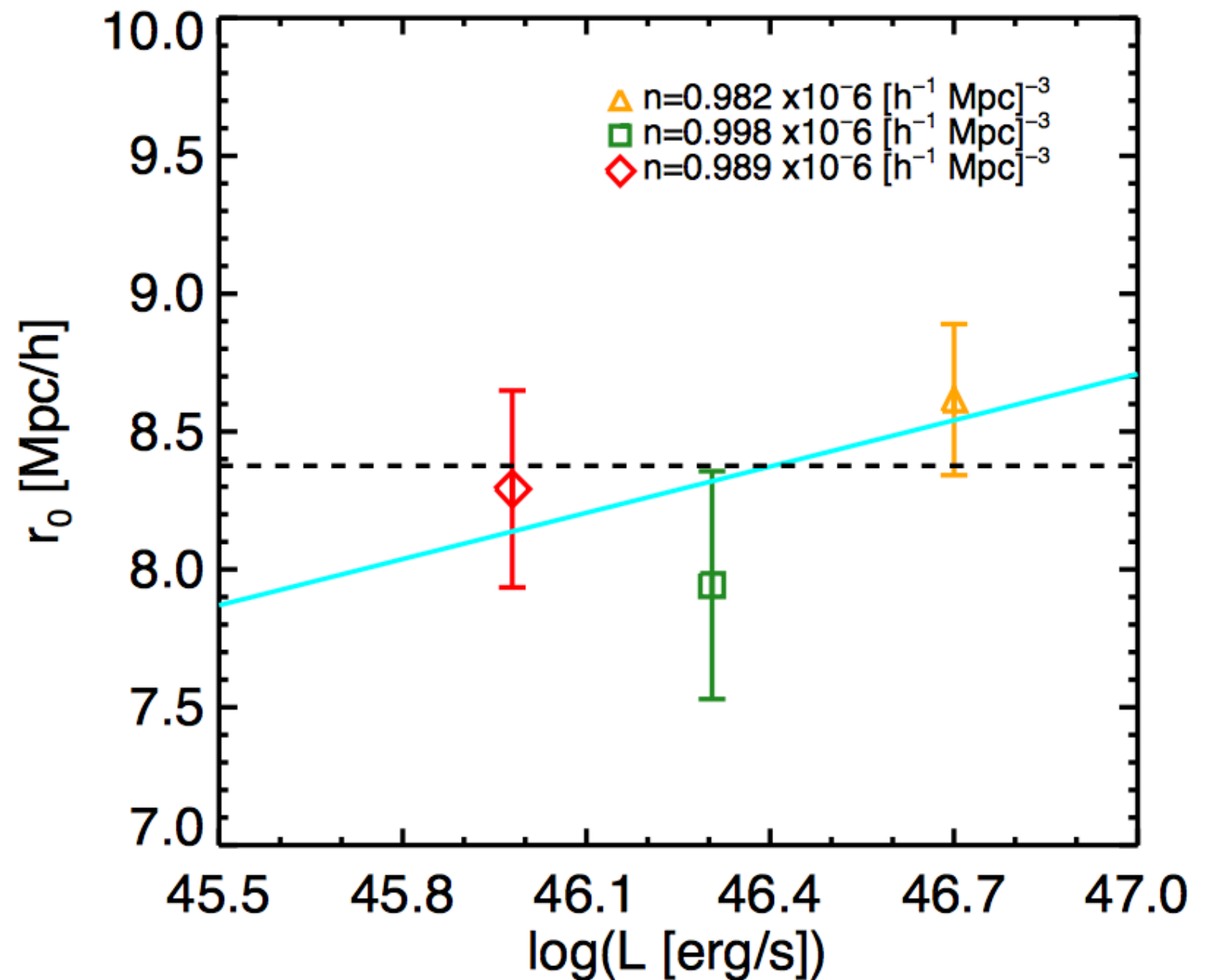
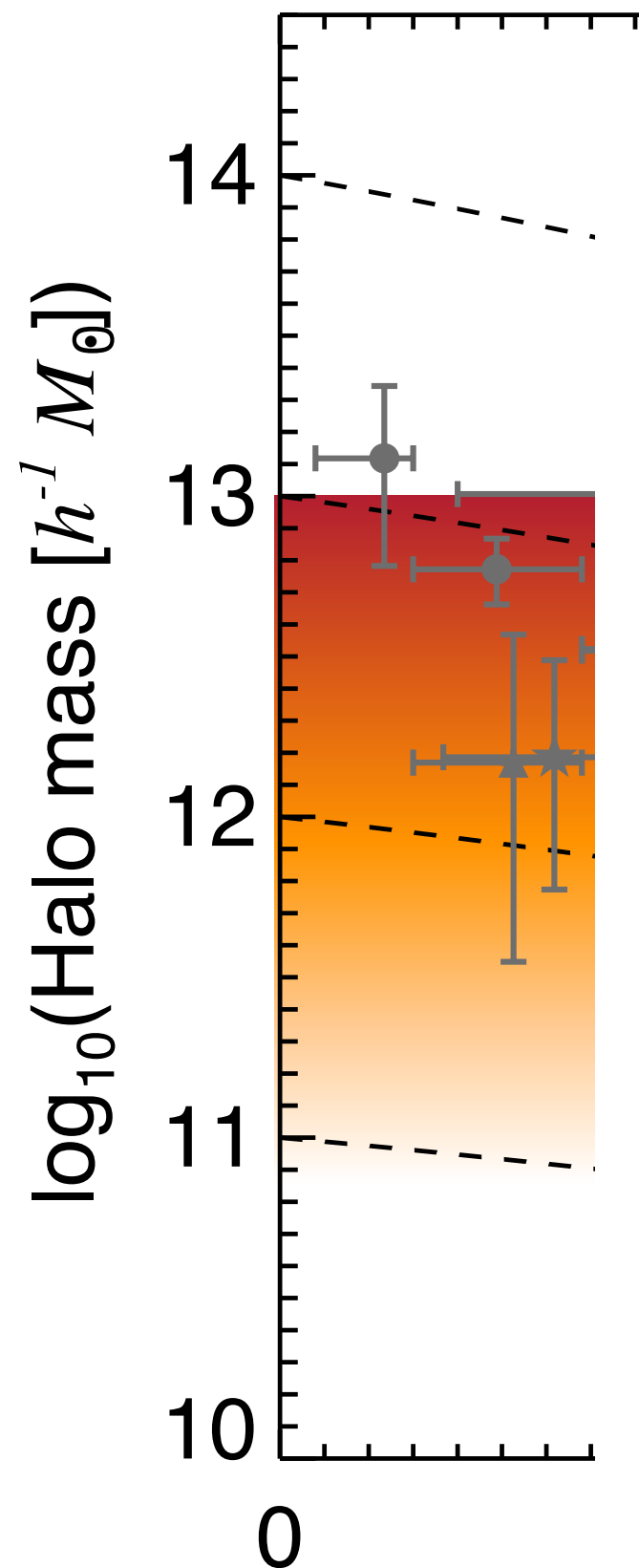
Ross et al. (2009) , too many other references to list here!

Optical quasars reside in halos of ~**constant mass** with **redshift**



Optical quasars res

Optical quasars reside in halos of
~**constant mass** with **luminosity**

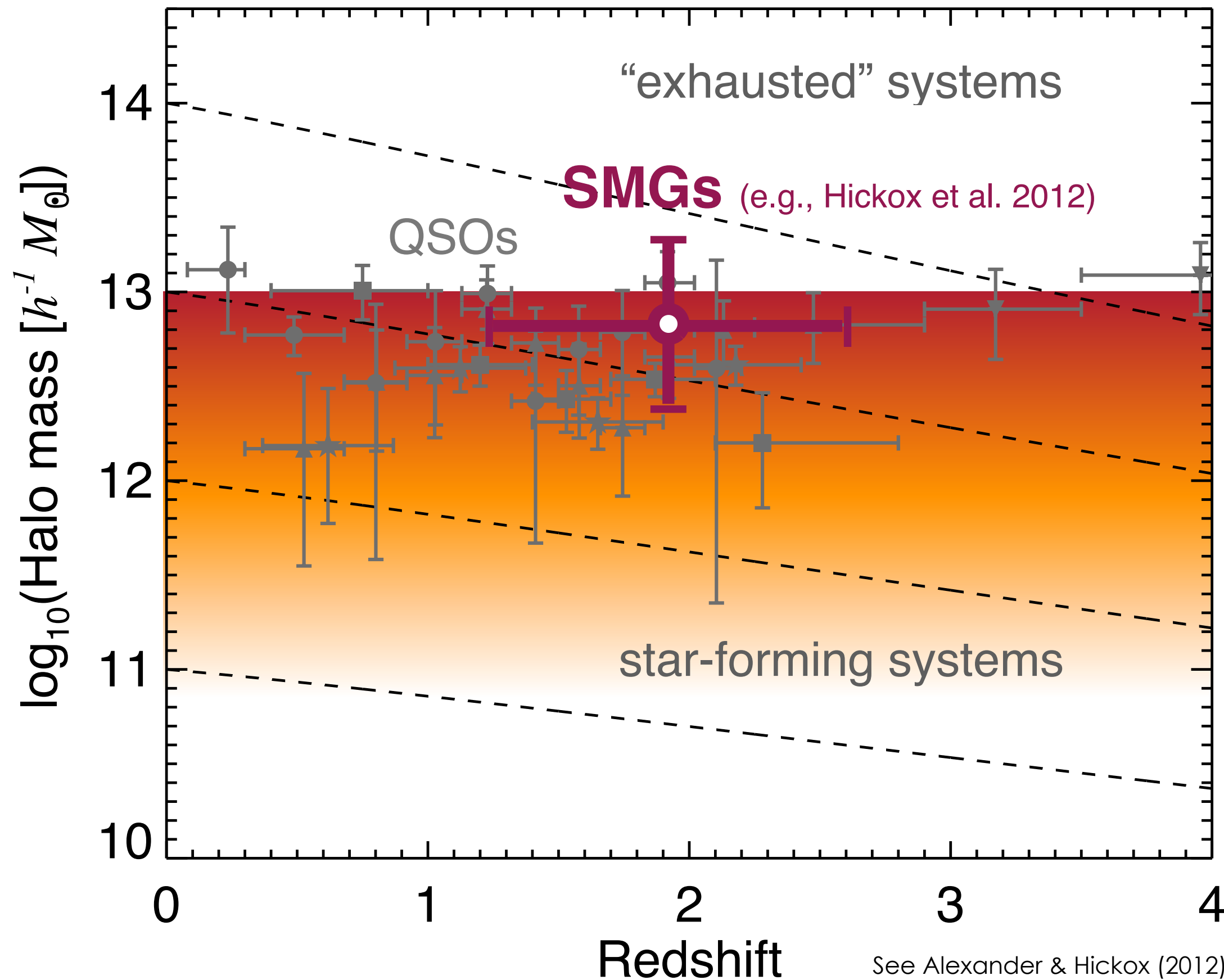


Eftekharzadeh et al. (2016)

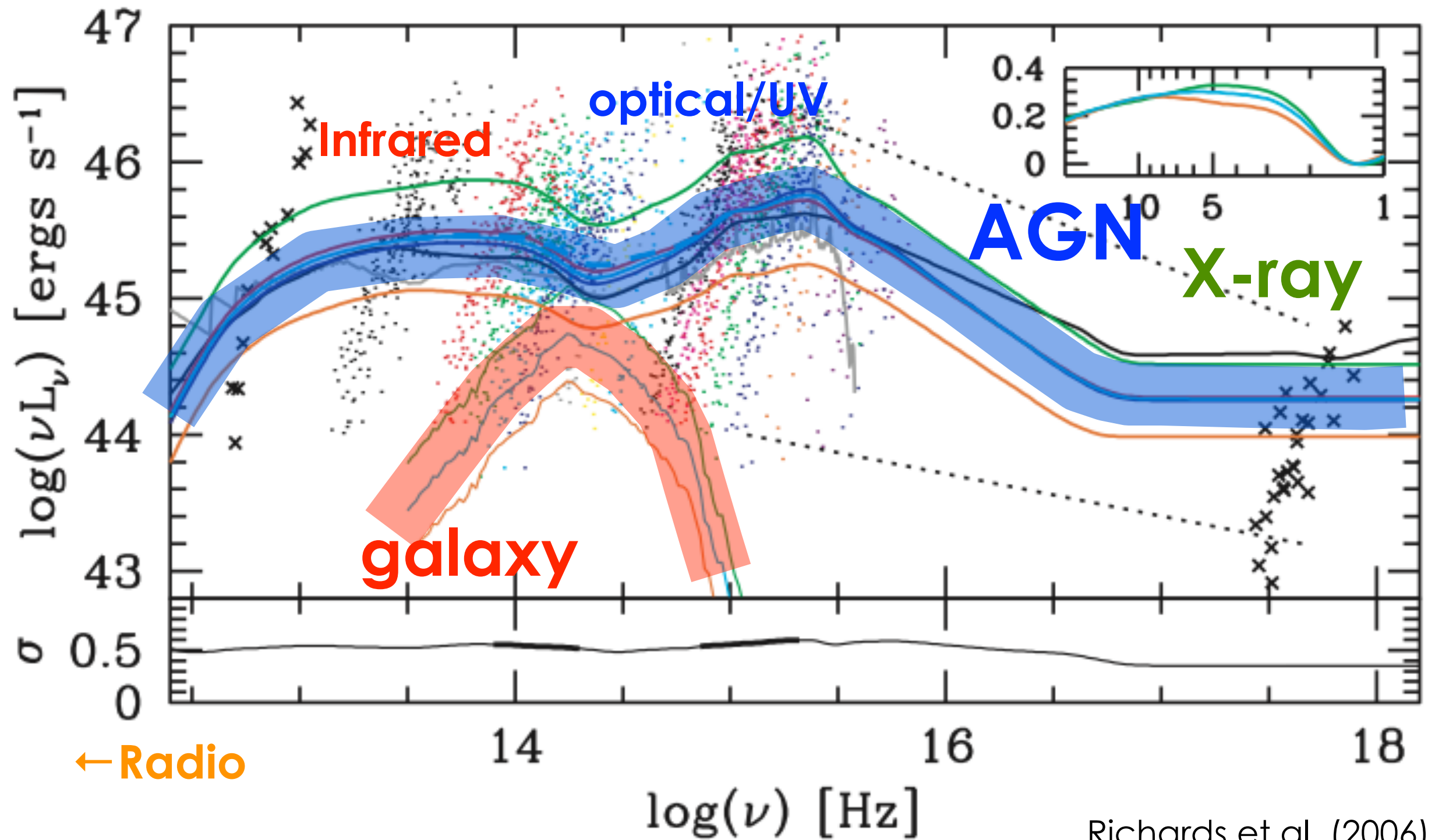
Redshift

See Alexander & Hickox (2012) for references

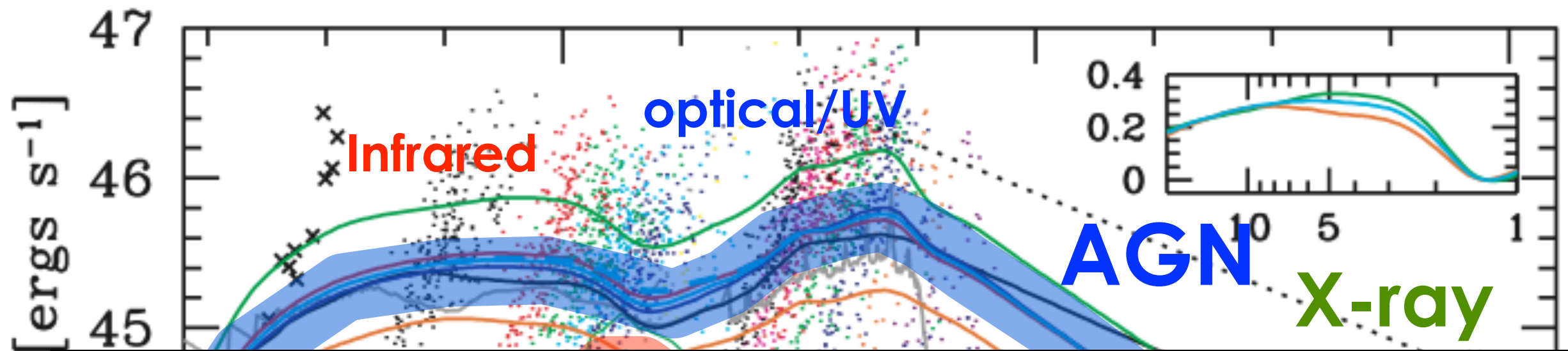
Quasars and **powerful starbursts** occupy the same halos



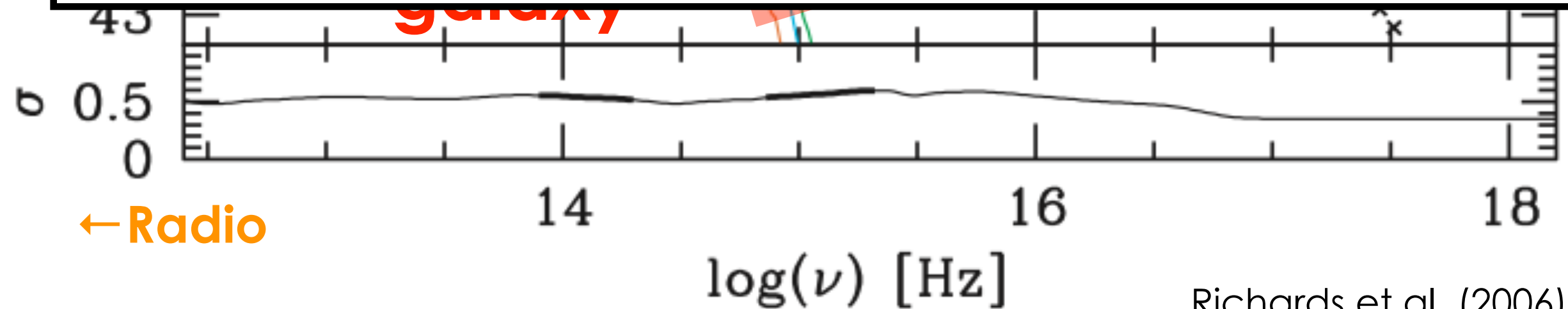
What about **other AGN populations?**



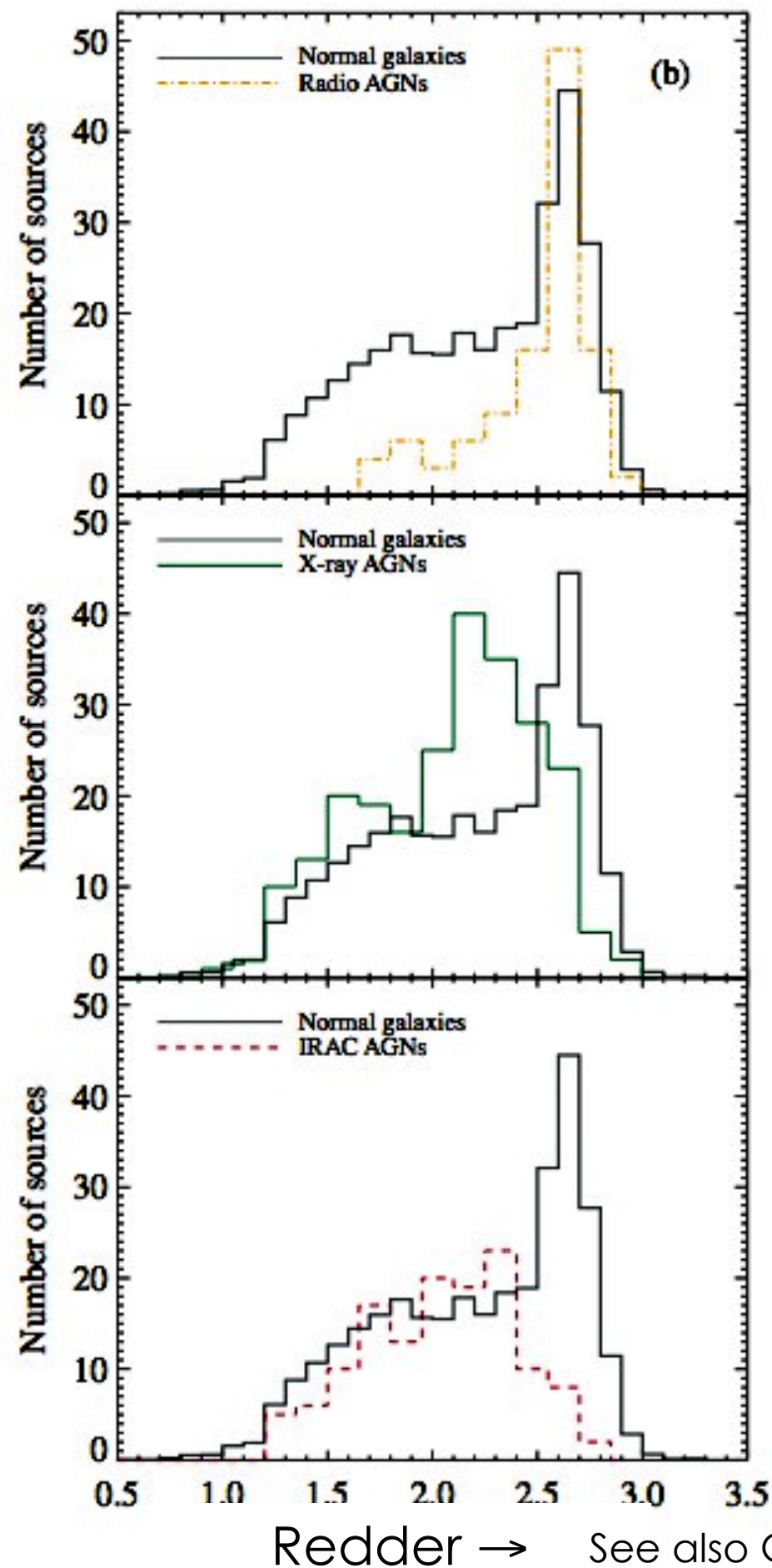
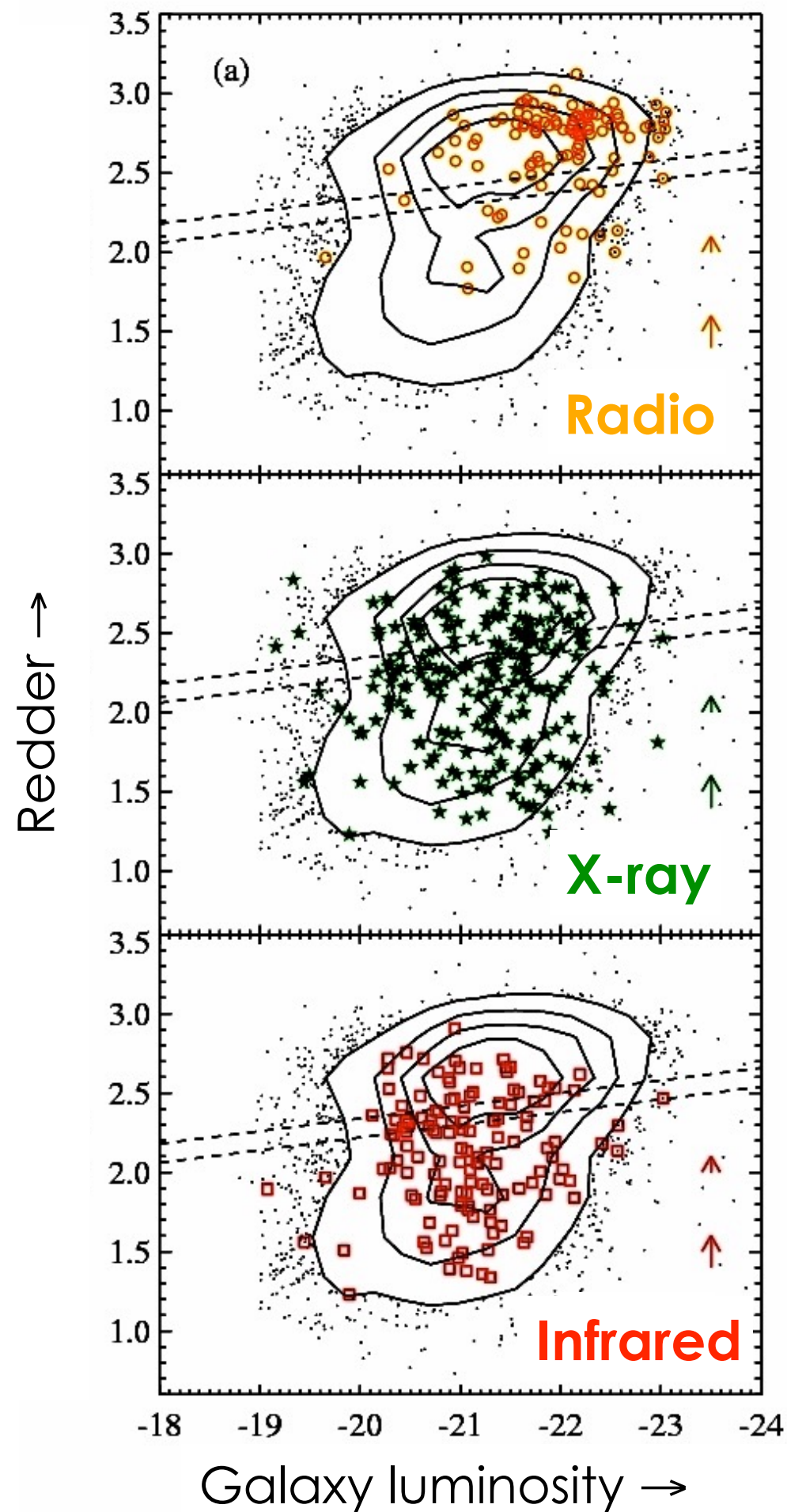
What about **other AGN populations?**



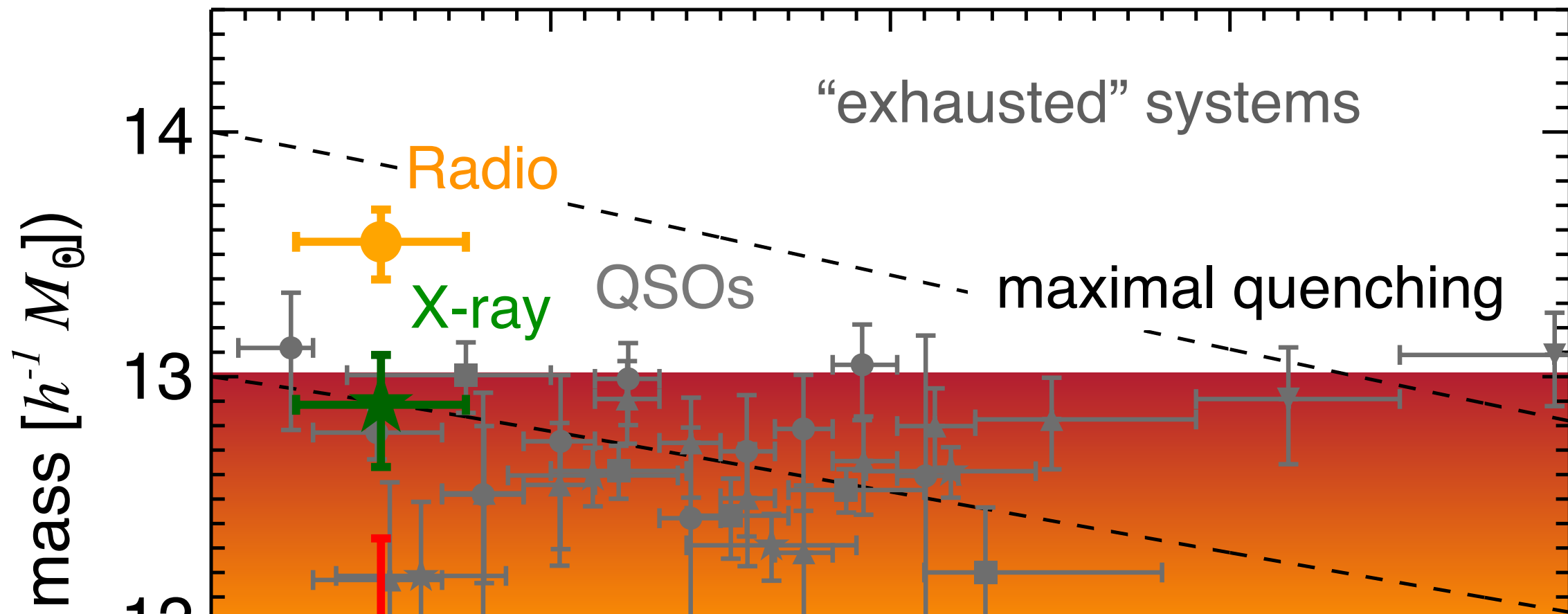
LUMINOSITY CUTS: X-ray, radio
COLOR/SPECTRAL CUTS: Infrared, optical/UV
Different selection effects! (e.g. Mendez et al. 2013)



Richards et al. (2006)



Hickox et al. (2009)
See also Goulding et al. (2014)
and many others

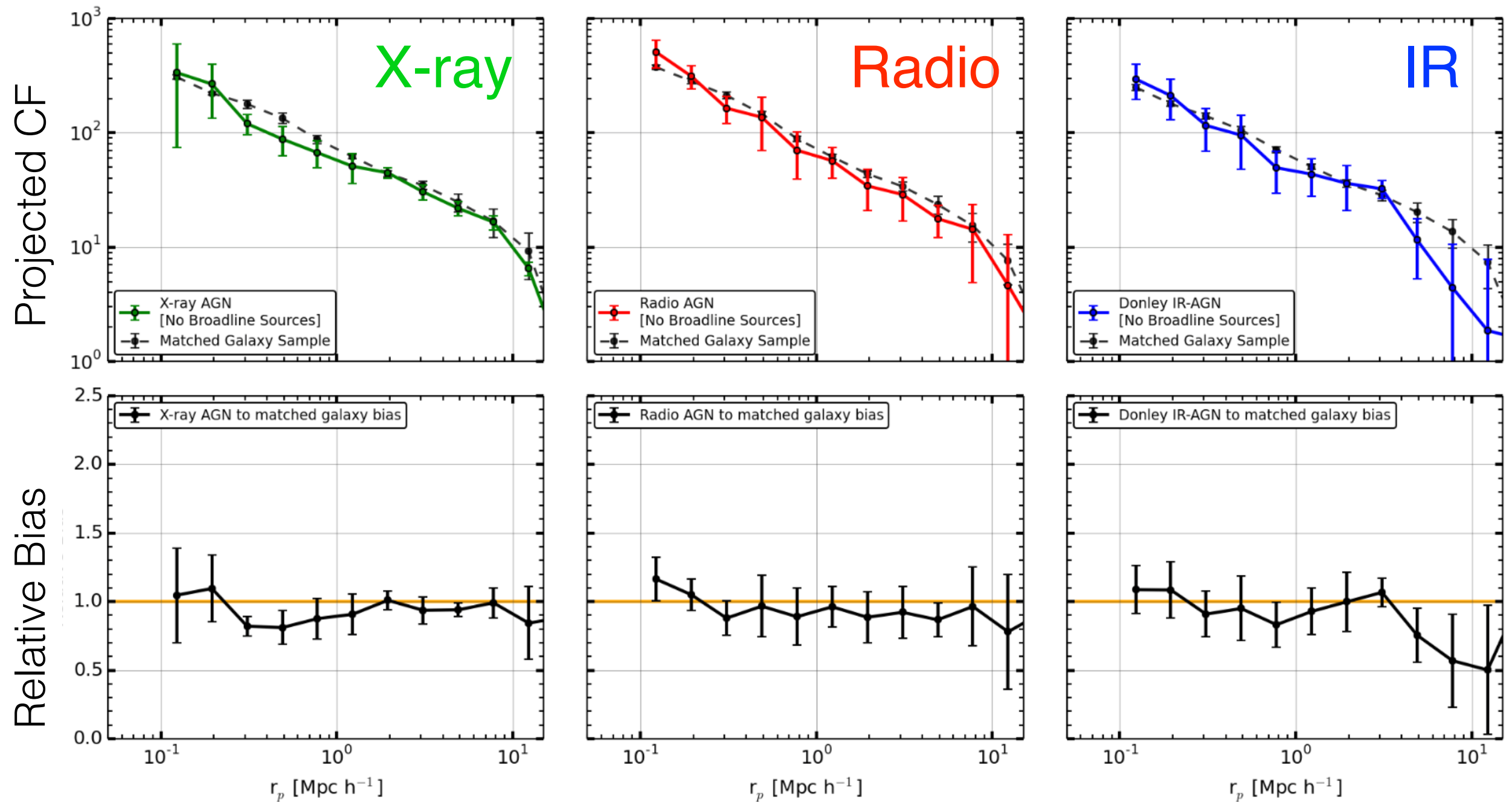


High-Eddington, radiative AGN — X-ray, Infrared, optical/UV — are found in star-forming halos

Low-Eddington, mechanical AGN — radio — are found in massive, passive halos

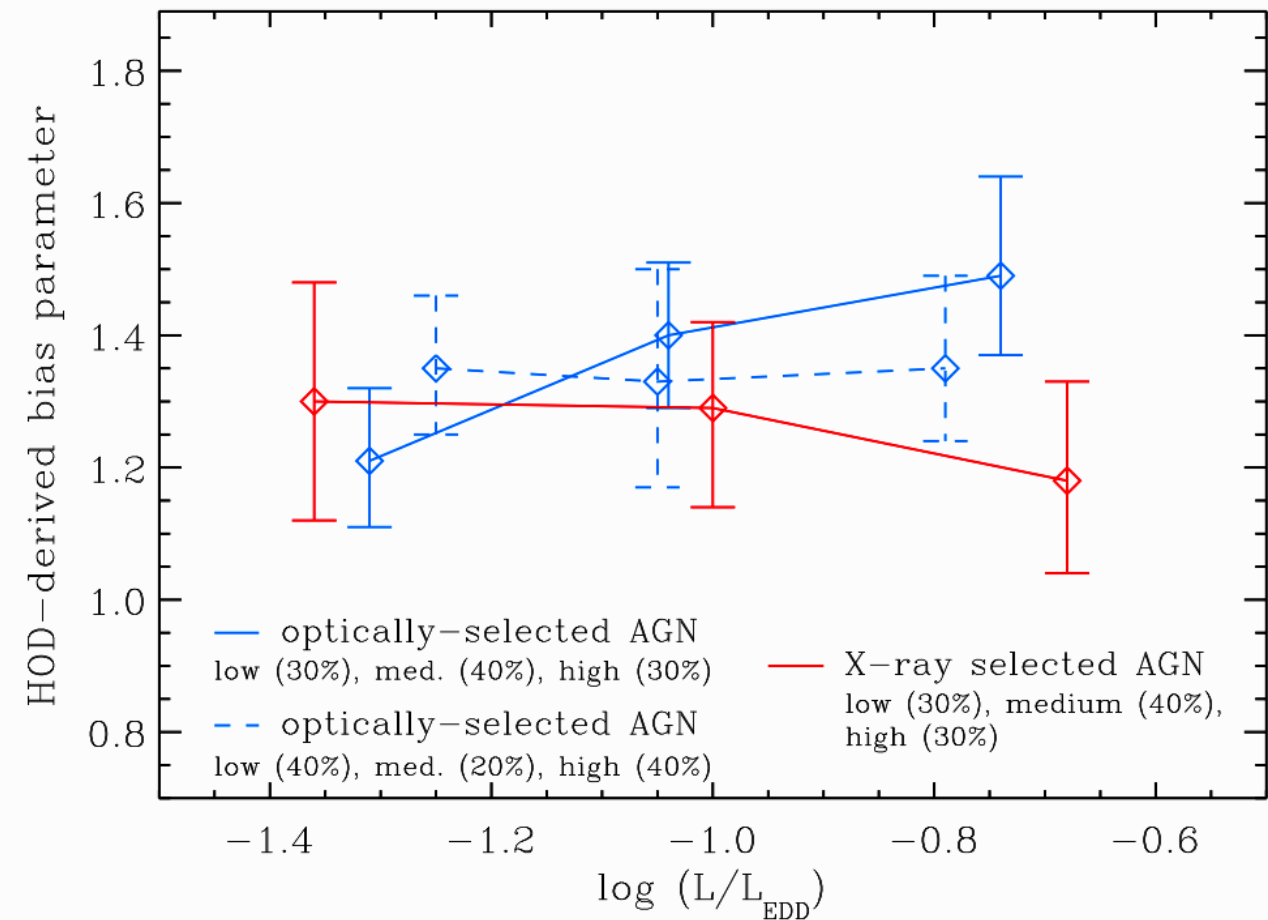
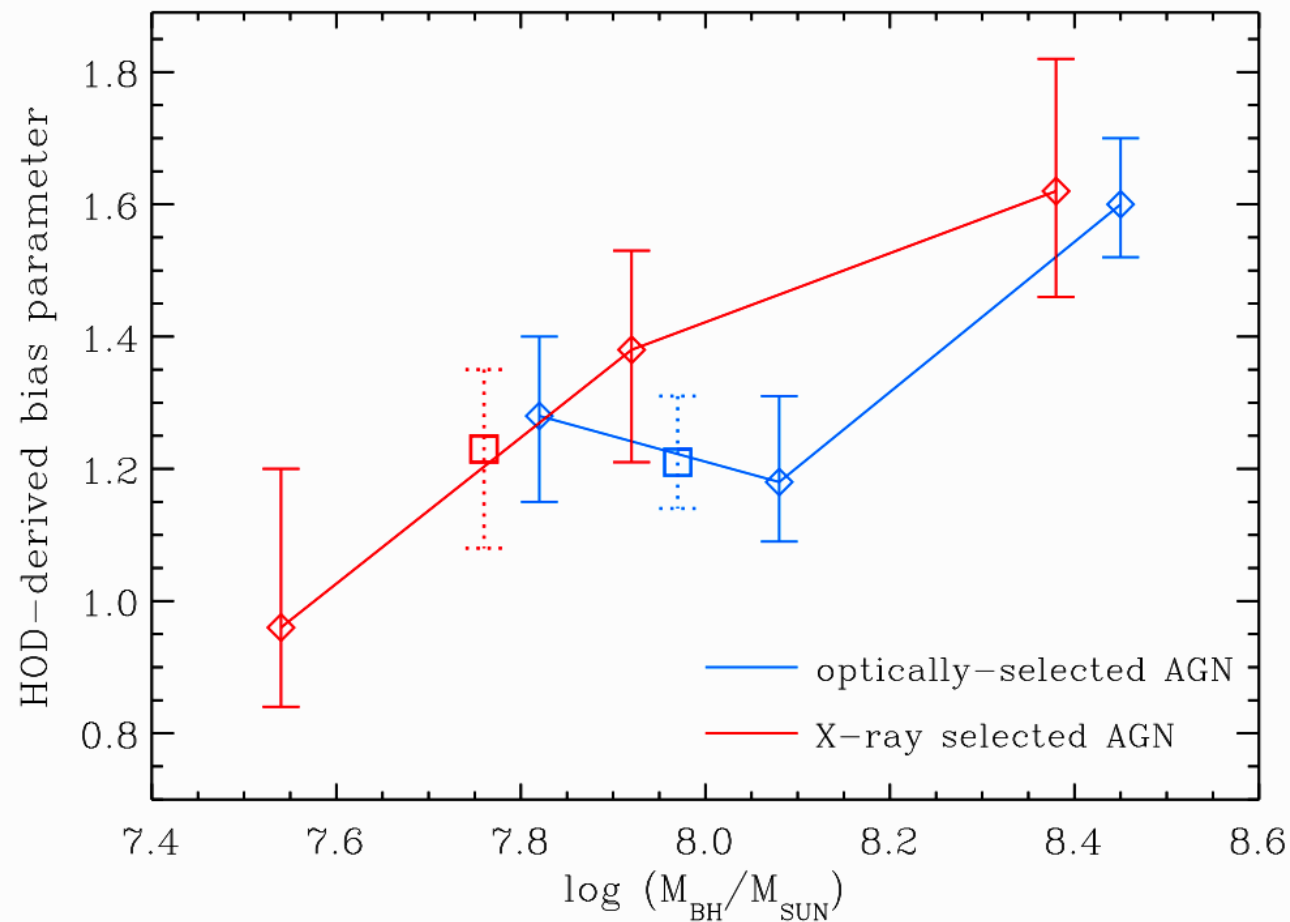
Redshift

AGN are in general clustered **consistently to matched host galaxies**



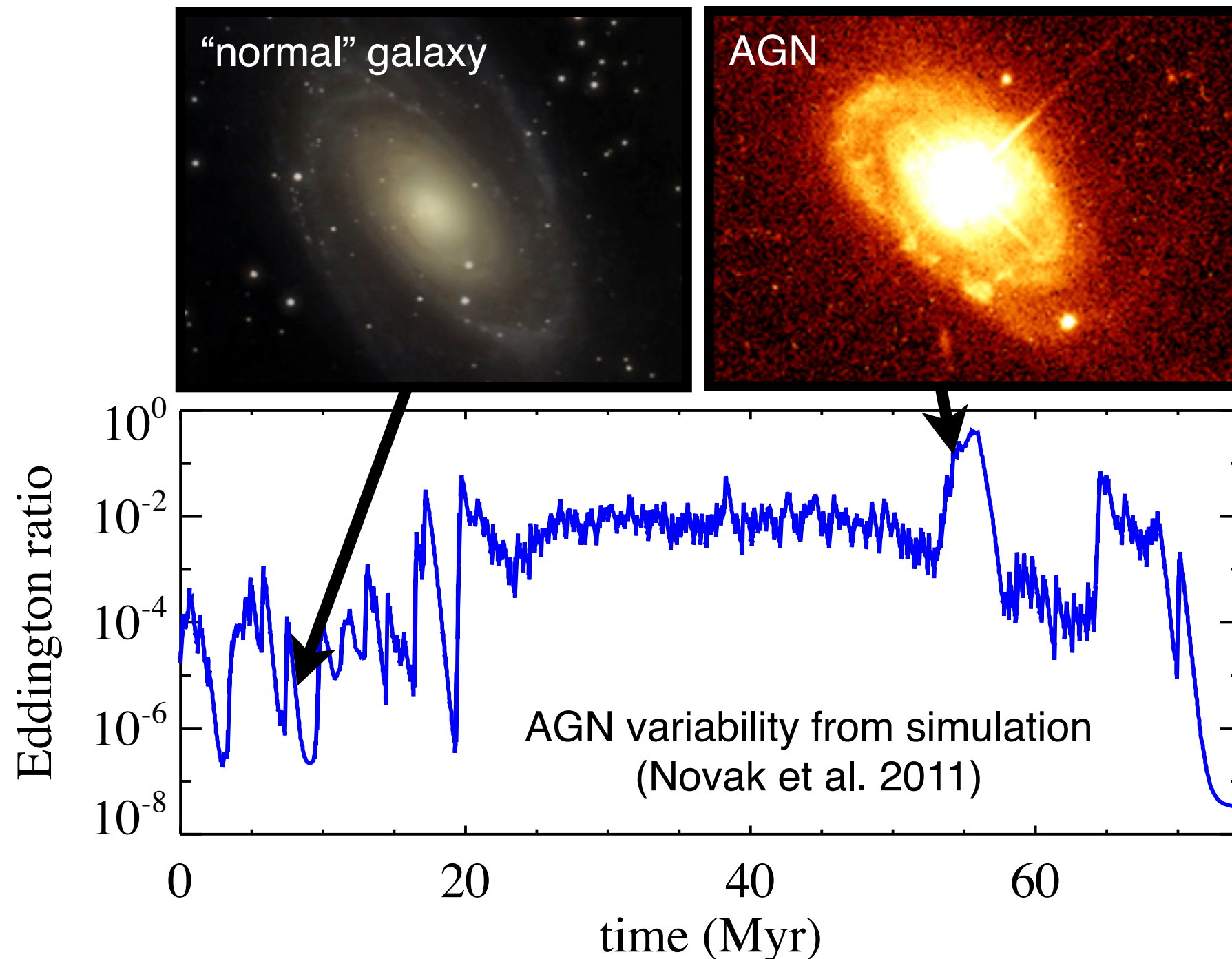
Mendez et al. (2015)

AGN clustering depends strongly on **black hole mass**, not on **Eddington ratio**



Krumpe et al. (2015)

How to explain this? Importance of **stochasticity** in the AGN population





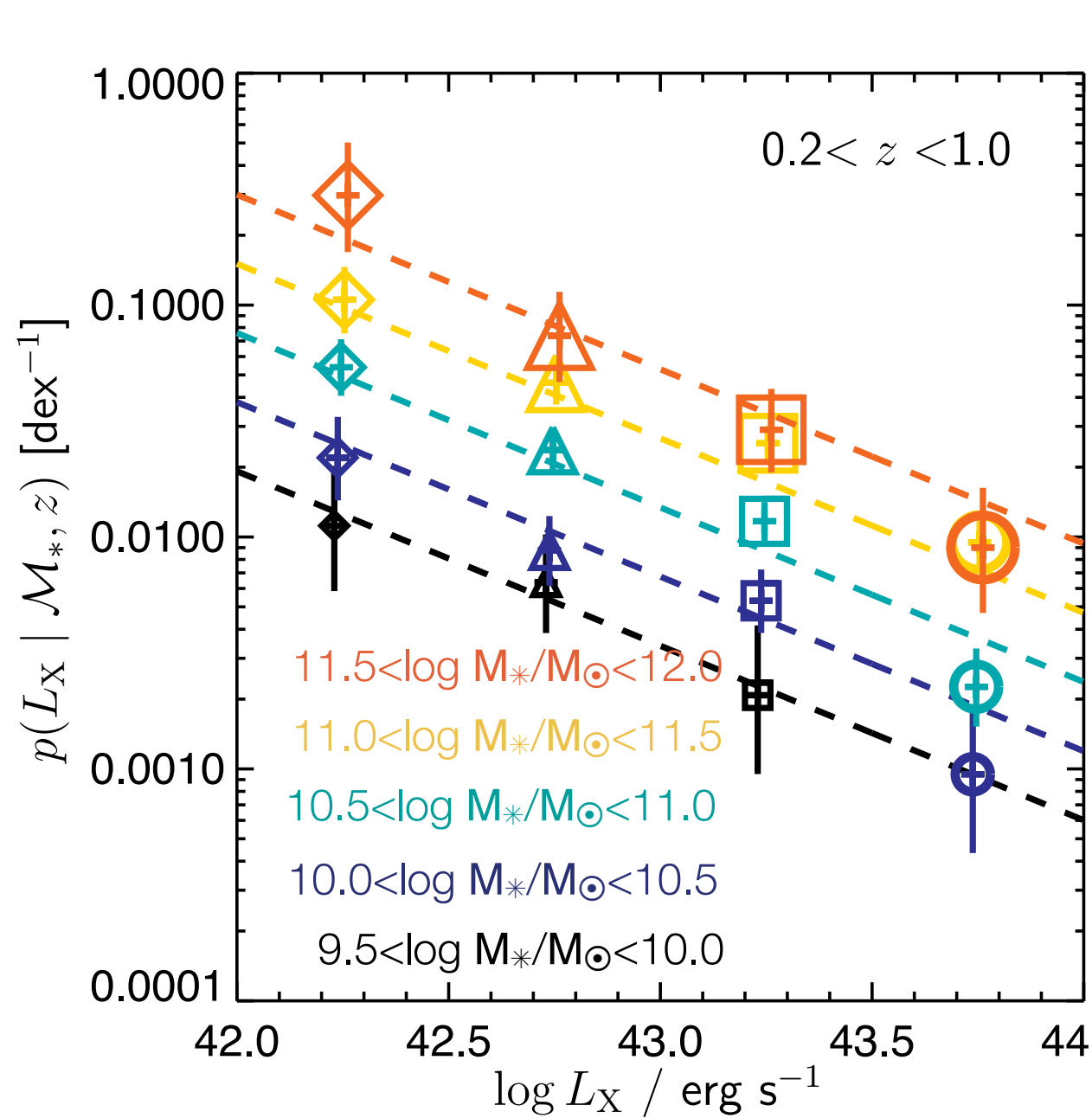
Time since the Big Bang: 5.7 billion years

ILLUSTRIS

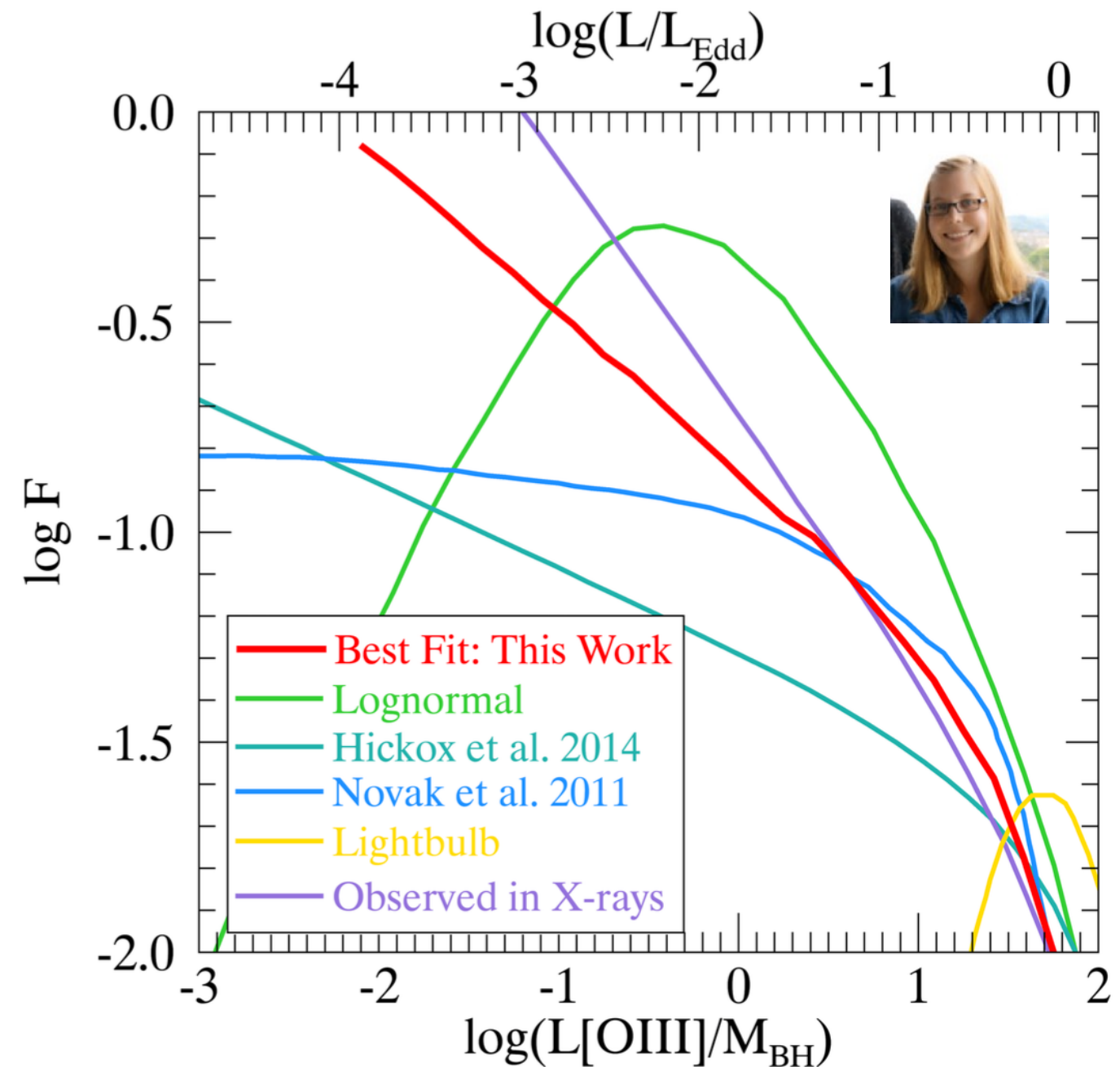
Must think of AGN in terms of **probability distributions**

The AGN Eddington ratio distribution

How likely is an black hole to be active as a function of L/L_{Edd} ?



Aird et al. (2012)



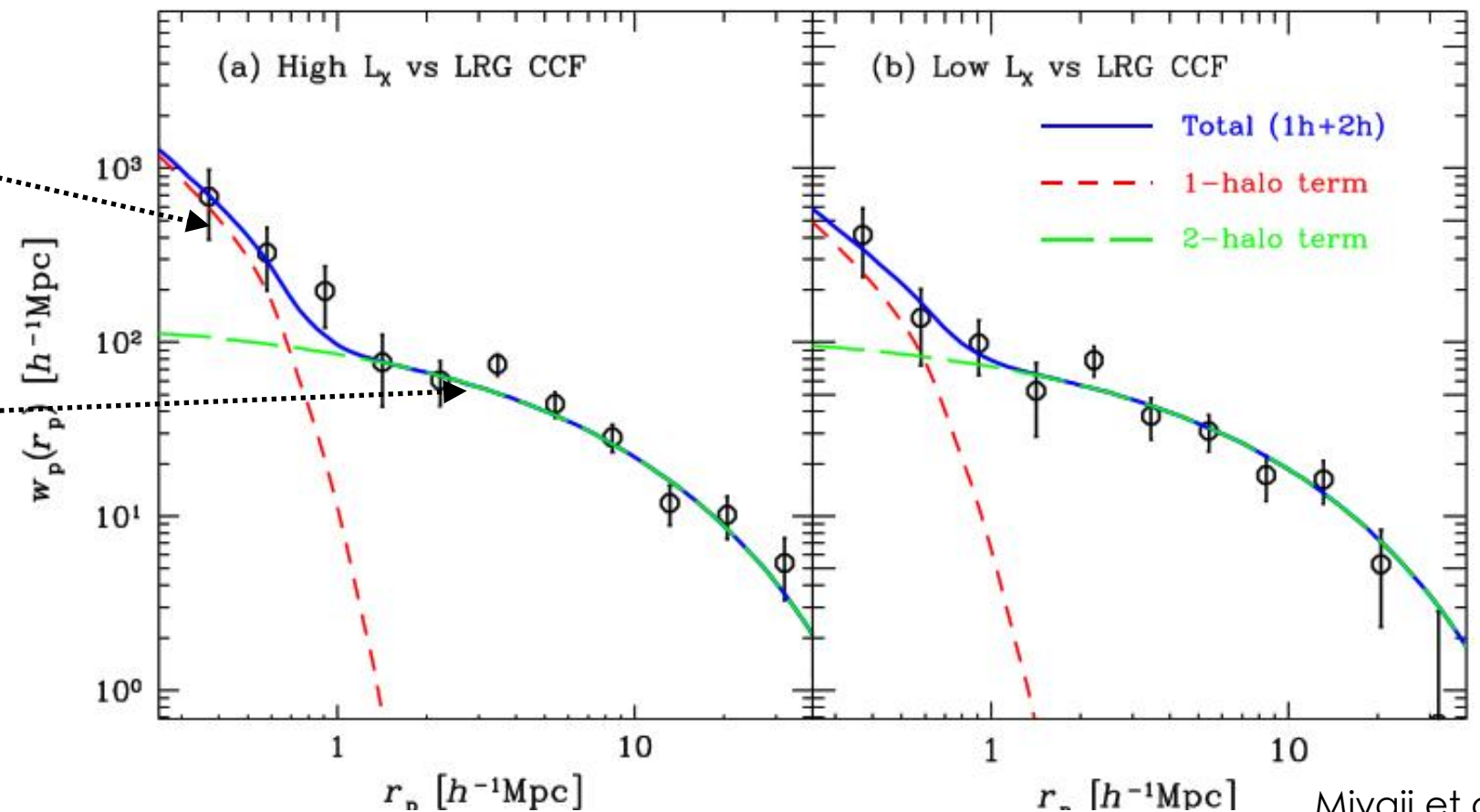
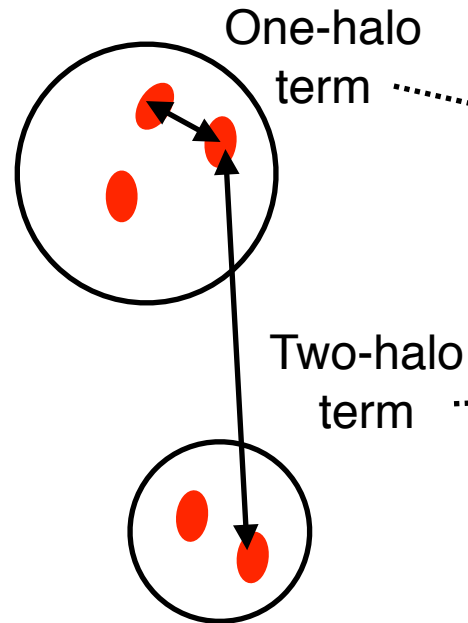
Jones et al. (2016)

The AGN halo occupation distribution

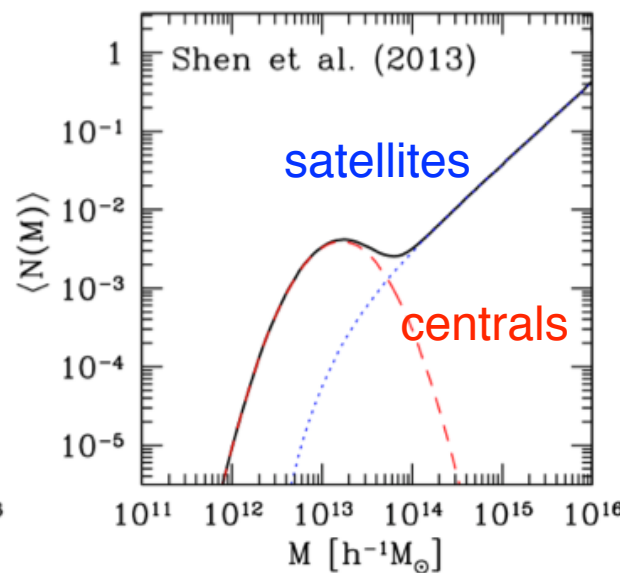
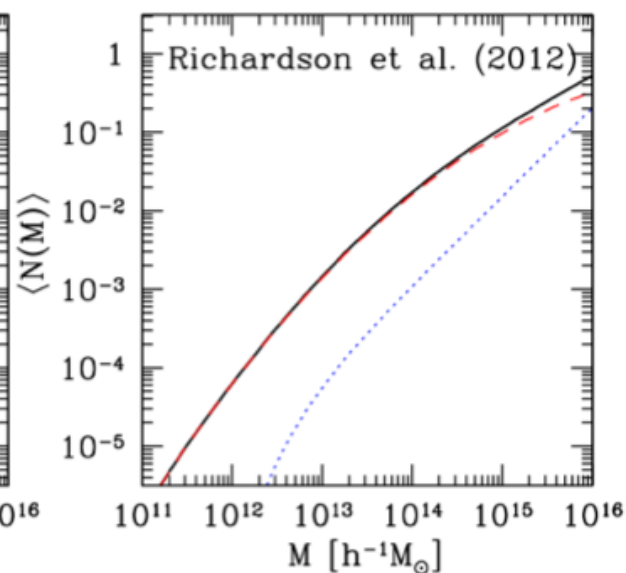
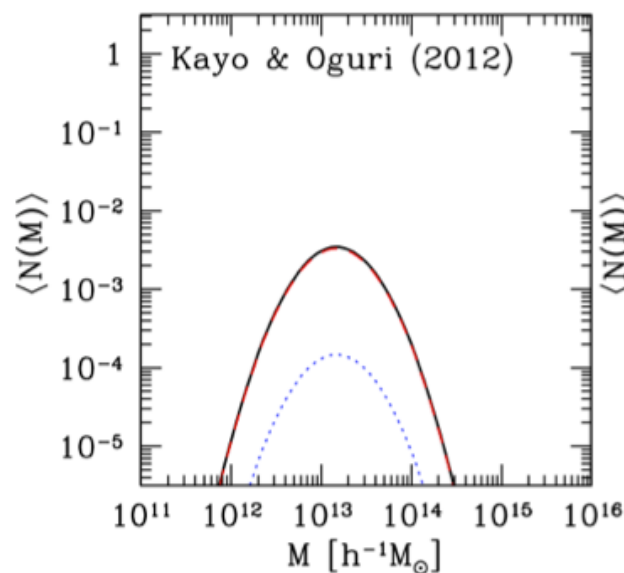
How likely is a DM halo to host an AGN as a function of **halo mass**?

Are AGN primarily in **central** or **satellite** halos?

The HOD formalism



Miyaji et al. (2011)

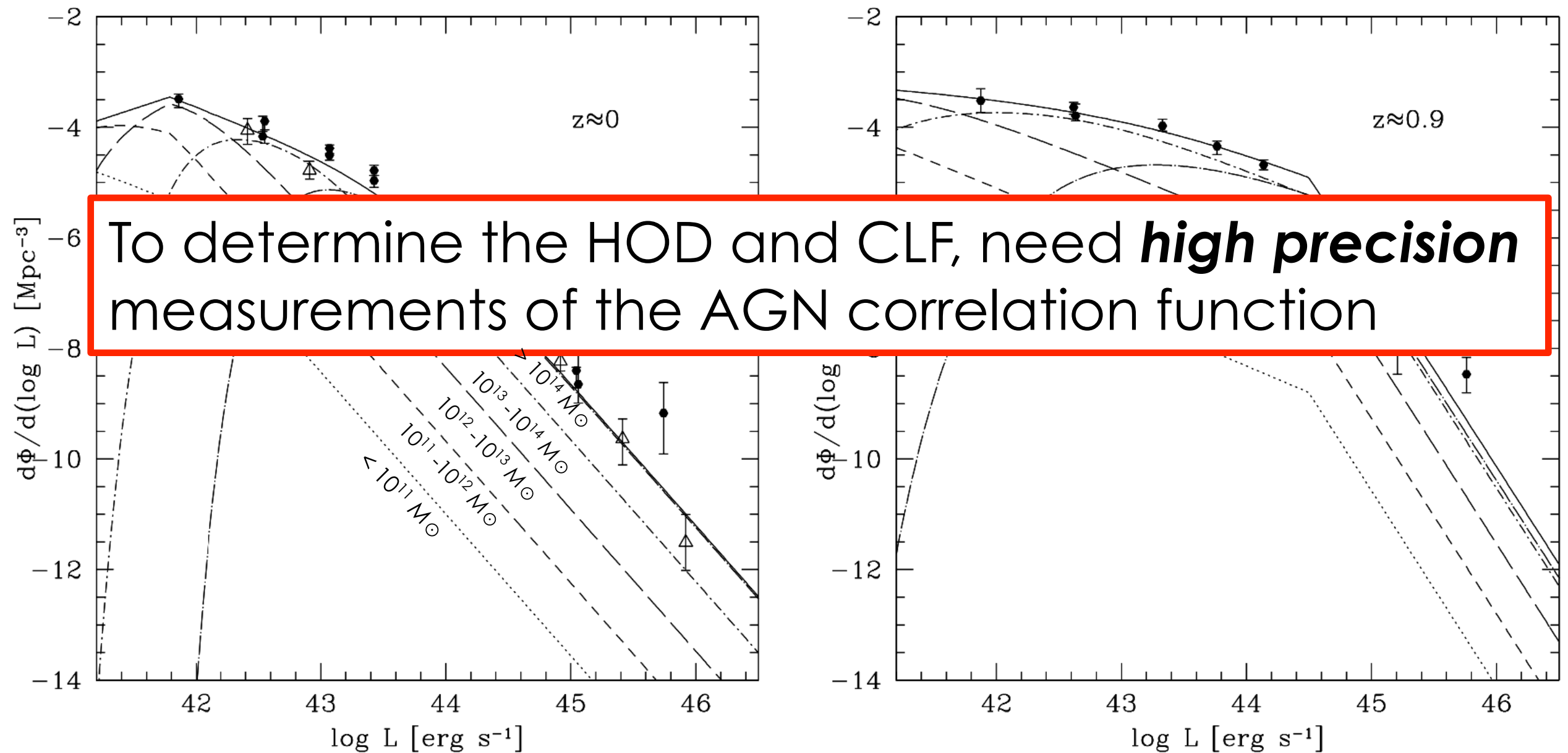


Also **direct measures** of AGN HOD — flat or declining with halo mass? (e.g., Allevato et al. 2012; Martini et al. 2013)

Credit: I. Kayo

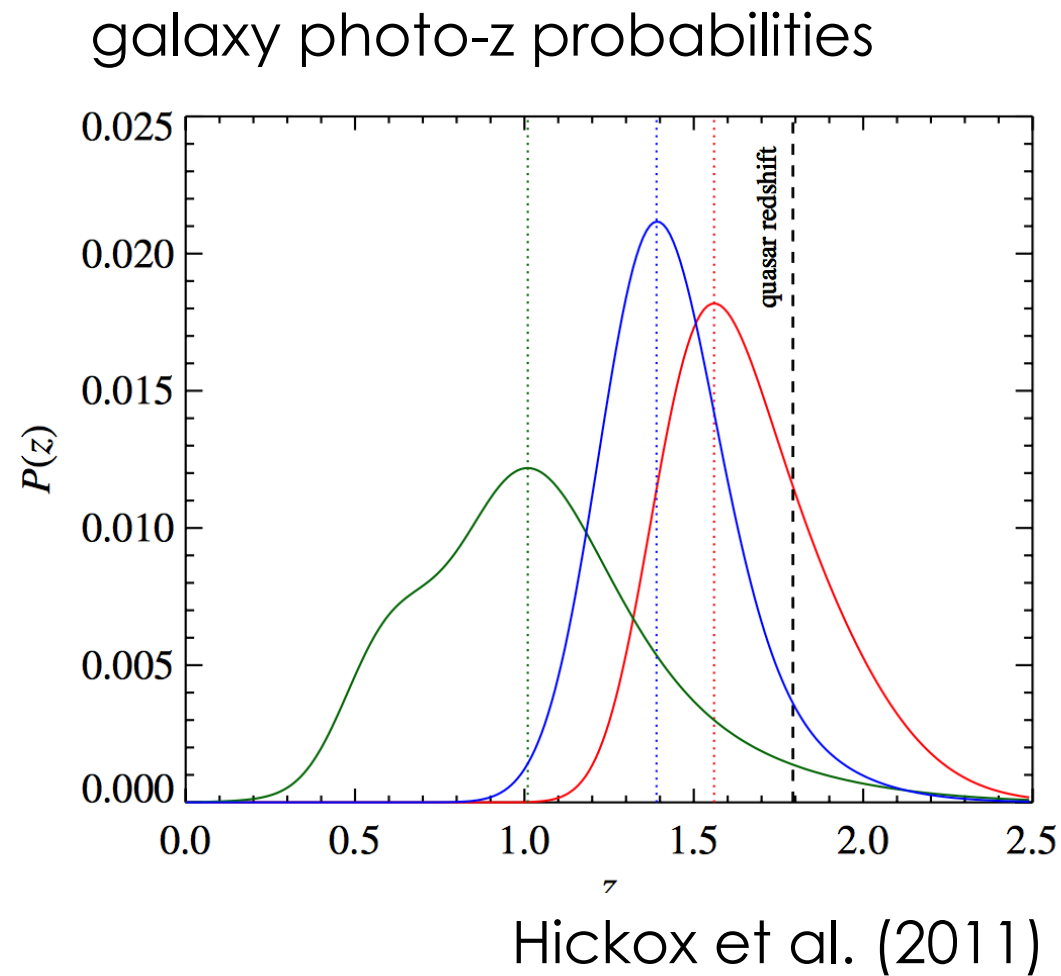
The **conditional luminosity function**

What is the **luminosity/Eddington ratio distribution** as a function of **halo mass**?



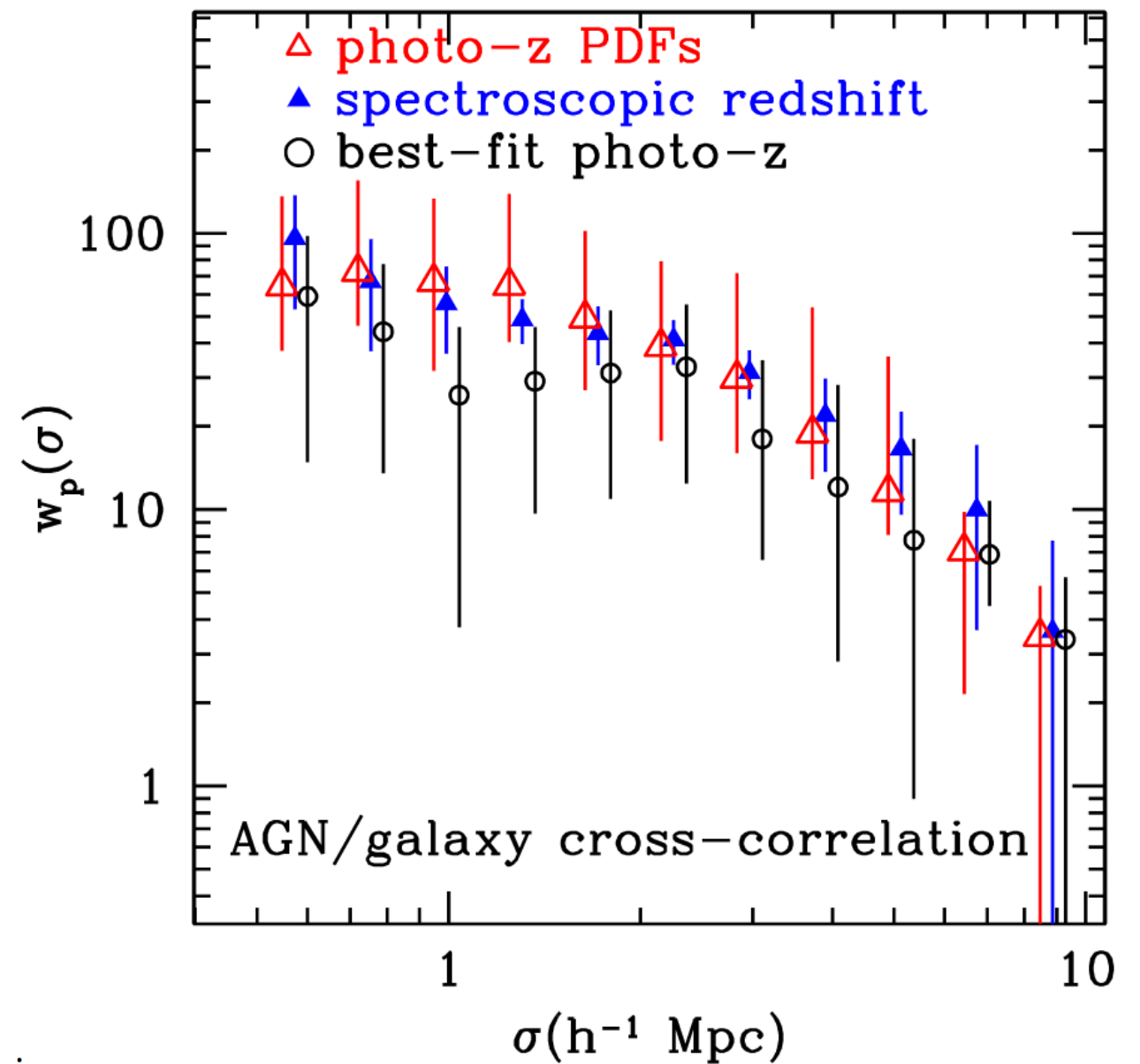
Ballantyne (2016a,b)

New AGN clustering techniques: **Redshift probability functions**



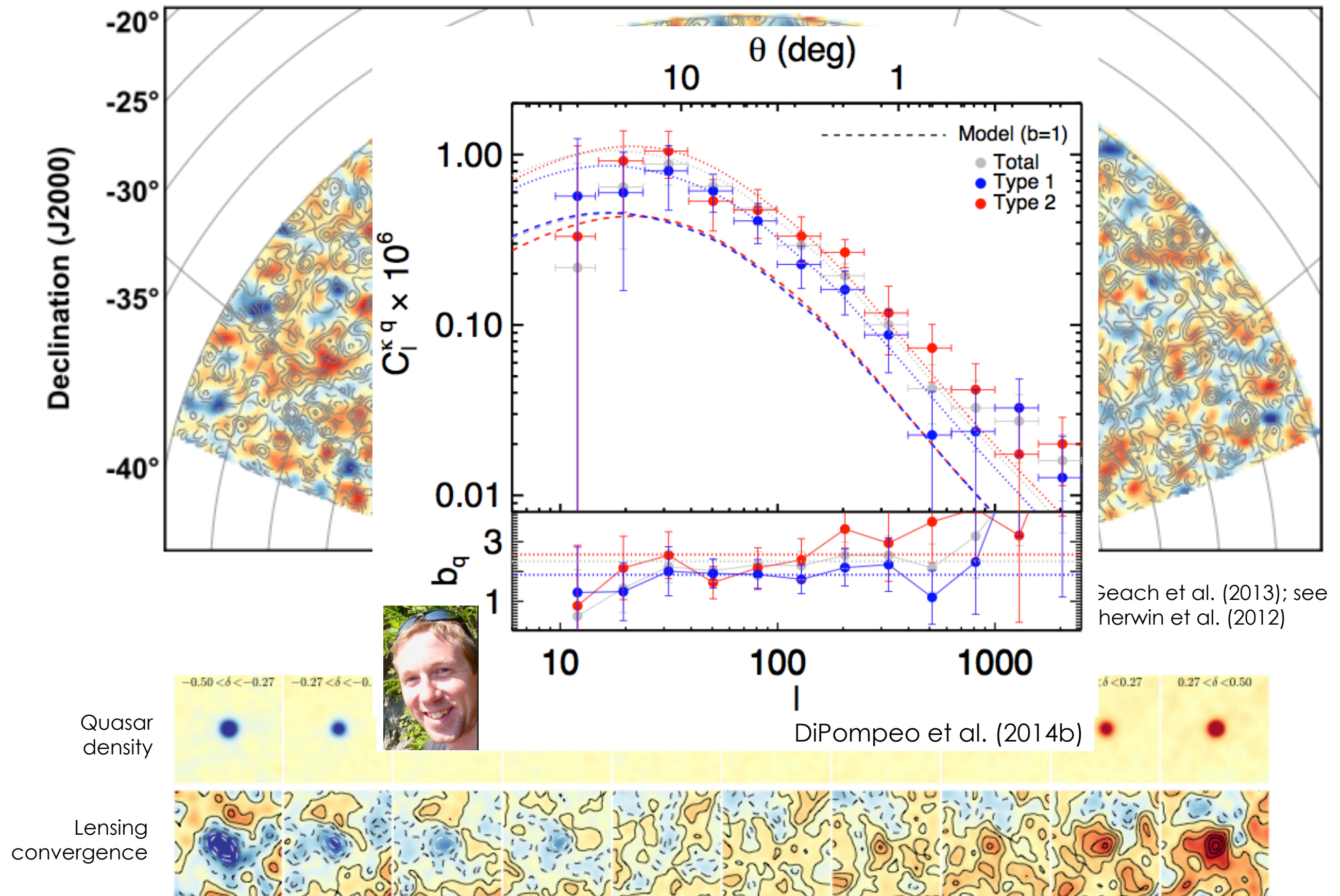
$$w_p(R) = N_R N_Q \sum_{i,j} c_{i,j} \frac{D_Q D_G(R)}{D_Q R_G(R)} - \sum_{i,j} c_{i,j}$$

Myers et al. (2009)

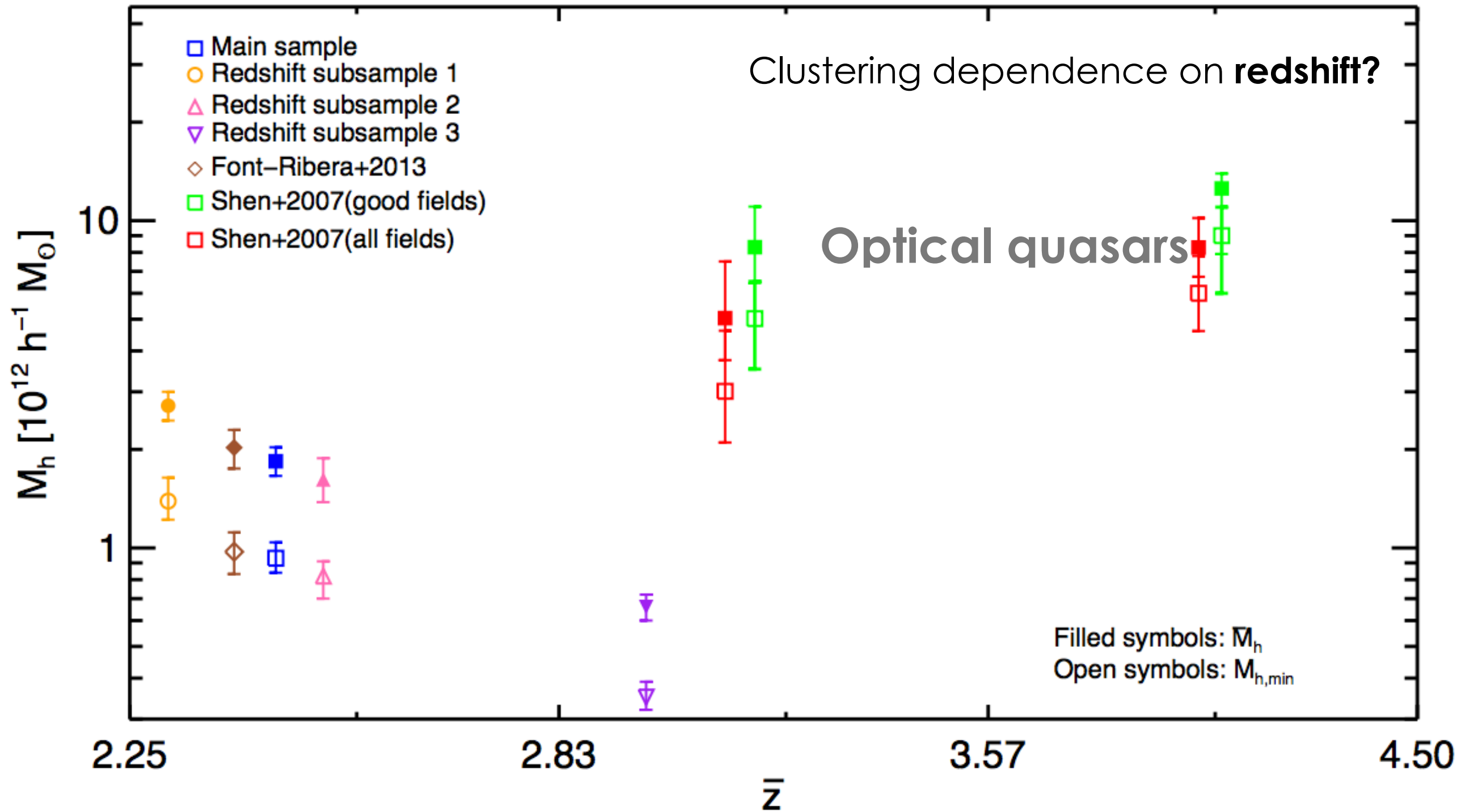


Georgakakis et al. (2014)

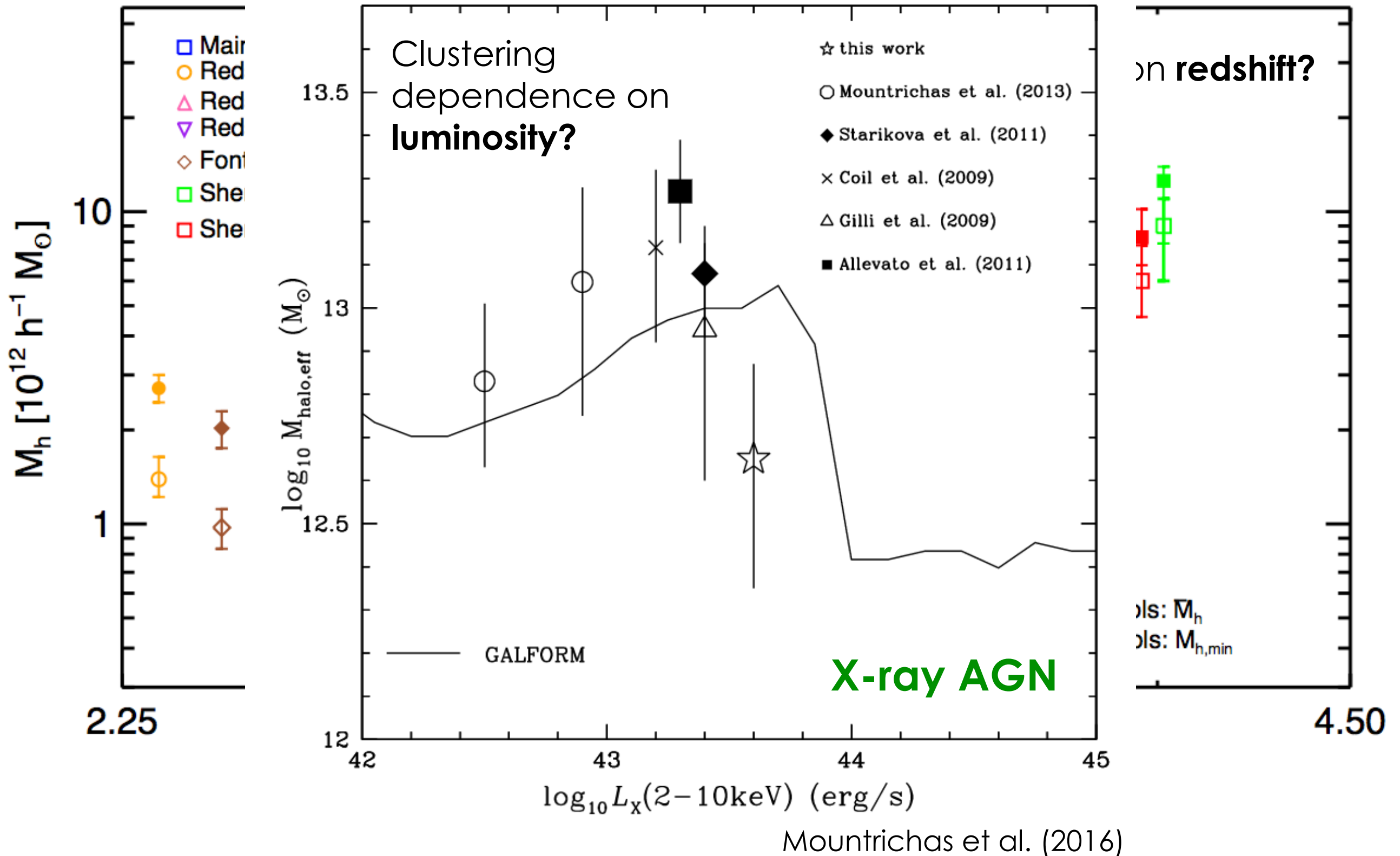
New AGN clustering techniques: **Cross-correlation with CMB lensing**



Maybe things not quite so simple?

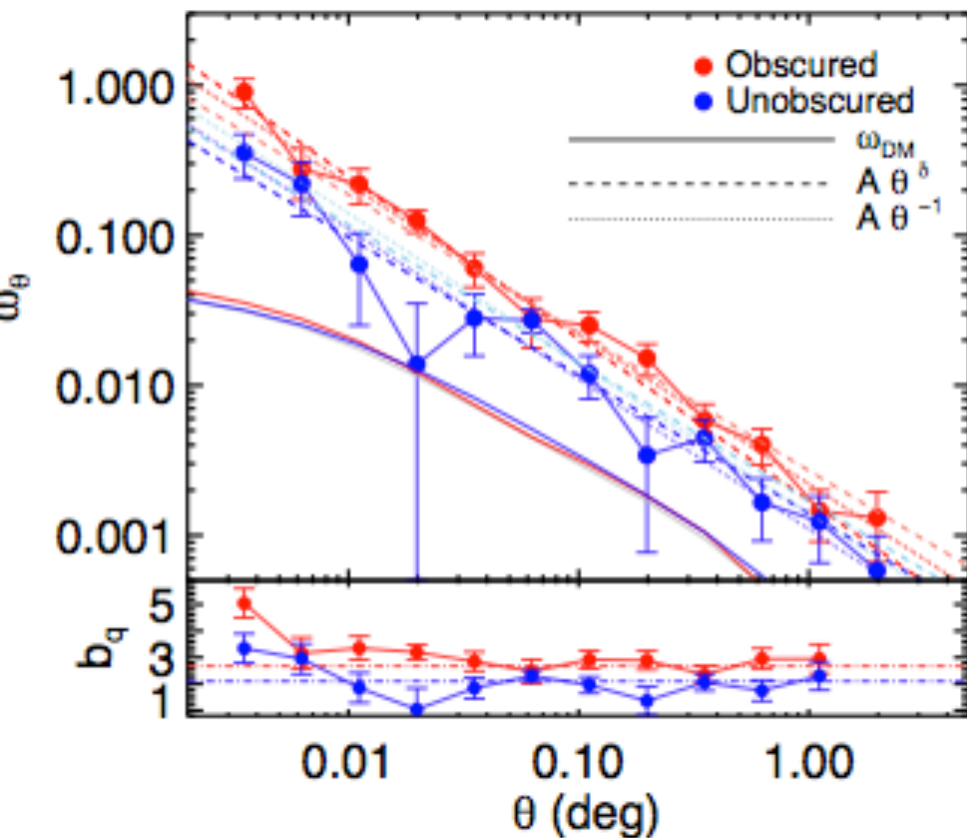


Maybe things not quite so simple?



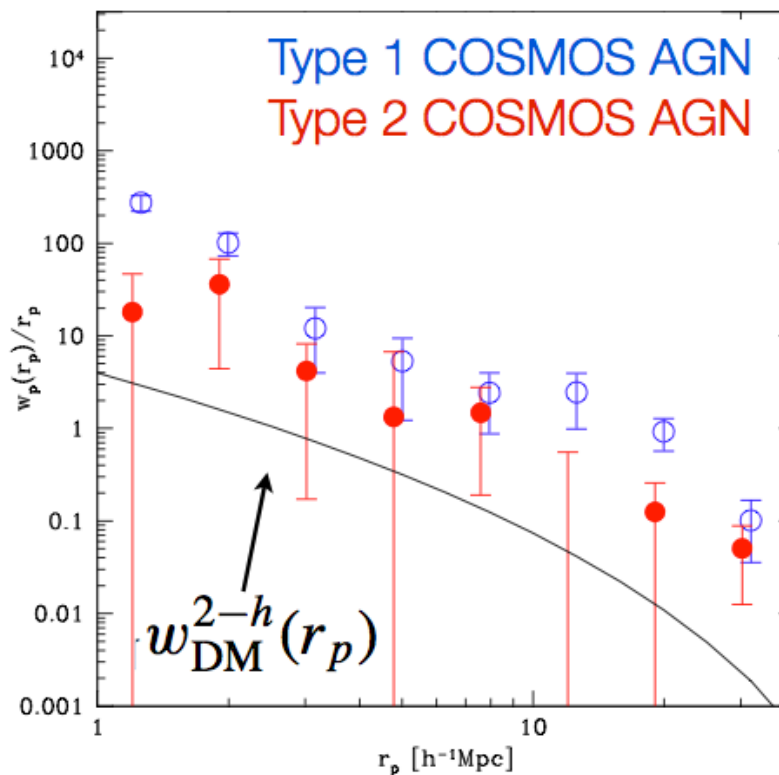
Maybe things are not quite so simple?

Clustering dependence on **obscuration**?



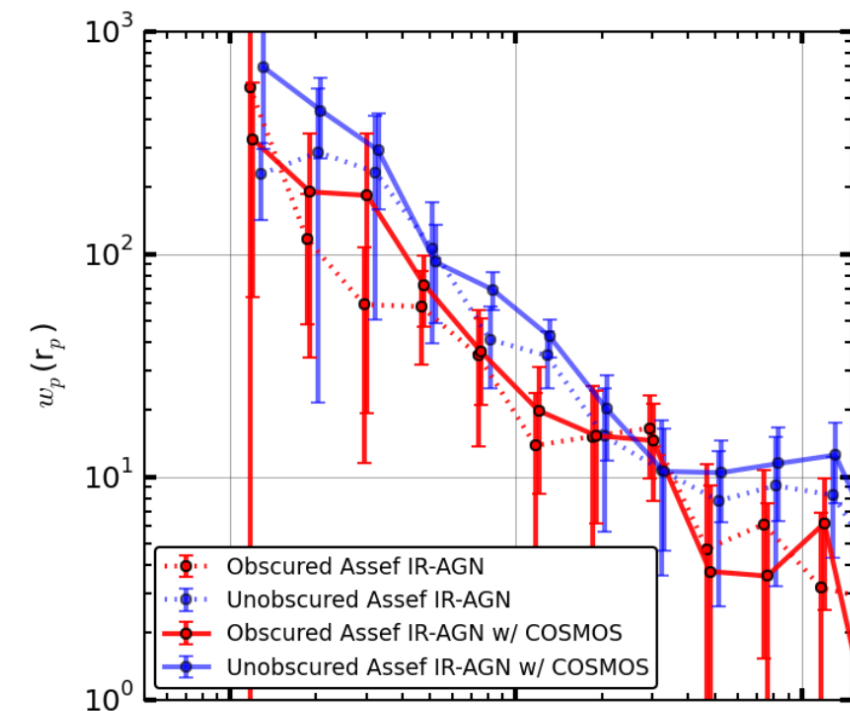
Obscured AGN
clustered more strongly

(Hickox et al. 2011, Donoso et al. 2014,
DiPompeo et al. 2014, 2015b, 2016)



Unobscured AGN
clustered more
strongly

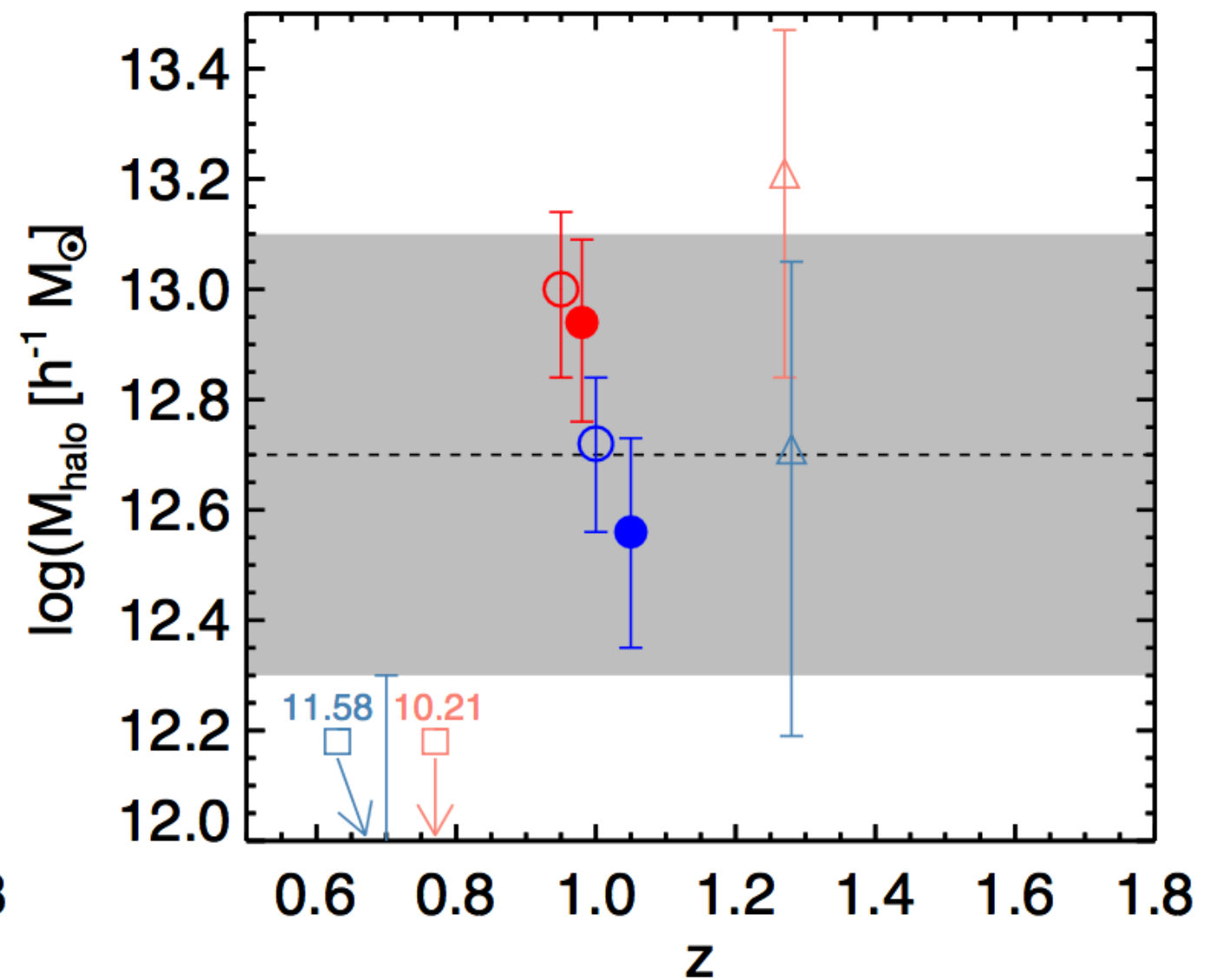
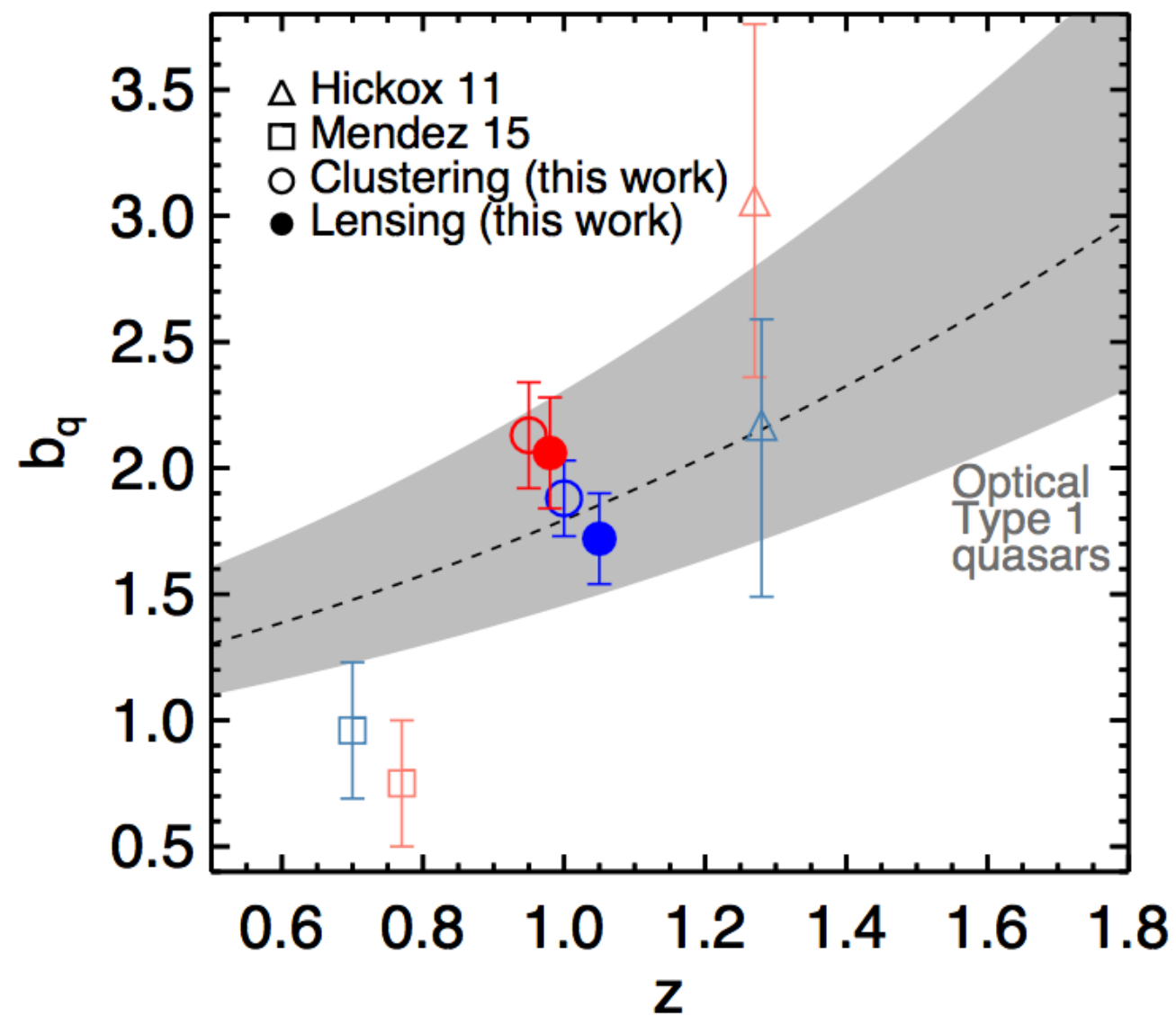
(Allevato et al. 2014)



No significant
difference

(Mendez et al. 2015)

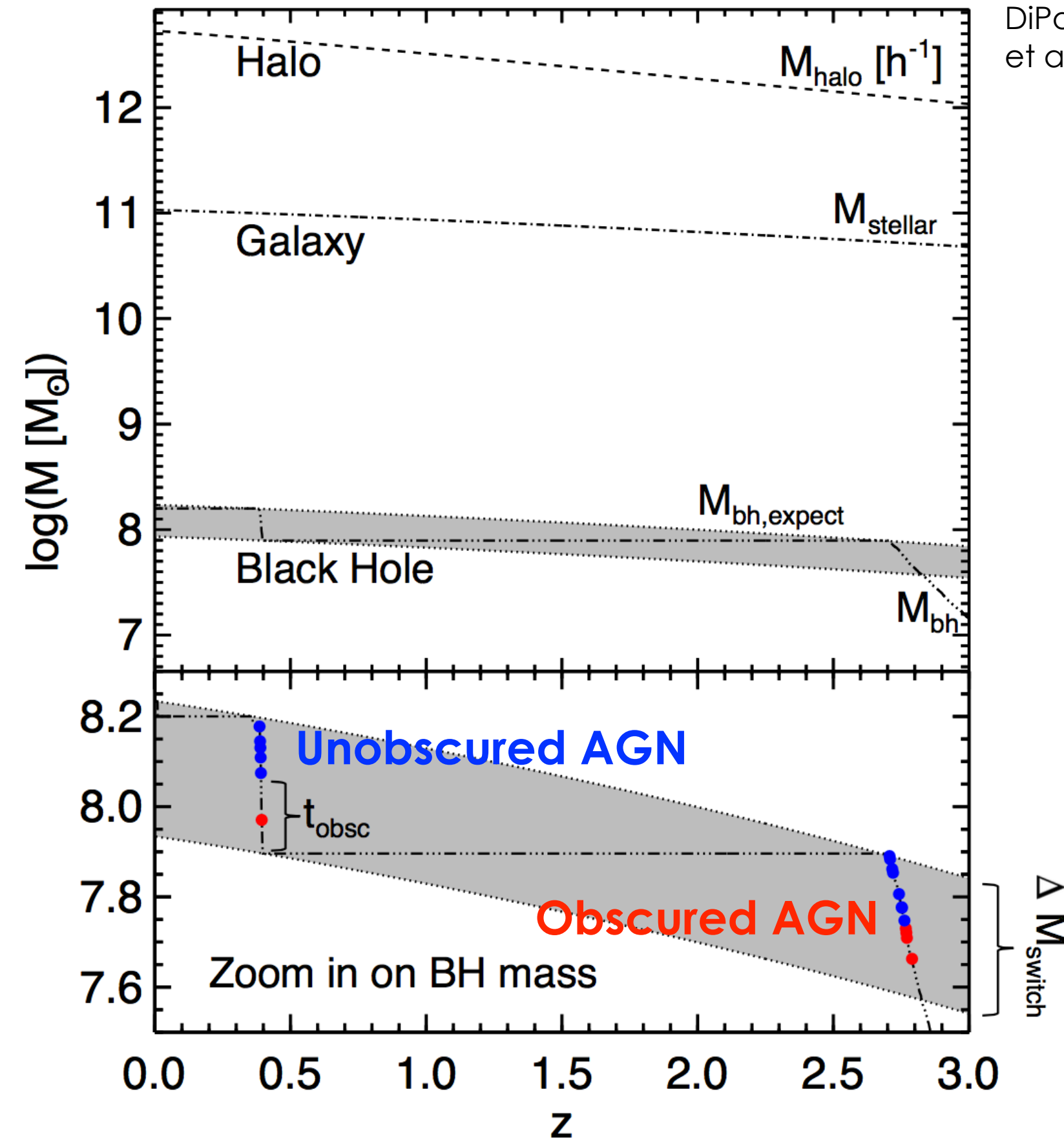
Luminous IR-selected obscured quasars appear to have on average **stronger clustering** and thus **higher halo masses** and **longer lifetimes**



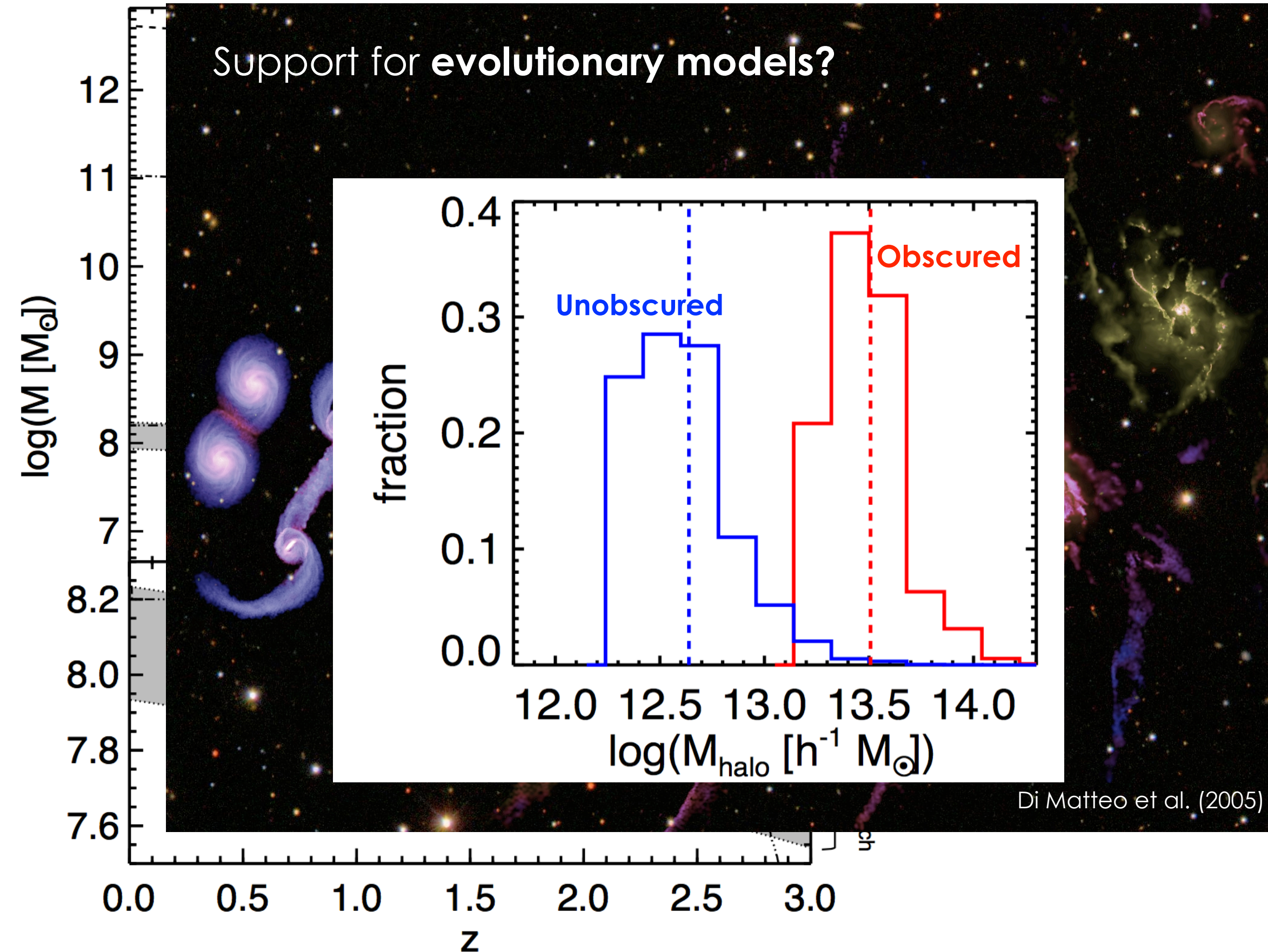
DiPompeo et al. (2015b)

A simple toy model for **obscured AGN clustering**

DiPompeo, Hickox
et al. (in prep)

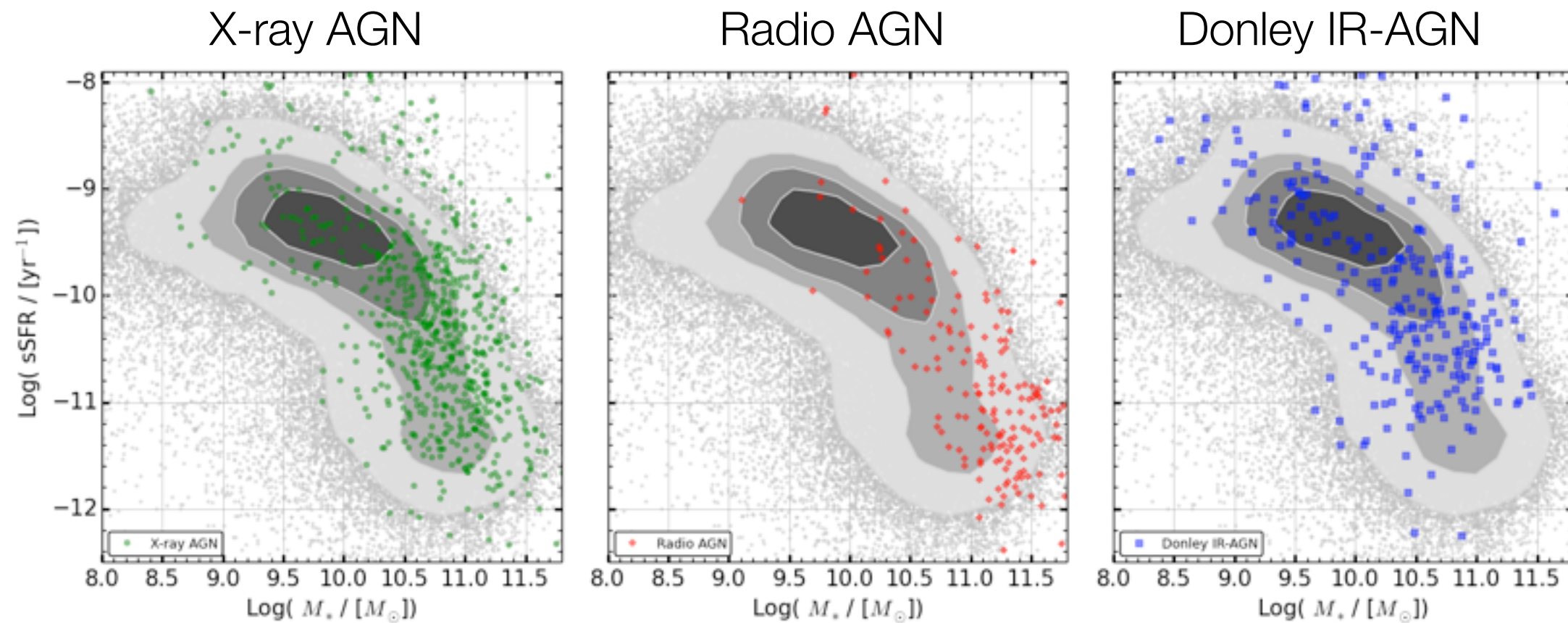


A simple toy model for **obscured AGN clustering**

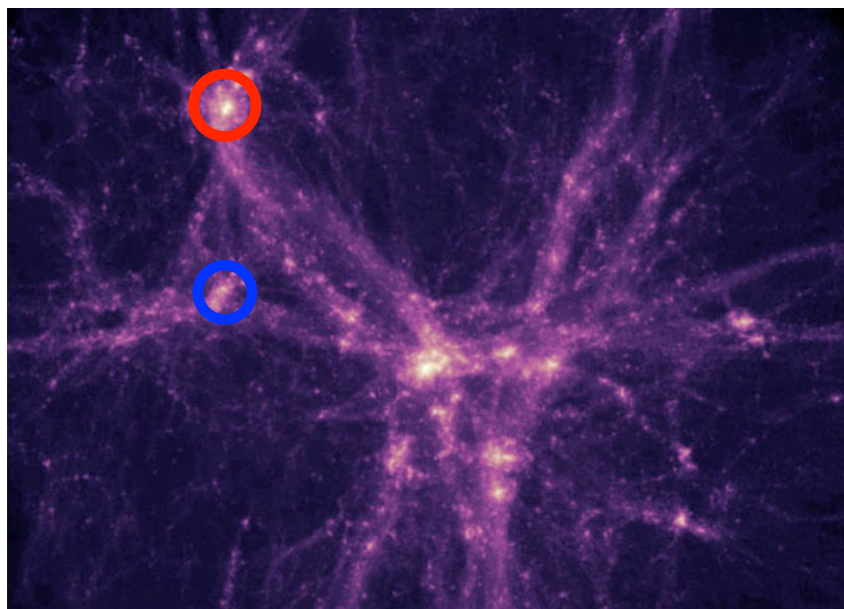


The future:

Understand **selection effects!**



Mendez et al. (2015)

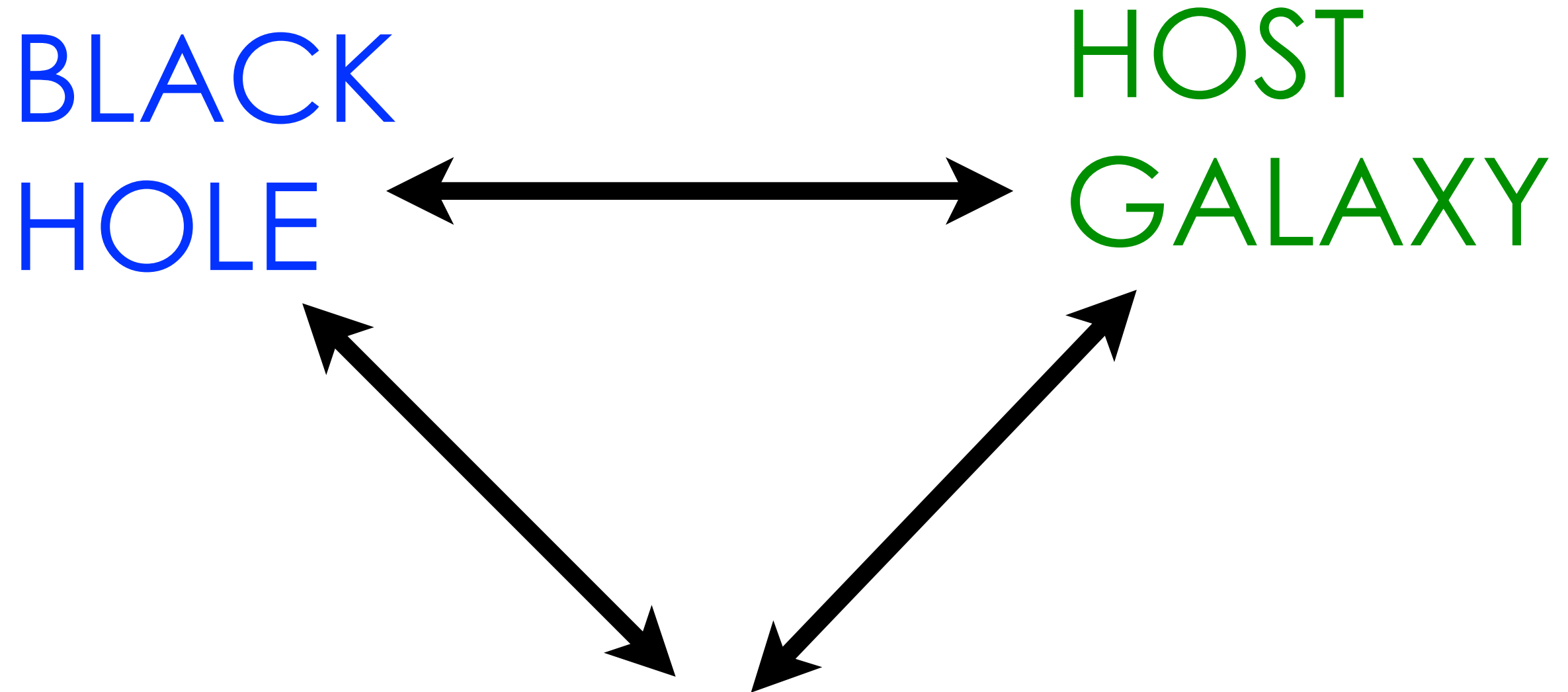


Populate galaxy formation model
with AGN and model the SEDs!



Ph.D. thesis project for M. Jones

Why study AGN clustering?



DARK MATTER HALO

Measure **halo mass** via clustering

Learn about **cosmological evolution**

The way forward

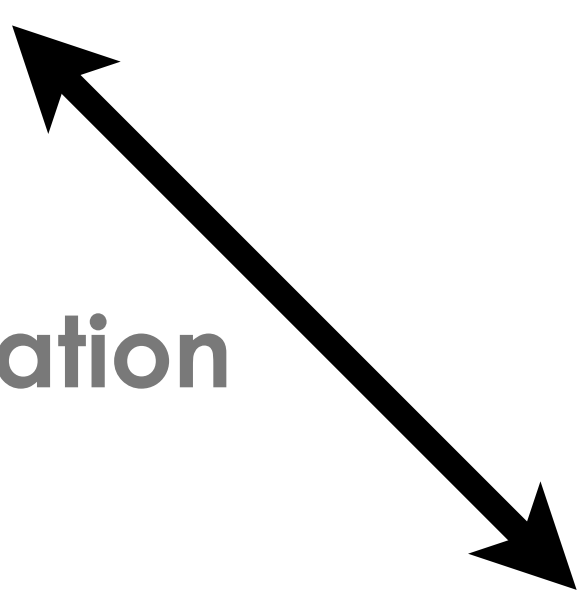
conditional
luminosity
function

Clustering

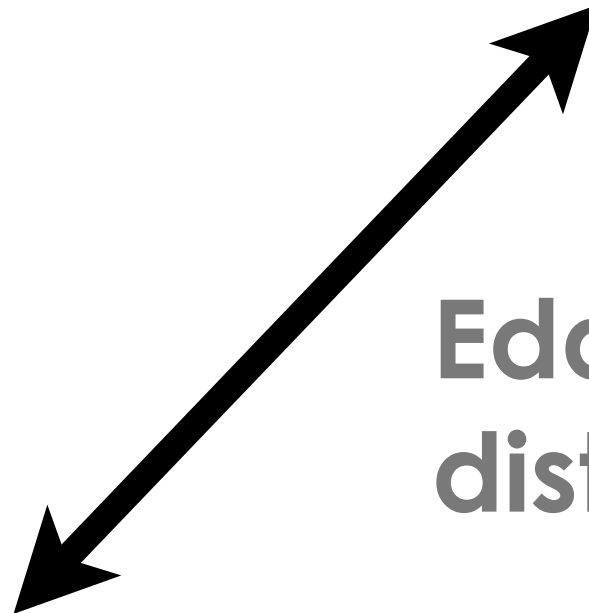
Luminosity
function



halo occupation
distribution

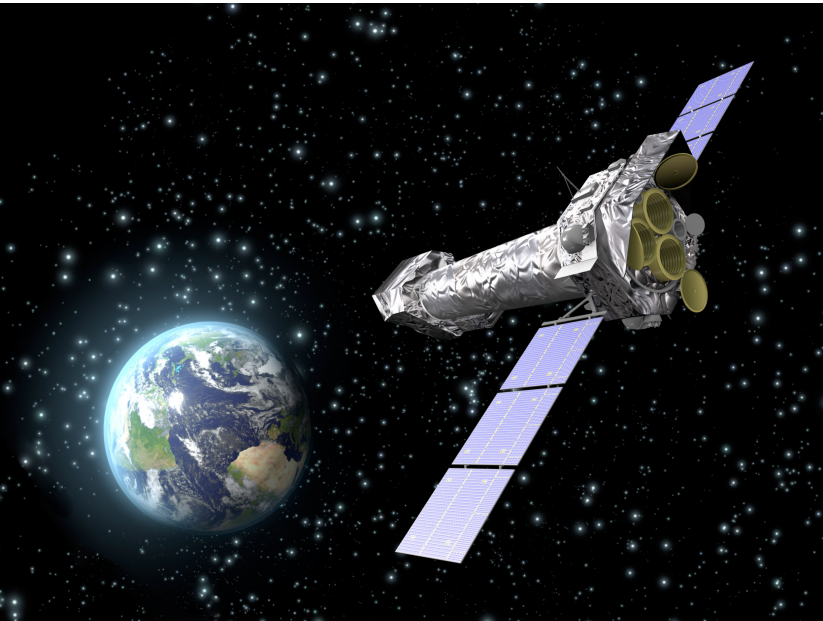


Eddington ratio
distribution



Host galaxy
properties

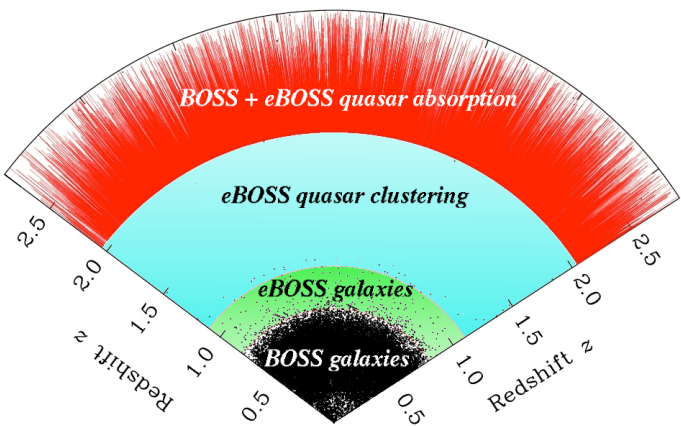
The future: New large-scale AGN surveys



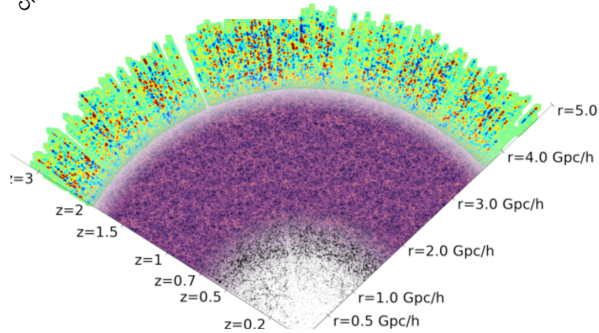
Large Chandra/XMM surveys



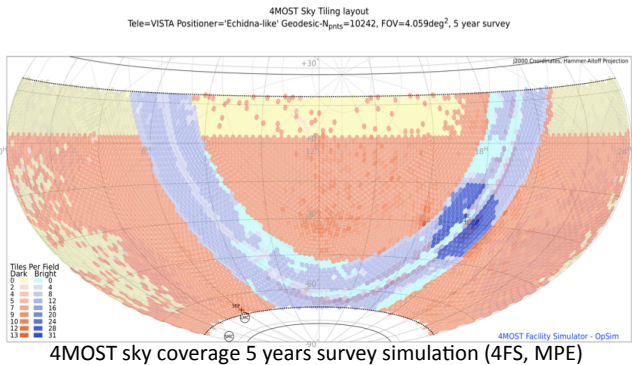
Athena



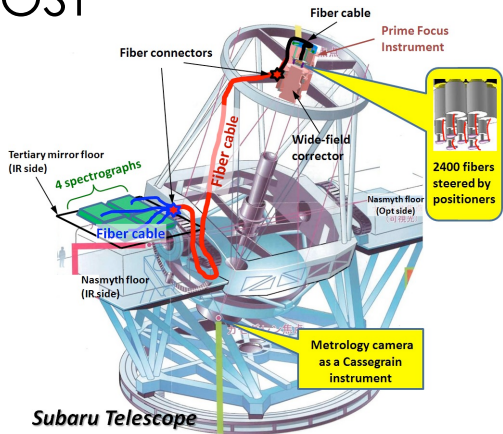
eBOSS



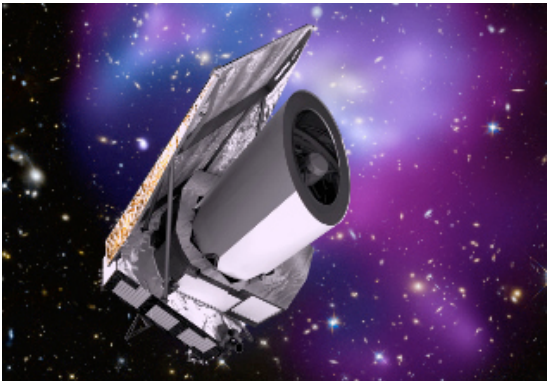
DESI



4MOST



Subaru PFS



Euclid



WFIRST

Ideas to take away

1. AGN clustering provides a **powerful probe of the cosmic evolution** of black holes
2. Growth of the most massive black holes as quasars occurs most prominently in **halos of $\sim 10^{12}$ solar masses**, where star formation is most efficient
3. To first order, AGN activity appears to be **stochastic** and clustering simply follows the scaling relations of the host galaxies, however there are some interesting complications (for example with **obscuration**)
4. **New techniques** and **large surveys** will dramatically increase the power of AGN clustering studies — the **future is bright!**

Thanks to



Alfred P. Sloan
FOUNDATION



Dartmouth