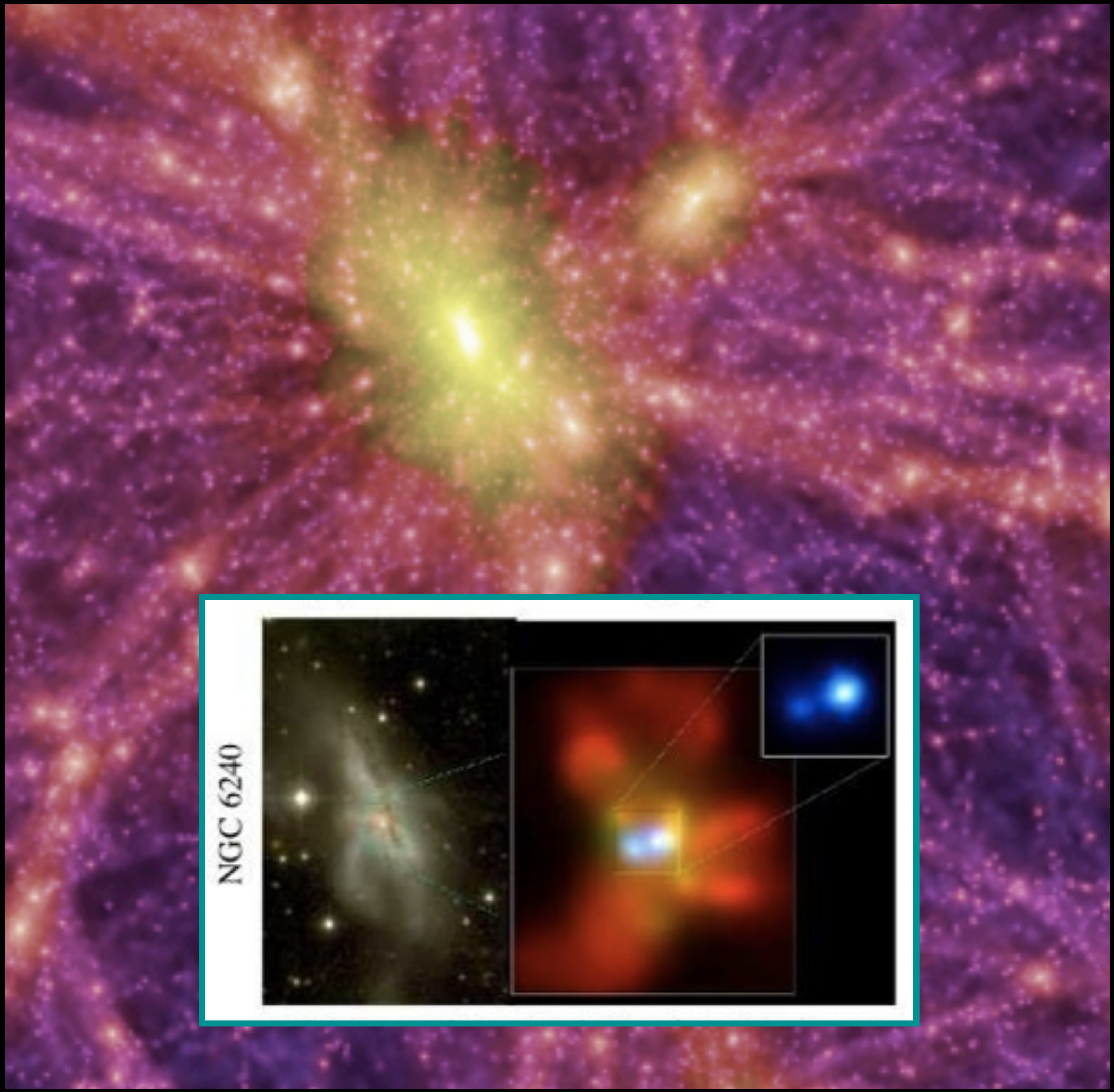
The Zoo of AGNs and a coherent picture of AGN clustering (part two)

Ryan C. Hickox

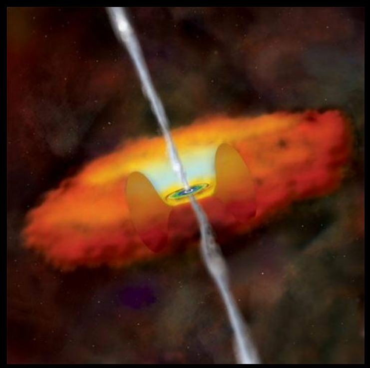
Dartmouth

Clustering Measurements of Active Galactic Nuclei
ESO, Garching
14 July 2014

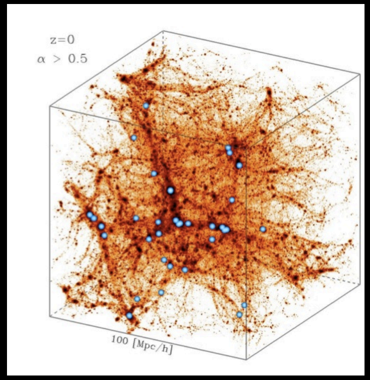


English Garden, Munich, ~11:30pm, 13.07.14

Outline



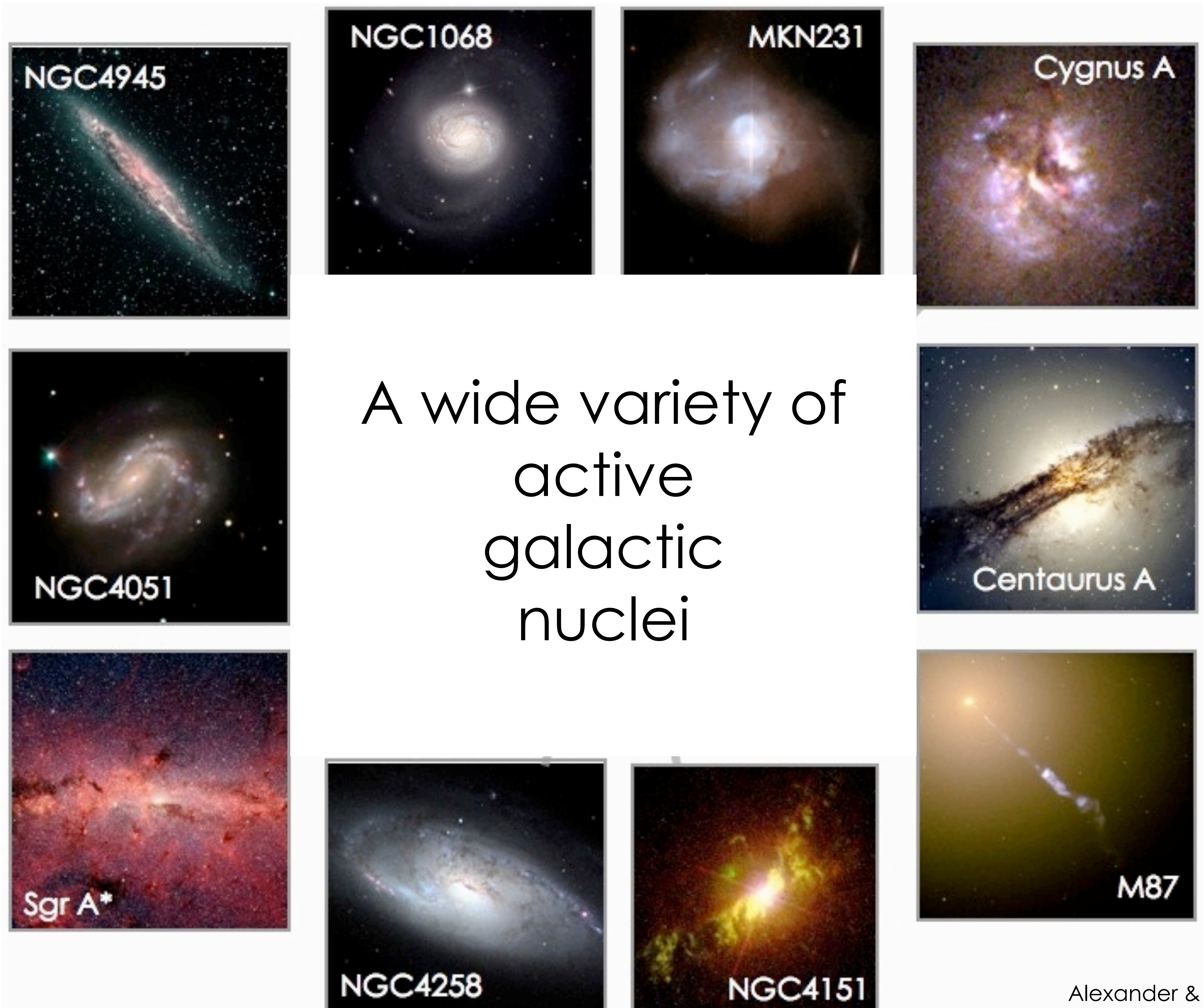
1. **The Zoo of AGNs:** Multiwavelength AGN selection



2. **The big picture:** Halo masses and evolution of different classes of AGN

3. **A mystery:** Clustering of obscured and unobscured quasars

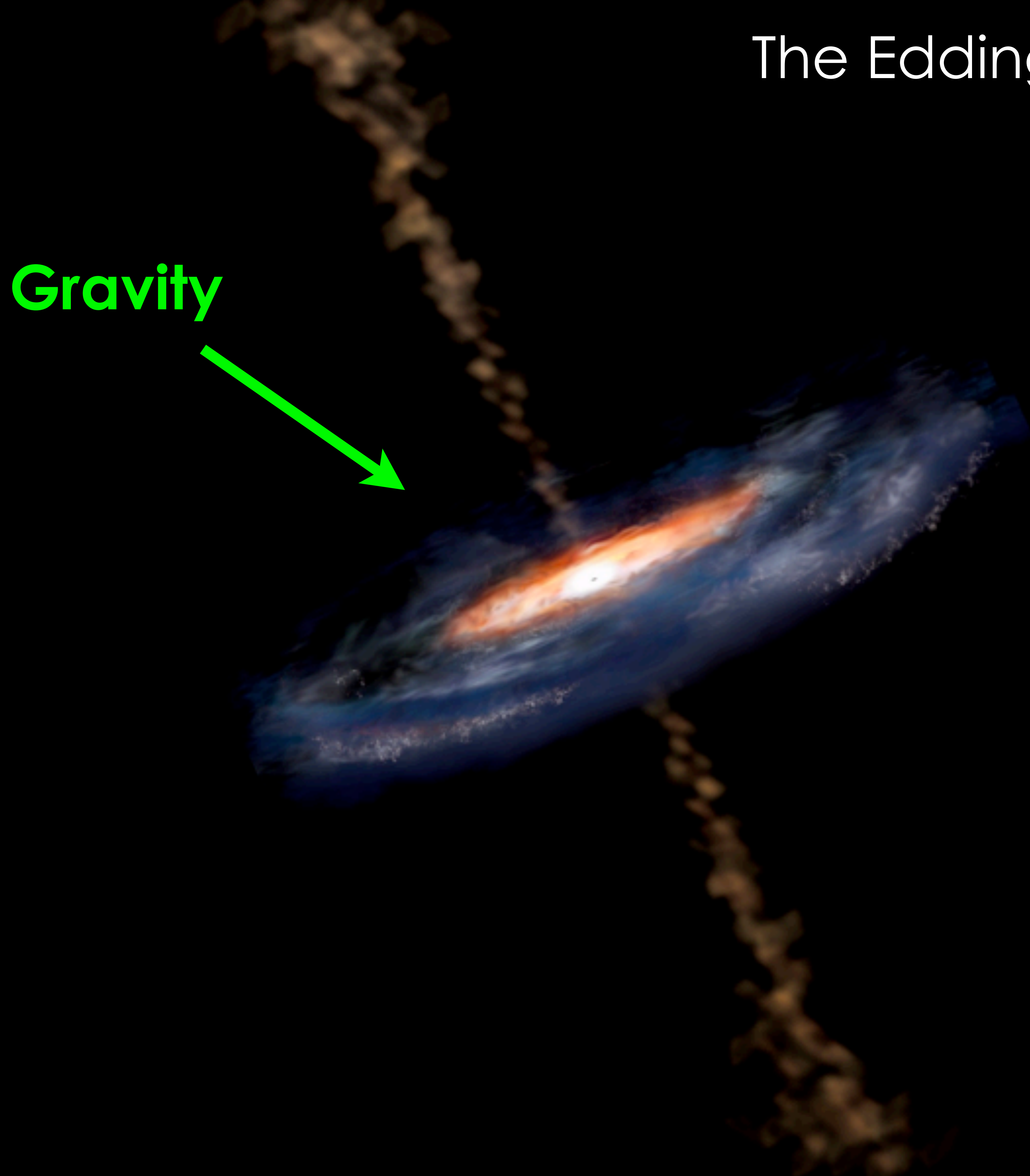
1. The Zoo of AGNs: Multiwavelength AGN selection



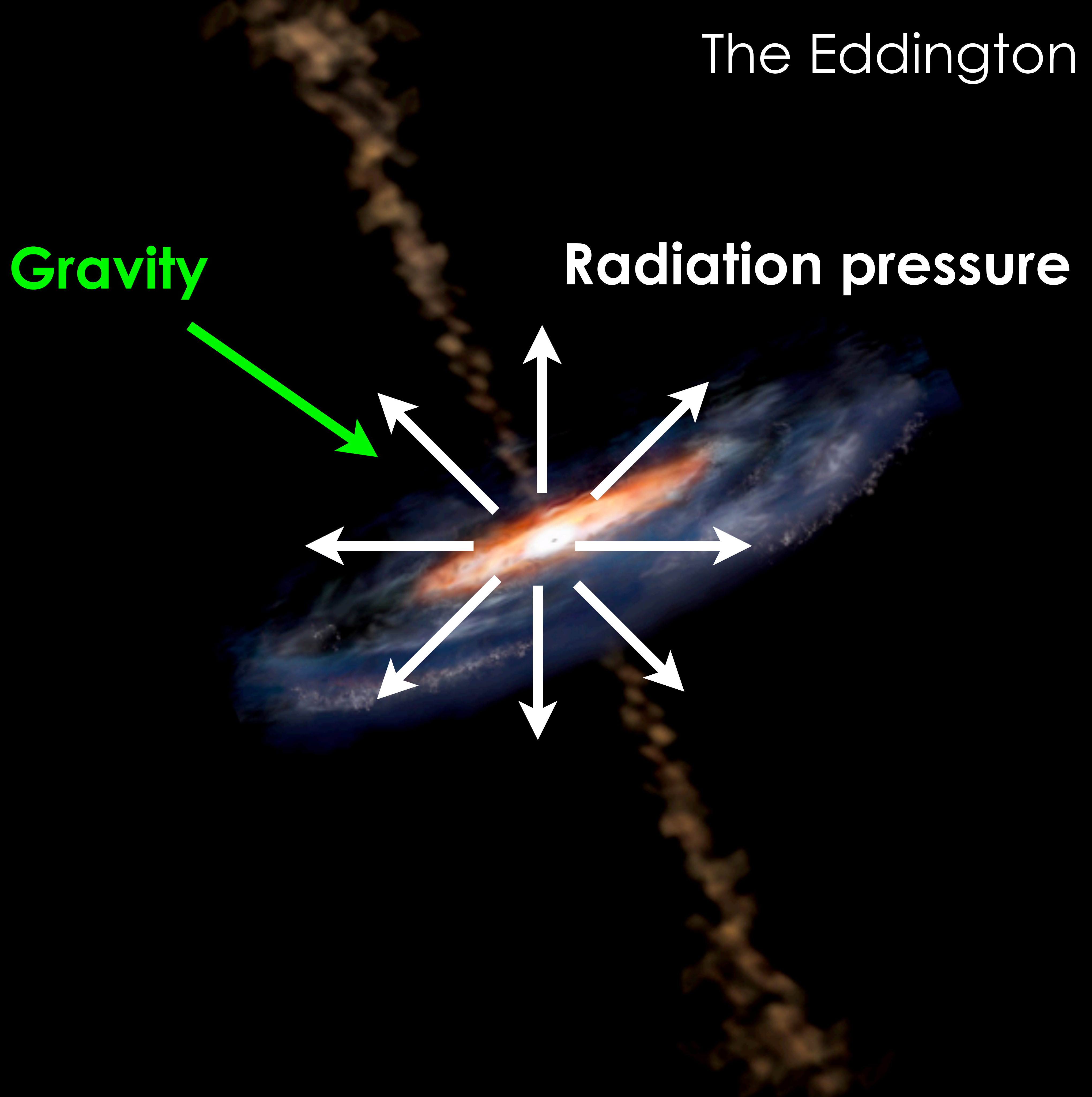
A wide variety of active galactic nuclei

Alexander & Hickox (2012)
New Astronomy Reviews

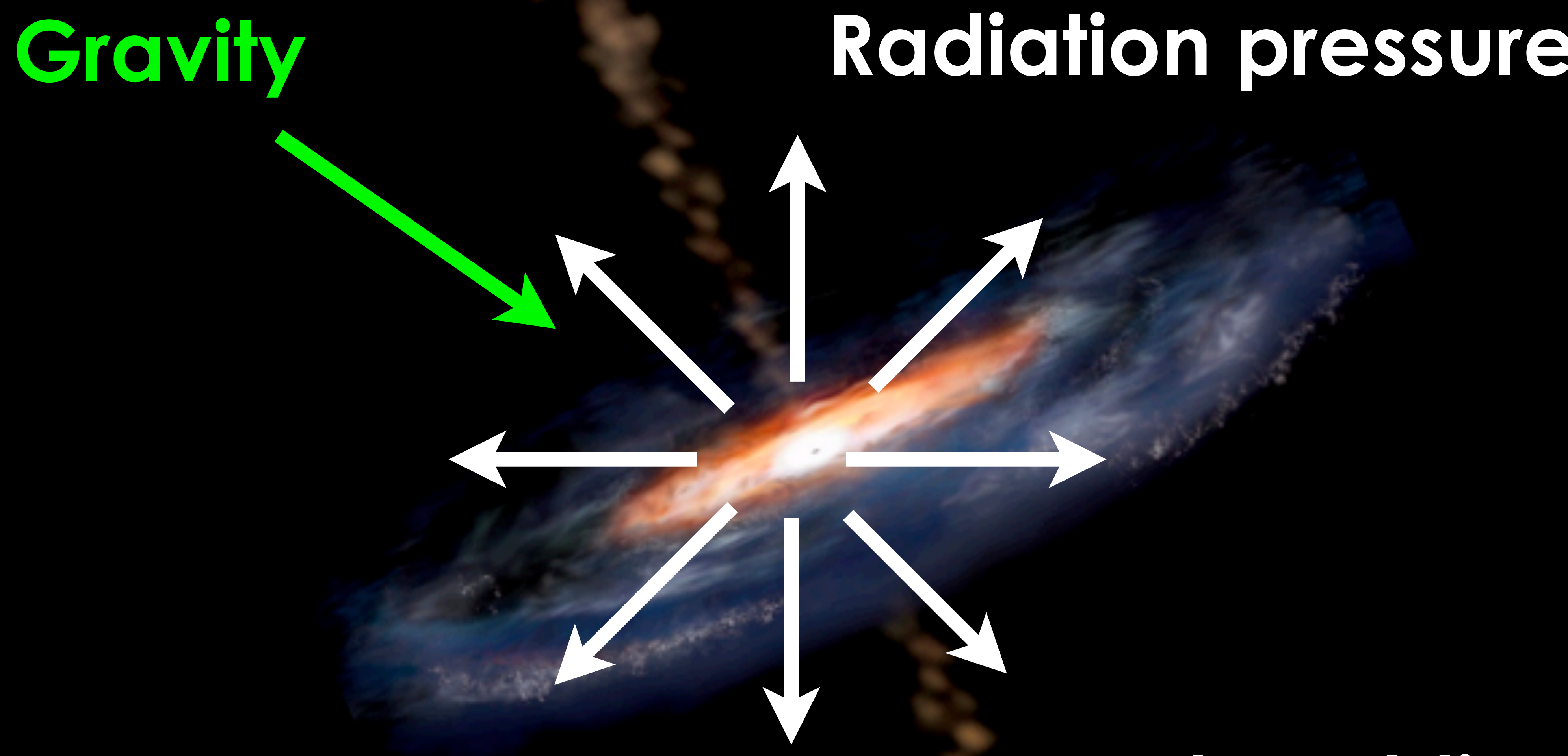
The Eddington limit



The Eddington limit



The Eddington limit

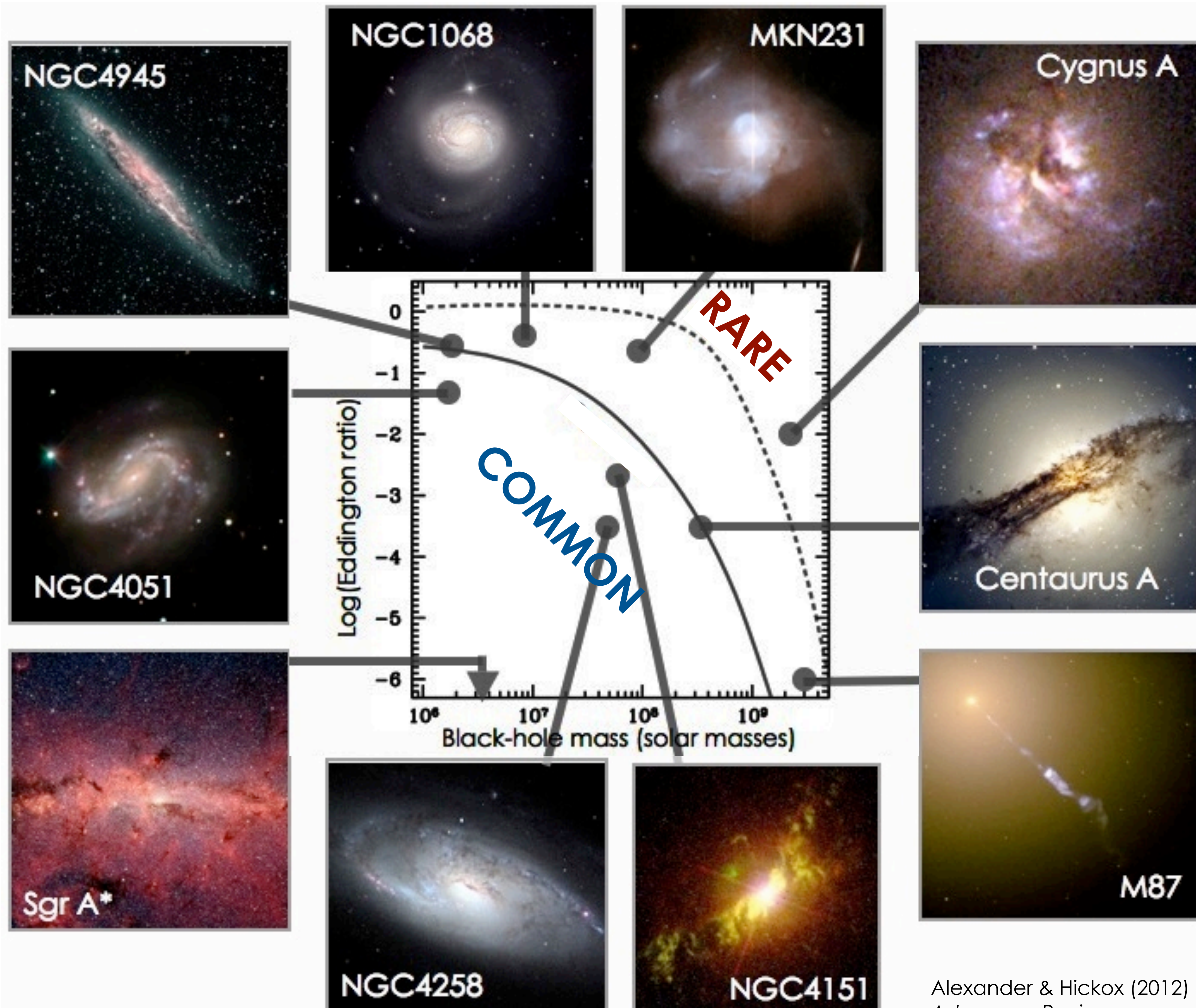


The Eddington ratio

$$\lambda = L/L_{Edd}$$

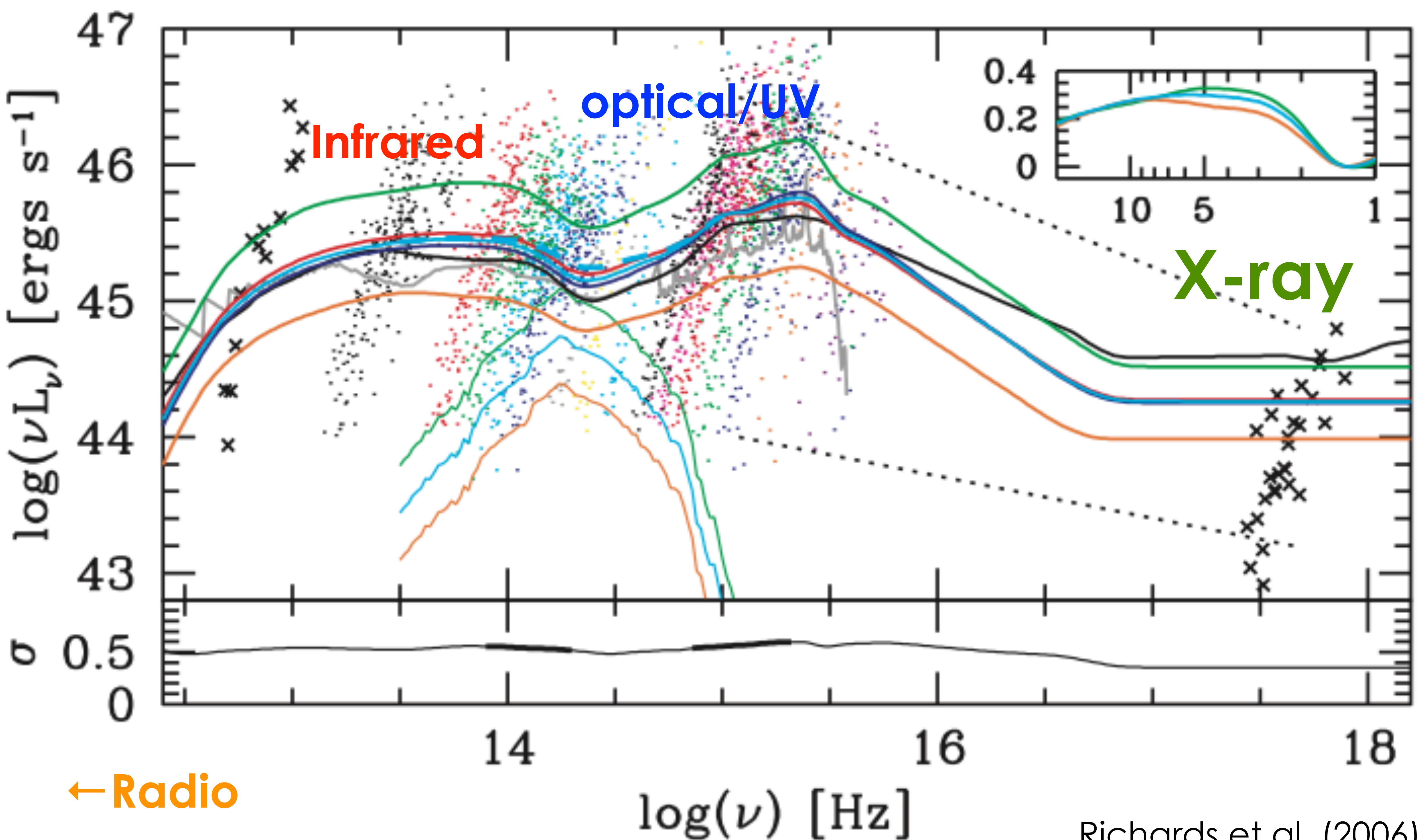
$$L_{Edd} \approx 10^{38} \text{ erg s}^{-1} M_{\mathrm{BH}}$$

Larger black holes can grow more rapidly



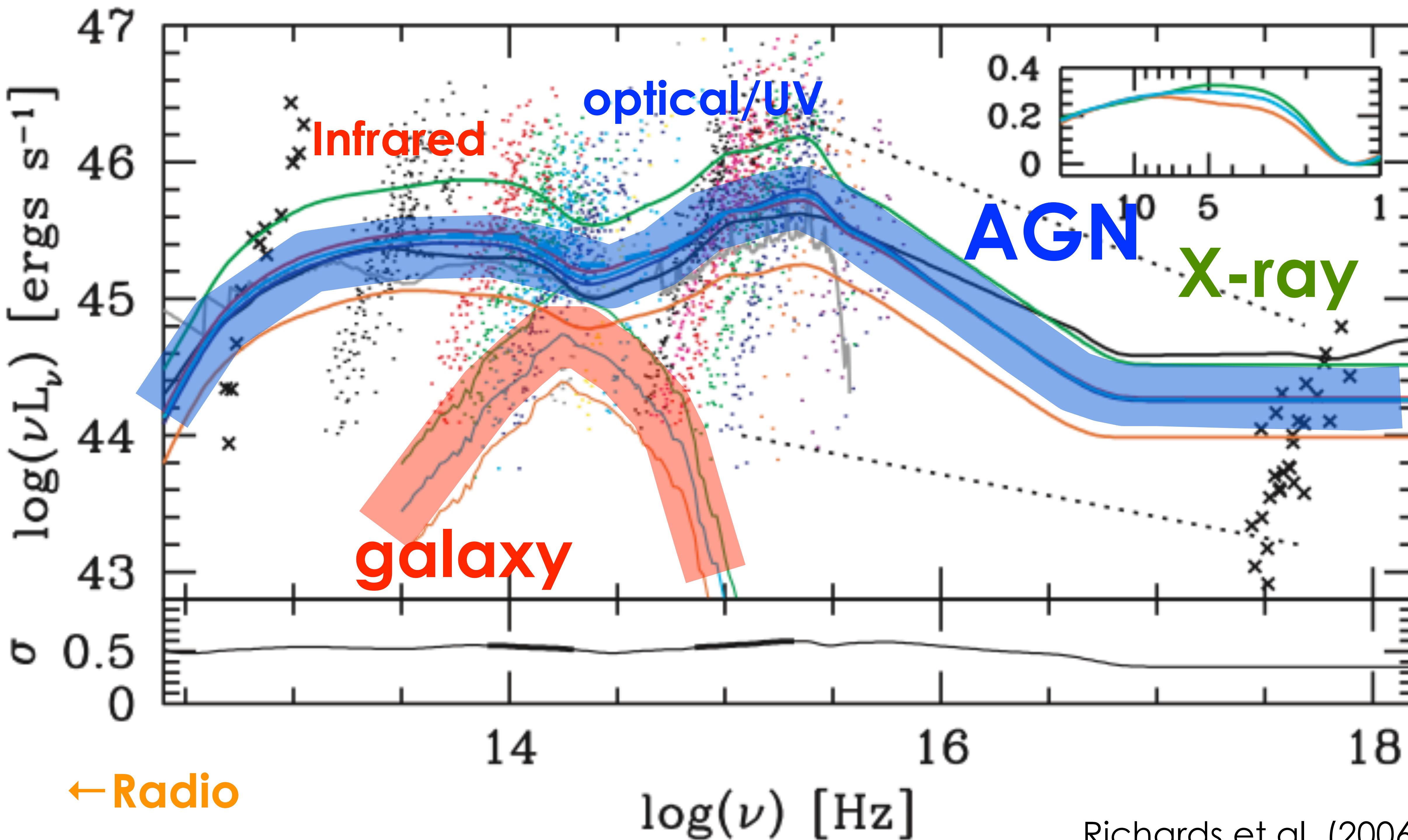
Alexander & Hickox (2012) *New Astronomy Reviews*
Model curves courtesy A. Merloni

How do we detect AGN?



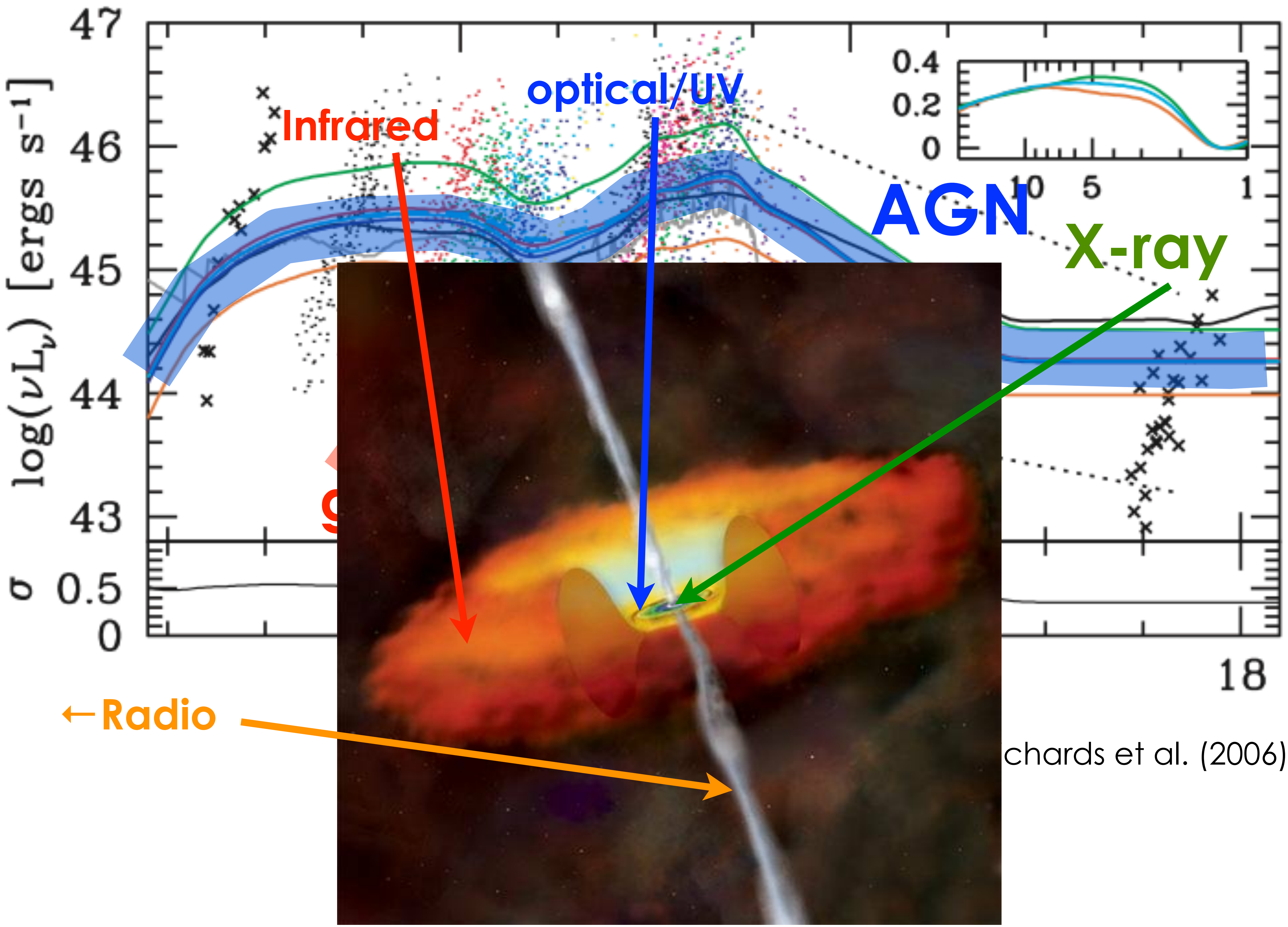
Richards et al. (2006)

How do we detect AGN?

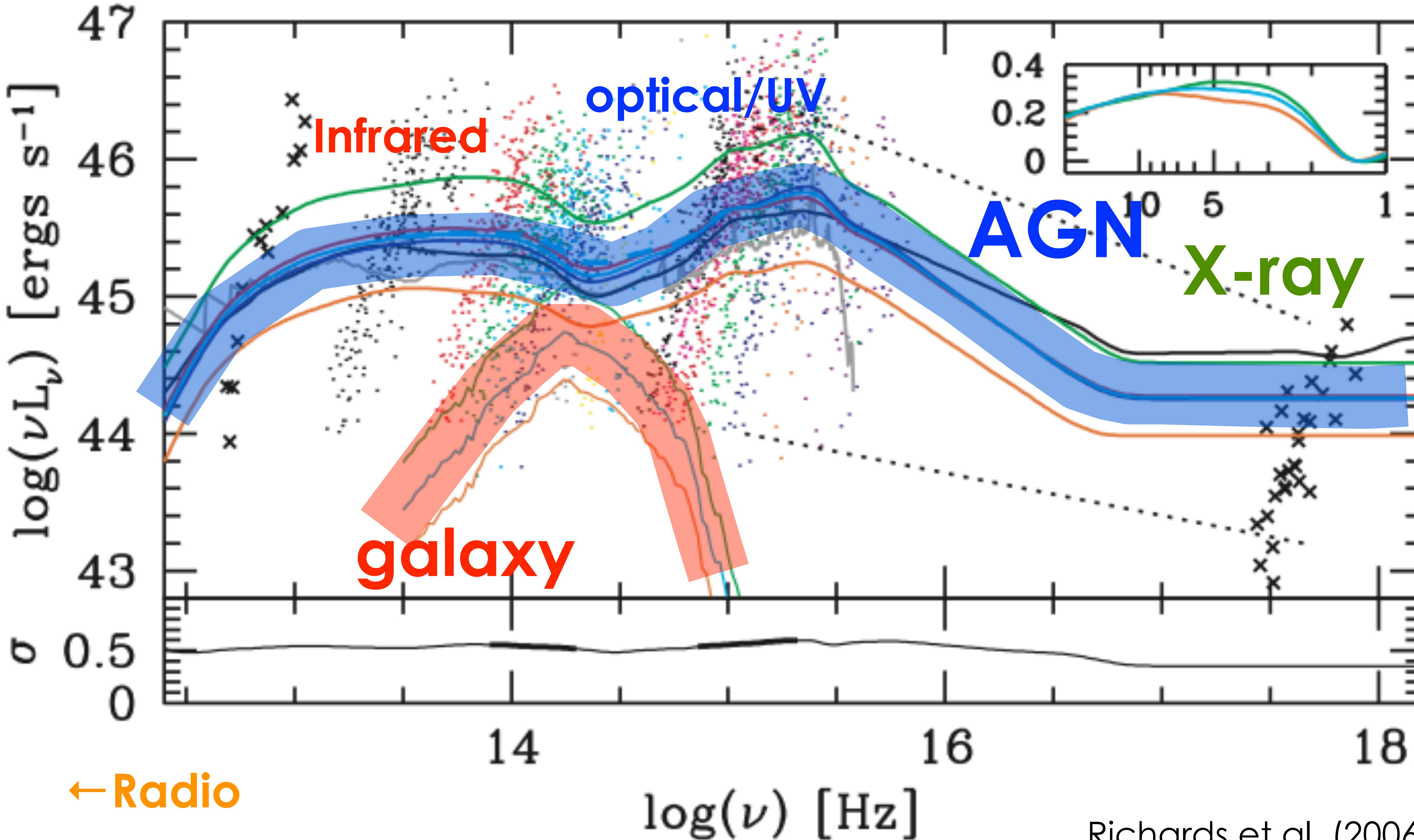


Richards et al. (2006)

How do we detect AGN?

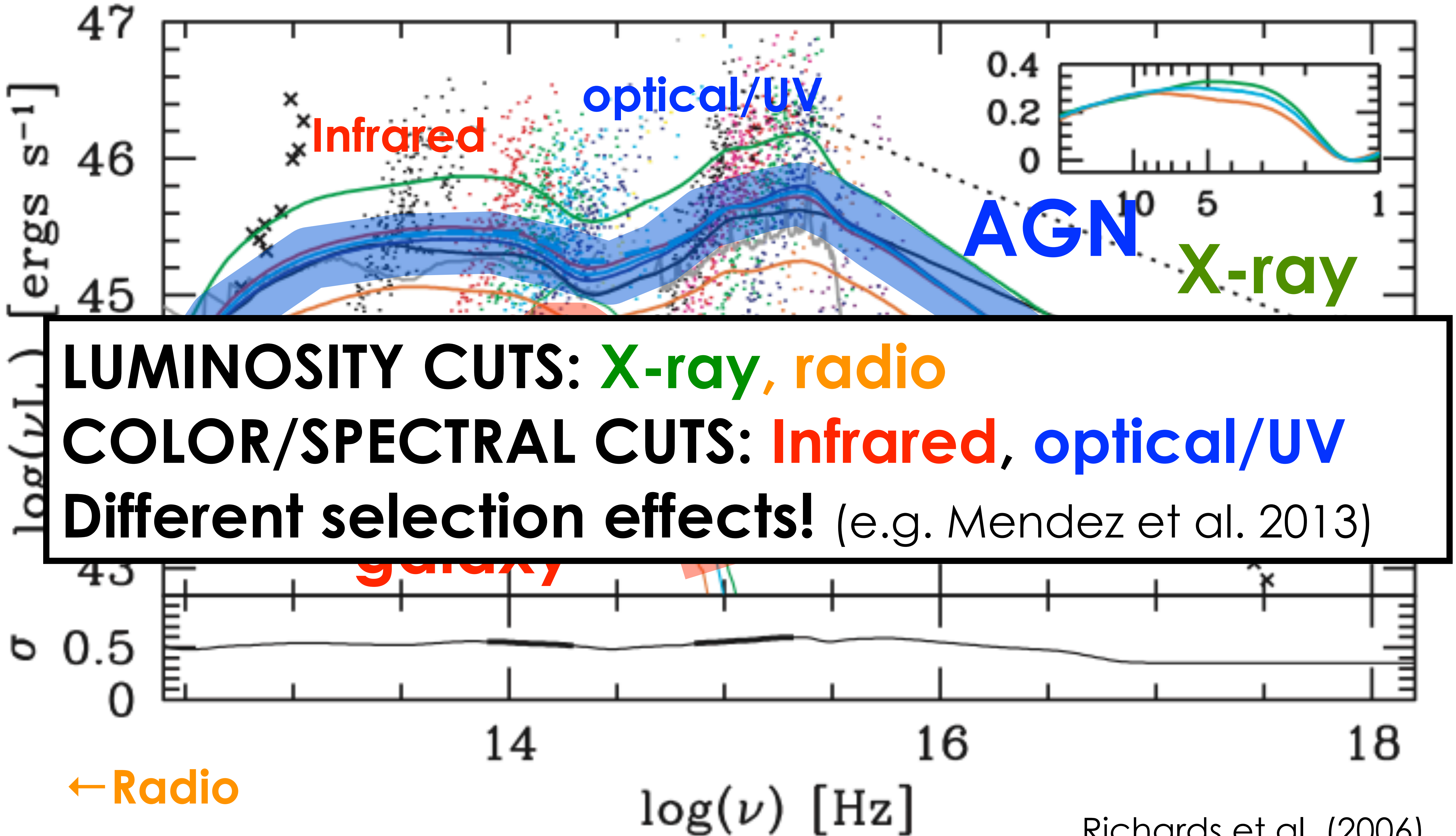


How do we detect AGN?



Richards et al. (2006)

How do we detect AGN?



LUMINOSITY CUTS: X-ray, radio

COLOR/SPECTRAL CUTS: Infrared, optical/UV

Different selection effects! (e.g. Mendez et al. 2013)

Richards et al. (2006)

Accretion state **changes with Eddington ratio**

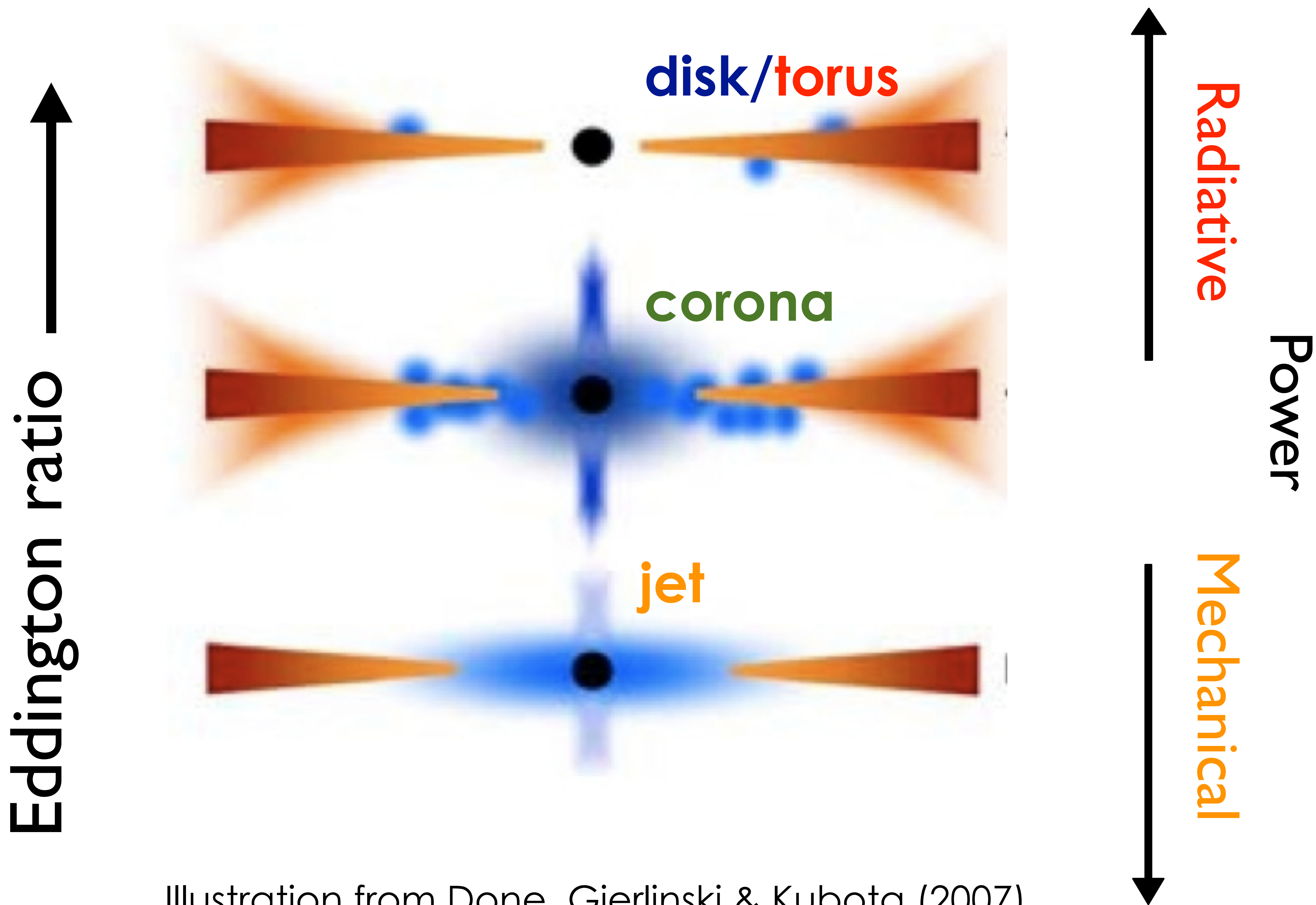


Illustration from Done, Gierlinski & Kubota (2007)
see also Churazov et al. (2005); Hopkins, et al. (2009)

Accretion state **changes with Eddington ratio**

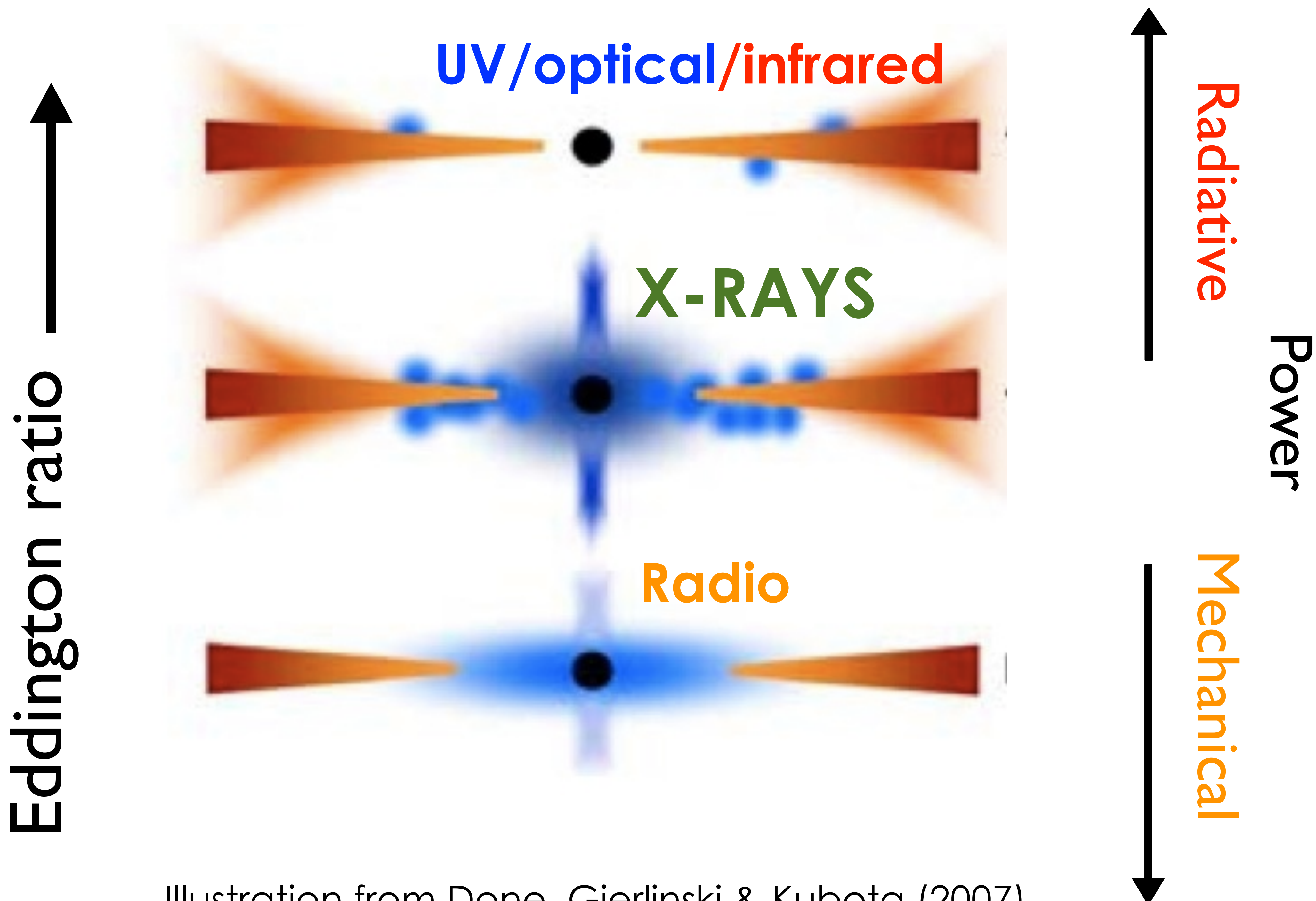
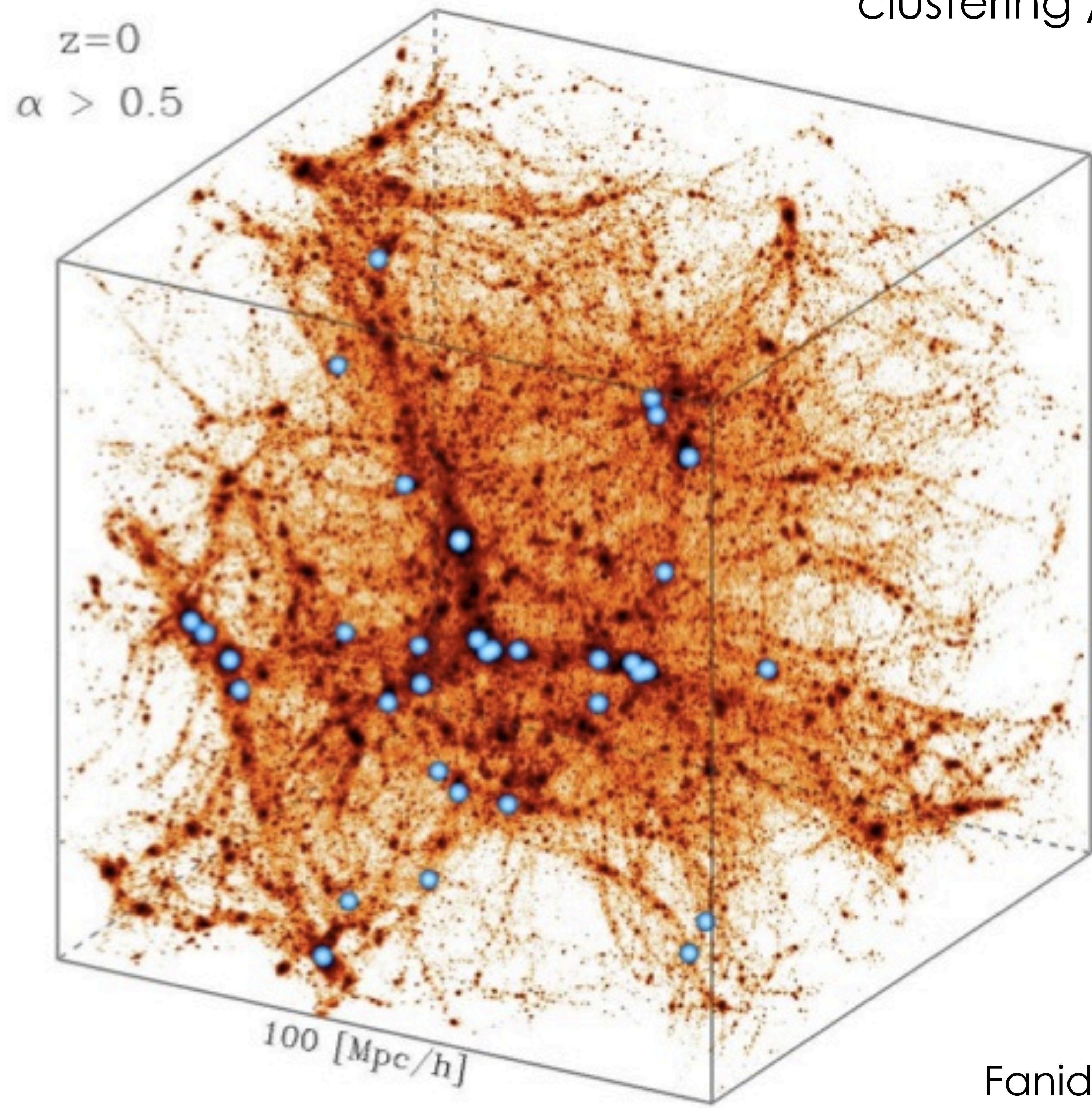


Illustration from Done, Gierlinski & Kubota (2007)

Also strongly affected by **host galaxy contamination and other selection effects:** Hopkins et al. (2009)

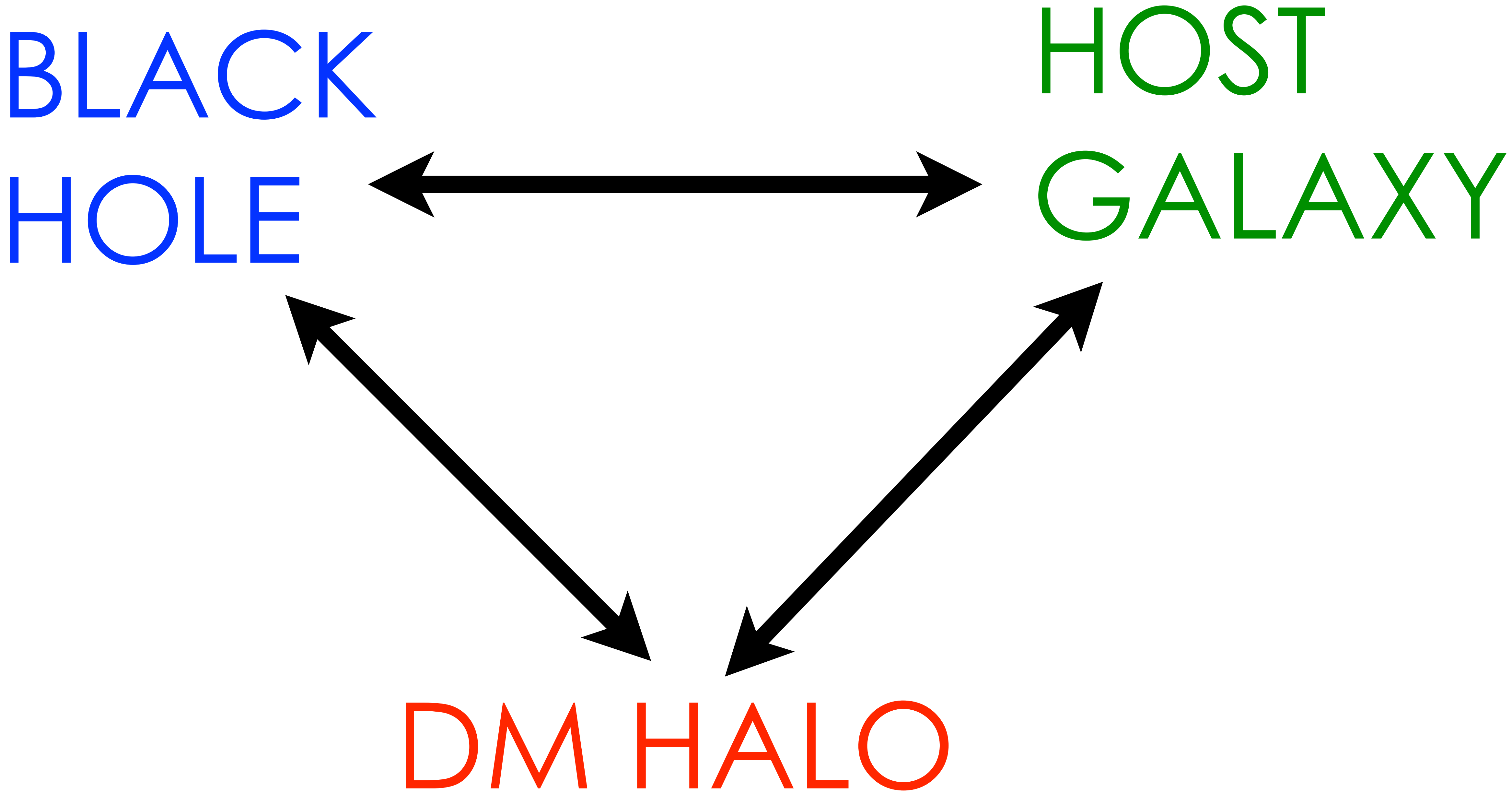
2. The big picture: Halo masses and evolution of different classes of AGN

Focus on l**arge-scale** clustering / linear bias

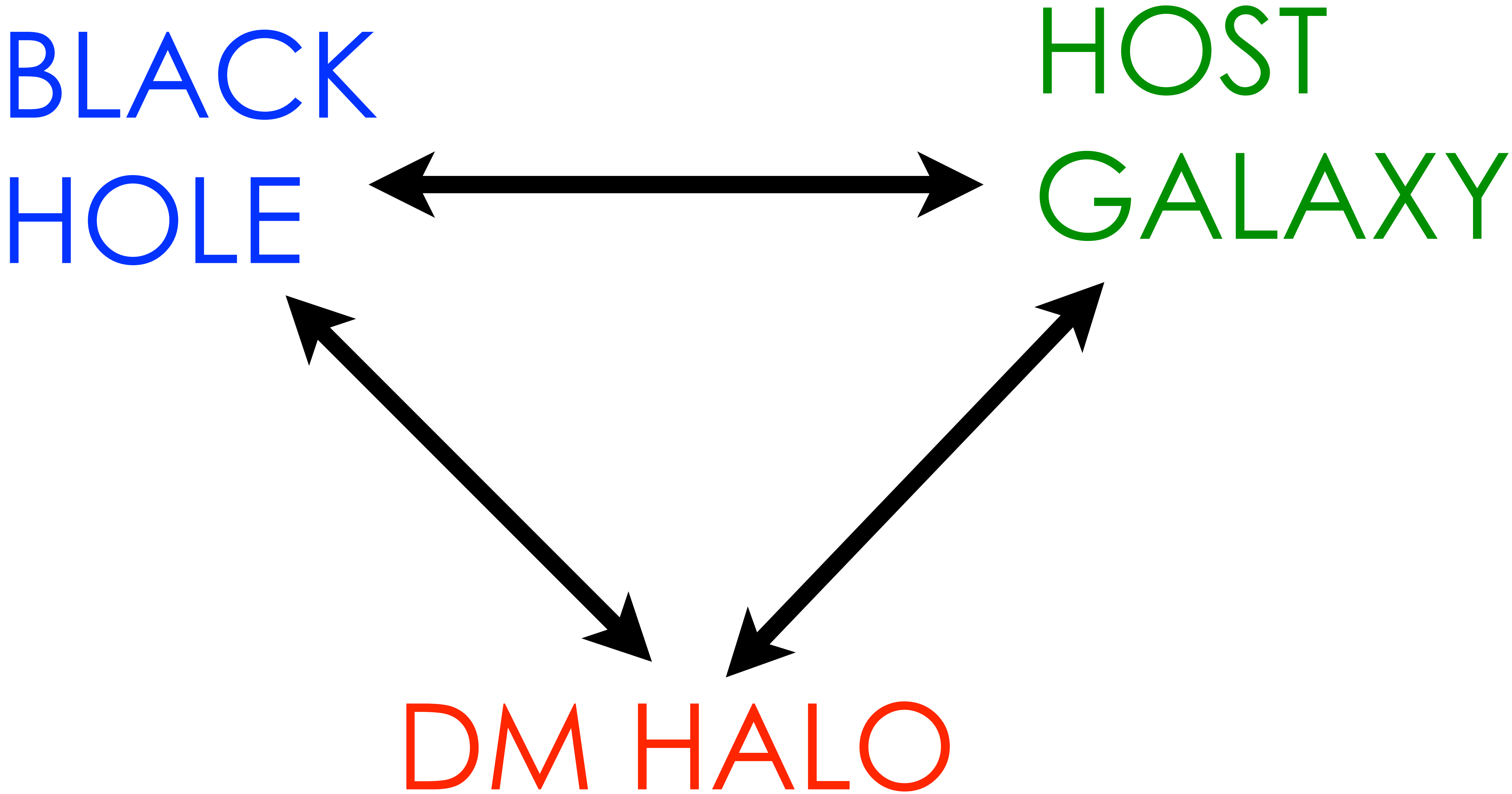


Fanidakis et al. (2010)

Why measure AGN clustering?



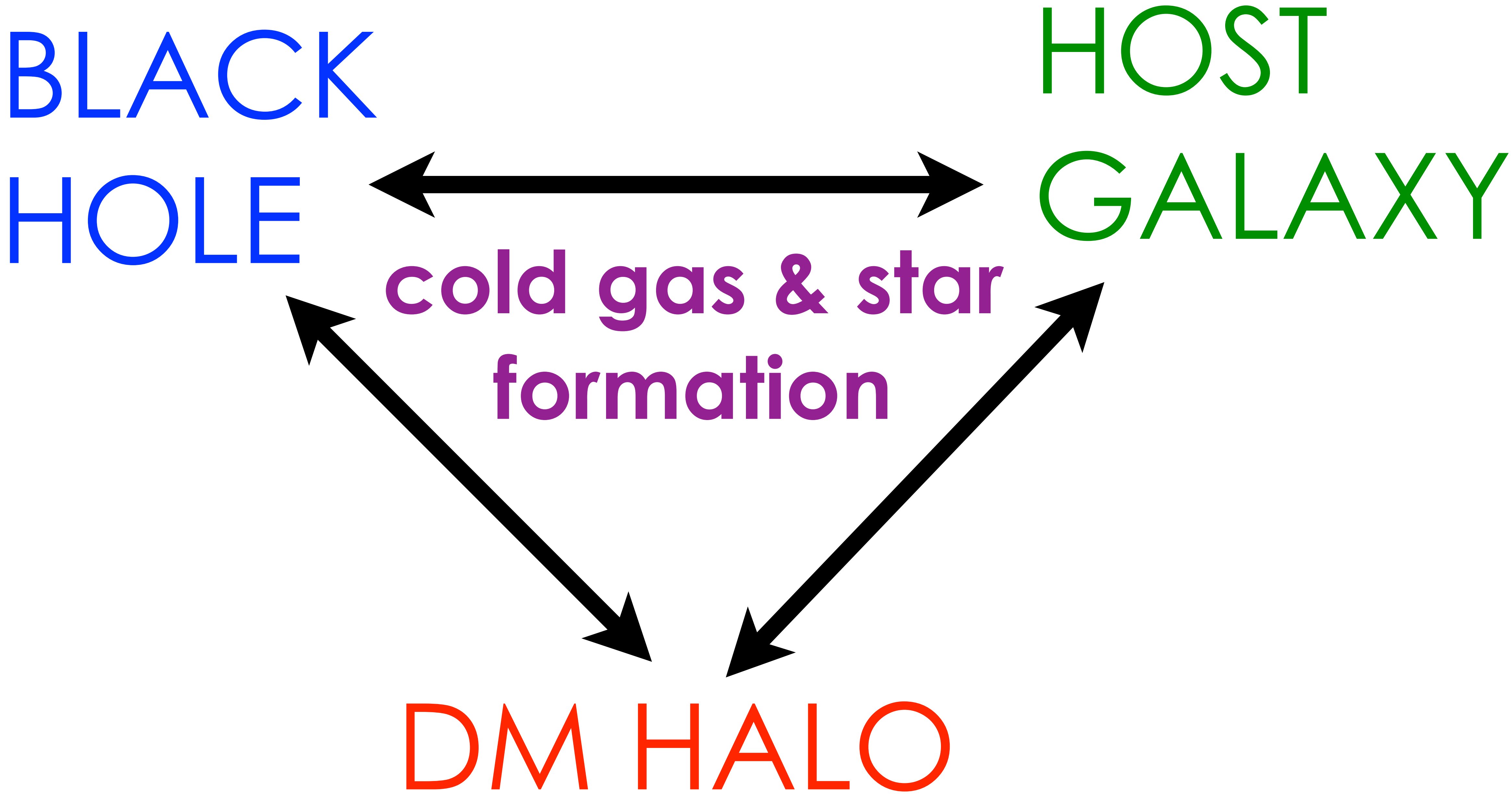
Why measure AGN clustering?



Measure **halo mass** via clustering

Learn about **cosmological evolution**

Why measure AGN clustering?



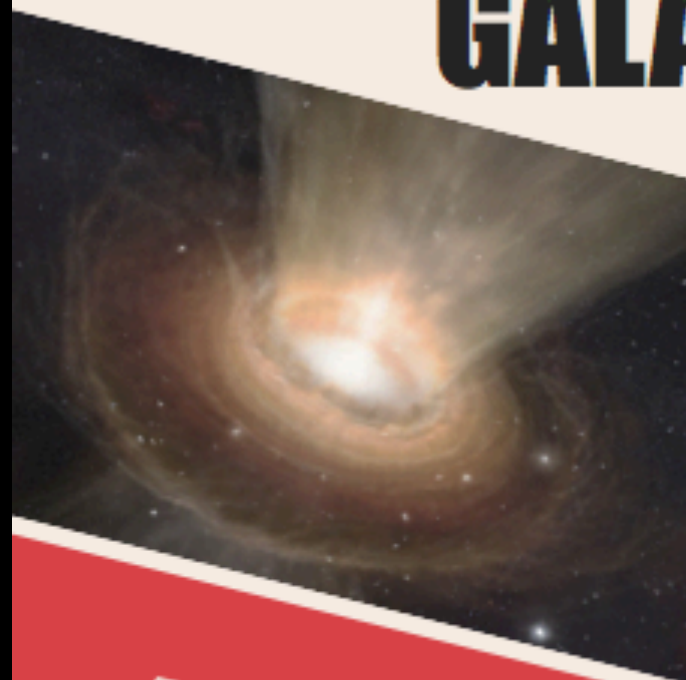
Measure **halo mass** via clustering

Learn about **cosmological evolution**

"THE GREATEST FIGHT IN THE HISTORY OF THE UNIVERSE"

DURHAM UNIVERSITY
Presents

THE FATE OF THE GAS IN GALAXIES



AGN VS. STAR FORMATION

28 JUL to 1 AUG 2014

Ringside seats limited to 70 people
Don't miss it!

INTERNATIONAL WORKSHOP DURHAM UK

SCIENTIFIC ORGANISING COMMITTEE

D Alexander, R Hickox, T Theuns, A Alonso-Herrero, F Bournaud, R Davies, R Morganti, J Mullaney, R Somerville

LOCAL ORGANISING COMMITTEE

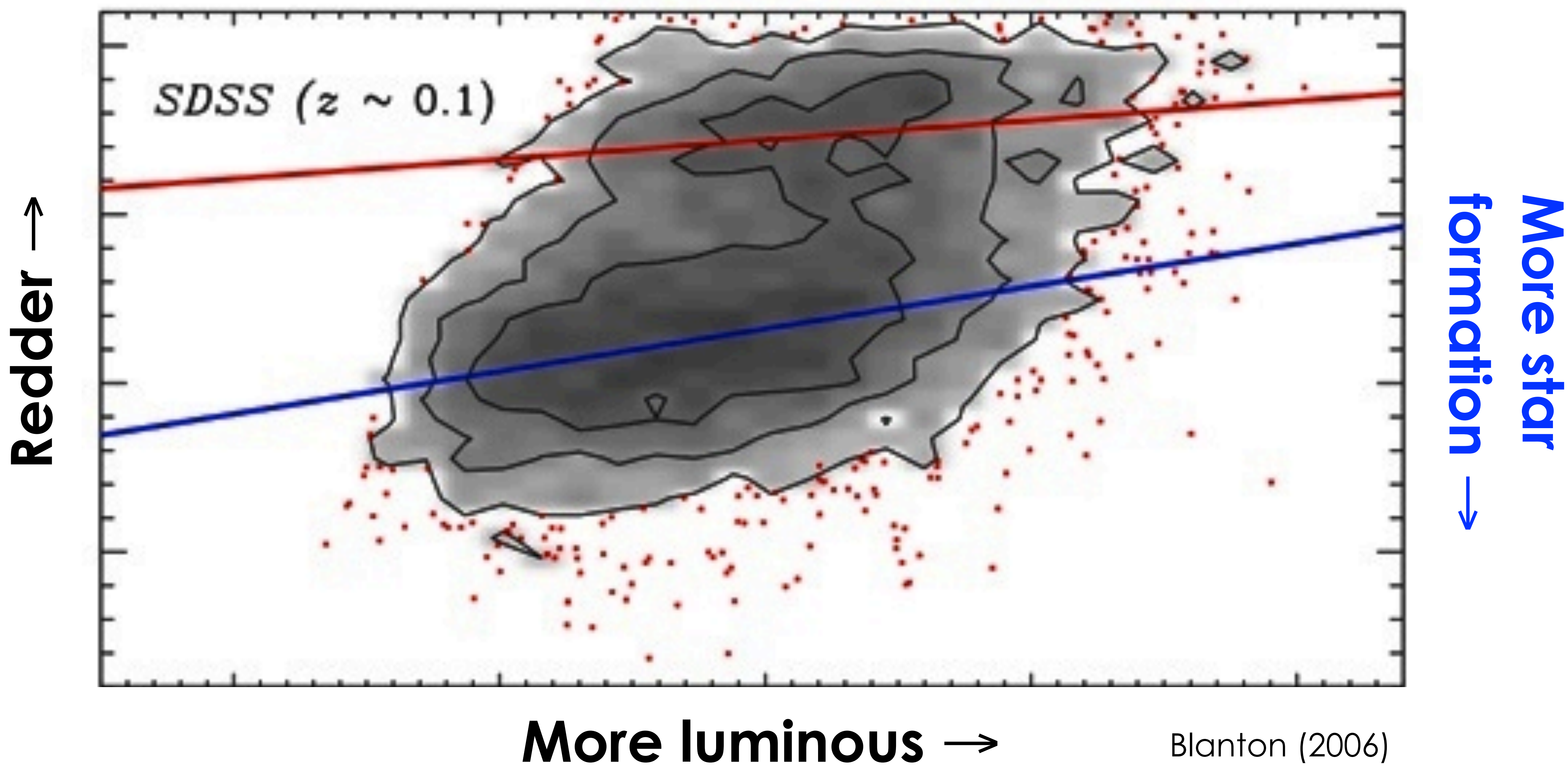
J Aird, A Annuar, R Bower, A Del Moro, P Gandhi, C Harrison, G Lansbury, E Rovilos, F Stanley, M Swinbank

Durham University · Dartmouth

http://astro.dur.ac.uk/~erovilos/AGNvsSFConference/agnsf.html

Image credit: ESO/M. Kornmesser; NASA/JPL-Caltech/STScI/Institut d'Astrophysique Spatiale

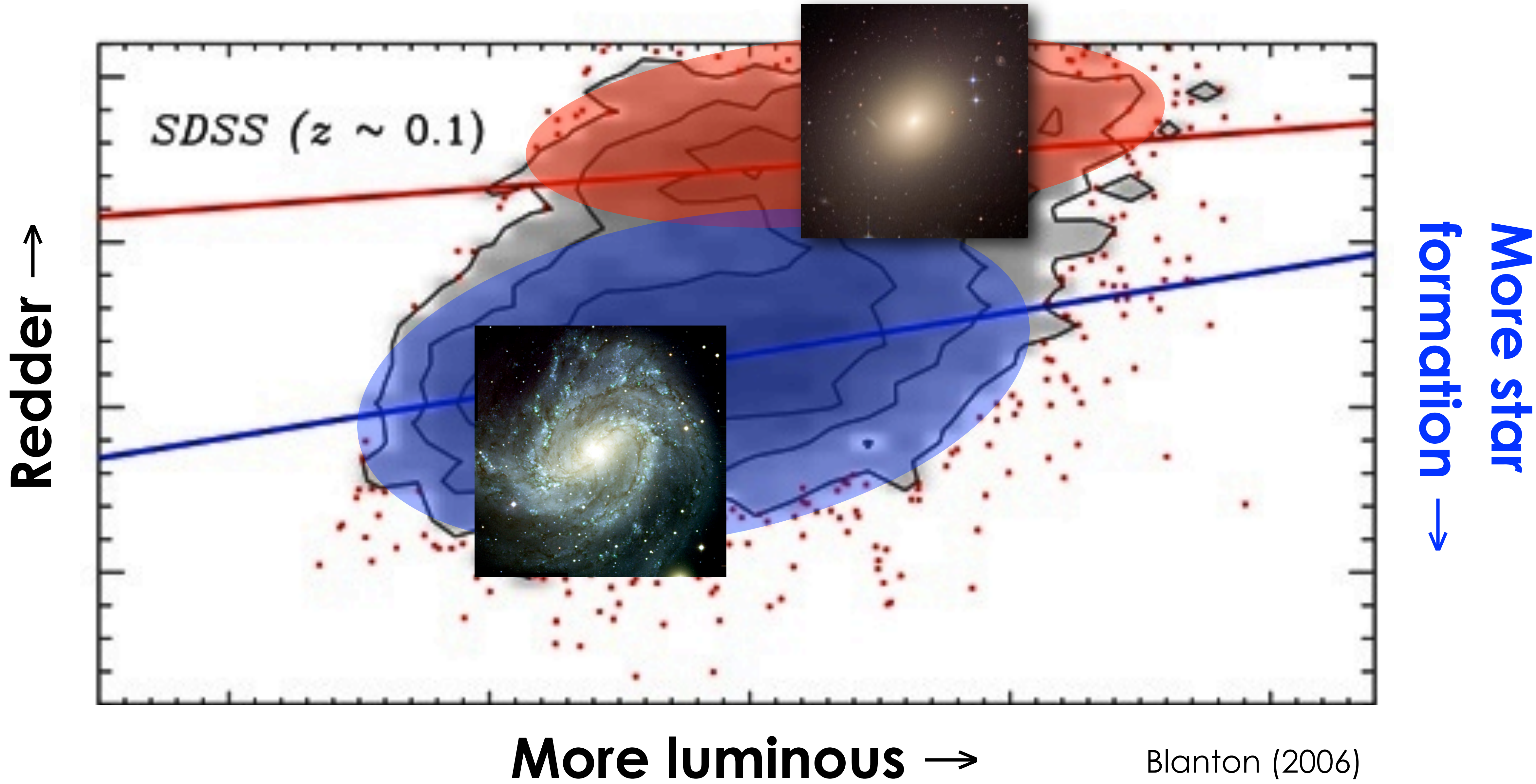
The galaxy population



Blanton (2006)

[Coil, Cole]

The galaxy population

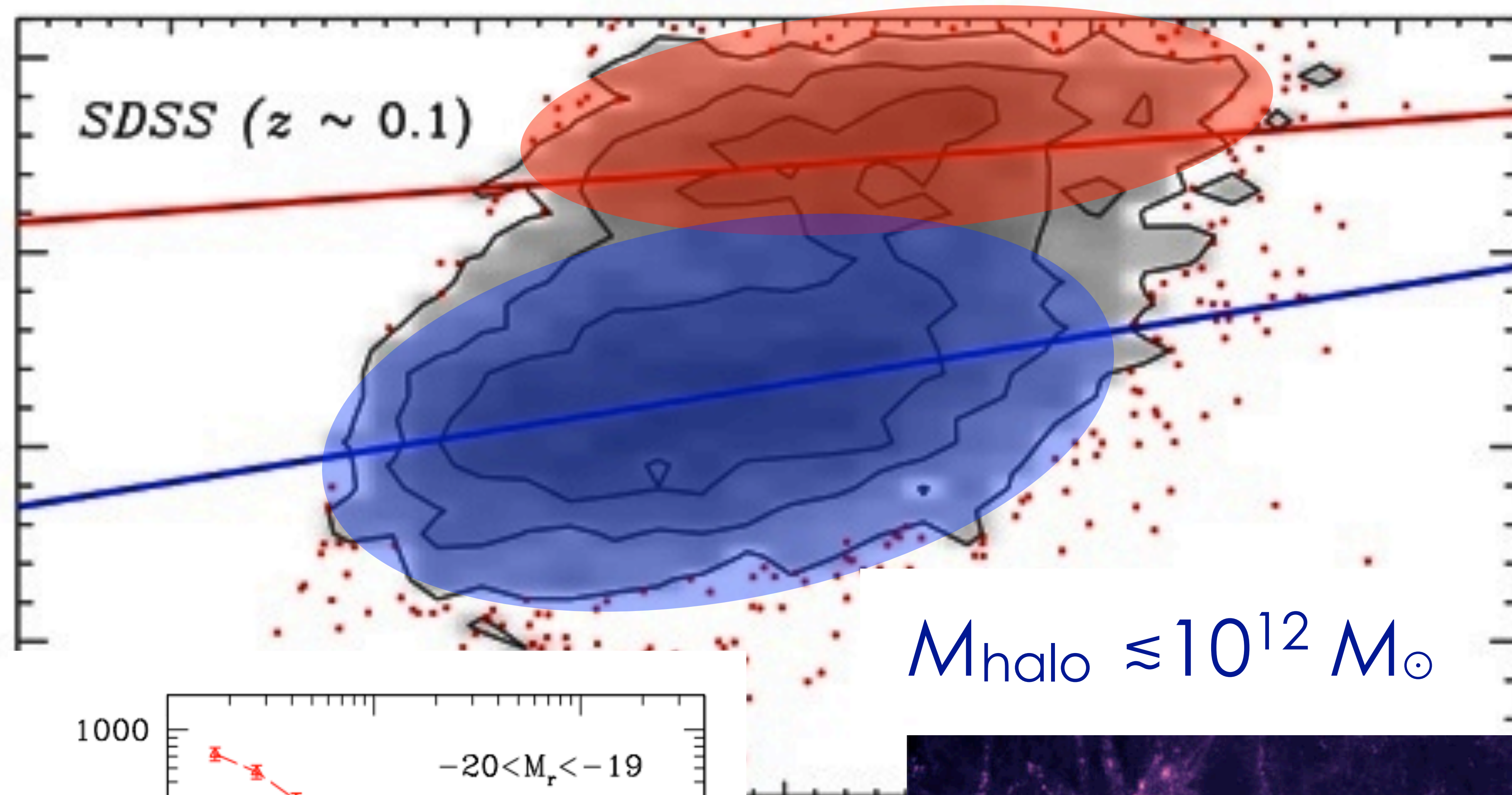


Blanton (2006)

[Coil, Cole]

The galaxy population

$M_{halo} \sim 10^{13} M_\odot$

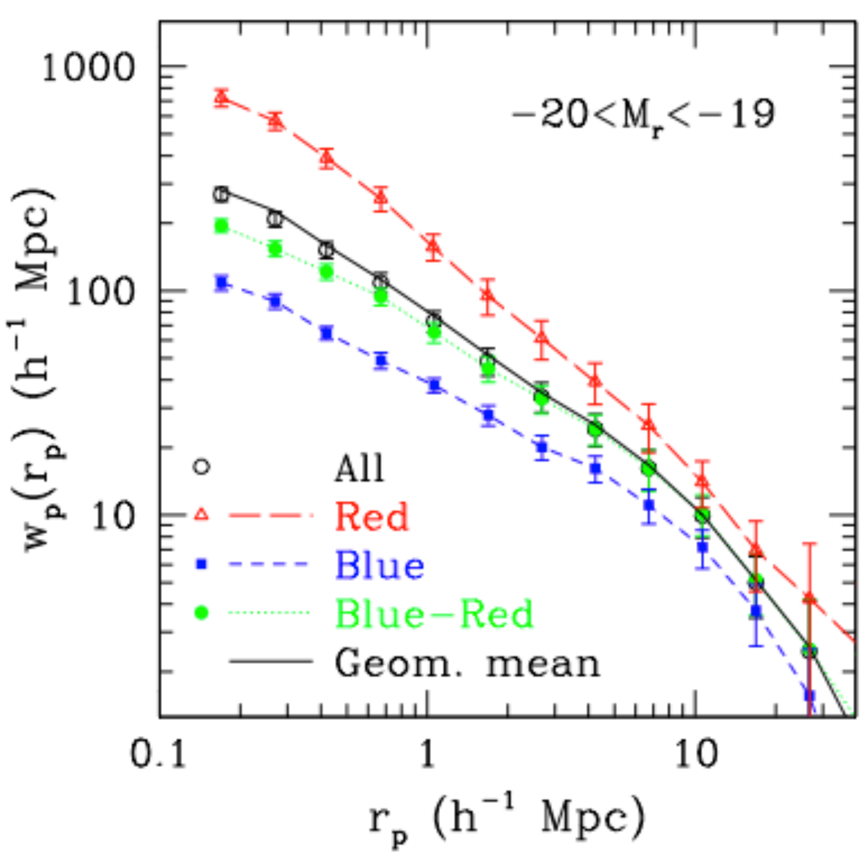


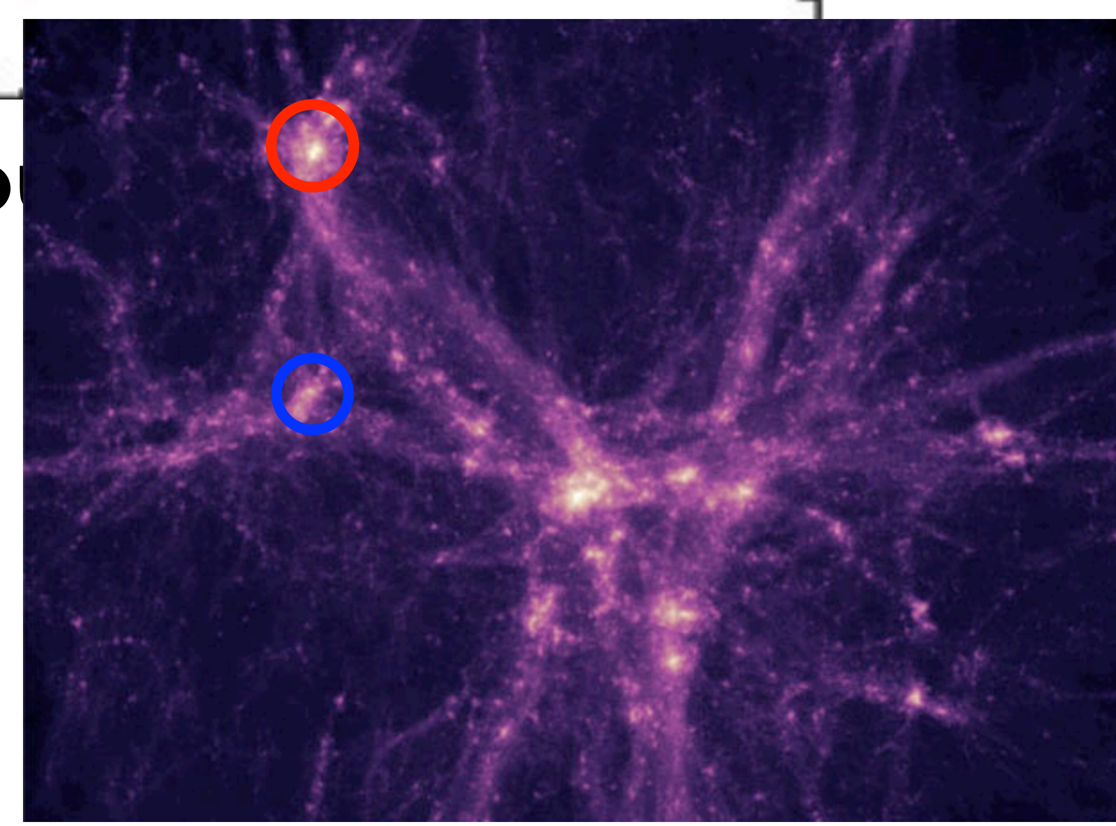
Redder →

More star formation →

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

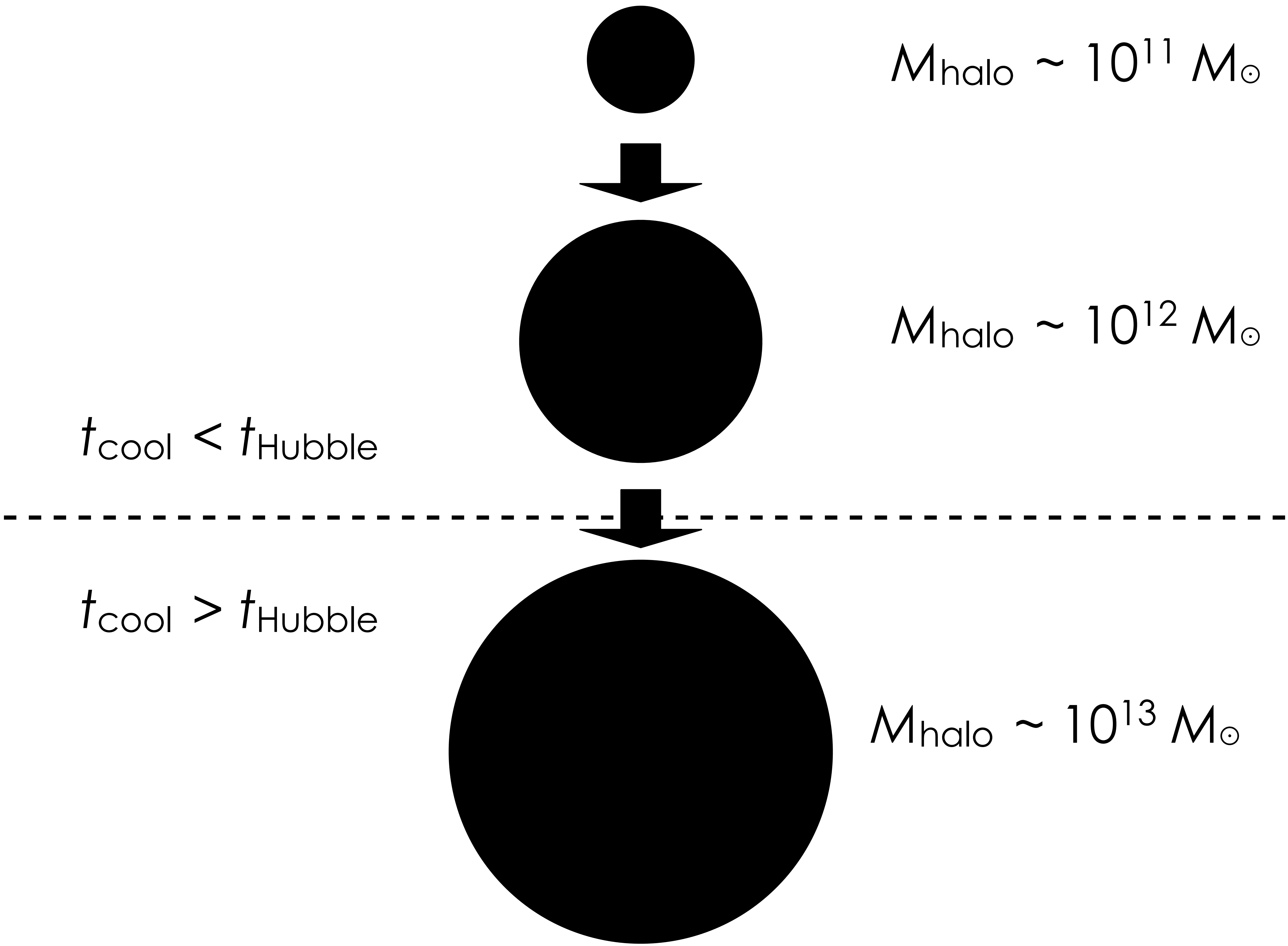
minou



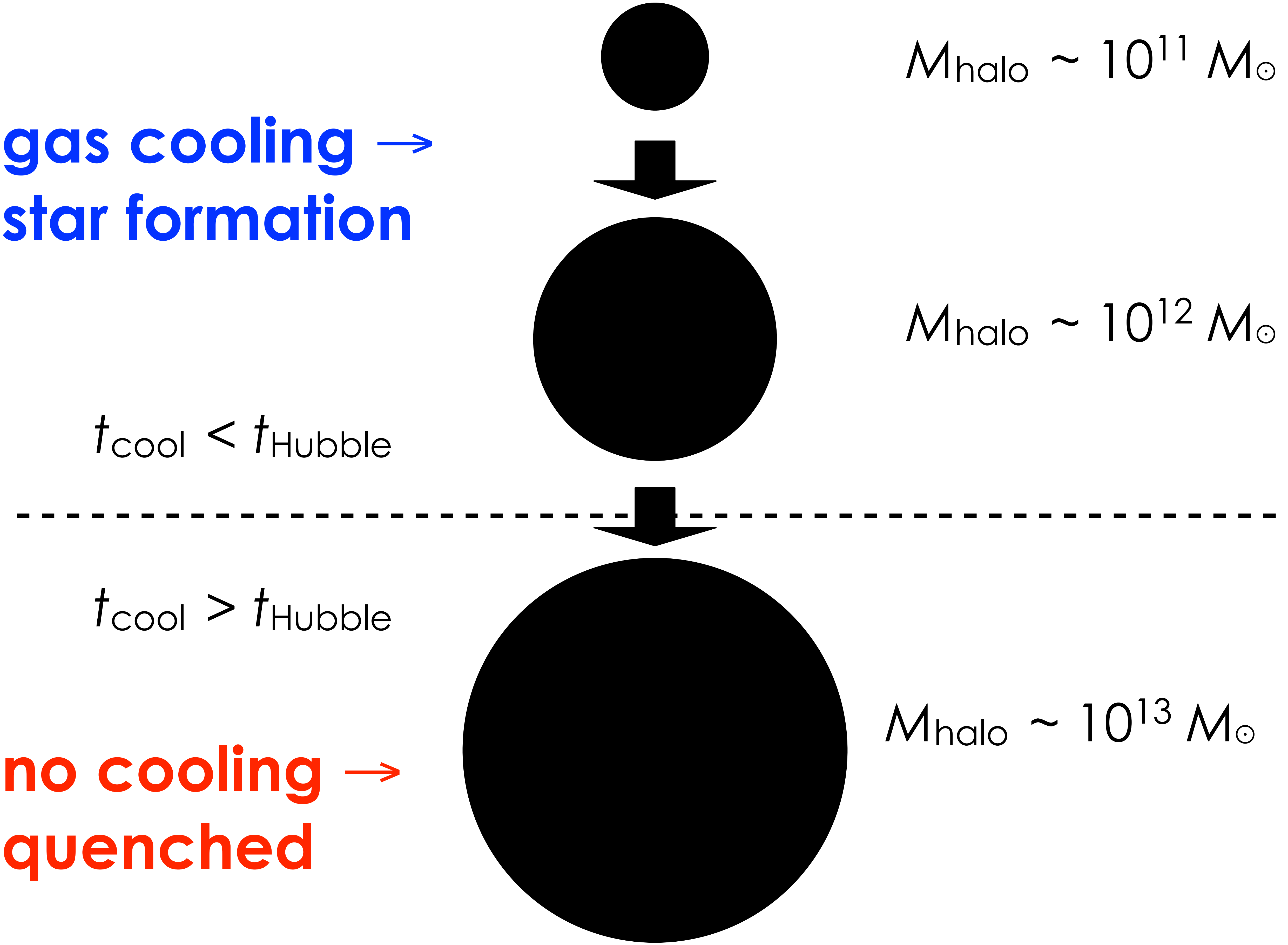


[Coil, Cole]

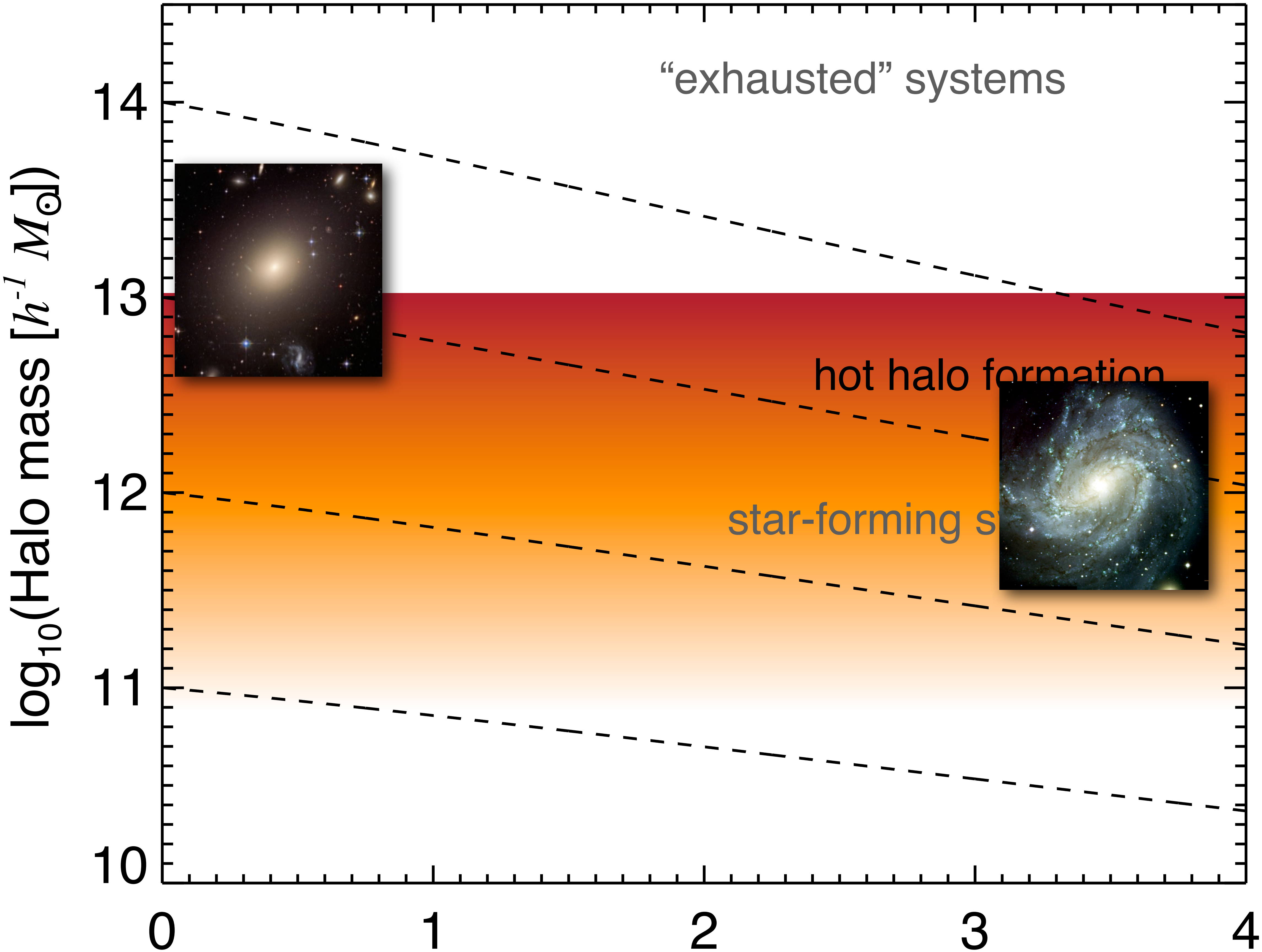
Zehavi et al. (2011)



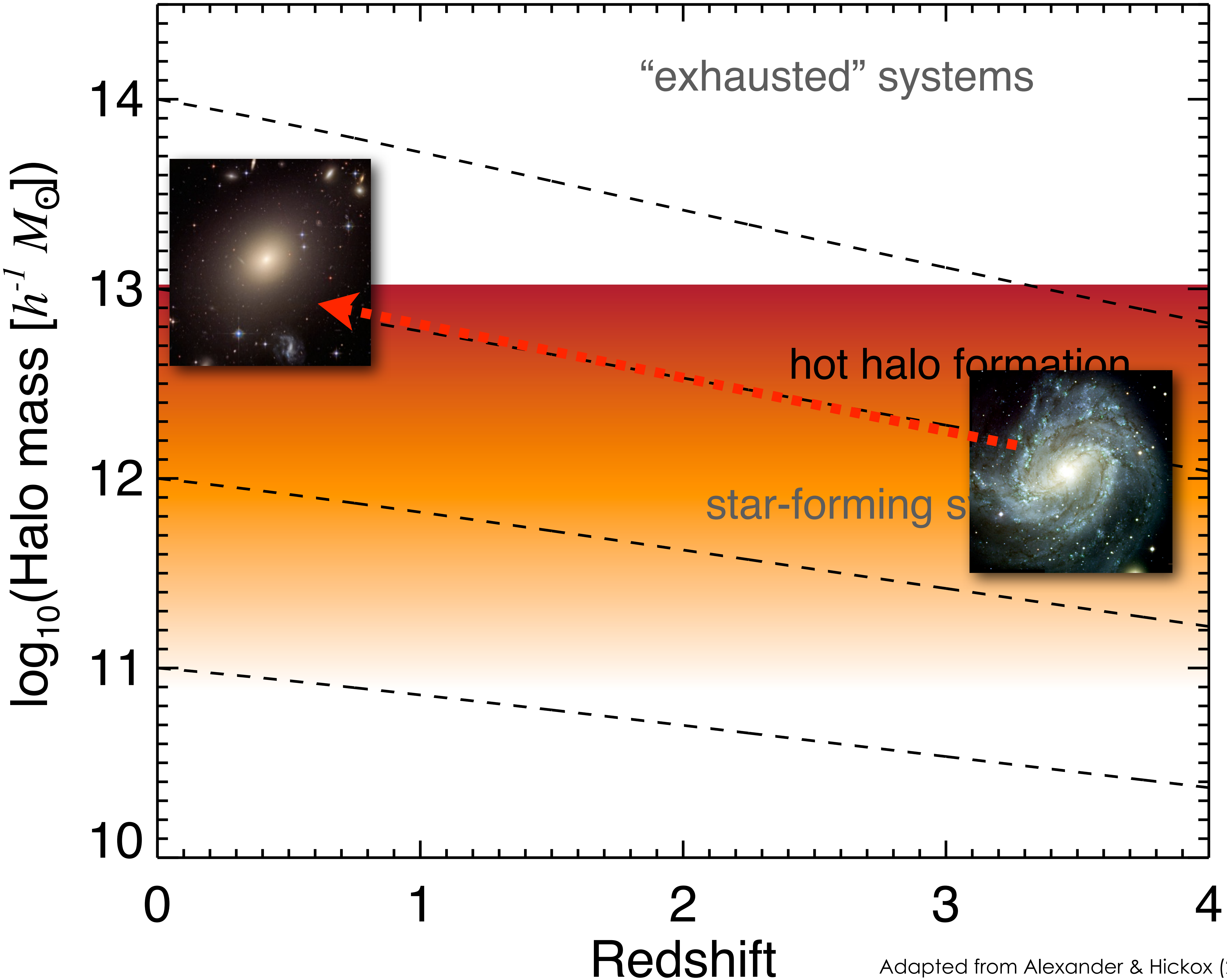
$M_{halo} \sim 10^{11}\,M_\odot$
$M_{halo} \sim 10^{12}\,M_\odot$
$t_{cool} < t_{Hubble}$
$t_{cool} > t_{Hubble}$
$M_{halo} \sim 10^{13}\,M_\odot$



$M_{halo} \sim 10^{11} M_\odot$
gas cooling → star formation
$M_{halo} \sim 10^{12} M_\odot$
$t_{cool} < t_{Hubble}$
$t_{cool} > t_{Hubble}$
$M_{halo} \sim 10^{13} M_\odot$
no cooling → quenched

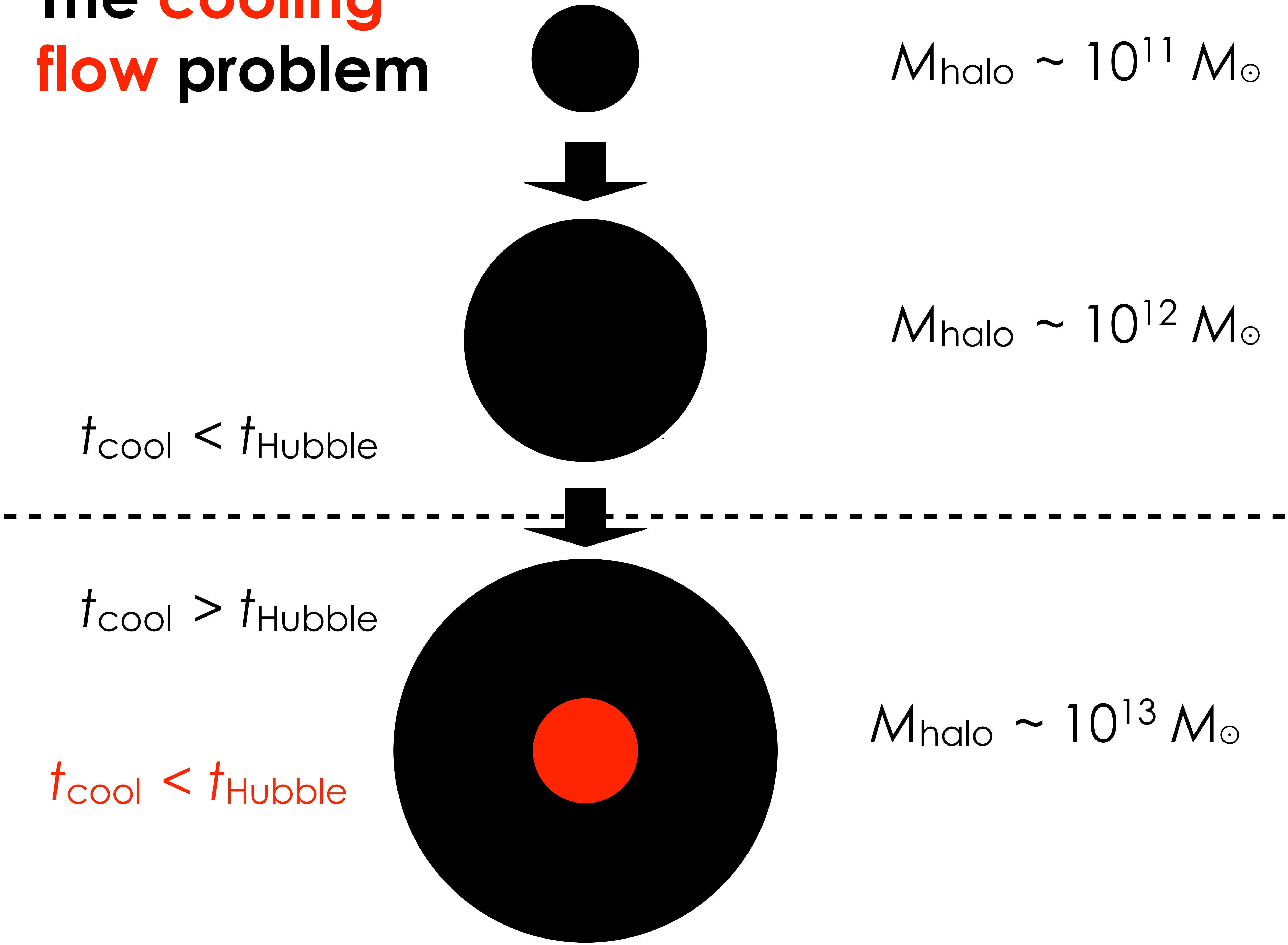


Adapted from Alexander & Hickox (2012),
Following D. Croton

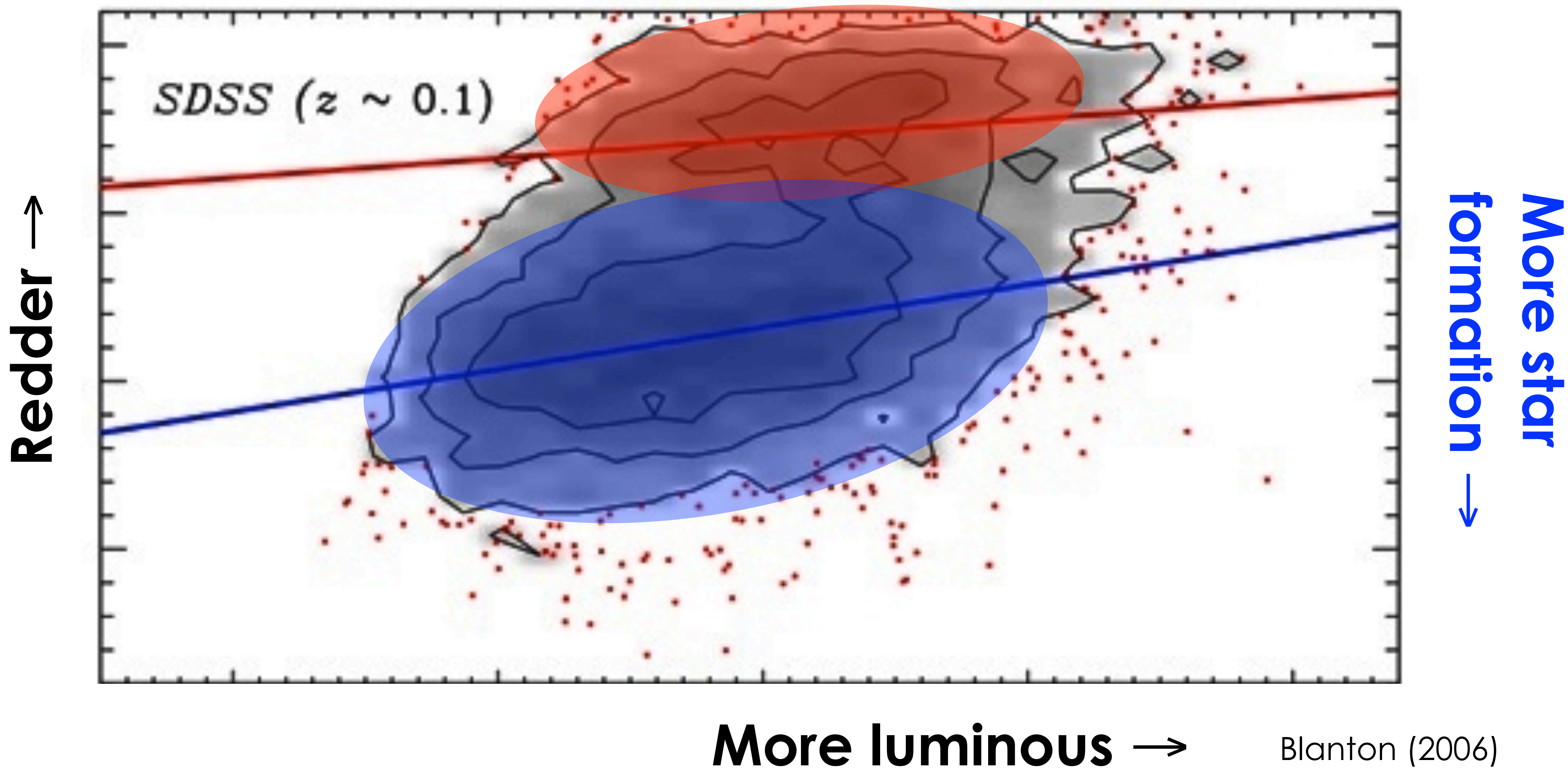


Adapted from Alexander & Hickox (2012),
Following D. Croton

The cooling flow problem



The need for black hole feedback



Blanton (2006)

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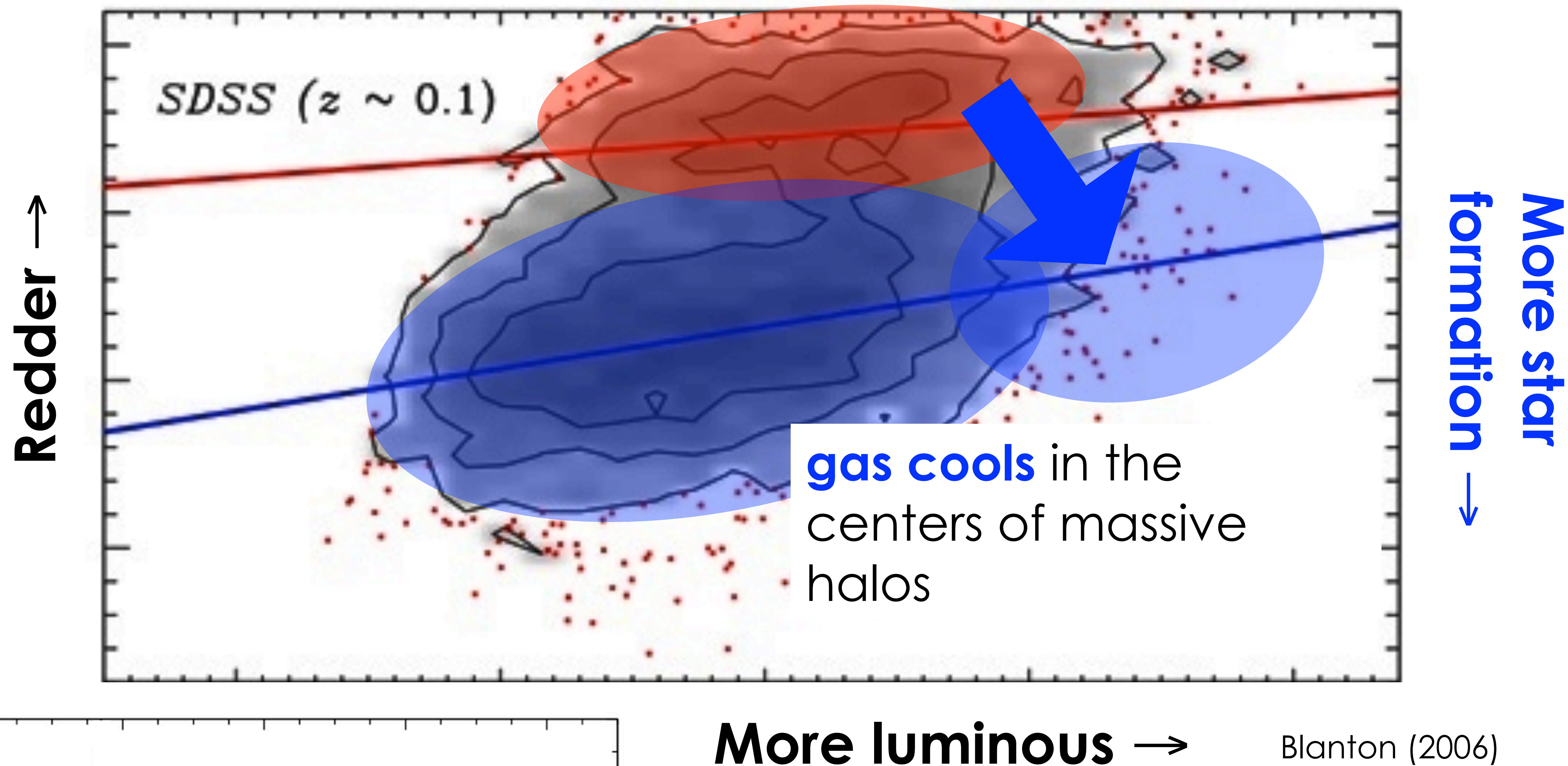
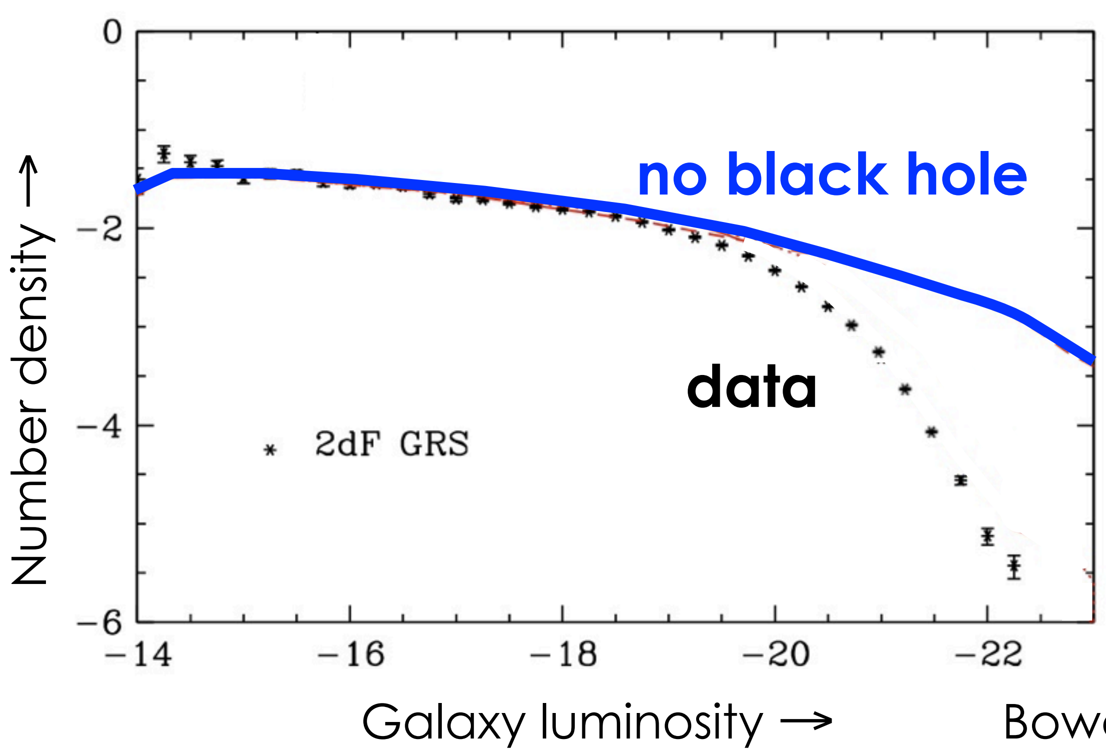
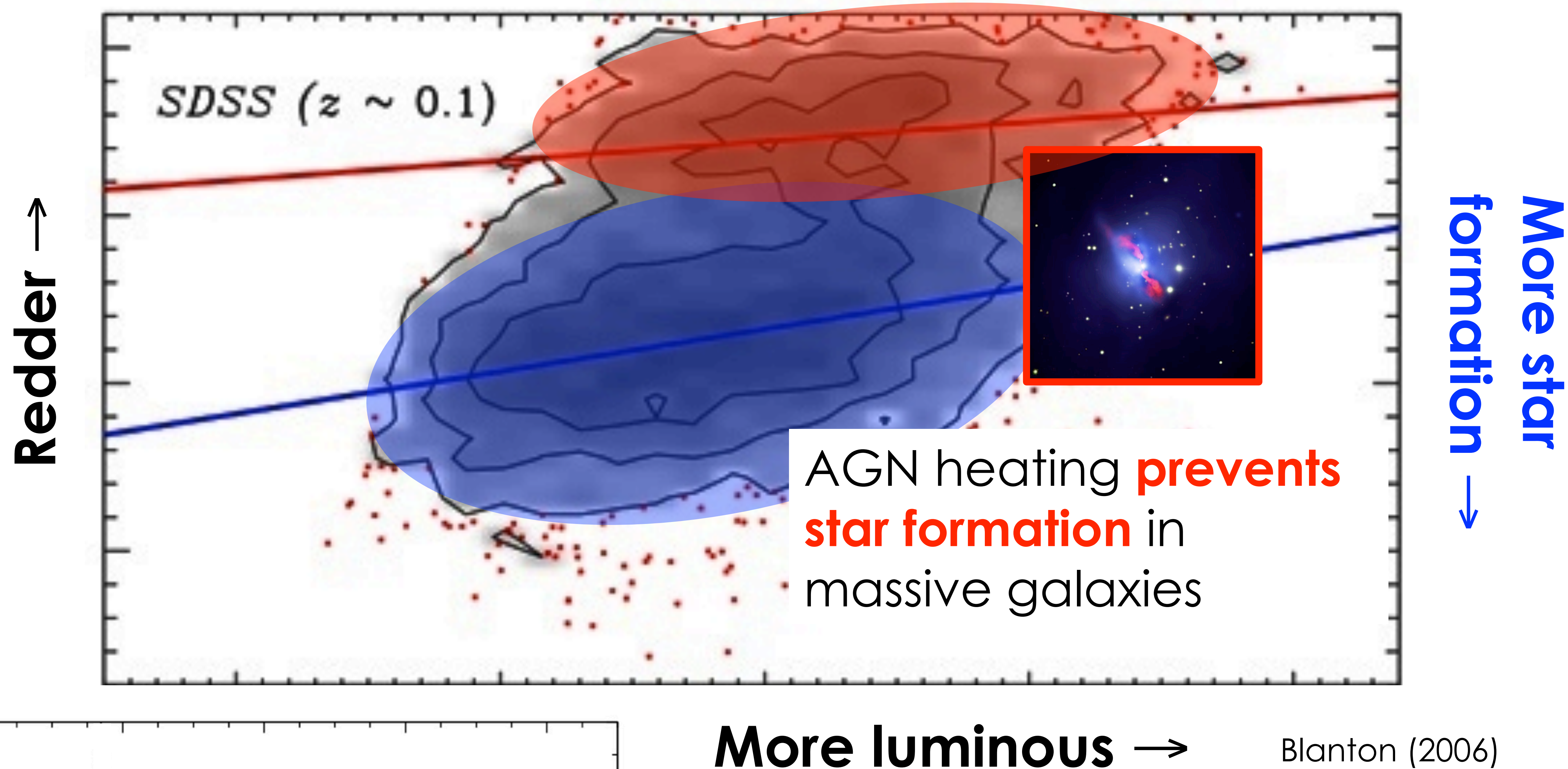


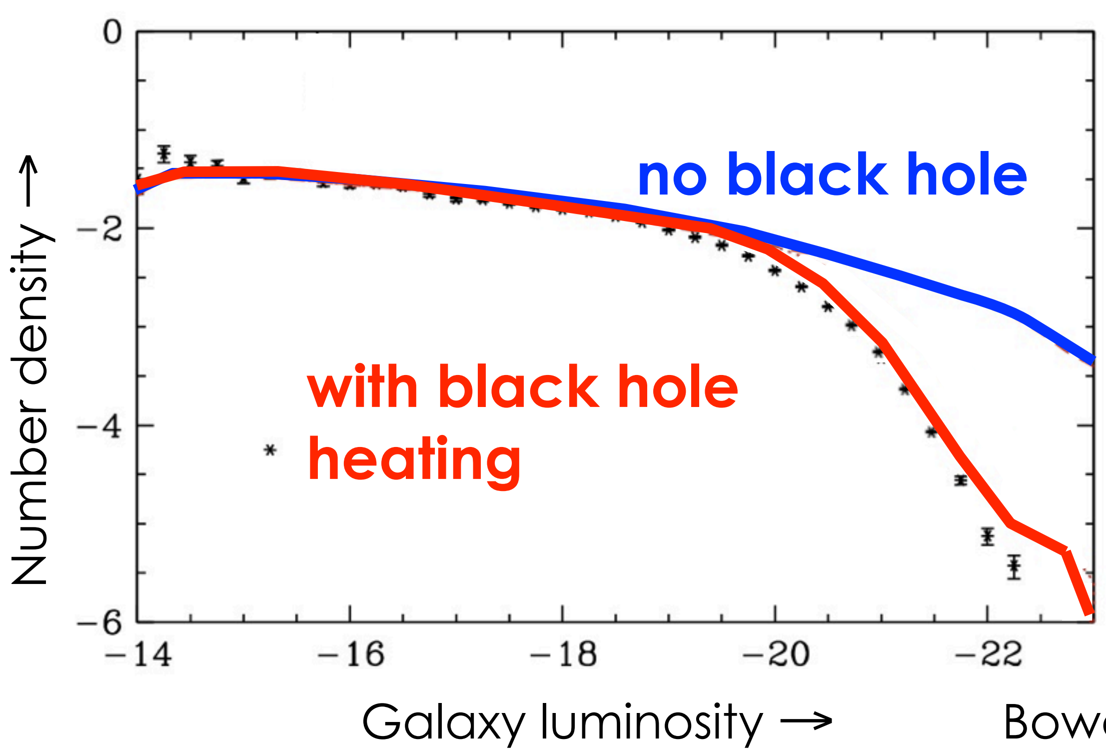
Blanton (2006)



Bower et al. (2006), see also Croton et al. (2006), etc.

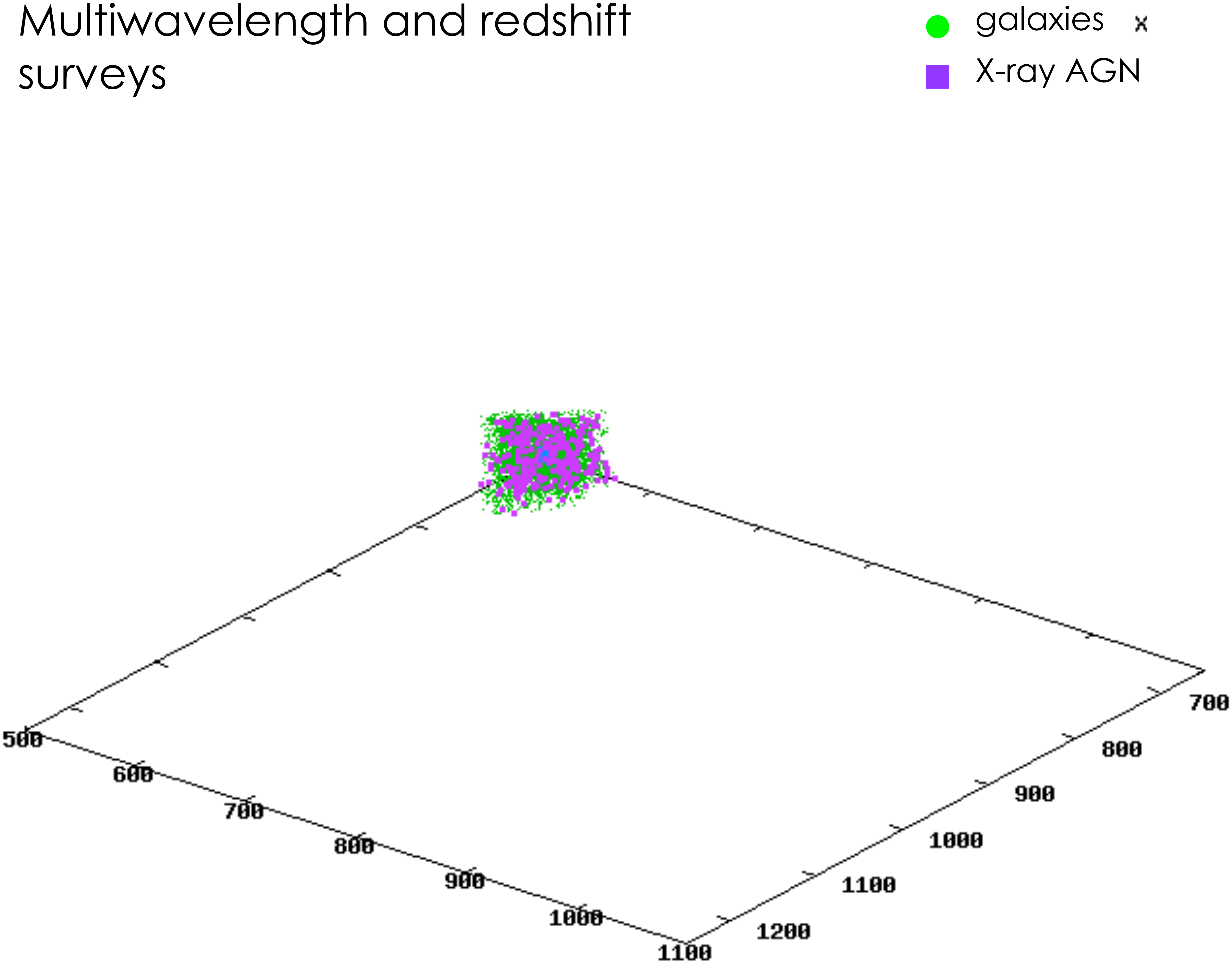
The need for black hole feedback





Bower et al. (2006), see also Croton et al. (2006), etc.

Multiwavelength and redshift surveys

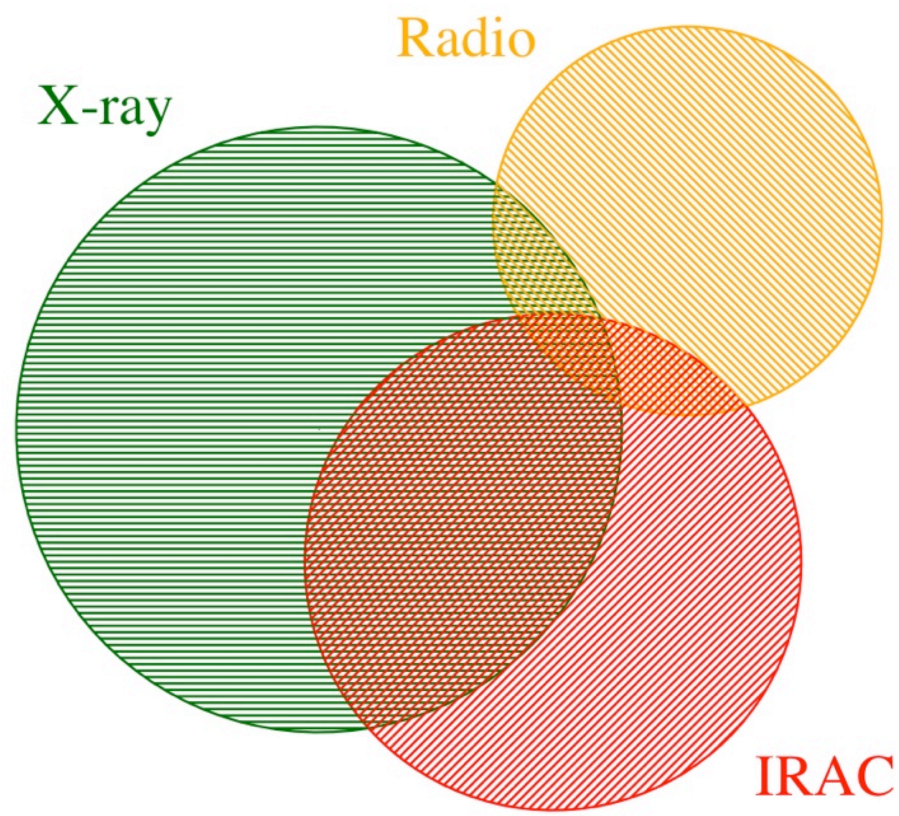


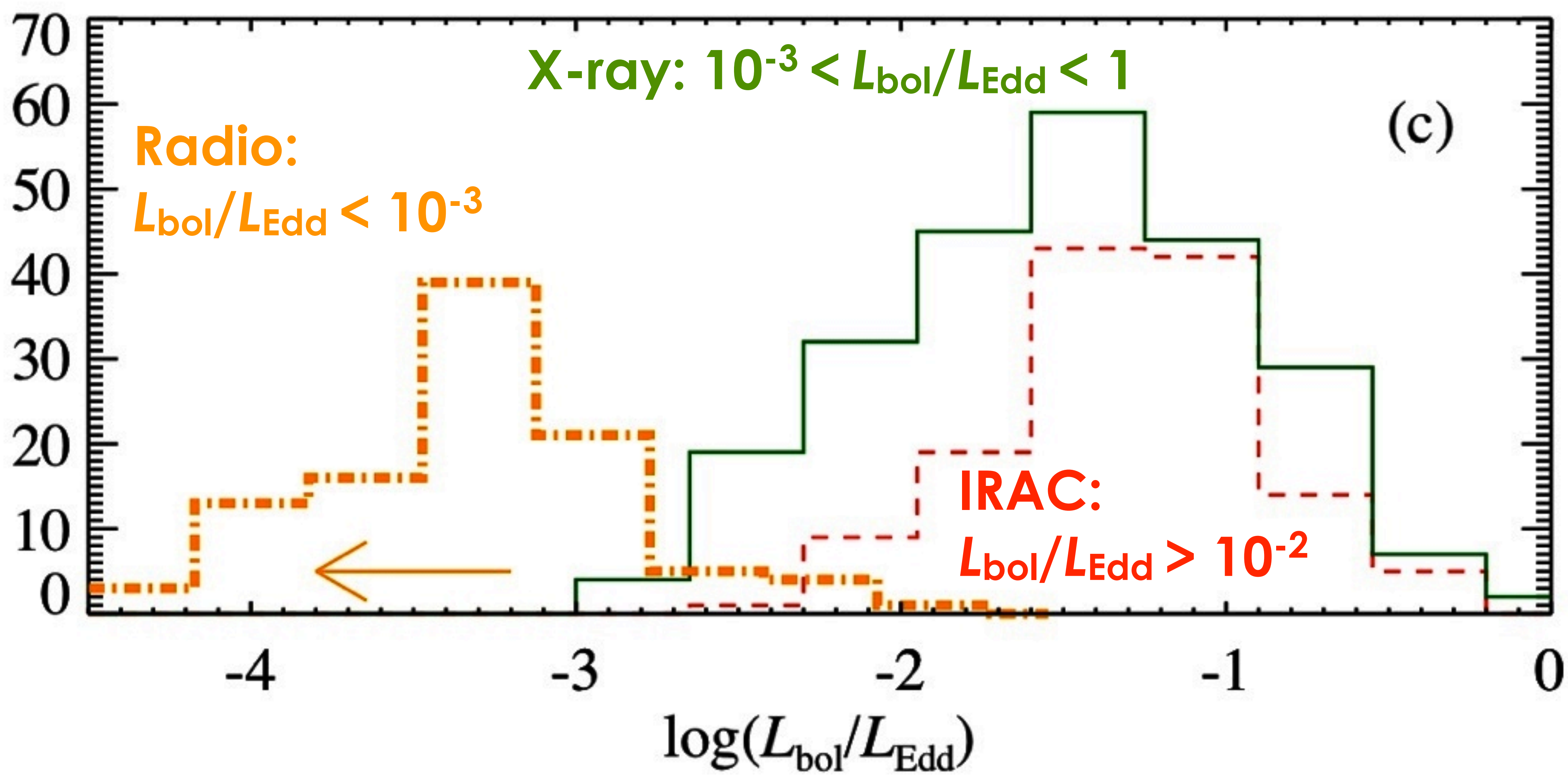
XBootes/AGES (S. Murray/C. Kochanek)

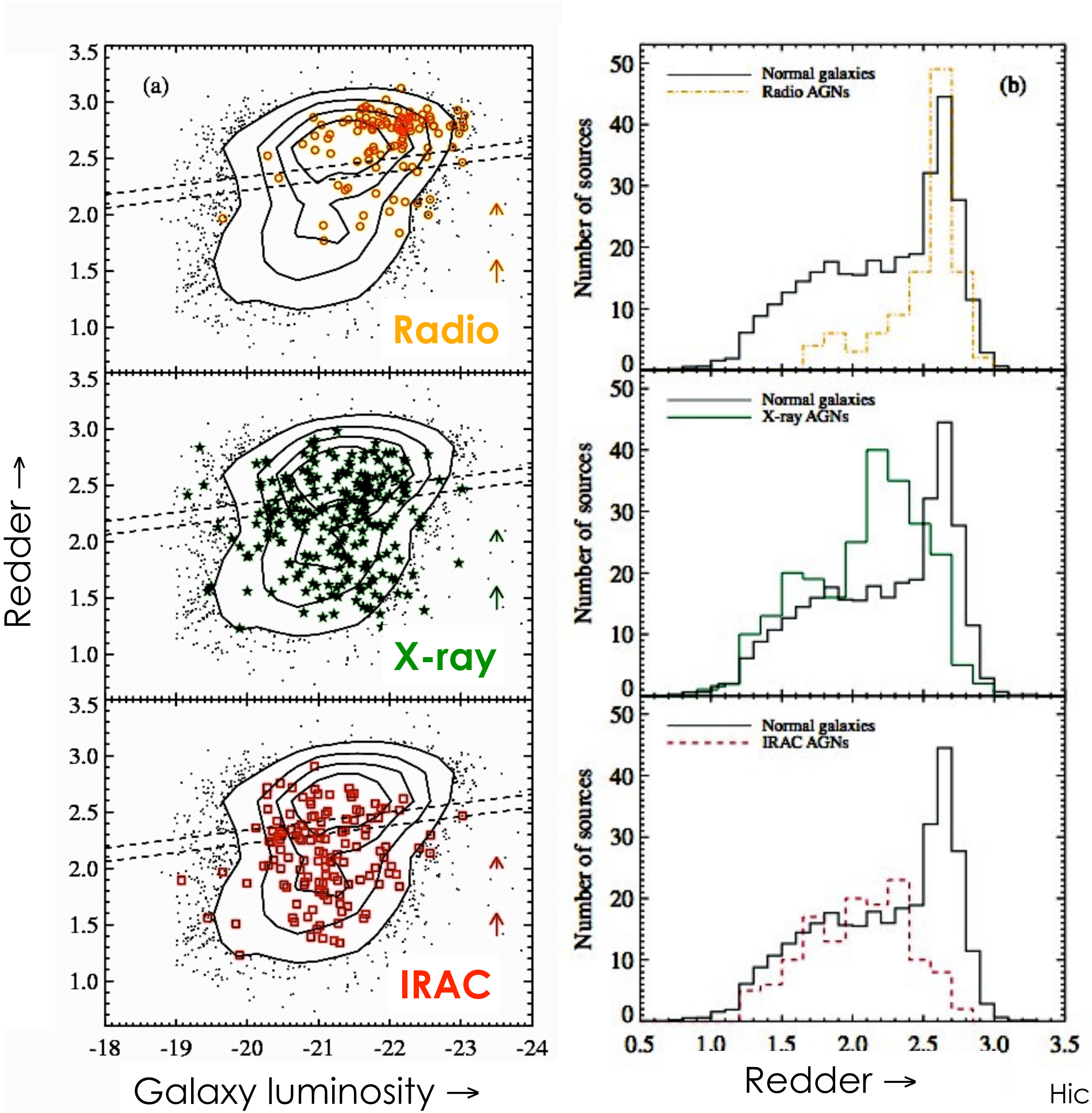
Hickox et al. (2009)

An example:

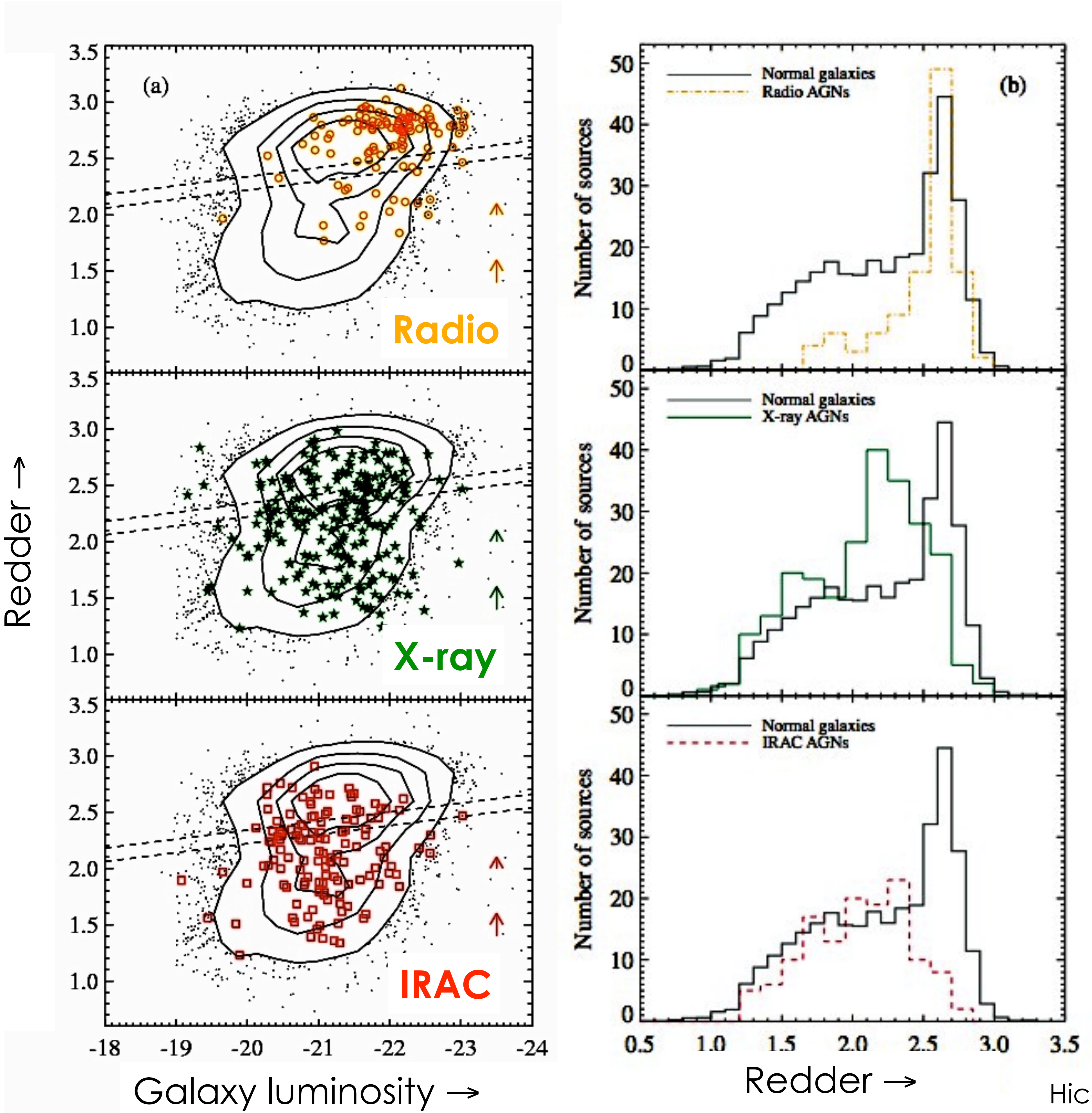
AGN populations at z ~ 0.5





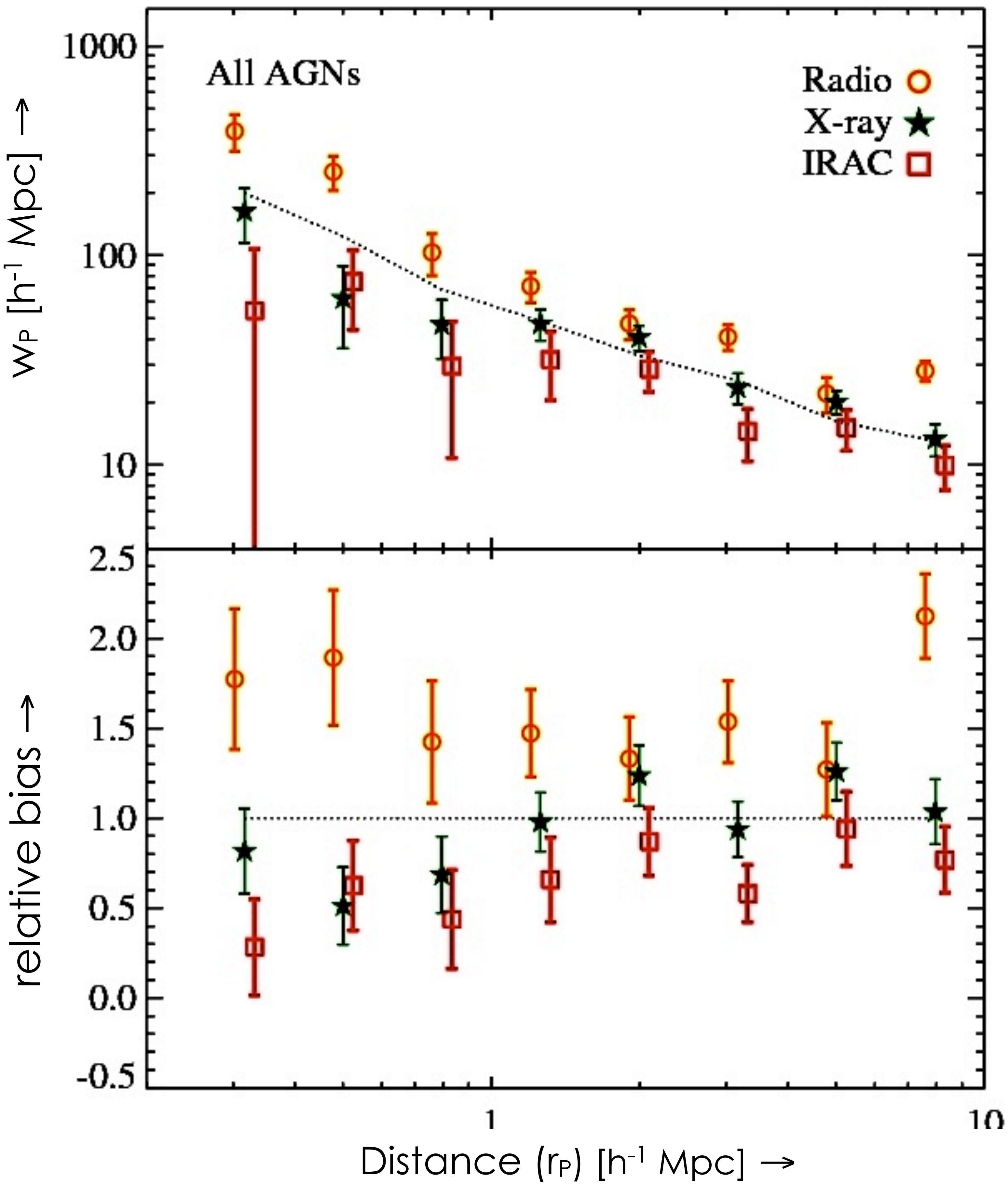


Hickox et al. (2009)



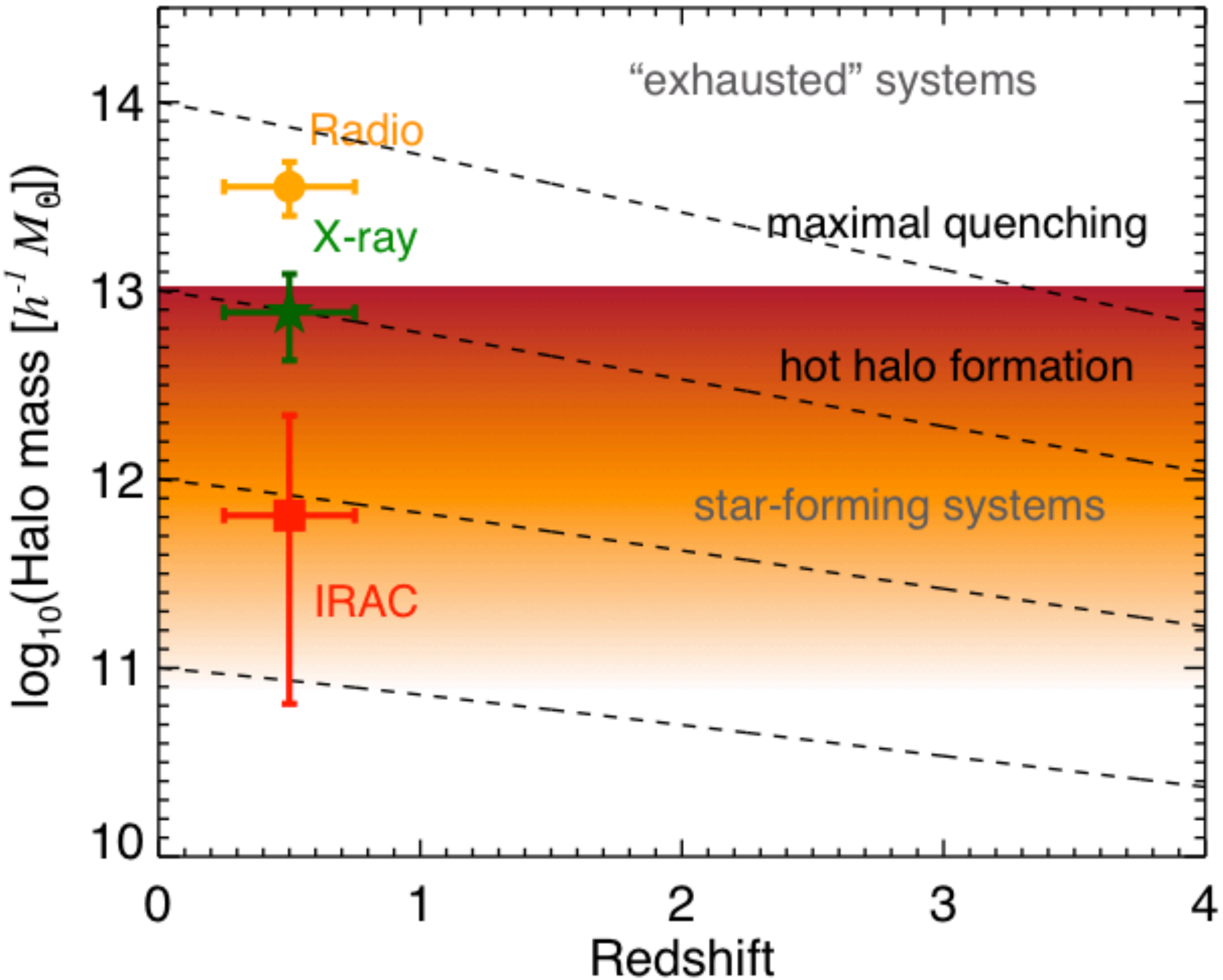
See also:
X-ray (e.g., Nandra et al. 2007, Silverman et al. 2007, Alonso-Hererro et al. 2008, Georgakakis et al. 2008, Schawinski et al. 2009, Cardamone et al. 2010, Xue et al. 2010) as well as radio (Smolcic et al. 2009) optical (Kauffmann & Heckman 2009) and infrared (Goulding et al. 2009)

Hickox et al. (2009)

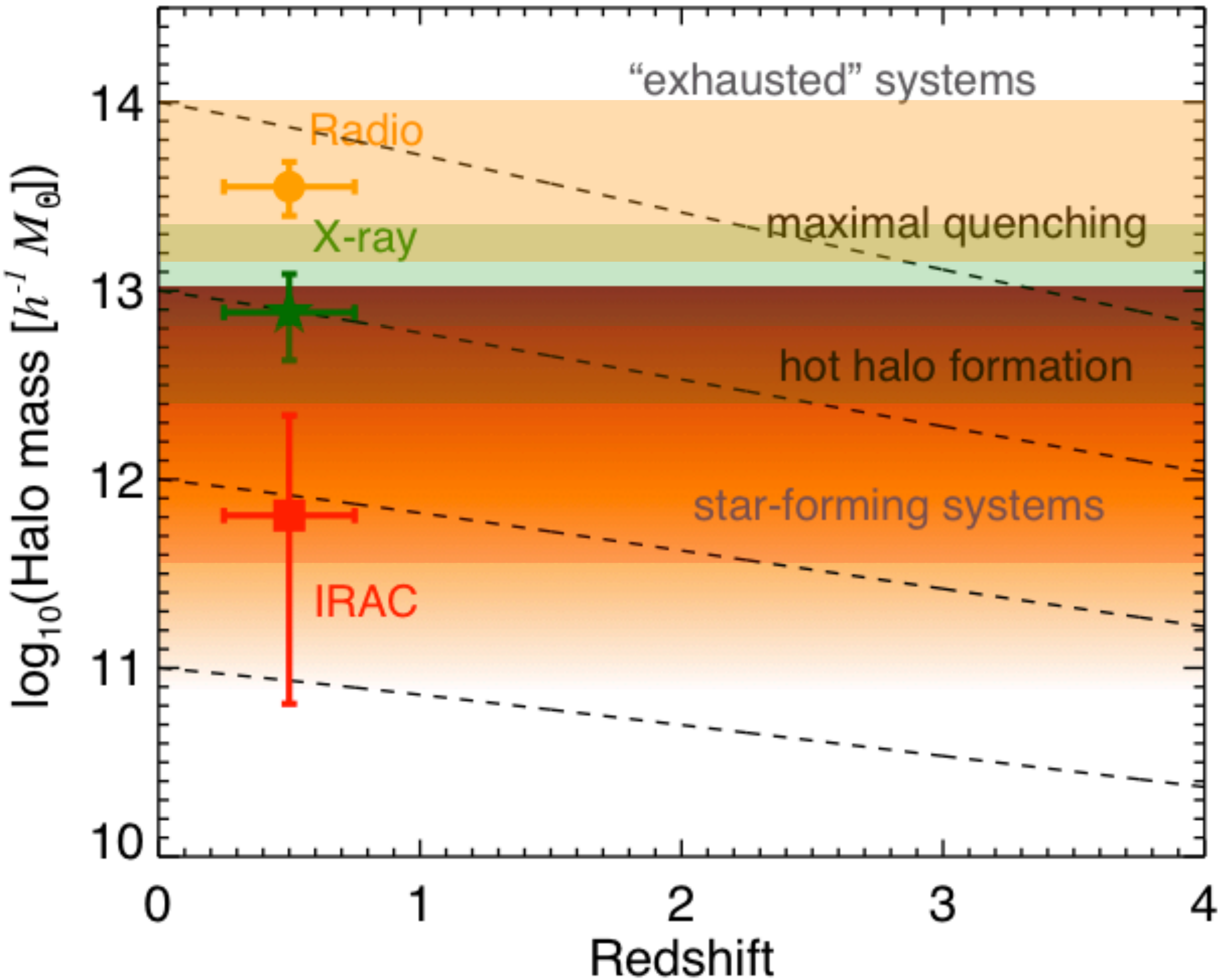


Hickox et al. (2009)

Clustering is different for the classes of AGN



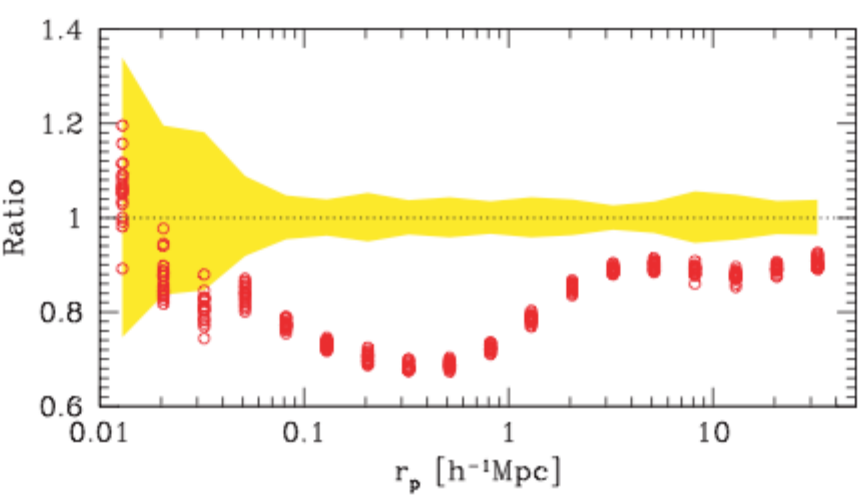
Clustering is different for the classes of AGN



see also Wake et al. (2008), Mandelbaum et al. (2008), Coil et al. (2009), Cappelluti et al. (2010), Fine et al. (2011), Hickox et al. (2011), Krumpe et al. (2012), Mountrichas et al. (2012), Koutolidis et al. (2013), Georgakakis et al. (2014), Geach et al. (2013)

Do AGN hosts lie in different halos compared to similar “normal” galaxies?

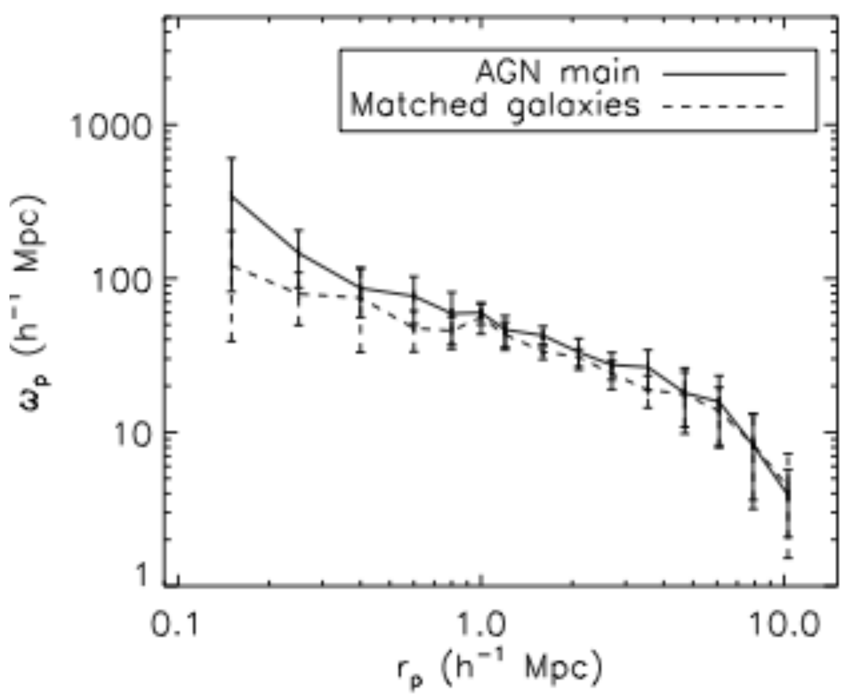
Optical/IR



Slightly weaker or similar clustering

e.g., Li et al. (2006), Hickox et al. (2009) BUT see Mandelbaum et al. (2008)

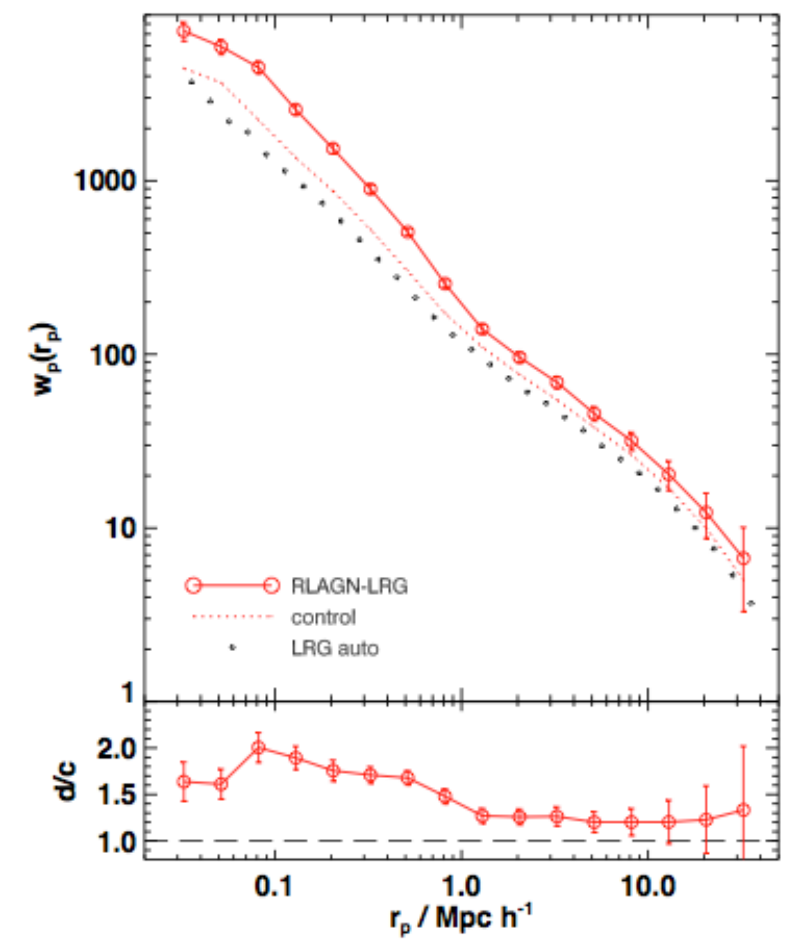
X-ray



No large difference

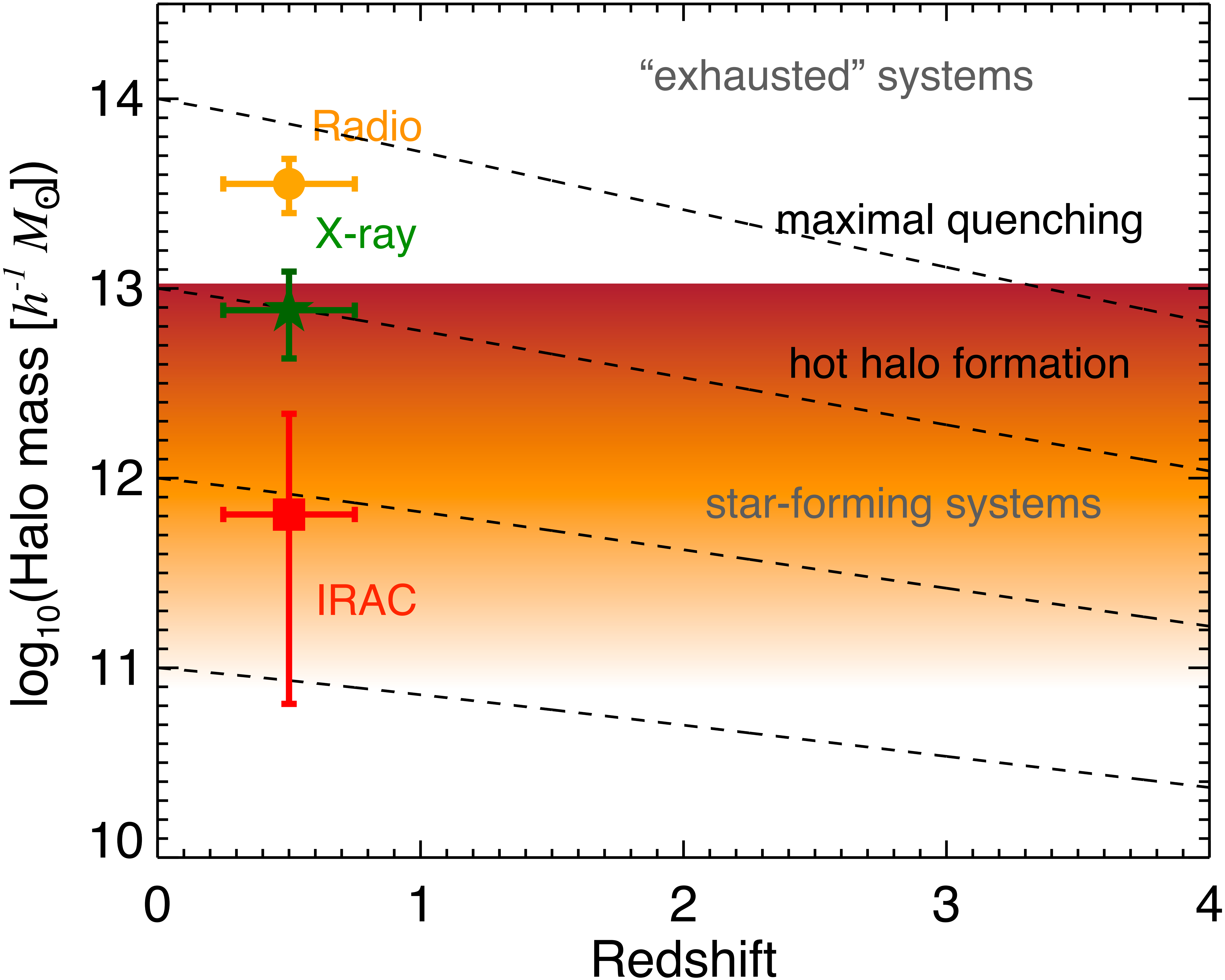
e.g., Coil et al. (2009), Hickox et al. (2009), Georgakakis et al. (2014)

Radio

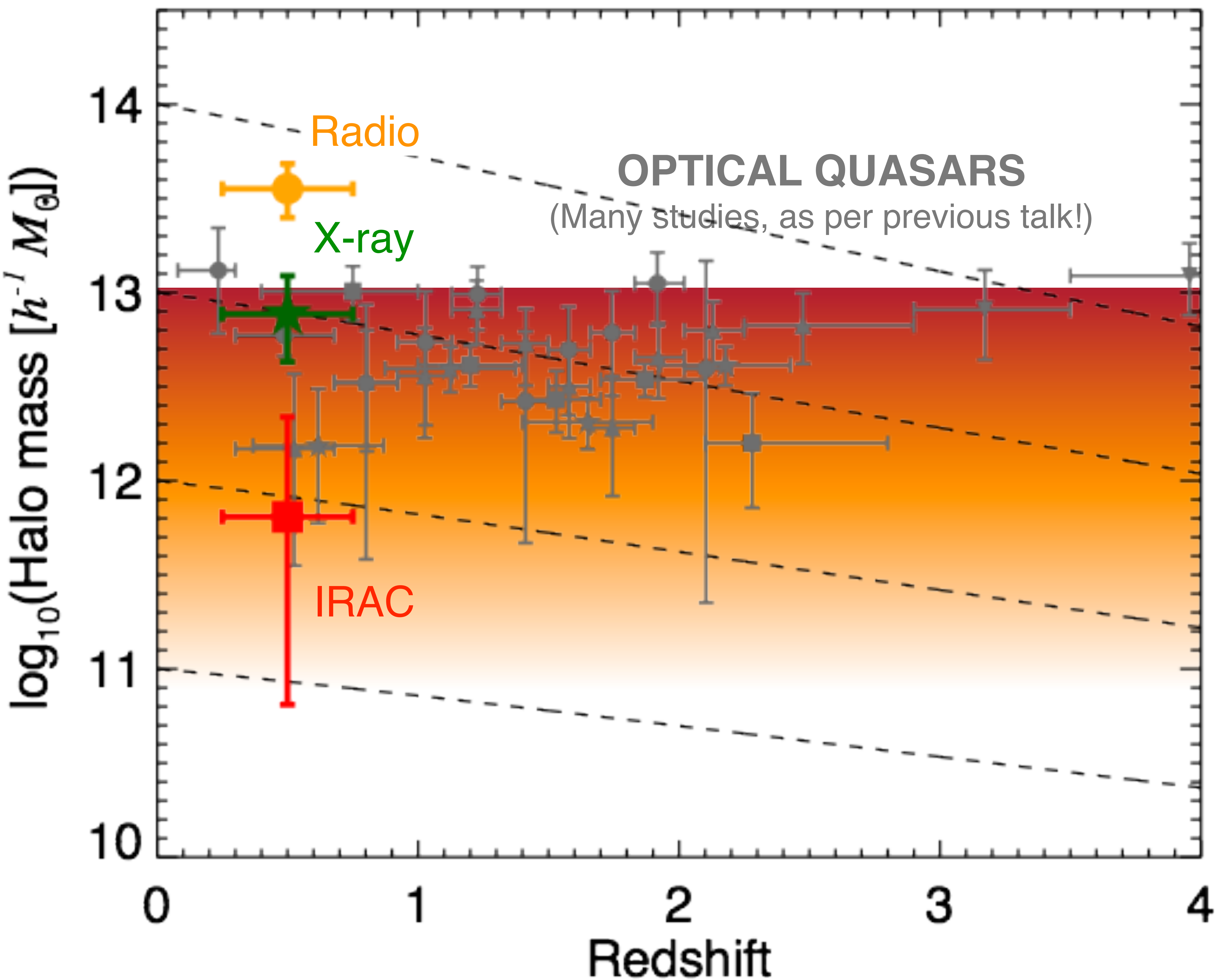


Stronger clustering

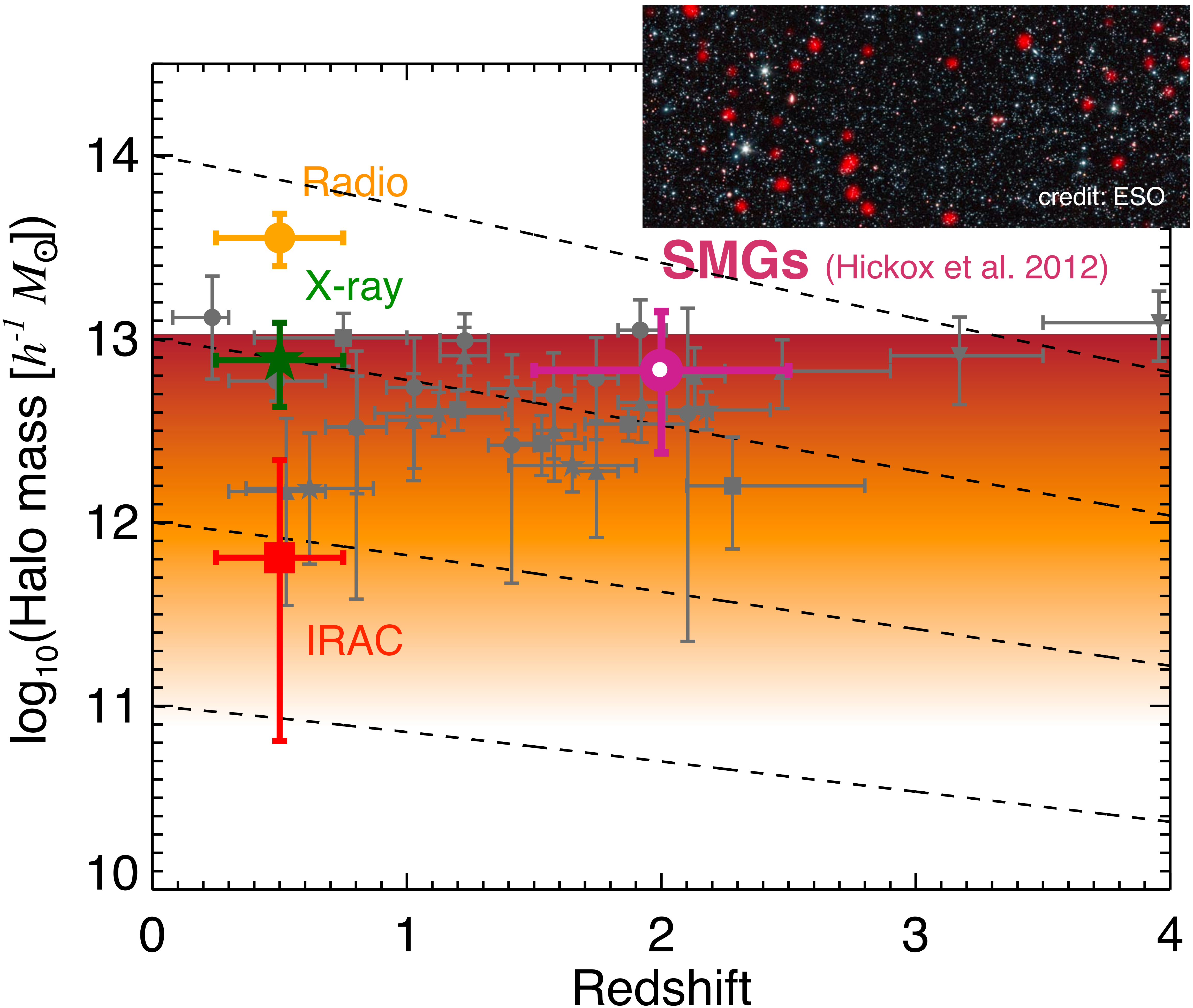
e.g., Wake et al. (2008), Donoso et al. (2010) BUT see Hickox et al. (2009)



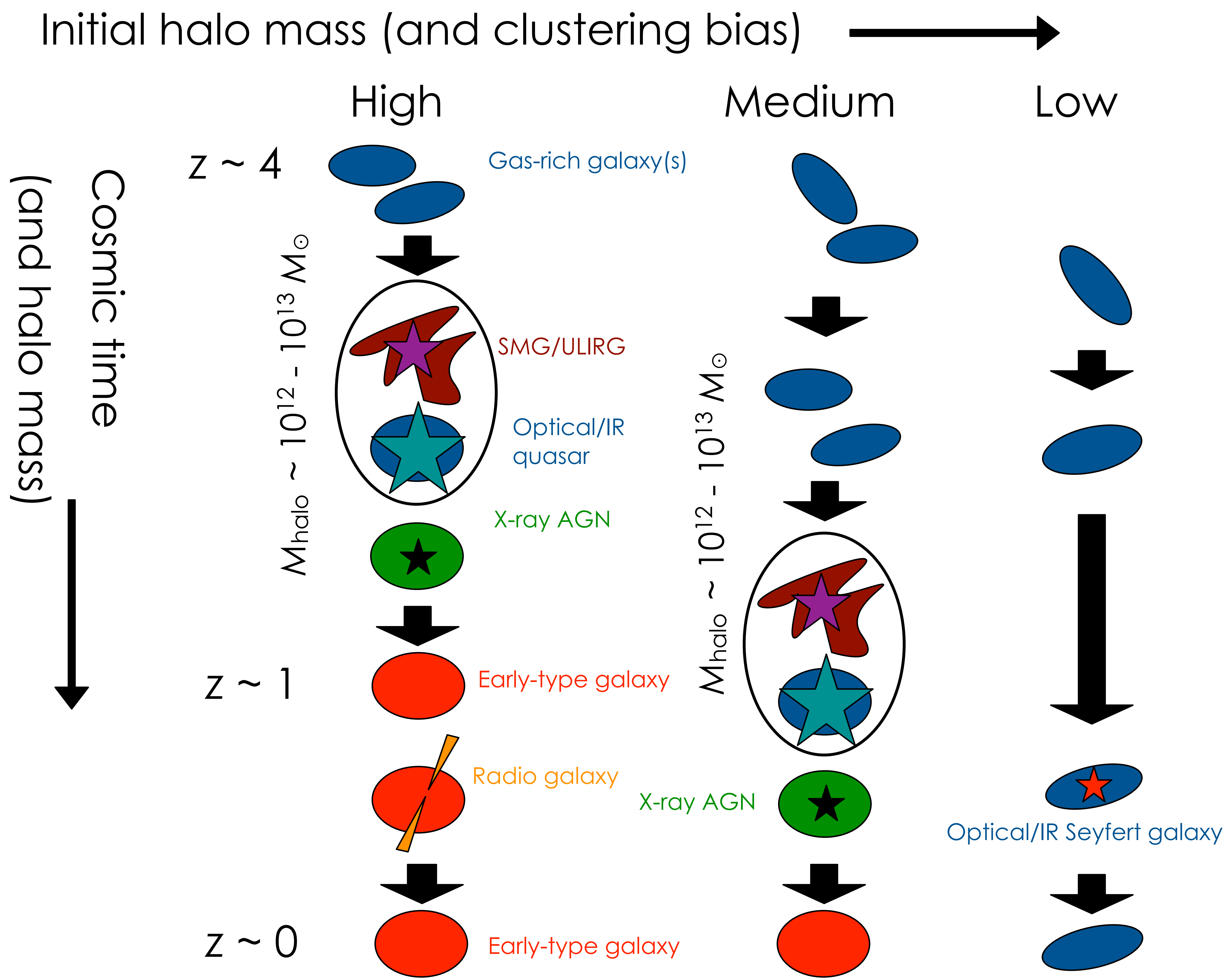
"exhausted" systems
Radio
maximal quenching
X-ray
hot halo formation
star-forming systems
IRAC
14
13
12
11
10
0
1
2
3
4
Redshift
log10(Halo mass [h^-1 M☉])



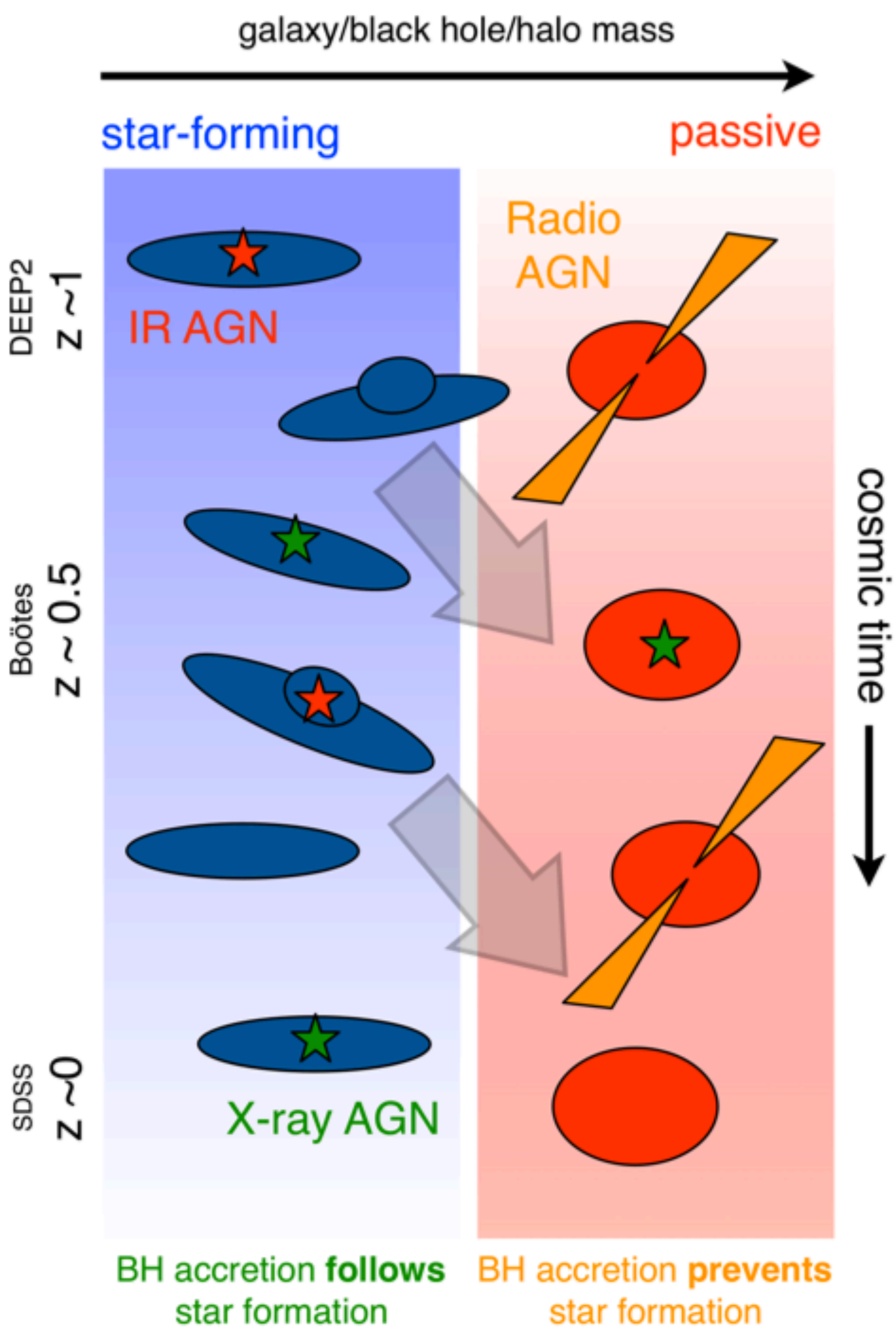
Radio
X-ray
IRAC
OPTICAL QUASARS
(Many studies, as per previous talk!)
log$_{10}$(Halo mass [h^{-1} $M_\odot$])
Redshift
14
13
12
11
10
0
1
2
3
4



credit: ESO
SMGs (Hickox et al. 2012)
Radio
X-ray
IRAC
14
13
12
11
10
0
1
2
3
4
Redshift
log10(Halo mass [h^-1 M⊙])



Initial halo mass (and clustering bias)
High
Medium
Low
Cosmic time
(and halo mass)
z ~ 4
z ~ 1
z ~ 0
Gas-rich galaxy(s)
$M_{halo} \sim 10^{12} - 10^{13}\ M_{\odot}$
SMG/ULIRG
Optical/IR
quasar
X-ray AGN
Early-type galaxy
Radio galaxy
Early-type galaxy
$M_{halo} \sim 10^{12} - 10^{13}\ M_{\odot}$
X-ray AGN
Optical/IR Seyfert galaxy



AGN **follow** star formation in low-mass, cold gas-rich halos

AGN **prevent** cooling flows and star formation in massive halos

Stochasticity may produce weak luminosity dependence on clustering
(e.g. Hickox et al. 2014)

Goulding et al. (2014)

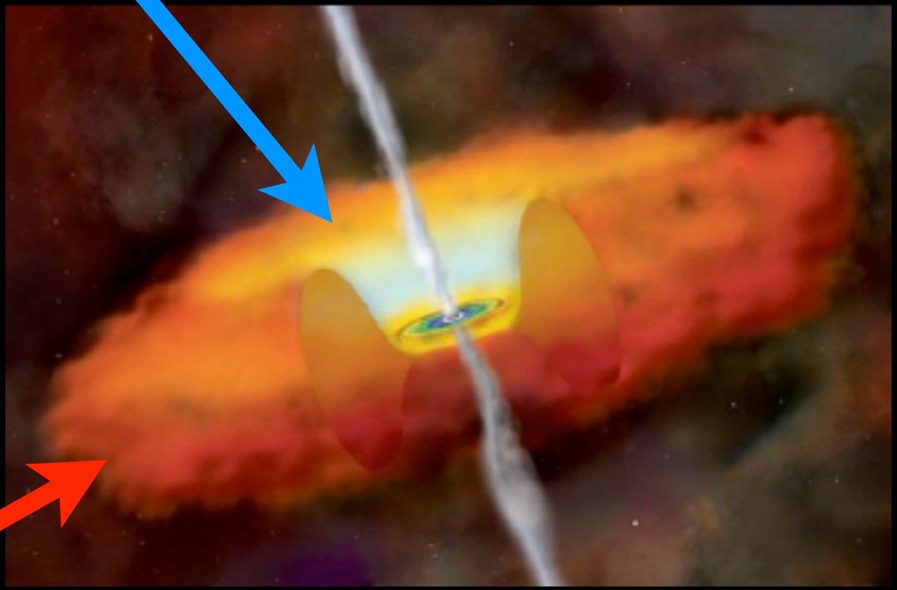
3. A mystery: Clustering of obscured and unobscured quasars

At least half of all AGN are **obscured by gas and dust**, but what is the nature of this material?

3. A mystery: Clustering of obscured and unobscured quasars

unified model “torus”:
no difference in clustering

Unobscured

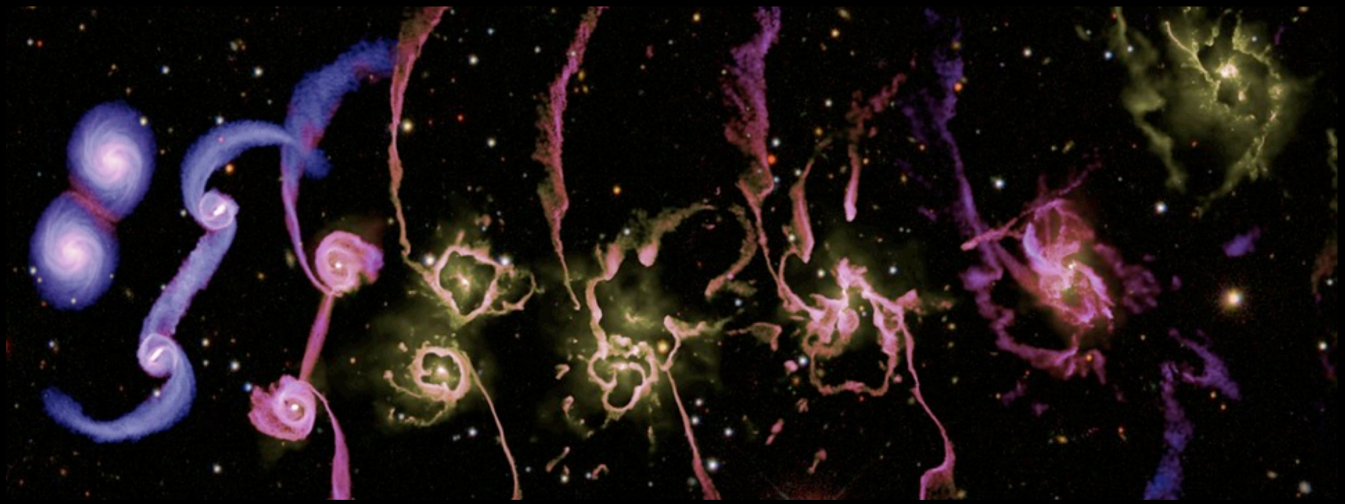


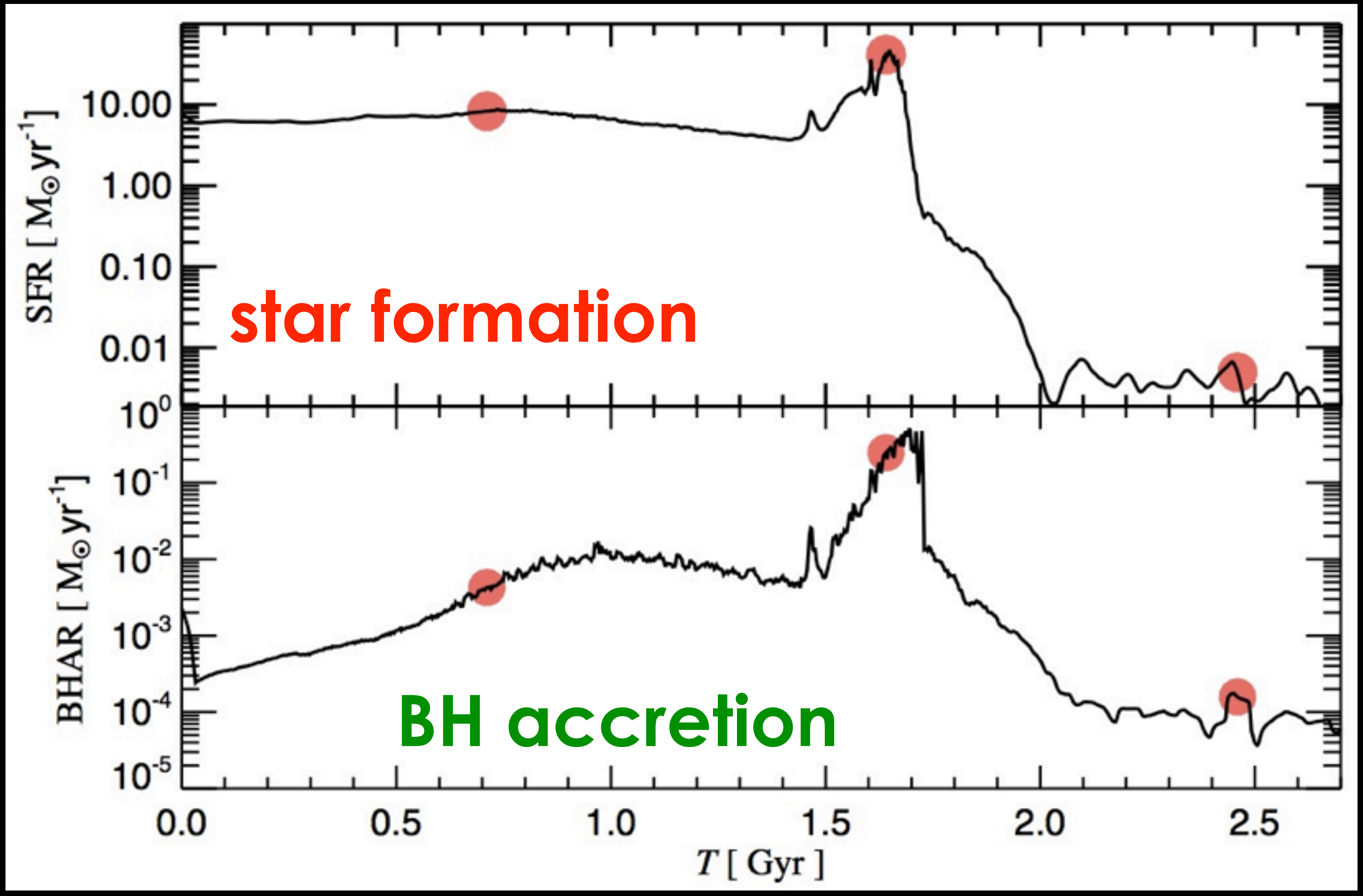
At least half of all AGN are **obscured by gas and dust**, but what is the nature of this material?

Obscured

galaxy-scale structures and interactions: **possible difference in clustering**

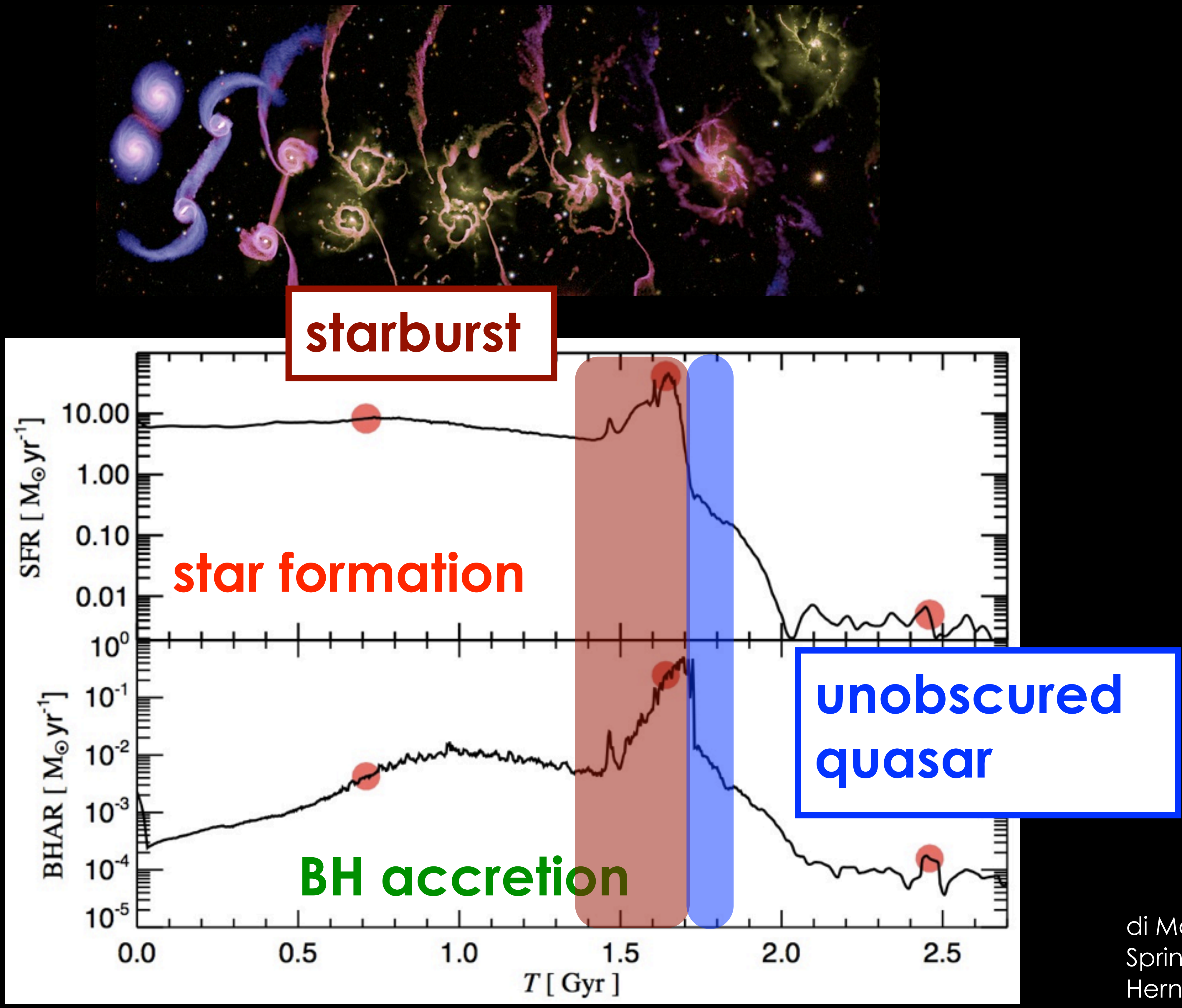
Obscured quasars as an evolutionary phase





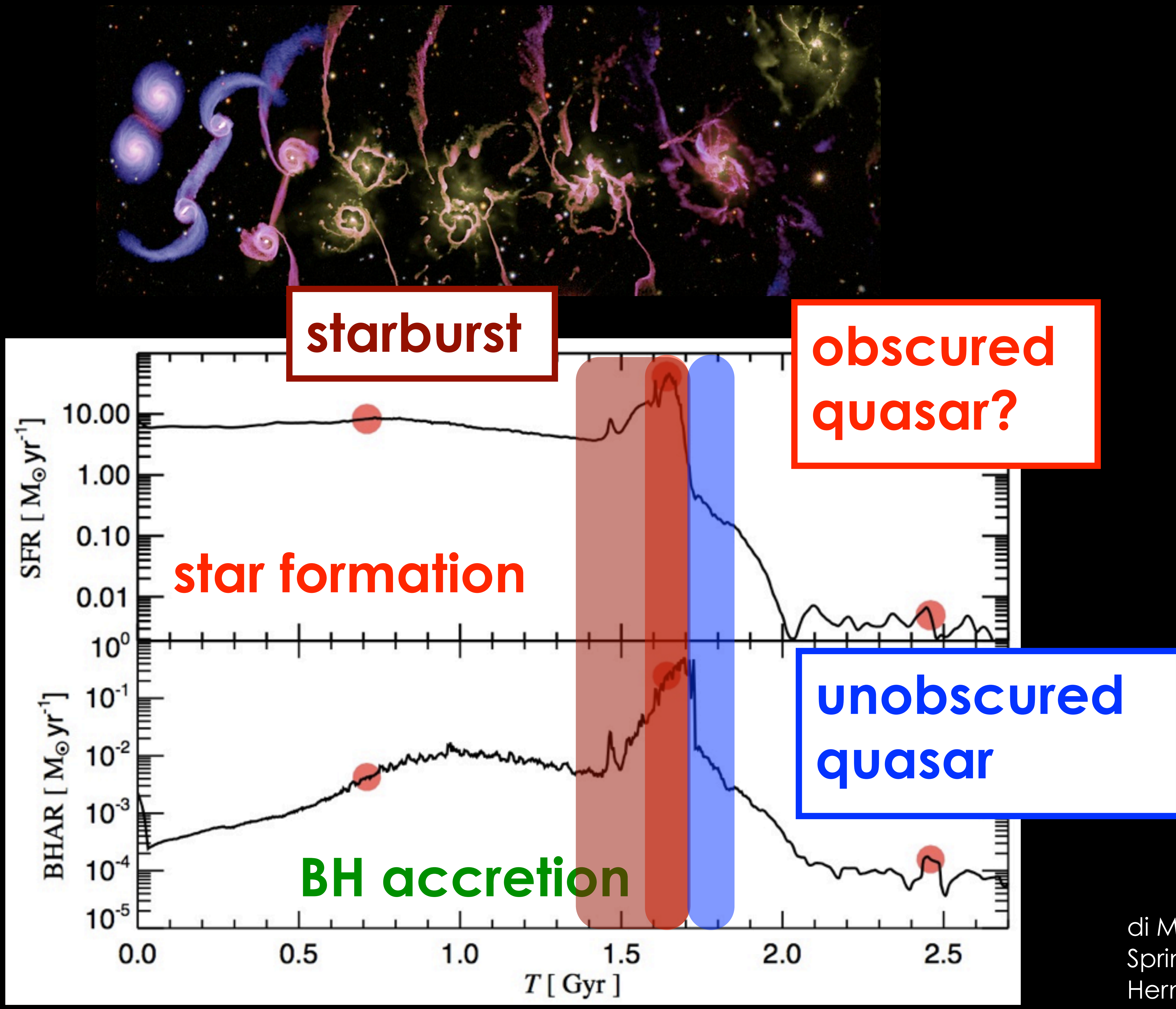
di Matteo et al. (2005), Springel, di Matteo & Hernquist (2005)

Obscured quasars as an evolutionary phase



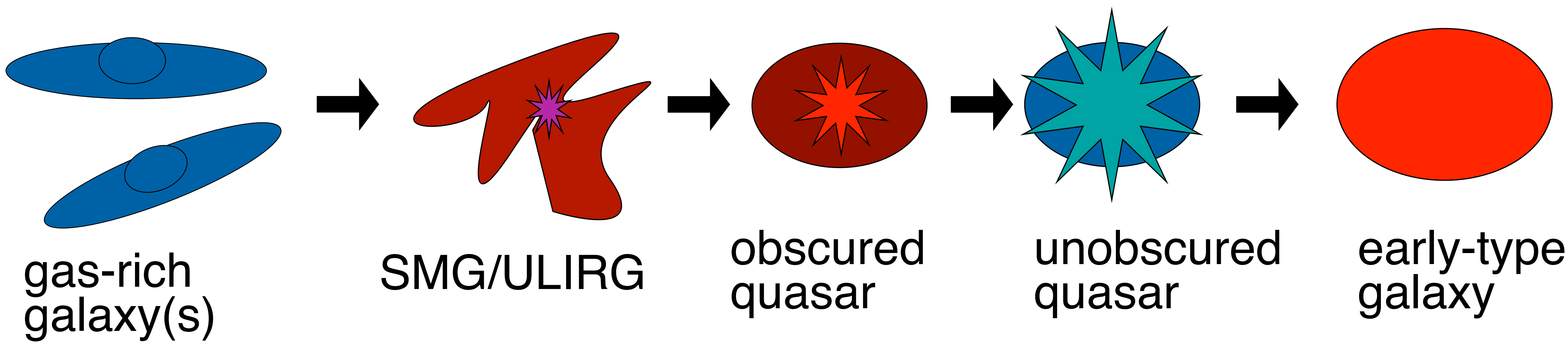
di Matteo et al. (2005),
Springel, di Matteo &
Hernquist (2005)

Obscured quasars as an evolutionary phase



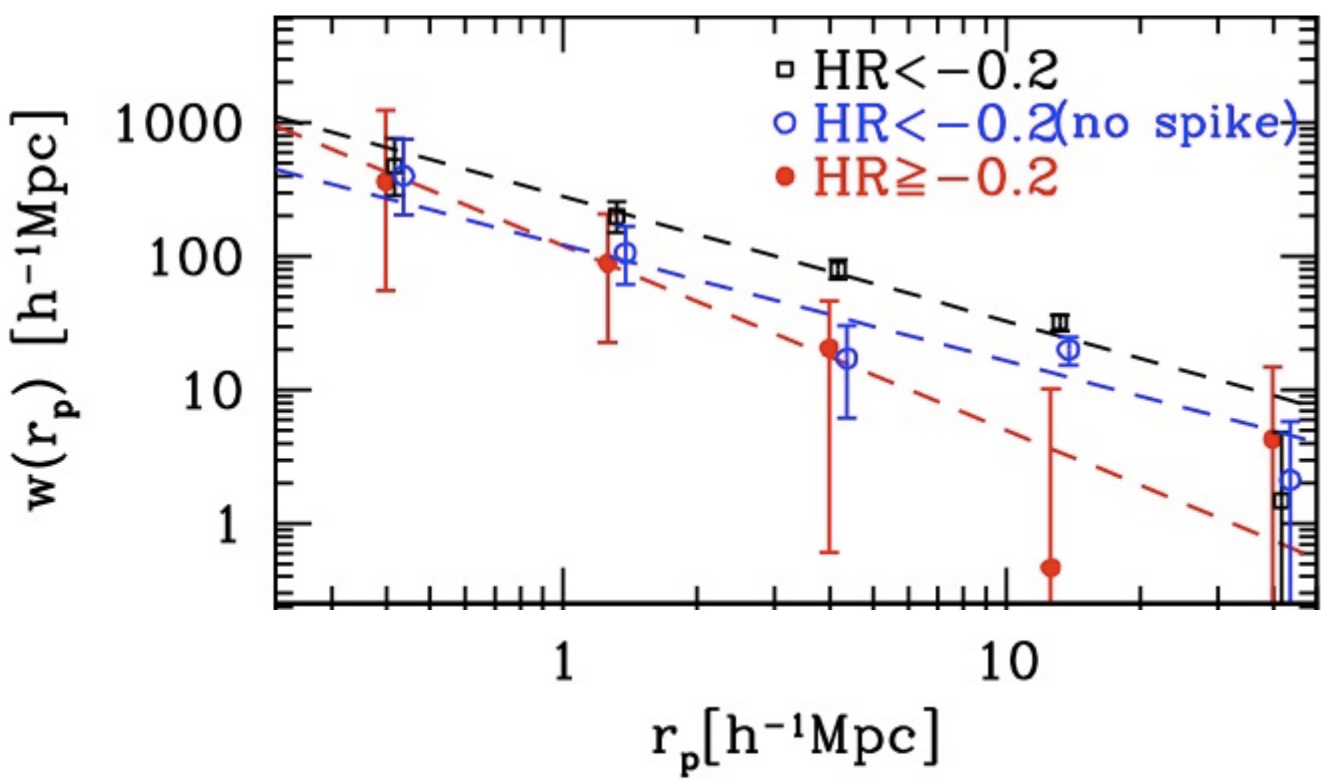
di Matteo et al. (2005), Springel, di Matteo & Hernquist (2005)

Obscured quasars as an evolutionary phase

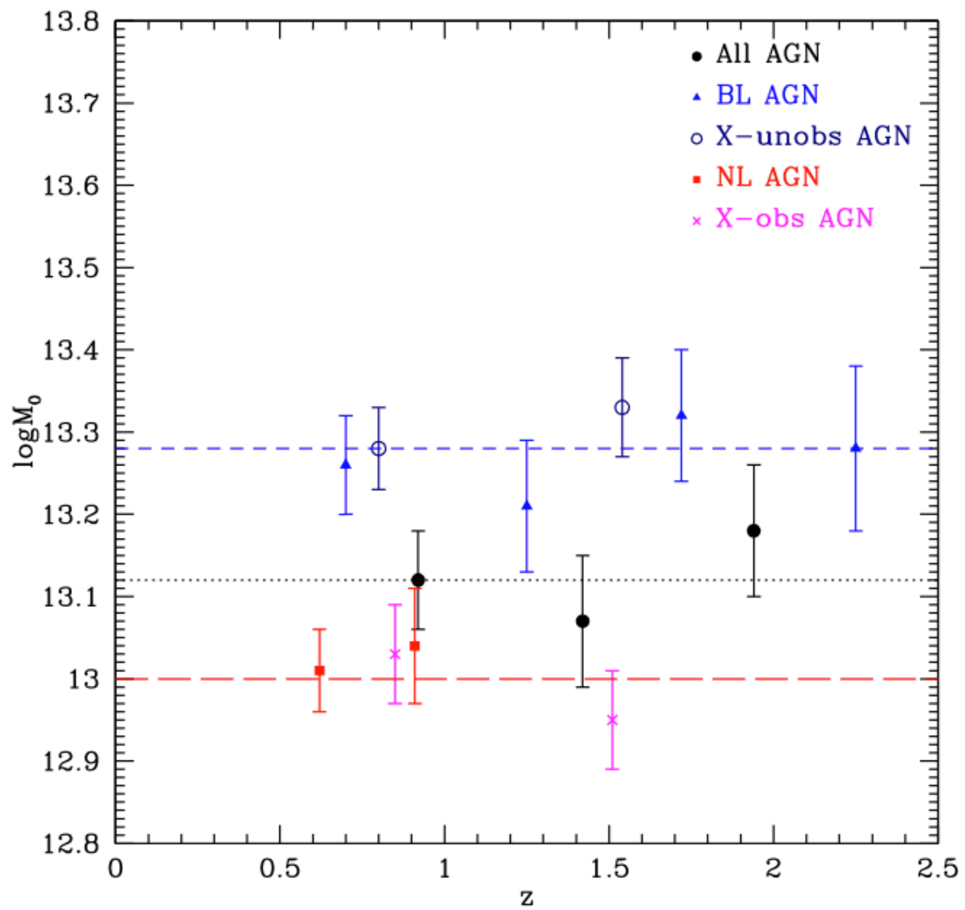


e.g., Sanders et al. (1988), figure from Alexander & Hickox (2012)

Previous studies of X-ray AGN



OR



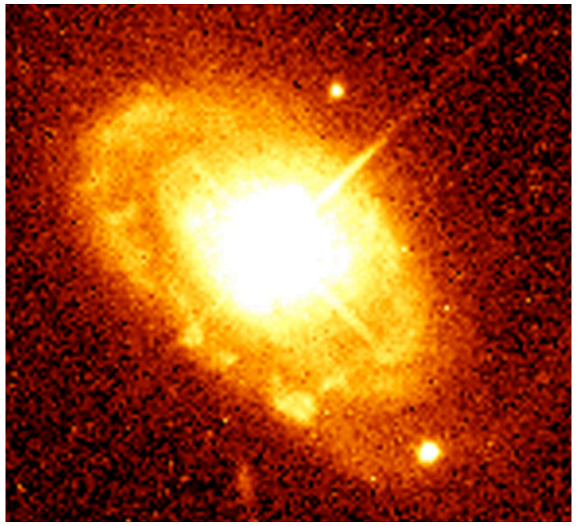
NO significant difference between obscured and unobscured X-ray AGN

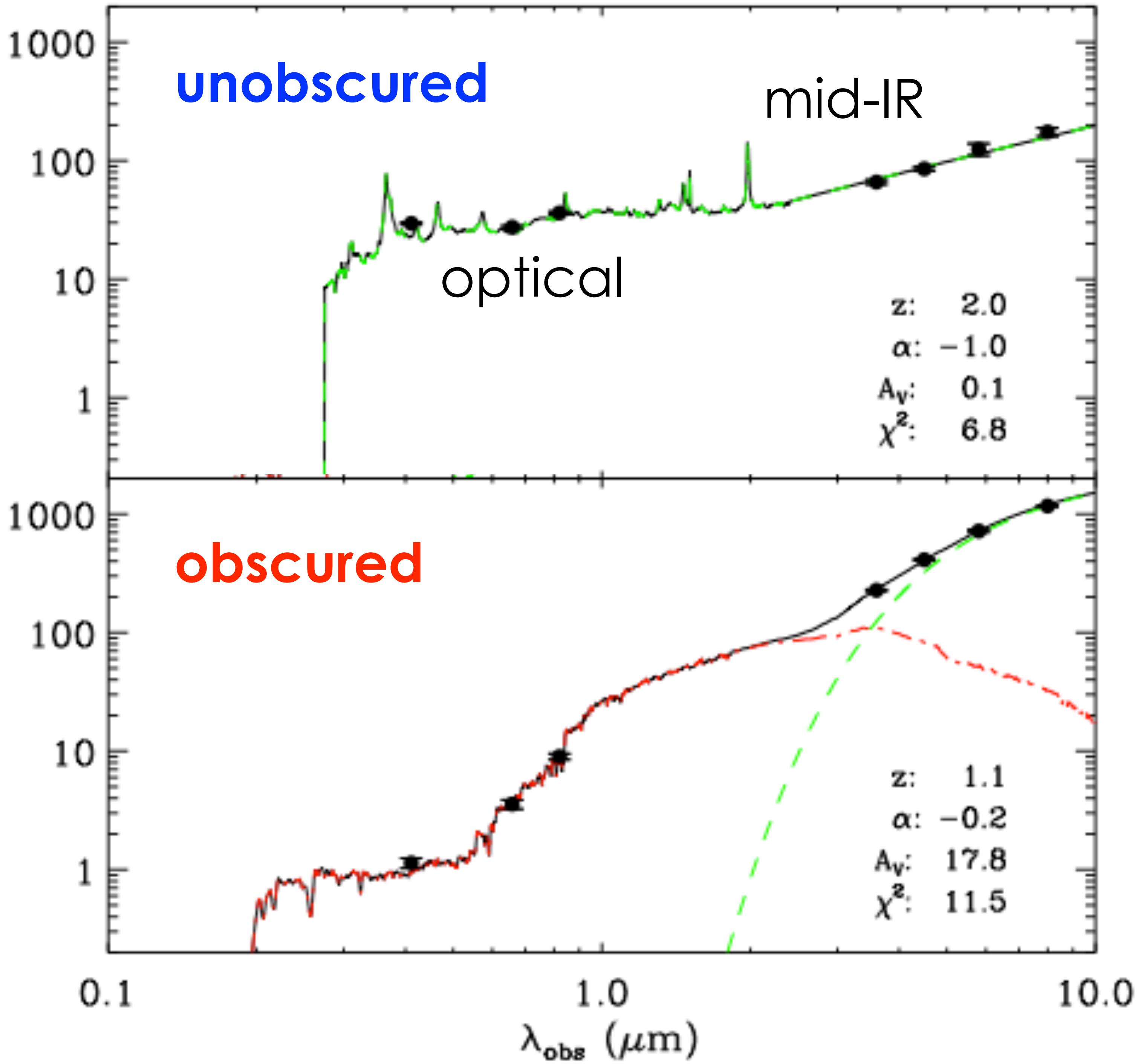
(Gilli et al. 2009, see also Gandhi et al. 2006, Krumpe et al. (2012))

Stronger clustering for unobscured X-ray AGN

(Allevato et al. 2011, see also Cappelluti et al. ??)

Mid-IR selection of obscured quasars

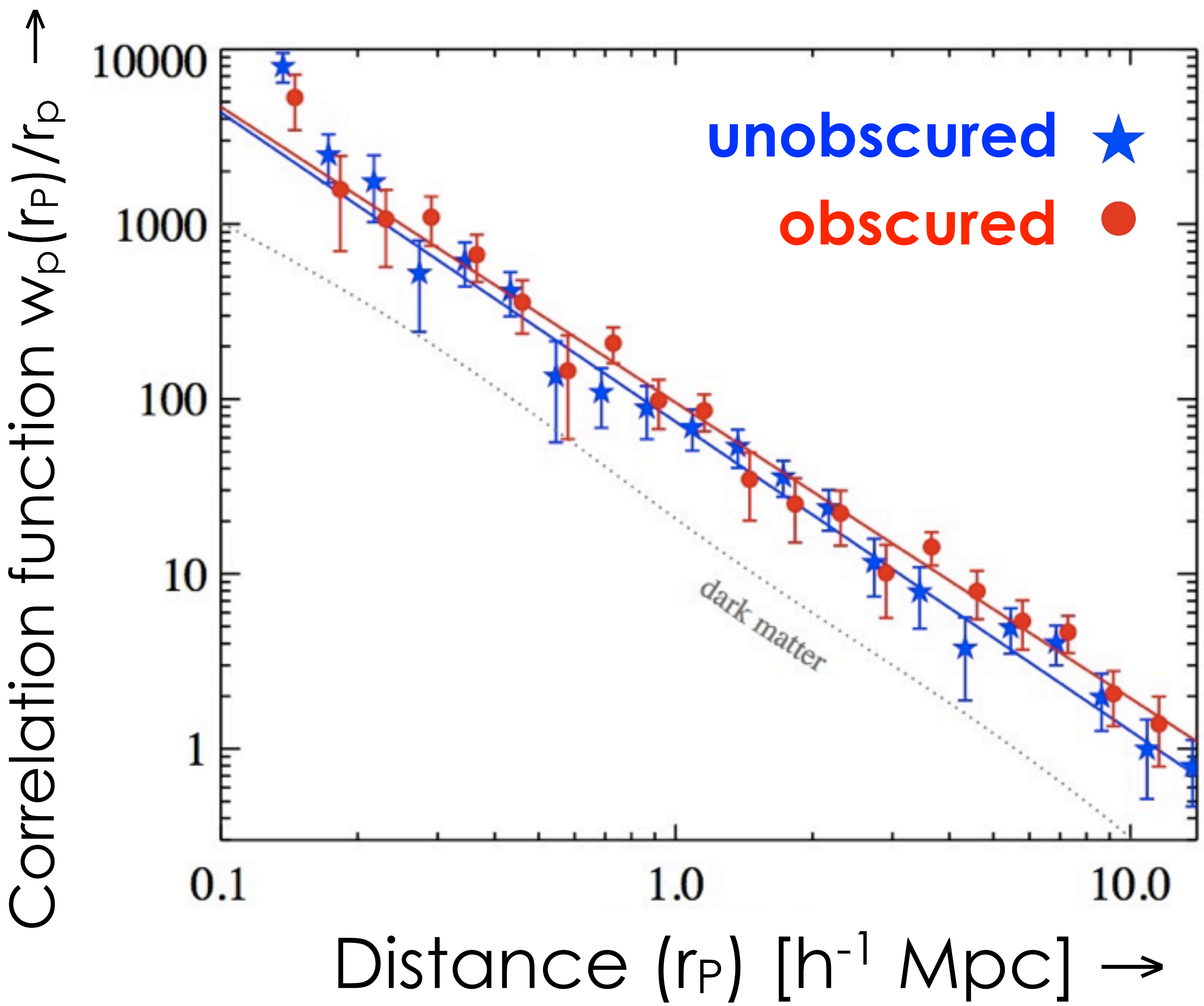


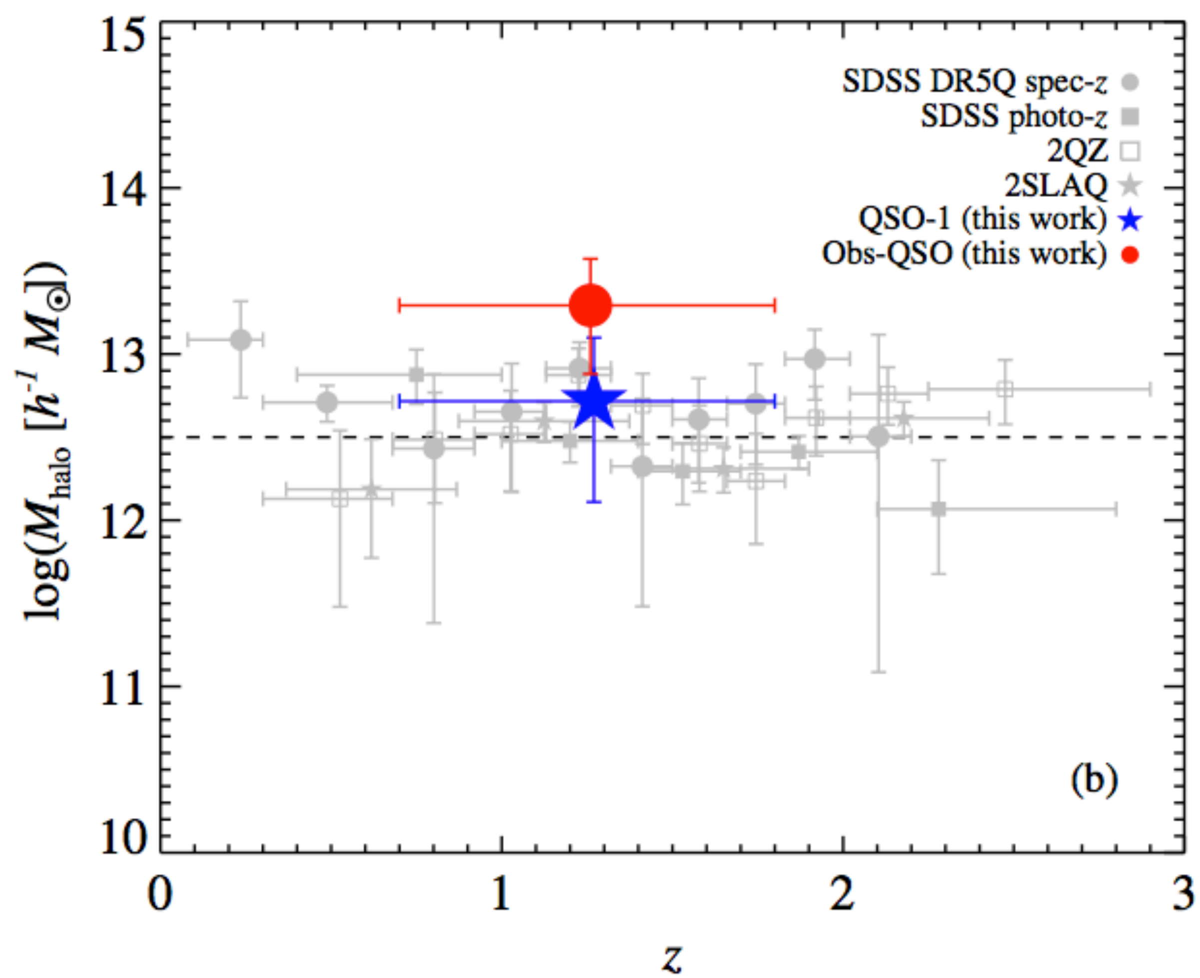


Can be differentiated based on **optical-IR color**

Hickox et al. (2007)

IRAC-selected quasar clustering

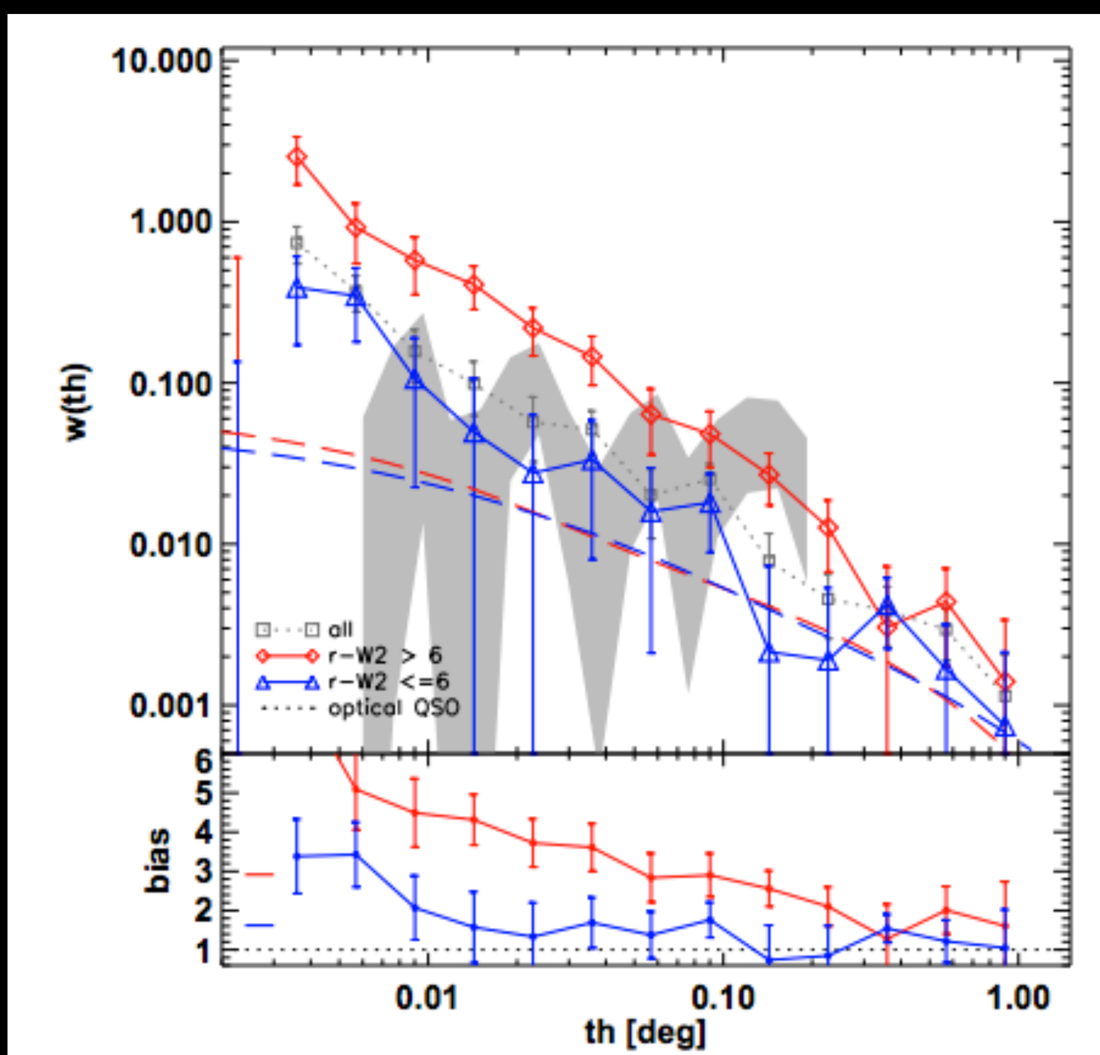




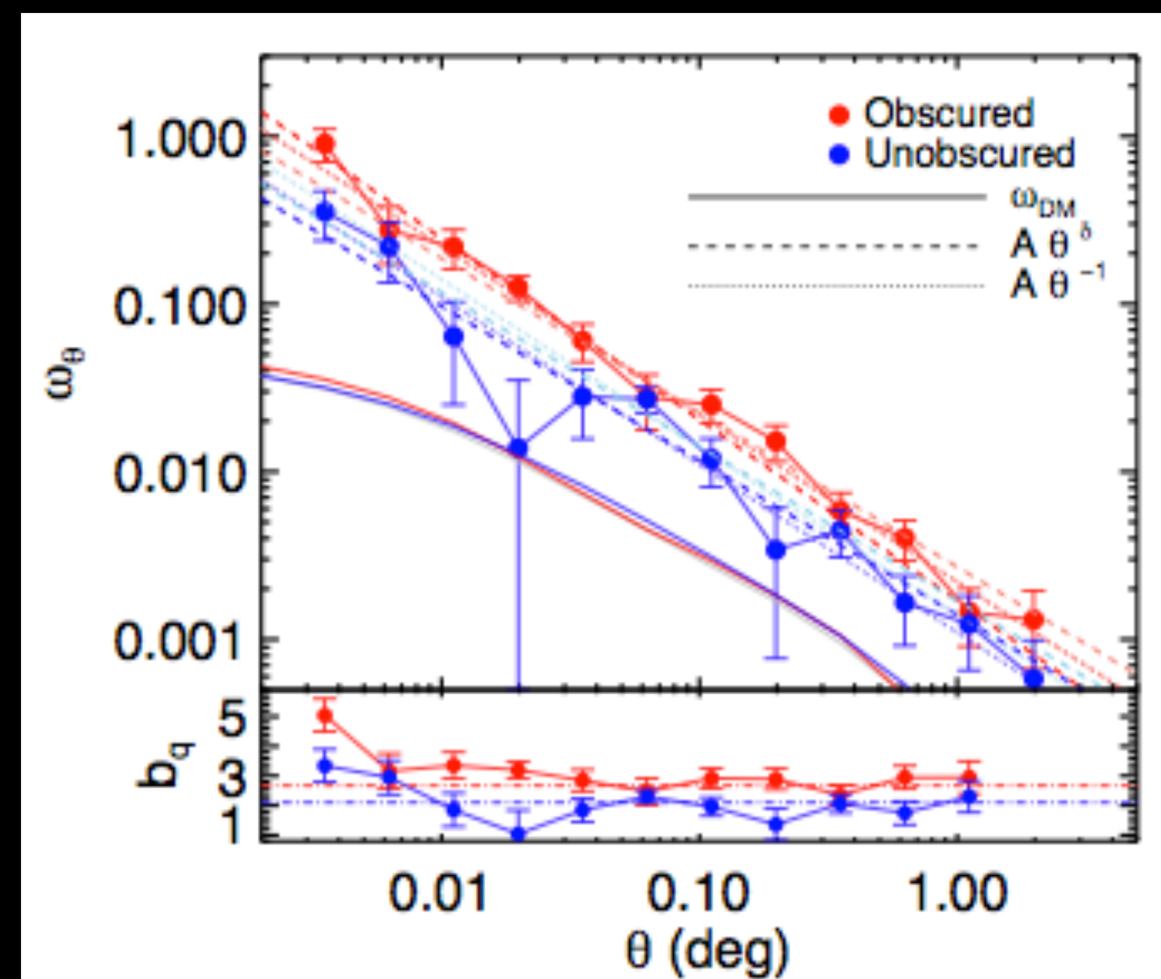
Hickox et al. (2011)

The next step: *Wide-Field Infrared Survey Explorer*

Sensitive all-sky mid-IR survey with hundreds of thousands of **obscured quasars**

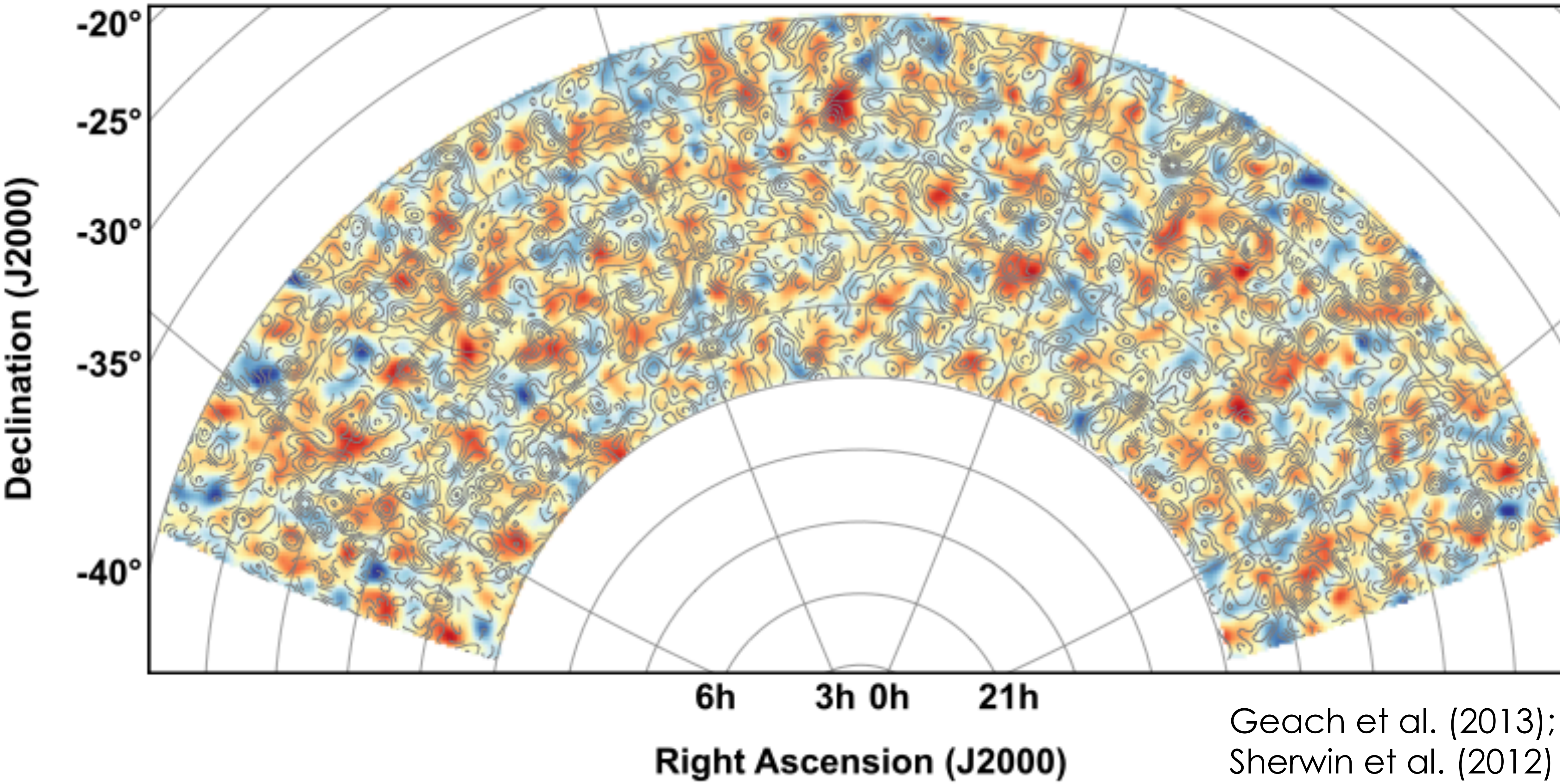


Donoso et al. (2014)

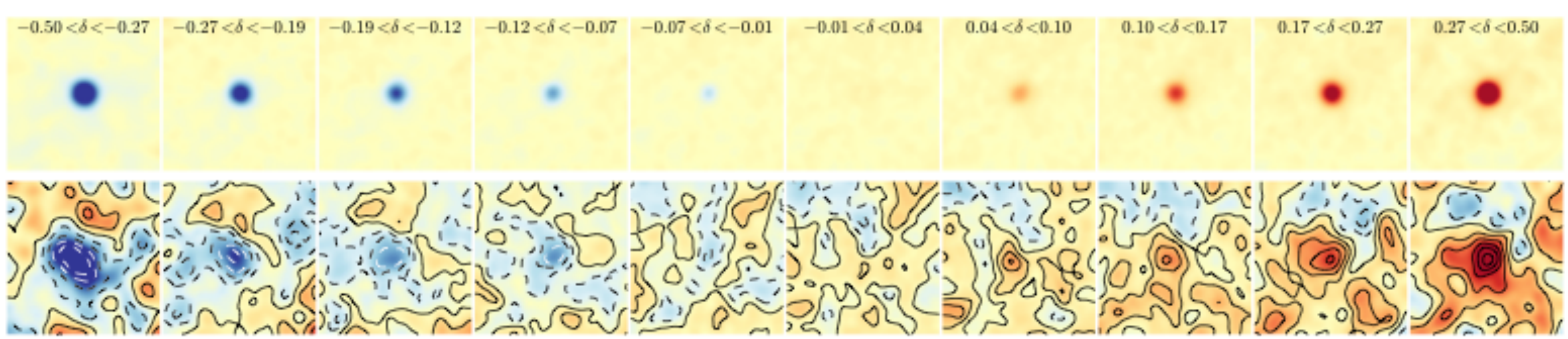


DiPompeo et al. (2014a)

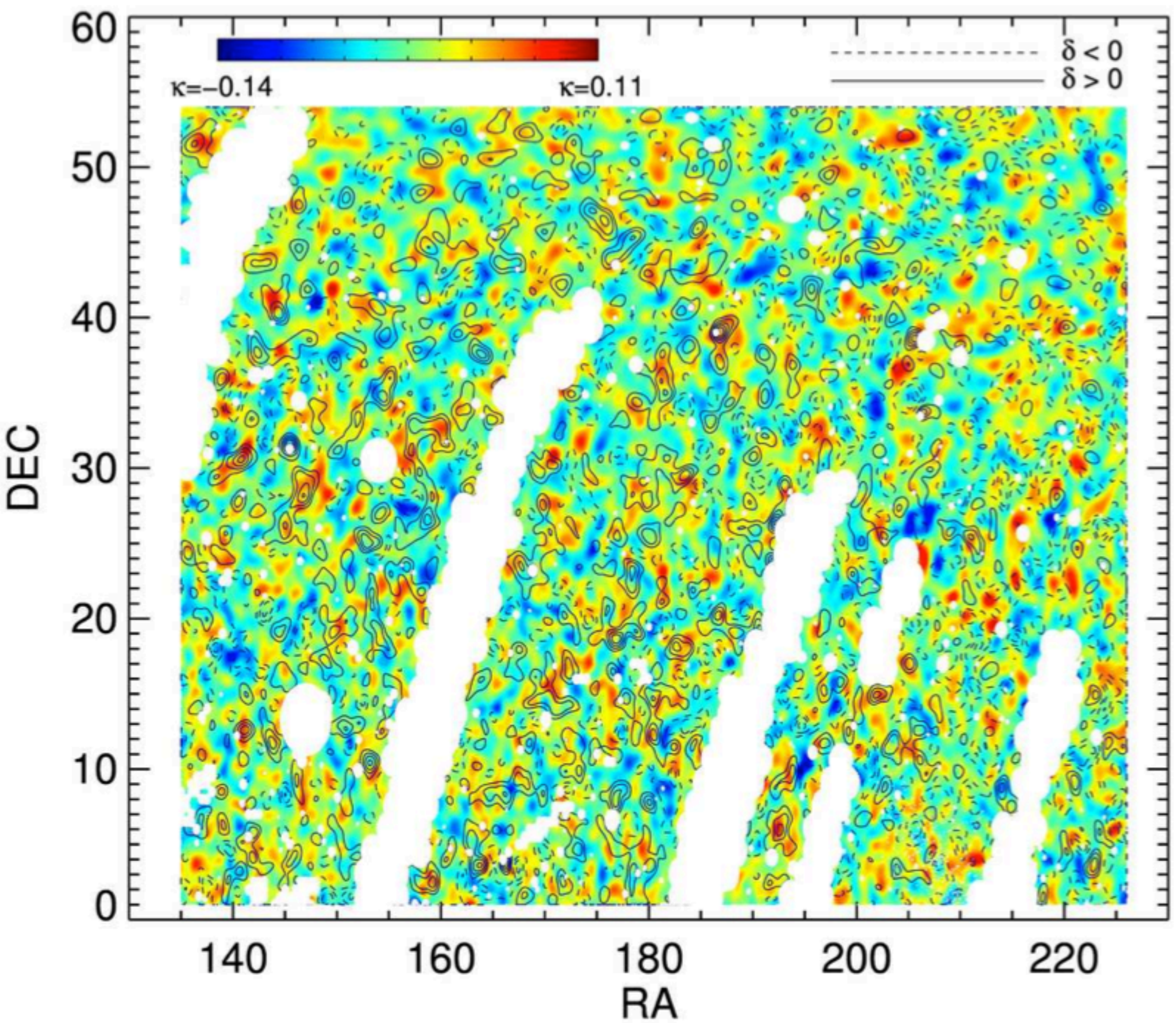
Independent check: Cross-correlation with **CMB lensing**

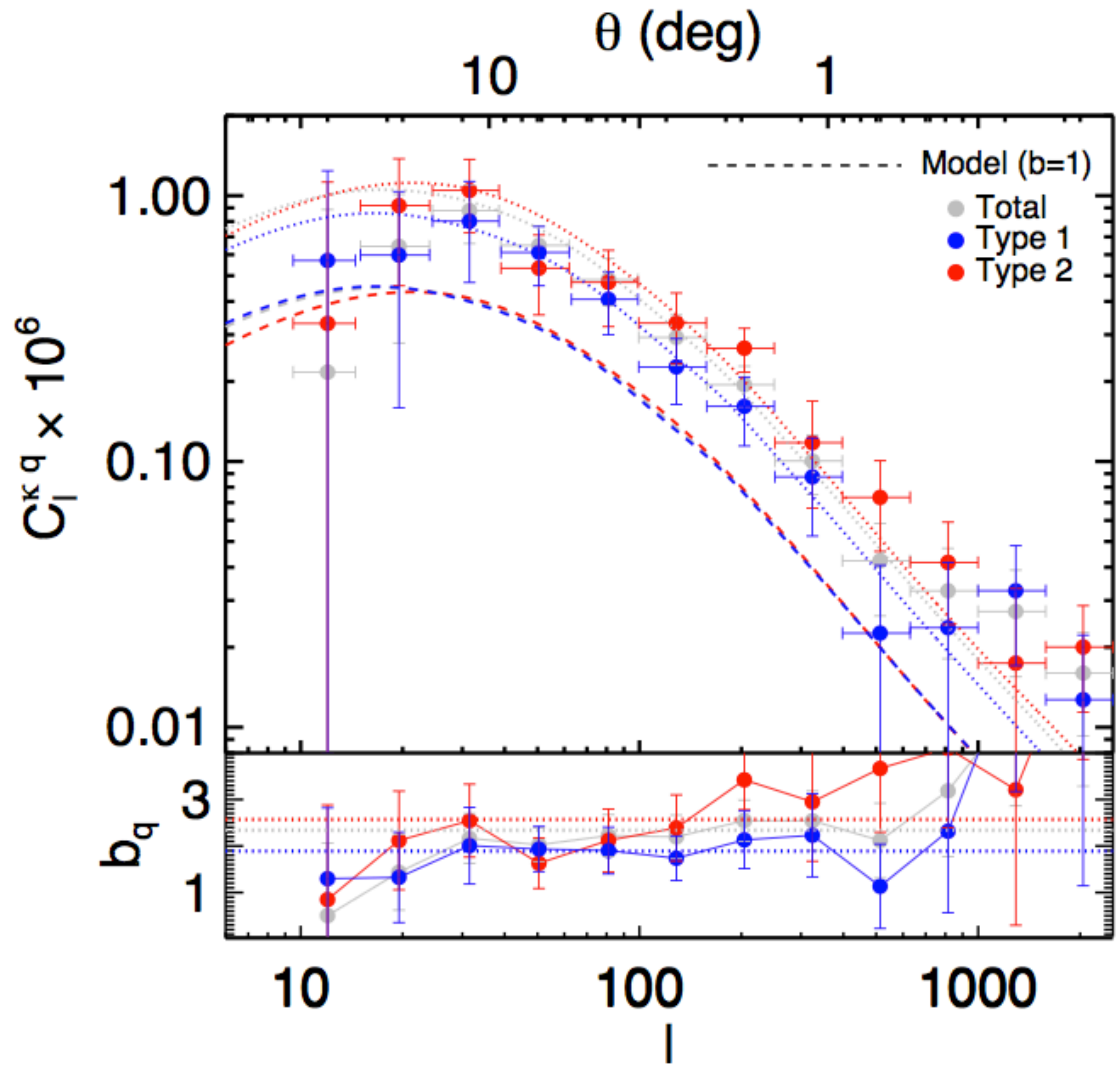


Geach et al. (2013); see Sherwin et al. (2012)



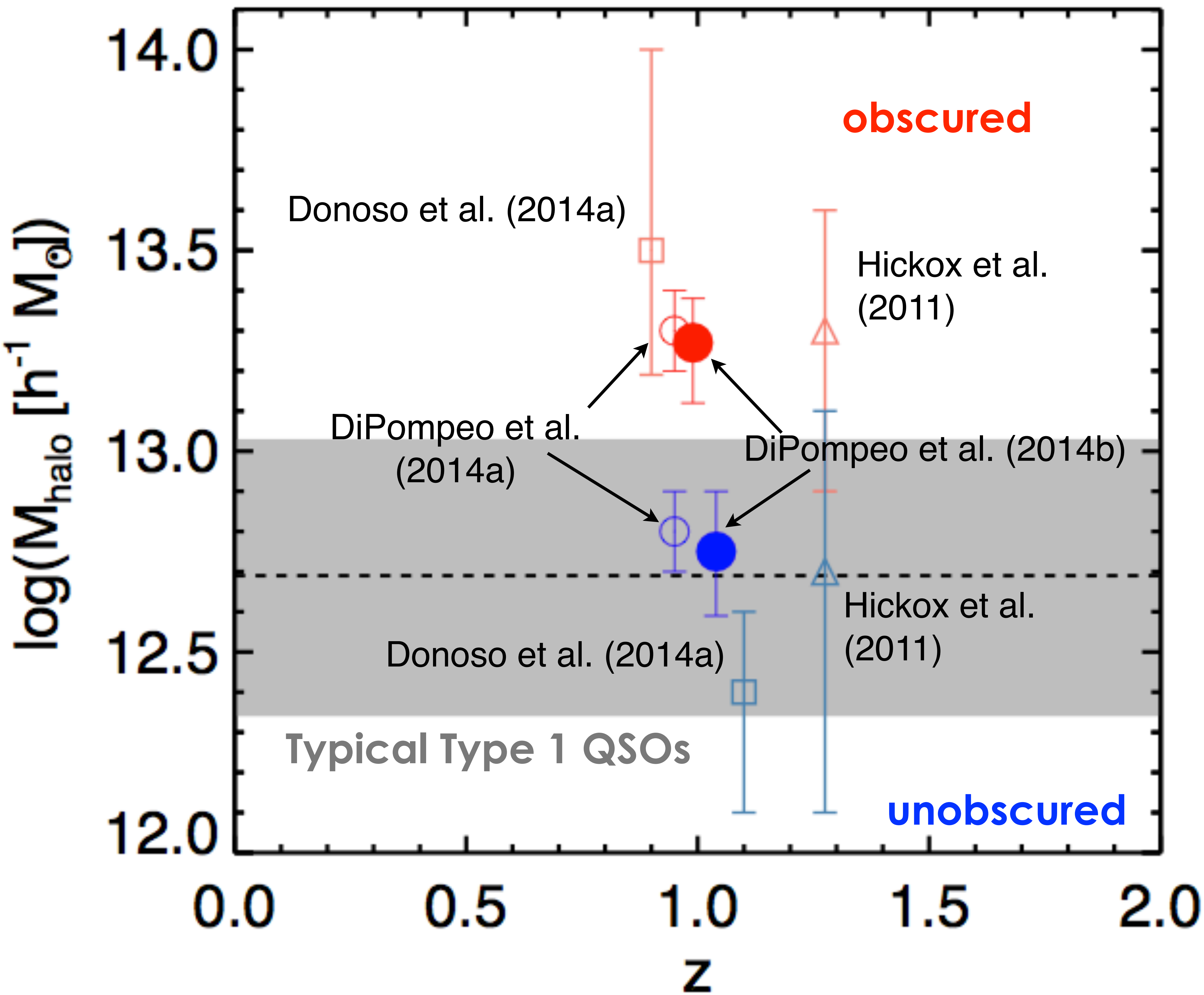
Independent check: Cross-correlation with **CMB lensing**





DiPompeo et al. (2014b, in prep)

Mid-IR selected quasar clustering: The current view

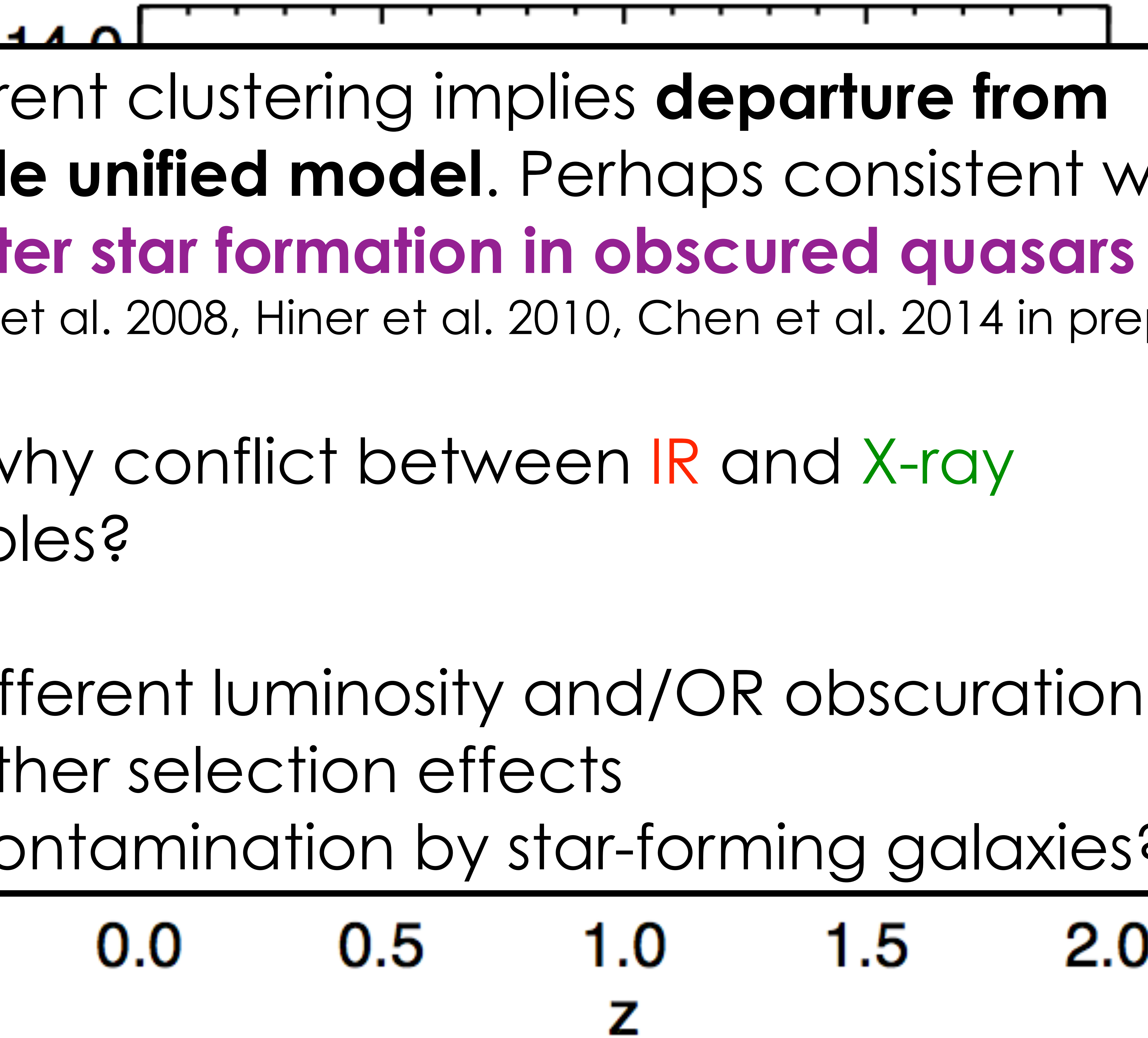


Mid-IR selected quasar clustering: The current view

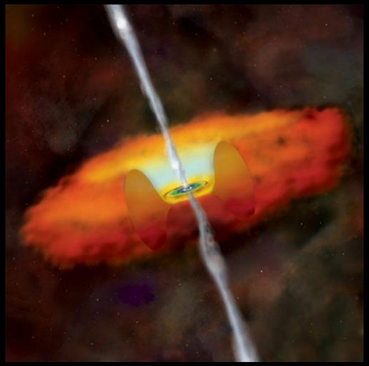
Different clustering implies **departure from simple unified model**. Perhaps consistent with **greater star formation in obscured quasars**
(Brusa et al. 2008, Hiner et al. 2010, Chen et al. 2014 in prep)

BUT why conflict between IR and X-ray samples?

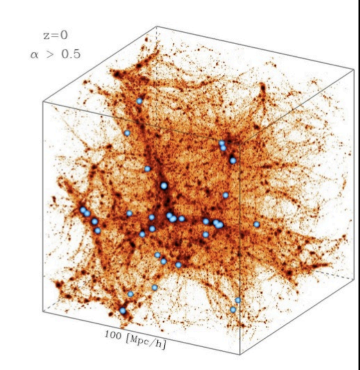
- Different luminosity and/OR obscuration
- Other selection effects
- Contamination by star-forming galaxies?



Ideas to take away



1. **The Zoo of AGNs:** Multiwavelength selection is **required** to explore as much as possible of the AGN population



2. **The big picture:** Radiatively-dominated AGN **follow** star formation in low-mass halos, while mechanically-dominated AGN **prevent** star formation in massive halos

3. **A mystery:** Different clustering of obscured quasars indicates obscuring material beyond the unified model "torus". Why difference from X-ray studies?

A couple thoughts

1. **Power of AGN clustering** in revealing interesting physical insights about black hole, galaxy, and halo evolution

2. Important to place observations into **larger context**

Thanks and looking forward to an exciting week!