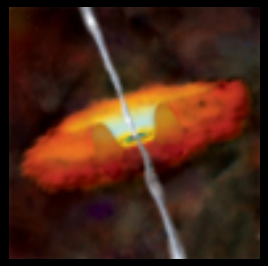
AGN evolution and the growth of supermassive black holes

Ryan C. Hickox
Dartmouth College

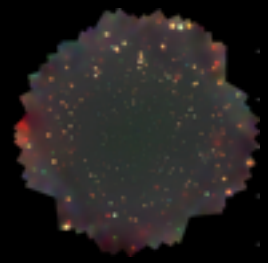
Black Hole Universe 2012
Bamberg, Germany
21 June 2012

Illustration courtesy NASA

Outline

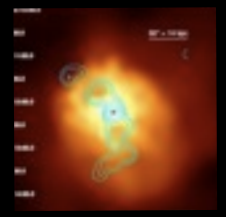


(Brief) introduction to supermassive black holes and active galactic nuclei



How does the BH population grow over cosmic time?

How is BH accretion connected to the growth of the host galaxy and dark matter halo?



Where and when is AGN feedback important?

Prospects for the future

What drives the growth of black holes?

D.M. Alexander [a,*], R.C. Hickox [a,b]

[a] Department of Physics, Durham University, South Road, Durham DH1 3LE
[b] Department of Physics and Astronomy, Dartmouth College, 6127 Wilder Laboratory, Hanover, NH 03755, United States

arXiv:1112.1949

Evolution of active galactic nuclei

A. Merloni*,[1] and S. Heinz†,[2]

[1]Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstr., D-85741, Garching, Germany
[2]Astronomy Department, University of Wisconsin-Madison, Madison, WI 53706

arXiv:1204.4265

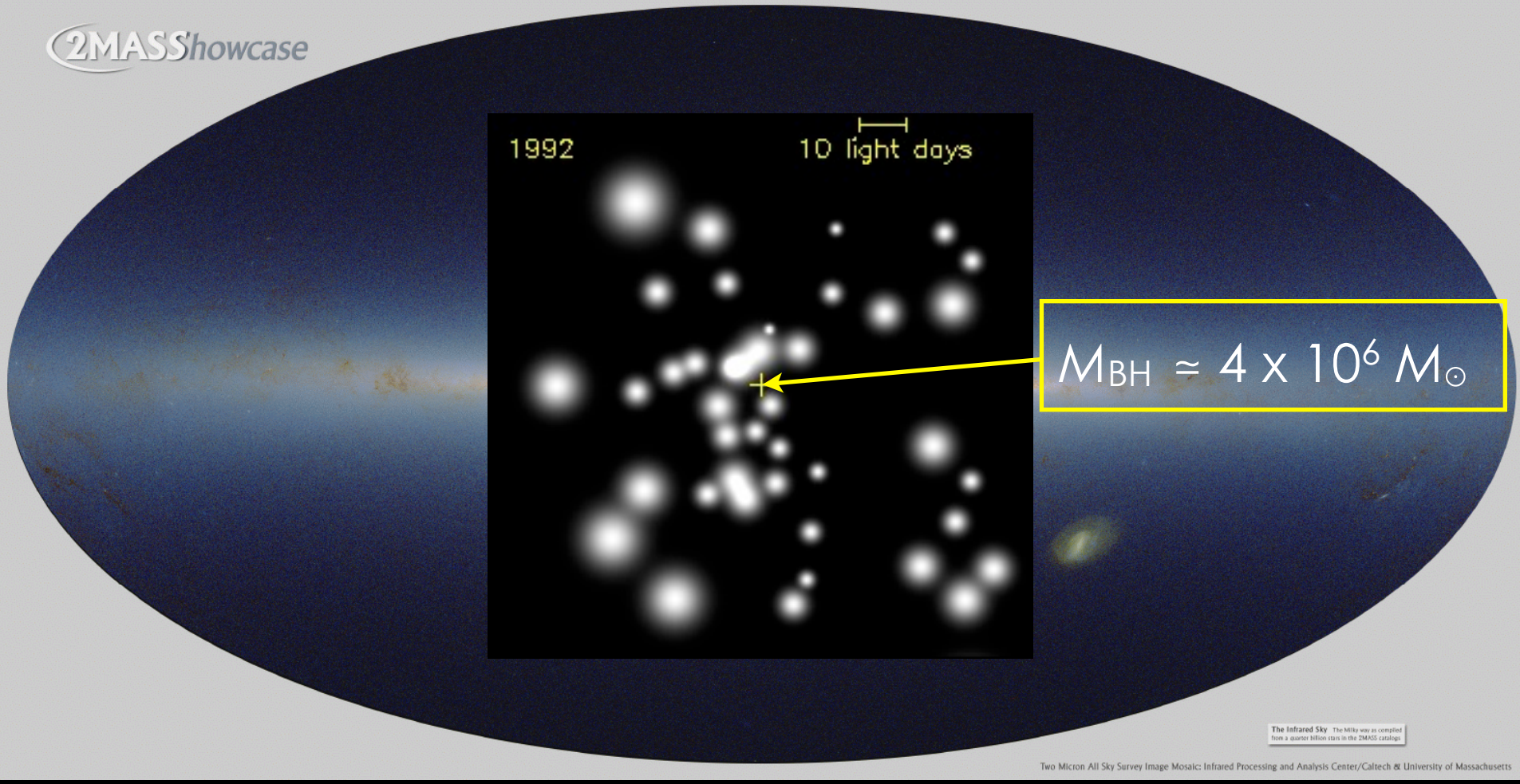
Observational Evidence of AGN Feedback

A.C Fabian

Institute of Astronomy, Madingley Road Cambridge CB3 0HA, UK

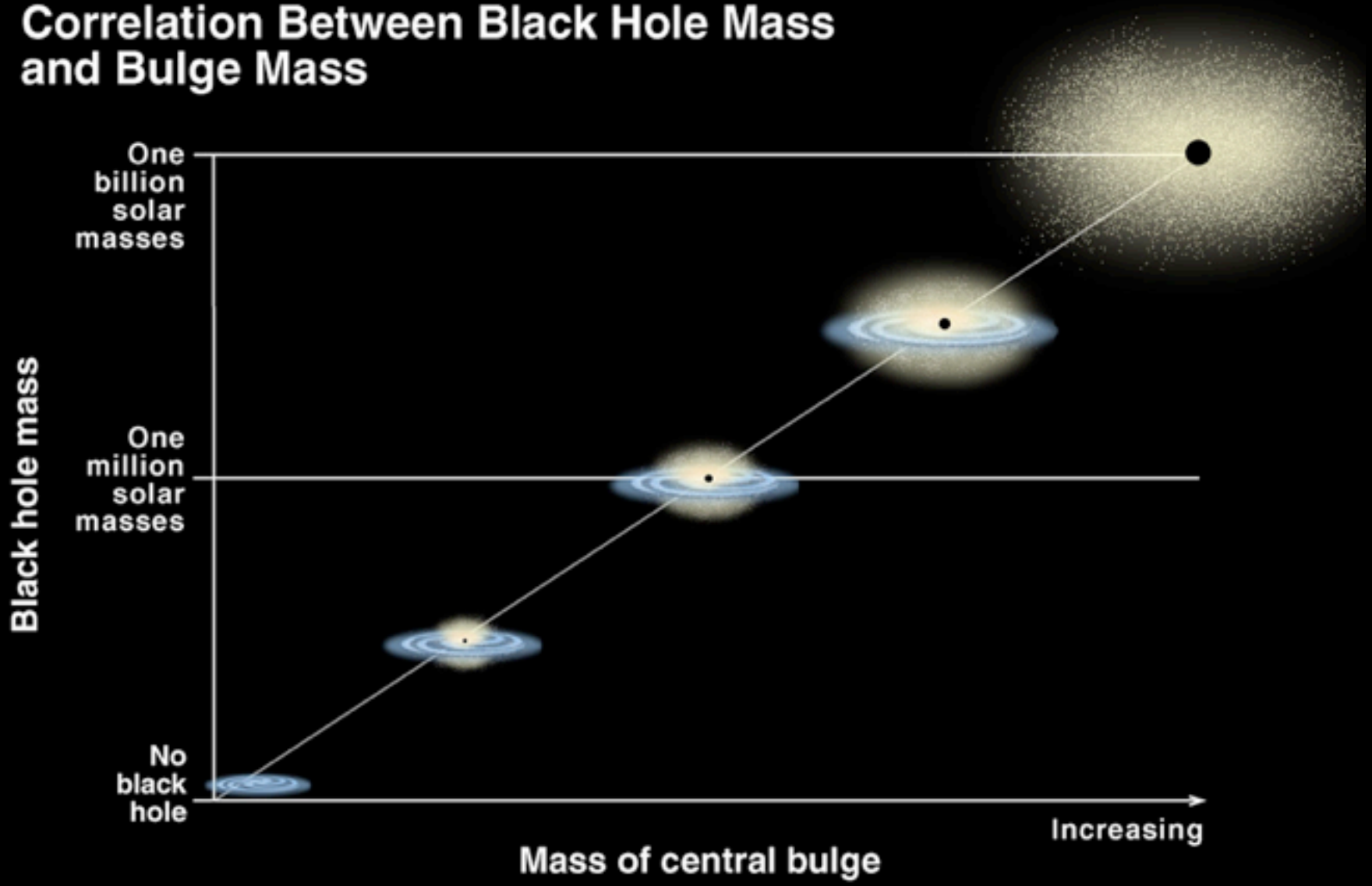
arXiv:1204.4114

Supermassive black holes are common!

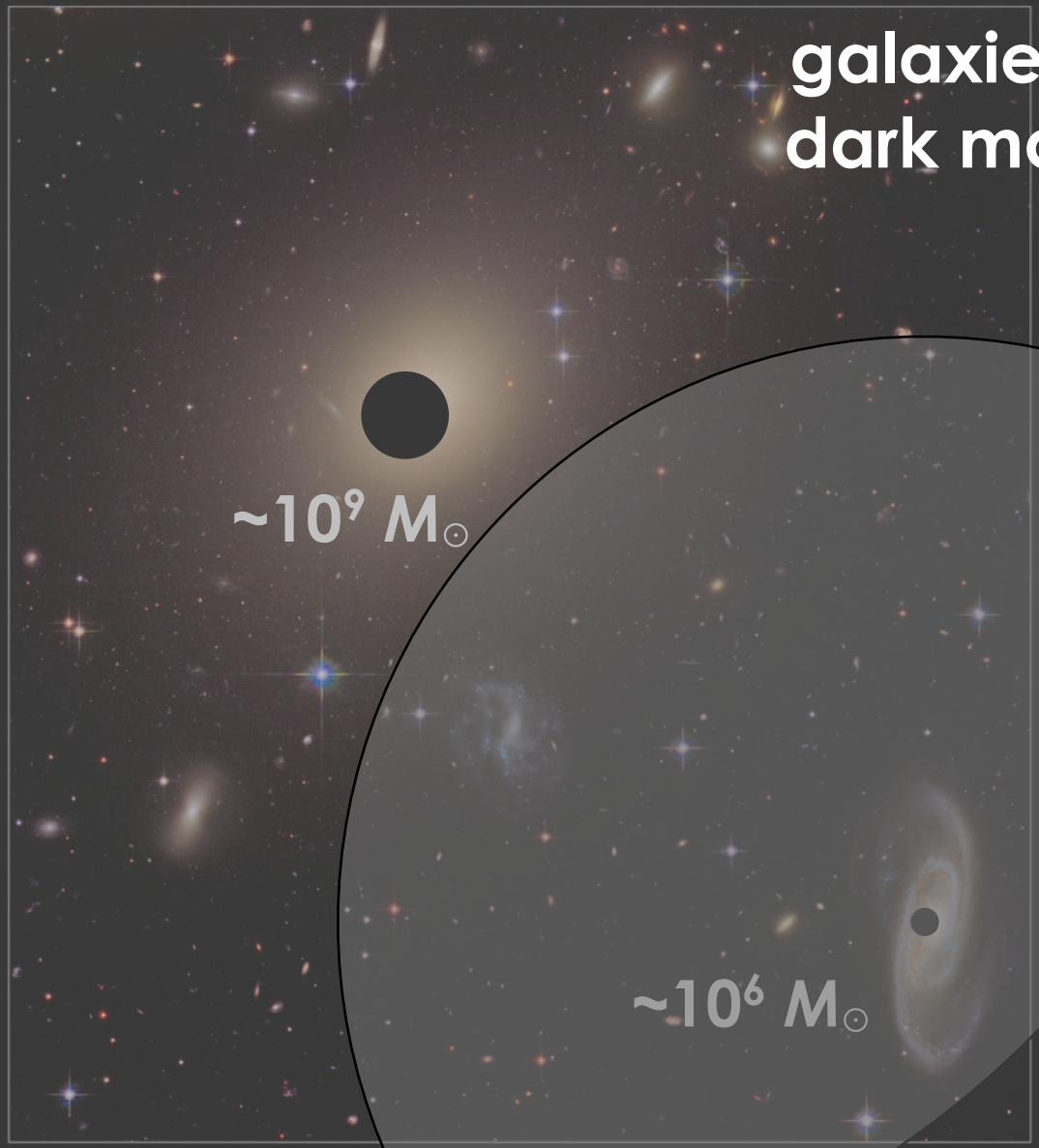


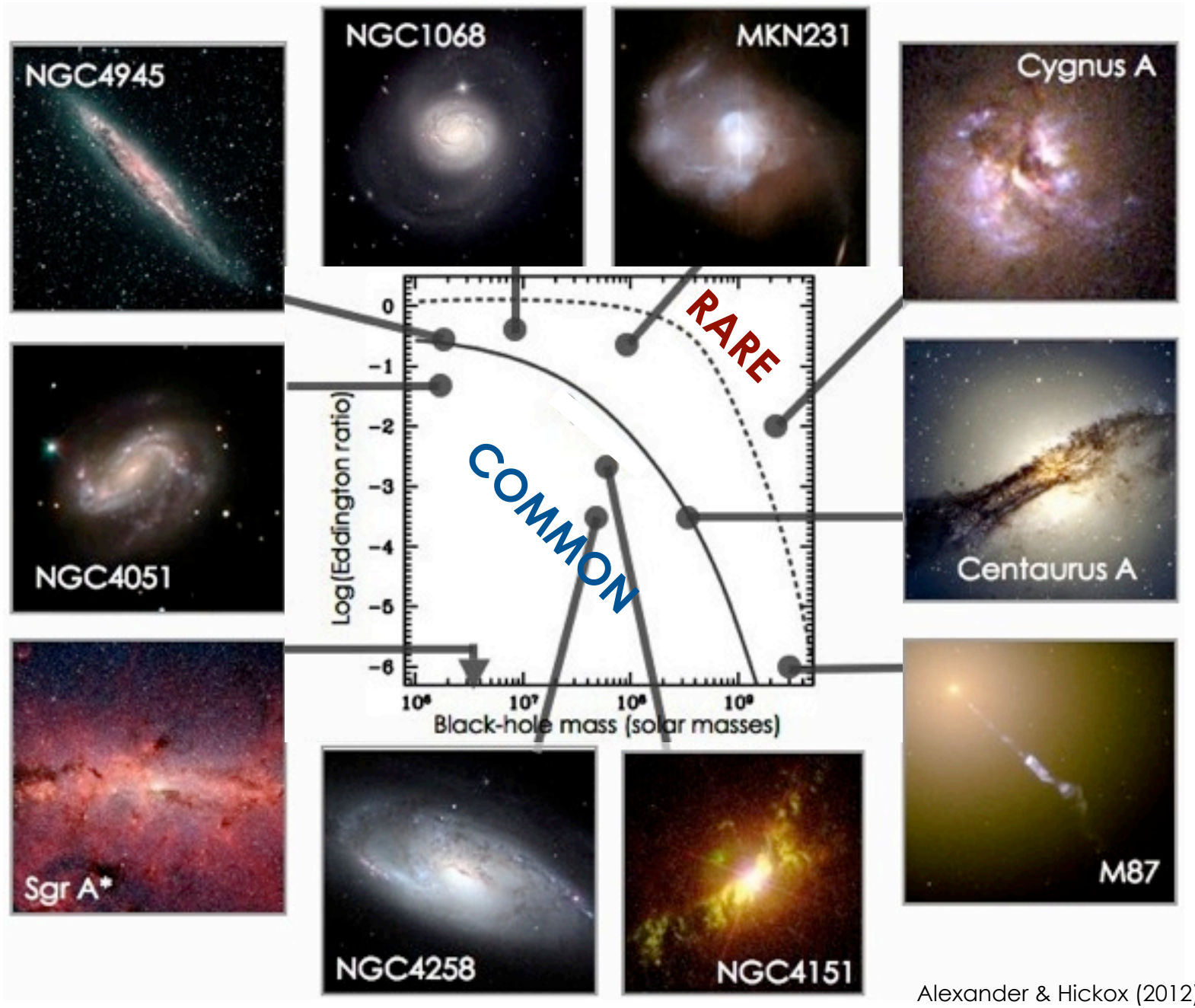
see e.g., Ghez et al. (2008), Gillessen et al. (2009)

Correlation Between Black Hole Mass and Bulge Mass



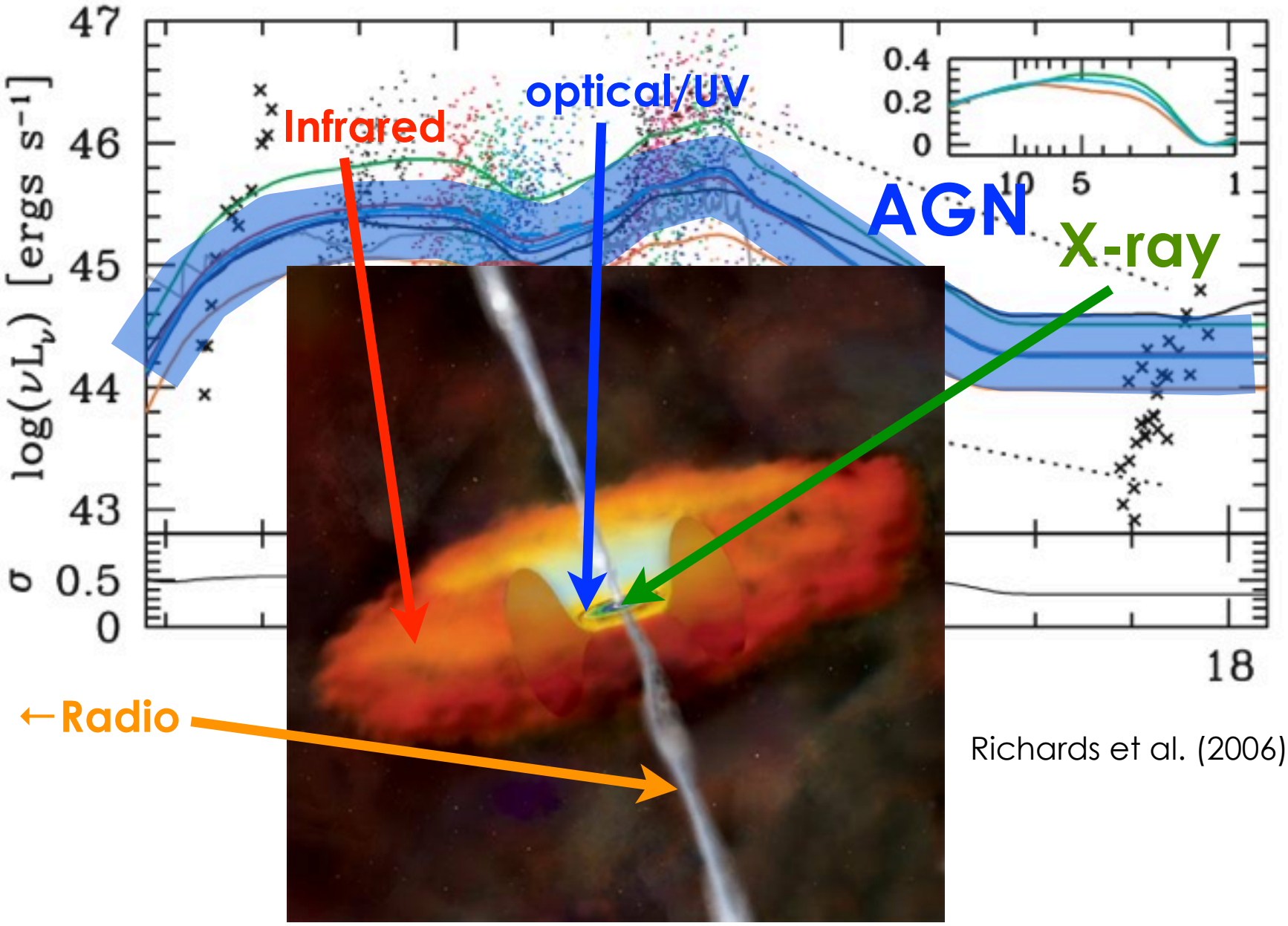
galaxies reside in dark matter halos





Alexander & Hickox (2012) *New Astronomy Reviews*

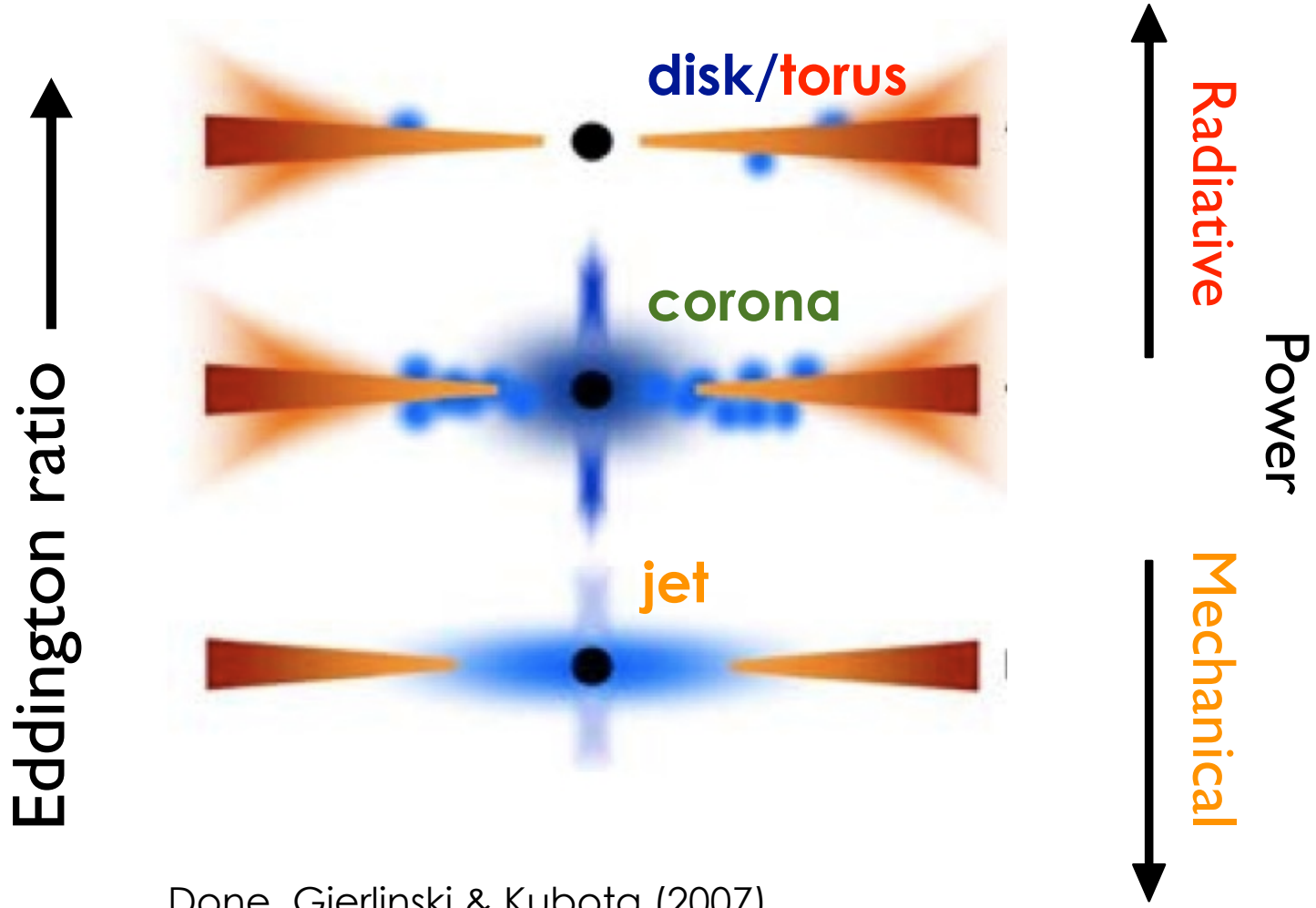
How do we detect AGN?



Richards et al. (2006)

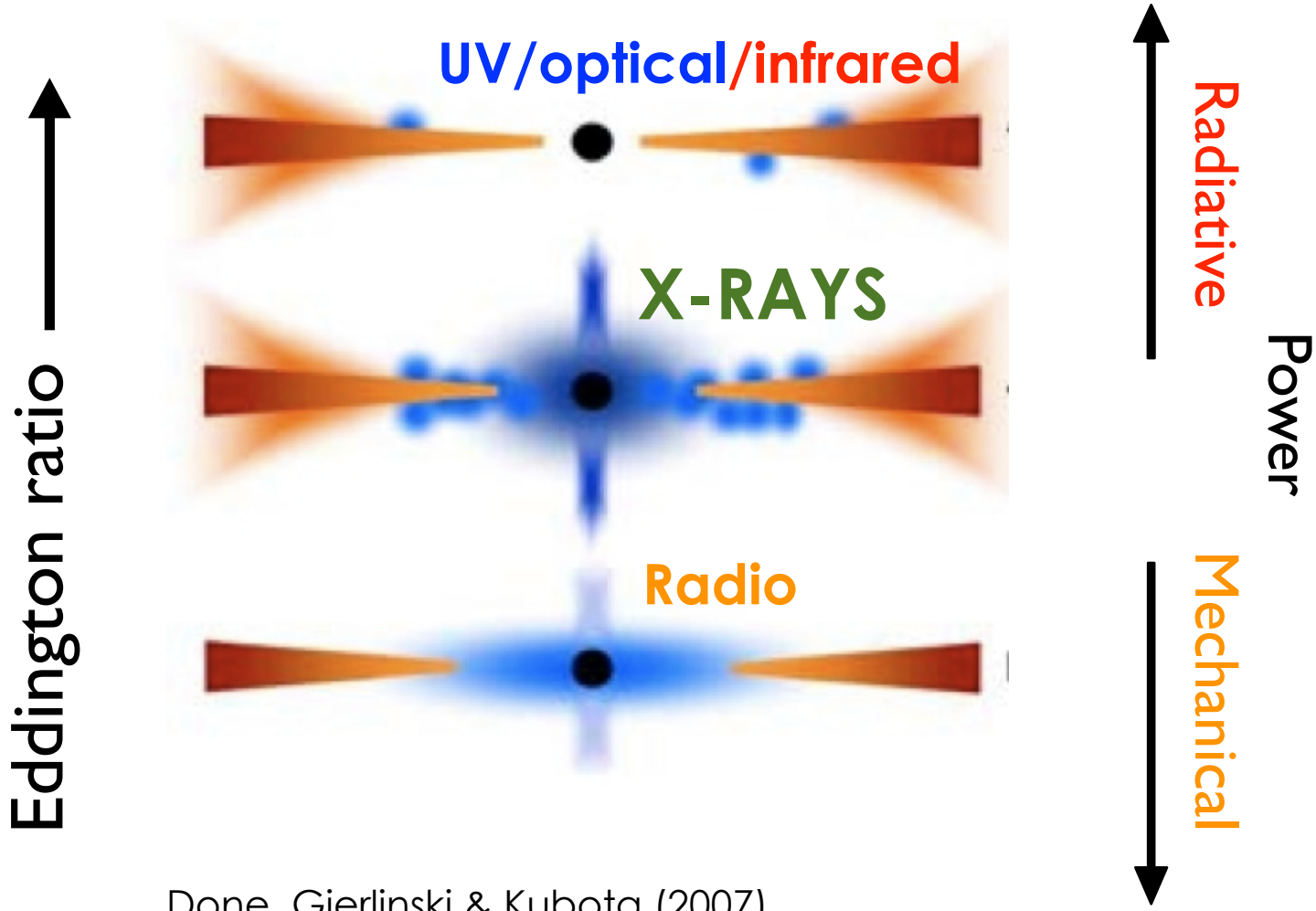
=

Accretion state **changes with Eddington ratio**



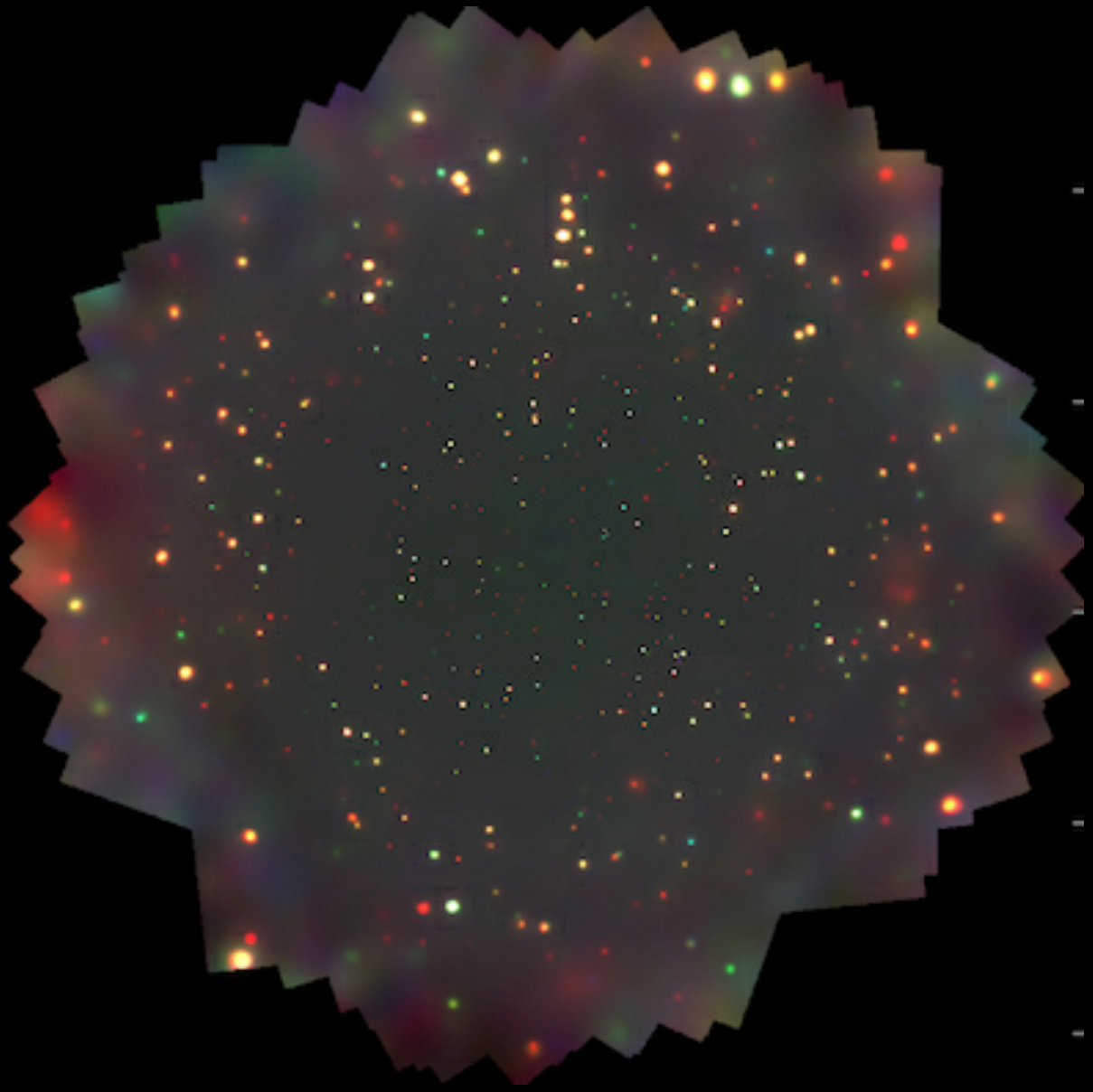
Done, Gierlinski & Kubota (2007)
see also Hopkins, Hickox et al. 2009

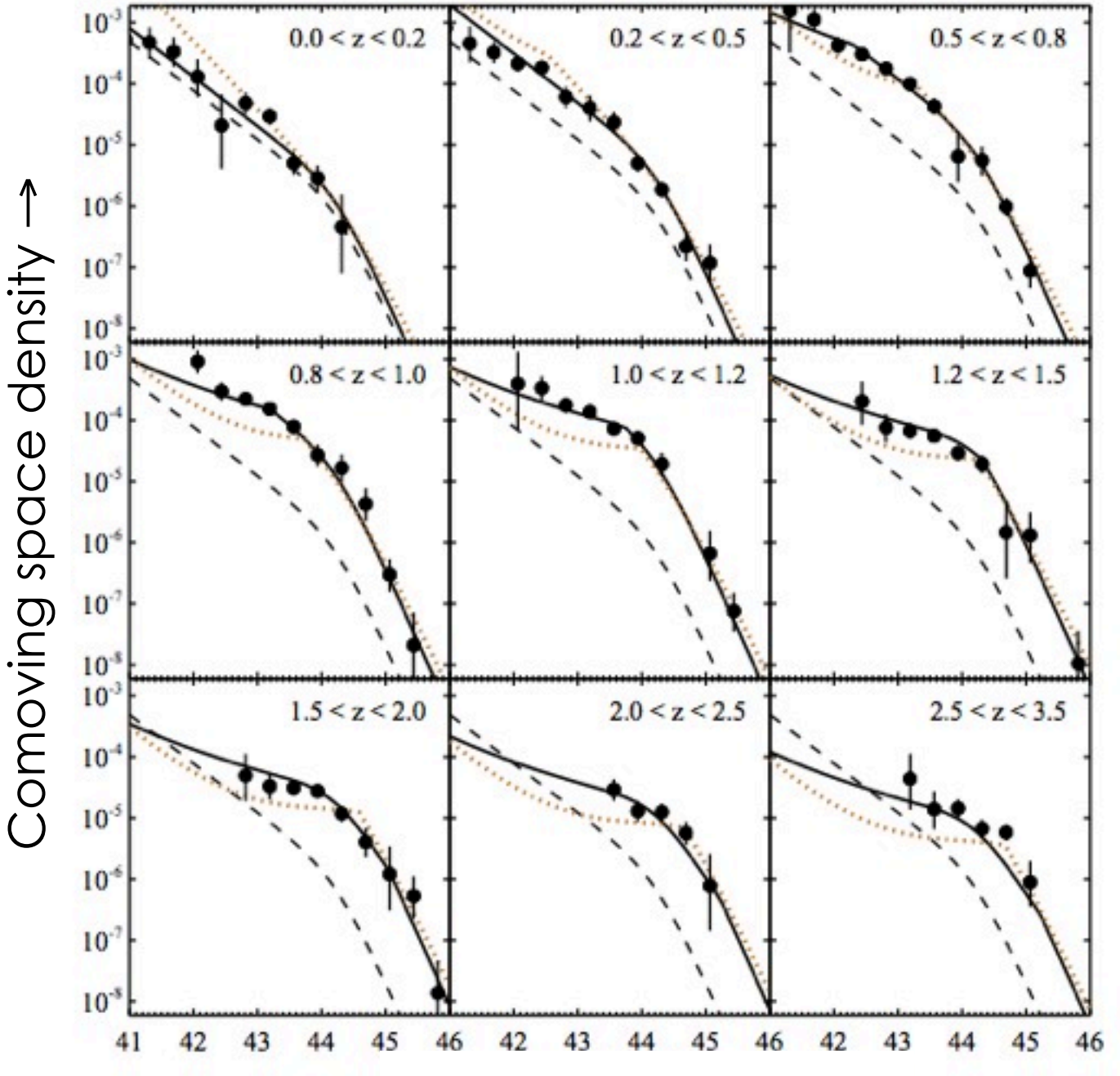
Accretion state **changes with Eddington ratio**



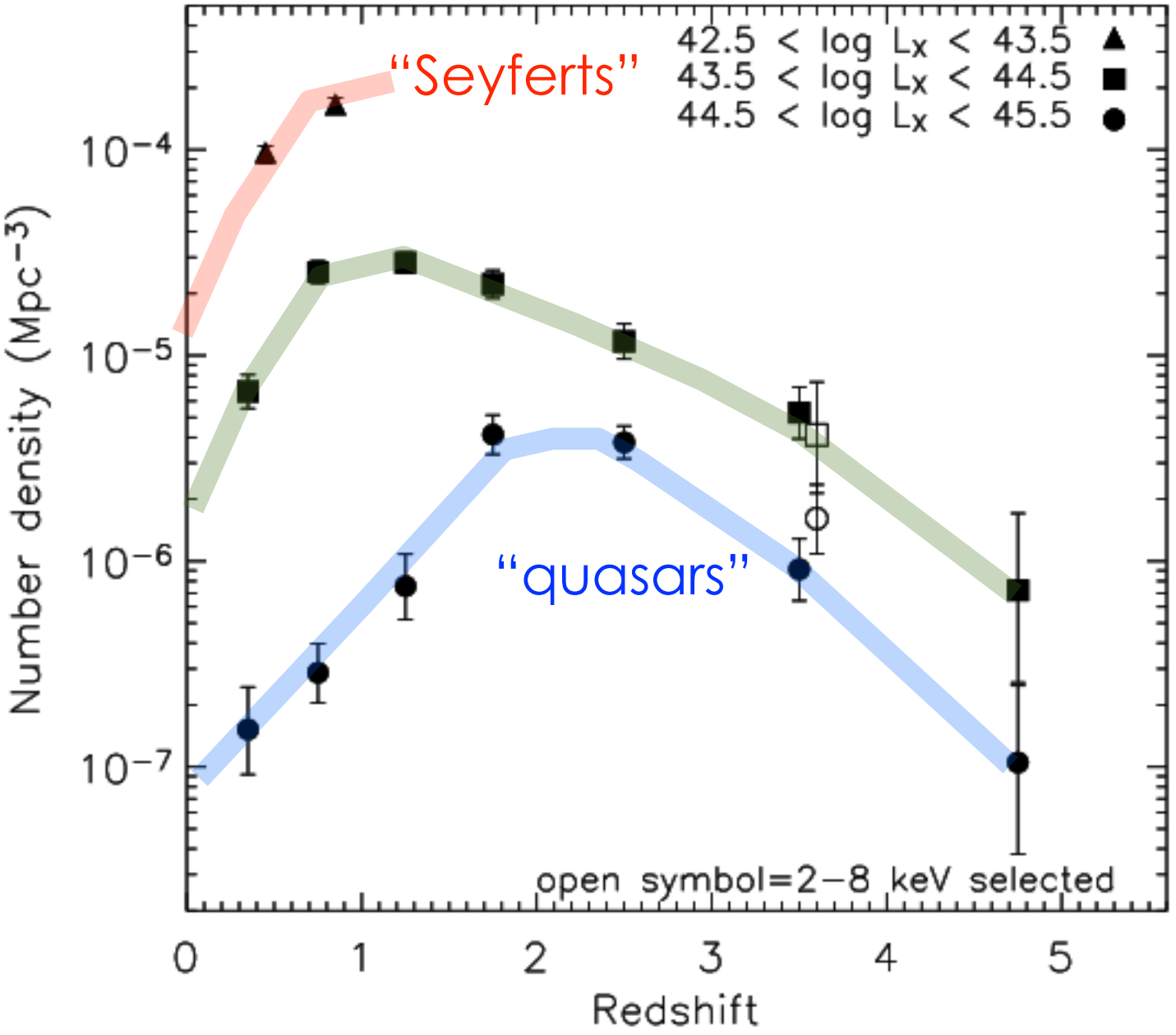
Done, Gierlinski & Kubota (2007)
see also Hopkins, Hickox et al. 2009

How does BH accretion evolve over cosmic time?





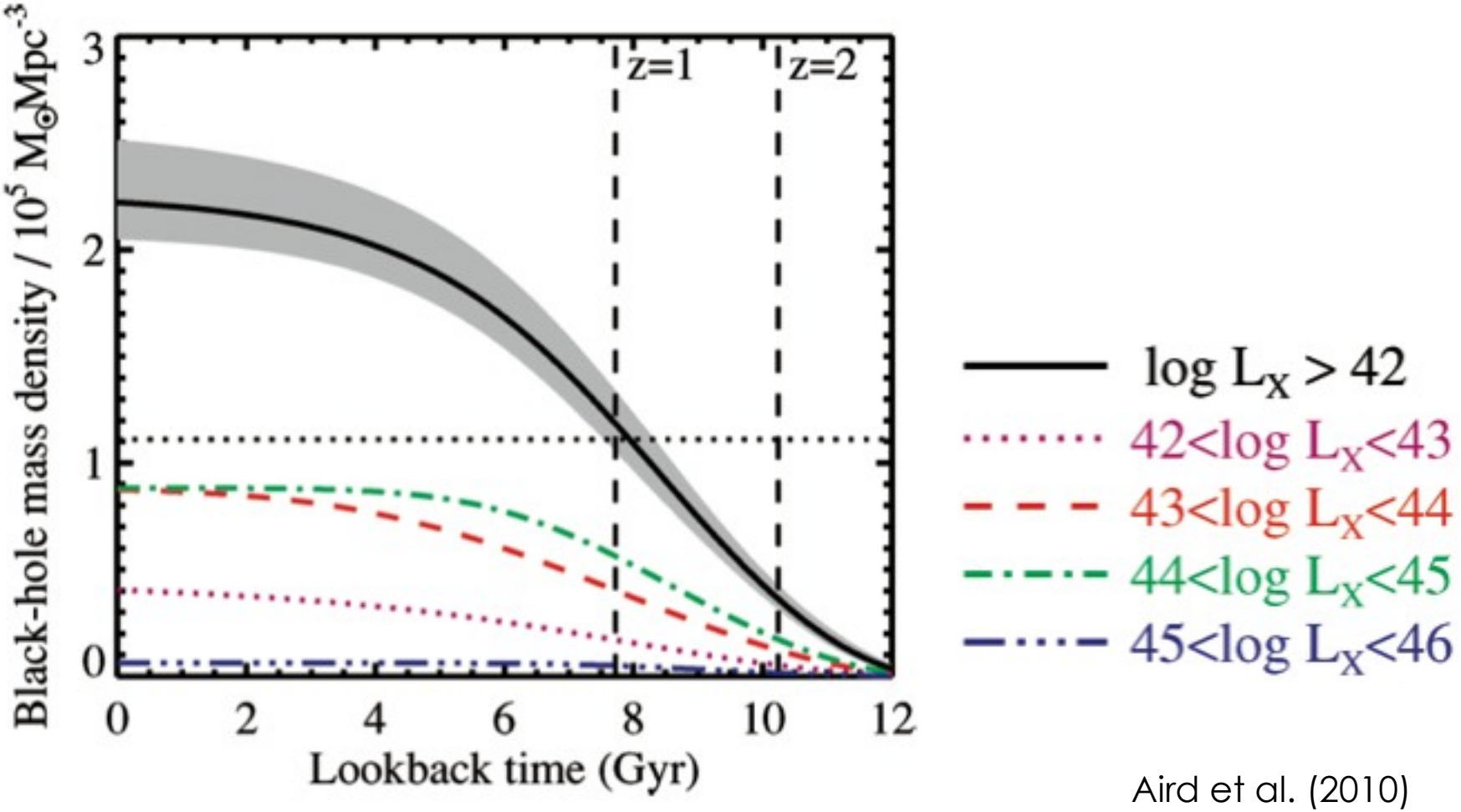
Aird et al. (2010)



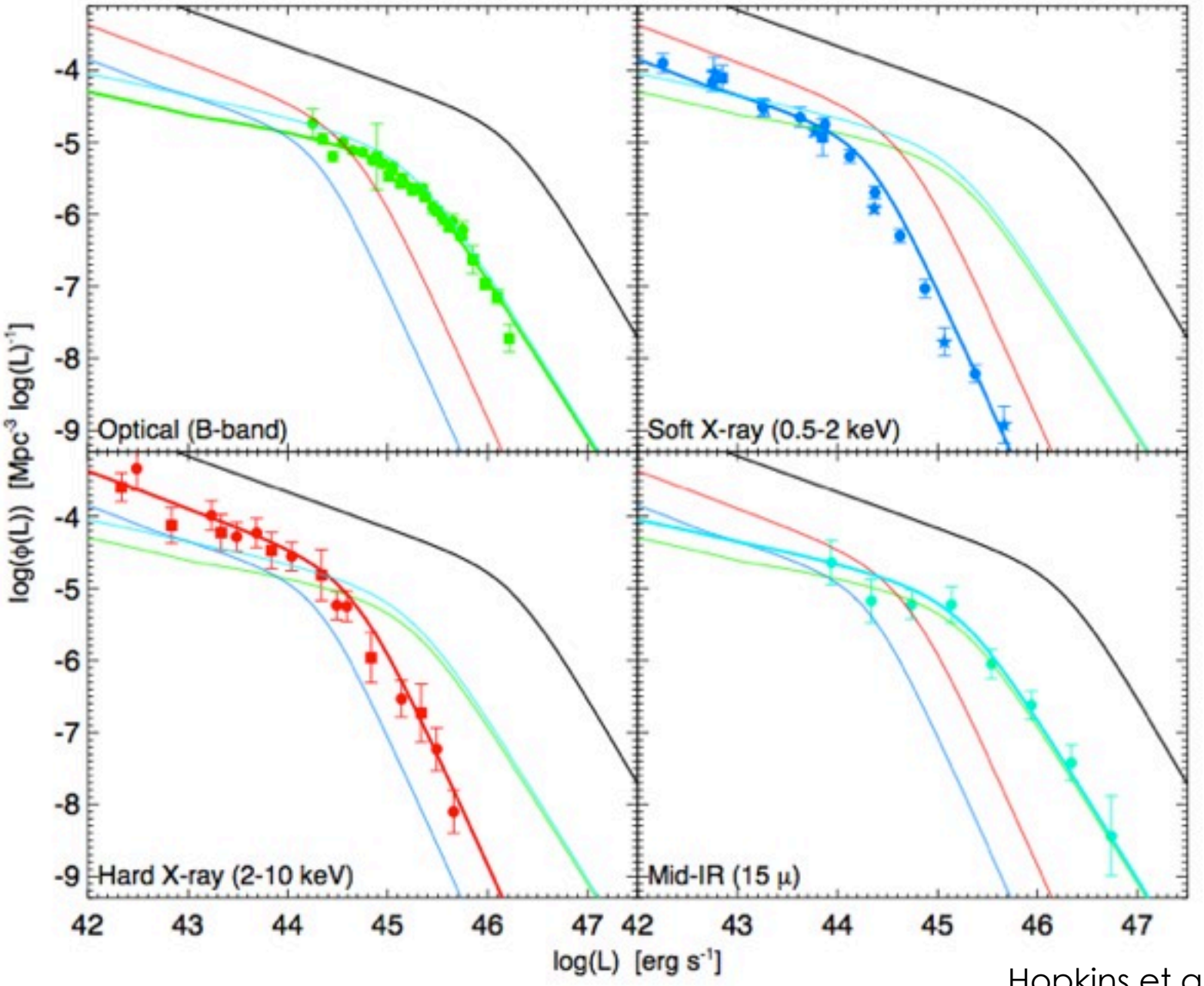
Silverman et al. (2010)

Cosmic evolution of BH mass density

$$\dot{m}_{\rm BH} = 0.15\left(\frac{0.1}{\epsilon}\right)\left(\frac{L_{\rm bol}}{10^{45}{\rm ergs}^{-1}}\right)M_{\odot}yr^{-1}$$

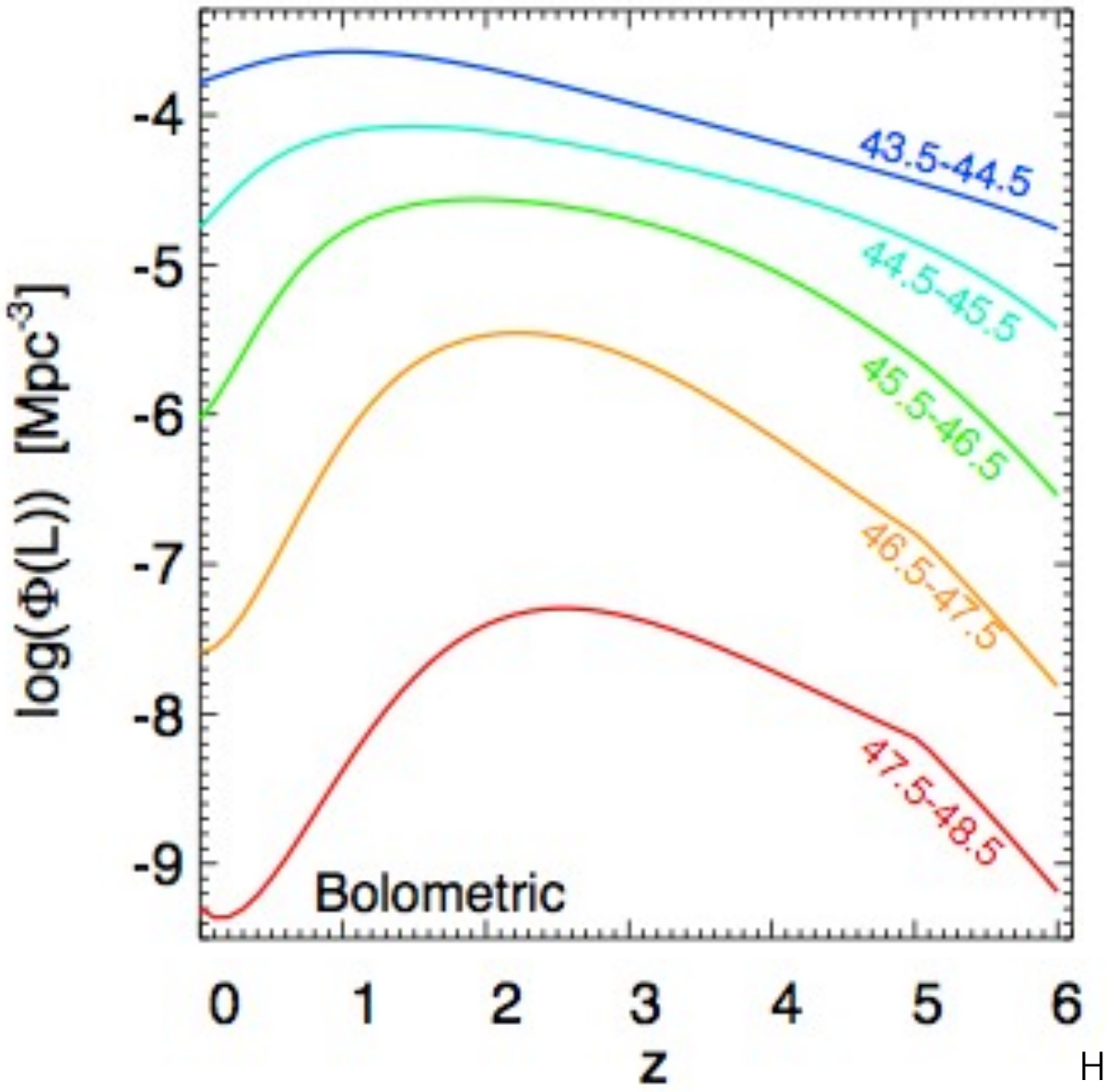


Aird et al. (2010)



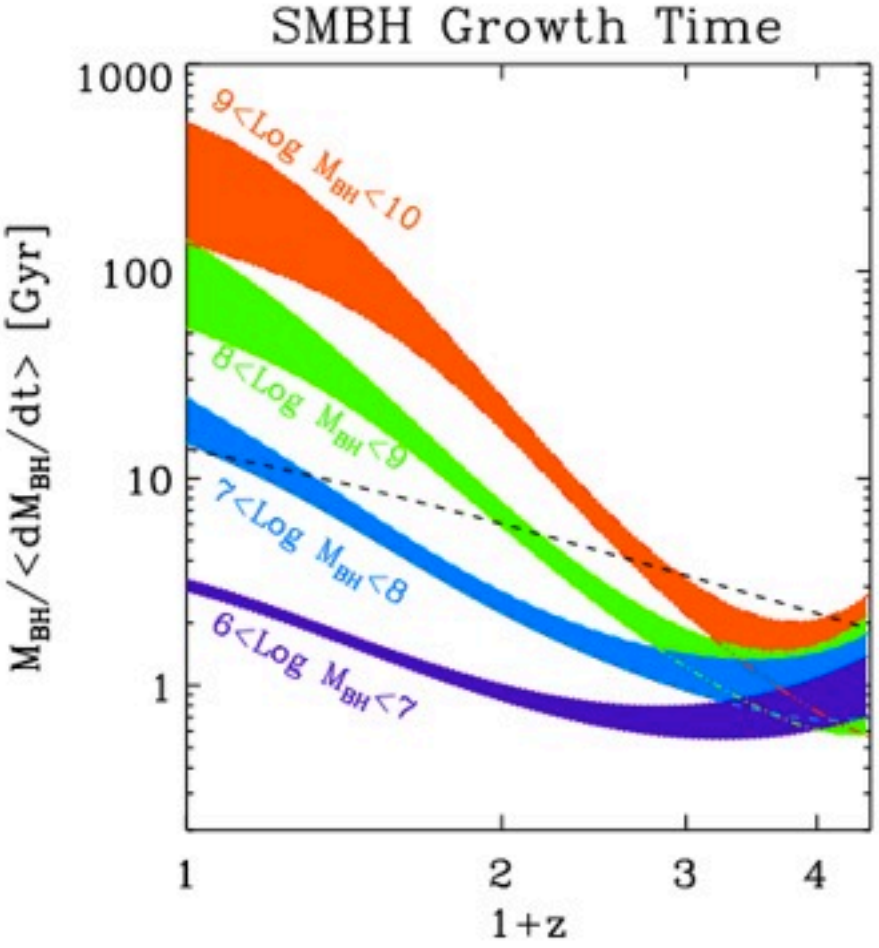
Hopkins et al. (2007)

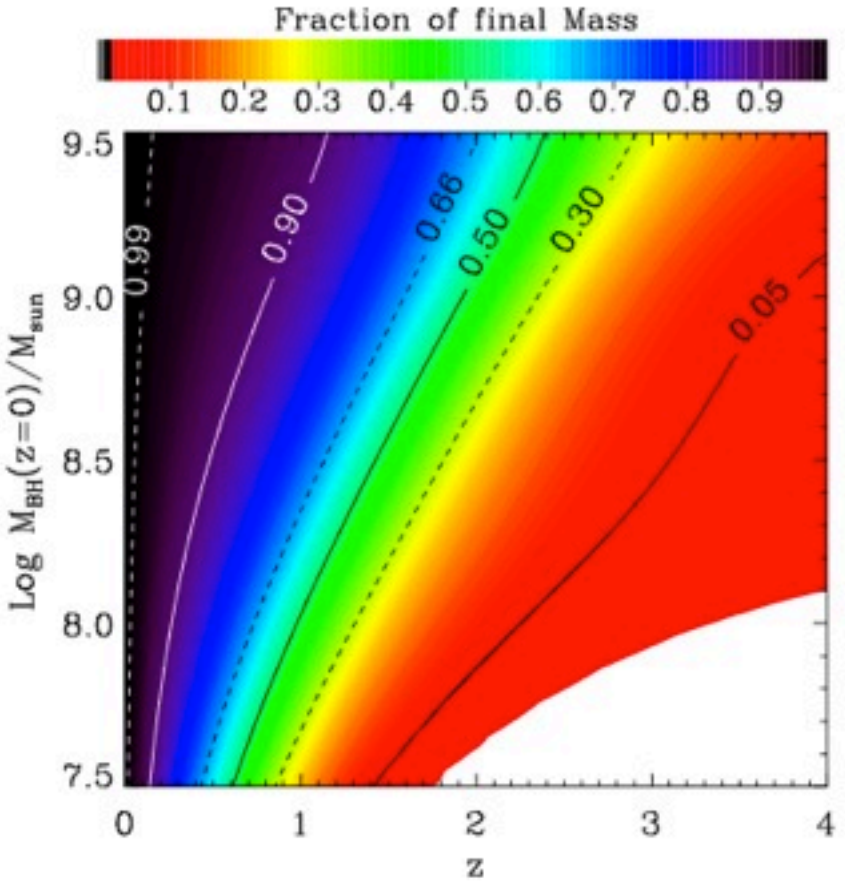
Bolometric luminosity density



Hopkins et al. (2007)

Synthesizing the cosmic growth of BHs



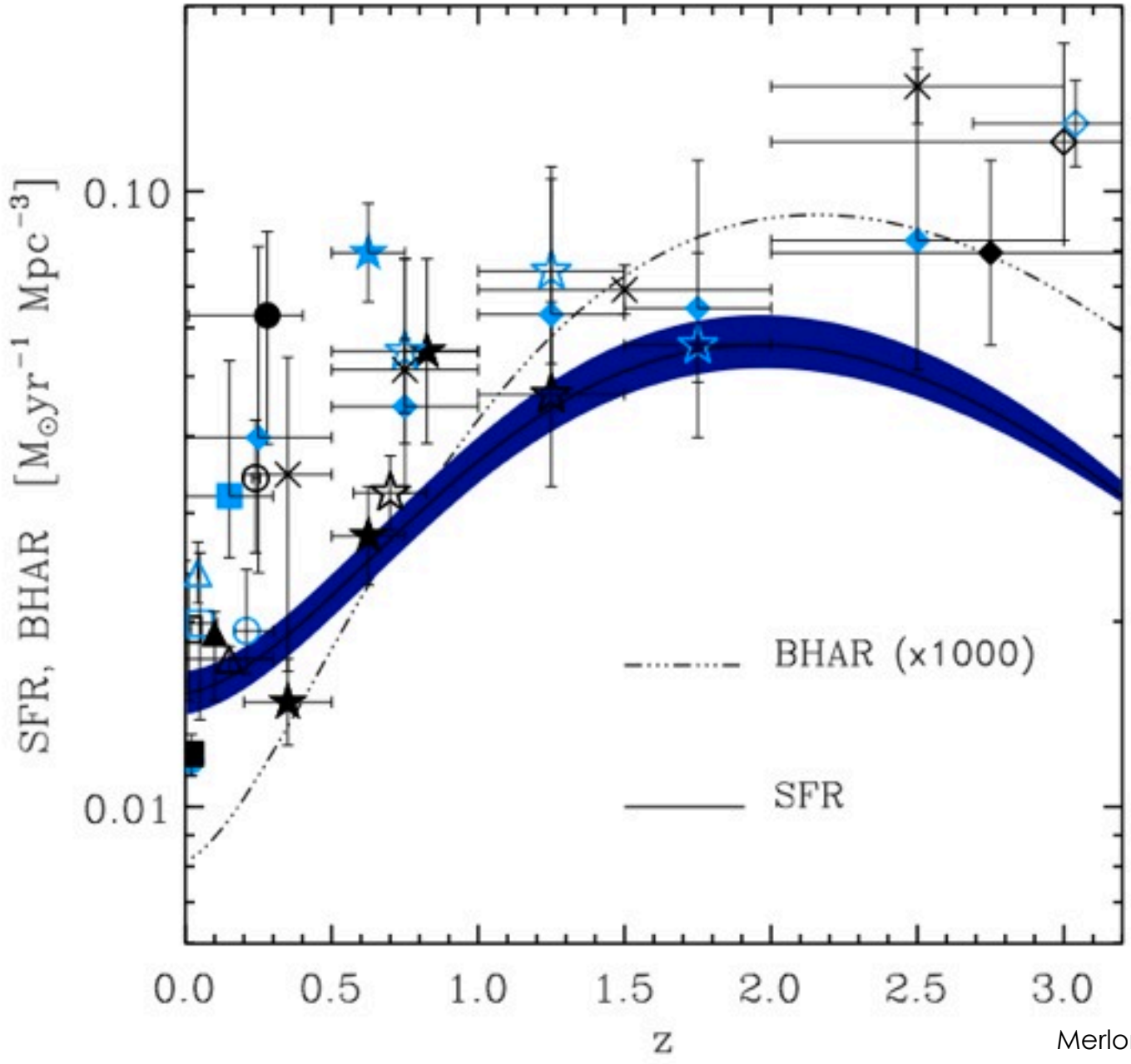


Merloni & Heinz (2012)

Small black holes are still growing, large ones shut off at z > 2

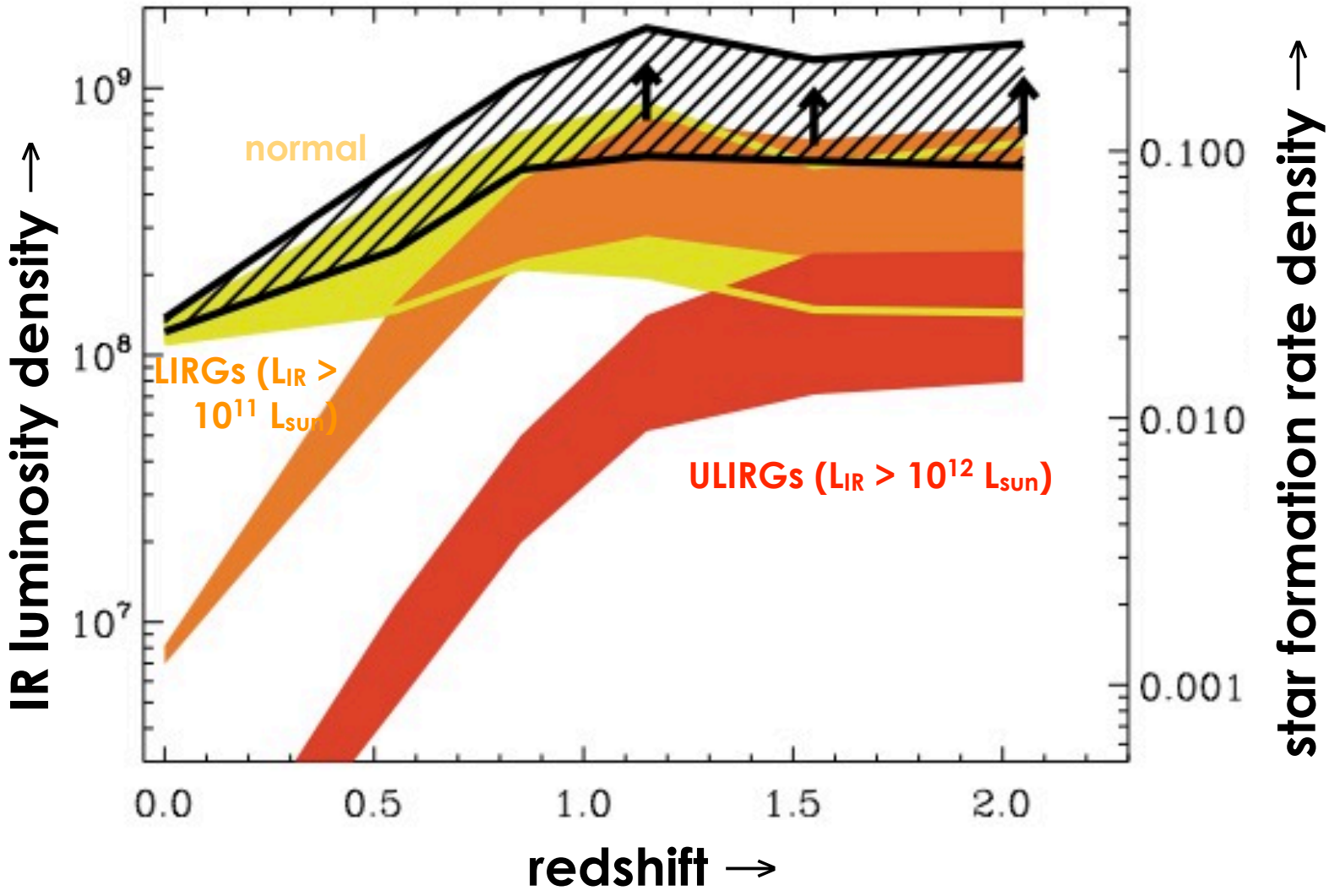
How is BH accretion connected to the host galaxy and dark matter halo?

Cosmic evolution of star formation



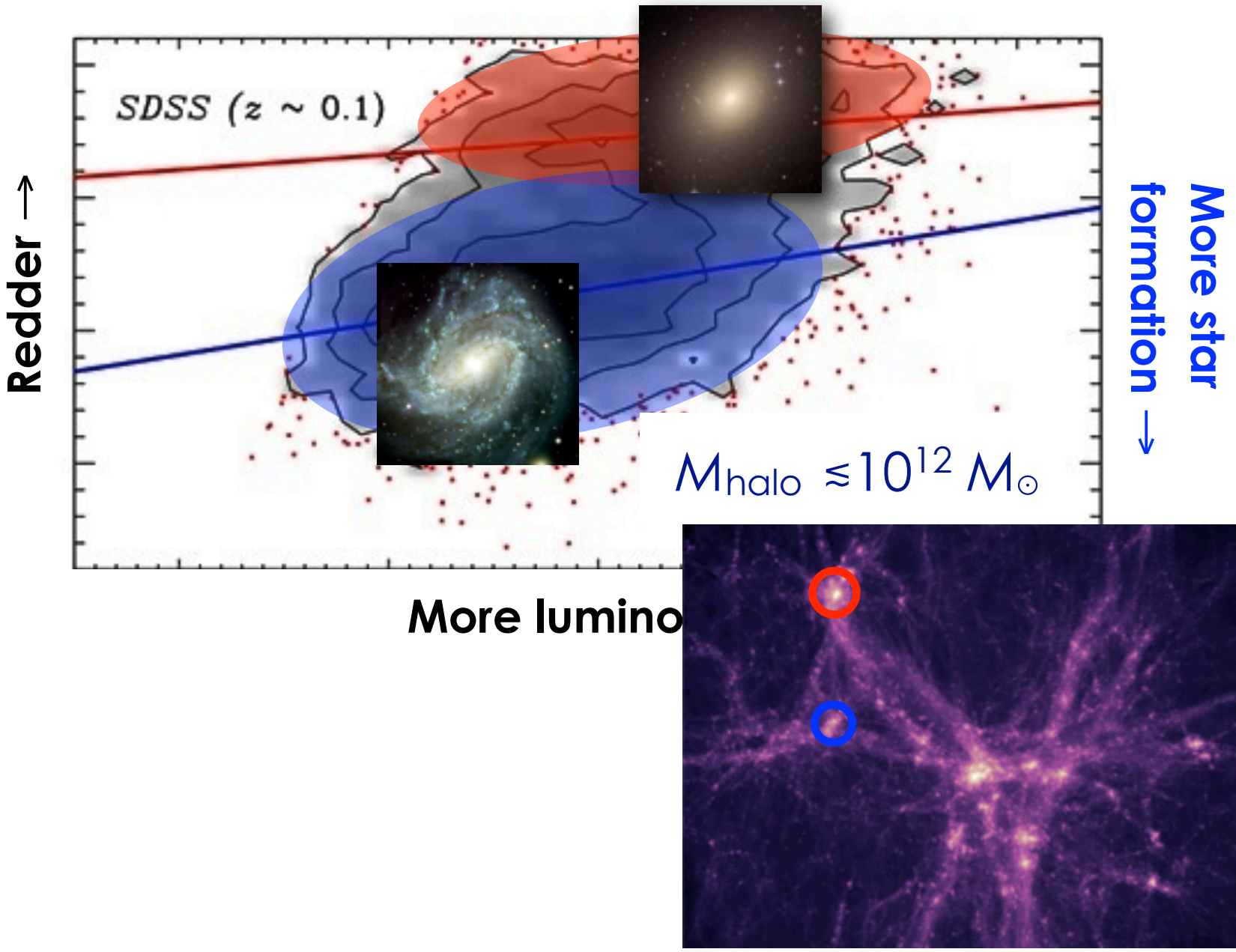
Merloni & Heinz (2012)

Cosmic evolution of star formation

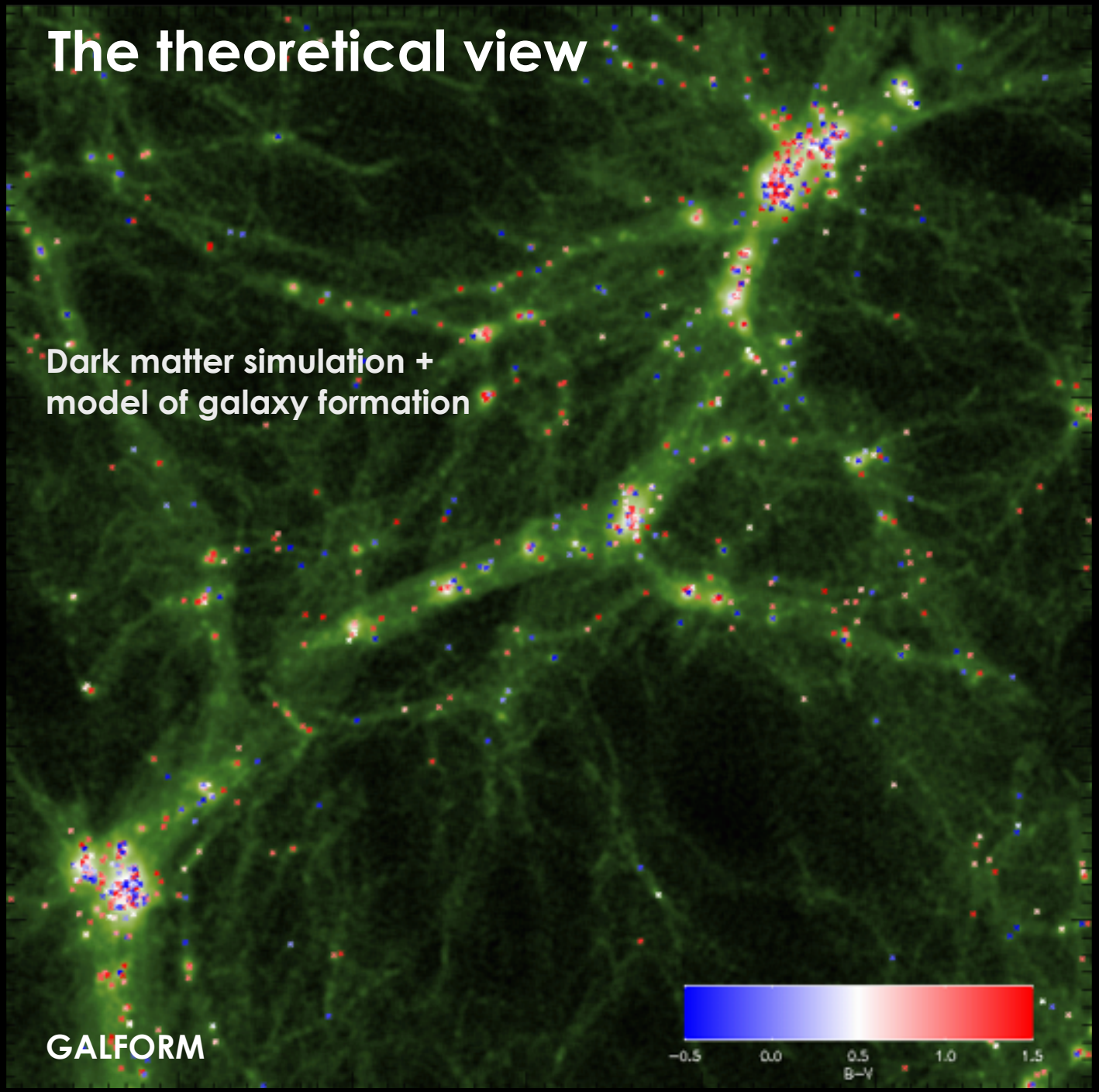


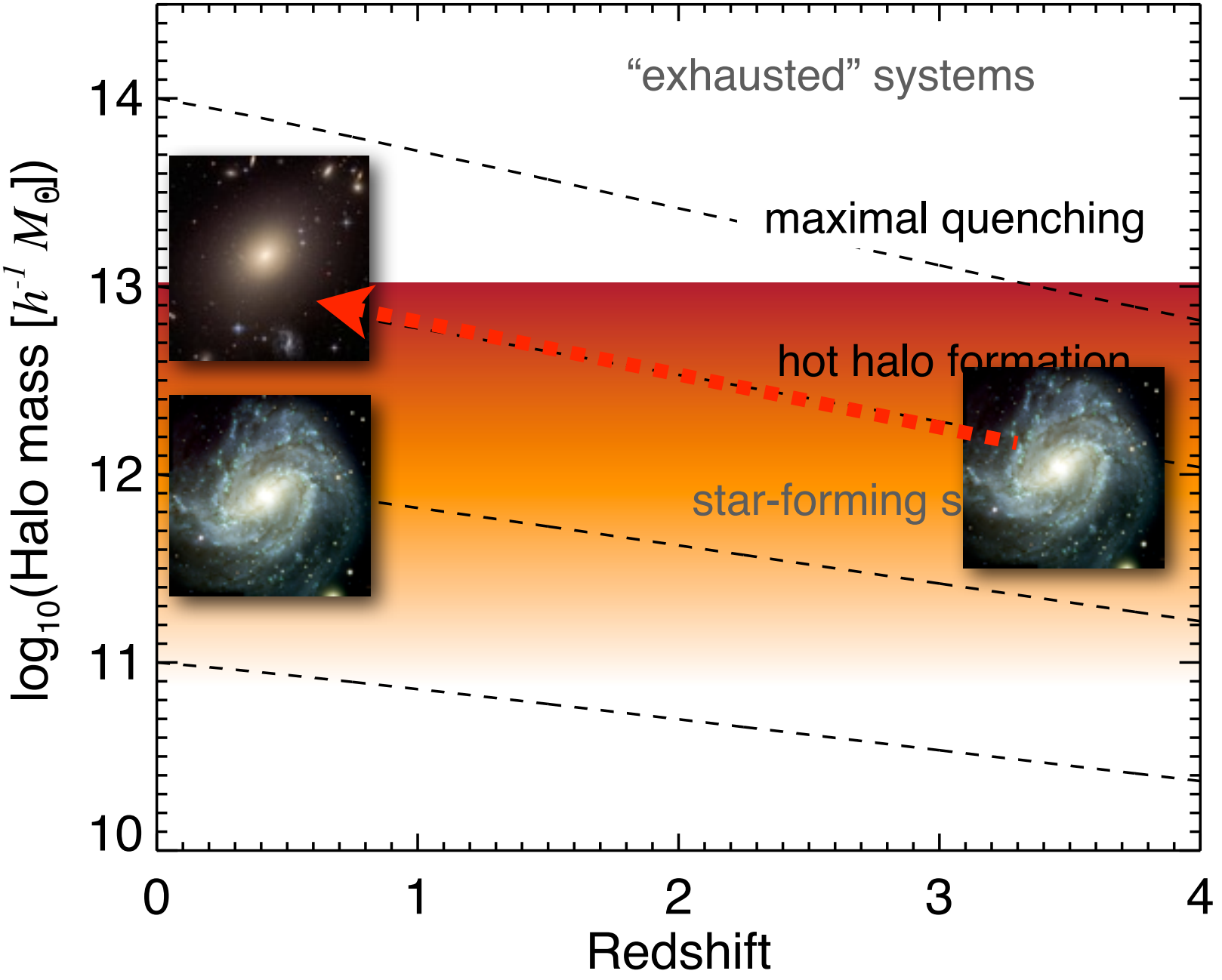
Magnelli et al. (2009)

Properties of galaxies

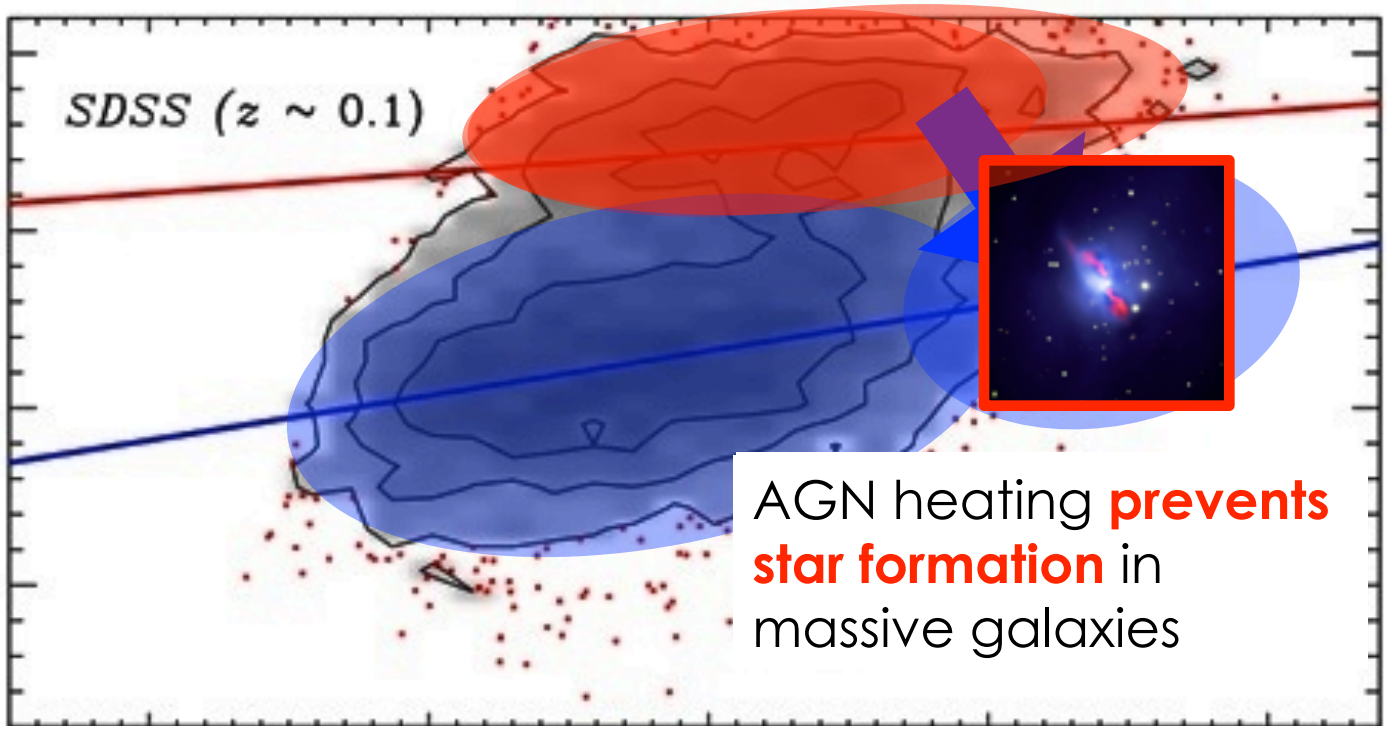


The theoretical view



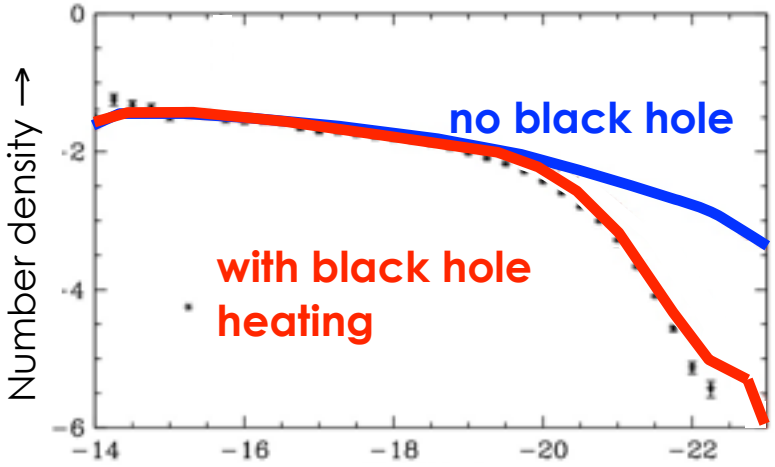

"exhausted" systems
maximal quenching
hot halo formation
star-forming s
14
13
12
11
10
0
1
2
3
4
Redshift
log10(Halo mass [h-1 M⊙])

In the models...

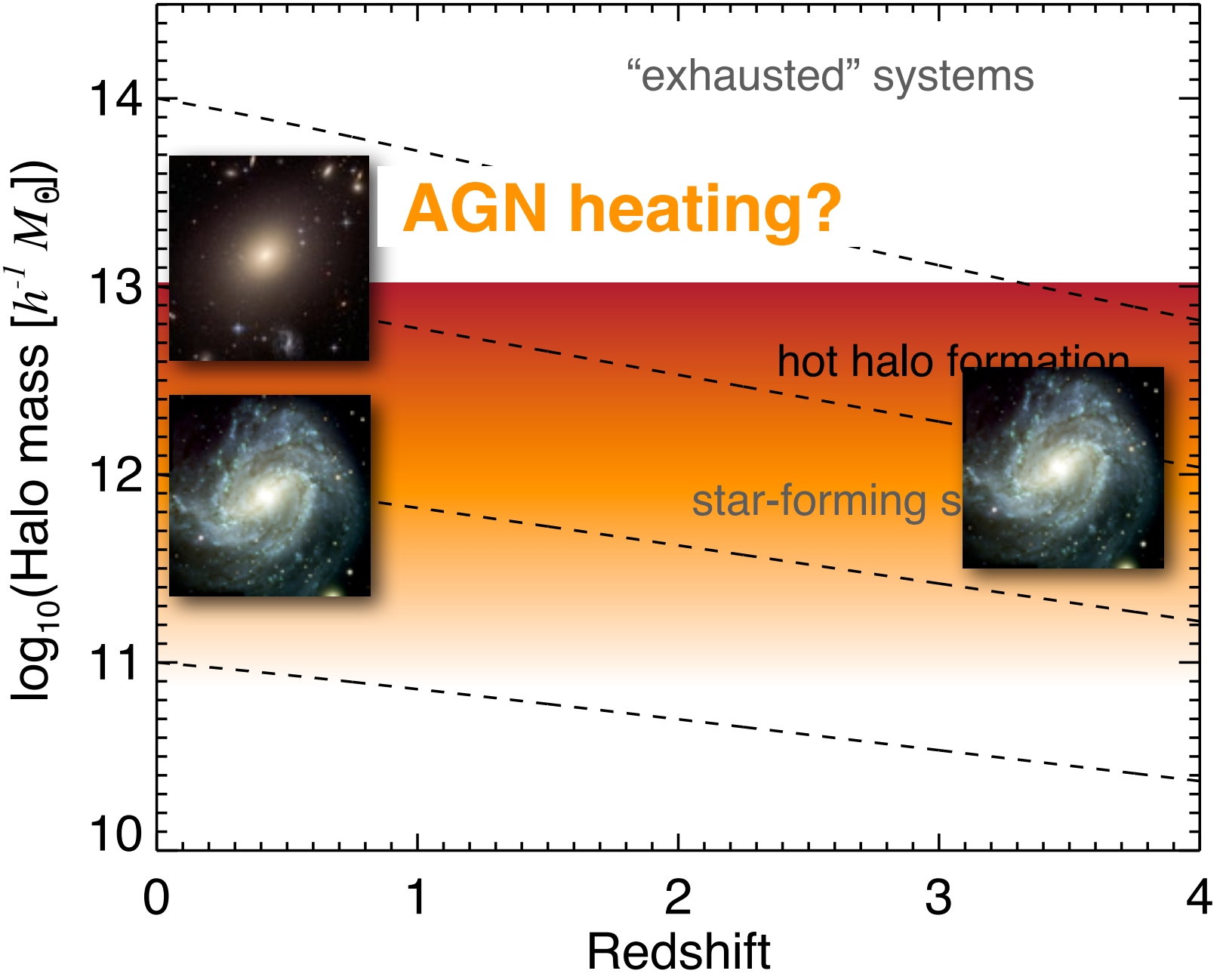


More luminous →

Blanton (2006)



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


"exhausted" systems
AGN heating?
hot halo formation
star-forming s
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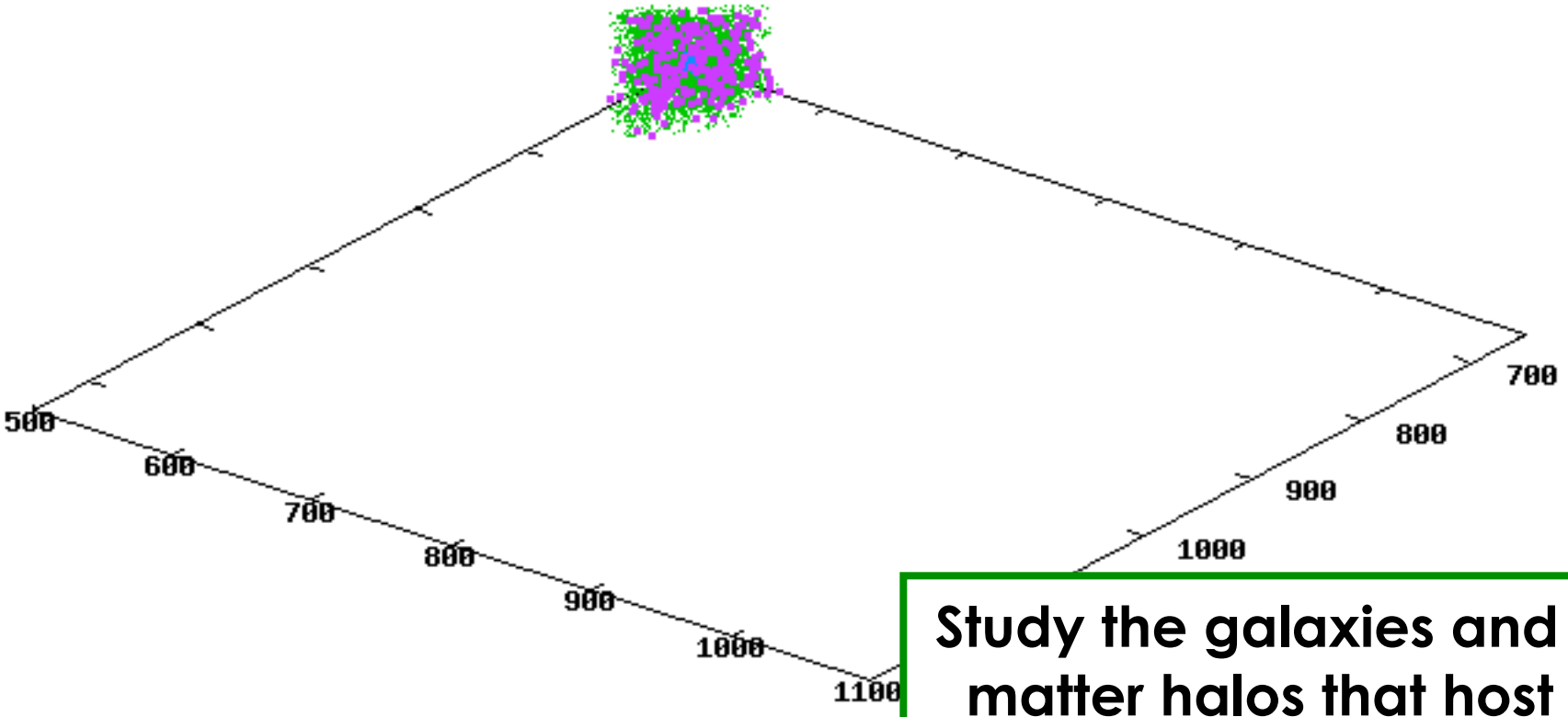
Redshift
log10(Halo mass [h-1 M⊙])

Observing the co-evolution of galaxies and black holes

galaxies
X-ray AGN



Study the galaxies and dark matter halos that host AGN

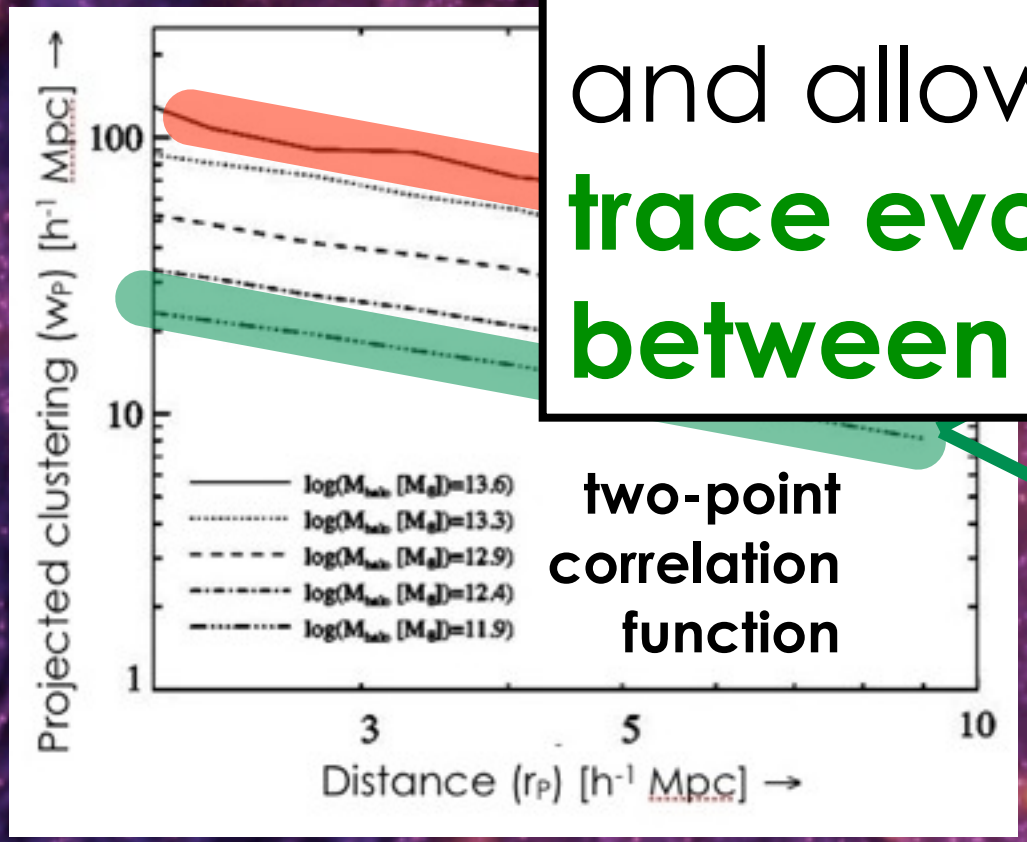
XBootes/AGES (S. Murray/C. Kochanek)

How do we measure dark matter halo mass?

Courtesy Virgo consortium

31.25 Mpc/h

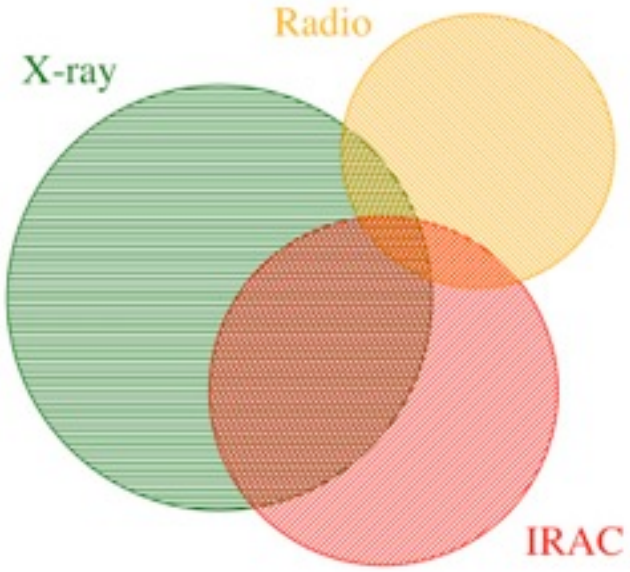
SPATIAL CLUSTERING
tells us **HALO MASS**
and allows us to
trace evolution between populations

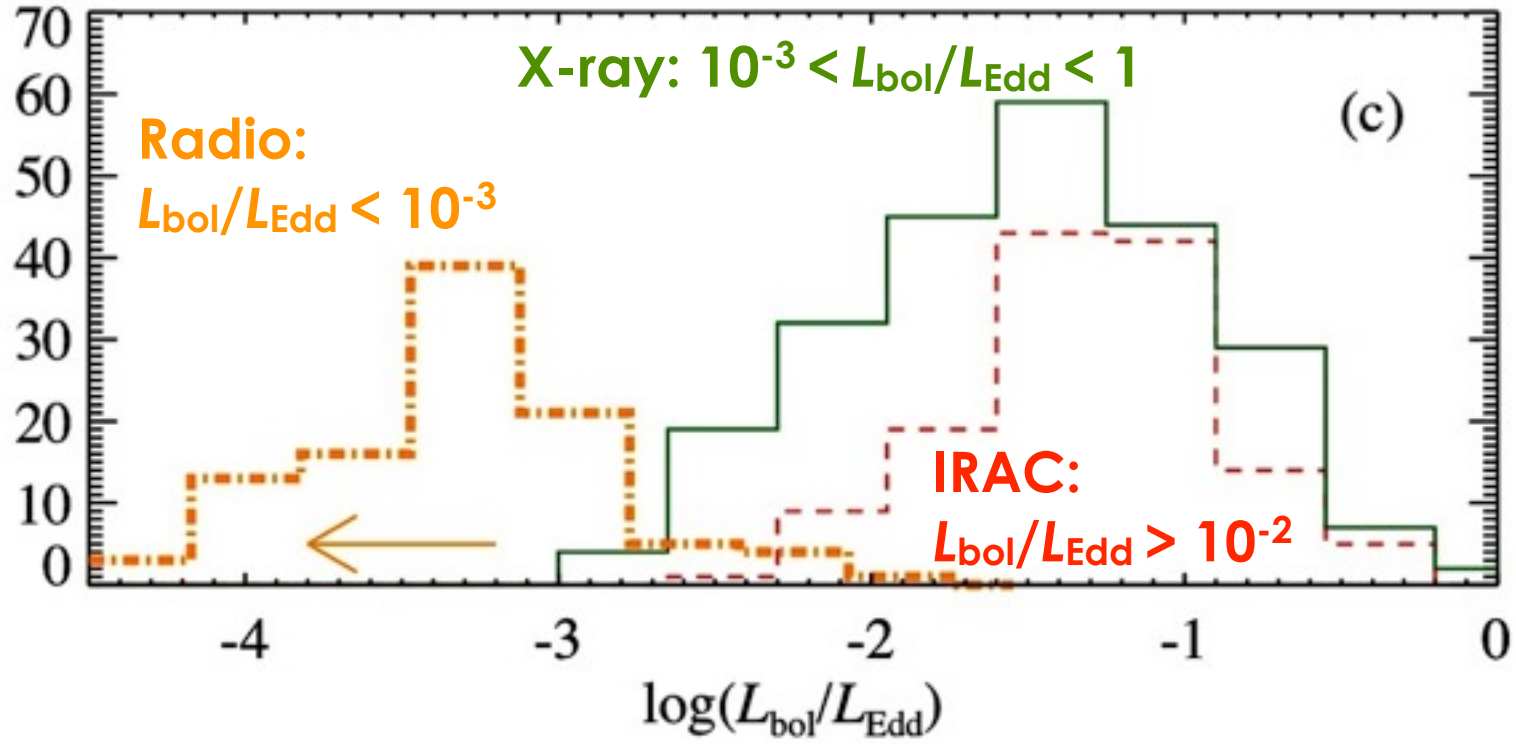


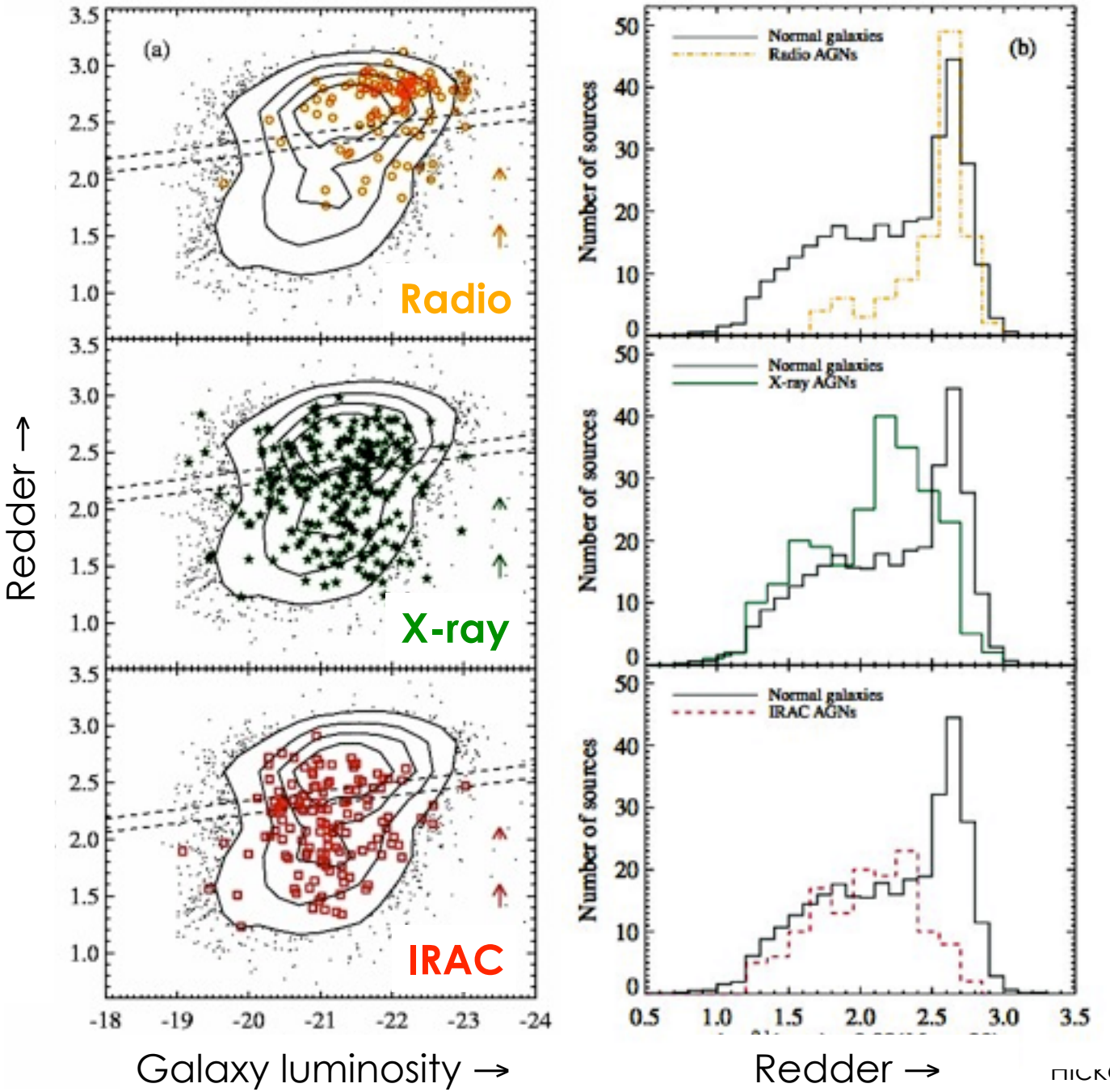
two-point correlation function

AGN populations at z ~ 0.5

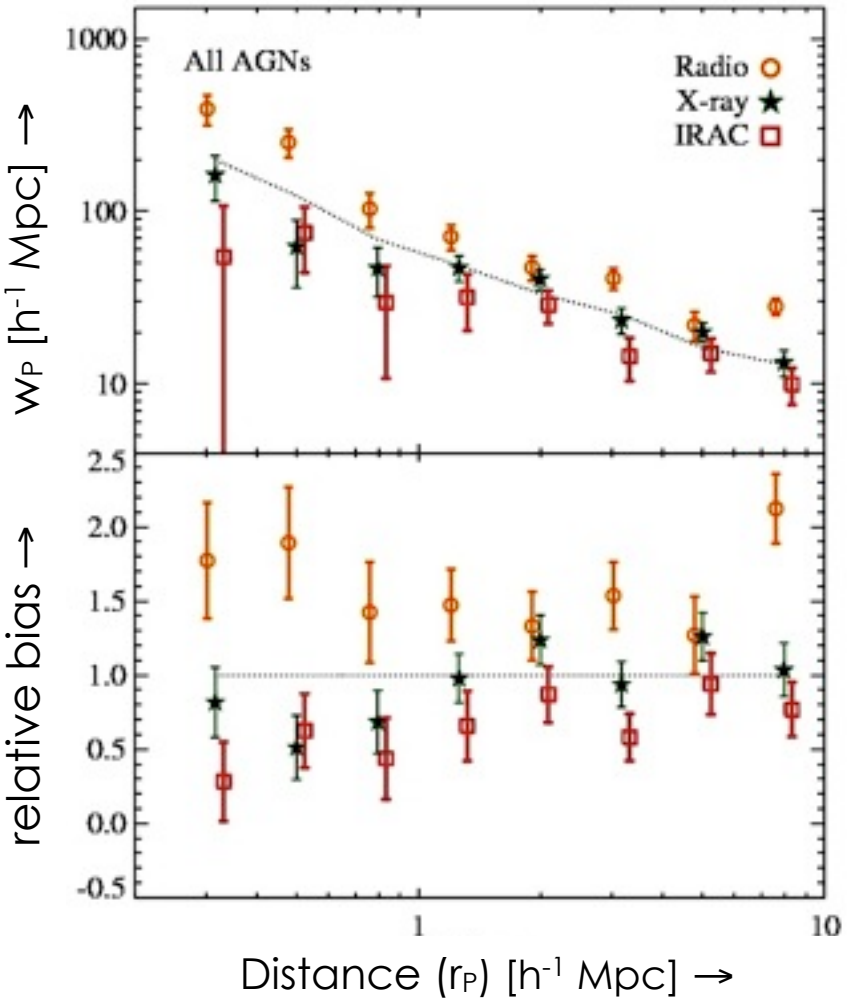
Hickox et al. (2009)



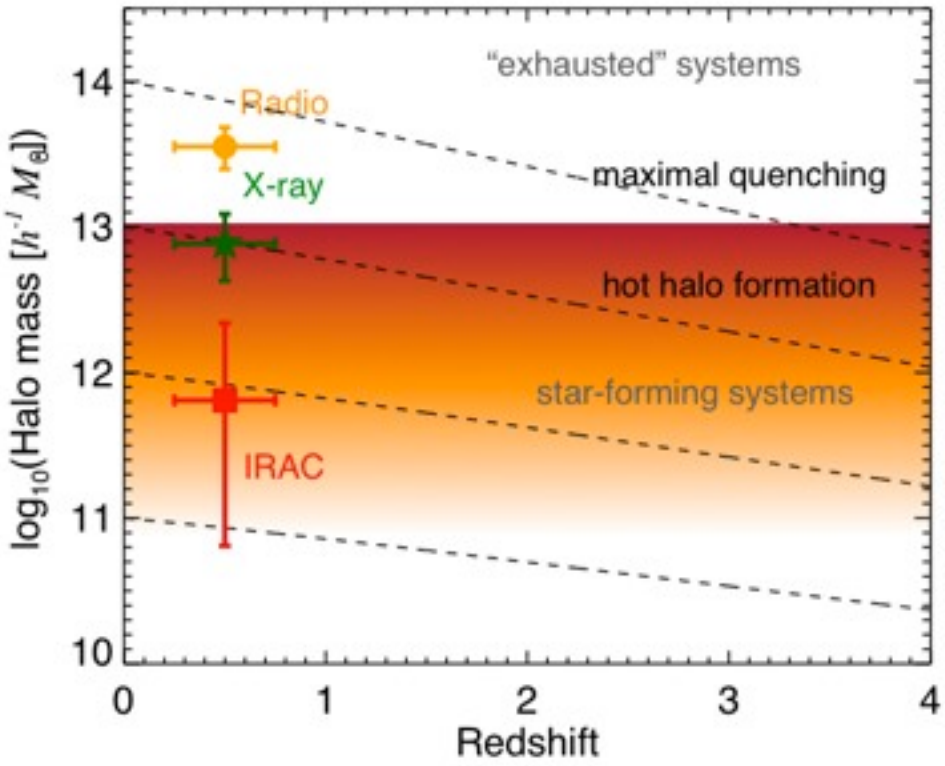




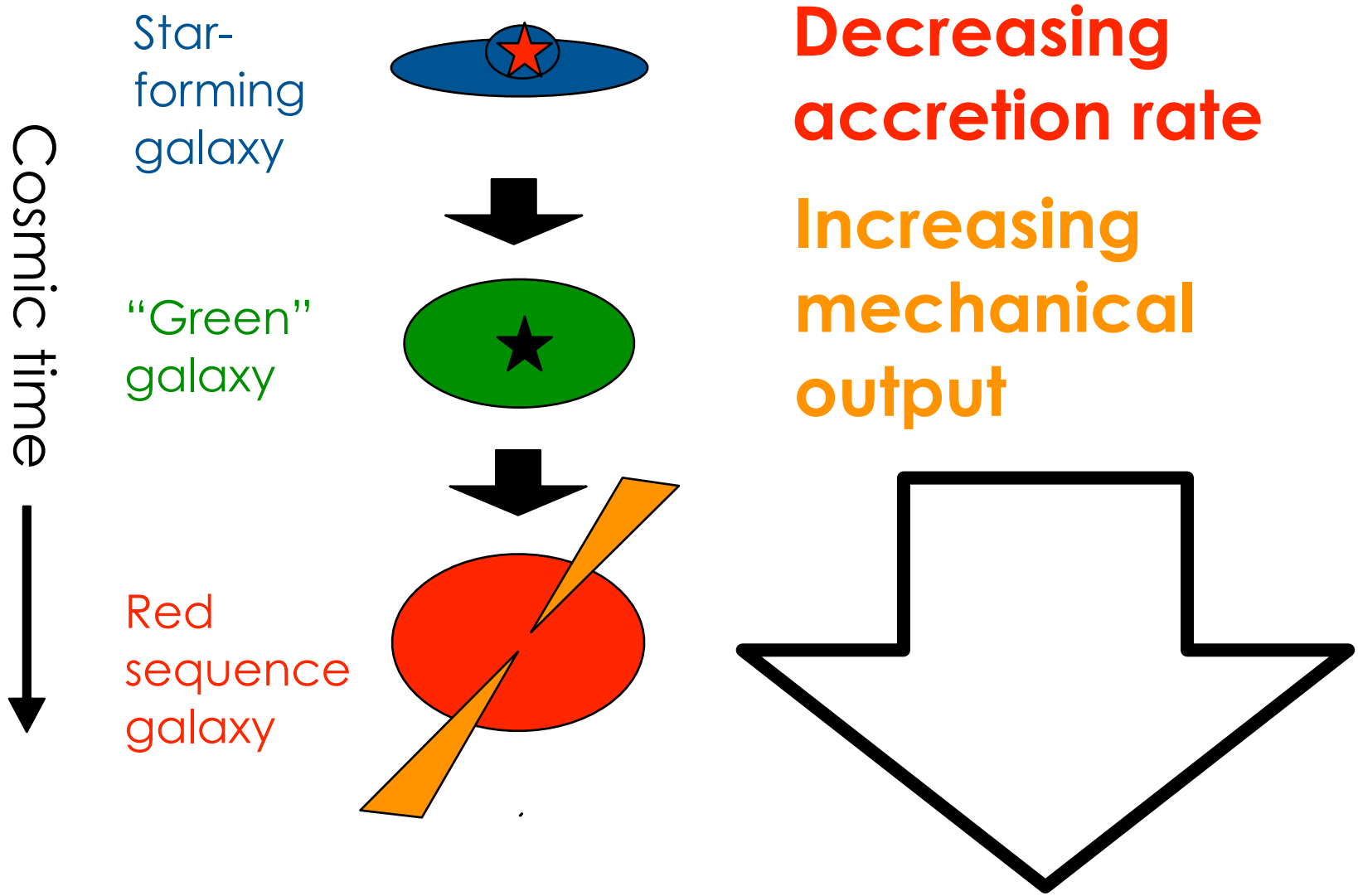
Nickox et al. (2009)

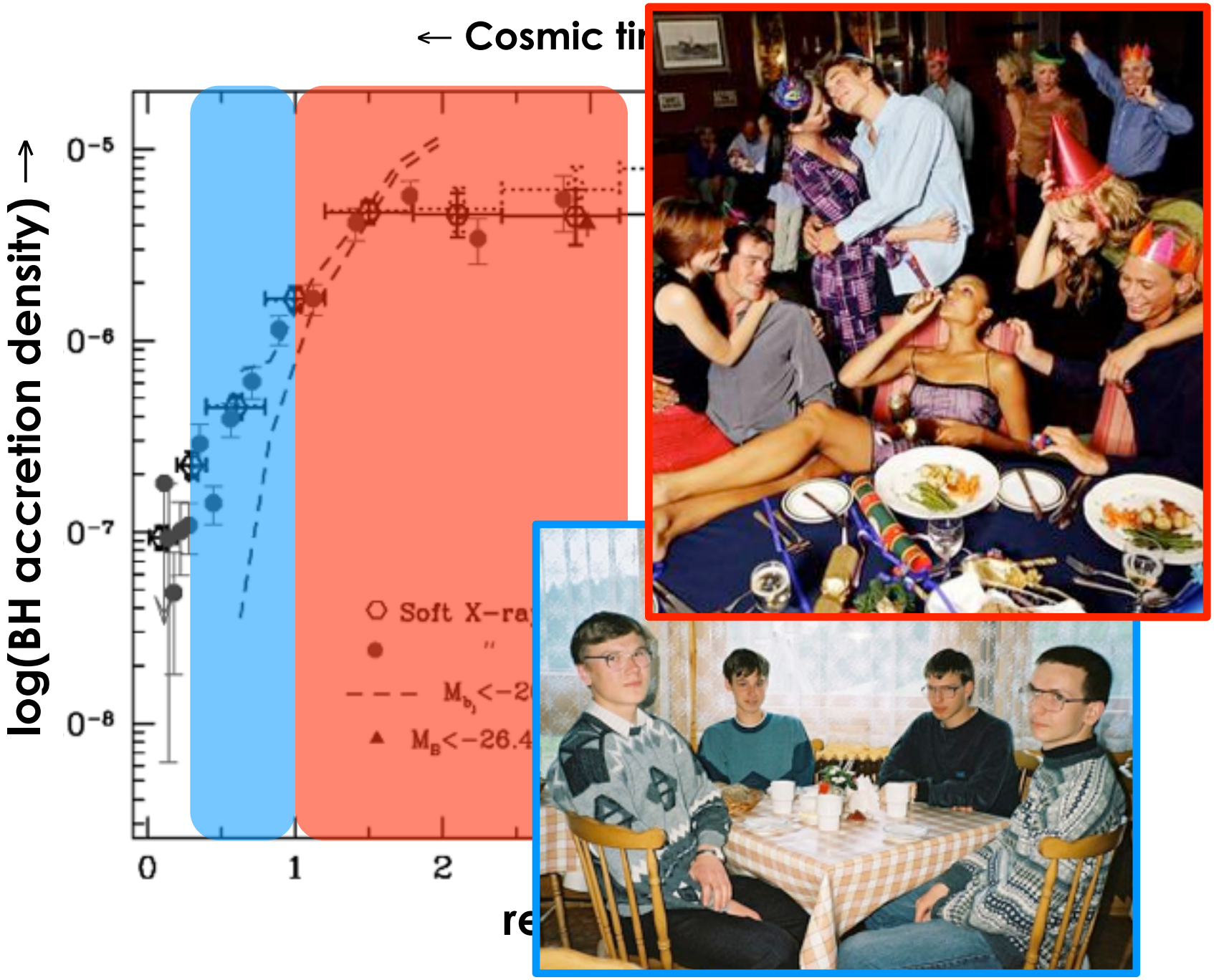


Hickox et al. (2009)

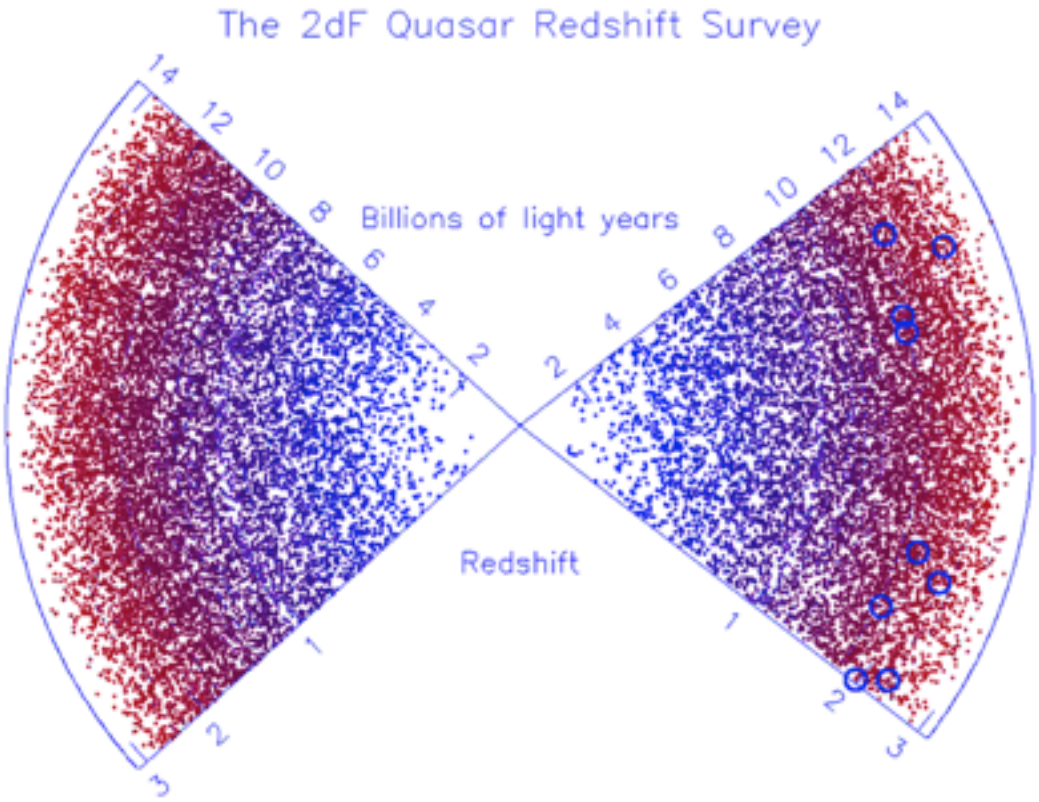


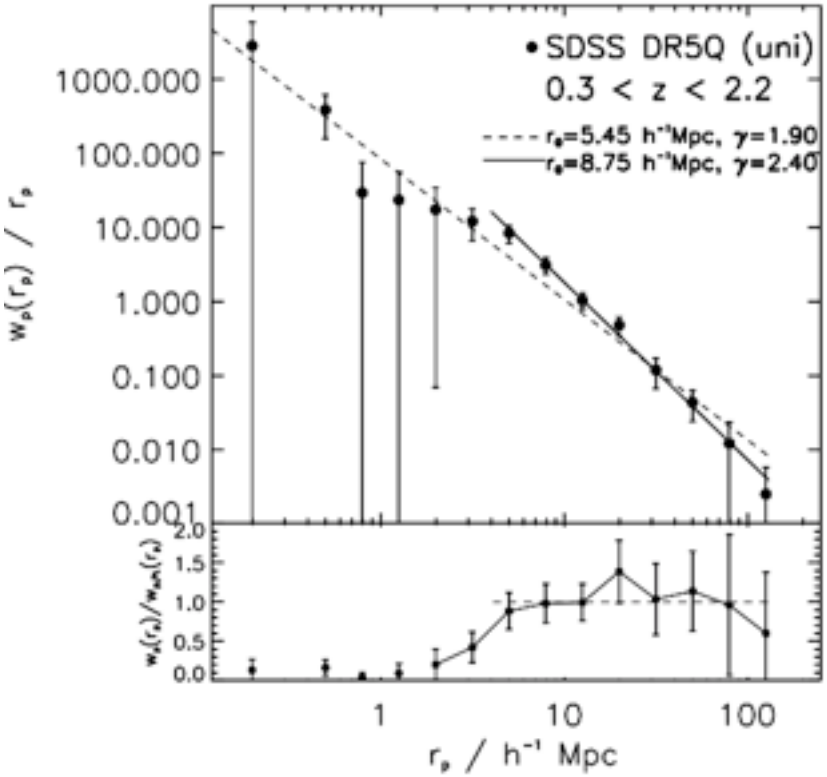
see also Li et al. (2006), Coil et al. (2009), Wake et al. (2008), Mandelbaum et al. (2008)


Star-forming galaxy
"Green" galaxy
Red sequence galaxy
Cosmic time
Decreasing accretion rate
Increasing mechanical output

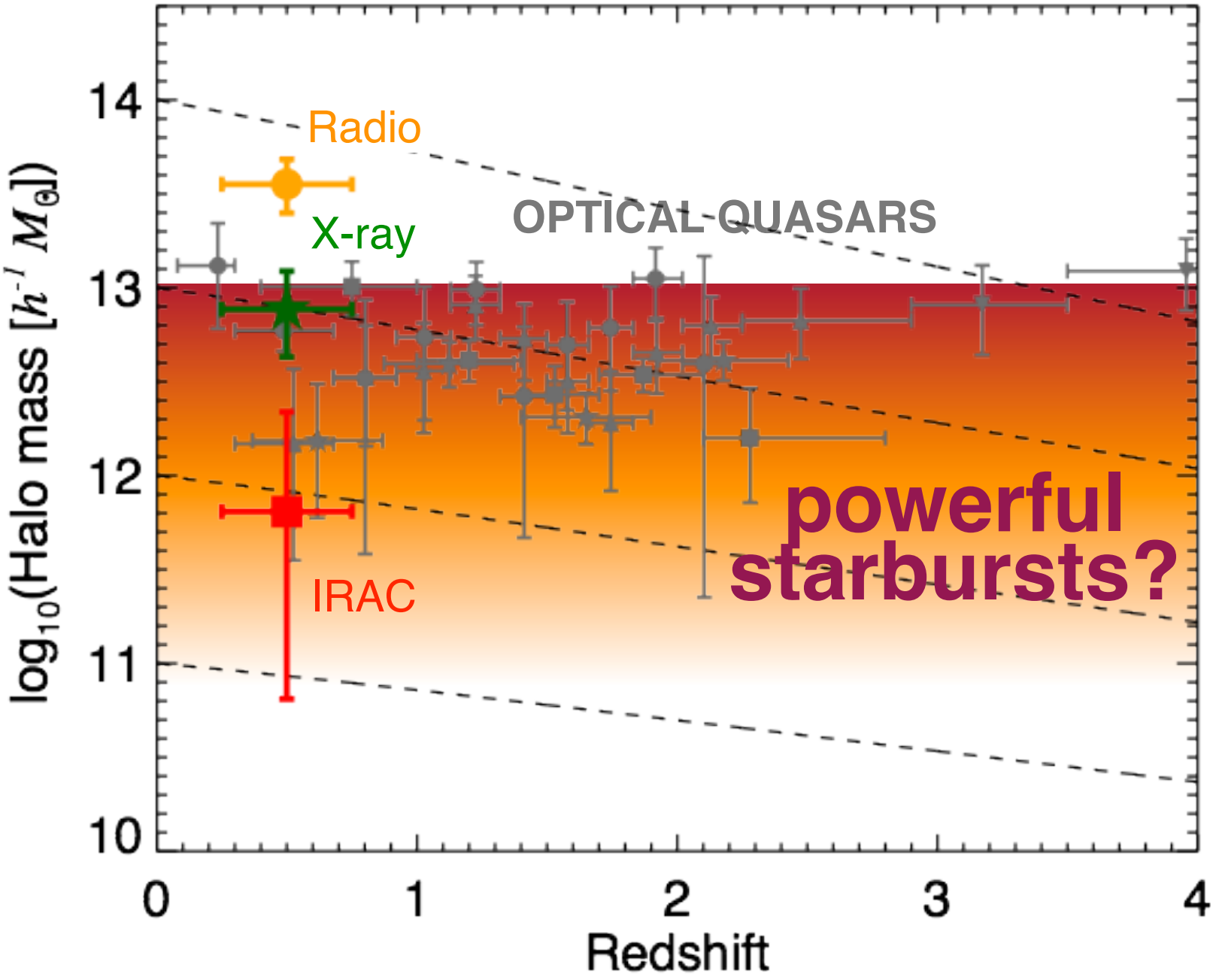

← Cosmic ti
log(BH accretion density) →
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
1
2
re
Soft X-ra
"
M_{b_j}<-2
M_B<-26.4

Clustering of quasars



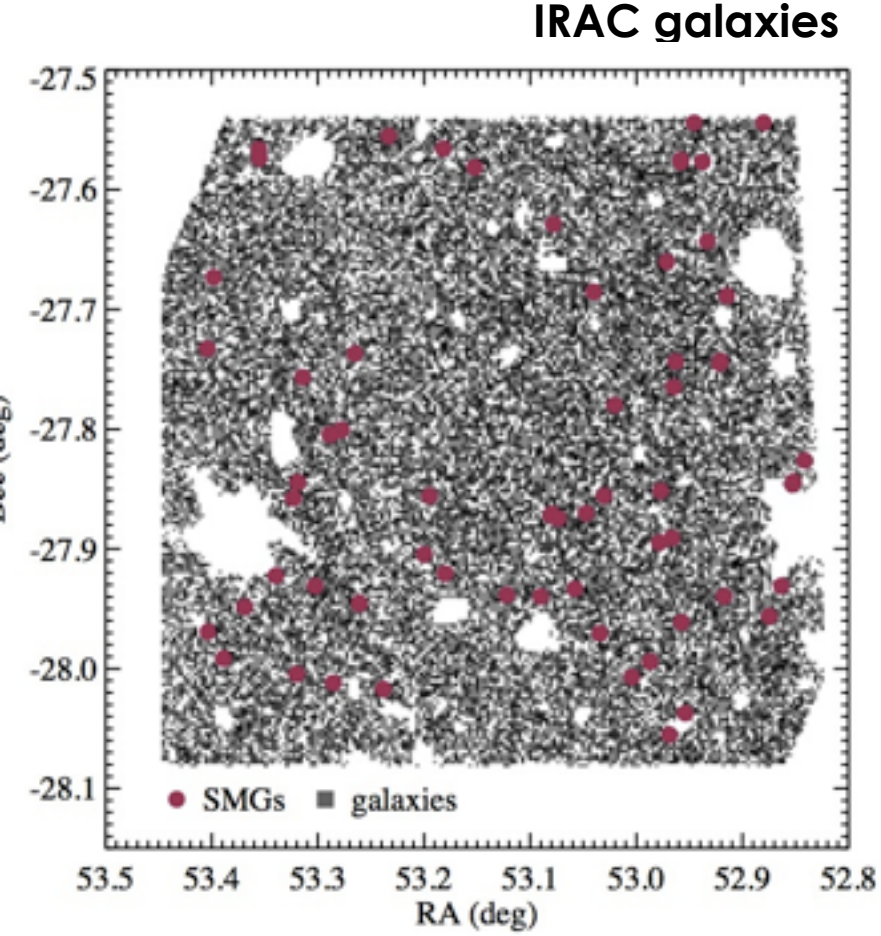


Ross et al. (2009) , see also Croom et al. (2005), Myers et al. (2006), da Angela et al. (2008), Hickox et al. (2009), many others

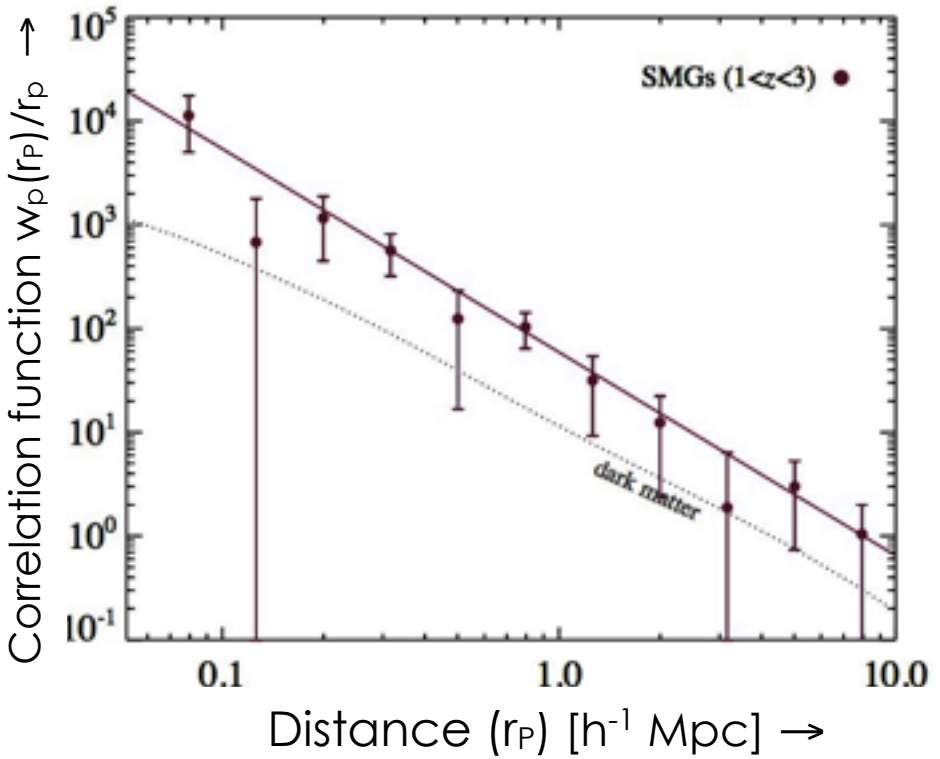

Radio
X-ray
IRAC
OPTICAL QUASARS
powerful
starbursts?
log10(Halo mass [h-1 M⊙])
Redshift
14
13
12
11
10
0
1
2
3
4

Clustering of submillimeter galaxies

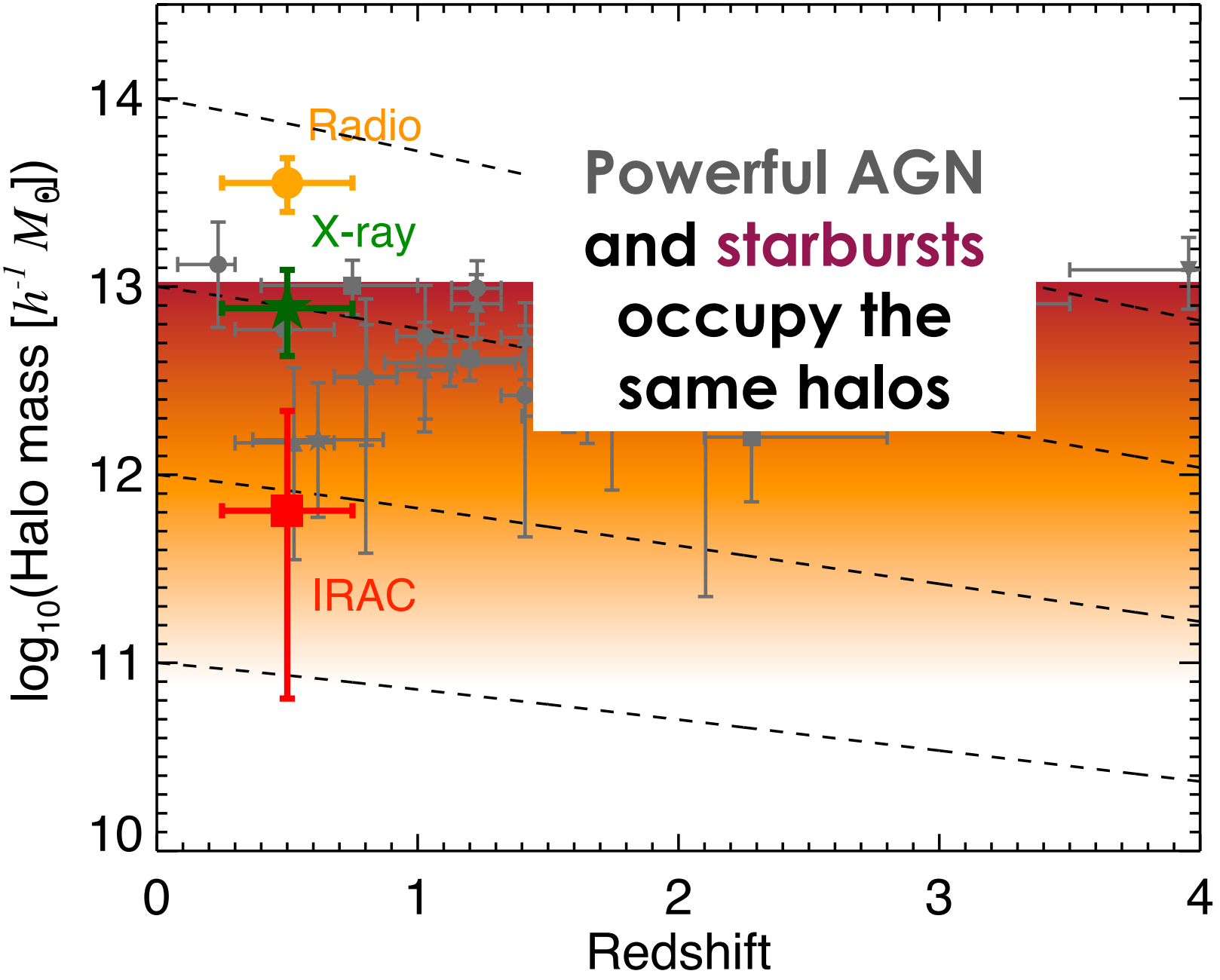
870 μm SMGs: SFR ~ 1000 $M_\odot$ yr^{-1}



LESS Survey, Weiß et al. (2009)



(Hickox et al. 2012)


Radio
X-ray
IRAC
Powerful AGN
and starbursts
occupy the
same halos
14
13
12
11
10
0
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2
3
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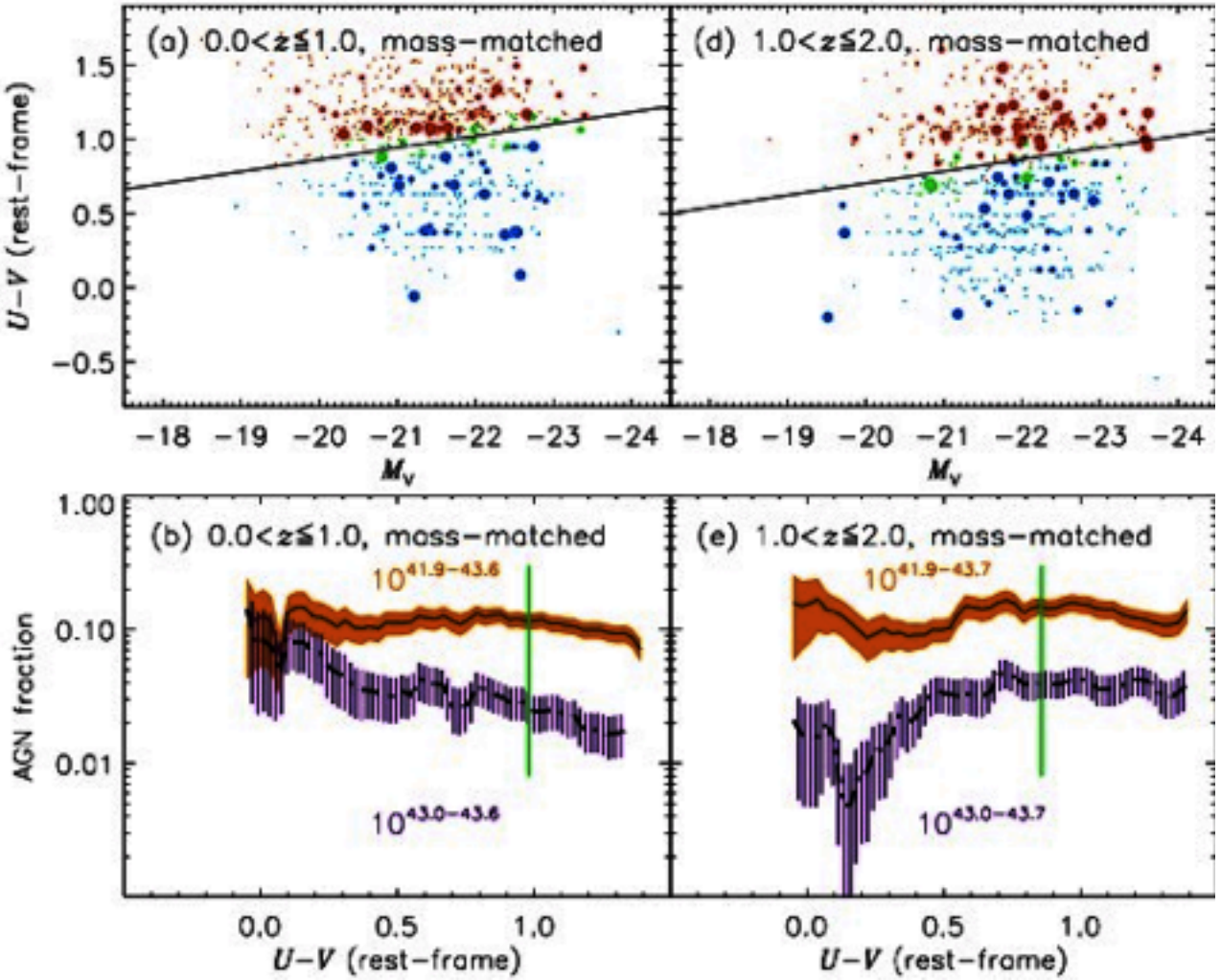
Redshift
log10(Halo mass [h-1 M⊙])


Why doesn't EVERY
star-forming galaxy
host an AGN?

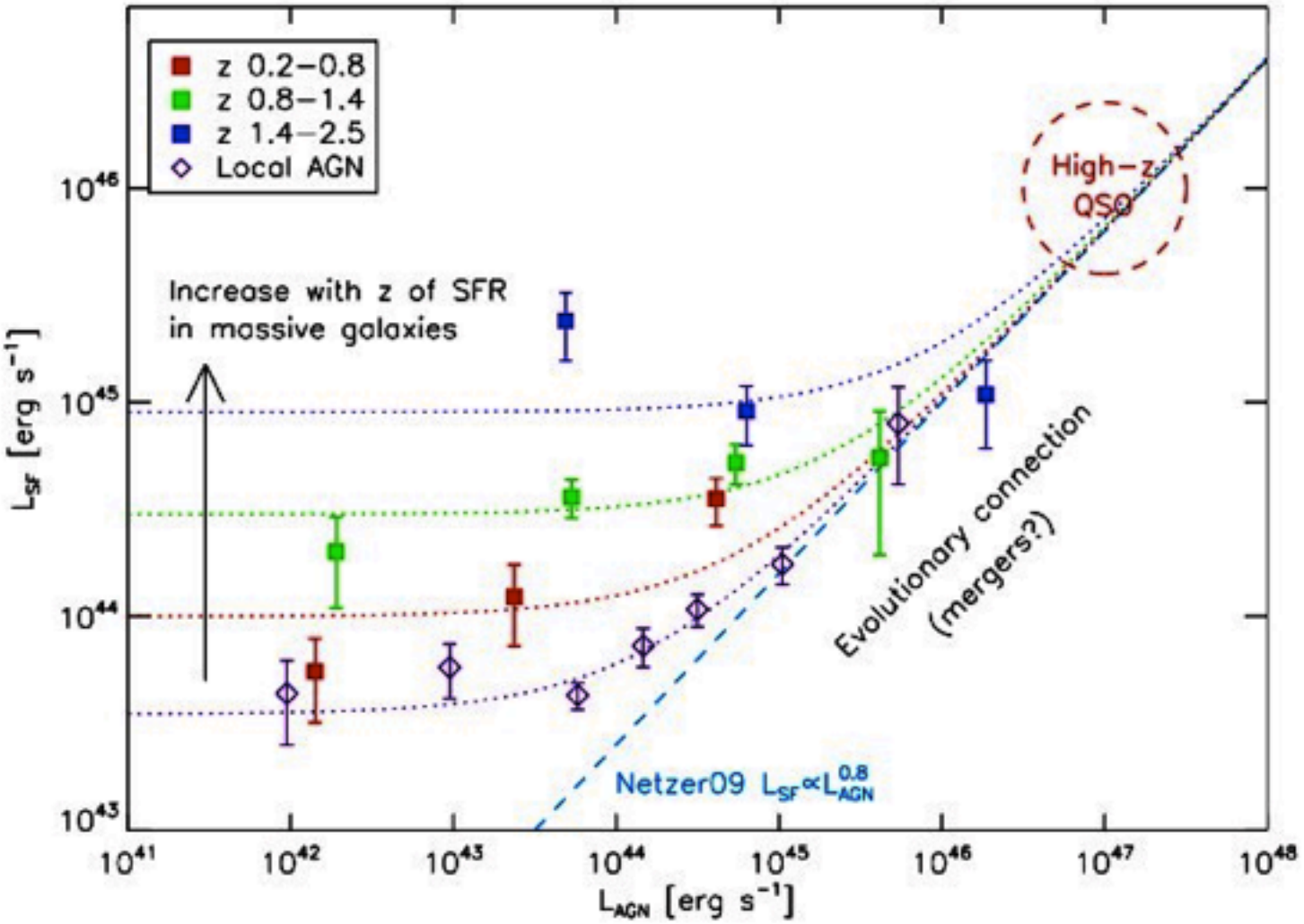
"Typical" AGN: no connection to host star formation?



Xue et al. (2010) [X-ray]

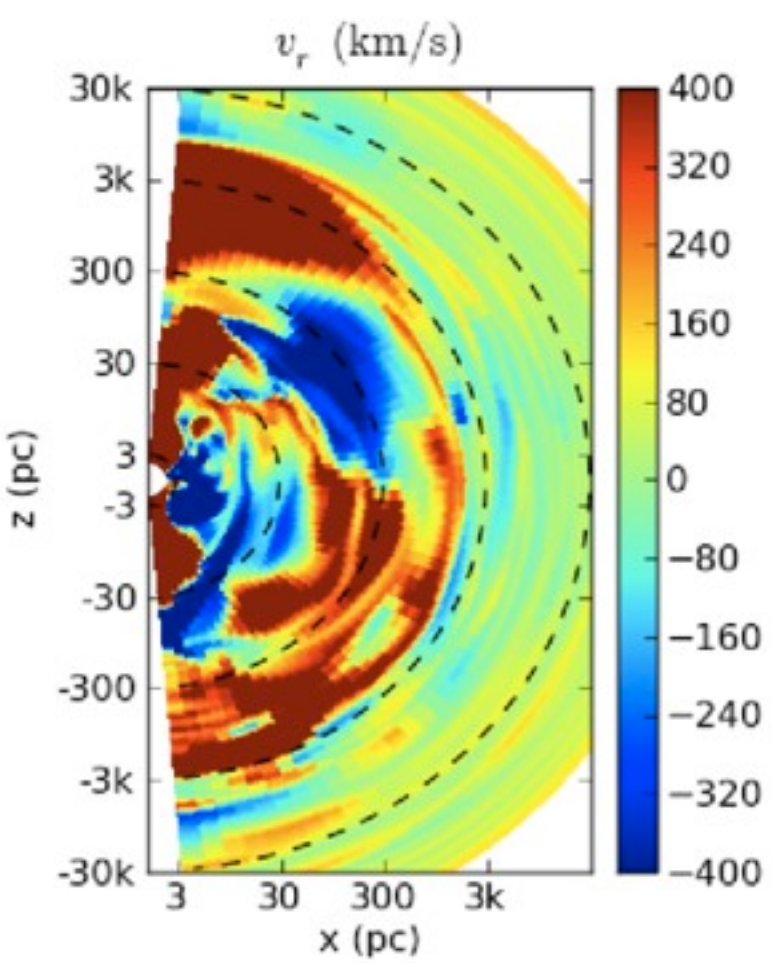
see also Cardamone et al. (2010) [X-ray]

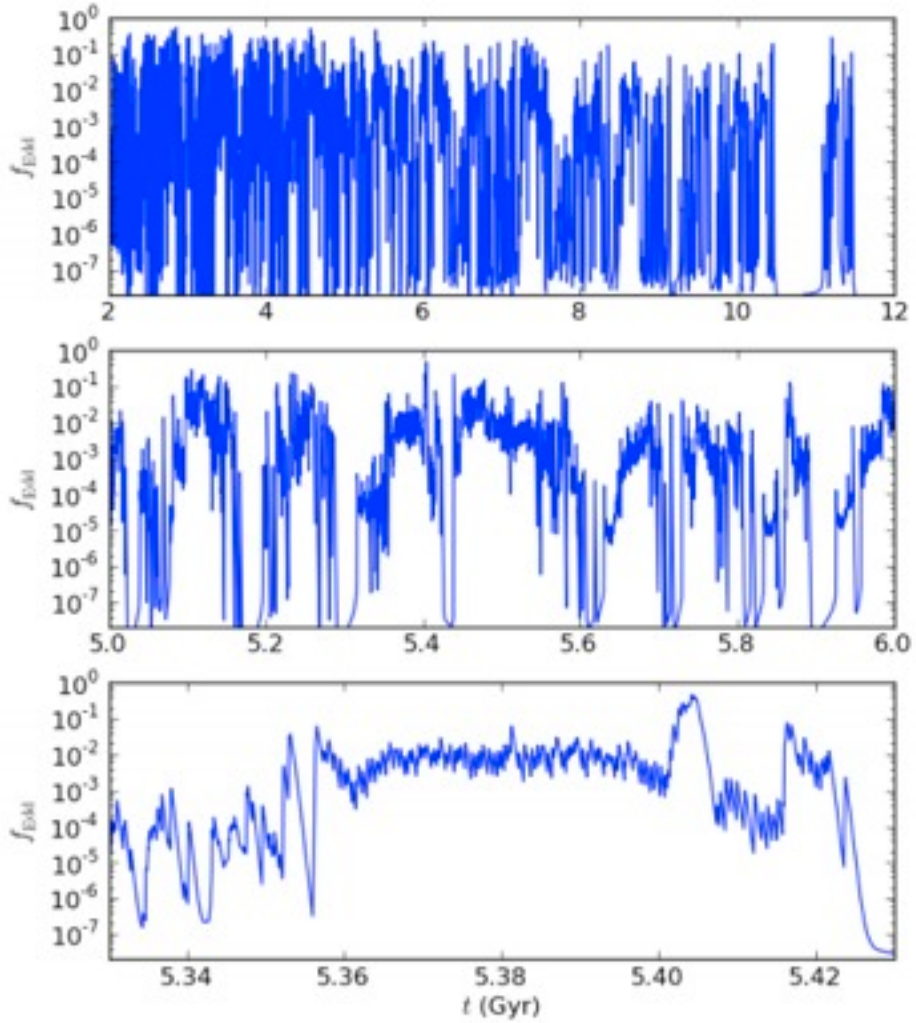
"Typical" AGN: no connection to host star formation?



Shao et al. (2010) [X-ray], see also Mullaney et al. (2010), Laird et al., Silverman et al.

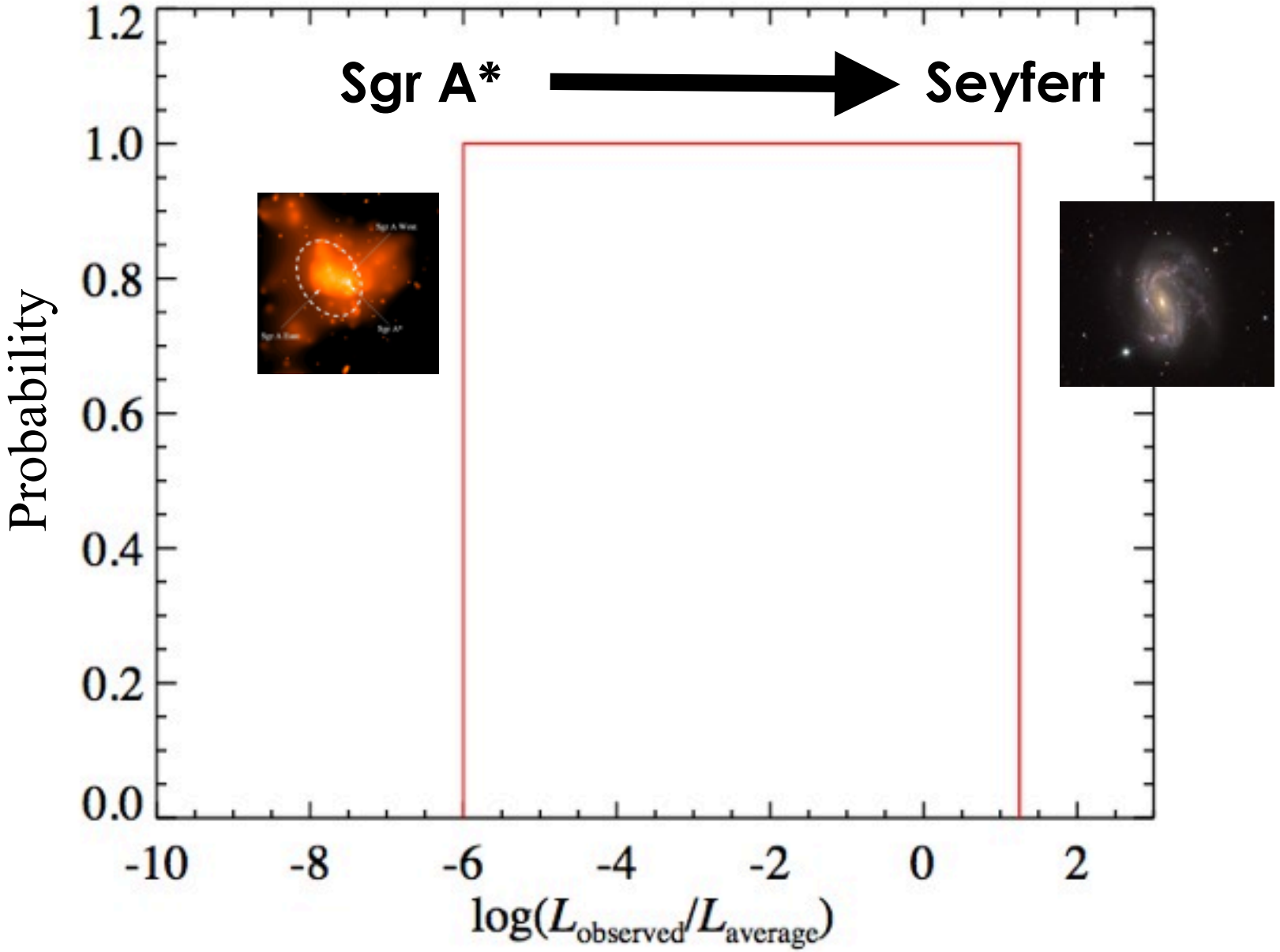
Importance of AGN **variability**

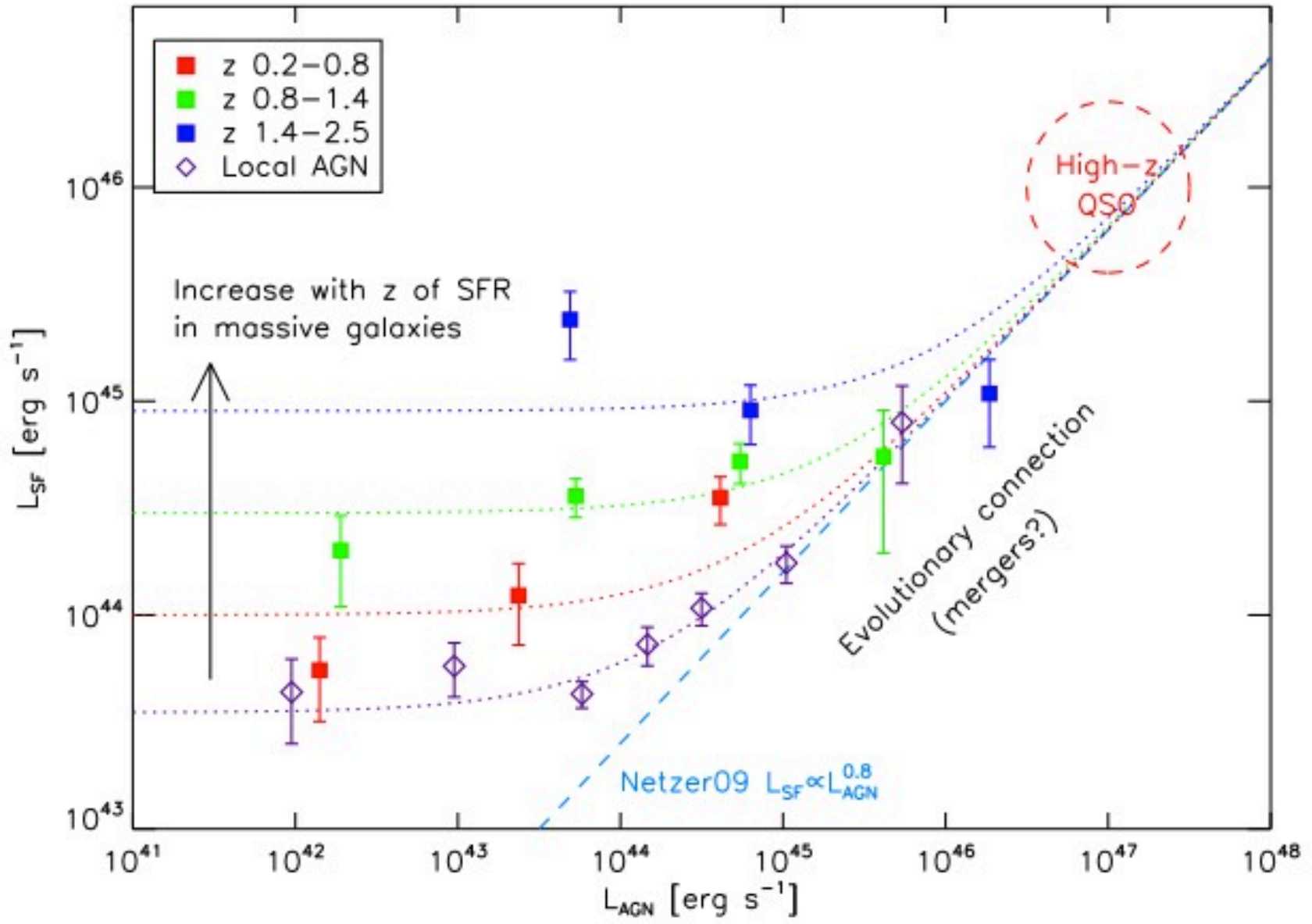




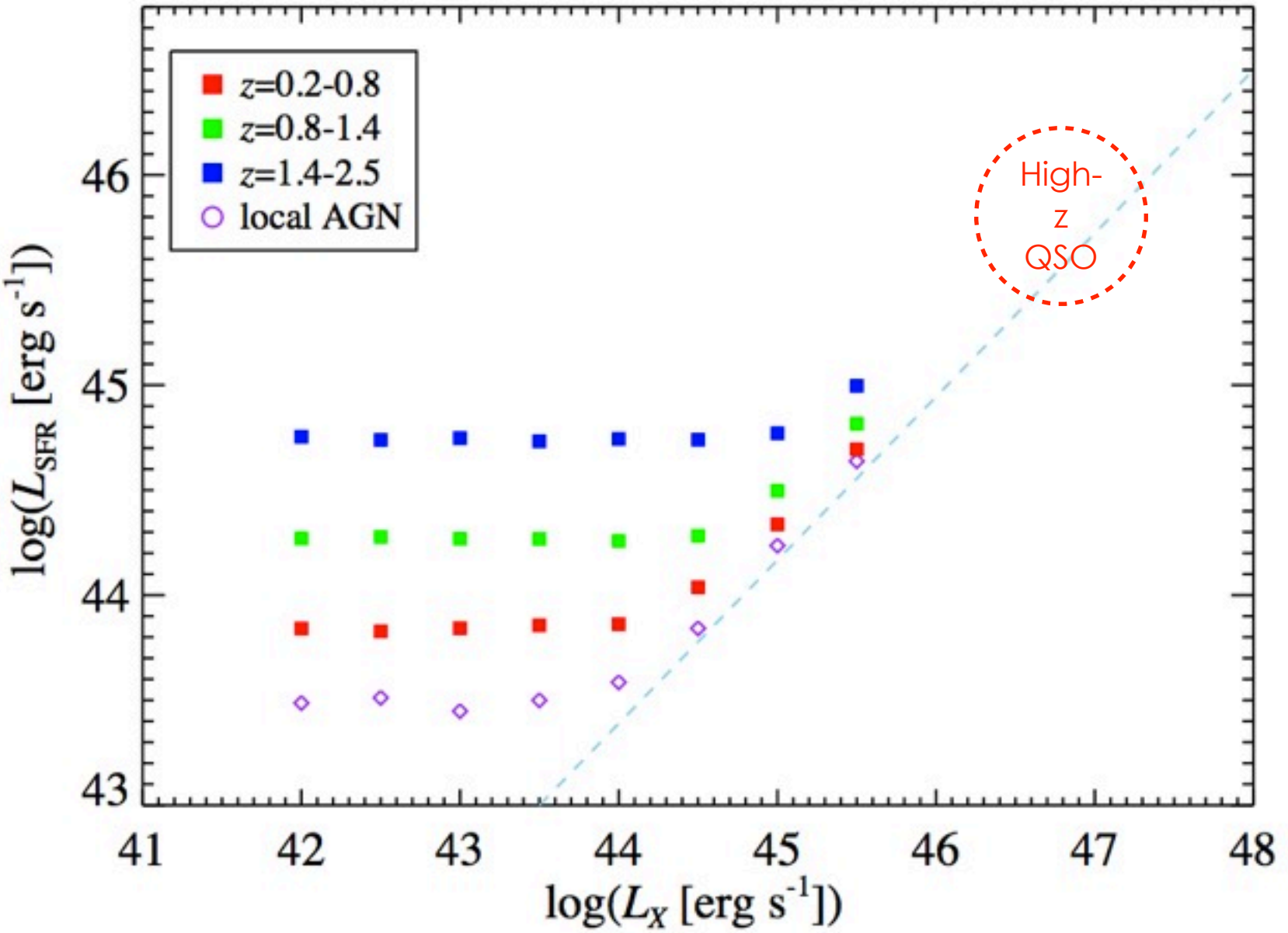
Novak et al. (2011)

Simplest possible model for AGN variability

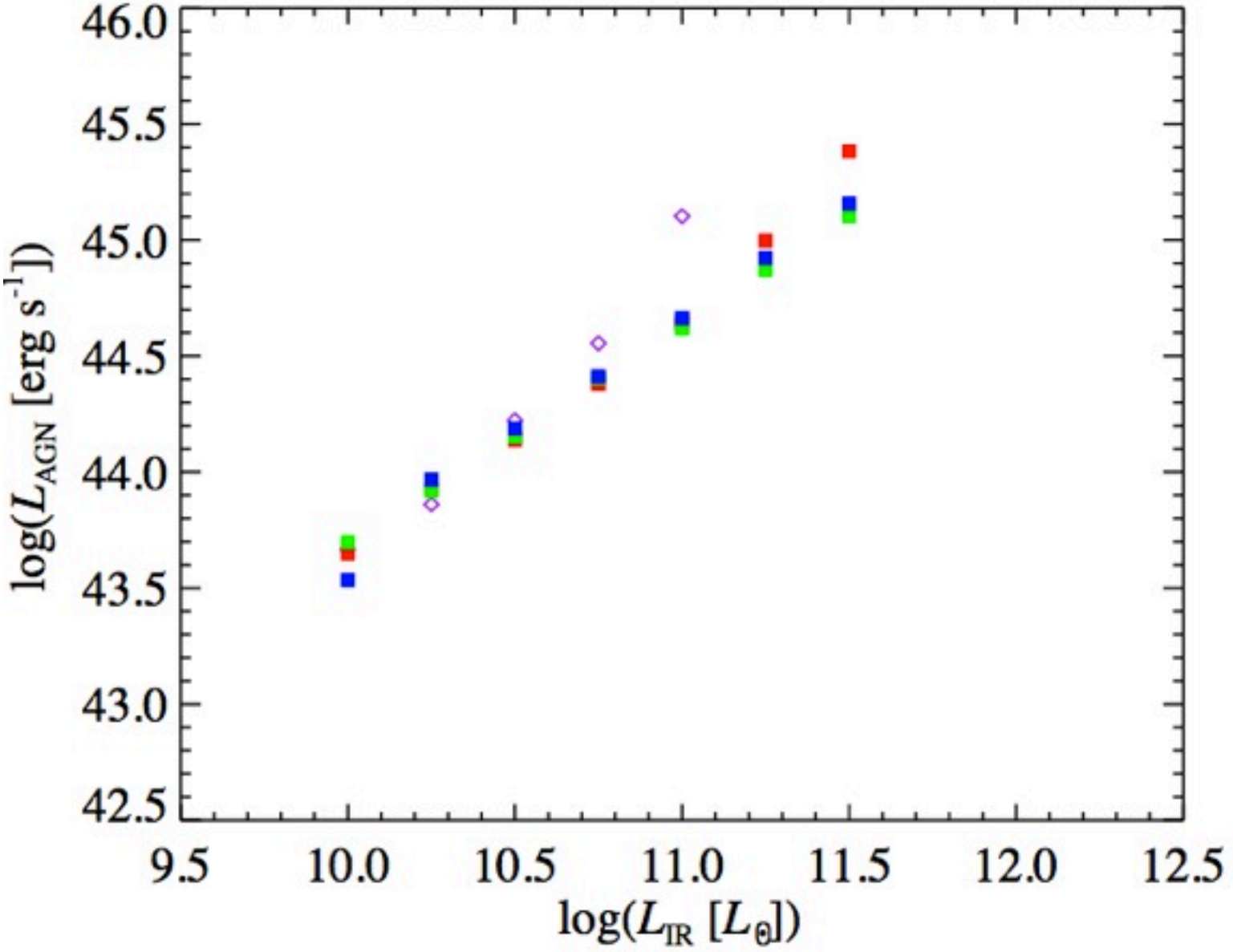




Shao et al. (2010)



Hickox et al. (in preparation)



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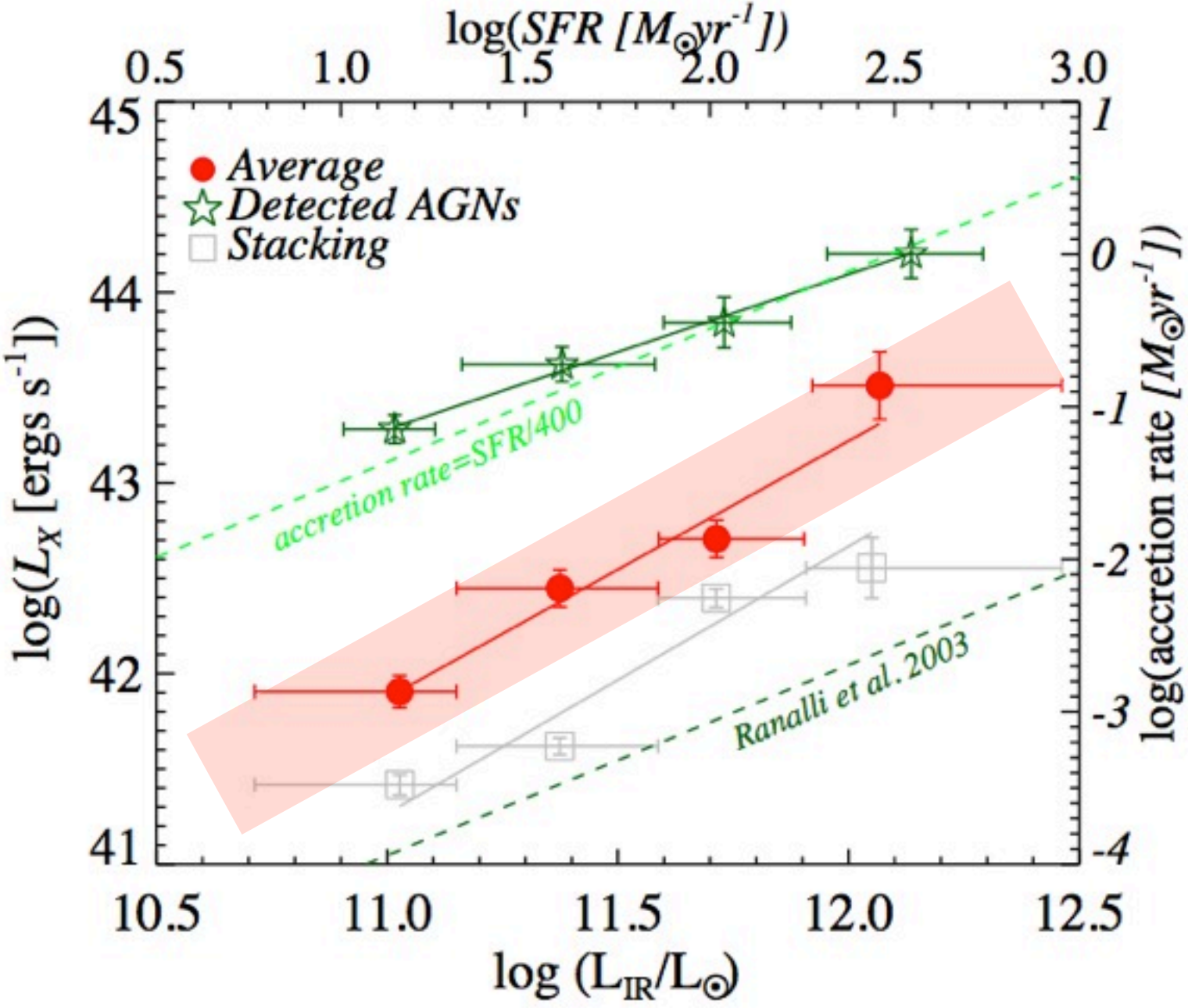
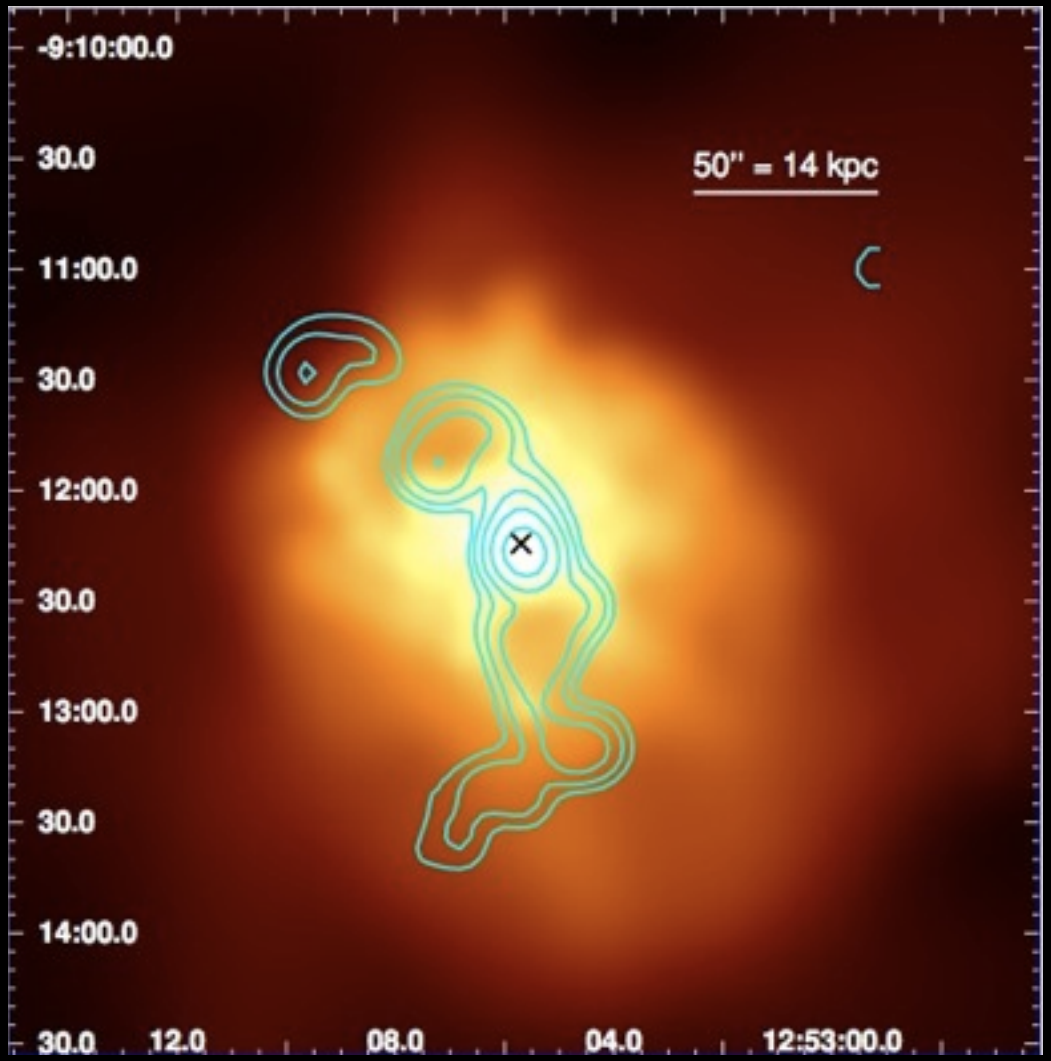


Chen et al. (in preparation)

Do ALL star-forming galaxies host AGN?
(over galaxy timescales)

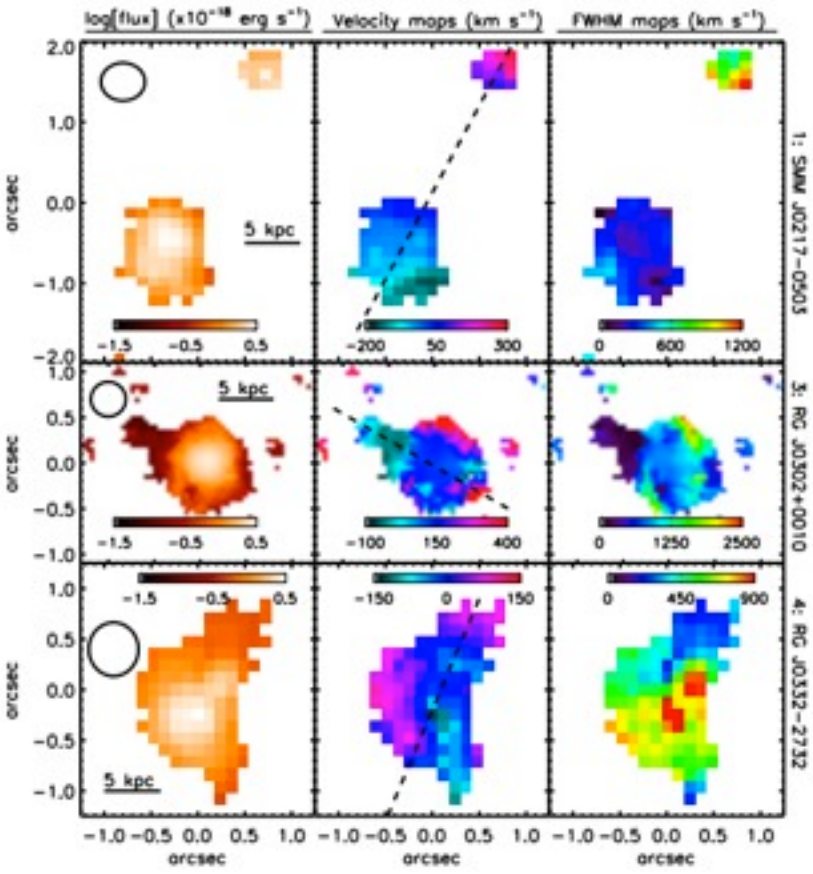
Where and when is AGN feedback important?

Hot atmosphere heating by jets

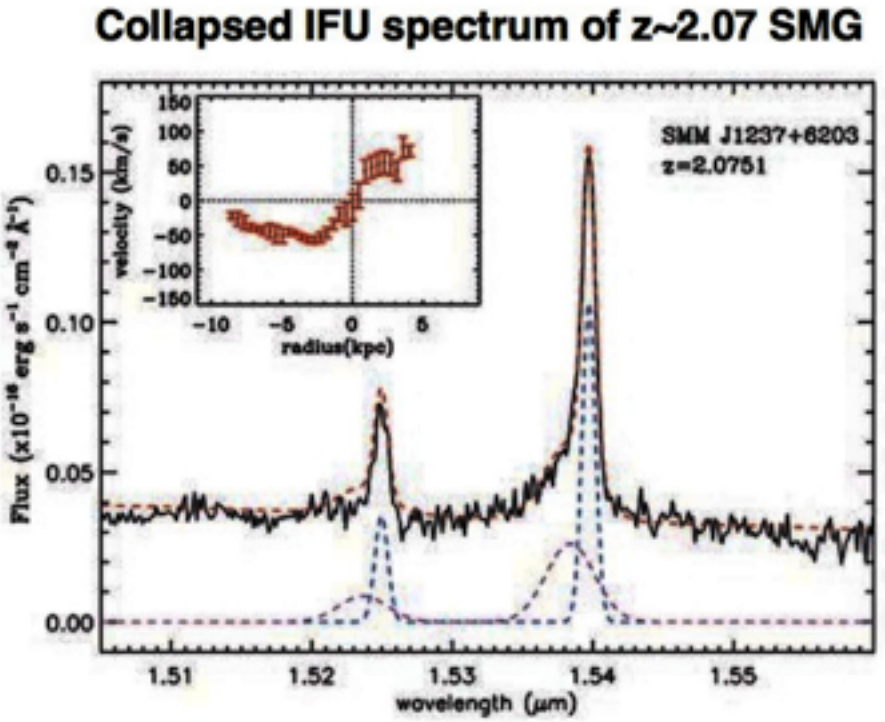


HCG 62 (Gitti et al. 2010), see many others for similar examples

Powerful radiatively-driven AGN outflows



Harrison et al. (2012)

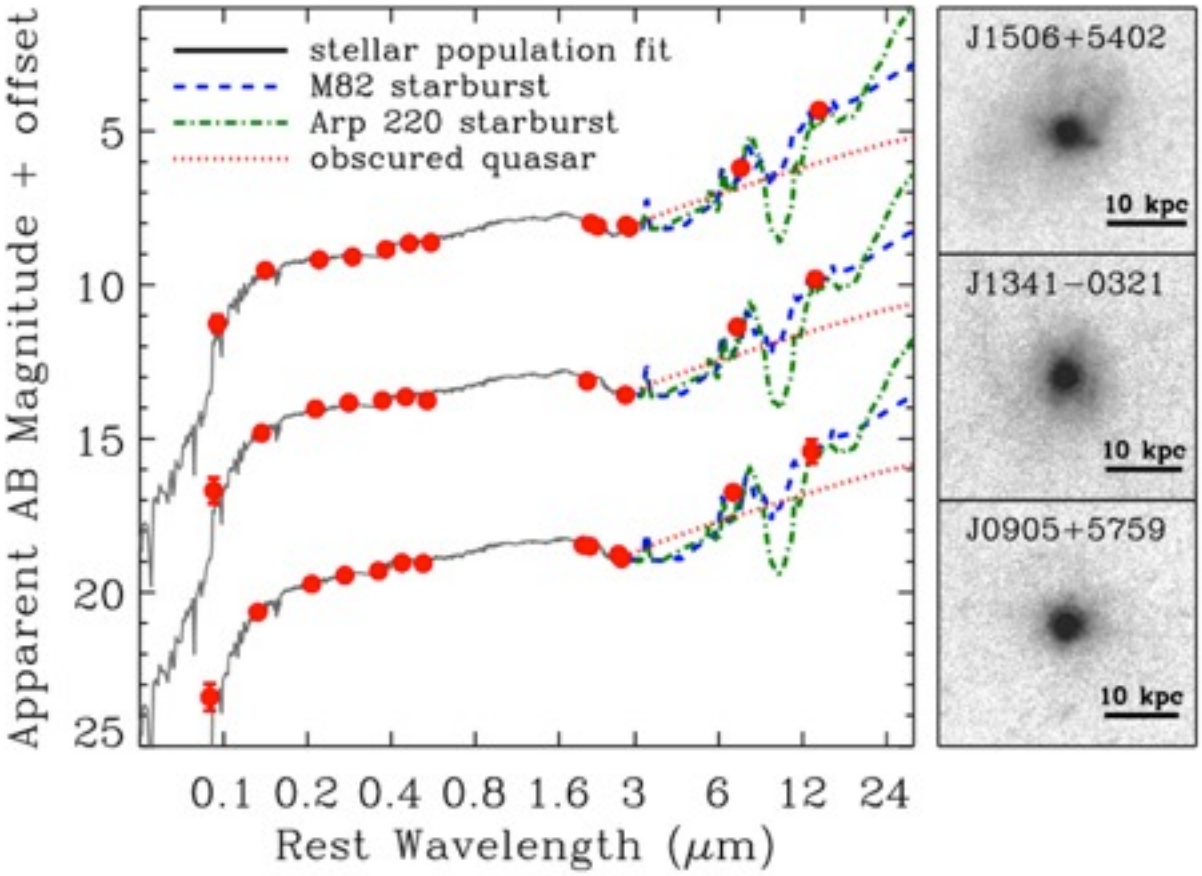


Alexander et al. (2012)

Broad (> 1000 km/s) high-velocity (200-500 km/s) [OIII] gas

For radio-loud sources see Nesvadba et al., Siemignowska et al.

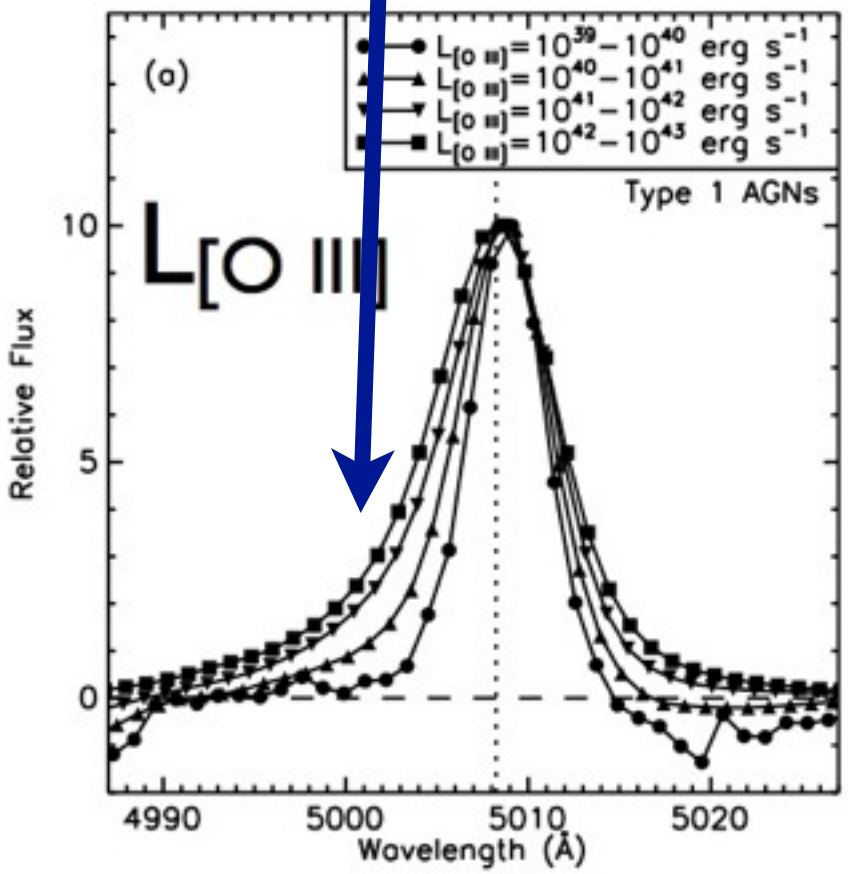
Perhaps AGN not **always** needed for high-velocity outflows?



SFR surface density > 2000 M_{sun} yr^{-1} pc^2!
Outflow velocity > 1000 km/s

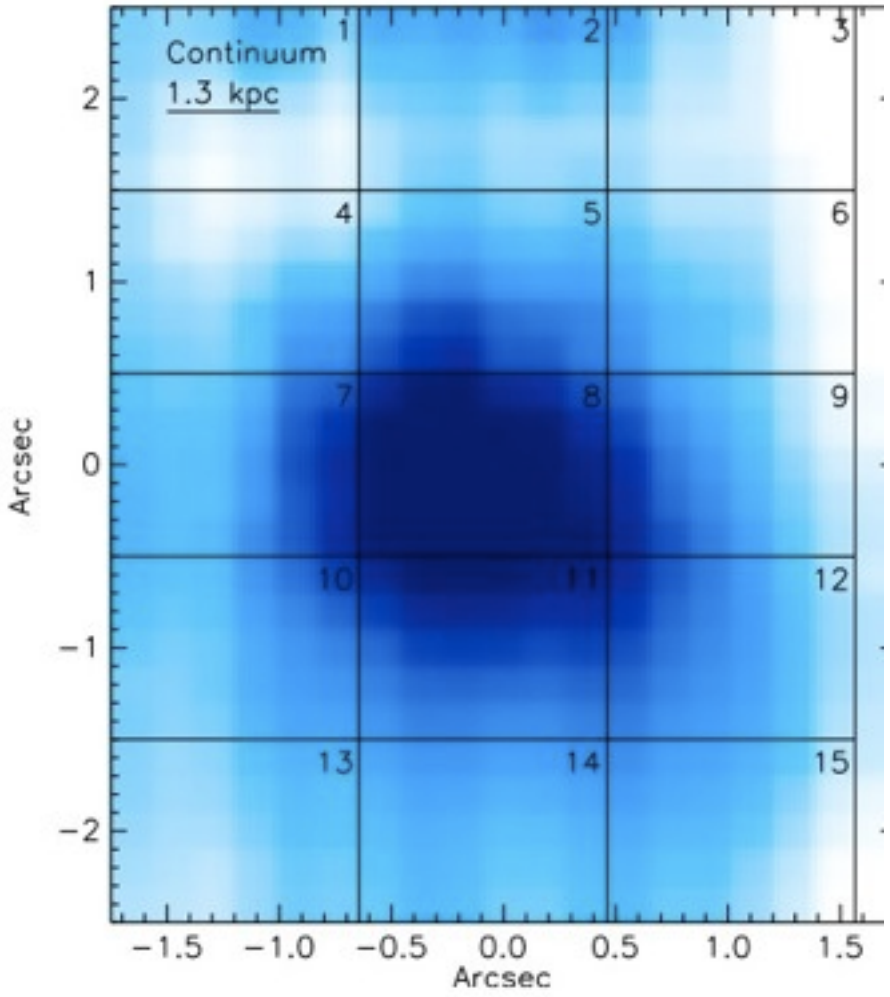
Diamond-Stanic et al. (2012)

Ubiquitous outflows at low z?



Mullaney et al. in prep [optical]

Black hole self-regulation?

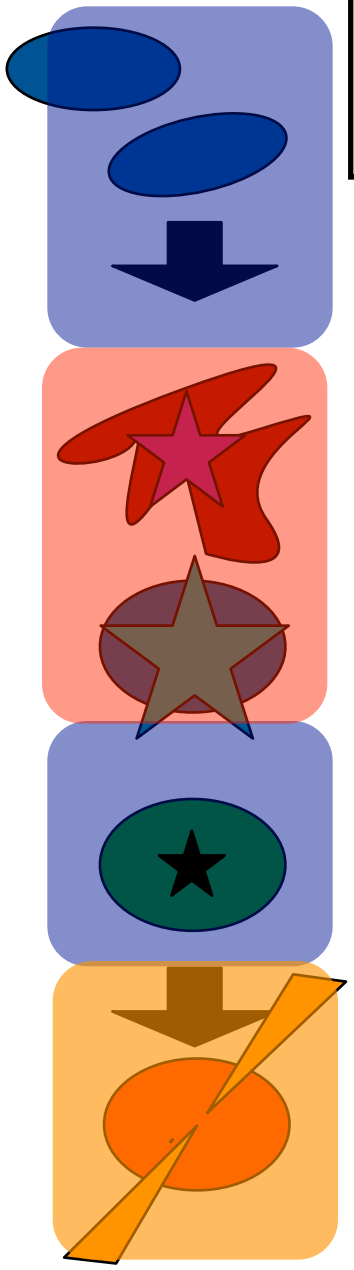


Gas-rich galaxy(s)

Cosmic time

Starburst galaxy/ quasar

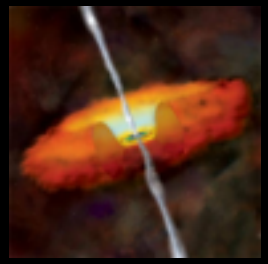
Red sequence galaxy



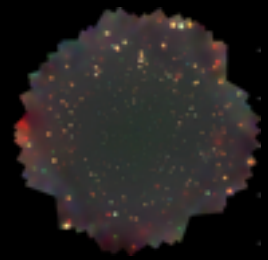
Radiative and **mechanical** feedback can strongly affect host

Black hole **self-regulation?**

What have we learned?

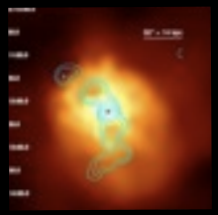


- Accretion state depends on **Eddington ratio**, broadly analogous to XRBs
- Different techniques **select different AGN populations**



- **Most BH growth occurs at early epochs**, with massive BHs shutting off first

- **BH accretion rates and star formation may be closely linked** in galaxies and trace the growth of dark matter halos



- **Mechanical energy input** from jets is observed in massive systems where star formation is shut off
- **Radiative feedback** may regulate BH growth

THE FUTURE: BETTER STATISTICS!

X-ray:
XMM/XXL survey
Possible Chandra XVP?
eROSITA

Infrared: WISE

Study **distribution** of accretion rates, and **halo occupation distribution** from clustering

Black hole evolution --> galaxy evolution