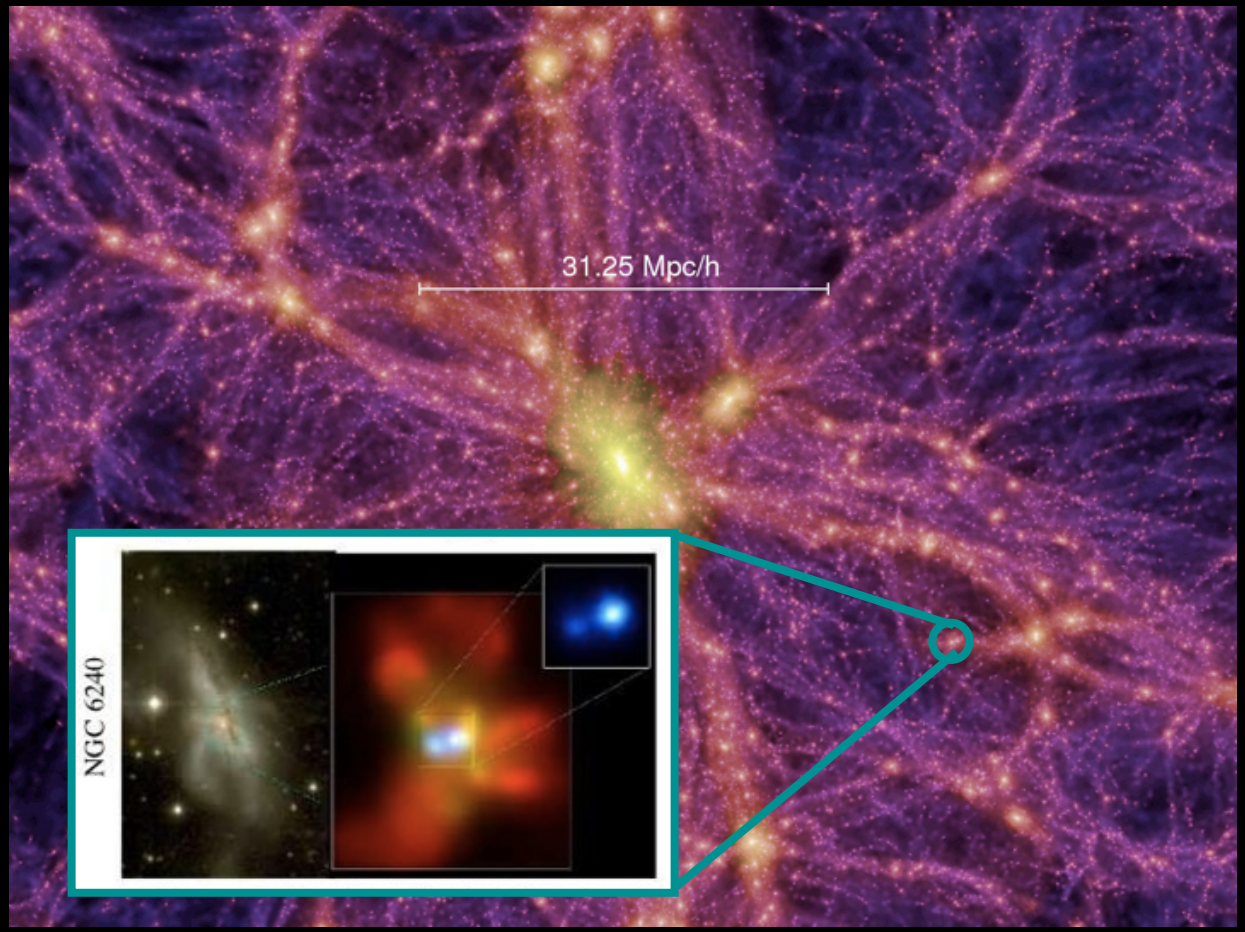
THE DARK AND THE LIGHT: Black holes, dark halos, and their influence on galaxy evolution



Ryan C. Hickox
STFC Postdoctoral Fellow

Durham University

INAF/OABO/
Universita di Bologna
12 May 2011

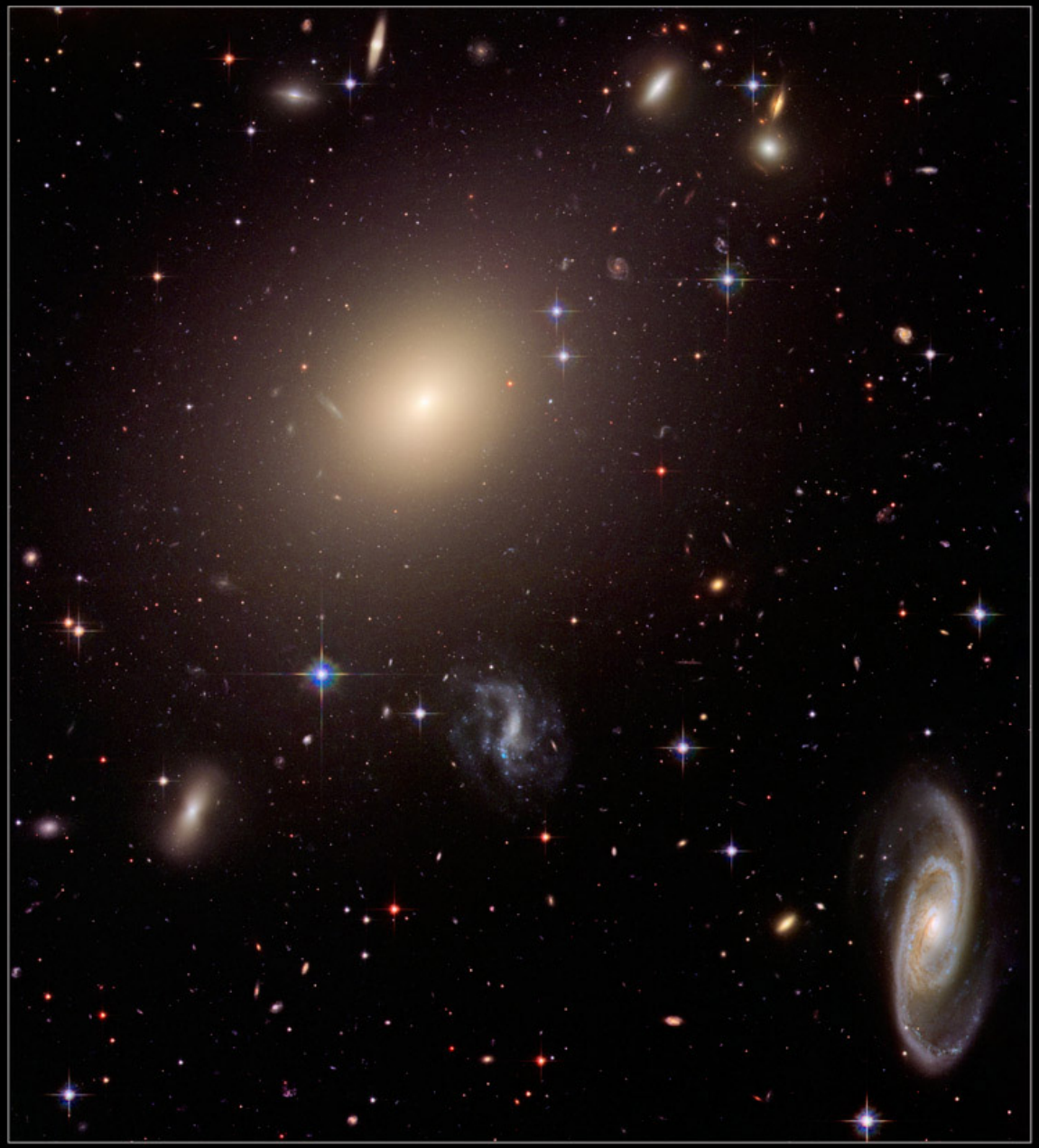
On the menu:

PART 1: Host galaxies and environments of different classes of AGN

PART 2: Where and when does AGN feedback occur?

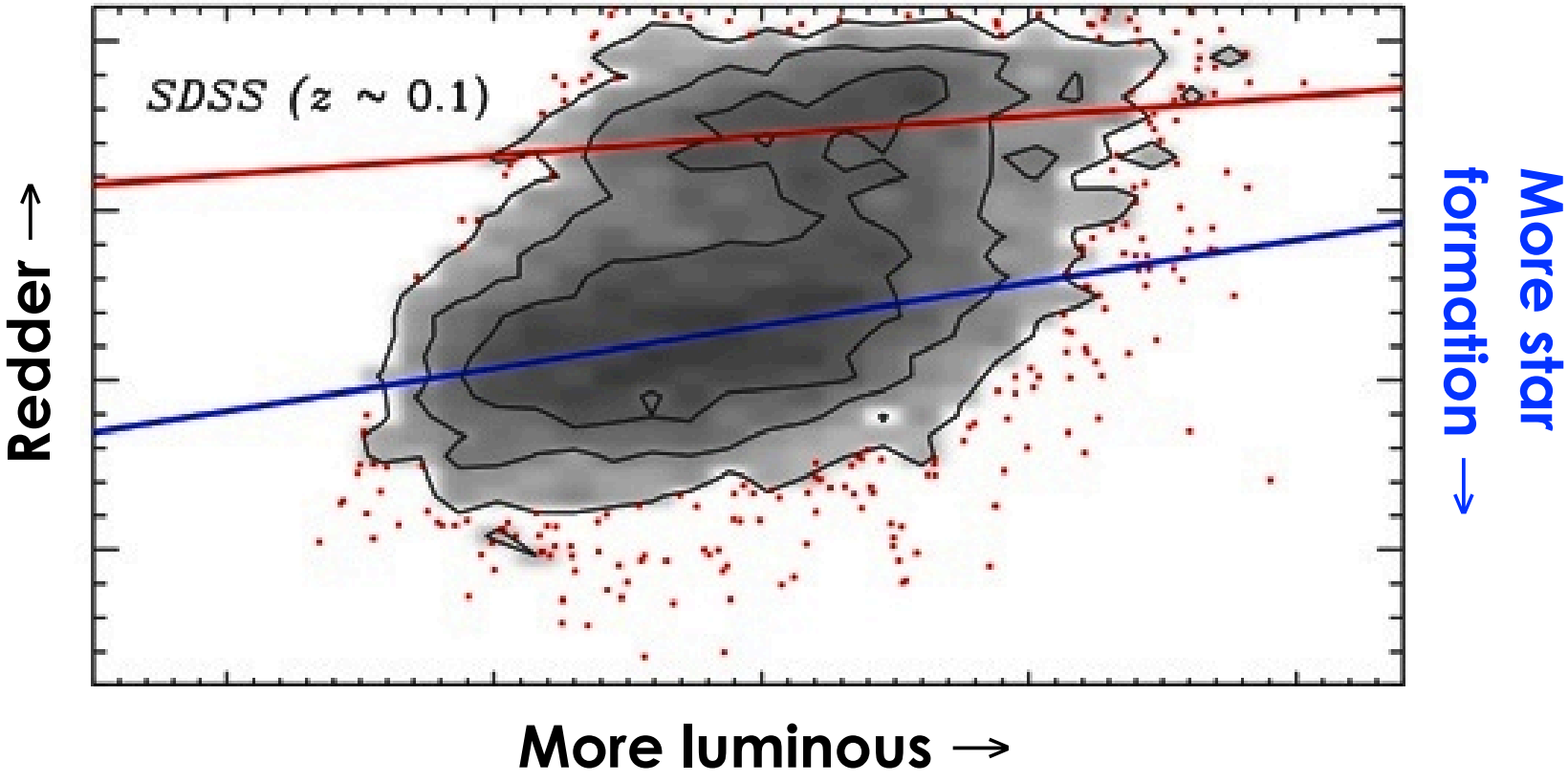
PART 3: Environments of star-forming galaxies

Elliptical Galaxy ESO 325-G004 in the Abell Cluster S0740



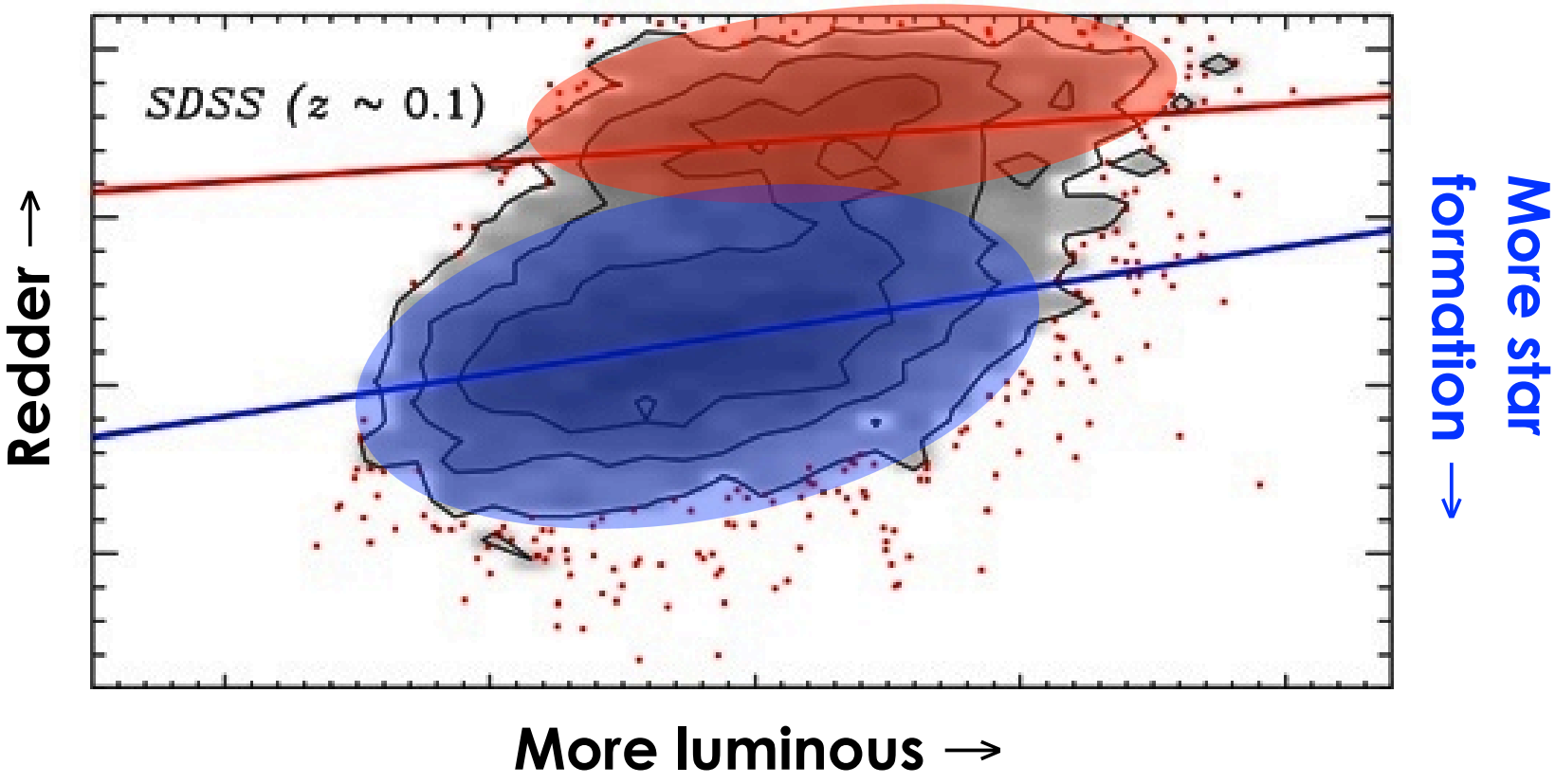
Hubble Heritage

Statistics of galaxies



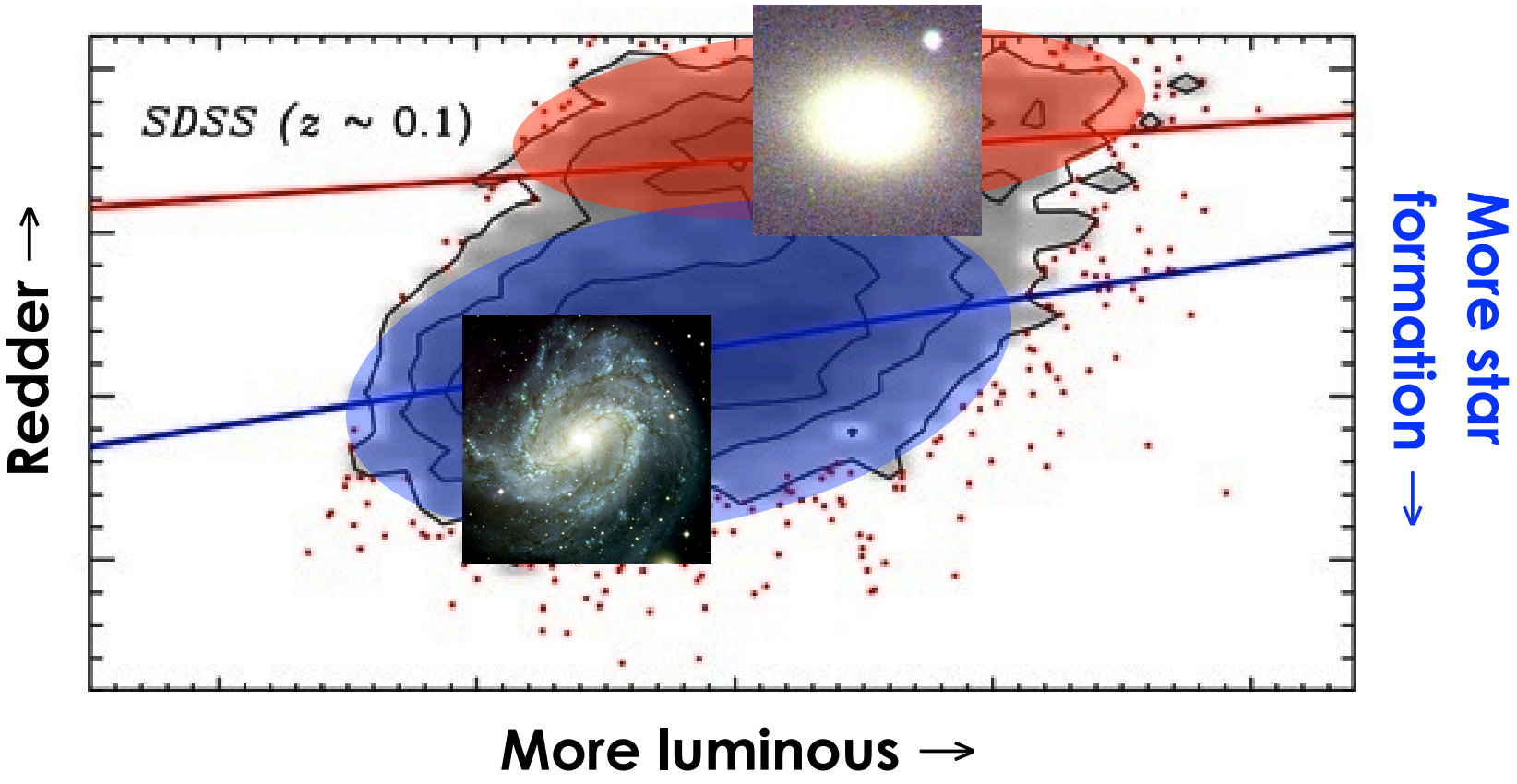
Blanton (2006)

Statistics of galaxies



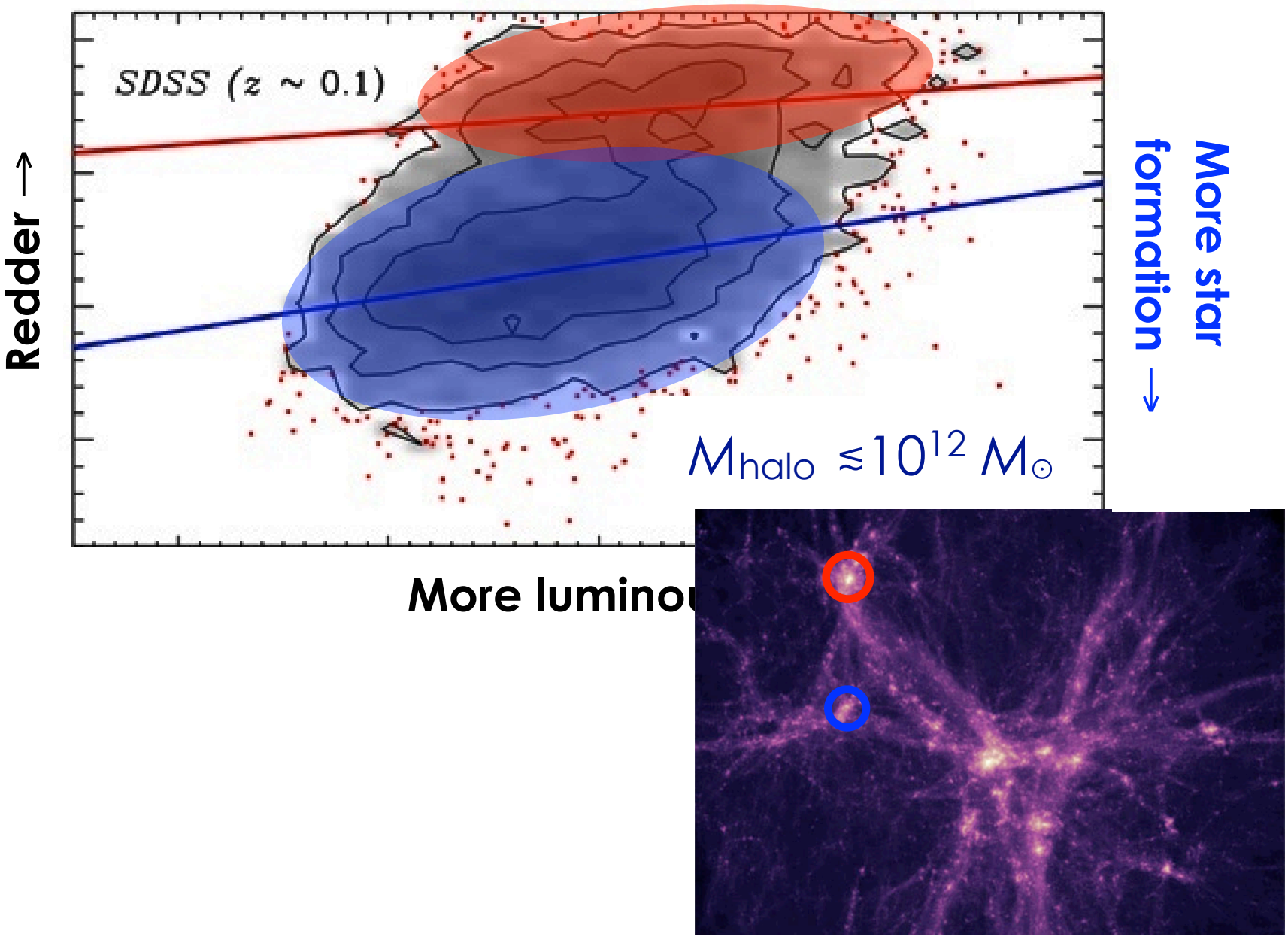
Blanton (2006)

Statistics of galaxies



Blanton (2006)

Statistics of galaxies



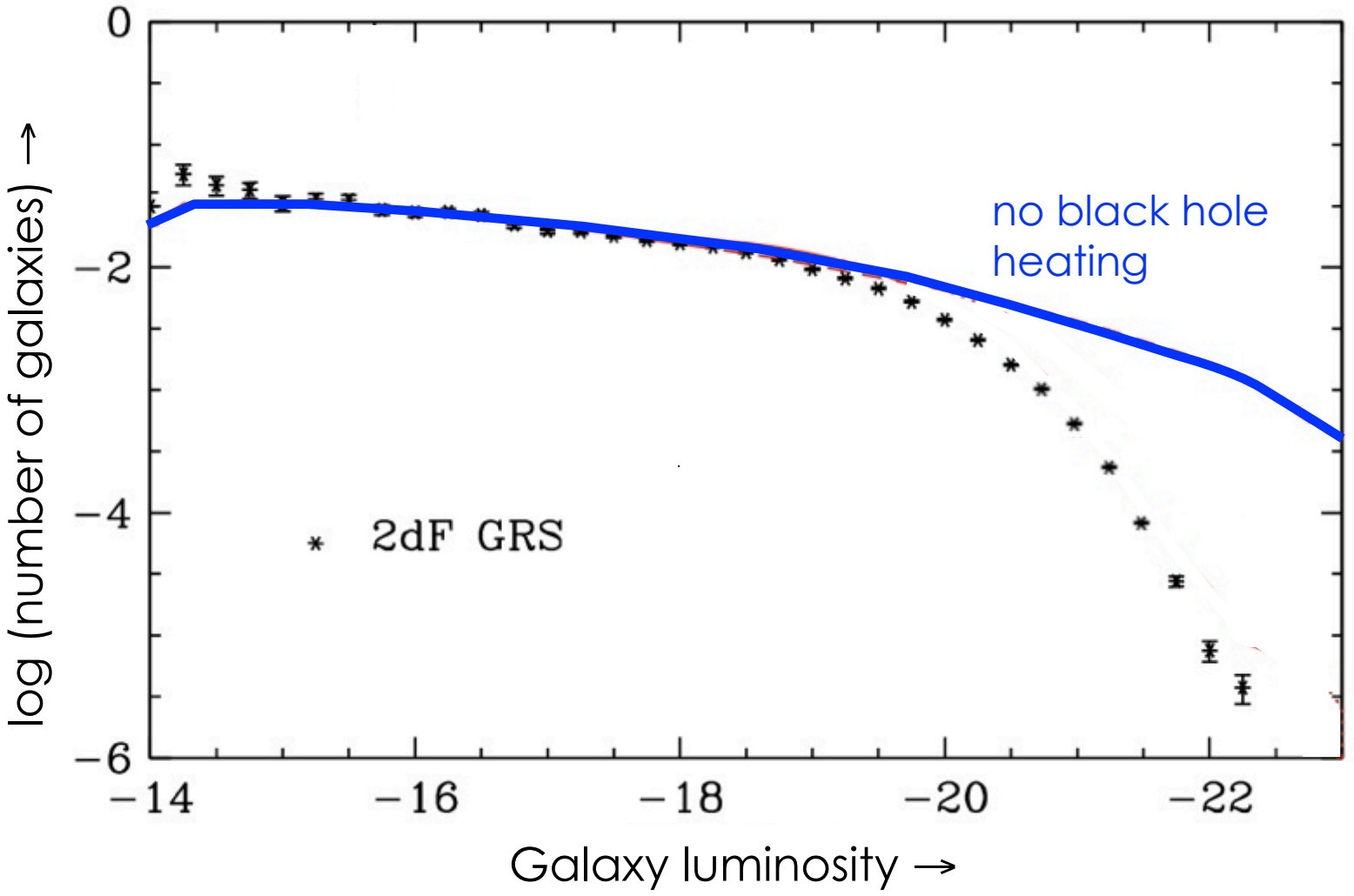
Galaxy NGC 7742

PRC98-28 • Space Telescope Science Institute • Hubble Heritage Team

Hydra A

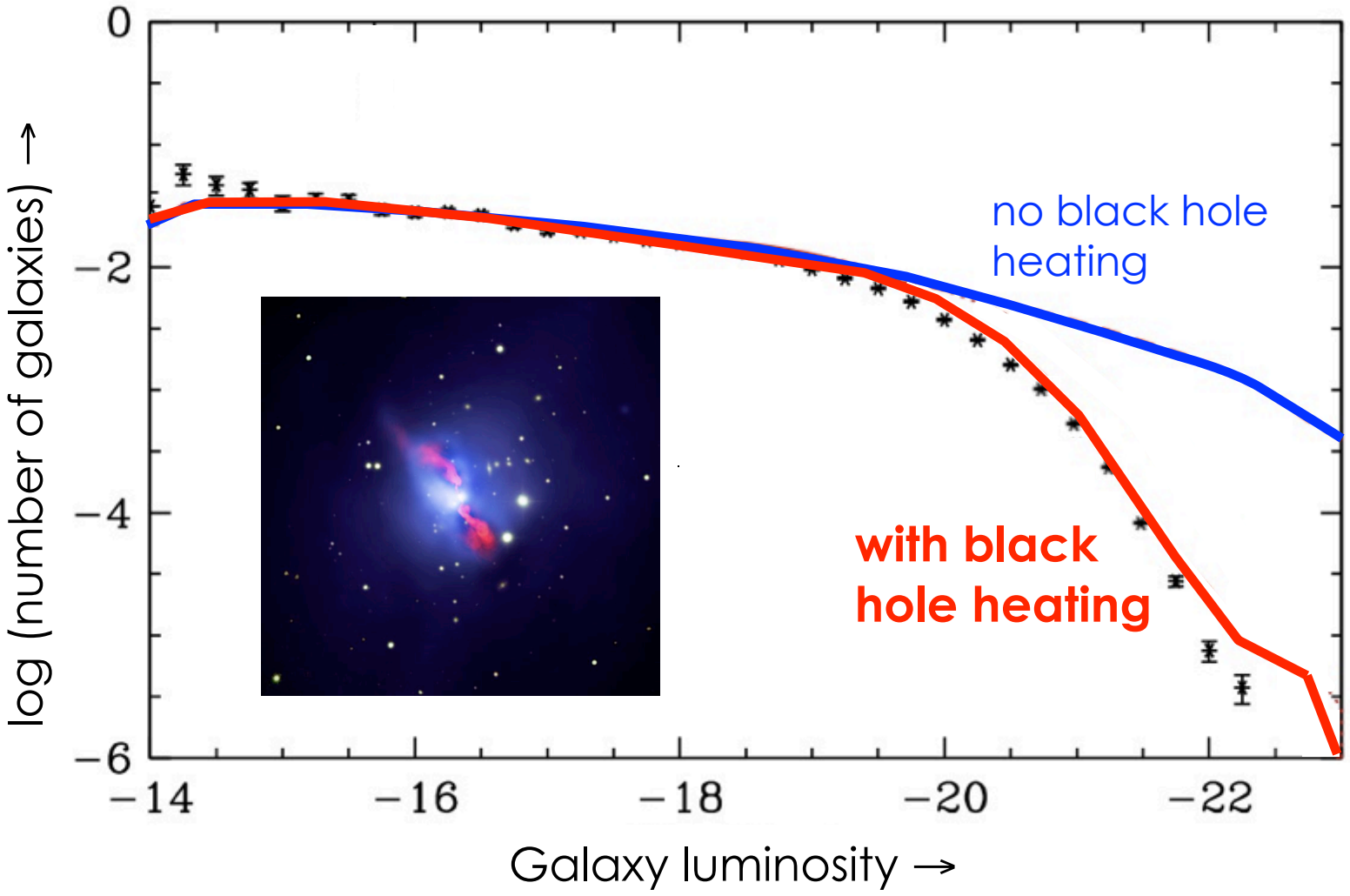
X-ray: NASA/CXC/U.Waterloo/C.Kirkpatrick et al.; Radio: NSF/ NRAO/VLA; Optical: Canada-France-Hawaii-Telescope/DSS

Statistics of galaxies



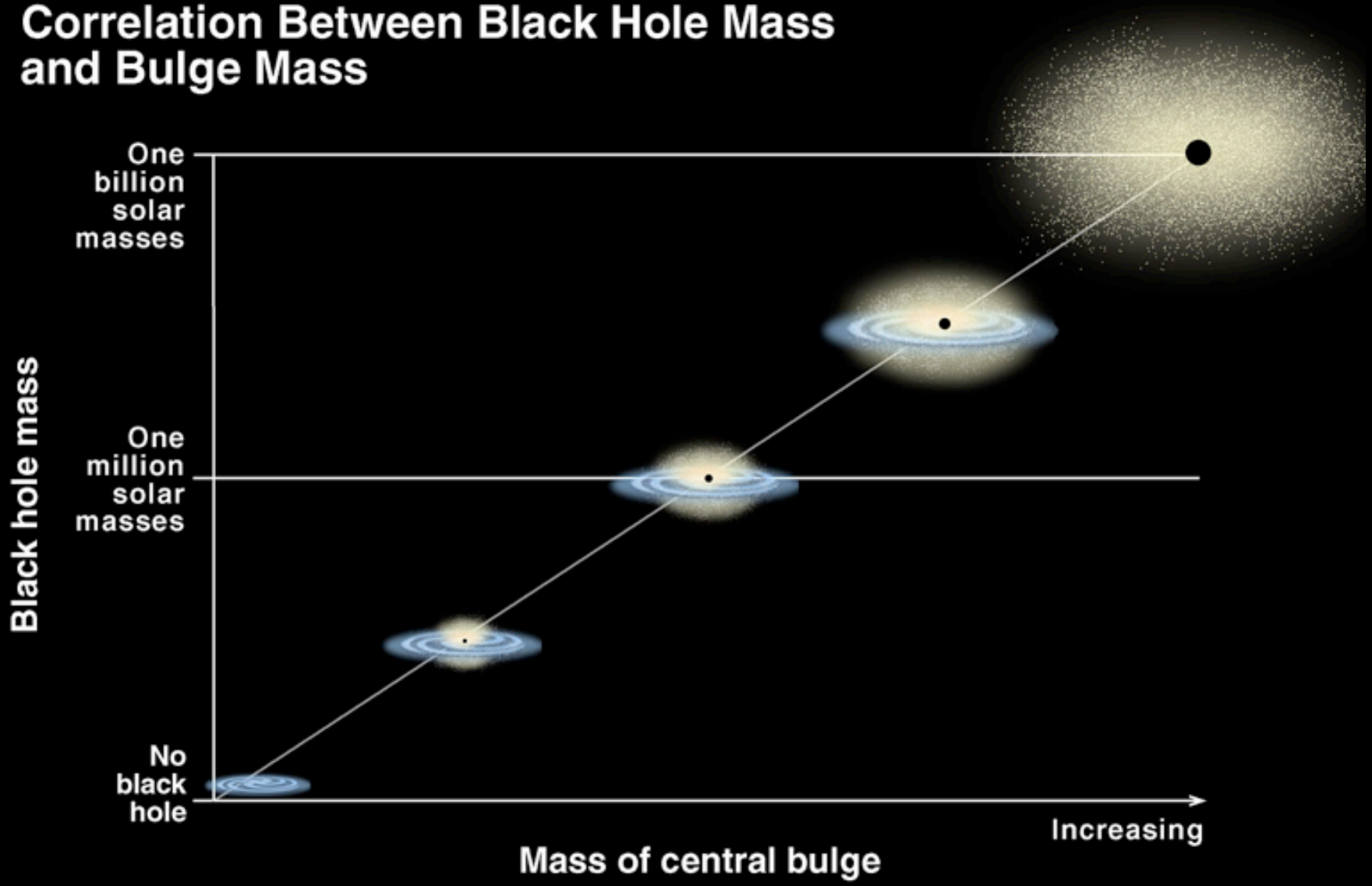
Bower et al. (2006), see also Croton et al. (2006) and many others

Statistics of galaxies

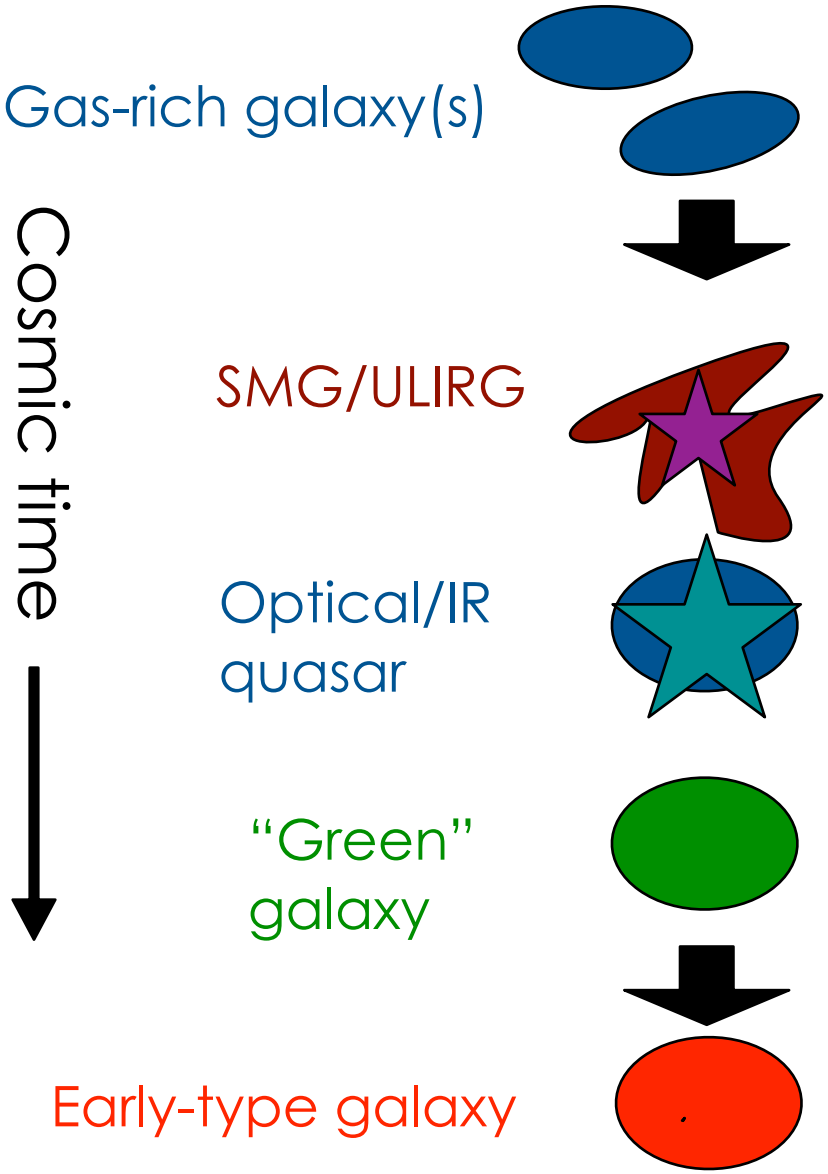


Bower et al. (2006), see also Croton et al. (2006) and many others

Correlation Between Black Hole Mass and Bulge Mass

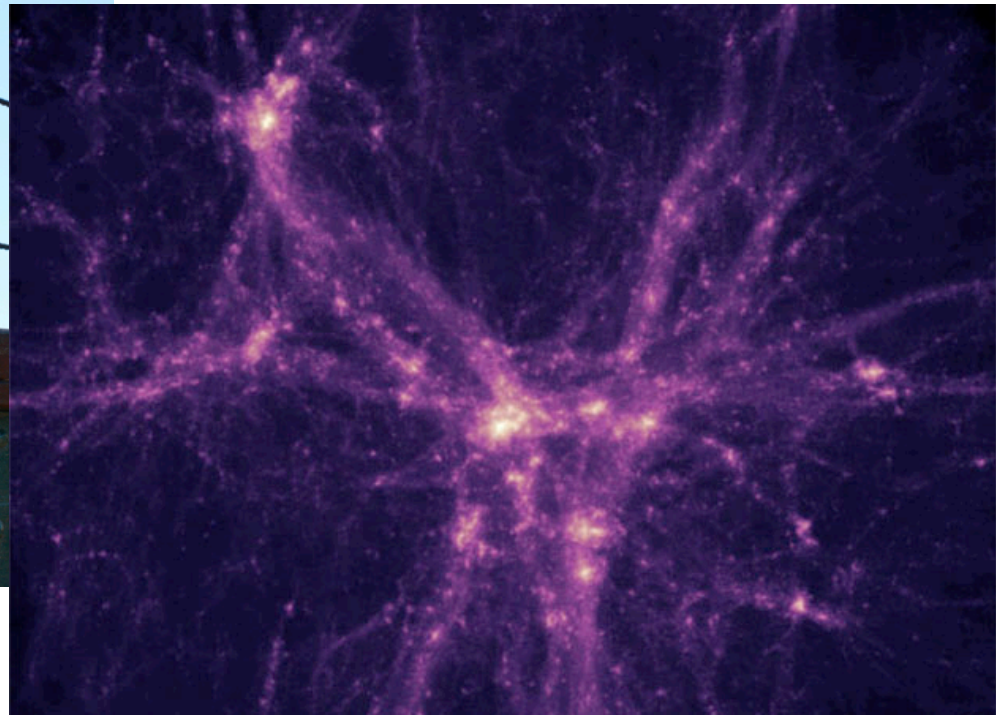


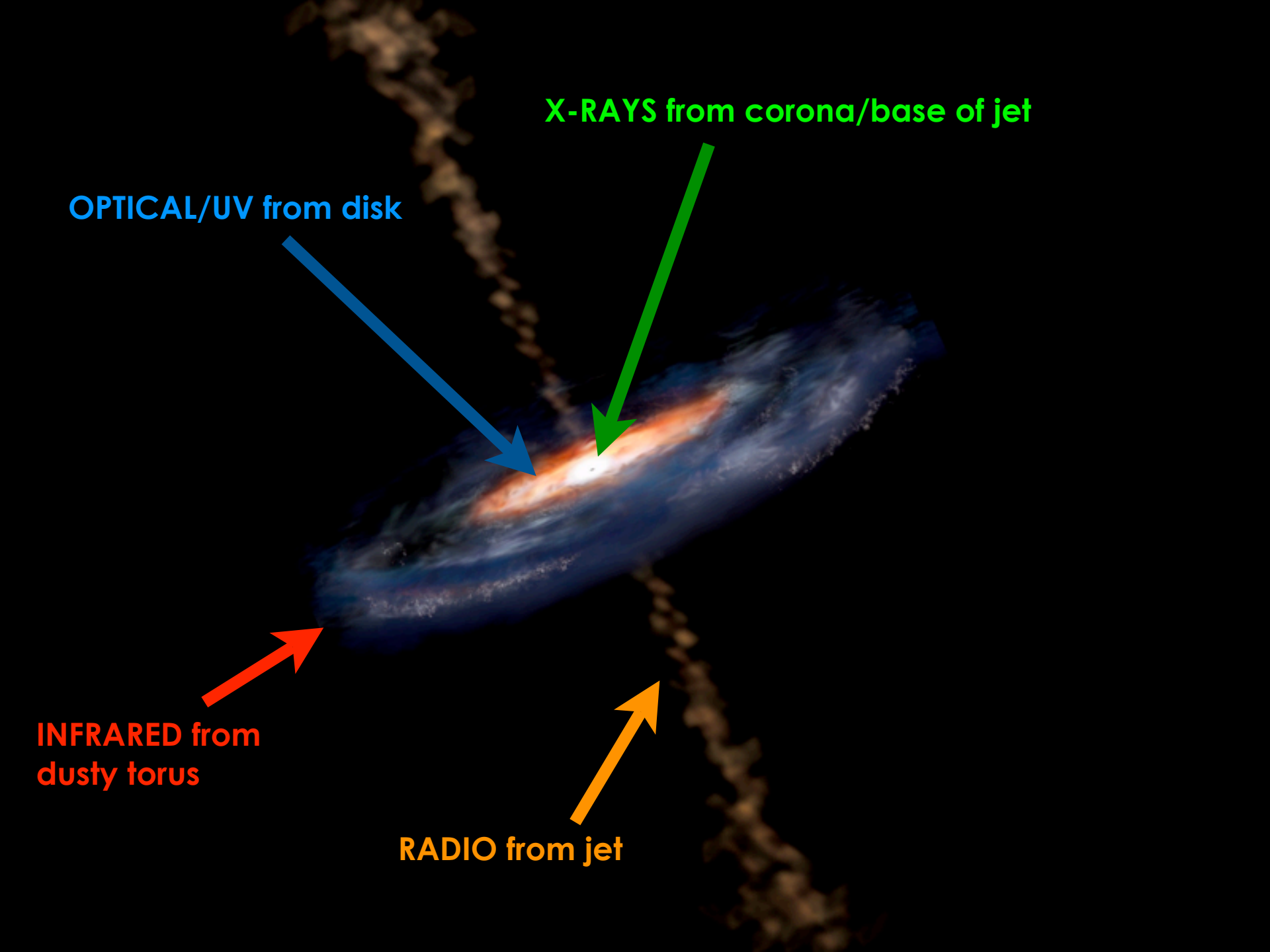
Cartoon of massive galaxy evolution



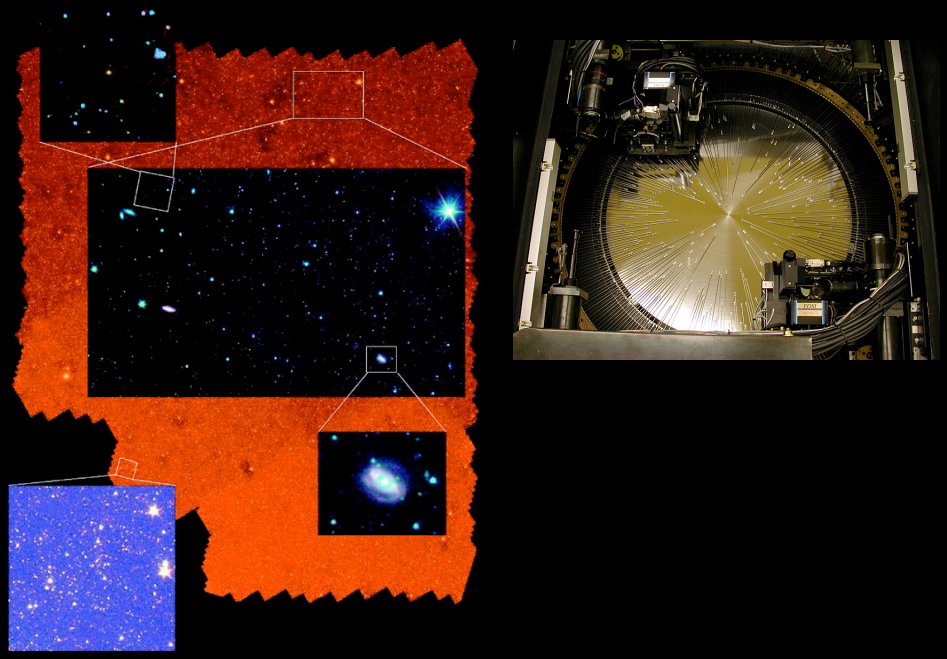
a la Sanders et al. (1988)

Part 1: Where are the AGN?




X-RAYS from corona/base of jet
OPTICAL/UV from disk
INFRARED from dusty torus
RADIO from jet

The 9 deg^2 Boötes survey

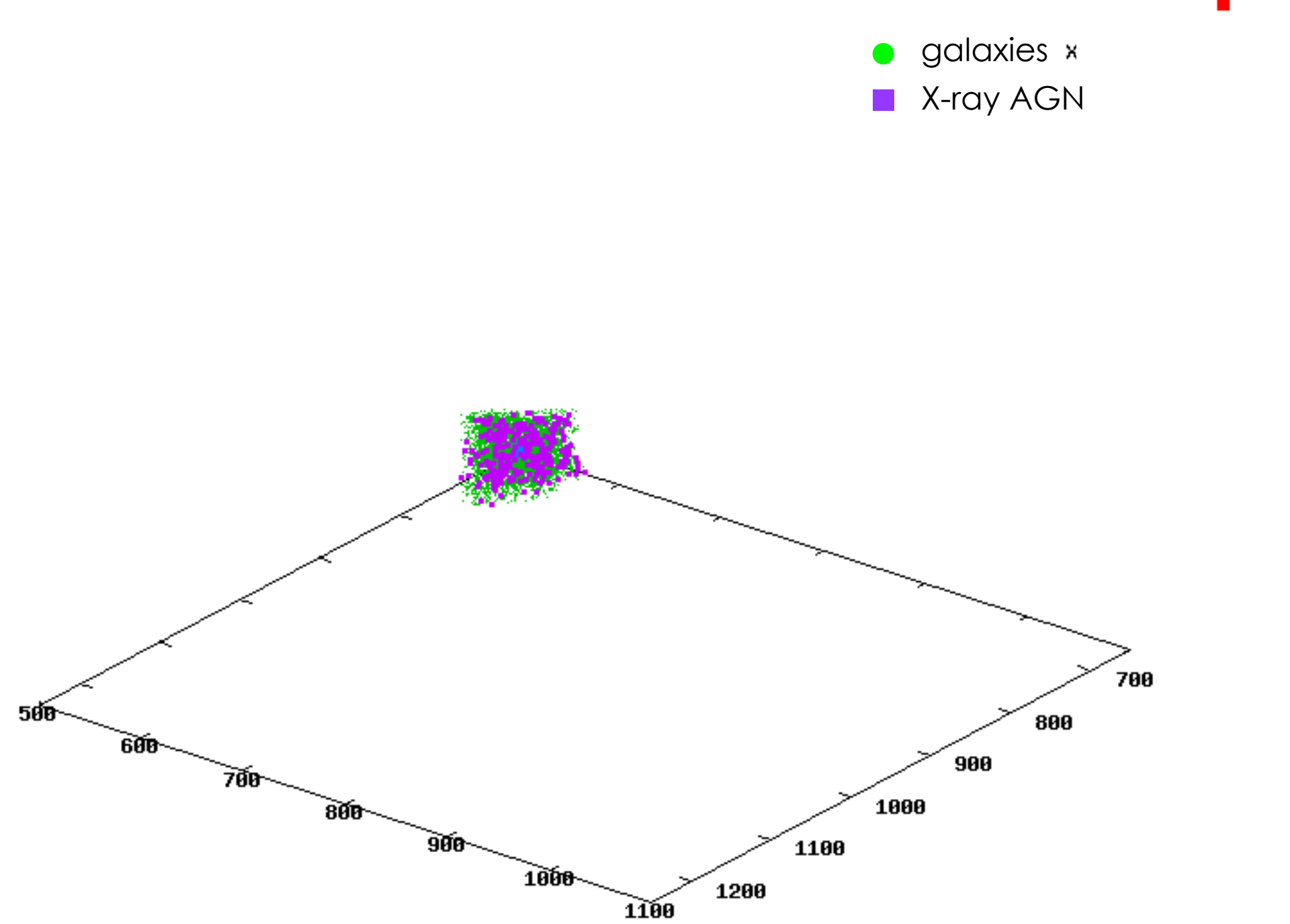


Chandra (CfA)
C. Jones
W. Forman
S. Murray
A. Kenter
R. Narayan

Optical photometry (NOAO/etc.)
B. Jannuzi
A. Dey
K. Brand
M. Brown
and the NDWFS Team

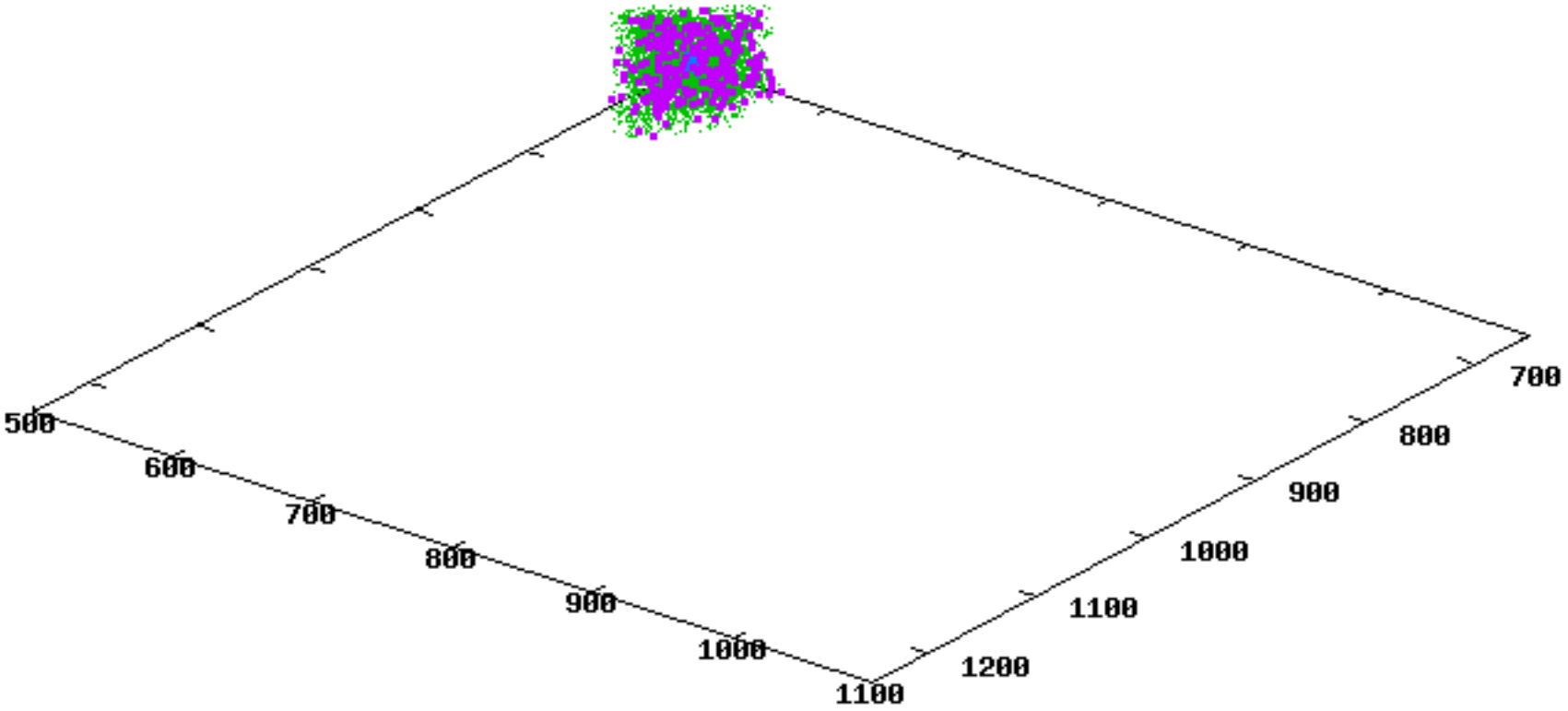
Spitzer IRAC (JPL/Caltech/CfA)
P. Eisenhardt
M. Brodwin
V. Gorjian
D. Stern
M. Pahre
and the IRAC Shallow Survey Team

Optical spectroscopy (OSU/Arizona/CfA)
K. Kochanek
D. Eisenstein
R. Cool
N. Caldwell
and the AGES Team

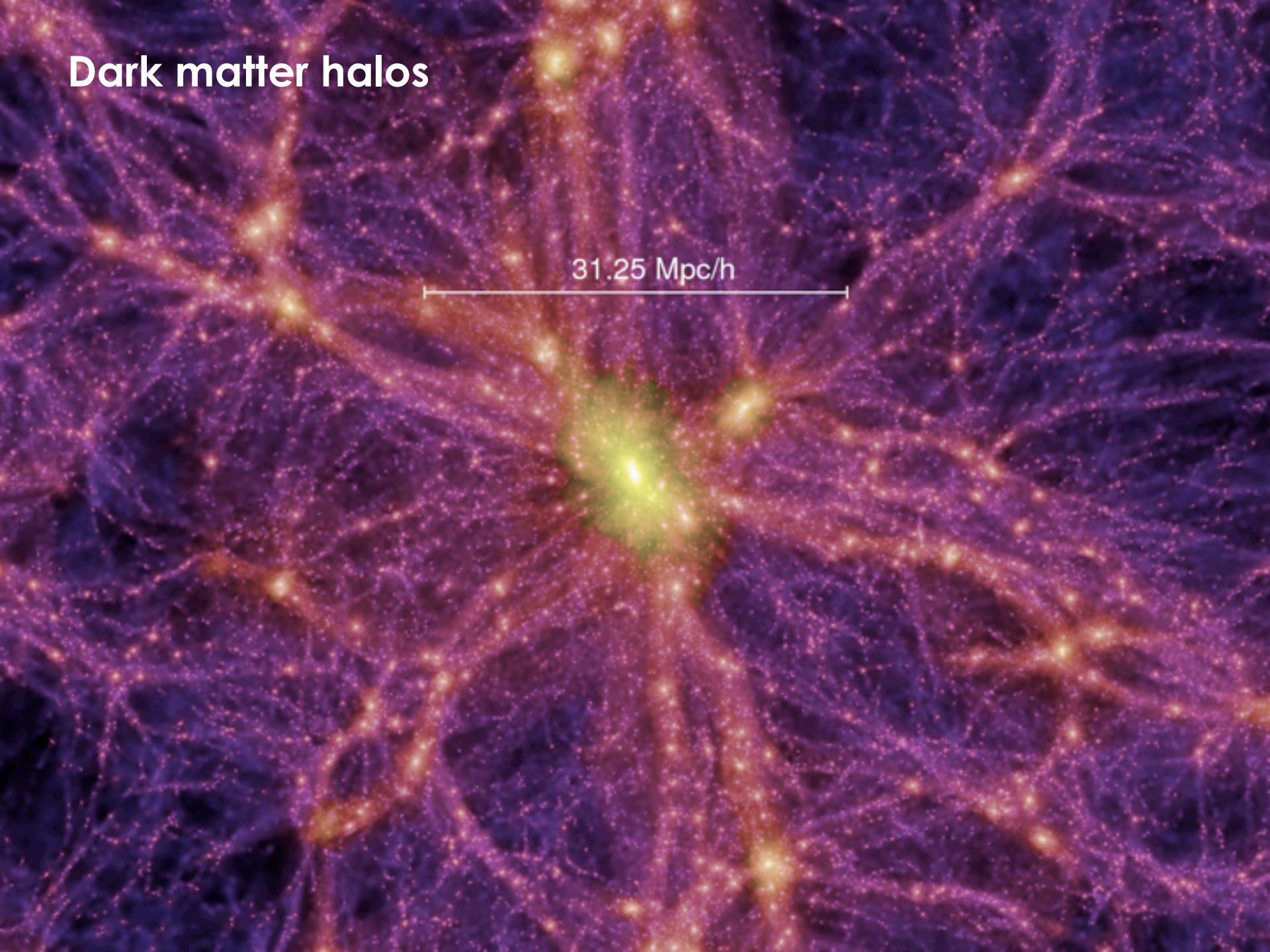

galaxies
X-ray AGN
500
600
700
800
900
1000
1100
1200
700
800
900
1000
1100

galaxies

X-ray AGN

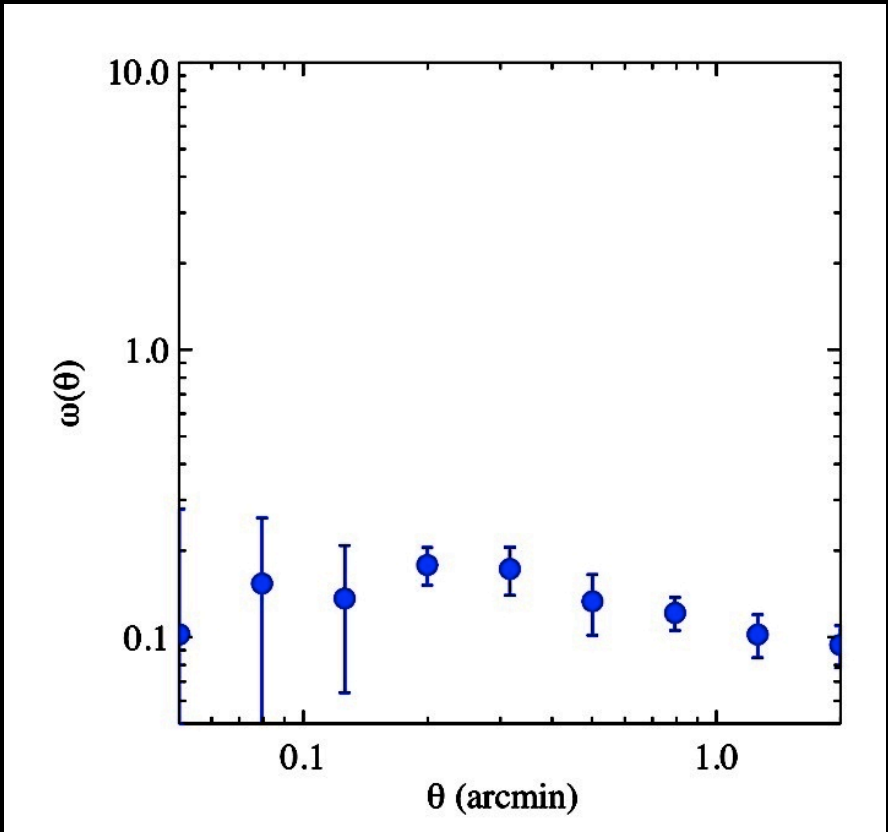


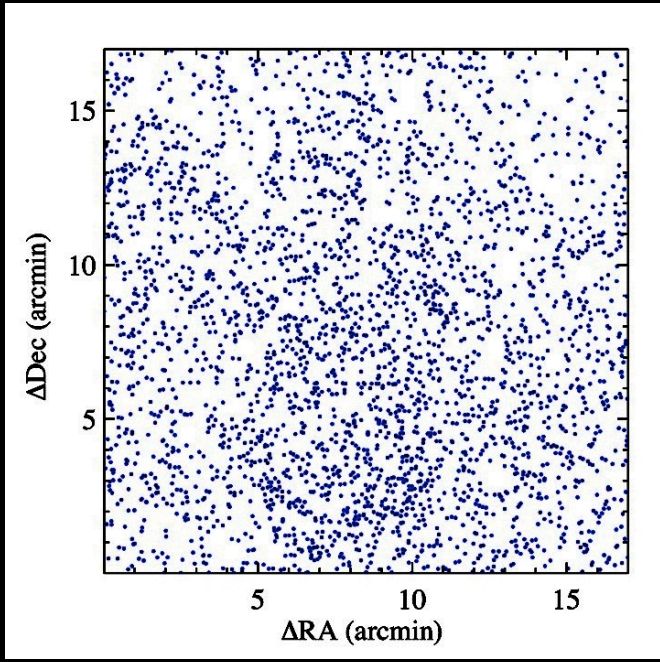
Dark matter halos



Angular two-point correlation

$\omega(\theta)$: $dP = n\,[1 + \omega(\theta)]\,d\Omega$





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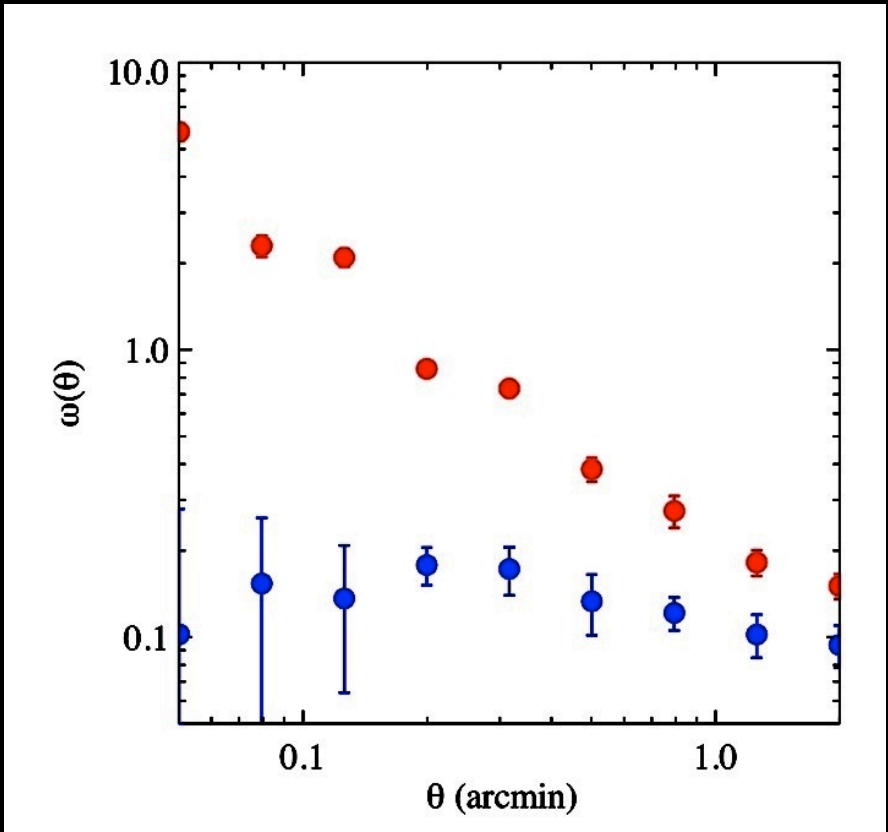
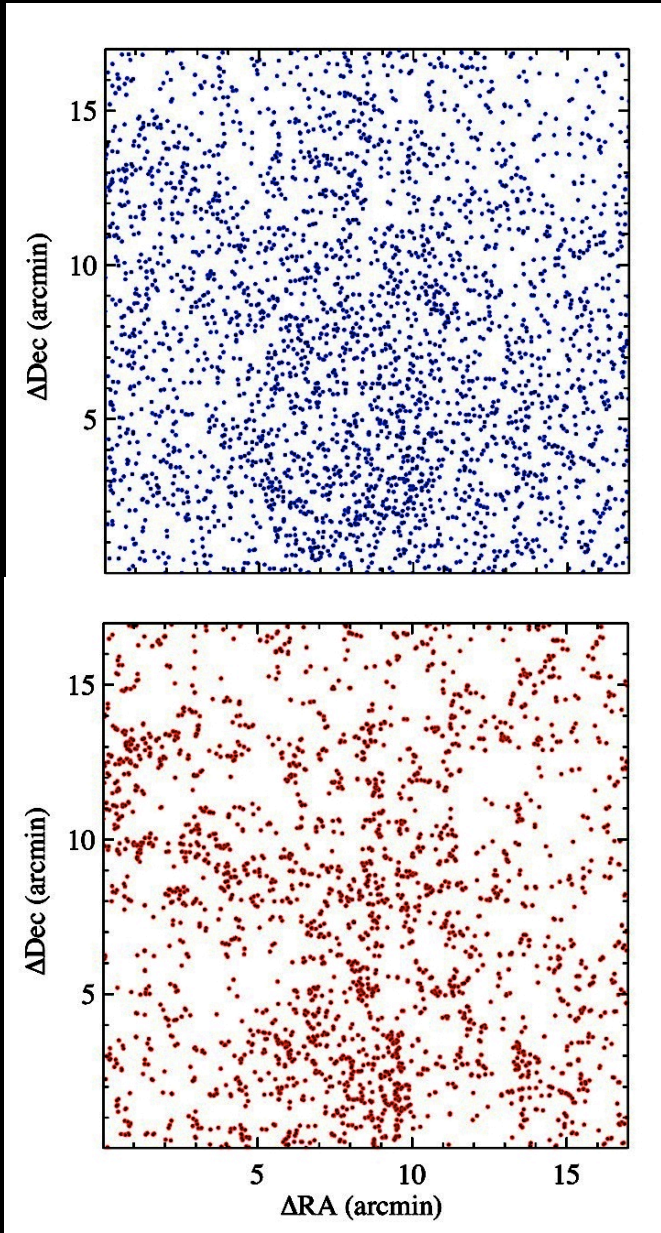
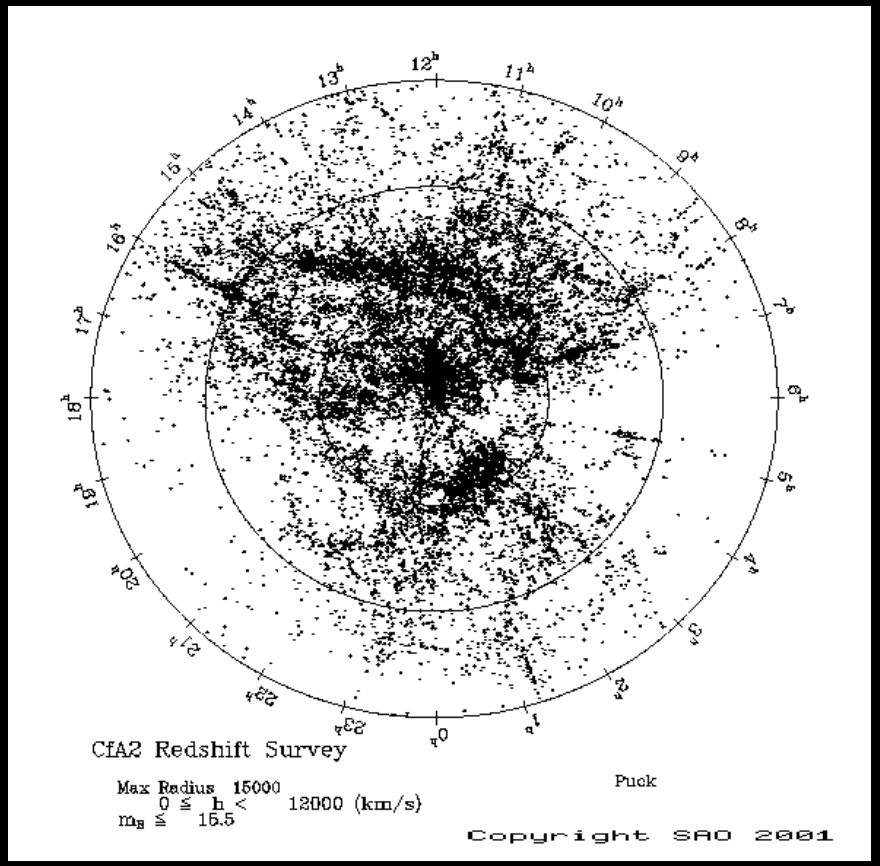




3-D spatial correlation

$\xi(r)$: $dP = n\,[1 + \xi(r)]\,dV$



3-D spatial correlation

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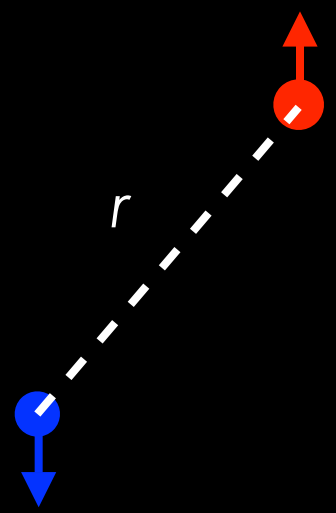

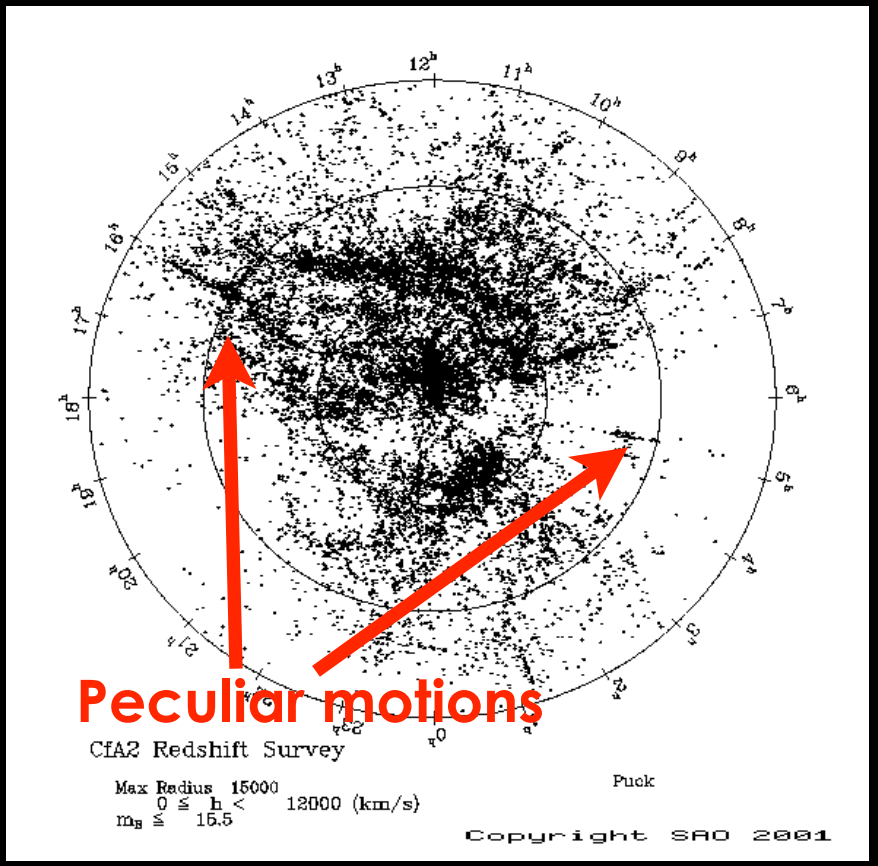

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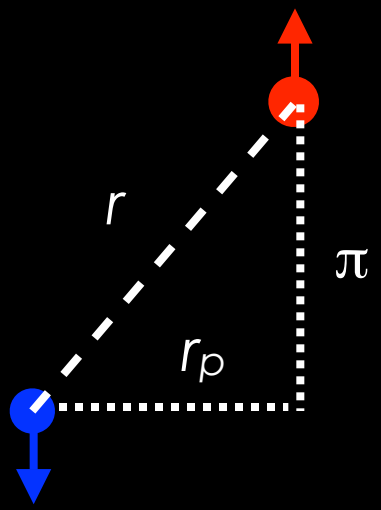
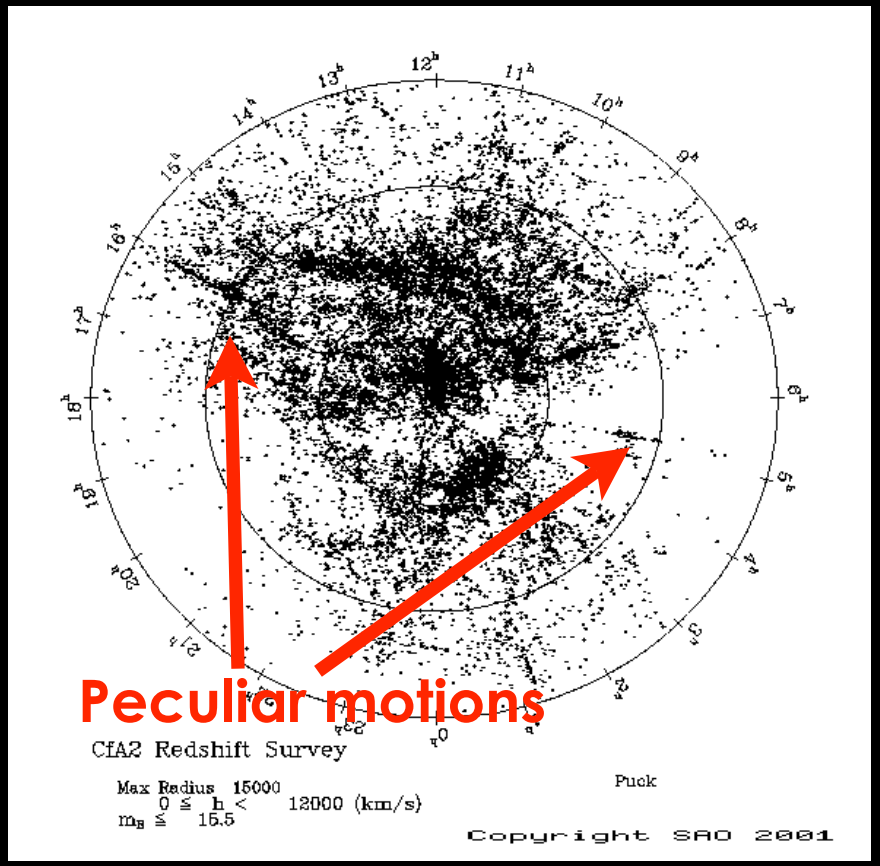
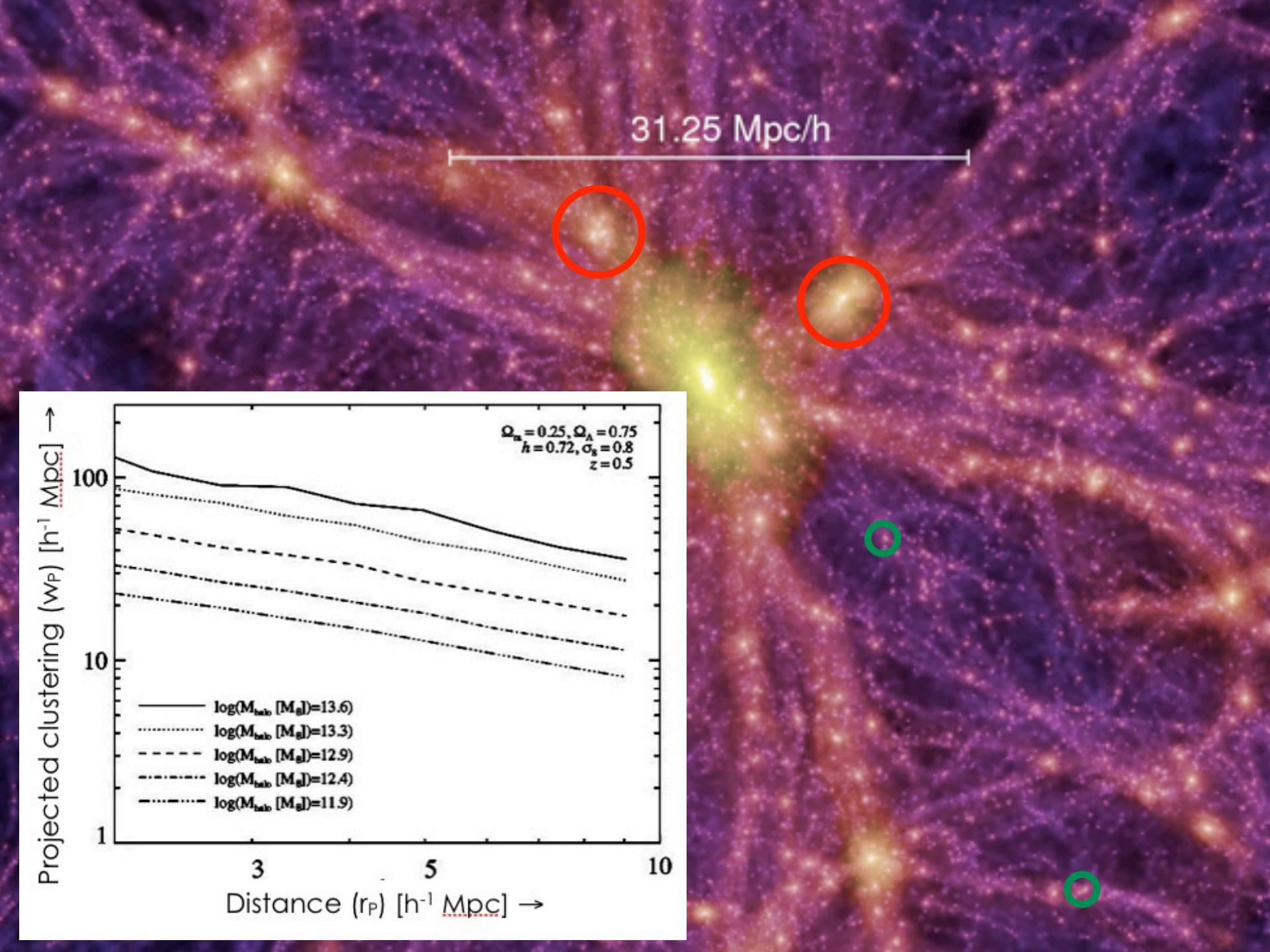
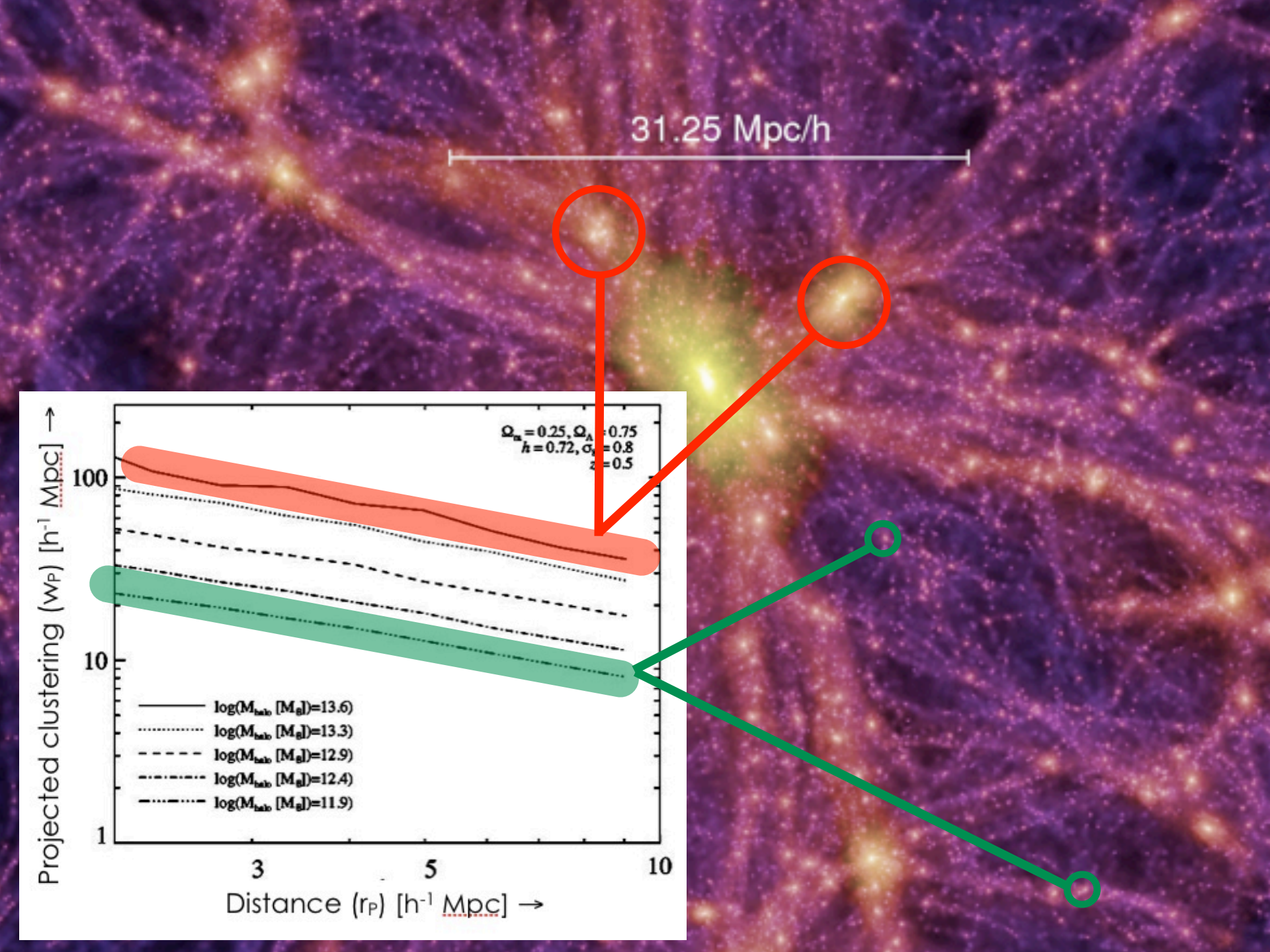


Projected correlation

$$w_p(r_p) = 2 \int \xi(r_p, \pi)\, d\pi$$

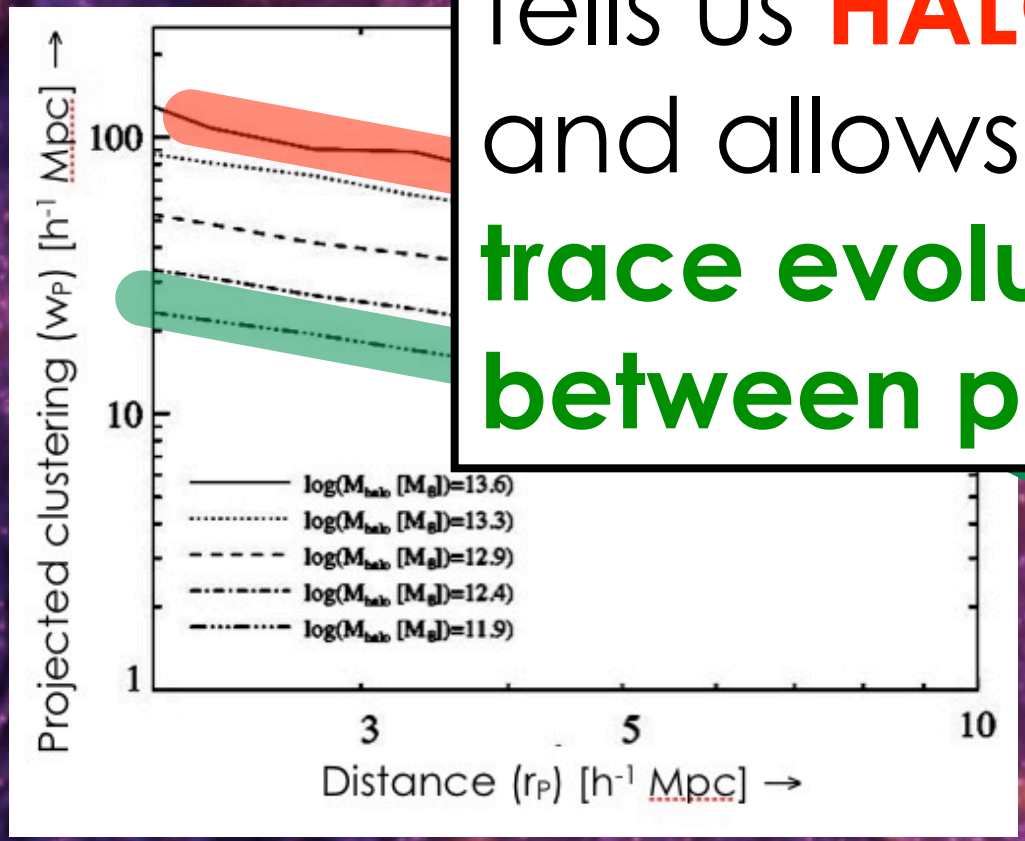



31.25 Mpc/h
$\Omega_m = 0.25, \Omega_\Lambda = 0.75$
$h = 0.72, \sigma_8 = 0.8$
$z = 0.5$
log(M_{halo} [$M_\odot$])=13.6)
log(M_{halo} [$M_\odot$])=13.3)
log(M_{halo} [$M_\odot$])=12.9)
log(M_{halo} [$M_\odot$])=12.4)
log(M_{halo} [$M_\odot$])=11.9)
Projected clustering (w_P) [h^{-1} Mpc] →
Distance (r_P) [h^{-1} Mpc] →
100
10
1
3
5
10

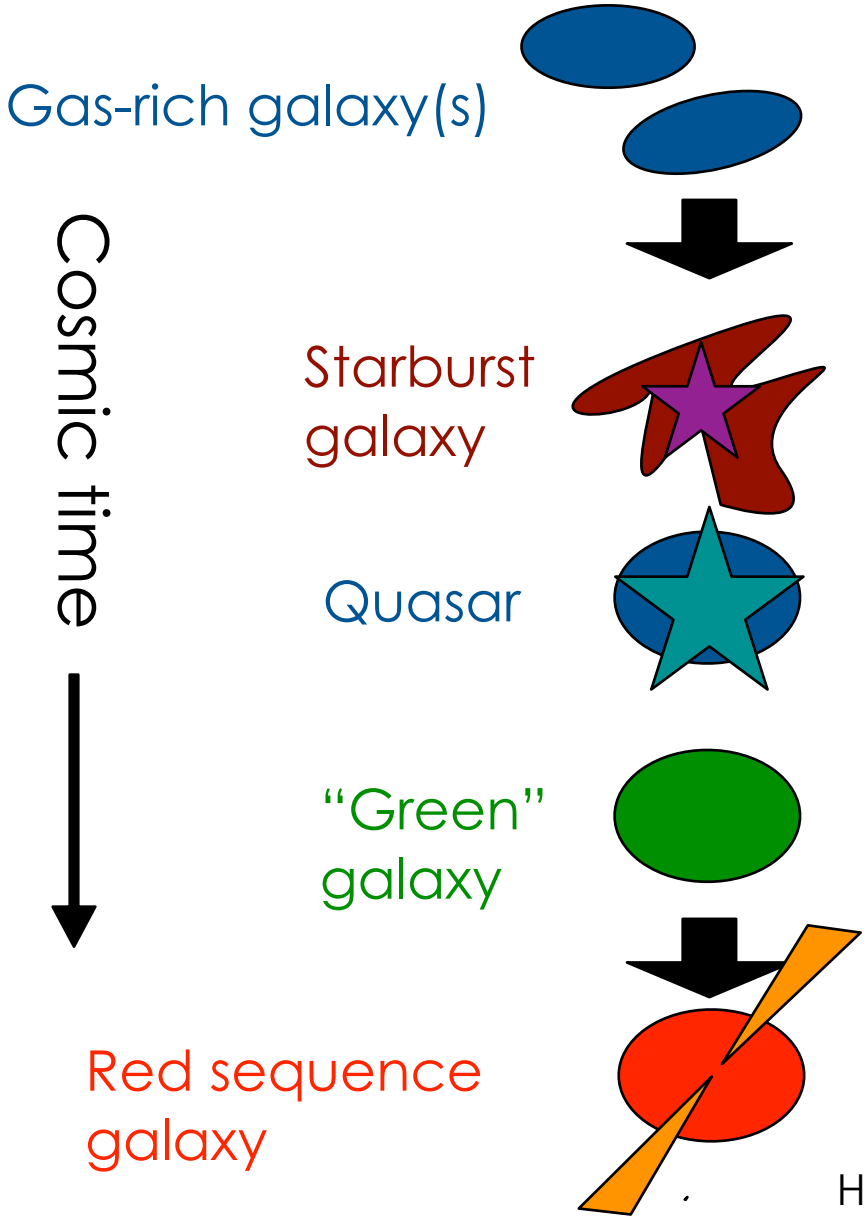

31.25 Mpc/h
Projected clustering (wP) [h-1 Mpc] →
Distance (rP) [h-1 Mpc] →
100
10
1
3
5
10
log(Mhalo [Mo])=13.6)
log(Mhalo [Mo])=13.3)
log(Mhalo [Mo])=12.9)
log(Mhalo [Mo])=12.4)
log(Mhalo [Mo])=11.9)

31.25 Mpc/h

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

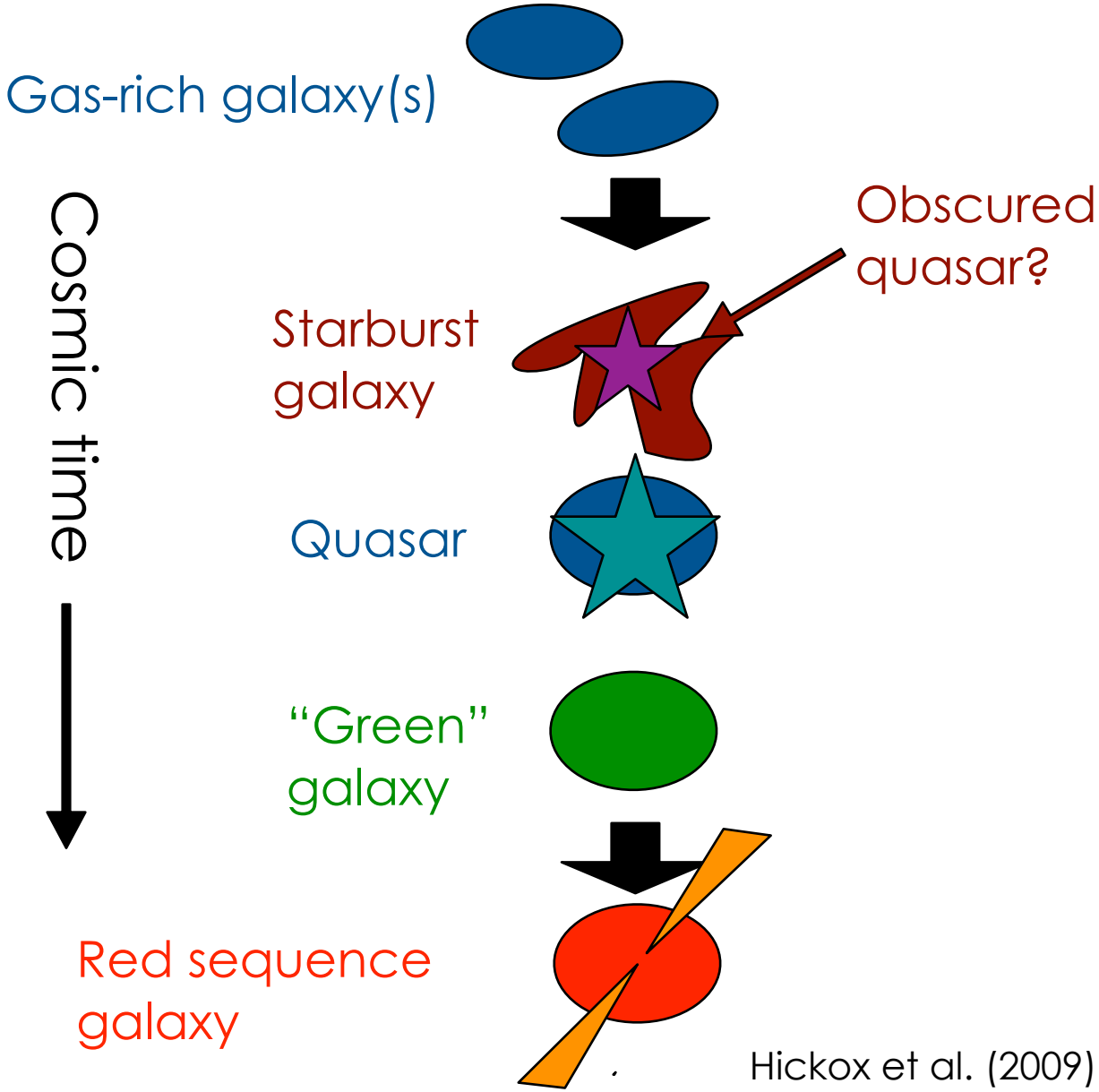


Current theory (the cartoon version)



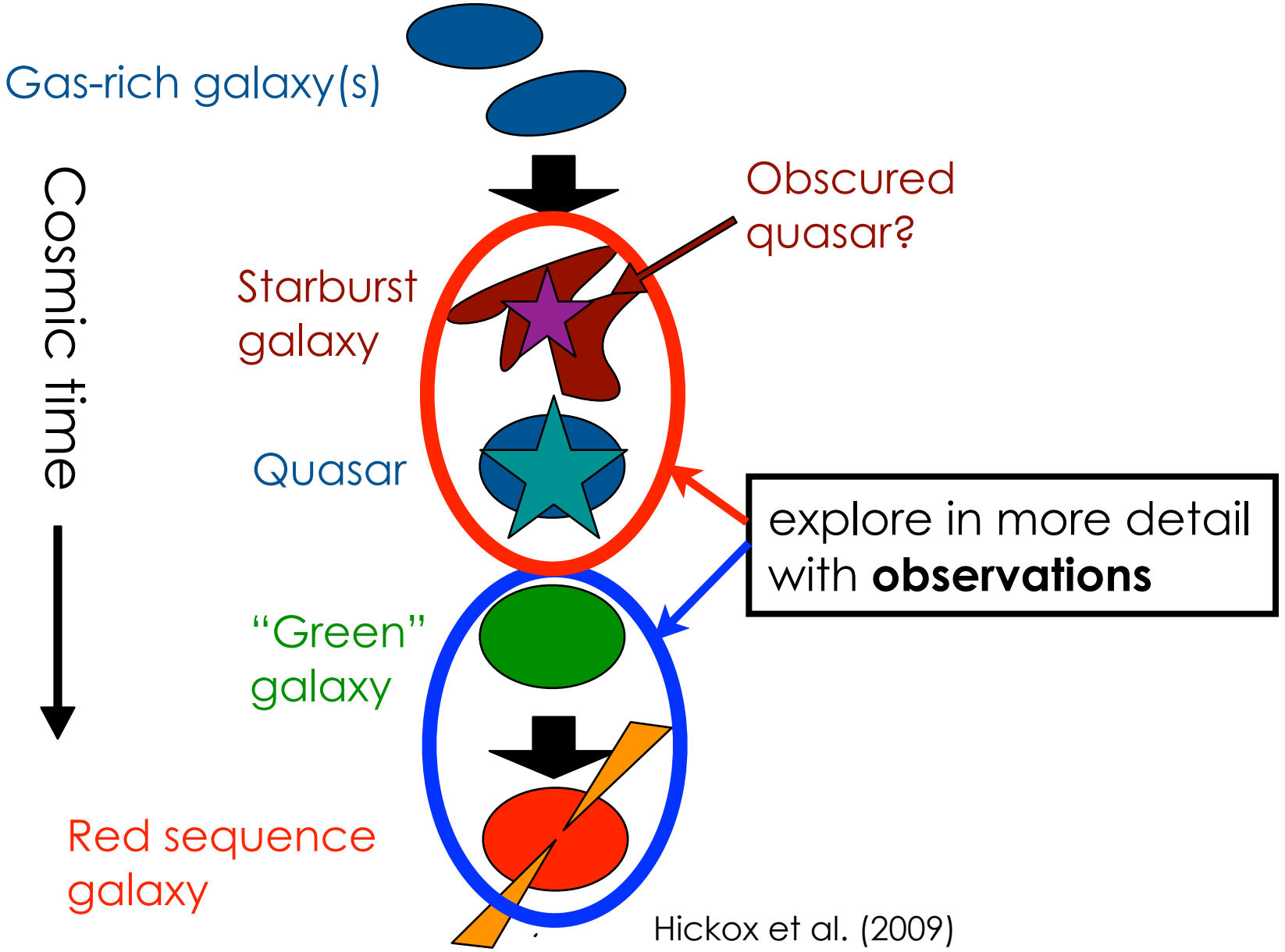
Hickox et al. (2009)

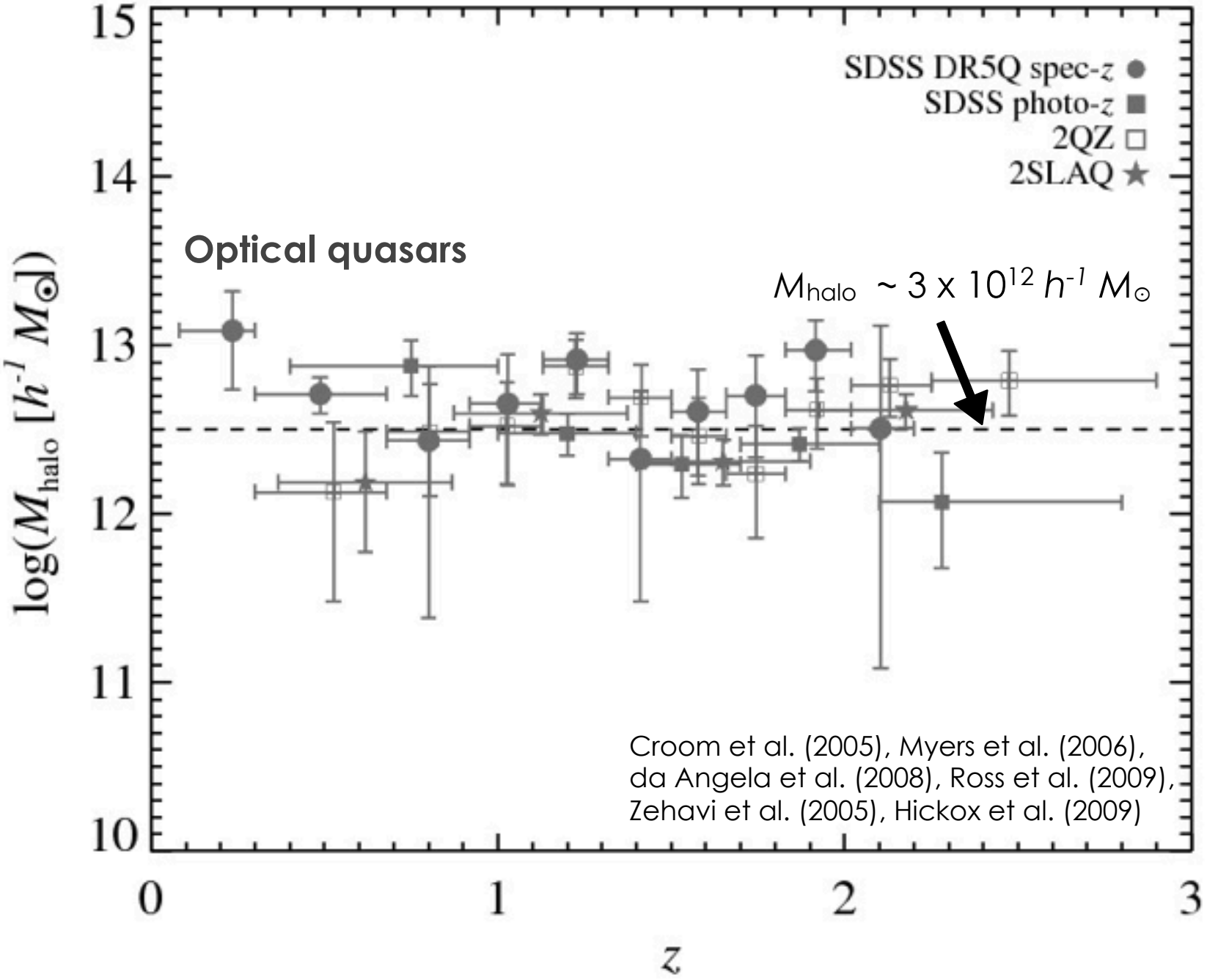
Current theory (the cartoon version)

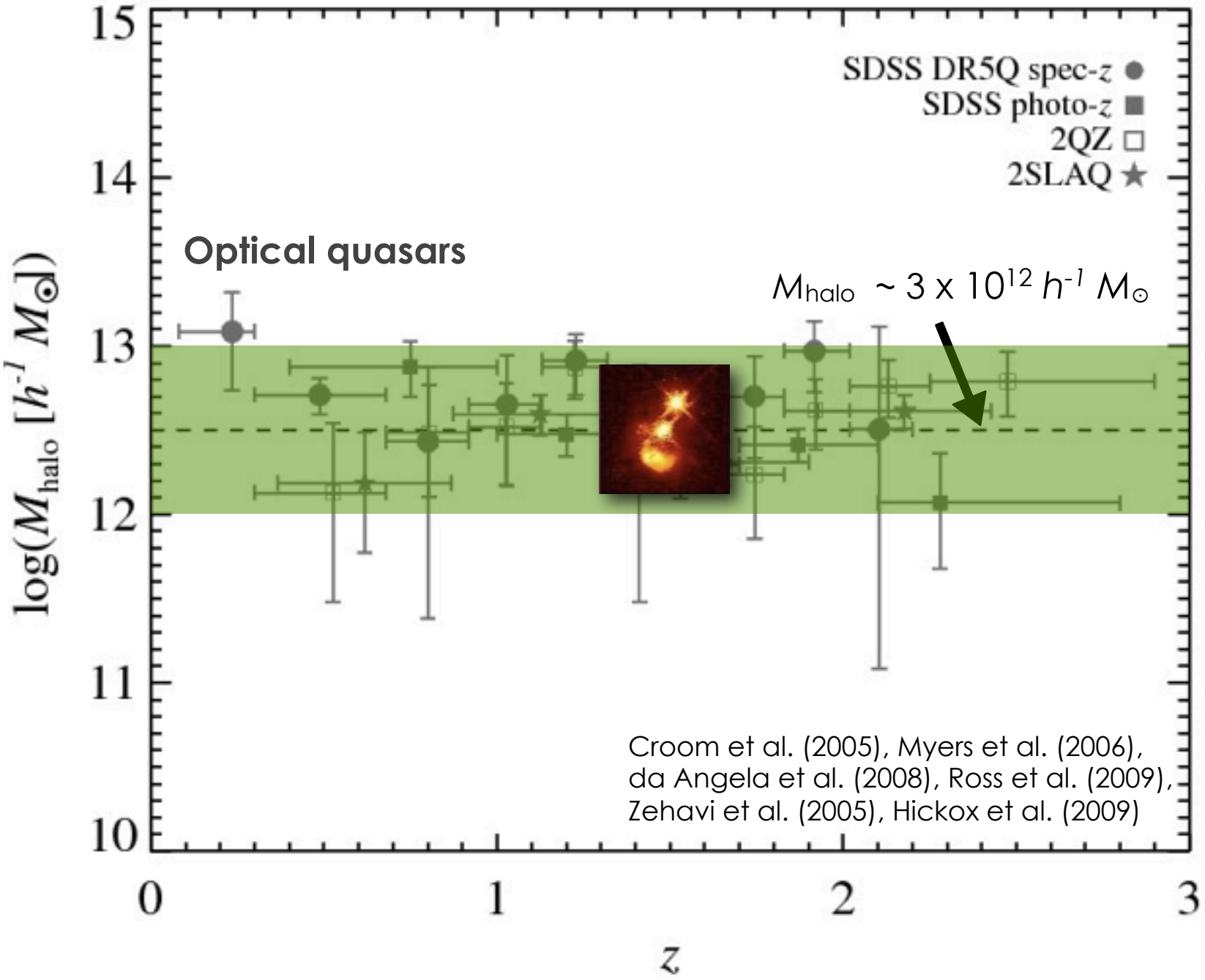


Hickox et al. (2009)

Current theory (the cartoon version)




SDSS DR5Q spec-z
SDSS photo-z
2QZ
2SLAQ
Optical quasars
M_{halo} ~ 3 x 10^{12} h^{-1} $M_\odot$
Croom et al. (2005), Myers et al. (2006),
da Angela et al. (2008), Ross et al. (2009),
Zehavi et al. (2005), Hickox et al. (2009)
$\log(M_{halo}\ [h^{-1}\ M_\odot])$
z
15
14
13
12
11
10
0
1
2
3


SDSS DR5Q spec-z
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Optical quasars
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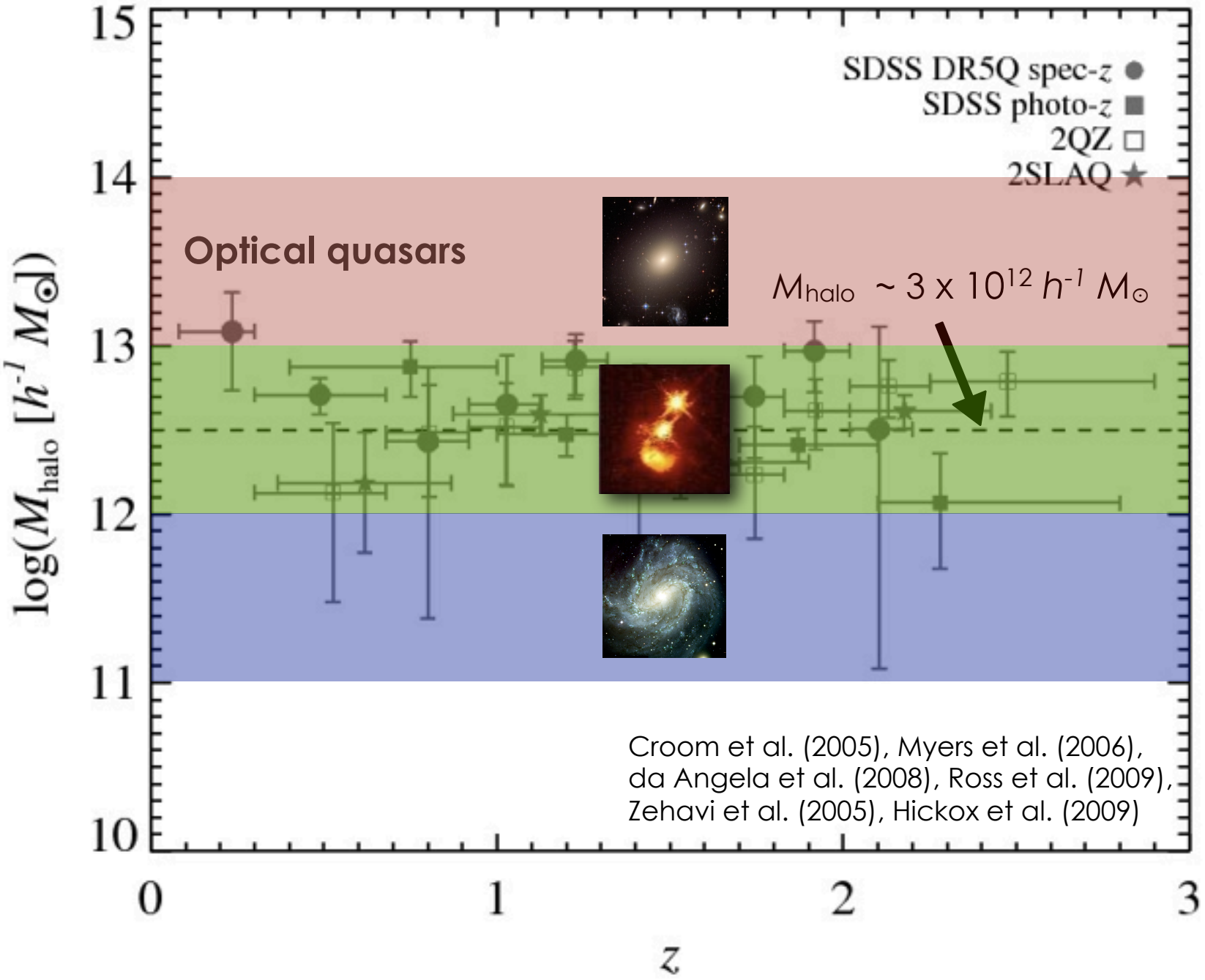
$\log(M_{halo}\ [h^{-1}\ M_\odot])$
z
15
14
13
12
11
10
0
1
2
3


SDSS DR5Q spec-z
SDSS photo-z
2QZ
2SLAQ
Optical quasars
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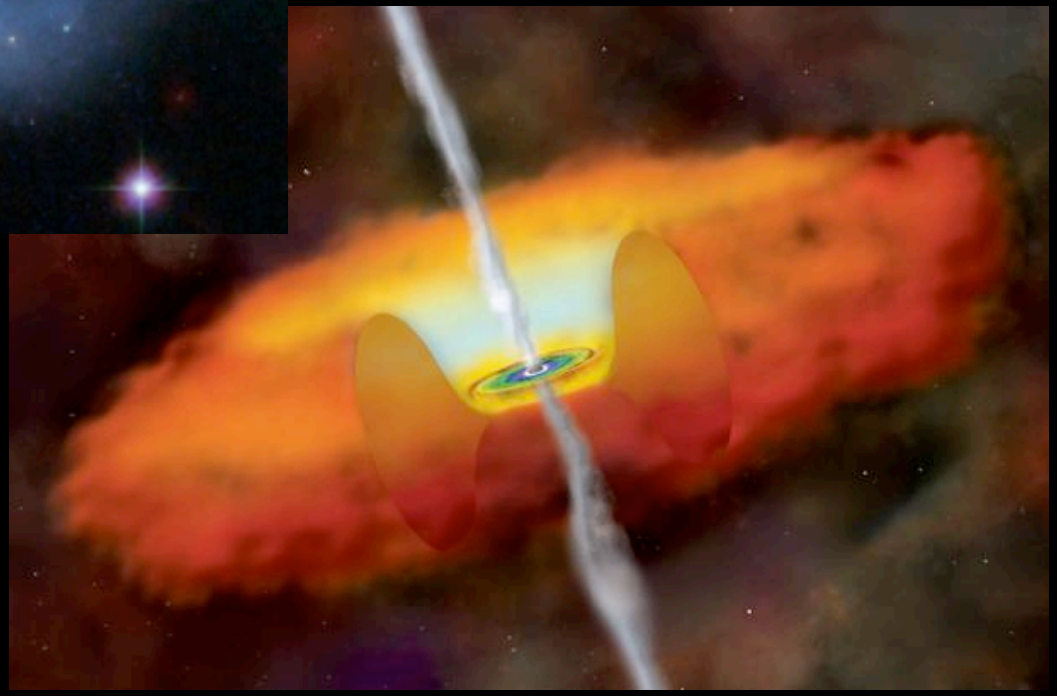
$\log(M_{halo}\ [h^{-1}\ M_\odot])$
z
15
14
13
12
11
10
0
1
2
3

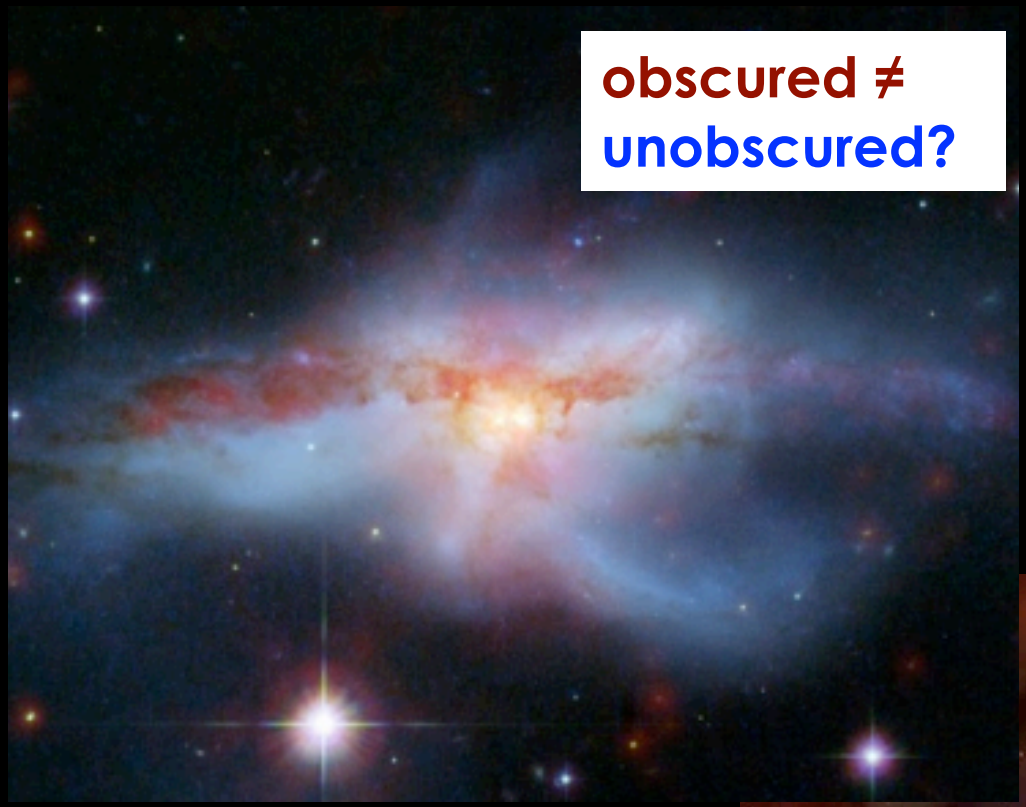
Obscured quasars



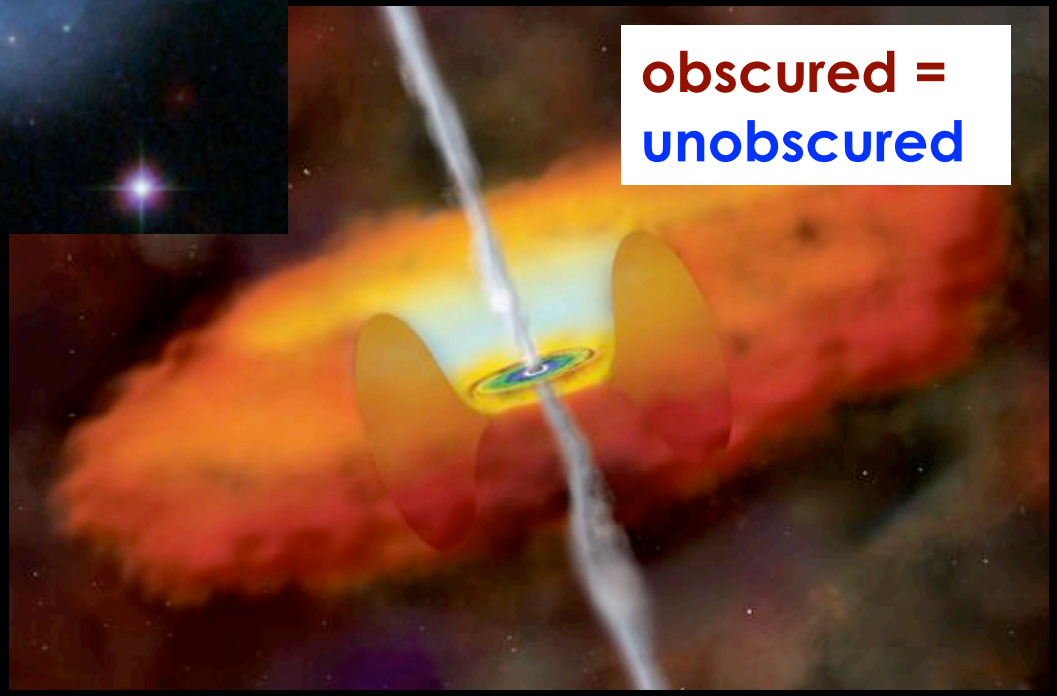
detect with **IRAC:** Lacy et al. 2004, Stern et al. 2005, Rowan-Robinson et al. 2005, Martinez-Sansigre et al. 2006, 2008, Polletta et al. 2006, 2008, **Hickox et al. 2007**, Donley et al. 2007, 2008, Alexander et al. 2008

Obscured quasars

predictions for halo mass



obscured ≠ unobscured?



obscured = unobscured

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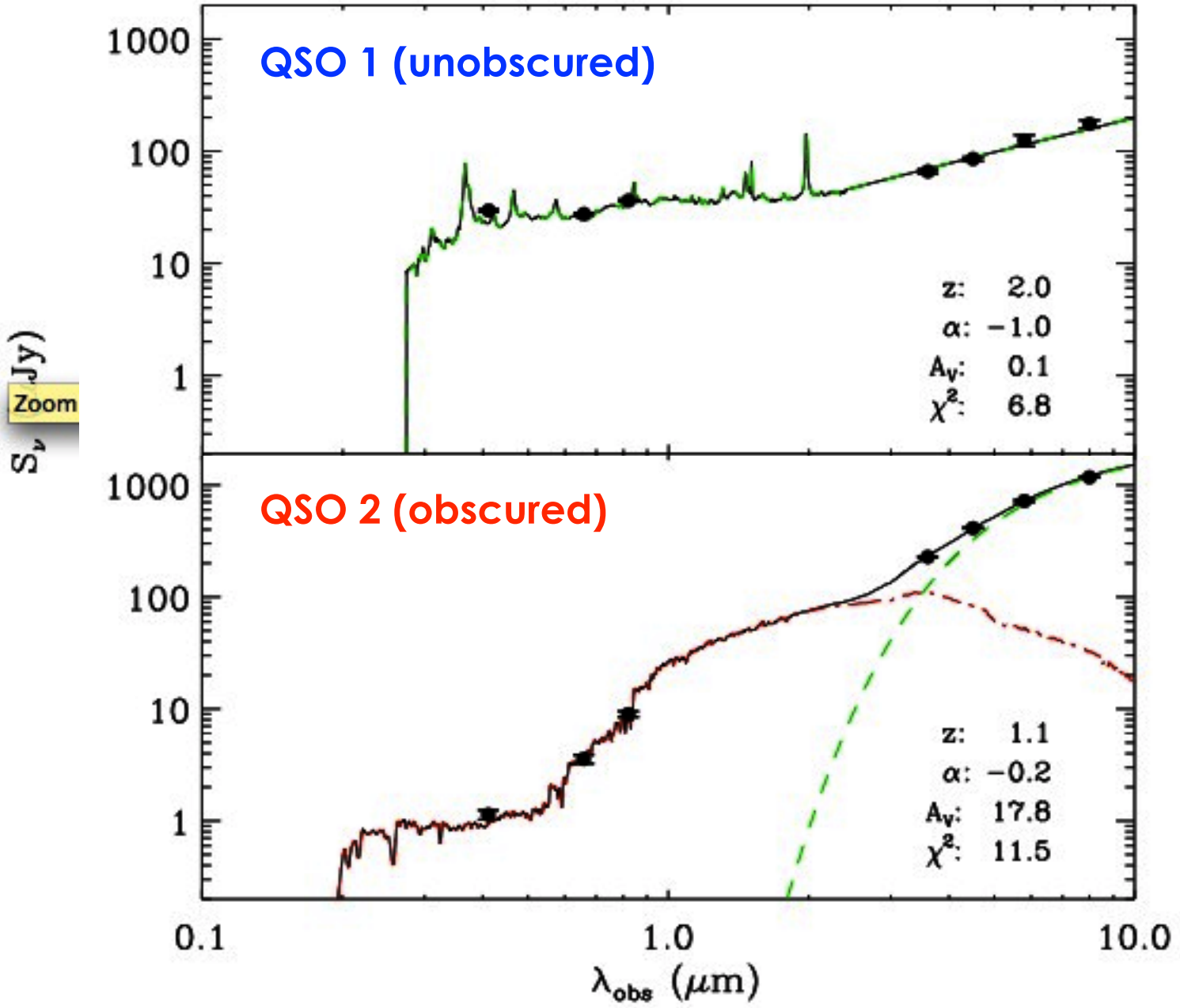
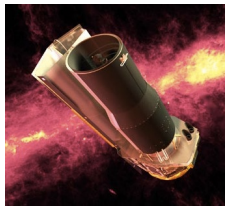
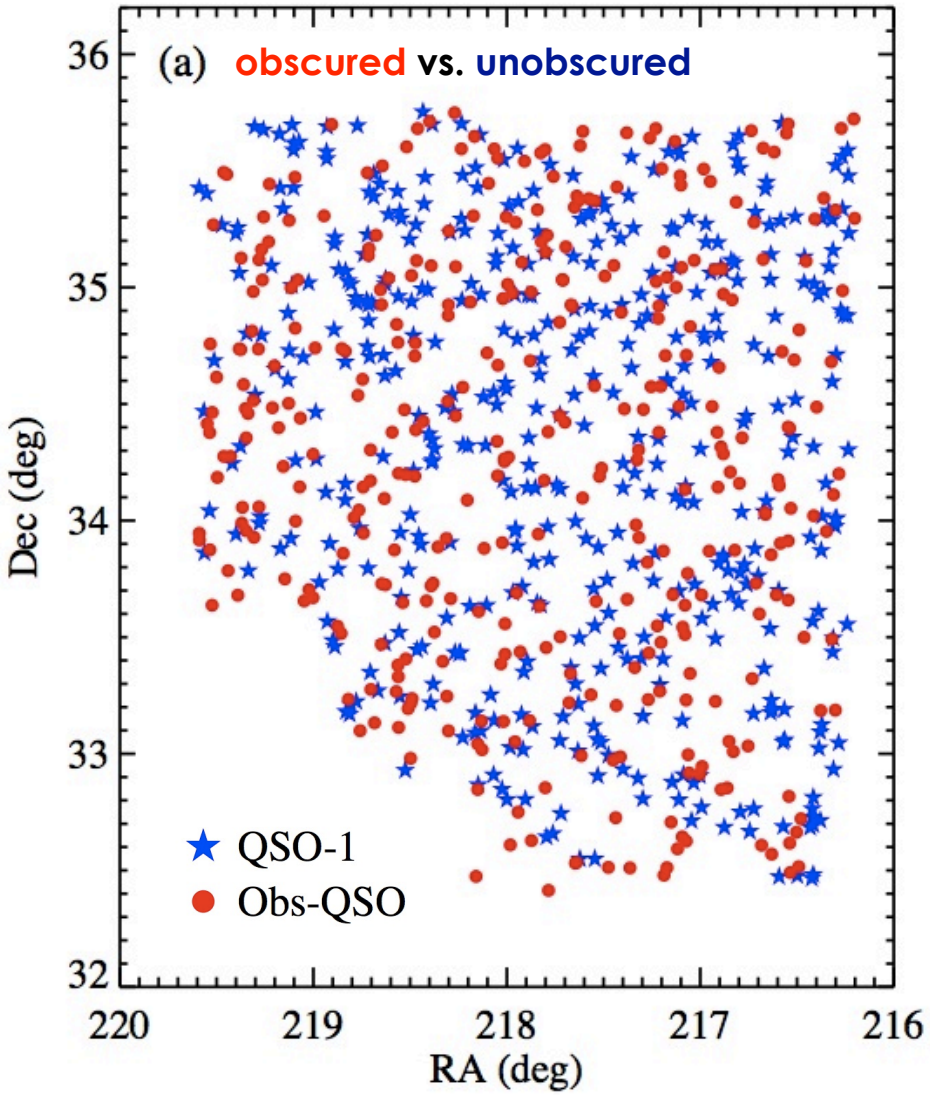


Hickox et al. (2007)

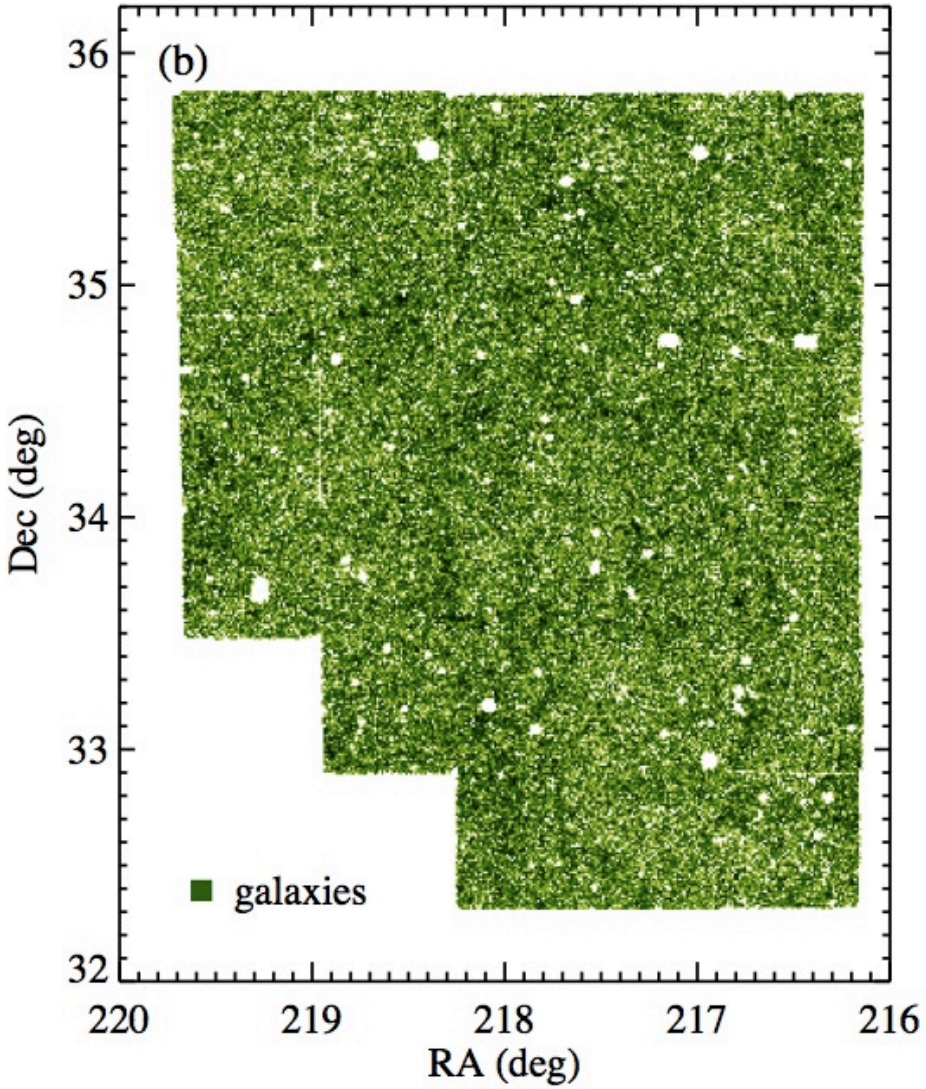
Quasars and galaxies selected with IRAC

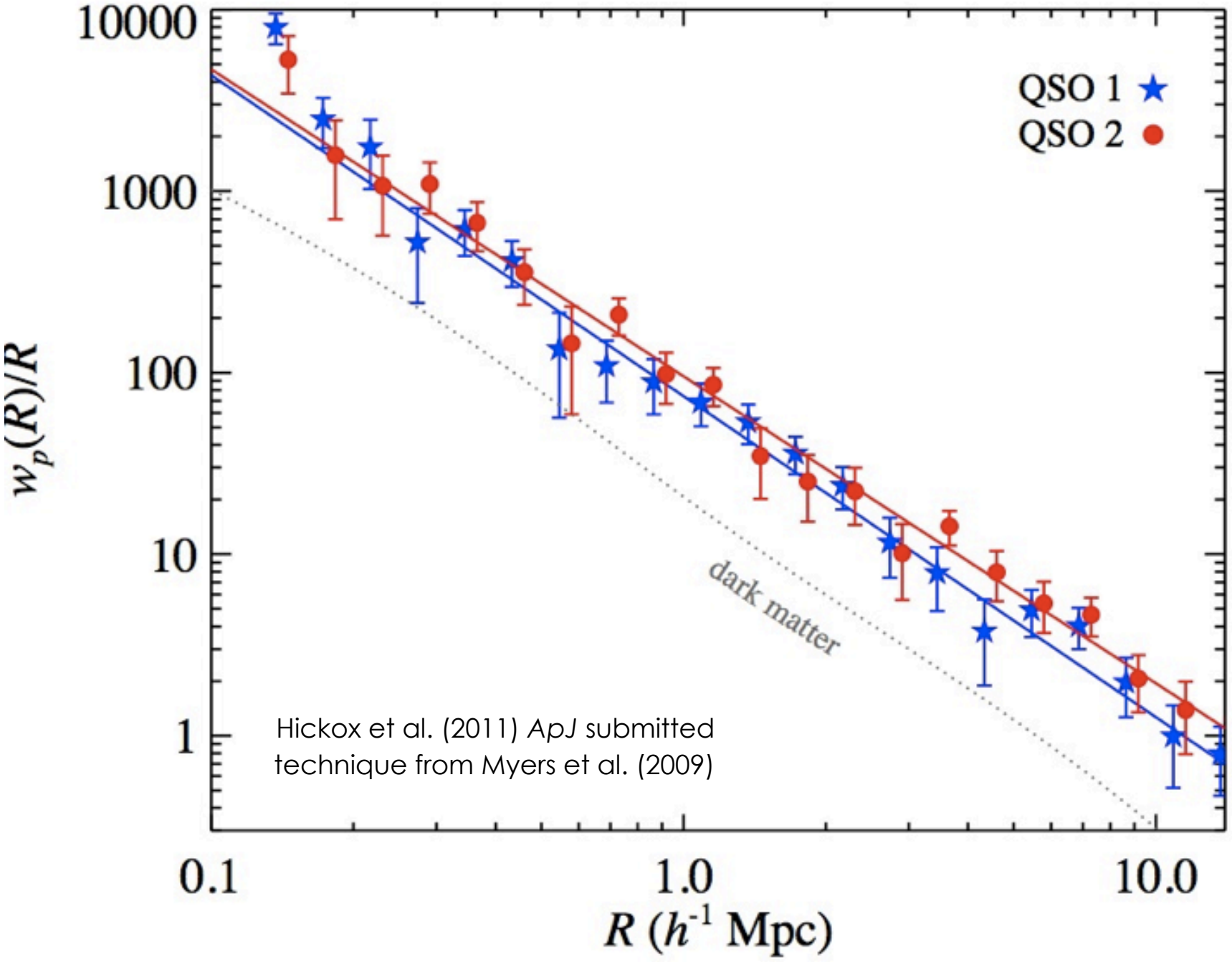


Quasars Hickox et al. (2007)



Galaxies Brodwin et al. (2006)

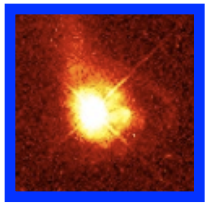




Hickox et al. (2011) *ApJ* submitted
technique from Myers et al. (2009)

Distance

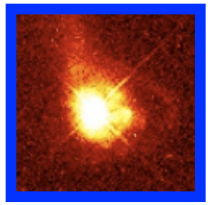
quasars



galaxies

Distance

quasars

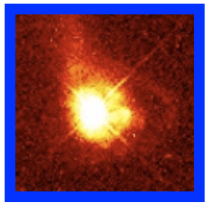


galaxies

exact distance from spectroscopic redshift

Distance

quasars



exact distance from spectroscopic redshift

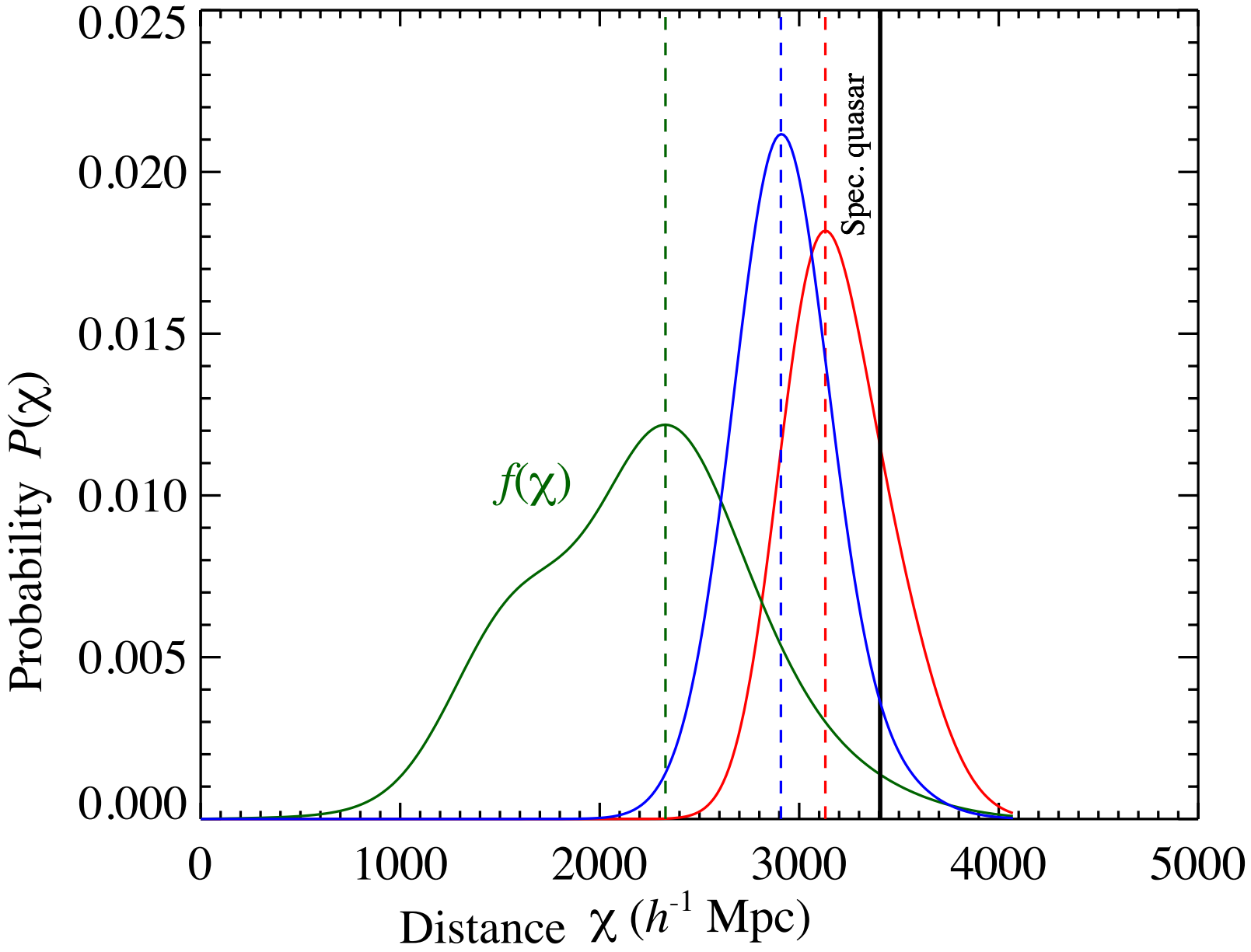
?

galaxies

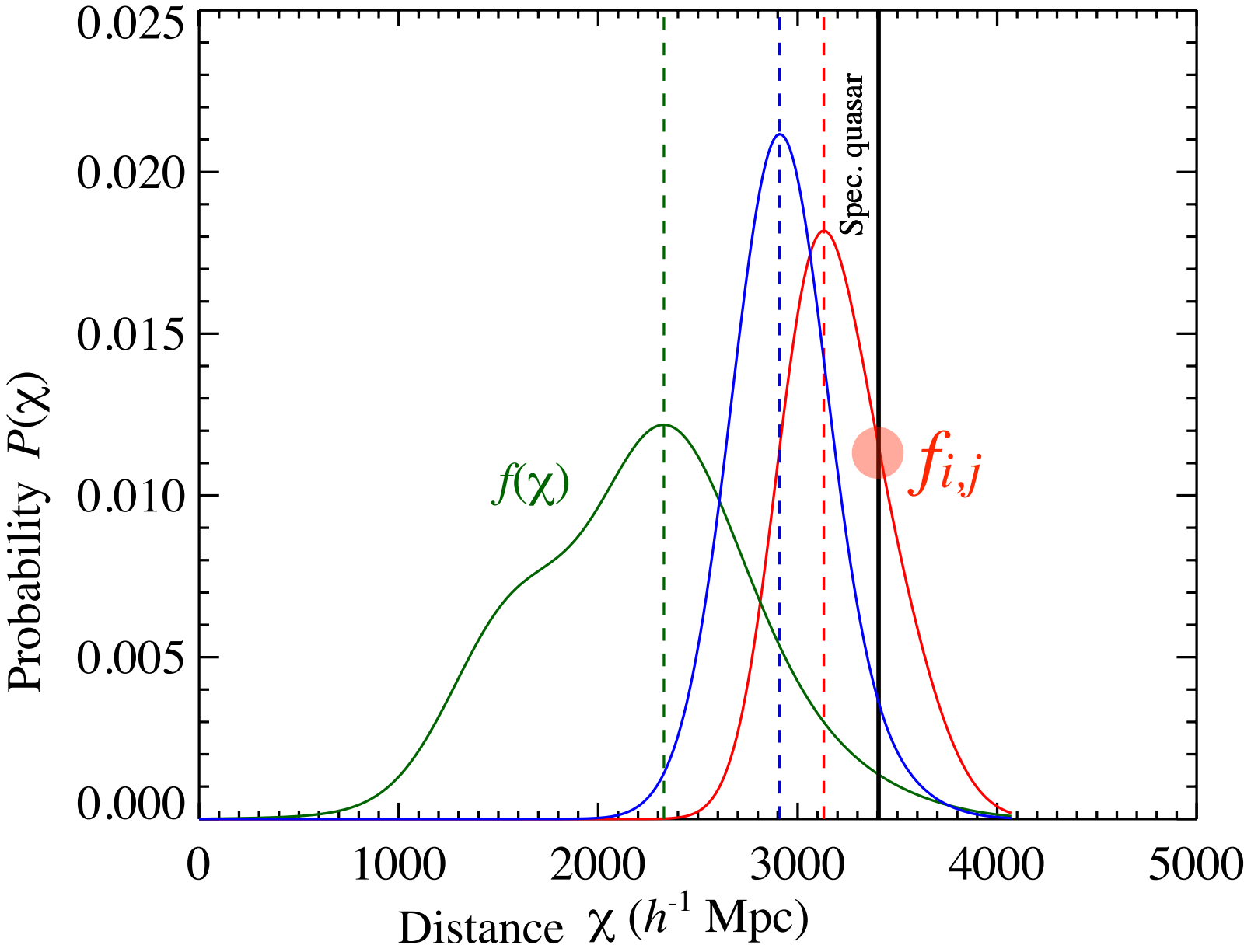
?

uncertain distance from photometric redshift

technique from Myers et al. (2009)



technique from Myers et al. (2009)



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

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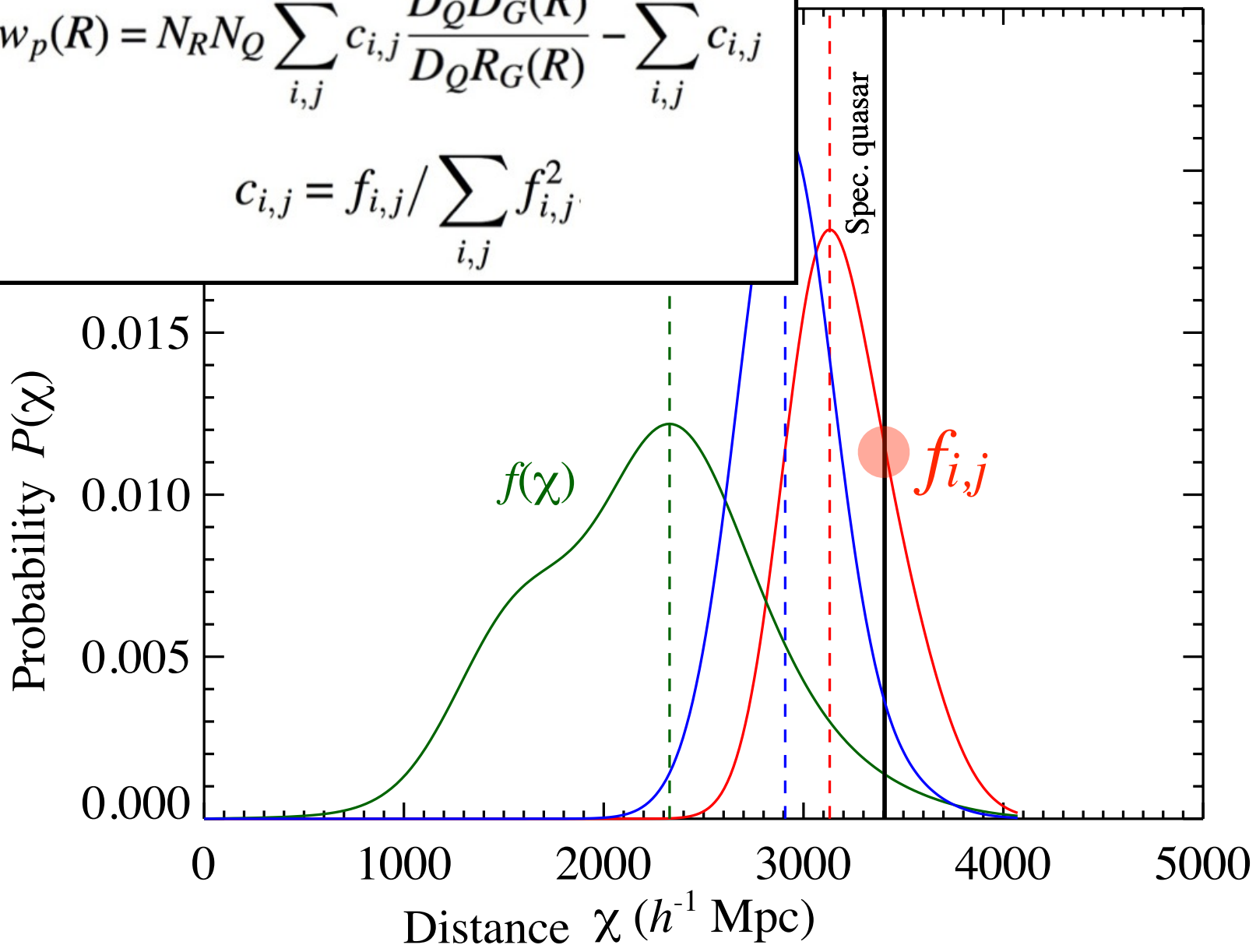

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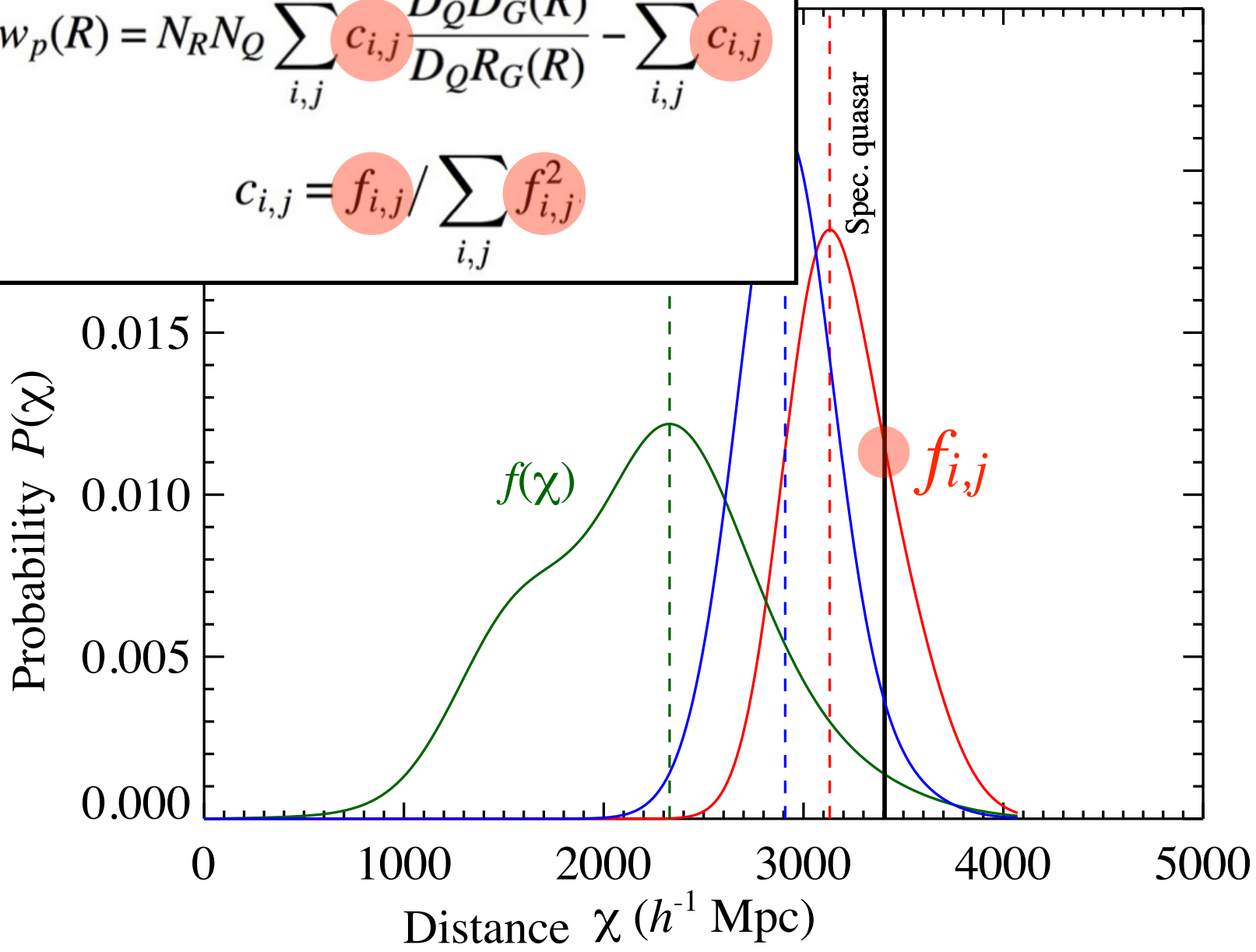
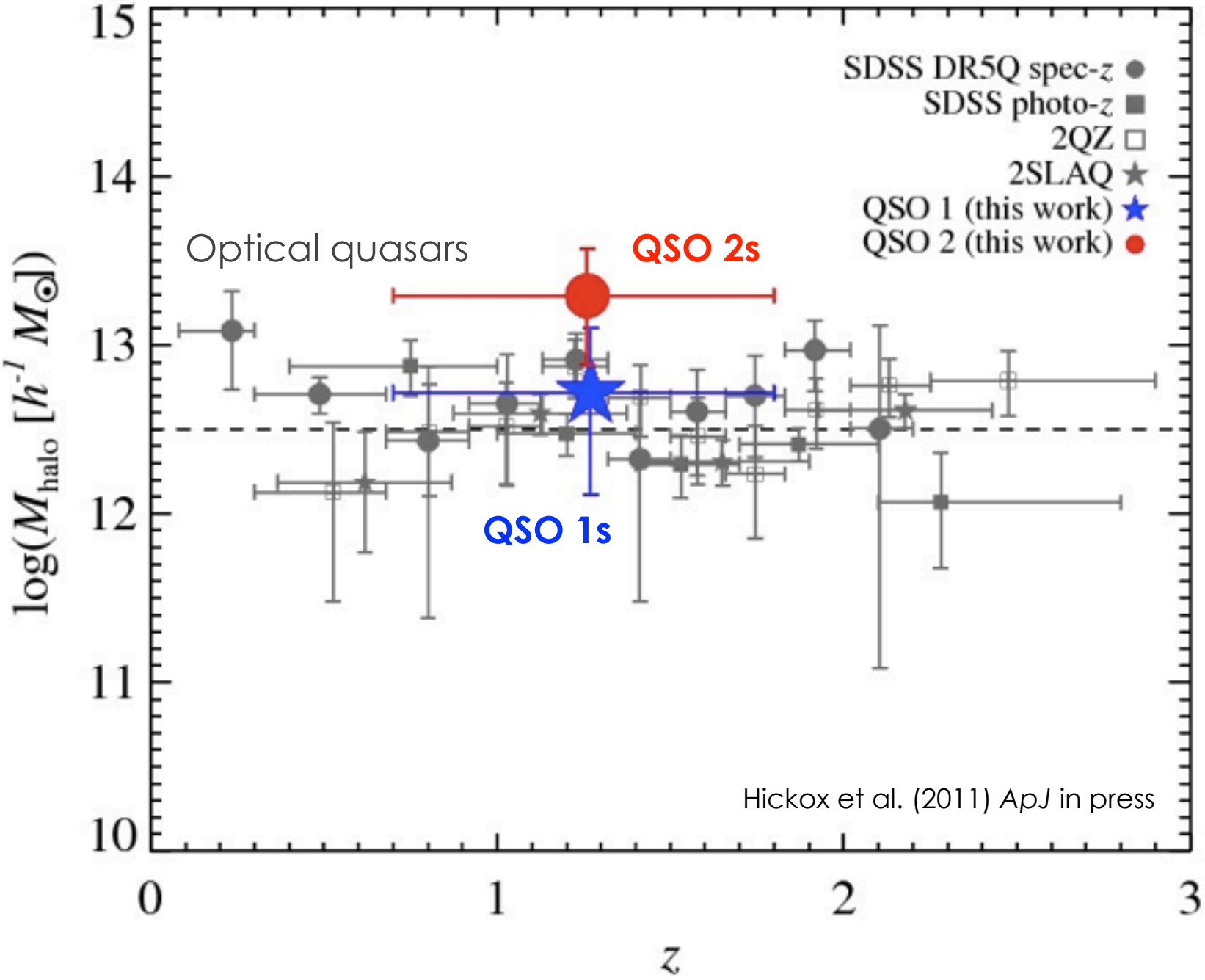
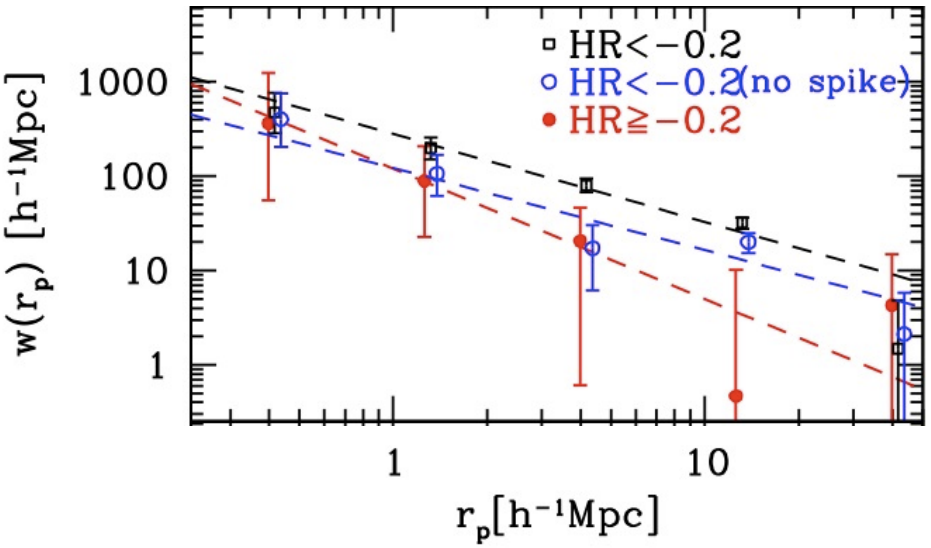



SDSS DR5Q spec-z
SDSS photo-z
2QZ
2SLAQ
QSO 1 (this work)
QSO 2 (this work)
Optical quasars
QSO 2s
QSO 1s
Hickox et al. (2011) ApJ in press
log(M_halo [h^-1 M_⊙])
z
15
14
13
12
11
10
0
1
2
3

Comparison to other results

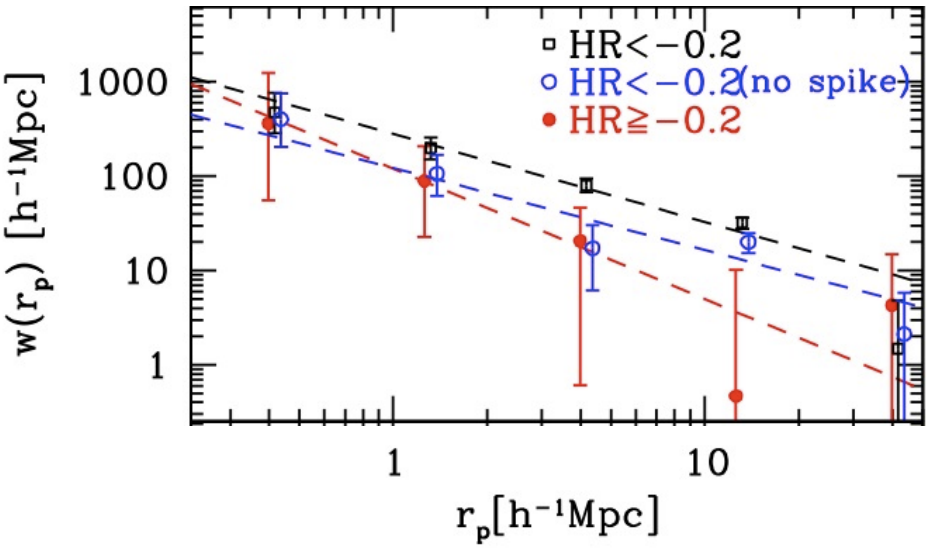
but...



NO significant difference in clustering between obscured and unboscured X-ray AGN
(Gilli et al. 2009, see also Gandhi et al. 2006)

OR unobscured AGN are more strongly clustered?
(Allevato et al. 2011)

Comparison to other results



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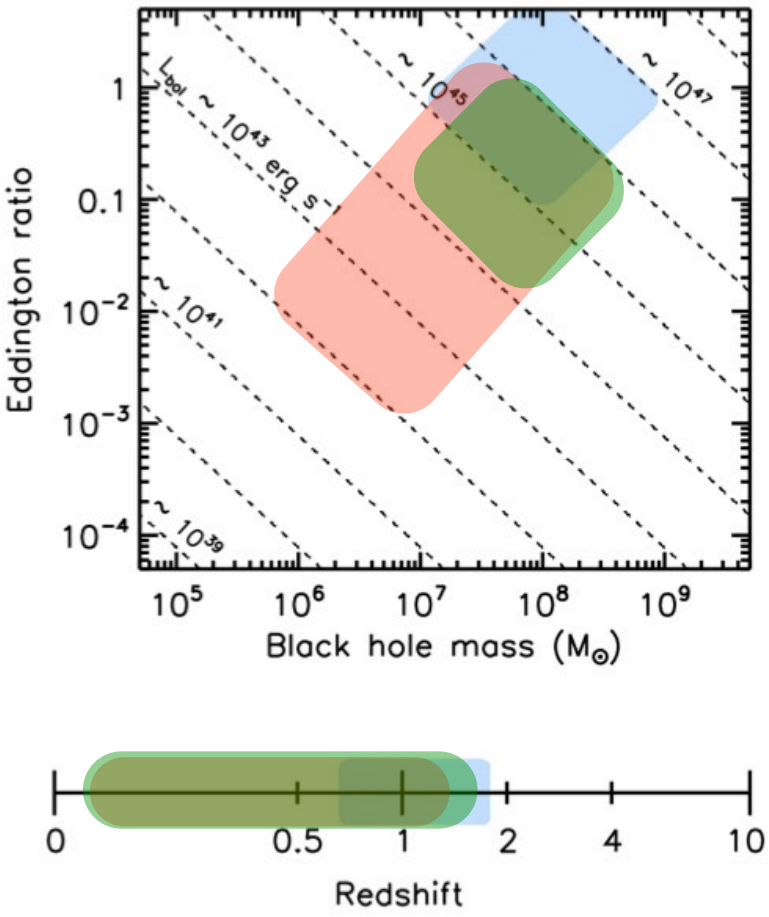

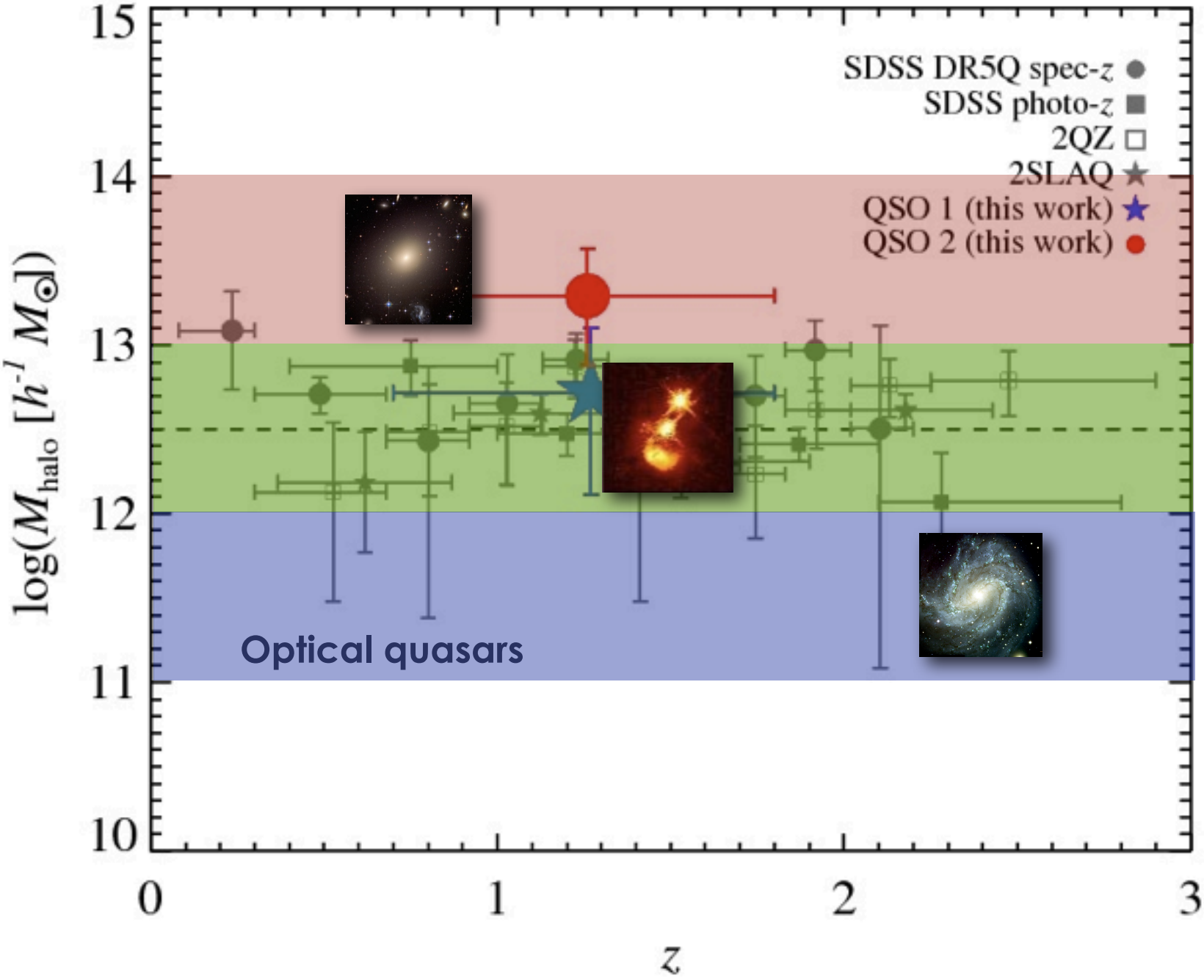
SDSS DR5Q spec-z
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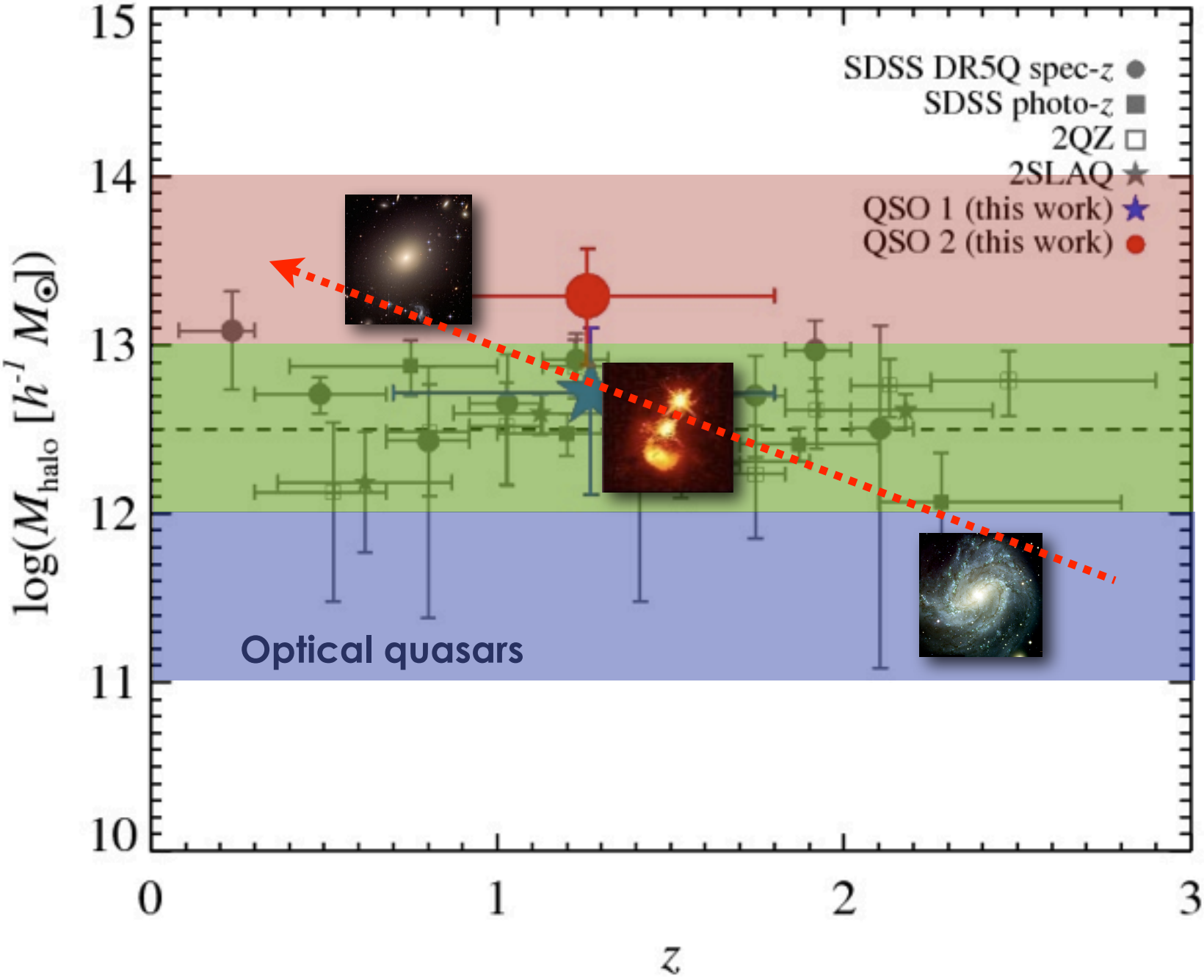
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z
15
14
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10
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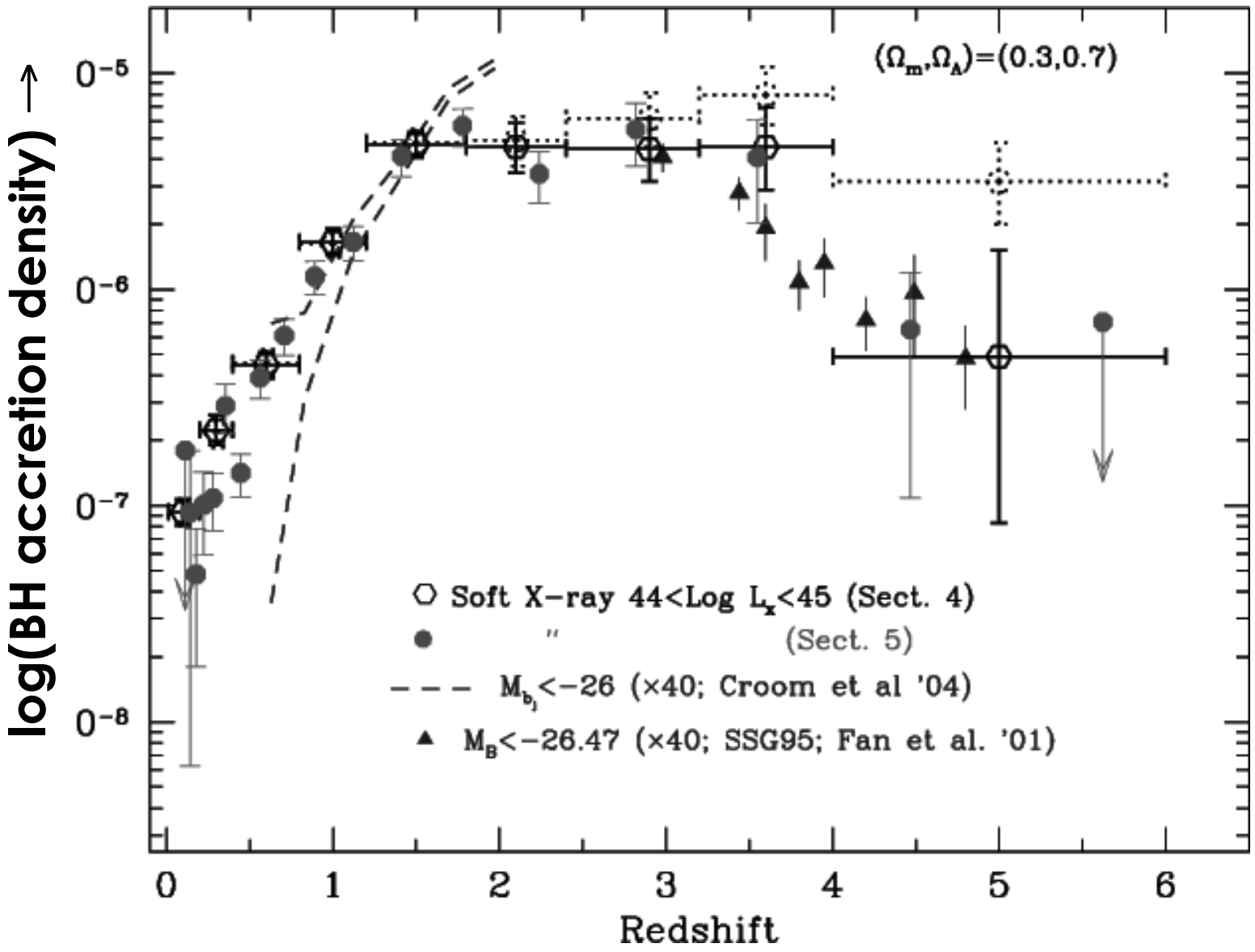
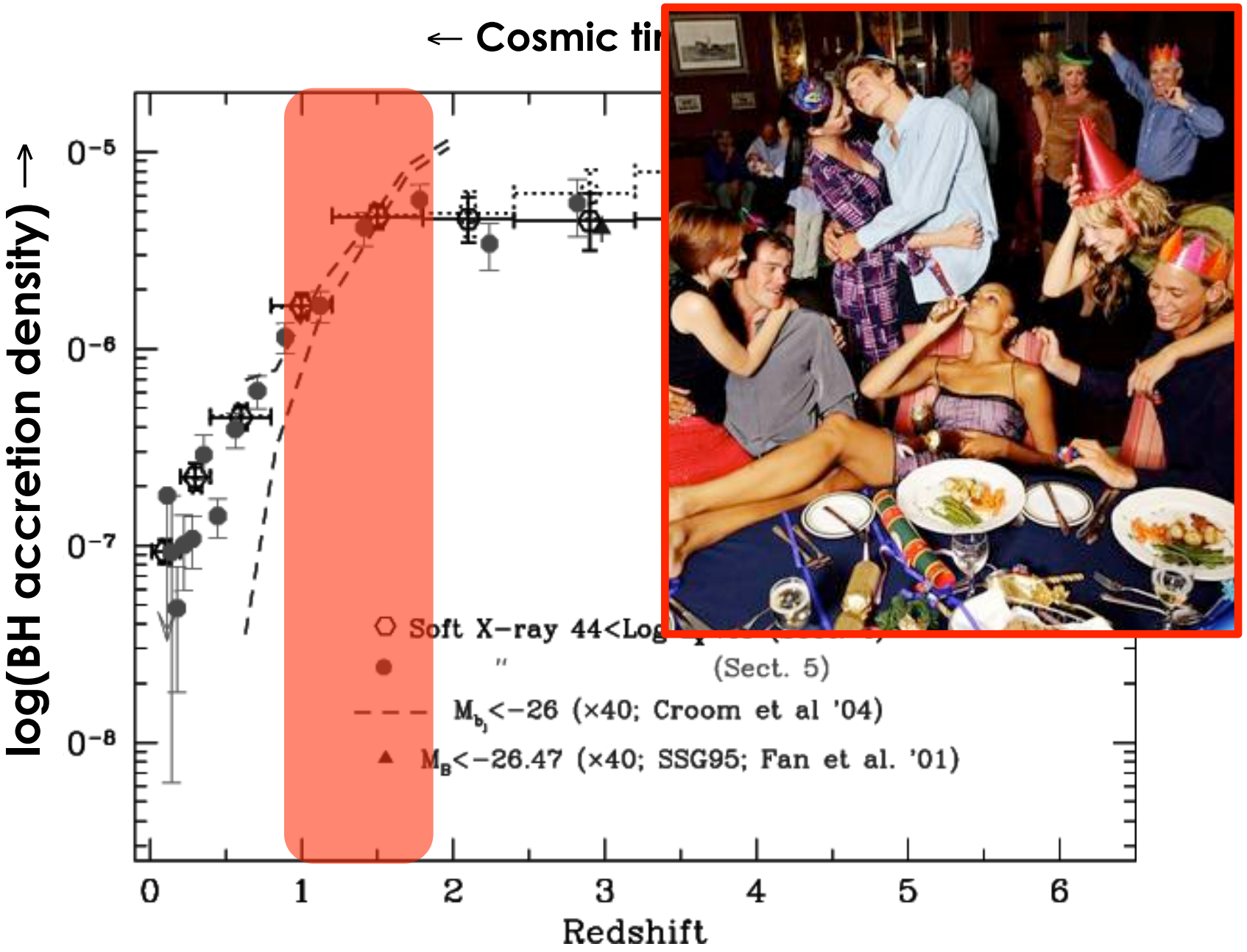
3

← Cosmic time



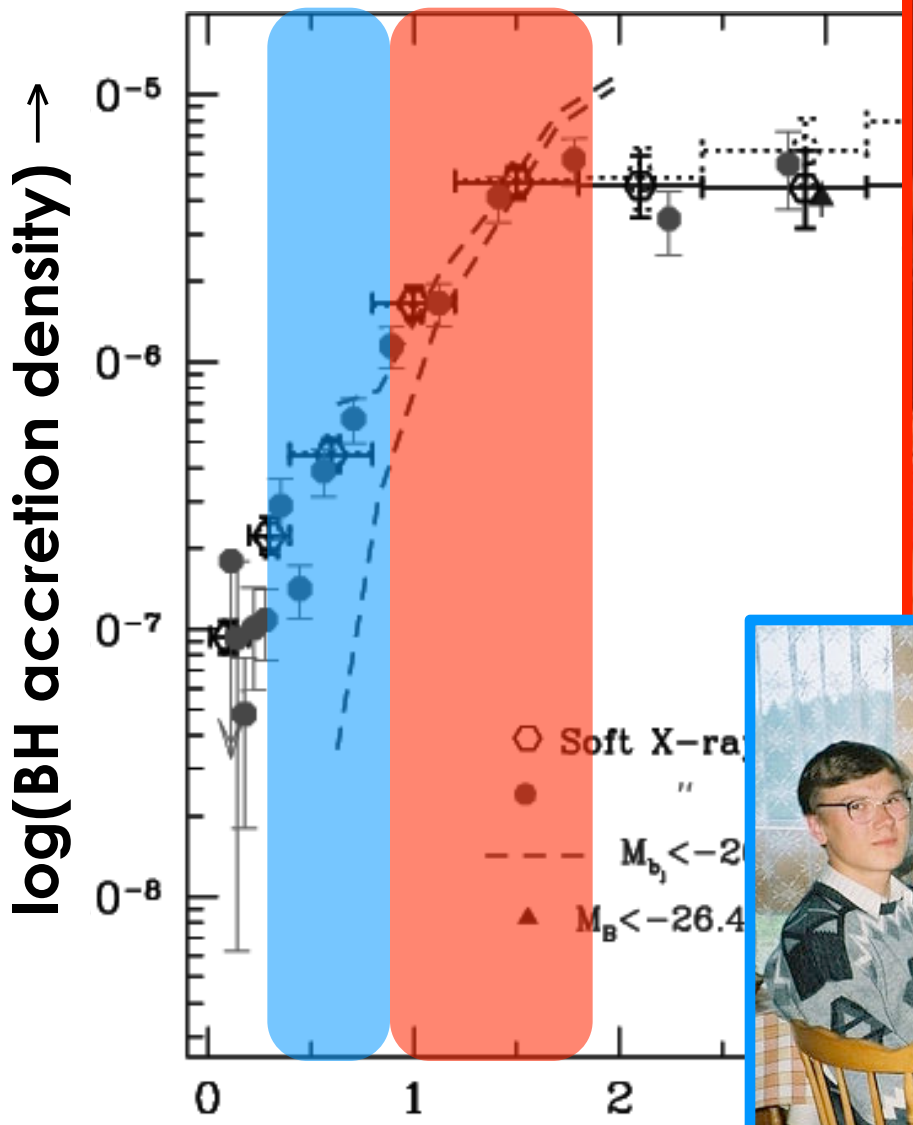
Hasinger et al. (2005)

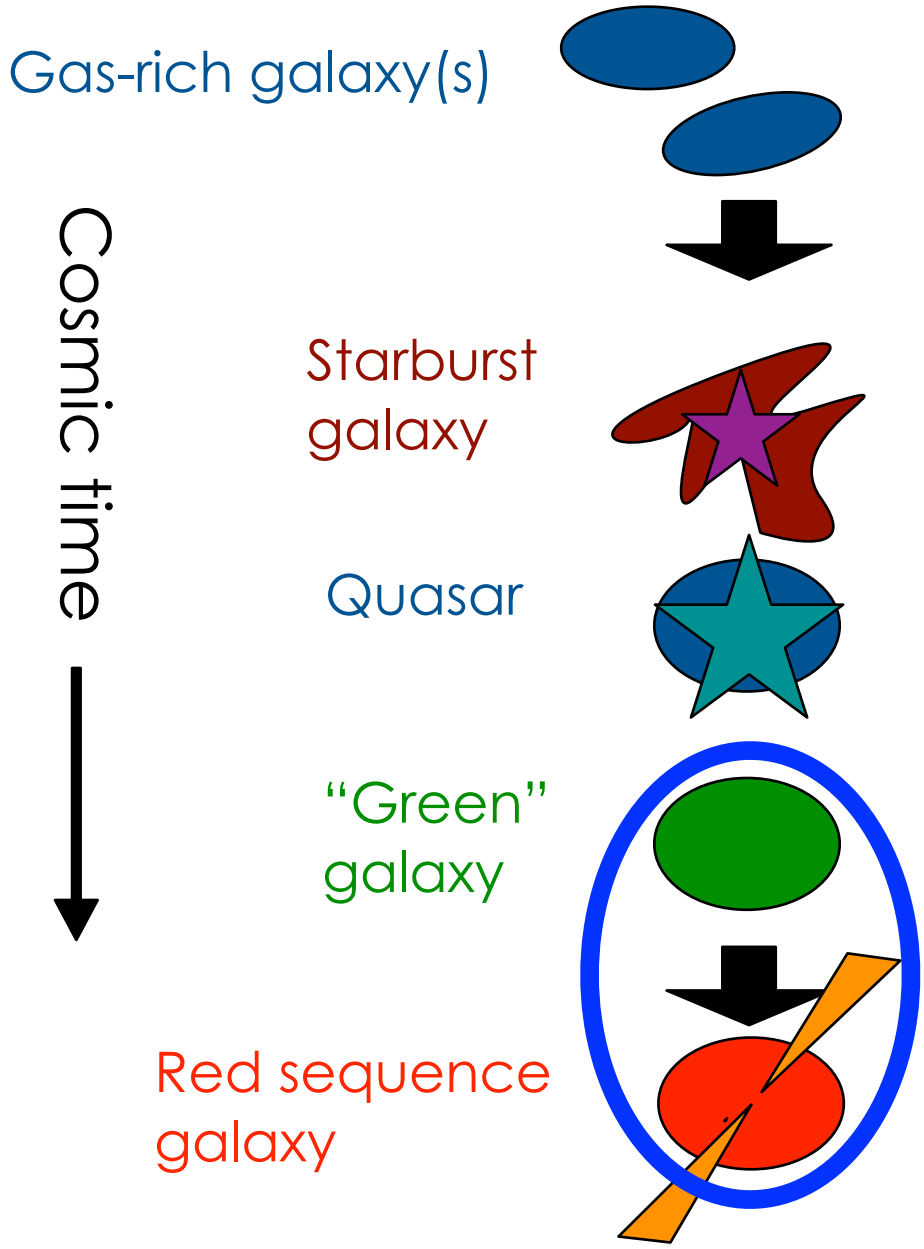


Hasinger et al. (2005)

← Cosmic ti

log(BH accretion density) →




Gas-rich galaxy(s)
Cosmic time
Starburst galaxy
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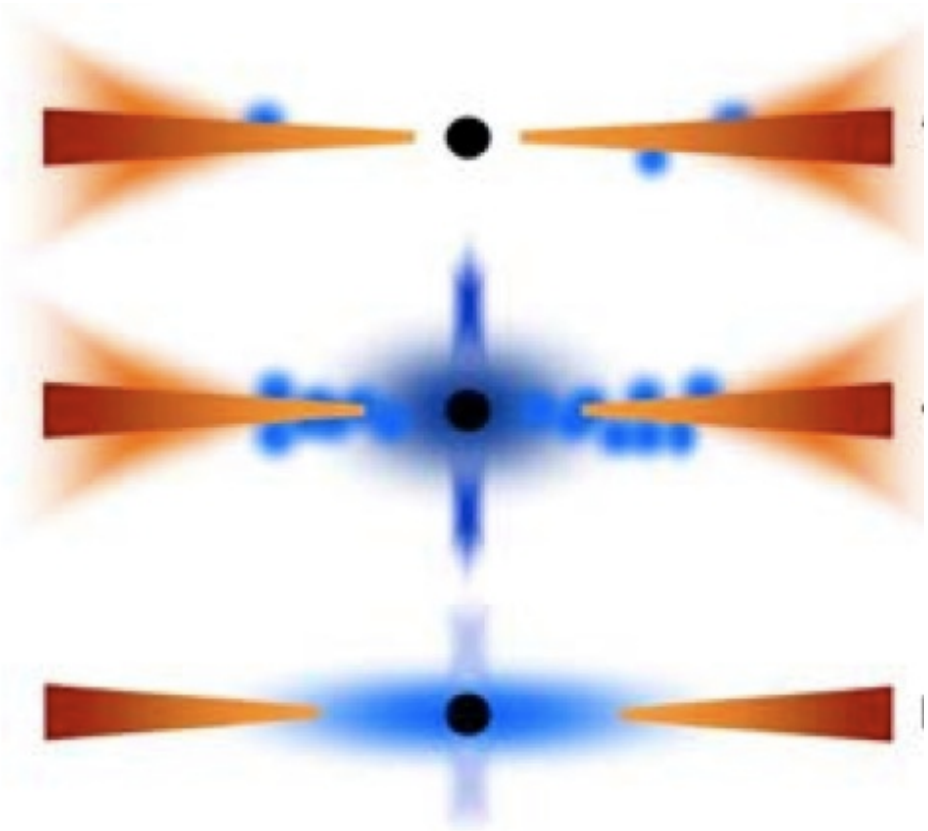
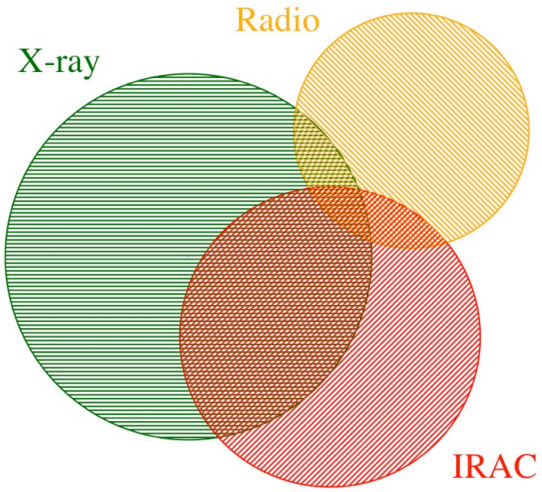


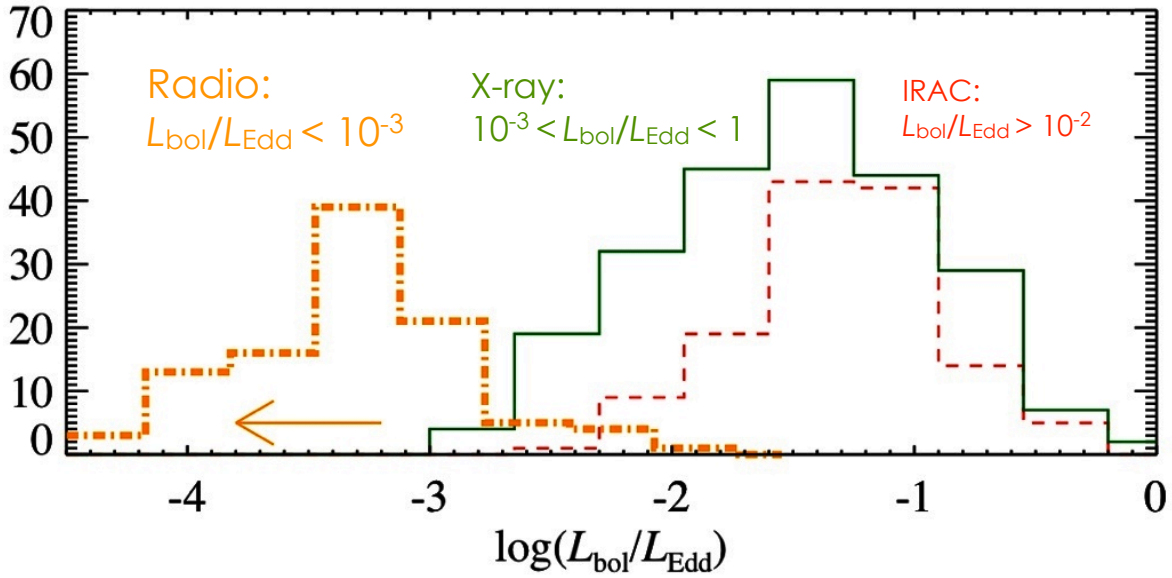
Done, Gierlinski & Kubota (2007)

Observational selection effects can severely bias some selection techniques toward particular Eddington ratios (e.g., Hopkins, Hickox, et al. 2009)

Boötes AGN sample

Hickox et al. (2009)

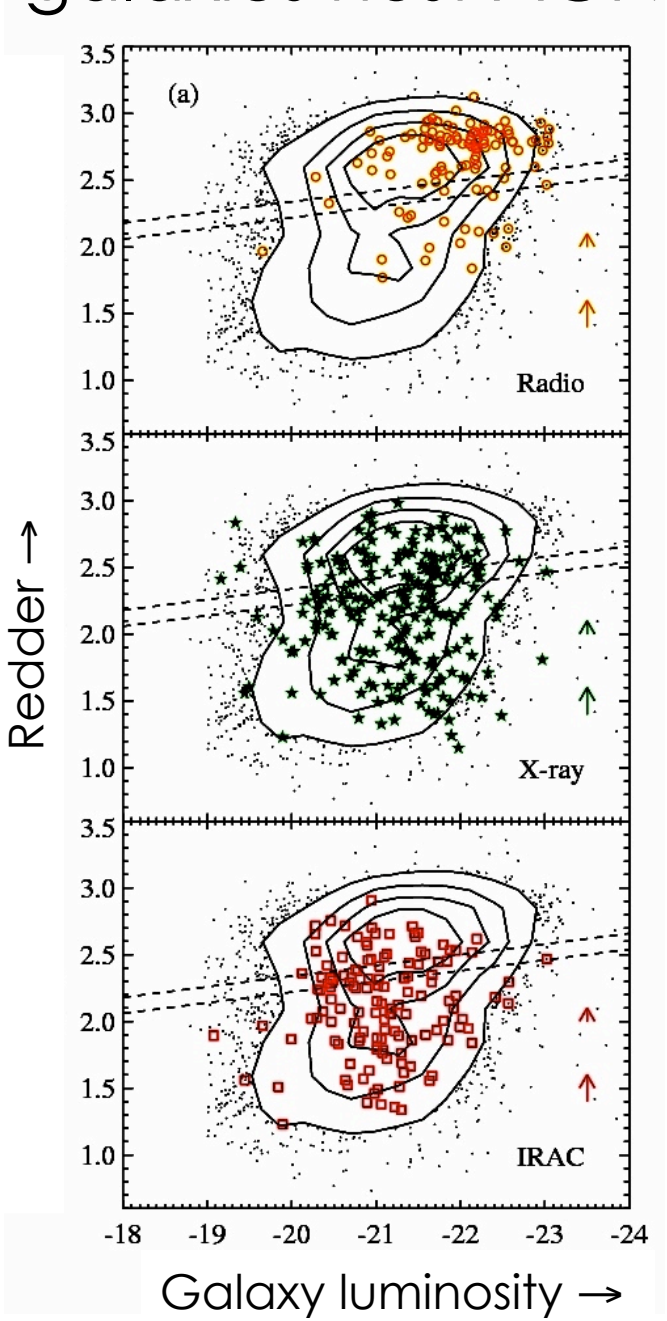


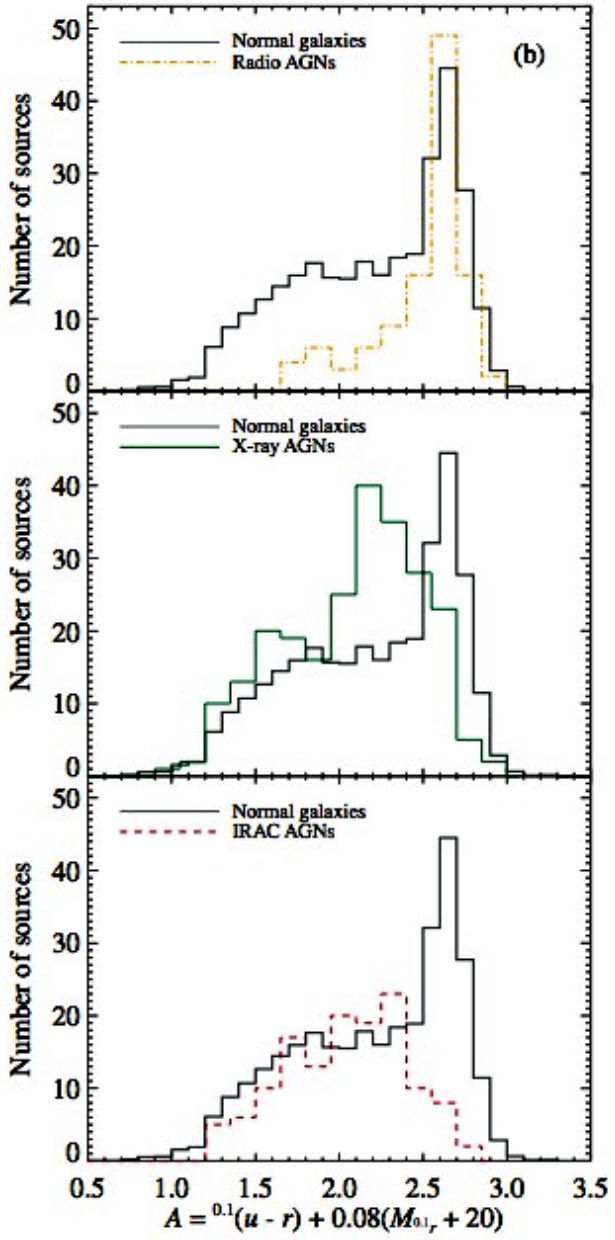


~6000 galaxies and 600 AGN with AGES redshifts at $0.25 < z < 0.8$

What types of galaxies host AGN?

Hickox et al. (2009)





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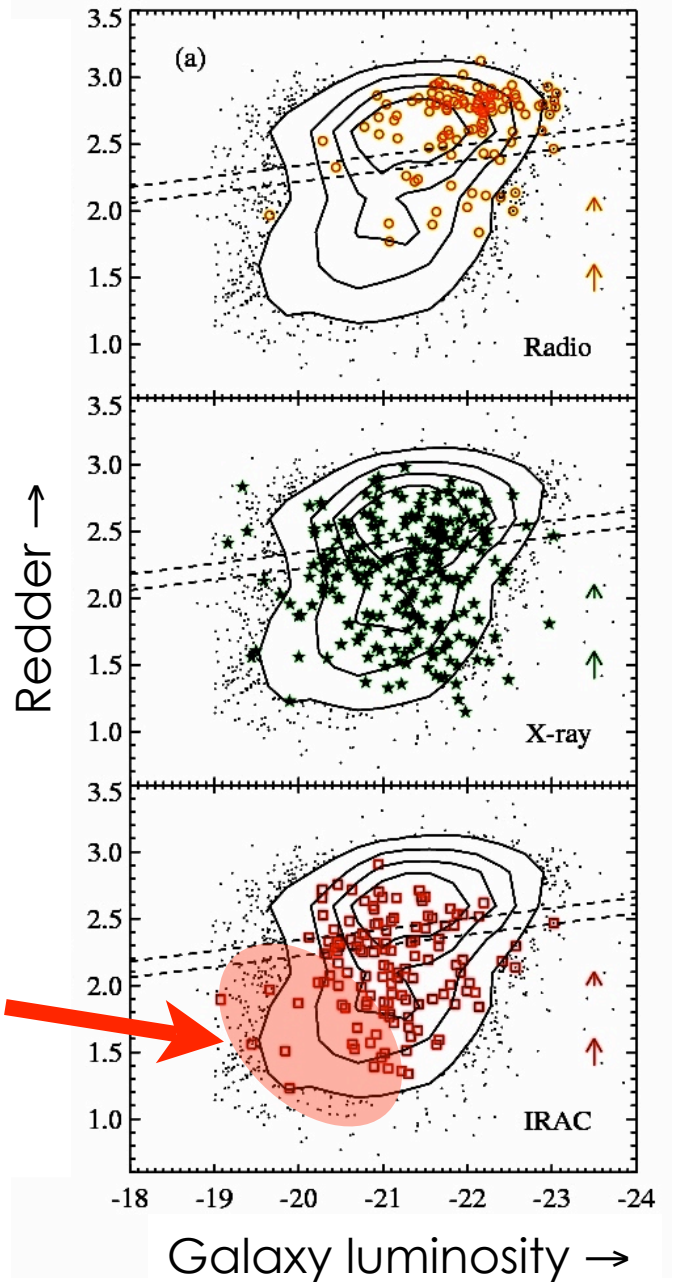
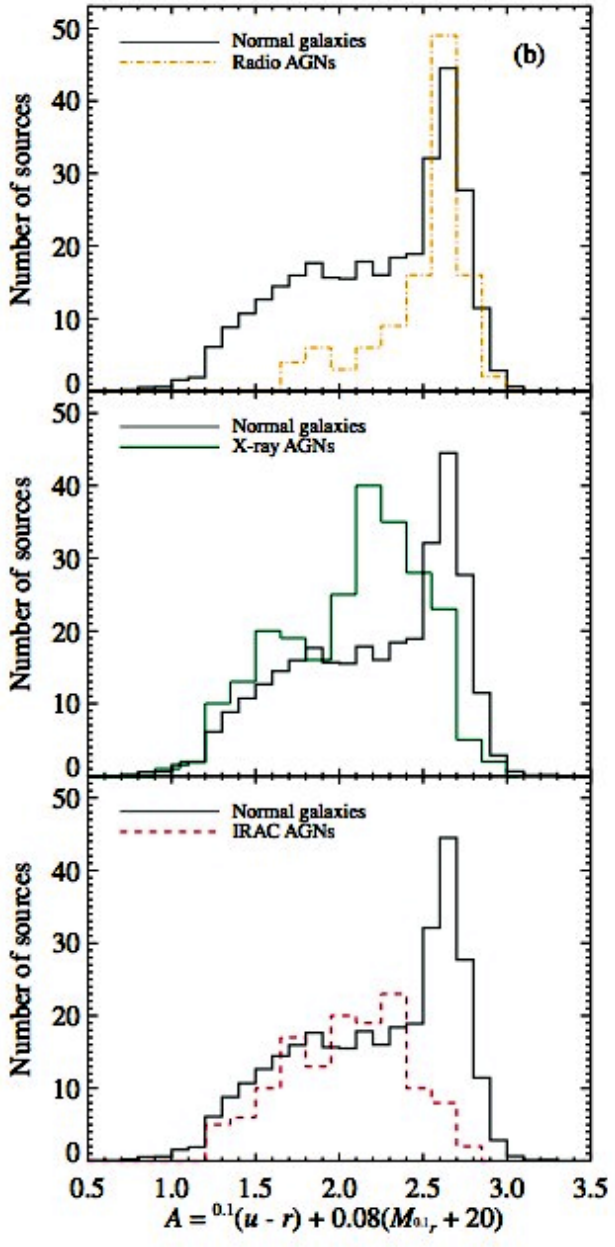




weak AGN found through mid-IR spectra
(Goulding et al. 2009)

many Compton-thick
(Goulding et al. 2010)

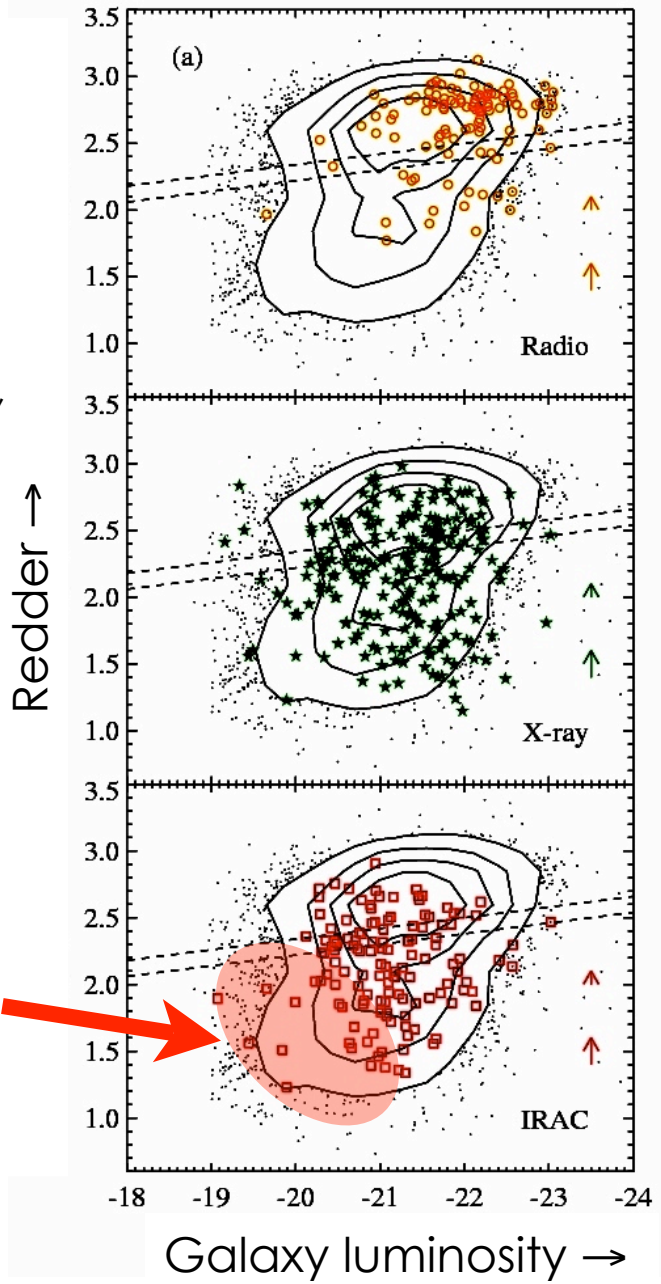
What types of galaxies host AGN?

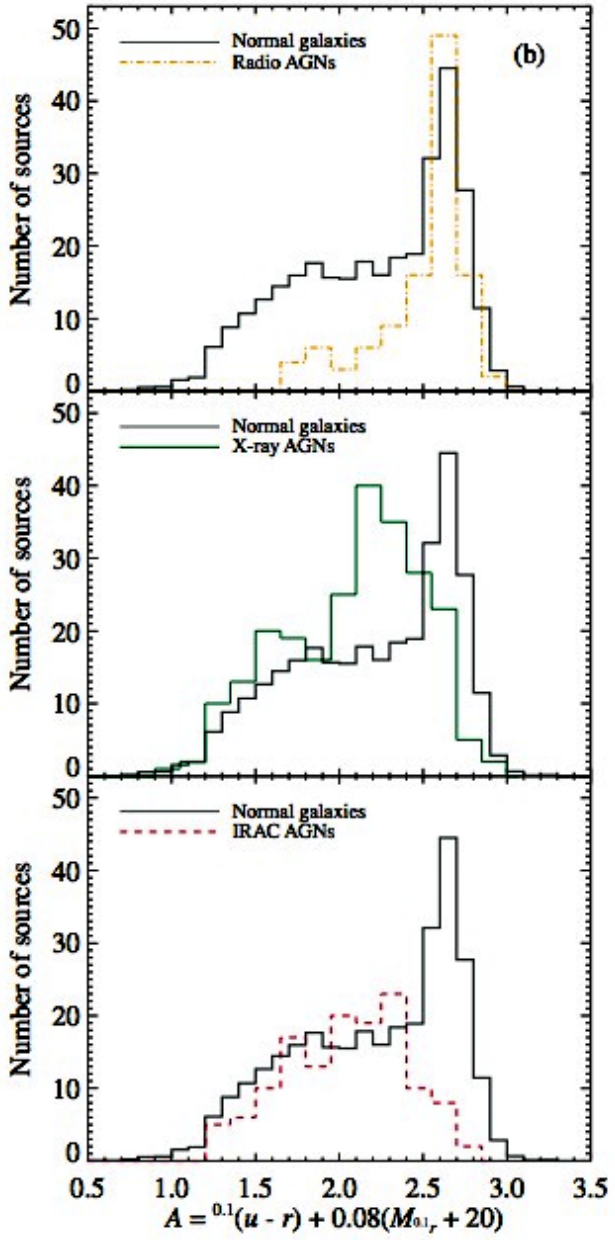
Hickox et al. (2009)

Similar results seen in other surveys for **X-ray AGN** (e.g., Nandra et al. 2007, Silverman et al. 2007, Alonso-Hererro et al. 2008, Georgakakis et al. 2008, Schawinski et al. 2009, even to z~3) as well as **radio** (Smolcic et al. 2009, Bardelli et al. 2010) and optical (Kauffmann & Heckman 2009)

weak AGN found through mid-IR spectra (Goulding et al. 2009)

many Compton-thick (Goulding et al. 2010)





AGN host morphologies

X-ray AGN, Georgakakis et al. (2009)

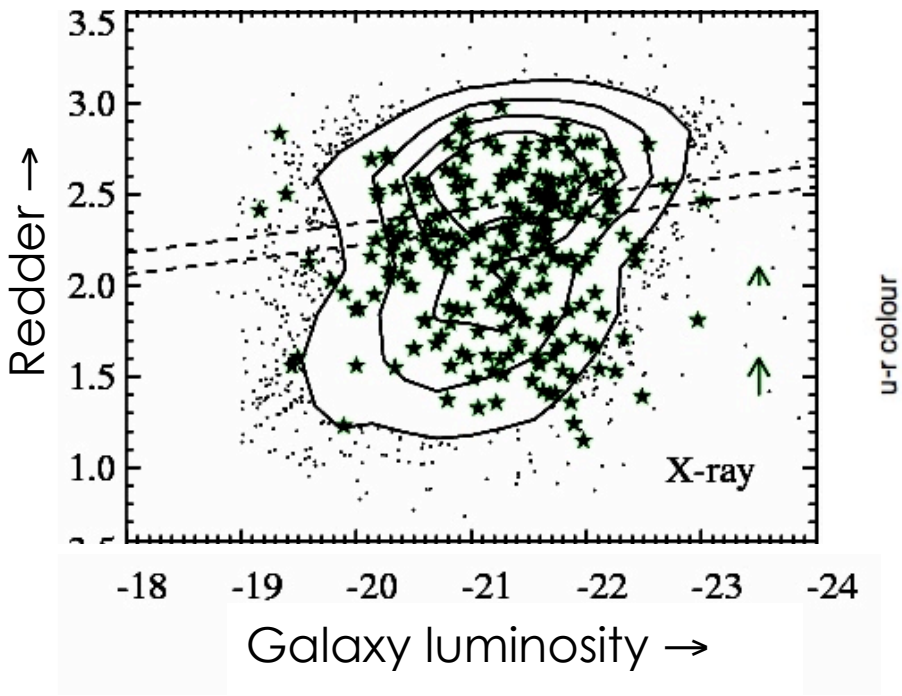
Radio AGN are almost all in bulge-dominated galaxies

X-ray AGN are primarily in bulge-dominated galaxies,

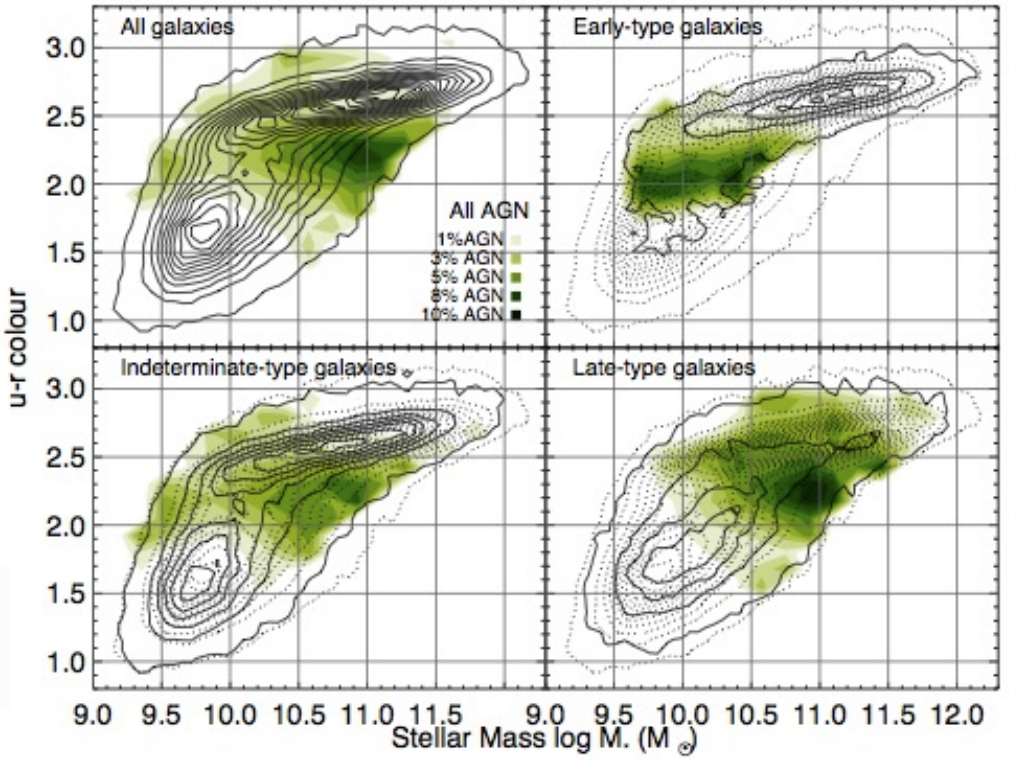
IR AGN are more likely to be in disks

(e.g., Georgakakis et al. 2009, Griffith & Stern 2010)

A cautionary note

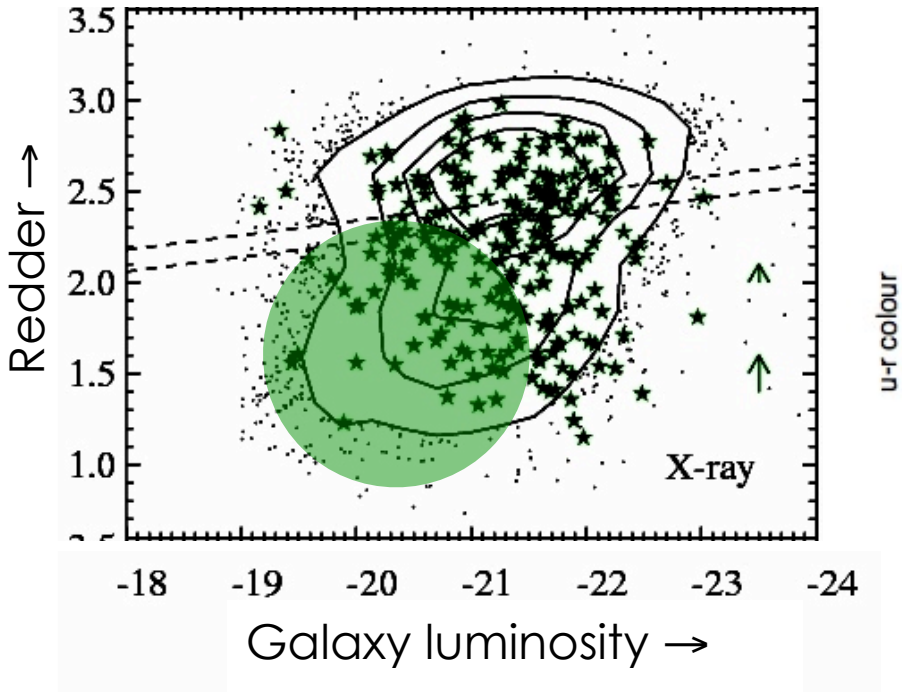


Hickox et al. (2009) [X-ray]

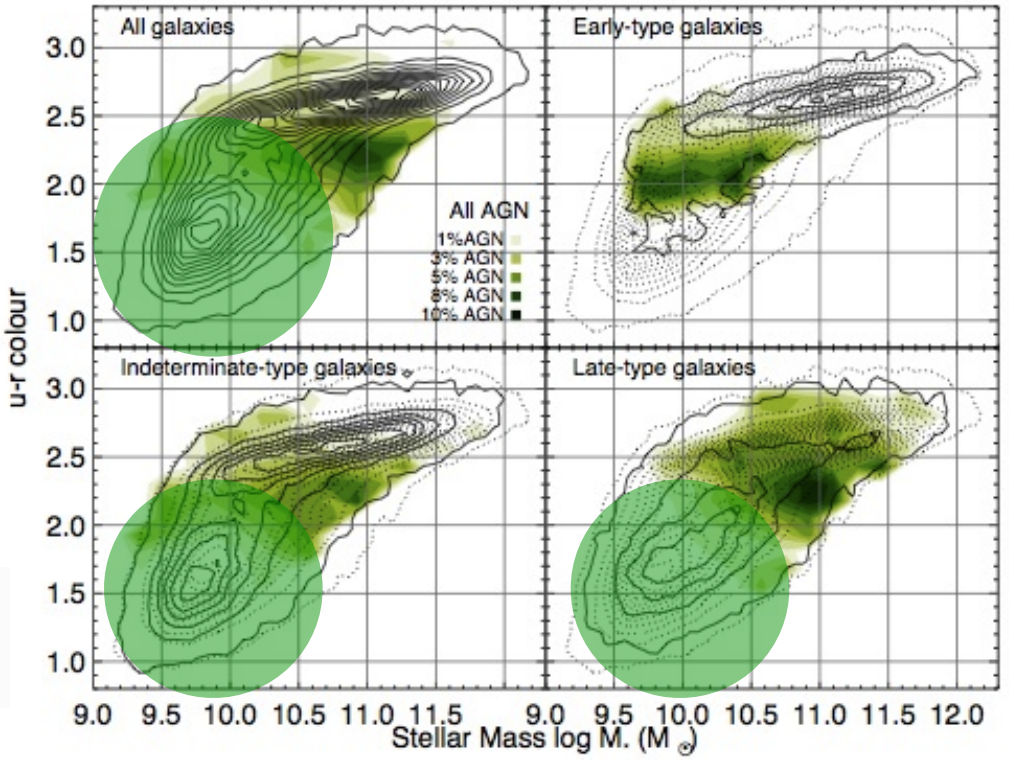


Schawinski et al. (2010) [optical]

A cautionary note

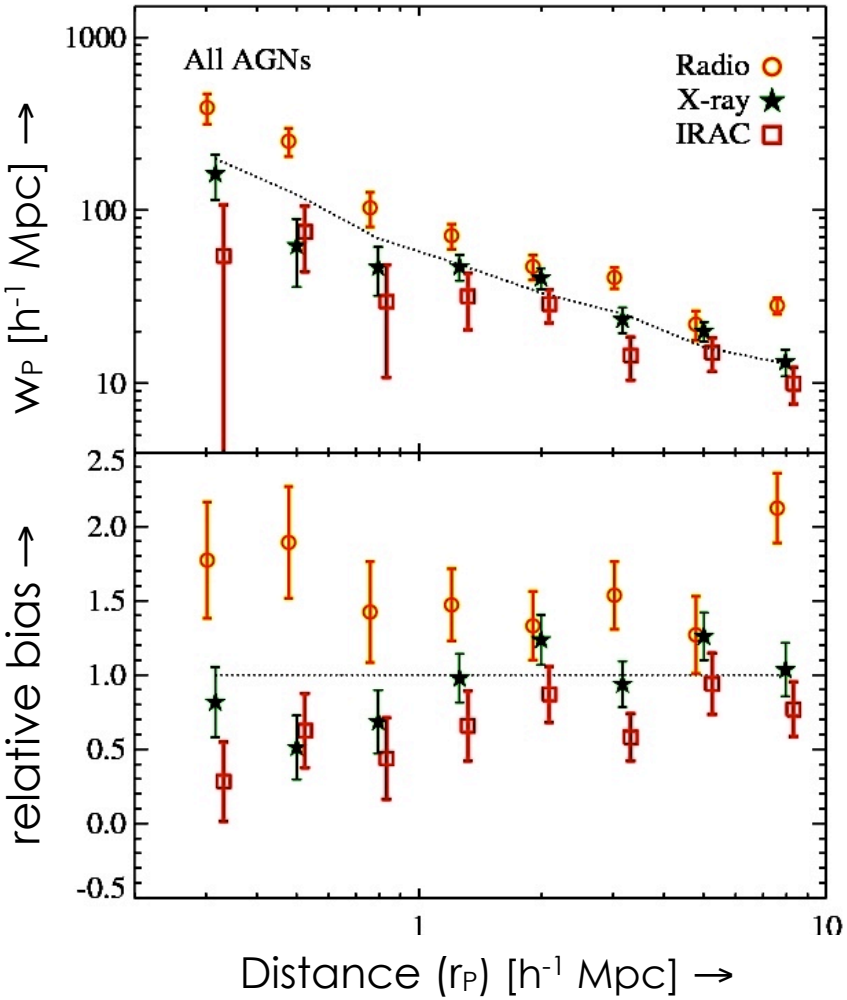


Hickox et al. (2009) [X-ray]

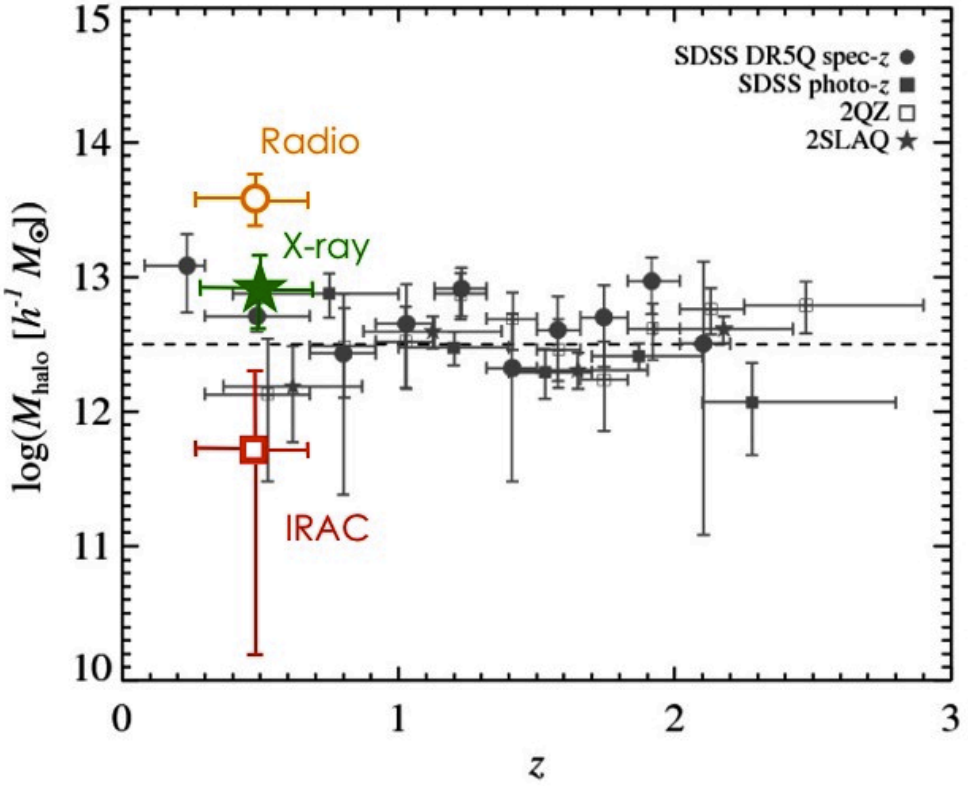


Schawinski et al. (2010) [optical]

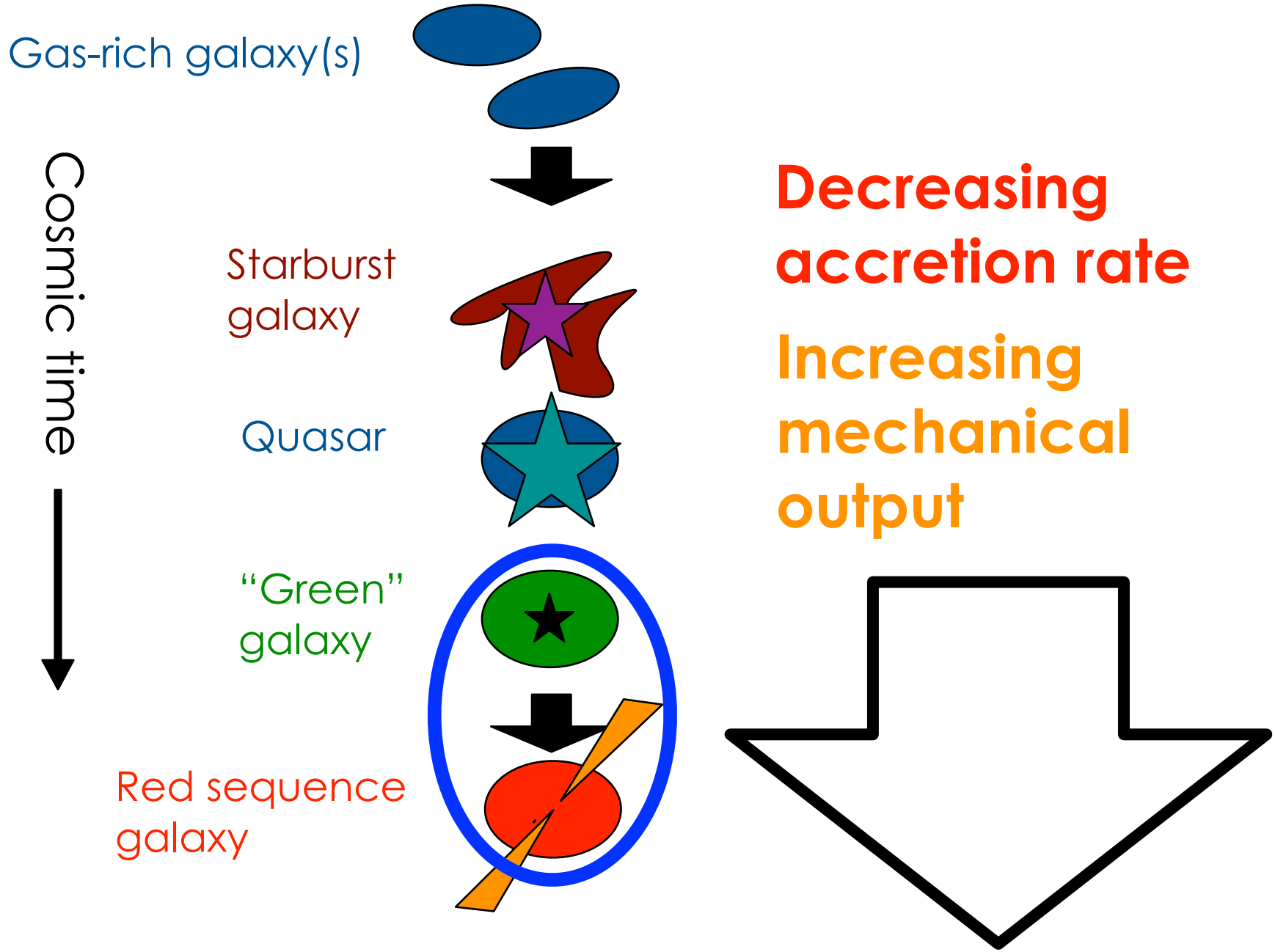
A paucity of AGN in low-mass blue cloud is likely be due to **selection effects** (small black holes, larger host galaxy contamination)

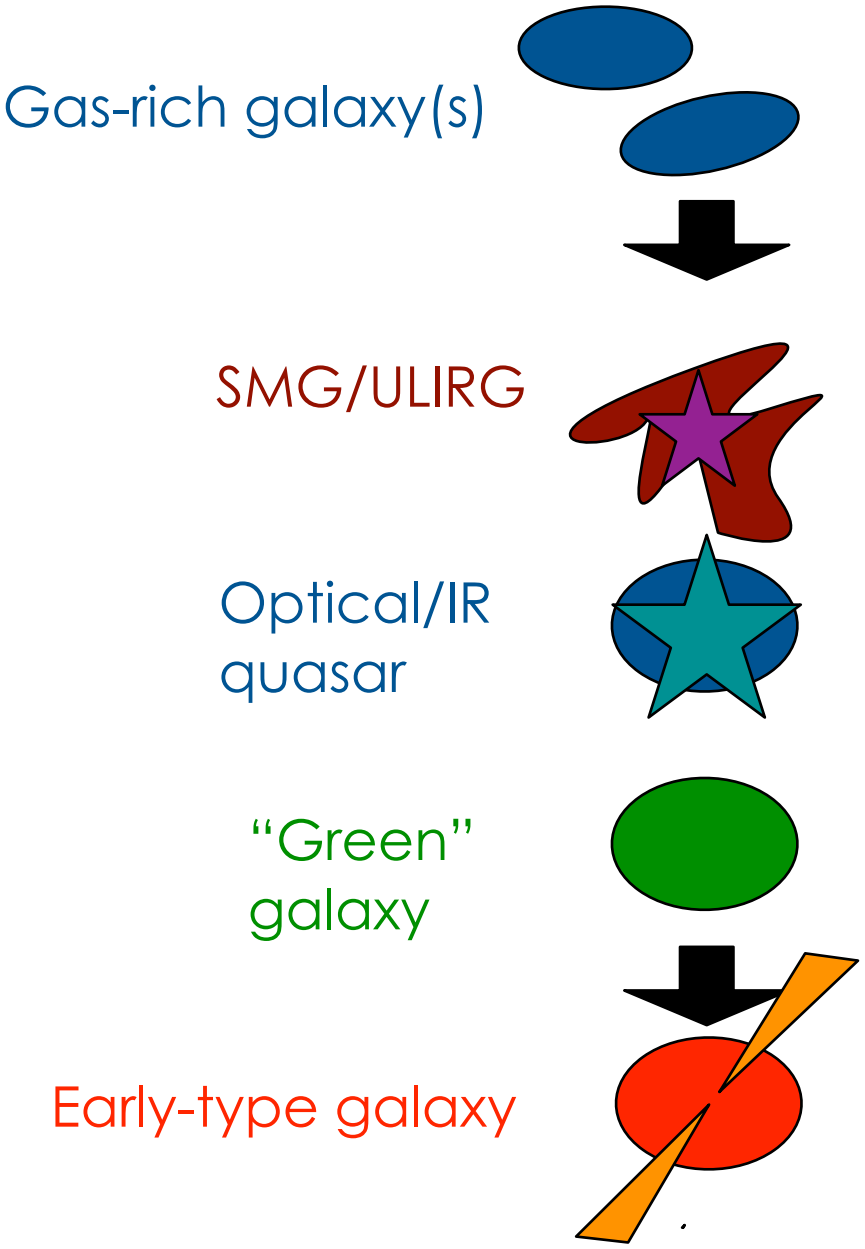


Hickox et al. (2009)

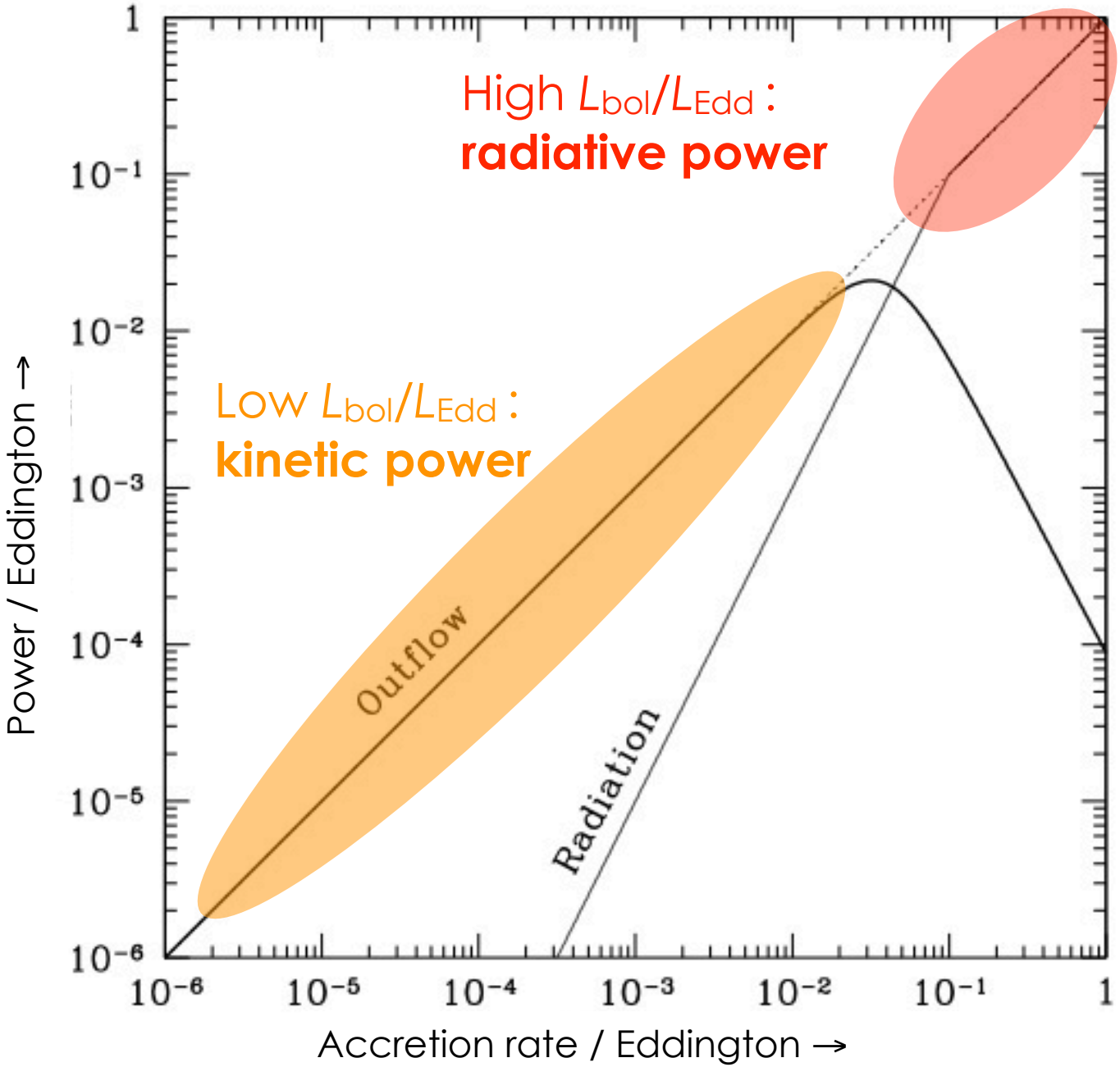


see also Li et al. (2006), Coil et al. (2009), Wake et al. (2008), Mandelbaum et al. (2008)

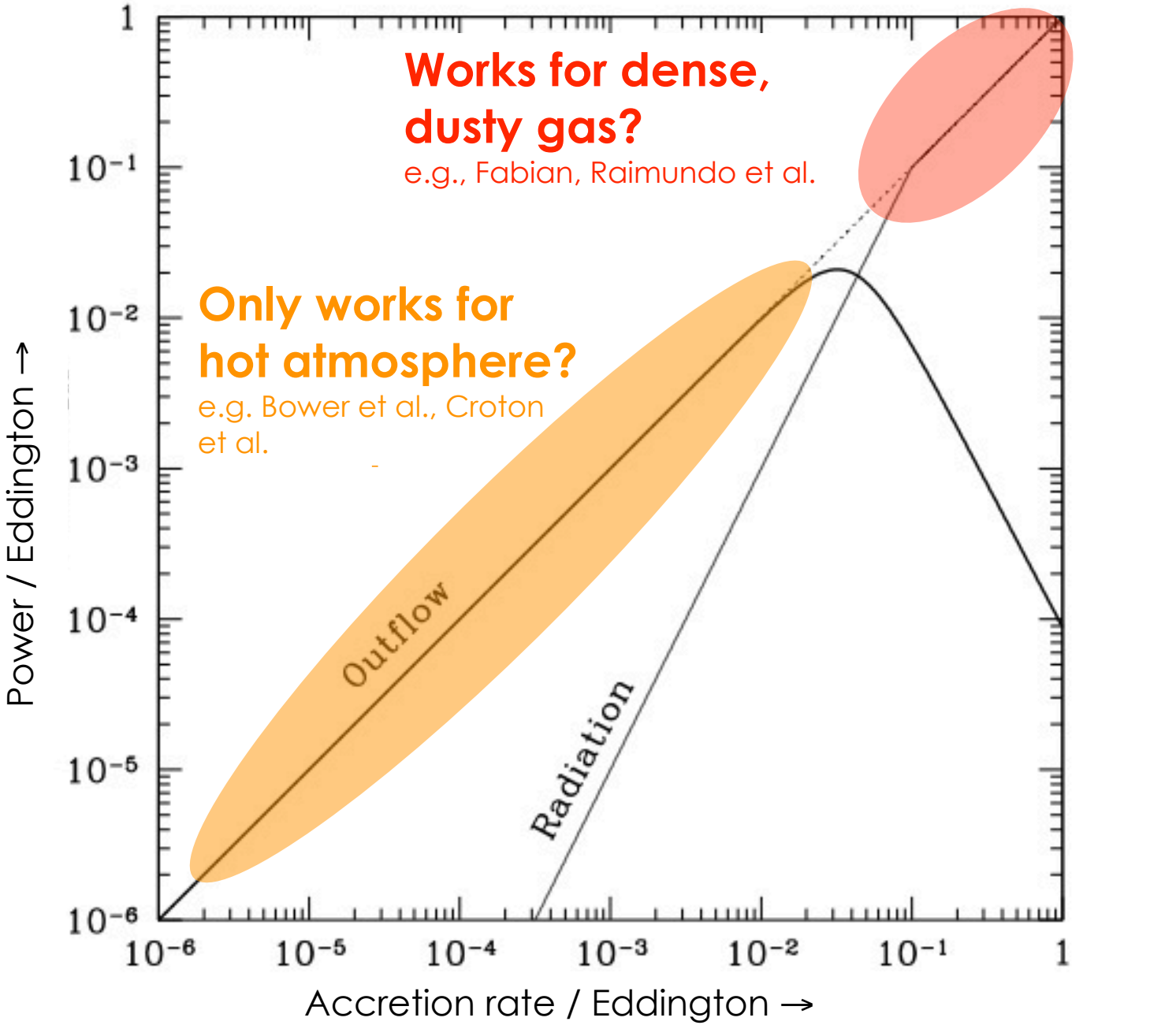

Gas-rich galaxy(s)
Cosmic time
Starburst galaxy
Quasar
"Green" galaxy
Red sequence galaxy
Decreasing accretion rate
Increasing mechanical output



Part 2: Where is feedback at work?

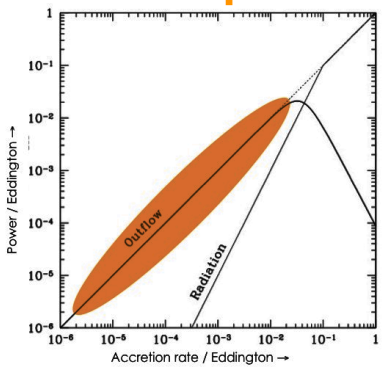


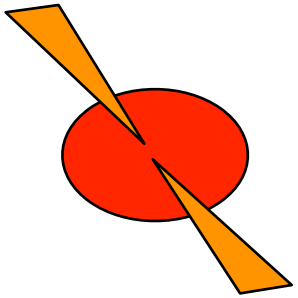
Churazov et al. (2005)

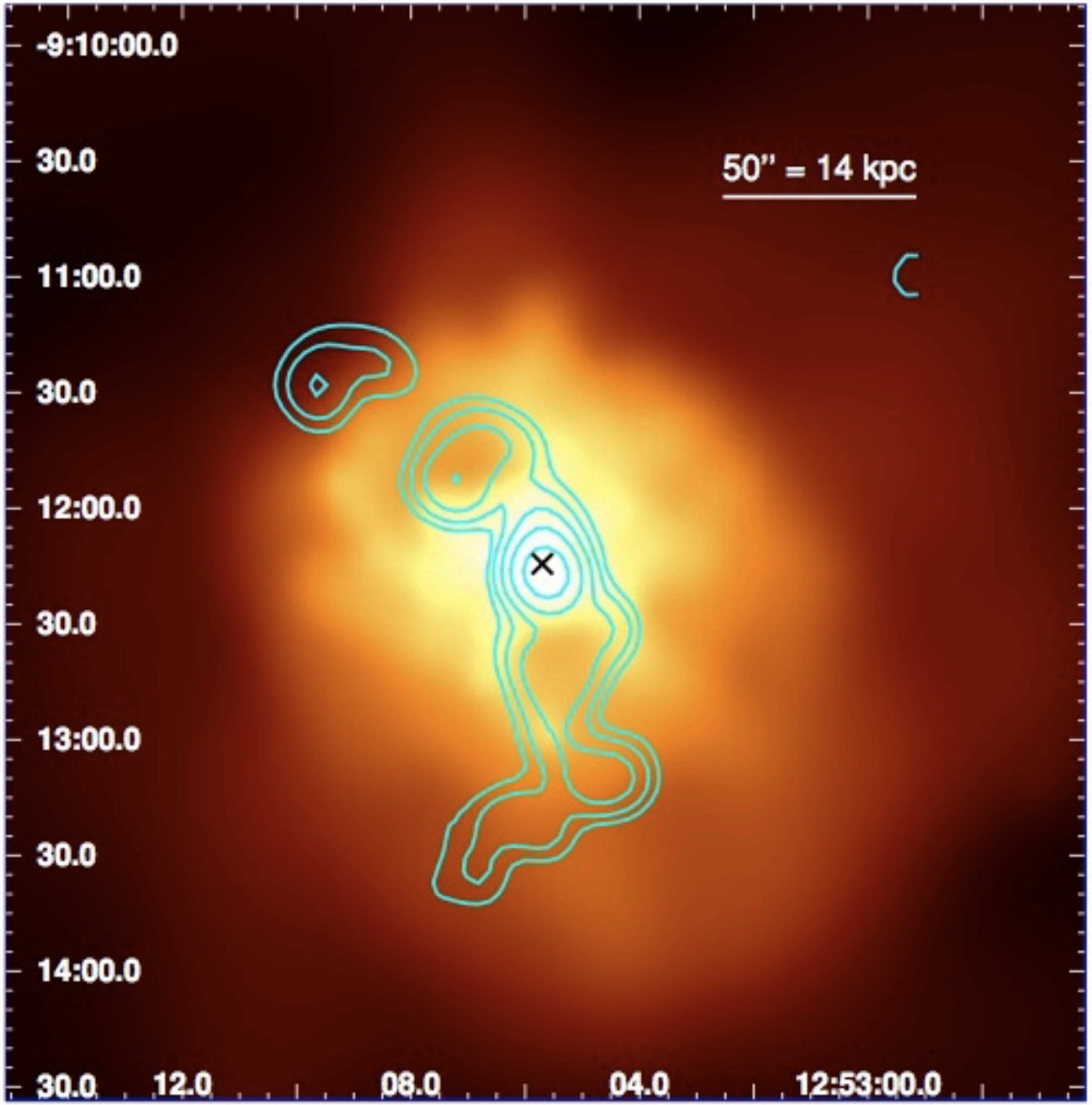


Churazov et al. (2005)

Kinetic power

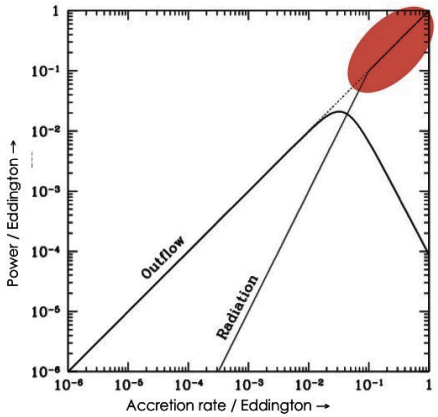


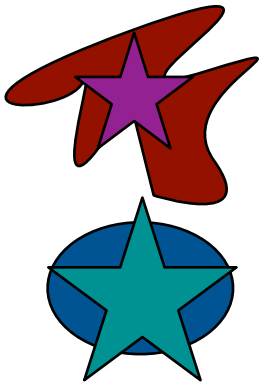




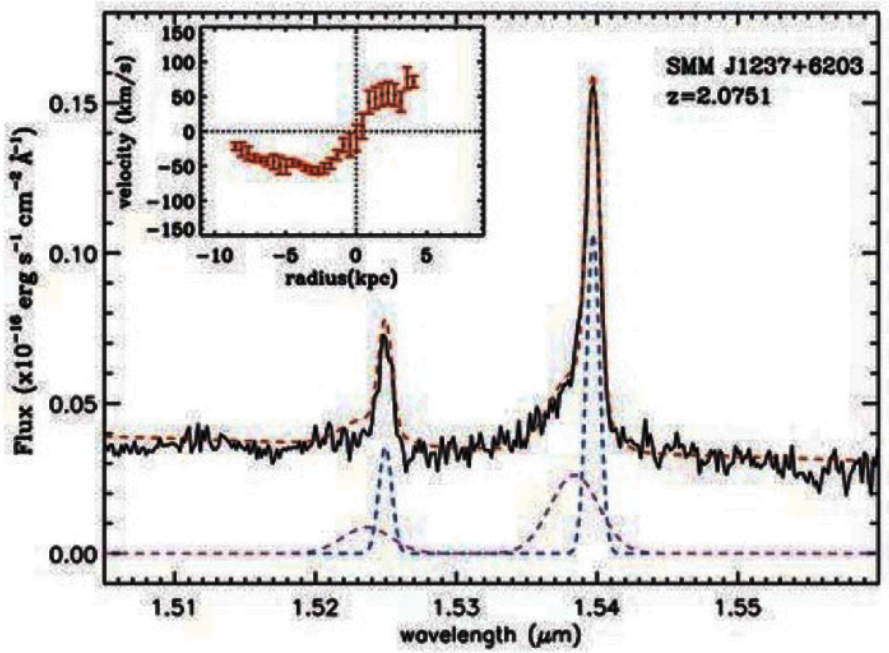
HCG 62 (Gitti et al. 2010), see many others for similar examples

Radiative power



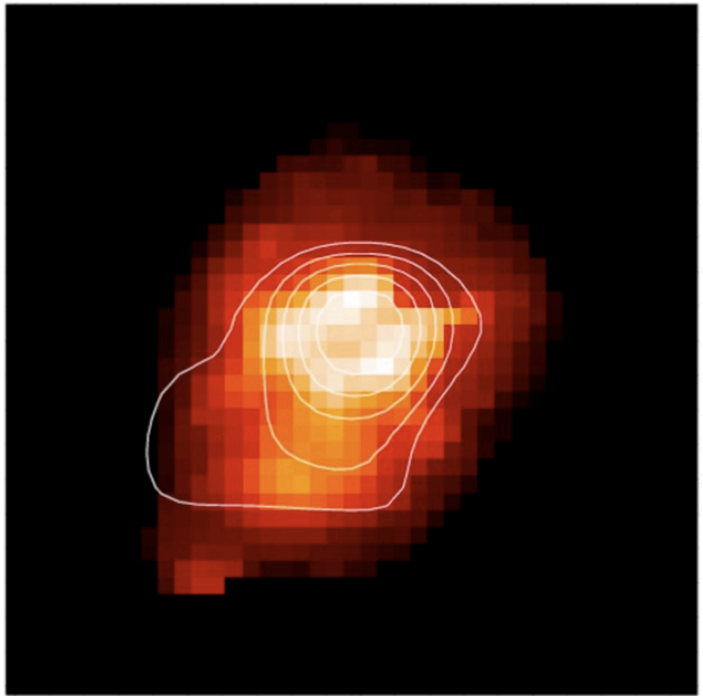


Collapsed IFU spectrum of z~2.07 SMG



Alexander et al. (2010)

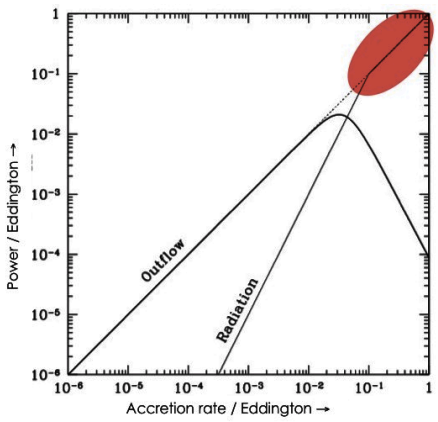
~4-8 kpc extent of broad [OIII gas]

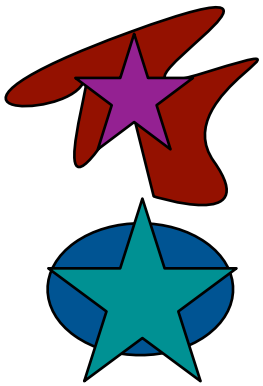


Broad (800 km/s) high-velocity (200-500 km/s) [OIII] gas

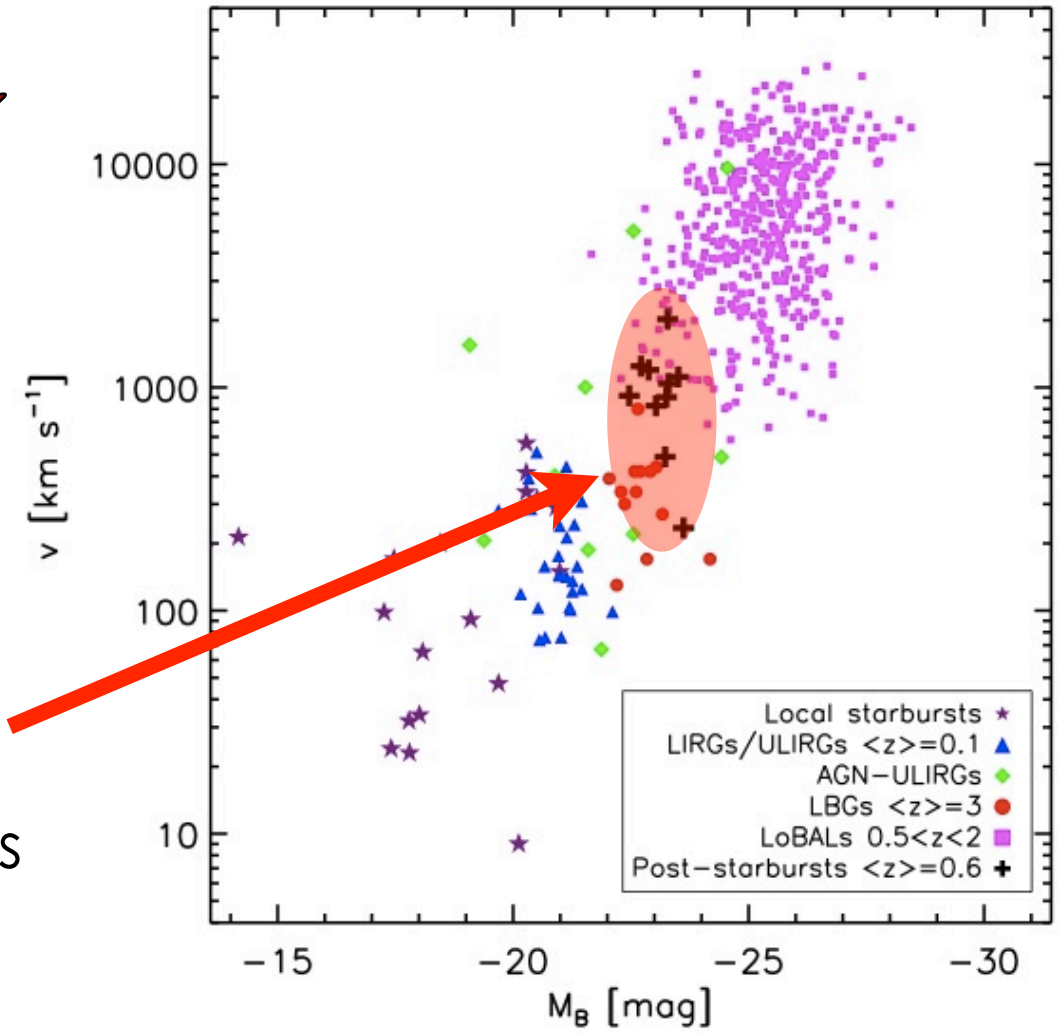
For radio-loud sources see Nesvadba et al., Siemignowska et al.

Radiative power



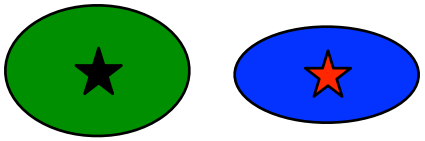


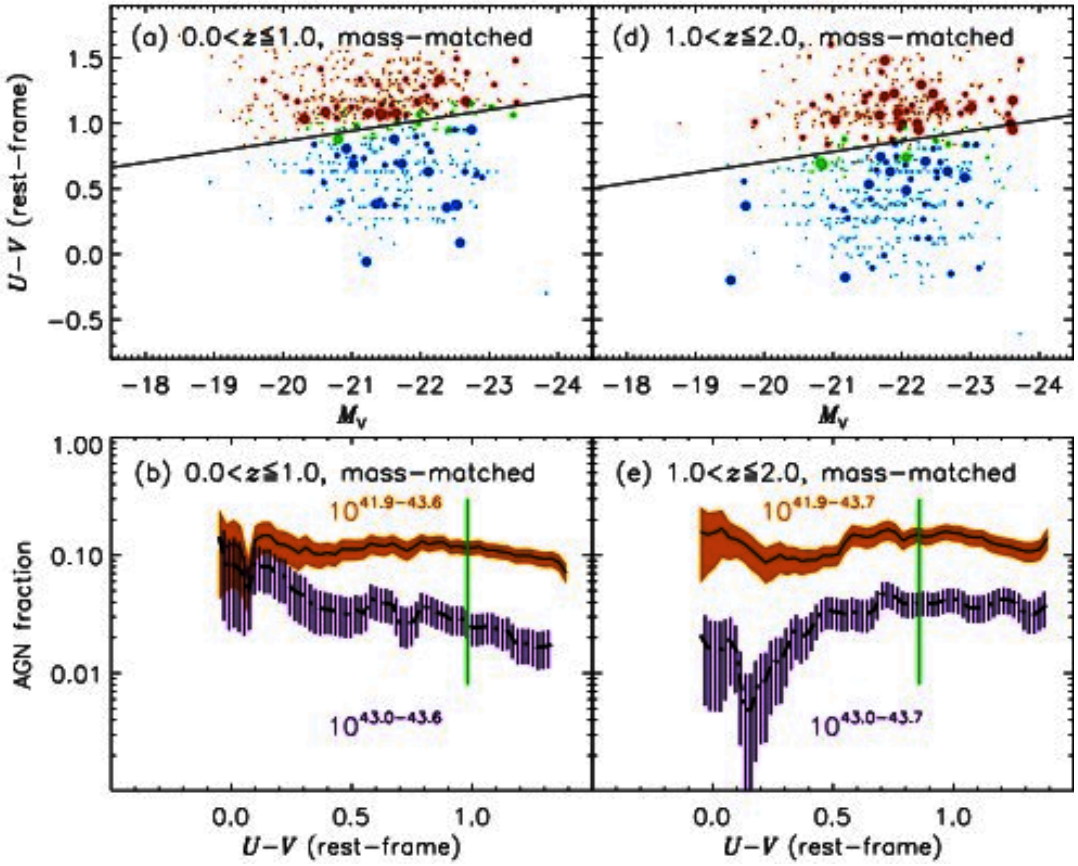
v ~ 1000 km/s winds from massive, young post-starburst galaxies



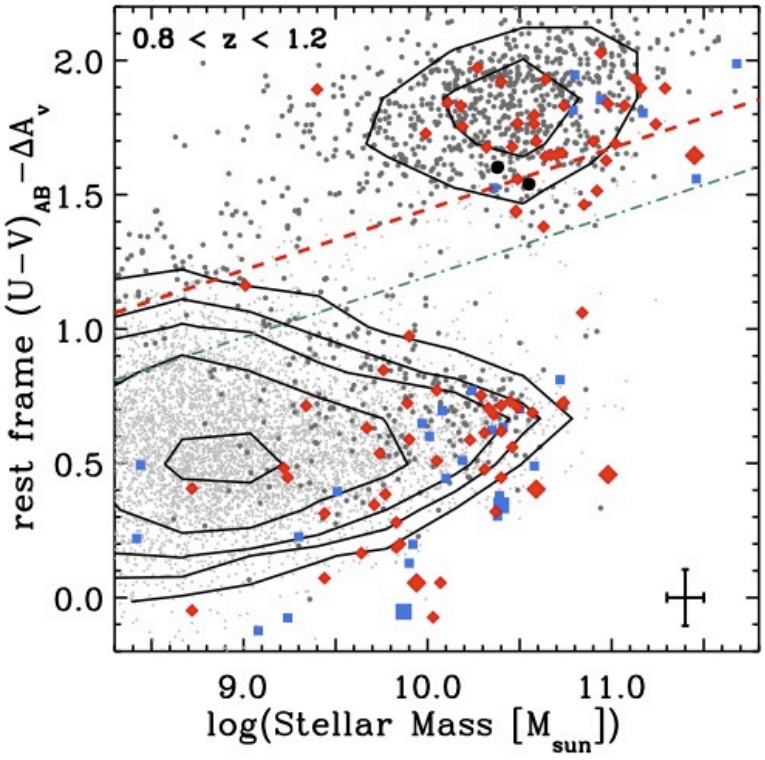
Tremonti et al. (2007) [optical]

"Typical" AGN
no impact on host?





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



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

"Typical" AGN
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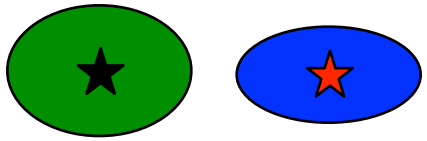
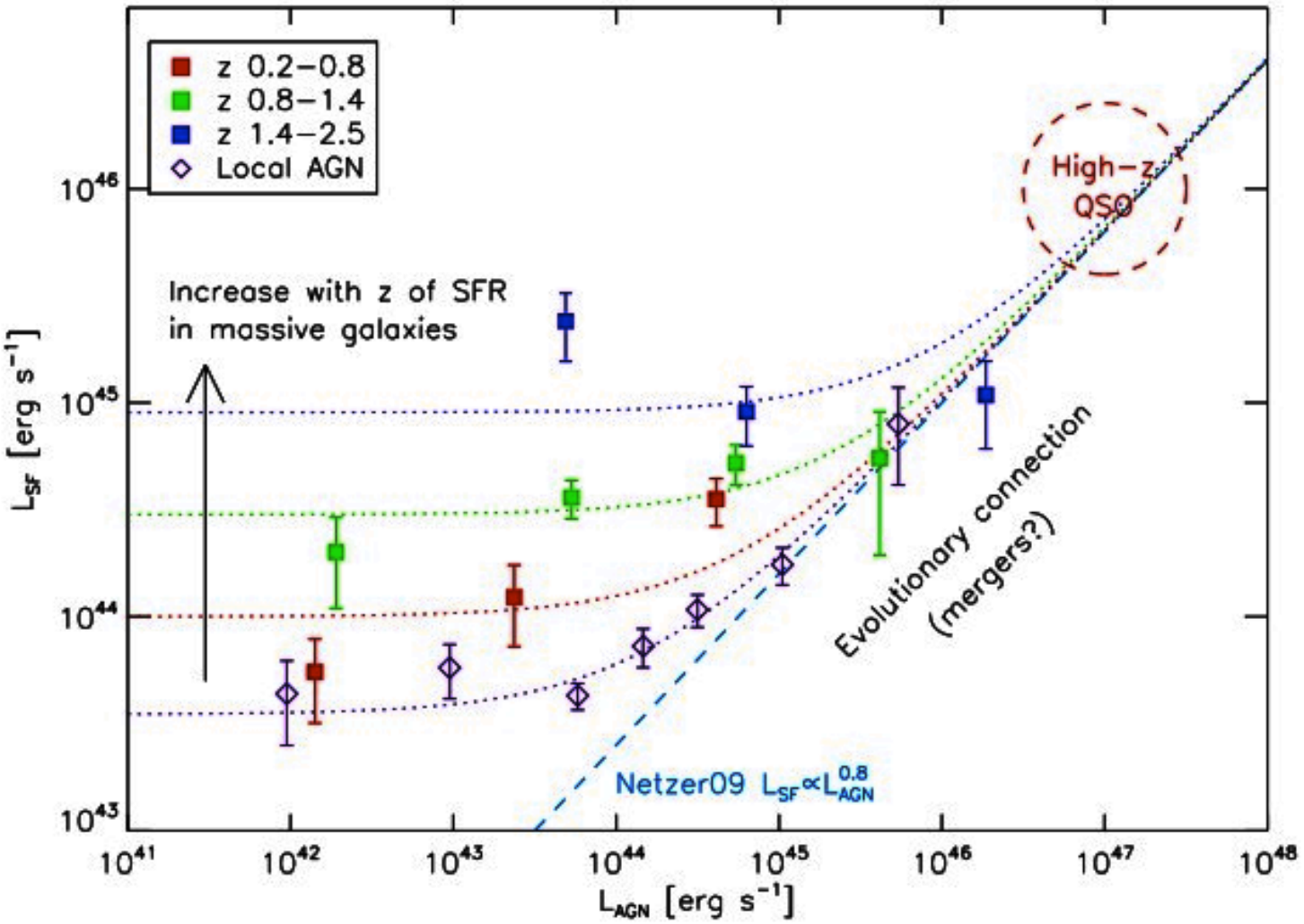
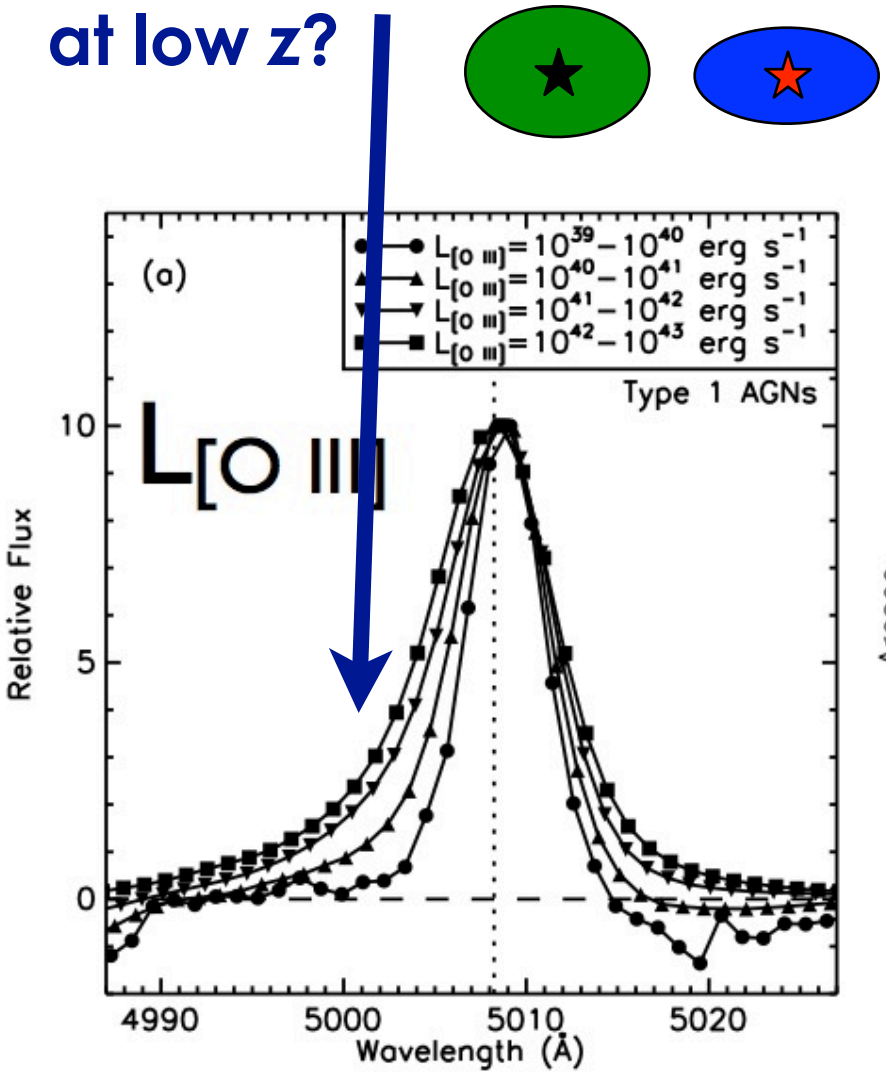
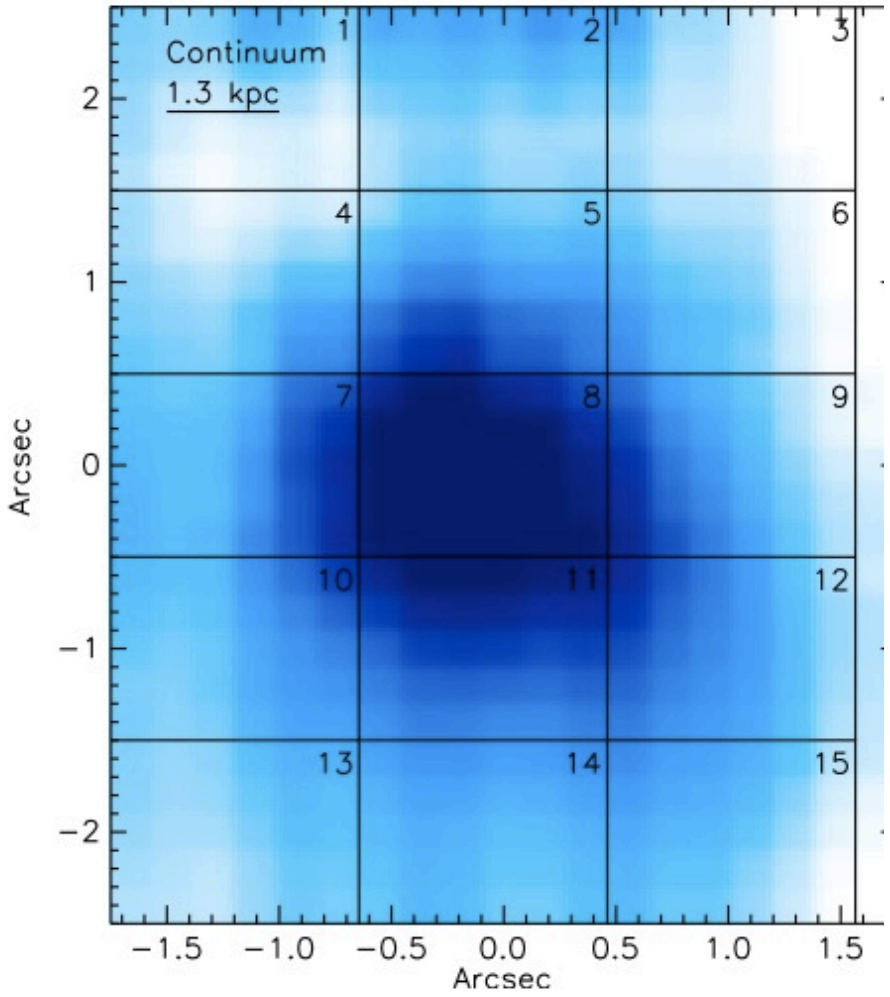




Shao et al. (2010) [X-ray], see also Mullaney et al. (2010), Laird et al., Silverman et al.

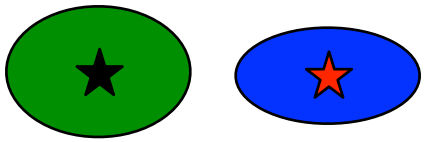
Ubiquitous outflows at low z?

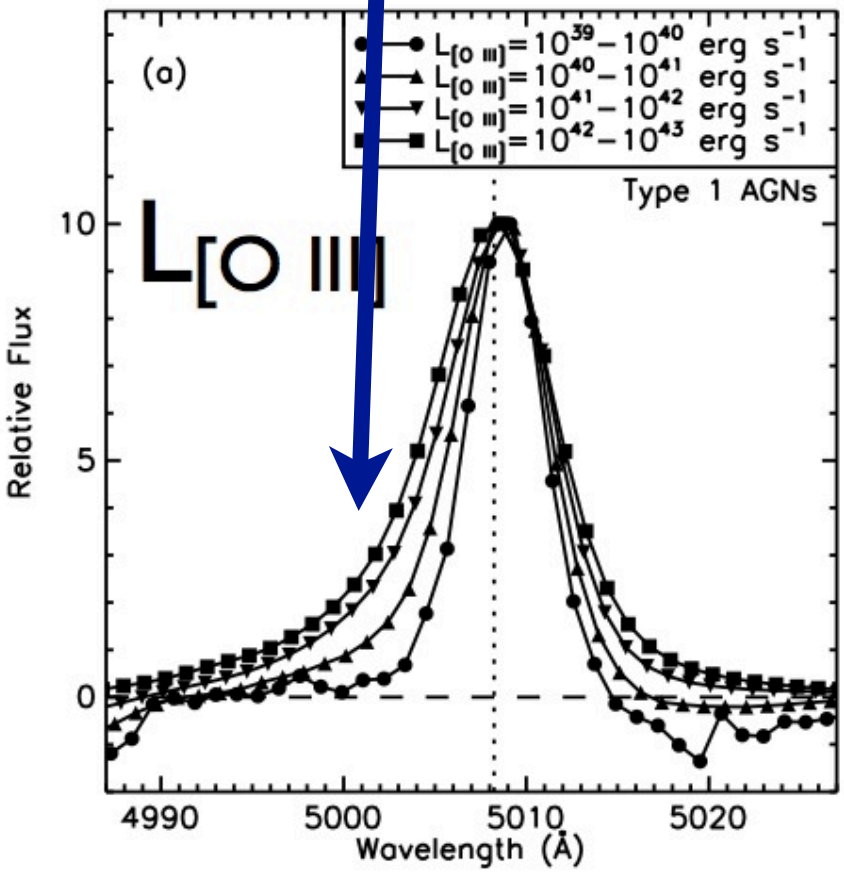




Mullaney et al. in prep [optical]

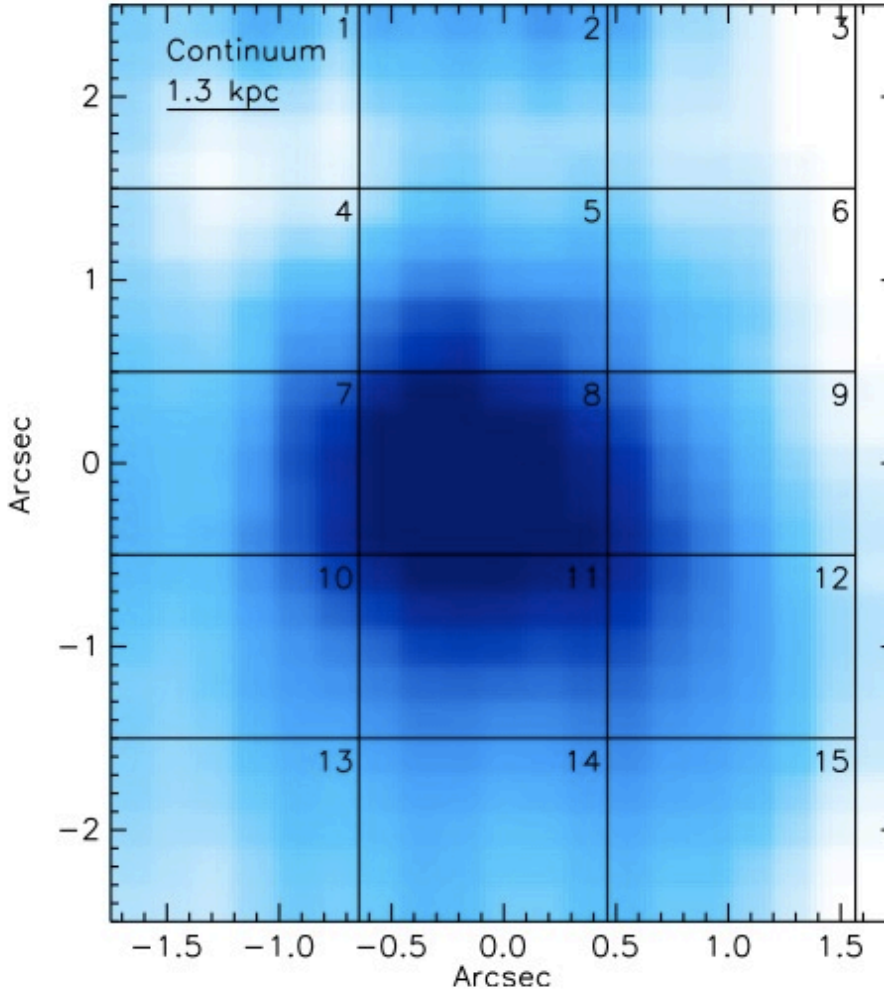
Ubiquitous outflows at low z?

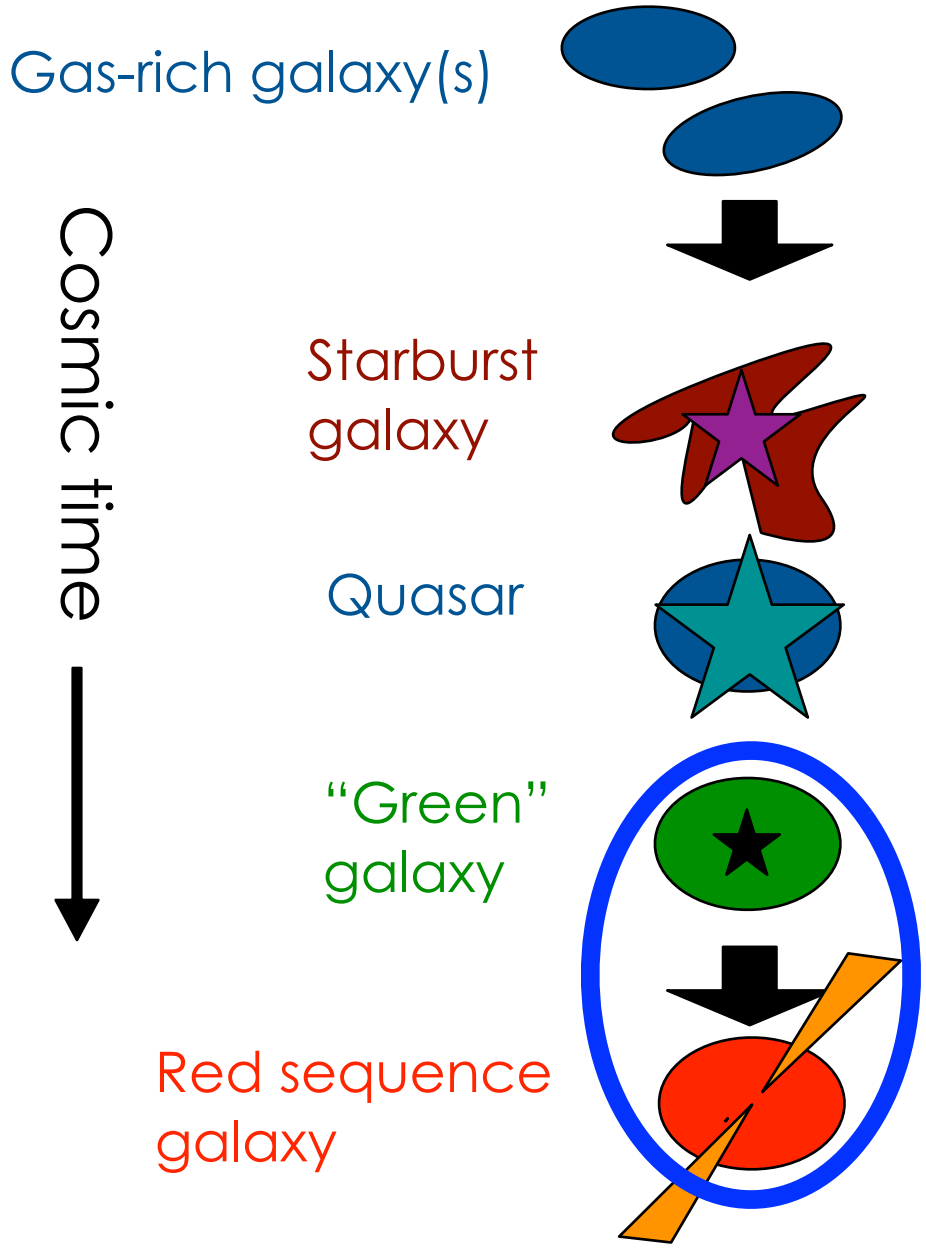




Mullaney et al. in prep [optical]

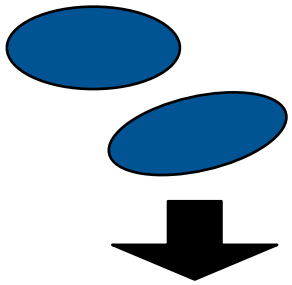
Black hole self-regulation?




Gas-rich galaxy(s)
Cosmic time
Starburst galaxy
Quasar
"Green" galaxy
Red sequence galaxy

Radiative and **mechanical** feedback strongly affects host

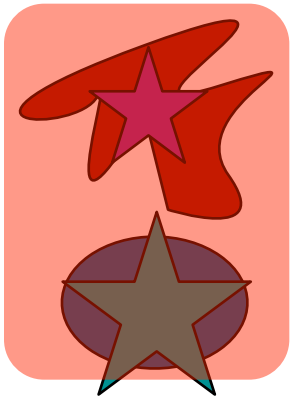
Gas-rich galaxy(s)



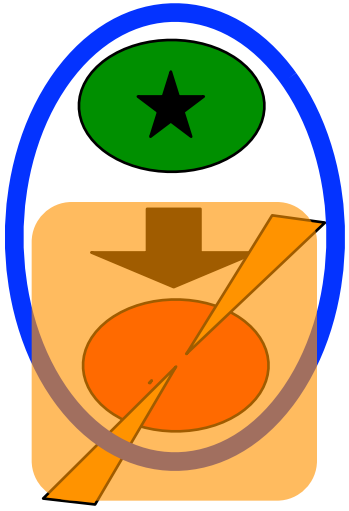
Cosmic time

Starburst galaxy

Quasar



"Green" galaxy



Red sequence galaxy

Gas-rich galaxy(s)

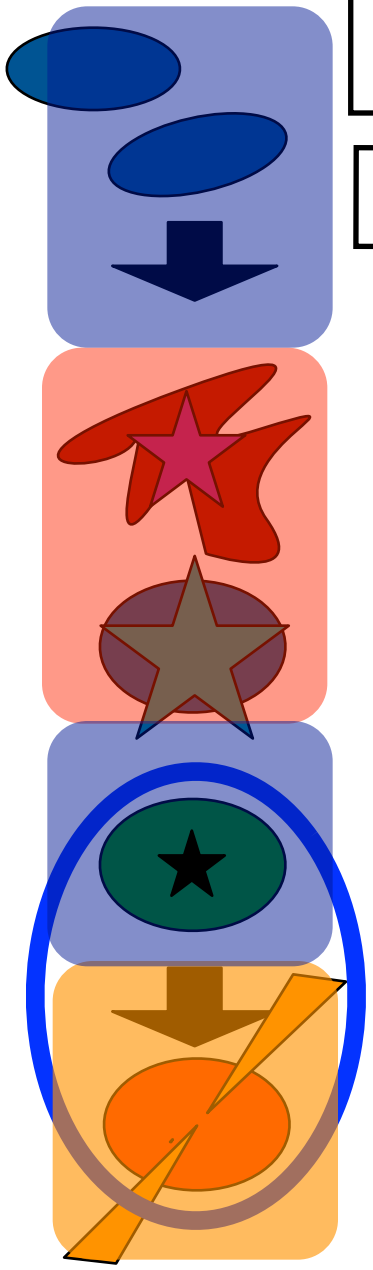
Cosmic time

Starburst galaxy

Quasar

"Green" galaxy

Red sequence galaxy

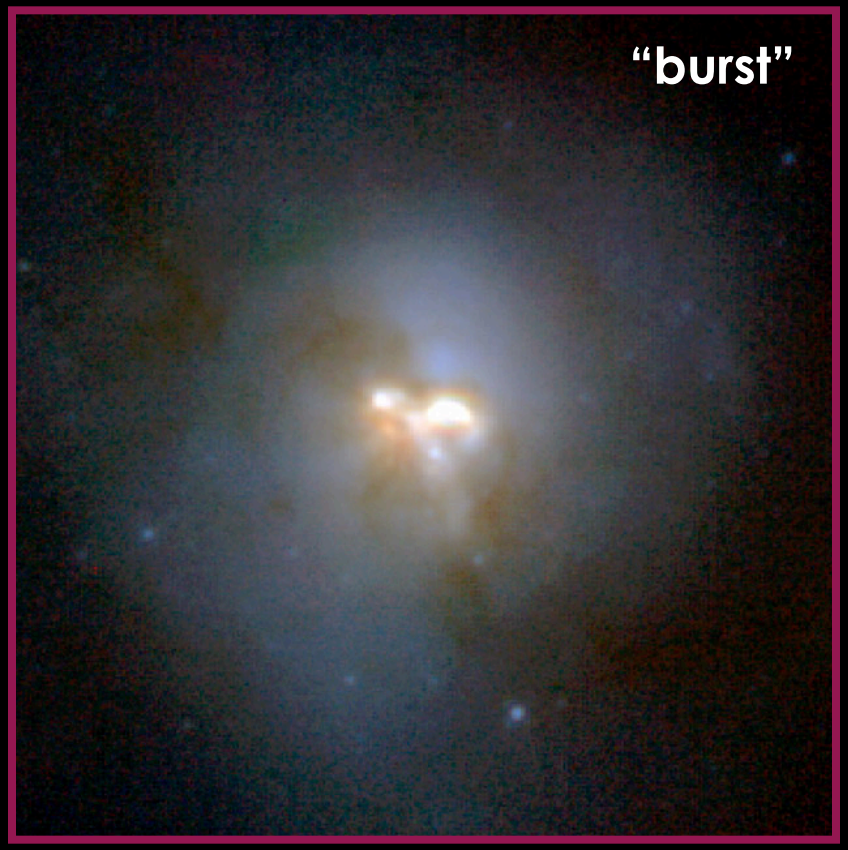


Radiative and **mechanical** feedback strongly affects host

Black hole **self-regulation?**

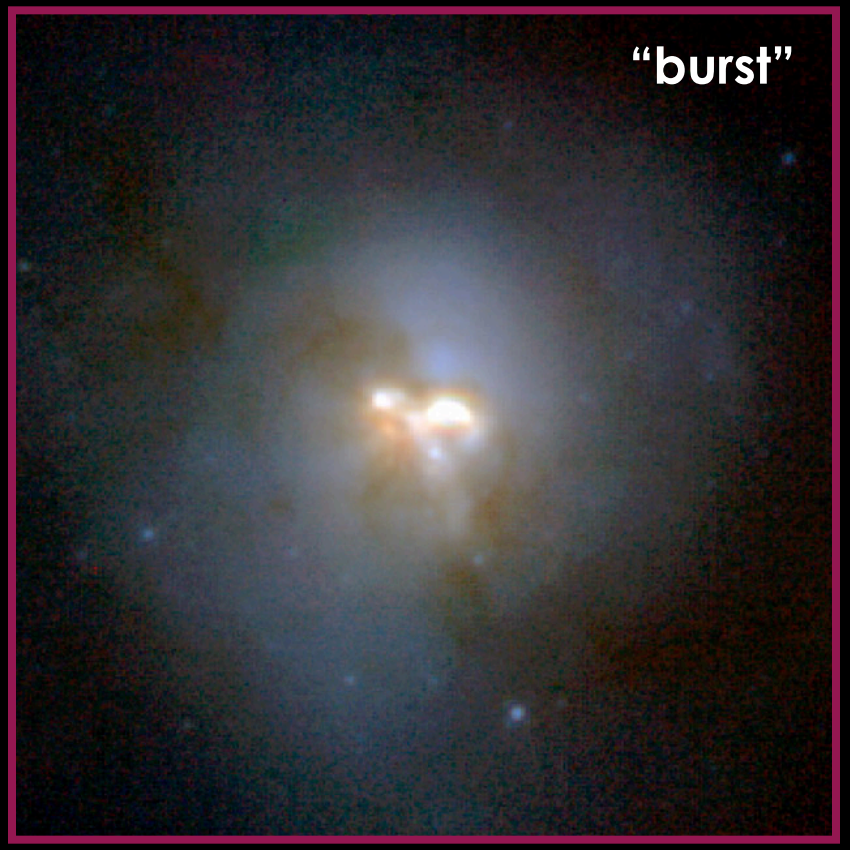

Part 3: Environments of
star-forming galaxies

Two modes of star formation

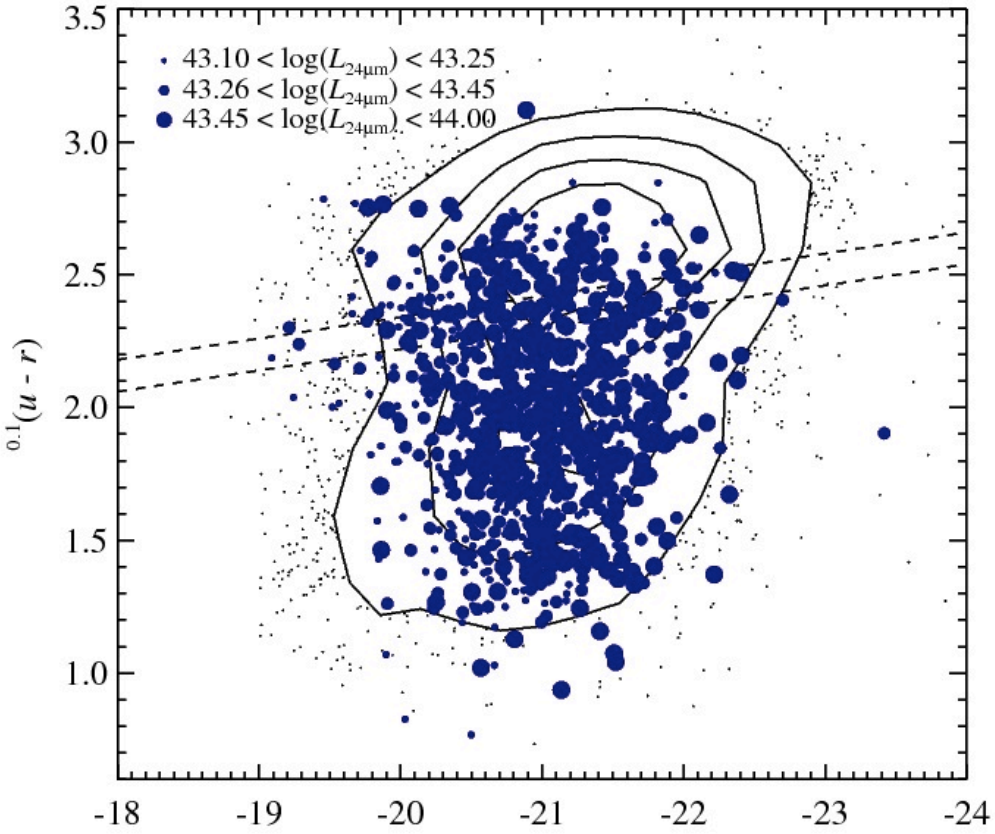


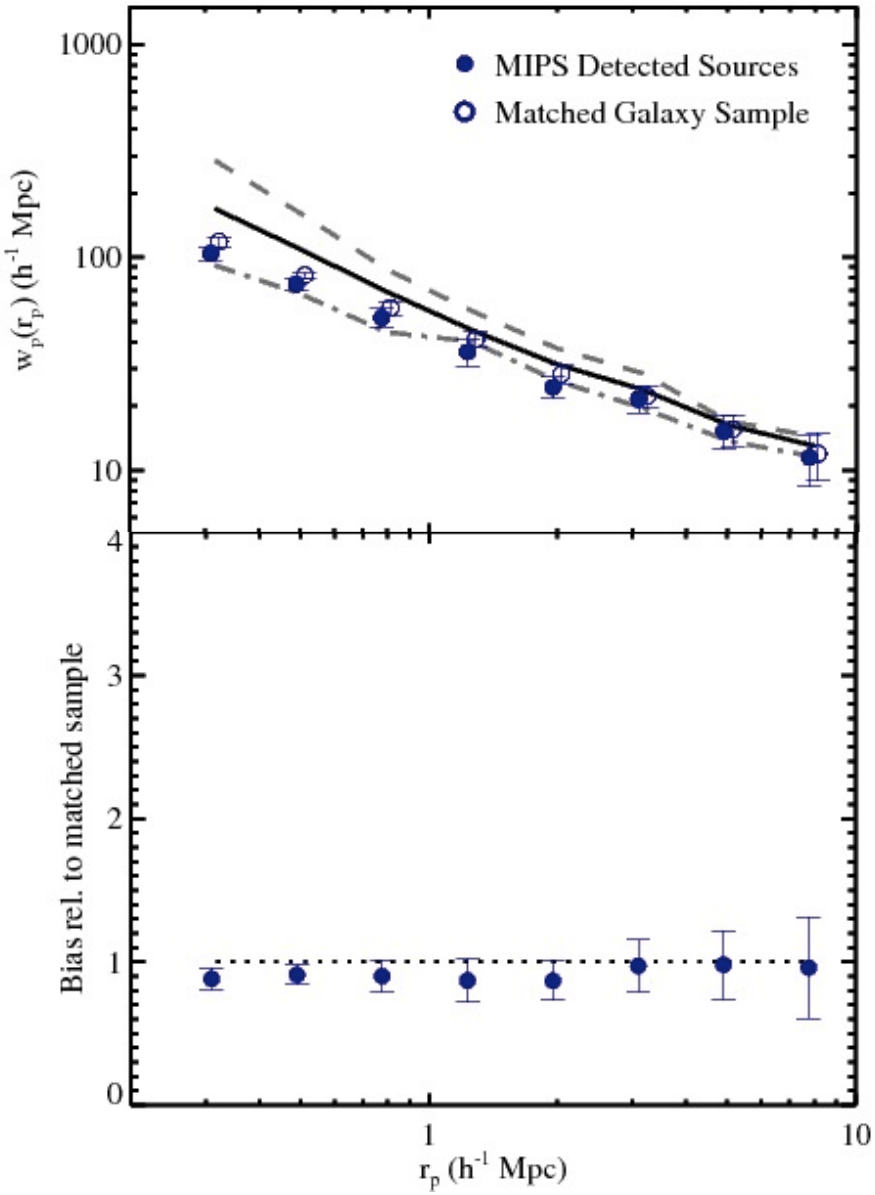
e.g., Elbaz et al. (2010), Peng et al. (2010)

Two modes of star formation



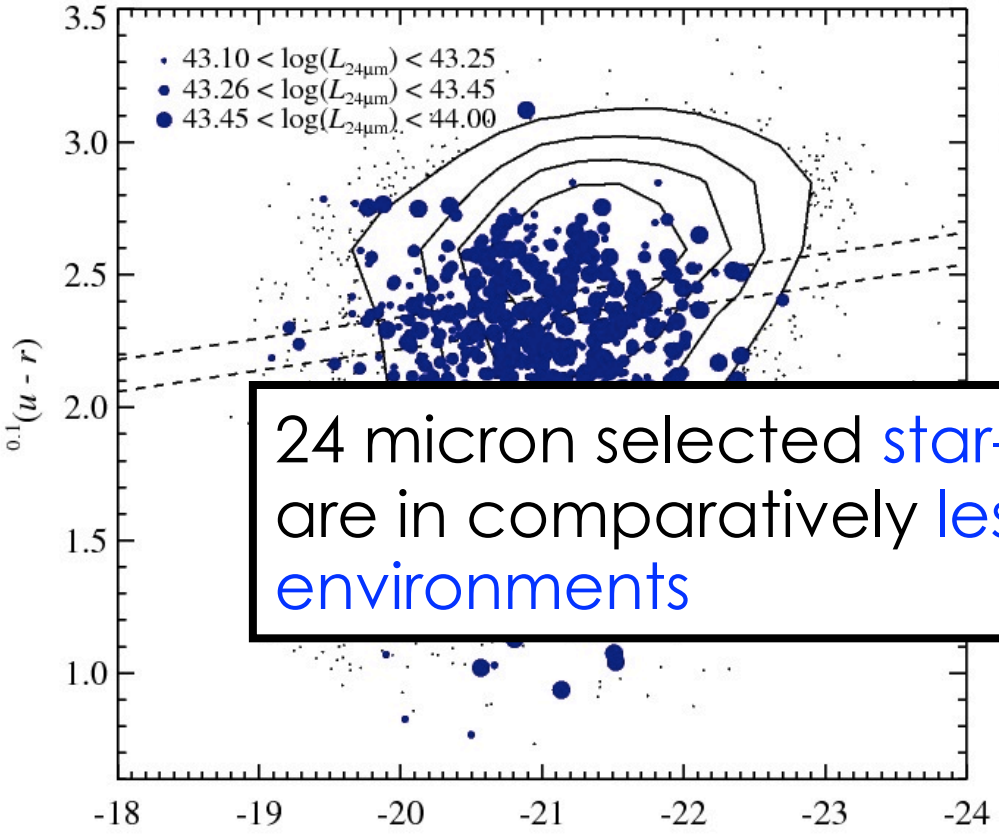
e.g., Elbaz et al. (2010), Peng et al. (2010)

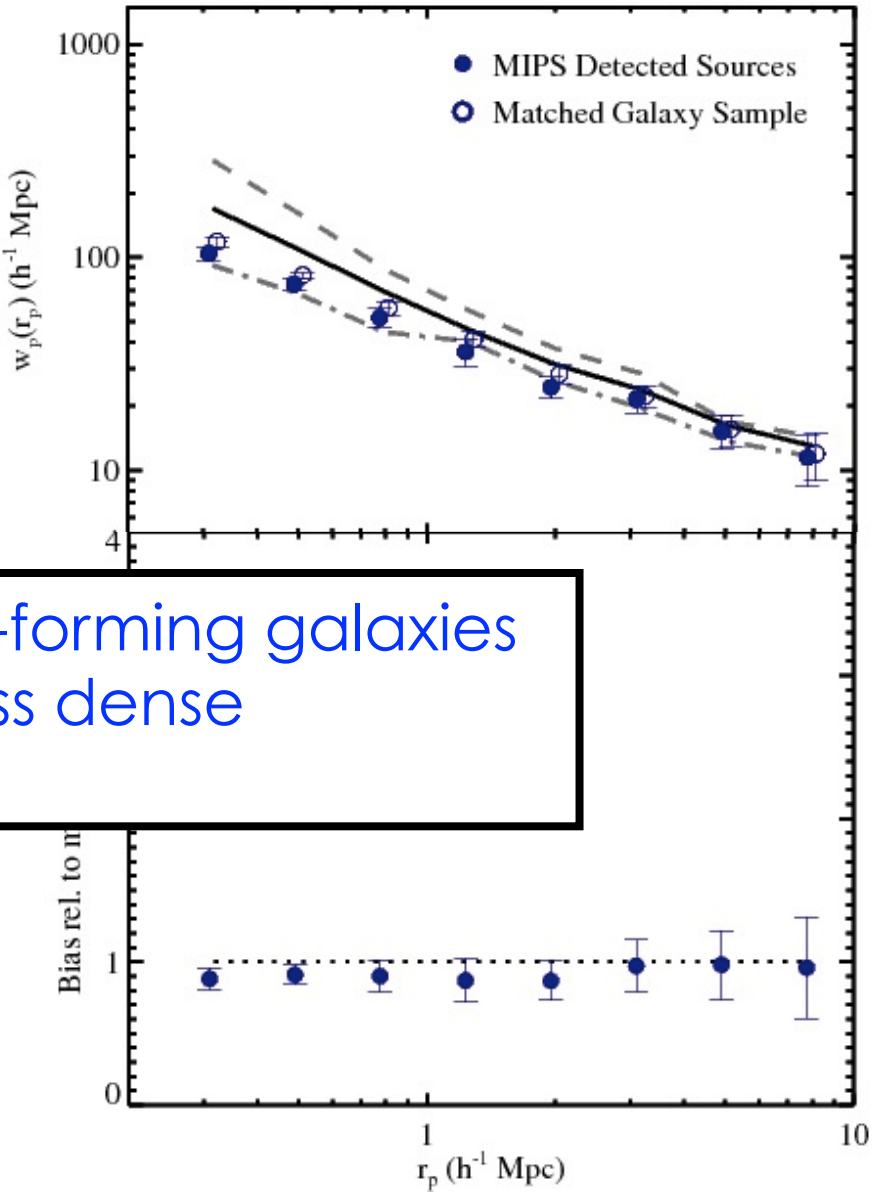




MIPS 24 micron-selected star forming galaxies

(Hickox, Duncan, et al.)



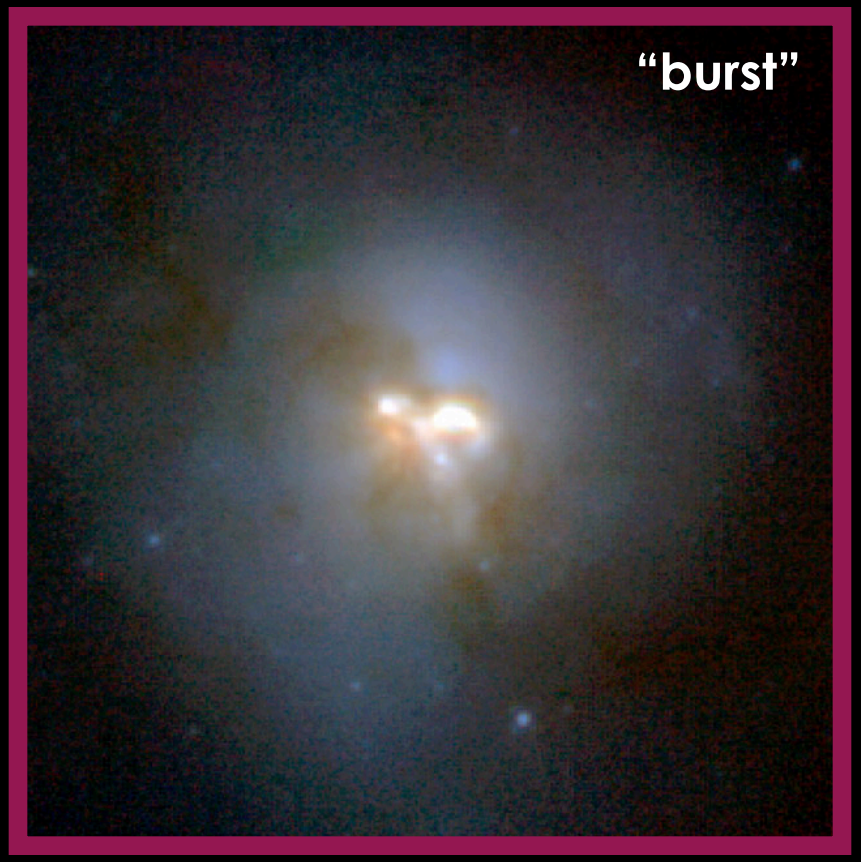


24 micron selected star-forming galaxies are in comparatively less dense environments

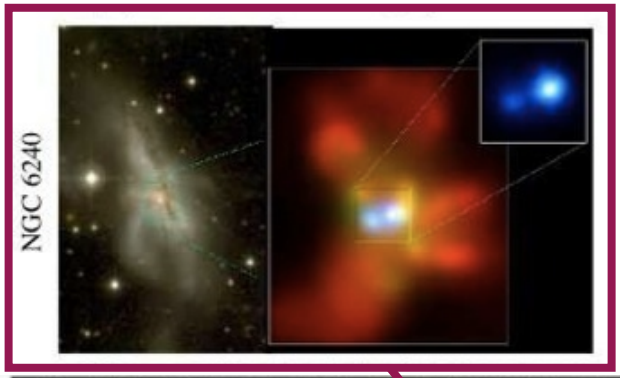
MIPS 24 micron-selected star forming galaxies

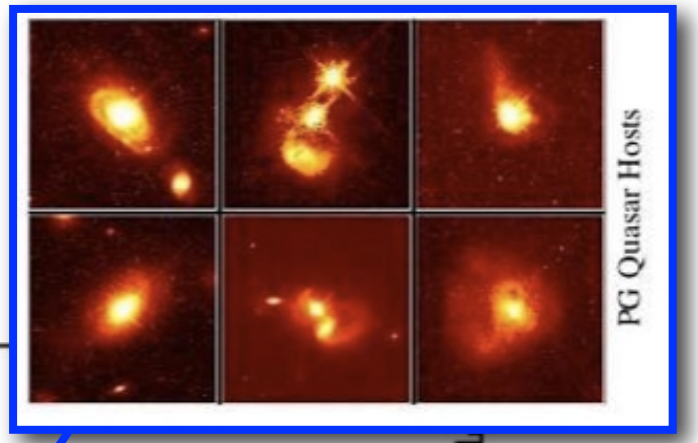
(Hickox, Duncan, et al.)

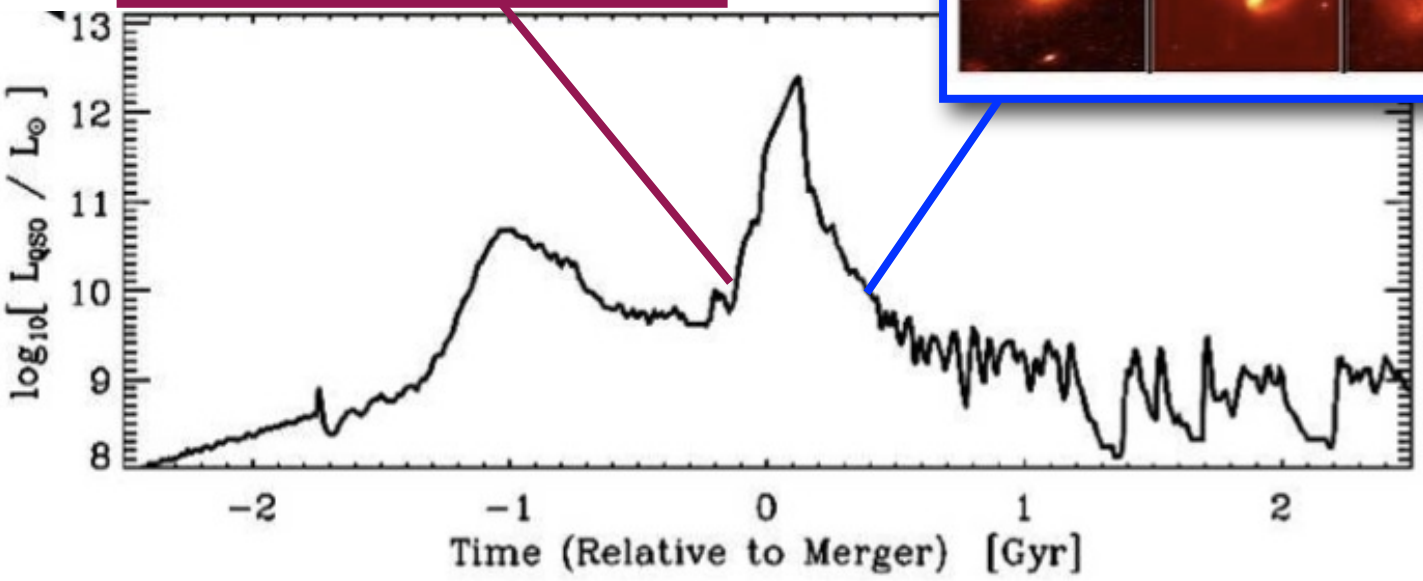
Two modes of star formation



e.g., Elbaz et al. (2010), Peng et al. (2010)





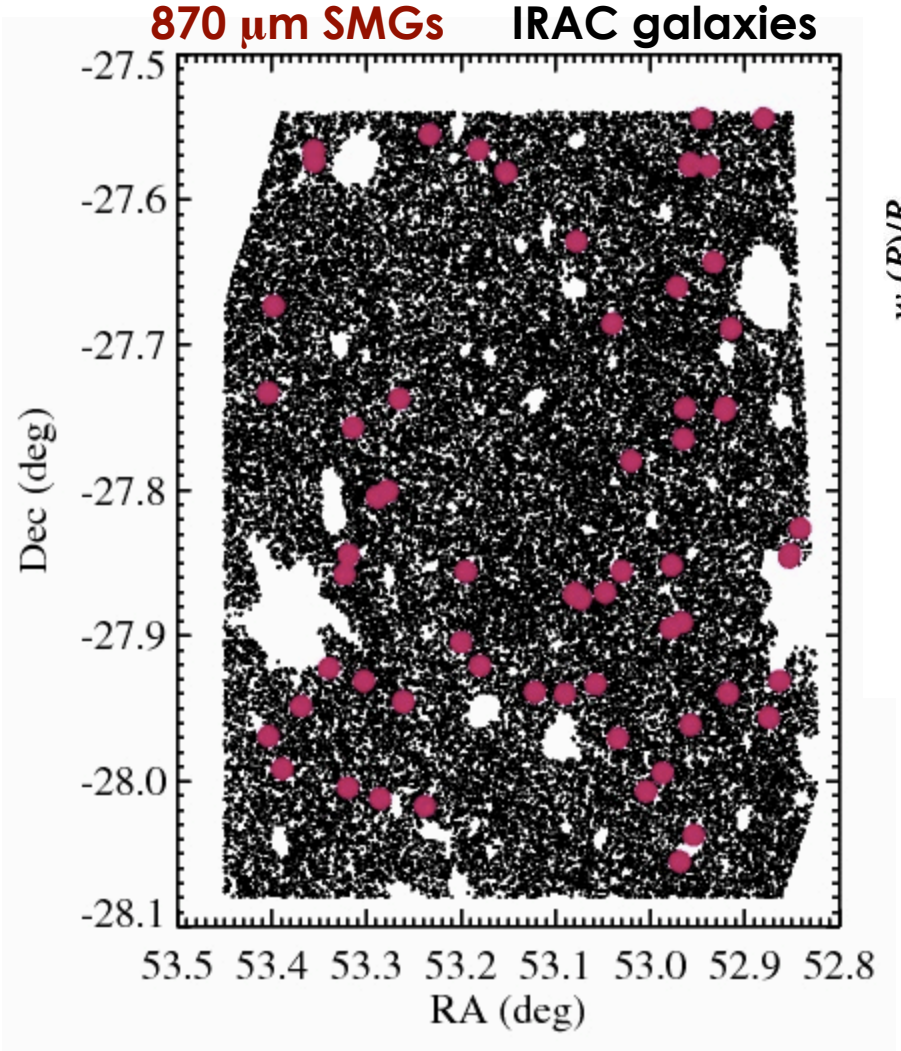


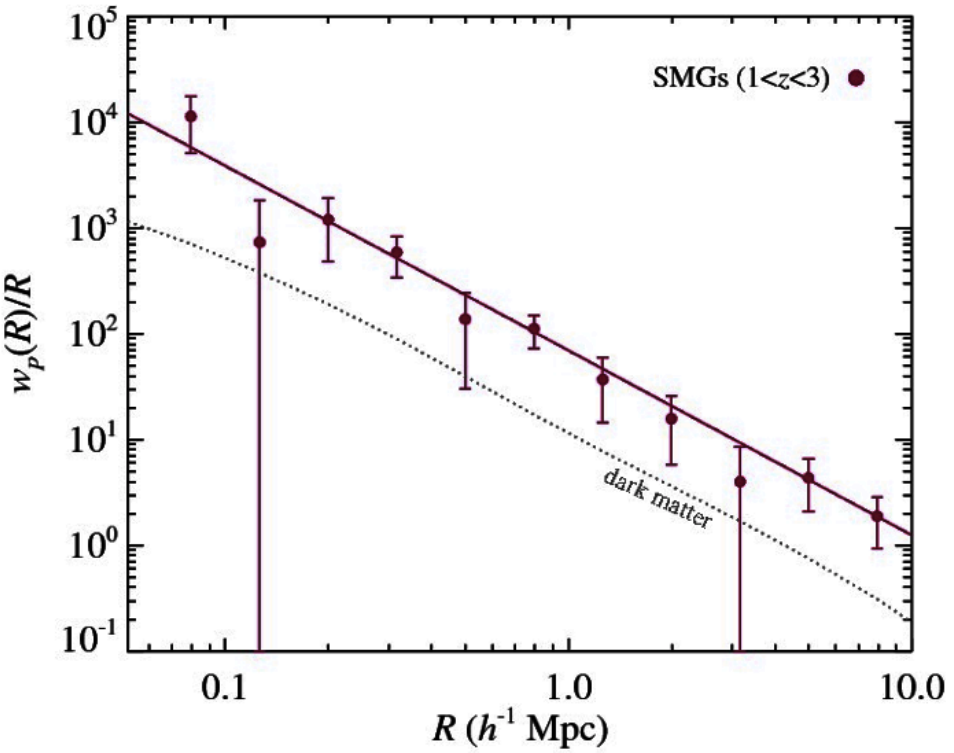
?

Hopkins et al. 2008

SMGs: powerful starbursts

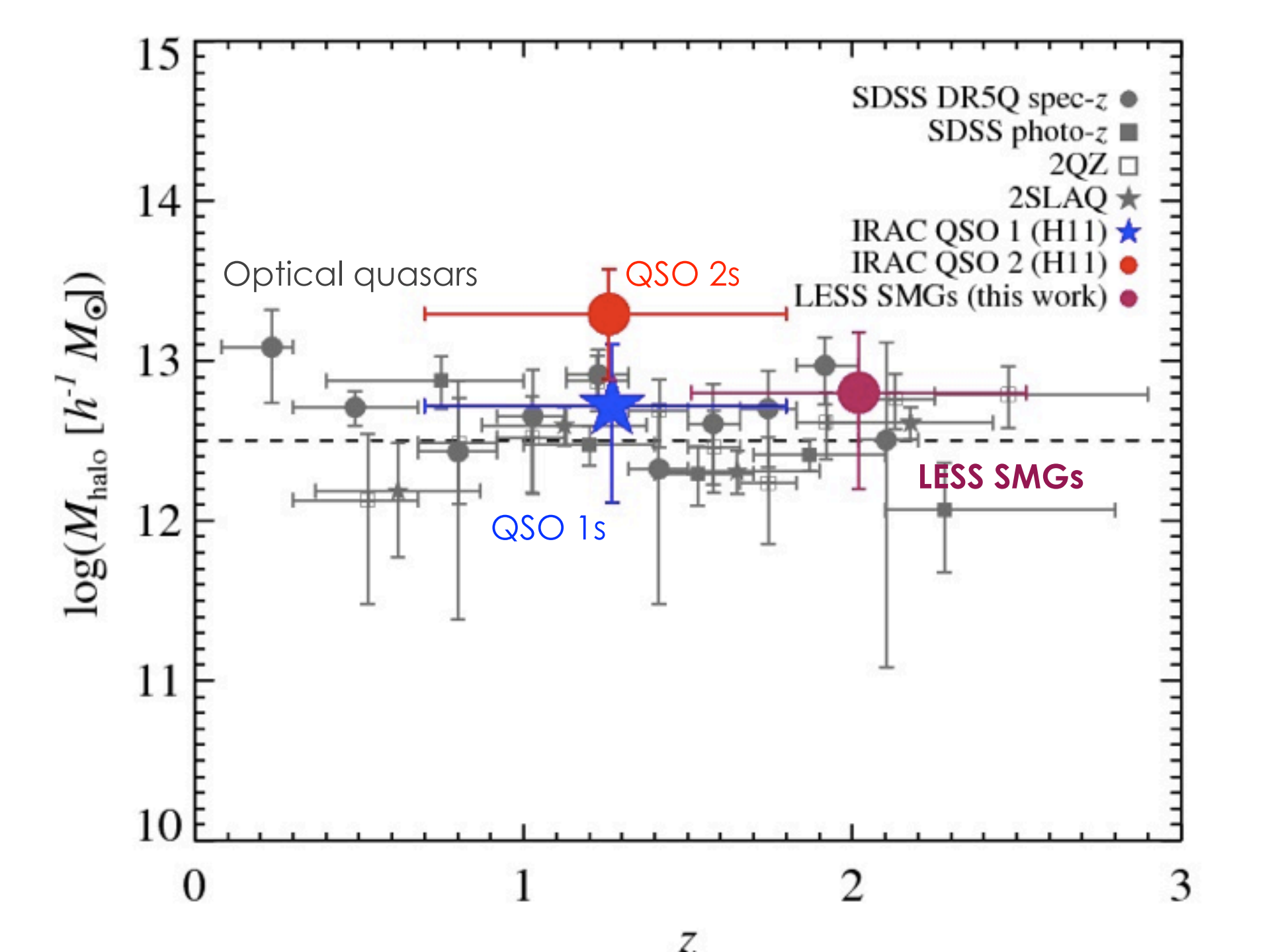
data from LABOCA survey of CDF South

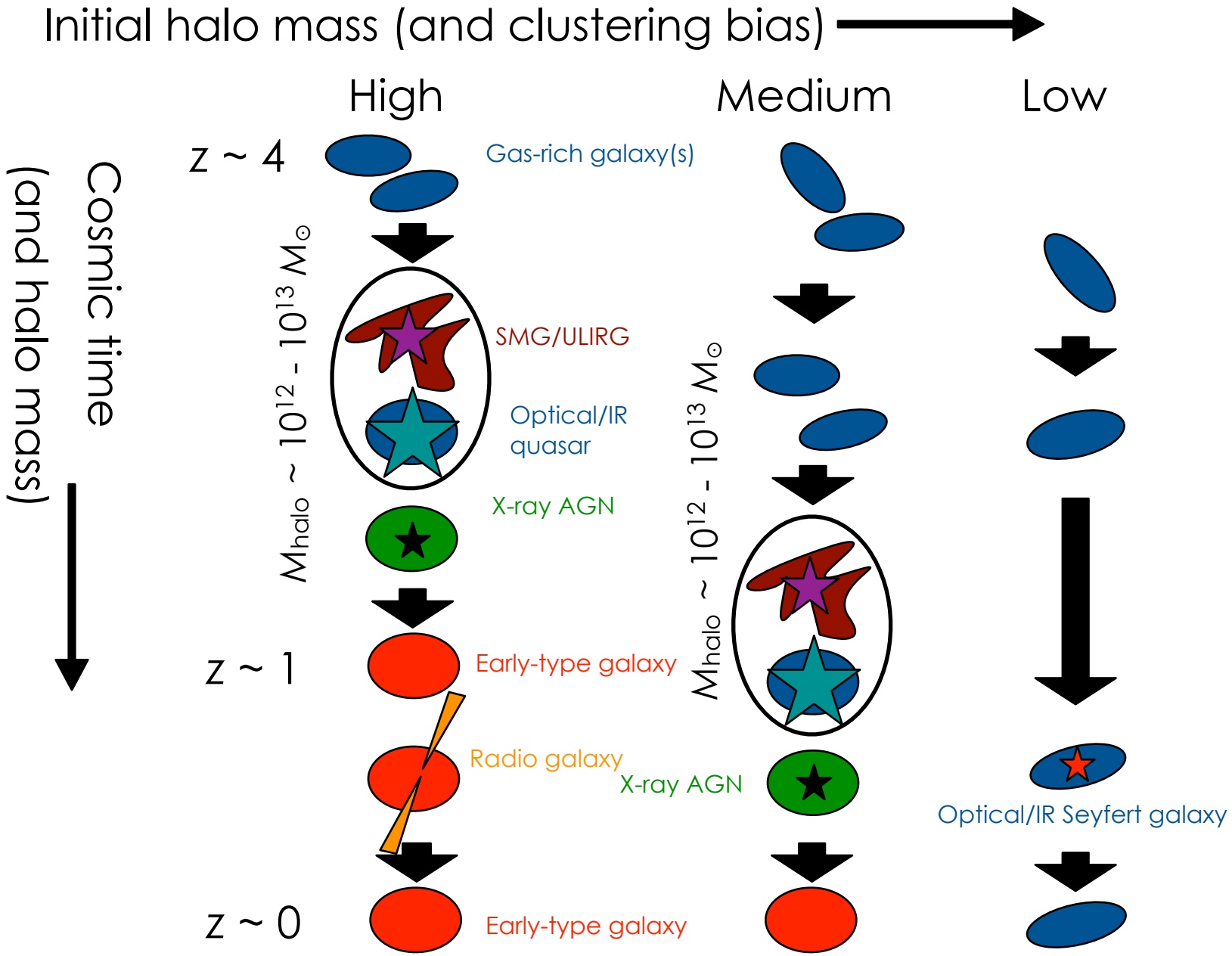


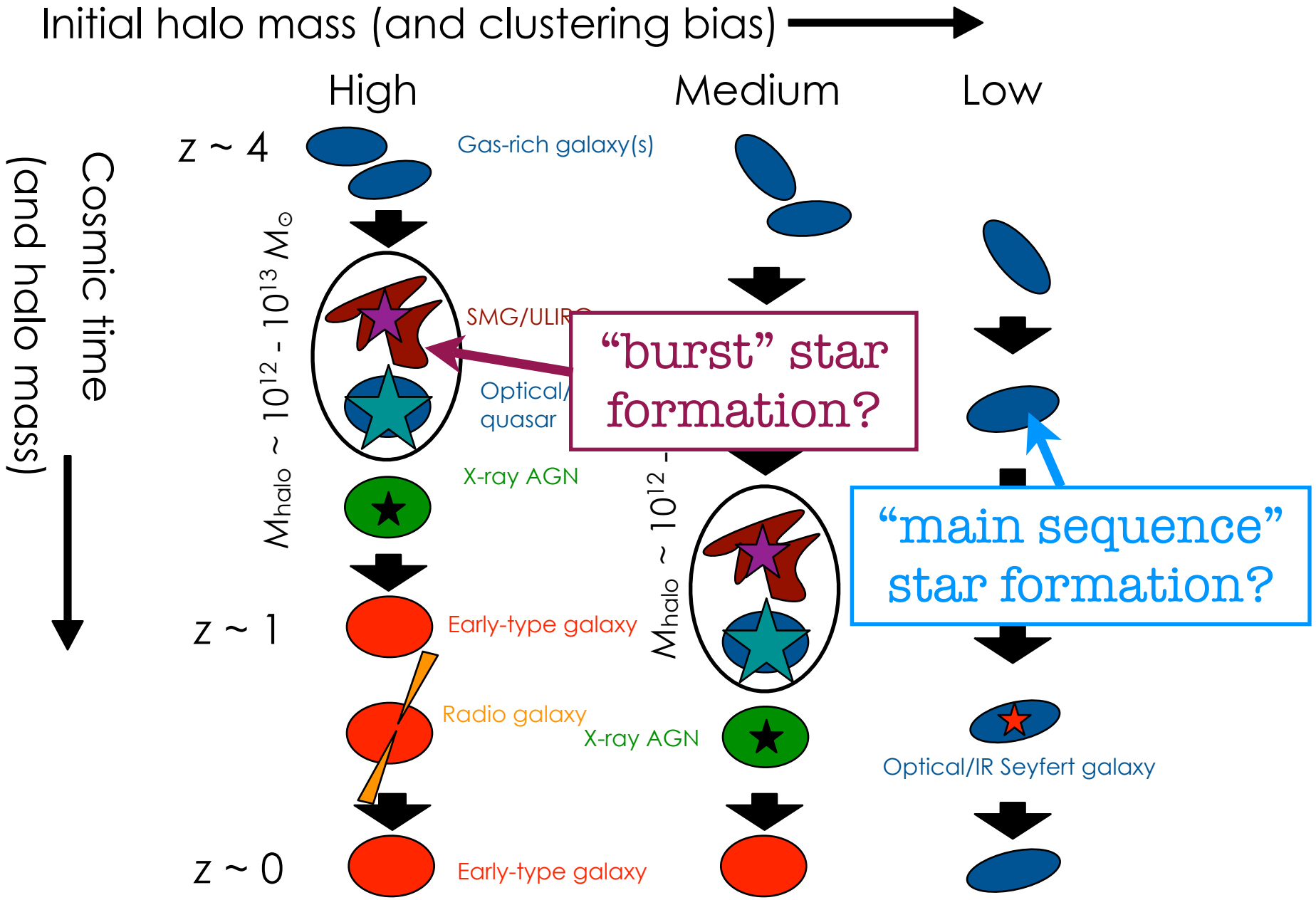


LESS submm galaxies

(Hickox et al. in prep, Wardlow et al. 2011,
see also e.g., Weiss et al. 2009, Blain et al. 2004)


SDSS DR5Q spec-z
SDSS photo-z
2QZ
2SLAQ
IRAC QSO 1 (H11)
IRAC QSO 2 (H11)
LESS SMGs (this work)
Optical quasars
QSO 2s
QSO 1s
LESS SMGs
log(M_halo [h^-1 M_⊙])
z
15
14
13
12
11
10
0
1
2
3


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


Initial halo mass (and clustering bias)
High
Medium
Low
Cosmic time (and halo mass)
z ~ 4
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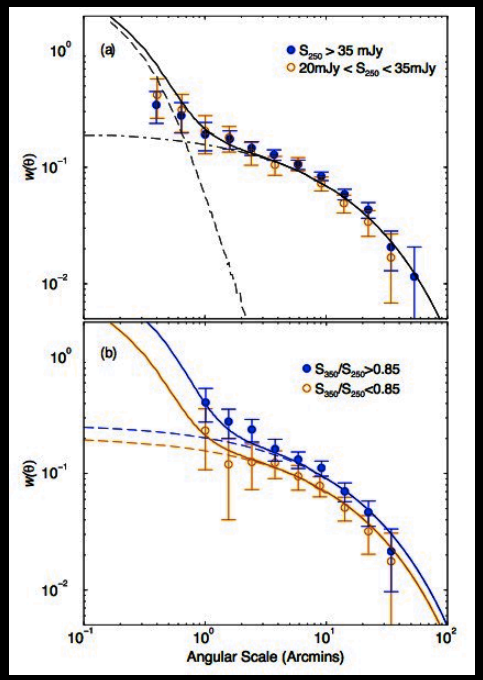
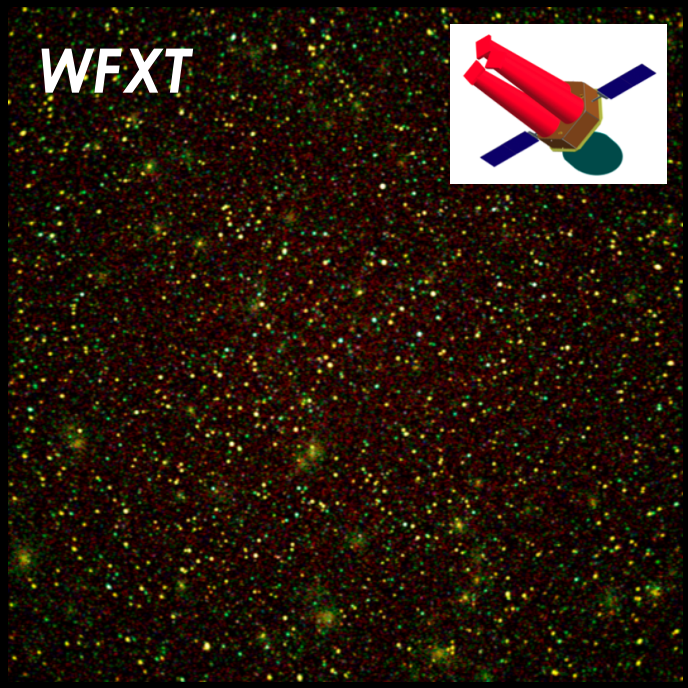
Gas-rich galaxy(s)
SMG/ULIRG
Optical/ quasar
X-ray AGN
Early-type galaxy
Radio galaxy
X-ray AGN
Early-type galaxy
Optical/IR Seyfert galaxy
Mhalo ~ 10^12 - 10^13 M⊙
Mhalo ~ 10^12 -
"burst" star formation?
"main sequence" star formation?

The future



Cooray et al (2010)



Simulated 1 deg^2 WFXT image