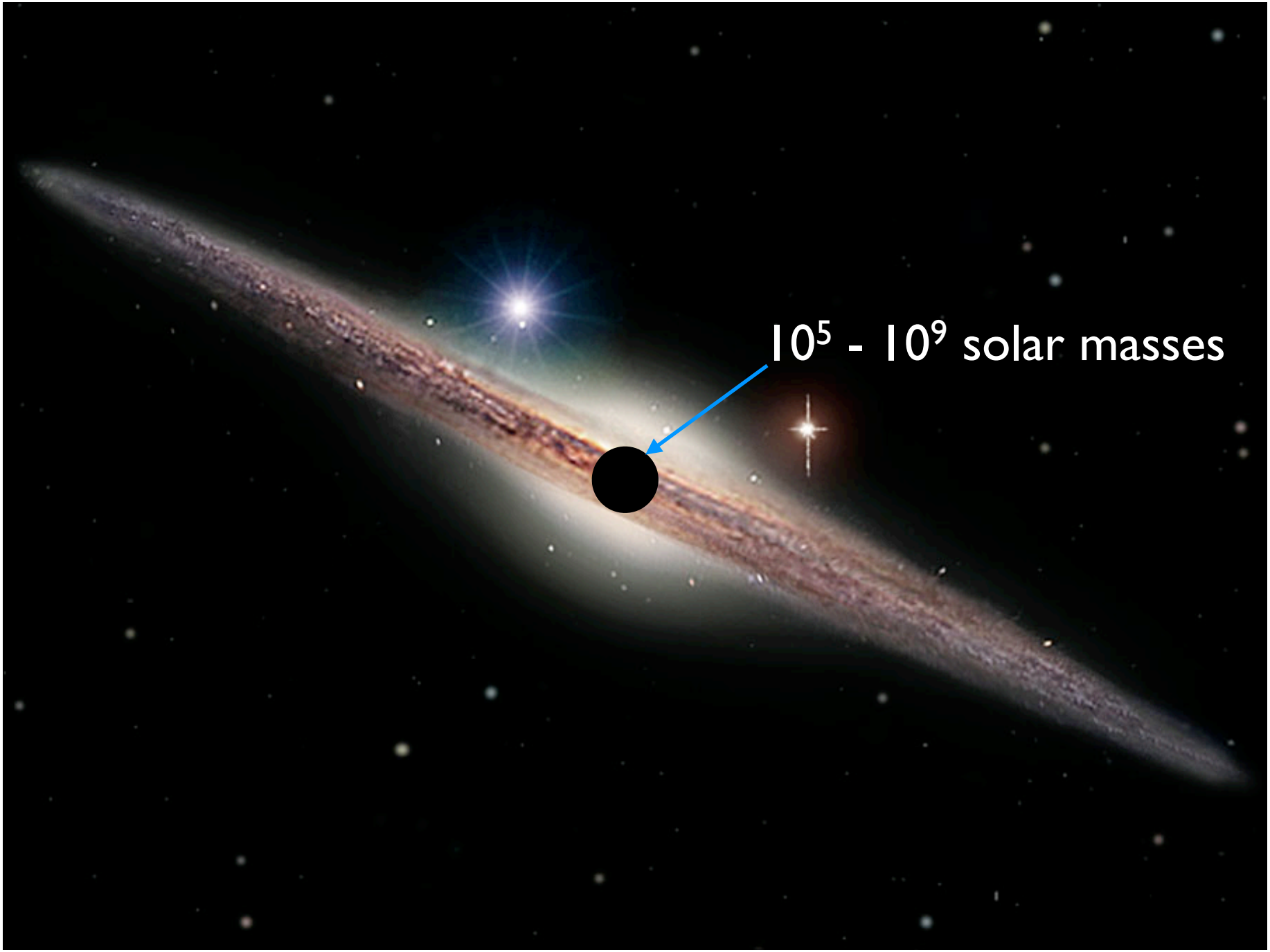
Durham University

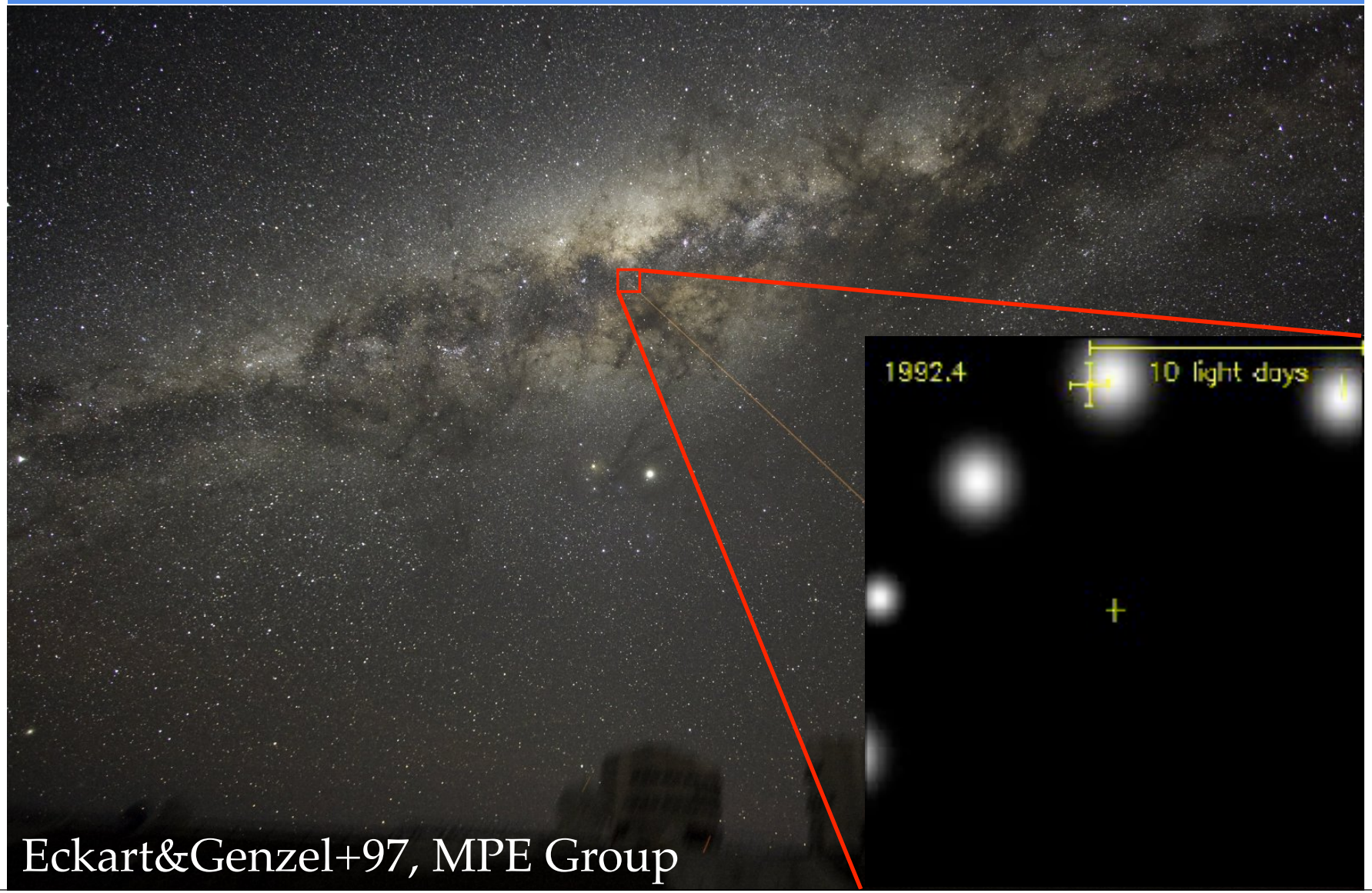
The Leverhulme Trust

The coevolution of black holes and galaxies over the last 11billion years

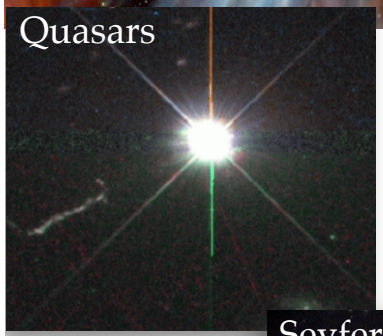
James Mullaney
Durham University


10^5 - 10^9 solar masses

Massive BHs in the centres of galaxies are ubiquitous

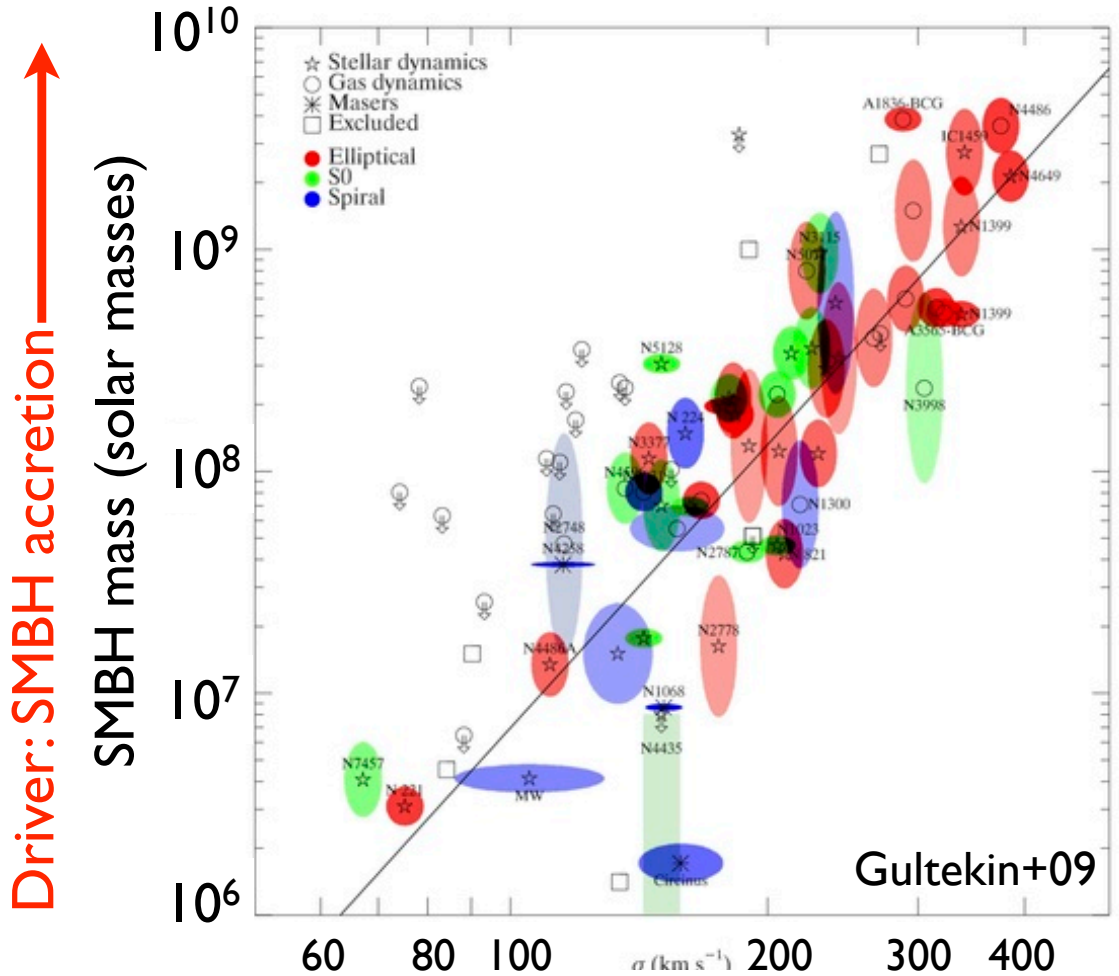


Growing BHs

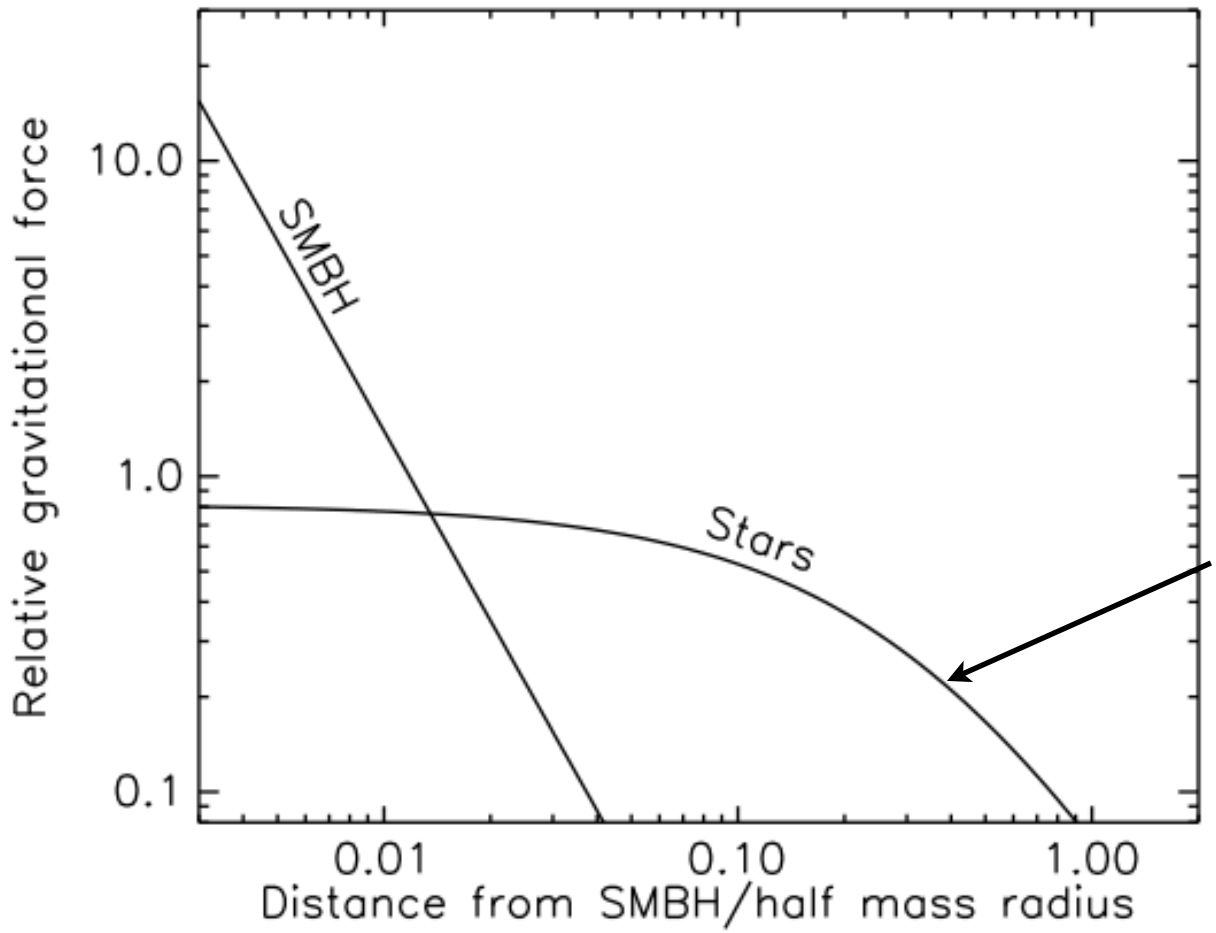


- These BHs predominantly grow via accretion - witnessed as AGN. (Mergers don't affect total mass in BHs).
- All massive galaxies have experienced a period of nuclear activity (AGN) (Soltan, `82).

Throughout:
$L_X < 10^{44}$ erg/s = 'Seyferts'
$L_X > 10^{44}$ erg/s = 'Quasars'



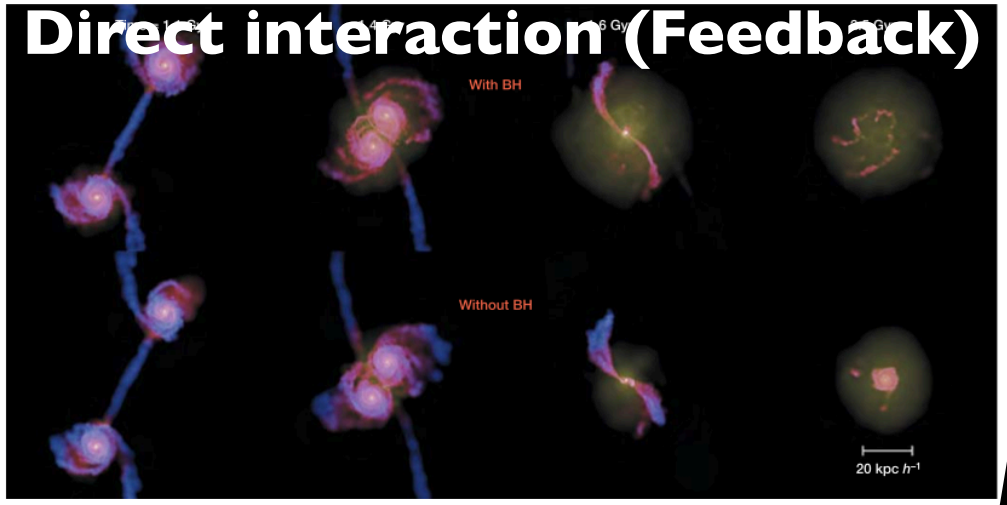
(also, Magorrian+98, Gebhardt+00, McLure+02, Marconi+Hunt 03, Haring+Rix 04, Gultekin+09, Kormendy+11, Bennert+11, etc)



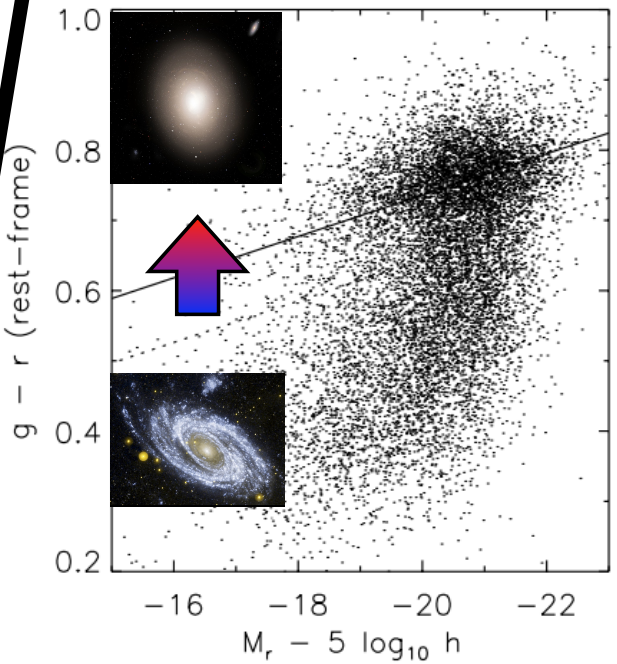
from Hernquist 90 stellar density profile

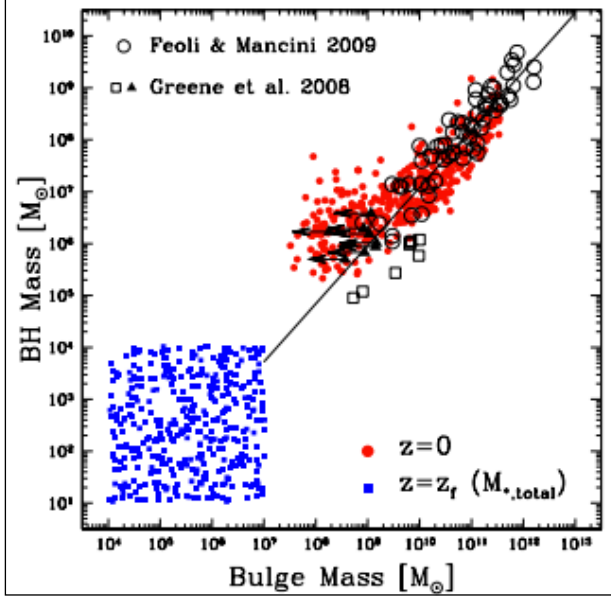
In terms of gravity, SMBH and galaxy are ignorant of each other!

Explanations???



e.g., Silk & Rees 98, King+, Springel+05, Di Matteo+06, Hopkins+, (Sanders+88)





No interaction.

'Central limit theorem'

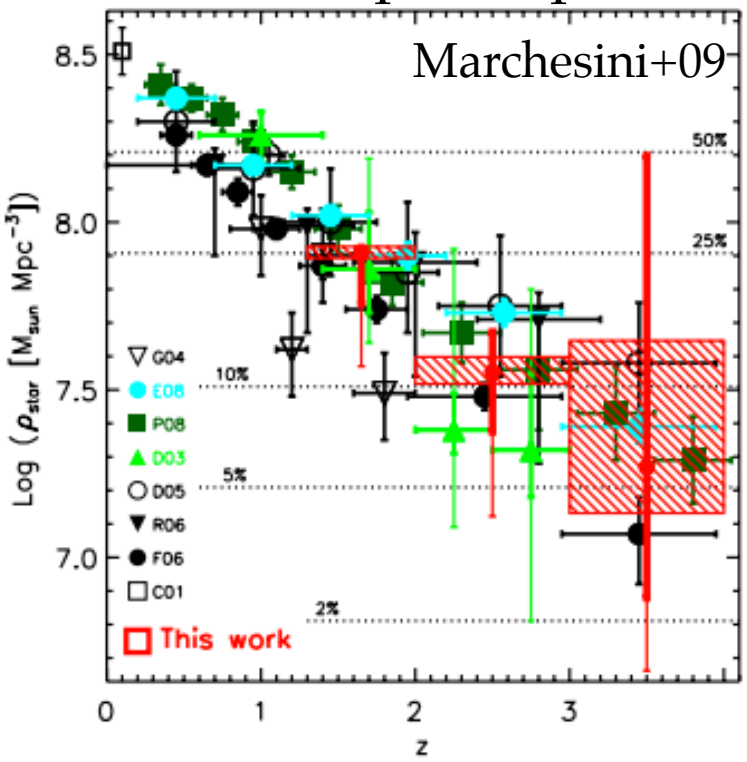
e.g., Peng+07, Jahnke+11

...or common fuel supply

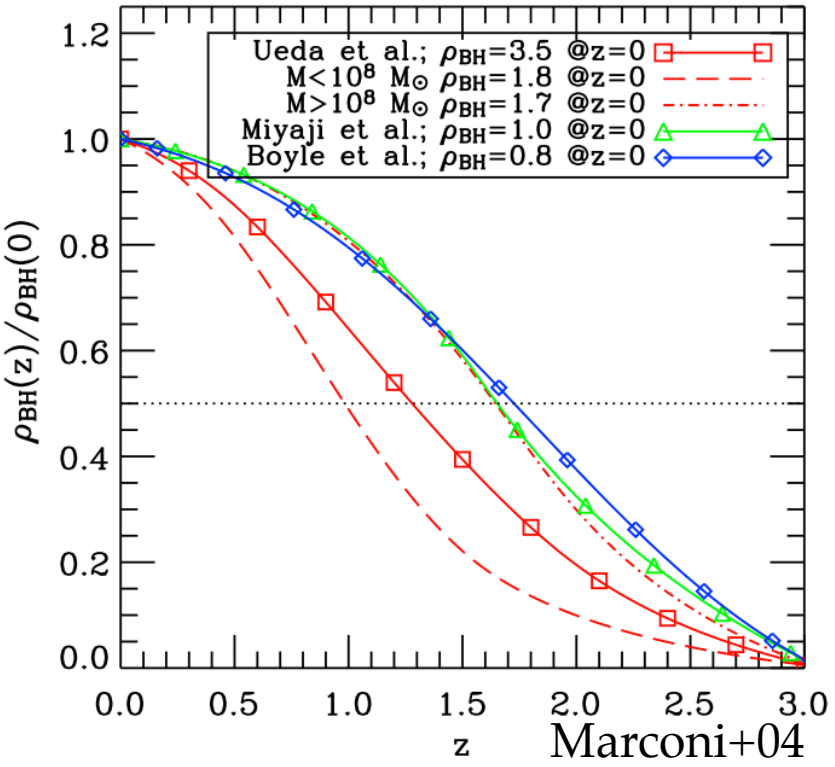
...etc, etc

When galaxies and SMBHs grew

When today's stellar mass was put in place:

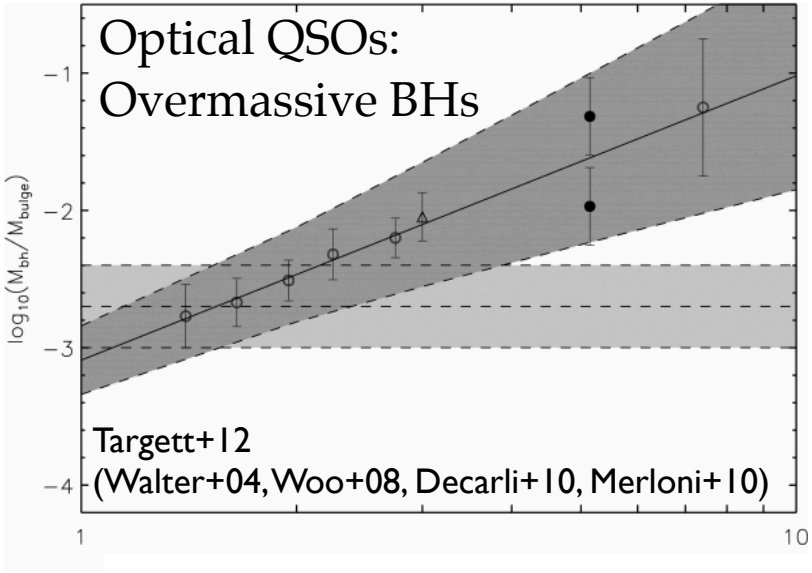


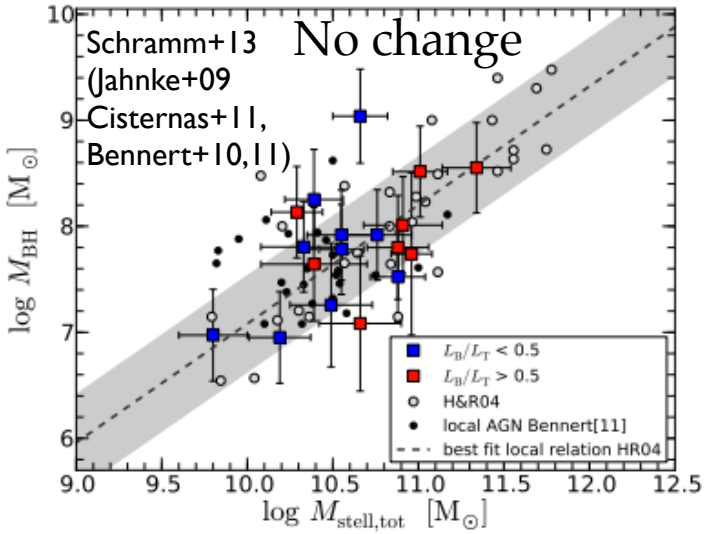
When today's SMBH mass was put in place:



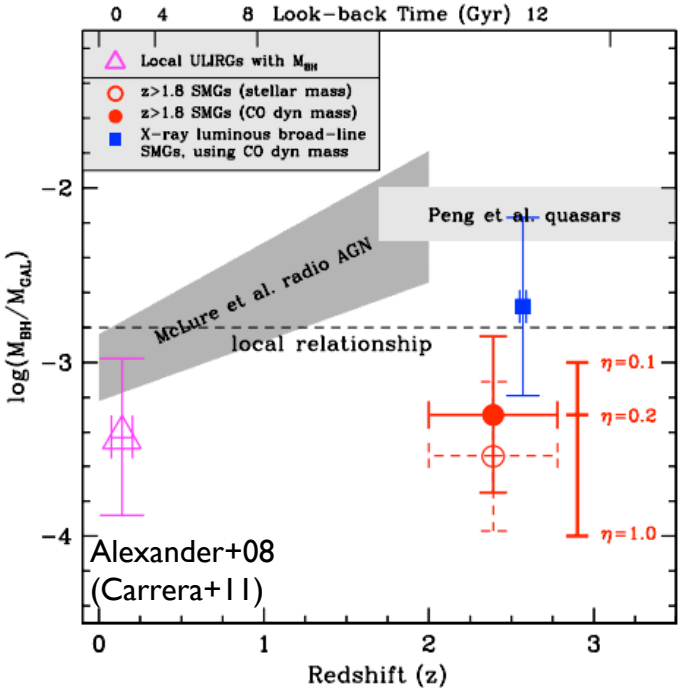
Majority of stellar and BH mass put in place at 0.5<z<3

M_{BH}-M_{Bulge} at high-z



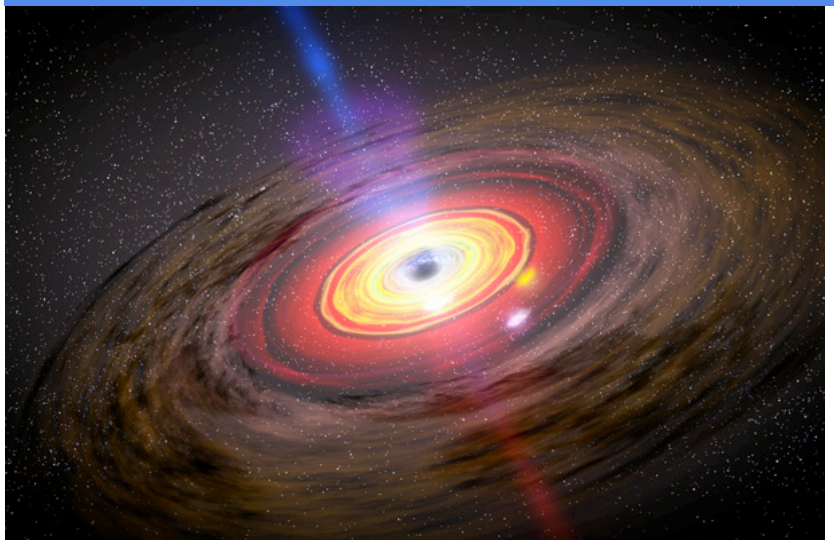


Strongly SFing galaxies (SMGs):
Undermassive BHs



- ...or selection effects?
  (e.g., Shen & Kelly 10, Volonteri & Stark 11)

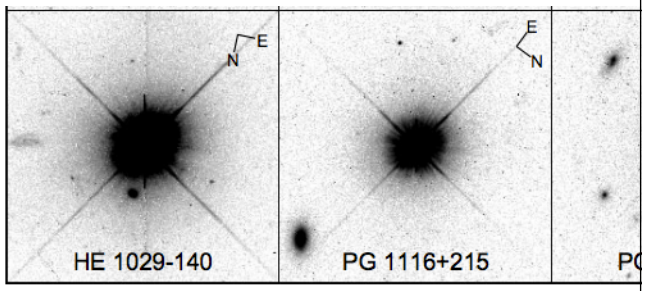
The growth of BHs and galaxies



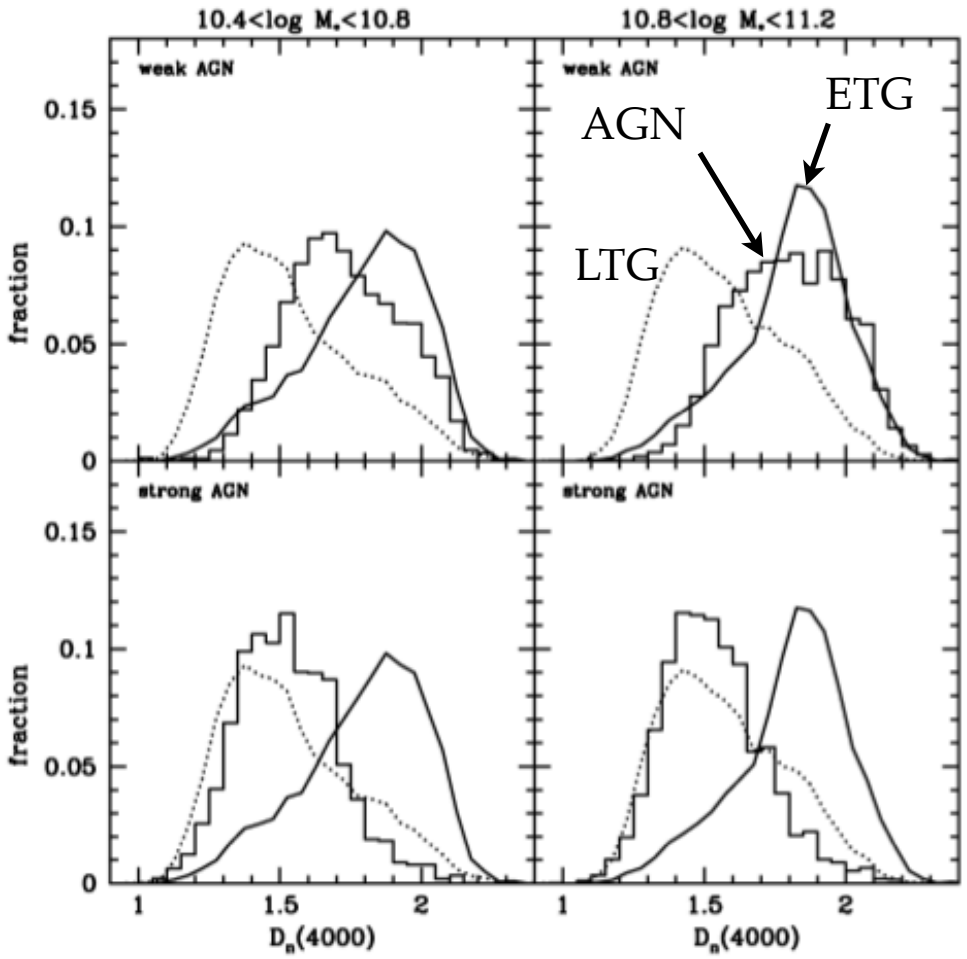
What is the connection between black hole and galaxy *growth*?

Where do AGN live?

- Early studies, small samples, nearby (z<0.3) AGN:
  - Quasar hosts: Mostly dead ellipticals (e.g., Bahcalls+97, McLure+99, 00)
  - Seyferts in galaxies showing younger stellar populations (e.g. Schmitt+99, Heckman+01, Cid-Fernandes+01)
  - Weaker AGNs (LINERS) in early type galaxies with older populations. (e.g., Heckman+80, Ho+03)



Star-formation in AGN hosts



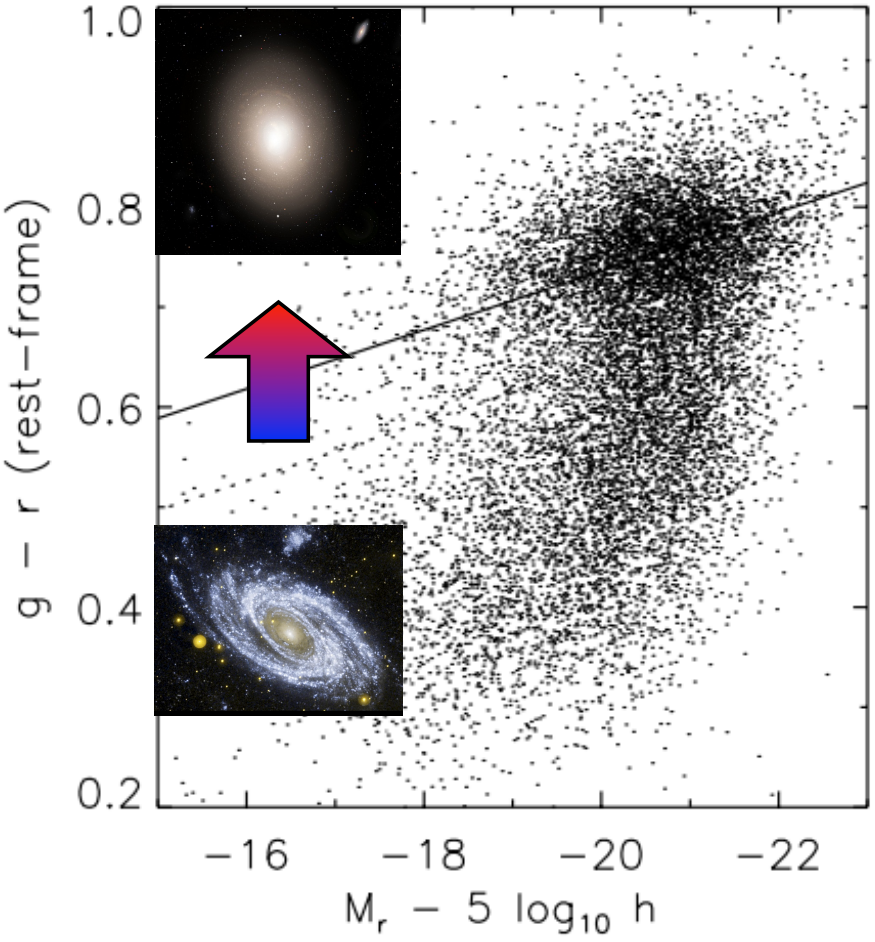
Kauffmann+03

SDSS: 22,623 optically selected AGN.

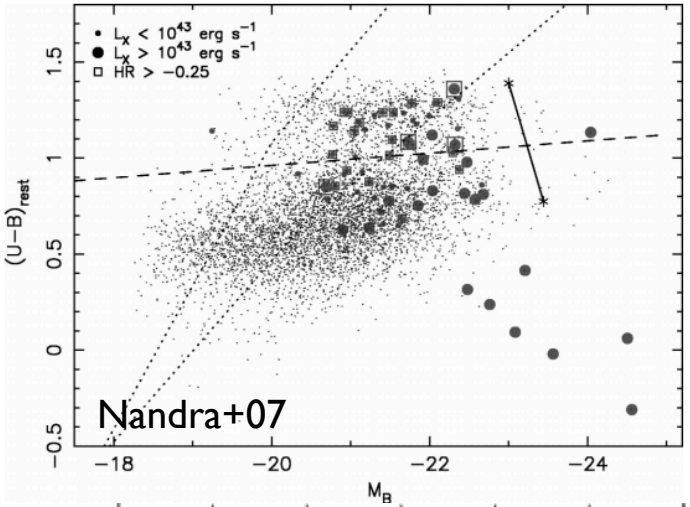
- Local (z<0.3), powerful AGNs live in massive (>10^{10}M), late type galaxies.
- Galaxies with low mean stellar ages (recent/ ongoing star-formation)

Here, "strong": L_X>~10^{42} ergs/s

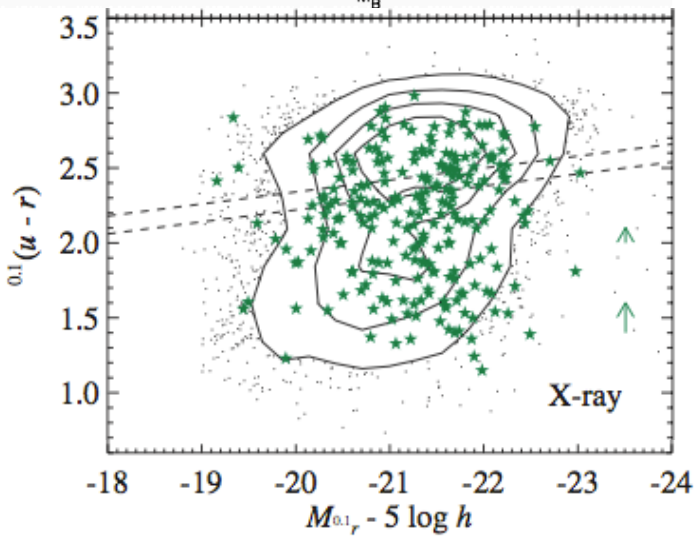
Star-formation in AGN hosts

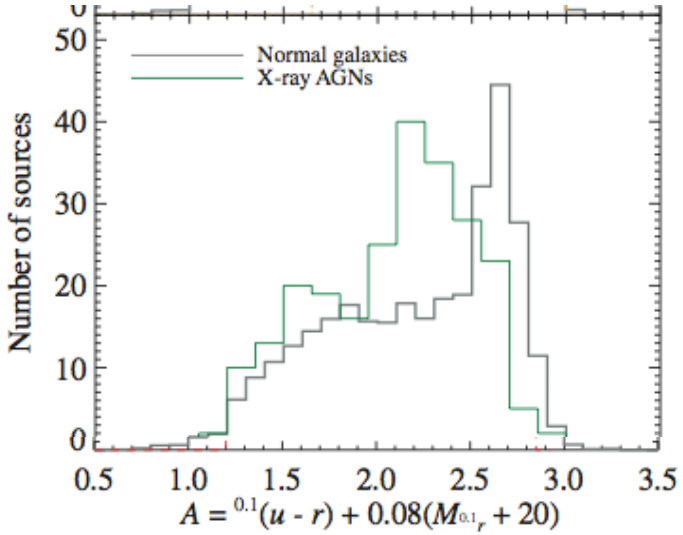


Star-formation in AGN hosts



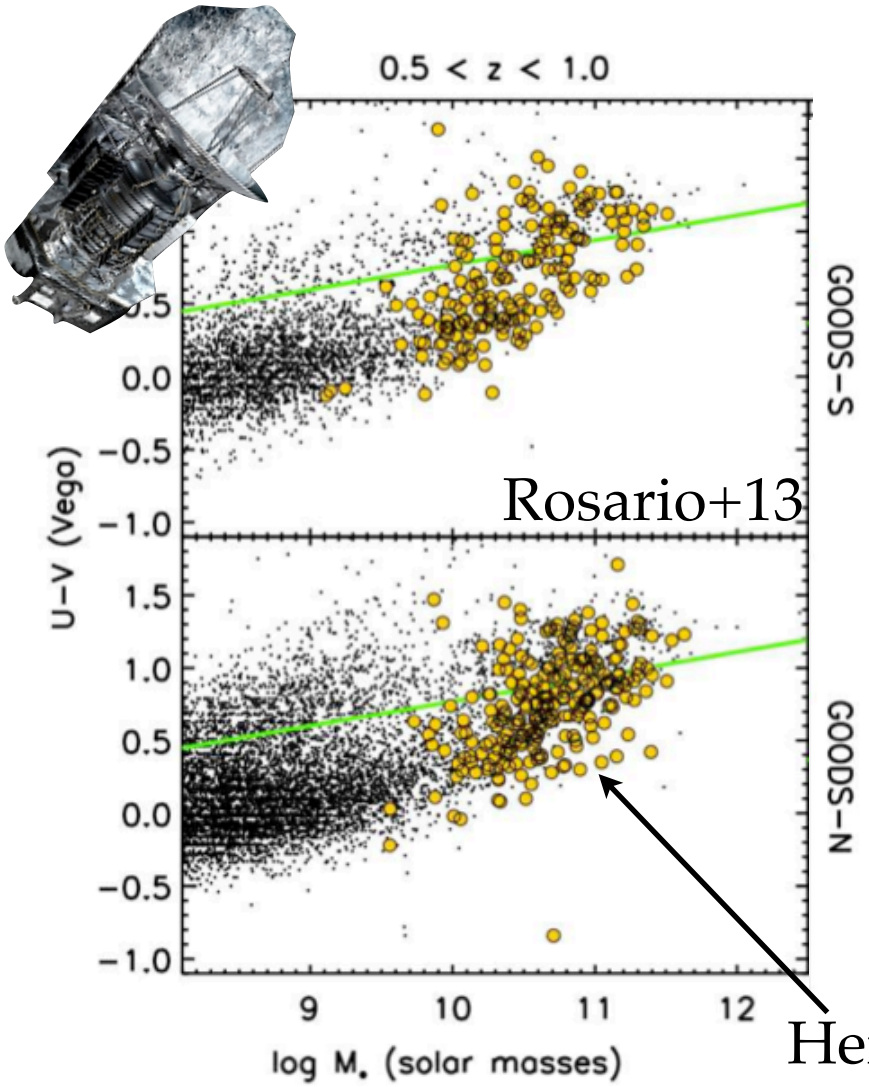
- Low/moderate redshift X-ray AGNs peak in 'green valley'
  ➡AGN quenching?
  (e.g., Nandra+07, Schawinski+07, Hickox+09)





Confirmation of models predicting shutting off star-formation?

Star-formation in the 'green valley'



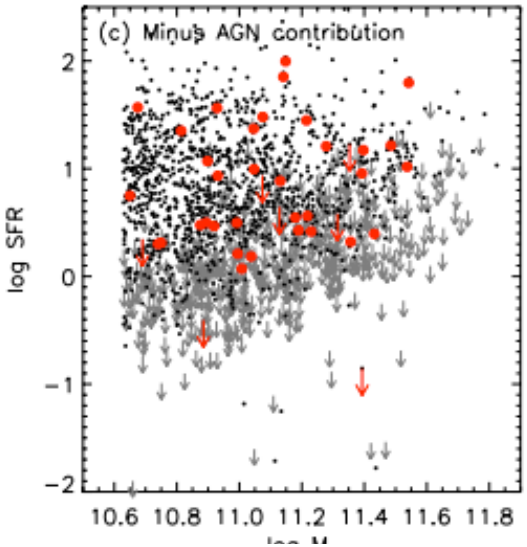
- Dust-reddened, strongly SF galaxies known to populate red sequence.
  (e.g., Cimatti+98, Smail+99)
- Galaxies across the Red sequence/Green Valley/Blue cloud divide are IR emitters
  ➡Star-forming

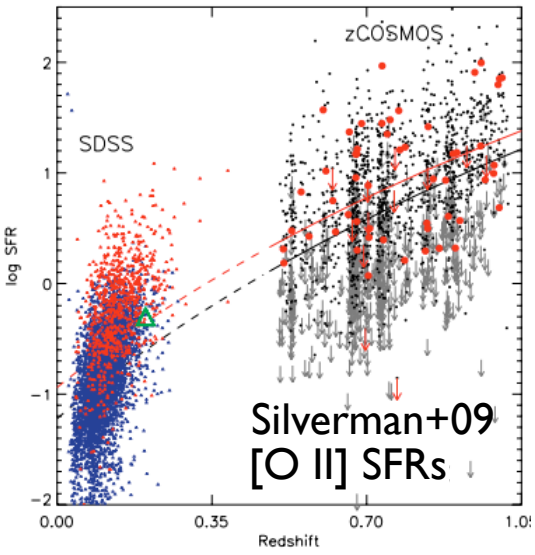
More direct SF indicators

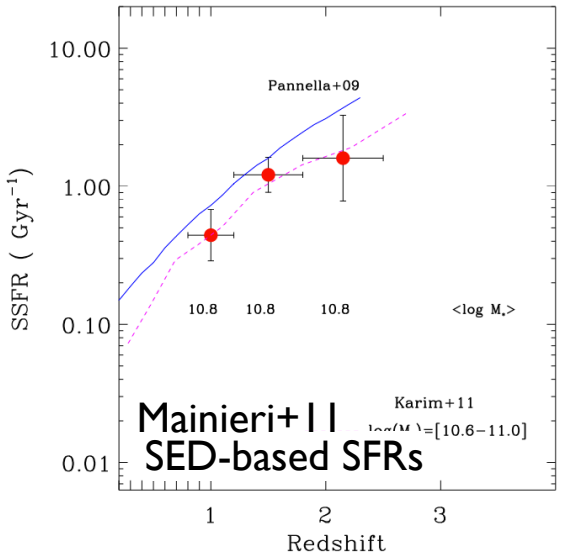
For ~moderate luminosity AGN:

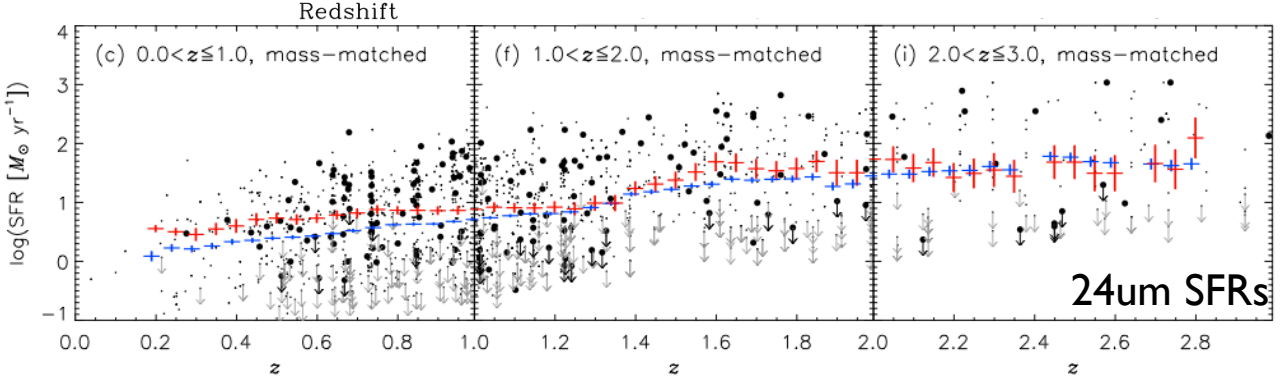
Pre-Herschel:

- Signs to the contrary.
- AGNs live in star-forming galaxies out to high redshifts (z~3).

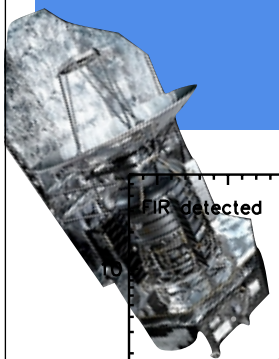


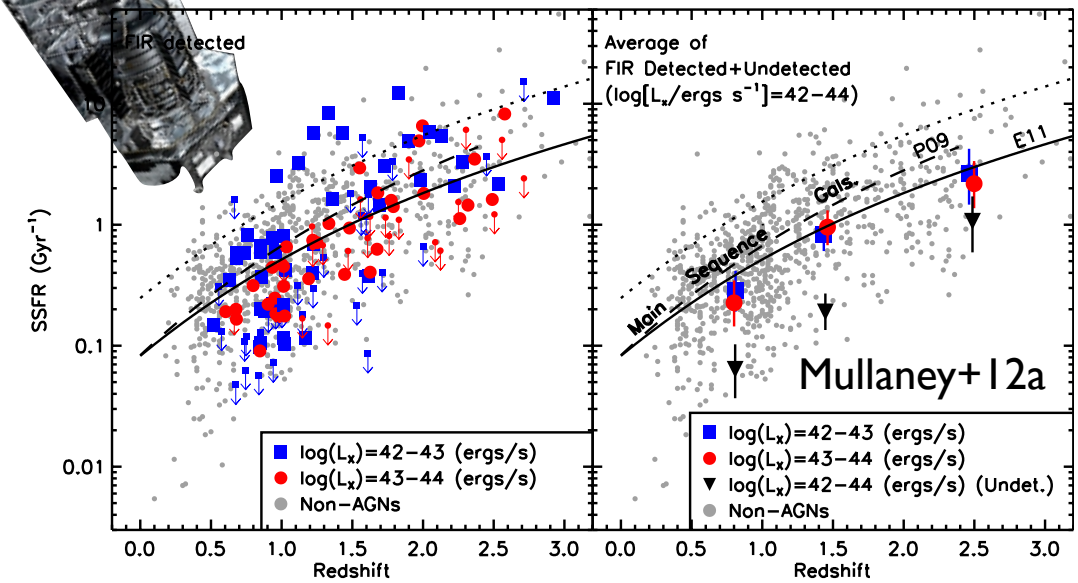




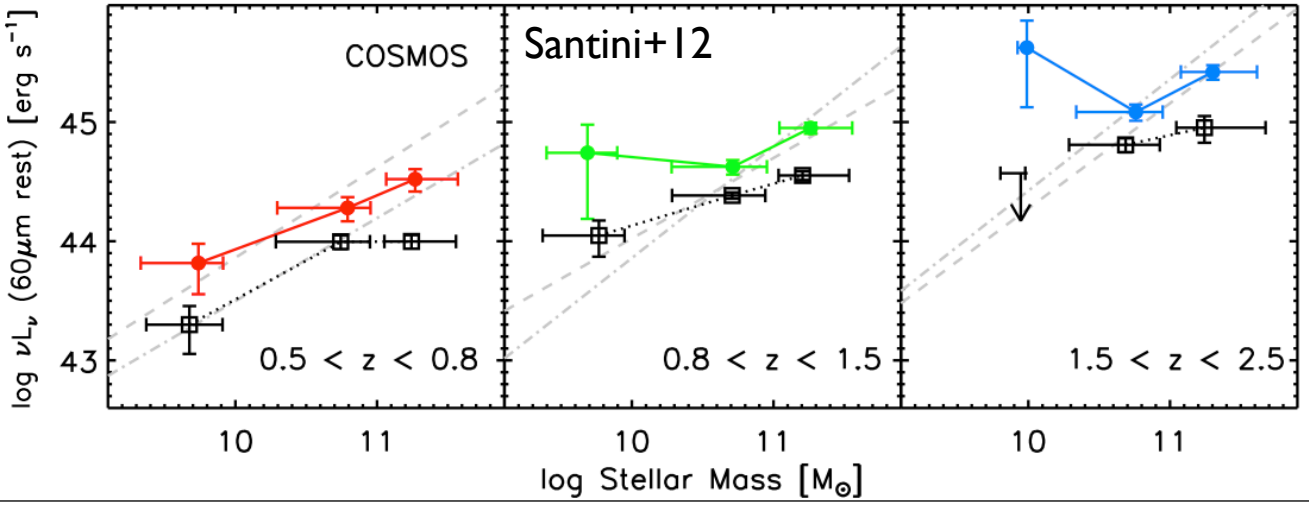


Far-IR SFR indicators





Confirmed by Herschel.
~80% of Seyferts are in typical SFing galaxies.
~10-15% in 'quiescent'
<10% in 'starburts'

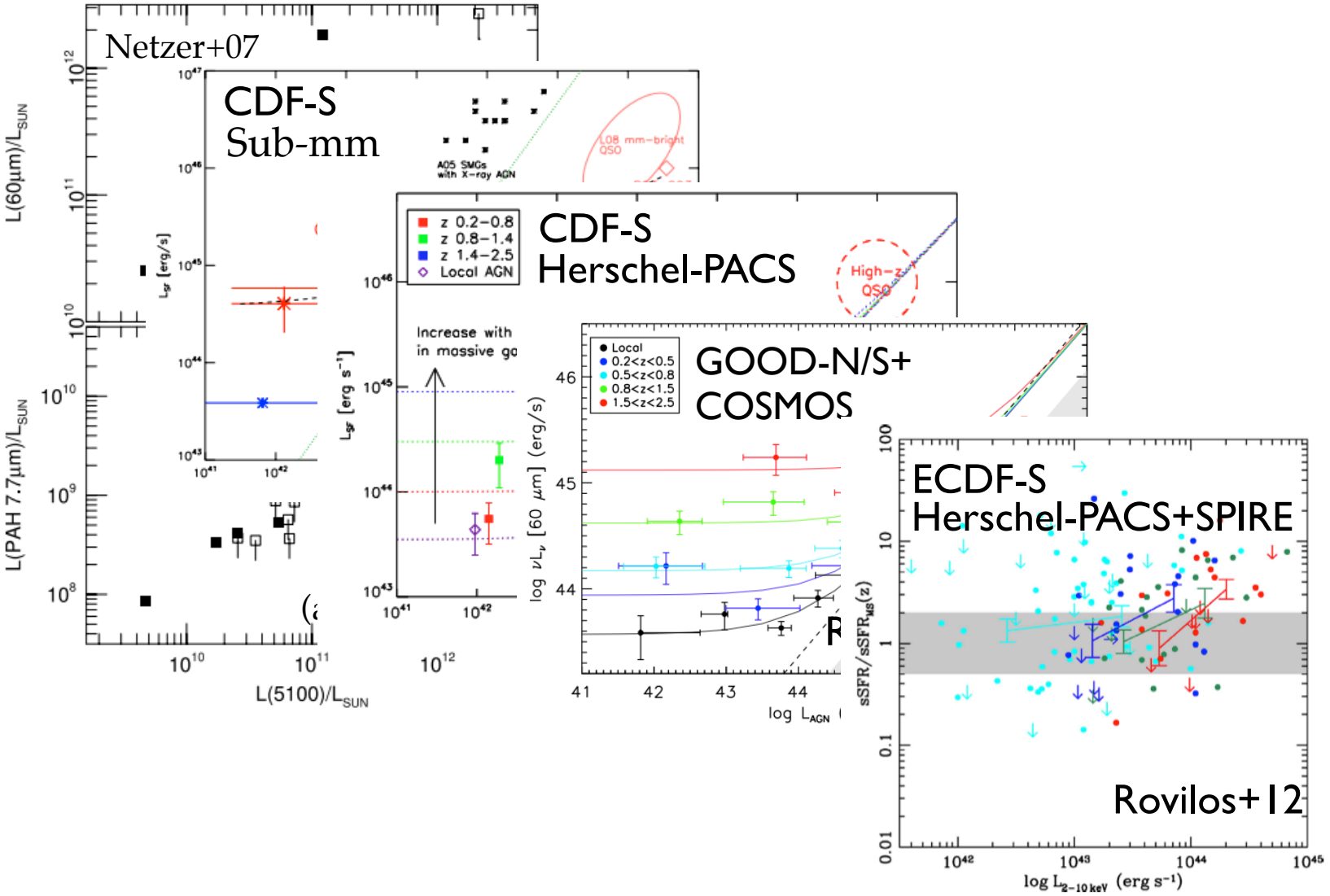


also Rosario+13

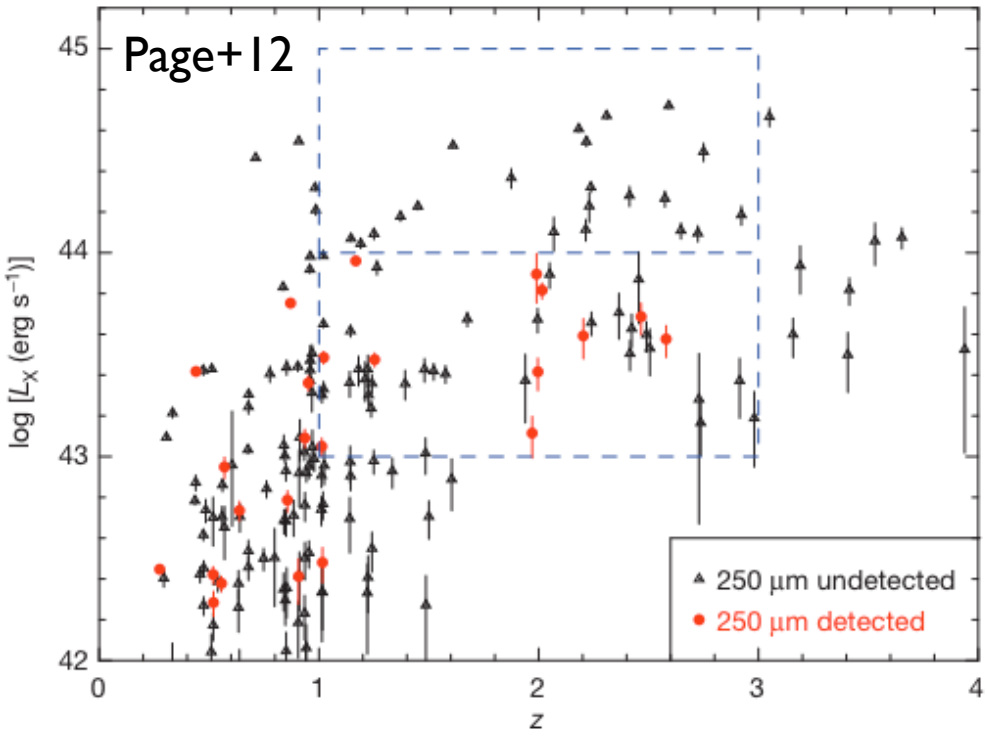
0th order

Rapidly growing BHs *mostly* associated with star-forming galaxies

Is BH growth correlated with SF?



Far-IR signs of 'quenching'

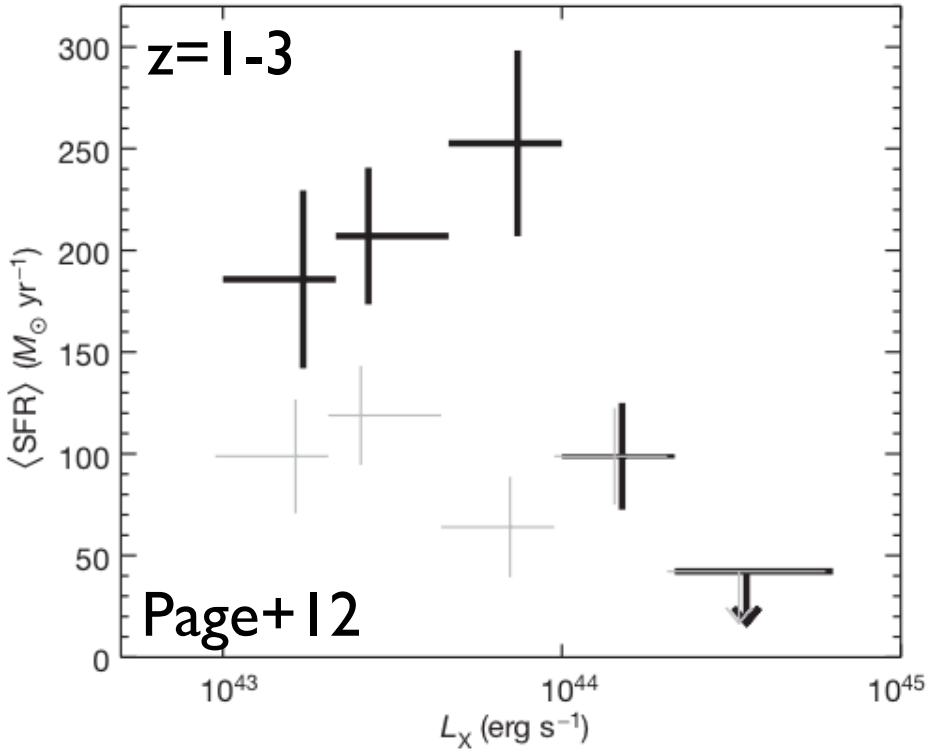


Moderate AGNs detected with Herschel but...

...few, if any, z>1

Quasars in CDF-N are detected.

Far-IR signs of 'quenching'

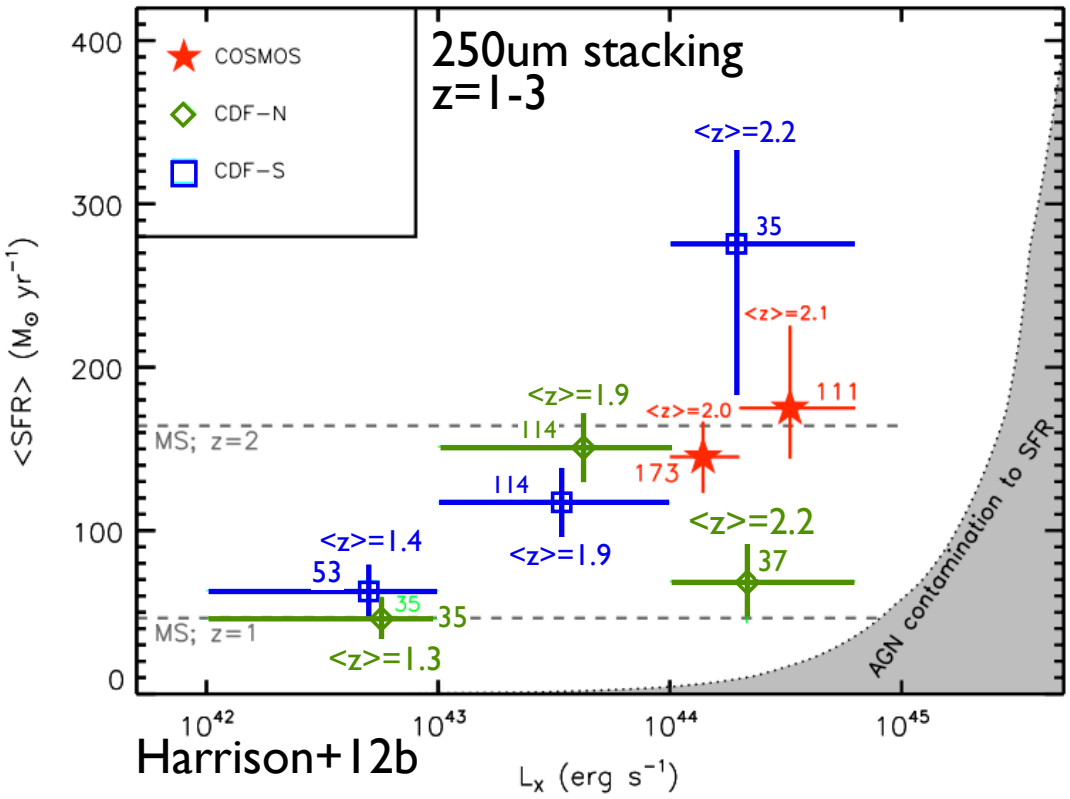


Moderate AGNs detected with Herschel but...

...few, if any, z>1 **Quasars** in CDF-N are detected.

Stacking reveals a cut-off of SF in brightest AGN.

Far-IR signs of 'quenching'



Reconcile with previous results:
Reproduce fall in CDF-N
and
Reproduce rise in CDF-S.

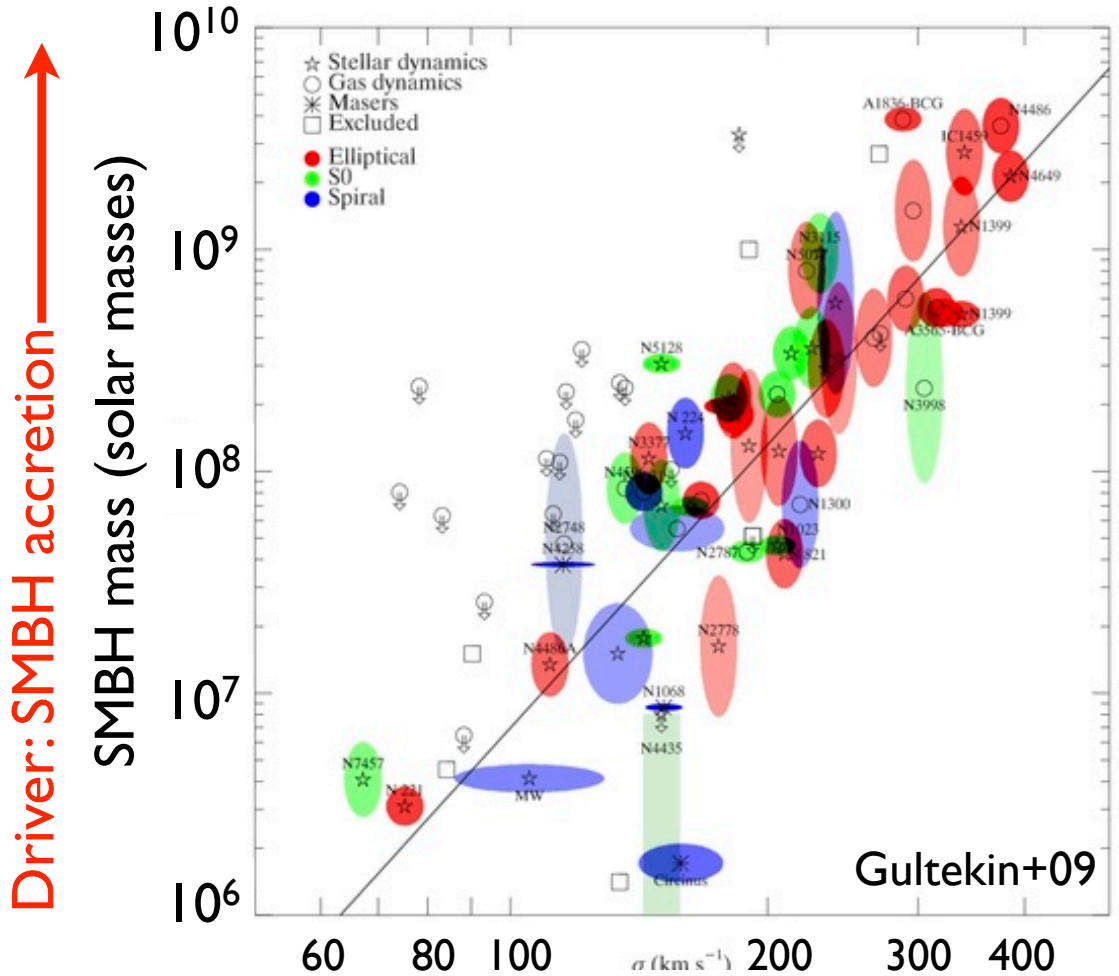
Larger numbers of COSMOS suggest flat.

0th order

Rapidly growing BHs mostly
associated with star-forming galaxies

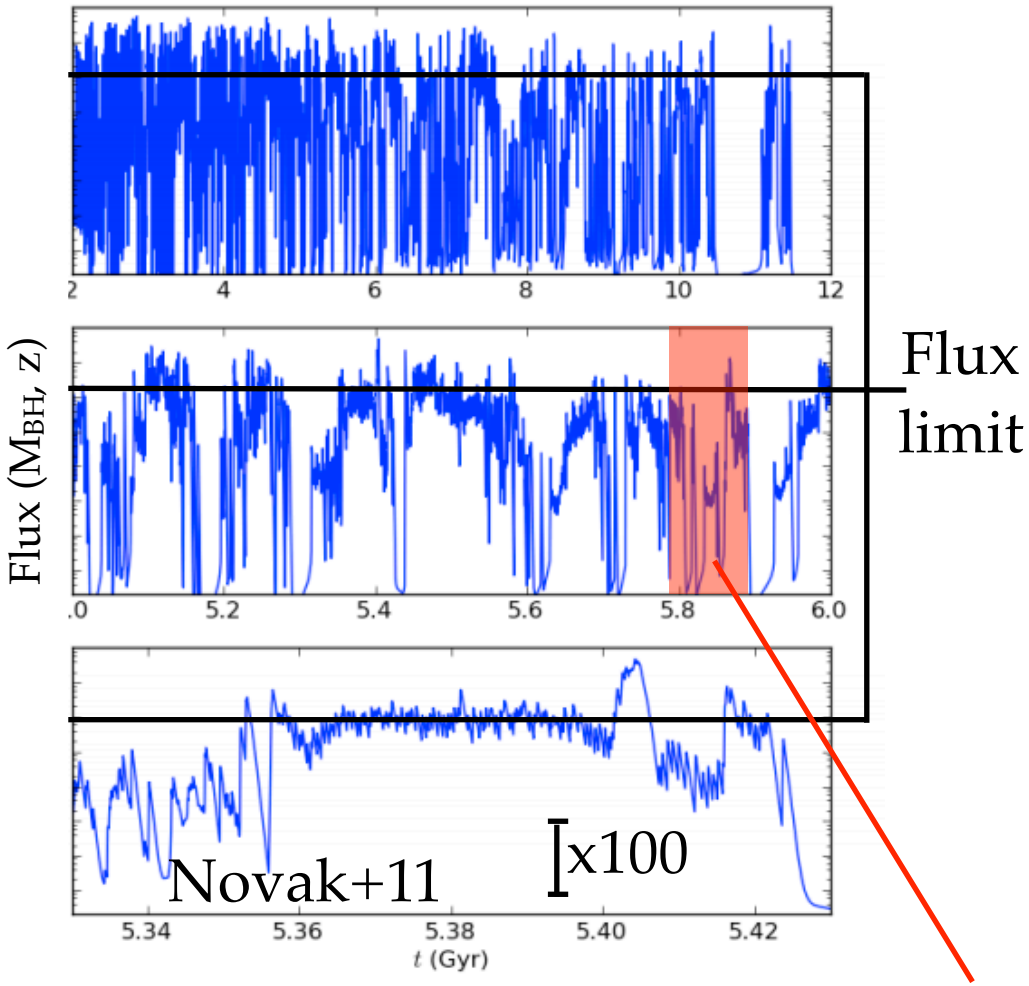
1st order

For X-ray selected AGNs at z>1,
no *strong evidence* for a correlation
between BHAR and SFR (globally).



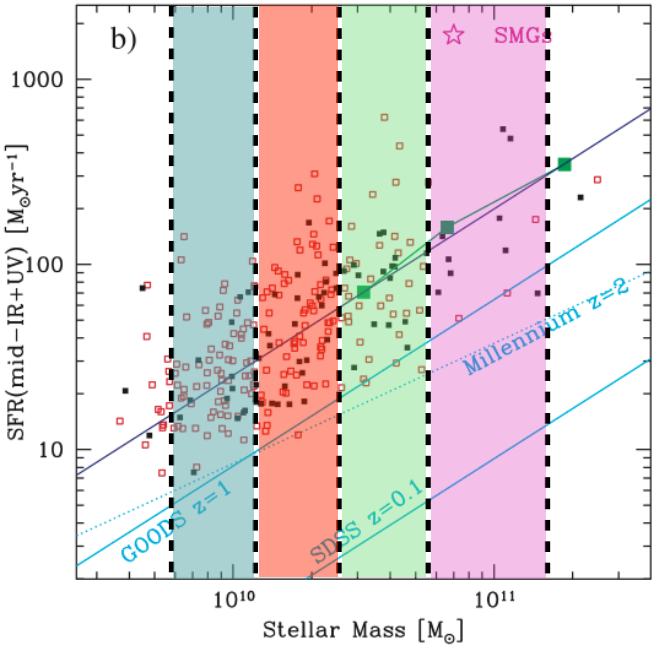
(also, Magorrian+98, Gebhardt+00, McLure+02, Marconi+Hunt 03, Haring+Rix 04, Gultekin+09, Kormendy+11, Bennert+11, etc)

Randomising affect of duty cycles



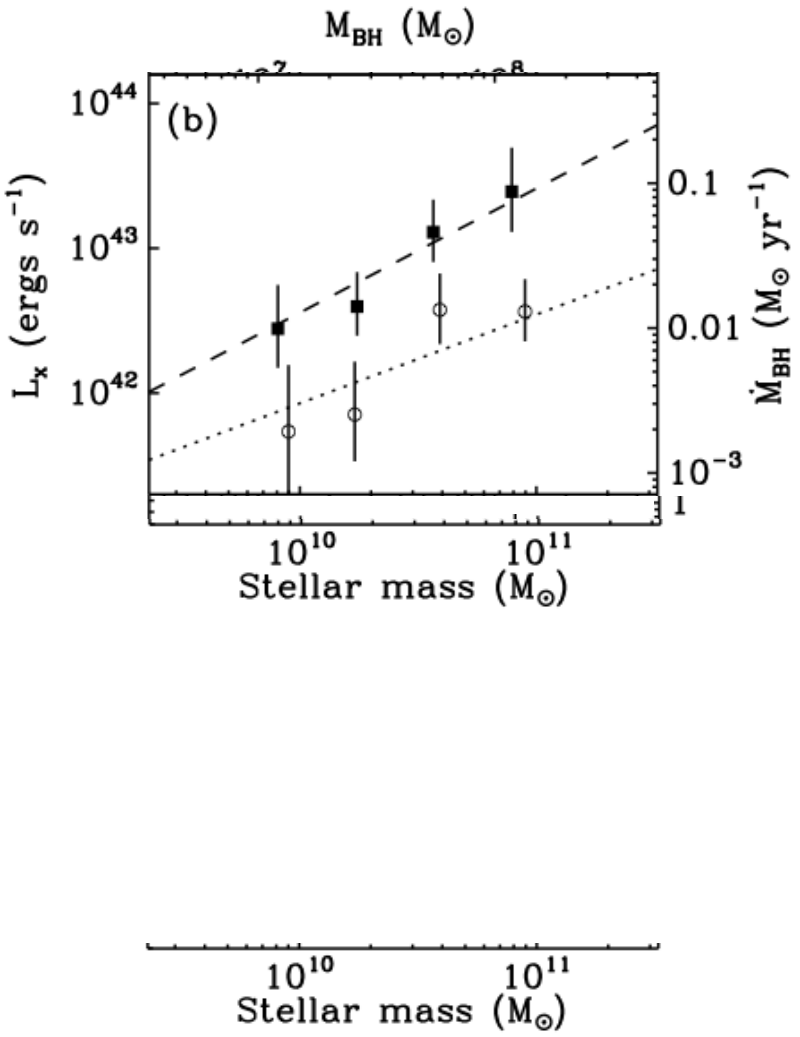
- AGNs lum. change on short time scales.
- Introduces scatter in relations.
- Even binning in L_X can be affected, as AGNs scatter in and out of bins.

A different approach



- Identify a complete sample of SF galaxies.
  - BzK (z~1.5-2.5), 24um (z~0.5-1.5) selected
- Average over AGN duty cycles using X-ray stacking.
  - 4Ms CDF-S
- Takes into account undetected, 'quiescent' AGNs.
- Will miss AGNs in low-SFR galaxies
  - estimated as ~10% contribution at z=0.5-2.5

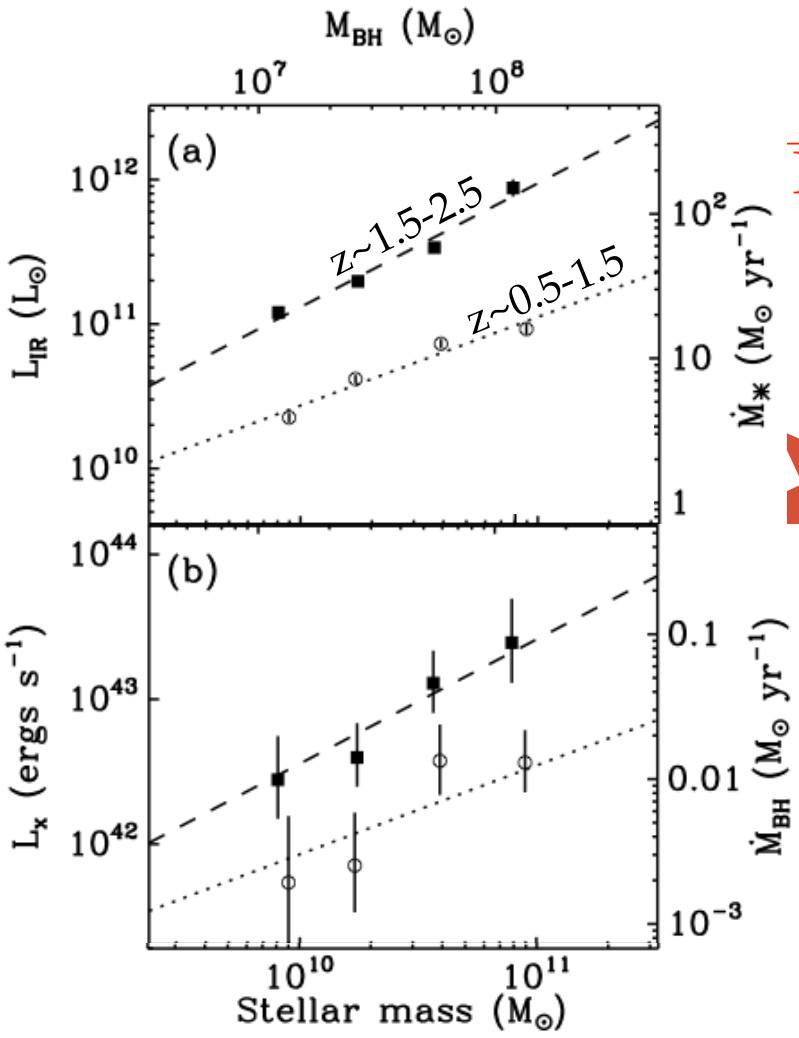
An AGN "main sequence"?

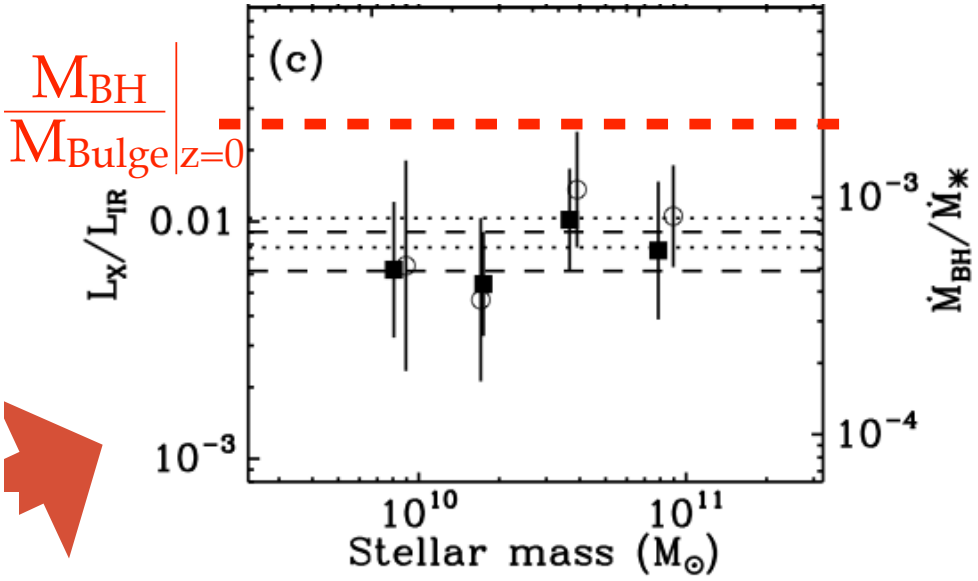


- Average SFR vs. M* shows MS trend.
- On average, M_{BH} growth rate follows same trends with M* and redshift.

Mullaney+12b

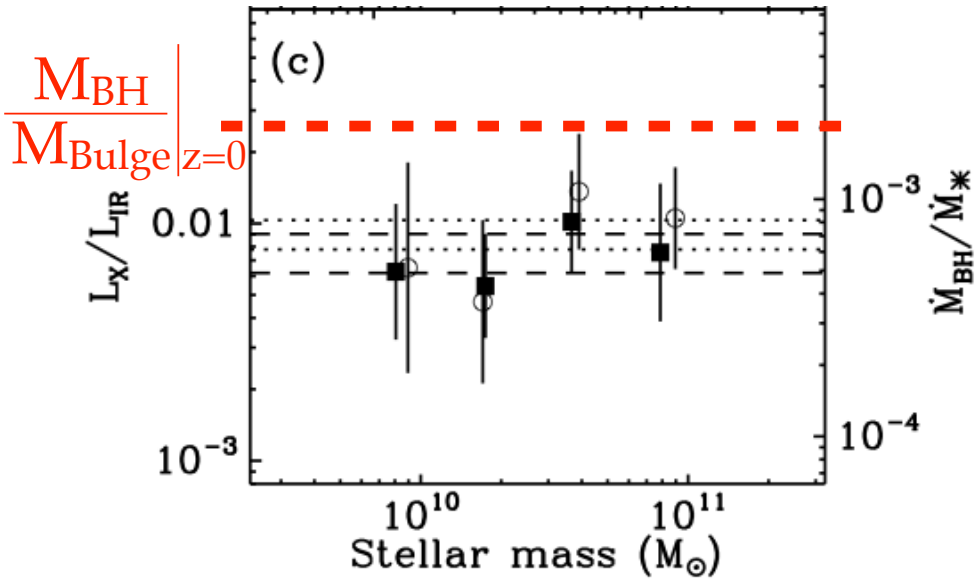
An AGN "main sequence"?





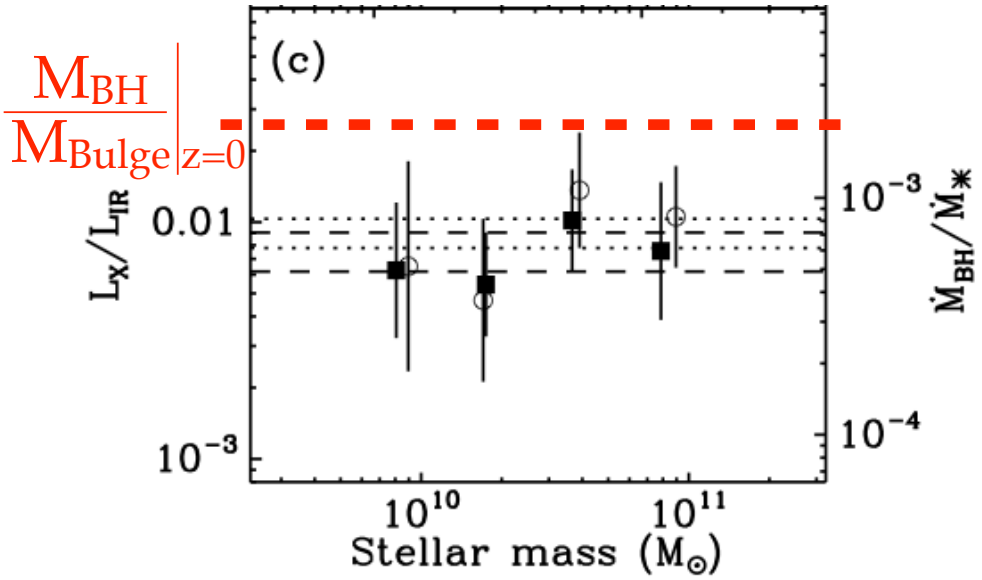
- Crucially, **M_{BH}/SFR is constant with M* and redshift.**
- and:
  $\dot{M}_{BH}/SFR \sim M_{BH}/M_{Bulge}$

An AGN "main sequence"?



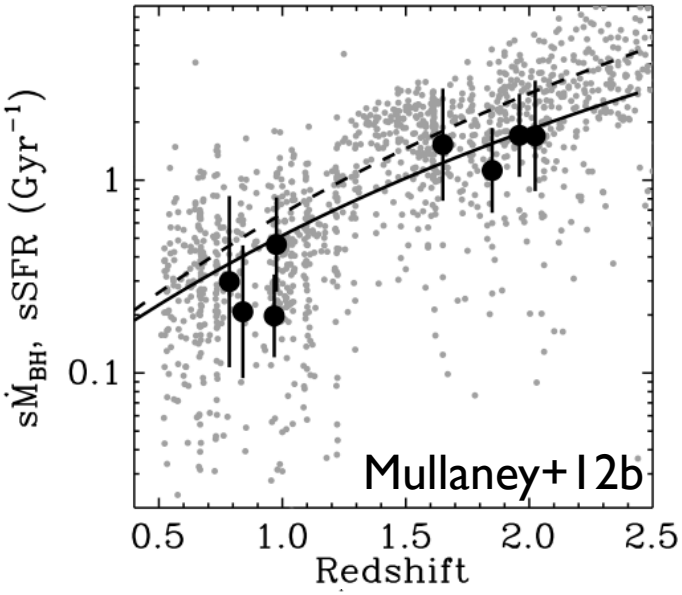
- Important to note:
  - Still missing heavily obscured AGN - reason for 'deficit'?
  - Measure total SFR; local relationship is with bulge mass. (e.g., Kormendy, 2012)
  - Small volume, missing most luminous Quasars - account for 20-30% BH growth

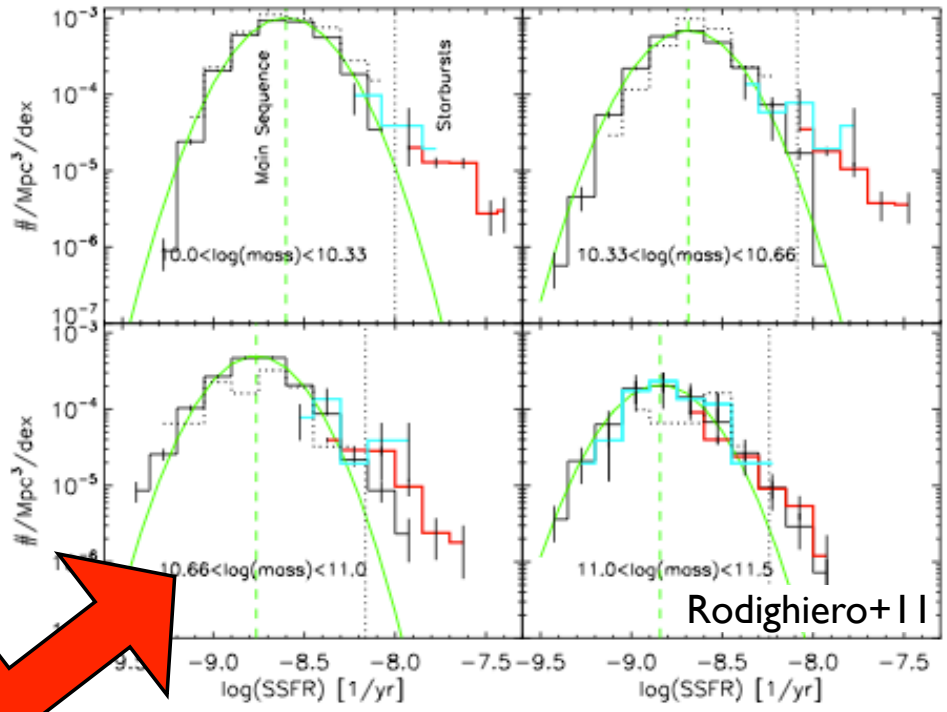
An AGN "main sequence"?



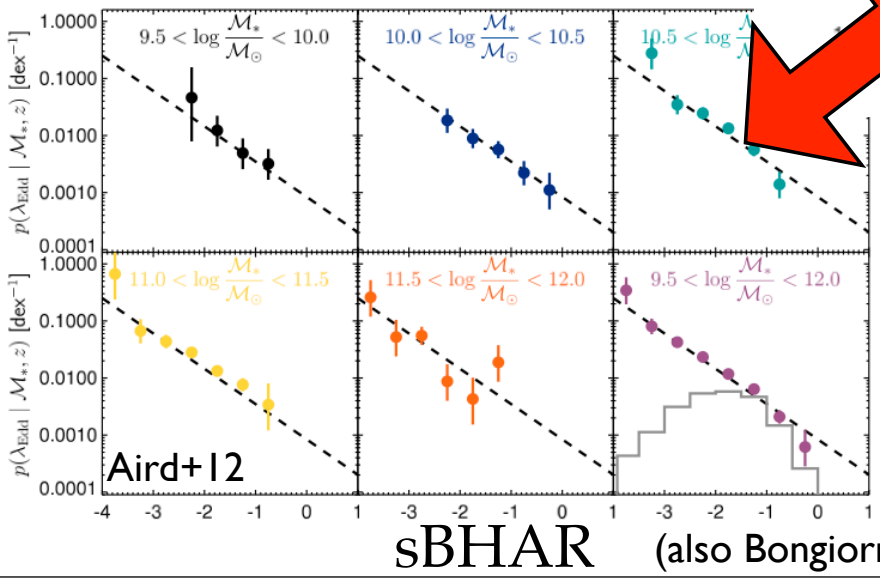
- For over ~5Gyr (z~0.5-2.5) SMBH and galaxies grew at a rate close to today's M_{BH}/M_{Bulge} ratio.
- True for our full galaxy mass range - spans over an order of magnitude: $6x10^9$ - 10^{11} $M_\odot$.

sSFR-sBHAR connection





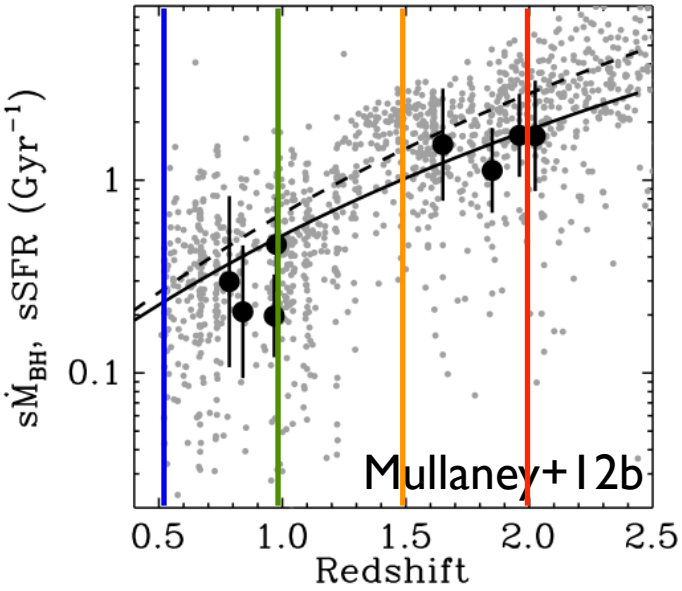
also Sargent+12



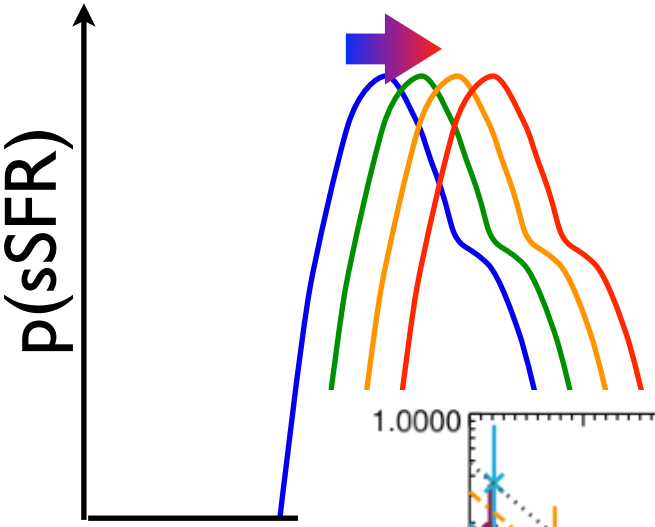
(also Bongiorno+12)

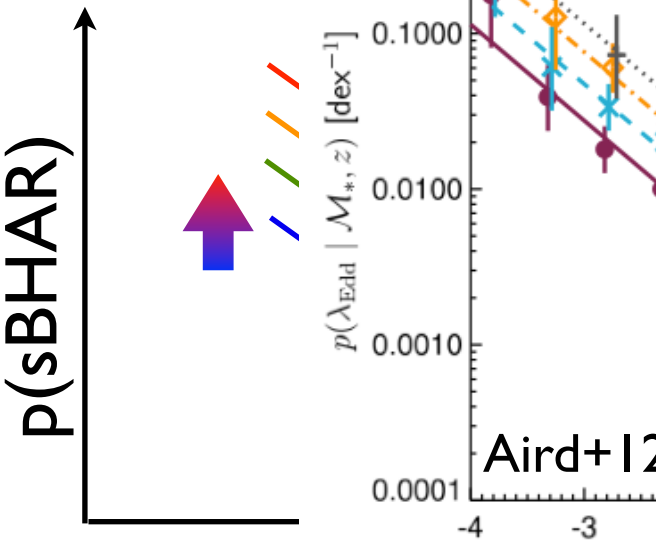
Equivalent properties, sBHAR and sSFR, both have M*-independent distributions.

sSFR-sBHAR connection



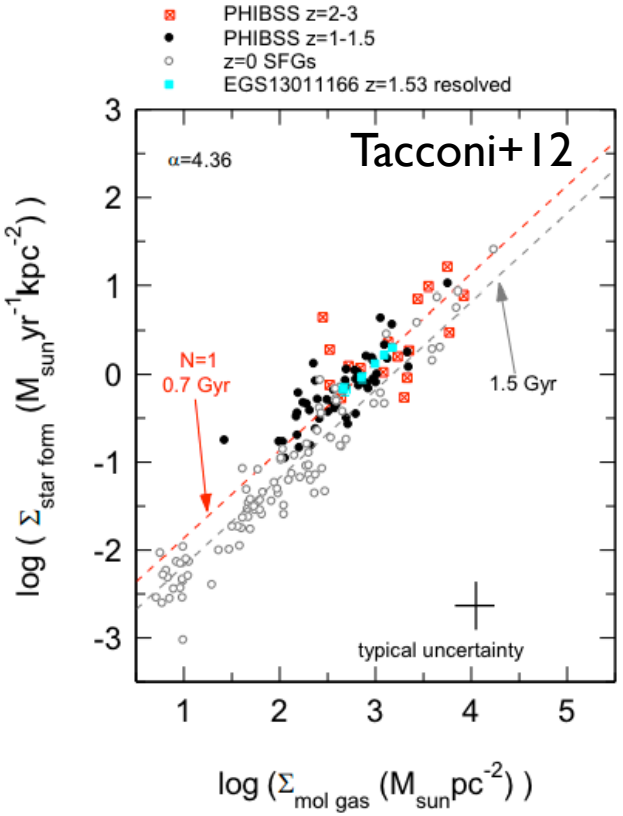
- Characteristic sSFR increases with z.
- *Duty cycle* of a given sBHAR ($\propto\lambda_{Edd}$) increases with z (occurs more often at high-z).



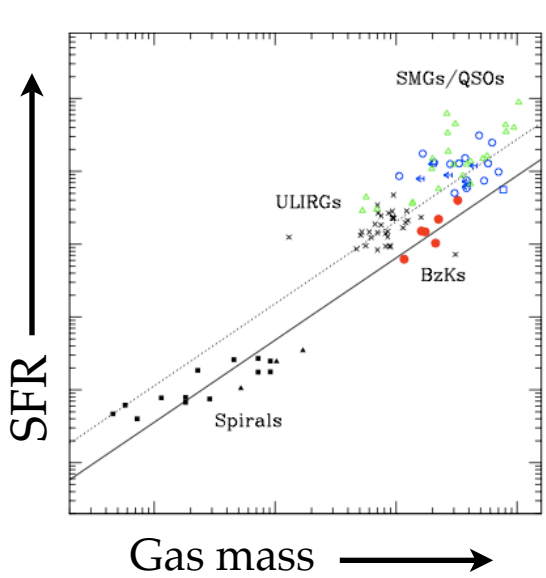


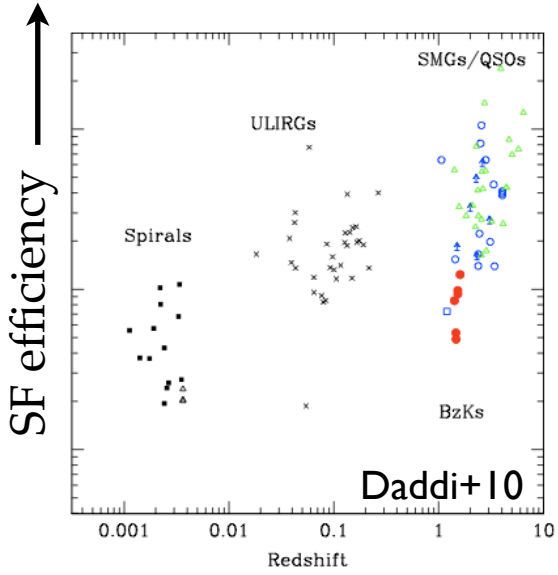
(also Bongiorno+12)

Connection to gas



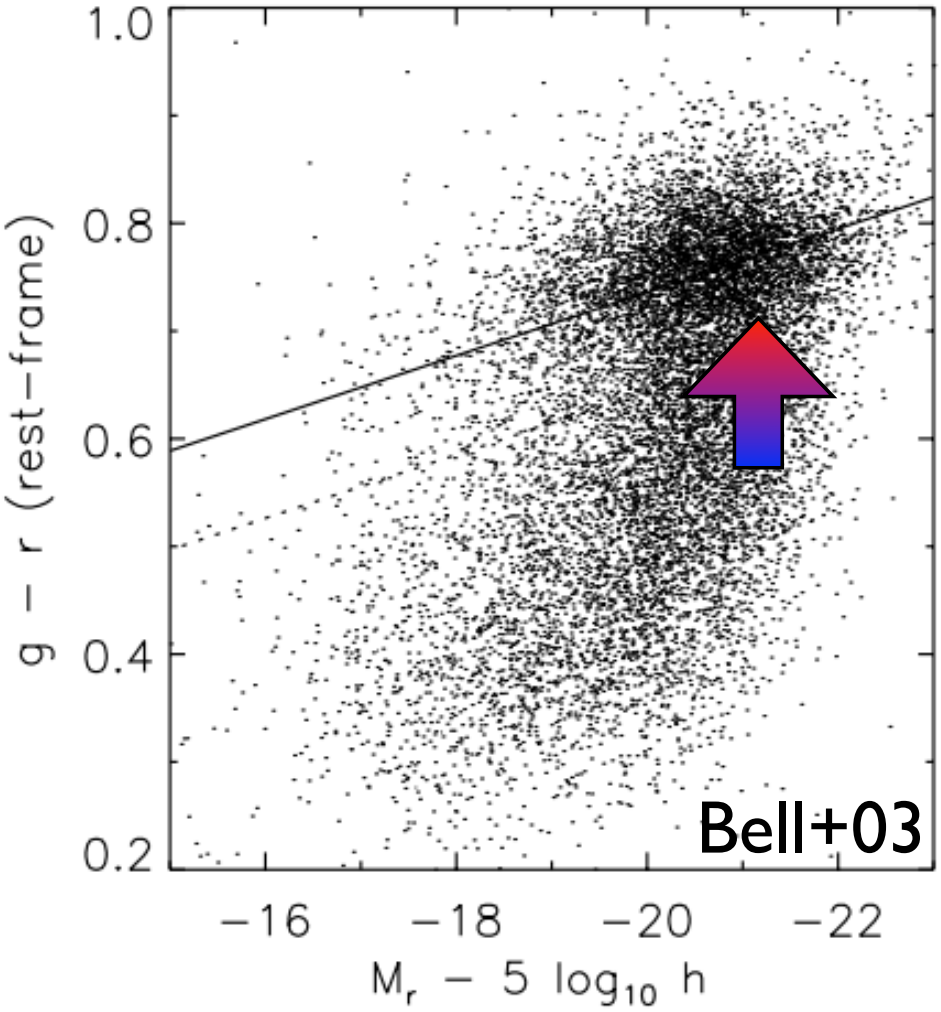
- Cold gas densities play key role in dictating characteristic sSFRs of most SF galaxies.
- Do cold gas fractions/densities dictate the frequency of AGN activity?
  - What is their role in forming scaling relations?





(e.g., Genzel+, Combes+11, Geach+11, Magdis+12, Tacconi+)

So, do AGNs affect their host galaxies?



(e.g., Springel+05, Di Matteo+05, Croton+06, Hopkins+06)

Feasible in terms of binding energy: $E_{\rm Bnd} = \frac{GM^2}{r}$

For $10^8 M_\odot$ BH in $10^{11} M_\odot$ galaxy:

$E_{\rm Bnd}^{\rm BH} \sim 10^{61} {\rm ergs}$ (r = Schwarzschild radius)

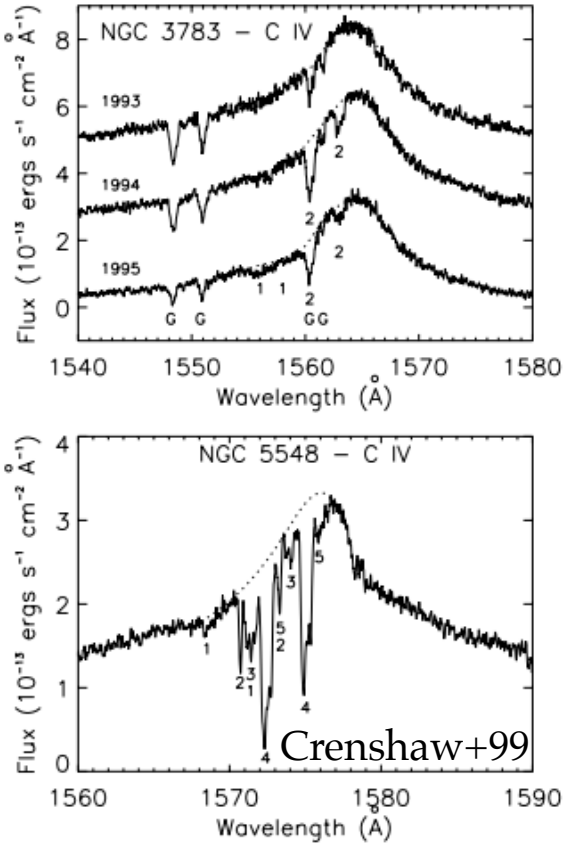
$E_{\rm Bnd}^{\rm Gal} \sim 10^{59} {\rm ergs}$ (r = 10 kpc)

Few % of gravitational energy released in growing BH could significantly disrupt galaxy.

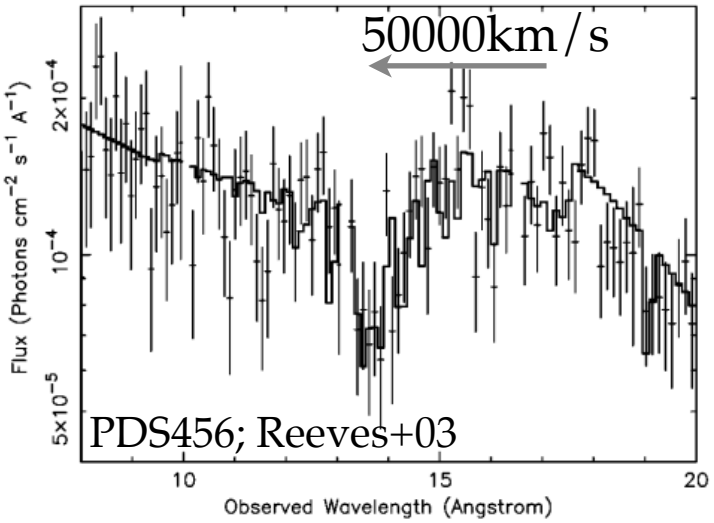
AGN driven outflows

UV absorption lines

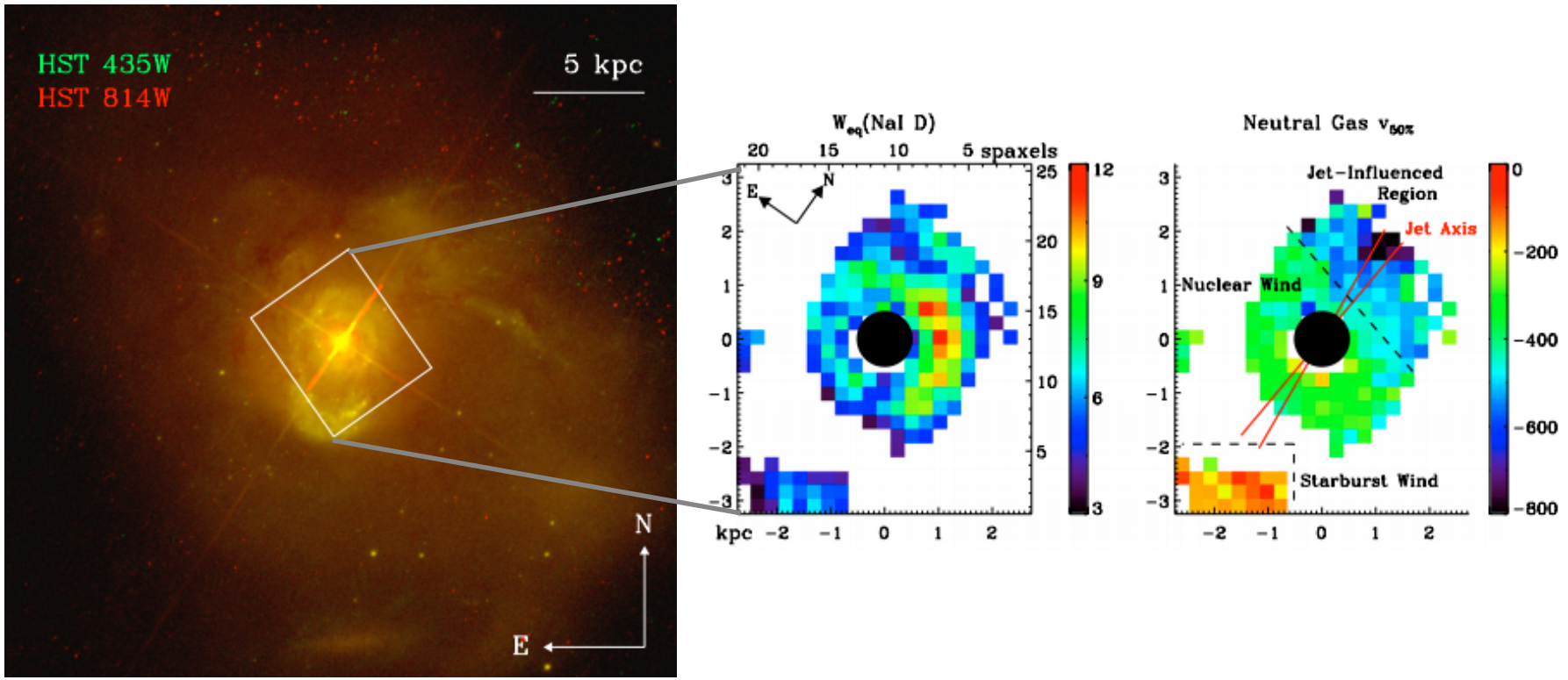
~500km/s outflows



- Small (~10s-100s parsecs) scale outflows common (~60%) among moderate & high luminosity AGNs (Ganguly+08).
- Kinetic energy of outflows: ~<10% of AGN bolometric luminosity

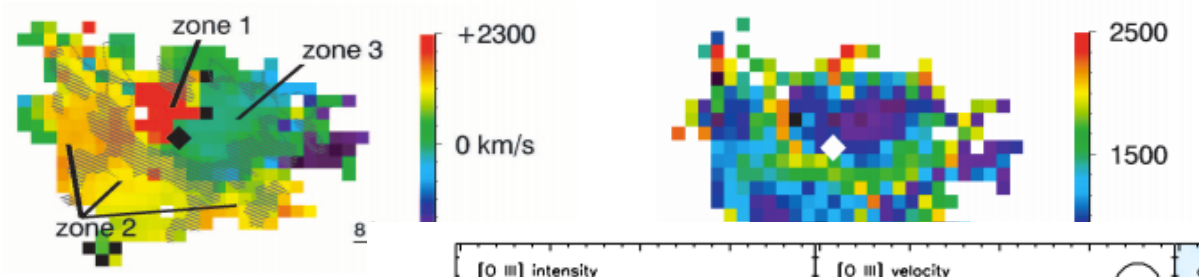


Mrk231: kpc-scale outflows

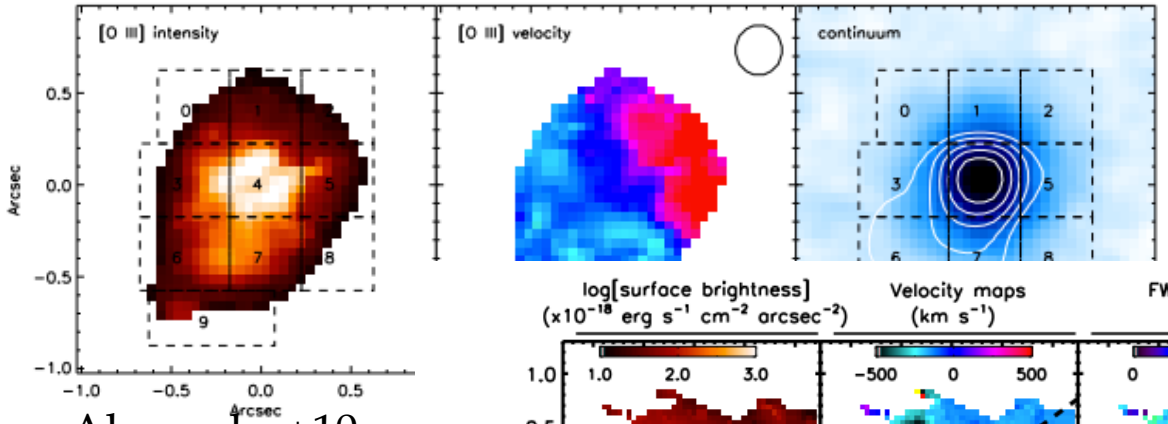


Rupke+11

Outflows at high-z (z>1)

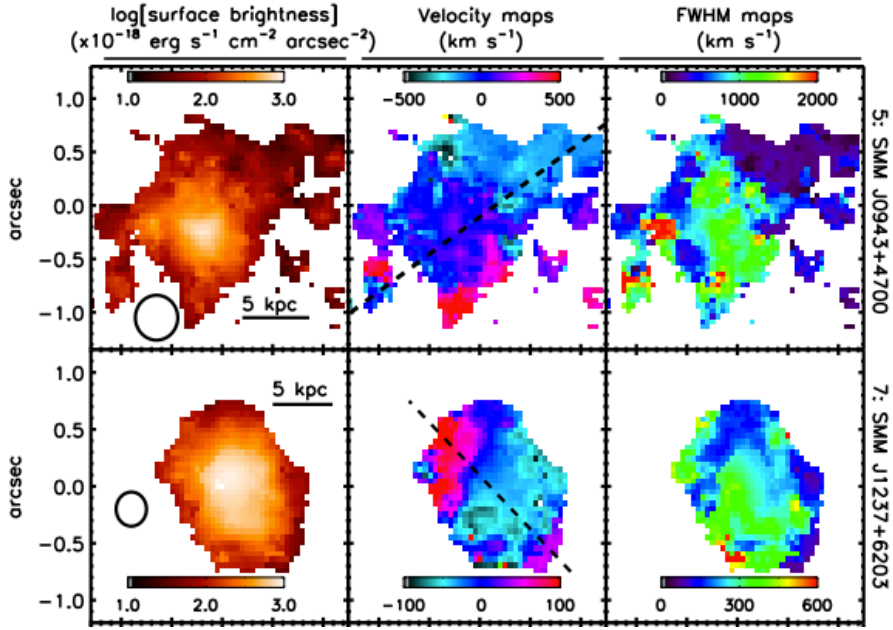


Nesvadba+06, 08



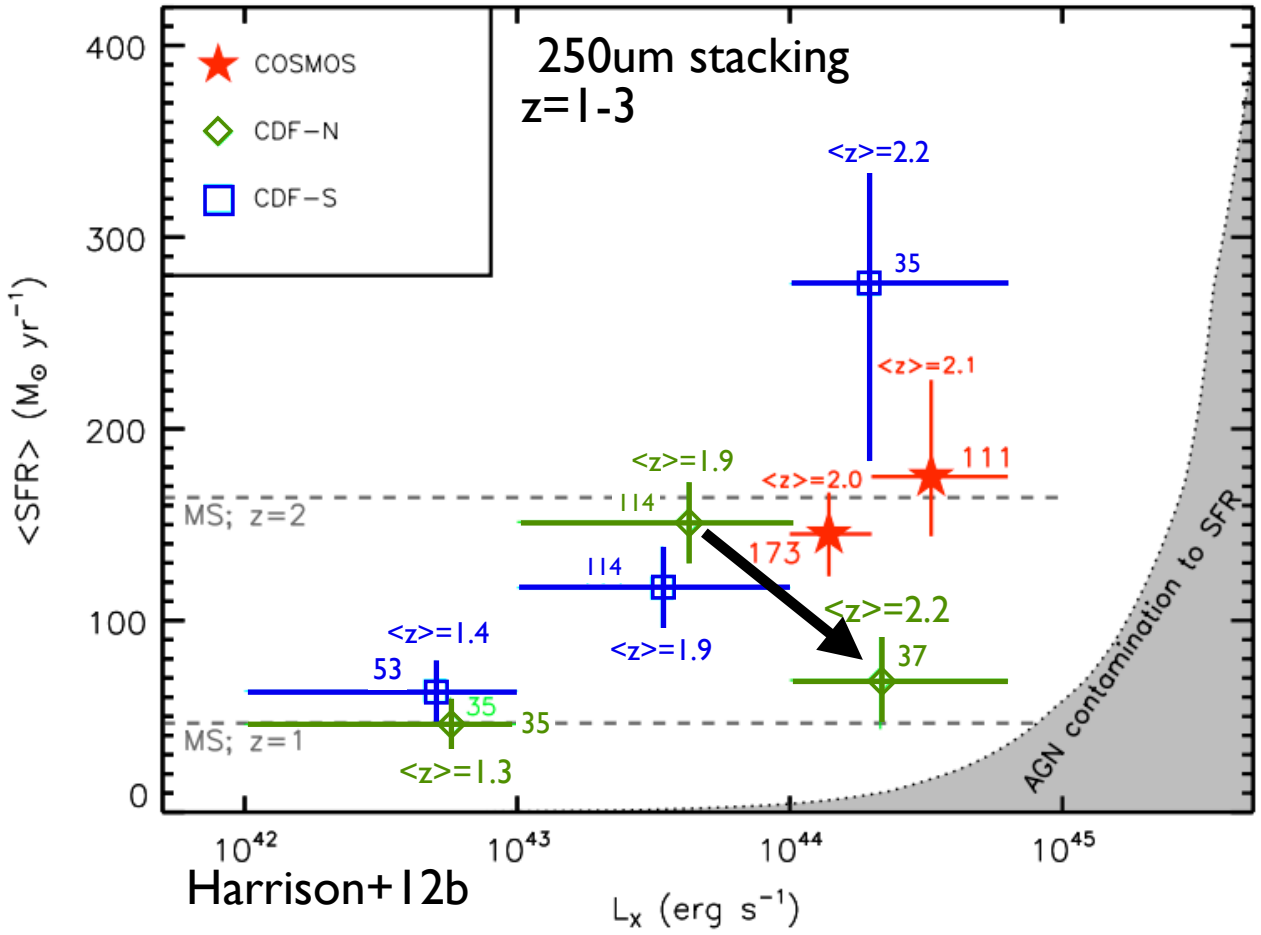
Alexander+10

- ~10^{59}-10^{60} erg over AGN lifetime
- Sufficient to unbind the gas from the host galaxy.
- Probably not sufficient to blow the gas out of the galaxy halo



(also Liu+13, Greene+12, Polletta+11, Cano Diaz+12, Feruglio+10)

Harrison+12


COSMOS
CDF−N
CDF−S
250um stacking
z=1-3
<z>=2.2
35
<z>=2.1
111
<z>=1.9
<z>=2.0
114
173
114
<z>=1.9
<z>=2.2
37
<z>=1.4
53
35
35
MS; z=2
MS; z=1
<z>=1.3
AGN contamination to SFR
<SFR> (M⊙ yr⁻¹)
Lx (erg s⁻¹)
400
300
200
100
0
10^42
10^43
10^44
10^45
Harrison+12b

Conclusions

- Most AGNs are found in star-forming galaxies at $z<3$.
- Not strong evidence of an (anti-)correlation between BH growth and star-formation for AGNs.
- But...when averaged over population, the two do appear to be tightly linked.
  - Is gas the underlying factor?
- However, AGN can and do drive powerful outflows that could impact their host galaxies.
- But directly witnessing 'quenching' is likely to be difficult.