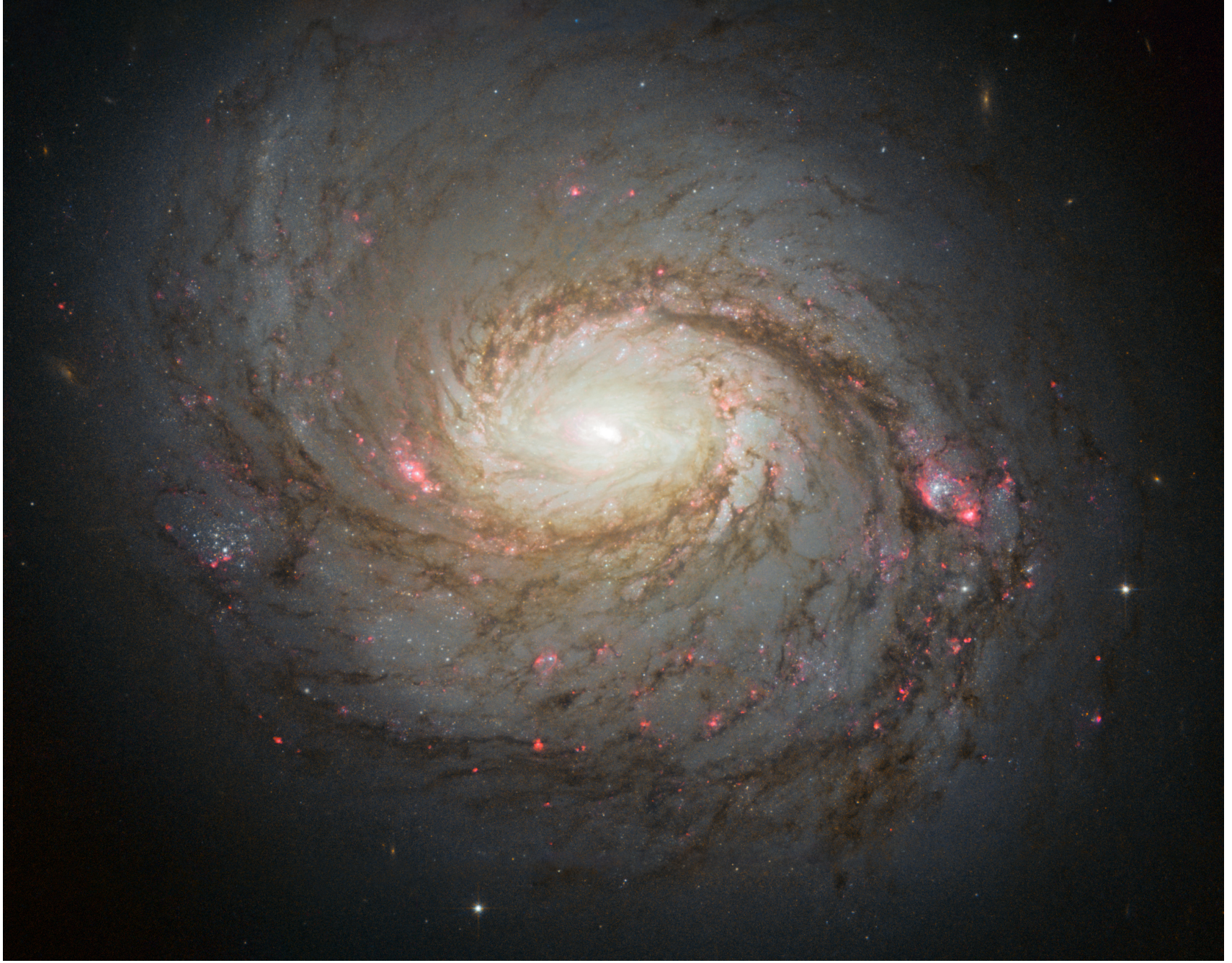

# The host galaxies of AGN

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# How can we learn about AGN host galaxies?

## "Ingredients" to facilitate (radio-quiet) AGN activity

- Properties of host galaxy: morphological types, stellar masses, molecular gas content (gas reservoir)

## Mechanisms to transport gas from host galaxy to black hole

- Major mergers, bars, nuclear bars, nuclear spirals, (minor mergers, external accretion)

## Physical phenomena accompanying AGN activity on nuclear/ circumnuclear physical scales

- Nuclear/circumnuclear SF activity, post-starburst activity, nuclear molecular content, inflows/outflows

**Importance of taking into account: AGN selection technique, AGN luminosity, and sample matching for non-AGN samples. All for field AGN**

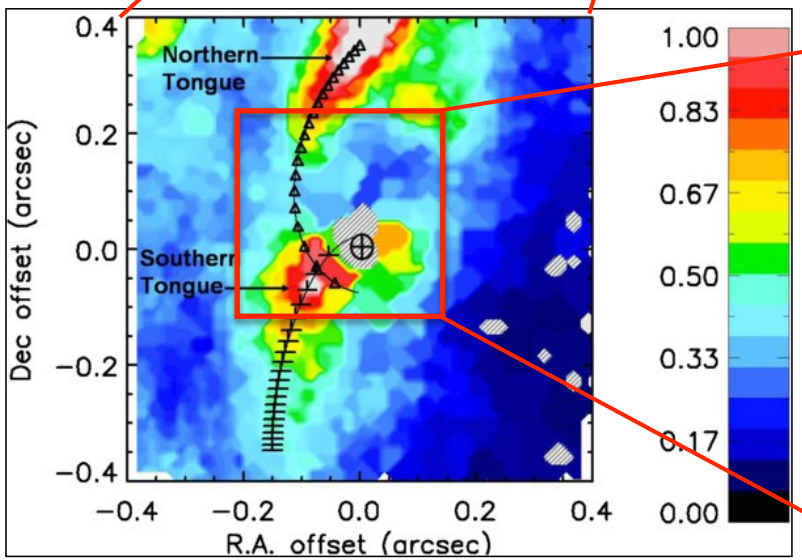
NGC1068: Massive gas-rich barred galaxy

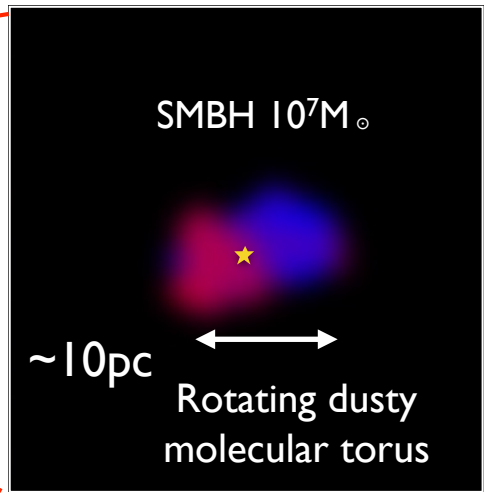
Molecular gas in the circumnuclear disk + SF activity

~350pc

Credit: ALMA (ESO/NAOJ/NRAO), Imanishi et al.

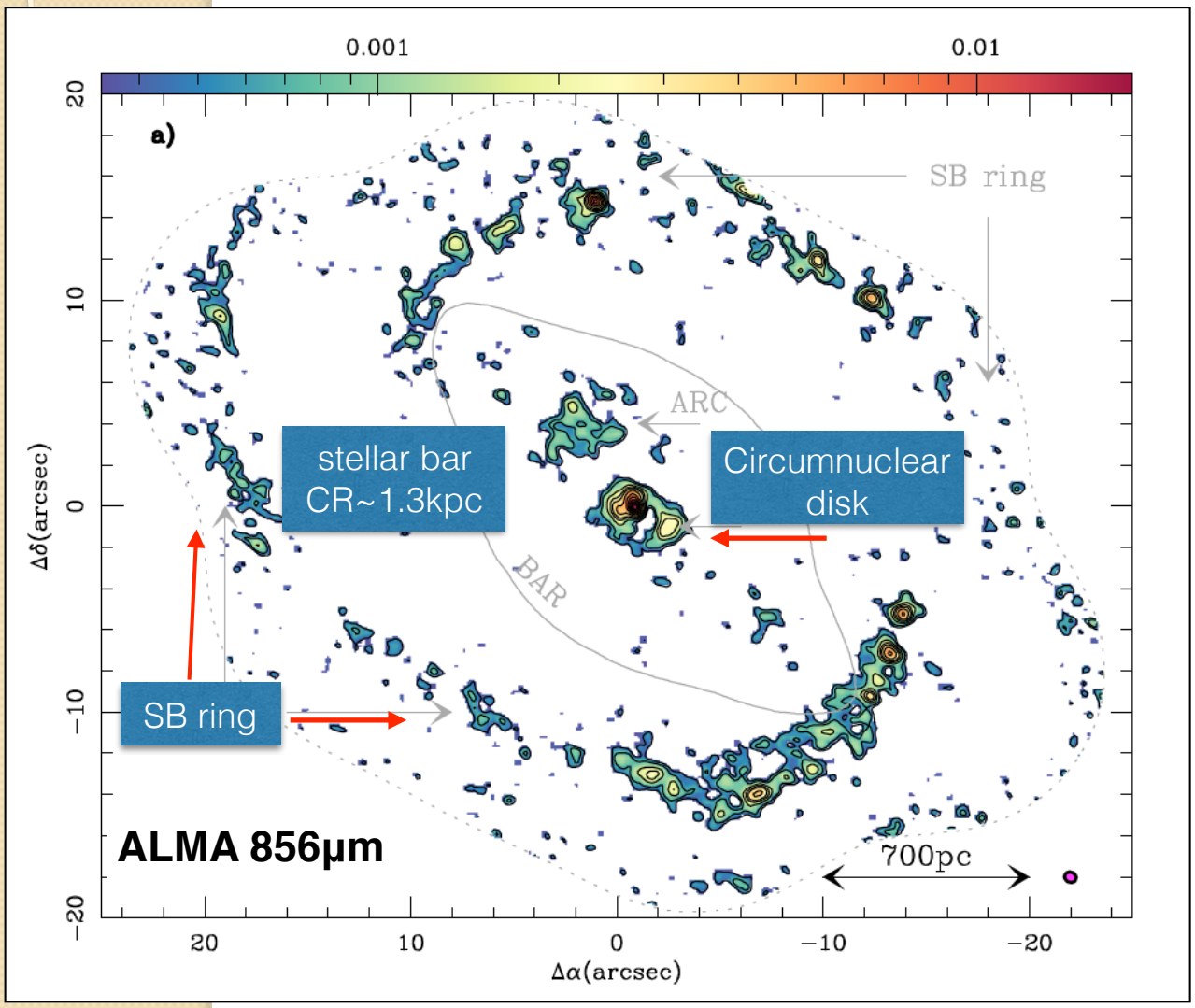
Fuelling the AGN




**Müller-Sánchez+2009; García-Burillo+2014, 2016; Gallimore+2016; Imanishi+2018**

# NGC1068, a typical Seyfert in numbers




**García-Burillo+2014,**
also Planesas+1991, Schinnerer+2000, Storchi-Bergmann+2012, Esquej+2014, Barbosa+2014

**AGN bolometric luminosity**

$L_{AGN}$~a few $10^{44}$ to $10^{45}$ erg/s

**Integrated Star Formation Rate in SB ring (r~1.5kpc)**

10-15$M_\odot$/yr

**Circumnuclear disk (r~100pc):**

on-going SFR=1$M_\odot$/yr, 2 recent episodes of SF, one started 300Myr ago and second one 30Myr

**Ionized and molecular outflow rates (scales of 50 to 400pc):**

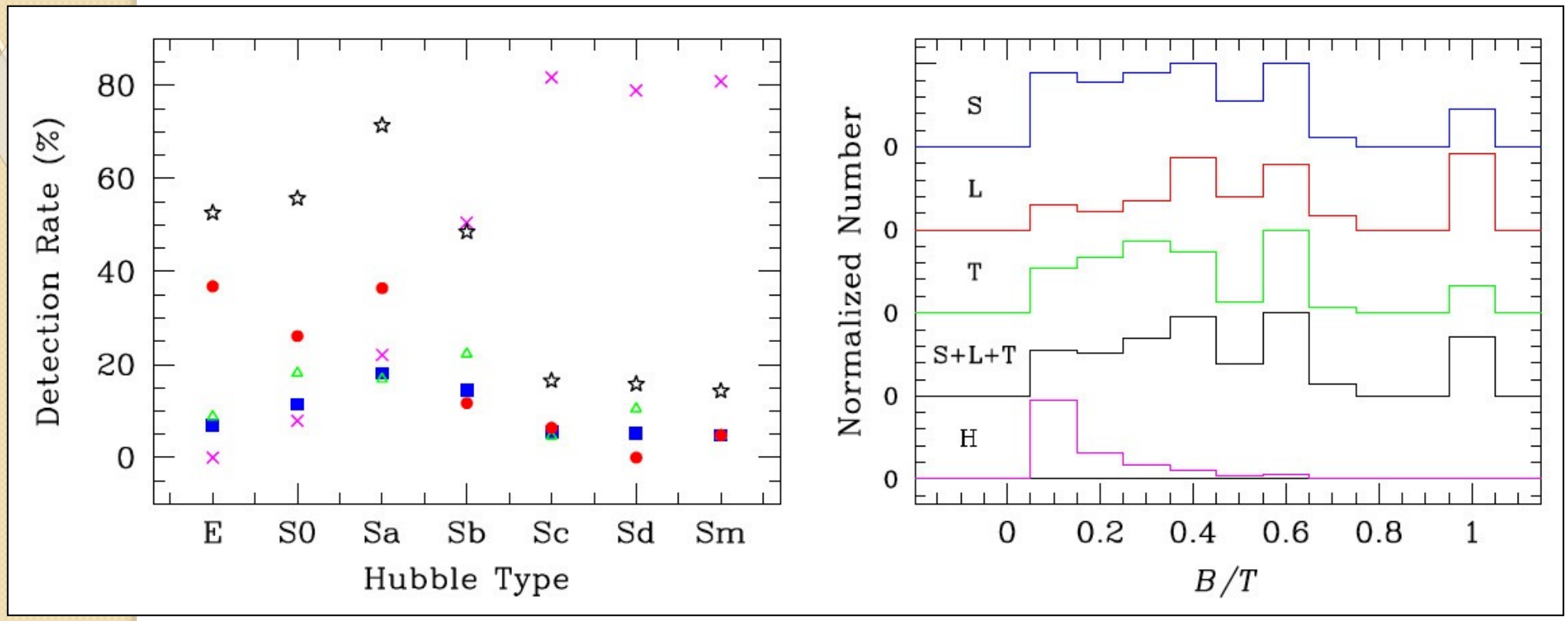
dM/dt~2$M_\odot$/yr and dM/dt~68$M_\odot$/yr

**Total and torus molecular gas mass:**

$7\times10^8$ $M_\odot$ and $10^6$ $M_\odot$

# AGN detection vs. morphological type

**Ho 2008 review of results in Ho+1997 series**

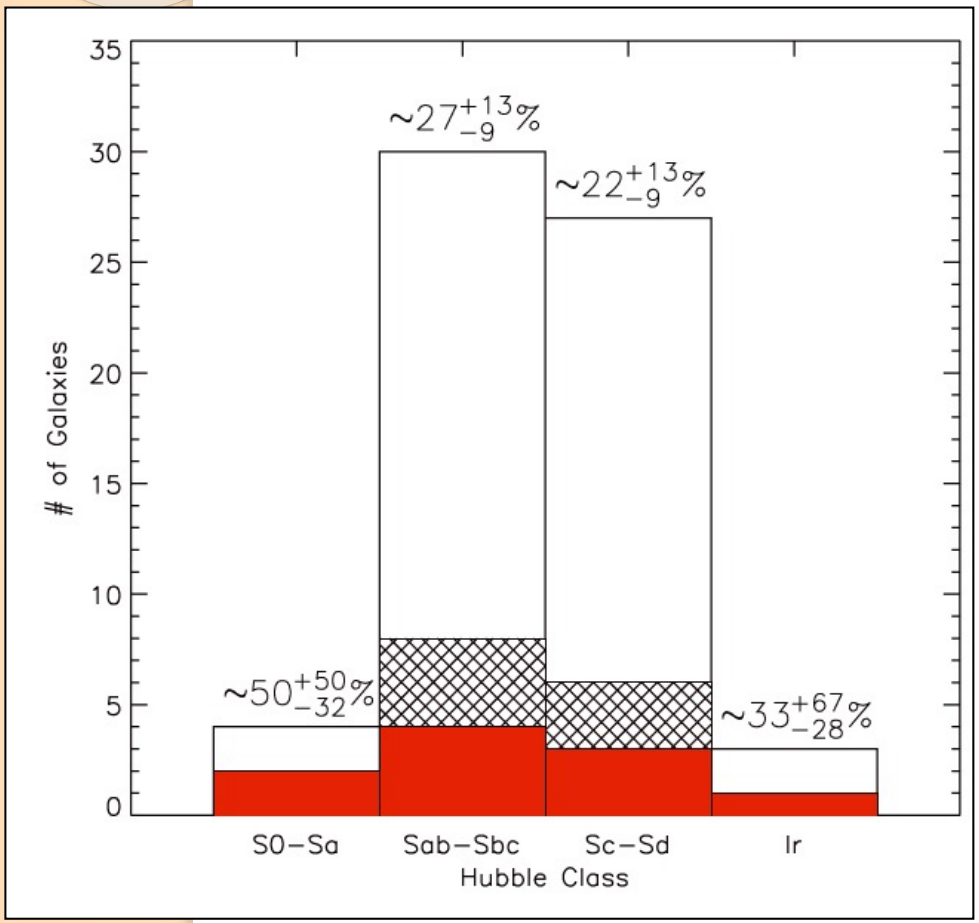



**Palomar Survey**- very sensitive optical spectroscopic survey of nearby (median 17Mpc) galaxies

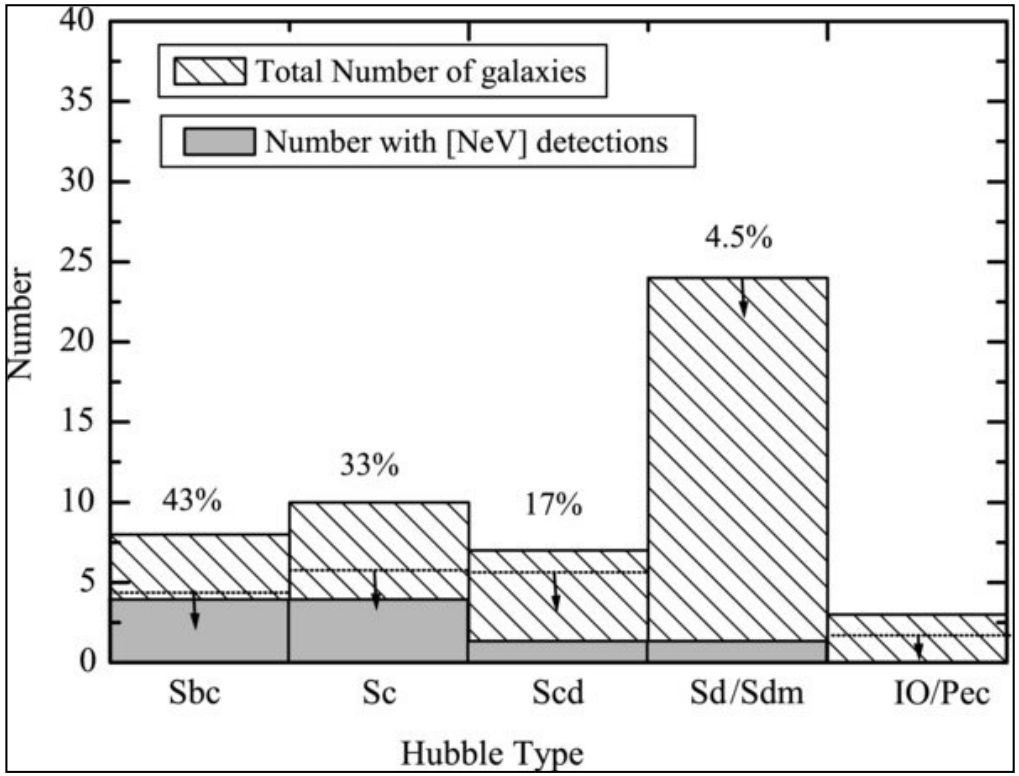
- Over all Hubble types: 43% are classified as "active galaxies" (Sy + LINERs)
- Galaxies with strong bulge component (E-Sb): AGN fraction ~50-70%
- Later Hubble types (Sc and later): AGN fraction ~10% or less

# AGN detection in late type galaxies

**Infrared techniques (e.g., detection [NeV])** identify low luminosity AGN in the local Universe residing in starburst dominated galaxies and not previously detected in the optical




**Goulding & Alexander 2009,** see also Satyapal+2008, Dudik+2009

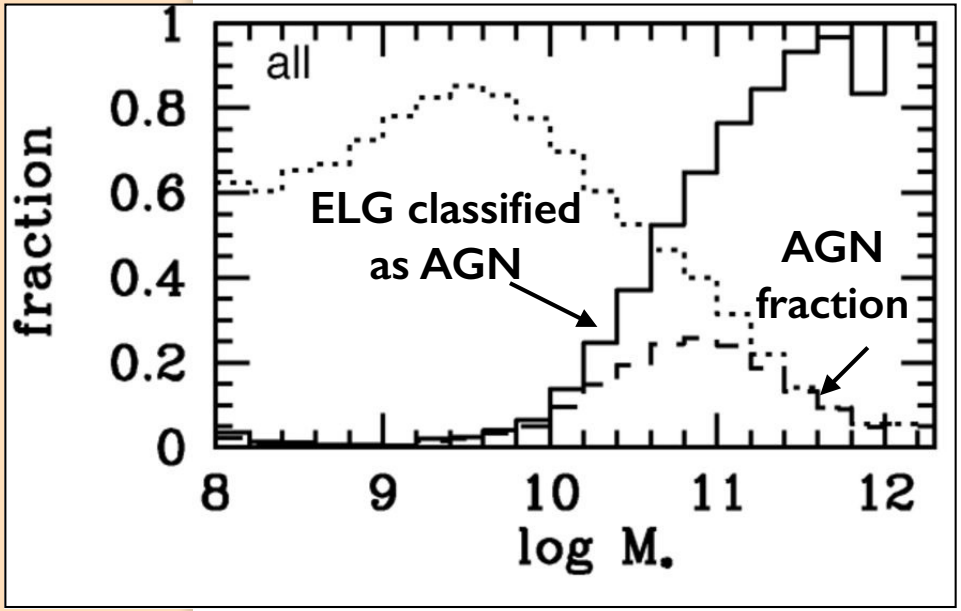


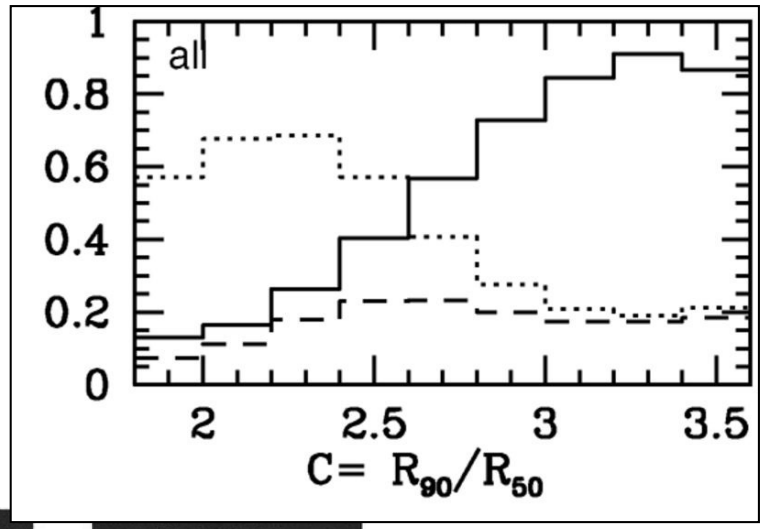

**Satyapal+2009**

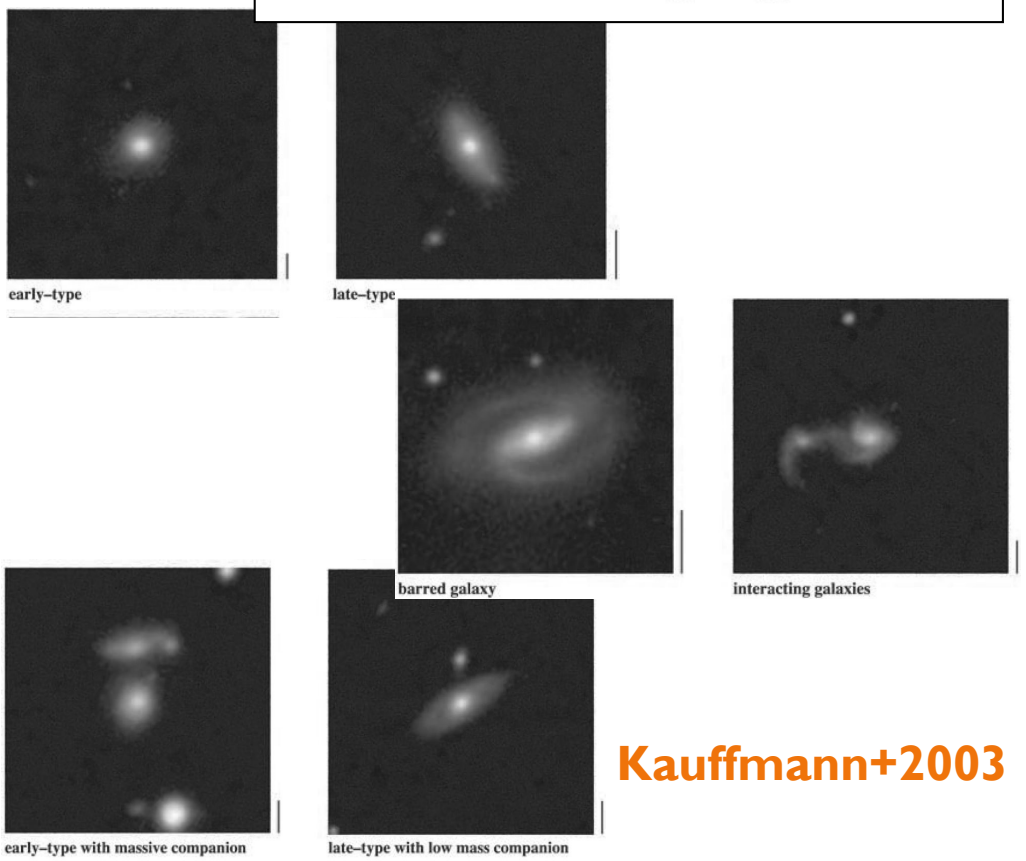
# Morphologies and host galaxies of local AGN

**SSDS** - [OIII] selected type 2 AGN at z<0.1

- reside in the most massive galaxies
- show high concentration indices




40% spheroids/amorphous

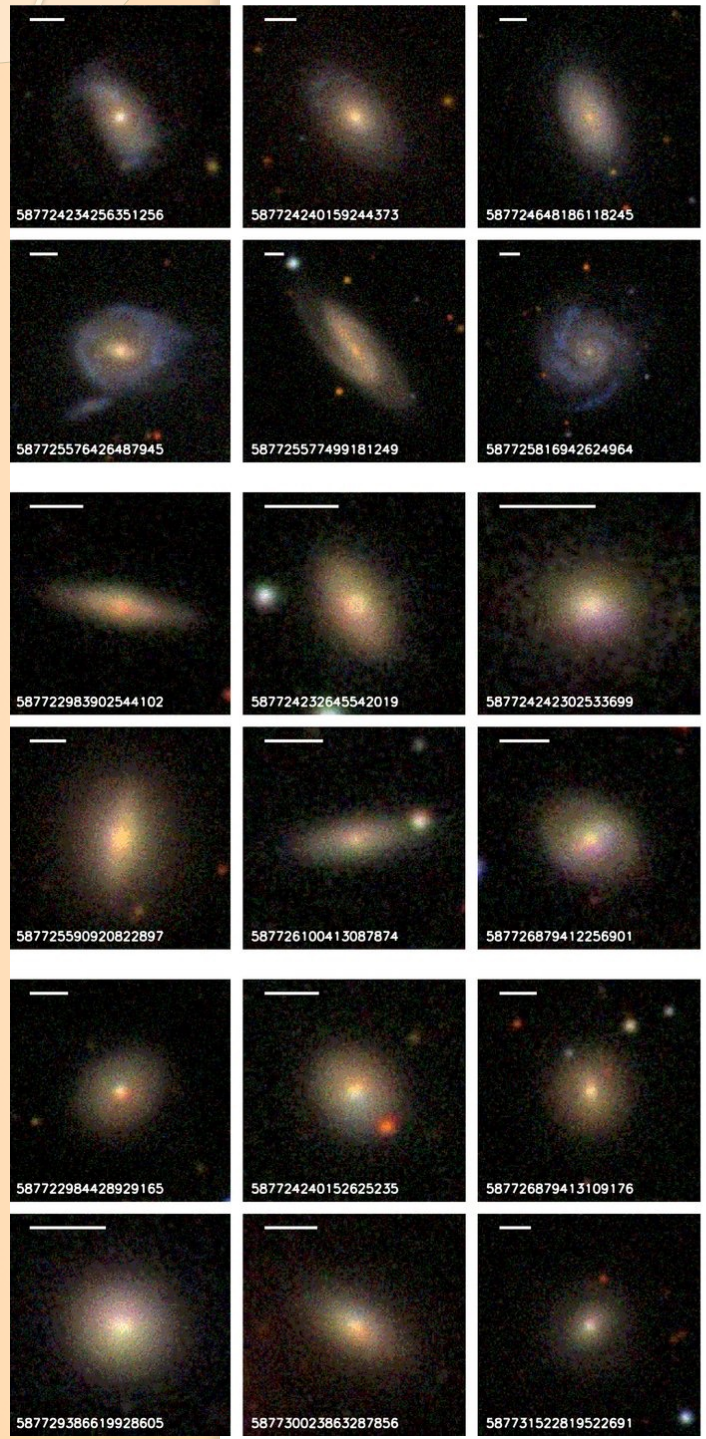
30% single disk galaxies

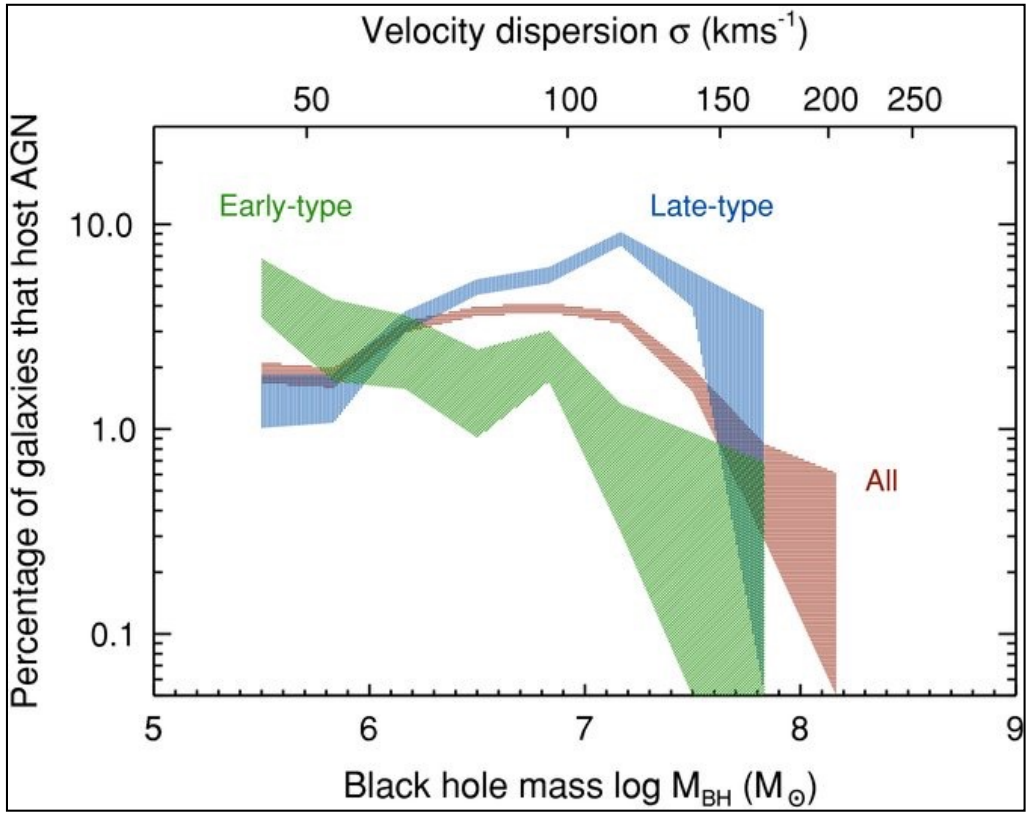
30% disturbed/interacting galaxies

Kauffmann+2003

# Morphological type and BH mass

Schawinski+2010




**SSDS + Galaxy Zoo** - Type 2 AGN at z<0.05, **~2% rate**

AGN reside in the most massive galaxies but do not care about the host galaxy morphology

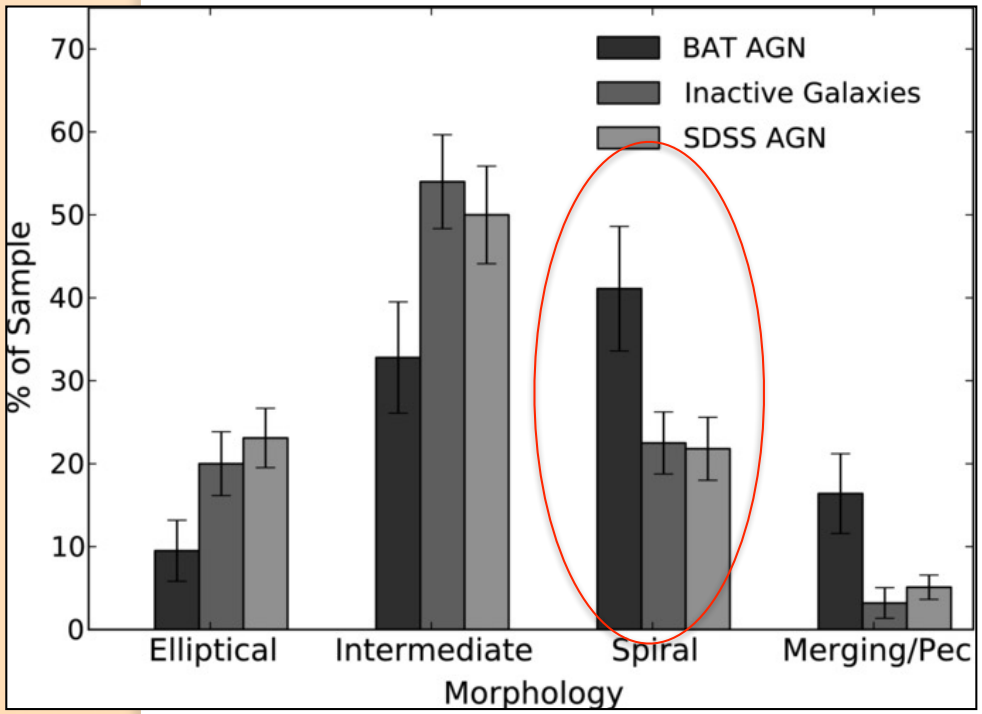
- Early type galaxies: mostly the less massive BH growing
- Late type galaxies: most massive BH are preferentially growing

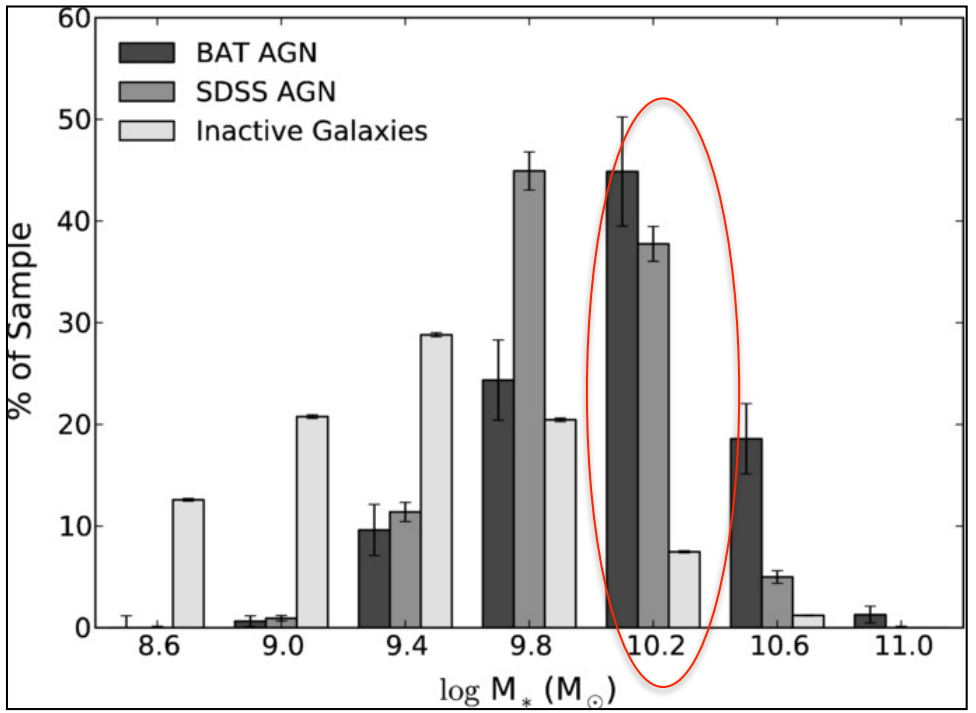
# AGN host galaxy dependence with selection method (I)

**Swift/BAT selection** - Ultra-hard X-ray selected AGN at z<0.05

- Higher fraction of spiral galaxies compared to optically selected SDSS AGN
- Bluer optical colors and excess of 90μm -> higher merger fraction and excess SF activity
- More massive than inactive galaxies and SDSS AGN

**Koss+2011**



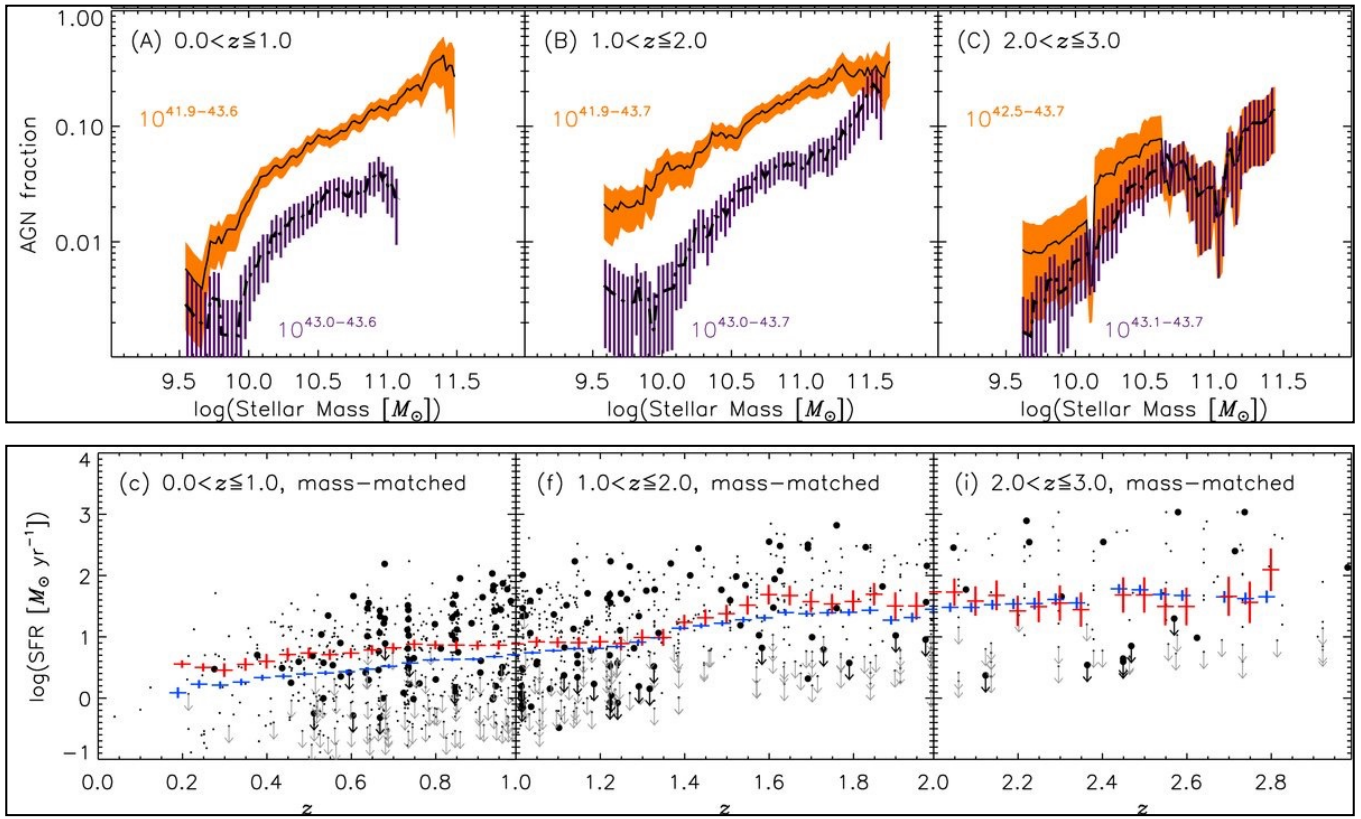



# Stellar masses and SFR of intermediate-z AGN

## X-ray selected AGN at z~0-3 from deep observations

Reside in the most massive galaxies and AGN fraction increases strongly in more massive galaxies

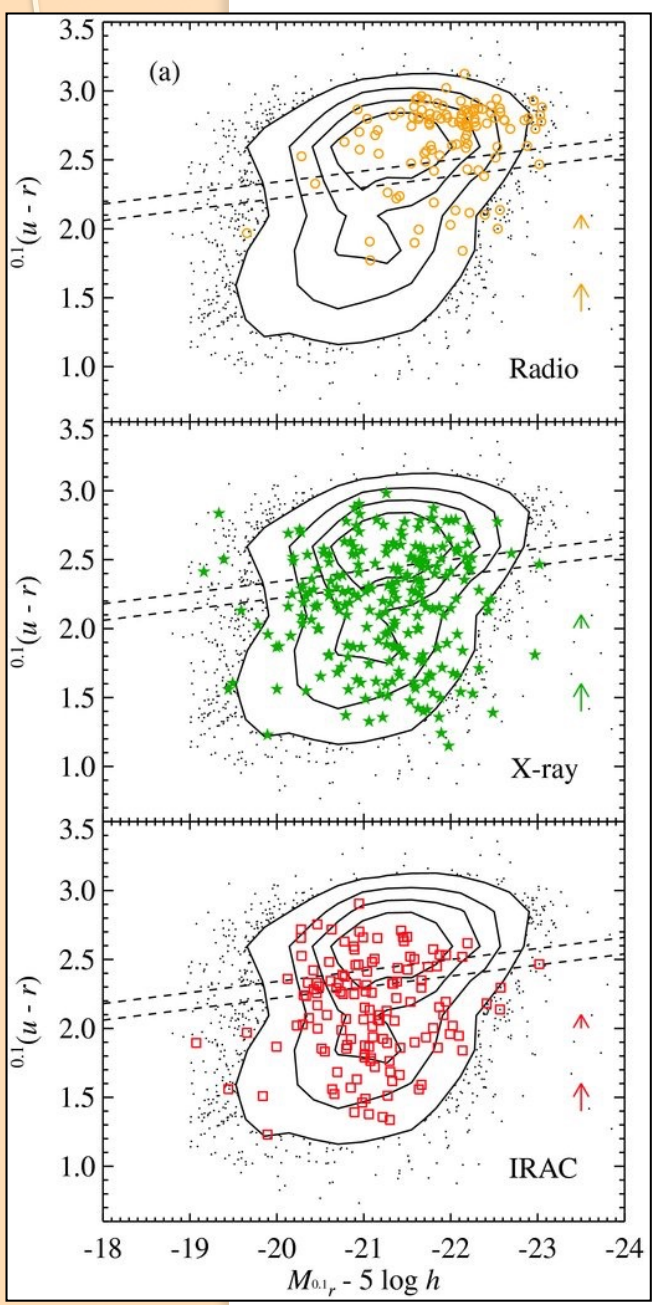
- Importance of matching AGN and non-AGN samples in stellar mass
- No color dependence of host galaxies of AGN and non-AGN




**Xue+2010,** also Alonso-Herrero+2008, Bundy+2008, Silverman+2009, Mullaney+2012, Hernán-Caballero+2014

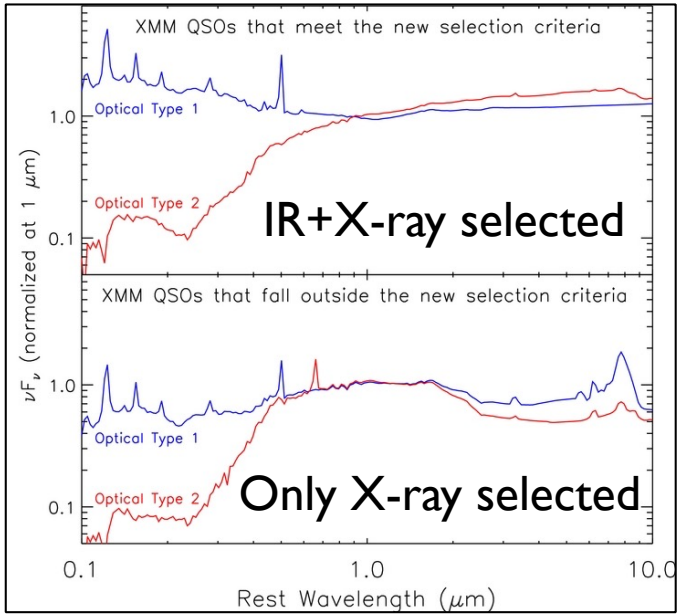
# AGN host galaxy dependence with selection method (II)

Hickox+2009

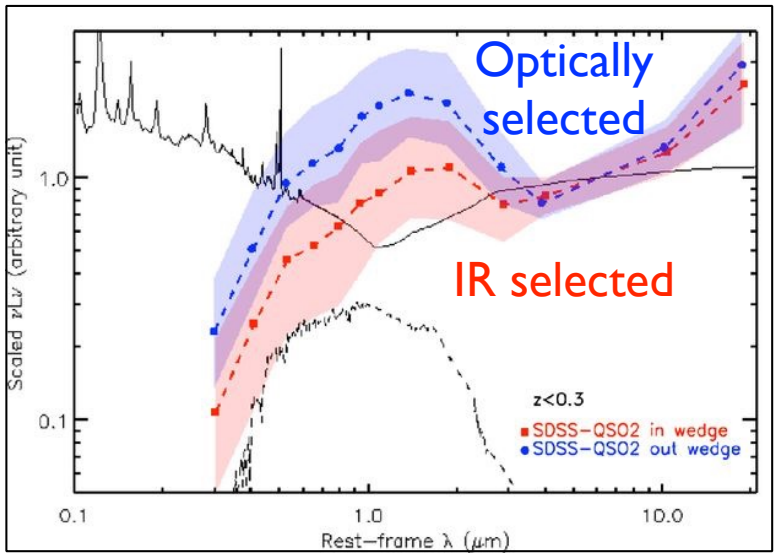



**Host galaxies of distant radio-loud AGNs** typically lie in the "red sequence" of the CMD, as expected for massive elliptical galaxies.

**Host galaxies of infrared selected AGN** might be less massive than optically and X-ray selected AGN to be able to see "the IR part of the AGN emission"

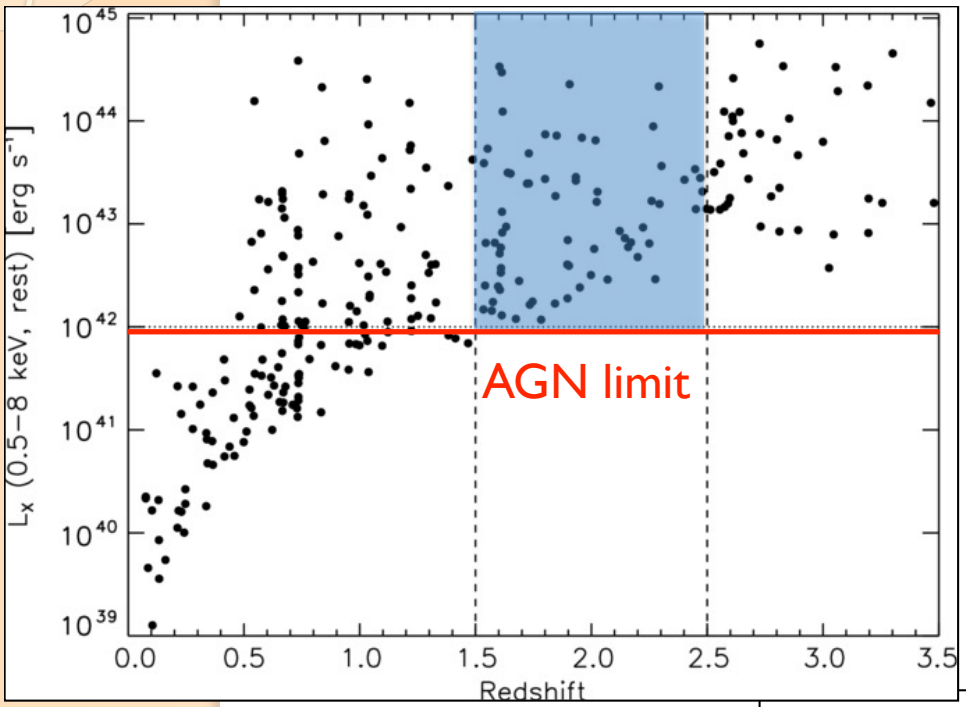



**Donley+2012,** see also Mendez+2013




**Mateos+2013**

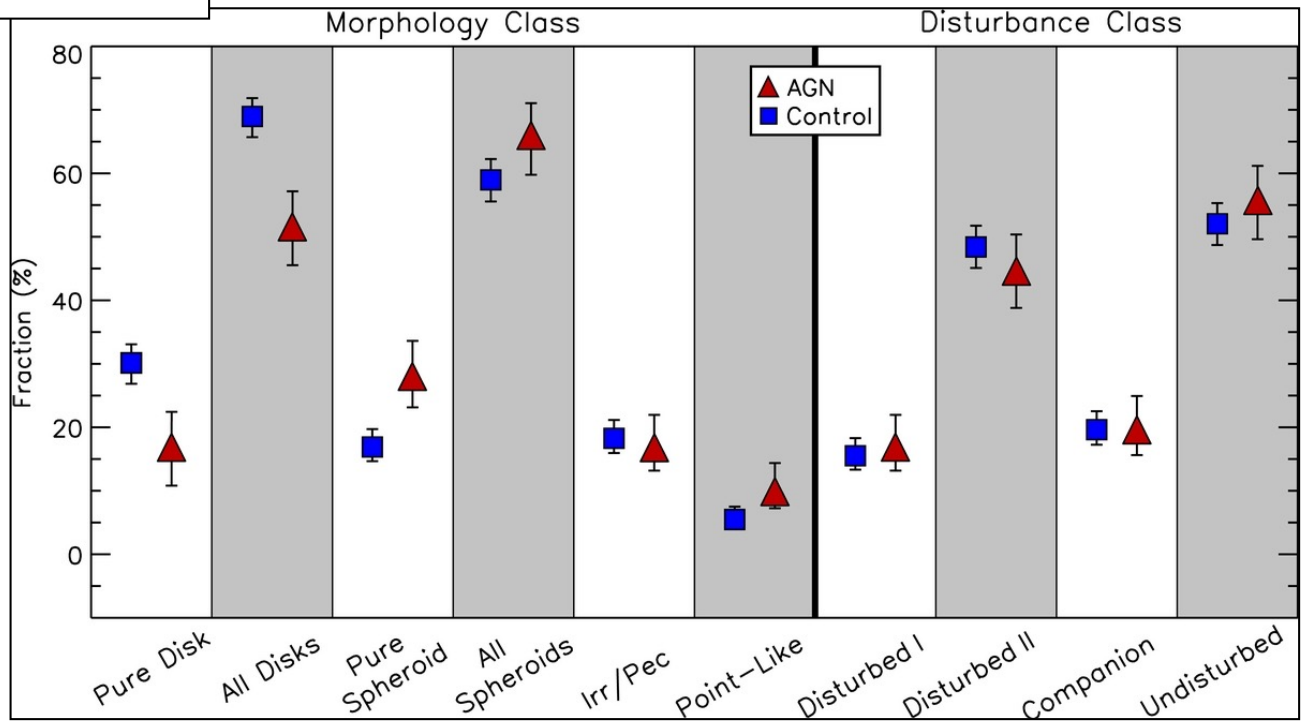
# Do major mergers drive AGN activity?




**X-ray selected AGN** - "Seyfert-like" luminosities at z~1.5 - 2.5, activity not driven by mergers

- ~50% reside in disk galaxies
- ~28% spheroids
- ~17% disturbed morphologies (mergers/ interactions)

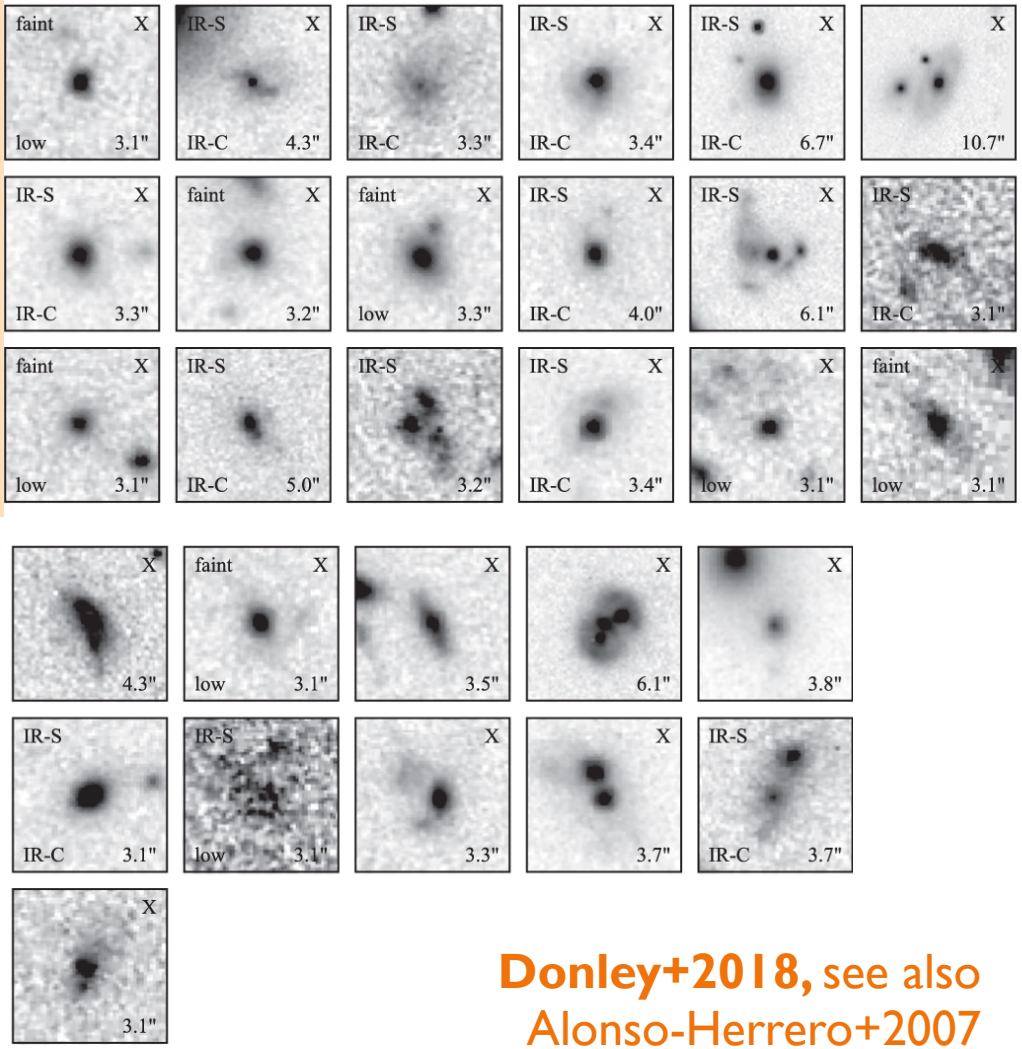
**Kocevski+2012**



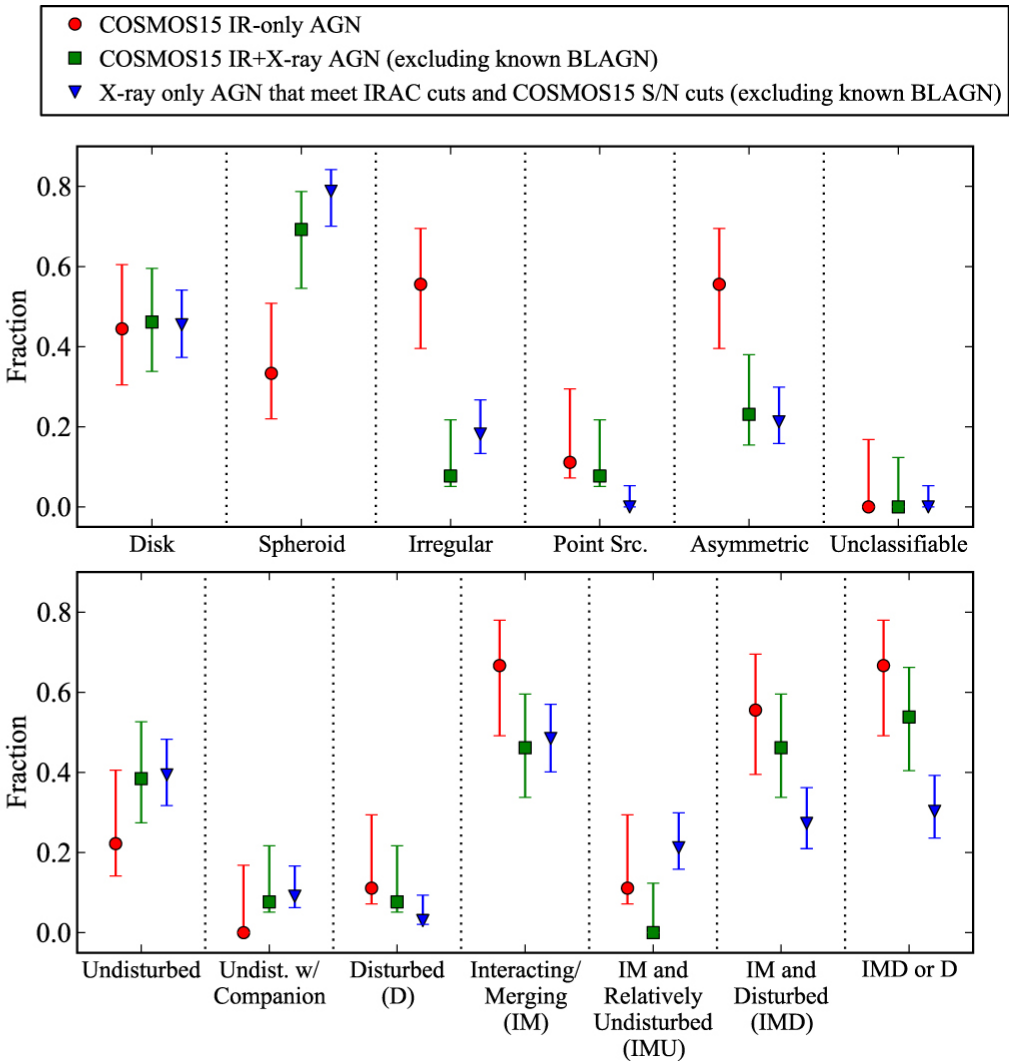

See also Schawinski +2011, Cisternas+2011, Villforth+2014, Rosario +2015

# However IR selected AGN…

- … are luminous and heavily-obscured AGN and more likely to be classified as irregular and asymmetric than X-ray selected AGN and more likely to be classified as disturbed and interacting

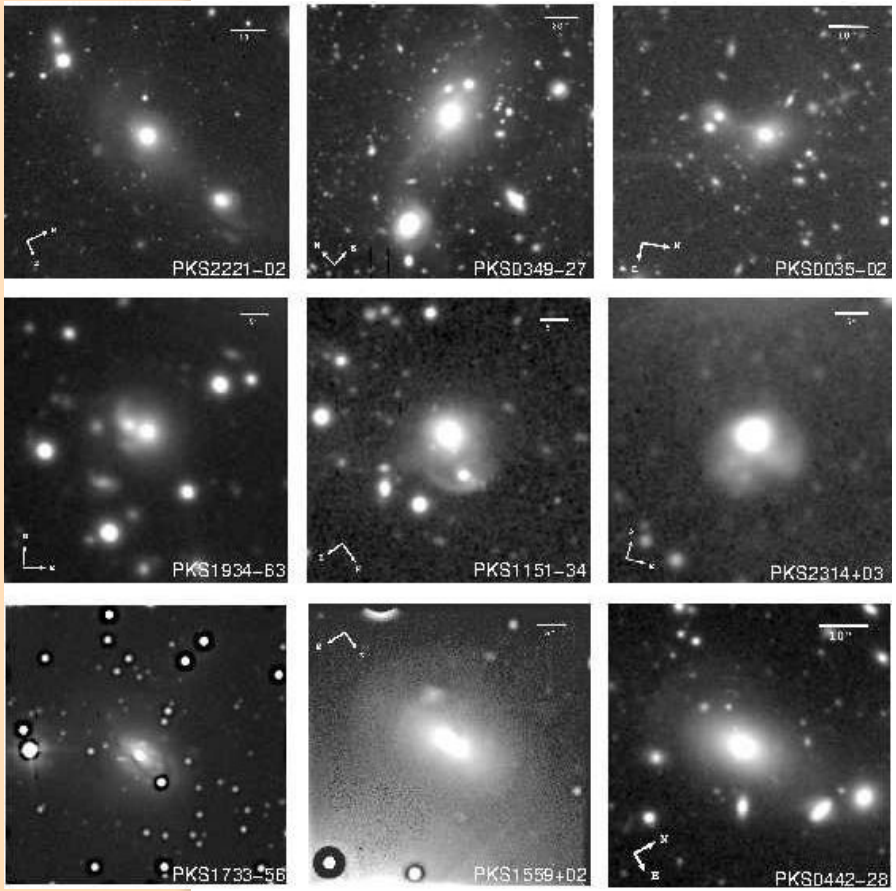



**Donley+2018,** see also Alonso-Herrero+2007

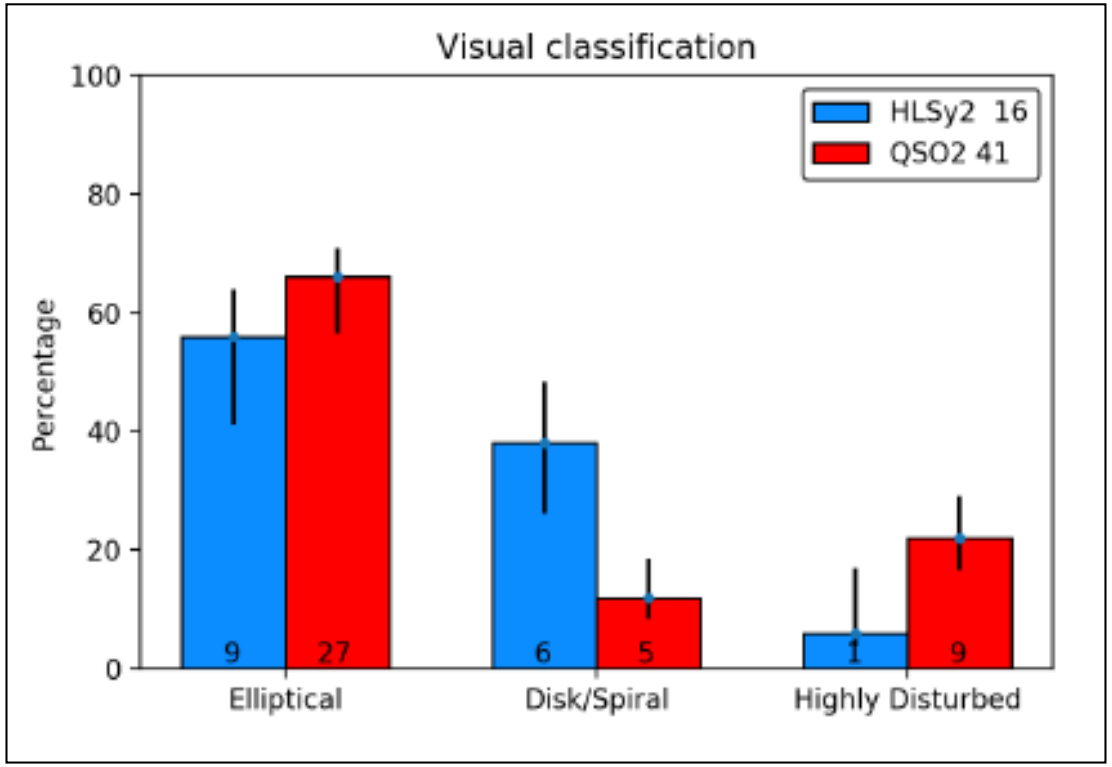


# Radio galaxies and quasars

- Radio galaxies and type 2 quasars show a higher incidence of hosts with disturbed/peculiar morphologies → past or on-going interactions but mergers not dominant
- QSO 1 hosts are mostly bulge dominated galaxies but still a lot of conflicting results and QSO 2 hosts show a small fraction of disk-like galaxies



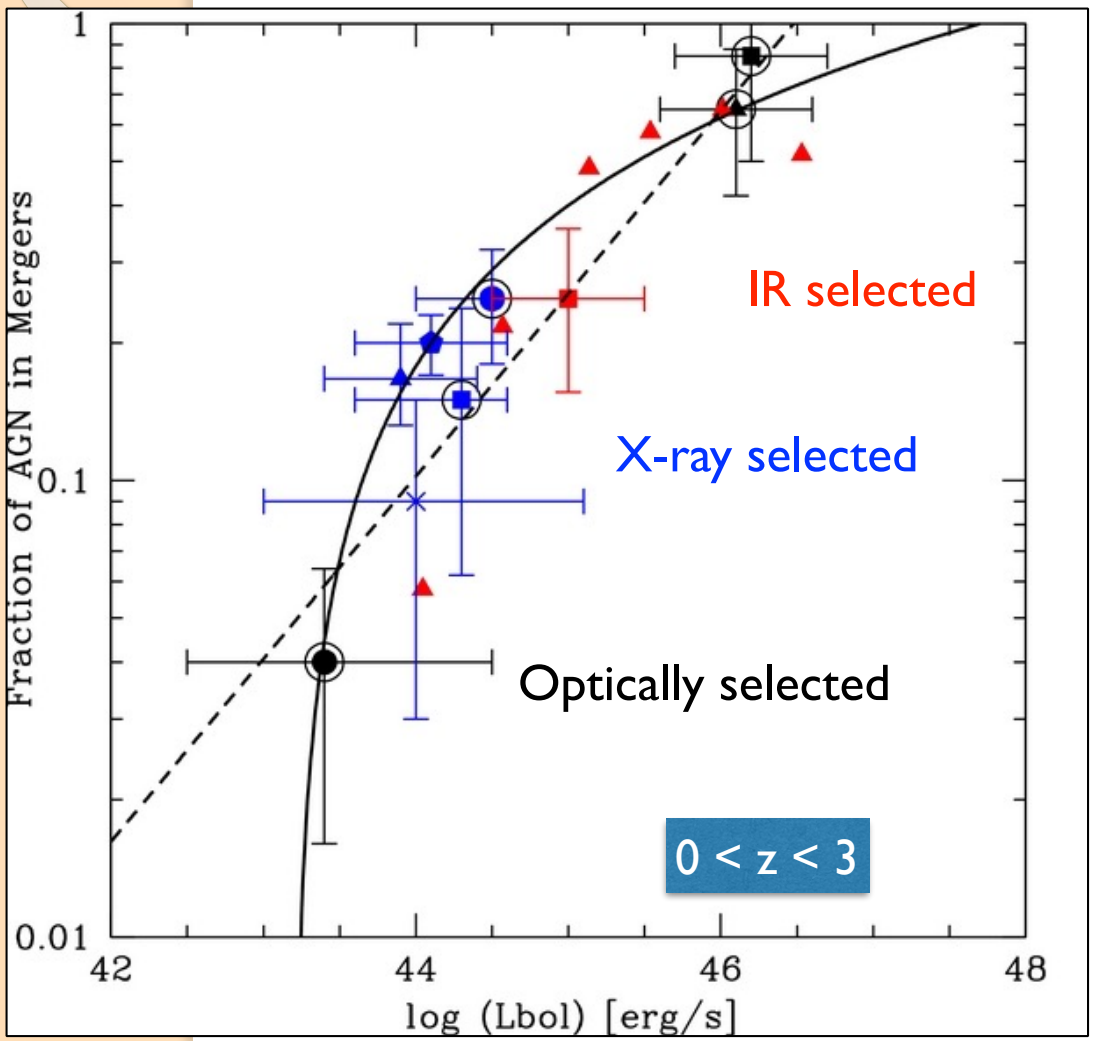

Ramos Almeida+2011




**Mayorgas-Urbano, Villar-Martin+2018,** see also Dunlop+2003, Green+2009, Cales+2011, Bessiere +2012, Falomo+2014, Wylezalek+2016, Villforth+2017

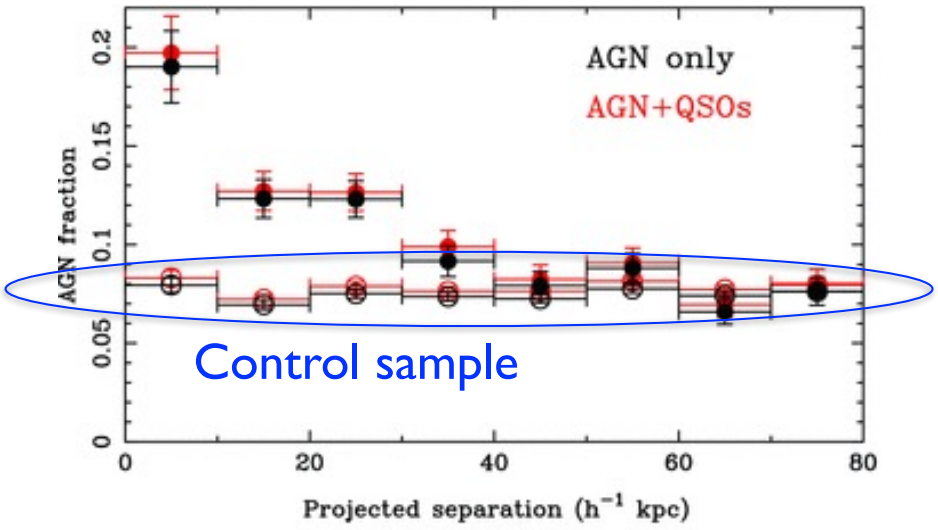
# Fraction of AGN in mergers and interacting galaxies with AGN

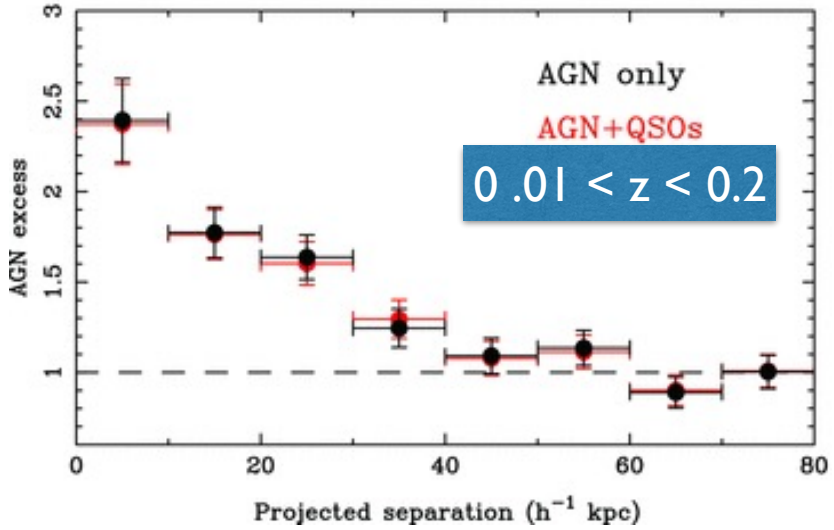
- Most luminous AGN appear to be connected with major mergers
- Excess of AGN in interacting galaxies




Treister+2012

Ellison+2011

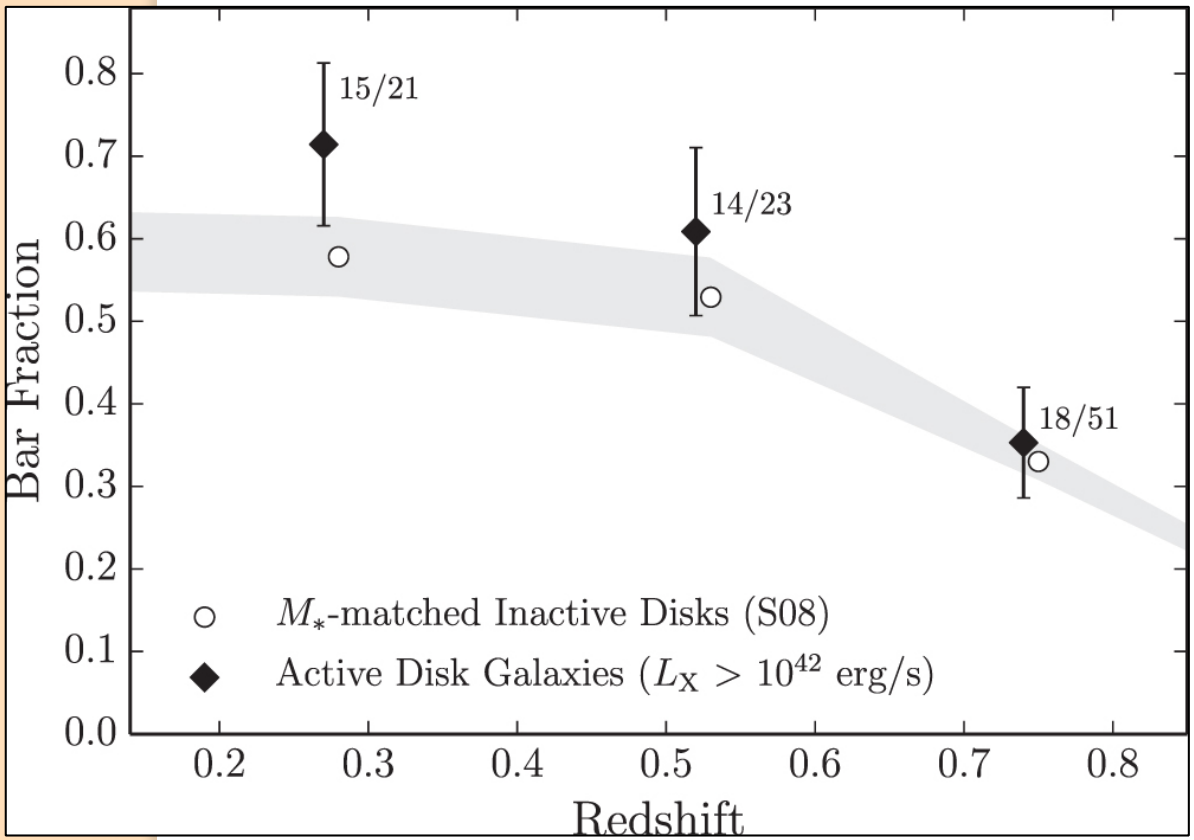


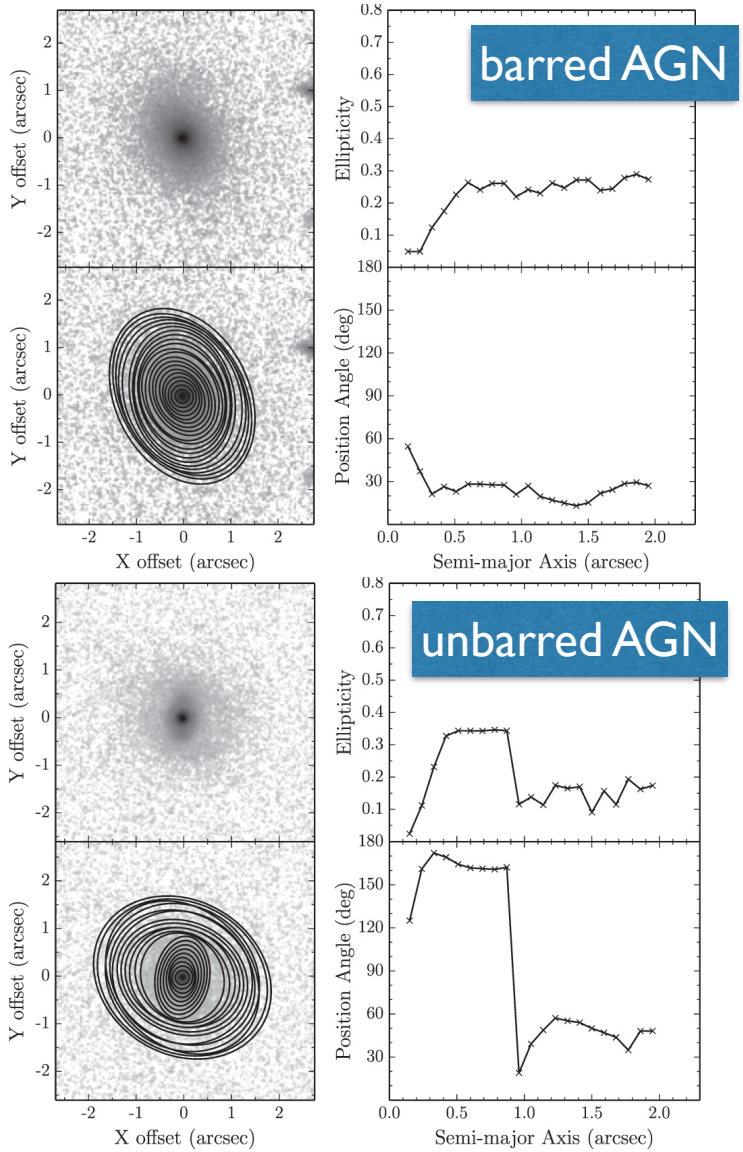



# Bars in AGN vs. non-AGN

**X-ray-selected AGNs at 0.15 < z < 0.84** - HST imaging:

- similar evolution of bar fraction for AGN and non-AGN
- barred and unbarred galaxies show indistinguishable levels of AGN activity

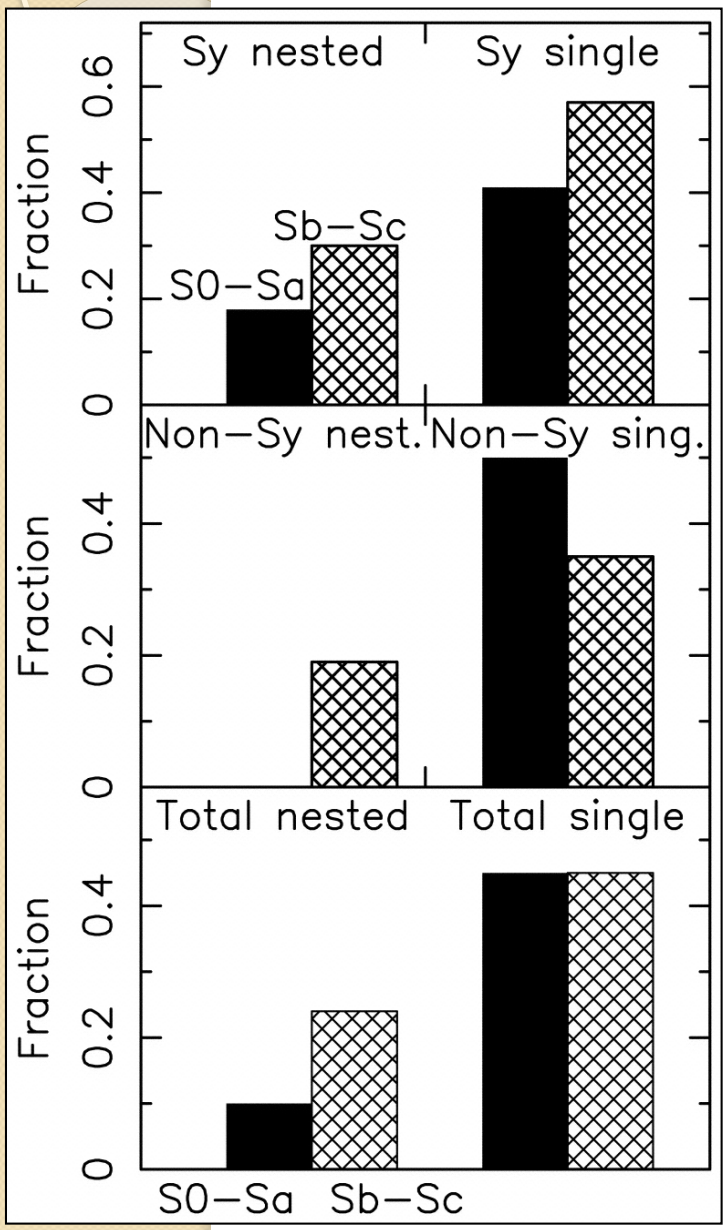



**Cisternas+2015, 2013** see also Ho+1997, Knapen+2000, Hunt & Malkan 1999, Regan & Mulchaey 1999

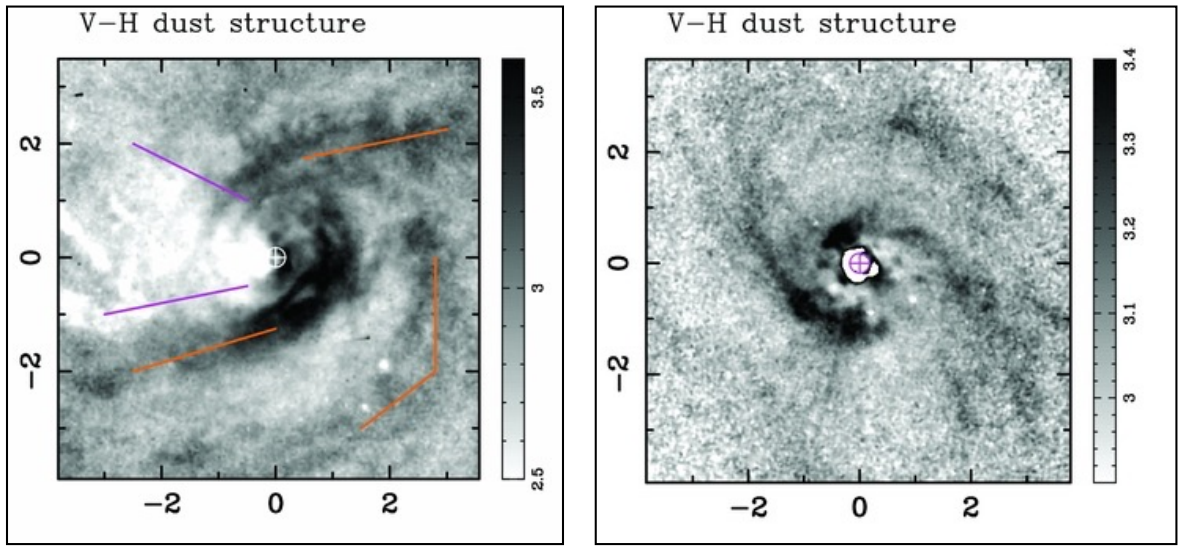
# Nested bars, nuclear spirals, dusty features

Laine+2002



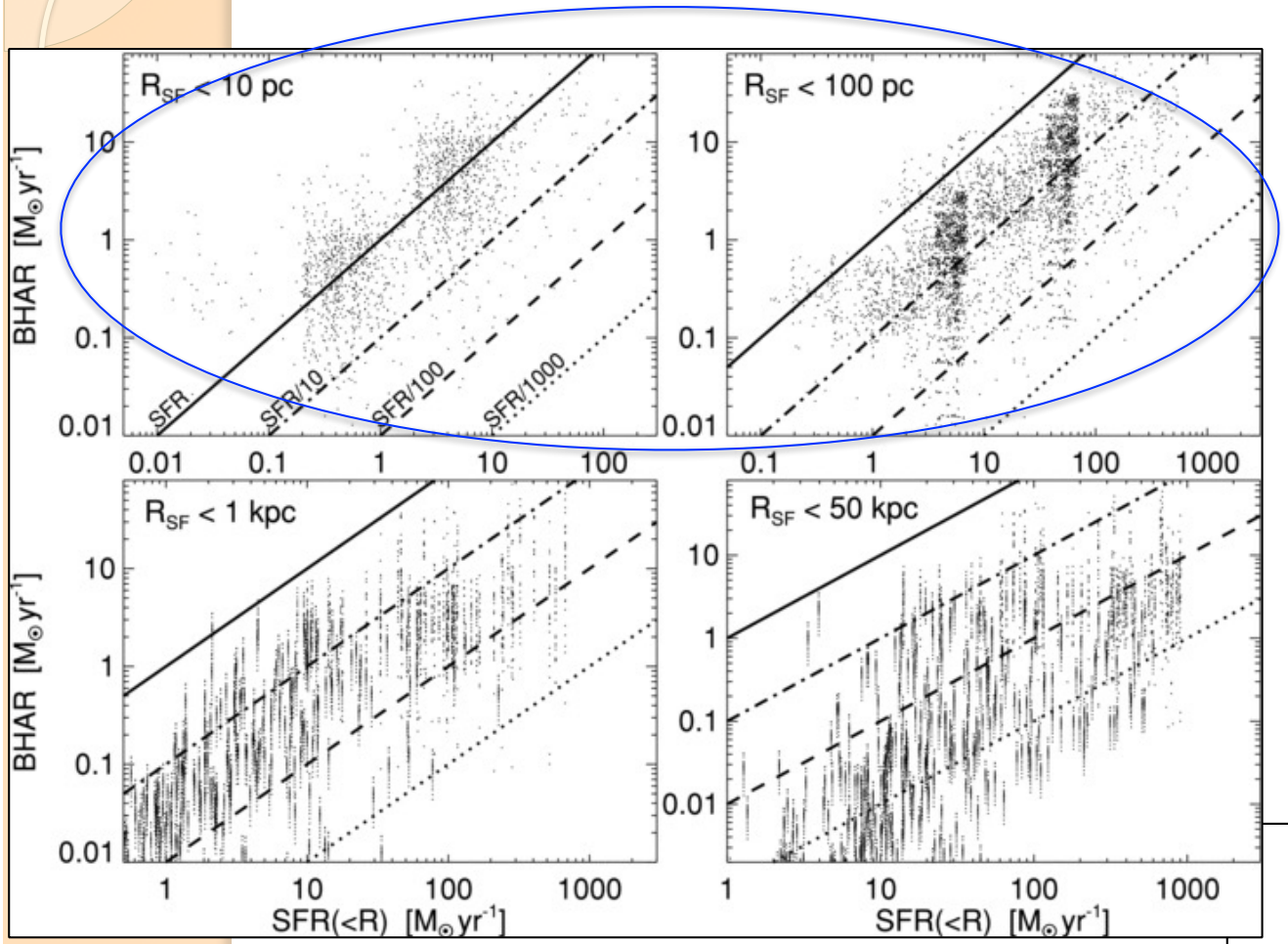

**Nearby Seyfert and matched non-Seyferts** - HST imaging

- Seyferts have an excess of bars, with 73% ± 6% having at least one bar, against only 50% ± 7% of non-Seyferts
- Nuclear dusty features and mini-spirals are common in both AGN and non-AGN. The latter could reflect future inflow for the non-AGN




Davies+2014, also Martini+2003

# Star Formation Activity and AGN

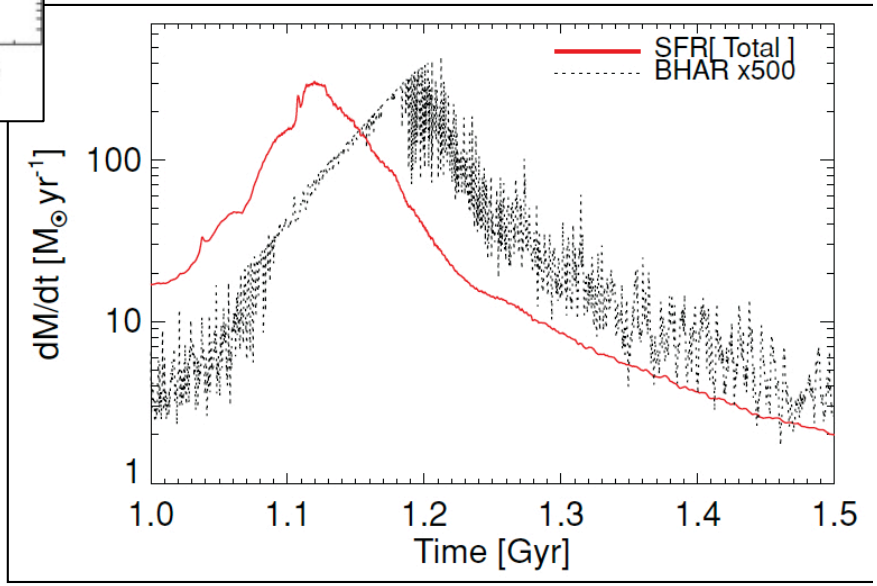



**Hopkins & Quataert 2011**

Predictions from numerical simulations:

nuclear star formation is more tightly coupled to active galactic nucleus activity than the global star formation rate of a galaxy

**Hopkins+2012**



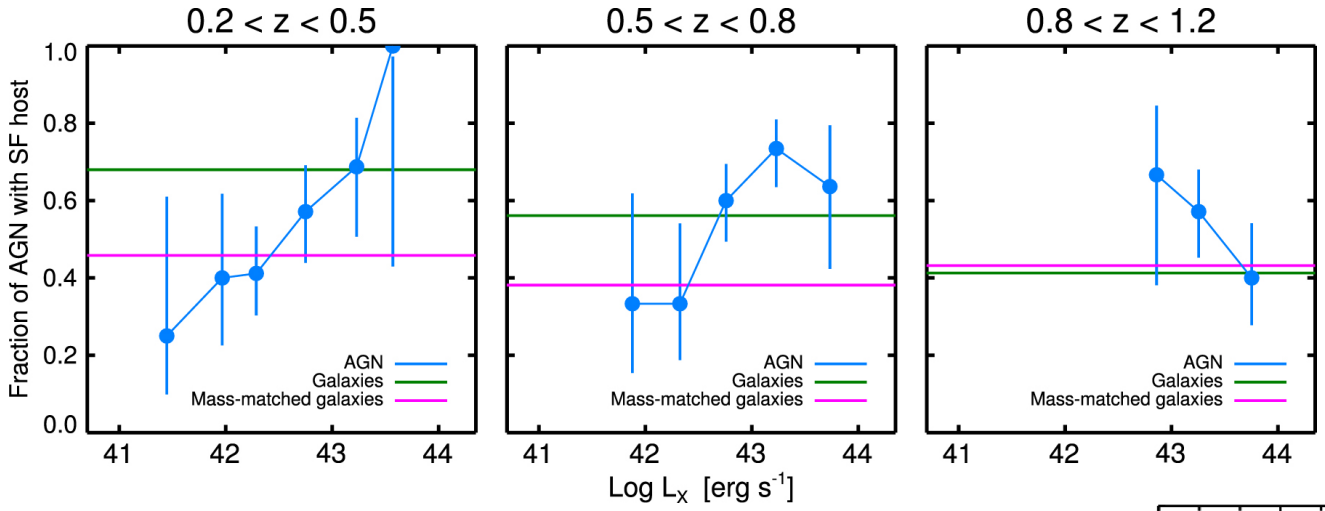

Peak of AGN activity occurs ~50–200 Myr after onset of SF activity

delays between AGN and SF activity

# Are AGN more likely hosted by SF galaxies?

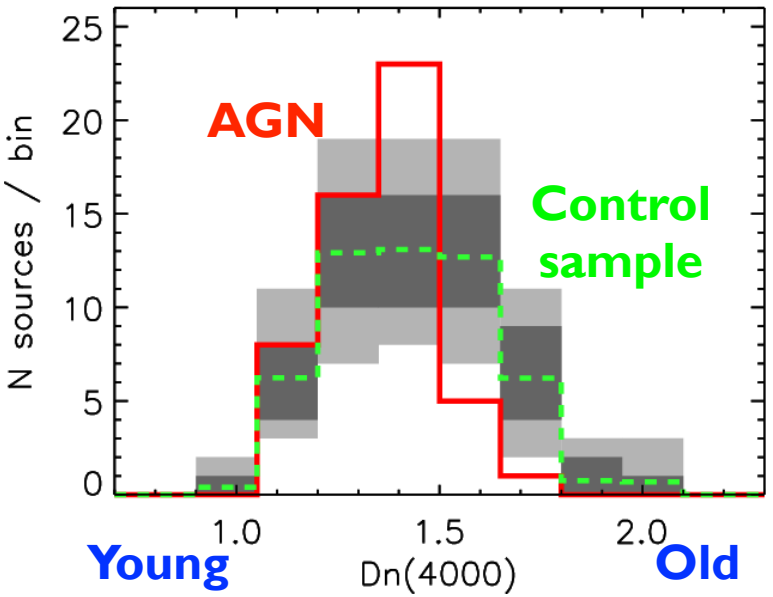
**Deep X-ray observations -** X-ray selected AGN out to z~2

- Fraction of AGN in star forming galaxies is higher for more luminous AGN
- No strong correlation between integrated SFR and $L_{AGN}$




**Azadi+2015**

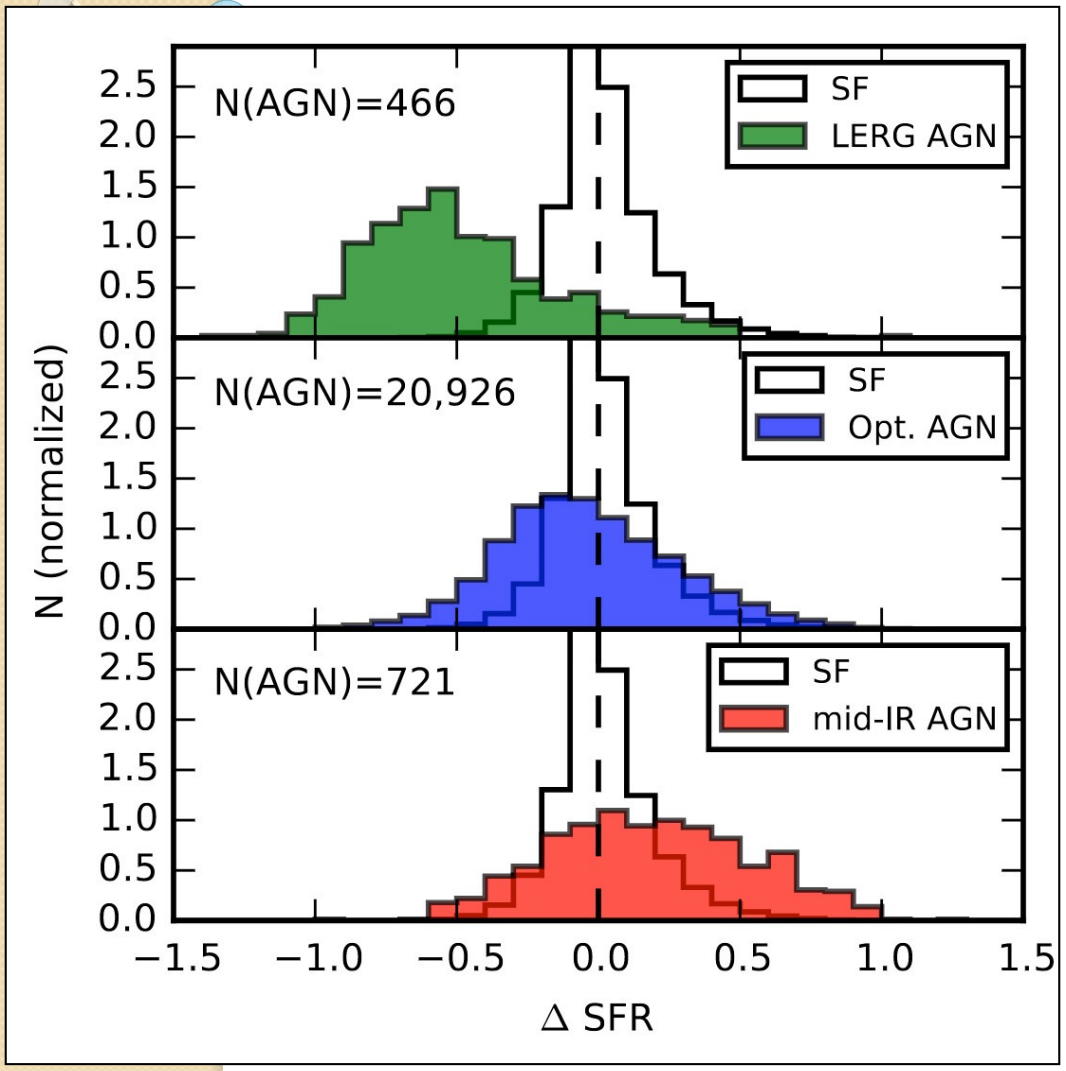
- AGN are more likely to be hosted by star-forming galaxies and/or galaxies with *younger* stellar populations -> SF first, then AGN activity




**Hernán-Caballero+2014,**
also Kauffman+2003 at low z for optically selected AGN

# … dependence on AGN selection method

**Ellison+2016**



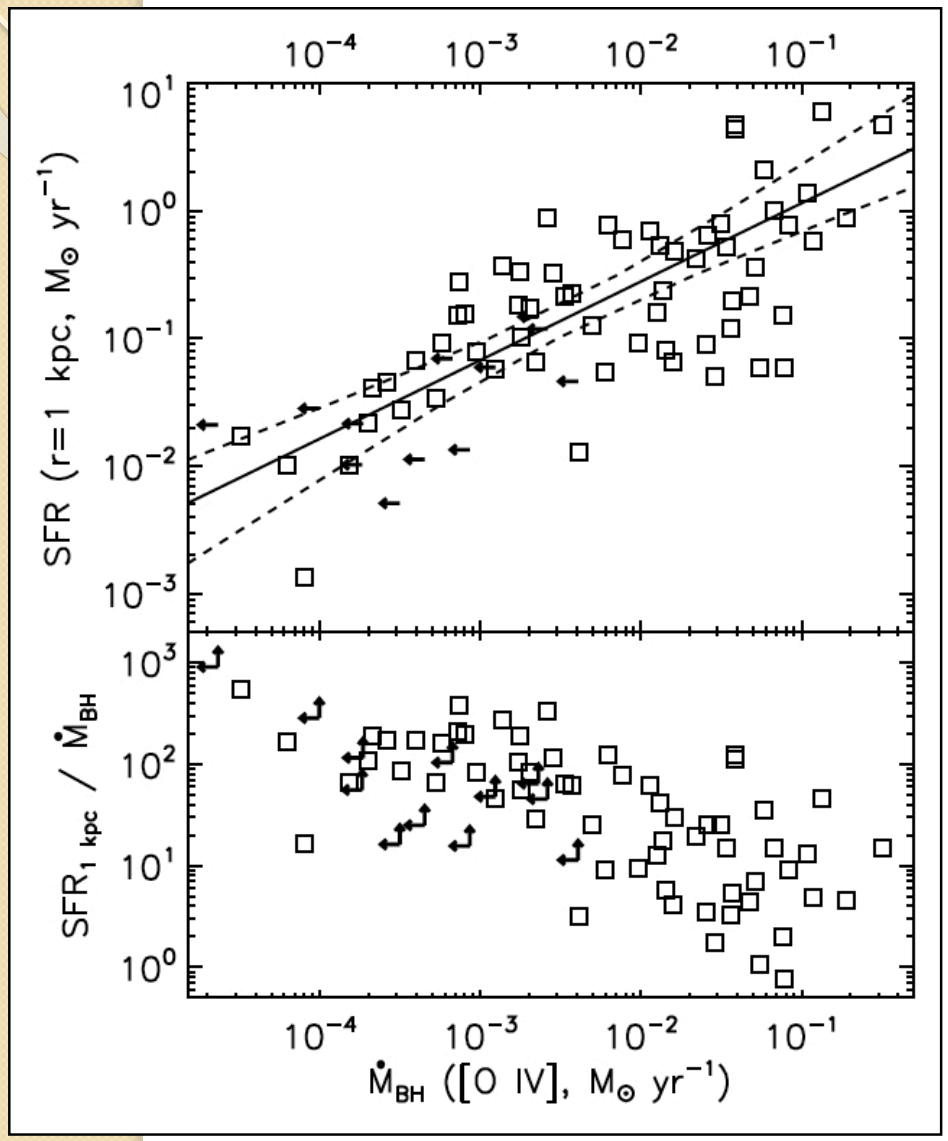

**Redshift range 0.04 < z < 0.15 and SFR from SDSS spectra**

- IR selected galaxies show a median SFR enhancement of a factor of ~1.5 due probably to higher fraction of mergers
- Optically selected AGN show a slight under abundance of SFR
- Low luminosity radio-selected show SFR a factor of 3 lower than SF galaxies, probably dominated by secular fuelling processes

See also for other works on issue of star forming hosts in AGN: Salim+2207, Silverman+2009, Santini+2012, Juneau+2013, Rosario+2012, 2013, Mullaney+2012, Shimizu+2015

# Nuclear/Circumnuclear SF vs. BH accretion rate

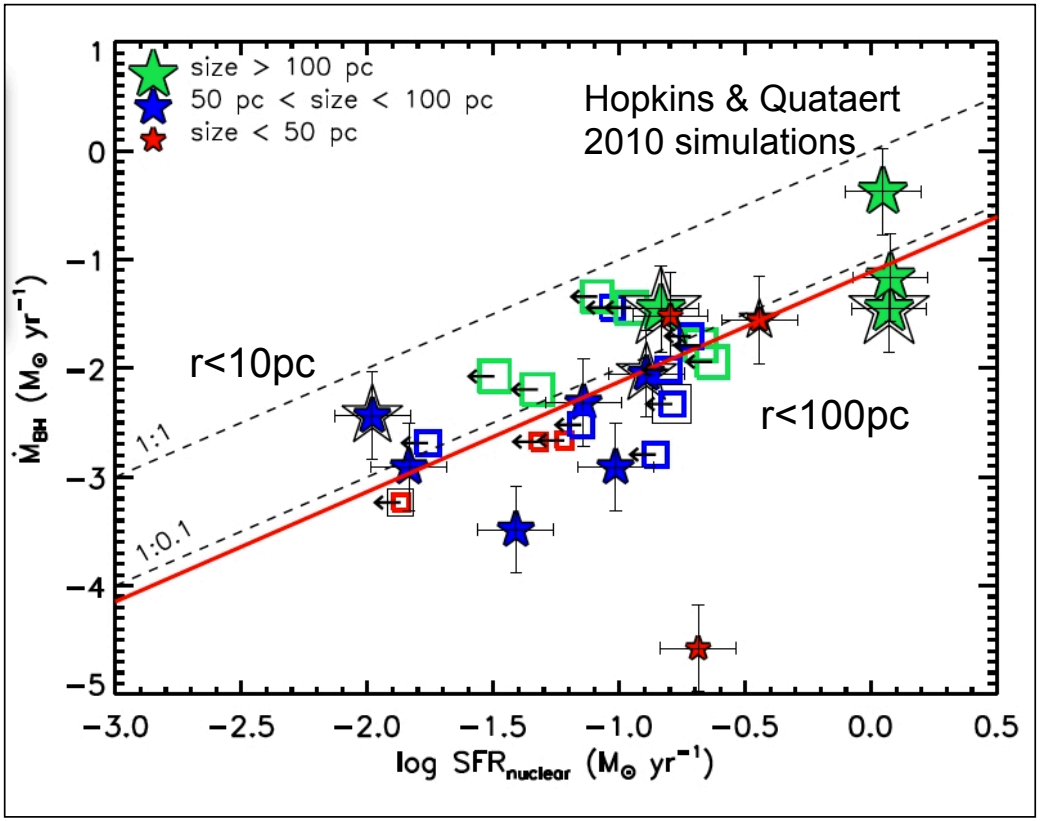
**Diamond-Stanic & Rieke 2012**




**Circumnuclear** (r=1kpc) SFR from Spitzer 11.3μm PAH and 24μm

**RSA sample of AGN -** optically identified in magnitude selected sample in the local Universe

**Esquej+2014**



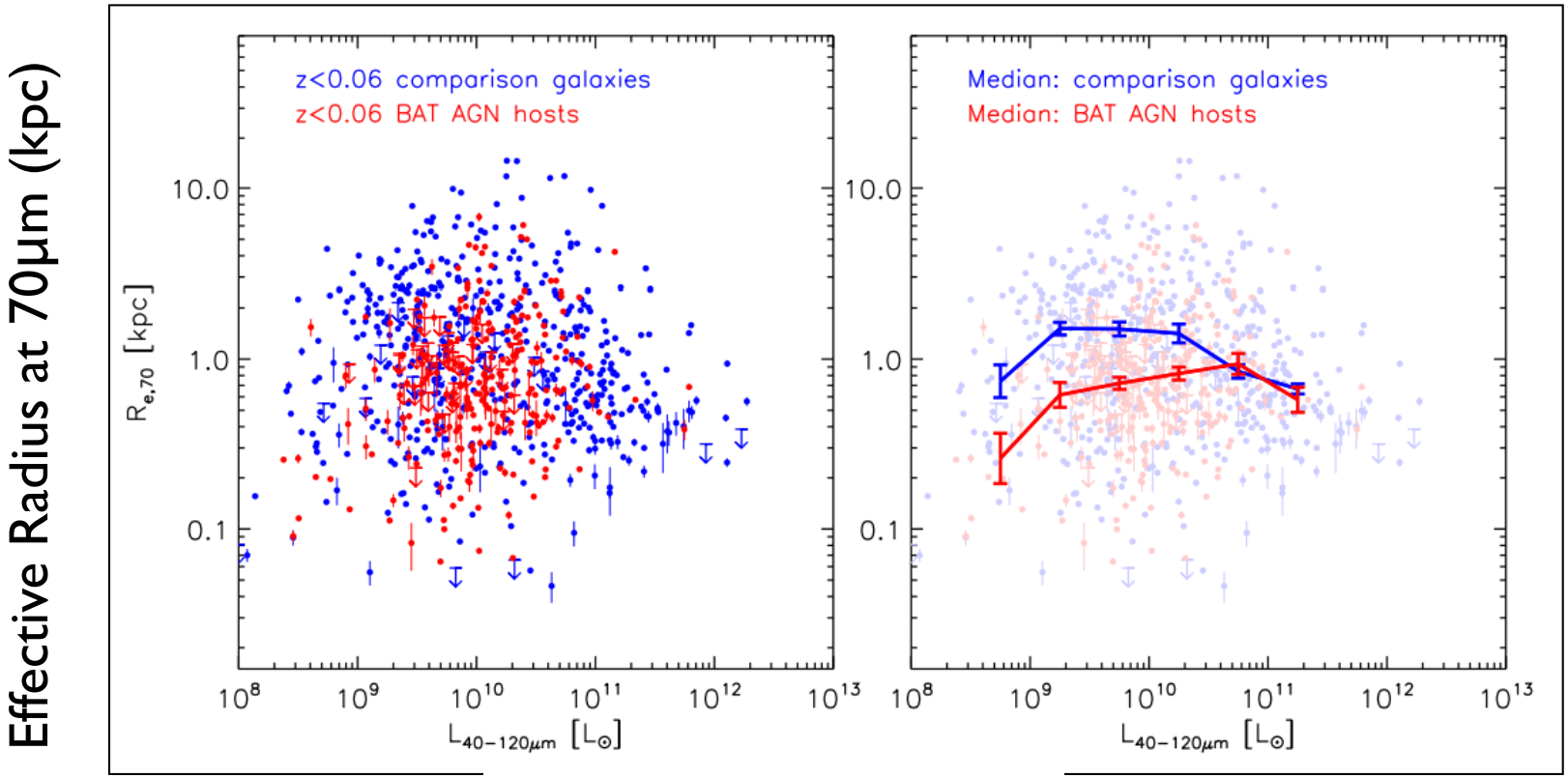

**Nuclear** (r=50-200pc) SFR from ground-based 11.3μm PAH

# X-ray selected AGN prefer compact circumnuclear activity

**Swift/BAT X-ray selected AGN at z<0.06** - median size of 70μm emitting regions are smaller than in comparison galaxies

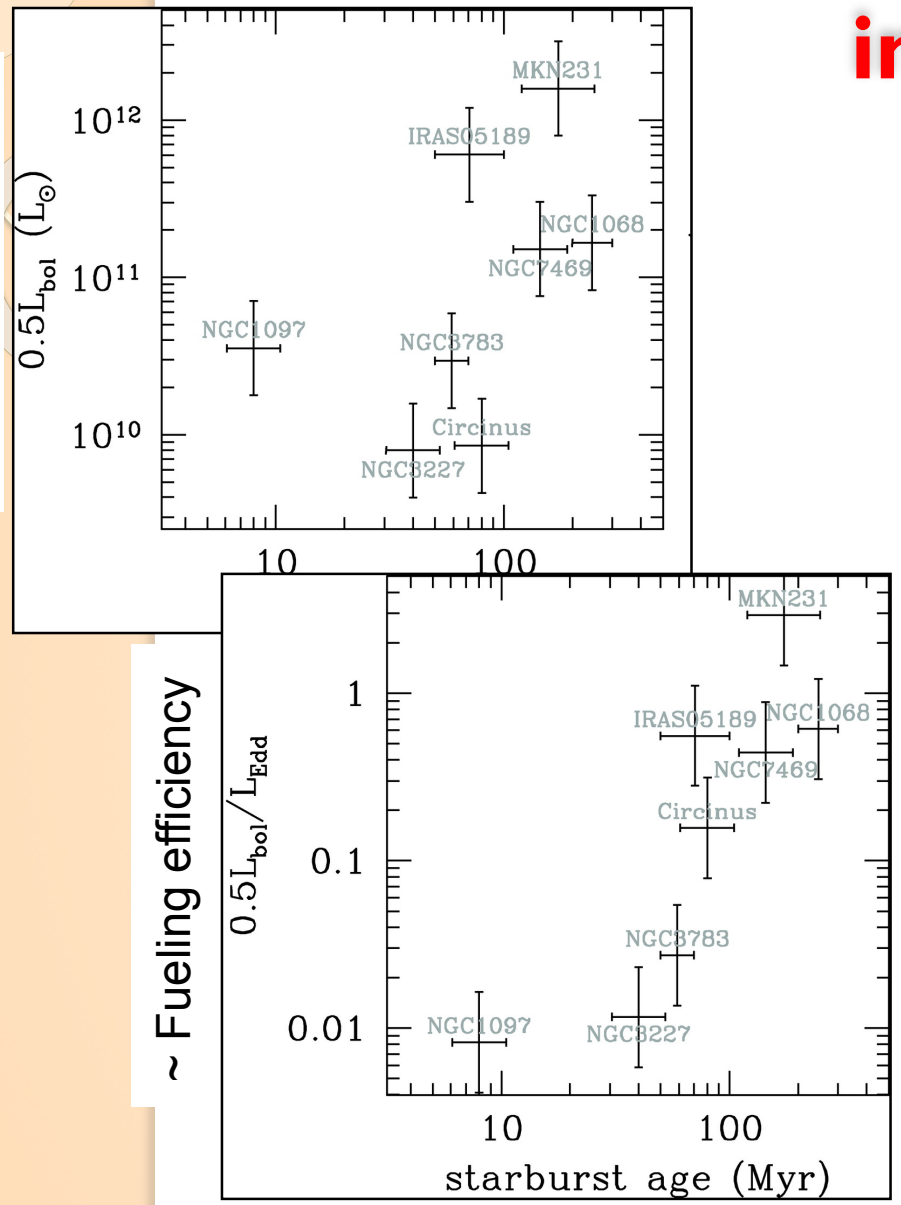
- *Compact* star forming regions may favor AGN feeding at SFR of less than ~6$M_\odot$/yr

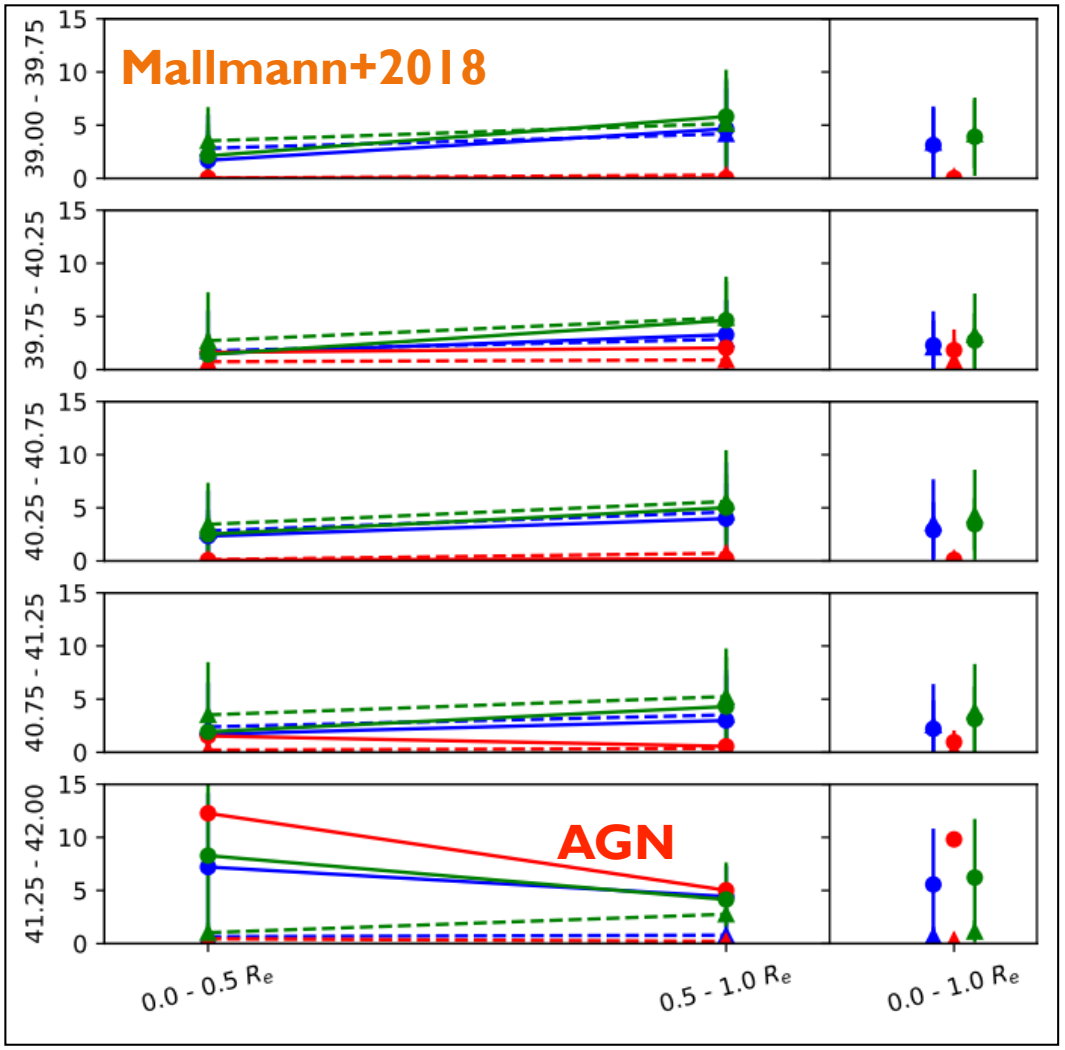
Lutz+2018



# Ages of stellar populations in (circum)nuclear regions

Davies+2007



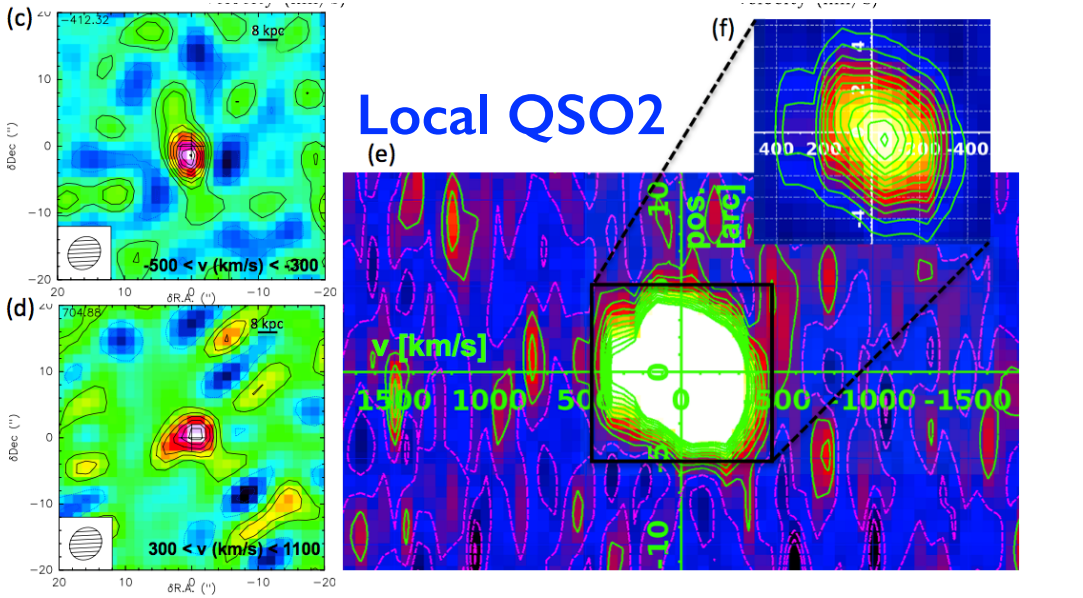

Peak of AGN activity occurs ~50–200 Myr after onset of SF activity

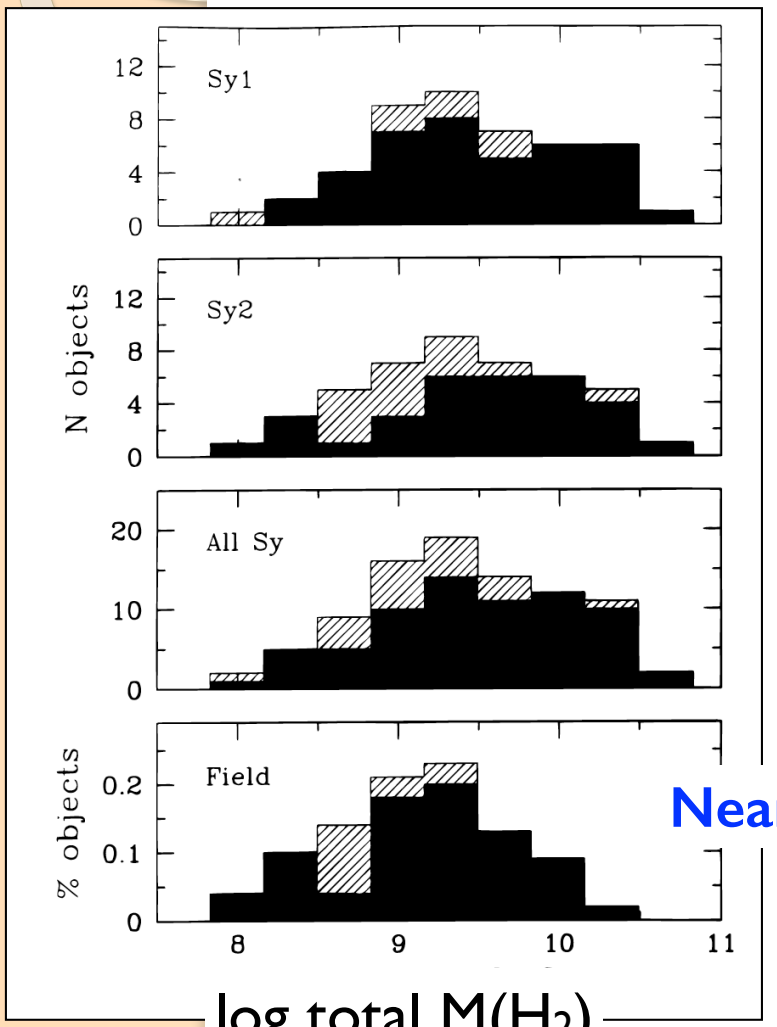
Fraction of young stellar(1-40Myr) populations in inner regions is only higher in luminous AGN compared to non-AGN

# Molecular Gas

Many AGN at all redshifts have large quantities of molecular gas but integrated values are more related to star formation activity and massive outflows

Cicone+2014

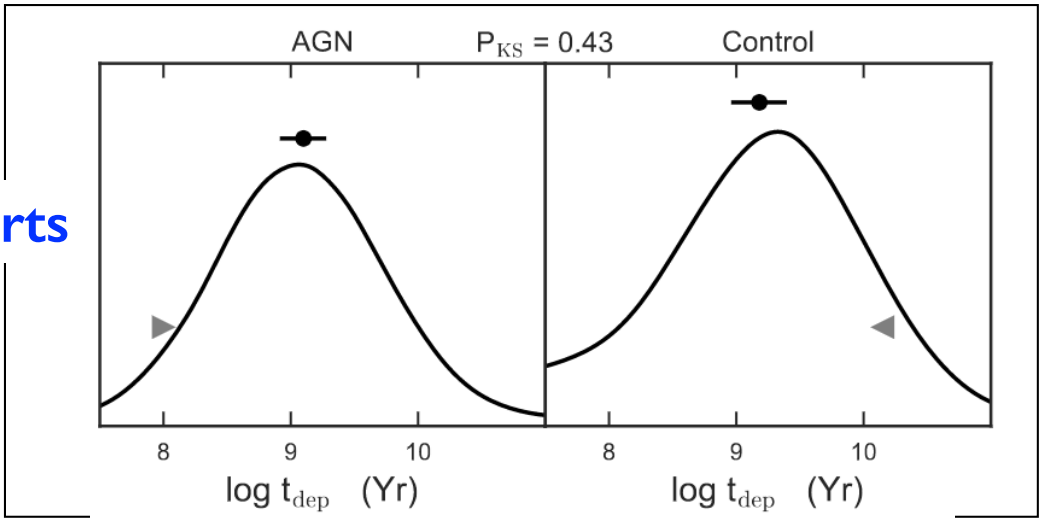



Nearby Seyferts

Maiolino+1997

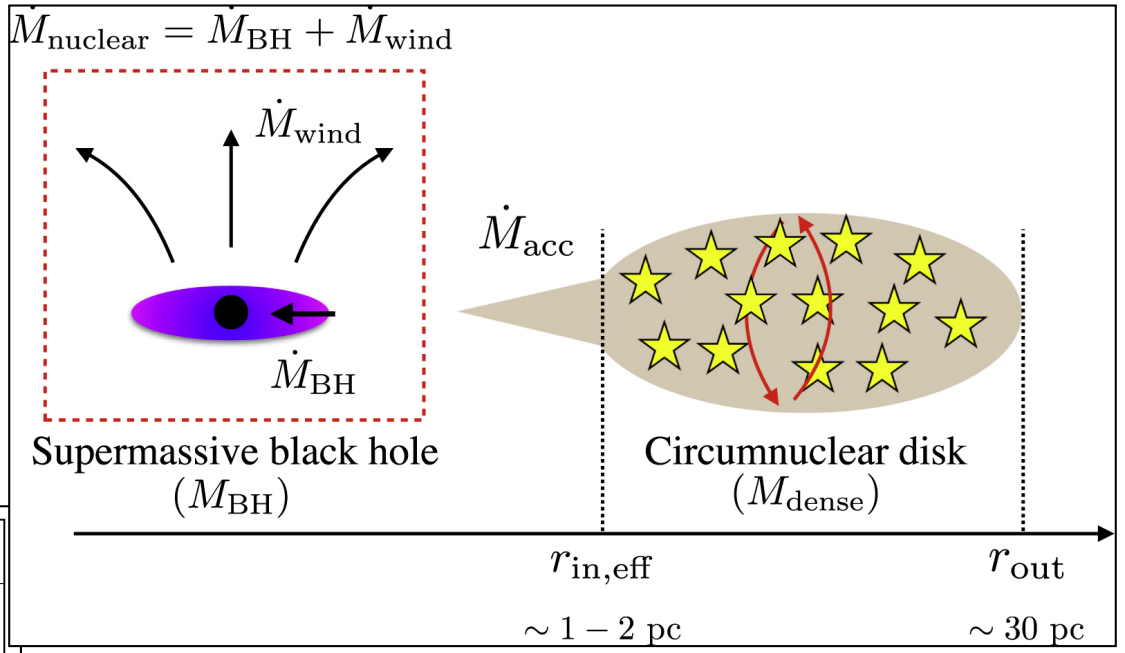
Rosario+2018

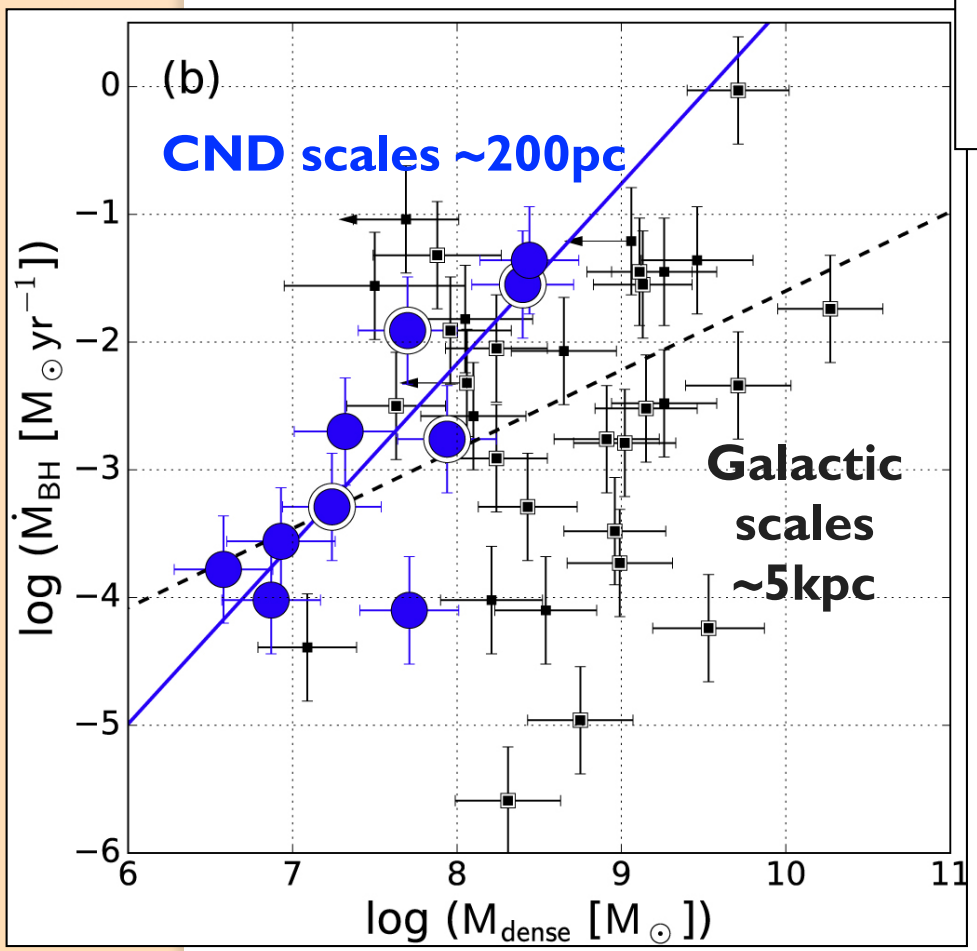


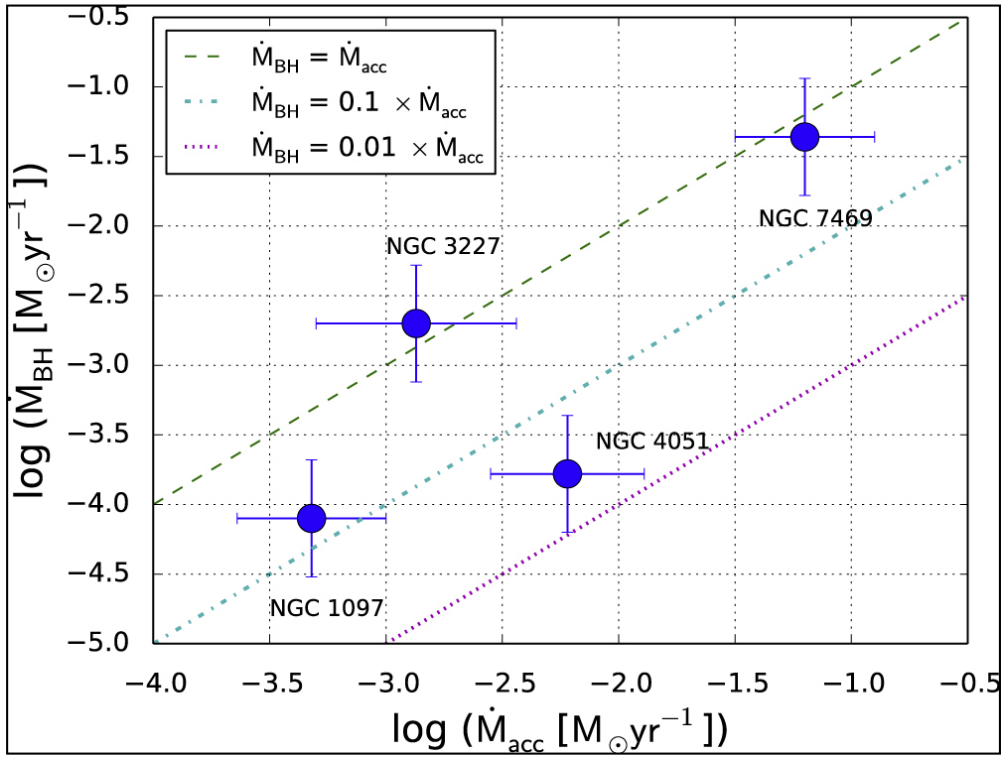

scales 3kpc SF depletion time (yr)

# CNDs, Inflows, Outflows, and BH accretion rates

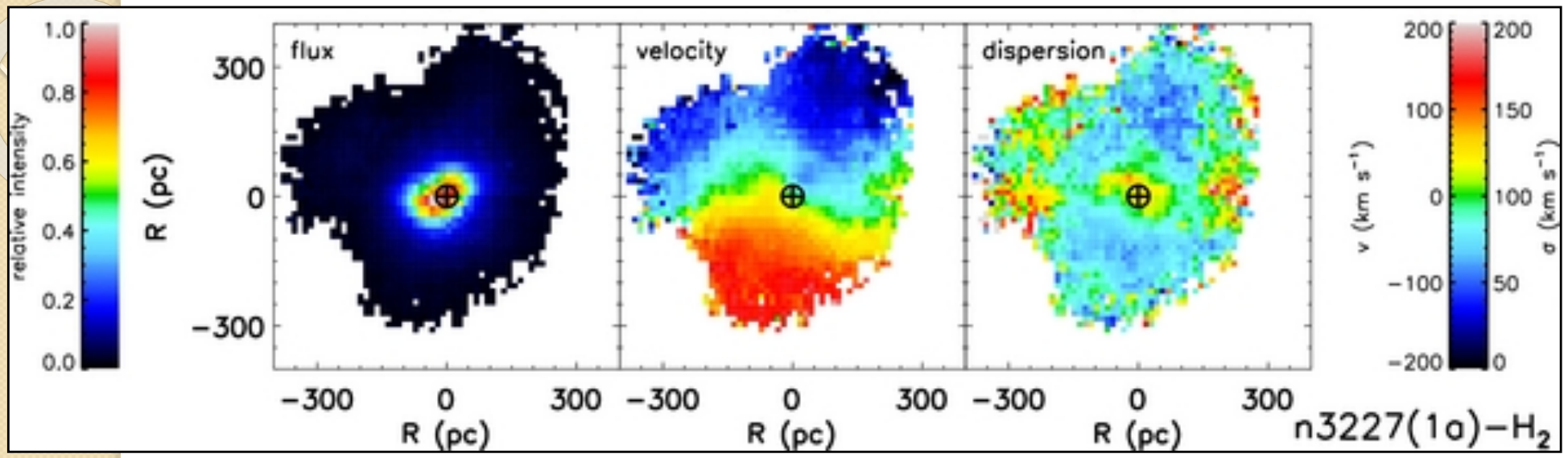
Izumi+2016



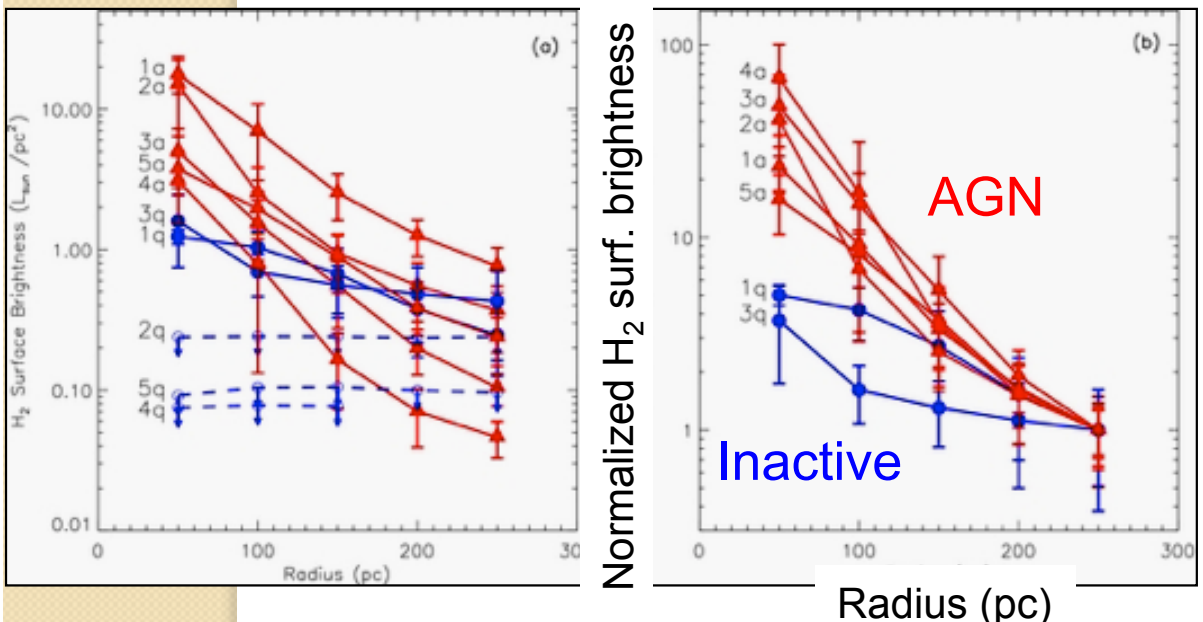



# Molecular gas nuclear disks in active and inactive galaxies




Hicks+2009, 2013

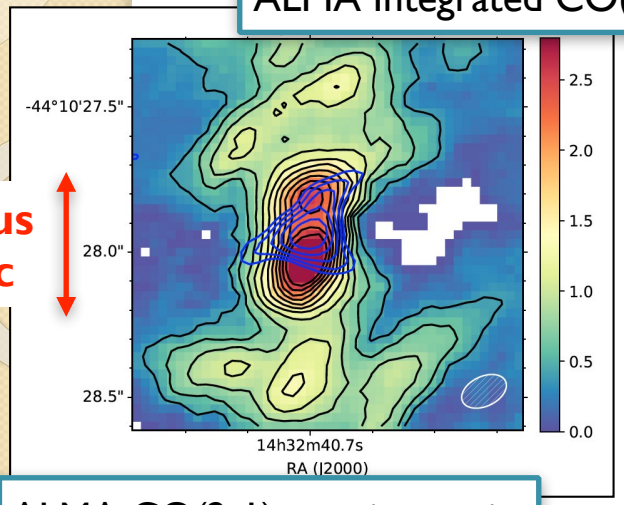



Seyferts show **rotating nuclear thick $H_2$ (hot molecular gas at 2.12μm) disks (d~60pc)** with enhanced $H_2$ emission compared to non-active galaxies

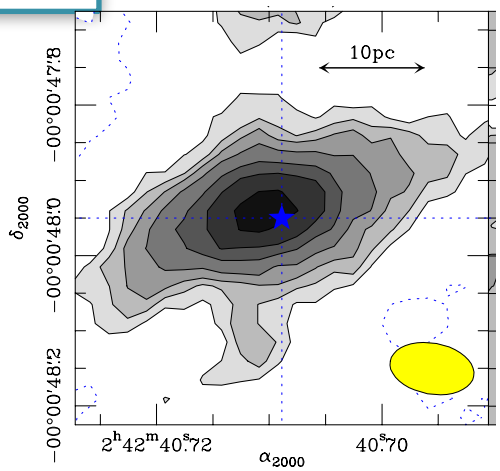
Role in feeding AGN, SF?

# AGN flickering and molecular gas reservoirs

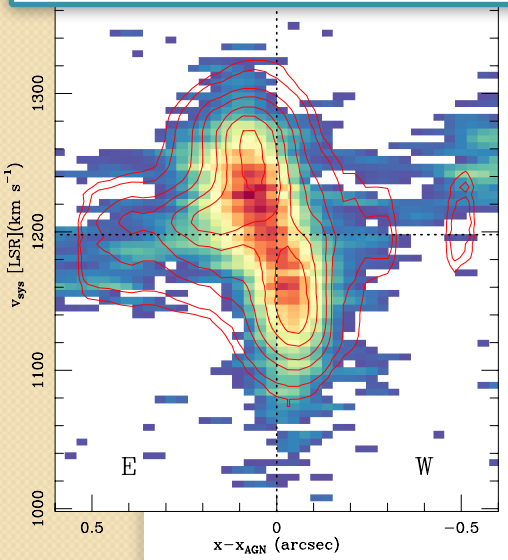
ALMA Integrated CO(2-1)

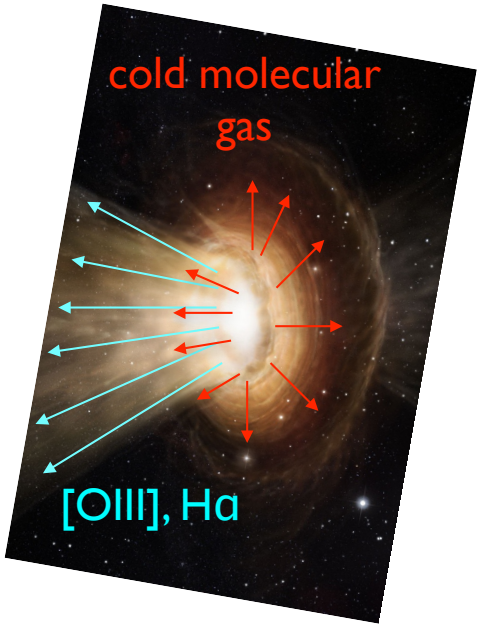


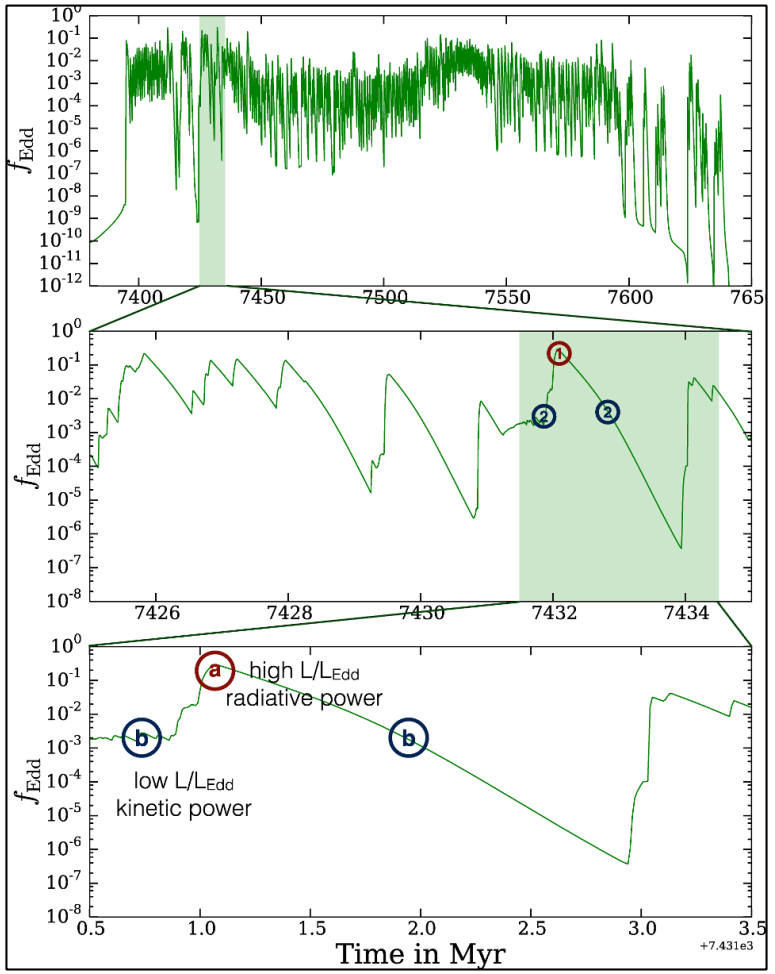

Torus
26pc




ALMA CO(2-1) pv minor axis




Alonso-Herrero+2018,
García-Burillo+2018 in prep.

Schawinski+2015

**Massive tori (r~10pc)** with $M_{GAS}$~$10^6$-$10^7 M_\odot$ and outflowing in equatorial/ vertical direction with v~100km/s ➡ would take ~$10^6$ yr to disappear

# Conclusions

- AGN reside in the most massive galaxies whose properties depend on:
  - AGN luminosity, AGN selection method, physical scales involved
- Luminous AGN have a higher incidence of major mergers while mass matched AGN and non-AGN show similar bar fractions
- SF activity is related to AGN luminosity when measured on <1kpc scales and AGN tend to show signs of young stellar populations (SF first then AGN activity?)
- The physical scales relevant to AGN activity are <100pc
  - AGN show more centrally concentrated molecular hydrogen emission when compared with mass matched non-AGN
  - ALMA reveals massive molecular disks in AGN which are likely the gas reservoirs needed to feed the BH
  - In some cases the nuclear molecular disks are outflowing with v~100km/s and thus could survive for about $10^6$ yr