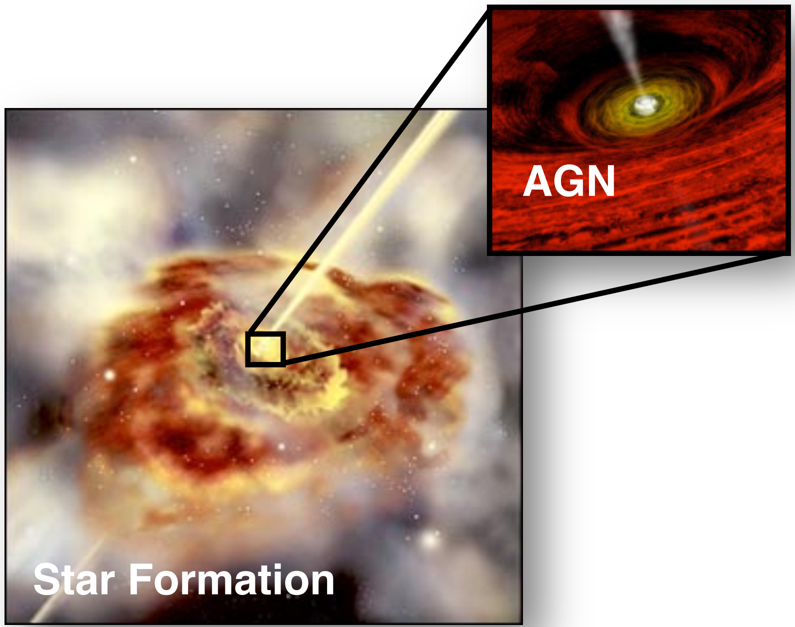
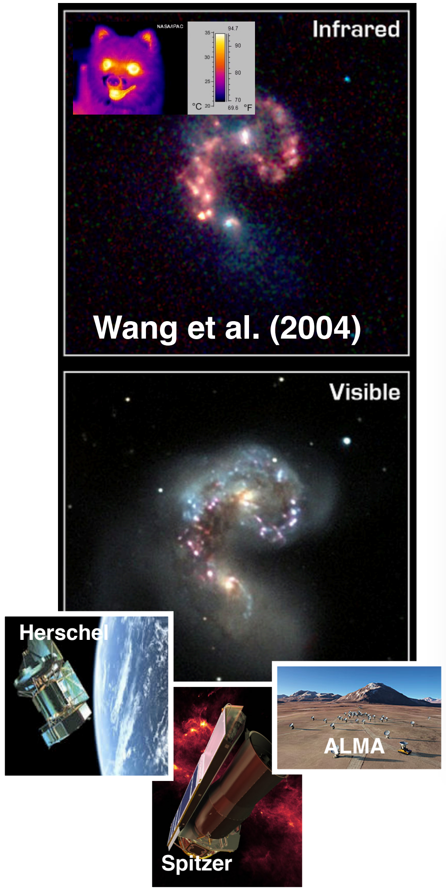
The AGN-star formation connection

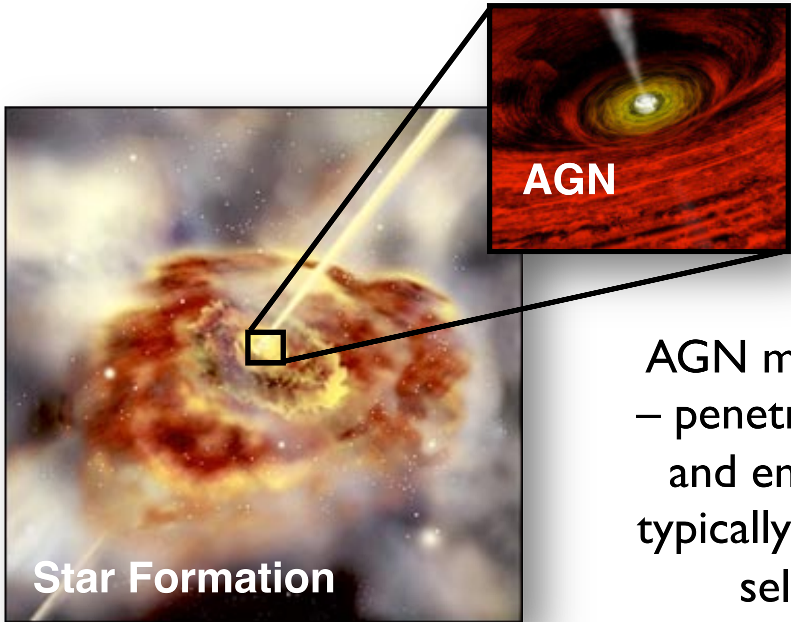
David M Alexander (Durham)

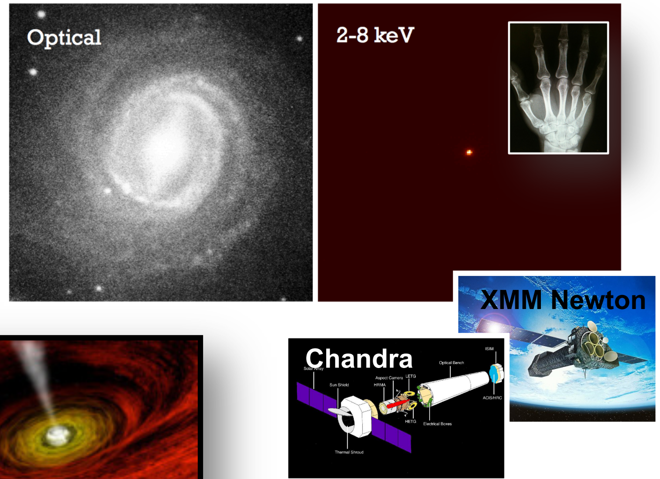


Overview of this talk

Star formation measurements: infrared – traces intense dust-obscured star formation







AGN measurements: X-rays – penetrate high obscuration and emission from host is typically weak (most efficient selection of AGNs)

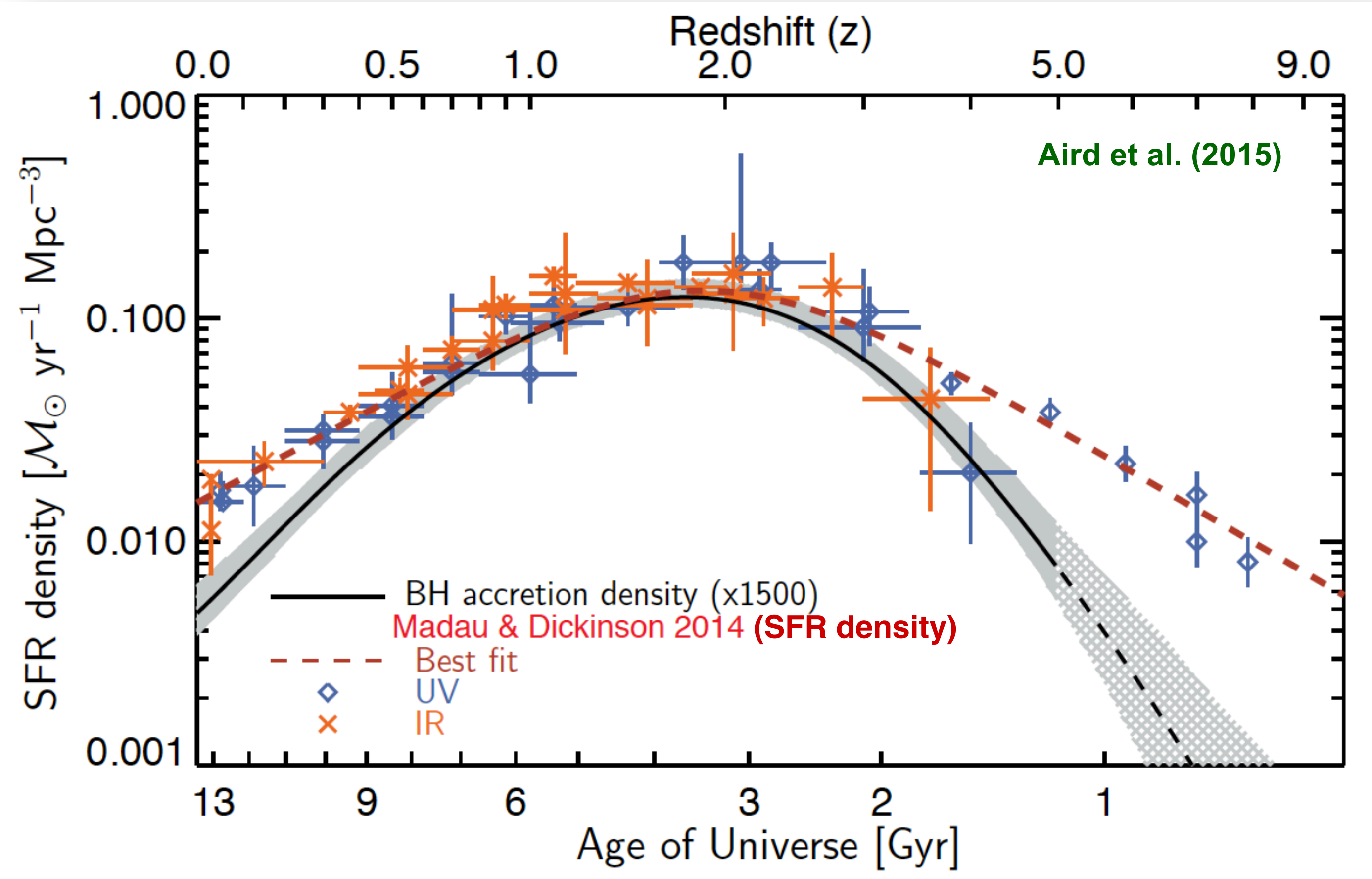
Georgantopoulos; Vignali talks

Focus on AGN-SF connection of distant X-ray AGNs (bulk of BH and galaxy growth)

Kalfountzou talk on AGN-SF connection for radio-loud AGN

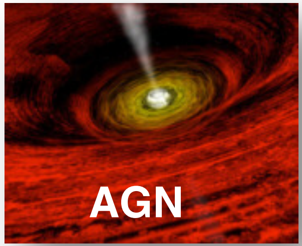
Motivation for studying AGN-SF connection

Broad connection from AGN and SF cosmic histories

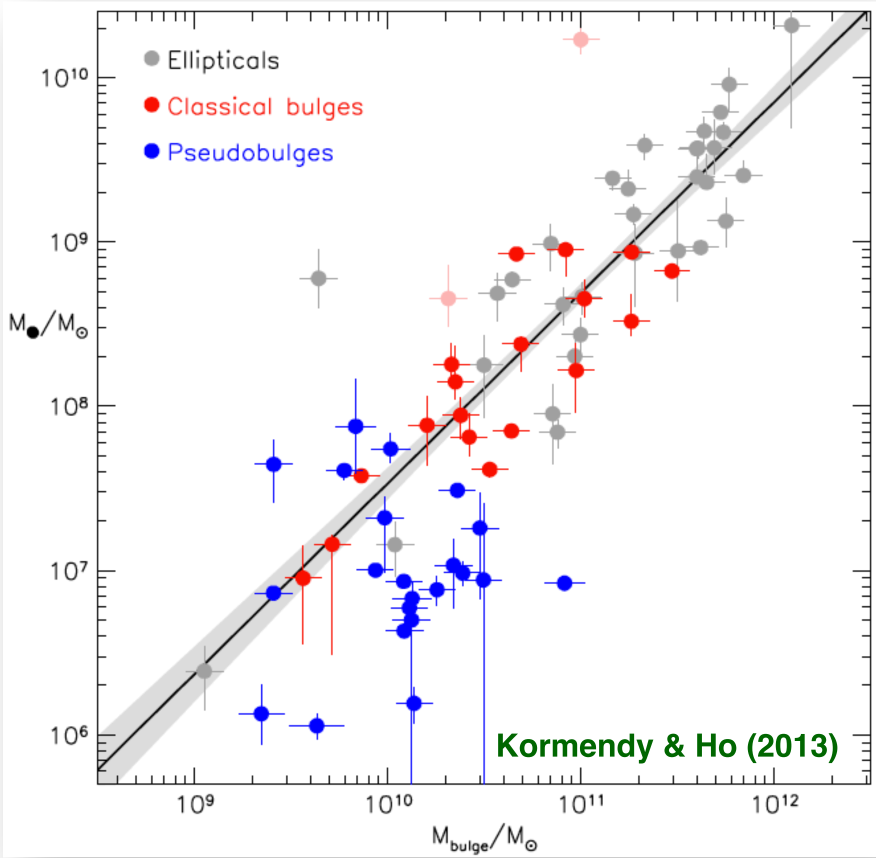


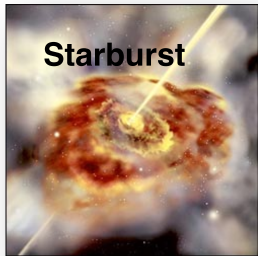
Factor ~1500x offset between BH accretion and SFR cosmic histories in broad agreement with M_{BH}-M_{sph} relationship

Relic evidence from M_{BH}-M_{sph} relationship



[BH mass] Driver: AGN activity

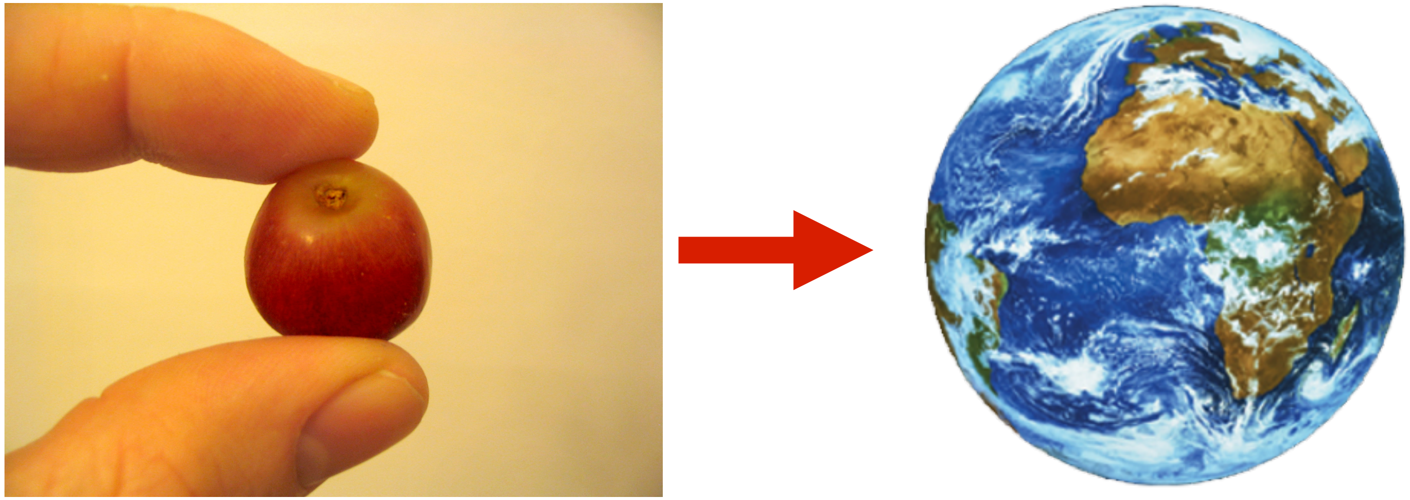




[Spheroid mass] Driver: Star formation (gas accretion)

(e.g., Magorrian et al. 1998, Ferrarese & Merritt 2000; Gebhardt et al. 2000; Tremaine et al. 2002; Marconi & Hunt 2003; Haring & Rix 2004; Gultekin et al. 2009; Shankar et al. 2016)

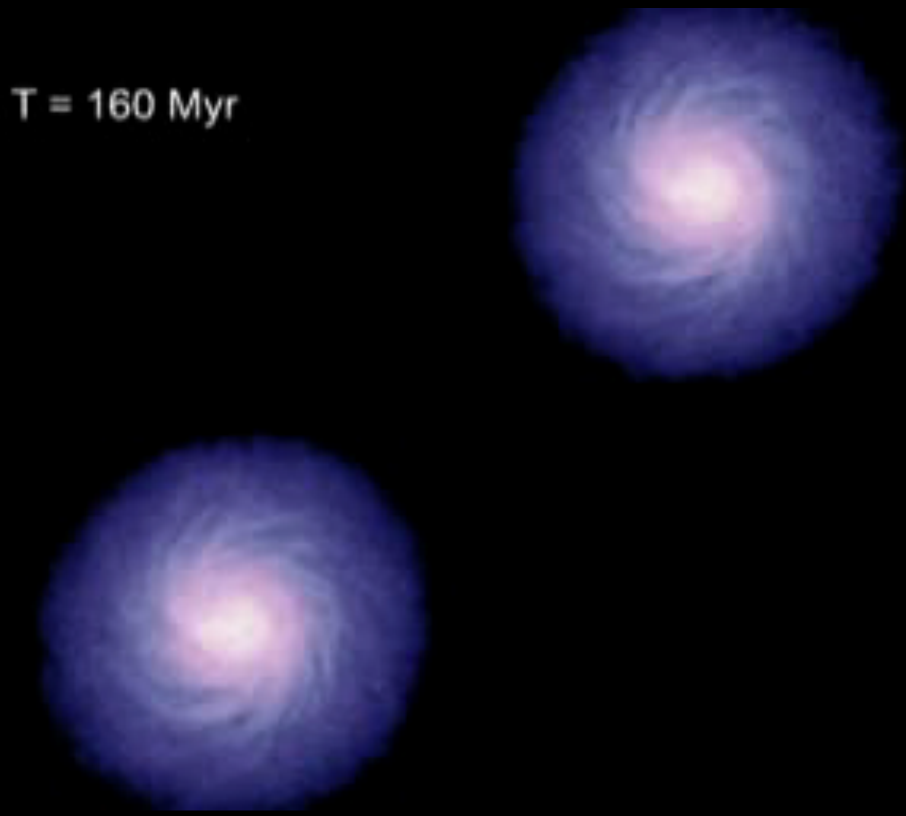
Why this seems crazy: huge difference in size scales

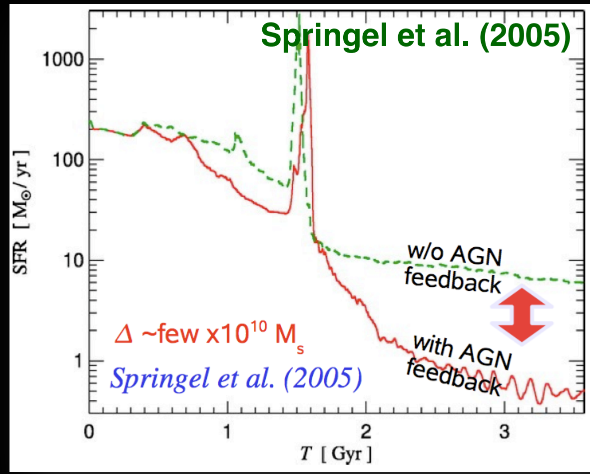


Black-hole-galaxy: ~10^9 difference in size scale (grape-Earth)
Radius of influence of the black hole: <10^{-3} that of the galaxy

This suggests some sort of regulation between AGN activity and star formation

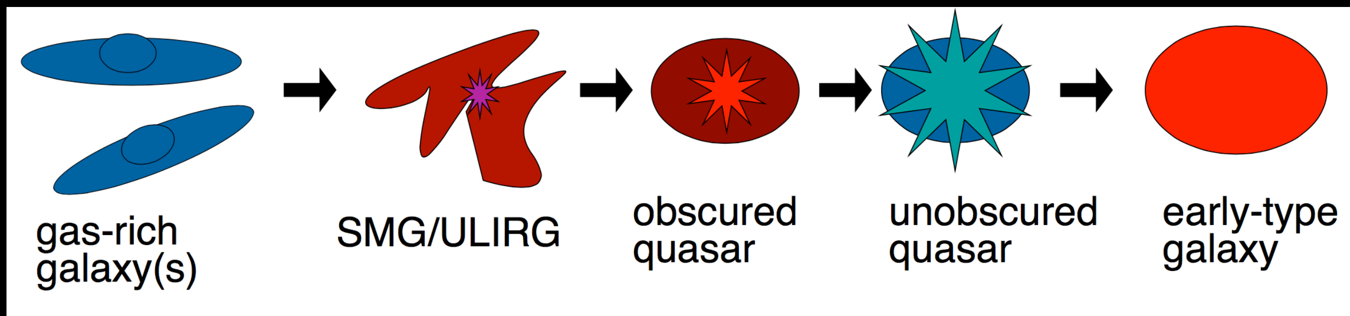
Regulation: outflow - the AGN as the driver/boss





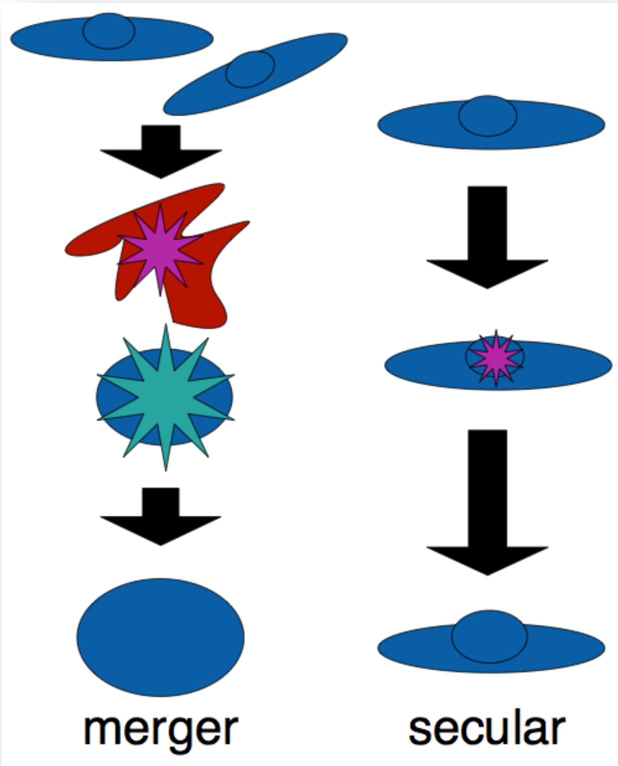
The winds/outflows from the AGN could provide an "arm" for the black hole to orchestrate kpc-scale star formation

(e.g., Di Matteo et al. 2005; Granato et al. 2004; Hopkins et al. 2006; Lapi et al. 2014)



Regulation: inflow - the galaxy as the driver/boss

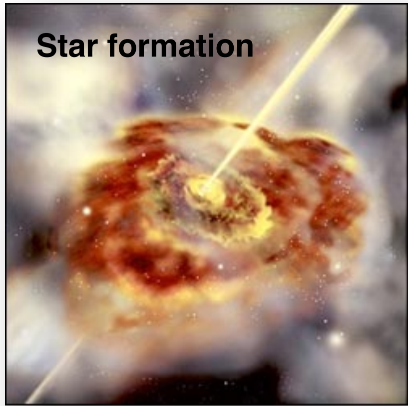
Regulated gas inflow?

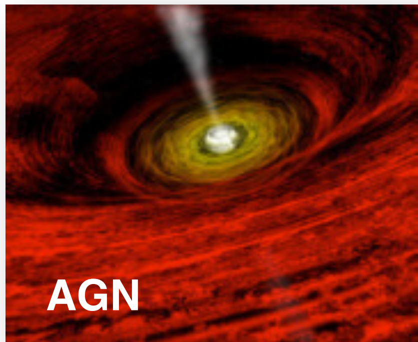


Can be challenging to distinguish between all these scenarios due to uncertain gas inflow/outflow timescales

Alexander & Hickox (2012)

Star-formation regulated growth?

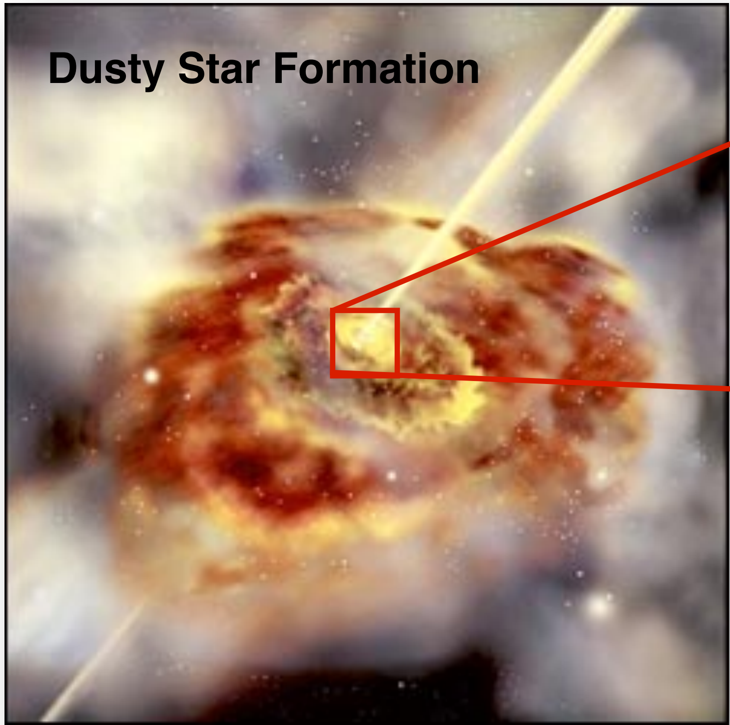




(i.e., driven by same gas supply)

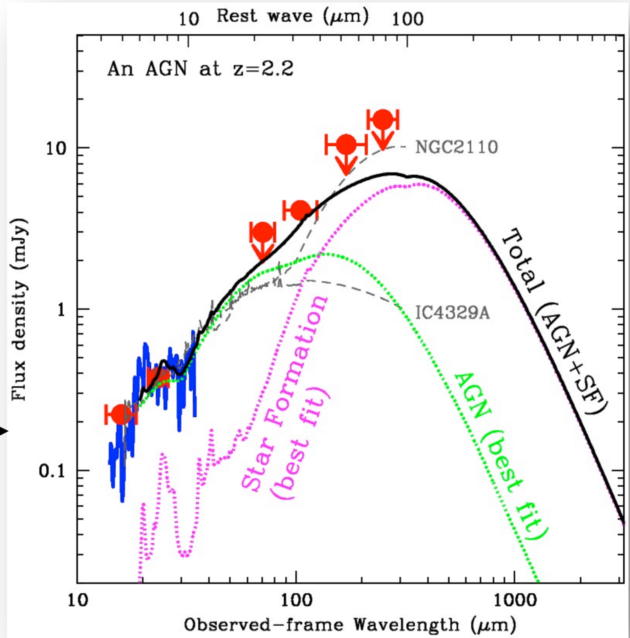
Measuring star-formation rates in the far-IR waveband

Measuring star-formation rates: far-IR emission

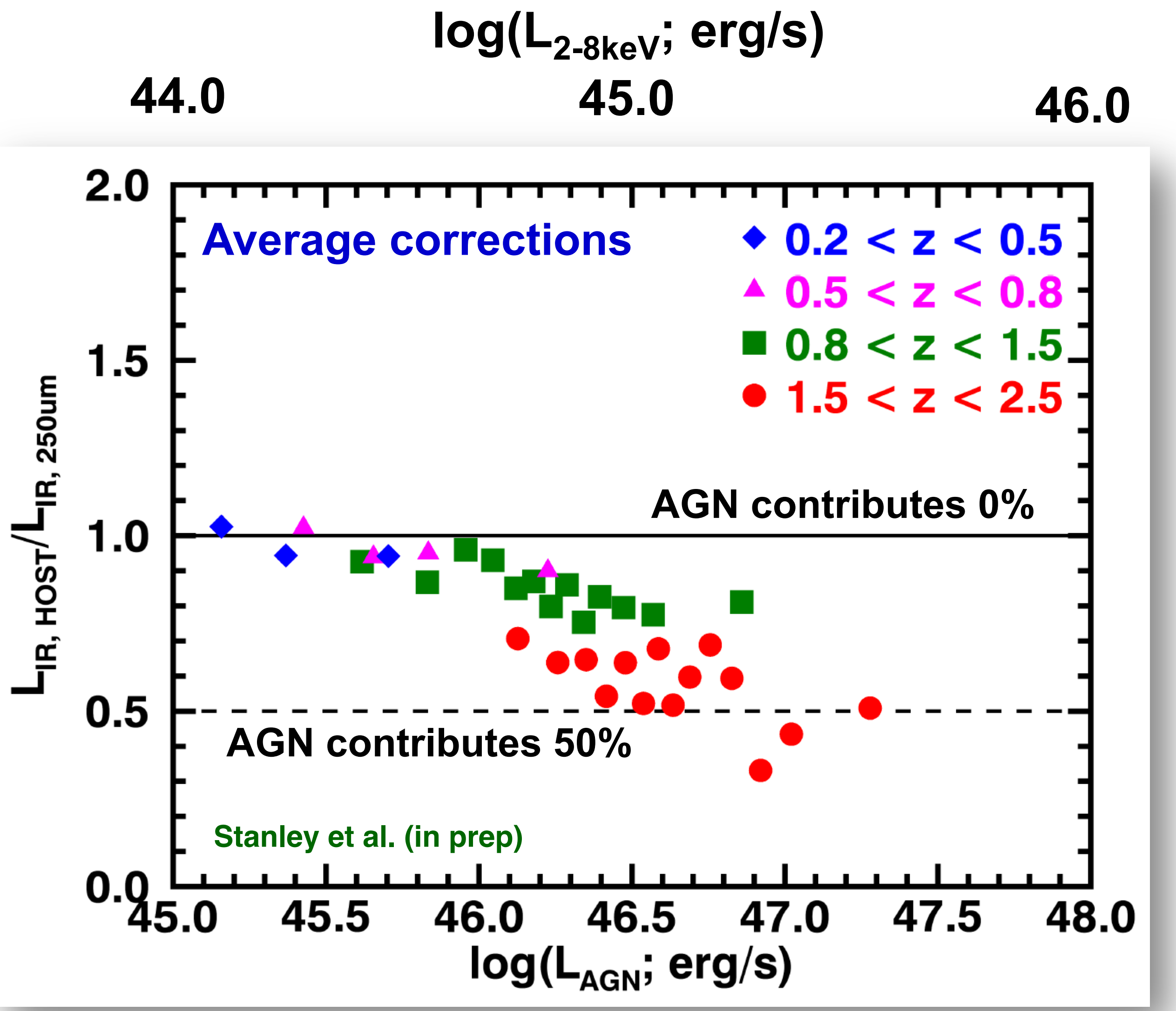


Both emit strongly at infrared wavelengths

Ideally, decompose the SED but often just the far-IR luminosity is used (e.g., Herschel), which is typically star-formation dominated unless a luminous AGN



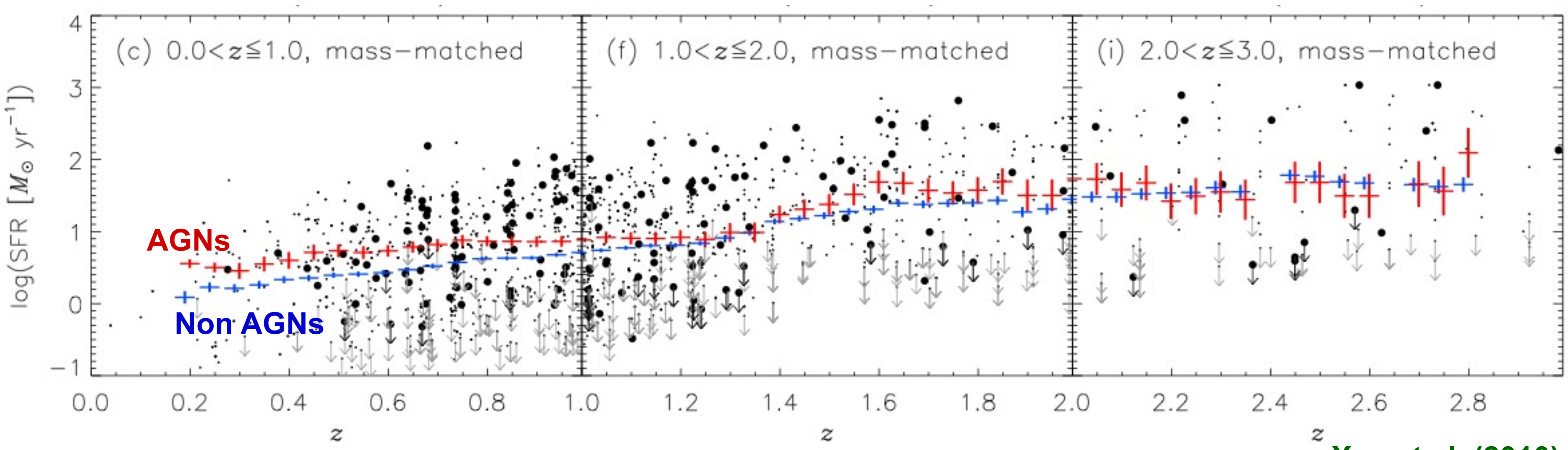
Effect of AGN on star-formation rate measurements



Key message: AGN contaminate/increase average SFR over 250um photometry by >2 for luminous/dominant AGN – can be higher for individual sources and shorter wavelengths

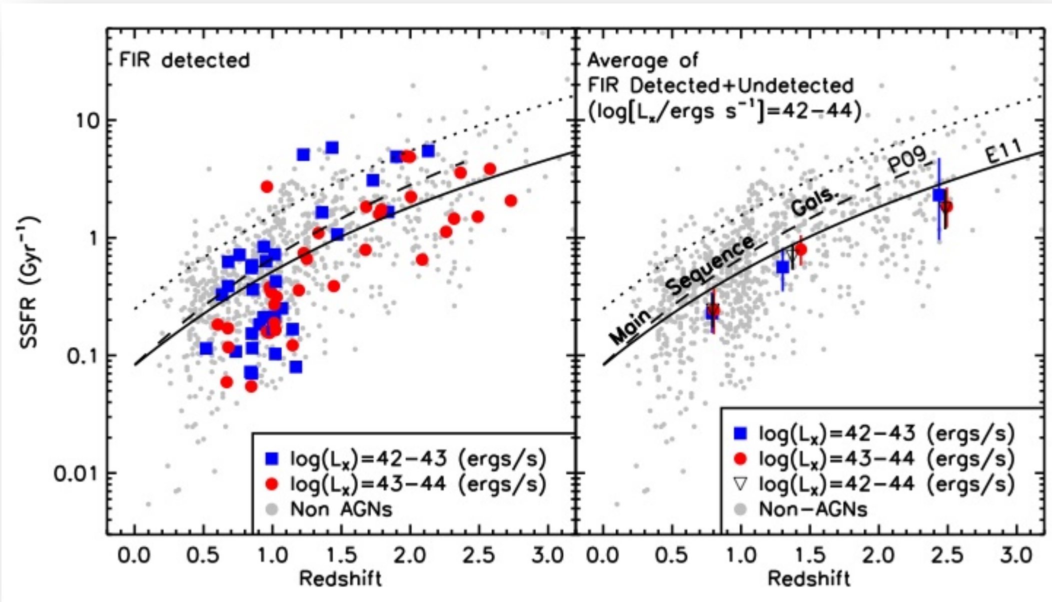
The AGN-SF connection of X-ray AGNs

SF in distant AGNs tracks SF galaxies – on average



Xue et al. (2010)

Specific SFR (sSFR=SFR/mass): relative growth rate



Increase in average SFR of AGNs with redshift tracks that seen for SF galaxies

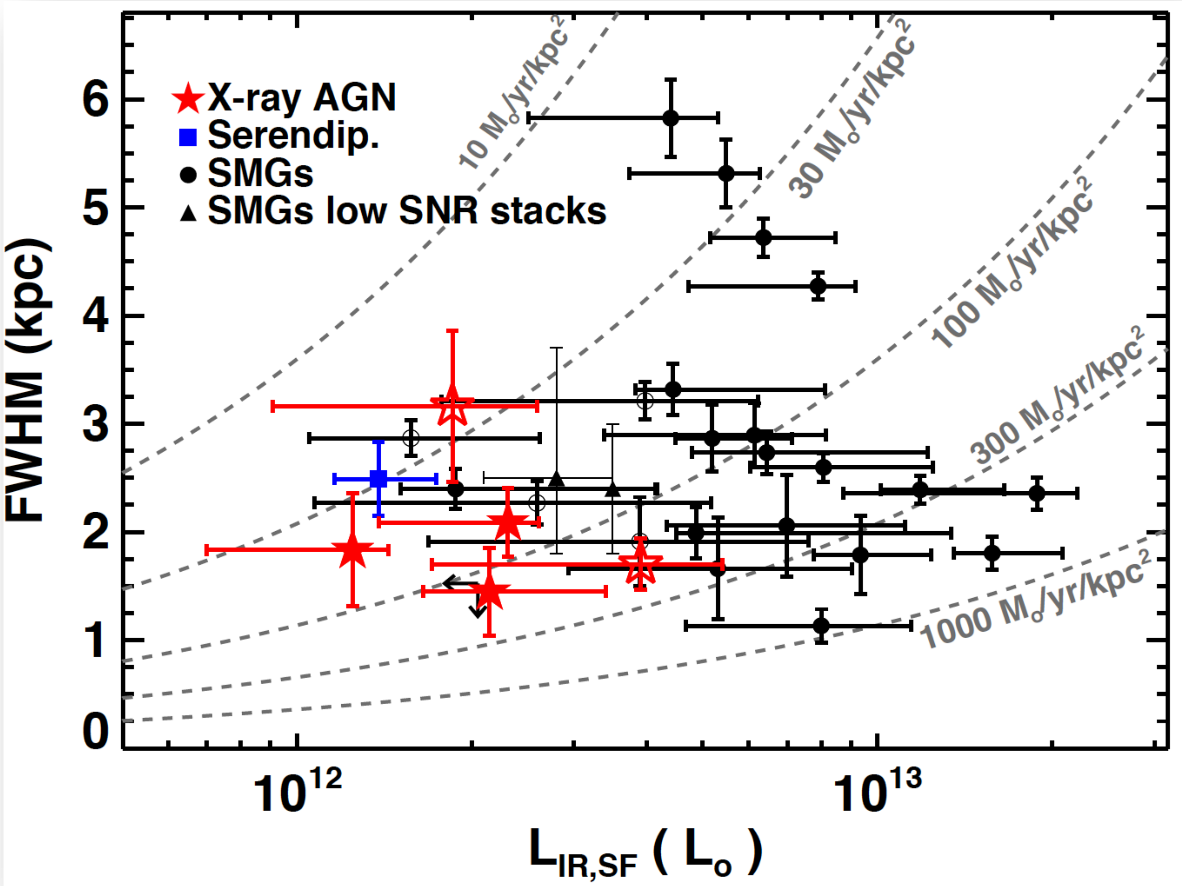
Increase in the average sSFR of AGNs with redshift also tracks that seen for SF galaxies: the "main sequence"

Mullaney et al. (2012)

Also Lutz et al. (2010), Mullaney et al. (2010); Shao et al. (2010); Rosario et al. (2012, 2015); Harrison et al. (2012); Santini et al. (2012)

ALMA reveals similar SF extent in FIR bright AGN

High resolution (~1-3 kpc) ALMA 870um data of some z>1.5 X-ray AGNs and star-forming galaxies (SMGs)



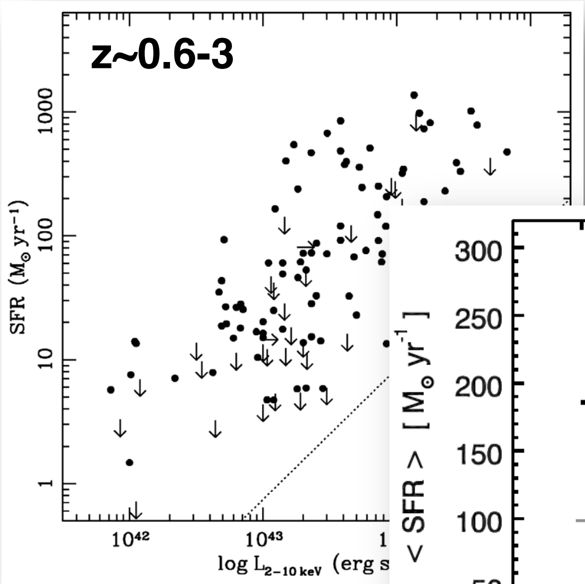
Harrison et al. (2016)

No clear differences in galaxy wide SF environment – SF extent and surface density for X-ray AGNs comparable to SF galaxies. **Caution:** only a few FIR-bright AGN observed.

What about the L_{SF}-L_{AGN} relationship?

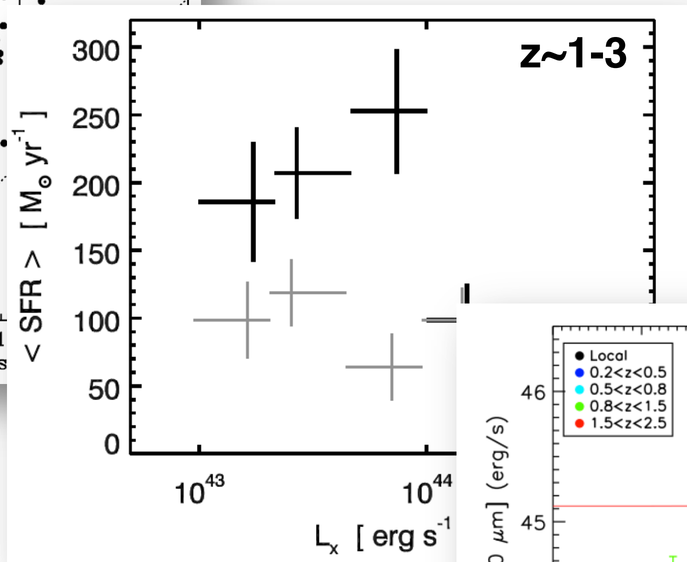
Early Herschel results of mean L_{SF} for L_{AGN} bins showed a large amount of diversity

Positive relationship



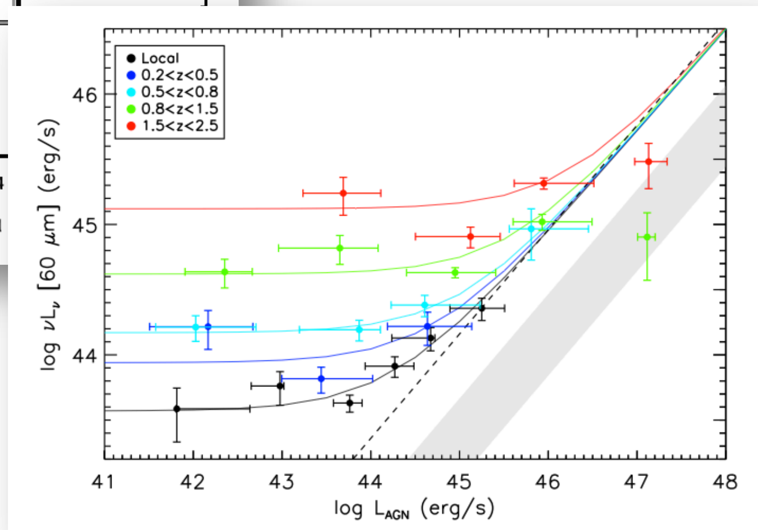
Rovilos et al. (2012)

Negative relationship (at high L_X)



Page et al. (2012)

Predominantly flat relationship

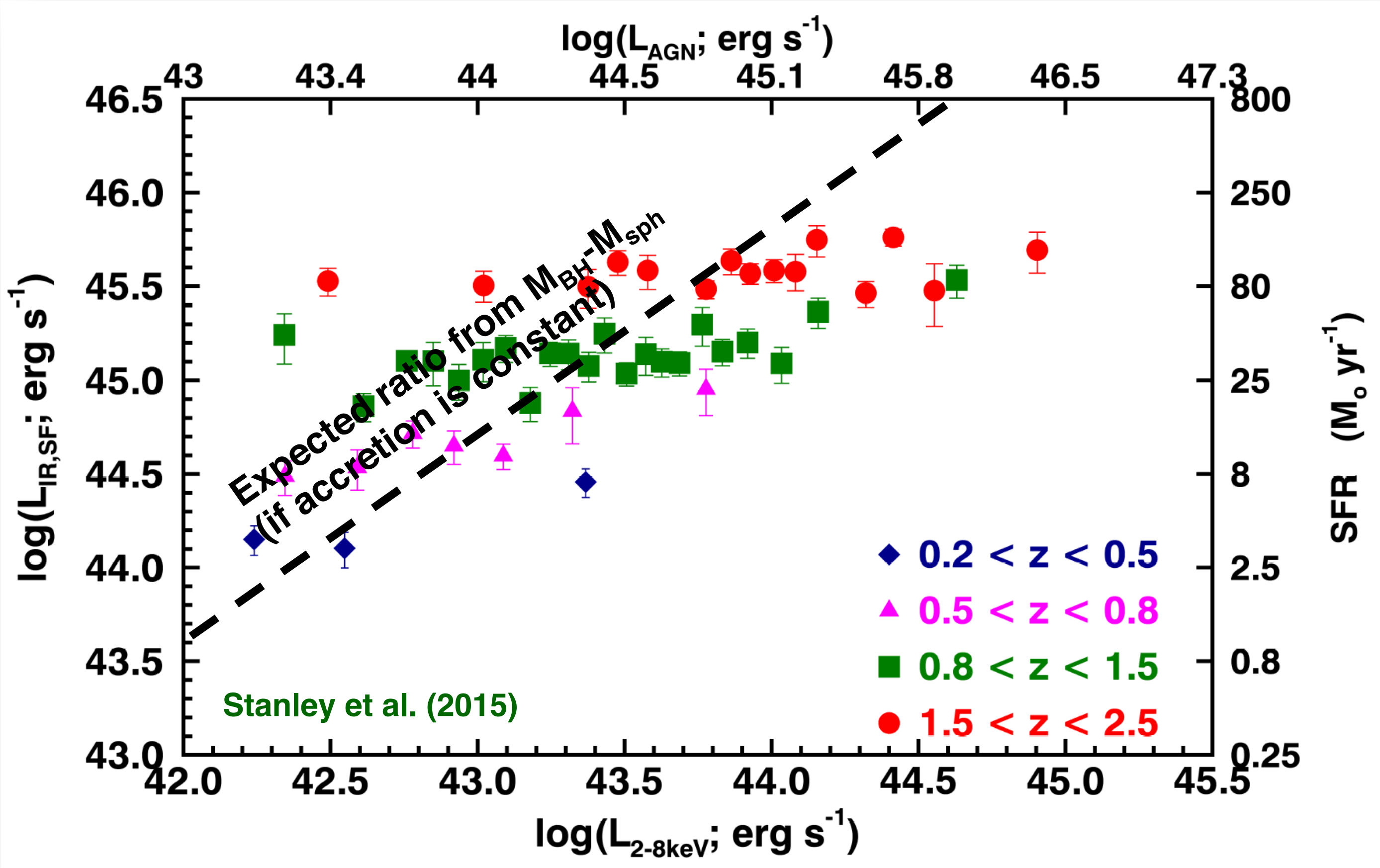


Rosario et al. (2012)

Differences often driven by low source statistics, cosmic variance (small fields), wide redshift ranges, and/or AGN contamination (e.g., Harrison et al. 2012)

Now clear the mean L_{SF}-L_{AGN} relationship is flat

Mean L_{SF} for L_{AGN} bins for X-ray AGN: remarkably flat relationship



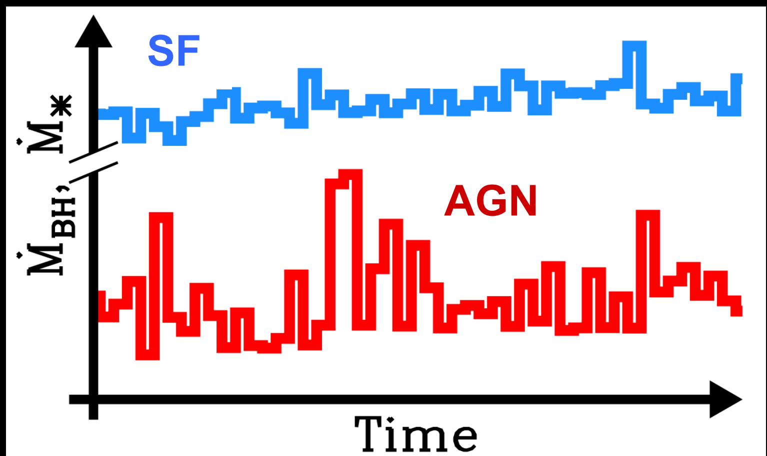
At first this seemed an absurd result – how can a flat L_{SF}-L_{AGN} relationship be consistent with the M_{BH}-M_{sph} relationship?

Key to understanding this: changes in accretion rate

AGNs likely vary on short timescales when compared to and star formation – so the observed L_{AGN} can vary substantially for a (relatively) constant L_{SF}

A fluorescent bulb at 1000 frames per second

Mullaney et al. (2012); Hickox et al. (2014)

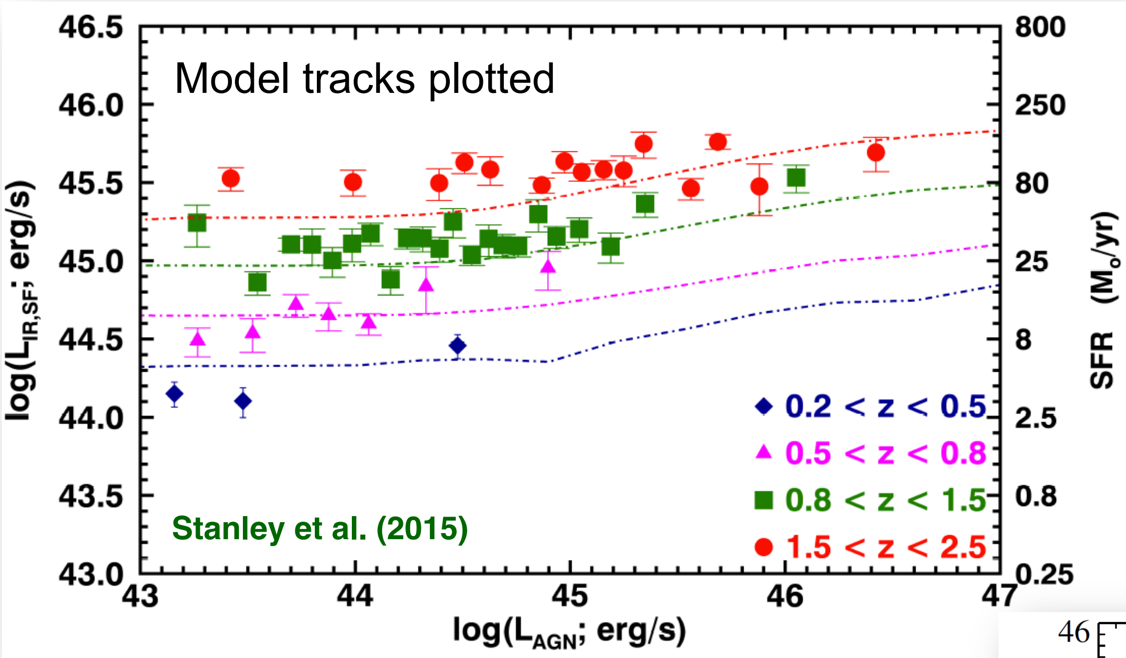


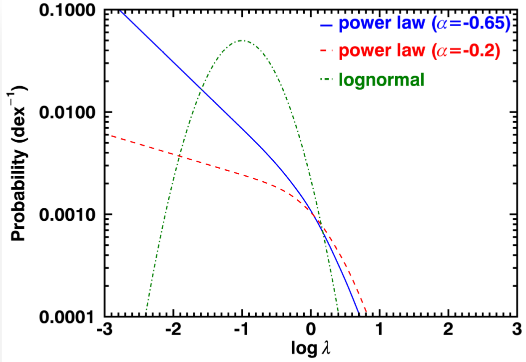
SF: comparatively constant with time

AGN: more variable with time

Expectations from simple accretion variability model

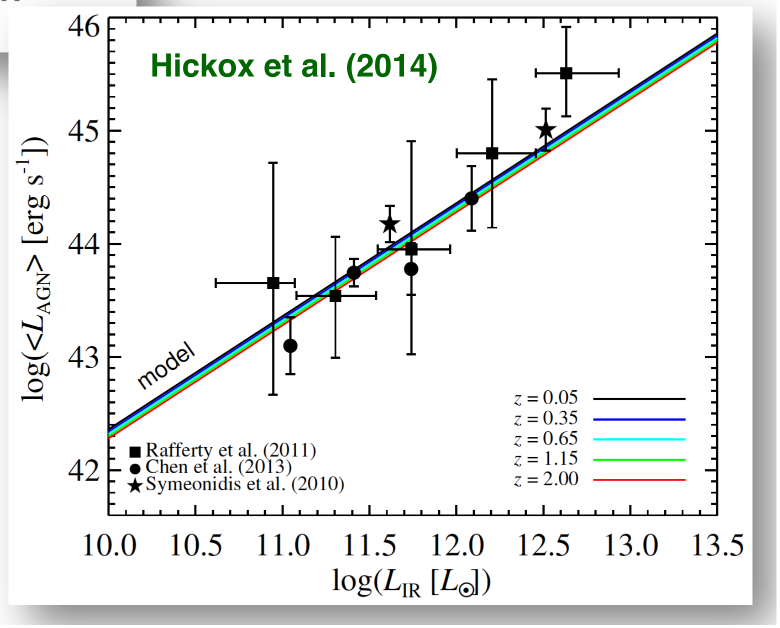
Mean L_{SF} for L_{AGN} bins for X-ray AGN





Simple model: assume AGN vary based on Aird et al. (2012) Eddington-ratio distribution and hosts are SF galaxies

Not convinced? If instead calculate mean L_{AGN} for L_{SF} bins using SF galaxies (i.e., selected on more stable quantity) then a remarkably tight relationship is seen



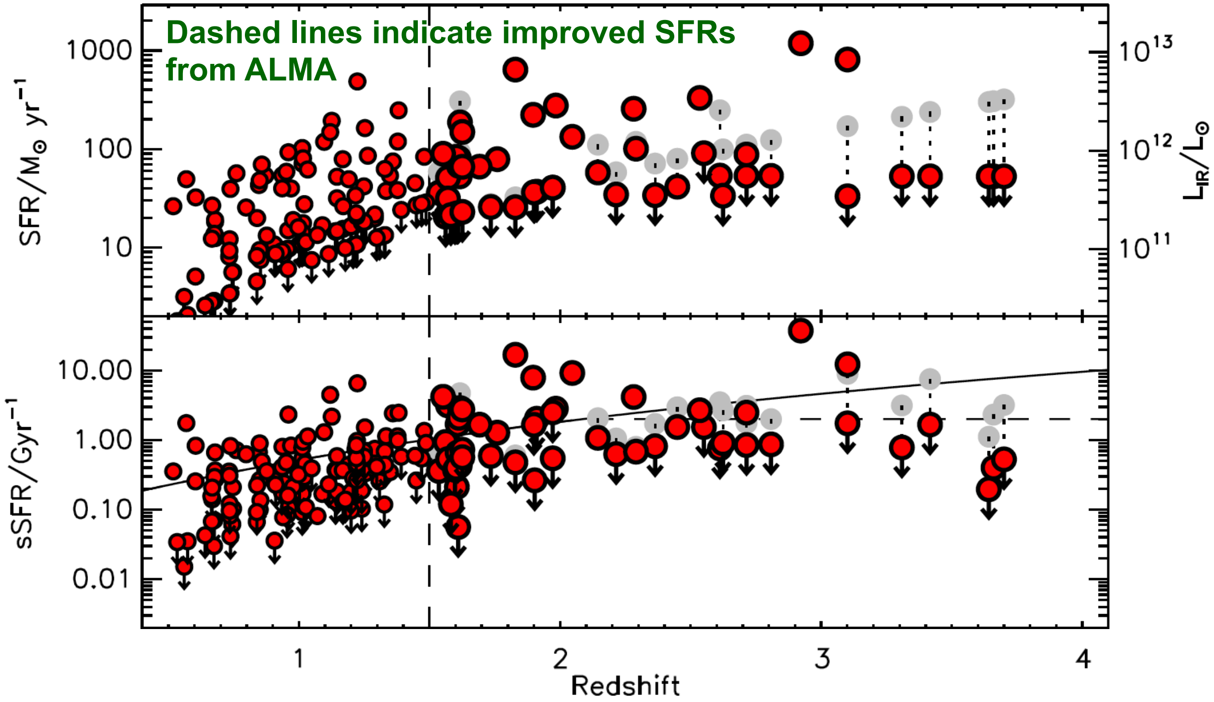
See also Aird et al. (2010, 2015), Mullaney et al. (2012), Chen et al. (2013), Rodighiero et al. (2015)

So when take account of mass, redshift, and AGN variability all X-ray AGN reside in SF galaxies – right?

No this is only for the mean SFR – need to calculate a more refined quantity: SFR distributions, which requires deeper data

Using ALMA to constrain the SFR distribution

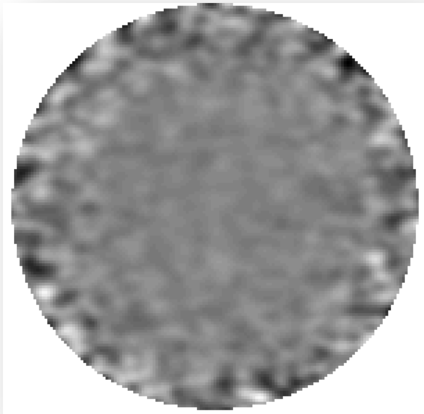
Few X-ray AGN detected by ALMA but upper limits valuable: updated SFRs place them below typical star-forming galaxies



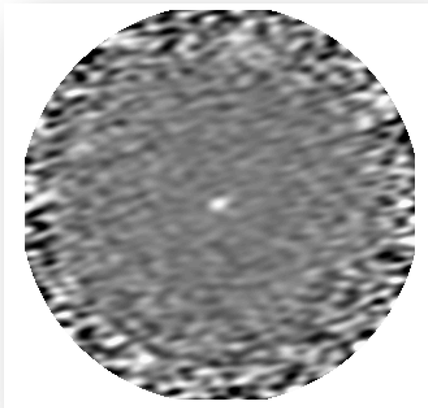
Mullaney et al. (2015); Scholtz et al. (in prep); Stanley et al. (in prep)

ALMA 870um of X-ray AGN

Majority: undetected

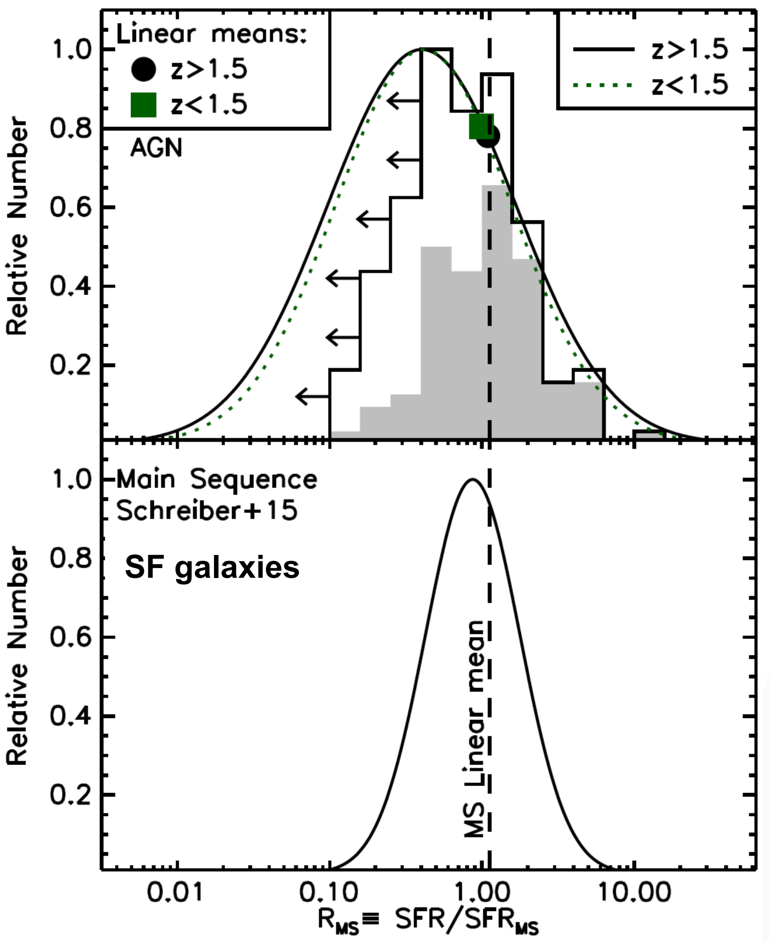


Minority: detected



ALMA shows not all X-ray AGN reside in SF galaxies

Relative distribution of SFRs: AGN median lower than for SF galaxies

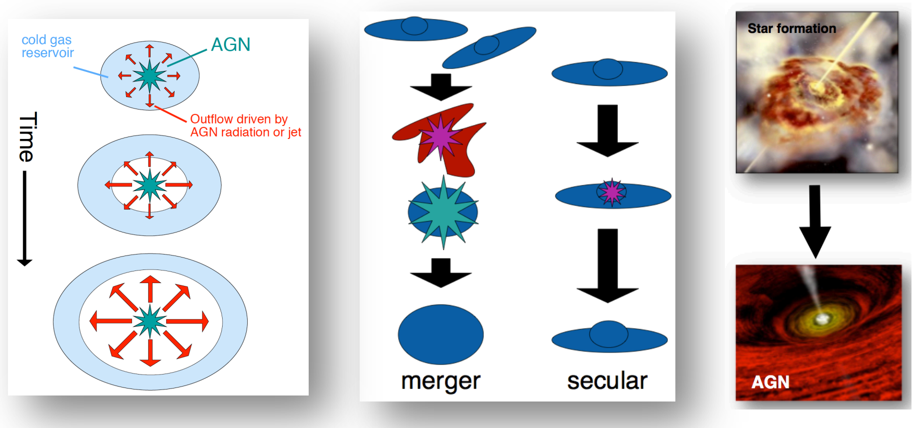


Mullaney et al. (2015); Scholtz et al. (in prep); Stanley et al. (in prep)

Key message: a **typical** X-ray AGN does not appear to reside in a SF galaxy

Interpretation? AGN suppressing SF (gas outflows)? Or delays in gas inflow from galaxy/star formation?

Gas outflow? **Gas inflow?**



We are starting to distinguish using (1) ALMA data for factor ~3 more X-ray AGN and (2) VLT-KMOS IFU data to connect gas outflows to SFR constraints

See Bongiorno talk for complementary constraints

Key messages from this talk

Measuring accurate SFRs in AGN can be challenging, particularly when AGN:SF ratio is high

Most critical for high-luminosity or low-z AGN (where SF low)

<u>Mean</u> SFRs for X-ray AGN consistent with typical SF galaxies

Need to take into account redshift, mass, and AGN variability

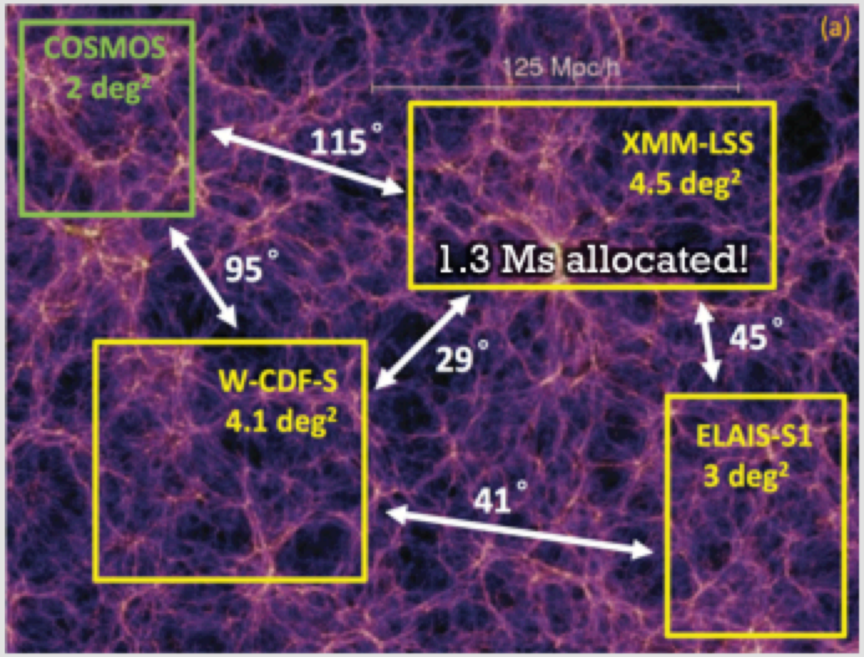
But tentative differences found in the <u>distribution</u> of SFRs – many X-ray AGN reside in more quiescent galaxies

However, it is unclear what is the driver – regulation from AGN gas outflows or galaxy/SF gas inflow timescale to get to BH?

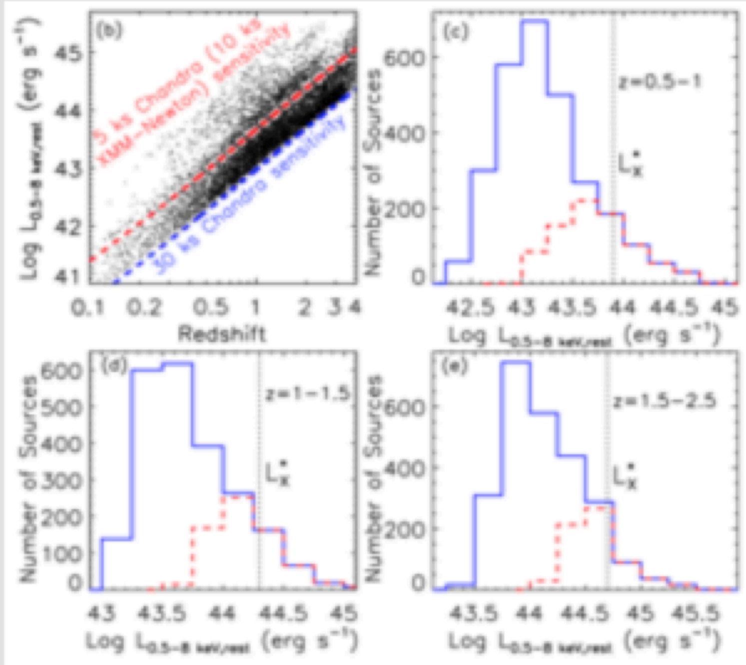
…and now for something a (bit) different

X-SERVS: New X-ray survey of the LSST/DES Deep-Drilling Fields

X-SERVS Fields



Expected Source Yields



Ultimate aim: 14 deg^2 solid-angle coverage in total – factor of ~ 7 improvement over COSMOS alone (4.5 deg^2 allocated so far). Reduces cosmic variance and allows robust studies of large-scale structures.

Observations: can be done with XMM-Newton and/or Chandra – aiming for 50 ks XMM-Newton depth, so that we sample the AGN populations producing the bulk of cosmic accretion power.

Overall: expect 11,000 AGNs and 760 X-ray groups/clusters. **Contact:** me or email niel@astro.psu.edu

Primary Science Goals for X-SERVS

SMBH growth across the full range of cosmic environments from voids to massive clusters.

Links between SMBH accretion and star formation.

Improved measurements of the $z \sim 4$-7 AGN space density.

Constraints upon $z > 10$ direct-collapse black holes via X-ray/NIR cross correlation.

Rare and luminous sources – e.g., luminous type 2 quasars, extreme X-ray/optical sources, intrinsically X-ray weak AGNs, SMBH pairs, X-ray bright but radio-faint jets.

Cosmology with clusters and groups.

Incredible Legacy Value: Likely the Best Multiwavelength Fields for Decades

Fantastic Current/Scheduled X-SERVS Multiwavelength Coverage

Table 1: Current/Scheduled 1–10 deg^2 Multiwavelength Coverage of X-SERVS

Band	Survey Name	Coverage (W-CDF-S, ELAIS-S1, XMM-LSS); Notes
Radio	Australia Telescope Large Area Survey (**ATLAS**)[a]	3.7, 2.7, – deg^2; 15 μJy rms depth at 1.4 GHz
	MIGHTEE Survey (Scheduled)[b]	4.5, 3, 4.5 deg^2; 1 μJy rms depth at 1.4 GHz
FIR	*Herschel* Multi-tiered Extragal. Survey (**HerMES**)[c]	0.6–18 deg^2; 5–60 mJy depth at 100–500 μm
MIR	*Spitzer* Wide-area IR Extragal. Survey (**SWIRE**)[d]	8.2, 7.0, 9.4 deg^2; 0.04–30 mJy depth at 3.6–160 μm
NIR	*Spitzer* Extragal. Rep. Vol. Survey (**SERVS**)[e]	4.5, 3, 4.5 deg^2; 2 μJy depth at 3.6 and 4.5 μm
	VISTA Deep Extragal. Obs. Survey (**VIDEO**)[f]	4.5, 3, 4.5 deg^2; $ZYJHK_s$ to $m_{AB} \approx 23.5$–25.7
Optical Photometry	Dark Energy Survey (**DES**)[g]	9, 6, 9 deg^2; Multi-epoch *griz*, $m_{AB} \approx 27$ co-added
	Hyper Suprime-Cam (**HSC**) Deep Survey[h]	–, –, 5.3 deg^2; *grizy* to $m_{AB} \approx 25.3$–27.5
	Pan-STARRS1 Medium-Deep Survey (**PS1MD**)[i]	8, –, 8 deg^2; Multi-epoch *grizy*, $m_{AB} \approx 26$ co-added
	VST Optical Imaging of CDF-S and ES1 (**VOICE**)[j]	4.5, 3, – deg^2; Multi-epoch *ugri*, $m_{AB} \approx 26$ co-added
	SWIRE optical imaging[d]	7, 6, 8 deg^2; $u'g'r'i'z'$ to $m_{AB} \approx 24$–26
	LSST deep-drilling field (Planned)[k]	10, 10, 10 deg^2; *ugrizy*, 20 000 visits total
Optical/NIR Spectroscopy	Carnegie-*Spitzer*-IMACS Survey (**CSI**)[l]	4.8, 3.6, 6.9 deg^2; 140 000 redshifts, 3.6 μm selected
	PRIsm MUlti-object Survey (**PRIMUS**)[m]	2.0, 0.9, 2.9 deg^2; 77 000 redshifts to $i_{AB} \approx 23.5$
	VLT **MOONS** Survey (Scheduled)[n]	4.5, 3, 4.5 deg^2; 210 000 redshifts to $H_{AB} \approx 23.5$
UV	*GALEX* Deep Imaging Survey[o]	7, 7, 8 deg^2; Depth $m_{AB} \approx 25$

References: [a] Hales et al. (2014); [b] http://public.ska.ac.za/meerkat/meerkat-large-survey-projects; [c] Oliver et al. (2012); [d] Lonsdale et al. (2003); [e] Mauduit et al. (2012); [f] Jarvis et al. (2013); [g] Diehl et al. (2014); [h] http://www.naoj.org/Projects/HSC/surveyplan.html; [i] Tonry et al. (2012); [j] http://www.mattiavaccari.net/voice/; [k] http://www.lsst.org/News/enews/deep-drilling-201202.html; [l] Kelson et al. (2014); Patel et al. (2015); [m] Coil et al. (2011); [n] http://www.roe.ac.uk/~ciras/MOONS/VLT-MOONS.html; [o] http://www.galex.caltech.edu/researcher/techdoc-ch2.html.

Coverage of an AGN Spectral Energy Distribution