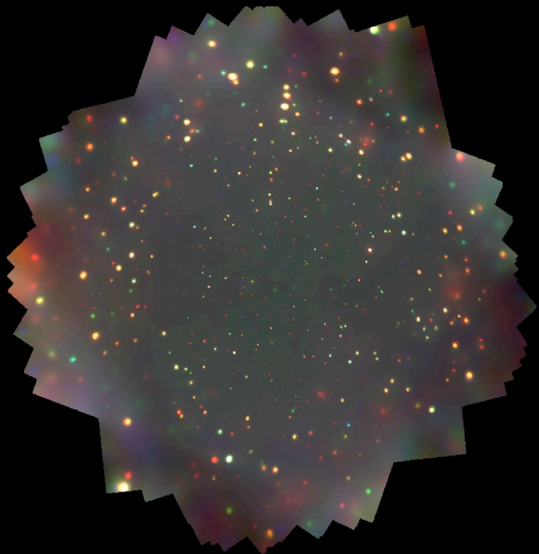
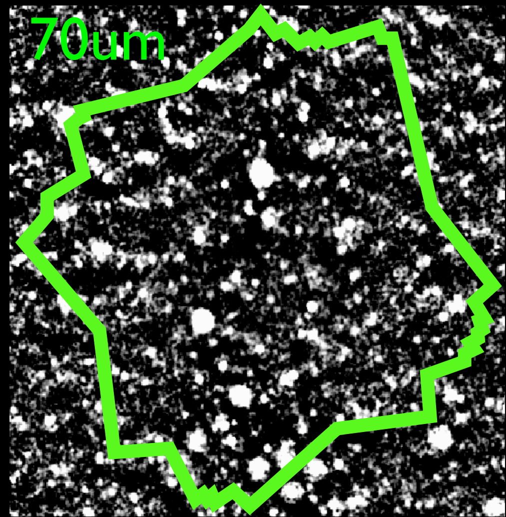
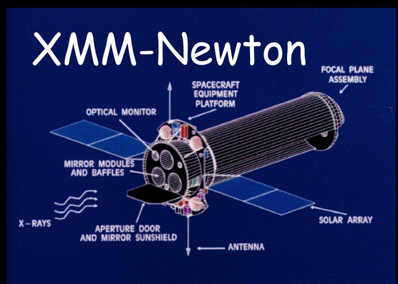
Synergy between deep X-ray and infrared surveys: AGN and star formation activity



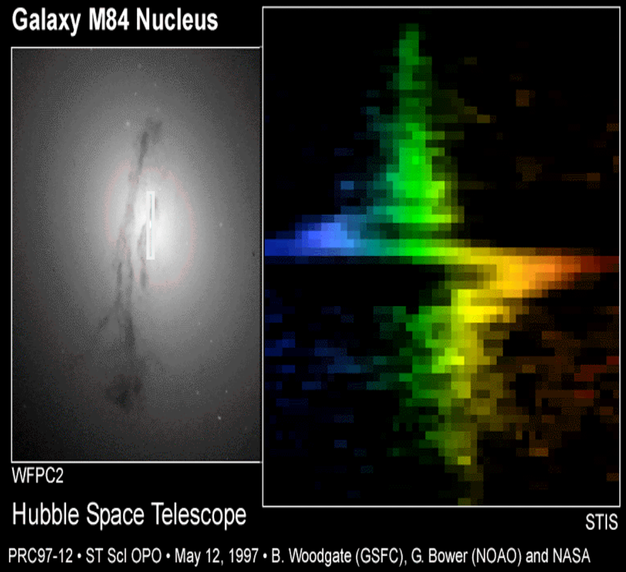


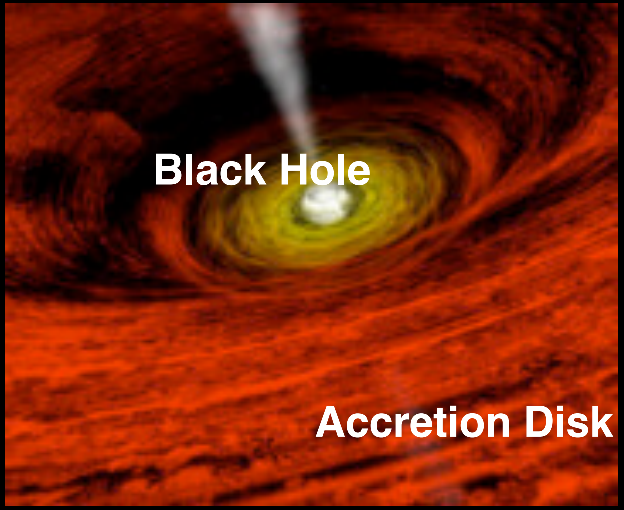
David M Alexander (Durham)



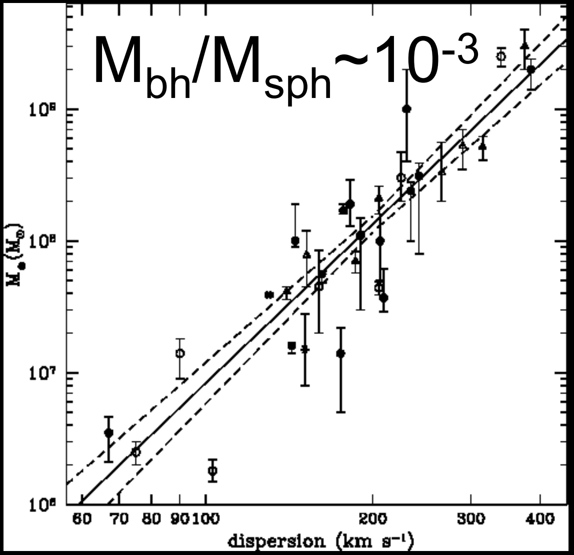
Two key issues in observational cosmology

Census of AGNs/black-hole growth

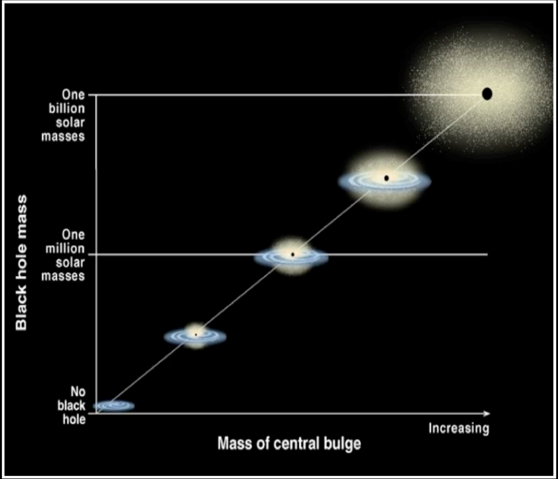




AGN-star formation connection

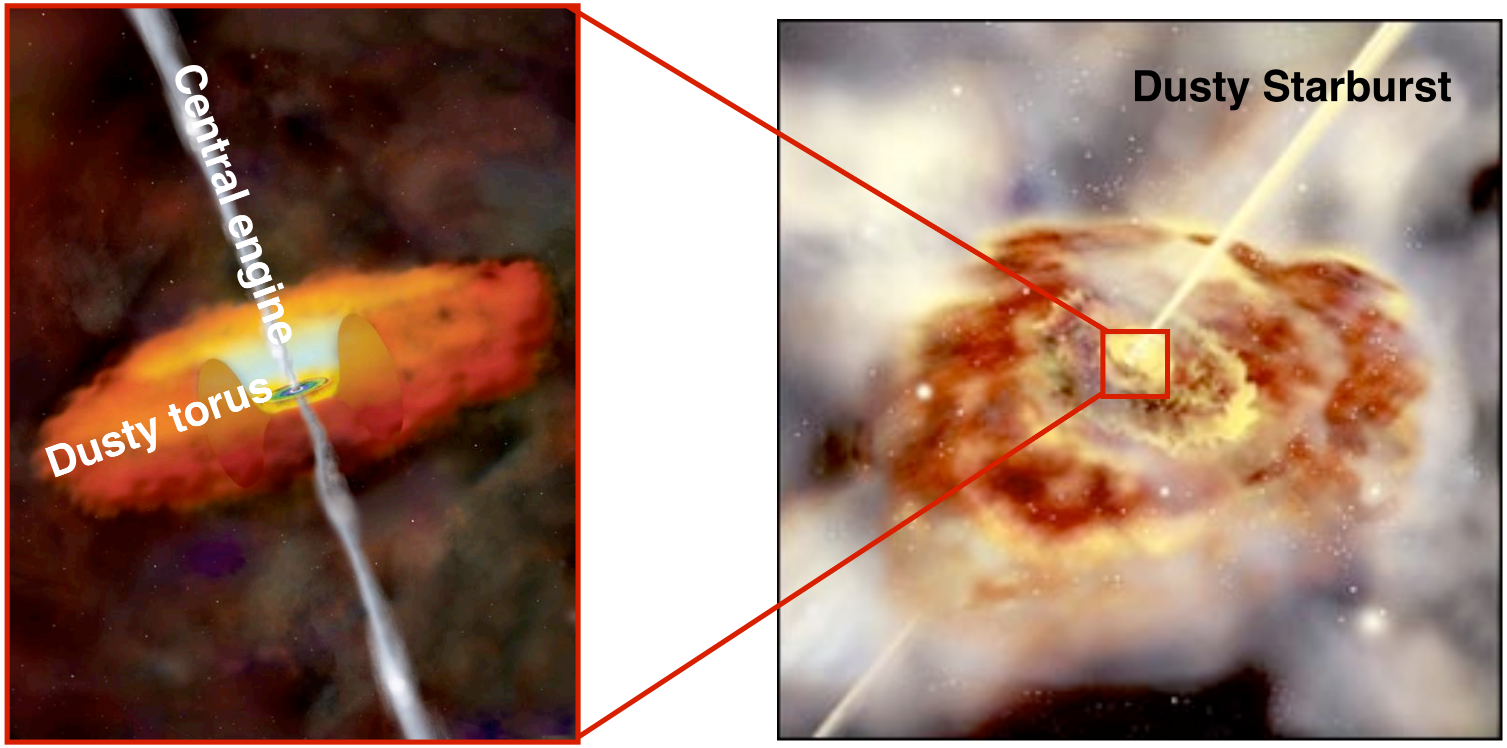


Action: AGN activity



Action: Star formation

Obscured Growth of Galaxies and Black Holes



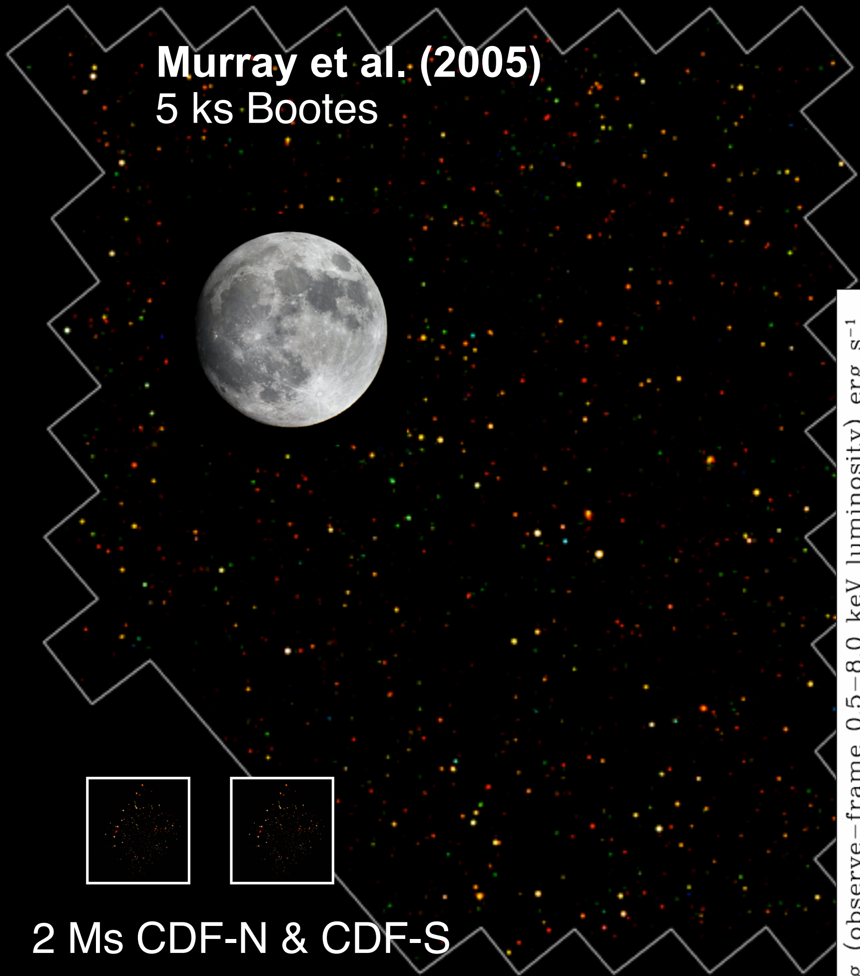
Primary source (X-ray-optical)

Dust

≈ Reprocessed emission (infrared/submm)

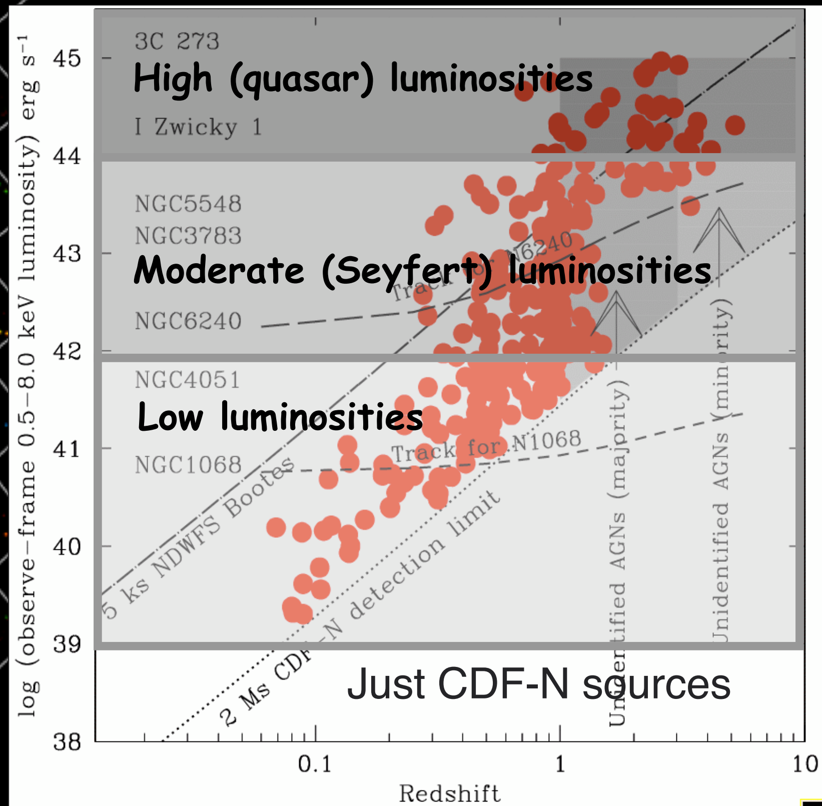
AGN, star formation → Heats the dust → Observe thermal spectrum in ~3-300um band

X-ray Surveys: Penetrating Probe of AGN activity



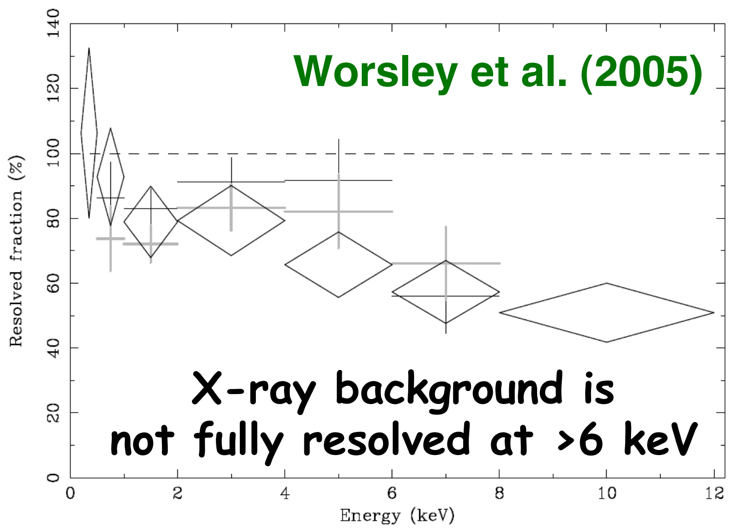
2 Ms CDF-N & CDF-S

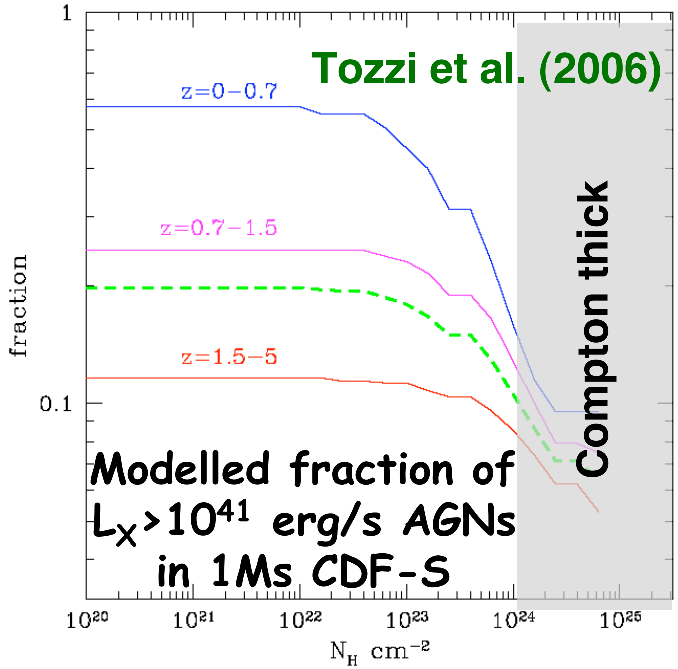
Alexander et al. (2003); Luo et al. (2008)

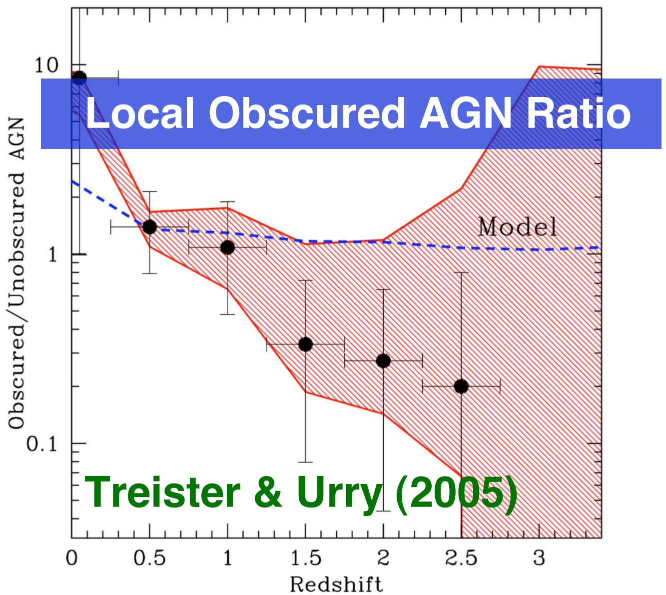


Detection of even low-luminosity AGN out to high redshift

Even the deepest surveys are missing many AGNs

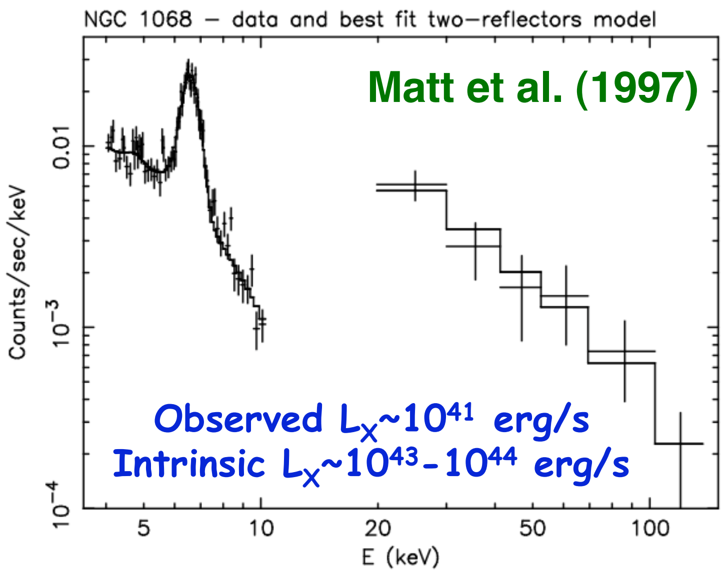






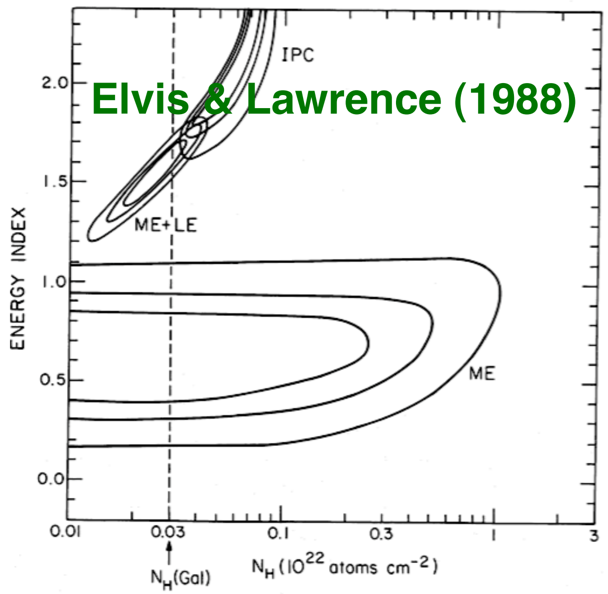
Many of these "undetected" AGNs will be luminous C-thick objects: IXO will ID many but can we progress before then?

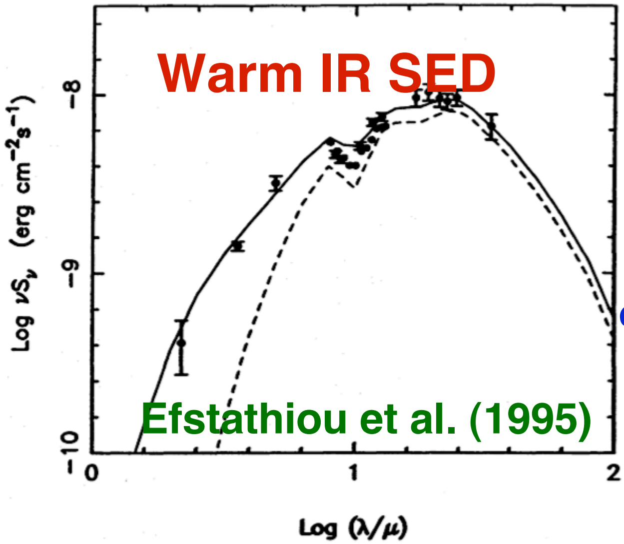
NGC1068: A Nearby Example



Good quality data

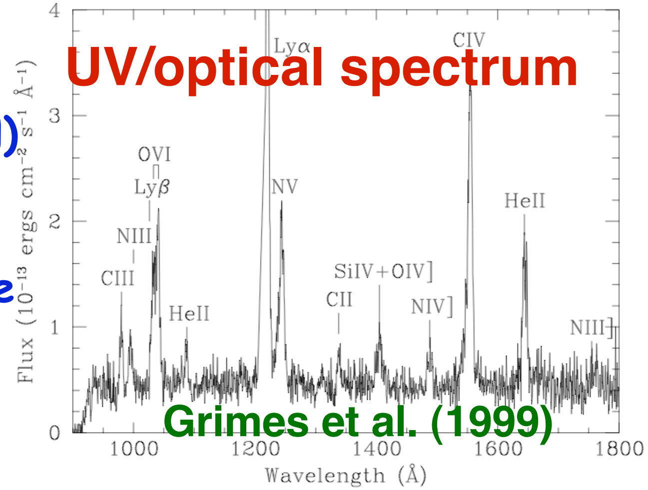
Poor quality data



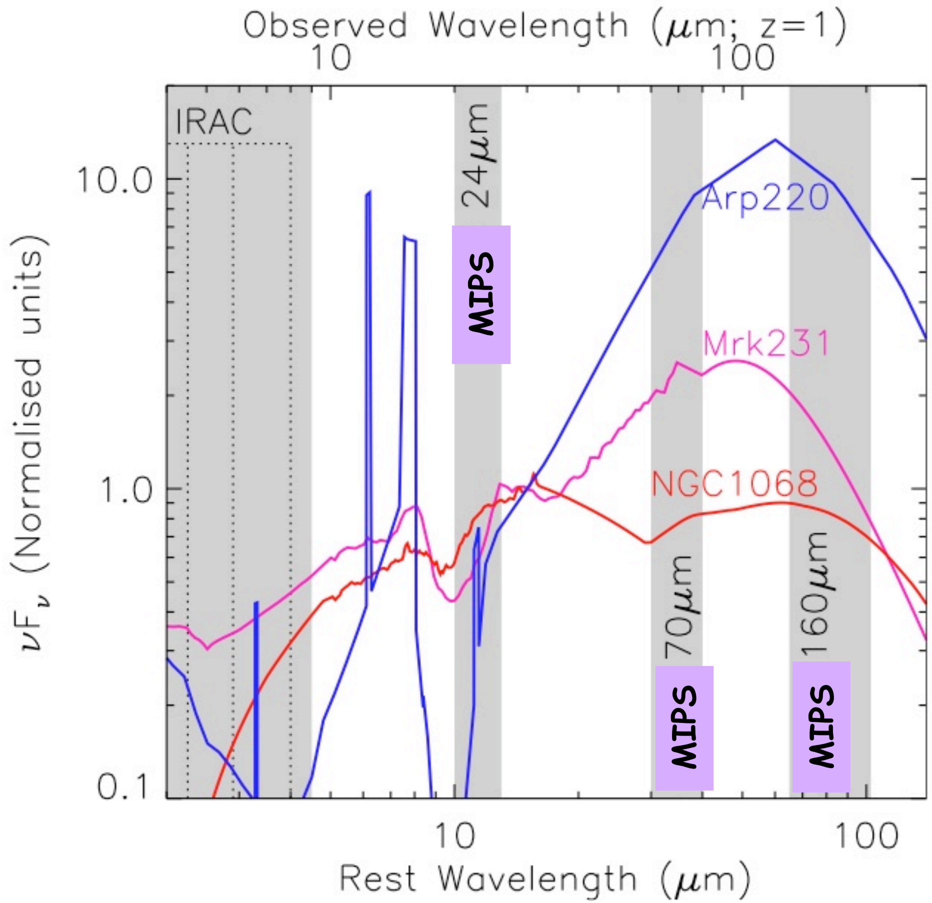


A low L_X/L_{IR} ratio
(~2-3 orders of mag
lower than typical AGN)

But the IR SED
and optical lines indicate
a luminous obscured
AGN is present



AGN and starburst SEDs



AGNs typically have "warmer" IR SED, although sometimes AGNs can be buried in a starburst SED

X-rays alone can often identify an AGN in a strongly starbursting galaxy (and provide black-growth cycle)

But we also needw both deep X-ray and IR observations to identify potential C-thick AGNs

With Spitzer (and in near future Herschel, SCUBA2, ALMA), we can make great progress in identifying X-ray undetected AGNs and discrimating between starbursts and AGNs

Overview

- Characterising the far-infrared properties of distant AGNs

  Result - L_{IR}/L_X increases with redshift for modest AGNs (L_X~10^{42}-10^{43} erg/s: either increase in AGN dust covering or star formation?

- Identifying individual X-ray undetected/weak distant AGNs (typically heavily obscured systems)

  Result - (potential) C-thick AGNs appear to be at least as common as unobscured AGNs at high redshift

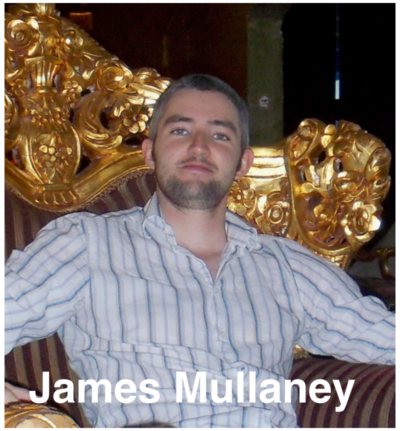
- Exploring AGN activity in distant star-forming galaxies

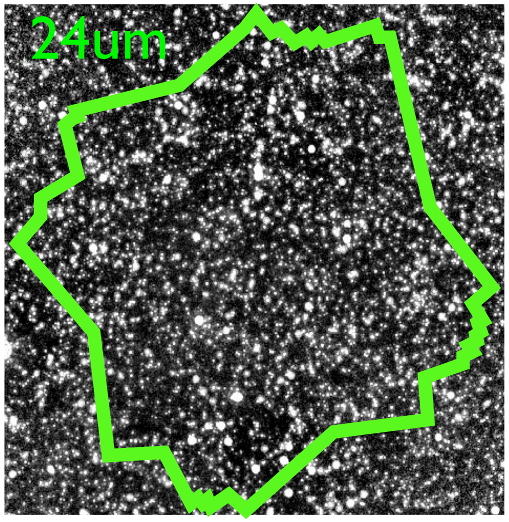
  Result - luminous AGN fraction increases with star-formation rate (longer black-hole duty cycle) but overall mass accretion-star formation rate in agreement with local Universe

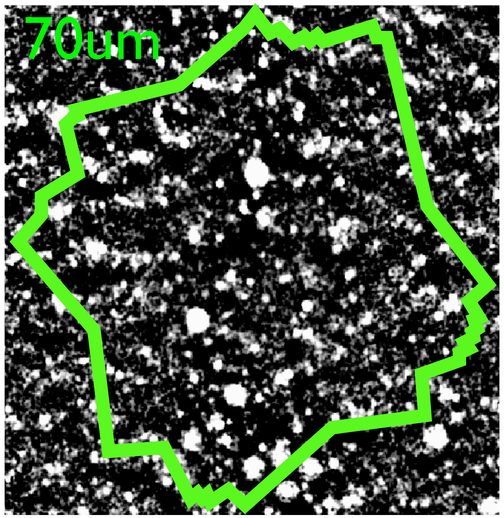
Characterising the far-infrared properties of distant AGNs

Characterising infrared properties of distant AGNs

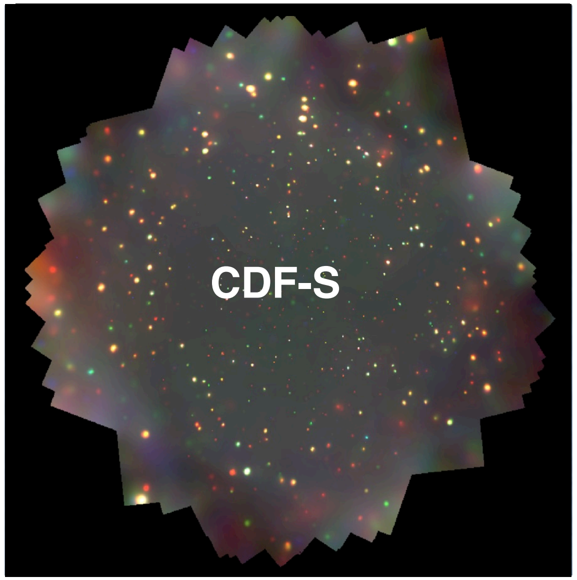
Mullaney, DMA et al. submitted





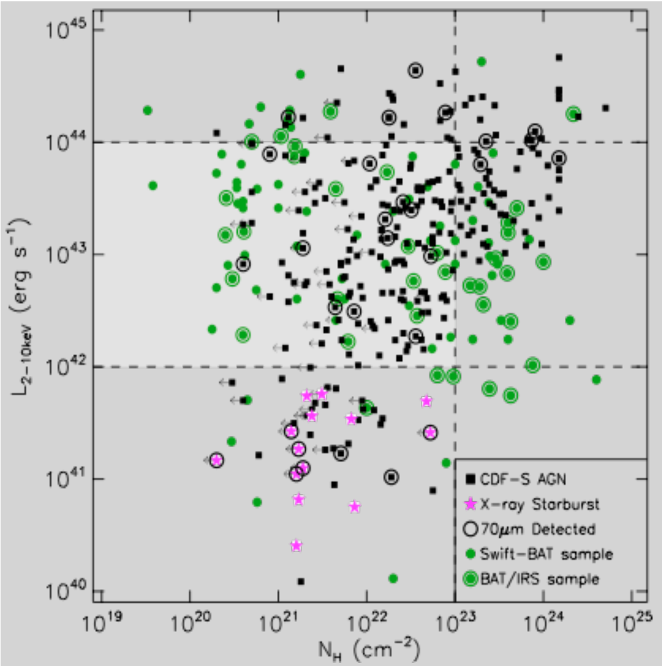


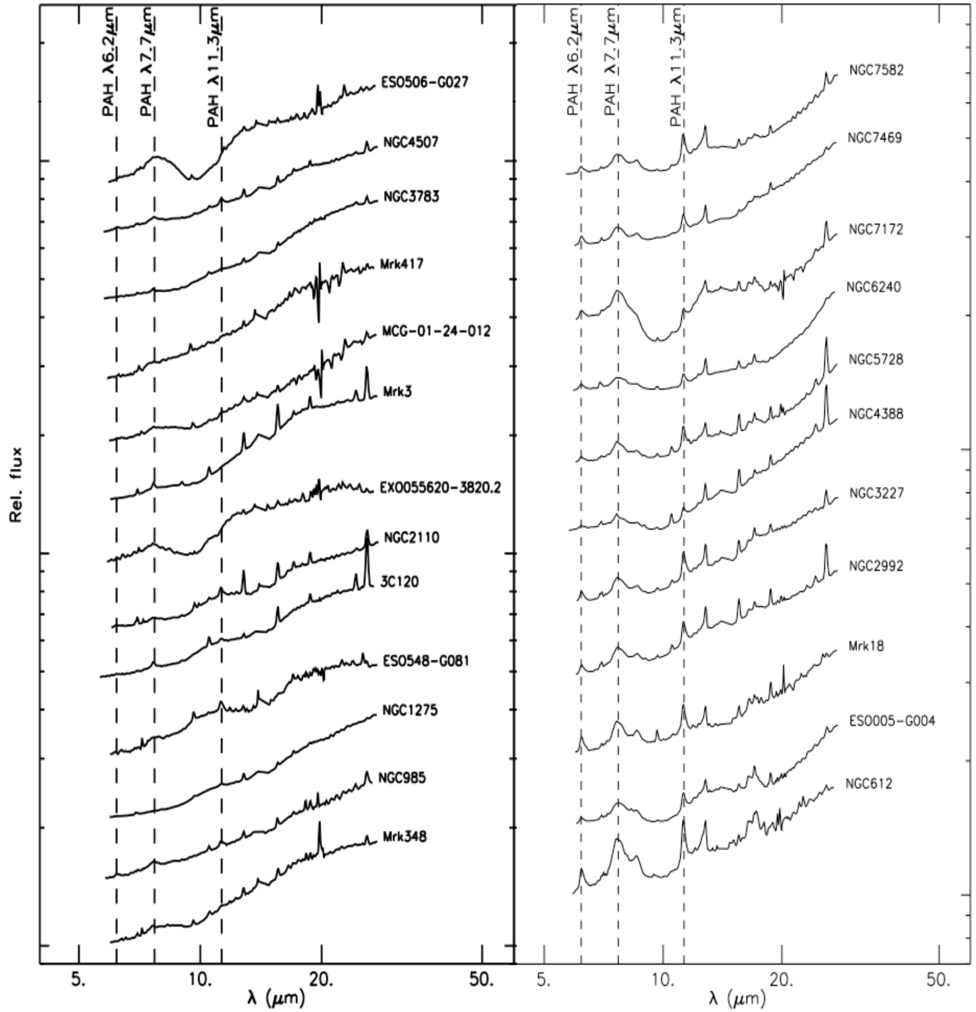
- 70 um data easier to interpret than 24 um data but lower sens
- 1Ms CDF-S with X-ray spectral analysis from Tozzi et al. (2006): specifically $L_{2\text{-}10keV}$ and N_H
- Only 30 of 266 detected at 70 μm
  - Use stacking analysis to derive *average* 70 μm flux densities.



Expectations based on z~0 Swift-BAT AGN sample

Mullaney, DMA et al. submitted

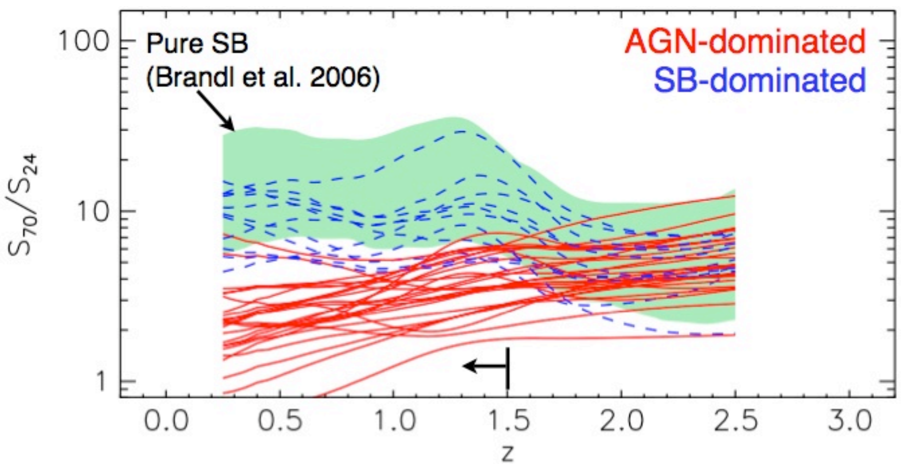




- Sensitive to very hard X-rays (14-195 keV): Tuller et al. (2008); Winter et al. (2009)
- Same intrinsic properties as CDF-S AGNs (N_H; $L_{2-10keV}$) but at z<0.1 (compared to z>0.5)
- 36 have Spitzer-IRS (5-35 μm) to ID between SB/AGN-dominated SEDs and make high-z predictions

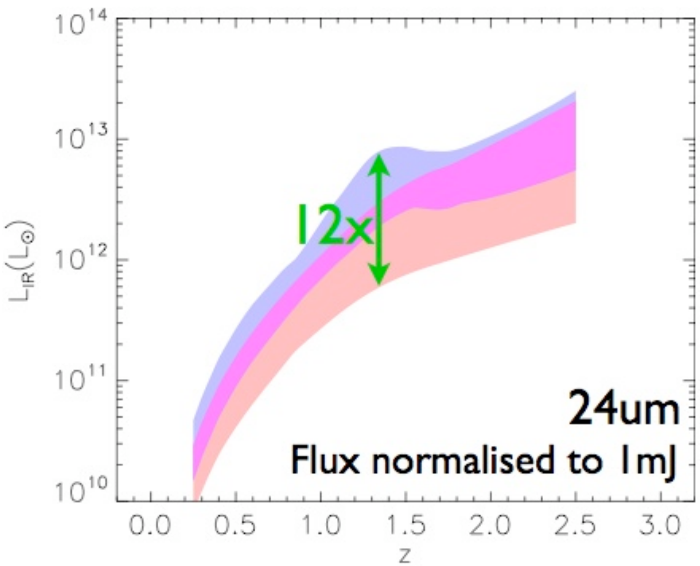
Predictions from z~0 Swift-BAT AGN sample

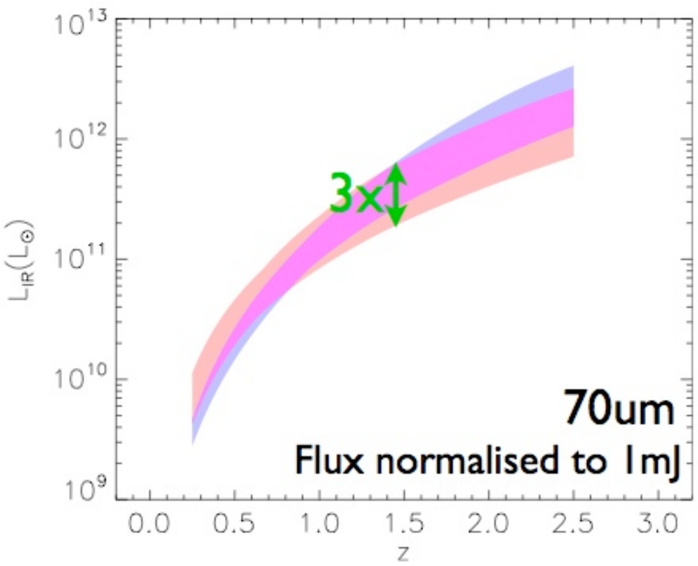
Mullaney, DMA et al. submitted



- 70/24um colours can discriminate between AGN-dom and SF-dom sources out to z~1.5

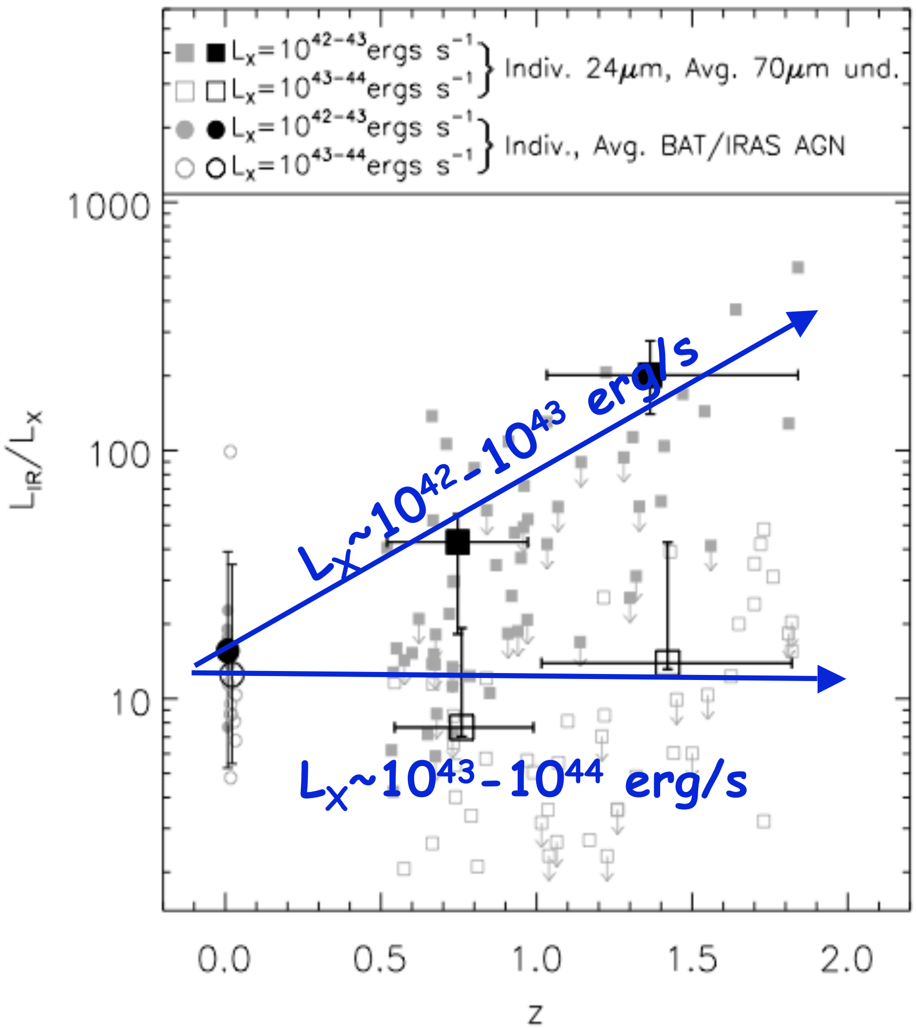
- 70um data gives robust infrared luminosity assessment irrespective of whether source is AGN-dom or SF-dom





Key result: evolution in L_{IR}/L_X ratio with redshift

Mullaney, DMA et al. submitted



Evidence for increase in L_{IR}/L_X for modest luminosity AGNs from both 70um AND 24um data:

Increase in AGN dust-covering factor?

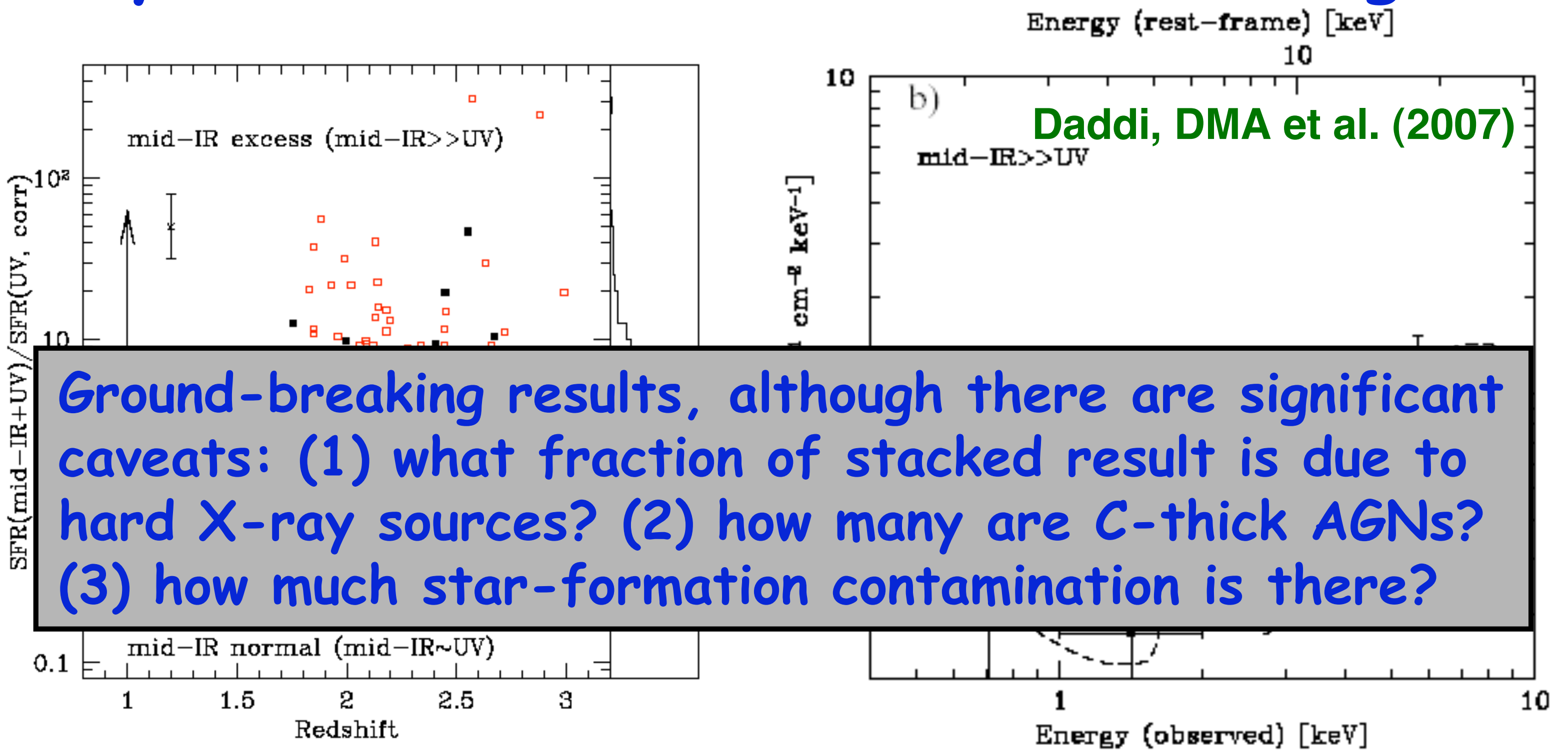
- Tentative qualitative support for increased absorption with redshift from X-ray surveys (La Franca et al. 2005; Hasinger 2008) BUT increase implied here is far larger

Increase in star-formation?

- L_{IR}/L_X of z=1-2 AGNs similar to z~2 submillimetre of Alexander et al. (2005), which is due to large star-formation fraction

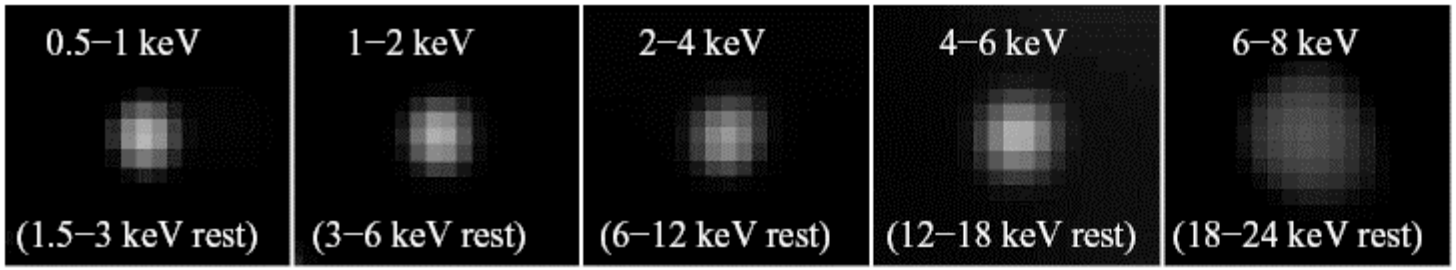
Identifying individual X-ray undetected/weak distant AGNs

X-ray undetected mid-IR AGNs in z~2 galaxies



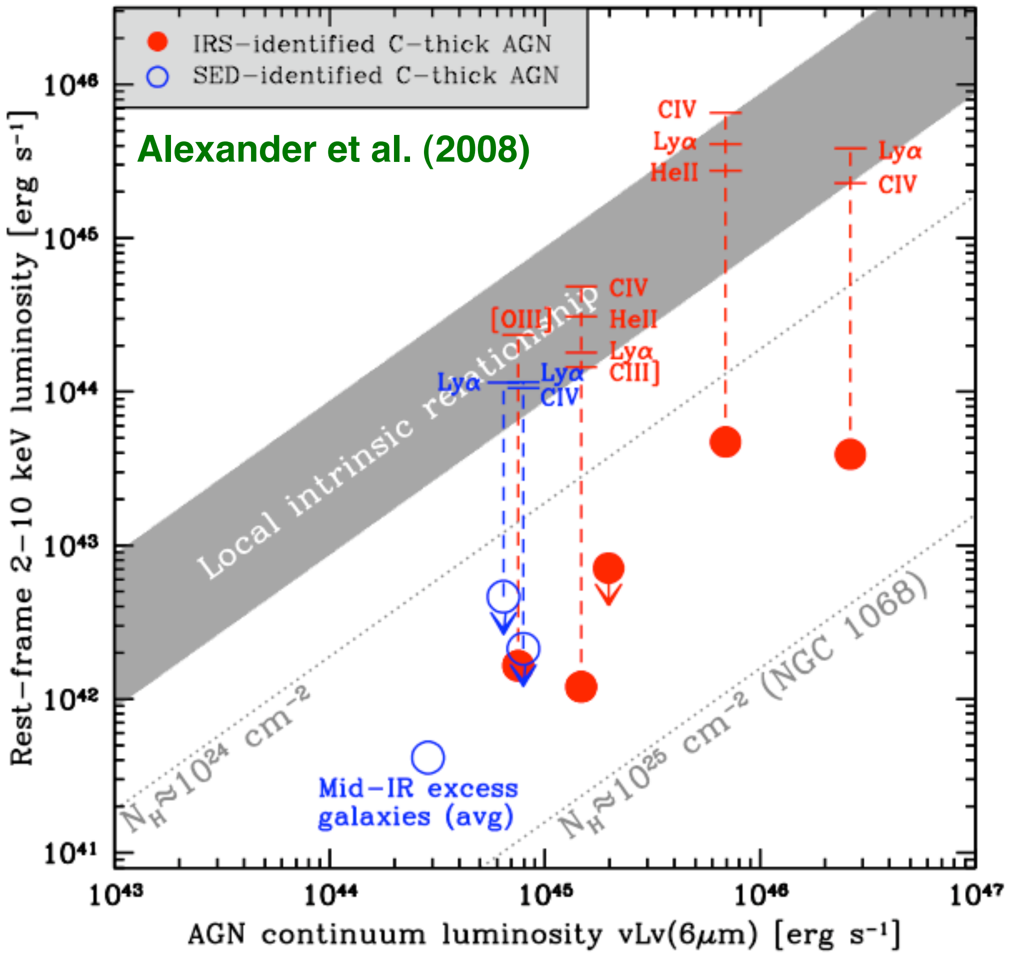
Ground-breaking results, although there are significant caveats: (1) what fraction of stacked result is due to hard X-ray sources? (2) how many are C-thick AGNs? (3) how much star-formation contamination is there?

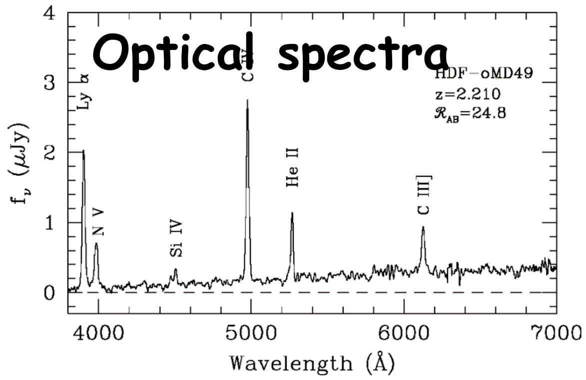
Stacked X-ray data of mid-IR galaxies in narrow bands

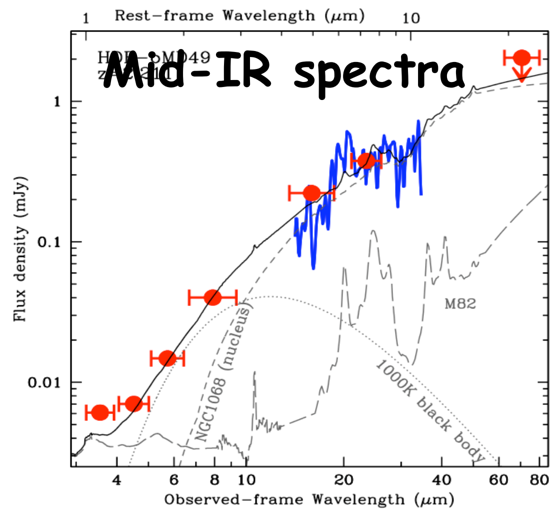


Very hard signal => significant fraction of obscured AGNs (see also Fiore et al. 2008, 2009 amongst others)

Working towards ID'ing individual distant C-thick AGN

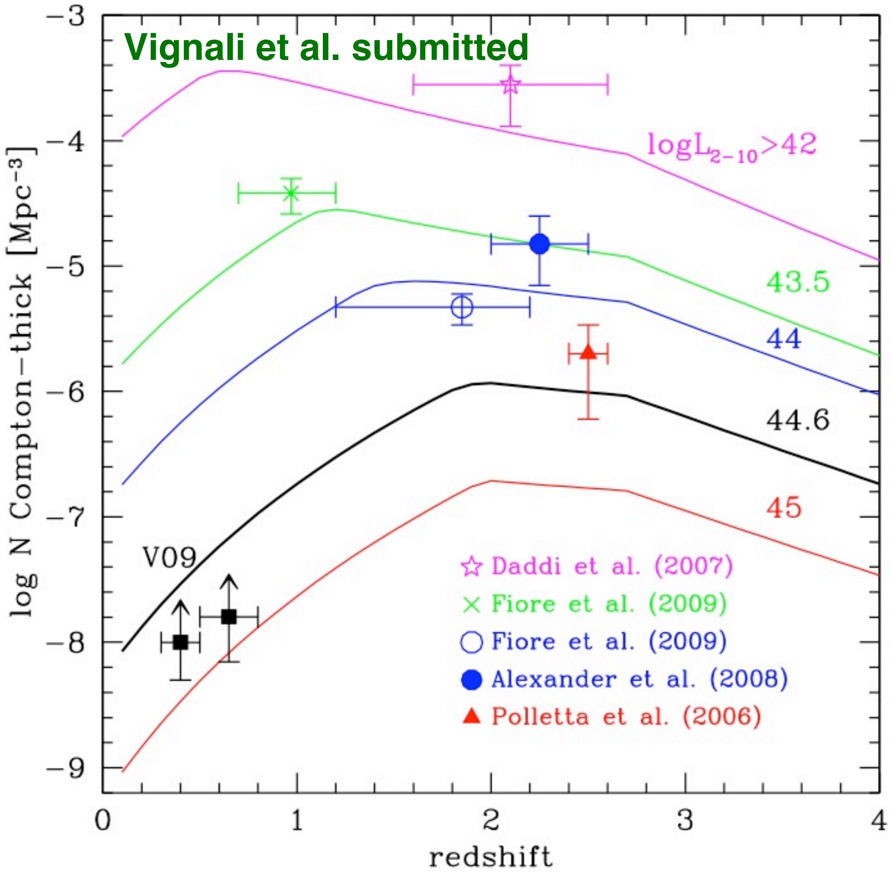






With this more robust approach we ID 7 z~2 (likely) Compton-thick AGNs: not a large number but significant since these are the first z~2 sources (and remember only ~50 C-thick AGNs known to date!)

Progress is being made from a variety of studies



Individual distant C-thick (or heavily obscured) AGNs being identified using spectoscopy with variety of samples/redshifts:

z~0.5 SDSS obscured quasars (Vignali et al. submitted)

z~1-3 infrared-bright AGNs (Bauer et al. submitted) (Donley et al. in prep)

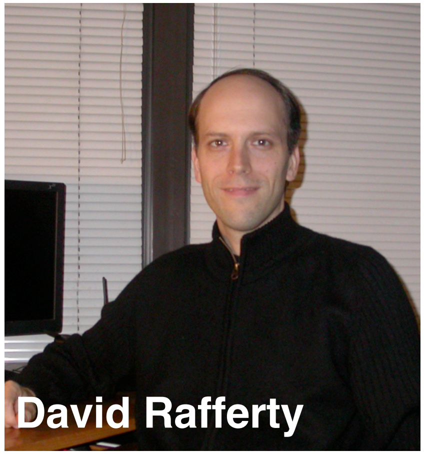
z~0.5-2 "IR warm" X-ray undetected objects (Alexander et al. in prep)

The consistent result coming from these works is that the potential C-thick AGN space density at high redshift is at least as large as the unobscured AGN space density, broadly consistent with X-ray background models (Gilli et al. 2007)

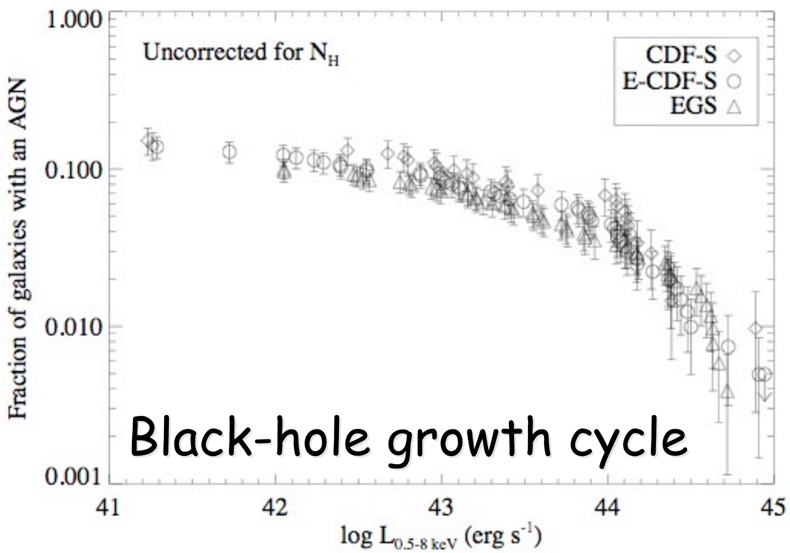
Exploring AGN activity in distant star-forming galaxies

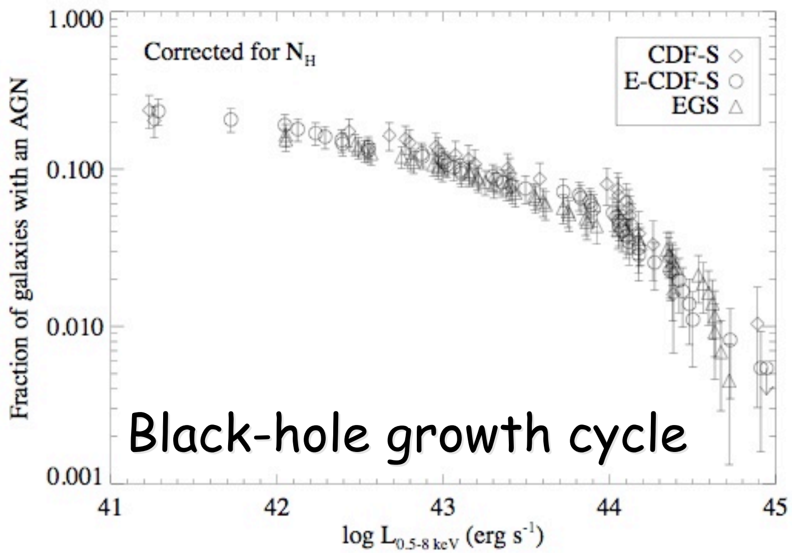
AGN activity in distant starburst galaxies

Rafferty, Brandt, DMA et al. in prep

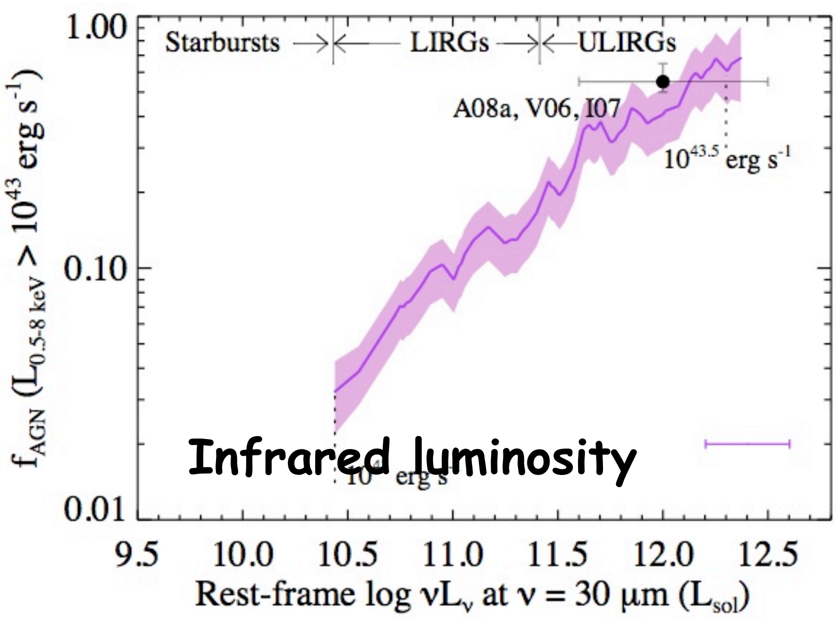


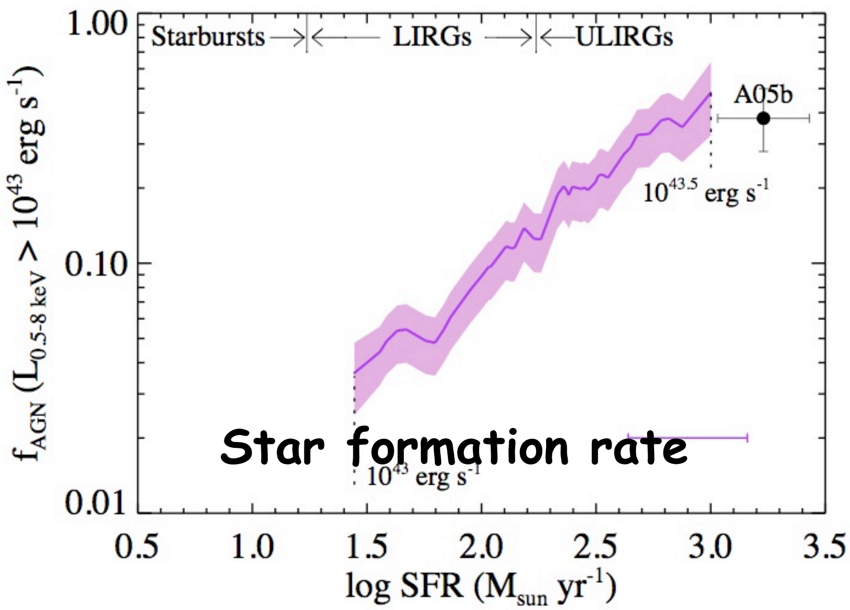
- Based on 70 um data in variety of deep fields (E-CDF-S; EGS)
- Identify AGN using X-rays and remove AGN contribution from infrared to estimate star-formation rates
- Takes into account sensitivity effects due to absorption

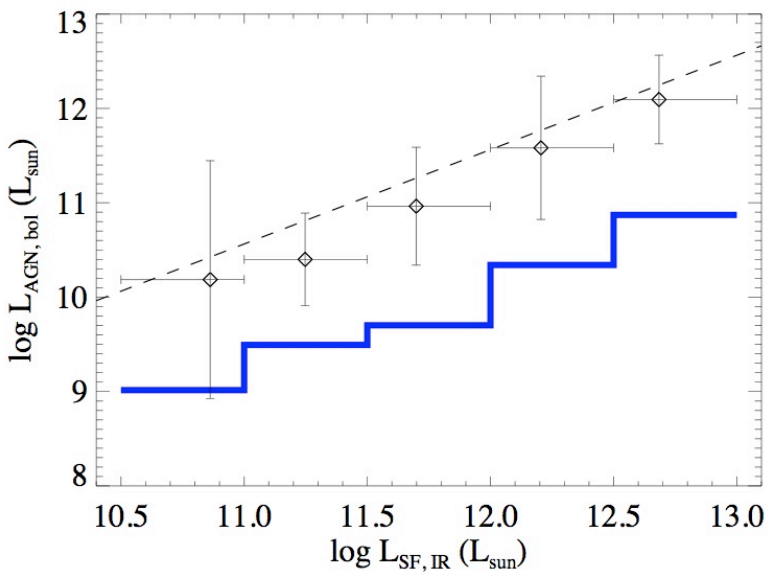




z<2 AGN fraction as function of L_{IR} and SFR







X-rays & Spitzer 24+70um

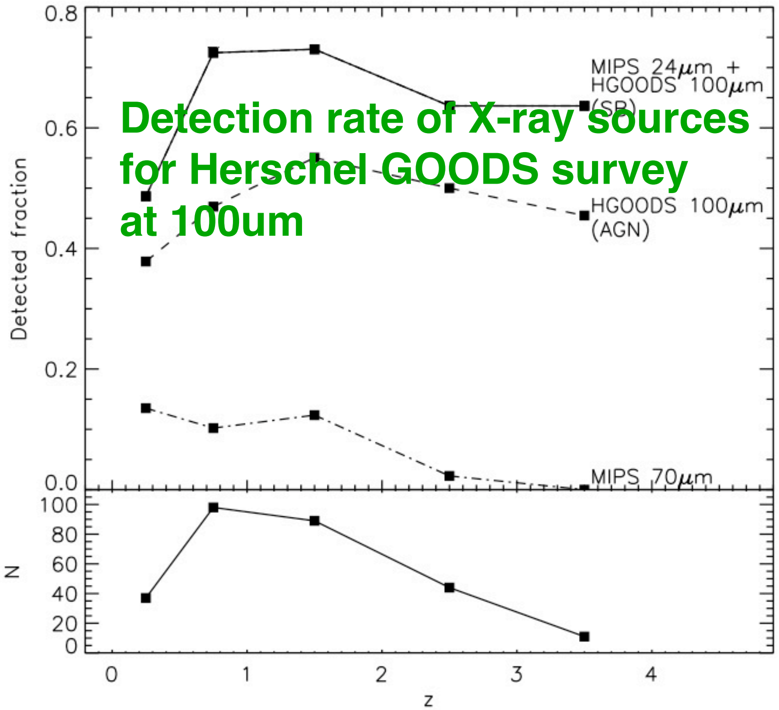
AGN fraction increases with both L_{IR} and SFR (consistent with nearby ULIRGs and submm galaxies): long black-hole growth cycle

Average accretion rate and star-formation rate consistent with local black-hole-spheroid mass ratio

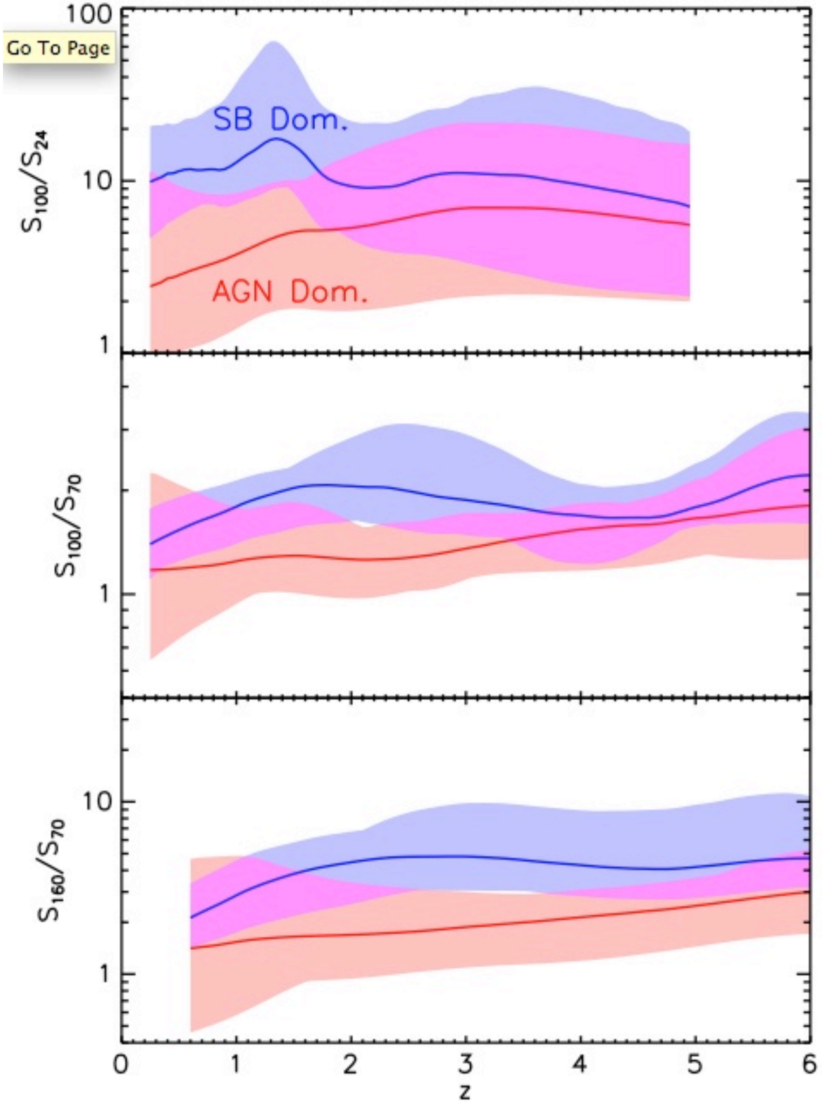
Rafferty, Brandt, DMA et al. (in prep)

Potential of deep Herschel surveys

Herschel (70-500um) extents wavelength coverage and sensitivity: discriminate between star formation and AGN processes



Detection rate of X-ray sources for Herschel GOODS survey at 100um



Mullaney, DMA et al. submitted

Summary

• L_{IR}/L_X of modest-luminosity AGNs (L_X~10^{42}-10^{43} erg/s) evolves with redshift:

- •~5-20x higher at z>1… not clear if increase is due to AGN activity or star formation; L_{IR}/L_X constant for higher-luminosity AGNs (L_X~10^{43}-10^{44} erg/s)

• Variety of studies working towards identification of individual (potentially) C-thick distant AGNs using mid-IR/optical spectroscopy

- • general concensus is that there are at least as many C-thick AGNs as unobscured AGNs at high redshift

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• Luminous AGN fraction in distant star-forming increases with star-formation rate but average mass accretion rate vs star formation rate is consistent with local black-hole-spheroid mass ratio

Improved sensitivity and broader wavelength coverage of Herschel (and SCUBA2) offers great potential to extend these studies to identify accurately between AGN and star-forming SEDs and to identify (potential) distant Compton-thick AGNs