AGN and the FIR - A Strong Science Driver for a Future IR Mission

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AGN and the FIR

Main Goals of AGN research

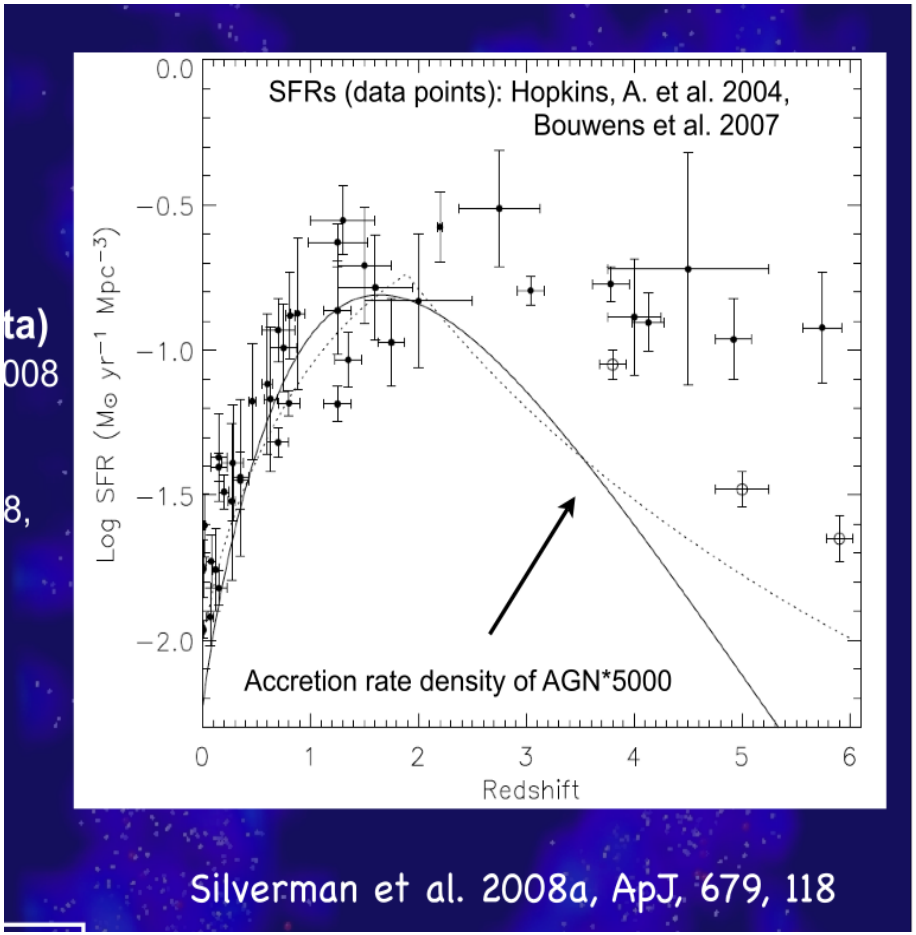
- How do AGN 'work' ?
  - e.g. how does gas flow into the Super Massive Black Hole and produce the enormous luminosity and broad band observed spectrum
- How do AGN form and evolve ?
  - What is the origin of the SMBHs and their evolution over cosmic time
- How do AGN influence the formation and evolution of all structure (galaxies- clusters) across cosmic time ?
  - What are the processes that cause the feedback (winds, jets, radiation etc etc) and how does feedback actually work

high quality imaging and spectral data in the mid-far IR are crucial for progress in all of these areas

Why Mid-Far IR for AGN

- Probable direct signatures of feedback (winds/star formation) and perhaps accretion
- Significant fraction of the total AGN luminosity
- Probes connections between star formation and AGN (not seen in other wavelengths -obscuration)
  - Measure co-eval growth of black holes and galaxies
    ~1/2 of all AGN growth is 'hidden' by dust only x-ray and IR can find them

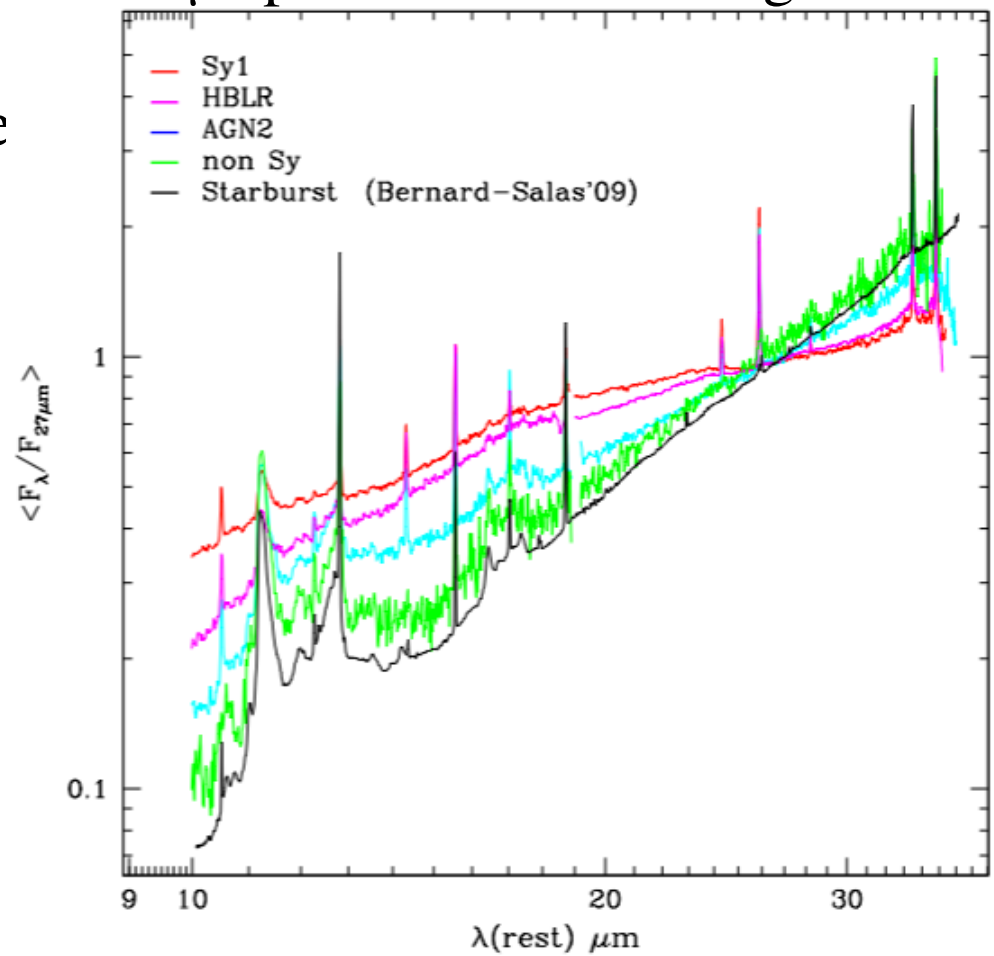
Spectral lines indicative of AGN
Not influenced by extinction
Sensitive
– negative redshift correction-
easy to probe high z universe



Why Mid-Far IR for AGN

- Rest-frame MIR/FIR imaging spectroscopy provides a complete view by measuring the role of BH **and** SF
  - With proper instrumentation and sensitivity can trace simultaneously both SF and AGN and measure redshifts out to z>6

10-30μ spectra of AGN+SF galaxies



Spinoglio, Dasyra, Franceschini, Gruppioni, Malkan, Maiolino

Without feedback have

- ◆ Too many small galaxies,
- ◆ Too many big galaxies in the nearby universe,
- ◆ Wrong colors of massive galaxies
- ◆ Too many baryons within the galaxy halos

Far IR and AGN

- The Far IR (defined as $\lambda > 10\mu$?− factor of 100 in λ!) contains signatures of
  - AGN continuum and line emission
  - star formation (which may or may not be related to the AGN)
  - Winds and accreting gas

Recent results indicate that:

there maybe (or may not be) a positive/negative relationship between SF and the AGN which changes with redshift? (Rosario et al 2013ab)

the presence of a star burst nucleus in ALL AGN

a relationship between winds and the presence of an AGN

- 'ubiquity' of winds

Discovery of large numbers of 'obscured' AGN

First results on nature of central regions near SMBH

What Do we Want to Do

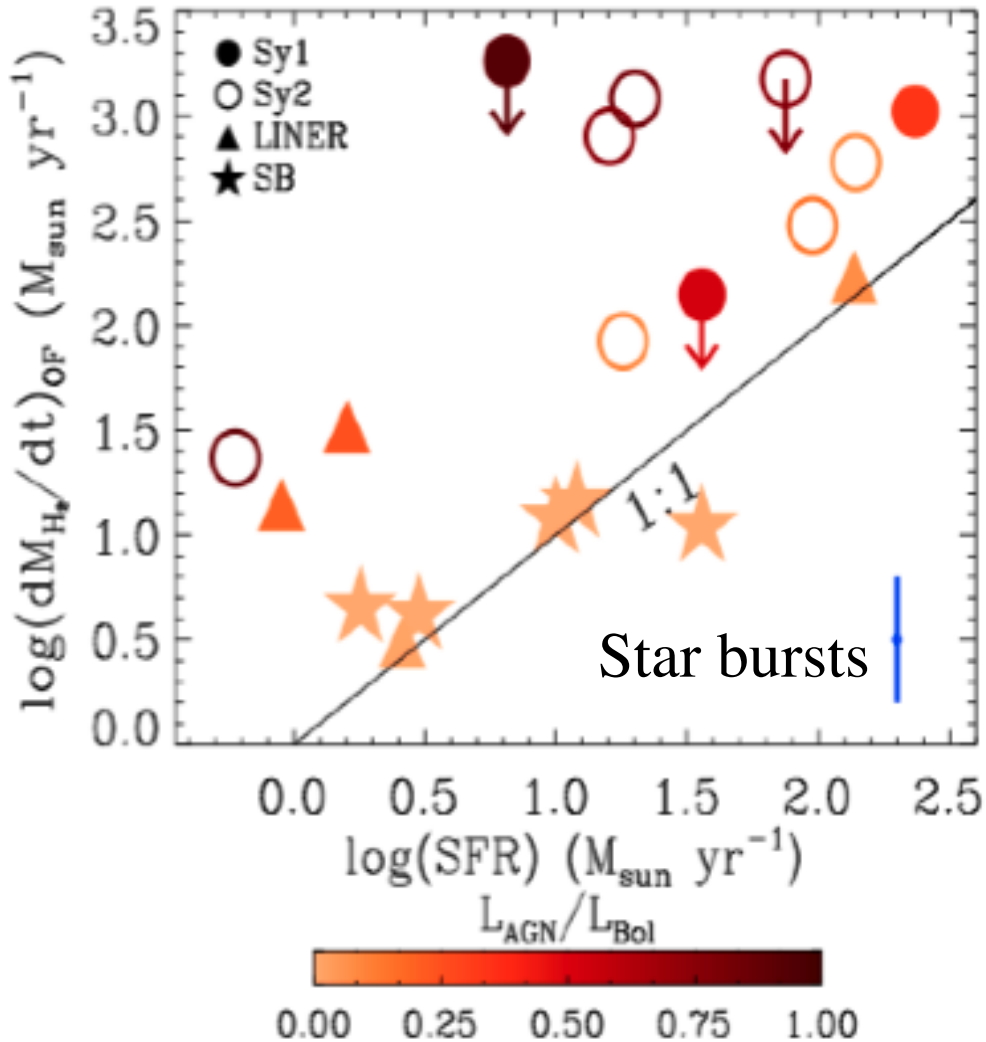
- Find AGN:
  - >50% of AGN (perhaps more at higher z) are obscured: IR is a preferred place to look
    - continuum selection is subtle subject to strong contamination from star formation
    - Use lines, just like in the optical and UV- need moderate resolution sensitive spectroscopy (also get BH masses)
      - OIV (~ $10^{-2.5}$ of x-ray luminosity**) need to reach fluxes of $3x10^{-18}$ ergs/cm^2**
        - » **~ 3-4 orders of magnitude fainter than Spitzer – this is reached by most of the missions**

- Study AGN
  - What is relationship of star formation to AGN
    - **Spatial resolution: at z<0.03 need ~1" or better to spatially resolve mid-IR (70μ) emitting region**
    - Survey- space density of AGN at faint levels ~3000/sq deg **need sufficient angular resolution (~10") to avoid source confusion**
    - Sensitivity: recent work with Scuba (Barger et al 2014) and Herschel shows that at z~1

      νL_ν (50μ)~3- 30νL_ν (0.5μ) – high z **AGN need continuum sensitivity of 10^{-14} ergs/cm^2/sec =300μJy @100μ**

Study Feedback

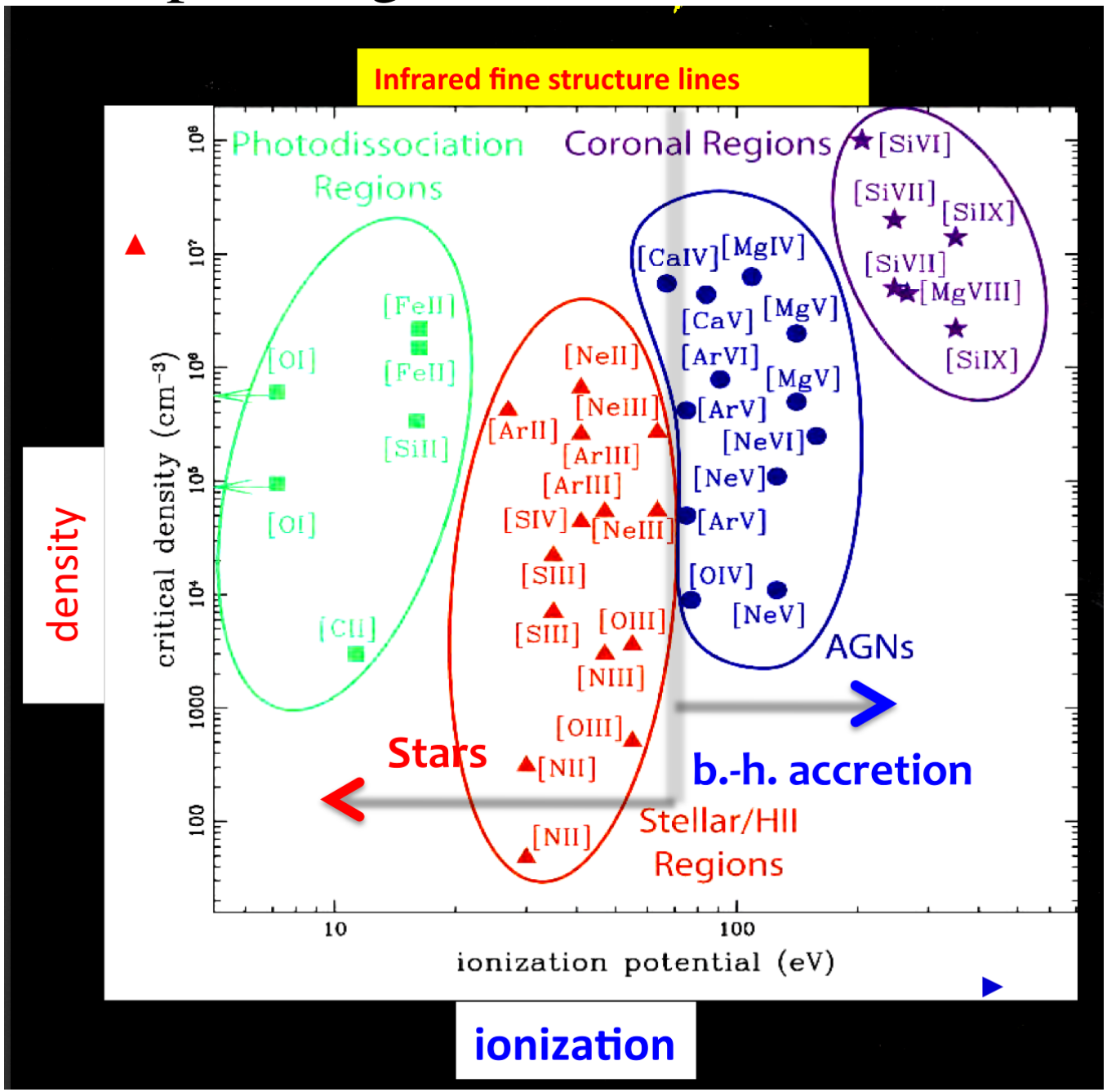
- Follow-up discoveries that much (most) of momentum/energy in winds is best measured in the mid-far IR
  - Ability to trace this over cosmic time and full range of AGN/ galaxy properties
  - **Spectral resolution, sensitivity and bandpass constraints**



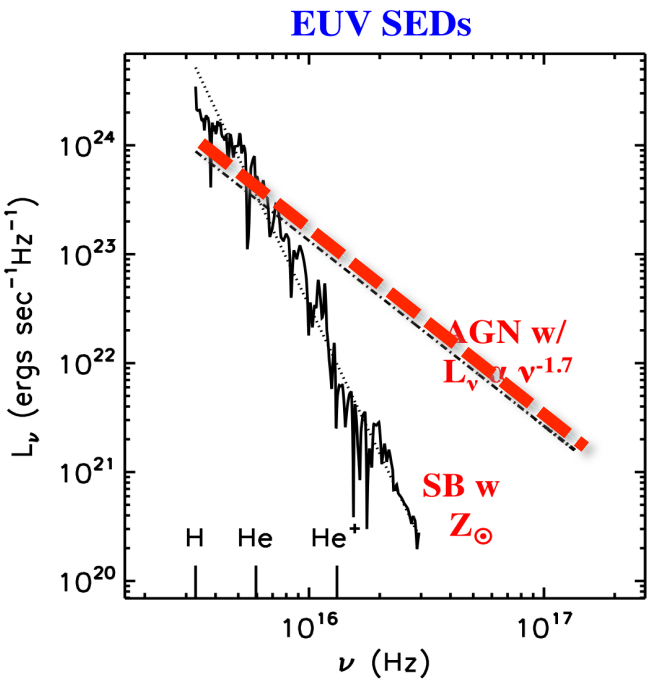
Winds in AGN hosts
Cicone et al 2014

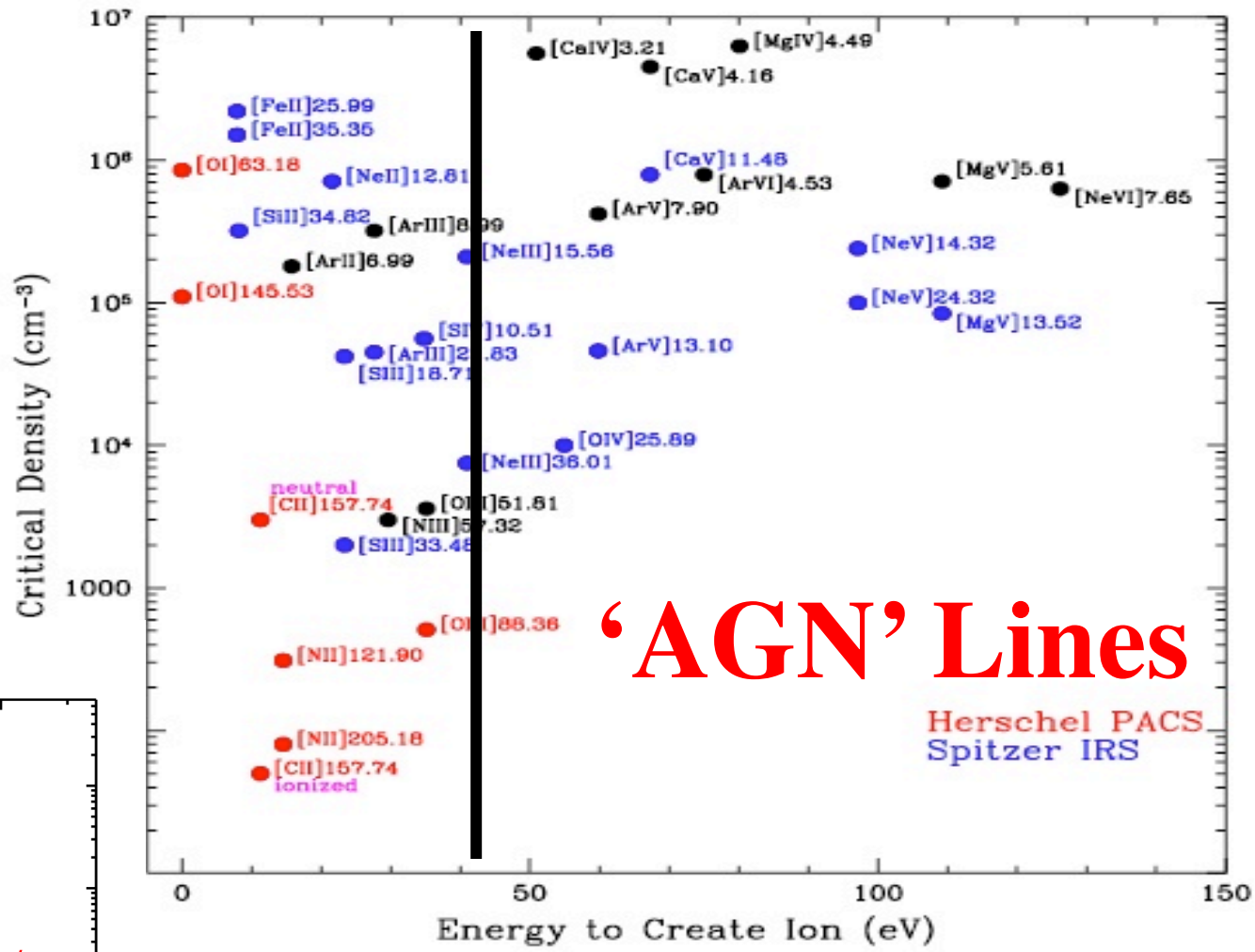
Spectroscopic Diagnostics of AGN

- Most AGN diagnostic lines in 2-26μ band+[OIII] at 88μ.
- Far-IR diagnostic toolbox to characterize galaxy nuclei (Spinoglio)
- Atomic fine structure lines
- High-J CO, light hydrides
- Other molecules



Scoville



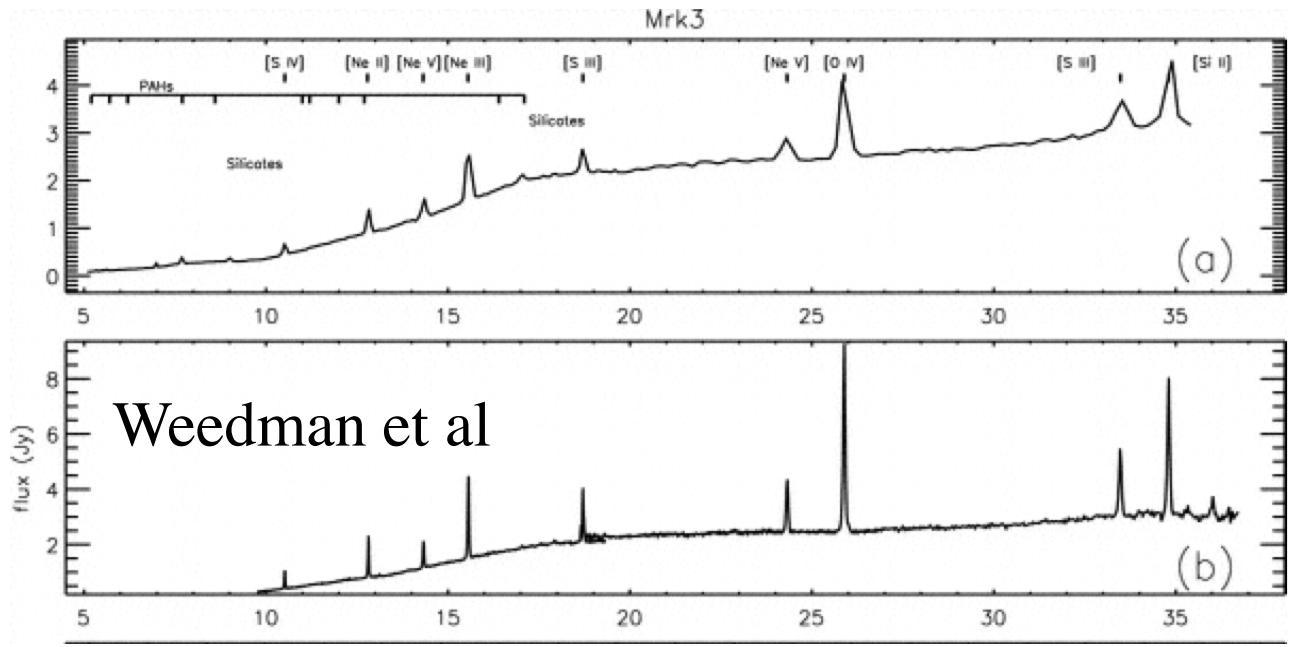


http://www.ast.cam.ac.uk/research/galaxies.and.active.galactic.nuclei/kingfish/science

AGN IR Diagnostic Line

- [OIII] 52,88μm
- [OI] 63,145μm
- [CII] 158μm
- [NIII] 57μm
- [NII] 121, 206μm
- ^{12}CO(J=4 to 24)
- [CI] 370,609μm
- ^{13}CO(J=5 to 12)

Spinoglio 2007, Fisher 1999



Strongest high ionization lines

OIV 25.9 μm

NeV14.3 μm; 24.3 μm

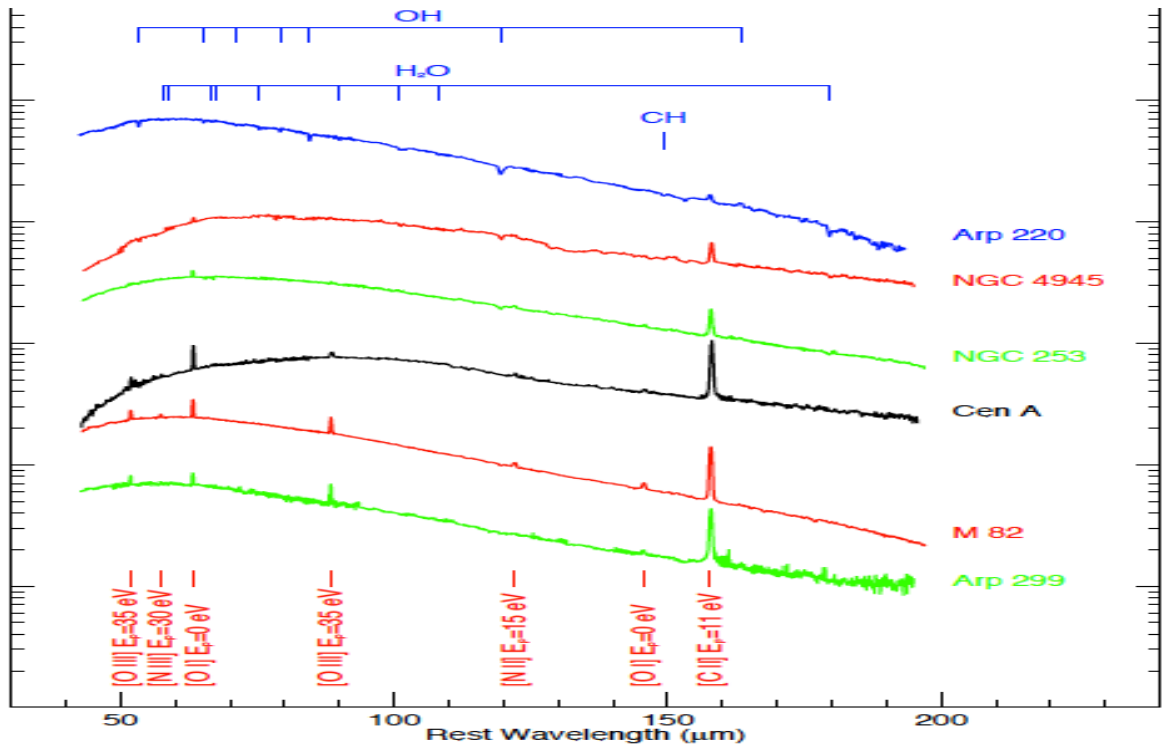
[Ne III]15.56 μm

Si[IV] 10.5 μm

These are forbidden lines

'narrow' δv<2000km/sec-

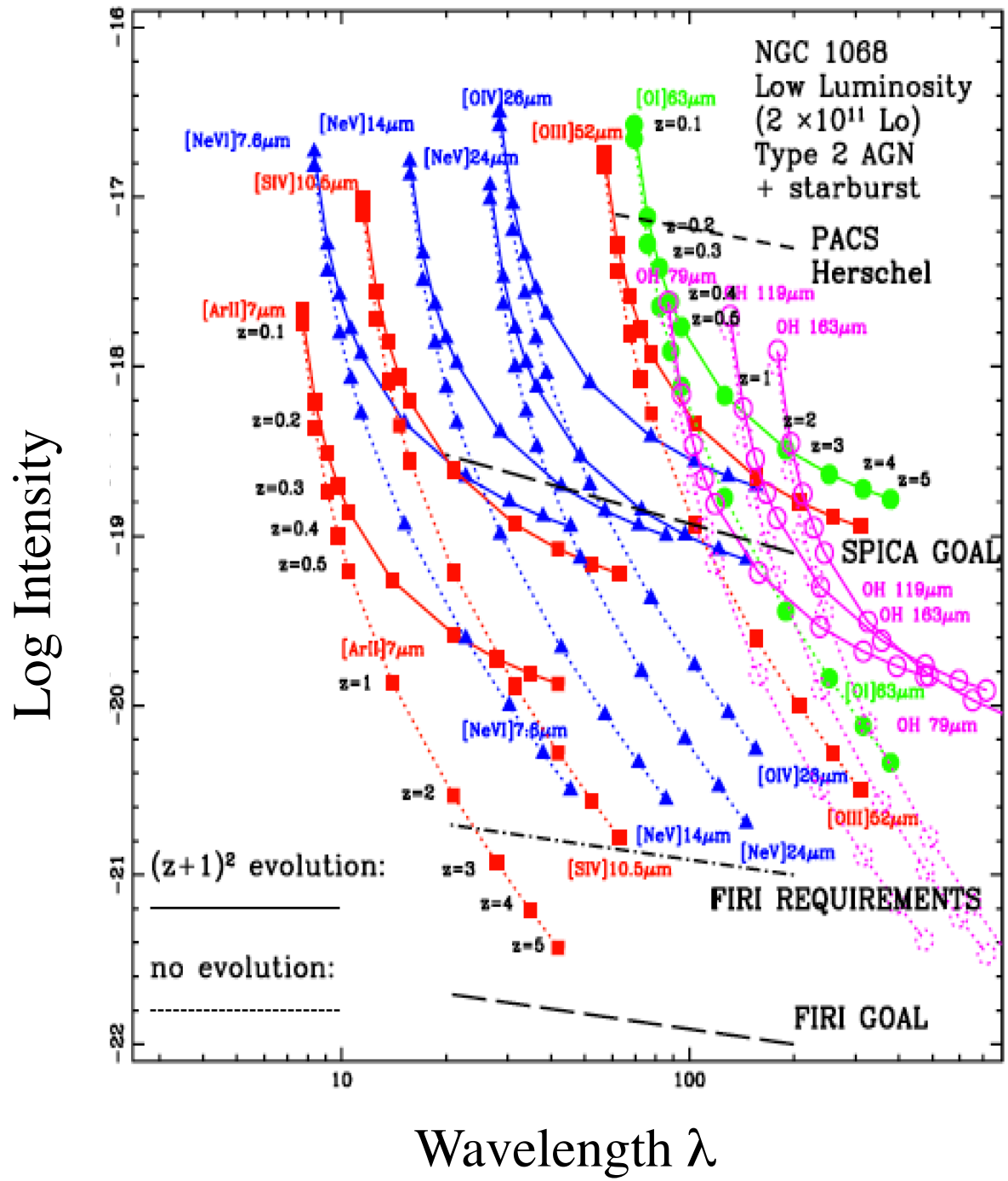
can be used for black hole mass estimates



Redshift

All the high ionization (AGN dominant lines) except [OIII] are at rest wavelengths 2-26μ

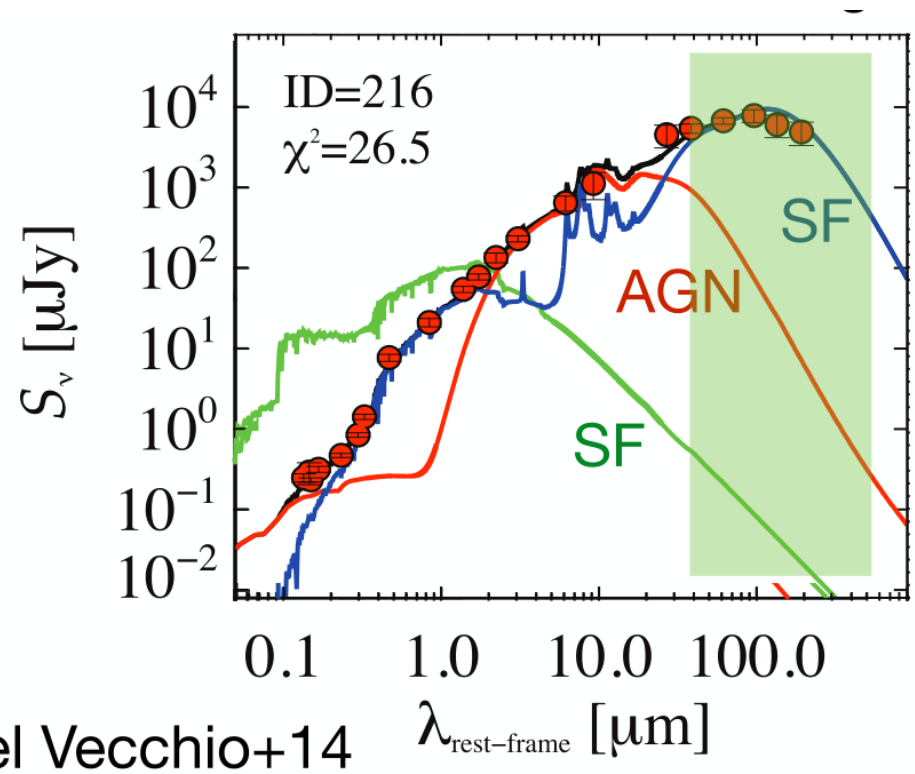
- Strong reason to extend bandpass down to ~10μ for low z or for high redshift (5) to 180μ
- (Spinoglio 2007)



Fundamental Problem - Separating AGN from SF Light

- **" The freedom to distribute dust outside the sublimation radius in different ways leads to a large variety of warm to cold SEDs, .. " Lutz 2014**

- If SF in an AGN host is similar to that in 'normal' galaxies -use template fitting (Netzer 2007, Mullaney 2011) **but if feedback ideas are correct this is not a good approach.**
- Alternatively one can use secure AGN or SF signatures (e.g. NeV or PAHs) and then scale the continuum.
  - however it seems that in AGN hosts PAHs are suppressed
  - correlation of NeV and IR continuum is not well studied

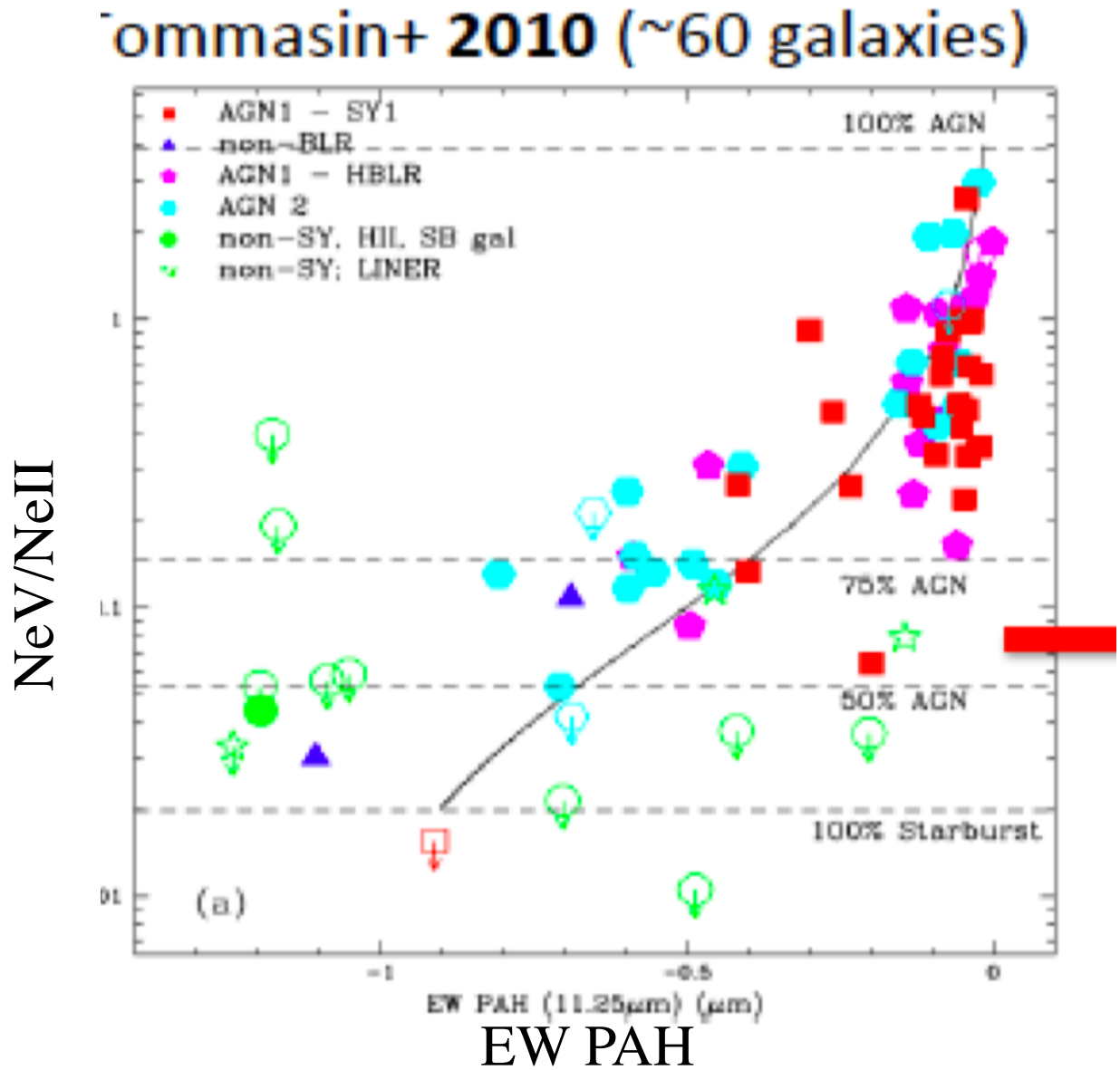


Del Vecchio+14

Pathology of SED- since AGN and SF should not be correlated the 1-500μ spectra should show inflections

AGN Spectroscopic Diagnostics

- Strong high ionization lines and low EW of PAH indicates AGN dominance as does strong Si features –



Herschel: Powerful Molecular Outflows in Local ULIRGs and FIR-Bright Quasars

(Fischer + 2010; Sturm + 2011; Veilleux + 2013; Spoon + 13; Gonzalez-Alfonso + 2012, 2014)

OH 65 / 79 / 119 um PACS Spectroscopy

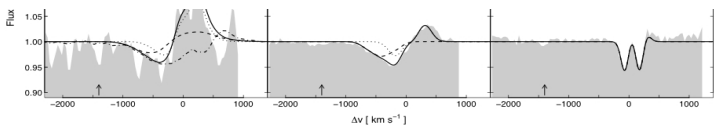


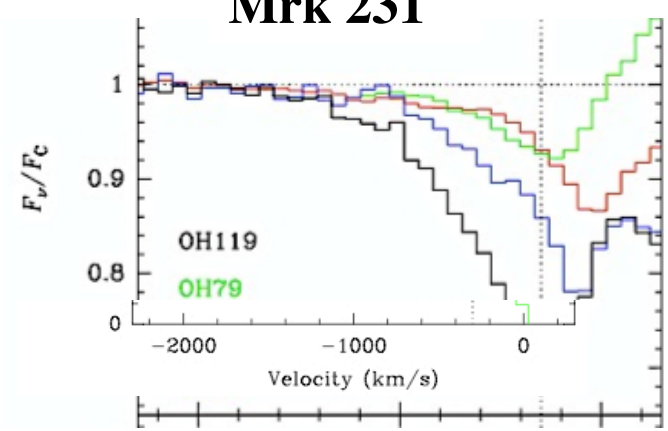
Fig. 1.— Observed PACS spectra (continuum normalized) of the OH transition at 79 μm (*grey*). Overplotted are the low velocity (*dotted*) and high velocity (*dashed*) fit components and the total fit (*full*). The arrow indicates the rest position of H_2O 4_{23}-3_{12}. The dash-dotted line for IRAS 14378 shows the observed spectrum of the OH transition at 119 μm for this object.

Table 1: Target properties, outflow rates and outflow velocities (1σ uncertainties in brackets)

Source	SFR $M_\odot/yr$	α^a %	L_{AGN} $10^{11}L_\odot$	M^b_{gas} $10^9 M_\odot$	$\dot{M}^c$ $M_\odot$/yr	v^d_{peak} km/s	$v^e_{85\%}$ km/s	v^f_{max} km/s
Mrk 231	101 (15)	71 (11)	28 (4)	4.2 (1.3)	1190^{+4700}_{-890}	-600	-660	-1170
IRAS 08572+3915	42 (6)	72 (11)	12 (2)	1.3 (0.4)	970^{+2900}_{-730}	-700	-740	-1260
IRAS 13120-5453	168 (25)	9 (1.4)	1.8 (0.3)	5.8 (1.7)	130^{+390}_{-95}	-520	-600	-860
IRAS 14378-3651	>79	<45	<7.2	4.2 (1.3)	740^{+2200}_{-550}	-800	-860	-1170
IRAS 17208-0014	274 (41)	11 (1.7)	3.4 (0.5)	12.2 (3.7)	90^{+270}_{-65}	-100	-170	-370
NGC 253	1.7 (0.3)	0	0	0.7 (0.2)	$1.6^{+4.8}_{-1.2}$	-75	-130	-280

Δv [km s^{-1}]

Mrk 231



- ***Statistics:*** **~70% of local ULIRGs have molecular (OH) winds**
  - **→ wide-angle geometry (~145°)**
- ***Outflow velocities:*** **$\langle v_{50}\rangle$, $\langle v_{84}\rangle$, $\langle v_{max}\rangle$ ~ -200, -500, -925 km s^{-1}**
- ***Kinematic trend with L_{AGN}:***
  → AGN plays a dominant role when L_{AGN} exceeds ~ $10^{11.8}$ L_{sun}
- ***Energetics*** **(from profile comparison of multiple OH transitions*):***
  - **d*M* / *dt* up to 1000 M_{sun} yr^{-1}**
  - **$L_{mech} = 10^{10} – 10^{11}$ erg s^{-1}….**
  - **E_{mech} = few x 10^{56} ergs**
  - **d*p*/dt = (1 – 30) L_{AGN}/c**

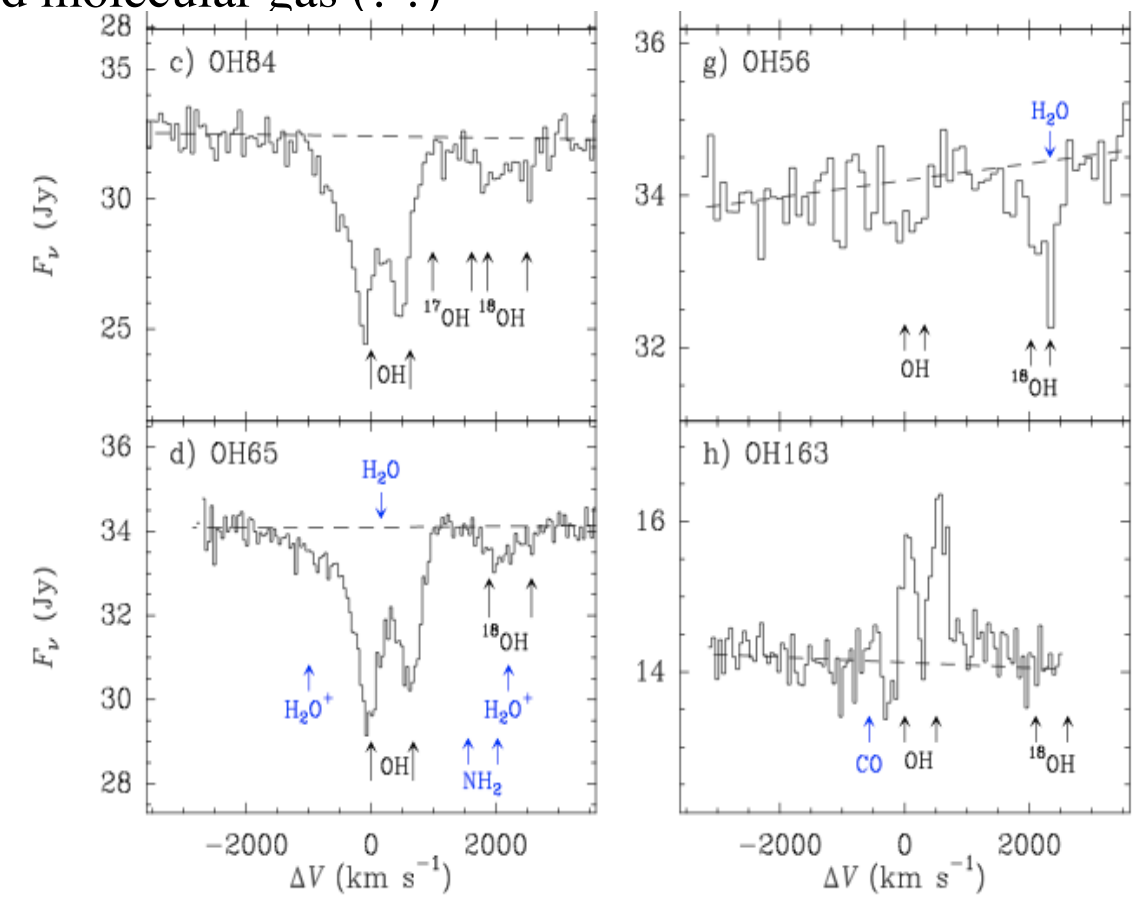
Outflows
MKN231 OH Lines Herschel

- Large velocities and high mass flow rates (Gonzalez-Alfonso et al 2014) – complex velocity field and a strong enhancement of ^{18}OH indicative of high rate of massive star formation (also CO, [CII] in emission)
- Most of mass in winds is in cold molecular gas (! ?)

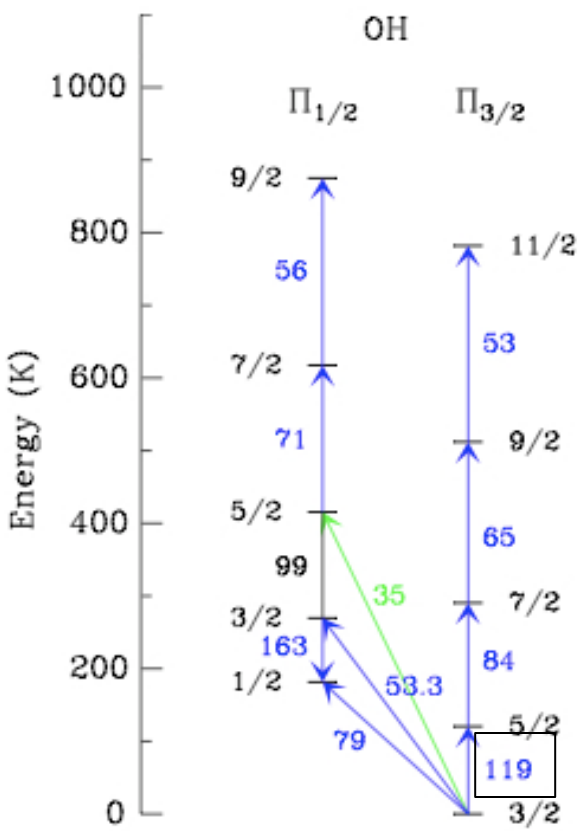
The (strength of the absorption relative to the emission)of the OH feature correlates with that of the 9.7-μ silicate feature, a measure of obscuration in ULIRGs (Veilleux 2013)

These sources are very bright >1 Jy at 65μ

Need much better sensitivity to go to a much larger sample/ higher redshift



Search and Characterization of Local and Distant Molecular Outflows



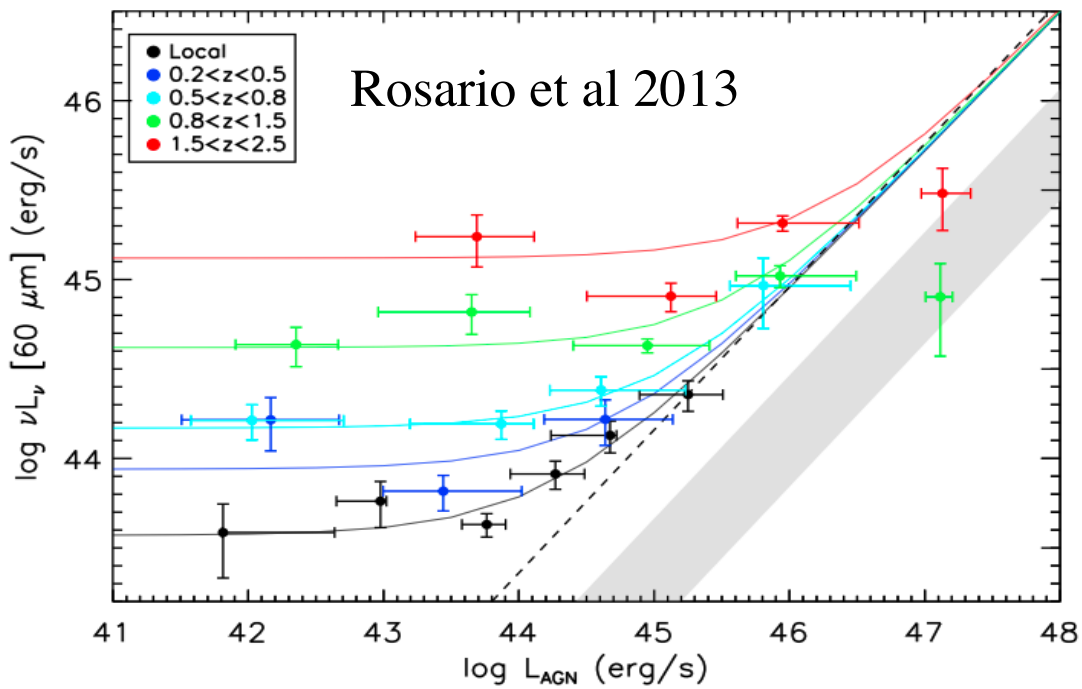
OH Ladder

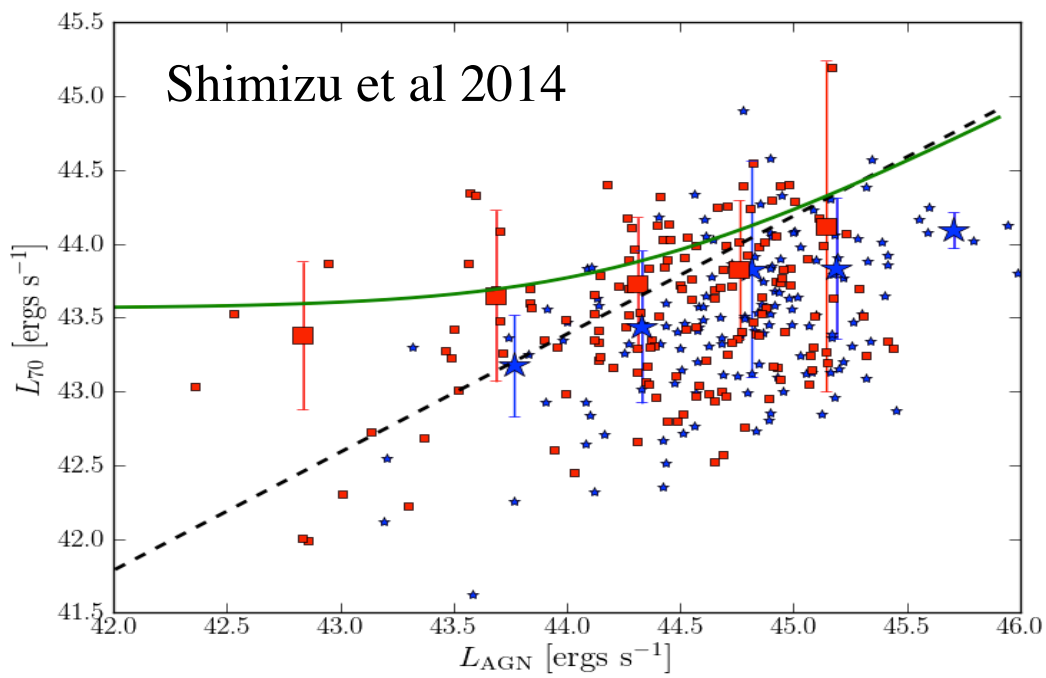
S/N **~ 30-40 in the continuum at 119 *(1 + z) μm* required**
~5 hrs for a ~1 Jy source with Herschel

- **Wish-list of Future Missions:**
  - ***Excellent sensitivity in spectroscopic mode***
  - ***Broadband coverage*: ~ (1 + *z*) (35 – 119 um) to determine outflow energetics (from multi-transition profile comparison)**
  - ***Moderate spectral resolution:*** **$\lambda / \Delta\lambda$ ~ 1000 – 3000**
  - ***Hight angular resolution:*** **not essential but useful ! Size (OH outflow) < 200 pc implies:**
    - **$\Theta < 1''$ at $z = 0.01$ → D > 10 – 20 m**
    - **$\Theta < 0.1''$ at $z = 0.1$ → D > 100 – 200 m**
    - **$\Theta < 0.02''$ at $z = 1$ → D > km**
    - **$\Theta < 0.05''$ at $z = 10$ → D > km**

Connection Between X-ray and FIR

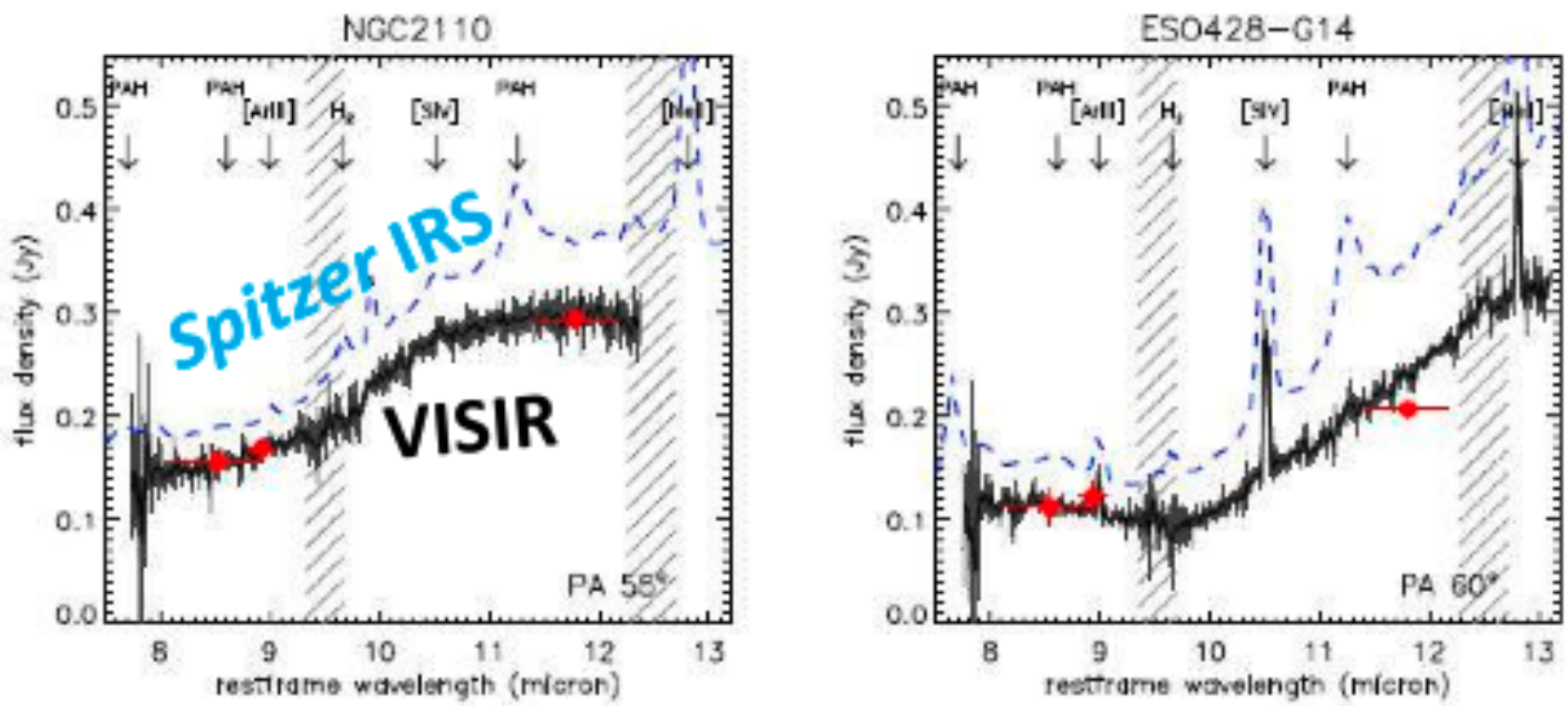
- Luminous AGNs (L_{AGN}> 44.8 erg/s) at z < 1 show a strong correlation between $L_{60\mu}$ and AGN luminosity,
- IF $L_{60\mu}$traces star formation- implies a close relationship between the growth of the stellar component of the host galaxy and the growth of the SMBH-
  - alternatively much of the 60μ radiation comes from the AGN and indicates that torus models are wrong (major change in understanding of central regions of AGN)





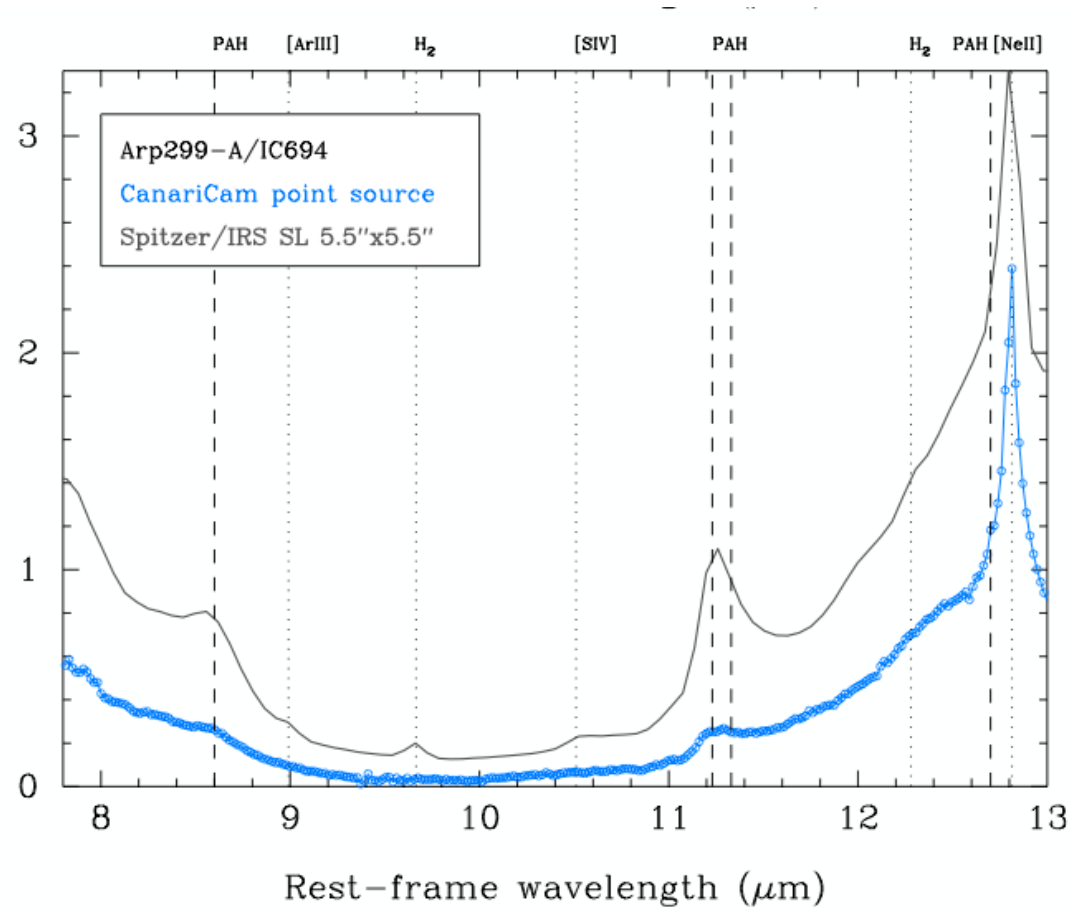
'Where' Is the FIR Light

- Herschel 7-500μ observations of ~320 low redshift hard x-ray AGN (Mushotzky et al 2014) show that the FIR light is concentrated in the central 1kpc
  - **Low Z AGN seem to be embedded in nuclear star bursts**
- Comparison of VISIR and Spitzer spectra (Hoenig et al 2010++; also Young et al 2014, LaMassa 2013, Diamond-Stanic 2013) show that PAH features 'disappear' on small scales (<1")- either NO SF in center or PAH destroyed



Spatial Resolution

- Comparison of high angular resolution vs 3” Spitzer data for Arp299 (AGN) 8-13μ band
- AGN lines+Silicate features are ‘point-like’ at 0.1” (z<0.03) resolution as is most of the contiuum
- Star formation signatures (PAH) are resolved (eg ~50 pc size at 100Mpc)

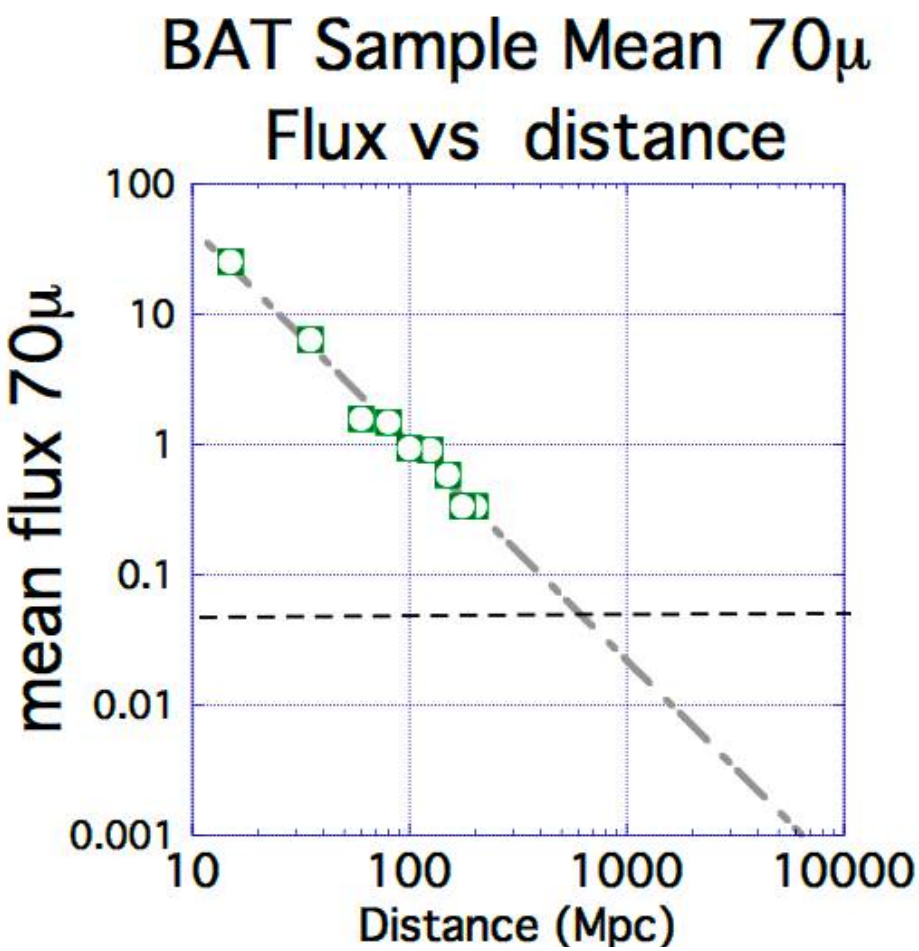


Alonso-Herrero+13

See Asmus et al 2014

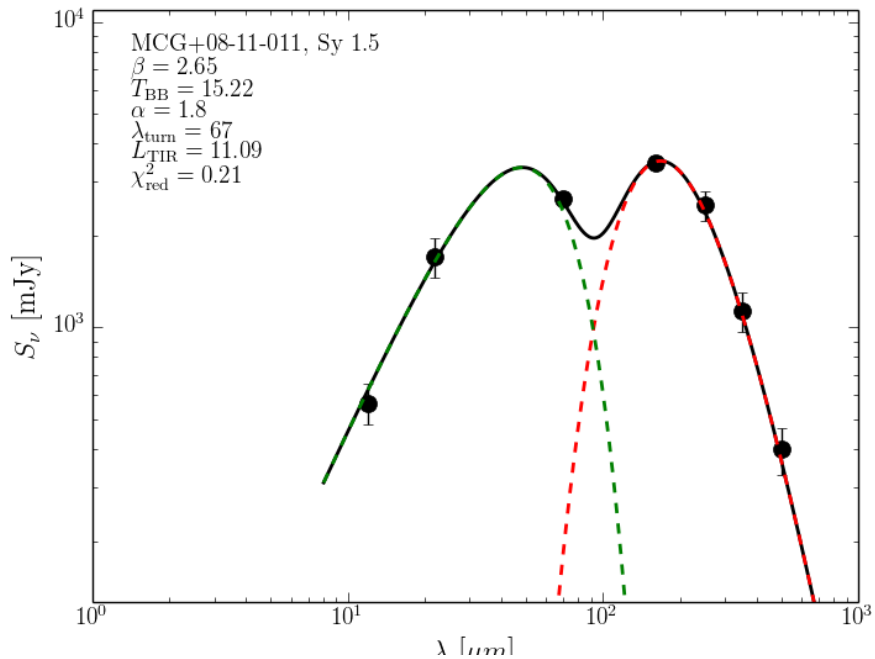
How Faint Do We Need to Go?

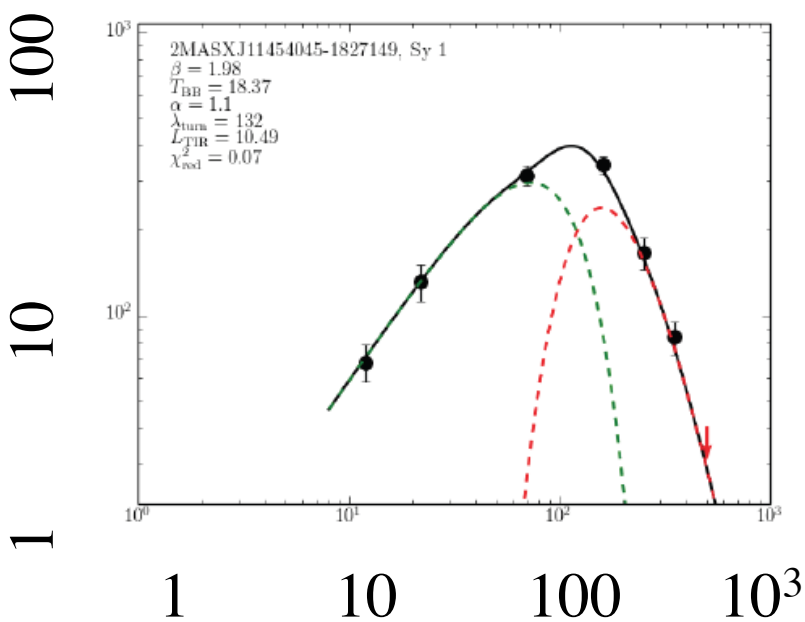
- At 200 Mpc the median 70μ flux is 3Jy and the observed flux is dropping as $D^{-1.75}$
- Larger distances (e.g. 1Gpc) need ~1mJy Jy sensitivity ~20x better than the present survey - result is similar for and 160μ (20 mJy) (ignoring K corrections)

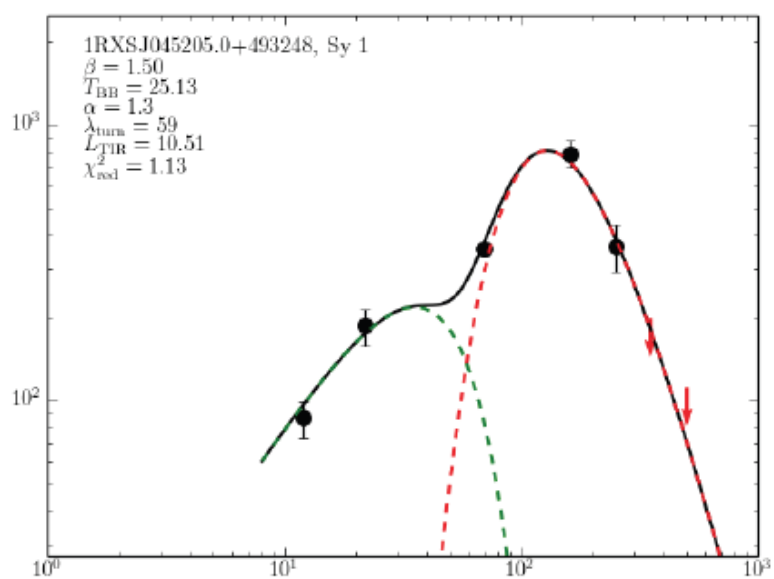


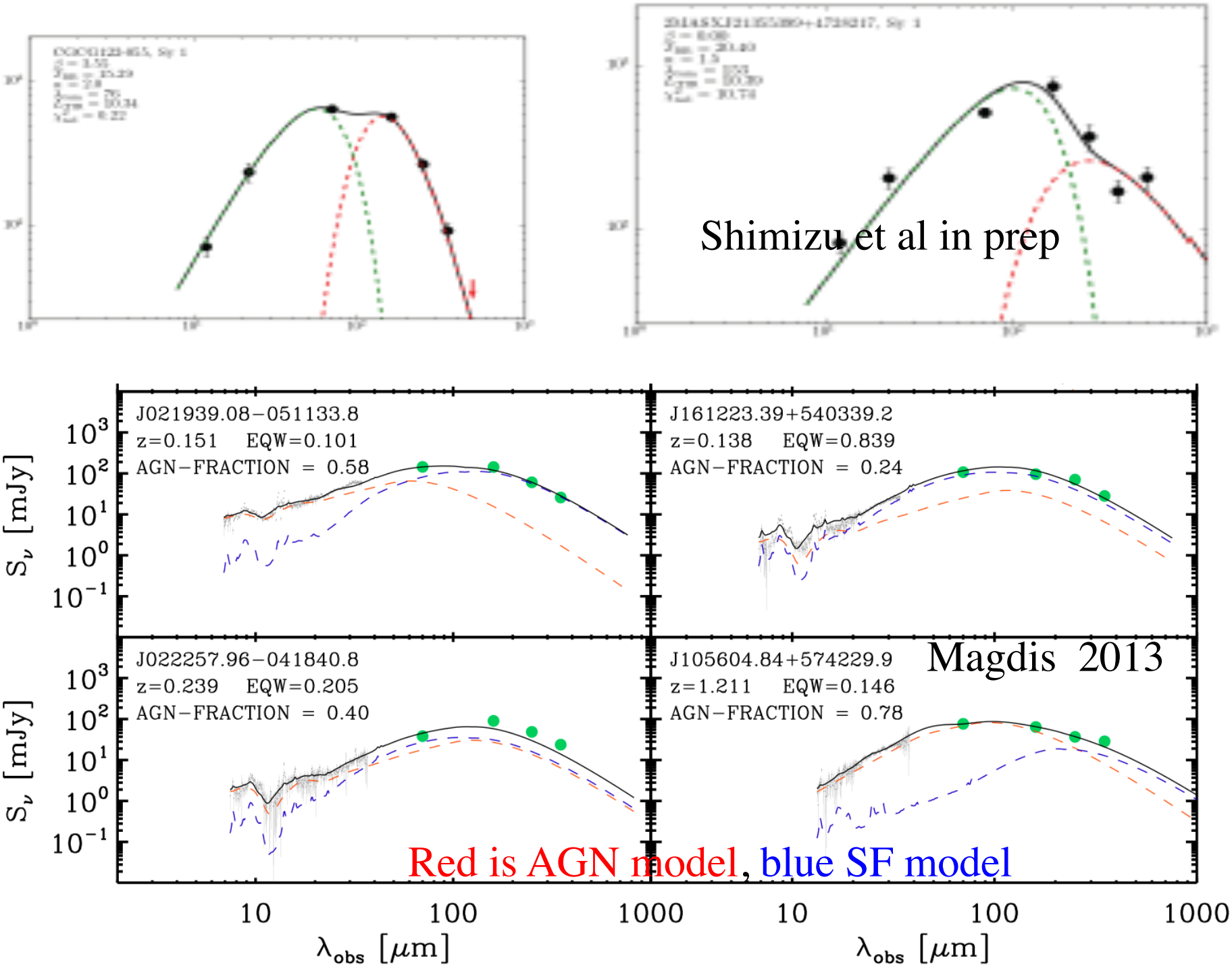
Broad Band Spectra

- Decomposition of spectra into 2 components is not so simple!
  - Short wavelength 10-100μ AGN dominated ?
  - Long wavelength SF dominated
  - NEED broad band *and* good spacing of photometric points (present data suffers from lack of 30-50μ band)



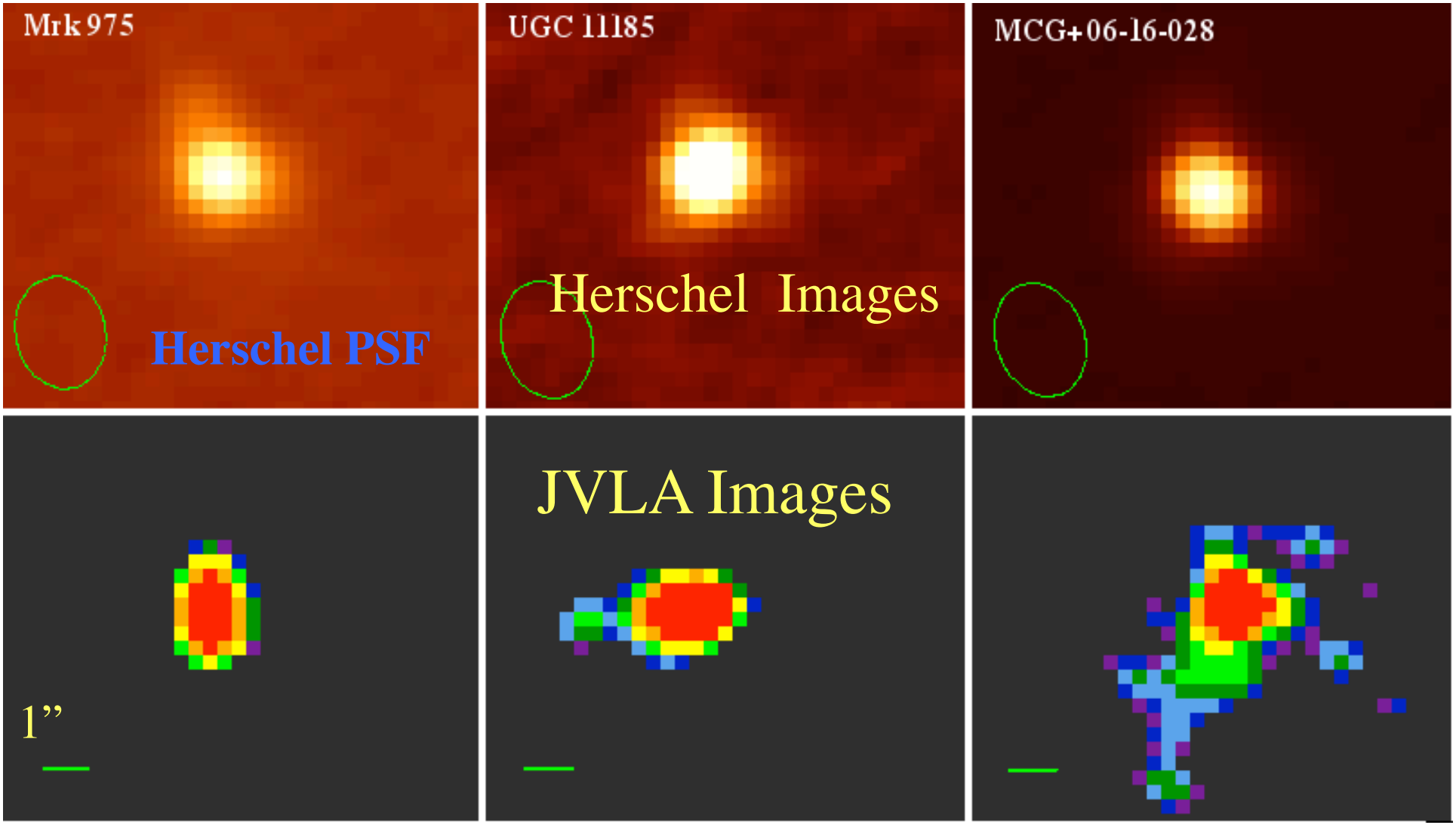





Shimizu et al in prep
J021939.08−051133.8
z=0.151 EQW=0.101
AGN−FRACTION = 0.58
J161223.39+540339.2
z=0.138 EQW=0.839
AGN−FRACTION = 0.24
J022257.96−041840.8
z=0.239 EQW=0.205
AGN−FRACTION = 0.40
J105604.84+574229.9
z=1.211 EQW=0.146
AGN−FRACTION = 0.78
Magdis 2013
Red is AGN model, blue SF model
S_ν [mJy]
λ_{obs} [μm]

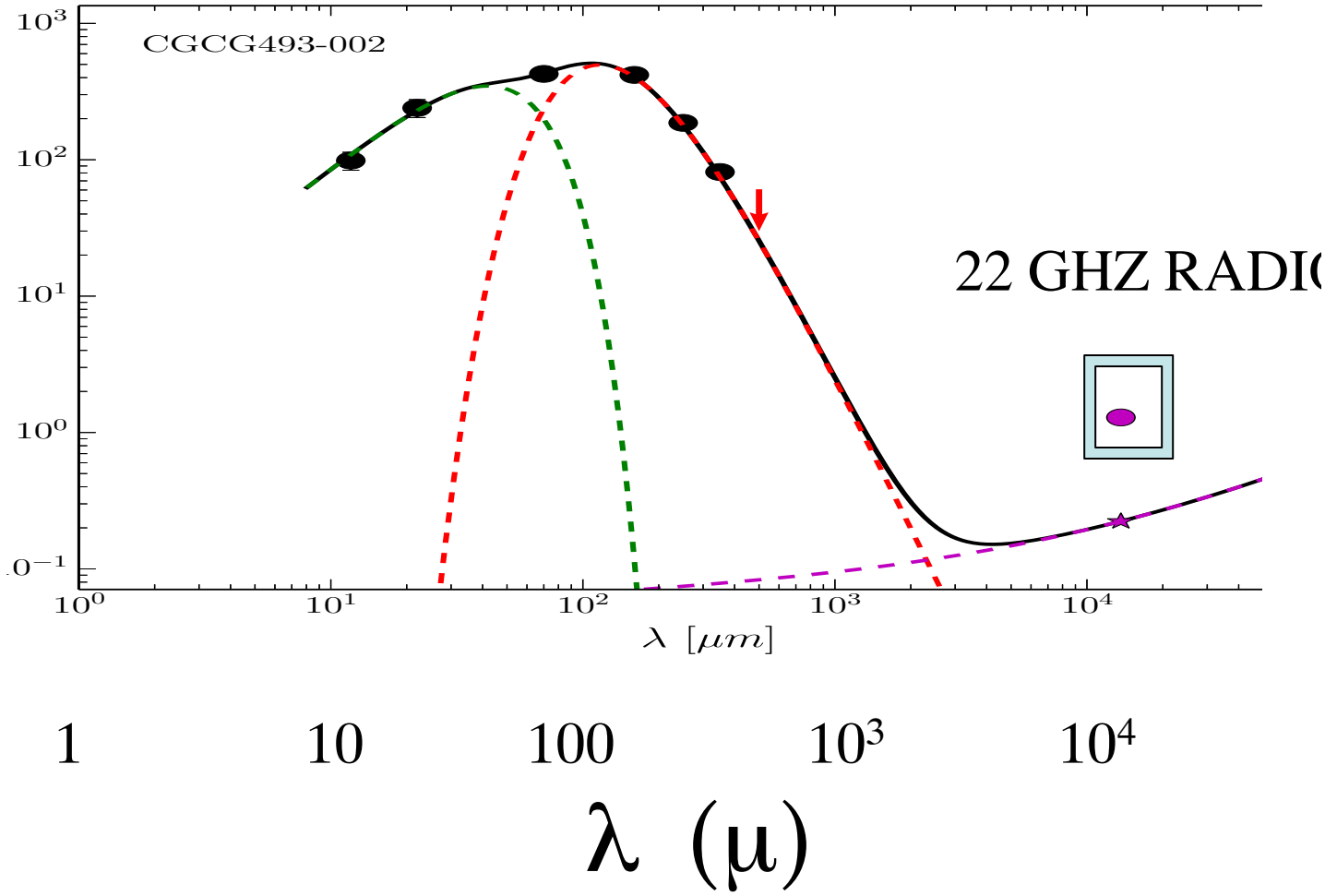
Herschel 70μ and Radio Images of Hacd X-ray Selected AGN

Almost all the IR flux is compact (<3" in size) as is the radio (<1") implying very compact star forming regions OR AGN dominance



What other data will there be?

- SKA will be able to determine the radio emission associated with star formation
- At present use of radio to measure SF in AGN is unreliable- need angular resolution to separate out SF from AGN



X-ray induced chemistry

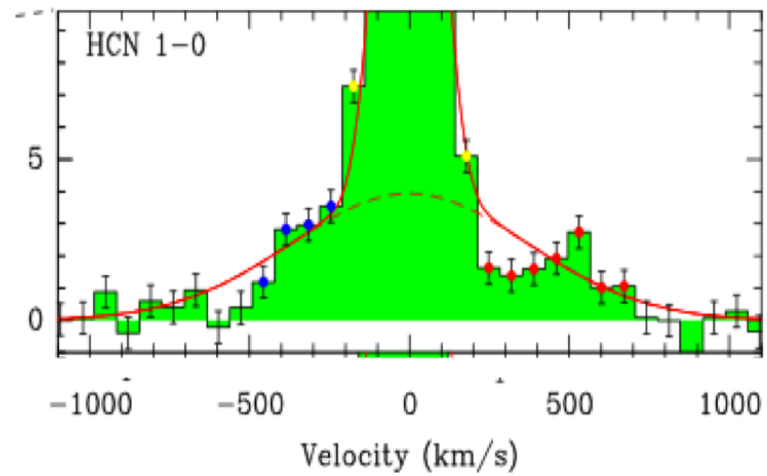
- There are many indications (e.g. Hocuk and Spaans 2010) that the AGN should strongly influence the nature of star formation near to it- Use of standard SF templates to analyze AGN spectra should be examined more carefully
- Various molecular transitions have rather different intensity ratios in AGN than in starbursts- especially those originating in dense gas e.g. HCN (J = 4-3) to HCO^+ (J = 4-3) ratio low intensity ratio of N_2H^+ relative to ^{13}CO, and high ratios of CN and HCN

Is AGN influenced SF important?
(yes if feedback is important)
A new look at SF physics

Killer Apps

- Finding z>4 Obscured AGN- Chandra reaches its limits at z~4 – need OIV, NeV at λ~ 120μ
- Studying feedback at 0<z<5
  - need OH lines (119μ) at 1+z in absorption
  - Continuum sensitivity + angular resolution
- Feeding and fueling the AGN – variety of molecular lines
- Star formation/AGN connection at all redshifts (Negative K correction a major help for 'quasi-BB' shapes)

HCN wings: dense gas in the outflow



Aalto+12

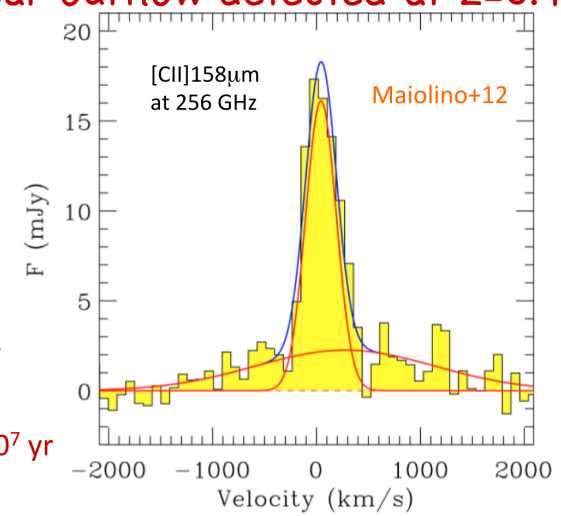
Massive quasar outflow detected at z=6.4

Broad wings tracing outflow with v~1300 km/s

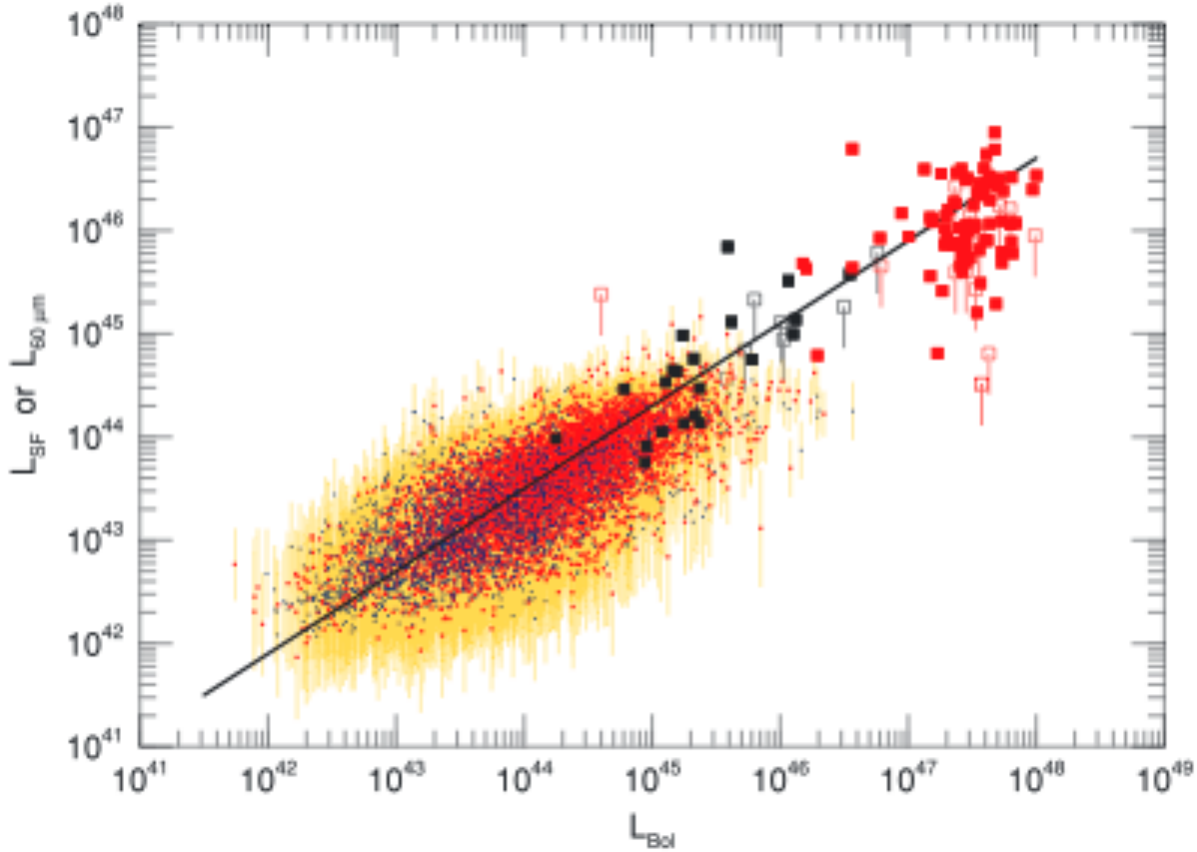
Size: ~16 kpc !

$\dot{M}_{outflow}$ > 3500 $M_\odot$/yr

Depletion timescale < 10^7 yr



- Netzer, H. 2009, found a strong relationship at low z between L(AGN) and SFR.



Star Formation and AGN

- Recent Herschel (Mushotzky et al 2014) and 9-13μ adaptive optics (Asmus et al 2014) and Spitzer results (a Mass et al 2013, Diamond-Stanic et al 2013) results have shown

  that in LOW Z AGN

  most AGN are dominated by point-like component at 9-13μ that DOES NOT show evidence of SF

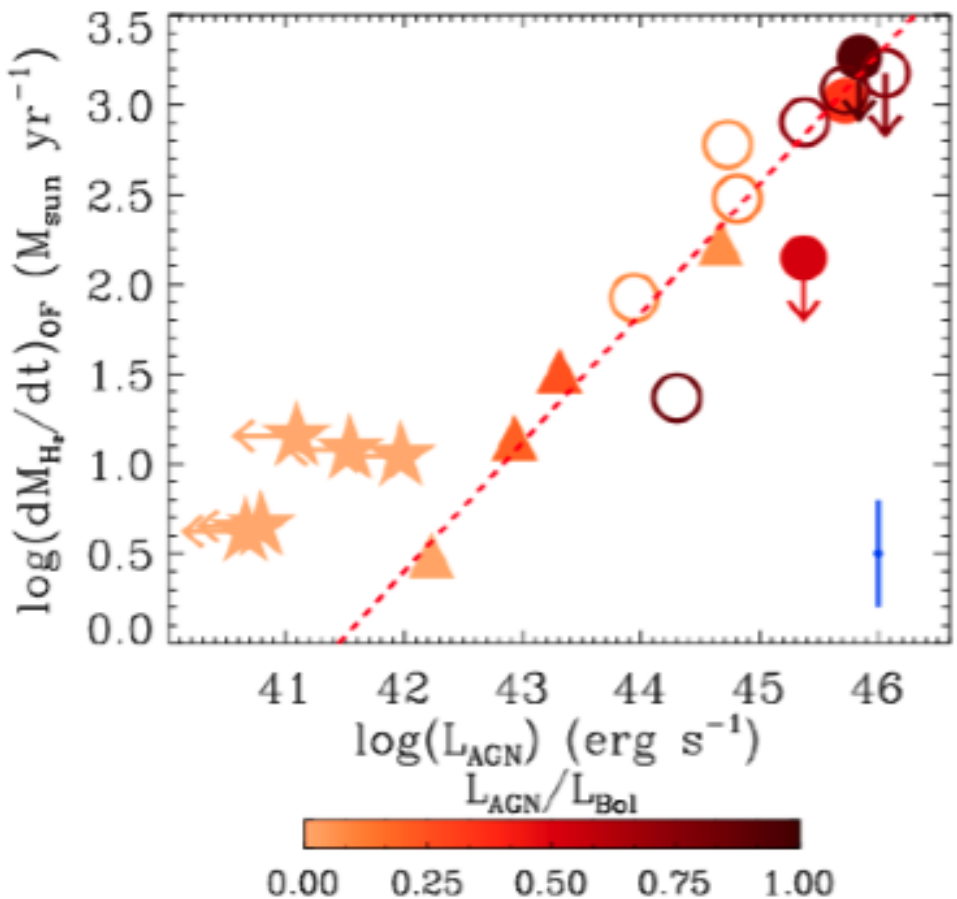
  BUT on scale of ~3" there is frequently a strong signature of star formation

It is not clear at what scale the tradeoff between star formation and AGN emission occurs and how to partition the total spectrum. Need better angular resolution over a wide range of wavelengths

Most attempts have used templates based on star forming galaxies and AGN 'without' SF (e.g weak or absent PAH) – VERY MODEL Dependent

Relation of AGN Luminosity to Wind Mass Loss Rate

- Recent CO (PdB and Herschel) OH, CII 158μ data show 'winds' detected in molecular absorption lines.
- These sources are very bright >1 Jy at 65μ
- Need much better sensitivity to go to a much larger sample/ higher redshift

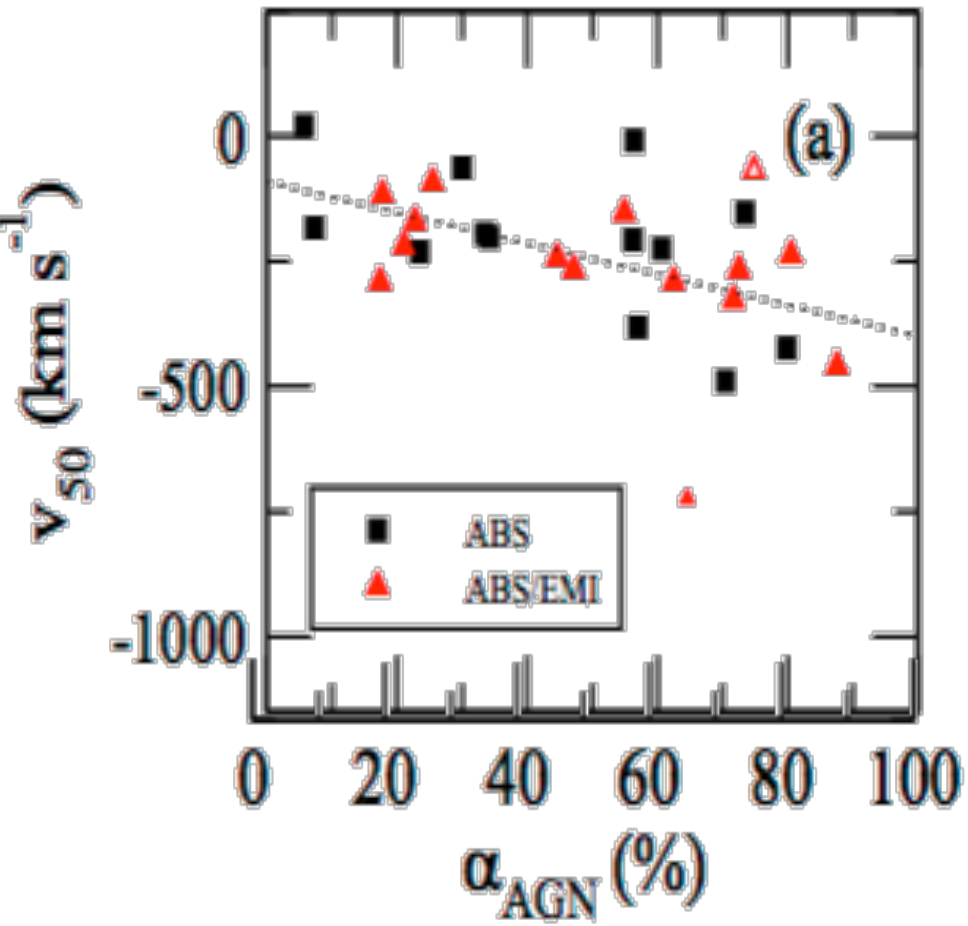


Cicone et al 2014

- Veilleux 2013 show that OH velocities in ULIRGS are related to the amount of radiation in the AGN- **more AGN dominated the faster the gas moves**.

- Features are ~1 Jy at best

- The nature of the OH 119 μ feature (emission, absorption, or both)
  - OH emission is stronger relative to OH absorption in quasar-dominated systems, becoming completely dominant (i.e. pure OH emission) in objects where the quasar contributes more than 90% to the bolometric luminosity



Outflows Other Wavelengths

- Recent IFU studies in the optical and IR (Davies et al 2008, Storchi-Bergmann) show evidence of outflow and inflow (and maybe rotation) on scales of 10-100pc in low redshift AGN
- The masses involved are low and the interference is that **MUCH more molecular gas is involved** (cf OH and CO results).
  - ALMA will do the high angular resolution CO stuff in emission

Nature of Templates is Not Clear

- Evidence that both SF and AGN templates maybe functions of redshift, AGN fraction and SF rate (Kirkpatrick et al 2013)

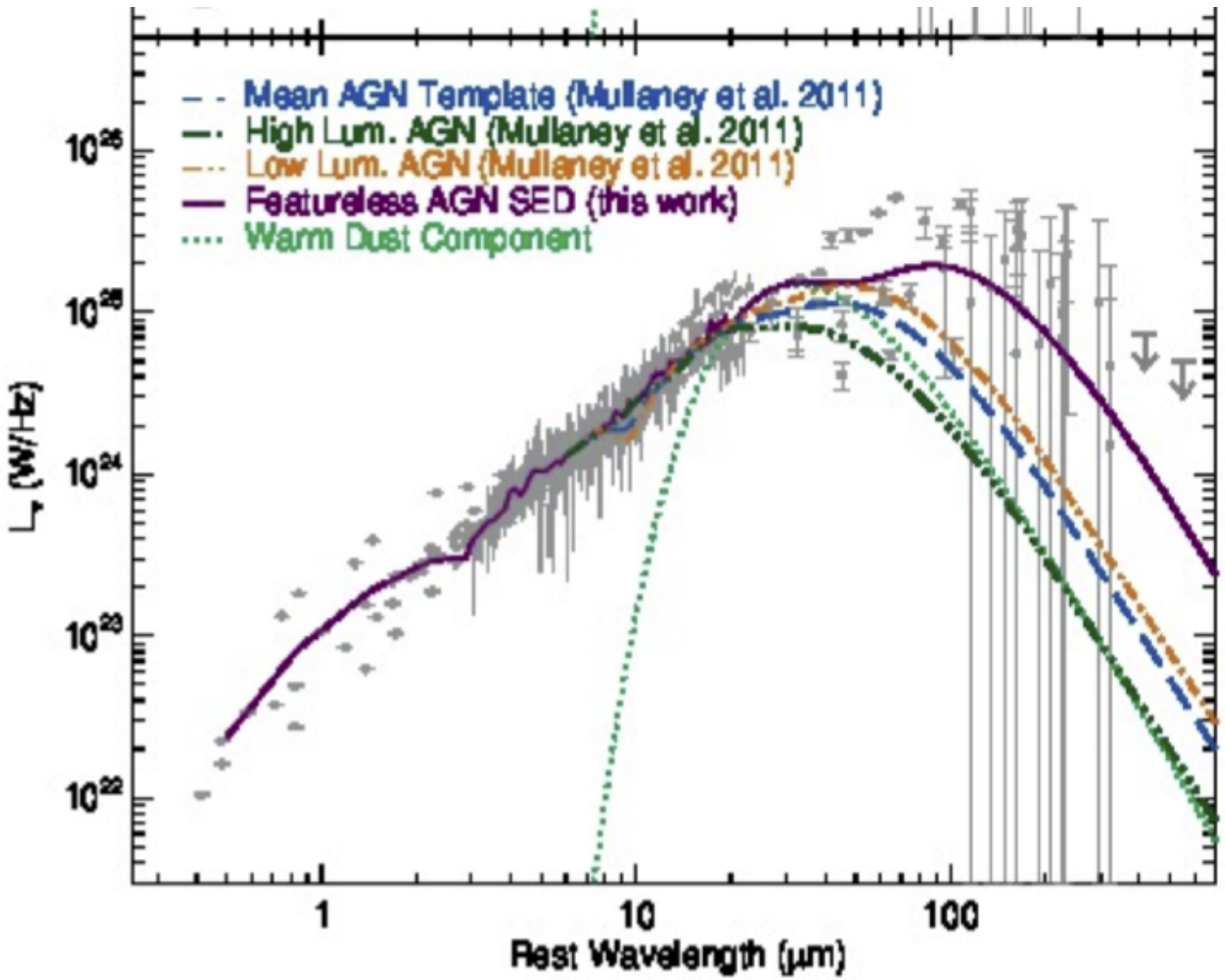
Not clear that all (most) of the λ<100μ flux in AGN is due to star formation

Different assumptions about templates +stacking leads to

- ◆ AGN suppress SF

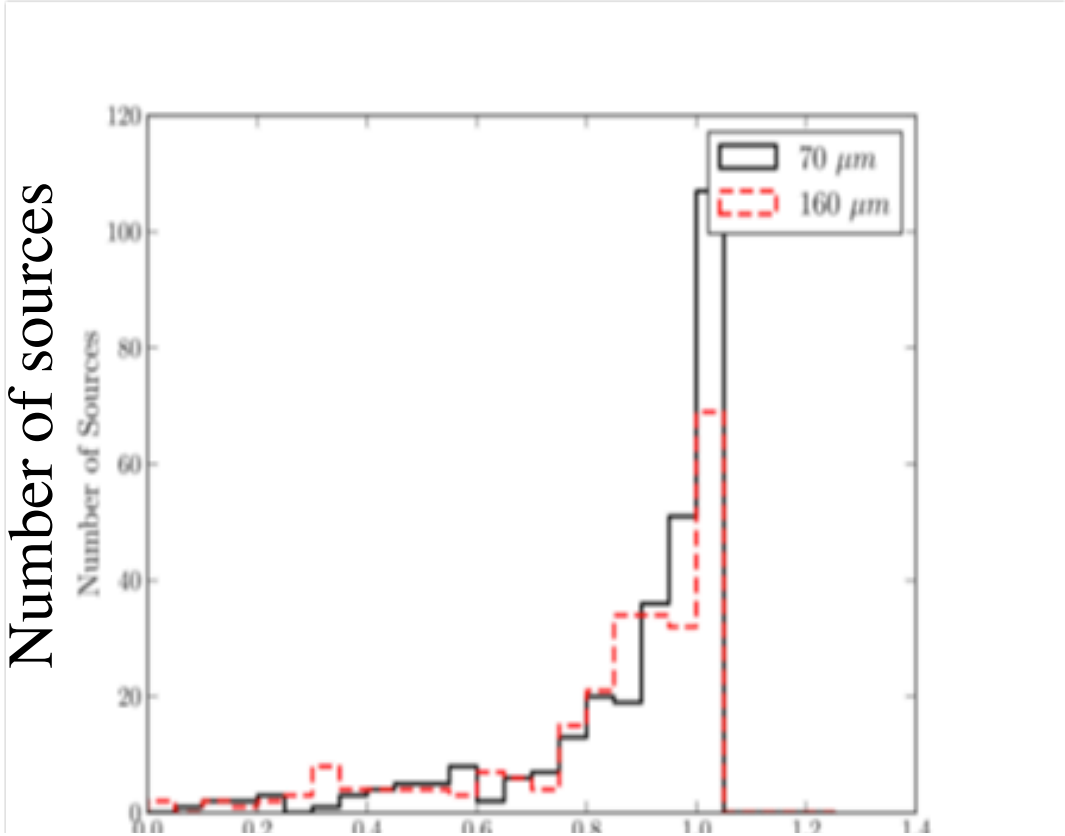
  or

- ◆ AGN occurs in more rapidly SF galaxies



Importance of Spatial resolution
BAT AGN Sample is Mostly Point-like at 70 and 160μ

- More than 80% of the sources (z<0.04) are dominated by ‘point like’ emission
  - Either very compact star formation or
  - AGN light
- At z~0.0,3 6 “ was not good enough



fraction point-like emission