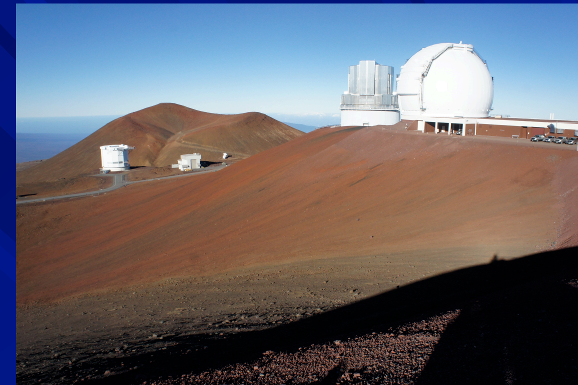


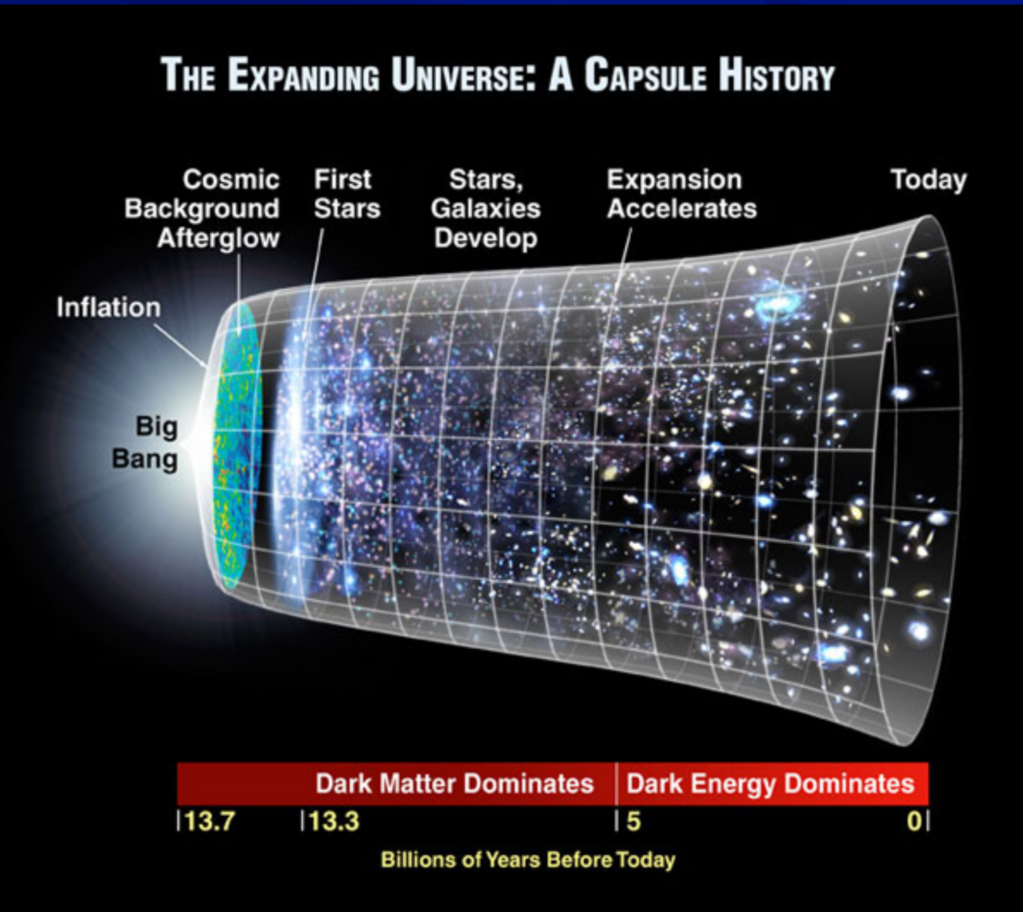
Extreme WISEgalaxies

Andrew Blain, June 2016

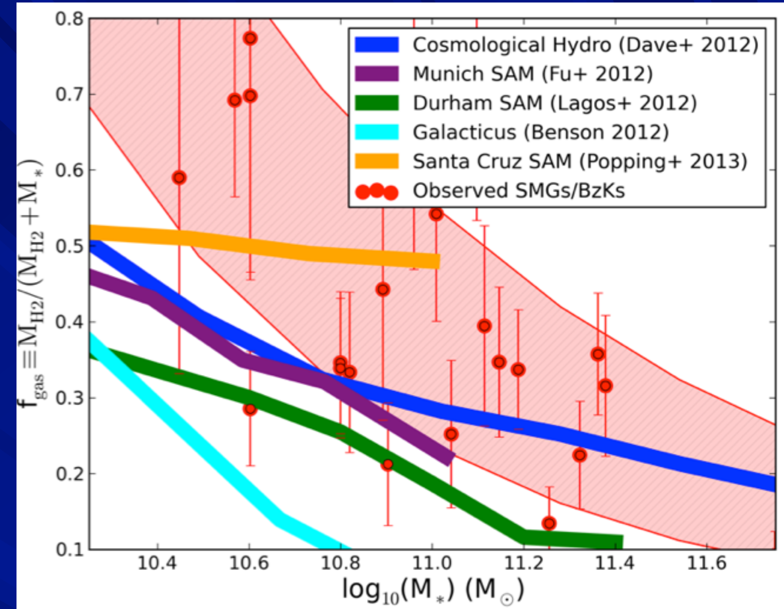
Contents

- AGNs can have very high luminosities, powerful feedback effects: luminosity key
- Many (most?) are obscured heavily by gas and dust in their immediate surroundings, and/or in the wider host ISM
- Unusual SEDs from near- to far-IR are appearing – incorporate useful information
- Can probe structure in the innermost regions, even without direct resolution

Pictures of galaxy evolution

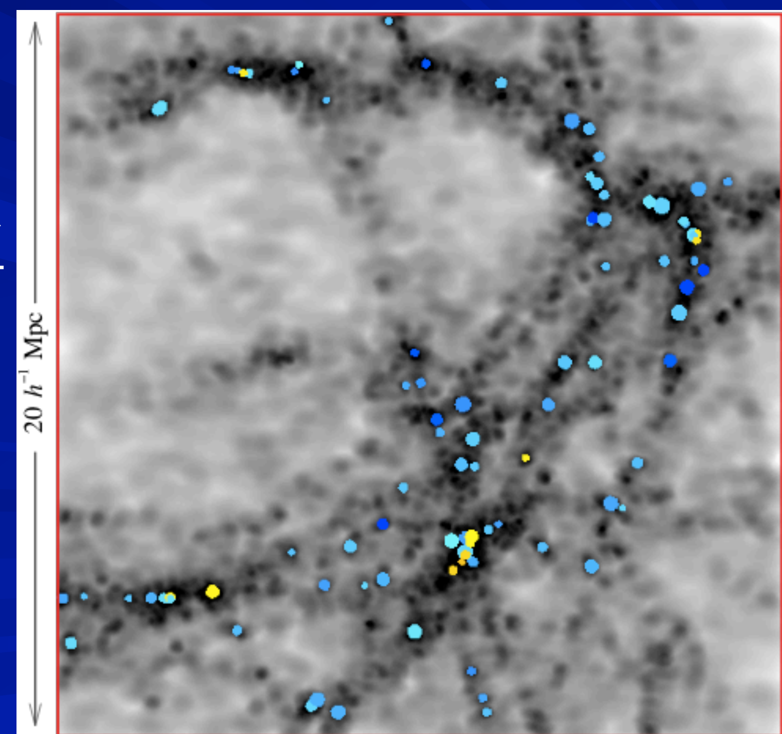


Hobby Eberly HetDex



Casey, Narayanan & Cooray (2014)

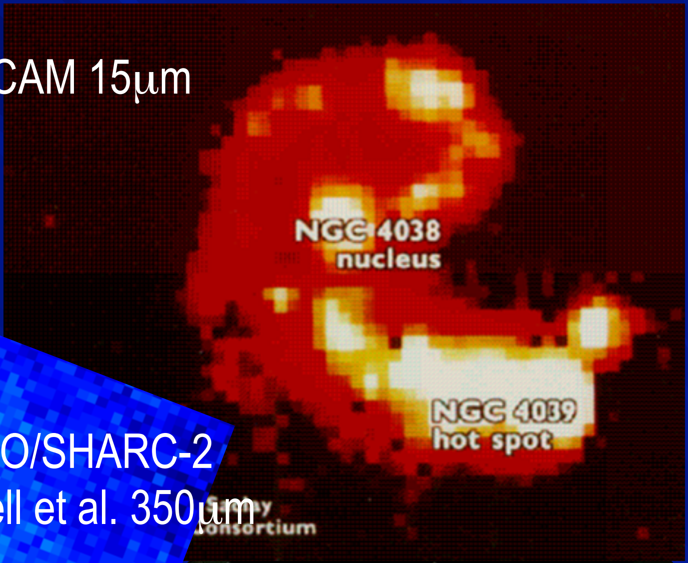
Benson et al. ~30 Mpc; z~2 cluster



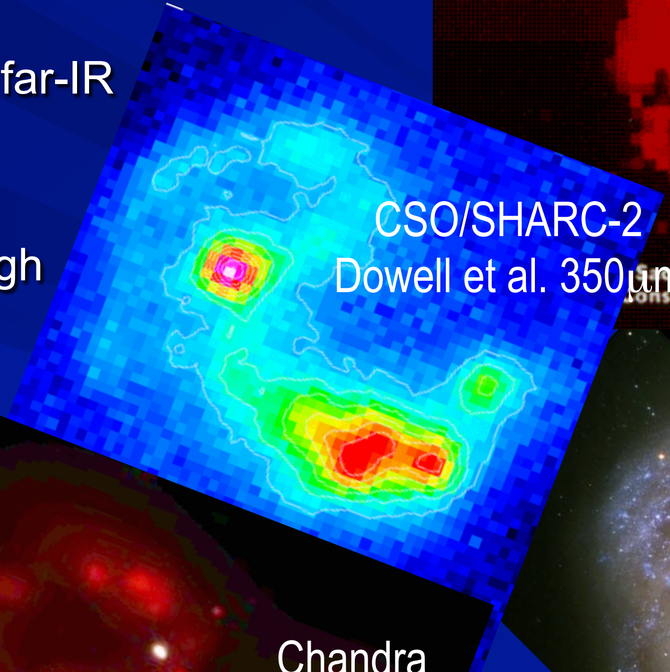
Resolved imaging with ALMA shows that gas simulations are important. On ~10pc scales this might always be the case – factors of millions in density to handle

Resolved non-AGN: the Antennae

- Excellent example of distinct opt/UV and IR luminosity; BUT modest luminosity
- Interaction long known, but great IRAS luminosity unexpected
  - ~90% energy escapes at far-IR wavelengths
- Resolved images important
  - Relevant scales ~1” at high redshift

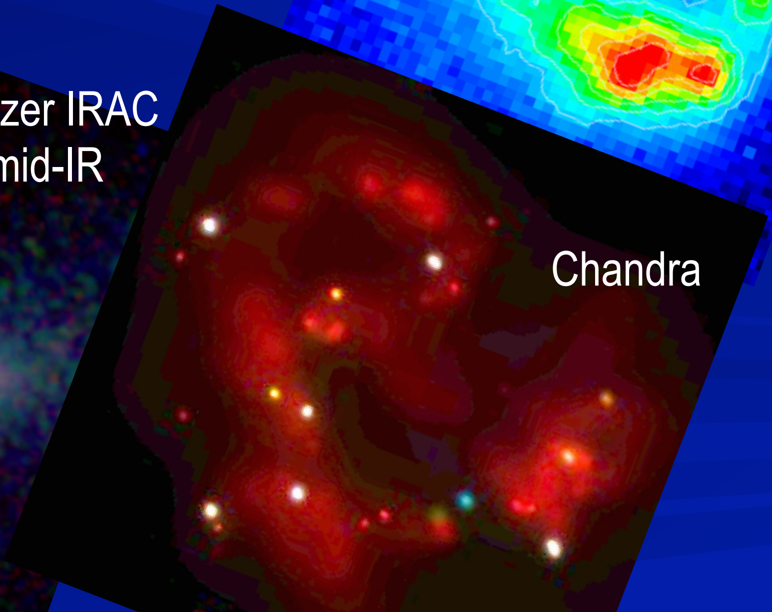


ISOCAM 15μm

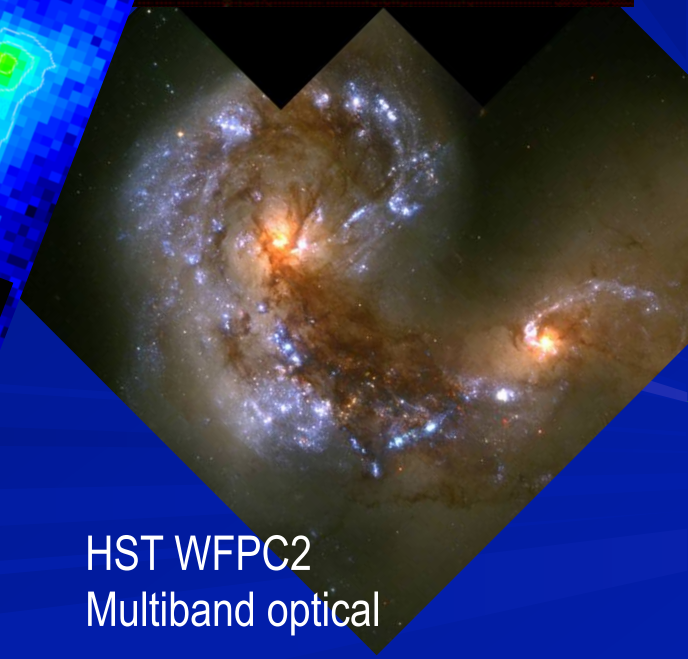


CSO/SHARC-2
Dowell et al. 350μm

Spitzer IRAC
mid-IR

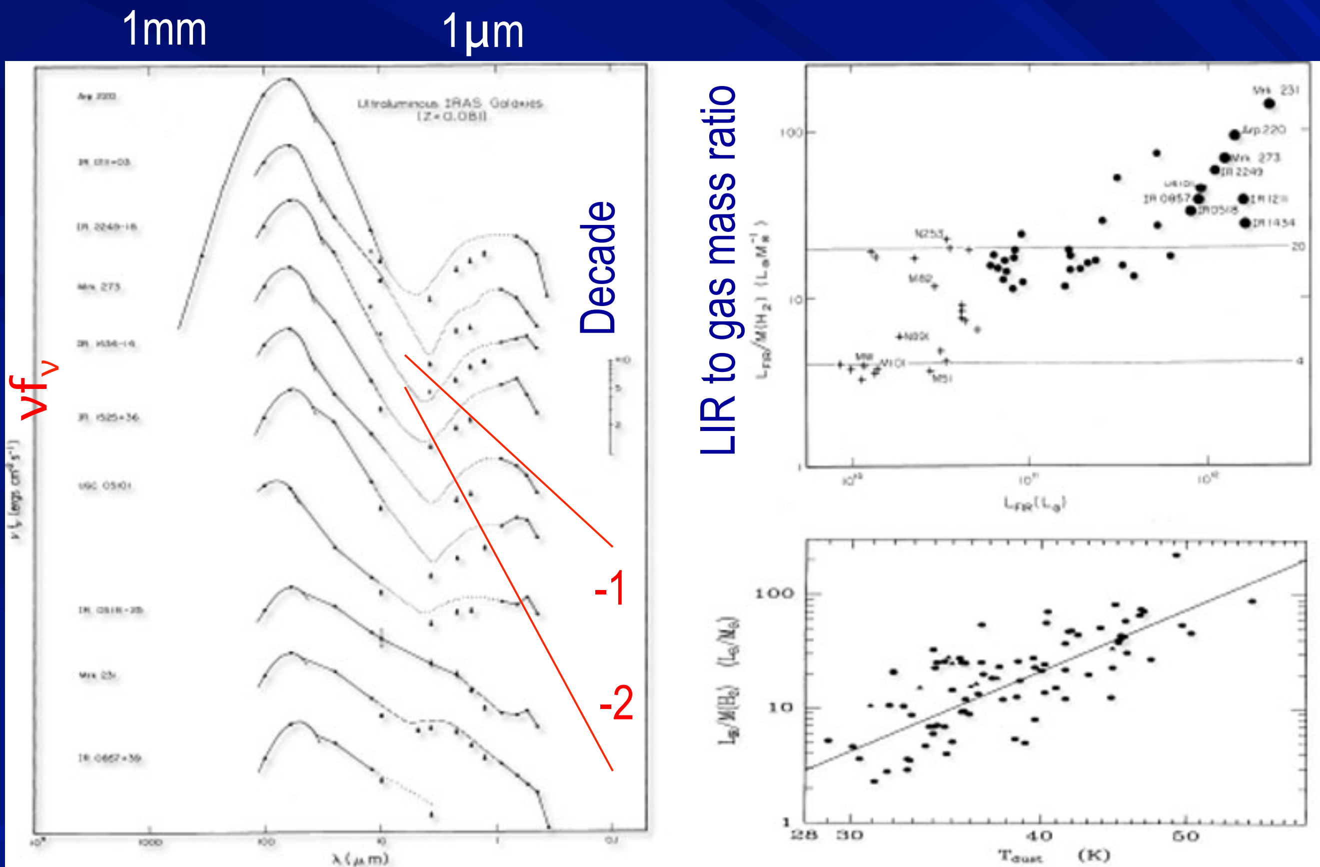


Chandra



HST WFPC2
Multiband optical

Far-IR SEDs from discovery



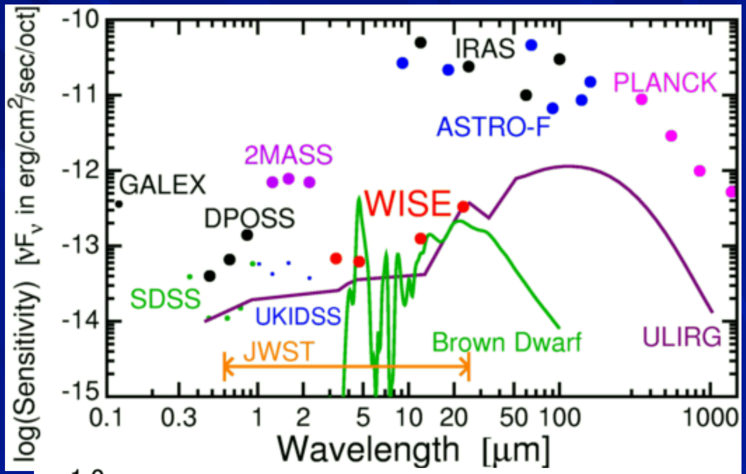
Sanders et al 1986

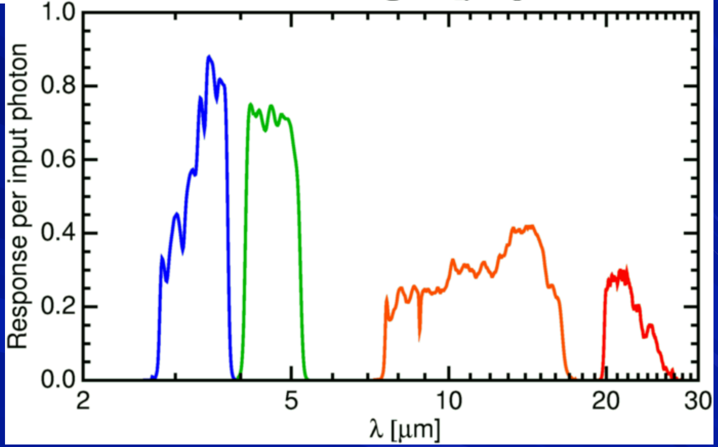
Even IRAS F15307+3252, one of hottest IRAS galaxies has spectral Index a~-1.9 in the mid-IR (slope ~-1 on plot)

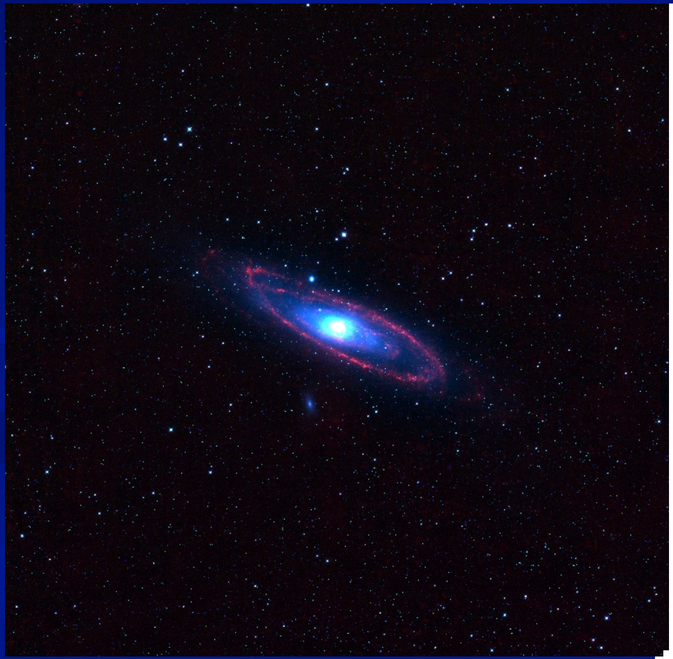
- IRAS 12-100 microns
- Non-thermal?
- Double peaked?
- Host peak?
- Static?
- Correlations
  - T/L
  - Dust L/gas M
- Resolution not much improved since
- Features
  - Si absorption/ PAH emission

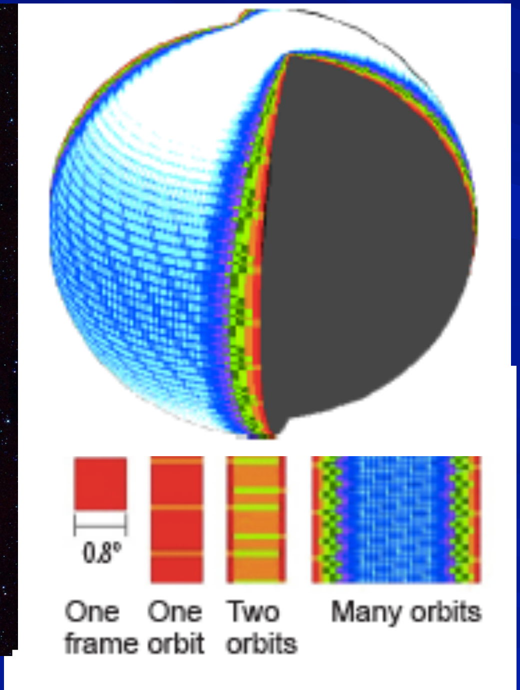
WISE: Dec 2009 to Jan 2011

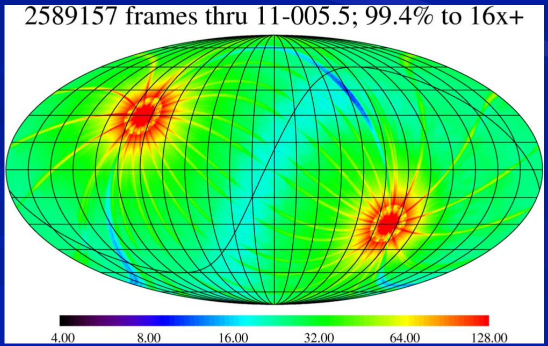
- Finished 1st sky pass 17th July 2009
- All-sky releases 14/3/2012, 12/11/2013
- 3.4, 4.6, 12, 23μm (W1-4)
- 6, 6, 6, 12” resolution
- 0.08, 0.08, 0.8, 4mJy
- More data taking in 3.4, 4.6 μm (2014-2016)





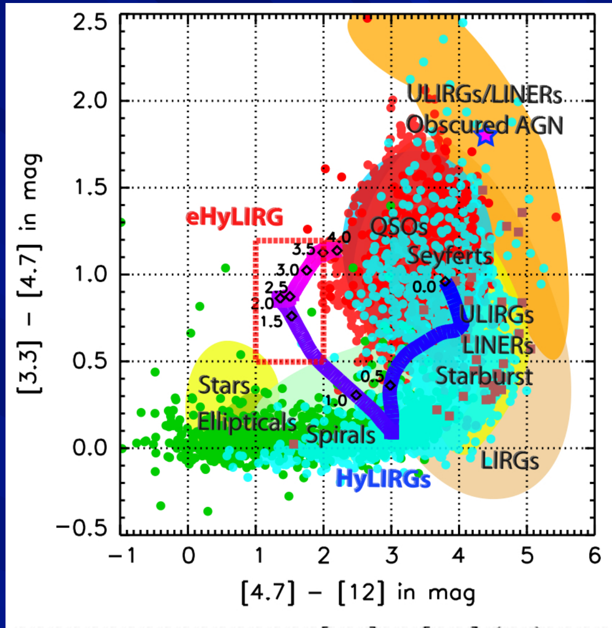






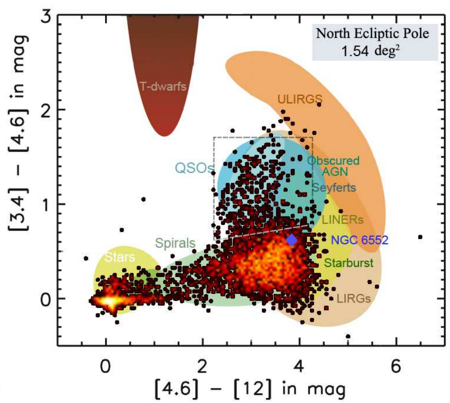
WISE colors

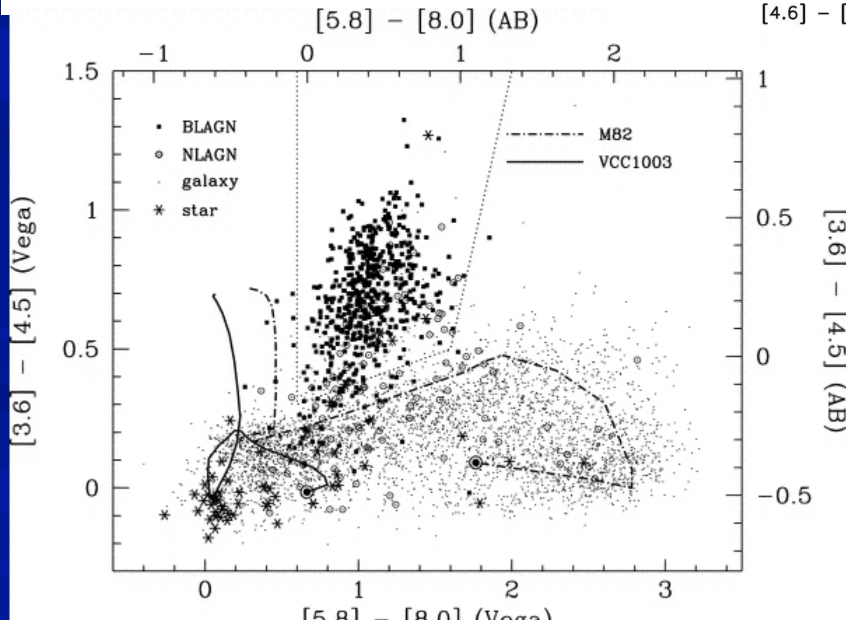
- 23μm W4 band is not as sensitive
- W1, W2, W3 provide best insight into galaxy and stellar populations
- Note that AGB stars scatter over the same region as 'eHyLIRGs', but they tend to be bluer in [3.3]-[4.7] and to have 2MASS/SDSS/DPOSS counterparts. Follow-up spectroscopy rate is <2% for stars.



SDSS comparison by Lin Yan

Jarrett et al. NEP



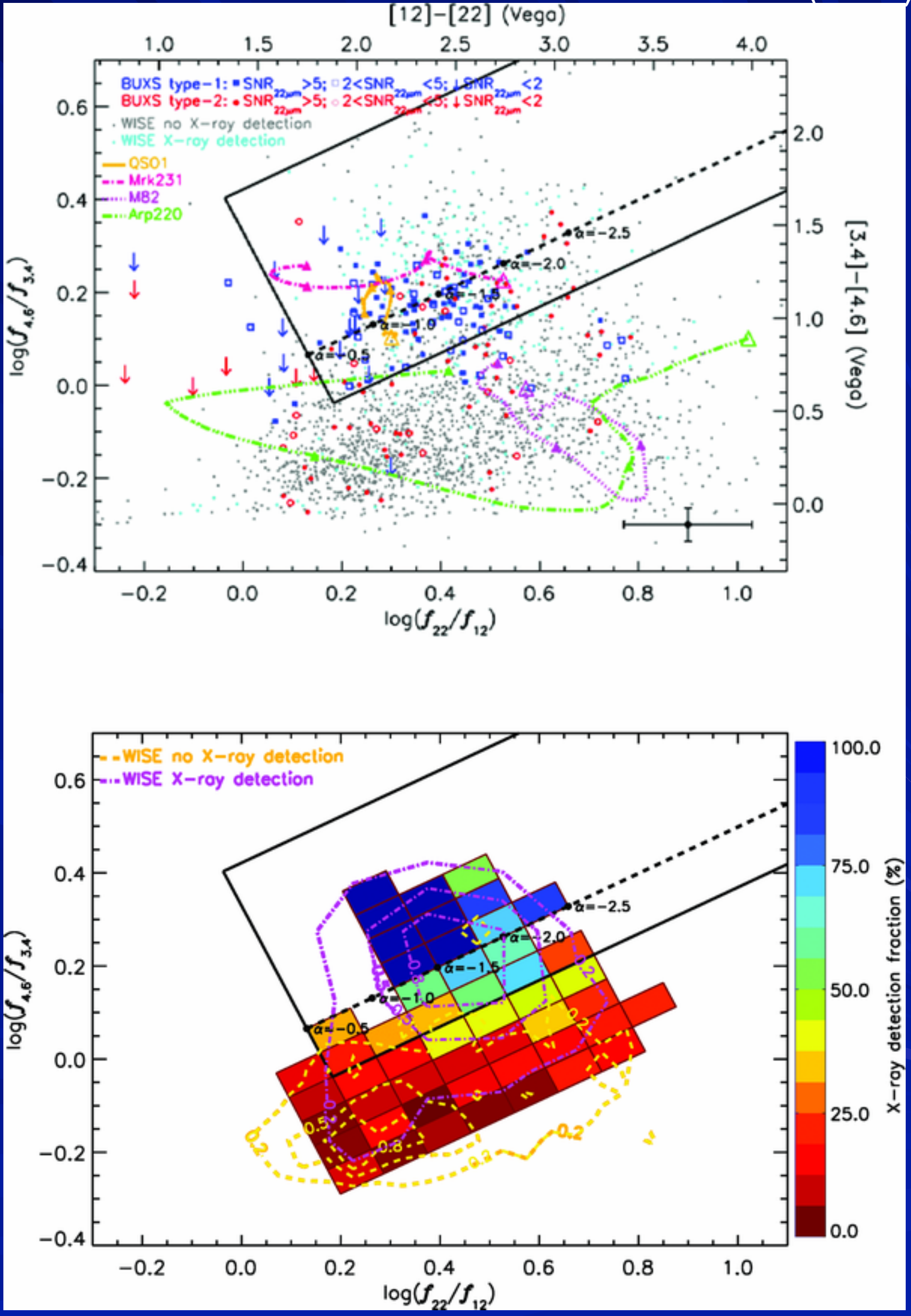


Stern & Eisenhardt

Mateos et al (2012)

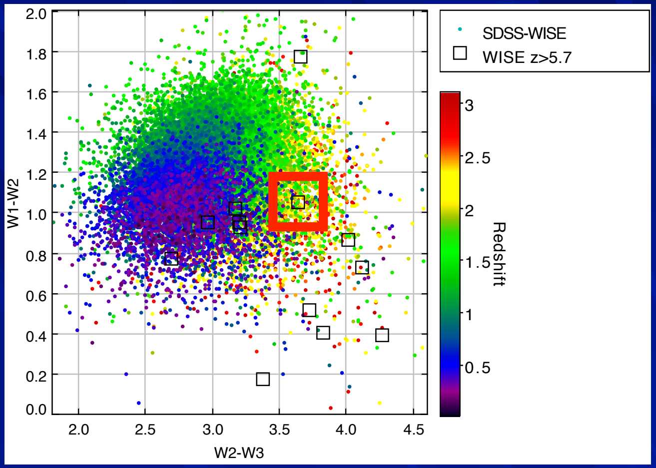
WISE AGN Selection

- Stern/Eisenhardt
  - COSMOS
- Mateos et al.
  - Trained using hard sample (2XMM)
- Assef et al.
  - Deeper Bootes sample
- Lots of spectra required
  - SDSS/3XMM

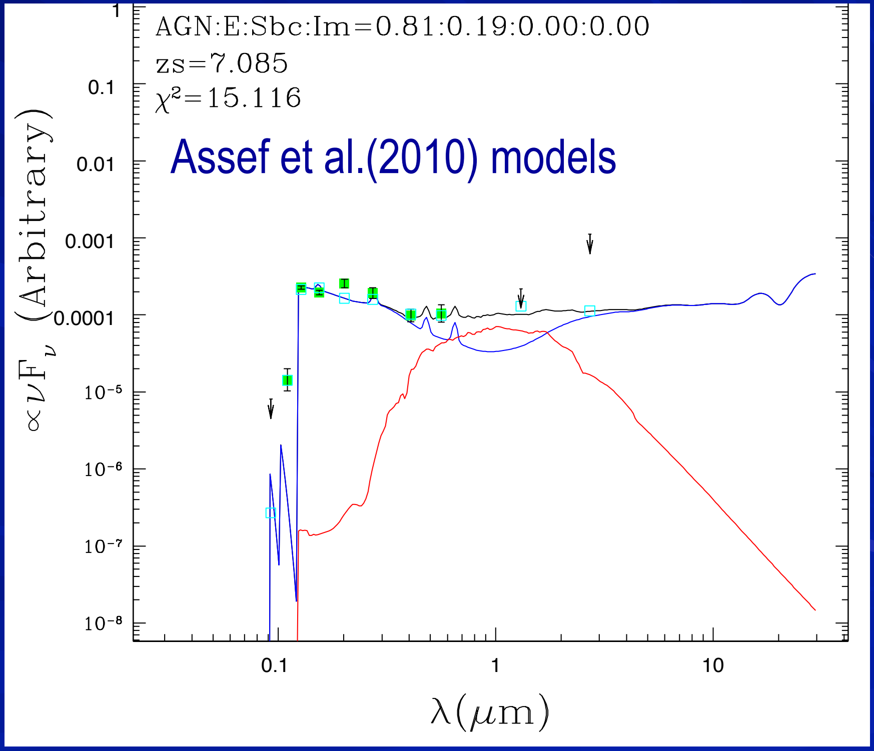


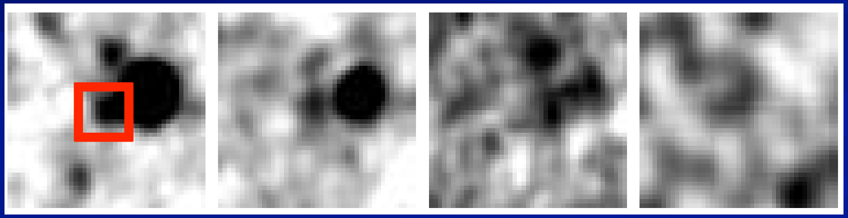
Highest z QSOs

- Individual targets.
  - SDSS, CHFTLS, **UKIDSS**, Spitzer
  - ~25 found over the sky
  - WISE detects ~ 60%
  - Spitzer can also do, but WISE makes it free, and adds in 12 microns.
  - VISTA-LSST-WISE?



ULAS1120 from Mortlock et al. (2011)

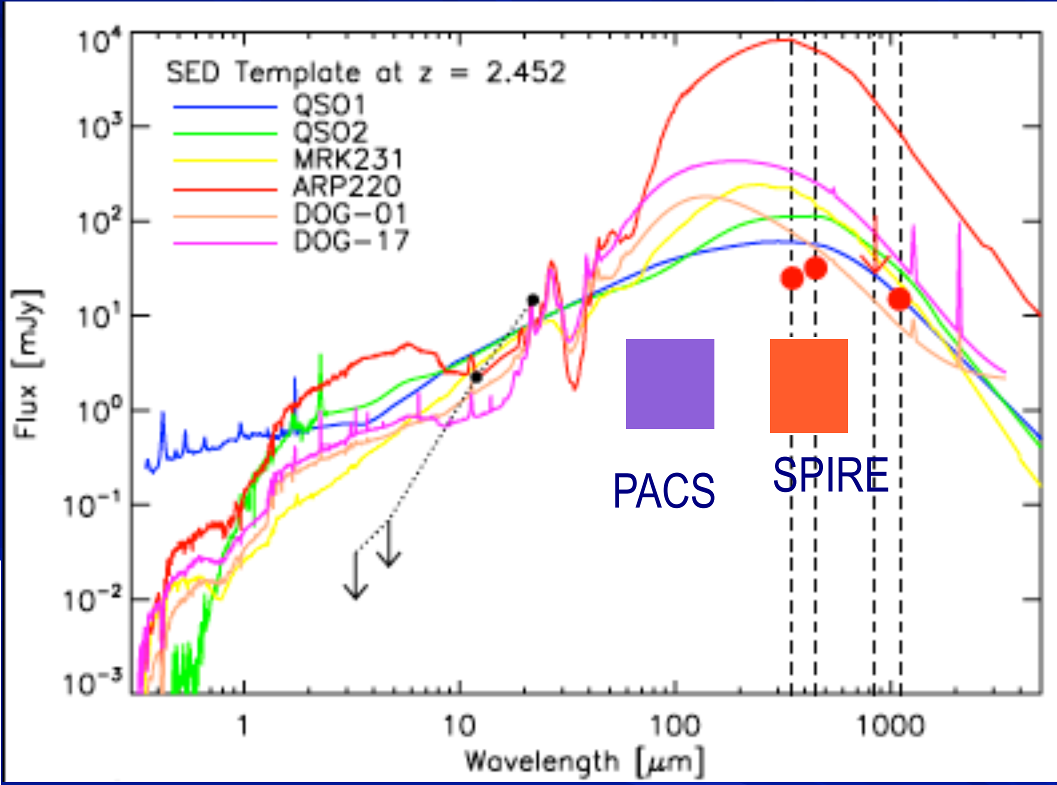


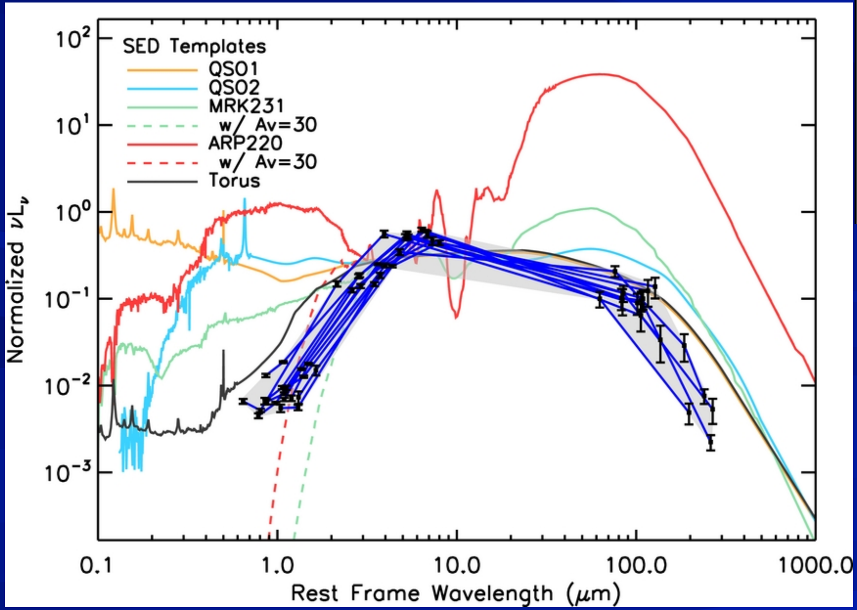


W1-W4; 1 arcmin

WISE "HotDOGs": odd SEDs

- WISE sources are sampling different regime of L,ρ
- Libraries of far-IR SEDs don't stretch far enough
- WISE hot/blue far-IR objects





Compiled CSO results on 1814
Eisenhardt et al. (2012)
Tsai et al. (2015)

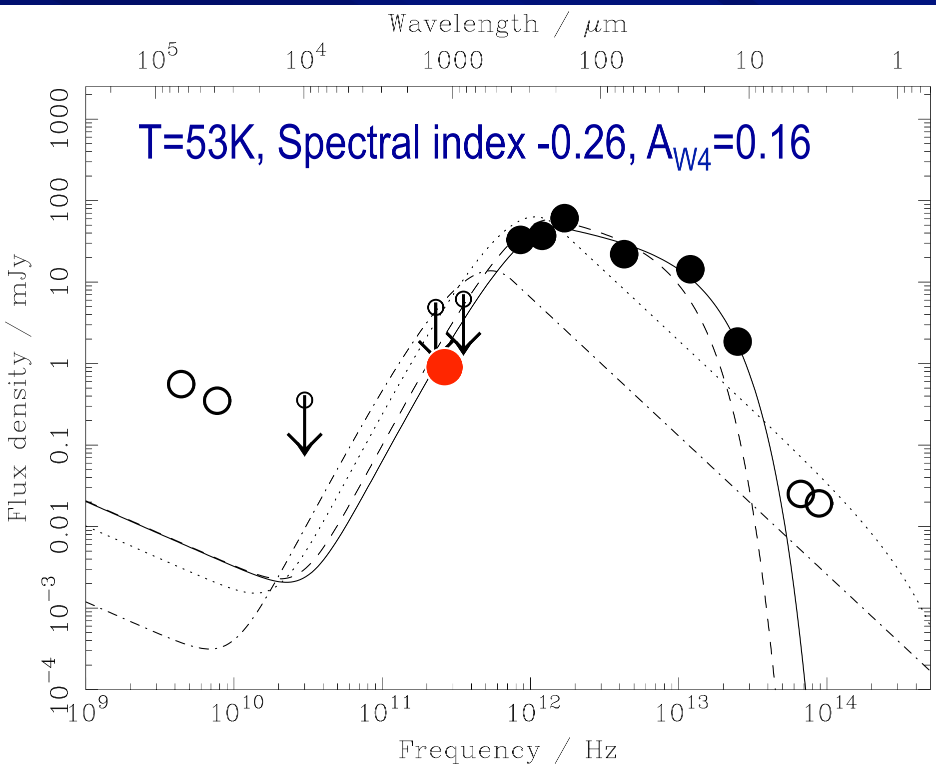
Jingwen Wu et al. (2012)

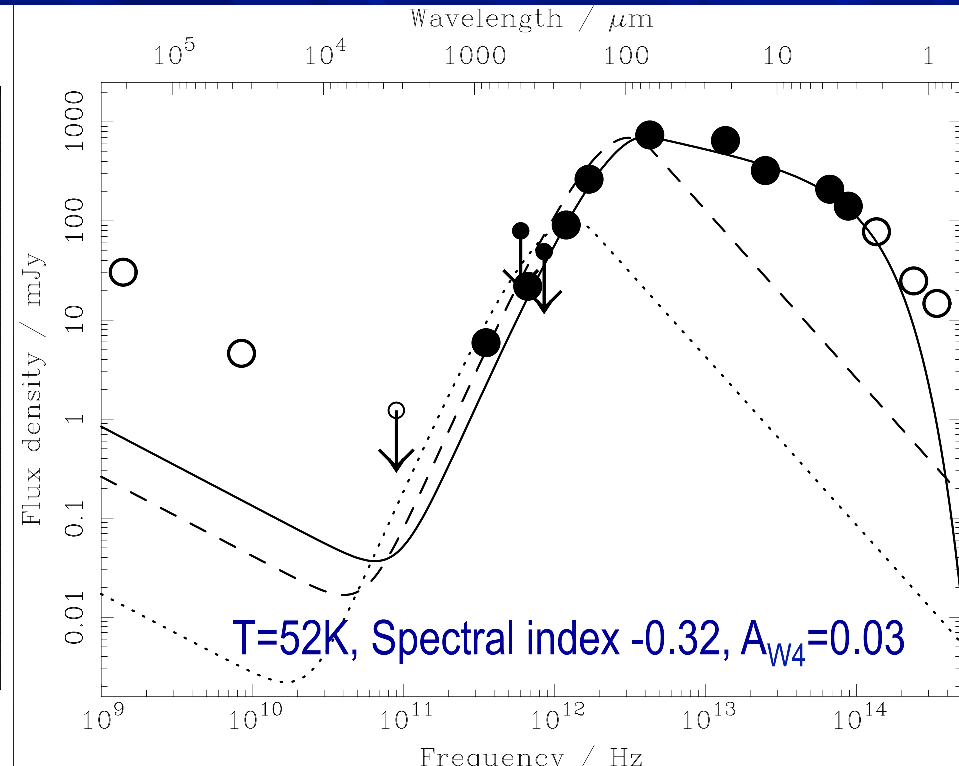
Plus JCMT from Suzy Jones

AGN IR SED issues

- IR is more isotropic, less obscured
- Host galaxy can contribute
- No spatial resolution yet in mid-IR
- Improvements:
  - ALMA (and precursors) resolve at longer wavelengths
  - Coverage with Herschel/WISE (BUT short!)
  - Ultimately mid-IR space interferometer?
- Silicate absorption ~9.7 microns?

W1814 SED & low-z analogue?



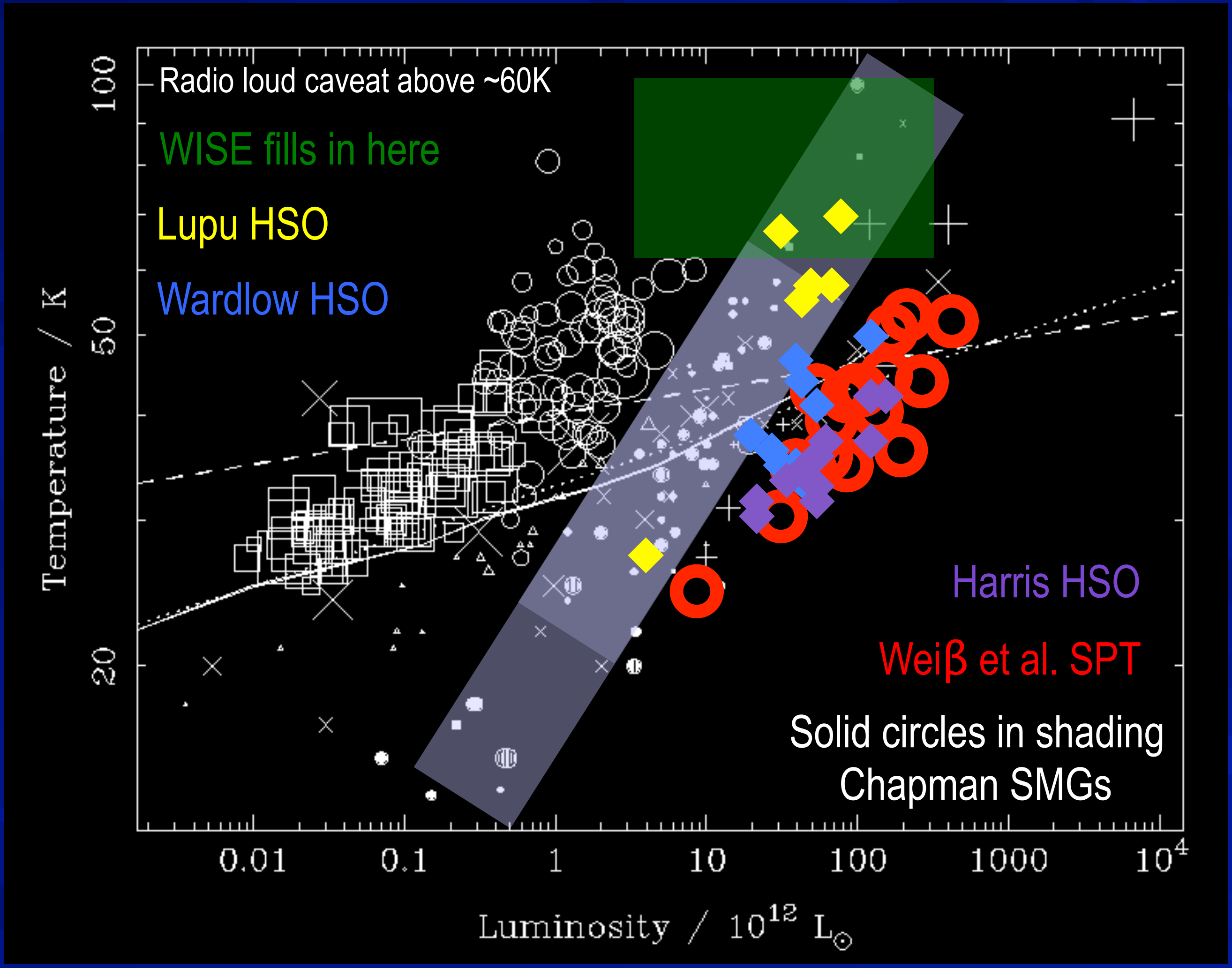


- Left: W1814 (z=2.54, IRAM in red, Herschel & WISE)
- Right: PDS456 (z=0.184, SCUBA2, Herschel & WISE)
- Milky Way (T~17K,a~-1.8,A~0), ULIRG (T~40K,a~-1.8,A~0) & fitted SEDs
- Rather similar, although power from W1814 much more heavily obscured. Note radio model from low-z correlation

SED interpretation

- Libraries from e.g. Polletta
  - Compiled from observations
- Radiative transfer in various geometries, reasonable and otherwise (Antennae!)
  - Geometry is crucial – tough (as it is around stars)
- Empirical evidence for discriminating between them not clear
- More data helps. Span whole IR bump(s)

High-z ULIRGs with redshifts



Blain, Barnard & Chapman 2003 & Chapman et al. 2003

Uncapped magnification μ distribution?

2-5: 3, 5-10: 4, 10-20: 5, 20-50: 9, 50-100: 7

Squares: low-z, Dunne et al.

Empty circles: moderate z, mainly Stanford et al.

Crosses: variety of known redshifts (vertical = lensed)

Lines: low-z trends

Scatter in T by at least ~40%

Argues for cap at mag' μ~50, Harris

Broadband near-/far-IR SED

- Reflect many dust clouds at different T
  - Emissivity $\beta \sim 1.5$, $L \alpha m T^{4+\beta}$
- Sublimes at ~2000K ~1 micron
- Host emission peaks at ~40K ~100 microns
- $m(T) \alpha T^{\alpha}$, SED $\alpha \nu^{a}$, $a \approx 3 + \beta + \alpha$
  - $a \approx -2.5$, $\alpha \approx -7$
  - [If a>-1, total L diverges: needs cutoff]
  - Much less hot dust mass than cold
  - Care with opacity: optically thick at ~100μm?
- And an averaged radial description

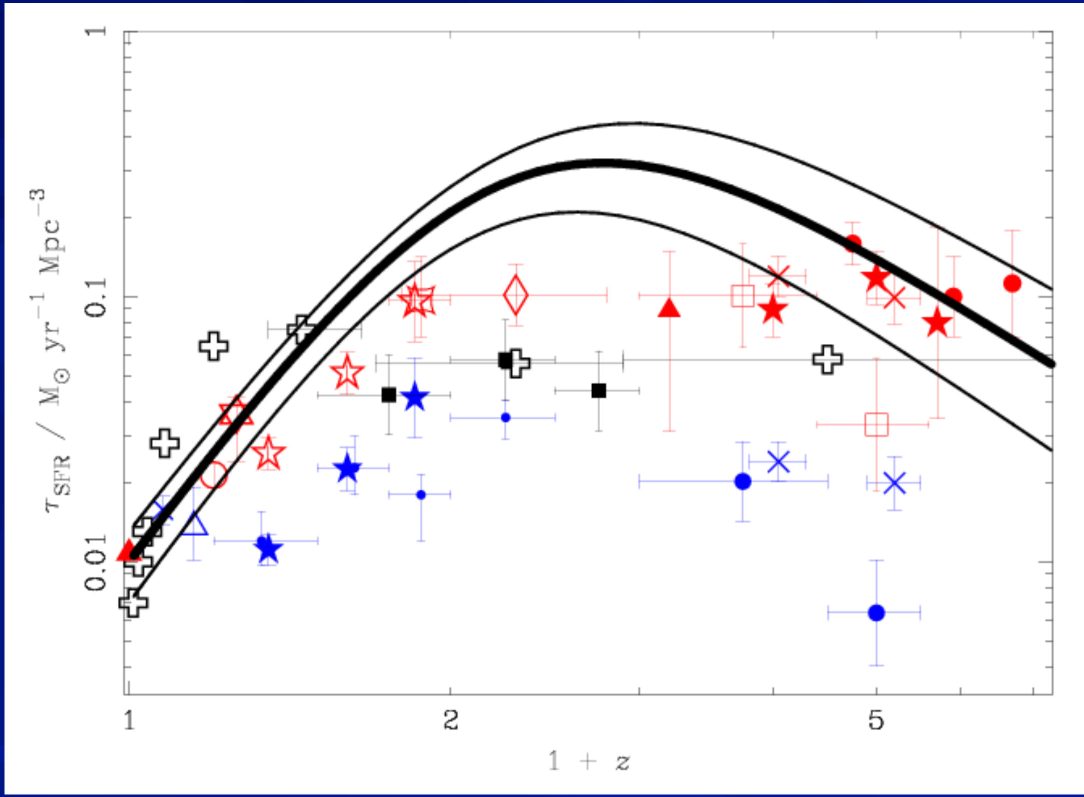
Radial dependence of m, T

- Sum sets of dense molecular clouds, or single AGN that dominates total emission
- $T(r) \propto r^{\eta}$, $m(r) \propto r^{\gamma}$, SED $a \approx 3+\beta+(\gamma+1)/\eta$
  - "Optically thin", expect $\eta \approx -1/2$ (or more –ve)
  - If SED $a \approx -2$, $\gamma \approx 2.2$ ($\approx$ constant density)
  - If SED $a \approx 0$, $\gamma \approx 1$ – more mass at smaller radii
    - Screen, wall, but then…
- At some point, the SED cuts off at short λ

Opacity

- Striking drop in emission into the near-IR
  - Extremely steep spectrum at ~10 microns
- Not sublimation temperature:
  - Substantially longer wavelength
  - Requires ~10 mag. of extinction in near-IR
- Tidy, adequate description from: "coolest" T present, mid-IR index a, opacity at 22 microns A_w
  - Consistent, but is it physically relevant?

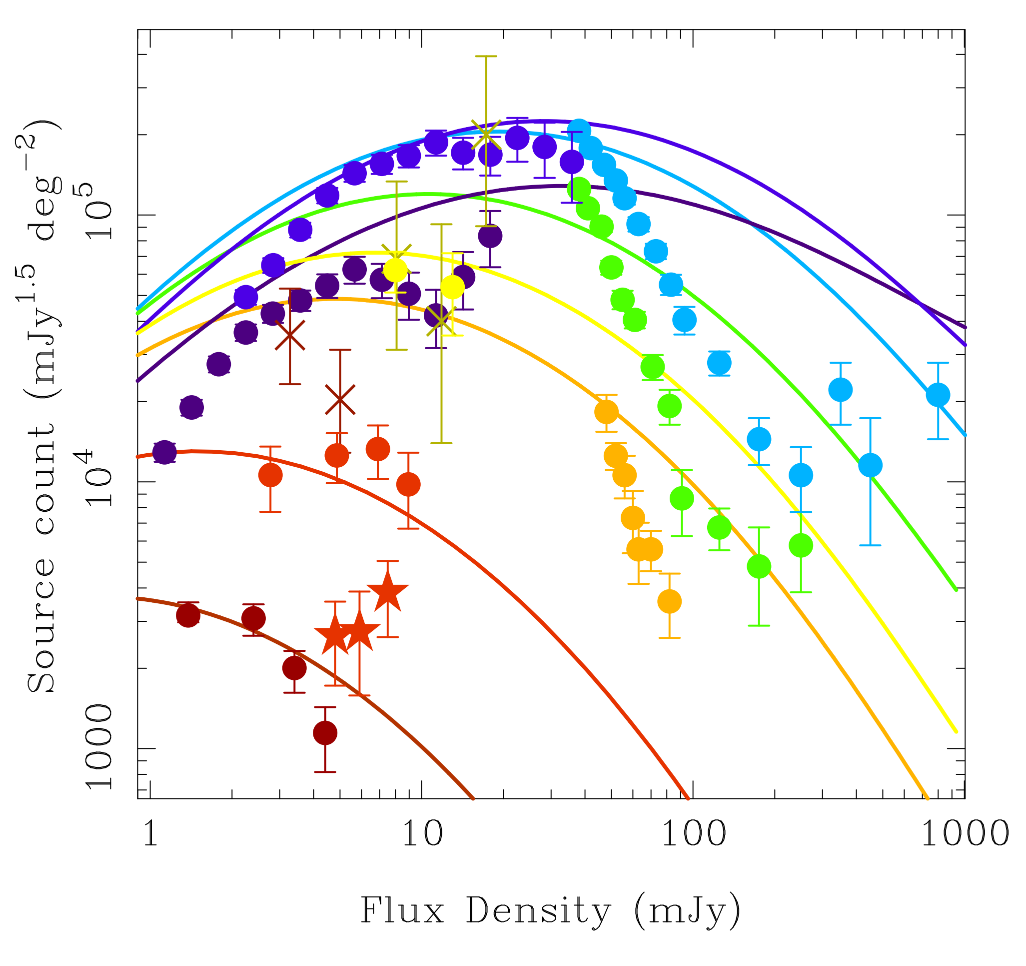
Global luminosity evolution



WMAP cosmology

- Points
  - Blue: optical / UV
  - Red: IR and dust corrected
  - Black: SDSS fossil record
  - Uncertainty remains
- Lines:
  - results from combined submm/ far-IR information
  - Note high-z decline certain
  - Less rapid than for QSOs?
- Caveats
  - AGN power (modest?)
  - High-z / high-L IMF change
- Submm-selected sample probes most intense epoch of galaxy evolution directly

And an ancient model



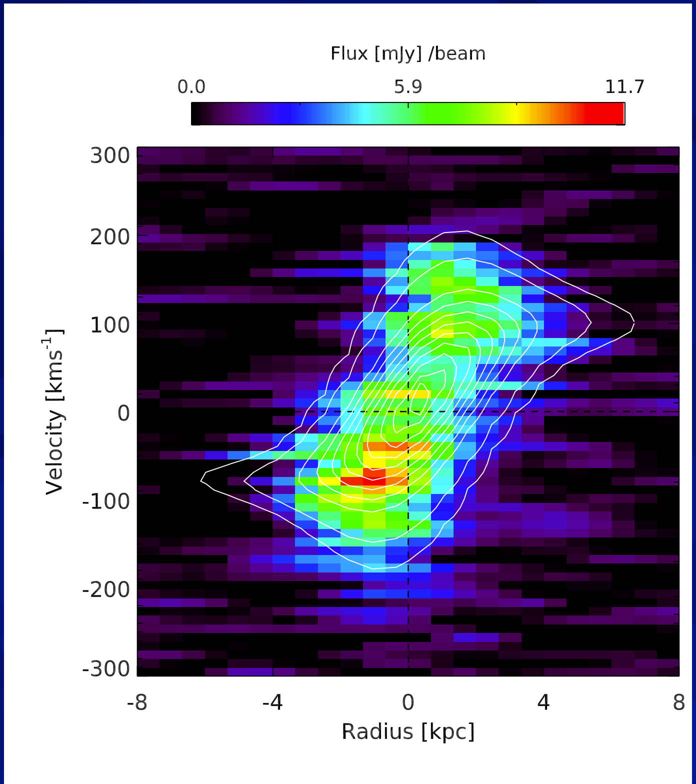
- 2002
  - Right cosmology
  - Matched to ~175/850 microns
  - IRAS LF
- Misses sharp upturn at SPIRE
  - Needs more hierarchical behaviour
  - Also at 1.1mm AzTEC?
  - Also needs Low-z cool things
- Too many objects with ~mJy fluxes in PACS
  - Not incompleteness
  - Needs tweak near z~1 with hotter SEDs in too
  - PACS faint downturn too slow

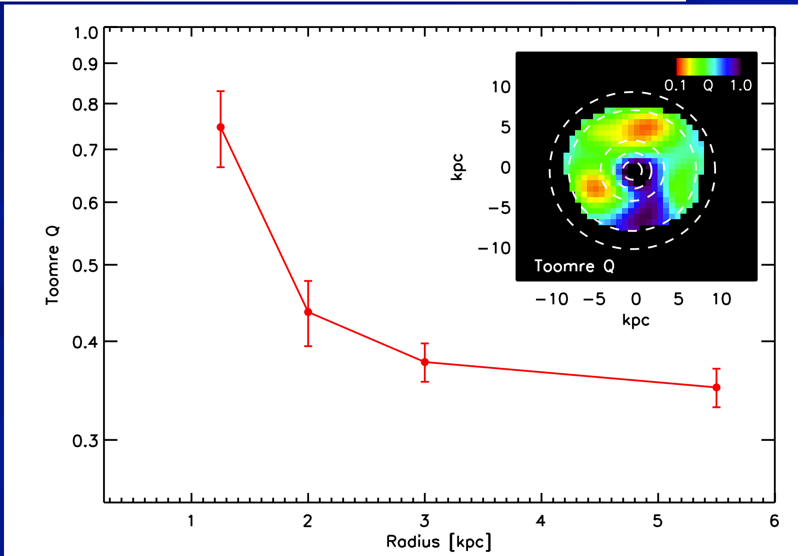
Improving/testing models

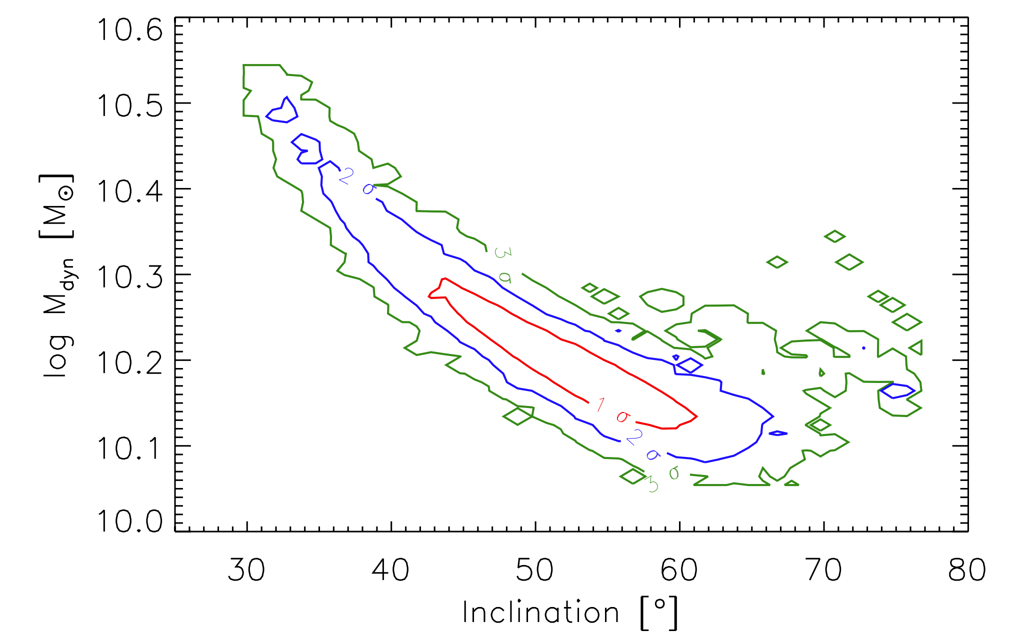
- Resolved multi-color images of dust
  - ALMA but only longwards of SED peak
    - Unless very high redshift
- Dynamics of host
  - Squarely with ALMA, & scale reaches down to ~100pc, but resolved imaging in detail is challenging
- Ultimately mid-IR interferometry?
  - Mid-IR spectroscopy from JWST (~2019); Longer from SPICA (~2028)

Dissecting astrophysics

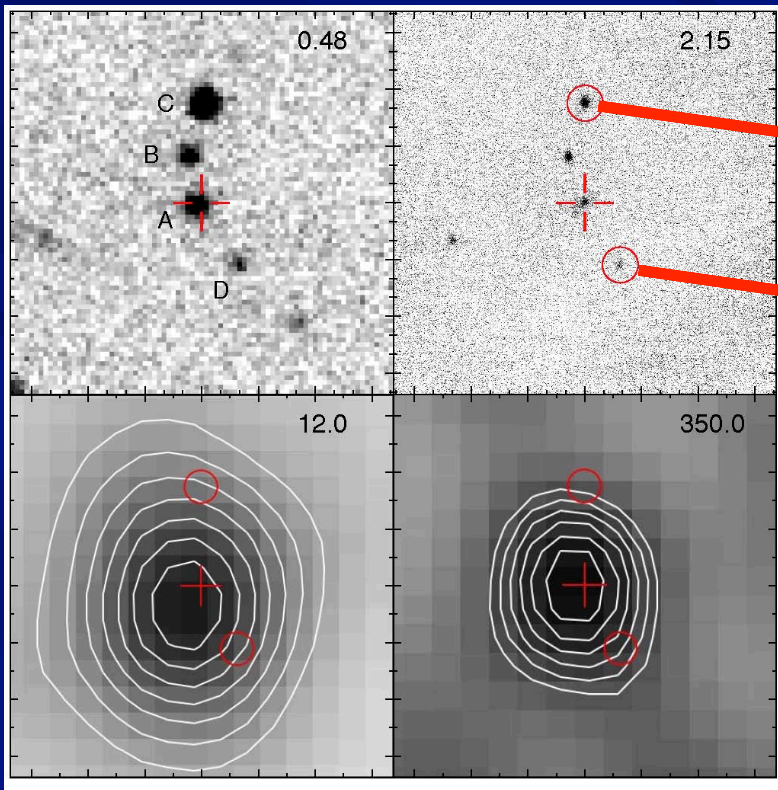
- De Breuck et all: ALESS73.1 z=4.8
- Resolve gas in disk (CII)
- Infer inclination, unstable everywhere
- Most markedly at larger radii
- NI/CII ratio hints at ~solar metallicity
- Turbulence/rotation ~ 0.3
- First WISE/ALMA sources: values

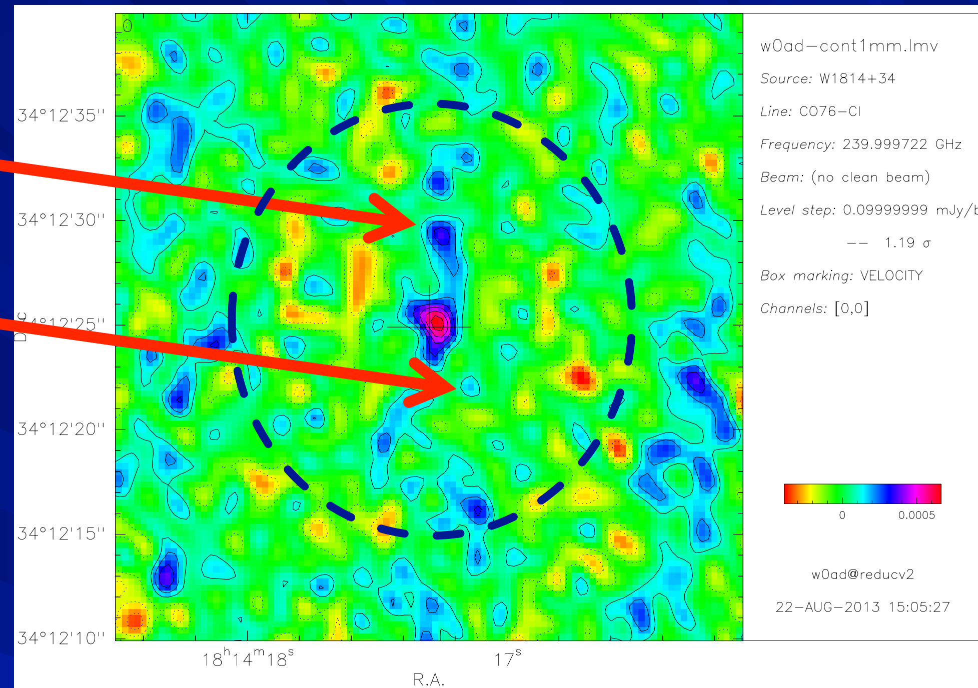






Imaging of WISE ULIRG W1814



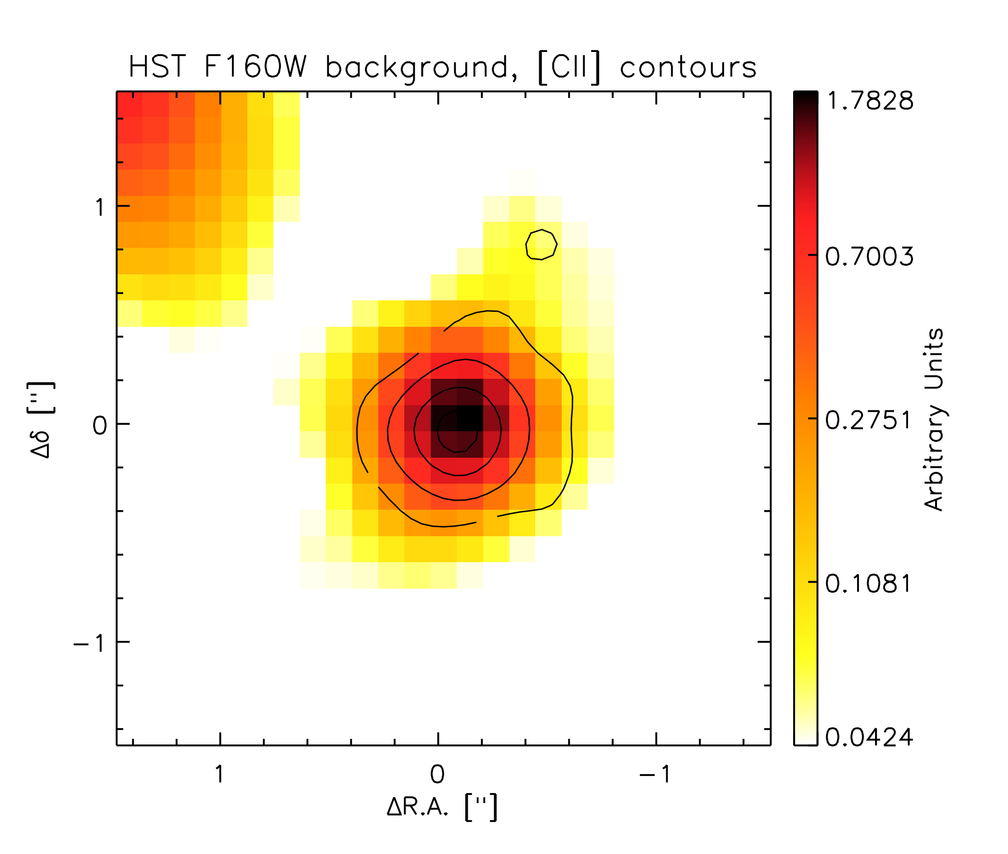


IRAM PdBI, ultrared A is dominant at 233GHz, not broad-line AGN C. Mystery D positive flux

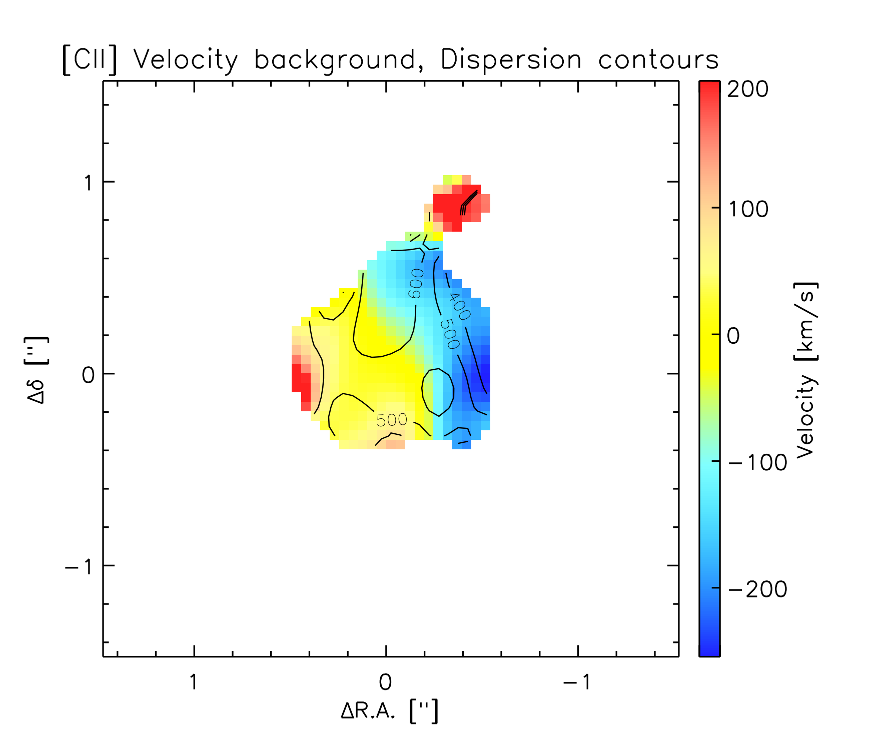
Keck z=2.54, optical, near-IR AO
WISE 12, CSO SHARC-2 images

- WISE “HyLIRG”
- Very clear SED
- Complex – an AGN & dustier object
- Too far North for ALMA

Example of resolved WISE case



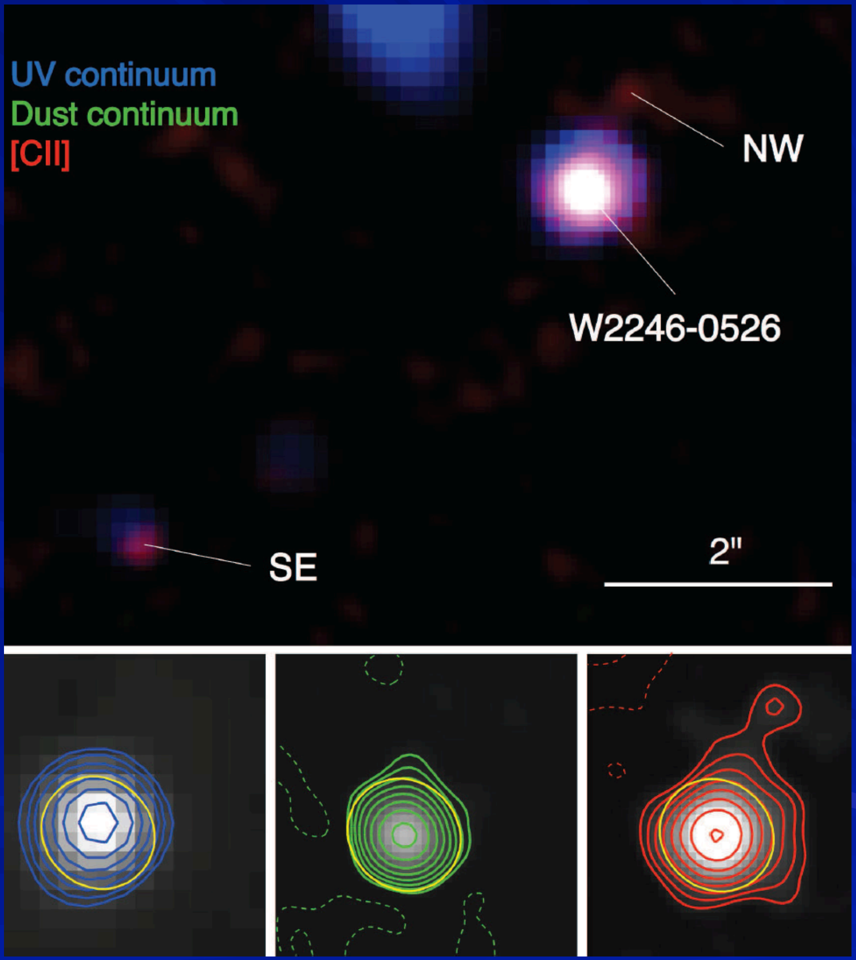
Diaz-Santos et al (2015); ALMA2 Assef PI

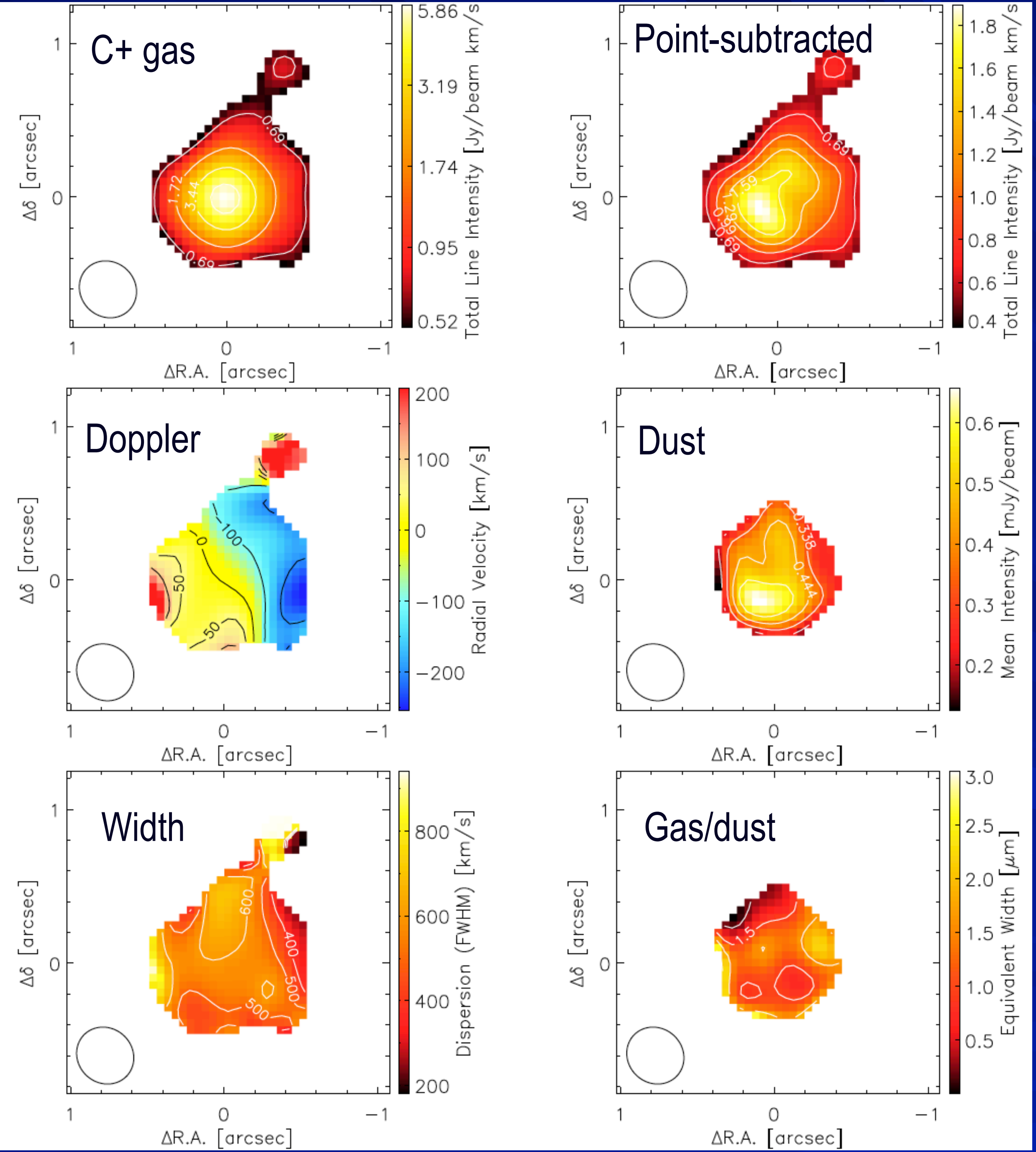


- ALMA, CII & continuum; W2246
- ~600 km/s dispersion; uniform; CII less extended than UV; Companions (in CII). Nature of wind?
  - No obvious extended component in velocity

“The most luminous galaxy”

- W2246-0524 at redshift 4.59
- Identified by WISE
- Right redshift for ALMA C + line observations
- ALMA and HST images
- 10^{15} solar luminosities
- Small, but **resolved**
- Dust more compact than gas





ALMA data

On the C+ line

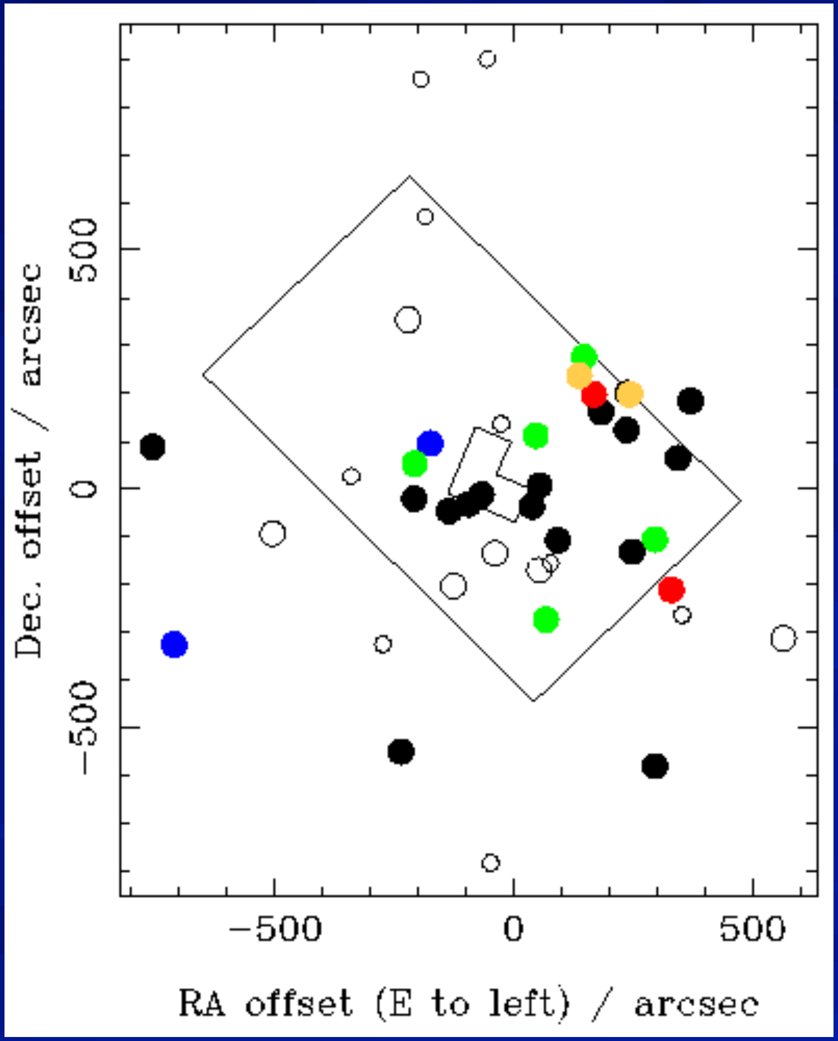
Remarkably wide, and uniform across the galaxy

Shows turbulence – gas is hot and swirling

Left hand: total
Right hand: point source subtracted

Can't be stable

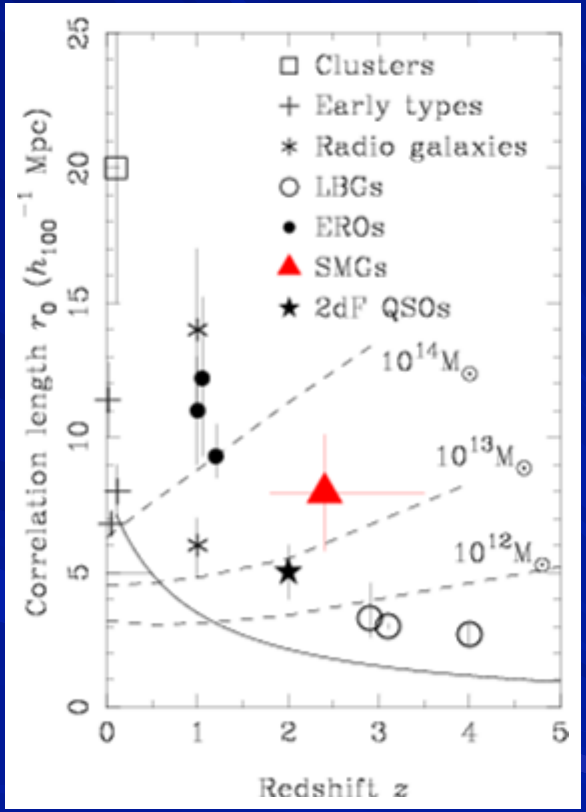
SMGs trace 3D large-scale structure (LSS) peaks?



- Largest number of SMGs are in and around the HDF field
  - HDF & GOODS frames show where morphology information is available
- Circles: all known radio-submm galaxies
  - Small empty: no z attempt
  - Large empty: no z found
  - Black filled: z found
  - Colored filled: 'associations' - all z's within 1200 km/s
- Green points (z=1.99) match optical galaxy z spike (Steidel et al)
- Only the spectroscopic redshifts from LRIS reveal structure
- Many more 'clusters' or associations expected than expected from our knowledge of SMG N(z)
- Narrow-band searches under way

Comparison with other populations

- Other more numerous high-z populations have less powerful clustering
- Are SMG redshift associations linked to overdensities of more numerous galaxy classes at the same redshift?
  - At z~2.5 spectroscopy essential to test
  - Links with 'BX' optically selected galaxies at z~2 in HDF
  - Narrow-band imaging can search for associated less-luminous optical galaxies
- Do they reside in such massive halos?
  - Not every 10' field can contain such an object
  - What is the nature of the biasing process?
  - Near-IR spectra hint at central 4-kpc dynamical masses of few $10^{11}M_o$
  - Stellar population fitting implies few $10^{10}M_o$, but uncertainties from complex morphology



After Overzier et al. (2003)

JCMT HotDOG non-detections

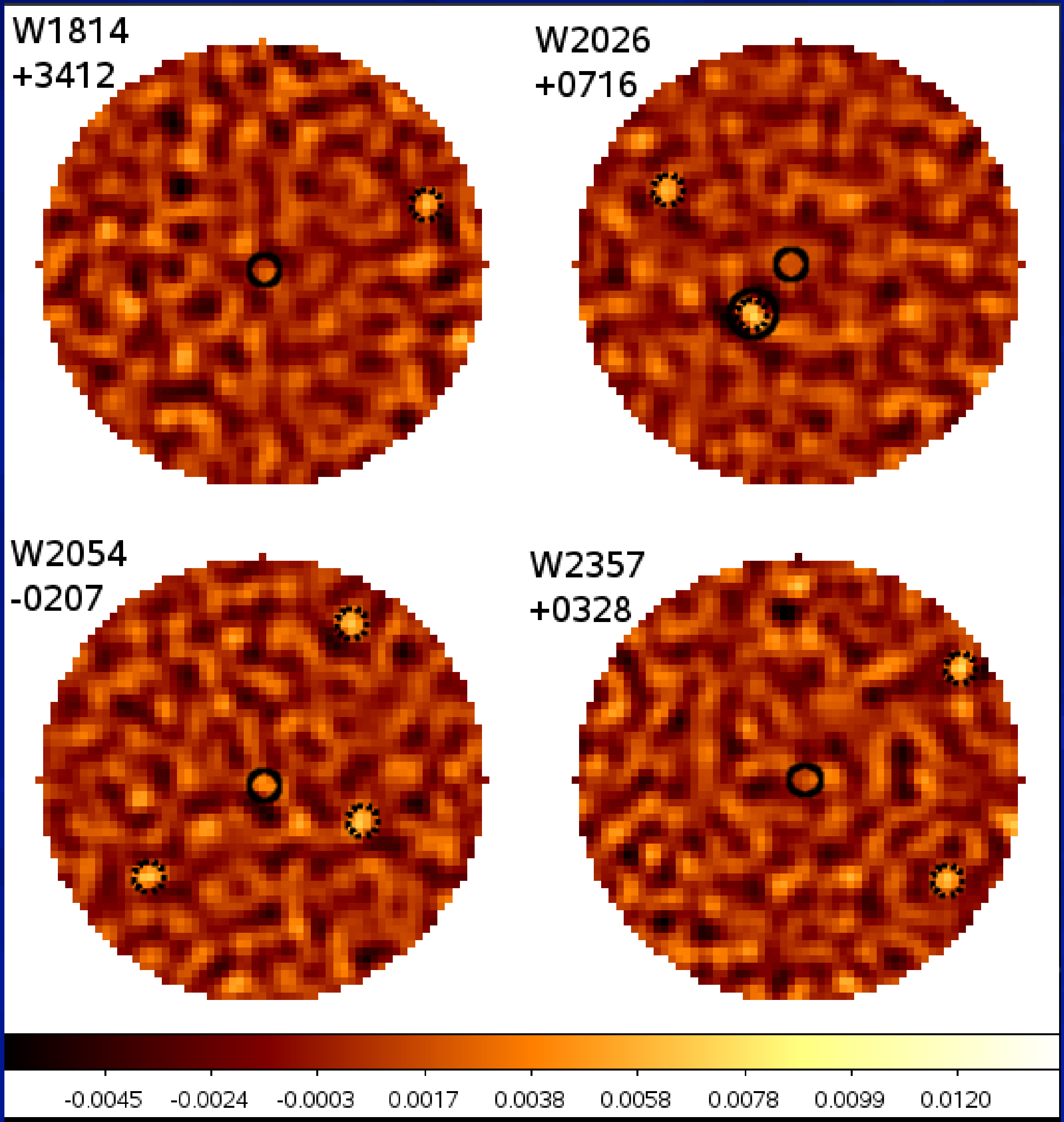
3 arcmin diameter fields. Surrounded by wider 8' noisier areas

See net stacked signal from the central WISE-selected target

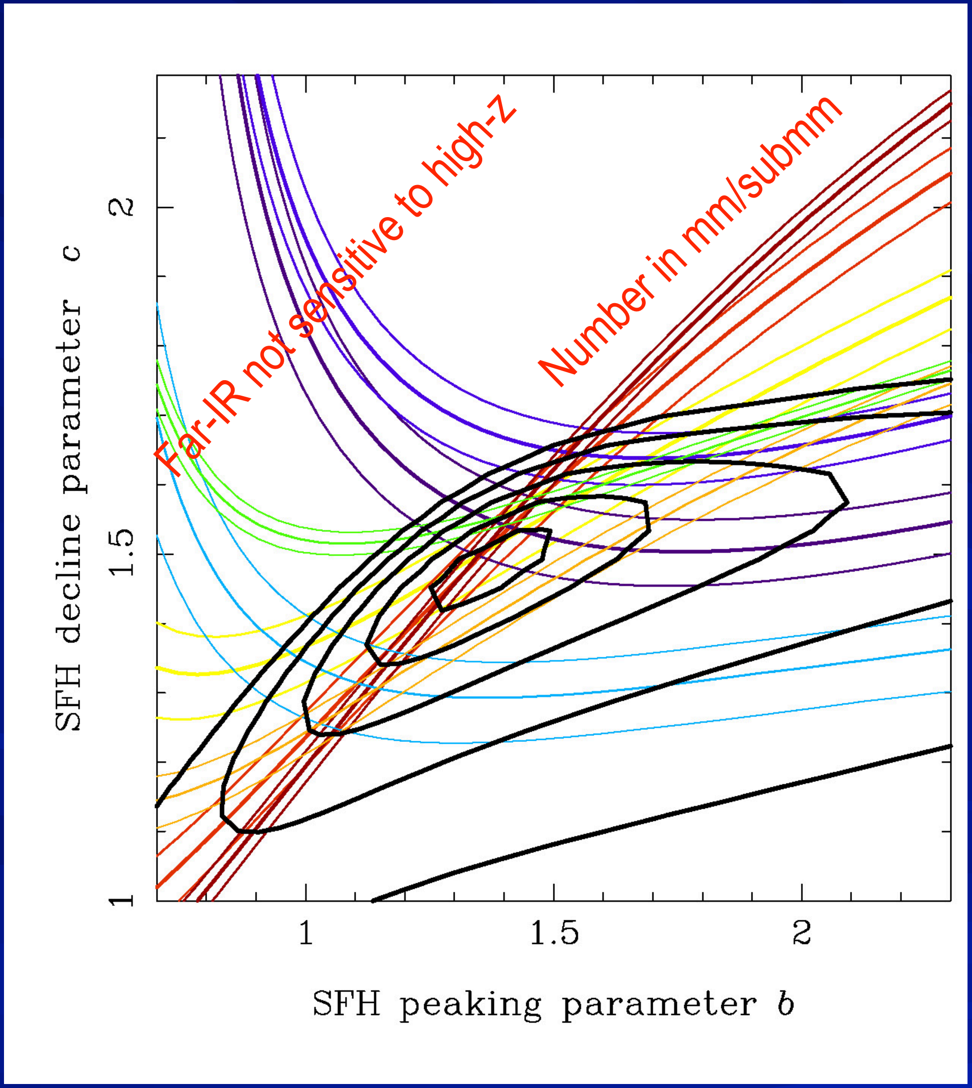
Also see ~5x more sources c.f. field

Also Sajina et al. ALMA on 10x smaller scale

Suzy Jones et al. 1406.2506

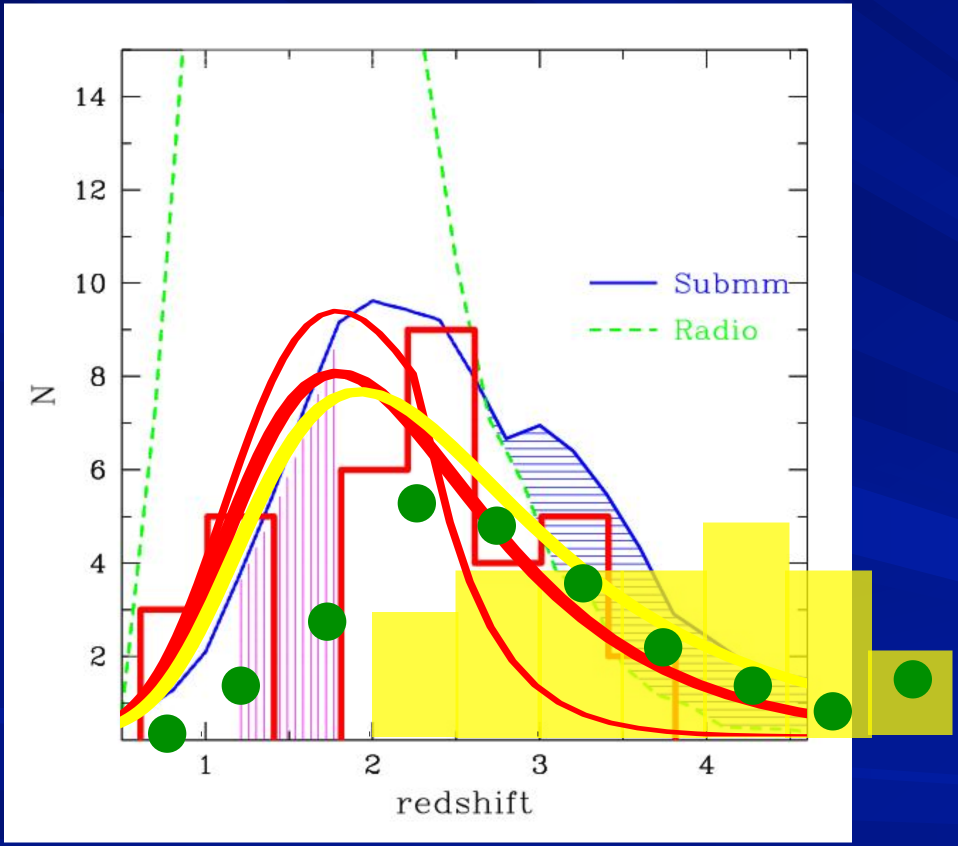


Luminosity density history



- Without redshift information
  - Was b,c~2.0,1.7
  - Now b,c~1.4,1.5
- Add redshifts gets more complex
- Not radically different

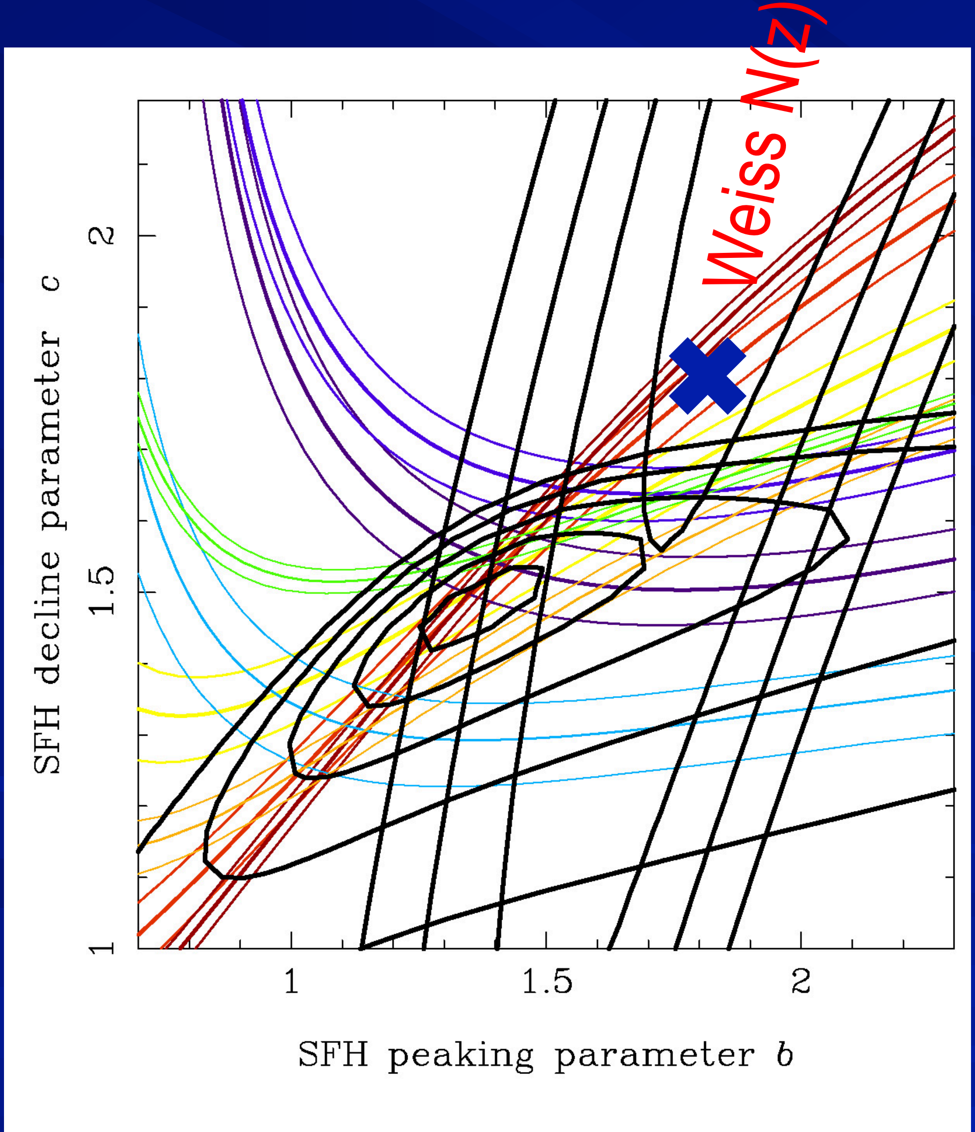
Redshift distribution N(z) for SMGs



Chapman et al. (2003; 2005); Weiβ et al. (2013)
Red lines: BSIKF 0.85mm 5mJy, w/wo radio cut
Yellow line: BSIKF 1.4mm 1mJy, green lenses

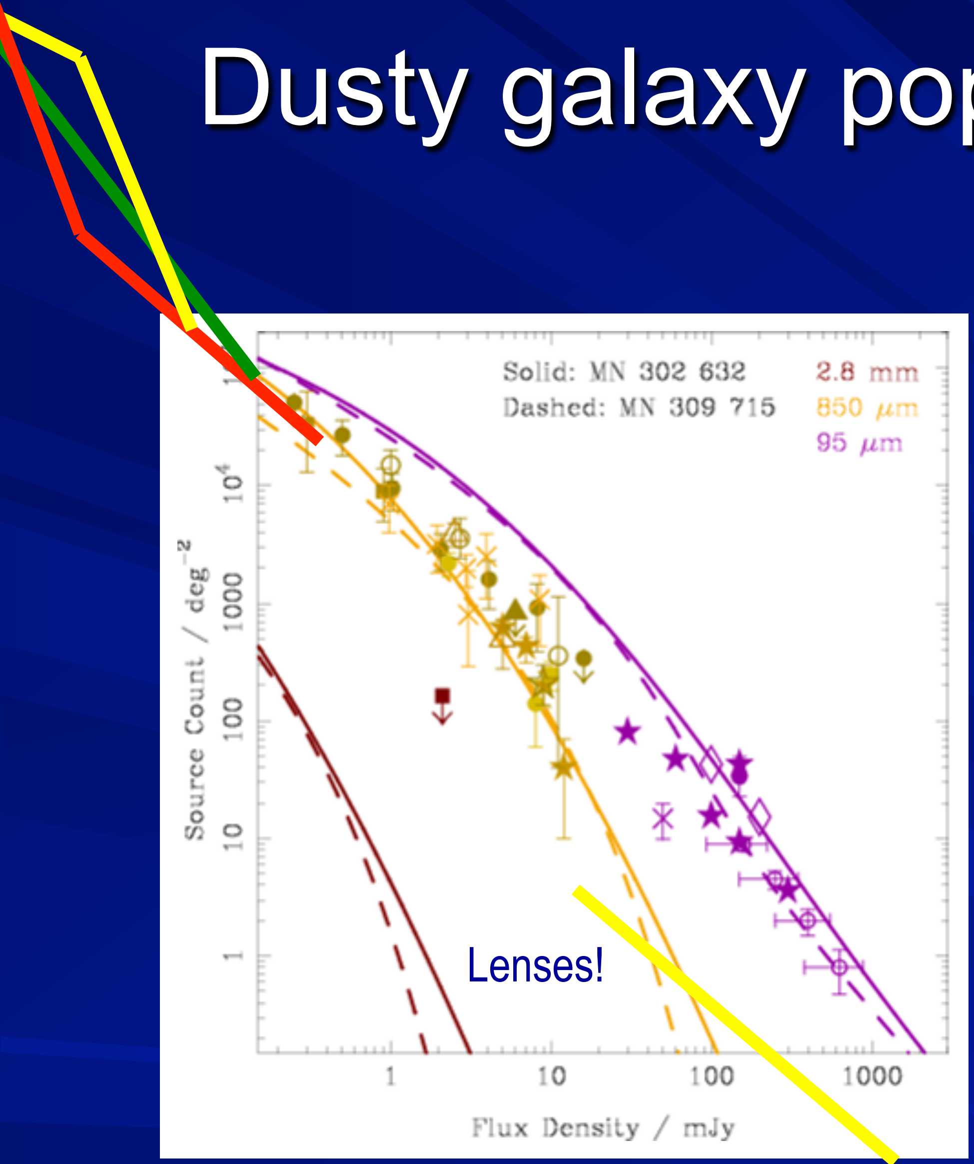
- Red histogram, blue & green
  - Chapman et al. (2005)
- Red lines: previous model
  - With and without radio cut
- Yellow histogram: SPT N(z)
  - SPT selected, ALMA confirmed with CO-line redshift
  - Censored modestly by lensing, in both redshift and size (distant, small objects preferred).
- Yellow line. Previous model
- Green dots. Censured by lensing. Effects clear?
- Significant tension
  - COSMOS (Smolcic)
  - Disk lens (Maller/Moeller)
  - Multiple components (Hodge)
- Redshifts most powerful constraints

SPT/ALMA redshifts and N(S)



- Weiβ et al. (2013)
- Modest change b~1.7, c~1.7
  - Bet on X for simple high-z dust model?
- Not an excellent fit!
  - But very minimal model
- Caveats:
  - SED range
  - Cool/warm far-IR
  - Other populations
    - WISE, ALMA

Dusty galaxy populations extended



- Bright 95 (&175) μm counts from ISO dramatically improved at 70 & 160 μm by Spitzer-MIPS, Herschel-PACS
- Also data at IRAM's MAMBO/GISMO); CSO's BOLOCAM/SHARC-2; APEX's LABOCA; Herschel SPIRE; ALMA.
- Little more so far at <mJy level
  - IRAM & ALMA deep fields
- Faint counts ill-constrained by background/N(z) measurements
  - Could be faint dwarf population (green)
  - Could be continuing very distant LIRGS (yellow)
  - Could be μJy 1st light fragments (red)

Summary

- New very hot SEDs have been found for IR-luminous AGNs from WISE & follow up
  - Exceed previous extremes
- Out to 22 microns, have power-law SED in the mid-IR for a huge sample. Selection (but not study!) for large samples of AGNs now possible.
- Striking, shallow SEDs 10-100 microns
- Remarkable overdensities on ~5' scales
  - Importance, details still open…