

# AGN Contribution within SCUBA-2 Detected Sub-mm Galaxies

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# Sub-millimetre Galaxies; Introduction

- Galaxies observed in the sub-mm part of the spectrum. Consisting of high-redshift dusty star-forming galaxies.
- Observations benefit from a very negative K-correction. For a wide interval of redshifts ( $z \approx 1 - 8$ ) the observed flux is approximately constant.
- Exhibiting very large star-formation rates (thousands solar masses per year). More numerous than local (U)LIRGs

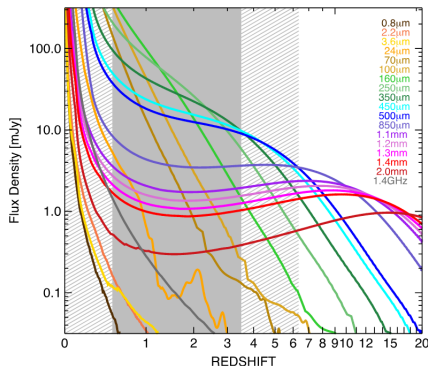


**Figure:** Flux density for a typical infrared-luminous galaxy as a function of redshift. Taken from Casey et al., 2014.

# Sub-millimetre Galaxies; Comparison with ULIRGs

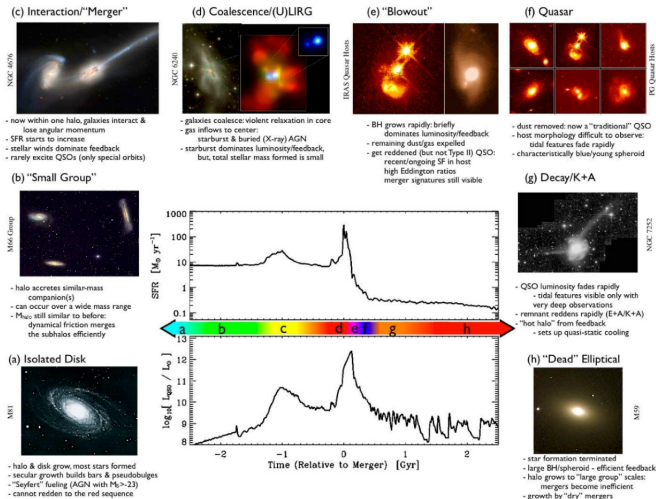


Figure: Schematic evolution by merger. Taken from Casey et al., 2014.

# Sub-millimetre Galaxies; Formation & Evolution

- A question of formation and evolution of sub-mm galaxies.
- Local ULIRGs understood within an evolutionary picture of merging gas-rich disk galaxies. The system experiences a period of intense star-formation due to in-falling gas.
- Possible connection with formation of AGN and subsequent quenching, further supported by redshift distribution of sub-mm galaxies.

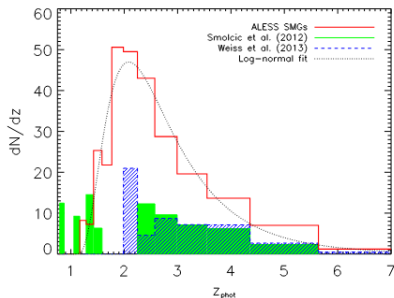
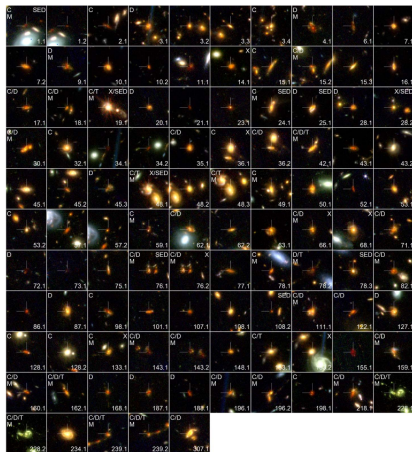


Figure: Redshift distribution of ALMA-LESS-detected SMGs.  
Taken from Simpson et al., 2014.

# Sub-millimetre Galaxies; AGN Prevalence

| Method     | Paper                       | AGN %                         | N    |
|------------|-----------------------------|-------------------------------|------|
| X-ray      | Alexander et al. 2005       | 75                            | 20   |
|            | Alexander et al. 2005b      | $> 38^{+12}_{-10}$            |      |
|            | Laird et al. 2010           | $20^{+7}_{-7} - 29^{+8}_{-8}$ | 35   |
|            | Georgantopoulos et al. 2011 | $< 26^{+9}_{-9}$              | 126  |
|            | Johnson et al. 2013         | 14                            | 271  |
|            | Wang et al. 2013            | $17^{+16}_{-6}$               | 99   |
|            | Ueda et al. 2018            | $90 - 57 (*)$                 | 25   |
|            | Uematsu et al. 2025         | $> 16$                        | 260  |
| IR         | Pope et al. 2008            | $< 30 L_{IR}$                 | 13   |
|            | Menendez et al. 2009        | $< 32 L_{Bol}$                | 24   |
| X-ray & IR | Stach et al. 2019           | $8 - 28$                      | 716  |
| Radio      | Wang et al. 2024            | 13                            | 7494 |

# Sub-millimetre Galaxies; Merger Study



- From 260 SMGs, 40 were classified as AGN (via SED and X-ray).
- By looking at the prevalence of mergers, it was found that it equaled 25% for non-AGN sources and 47% for AGNs.

Figure: Sources from Uematsu et al. 2025.

# Sub-millimetre Surveys; SCUBA-2



Figure: The James Clerk Maxwell Telescope. Taken from <https://www.eaobservatory.org>

- SCUBA-2 camera at the James Clerk Maxwell Telescope (JCMT).
- Single dish observations. Fast coverage (cca. 2200 sources) with less resolution than interferometers (i.e. ALMA).
- Cross-correlation with surveys at other frequencies.

# Single-dish Observations; Resolution

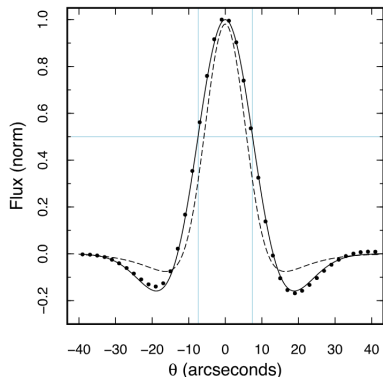
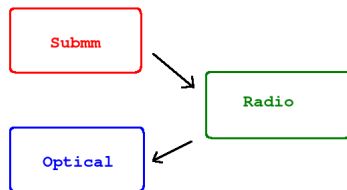


**Figure:** The PSF of the single-dish SCUBA-2 observations. The FWHM equals 14.8 arcsec Taken from Geach et al., 2017.

- Resolution of single-dish sub-mm observations is low.
- Low resolution complicates the cross-correlation. A common approach is to use the less-dense radio surveys, relying also on the Far-IR to radio correlation.



# A Question of Cross-correlation; Poisson Probabilities

- A common method to estimate the "goodness of match" is the use of the Poissonian probabilities.
- By comparison with the chance of a random match we can estimate the probability of the match being real.
- The formula also implicitly takes into account the flux of the possible counterpart as the density is calculated for sources above this threshold.

$$p_S = 1 - \exp[-\pi n_{(>S)} \theta^2]$$

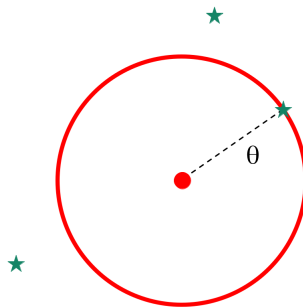


Figure: A schematic picture of the Poisson-probability estimate via the radius spanned between the sources of a possible match.

# Cross-Correlation; Astrometric Offset

- We created an incomplete but reliable radio catalogue with  $SNR > 10$  and only the unresolved sources.
- Using this catalogue we estimated the mean systematic offset between the surveys by performing the matching. We compared all the surveys to the radio data as it was deemed the most accurate.

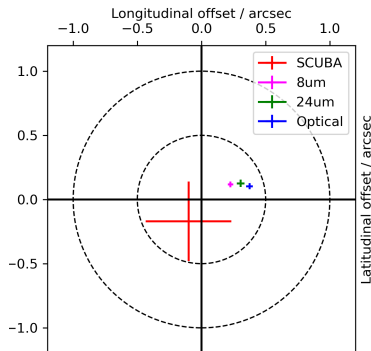


**Figure:** The mean and 3-sigma error values of the astrometric offsets for all the surveys in the legend compared to the radio data. This plot corresponds to the COSMOS field.

# AGN Selection

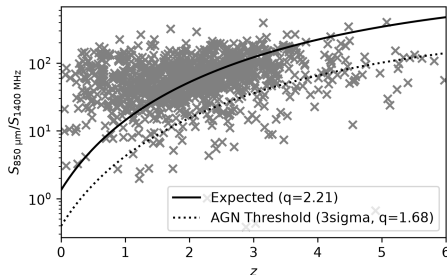


**Figure:** Ratio of sub-mm to radio flux. The grey crosses are the data, while the lines represent the expected and threshold (dashed) values of the ratio.

- The ratio of sub-mm to radio flux has been extensively studied. This ratio was usually used as a way of determining redshift.
- A widely-used example is the line from Barger et al. 2000., derived by assuming a modified blackbody for the IR part of the spectrum and a power law for the radio, normalised on a single typical galaxy (Arp 220;  $z = 0.018$ )

- The fraction can also be normalised via the well-studied luminosity relation.

$$S_\nu = C_{\text{smm}} \cdot \frac{2h}{c^2} \cdot \frac{1}{e^{h(1+z)\nu/kT} - 1} \cdot [(1+z)\nu]^{3+\beta} \cdot \left[ \frac{1}{d_L(z)} \right]^2 \cdot \frac{1}{1+z}$$

$$S_\nu = C_R [(1+z)\nu]^\alpha \cdot \left[ \frac{1}{d_L(z)} \right]^2 \cdot \frac{1}{1+z}$$

$$q_{IR} = \log_{10} \left( \frac{L_{IR}}{3.75 \cdot 10^{12} \text{ W}} \right) - \log_{10} \left( \frac{L_{1400 \text{ MHz}}}{\text{WHz}^{-1}} \right)$$

$$\frac{S_{353 \text{ GHz}}}{S_{1.4 \text{ GHz}}} = 10^{q_{IR}} \cdot \frac{3.75 \cdot 10^{12} \text{ W}}{\text{WHz}^{-1}} \cdot \frac{[353 \text{ GHz}]^{3+\beta}}{I(\beta, T)} \cdot \frac{1}{e^{h(1+z)(353 \text{ GHz})/(kT)} - 1} \cdot [1+z]^{3+\beta-\alpha}$$

- The IR here is the FIR from 42.5  $\mu\text{m}$  to 122.5  $\mu\text{m}$

# AGN Selection; Comparison

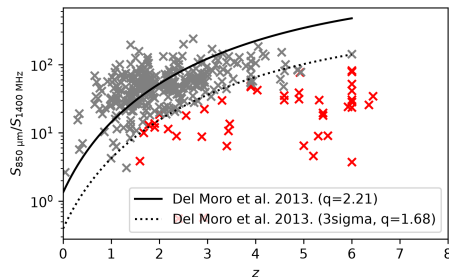


**Figure:** Ratio of sub-mm to radio flux. The red data-points were selected as AGN via a SED-fitted luminosity comparison.

- A comparison can be made with a dataset where SED fitting was performed (Michałowski et al. 2017.).
- The threshold line seems to follow the AGN selection well. The details depend on the details of the model.

# Cross-Correlation; Multi-component Sources

- Multi-component sources need to be investigated.
- By using the radio maps and the corresponding matched catalogues, we can visually identify these sources. Radio fluxes can then be summed.
- Radio morphology of sub-mm detections.

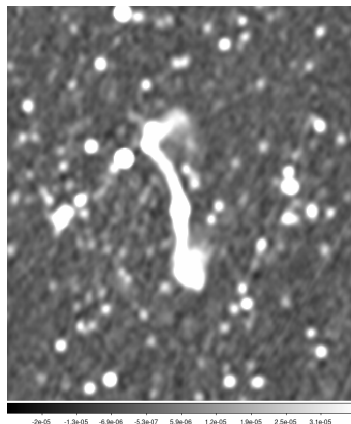


**Figure:** An example of an obviously multi-component source from the COSMOS MIGHTEE map.

# Cross-Correlation; Submm Multiples

- Problem of counterpart identification. Danger of blended sub-mm sources (i.e. confusion limit) and the dependence of this on sub-mm flux.
- The number of multiples can depend on the sub-mm flux, as seen by surveys which resolve the single dish sources via ALMA.

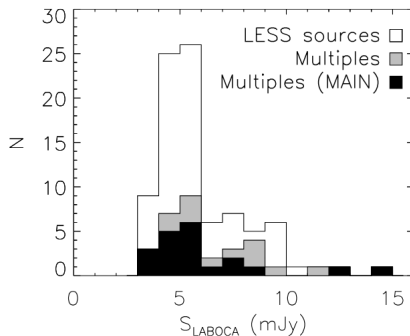


Figure: LABOCA sources resolved into multiples with ALMA. Taken from Hodge et al., 2013.

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