Extragalactic Science with ALMA

First results from Cycle 0 Early Science and from Science Verification

North American ALMA Science Center

Carol Lonsdale

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Large Baseline Array

NRAO

Science Verification Data ALMA

- ALMA data released for:

  NGC 3256* BAND 3, CO (1-0) MAP, DISPERSION, VELOCITY FIELD

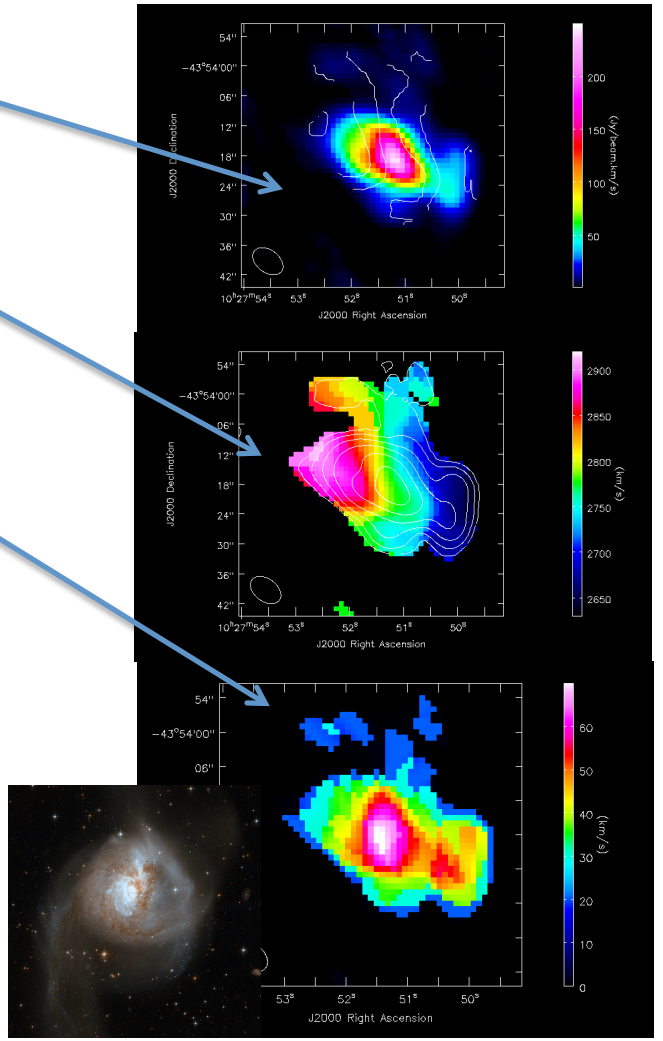
  M100

  THE ANTENNAE GALAXIES*

- download from ALMA Science Portal http://almascience.org/

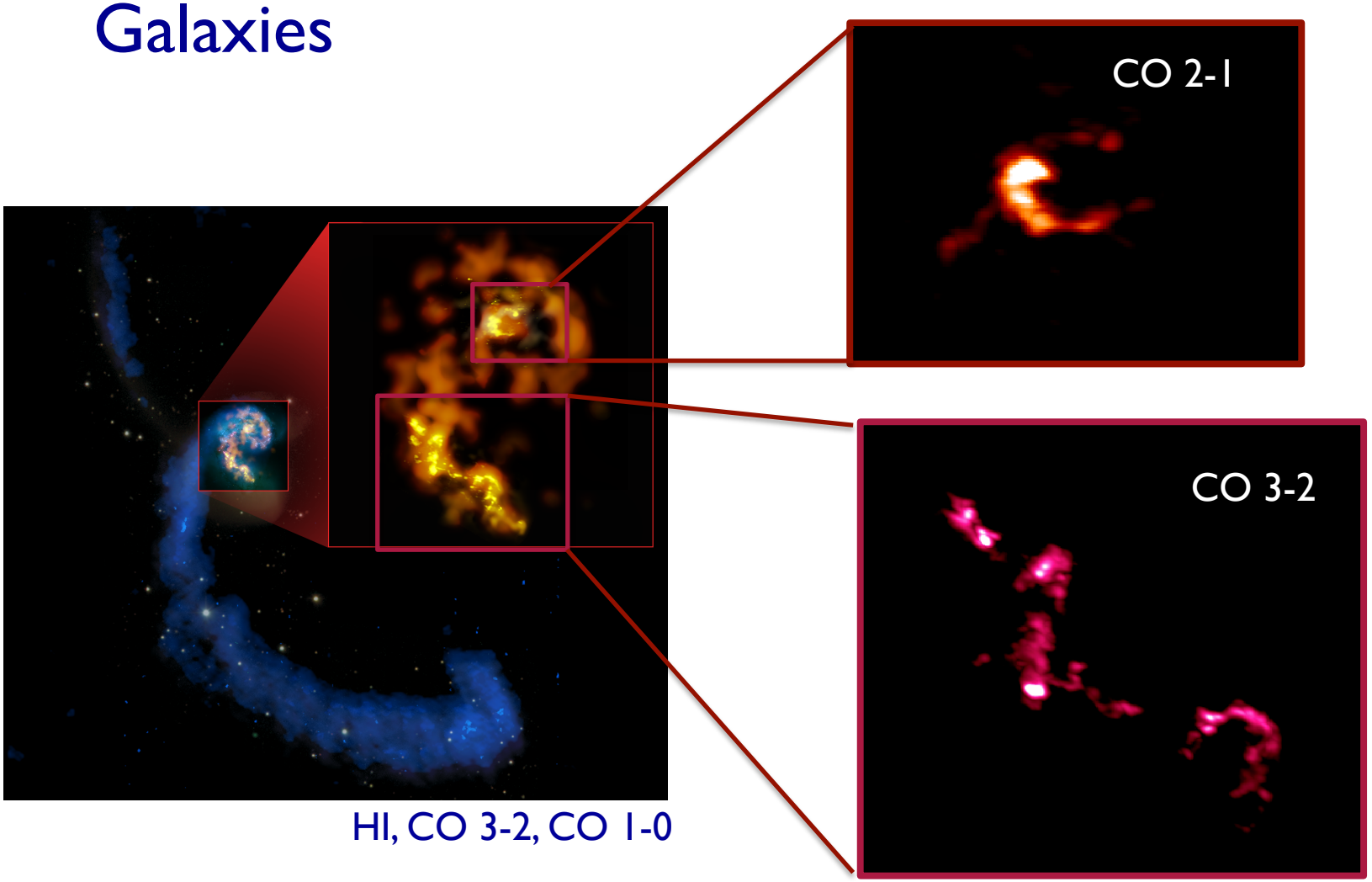
- Calibrated & uncalibrated data, images.

  - * - CASA guide available at http://casaguides.nrao.edu



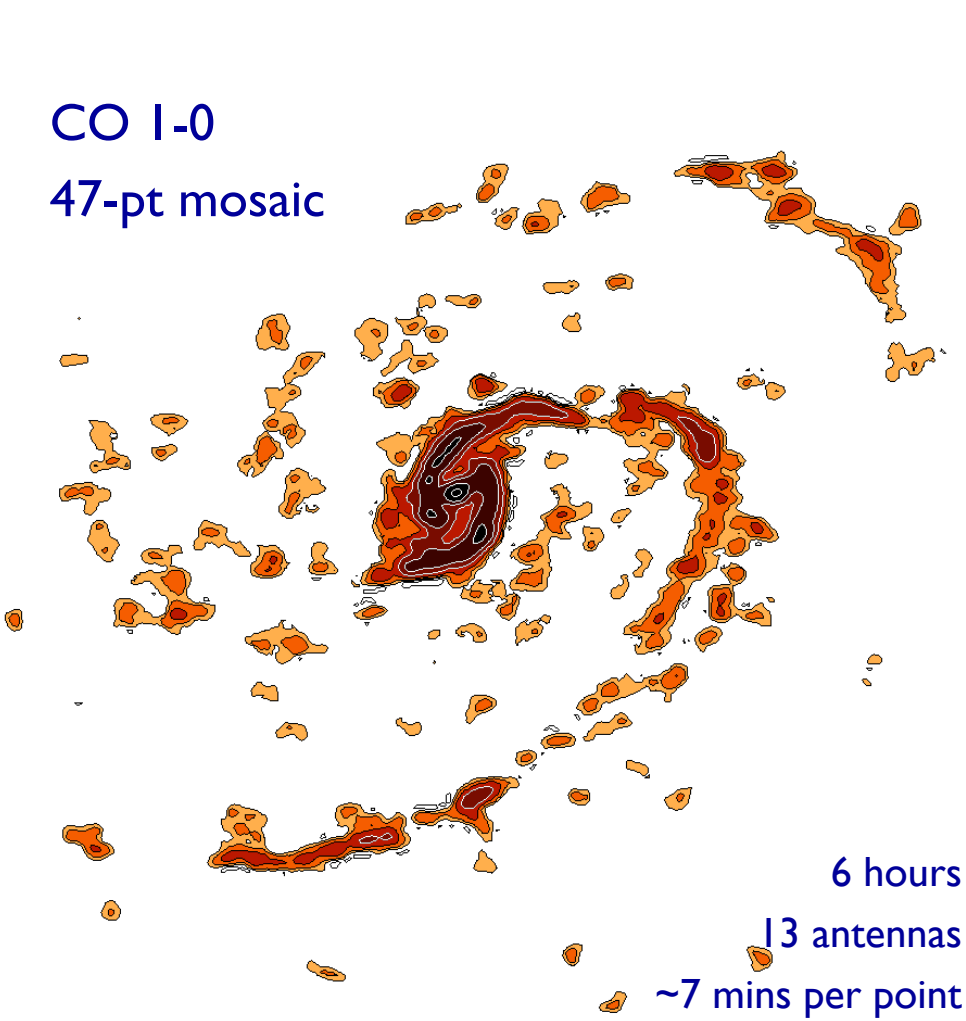
ALMA Images Nearby Galaxies

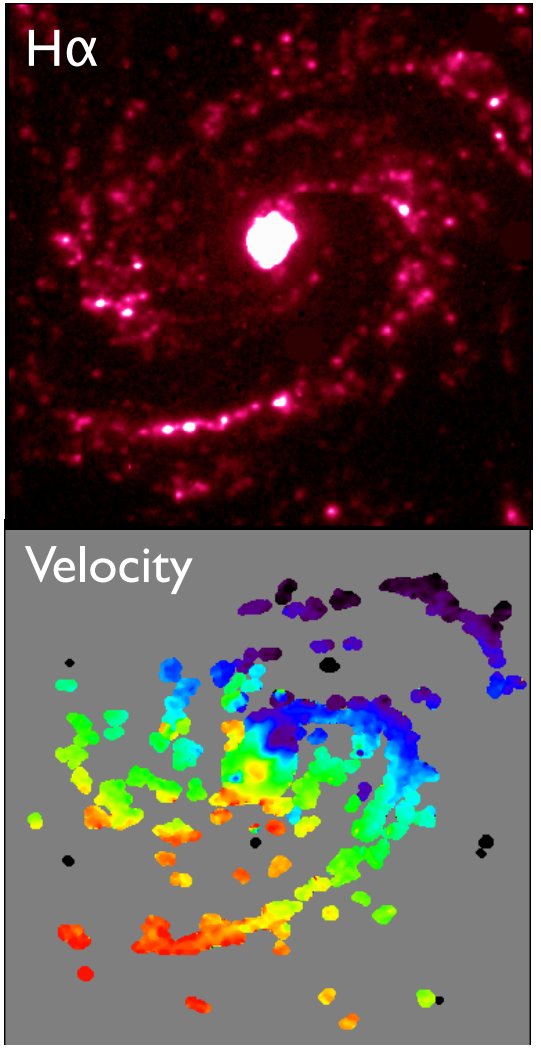
- Science verification imaging of the Antennae Galaxies



ALMA Images Nearby Galaxies

- Science verification imaging of M100





ALMA Cycle 0 Underway

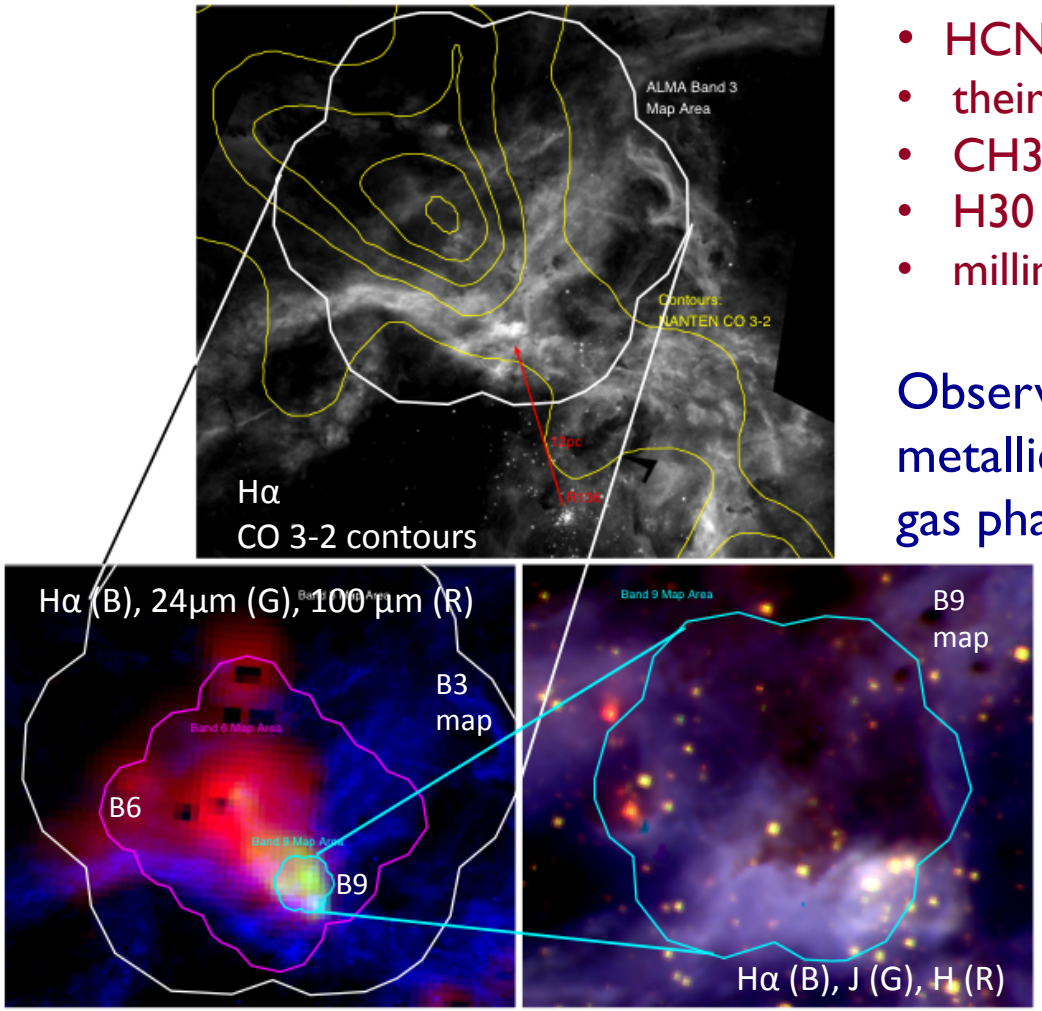
- Observations of fine structure lines at high redshift.
  Resolve and detect [CII] out to z > 6, contrast with [NII], reach 300 pc resolution

- Detailed physical conditions at high resolution in local galaxies.
  - Starbursts & Mergers: Arp 220, Antennae, II Zw 96, NGC 253, NGC 6240, NGC 1068
  - Galactic Nuclei: Cen A, NGC 1266, Sombrero, NGC 1433 & 1566, NGC 1097
  - Brightest Cluster Galaxies
  - Dwarfs and Normal Spirals: M83, SBS 0335-052
  - Our Closest Neighbors: Super star cluster 30 DOR

- Measuring the gas in normal galaxies at intermediate redshift.

- Exploring new populations.
  SPT Sources, WISE QSOs, Blind Survey behind a Lensed Cluster, Localizing SMGs

Indebetouw et al.: The Subparsec Scale Environment of the Super Star Cluster 30 Doradus



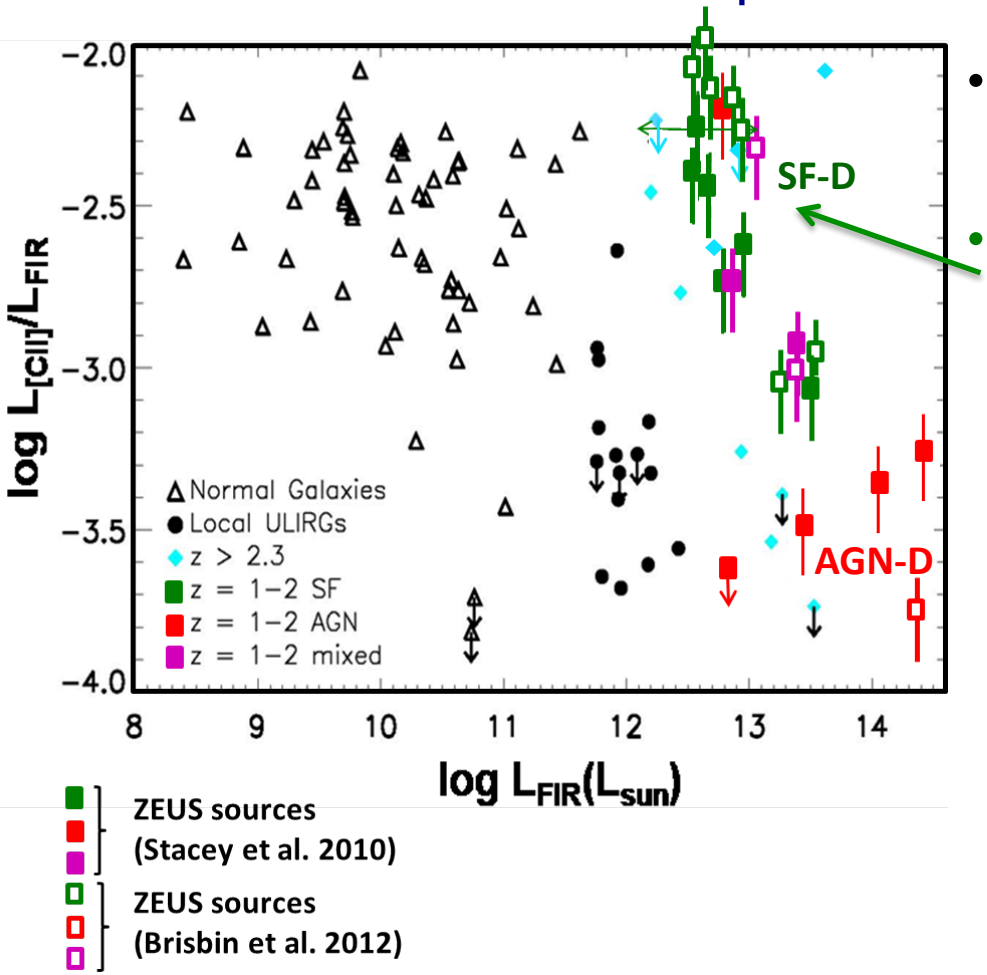
Matched 1-2" tiered Band 3, 6, & 9 imaging:

- HCN, HCO+, and CS
- their isotopologues
- CH3OH
- H30 α and H40 α recombination lines
- millimeter continuum

Observing sub-parsec scale clumps in low metallicity starburst PDR, tracing different gas phases

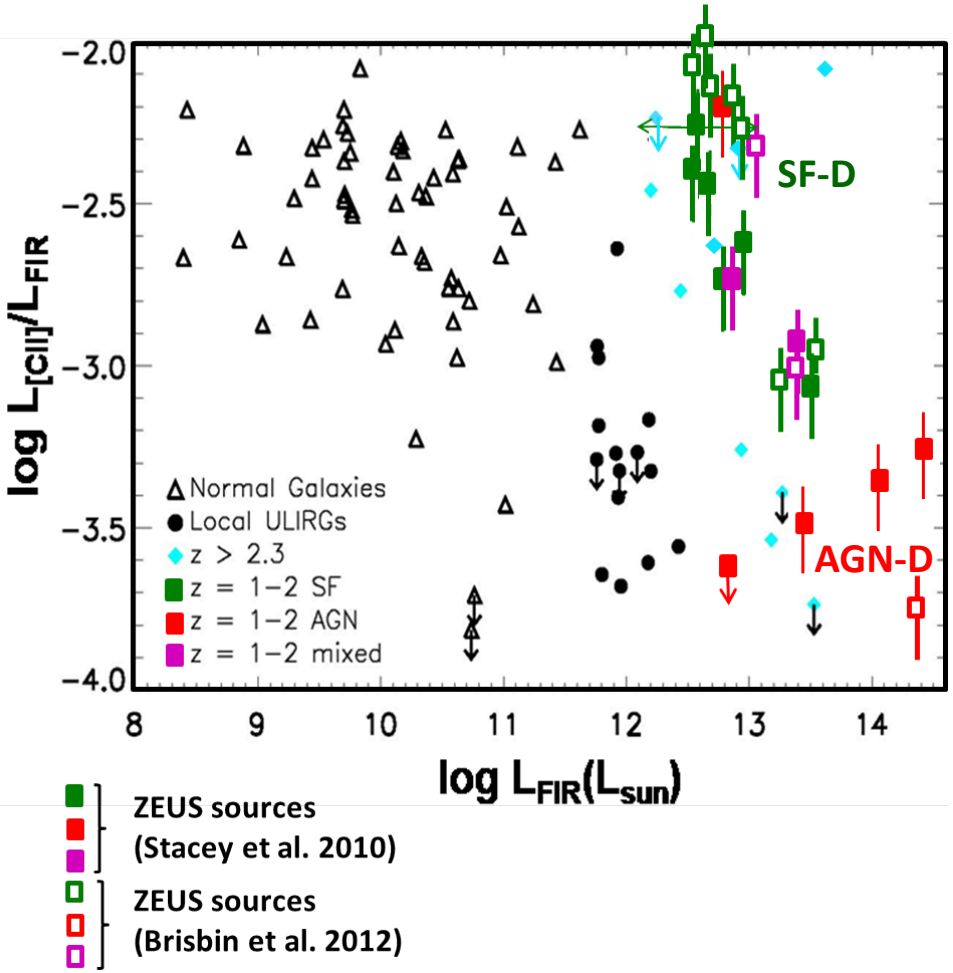
G.J Stacey, S. Hailey-Dunsheath et al.
ALMA Imaging of the Star Formation Process at the Historic Peak

Builds on ZEUS-CSO study of 23 galaxies in 158μm [CII] line at z ~ 1-2 – the historic peak of star formation activity



- [CII]/far-IR luminosity ratio, R traces strength of far-UV fields, G_0
- Large R for star formation dominated (SF-D) systems
  - Far-UV fields and molecular cloud densities like local starbursts (e.g. M82) ***BUT kpc in size***
  - ***Unlike*** the collision-induced, confined and very intense ***local ULIRG starbursts***
  - Likely reflects the enormous gas reservoirs at this epoch – and ***continuous-mode star formation***

G.J Stacey, S. Hailey-Dunsheath et al.
ALMA Imaging of the Star Formation Process at Historic Peak



- G_0 is 8 × larger in AGN-D
  - Collision-induced ULIRG-like starbursts ***on much larger scales,*** or
  - younger starbursts than SB-D systems

ALMA Imaging of the Star Formation Process at the Historic Peak

ALMA Science Goals

Image [CII] and far-IR in 3 representative sources:

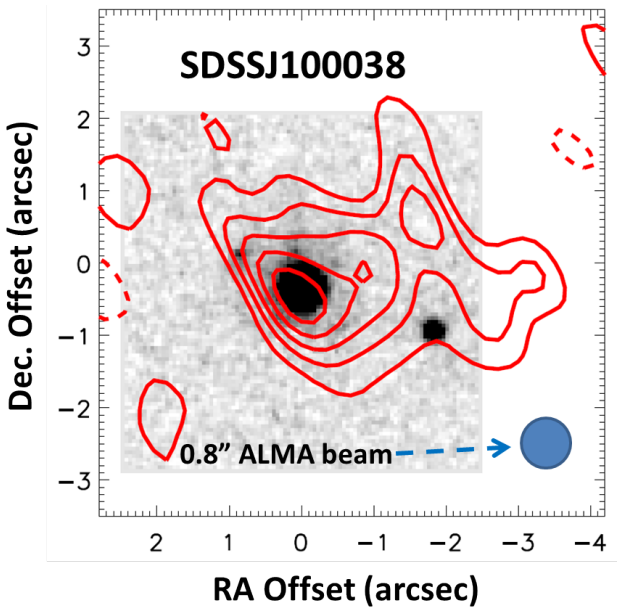
PKS 0215 (AGN-D), SDSS J100038 (SF-D), RX J094144 (mixed)

Traces the far-UV field strength and star formation activity across these galaxies:

- relative importance of collision-induced over continuous-mode star formation
- AGN/starburst link at z ~ 2 – the epoch of peak star formation activity in the Universe.

Expectation are:

1. Similar distributions to CO(4-3) for SDSS J100038
2. Extended emission plus a nuclear spike? ([CII] and/or far-IR) for RX J094145
3. Strong nuclear (AGN/XDR associated) emission in both [CII] and the far-IR from the Blazar PKS 0215



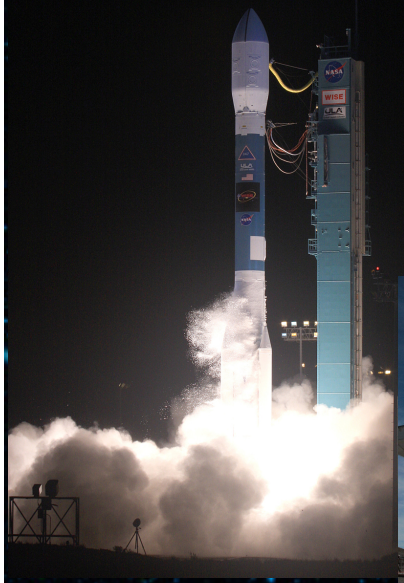
PdBI CO(4-3) overlaid on HST I-band image (Hailey-Dunsheath et al. in prep.

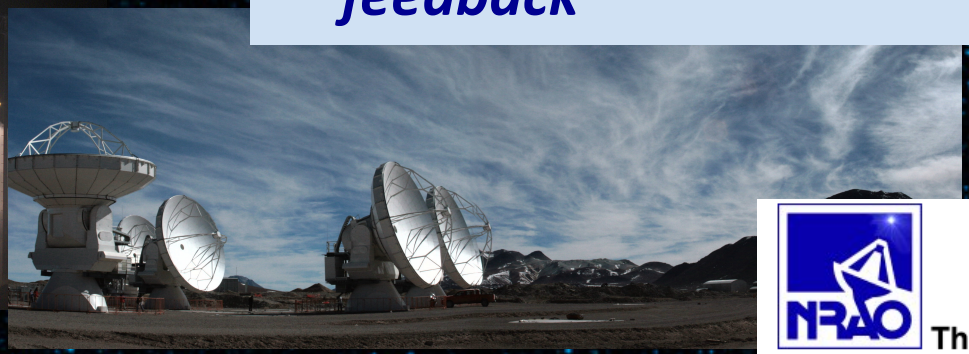
Lonsdale et al: The most luminous obscured quasars in the universe: the role of radio feedback

Carol J Lonsdale, NRAO
Amy Kimball, NRAO
Jim Condon, NRAO
Minjin Kim, Korea
Mark Lacy, NRAO
Tom Jarrett, IPAC
Andrew Blain, U. Leicester
Dominic Benford, Goddard
Frank Masci, IPAC
Dan Stern, JPL
Chao-Wei Tsai, IPAC

49 obscured quasars

1. Bright at 22μm and very red MIR-optical colors from WISE
2. Radio-intermediate, compact, from NVSS: AGN is present
3. ALMA: measure starburst/AGN flux ratio to find sources in early stages of turning off star formation via ***radio-mode feedback***

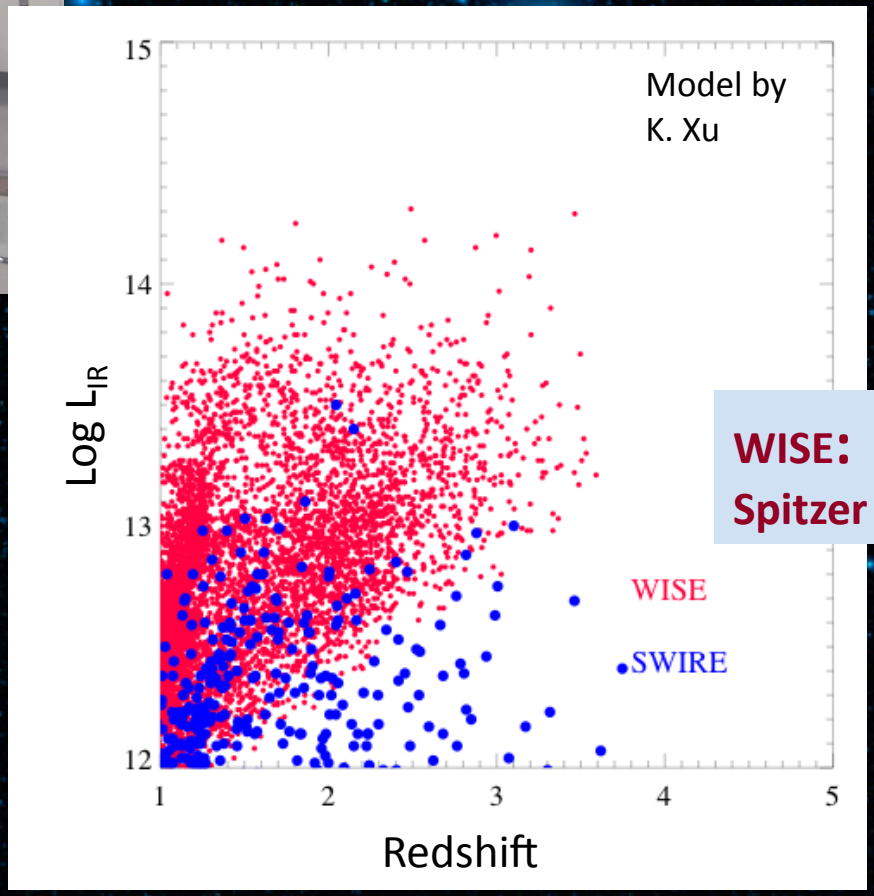




NRAO The NRAO VLA Sky Survey

WISE Excels at Discovering Obscured QSOs

WISE finds the most luminous ULIRGs and obscured QSOs to z>3



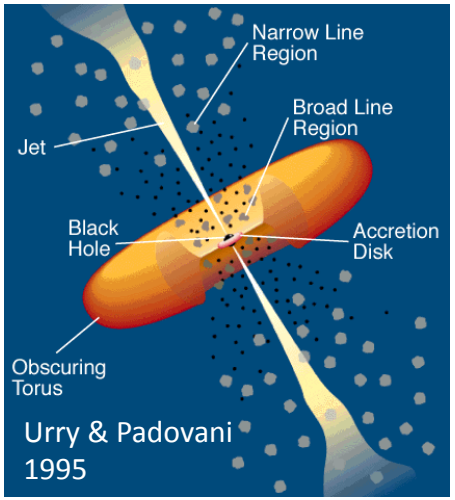
NGC 253

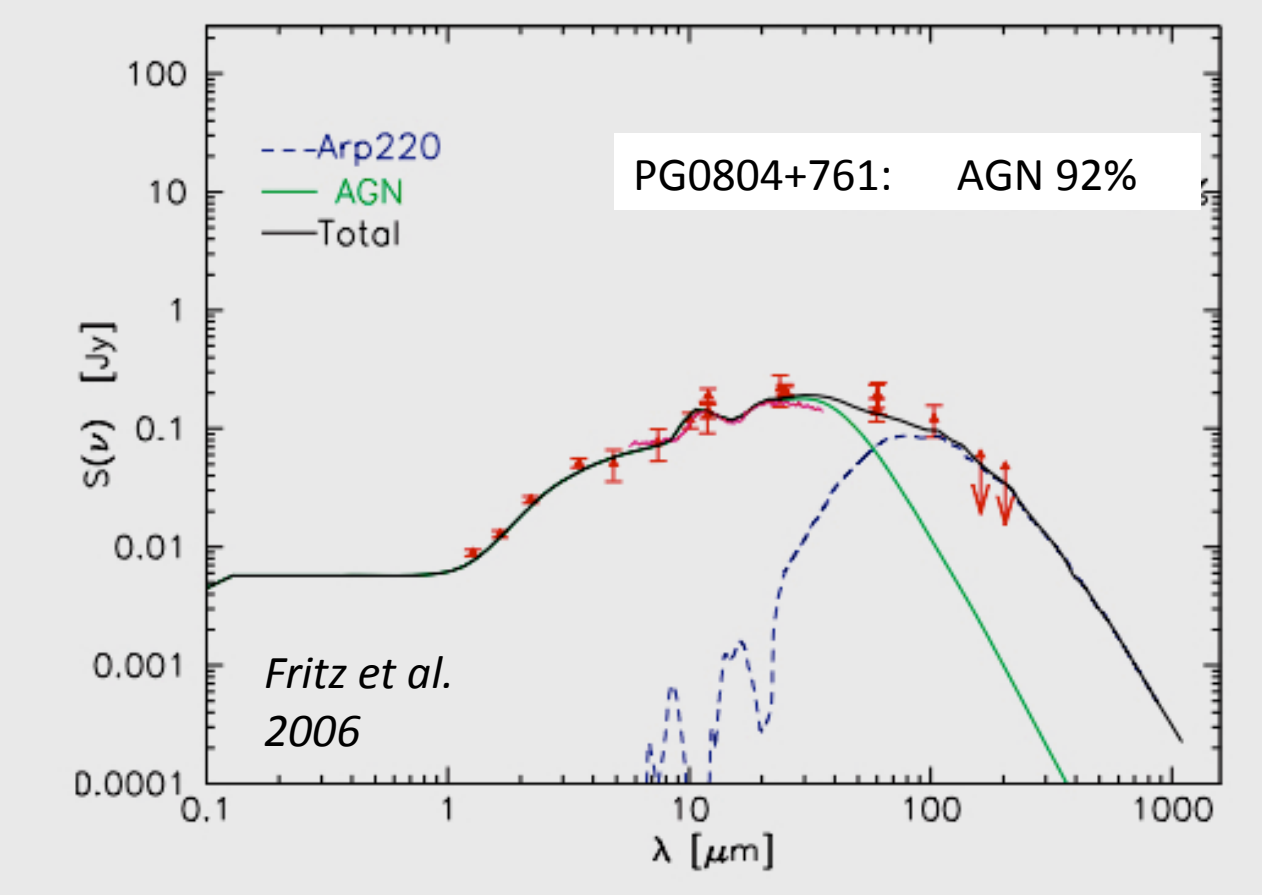
Circinus

WISE: *all sky*

Spitzer surveys: ~0.2% of the sky

Warm dust from AGN-heated dust peaks in mid-IR

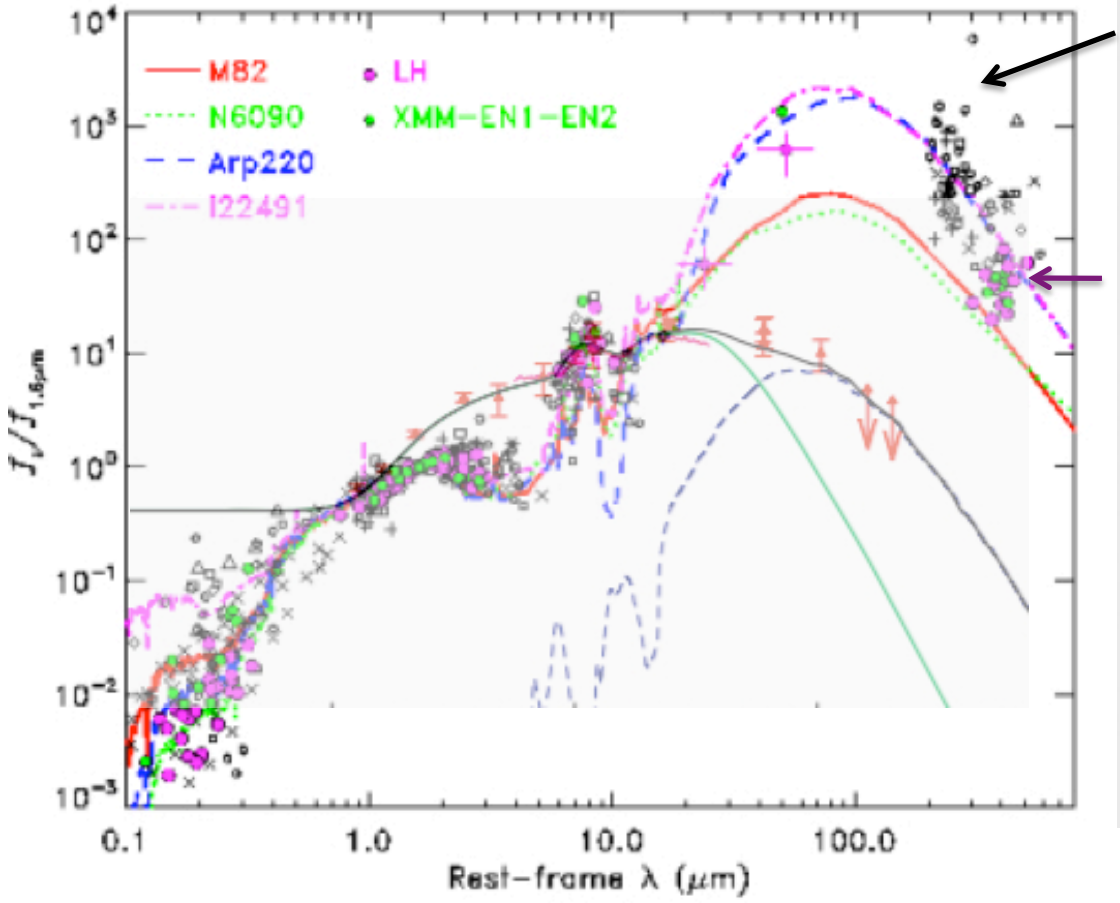




Radio jet can interact mechanically with ISM

- halt infall
- halt starbursting
- eject matter

In contrast: starburst-dominated z~2 ULIRGs



SMGs, 850μm

Spitzer starburst-dominated ULIRGs Lonsdale et al. (2009), Mambo 1.2mm

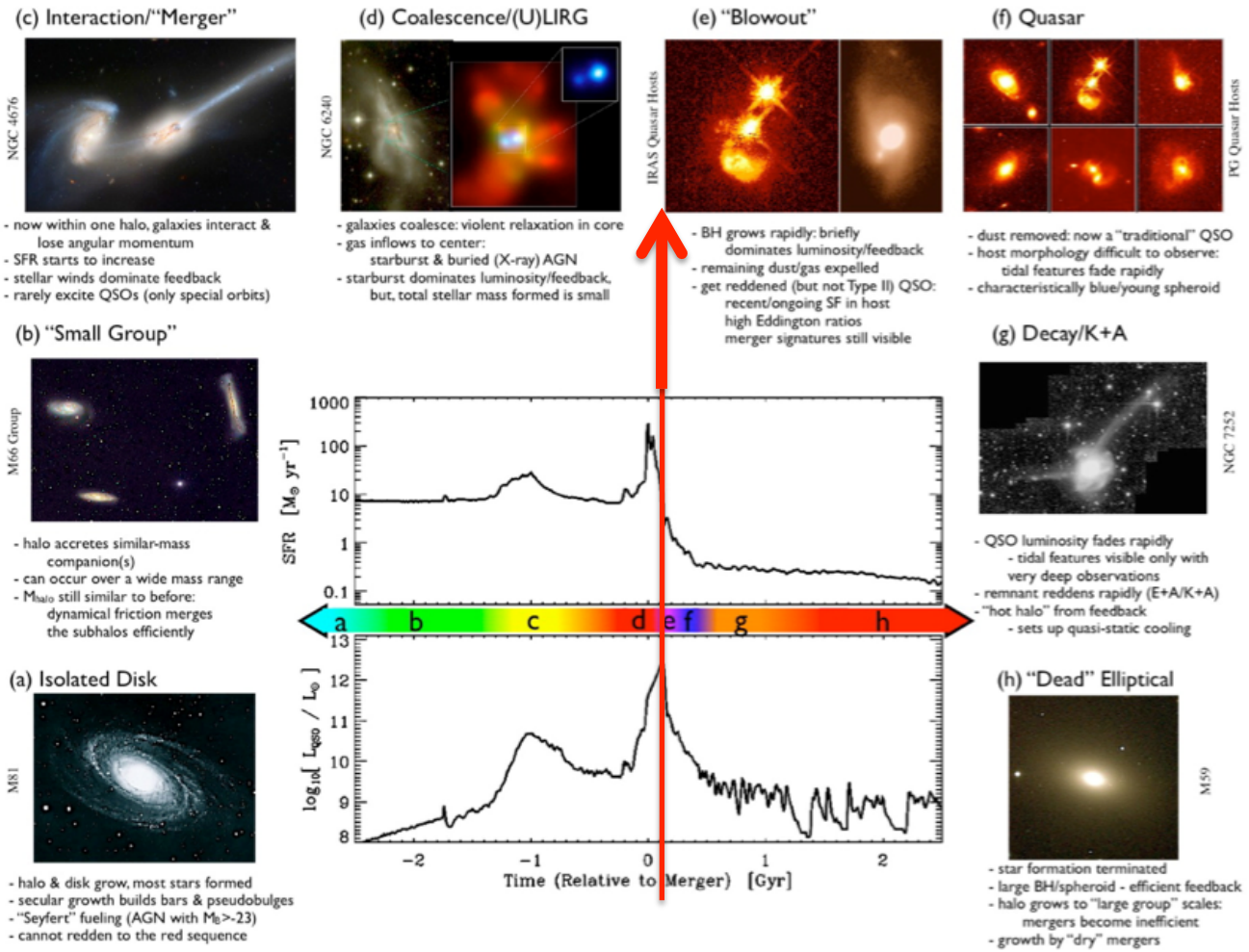
Much larger submm/ 24um ratios than MIR-selected AGN

Merger Sequence, Hopkins et al. (2008)

d: Peak SFR.
FIR dominated

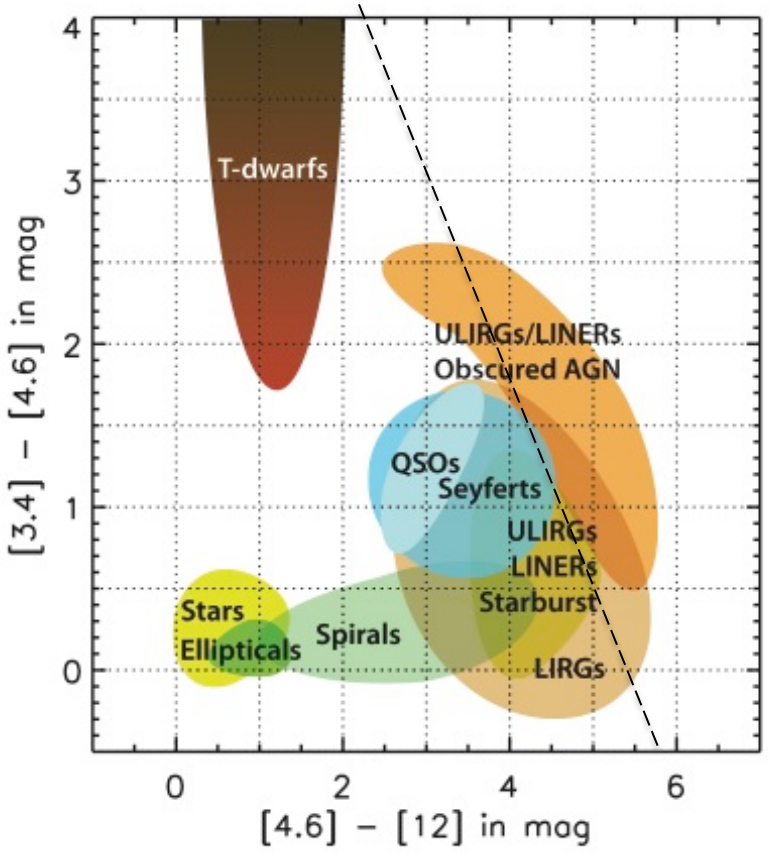
d-e: Peak QSO.
Mid-IR dominated

e: Blowout phase / AGN feedback
Radio jet

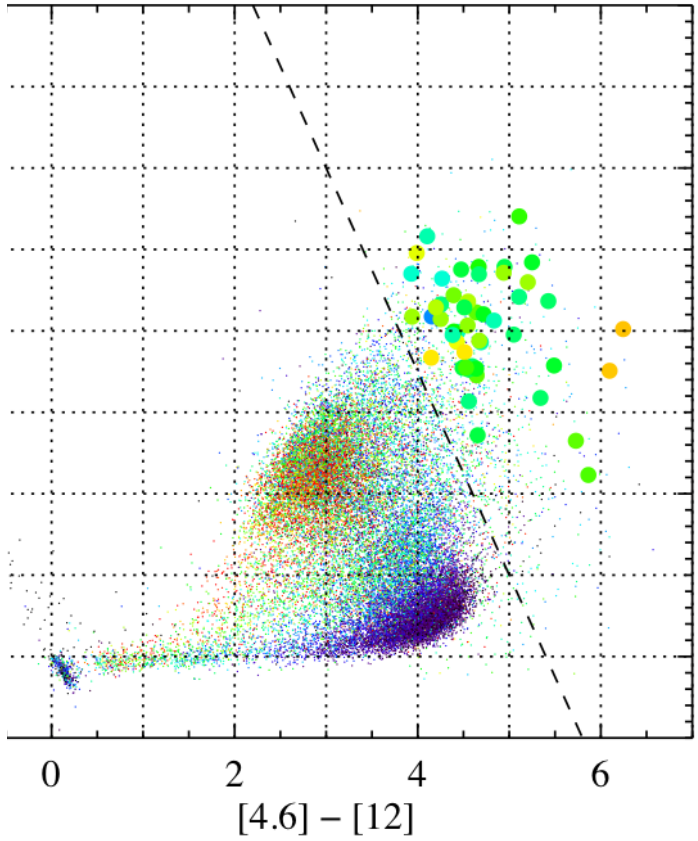


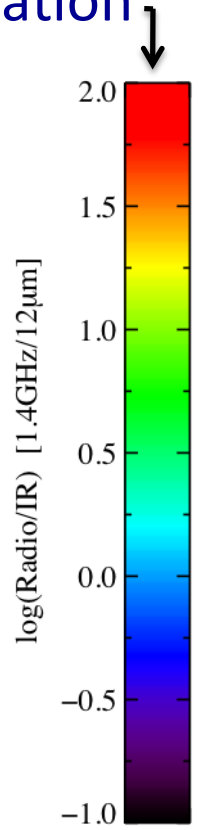
ALMA Sample
49 extremely red WISE sources

Moderately radio-loud from Ibar et al (2008) 1.4GHz/24μm relation



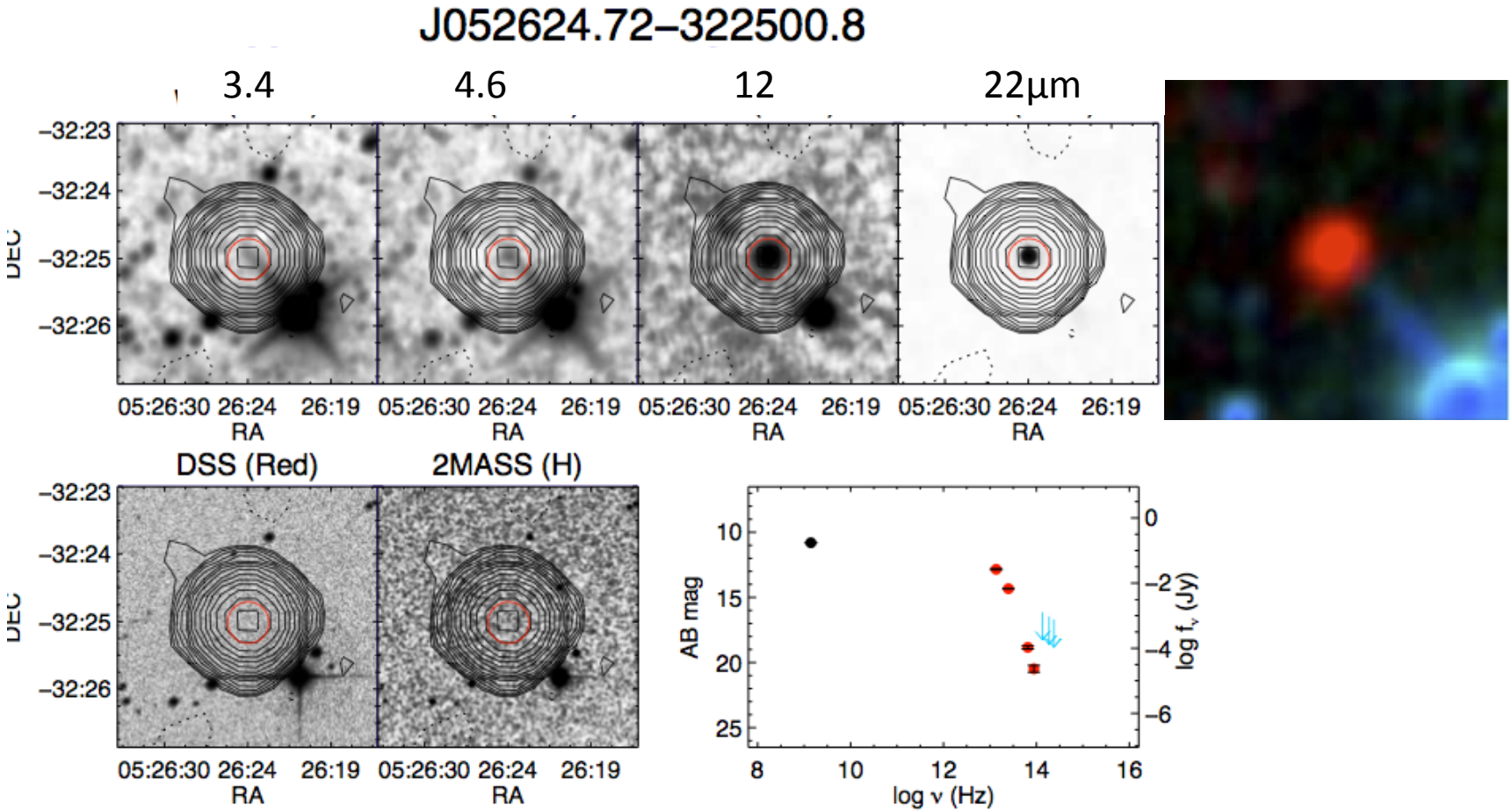
Wright et al. (2011); Jarrett et al. (2011)





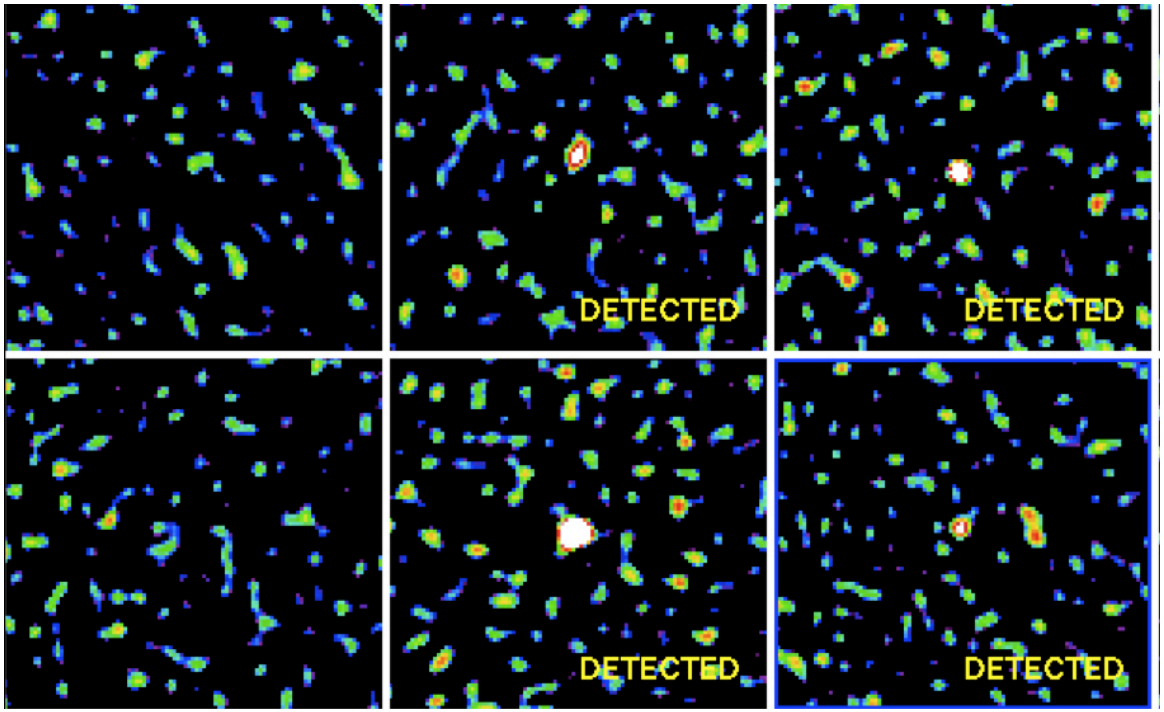
Lonsdale et al. (2012)

WISE images and NVSS contours.



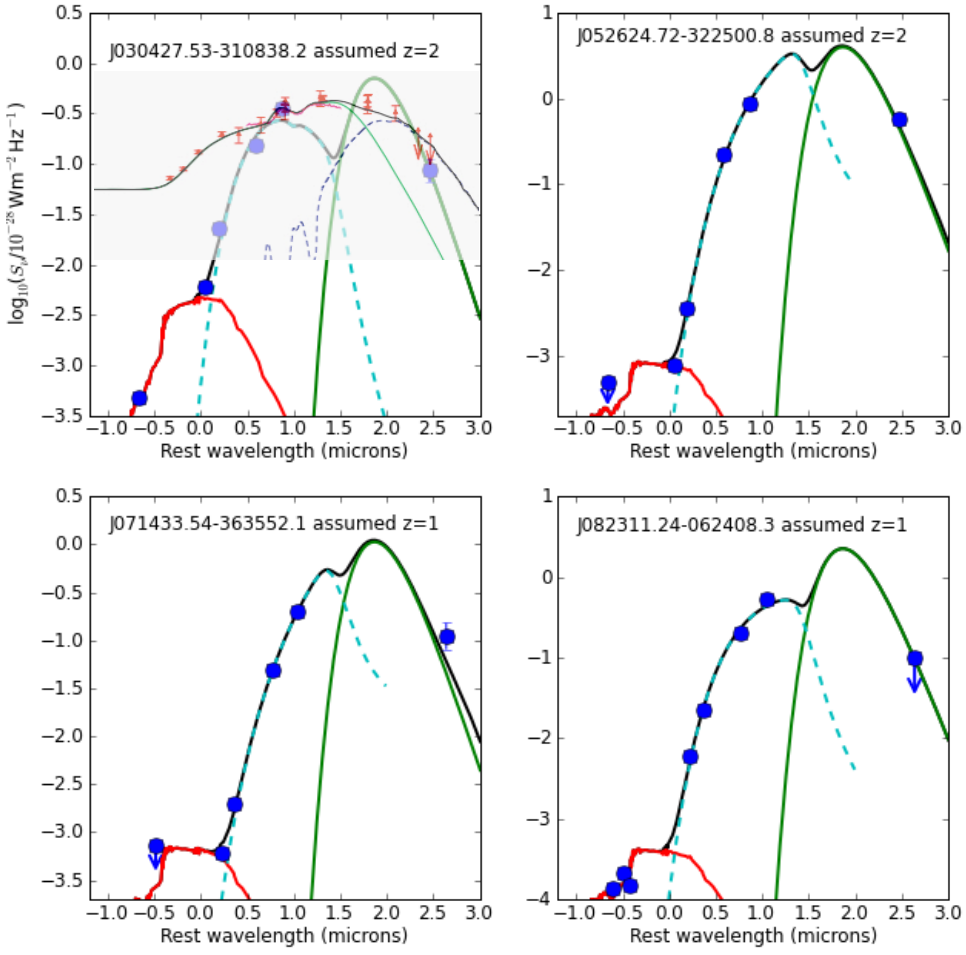
First ALMA Results

- > 50% detections at 870μm (Band 7).
  - 0.5 mJy rms, 90 secs, 16 antennas, Cycle 0 compact array
  - 26 more to be observed



ALMA Results

- All fall well below expected color for starburst-dominated phase
- Likely to be in post-starburst, radio feedback phase
- Upcoming EVLA study of 150 sources will determine radio shape, size.
- Spectroscopy at SOAR late January



Modeling by M Lacy

Stellar population
Modified BB
AGN torus