Jets in Radio Loud Hot DOGs

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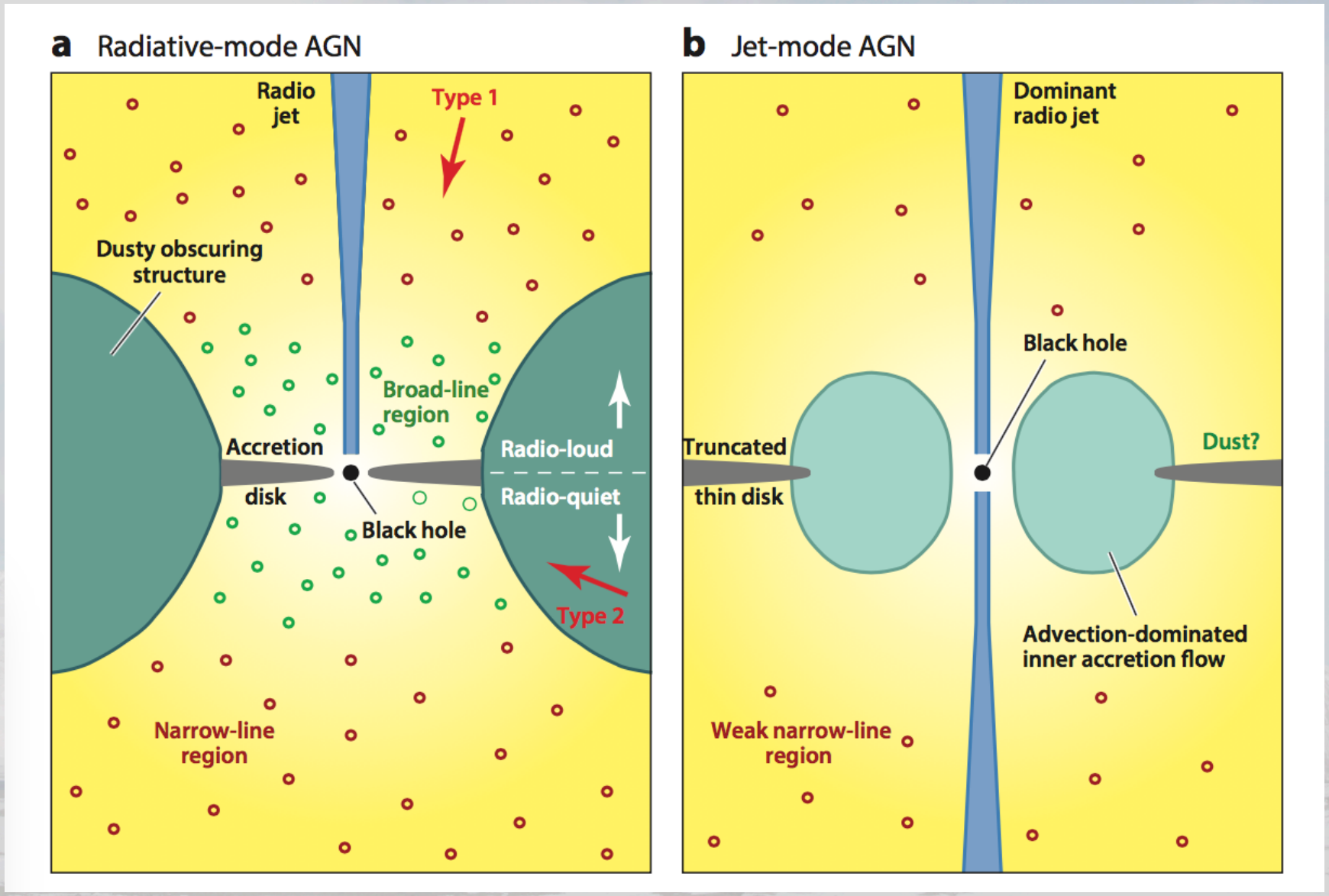
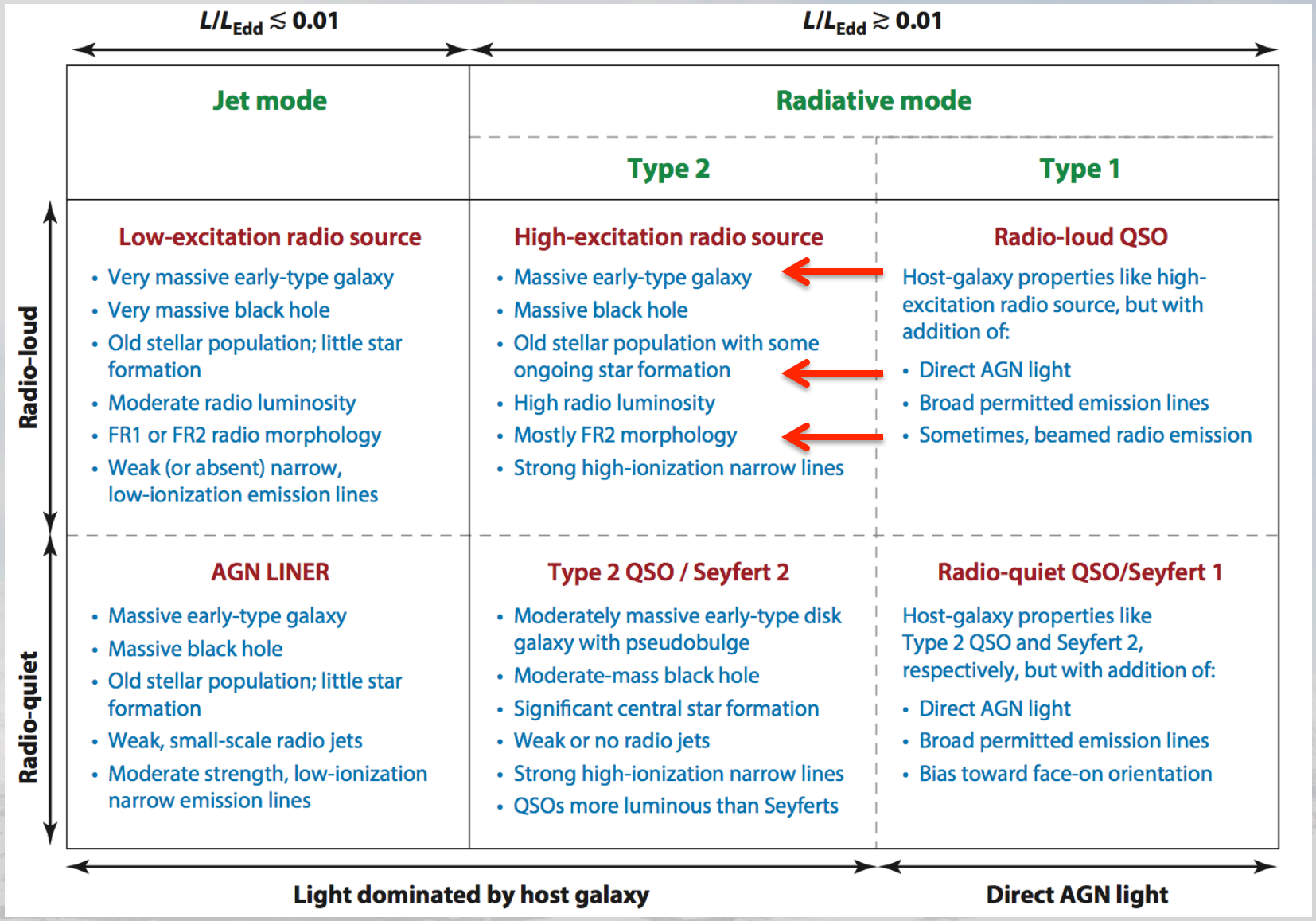
Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

Heckman and Best 2014



Heckman and Best 2014

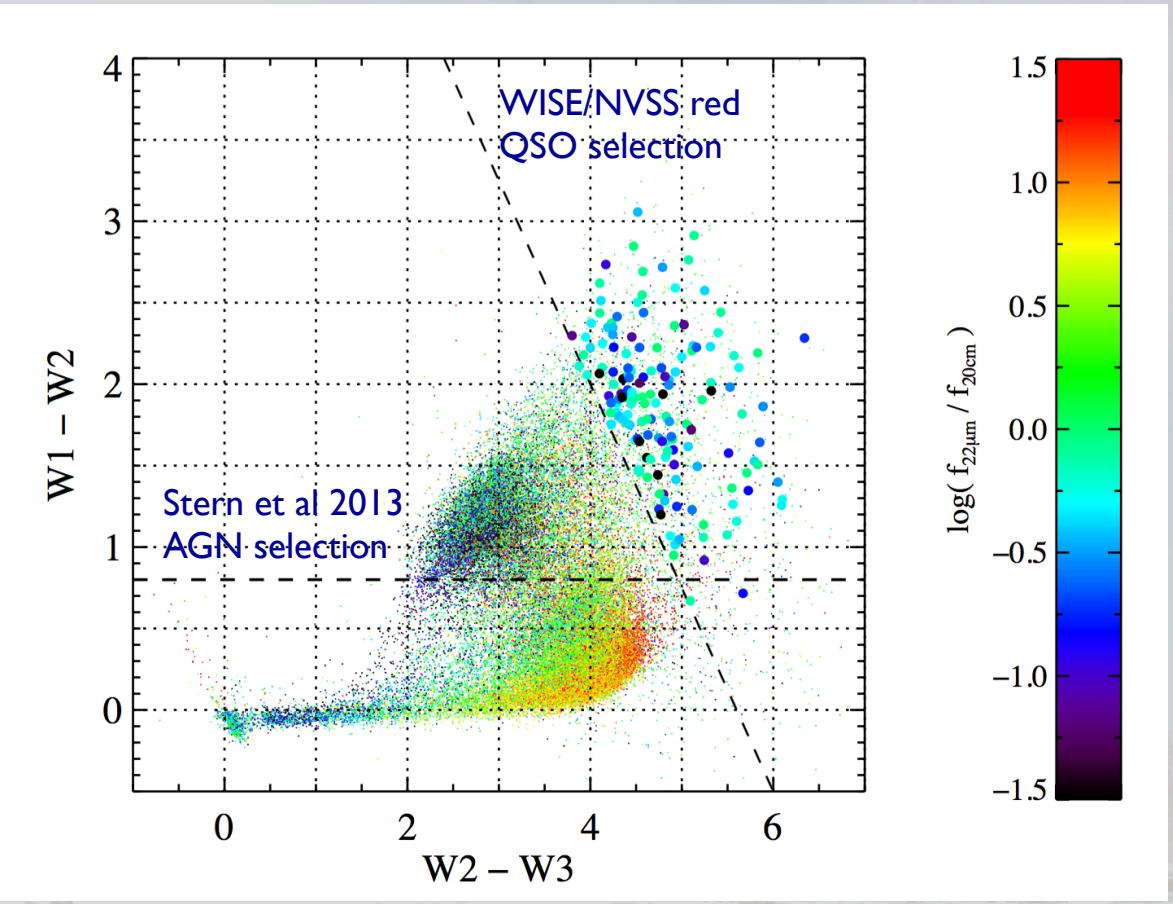


Jets in Hyper-Luminous Obscured Quasars

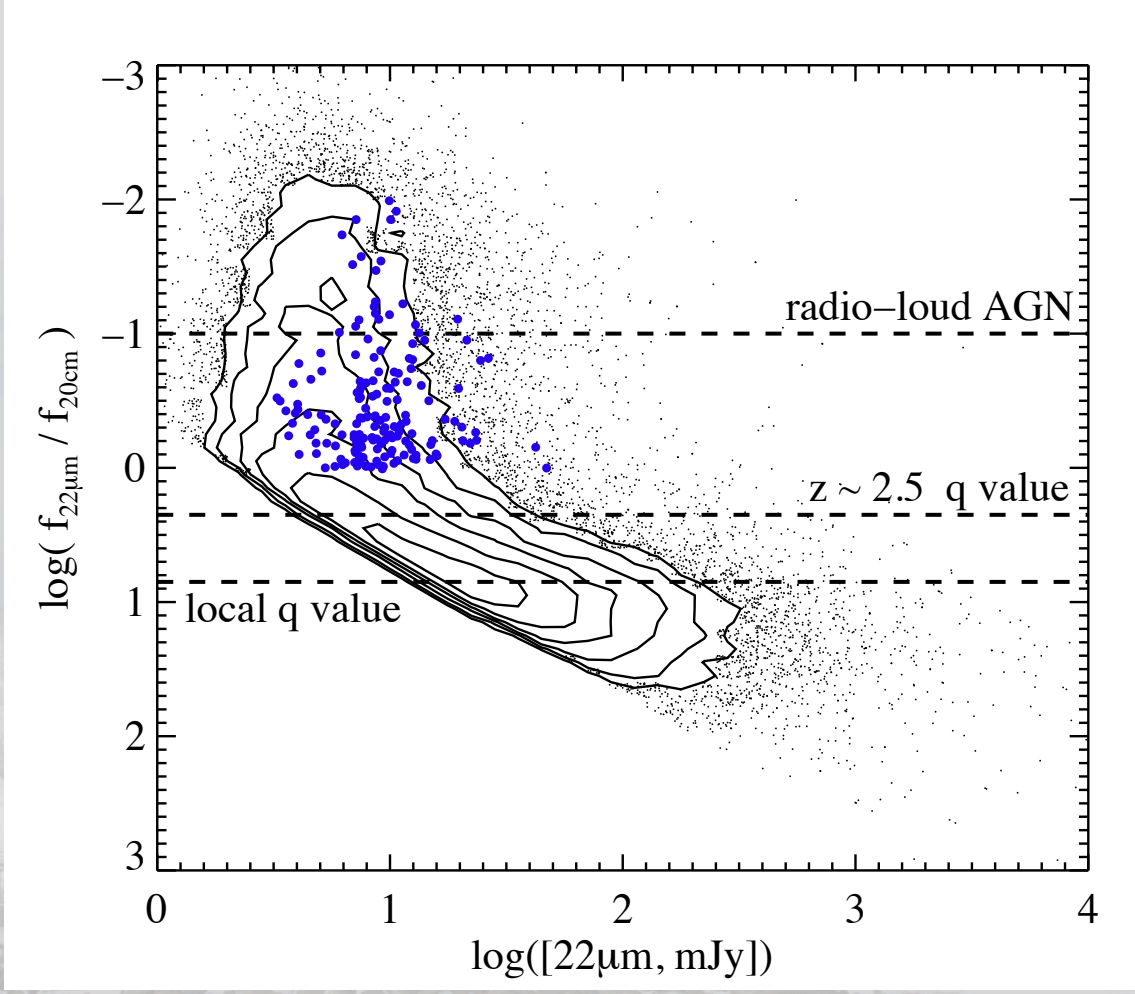
- Cross-match of WISE very red selection with compact NVSS radio sources
- Image with JVLA, VLBA, MERLIN

Lonsdale et al. 2015, ApJ in press

Kimball & Lonsdale, in prep.
RL AGN in WISE color space



20cm selection: >5mJy; radio-intermediate or RL



The WISE Red Samples compared to Spitzer DOGs

Eisenhardt et al. 2012

Wu et al. 2103

Bridge et al. 2013

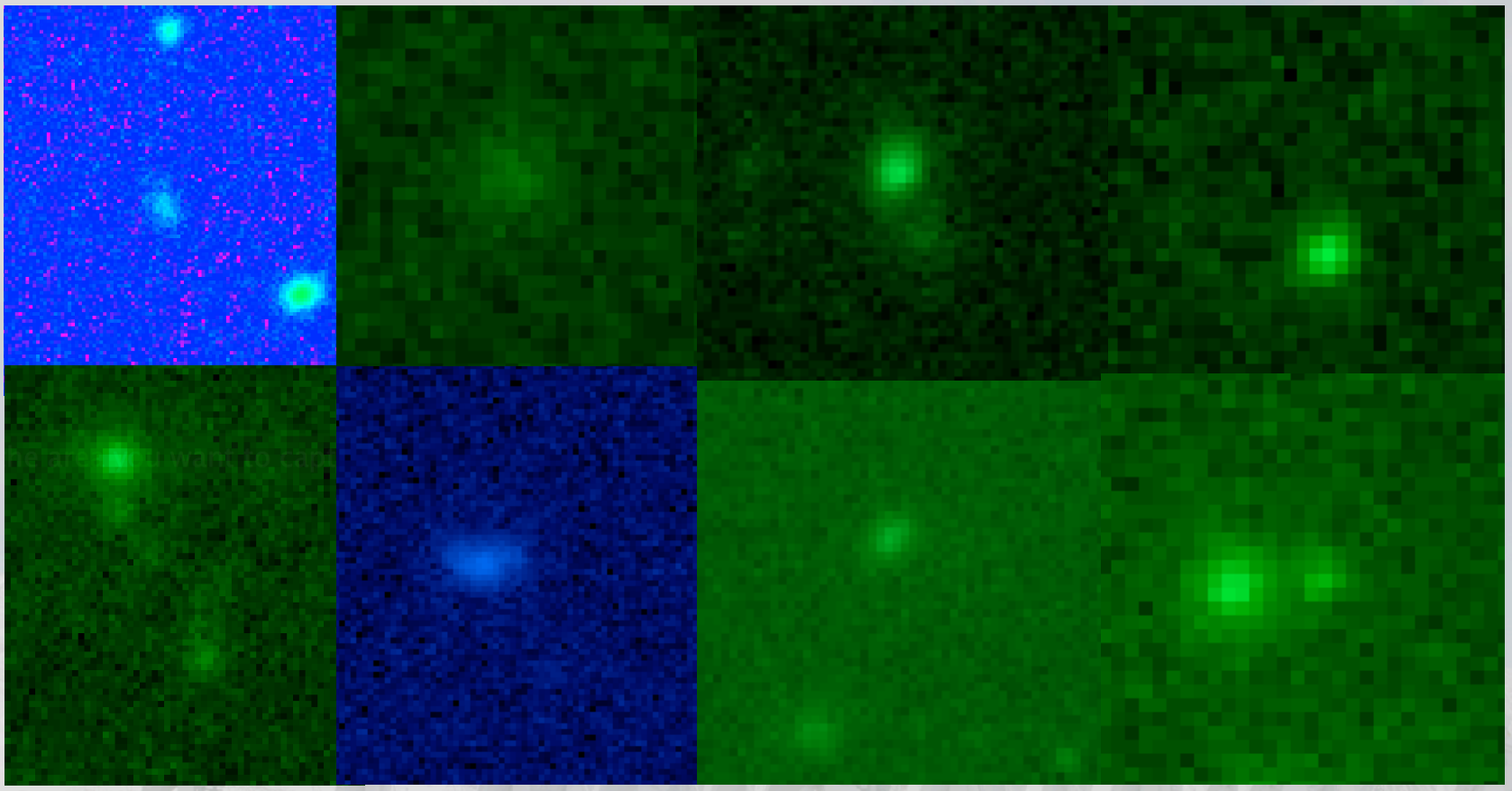
Very similar WISE selection but RADIO-BLIND

WISE:

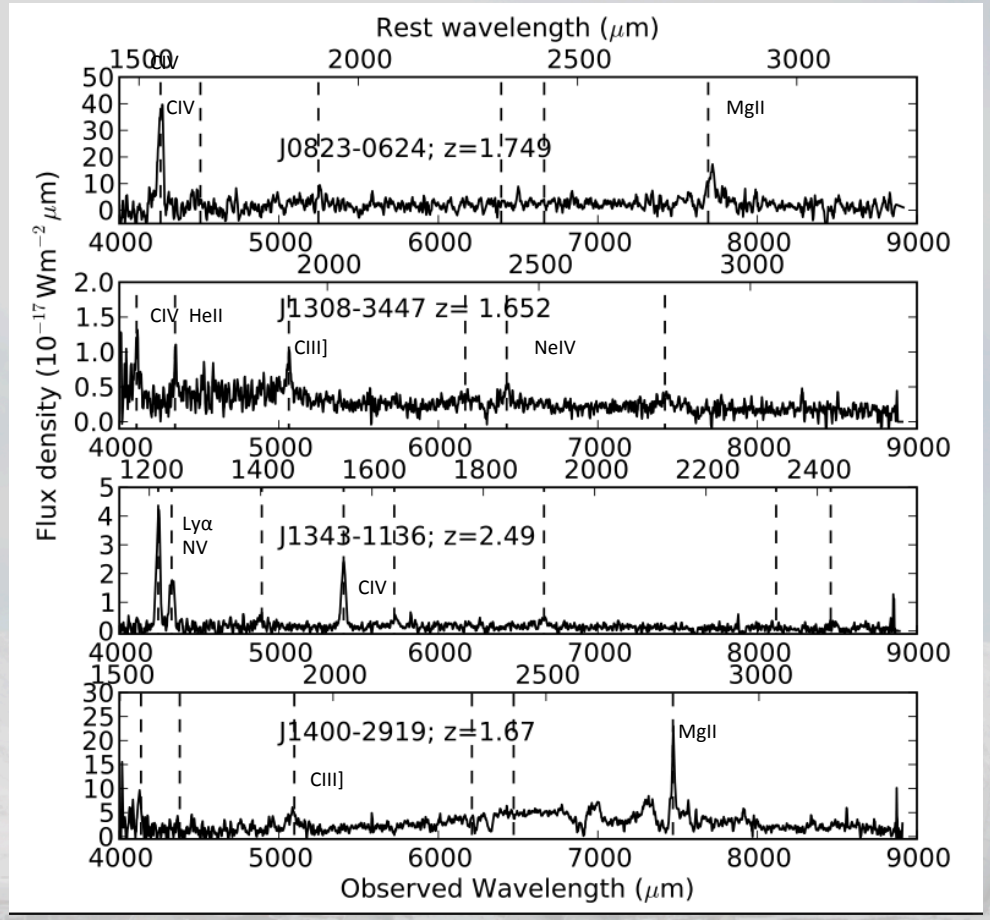
- Has all-sky coverage with enough depth to see quasars to z > 4
- Finds brighter, redder & rarer samples than Spitzer

J and Ks Imaging at VLT/ISAAC

Andrew Blain et al. in prep

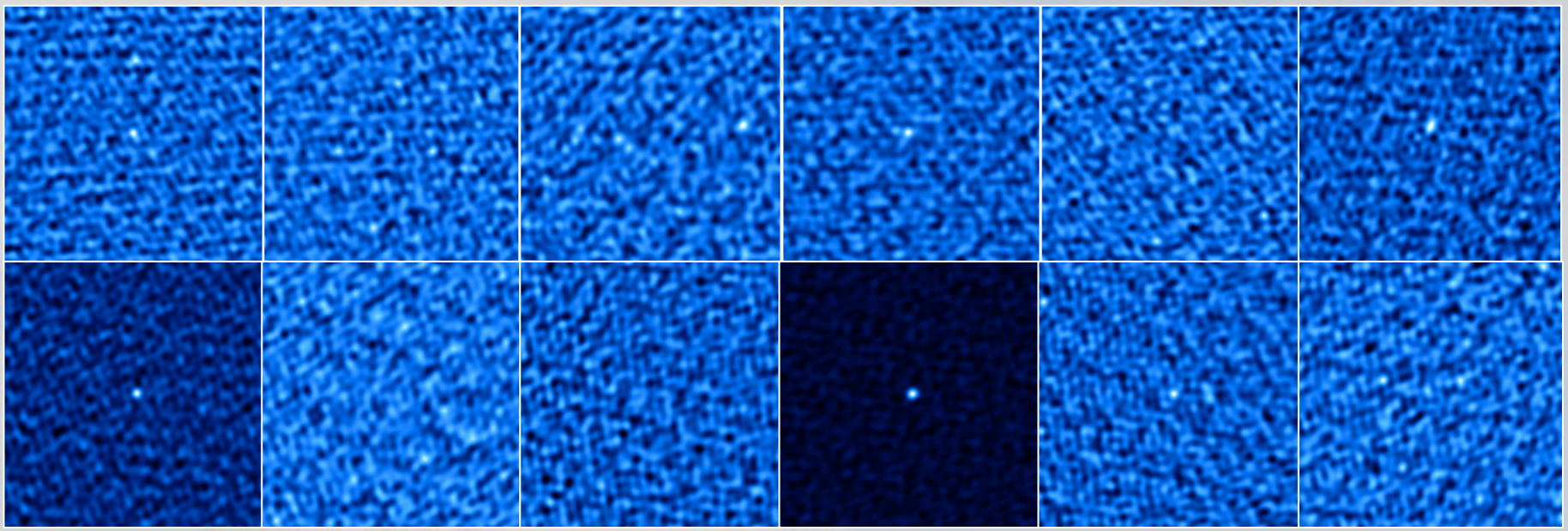


Optical-NIR Spectroscopy, ~60 sources



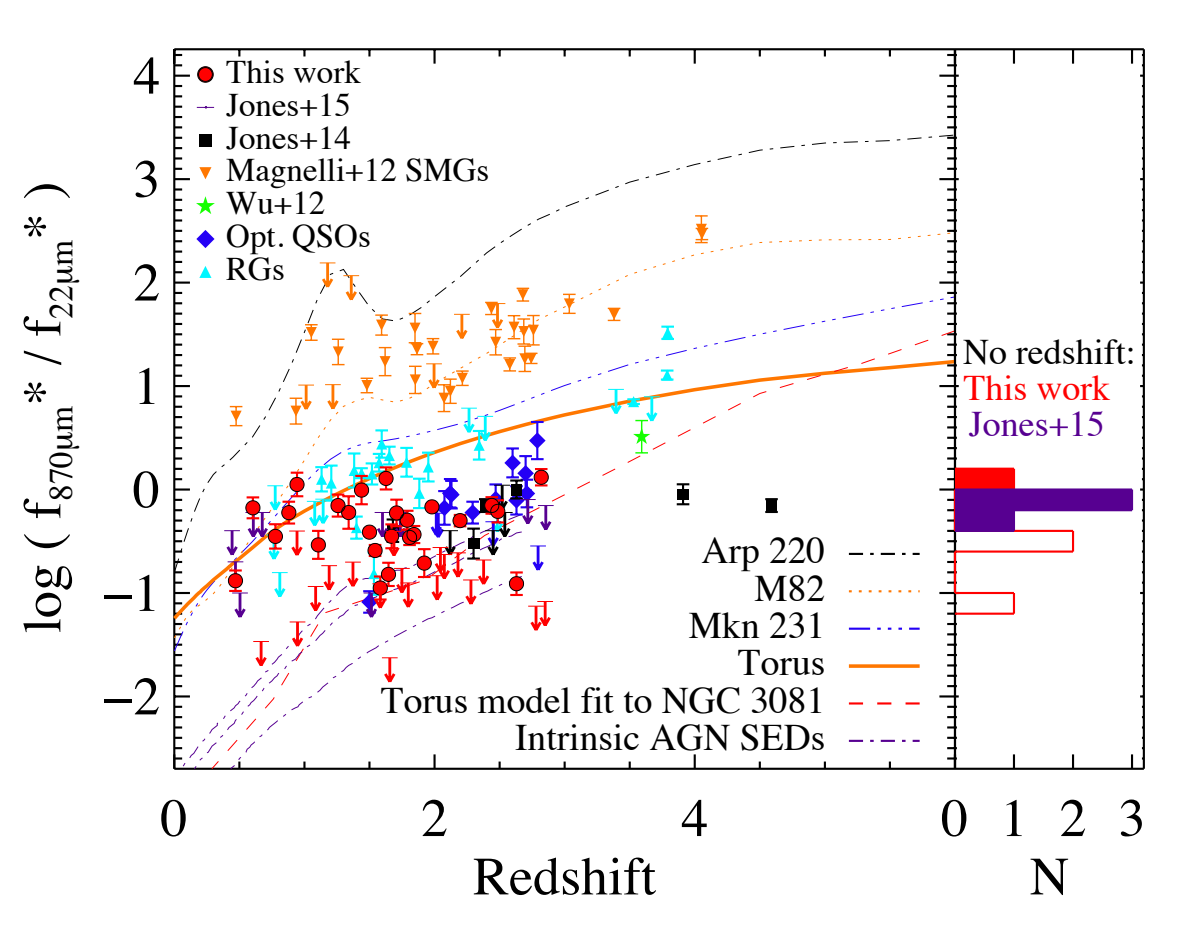
- SOAR 4m, CTIO, Palomar 200 inch, VLT/XShooter: high excitation narrow lines
- Magellan 8m, FIRE NIR: [OIII]: some evidence for shocks & outflows; (Kim et al 2103)
- ULIRG - HyLIRG AGN luminosities

49 observed with Cycle 0 ALMA at 345 GHz to constrain cool dust



- 15-23 antennas
- 90s on source
- 0.3-0.5 mJy rms
- 55% detections

Low 870 / 22µm flux ratios: MIR-dominated



The ALMA sample lies well below starburst-dominated SMGs and most templates

Templates from Polletta et al. (2008)

Torus model: Honig et al. (2006)

Normalized (4.6μm) Rest-frame SEDs

Our Radio-selected sample and the radio-blind WISE samples are similar in MIR SED shape

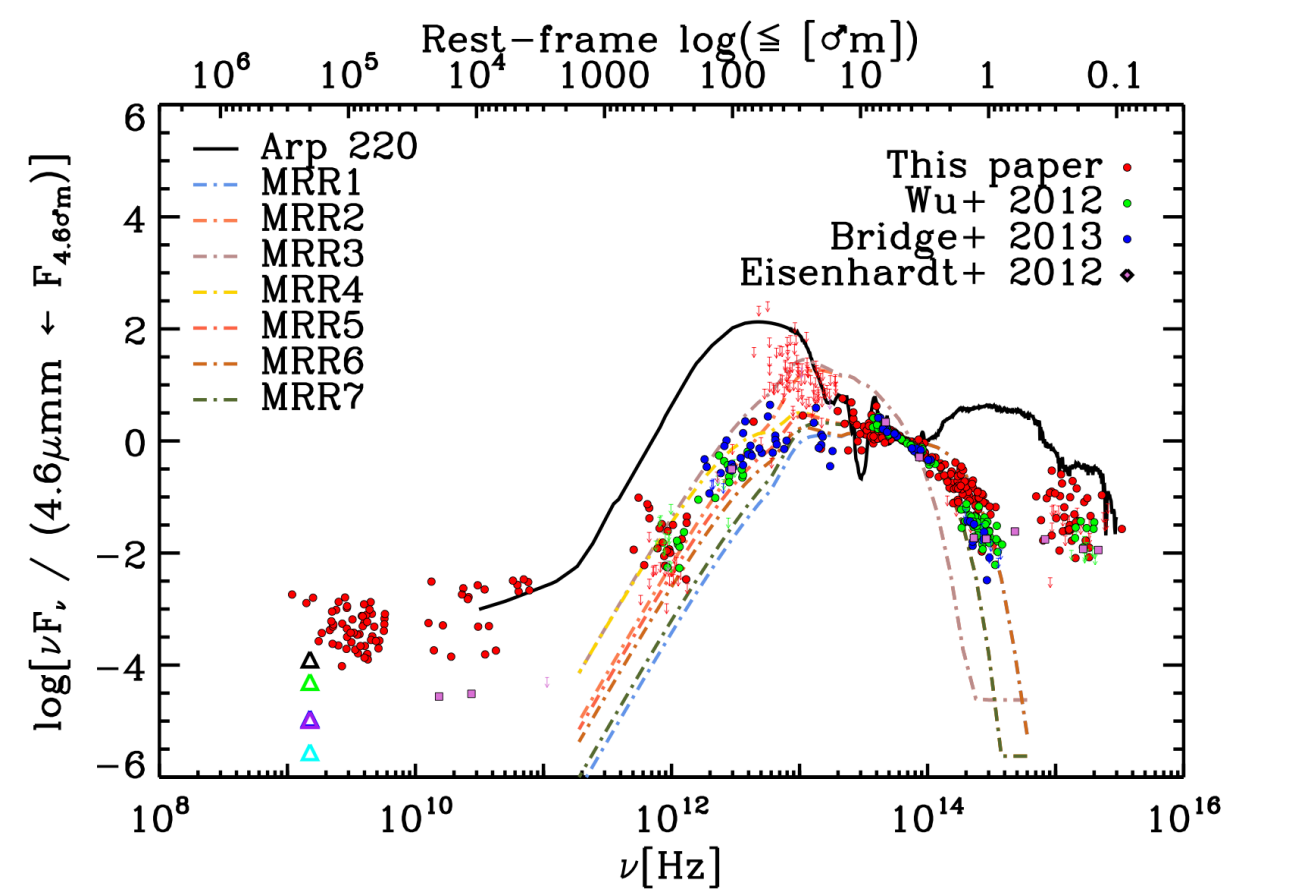
Herschel & ALMA data: SED shape is AGN-dominated

Much redder in MIR than templates

As expected, the Spitzer-selected DOGs are not as red

Torus Models

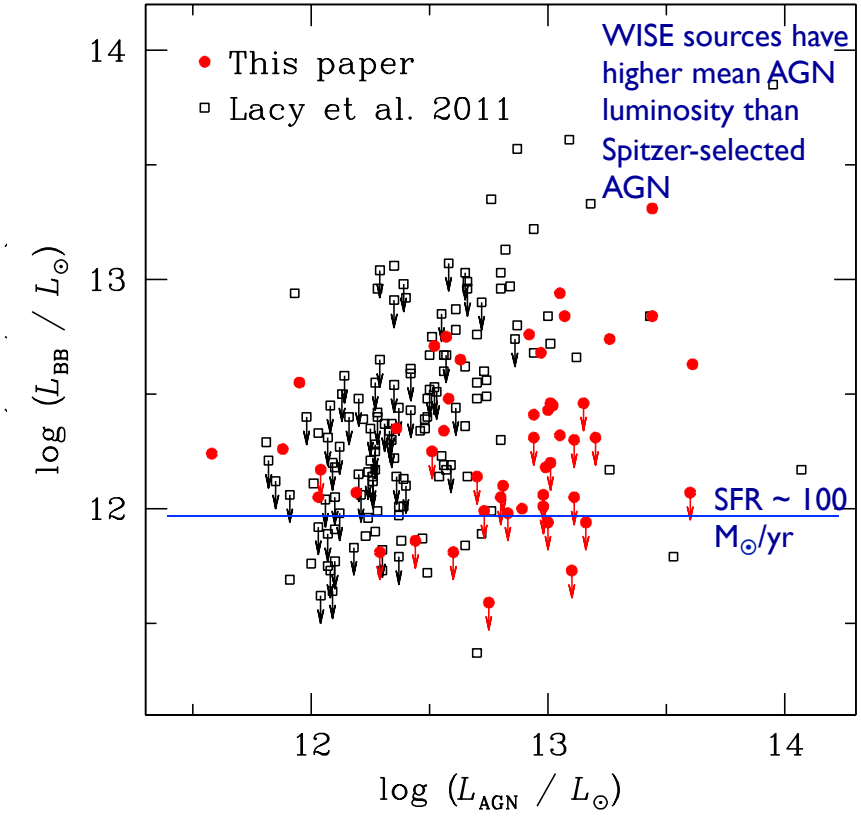
Rowan-Robinson 2000

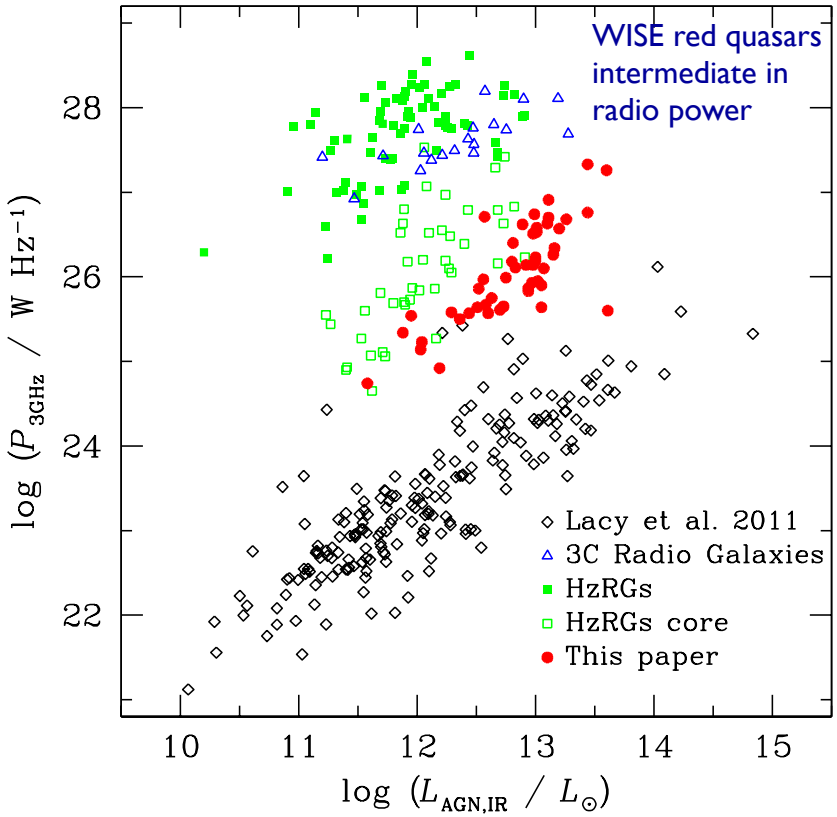


- Av = 50 mag.
- $n(r) \sim r^{-1}$
- T_{inner} =500-1600K
- T_{outer}=50-160K

3C RGs, Hiz RGs and Spitzer-selected red quasars

Comparable radio power to HzRG cores but with enhanced L_{AGN-IR}





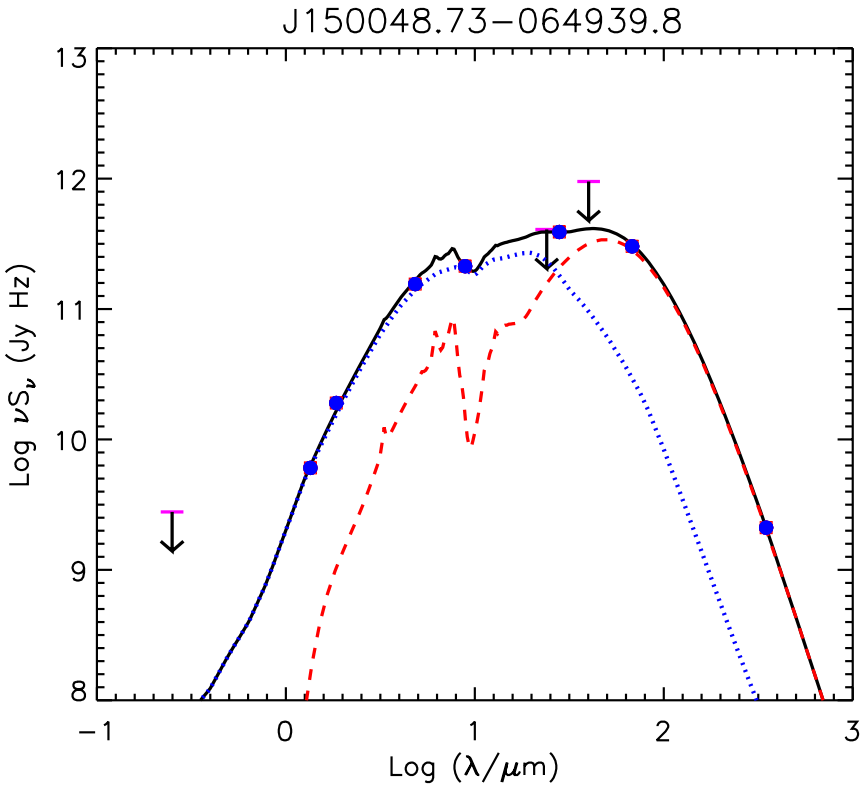
De Brueck et al. 2010 Cleary et al. 2007

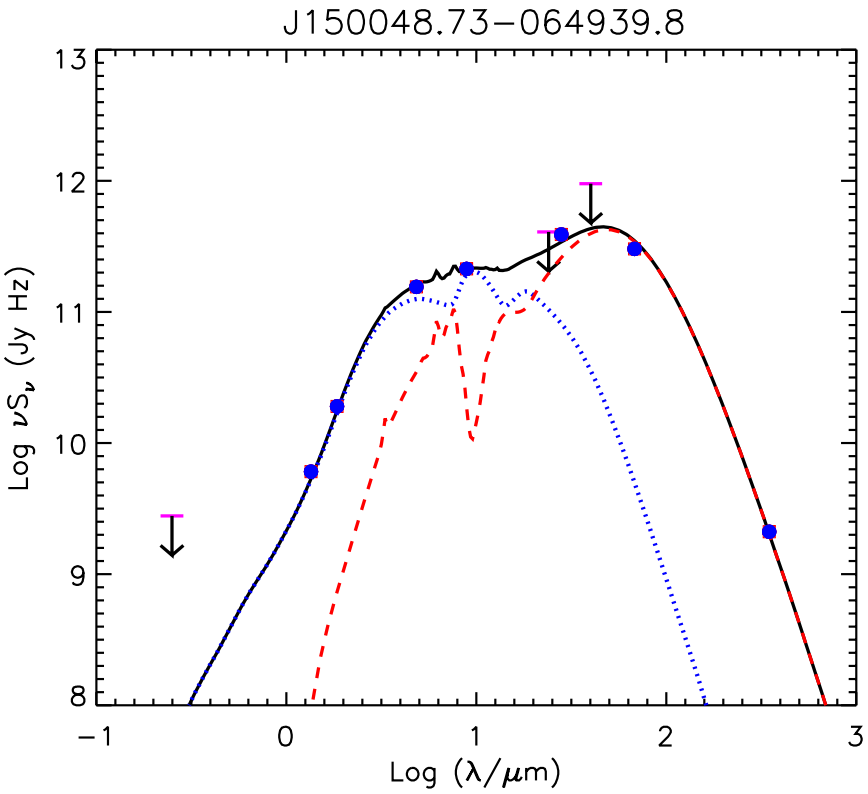
Torus + starburst models

Efstathiou et al. 1995+ tapered disk.

Stalevski et al. 2012 clumpy torus

~3 x 10^{13} $L_{\odot}$; 15 Myr compact starburst

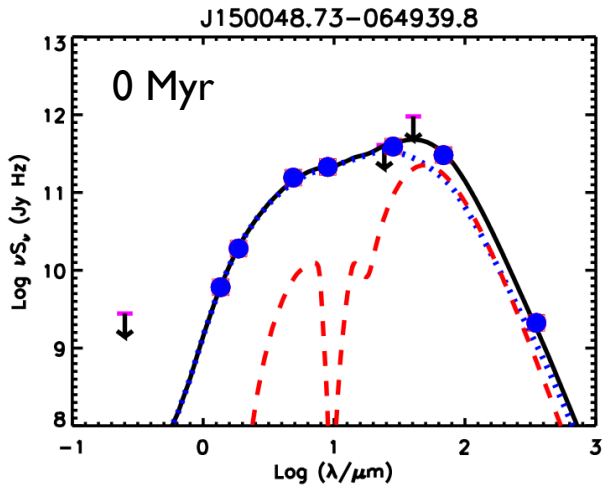


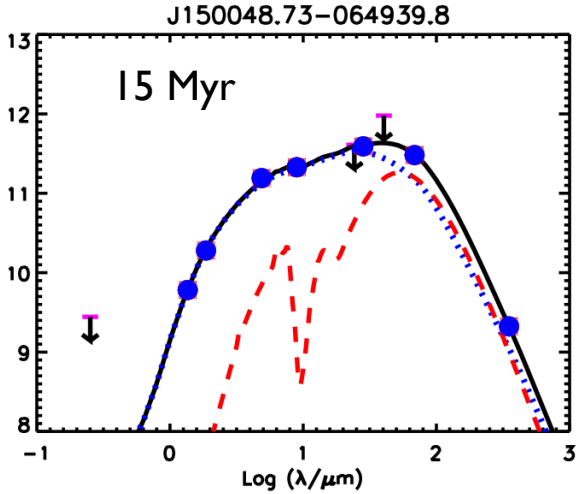


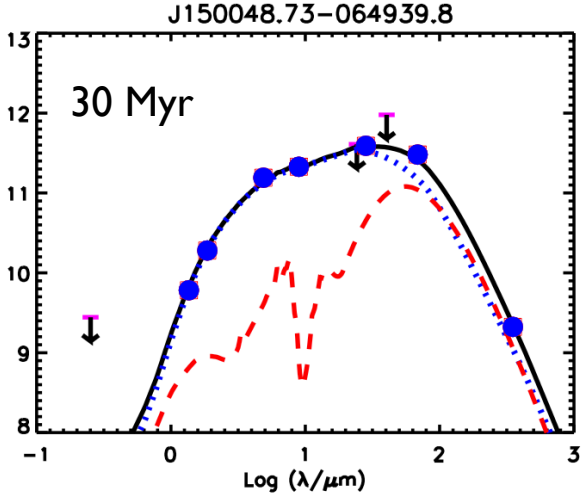
r_out/r_in = 160 Tau_torus 500

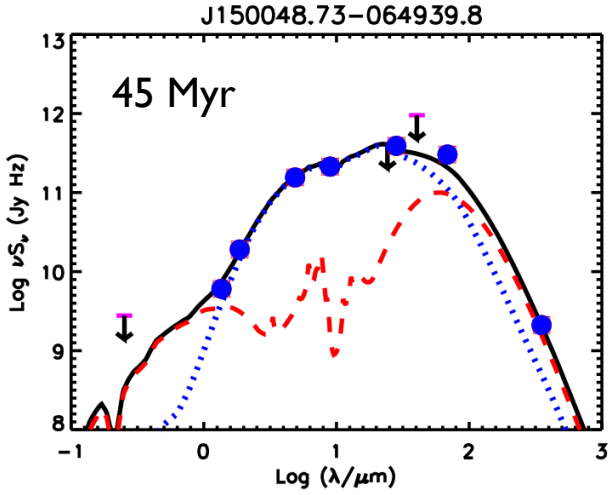
Torus + starburst models A. Efstatiou et al. in prep.

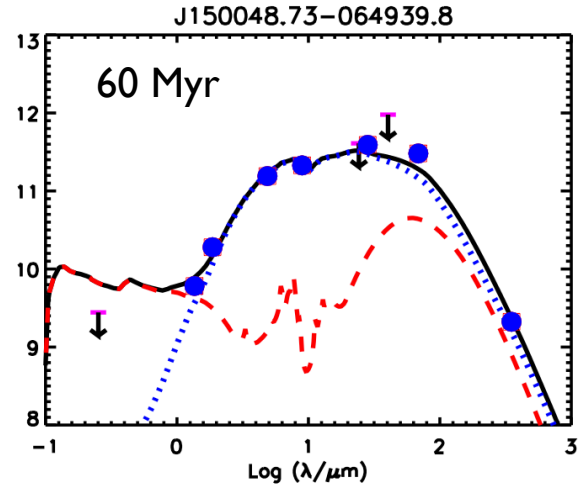
Torus can power all emission if large enough









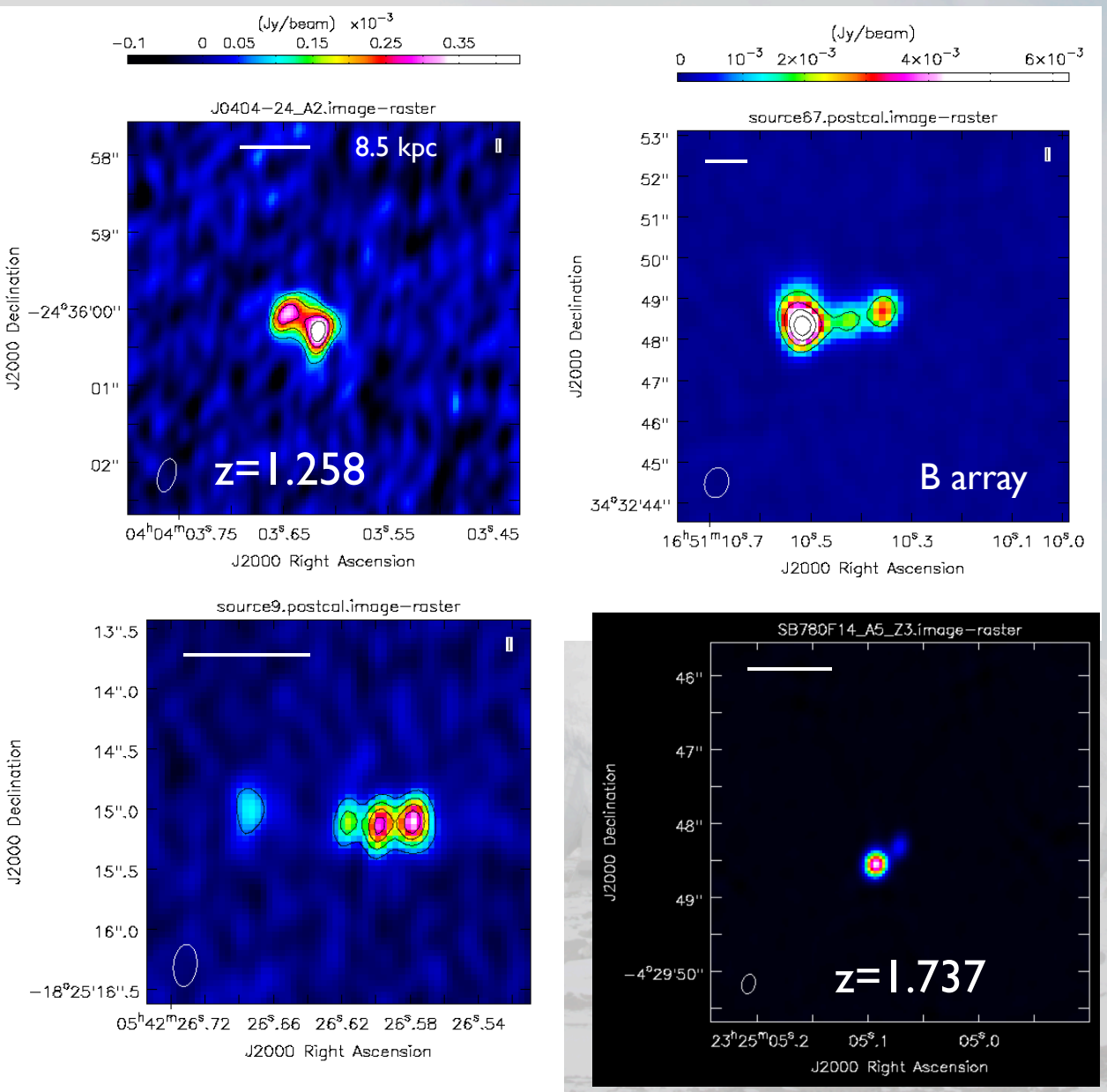


Fixed starburst age, varying torus parameters

- r^{-1} profile
- r_out/r_in < 1280
- Tau_sb = 100
- Tau_torus 750
- Opening angle 45 deg.

- Requires very large size to explain submm

JVLA X-band A and B-array Imaging, 156 QSOs

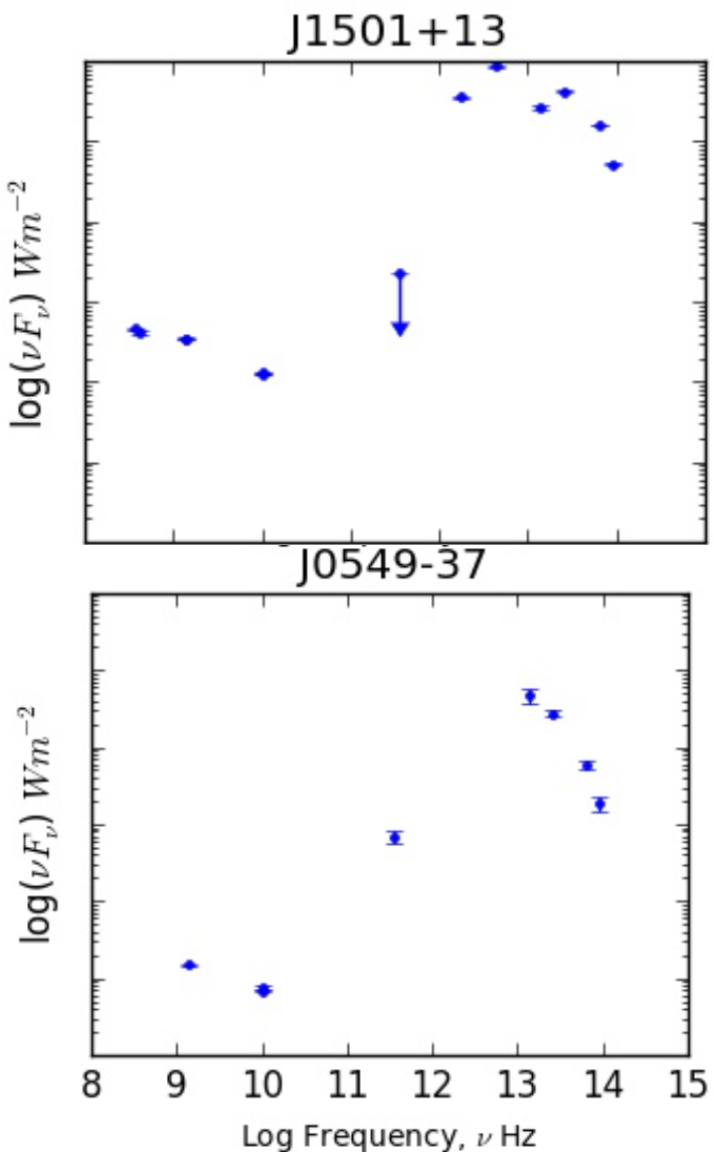


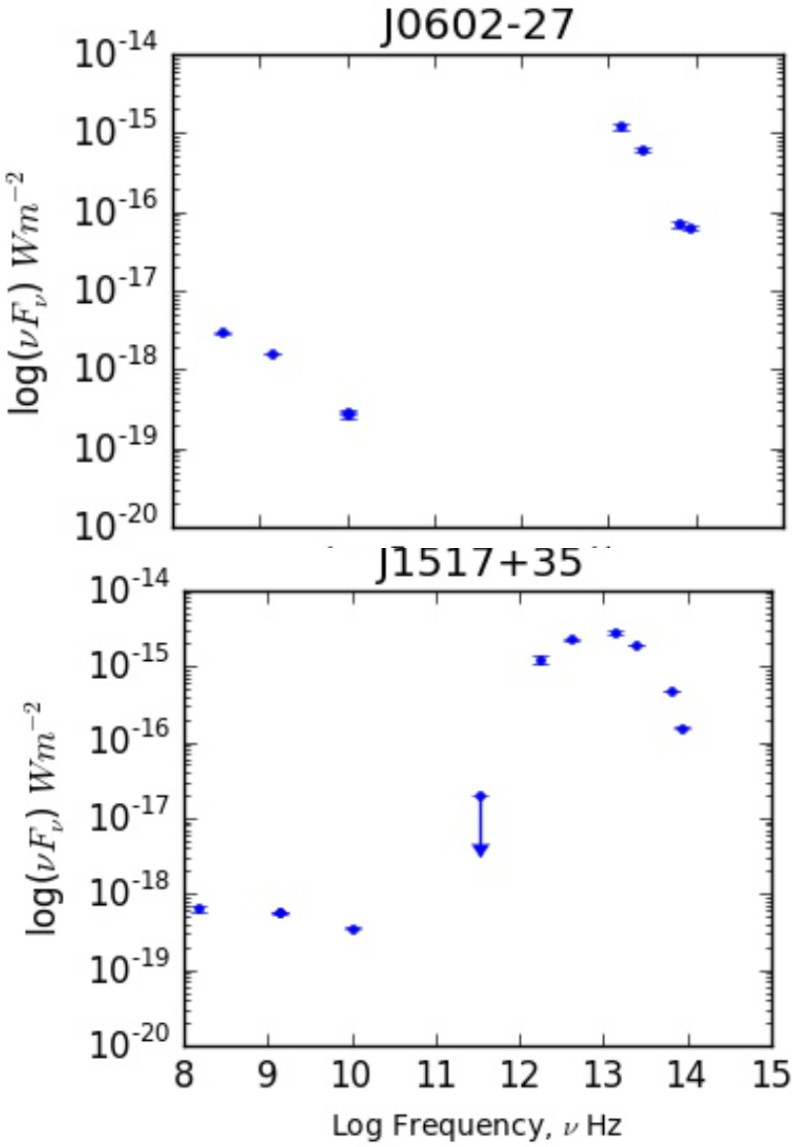
X-band (8-12 GHz) A-array

Majority unresolved on <1 kpc scales

Rimini, CSSGPS

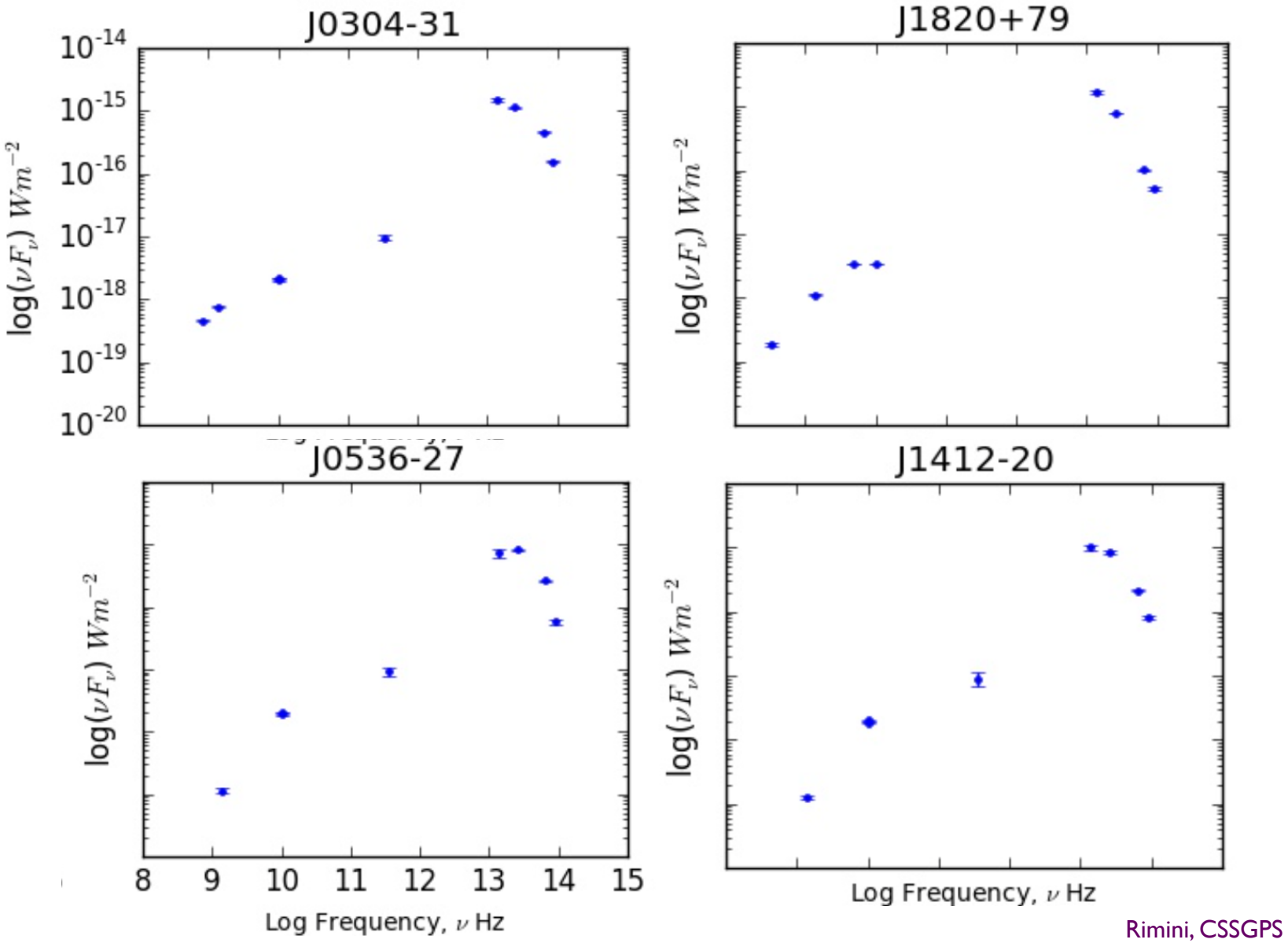
Steep radio SEDs





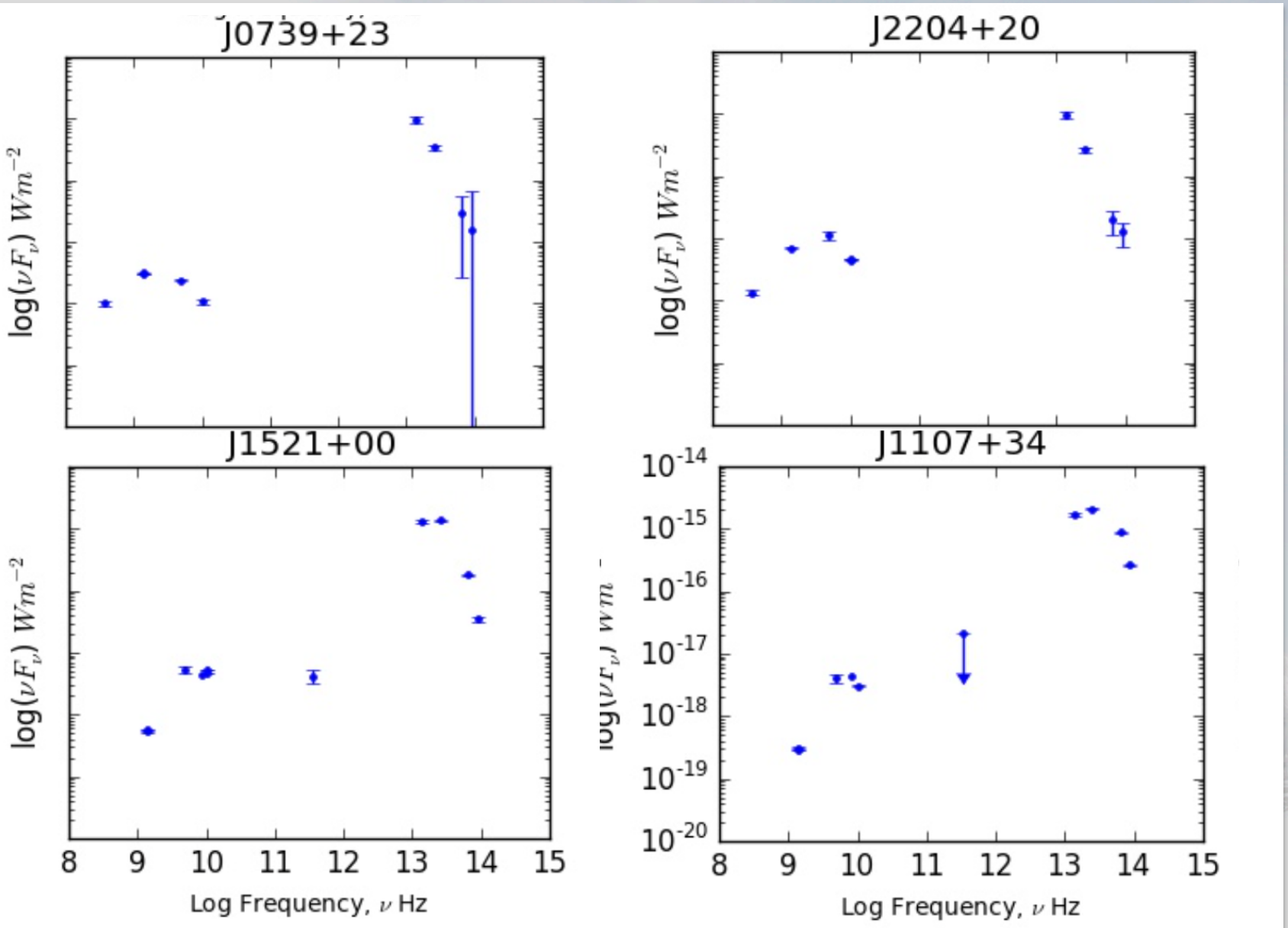
Rimini, CSSGPS

Flat and inverted radio SEDs



Rimini, CSSGPS

GPS / HFP SEDs ?


J0739+23
J2204+20
J1521+00
J1107+34
$\log(\nu F_\nu)\ Wm^{-2}$
Log Frequency, ν Hz
8
9
10
11
12
13
14
15
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}

VLBA Results

VLBA snapshot imaging of 90 quasars at 5GHz

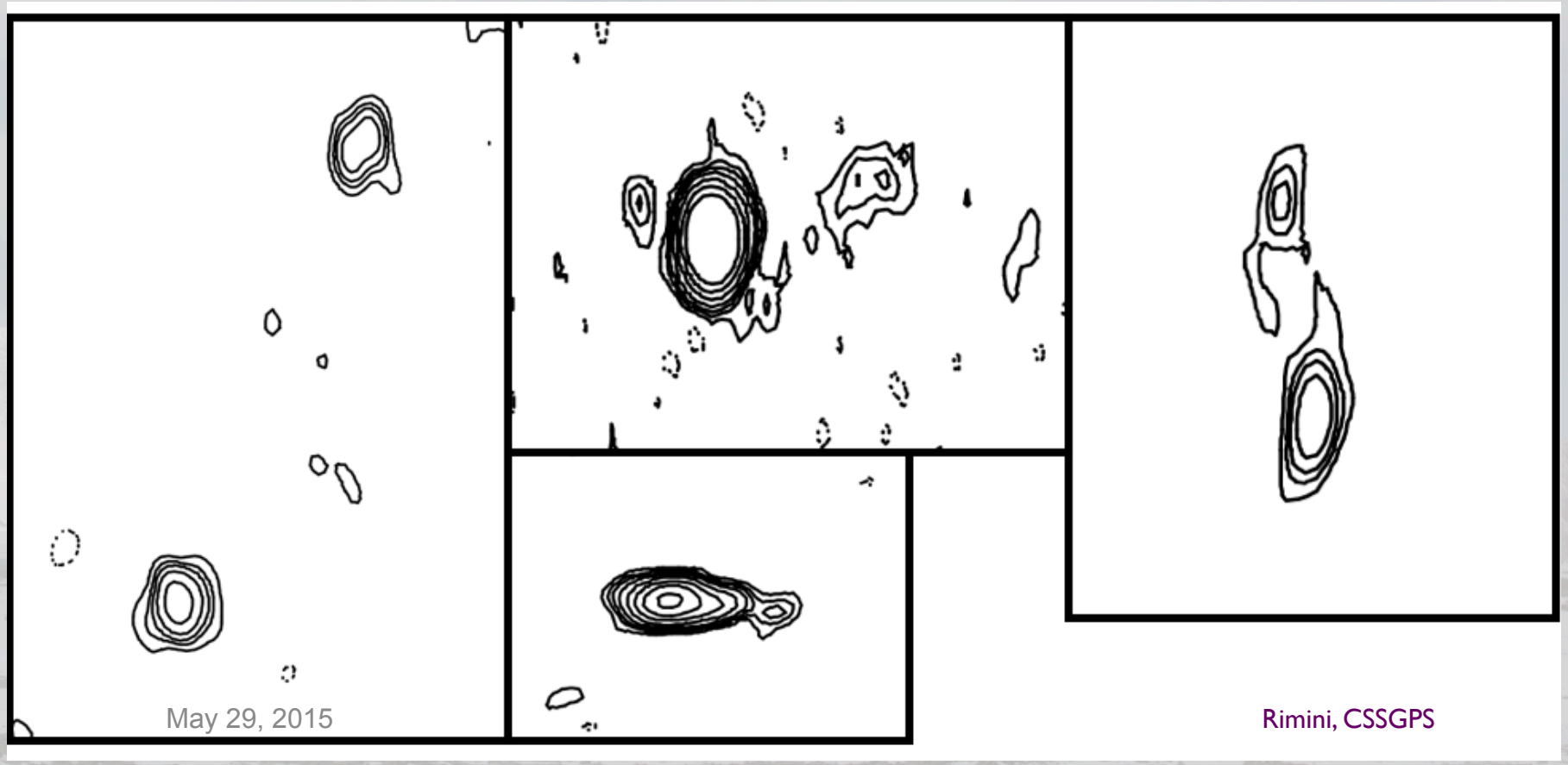
20m per source

$T_b \geq 10^7$ K ➔AGN-powered

beam ~ 10-15pc

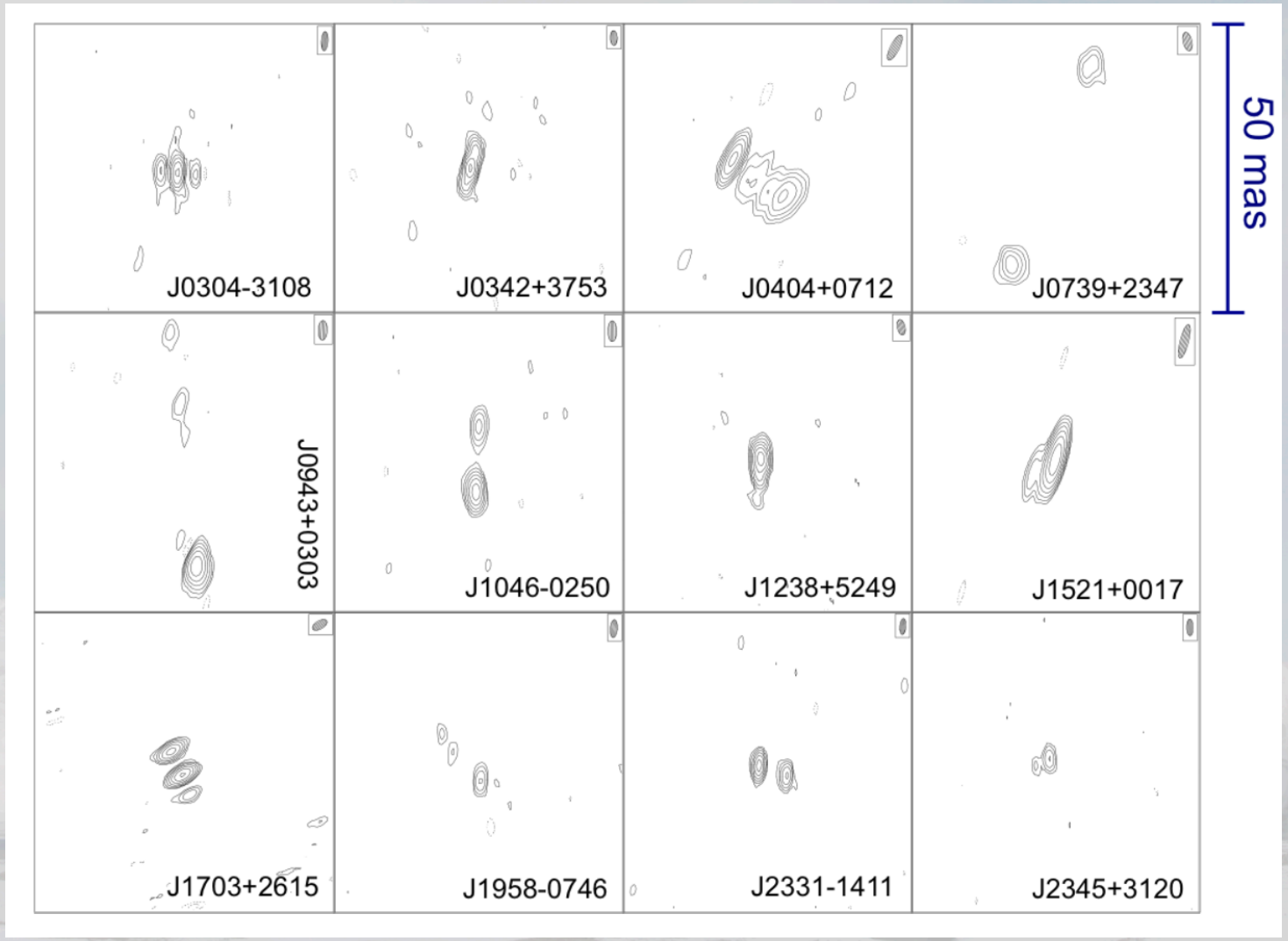
rms ~ 50uJy

structures ~ 100pc



VLBA multi-frequency imaging ongoing

1.4, 4, 8, 15 GHz ~0.5 - 50 mas spatial scales ~5 - 500 pc



MERLIN proposed

1.4 & 5 GHz

350 – 1200 pc spatial scales

Summary: the sources

- Strongly MIR-dominated
- Redder at λ < 10μm than any other known quasar samples
- Luminosities $10^{12.5}$ – >10^{14} $L_{\odot}$ 0.2< z < 3
- Similar to Spitzer PL DOGs but redder and more MIR-dominated
- SFRs hard to constrain: SEDs can be fit with warm AGN-heated dust
  - But would require ~kpc scale AGN-heating – unlikely

- High radio powers similar to HzRGs cores
- Most are compact in the radio at 10 GHz on <~kpc scales
  - ~10% resolved CSS on <10 kpc scales
  - Most 1.4 – 10 GHz SEDs are steep, from -0.7 to -1.6
  - at least 4 likely GPS but insufficient data
  - significant fraction are flat

- Range of morphologies at 5 GHz (VLBA) on ~200 pc scales

Summary: implications and future

- Highly luminous, radiatively efficient (quasar mode) AGN can drive powerful jets at z~2
- Jets can reach CSS stage on ~10 kpc scales
- Very high obscuration implies very large central ISM columns (densities?)
- Jets probably co-exist with substantial star formation,
  - but could be very young starbursts: $<10^7$ years
  - SF needs confirmation at other frequencies

- ALMA proposal to map CO in 3 sources
- Ongoing VLSA, VLBA MERLIN imaging of subset
- HST imaging proposed for 10; Chandra for brightest source