Millimeter and Radio studies of z~6 Quasars

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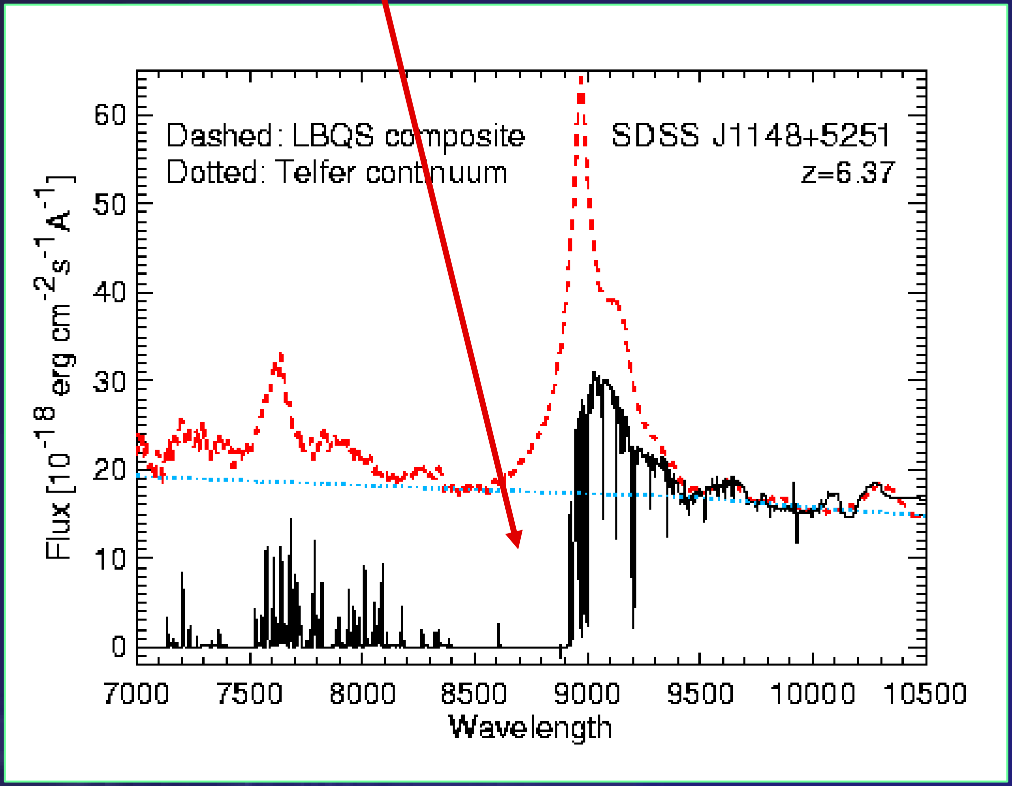
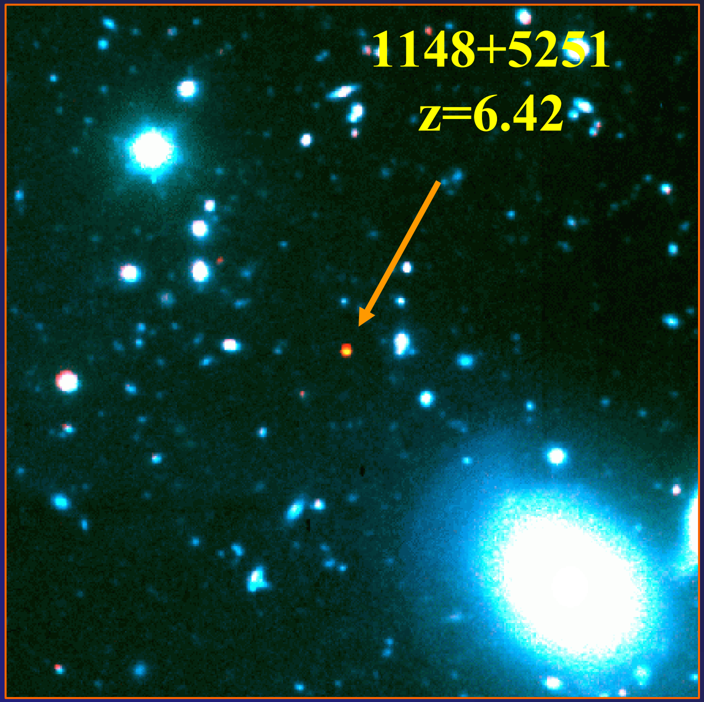
Introduction – The discovery of SDSS J1148

Gunn-Peterson absorption in the quasar spectra.

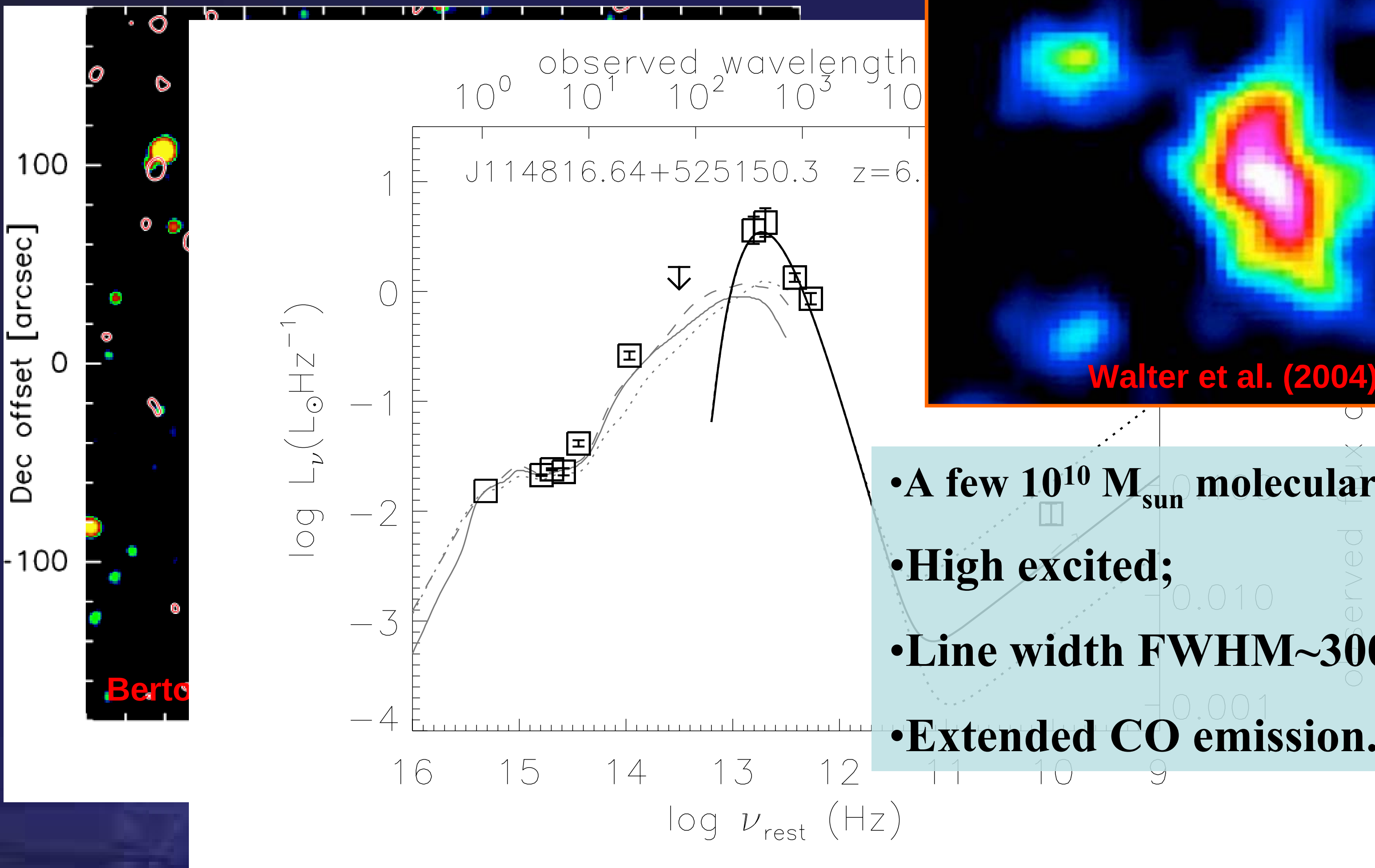


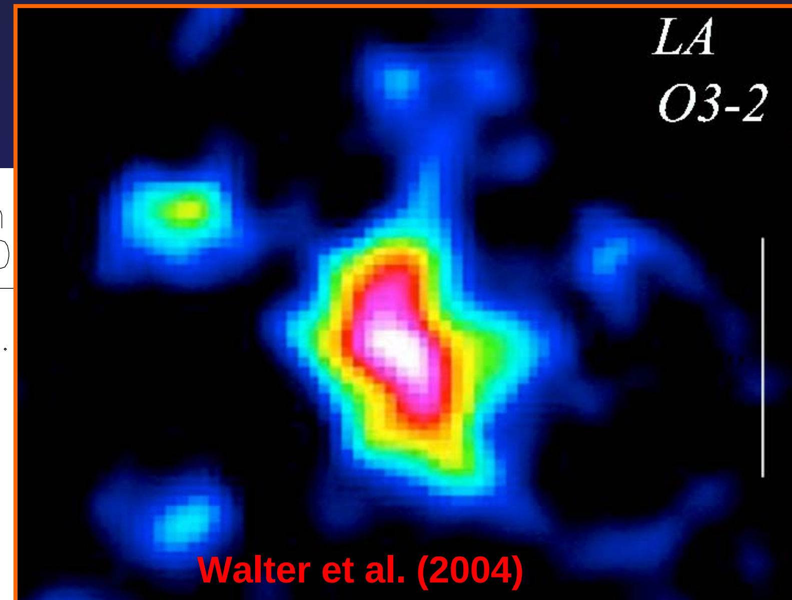


- The discovery of the z=6.42 quasar, SDSS J1148+5251, in Fan et al. (2003).

Introduction – The discovery of SDSS J1148

The detection of warm dust by MAMBO at 250 GHz in 2003.





- A few 10^{10} M_{sun} molecular gas;
- High excited;
- Line width FWHM~300km/s;
- Extended CO emission.

Introduction

- We are pursuing cm and mm studies of all the quasars discovered at z~6
  - We first do a millimeter and radio continuum survey with all the z~6 quasars.
  - Further observations at submm wavelengths with strong millimeter detections to measure the FIR SED and determine the dust temperature.
  - Search for CO with the millimeter detections.

Sample

- There are totally Thirty-three quasars discovered at z~6.
  - z=5.71 to 6.43
  - M_1450A < -25.0
- Twenty-two from the SDSS survey of ~8000 deg^2 area, with m_{1450A} < 20; Fan et al. 200x
- Nine from Deeper optical imaging with m_{1450A}>20, Jiang et al. 2007; Wollitt et al. 2007
- IR (Spitzer) + optical: one; Cool et al. (2006)
- Radio (FIRST) + optical: one; McGreer et al. (2006)

Most of these objects were optically selected from the SDSS survey

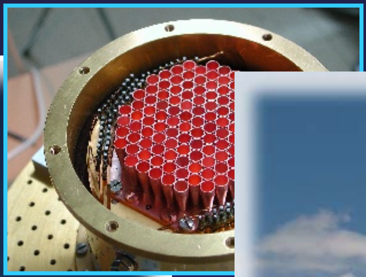
→ Represent the most luminous quasar population at z~6.

Observations

IRAM-30m telescope:

MAMBO at 250 GHz;

Two to Three hours observing time, down to sub-mJy sensitivity.



VLA:

L-band;

Three to four hours observing time, down to $\leqslant 20$ μJy sensitivity.

A summary of the (sub)mm and radio Results

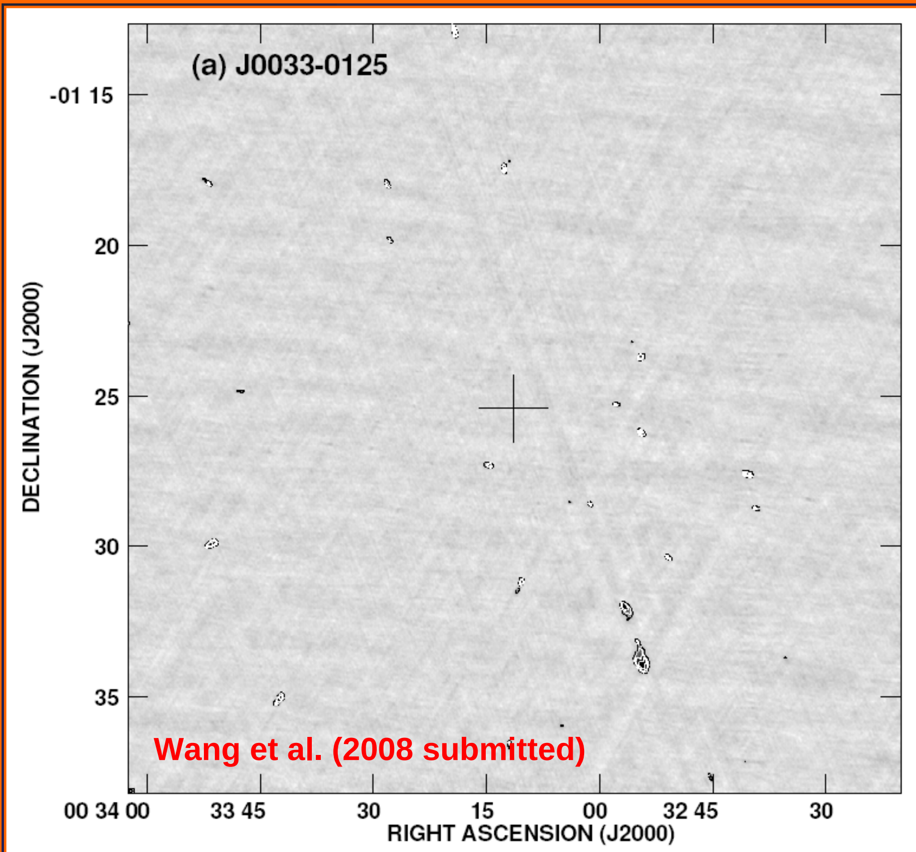
- VLA observation of 32 sources
  - rms <= 20 uJy for most of the sources
  - Ten were detected, with two of them having flux densities > 1mJy
  - Three of them have radio loudness R ⩾10

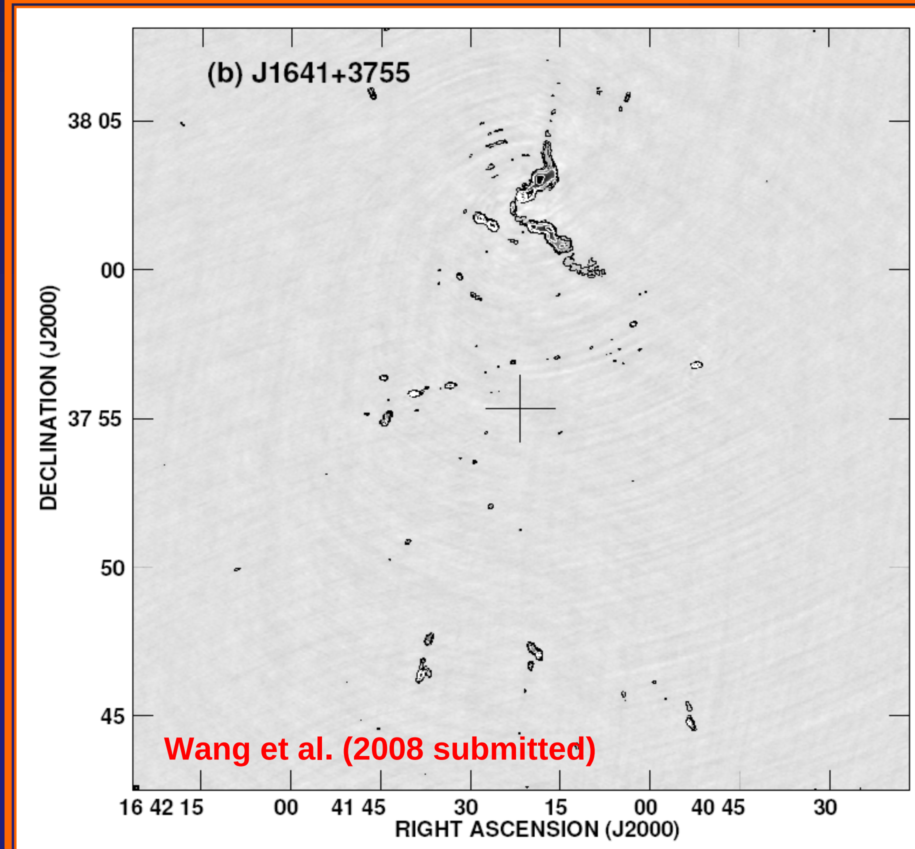
$$R \equiv \frac{f_{\nu,5\ GHz}}{f_{\nu,4400\ A}}$$

- The radio loud fraction at z~6: one out of the primary SDSS sample of 22 sources.

A summary of the (sub)mm and radio Results

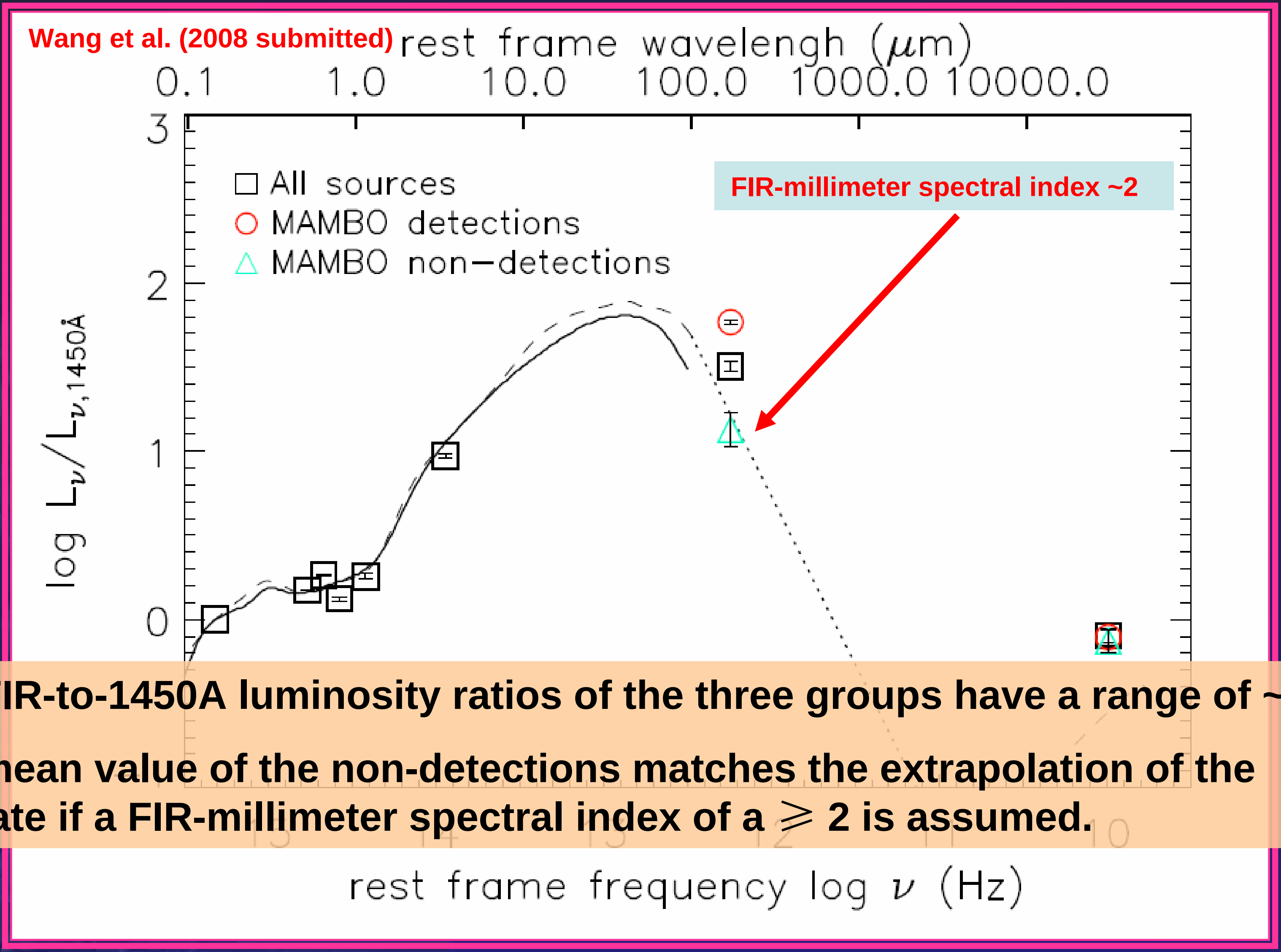
- Over-densities of radio sources in the fields of two optically fainter quasars.





One and five >10 mJy sources are found within 10’ from the quasar positions, while 0.1 source is expected within this amount of random sky area.

Analysis – the average FIR and radio emission

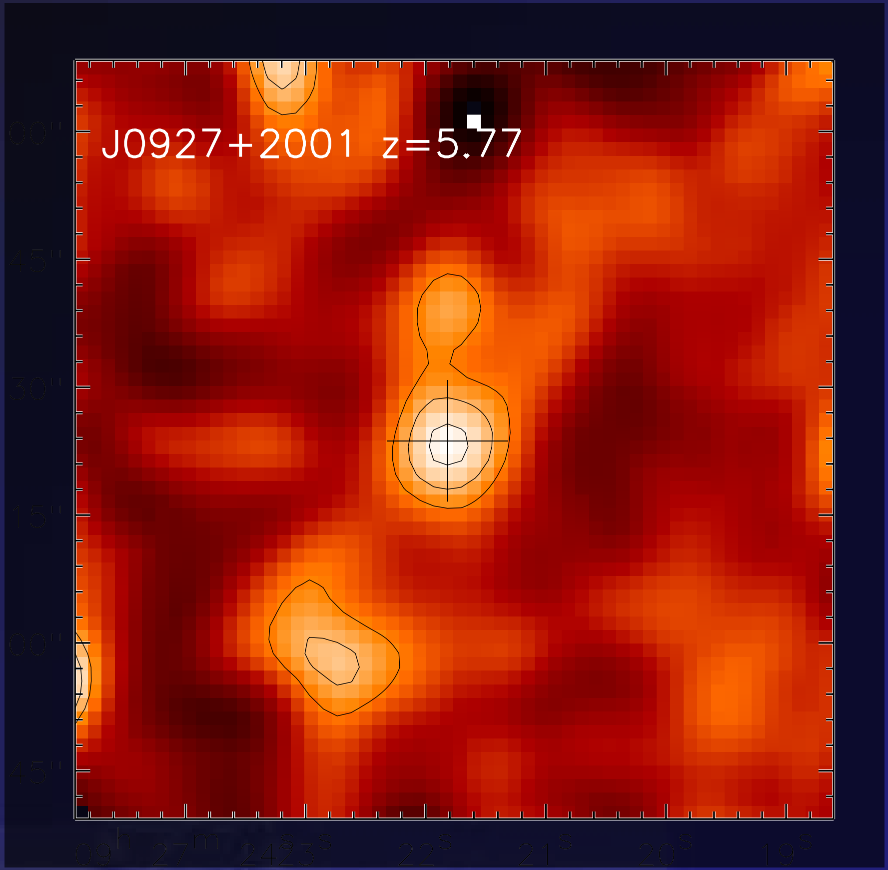


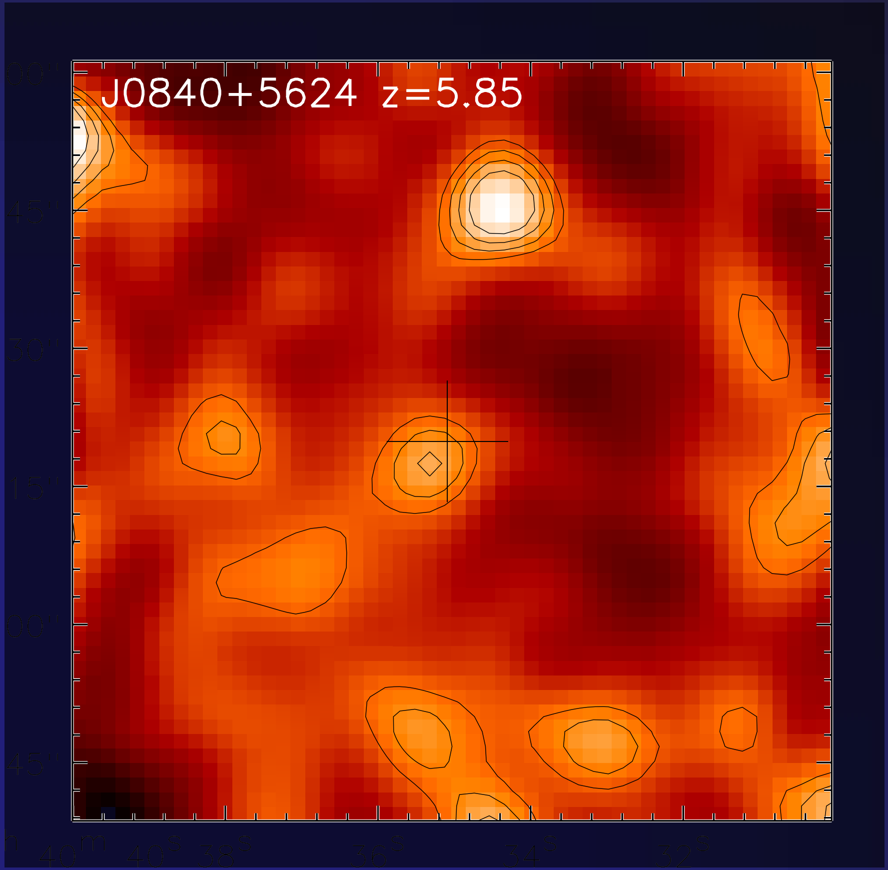
•The FIR-to-1450A luminosity ratios of the three groups have a range of ~0.6dex.

•The mean value of the non-detections matches the extrapolation of the template if a FIR-millimeter spectral index of a $\geqslant$ 2 is assumed.

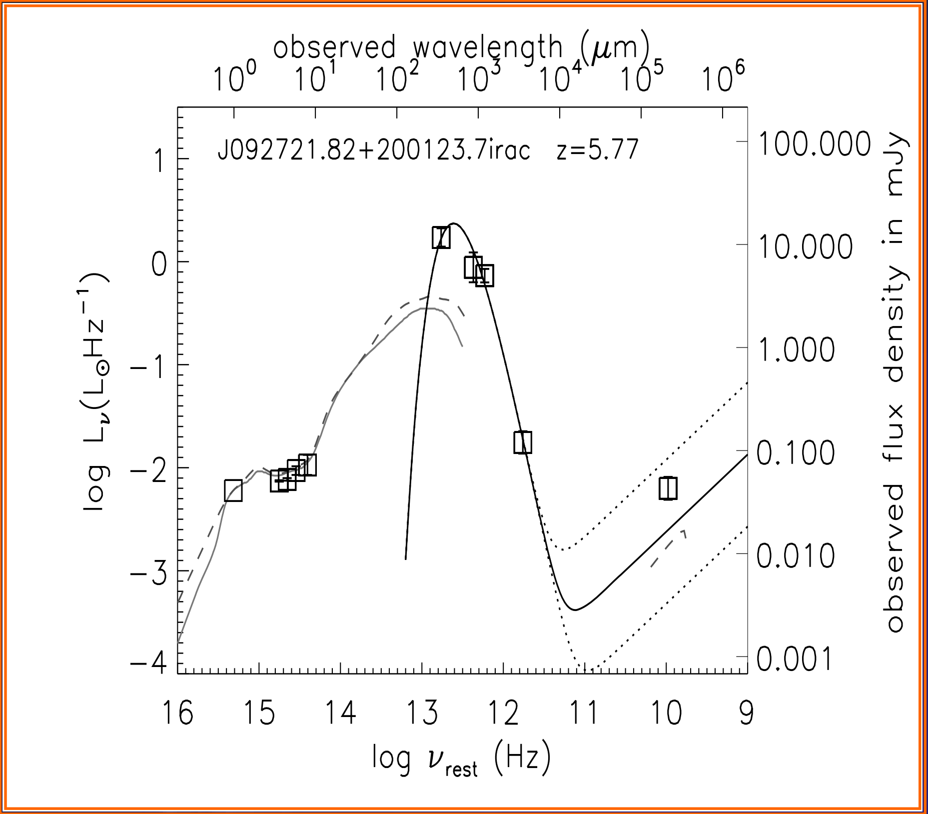
The bright millimeter detections

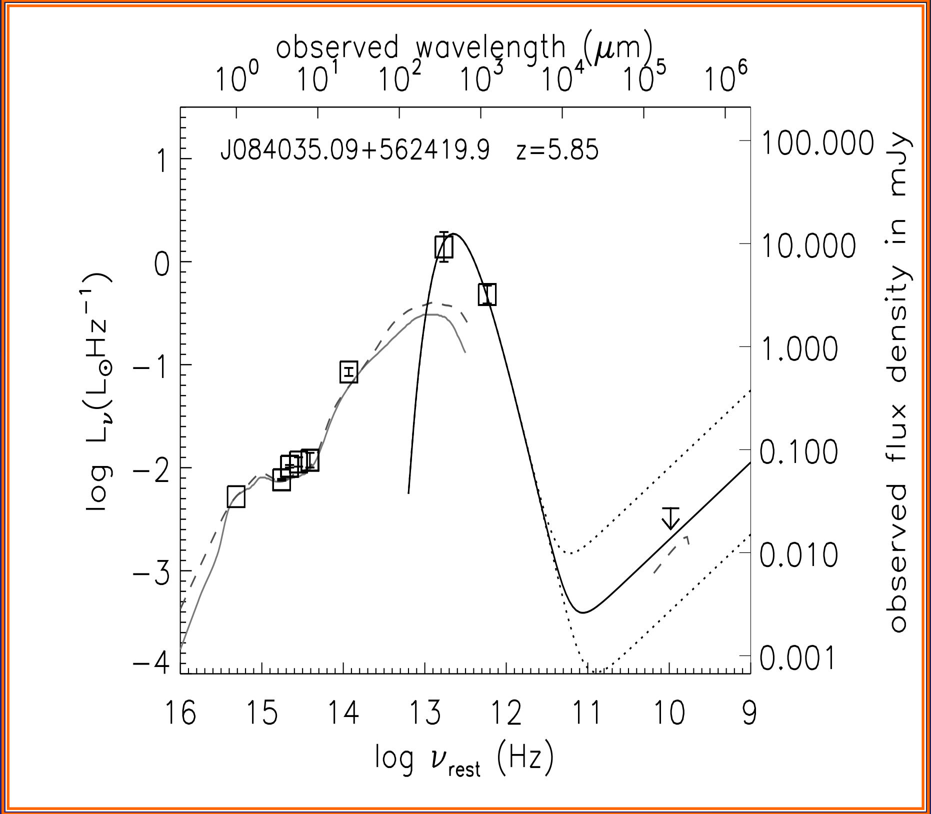
- CSO observations of the bright millimeter detections – SHARC-II at 350 um.





The bright millimeter detections

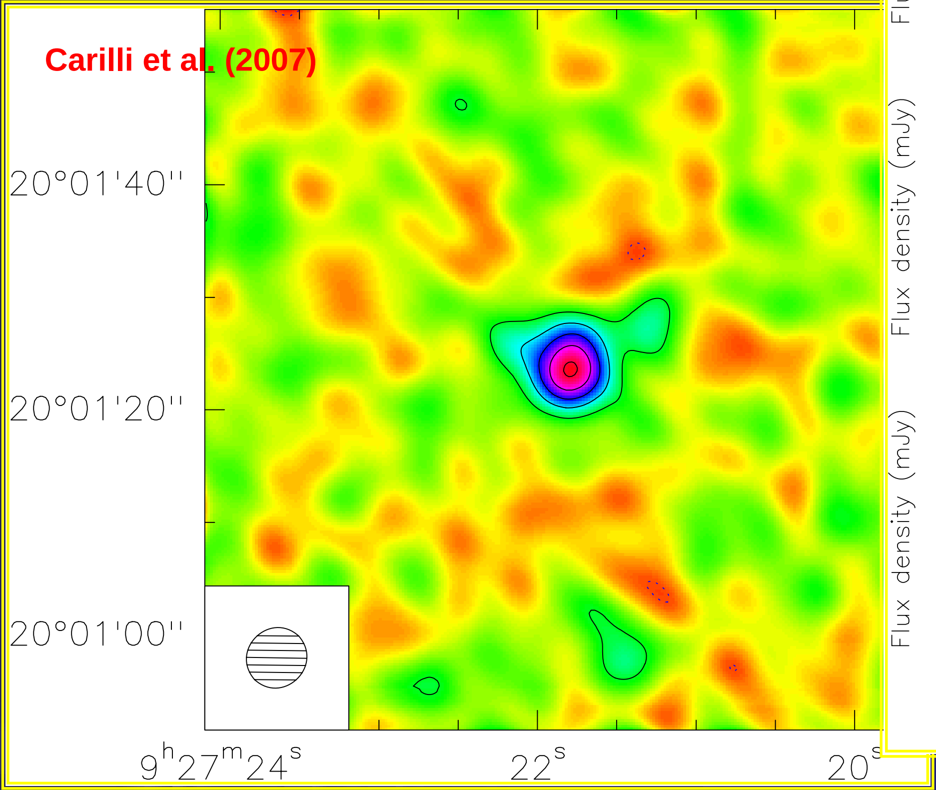


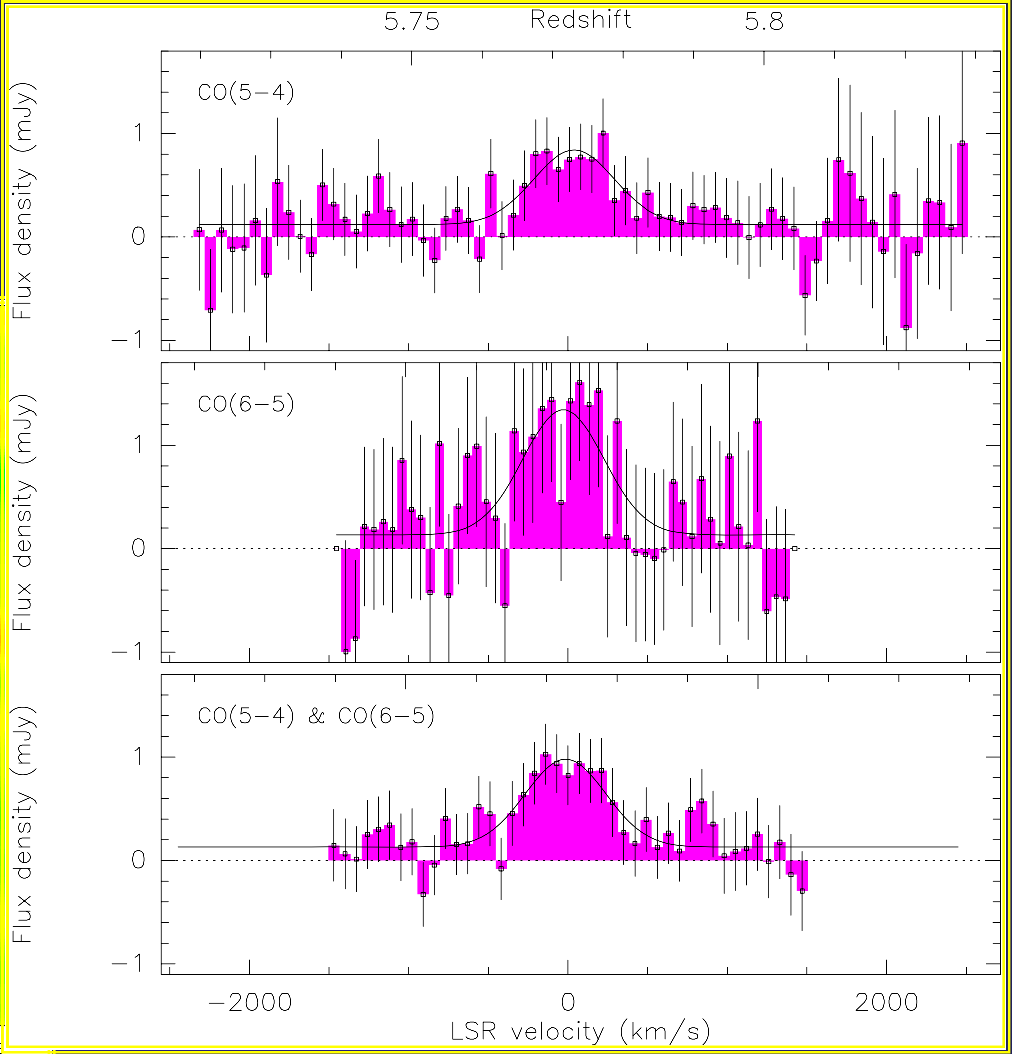


- Fit the FIR SED of J0927+2001:
  - Dust temperature: ~40K
  - Emissivity index: ~2

CO detections in the bright mm detections

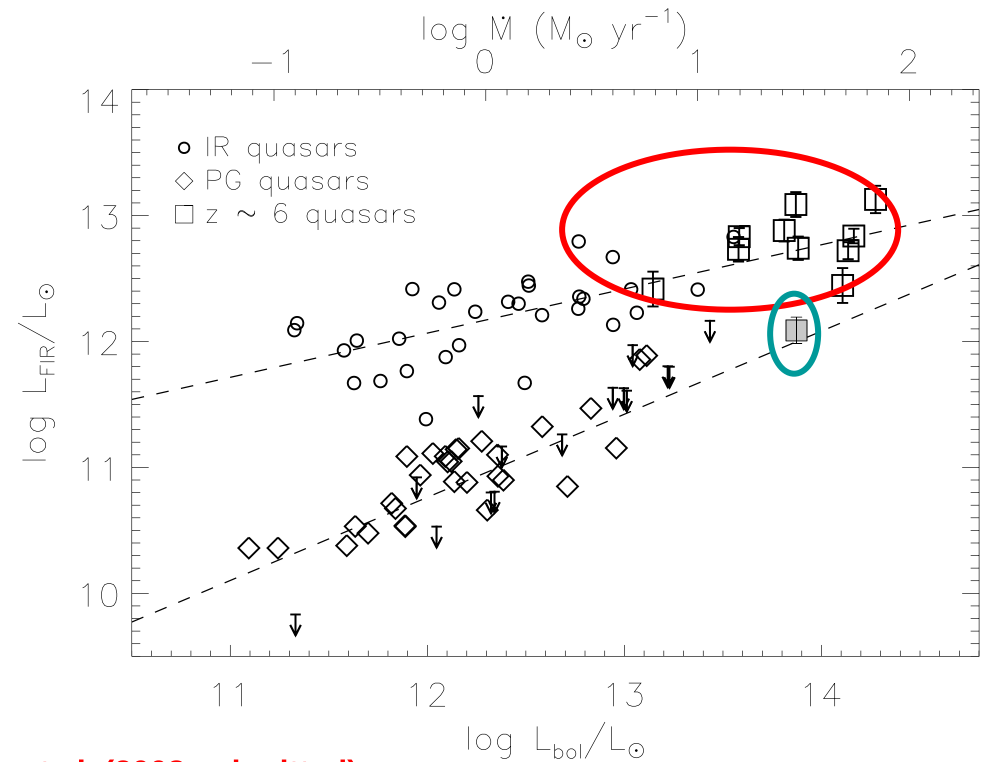
- **J0927+2001 was detected in CO (5-4) and CO (6-5) emission with the PdBI.**





Luminosity correlation L_{FIR} - L_{Bol}

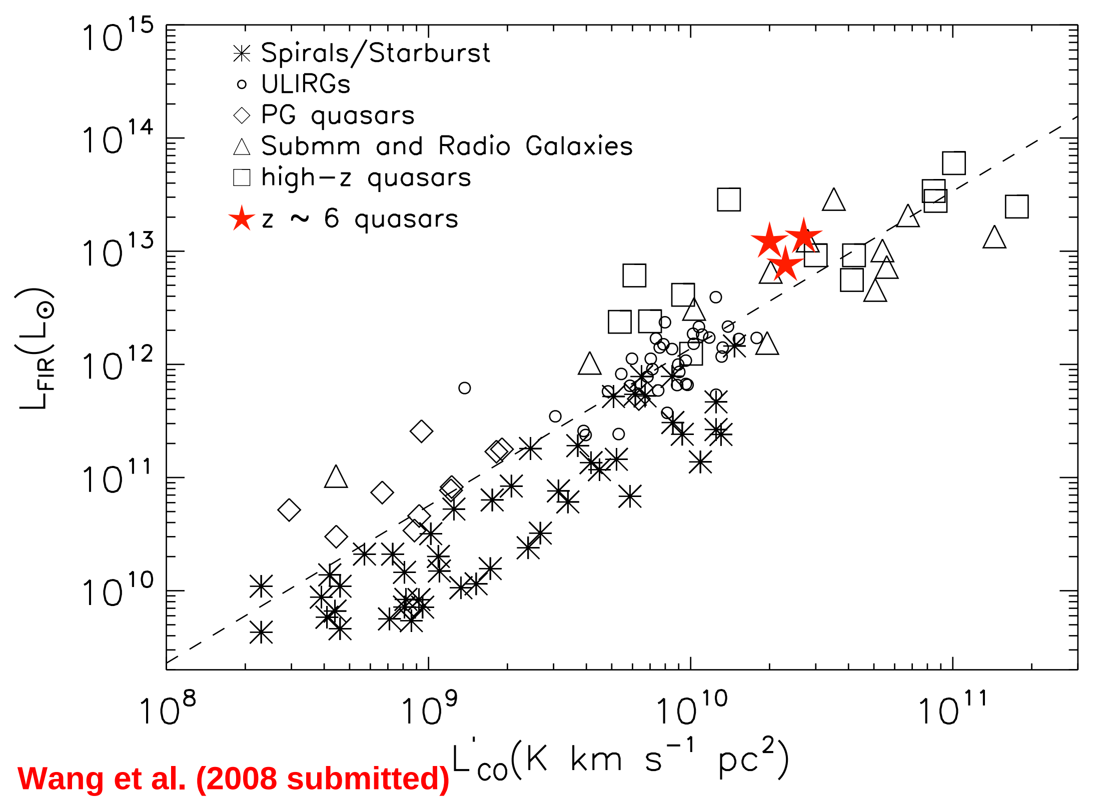
- The relationships between FIR and AGN bolometric luminosity derived from local quasar samples (Hao et al. 2005).
  - More than half of the MAMBO detected quasars at z~6 follow the relation defined by the IR luminous quasars hosted in ULIRGs
  - The average value of the non-detections.



Wang et al. (2008 submitted)

Discussion – star formation in the z~6 quasars

- It is likely that active star formation is ongoing in the host galaxies of the strong millimeter detected quasars at z~6.
- The contribution to the FIR dust heating (how much percent ?): still an open question.
  - According to the FIR – CO luminosity correlation, at least 30 to 50% is from star formation.
  - Star formation rate ≥ 1000 M_{sun} yr^{-1}.



Wang et al. (2008 submitted)

Further observations

- Map the dust and CO emission at sub-arcsecond resolution to confirm the 10^3 M_{sun} yr^{-1} star formation:
  - CO mapping: give the size of the emission region → dynamical mass (PdBI, EVLA).
  - Dust heated by star formation should be extended and have comparable size with the CO emission (PdBI).
- Low-J CO observations to study the CO excitation:
  - The CO (2-1) line peak flux density of J1148 and J0927 should be about 0.27 and 0.13 mJy, respectively.
  - Frequency: Ka-band
  - The required RMS: <90 uJy per 100 km/s channel.
  - The strongest sources should be detectable with the GBT.
  - Difficulties: determine and remove the baseline.

Summary

- The current sample of quasars at z~6 is studied at millimeter and radio wavelengths.
- Radio loud fraction: argue against RLF >20%.
- Overdensity.
- About 30% of these sources have been detected in warm dust continuum at 1.2 mm.
- The average FIR-to-radio SED of the non-detected sources is comparable to that of local optical quasars.
- Obvious FIR excesses in the SEDs of the strong millimeter detections.
- FIR dust heating is likely to be dominated by Star formation at a rate of a few 1000 M_{sun} yr^{-1} ?
  - L_{FIR}-L_{radio}; L_{FIR}-L_{bol} ratios
  - CO detection, huge amount of molecular gas
  - L_{FIR}-L'_{co} correlation