Millimetre astronomy: Galaxies

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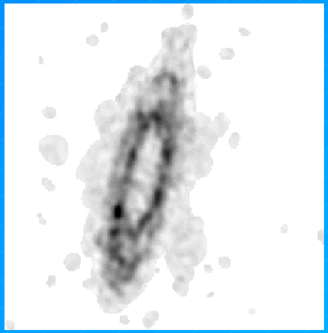
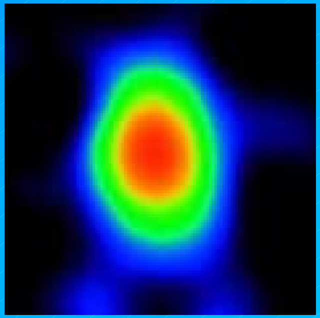
What new opportunities flow from the ATCA mm upgrade?

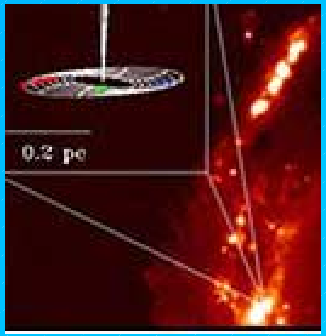
- mm continuum emission from galaxies
- CO line emission from galaxies



CO at z=0 (BIMA/SONG)



CO at z=3.91 (VLA)



H_2O masers (VLBA)

The ATCA at 90 GHz...

Comparison with other mm arrays

Array	Total Area (m^2)	Mosaic Speed (nD)	SSB Tsys @ 90 GHz	η_a	Freq. range (GHz)	Pol	BW (GHz)	Max. Bsln (km)	Line sens. (mJy)	Cont. sens. (mJy)
BIMA (10*6.1m)	290	61	150	0.7	70-115, 210-270	1	0.8	1.5	23	1.4
OVRO (6*10.4m)	510	62	250	0.7	86-116, 210-270	1	1.0	0.2-0.4	23	1.3
NMA (6*10m)	470	60	400	0.65	85-116, 126-152, 213-237	1	1.0	0.4	43	2.4
IRAM PdB (5[6]*15m)	880 [1060]	75 [90]	150	0.7	80-115, 210-250	1	0.5	0.4	8.2 [6.7]	0.63 [0.5]
ATCA (5*22m)	1900	110	250	0.4	85-110	2	0.2	3.0	7.9	1.0

Sensitivity estimates are for 1 hr integration at 90 GHz, all pols. combined.
Line sensitivity is for a 10 km/s channel.
Actual sensitivity will depend on atmospheric phase.

http://www.atnf.csiro.au/observers/docs/3mm/mmcompare.jpg

ATCA Broadband Correlator

(Wilson, 2002)

AIM:

To increase the maximum instantaneous bandwidth of the ATCA

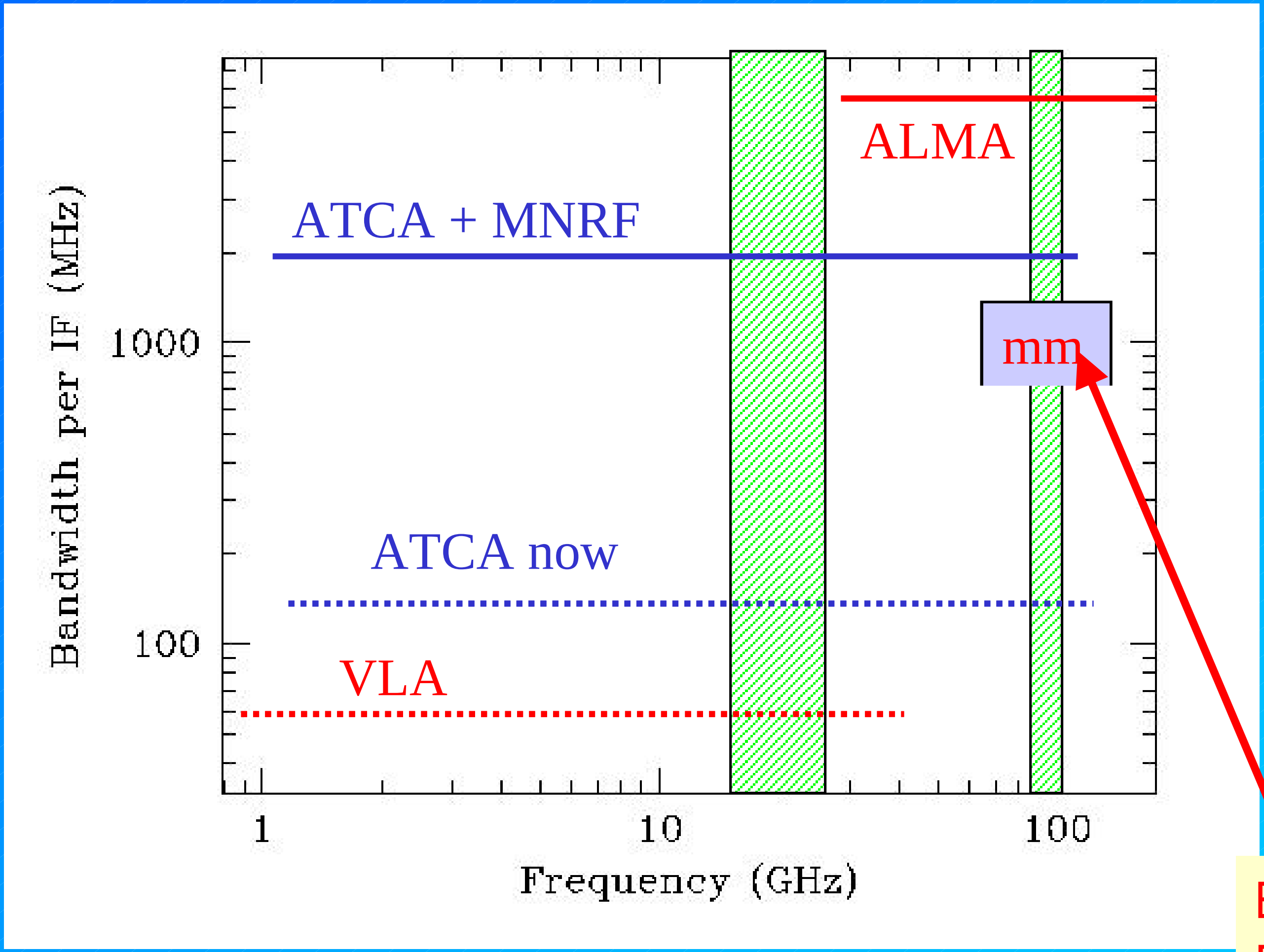
- from 128MHz to 2GHz.

GAINS:

- Enhanced frequency coverage - up by factor 16
- Continuum sensitivity up by at least a factor of 4
- Increased flexibility - simultaneous spectral lines

Ready by 2006/7...

Frequency and bandwidth coverage of current and planned telescopes



New MNRF wideband correlator from 2006/7 will make the ATCA more powerful for both line and continuum obs, especially at mm λ

Existing mm arrays: BIMA, IRAM etc.

Bandwidth and velocity coverage

For bandwidth $\Delta\nu$, velocity coverage at frequency ν is $\Delta v = c.\ \Delta\nu/\nu$

At 100 GHz (3mm)

128 MHz bandwidth, Δv = 375 km/s

2 GHz bandwidth, Δv = 6000 km/s

At 20 GHz (12mm)

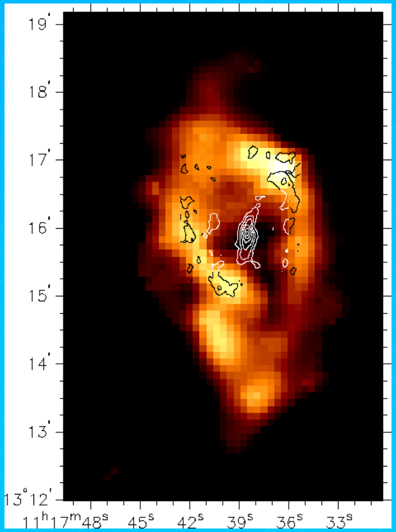
128 MHz bandwidth, Δv = 1900 km/s

2 GHz bandwidth, Δv = 30,000 km/s

[HIPASS velocity coverage was 12,000 km/s for HI]

Typical spiral galaxy, velocity width ~200 km/s

ULIRG, QSO CO line widths up to 1000 km/s



NGC 3627 CO+HI (BIMA/VLA)

`Strategic advantages' of the ATCA for mm studies

Only southern mm array (to ~2010, ALMA)

3mm band (85-105 GHz)

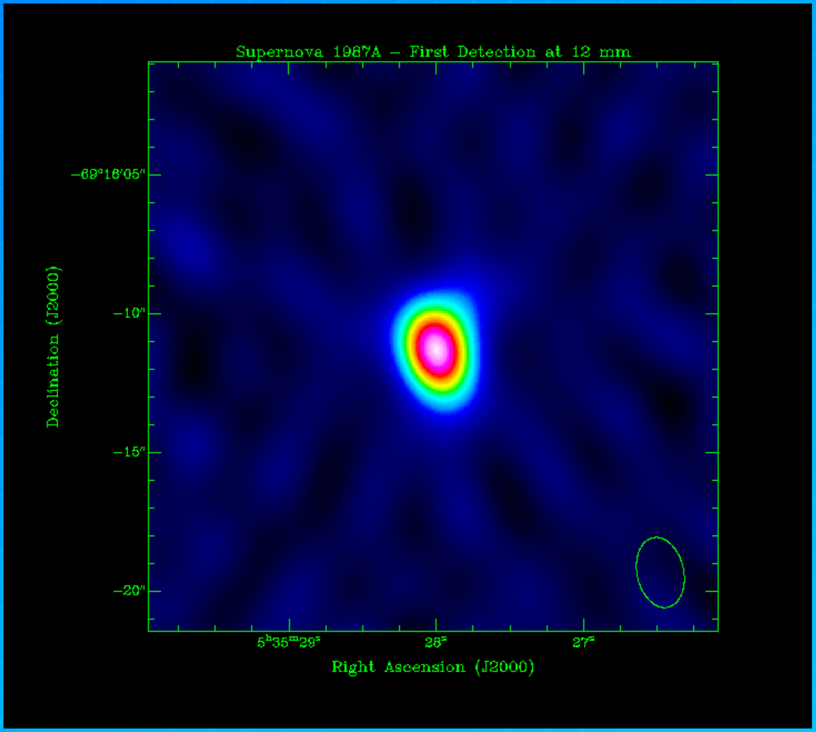
- Largest collecting area (to ~2010)
- Largest bandwidth (2 GHz, ~2007 to ~2010)

12mm band (16-26 GHz)

- Largest bandwidth (to ~2010)
- Unique capability for blind CO survey (~2007)

Continuum emission - SN 1987A at 12mm

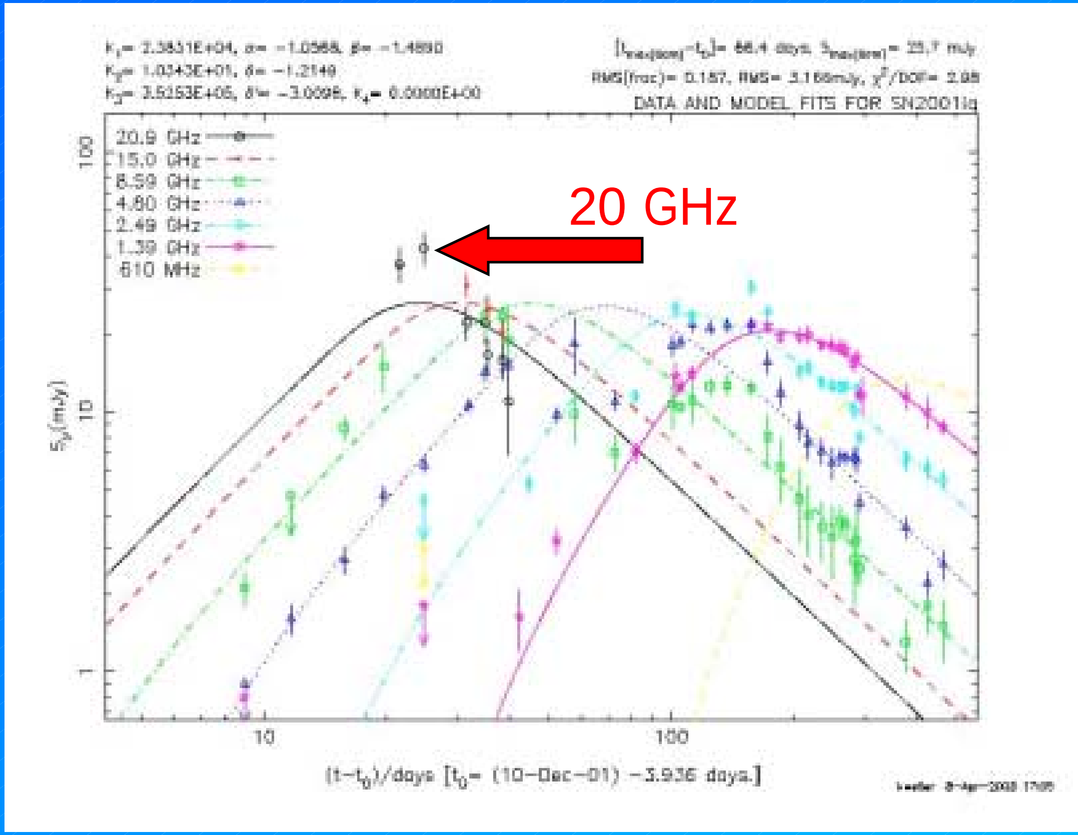
Optical (HST)



12mm radio (Manchester et al. 2001)

Radio telescopes are diffraction limited - higher freq. allows higher spatial resolution on 6km baseline

Radio supernovae - SN2001ig



ATCA, SN2001ig radio light curve (Ryder et al.)

IIb SN 2001ig in NGC 7424 (CTIO)

Radio supernovae - explosions of massive stars, shock interactions with CSM. Usually peak first at highest freq.

First results from the ATCA 20 GHz Continuum Survey

The 20 GHz Survey Team: R. Ekers (PI), L. Staveley-Smith, W. Wilson, M. Kesteven, R. Subrahmanyan (ATNF) , E. Sadler, M. Walker (Sydney), M. Dopita, C. Jackson (MSO), R. Ricci (SISSA), G. De Zotti (Padua Obs.)

First all-sky radio survey at 20 GHz (12 mm)

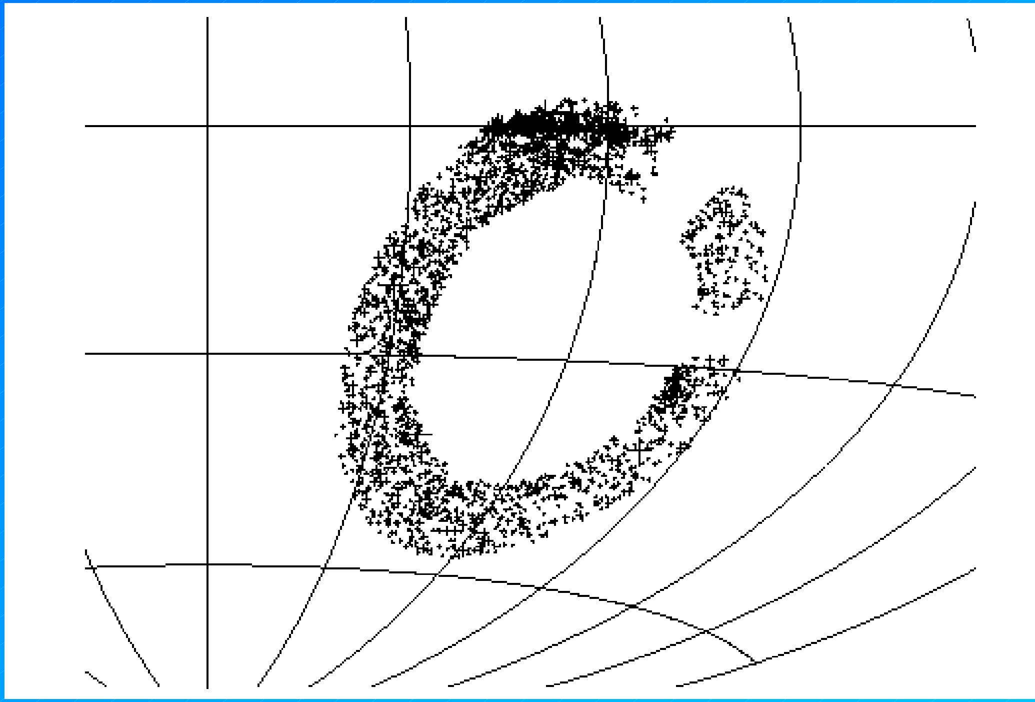
- Preliminary analysis of scans and 18 GHz images from Sept/Oct 2002 ATCA sessions
- What kinds of astrophysical objects are these?

Survey Strategy

- 1 ATCA baseline: CA02 – CA03
- Wide-band analogue correlator (WBC)
  - frequency range: 16-20 GHz
  - BW: 4 GHz (8 frequency channels)
- Active scanning, high scan rate: 10 degrees/min
- No delay correction, so need to scan along meridian

Survey Characteristics

- Surveyed area: ~1200 sq. deg.
- S_{lim} = 60 mJy (4 σ)
- Sky strip covered: dec = -70^o to -60^o

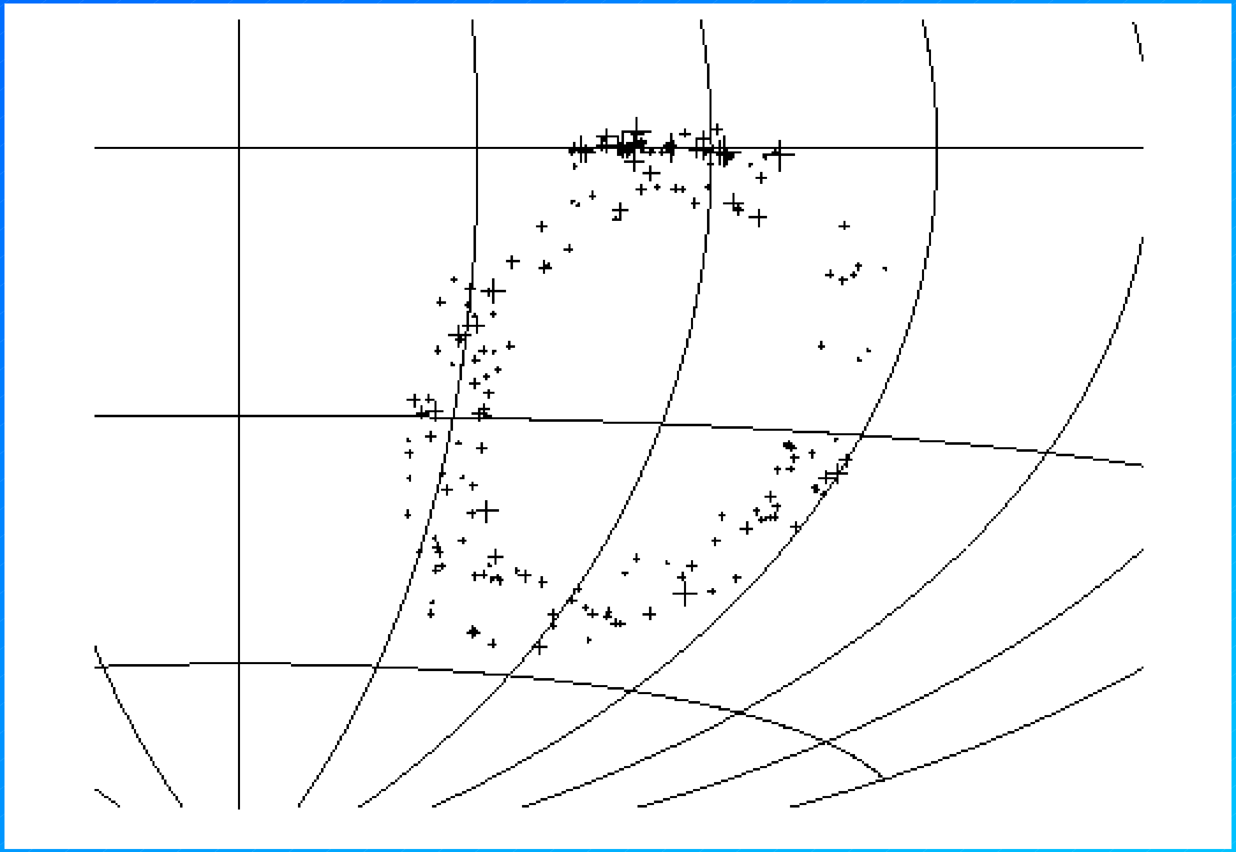


PMNS sources present in 20 GHz Survey area

The 20 GHz data set

- 226 detected (5σ) sources above ~60 mJy, Dec strip at -60 to -70, RA 0h to 24h
- More than half lie within 10^{o} of the Galactic Plane or in the LMC (HII regions, PNe etc.)
- Work so far: cross-matching and identifying ~100 sources at high Galactic latitude.
- Cross-match with 843 MHz SUMSS catalogue to get two-point spectral indices
- Optical ID s from NED and Cosmos

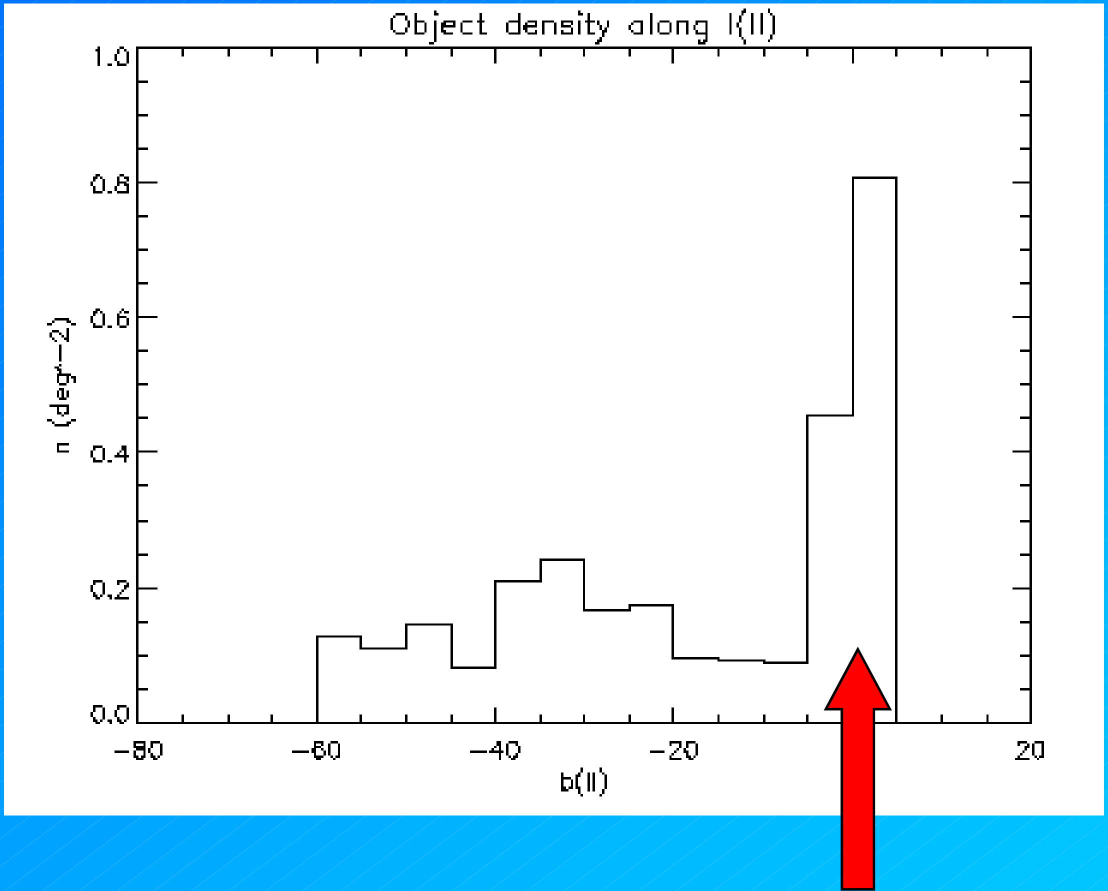
Two source populations...



Aitoff equal area projection of the confirmed sources, in Galactic coordinates

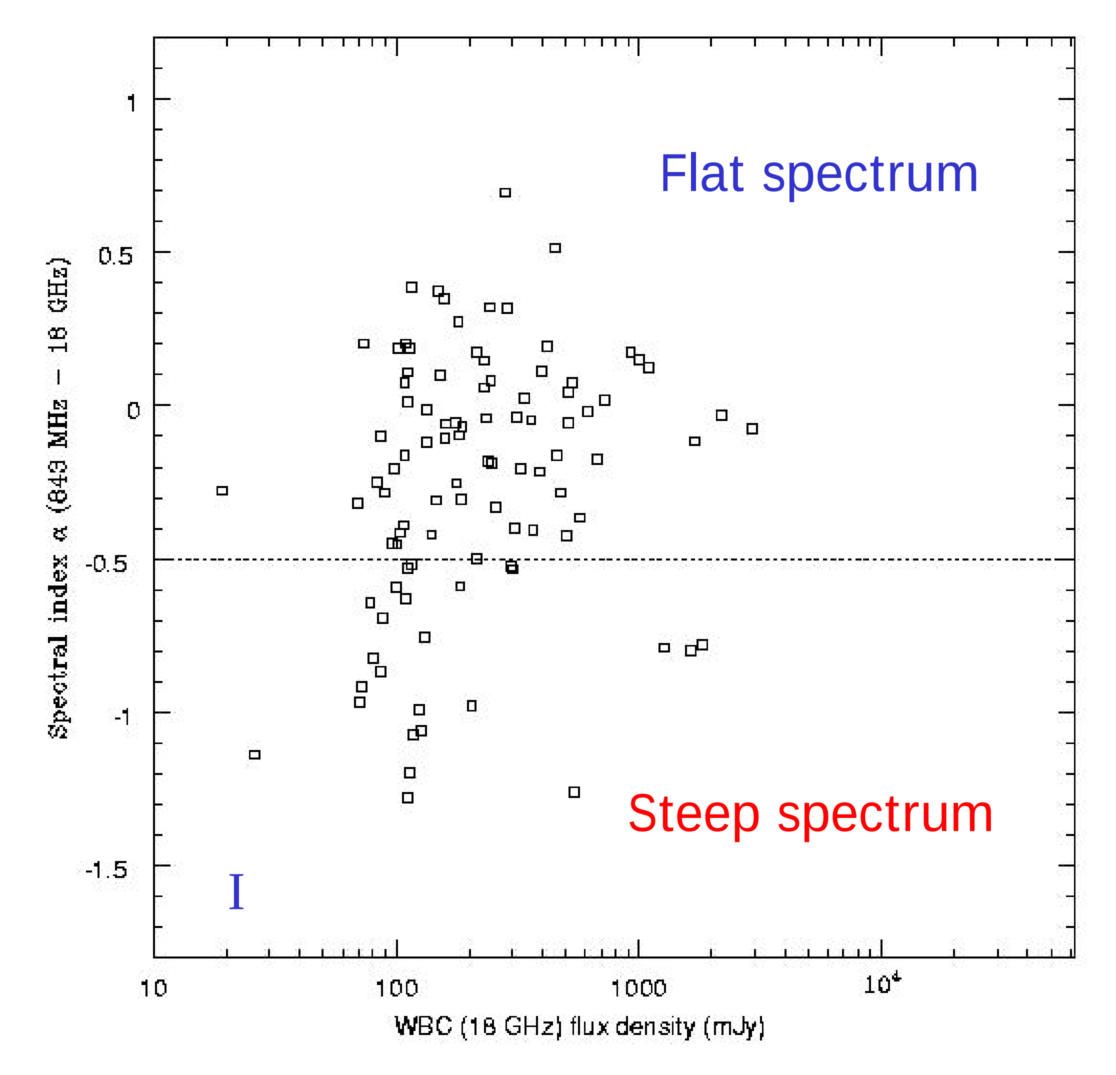
Two populations (galactic & extragalactic)

20 GHz Source Density



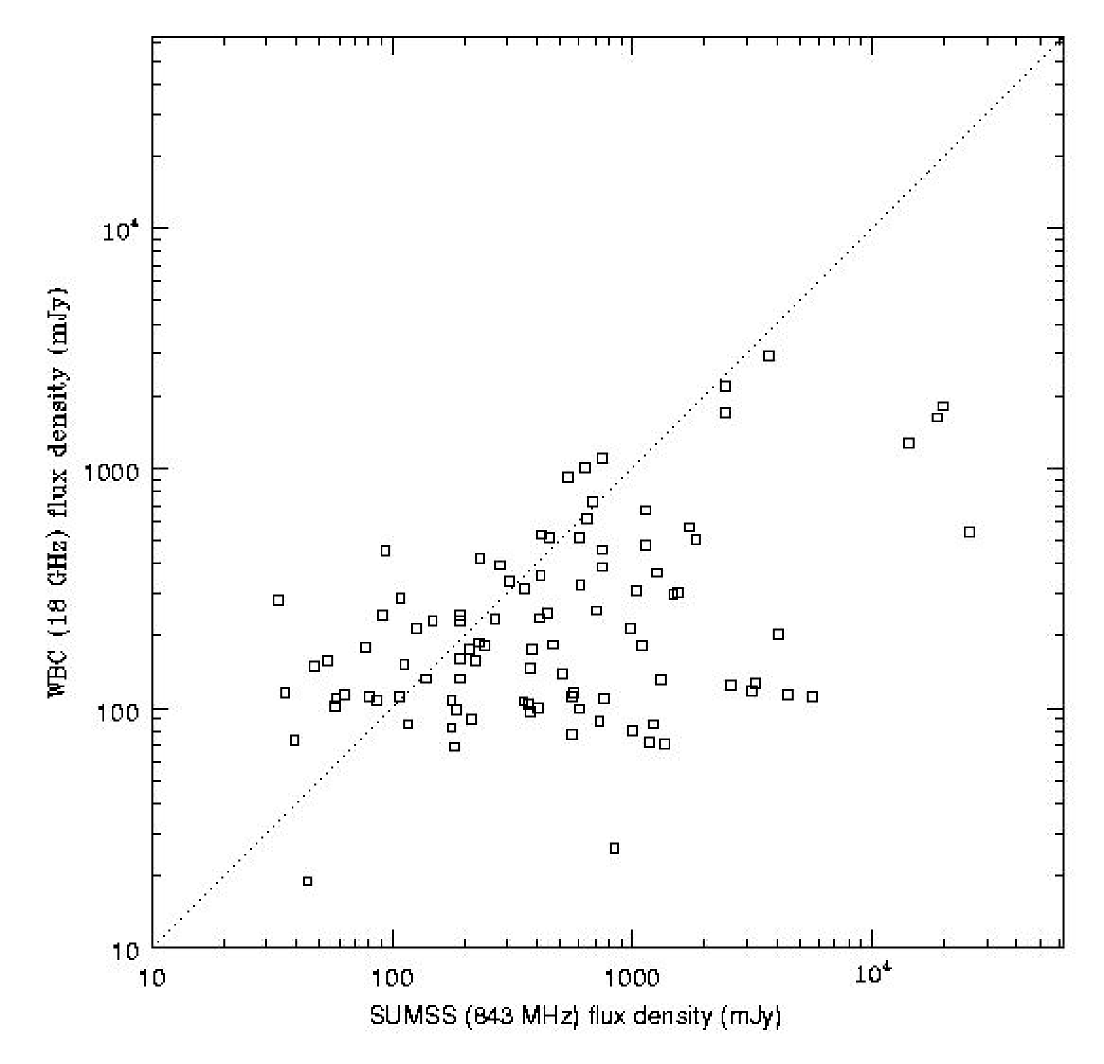
Steep increase in source density near the galactic plane - Galactic sources are typically HII regions & a few SNRs, PNe

Radio spectral indices



- The sample is dominated by sources with flat/inverted radio spectra.
- No obvious sign that α varies with flux density
- Wide range in α

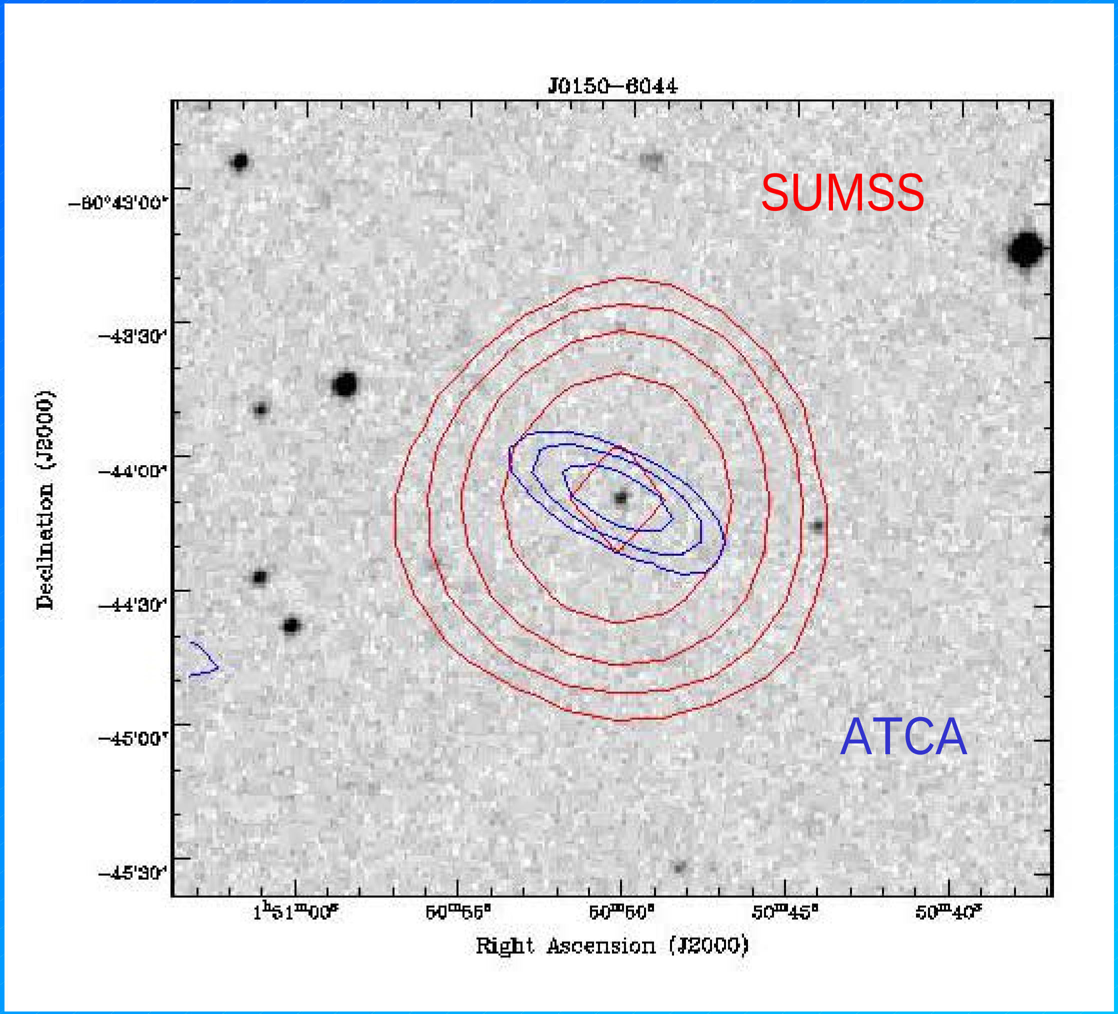
WBC-SUMSS cross-match



- All ($|b|>10^o$) sources detected at 18 GHz are also present in the 843 MHz SUMSS catalogue (and well above the 6 mJy limit)
- The 843 MHz and 18 GHz flux densities are essentially uncorrelated

No 'new' sources yet!

Optical identification



- Both ATCA and SUMSS have good positional accuracy (~1 arcsec).
- Cross-match with NED for existing IDs
- Other optical IDs via Cosmos cat.

Optical ID rate

• High optical ID rate for 18 GHz sources,
(80/82 have a candidate DSS ID within 8 arcsec, versus ~35% for low-freq surveys)

Optical IDs for 82 18 GHz sources:

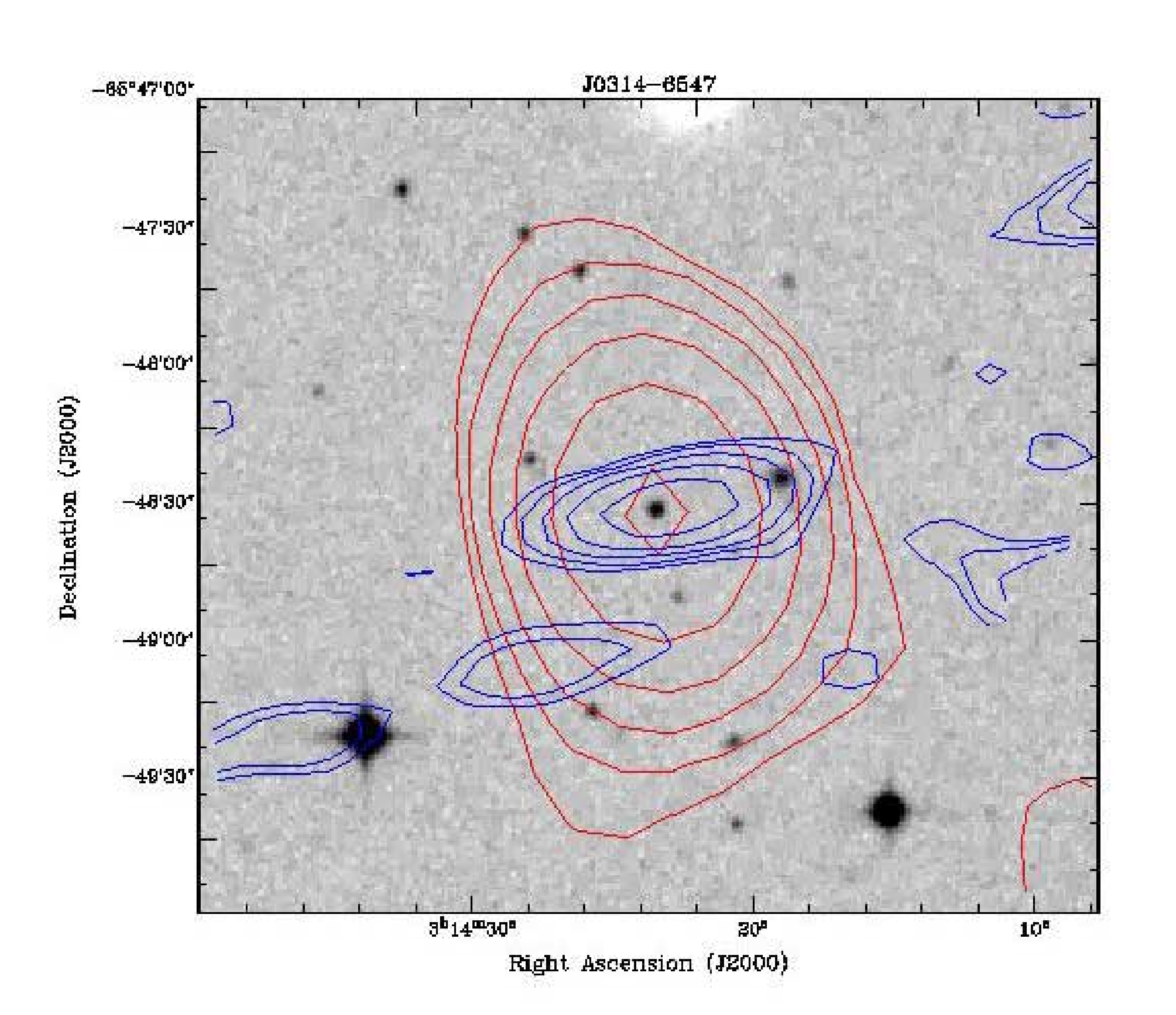
13 galaxies

21 catalogued QSOs

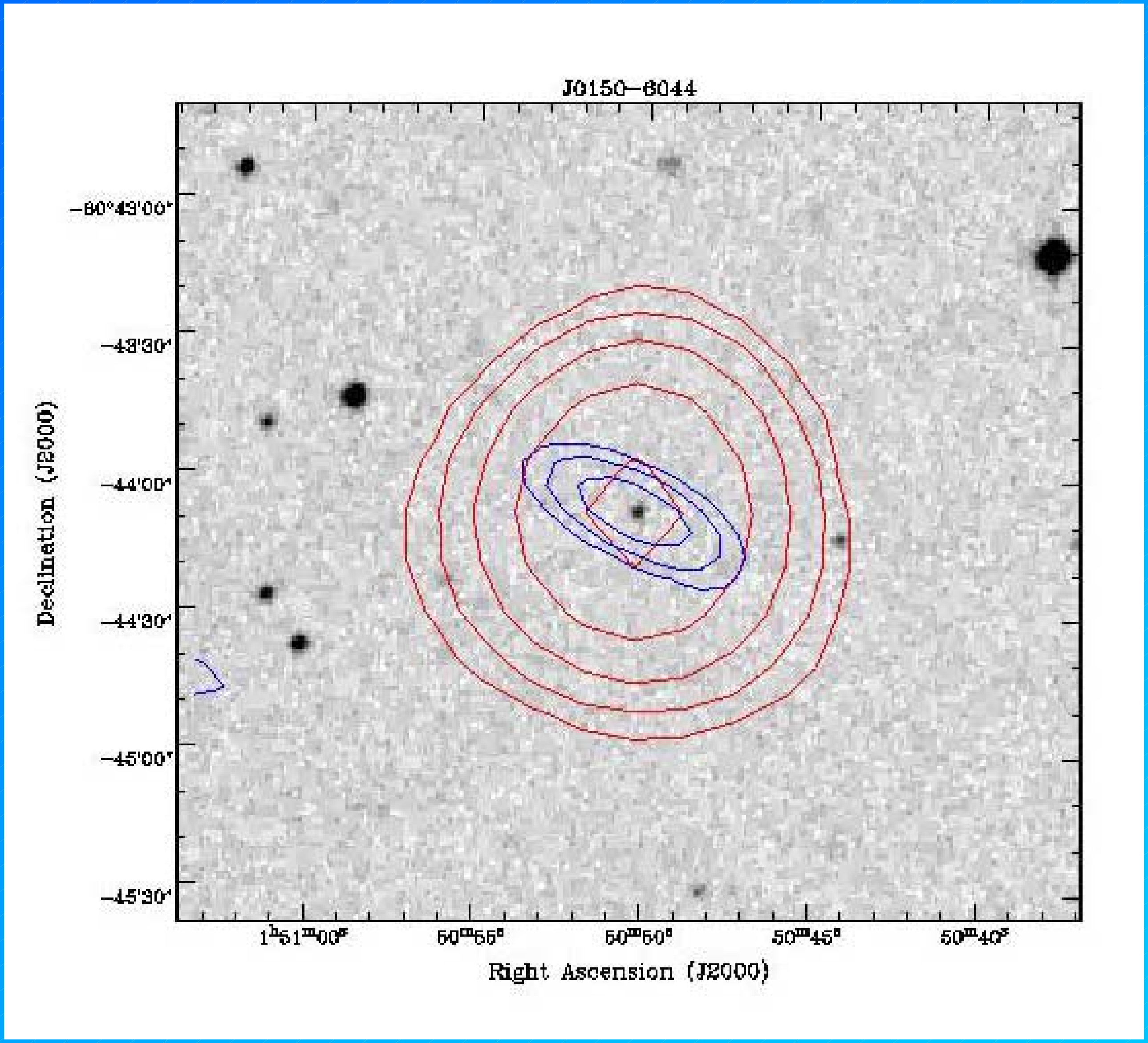
38 new candidate QSOs (~20 likely to be genuine)

10 faint objects or blank fields

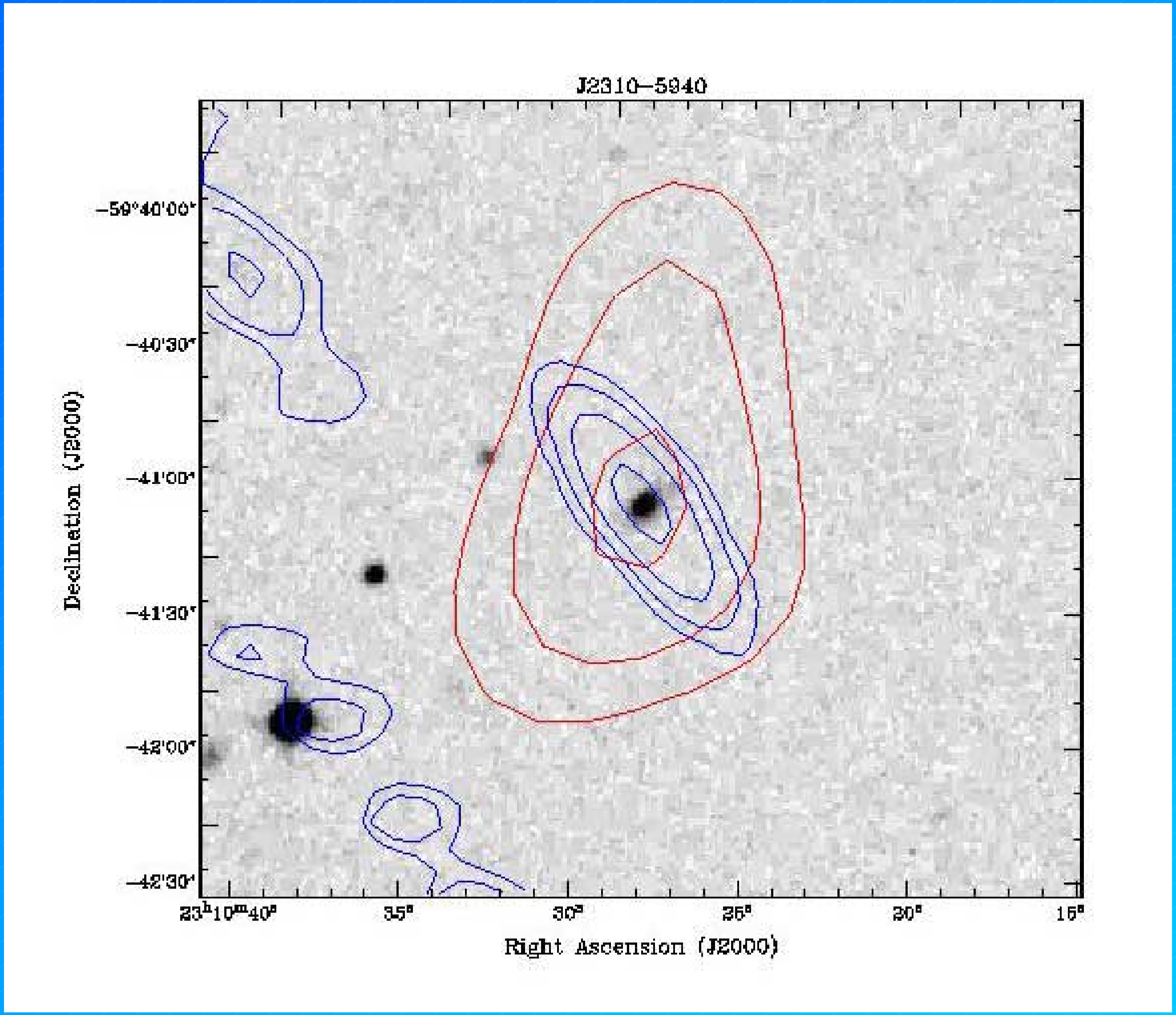
PKS 0313-660 - a known QSO (z=0.636)



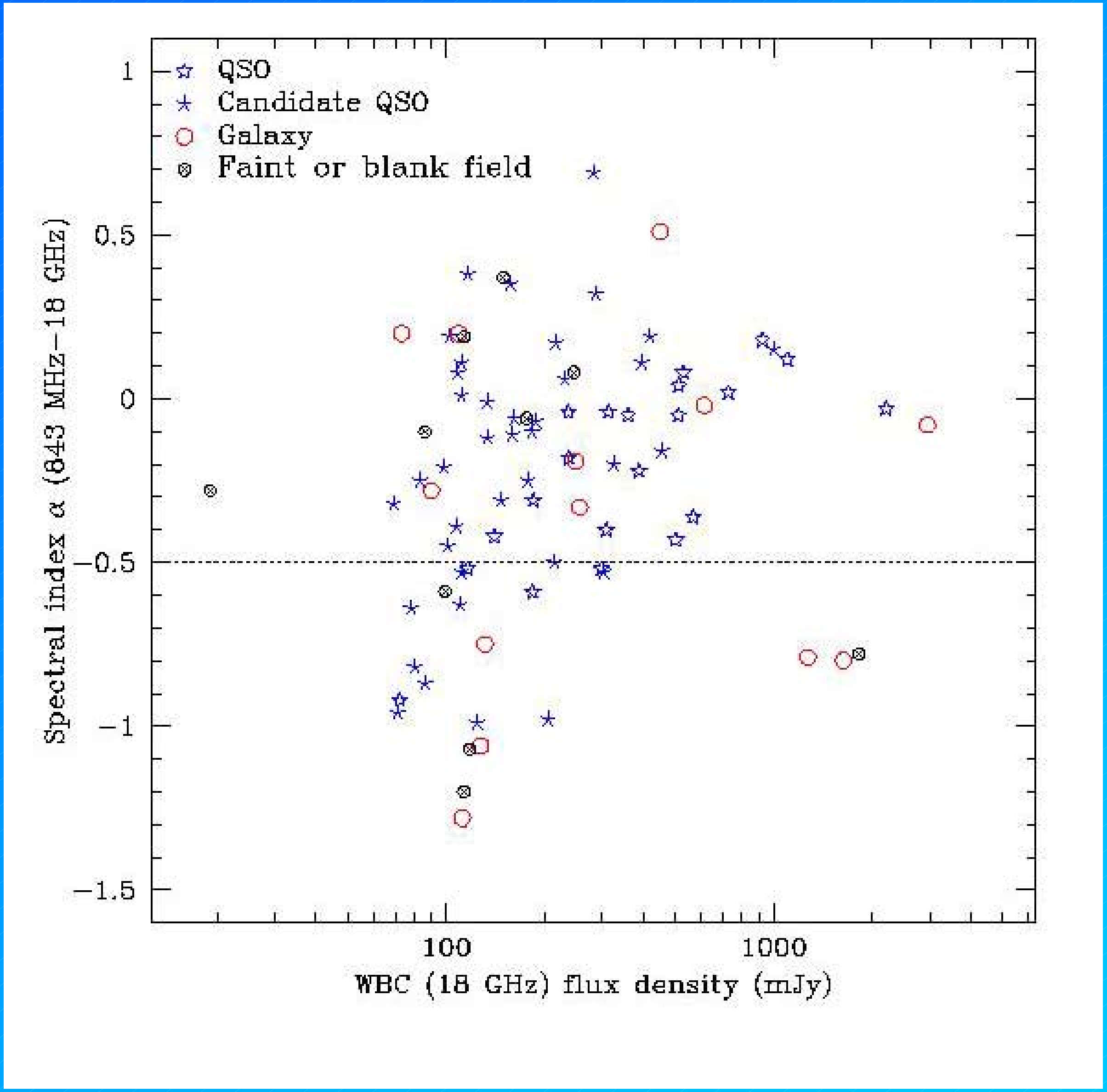
PMNJ 0150-6044 - a new QSO candidate



IRAS 23074-5957 - a galaxy at z=0.142



20 GHz source populations



The next steps…

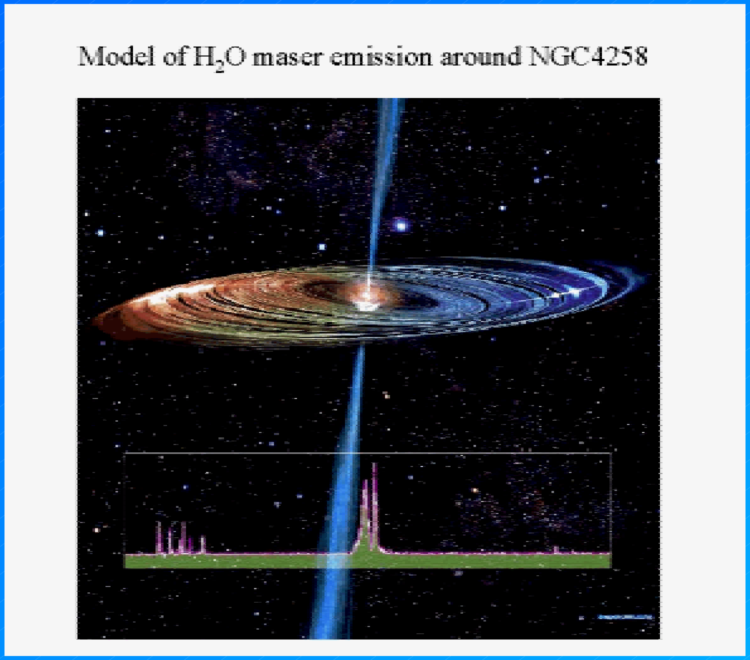
- Radio spectra of confirmed source sample
- Redshift determination (optical spectra)
- Better constraints to models of radio source confusion noise contaminating CMB anisotropies
- Plans for a 20 GHz all southern sky survey in 2003/4

  - 3 ATCA baselines

  -WB correlator (8 GHz BW)

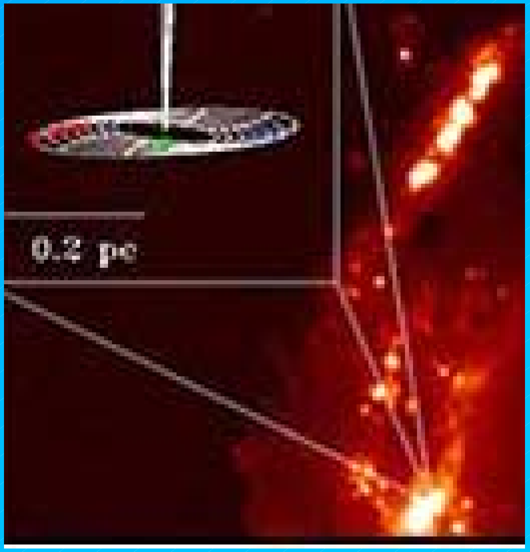
  - simultaneous follow-up capabilities

H_2O maser lines - probes of central black holes



H_20 masers:

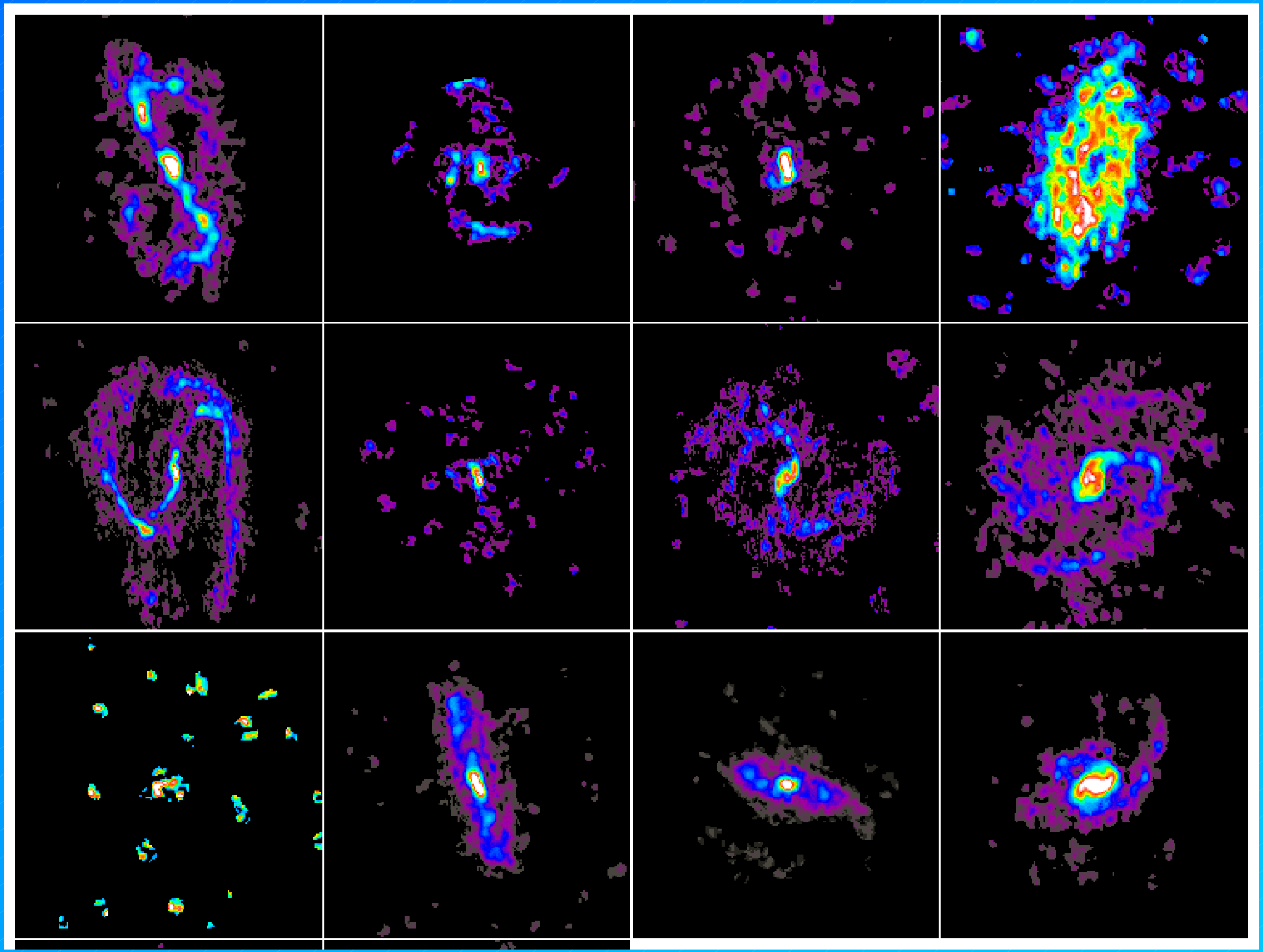
22.235 GHz emission line, searches already in progress with Parkes and ATCA (Greenhill, Ellingsen et al.)



NGC 4258 (D=6.4 Mpc) masers lie in a fast-rotating disk of radius 0.2 pc. Black hole mass ~10^6 M_{sun} (Miyoshi et al. 1995).

CO line emission in galaxies

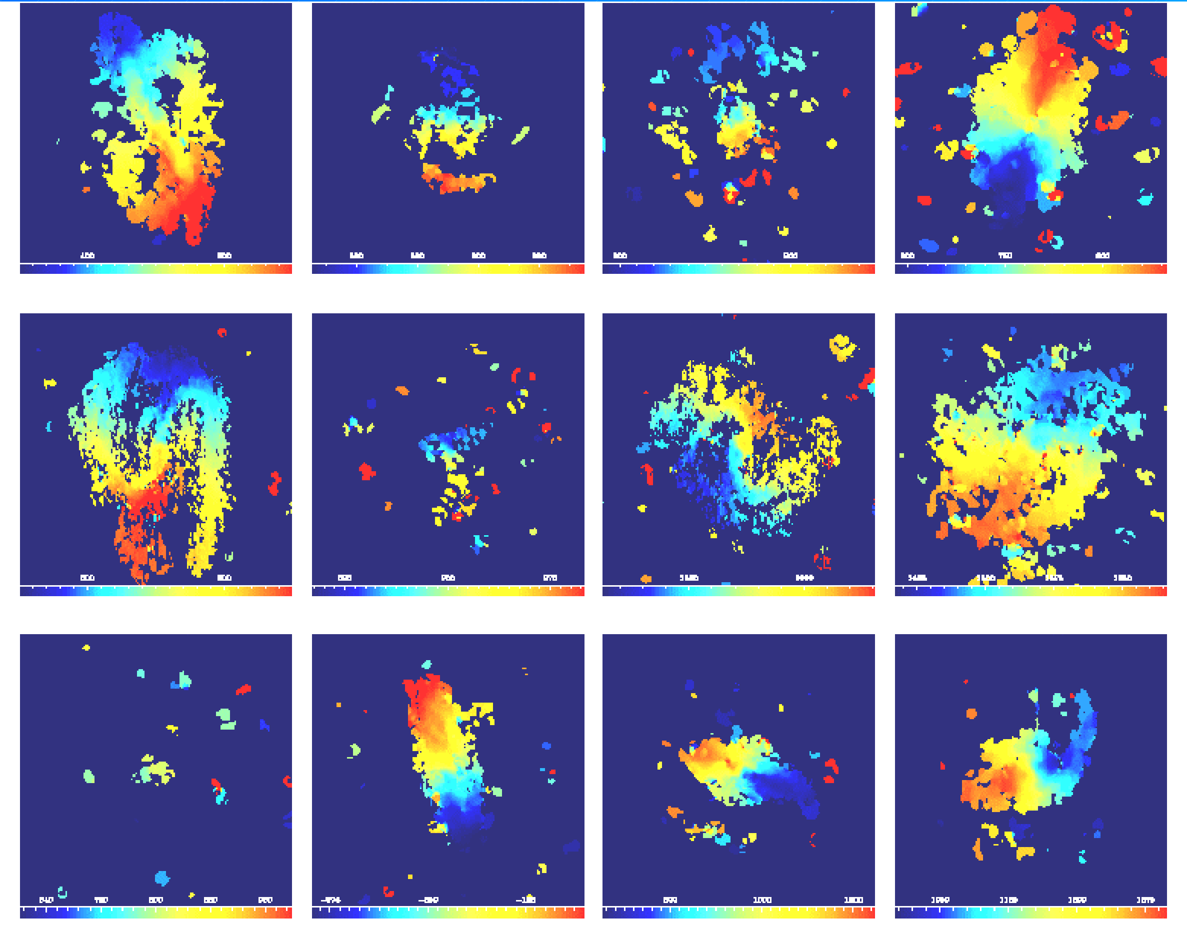
CO J=1-0 rotational line, 115 GHz - nearby spirals



BIMA/SONG survey, Helfer et al. (2003)

CO line emission in galaxies

Probe of gas dynamics, star-formation in inner regions



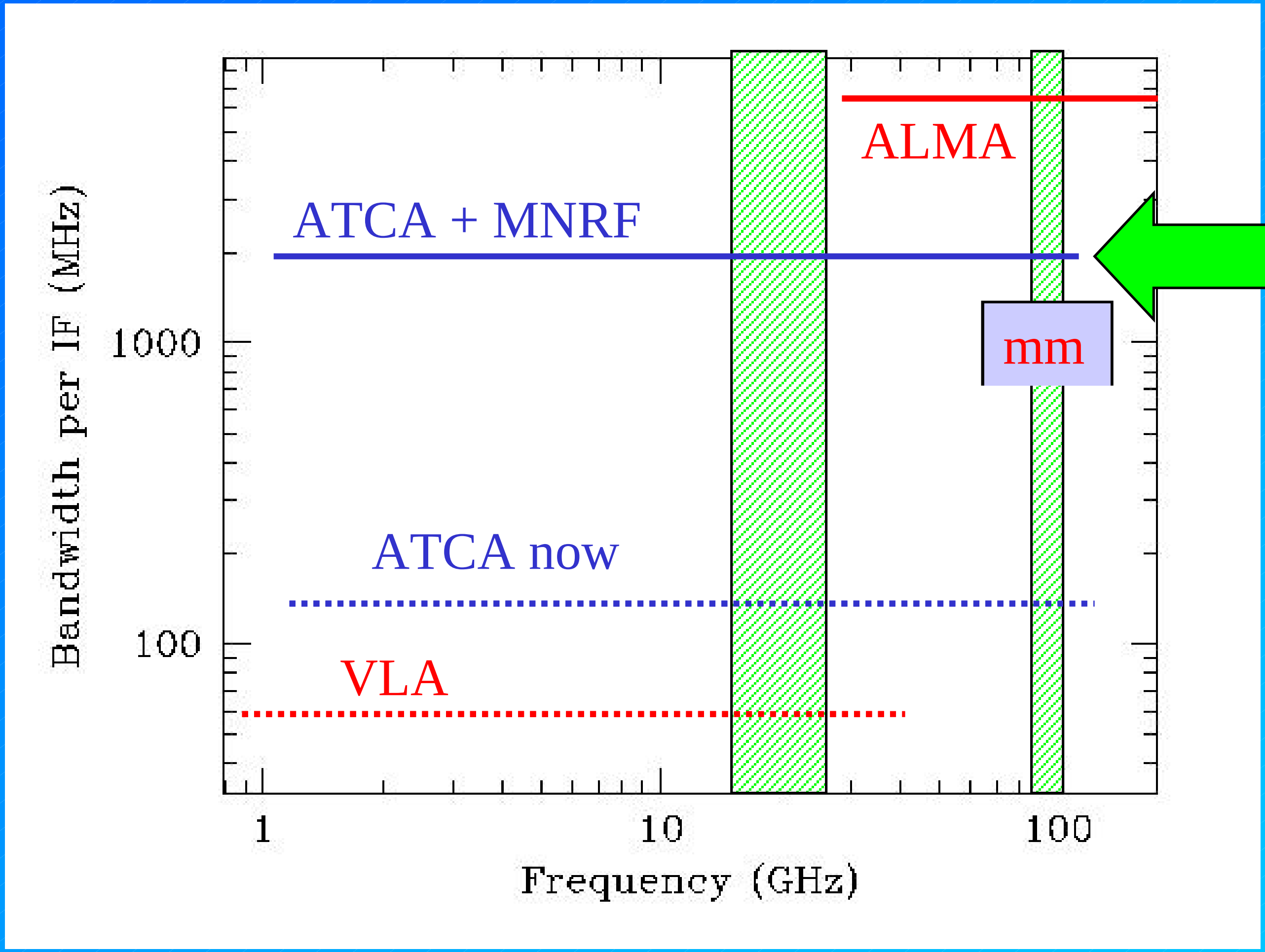
BIMA/SONG survey, Helfer et al. (2003)

Some interesting southern galaxies…

Circinus galaxy - nearest AGN

NGC 5128 - nearest radio galaxy

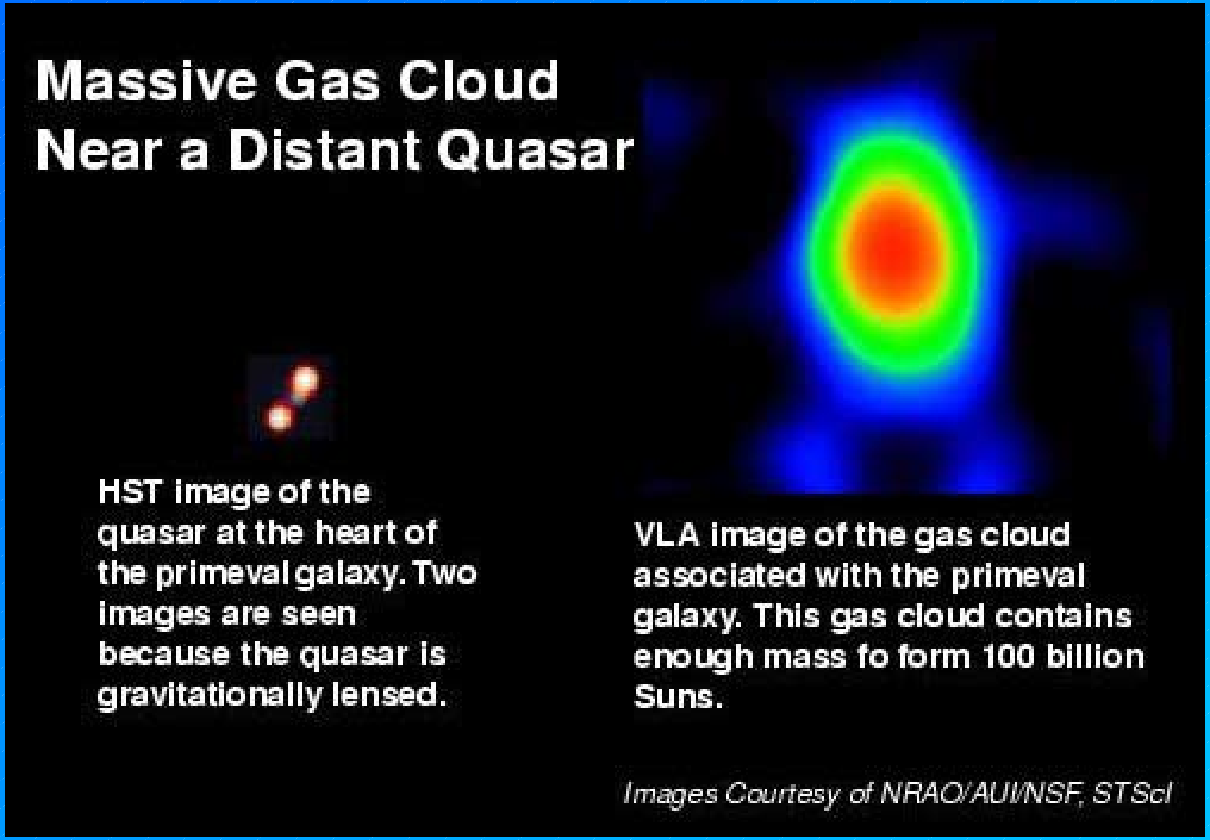
Frequency and bandwidth coverage of current and planned telescopes



From 2006/7, ATCA has *unique* capability for blind CO surveys at z=3.6 to 6

Can the ATCA do the first `blind' CO survey?

High-z CO already seen in pointed observations…



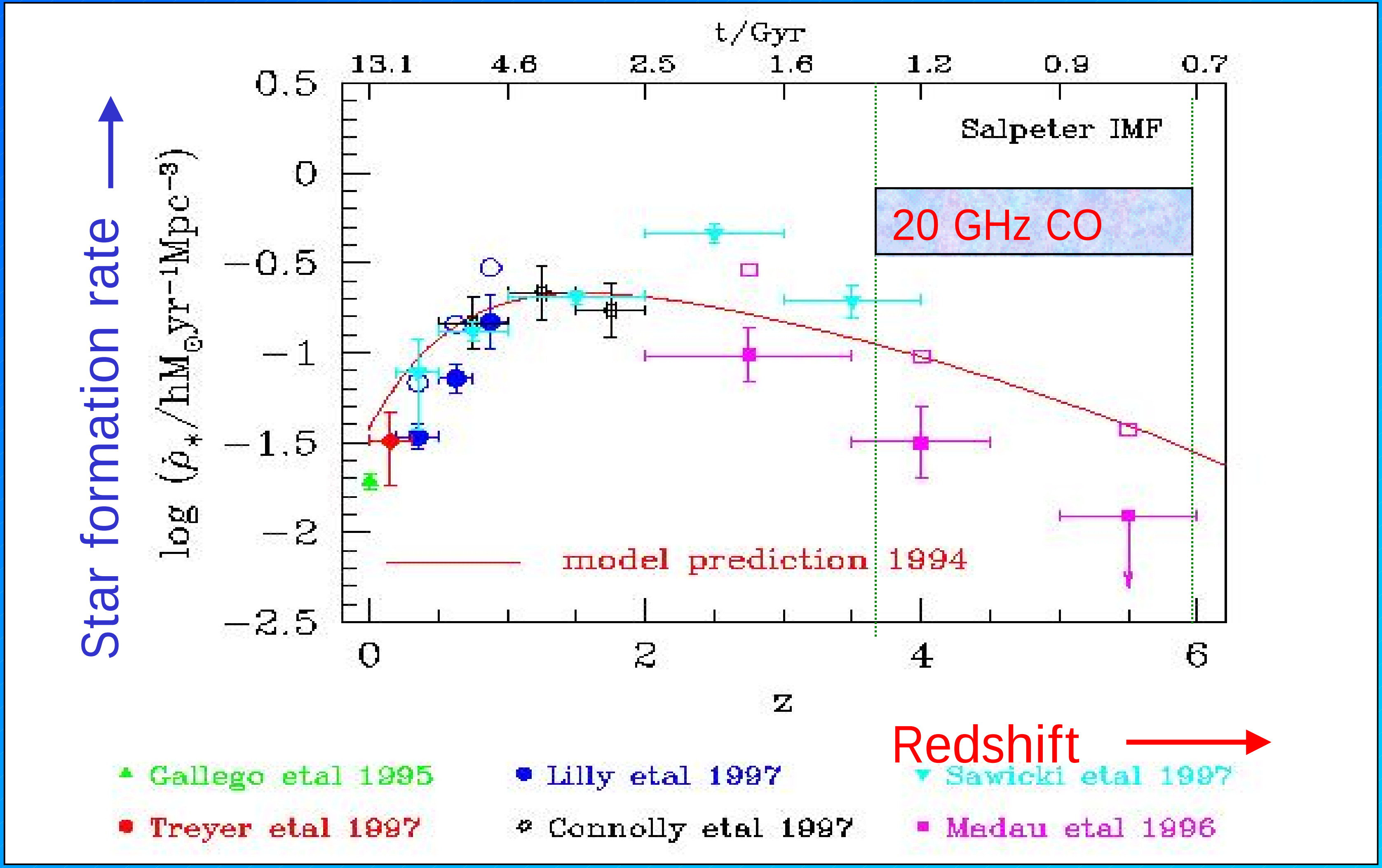
APM 08279+5255

Large (10^{11} M_{sun}) disk of molecular gas in a quasar at z=3.91, detected by the VLA in CO at 23 GHz.

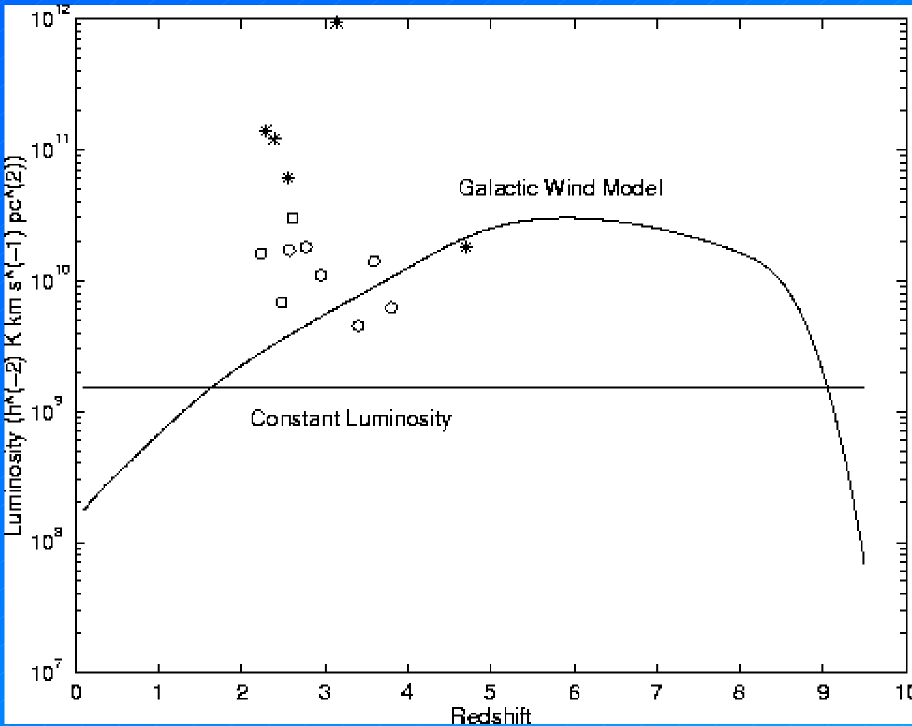
N.B. Grav. lens!

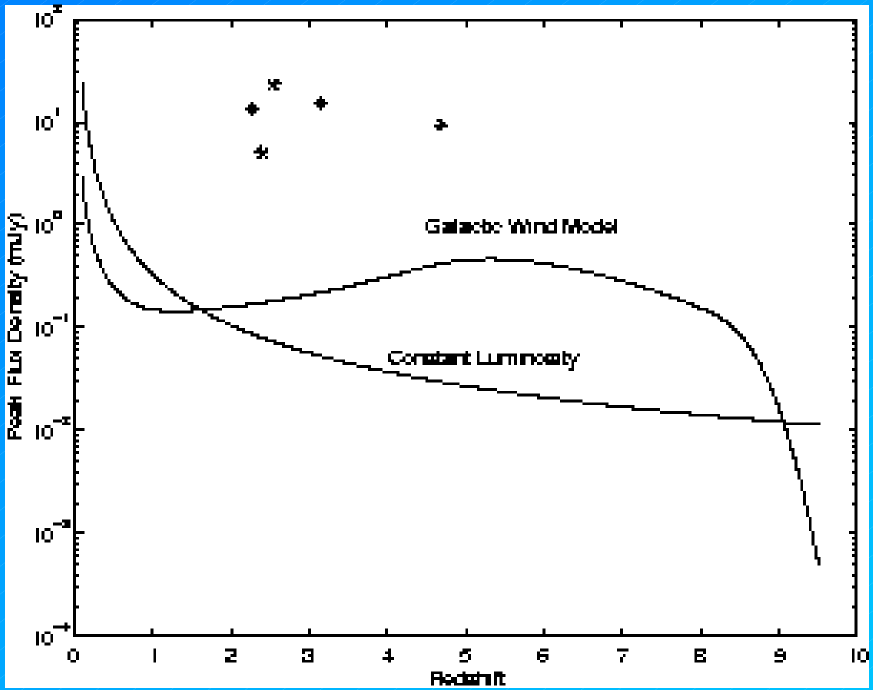
(Papadopoulos et al. 2001; Lewis et al. 2002)

The star formation history of the Universe (Baugh et al. 1998)



Why the 16-25 GHz band?





(Taylor et al, SKA science case)

- CO luminosity predicted to *increase* at higher redshift, peak flux density roughly constant with redshift
- Wider field of view, larger volume of space, better sensitivity and phase stability than in 90 GHz (3 mm) band

Expected detection rate for CO survey

Based on ATCA sensitivity figures, and calculations by Blain et al. (2000):

• A 12hr synthesis with 4 GHz bandwidth at 20 GHz should reach a surface density of ~ 100 galaxies/deg^2 with detectable CO emission (peak flux ~ 0.1 mJy)

• 2.3 arcmin field means expected ATCA `success rate' is ~ one detection per 100 hours for unlensed galaxies, higher for lensed galaxies

• More sensitive CO surveys will need eVLA (2009), ALMA (2010) or SKA

Targeted high-z CO observations

(Ilana Klamer's thesis)

- Only eight galaxies at z>3.6 so far detected in CO (all in N. Hemisphere). CO/dust associated with high rates of star formation, often seen in QSOs (AGN/starburst connection?)
- Many detections are grav. lensed objects (magnification factors up to ~10)
- Not clear yet whether J=1-0 is strongest CO transition - work to be done!
- Southern ATCA targets - high-z radio galaxies, QSOs with known redshift. First observations tomorrow!