Size and resolution of the compact radio sources in ARP220

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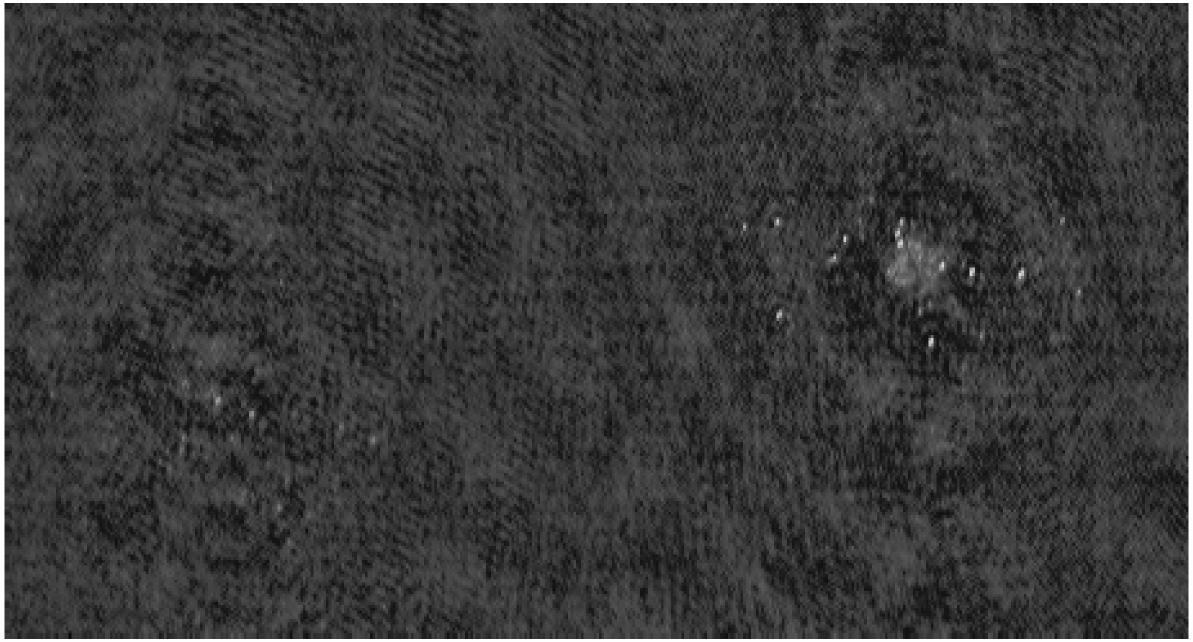
Outline

- Previous radio observations of ARP220.
- New 2cm and 3.6cm data
- Source size and resolution
- Source Spectra
- Conclusions and the future

18cm Global VLBI – A starburst revealed

Arp220, 77 Mpc, East and West Nucleus. Prototype ULIRG.

450 pc



Smith et al (1998), Rovilos et al (2003), Lonsdale et al (2006), decade long monitoring campaign. Never detected at $\lambda<18$cm?

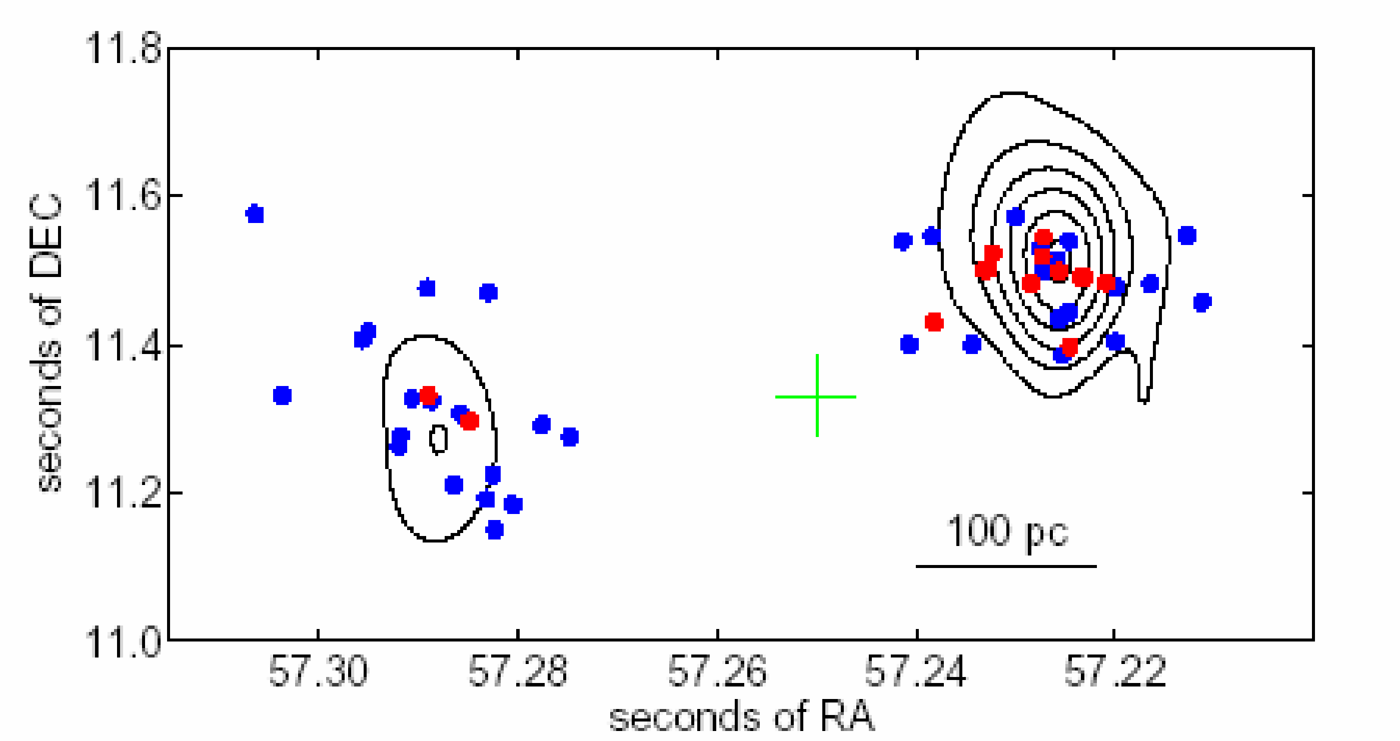
Pretty picture-but why important?

- Arp220 is closest ULIRG (L_fir >10^(12) Lsol). If we don’t understand this we don’t understand nuclear SF.
- SNe and SNR can probe respectively stellar evolution and ISM Pressure/density.
- Probe top end of IMF and can constrain it in regions with 100’s mag of optical extinction.
- Are ULIRGs just scaled up disk star-formation? Or fundamentally different?

18cm Monitoring Results

- Rate of appearance of new sources, estimated 4 ± 2 year/yr (Lonsdale et al 2006).
- Many 18 cm light curves too stable to be SNe (Rovilos, 2003).
- Nothing detected at shorter wavelengths (Rovilos et al 2003).

ARP220 - 6 cm Eb–Wb–Ar @ 1 Gbit/s COLA Sample

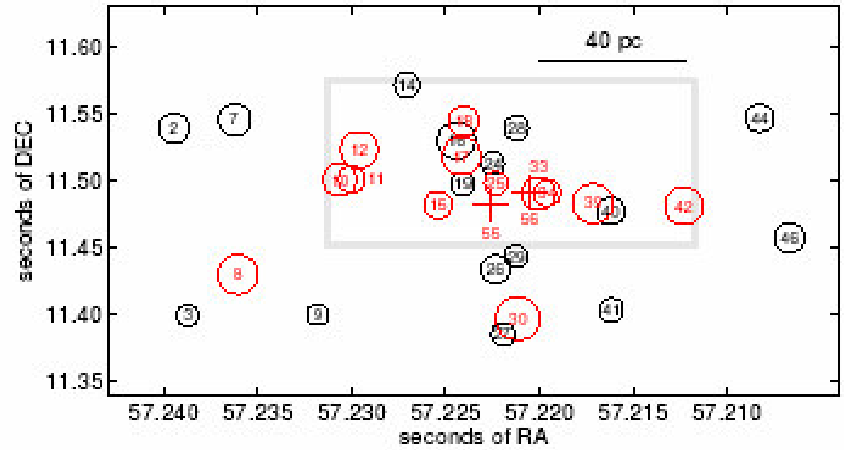


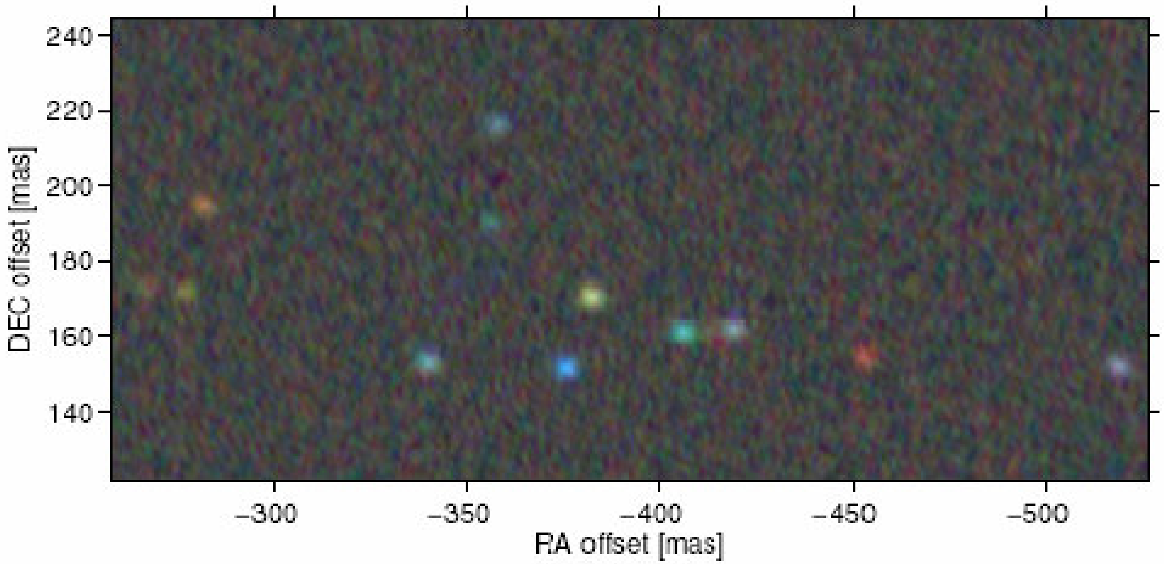
10mins of data, contours show delay-rate map. Dots are Lonsdale et al compact sources.

First detection of compact sources at λ<18cm!! (calibrator too distant, solar max)

13, 6 and 3.6 cm VLBA, January 2006

Parra et al., 2007

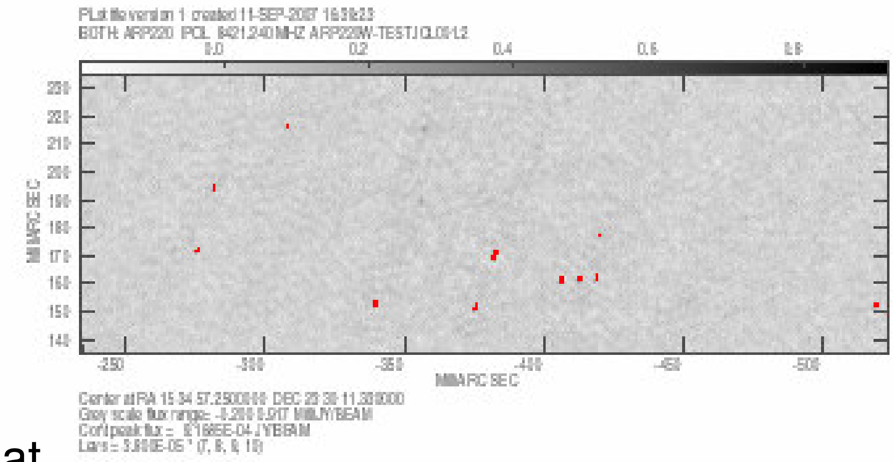




RGB (13,6,4cm bands respectively) composite image of the central region of the western nucleus (Parra et al. 2007, ApJ 658,314). Also three sources detected in Eastern nucleus.

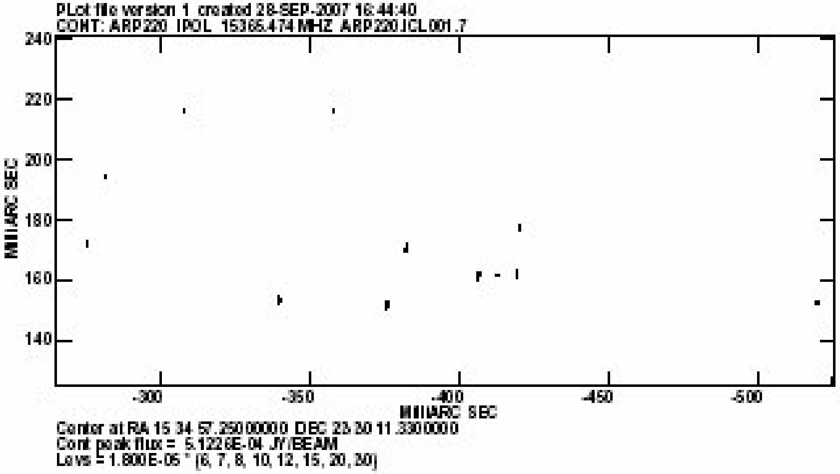
New VLBI data, 3.6cm (global) and 2cm (HSA), Nov/Dec 2006, three to four times deeper than VLBA only epoch 11 months earlier.

3.6cm, 35 μJy/beam

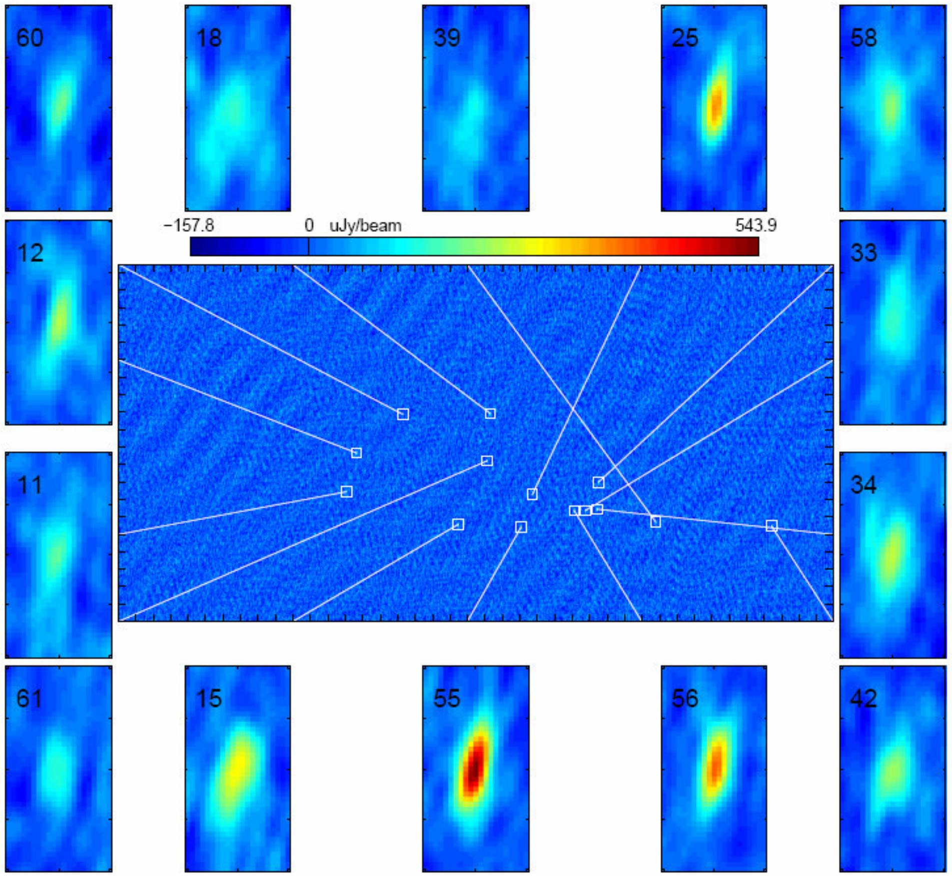


3 newly detected sources – both at 3.6cm and 2cm. No 18cm counterparts.

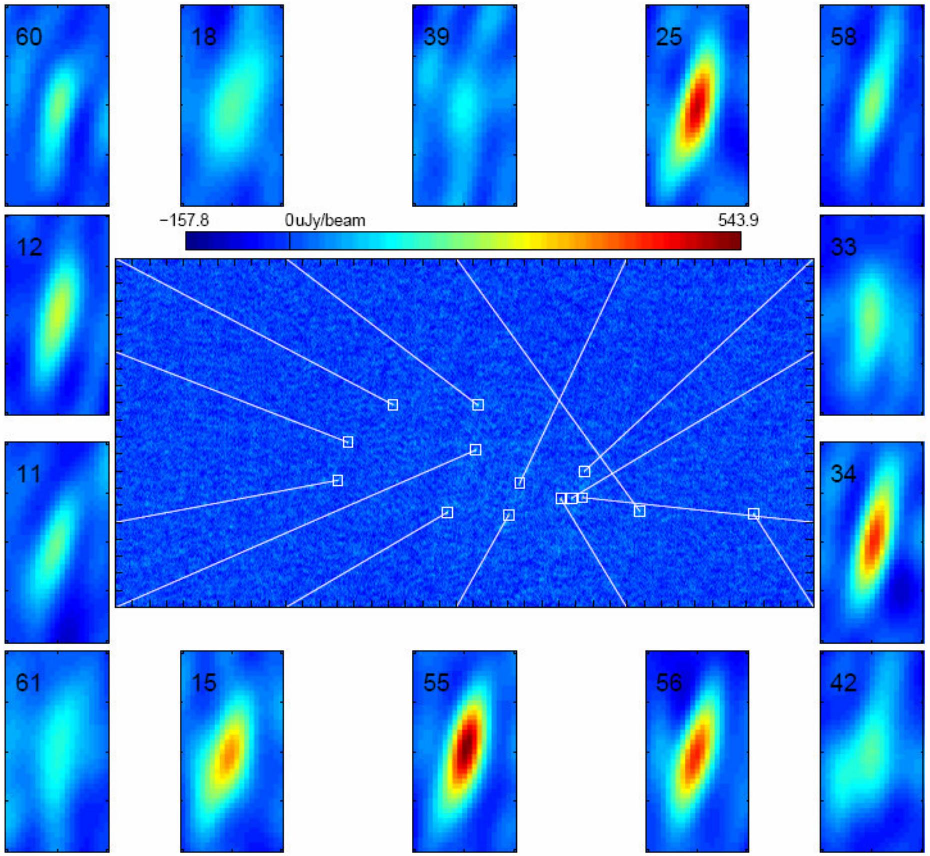
2cm, 28 μJy/beam



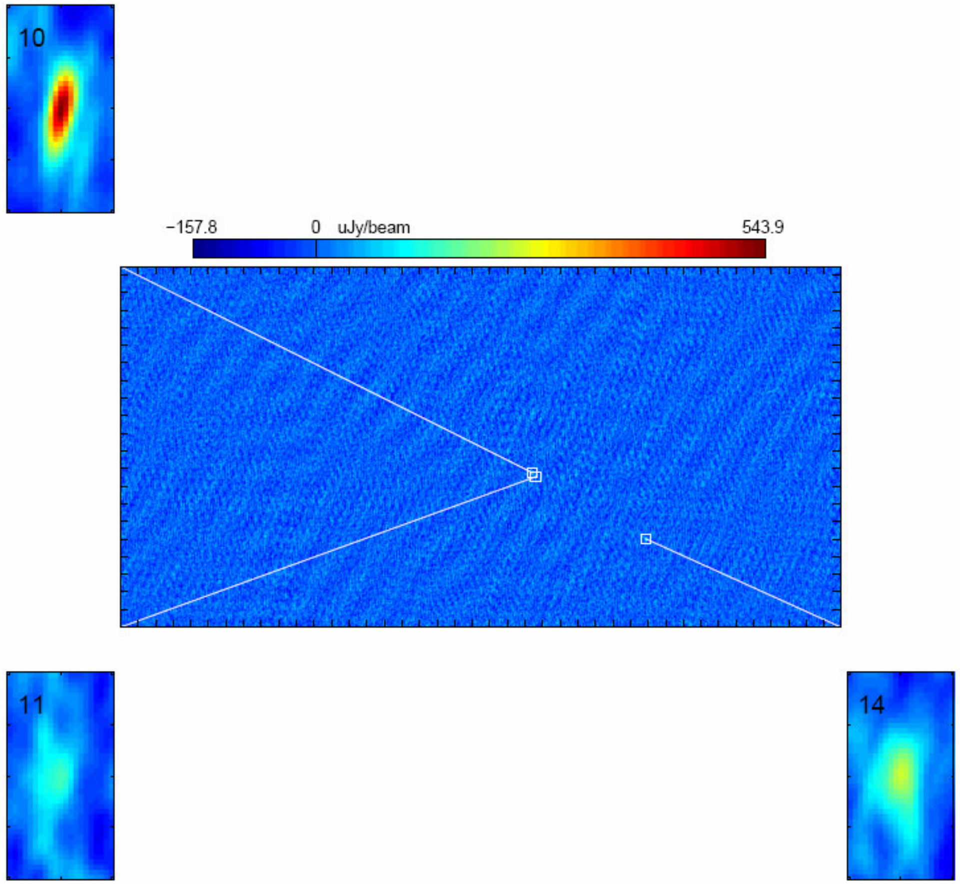
U West



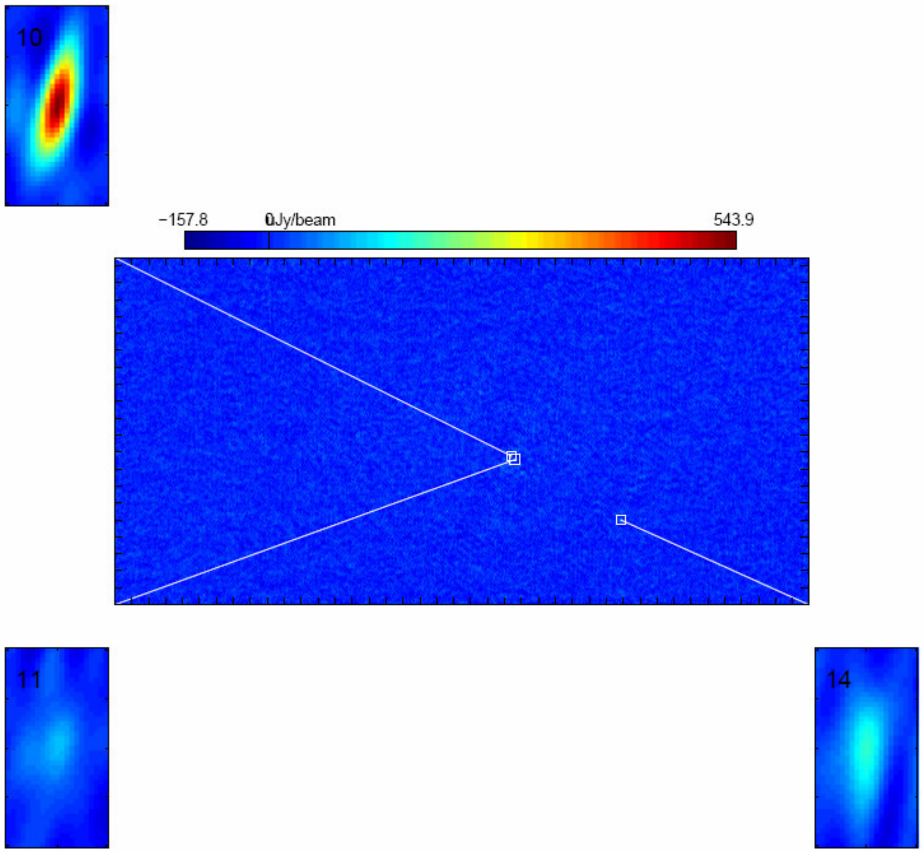
X West



U East



X East



Source resolution

- Our objective is to see if the sources are resolved. If a source is resolved we can find its size.
- Combining size and age we can work out expansion velocities.

Source resolution

- Recap – interferometry
- Point source (delta fct) * beam (gaussian) = beam
- $\delta(x-x_0, y-y_0) * I_p exp\{\frac{-\Delta X'^2}{2\sigma_x^2}\} = I_p exp\{\frac{-\Delta X'^2}{2\sigma_x^2}\}$ (4) the observation size is bigger than the beam we say that the source is resolved (not an underlying point source).

Source resolution

- Need to calculate the dispersion of the source along the minor axis and compare to beam.

- Dispersion of observation (along minor axis)

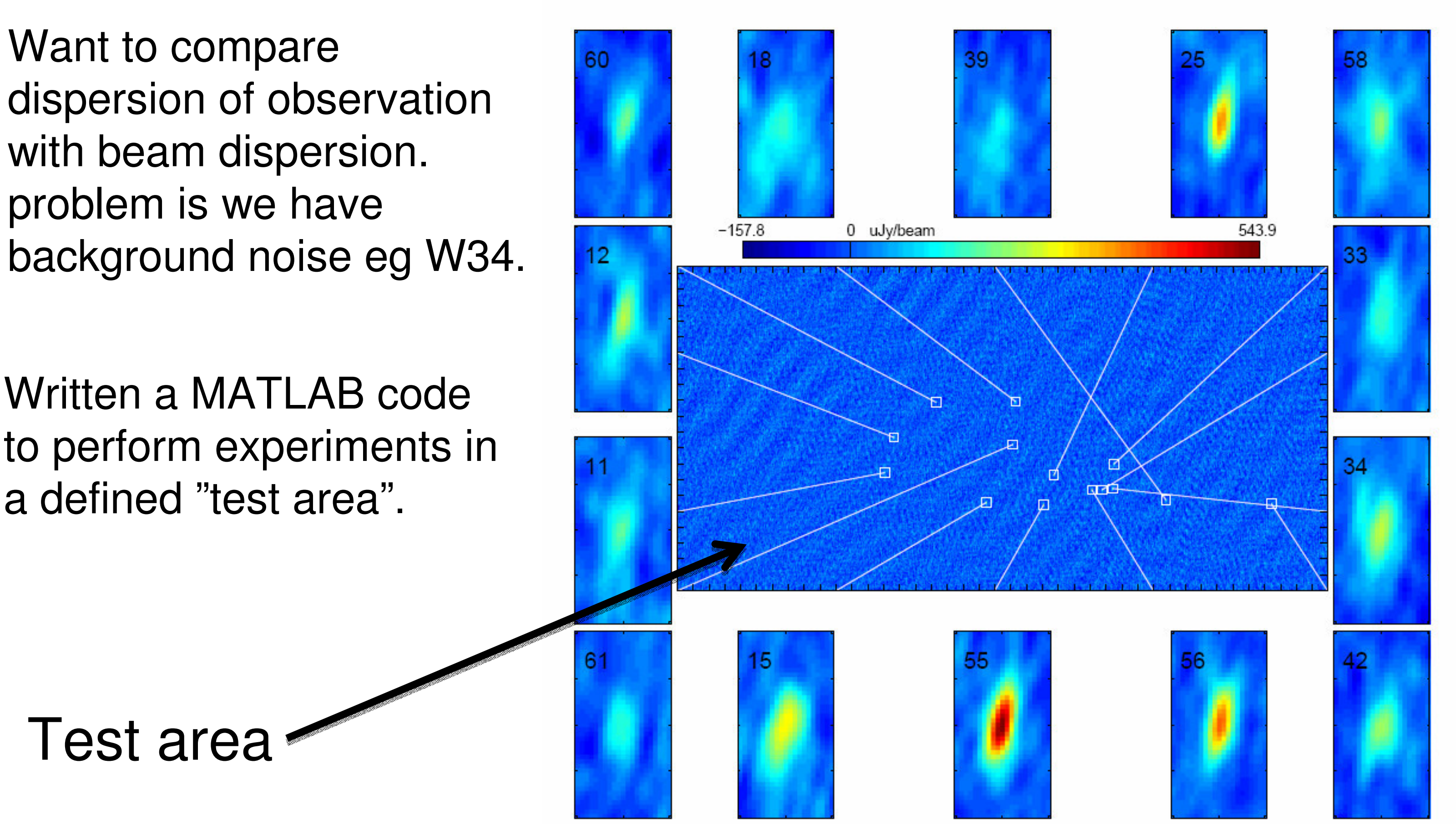
  $\sigma(obs) = \int I(x,y)(x-\mu)dx \,/\, \int I(x,y)dx$

- Dispersion of Gaussian beam $\sigma_x = FWHM/\sqrt{8 ln2}$

Resolution

Want to compare dispersion of observation with beam dispersion. problem is we have background noise eg W34.

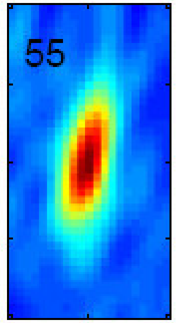
Written a MATLAB code to perform experiments in a defined "test area".



Want to quantify the risk of b.g noise contributing significantly to dispersion measurement.

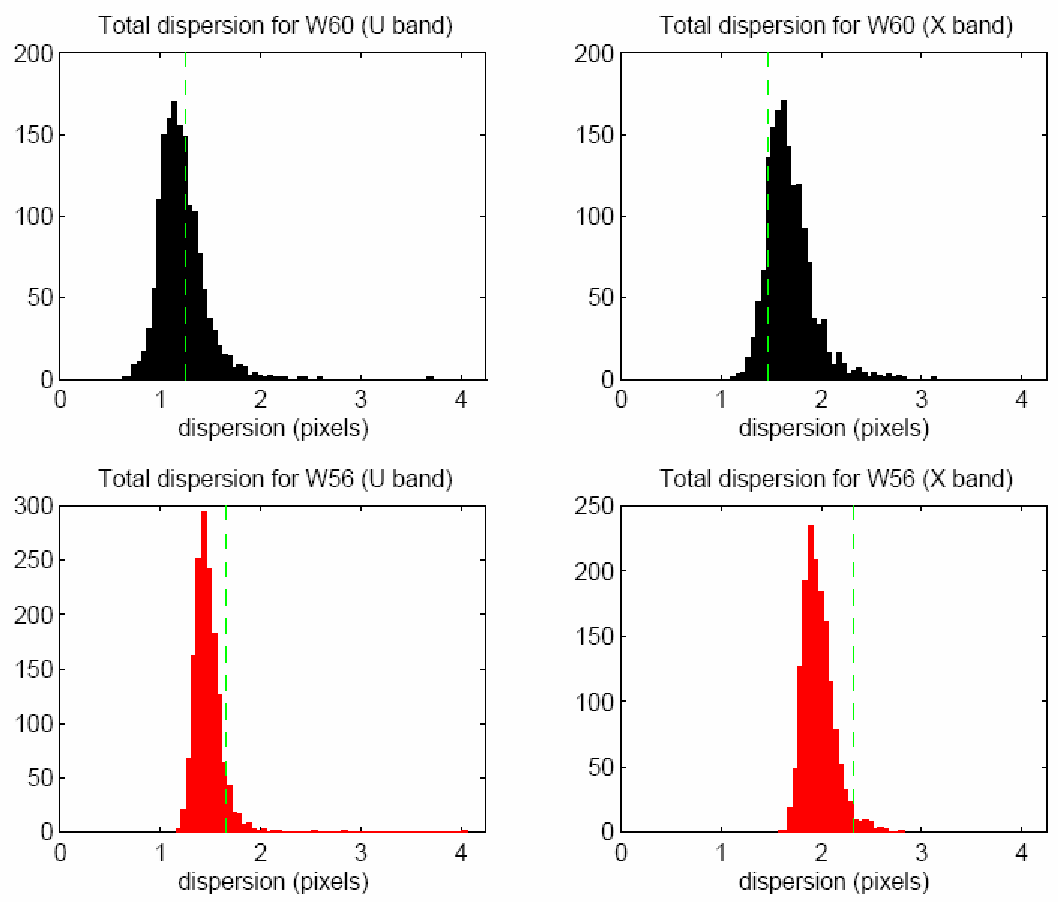
Definitions

- Source = Actual, physical radio emitting region of ARP220.
- Observation = (source * beam) + noise =



- Model = observation peak intensity (Ip) * beam (FWHM from AIPS)

Histogram A



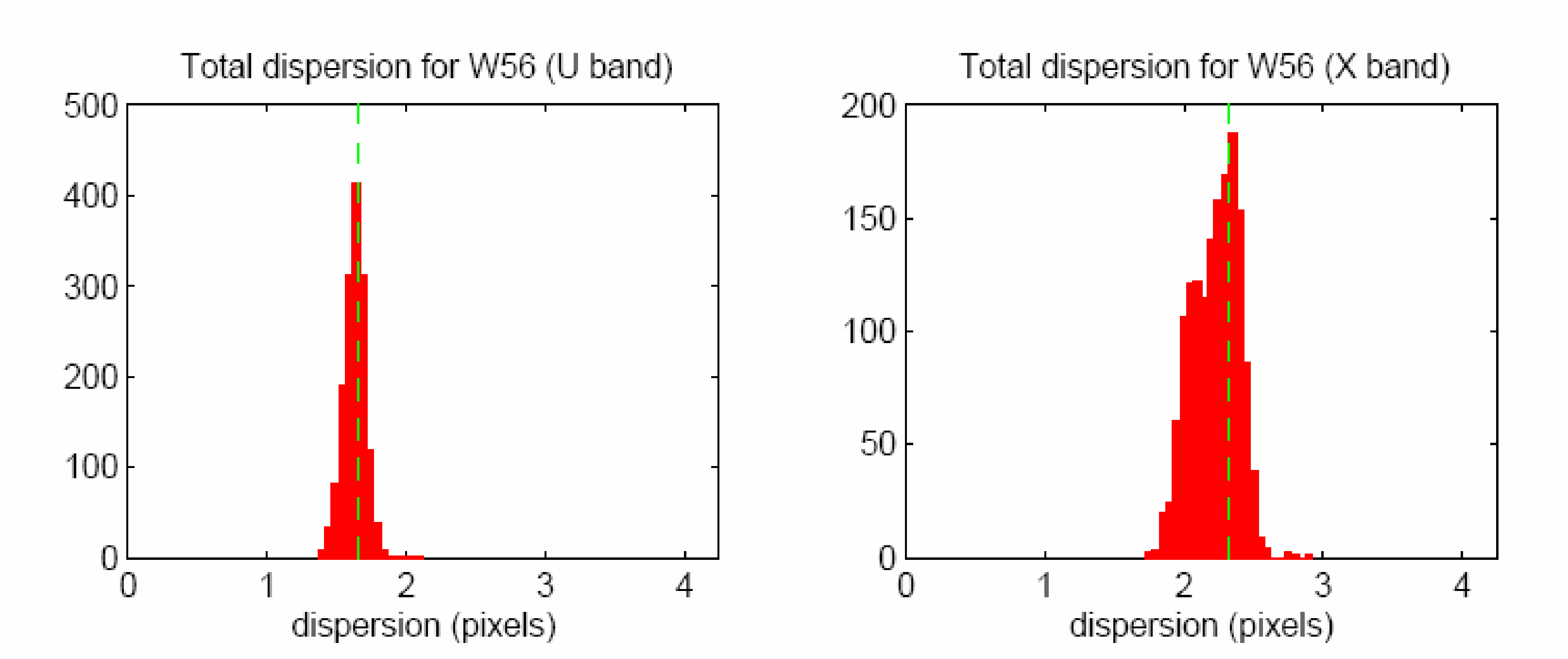
Dashed green line shows dispersion of observation at its position in the map.

We place our model (point source * beam) at 1521 independent positions in our test area and populate histogram A.

Our criteria for resolution is if the dispersion of the observation is greater than the models dispersion in >90% of the cases

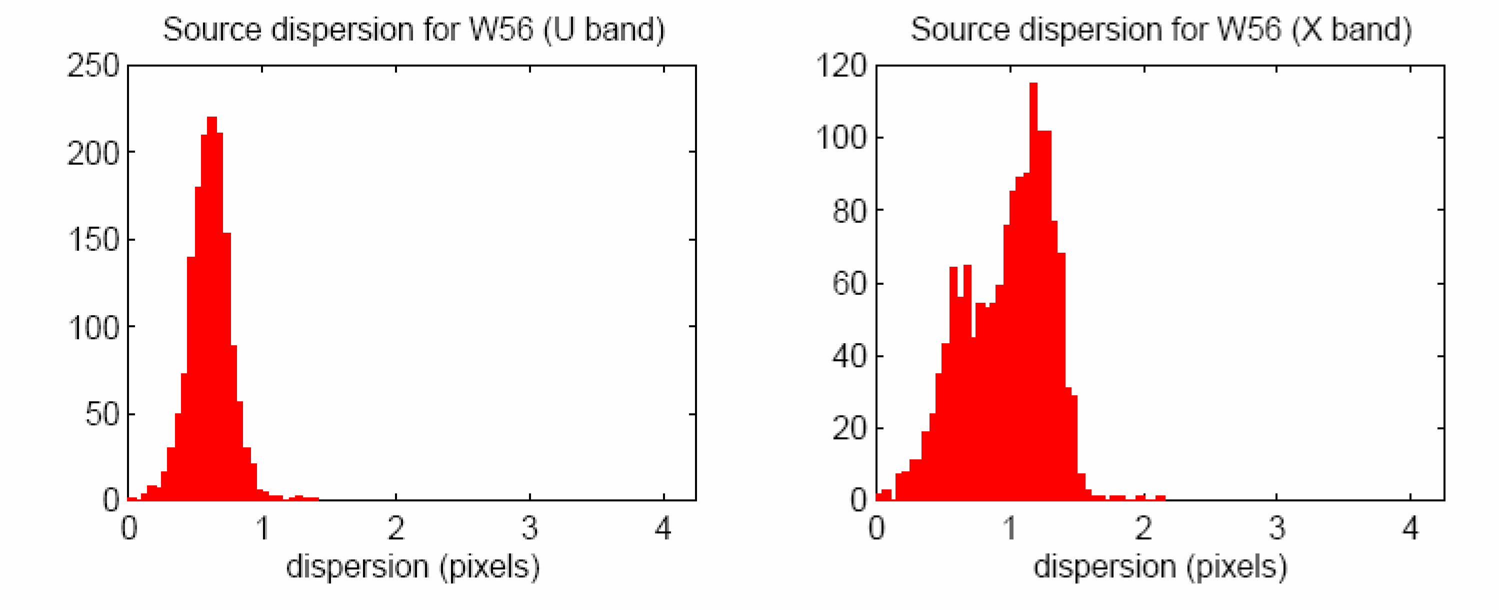
Red = resolved
Black = non resolved

Histogram B



Green line is rather Arbitrary. Place masked observation at 1521 places in test area
Measure dispersion and populate histogram B. Take mean and consider this the
size of (true source * beam).

Histogram C



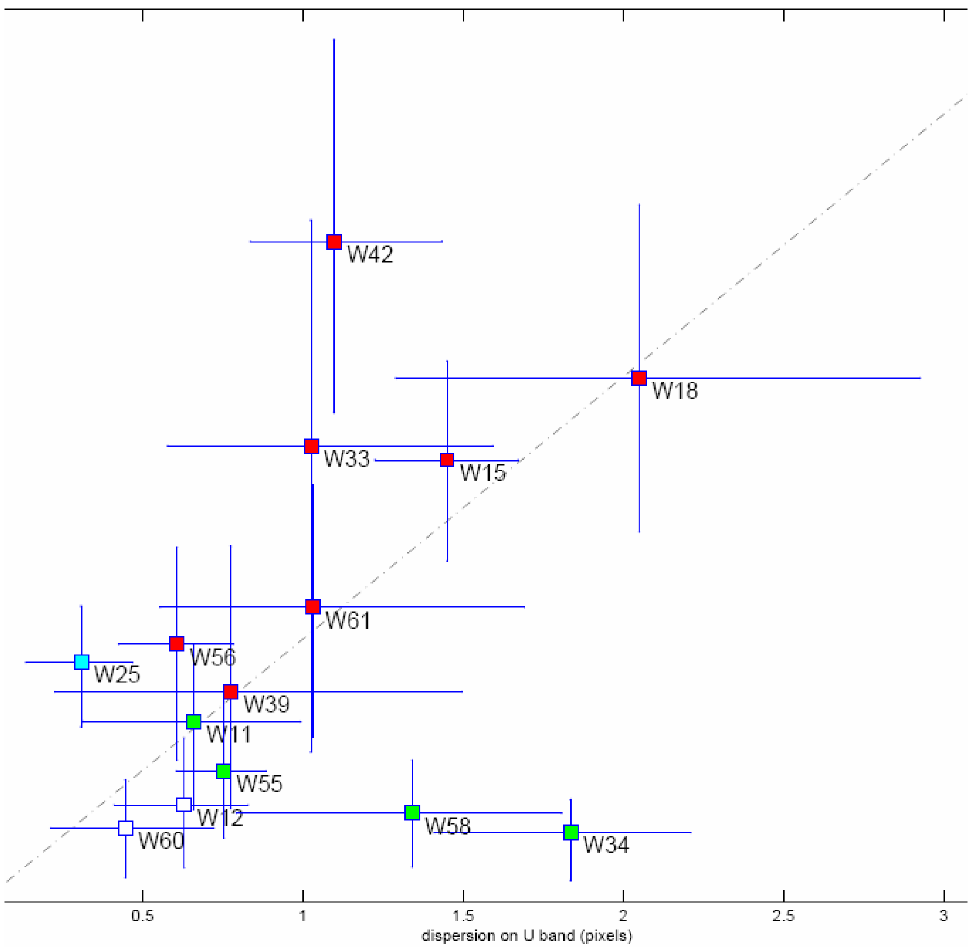
Finally to get the dispersion of the true, physical underlying radio source we Populate histogram C according to

$$\sigma_{source} = \sqrt{(\sigma_{obs})^2 - (\sigma_{beam})^2}$$

Take the mean of this as source dispersion measurement. Errors (10th – 90th Percentile).

Errors West

X



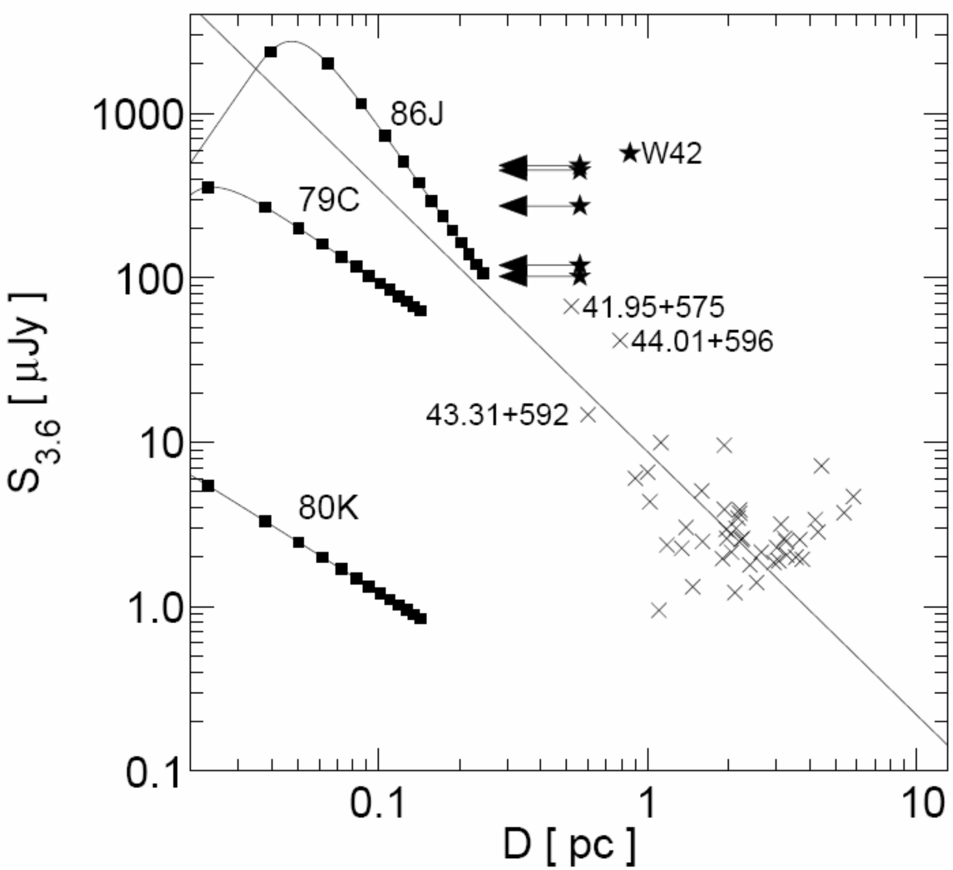
10th – 90th percentile

U

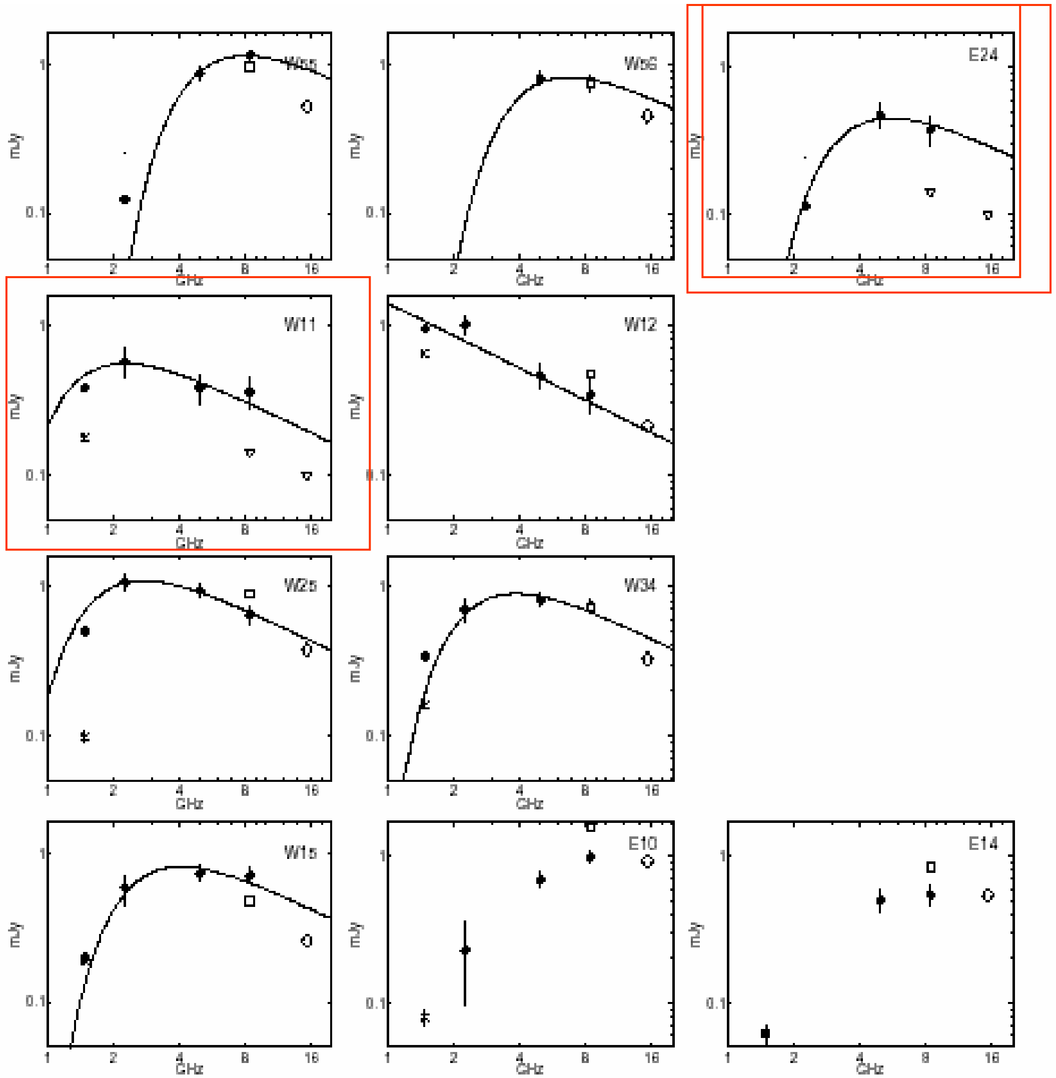
Expansion velocities

- 1 pix = 0.1mas (defined)
- 1mas = 0.374pc (at distace of ARP220, 77Mpc)
- 1pc ≈ 3.09 x 10^13 km
- 1yr = 3.16 x 10^7 sec
- Source sizes range from ~0.02pc – ~0.08pc
- Source velocities range from ~ 4000 – ~30000 km/s

Sigma – D relationship

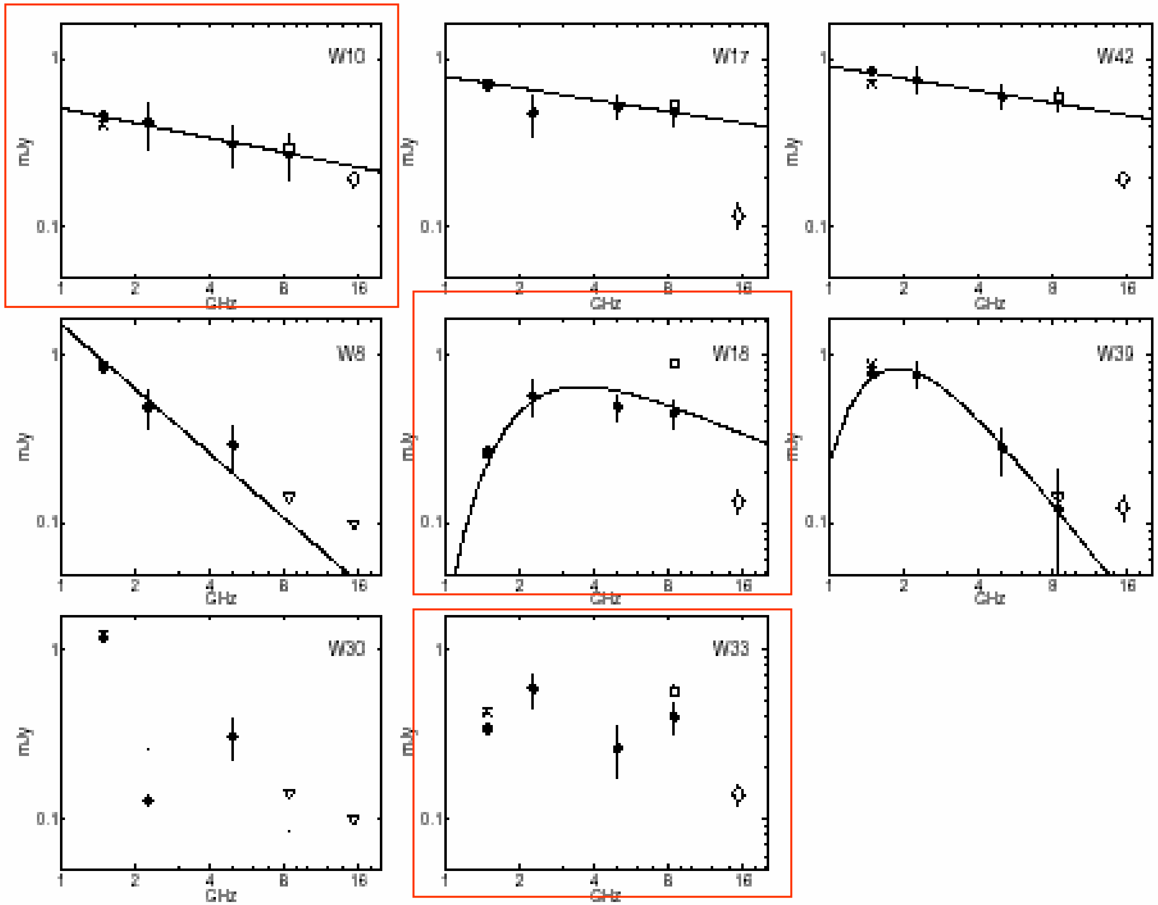


Can plot our 9 resolved sources on luminosity diameter diagram for SNRs.



Revised/extended spectra for ‘recent’ sources appearing after 1995

Two sources, have faded drastically at 3.6cm in 11 months (Ib/c, IIb).



Updated spectra of long lived sources

Two sources show high variability and/or weird spectra. One is still flat to 2cm. (best candidates for an AGN core?)

Future

- Complete analysis and publish paper on source sizes.
- Applied for multi-frequency VLBI monitoring every 4 months.
- In 1 hour, at 5GHz -8GHz, SKA could detect Arp220 SNe/SNR out to 30 times distance, i.e. z=0.5.
- Problem is confusion, hard to separate individual sources at this z. Need 3000km-6000km baselines and higher frequency.

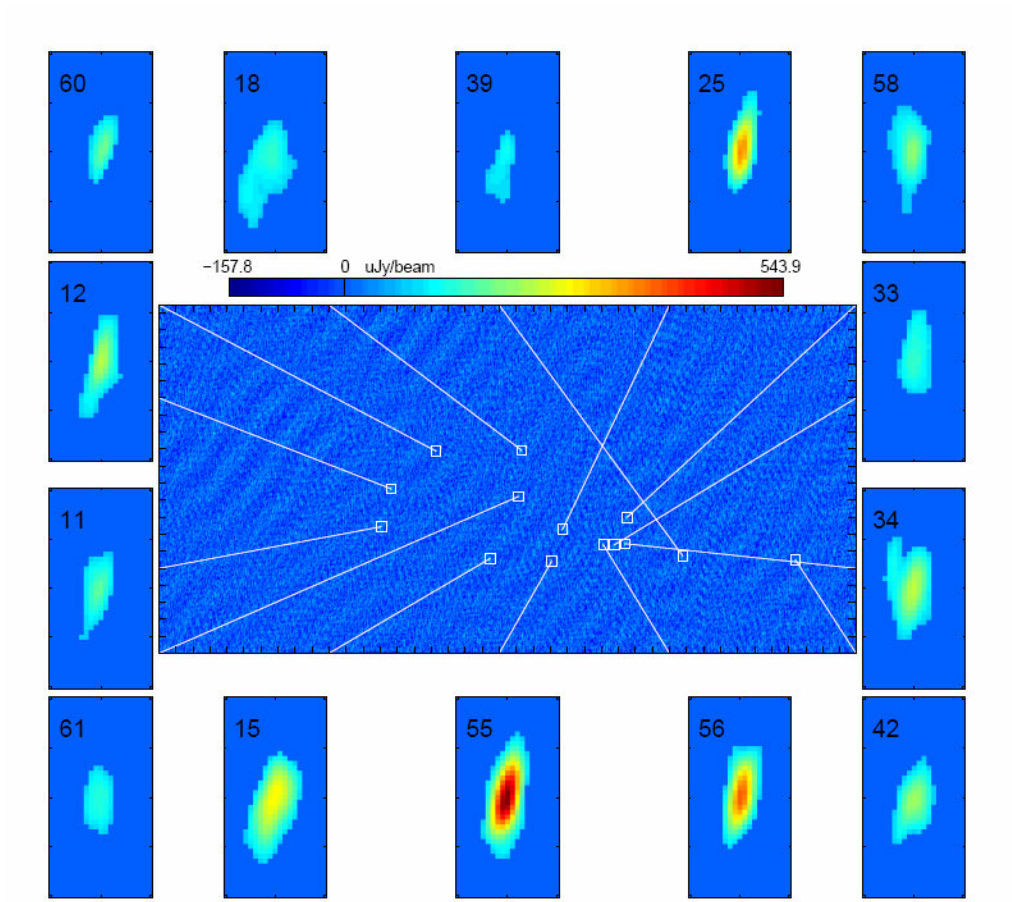
Conclusions

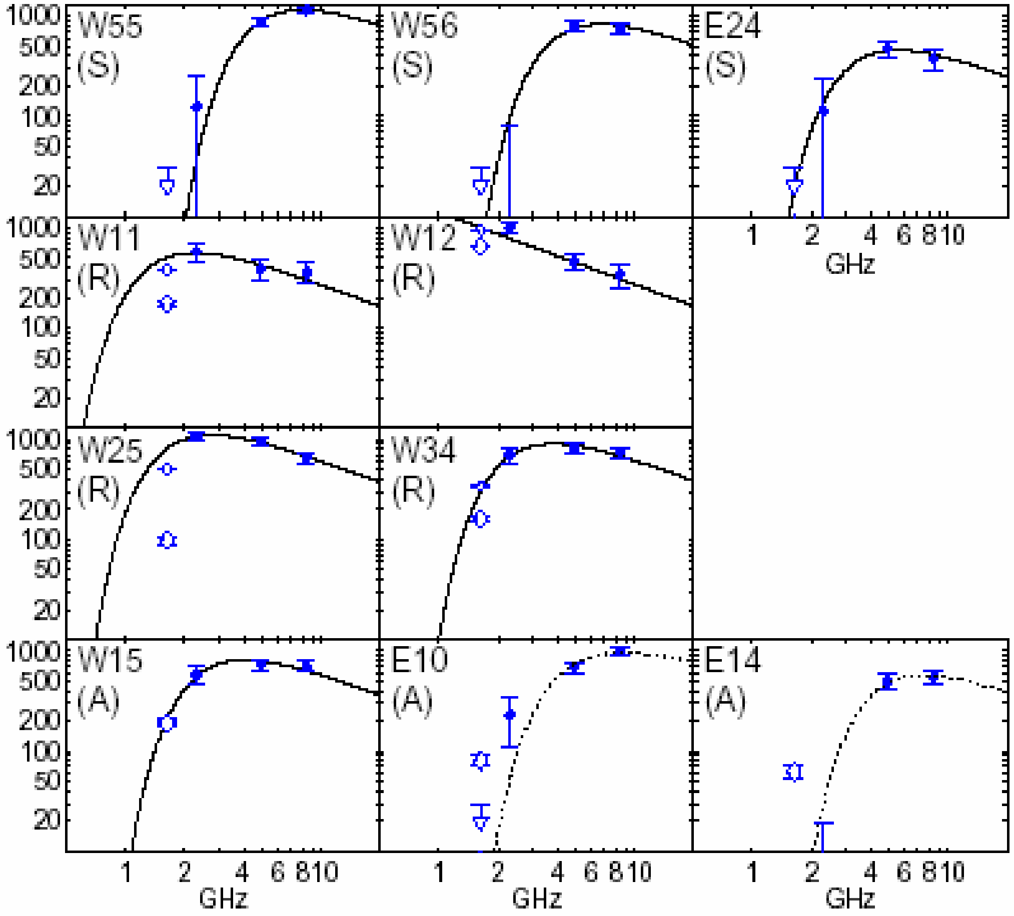
- We claim 9 sources to be resolved at both U band and X band.
- Source sizes range from ~0.04pc – ~0.16pc diameter
- Source velocities range from ~ 4000 km/s – ~30000 km/s
- Our results are consistent with models and other observations eg in M82.
- SNe/SNR can be used to probe IMF and ISM pressure/density in LIRGS/ULIRGS
- Most sources behave like standard SNe/SNR but a few oddballs, plerions?, AGN?, new classes of object?

Collaborators

- John E. Conway, Fabien Batejat (Onsala)
- Philip J. Diamond, Jodrell Bank.
- Rodrigo Parra, APEX.
- Colin J. Lonsdale, Haystack, MIT.
- Carol J. Lonsdale, IPAC, Caltech.

Additional slides – Blanked U W





New sources since Smith et al (1998) discovery paper which are also detected at high frequency. Majority modeled as power law plus free-free absorption-evolution consistent with SNe, evolving in progenitor wind bubbles.

SNe rate, SFR, IMF

- From FIR luminosity estimate a star formation rate of 110 Msol/yr.
- For a standard (Salpeter) IMF implies a total core collapse SNe rate of 2 per year.
- We see on average two new bright radio sources per year, but they are of the most luminous class type IIn, which in disks account for only 2% of core collapse SNe.! (possibly progenitors >80Msol). Oops mismatch of 50!
- Parra et al proposed very top heavy IMFs, weird stellar evolution, very short bursts.
- Possible general implications for extragalactic astronomy – nuclear starbursts not just scaled up galactic star-formation – can we trust the SFR indicators used in cosmological studies?

Source resolution

$$I(x,y) = I_p exp\{\frac{-\Delta X'^2}{2\sigma_x^2} - \frac{-\Delta Y'^2}{2\sigma_y^2}\} \qquad (1)$$

$$I_p/2 = I_p exp\{\frac{-\Delta X'^2}{2\sigma_x^2}\} \qquad (2)$$

$$\sigma_x = FWHM/\sqrt{8ln2}$$

$$\delta(x-x_0, y-y_0) * I_p exp\{\frac{-\Delta X'^2}{2\sigma_x^2}\} = I_p exp\{\frac{-\Delta X'^2}{2\sigma_x^2}\} \qquad (4)$$

$$\sigma_{source} = \sqrt{(\sigma_{obs})^2 - (\sigma_{beam})^2}$$