High Redshift Starbursts in the Hubble Deep Field

Tom Muxlow

Anita Richards, Peter Wilkinson, Simon Garrington, Eric Richards, Ken Kellermann, Ed Fomalont, Brian Anderson, Bruce Partridge, Dave Axon

Evolution of Starbursts Conference

16th – 20th August 2004

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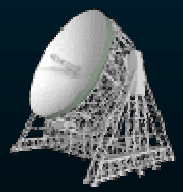

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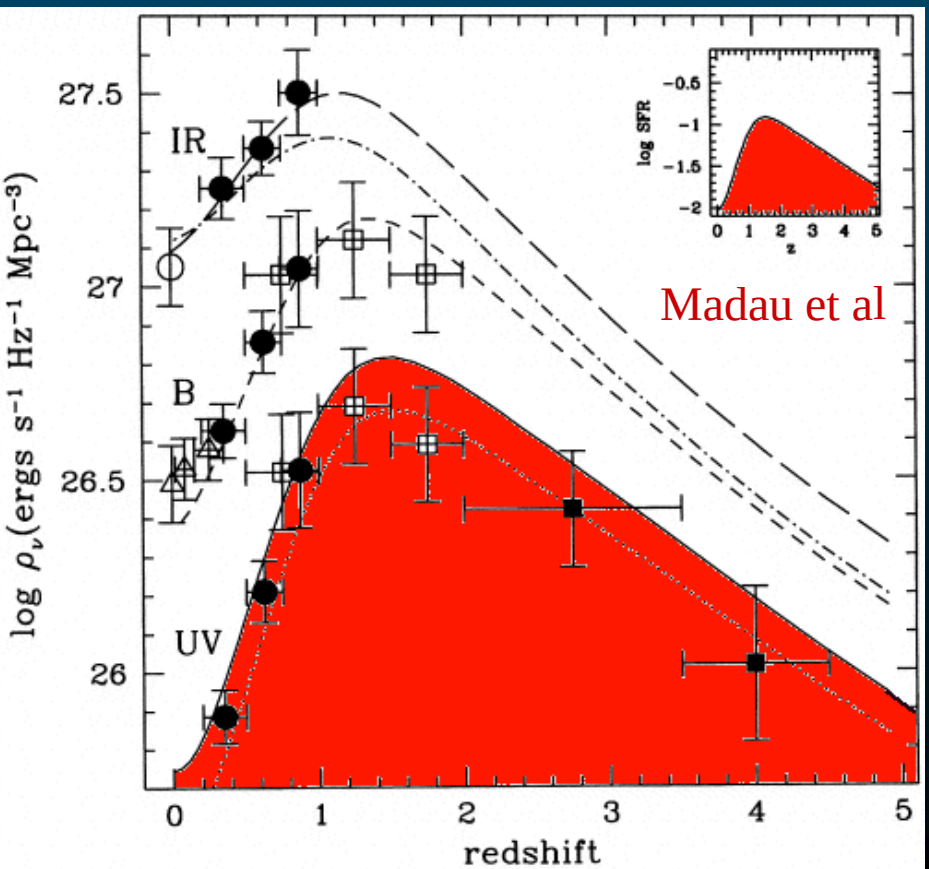
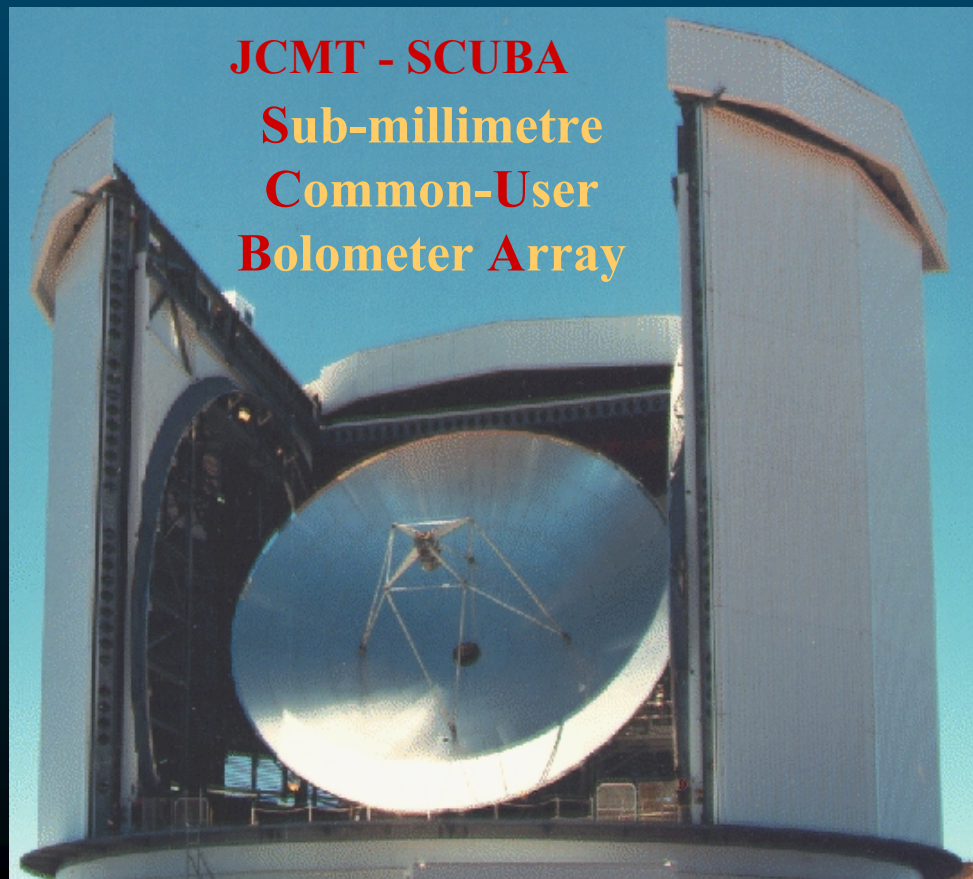
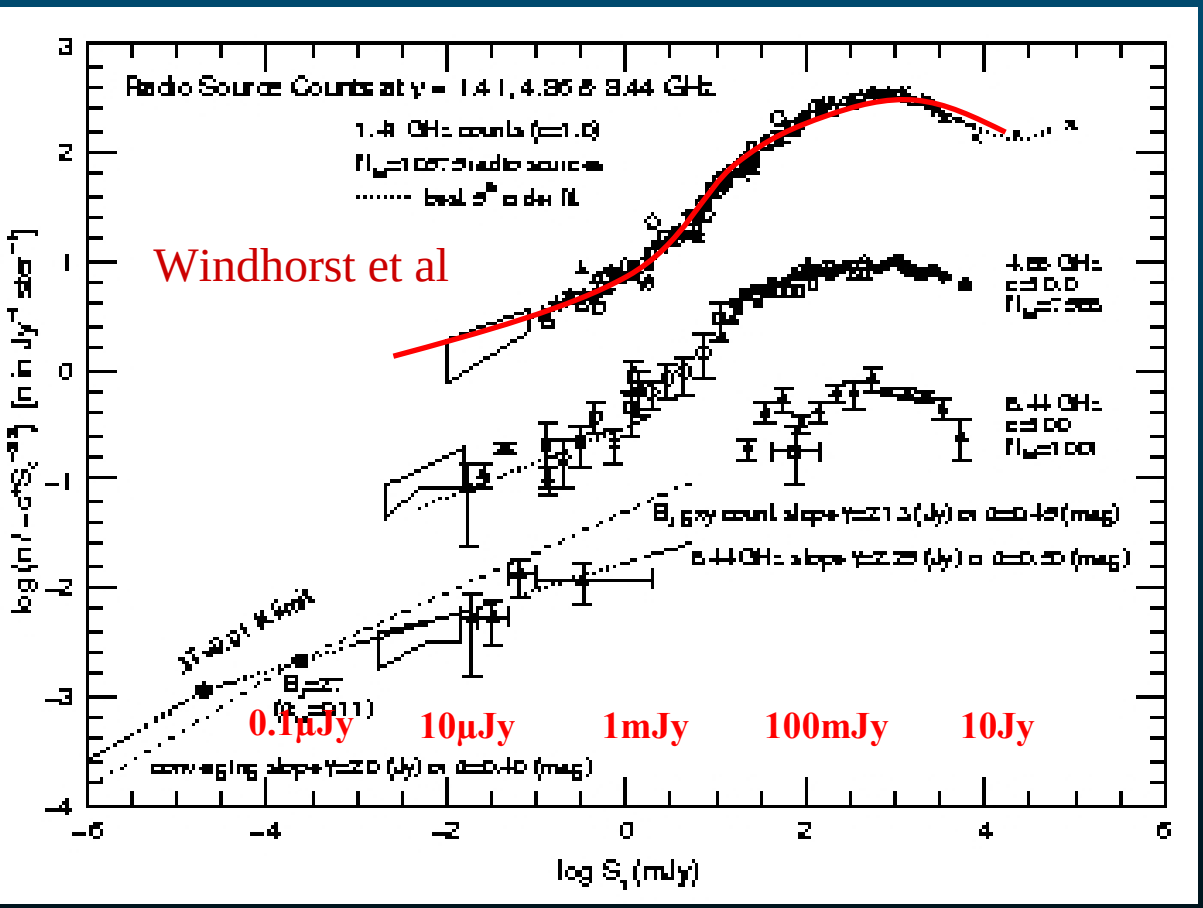
Star-formation At High Redshift

Infra-red, sub-mm, and radio observations are revealing enhanced star-formation at high redshift. Some of these systems may be dust obscured





µJy Radio Source Population

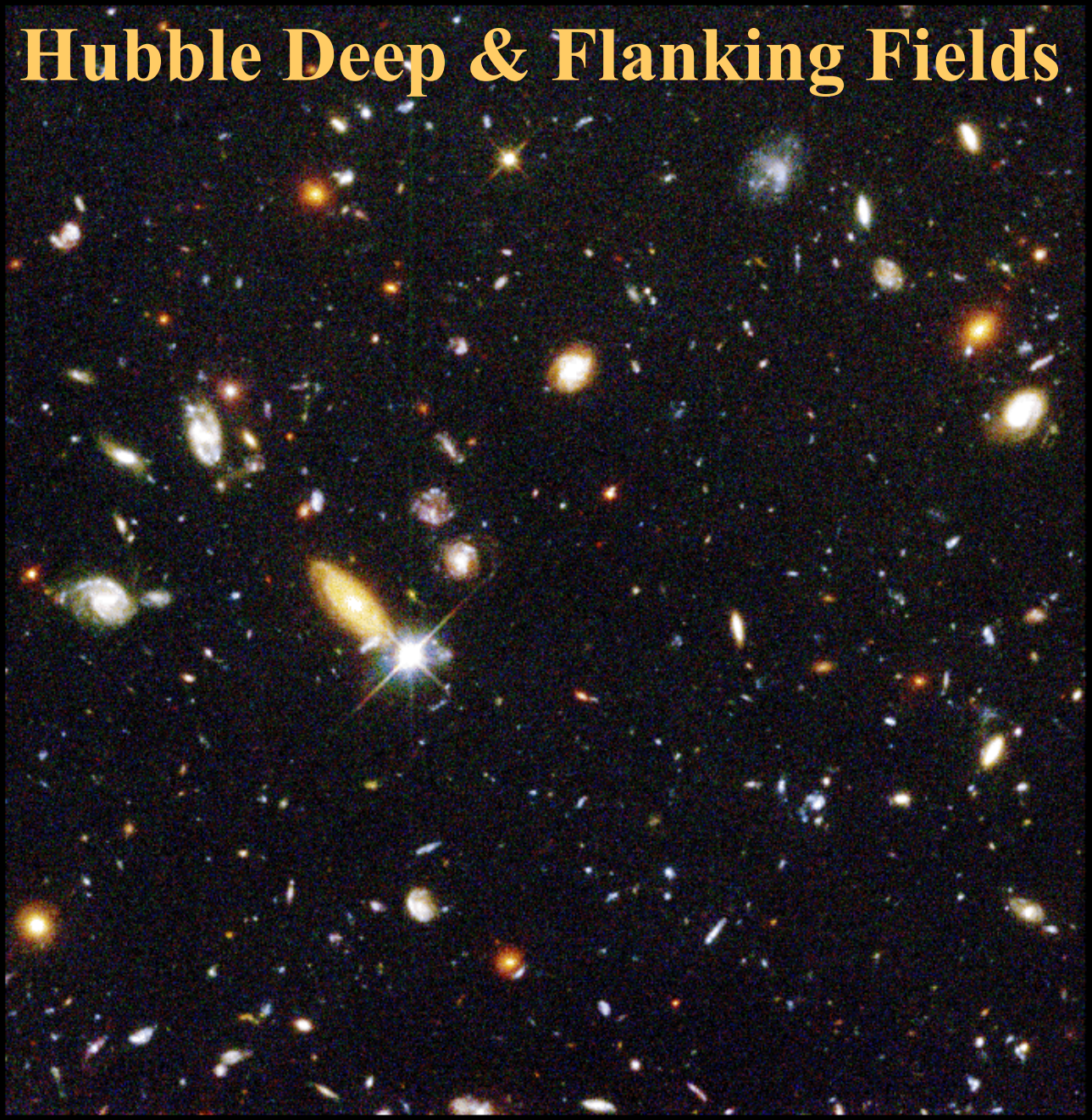


- Differential source counts show an upturn below flux densities of a few mJy
- A new population of starburst systems ?

The Hubble Deep Field – A Window On The Distant Universe

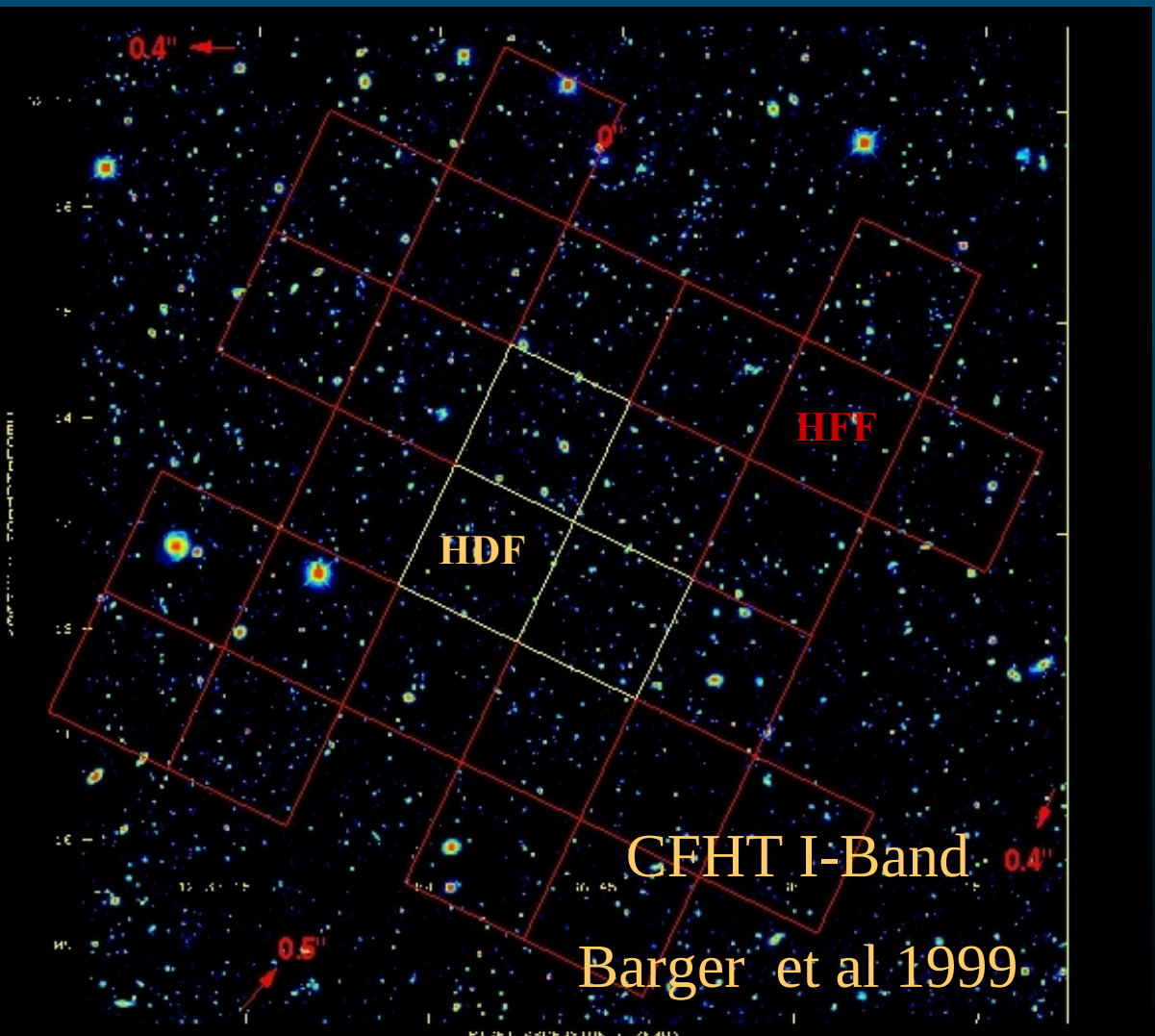
- ~2500 distant galaxies in an area covering just 5.3 square arcminutes.
- Are we seeing a population of distant starburst galaxies ?
- With such a crowded field, astrometric alignment between wavebands is essential in order to obtain reliable identifications

Hubble Deep & Flanking Fields

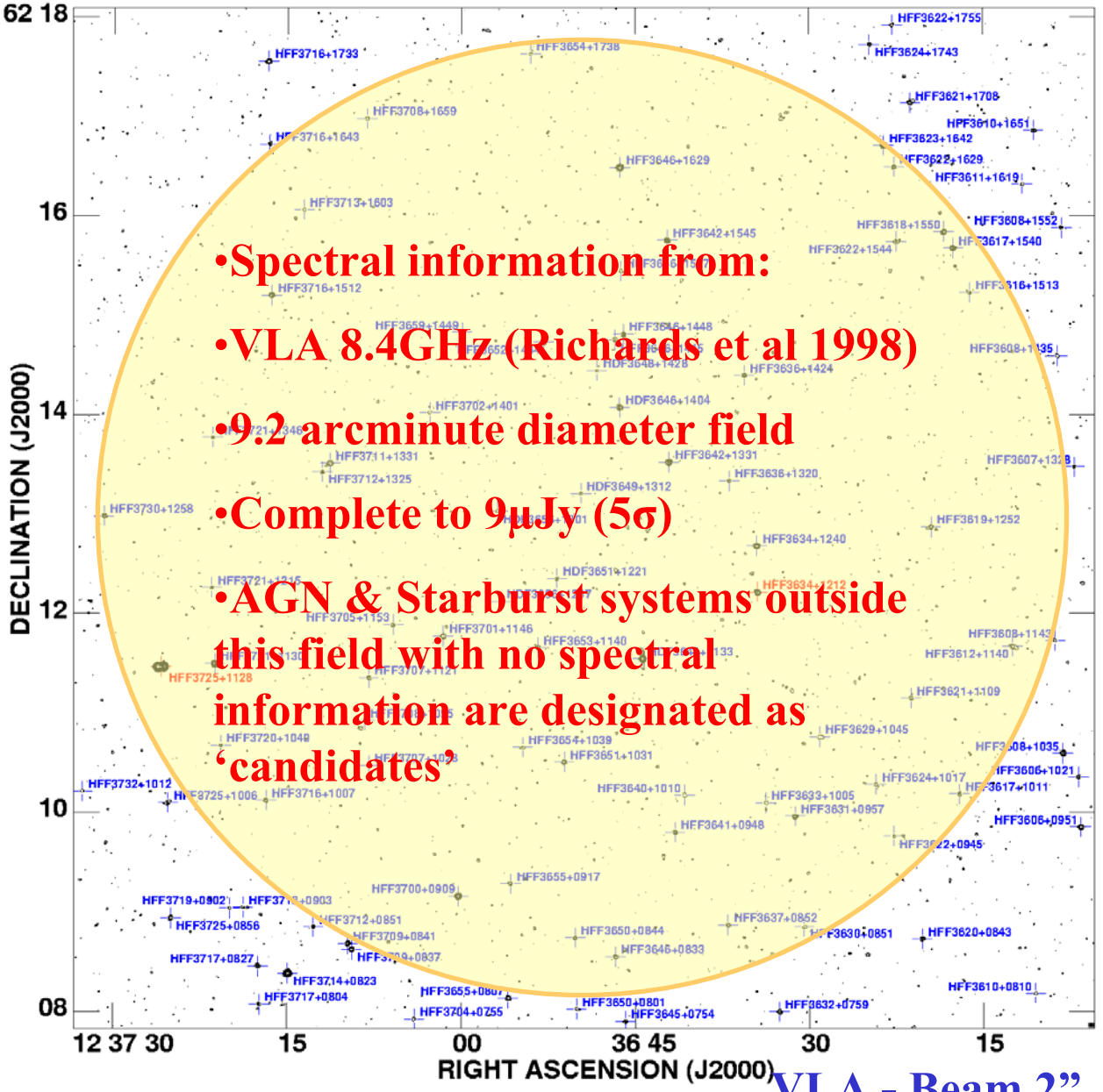


- HST WFPC2 (Williams et al 96)
- Central HDF – 150 orbits complete to R>29
- Surrounding HFF – 10 orbits Complete to R>25

Aligning the HST WFPC2 Images to the Radio Reference Frame (ICRF)

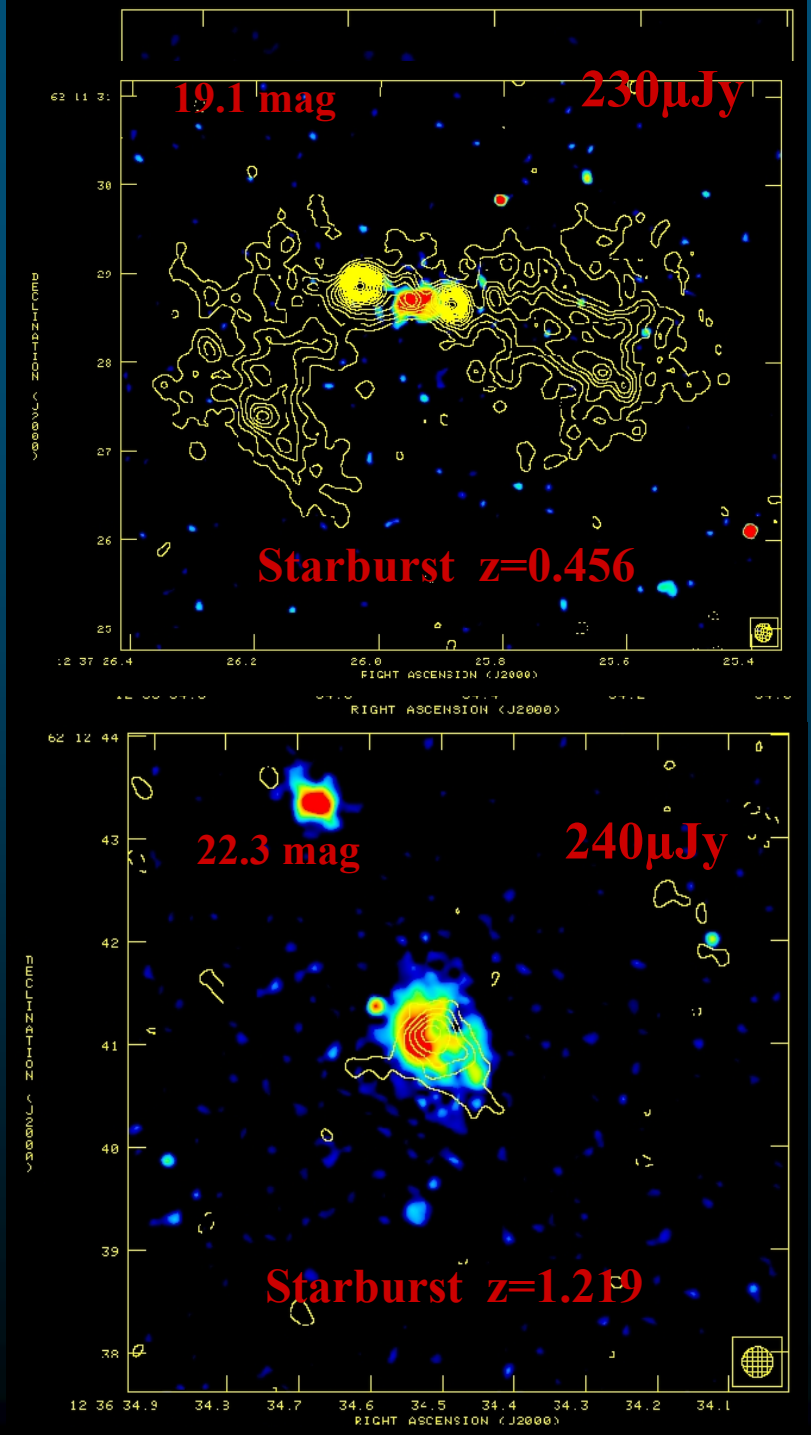


- The HDF and HFF are enclosed in an area of ~10 arcminutes square.
- 10 arcminute field mapped by MERLIN+VLA
- CFHT I-Band image (9 arcminute field) aligned under radio sources (4 parameter solution to distortion).
- HDF/HFF frames aligned under CFHT image for compact galaxies.
- Alignment to better than 50mas in HDF, rising to ~150mas in outer HFF & 150-250 beyond the HFF



VLA - Beam 2"

- MERLIN (18 days) + VLA (42 hours) 1.4 GHz image is amongst the most sensitive ever made (σ ~3.2μJy) Beams 0.2 - 0.5 "
- In 10 arcmin FOV there are 92 sources > 40μJy
- AGN have compact cores and inverted radio spectra
- Starburst systems have steep radio spectra, are extended on sub-galactic scales, and often have I-R detections

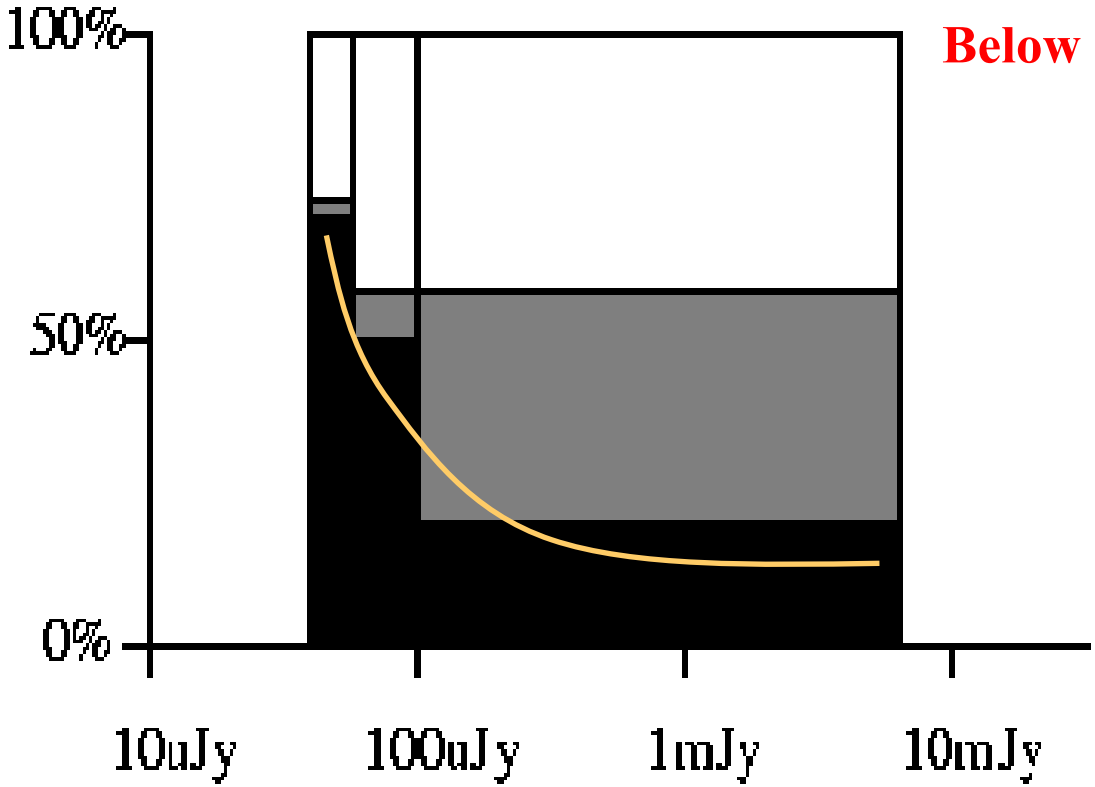


Radio Structures

- Most have angular sizes in the range 0.2 – 3 arcseconds
- Tail of mJy population show high luminosity radio structures
- ~85% are identified with galaxies brighter than R=25.
- Most AGN systems show small core-jets (flat-spectrum cores)
- Starbursts have steep radio spectra and are extended
- Sources which cannot be identified as AGN or Starburst are listed as ‘Unclassified’

The 15% unidentified sources appear to be very distant dust-obscured starburst systems…

Distribution of Source Structure with Flux Density



Below 60μJy ~70% of radio sources are Starburst systems

Unclassified

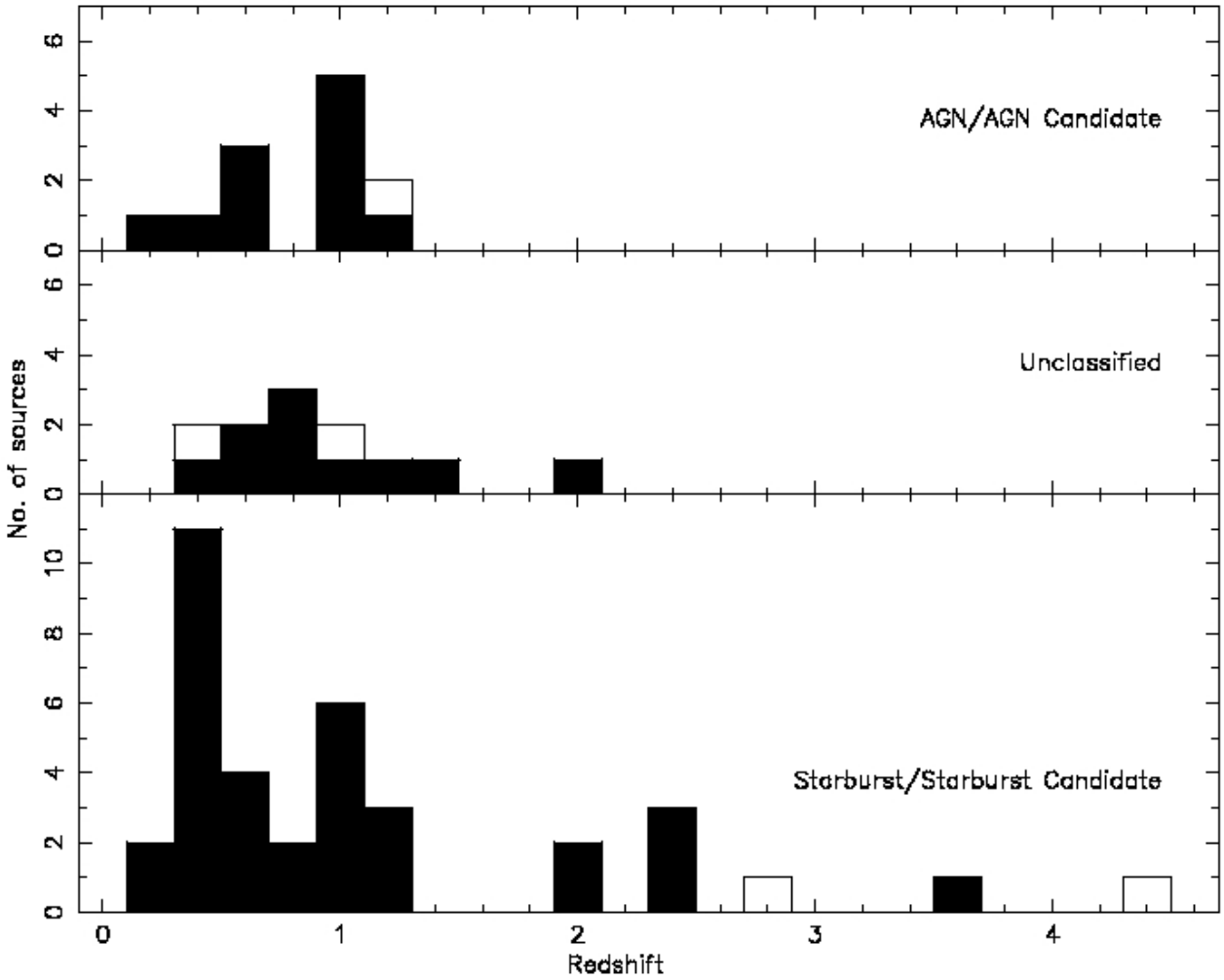
AGN/AGN Candidate

Staburst/Staburst Candidate

3 flux density bins, each containing ~30 sources

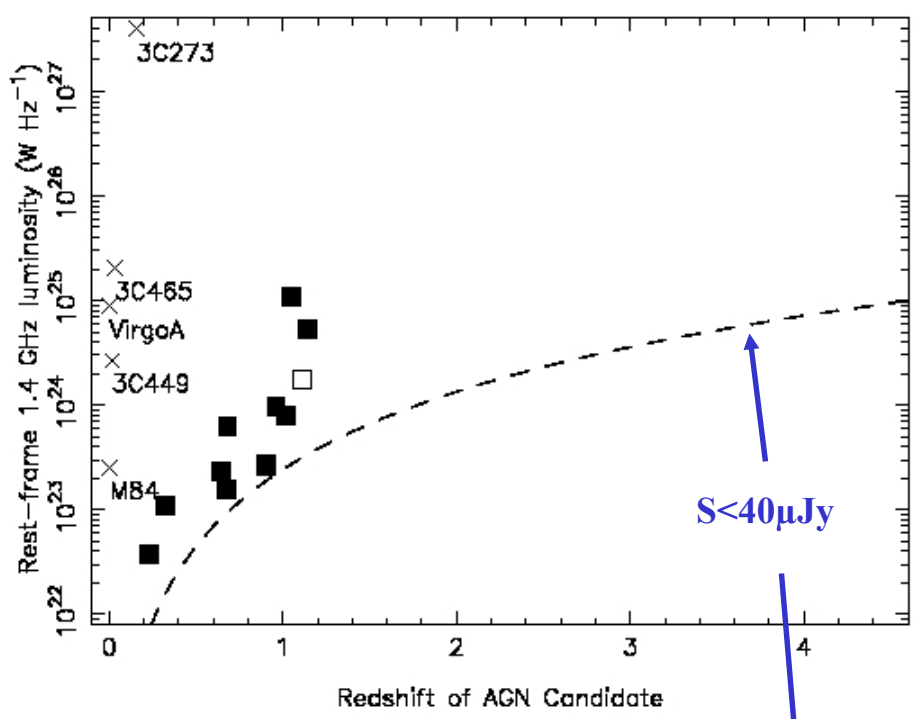
Increasing proportion of Starburst/Starburst Candidates with decreasing source strength

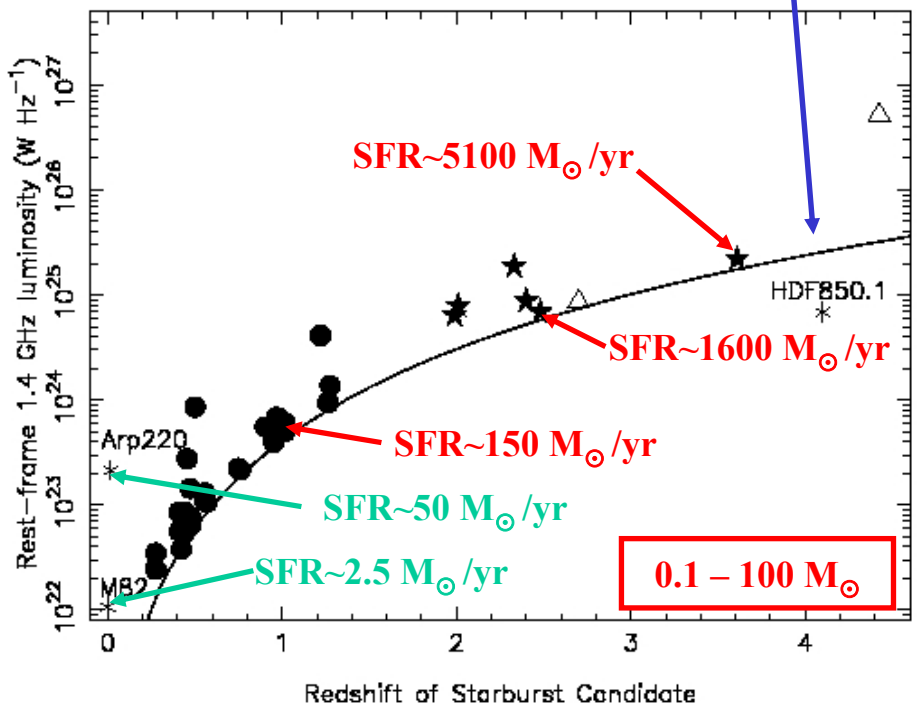
Redshift Distribution



60 / 92 radio sources in the 10-arcminute field have measured spectroscopic (Black) or photometric (white) redshifts

- Similar redshift distribution for AGN & Unclassified source types – median redshifts of 0.91 & 0.85 respecively
- Starburst systems are mostly at lower redshifts (*nb 2 clusters within the field with z~0.4*) with a tail to redshifts >4 !! Median redshift=0.56



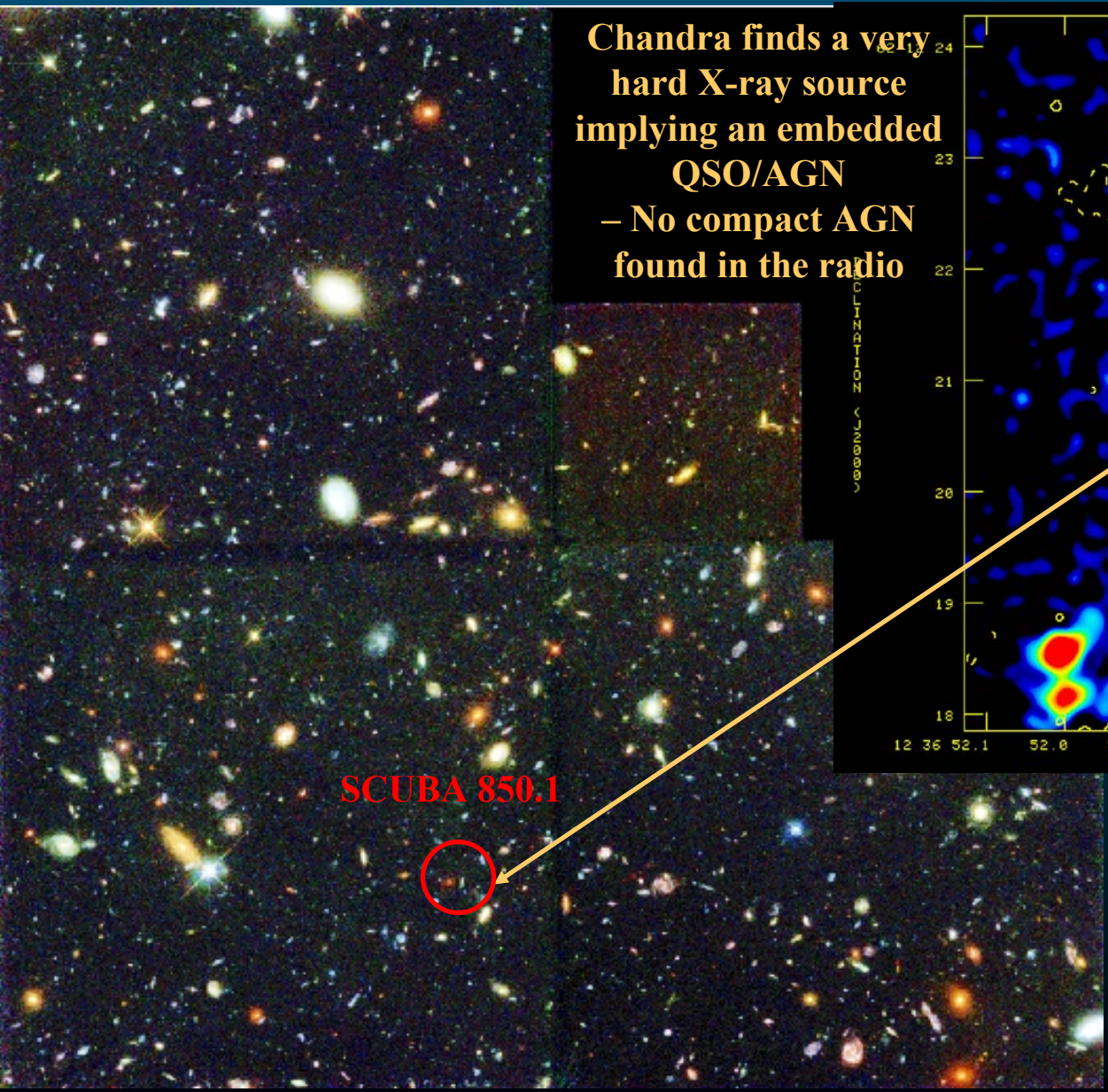


For those sources with measured redshifts (65%):

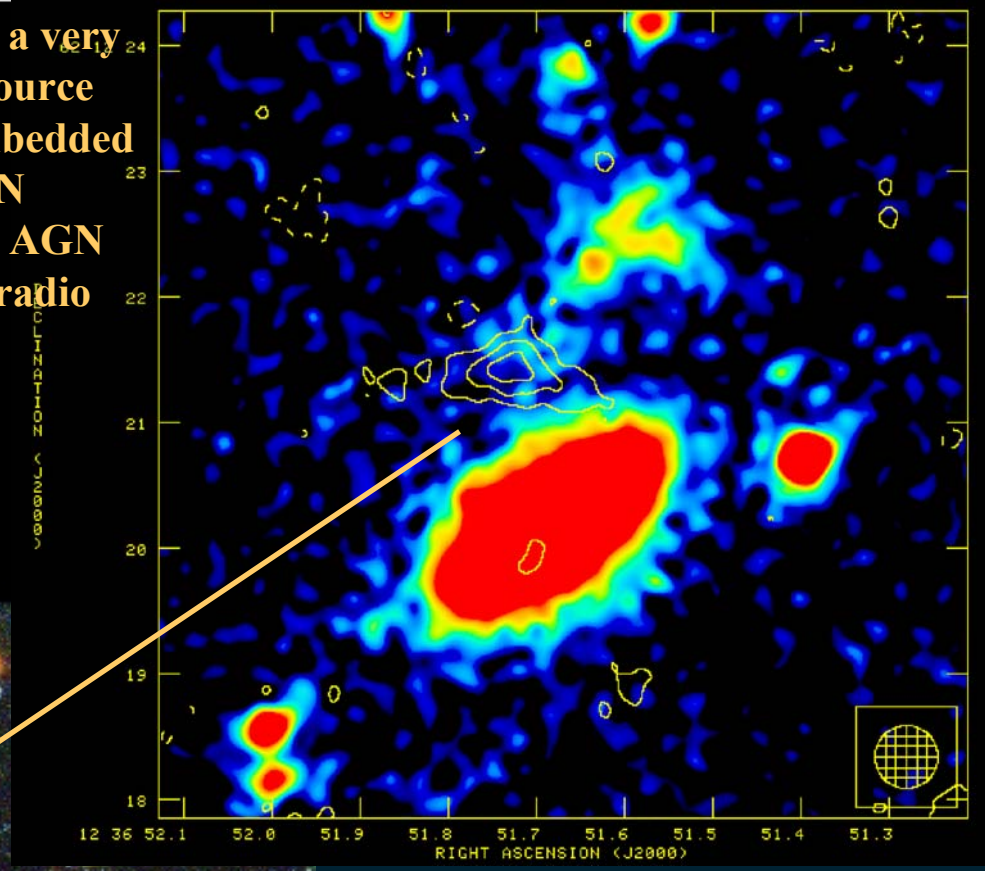
AGN systems have luminosities typical of lower luminosity 'classical' double AGN systems - although very few are doubles, most are small core-jet sources

Starburst systems have luminosities far greater than M82. Most high redshift starbursts and the sub-mm starbursts (★) have luminosities orders of magnitude larger than M82 – and even the luminous local starburst Arp220. 2 optically faint EROs (△) have very high luminosities and may contain embedded AGN

Starformation at high redshift: – The optically faint systems -- A new population of very high redshift, dust-shrouded starburst galaxies



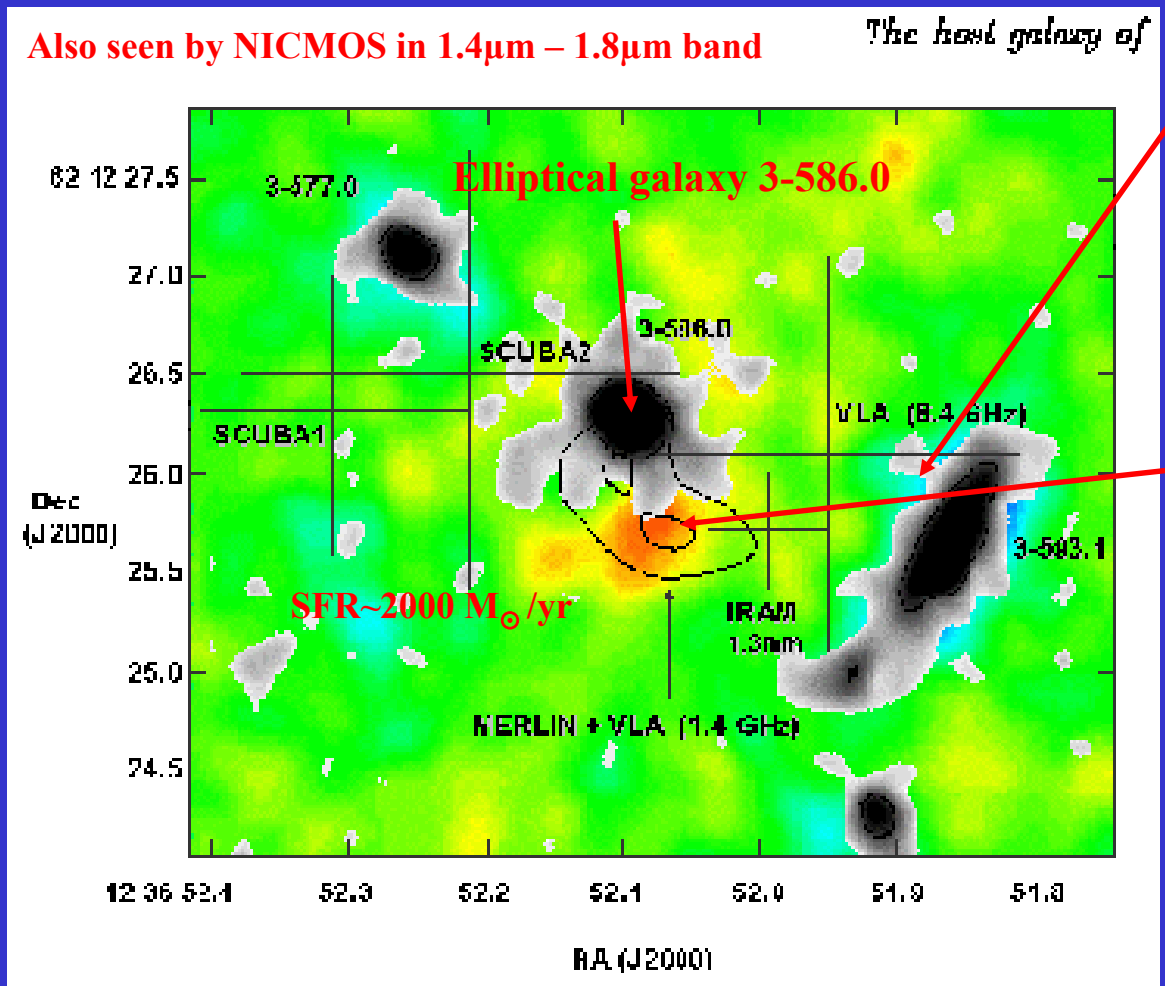
Chandra finds a very hard X-ray source implying an embedded QSO/AGN
– No compact AGN found in the radio



J123651+621221 at 1.4GHz with MERLIN+VLA – Red NICMOS detection implies z~2.6-2.7 ($S_{1.4}$=49μJy) – (Dickinson et al 2000)

Starformation at high redhift: HDF850.1

Subaru K'-band residual image (false colour) after subtraction of WFPC2 image (greyscale) smoothed to the angular resolution of the Subaru image

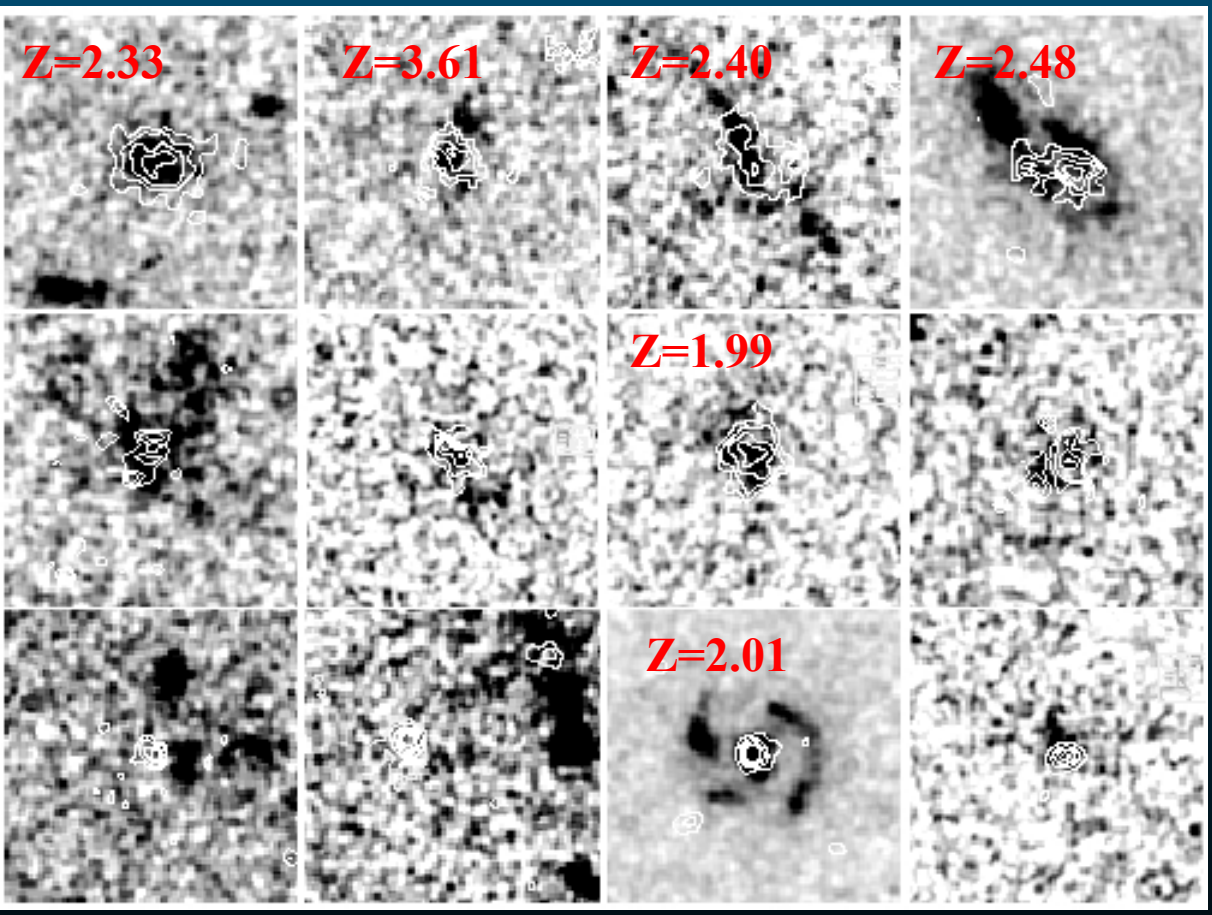


Dunlop et al (2004) MNRAS 350, 769

- MERLIN(+VLA) observations have allowed the WFPC2 HDF frames to be aligned to the ICRF to better than 50mas
- The IRAM detection of the original SCUBA HDF850.1 sub-millimetre source can now be seen to be associated with an optically faint system lying beyond the limit of the HST HDF observations
- Radio emission close to the detection limit with present sensitivity (4σ--16μJy) has been found from close to this position together with a very red object suggesting a distant starburst system at a redshift ~4.1 – derived from the shape of the SED

Sub-mm / Radio Source Associations

Chapman et al (2004) have identified a number of brighter sub-mm sources (in a field centred in the HFF to the North of the HDF) with radio sources in the 10-arcminute field

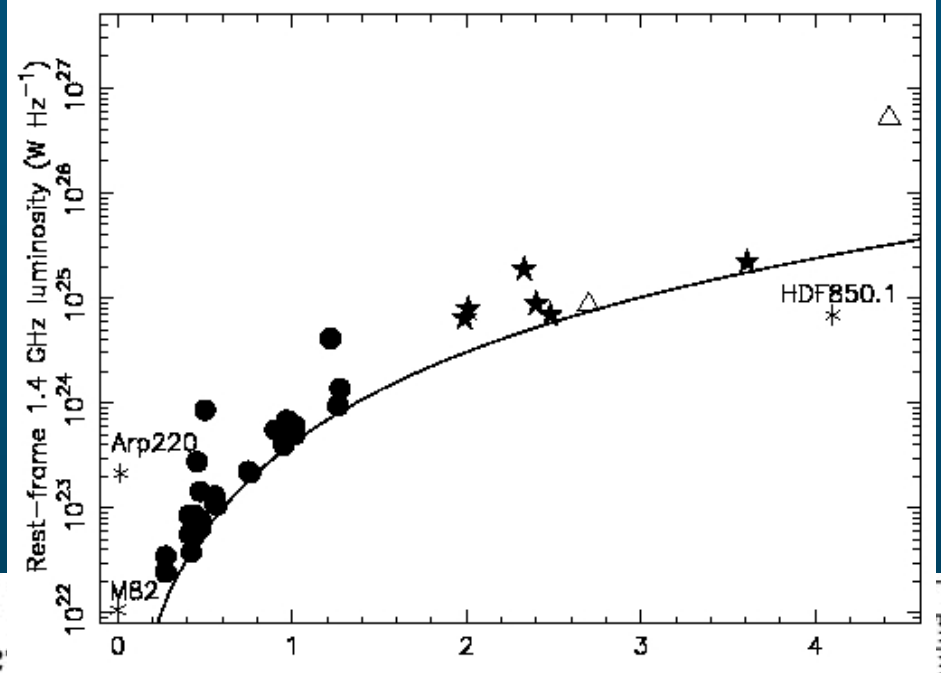


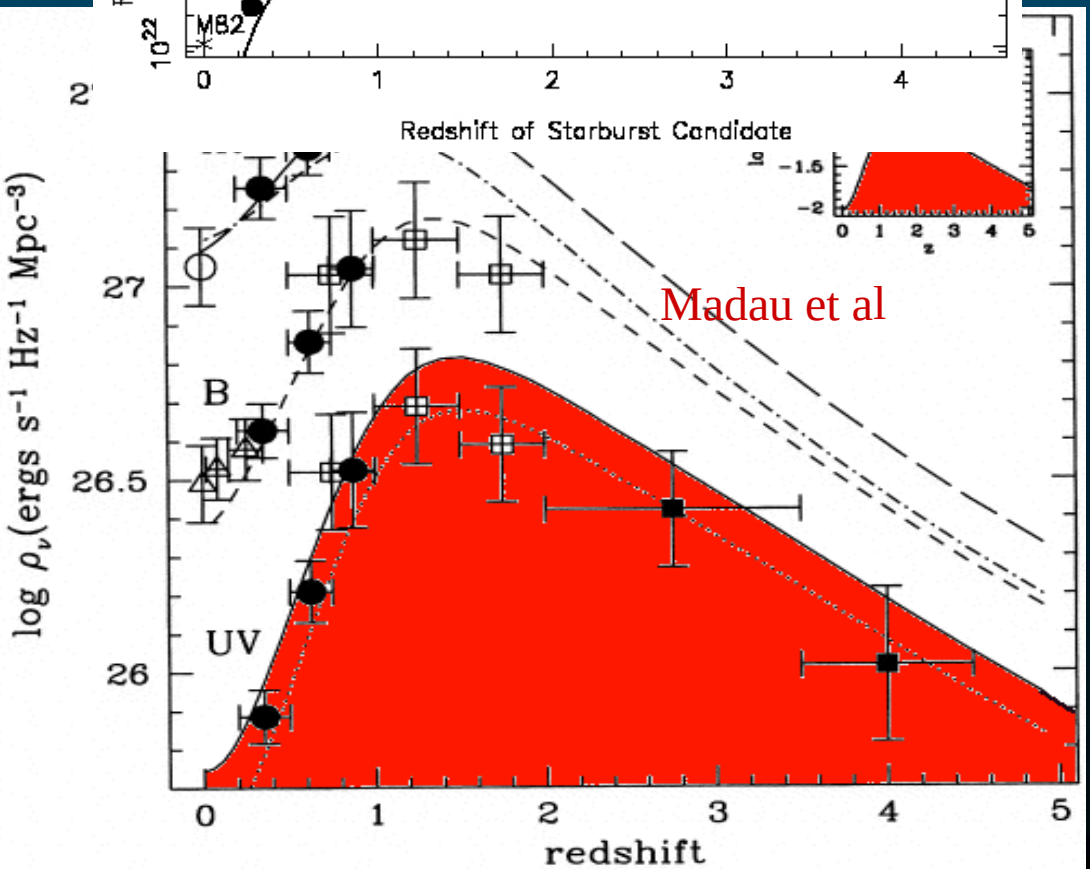
Optical counterparts are typically fainter than most Starburst systems in the 10-arcminute field ($22 < I_{mag} < 26$) and lie at significantly higher redshifts

Redshifts shown for those sources with $S_{1.4GHz} > 40\mu Jy$

Contours MERLIN+VLA 1.4GHz, greyscale HST STIS/ACS

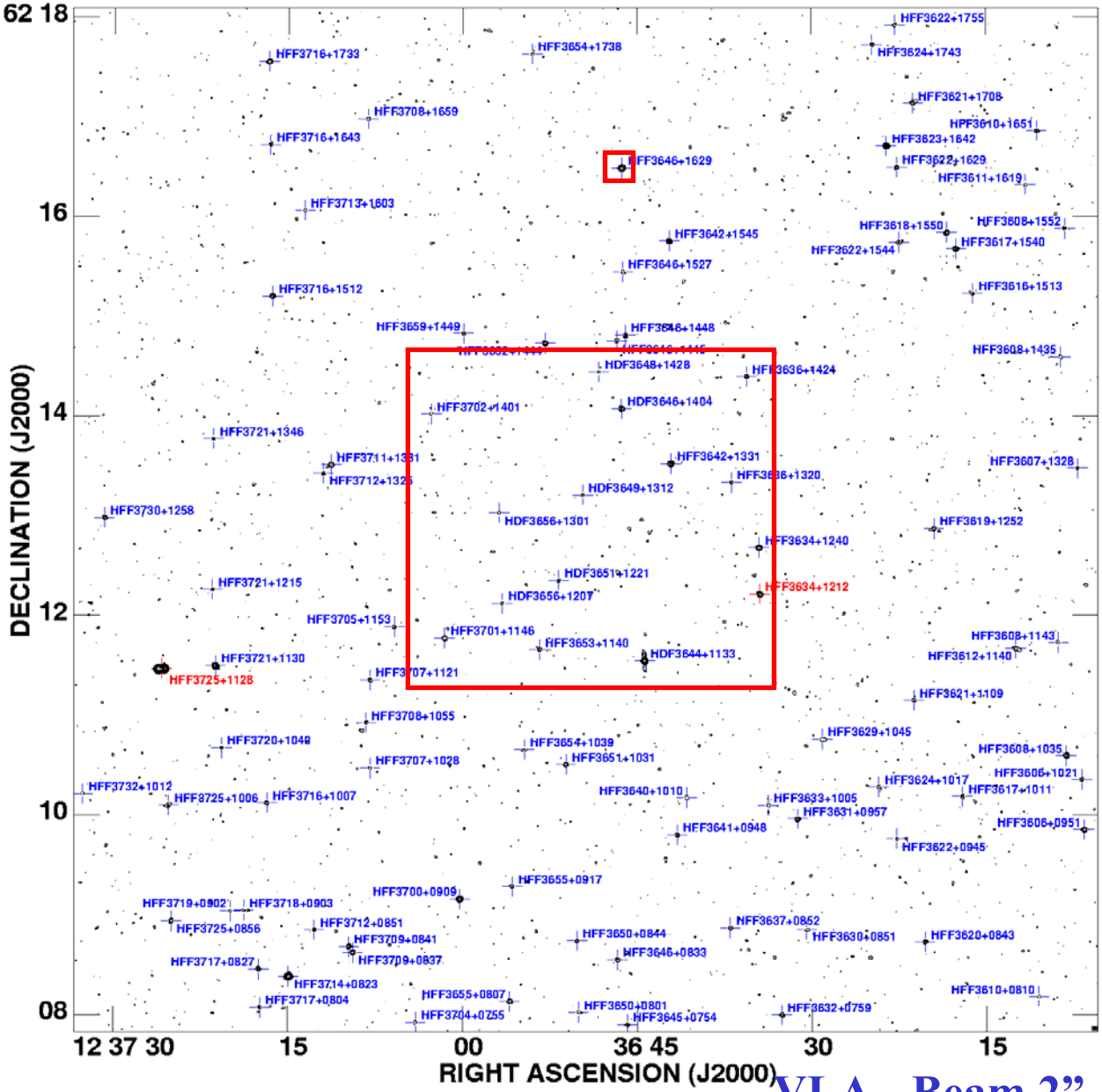
Star-formation At High Redshift





- Most Starburst systems in the 10-arcmin field (●) are galaxies at redshifts less than z=1.5
- The sub-mm Starbursts (∗) are at high redshifts typically in excess of z=2
- The optically faint, dust obscured systems (▲)also lie at high redshift. Some of these may be Starbursts with embedded AGN
- We are only beginning to sample the population of high redshift star-forming galaxies

The 3 Arcminute Field



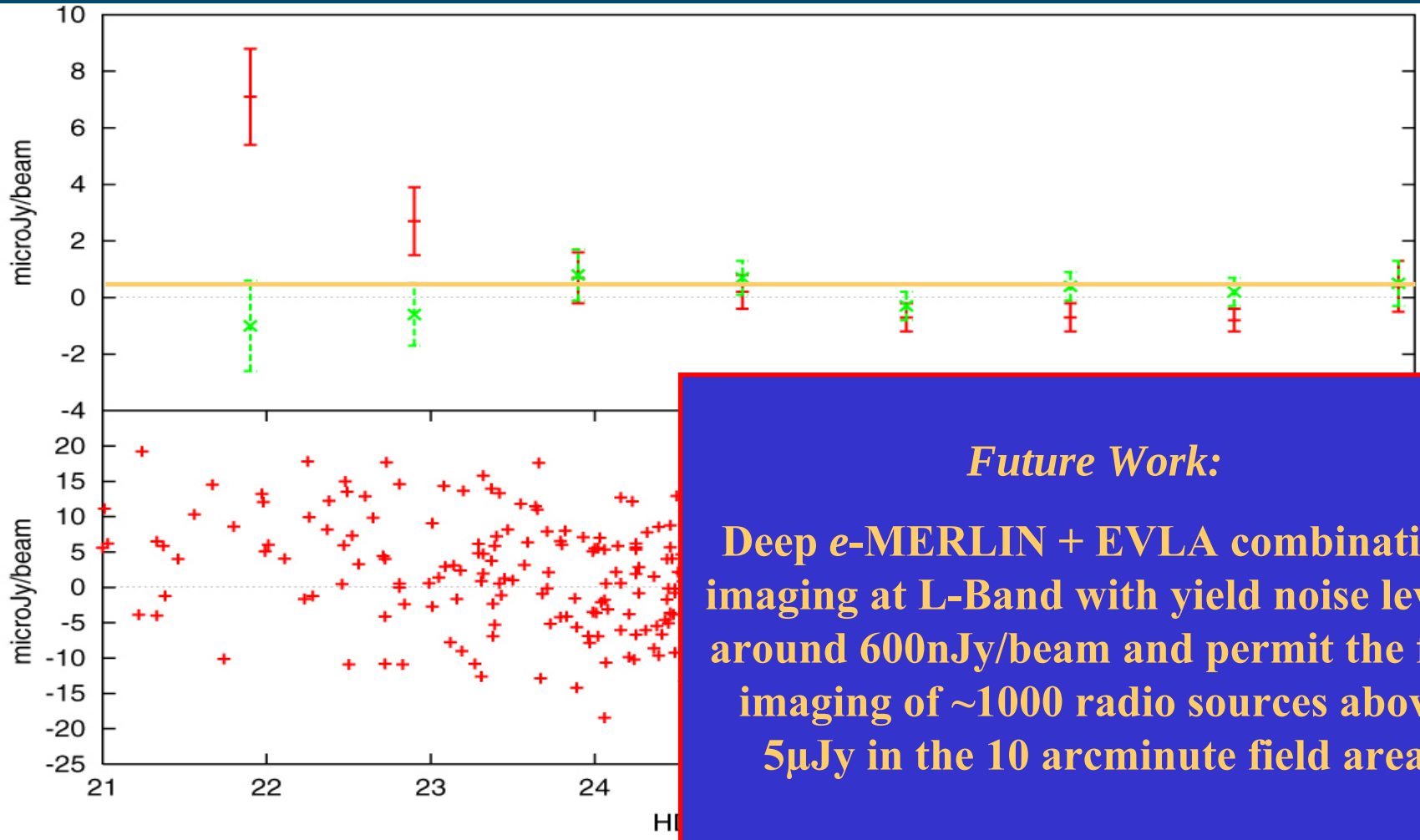
VLA - Beam 2”

- Central 3.4x3.8 arcminutes of the field have been fully mapped with combination MERLIN+VLA images
- Statistical analysis of radio/optical positions made

Radio brightness at 1.4GHz (smoothed to 1-arcsec resolution) at the positions of known galaxies plotted against WFPC2 I-magnitude

Control data incorporate a random 7-arcsec shift applied to the radio position

Upper panel – binned by I-magnitude **Lower panel – data shown unbinned**



Future Work:

Deep *e*-MERLIN + EVLA combination imaging at L-Band with yield noise levels around 600nJy/beam and permit the full imaging of ~1000 radio sources above 5μJy in the 10 arcminute field area

3-Arcminute Field – Statistical Analysis of Radio/Optical Positions

Conclusions:

- Radio data have been used to astrometrically align multi-waveband images of the HDF and HFF allowing unambiguous identifications for the first time
- Most radio structures have angular sizes in the range 0.2 to 3 arcseconds
- AGN systems are nearly all small core-jet structures
- Proportion of starbursts increases with decreasing flux density – below 60μJy >70% of sources are starburst type systems
- ~85% of radio sources identified with galaxies brighter than I=25mag
- ~15% optically faint systems are thought to be mostly dust obscured high redshift starbursts, some of which may contain embedded AGN
- Most starburst galaxies are associated with galaxies at redshifts less than z=1.5
- Sub-mm source identifications bedevilled by poor sub-mm astrometry
- Identified sub-mm starburst systems are associated with galaxies which are fainter than most HDF/HFF starbursts and found at high redshift with z typically > 2