The University of Manchester
Jodrell Bank Observatory

e-MERLIN+EVLA:

nJy sensitivity at 50 – 200 mas resolution

A very deep directed survey of the μJy/nJy radio source population (e-MERLIN Legacy)

Tom Muxlow

EVLA Visions, 17th December 2008

Science & Technology Facilities Council

JIVE JOINT INSTITUTE FOR VLBI IN EUROPE

Outline

Star-formation at high redshift

e-MERLIN

Original MERLIN + VLA combination studies

Developments from the original study of GOODS-N

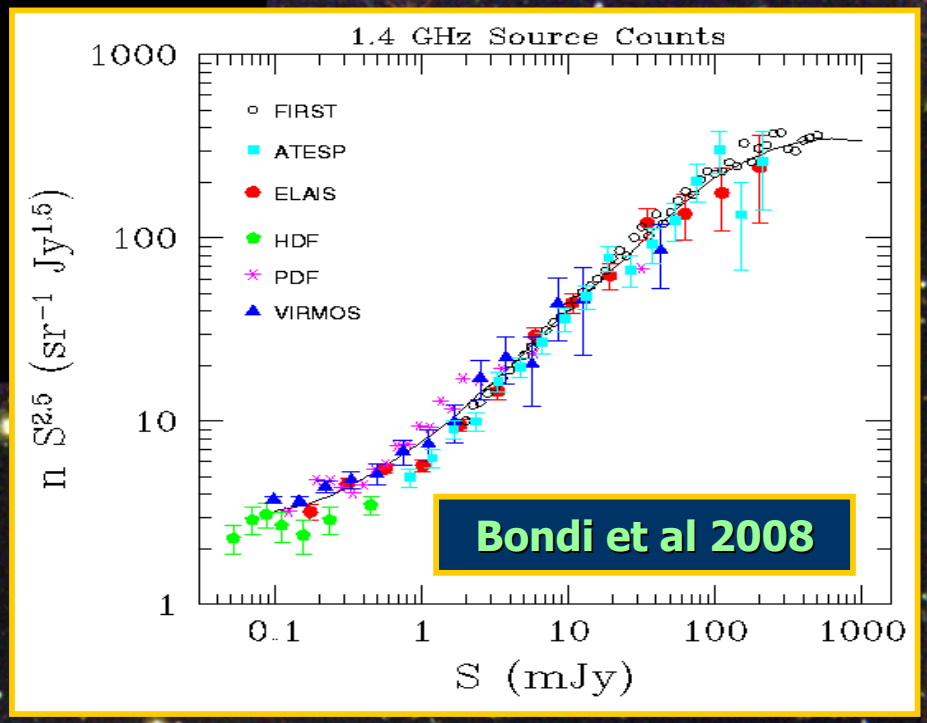
Statistical properties of the radio source population to a few μJy

The proposed new ultra-deep *e*-MERLIN + EVLA study of the GOODS-N field (*e*-MERGE Survey)

Imaging the radio source population to a few μJy

Star-formation at High Redshift

HDF (N)



At flux densities <1mJy (1.4GHz) there is an emerging population of faint radio sources that are dominated by distant star-forming galaxies.

However there is continuing debate as to the nature of any underlying, possibly obscured AGN population present in the μJy radio sources.

Richards, Owen, Fomalont, Kellermann, Windhorst, Smolcic, Yun, Biggs, Seymour, Jarvis, Chapman, McHardy, Norris, Garrett, Muxlow……

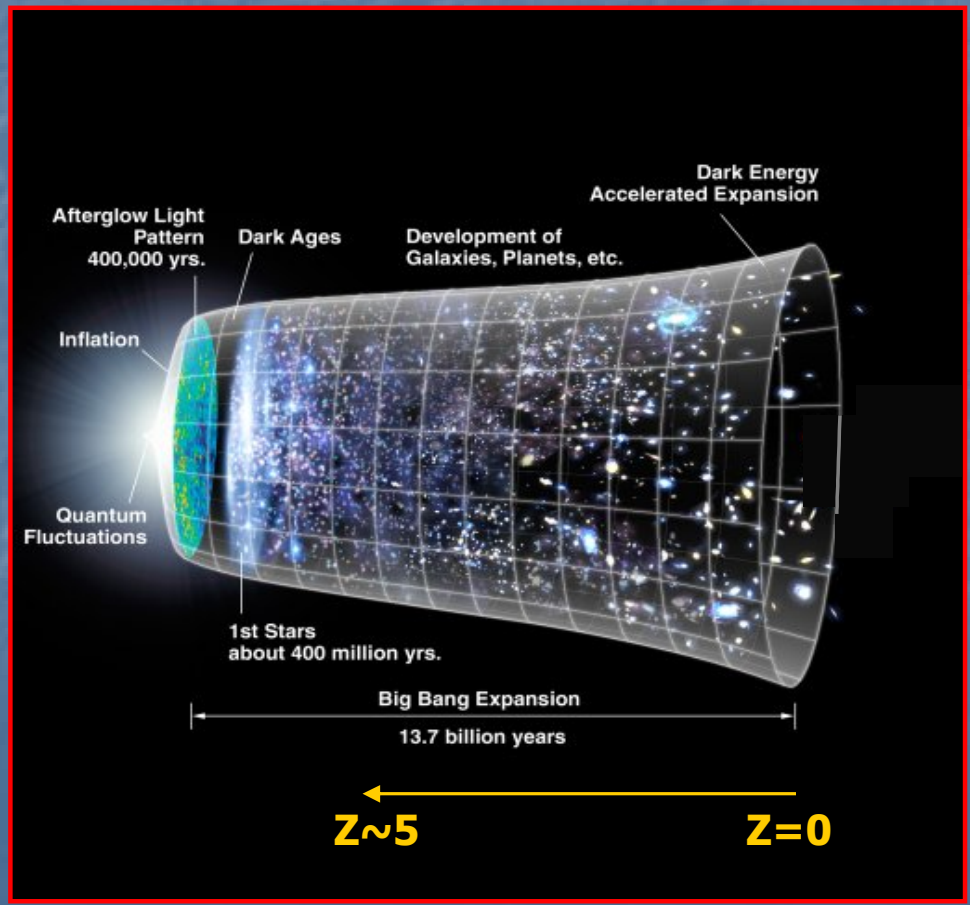
- For those obects with measured redshifts, centimetric radio and far-IR luminosities are two of the best extinction-free measures of star-formation rate at high redshift.
- Radio observations of the sub-mJy radio source population can thus be used to study how the star-formation density varies with cosmic epoch?
- How does AGN activity (feedback) effect star-formation ?
- What is the nature of the faint AGN population ?

EVLA

The EVLA with a continuum sensitivity 10 times that of the VLA, is a superbly powerful survey instrument to detect distant star-forming galaxies – See talks in this session

Radio emission from these star-forming galaxies is steep-spectrum, so observations are at relatively low frequencies, where most of the systems are only marginally resolved.

Higher angular resolution is required to investigate the detailed nature of the star-formation processes and to investigate feedback mechanisms and separate the AGN and starburst emission in individual galaxies.



e-MERLIN – extending the EVLA resolution

- when observing at higher frequencies is inappropriate…

Optical fibre connection to telescopes replacing narrow-band radio links.

New WIDAR correlator.

2GHz/pol (C & K), 400MHz/pol (L).

Data rate 128Mb/s/tel → 30Gb/s/tel.

Sensitivity → 1 μJy/bm in 18hrs
(~ 30 over current system).

MFS produces full *uv*-coverage.

Resolution: 200mas L-Band
50mas C-Band

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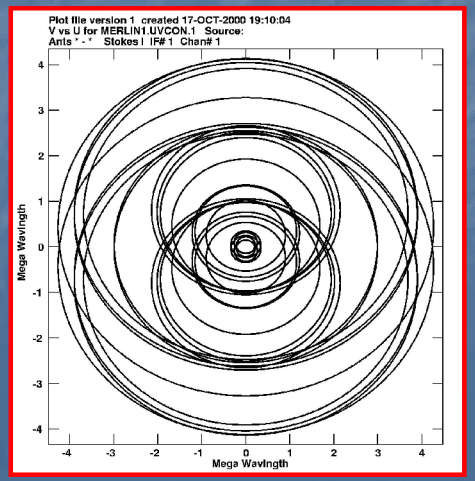
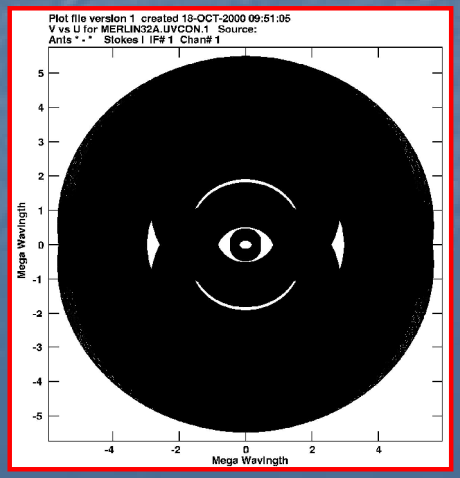




Original MERLIN+VLA Deep L-Band Studies

Deep integrations on a number of fields (eg SA-13, Lockman, HDF-N).

Correlator limitations restrict fields of view (typically 10 arcmin diameter)

Resultant combination images with resolutions 200-500 mas and noise levels of 3 - 6μJy/bm

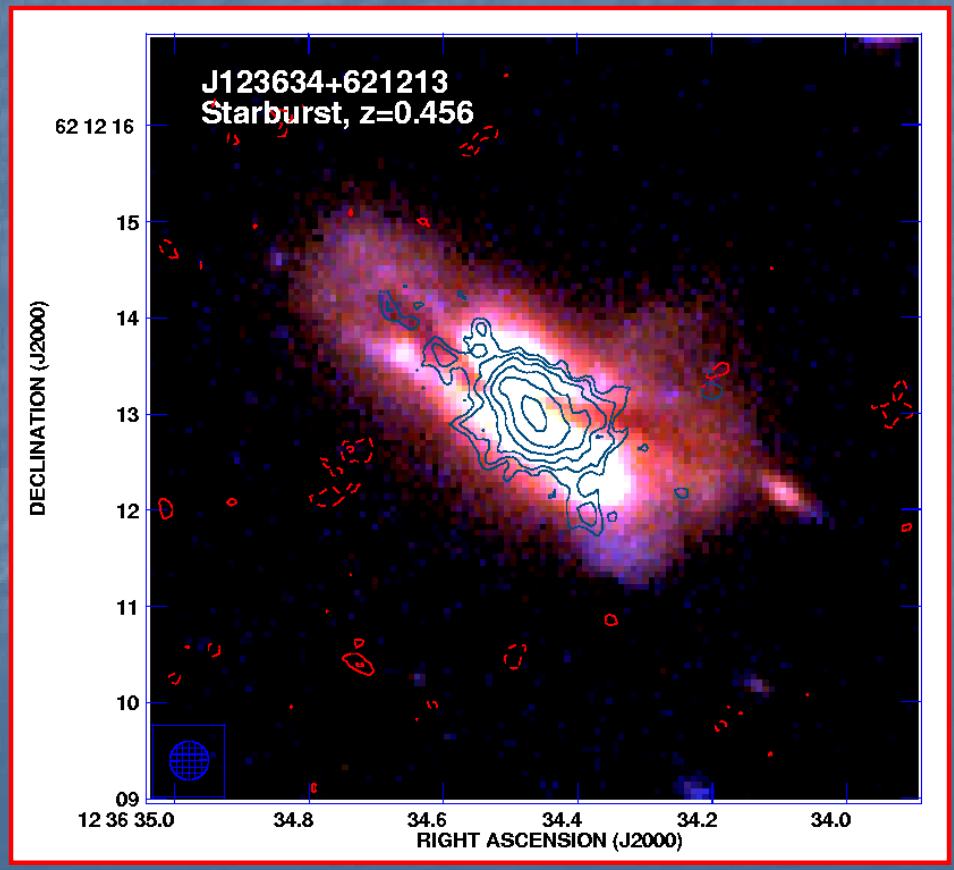
Original MERLIN+VLA Deep L-Band Studies

Hubble Deep Field North, ~100 radio sources were imaged above a completeness limit of 40μJy. Data date from mid 90's

[Muxlow et al 2005]

Established that high-resolution combination L-Band MERLIN/VLA observations can morphologically distinguish AGN from starburst systems

Below ~70μJy the radio population becomes dominated by powerful star-forming galaxies typically at z<1.5 and with SF rates of many times those seen in nearby star-forming galaxies



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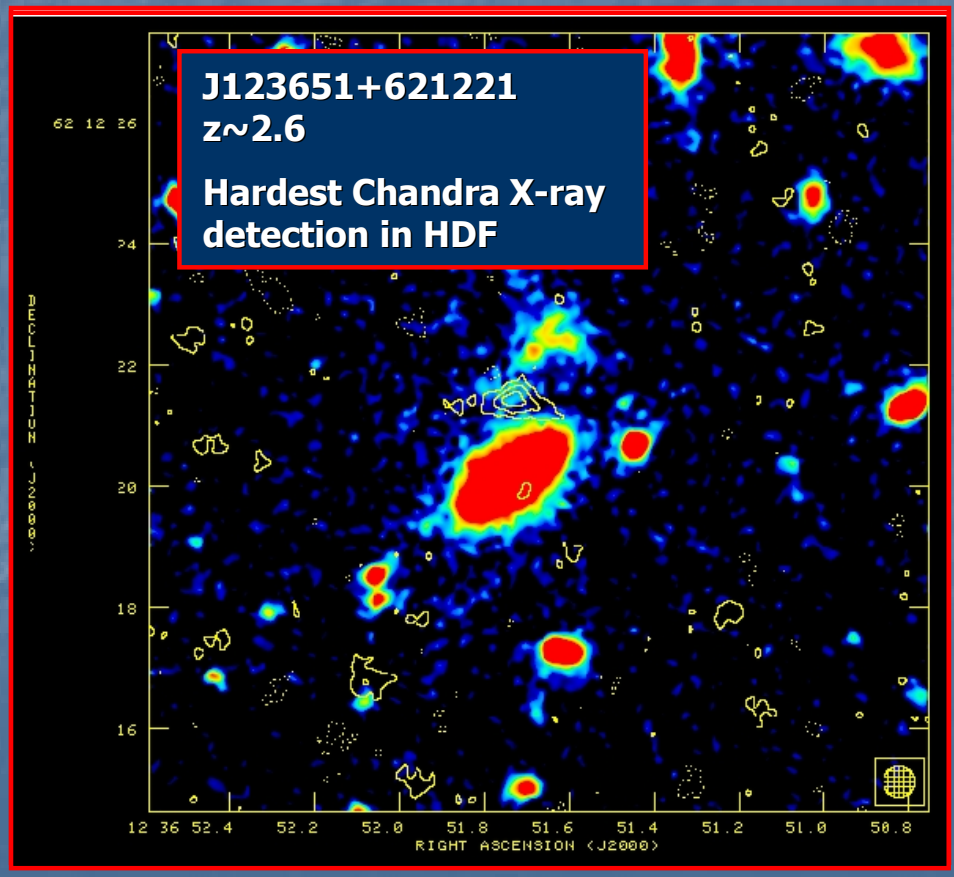
Around 15% of the population lie at higher redshifts, many of which are also identified as sub-mm sources.

Some of the most luminous starburst systems also show evidence for powerful embedded AGN

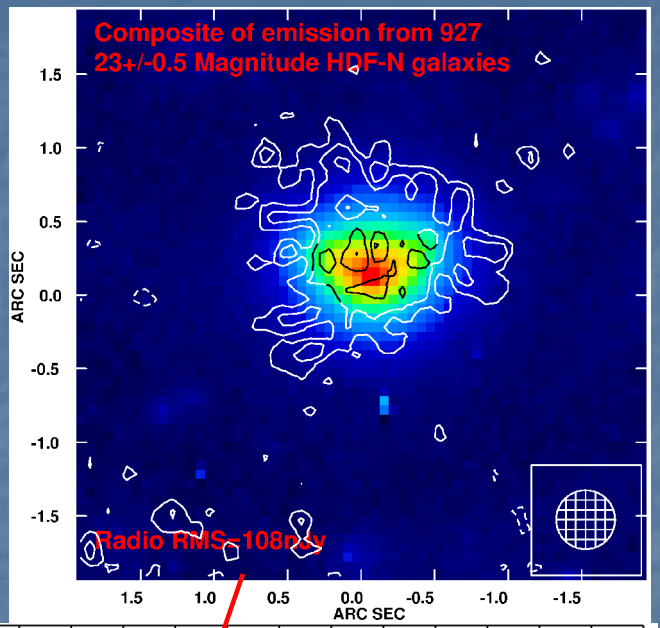


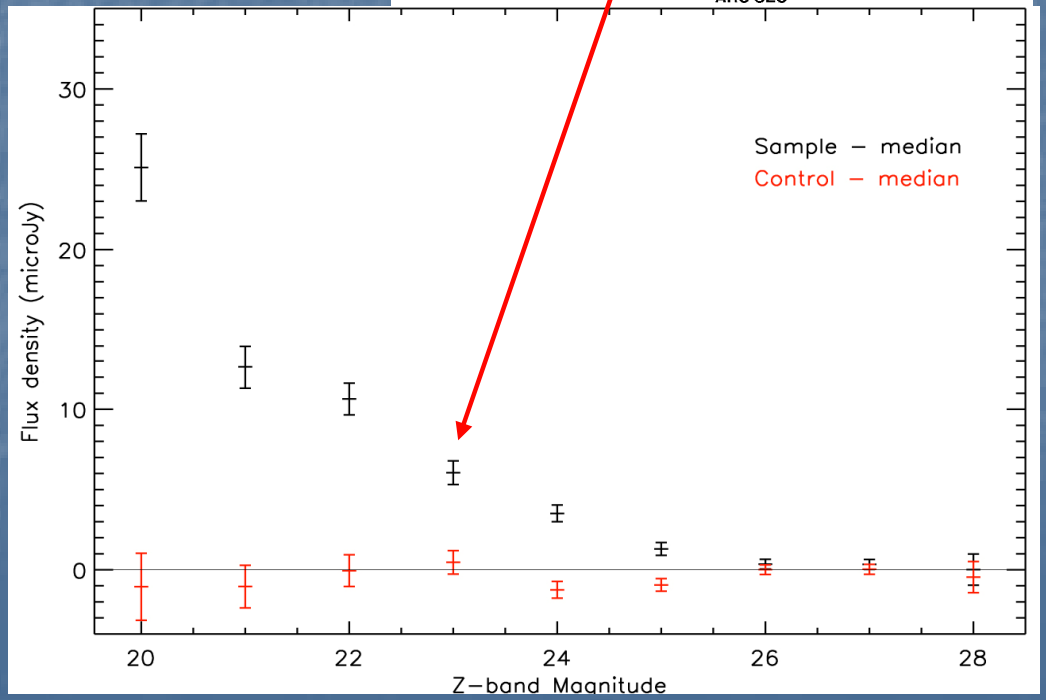
Recent Developments

From full combination imaging of the 8’ overlap region with GOODS-N, radio emission at the level of a few μJy has been statistically detected associated with ACS galaxies brighter than a z-band magnitude of 26

Identified as extended starburst systems with average properties similar to those star-forming galaxies studied individually at higher flux densities

Average source diameters:
1.2 – 1.6 arcsec





Radio emission within 2.0” radius of 13030 z-band galaxies – excluding bright sources and close galaxy pairs

Muxlow et al 2007

New Ultra-Deep Study of GOODS-N

Part of a tiered *e*-MERLIN Legacy proposal – the *e*-MERGE Survey is designed to study the formation and evolution of star-forming galaxies and AGN out to redshifts > 5

– The *e*-MERlin Galaxy Evolution Survey

All tiers will require matched EVLA data

Tier 0 – *Imaging radio emission from normal galaxies out to z ~ 5*
Deep imaging around clusters to utilise amplification by lensing

Tier 1 – *A very deep directed survey of the μJy radio source population*
Deep imaging of the μJy radio source population in GOODS-N

Tier 2 – *A reliable cosmic census of starburst and AGN populations*
Medium depth imaging over a number of fields (total area ~2 sq. degrees)

The combination of these tiers will ensure a full sampling of the active and star-forming galaxy radio luminosity function out to z~5

>60 CO-Is from 9 countries

Tier 0: Ian Smail [Durham], Tier 1: Tom Muxlow [Manchester] Tier 2: Ian McHardy [Southampton]

~2400 hours of *e*-MERLIN time proposed

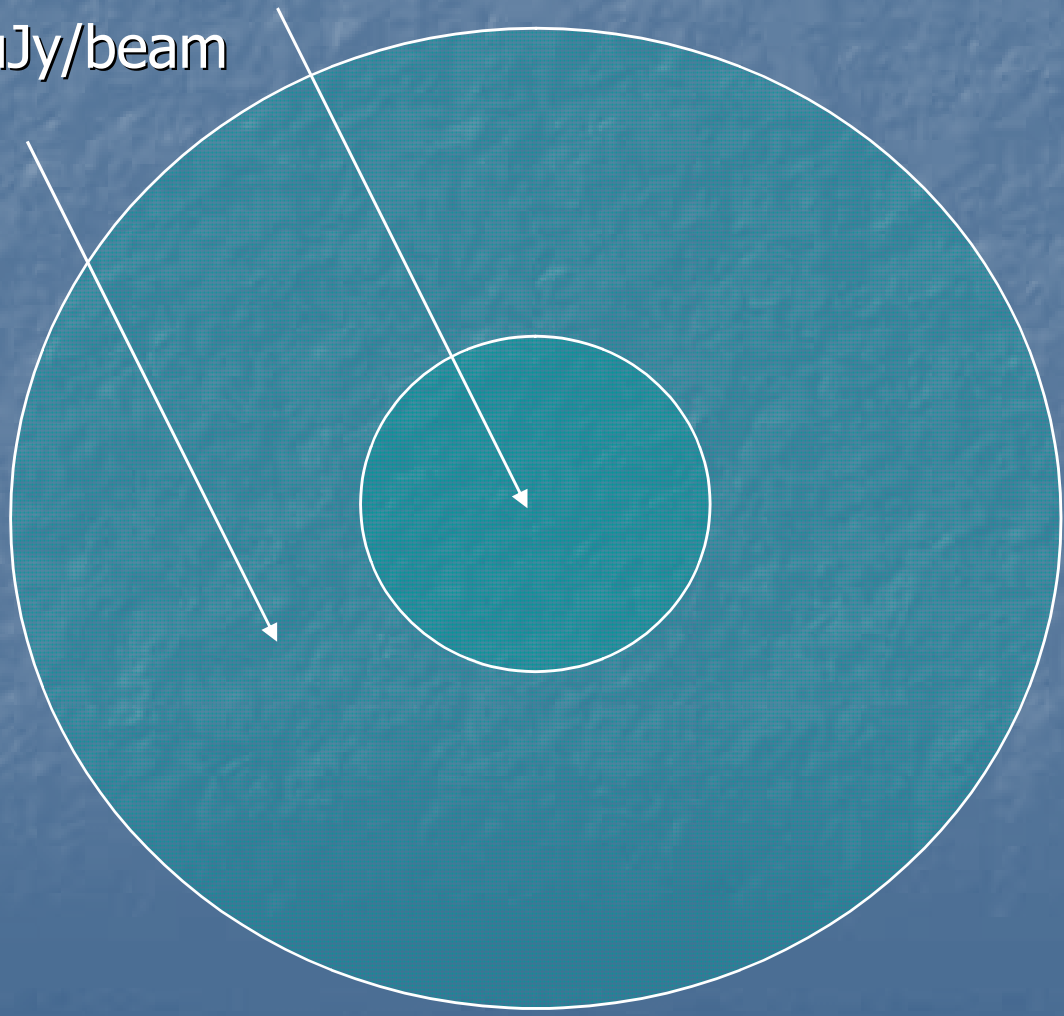
New Ultra-Deep Study of GOODS-N

- To image the faintest radio starburst galaxies and AGN systems in the GOODS-N region which to date have only been studied statistically – designed to directly address the following key science drivers:
  - To extend the star-formation (SF) density history to redshifts >5 and thus trace the evolution of star-formation through cosmic time.
  - To determine the contribution of AGN to activity in the distant galaxy population and separate AGN from starbursts by high resolution multi-frequency observations.
  - To investigate the role of AGN in driving and controlling the SF processes
  - To statistically characterize the nature of the sub-μJy radio population – the target objects for the SKA

New Ultra-Deep Study of GOODS-N

- *e*-MERLIN will exceed the depth of the existing MERLIN combination map in just 24 hours of on-source integration.
- L-Band: Single pointing centre, 20 full tracks including Lovell telescope.
- Central 10 arcminute field $1\sigma \sim 500$nJy/beam
- Outer 30 arcminute field $1\sigma \sim 1\mu$Jy/beam

Adding matched EVLA A-array data to recover source structures >3.5 arcsec:



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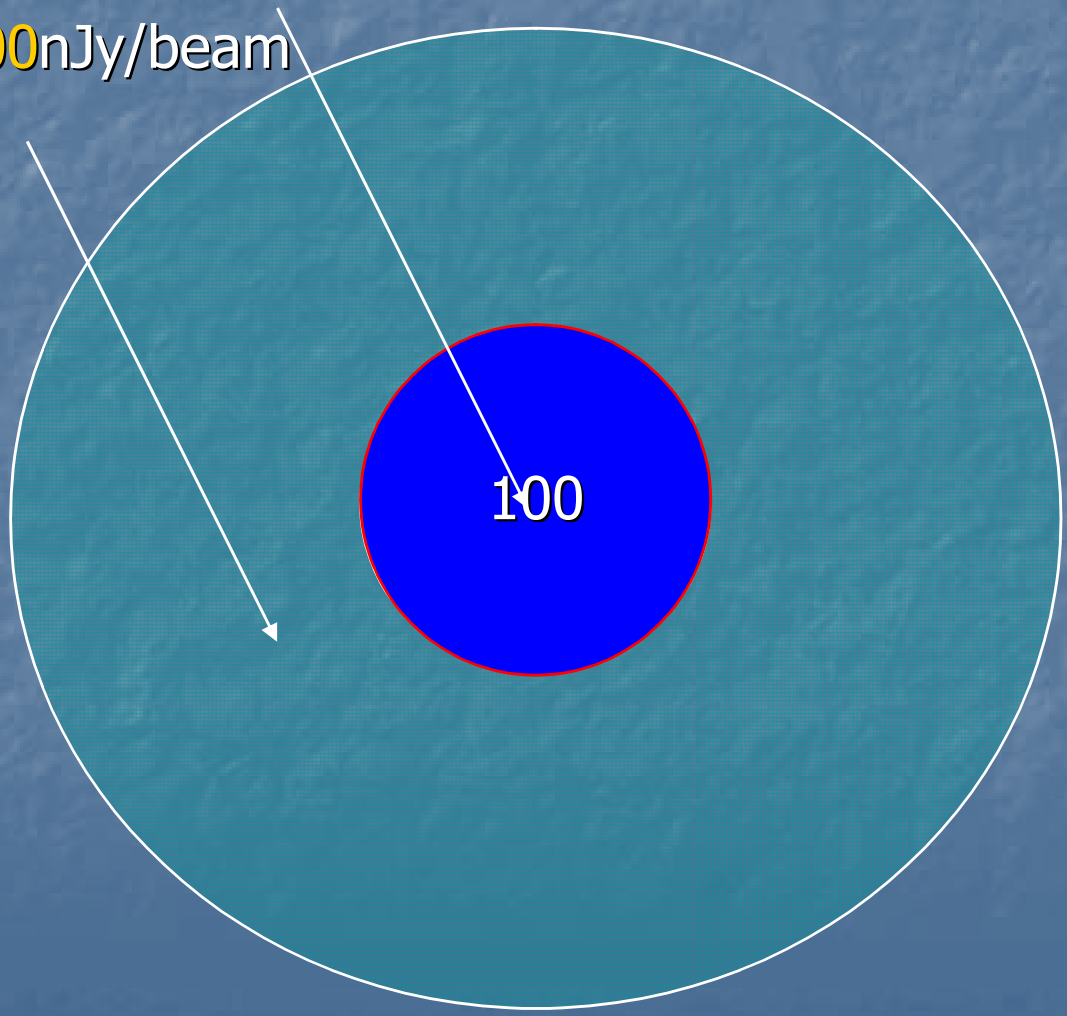
- *e*-MERLIN will exceed the depth of the existing MERLIN combination map in just 24 hours of on-source integration.
- L-Band: Single pointing centre, 20 full tracks including Lovell telescope.
- Central 10 arcminute field 1σ ~ 350nJy/beam
- Outer 30 arcminute field 1σ ~ 700nJy/beam



- cf – Original study:18 full tracks +42 hours VLA A-array
- Central 10 arcminute field only
- 1σ ~ 3.3 μJy/beam

- ~100 sources >40μJy

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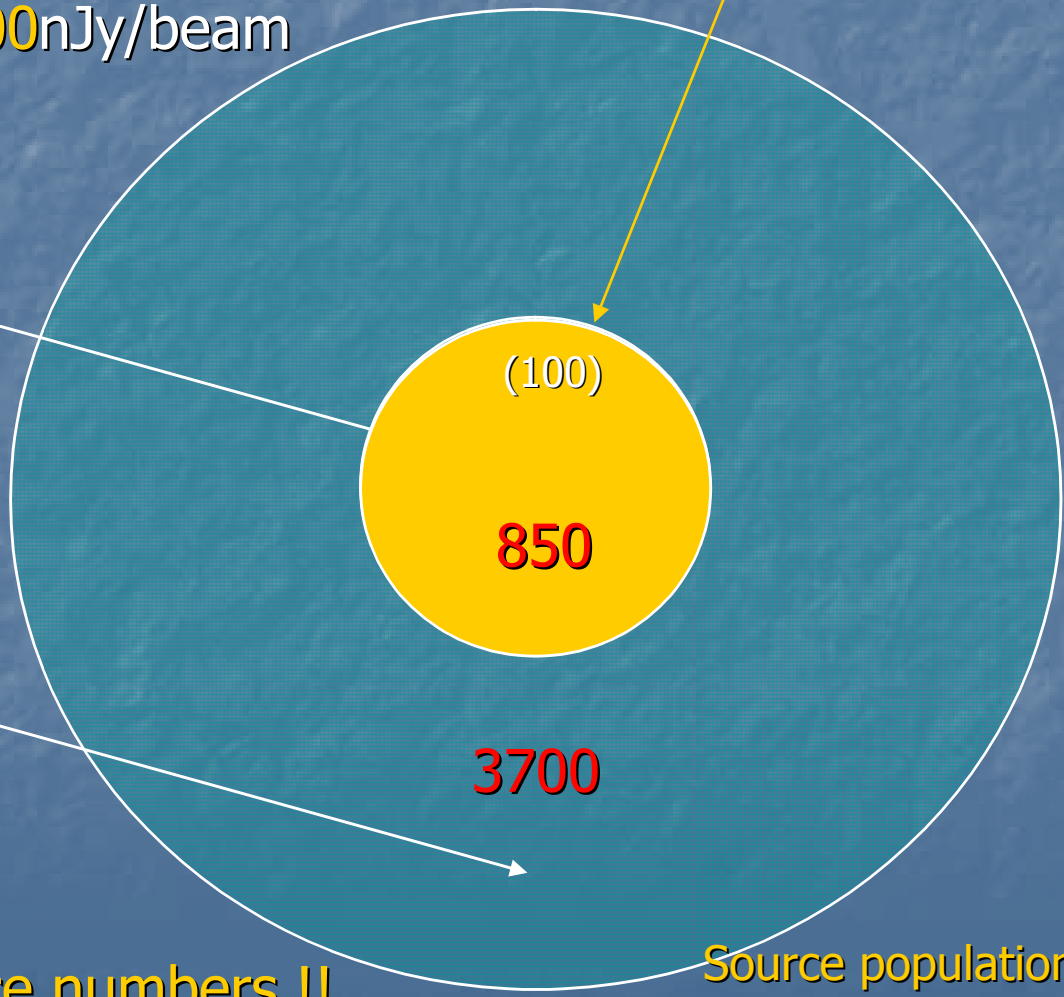
- *e*-MERLIN+EVLA will image ~850 individual starburst and AGN with an angular resolution of 200 mas, complete to ~3μJy

  (>10 times deeper than the original study)

- In the surrounding 800 square arcmins, *e*-MERLIN+EVLA will image ~2500 star-forming galaxies and ~1200 AGN brighter than ~6μJy



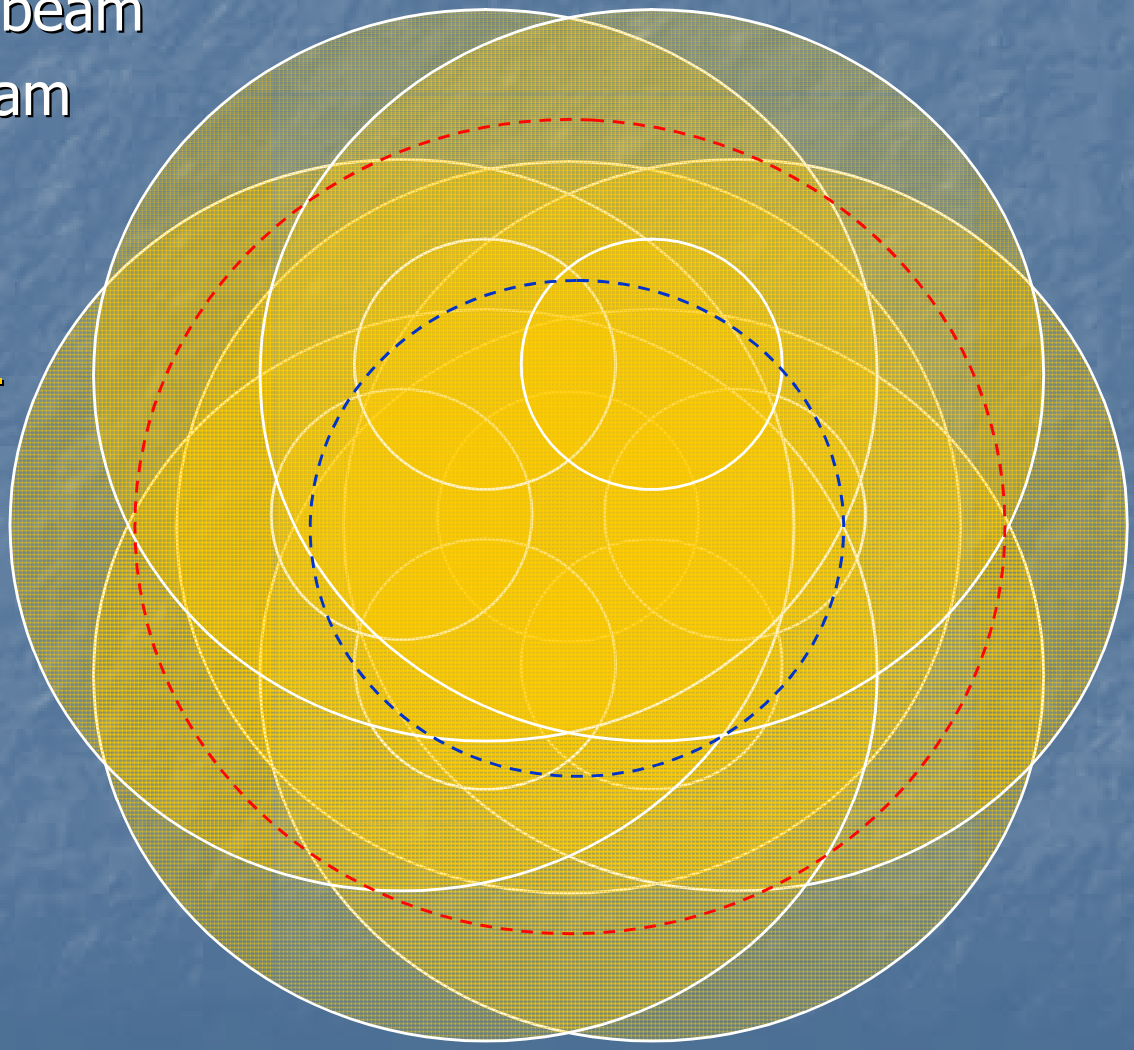
- 5250:100 >50x increase in source numbers !!

Source populations from Wilman et al 2008

New Ultra-Deep Study of GOODS-N

- New C-Band image: 7 pointing centres each with 3 long tracks
- Mosaic pattern set for Lovell 3 arcminute beam
- Inner 6′ 1σ ~ 350nJy/beam
- 6-10′ 1σ ~ 470nJy/beam
- Resolution 40 mas

- Matched C-Band EVLA data adds short-spacing *uv*-coverage to recover the very heavily resolved radio structures with sizes > 1.2 arcseconds



New Ultra-Deep Study of GOODS-N

The ultra-deep C-Band combination image will:

Map the star-forming regions in great detail (for the brighter starbursts)

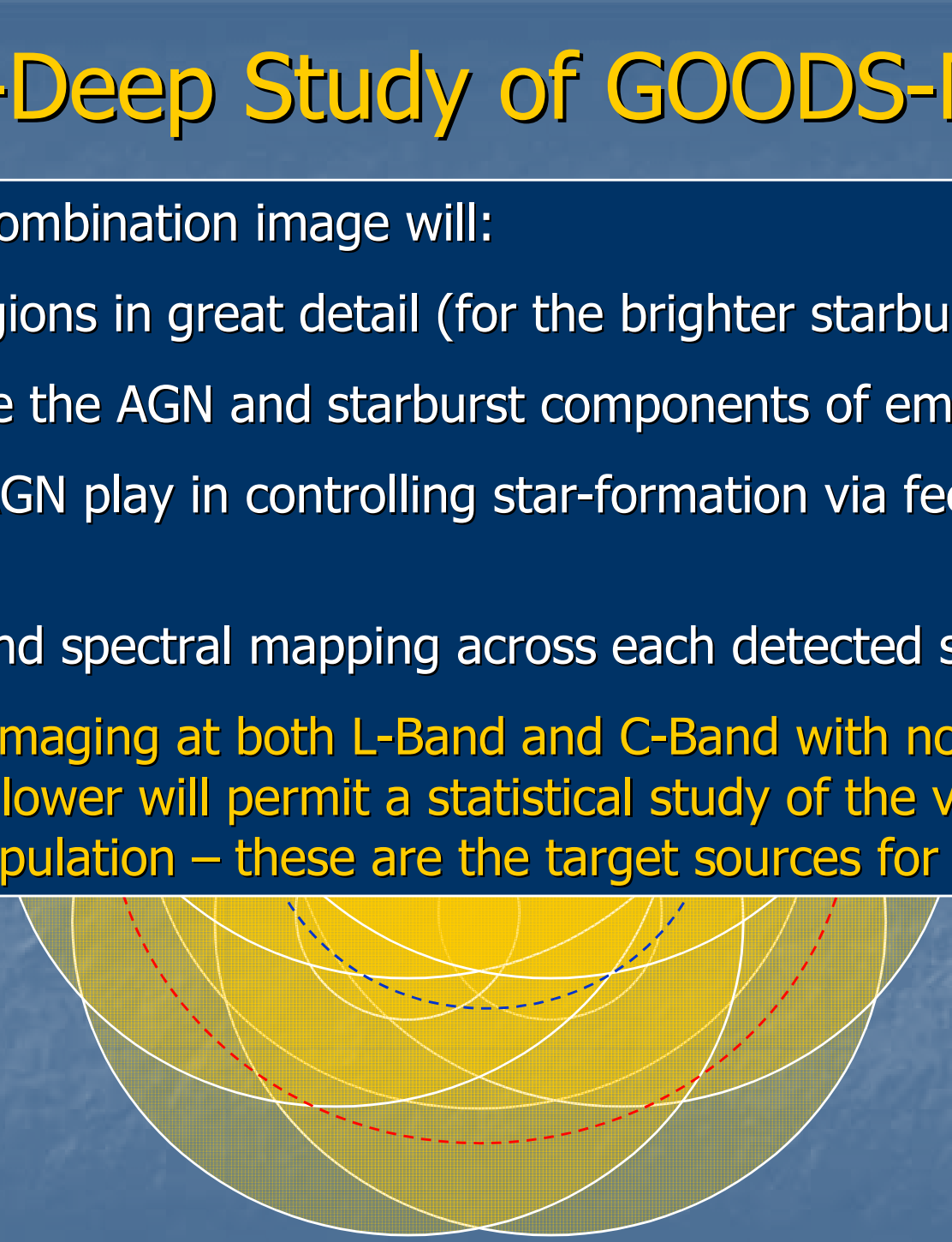
Separate and disentangle the AGN and starburst components of emission

Study the role that the AGN play in controlling star-formation via feedback - on sub-kpc scales

Produce total intensity and spectral mapping across each detected system

Ultra-deep combination imaging at both L-Band and C-Band with noise levels ~500nJy/beam or lower will permit a statistical study of the very faint nJy radio source population – these are the target sources for SKA

structures with sizes
> 1.2 arcseconds



Tier 1 – GOODS-N Summary

- Combination L-Band images for several x 10^3 individual sources across a 30′ field complete to a few μJy with $1\sigma \sim 500$nJy/beam (200mas).
- Combination C-Band images for ~250 individual sources in the inner 10′ field, again with $1\sigma \sim 500$nJy/beam (50mas).
- Statistical investigation of the nJy population from galaxy stacking.
- These will be large datasets.
- All continuum images are wide-field continuum images.
- For the EVLA and *e*-MERLIN ultimate sensitivity requires high-dynamic range image subtraction of confusing sources on edge of primary beams

- *e*-MERLIN should be running at close to full specification from mid 2010

References:

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The basic observing capabilities of *e*-MERLIN are summarized below

Observing Band	L	C	K	Comments
Resolution (mas)	150	40	12	Uniform weighting at central frequency
Field of View (arcmin)	30	7	2.0	FWHM of 25-m dishes; reduced when Lovell Telescope included at L,C-band (1)
Freq. range (GHz)	1.3-1.7	4-8	22-24	
Bandwidth (GHz)	0.4	2	2	Max. bandwidth per polarization. Can use 4 GHz bandwidth, single polarization at C-and K-band
Sensitivity μJy/beam (full imaging run)	5-6	1.8-2.3	~15	Final performance will depend on useable bandwidth, final receiver optimization, Lovell Telescope performance. These figures are for *e*-MERLIN with the Lovell Telescope (1)
Surface brightness Sensitivity (K)	~190	~70	~530	As above
Astrometric performance (mas)	~2	~1	~2	Wrt the ICRF (typical 3 degree target – calibrator separation using VLBA Calibrator Survey sources)
	~0.5	~0.2	~1	Day-to-day repeatability using surveyed or in beam sources, and assuming full imaging run
Amplitude Calibration	2%	1%	10%	Targets for day-to-day repeatability.

Notes

(1) The Lovell telescope may be included in *e*-MERLIN and L and C-band. Its inclusion increases the sensitivity by a factor of between 2 and 3 and reduces the field of view to approximately 20/(ν/1.4 GHz) arcmin, depending on the data weighting scheme adopted.