The University of Manchester
Jodrell Bank Observatory

MANCHESTER 1824

e-MERLIN – an update on delivery

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YERAC 2011 – 19th July 2011

Science & Technology Facilities Council

SKA SQUARE KILOMETRE ARRAY

Outline

Upgrade News – Original MERLIN transformed....

– What's delivered...

– What's still to come...

e-MERLIN and star-formation at high redshift:

Historical – Original MERLIN studies of nearby star-forming galaxies

Constraining our models and refining our s-f rate measurements

– Deep study of μJy radio sources in GOODS-N

Statistical properties of the radio population down to ~μJy

Coming soon – The *e*-MERGE Legacy programme:

An ultra-deep *e*-MERLIN+EVLA study of the μJy population

– Role of AGN feedback & mergers in triggering/controlling star-formation

– History of star-formation through cosmic time....

e-MERLIN upgrade to UK 7-element interferometer

Baselines to ~220 km baselines

Observing bands: 1.3-1.7, 4-8, 21-26 GHz

200 - 10 mas angular resolution

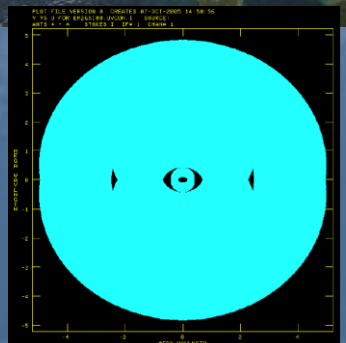
Optical fibres, new receivers, new correlator

2 GHz bandwidth fills aperture<8 GHz

μJy continuum sensitivity (improved by ~30)

Spectral line sensitivity more than doubled

High sensitivity, high fidelity imaging



e-MERLIN progress

Optical fibres to all telescopes in place and tested

New updated broadband 1.2-1.7 and 4-8 GHz receivers

- 21-26 GHz under development
- Broadband electronics installed (IFs etc.)

First correlator quadrant working

- First images: 512MHz bandwidth between 4 - 7GHz
- Characterising polarization performance

To Come.....

- L-Band testing – Q3 2011
- Broad-band samplers & 2GHz BW operations - Q4 2011
- Transfer of timing links to fibres imminent
- Some initial shared-risk observations in progress – official shared-risk announcement Q3 2011

Merlin Telescope Links

Original MERLIN connected by fixed-link radio masts

Astronomy returned over μ-wave links – principle BW limitation

Coherence achieved via two-way L-Band radio timing links

Direct links to close outstations, multiple hops to distant telescopes – 5 link towers used JBO-Cm

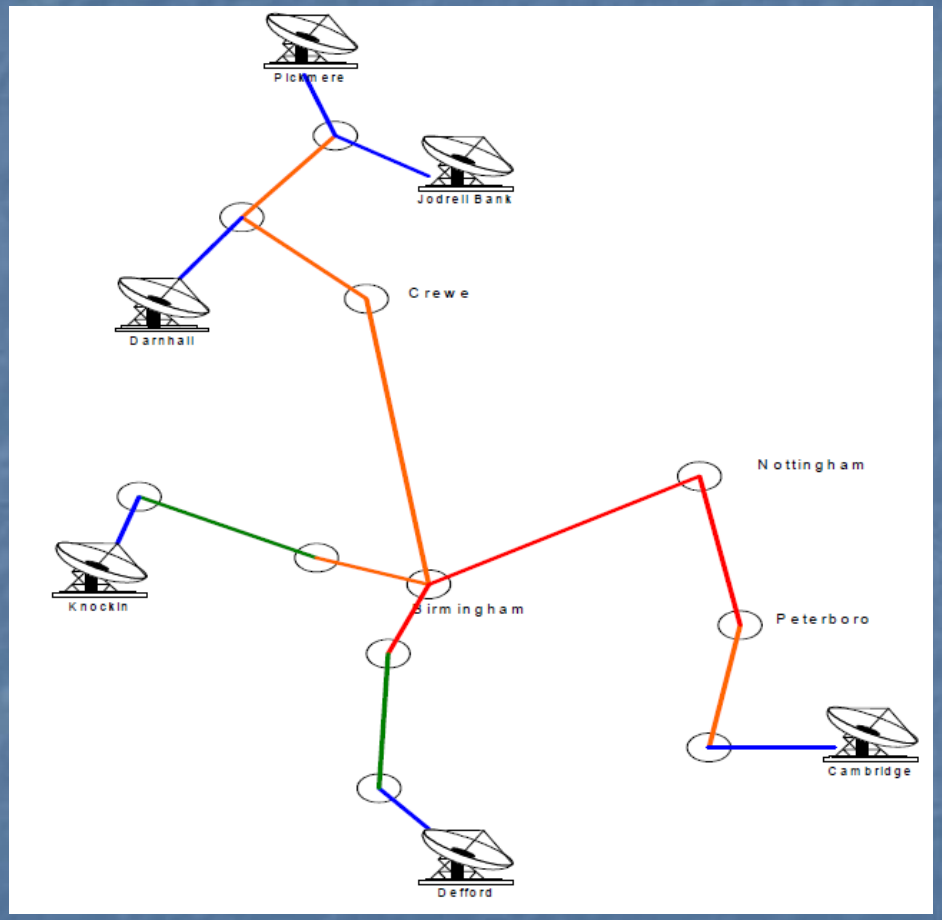
e-Merlin Telescope Links

e-MERLIN – radio links replaced by leased dark optical fibres running beside major railway lines

Useable bandwidth increased from 15MHz/polzn to 2GHz/polzn (*cf »dial-up → cable broadband*)

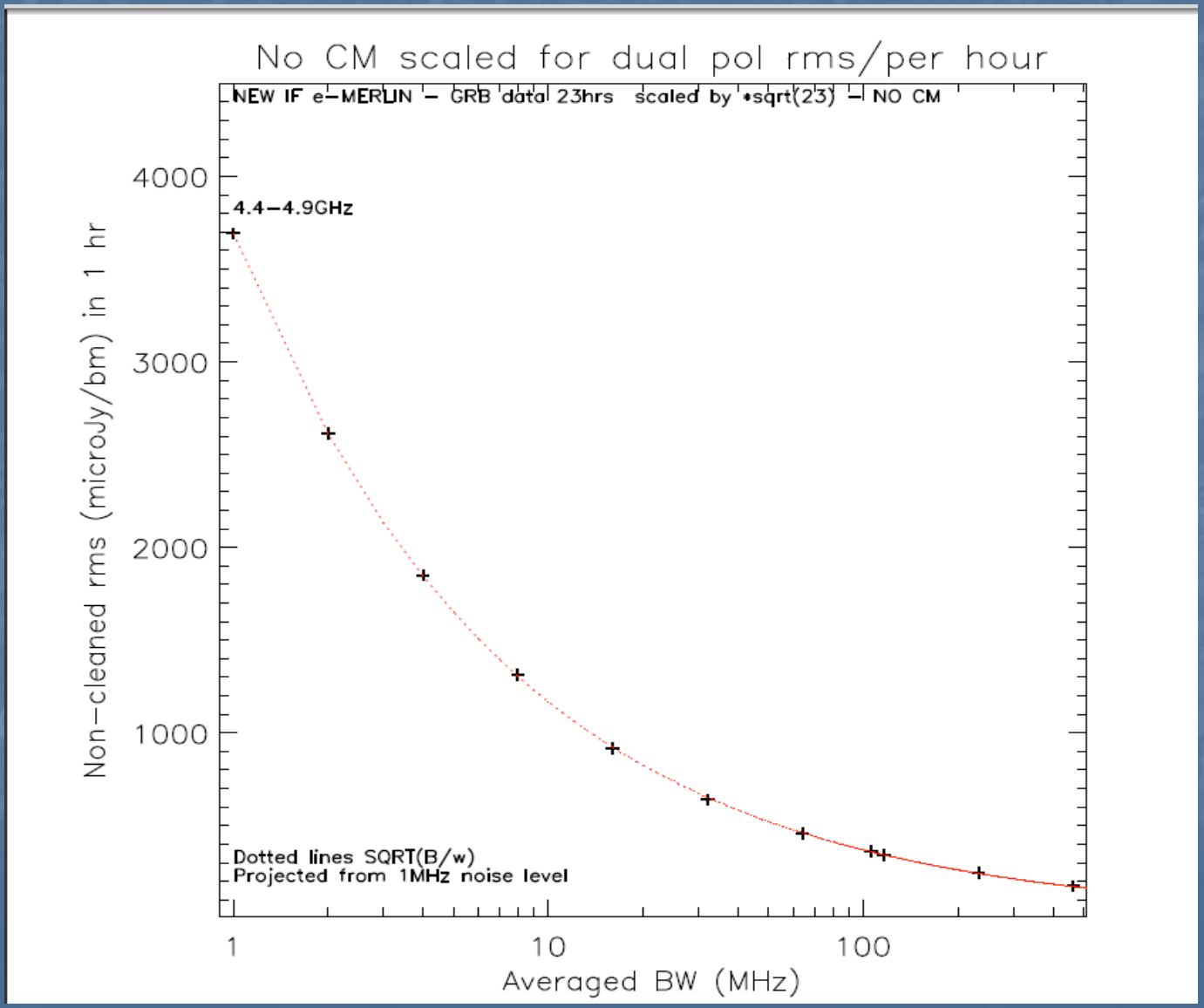
Wide-band astronomy return links in place and under test

Coherence timing links to be removed from radio masts and implemented over optical fibre network – scheduled August-September 2011



e-Merlin Sensitivity Tests (512MHz BW)

- Scales as √BW
- Scales as √τ
- Noise ~Gaussian
- As with EVLA some sensitivity issues being identified and optimised
- Polarization performance now being characterised



e-MERLIN sensitivity

Sub-mas ICRF astrometry (in-beam calibration)

Full polarization, 512MHz continuum under test

Resolution matches HST/JWST, ALMA

VO access to customised archive products

Addition of 76m Lovell telescope improves sensitivity by~2

	L-band	C-band	K-band
GHz/cm	1.3-1.725/23-17.4	4.2-7.8/7.1-3.8	21.5-24.5/1.4-1.2
Ang. resol'n	220 - 110 mas	70 - 30 mas	13 - 8 mas
FoV	13 - 30 arcmin	4 - 7 arcmin	2 arcmin
Continuum	sensitivity/beam	sensitivity/beam	sensitivity/beam
3σ 12 hr	14μJy	6μJy	15μJy

Spectral capability

High spectral resolution possible $\delta\nu \geqq 2$ Hz ($\lambda/\delta\lambda \leqq 7\times10^8$ @ 21cm)

- Multiple lines/high velocity sources in a single band
- Transfer calibration between lines and continuum
- Almost always a good, close calibrator

Optimal sensitivity even if line too weak to self-cal

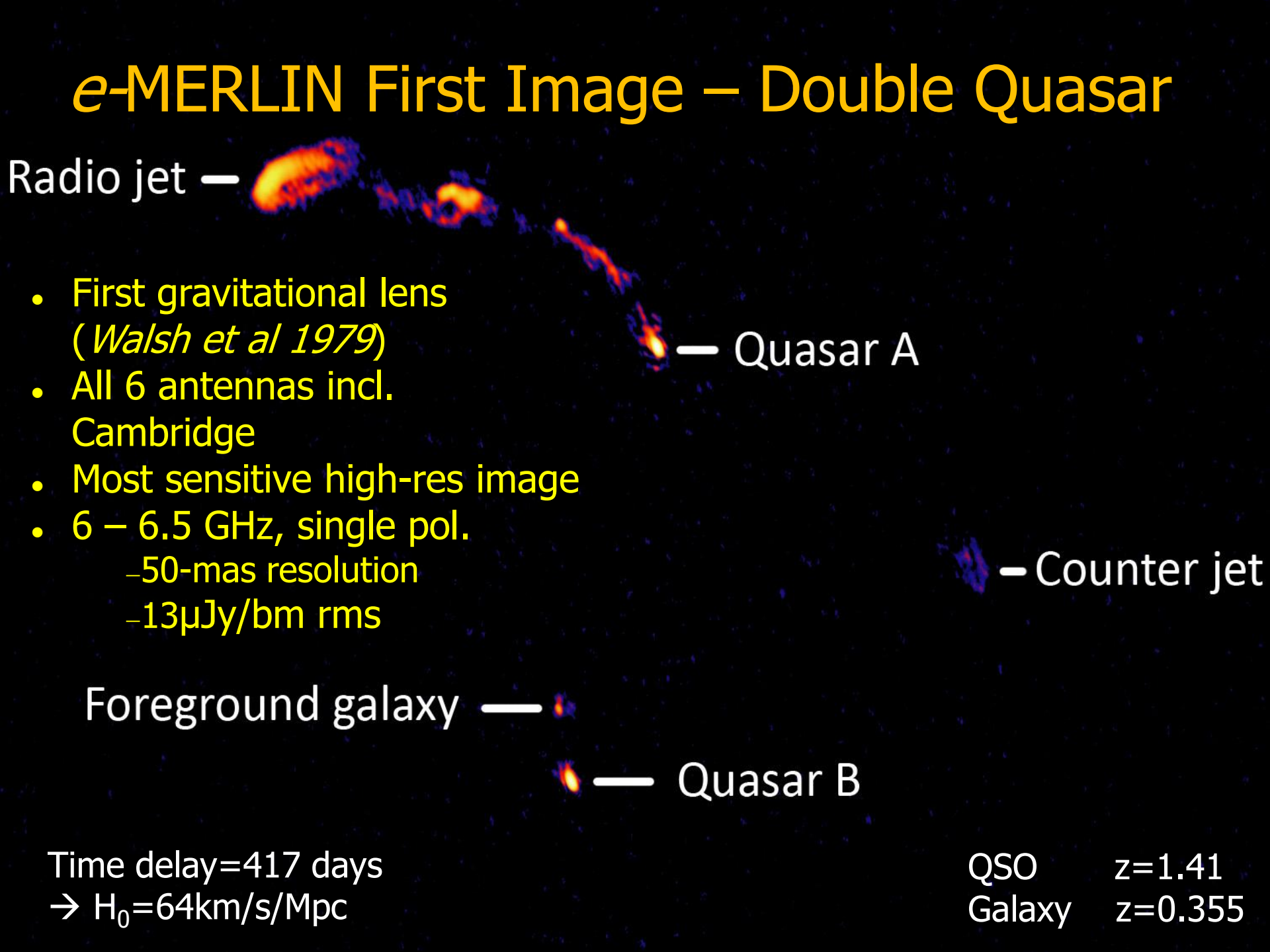
Initial spectral configurations now under test

Flexible configurations – 16 independent sub-bands

- Use rest of band for high-sensitivity continuum
- Easy to match spectral configurations with EVLA or VLBI

Spectral	L-band	C-band	K-band
3σ 12 hr	sensitivity/beam (per channel)	sensitivity/beam (per channel)	sensitivity/beam (per channel)
0.05 km/s	23 mJy	10 mJy	32 mJy
3 km/s	2.9 mJy	1.3 mJy	4 mJy

e-MERLIN First Image – Double Quasar



- First gravitational lens (*Walsh et al 1979*)
- All 6 antennas incl. Cambridge
- Most sensitive high-res image
- 6 – 6.5 GHz, single pol.
  - 50-mas resolution
  - 13μJy/bm rms

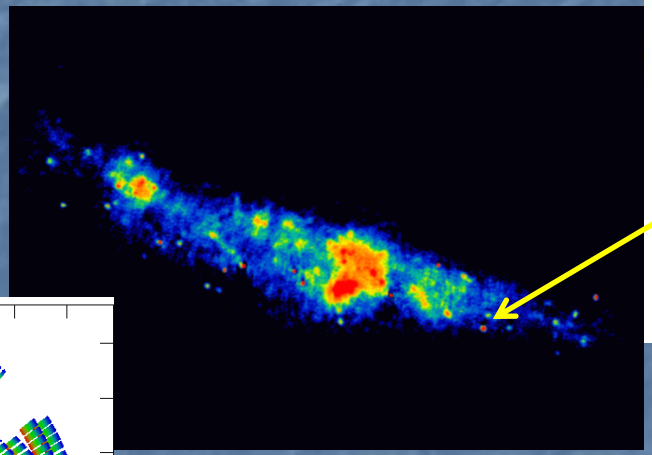
Time delay=417 days
→ H_0=64km/s/Mpc

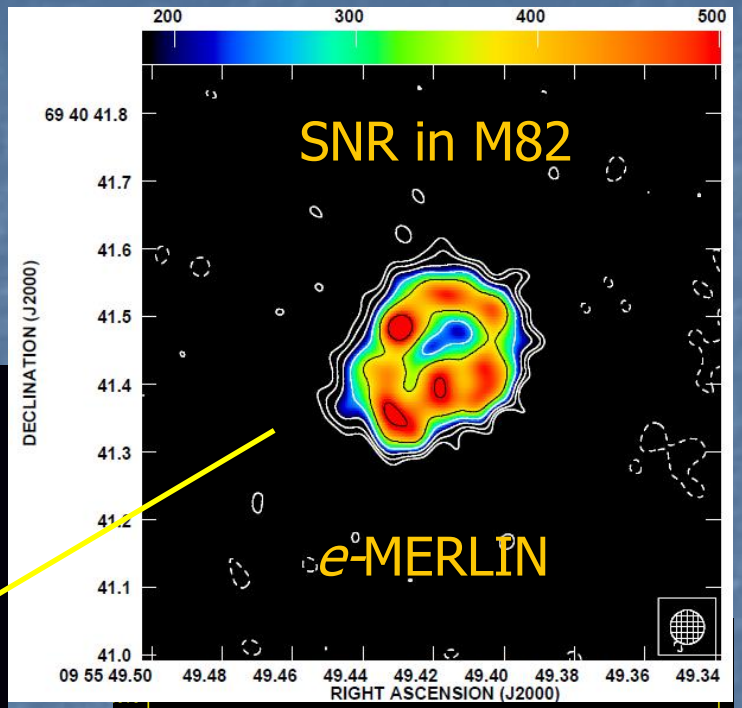
QSO z=1.41
Galaxy z=0.355

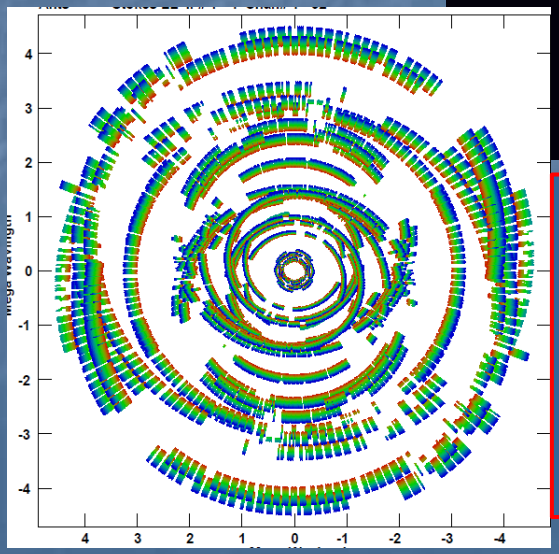
More Test Images – M82

Even with only 512Mhz of the planned 2GHz of total bandwidth at C-Band, *e*-Merlin sensitivity *uv*-coverage and image fidelity is transformed.

e-Merlin C-Band image (right), resolution 35mas. VLA+MERLIN (below), resolution 120mas

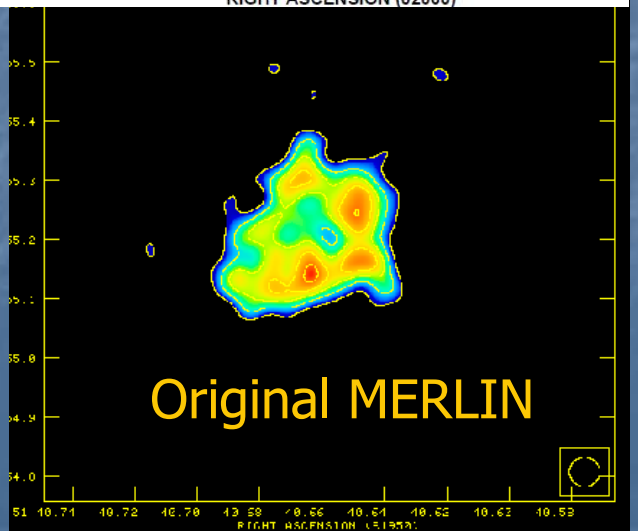






Full operations at L & C-Band expected by end of calendar year 2011

PATT – Semester 2012A



e-MERLIN and Star-formation Studies at High Redshift

Original study MERLIN+VLA – Muxlow et al 2005

10×10 arcmin field centred on the GOODS-N
92 radio sources >40μJy. Data from ~1996

High resolution imaging can morphologically distinguish AGN & SF. Source sizes ~1.5”

Below ~70μJy the radio population becomes dominated by powerful star-forming galaxies typically at z<1.5

Radio emission at ~few μJy statistically detected from ~13,000 z-band galaxies

New Ultra-Deep Study of GOODS-N

A tiered *e*-MERLIN Legacy proposal – the *e*-MERGE Survey will study the formation and evolution of star-forming galaxies and AGN to redshifts > 5

– The *e*-MERlin Galaxy Evolution Survey

- 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 – Tiers 0 & 1 approved

Tier 1: New Ultra-Deep Study of GOODS-N

e-MERLIN+EVLA will exceed the depth of the existing MERLIN study in just 24 hours of on-source integration.

λ 20cm: Single pointing centre, 20 days including 76m Lovell telescope.

Central 10 arcminute field 1σ ~ 500nJy/beam

Outer 30 arcminute field 1σ ~ 1μJy/beam

only

Tier 1: 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.

λ 20cm : Single pointing centre, 20 full tracks.

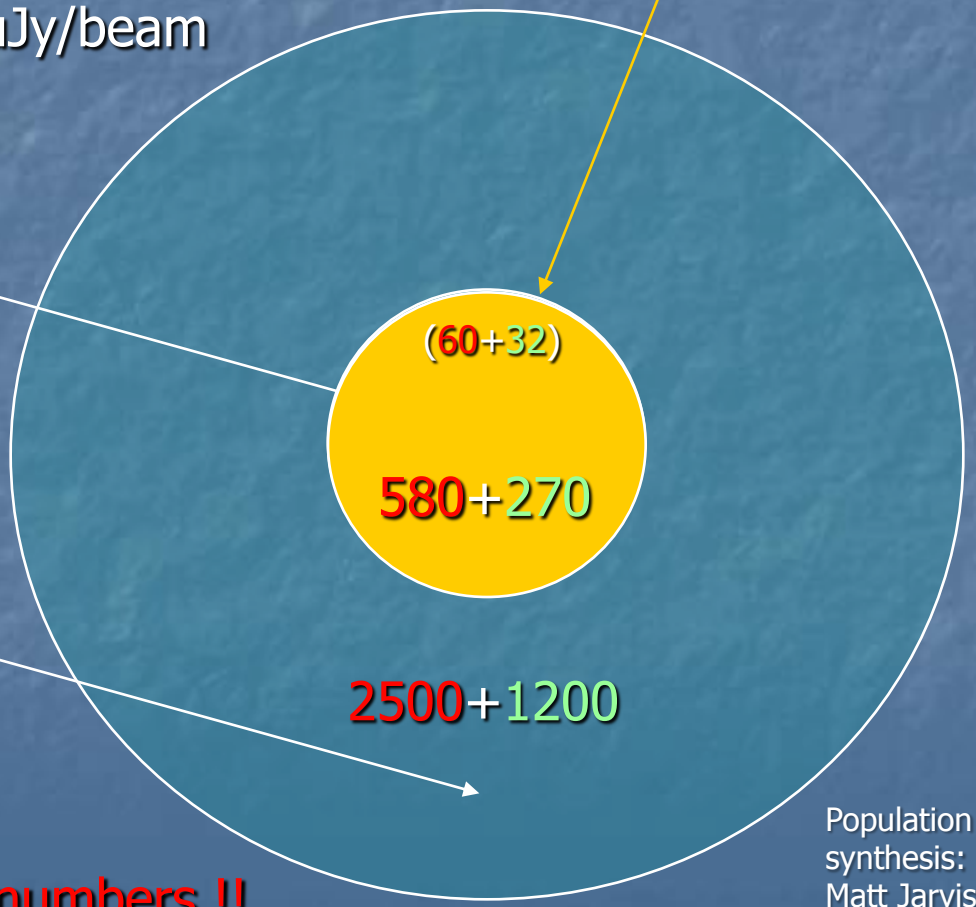
Central 10 arcminute field 1σ ~ 500nJy/beam

Outer 30 arcminute field 1σ ~ 1μJy/beam

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

(>10 times deeper than the original study)

Surrounding 800 square arcmins, ~2500 star-forming galaxies and ~1200 AGN brighter than ~6μJy

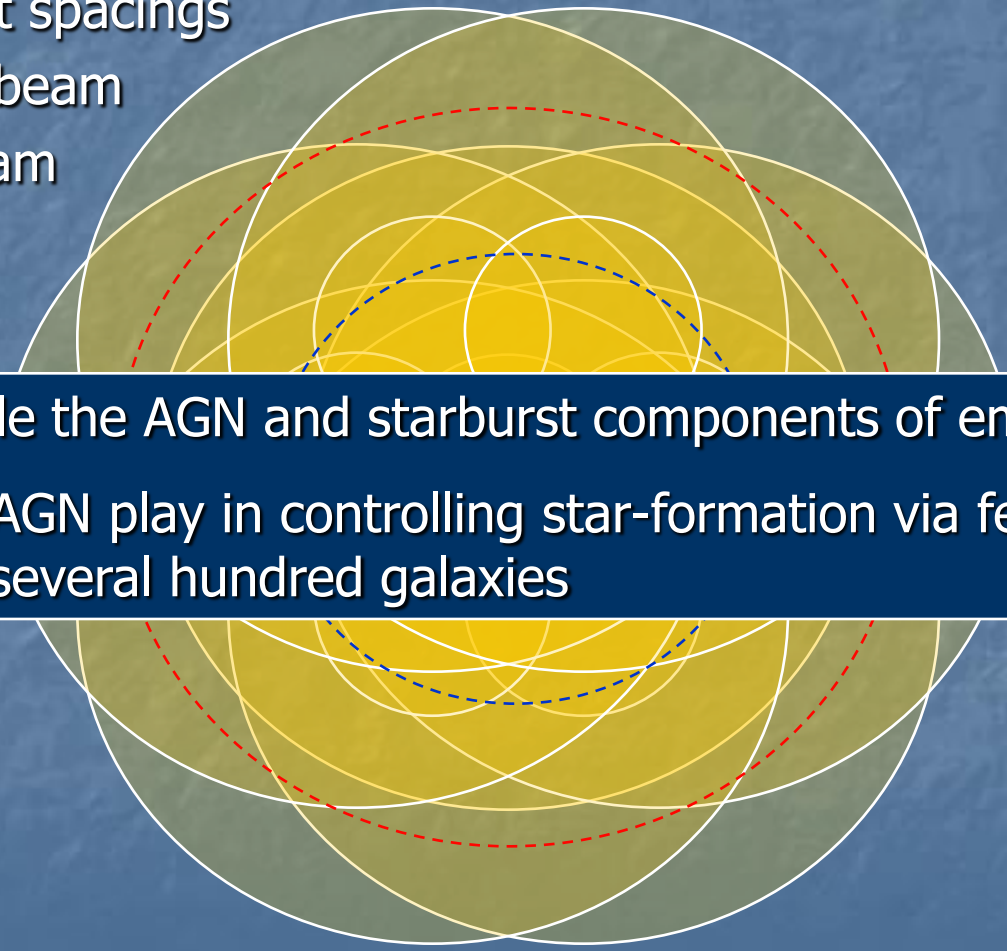


Population synthesis: Matt Jarvis

5250:92 >50x increase in source numbers !!

Tier 1: New Ultra-Deep Study of GOODS-N

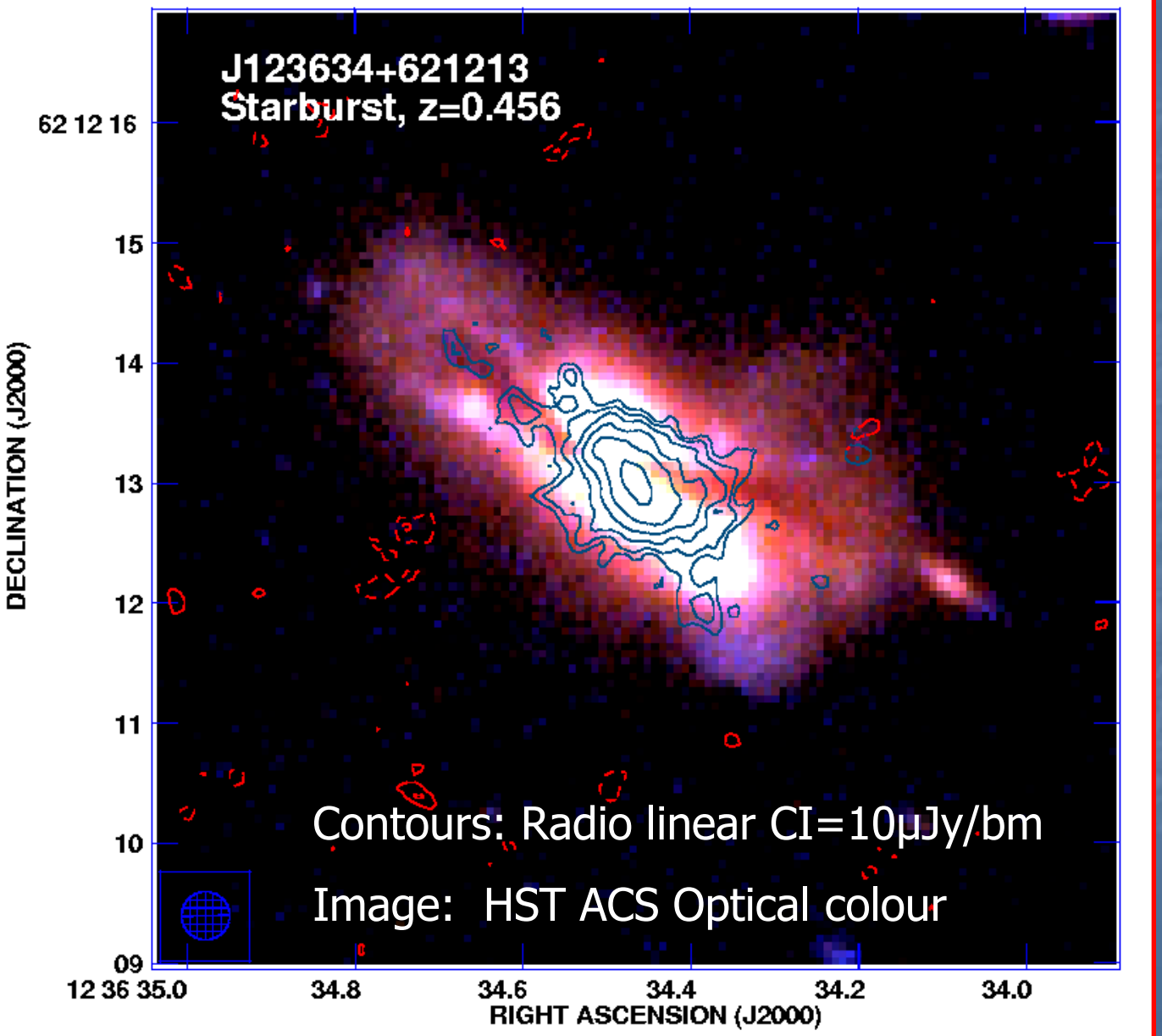
- New λ 6cm image: 7 pointing centres each with 3 long tracks
- Mosaic pattern set for Lovell 3 arcminute beam
- EVLA will provide short spacings
- Inner 6′ 1σ ~ 500nJy/beam
- 6-10′ 1σ ~ 700nJy/beam
- Resolution 40 mas



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 for several hundred galaxies

Tier 1: New Ultra-Deep Study of GOODS-N



Merging system with a dust lane

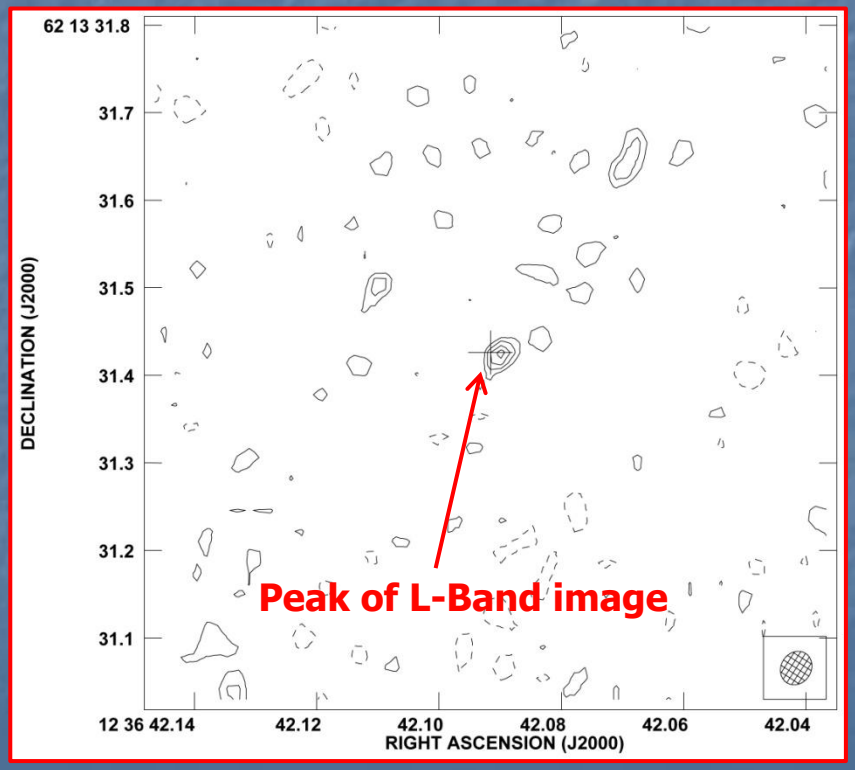
e-MERGE at 6cm will image this system at 40 mas + EVN → 1mas

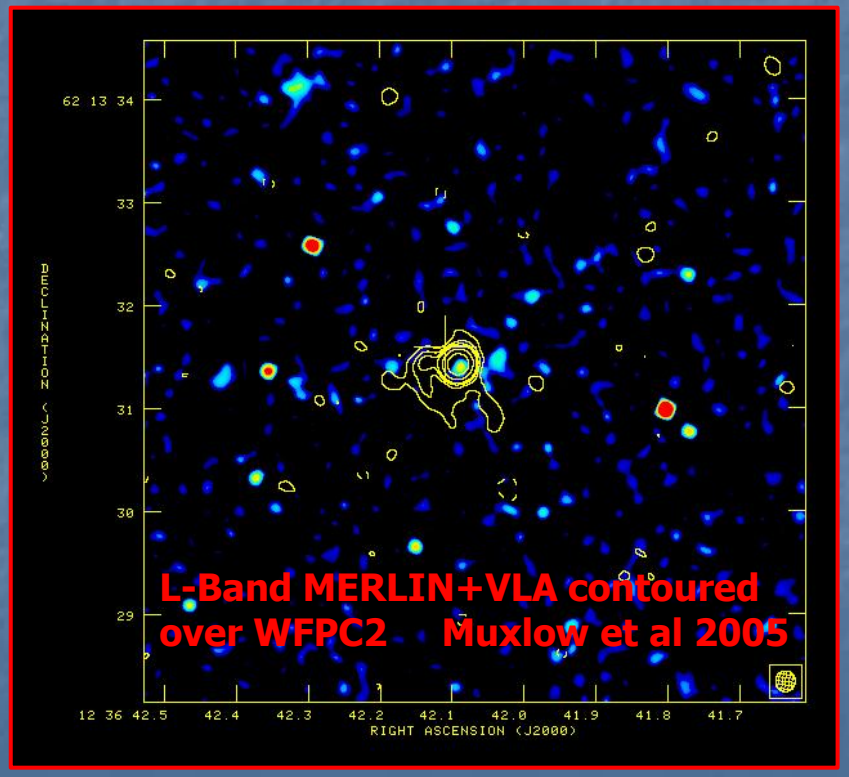
→ detailed SF activity & role of any embedded AGN

e-MERLIN GOODS-N Test Image

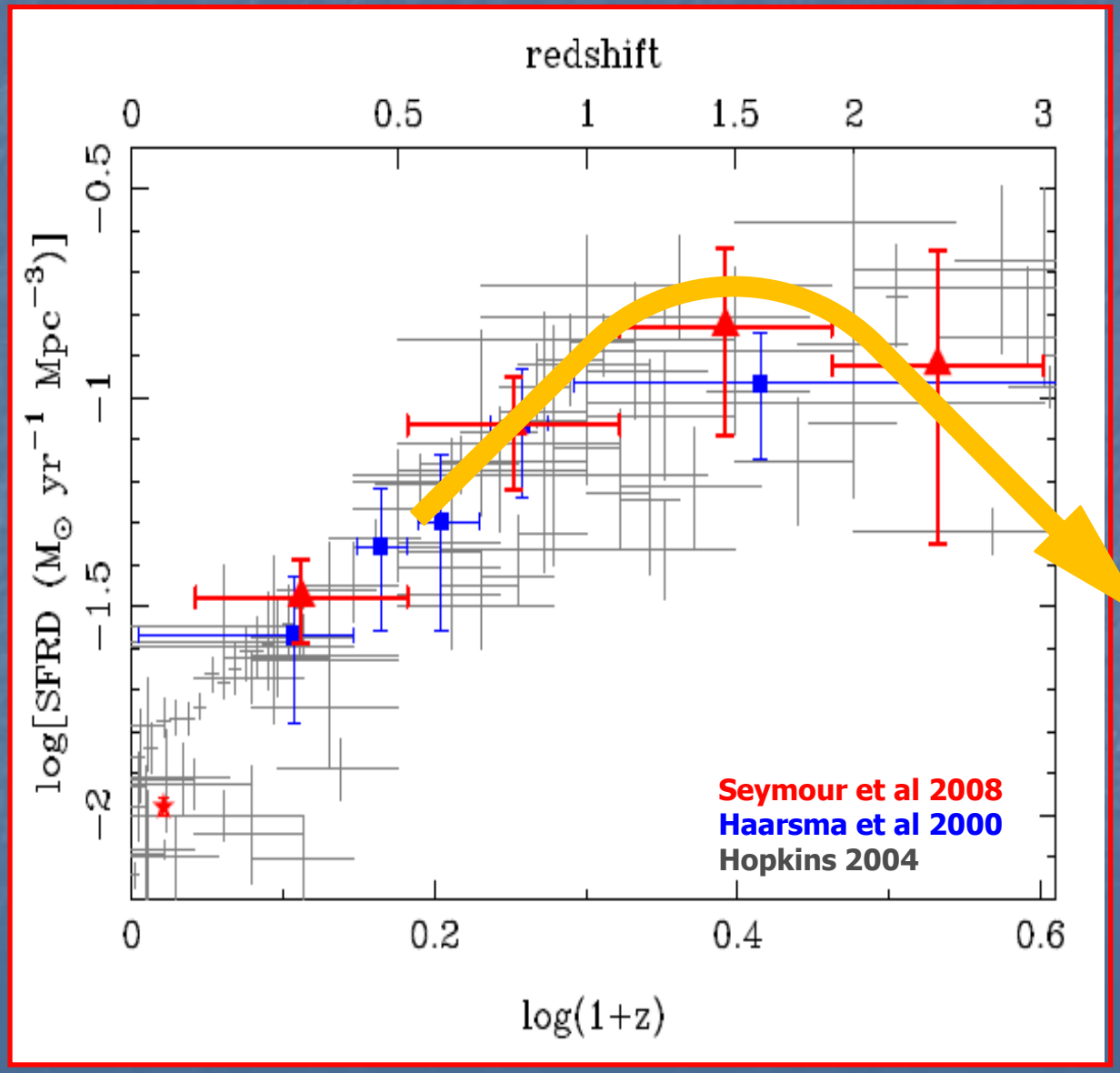
J123642+621331 is a composite AGN-Starburst system at a redshift of 4.424

The new *e*-MERLIN C-Band image (left, rms 13μJy/bm) shows the detection of a faint flat-spectrum core component at the base of the jet confirming the composite nature of this system. C-Band *e*-MERLIN is a fantastic AGN finder



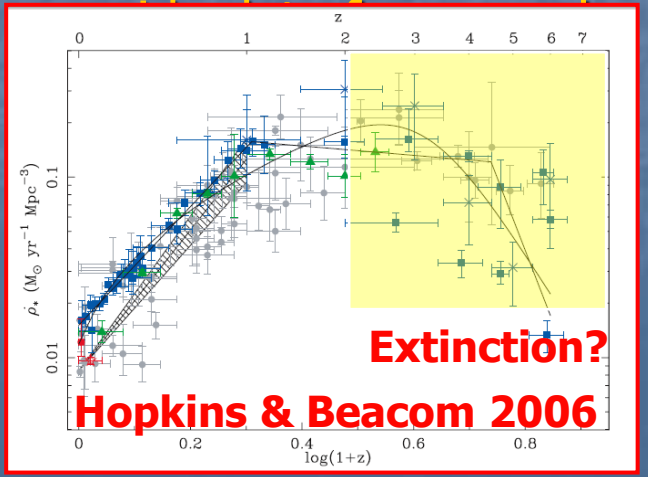


Star-formation History of the Universe
- from Extinction-free Starburst Radio Luminosities



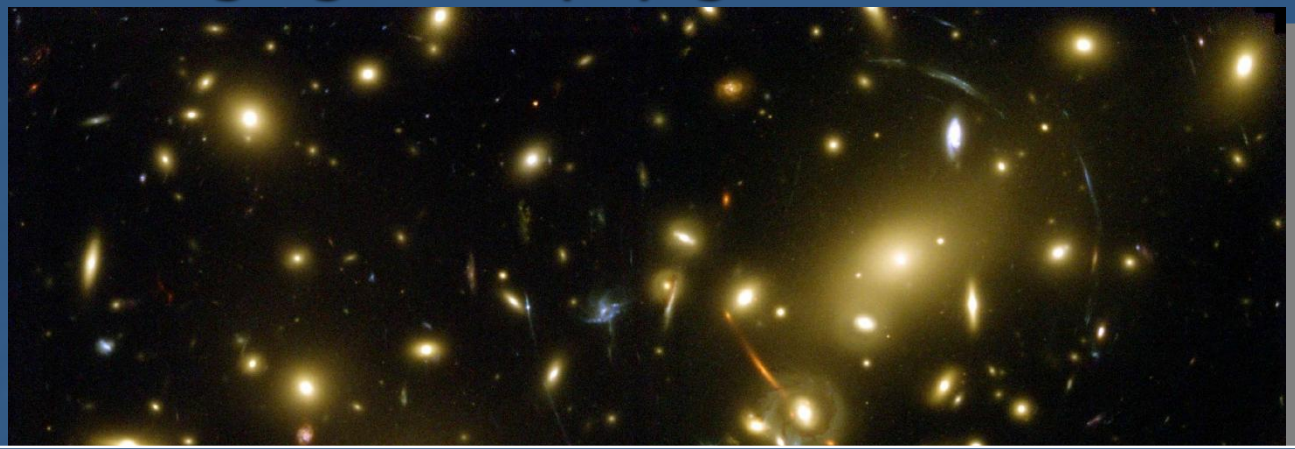
The co-moving Star-Formation Rate Density of the Universe from L-Band radio studies by Seymour et al (2008), Haarsma et al (2000) , & UV, Hα, Far-IR... Hopkins (2004)

L-Band results from the *e*-MERGE survey will



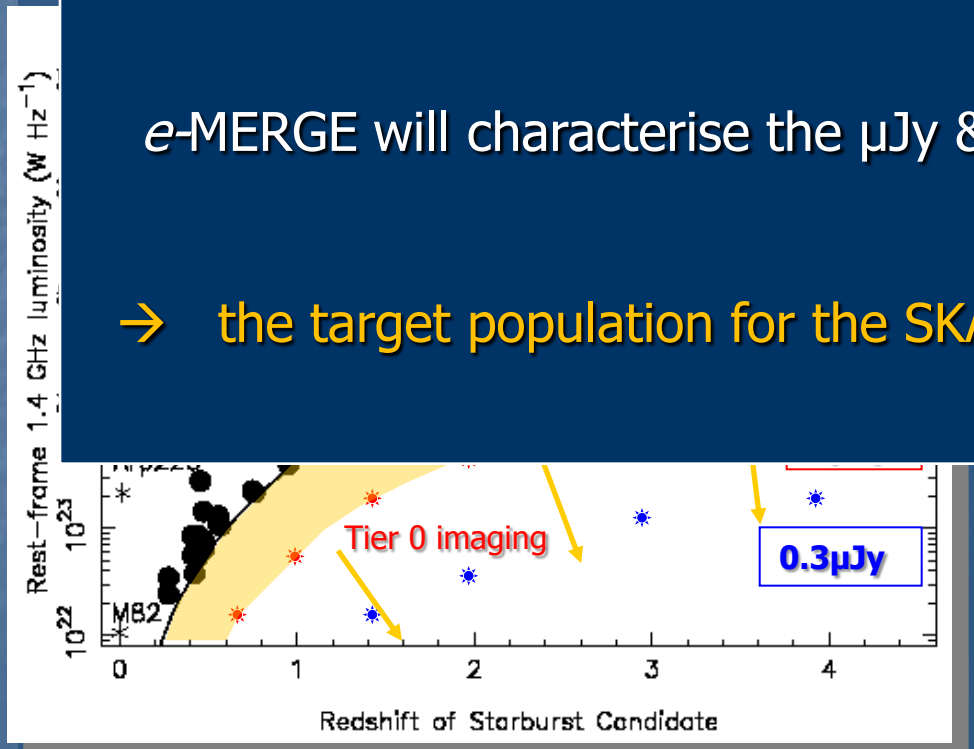
Tier 0: Imaging sub-1μJy galaxies

A single 180-hr L-band pointing on strong lensing cluster A2218 (z=0.18).



e-MERGE will characterise the μJy & sub-μJy radio source population

→ the target population for the SKA in future high redshift SF studies



300nJy

Measure faint radio counts

May include SF galaxies with SFR~200M$_\odot$/yr to z~5

The New Generation of Imaging Arrays

Extragalactic Star-formation:
(a very vestigial description)

EVLA:
Deep, wide μJy source surveys at ~2 arcsec resolution

e-MERLIN:
Detailed imaging of nearby & distant star-forming galaxies
Deep, narrow μJy source surveys at ~0.1 arcsec resolution

EVN+:
Ultra-high resolution imaging of Sne/SNR in nearby galaxies and star-forming regions in high redshift systems

The dawn of a transformative era with massively improved imaging capability with the potential of studying a substantial proportion of the galaxy population to high redshifts

Major multi-wavelength studies of several equatorial fields

...and SKA still to come...!!

ALMA:
Early Science – detailed imaging of molecular gas dynamics in nearby galaxies
Full Operations – extensive detailed imaging of molecular gas dynamics in high redshift galaxies