

# The e-MERGE Legacy Survey – an e-MERLIN+JVLA Ultra-Deep Survey

High-resolution mapping of the  $\mu$ Jy radio source population

Being planned 2006 – First results 2015

Tom Muxlow JBCA Manchester  
Ian Smail, Ian McHardy, Nick Wrigley, Alasdair Thompson,  
Daria Guidetti, Jack Radcliffe, & the e-MERGE Consortium

Back at the Edge of the Universe Meeting

Sintra 17<sup>th</sup> March 2015

# Archival MERLIN+VLA study of faint radio sources in GOODS-N

10'×10' L-Band field centred on GOODS-N

Muxlow et al 2005

92 sources  $>40\mu\text{Jy}$ . Observed 1996 - 1998

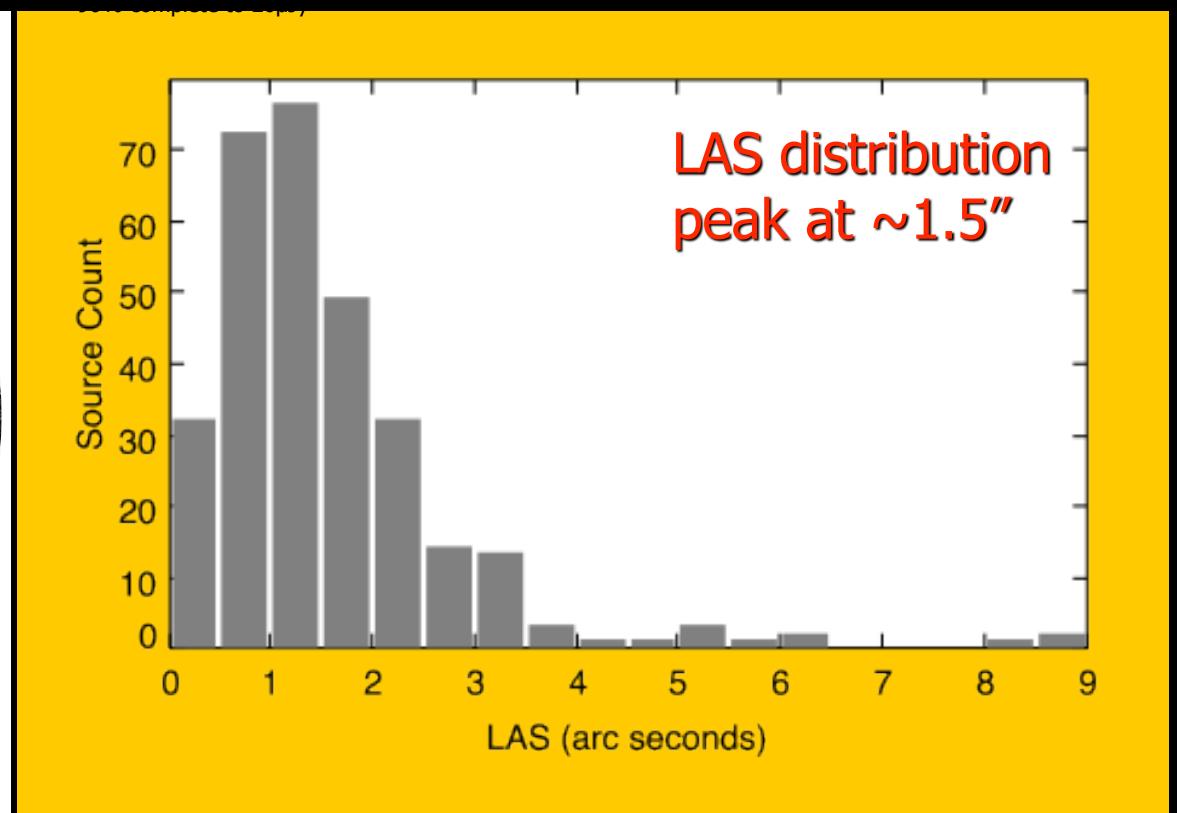
High resolution imaging can morphologically distinguish AGN & SF

$<70\mu\text{Jy}$  population dominated by s-f galaxies typically at  $z<1.5$

Data reworked with enhanced fast imaging: Wrigley et al in prep.

→ 15' diameter contiguous combination image

178 sources imaged with flux densities  $>5\sigma$  (beam corrected)



# e-MERGE Survey

## A tiered e-Merlin + JVLA + EVN Legacy proposal

### The e-MERlin Galaxy Evolution Survey

Tier 0 – *Normal galaxies out to  $z \sim 5$*  [Ian Smail – Durham]

*Deep imaging around clusters to utilise amplification by lensing*

Tier 1 – *Deep survey of  $\mu$ Jy radio source s* [Tom Muxlow – Manchester]

*Deep imaging of the  $\mu$ Jy radio sources in GOODS-N*

e-MERLIN Legacy

Tier 2 – *Shallow-wide survey over  $\sim 2$  square degrees*

[Ian McHardy – Southampton]

Via SuperClass ?

>60 CO-Is from 9 countries

Tier 0 – [2016→]

1 – *15 days e-Merlin+40hrs JVLA-A (L-band)*  
*15 days e-Merlin+ JVLA-A/B/C (C-band)*

Tier

[ $\sim 15\%$  data reduced] [Complete]  
[Q3 2015→] [Complete]

→ full sampling of AGN & s-f galaxy radio luminosity function to  $z \sim 5$

# e-MERGE Survey

## A tiered e-Merlin + JVLA + EVN Legacy proposal

### e-MERGE Goals:

Characterise the radio structures of  $\mu\text{Jy}$  source population

Investigate AGN – star-formation feedback at high  $z$

Constrain the radio (extinction-free) Madau plot for  
 $z < 5$

Interim publications with part-completed observations in 2015

>60 CO-Is from 9 countries

*Tier 0* – [2016→]

1 – *15 days e-Merlin + 40hrs JVLA-A (L-band)*  
*15 days e-Merlin + JVLA-A/B/C (C-band)*

*Tier*

[*~15% data reduced*] [Complete]  
[Q3 2015→] [Complete]

→ full sampling of AGN & s-f galaxy radio luminosity function to  $z \sim 5$

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

e-MERLIN matches sensitivity of old (18 days) MERLIN in 24 hrs on source

L-band: Single pointing centre, ~20 days

Central 12 arcminute field  $1\sigma \sim 500\text{nJy}/\text{beam}$

Outer 30 arcminute field  $1\sigma \sim 1\mu\text{Jy}/\text{beam}$

Ultra-deep C-band mosaic  
+ ultra-deep EVN L-Band

→ AGN activity & feedback

e-MERLIN will image ~580 starbursts and ~270 AGN with an angular resolution of ~200 mas, complete to ~ $3\mu\text{Jy}$

(>10 times deeper than the 2005 study)

In the surrounding 800 square arcmins, e-MERLIN will image ~2500 star-forming galaxies and ~1200 AGN brighter than ~ $6\mu\text{Jy}$

>5000 sources in 0.2 square degree field

580+270

2500+1200

Population synthesis:  
Matt Jarvis

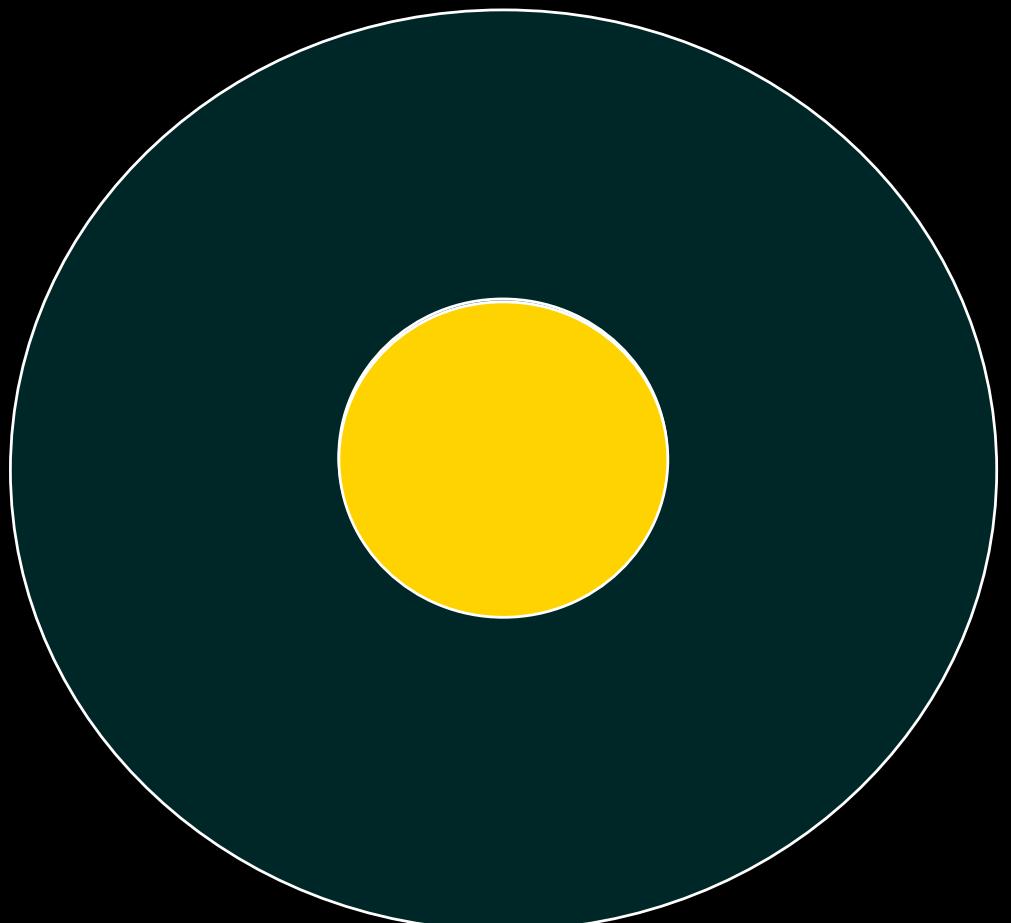
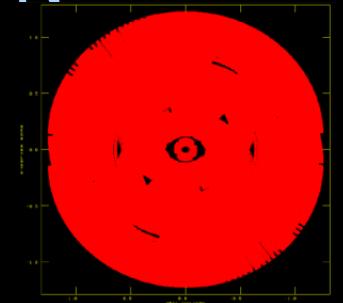
# Tier 1: New Ultra-Deep Study of GOODS-N

e-Merlin L-band data (1.23-1.74GHz → full *uv* coverage)

→ High fidelity imaging of faint radio structures at full resolution

Initial (2015) detailed investigation of >200 SF galaxies and AGN  
in central area (L-Band e-MERLIN/JVLA + C-Band JVLA mosaic)

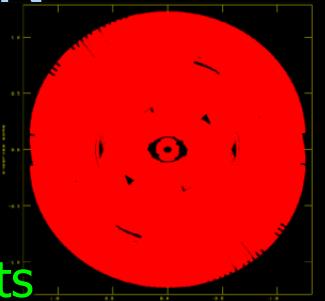
Complete deep study over full 0.2 square degree field will image >5000 galaxies



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

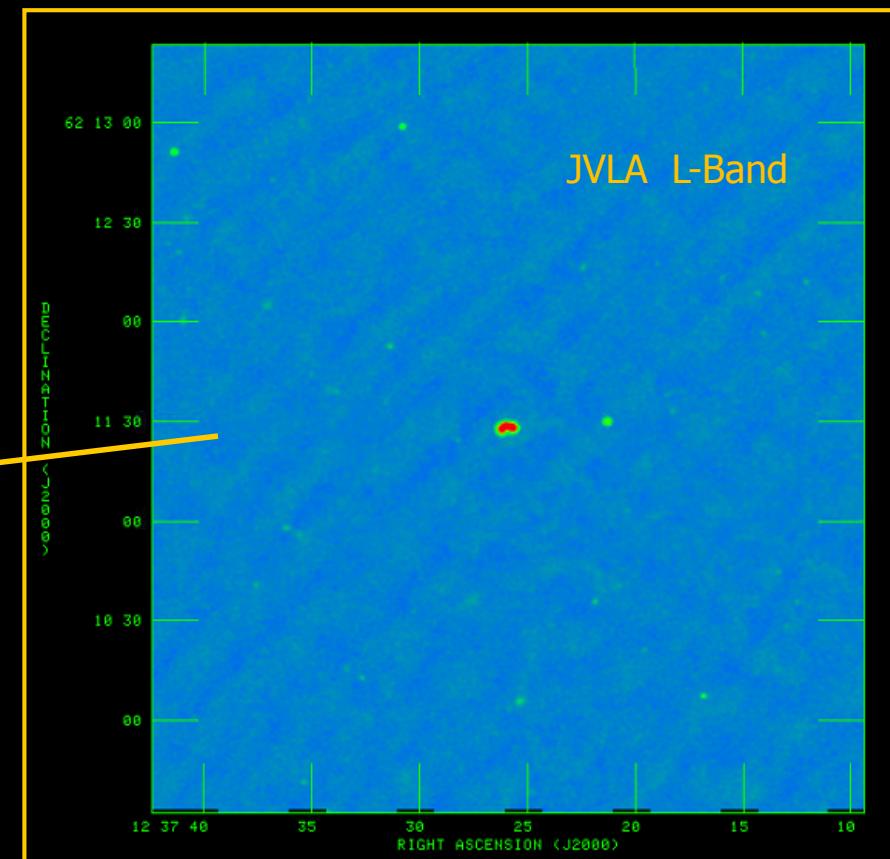
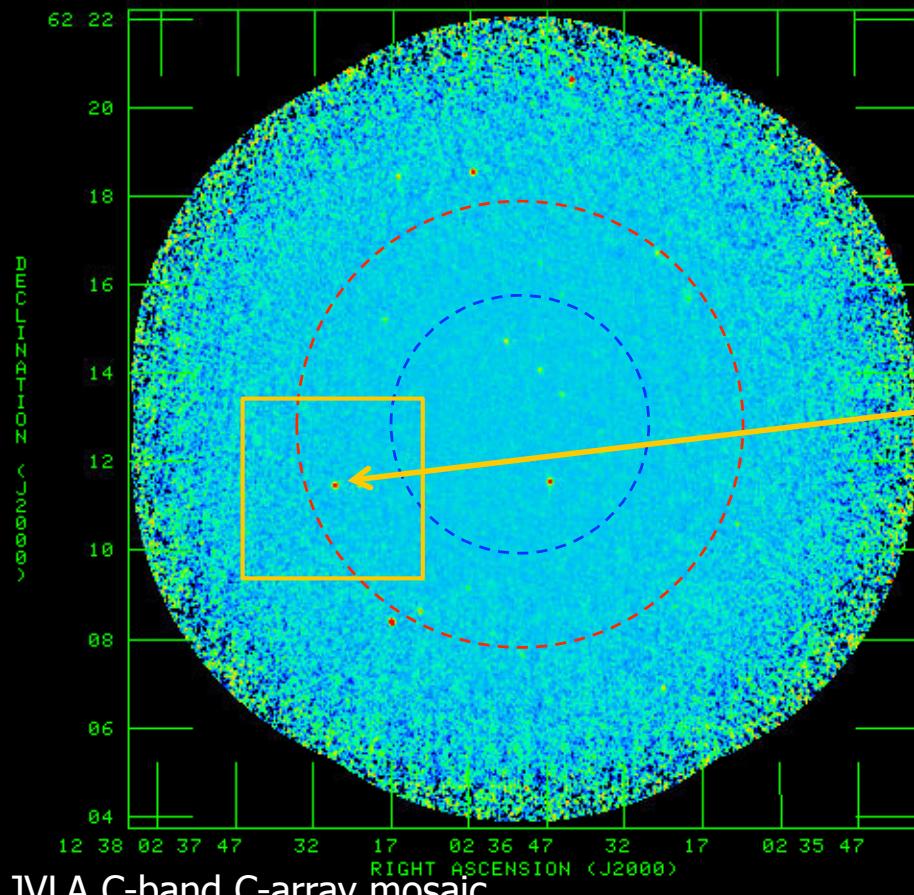
e-Merlin L-band data (1.23-1.74GHz → full *uv* coverage)

→ High fidelity imaging of faint radio structures at full resolution



Only a few classical radio galaxy structures – most AGN are small core-jets

AGN Wide-angled tail radio galaxy (Total 5.3mJy)

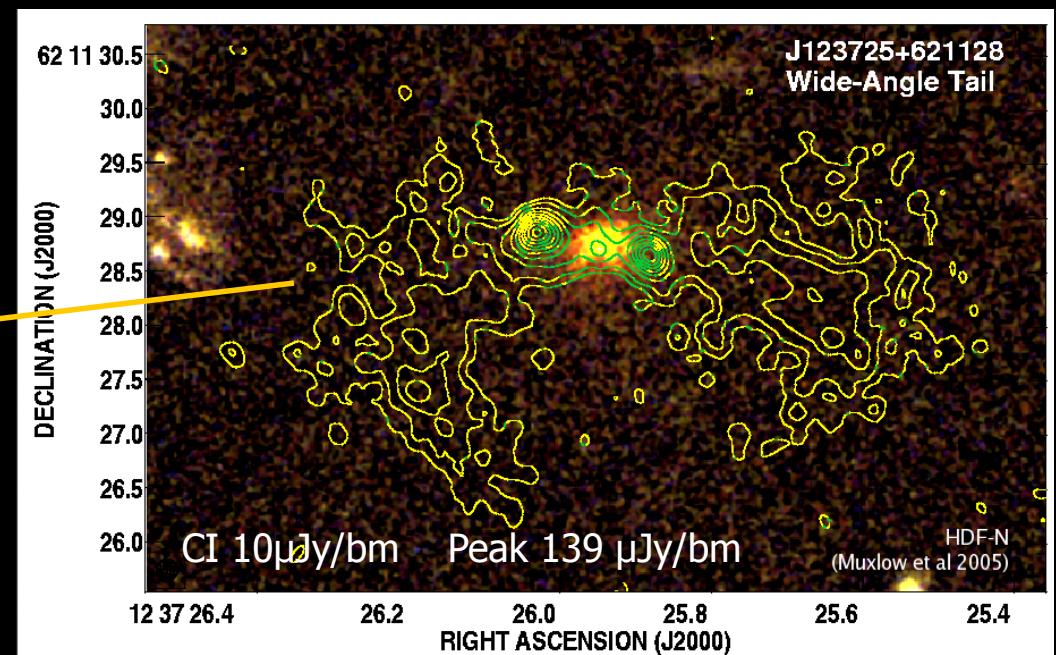
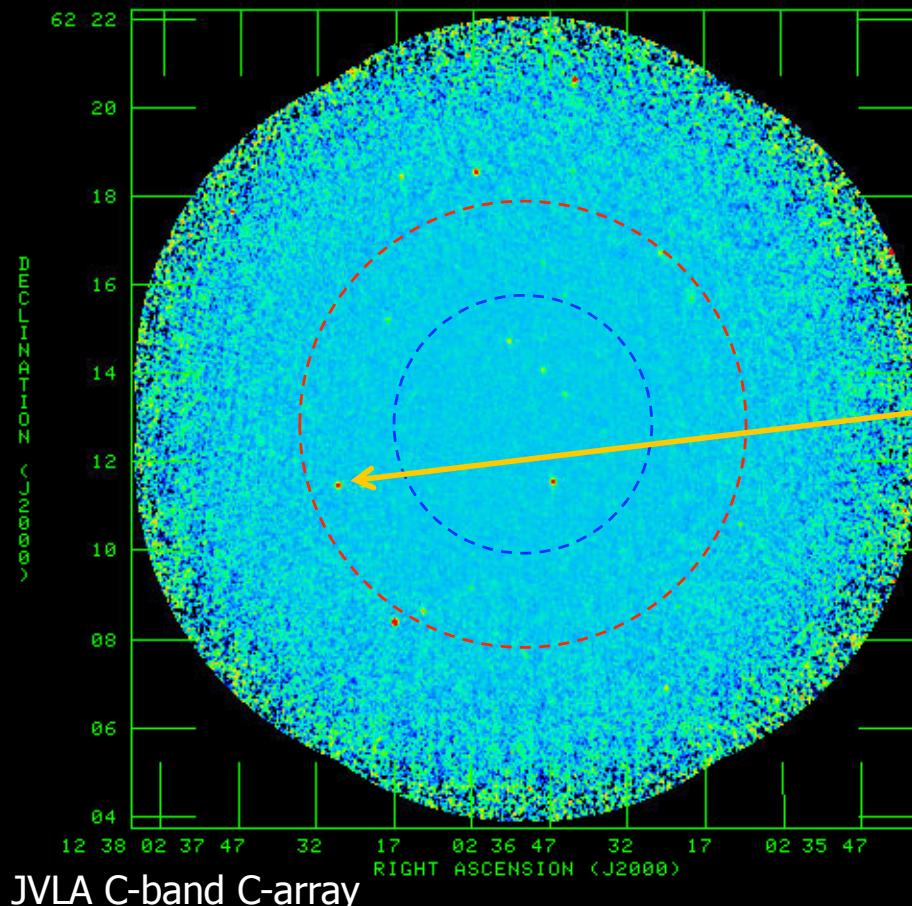


AGN

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

e-Merlin L-band data + 29 hrs JVLA A-array

AGN Wide-angled tail radio galaxy (Total 5.3mJy)



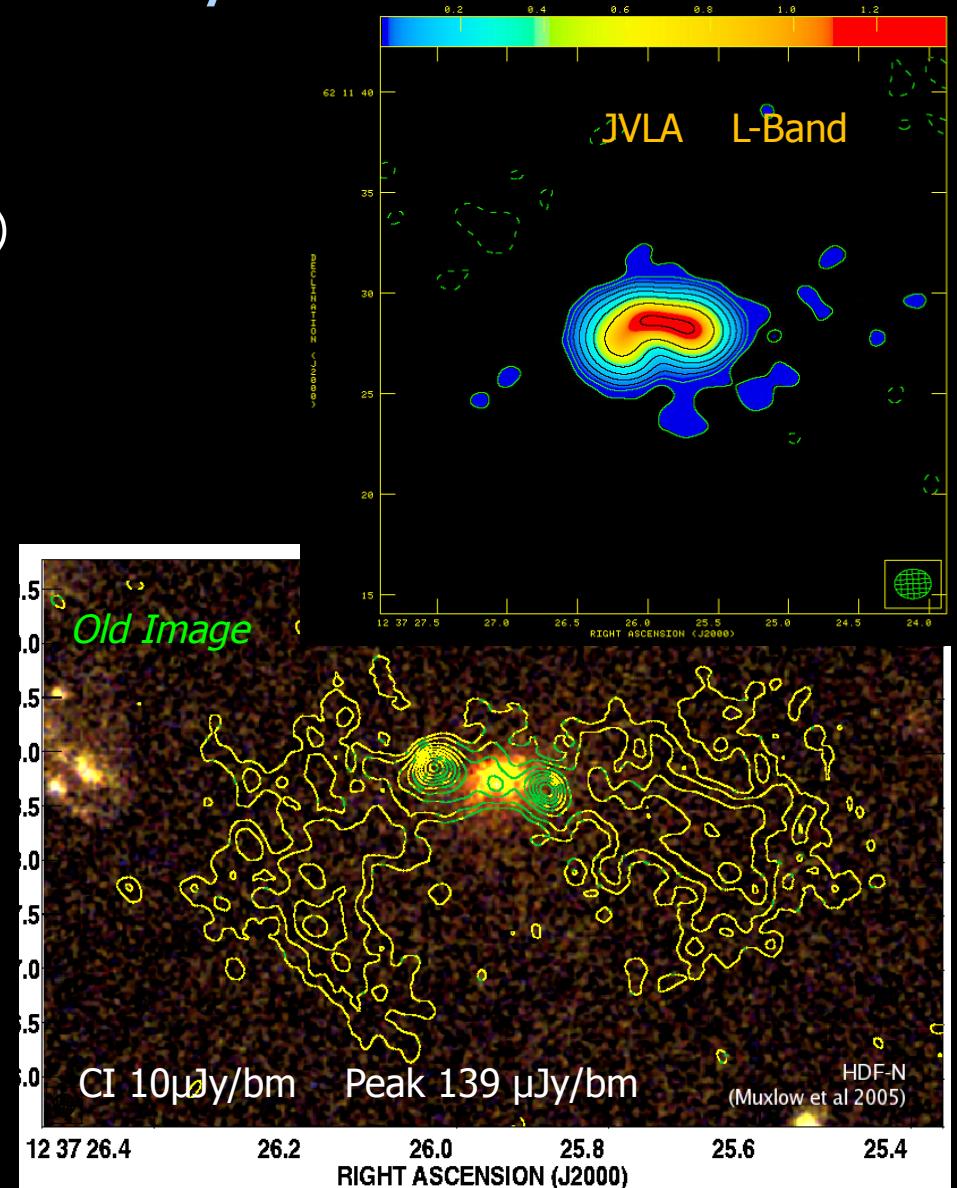
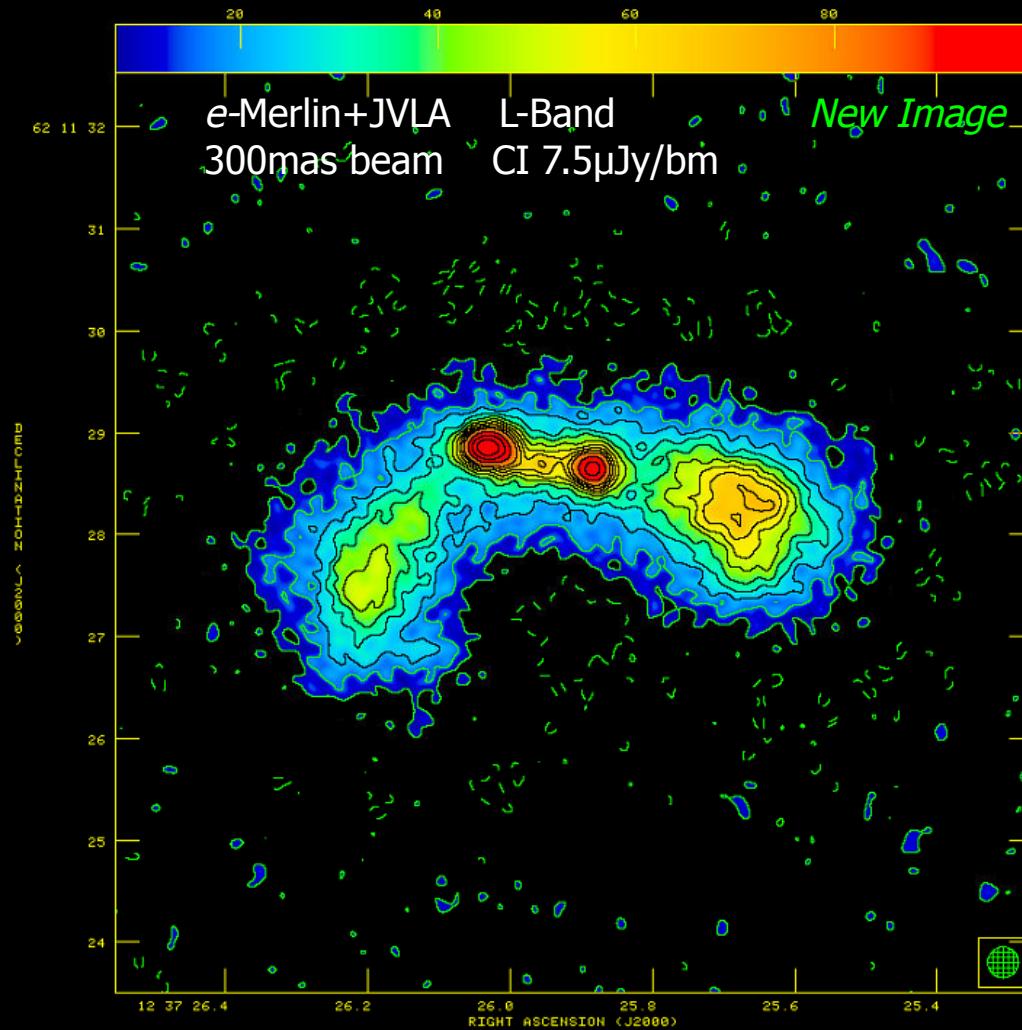
HST ACS: I=22.9<sup>mag</sup> galaxy z=1.2653

AGN

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

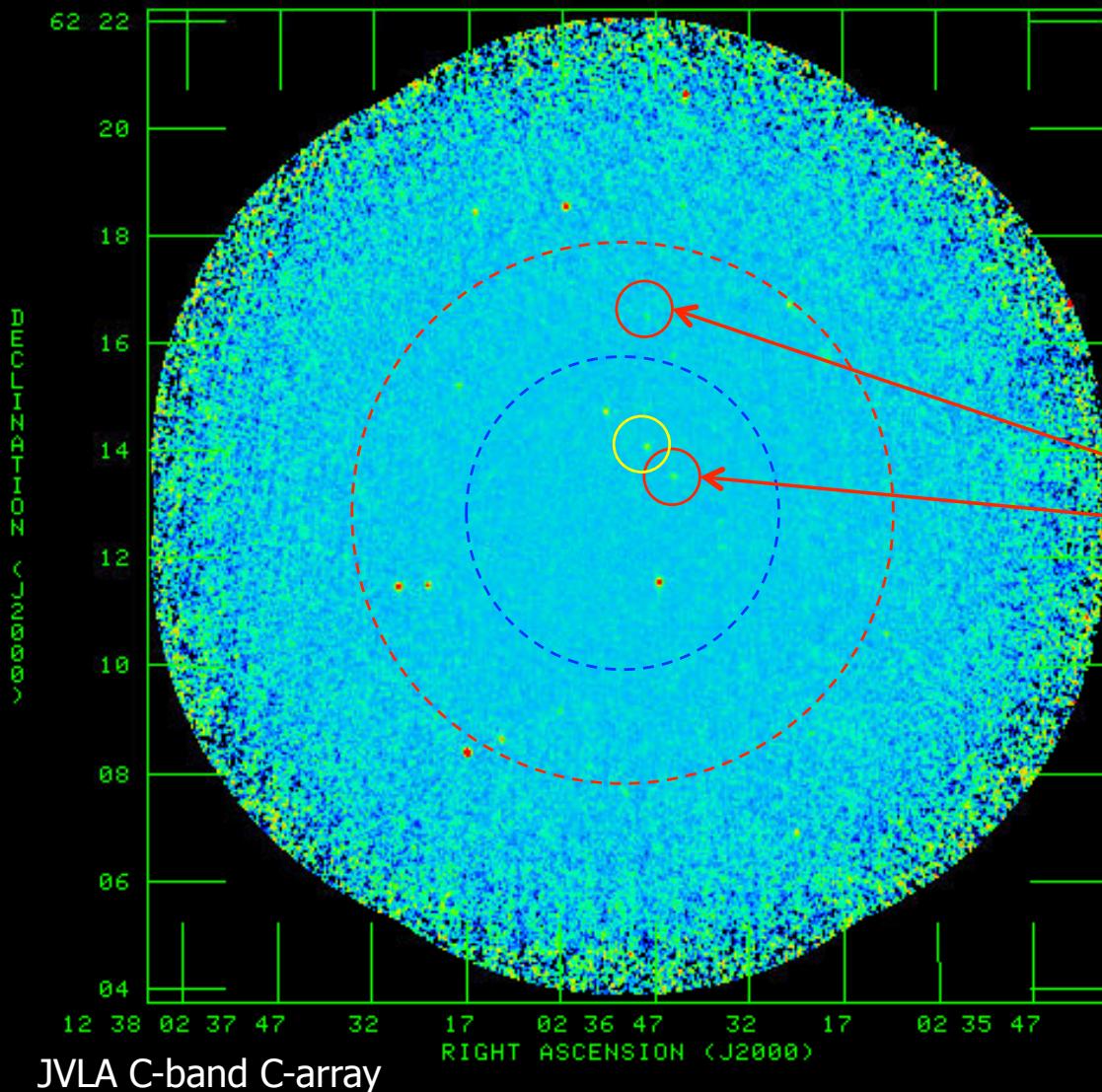
e-Merlin L-band data + 29 hrs JVLA A-array

AGN Wide-angled tail radio galaxy (Total 5.3mJy)



HST ACS: I=22.9<sup>mag</sup> galaxy z=1.2653

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



Latest deep high resolution  
e-MERLIN images of  
starburst galaxies:

J123646+621629

J123634+621221

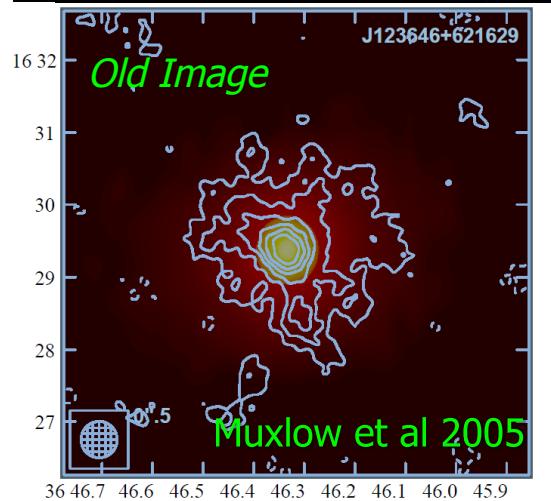
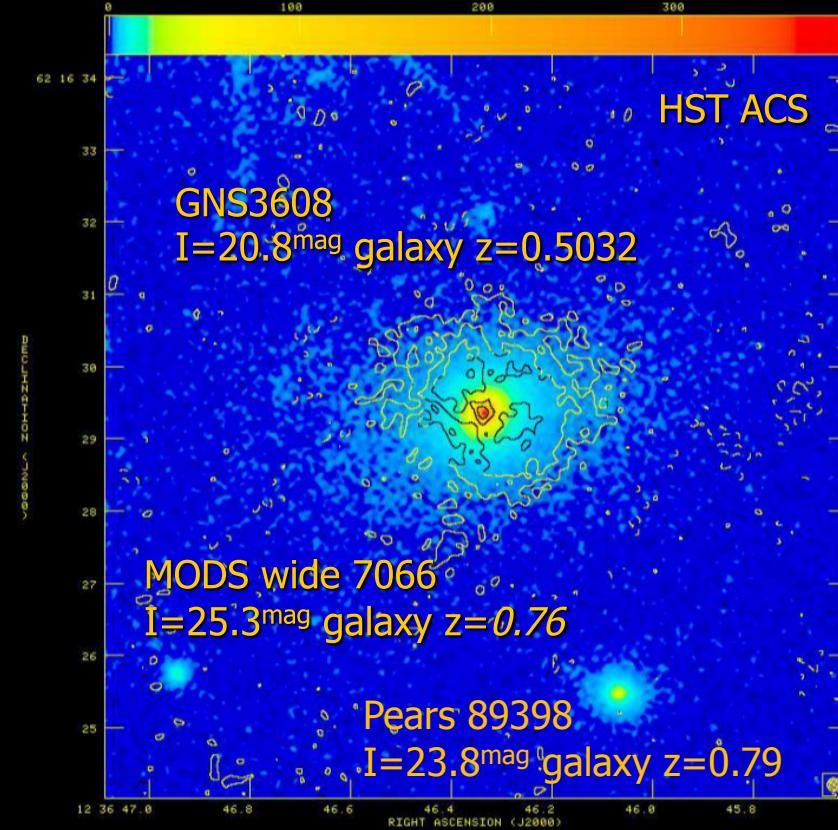
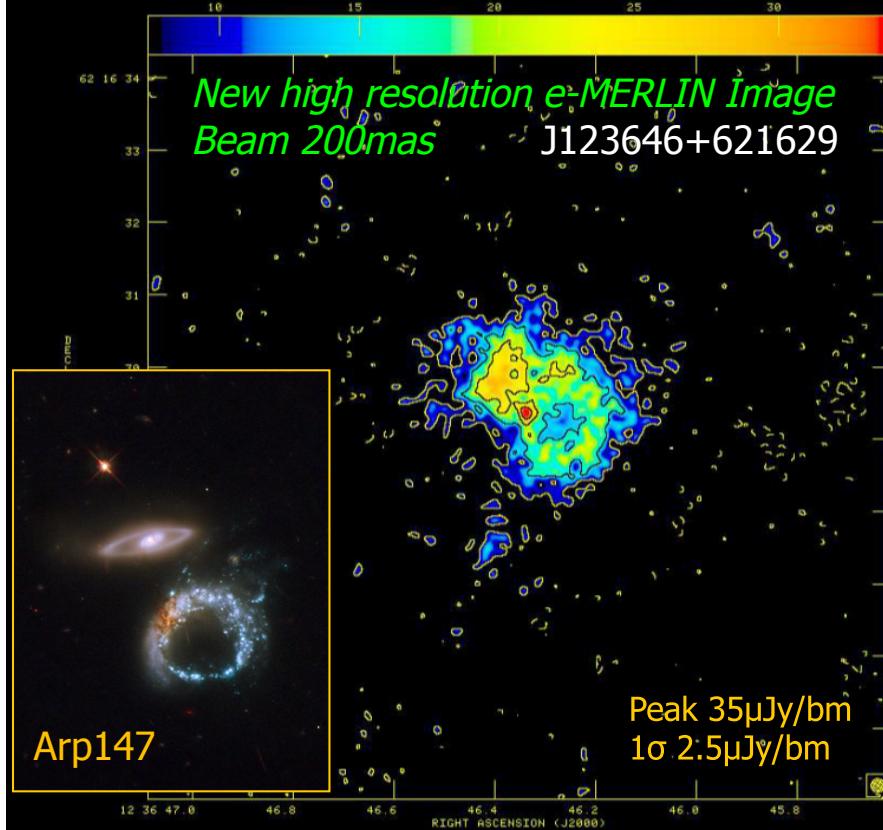
J123642+621331 Composite

3 e-MERLIN datasets ( $\sim 60$  hrs)  
+ archival MERLIN+VLA

In progress:  
Optimising weighting scheme  
for JVLA L-Band data with sub-  
set of e-MERLIN dataset  
 $\rightarrow \sigma \sim < 2\mu\text{Jy}$

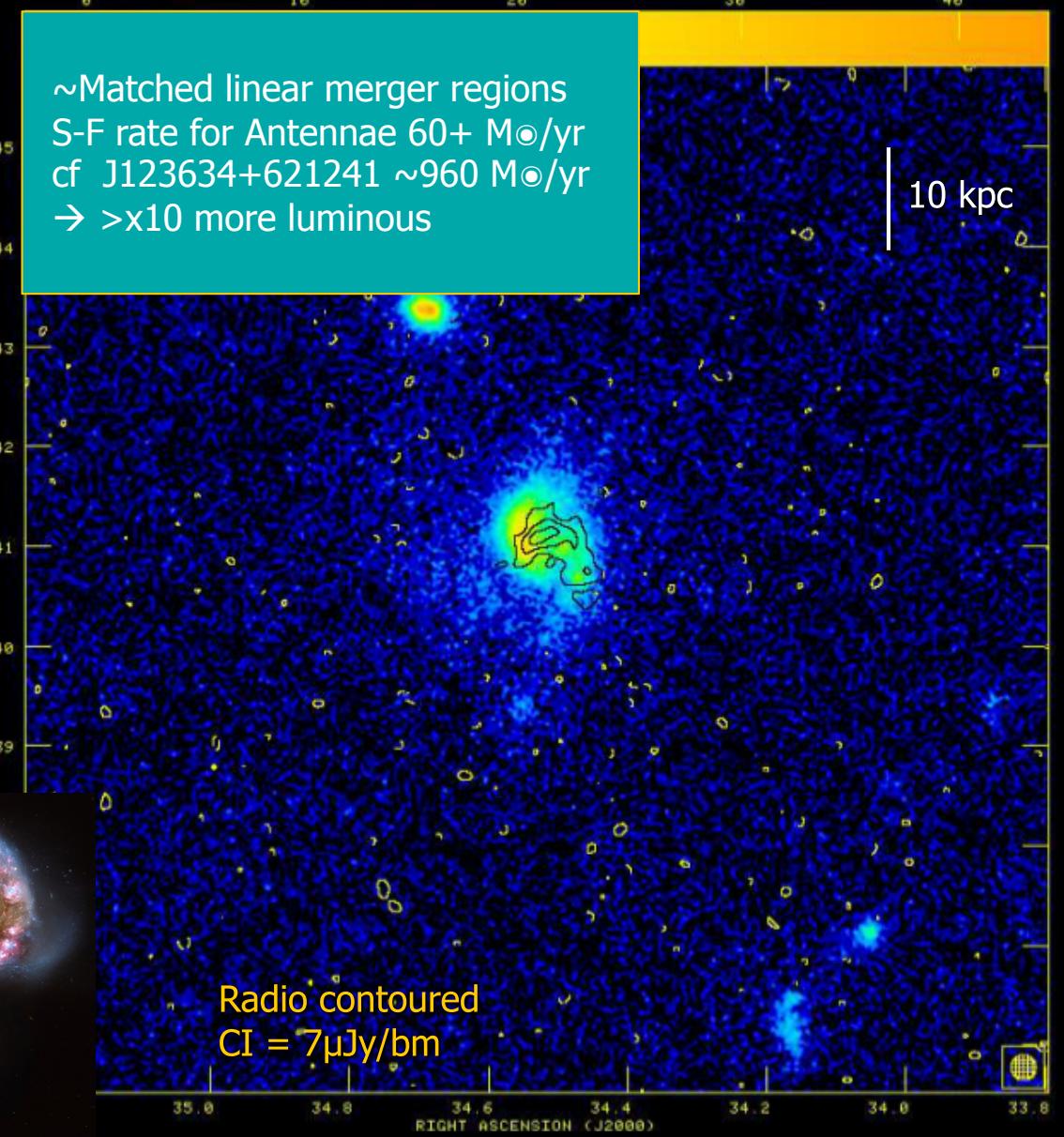
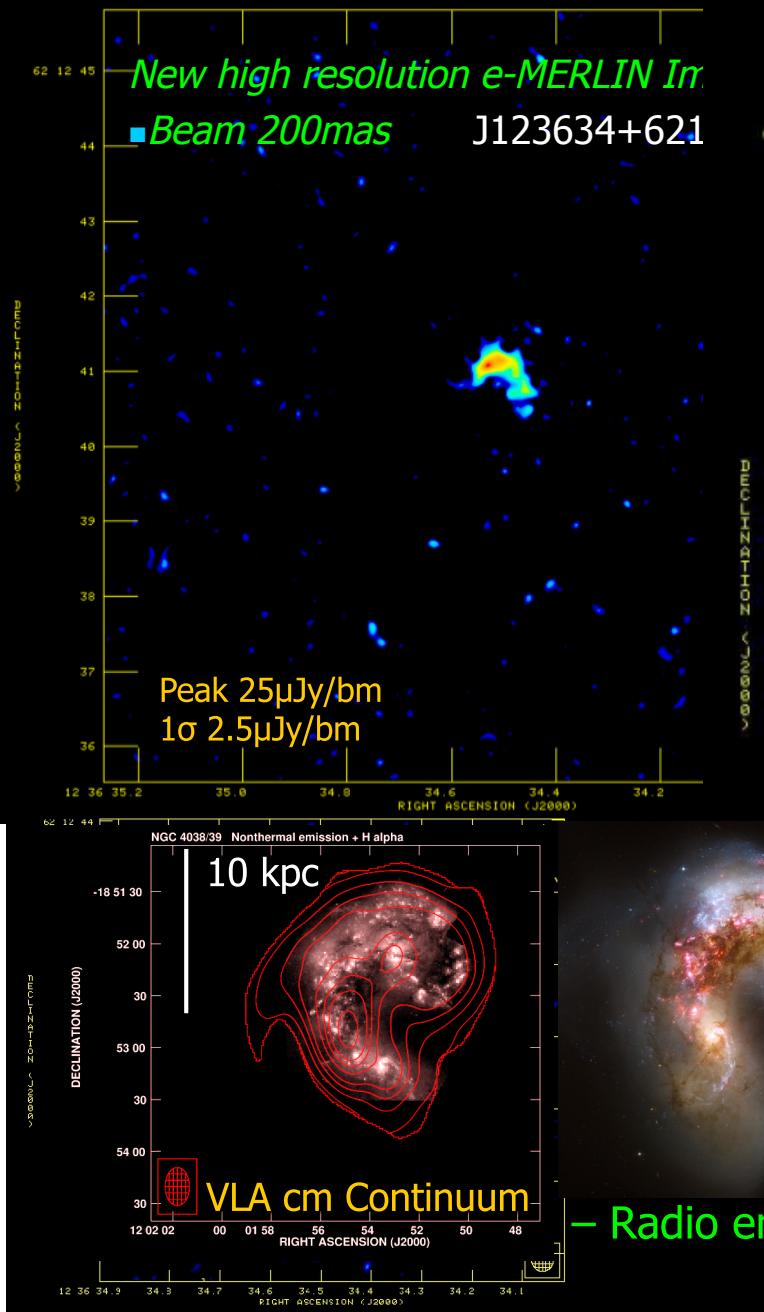
Starburst  
+ AGN?

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



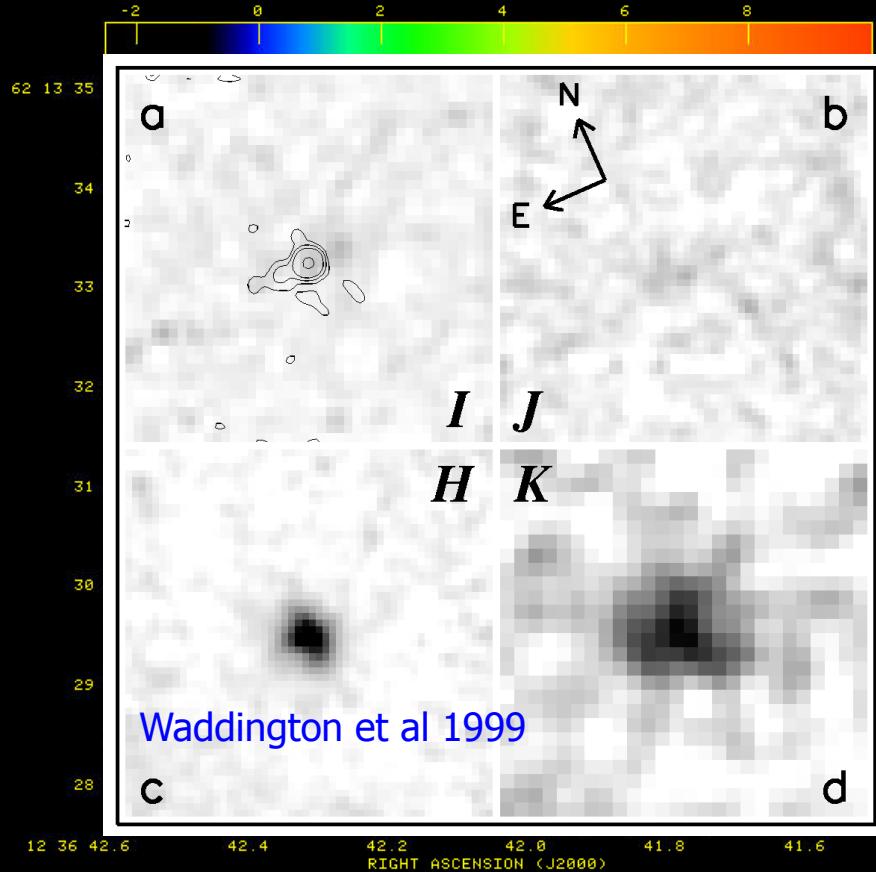
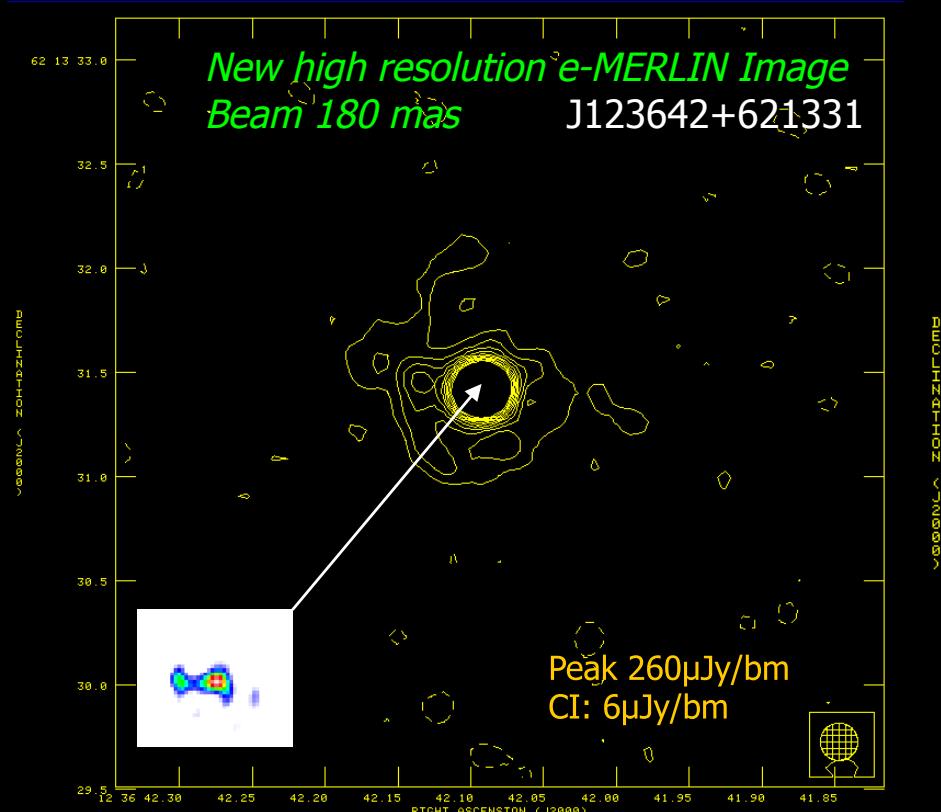
Extended steep-spectrum ( $\alpha > 1.62$ ) starburst with embedded AGN?  
( $S_{1.4} = 393\mu$ Jy). → Ring of star-formation – interacting galaxies?  
Radio emission extends across face of massive spheroidal galaxy  
 $L_{1.4} = 8.5 \times 10^{23}$  W/Hz → Star-formation rate  $\sim 200$   $M_\odot$ /yr  
(0.1-100 $M_\odot$  assuming Salpeter IMF)  
Bright galaxy core shows BL emission → Optical AGN activity  
AGN or nuclear starburst? – C-Band/VLBI to look for faint radio core...

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



– Radio emission follows merger & extends towards tail (cf 'Antennae')

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



Extended steep-spectrum ( $\alpha=0.94$ ) composite starburst and embedded AGN core-jet  
 $S_{1.4} = 467\mu\text{Jy}$

**Detected Global VLBI Core-jet (Chi et al 2013)**

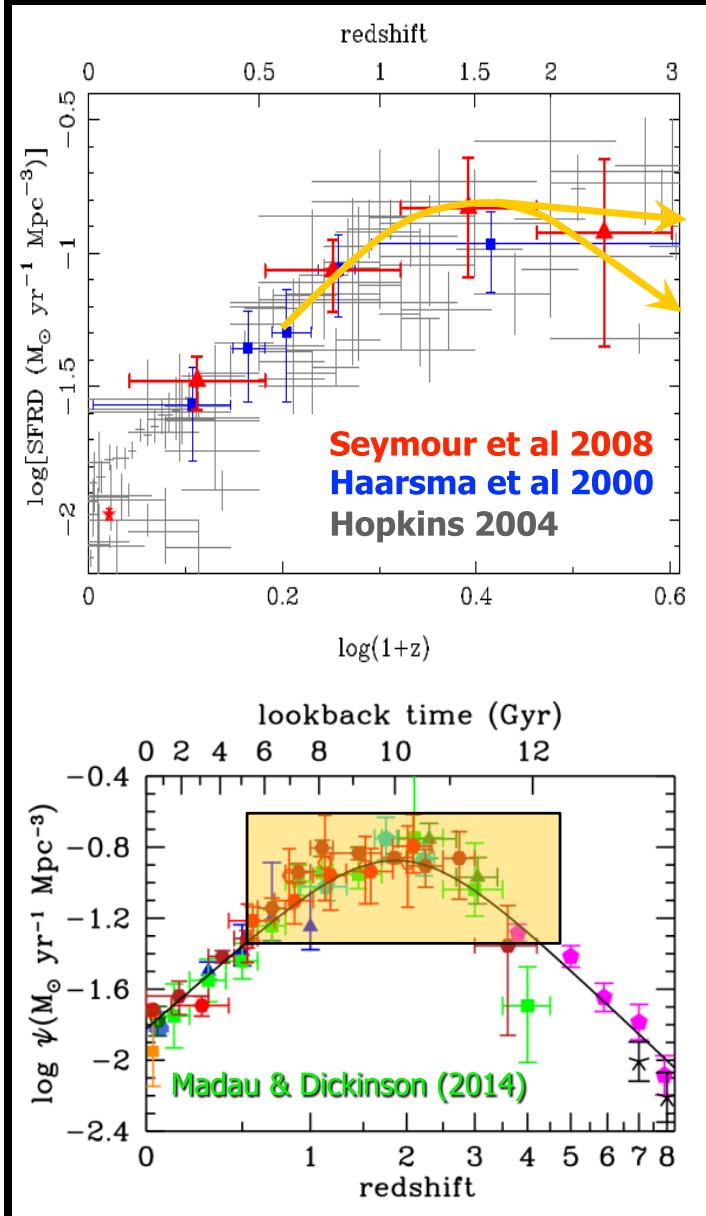
Radio emission associated with very red object –  $z=4.424$  from single H $\alpha$  detection

ISOCAM 15 $\mu\text{m}$  detection  $\sim 23\mu\text{Jy}$

(– or  $z=1.77$  if line is [OII])

$L_{1.4} = 5.2 \times 10^{26} \text{ W/Hz} \rightarrow \text{AGN dominated (>90%)} – \text{investigate with combined e-MERLIN/VLBI}$

# Star-formation History of the Universe - from Starburst Luminosities



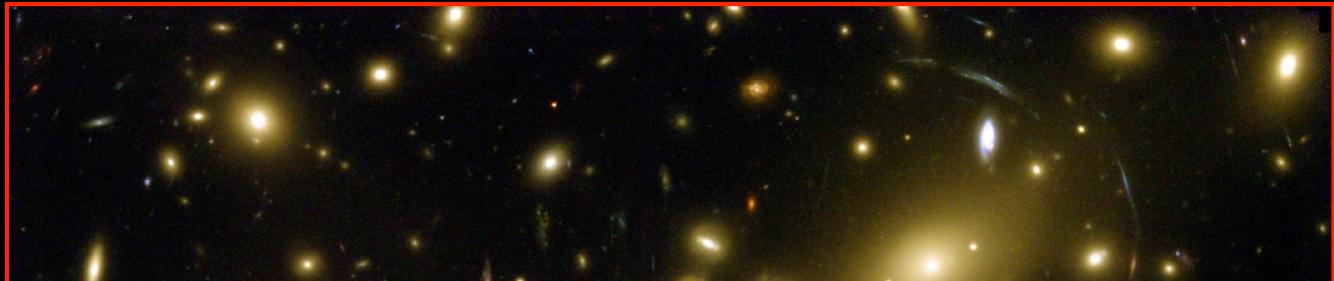
The co-moving Star-Formation Rate Density of the Universe from L-Band radio studies by Seymour et al (2008), Haarsma et al (2000), & UV, H $\alpha$ , Far-IR... Hopkins (2004)

L-Band results from the e-MERGE survey will provide data for several thousand more sources → tightening the Seymour error bars by a factor ~4 & extending to z~5

Constrain position of maximum from extinction-free SF indicator

# Tier 0: Imaging sub- $\mu$ Jy galaxies

A single L-Band pointing on a strong lensing cluster A2218 ( $z=0.18$ ).

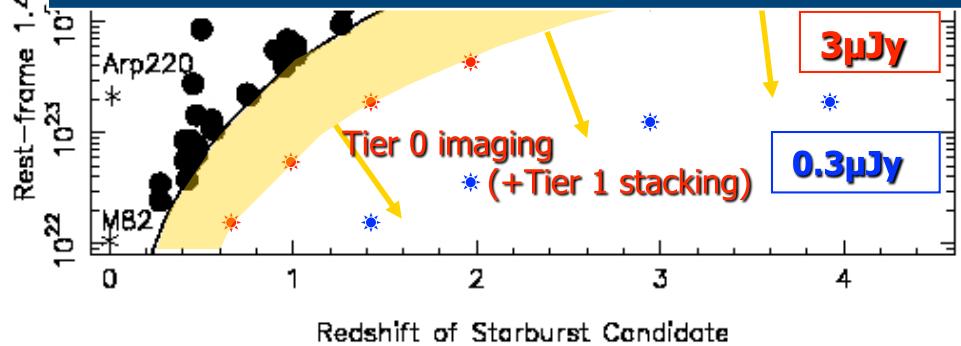


e-MERGE will characterise the  $\mu$ Jy & sub- $\mu$ Jy radio source population

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

→Sub-arcsec resolution broadly separates SF and AGN

→100-200mas resolution required to study feedback in faint sources



Measure faint radio counts

May include SF galaxies with  
 $SFR \sim 200 M\odot/\text{yr}$  to  $z \sim 5$

