
MANCHESTER
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NOWHERE TO HIDE
WIDE-FIELD VLBI OF GOODS-N
Jack Radcliffe
Tom Muxlow & Rob Beswick & Nick Wrigley (University of Manchester)
Michael Garrett (ASTRON/Leiden)
Peter Barthel (University of Groningen)
Bologna, Italy - 22/10/2015

INTRODUCTION

1. Wide-field VLBI - why and how
2. Wide-field EVN observations of GOODS-N
3. Untangling SF and AGN - first results from the first epoch of data in combination with eMERGE
4. The future. How we will make the most of the data.

TURNING VLBI INTO A SURVEY INSTRUMENT

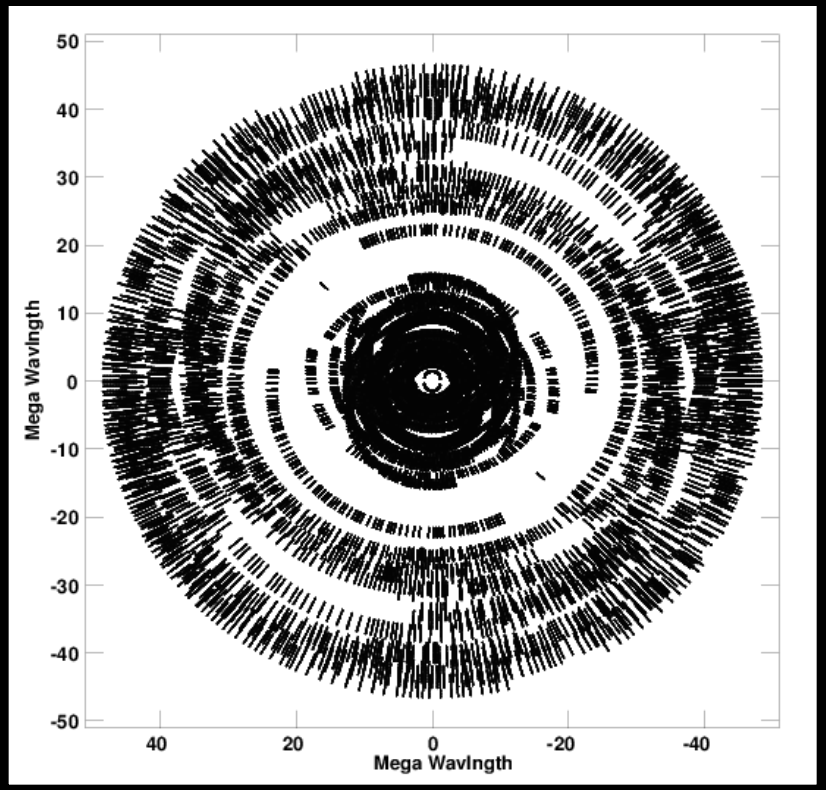
- VLBI resolves out diffuse emission and only detects **bright** ($T_B > 10^6$K) and **compact** objects (e.g. SNR & AGN)

- WF-VLBI can detects multiple compact sources within the primary beam of a VLBI telescope in one observation.

▻ Disentangle bright compact emission from diffuse emission. In distant galaxies, we can separate AGN from star formation.

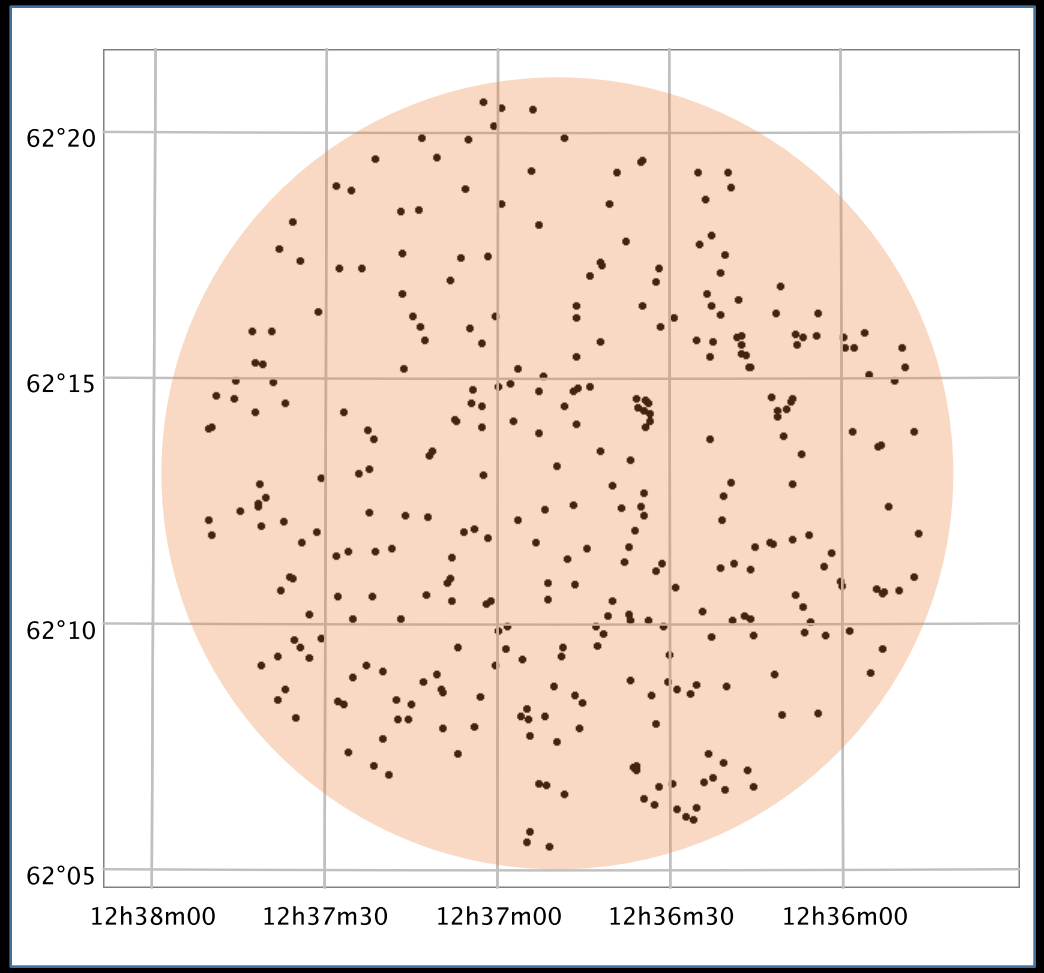
WIDE-FIELD VLBI ON FAINT FIELDS - ARE WE MAD?

- Computationally intensive correlation
- Extremely sensitive to phase calibration
- Very sparse uv coverage
- Low dynamic range imaging
- a & w projections…



"Why, sometimes I've believed as many as six impossible things before breakfast." - Lewis Carroll, Alice in Wonderland

CONVENTIONAL WF-VLBI

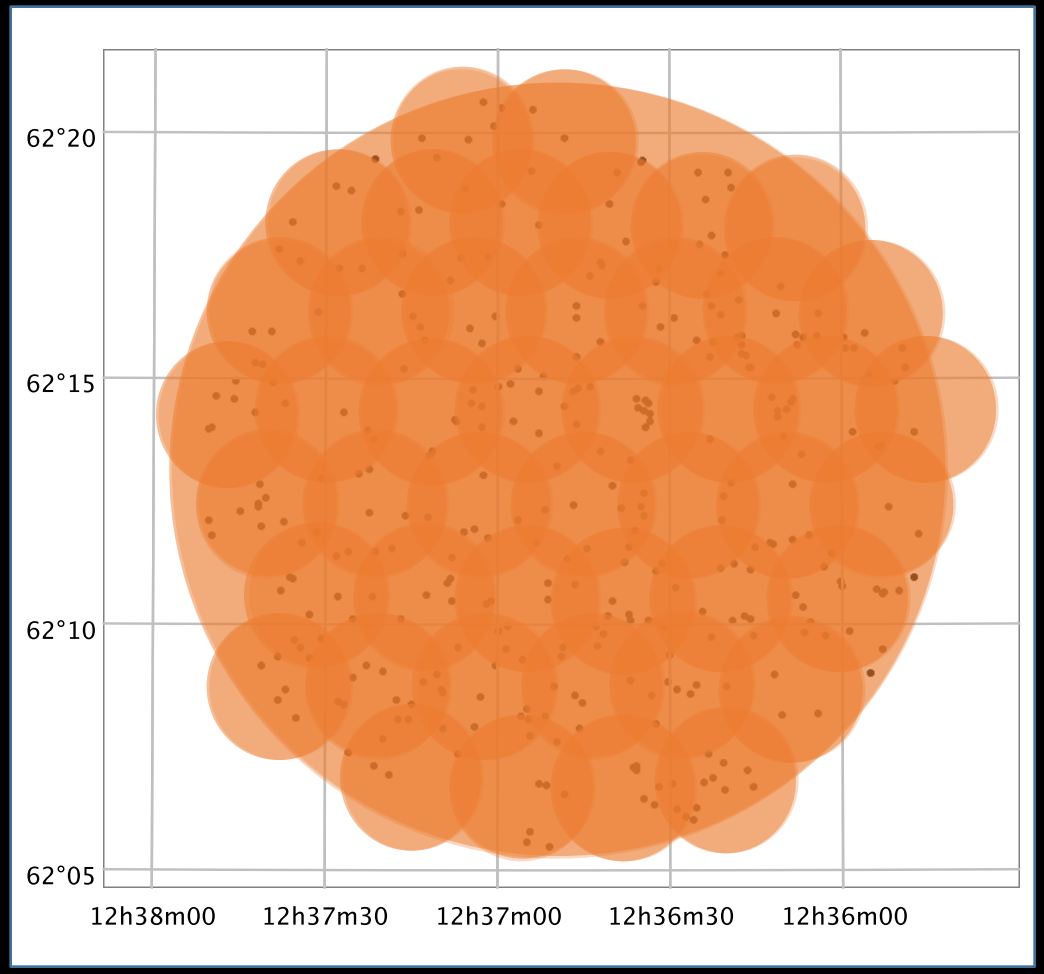


HDF-N eMERGE positions (Wrigley et al. in prep)

- Correlate on pointing centre (ultra high spectral & temporal resolutions)
- Large (>TB), single data set
- Have to phase shift whole data set to image sources

MULTIPLE SIMULTANEOUS PHASE CENTRE OBSERVING

(DELLER ET AL. 2011, KEIMPEMA ET AL. 2015)



HDF-N eMERGE positions (Wrigley et al. in prep)

- Correlate on pointing centre, shift and re-correlate w/ coarser temporal & spatial averaging.
- Large (>TB) data but comprised of small (~GB) sets
- Same calibration applies to all

→ embarrassingly parallel

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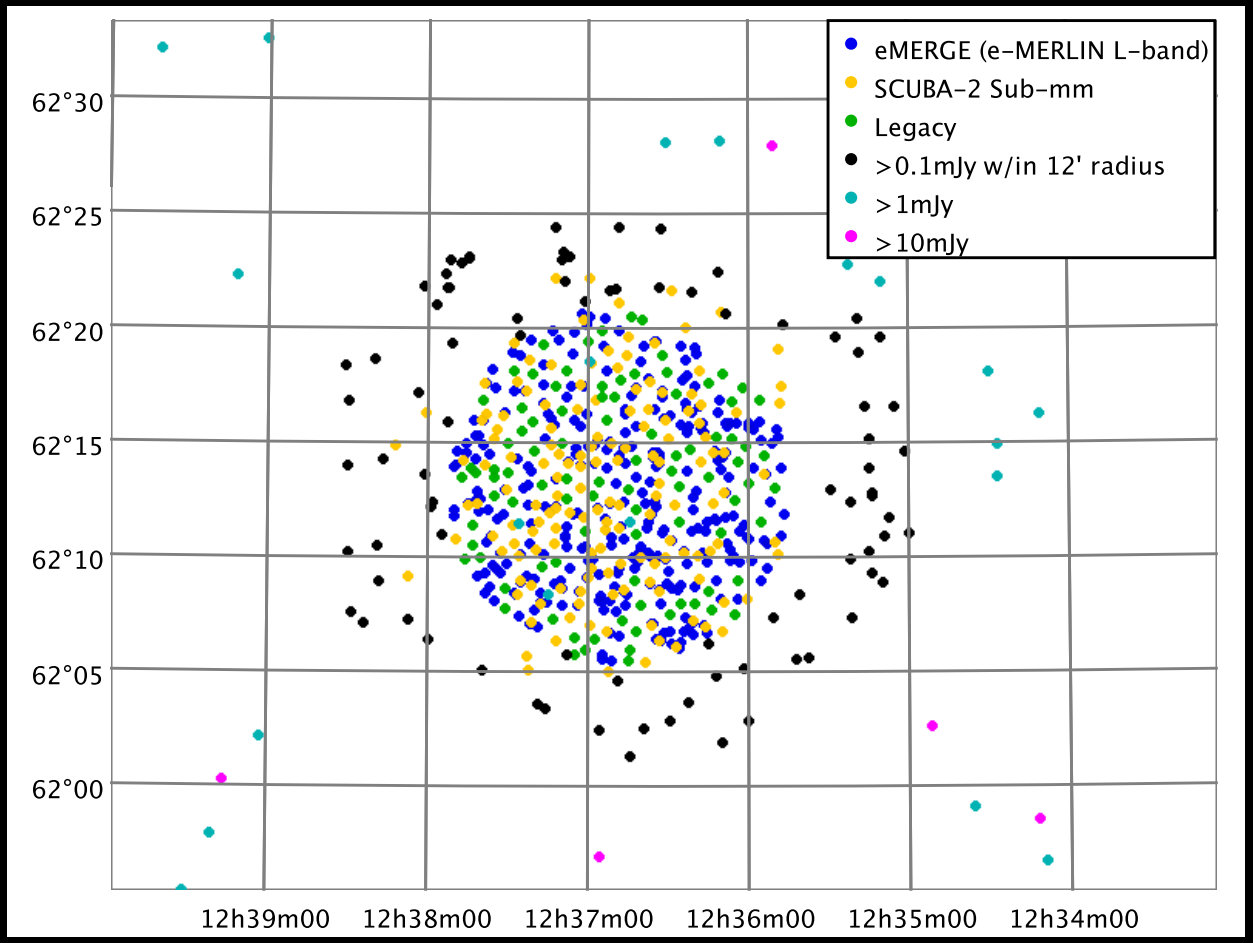
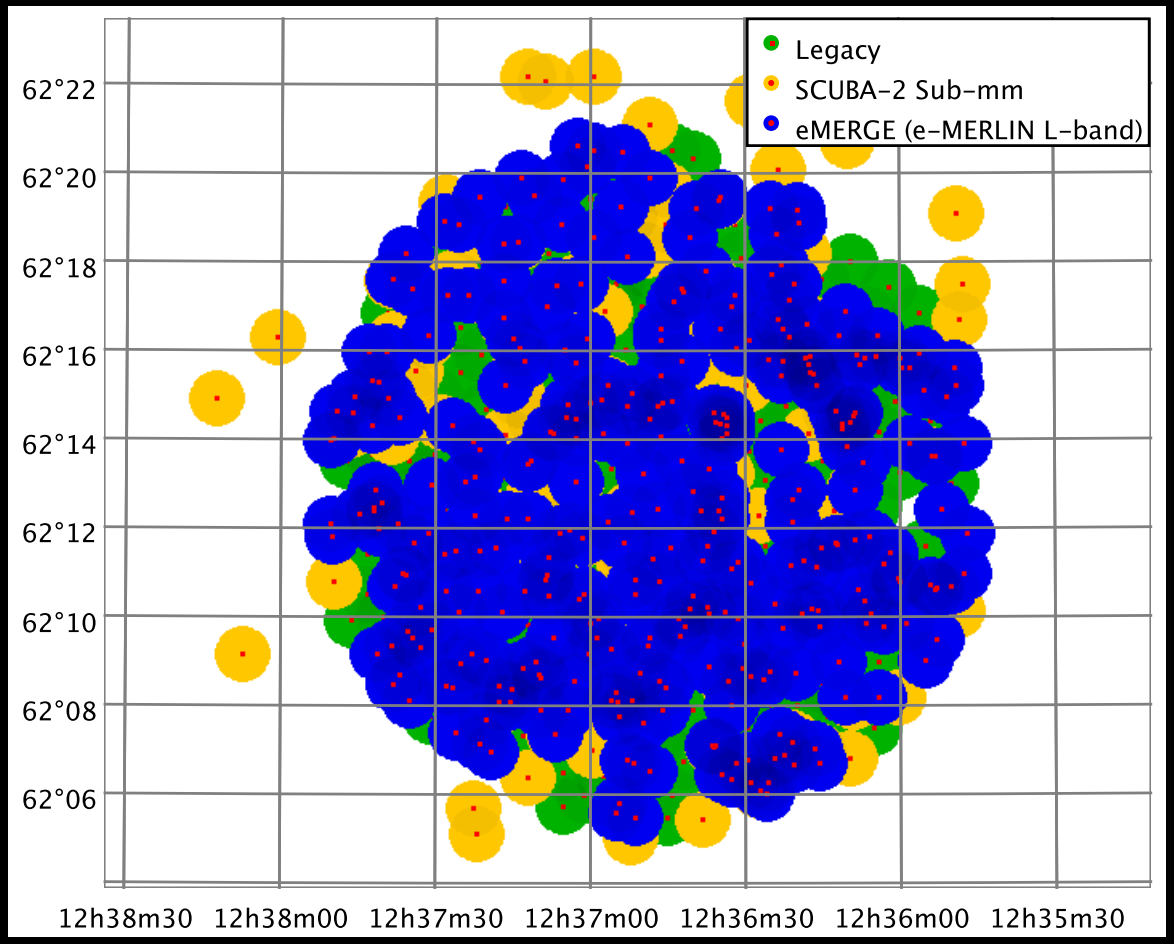
OBSERVATIONS OF GOODS-N



- 699 targeted sources
- EVN 1.6 GHz, 128MHz BW
- Two areas:
  - Central 15’
  - Outer annulus (20’ diameter)
- Science targets
  - Sub-mm
  - eMERGE
  - Transients

CENTRAL AREA

- Covers 15' diameter area to complement the eMERGE project (see talk by R. Beswick & D. Guidetti)



- Ef & Lovell offset to create even sensitivity
- 24/72 hrs taken w/ max. r.m.s of 5μJy/bm
- Expect 1.5-3μJy/bm
- Cover entire area w/in 1% smearing

HDF-N/GOODS-N VLBI SURVEYS

- Garrett et al. 2001
  - 3 detections w/ EVN (including FR-I and possible z=4.4 source..)
  - 42μJy/bm r.m.s

- Chi et al. 2013:
  - Wider-field, global VLBI.
  - 12 detections, with r.m.s. 7.3μJy/bm r.m.s

  -> detections of weak AGN in star-forming systems.

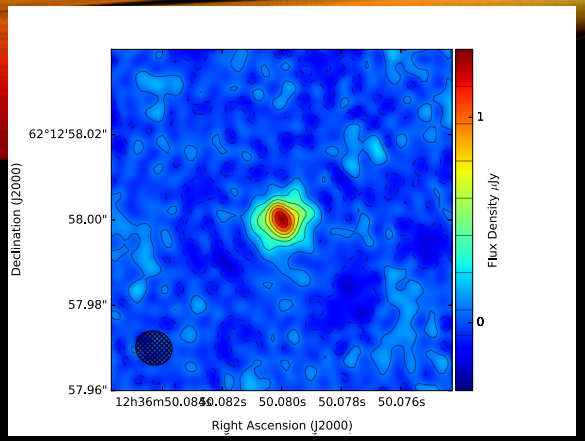
- New EVN VLBI observations:
  - 20 detections (11/12 of Chi - missing one)
  - Currently 5μJy/bm rms sensitivity
  - More detections w/ further epochs

MULTI-FIELD SELF CALIBRATION

UNVEILING THE μJy POPULATION OF COMPACT RADIO SOURCES

- Some fields do not have bright compact sources nearby ▻ induces nasty phase errors.
- MFSC combined response of targeted sources to self-calibrate and massively reduce phase errors. (Garrett ’04 & Middelberg ’12)
- **Every** VLBI source in **any** direction can be used to calibrate with.
- Noise drop, flux increase ▻ Huge improvement in signal to noise in 75% of target sources

Radcliffe et al. 2015, in prep.



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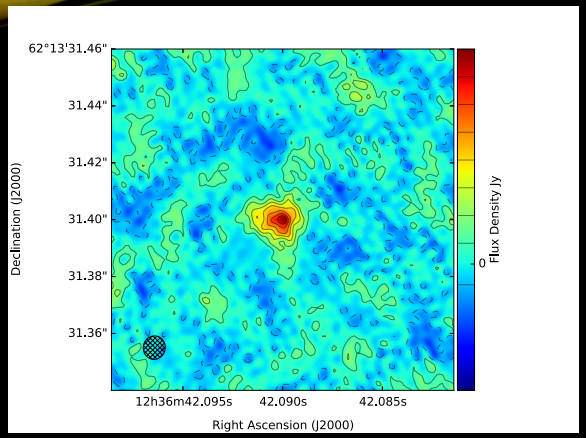

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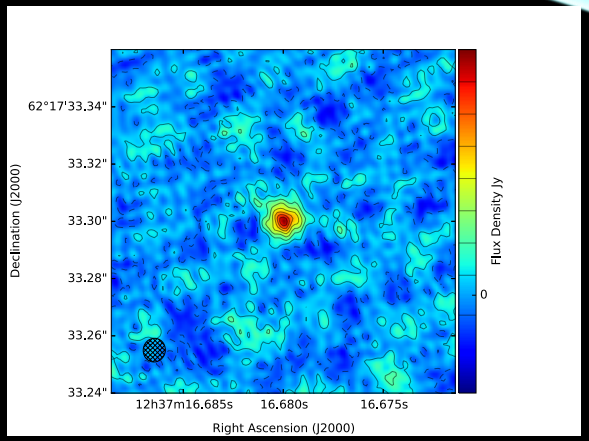

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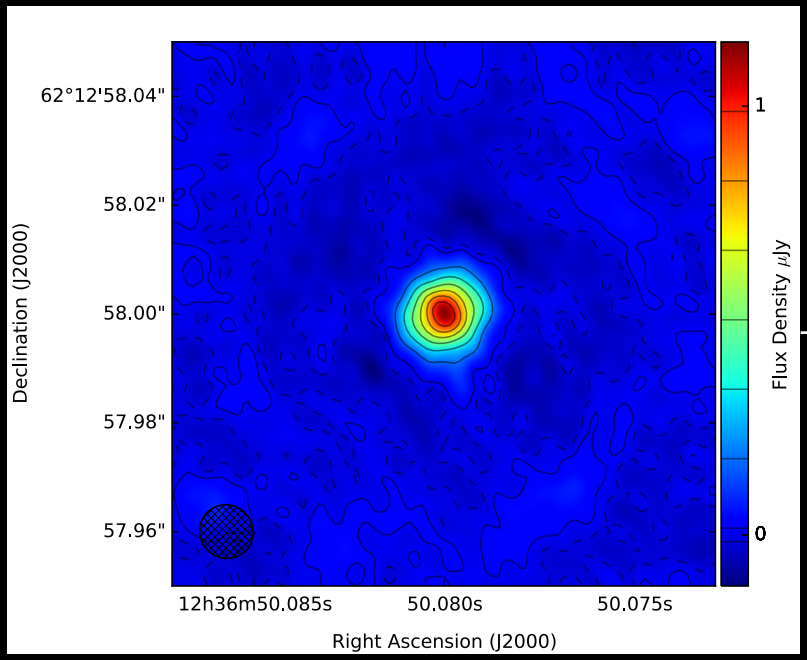
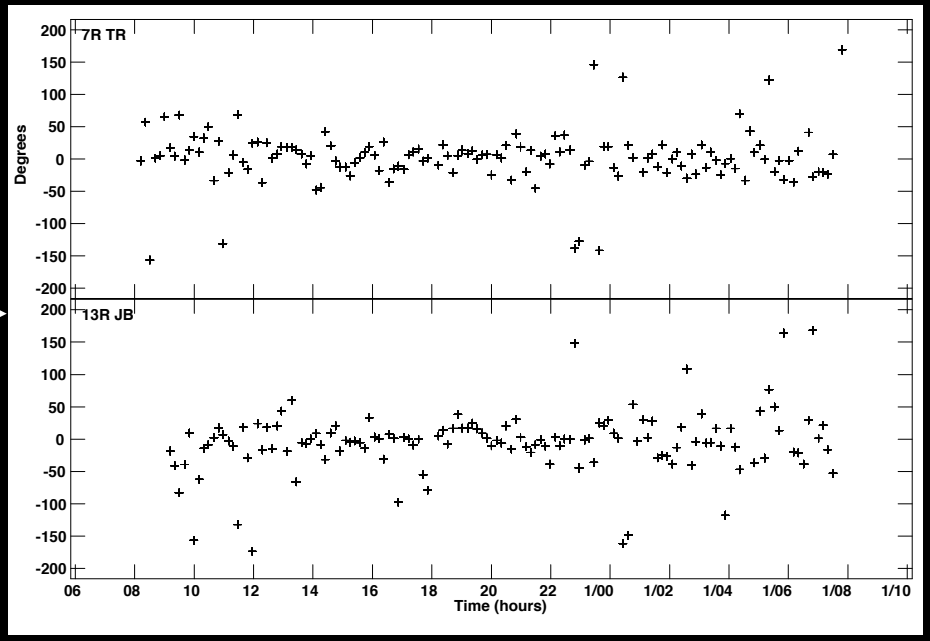
Calibrate for phase





- Noise profile more uniform ▻ reduction in phase errors

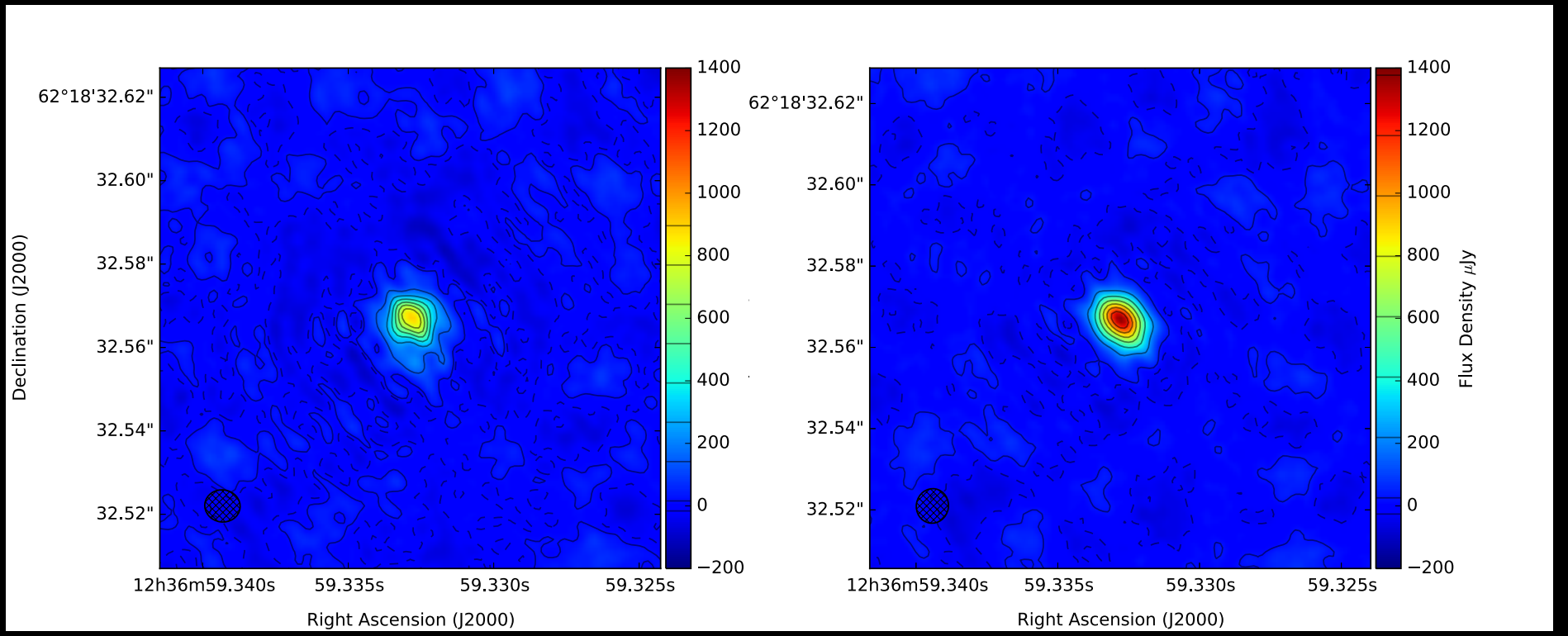
- This can be used on **any** future VLBI observation!

Phase referencing

SNR = 43.2

Multi-field self calibration

SNR = 102 (**242%** increase!!)



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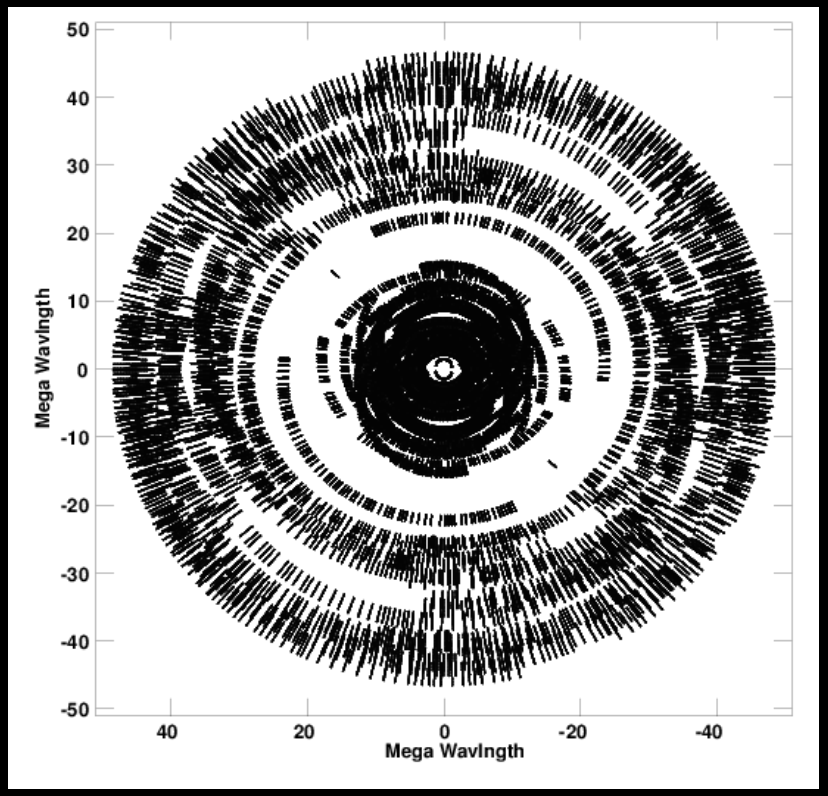

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"Why, sometimes I've believed as many as six impossible things before breakfast." Jack Radcliffe, VLBW Workshop

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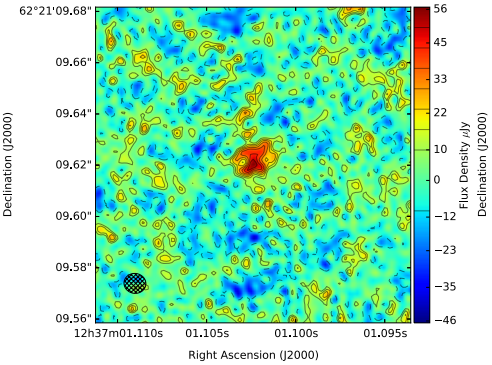
eMERGE

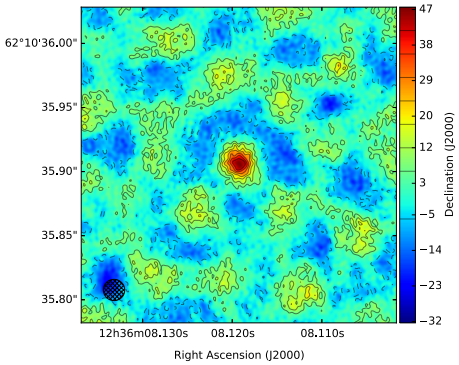
e-**MER**lin **G**alaxy **E**volution **S**urvey

- Three tiers - only talk about Tier 1 Ultra Deep GOODS-N
- Allocated 738 hours of e-MERLIN time (360 hr at 1.4GHz & 378 at 5GHz) - sensitivities <1uJy! + VLA data
- Compile multi-wavelength, multi-resolution data to:
  - Extend the star formation history to z = 3
  - Allow insights into AGN feedback
  - Separate AGN & star formation
- Only 25% of L-band & no C-band data taken!


1.4GHz e-MERLIN - 2.7μJy/bm
Wrigley et al (in prep.)

DETECTIONS


Declination (J2000)
Right Ascension (J2000)
Flux Density μJy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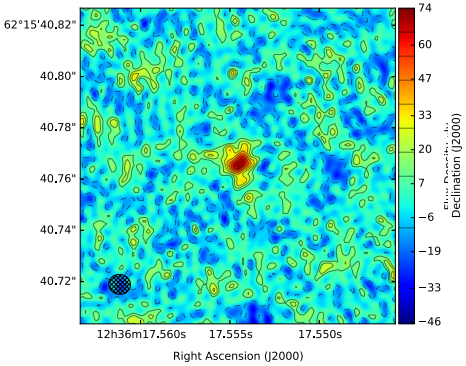
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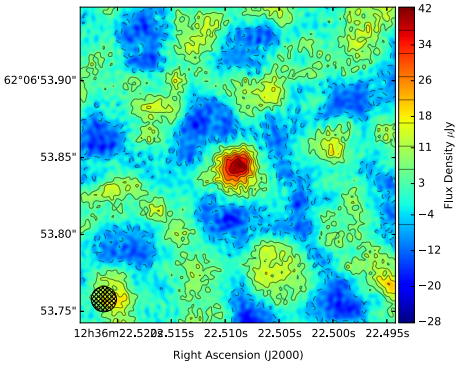
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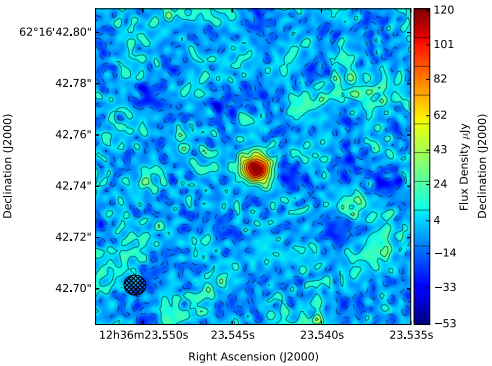
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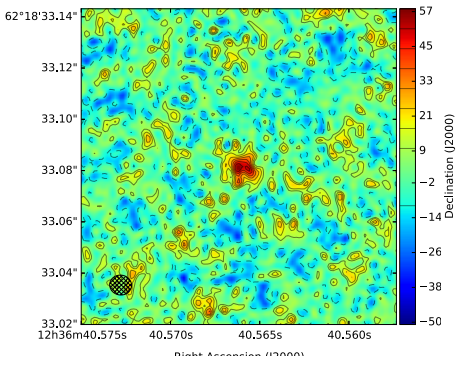
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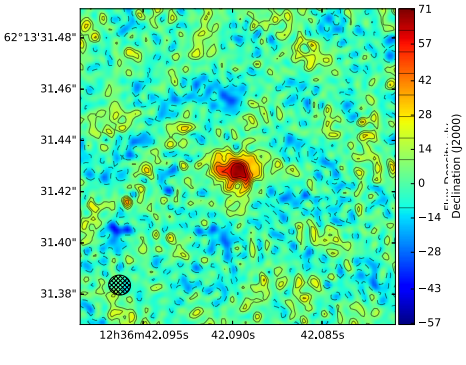
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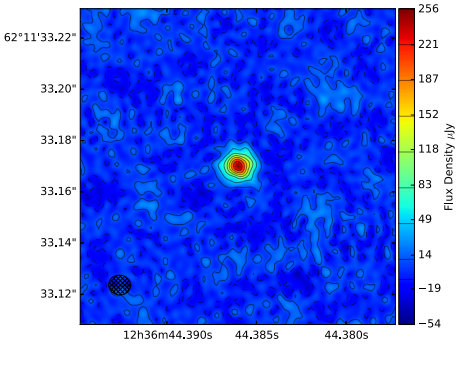
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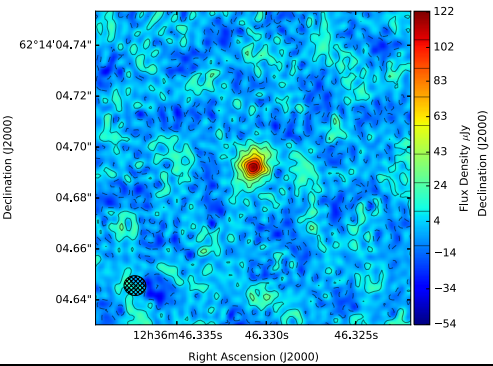
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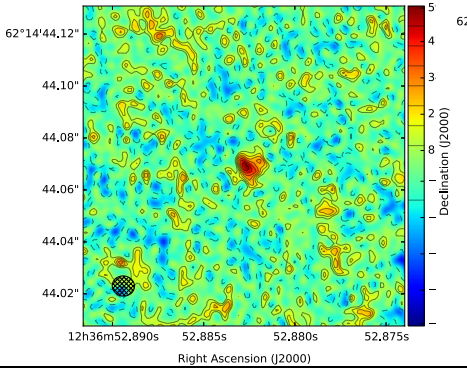
Declination (J2000)
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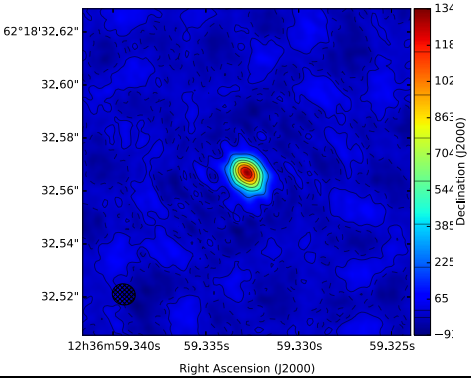
Declination (J2000)
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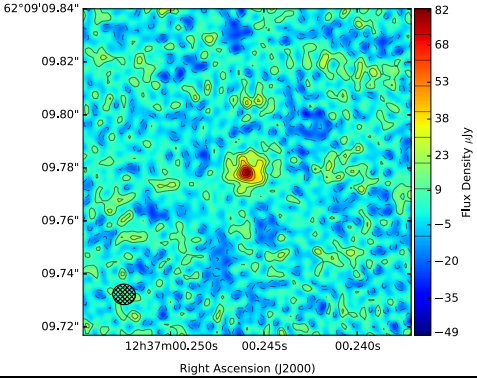
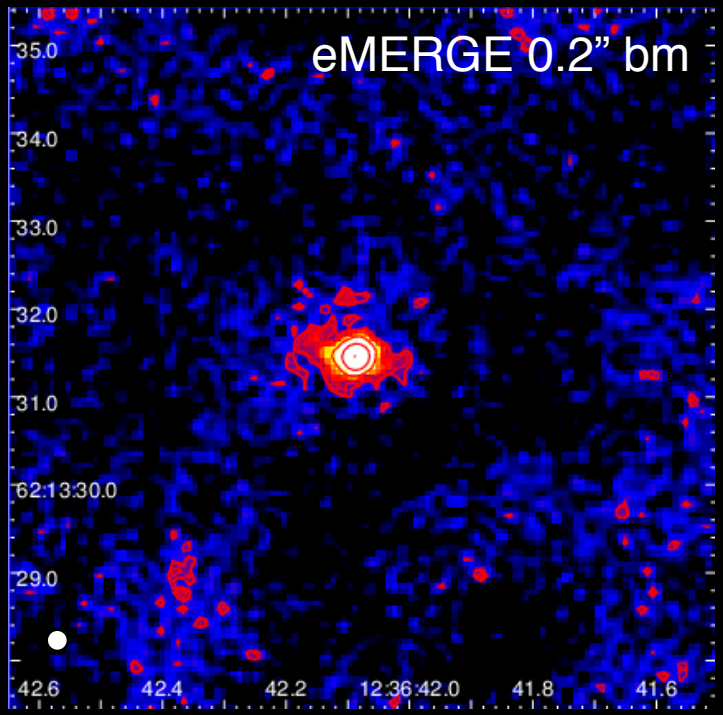
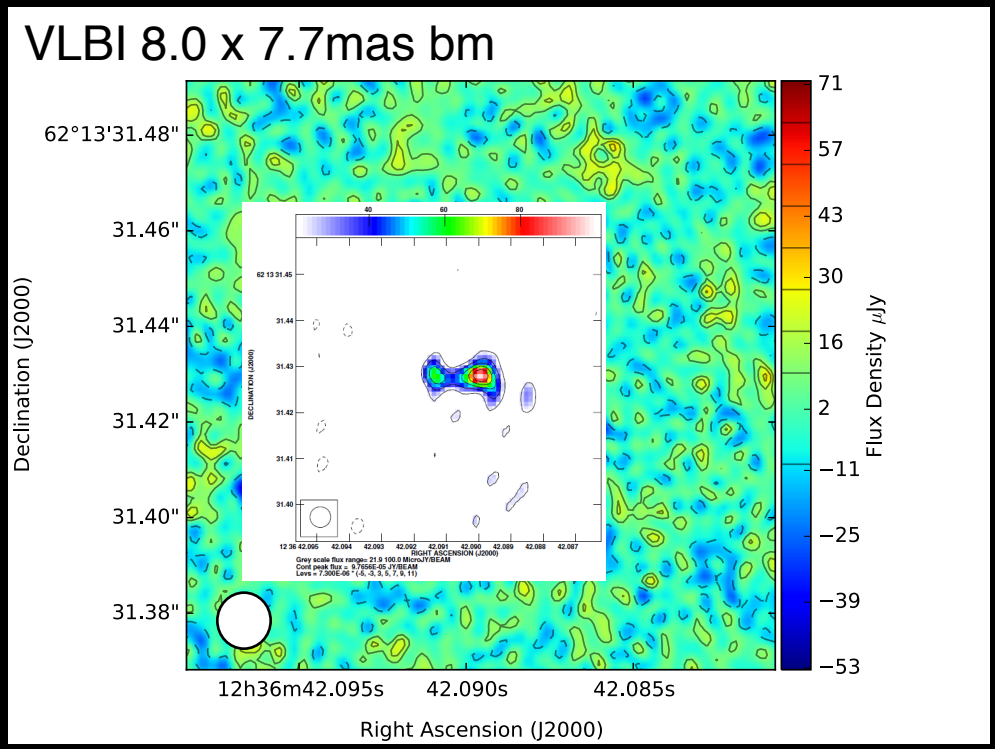

Flux Density μJy
Right Ascension (J2000)

- VLA J123642+621331
  - Muxlow ‘05 suggests AGN & SB -> eMERGE agreement
  - Confirmed w/ detection by Garrett ‘01 & Chi ’13
  - Originally z=4.424 via Lyα emission (Waddington ’99)
  - ▻ phot-z suggests z~2 (Cowie priv. comm.), awaiting MOSFIRE.





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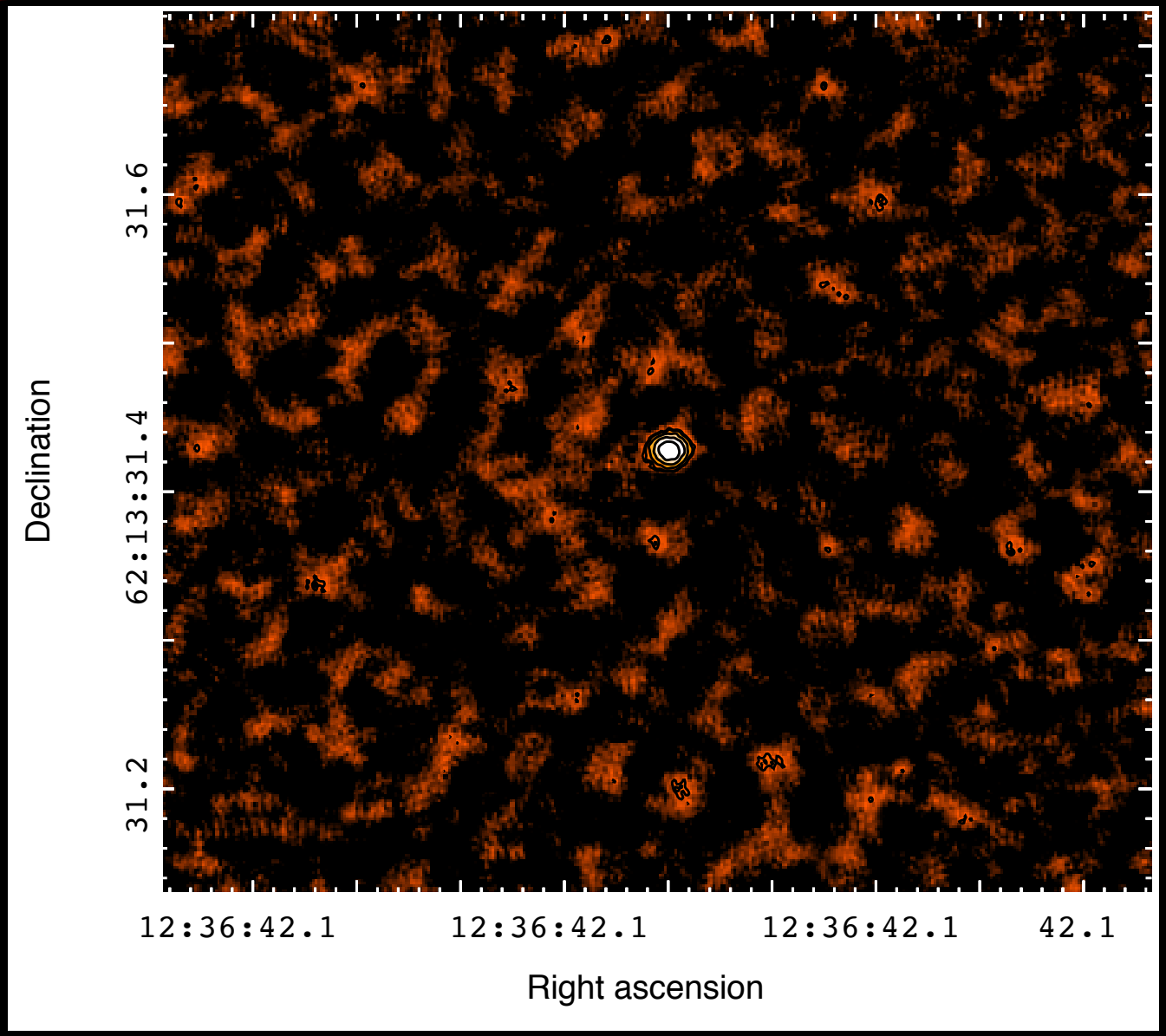
COMBINATION IMAGING USING eMERGE

- GOODS-N field now has multiple observations at 1.4GHz (or within the BW of each observation)
- Can combine arrays to become sensitive to many more angular scales.
- For non-variable sources, we will combine:

VLA (A) + JVLA (A) + MERLIN + e-MERLIN
+ Global VLBI (Chi et al.) + EVN

e-MERLIN to VLBI resolutions



CONCLUSIONS

- Wide-field VLBI is here and now.
- Multi-field self calibration makes **every** field accessible to VLBI ▻ see the paper!
- GOODS-N EVN observations detect 20 sources (8 more than Chi.) with a population of AGN + SF hybrids.
- eMERGE + VLBI can distinguish between SF and AGN to get a clear picture on AGN feedback from z = 1-3
- Much more to come! Two more 24hr epochs, combination imaging, stacking, 75% of eMERGE data


Thanks for Listening!

The one that got away: VLA J123642+621545

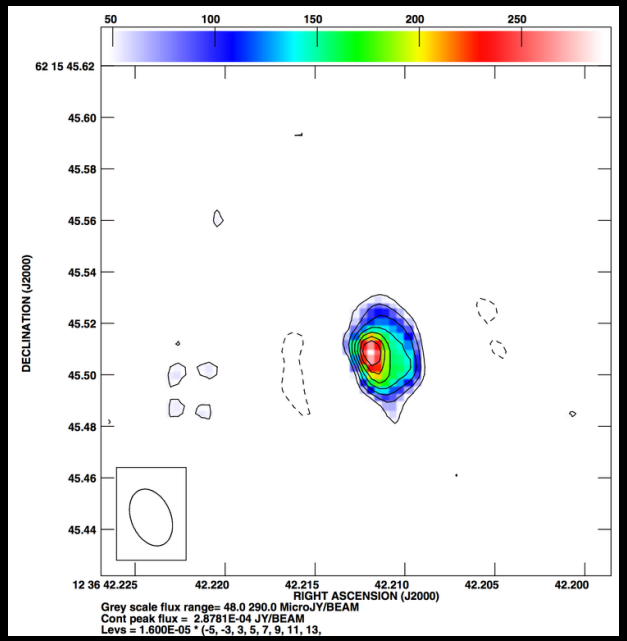
- z = 0.857

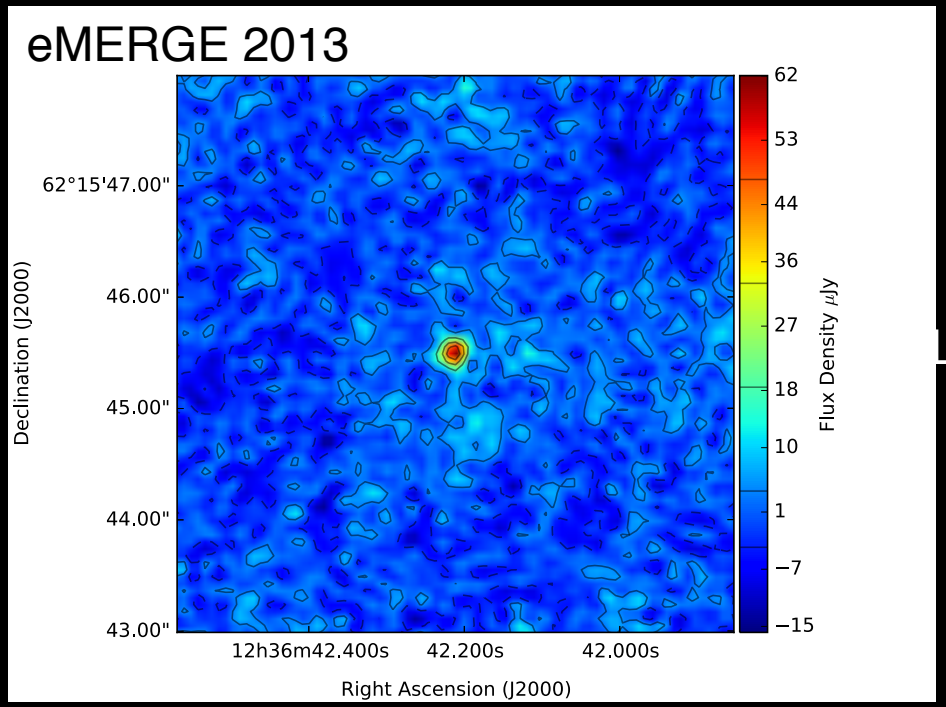
- Muxlow ‘05 classed AGN candidate (150μJy eMERLIN+VLA), detected ISO & Chandra

- Chi ‘13 (data taken in ‘04) detected extremely bright (343μJy) -> brighter than VLA in Morrison 2010 (158μJy)

- Undetected in new VLBI, eMERGE 2013 data supports this. Now only 60μJy

Chi ‘13 Global VLBI



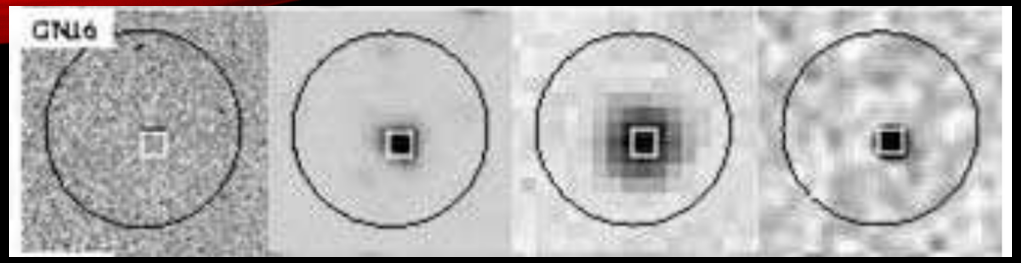


LA

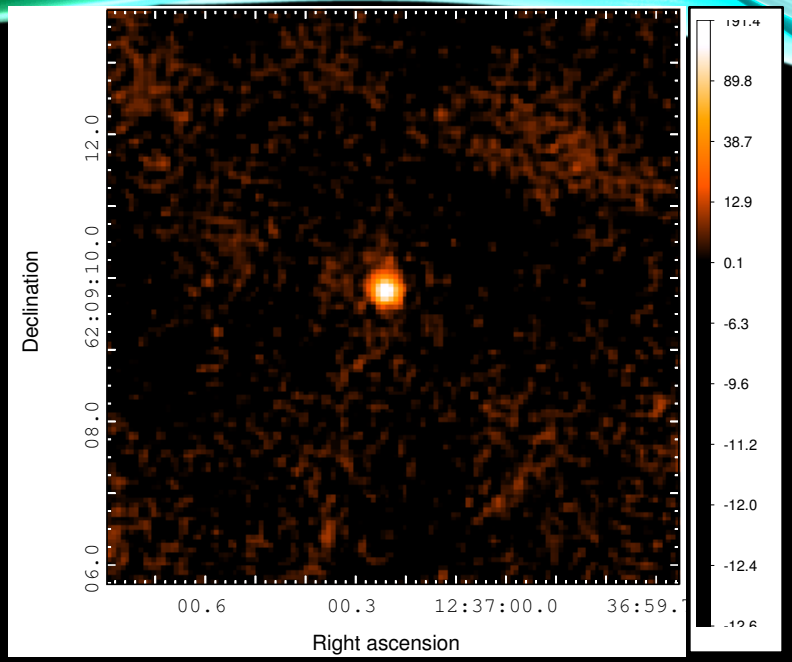
SUB-MM SOURCES

- Single detection of a sub-mm source J123700+620909 (GN16) ▻ similar properties to J123642+621331
- Detected in Spitzer IRAC + MIPS as well as SCUBA 850um (Pope et al. ‘06)
- Considering ERO character, considered to be a starburst galaxy at z=1.7, SFR ~1000$\mathrm{M}_{\odot}/\mathrm{yr}$ but there’s a weak AGN present.
- AGN detected by Chi et al. + radio excess measurements.

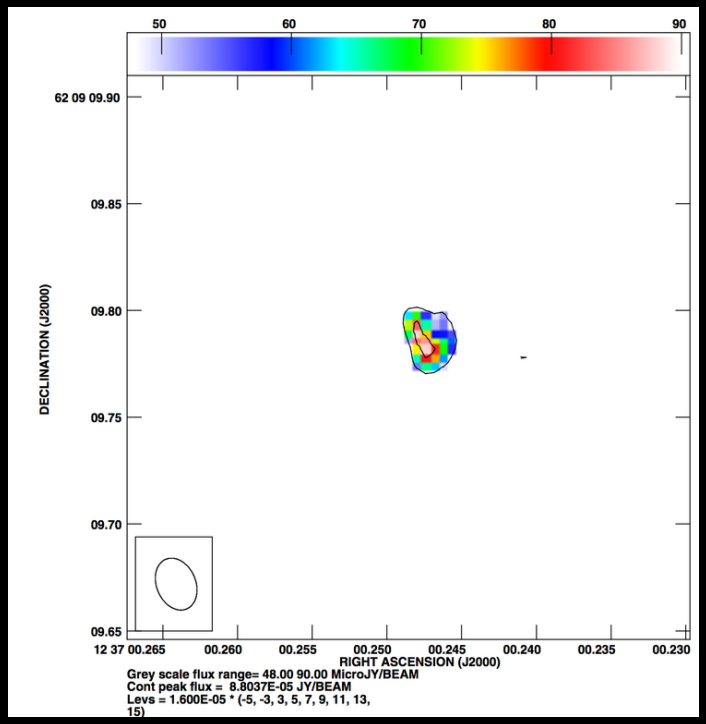
eMERGE L-band



Pope et al ‘06



Chi VLBI



EVN 1.6GHz