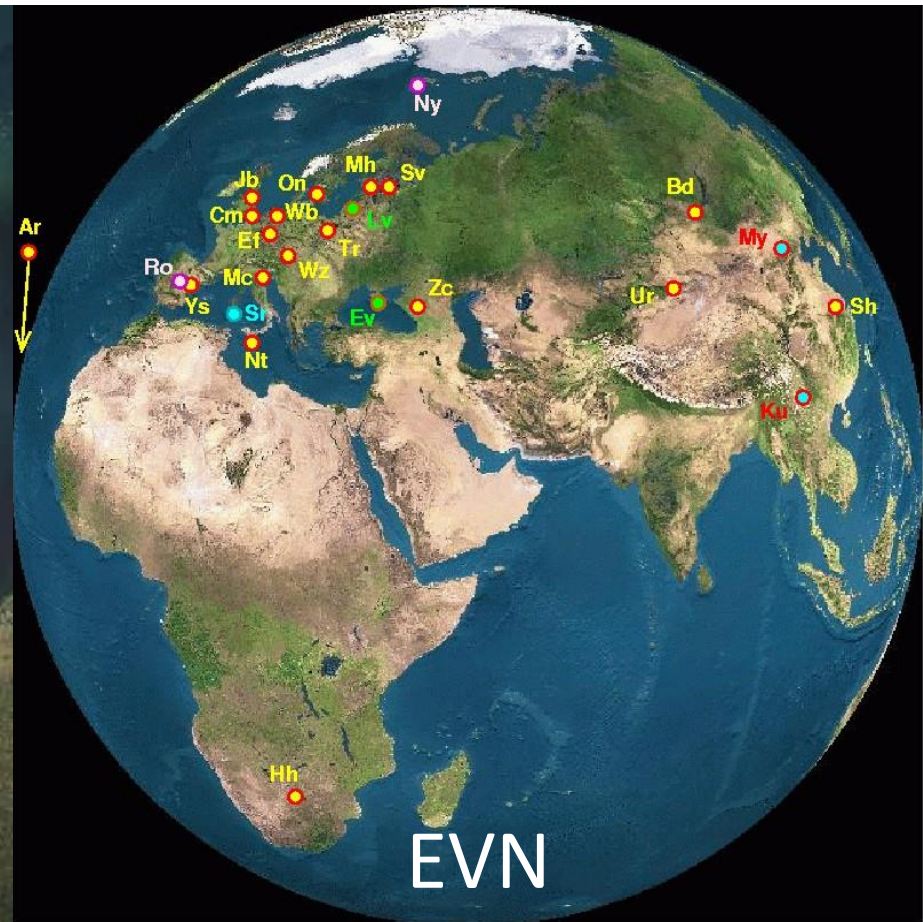


Prospects for e-Merlin – EVN

Tom Muxlow JBCA / JBO
Jumping JIVE – VLBI Futures Meeting
Zaandam, the Netherlands 1st March 2018



Prospects for e-Merlin – EVN

Outline:

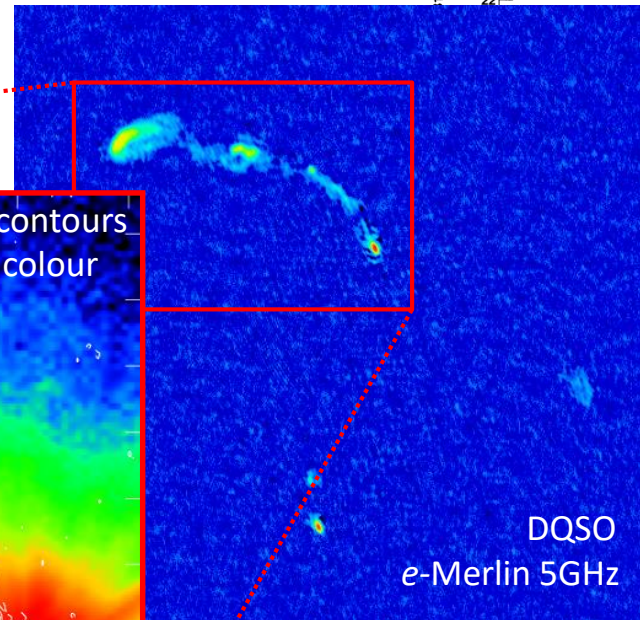
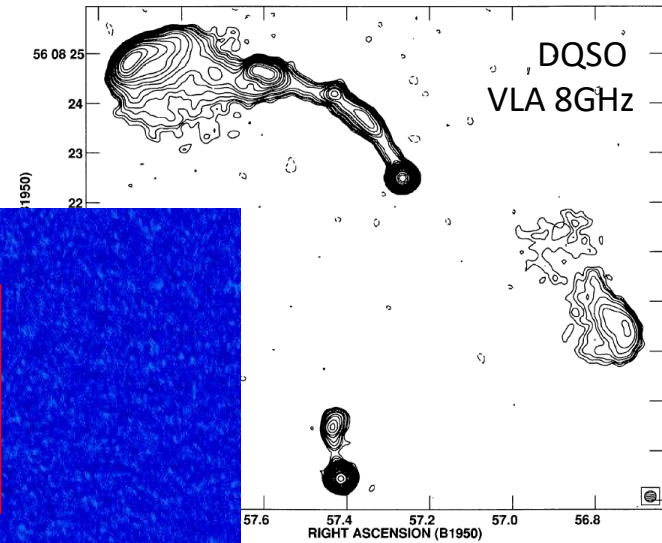
- e-Merlin – Description, recent developments, and planned new facilities
 - Science-driven upgrades
 - Unique spatial frequency coverage at cm-wavelengths
 - e-Merlin + EVN – Combination imaging
 - e-Merlin + EVN + Goonhilly
 - The CUGA consortium
 - e-Merlin + EVN – Delivery...
 - e-Merlin + EVN – In the SKA Era (e-MERGE + EG078)

e-Merlin

– Unique spatial frequency coverage at cm-wavelengths

– A dedicated compact VLBI imaging array

Deep high-resolution imaging of well-known radio structures leading to new discoveries....



e-Merlin contours
HST false colour

Optical synchrotron from jet interaction
– or jet-induced star-formation?

e-Merlin

– Recent improvements and planned new facilities

On-going Operational upgrades

- Final commissioning of 2GHz bandwidths (C/K-band)
- Phasing up of array – sensitive PSR/transient instrument ~equivalent to 110m dish
- Inclusion of new dishes – Goonhilly + others? – More resolution, more uv coverage
- Lovell Telescope: New elevation encoder and ASKAP PAF
- e-MERLIN fully integrated into EVN \rightarrow baselines from 10 to 10,000 km



e-Merlin

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Funding confirmed for further 5 years

- New SDP-like software pipelines – look, feel, & behave like SKA
- ~20% increase in operational funding

Ambitious cost-effective planned upgrades

– noted, but awaiting future funding

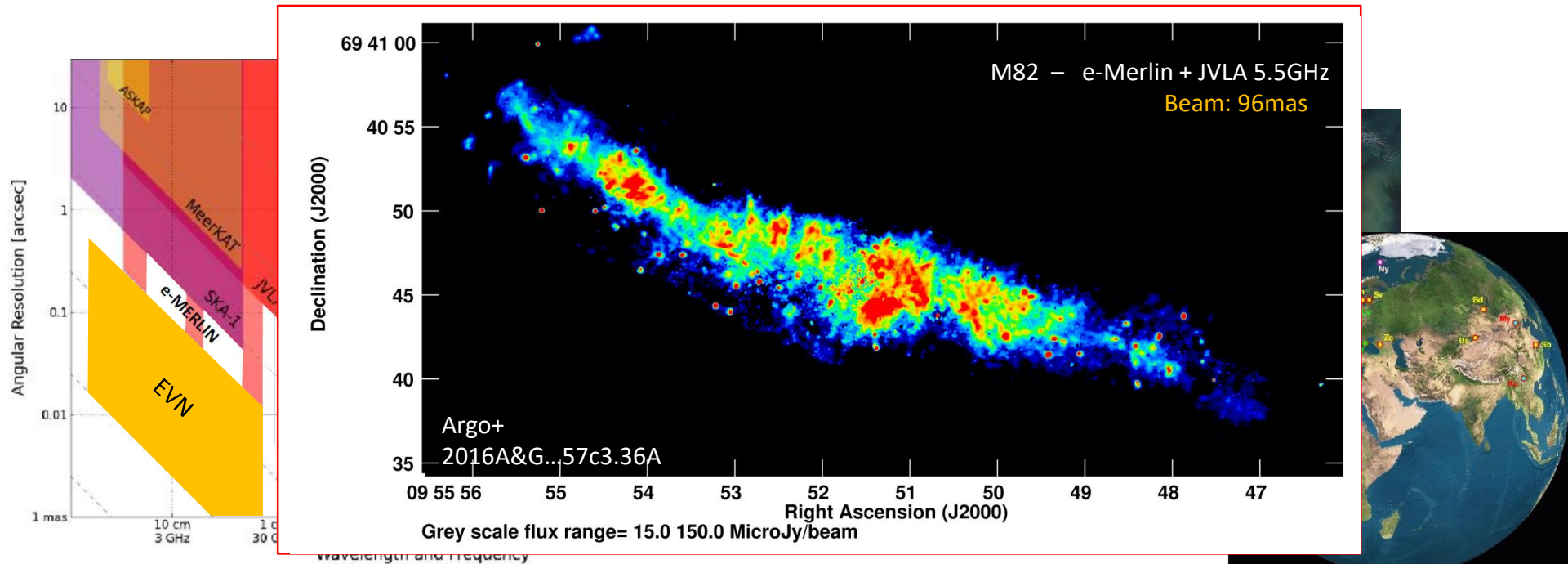
- New frequency bands – S-band & X-band (SKA Band 5b)
- Cyro-PAF (S- or L-band)
- Replacement of Defford telescope (with SKA1-mid dish) – allow better performance at $>\sim 6\text{GHz}$
- Digital upgrades → increase bandwidths

e-Merlin

– Unique spatial frequency coverage at cm-wavelengths

e-Merlin with baselines from 10km – 220km provides imaging capability covering a unique range of spatial scales overlapping with the JVLBA at lower angular resolution and extending up to the EVN with ultimate angular resolution < 1mas

In addition to being a dedicated compact VLBI imaging array, e-Merlin is used in combination with the JVLBA for increased angular resolution whilst retaining superb surface brightness sensitivity

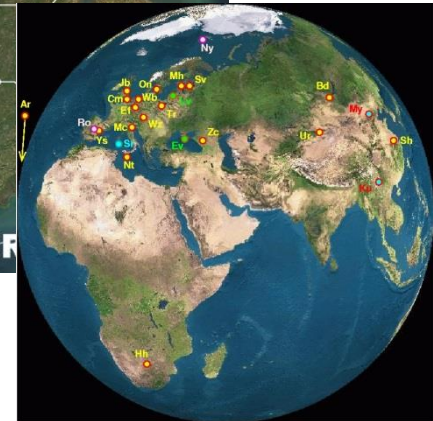
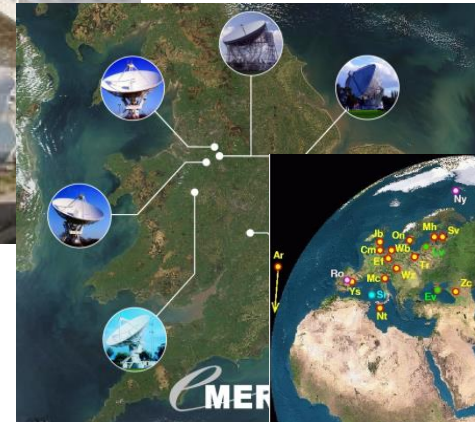
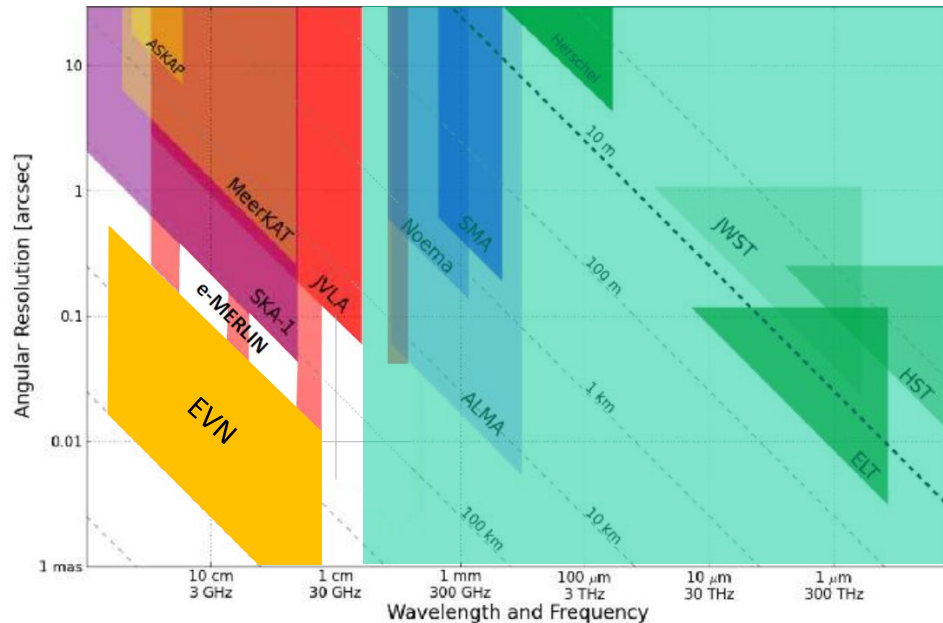


e-Merlin

– Unique spatial frequency coverage at cm-wavelengths

e-Merlin with baselines from 10km – 220km provides imaging capability covering a unique range of spatial scales overlapping with the JVLAs at lower angular resolution and extending up to the EVN with ultimate angular resolution $< 1\text{mas}$

...and in combination with the EVN to provide short-spacing coverage to the EVN to place the mas-scale VLBI images in context with regard to any extended radio structure present.



e-Merlin + EVN

The Intermediate baselines for high fidelity imaging at angular resolutions between e-Merlin and the EVN – Long promised but finally on the way !!

Galactic stellar evolution: Maser Emission in U Orionis – Richards+ (2008)

Main requirements for investigating mass loss mechanisms and wind driven material from evolved stars are: *Good baseline coverage (image fidelity) from tens to hundreds of kms (thousands at L-band)*

→ Sample all scales from a (few) hundred mas (depending on frequency) down to ~1 mas.

→ Higher resolution valuable for very rapid proper motion studies, & avoiding beam depolarization.

To image masers and place them within their environments:

H₂O: Ideally want baselines in the range 10 → 500kms

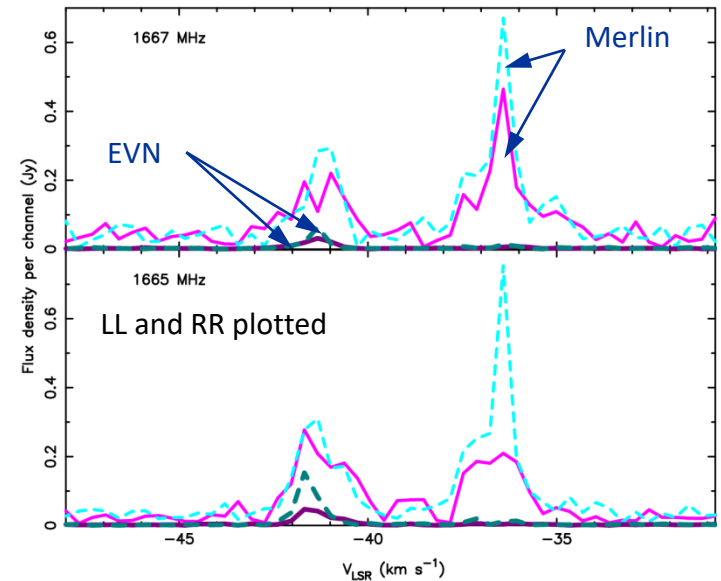
OH: Ideally want baselines in the range 40 → 2000kms

U Orionis – OH masers

Separate Merlin and EVN images

OH masers observed by EVN and Merlin within a few weeks (1998)

EVN heavily resolves the masers, virtually unresolved by Merlin



e-Merlin + EVN – Combination imaging

The Intermediate baselines for high fidelity imaging at angular resolutions between e-Merlin and the EVN – Long promised but finally on the way !!

Extragalactic star-formation: The Radio Core Structure in NGC4418 – Varenius+ (2014)

Inverted spectral index $\alpha \geq 0.7$ ($S_\nu \propto \nu^\alpha$) for the compact regions of radio emission.

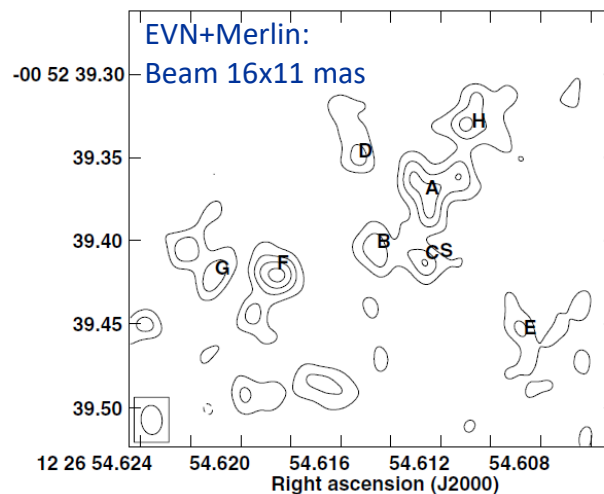
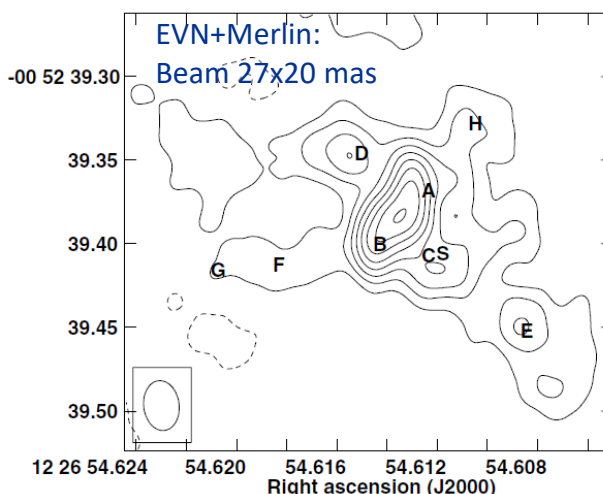
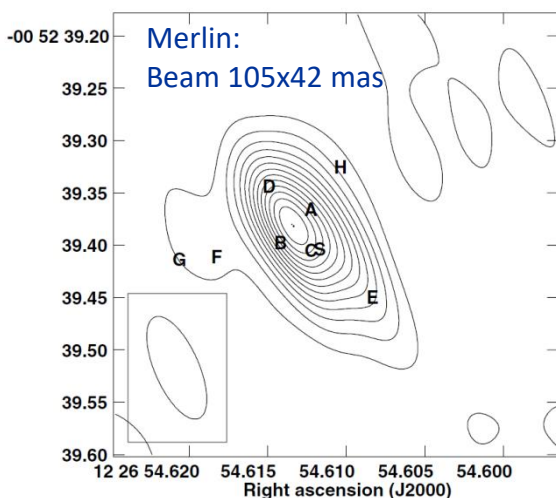
$T_B > 10^{4.8}$ K indicate that these compact features cannot be HII-regions.

→ 8 Super star clusters (intense star formation) with associated free-free absorption (A→H)

→ Low radio-to-IR ratio of the nucleus.

Separate Merlin and EVN C-Band datasets – Merlin + combination
Images at intermediate resolution to study individual star clusters.

Image fidelity can be limited by
lack of uv -coverage overlap



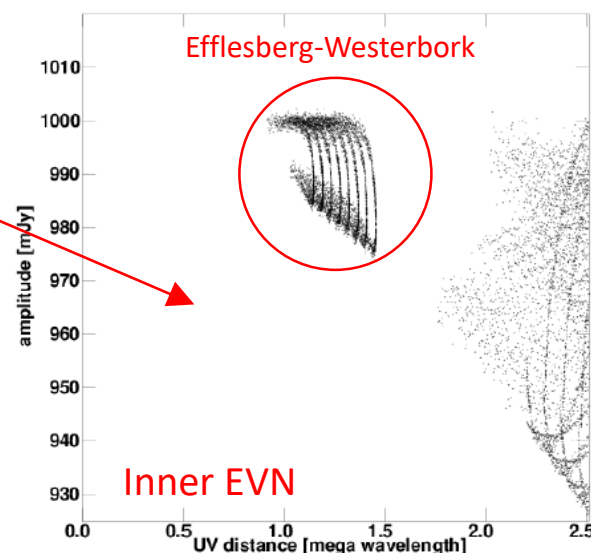
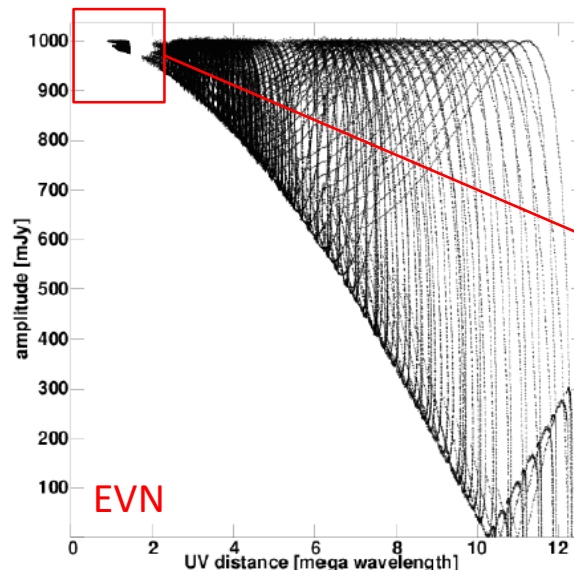
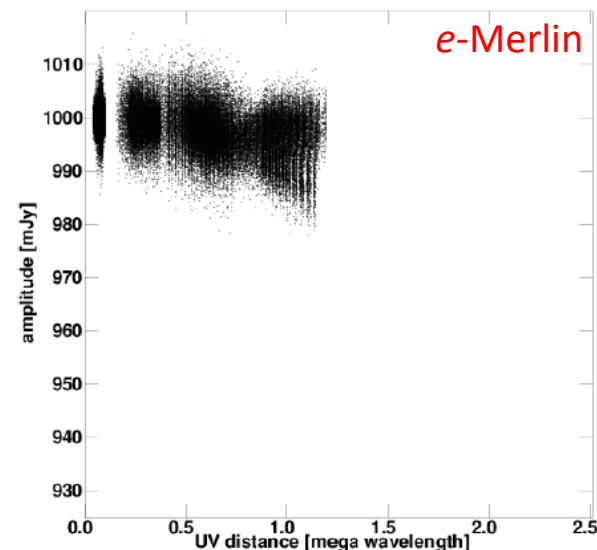
e-Merlin + EVN

Simulated amplitude data for e-Merlin and the Western EVN for a two Declination $+60^\circ$ 0.5Jy point sources separated by 9mas . Bandwidth 400 MHz
[Klockner+ \(2011\)](#)

EVN simulations based on JB-Lovell, Efflesberg, Westerbork, Onsala, Noto, Torun, Medicina

Separately correlated e-Merlin+EVN imaging add short spacings but has very little *uv*-coverage overlap.

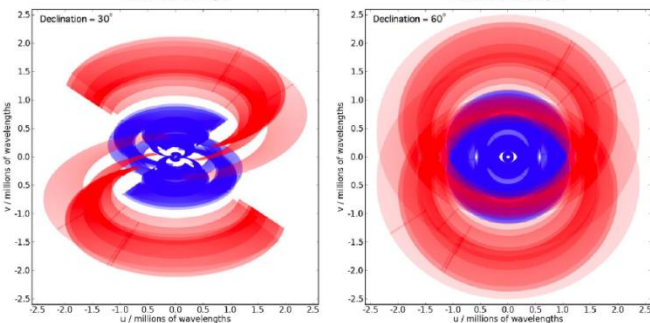
e-Merlin telescopes → EVN correlated datasets begins to populate the overlap region.



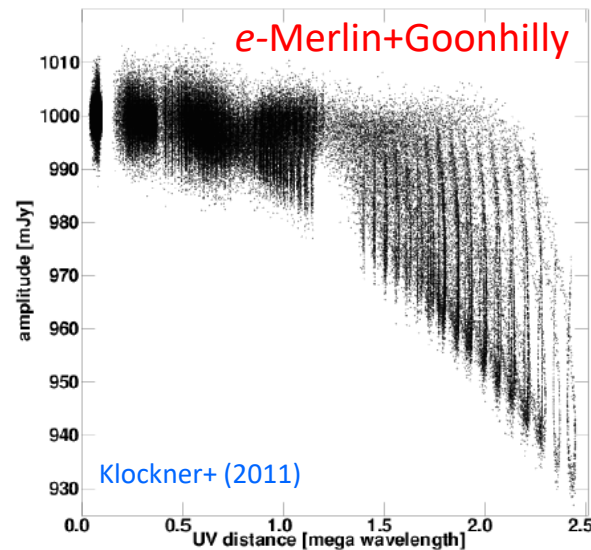
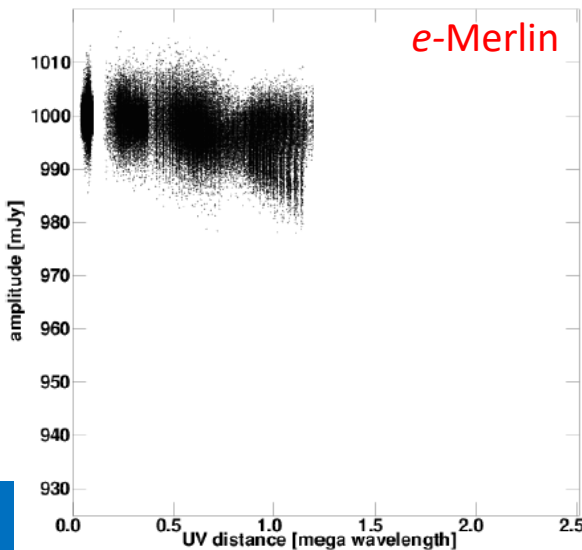
e-Merlin + EVN + Goonhilly

Adding Goonhilly to e-Merlin both fills in the overlap region with EVN and doubles the angular resolution of e-Merlin – and also improves image fidelity at low Declinations

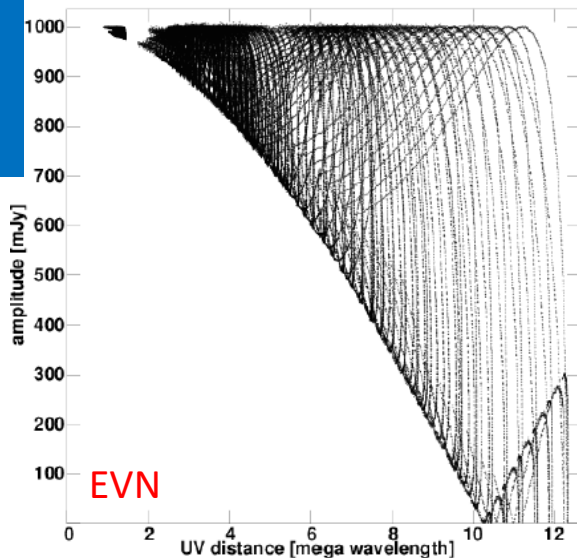
e-Merlin+Goonhilly added to EVN-correlated datasets adds short uv spacings and fills the coverage holes at baselines $< 5M \lambda$



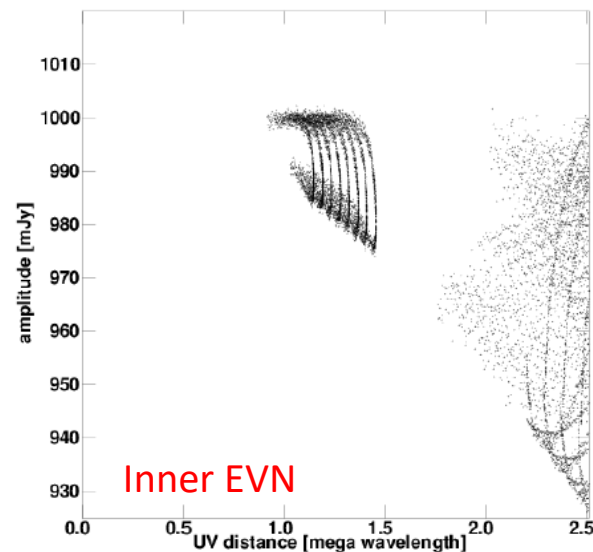
Heywood+ (2011)



Klockner+ (2011)



EVN



Inner EVN

e-Merlin + Goonhilly

<http://www1.ast.leeds.ac.uk/~mgh/CUGA.htm>

CUGA

Consortium of Universities for Goonhilly Astronomy



26m L-Band



30m C-Band



CUGA Consortium:

Leeds (Lead)
Manchester
Hertfordshire
Durham
Oxford
UCLAN
Bristol
Delivery 1-2 years (?)

Consortium of Universities for Goonhilly Astronomy (CUGA) is a consortium of Universities bound by Memorandum of Agreement to use Goonhilly Earth Station Ltd (GES) assets for astronomical research, training and outreach.

Envisage data transmission back to JBO for inclusion into the e-Merlin correlator
– and available for recording with other e-Merlin antennas for correlation in JIVE.
Antenna duty cycle of availability and JBO returned bandwidth still being finalised

e-Merlin + EVN Delivery...

e-MERLIN in EVN: Including e-MERLIN antennas provides continuous sampling of antenna separations between 10km and 10,000 km allowing combination imaging across a wide range of angular scales – some early successes in 2017 – but issues remain...

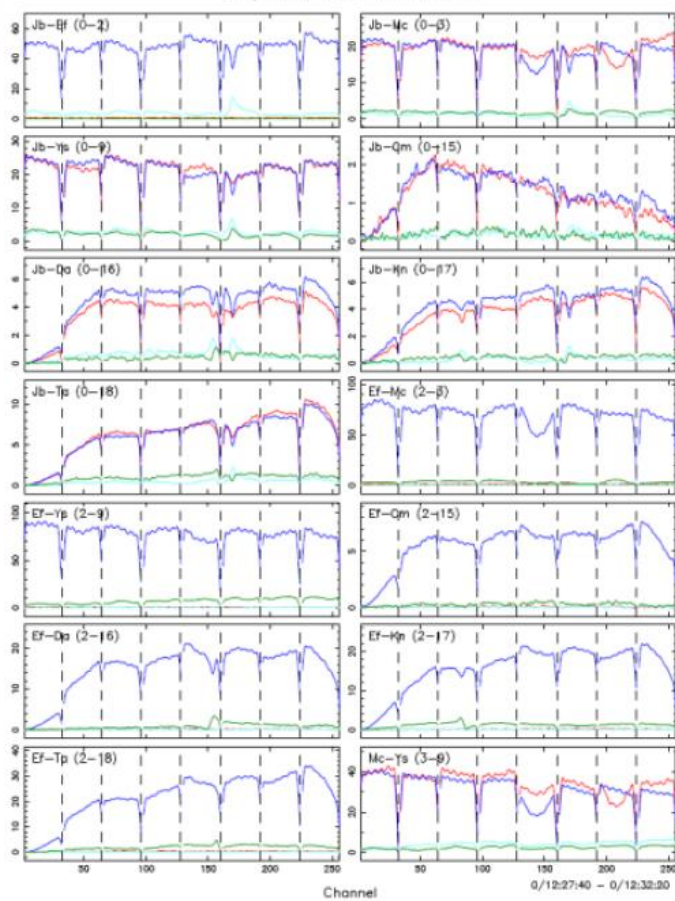
Initially 1Gbps divided between all selected e-Merlin antennas – Ultimately up to 2Gbps per antenna.

Eskil Varenius joined the e-MERLIN / VLBI Operations Team October 2017 with initial goal to focus on the development of the EVN + e-MERLIN project. New test procedures implemented, project to identify the remaining tasks and actions started.

Latest sample statistics from recent NME recordings now appear correct – but still awaiting strong fringes

Fringe amplitudes from strong calibrator sources detected between e-MERLIN and EVN antennas – C-Band NME in May/June 2017

Amplitude for n17c2.eMERL2



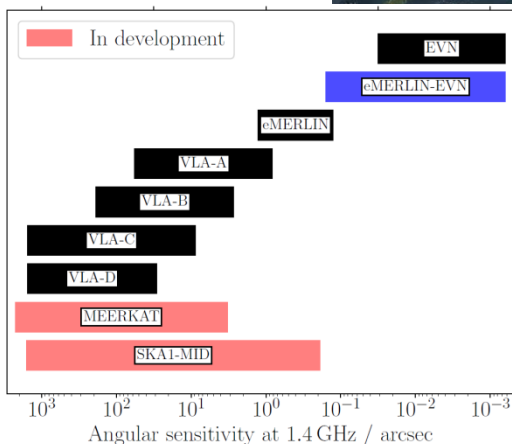
e-Merlin + EVN – In the SKA Era

High resolution high fidelity imaging
Large datasets
High powered computing
Sophisticated software packages



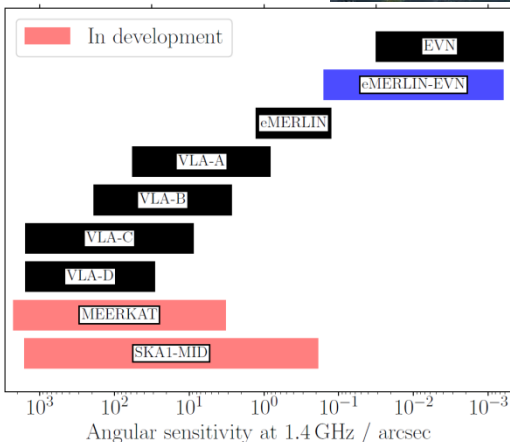
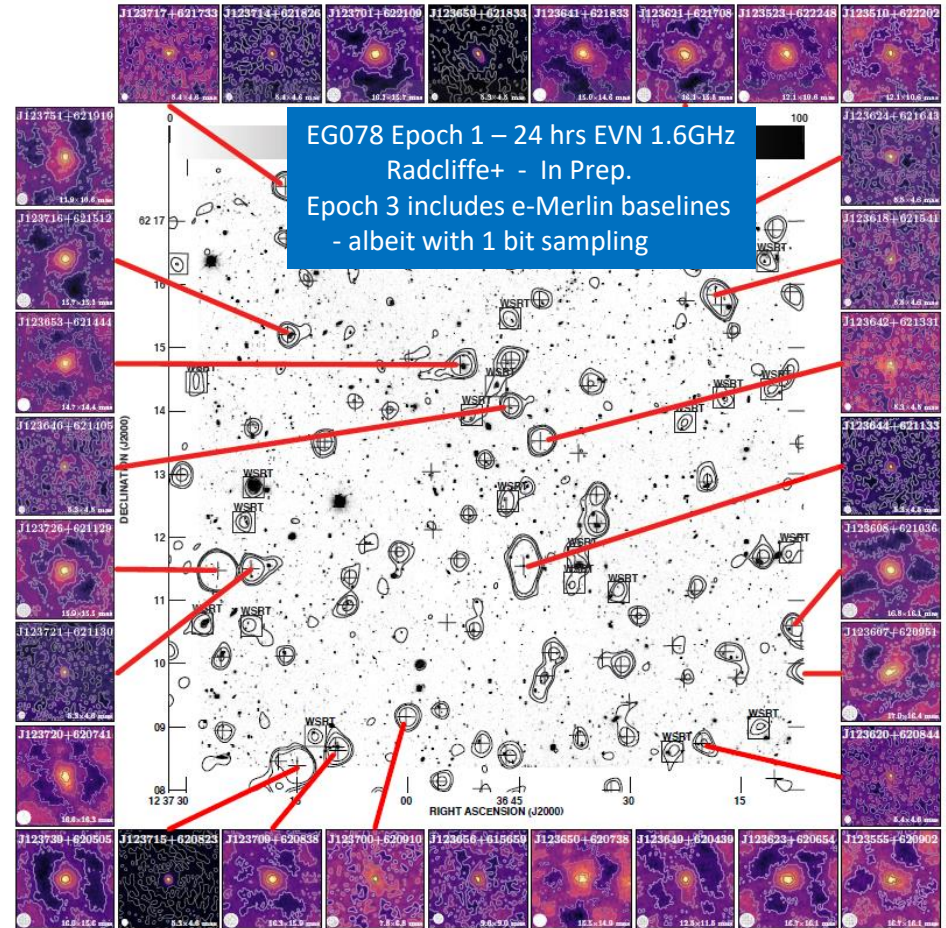
Full integration of wide-field EVN into the centimetric radio astronomy instruments to provide seamless imaging at angular resolution from 10s of arcseconds to milliarcseconds as part of a ‘World Telescope’ to image astronomical objects across all the angular scales

e-MERLIN+JVLA characterised with e-MERGE DR-1 in GOODS-N
– Extending to include EVN with EG078 to image AGN/jet feedback embedded in extended starbursts...



e-Merlin + EVN – In the SKA Era

- High resolution high fidelity imaging
- Large datasets
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e-MERLIN+JVA characterised with e-MERGE DR-1 in GOODS-N
– Extending to include EVN with EG078 to image AGN/jet feedback embedded in extended starbursts...

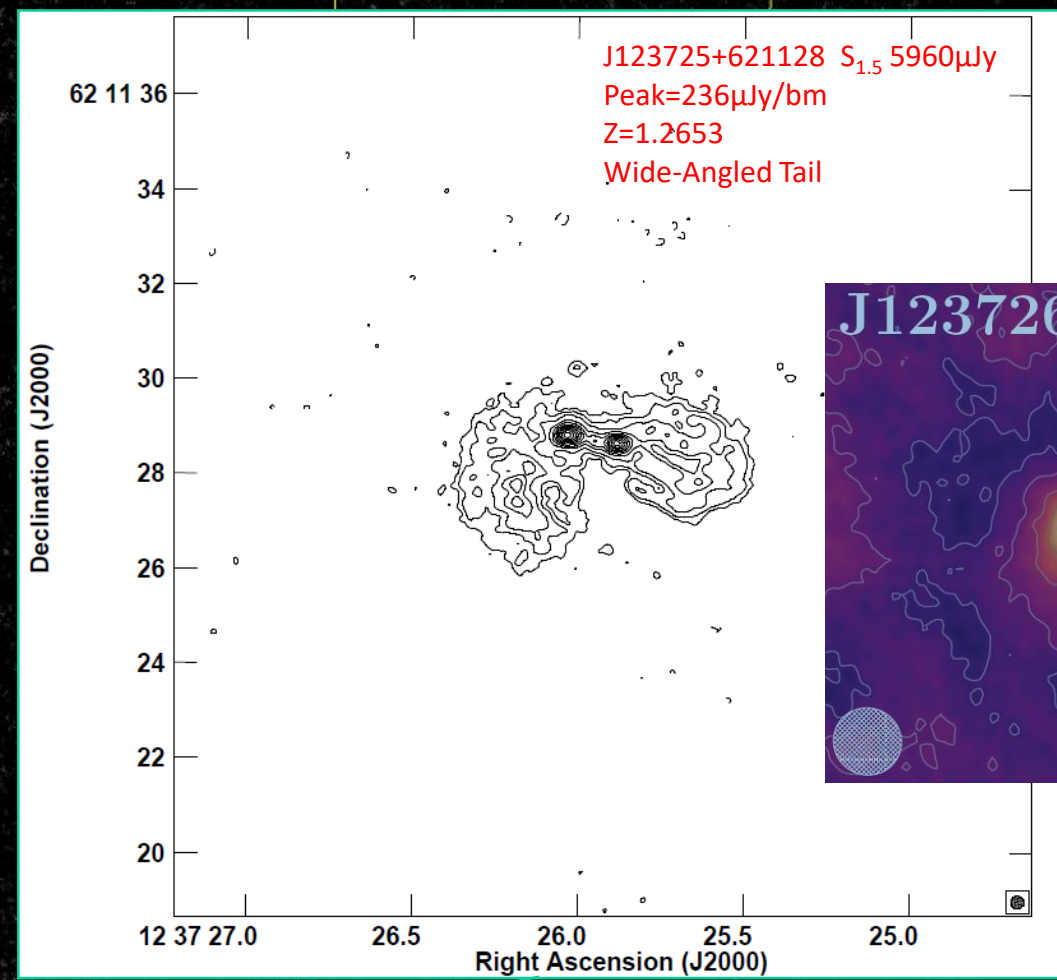
e-MERGE 1.5GHz

DR-1 Release:
38 hrs JVLA (BW 1GHz)
127hrs e-MERLIN (BW 512MHz)
42 hrs VLA (BW 43.75MHz)
18 days Merlin (BW 15MHz)

20k x 20k image (15' fov)
Beam 280x260mas
WSClean (mfs)
~820 sources

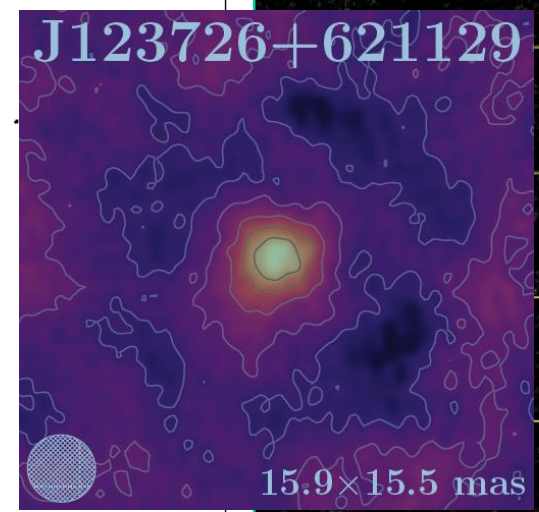
3.5 days for 1.06TB data
with 150,000 cleans.
64core Intel Xeon v3 @
2.3GHz

Muxlow, Smail, McHardy,
Beswick, Wrigley,
Thomson..



J123725+621128 $S_{1.5}$ 5960 μ Jy
Peak=236 μ Jy/bm
Z=1.2653
Wide-Angled Tail

GOODS-N
L-Band DR-1
Central 5'
1 σ =1.49 μ Jy/bm



J123726+621129

15.9 x 15.5 mas



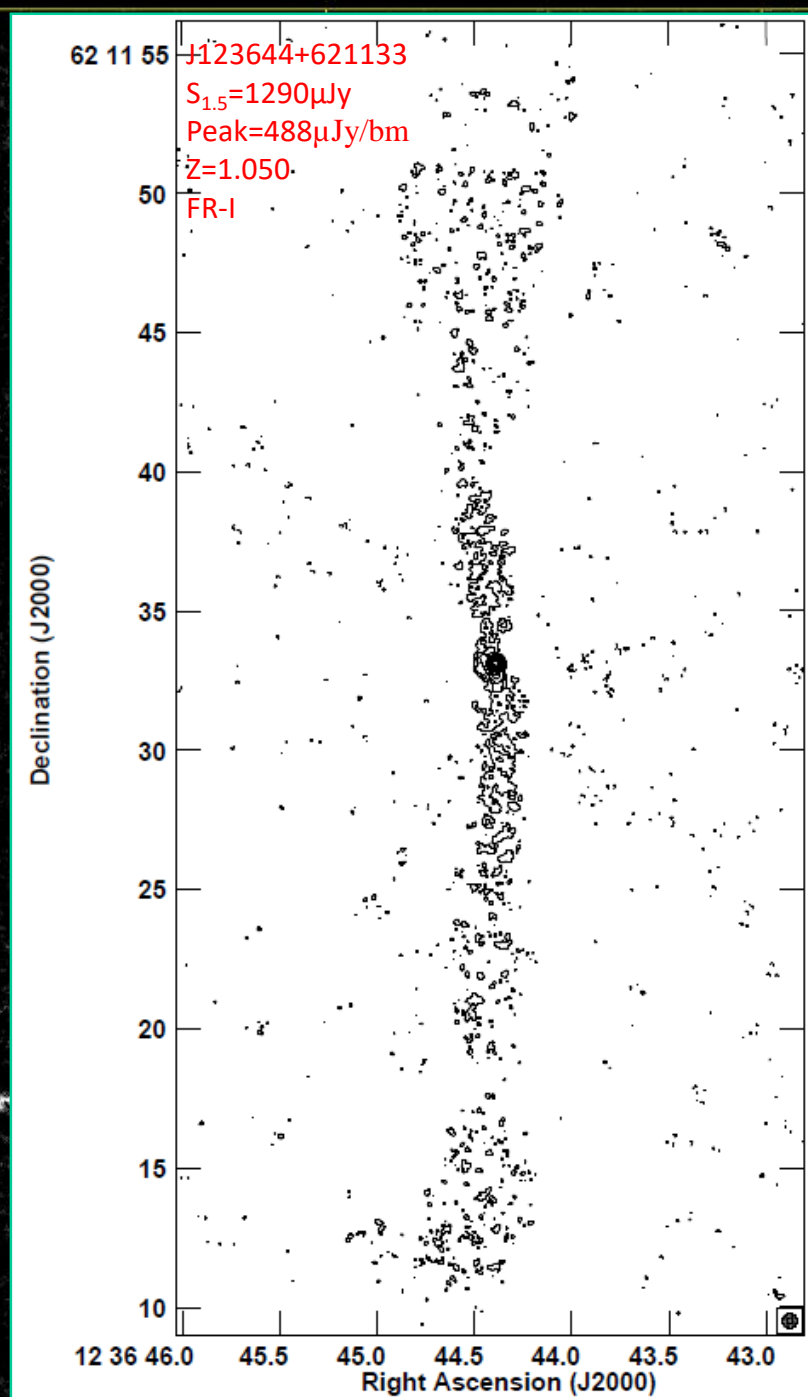
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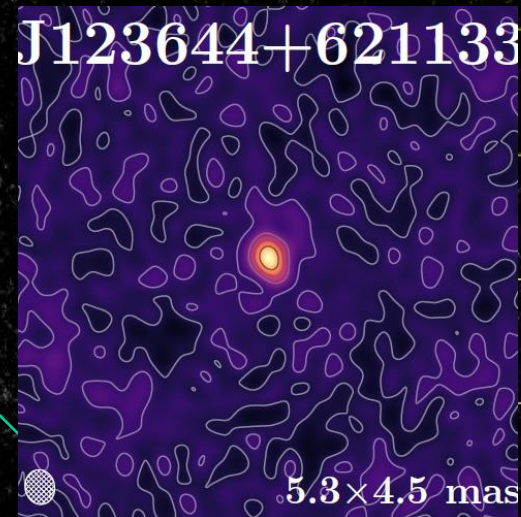
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Muxlow, Smail, McHardy,
Beswick, Wrigley,
Thomson..



GOODS-N
L-Band DR-1
Central 5'
 $1\sigma=1.49\mu Jy/bm$



e-MERGE 1.5GHz

+EG078

DR-1 Release:

- 38 hrs JVLA (BW 1GHz)
- 127hrs e-MERLIN (BW 512MHz)
- 42 hrs VLA (BW 43.75MHz)
- 18 days Merlin (BW 15MHz)
- + 3x24hrs EVN (BW 128MHz)

20k x 20k image (15' fov)
Beam 280x260mas
WSClean (mfs)
~820 sources

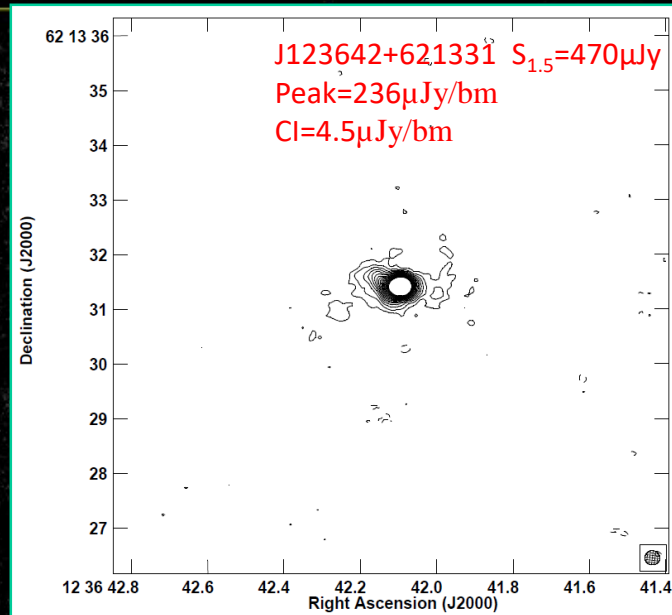
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64core Intel Xeon v3 @
2.3GHz

Muxlow, Smail, McHardy,
Beswick, Wrigley,
Thomson..

Garrett, Barthel, Deller,
Radcliffe...

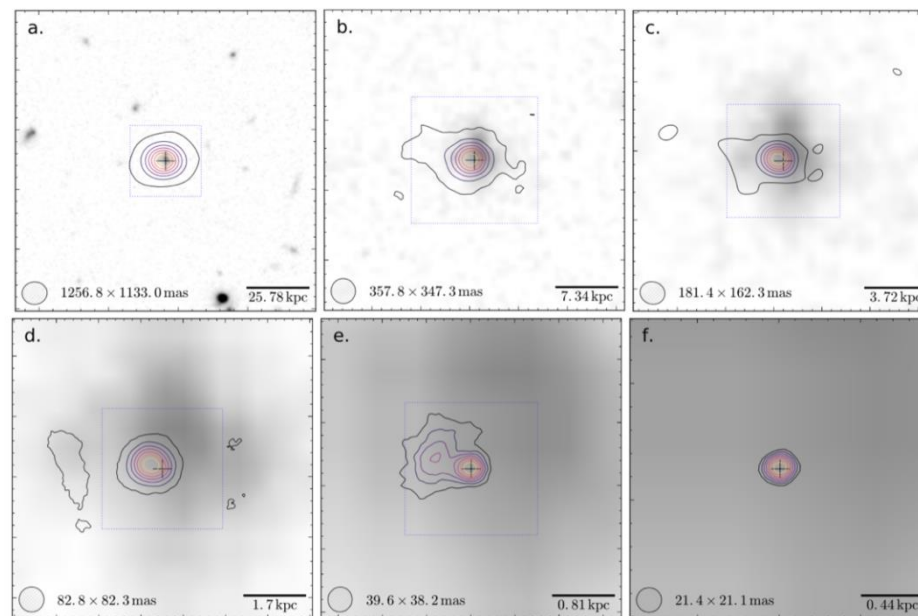
→ Initial tests:

1st EG078 24hrs epoch
+ 46hrs e-Merlin+JVLA



e-Merlin + EVN integration
→ seamless imaging from
arcsecond to mas scales

GOODS-N
L-Band DR-1
Central 5'
 $1\sigma=1.49\mu\text{Jy/bm}$



J123642+621331 ($z \sim 2.28$), a composite star-burst ($\sim 100 M_{\odot} \text{yr}^{-1}$ from integrated IR flux) and AGN candidate, shown at increasingly higher resolutions. Magnification increases from a-f with the blue dotted outline indicating field-of-view of the subsequent image. The radio is overlaid on HST near-IR (F125W). The cross indicates the VLBI location of the AGN. The arcsecond to milliarcsecond resolutions, utilising a combination of JVLA, e-MERLIN and EVN, reveal the existence of an AGN (Radcliffe+in prep.).