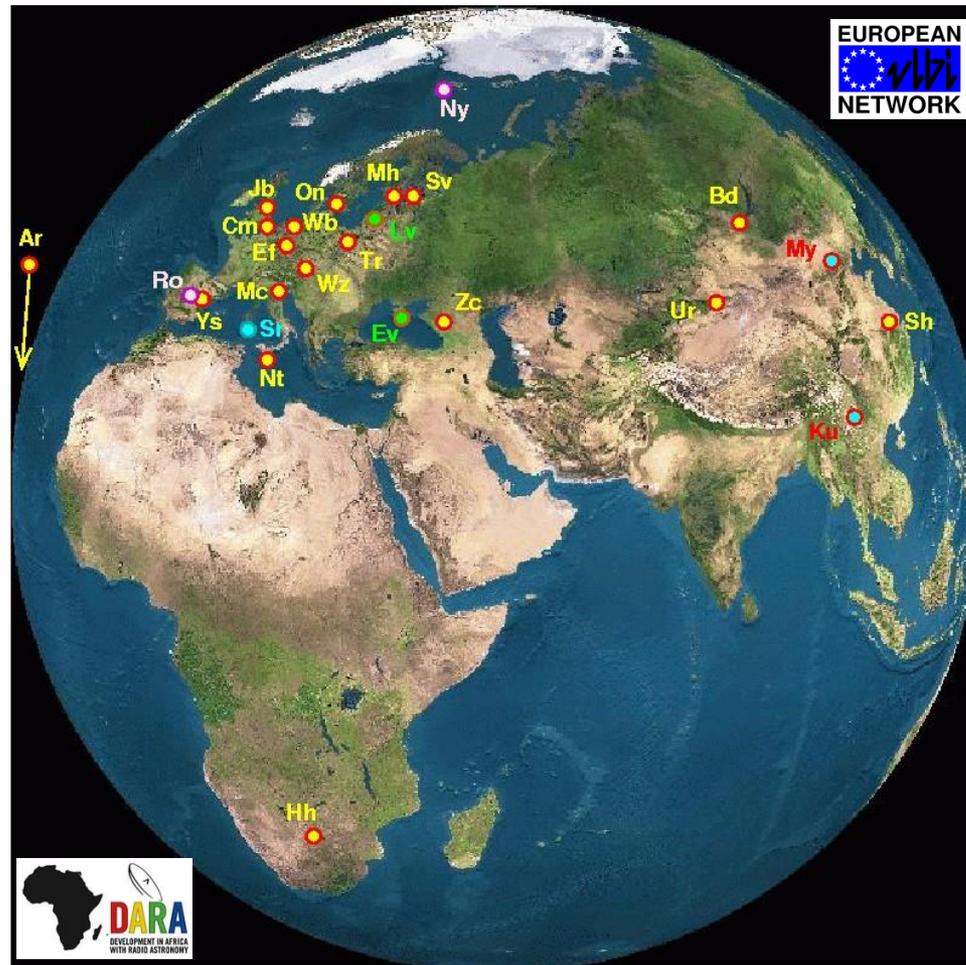


The Impact of VLBI Observations on our Understanding of Star-formation Activity and Low-Luminosity AGN Systems

Tom Muxlow JBCA / JBO

SS11 - Exploring the Universe: a European vision for the future of VLBI
EWASS, Liverpool - 4th April 2018



Where we are

– and where we are going in the era of the SKA...



Outline

With input from:

Rob Beswick, Alastair Thomson, Nick Wrigley, Jack Radcliffe:

Census of high resolution radio telescopes use for star-formation & feedback

Concentrate on:

Deep wide-field imaging of star-formation and AGN feedback across cosmic time
JVLA + e-MERLIN + EVN in the SKA Era (e-MERGE + EG078 as an example)

How spectral properties of SFGs influences what you see with radio interferometers

The need for low-frequency radio imaging on the 10 – 300mas scale size range

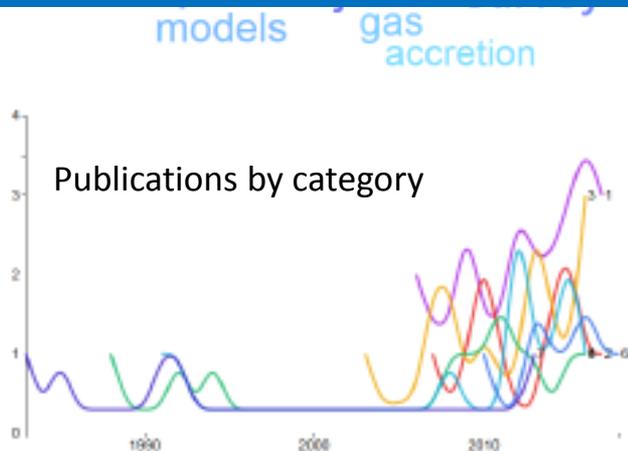
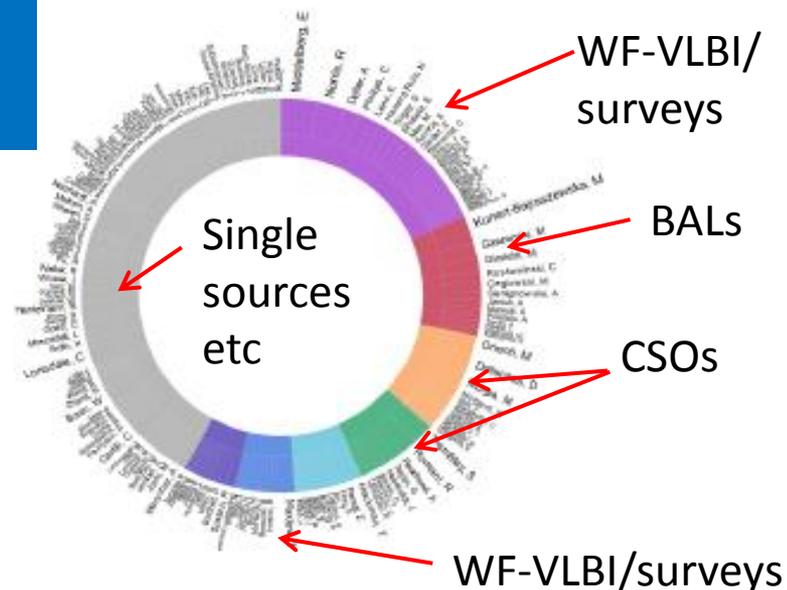
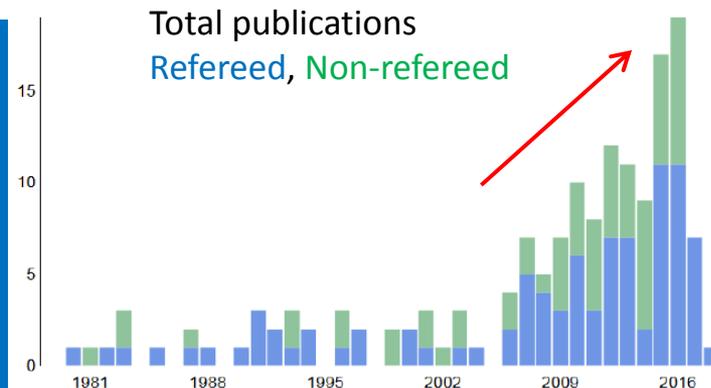
Integration of EVN into other interferometric arrays for seamless imaging of radio structure of angular scales of arcseconds to milli-arcseconds

→ The future role of the integrated EVN on the study of SFGs and low-luminosity AGN across cosmic time

A Quick Census of the Subject

NASA ADS search : (abs:"EVN" or abs:"VLBI" or abs:"VLBA" or abs:"e-MERLIN") and (abs:"Galaxy formation" or abs:"Galaxy evolution" or abs:"feedback")

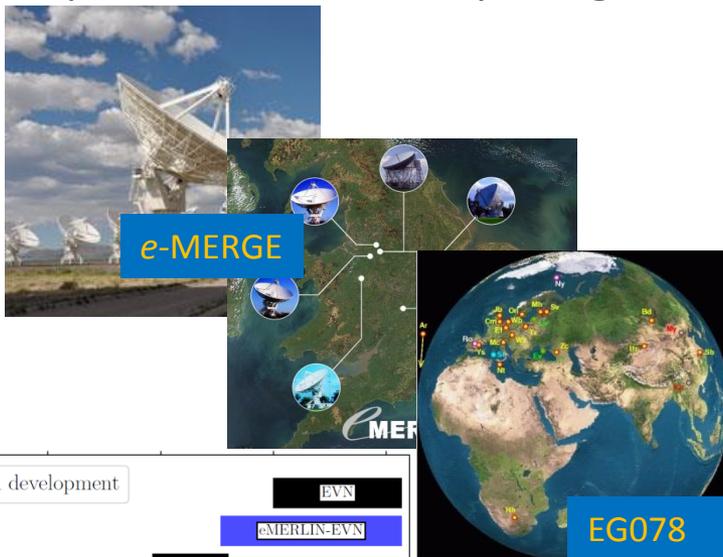
Increased research usage / publications since 2005
Enhanced imaging & sensitivity: – Instrument of choice for detailed study of individual sources
 → Nearby SFGs + low and high-luminosity AGN systems
Technical + software developments: – Wide-field imaging + Integration of VLBI into lower resolution imaging arrays
 → Full spatial frequency-coverage → Angular resolutions selected to address specific science-driven questions



Imaging Star-formation Across Cosmic Time

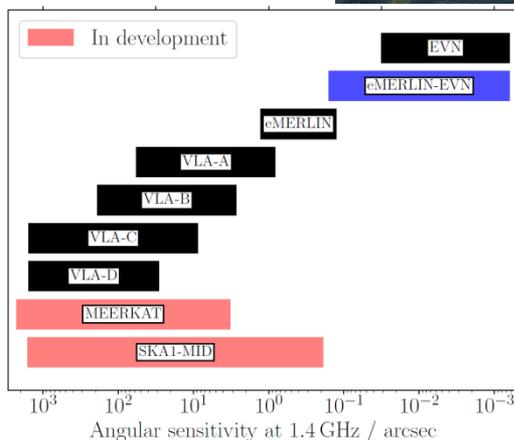
Integrated Imaging – e-MERGE Legacy Project

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



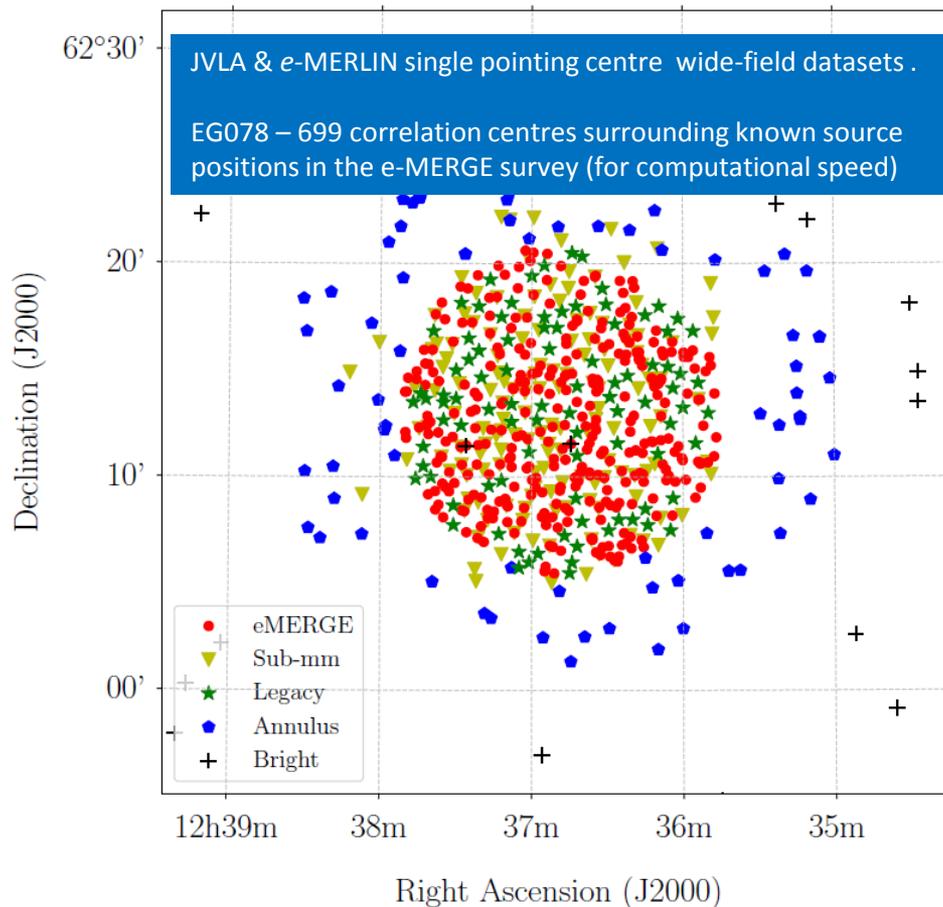
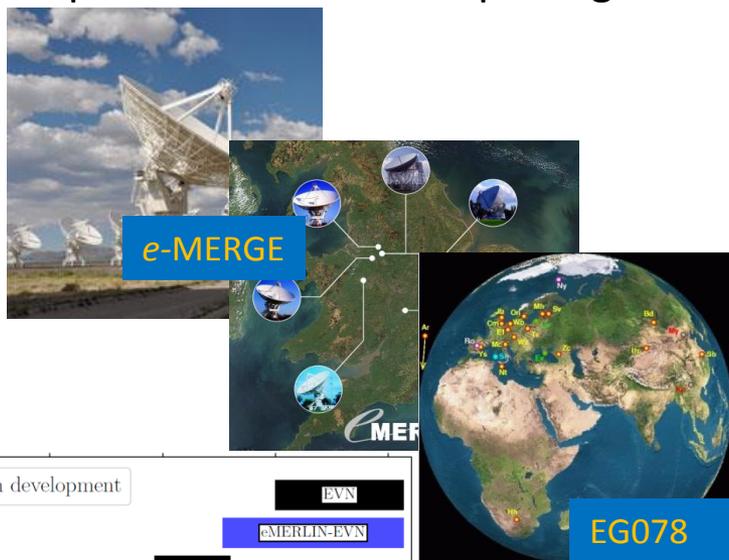
Full integration of wide-field EVN into the centimetric radio astronomy instruments to provide seamless imaging from arcsecond to mas resolution as part of a 'World Telescope' to image the μJy radio population across all angular scales

e-MERLIN+JVLA integration with e-MERGE DR-1 in GOODS-N – Extending to include EVN with EG078 to image AGN/jets & feedback from faint AGN embedded within SFGs...

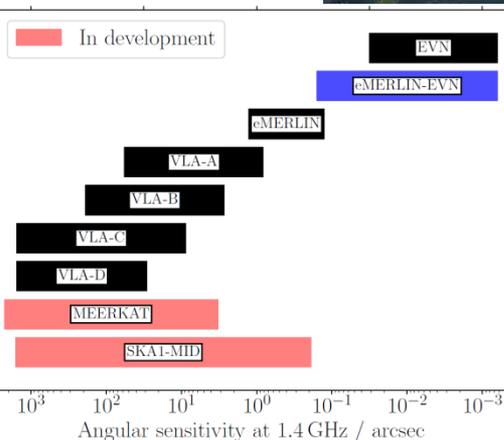


JVLA + e-Merlin + EVN – In the SKA Era Integrated Imaging – e-MERGE Legacy Project

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

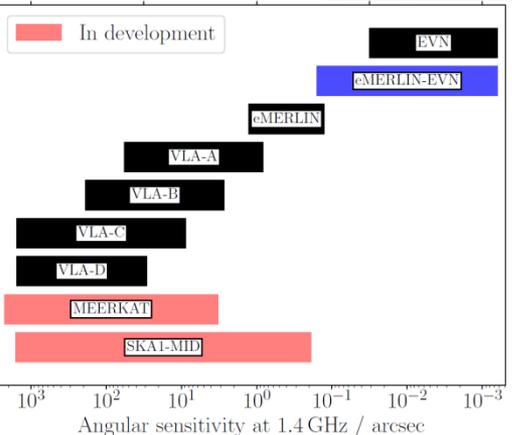
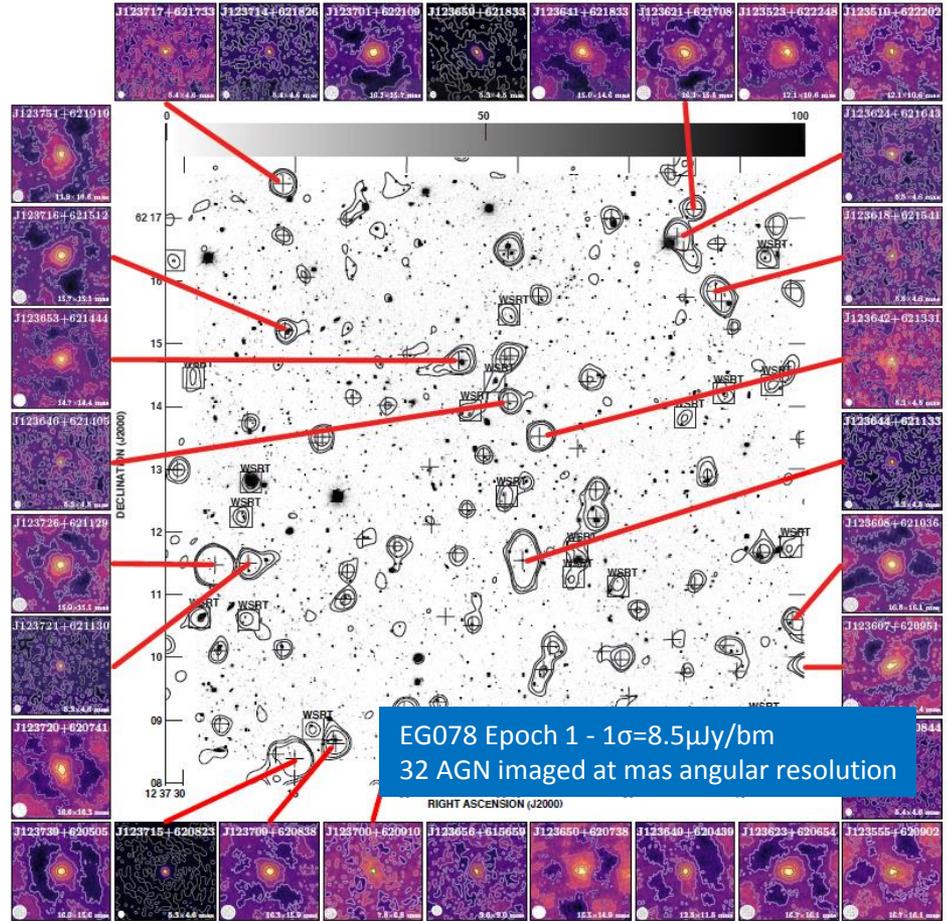
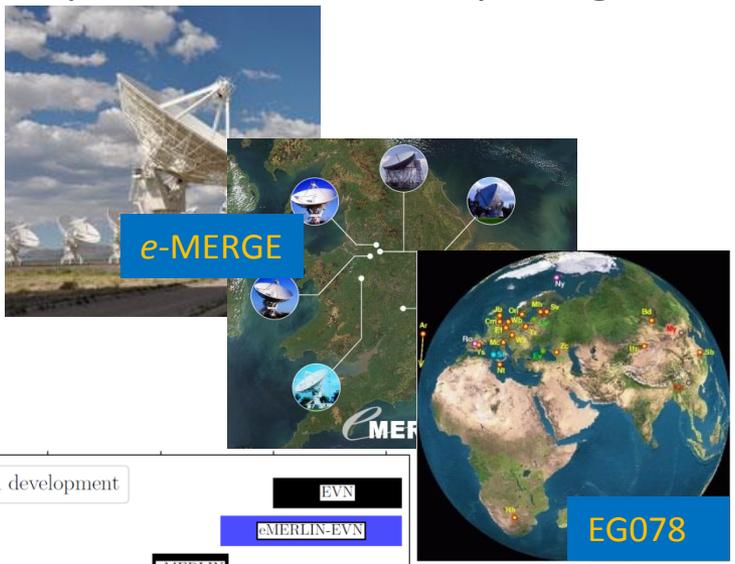


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JVLA + e-Merlin + EVN – In the SKA Era

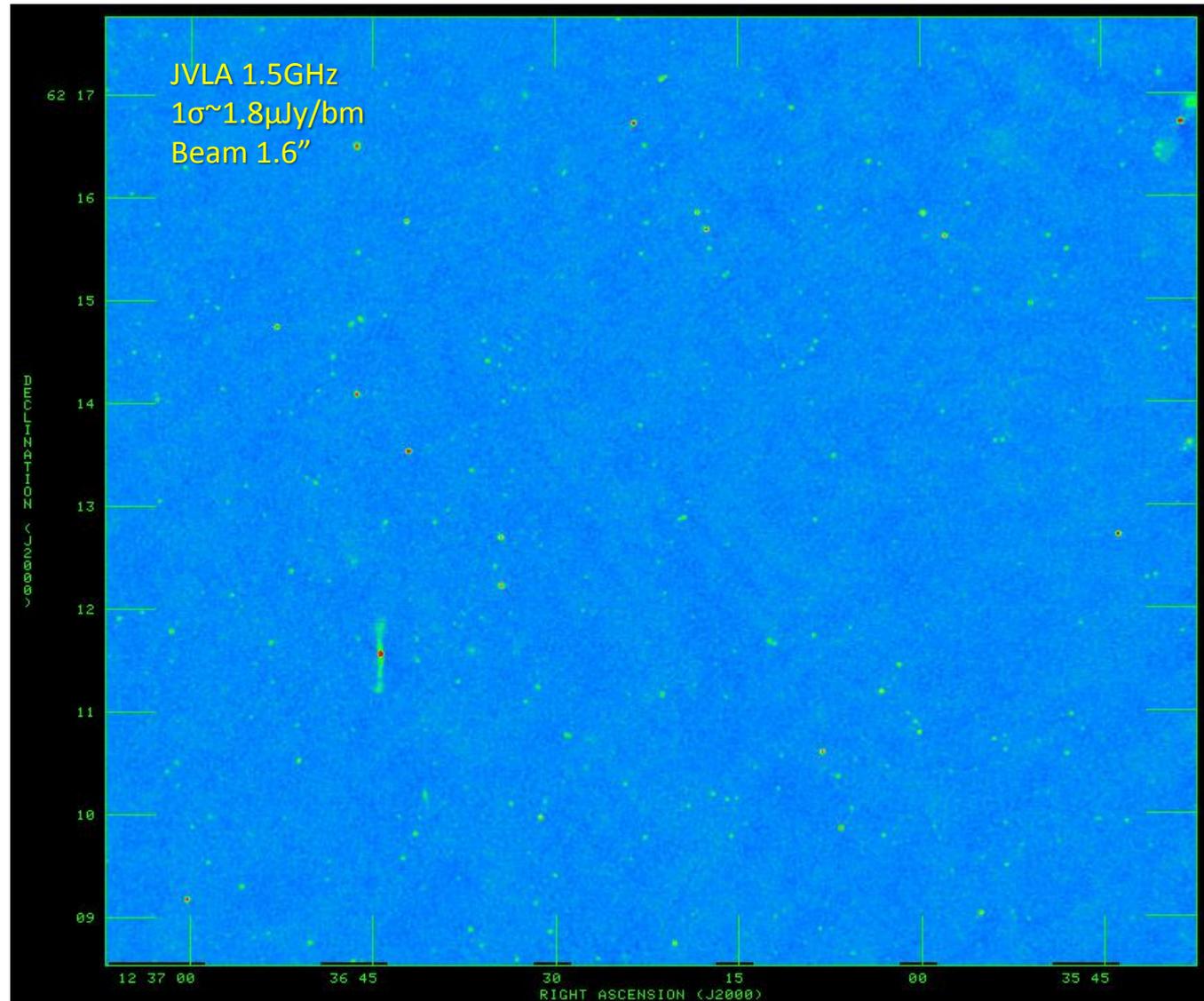
Integrated Imaging – e-MERGE Legacy Project

JVLA L-Band image of central 9' of GOODS-N
Full image to 30' – Most sources ~unresolved
→ 'Finding chart'

~820 detections in inner 15' field to 5σ locally

Sub-arcsecond imaging can separate AGN-jet emission from star-formation. SF-rate estimates from 1.5GHz SF luminosity.

Radio is extinction-free



JVLA + e-Merlin + EVN – In the SKA Era

Integrated Imaging – e-MERGE Legacy Project

e-MERGE 1.5GHz

DR-1 Release:

38 hrs JVLA

127hrs e-MERLIN (25% data)

Archival VLA+MERLIN data

from Muxlow + (2005)

1.06TB data

400Mpixel image (15' fov)

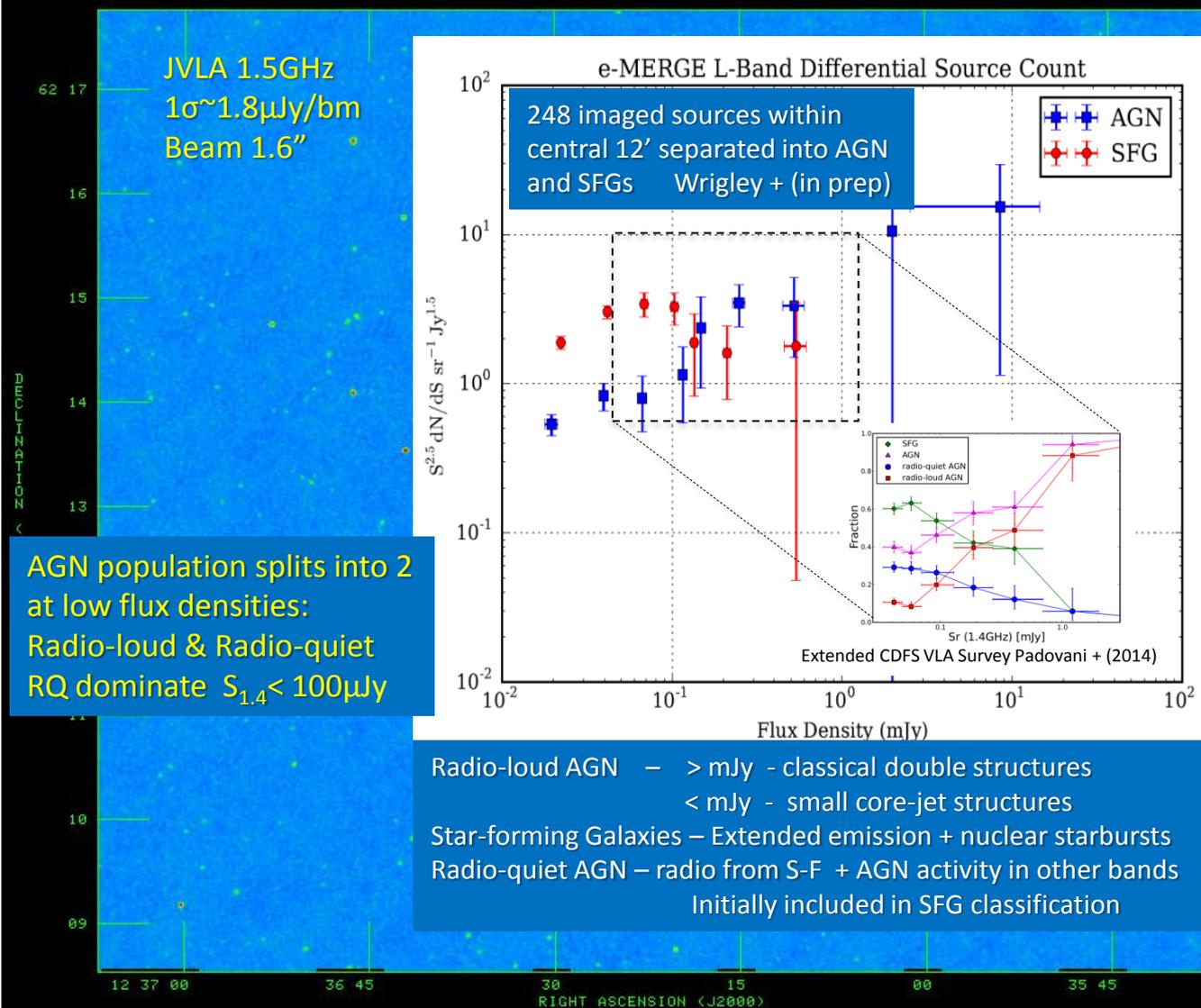
Beam 280x260mas

$1\sigma = 1.5\mu\text{Jy}/\text{bm}$

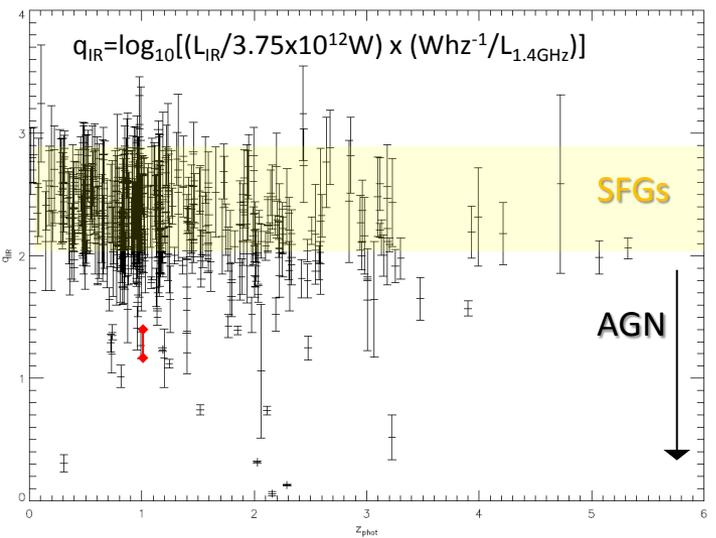
+ EG078 EVN 72hrs 1.6GHz

$1\sigma \sim 5\mu\text{Jy}/\text{bm}$

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

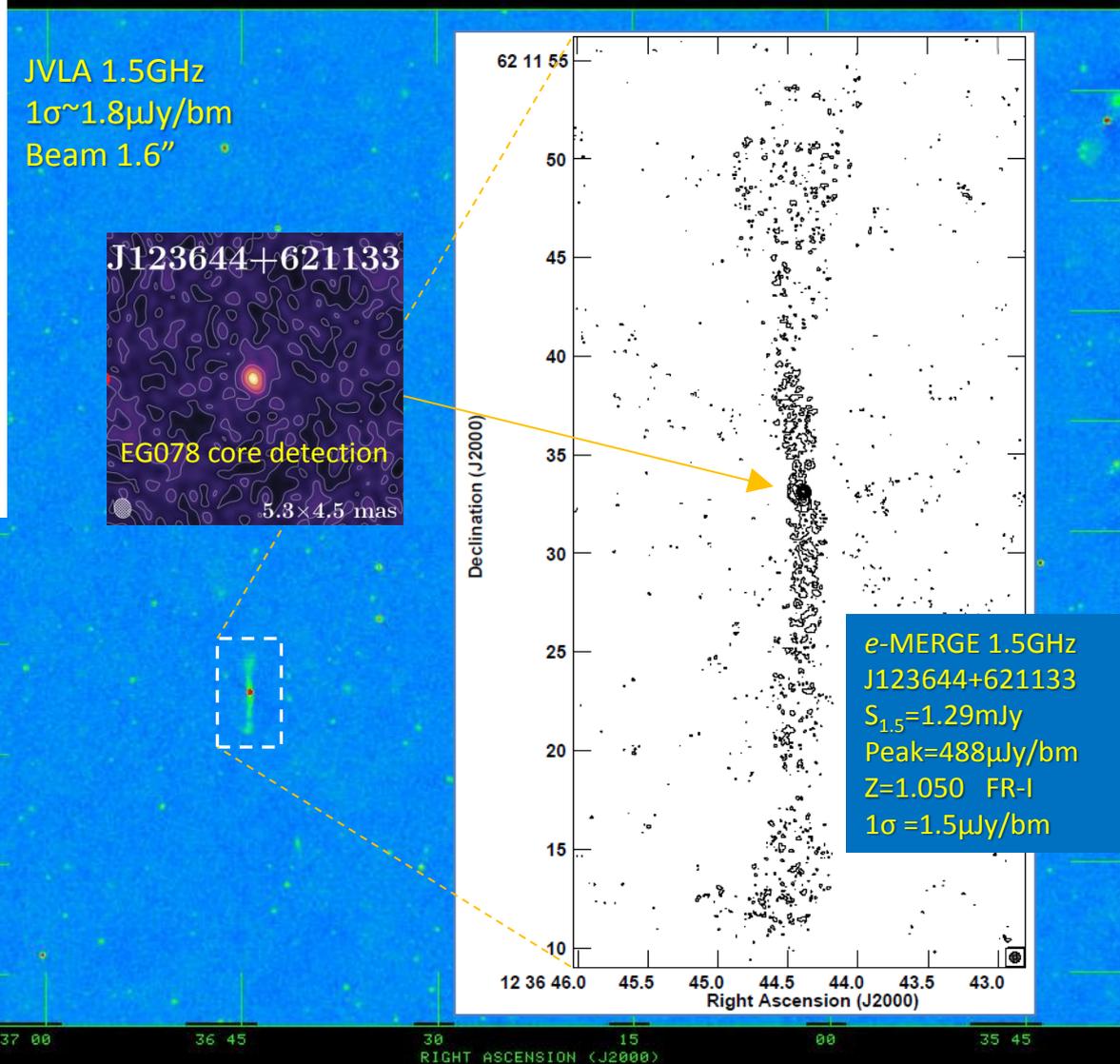


Classical AGN-loud Radio Structures

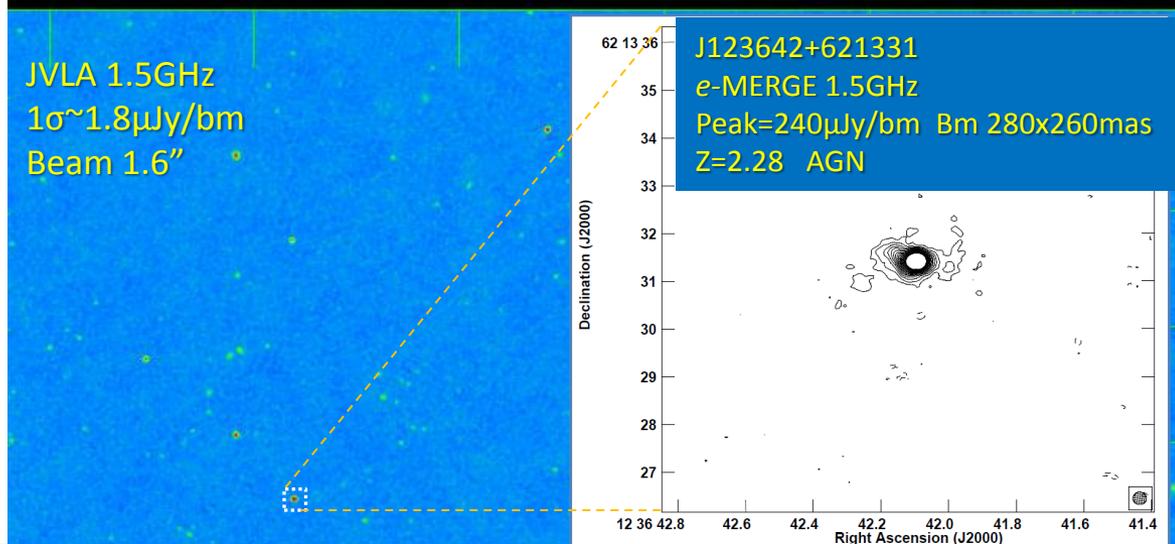
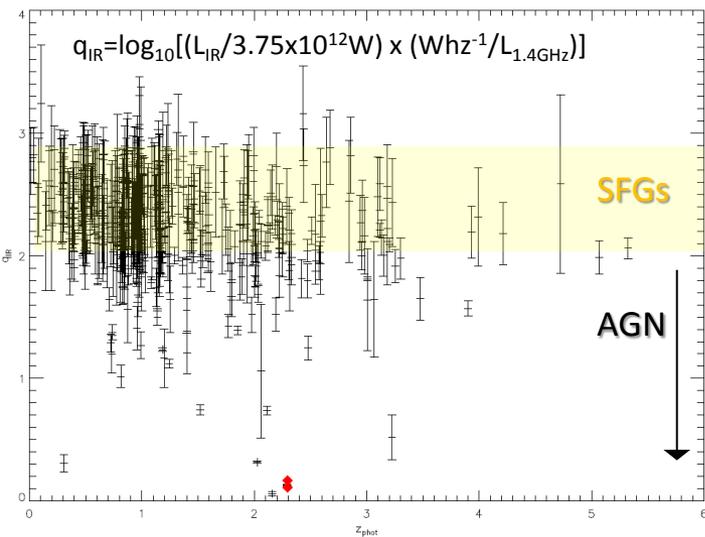


500 e-MERGE radio-selected galaxies with optical counterparts and de-blended Herschel SPIRE photometry Thomson+ 2018 *in prep.*

~15% AGN with $q_{IR} < 1.95$



AGN-loud Core-jet Structures



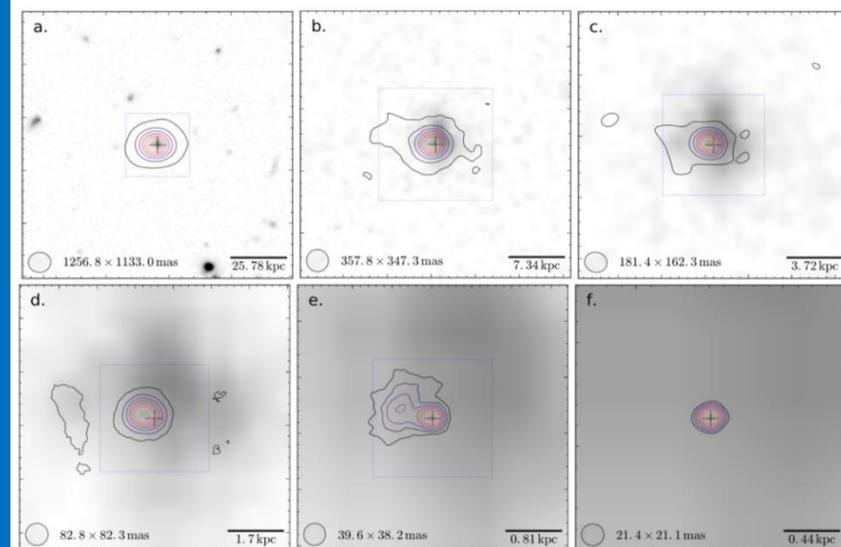
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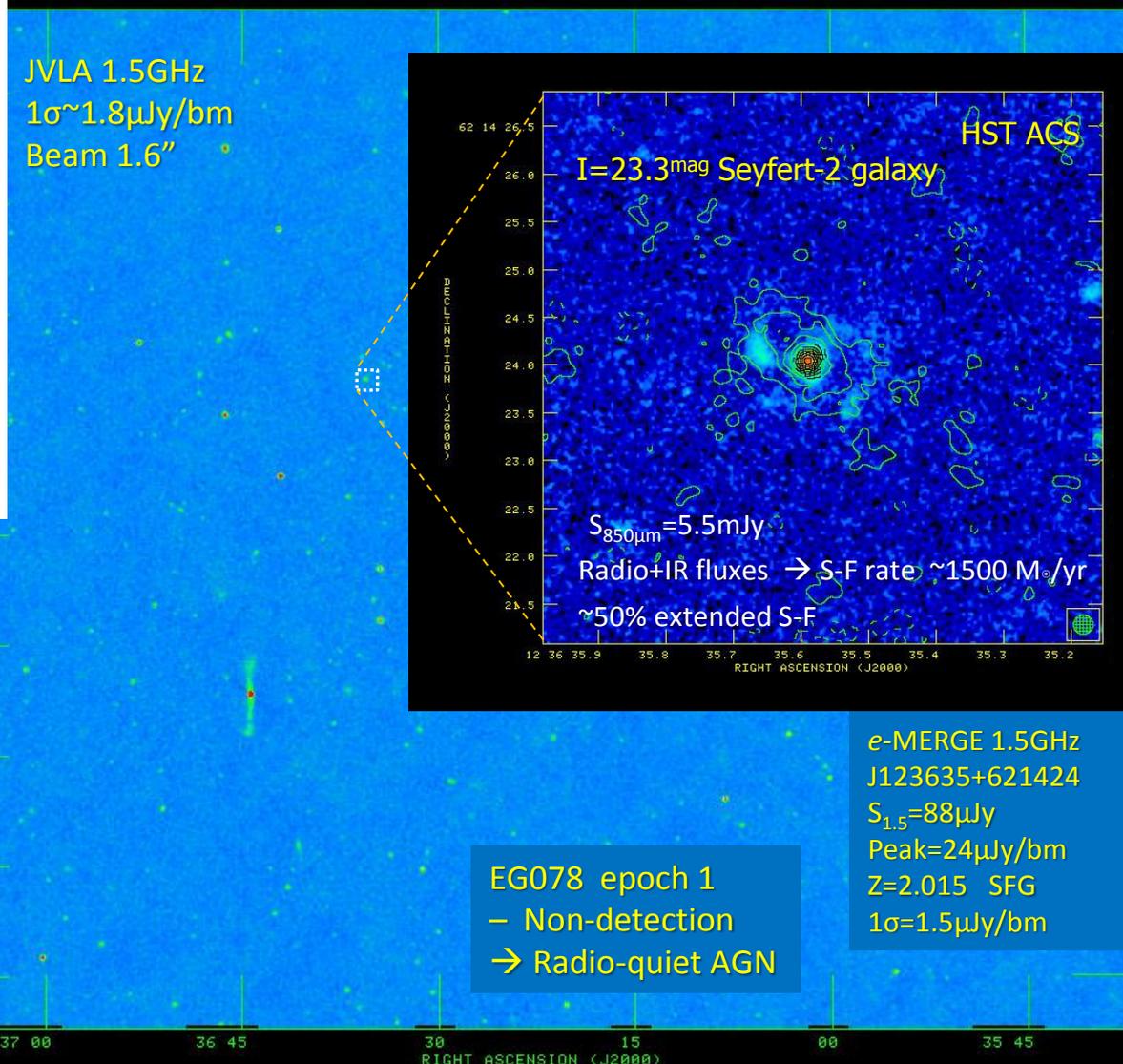
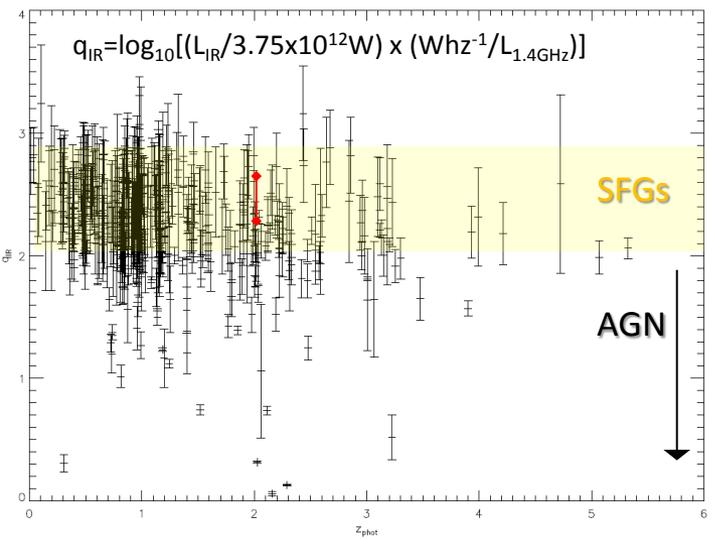
J123642+621331
e-MERLIN + EG078 epoch 1
Integrated imaging:
Resolution $\sim 1200 \rightarrow 21\text{mas}$
ID with faint red object
– Classified as a distant dusty starburst with embedded AGN (Waddington+ 1999)

Now identified as AGN-jet dominated structure

Greyscale:
HST near-IR (F125W)



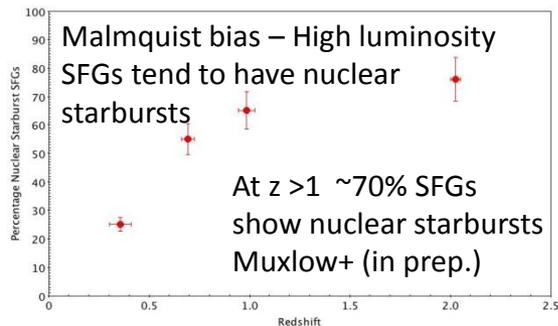
High Redshift Star-forming Galaxies & Radio-Quiet AGN Population



Radio structure looks possibly AGN-related, but no EG078 core detection & e-MERGE resolves central component. $Q_{IR} \rightarrow$ SFG

$\sim 85\%$ SFG with $q_{IR} > 2.05$

High Redshift Star-forming Galaxies & Radio-Quiet AGN Population



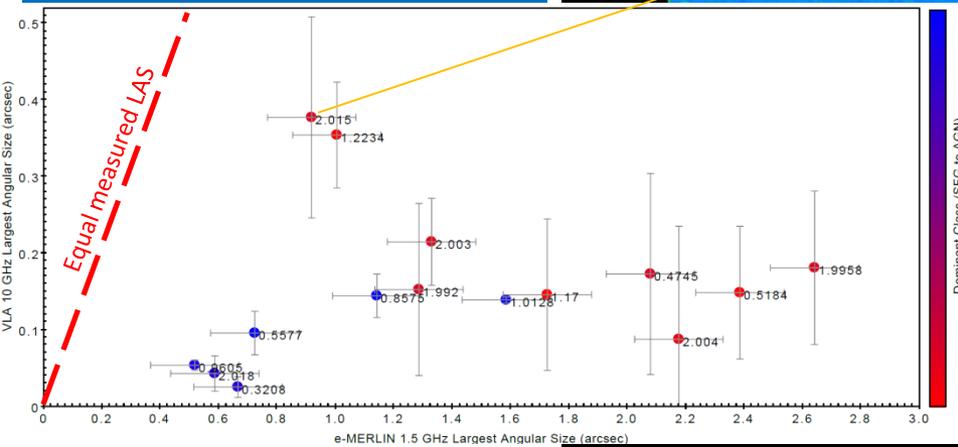
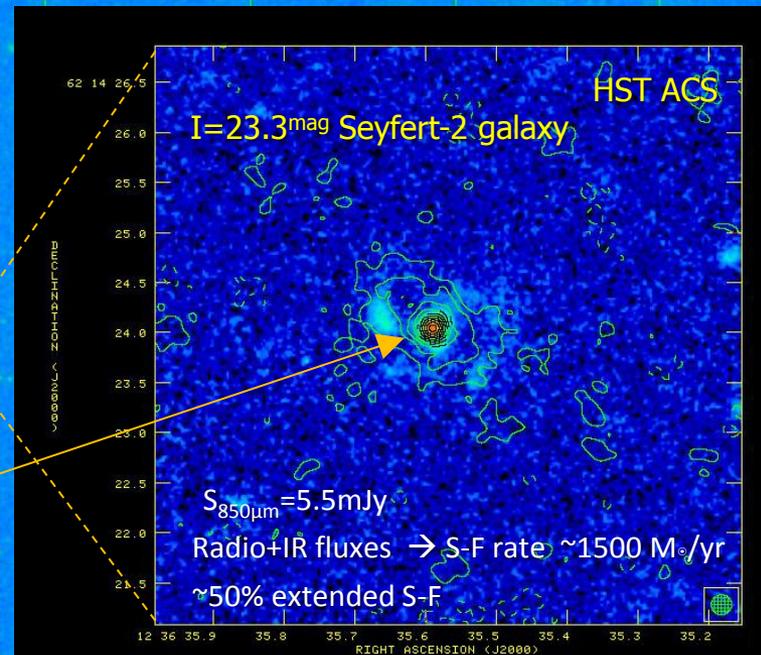
For 15 sources common to both e-MERGE and Murphy+ 2017:

- 10GHz median LAS~170mas – up to 10x smaller than at 1.5GHz
- Extended emission lost
- 10GHz selects flatter spectrum nuclear starbursts at high z

Murphy+ 2017

JVLA A+C-array
10GHz Beam 220mas
 $1\sigma = 572\text{nJy/bm}$
X-band fitted size
380x270mas
 $S_{10\text{GHz}} = 12\mu\text{Jy}$

– Detects only a nuclear starburst



Padovani+ (2014):
Radio-quiet (RQ) – radiative-mode AGN
Radio-loud (RL) – jet-mode AGN

Radio power of RQ AGN evolves $\sim \alpha(1+z)^{2.5}$ similar to star-forming galaxies, while the number density of RL AGN peaks at $z \sim 0.5$ and then declines at higher z

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RL AGN:

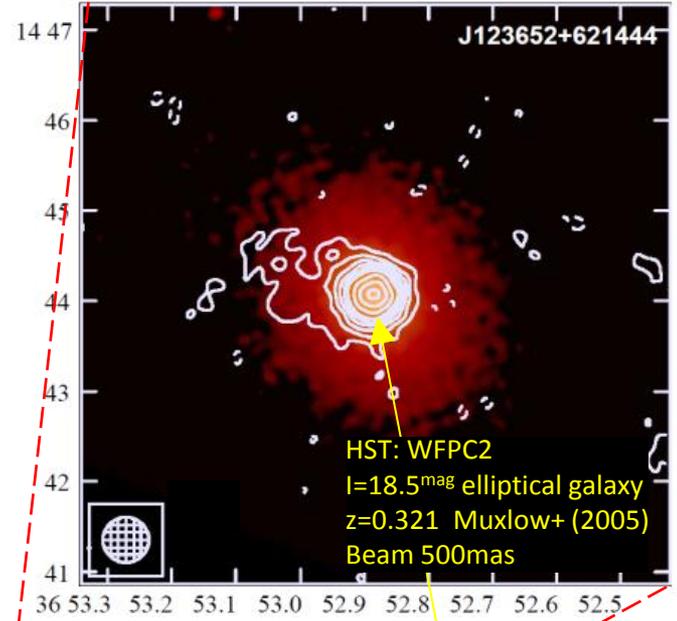
Most core-jet AGNs have projected sizes close to or smaller than that of the host galaxy – but a minority are much larger

Why?

What is the nature of these faint core-jets?

How do these differ from local low-luminosity core-jet systems?

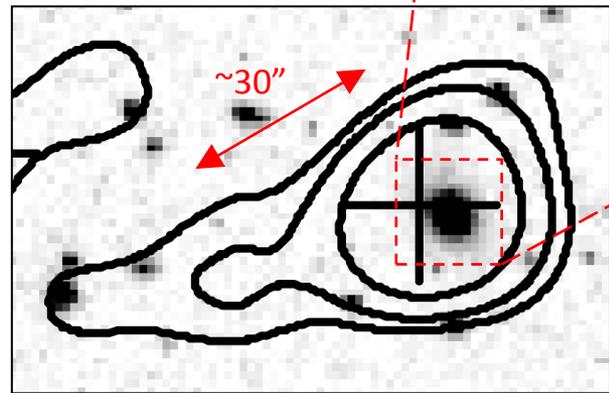
How are these related to SMBH growth through cosmic time?



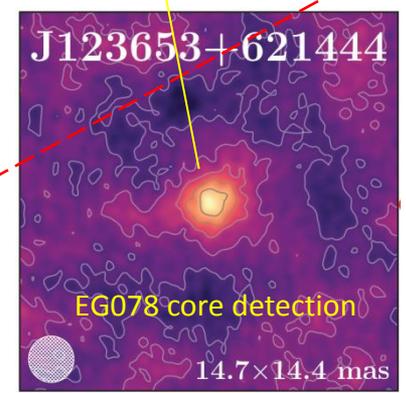
Required Imaging:

Integrated deep EVN + e-MERLIN + VLA imaging at 1.5GHz with resolutions on scales from 10 – 300mas – ~10''

→ Image the steep-spectrum jet emission and constrain its properties as it transitions from the core to the outer host galaxy and beyond....



WSRT 1.4GHz Garrett+ (2000) Beam 15''



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SFGs:

What is the nature of the nuclear starbursts – only just resolved by e-MERLIN at 1.5GHz & VLA at 10GHz – and resolved out by EVN at full angular resolution?

Are there differences between nuclear starbursts in conventional SFGs and those containing RQ AGN?

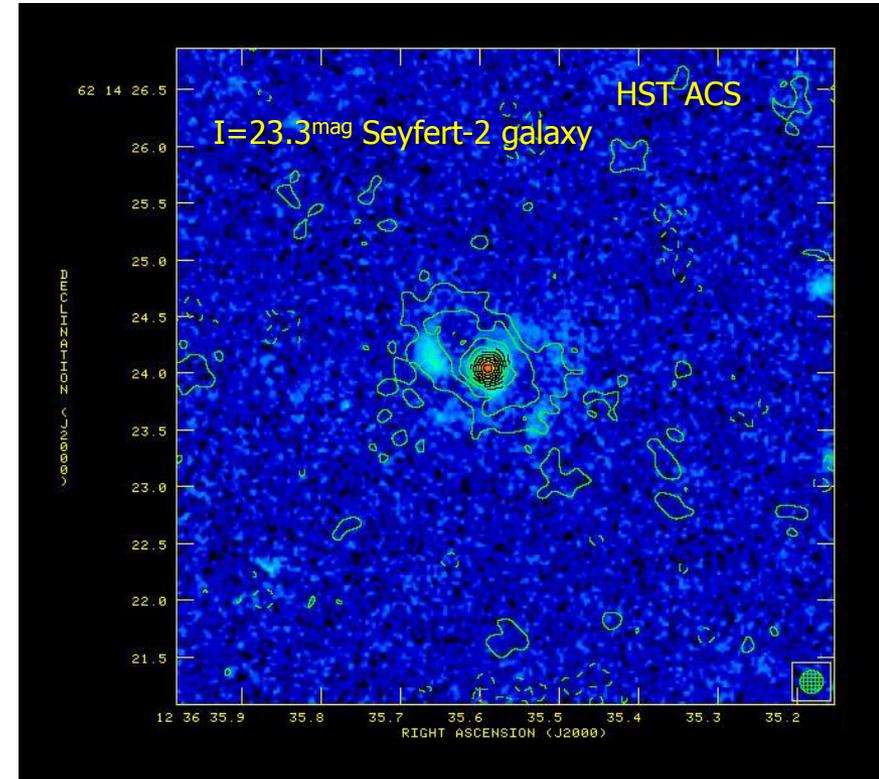
Do conventional nuclear starburst SFGs contain faint embedded AGN-jets?

What is the nature of any feedback from AGN activity in the SFG population?

Required Imaging:

Integrated deep EVN + e-MERLIN (+VLA) imaging at 1.5GHz with resolutions on scales from 5 – 200mas

→ Image the nuclear starbursts in detail and search for any AGN induced feedback in the heterogeneous SFG population



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Additional Goonhilly antenna for e-MERLIN together with AVN + EVN will extend high fidelity deep wide-field imaging to equatorial fields with extensive multi-band coverage and complimentary imaging from ALMA and the SKA

See also posters:

SS11 – Nowhere to Hide – Jack Radcliffe
963 – Galaxy Evolution – Alasdair Thomson
649 – e-MERGE DR-1 – Tom Muxlow

Also Required.....

Calibration pipelines
Standardised calibration
Beam models
Imaging pipelines
User support...

Concluding Thoughts...

Full integration of μJy -sensitivity wide-field EVN into e-MERLIN+.... required to:

→ Characterise the S-F processes & AGN activity at redshifts close to the peak of cosmic star-formation and investigate possible AGN feedback mechanisms in play

→ Investigate the faint AGN core-jet structures at redshifts close to the peak of SBMH growth. How do such systems differ from those seen in the nearby Universe?