The University of Manchester Jodrell Bank Observatory





Star-formation Across Cosmic Time: Initial Results from the e-MERGE Study of the µJy Radio Source Population

SPARCs VII – The Precursors Awaken

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The e-MERGE Survey (e-MERLIN+JVLA)

Tier 1: *Deep high resolution imaging of the μJy radio sources in GOODS-N*

EMU: 10" resolution over \sim 30k deg² -> \sim 70M galaxies e-MERGE: 200mas resolution over \sim 0.2 deg² -> \sim 5000 galaxies

~200mas – detailed investigation of SF activity / AGN feedback

L-Band imaging of 30' field (200mas) C-Band mosaic of the inner 12' field (50mas)

L-Band – Central 12' $1\sigma \sim 500$ nJy/bm Outer 30' annulus $1\sigma \sim 1\mu$ Jy/bm In full 30' field ~1500 AGN and ~3100 S-F galaxies complete to local ~ 6σ [2019]

Q3 2017 \rightarrow First consortium data and image release [DR-1]:

L-Band: JVLA 30' field, beam~2", 1σ~1.8µJy/bm ✓ + e-MERLIN(130hrs)+JVLA 12' field , beam ~200mas, 1σ~1.5µJy/bm*—Soon!!* C-Band: JVLA mosaic of 12', beam ~500mas, 1σ~3µJy/bm ✓ [+EVN L-Band12' field (72-hrs), beam ~5mas, 1σ~3µJy/bm] ✓ 30% → Detailed investigation of >500 SF galaxies and AGN in 12' field

Interim L-Band images from 12' field (90hrs e-MERLIN) 1σ ~2.5µJy/bm

Central 12 Arcminute Field

JVLA L-Band image of the central 9' of 62 17 GOODS-N . Full image to 30' 16 38 hrs, BW 1GHz $1\sigma \sim 1.8\mu$ Jy/bm 15

~600 detections in the inner 12' field to 5x local noise level. Complete to 9µJy

Few classical AGN double structures seen – confined to the mJy sources



Radio-Loud Classical AGN Systems

Radio-loud AGN: Nearly all are small core-jet structures

J123652+621444 MERLIN+VLA Flat spectrum core + jet Compact cores confirmed by deep VLBI imaging



Relative proportion of source types with 1.4GHz flux density

Star-forming Galaxies

Star-forming Galaxies: Extended radio emission across star-forming regionTypical example – J123708+621056 – steep-spectrum starburst ($S_{1.5} = 45 \mu$ Jy)Emission across central region of 10^{10} M_{\odot} dust-obscured irregular galaxy at z=0.422 $L_{1.4} = 3.8 \times 10^{22}$ W/Hz \rightarrow S-F rate 20 M_{\odot}/yr(0.1 - 100 M_{\odot} assuming Kroupa IMF)

~5x linear size of M82



Nuclear Activity within Star-forming Galaxies

SFGs with z>0.5:

Tend to contain centrally condensed nuclear starbursts + extended star-formation Many found in galaxies with AGN only visible in other wavebands

10¹¹M_☉ Seyfert-2 galaxy z=0.5186

Steep-spectrum (α <-0.56) starburst extended along galaxy major axis with nuclear radio emission (S_{1.5} = 76µJy).

 $L_{1.4}$ =1.7x10²³ W/Hz → S-F rate 88 M_☉/yr





Initial Results From Interim Images:

From Nick Wrigley's PhD Work

Sample of 248 detected sources within central 12' field from ~90 hrs of data. Assign probabilities of being AGN or SF from radio structures and spectral properties...



Machine-learning (SVM – Support Vector Machine)

26 AGN & 80 SFGs with spectroscopic redshifts

SFGs Radio Structures The proportion of SFGs with nuclear starbursts are seen to increase with redshift 10^{25} 100 90 $\rm WHz^{-}$ 80 Starburst SFGs 70 60 4GHz Radio Power 0^{24} Percentage Nuclear 50 40 30 20 10 10^{23} 0 0.5 1.0 1.5 2.0 At high redshifts the proportion Sensitivity Limit Starburst with nuclear starburst $\sim 70\%$. Nuclear SB 10^{22} 2 3

Malmquist bias since SFGs containing nuclear starbursts are more luminous systems – although some extended only SFGs are still found in high redshift systems

Redshift

Imaging SFG Radio Structures Strongly dependent on spectral properties....



Comparison of GOODS-N SFG radio structures seen by e-MERGE at 1.5GHz and the JVLA at 10GHz

e-MERLIN+JVLA L-Band

- shows nuclear starburst + fainter emission extending across face of Seyfert-2 galaxy



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Anna Cibinel (Sussex) – private communication – multiband star-formation mapping

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Matched Resolution Imaging of SFGs at 1.5 GHz and 10GHz... JVLA 10GHz v e-MERLIN 1.5GHz (Beam~200mas)

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

JVLA LAS at 10GHz are up to an order of magnitude smaller than e-MERGE at 1.5GHz (Median ~170mas)

- also significantly smaller than 3GHz sizes of 115 SMGs in COSMOS (median FWHM ~0.54") Miettinen+ 2017



to AGN)

Class (SFG







Some Concluding Thoughts...

- Most radio-loud AGN are simple core-jets.
- Classical extended starbursts dominate at z<0.5
- At higher redshifts star-formation in intense nuclear starbursts appears to be common

 but extended star-formation is also present
 but extended star-formation is also present
- Some nuclear starbursts contain AGN visible in other wavebands Are these young systems where the AGN activity has not yet quenched SF?
- Is the evolution of nuclear starburst SFGs and AGN related? Is there a common recent trigger?
- Need deep C-Band e-MERLIN+JVLA (50mas beam) + full depth L-Band EVN (5mas beam) to confirm the nature of these nuclear starbursts
- At higher redshifts, high-frequency imaging is insensitive to steep spectrum emission from extended regions of SF & may detect only nuclear starbursts – very deep images will be required to recover the extended structure!!
- Extended starburst regions may contain substantial SF
- \rightarrow Fuller analysis to follow from DR-1 release with better images on ~500 sources