Studying galaxy evolution through cosmic time via the μJy radio population: early results from eMERGE DR1

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At 1.4GHz, eMERLIN + VLA A-configuration provides baselines from 0.68km → 217km & a fully-filled uv-plane, sensitive to spatial scales from 40” → 0.18” with σ~1.2μJy/bm on inner 15’ (Lovell PB)
– Full FoV of 25m telescopes will be imaged as part of DR2
• eMERGE 6GHz data from VLA at 0.5” beam – Guidetti + (2017)

Wealth of public/ancillary data on GOODS-N including EVN (EG078 epoch 1 of 3) observations (Radcliffe+ 2018, in prep), VLA 10GHz (Murphy+, 2017), SCUBA-2 (Geach+, 2017), Herschel SPIRE (Elbaz+, 2011), HST CANDELS (Grogin+ 2011) +…

EG078 extends scale coverage to mas – See following talk…..
eMERGE DR1 – Comparison with JVLA angular resolution

EG078 detection of $z=1.2653$ $I=24^{\text{mag}}$, elliptical galaxy AGN core

280mas beam
$1\sigma = 1.2\mu\text{Jy/bm}$
CI=$3\sigma$ (PB-corrected)

Beam area ratio $\sim 30x$
Emerge DR1 – The evolving radio source population

820 sources within central field (5σ) – subset separated into AGN and SFGs via machine learning by Wrigley+ (in prep)

R-Q AGN are a complex & diverse population potentially containing AGN activity which has recently turned on and which may eventually quench the S-F

Simple Model:
- R-L AGN > mJy – classical double structures
- < mJy – small core-jet/core-extended structures
- SFGs – Extended emission + nuclear starbursts
- R-Q AGN – radio from S-F + AGN in other bands

Extended CDFS VLA Survey Padovani+ (2014)
**eMERGE DR1 – The evolving radio source population**

**R-L AGN:** Core-dominated with a mixture of one- & two-sided emission on galactic / sub-galactic scales (Marginally resolved by JVLA)

**SFG/ R-Q AGN:** Extended radio structures on galactic / sub-galactic scales – associated with star-formation (SF) processes. Luminous SFGs contain nuclear starbursts marginally resolved by e-MERLIN + extended SF emission. AGN activity seen primarily in other wavebands

Need EVN + e-MERLIN combination imaging to separate: Faint AGN-jets in SFGs & jet-induced SF in R-L AGN core-jets
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- 820 sources in DR1 region
- Many with useful 1.4-to-6GHz spectral index information
- A rather smaller fraction of which with 10GHz detections/limits
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  - *Herschel* PACS/SPIRE, SCUBA-2
  - 450/850µm, *Spitzer* MIPS
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Much of this pre-compiled by 3D-HST (Momcheva+ 2015)
- A ready-made optical/IR catalogue for eMERGE?
The eMERLIN Galaxy Evolution Survey (eMERGE) - DR1

3D-HST: counterparts to 612/820 radio sources in DR1 region

Missing sources due to multiband mismatch in area + 3D-HST near-IR selection criterion

Median redshift $<Z> \sim 1.1$, but expect this to rise a little once SED fits to optically-faint radio sources are available

5σ sensitivity limit allows detection of SFR~250 $M_\odot$/yr starbursts at $z \sim 3$
eMERSE DR1 – deblended *Herschel SPIRE*

- eMERLIN resolution ~0.2”.
- *Herschel SPIRE* resolution ~18” at 250μm
  ~35” at 500μm

On average, density of radio sources > density of SPIRE beams (i.e. confusion-limited), so galaxies blend together in far-IR

To estimate SPIRE flux densities for radio sources, need to model far-IR emission (i.e. deblend) using a prior catalogue (see also Thomson+ 2017)

(Thomson+, *in prep*)
Chop each SPIRE 250/350/500μm image into 1’x1’ tiles
Prior catalogue of 24µm and VLA 1.4GHz detections recovers ~90% of SPIRE flux.

Chop each SPIRE 250/350/500µm image into 1’x1’ tiles.

Add delta functions at prior positions & vary fluxes convolved with appropriate psfs until residual image is minimised – Residual image contains faint sources...

Faint flux in residual maps from sources not in prior catalogue – can stack to derive typical SFG properties (e.g. Thomson+, 2017)
Selected far-IR SEDs from deblended Herschel SPIRE photometry (Thomson+, in prep)

Dust temperatures in the range 10 - 100k
eMERGE DR1 – the far-IR/radio correlation

\[ q_{IR} = \log \left[ \frac{L_{IR}}{3.75 \times 10^{12} W} \times \frac{W \text{ Hz}^{-1}}{L_{1.4 \text{GHz}}} \right] \]

Locus of *Herschel* selected SFGs (Ivison+ 2010)

Radio excess sources (candidate AGN)

Majority of sources have radio emission compatible with SFGs

Far-IR/radio correlation q parameter – Thomson+, in prep

\( L_{IR} \) from integrating the deblended FIR SEDs

FIR non-detection upper limits not shown here – almost certainly AGN
eMERGE DR1 – molecular gas in z~2 SMGs

- False colour: SUBARU U/I/Z
- Yellow contours: SCUBA-2 850μm
- Green contours: eMERGE 1.4GHz
eMERGE DR1 – molecular gas in z~2 SCUBA-2 SMGs

Greyscale + red contours: VLA Ka-band CO(1-0) (Thomson/Ivison+ in prep) → Molecular gas
→ One SMG and one SMG-SMG pair (~20kpc separation)
→ Giant molecular gas reservoirs: 2-3x10^{10}M_☉, SFR=500-800M_☉yr^{-1}, τ_{depletion} ~50Myr
→ 1.4GHz sizes ~0.8-1.0” (6-8kpc), cf typical 2-3kpc dust continuum sizes from ALMA SMG studies (Simpson+ 2015)
→ SF condensations within molecular clouds with compact nuclear starbursts and extended SF
Conclusions/future work

- **eMERGE** combines resolving power of e-MERLIN and sensitivity of VLA to provide deep (~1.2 μJy/beam) imaging at 0.28” resolution over 15’ in GOODS-N at 1.4GHz
- **eMERGE DR1** data products released to consortium members **Q4 2018**
- First papers expected ~end 2018 – survey description paper (Muxlow et al.), the far-IR/radio correlation (Thomson et al.), EVN observations of GOODS-N (Radcliffe et al.), the radio morphologies of SCUBA-2 SMGs (Smail et al.), the resolved Schmidt-Kennicutt law in z~2 SMGs (Thomson/Ivison et al.), ML-classification of AGN/starbursts (Wrigley et al.)
- Existing optical/near-IR multiwavelength catalogue (3D-HST) lacks counterparts to ~20% of >5σ 1.4GHz sources in inner 15’ – effort underway to “fill in the blanks” via source-extraction on publicly available maps (Tracy Garratt MScR project)
- DR2 will image full 25m primary beam using ~4x as much uv data (≥10TB) and 9x as many pixels (~3.6Gpixels) as DR1. Aim to process/image with as little *a priori* averaging as possible – eMERLIN CASA pipeline **essential** (Moldon et al. *in prep*)
- **EG078 + e-MERLIN** uv-combination imaging planned to investigate AGN feedback and faint embedded AGN-jets in SFGs, to image in detail the nuclear starbursts in SFGs, and characterise the nature of the faint R-L AGN systems

TO BE CONTINUED...