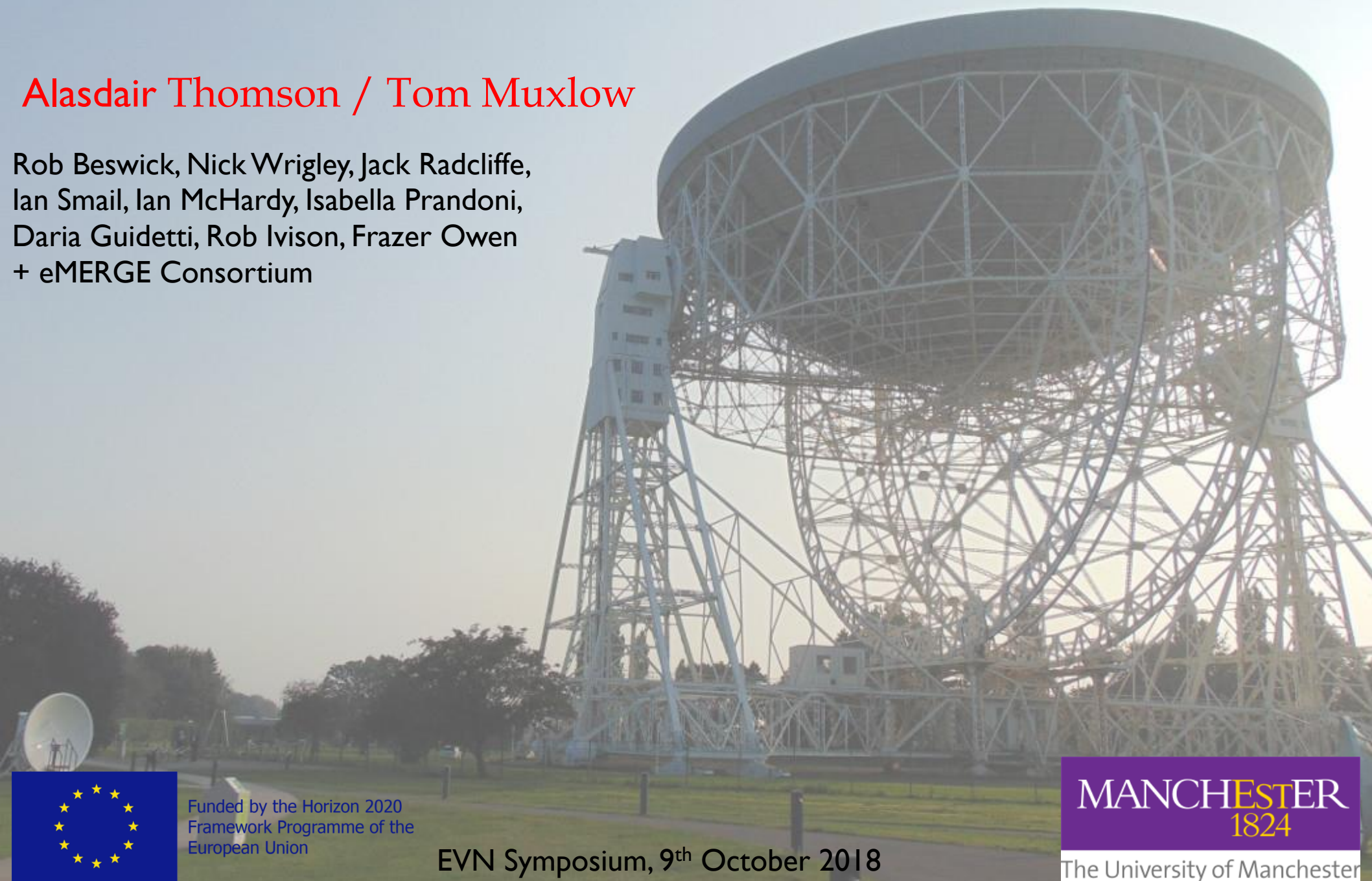


# Studying galaxy evolution through cosmic time via the $\mu\text{Jy}$ radio population: early results from eMERGE DR1

Alasdair Thomson / Tom Muxlow

Rob Beswick, Nick Wrigley, Jack Radcliffe,  
Ian Smail, Ian McHardy, Isabella Prandoni,  
Daria Guidetti, Rob Ivison, Frazer Owen  
+ eMERGE Consortium



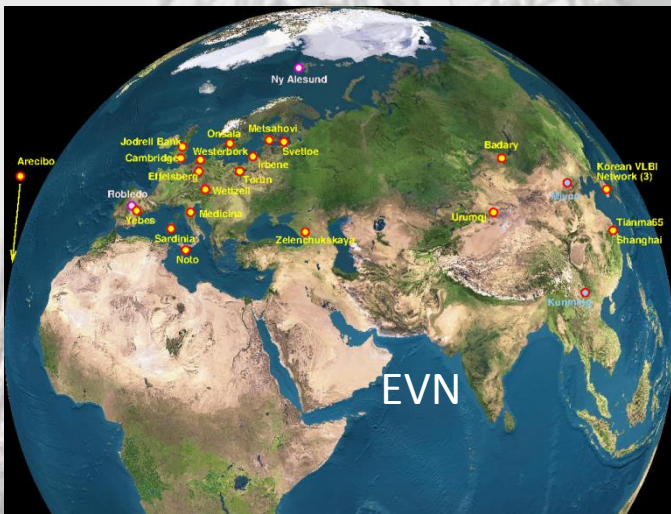
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European Union

EVN Symposium, 9<sup>th</sup> October 2018

MANCHESTER  
1824

The University of Manchester

# The eMERLIN Galaxy Evolution Survey (eMERGE) - DR1

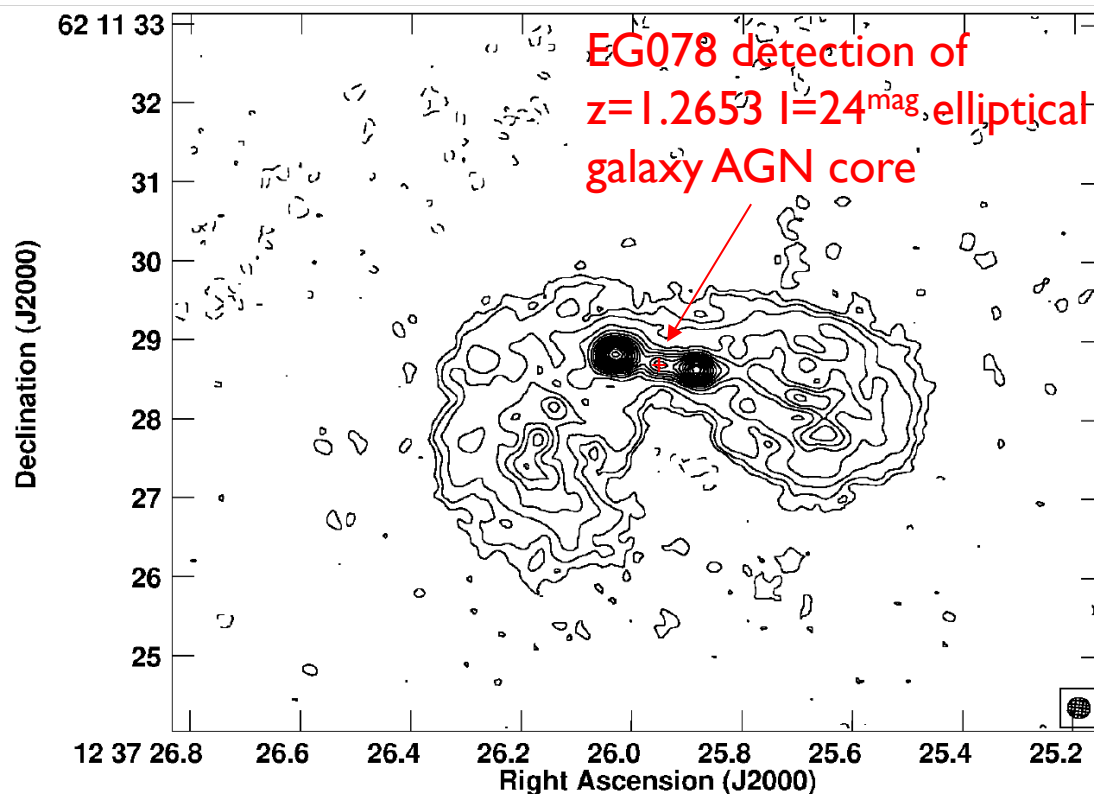
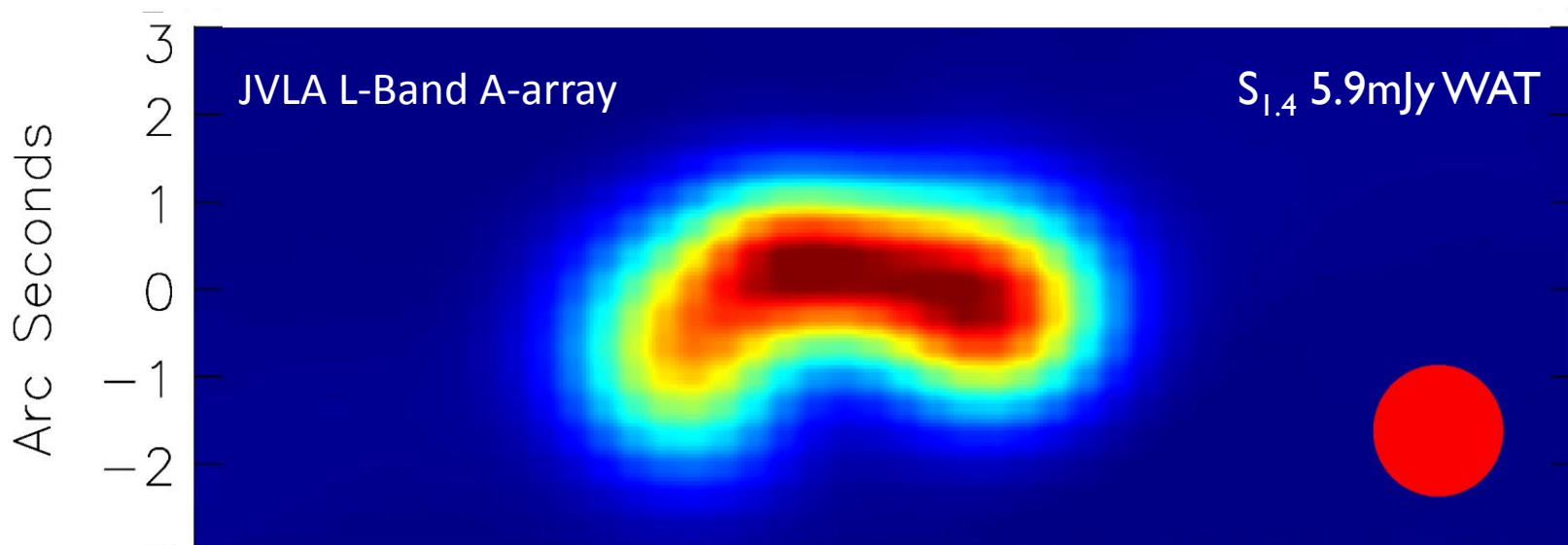


- At 1.4GHz, eMERLIN + VLA A-configuration provides baselines from 0.68km  $\rightarrow$  217km & a fully-filled  $uv$ -plane, sensitive to spatial scales from 40''  $\rightarrow$  0.18'' with  $\sigma \sim 1.2 \mu\text{Jy/bm}$  on inner 15' (Lovell PB)
- Full FoV of 25m telescopes will be imaged as 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 JVL A angular resolution



DR1 eMERGE  $uv$ -comb image (25% of e-M data)

20,000x20,000 pixels image 1.6M cleans

Bespoke suite of images

280mas beam

$1\sigma = 1.2\mu\text{Jy/bm}$

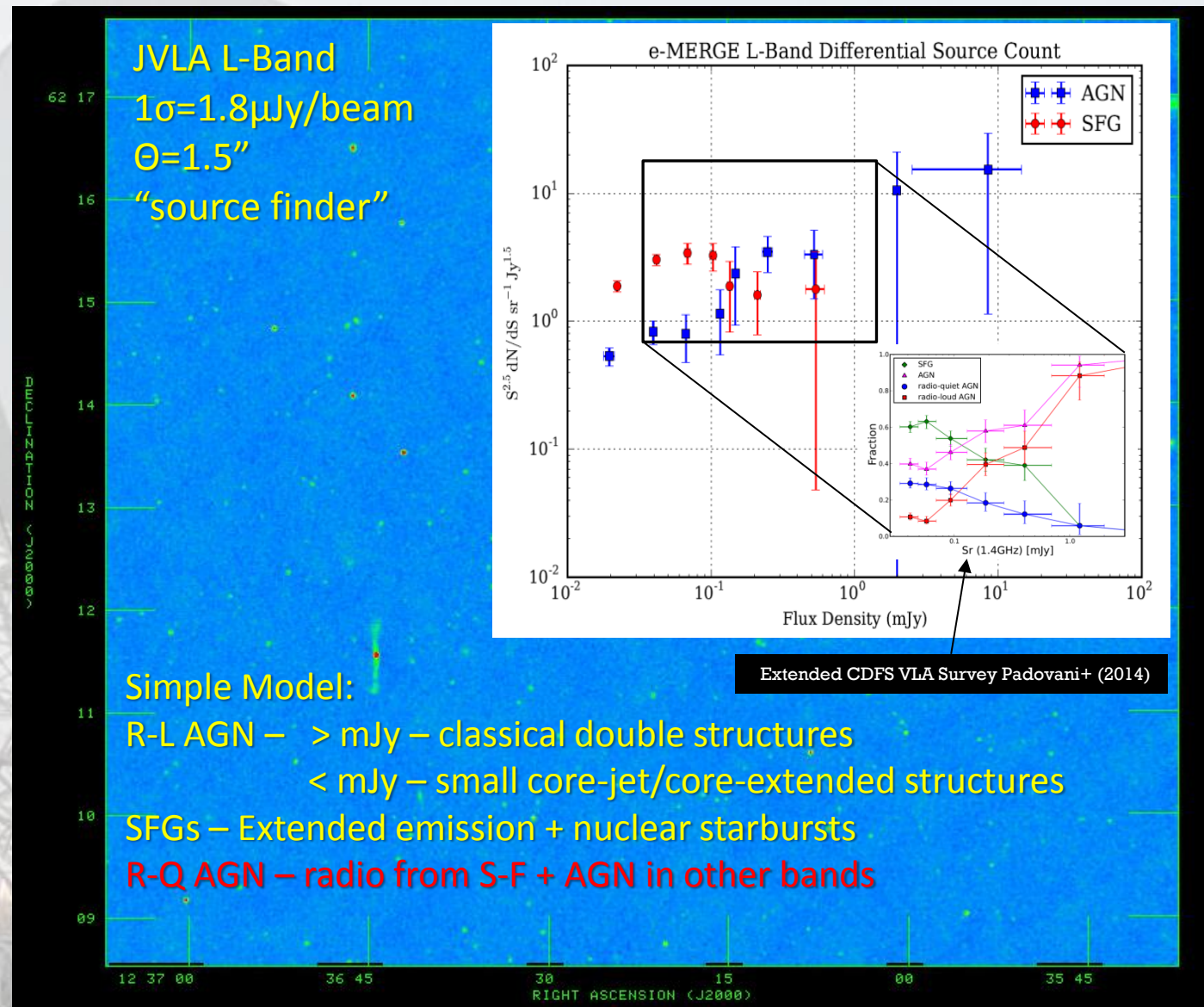
$\text{CI}=3\sigma$  (PB-corrected)

Beam area ratio  $\sim 30\times$

# eMERGE DR1 – The evolving radio source population

820 sources within central field ( $5\sigma$ )  
– 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

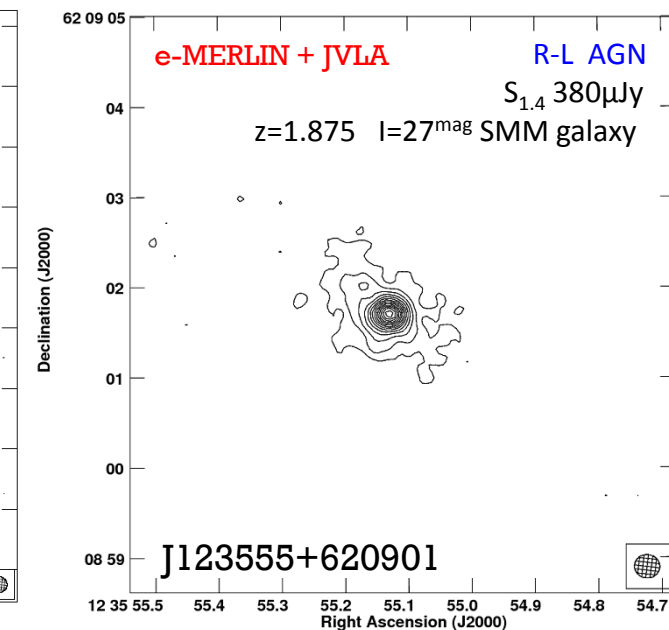
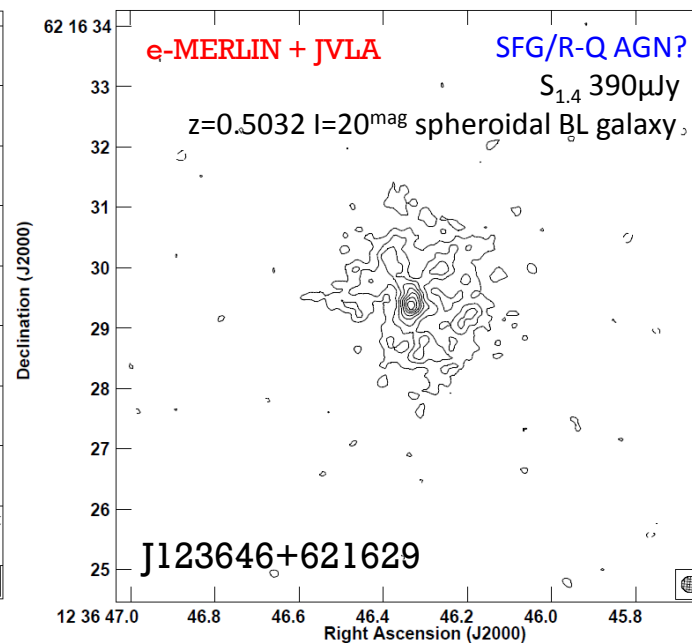
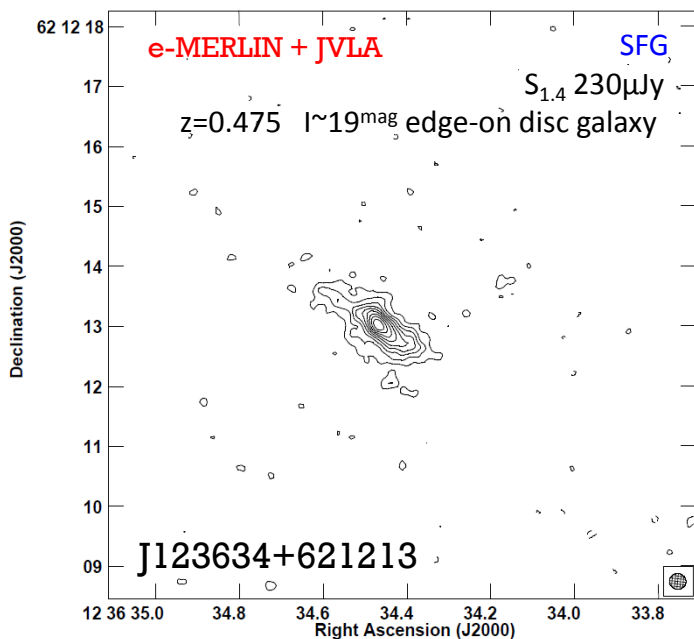
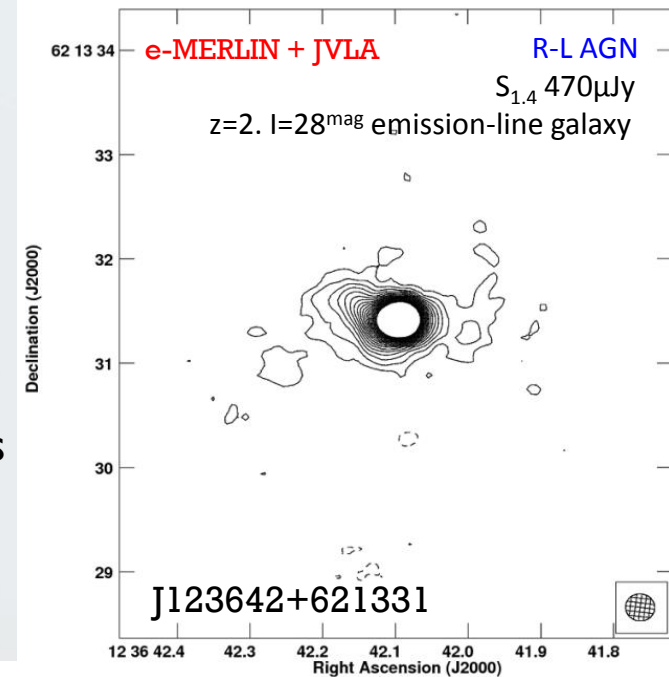


# eMERGE DR1 – The evolving radio source population

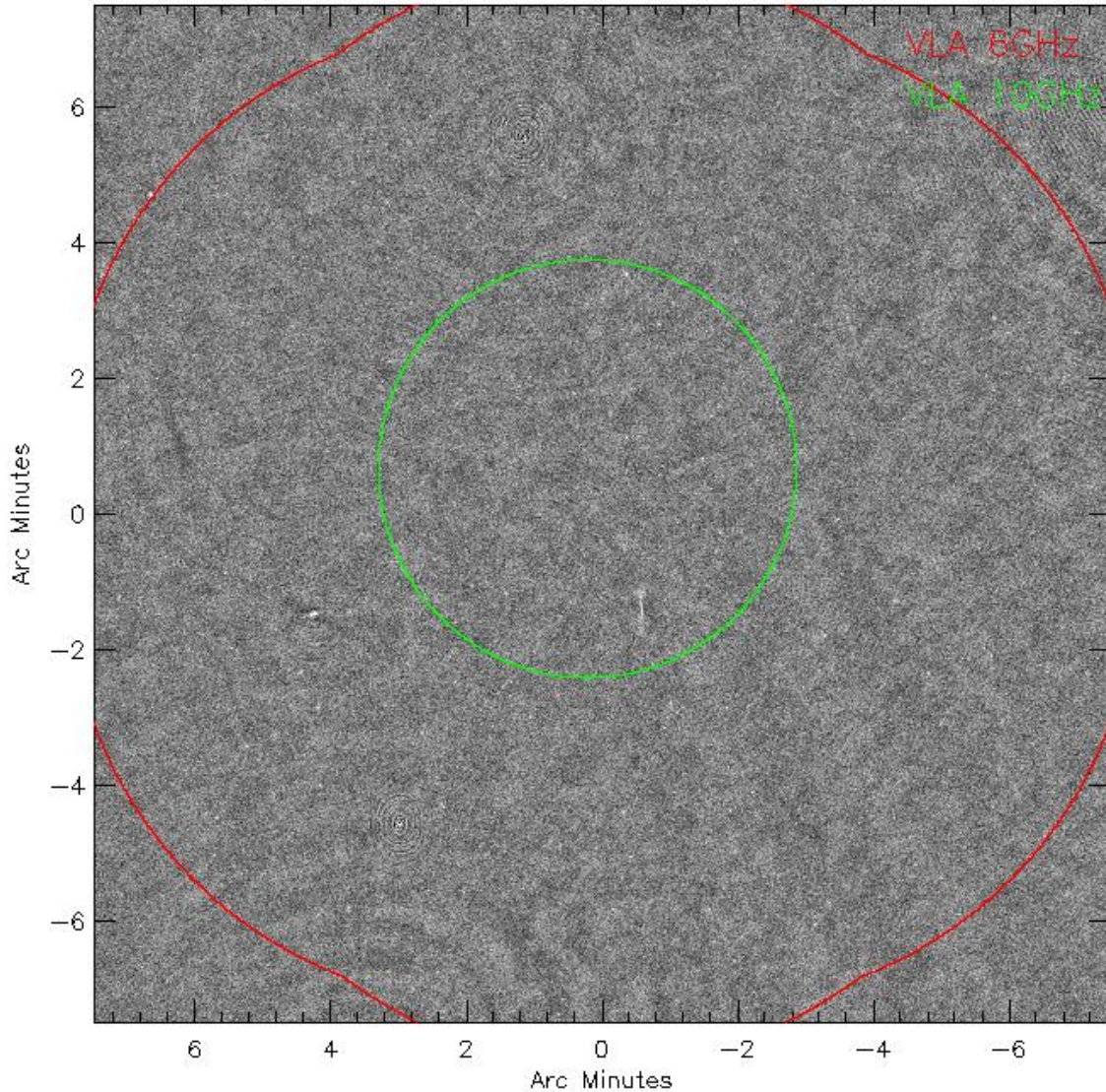
**R-L AGN:** Core-dominated with a mixture of one- & two-sided emission on galactic / sub-galactic scales (Marginally resolved by JVLA)

**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



# The eMERLIN Galaxy Evolution Survey (eMERGE) - DR1

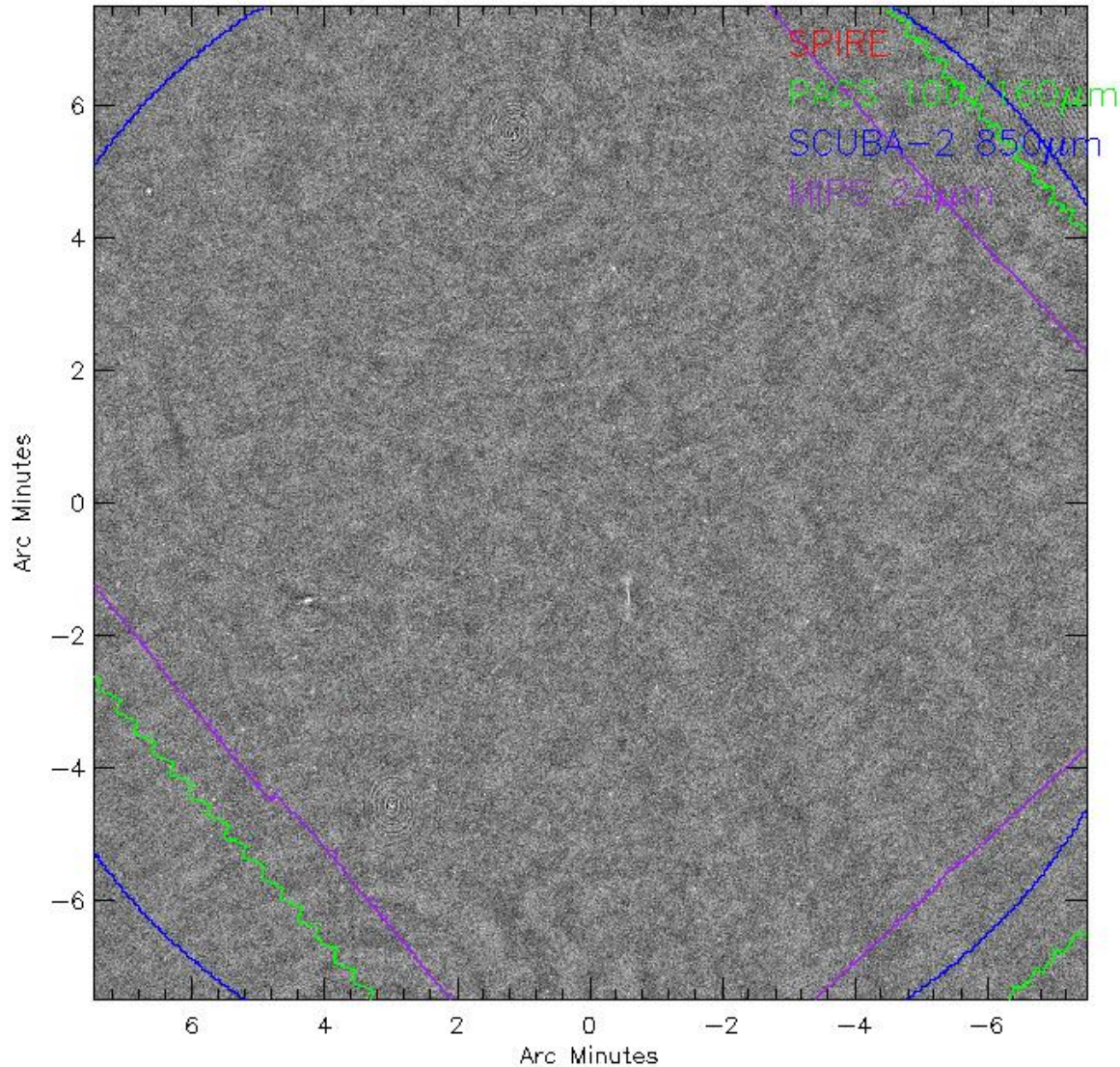


820 sources in DR1 region

Many with useful 1.4-to-6GHz  
spectral index information

A rather smaller fraction of  
which with 10GHz detections/limits

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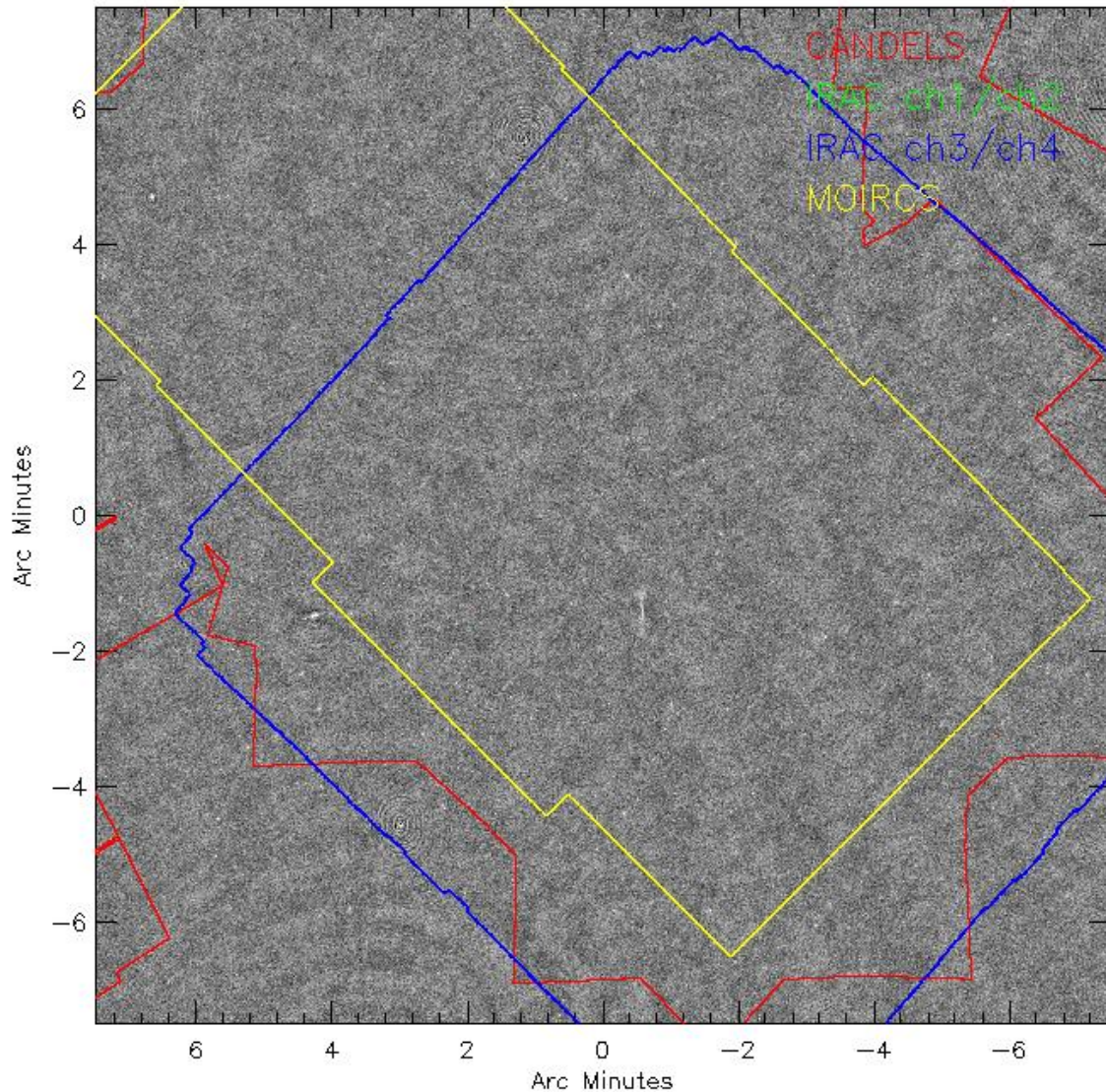
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**Sub-mm, (F)IR, Optical cover**

*Herschel PACS/SPIRE, SCUBA-2  
450/850 $\mu$ m, Spitzer MIPS*

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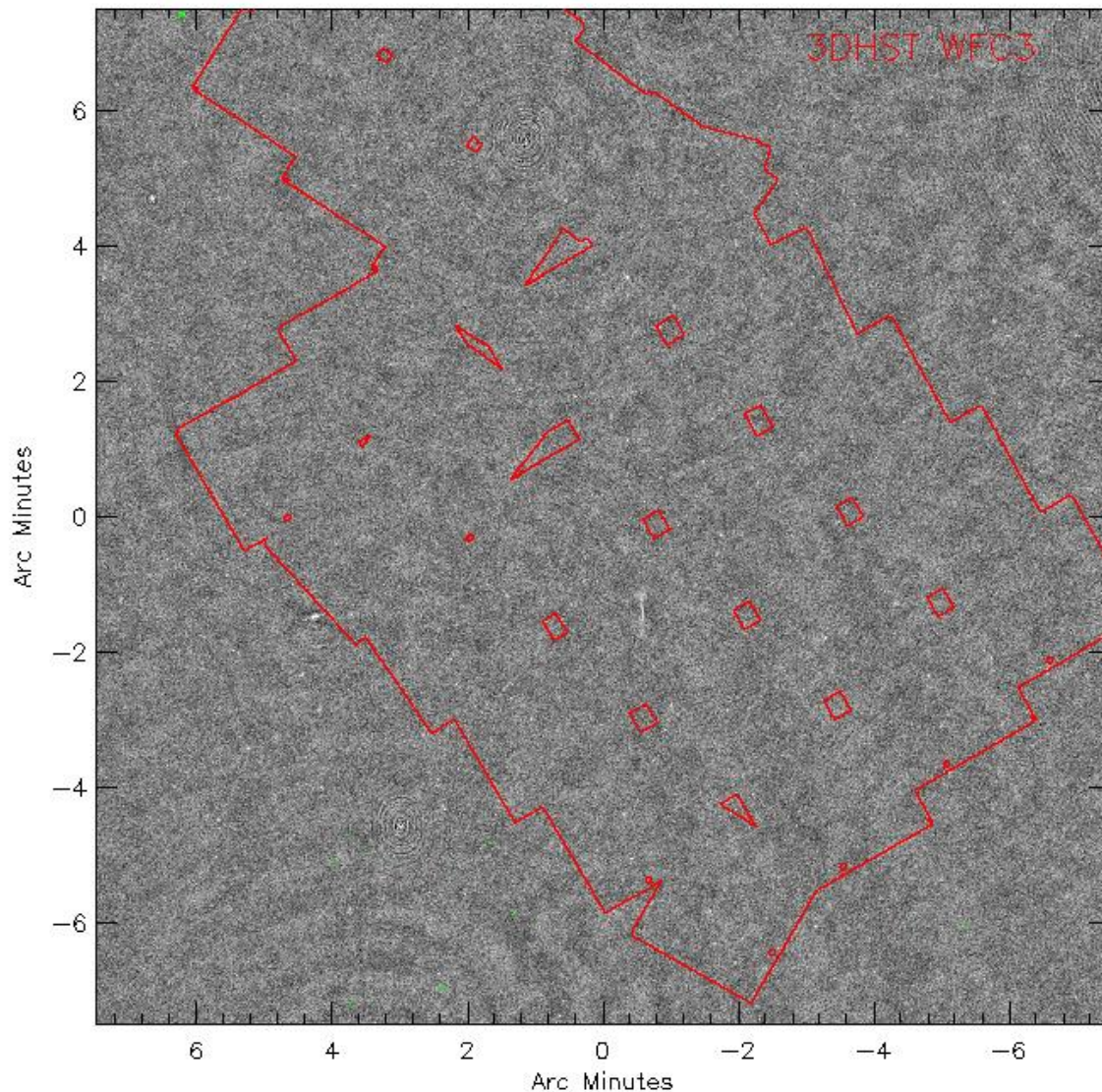
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*Herschel* PACS/SPIRE, SCUBA-2  
450/850 $\mu$ m, *Spitzer* MIPS

Optical/near-IR (*HST*/*Subaru*)  
+ mid-IR (IRAC)



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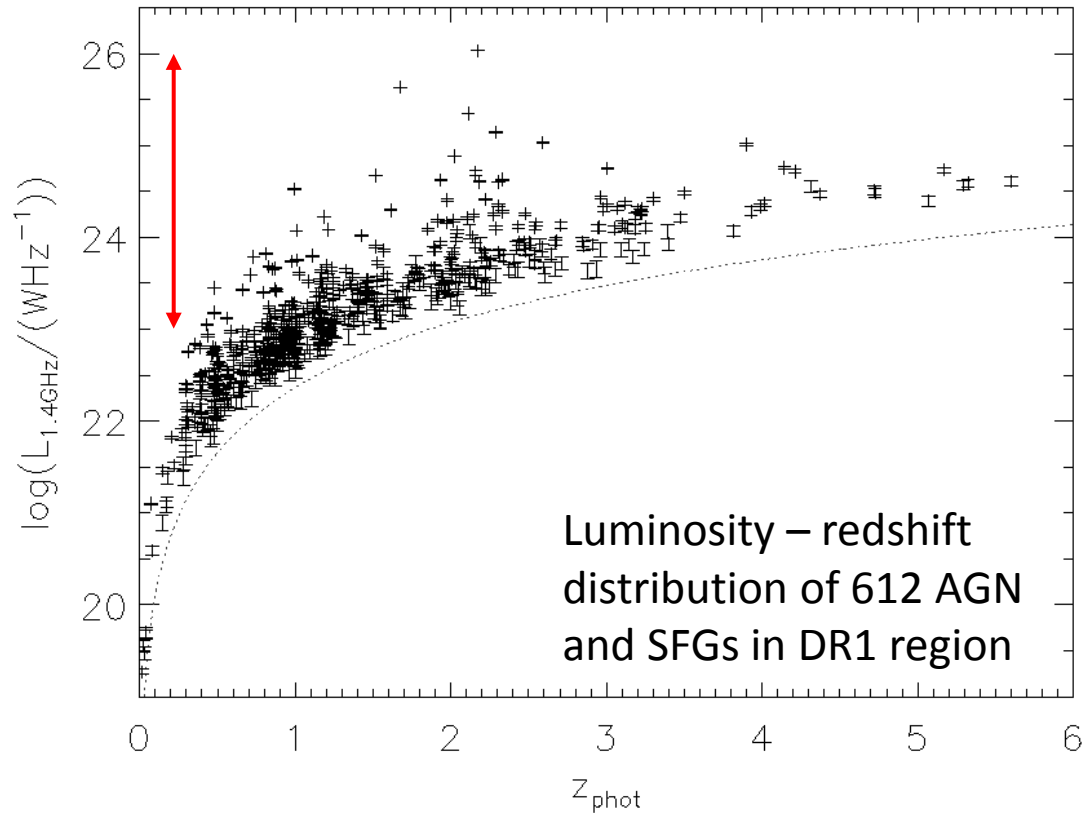
Optical/near-IR (*HST*/Subaru)  
+ mid-IR (IRAC)

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

## Luminosity range of EG078 R-L AGNs



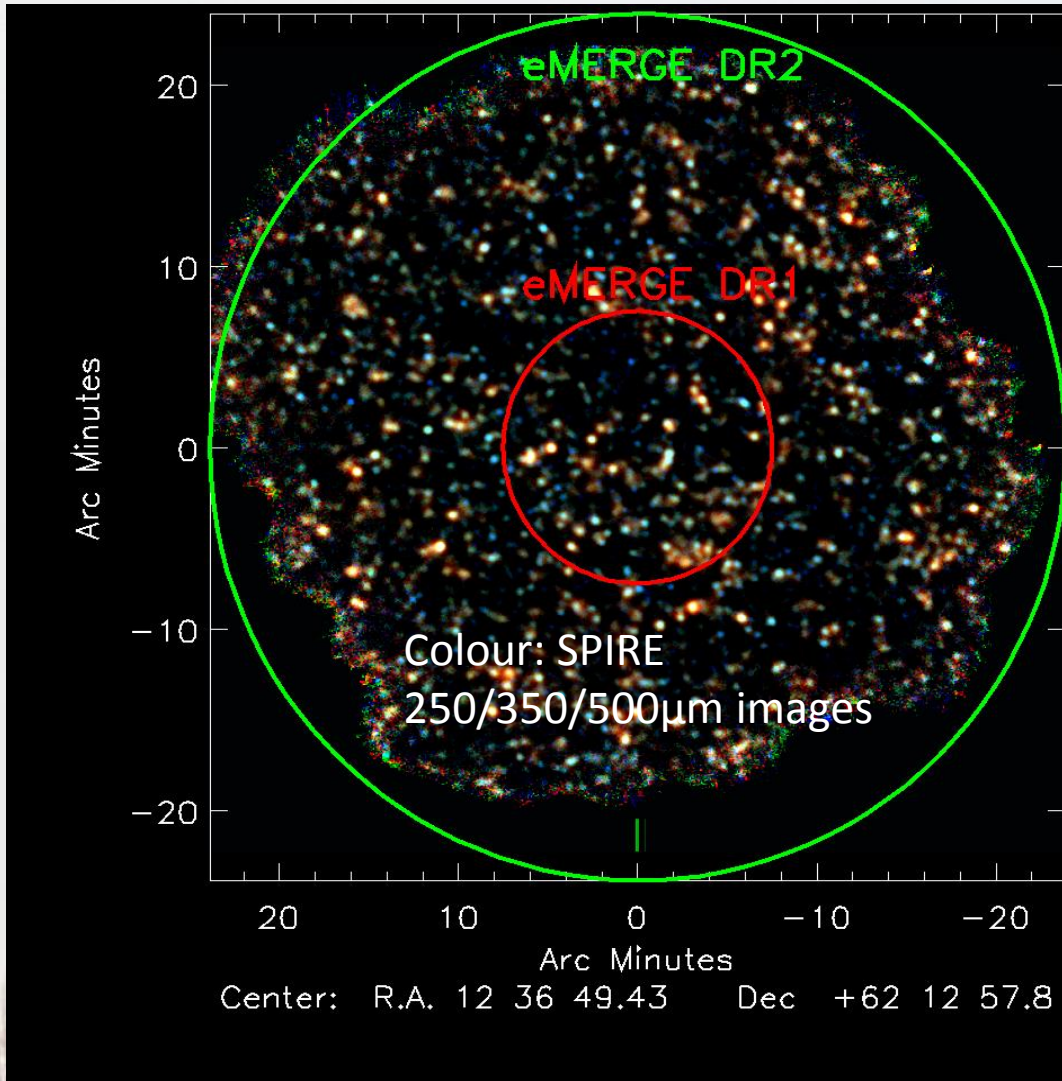
3D-HST: counterparts to 612/820 radio sources in DR1 region

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

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

$5\sigma$  sensitivity limit allows detection of  $SFR \sim 250 M_{\odot}/yr$  starbursts at  $z \sim 3$

# eMERGE DR1 – deblended *Herschel* SPIRE



eMERLIN resolution  $\sim 0.2''$ .

*Herschel* SPIRE resolution  $\sim 18''$  at 250 $\mu$ m

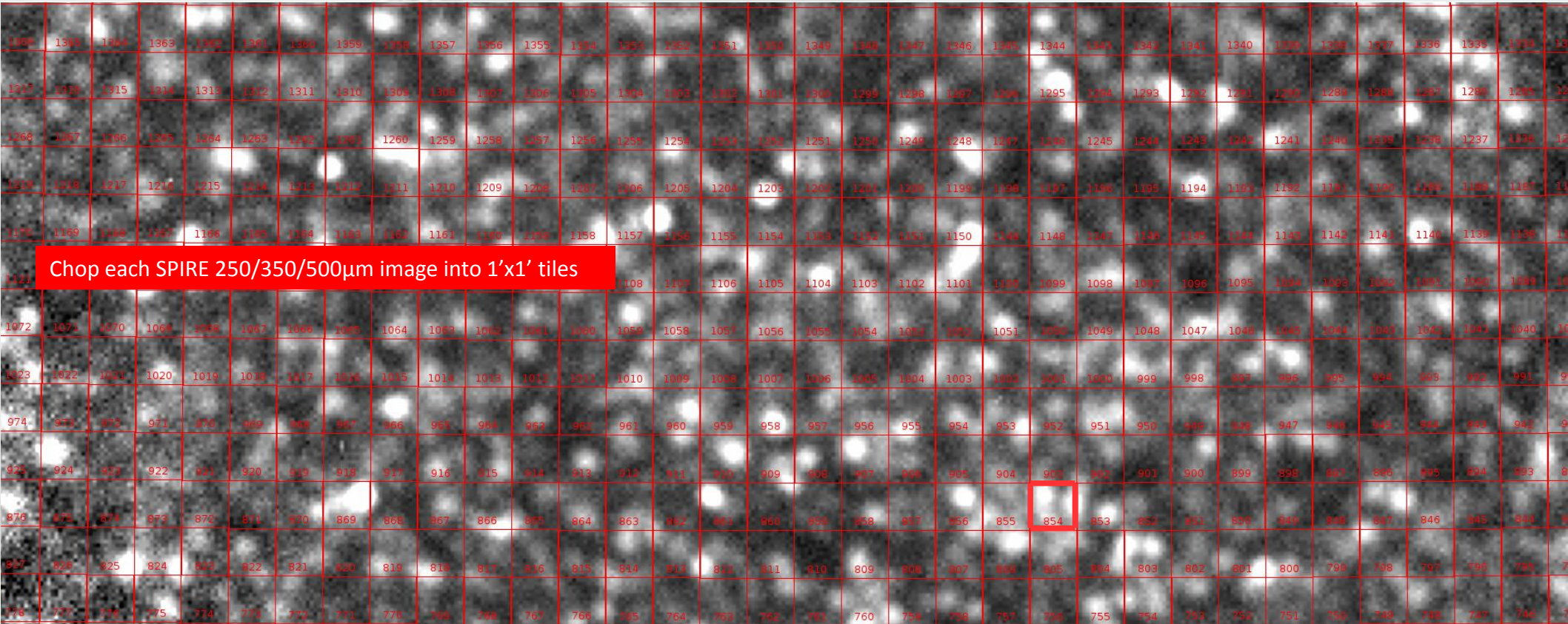
$\sim 35''$  at 500 $\mu$ m

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)

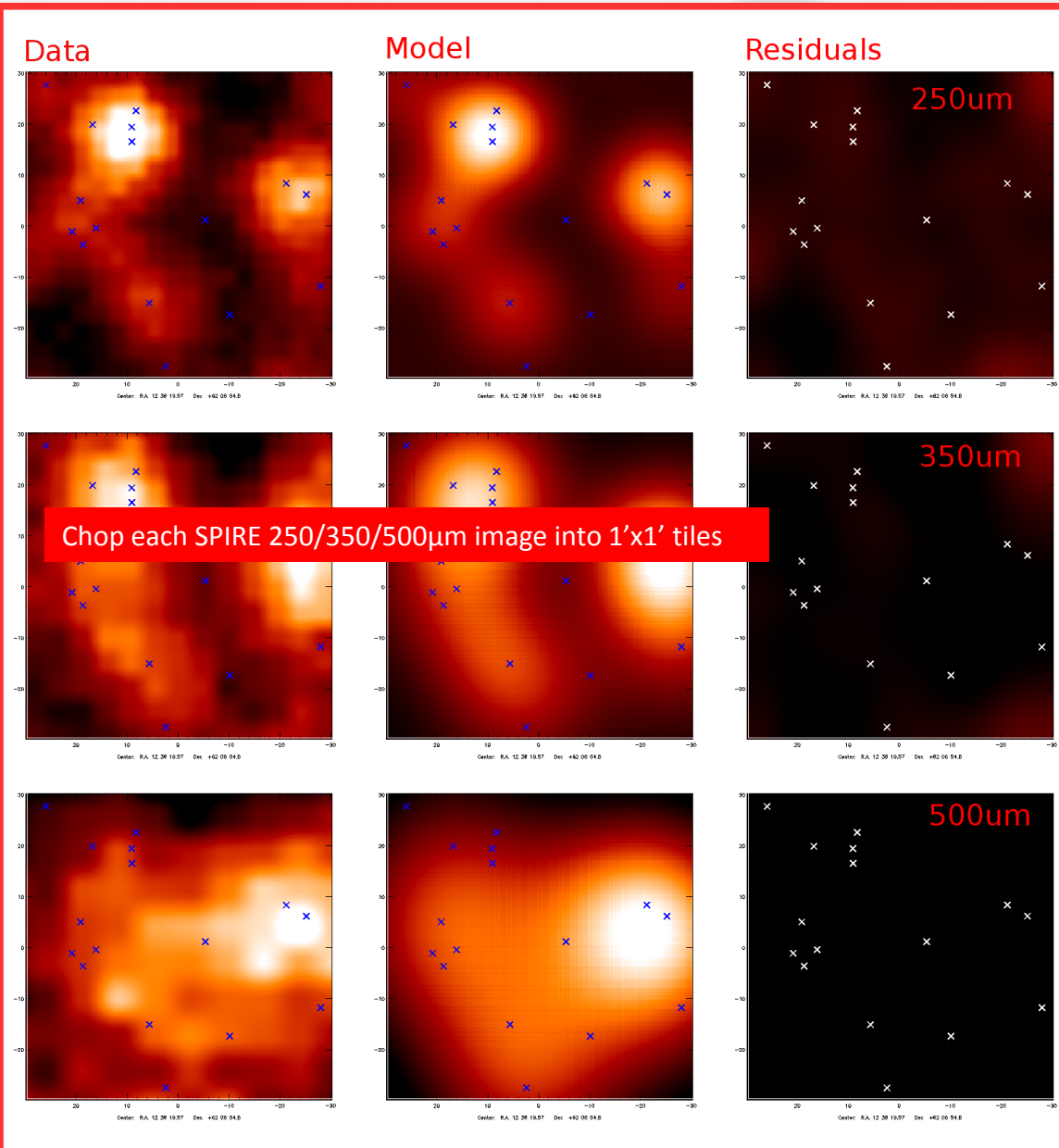
(Thomson+, *in prep*)

# eMERGE DR1 – deblended *Herschel* SPIRE

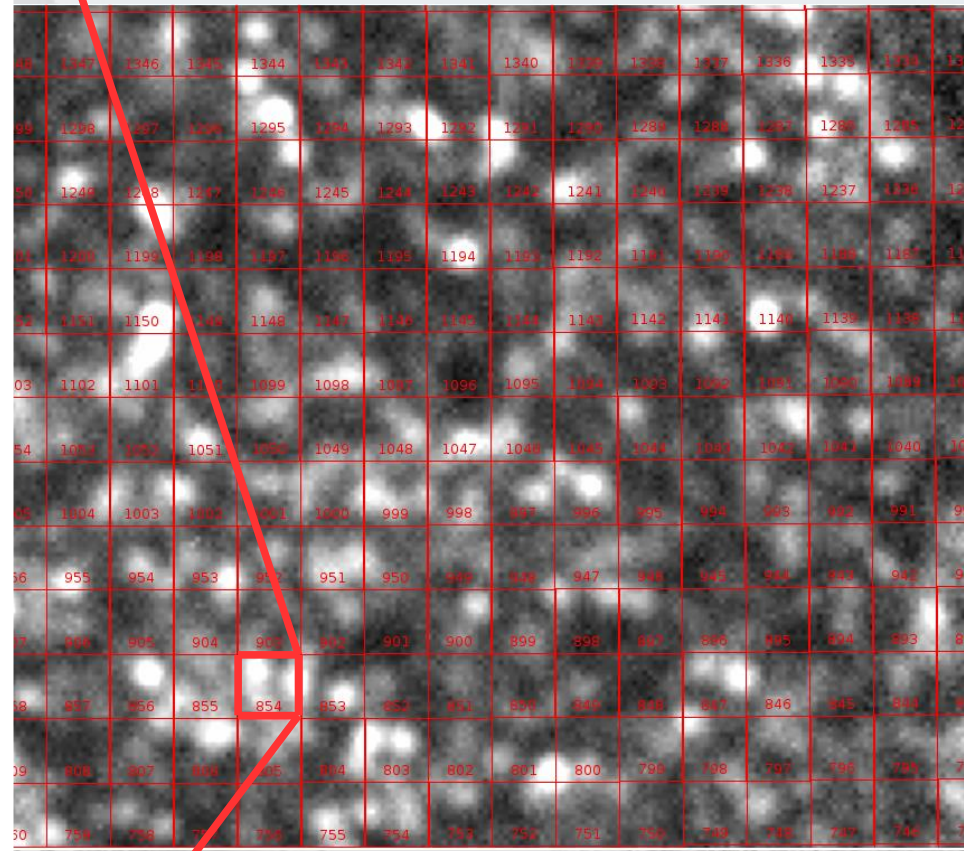


# eMERGE DR1 – deblended *Herschel* SPIRE

Prior catalogue of 24 $\mu$ m and VLA 1.4GHz detections recovers ~90% of SPIRE flux.



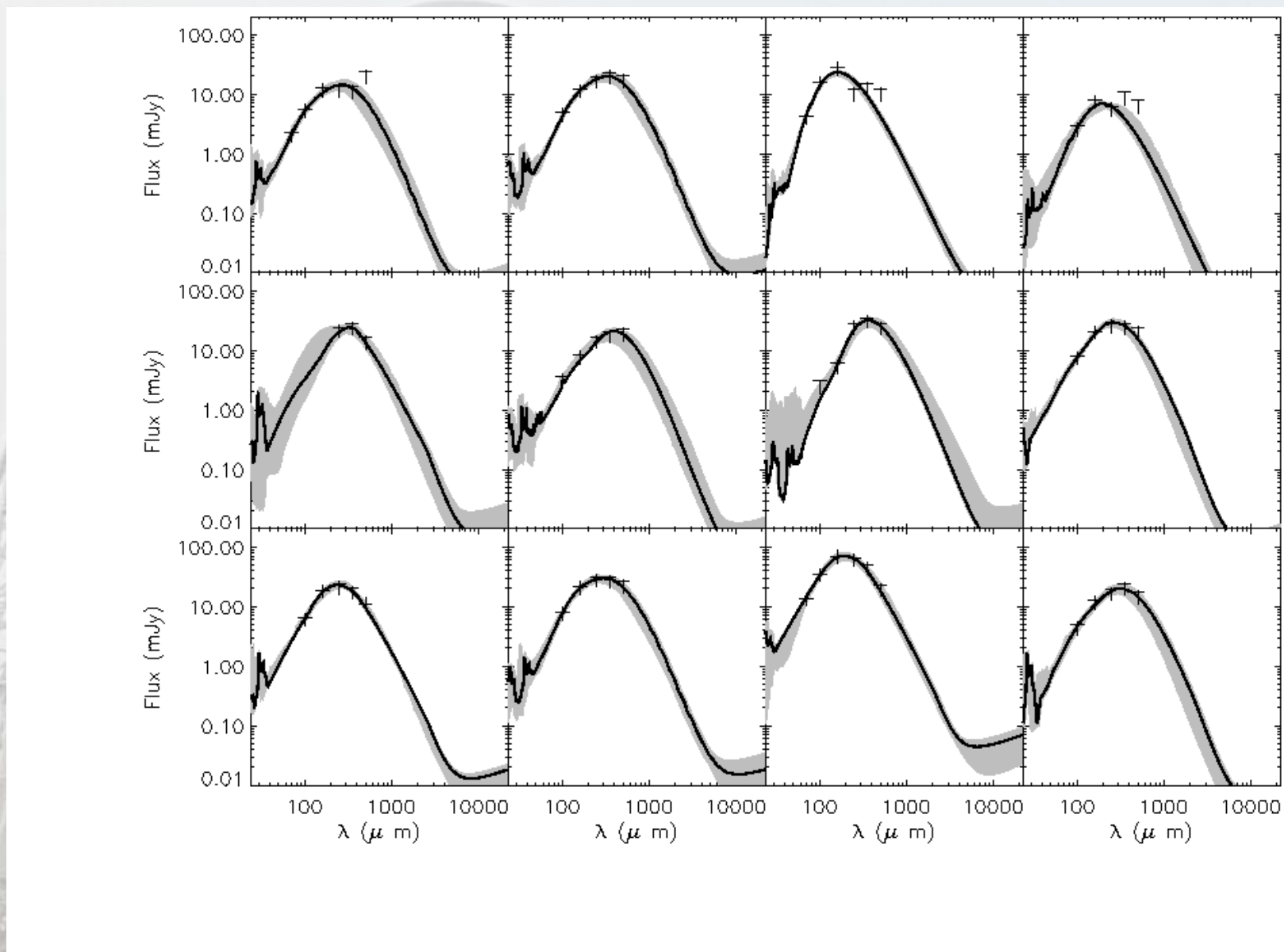
Chop each SPIRE 250/350/500 $\mu$ m image into 1'x1' tiles



Faint flux in residual maps from sources not in prior catalogue – can stack to derive typical SFG properties (e.g. Thomson+, 2017)

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

# eMERGE DR1 – far-IR SEDs of faint radio source population



Selected far-IR SEDs from deblended *Herschel* SPIRE photometry (Thomson<sup>+</sup>, in prep)

→ Dust temperatures in the range 10 -100k

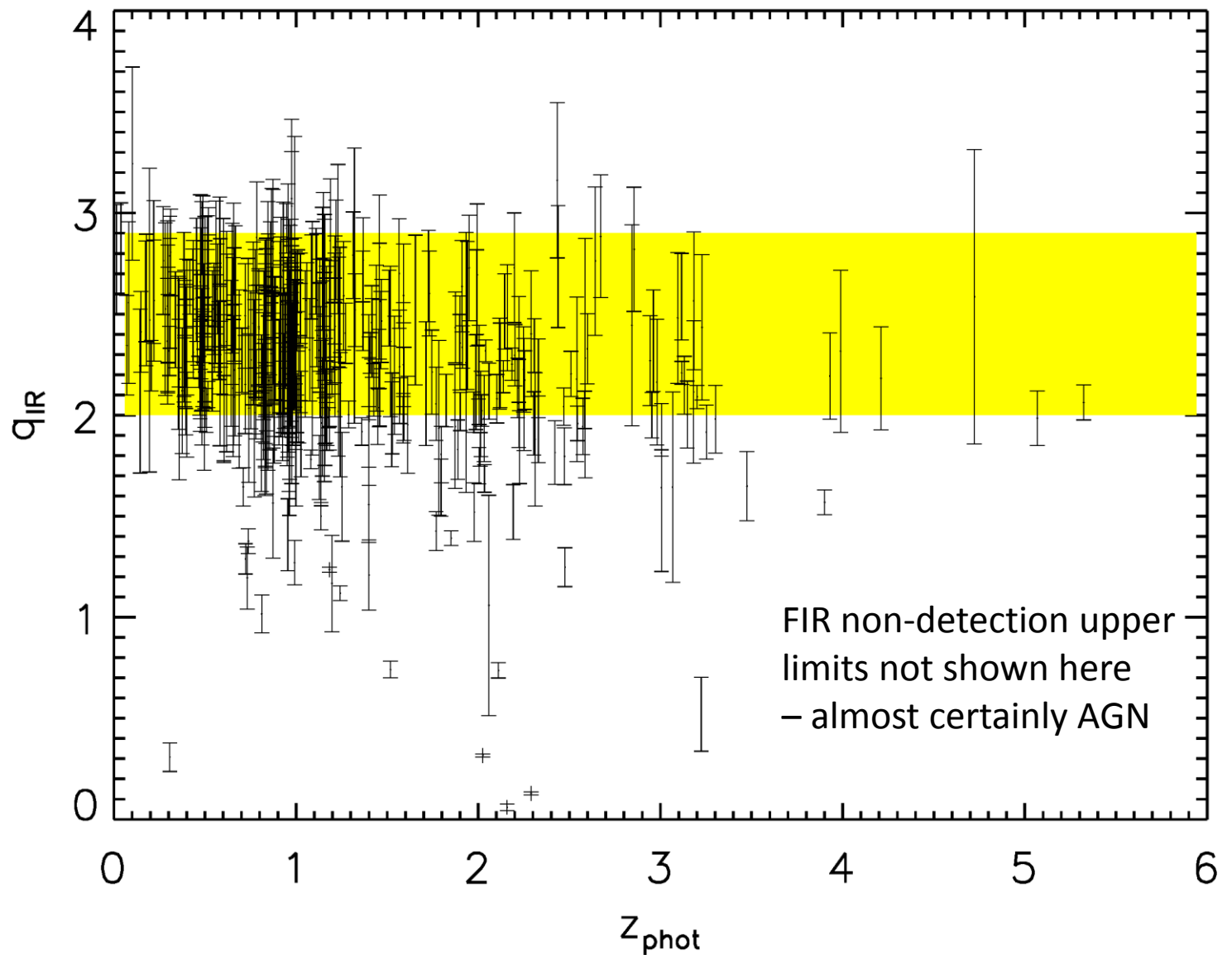
# eMERGE DR1 - the far-IR/radio correlation

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

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

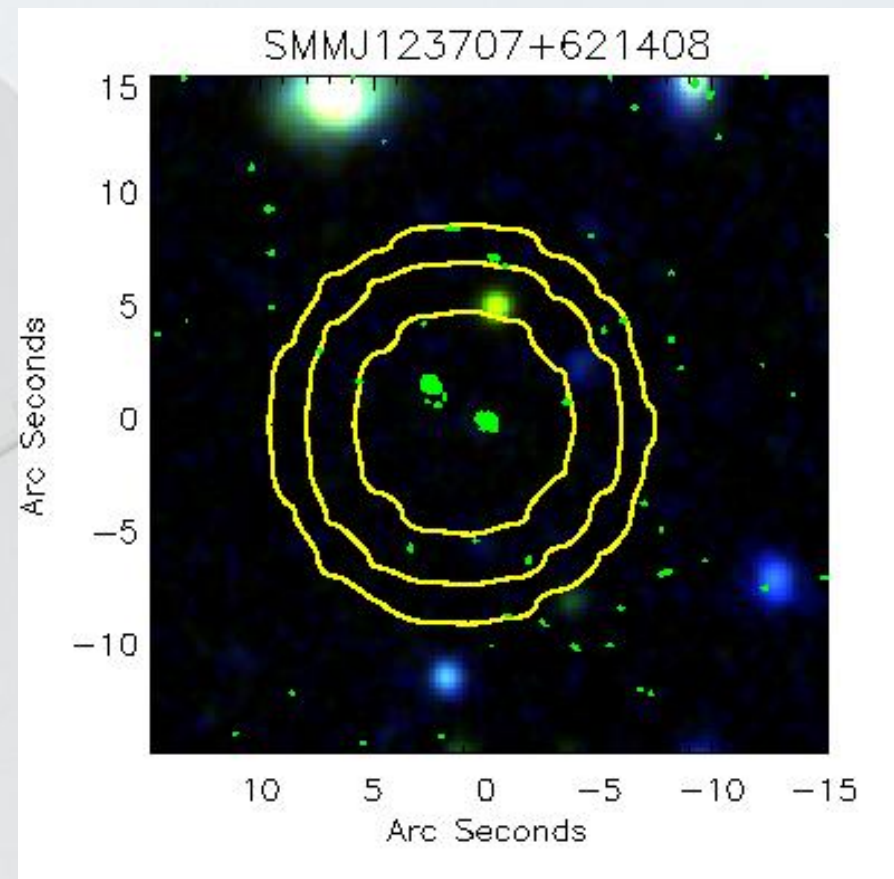
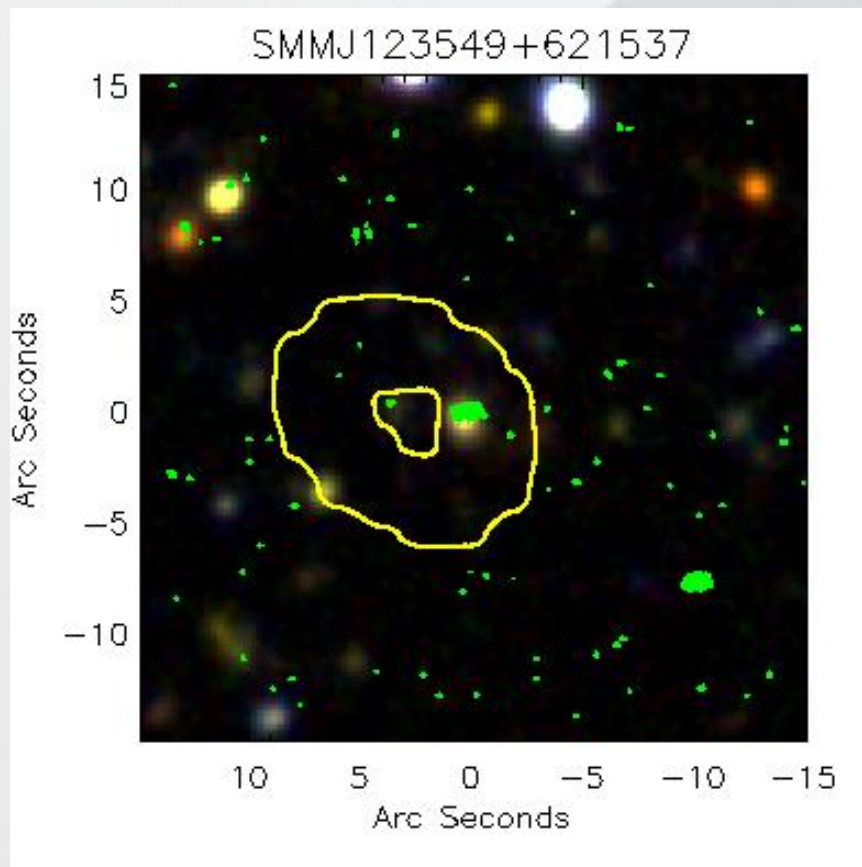
Radio excess sources  
(candidate AGN)

Majority of sources  
have radio emission  
compatible with SFGs



Far-IR/radio correlation  $q$  parameter – Thomson+, in prep  
 $L_{\text{IR}}$  from integrating the deblended FIR SEDs

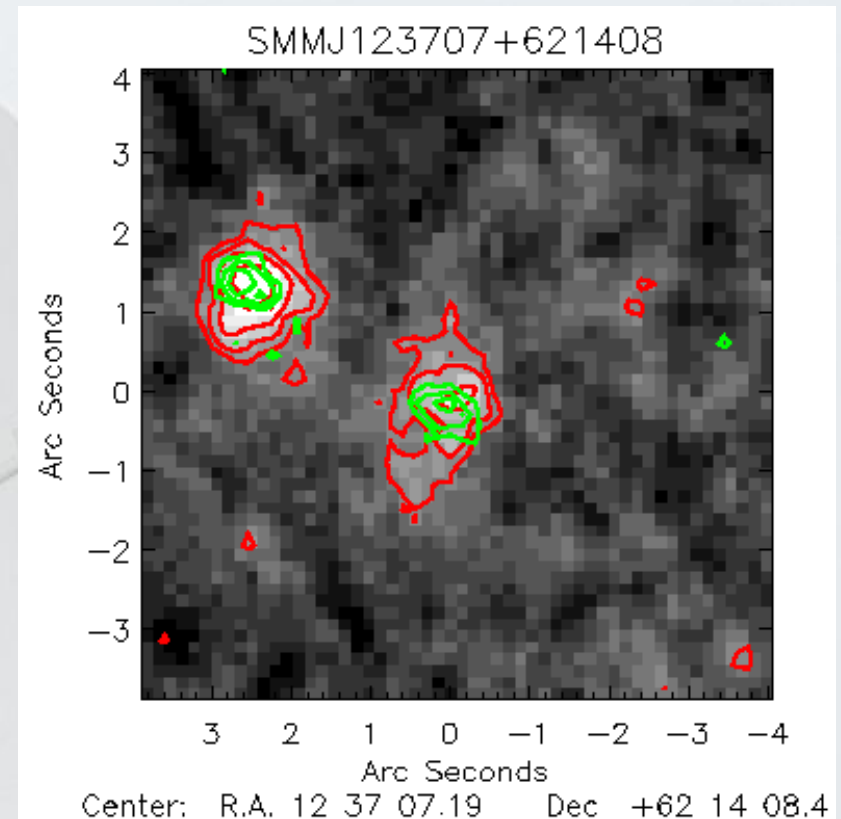
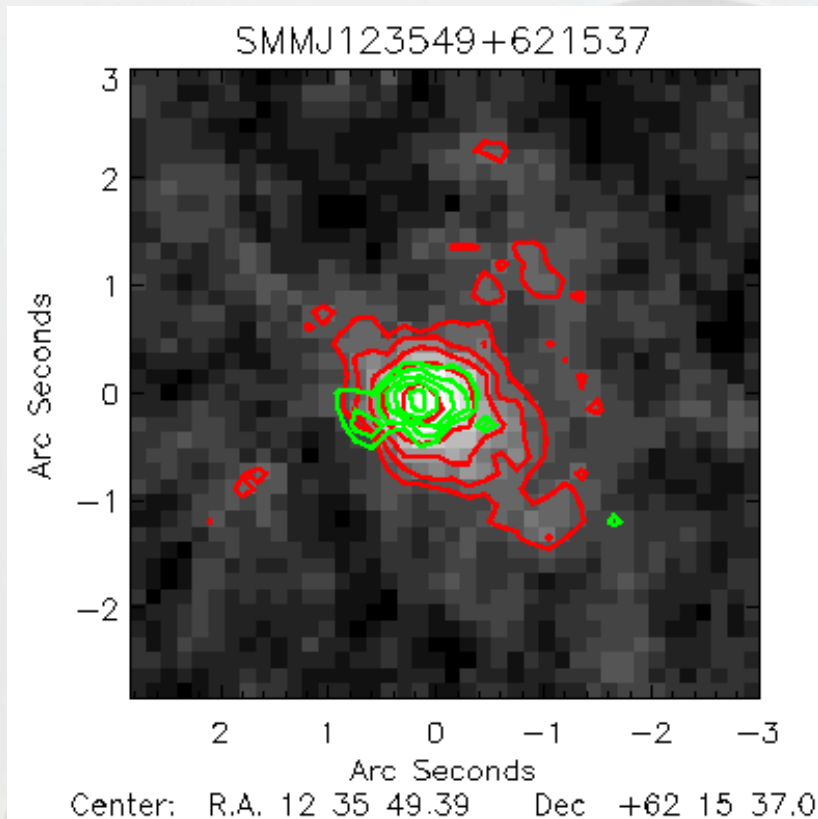
# eMERGE DR1 – molecular gas in $z \sim 2$ SMGs



- False colour: SUBARU U/I/Z
- Yellow contours: SCUBA-2 850 $\mu$ m
- Green contours: eMERGE 1.4GHz



# eMERGE DR1 – molecular gas in $z \sim 2$ 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 ( $\sim 20$  kpc separation)
- Giant molecular gas reservoirs:  $2-3 \times 10^{10} M_{\odot}$ ,  $\text{SFR} = 500-800 M_{\odot} \text{yr}^{-1}$ ,  $\tau_{\text{depletion}} \sim 50 \text{ Myr}$
- 1.4 GHz sizes  $\sim 0.8-1.0''$  (6-8 kpc), cf typical 2-3 kpc 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 ( $\sim 1.2 \mu\text{Jy}/\text{beam}$ ) imaging at  $0.28''$  resolution over  $15'$  in GOODS-N at 1.4GHz
- eMERGE DRI data products released to consortium members **Q4 2018**
- First papers expected  $\sim$ 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  $z \sim 2$  SMGs (Thomson/Ivison et al.), ML-classification of AGN/starbursts (Wrigley et al.)
- Existing optical/near-IR multiwavelength catalogue (3D-HST) lacks counterparts to  $\sim 20\%$  of  $>5\sigma$  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  $\sim 4x$  as much *uv* data ( $\geq 10\text{TB}$ ) and  $9x$  as many pixels ( $\sim 3.6\text{Gpixels}$ ) as DRI. 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...**

