First sub-arcsec resolution observations of the GOODS-N field at 5 GHz

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And the eMERGE collaboration

Outline

- Scientific framework
- eMERGE Legacy Project
- Ultra-deep 5 GHz JVLA observations of GOODS-N
- First results from a spectral index analysis of the faint radio source population

Context

Deep radio surveys provide a powerful obscuration-independent tool to reveal star formation (SF) and AGN activities.

- Evidence for both Radio Quiet/Loud AGNs in radio fields in the sub-mJy regime (e.g. Seymour+08,Padovani+09)
- Evidence for composite AGN/SF systems, especially at z~2 (e.g. Alexander +05,08; Mullaney+12)

Identification of low luminosity AGNs to get a complete census of SMBH's growth and determine the AGN role in driving SF

Deep radio surveys (~μJy level) with high spatial resolution (sub-kpc – 10 kpc) allow us to study the overall AGN population (RL&RQ) and distinguish extended SF emission (> 1 kpc) from more compact AGN components (< 1 kpc)

The eMERGE survey

eMERLIN Galaxy Evolution survey

PI: Muxlow, Smail & McHardy and >60 CO-Is from 9 countries

A ultra-deep survey of the μJy radio source population in GOODS-North (30 arcmin-diameter)

The deepest radio imaging of GOODS-N

How

- 400 hrs eMERLIN+JVLA (Array A) @ 1.4 GHz
- 378 hrs eMERLIN + JVLA (Array A, B, C) @ 5 GHz
- resolution 50-5000 mas (0.5-tens of kpc at z >1) with 0.5-1 μJy/b rms

What

- morphological and spectral identification of AGNs & SFgs up to high z
- Thanks also to the unique spectral and photometry coverage of GOODS-N (from radio to X-ray)
- Observations started in 2013, completed in 2016
- I.Prandoni PI of the 5 GHz survey

The hybrid system J123649+620737 @ z~2

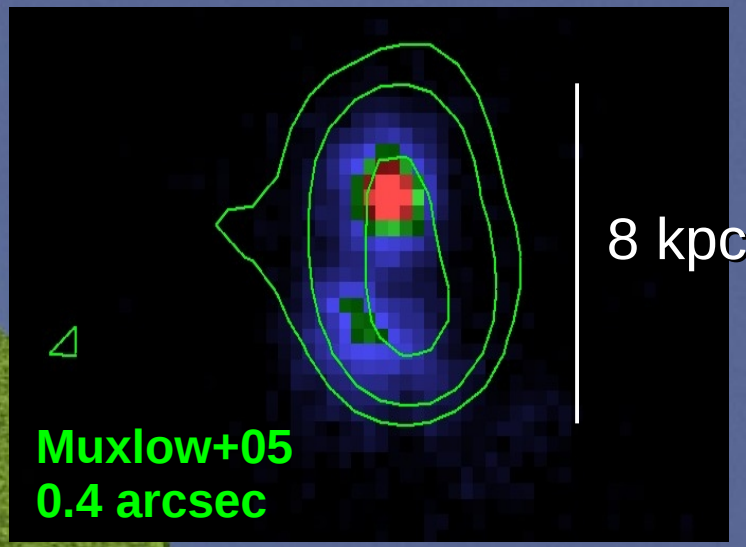
Casey+09

SF galaxy

- Optical/near IR spectra: z~2.3
- No AGN spectral features
- No radio core in 1.4 GHz MERLIN image at 0.4 arcsec FWHM

AGN

- X-ray luminosity [2-10 keV]: 1.3×10^{45} erg/s
- Optical compact core



1.4 GHz MERLIN contours on HST ACS i band image

AGN flux density ~130 μJy assuming a core of 0.4 arcsec (dati MERLIN) accounting for the ~<40% of the total radio emission

--> SFR ~ 4000 $M_\odot$/year !!

The 5 GHz eMERLIN view (commissioning data)

Casey+09

Guidetti+13

SF galaxy

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AGN

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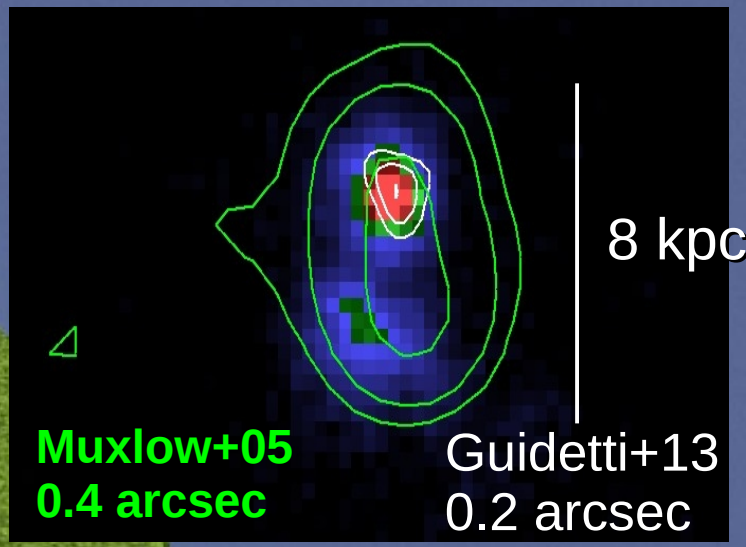


1.4 GHz MERLIN / 5.5 eMERLIN contours on HST ACS i band image

AGN flux density ~130 μJy assuming a core of 0.4 arcsec (dati MERLIN) accounting for the ~<40% of the total radio emission

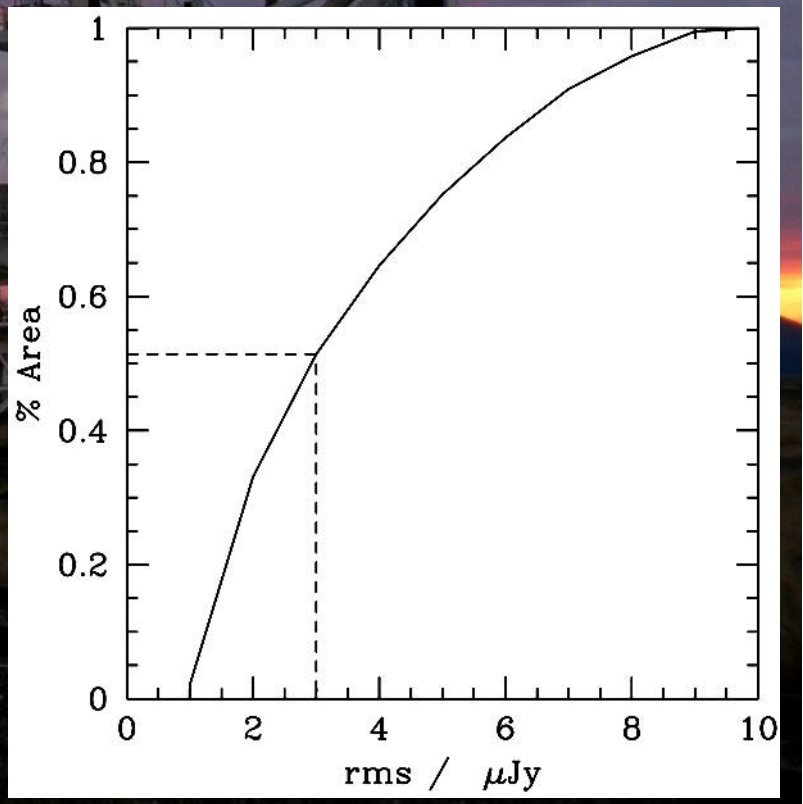
--> **SFR ~ 4000 $M_\odot$/year !!**

AGN accounts at least for 60% for the total radio flux

--> **SFR < 2800 $M_\odot$/year** from our eMERLIN flux density

The first eMERGE step: 5 GHz JVLA observations

- 7-pointing mosaic in GOODS-N (7 arcmin-diameter field)
- 16 hrs in Array A & B (Oct 2012 & Oct. 2013)
- Frequency range 4.5-6.5 GHz
- 0.7 arcsec FWHM
- 1.5 μJy rms at the center consistently with expectation



The highest sensitivity ever reached by a radio survey at 5 GHz!

Pre-existing 1.4 GHz VLA observations of GOODS-N

Morrison et al. 2010

- VLA observations of GOODS-N at 1.4 GHz
- 40 × 40 arcmin (<-> 7 arcmin @5GHz, same pointing centre)
- 1.7 arcsec FWHM (<-> 0.7 arcsec @ 5 GHz)
- 4 μJy rms at the centre (<-> 1.5 μJy @ 5 GHz)
- >1000 sources with completeness limit of 20 μJy (5 sigma)
- Morrison catalogue as a reference
  (waiting for the 1.4 GHz eMERGE obs.)

1.4 and 5 GHz cross-correlations

5 GHz selected sample

- 120 sources with S/N>5
- 92 (77%) in the 1.4 GHz Morrison+10 catalogue with $S/N_{1.4GHz} > 5$
- 28 (23%) new detections
- Fluxes: 7 μJy -->6 mJy

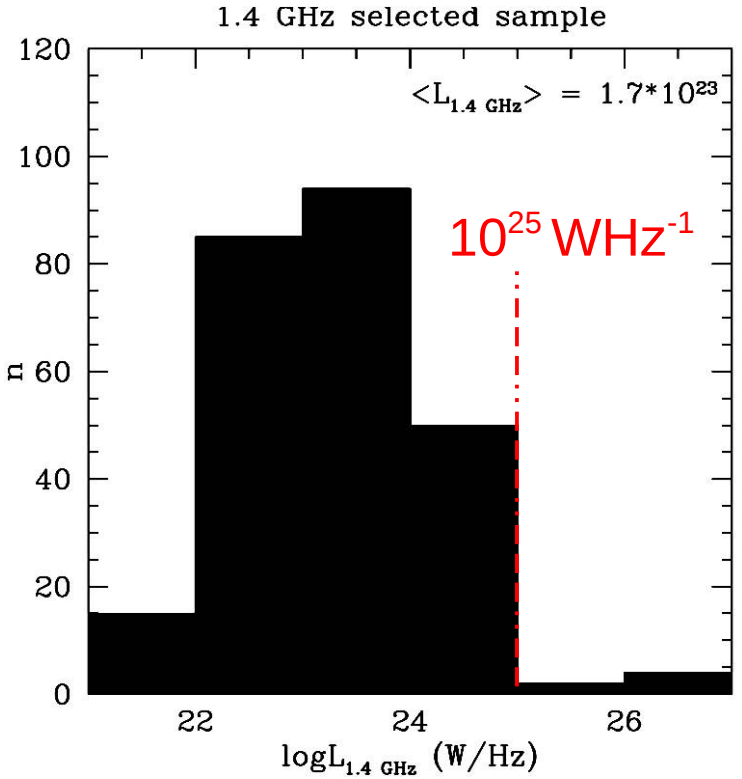
1.4 GHz selected sample

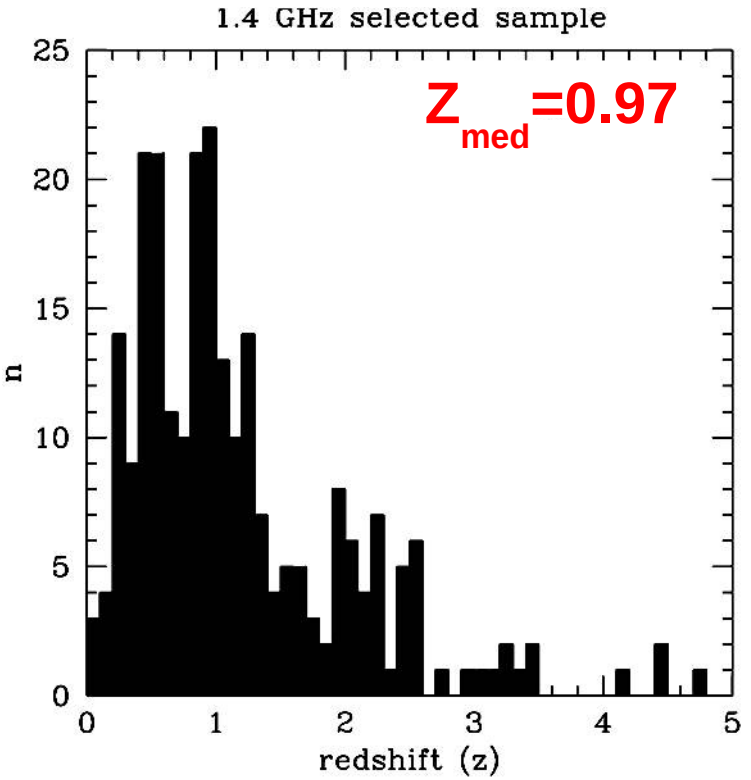
- 300 sources (within 7 arcmin)
- 180 (60%) with $S/N_{5\ GHz} > 3$
- 120 (40%) with $S/N_{5\ GHz} < 3$ (upper limits)
- Fluxes: 20 μJy --> 6 mJy

1 arcsec search radius
All associations visually inspected

Redshift and radio luminosity distribution of the 1.4 GHz selected sample

- Cross-correlation with Ks and optical catalogues with search radius of 2 arcsec
- 89% (266/300) of the 1.4 GHz selected sample identified (Wang+10)
- 68% (205/300) z spec (Barger+08)
- 15% (45/300) z phot (Kajisawa+10)
- 6% (17/300) no z





$L_{1.4\ GHz} = 10^{21\text{-}26}\ WHz^{-1}$

96% $L_{1.4\ GHz} < 10^{25}\ WHz^{-1}$

Mostly low radio luminosity sources

Sub-arcsec 1.4-5 GHz spectral indeces

Resolution: 0.7 arcsec @ 5 GHz <-> 1.7 arcsec @ 1.4 GHz

Extraction of a sub-sample with
$\theta_{1.4\ GHz} < 1$ arcsec
(173 sources, 68%)

< 10 kpc @ z~1 --> radio emission on (sub)-galactic scale: AGNs cores of radiogalaxies, Quasars, Sfgs...

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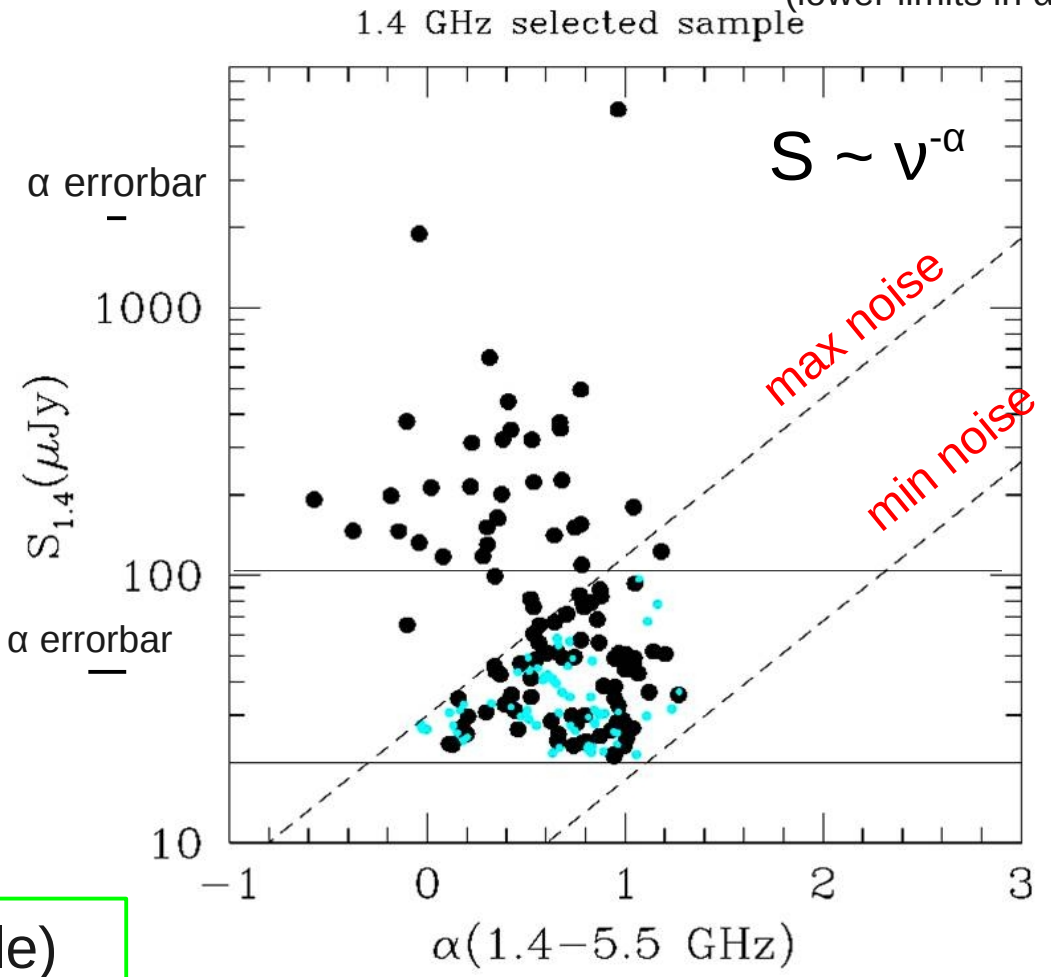
<α>=0.74+/-0.03



$S_{1.4\ GHz}$ > 100 μJy (complete sample)

$S_{1.4\ GHz}$ < 100 μJy (40% upper limits)

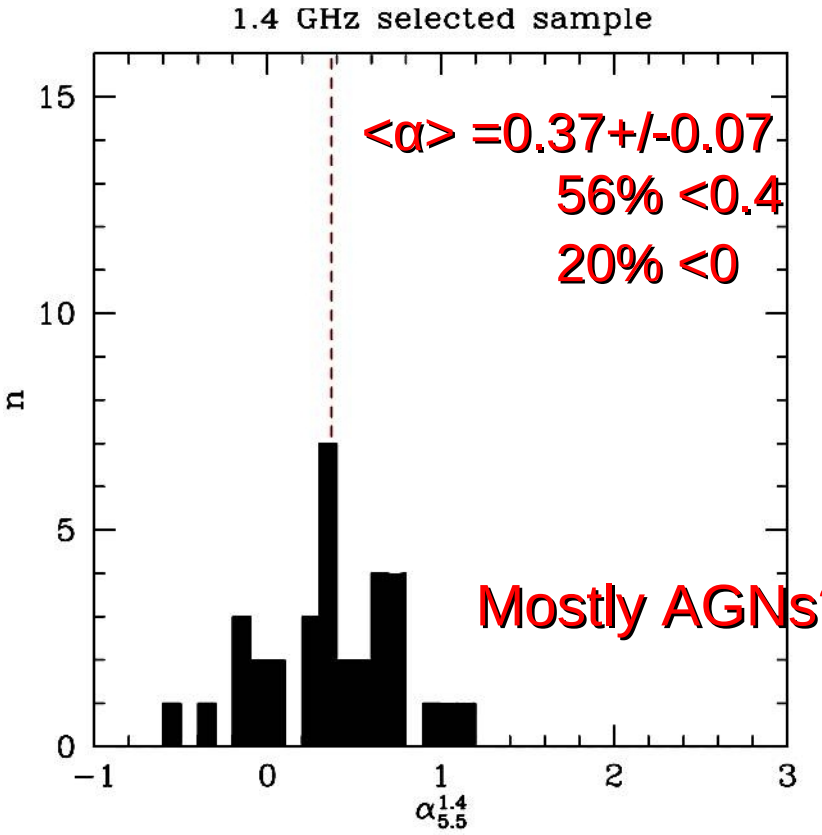
Similar redshift distribution peak @ z~1 --> no z-effect

1.4 GHz compact sample spix distribution

$S_{1.4\ GHz}$ > 100 μJy

(27 detect. 0 lower lim)

$L_{1.4\ GHz}$ ~ 2* 10^{24} W/Hz

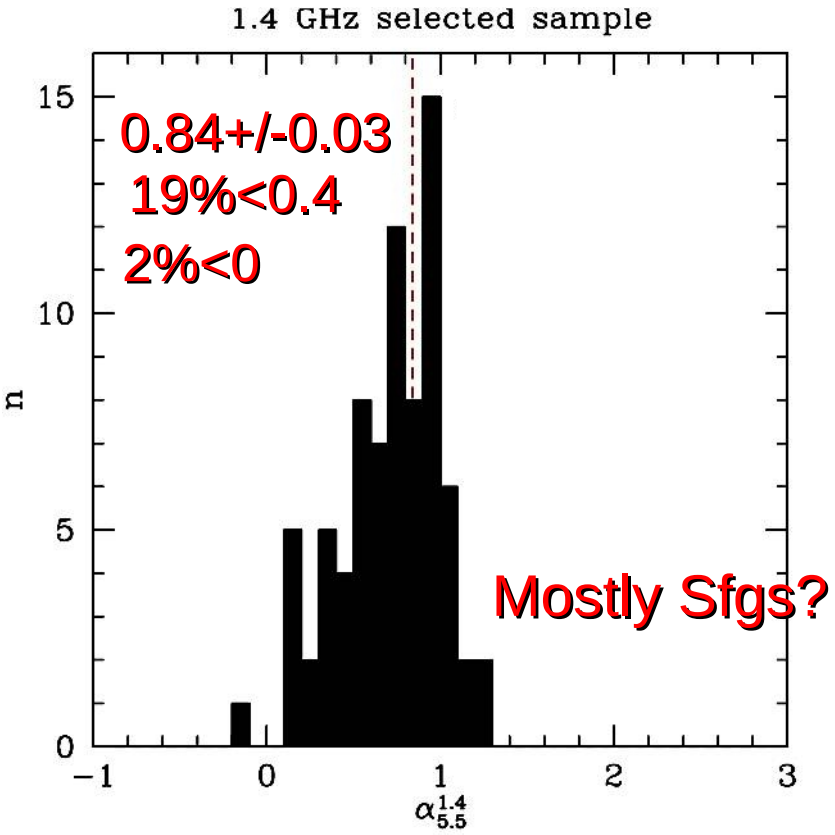


Probability of being the same population <0.1%

$S_{1.4\ GHz}$ < 100 μJy

(114 detect. 45 lower lim)

$L_{1.4\ GHz}$ ~ 3* 10^{23} W/Hz



compact core for 6 sources in higher resolution works (Muxlow+05, Guidetti+13), (Chi+13, VLBI obs.)

α behavior consistent with other works (e.g. Hyun+12, Prandoni+01)

X-ray luminosities

- $L_{X\text{-}ray} > 10^{42}$ erg/s: one of the best indicator of AGN activity
- Cross-correlation with the 2 Ms Chandra catalogue (Alexander+03, Xue+11)

with search radius of 2 arcsec

$S_{1.4\ GHz} > 100$ μJy

$L_{1.4\ GHz} \sim 2 * 10^{24}$ W/Hz

70% $L_{X\text{-}ray} > 10^{42}$ erg/s

30% $L_{X\text{-}ray} < 10^{42}$ erg/s

Mostly AGNs

$S_{1.4\ Ghz} < 100$ μJy

$L_{1.4\ GHz} \sim 3 * 10^{23}$ W/Hz

23% $L_{X\text{-}ray} > 10^{42}$ erg/s

77% $L_{X\text{-}ray} < 10^{42}$ erg/s

Mostly Sfgs , normal galaxies

Change in the source population consistent with the spectral index analysis

First results and future

- Steepening of the α distribution below 100 μJy confirmed on robust statistical basis what found on smaller samples and at lower resolution (e.g. Hyun+12)

- α distribution suggests a change in the radio source population around 100 μJy as observed in other (less) deep radio surveys (Prandoni+01,Bondi+03, Muxlow+05,Seymour+08)

- Cross-correlation with other multi-λ catalogues (IRAC colors, mid-IR flues, radio/optical fluxes)

- Similar analysis for the 5 GHz selected sample

- With the completion of eMERGE observations at 1.4 and 5 GHz will be possible a spectral investigation over much larger samples