AGN populations in GOODS-N through eMERGE ultra-deep JVLA observations

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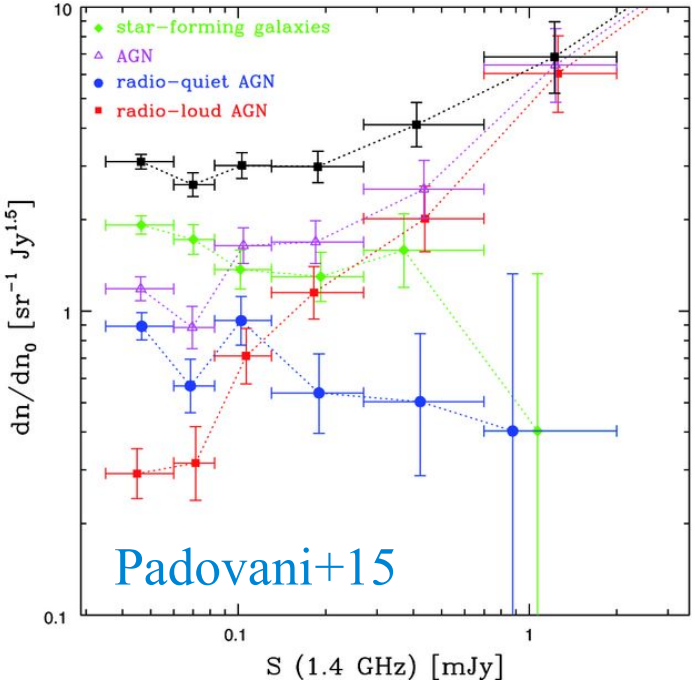
And the eMERGE collaboration

Garching, June 30, 2016

Context

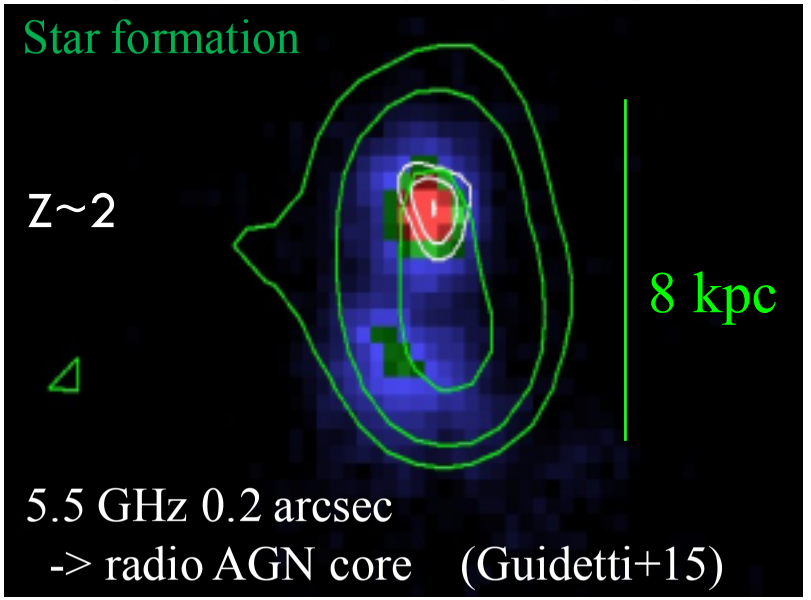
A complete census of faint AGNs in distant galaxies is crucial to understand AGN feedback, accretion regime and possible co-evolution with SF processes

Radio surveys increasingly important → unbiased and resolved view of AGNs & SF



- Composite sub-mJy radio source population
- RQ AGNs start to appear at μJy levels in deep radio Fields (e.g. Seymour+08,Padovani+09,+11,+15 Bonzini+13)

Ultra-deep radio obs. (~μJy rms) with high spatial resolution (sub-kpc → kpc) allow us to study the overall AGN population and distinguish extended kpc scale SF emission 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 very deep directed survey of the μJy radio source population in GOODS-N

Goal

- morphologically and spectrally identification of AGNs & SFgs up to z~5

How

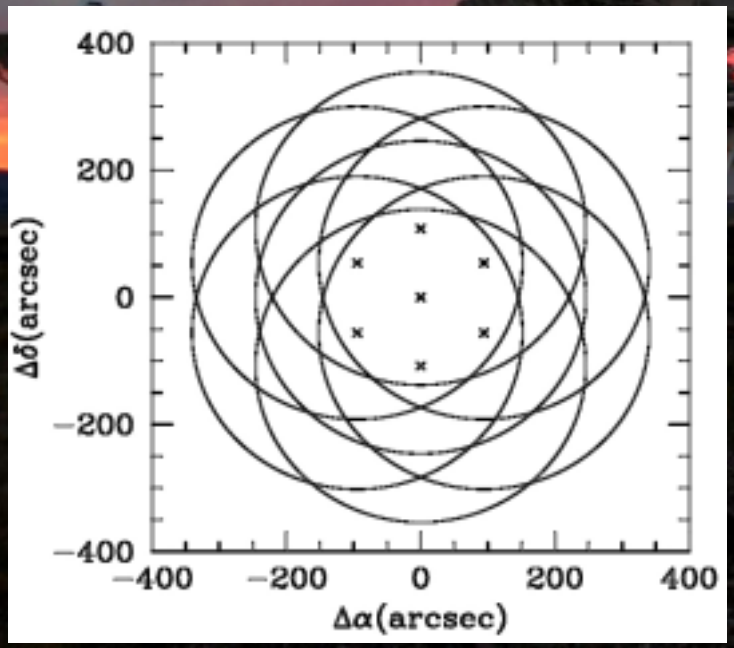
- 400 hrs eMERLIN+ JVLA @ 1.4 GHz
- 378 hrs eMERLIN +JVLA @ 5 GHz (PI Prandoni)
- resolution 50-2000 mas (0.5-tens of kpc at z >1) with 0.5-1 μJy/b rms
- ancillary coverage of GOODS-N from radio to X-ray

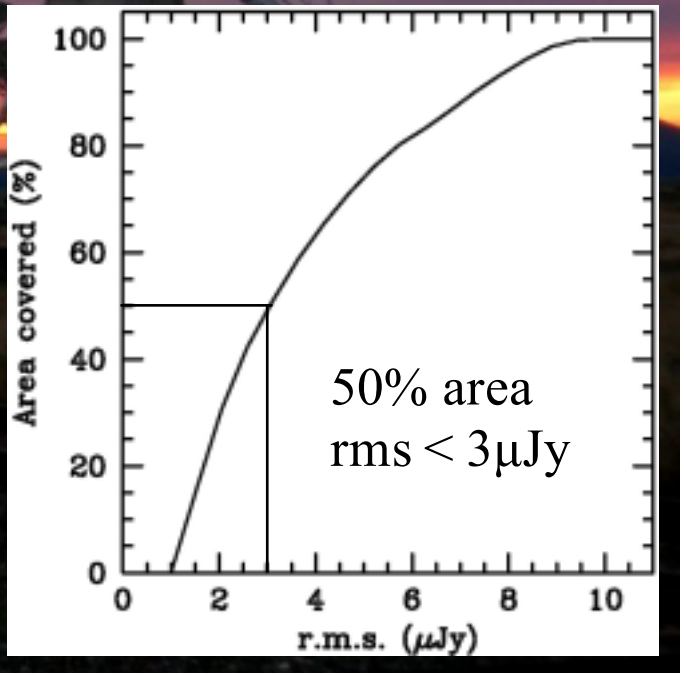
Status

- 5 GHz JVLA A/B survey [complete] (Guidetti+ I & II in prep)
- 1.4 GHz JVLA-A (39 hrs) [complete] (Owen+in prep)
- 1.4 GHz (20 days, 15% data reduced) & 5 GHz eMERLIN (Q2->2016)

5.5 GHz JVLA MOSAIC

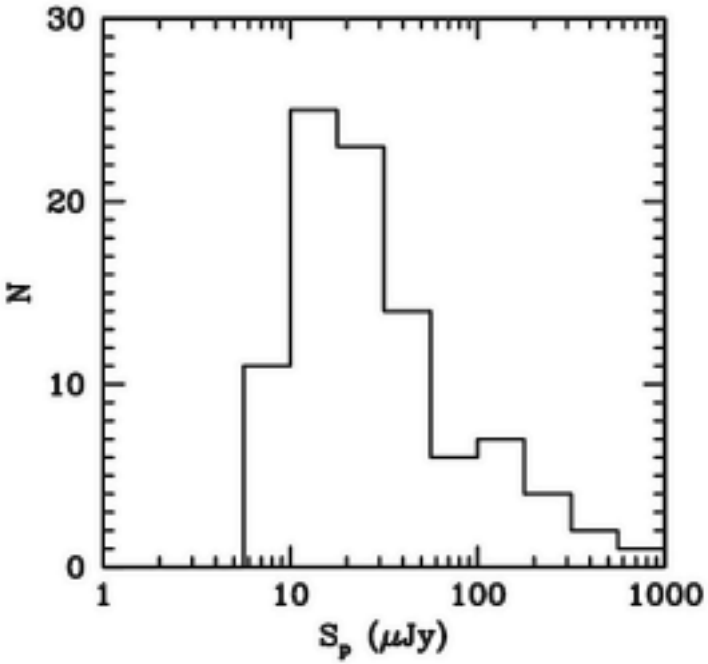
- 7-pointing mosaic in GOODS-N (matching the 5 GHz e-MERLIN FoV)
- 14+2 hours in Array A & B [PI: Muxlow] (Oct 2012 & Oct. 2013)
- Central frequency 5.5 GHz , 2 GHz bandwidth
- 0.5 arcsec resolution, ~1 μJy rms at center (1 sigma)

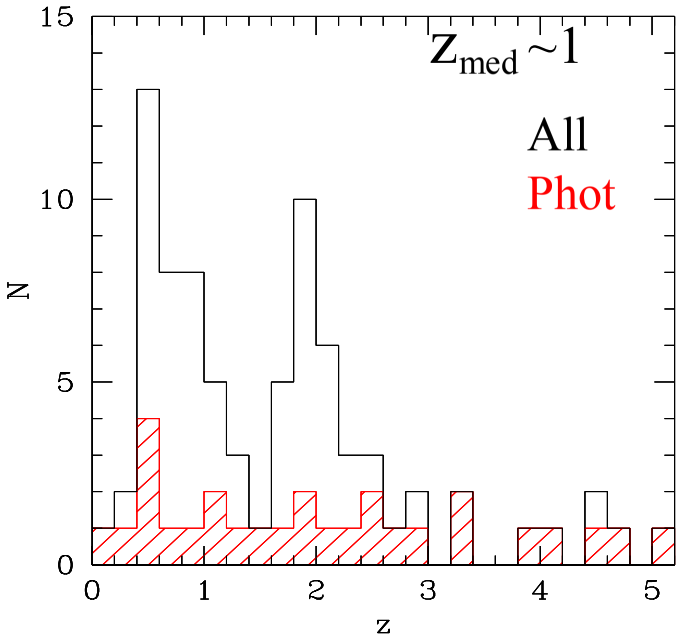




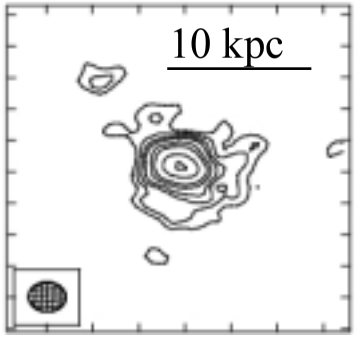
5.5 GHz catalogue

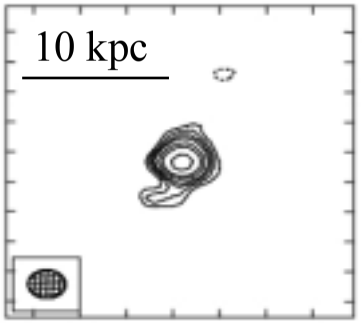
- 94 sources (S/N>5), at <7 arcmin from the centre
- $S_{5.5GHz}$> 6 μJy, 50% with $S_{5.5GHz}$<30 μJy
- 88% (83/94) secure Ks indentifications within <0.5”
  (WIRCam, 5σ depth of Ks, AB=24.45, Wang+10)
- 95% (79/83) with redshift (51 spec 28 phot)
  (Cowie+01,Wirth+04,Barger+08, Kajisawa+10, Momcheva+15)

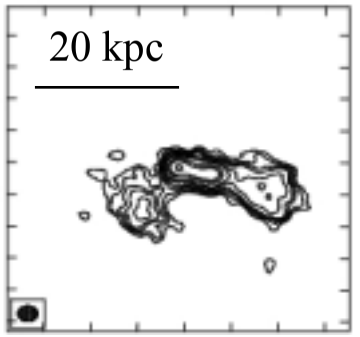




- <size> ~ 0.4 arcsec (~3 kpc at z =1)







First contour @ 3σ

Multi-λ classification of the 5.5 GHz sources

- 5 IR colour-colour plots (NIR-> FIR) ➜ quasar mode AGNs, passive (radio mode), star forming galaxies
- $L_{x\text{-}ray}$ ➜ quasar mode AGNs
- radio excess sources (Del Moro+13) ➜ radio AGN (RM&QM)
- VLBI detections ➜ radio AGN (RM&QM)

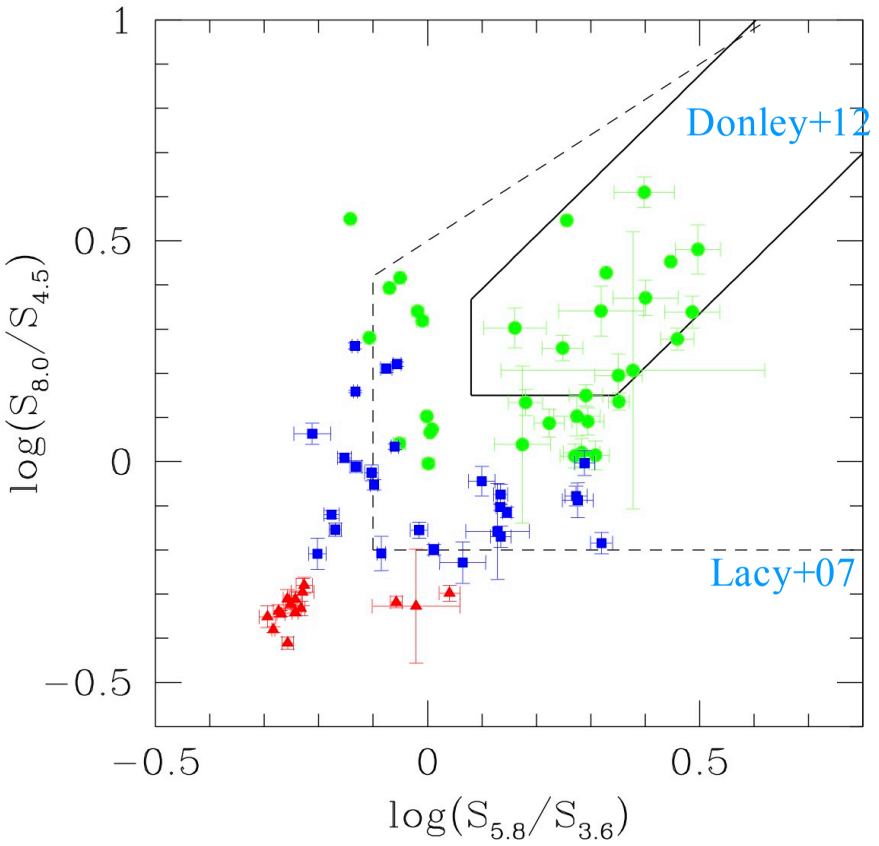
Samples of quasar/radio mode AGNs and star forming galaxies

IR classification of the 5.5 GHz sources

- 93% (77/83) of the Ks-identified sources with 4-IRAC bands data (Wang+10)
- 78% (65/83) MIR, FIR Herschel+PEP data (Elbaz+11, Magnelli+13)

5 IR CC criteria

- Stern+05 (IRAC), Donley+12 (IRAC)
- Kirkpatrick+12 (IRAC, 24μm, 100μm, 250μm)
- Messias+12 (Ks-band, IRAC)
- 3 account for redshift evolution
- 94% (77/83) IR- classified sources



■	35 AGNs (quasar mode)	45%
▲	15 passive galaxies	20%
●	27 SF/hyb systems	35%

X-ray & radio AGNs

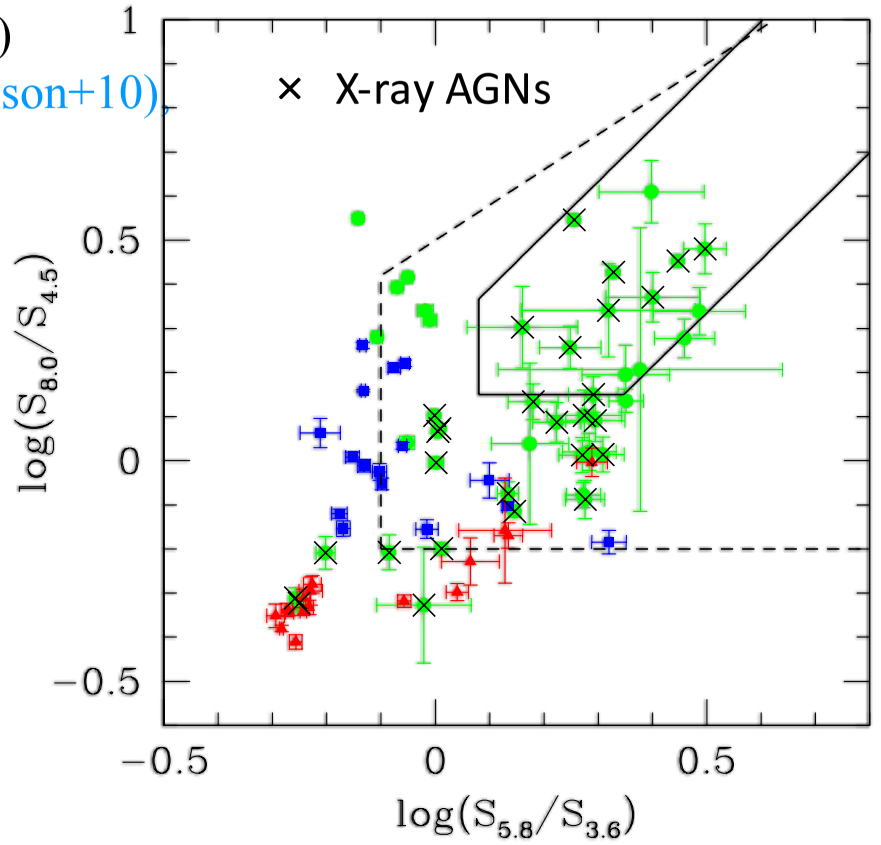
X-ray for 63% (52/83) (Xue+16), 100μm for 63% (52/83) (Elbaz+11,Magnelli+13), 1.4 GHz VLA for 100% (Morrison+10), 1.6 GHz VLBI (Chi+13, Radclife+15)

- QM AGNs if :
  Lx [2-7 keV] $> 10^{42}$ erg/s
  Lx [0.2-7 keV] $>3\times10^{42}$ erg/s (for upp limits)
  ➜ 29 X-ray QM AGN (30% not IR QM AGNs)

- radio excess sources if:
  q100 (log [$S_{100\mu m}/S_{1.4GHz}$]) <1.5 (Del Moro+13)
  $S_{100\mu m}$=1mJy (3 sigma) for upper limits

➜ 31 radio excess (~10% not IR RM AGN)

- 1.6 GHz VLBI ➜ 18 sources (~10% not IR RM AGNs)

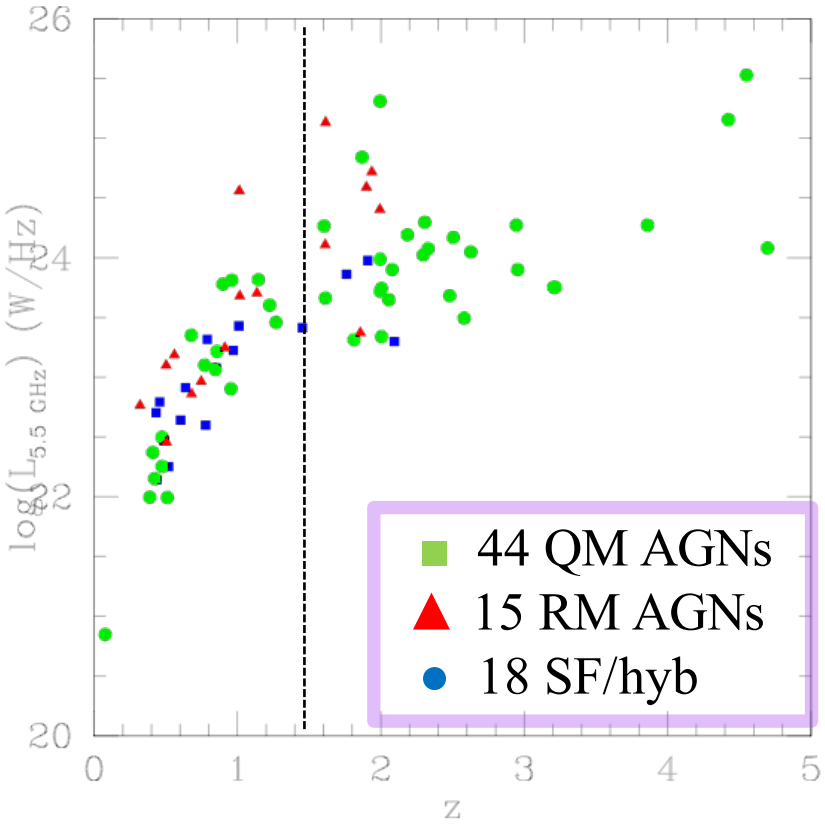


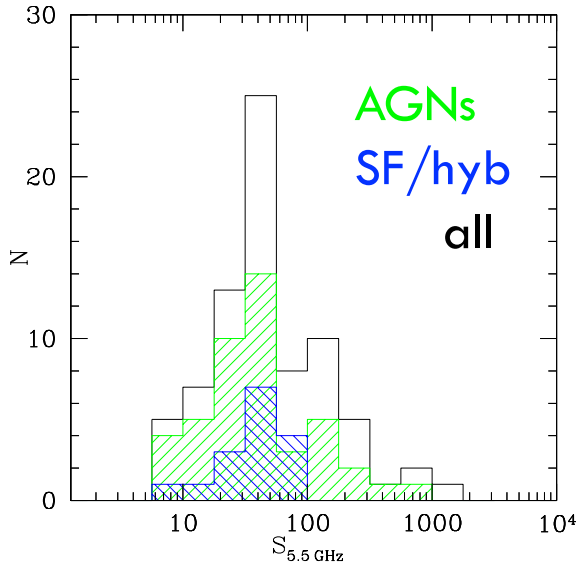
■ 35 QM AGNs	■ 44 QM AGNs 57%
▲ 15 RM AGNs	▲ 15 RM AGNs 20%
● 27 SF/hyb	● 18 SF/hyb 23%

77% of the classified sources are AGNs!!

AGN content in the 5.5 GOODS-N catalogue

- ~ 78% of the sources host an AGN (RM+QM)
- AGNs over all z & $L_{5.5GHz}$
- at z>1.5 >90% (34/37 sources) are AGNs
- 3 SF/hyb at z>1.5 are sub-mm galaxies (Barger+12)
- AGNs dominate down to few μJy (most QM)





1.4-5.5 GHz spectral index & optical images

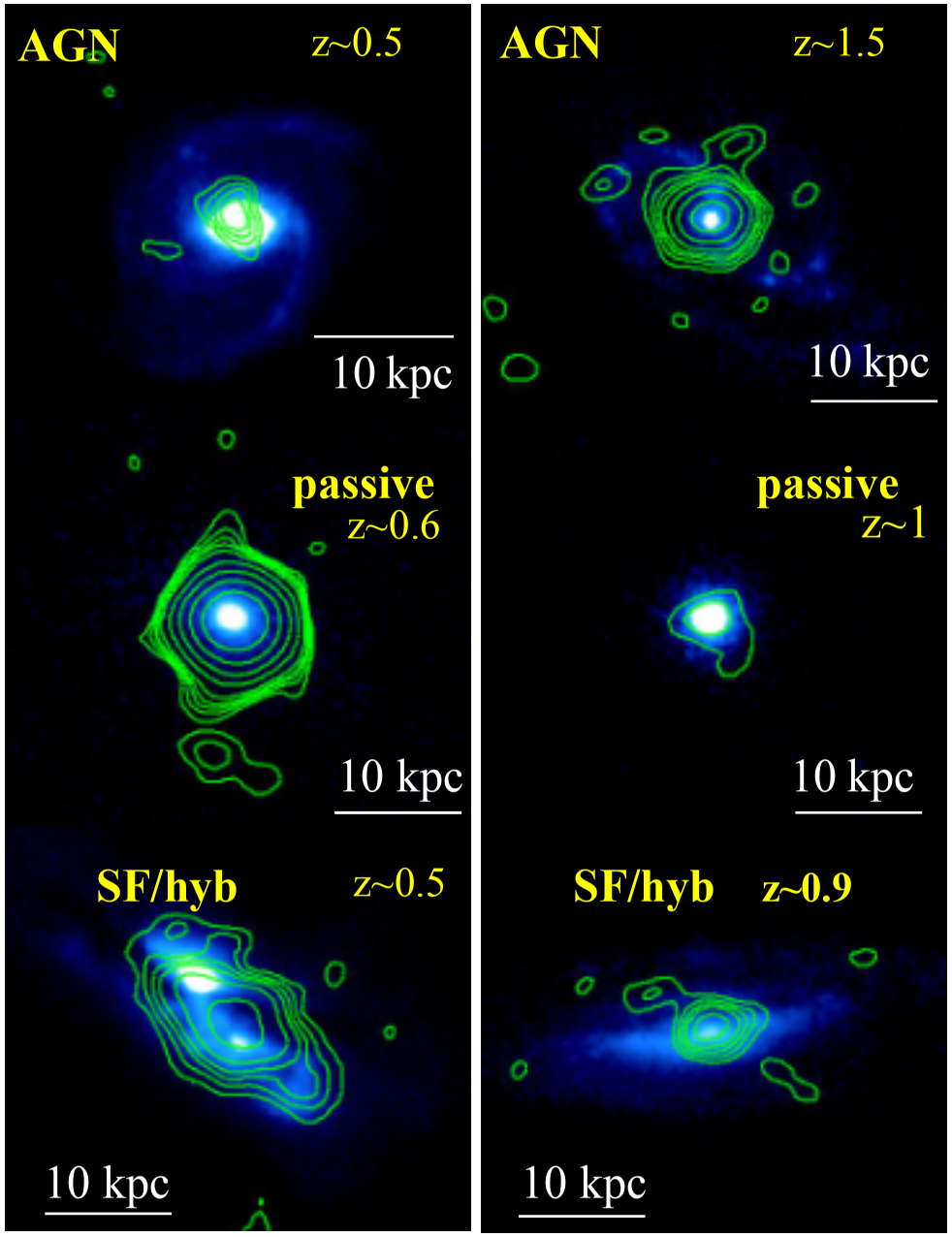
- 1.4 GHz information from VLA catalogue (1.7" FWHM Morrison et al. 2010)

- Spectral analysis limited to compact sources:
  61 with size <1 arcsec
  (~ 8 kpc @ z=1)

$$S_\nu \propto \nu^{-\alpha}$$

■	31 QM AGNs	α_{med}~ 0.73
▲	14 RM AGN	~ 0.40
●	16 SF/hyb systems	~ 0.72

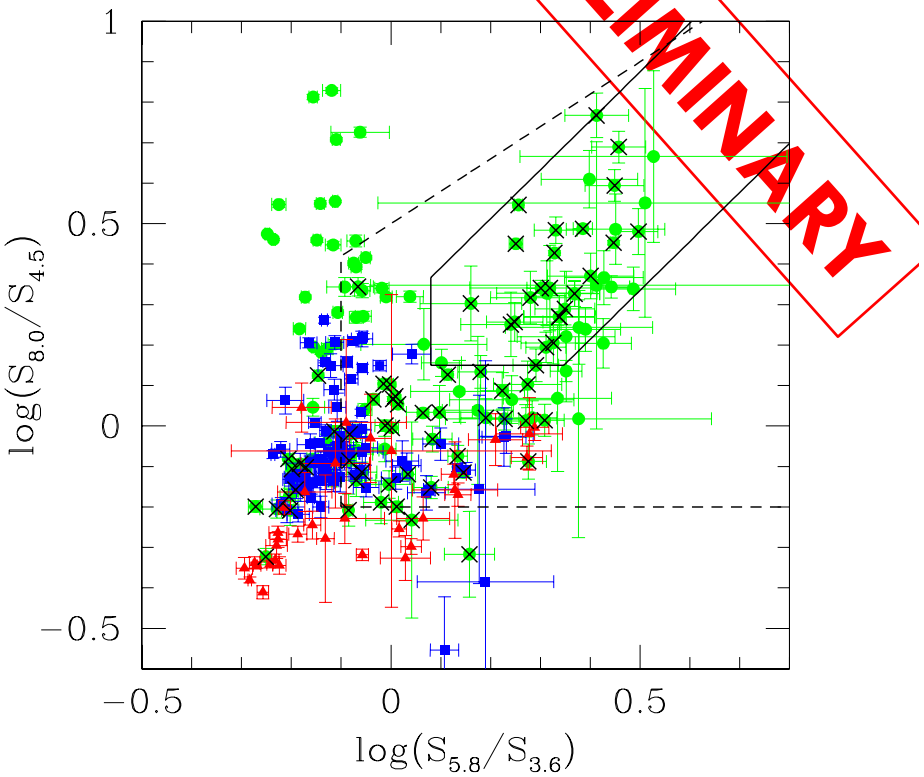
5.5 GHz contours/ HST I band image



1.4 GHz selected sample

from VLA catalogue (1.7" FWHM Morrison+10)

300 1.4 GHz sources selected in the same area of our 5.5GHz mosaic (99% $20\mu Jy > S_{1.4GHz} > 1mJy$)



1.4 GHz selected sources

- 142 QM AGNs
- 34 RM AGNs

] ➜ ~65%

- 86 SF/hyb systems ➜ ~35%

5.5GHz selected sources

- 44 QM AGNs
- 15 RM AGN

] ➜ ~80%

- 18 SF/hyb systems ➜ ~20%

a larger fraction of SF/Hyb and steep spectra (84% ←→ 49% at 5.5 GHz) but AGNs still dominate

Summary

- First catalogue of radio sources in GOODS-N at 5.5 GHz based on ultra-deep JVLA data with sub-arcsec resolution

- Analysis of the AGN/SFg content in the 5.5 GHz catalogue via 5 IR cc plots, hard X-ray luminosity, q_{100} radio excess and VLBI detections

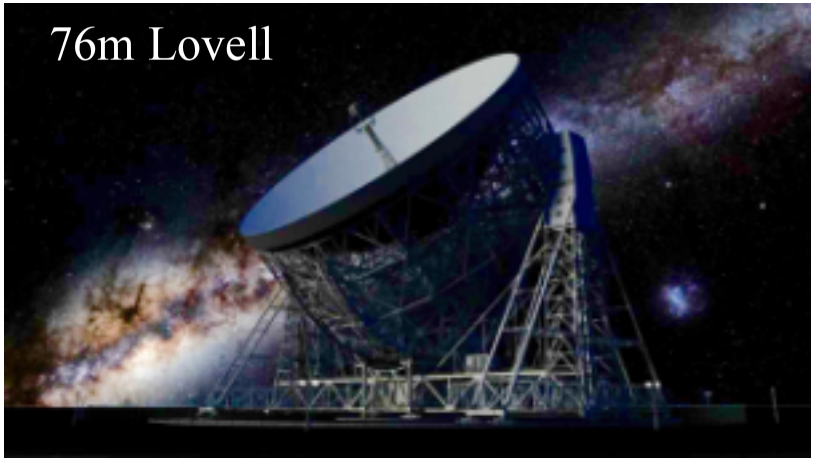
- The majority of the sources are AGN related (mostly quasar mode) down to a few μJy

- 30% of quasar mode AGNs show a radio excess, 15% VLBI detected

- quasar mode AGNs and SF/hyb have similar steep radio spectra, radio mode AGNs flat/inverted spectra

- In the same sky area, a 1.4GHz selected sample at arcsec resolution contains a larger fraction of SF/hyb and steep spectra, but AGNs still dominate

- Looking forward for eMERLIN data (Lovell included) to explore the μJy & sub-Jy sky with ~ 50 mas resolution → truly resolved & unbiased view of AGN & SF processes up to high redshifts in GOODS-N



X-ray AGNs

- X-ray for 63% (52/82) (Xue+16)
  (20 AGNs, 9 pas, 15 SF/hyb)

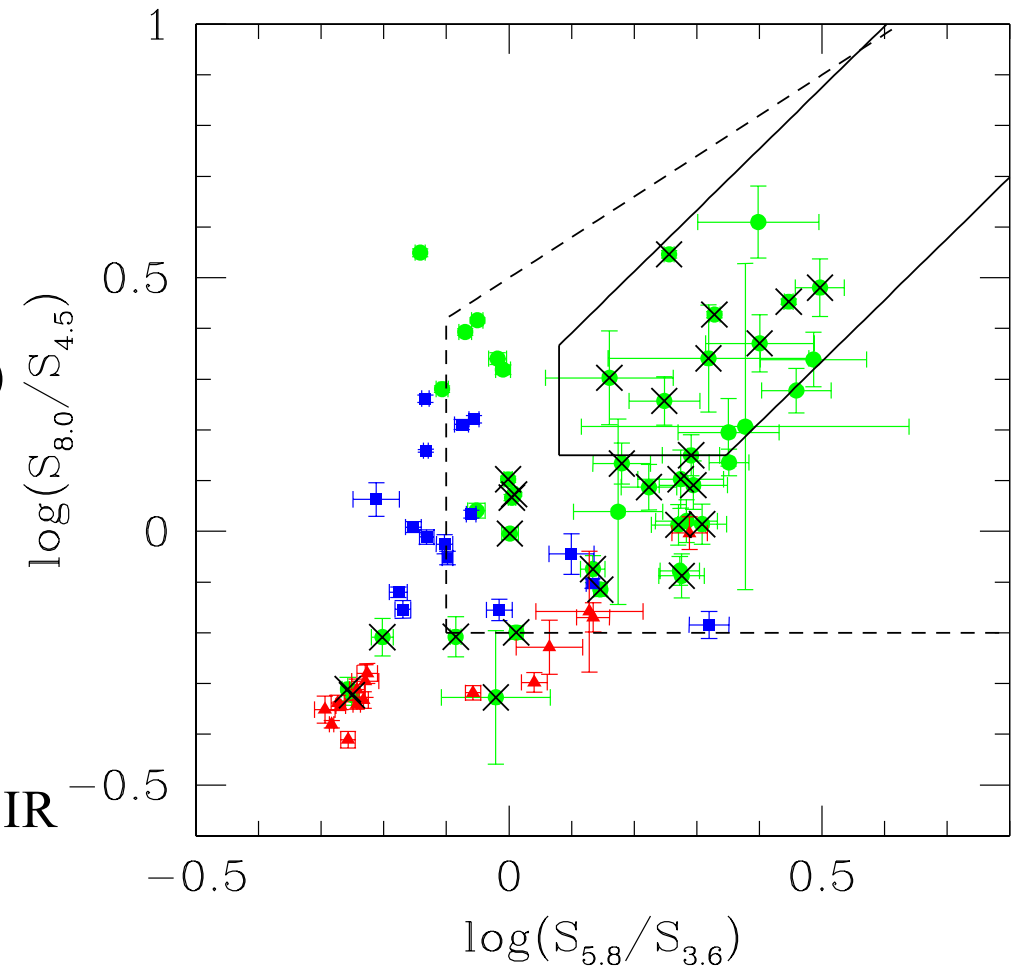
X-ray AGN if:

- Lx [2-7 keV] $> 10^{42}$ erg/s
- Lx[0.2-7 keV] $>3\times10^{42}$ erg/s (for upp limits)

➜ 29 sources

- 20/35 in QM AGNs
- 3/15 in RM AGNs
- 6/27 in SF/hyb

- 22% of SF/hyb contains an AGN not seen in IR



- AGN brightest X-ray sources
  $Lx_{med} \sim 5\times10^{43}$ erg/s
  $Lx_{med} \sim 1.7\times10^{41}$ erg/s
  for pas & SF/hyb

- 44 QM AGNs
- RM AGN
- SF/hyb systems

Radio active AGNs

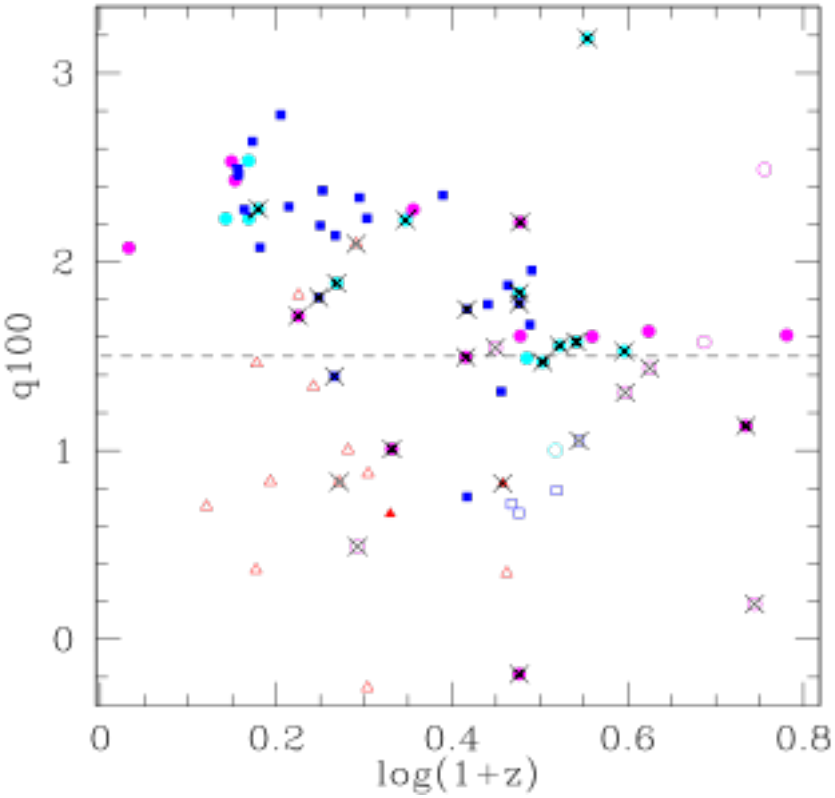
Rifare con nuovi colo
Aggiungere le VLBI

Radio AGN revelead by a radio excess wrt what expected from star formation (from FIR/radio ..) & by VLBI detections

- 100μm for 63% (52/82) (Magnelli+13,+15)
- $S_{100\mu m}$=1mJy (3 sigma) for upper limits
- 1.4 GHz VLA for (82/82) (Morrison+10)

Radio excess if:

- q100 ($\log [S_{100\mu m}/S_{1.4GHz}]$) <1.5 (Del Moro+13)



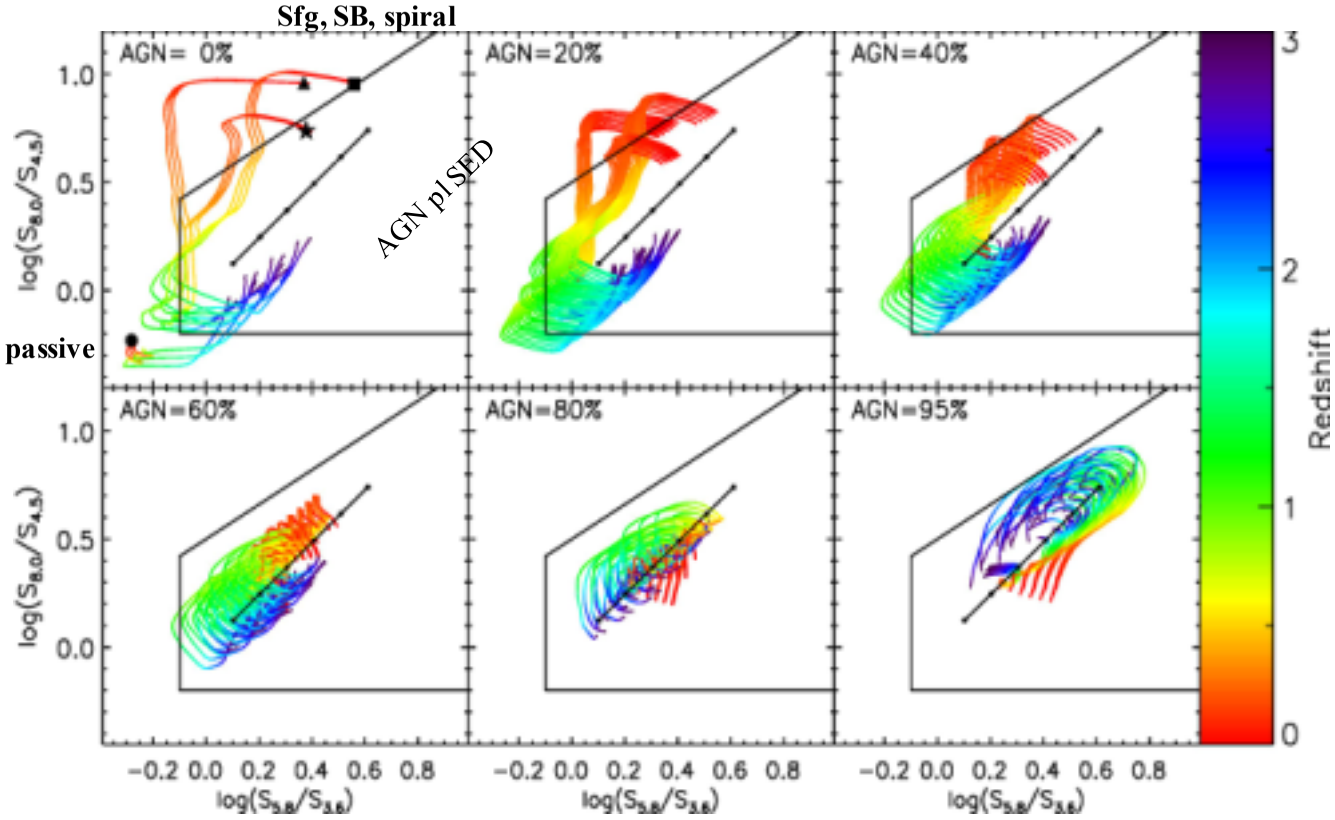
➜ 31 radio excess sources:

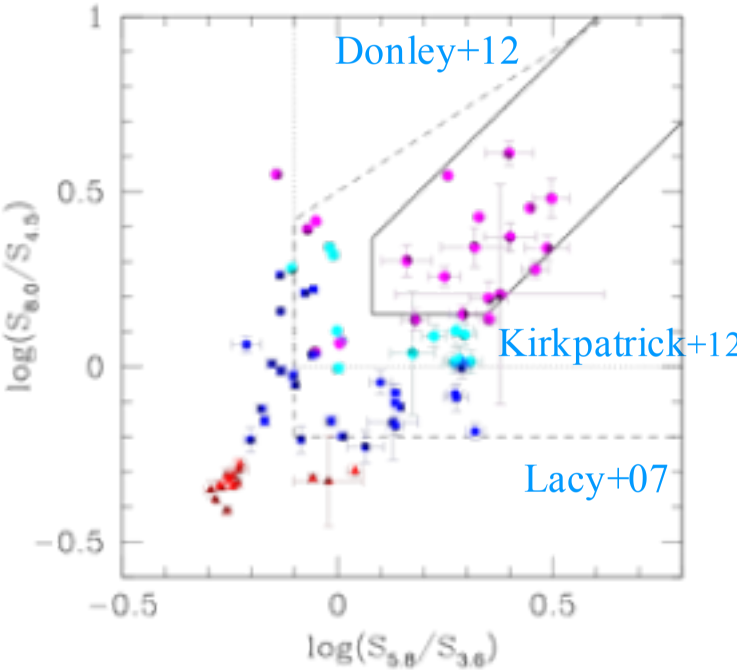
- 13/15 passive
- 12/36 ? QM AGNs -> AGN-related radio emission
- 6 /27 AGN in SF/hyb
  - ➜ AGNs which only appear in radio

- 1.4 GHz VLBI (Chi+13, Radclife+15)
  - ➜ 13 sources (all radio excess)

IR classification of the 5.5 GHz sources

Donley+12





- 5 IR CC criteria by Stern+05 (IRAC), Donley+12 (IRAC), Kirkpatrick+12 (IRAC, Far-IR), Messias+12 (Ks, IRAC)
- 4-IRAC bands photometry for 90% (74/82) of the Ks-identified sources (Wang+10)
- Far-IR Herschel photometry for 79% (65/82) (Elbaz+11)

- ■ 36 AGN candidates (selected by at least 1 IR criterium)
- ▲ 14 candidate passive ellipticals
- ● 24 SF/comp systems

THE HYBRID SYSTEM J123649+620737: EMERLIN VIEW @ 5 GHZ

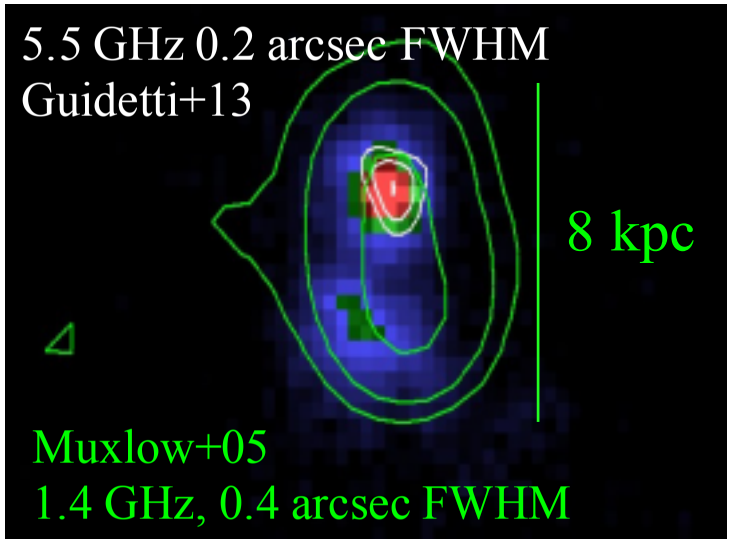
potential hot ULIRG at z~2.2
(Casey+09)

SF galaxy

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

AGN

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



1.4 GHz MERLIN contours on HST ACS i band image

- AGN flux density ~130 μJy assuming a radio core of 0.4 arcsec (MERLIN)

Radio emission: ~40% AGN + 60% SF → **SFR ~ 4000 $M_\odot$/year** (Casey+09)

We found that AGN accounts at least for 60% for the total radio flux
→ SFR < 2800 $M_\odot$/year from our eMERLIN flux density