Faint AGNs in Deep Radio Fields
Ongoing Activity

I. Prandoni ... and many others

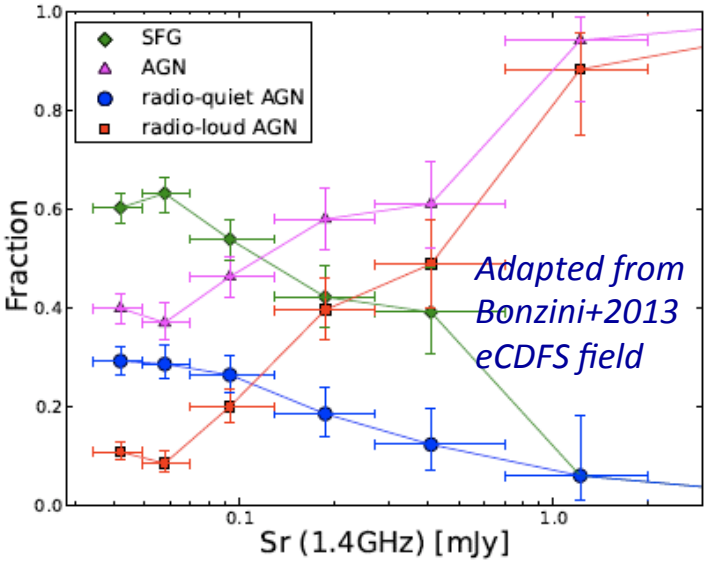
Lockman: E. Mahony et al.

GOODS-N: D. Guidetti, M. Bondi et al.

eCDFS: A. Maini et al.

(PhD Uni Bologna/Maquarie)

Scientific Background



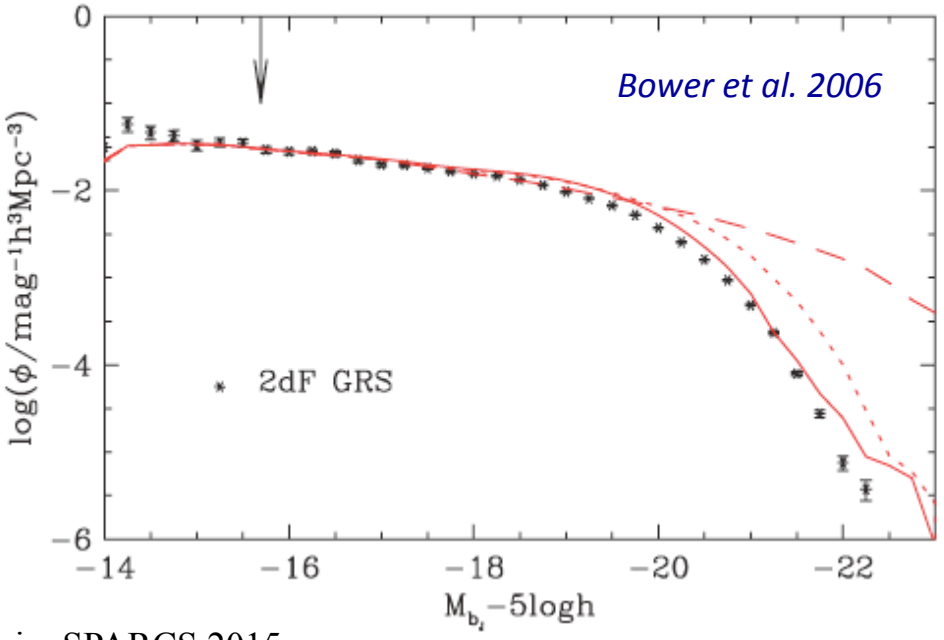
RQ-AGN start to appear at uJy levels in deep radio fields → hosted by disk galaxies

Complete census of RL and RQ AGNs
→ Evolution of radio-selected AGN down to RQ regime
→ complete view of AGN feedback
→ Not affected by gas obscuration

- Physics of RQ/RL Dichotomy
- Role of AGN feedback in gal. evol.

RL AGN – Radio/Hot Mode
→jet-driven mechanical feedback

RQ-AGN – QSO/Cold Mode
→radiation-driven feedback (winds)



Separating AGN/SF activity

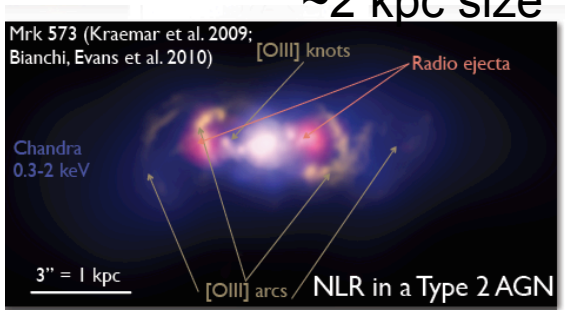
- RQ/RL dichotomy?
- What triggers radio emission in RQ AGNs?

SF? Mini-jets?

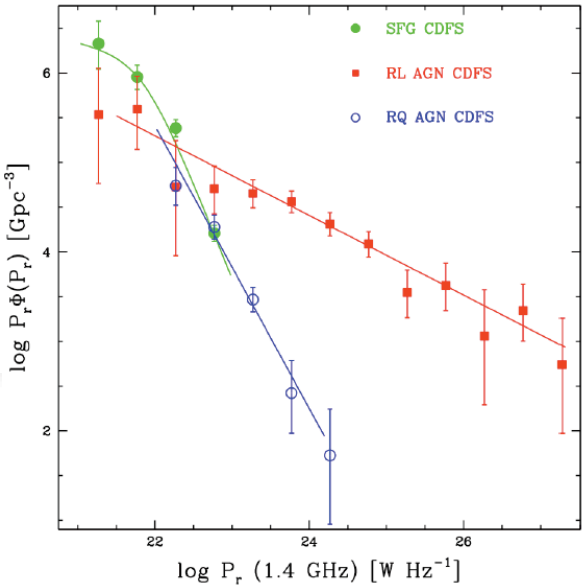
SF/AGN co-existing processes?

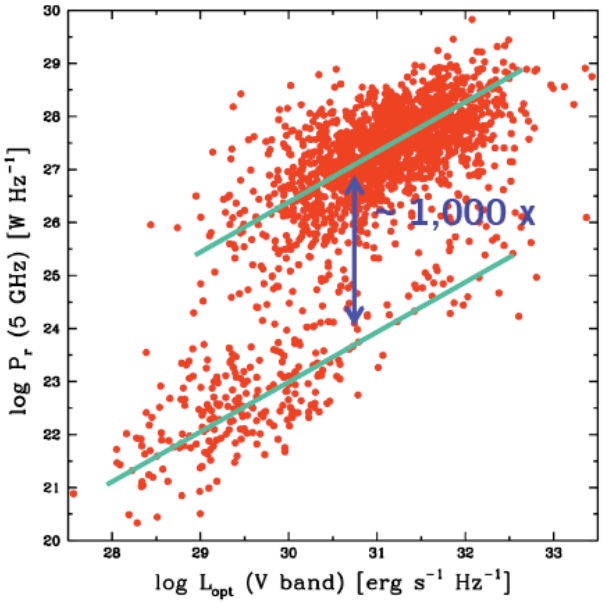
Radio AGN cores
Difficult to detect at uJy levels

~2 kpc size



5 kpc → ~0.7" at z>1





Padovani+ 2011

Multi-band information

Radio-band:
Spatial Resolution &
Multi-frequency info

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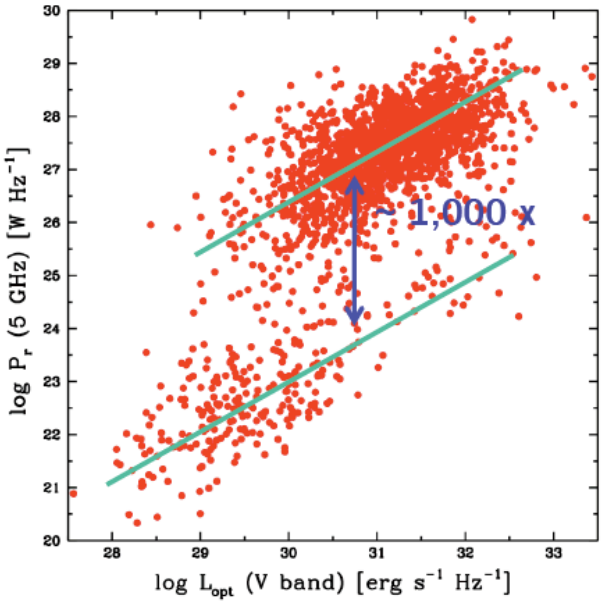

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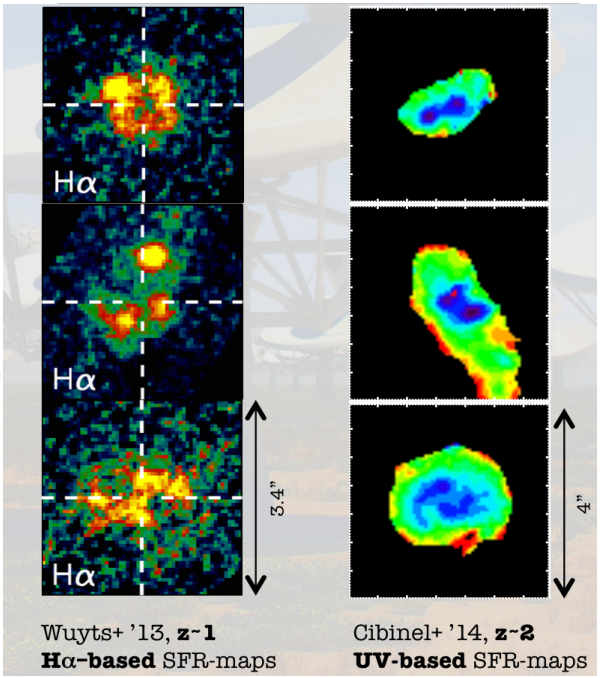

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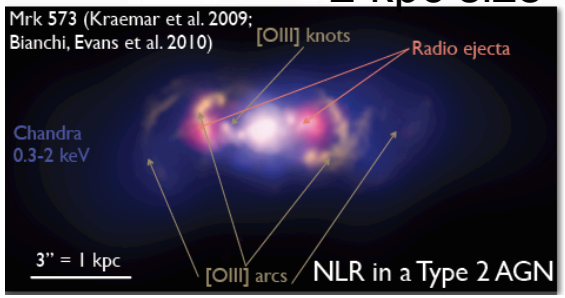
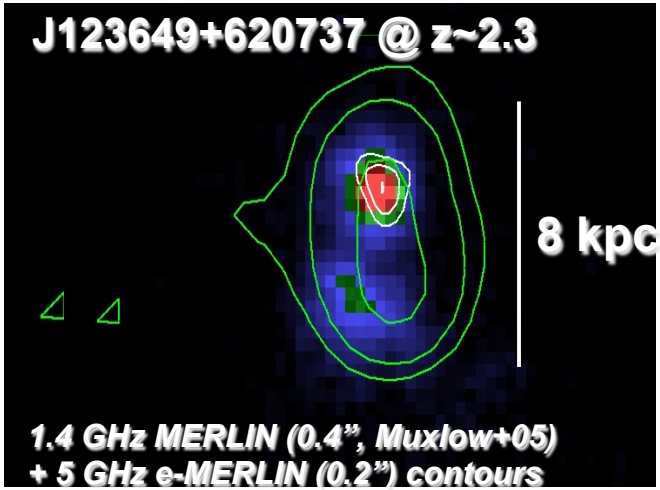


Multi-band information

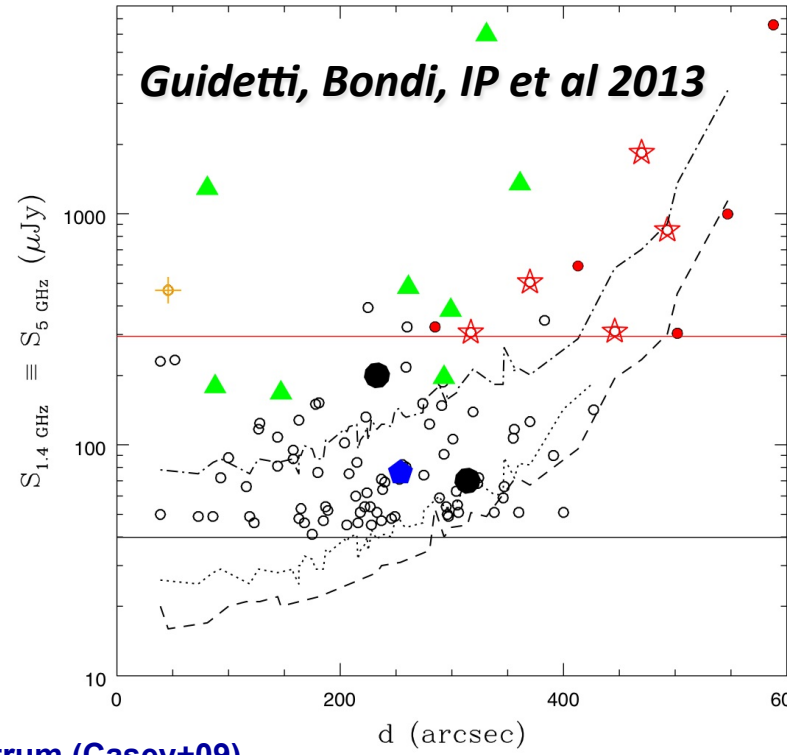
Radio-band:
Spatial Resolution &
Multi-frequency info

eMERLIN 5 GHz commissioning data

- GOODS-N: 156 hrs obs. @ 5GHz, 512 MHz
- no Lovell & Cambridge → 0.2" res.
- 0.2" res. (matching 1.4 GHz)
- Noise ~ 15-20 μJy/b → 2x σ_{th}
- 12+5 detected RS (3σ)
- Mostly AGN + 6 Unclass (→ AGN)
- Sub-arcsec sp. index 1.4 and 5 GHz



on HST ACS i band image (Casey+09)



SF: opt/NIR spectrum (Casey+09)
AGN: X-ray L~$10^{44.5}$ erg/s + compact opt. core + radio-excess
1.4 GHz 0.4" res. data not conclusive
- **AGN core confirmed by 5 GHz e-MERLIN data**
- **SFR from 4000 to <2800 $M_\odot$/yr**

The Lockman Hole Region @ 1.4 GHz

WSRT image @ 1.4 GHz:

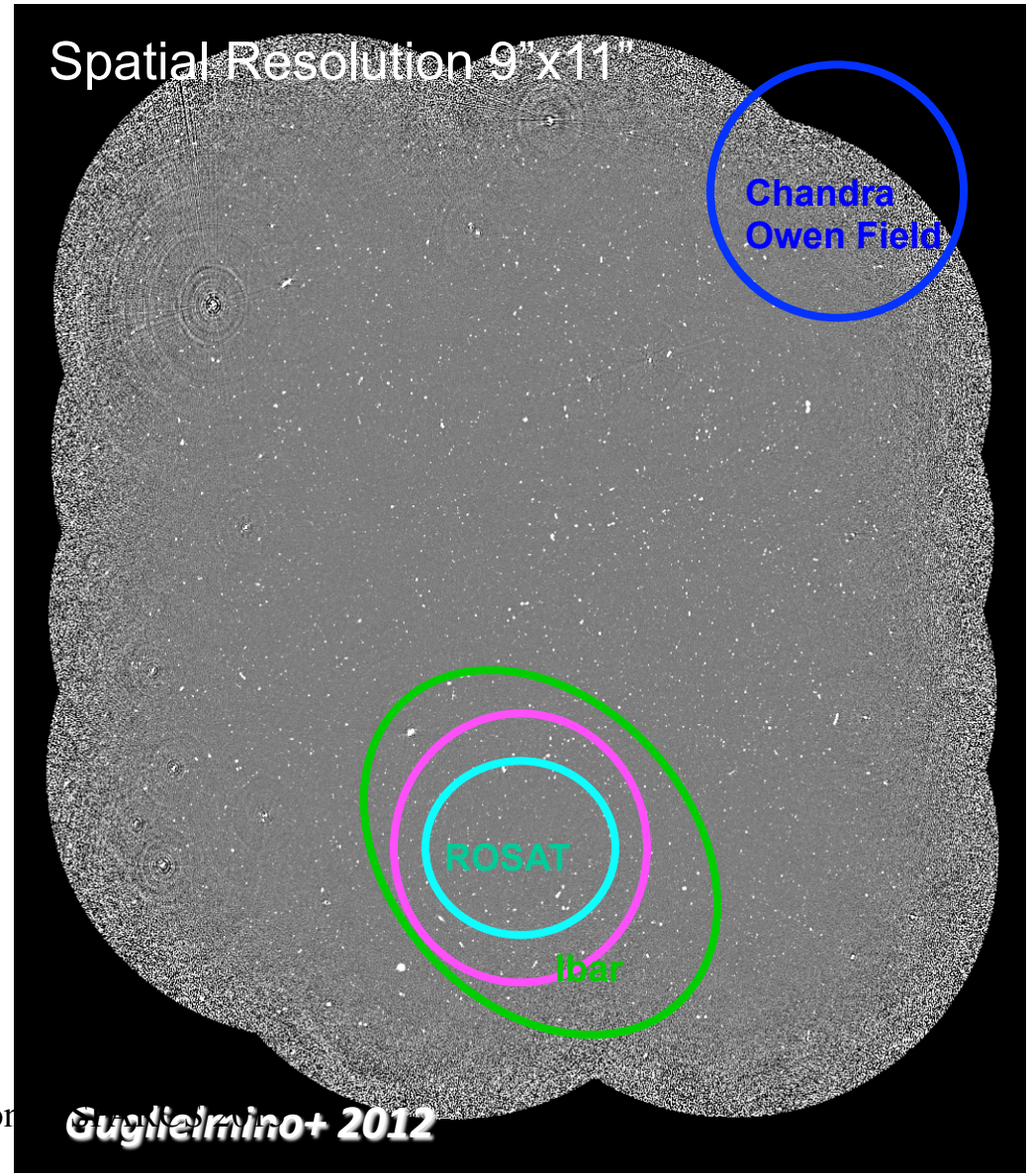
16 WSRT pointings (6.6 sq. degr.) taken over 208 hrs

The rms noise rises from 11 $\mu Jy/b$ (central 2 sq. degr.) to 200 $\mu Jy/b$ at the very border.

Source Catalog: 6002 sources with S> 55 $\mu Jy/b$

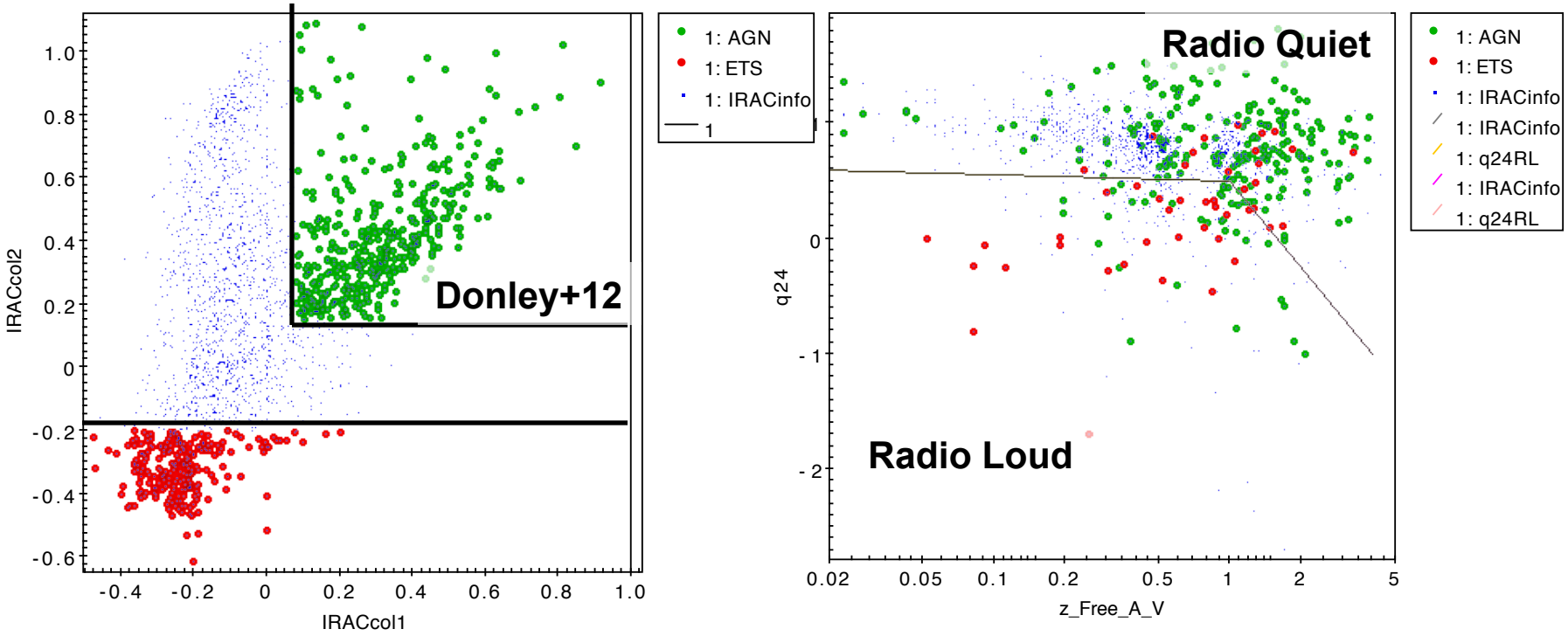
60-150-350-610 MHz; 15 GHz

Extensive multi-band data:
PanSTARRS, UKIDSS, SERVS, SWIRE, HerMES, VLA, GMRT, WSRT, Chandra, SCUBA, SCUBA-2, Galex



LH – AGN component

- 1842/6000 with IRAC + 24 um detection [S_{lim} (1.4 GHz) ~ 55 uJy)]
  → 392 AGN cold-mode (36 RL → 9%, following Bonzini+13)
  → 69 AGN hot-mode (27 RL → 39%, " ")
- In total 461 with **AGN activity (14% RL) → 25% of the sample**
- NB: this is a lower limit → up to 33% incl. other RL objects
- **To be compared to 40-50% of Bonzini et al.**



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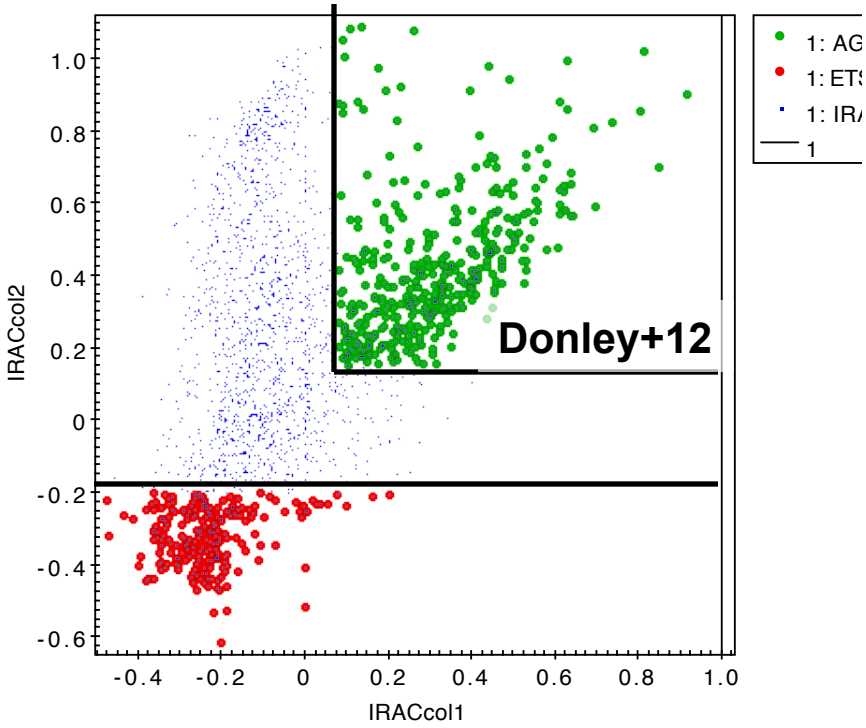
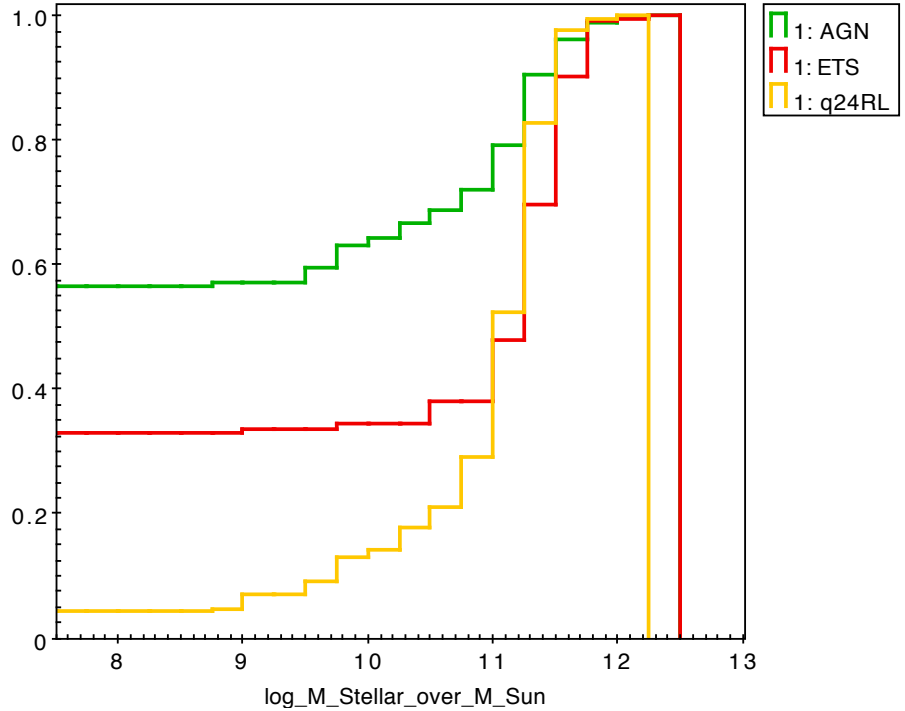
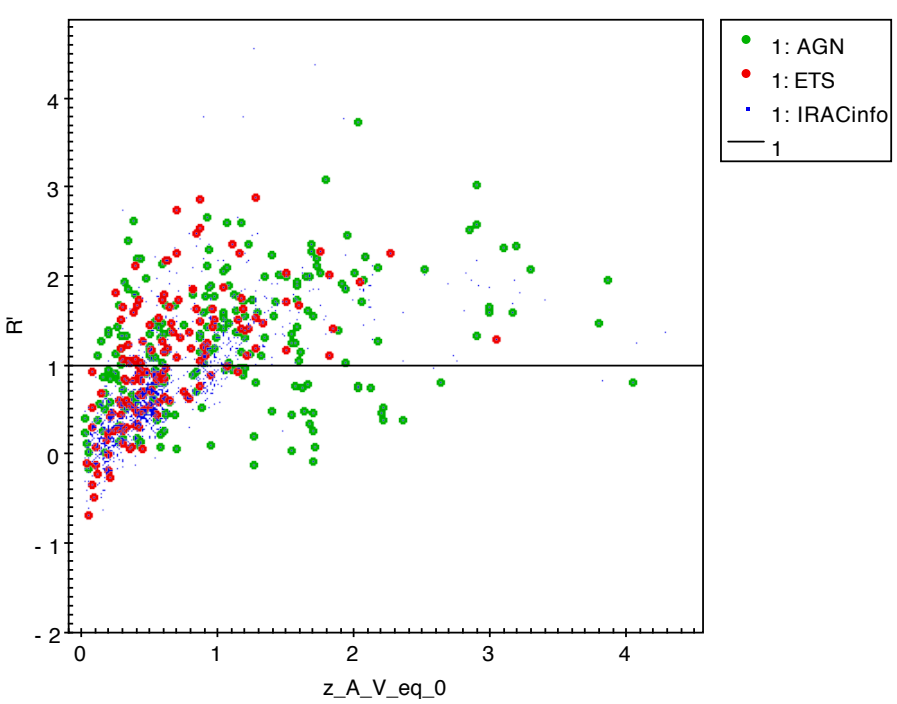
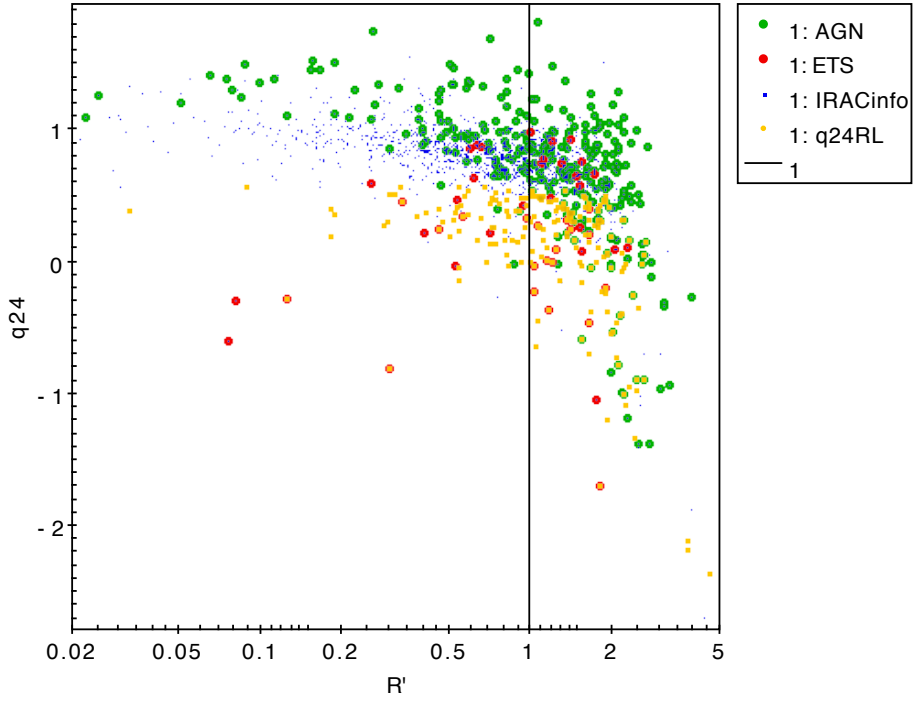




LH – AGN component

- R'=0.4(i-t) t=-2.5log(S/3461 Jy)
- Not good match between q24 and R' radio loudness parameters

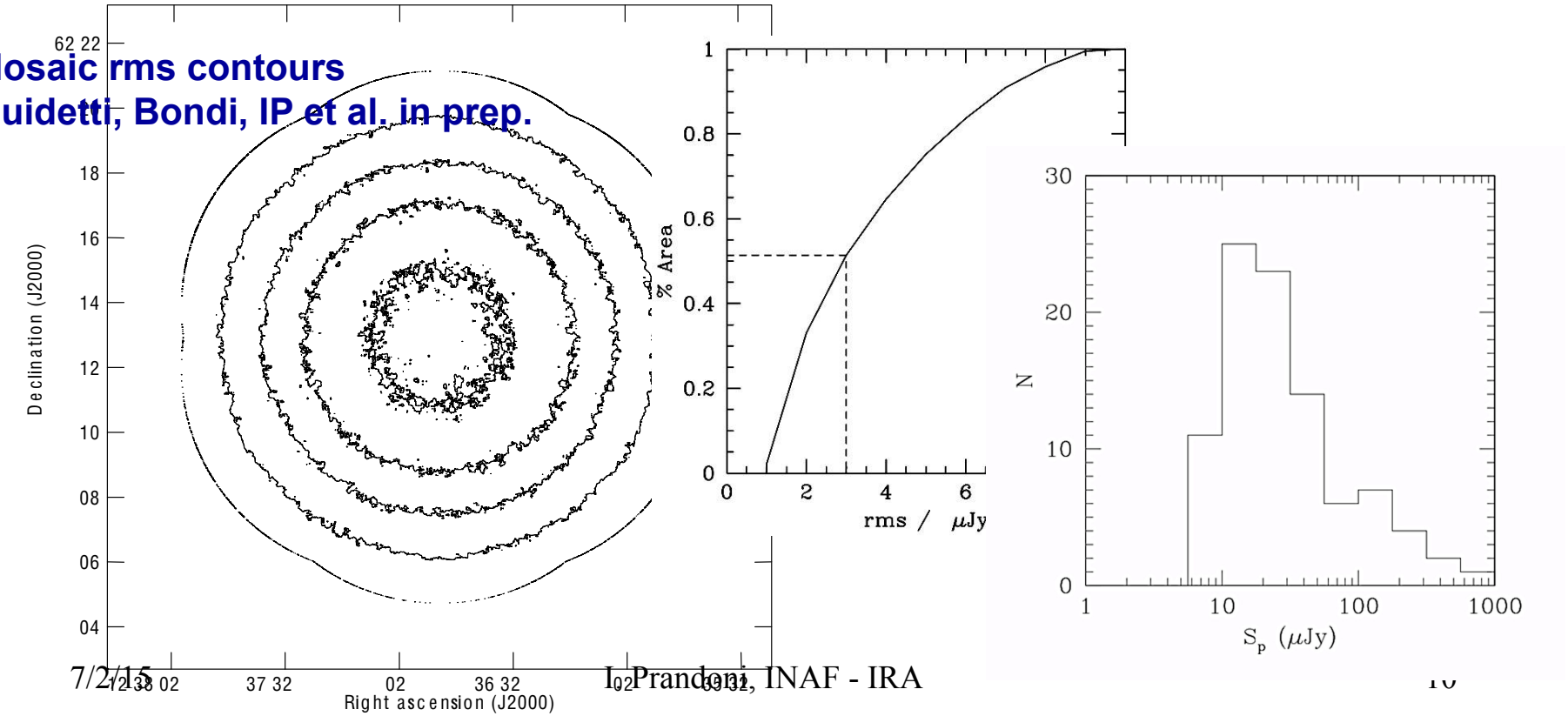




GOODS-N – JVLA 5.5 GHz Mosaic

- 14+2 hours in Array A & B [PI: Muxlow]
- 7 pointing mosaic (matching the e-MERLIN L-band FoV)
- 16 Ifs → 2048 MHz BW
- 1.4 uJy/b rms at center (50% < 3 uJy/b); 0.5 arcsec resolution (A+B arrays)
- **94 sources** at d<7 arcmin, **S>6 uJy; 50% with 10<S<30 uJy**

Mosaic rms contours
Guidetti, Bondi, IP et al. in prep.

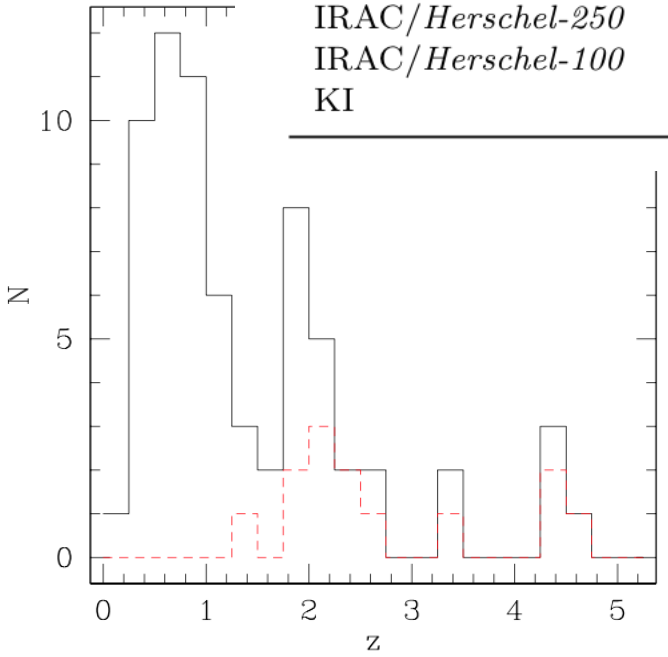


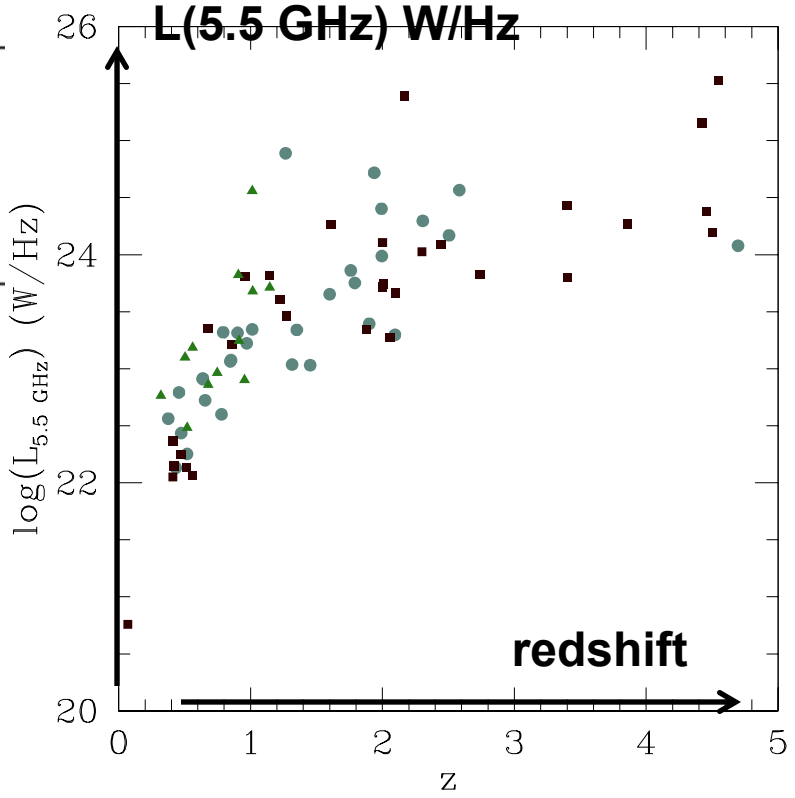
GOODS-N – Multi-band Analysis

- 82/94 (87%) secure identifications (<24 Ks AB mag) @ d<0.5 arcsec
- 68/82(86%) with redshift (13 photoz)
- 31 AGN (cold mode) + 12 AGN (hot mode) → 63% !!

AGN selection Criteria

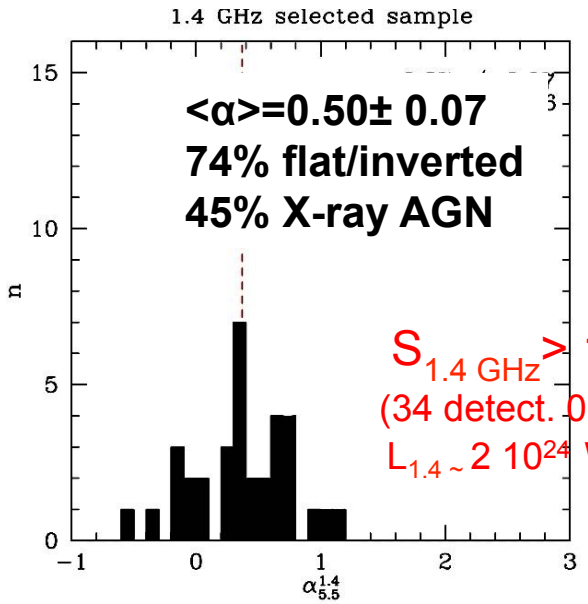
	N_c	$N_c/\sum N_c$
IRAC-Power-law	12	0.36
IRAC-Stern	18	0.55
IRAC/*Herschel-250*	14	0.42
IRAC/*Herschel-100*	16	0.48
KI	24	0.73





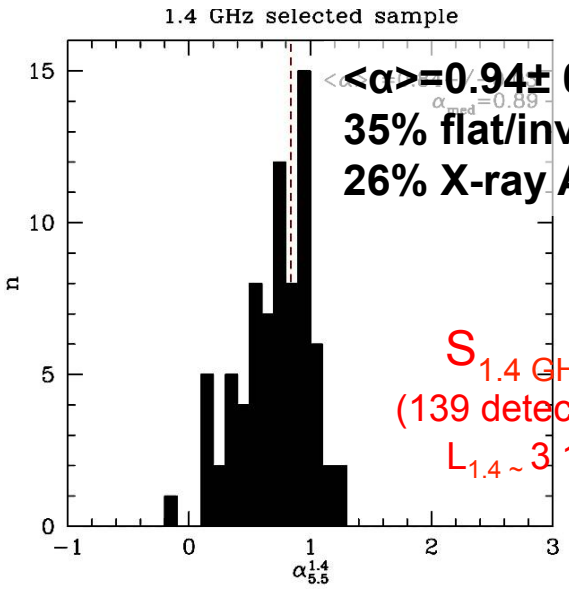
GOODS-N – Spectral Index Analysis

- 1.4 GHz information from VLA catalogue (Morrison et al. 2010):
  → 300 sources with S>20 uJy (1.7" resolution)
- Analysis limited to compact sources:
  → 173 with size < 1 arcsec (→ ~10 kpc at z~1)
- 153/173 (88%) with NIR identification
- 139/153 (91%) with redshift
- 65/139 (47%) with X-ray Luminosity measured



$S_{1.4\ GHz} > 100\ \mu Jy$
(34 detect. 0 lower lim)
$L_{1.4} \sim 2\ 10^{24}$ W/Hz

$S \sim \nu^{\alpha}$

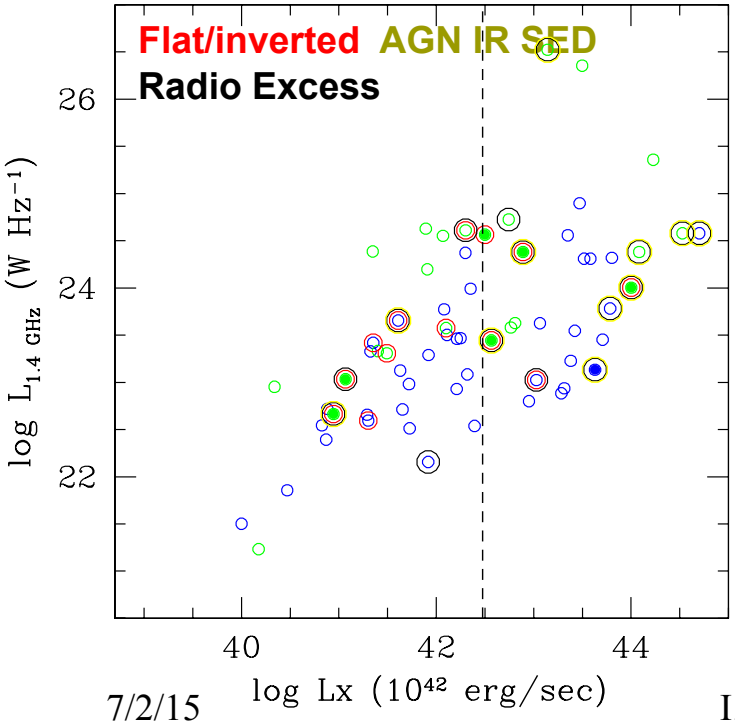


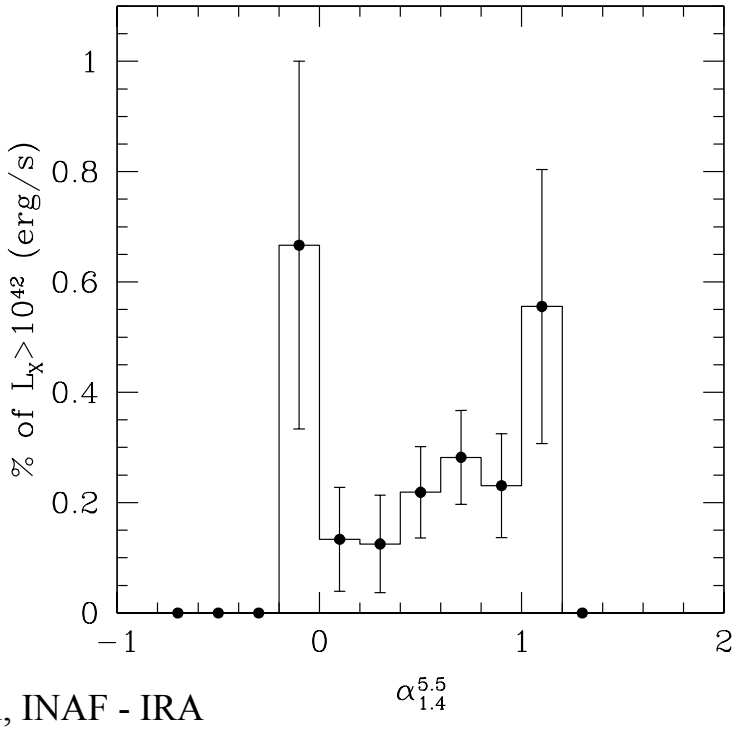
$S_{1.4\ GHz} < 100\ \mu Jy$
(139 detect. 73 lower lim)
$L_{1.4} \sim 3\ 10^{23}$ W/Hz

GOODS-N – AGN Indicators

- Flat/inverted spectra often associated to other AGN indicator
- High X-ray AGN fraction associated with inverted spectra

S>100 uJy; filled ➔ VLBI det
S<100 uJy; filled ➔ VLBI det

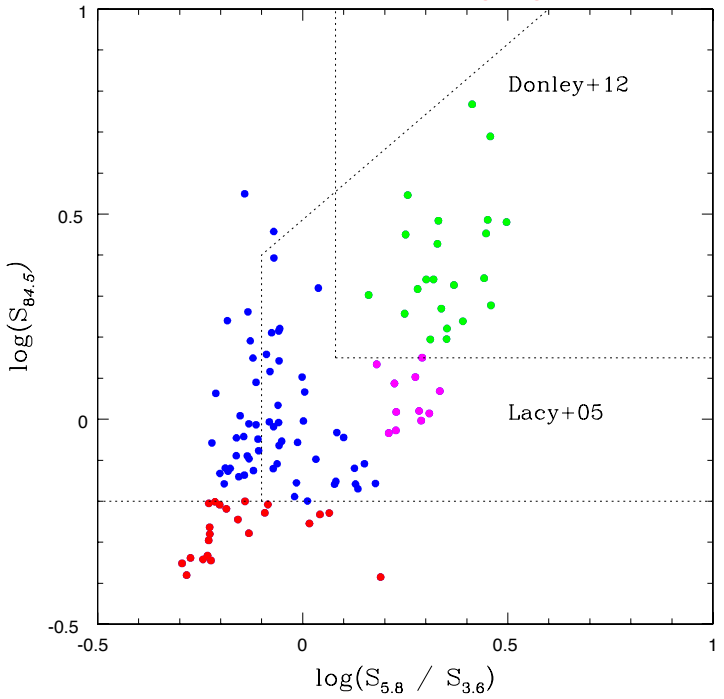


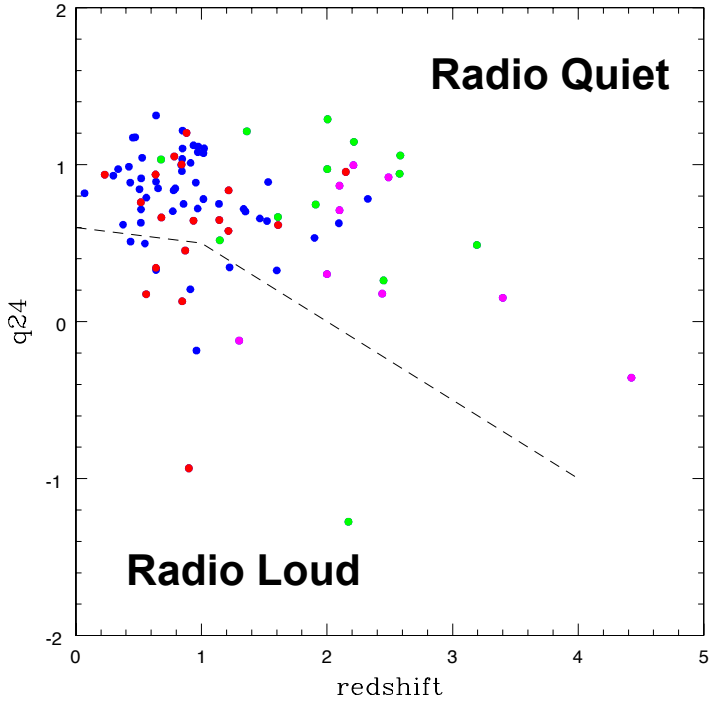


GOODS-N – Multi-band Analysis

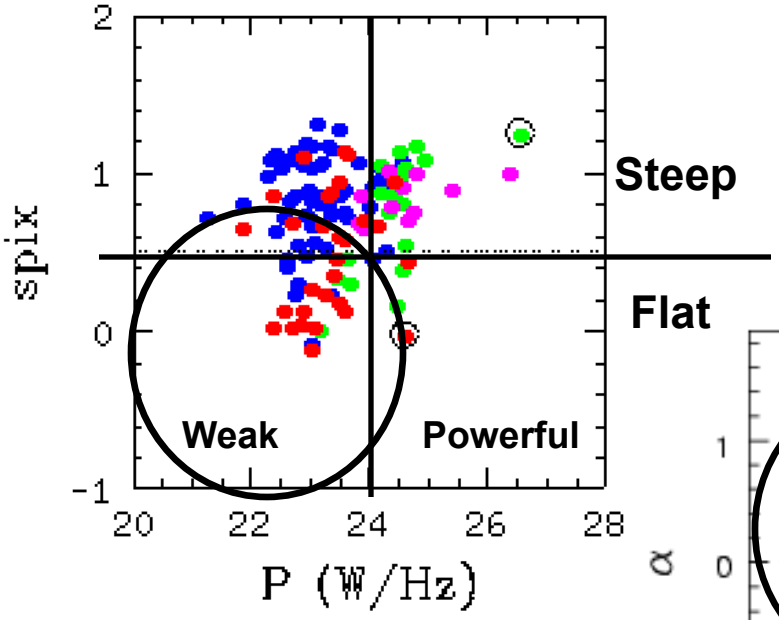
- 115 Sources with IRAC information [Slim~7 uJy]
  → 22-33 AGN cold-mode (20-30%) → 6% RL
  → 22 AGN hot-mode (20%) → 29% RL
- 40-50% of compact (<1") sources → 20-30% of full sample

AGN cold-mode (power-law)
AGN cold-mode candidate
AGN hot-mode (Early Type hosts)



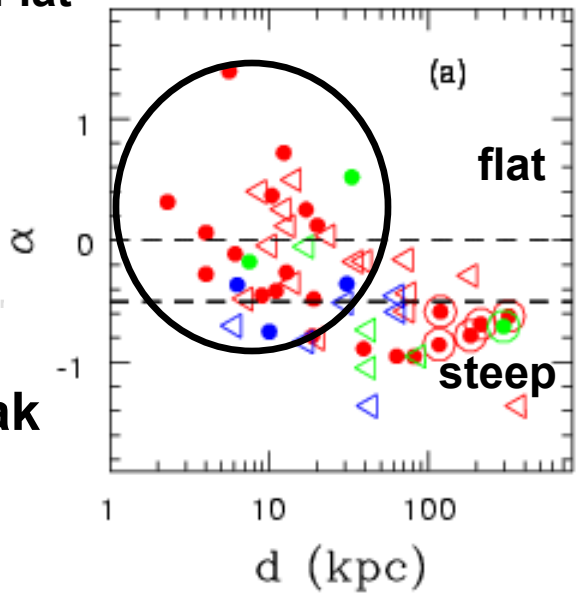


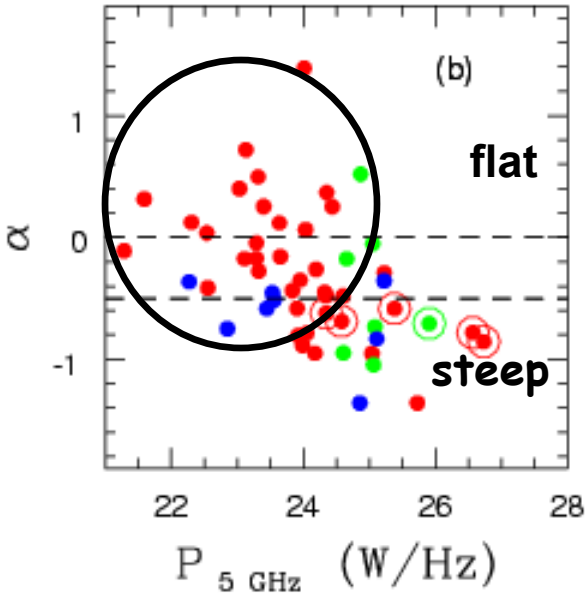
GOODS-N - Hot-Mode AGNs



ATESP 5 GHz 1deg^2 field, S_{lim}~500 uJy
Mignano, IP+ 08

ETS (64%) AGN (14%) SFGs (19%)

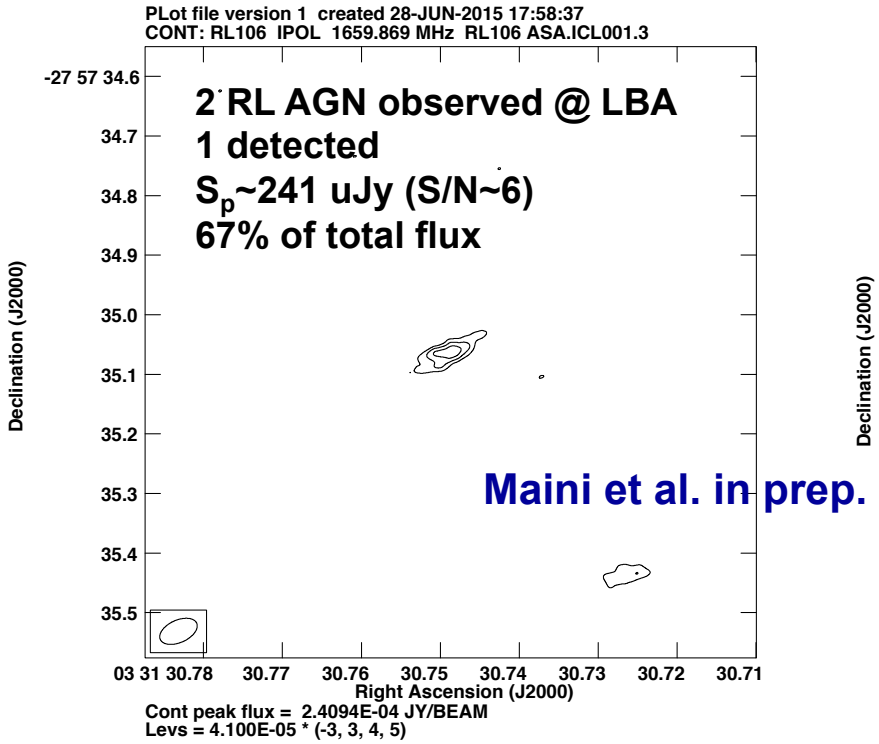




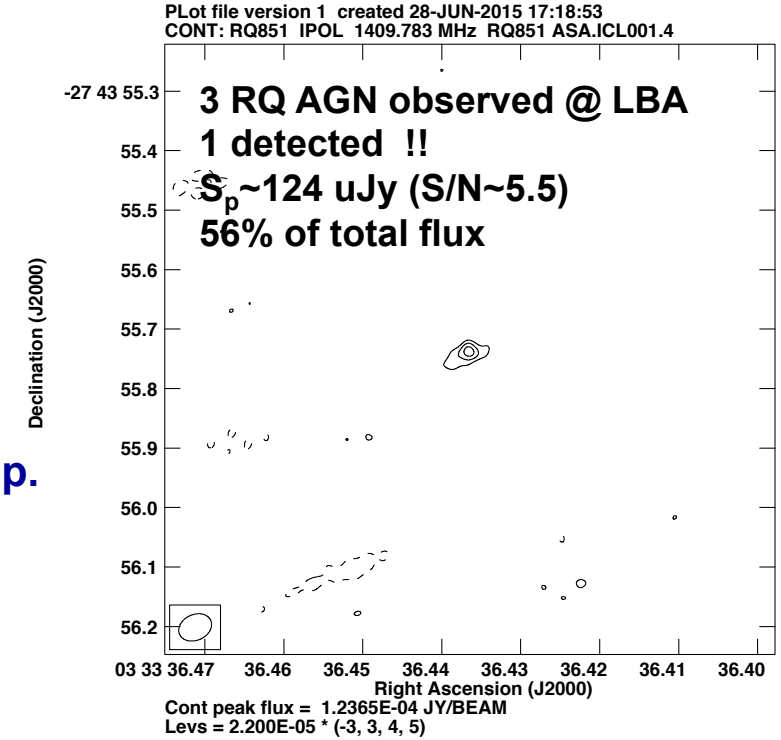
ETS: flat, compact, weak

eCDFS – Radio core detections

PREVIEW



Maini et al. in prep.



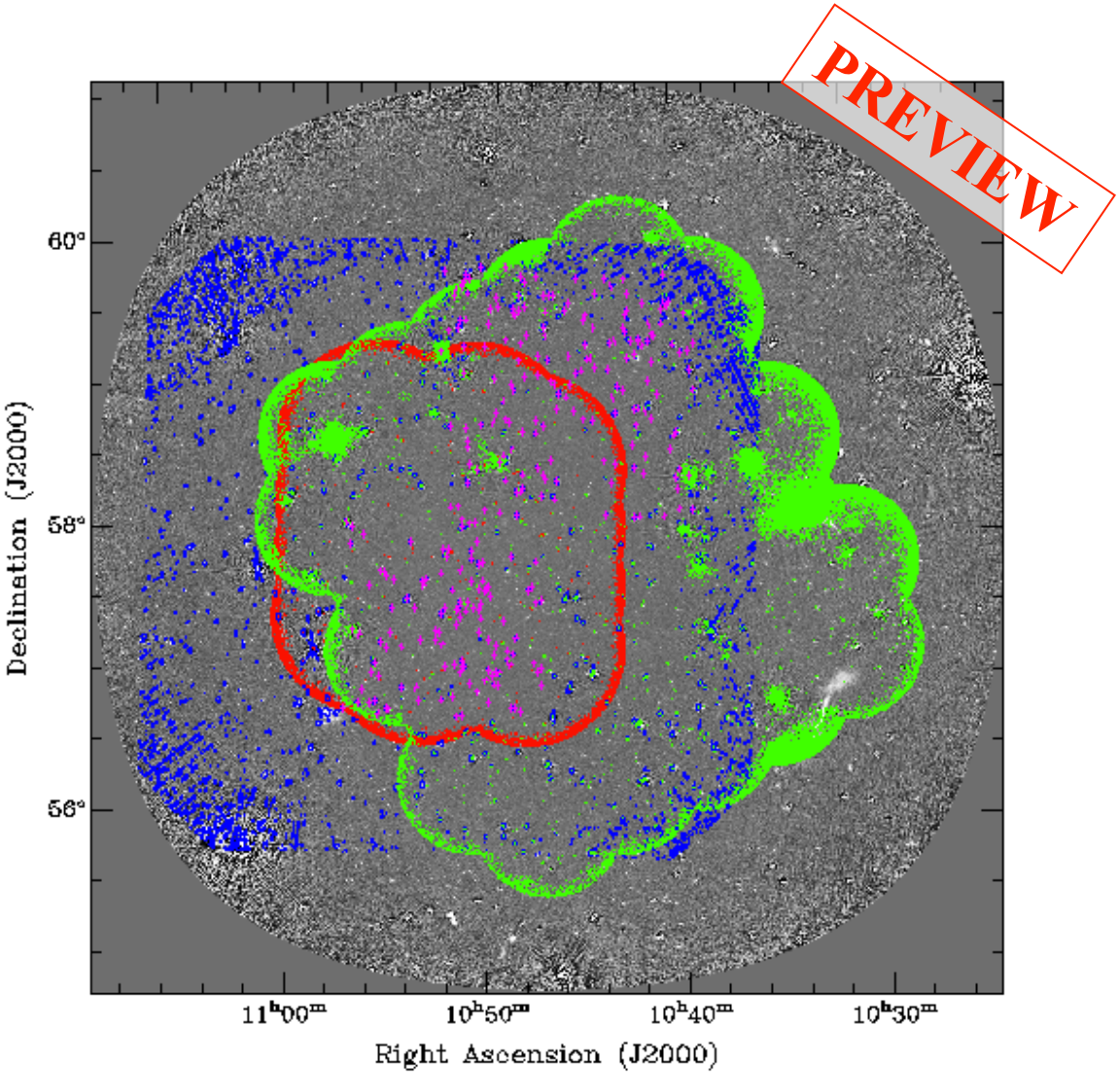
The LH Region: Multi-frequency Coverage

WSRT 1.4 GHz: 6 deg^2, 11 uJy
9x11 arcsec resolution

WSRT: 350 MHz, 0.7 mJy
GMRT: 610 MHz, 5 deg^2, 60 uJy
10C: 15 GHz, 4.5 deg^2, 0.1 mJy

LOFAR 150 MHz (10h, ~150uJy)
LOFAR 60 MHz
(Survey KP, PI P. Best)

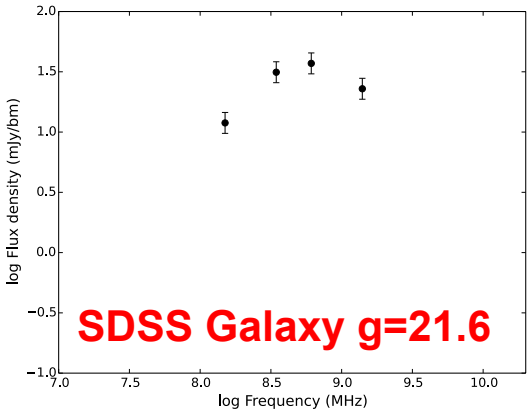
Extensive multi-band data:
PanSTARRS, UKIDSS, SERVS, SWIRE, HerMES, VLA, GMRT, WSRT, Chandra, SCUBA, SCUBA-2, Galex

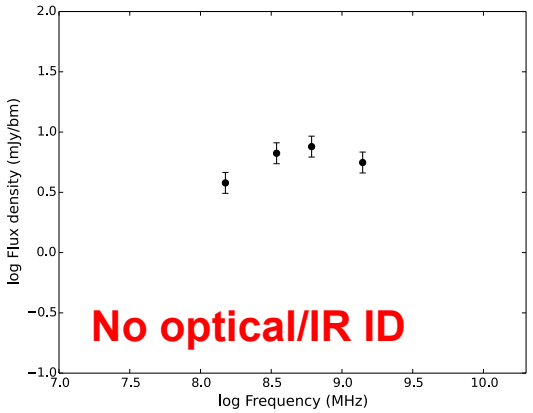


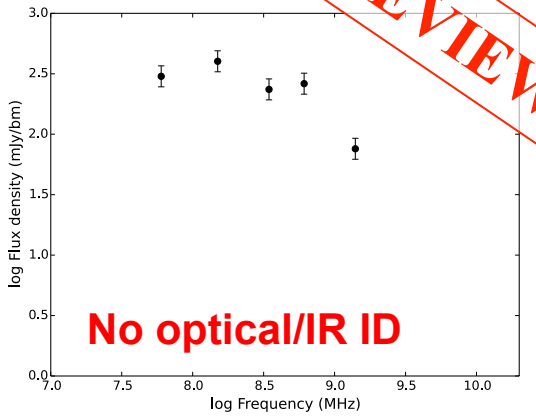
MHz-peaked spectrum sources in the LH

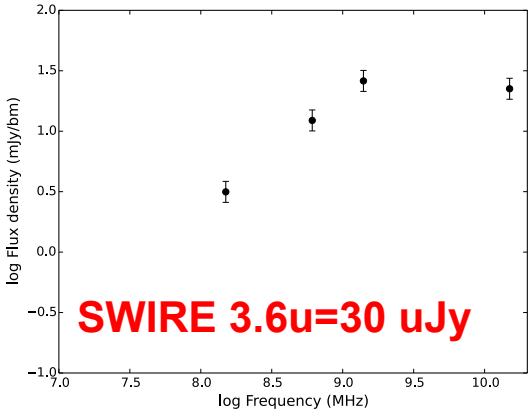
Mahony, Morganti, IP et al 2015, in prep.

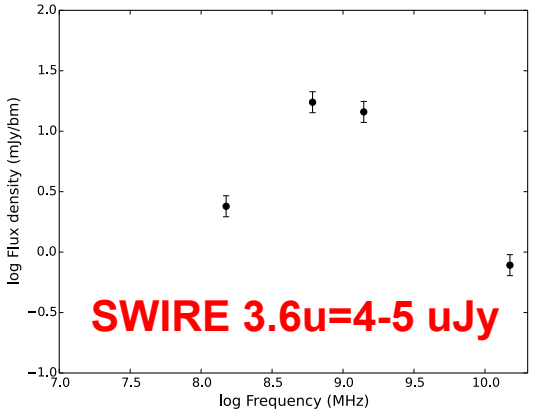
PREVIEW

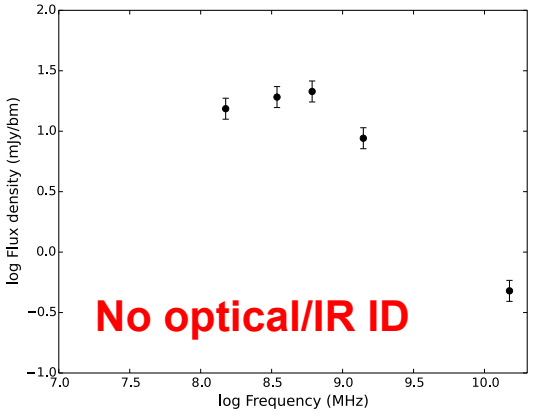












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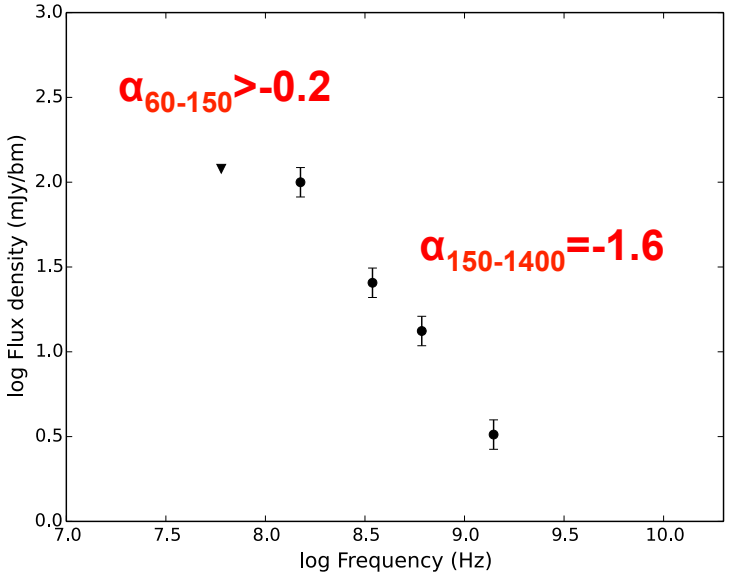

- Ultra Steep Spectrum (USS) source
  - 100 mJy at 150 MHz, very steep (α=-1.6) up to 1.4 GHz
  - No detection at 60 MHz (< 120 mJy)
  - Possible spectral peak @ 100 MHz?
  - No SDSS counterpart, 3.6um dectection at 10 uJy.

Mahony, Morganti, IP et al 2015, in prep.

Summary

- LOFAR is an ideal instrument for searching for high-z GPS candidates (where the spectral peak occurs at MHz frequencies), but need multi-frequency coverage
- In the LH we discovered 7 new GPS/CSS sources peaking at MHz frequencies → **expect > 20,000 in full LOFAR sky survey**
- AGN component still significant at uJy levels (20-30%)
- RL fraction decreases considerably, but depends on definition
- Hot-mode/RL AGN associated to massive galaxies and show flat-spectra like their brighter counterparts
- First radio core detection in a RQ AGN in eCDFS field !