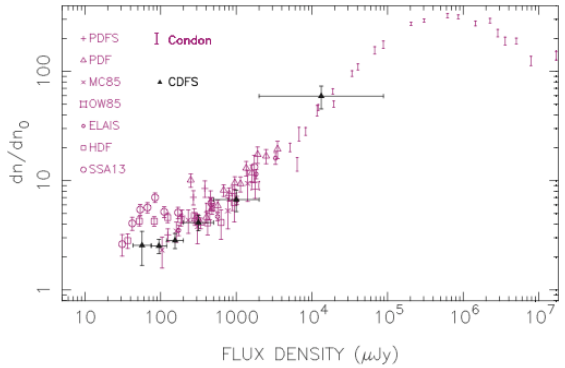
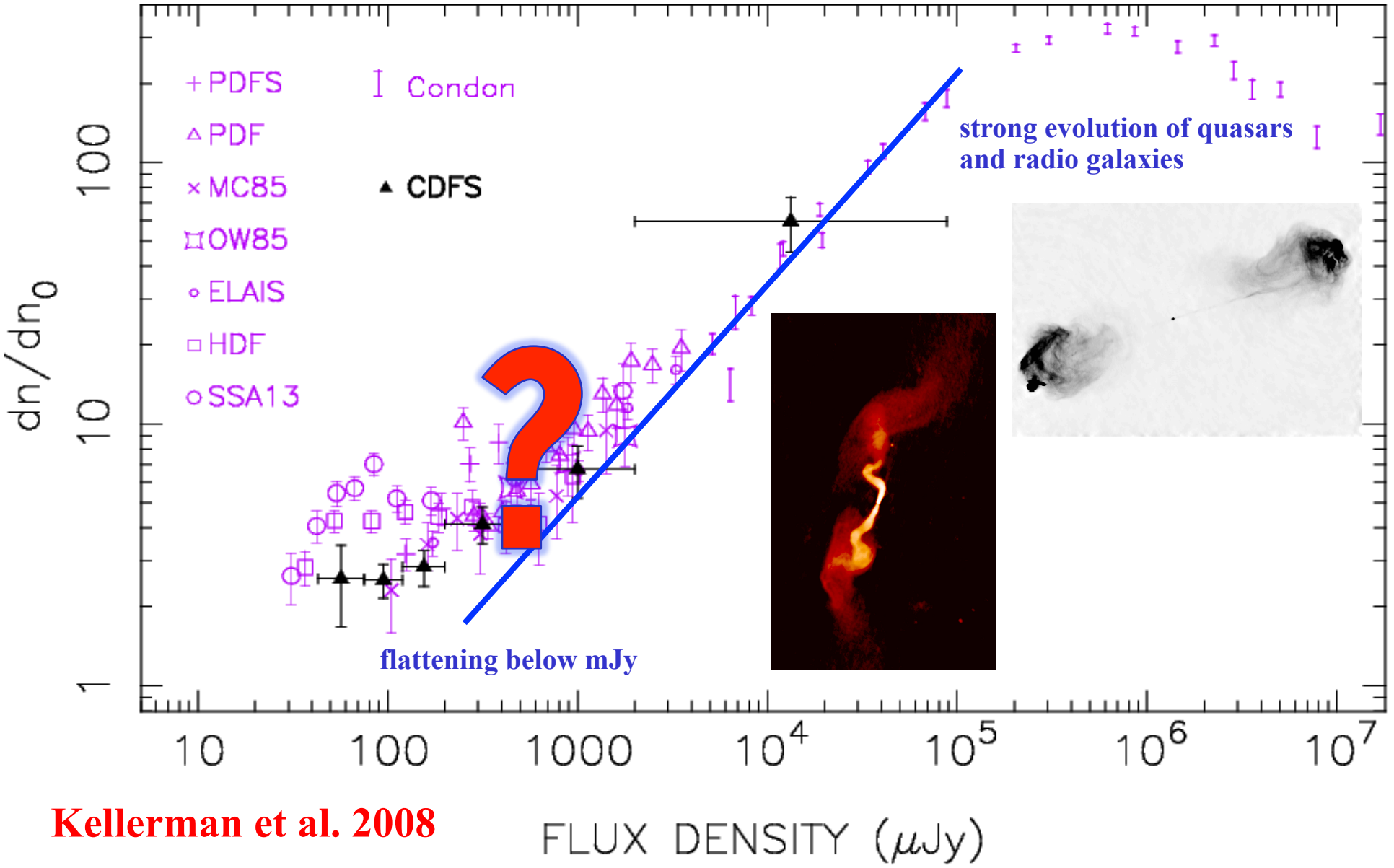


The faint radio sky: a tale of three populations

Paolo Padovani, ESO, Germany

M. Bonzini (ESO), K. Kellermann (NRAO), V. Mainieri (ESO), N. Miller (SU), Tozzi (INAF) and others

1.4 GHz number counts



Kellerman et al. 2008

Why should non–radio astronomers care about this?

- Radio emission ("radio-mode" feedback) appears to play important role in galaxy evolution (Croton et al. 2006)
- Radio-quiet AGN typically in spiral galaxies → vital contribution to our understanding of AGN – galaxy co-evolution
- Radio observations unaffected by absorption
- Need to go faint to detect the bulk of the AGN population and SFG (and not only the small minority of radio quasars and radio galaxies) → radio astronomy no longer a "niche" branch but extremely relevant to many extragalactic studies!

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Because it's going to be useful to you!

population and SFG (and not only the small minority of radio quasars and radio galaxies) → radio astronomy no longer a "niche" branch but extremely relevant to many extragalactic studies!

VLA Observations of the E-CDFS

Miller et al. (2013)

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 205:13 (15pp), 2013 April

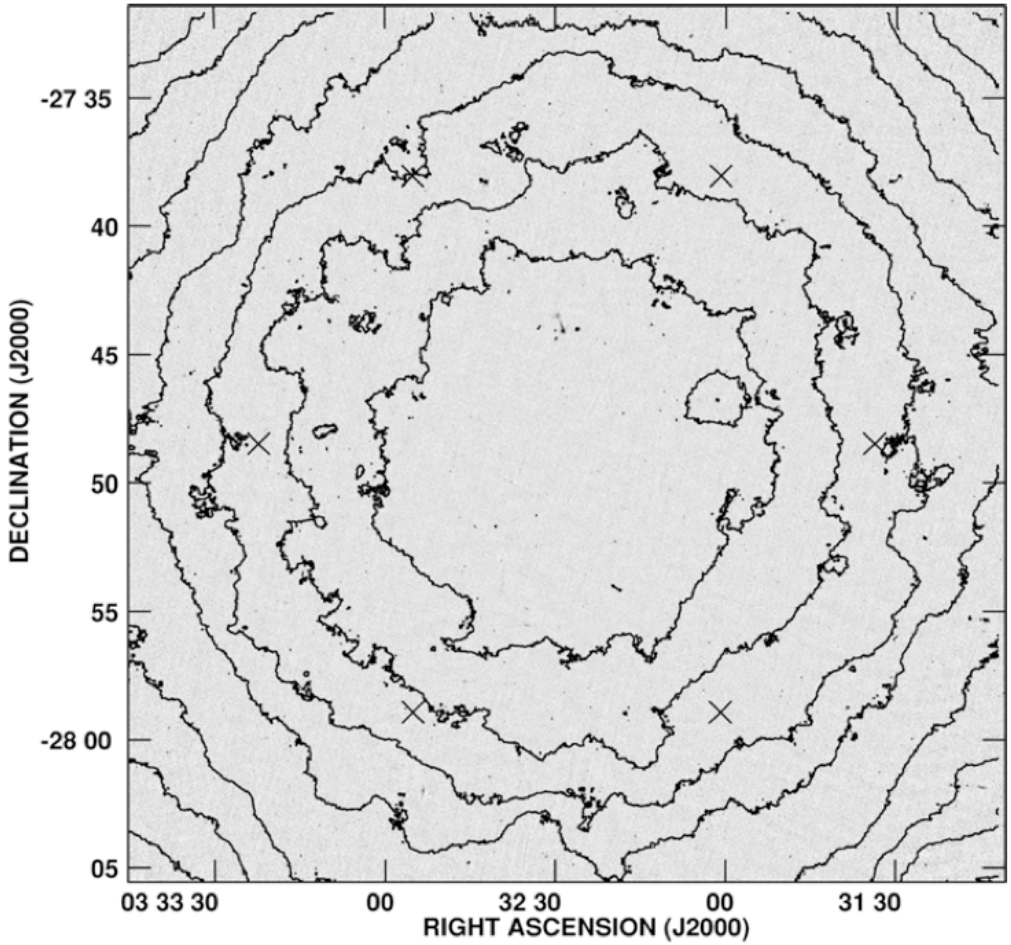


Figure 1. Gray-scale depiction of the DR2 mosaic image, with overlaid contours of constant rms noise. From the center, these contours represent 6.5 μJy, 7.0 μJy, 7.5 μJy, 8.0 μJy, 9 μJy, 10 μJy, 11 μJy, and 12 μJy beam^{-1}. The six pointing centers for the observations (Table 1) are indicated by crosses.

20 cm (6 pointings, 240 h)

θ = 2.8" x 1.6", 0.32 sq. deg.

σ_{20} = 6.4 μJy

883 radio sources

Subsample of 680 sources: redshift for ≈ 92% of them

The classification of faint (radio) sources

- … is complicated!
- … requires lots of multi-wavelength data
- … is under control: we use (Bonzini, PP, et al. 2013) slightly modified version of PP et al. (2011) scheme, which includes:
  - ✓ q_{24} value (= log [$f_{24\mu m}/f_{1.4Ghz}$]) [→ radio-loud AGN]
  - ✓ L_x [→ AGN/star-forming galaxies]
  - ✓ IRAC (near-IR) colour – colour plot [→ AGN/star-forming galaxies]
  - ✓ plus: X-ray spectra, (inverted) radio spectra, etc.
- Final result: samples of star-forming galaxies, radio-loud, and radio-quiet AGN

The μJy Radio Source Population: the VLA-CDFS View

Paolo Padovani (ESO)

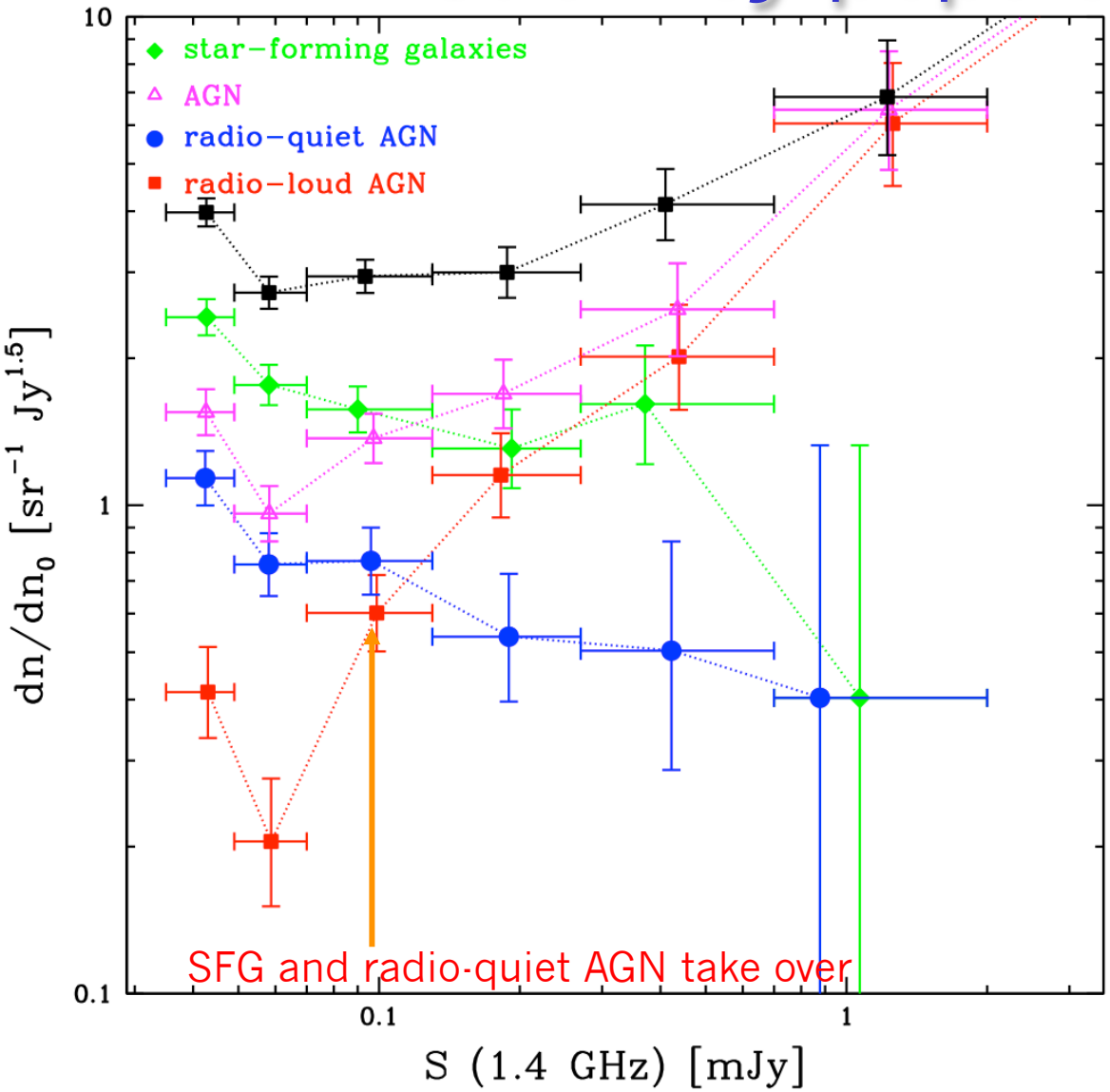
V. Mainieri* (ESO), P. Tozzi (INAF), K. Kellermann*, E. Fomalont (NRAO), N. Miller (JHU/NRAO), P. Rosati*, P. Shaver* (ESO)

- The VLA Survey of the Chandra Deep Field South
- Available data
- Source Population

- Main result: star-forming galaxies make up only ≈ 1/3 of the sub-mJy radio sources (contrary to the prevailing view)

* in the audience

Sub-mJy populations



Sub-mJy sources:

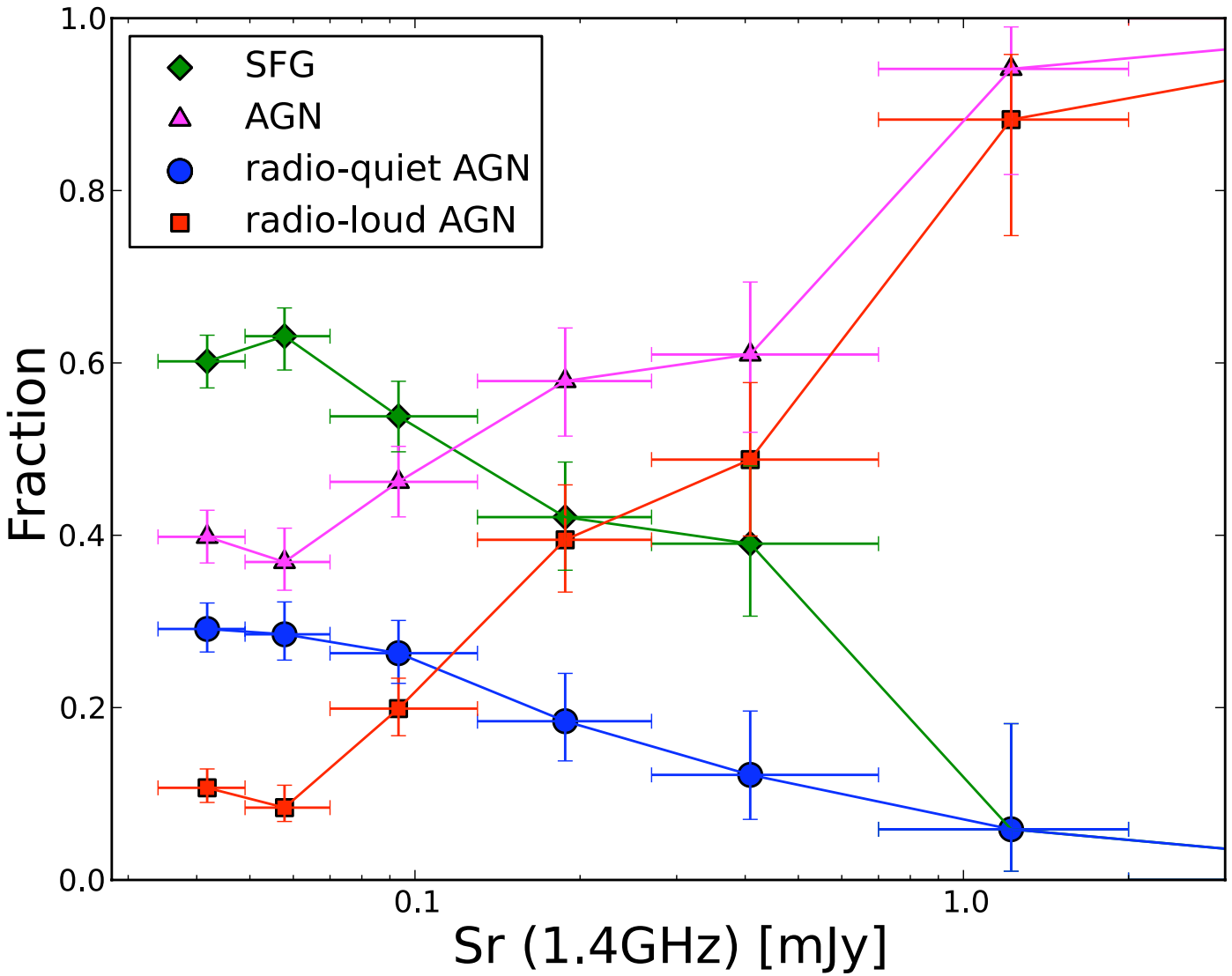
≈60% SFG **≈40% AGN**

≈40% radio-loud **≈60% radio-quiet**

(mostly low-power radio galaxies: jet-mode/LERGs/FRIs)

PP et al., submitted

Sub-mJy populations



Bonzini, PP, et al., 2013

Messages n. 1 & 2

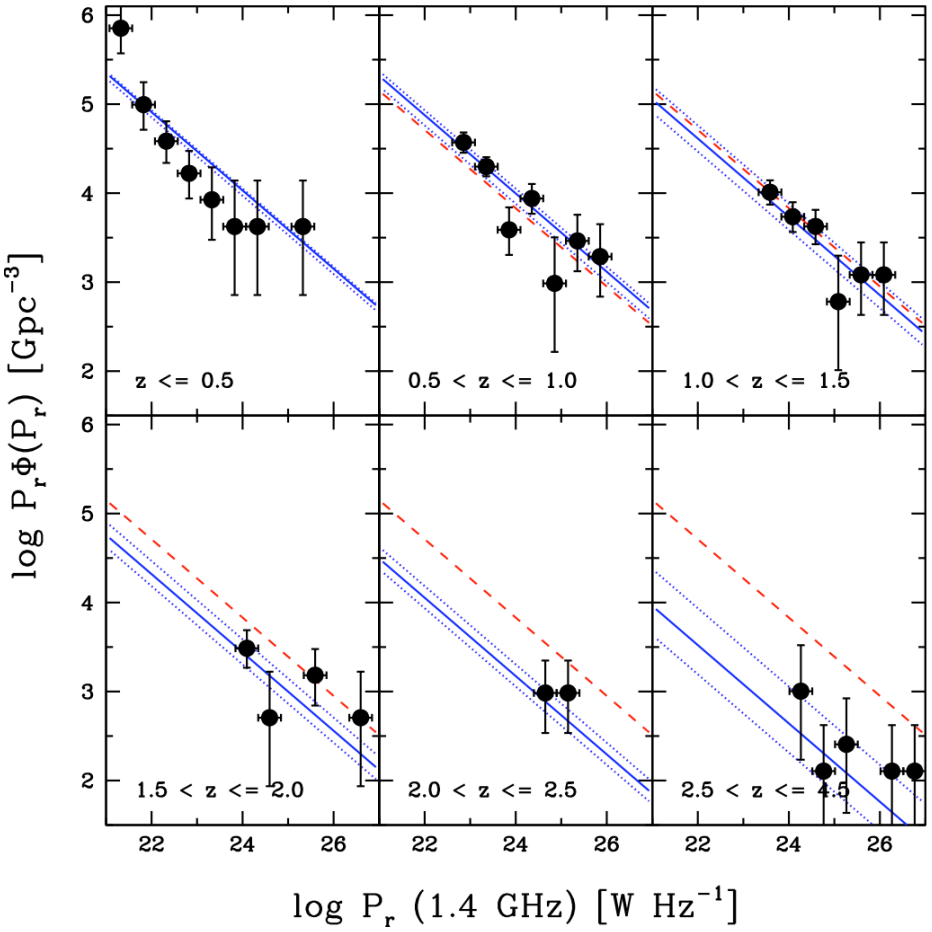
1. SFGs dominate the faint radio sky *only* below 0.1 mJy → radio jets small minority

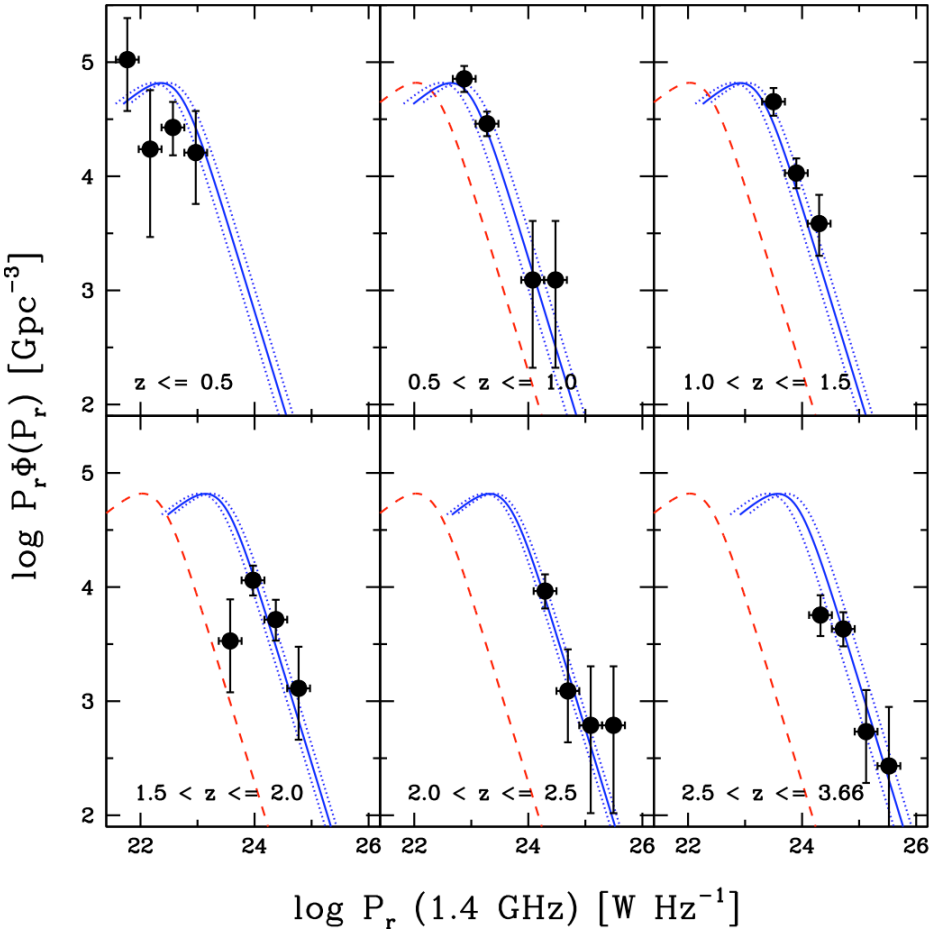
2. Still plenty of AGN in the μJy sky, mostly of the radio-quiet type (RQ AGN ~ 900/deg^2 > optical surveys)

Radio faint AGN: evolution

RL AGN

RQ AGN



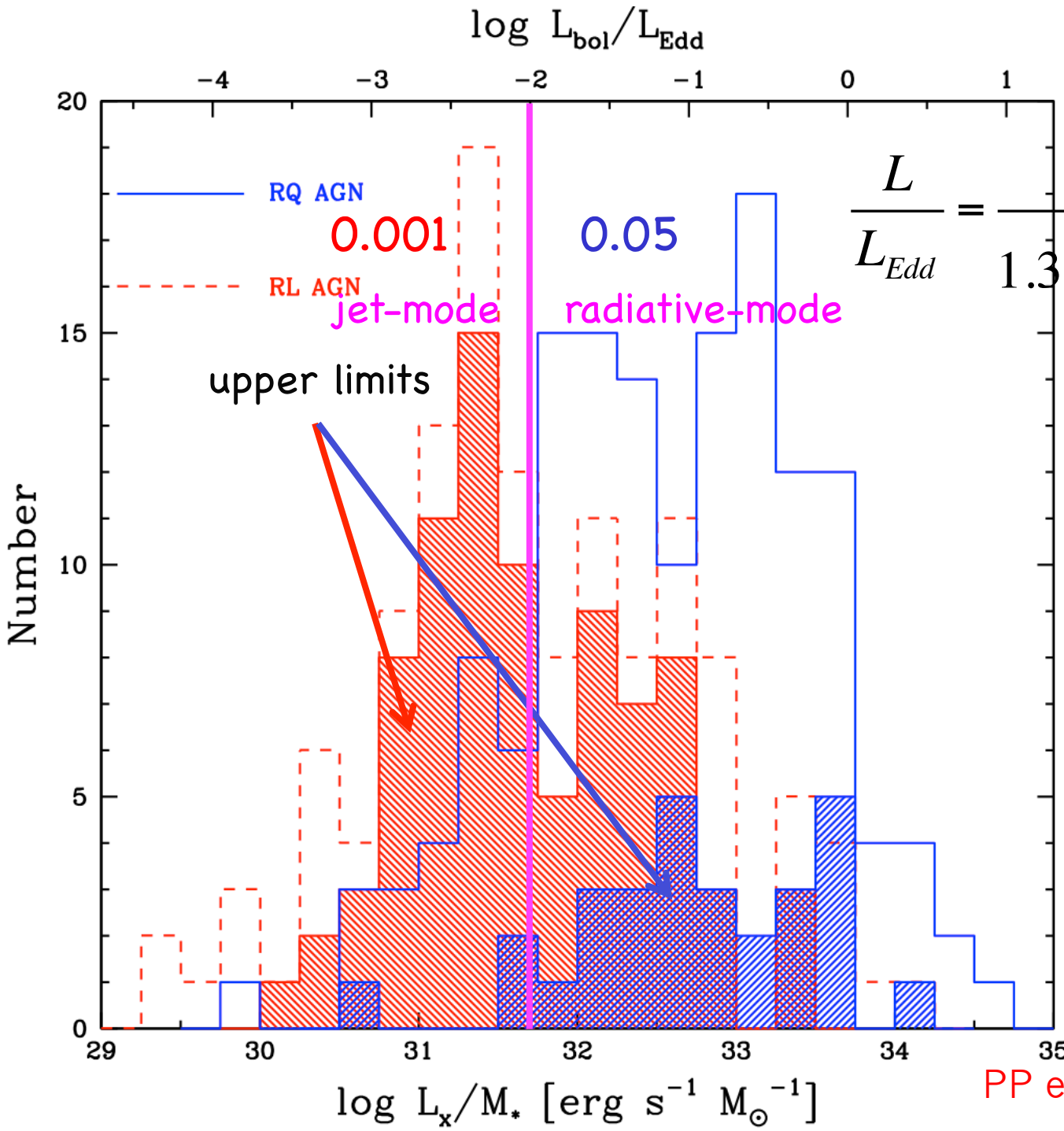


$z < 0.5$: $\Phi(z) \propto (1+z)^2$

$z > 0.5$: $\Phi(z) \propto (1+z)^{-4}$

$L(z) \propto (1+z)^{2.5}$

PP et al., submitted



$$\frac{L}{L_{Edd}} = \frac{k_{bol}}{1.3\times10^{38}\left(\frac{M_{BH}}{M_*}\right)} \times \frac{L_x}{M_*}$$

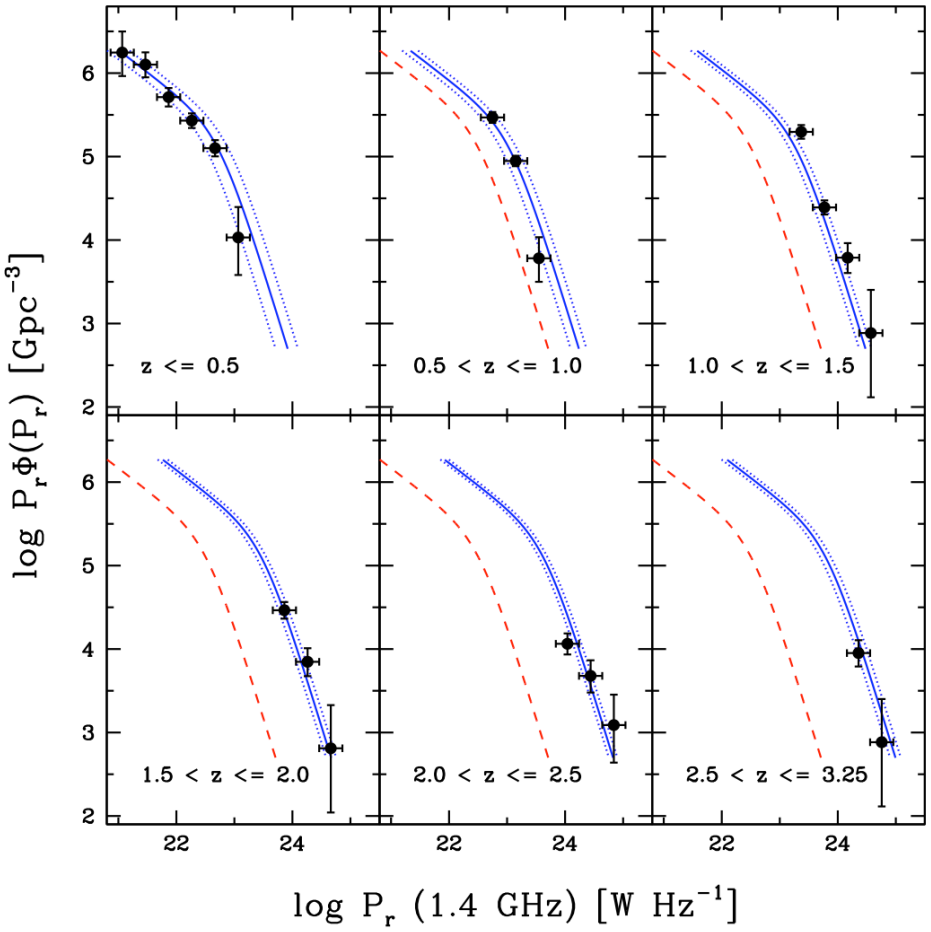
PP et al., submitted

Message n. 3

3. Faint radio sky consists of two totally distinct AGN populations:
   - ✓ RQ - radiative-mode AGN: strong evolution, steep LF, $L/L_{Edd} \gtrsim 0.01$
   - ✓ RL - jet-mode AGN: peak at z ~ 0.5 + negative evolution, flat LF, $L/L_{Edd} \lesssim 0.01$

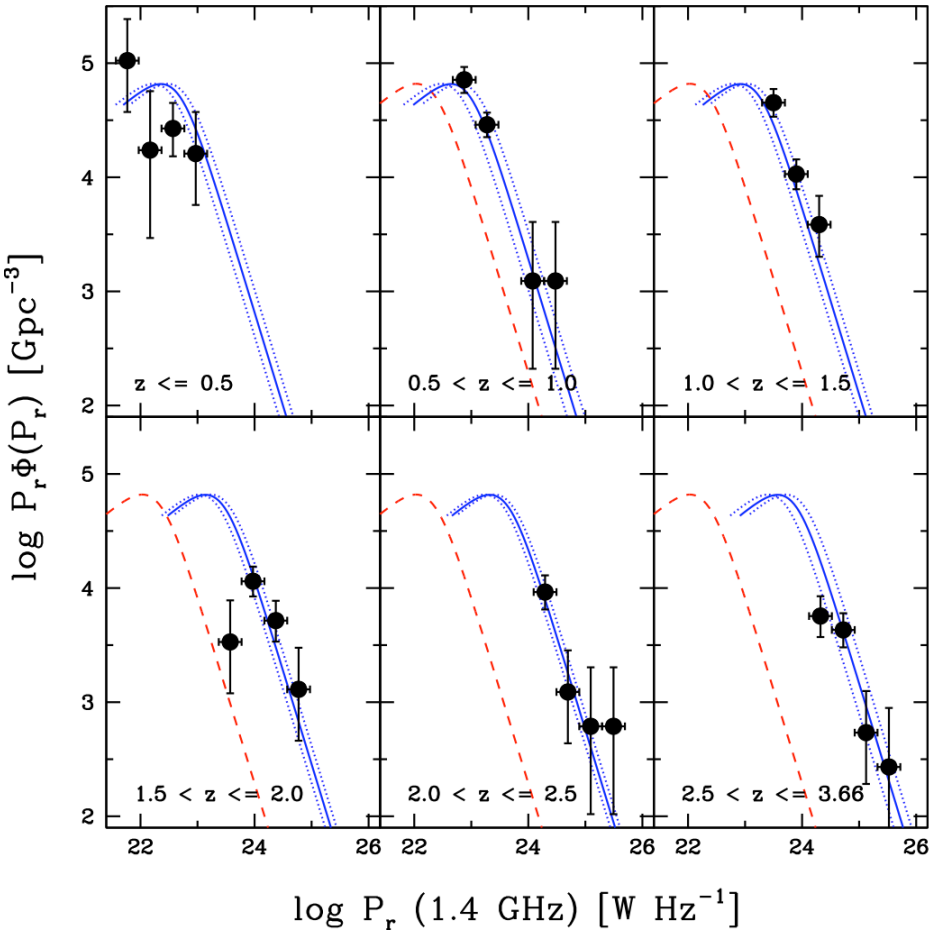
Radio faint AGN and SFG: evolution

SFG



$L(z) \propto (1+z)^{2.2\pm0.2}$

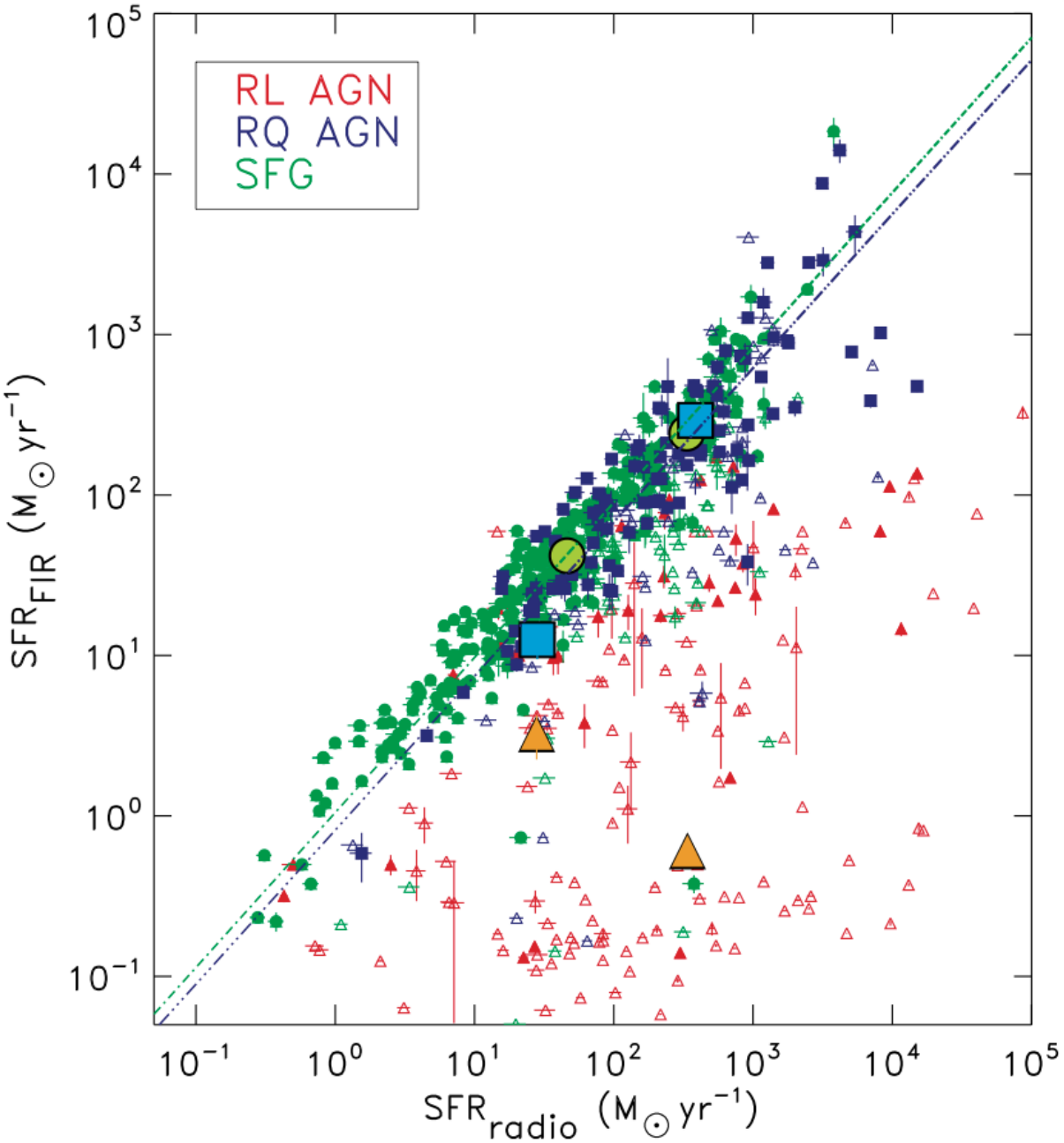
RQ AGN



$L(z) \propto (1+z)^{2.5\pm0.2}$

PP et al., submitted

Radio faint AGN and SFG: SFRs



Bonzini et al., submitted

Messages n. 4 & 5

4. SFGs and RQ AGN have similar evolutions

5. Radio power traces SFR in RQ AGN as well → radio emission SF related

Based on the following VLA-ECDFS papers:

- *The Sub-mJy Radio Population of the E-CDFS: Optical and Infrared Counterpart Identification,* Bonzini, Mainieri, PP, Kellermann, Miller, Rosati, Tozzi, Vattakunnel, et al. 2012, ApJS, 203, 15

- *The radio–X-ray relation as a star formation indicator: results from the Very Large Array–Extended Chandra Deep Field-South,* Vattakunnel, Tozzi, Matteucci, PP, Miller, Bonzini, et al. 2012, MNRAS, 420, 2190

- *The Very Large Array 1.4 GHz Survey of the Extended Chandra Deep Field South: Second Data Release,* Miller, Bonzini, Fomalont, Kellermann, Mainieri, PP, Rosati, Tozzi, Vattakunnel, 2013, ApJS, 205, 13

- *The sub-mJy radio sky in the E-CDFS: source population,* Bonzini, PP, Mainieri, Kellermann, Miller, Rosati, Tozzi, Vattakunnel, 2013, MNRAS, 436, 3759

- *Star formation properties of sub-mJy radio sources,* Bonzini, Mainieri, PP, Andreani, Berta, Bethermin, Lutz, et al. 2014, MNRAS, submitted

- *Radio faint AGN: a tale of two populations,* PP, et al., 2015, MNRAS, submitted

+ a paper in prep. on SFG

plus six VLA-CDFS papers

Main message (for non-radio astronomers)

- Radio surveys have got really deep: while previously only useful for RL AGN, now detecting plenty of SF galaxies and RQ AGN

- Radio surveys now dominated by the same galaxies studied by IR, optical, and X-ray surveys

- Next-generation radio surveys (by the Square Kilometre Array and its precursors) will play an increasingly important role in multi-wavelength studies of galaxy evolution

Messages

1. SFGs dominate the faint radio sky below 1 mJy → no more radio jets
2. Still plenty of AGN in the μJy sky, mostly of the radio-quiet type
3. Faint radio sky consists of two totally distinct AGN populations:
   - ✓ RQ - radiative-mode AGN: strong evolution, steep LF, $L/L_{Edd} \gtrsim 0.01$
   - ✓ RL - jet-mode AGN: peak at z ~ 0.5 + negative evolution, flat LF, $L/L_{Edd} \lesssim 0.01$
4. SFGs and RQ AGN have similar evolutions
5. Radio power traces SFR in RQ AGN as well → radio emission SF related