IV Estrela Workshop, January 19-22 Bologna

RADIO SURVEY

a brief report on the research carried out in Bologna

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Definition of Survey

(adapted from Wikipedia)

- Extensive imaging of regions of sky.
- Generally performed for the production of an astronomical catalog for a specific type of astronomical objects
- Usually restricted to one band of e.m. spectrum (e.g. optical or radio) or to measurements of flux of one type of particle (e.g. cosmic rays)
- Over the last ten years it has became commonplace to conduct surveys that join together different observations of a given region of the sky, obtained with different telescopes at different wavelengths (multi-wavelength approach)

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- Cons (but see later):
  - Not possible for radio emission alone to determine redshift or even distinguish between AGNs and galaxies
  - Only a small fractions of optical objects (AGNs and galaxies) are radio-loud

Content of the talk

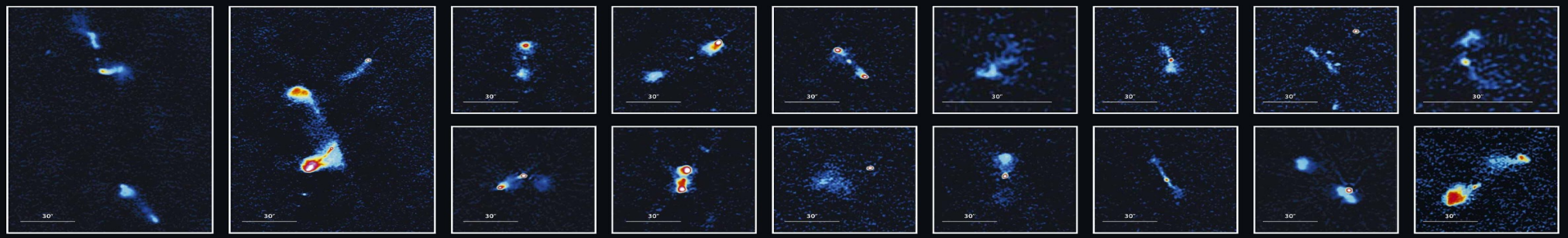
- What is not in this talk:
  - Historical approach
  - How radio surveys are done
  - All-sky surveys
- What is in this talk:
  - Some selected results from deep radio surveys carried out by research groups in Bologna (IRA + Observatory)

How a radio deep field looks like

Montage by E. Schinnerer

Deep Fields Projects

- Multi band (from radio to X-rays) very deep observations of small regions in the sky (< 1-2 degrees)
- Principal goals of radio observations:
  - Sub-mJy radio source counts
  - Radio spectral properties of sub-mJy populations as a probe of AGN or star formation origin of radio emission
  - Star formation rate history
  - Different evolutionary properties of radio emitting and not radio emitting galaxies



ISO-ELAIS and Lockman Hole

- ISO-ELAIS (Ciliegi et al. 1999, Ciliegi et al. 2001)
  - VLA observations at 1.4 GHz
  - Area about 4 square degree (noise not uniform)
  - Catalog of about 900 sources down to 0.135 mJy (1 mJy)
  - MIR, FIR and optical observations
- Lockman Hole (De Ruiter et al. 1997, Ciliegi et al. 2003)
  - VLA observations at 1.4 GHz and 5 GHz
  - Deep survey but on a small area
  - About 50 source with radio spectral index

ATESP Survey

(Prandoni et al. 2000, 2001, 2006; Mignano et al. 2008)

- Carried out at 1.4 GHz with the Australia Telescope Compact Array
- Large area 26x1 square degree
- Catalog of about 3000 radio source down to flux limit of 0.4 mJy
- Sub regions were followed up with radio observations at 5, 8 and 20 GHz plus multicolor optical imaging and optical spectroscopy
- Principally aimed at studying the radio spectral properties and evolutionary properties of low luminosity AGNs which dominate at the flux density probed by the ATESP survey

VVDS Radio Survey

(Bondi et al. 2003, 2007; Ciliegi et al. 2005; Bardelli et al. 2009)

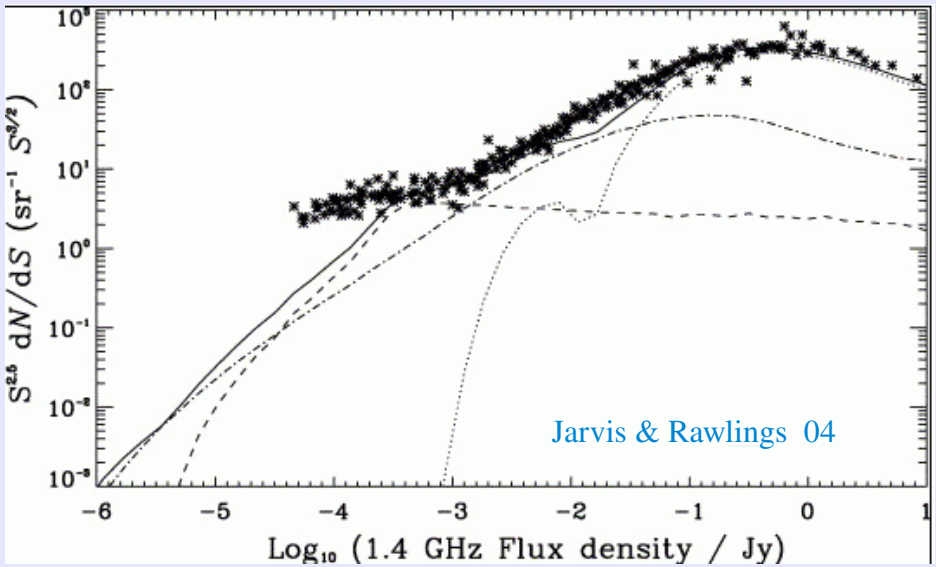
- Carried out with the VLA at 1.4 GHz and GMRT at 0.6 GHz
- Survey area: 1 square degree
- Catalog of about 1100 radio sources down to flux limit 0.1 mJy
- The whole area was followed up by multicolor optical and NIR imaging plus optical spectroscopy
- Aimed at obtaining the radio source counts down to 0.1 mJy and the radio spectral properties of the sub-mJy population.

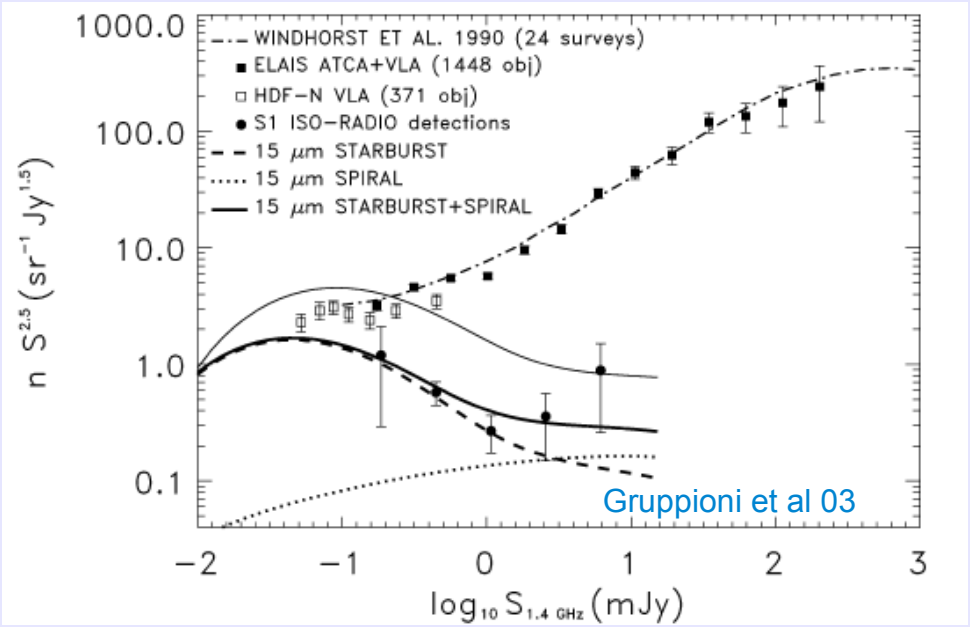
COSMOS-VLA Survey

(Schinnerer et al. 07; Bondi et al. 08; Ciliegi et al. 09; Smolcic et al. 09)

- VLA observations at 1.4 GHz
- 2 square degree region
- Catalog of about 2500 radio sources down to 0.06 mJy
- Massive broad-band multi-wavelength coverage and optical spectroscopy follow-up
- Main goals:
  - Star formation history up to redshift 1.5
  - Determination of the faint end of radio luminosity function
  - Redshift evolution, parent galaxy properties and environmental effects for radio loud and radio quiet objects can be addressed

Results: Radio Source Counts





- AGN and starburst contribution to the sub-mJy population
- First interpretation of change in the slope of sub-mJy counts was an evolving population of starbursts.
- Now it is clear that a mixing of different populations is responsible for the flattening

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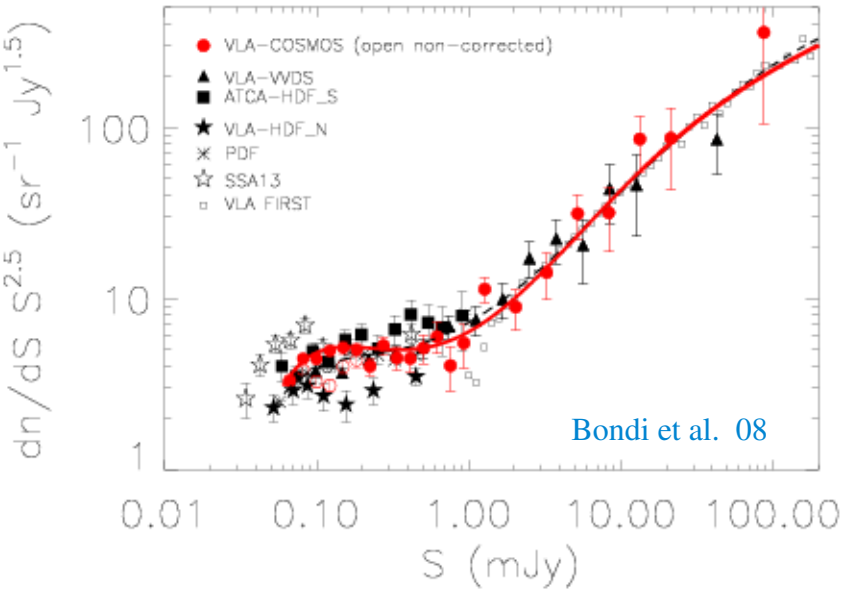
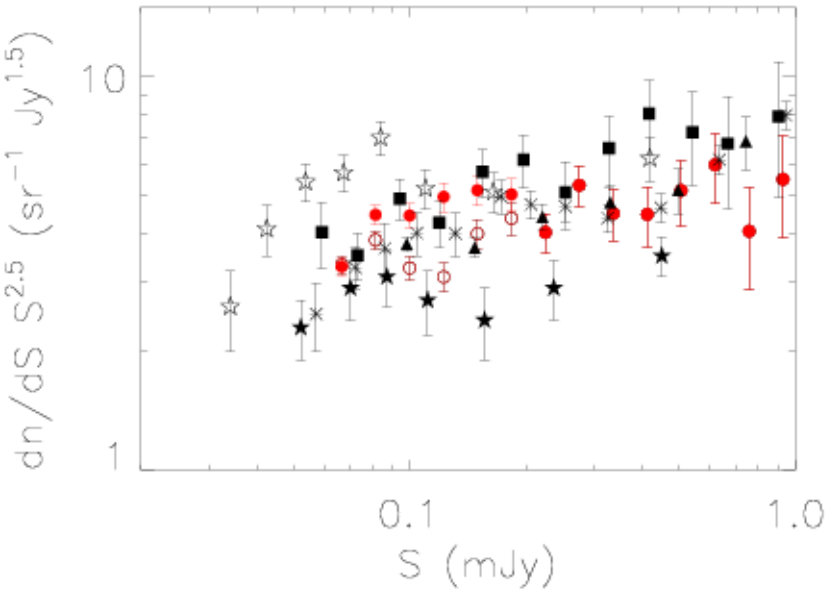




- Wide scatter of source counts below 1 mJy from different surveys (cosmic variance & incompleteness corrections)
- Optical classification of sub-mJy sources

Flux interval 1.4 GHz (μJy)	Early type	Late type	Starburst	Total
$S < 60$	29%	34%	37%	80%
$60 \leq S < 100$	34%	32%	34%	84%
$100 \leq S < 150$	42%	32%	26%	90%
$150 \leq S < 500$	48%	33%	19%	95%
$S \geq 500$	61%	20%	19%	95%

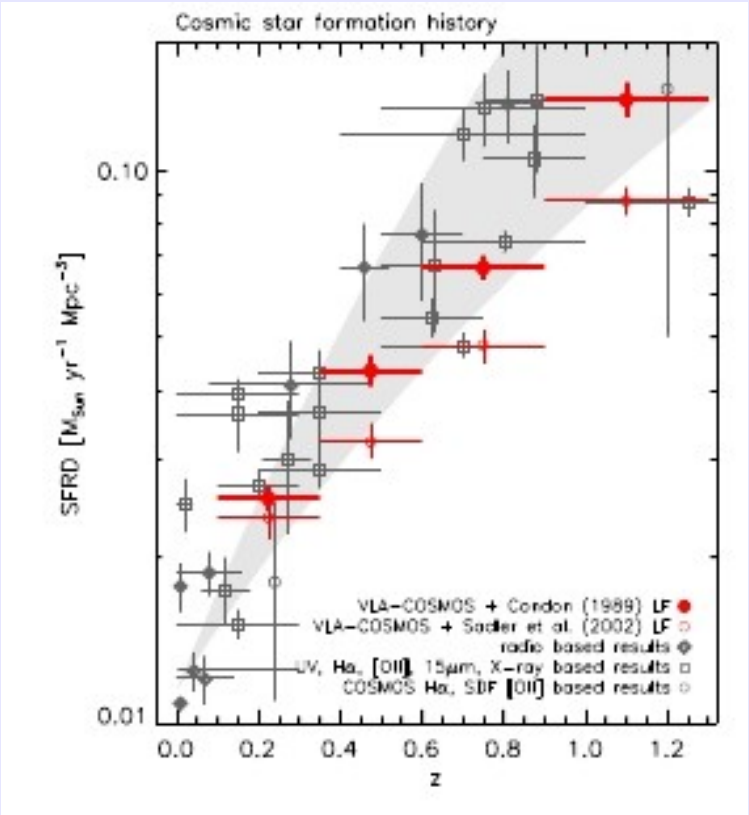
Results: radio spectral properties

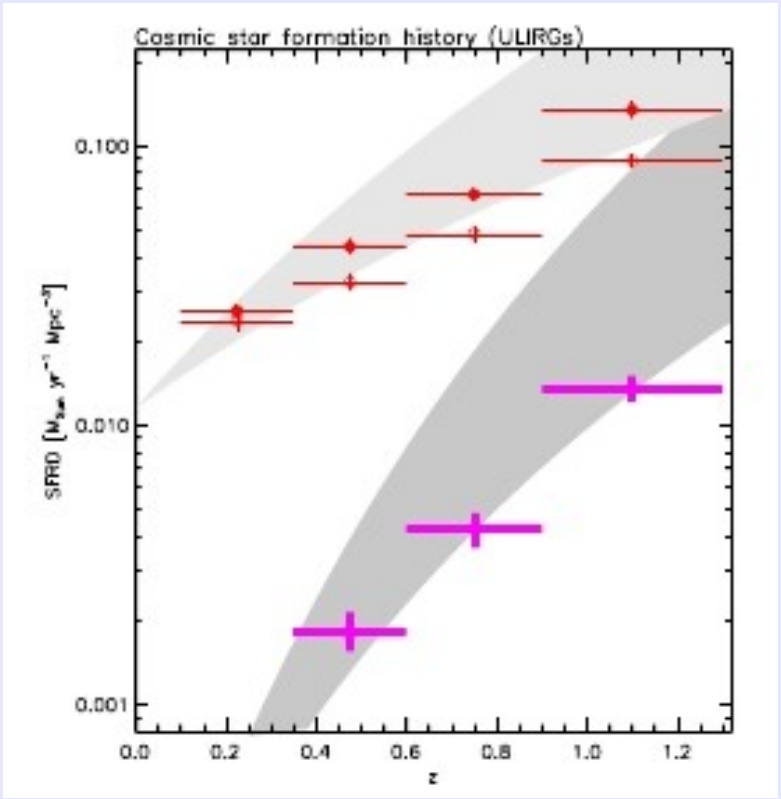
- Consistent results from Lockman Hole, ATESP & VVDS surveys: evidences of different populations at sub-mJy levels
- From VVDS VLA 1.4 GHz and GMRT 0.61 GHz observations: 812 radio sources with S(1.4 GHz) > 0.1 mJy

1.4 GHz Flux Interval (mJy)	Number of detection	Number of limits	Median α_{r_med}
$0.10 \leq S < 0.15$	171	110	-0.61 ± 0.04
$0.15 \leq S < 0.50$	304	69	-0.46 ± 0.03
$S \geq 0.50$	158	0	-0.67 ± 0.05

Optical Classification	Number of detection	Fraction of flat spectrum	Number of limits	Median α_{r_med}
Early	225	34%	65	-0.55 ± 0.04
Late	80	21%	21	-0.70 ± 0.04
Starburst	37	11%	8	-0.69 ± 0.10
Unidentified	263	34%	64	-0.59 ± 0.04

Results: cosmic SF history



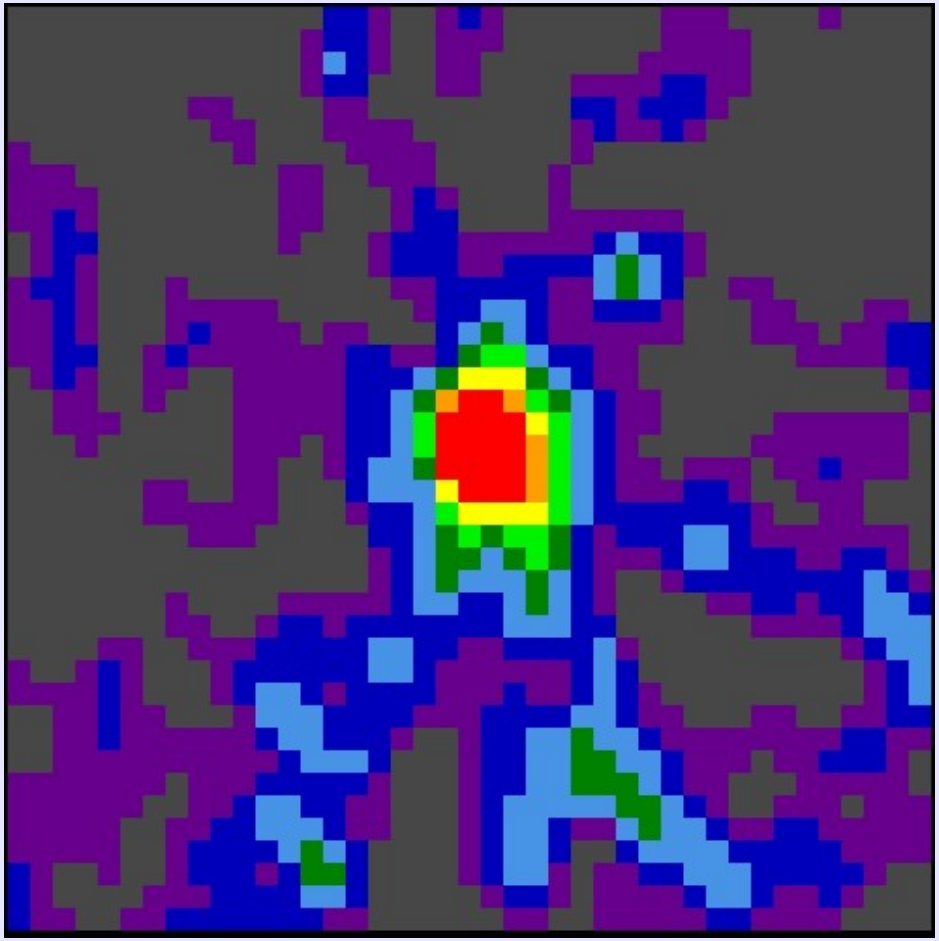


- Largest sample of radio selected star forming galaxies from the VLA-COSMOS Survey (Smolcic et al. 2009)
- Radio data consistent with the dust-corrected ones obtained from optical-UV surveys
- Somewhat slower evolution for ULIRGs with respect to MIR data

Results: radio properties of non-radio detected objects

- Only a small fraction of optical galaxies are radio detected.
- Stacking techniques can be used to derive the average radio properties of a large population of sub-threshold objects selected in a different band (optical, IR, X-rays...).
- Stacking *N* objects the noise in the stacked image can decrease by square root of *N.*
- Applied to a sample of about 800 Extremely Red Objects

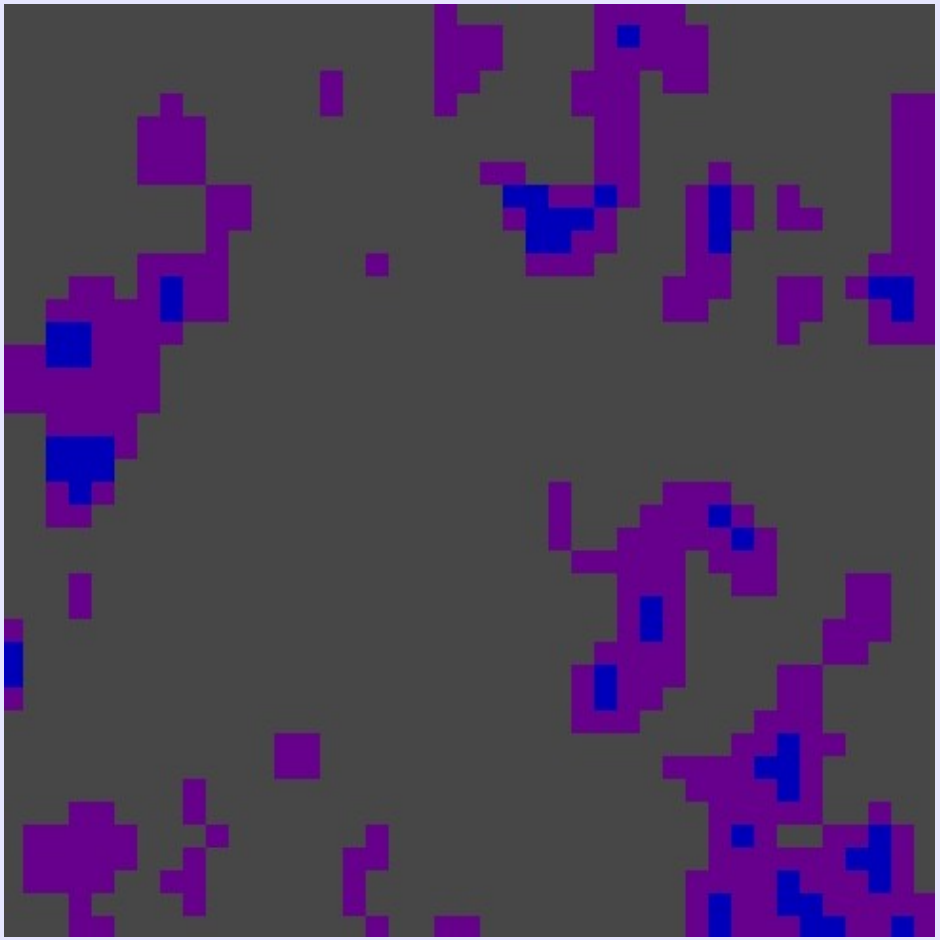
Stacking EROs



- Average of 740 fields centered on EROs with SNR<3, each field has an r.m.s = 17 μJy

Peak = 8.4 μJy
r.m.s. = 0.8 μJy
SNR = 10

Stacking Empty Fields



- Average of 740 fields centered on random position with SNR<3

Peak = 1.4 μJy
r.m.s. = 0.7 μJy
SNR = 2

Future

- The e-MERLIN Galaxy Evolution Survey:
  - Proposed as a Legacy Survey will exploit new improved capabilities of e-MERLIN at 1.4 and 5 GHz
  - couples μJy sensitivity with sub-arcsec resolution to disentangle the relative contribution of AGN and starburst within individual galaxies.

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- LOFAR All Sky Survey
  - Starting 2010
  - Will image the whole sky at 150 MHz with a sensitivity, scaled to 1.4 GHz, typical of the radio deep fields observed so far.