Netherlands Institute for Radio Astronomy

A multifaceted study of the Lockman Hole region: from HI to LOFAR

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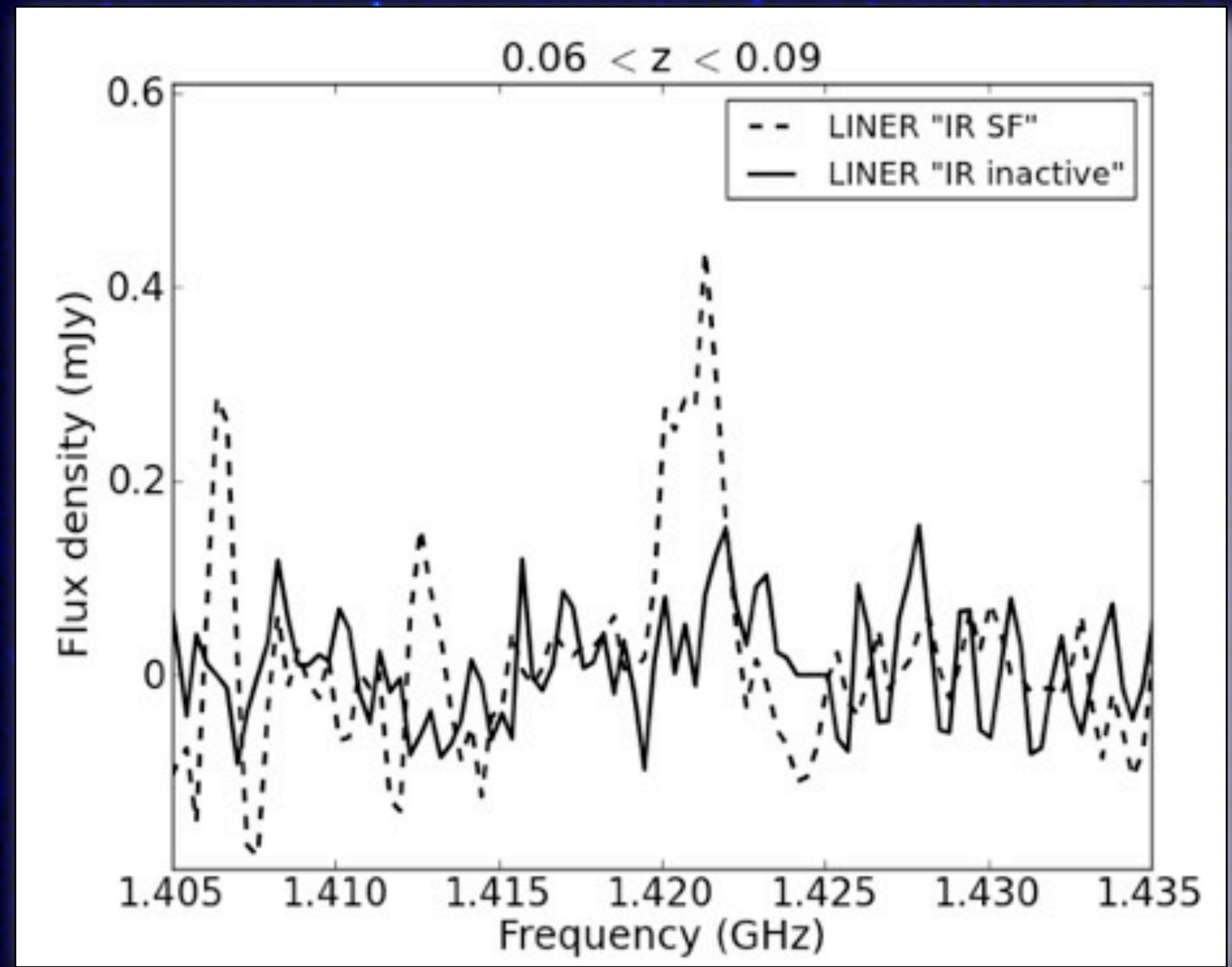
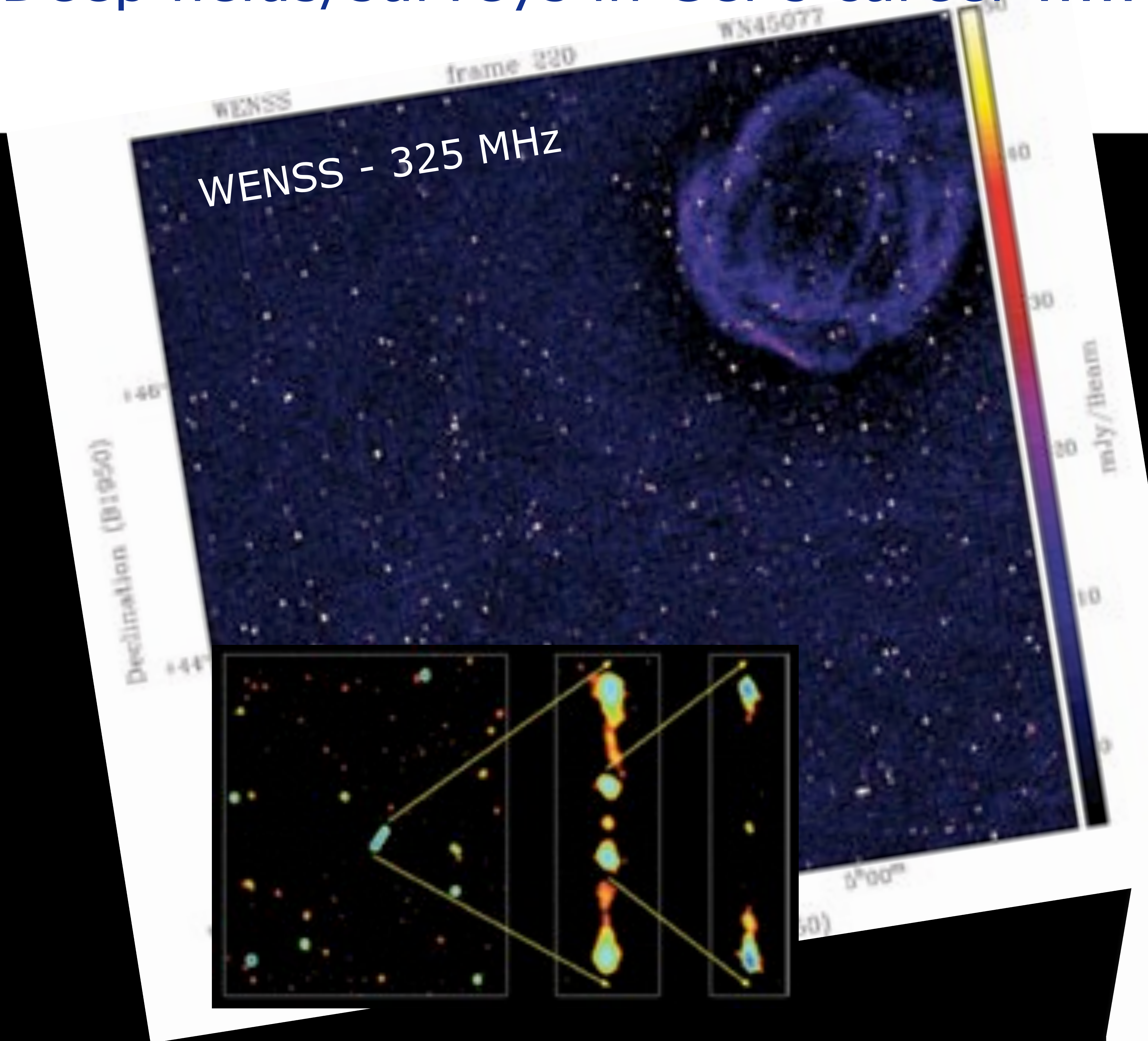
ASTRON (NL) and Kapteyn Institute (Groningen)

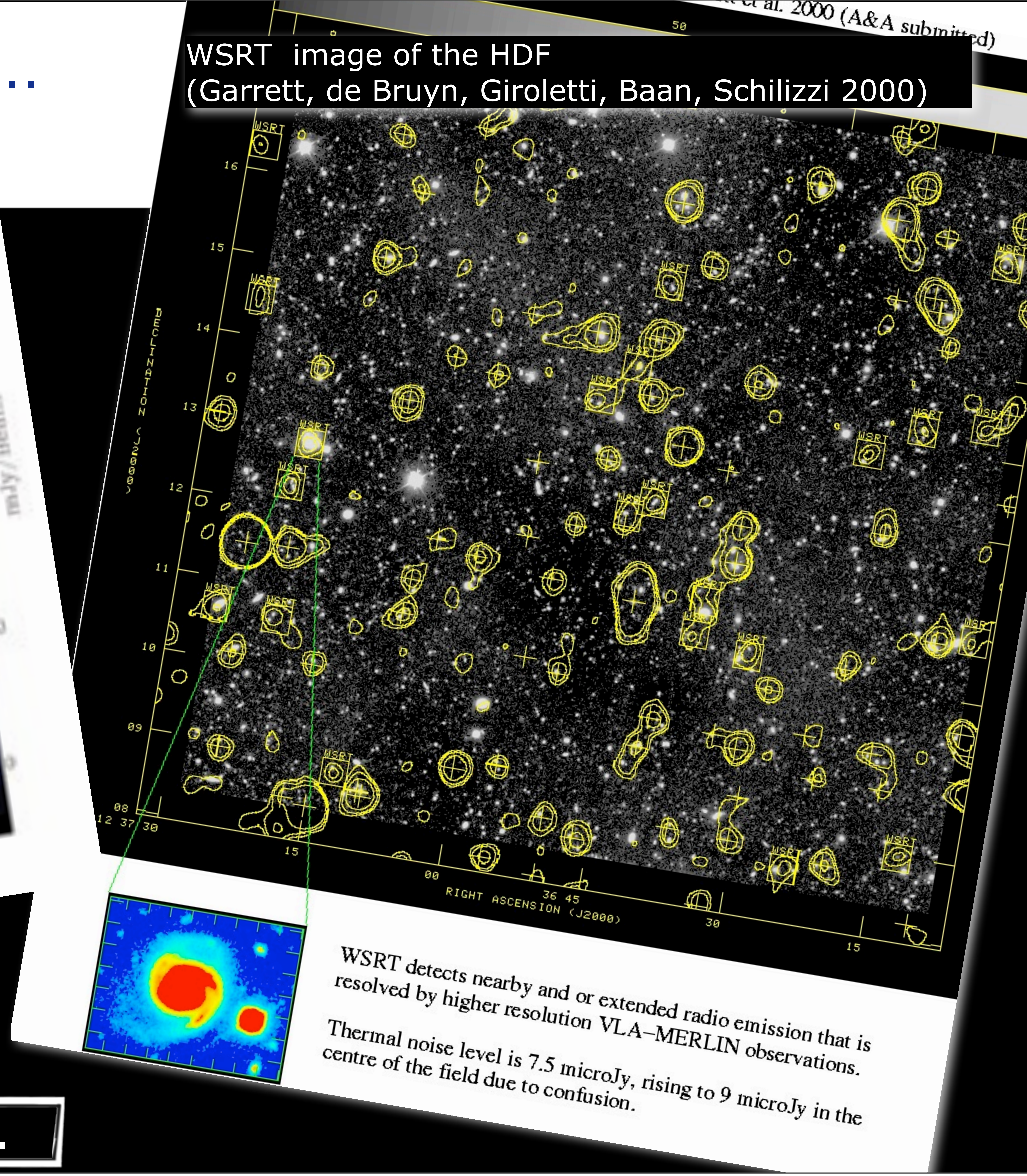
with the major contribution from: ***I. Prandoni, G. Guglielmino, K. Gereb, E. Mahony, I. van Bemmel***



Deep fields/surveys in Ger's career .....



work of Arno Schoenmakers, Ger, Emanuela Orru +



Many science goals can be covered .....

This talk

Faint (sub-mJy) radio population, their spectral index and the HI content

- Nature and properties of the faint radio population: AGN vs SF
  Relevance of faint radio AGN for feedback
- Gas content (for the low redshift z < 0.1 population)

The Lockman Hole: faint radio population, their spectra index and the HI content

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- Nature and properties of the faint radio population: AGN vs SF. Relevance of faint radio AGN for feedback.

↓

- From recent studies:

- High frequencies: Flatter spectral indices and larger dispersions at high frequencies (from 1.4 to 20 GHz) at sub-mJy radio fluxes, suggesting that core-dominated AGN are playing a key role in the sub-mJy radio population. [e.g. Prandoni+ 2006, Whittam+ 2012]

- Low frequency studies (0.3 – 0.6 – 1.4 GHz): important for investigating the presence of synchrotron self-absorbed mechanism Existence of flattening is controversial. Flattening more significant for compact (<3”) sources. optically thin (steep spectrum) or self-absorbed (flat spectrum) synchrotron emission.

The Lockman Hole:
faint radio population, their spectra index and the HI content

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- Nature and properties of the faint radio population: AGN vs SF. Relevance of faint radio AGN for feedback.

- Gas content (for the low redshift z < 0.1 population)

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- Multi-wavelength information and radio spectral indices to constrain the origin of the radio emission in sub-mJy radio sources. Importance of very low frequencies (30-200 MHz), where self-absorption phenomena are expected to be very important.

- Use the broad band @21cm to extract HI spectra and do stacking => derive the HI content of galaxies with z up to 0.1, compared to their optical and radio properties (using SDSS spectra)

- Field of choice: Lockman Hole
  => high Dec (ideal for WSRT and LOFAR observations), a lot of ancillary data .....

- Observations: WSRT 1.4 GHz (160 MHz, covering redshift range 0 - 0.1) and 325 MHz
  LOFAR 150 MHz (commissioning & Cycle 0), 60 MHz (Cycle 0)

Lockman Hole region
WSRT Mosaic @ 1.4 GHz

16 pointings (6.6 sq.degr.)

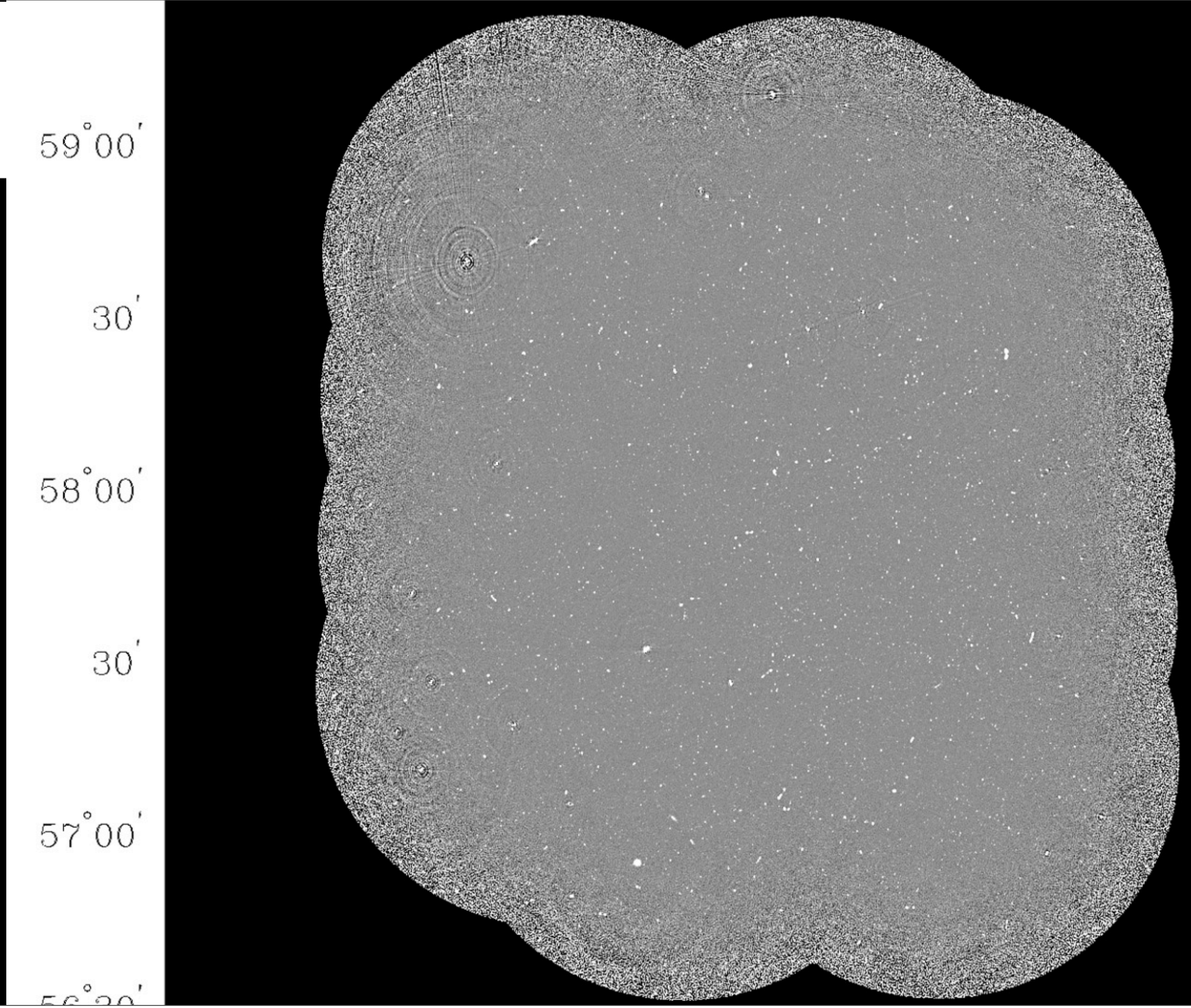
rms ~11 μJy (central 2 sq degr)

About 6000 sources with S>55 μJy

Source counts complete down to 70-80 μJy

Largest field imaged
at such depth

Guglielmino, Prandoni, Morganti, Rottgering, Jarvis, Garrett 2013, A&A in prep



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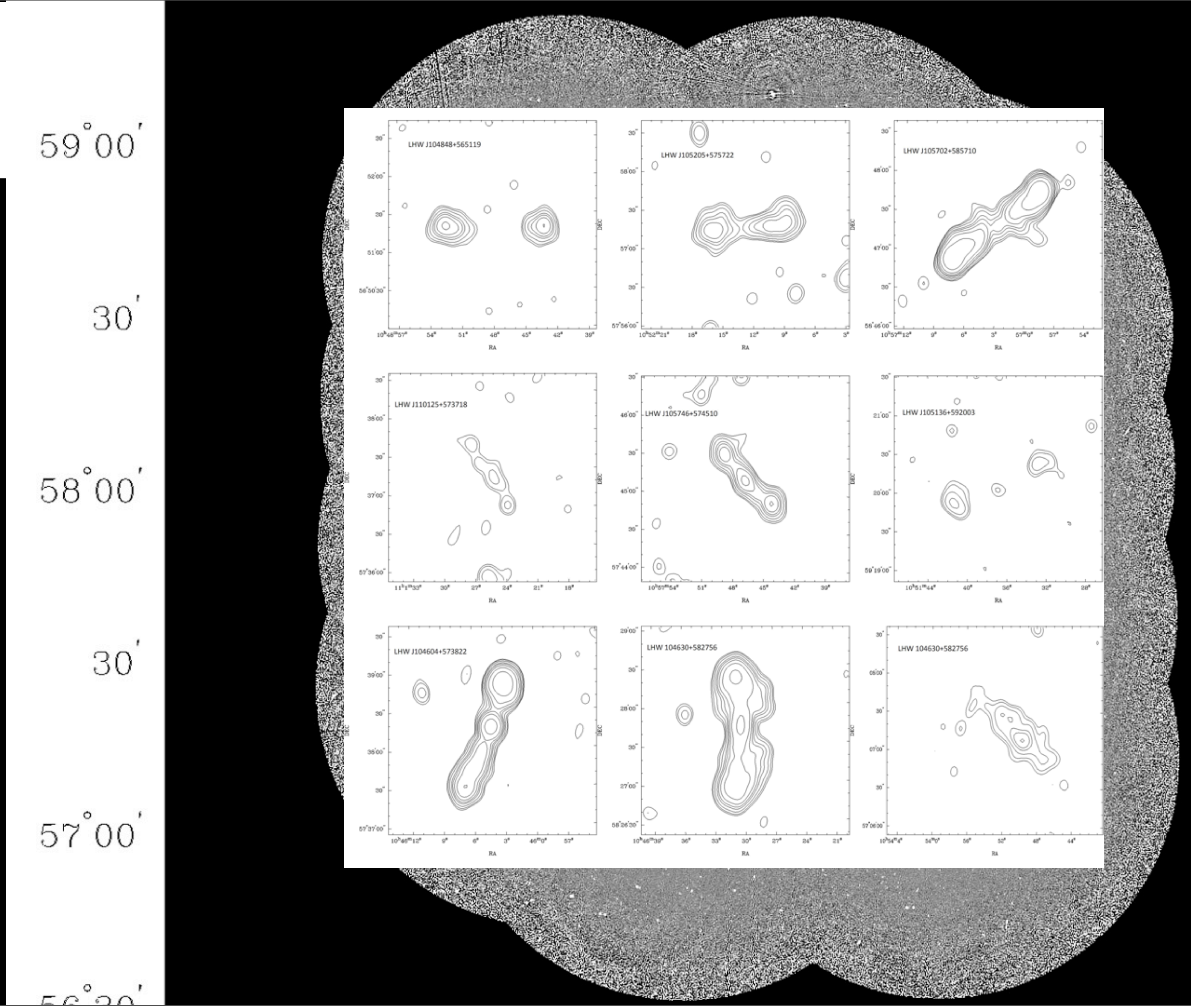

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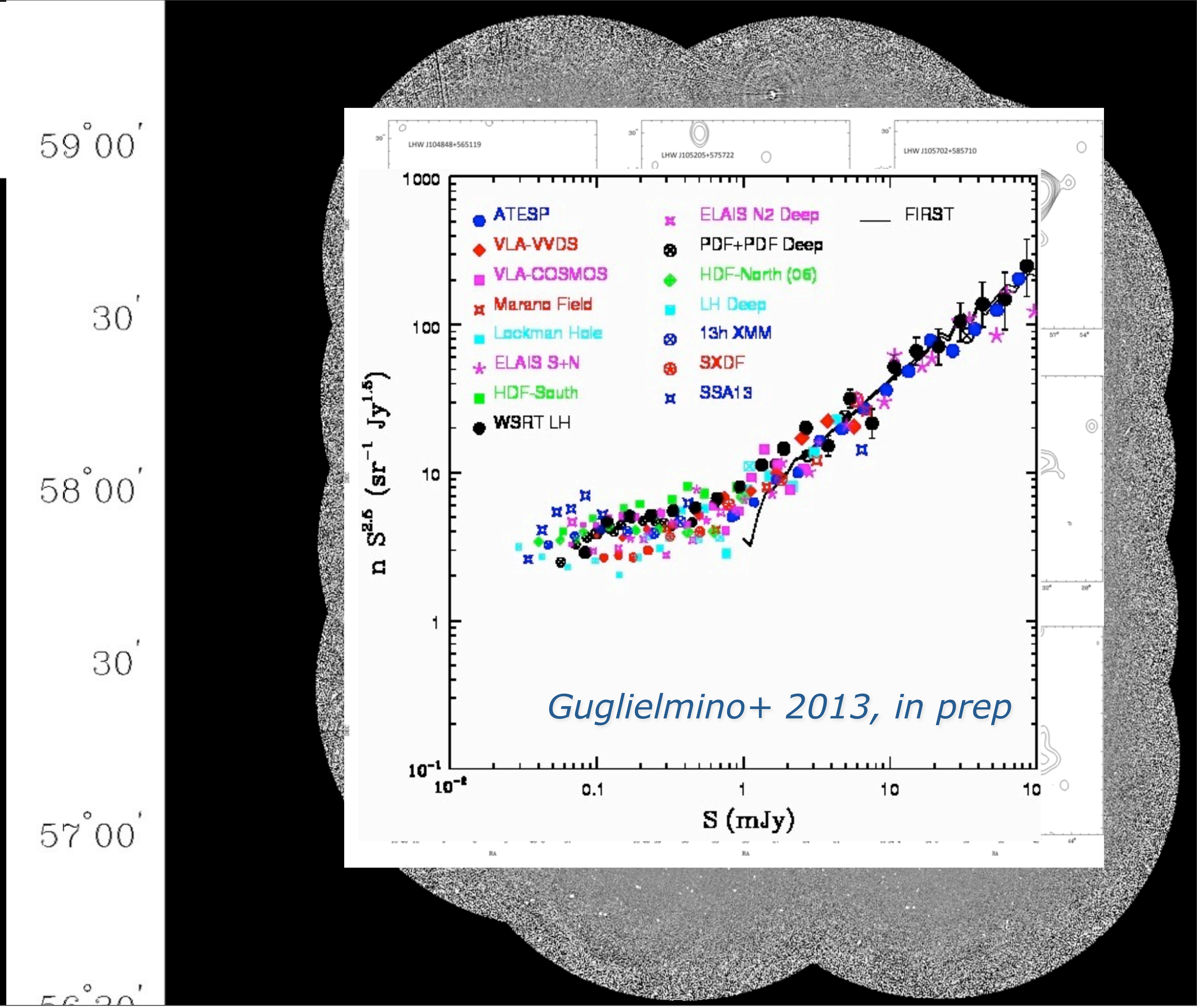
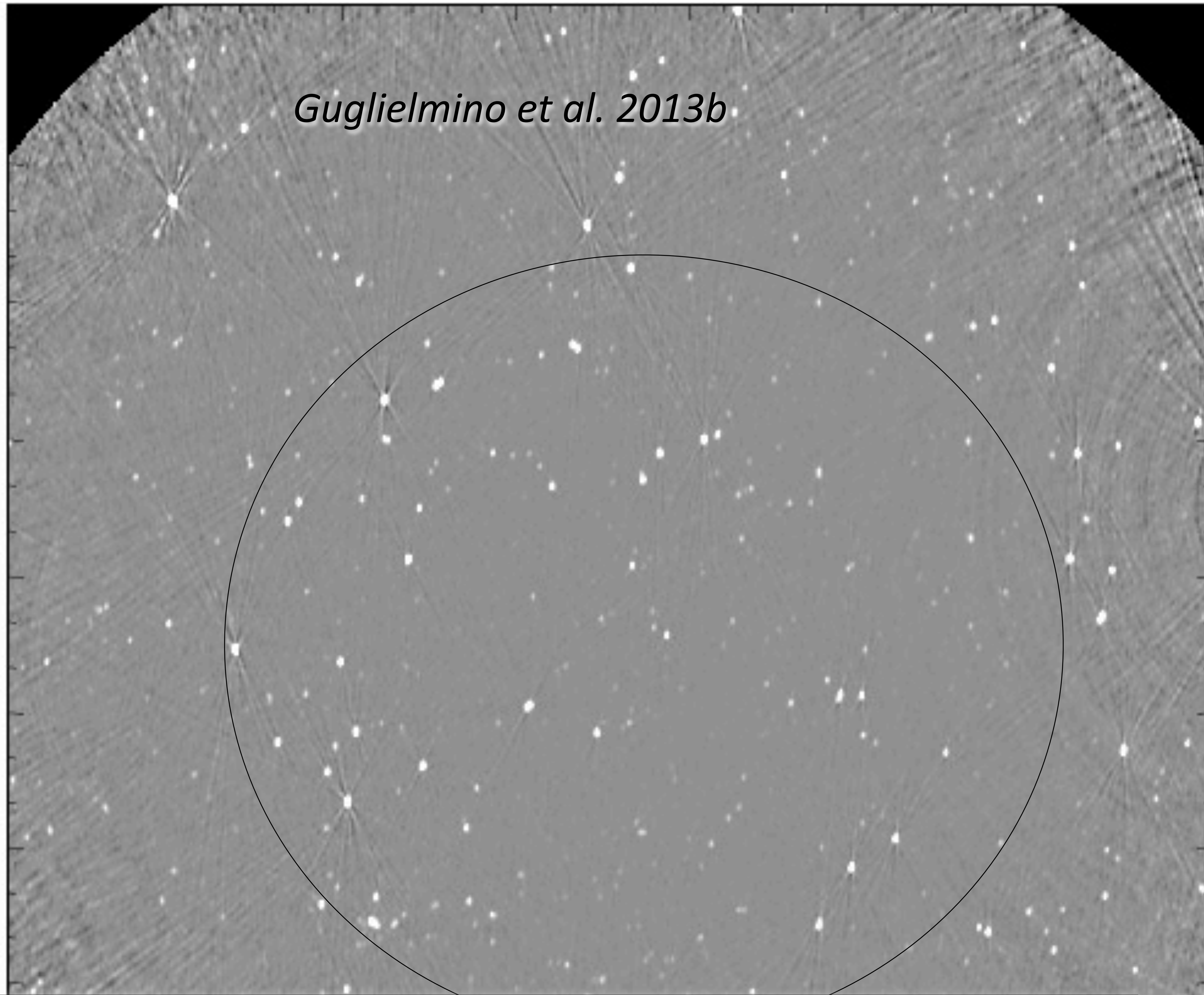


The Lockman Hole Region @ 345 MHz



WSRT 345 MHz observations in February 2012

Due to limited resolution (~40x70 arcsec) → confusion-limited image at a level of rms~0.7-0.8 mJy). Catalogue: 334 sources, complete down to 4.8 mJy (~3-4x deeper than WENSS).

Lockman Hole with LOFAR

Lofar commissioning
=> 6 hrs obs.

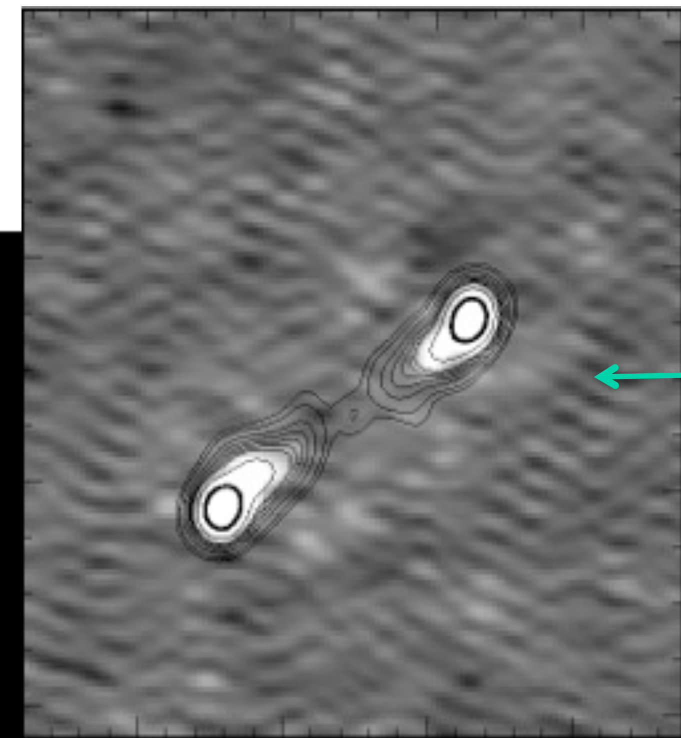
150 MHz Image (inner 2 sq. degr., 8”x4”) from 60 of the 120 SBs.

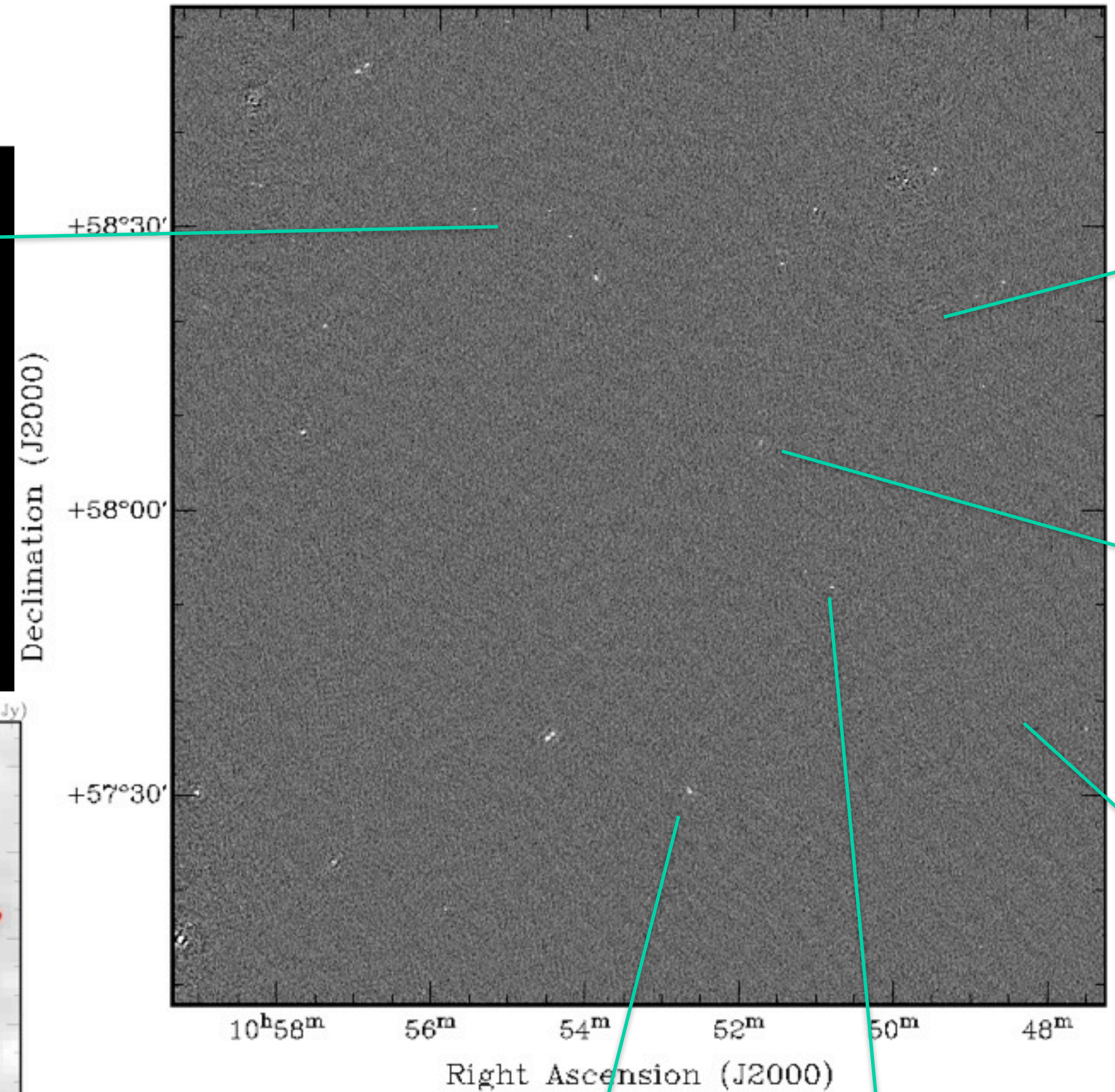
3C244.1 subtracted

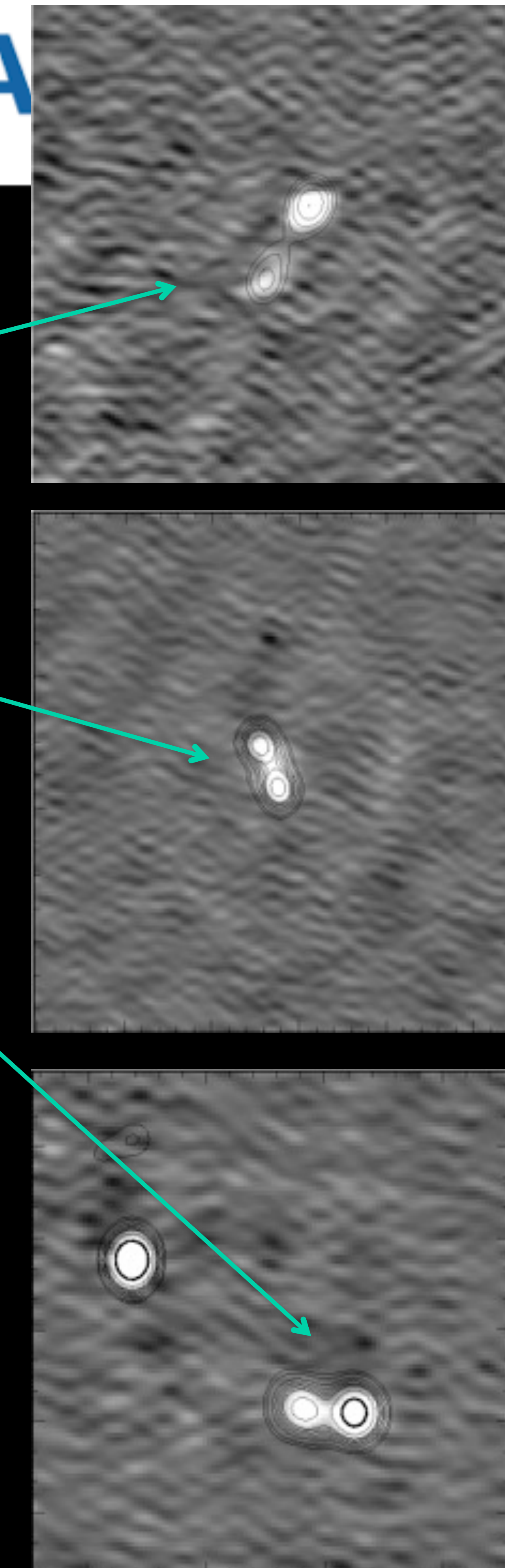
rms noise → 1.5 mJy

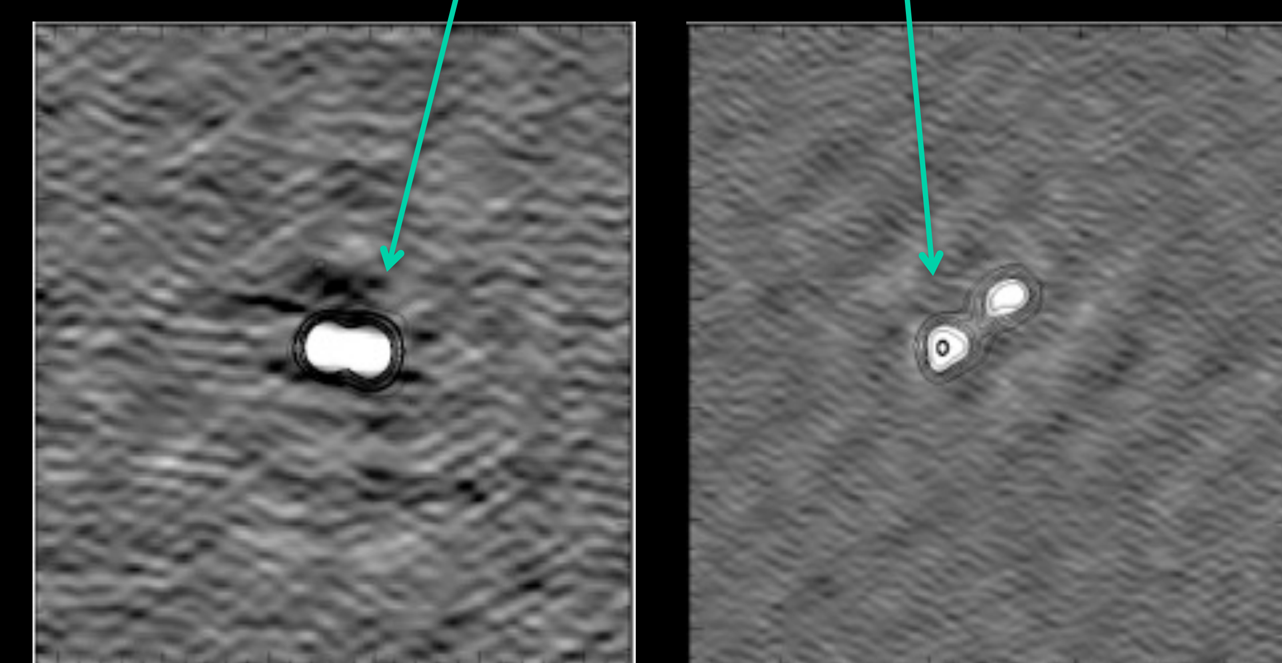
152 sources extracted in the 1.4 GHz mosaic region (5σ).

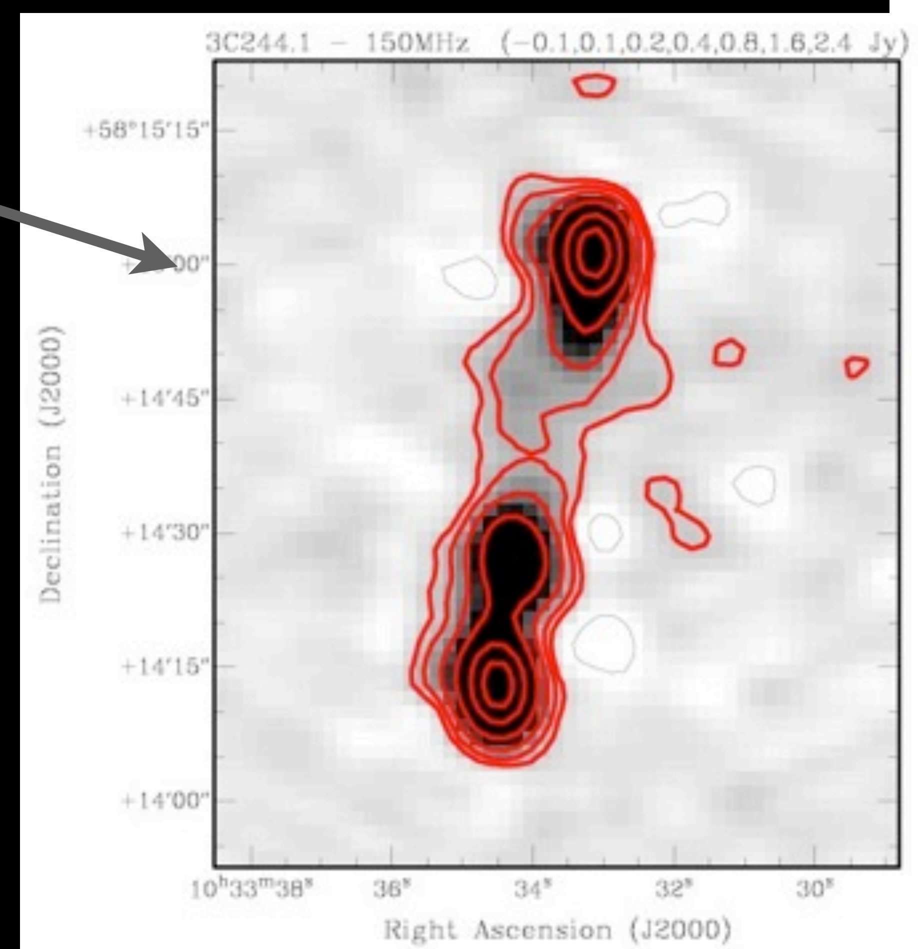
Several counterparts of brightest WSRT 1.4 GHz sources are clearly visible.











3C244.1: LOFAR 150 MHz
[8x4 arcsec res.]

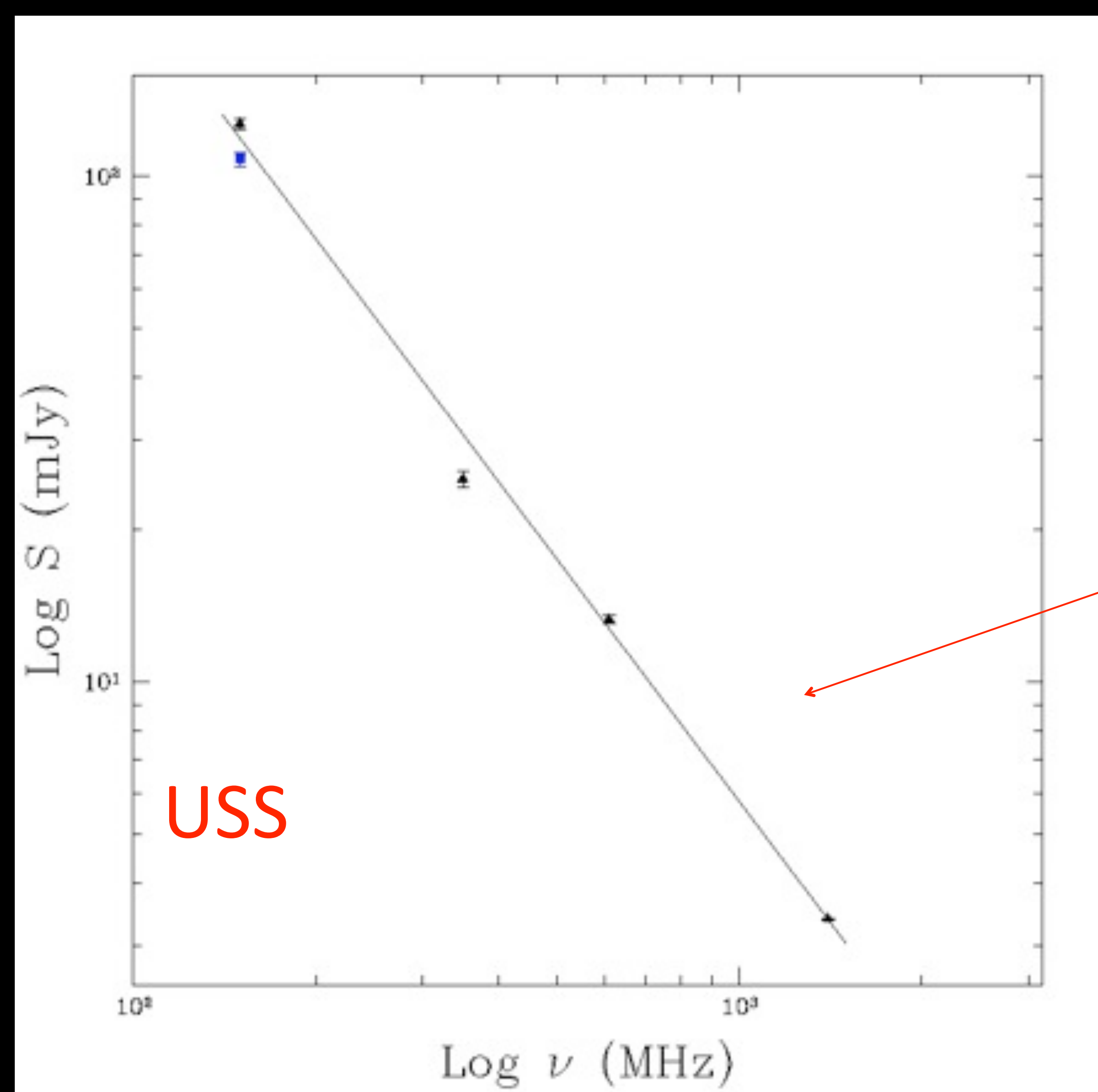
First full resolution image of a deep field
Guglielmino 2013 PhD thesis

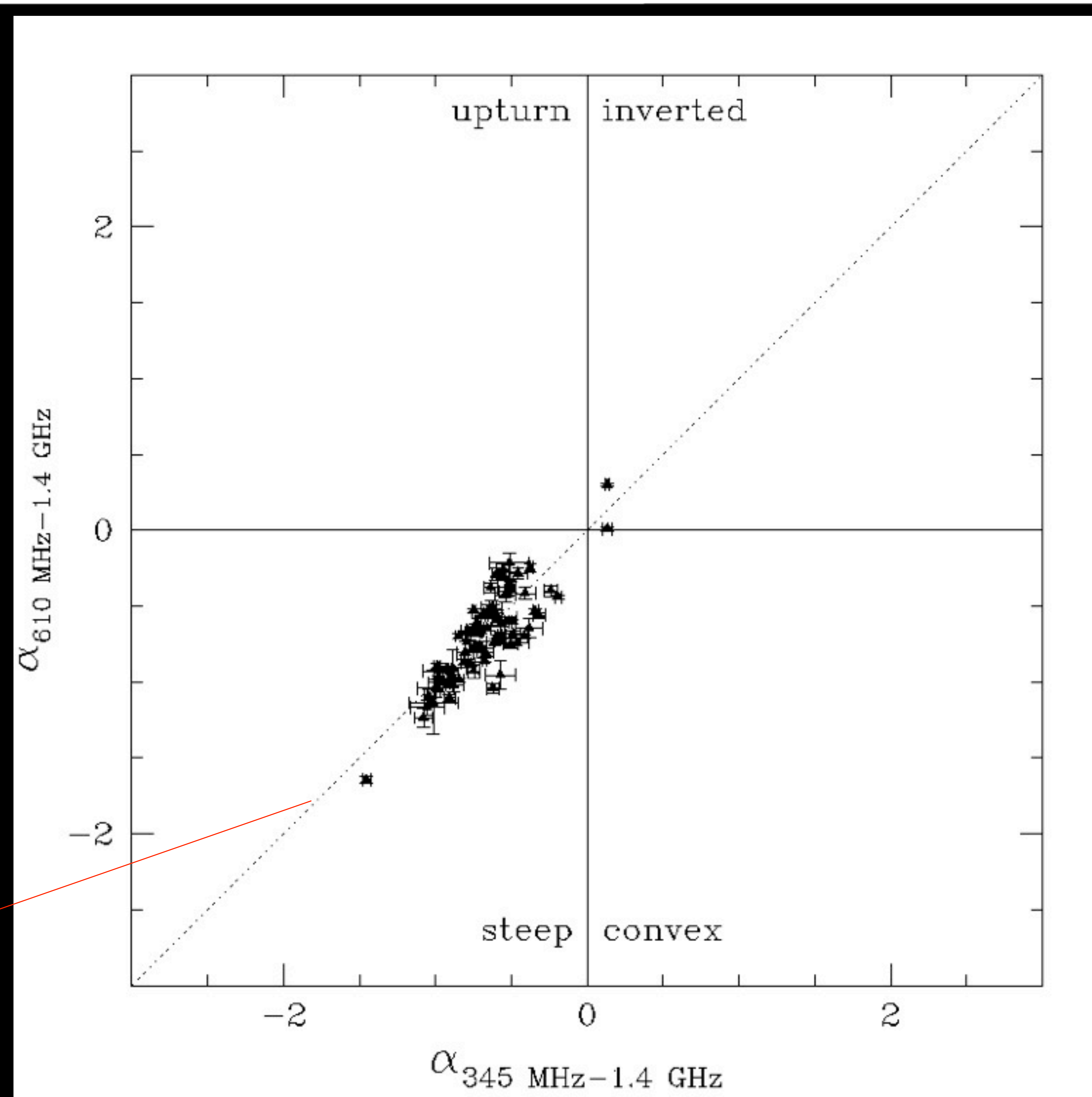
Spectra index analysis: radio *color-color* plots (150 – 345 vs 610 -1400 MHz)

Radio spectra are consistent with single power laws

→ no significant spectrum curvature (< C > ~ 0), at least down to 150 MHz

→ If self-absorption effects are in place, not very compact sources (>10 kpc)!





This study (from commissioning data) is still limited to the strongest sources....

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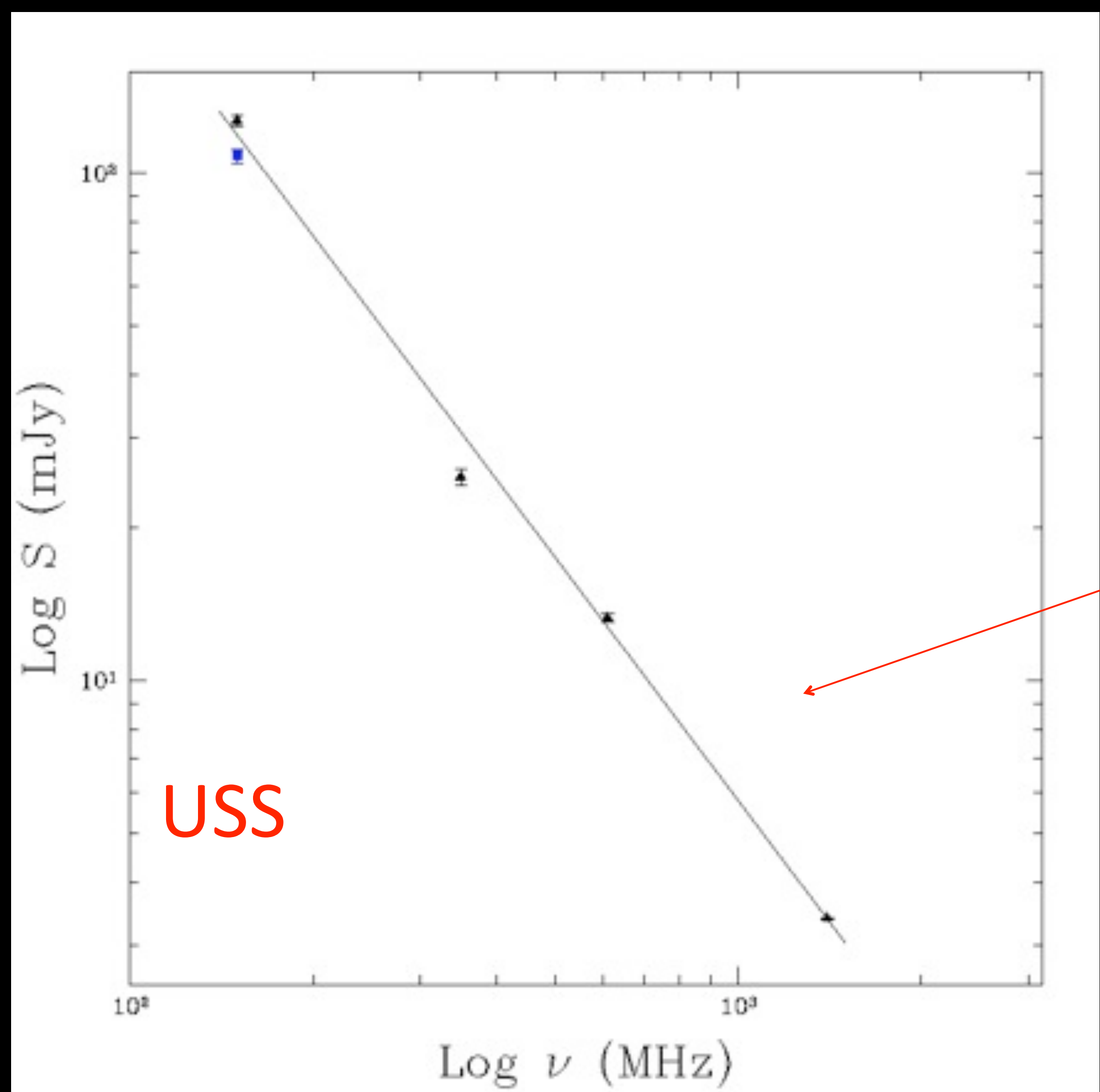

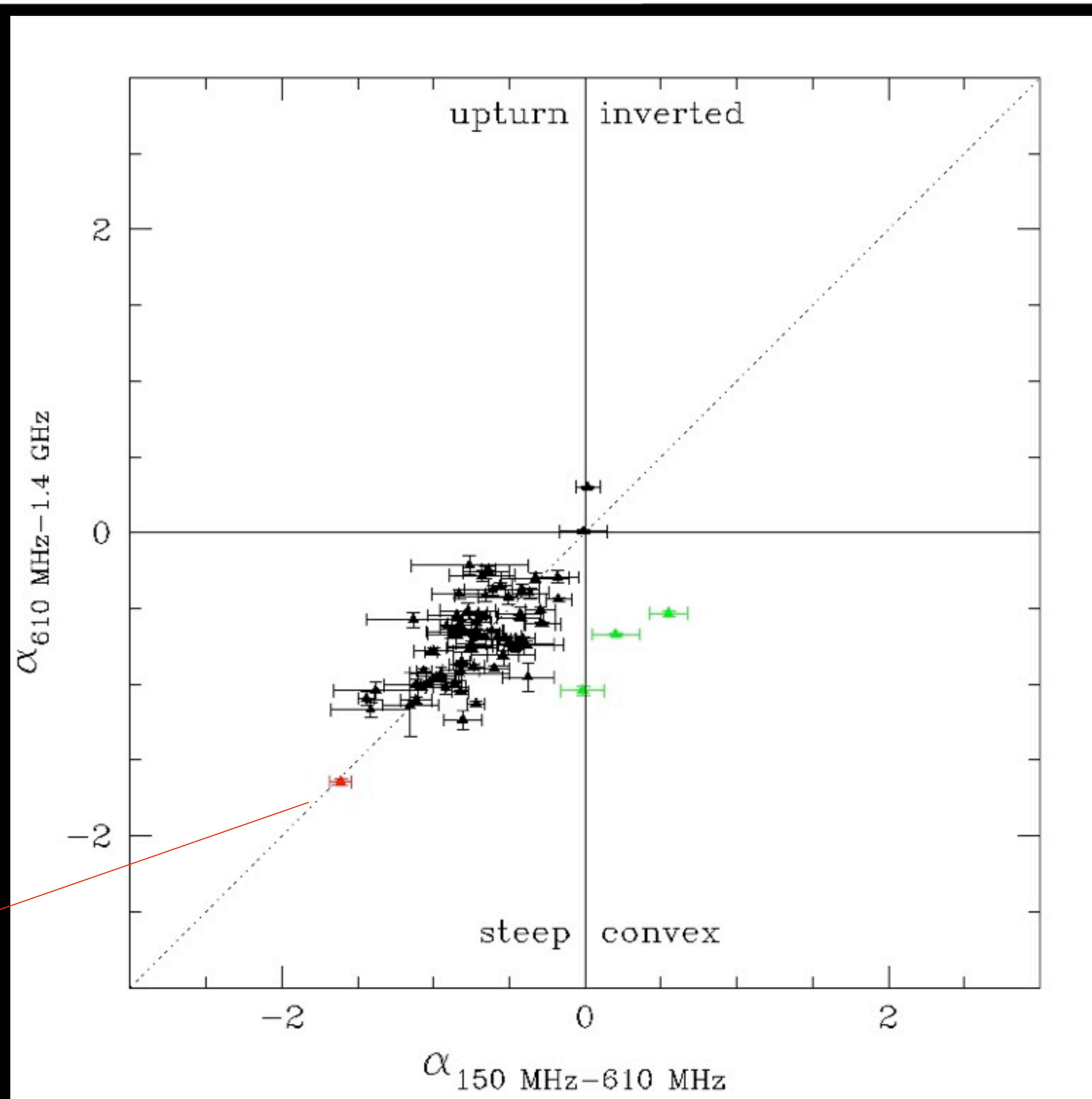

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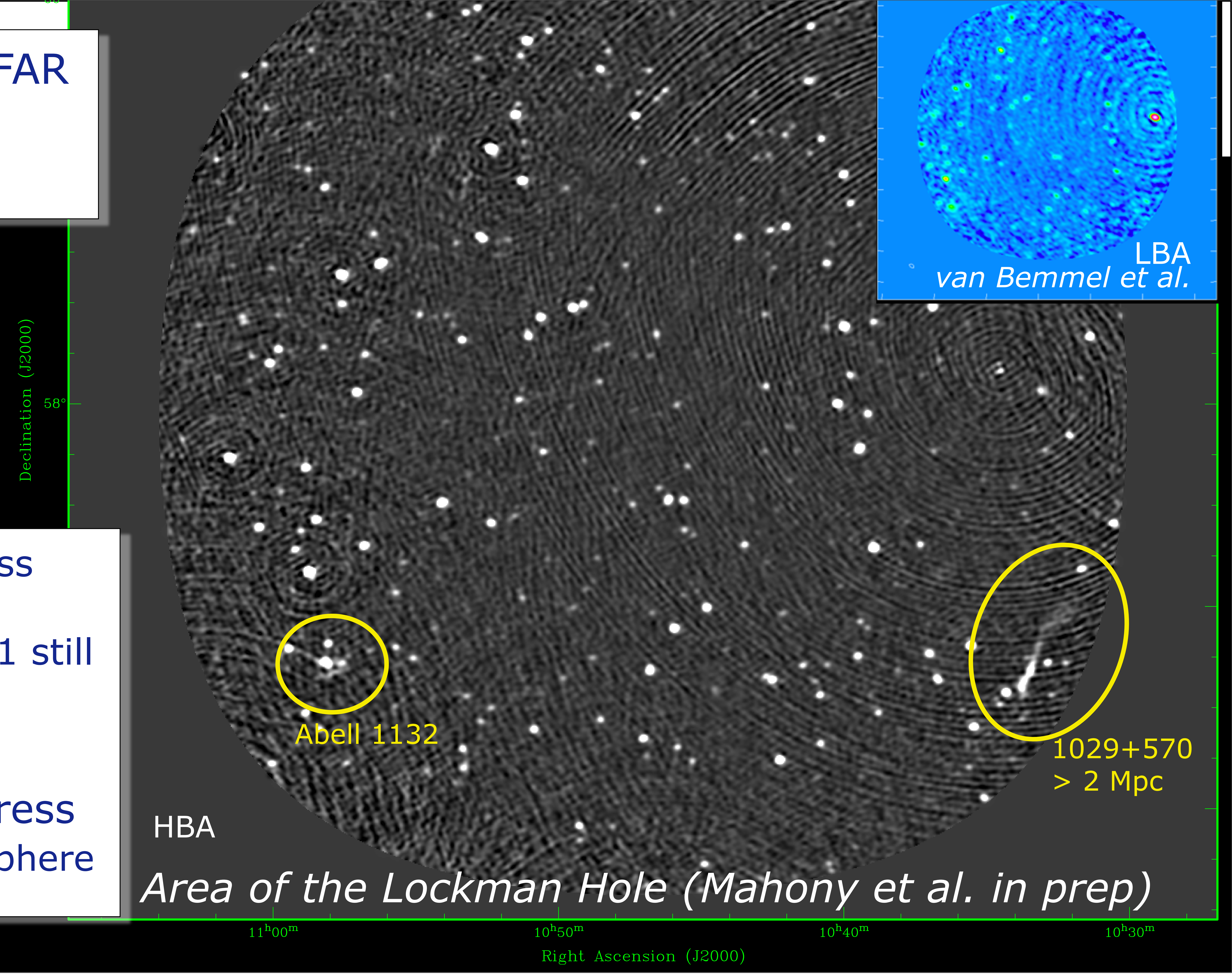
Status of the New LOFAR data (Cycle 0) (150 and 60 MHz)

HBA: reduction in progress => 10SB, rms ~2mJy/b, 19x16” Peeling of 3C244.1 still to be improved

LBA: reduction in progress
more problems with ionosphere



HI content via stacking

Cold gas (HI) plays an important role in the formation and evolution of galaxies

Main goals:

- Investigate relations between HI properties and other characteristics of the host galaxy (color, emission lines, SF & radio AGN properties)

- Evolution with redshift Stacking gives the opportunity to investigate the global HI properties beyond z = 0 with today telescopes

Preparation for higher-redshift HI surveys
(Apertif, ASKAP, MeerKAT…)

Geréb K., Morganti R., Oosterloo T.A., Guglielmino G., Prandoni I., 2013, A&A 558, 54

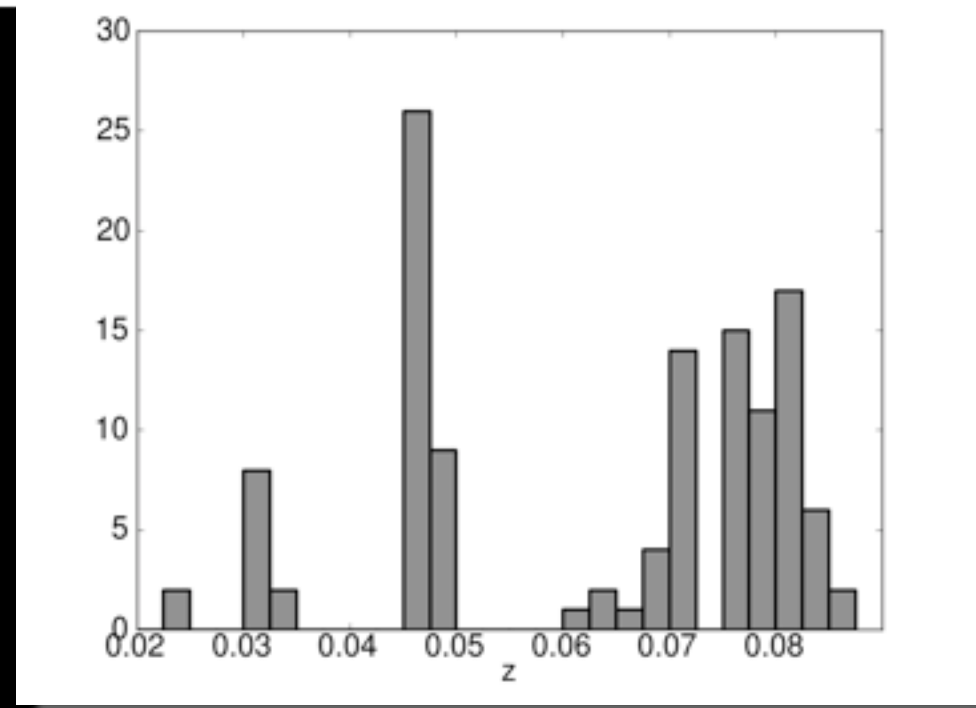
Stacking in the LH field: piggyback from the continuum observations

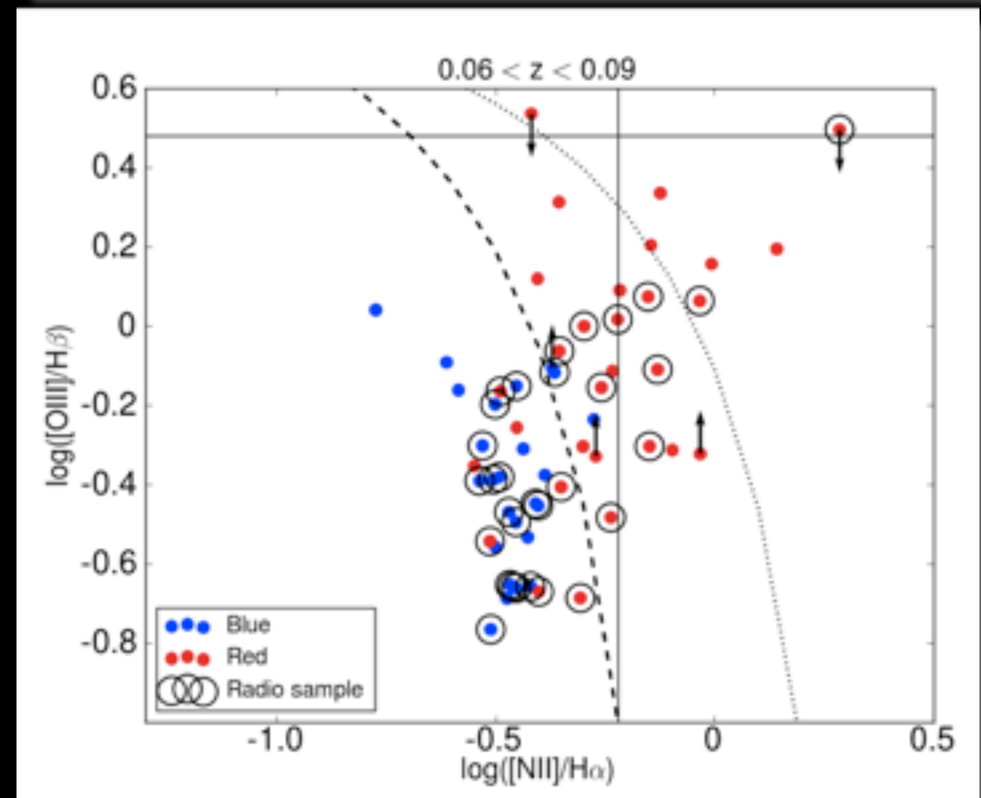
WSRT observations using 160 MHz band (1300 - 1460 MHz), 1024 chans => coverage 0<z<0.09, velocity resolution 60 km/s

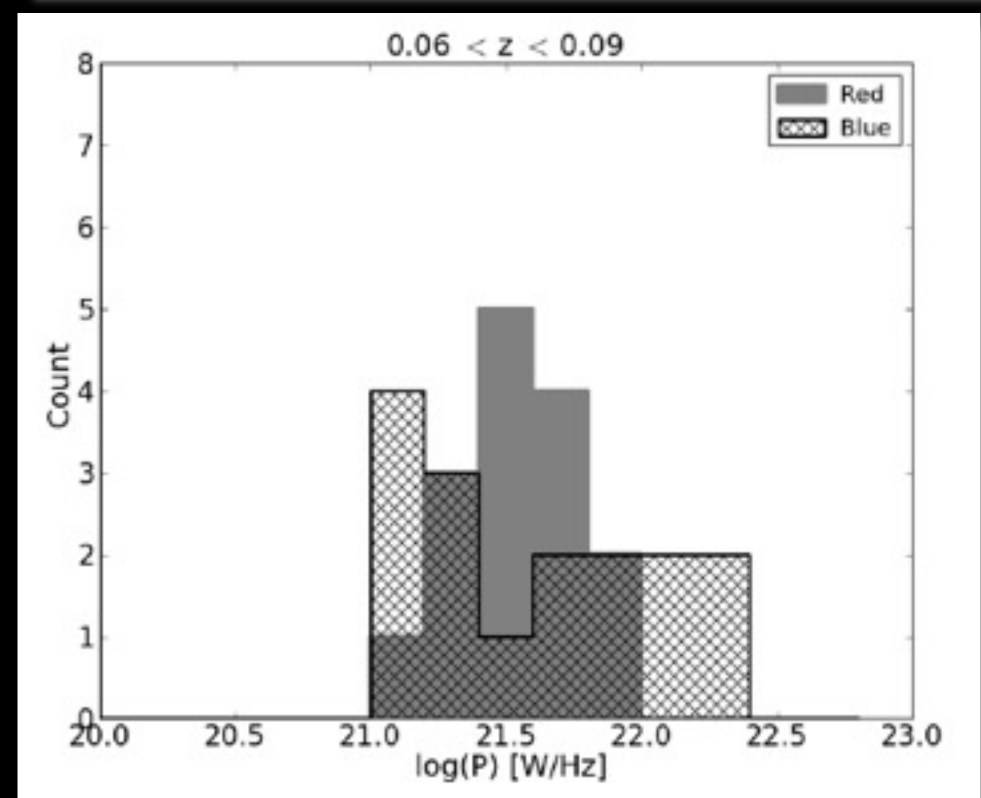
We use the HI spectra for stacking:
z < 0.09

Cross-correlation with SDSS spectroscopic catalog:
120 sources in total, 50 sources with radio continuum, IR Spitzer data

Noise level:
- initially ~ 0.150 mJy/beam/chan
- after stacking ~ 20 μJy







M_{HI}/L_r
(M_{Sun}/L_{Sun})

- Blue: ~ 0.4
- Red: ~ 0.1

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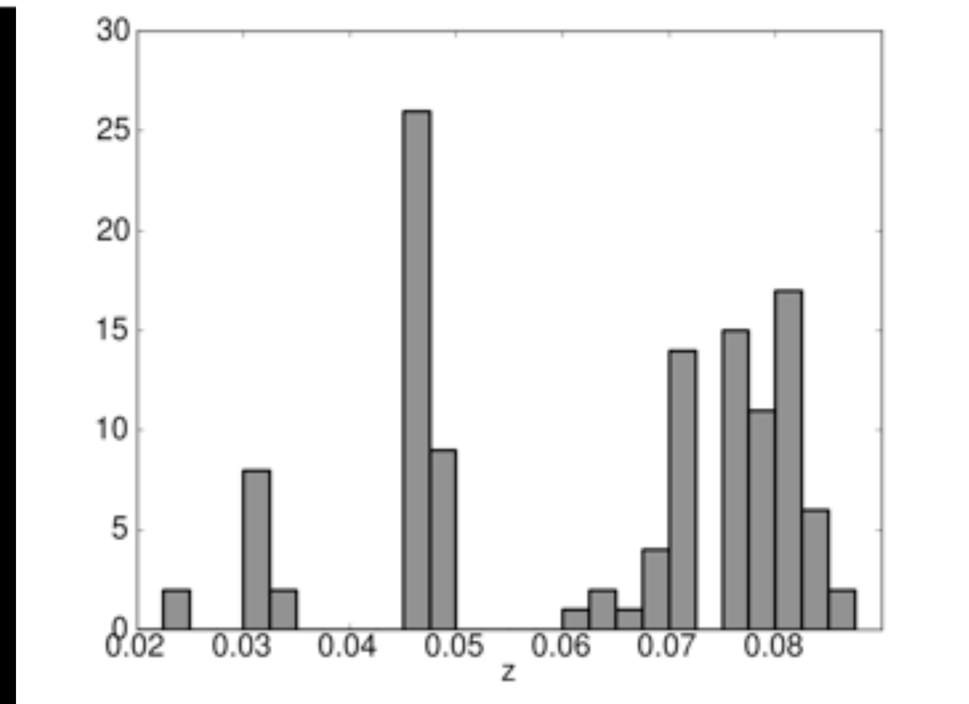

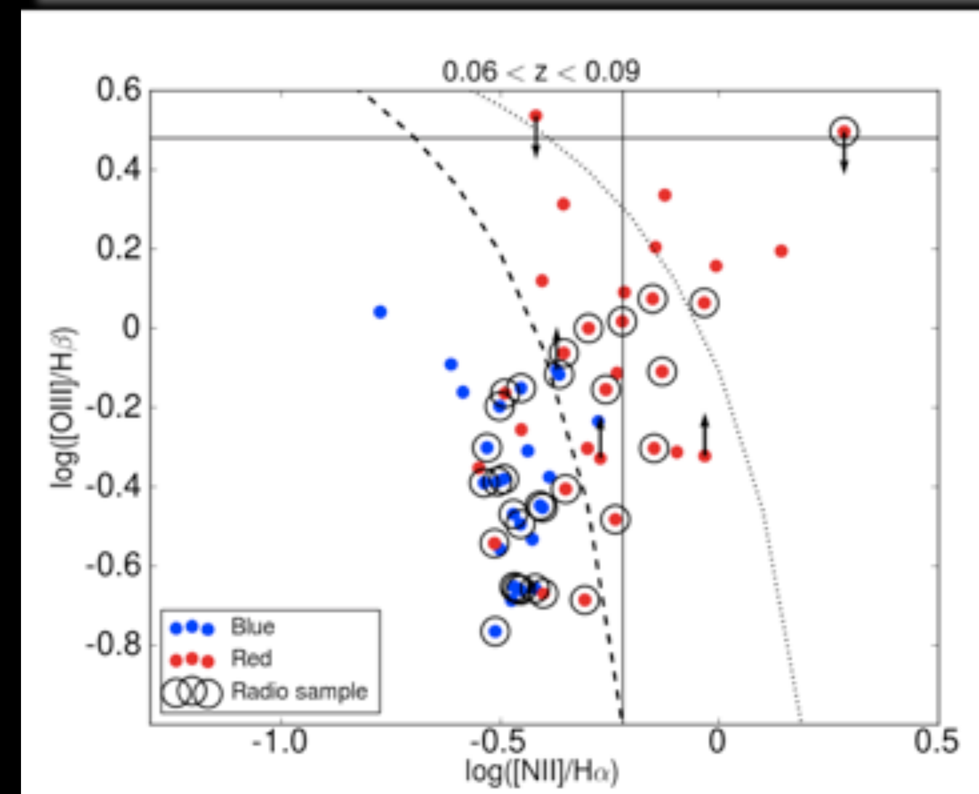

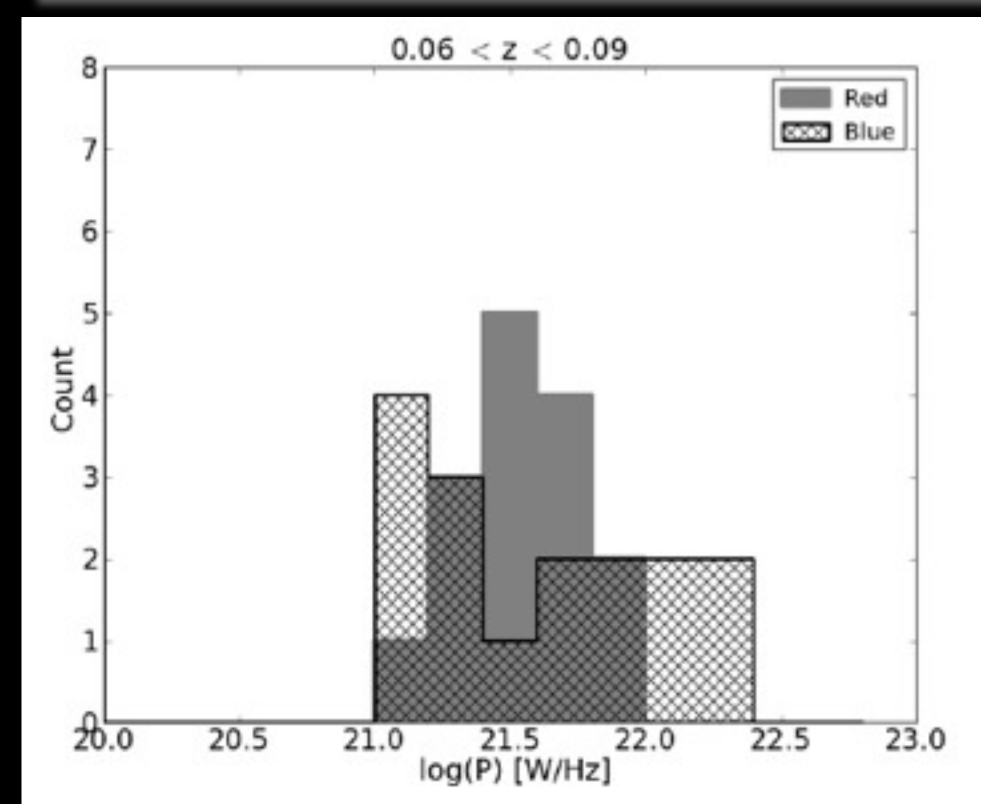

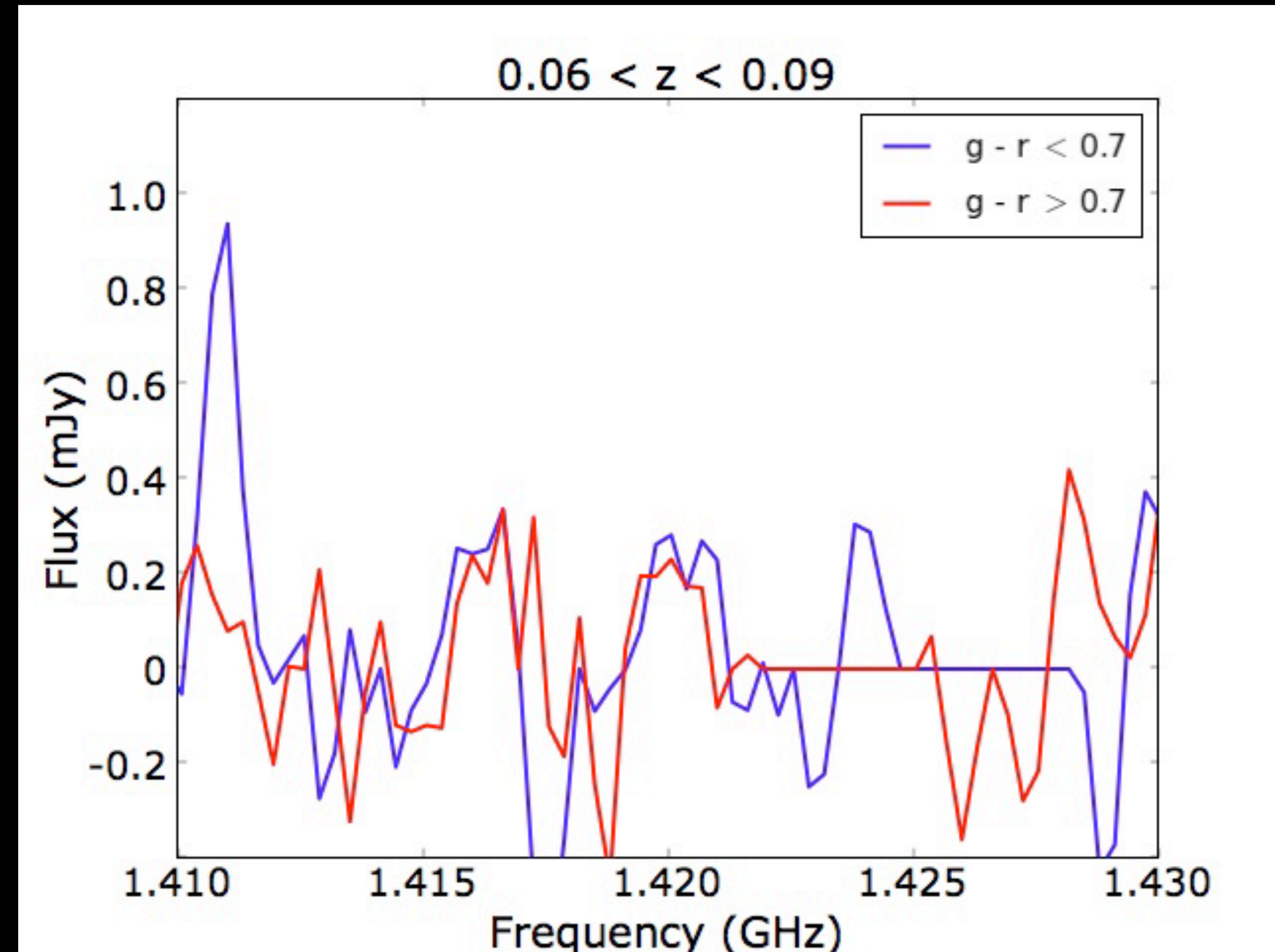

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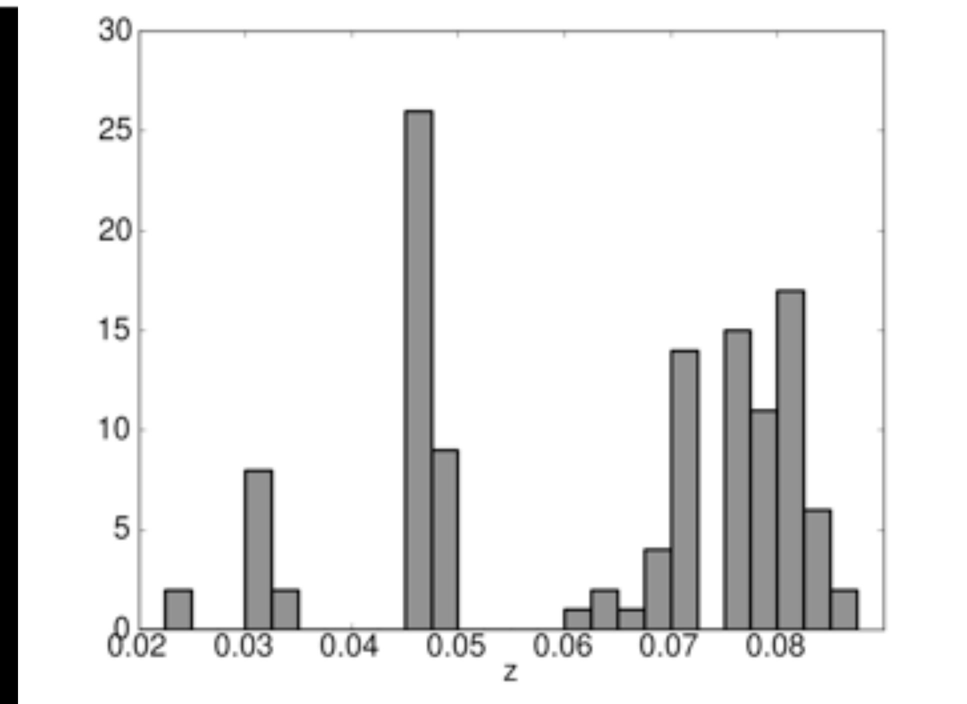

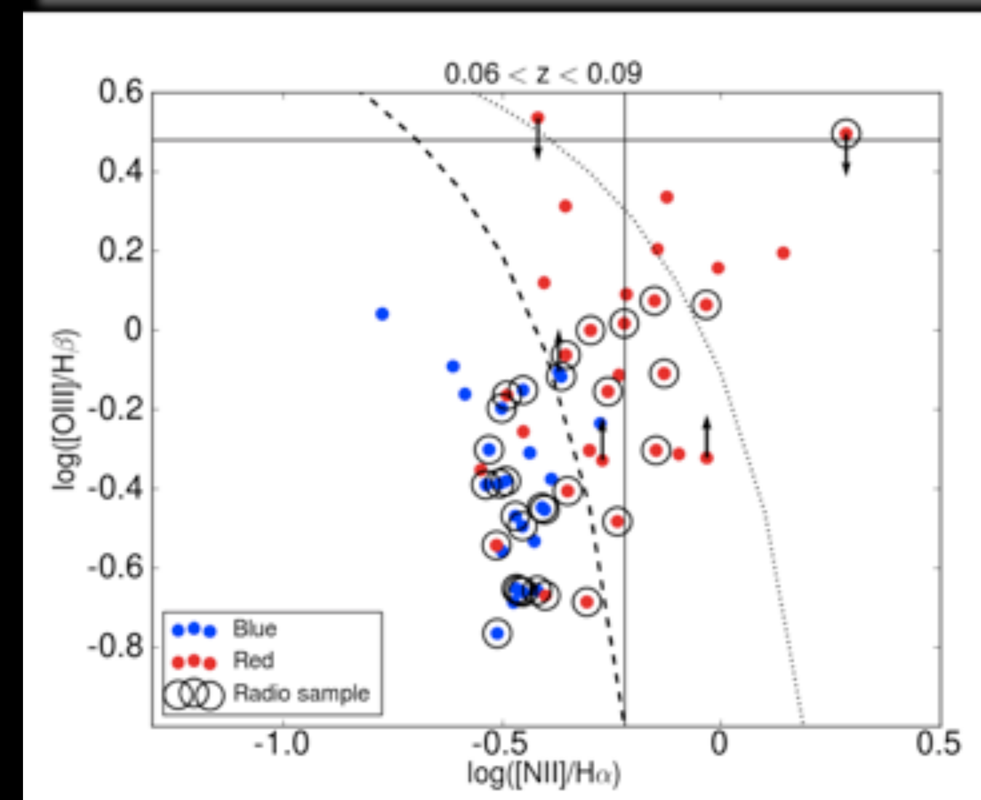

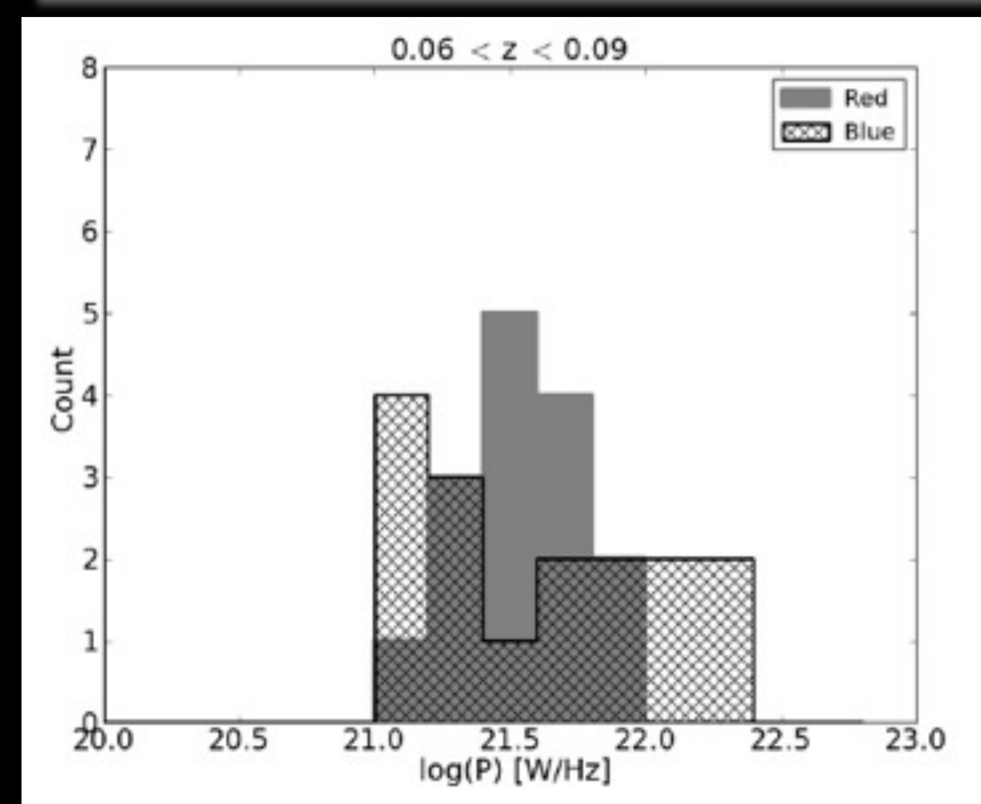

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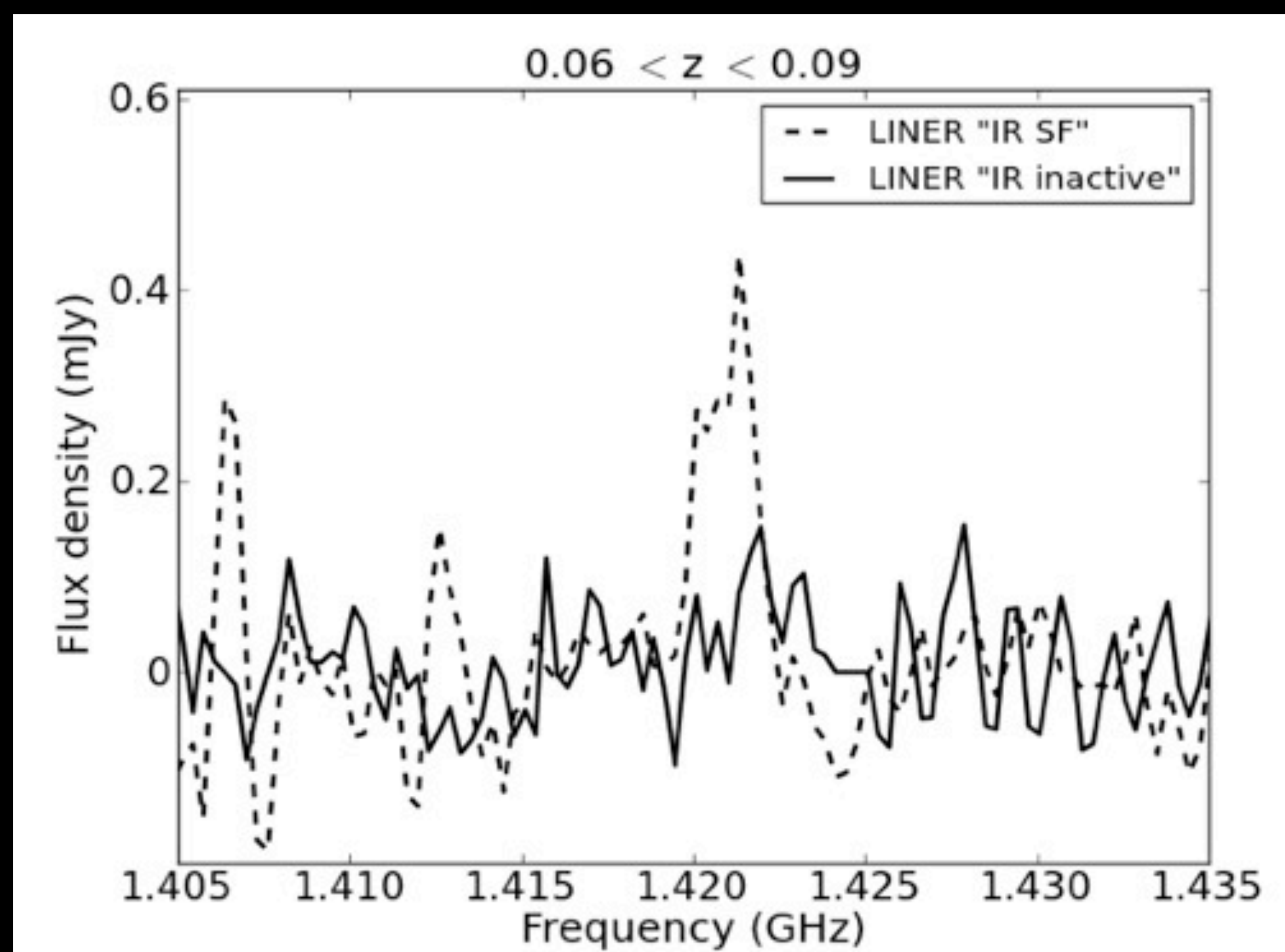
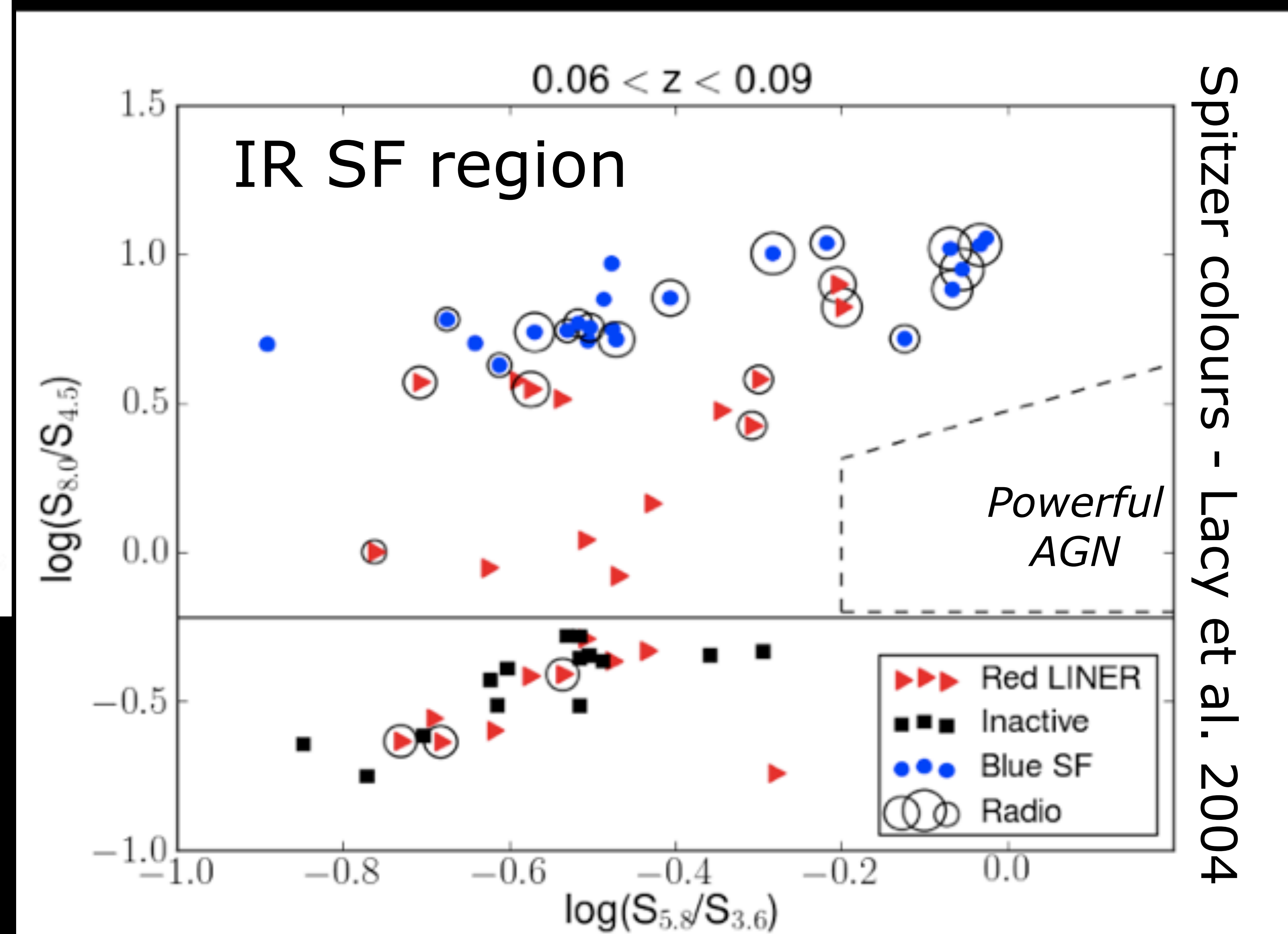
Radio sources and stacking

Geréb K., Morganti R., Oosterloo T.A., Guglielmino G., Prandoni I., 2013, A&A 558, 54

- Inactive (in terms of optical emission lines) galaxies are not detected in HI
- To first order (and for the low redshift range) => for the majority of **radio LINERs**, the radio emission seems to be connected with **SF**
- But: two groups based on 24 μm emission properties *(tracer of the warm dust component associated with current star-formation in galaxies)* => LINERs detected at 24 μm show relatively large amounts of HI, no detection for the other group



IR inactive region



LINERs in
IR SF region:
- 24 μm detection
- HI detection

LINERs in
IR Inactive region:
- no 24 μm
- no HI

- No powerful AGN in our sample
- Radio sources in the IR inactive region are the best candidates for hosting low-luminosity radio AGN

Conclusions and future perspectives

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LH region: 3 new radio catalogues obtained: 1.4 GHz, 345 MHz and 150 MHz.

No significant curvature found in the source spectra down to 150 MHz => (bright) sources analised so far have sizes >10 kpc.

=> Analysis to be extended to lower flux and frequency with Cycle 0 and new Cycle 1 observations (LBA and HBA).

[+ extensive multi-waveband information (optical/IR, MIR/FIR), photo-zs and galaxy types]

Piggyback HI stacking => feasibility proved (Gereb et al. 2013) => approach could become standard in all future radio surveys at L-band

- For the majority of radio LINERs (and for SF galaxies), the radio emission appears to be connected with star formation
- Radio sources in the IR Inactive region (no 24 μm and HI detection) are the best candidates for hosting low-luminosity radio AGN => to be confirmed with high resolution data

=> Analysis extended to larger sample (including Galex data) and results so far confirmed