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Netherlands Institute for Radio Astronomy

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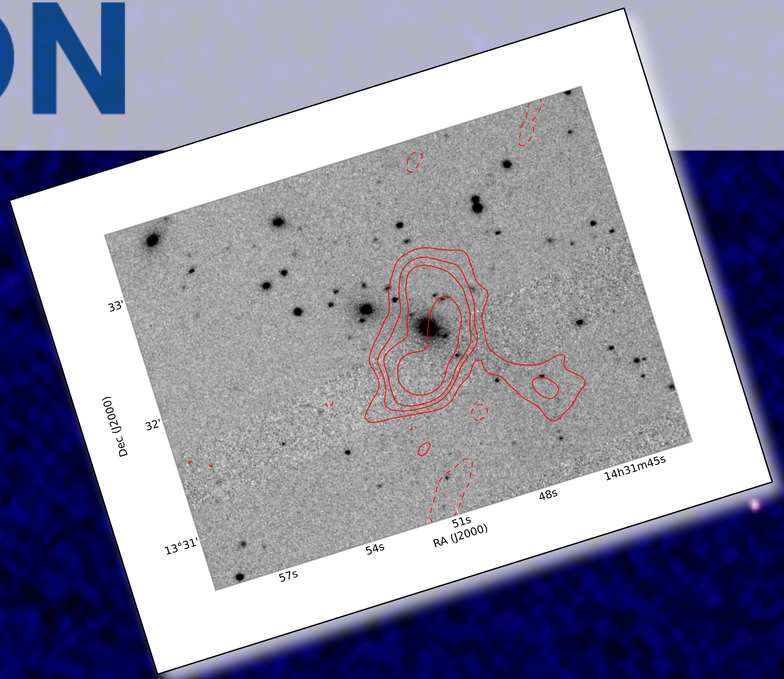
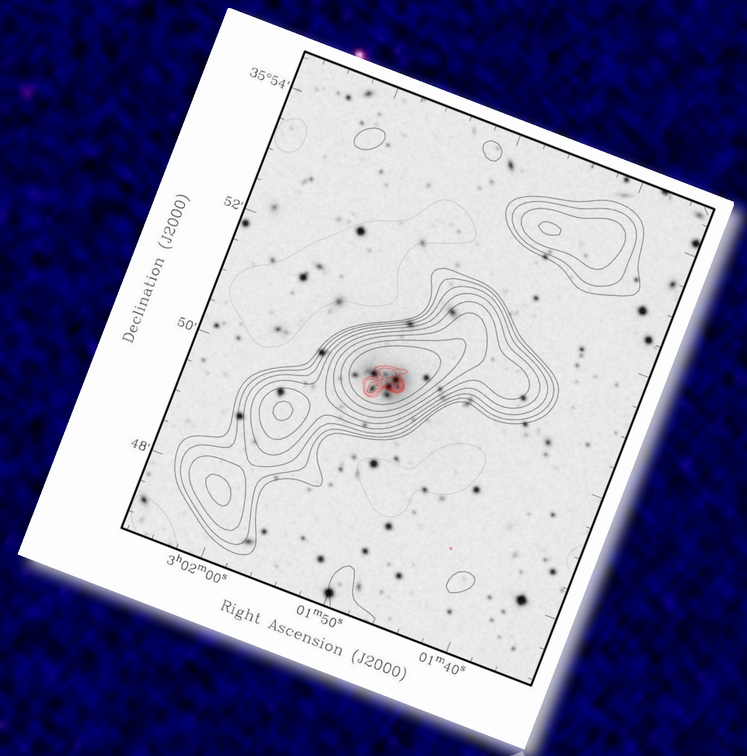




Radio archeology with LOFAR

(the life-cycle of radio sources with LOFAR)

Aleksandar Shulevski

ASTRON (NL) and Kapteyn Institute (Groningen)

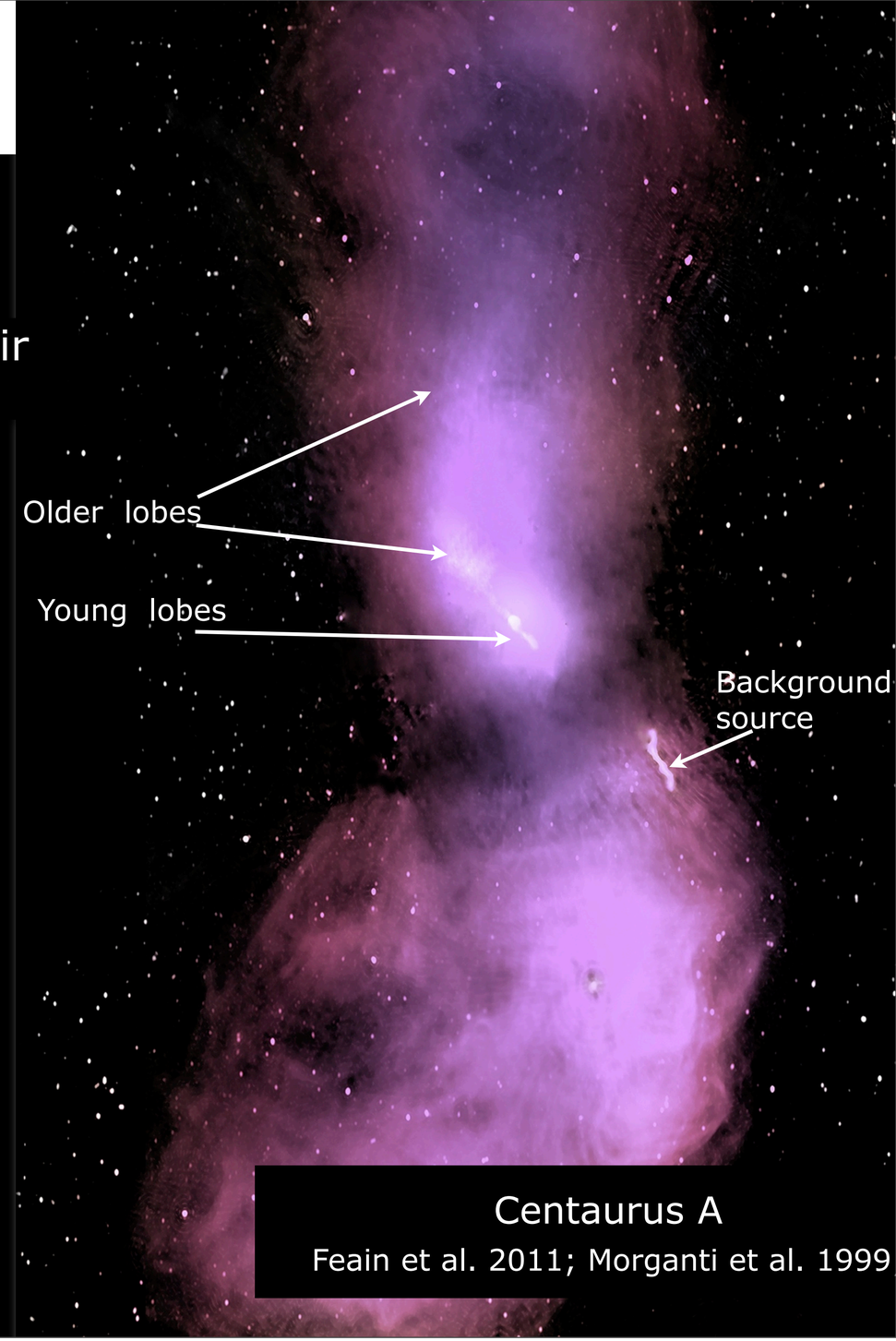
with the collaboration of: R. Morganti, P. Barthel, M. Murgia, N. Vilchez et al.

Life-cycle of radio sources

More than 25% of galaxies are radio sources
➔ radio-loud AGN phase only 10^7-10^8 yr
➔ the radio-loud phase **must be constantly re-triggered**
(Kauffmann et al., Best et al. 2005)

also seen from their morphology

Radio: best diagnostic for timing AGN activity



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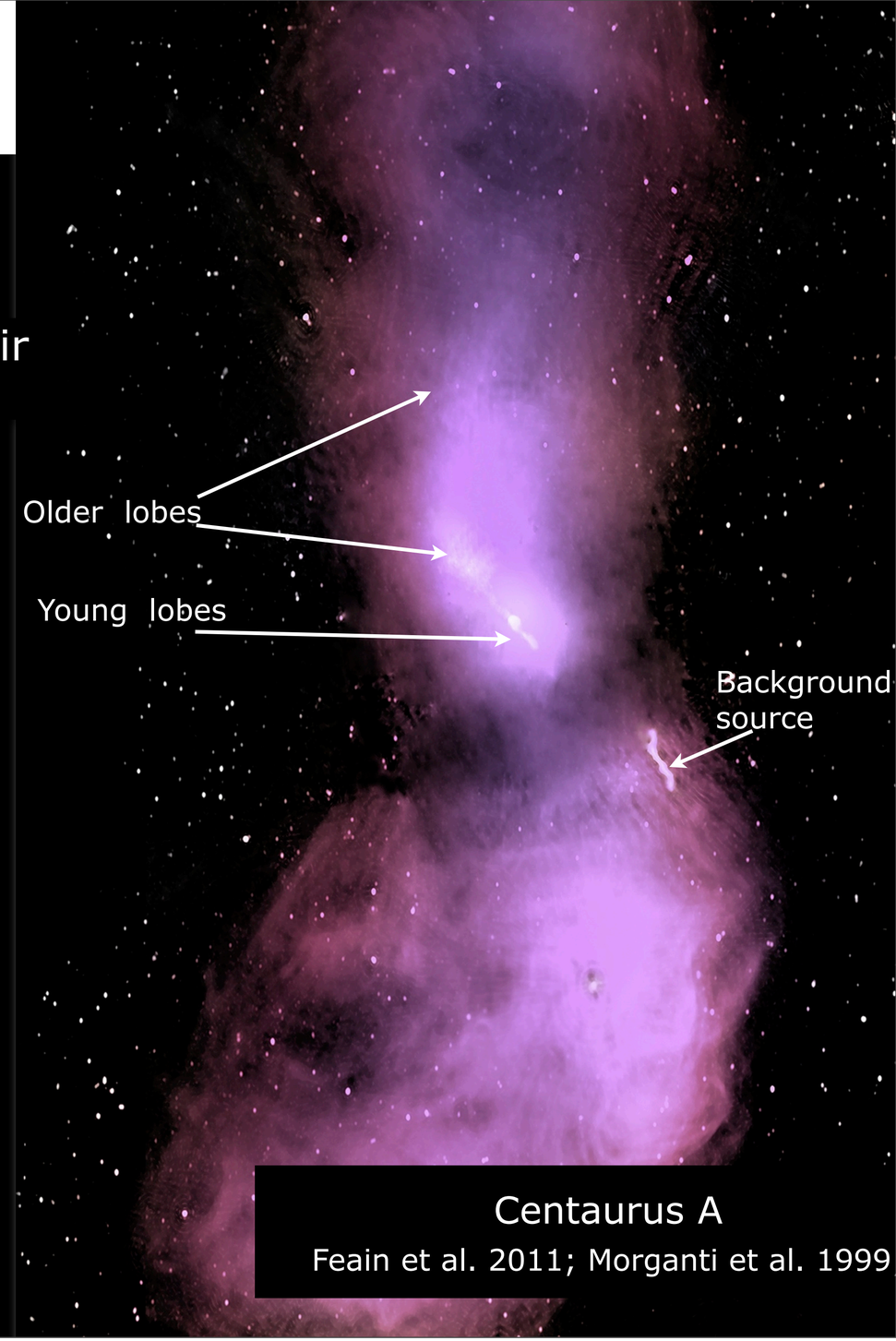
→ also seen from their morphology

Radio: best diagnostic for timing AGN activity

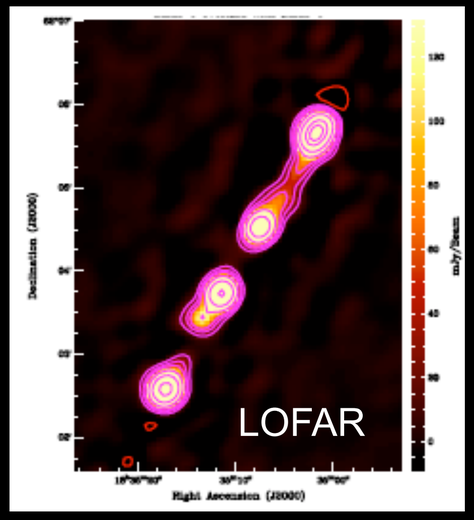
Why relevant:
- time scales on/off ➔ dependence on radio power
- triggering process
- dependence on host galaxy's properties
- impact on the host galaxy ➔ feedback
- different radio source in every phase?
- ....



Life-cycle of radio sources

Restarted/Dying radio galaxies ➔ variety of structures ➔ likely corresponding to different time/duration of the *on/off* phase

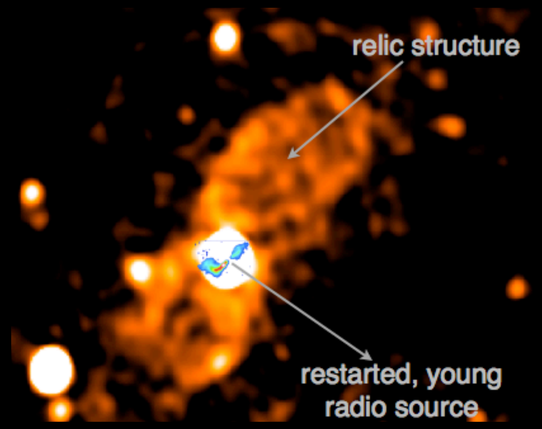
Double-double
repeated collimated jet



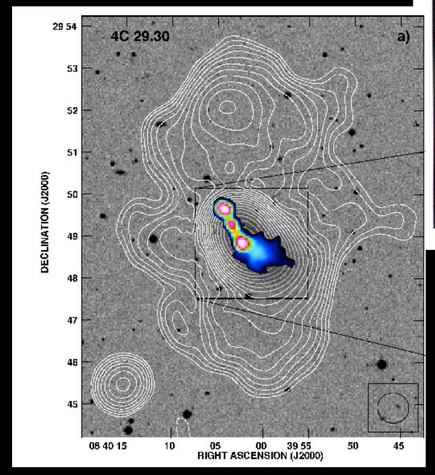
Orru` et al.

Restarted + relic/diffuse

still supplied vs relic/fading away
compact vs extended



Shulevski et al. 2012



4C29.30
Jamrozy et al. 2007

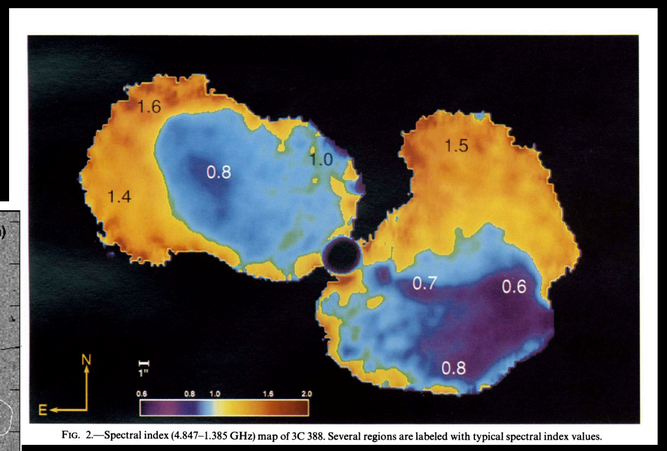
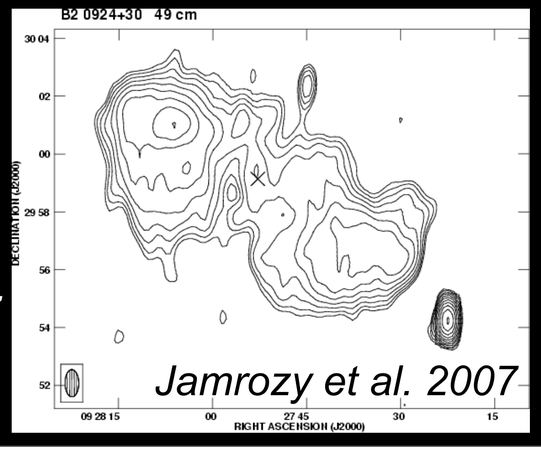


FIG. 2.—Spectral index (4.847–1.385 GHz) map of 3C 388. Several regions are labeled with typical spectral index values.

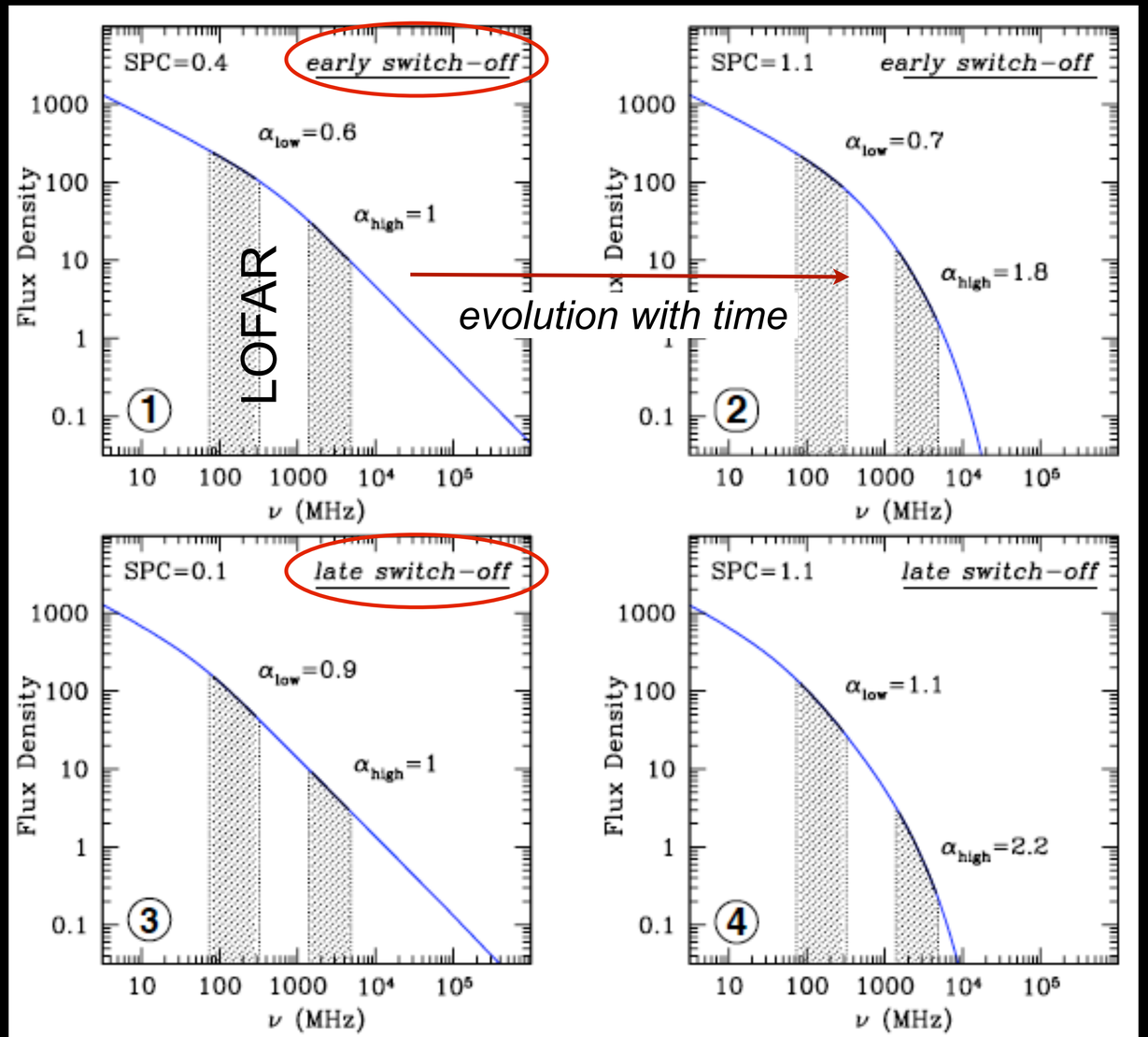
3C388
Roettiger et al.

Relics



0924+30
Cordey, 1987

Quantify the on/off phases with the radio spectrum....



Murgia et al. in preparation *"Life Cycles and Spectral Evolution of Active, Dying, and re-Starting Radio Galaxies"*

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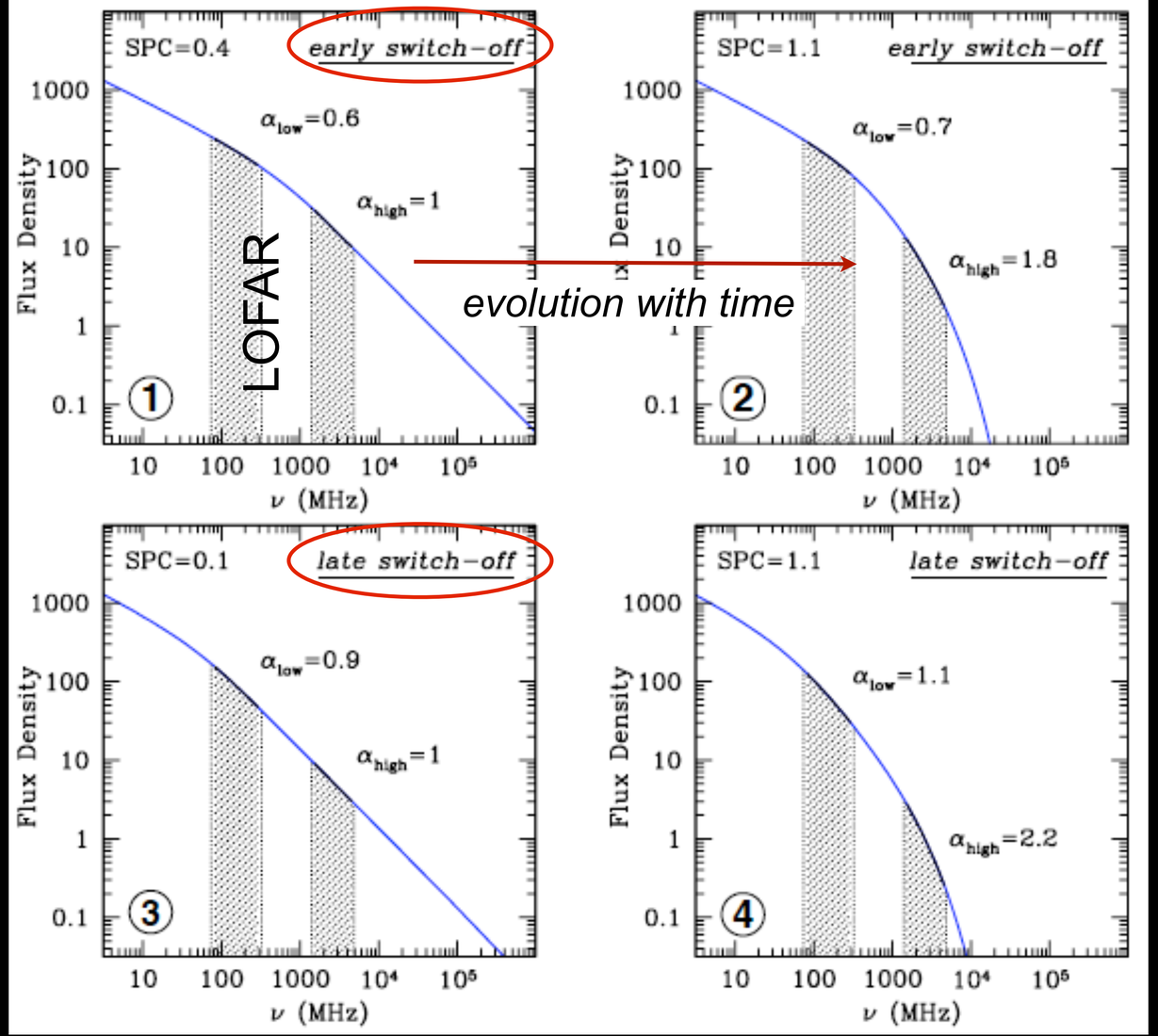

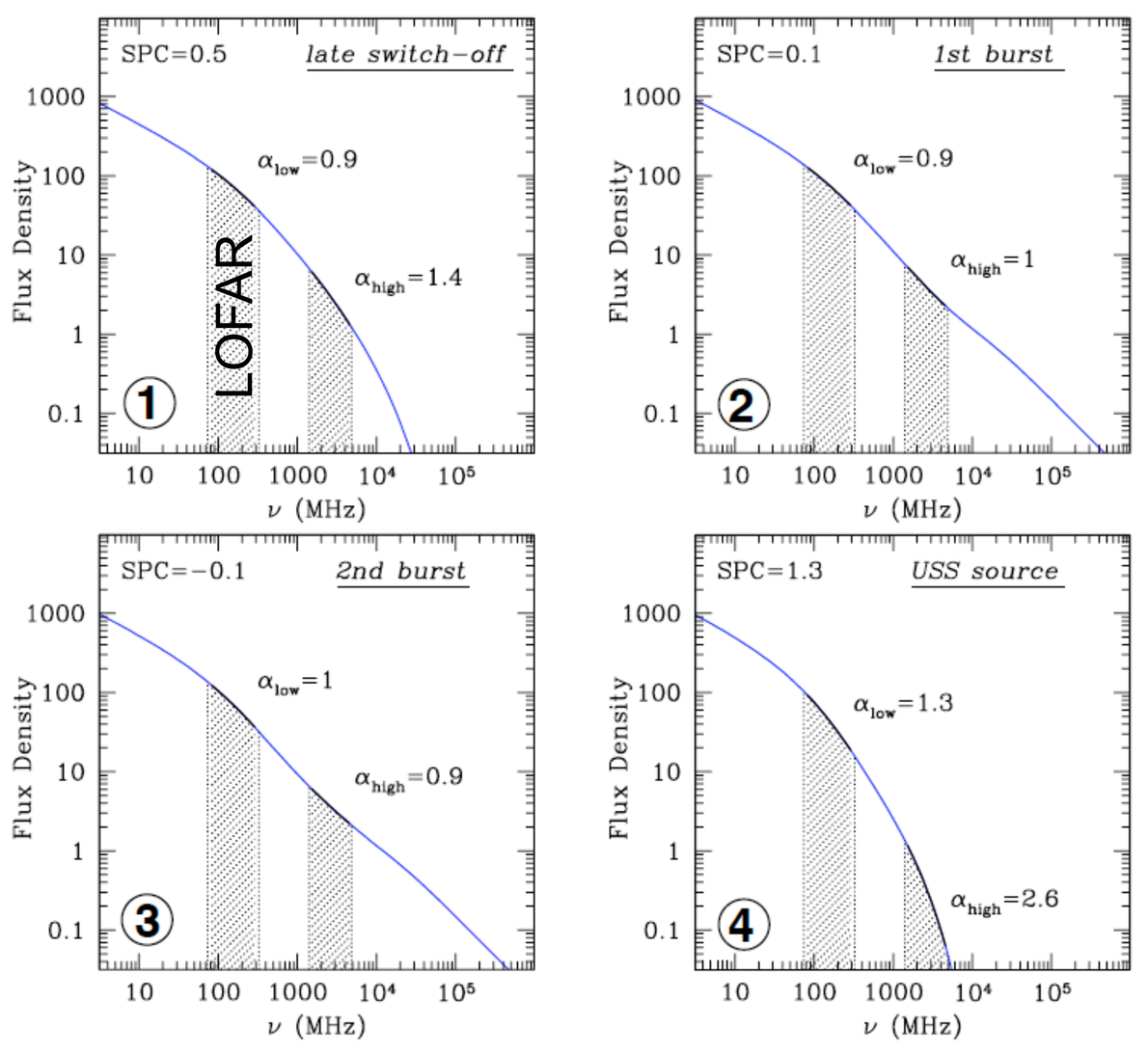

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What else do we know.....

★ Powerful (i.e. FRII) radio sources become active only every one-to-few Gyr, while low-power (FRI) would need to spend **more than a quarter of their life in an active phase** *(Best et al. 2005, Shabala et al. 2008)*.

➔ *signs of past radio-loud activity could be more common in the latter*

★ **Environment** plays a role

★ Time spent in active phase has same dependence on stellar mass as **cooling rate**: quiescent phase due to fuel depletion (*Shabala et al. 2008)*?

★ Connection to accretion mechanism/fuel: **connection with HI**

➔ *for low luminosity: if cooling from hot halo within the host galaxy is the trigger, a lot of restarted sources expected?*

Using LOFAR for more systematic studies

- Sparse sampling ➔ some groups better studied than others (e.g. double-double)
- Relics are rare ➔ 3% *(Giovannini et a. 1989)*

need for a **systematic search**, more objects, efficient selection

combination of **morphology, integrated spectra and spatially resolved spectra** for many sources on large, deep images !!!

as criteria for selecting samples

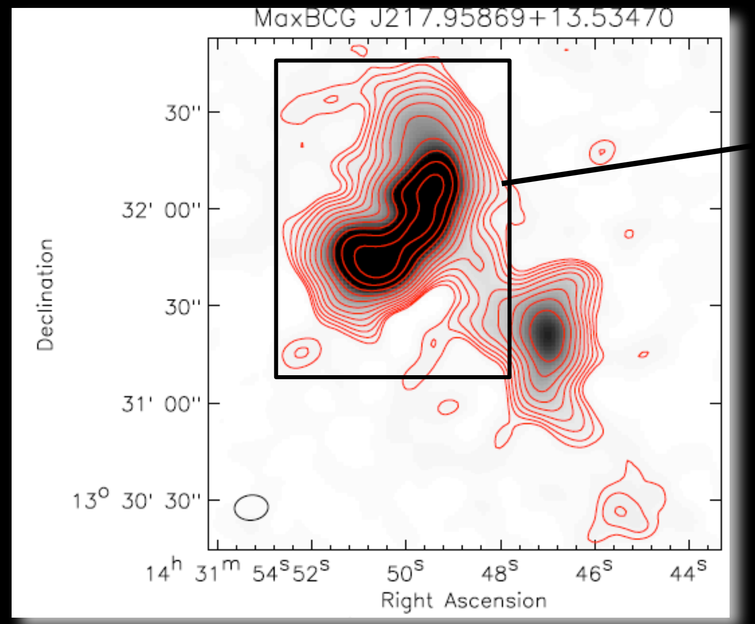
Part of the nearby AGN group - Surveys KSP

To start with: two case studies

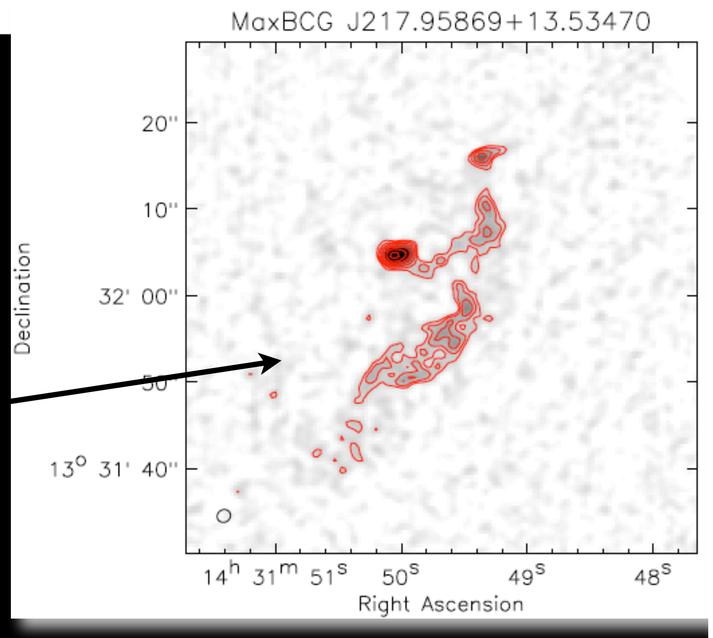
Shulevski PhD Thesis
Shulevski et al. in prep

J1431-13: Relic selected at 74MHz VLSS Survey

van Weeren et al.

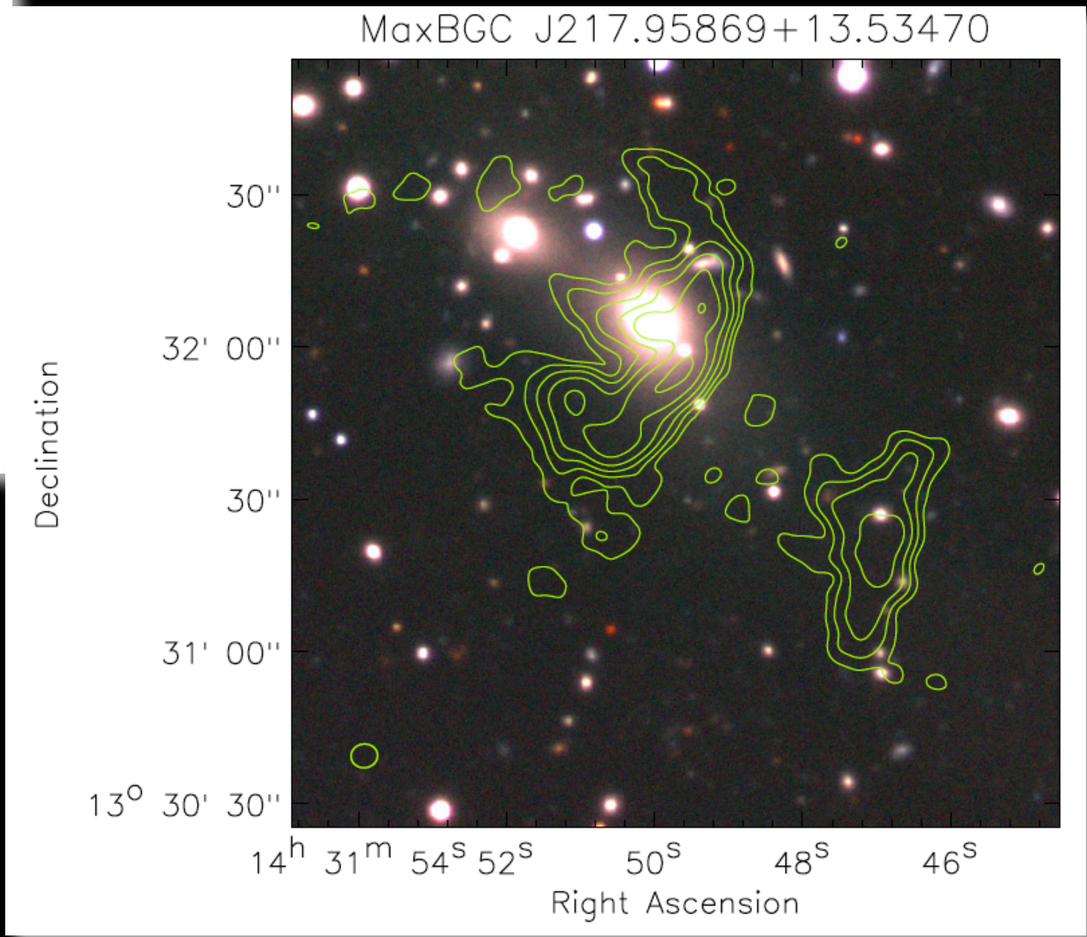


GMRT 325 MHz



VLA 1.4 GHz

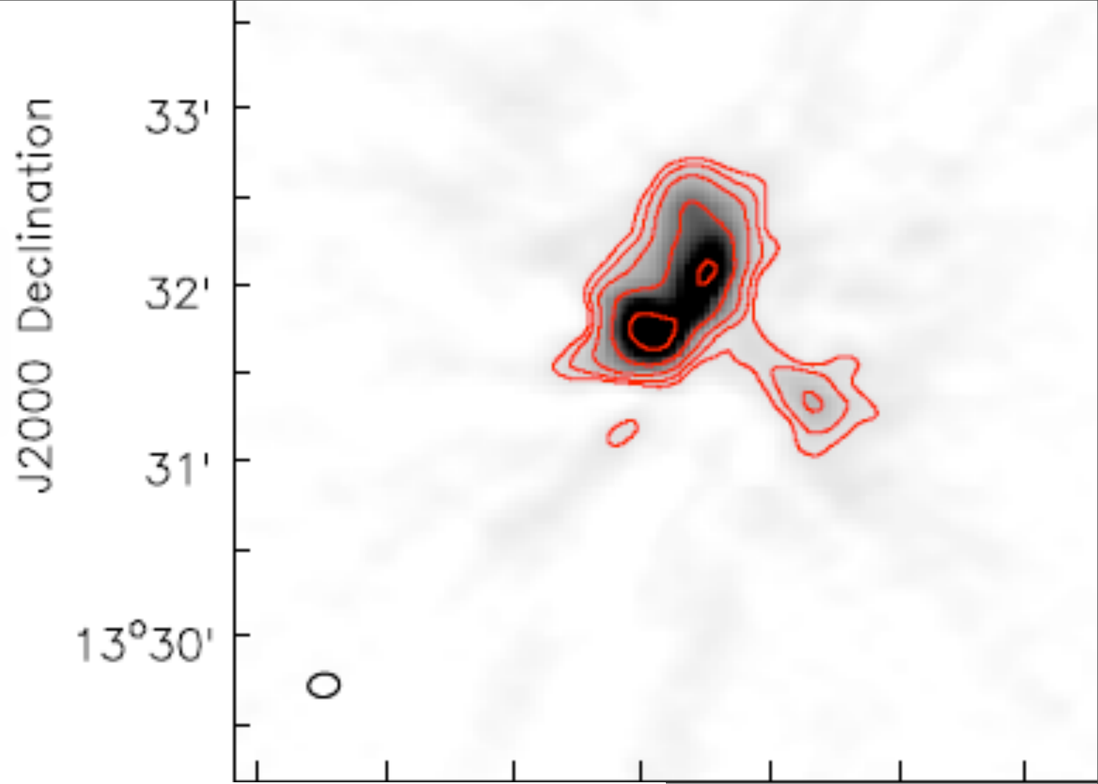
high spatial resolution



van Weeren et al. (2011)

LOFAR Cycle 0 data

Radio relic J1431+13
HBA 150MHz - 6h
rms 0.5 mJy/b - 10.5" x 8"
interleaved target-calibrator



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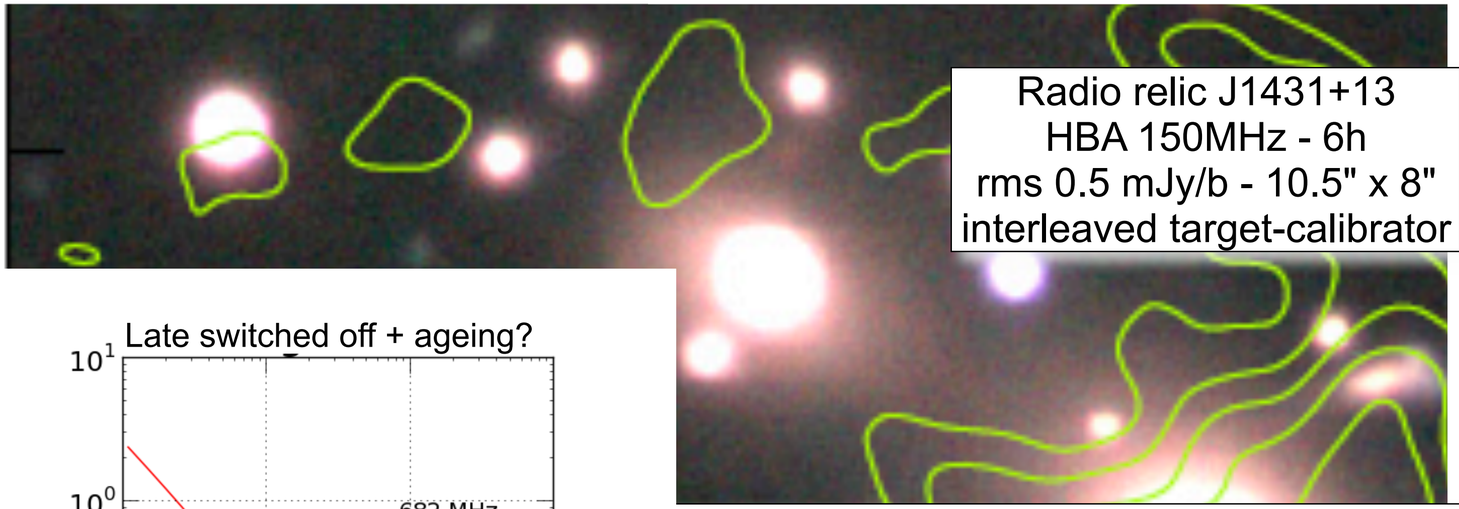

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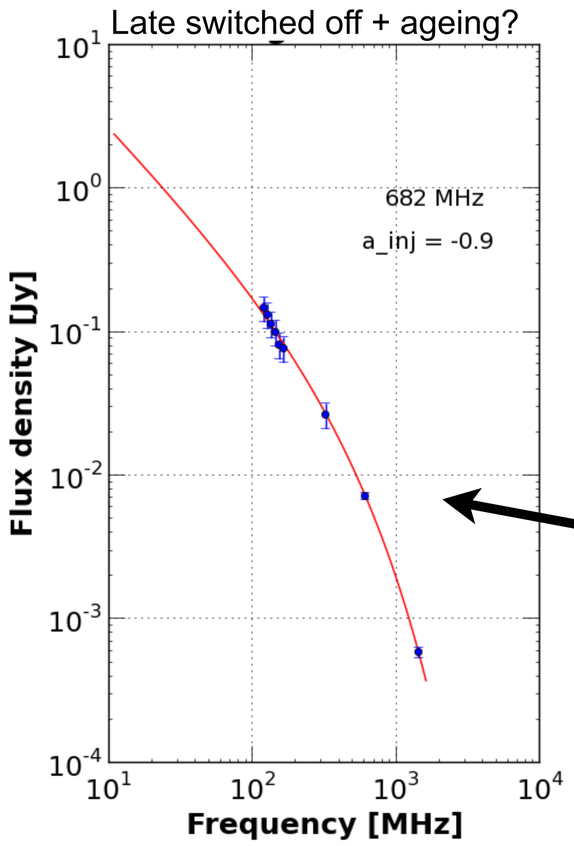
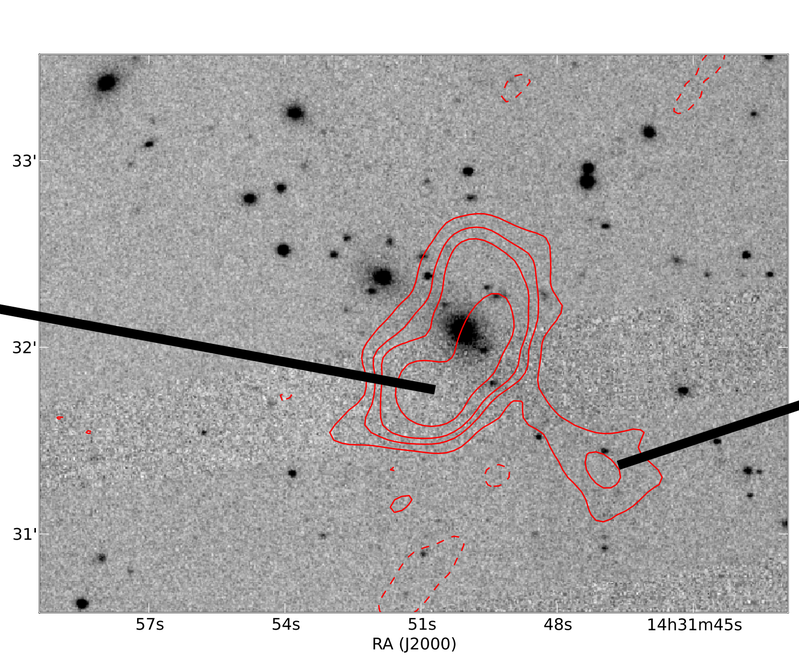
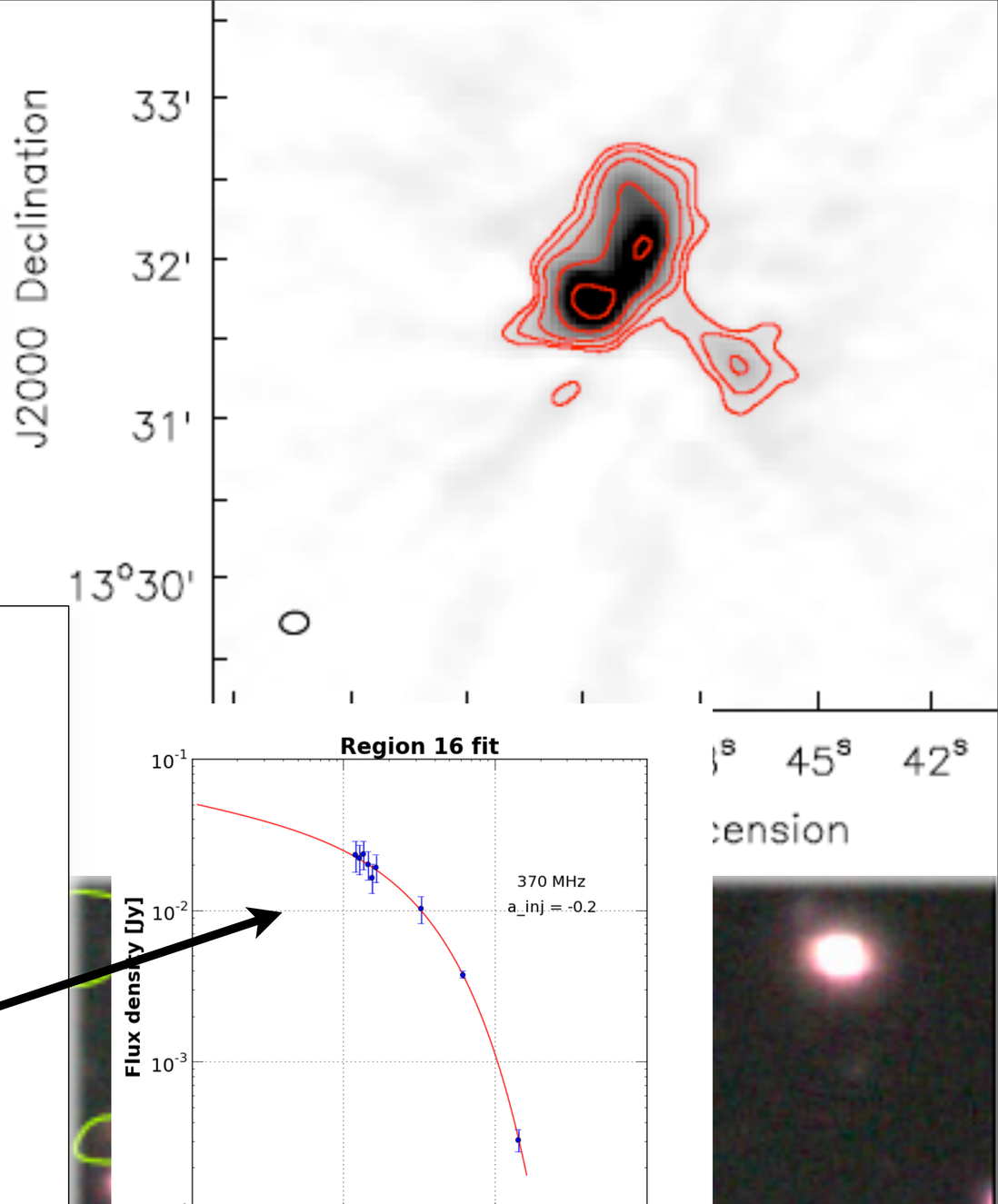
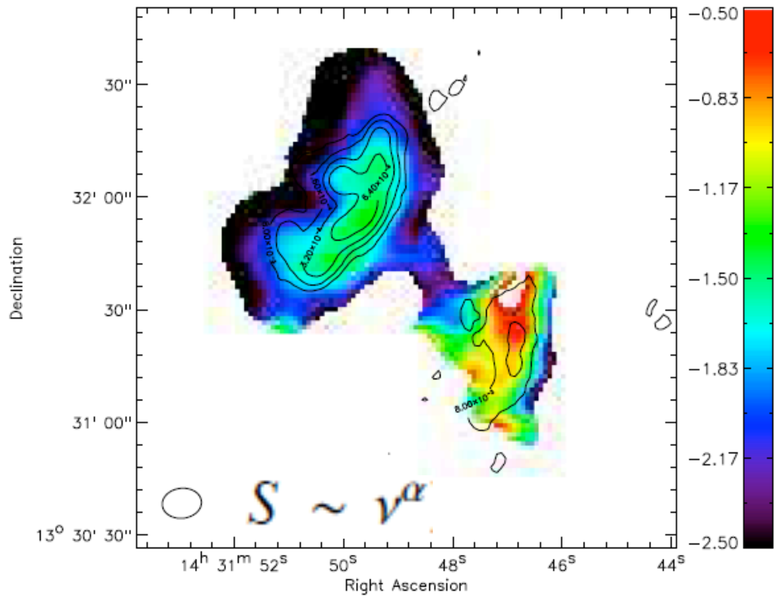






Shulevski et al. in prep.

LOFAR - GMRT - VLA



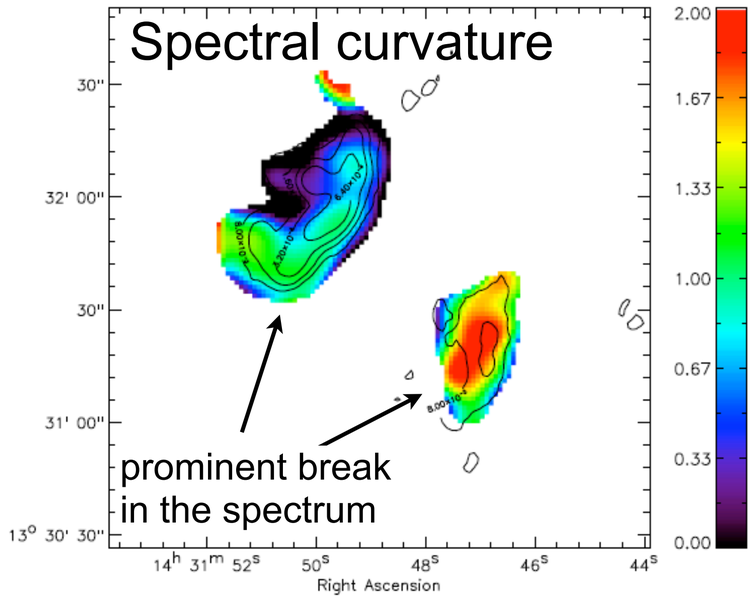
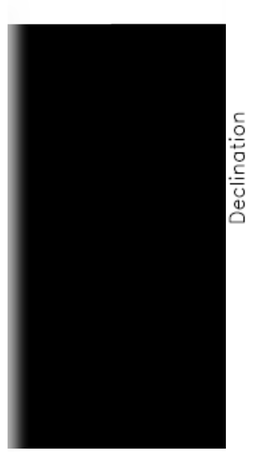
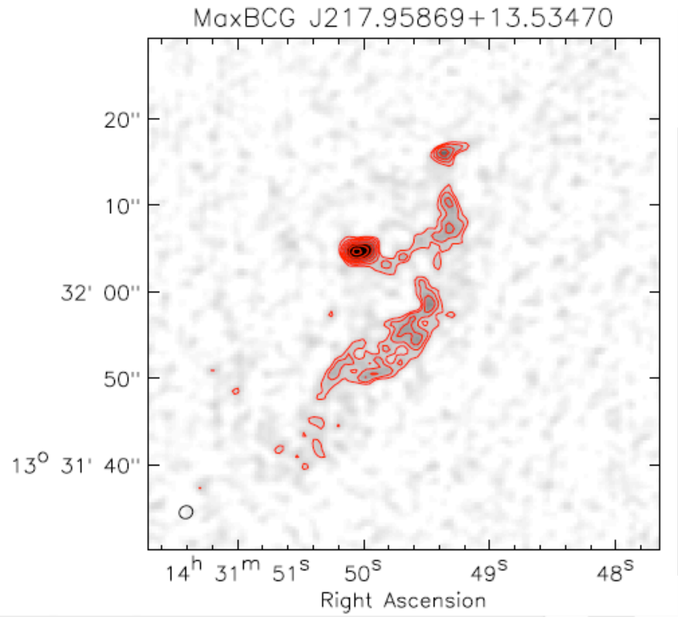
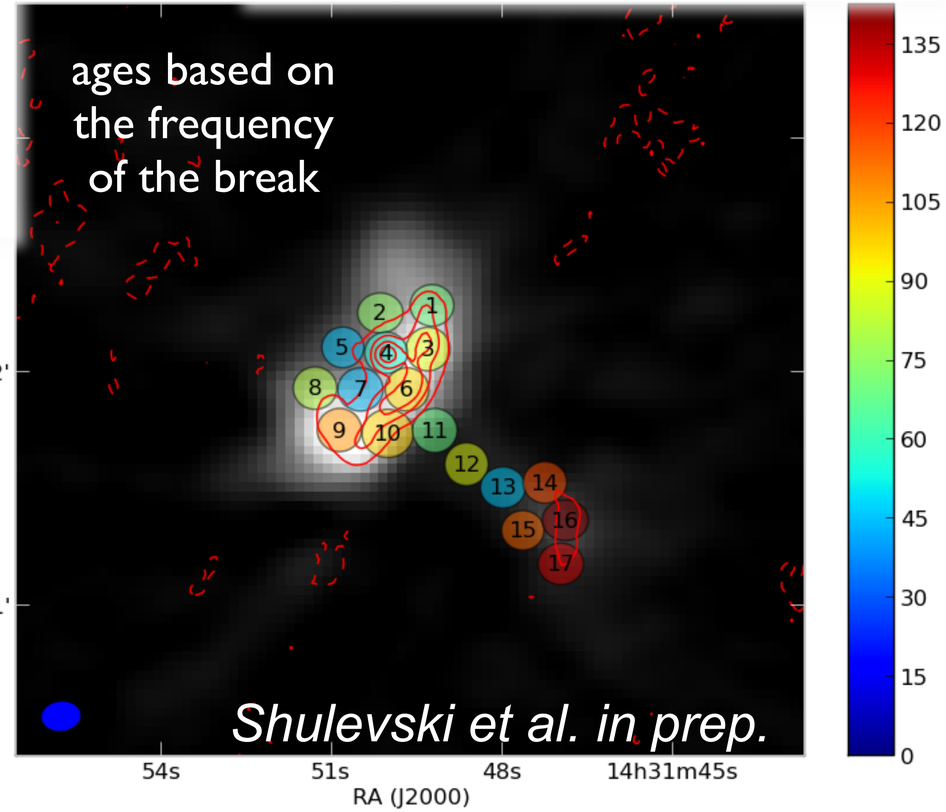


Fig. 4: Left: α_{127}^{325} spectral index map of VLSS J1431+1331. Overlaid are 1425 *MHz* high resolution VLA contours to help in locating the radio core. Right: $\alpha_{127}^{610} - \alpha_{610}^{1425}$ spectral curvature map using LOFAR, GMRT and VLA images. Contours taken from the highest resolution JVLA map at 1425 MHz are overlaid over the maps to indicate the position of the faint radio core. The beam size is indicated in the lower left corner.







Confirming and expanding van Weeren et al. results:

+ SW source has a prominent break in the radio spectrum and shifted to lower frequency: component from an older phase of activity of the AGN + confinement

+ southern end of the radio structure also with high curved => result of spectral ageing away from the core

"Bubbling" source while moving in the cluster

Entire imaged field
5x5 deg

Plenty of intersting sources to explore in the rest of the field...

J1431+13

LOFAR (150 MHz) - Shulevski, Vilchez et al.

Finding serendipitous objects in the field: the case of 4C35.06

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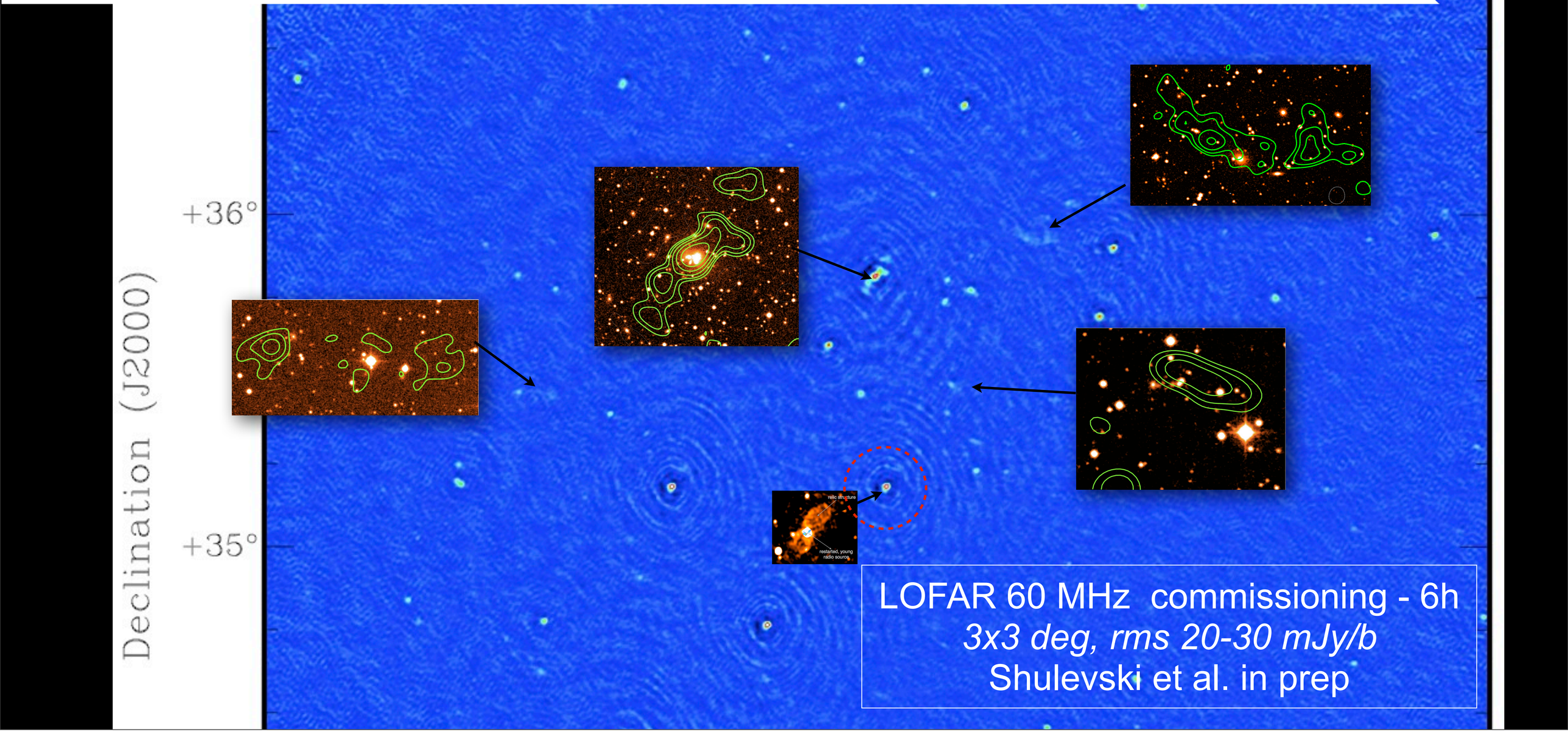
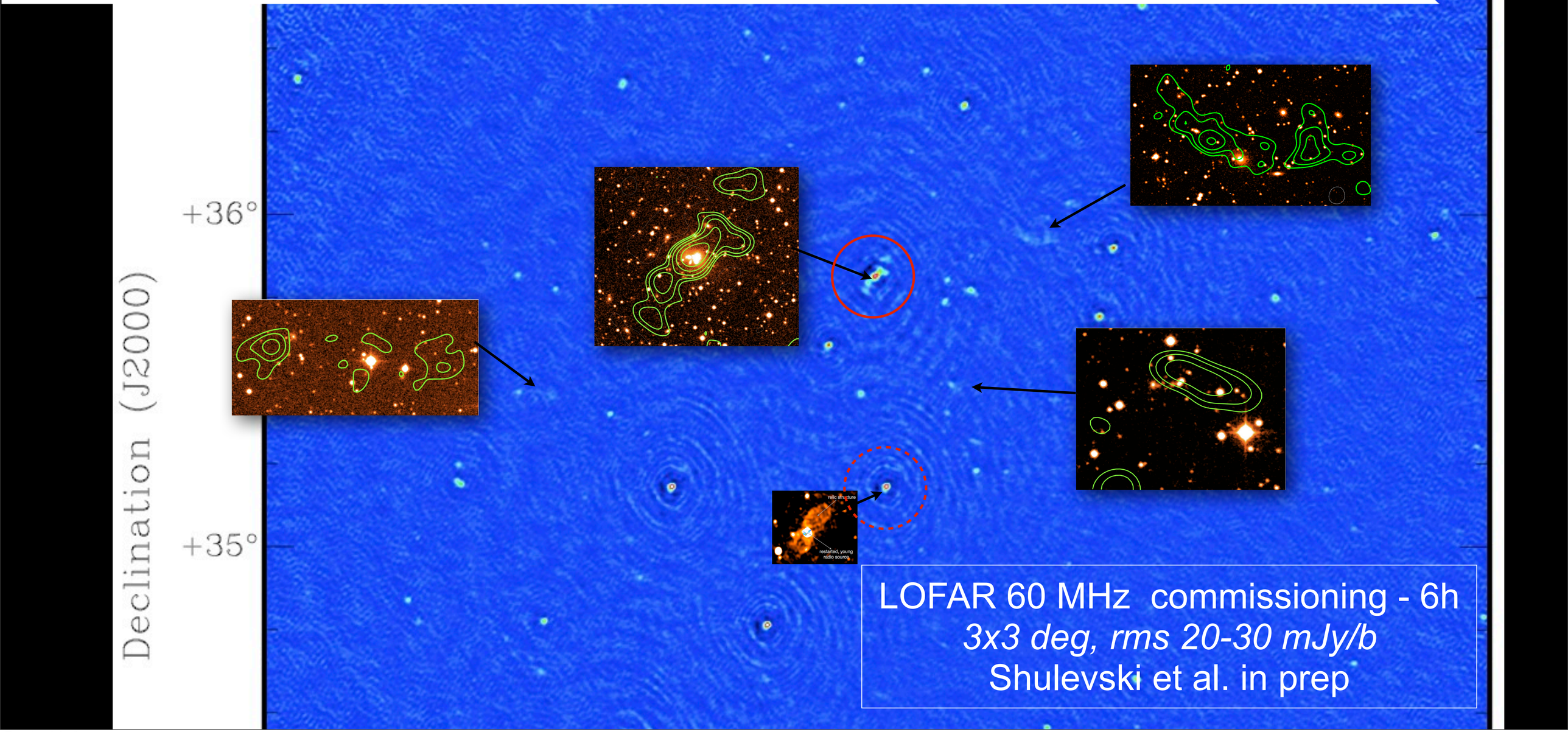


LOFAR 60 MHz commissioning - 6h
3x3 deg, rms 20-30 mJy/b
Shulevski et al. in prep

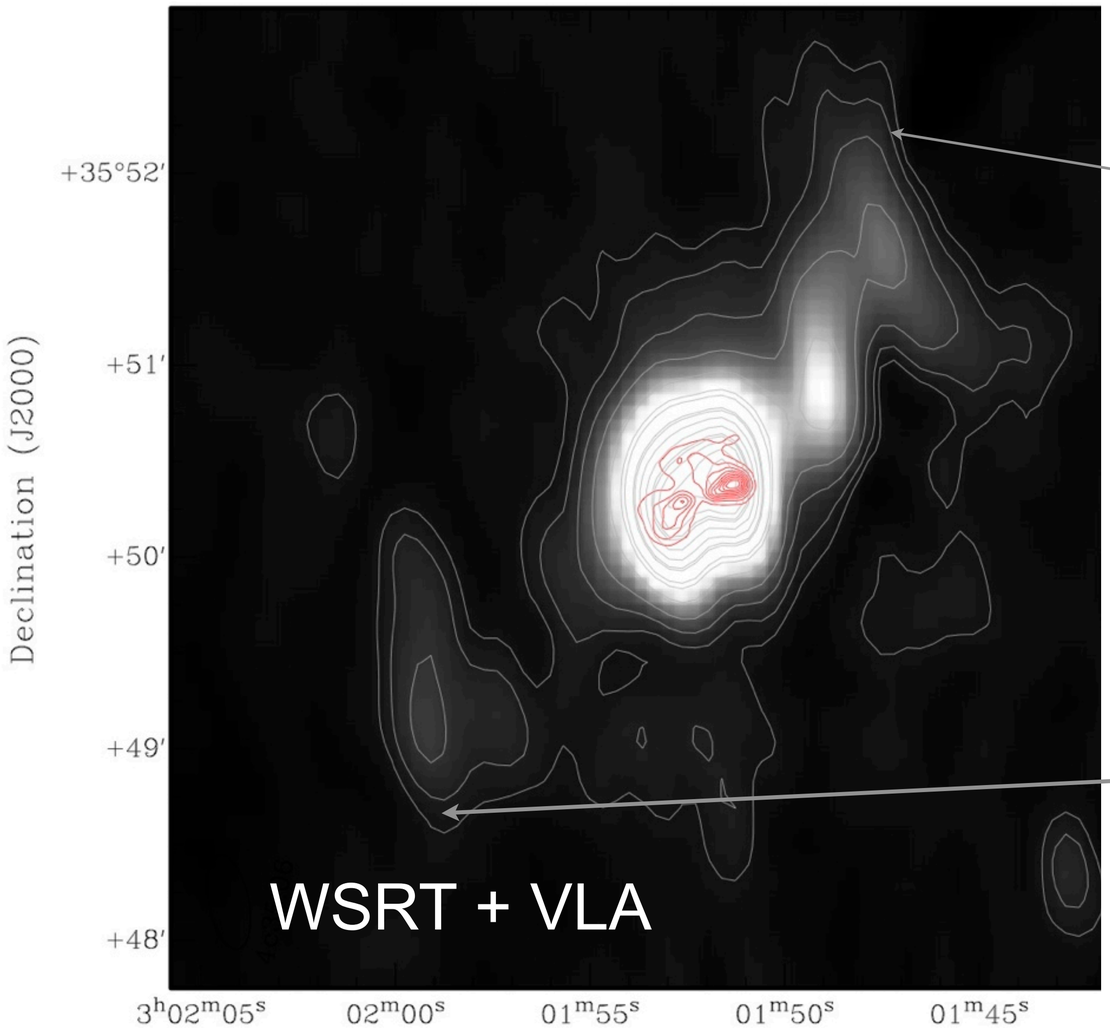
Finding serendipitous objects in the field: the case of 4C35.06

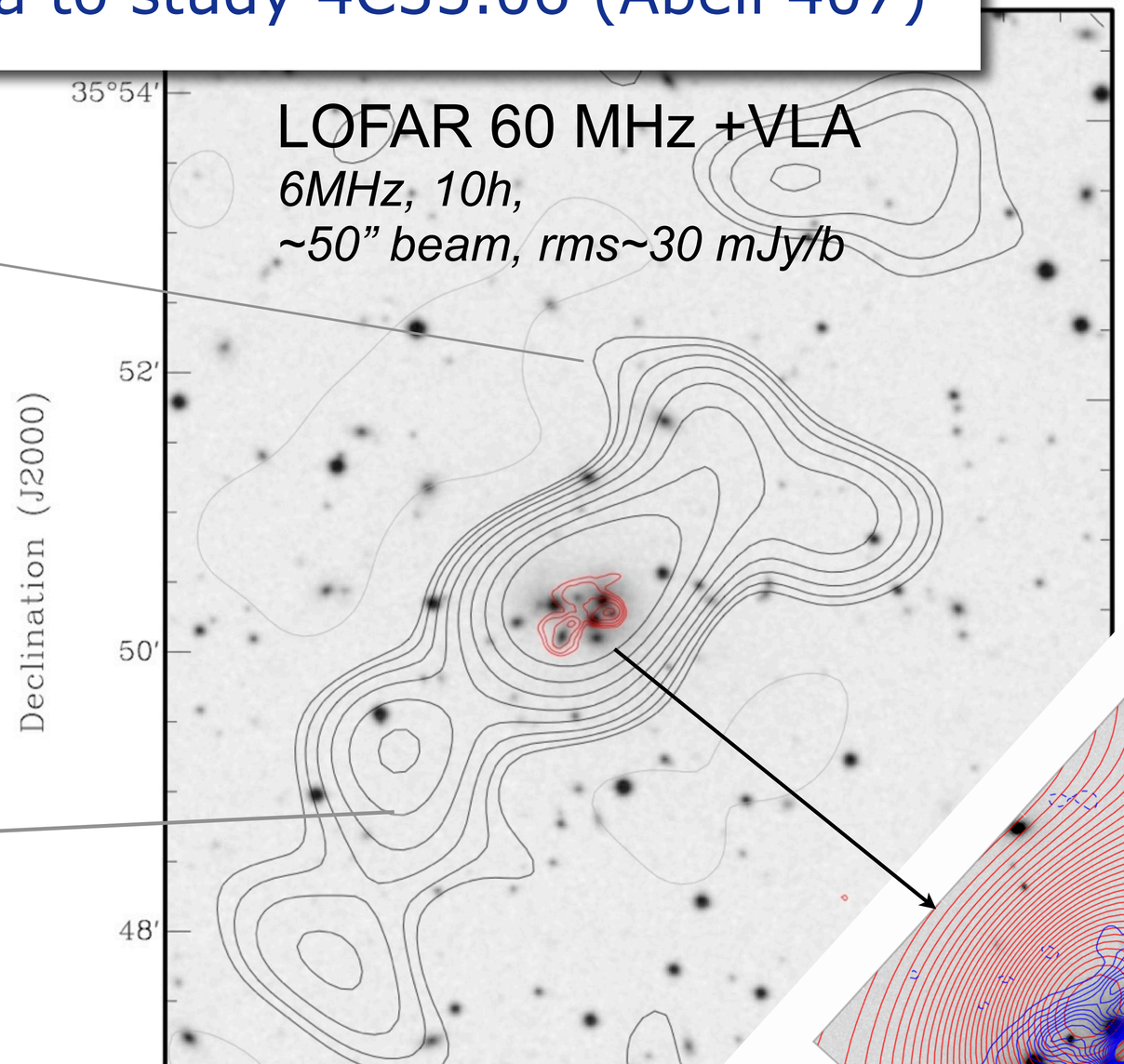
ASTRON

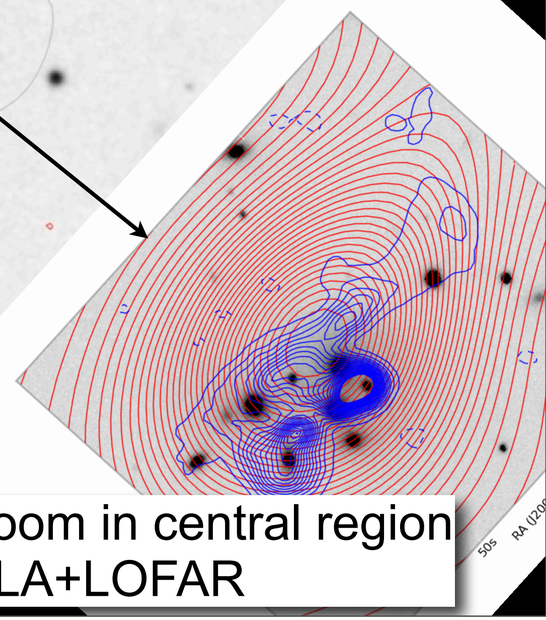


LOFAR 60 MHz commissioning - 6h
3x3 deg, rms 20-30 mJy/b
Shulevski et al. in prep

Using LOFAR commissioning data to study 4C35.06 (Abell 407)



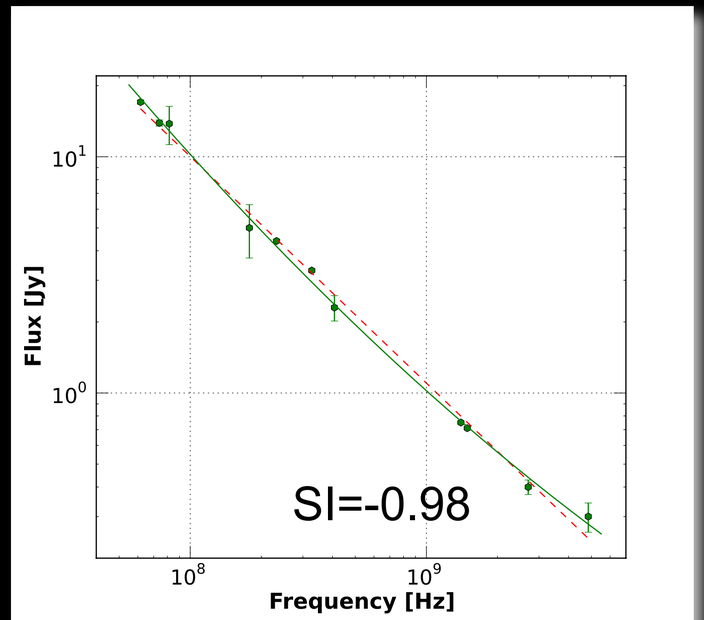


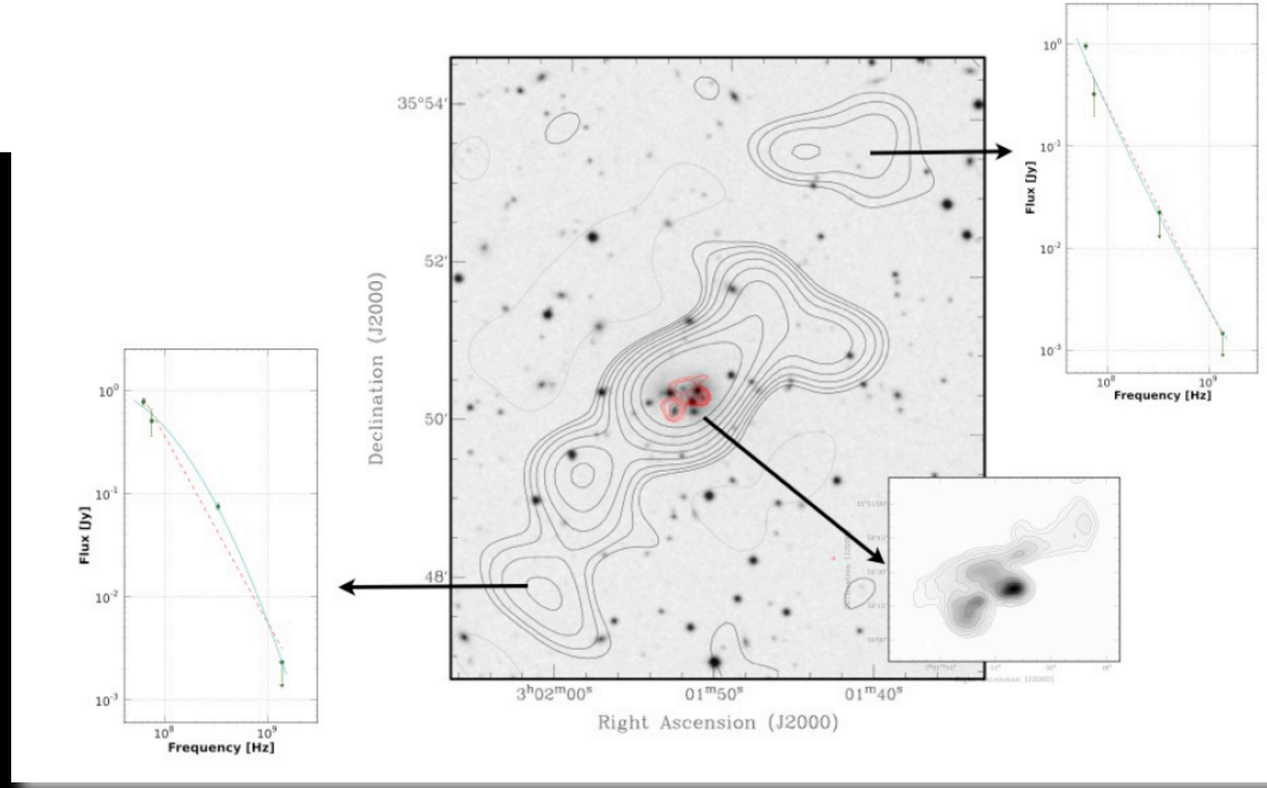


Much larger extension imaged by LOFAR

total size ~400 kpc

Tracing the spectral index....

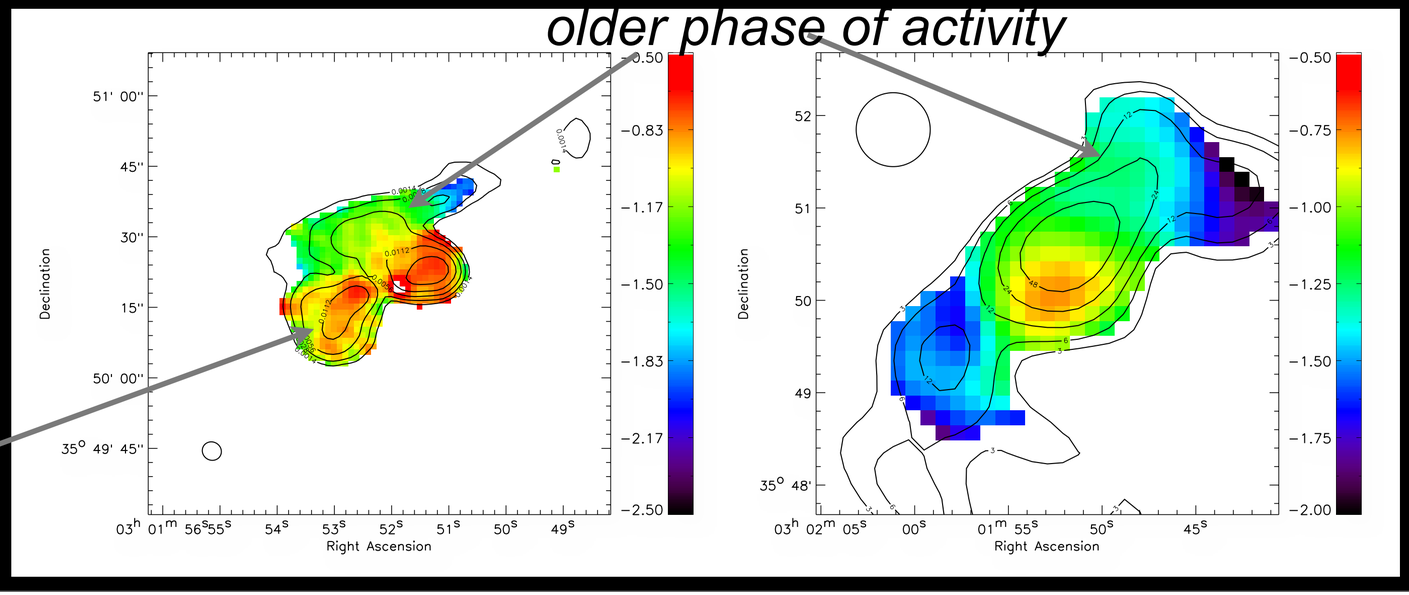




At least two epochs of activity (while moving in the cluster)

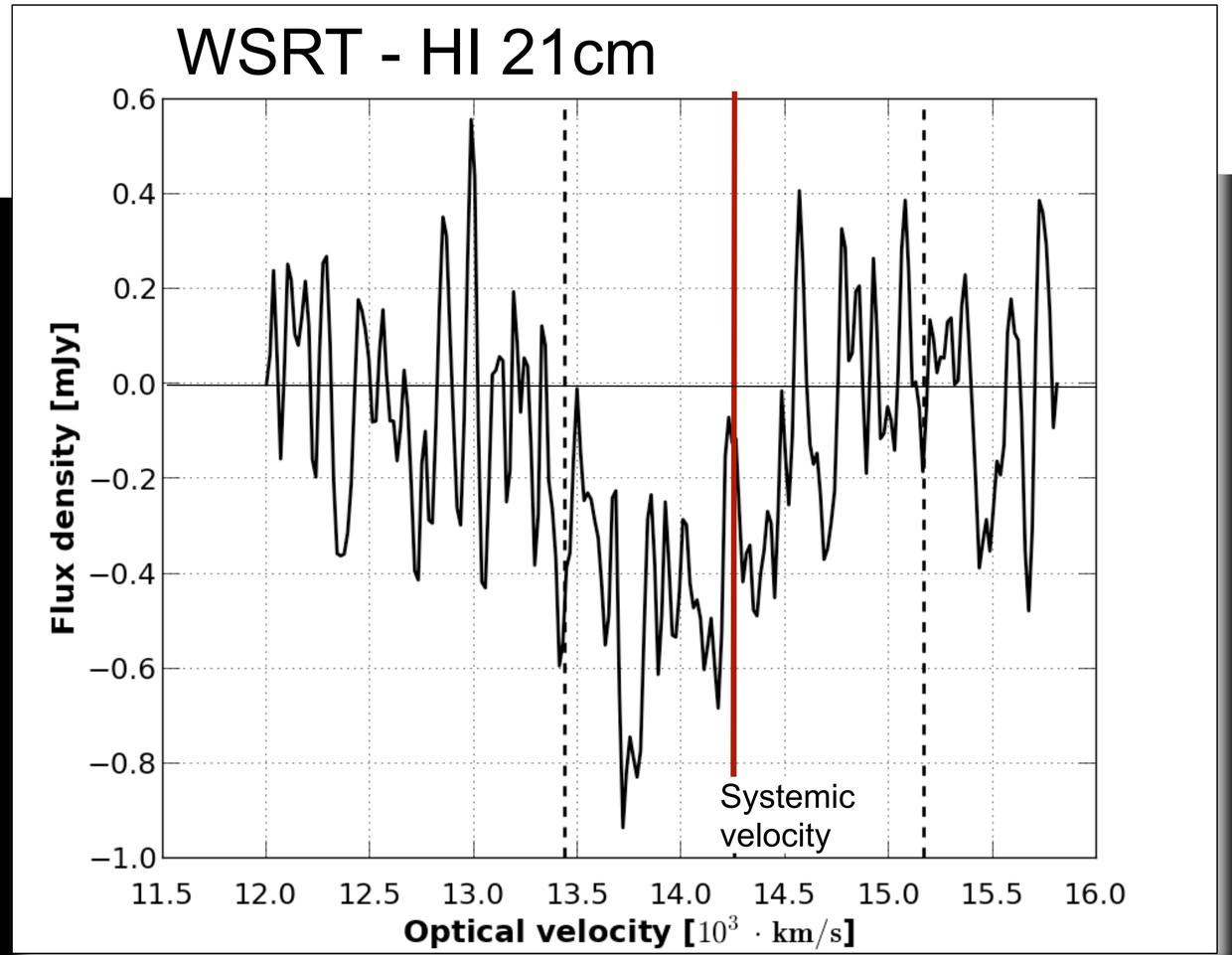
older phase of activity

active now



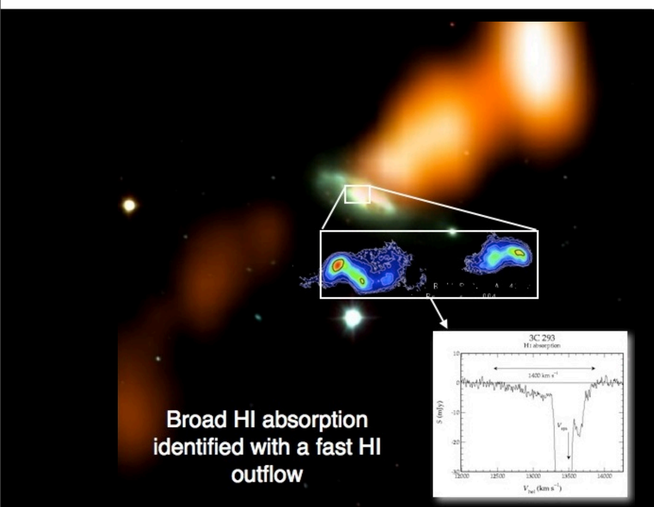
Detection of atomic hydrogen (HI)

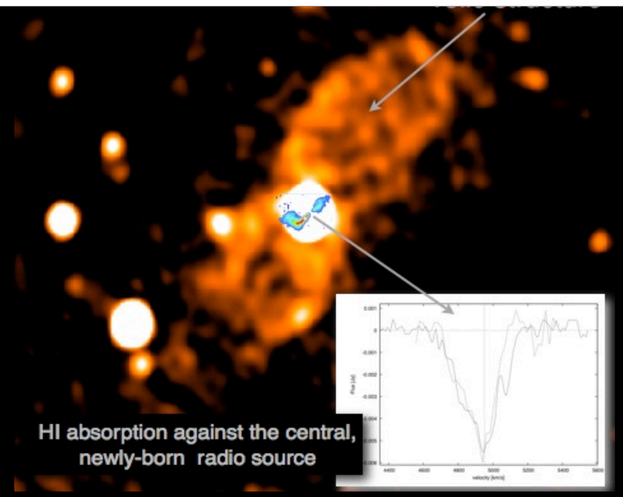
- Interesting WSRT detection of HI
  (against the brighter inner lobe of 4C35.06)
- Column density ~4x10^{20} cm^{-2} (Tspin=100K)
- Relatively broad absorption (~ 400 km/s) mostly blueshifted compared to systemic velocity
- Confirms the trend found for restarted radio sources (e.g. Chadola et al.)

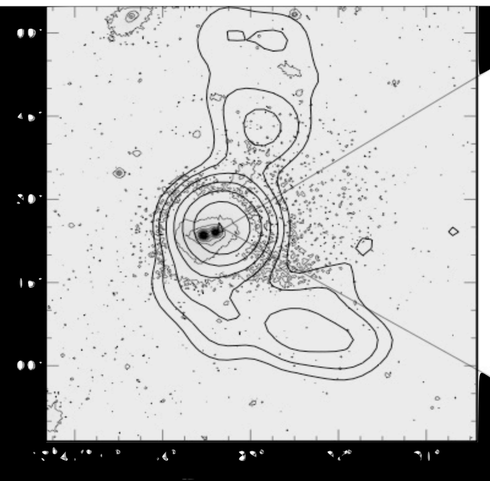


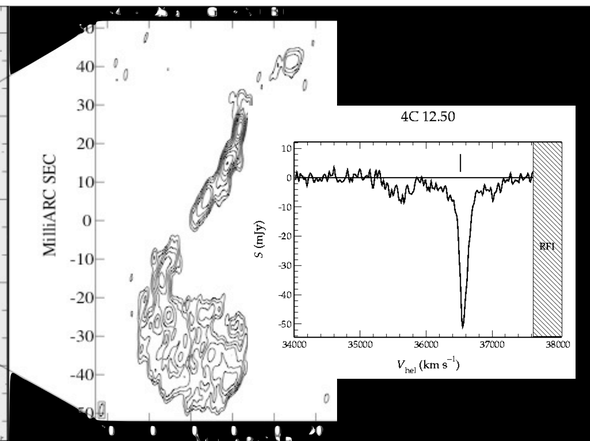
To be confirmed by deeper, higher spatial resolution observations

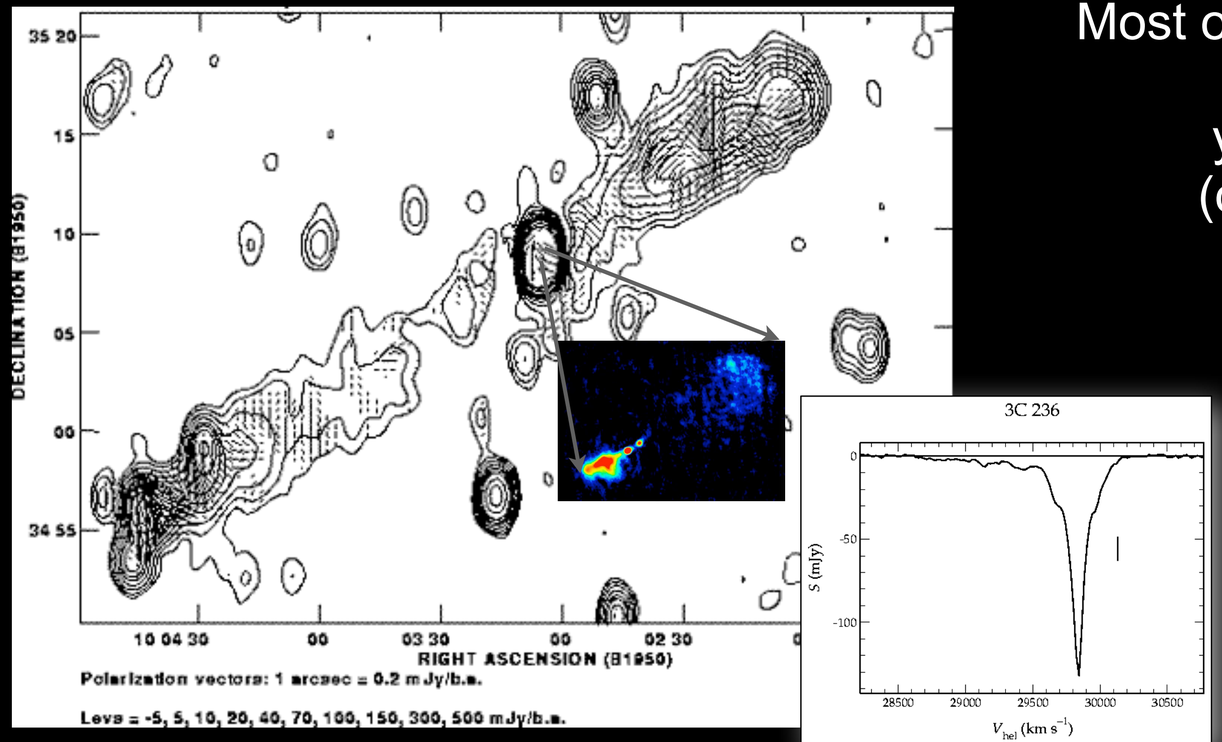
Restarted radio sources and gas (HI)





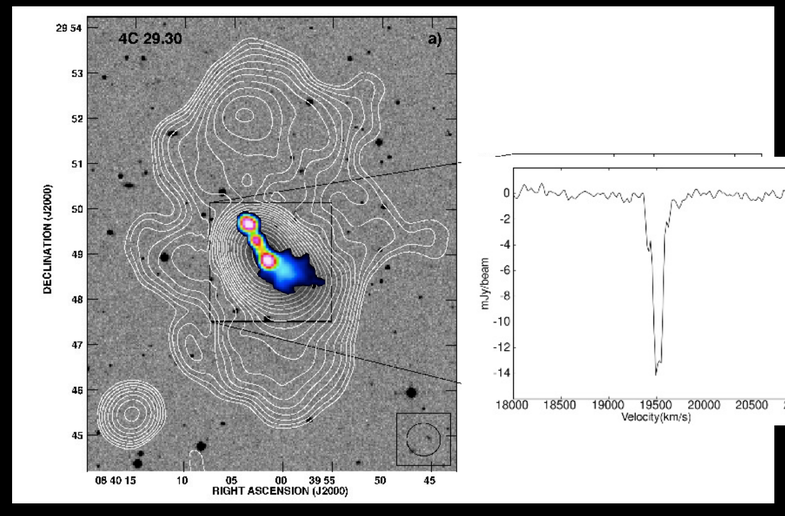






Most of HI absorption detections
are
young radio sources
(or recently restarted)

clearing up the gas
in the central
regions



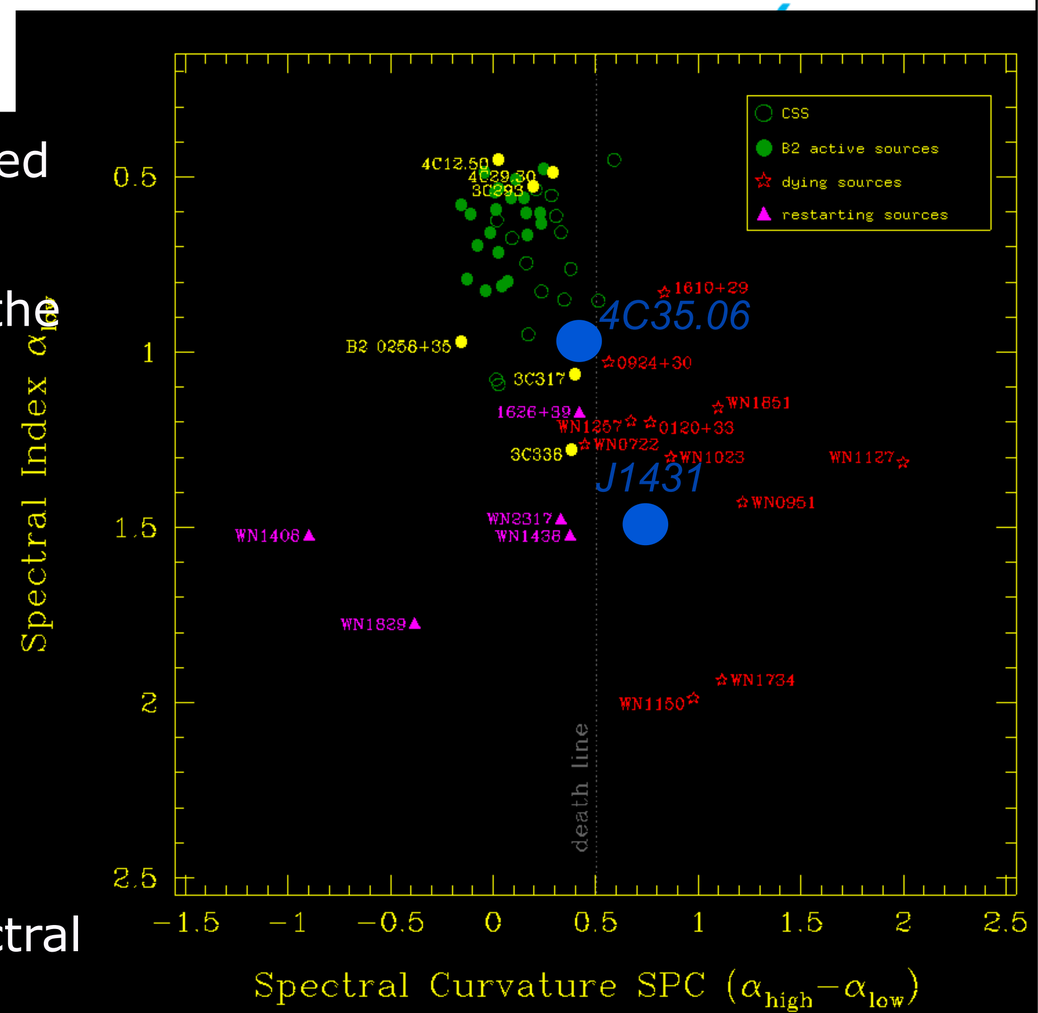
Summary and what next...

- Detailed study of two restarted/dying radio sources, one picked serendipitous from a LOFAR commissioning field

  => combine we can trace the ageing and derive info on the life of these radio sources

- Setup a path for handling and analysing HBA data
- LBA still lagging behind
- More objects from Cycle 1, data reduction in progress: *3C388 (Brienza, Godfrey), 0924+30 (Shulevski)*

- Move to blind search of candidates over the full field
- Test of the selection criteria based on spectral index and spectral break: *observations proposed for Cycle 2 (PI Brienza)*
- More sophisticated treatment of the dying phase, incorporating eg. expansion losses, => refined search techniques for the LOFAR survey fields *(Leith Godfrey)*.



Murgia et al. in preparation