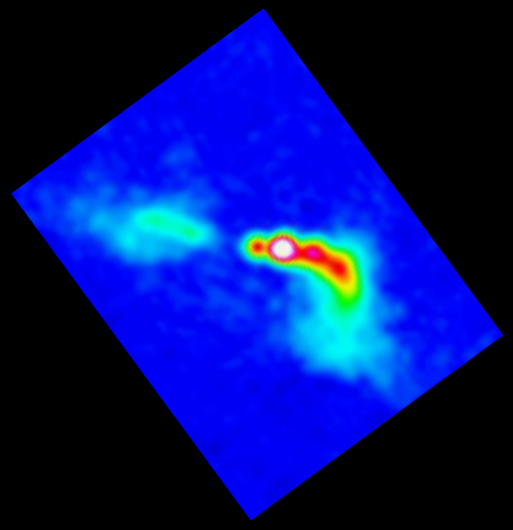
Restarted Radio Galaxies in the Lockman Hole

Nika Jurlin
Raffaella Morganti, Marisa Brienza

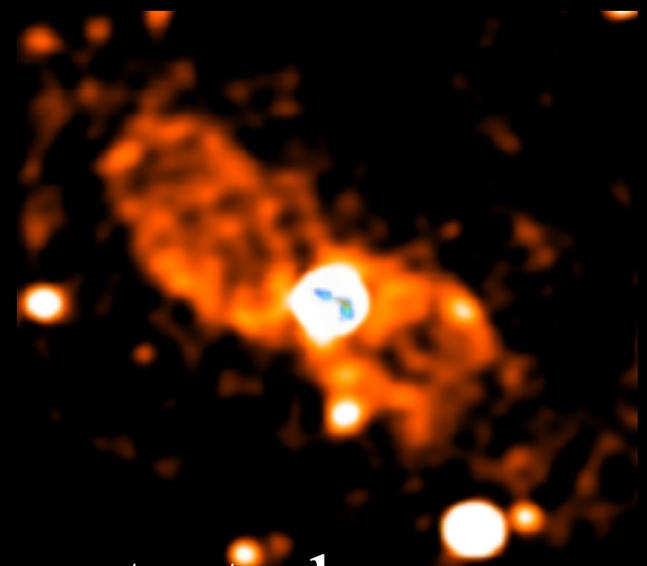
university of groningen
faculty of science and engineering
kapteyn astronomical institute

Giroletti+2005



young source

Giroletti+2005

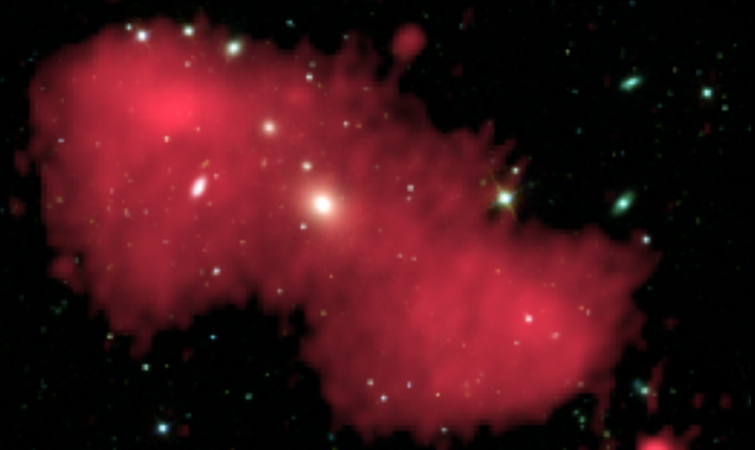


restarted source

VLA, 5 GHz

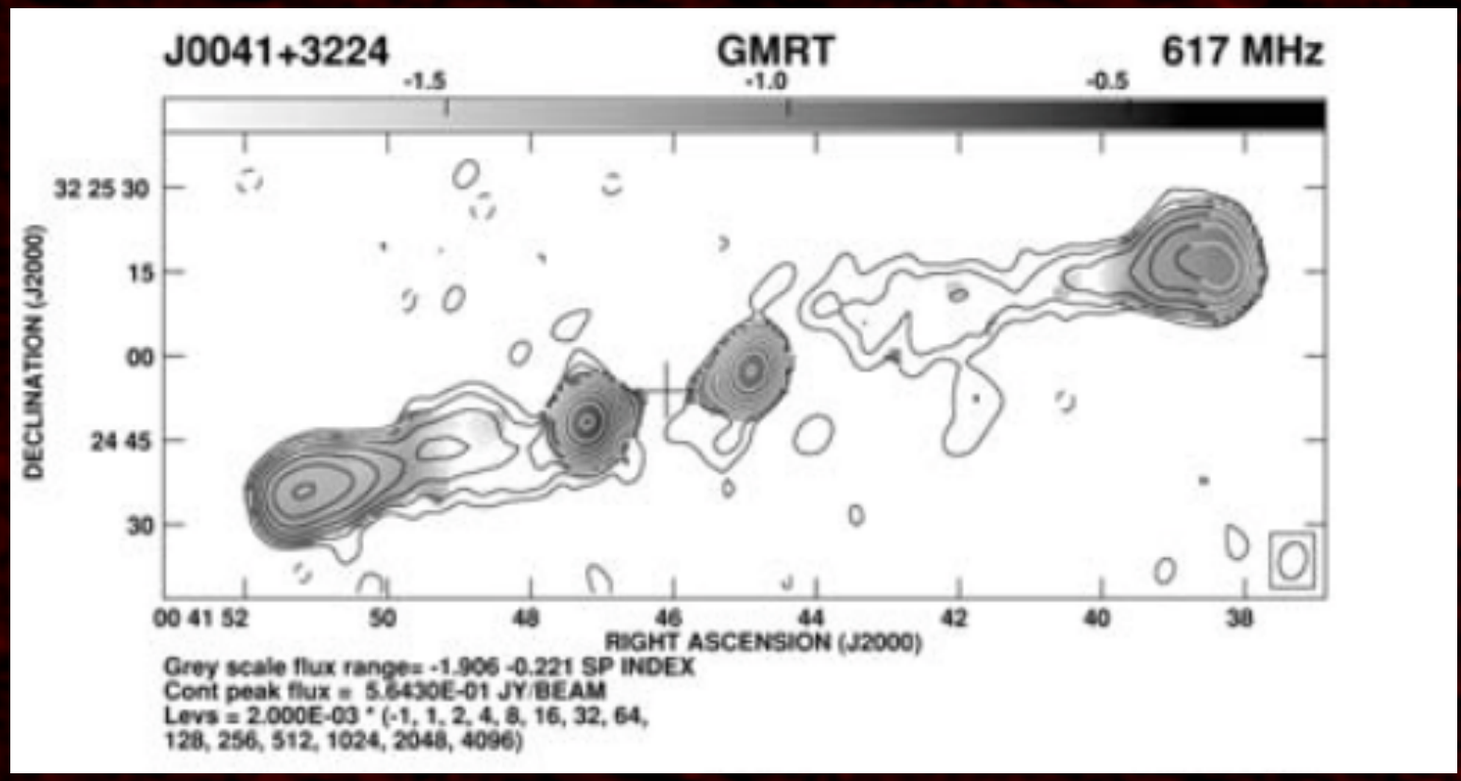
extended source

Shulevski **+17**



remnant source

1. Double - double radio galaxies

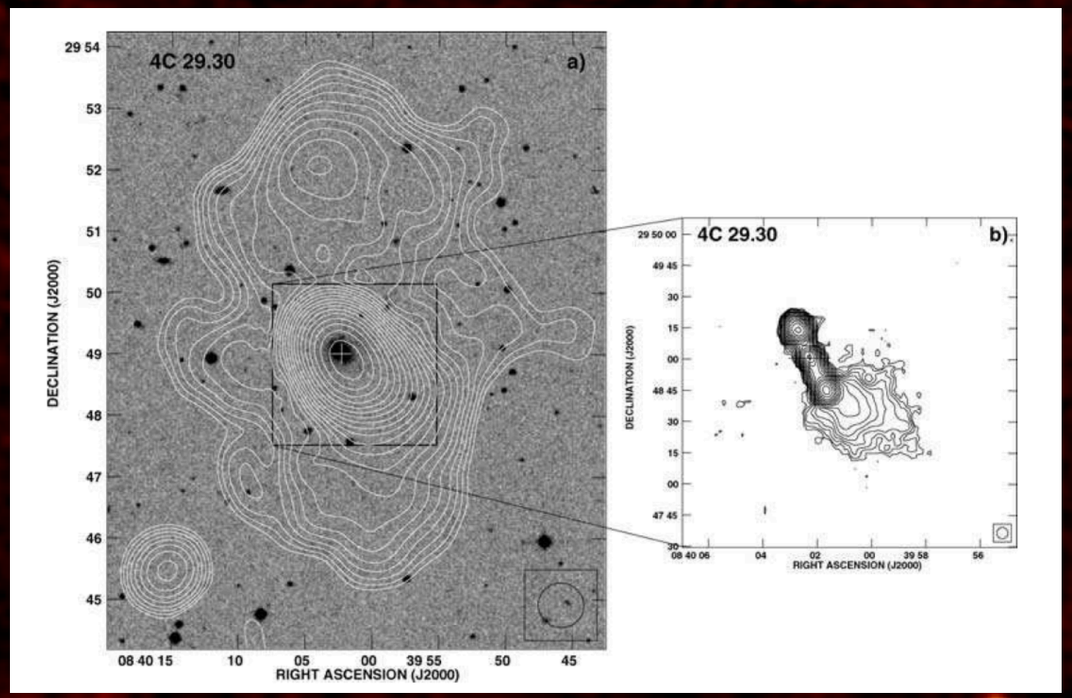


Credit: Saikia+06

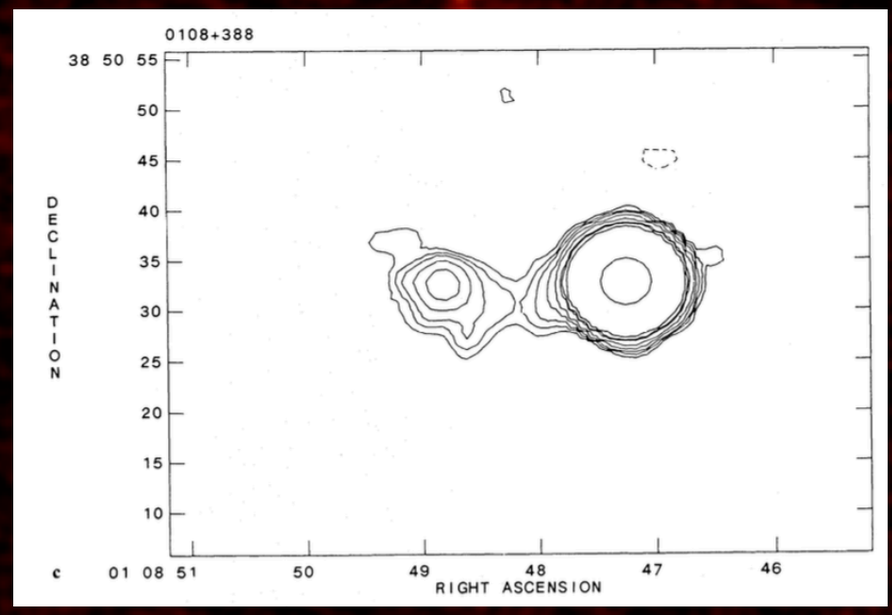
- Lara et al. 1999, Schoenmakers et al. 2000
- 10^5 - 10^7 yr (Konar et al. 2012, 2013) - spectral ageing modelling
- 10^5 yr (Jamrozy et al. 2009; Safouris et al. 2008) - observations of the hotspots

1. 1. Early stage of DDRG

2. Large scale diffuse radio emission around young compact radio source



Credit: Jamrozy+07



Credit: Baum+90

- quiescent phase ≥ 100 Myr

- Different phases of the AGN duty cycle
- Environment
- Radio power

Saripalli+2012 criteria:

- **FRI restarted:**

-> edge brightened lobes

-> contain either :

-> an inner (recessed) double source or

-> an elongated radio core or

-> an unusually (for FRI) bright radio core

- **FRII restarted:**

-> bright core / core with a pair of bright short extensions

+ emission regions detached from the core and fainter

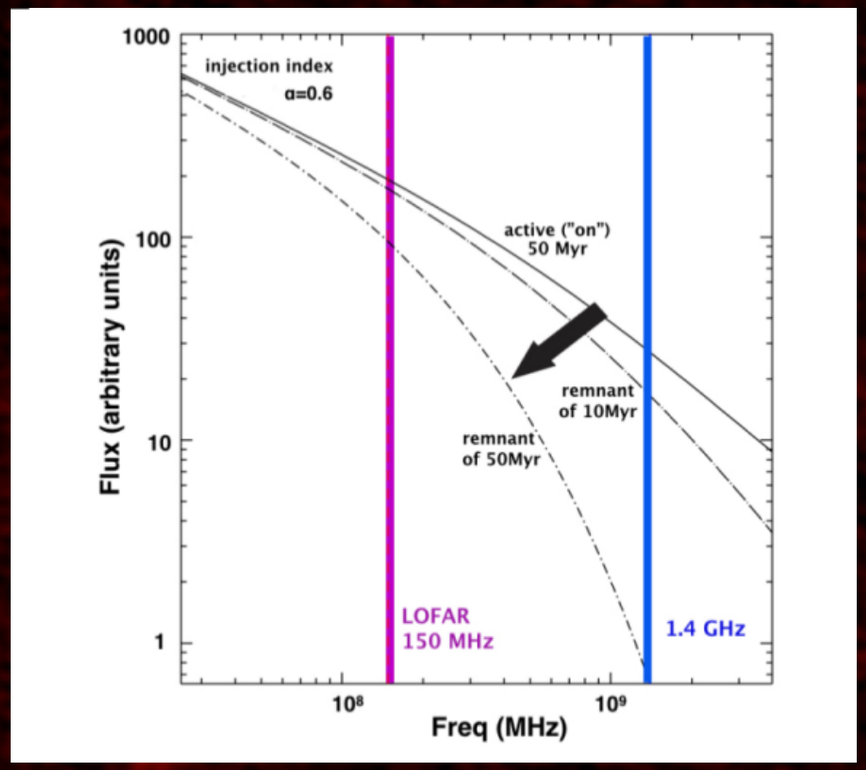
-> outer emission regions are not edge brightened

Total	119
FR-I	55
FR-II	64
FR-I	
Relics	2
Restarts	7
$z > 0.5$	22
FR-II	
Relics	2
Restarts	21
GRGs	14
FR-I	0
FR-II	14

~ 24 % candidate restarted radio sources

Credit: Saripalli+12

Restarted Radio Sources

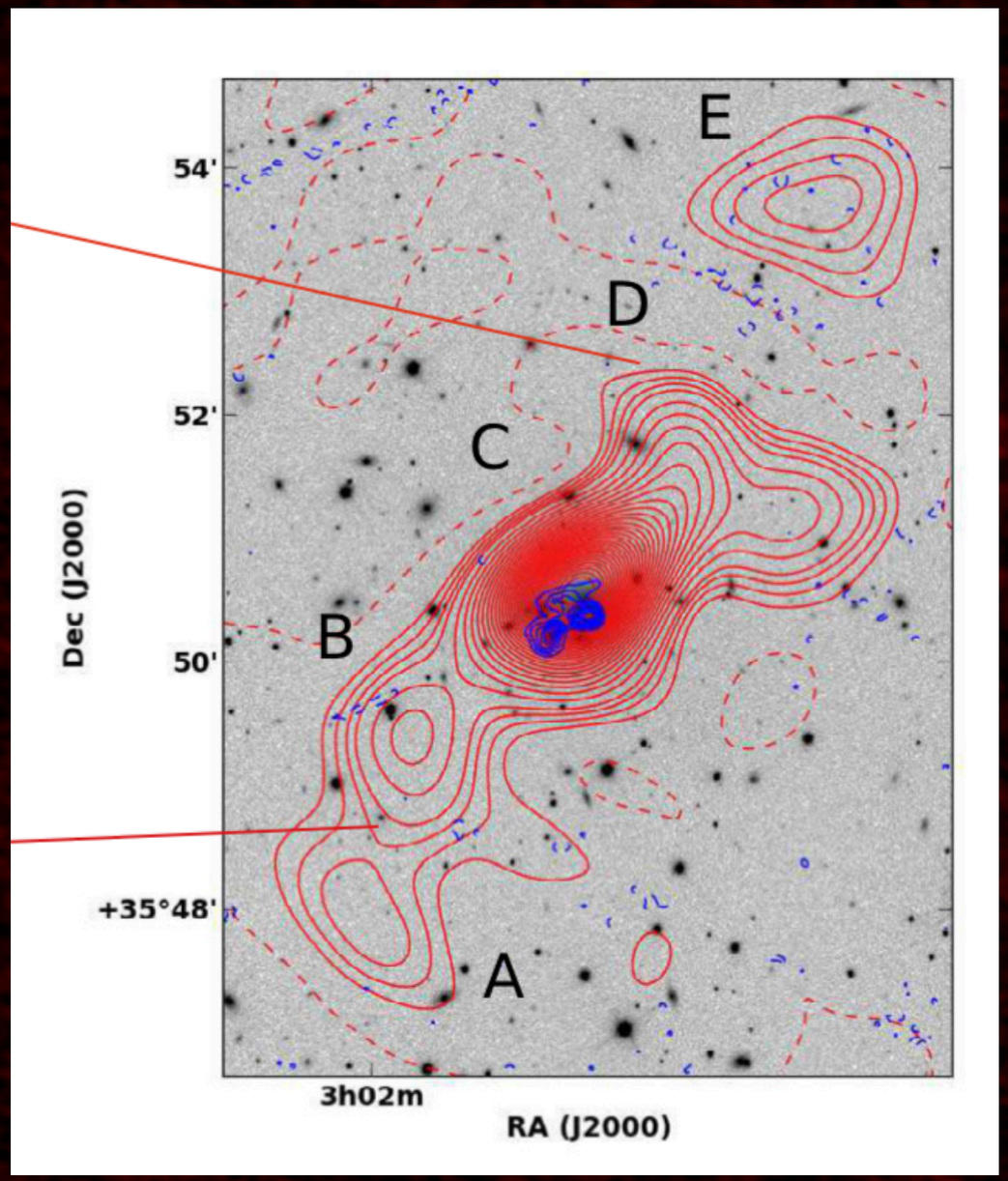


LOFAR:

- Core + remote (Netherlands, 38) + internetonal
- 150 MHz; 60 MHz
- Longest (Dutch) baseline: 80 km
- 6 arcsec (150 MHz)
- 150 - 900 μJy/beam

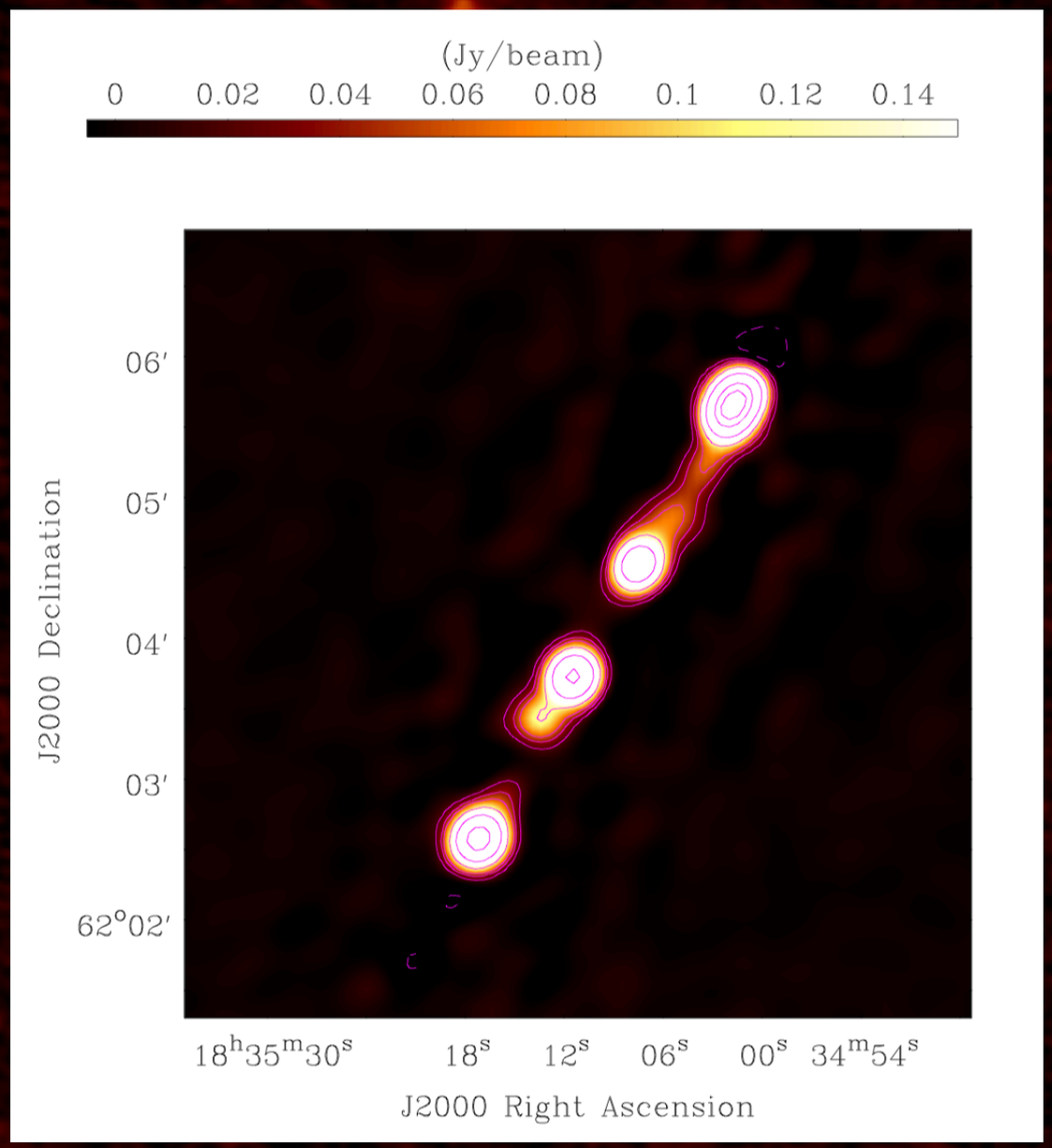
Restarted Radio Sources with LOFAR

4C 35.06



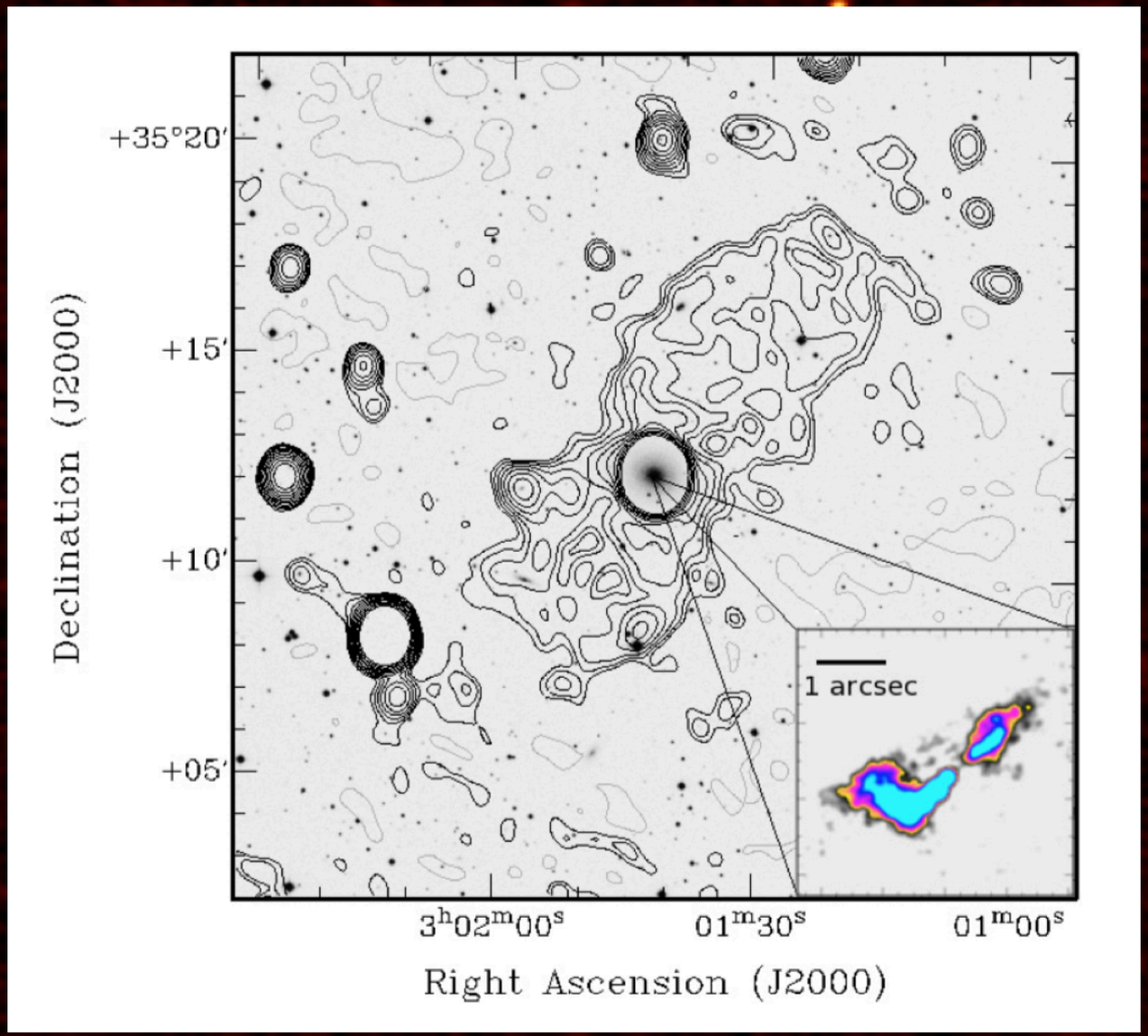
Credit: LOFAR and VLA Shulevski+15

B1834 + 620



Credit: LOFAR; Orrù+15

B2 0258 +35

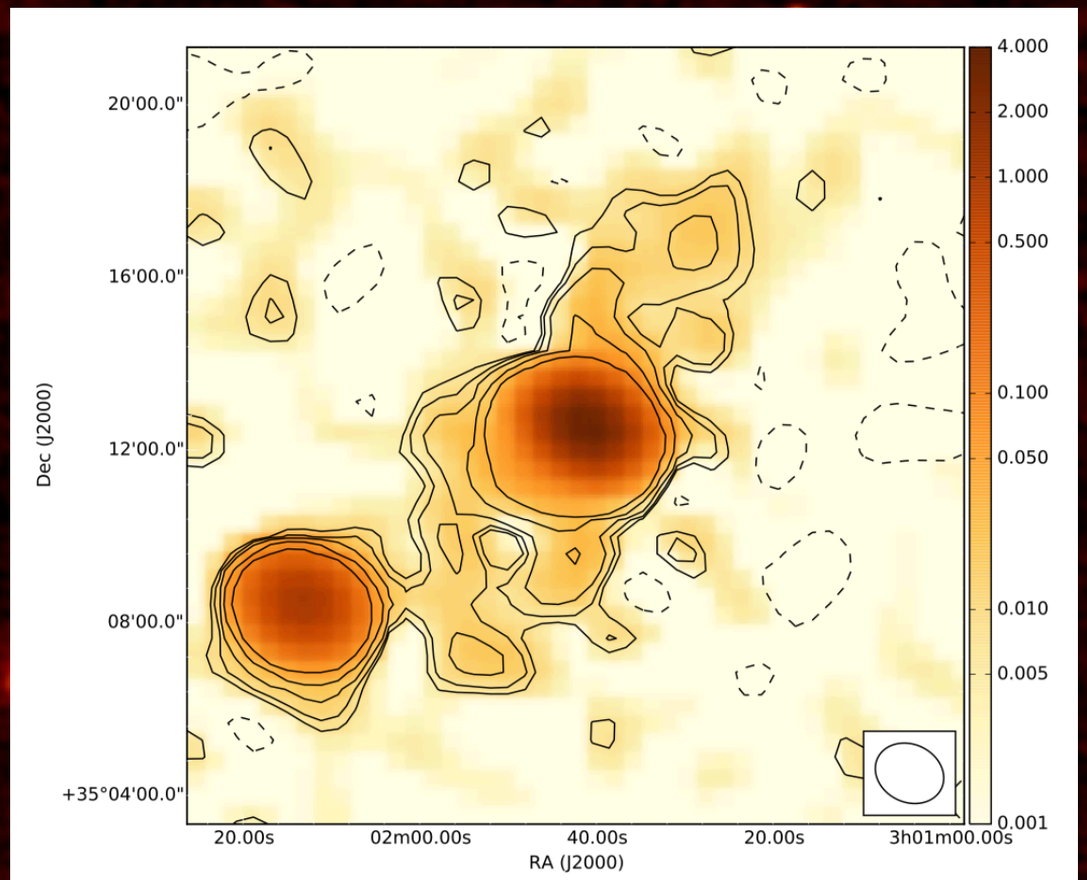


- Low surface brightness
- Amorphous morphology
- LOFAR 145 MHz
- SRT 6600 MHz
- WSRT 1400 MHz
  ⇢ spectral properties and age of the outer lobes

Credit: WSRT and DSS2 Shulevski+12
VLA Giroletti+05

Restarted Radio Sources

B2 0258 +35; Brienza et al 2018



Credit: LOFAR; Brienza+18

NORTHERN LOBE

$\alpha^{145}_{1400} = 0.48 \pm 0.11$

$\alpha^{1400}_{6600} = 0.69 \pm 0.20$

SOUTHERN LOBE

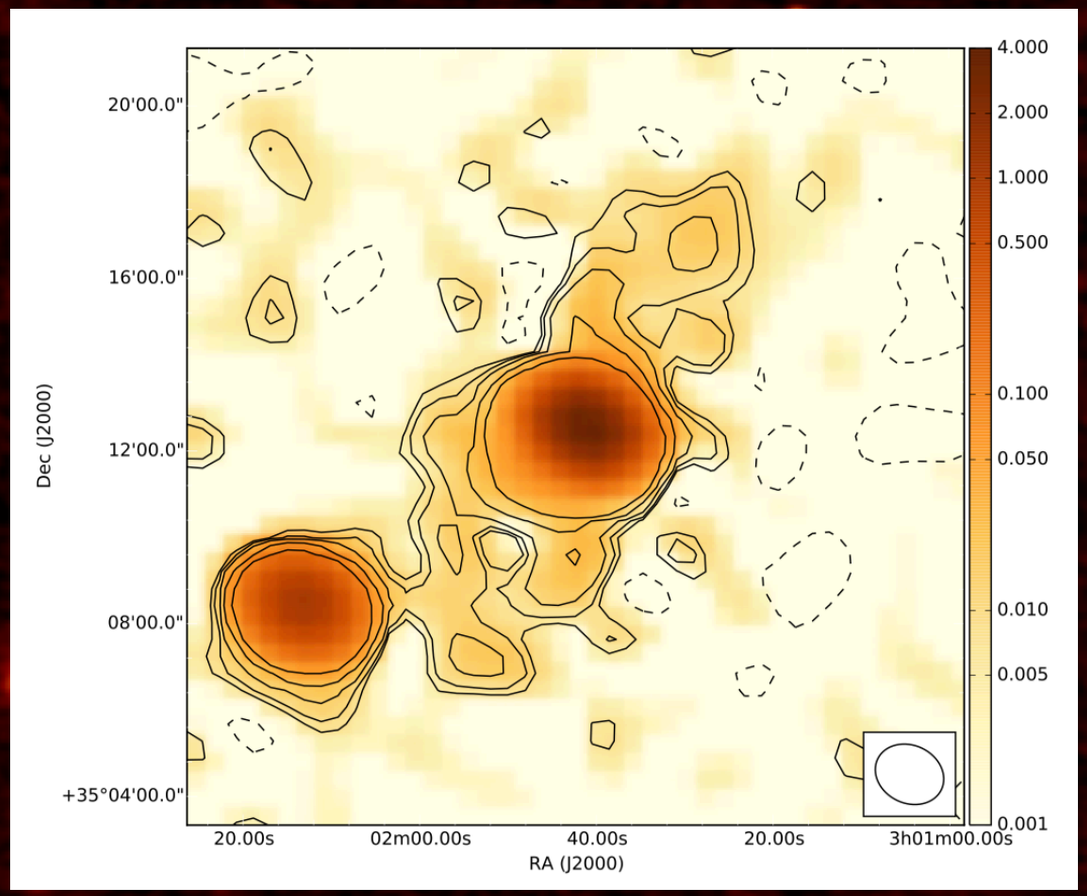
$\alpha^{145}_{1400} = 0.73 \pm 0.07$

No significant spectral curvature
SPC = 0.2 ± 0.2
(SPC > 0.5 expected for ageing plasma)

$$t_s = 1590 \frac{B_{\rm eq}^{0.5}}{(B_{\rm eq}^2 + B_{\rm CMB}^2)\sqrt{\nu_{\rm b}(1+z)}}$$

Restarted Radio Sources

B2 0258 +35; Brienza et al 2018



Credit: LOFAR; Brienza+18

Possible scenarios:

1. Outer lobes still fuelled with fresh particles
2. Short duty cycle
3. In situ particle acceleration, adiabatic compression, particle mixing

Restarted Radio Sources - statistical sample

Criteria :

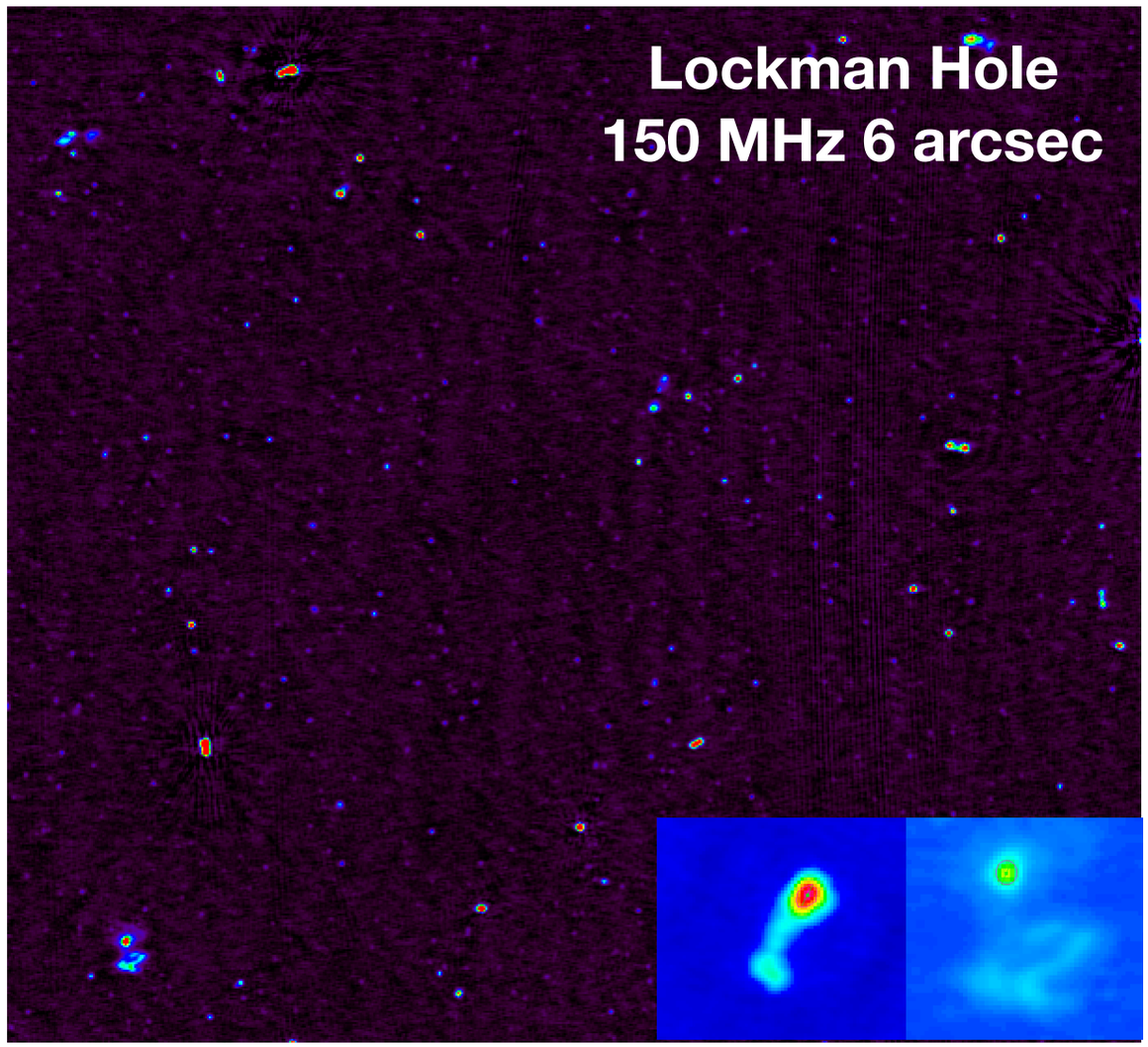
1. **Morphology**
   - Diffuse outer lobes with faint radio emission
   - Bright core (+ bright inner lobes)

2. **Core prominence (= S_{core}/S_{total})**
   - **$CP_{restarted} > CP_{active}$**

3. **Steep spectral index of the core**

} Indication of sub - arcsec jets

Data



FOV: 35 sqdeg

rms noise: 150 - 900 μJy/beam

resolution:

- 20 arcsec (Mahony et al. 2016)
- 6 arcsec (Mandal et al. in prep.)

LH -> many ancillary data available

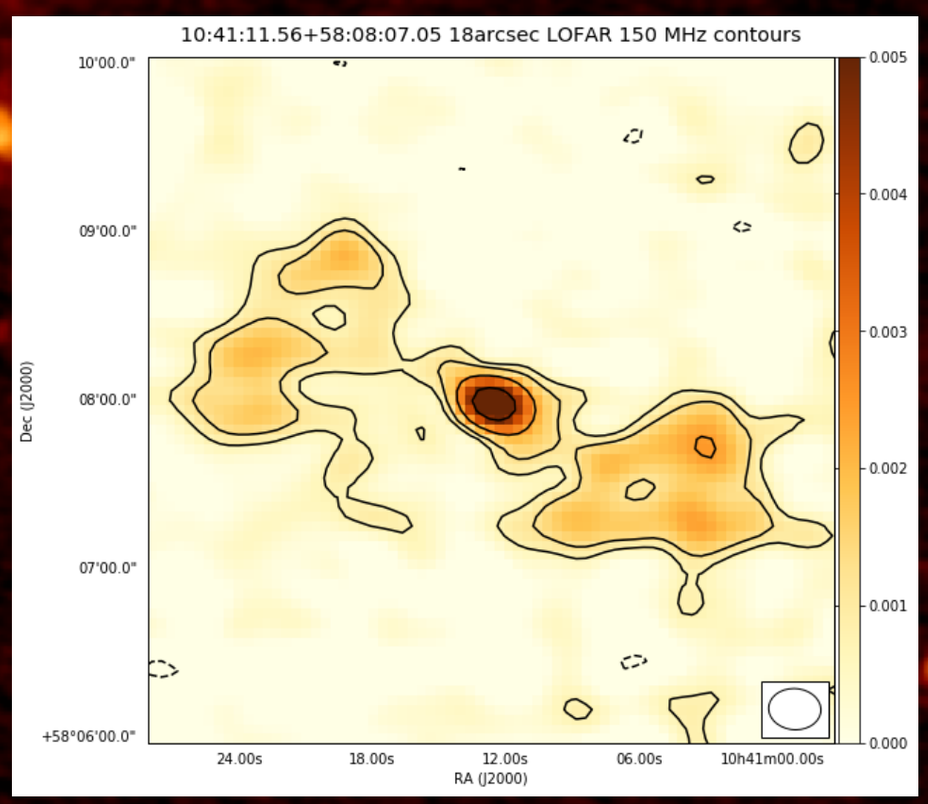
- FIRST
- NVSS

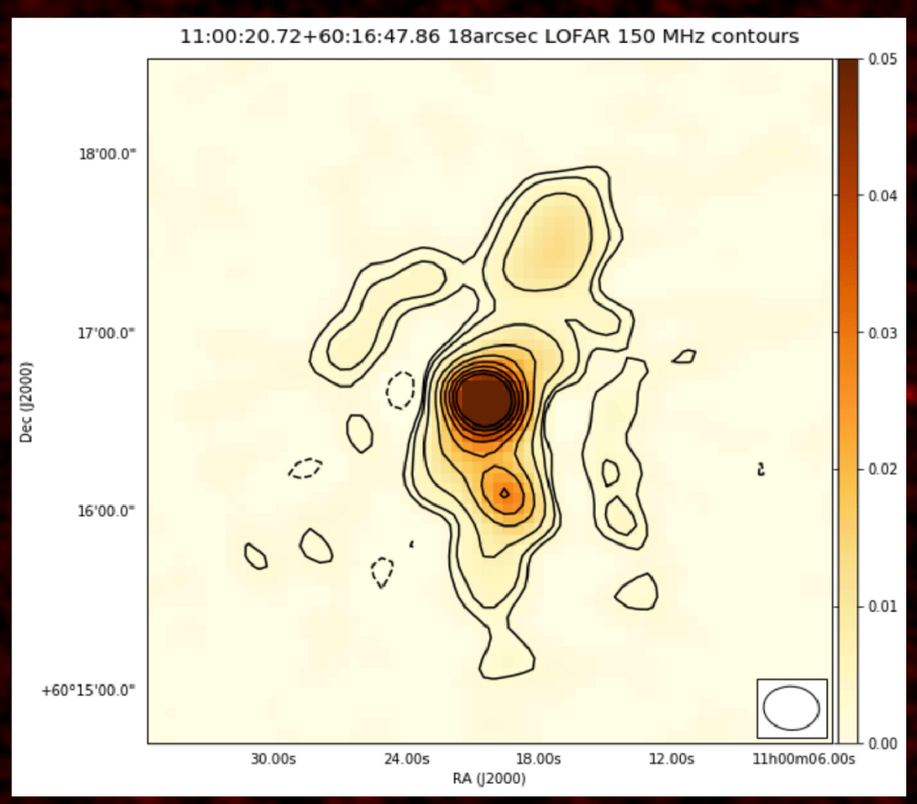
1. Morphology - visual inspection

- Diffuse outer lobes with faint radio emission
- Bright core (+ bright inner lobes)

LOFAR 150 MHz, 18 arcsec and 6 arcsec

- 19/201 -> 9%



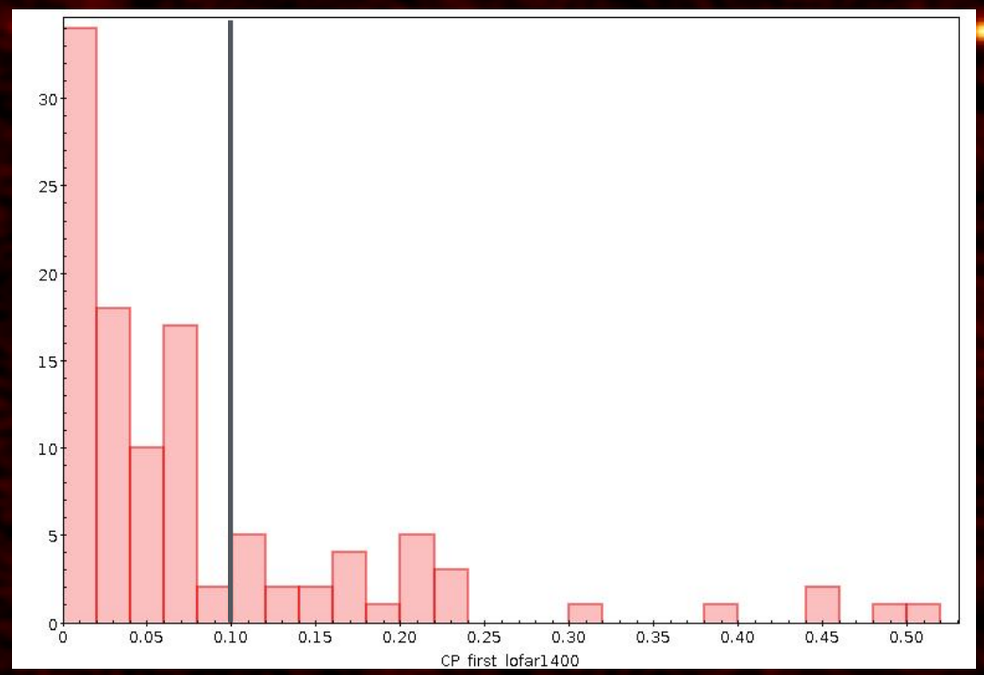


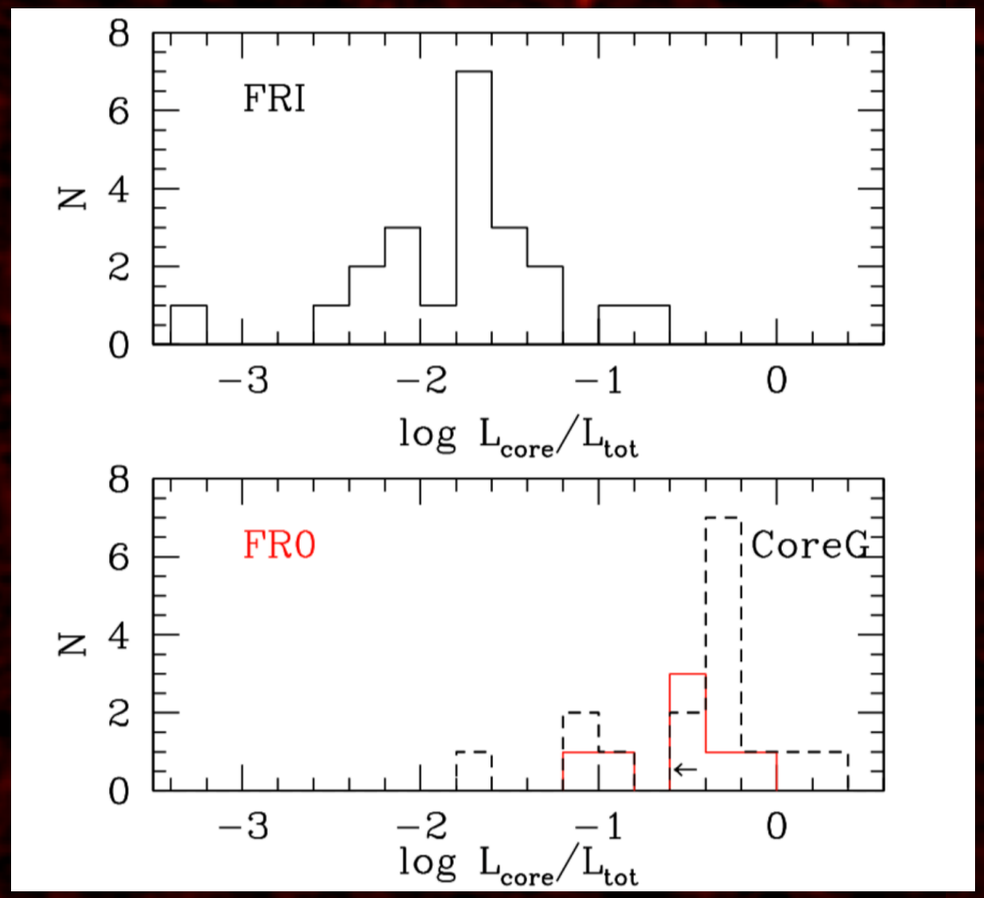
2. Core prominence (= S_{core}/S_{total})

- $CP_{restarted} > CP_{active}$
  -> indication of sub - arcsec jets

LOFAR 150 MHz 18 arcsec ⇢ 1.4 GHz (SI=0.7)
FIRST 1.4 GHz

- 28/109 -> 26%





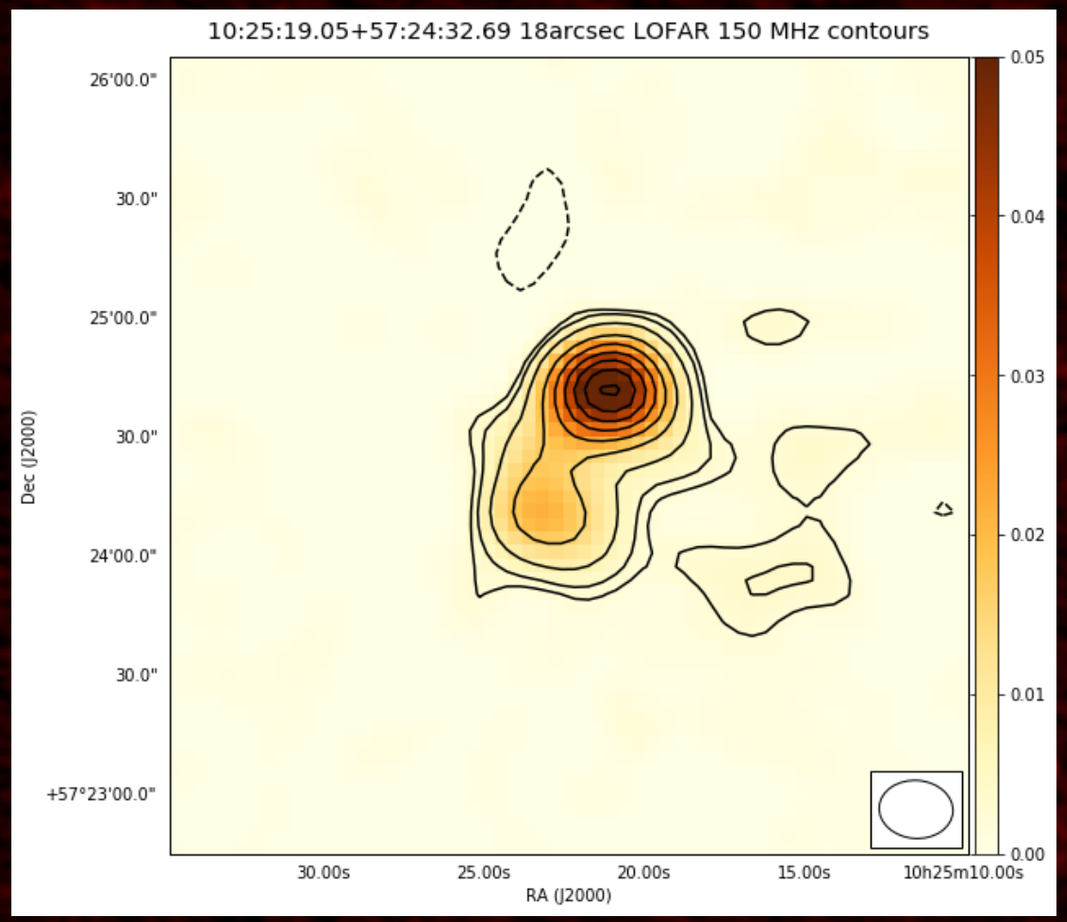
Credit: Baldi+

3. Steep spectral index of the core

- Indication of sub - arcsec jets

LOFAR 150 MHz 6 arcsec
FIRST 1.4 GHz 6 arcsec

- In progress



$\alpha_{1400}^{150} = 1.1$

Summary and future

- Restarted sources exhibit various radio properties and morphologies
  ⇢ need for statistical sample
- Test criteria ⇢ obtain a sample of candidates
- Look for HI (Apertif)
- Apply criteria to HETDEX