

Tracing radio jets from sub-kiloparsec to hundreds of kiloparsecs in giant radio galaxies using LOFAR and LOFAR-VLBI

Sagar Sethi

LOFAR Family Meeting 2026, Dublin



Space Radio-Diagnostics Research Centre
University of Warmia and Mazury in Olsztyn

Outline

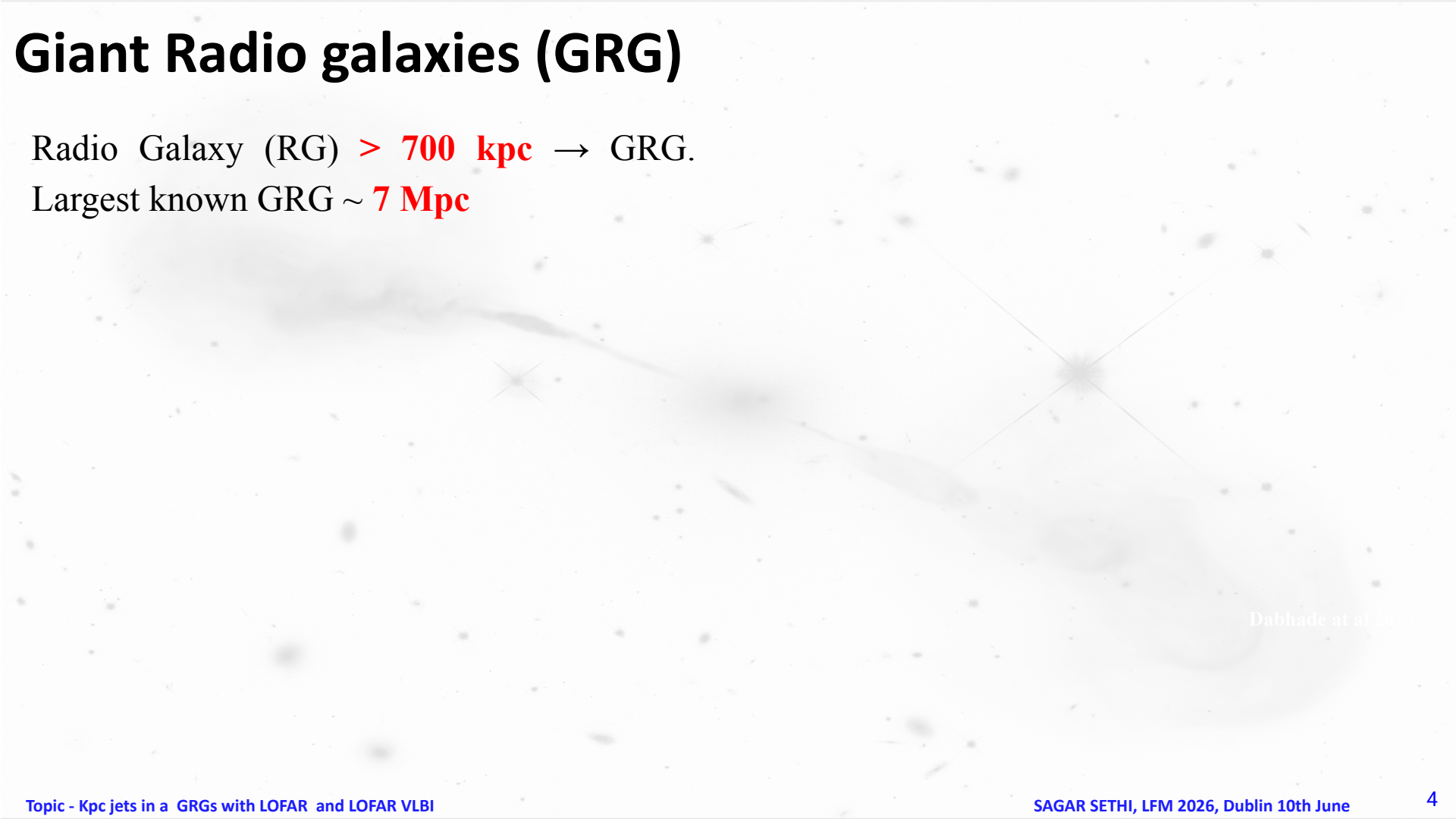
- Motivation for the study
- Target-1
 - J0644+1043, S-shaped GRG
- Target-2
 - J2145+8154, a 3 Mpc GRG
- Secondary goals
- Future perspective
- Conclusion and Summary

Motivation

Giant Radio galaxies (GRG)

Radio Galaxy (RG) $> 700 \text{ kpc}$ $\rightarrow$ GRG.

Largest known GRG $\sim 7 \text{ Mpc}$

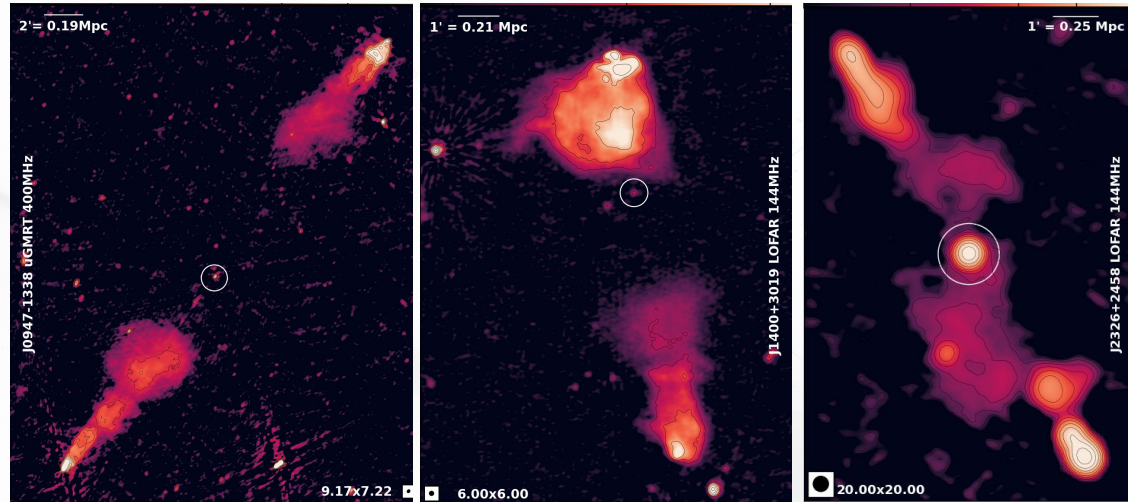


Dabhade et al. 2012

Giant Radio galaxies (GRG)

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Sethi et. al. in prep

Giant Radio galaxies (GRG)

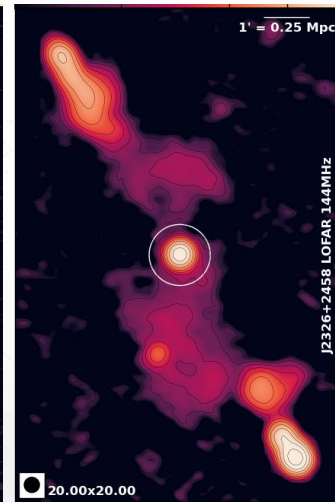
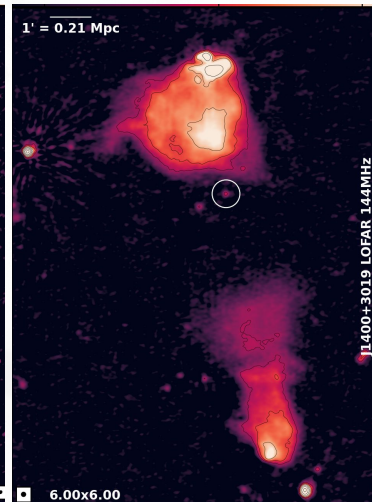
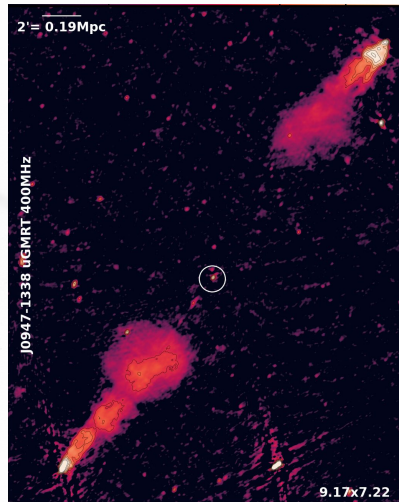
Radio Galaxy (RG) > 700 kpc $\rightarrow$ GRG.

Largest known GRG ~ 7 Mpc

Why some RGs are exceptionally large ?

1. Low-dense environment.
2. Powerful AGNs.
3. Recurrent activity
4. Late stage of radio galaxies.

The formation is solely not depends on only one factor but combination those.



Sethi et. al. in prep

Giant Radio galaxies (GRG)

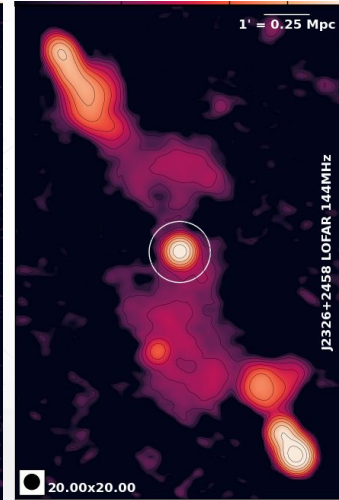
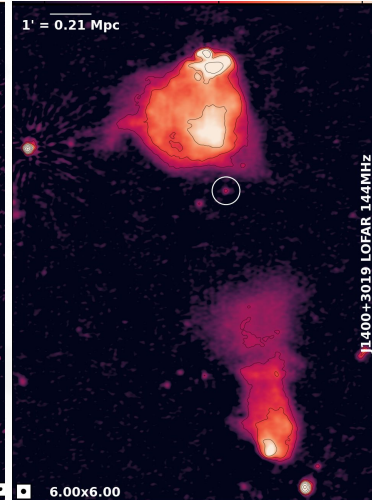
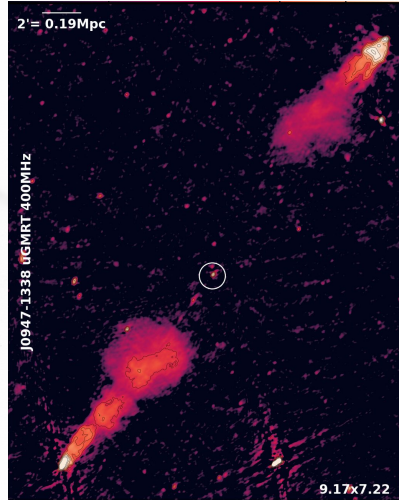
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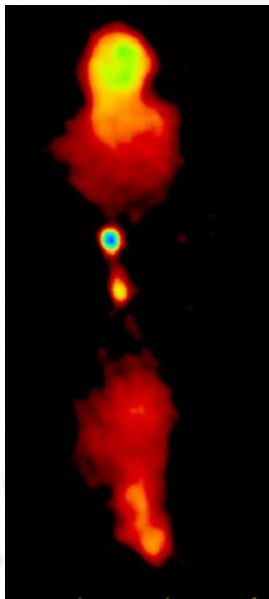


Sethi et. al. in prep

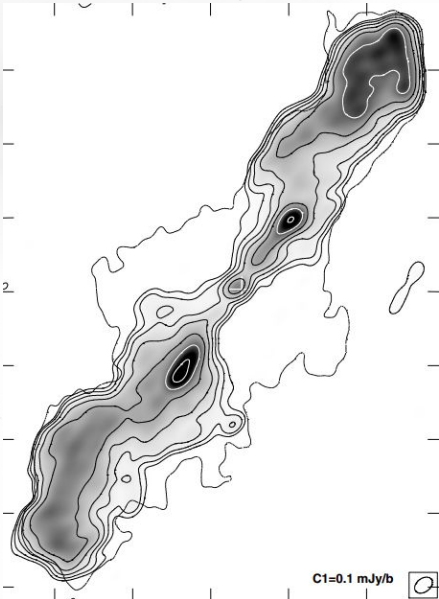
Recurrent activity

Recurrent activity in GRGs

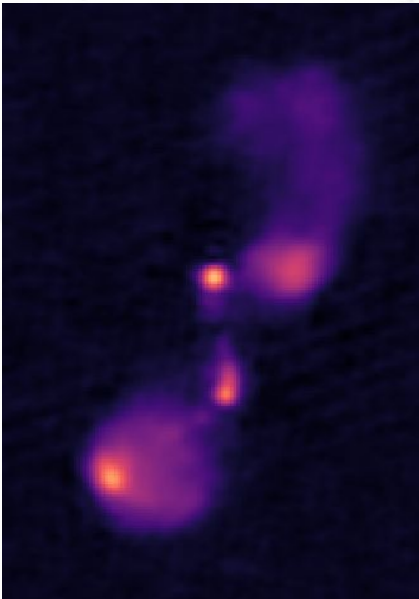
A few percent of GRGs show multiple episodes of activity, few examples below.



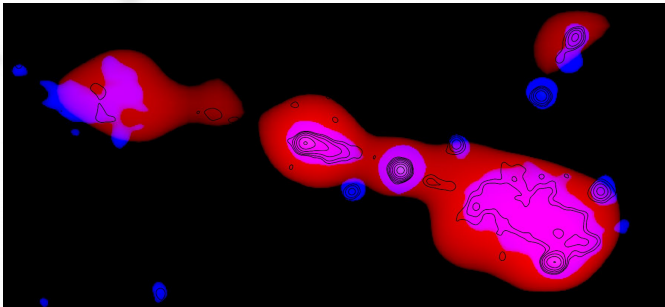
Konar et. al. 2006



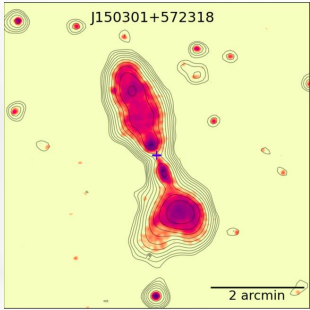
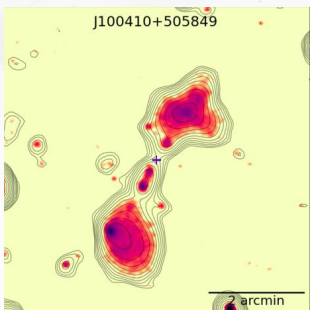
Machalski et. al. 2010



J1328+2752, LoTSS
DR3

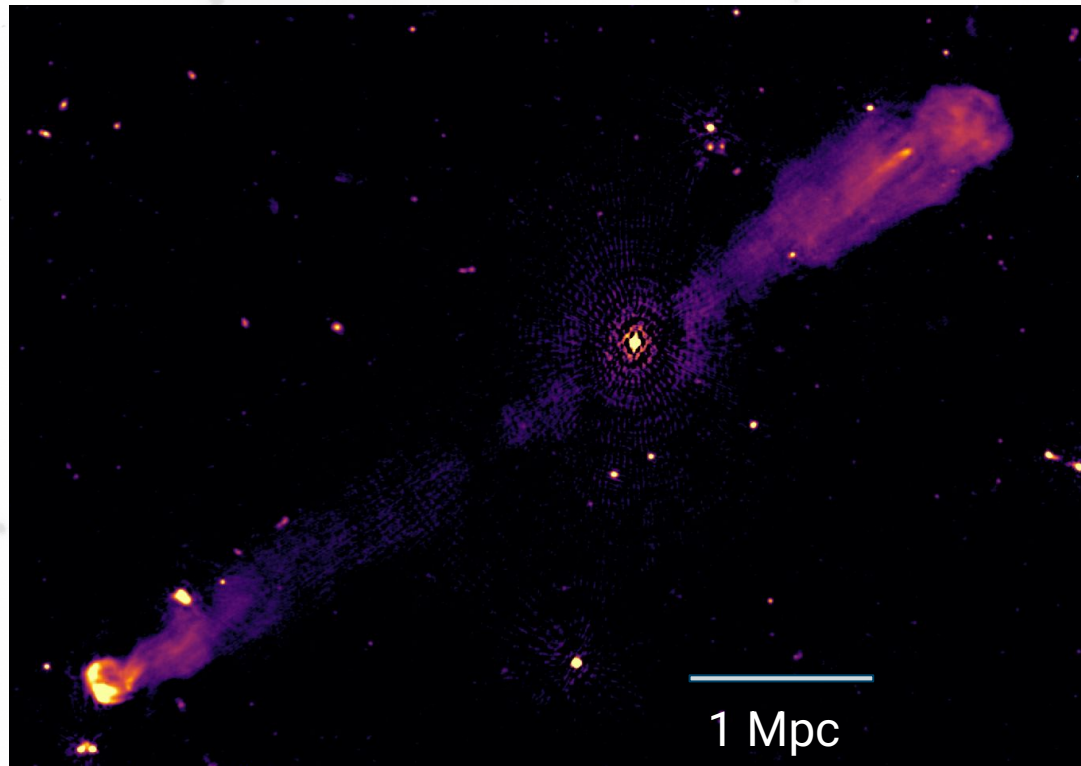


Sethi et. al. 2025, A&A L



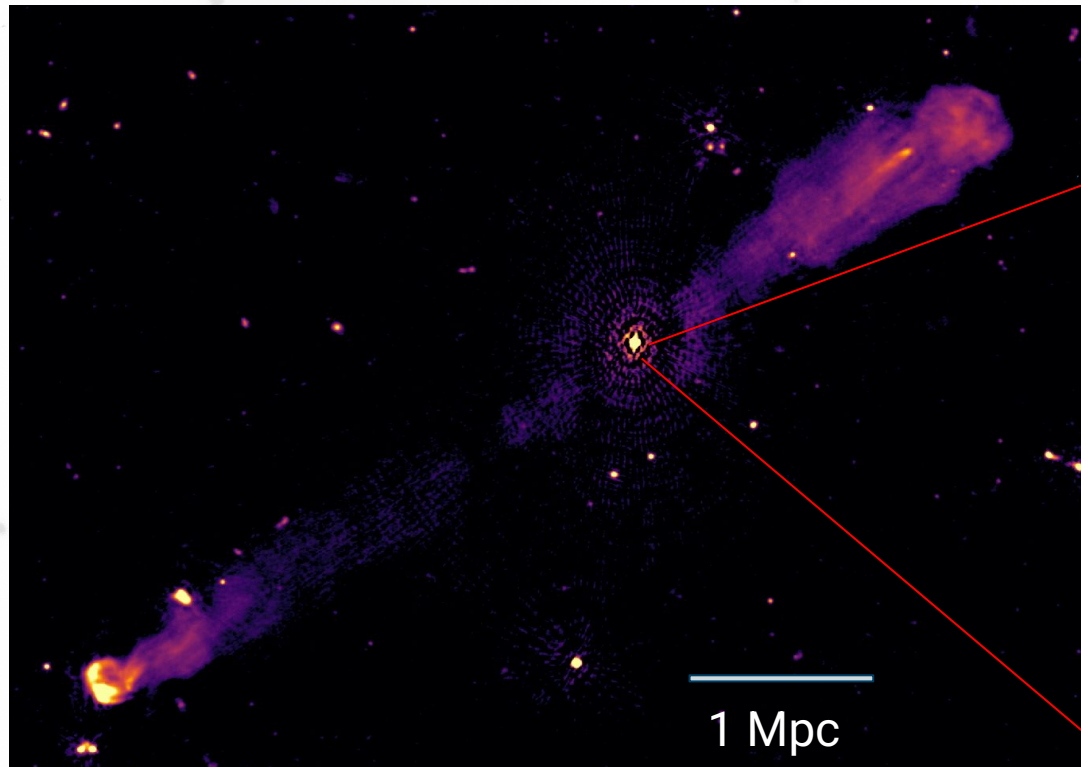
Dabhade et. al. 2025, A&A

3C 236 with a mini inner double



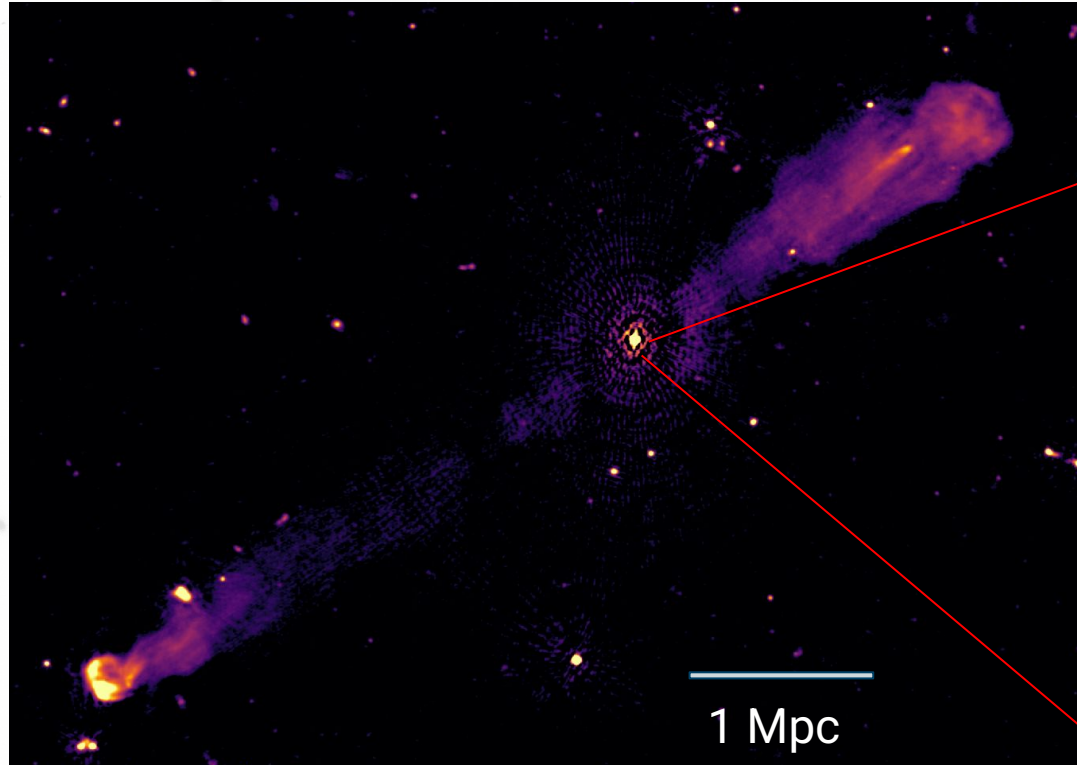
LoTSS DR3

3C 236 with a mini inner double



LoTSS DR3

3C 236 with a mini inner double



LoTSS DR3

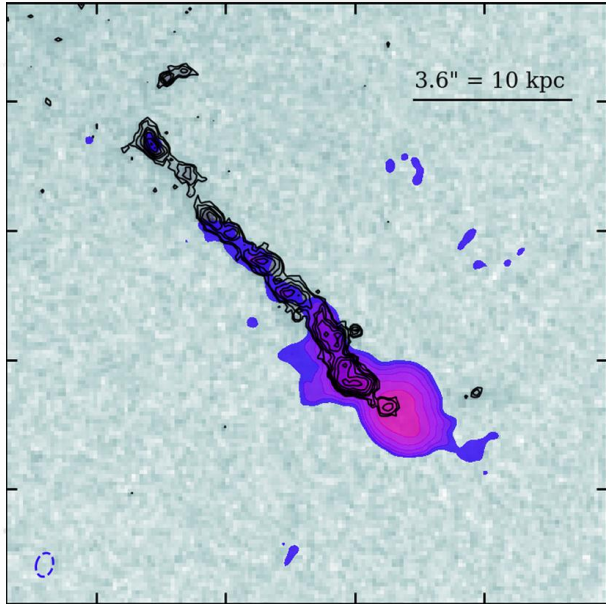
Mini “inner double” at sub kpc scale

Schilizzi et. al. 2001



Advantage of LOFAR-VLBI for studying restarted activity in GRGs

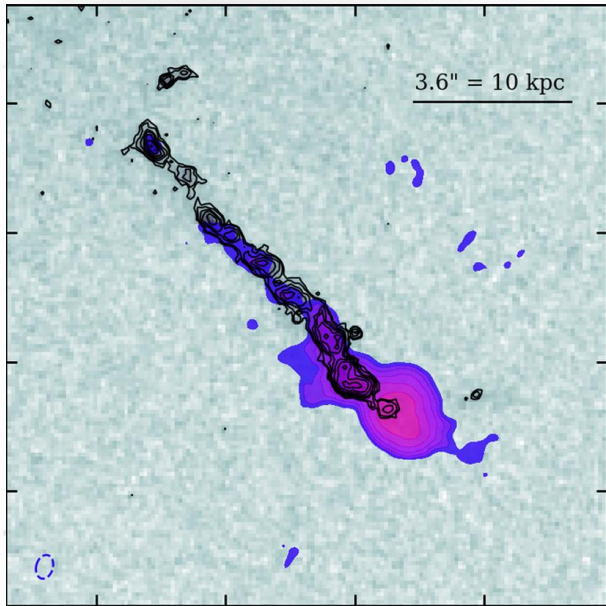
1. Resolution comparable to Optical Survey



3C 273, 144 MHz ILT + HST (Harwood et al., 2022)

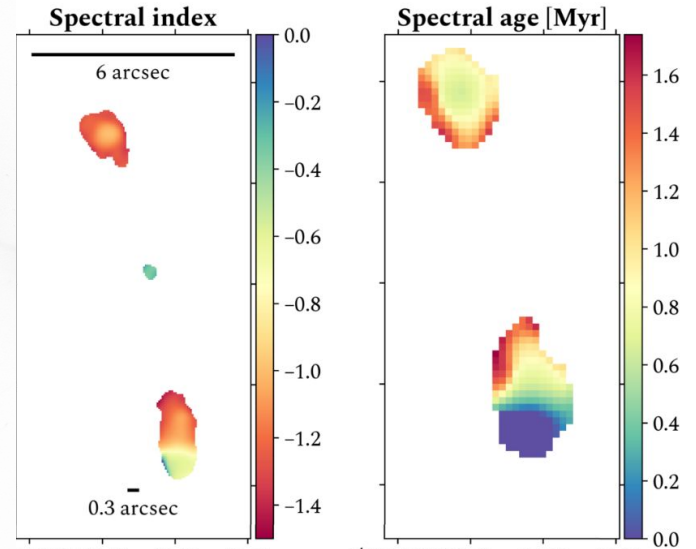
Advantage of LOFAR-VLBI for studying restarted activity in GRGs

1. Resolution comparable to Optical Survey



3C 273, 144 MHz ILT + HST (Harwood et al., 2022)

2. Spatially resolved spectral indices and ages at sub arcsecond resolution with LOFAR-VLBI & VLC C Band (5 GHz)



Spatially resolved spectral indices and ages of 4C 43.15 (Sweijen et al. 2022)

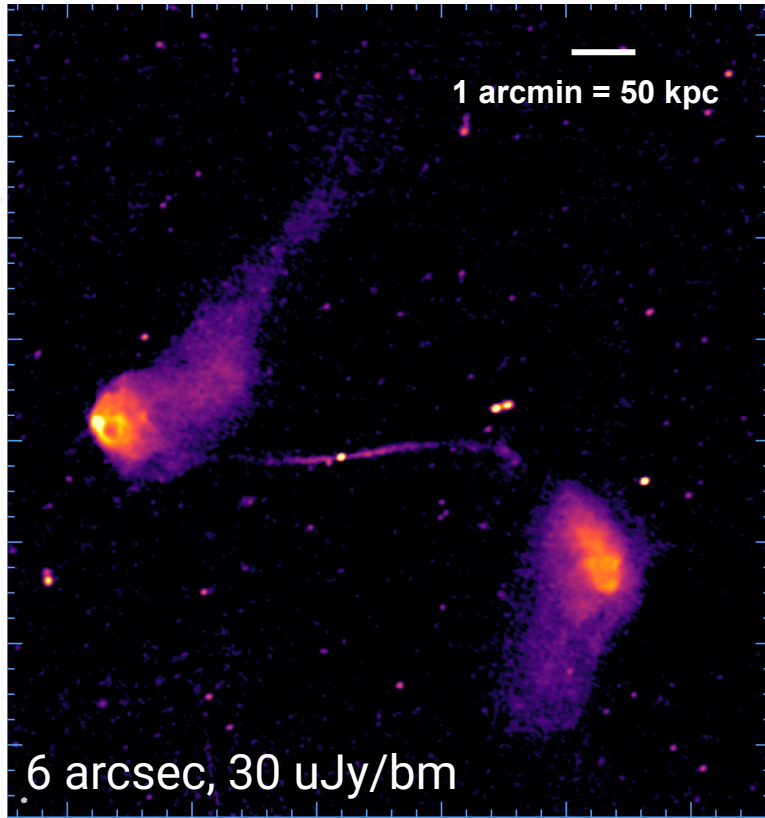
J0644+1043: S-shaped GRG

J0644+1043

Spec $z = 0.0489$

Size = 12 amin

Size = 711 kpc



uGMRT 650 MHz observation (Sethi et al 2024, ApJ)

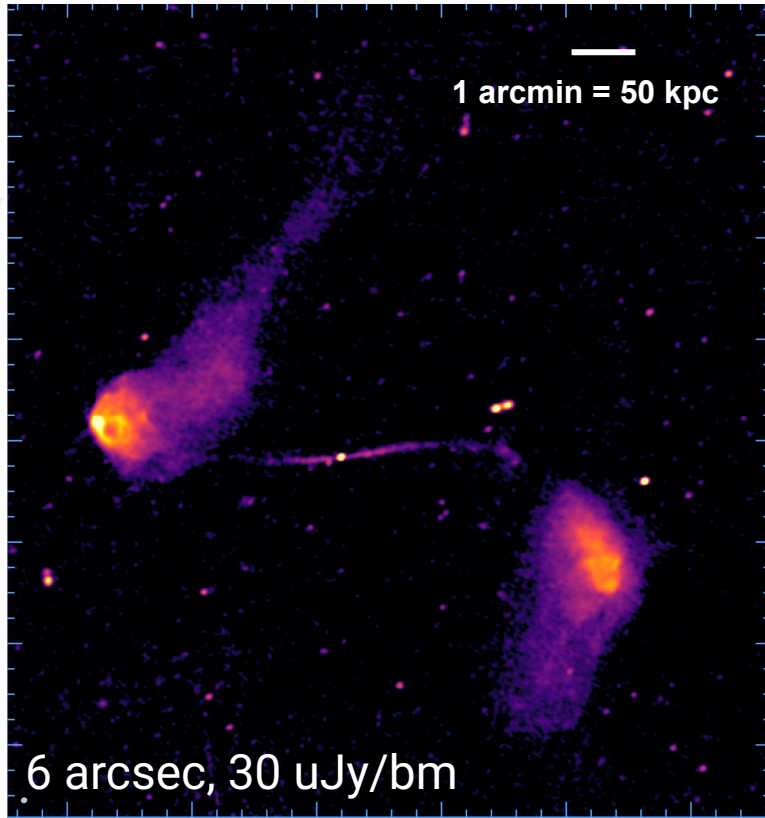


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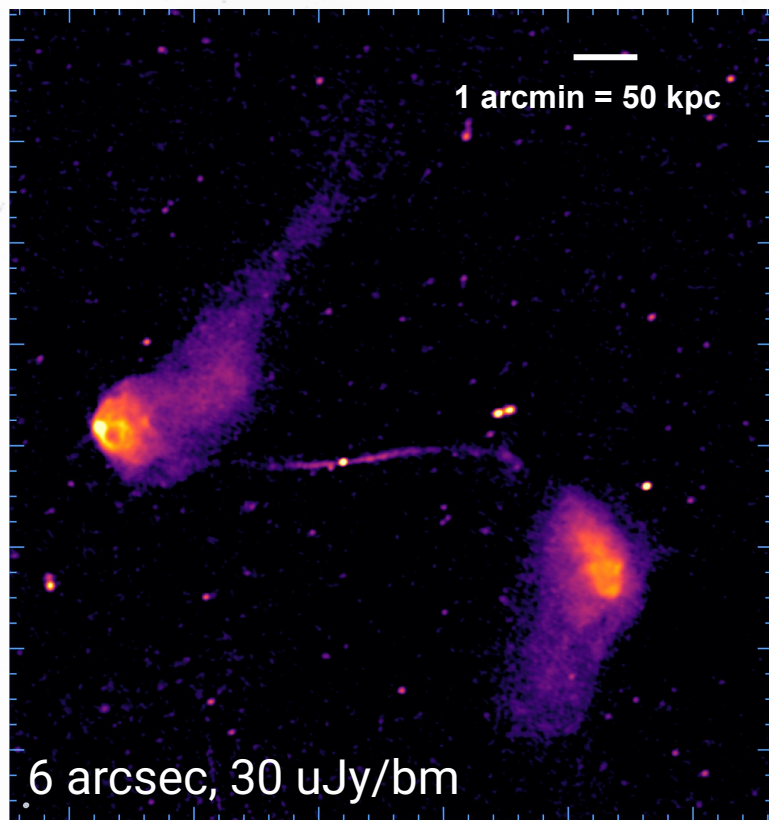
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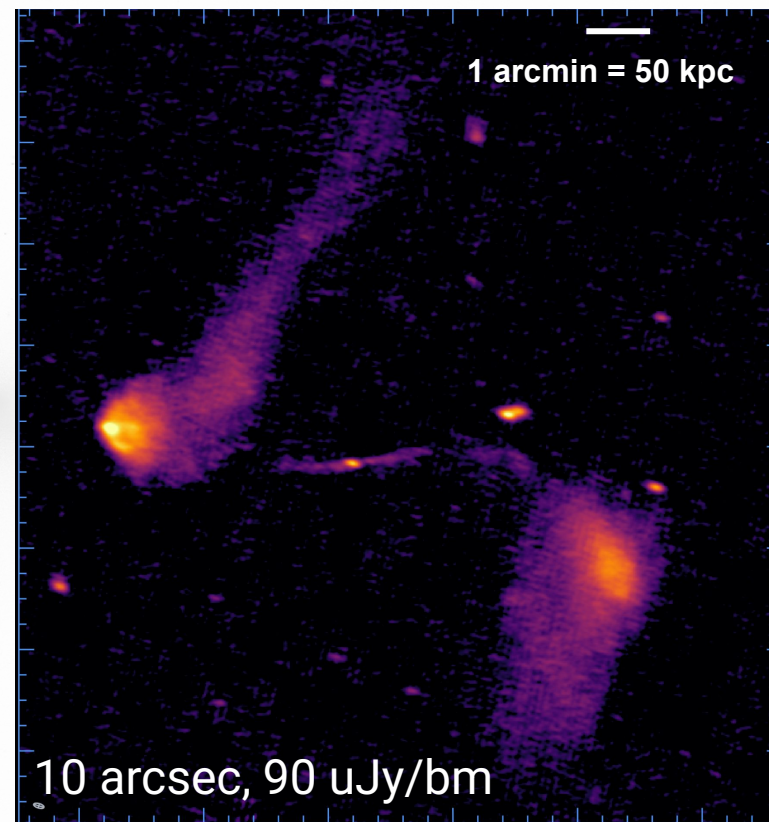
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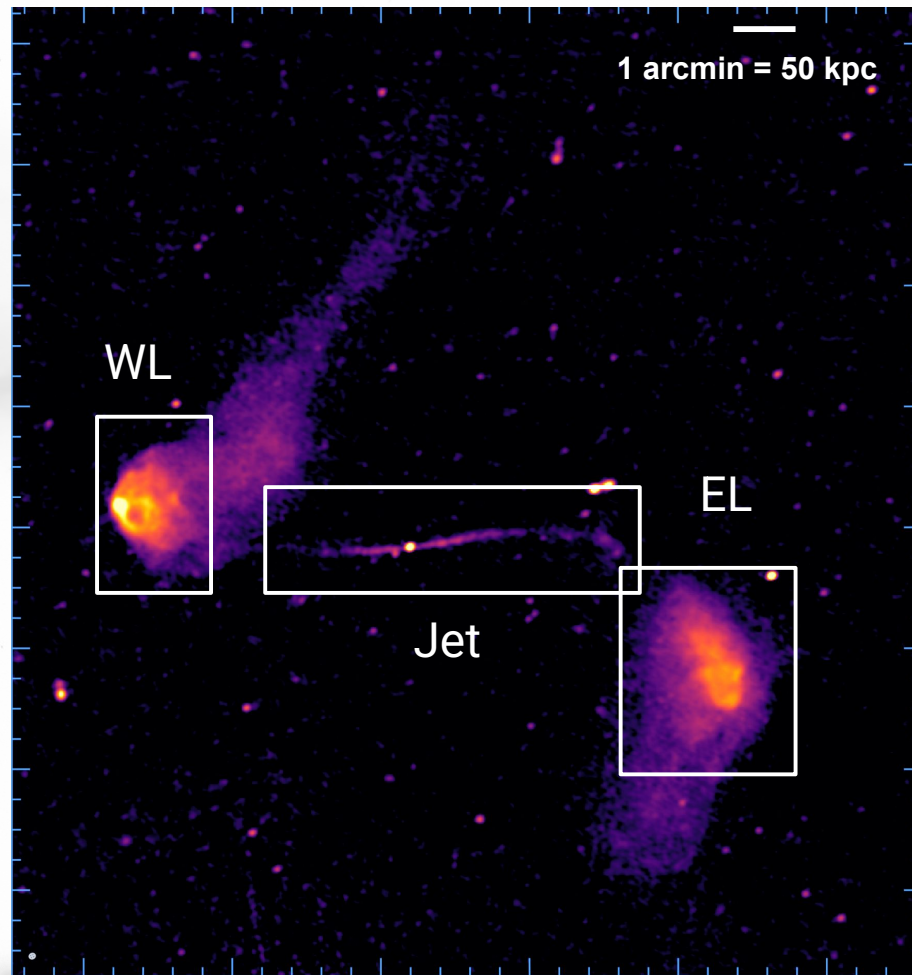
Size = 711 kpc



uGMRT 650 MHz observation (Sethi et al 2024, ApJ)



Dedicated LOFAR observation (PI: Sagar Sethi)



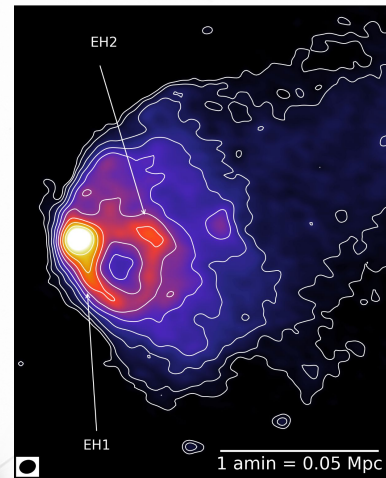
A low-power FR II RG ?

FR I features in SGRG:

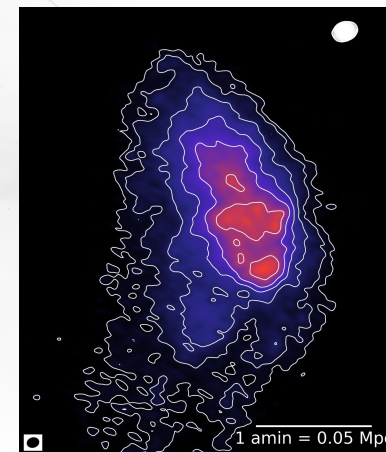
- Total radio power (1.4 GHz) $\sim 5.92 \times 10^{24}$ W/Hz
- Kinetic jet power (150 MHz) $\sim 2.01 \times 10^{42}$ erg/sec

FR II features in SGRG:

- Collimated narrow jet and counter jet
- Eastern hotspot
- Jet knots



Eastern hotspot region



Western plateau region

A low-power FR II RG ?

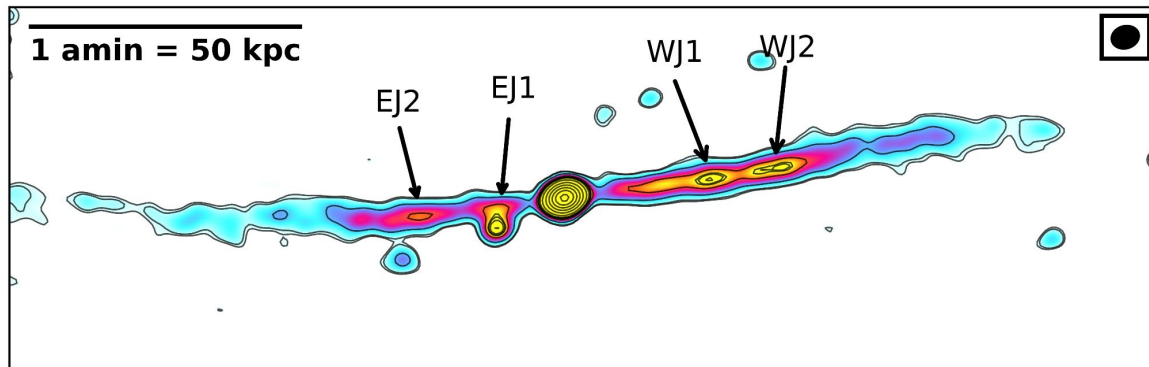
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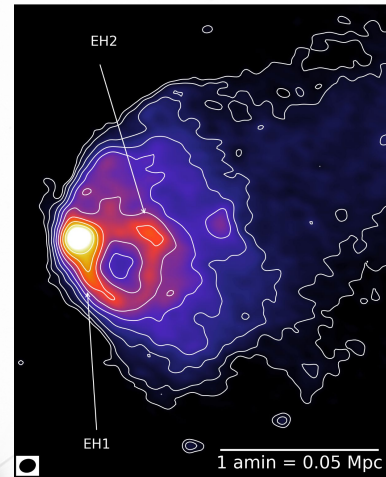
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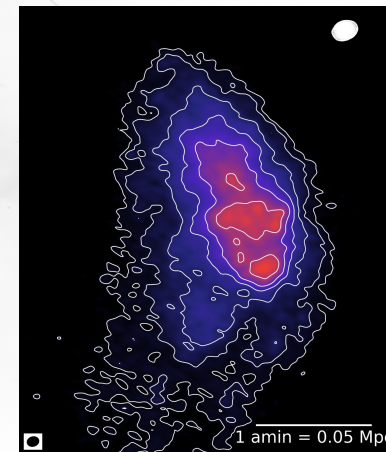
The most interesting case is, its 100 kpc twin jet.



(Sethi et al 2024, ApJ)



Eastern hotspot region



Western plateau region

100 kpc twin jet

Low frequency observations

90 $\mu\text{Jy/bm}$

LOFAR 144 MHz HBA (10 arcsec)

30 $\mu\text{Jy/bm}$

uGMRT 650 (6 arcsec)

100 kpc twin jet

Dedicated Low frequency observations

90 $\mu\text{Jy/bm}$

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Dedicated VLA observations

7 $\mu\text{Jy/bm}$

VLA B-Array, S-band, 3 GHz (3 arcsec)

5 $\mu\text{Jy/bm}$

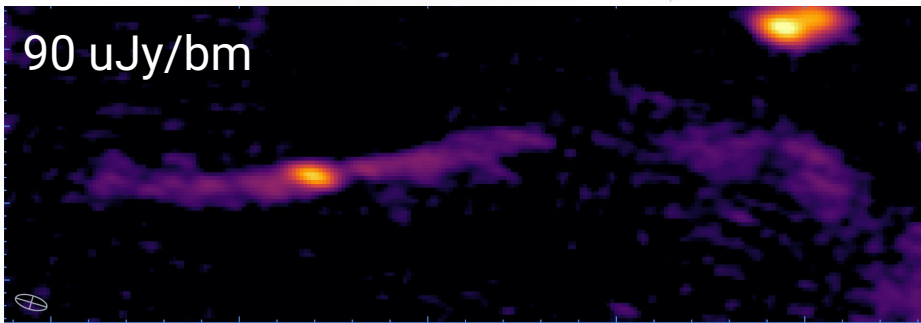
VLA B-Array, C-band, 5 GHz (0.7 arcsec)

100 kpc twin jet

Dedicated Low frequency observations

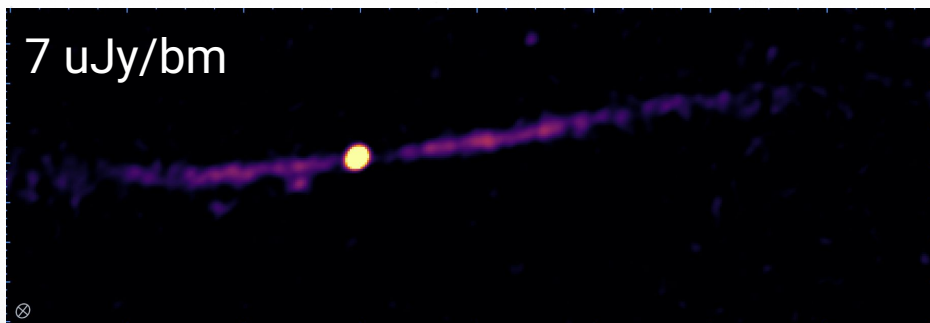
Dedicated VLA observations

90 $\mu\text{Jy/bm}$



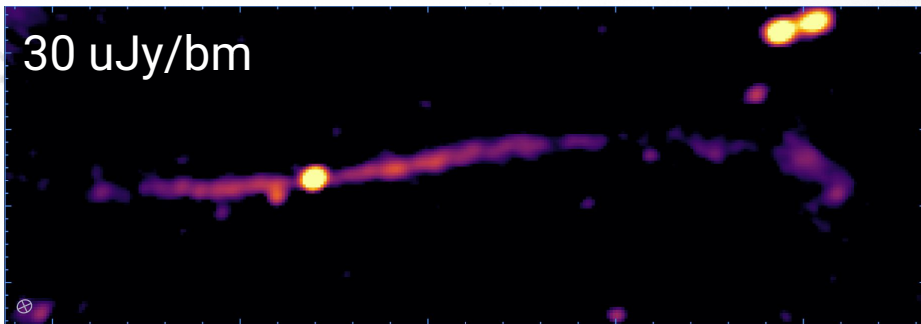
LOFAR 144 MHz HBA (10 arcsec)

7 $\mu\text{Jy/bm}$



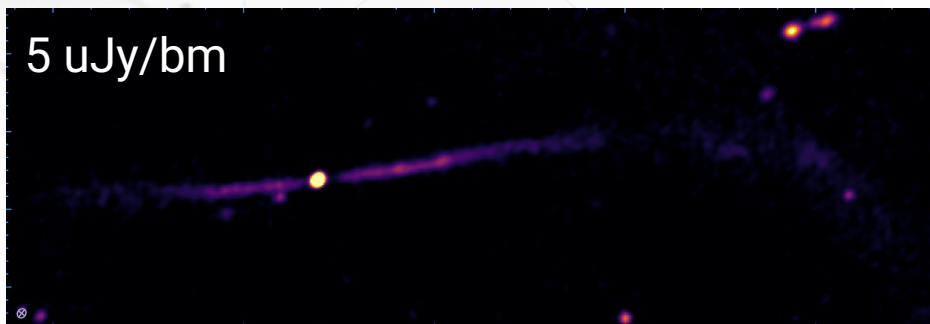
VLA B-Array, S-band, 3 GHz (3 arcsec)

30 $\mu\text{Jy/bm}$



uGMRT 650 (6 arcsec)

5 $\mu\text{Jy/bm}$



VLA B-Array, C-band, 5 GHz (0.7 arcsec)

LOFAR-VLBI data reduction

Follow: LOFAR-VLBI wiki,
FLoCS webpage

1. For the S-shaped GRG LOFAR observation has international stations (LC18_026, PI- Sagar Sethi)
2. Used the recipe provided in the LOFAR-VLBI wiki and FLoCS webpage.
3. Frits' LoFAR Containers (FLoCS) used.
4. Data reduction →
 - a. HPC available for LOFAR-VLBI in UWM, Olsztyn
 - b. A separate PLgrid HPC grant (PI- Sagar Sethi), Krakow.
5. I have done the entire setup for the data reduction.

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 - Total station (ILT, 4hrs)- 49

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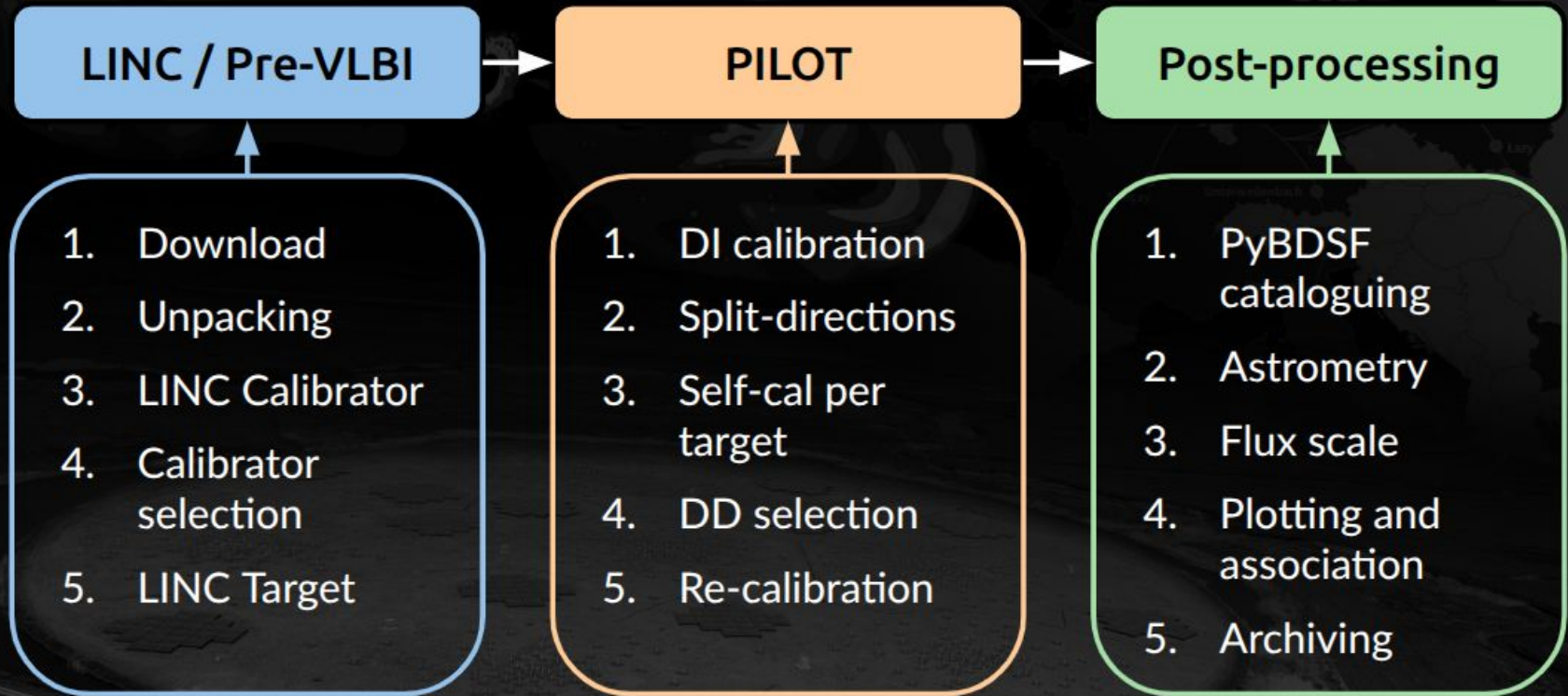
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Calibrators used during observation

1. 3C48
2. 3C295

The LoTSS-HR workflow



Timmerman's talk from 1st day

Workflow

Pre-LINC

**Download
the data**

Workflow

Pre-LINC

LINC



Workflow

Pre-LINC

Download
the data

LINC

LINC run on
Calibrator

LINC run on
Target

PILOT

VLBI Delay
Calibration

Split
Direction

Workflow

Pre-LINC

Download
the data

LINC

LINC run on
Calibrator

LINC run on
Target

PILOT

VLBI Delay
Calibration

Split
Direction

Imaging
with
WSClean

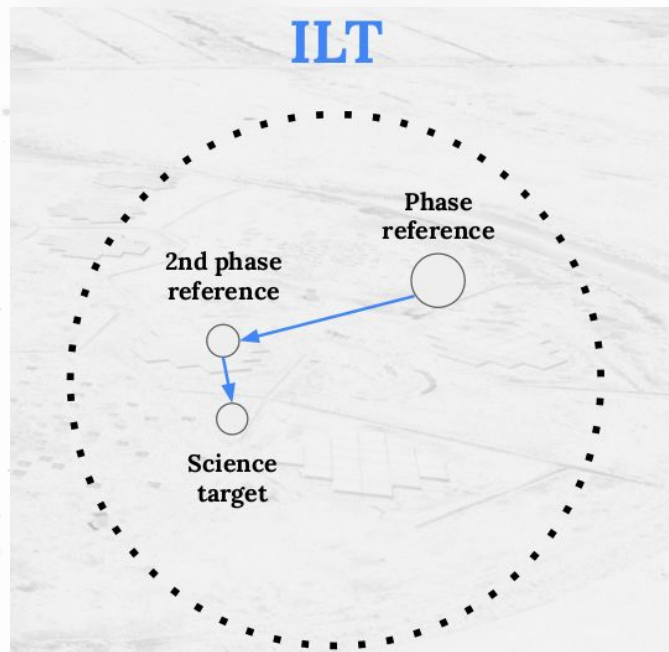
Problem with VLBI-delay calibration for this field

1. The nearest LBSC source is 2.3 degree away (requires less than 1 degree away).
2. This part skipped in LoTSS DR3.

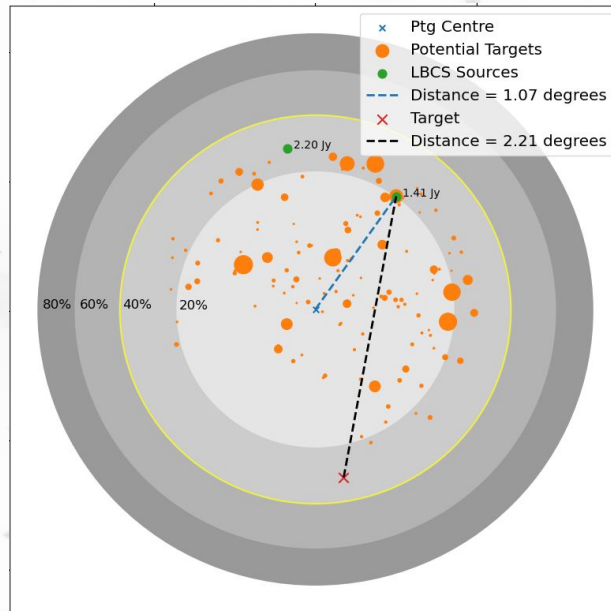


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Frits talk from 1st day



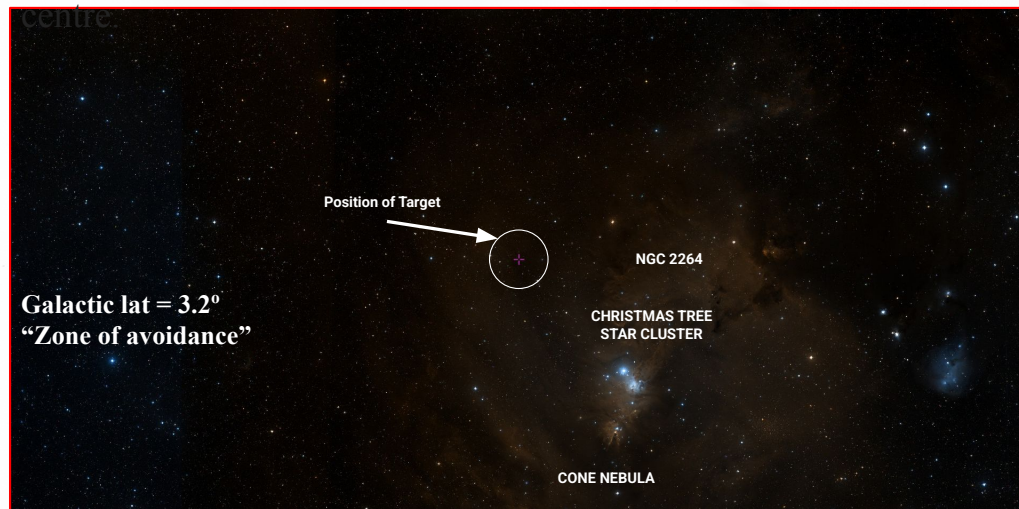
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Target location in the sky

The source is present in a crowded region of the galactic

centre



DSS2 colored image of the area near the target

Problem with VLBI-delay calibration for this field

1. Manually I ran pybdsf on my LOFAR image.
2. I tried out 2 nearby compact sources and manually ran VLBI delay.
But the phase scores are not good.

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1st one

Source_id = ILTJ064310.6+112546
Total_flux = 759.3
Peak_flux = 689.8
Distance = 0.73 deg

phase_score' :

0.0032694544282070685

2nd

Source_id = ILTJ064448.74+105121.7
Total_flux = 283.4 mJy
Peak_flux = 225.2 mJy
Distance = 0.21 deg

phase_score' :

0.01191600737935947

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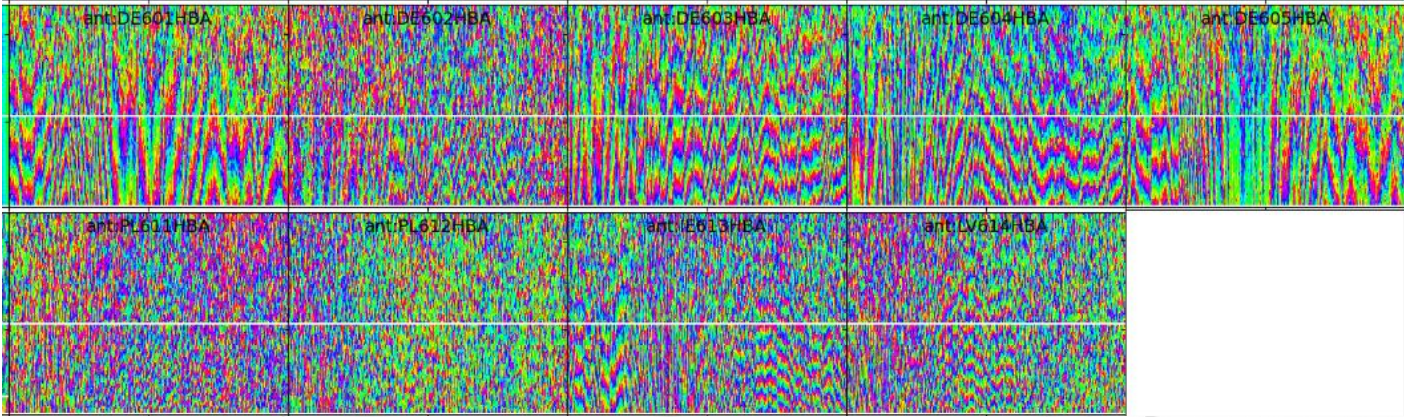
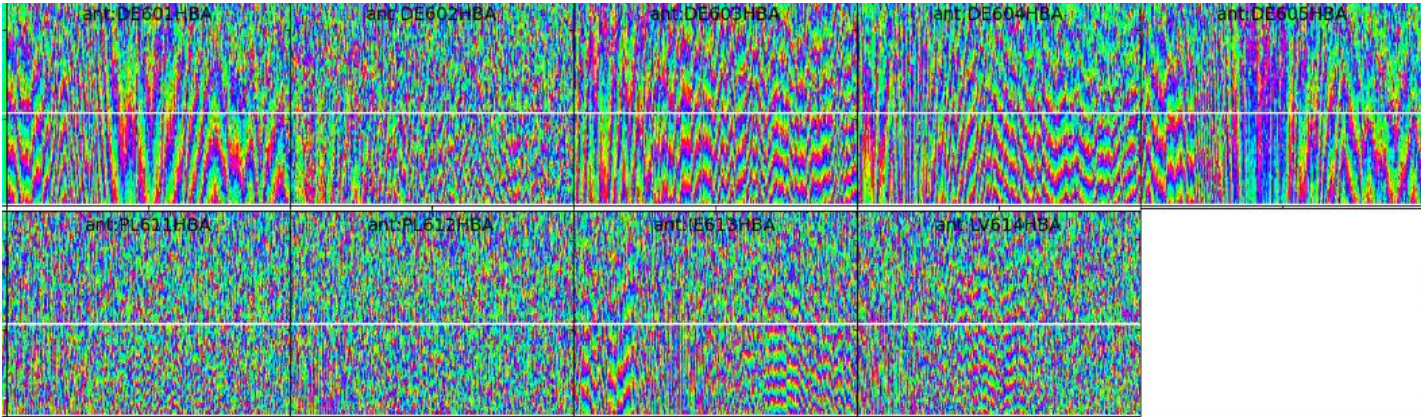
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**The ILT reduction near galactic region still problematic.
(as we seen in the Frits' talk on the first day).**

Bad phase solutions for international stations



J2145+81: GRG with size 3 Mpc

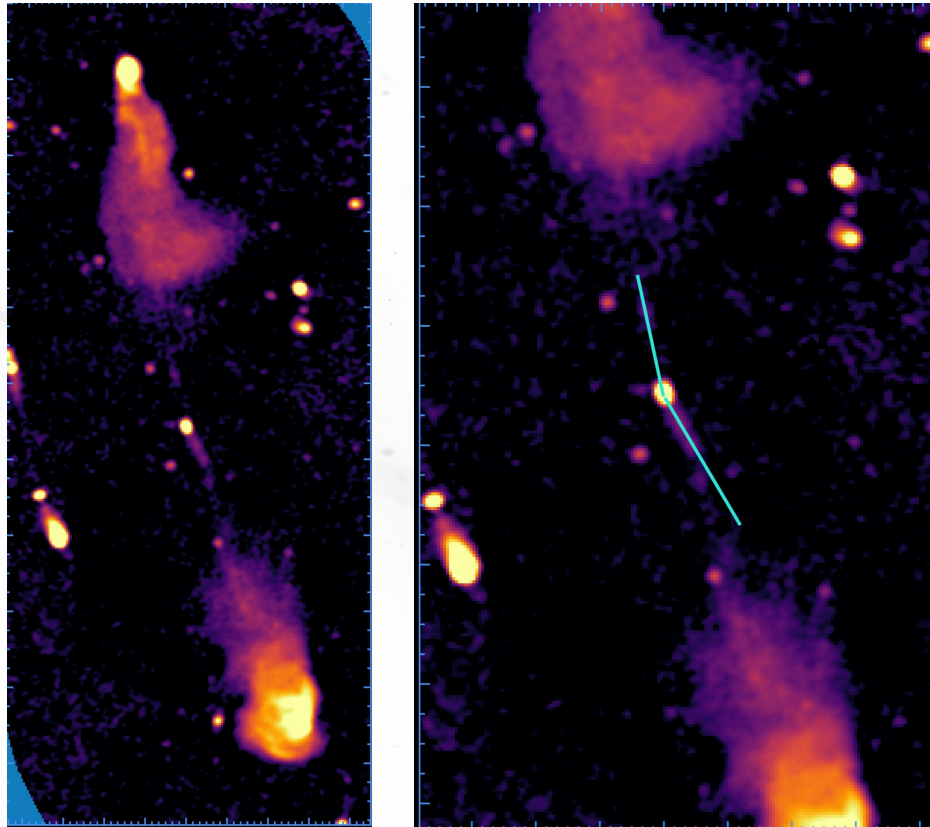
J2145+81

Spec $z = 0.146$

Size = 20 amin

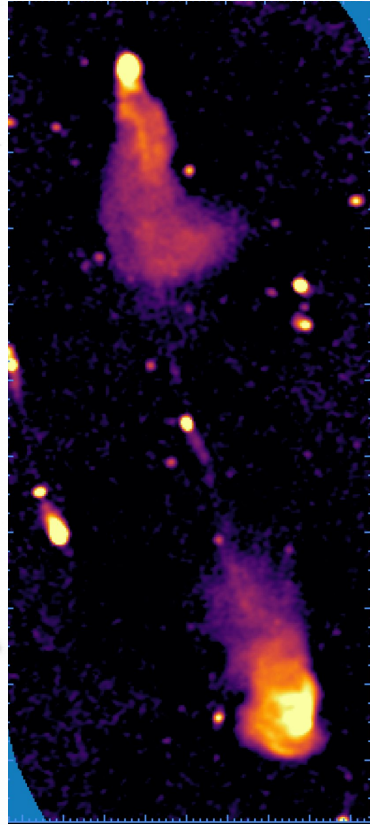
Size $\sim 3\text{Mpc}$

20'



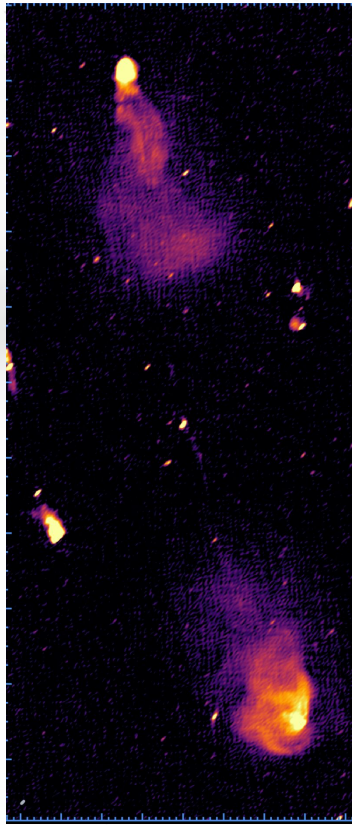
VLA1.4 GHz (Palma et. al. 2000)

Multi-frequency radio continuum maps of this 2.9 Mpc GRG from our dedicated LOFAR, uGMRT and VLA observations.



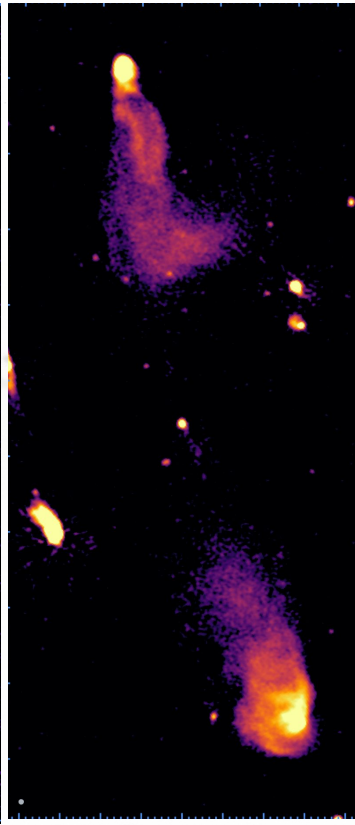
(Palma et. al. 2000)

rms= 30uJy/bm



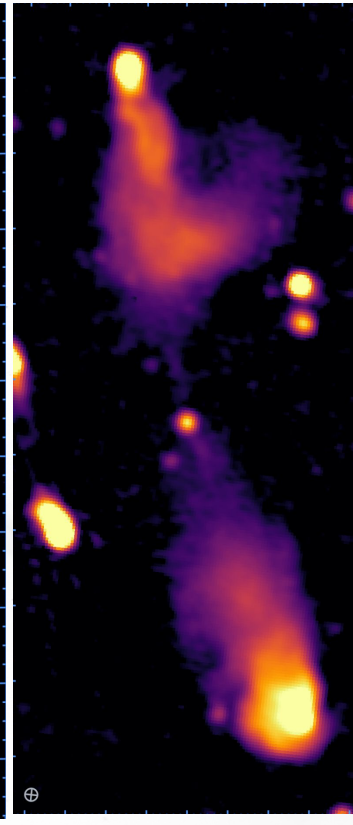
uGMRT 650 MHz

30uJy/bm



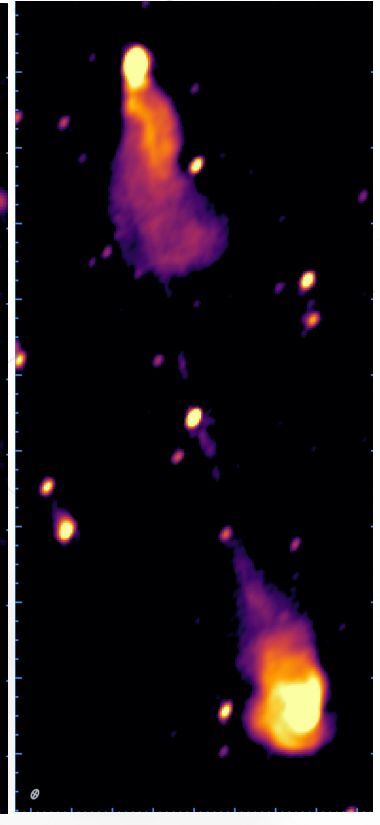
LOFAR 6''

70 uJy/bm



LOFAR 20''

120uJy/bm



VLA 5GHz, 15''

9uJy/bm

LOFAR-VLBI data reduction

Follow: LOFAR-VLBI wiki,
FLoCS webpage

1. For this GRG LOFAR observation has international stations (LC17_010, PI- Sagar Sethi)

- Total Observation- 8hrs
- Total Observation (with ILT)- 8hrs
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We attempted again here
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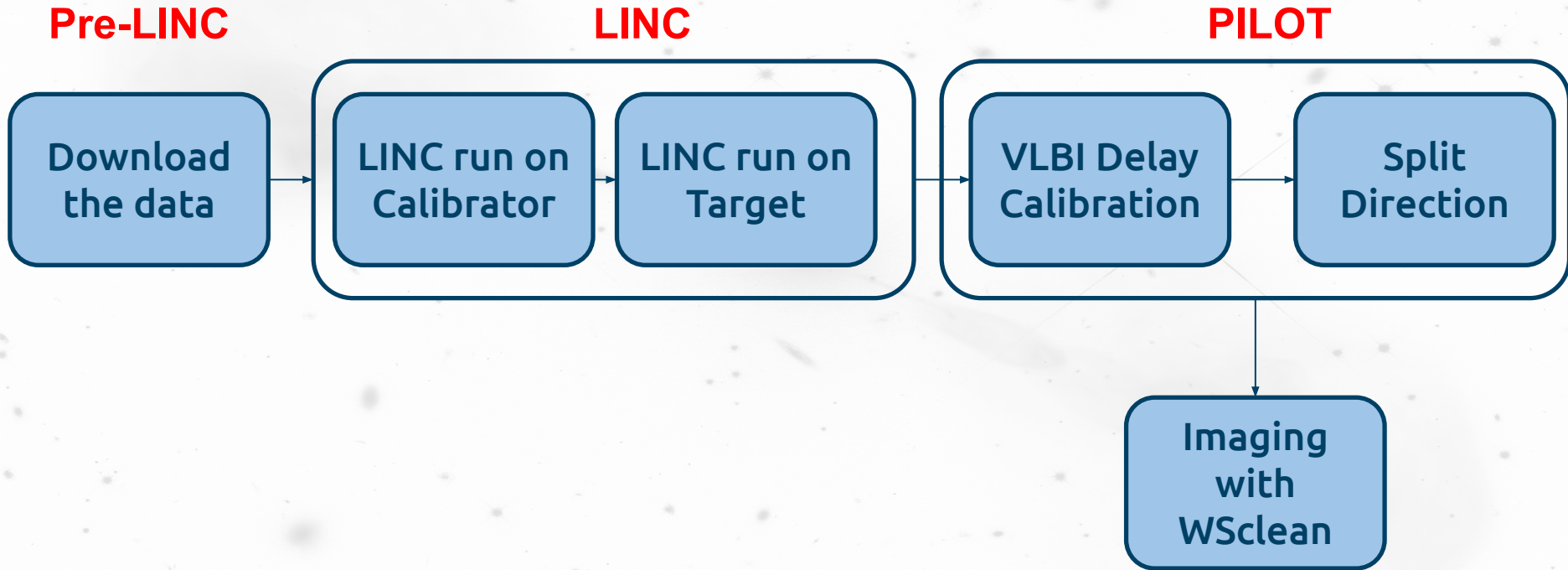
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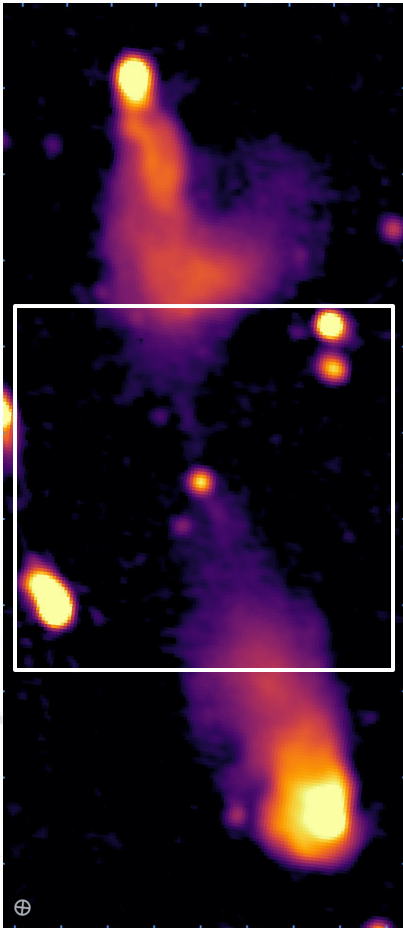
VLBI-delay
calibration is
successful
Phase_score':
0.9672074623350148



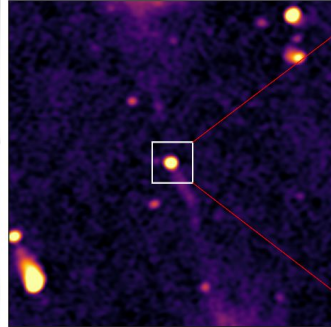
Same workflow followed



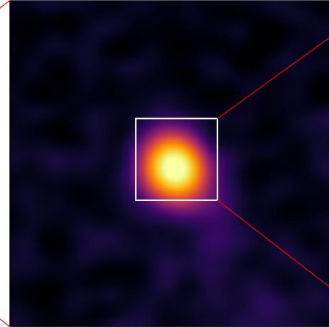
Successfully I made a preliminary postage stamp 0.6 arcsec resolution image of the core this 3 Mpc GRG.



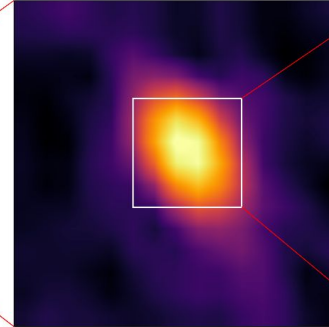
VLA L band 10 arc second



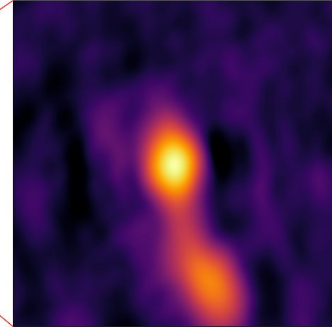
LoTSS 6 arc second



VLA3S 3 arc second

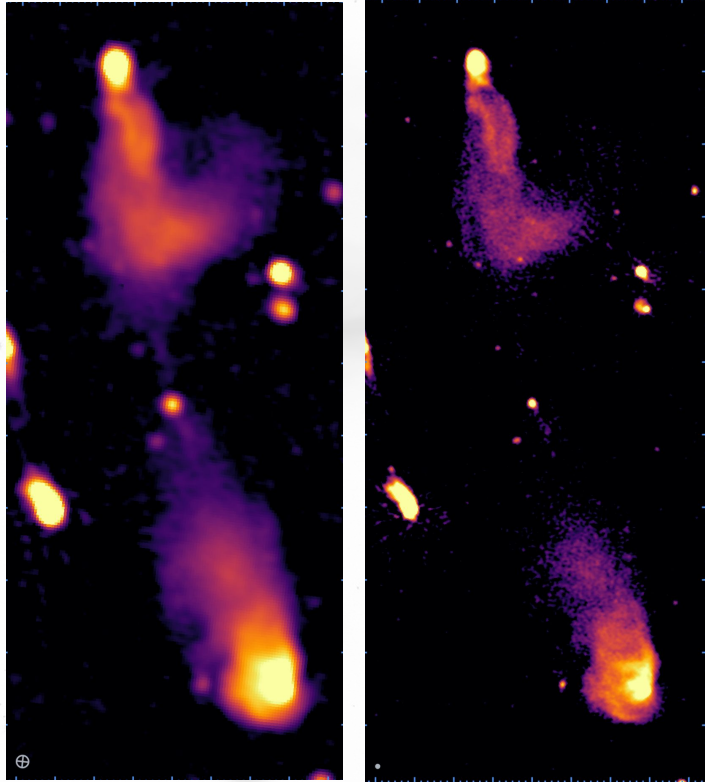


LOFAR-VLBI 0.6 arc second

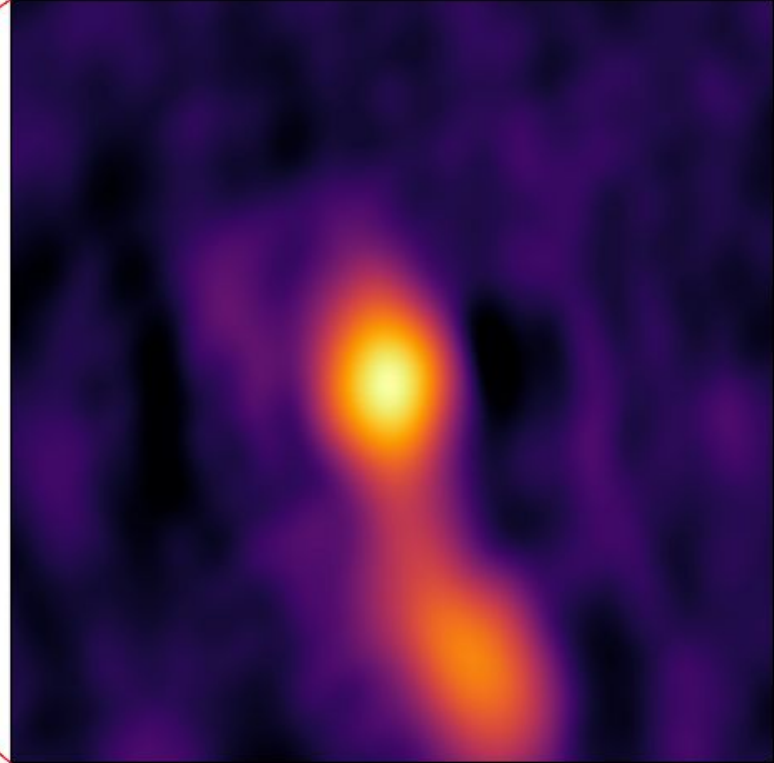


rms = 40 μ Jy

LOFAR 6 and 20 arcsecond images



LOFAR-VLBI 0.6 arc second



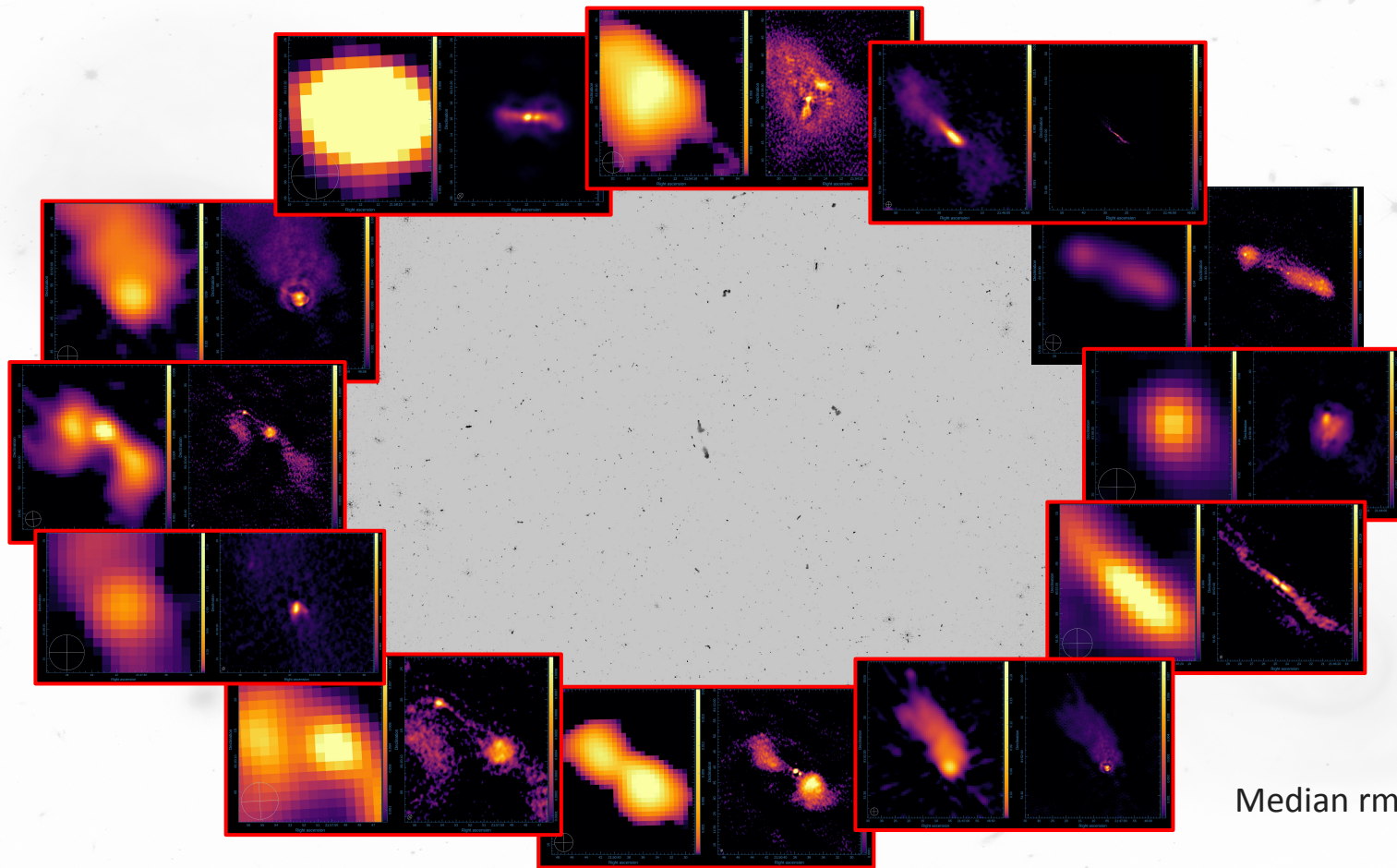
Together LOFAR and LOFAR-VLBI completes the picture, i.e. tracing a radio jet from Mpc to sub-kilo parsec scale this GRG.

LoTSS HR style postage stamp imaging of sources around



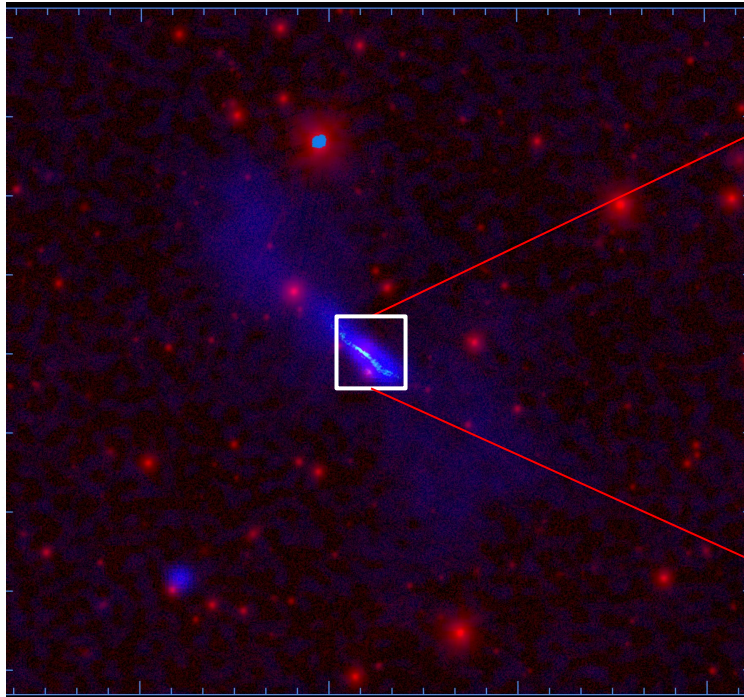
The entire LoTSS observation
field is 8 x 8 degree

LoTSS HR style postage stamp imaging of sources around

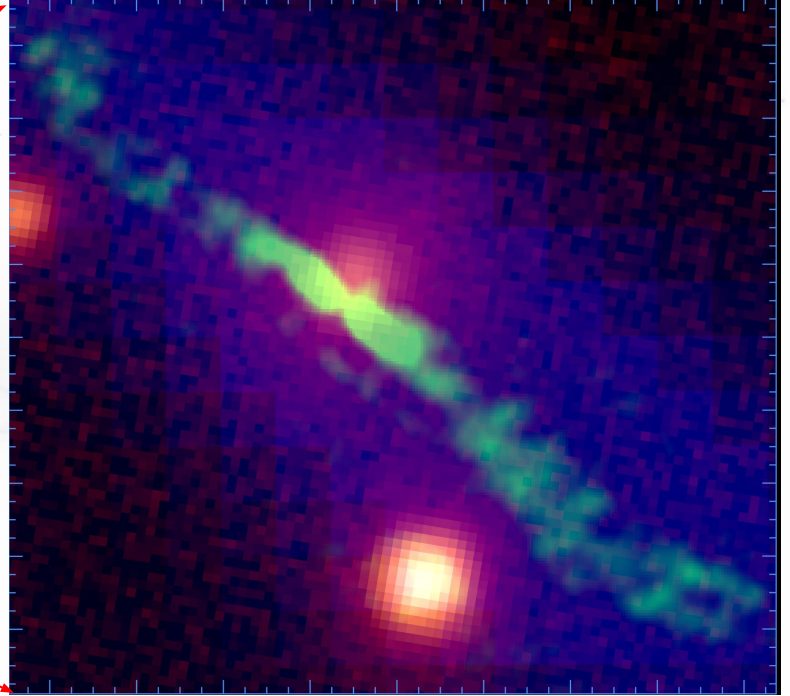


Median rms = 30-50 μ Jy

Tracing galaxy scale radio jets

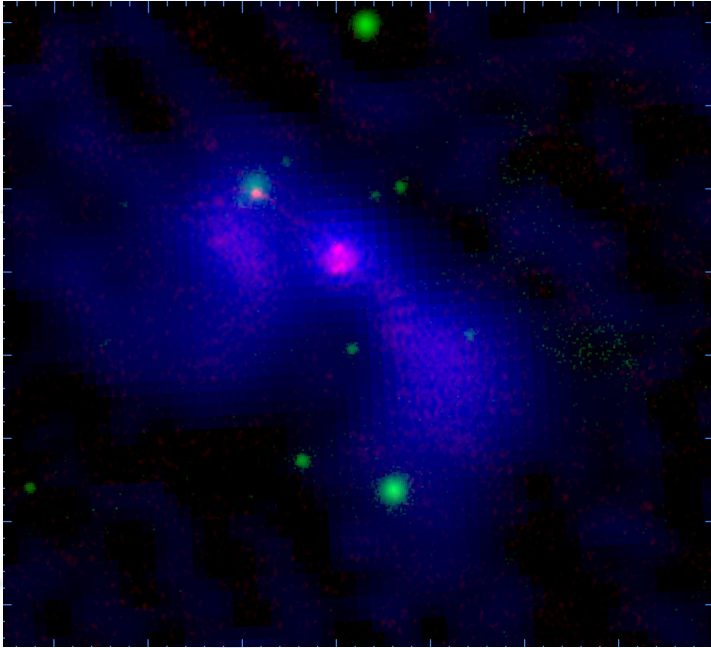


LOFAR 6 arcsec image overlay on PanSTARRS

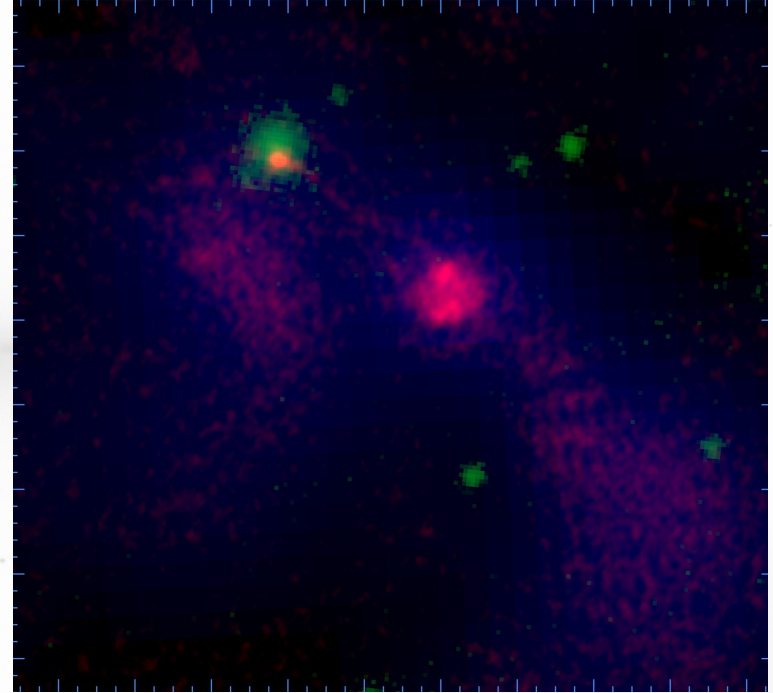


LOFAR-VLBI 0.6arcsec image overlay on PanSTARRS

Identifying the optical host of RGs/GRGs



LOFAR 6 arcsec image overlay on PanSTARRS



LOFAR-VLBI 0.6arcsec image overlay on PanSTARRS

Future perspective

- **Scientific**
 - Try to reduce the LOFAR-VLBI data for S-shaped GRG
 - VLA C Band (~ 0.3 asec) observation $\rightarrow$ constraint the duty cycle
 - Go for the full sample of GRG
 - Constraint the duty cycle
- **Technical**
 - Self-calibration and finalising the images
 - Beginner to LOFAR-VLBI need to understand more-wide-field imaging.

Thank you