

# Recent developments on giant radio galaxies and radio-AGN with LOFAR

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LoFAR Annual Meeting

June 2026



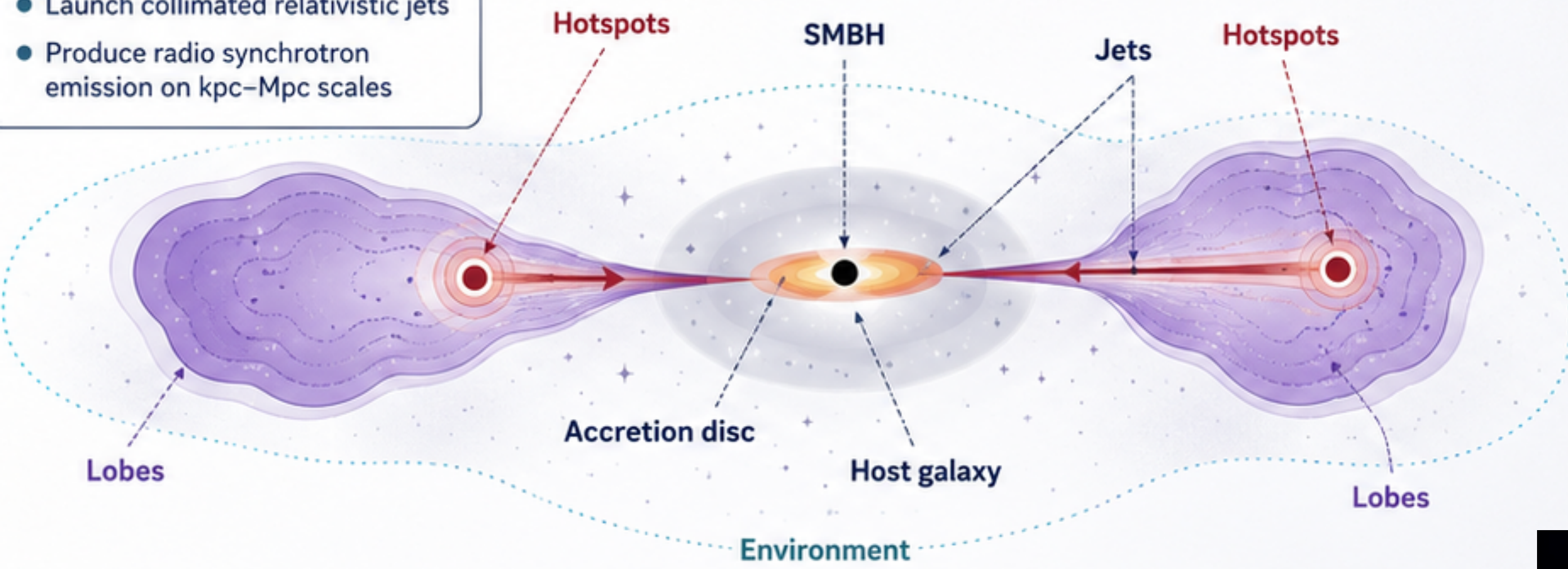


# Radio Galaxies

*Relativistic jets from accreting supermassive black holes*

## WHAT ARE THEY?

- Active galaxies powered by central supermassive black holes
- Launch collimated relativistic jets
- Produce radio synchrotron emission on kpc–Mpc scales



## KEY PHYSICS



Accretion powers the AGN



Magnetic fields collimate jets

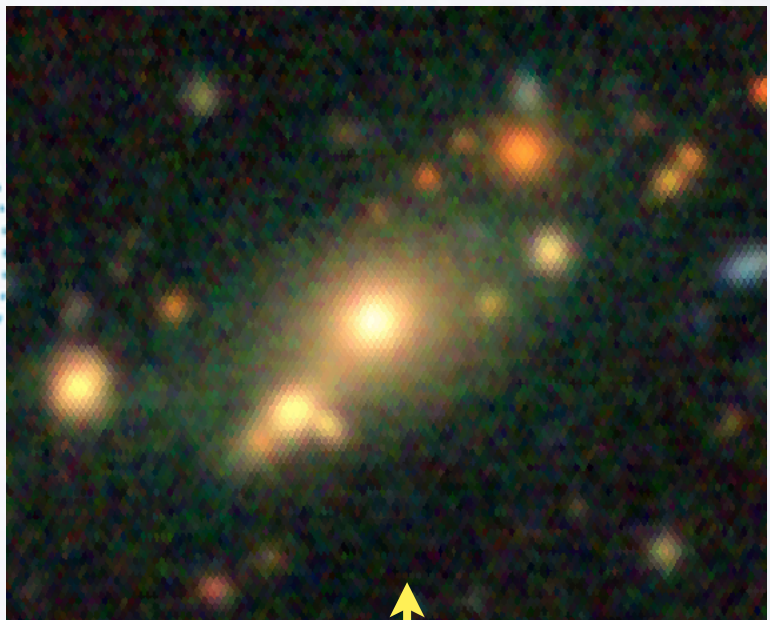


Synchrotron radiation traces relativistic electrons



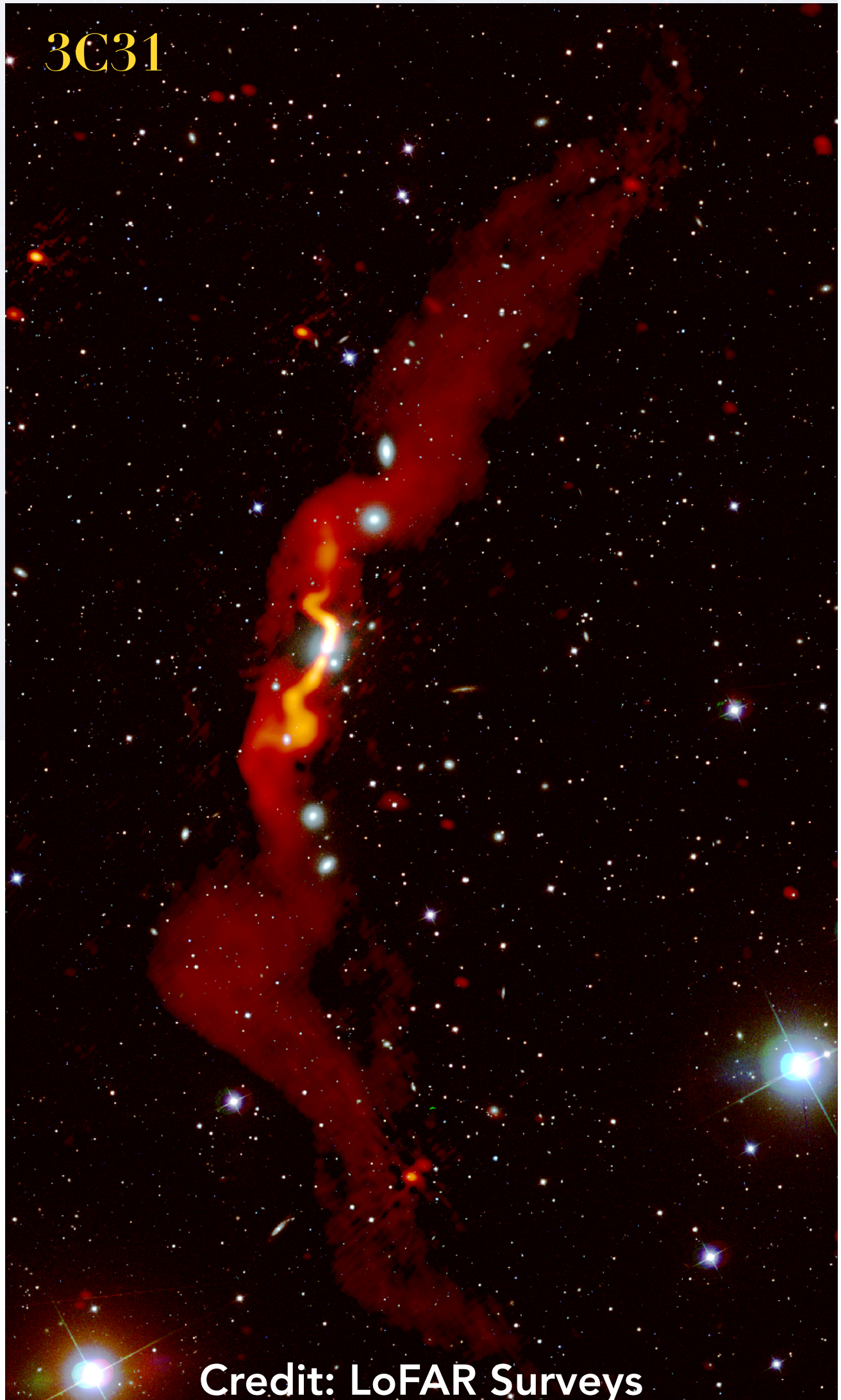
Interaction with the ambient medium shapes morphology and feedback

## TYPICAL SCALES



3C219

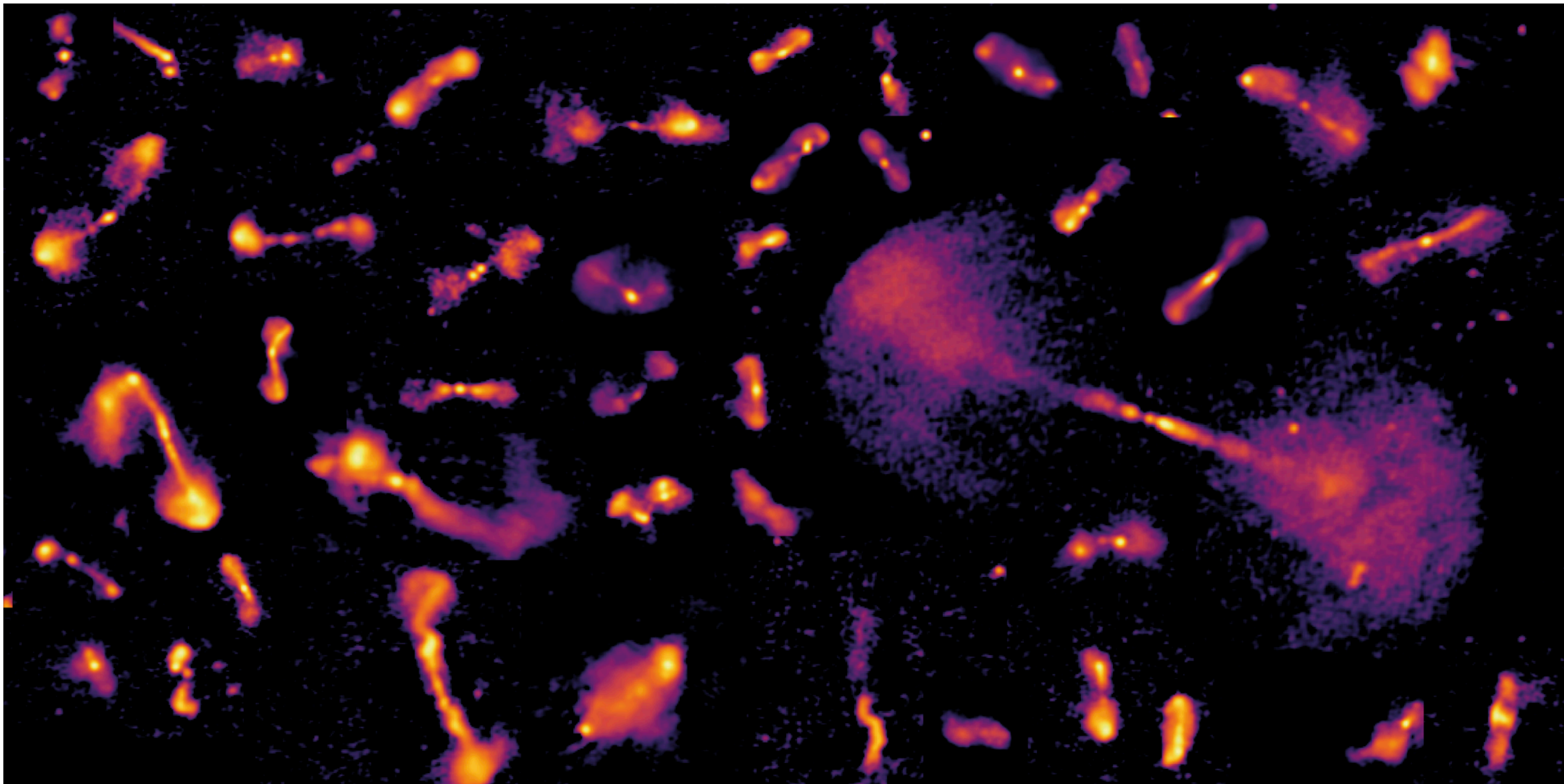
Credit: LoFAR Surveys



3C31

Credit: LoFAR Surveys



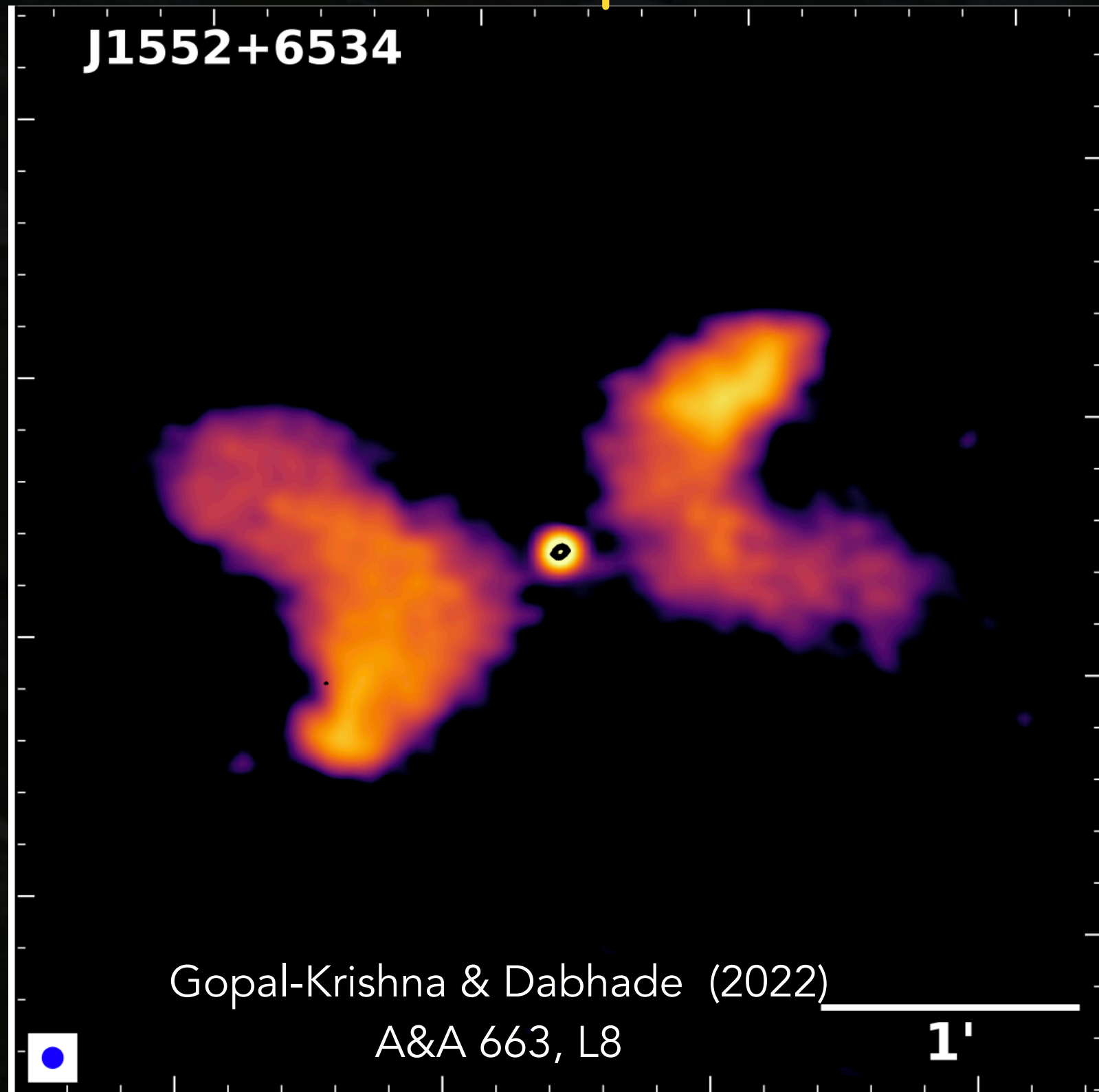


LOFAR 144 MHz

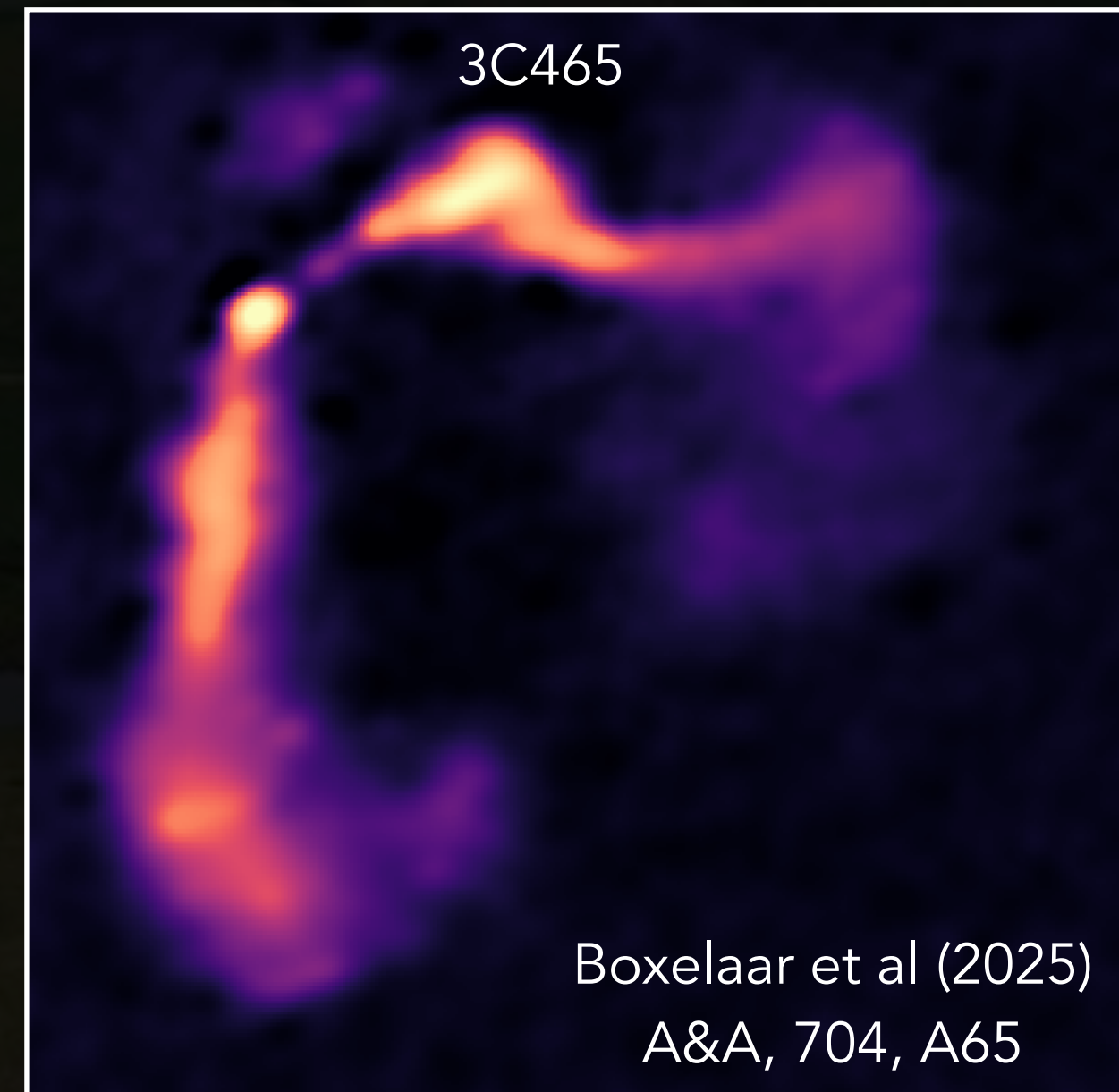
Reference : Horton, M. A., et al.: A&A (2025)



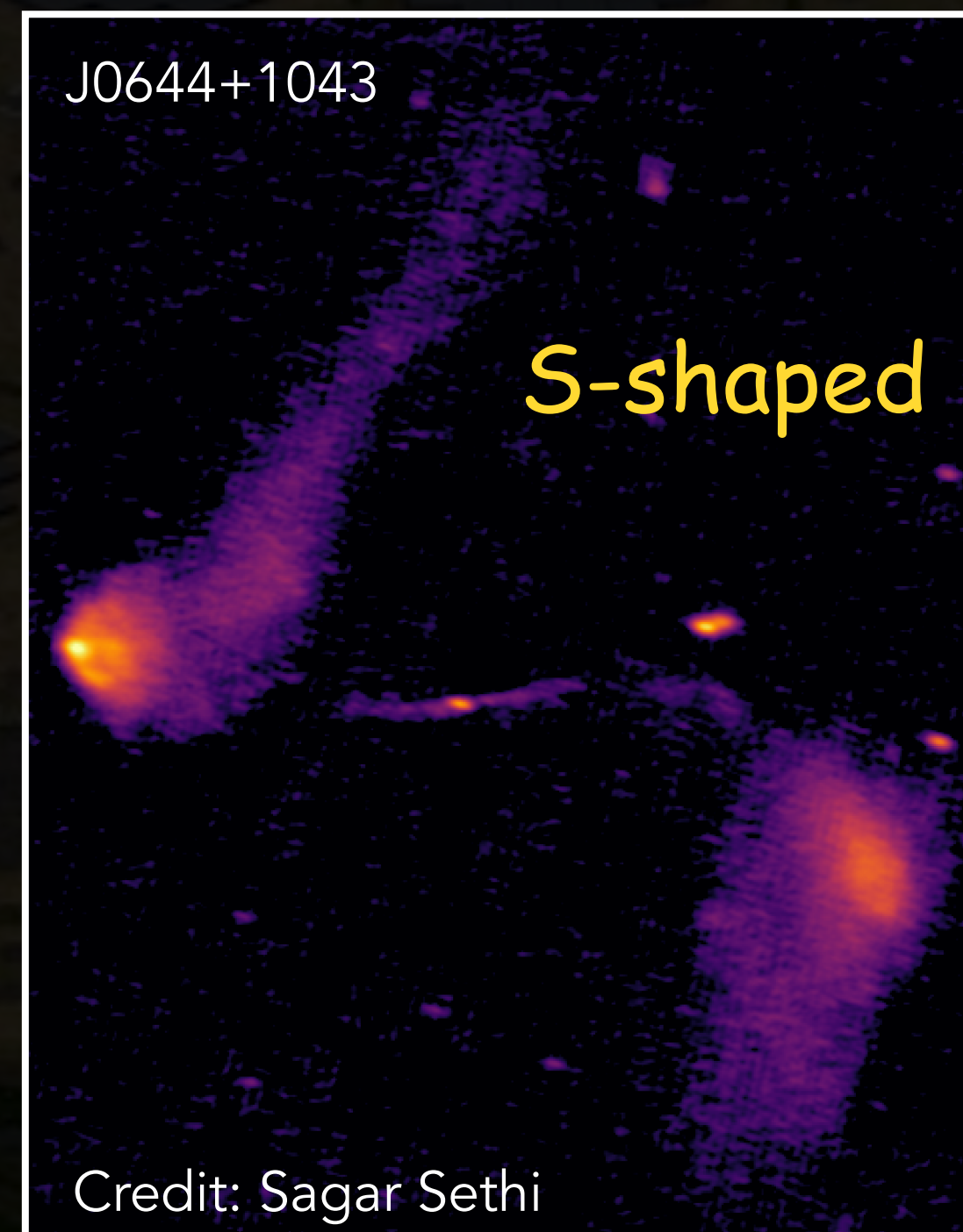
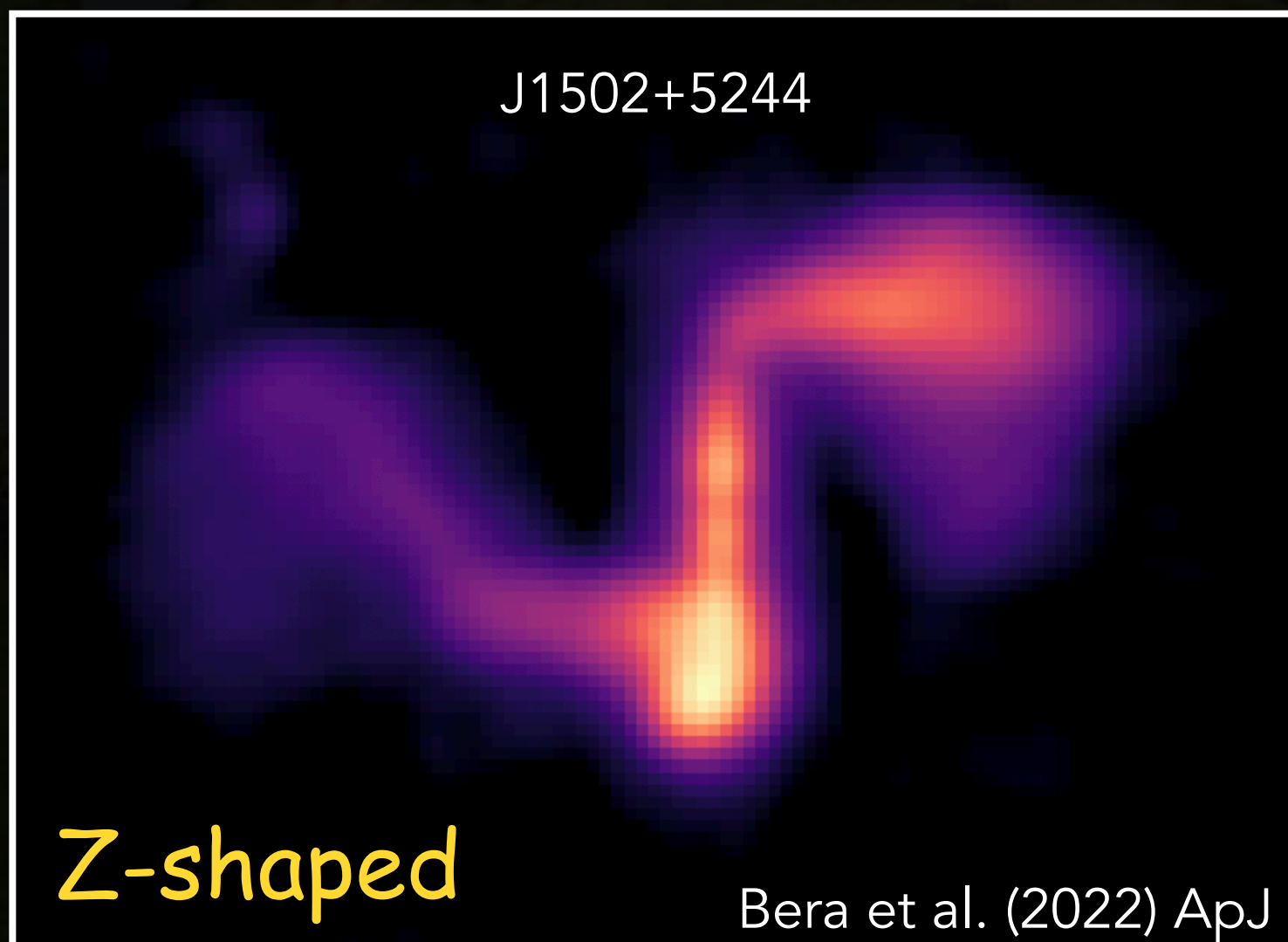
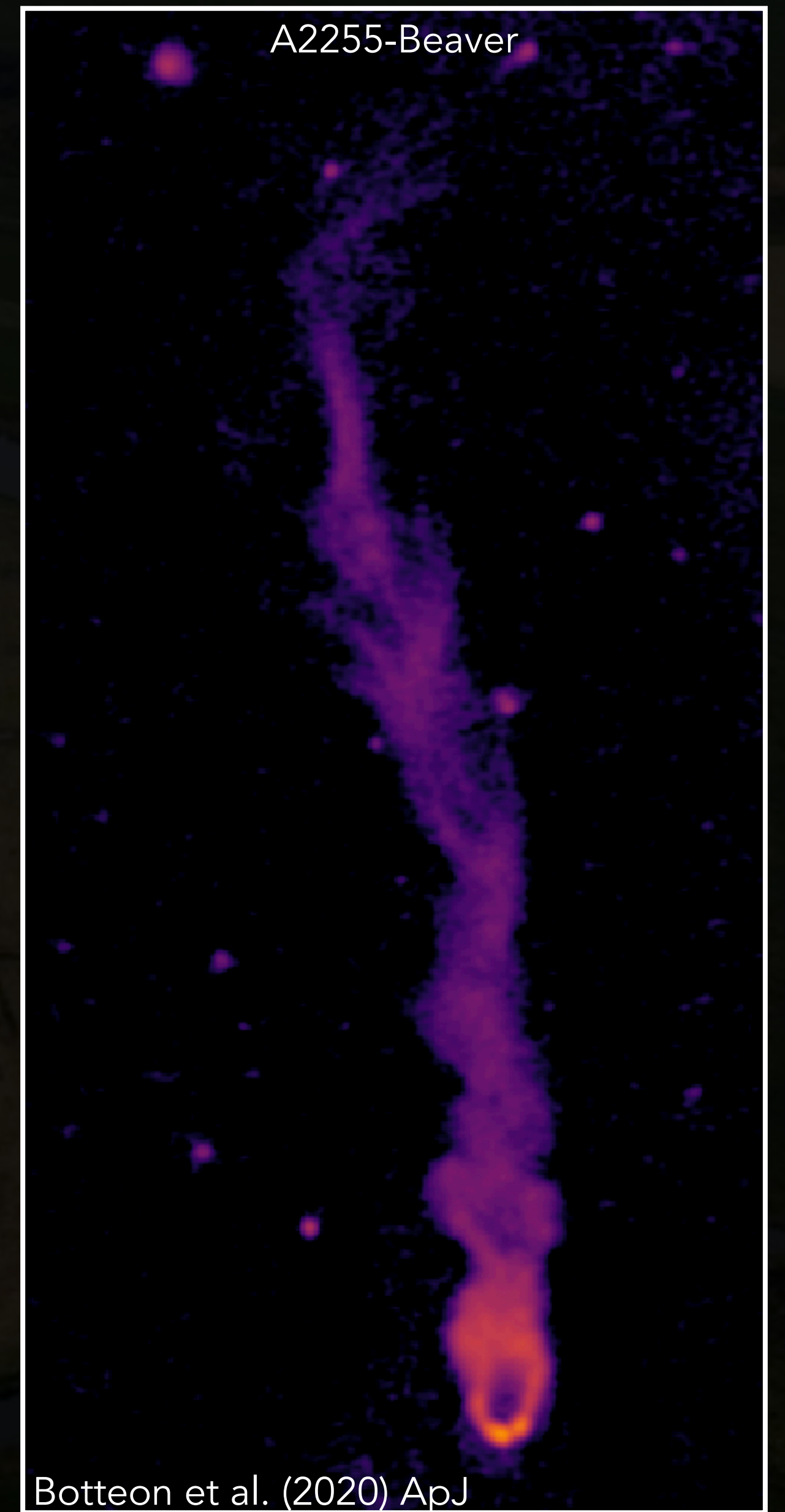
X-shaped



WAT (Wide-angle tail)



NAT (Narrow-angle tail)

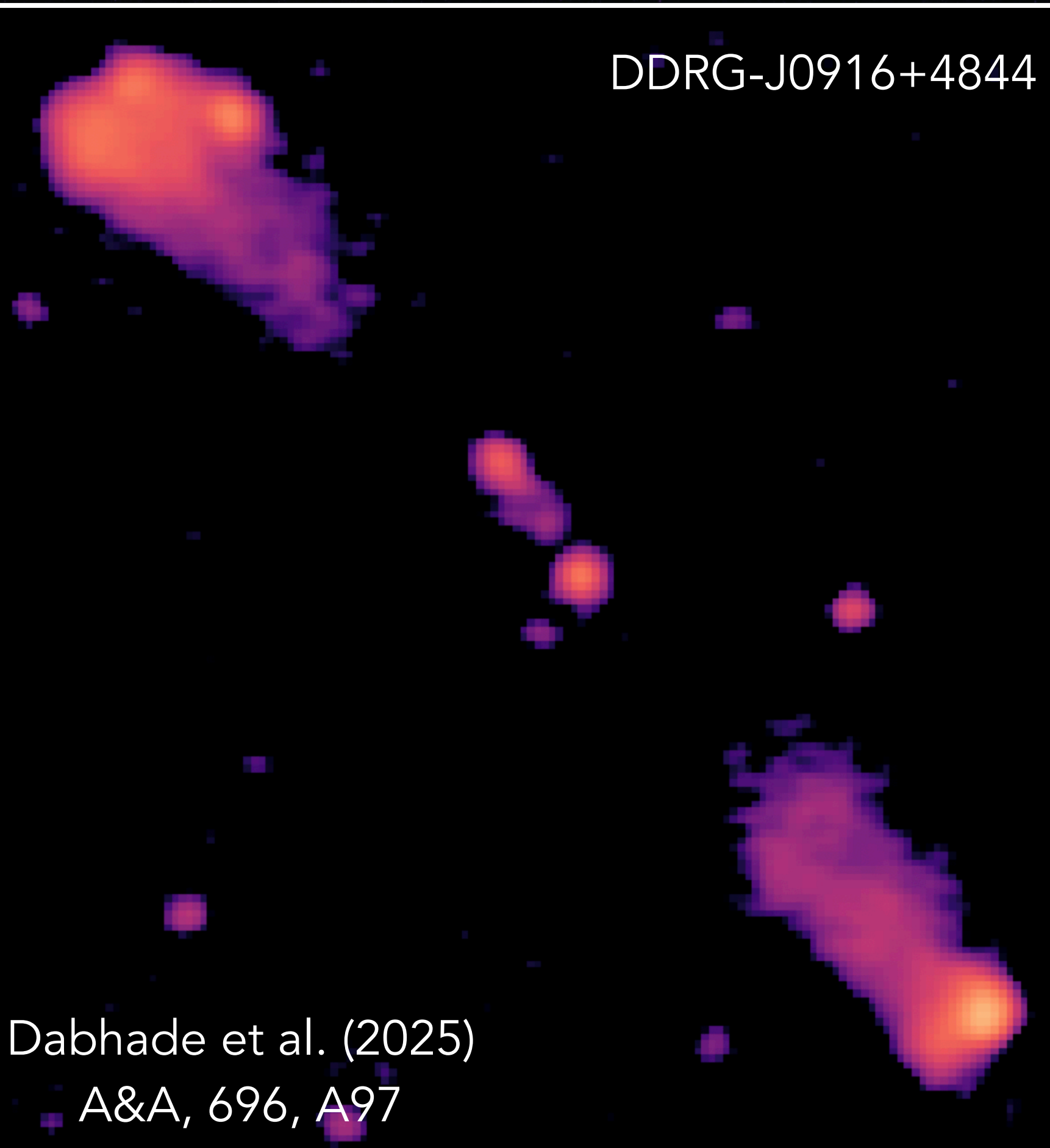




# Radio Galaxies: Shapes as Clues to Cosmic Physics

## Double-Double Radio Galaxy (DDRG)

DDRG-J0916+4844



Dabhade et al. (2025)

A&A, 696, A97

- ❖ Radio galaxies come in many forms, and each morphology carries physical information.
- ❖ Bent, twisted, X-shaped or restarted structures trace jet history, host motion, and environmental forces.
- ❖ Their shapes are therefore not just classifications, but diagnostics of AGN evolution, feedback and the cosmic environment.

*When Jets Write Their History in the Sky*

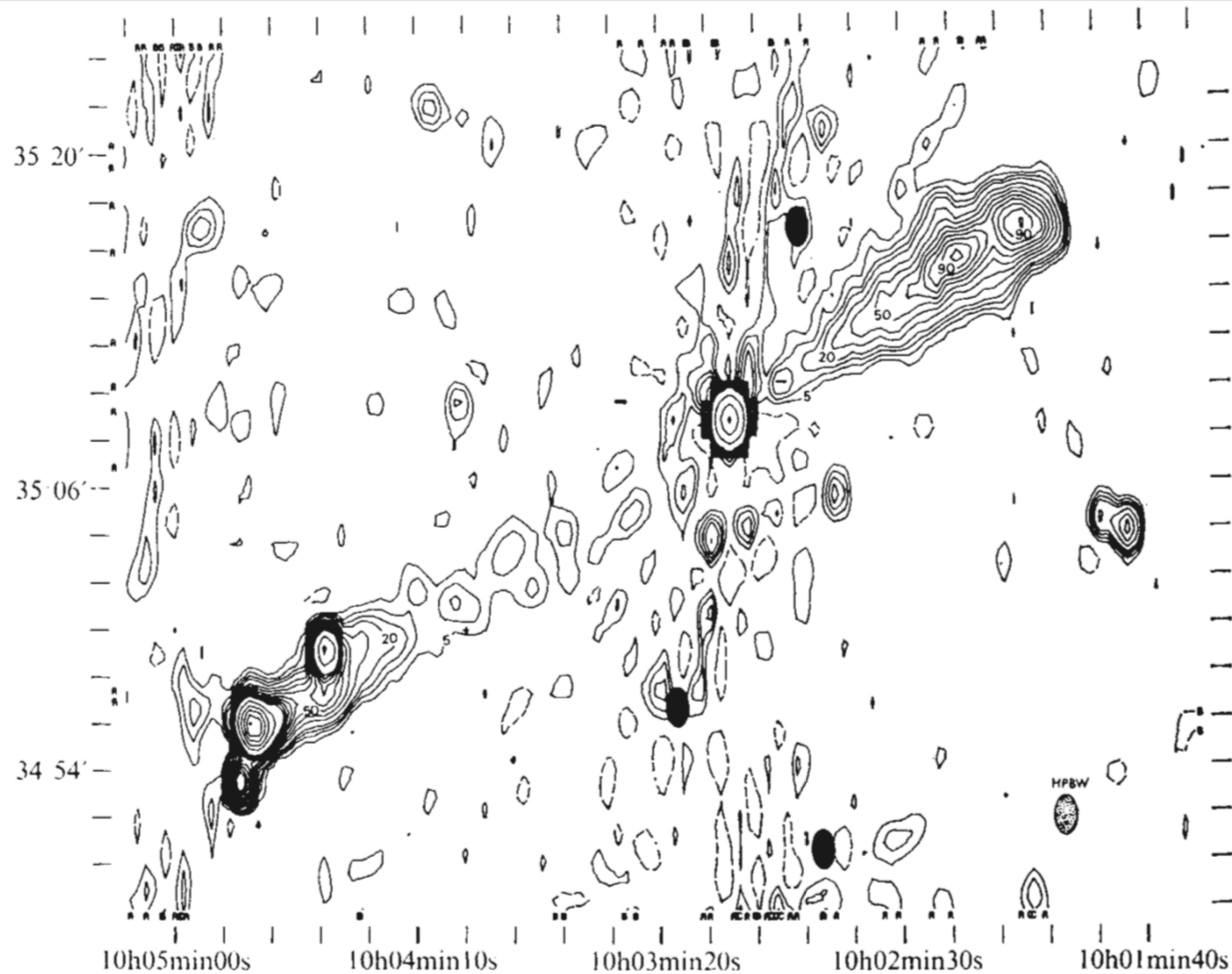


# Radio Galaxies Span Enormous Scales: Compact Jets to Megaparsec Giants

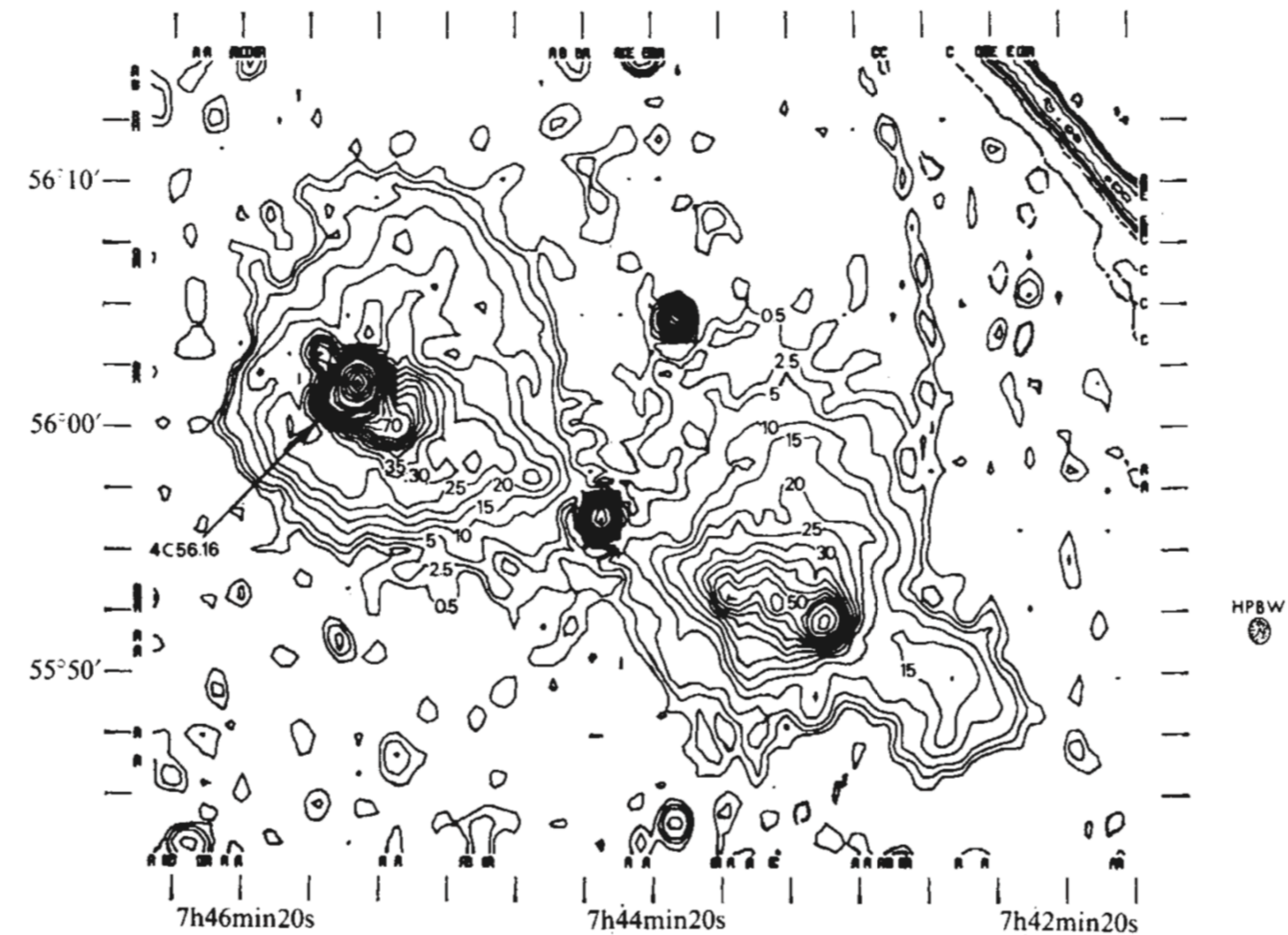
- ❖ Radio galaxies are not only diverse in shape, but also in scale, from compact young jets to structures extending across megaparsecs.
- ❖ Their size reflects a balance between jet power, lifetime, environment, duty cycle and projection.
- ❖ Small sources may reveal the birth or frustration of jets (PS), while large sources trace long-lived activity and the ability of jets to survive through the circumgalactic and intergalactic medium.
- ❖ At the extreme end lie giant radio galaxies, where black-hole activity imprints itself on scales comparable to  $\sim$ cosmic-web structures.



# 3C236, DA240; the largest radio sources known



© 1974 Nature Publishing Group

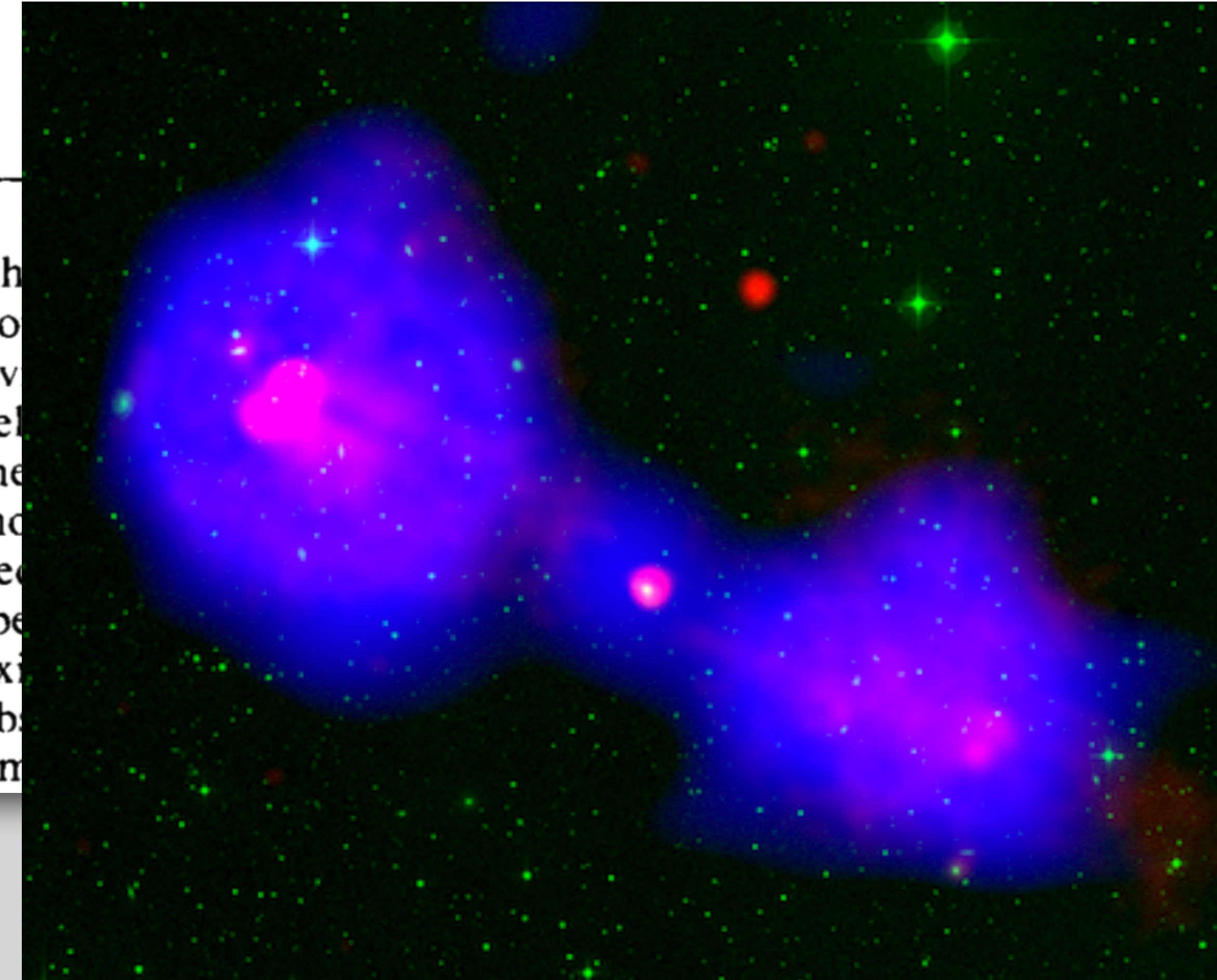
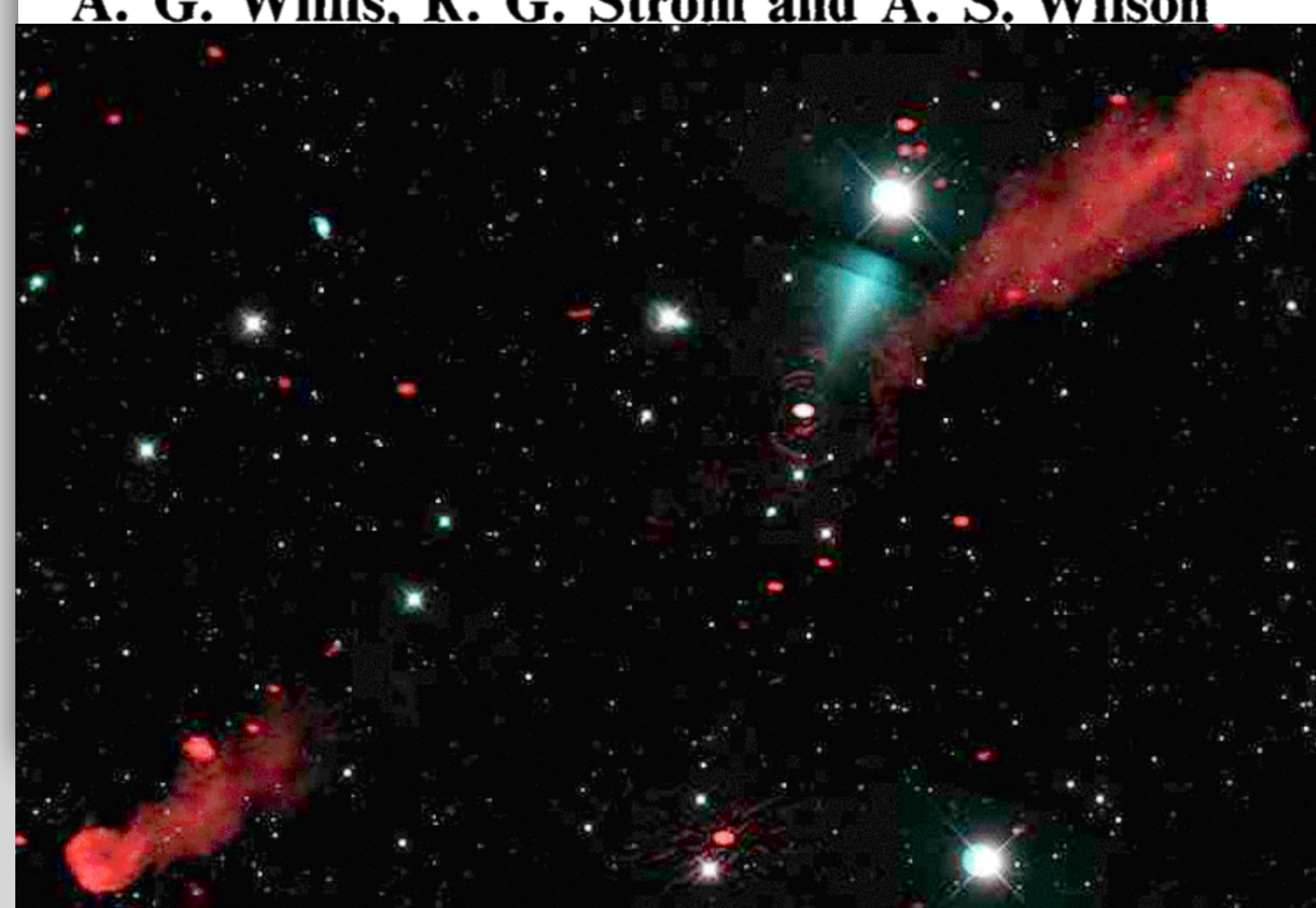


© 1974 Nature Publishing Group



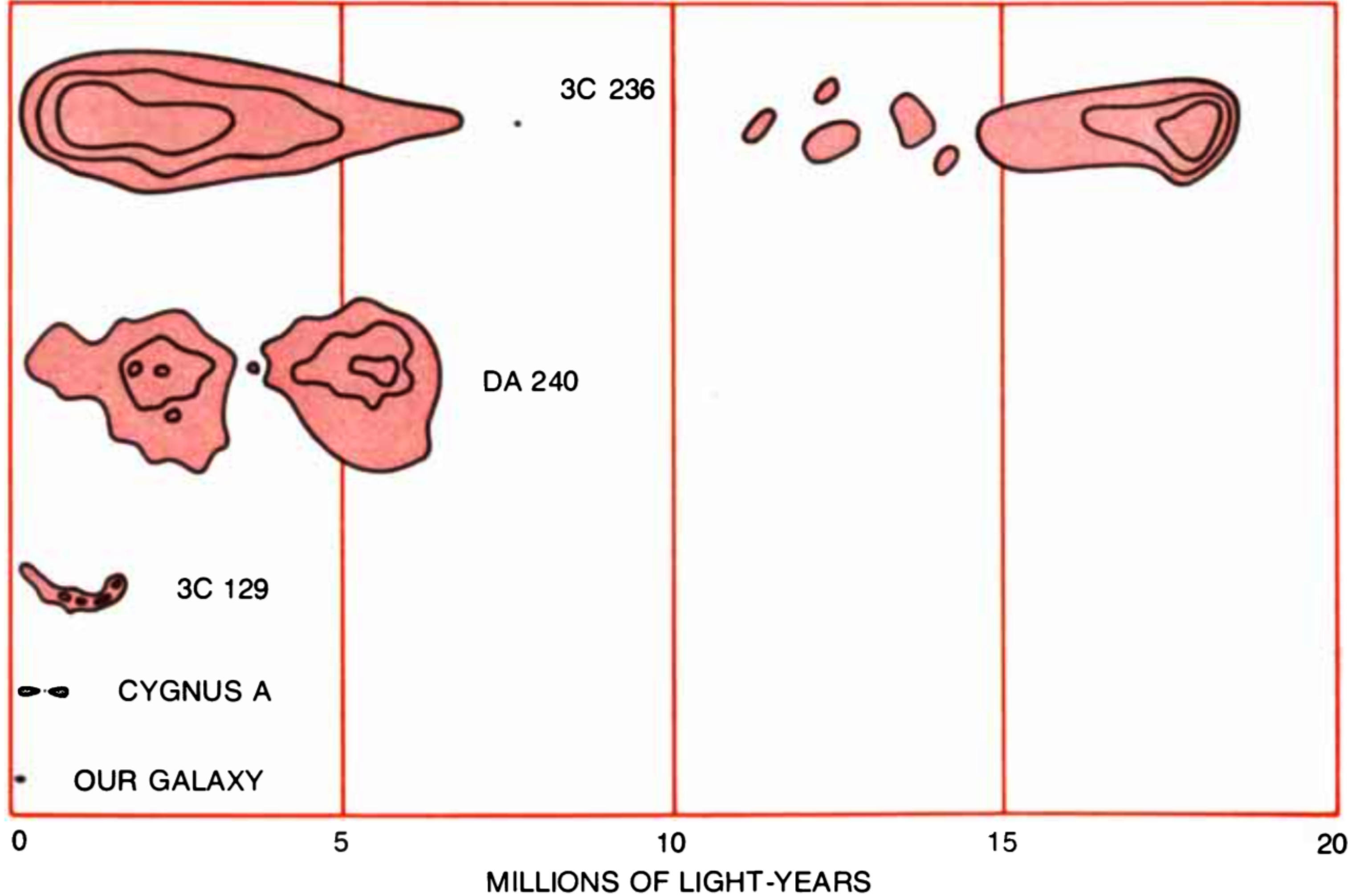
# 3C236, DA240; the largest radio sources known

A. G. Willis, R. G. Strom and A. S. Wilson





Scientific American 1975



**FOUR RADIO GALAXIES** are compared in size with our galaxy, which is 100,000 light-years in diameter. They range from Cygnus A, 600,000 light-years across, to DA 240 and 3C 236, which are exceptionally large. Typical double galaxies are about size of Cygnus A.

## GIANT RADIO GALAXIES

A powerful radio telescope in the Netherlands has revealed that energetic radio sources associated with galaxies are the largest objects known in the universe, extending millions of light-years

by Richard G. Strom, George K. Miley and Jan Oort

One of the most powerful of the present generation of radio telescopes is located at Westerbork in the northeastern Netherlands. The instrument operates by electronically combining the radio signals received by 12 antennas of relatively modest size, thereby simulating the response of a telescope of huge dimensions. Since the Westerbork telescope went into operation in 1970 its users have both discovered and examined a number of remarkable radio galaxies. Some are enormous double radio sources, hundreds of times larger than our own galaxy; others have a tadpole-like structure that is probably formed by a galaxy's hurtling through space and expelling clouds of gas that trail behind it. Such seemingly bizarre objects provide astronomers with exciting opportunities to study the evolution of radio sources and to probe the physical conditions within clusters of galaxies.

Radio astronomy had a troubled adolescence, when even the type of object being observed was often in doubt. How have the developments of the past 30 years led to instruments such as the one at Westerbork? A central concern has been the angular resolution of radio telescopes, which is proportional to the wavelength of the radiation divided by the reflector's diameter. Radio observations in the 1940's were made at wavelengths greater than one meter with telescopes less than 10 meters in diameter; their angular resolution was thus on the order of 10 degrees, or 20 times the diameter of the full moon.

It was possible to join two small reflectors with electrical cables, thereby achieving a resolution equivalent not to the diameter of the individual elements but rather to their separation from each other. It was extremely difficult, however, to keep the signals from the two elements in phase with each other, and

it is relative phase that carries all information about the radio source's position. The late Joseph L. Pawsey and his colleagues in Australia ingeniously sidestepped this problem and used the sea as a huge plane reflector, so that the reflected signal from a radio source and the direct signal from the same source would combine to generate interference fringes. Observing from the cliffs above Sydney harbor, John Bolton, Bruce Slee and Gordon Stanley were able to use such fringes to demonstrate that a few strong radio sources are associated with prominent visible galaxies.

After World War II radio astronomy benefited in a number of ways from radar technology. Precision radar dishes abandoned after the war were converted

to radio telescopes. With two of these dishes at his disposal, F. C. Smith of the University of Cambridge set about the difficult task of building an interferometer capable of measuring radio positions with an accuracy of one minute of arc. To achieve this he had to set his reflectors 1,000 feet apart, join them with cables, measure their relative position to within an inch and preserve the phase information of the incoming signals. He succeeded in his task and obtained an accurate position for Cygnus A, the strongest radio source in the constellation Cygnus. Training the 200-inch Hale telescope on the same spot, the optical astronomers Walter Baade and Rudolph Minkowski discovered that the radio position coincided with a distant galaxy. Cygnus A proved to be a watershed

**RADIO PHOTOGRAPHS** of two galaxies on the opposite page were made with the Westerbork synthesis radio telescope in the Netherlands. The Westerbork telescope consists of 12 dish-shaped antennas, each 25 meters in diameter, arranged in a line 1.6 kilometers long. Its sensitivity and resolution are equivalent to those that would be obtained by a single reflector 1.6 kilometers in diameter (see illustration on page 29). In the technique termed aperture synthesis the dishes are paired with one another to form a series of radio interferometers with different base lines. Observations from each of the interferometers are stored on magnetic tape. When all the observations are completed, a computer processes them and constructs a radio map of the object. The map can be displayed on a cathode ray tube so that the brightness of the visual image is related to the intensity of the radio emission. When the image is photographed, the resulting picture shows how the object would appear if the human eye were sensitive to radio wavelengths. The photographic method of representing the data was conceived by Walter Jaffe. The two radio galaxies shown, which are designated DA 240 (top) and 3C 129 (bottom), are two of the largest objects known in the universe. The double source DA 240 spans 34 minutes of arc in the sky, an angular diameter greater than that of the full moon. At the distance of DA 240 that angular diameter corresponds to a physical diameter of six million light-years. The central radio component of DA 240 coincides with a distant visible galaxy. The intense "hot spot" near the center of the component at left might be the seat of activity feeding energy to a huge cloud emitting energy at radio wavelengths. Double structure is typical of most strong radio sources outside our galaxy. The other object, 3C 129, is a head-tail radio source, so named because of its tadpole-like appearance. The narrow, delicately curved tail stretches over an angular distance of 20 minutes of arc, corresponding to a physical distance of about two and a half million light-years. The head coincides with a galaxy in a cluster of galaxies more than 400 million light-years away. Tail is believed to be a trail of gas left behind by the galaxy as it travels through the cluster. Its distorted shape is possibly due to turbulent motion of intergalactic gas. Ripples around the head are an artifact of the way the image was constructed.



# Standing on the shoulders of *giants*



## Discovery papers (not a complete list)

Willis *et al.* 1974   Bridle *et al.* 1976   Waggett *et al.* 1977  
Laing *et al.* 1983   Kronberg *et al.* 1986   de Bruyn 1989   Jones 1989  
Ekers *et al.* 1989   Lacy *et al.* 1993   Law-Green *et al.* 1995  
Cotter *et al.* 1996   McCarthy *et al.* 1996   Subrahmanyam *et al.* 1996  
Ishwara-Chandra & Saikia 1999   Lara *et al.* 2001   Machalski *et al.* 2001, 2007, 2008  
Kozieł-Wierzbowska & Stasińska 2011   Schoenmakers *et al.* 2001   Sadler *et al.* 2002  
Letawe *et al.* 2004   Saripalli *et al.* 2005   Saikia *et al.* 2006  
Huynh *et al.* 2007   Hota *et al.* 2011   Solovyov & Verkhodanov 2014  
Molina *et al.* 2014   Bagchi *et al.* 2014   Amirkhanyan *et al.* 2015  
Tamhane *et al.* 2015   Amirkhanyan 2016   Dabhade *et al.* 2017, 2020  
Clarke *et al.* 2017   Kapińska *et al.* 2017   Prescott *et al.* 2018  
Sebastian *et al.* 2018   Kuźmicz *et al.* 2018  
Kozieł-Wierzbowska *et al.* 2020   Tang *et al.* 2020  
Ishwara-Chandra *et al.* 2020   Galvin *et al.* 2020  
Bassani *et al.* 2021   Delhaize *et al.* 2021   Andernach *et al.* 2021   Masini *et al.* 2021  
Kuźmicz & Jamrozy 2021   Brüggén *et al.* 2021  
Mahato *et al.* 2022   Oei *et al.* 2022a   Gürkan *et al.* 2022  
Simonte *et al.* 2022   Oei *et al.* 2022b



## Papers with multi-frequency analysis

Liu *et al.* (1992)  
Ishwara-Chandra *et al.* (2001)  
Parma *et al.* (1999)   Leahy *et al.* (1988)  
Klein *et al.* (1995)   Mack *et al.* (1998)  
Marecki *et al.* (2021)   Godambe *et al.* (2009)  
Pirya *et al.* (2011)   Schoenmakers *et al.* (2000a)  
Jamrozy *et al.* (2008)   Konar *et al.* (2004)  
Ishwara-Chandra *et al.* (2001)   Marecki *et al.* (2021)  
Klein *et al.* (1995)   Konar *et al.* (2006)  
Nandi *et al.* (2010)   Lara *et al.* (2000)  
Harwood *et al.* (2017)   Sebastian *et al.* (2018)  
Tamhane *et al.* (2015)   Shulevski *et al.* (2019)

GRG  
literature

For more – Dabhade, Saikia, & Mahato 2023, Review article (JApA, V44, 1)





Home > Journal of Astrophysics and Astronomy > Article

Scientific Review | Published: 16 February 2023

# Decoding the giant extragalactic radio sources

Pratik Dabhade , D. J. Saikia & Mousumi Mahato

Journal of Astrophysics and Astronomy 44, Article number: 13 (2023) | Cite this article

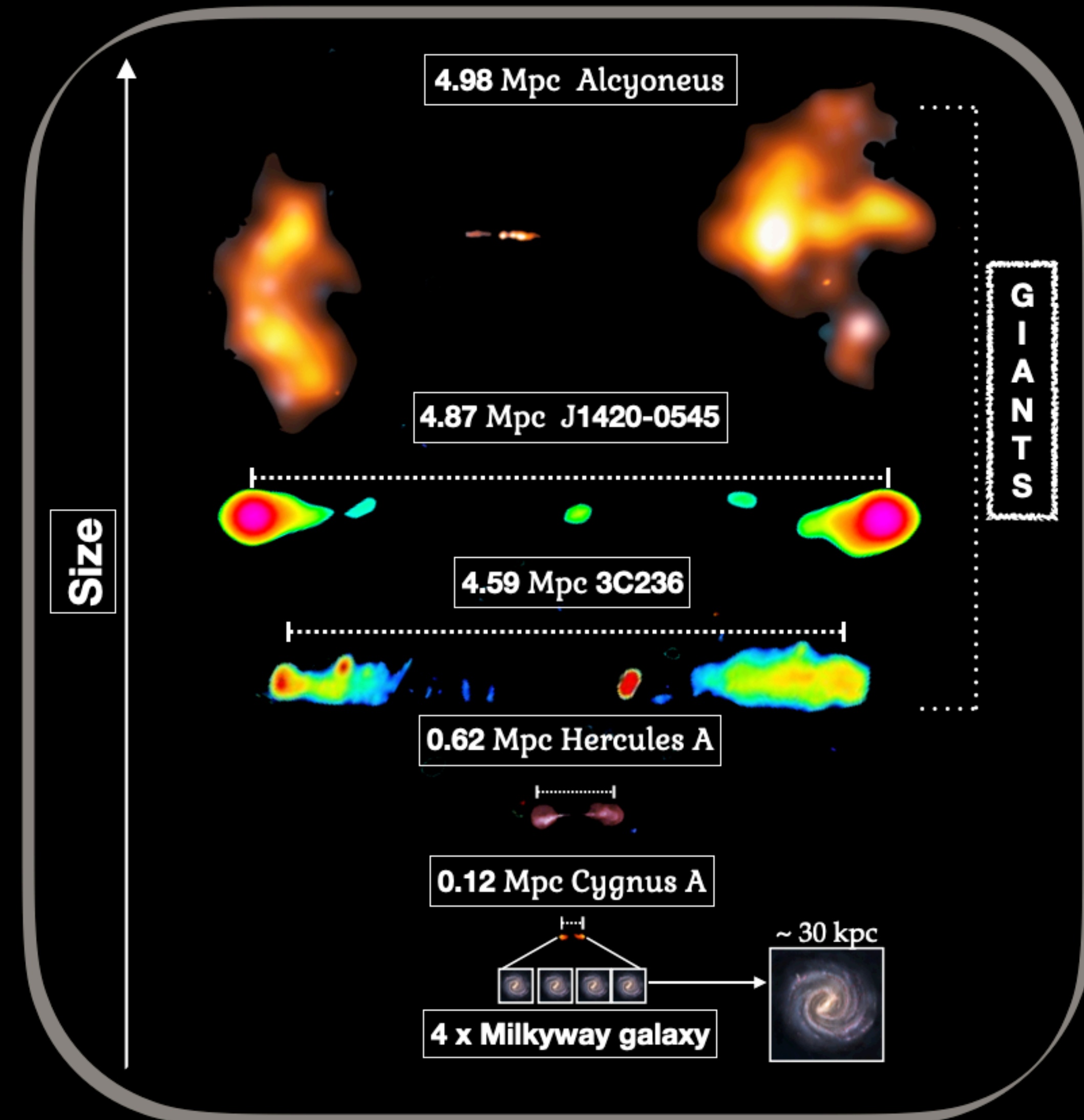
81 Accesses | 1 Citations | 11 Altmetric | Metrics



Special Issue on “Indian Participation in the SKA”

[https://www.ias.ac.in/Journals/Journal\\_of\\_Astrophysics\\_and\\_Astronomy/Indian\\_Participation\\_in\\_the\\_SKA](https://www.ias.ac.in/Journals/Journal_of_Astrophysics_and_Astronomy/Indian_Participation_in_the_SKA)

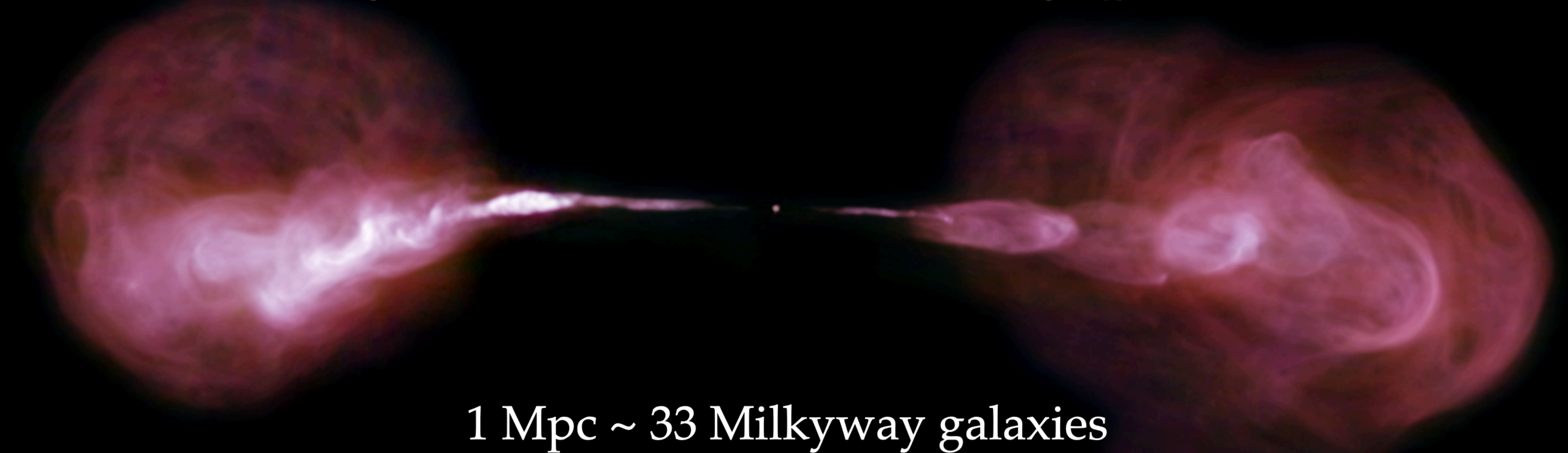
Summarising ~50 years research & future directions with SKA



Dabhade, Saikia, & Mahato 2023,  
Review article (JApA, V44, 1)



“Giant radio galaxies” → “Megaparsec scale”



1 Mpc  $\sim$  33 Milkyway galaxies



$\sim$  30 kpc



Size of Milky way galaxy  $\sim$  0.03 Mpc ; 1 Mpc  $\sim$   $10^{22}$  metres or 3.26 million light years

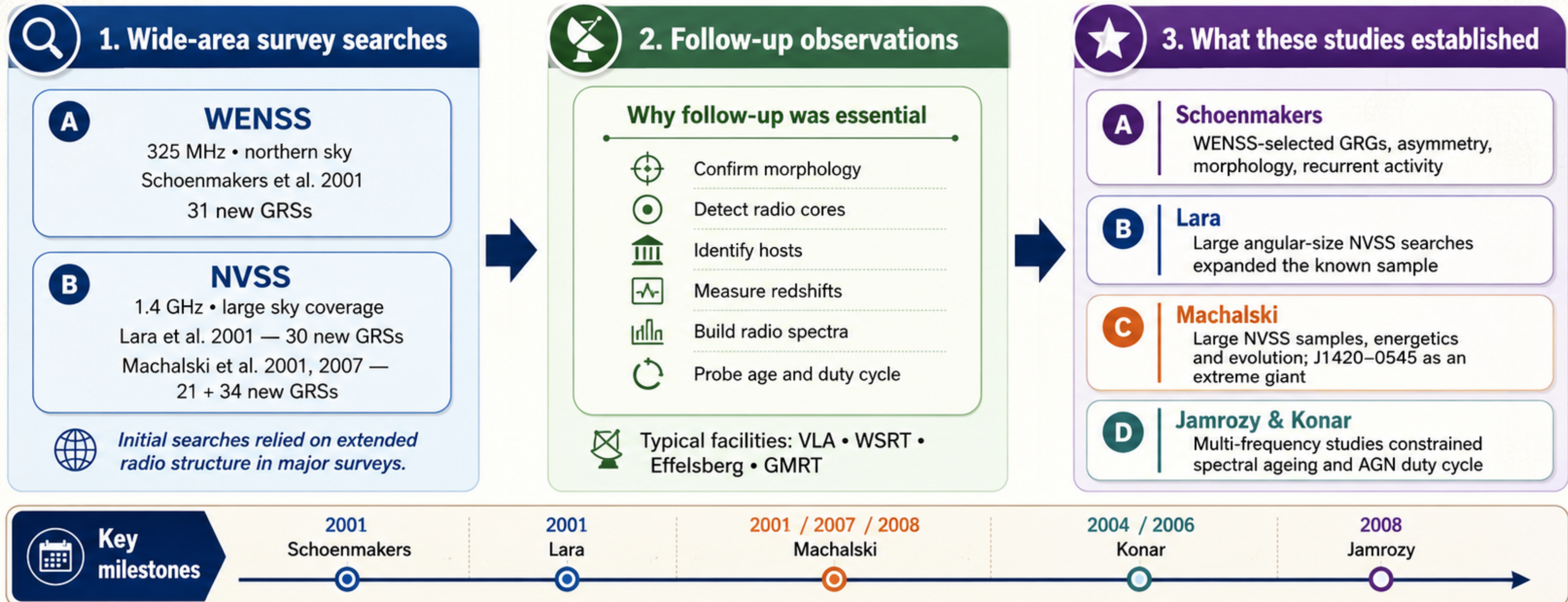


# GIANT RADIO SOURCES

Giant radio galaxies (GRGs)  
Giant radio quasars (GRQs)  
Giant radio sources (GRS)

## The pre-LOFAR groundwork: finding and understanding GRGs

Late 1990s to early 2000s: wide-area surveys + targeted follow-up transformed GRG studies







# OPEN PROBLEMS RELATED TO GRGs



Despite significant progress, many fundamental questions about **giant radio galaxies (GRGs)** remain unanswered.

## KEY OPEN QUESTIONS



What physical factors allow GRGs to reach **sizes** > 700 kpc up to ~ 5 Mpc?



How do GRGs **form and evolve**, and how **rare** are they in the Universe?



What is the role of **environment** – from the host galaxy to the supercluster/large-scale Cosmic Web?



Do GRGs experience **restarted or recurrent activity**, or a combination of multiple episodes?



What parameters control the stability and propagation of **magnetised jets** on Mpc scales?



How old are GRGs? Can we robustly estimate their **ages** (~ 8 – 200 Myr)?



Which **combination of factors** (black hole properties, accretion mode, jet power, environment) ultimately drives the growth of GRGs?

Hosted by very powerful AGN ?

Growth only in  
sparse environment ?

Recurrent activity ?

## WHY IT MATTERS



GRGs are among the **largest single objects** in the Universe.



They trace the interplay between **AGN jets** and the **Cosmic Web**.



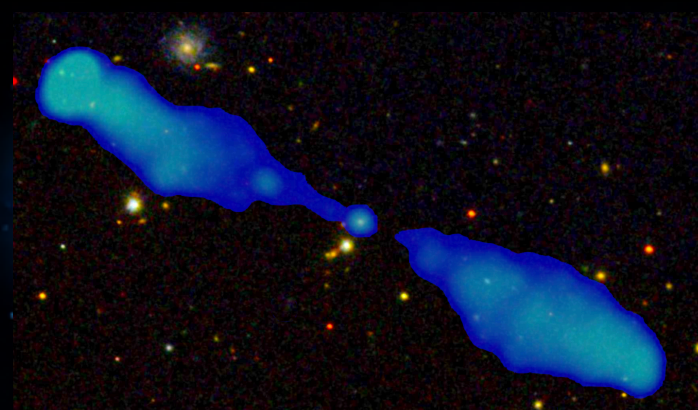
Understanding GRGs helps us understand **galaxy evolution** and **feedback**.



GRGs are natural laboratories for extreme jet physics and cosmic environments.

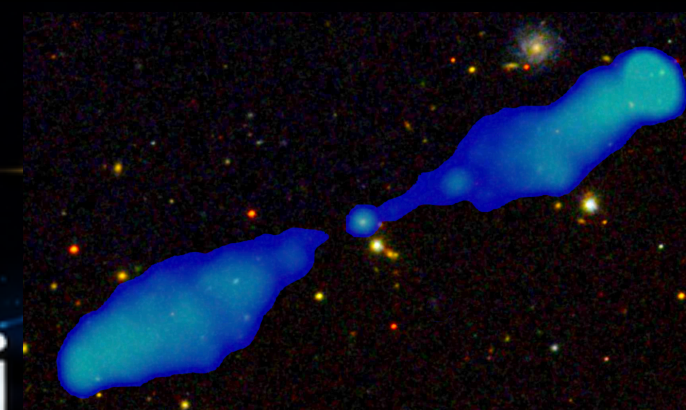
**Larger samples, multiwavelength data, and next-generation surveys are the key to unlocking these mysteries.**





# Project SAGAN

Search & Analysis of Giant radio galaxies with Associated Nuclei



Addressing key open problems in giant radio galaxy research



## OPEN QUESTIONS IN GRG RESEARCH



Why do some radio galaxies grow to giant sizes?



Are GRGs intrinsically rare?



How old are they really?



What role does restarted / recurrent activity play?



Do GRGs require very powerful AGN?



Do they grow only in sparse environments?



What maintains jet stability over Mpc scales?



Can GRGs contribute to other astrophysical processes?



## HOW SAGAN ADDRESSES THEM – OUR GOALS

1



Build a unified literature-based catalogue / database of all known GRGs.

2



Discover new low-surface-brightness GRGs from radio surveys with optical / spectroscopic synergy.

3



Measure host-galaxy and AGN properties through multi-wavelength analysis.

4



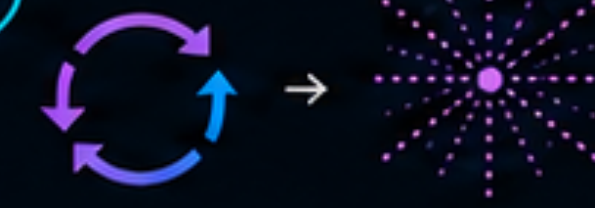
Obtain radio follow-up and broad-band spectral information for morphology and spectral ageing.

5

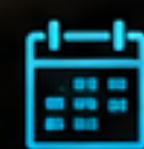


Study the environments of GRGs, from groups and clusters to large-scale structure.

6



Investigate restarted activity and use GRGs as probes of other astrophysical processes.



Started in 2016



PI: Pratik Dabhade



[sites.google.com/site/anantasakyatta/sagan](https://sites.google.com/site/anantasakyatta/sagan)



# 1. Building a complete GRG literature list (1974–present)

*The first difficulty was the naming problem.*



## Different names used for giant radio galaxies

Giant radio galaxy

Giant radio galaxies

GRG

GRGs

Giant radio source

Giant radio sources

GRS

GRSs

Giant extragalactic radio source

Large radio galaxy

Large radio source

Megaparsec radio galaxy

Megaparsec scale radio galaxy

Megaparsec-scale radio source

Mpc-scale radio galaxy

Mpc-scale radio source

Giant radio quasar

Giant radio quasars

GRQ

GRQs



**Additional issue:** some papers reported candidate giants without explicitly quoting the source size.

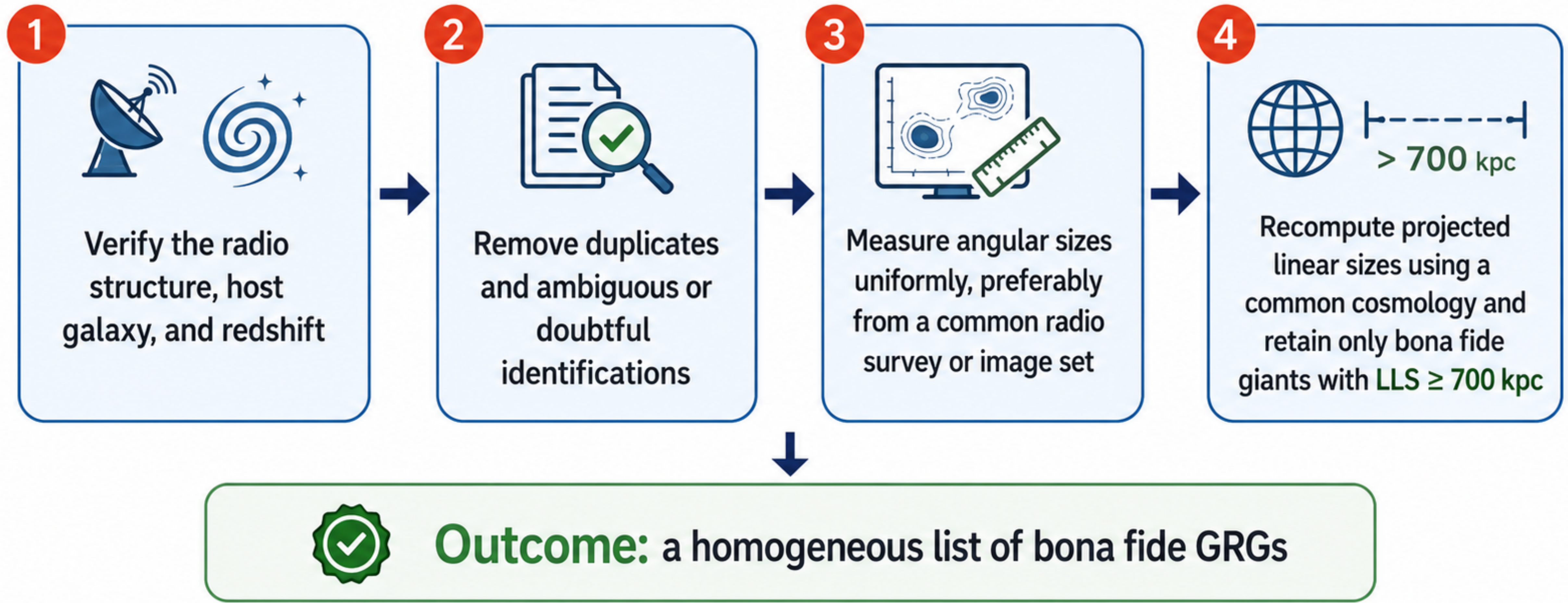


Therefore, the search had to be **broad, iterative, and manually screened.**



## 2. Verifying and homogenising the reported GRGs

*From literature candidates to a uniform catalogue*



★ Uniform size measurements and cosmological parameters are essential for a consistent GRG catalogue.



# DISCOVERIES OVER THE YEARS



~40 papers  
from 1974 to 2016

Giant Radio Galaxies (GRGs) are rarer  
compared to normal sized radio galaxies

*Dabhade et al. 2017, MNRAS*

~300 GRSs  
by 2016

## Discovery papers (not a complete list)



1970s

Willis et al. 1974

Bridle et al. 1976

Waggett et al. 1977



1980s

Laing et al. 1983

Kronberg et al. 1986

de Bruyn 1989

Jones 1989

Ekers et al. 1989



1990s

Lacy et al. 1993

Law-Green et al. 1995

Cotter et al. 1996

McCarthy et al. 1996

Subrahmanyan et al. 1996

Ishwara-Chandra & Saikia 1999



2000s

Lara et al. 2001

Machalski et al. 2001,  
2007, 2008

Schoenmakers et al. 2001

Sadler et al. 2002

Letawe et al. 2004

Saripalli et al. 2005

Saikia et al. 2006

Huynh et al. 2007



2010s

Hota et al. 2011

Kozieł-Wierzbowska &  
Stasińska 2011

Soloviyov & Verkhodanov 2014

Molina et al. 2014

Bagchi et al. 2014

Amirkhanyan et al. 2015

Tamhane et al. 2015

Amirkhanyan 2016



# DISCOVERIES OVER THE YEARS

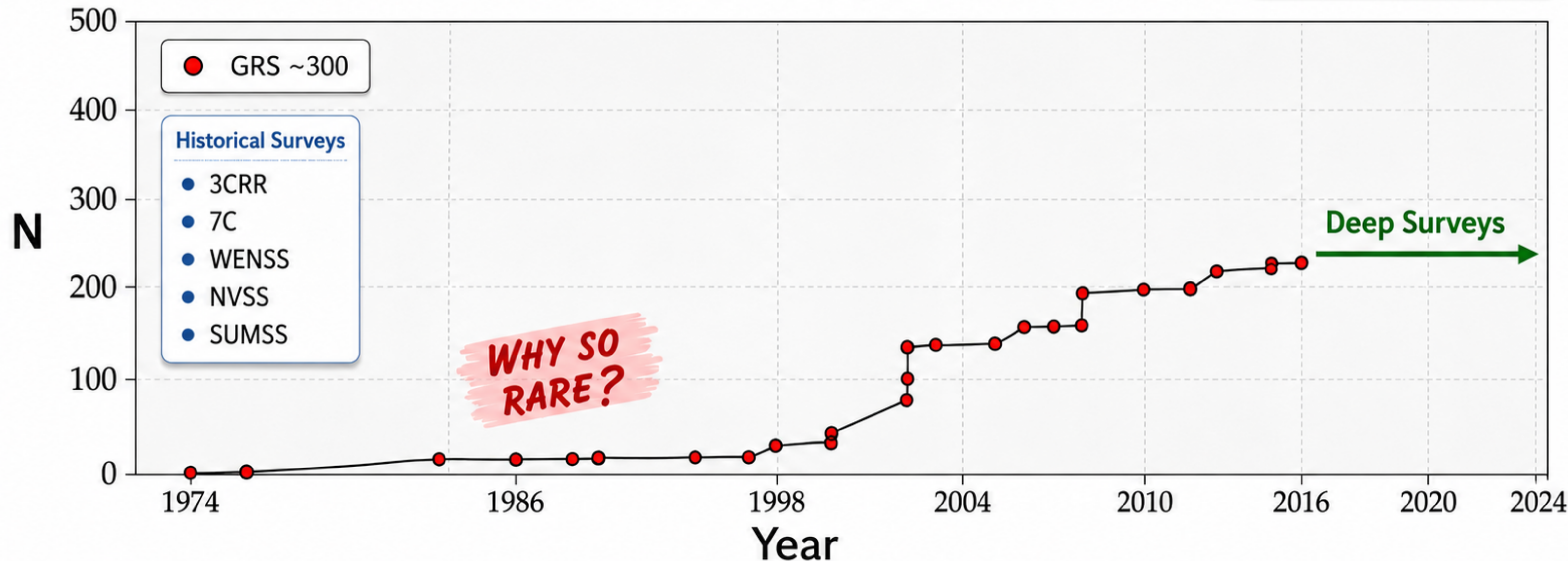


~40 papers  
from 1974 to 2016

Giant Radio Galaxies (GRGs) are rarer  
compared to normal sized radio galaxies

*Dabhade et al. 2017, MNRAS*

~300 GRSs  
by 2016



Early all-sky and targeted surveys yielded relatively few GRGs. The advent of deep, wide-field radio surveys significantly accelerated discoveries in the 2000s and beyond.



# THE GIANT RADIO GALAXIES



A rare population of radio galaxies that grow to megaparsec scales are known as **giant radio galaxies (GRGs)**.



Only **~300 GRGs** were known until **2016**

*Dabhade et al. 2017*

## GRG PROPERTIES KNOWN TILL 2016



Projected linear size **> 700 kpc**



Maximum size known then: **~5 Mpc**  
*cluster-size scale*



Host galaxies: mostly **giant ellipticals**



Radio morphology: predominantly **FR-II**



Spectral ages: **~8–200 Myr**  
*based on only ~20 GRGs*



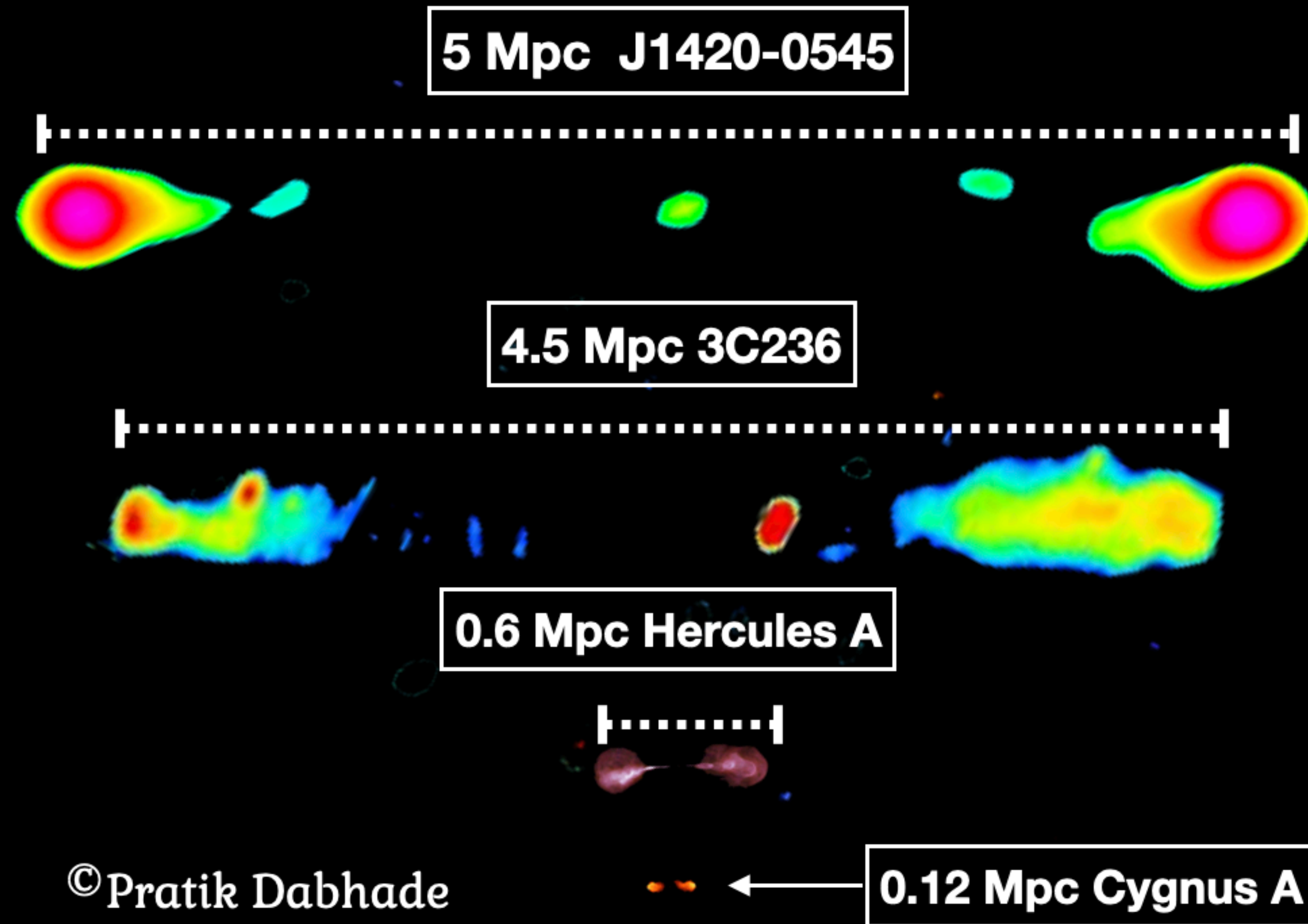
**They host the largest known astrophysical jets**





# The Giant Scale

## SCALE COMPARISON



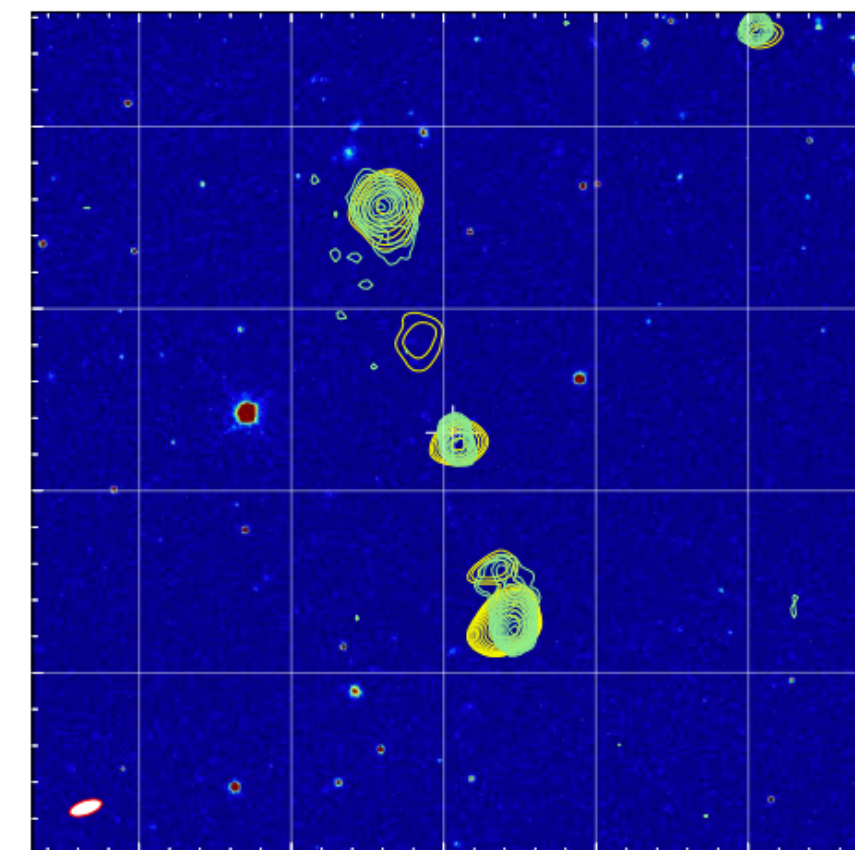
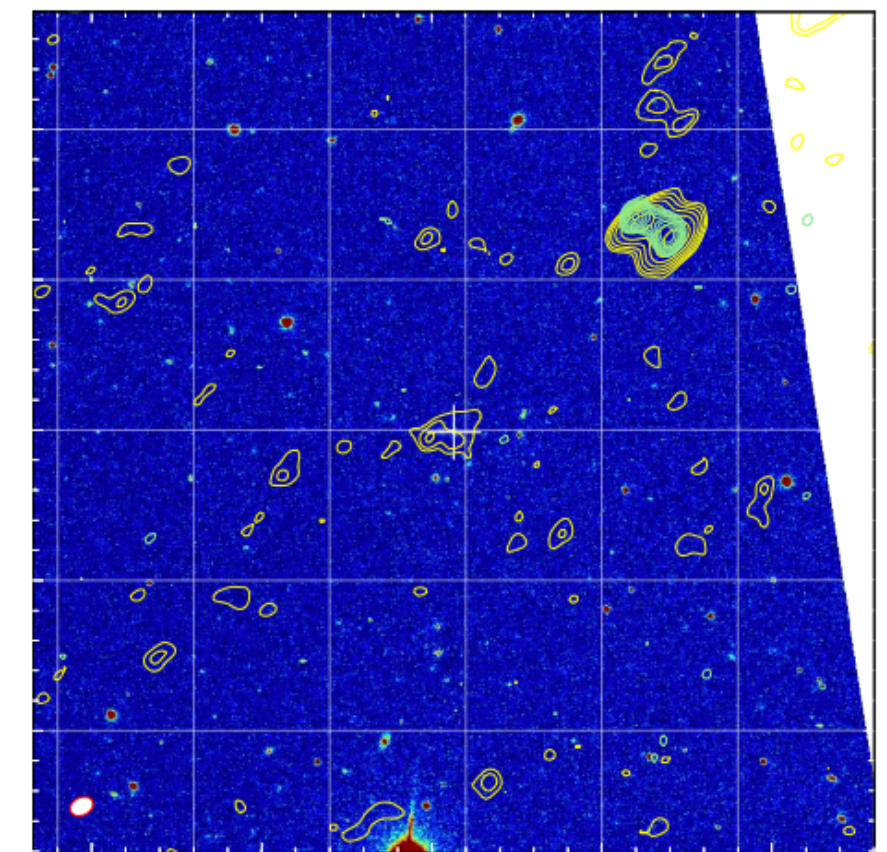
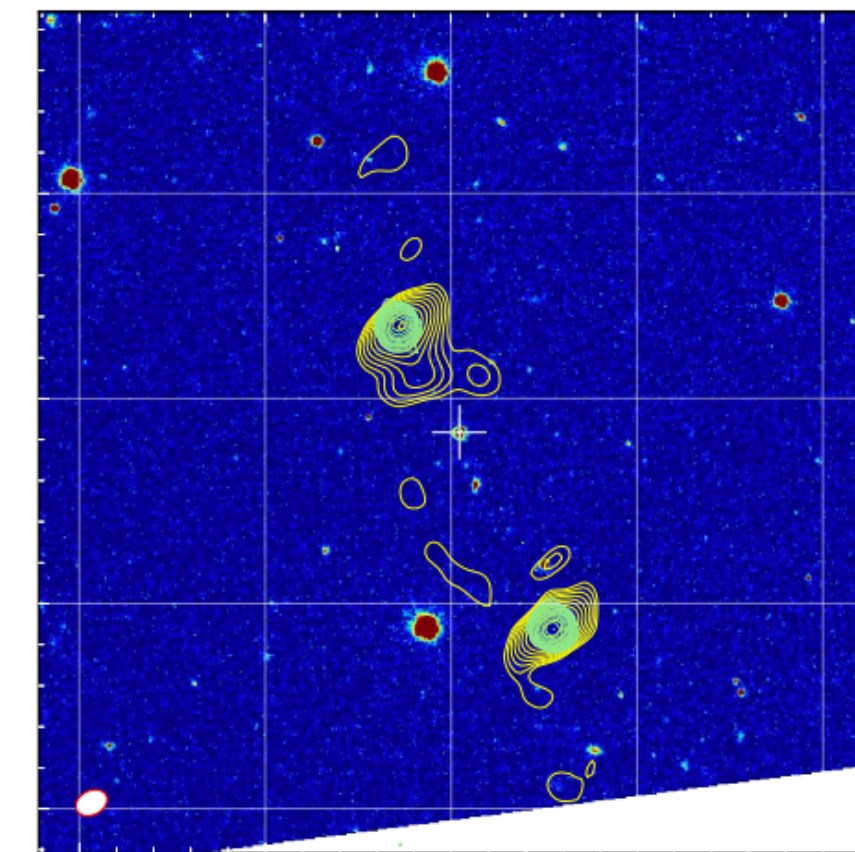
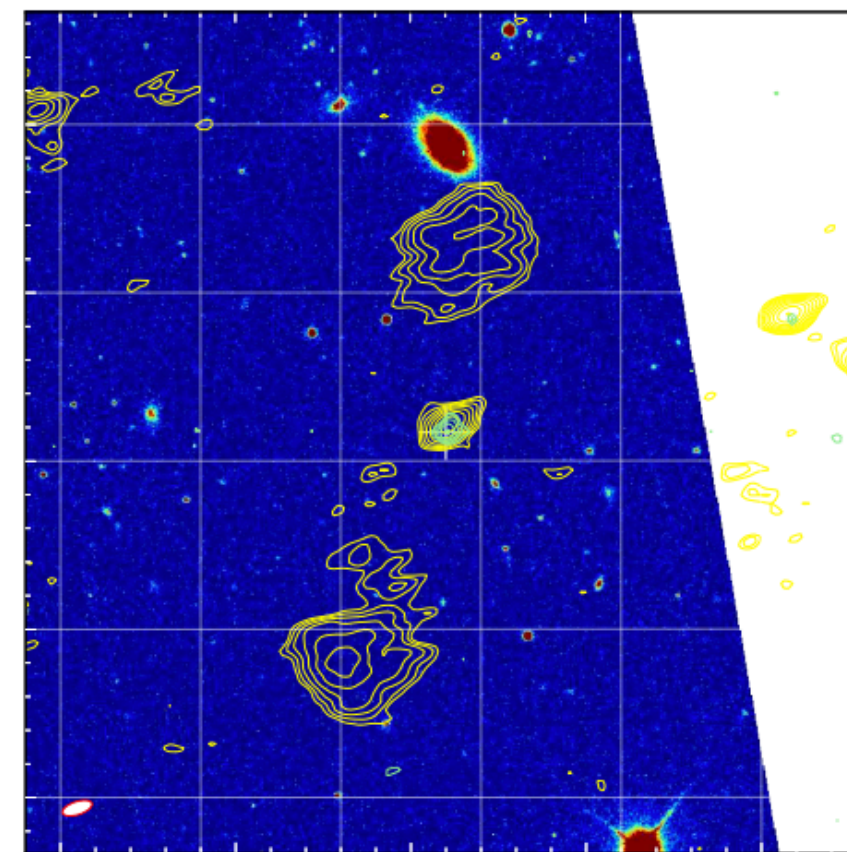
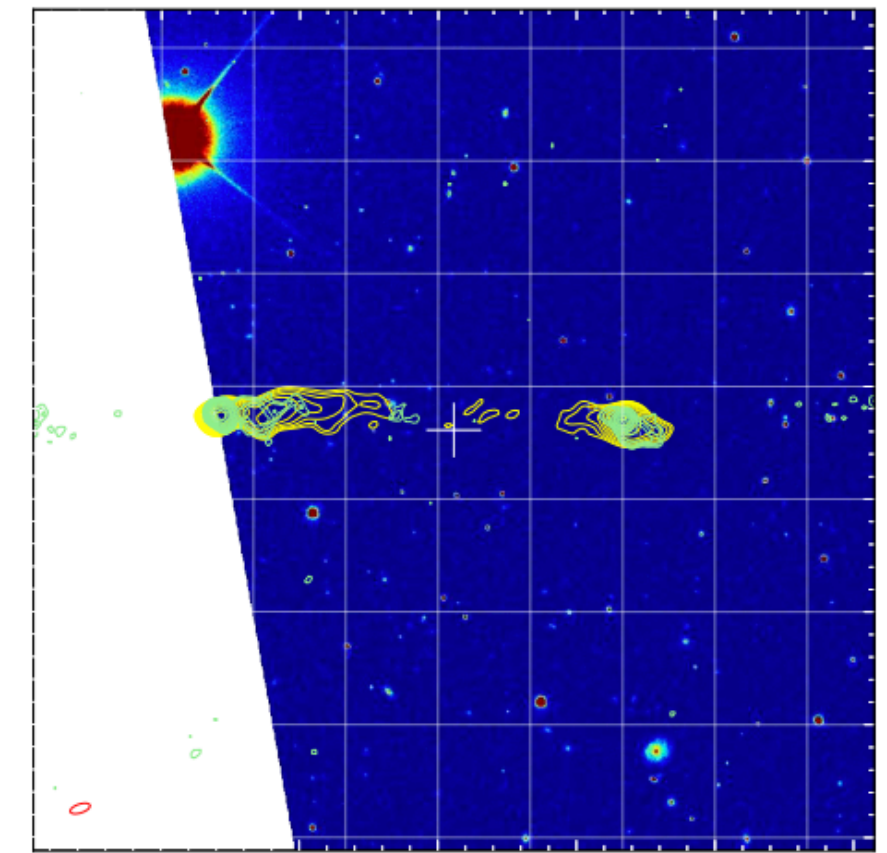
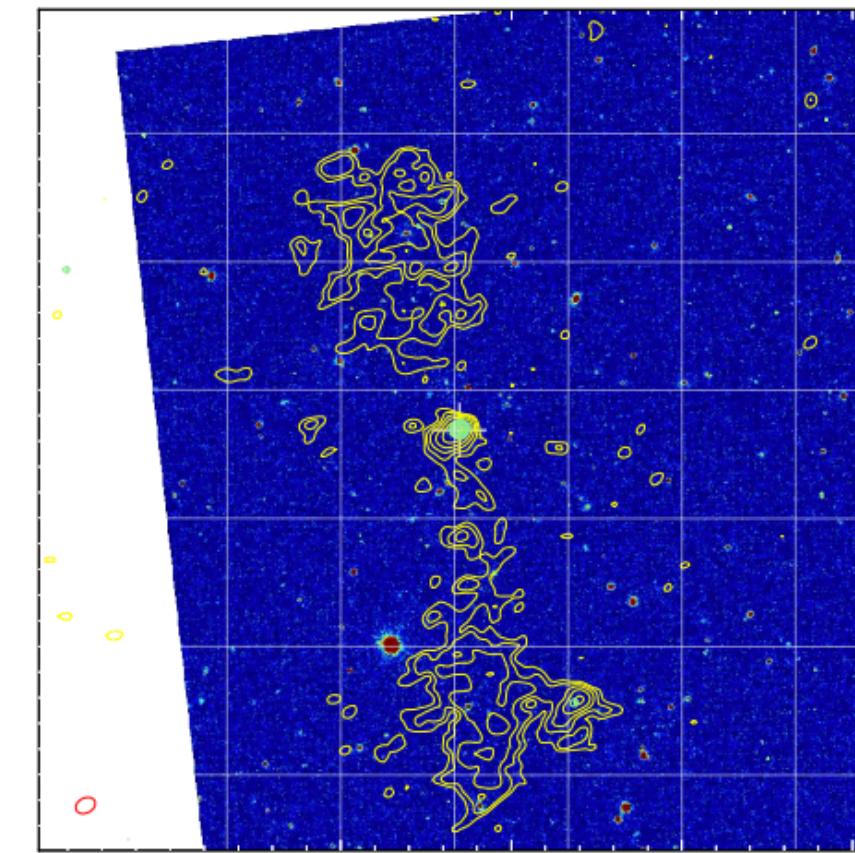
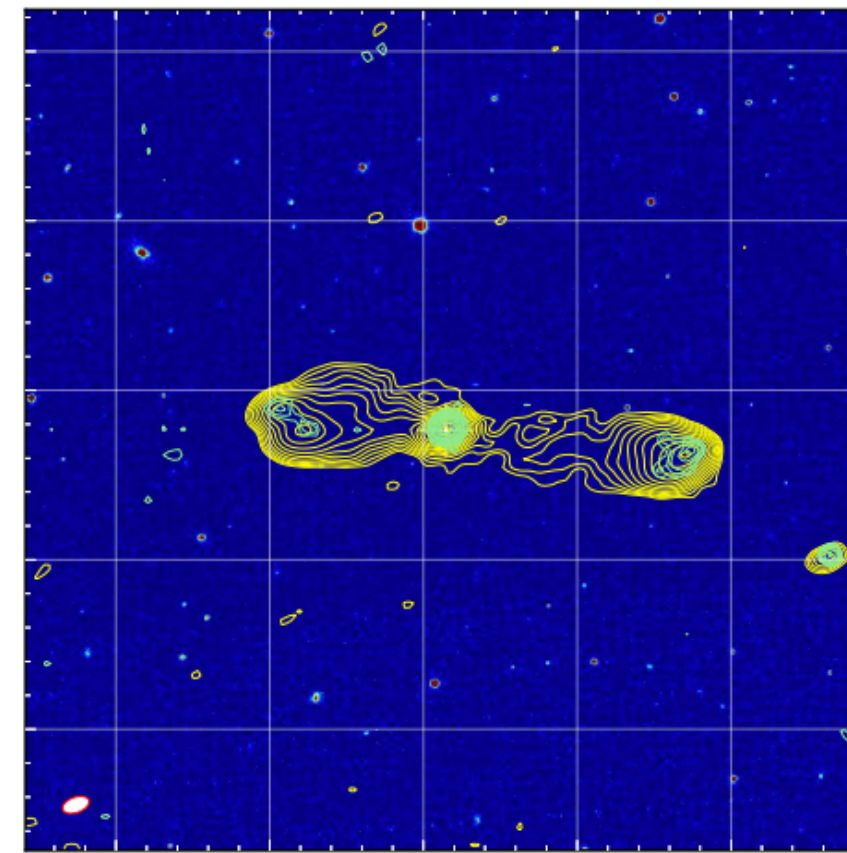
Size of Milky way galaxy ~ 0.03 Mpc ; 1 Mpc ~  $10^{22}$  metres or 3.26 million light years



# Earliest Giants from LoFAR

LOFAR High-Band Array (HBA)  
observations of the  
Herschel-ATLAS  
North Galactic Pole Field

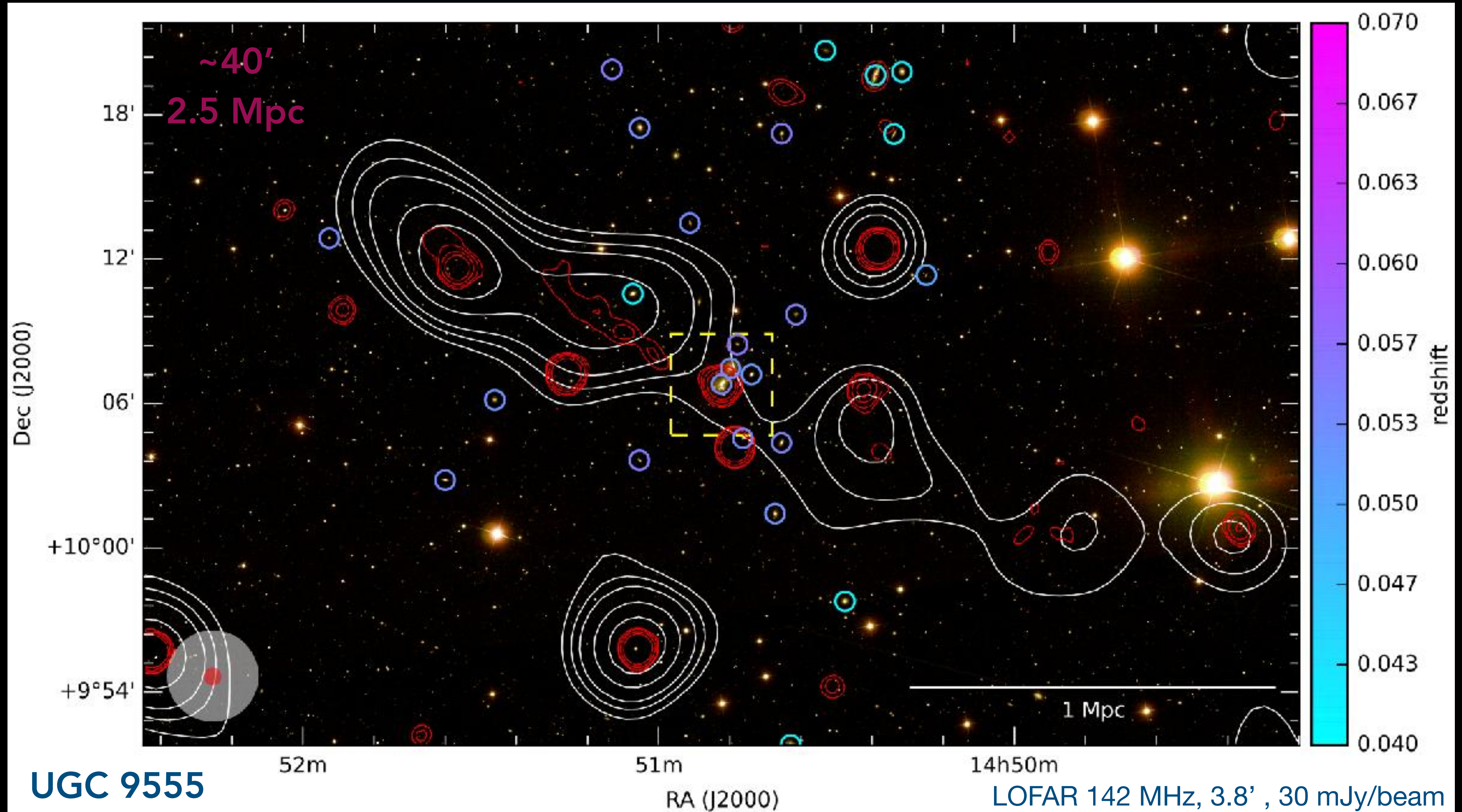
Freq: 126-173 MHz  
Sky Area: 142 sq deg  
Resolution: 10" x 6"  
Rms:  $\sim 0.1 - 2$  mJy/beam



Hardcastle et al. 2016  
MNRAS



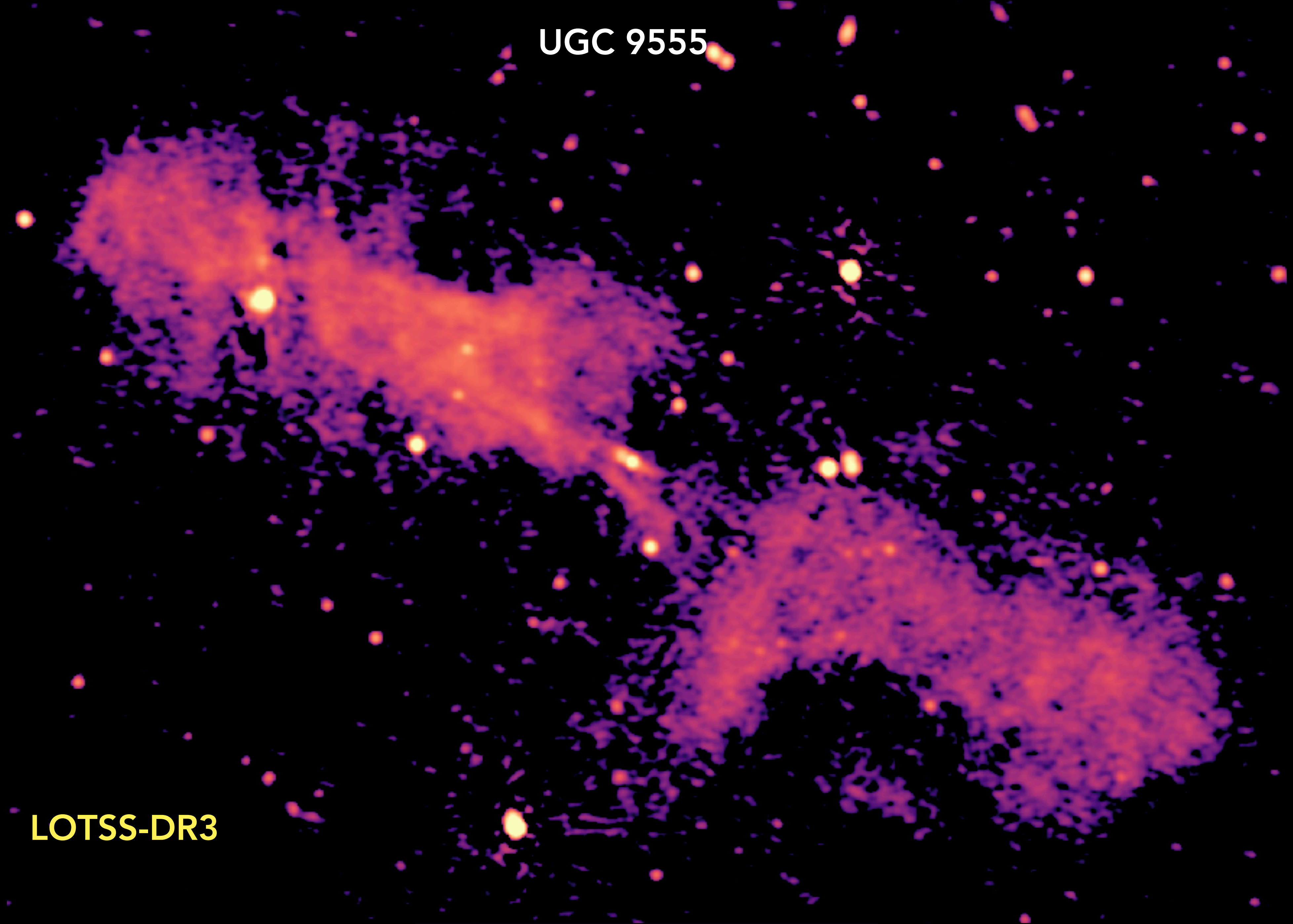
# LOFAR Multifrequency Snapshot Sky Survey (MSSS)





UGC 9555

LOTSS-DR3





# Giants in LoTSS (era)

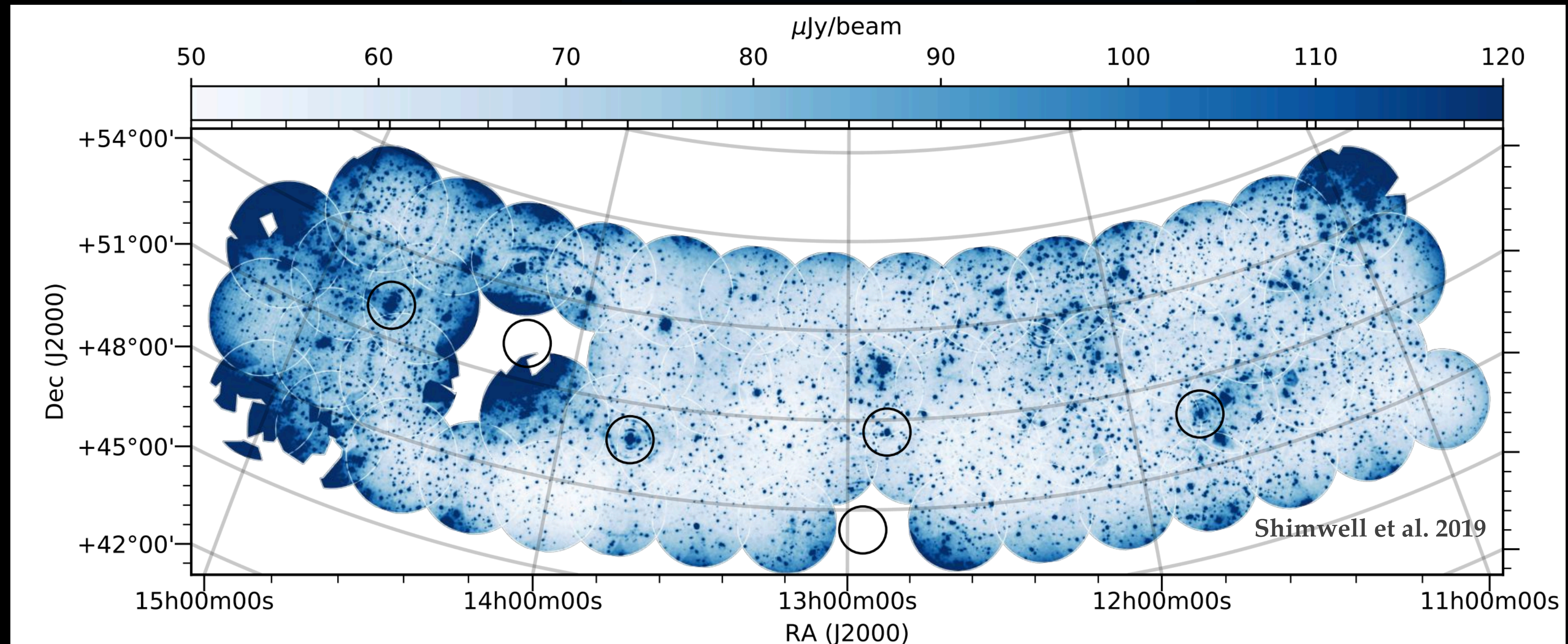
HBA: 120-180 MHz (144 MHz)

LoTSS DR1 (Hetdex)

~424 sq deg

~5"

~100 microJy/beam



✓ Ideal for finding diffuse lobes, relic emission and low-surface-brightness bridges.



# Discovery of 225 new Giant Radio Galaxies using LoTSS DR1

(Largest sample at the time)

A&A 635, A5 (2020)  
<https://doi.org/10.1051/0004-6361/201935589>  
© ESO 2020

Astronomy  
&  
Astrophysics

## Giant radio galaxies in the LOFAR Two-metre Sky Survey

### I. Radio and environmental properties★

P. Dabhade<sup>1,2</sup>, H. J. A. Röttgering<sup>1</sup>, J. Bagchi<sup>2</sup>, T. W. Shimwell<sup>1,3</sup>, M. J. Hardcastle<sup>4</sup>, S. Sankhyayan<sup>5</sup>, R. Morganti<sup>3,6</sup>,  
M. Jamrozy<sup>7</sup>, A. Shulevski<sup>8</sup>, and K. J. Duncan<sup>1</sup>

Received 31 March 2019 / Accepted 3 December 2019

#### ABSTRACT

Giant radio galaxies (GRGs) are a subclass of radio galaxies, which have grown to megaparsec scales. GRGs are much rarer than normal-sized radio galaxies ( $<0.7$  Mpc) and the reason for their gigantic sizes is still debated. Here, we report on the biggest sample of GRGs identified to date. These objects were found in the LOFAR Two-metre Sky Survey first data release images, which cover a  $424 \text{ deg}^2$  region. Of the 239 GRGs found, 225 are new discoveries. The GRGs in our sample have sizes ranging from 0.7 Mpc to 3.5 Mpc and have redshifts ( $z$ ) between 0.1 and 2.3. Seven GRGs have sizes above 2 Mpc and one has a size of  $\sim 3.5$  Mpc. The sample contains 40 GRGs hosted by spectroscopically confirmed quasars. Here, we present the search techniques employed and the resulting catalogue of the newly discovered large sample of GRGs along with their radio properties. In this paper, we also show for the first time that the spectral index of GRGs is similar to that of normal-sized radio galaxies, indicating that most of the GRG population is not dead or is not similar to a remnant-type radio galaxy. We find that 20 out of 239 GRGs in our sample are located at the centres of clusters and we present our analysis on their cluster environment and radio morphology.

**Key words.** galaxies: jets – galaxies: active – radio continuum: galaxies – quasars: general

| Classification | No. of objects |
|----------------|----------------|
| GRQs           | 40             |
| BCGs           | 20             |
| FR-II          | 215            |
| FR-I           | 18             |
| HyMoRS         | 6              |
| DDRGs          | 14             |

### Visual inspection

A total of 239 GRGs were found in  $\sim 424 \text{ degree}^2$  area using LoTSS, which is just 2% of the total survey that eventually covered northern sky !

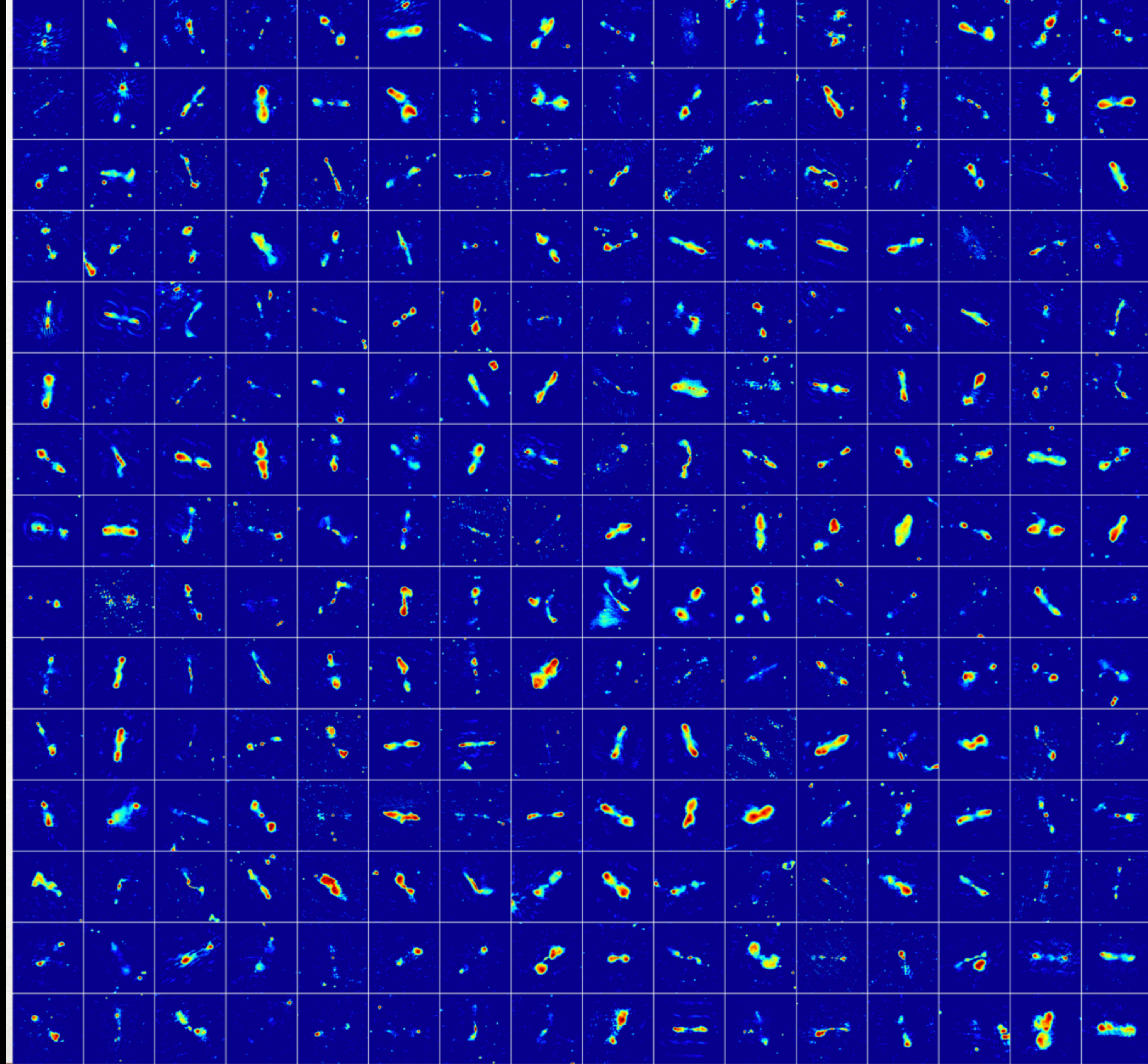
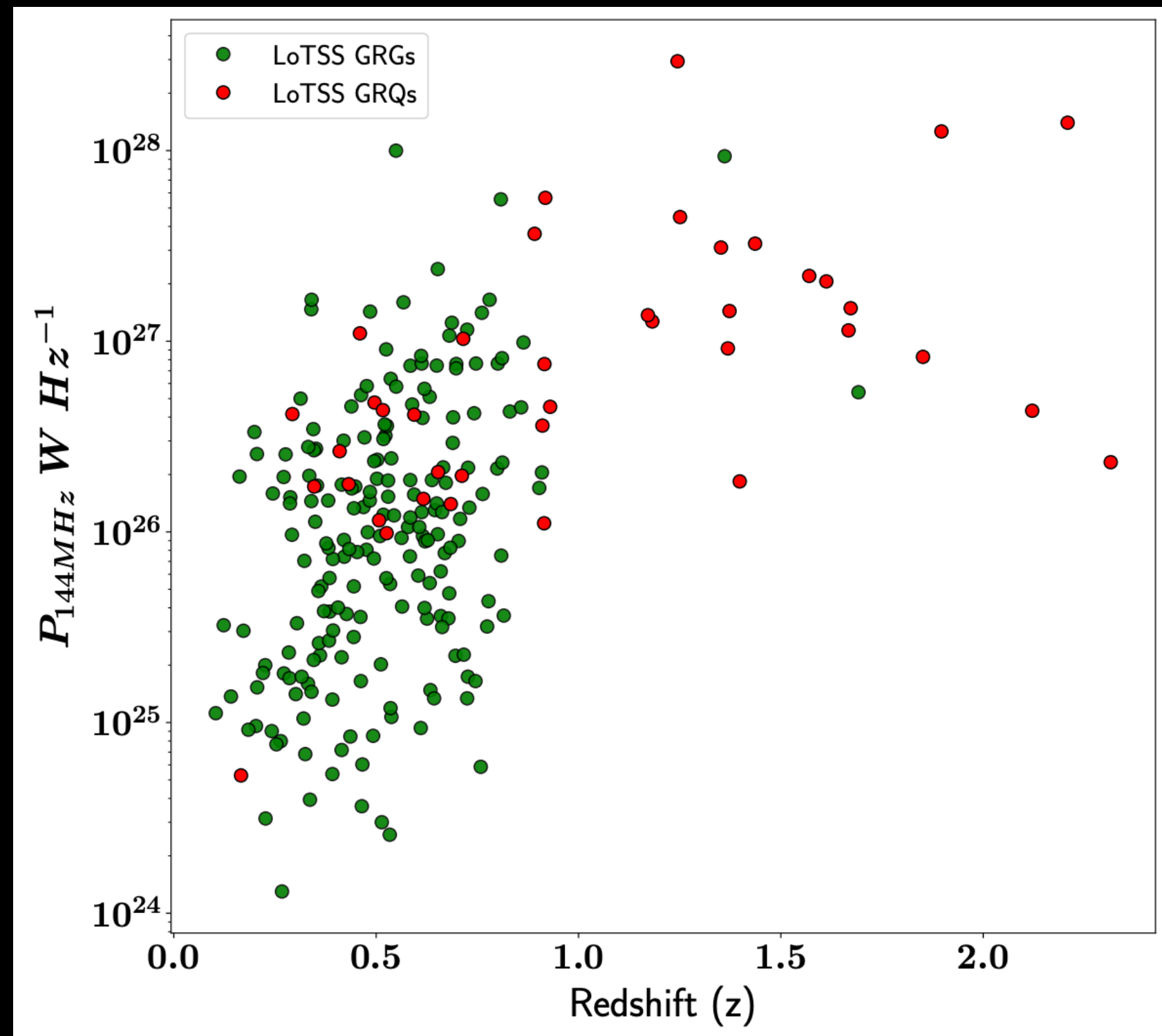


# LoTSS-DR1 GRG output

Dabhade et al. 2020a | A&A 635, A5

Not that rare!?

- ~16% hosted by quasars
- ~90% FR II
- ~5% Restarted-DDRGs
- ~16% as BCGs





Research Highlight | Published: 03 February 2020

RADIO GALAXIES

## LoTSS of giants

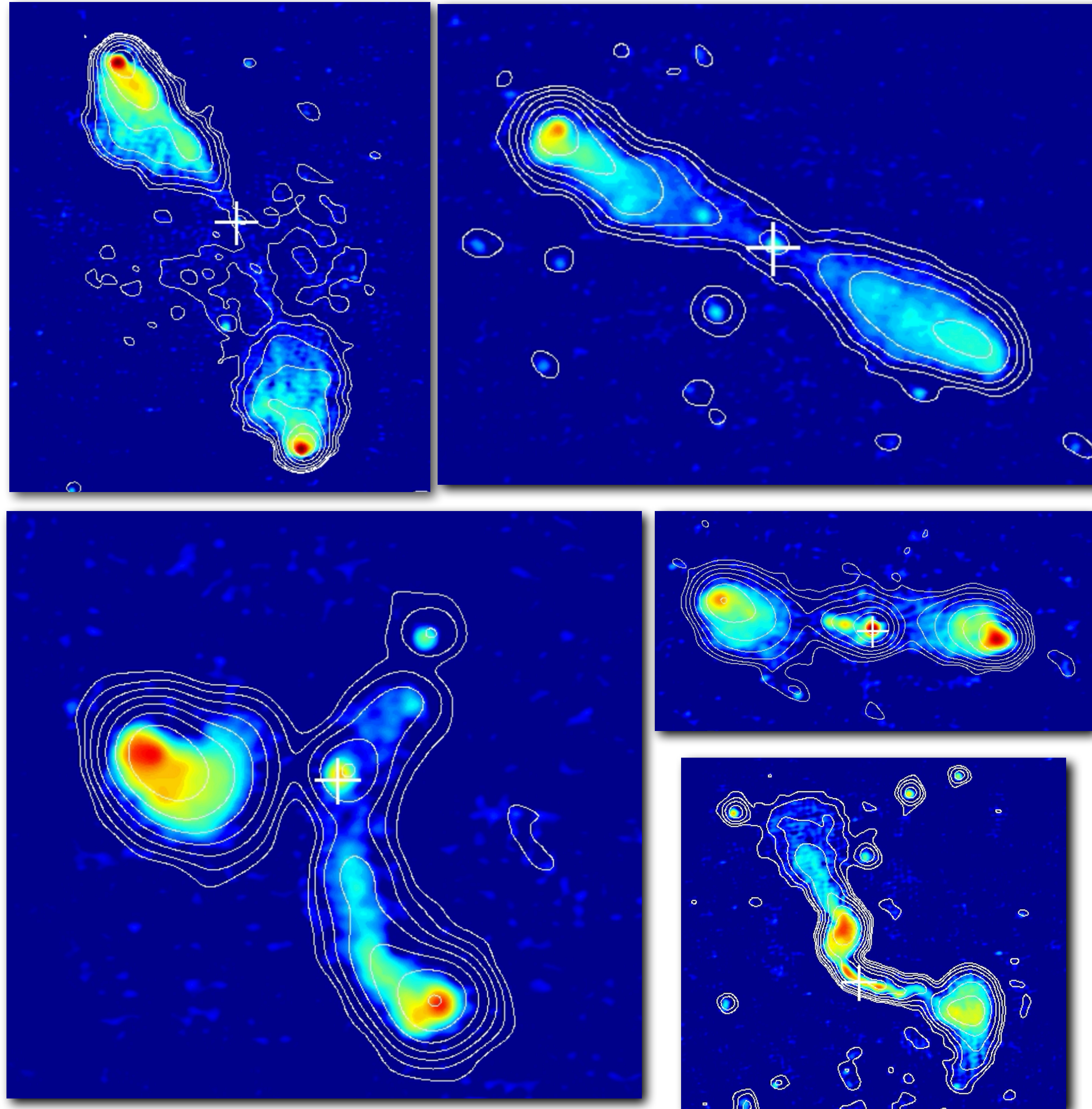
[May Chiao](#) ✉

*Nature Astronomy* **4**, 114 (2020) | [Cite this article](#)

917 Accesses | 12 Altmetric | [Metrics](#)

*Astron. Astrophys.* <https://doi.org/10.1051/0004-6361/201935589> (in the press)

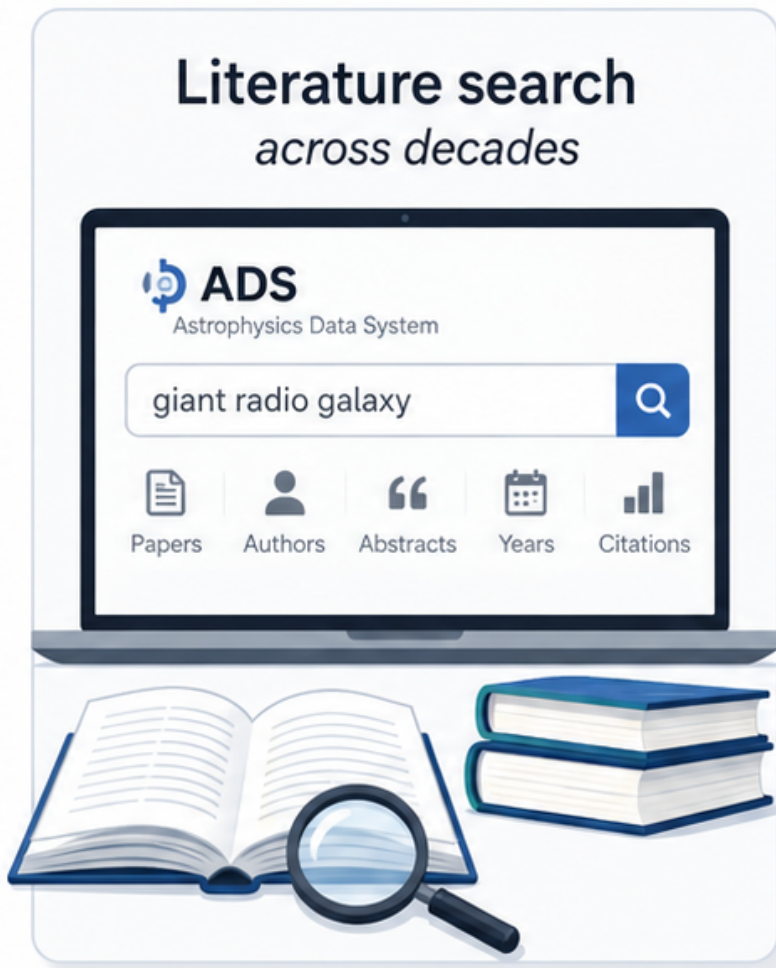
With high spatial resolution and sensitivity, the LoTSS survey has revealed the morphologies of the GRGs (cores, jets, hotspots and diffuse emission) in unprecedented detail. Roughly 90% of these GRGs are Fanaroff–Riley type-II, meaning their lobes are brighter than the nucleus, and hence have strong jets (type-I are brighter centrally). Six have rare hybrid type-I/type-II morphologies with asymmetric lobe brightness. Combining radio and optical data, Dabhade et al. conclude that none of the hosts is a spiral galaxy. Rather, GRGs are found in elliptical galaxies, sometimes within clusters of galaxies; 40 of these GRGs are powered by quasars; another 20 GRGs reside in dense cluster environments, though not in the highest mass clusters; fourteen GRGs are ‘double-double’ radio galaxies with two pairs of lobes, with the second set due to restarted jets. Despite the rarity of GRGs, their spectral index is similar to that of regular radio galaxies, implying that GRGs are part of the same active galaxy population. In tandem with more LoTSS coverage, deeper optical data for resolving the host galaxies will help us understand their properties.





# 1. Building a complete GRG literature list (1974–present)

The first difficulty was the naming problem.



## Q Different names used for giant radio galaxies

|                                  |                               |                               |      |
|----------------------------------|-------------------------------|-------------------------------|------|
| Giant radio galaxy               | Giant radio galaxies          | GRG                           | GRGs |
| Giant radio source               | Giant radio sources           | GRS                           | GRSs |
| Giant extragalactic radio source | Large radio galaxy            | Large radio source            |      |
| Megaparsec radio galaxy          | Megaparsec scale radio galaxy | Megaparsec-scale radio source |      |
| Mpc-scale radio galaxy           | Mpc-scale radio source        | Giant radio quasar            |      |
| Giant radio quasars              | GRQ                           | GRQs                          |      |

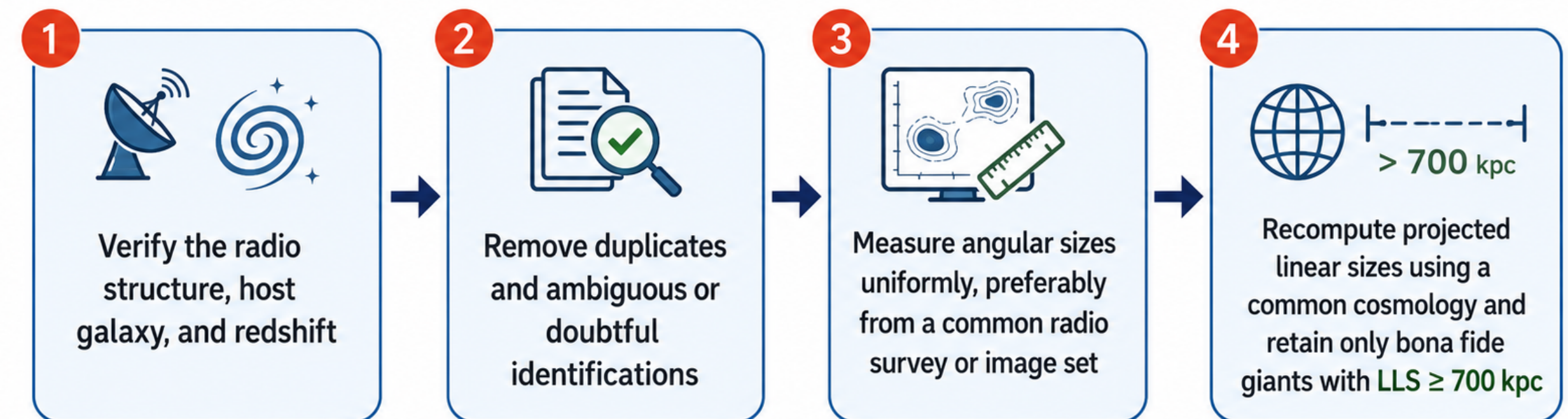


**Additional issue:** some papers reported candidate giants without explicitly quoting the source size.

✓ Therefore, the search had to be **broad, iterative,** and **manually screened.**

## 2. Verifying and homogenising the reported GRGs

From literature candidates to a uniform catalogue



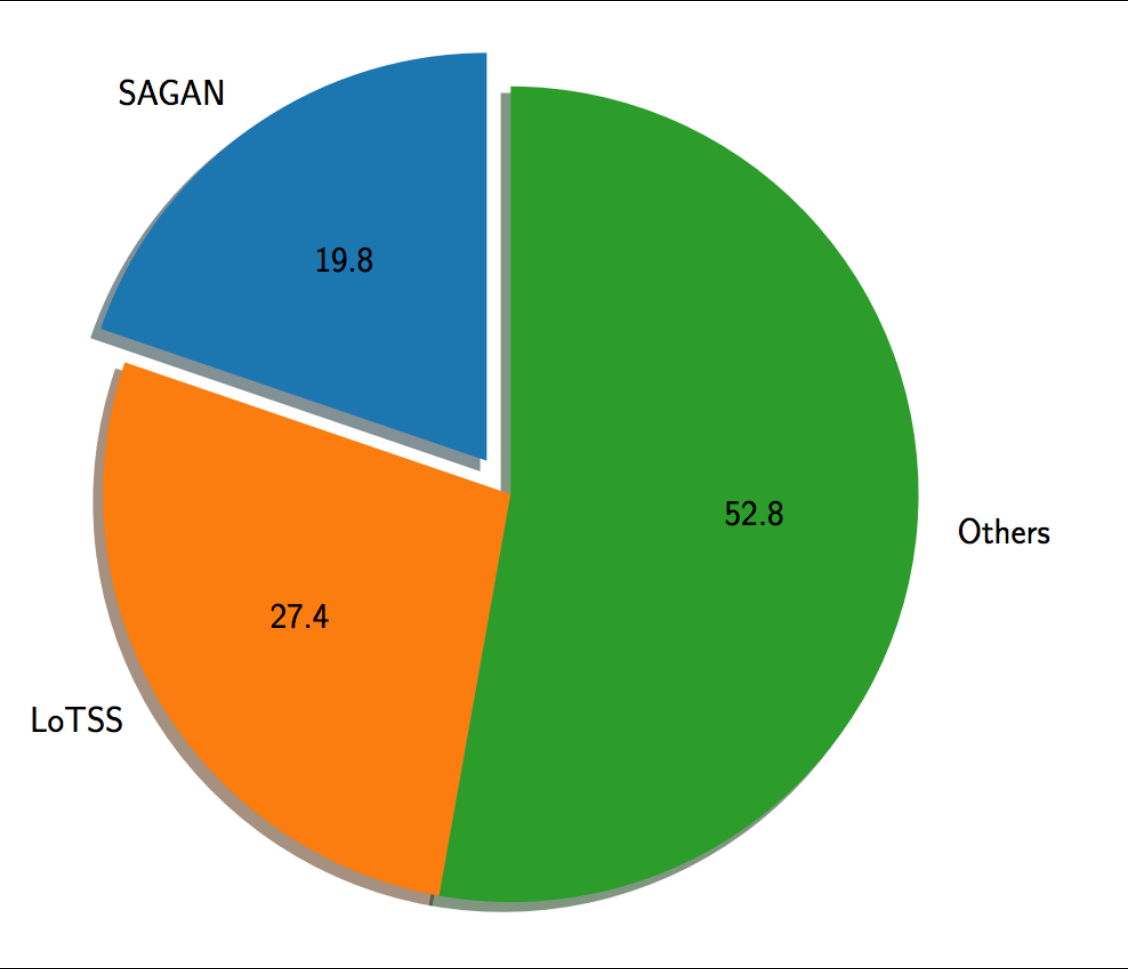
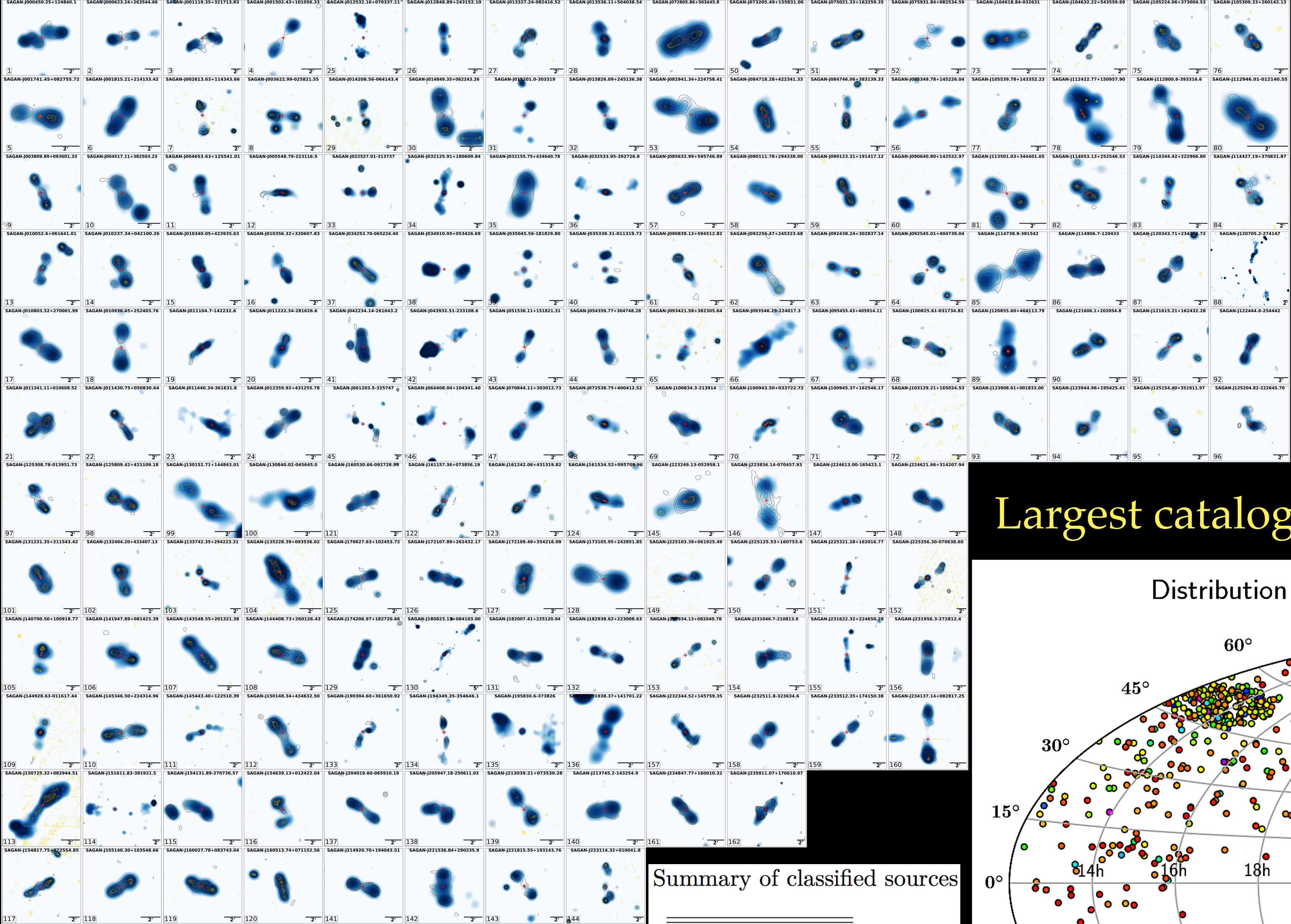
**Outcome:** a homogeneous list of bona fide GRGs

★ Uniform size measurements and cosmological parameters are essential for a consistent GRG catalogue.



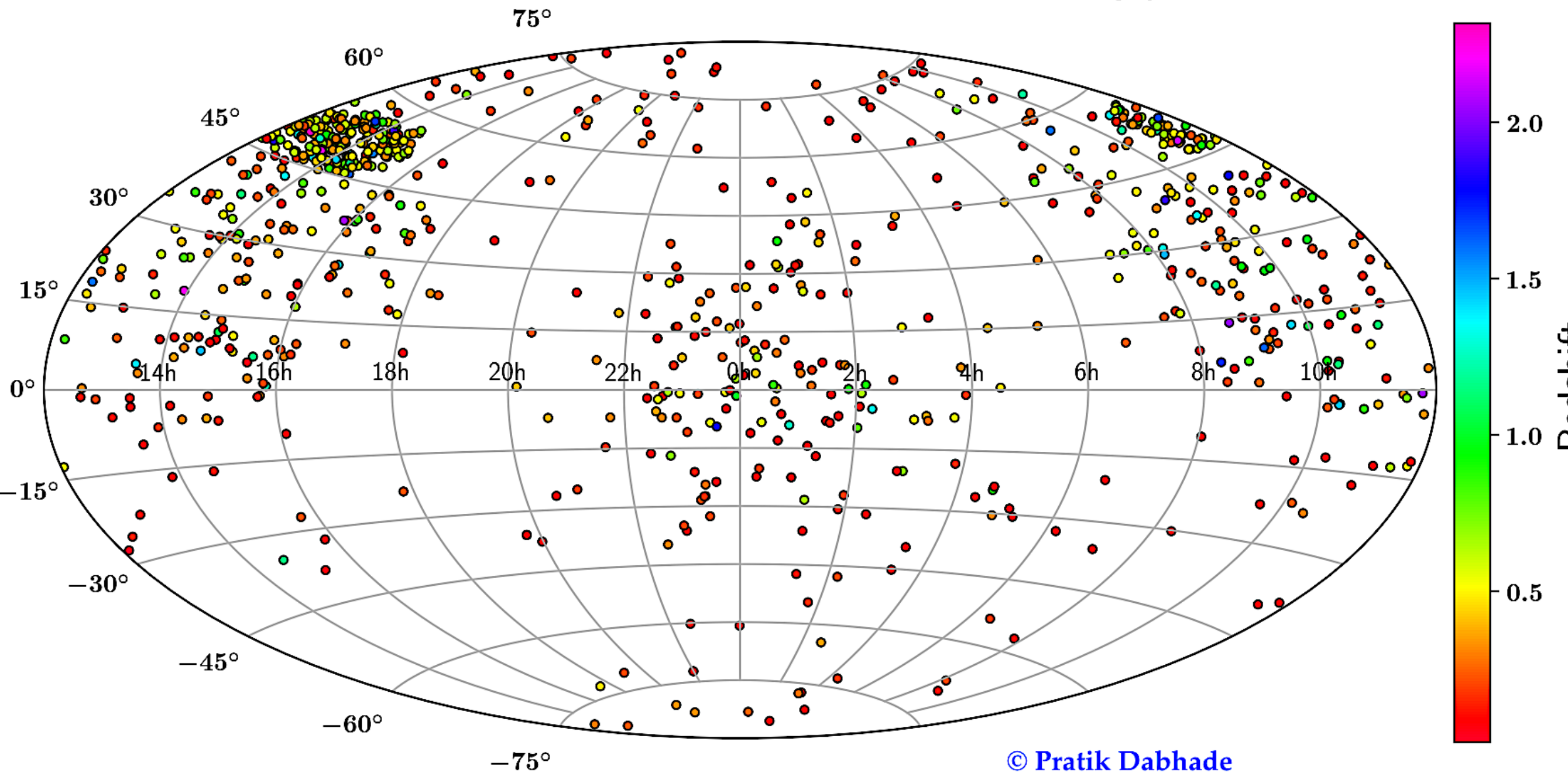
# SAGAN-I : Discovery of 162 GRGs

Dabhade et al. 2020b | A&A 642, A153



Largest catalogue-820 Sources!

Distribution of known 820 Giant Radio Galaxies on sky plane



Summary of classified sources

| Types  | No. |
|--------|-----|
| GRQ    | 23  |
| BCG    | 18  |
| FR I   | 8   |
| FR II  | 149 |
| HyMoRS | 4   |
| DDRG   | 1   |

Search- NVSS  
Complementary data-  
TGSS + FIRST





# SAGAN-I: GRGs Become a Statistical Population

*Dabhade et al. 2020*



## 1 Catalogue milestone



**820** GRGs

largest compilation at the time



**225** new GRGs

major boost from LoTSS DR1

This large, uniform sample enabled the first **statistical multi-wavelength** view of giant radio galaxies.



## 2 What the study showed



### 1 No preferred accretion state

GRGs include both HERGs and LERGs.



### 2 Power matters

HEGRGs are typically larger and more powerful, with higher radio power, jet kinetic power, and higher Eddington ratios.



### 3 GRGs host stronger engines

Giant radio quasars are generally more powerful than GRGs, although their projected sizes are similar.



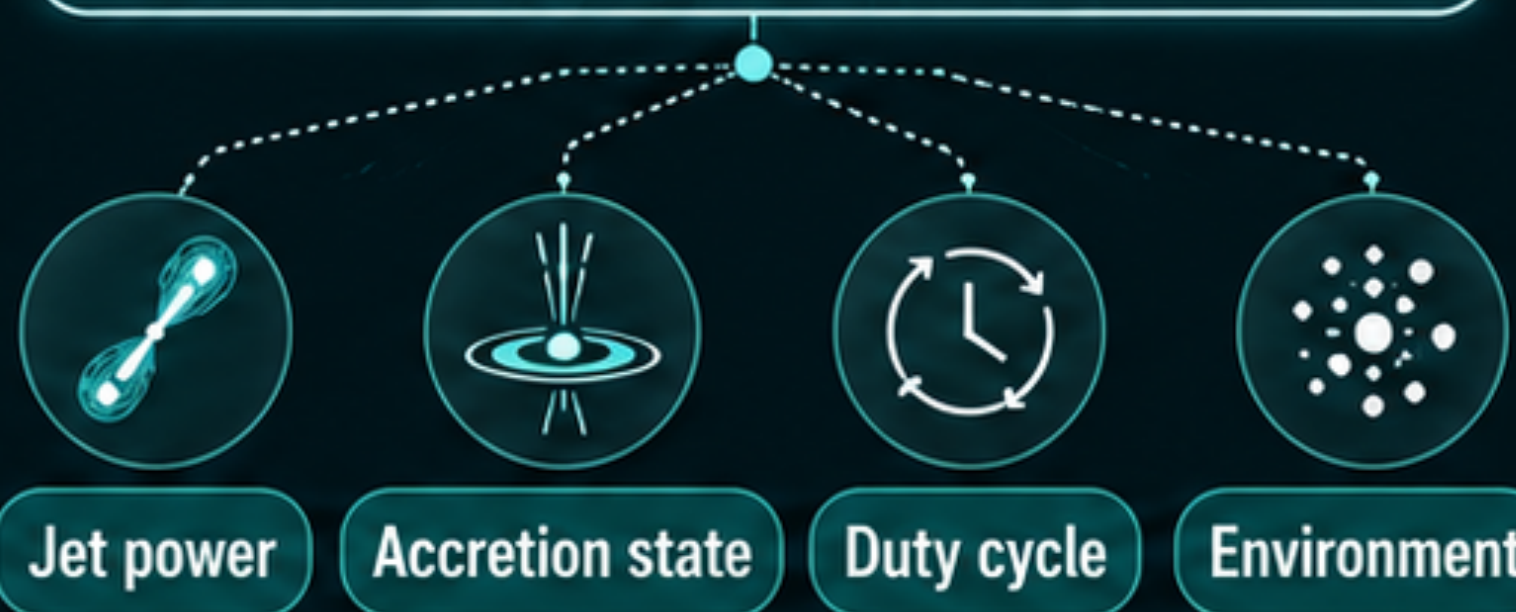
### 4 Environment is important, but not exclusive

About ~15% of GRGs are found in dense cluster centres.



## 3 Big picture

**GRG growth is not driven by a single parameter.**



Giant size likely reflects the **combined influence** of these factors.



## Key Impact



Shifted GRGs from individual curiosities to population studies



Established a multi-wavelength statistical framework

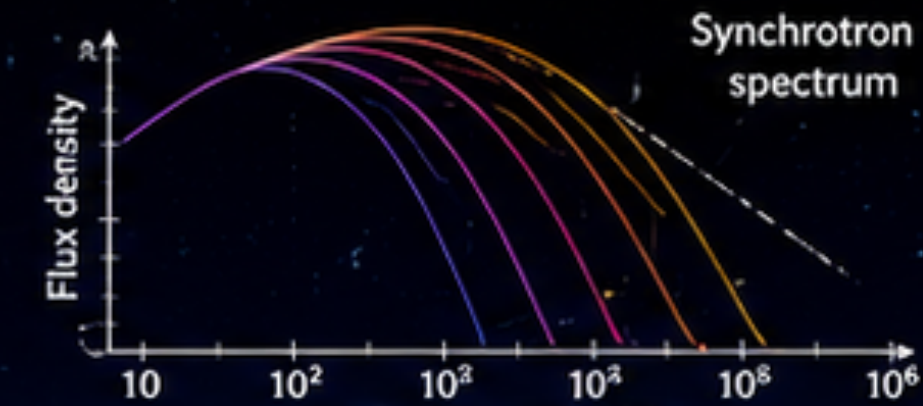


Set the stage for the LOFAR-era explosion in GRG science



# Are GRGs older than normal-sized RGs?

## Spectral ageing studies



### Spectral ages

#### Data intensive



Multi-frequency radio data, from low to high frequencies.



Spectral ageing requires observations with multiple telescopes and broad frequency coverage, ideally ~10 MHz to 15 GHz.



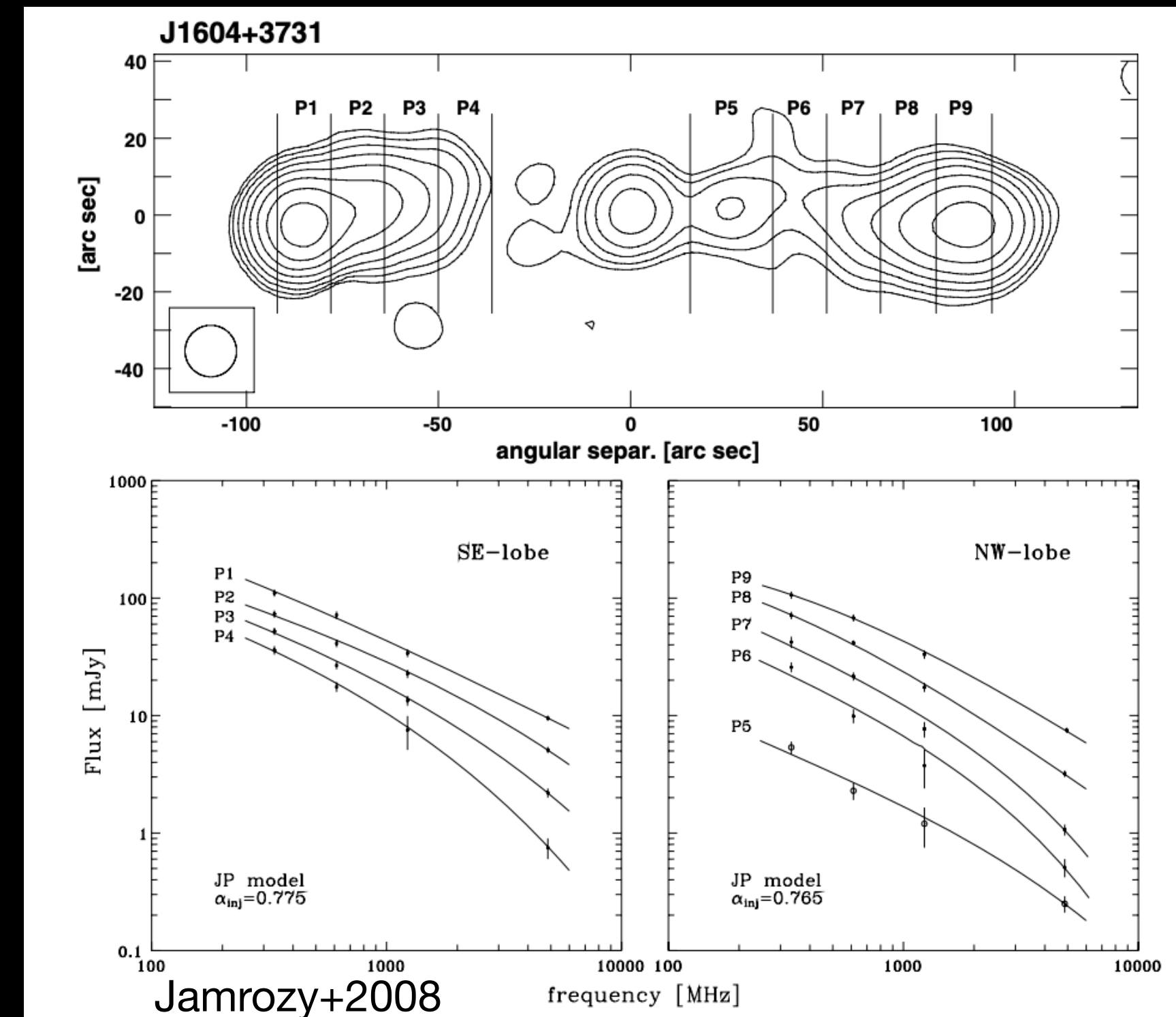
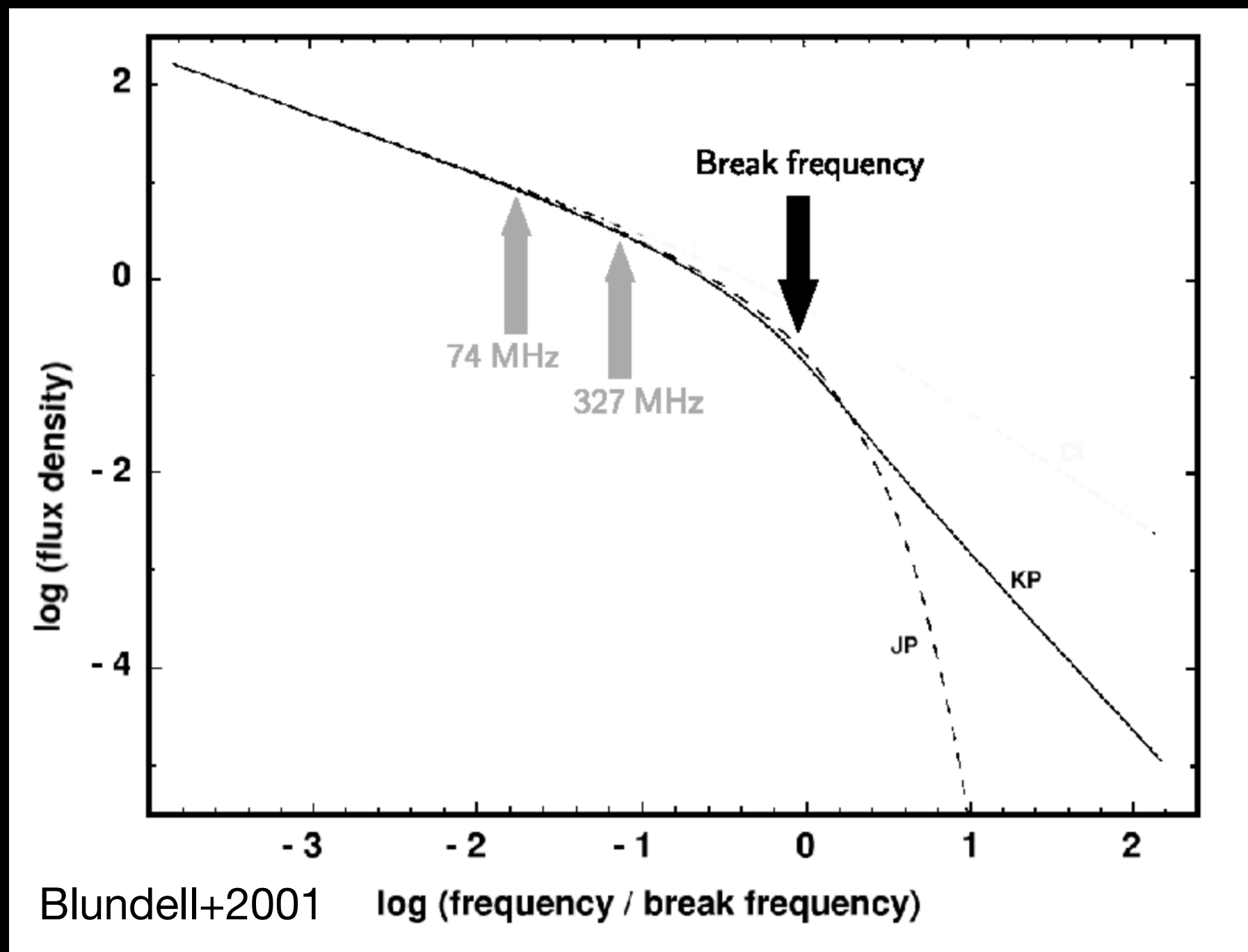
Accurate spectral modelling is essential.



Need recovery of all diffuse and extended structures.



Current limitations: small samples and limited frequency range in many studies.



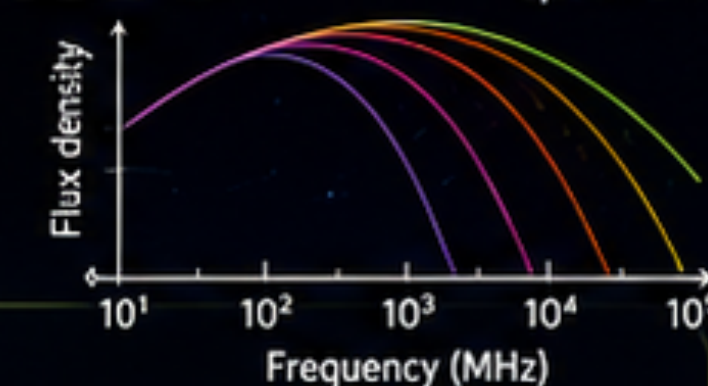
Current evidence suggests many GRGs are old, but available samples are small and heterogeneous.



# Mack et al. (1998): Spectral ageing and ambient medium of GRGs

*A landmark multi-frequency study of five giant radio galaxies*

Synchrotron spectrum



## WHY THIS STUDY MATTERED



One of the few dedicated studies of GRGs focusing on both spectral ageing and environment



Unique frequency coverage:  
~300 to 10000 MHz



Showed that GRG spectral ages are **not exceptionally high**



Suggested possible **re-acceleration, re-supply, or restarted activity**



**FREQUENCY SPAN**  
0.3–10 GHz



**AGE RANGE**  
10–42 Myr

$$t_{\text{spec}} \propto \frac{B^{1/2}}{B^2 + B_{\text{IC}}^2} \nu_{\text{br}}^{-1/2} \quad \text{spectral age as a proxy for source age}$$



## SAMPLE

**5 GRGs**

NGC 315

DA 240

3C 236

3C 326

NGC 6251

Ambient medium density ( $n_{\text{eq}}$ )  
( $\text{cm}^{-3}$ )

NGC 315

$3.0 \times 10^{-5}$

DA 240

$9.2 \times 10^{-5}$

3C 236

$1.5 \times 10^{-5}$

3C 326

$3.3 \times 10^{-5}$

NGC 6251

$1.8 \times 10^{-5}$

WSRT + Effelsberg



## MAIN RESULTS



Spectral ages:  
**~10 to 42 Myr**



Comparable to  
**normal-sized** radio galaxies



GRGs are **not necessarily older** simply because they are larger



Ambient densities are  
**relatively low**



**No such sources** found in rich cluster-like environments in this study



## IMPLICATIONS



Large size alone does  
**not imply extreme age**



GRGs may grow large because of  
**lower-density environments** and  
**continued or renewed energy supply**

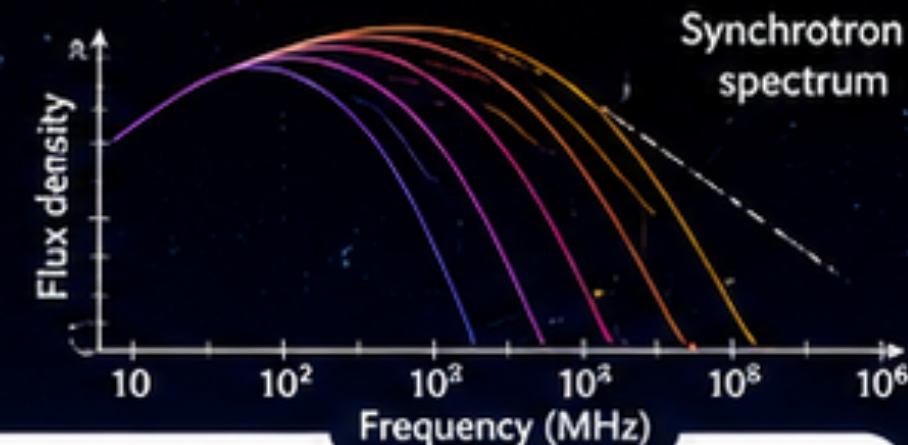


Later studies of individual GRGs, often with smaller frequency coverage, reported broader age ranges of  
**~10 to 200 Myr**



# Are GRGs older than normal-sized RGs?

## Spectral ageing studies



## Spectral ages

### Data intensive



Multi-frequency radio data, from low to high frequencies.



Spectral ageing requires observations with multiple telescopes and broad frequency coverage, ideally ~10 MHz to 15 GHz.



Accurate spectral modelling is essential.



Need recovery of all diffuse and extended structures.



Current limitations: small samples and limited frequency range in many studies.



Current evidence suggests many GRGs are old, but available samples are small and heterogeneous.

## Published spectral ageing results

| Sample type and size                 | Name             | Frequency range (MHz) | Size (Mpc) | Age range (Myr) | Median age (Myr) | Reference                            |
|--------------------------------------|------------------|-----------------------|------------|-----------------|------------------|--------------------------------------|
| <b>A. Normal-sized radio sources</b> |                  |                       |            |                 |                  |                                      |
| 14 RSs (3CR)                         | —                | 1400–15000            | 0.07–0.28  | 0.25–5.3        | —                | Liu <i>et al.</i> (1992)             |
| 38 RSs (MRC)                         | —                | 1400–5000             | 0.26–0.63  | 2.5–94          | 26               | Ishwara-Chandra <i>et al.</i> (2001) |
| 32 RGs (B2)                          | —                | 1500–5000             | 0.019–0.64 | 4–75            | 28               | Parma <i>et al.</i> (1999)           |
| 17 RSs (3CR)                         | —                | 151–1500              | 0.14–0.60  | 2.2–145         | 12               | Leahy <i>et al.</i> (1989)           |
| 9 RGs (B2)                           | —                | 600–1400              | 0.19–0.65  | 27–90           | 55               | Klein <i>et al.</i> (1995)           |
| <b>B. GRG / GRS samples</b>          |                  |                       |            |                 |                  |                                      |
| 5 GRGs                               | —                | 325–10500             | 1.18–4.59  | 7.6–42          | 12               | Mack <i>et al.</i> (1998)            |
| 5 GRSs <sup>†</sup>                  | —                | 70–10000              | 0.9–1.4    | 1–245           | 15.6             | Marecki <i>et al.</i> (2021)         |
| 3 GRGs                               | —                | 240–4800              | 1.21–1.56  | 5–151           | 64               | Godambe <i>et al.</i> (2009)         |
| 2 GRGs                               | —                | 240–4800              | 0.85–1.32  | 30–70           | 50               | Pirya <i>et al.</i> (2011)           |
| 6 GRGs                               | —                | 325–4850              | 0.84–1.79  | 23–80           | 48.5             | Schoenmakers <i>et al.</i> (2000a)   |
| 10 GRS                               | —                | 325–4800              | 0.84–2.28  | 6–46            | 23               | Jamrozy <i>et al.</i> (2008)         |
| 17 GRS                               | —                | 600–4800              | 0.77–2.45  | 23–45           | 40               | Konar <i>et al.</i> (2004)           |
| 4 GRS                                | —                | 1400–5000             | 0.71–0.98  | 14.3–134        | 34.5             | Ishwara-Chandra <i>et al.</i> (2001) |
| <b>C. Individual GRGs</b>            |                  |                       |            |                 |                  |                                      |
| GRG                                  | J0028+0035       | 70–10000              | 1.13       | 3.6–245         | —                | Marecki <i>et al.</i> (2021)         |
| GRG                                  | 4C39.04          | 1000–10600            | 1.21       | 27–62           | —                | Klein <i>et al.</i> (1995)           |
| GRG                                  | J1453+3308       | 240–4860              | 1.37       | 2–58            | —                | Konar <i>et al.</i> (2006)           |
| GRG                                  | 3C46             | 240–8000              | 0.95       | 2–9             | —                | Nandi <i>et al.</i> (2010)           |
| GRG                                  | 8C0821+695       | 150–10600             | 2.62       | 42              | —                | Lara <i>et al.</i> (2000)            |
| GRG                                  | 3C223            | 118–1477              | 0.76       | 84.9            | —                | Harwood <i>et al.</i> (2017)         |
| GRG                                  | J084408.8+462744 | 325–1400              | 2.21       | 13–20           | —                | Sebastian <i>et al.</i> (2018)       |
| GRG                                  | J021659–044920   | 325–1400              | 1.24       | 8               | —                | Tamhane <i>et al.</i> (2015)         |
| GRG                                  | 3C236            | 143–609               | 4.59       | 75–159          | —                | Shulevski <i>et al.</i> (2019)       |



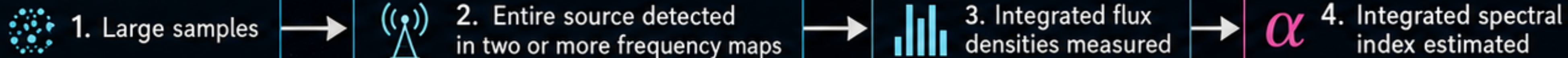
# Are GRGs older than normal-sized RGs?

## Spectral index as a proxy

Practical **proxy** when full spectral-age modelling is not feasible

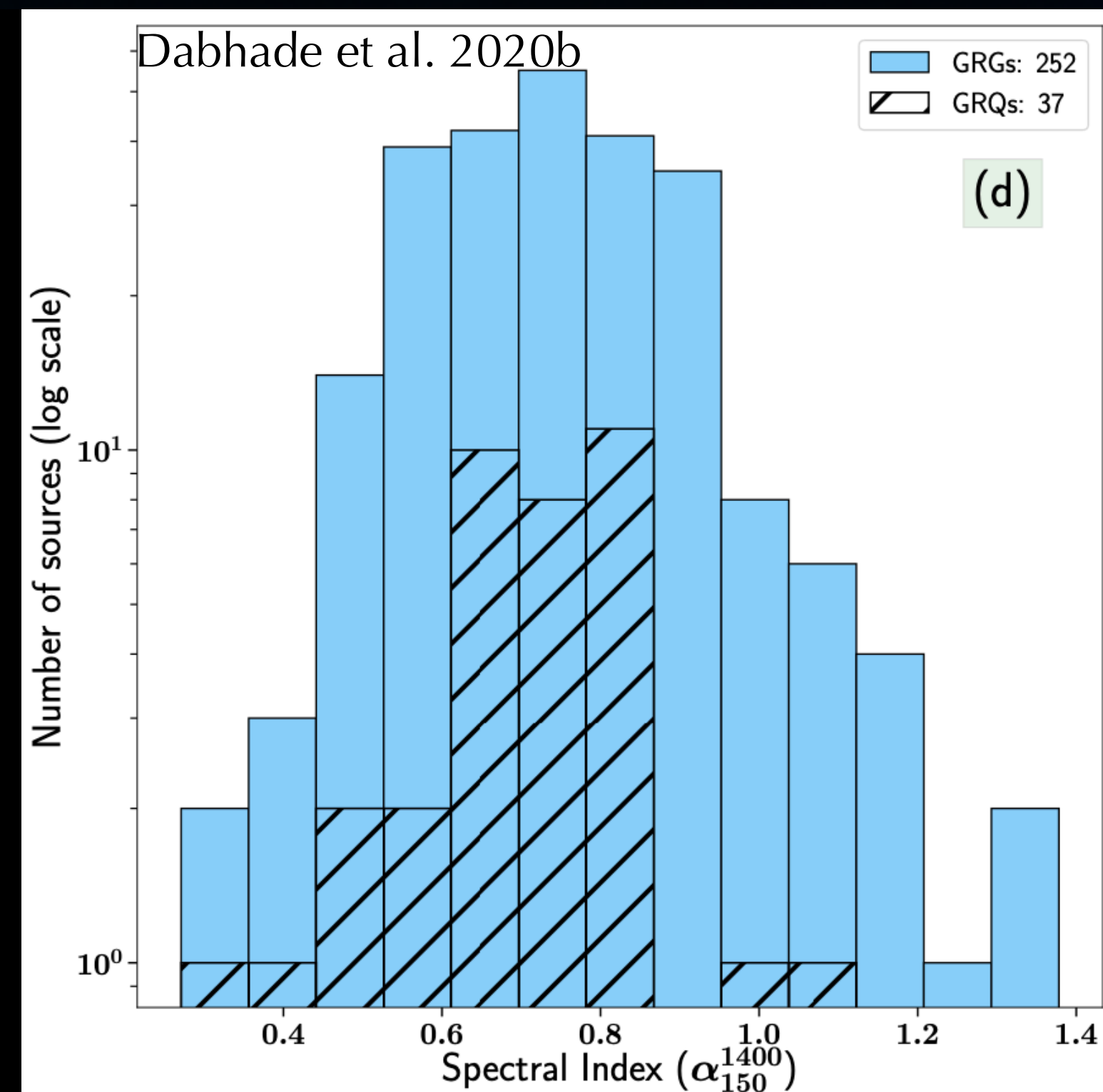
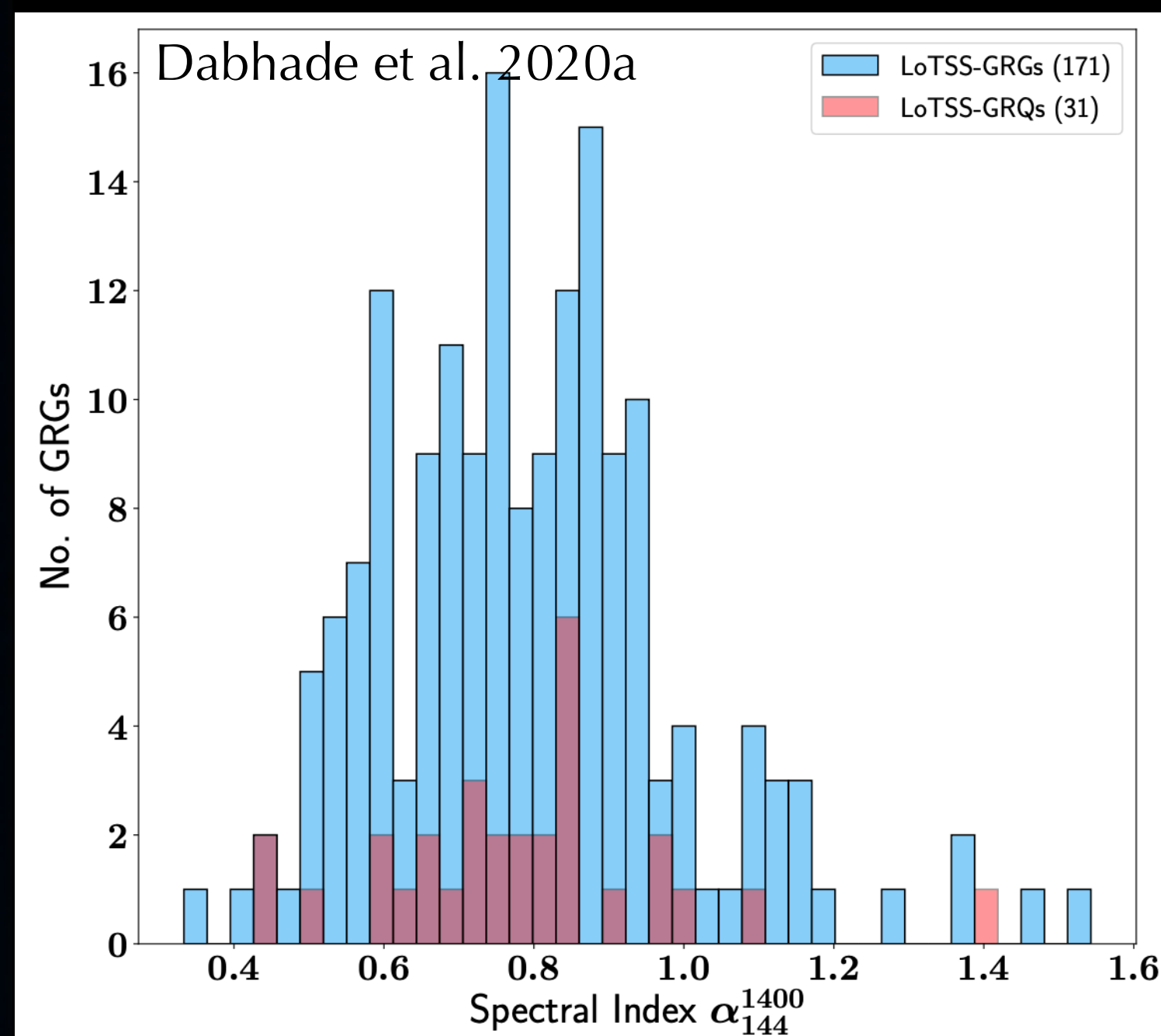
$$S_\nu \propto \nu^\alpha$$

$S_\nu$  = Flux density  
 $\nu$  = Frequency  
 $\alpha$  = Spectral index



### Key insights

- ★ First large-sample integrated spectral-index studies of GRGs
- 🎯 Still among the only studies performed at this scale
- 👥 Integrated  $\alpha$  distributions of GRGs are broadly similar to normal radio galaxies
- ⚖️ No strong evidence that GRGs are systematically much steeper overall
- 🔗 GRQs and GRGs show broadly comparable integrated spectral-index behaviour
- ✅ Integrated spectral index is useful, but only a proxy for true spectral age



### Surveys



📡 Median  $\alpha$   
 $\approx -0.78$

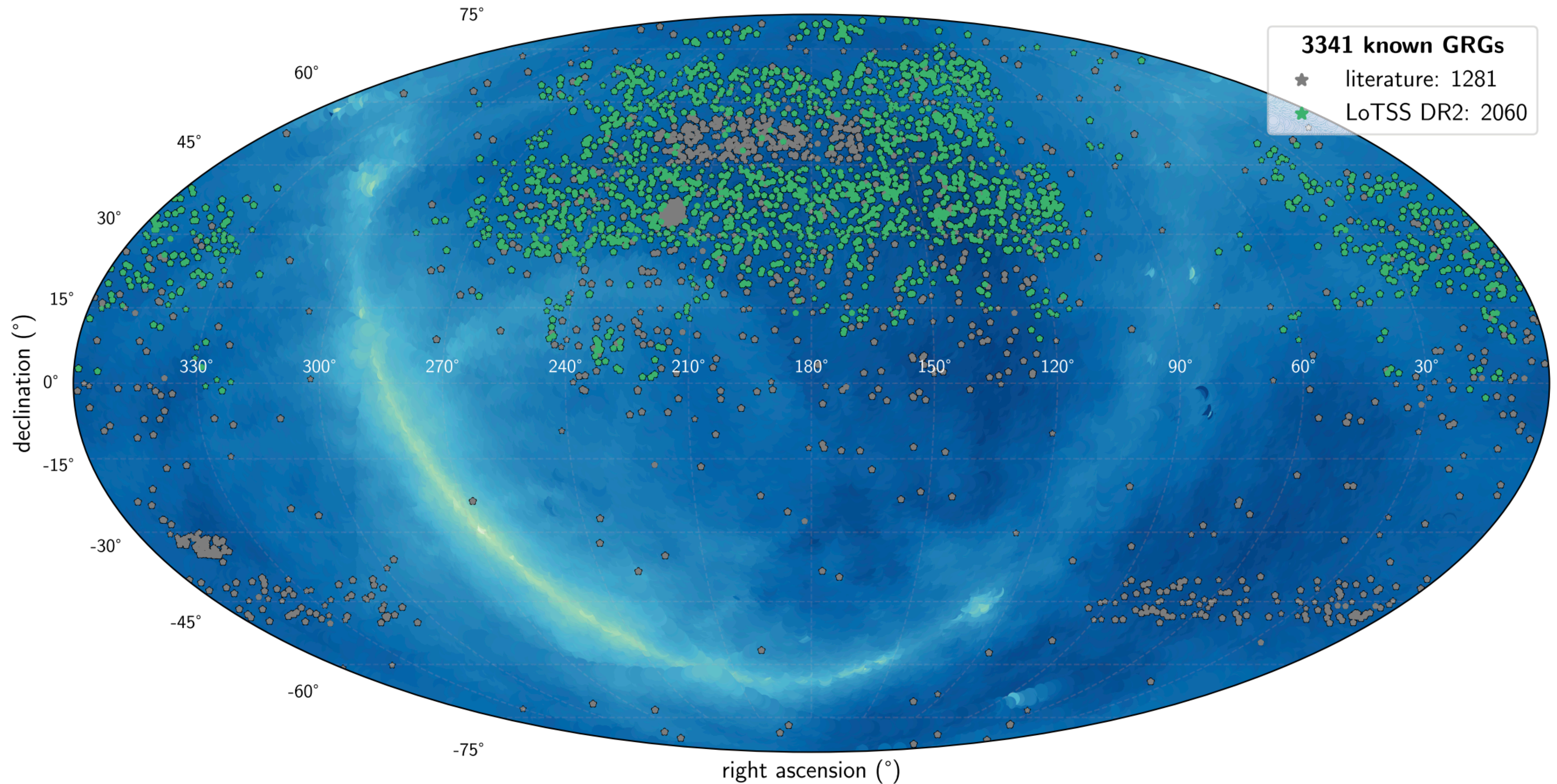


**Key takeaway:** For large samples, GRGs **do not appear dramatically different** from normal-sized radio galaxies in integrated spectral index; **any ageing signal is subtle**, and full spectral-age constraints still require broad multi-frequency data.



# LOTSS DR2- Rapid discoveries!

Oei, M. S. S. L., et al.: A&A 672, A163 (2023)



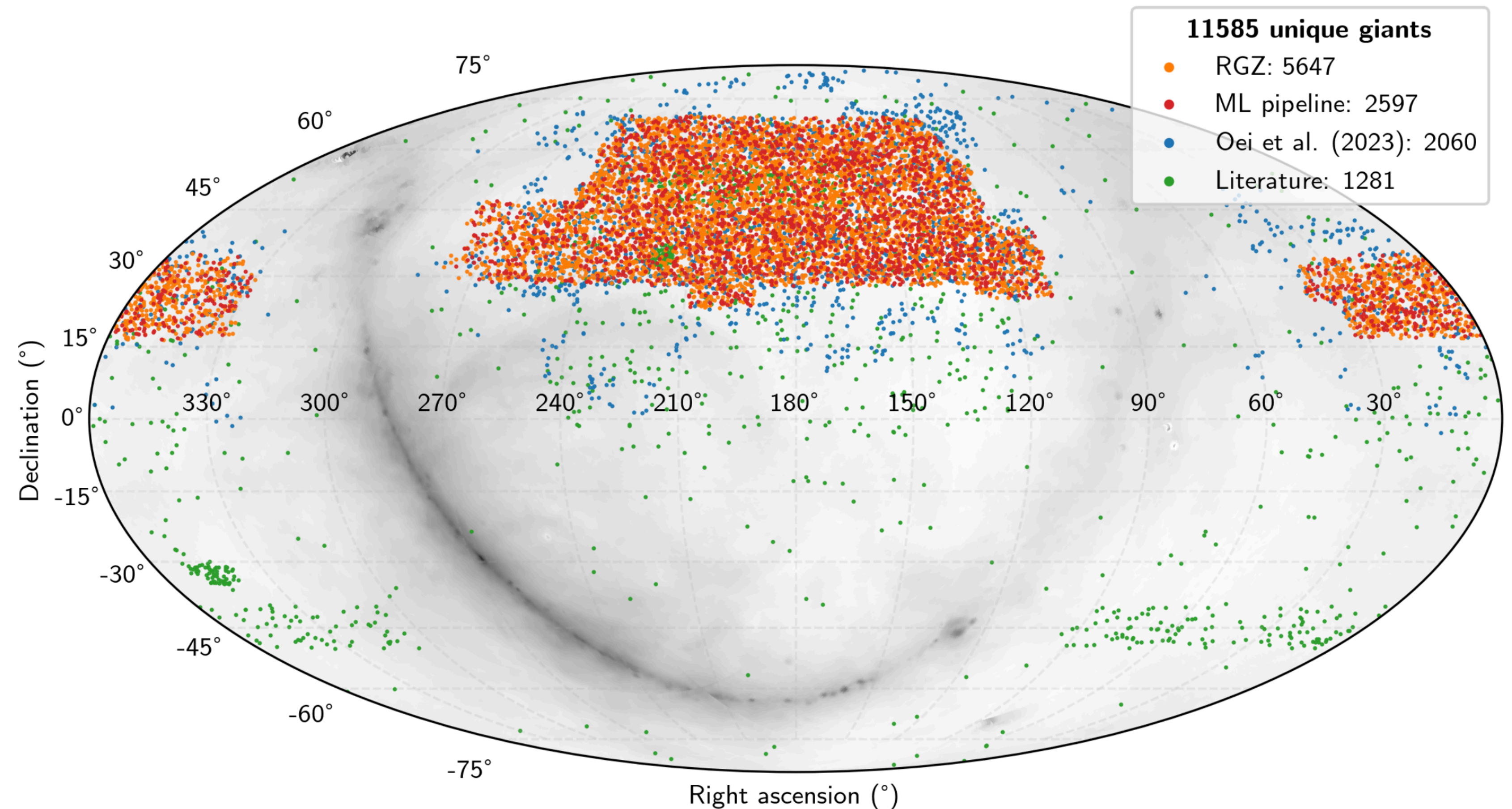
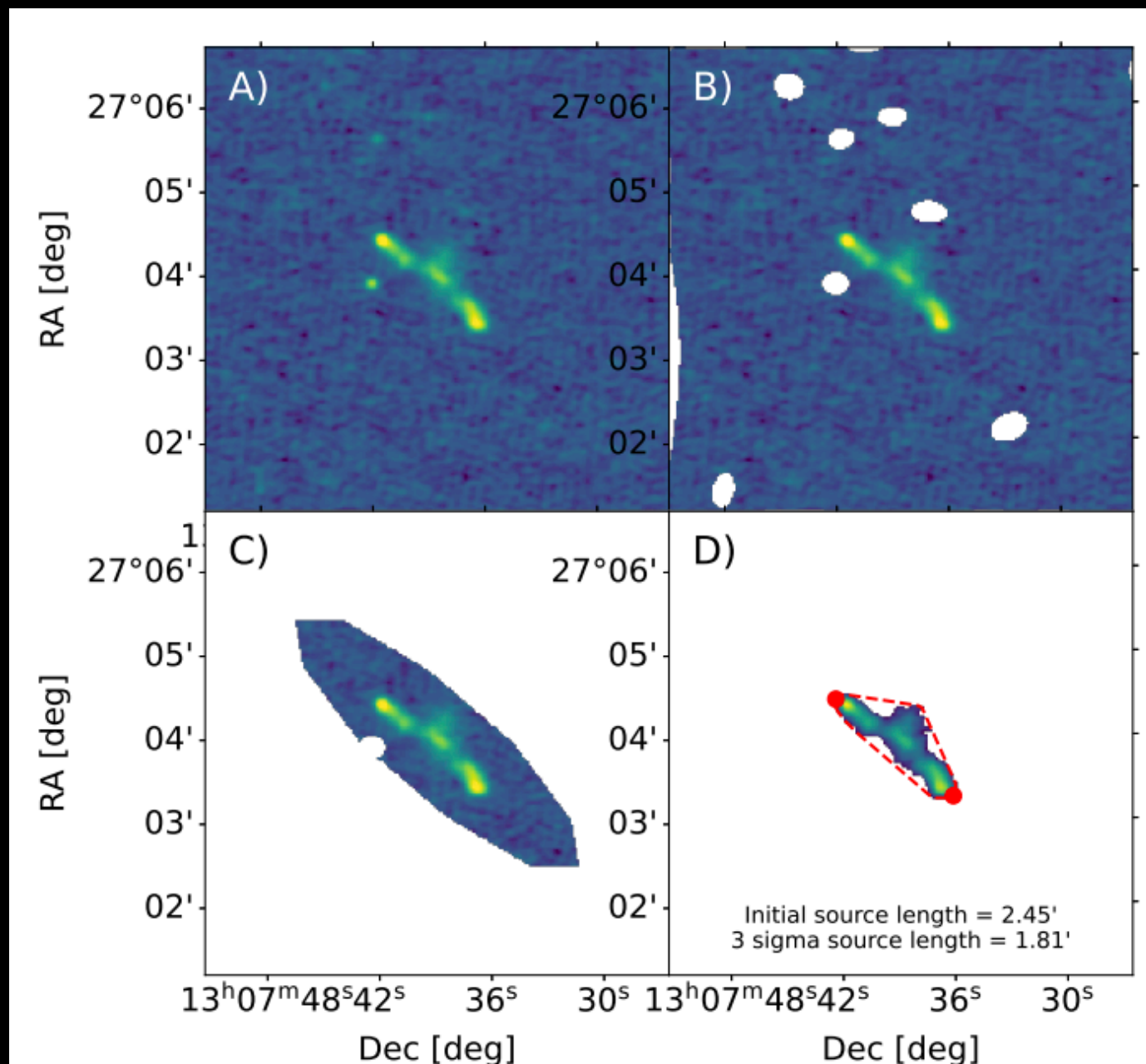


Big step forward-> Larger samples from LoTSS DR2

Machine learning + Radio Galaxy zoo

Mostert et al. 2024

~10,000 Giants!





# Mostert et al. 2024: GRGs become a population of $>10^4$

A&A, 691, A185

## 1 LoTSS DR2 + discovery pipeline



**841** pointings



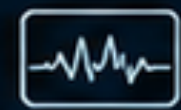
**>5000** deg<sup>2</sup>



**144** MHz



**6** arcsec



median rms **83**  $\mu$ Jy/beam



ML + RGZ + visual inspection



source finding



association



host ID



size



validation

## 2 Catalogue milestone



**7001** ML candidates



**7044** RGZ candidates



**6550** accepted RGZ giants (93%)



**2722** accepted ML giants (47%)



**5576** new RGZ giants



**2566** new ML giants not already in RGZ



Final catalogue:  
**11 485** unique GRGs

**FIRST GRG CATALOGUE  
ABOVE  $10^4$  SOURCES**

## 3 Population inference



Bayesian forward model using 2685 GRGs



$0 < z < 0.5$  ;  $0.7 < l_p < 5.1$  Mpc



GRGs are more common than previously thought



Number density:  $13 \pm 10$  (100 Mpc)<sup>-3</sup>



Mean two-lobe volume:  
 $5.1 \pm 0.3 \times 10^{-2}$  Mpc<sup>3</sup>



Present-day lobe volume-filling fraction in clusters + filaments:  
 $1.4 \pm 1.1 \times 10^{-5}$



**GRGs may have contributed non-negligibly to Cosmic-Web magnetisation.**



Key-

LoTSS transformed GRGs from rare discoveries into a statistically modelled population.



# Odd Radio Circles

- First discovered in 2019
- Only about a dozen examples known to date.

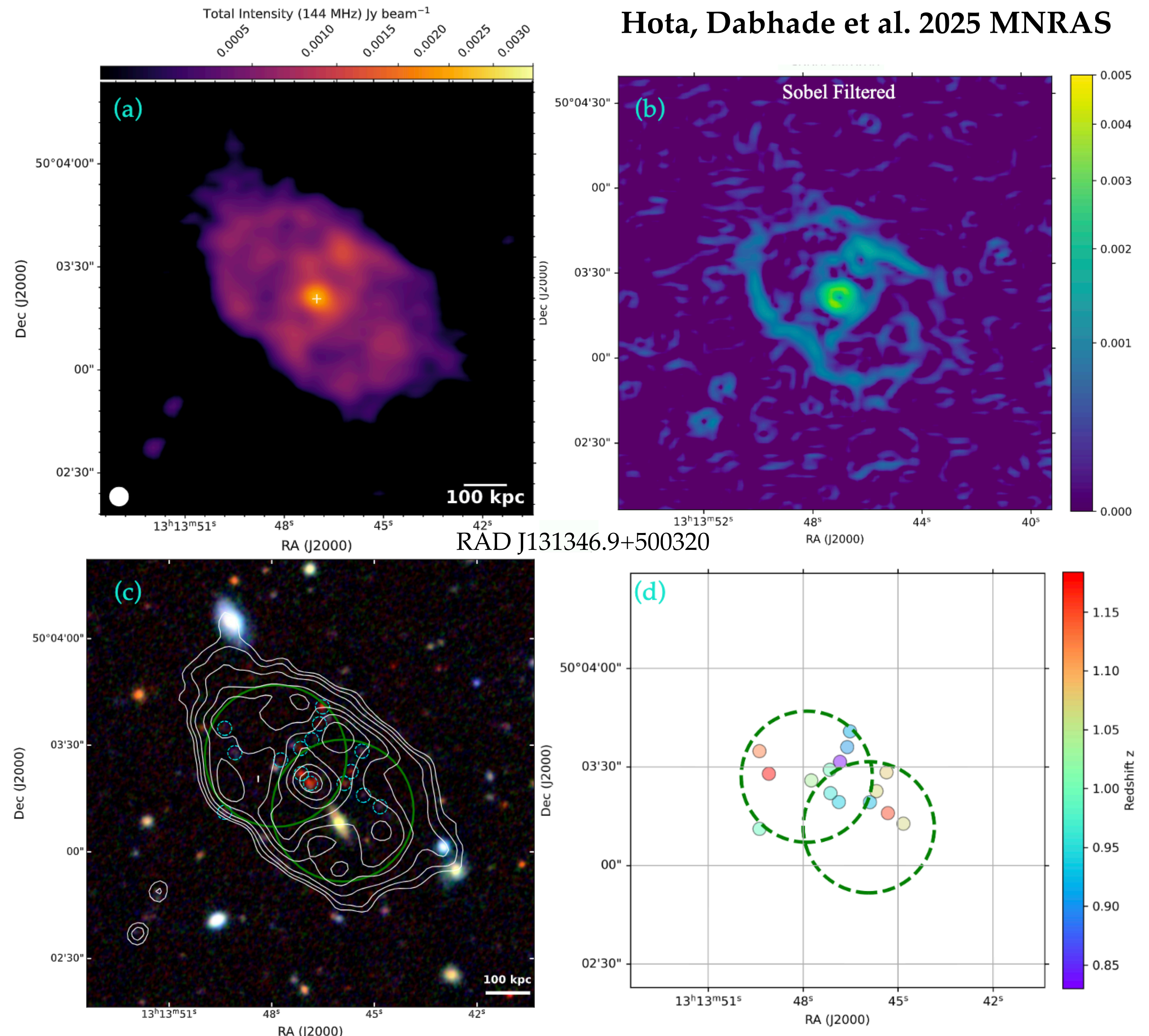
## RAD J131346.9+500320

### The Double-Ring Odd Radio Circle

- Discovery: By RAD@home citizen scientists using LOFAR (LoTSS) data
- Redshift:  $\approx 0.94$
- Physical size:  $\sim 865$  kpc
- Structure: Two intersecting rings - only the second known double-ring ORC
- Environment: Dense galaxy group/cluster; multiple nearby galaxies at similar redshift
- Radio power: Most powerful and most distant ORC known so far.
- Significance: First ORC discovered via citizen science and first found using LOFAR in the northern sky

**Lucky mistakes!**

Hota, Dabhade et al. 2025 MNRAS







# Simonte et al. 2024: GRGs in the LOFAR Deep Fields

A&A, 686, A21

## 1 Deep-field survey



Boötes, ELAIS-N1, Lockman Hole



Total area  $\sim 95 \text{ deg}^2$



LOFAR HBA 120–168 MHz



$> 80 \text{ h}$  per field



rms  $< 30 \mu\text{Jy/beam}$



**1609** extended radio galaxies  
(LAS  $> 20 \text{ arcsec}$ )



**280** GRGs ( $\geq 0.7 \text{ Mpc}$ )



**134** GRGs ( $\geq 1 \text{ Mpc}$ )

## 2 What the study found



84% FR II ; 8% FR I



36% of GRGs have spectroscopic redshifts



Deep data reveal faint, low-power GRGs



Includes  $> 1 \text{ Mpc}$  giants with  
 $P_{150} < 10^{25} \text{ W Hz}^{-1}$



Larger sources have steeper  
integrated spectra



Strongest trend for 150 MHz to 1.4 GHz:  
 $R = 0.36, p < 0.001$

## 3 Hosts & environment



GRG and RG hosts have  
similar stellar masses



40% of GRG hosts have  
 $\text{SFR} > 10 M_{\odot}/\text{yr}$



For smaller RG hosts: 20%



Larger RGs/GRGs prefer  
sparser environments



Only 3.6% of GRGs lie within  
5 Mpc of a known cluster



**Deep LOFAR fields uncovered a faint, evolved GRG population missed by shallower surveys.**



Key-

sensitivity, not just sky area, is crucial for revealing the low-power giant population.





# Oei et al. 2024: Luminous GRGs in the dense Cosmic Web

A&A, 686, A137



## 1 Sample & method



260 luminous GRGs



1443 LoTSS DR1  
radio galaxies (control)



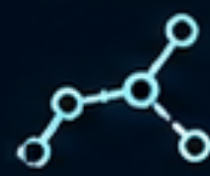
$z < 0.16$



BORG SDSS Bayesian  
3D density field



Density scale:  
 $2.9 \text{ Mpc h}^{-1}$



Environments: cluster / filament / sheet / void

## 2 Key results

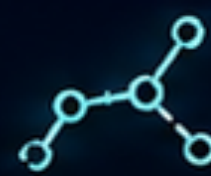


Luminous GRGs occupy denser  
large-scale environments than  
general radio galaxies.

### GRG Cosmic-Web fractions:



Cluster  
 $23 \pm 3\%$



Filament  
 $59 \pm 3\%$



Sheet  
 $17 \pm 2\%$



Void  
 $1 \pm 1\%$

### Comparison LoTSS RGs:

Cluster  
 $16 \pm 1\%$

Filament  
 $60 \pm 1\%$

Sheet  
 $23 \pm 1\%$

Void  
 $1\%$



60 / 260 GRGs are BCG giants (~23%).

## 3 Implication

Low-density environments  
are not a prerequisite  
for giant growth.



Luminous GRGs are part of the normal  
radio-galaxy population, but shifted  
toward denser Cosmic-Web environments.



# Radio surveys reporting giant radio galaxies

## Key survey-based GRG discovery samples

| Survey             | Frequency (MHz) | Sky area (deg <sup>2</sup> ) | rms (mJy beam <sup>-1</sup> ) | N    | Reference                               |
|--------------------|-----------------|------------------------------|-------------------------------|------|-----------------------------------------|
| LoTSS-DR1          | 144             | 424                          | 0.07                          | 206  | Dabhade <i>et al.</i> (2020a)           |
| LoTSS deep fields  | 144             | 95                           | <0.03                         | 280  | Simonte <i>et al.</i> (2024)            |
| LoTSS-DR2          | 144             | 5700                         | 0.08                          | 2050 | Oei <i>et al.</i> (2022b)               |
| LoTSS-DR2 (ML+RGZ) | 144             | 5700                         | 0.08                          | 9222 | Mostert <i>et al.</i> (2024)            |
| LOFAR-H-ATLAS      | 150             | 142                          | 0.1–2                         | 6    | Hardcastle <i>et al.</i> (2016)         |
| 7C                 | 151             | 473                          | 15                            | 14   | Cotter <i>et al.</i> (1996)             |
| 3CRR <sup>†</sup>  | 178             | 15287                        | 2000                          | 12   | Laing <i>et al.</i> (1983)              |
| WENSS              | 325             | 10176                        | 3                             | 31   | Schoenmakers <i>et al.</i> (2001)       |
| MRC                | 408             | 1937                         | 70                            | 8    | Kapahi <i>et al.</i> (1998)             |
| SUMSS              | 843             | 2100                         | 1                             | 17   | Saripalli <i>et al.</i> (2005)          |
| RACS*              | 888             | 1059                         | 0.25                          | 178  | Andernach <i>et al.</i> (2021)          |
| EMU                | 888             | 83                           | 0.04                          | 63   | Gürkan <i>et al.</i> (2022)             |
| EMU*               | 1000            | 30                           | 0.03                          | 19   | Brüggen <i>et al.</i> (2021)            |
| NVSS               | 1400            | 1543                         | 0.45                          | 21   | Machalski <i>et al.</i> (2001)          |
| NVSS               | 1400            | 4563                         | 0.45                          | 34   | Machalski <i>et al.</i> (2007a)         |
| NVSS               | 1400            | 10308                        | 0.45                          | 30   | Lara <i>et al.</i> (2001)               |
| NVSS               | 1400            | 34000                        | 0.45                          | 9    | Solov'yov & Verkhodanov (2014)          |
| NVSS               | 1400            | –                            | 0.45                          | 80   | Amirkhanyan (2016)                      |
| NVSS               | 1400            | –                            | 0.45                          | 22   | Dabhade <i>et al.</i> (2017)            |
| NVSS               | 1400            | –                            | 0.45                          | 148  | Dabhade <i>et al.</i> (2020b)           |
| NVSS               | 1400            | 14555                        | 0.45                          | 24   | Kozieł-Wierzbowska <i>et al.</i> (2020) |
| NVSS               | 1400            | 9376                         | 0.45                          | 134  | Kuźmich & Jamrozy (2021)                |
| NVSS               | 1400            | –                            | 0.45                          | 10   | Mahato <i>et al.</i> (2022)             |

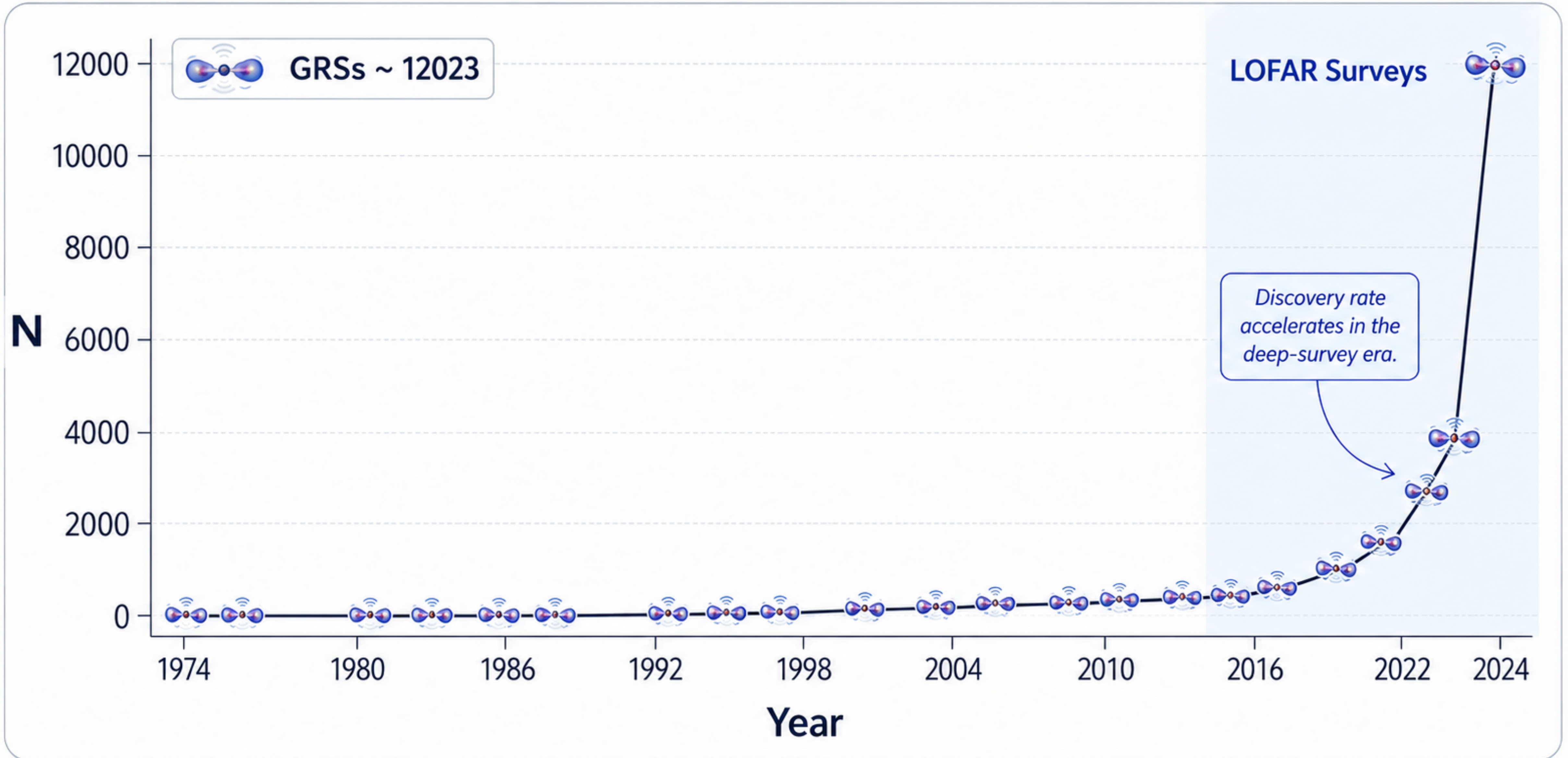
**i** N = number of GRGs reported in each survey-based study.

**i** LoTSS deep fields combines Boötes, ELAIS-N1, and Lockman Hole.



# Giant radio source discoveries over the years

Cumulative number of known giant radio sources (GRSs) / giant radio galaxies





# Andernach & Brüggen 2025: The extreme tail of the GRG population

A&A, 699, A257



## 1 Sample of extreme giants



**142** GRGs with LLS > 3 Mpc



**69** newly identified



**6** sources exceed 5 Mpc



**6.6** Largest reaches 6.6 Mpc



Parent compilation:

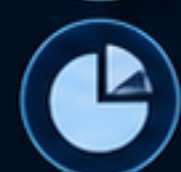
**28 700** extended radio sources



**>12 000** GRGs in the broader compilation



Median redshift:  **$z = 0.67$**

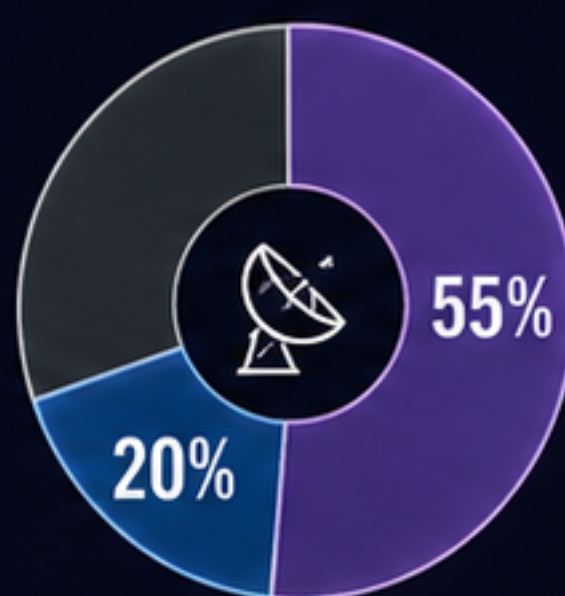


**33%** spectroscopic redshifts



## 2 How they were found

Multi-survey literature +  
new visual searches



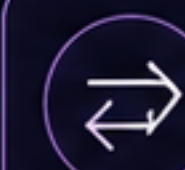
LOFAR / LoTSS  
**55%**

ASKAP / RACS  
**20%**

Other surveys  
**25%**



Also NVSS, FIRST, SUMSS,  
MWA, MeerKAT MGCLS, MALS,  
GLEAM follow-up, VLASS



Cross-survey searches enabled  
the census of >3 Mpc systems.



## 3 Key physical results



Extreme GRGs are overwhelmingly FR II-like



Only **~6%** deviate from FR II morphology



**25%** show remnant-like diffuse lobes



**59%** show hotspots in at least one lobe



**38%** show hotspots in both lobes



Quasar / quasar-candidate fraction: **16%**



At least **16%** associated with catalogued clusters

**Even the largest GRGs are not  
explained by sparse environments alone.**



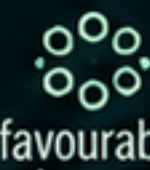
powerful jets



long lifetimes



stable axes



favourable  
environments



Key-

the most extreme giants provide a direct test of radio-galaxy evolution models.

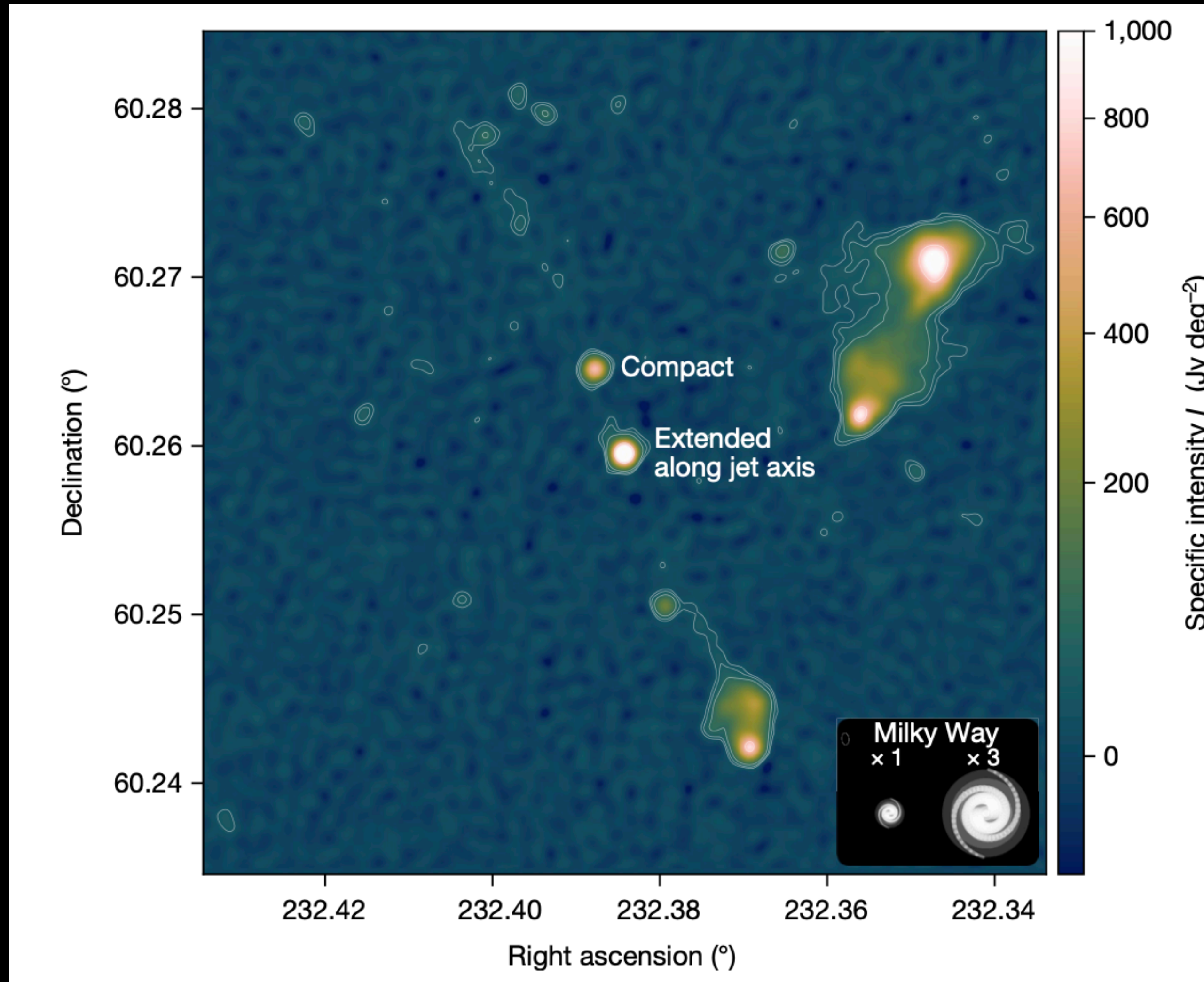




# Porphyron: The largest amongst the giants!

$7\text{ Mpc} ! @ z \sim 0.9$

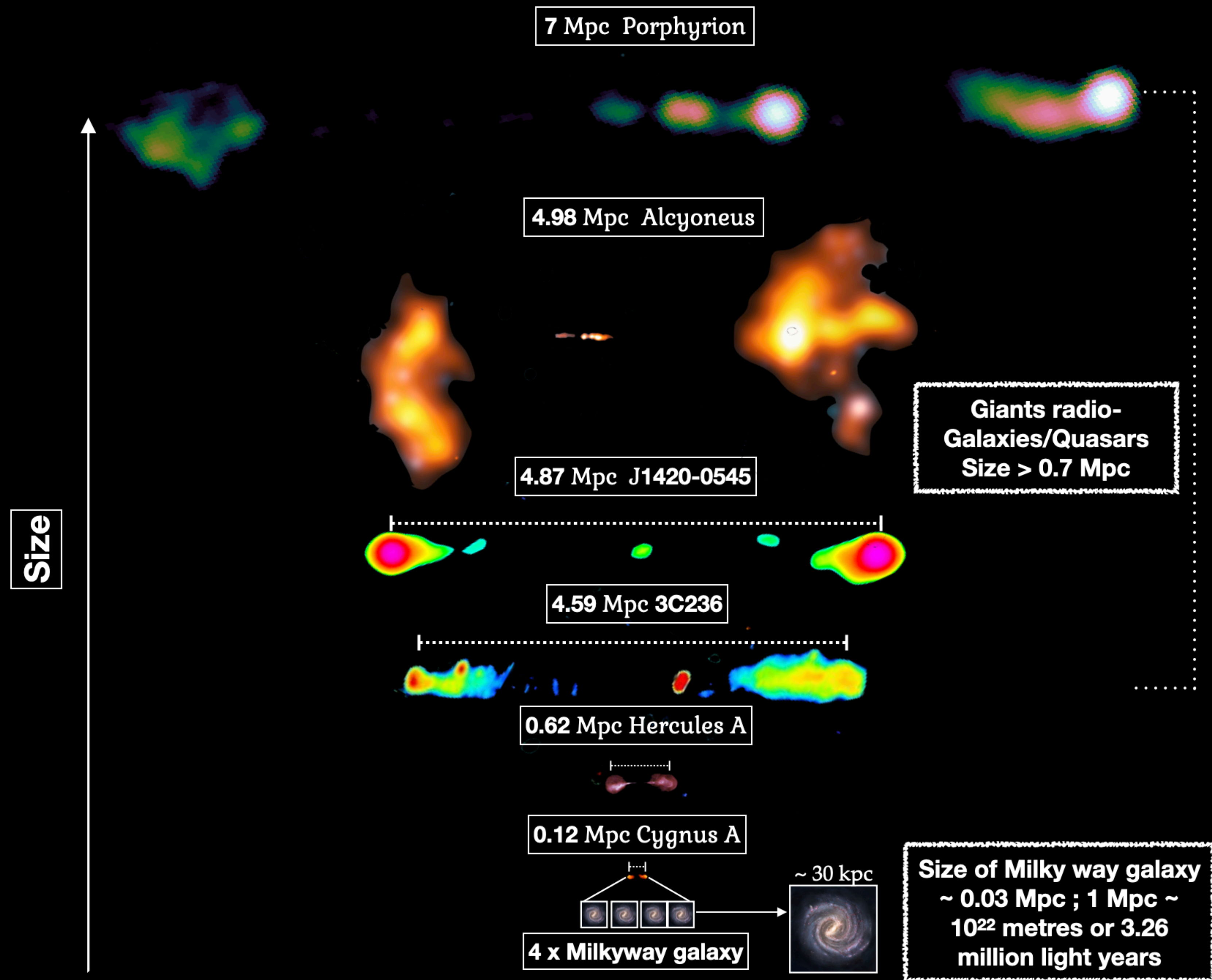
Oei et al. 2024



LoFAR+uGMRT







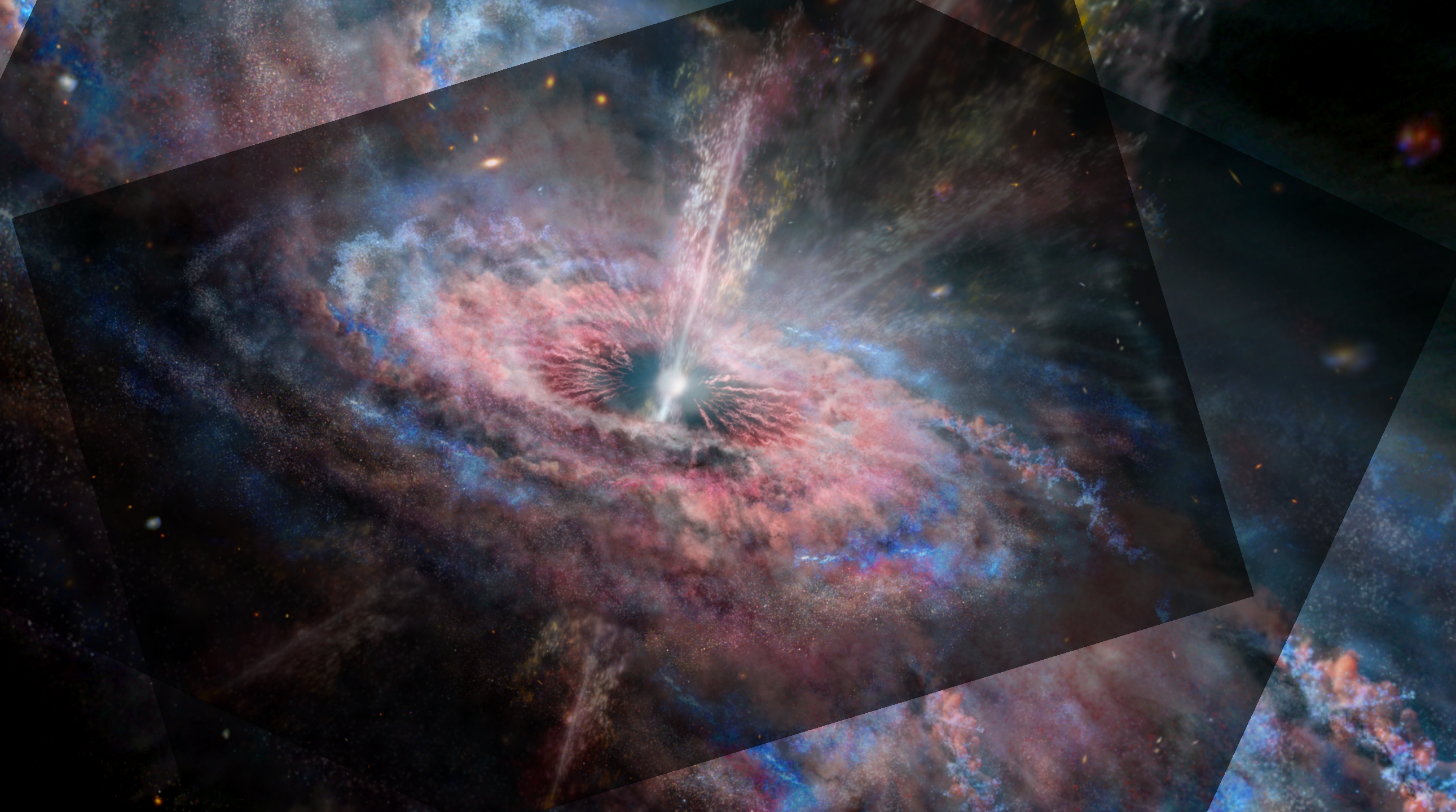
## Giant radio sources

Dabhade, Saikia, & Mahato 2023,  
Review article (JApA, V44, 1)

*Summarising ~50 years research &  
future directions with SKA*

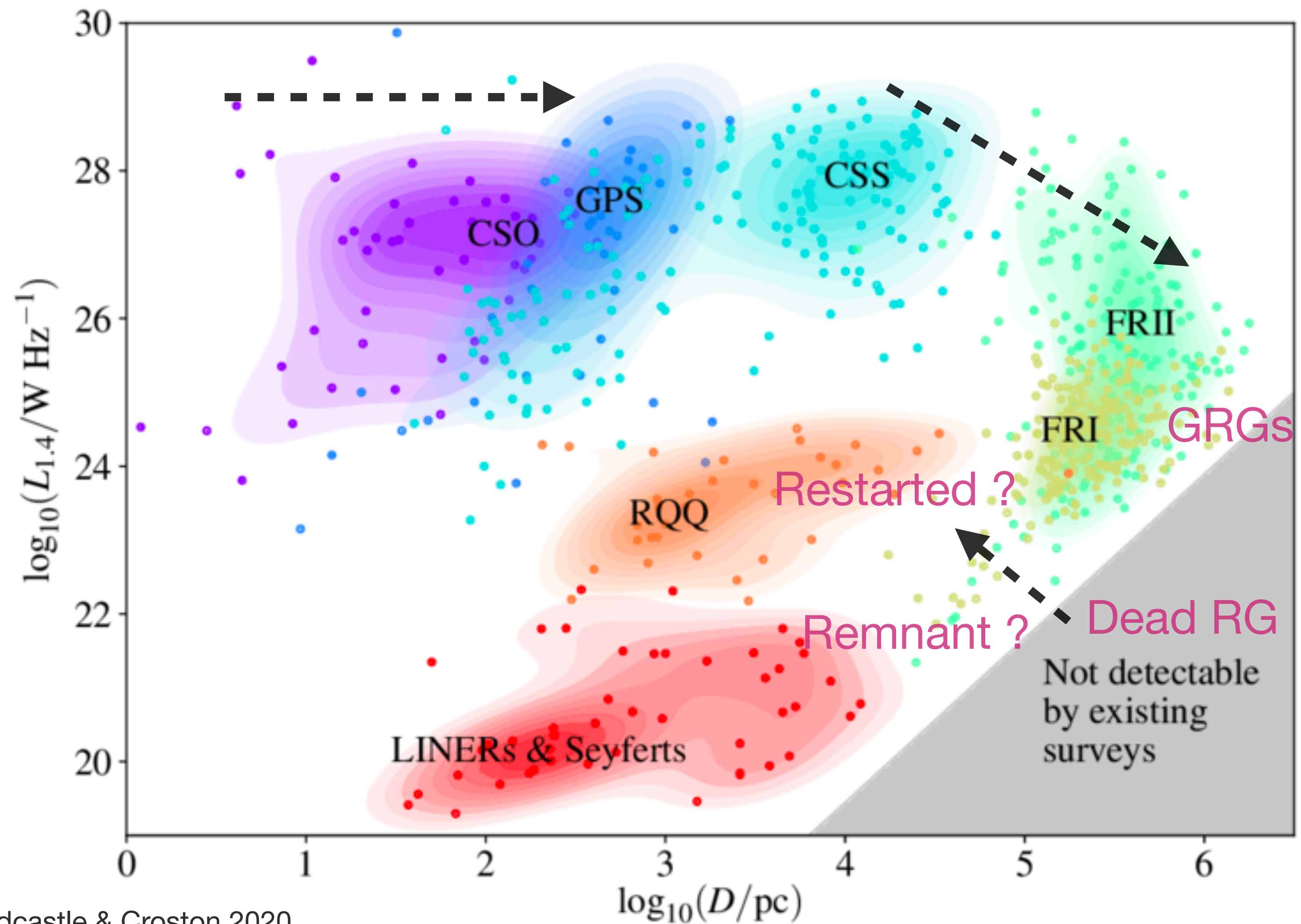


# Multiple cycles of AGN activity in Giant radio galaxies





# Different phases in the lifetimes of radio galaxies

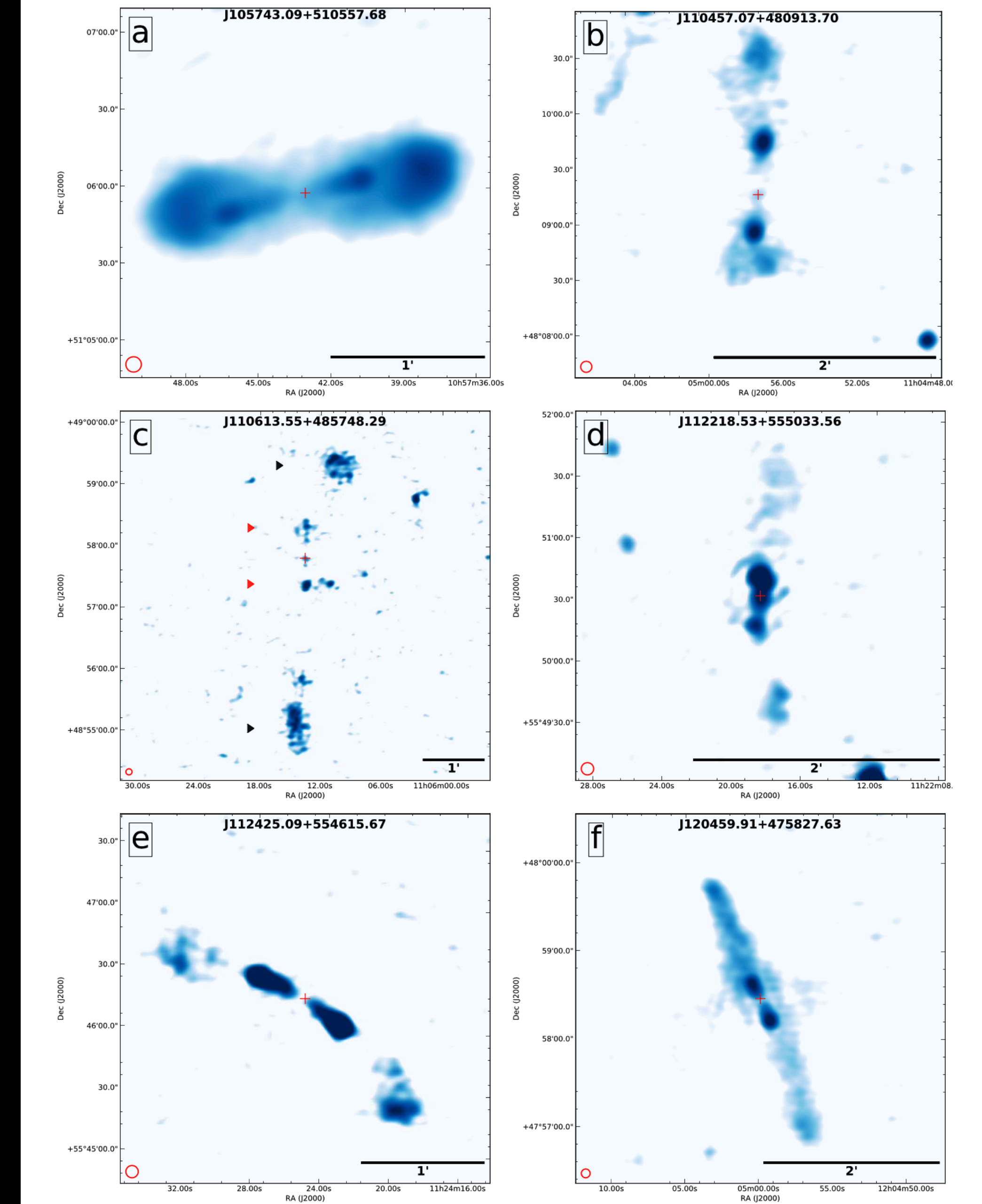
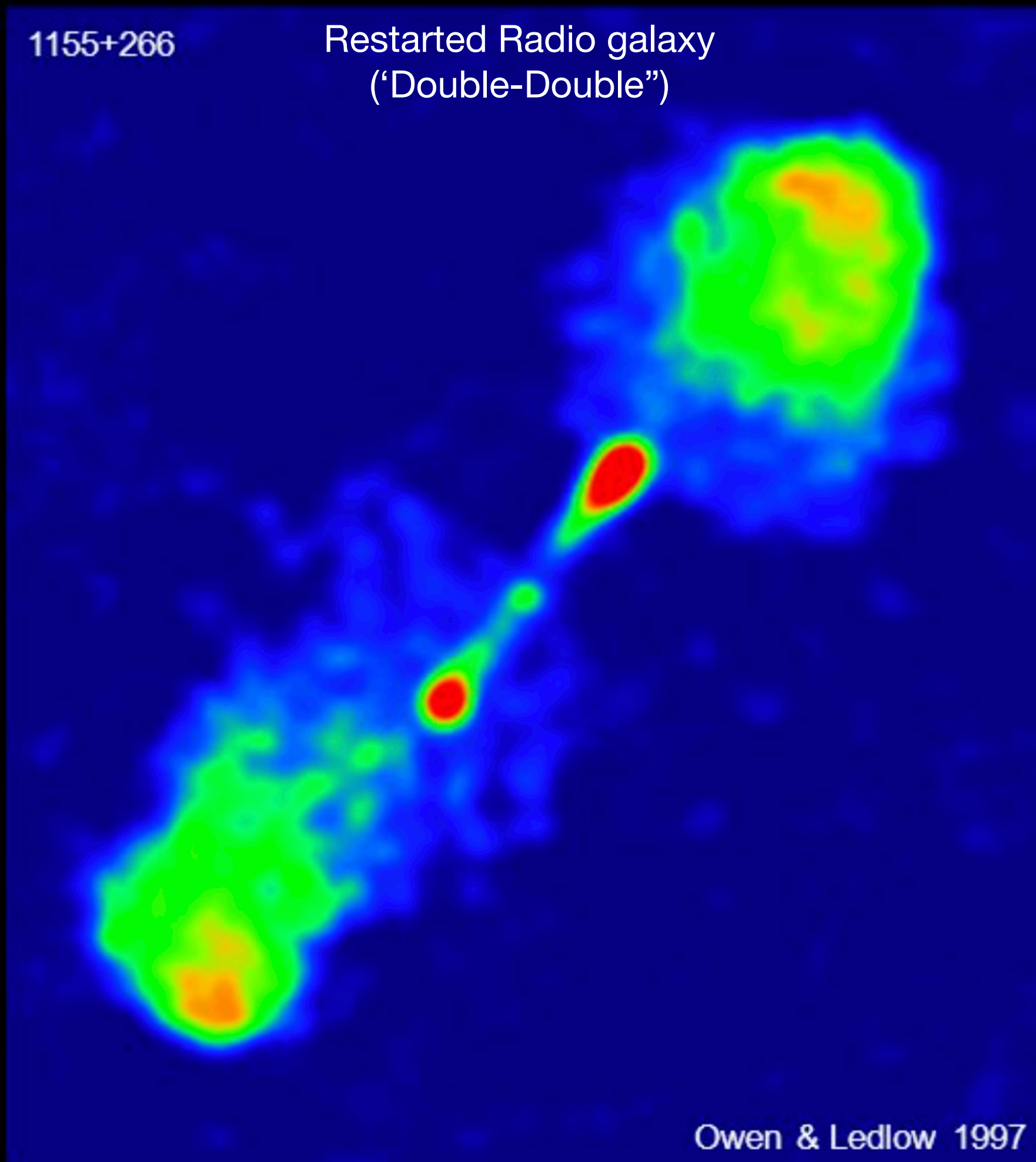


Hardcastle & Croston 2020



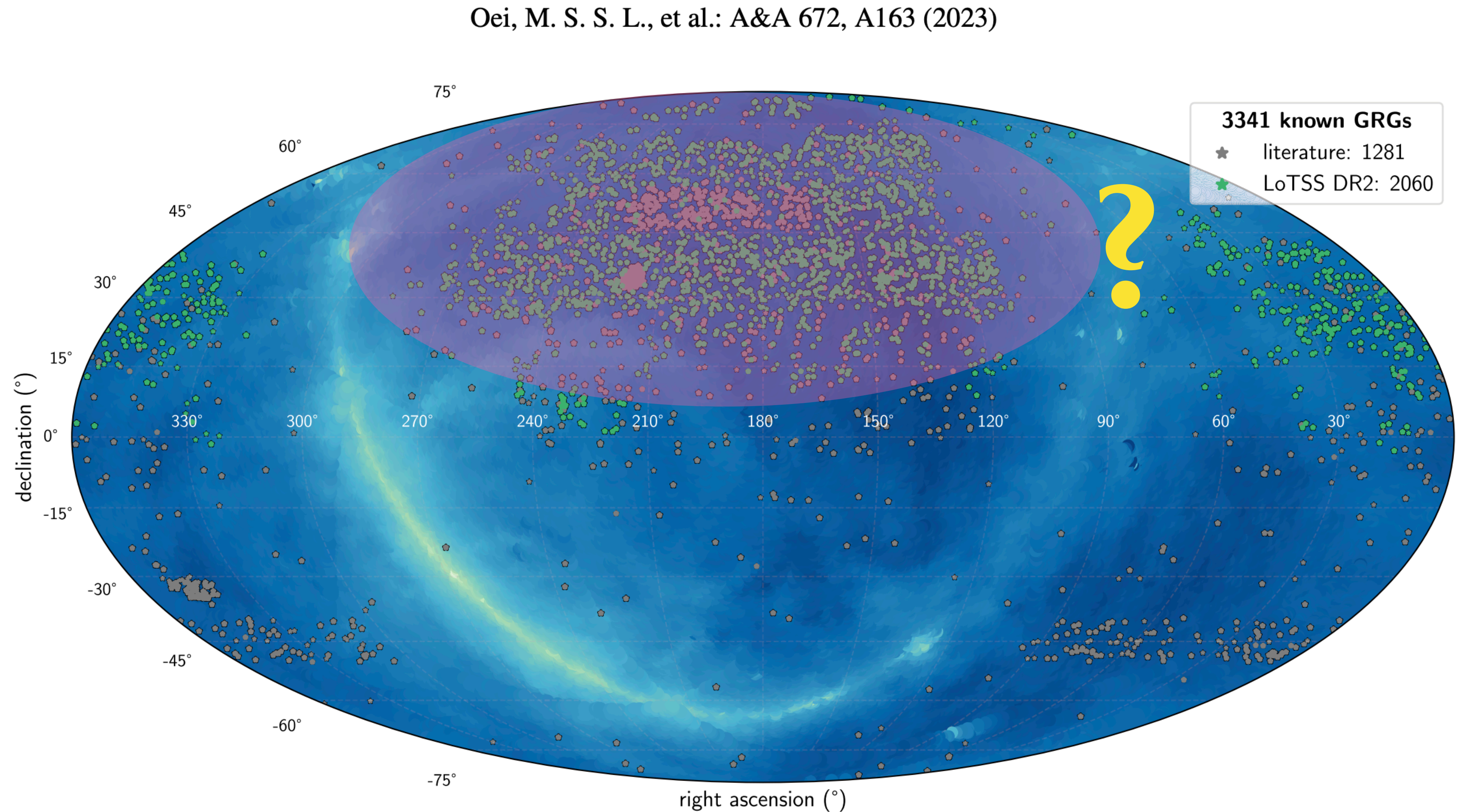
# DDRGs from LoTSS DR1

*“Double-double structure often associated with sources with megaparsec scale sizes”*





# How many GRGs in LoTSS DR2 show restarted activity?

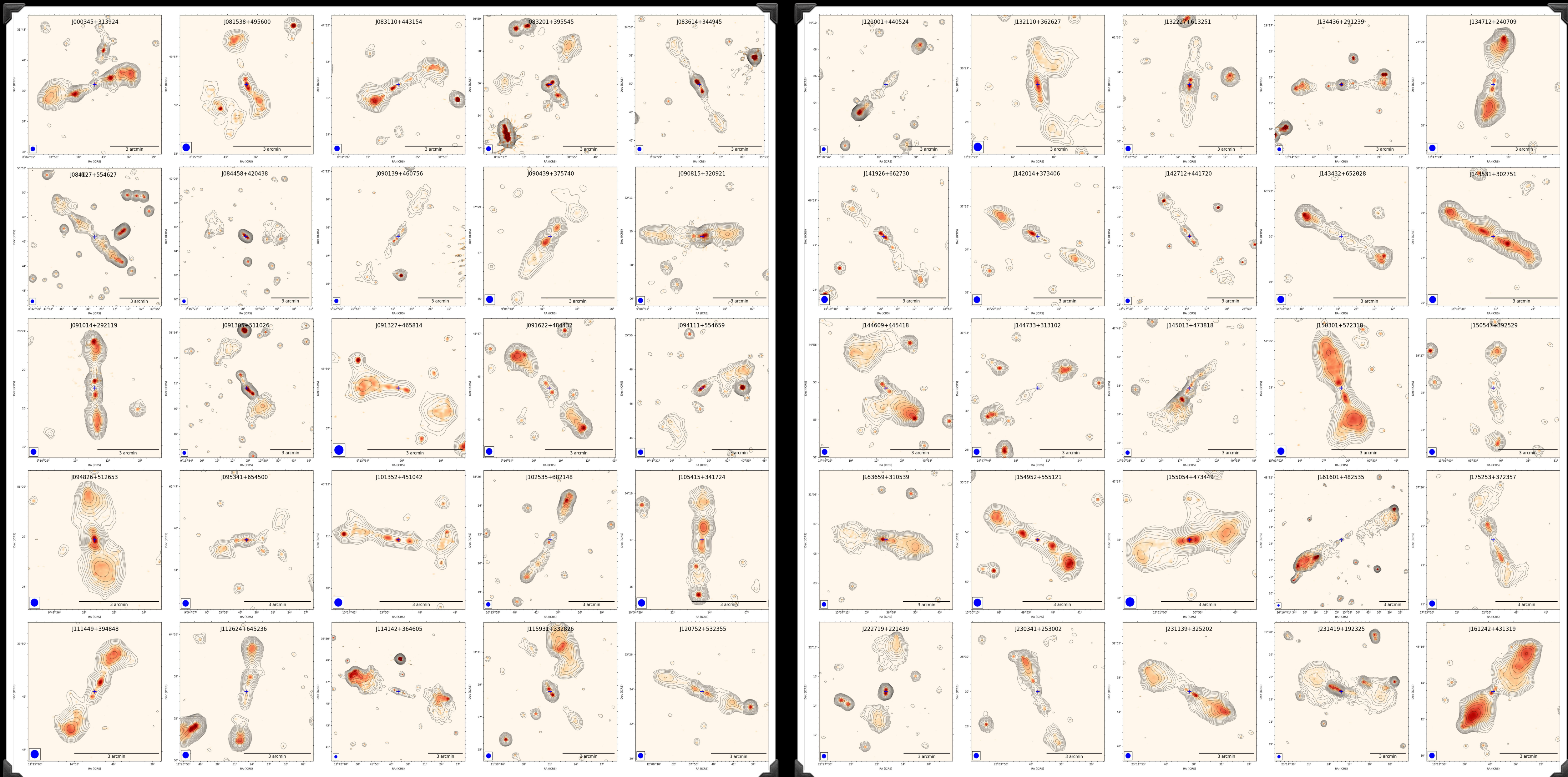




# Result 5: $\sim 3\%$ OF GIANTS SHOW RESTARTED ACTIVITY !

## SAGAN V

### DDRGs from LoTSS DR2 : Montage





# SAGAN V: Giant double-double radio galaxies in LoTSS DR2

*Restarted AGN activity on megaparsec scales*



## Sample & data



LoTSS DR2 at 144 MHz



Largest giant DDRG sample to date



111 giant DDRGs



76 newly identified



$z = 0.06 - 1.6$



outer sizes: 0.7–3.3 Mpc

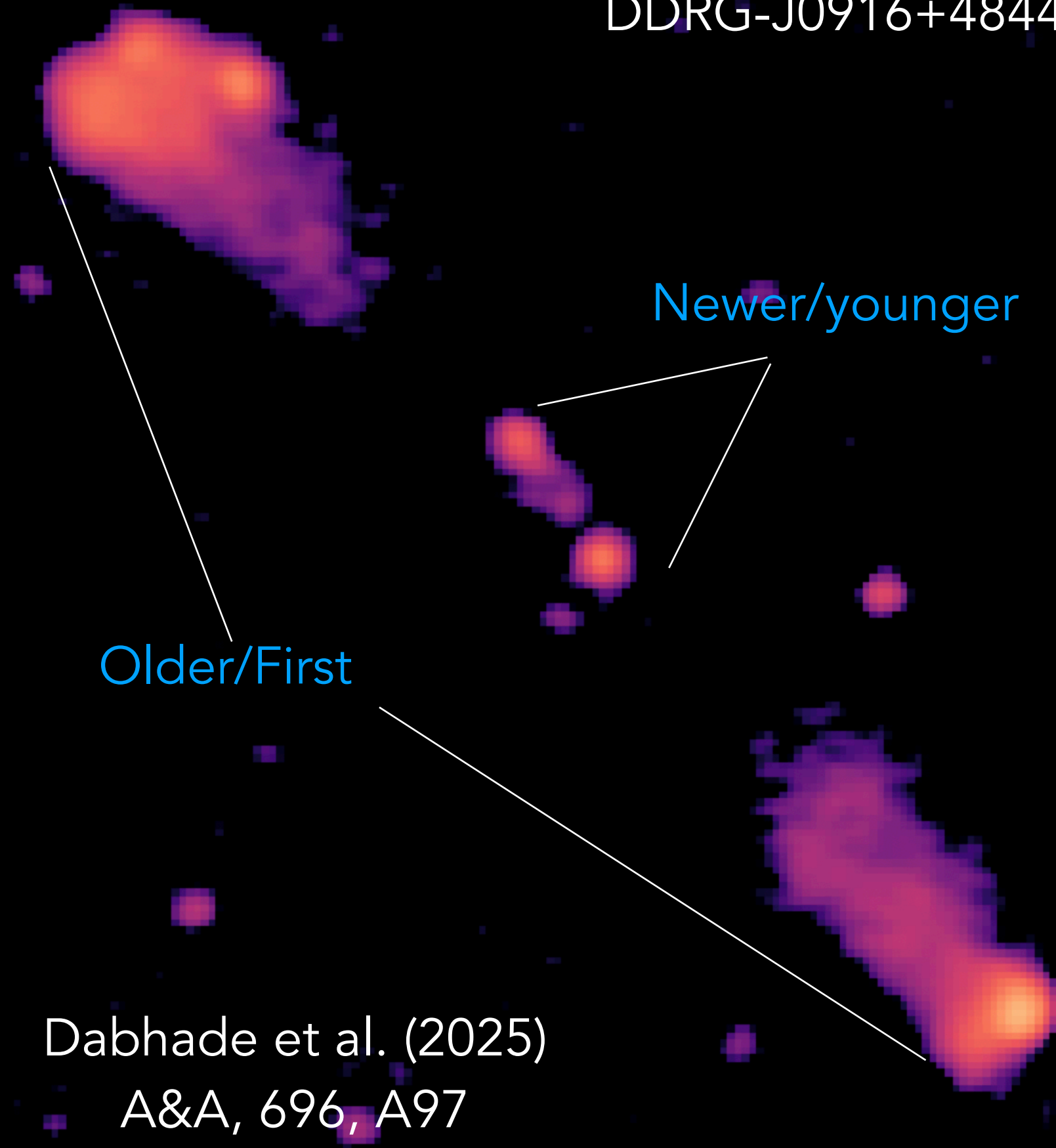


9 sources at  $z > 1$



inner doubles:  
35 kpc–1.5 Mpc

DDRG-J0916+4844



## Measured diagnostics



LoTSS



FIRST



VLASS



optical images

host/core  
verification

inner/outer lobe  
measurements

$R_\theta$ ,  $R_s$ ,  
misalignment angles



environment  
checks



## Main results



Clear DDRG morphology  
among LoTSS DR2 giants:  
<3% lower limit



Inner-lobe asymmetries imply  
disturbed/contaminated  
cocoon in ~26% of cases



Highly misaligned DDRGs  
trace jet-axis instability  
and/or environmental  
deflection



Cluster weather can shape  
DDRG morphologies



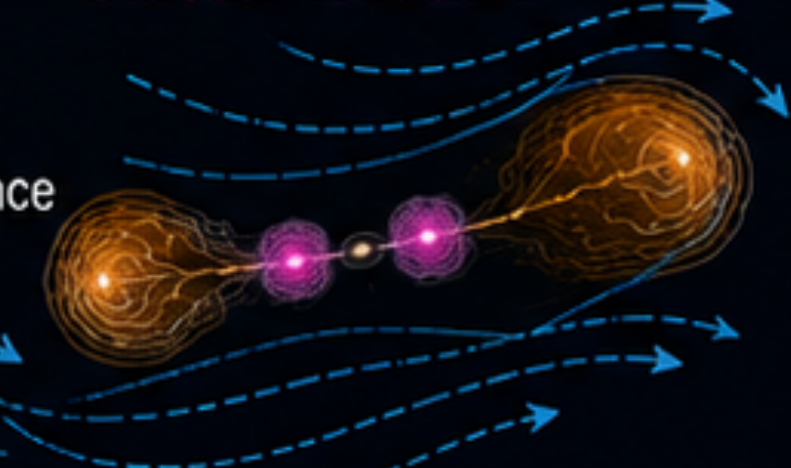
One DDRG found in a  
distant cluster at  $z \sim 1.4$



2 GPS-core candidates +  
1 triple-double candidate

## Cluster weather

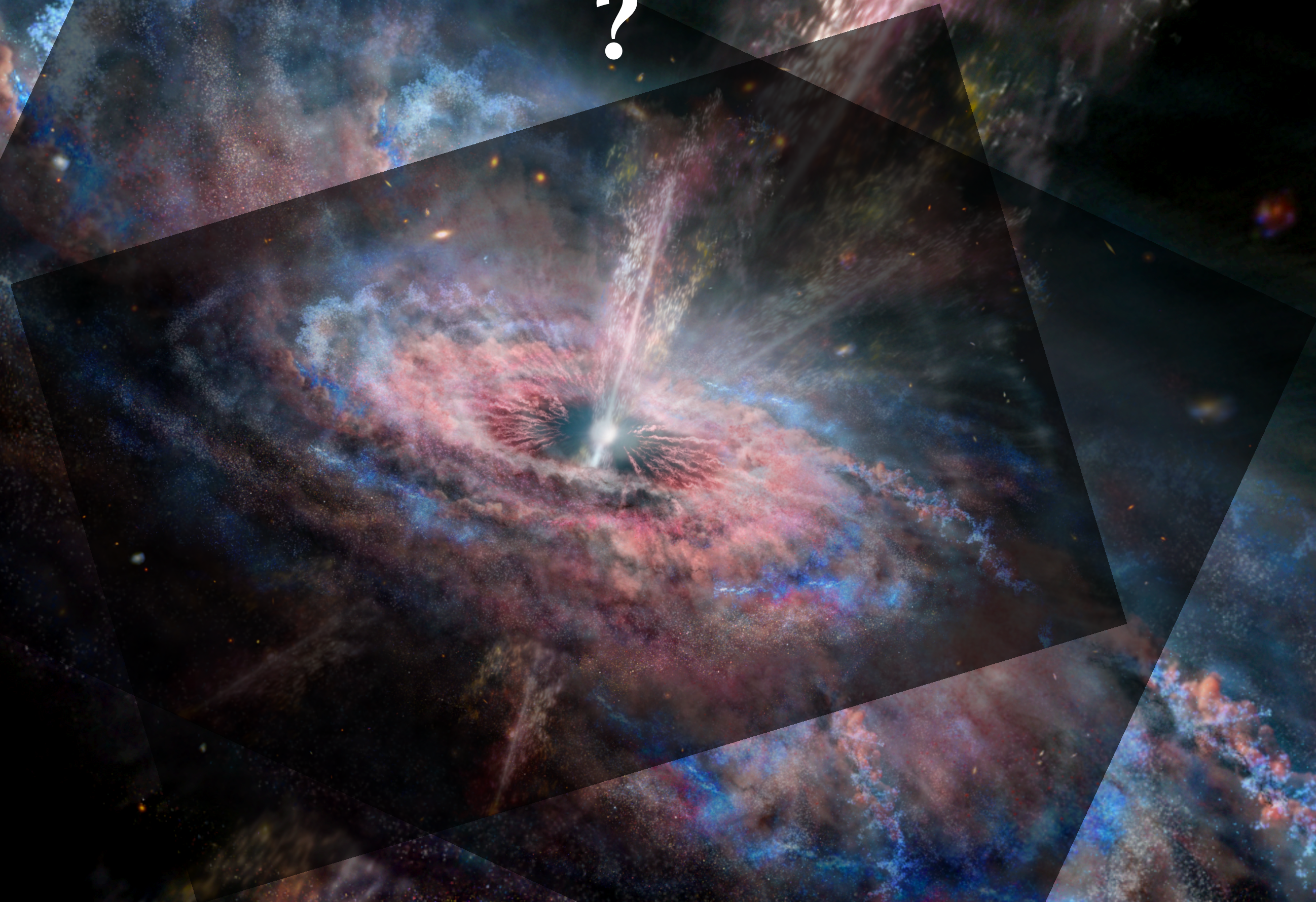
wind /  
turbulence



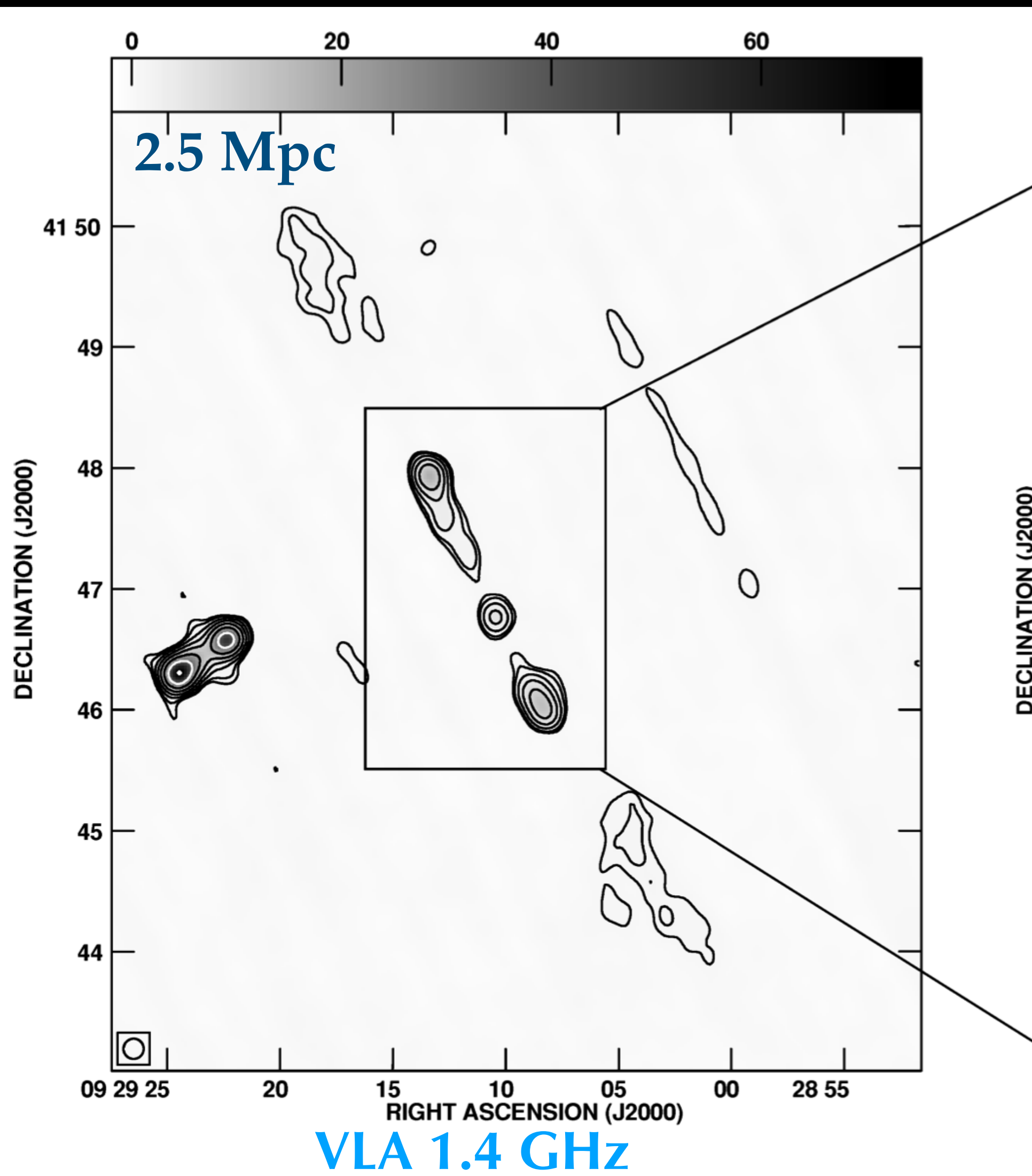
**Key takeaway:** LoTSS reveals **recurrent jet activity** as a rare but **direct window** into the radio-AGN duty cycle; **environment** and **previous jet episodes** shape the next generation of lobes.



Is there evidence for more than 2 cycles of AGN  
activity  
?

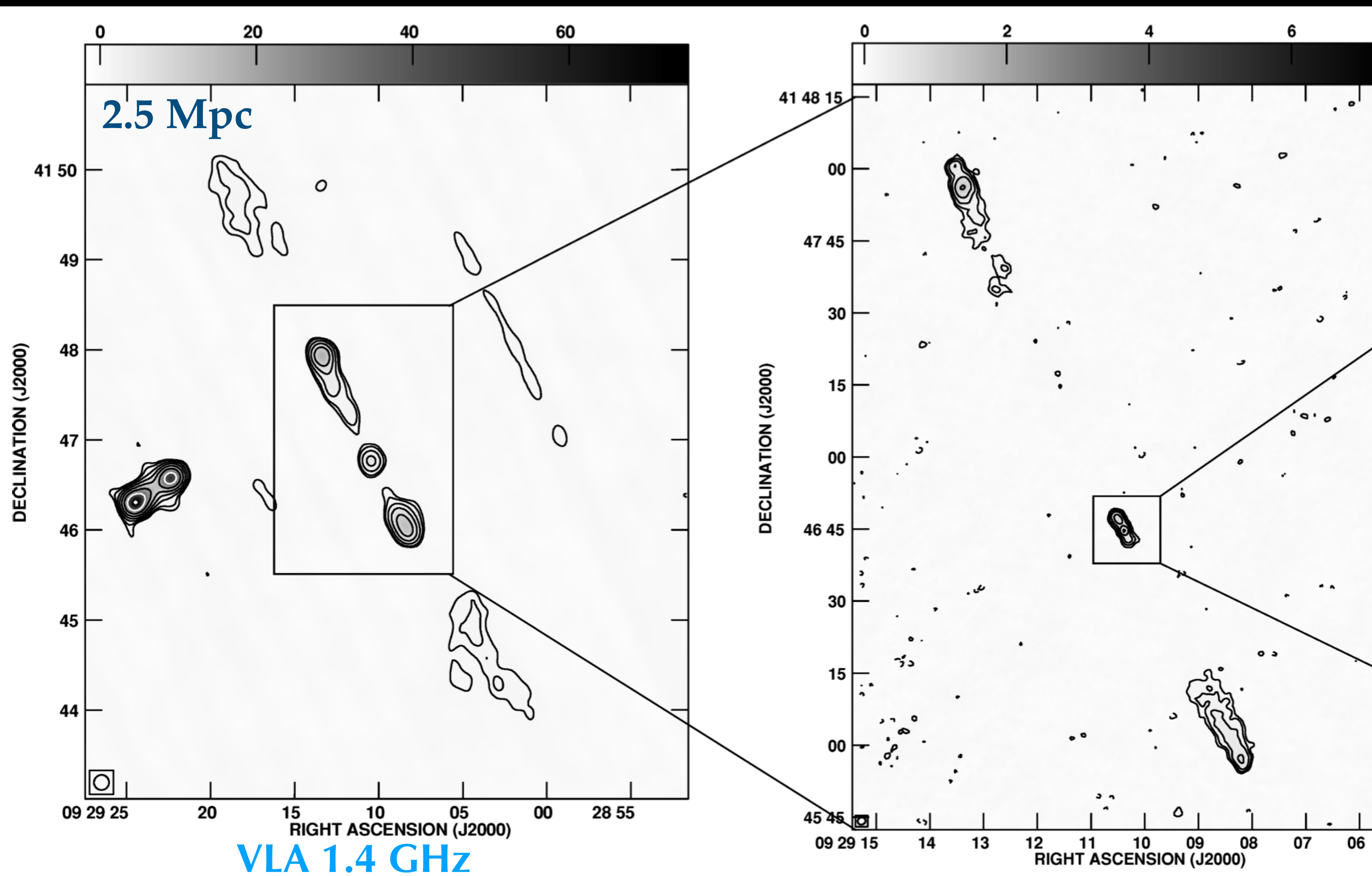






Brockopp et al. 2007



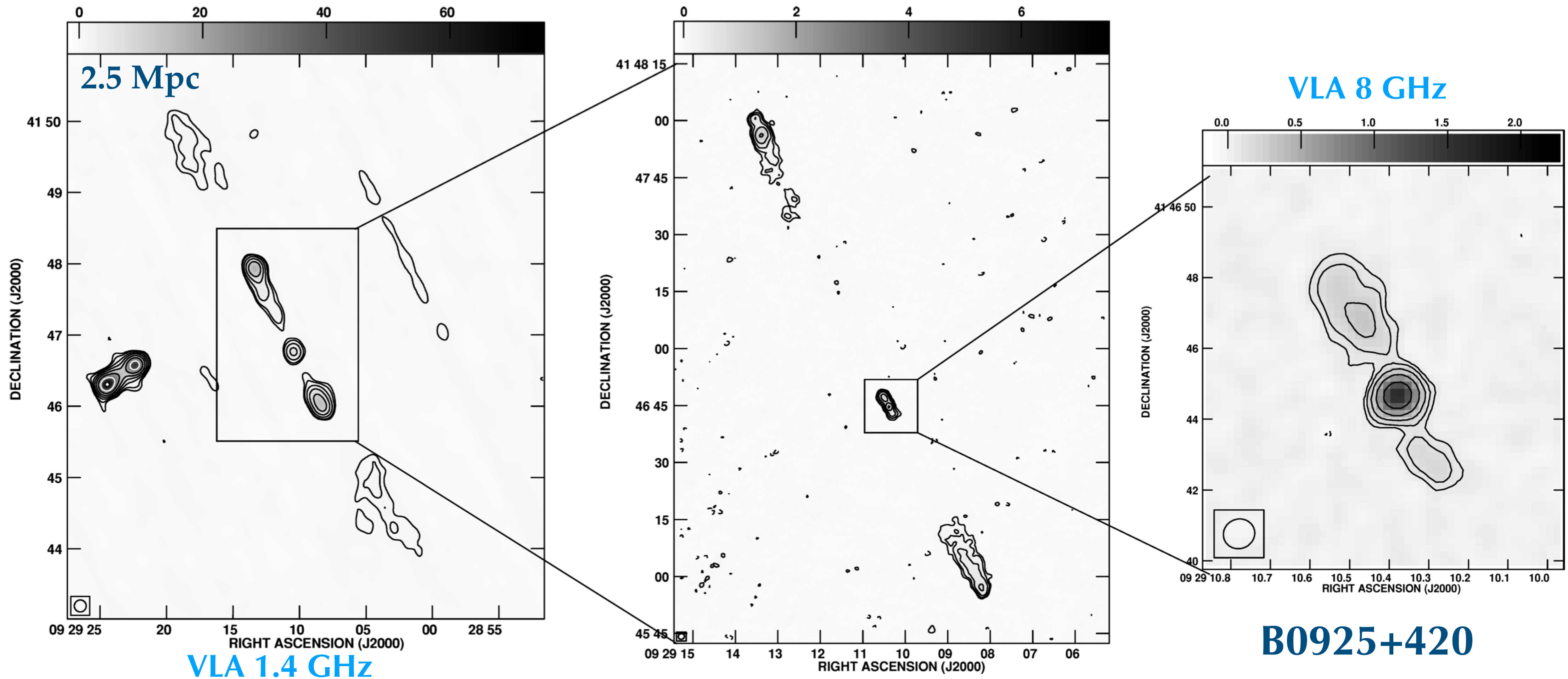


Brockopp et al. 2007



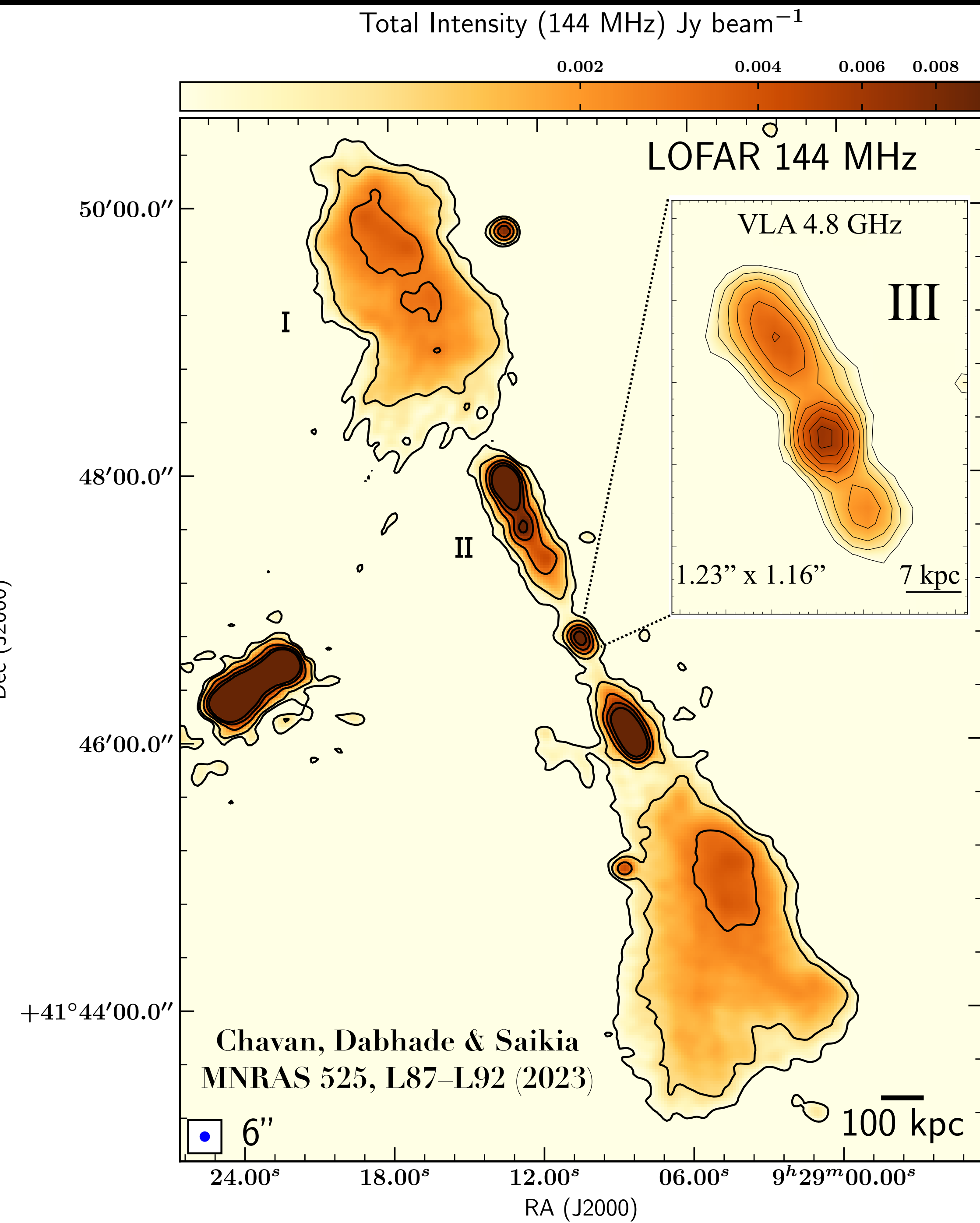
1<sup>st</sup>

# Triple double radio galaxies or TDRGs

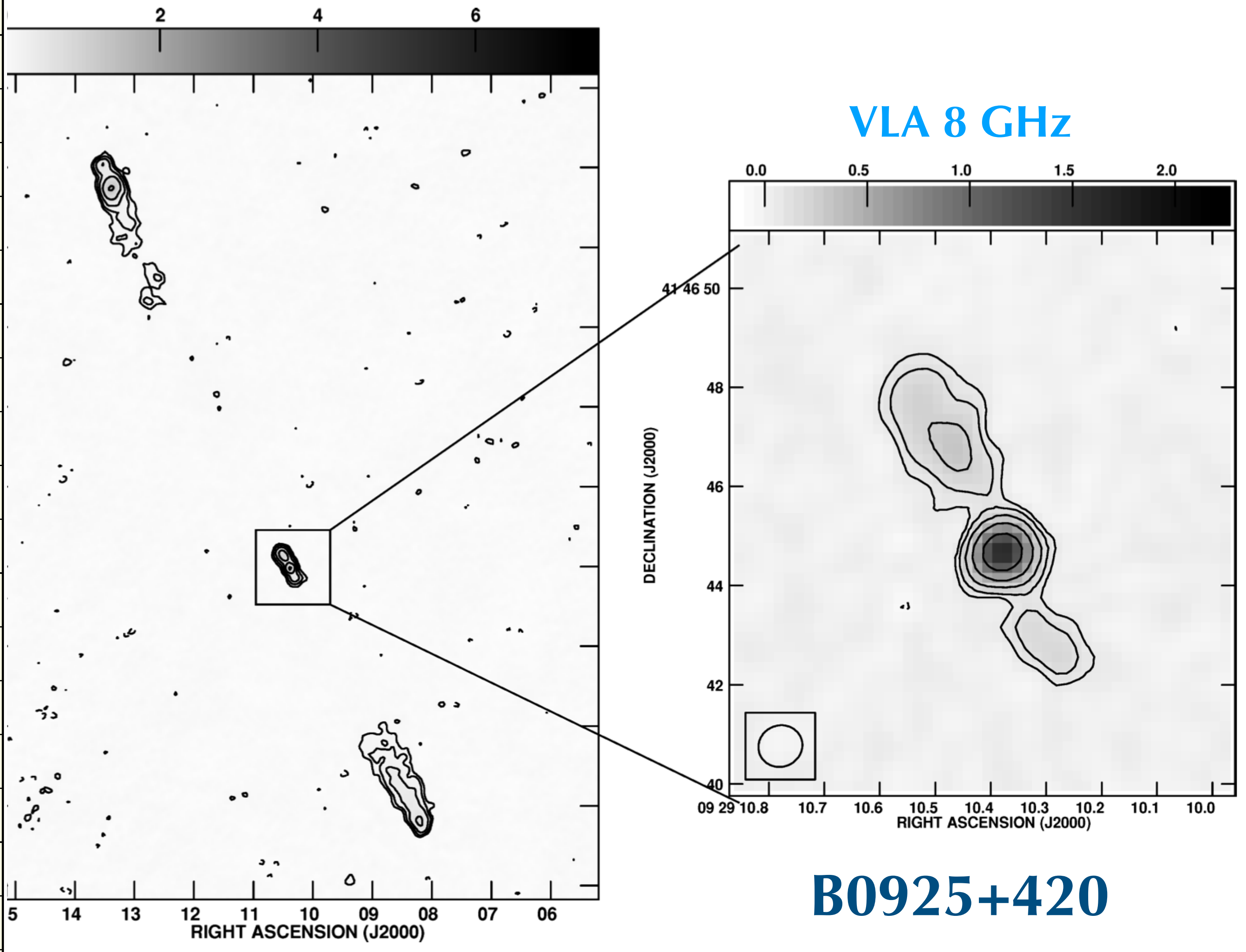


Brockopp et al. 2007



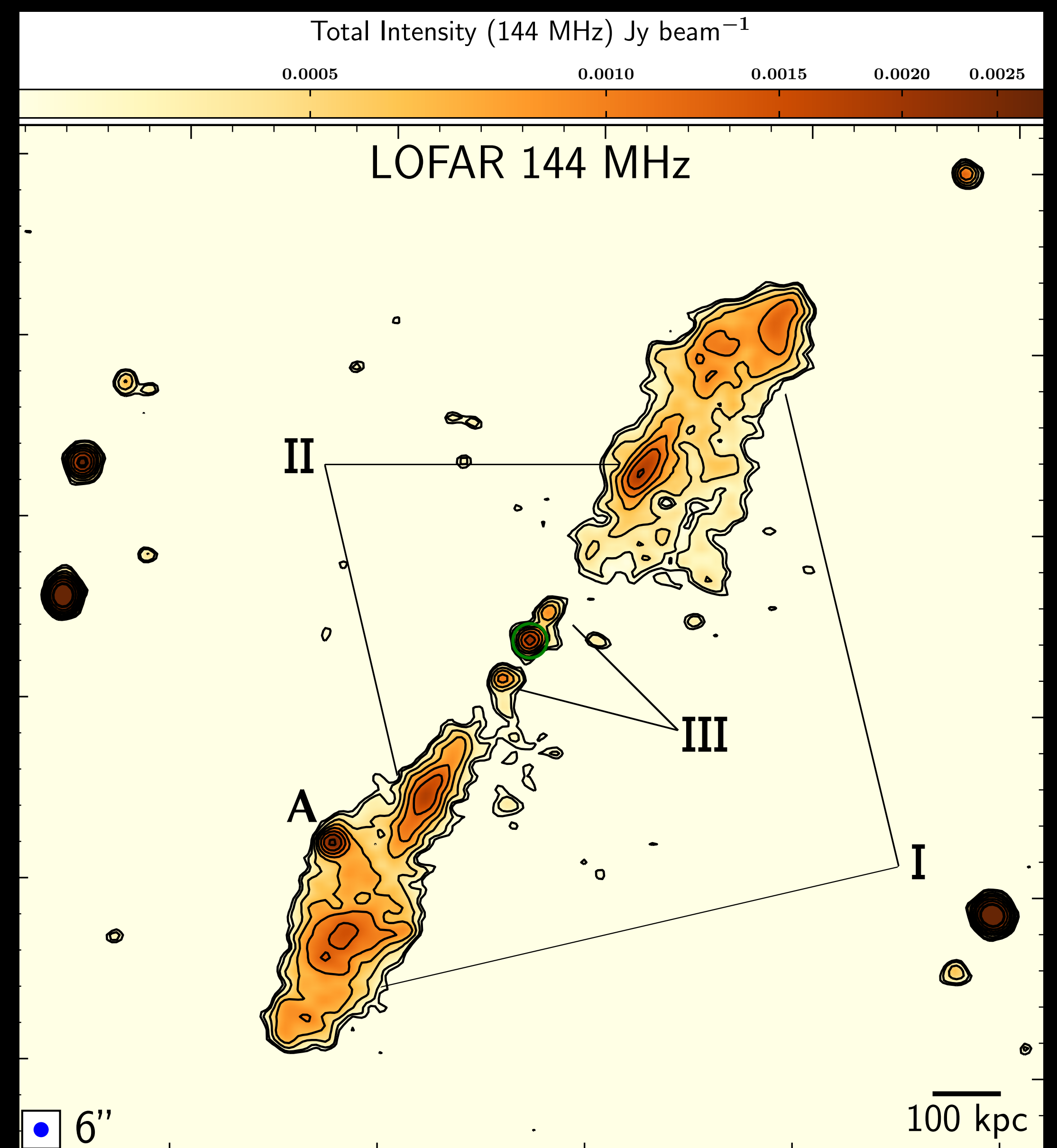
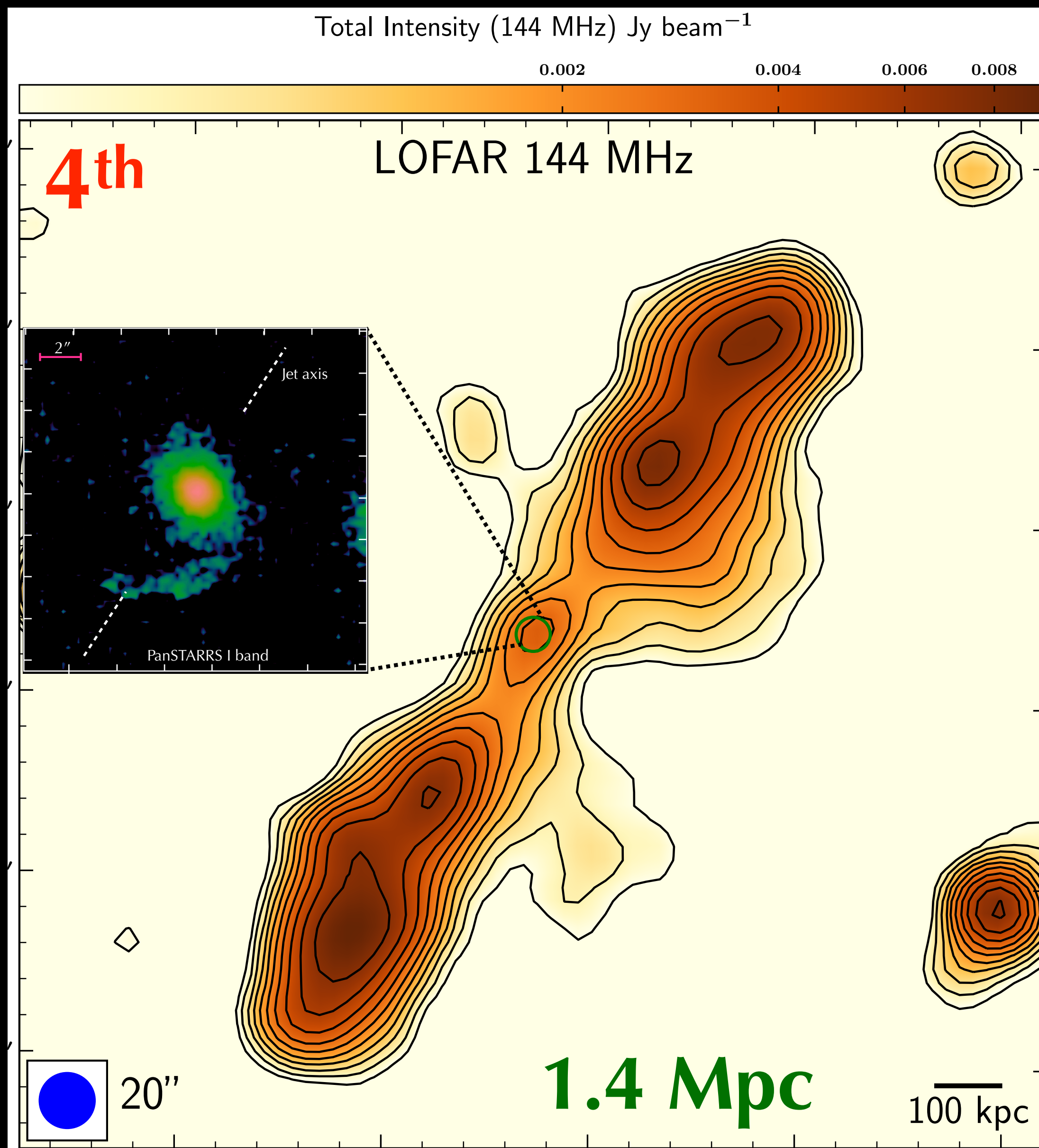


# radio galaxies or TDRGs





# New TDRG from LoTSS DR2

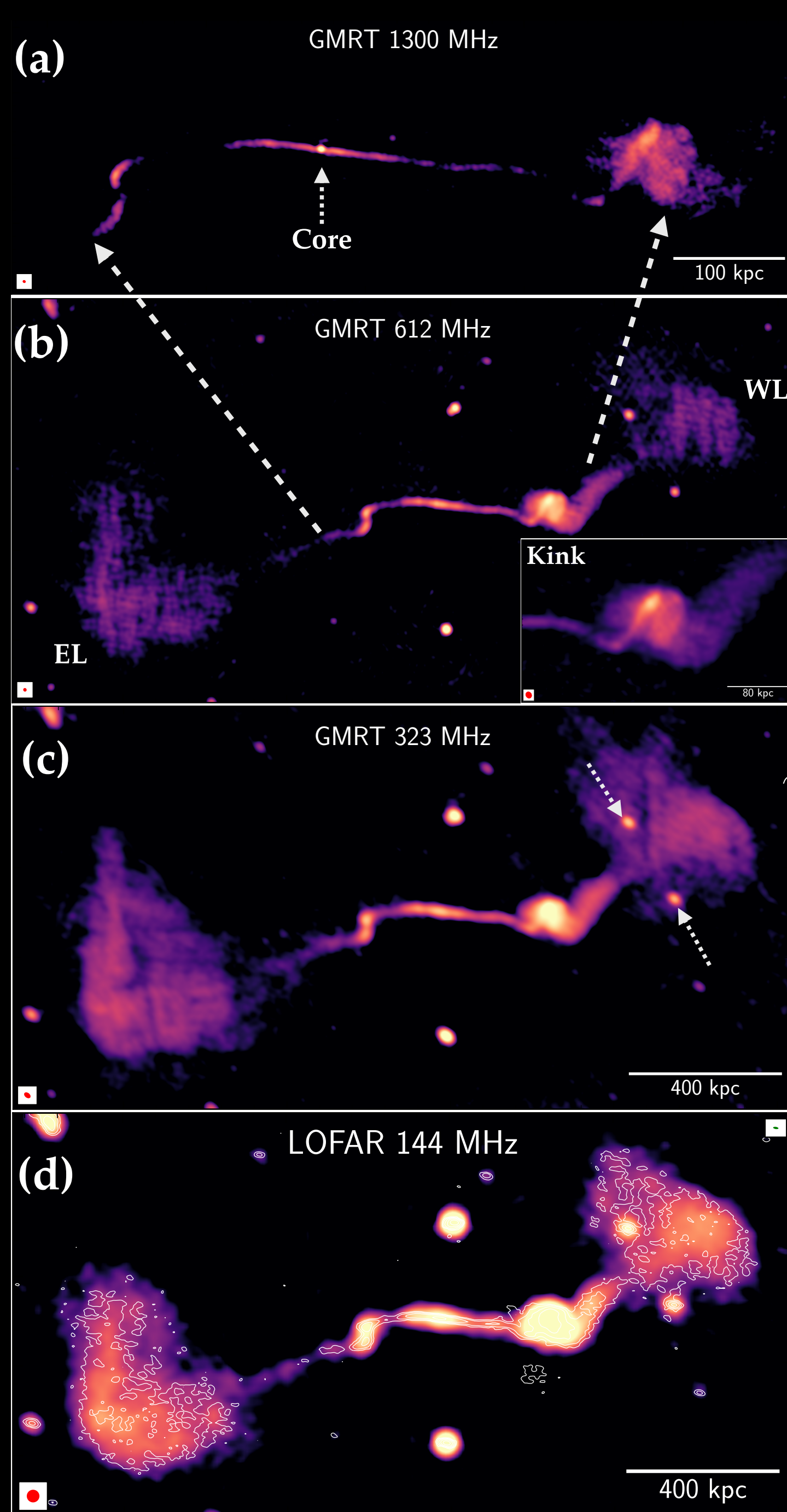


Chavan, Dabhade & Saikia, MNRAS 525, L87–L92 (2023)









Data:  
LoFAR  
GMRT

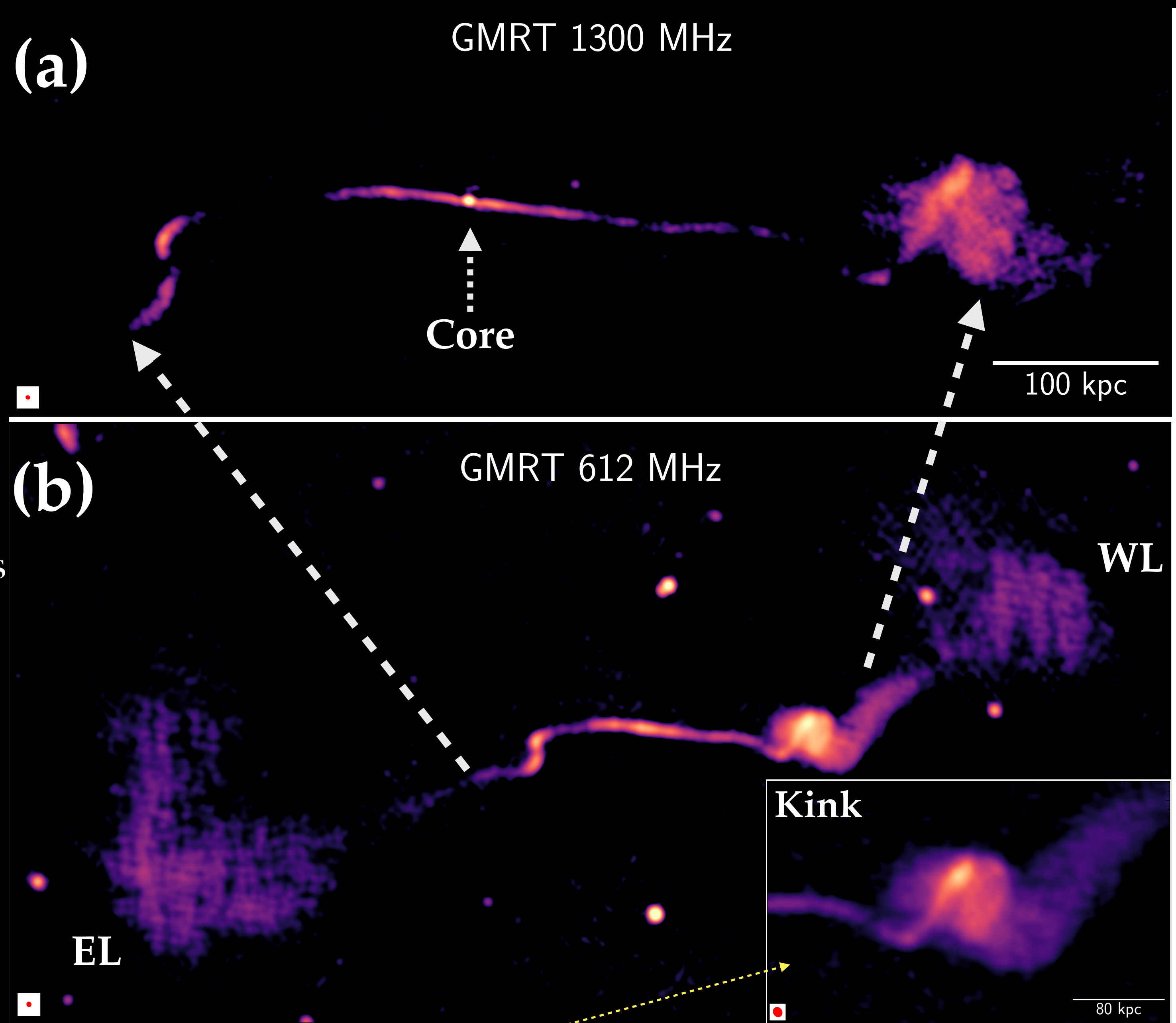
Size = 1.8 Mpc

Magnetic field:  
~ 5 micro Gauss

Age:  
~ 110 - 200 Myrs

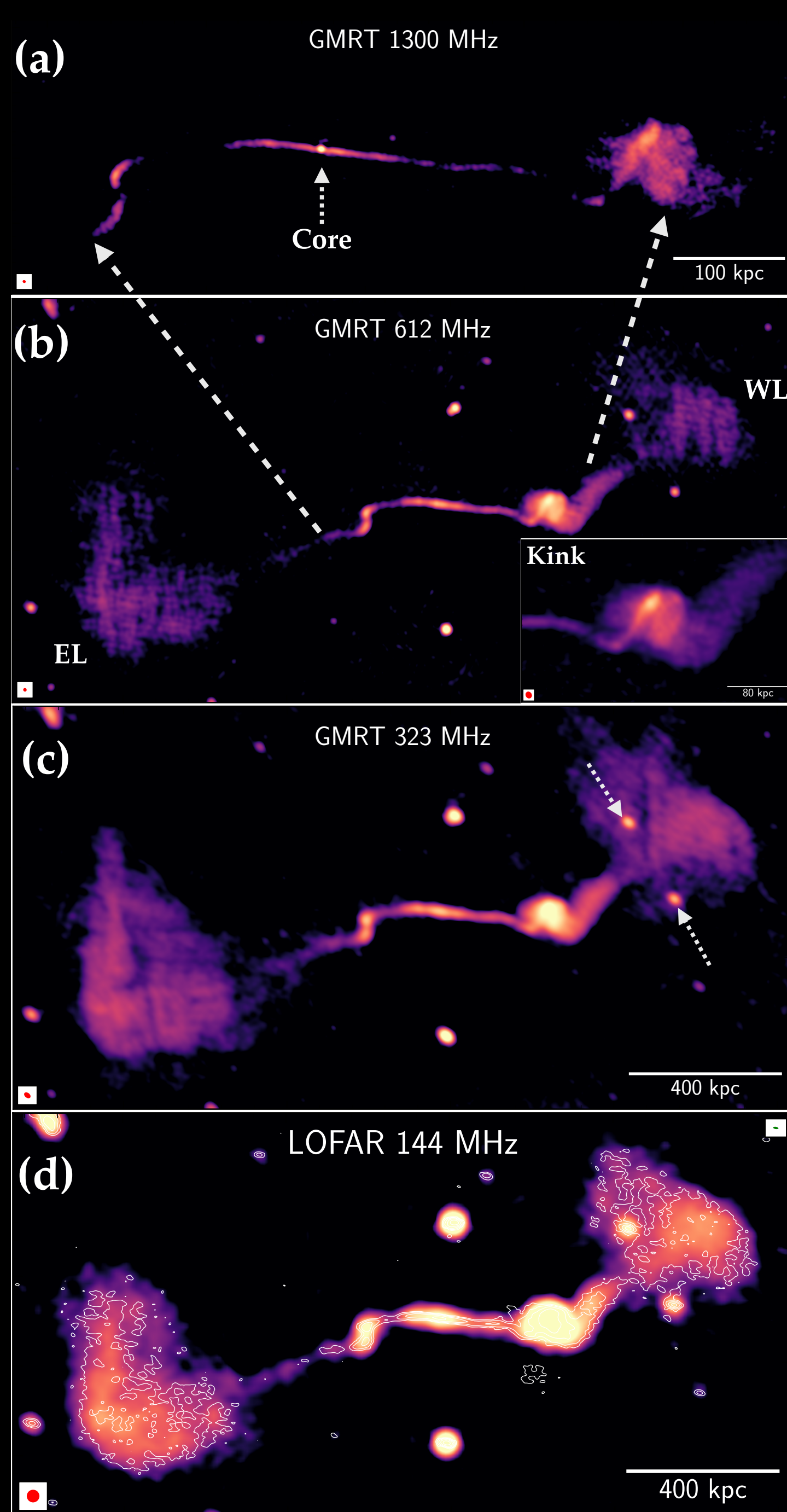
$\Omega$

Plasma Instability ?



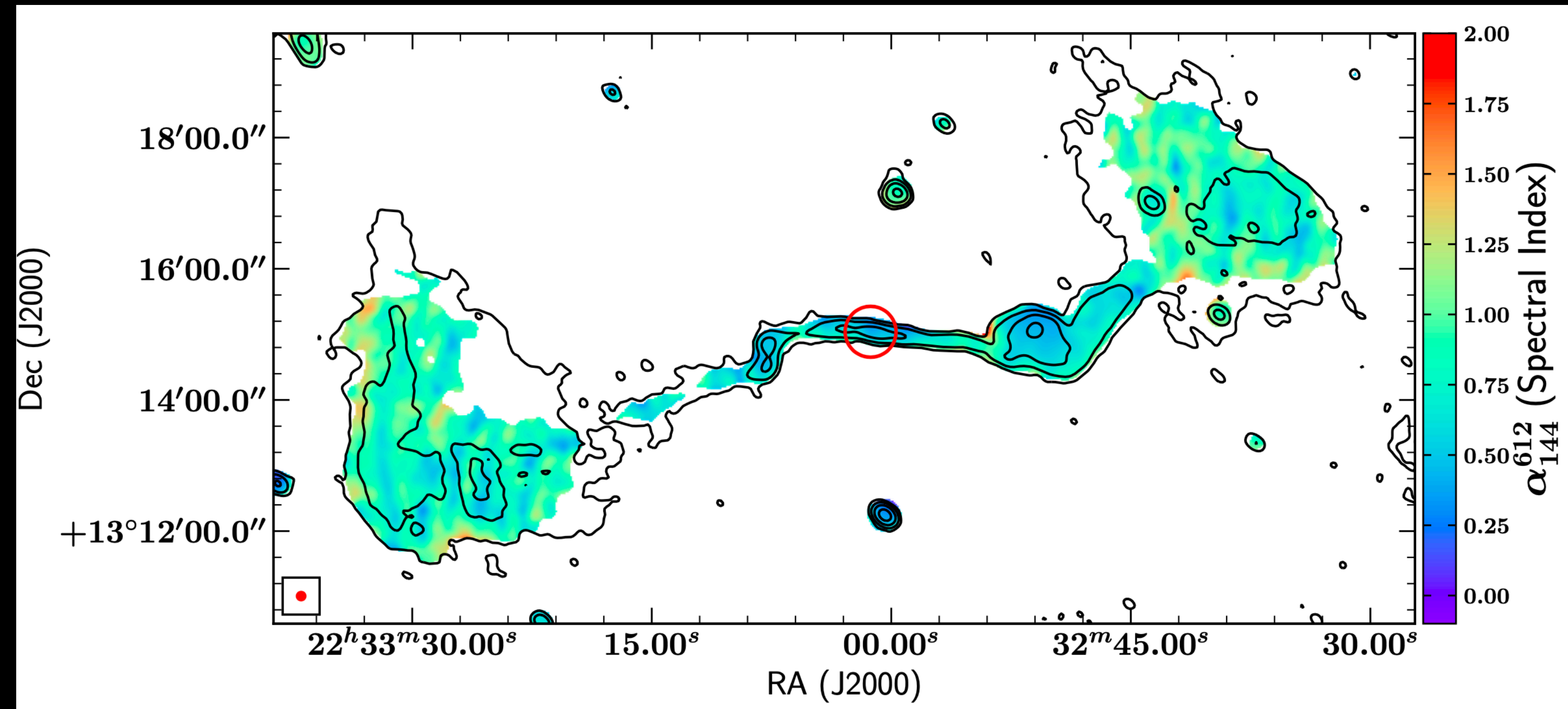
Dabhade et al. 2022 A&A 668, A64 (2022)





Data:  
LoFAR  
GMRT

Barbell GRG



Size = 1.8 Mpc

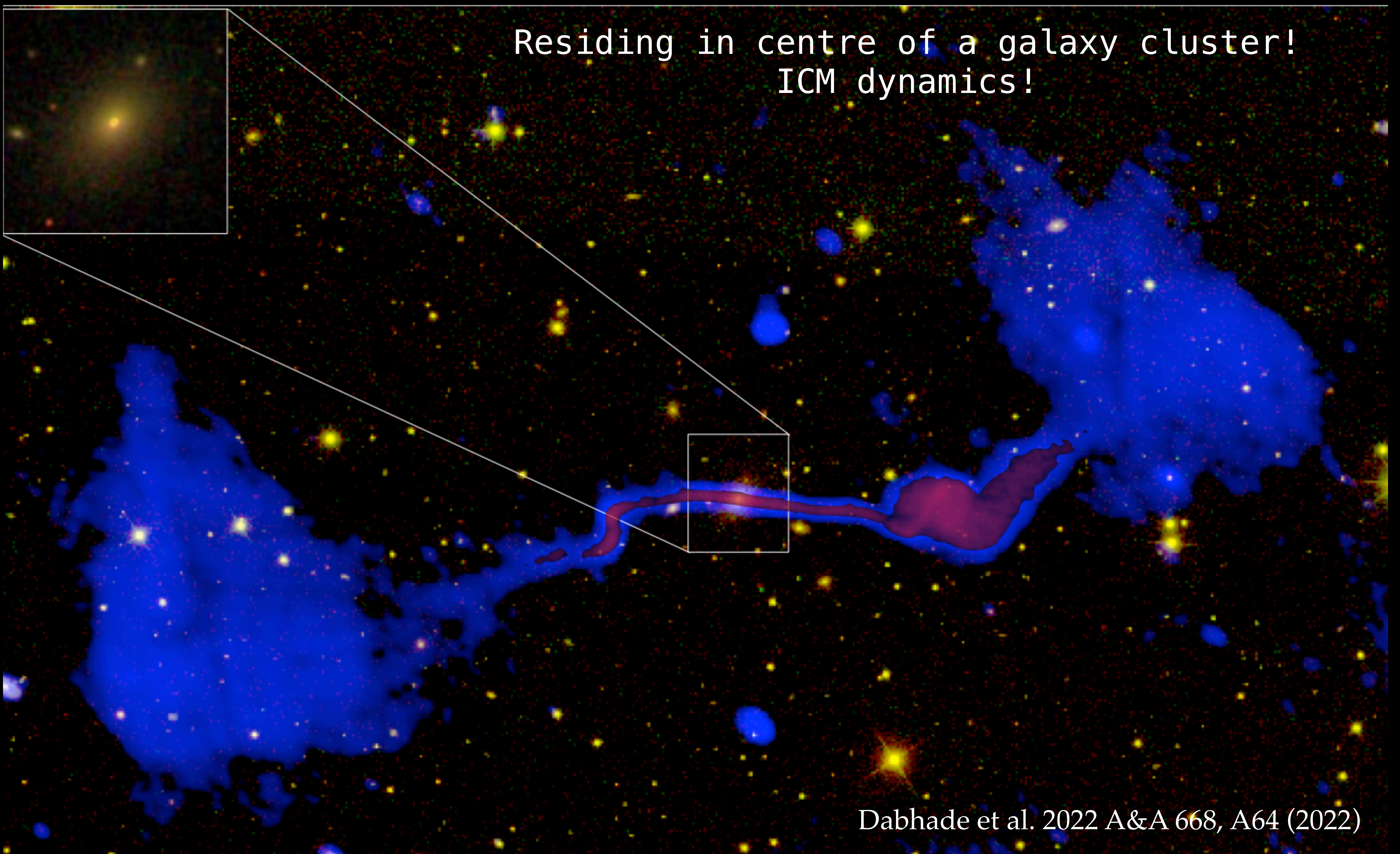
Age:  
~ 110 - 200 Myrs

Magnetic field:  
~ 5 micro Gauss

Dabhade et al. 2022 A&A 668, A64 (2022)



Residing in centre of a galaxy cluster!  
ICM dynamics!



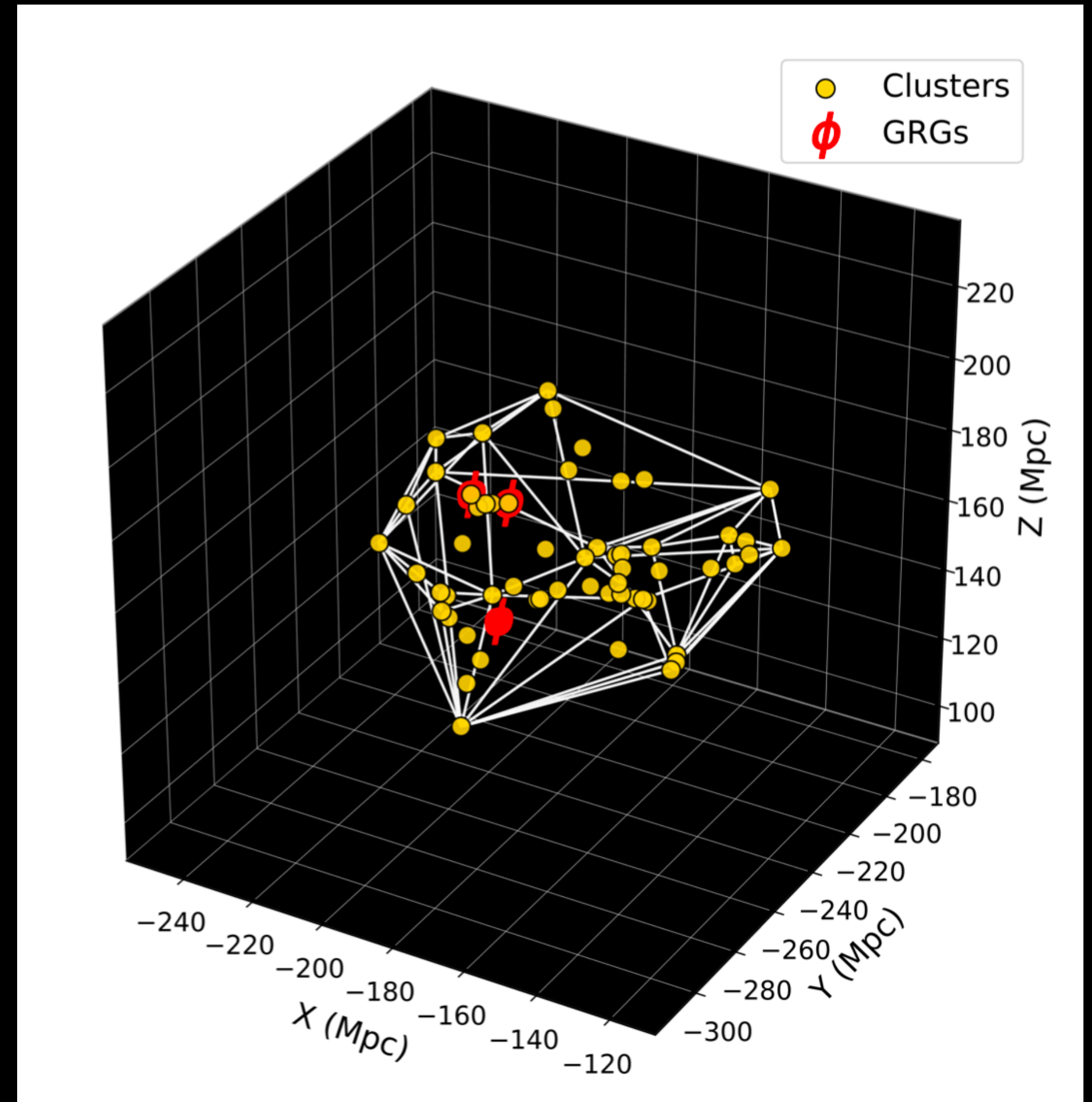
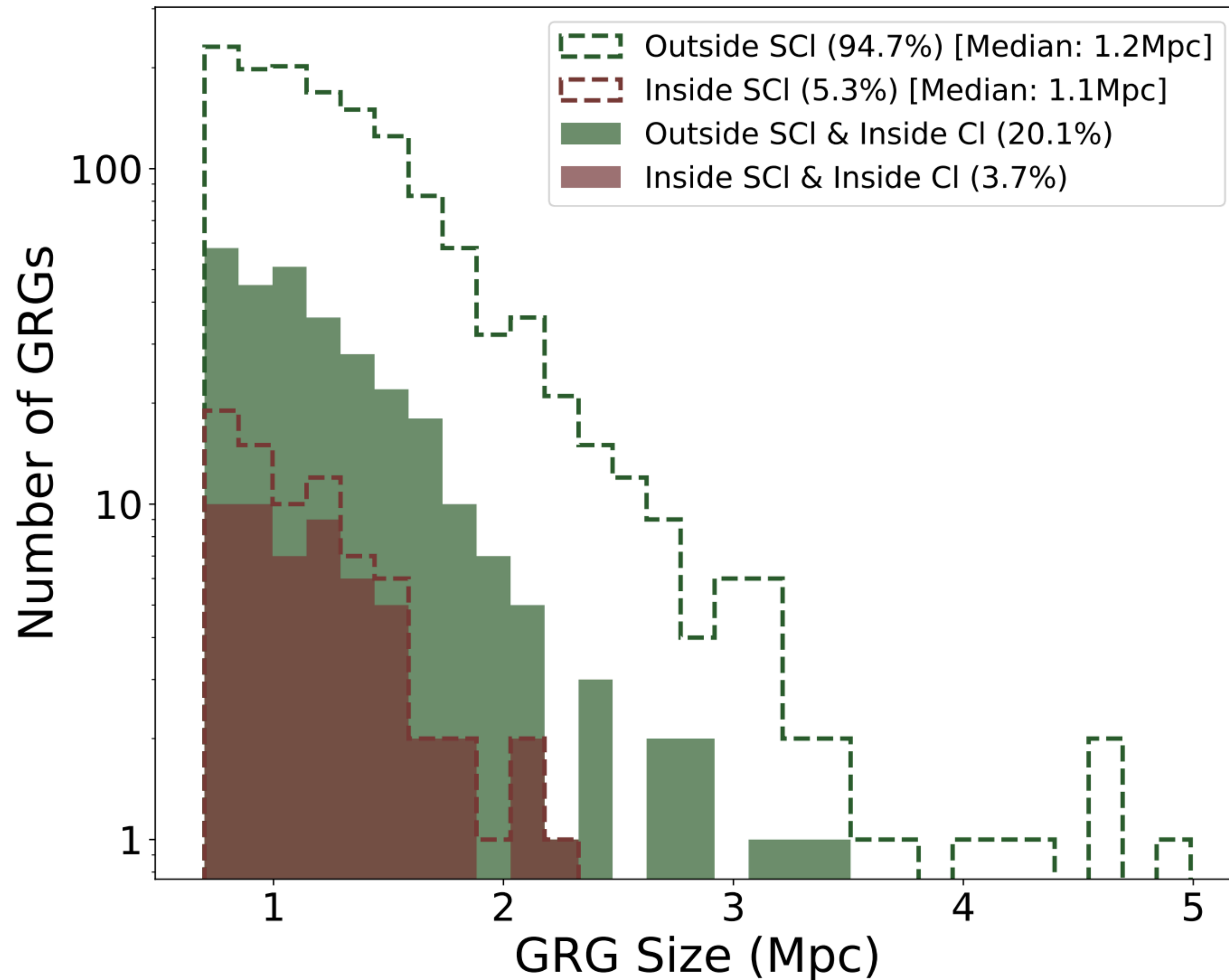


# Large-scale environment of Giants

## SAGAN-IV: Environment of GRGs and using them as probes

*Systematic study of GRGs in clusters, non-cluster and Supercluster environments*

~5% in Superclusters!  
24% in galaxy clusters!



Sankhyayan & Dabhade 2024 A&A



# SAGAN VI: When jets meet filaments

*Environmental imprints on the growth of giant radio galaxies*



## Sample & measurements



GRGs from Mostert et al. 2024 /  
LoTSS DR2



SDSS Bisous filament catalogue



$z \leq 0.155$ , SDSS footprint



final sample: **164** GRGs

**56** FR II GRGs

control: **51** FR II SRGs



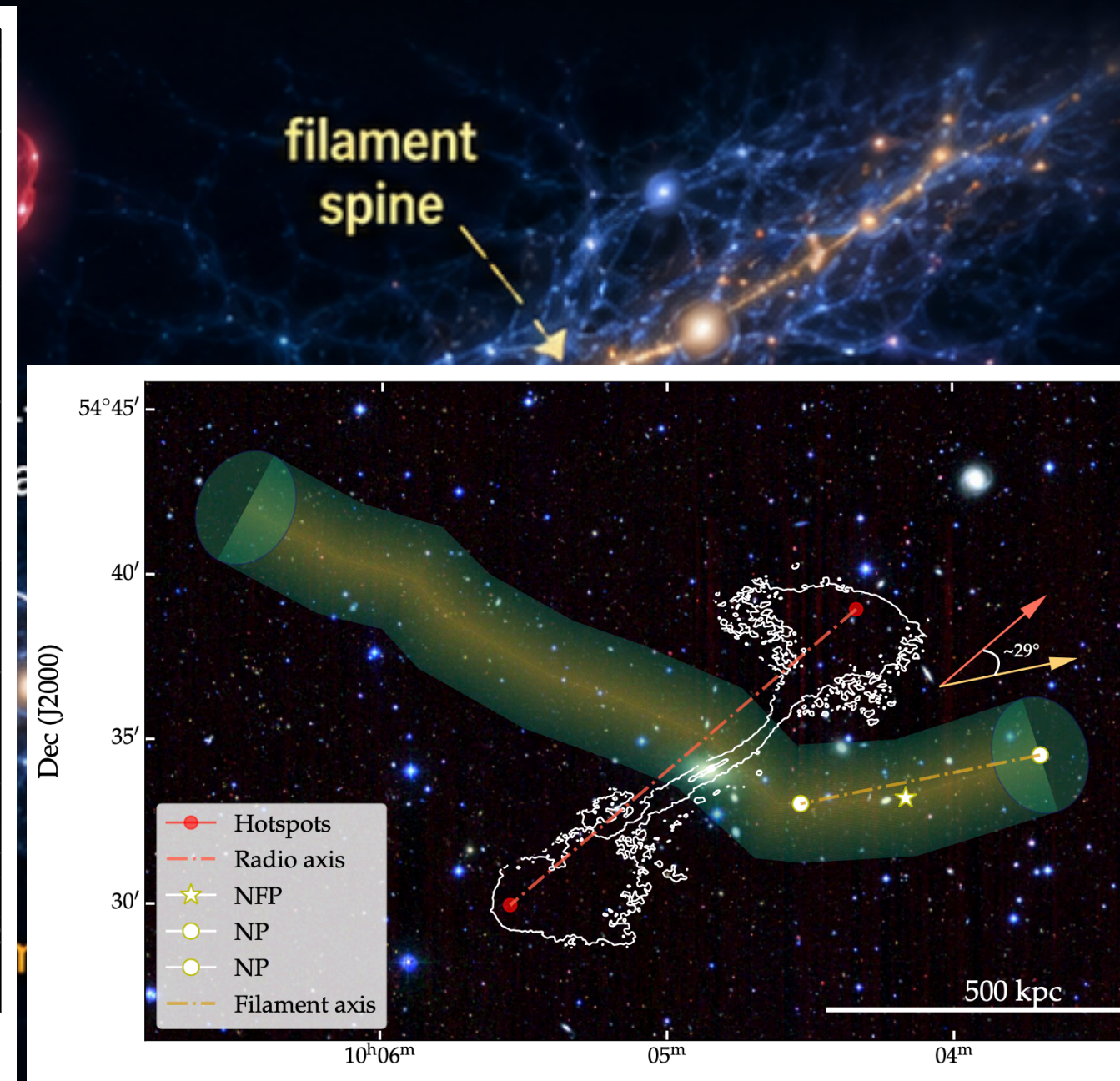
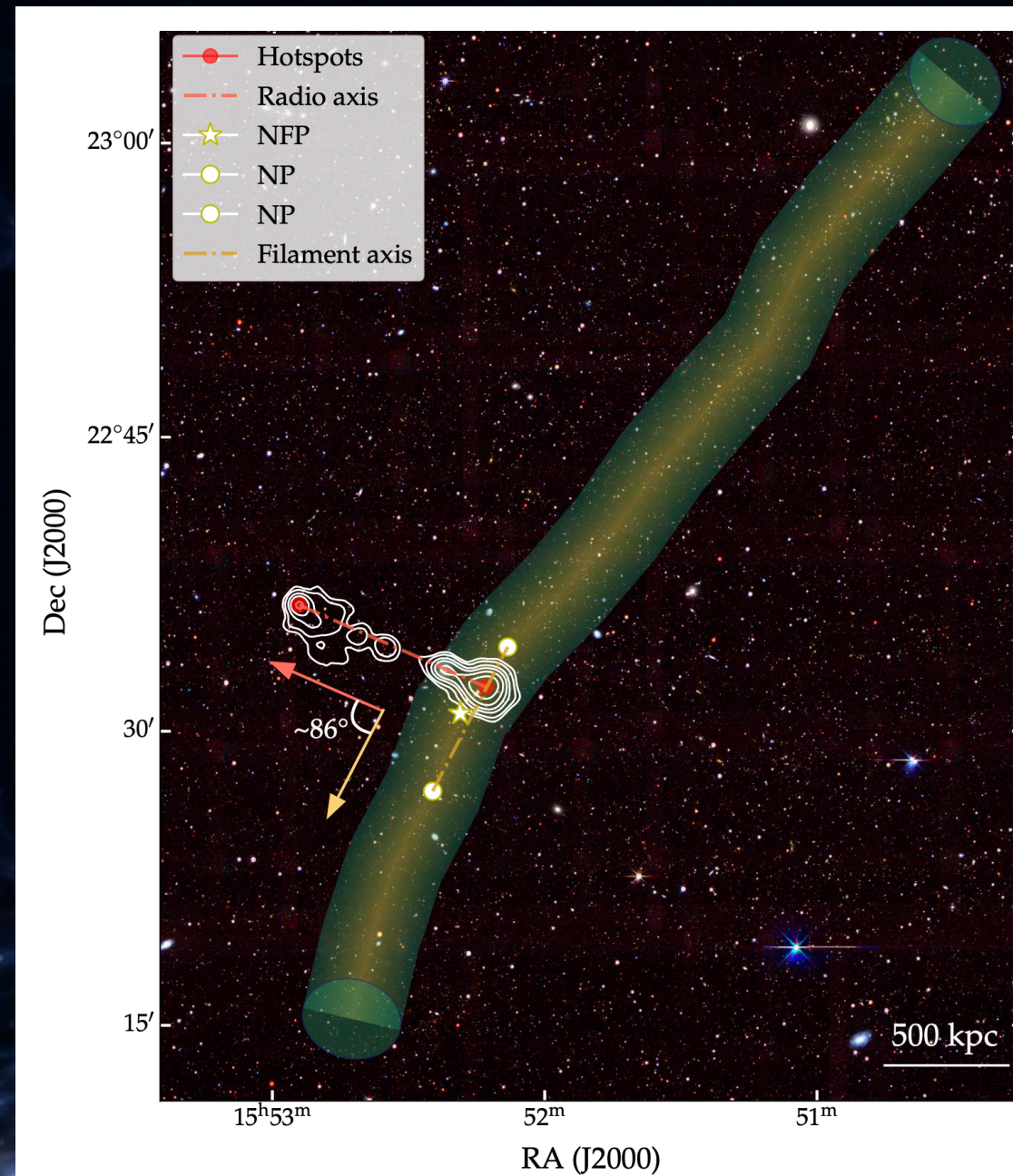
measured: 3D **distance** to  
nearest filament spine



measured: jet–spine  
orientation **angle**



measured: arm–length  
ratio (**ALR**)



## Key numbers

**1**

### Jet–filament alignment

**GRGs:** median **59°** within 5 Mpc;  
**65°** within 2 Mpc

**SRGs:** median **~42°**

**2**

### Filament proximity



no strong size–distance  
correlation



spatial excess within  
**~2 Mpc** of filament spines



## Main results



GRGs and SRGs have **similar**  
filament **occupancy**



GRG size is **not controlled**  
simply by proximity  
to filaments



FR II GRGs prefer **larger**  
jet–filament **angles**



SRG orientations are  
consistent with **random**  
**orientations**



FR II GRGs have **lower ALR**:  
stronger lobe **asymmetry**  
than FR II SRGs



Complex sources lie **closest**  
to filament spines;  
WATs/remnants tend  
farther out



**Key takeaway:** giant growth is linked **less** to **how close** a radio galaxy is to a filament,  
and **more** to **how its jets are oriented** within the filament's **anisotropic density field**.



# Stuardi et al. 2020

First large low-frequency polarisation study of giant radio galaxies

## 1 SAMPLE & DATA



240 GRGs



LoTSS  
120–168 MHz

+



NVSS  
1.4 GHz



RM synthesis

## 2 DETECTIONS

37

polarised GRGs  
detected

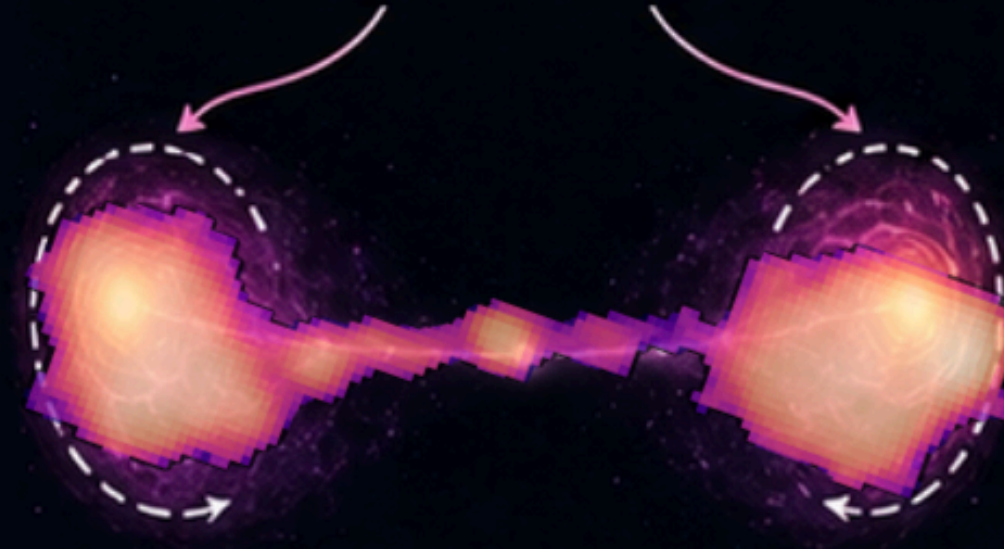


~20%

detection rate for  
 $S_{144} > 50$  mJy

## 3 WHERE IS THE POLARISED EMISSION?

Mostly from **hotspots**  
and **lobe edges**



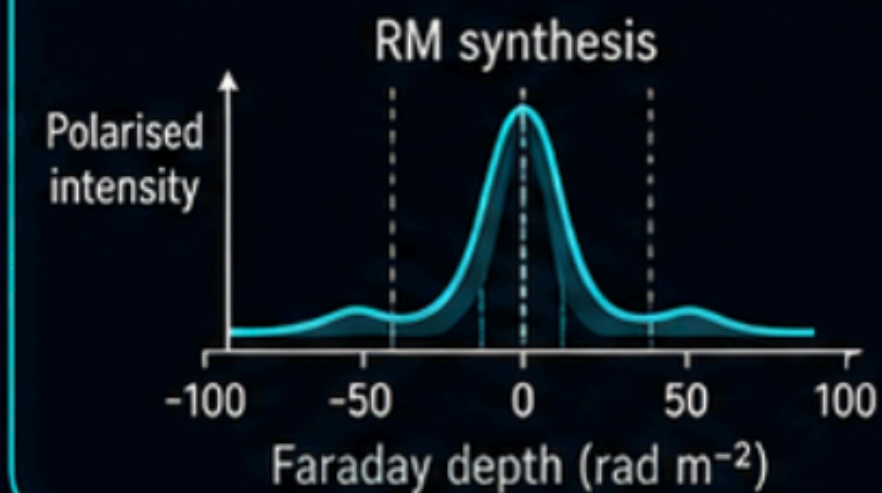
- Hotspots
- Lobe edges

## 4 FARADAY ROTATION

Median lobe-to-lobe

$\Delta RM \sim 1$   
 $\text{rad m}^{-2}$

Tiny RM differences  
detectable thanks to  
**LOFAR precision**



## 5 WHY IMPORTANT?



GRGs are ideal low-frequency  
**probes of rarefied magnetised environments**



# What did Stuardi et al. 2020 reveal?

## *GRGs as probes of intergalactic magnetic fields*



### 1. WEAK FARADAY DEPOLARISATION

Faraday dispersion

$$< 0.3 \text{ rad m}^{-2}$$



RM ( $\text{rad m}^{-2}$ )

-2 -1 0 +1 +2



Highly polarised emission retained over hundreds of kpc



### 2. ENVIRONMENT PROPERTIES



Electron density

$$n_e < 10^{-5} \text{ cm}^{-3}$$



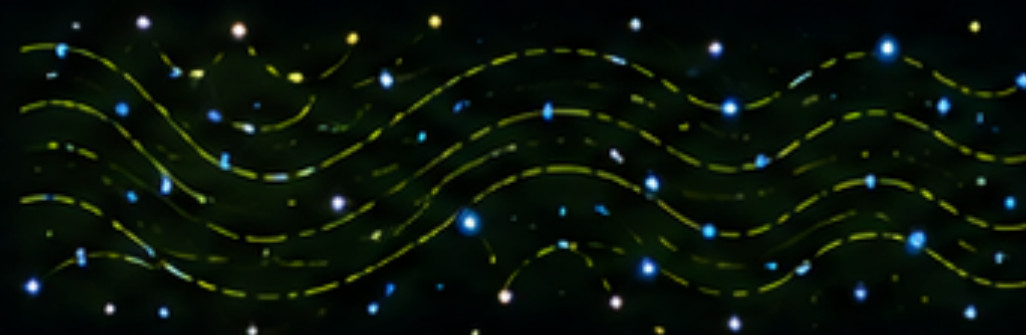
Magnetic field strength

$$B < 0.1 \text{ } \mu\text{G}$$



Fluctuation scales

$$3\text{--}25 \text{ kpc}$$



Diffuse, tangled magnetised medium



### 3. FOREGROUND CLUSTER EFFECT



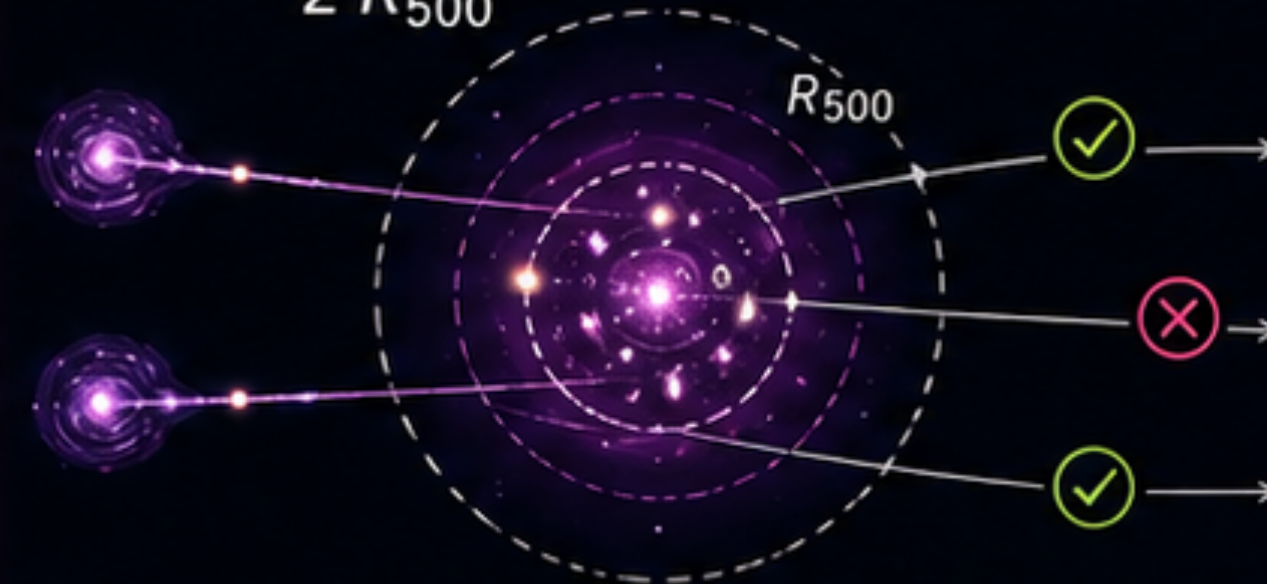
Polarisation detection is suppressed near clusters



Effect seen out to  $\sim 2 R_{500}$



GRGs are  $\sim 3\times$  more likely to be detected outside  $2 R_{500}$



✓ Higher detection probability ✗ Suppressed detection



### 4. INTERPRETATION

Lobes expand into **very low-density, weakly magnetised** environments





# Using Giants as probes

A&A 622, A16 (2019)

<https://doi.org/10.1051/0004-6361/201833832>

© ESO 2019

**Astronomy  
&  
Astrophysics**

Special issue

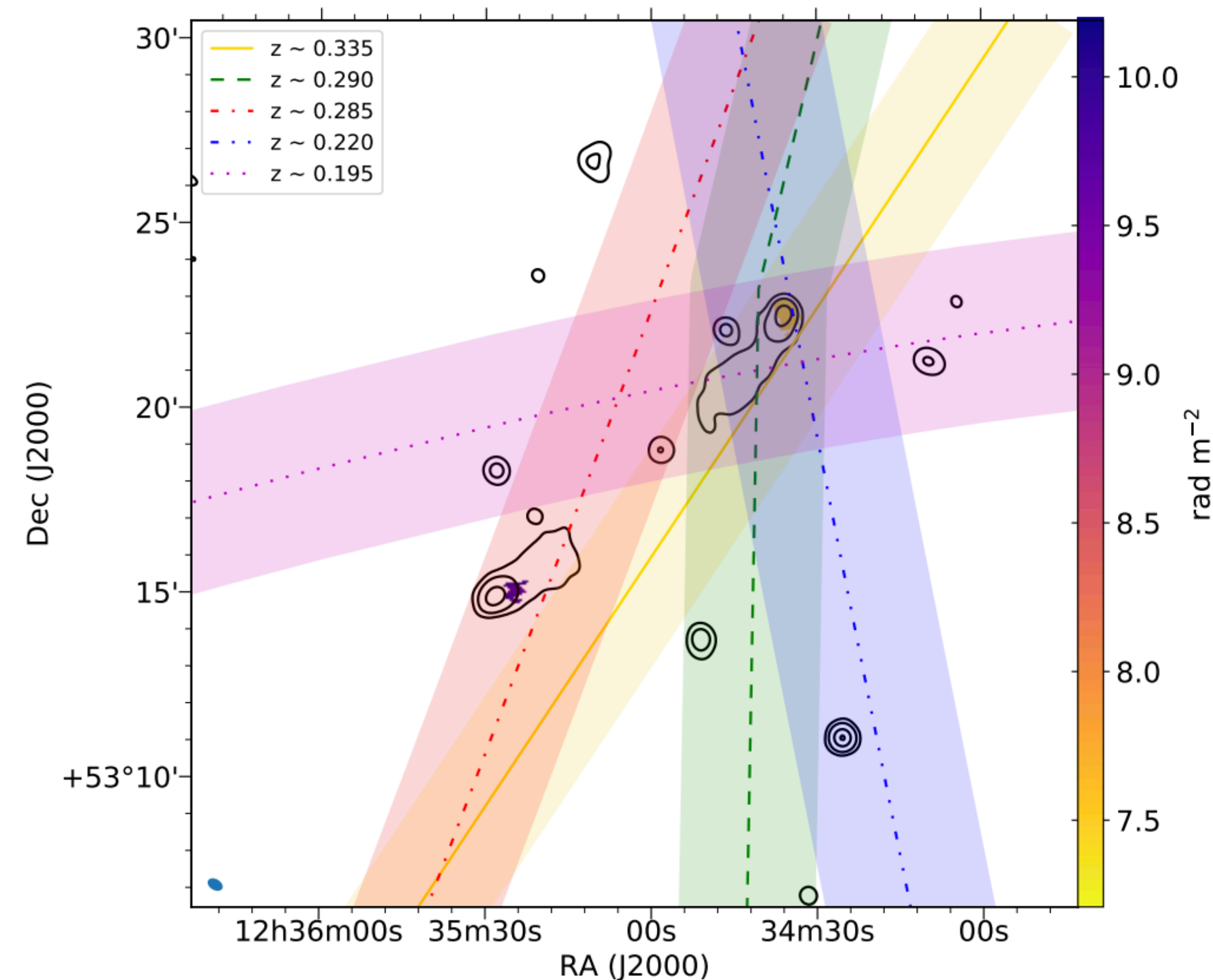
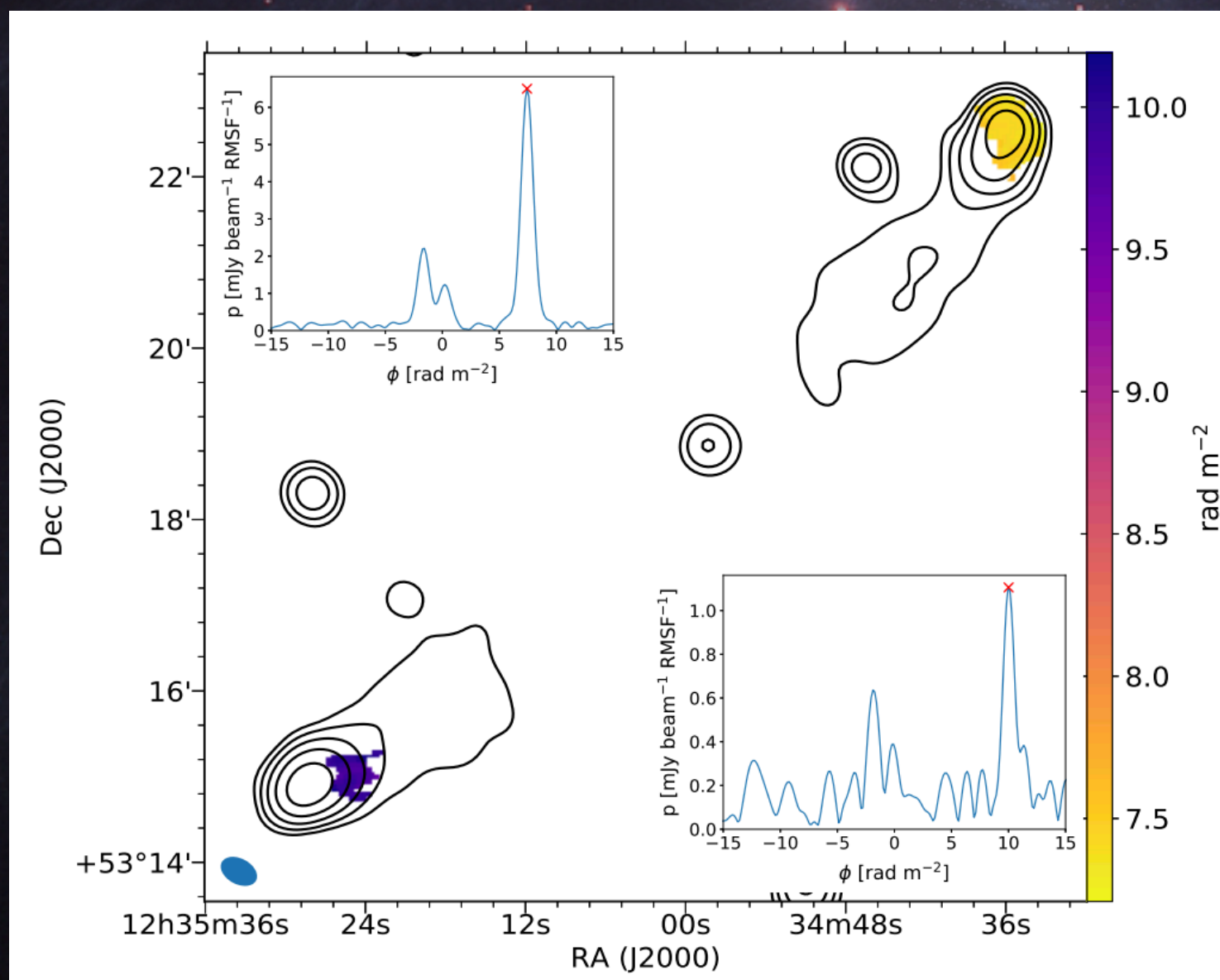
*LOFAR Surveys: a new window on the Universe*

## The intergalactic magnetic field probed by a giant radio galaxy

S. P. O'Sullivan<sup>1</sup>, J. Machalski<sup>2</sup>, C. L. Van Eck<sup>3</sup>, G. Heald<sup>4</sup>, M. Brüggen<sup>1</sup>, J. P. U. Fynbo<sup>5</sup>, K. E. Heintz<sup>6</sup>,  
M. A. Lara-Lopez<sup>7</sup>, V. Vacca<sup>8</sup>, M. J. Hardcastle<sup>9</sup>, T. W. Shimwell<sup>10,11</sup>, C. Tasse<sup>12,13</sup>, F. Vazza<sup>14,1,19</sup>, H. Andernach<sup>15</sup>,  
M. Birkinshaw<sup>16</sup>, M. Haverkorn<sup>17</sup>, C. Horellou<sup>18</sup>, W. L. Williams<sup>9</sup>, J. J. Harwood<sup>9</sup>, G. Brunetti<sup>19</sup>, J. M. Anderson<sup>20</sup>,  
S. A. Mao<sup>21</sup>, B. Nikiel-Wroczyński<sup>2</sup>, K. Takahashi<sup>22</sup>, E. Carretti<sup>19</sup>, T. Vernstrom<sup>23</sup>, R. J. van Weeren<sup>11</sup>, E. Orrú<sup>10</sup>,  
L. K. Morabito<sup>24</sup>, and J. R. Callingham<sup>10</sup>

*(Affiliations can be found after the references)*

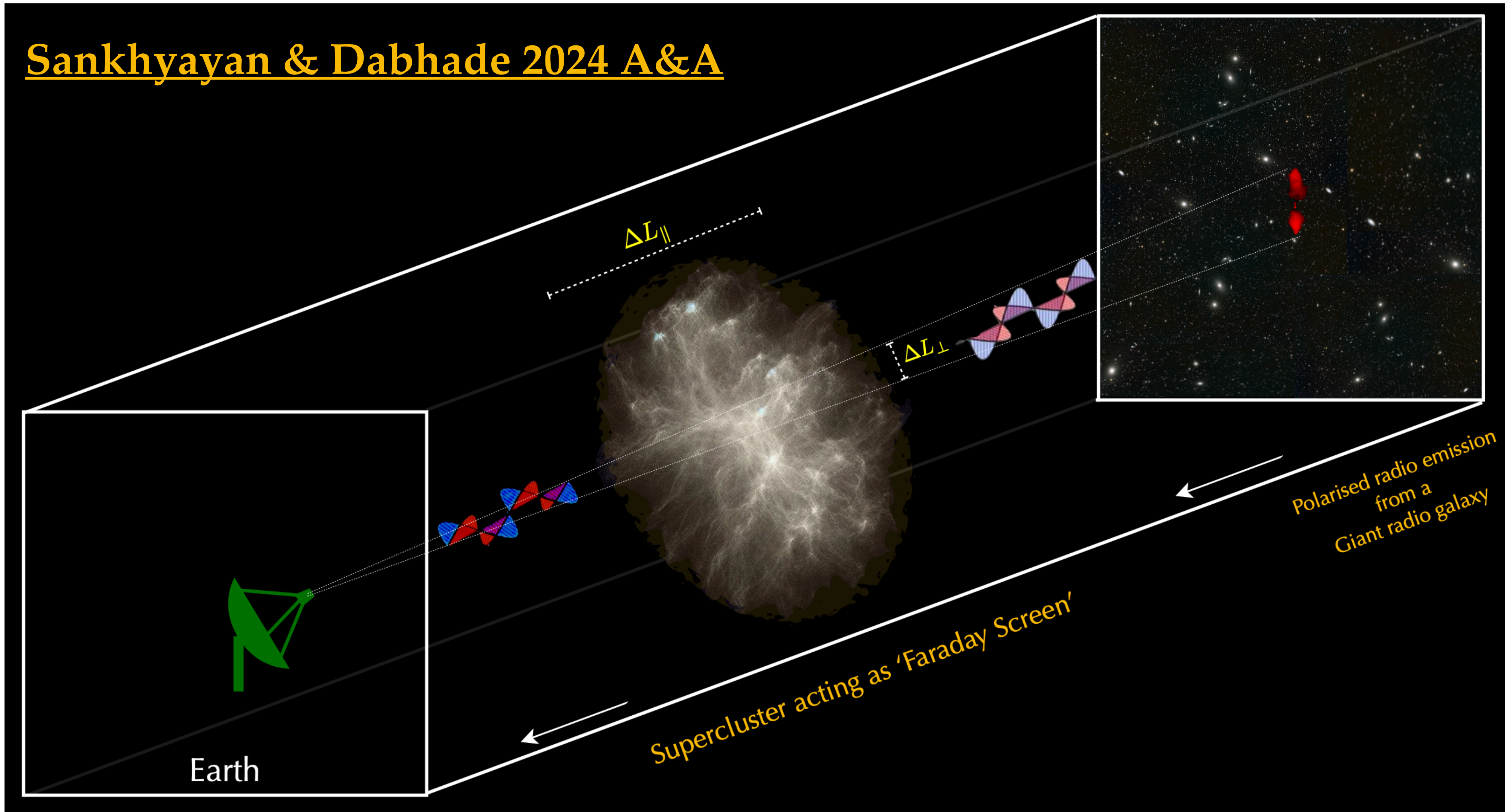
Received 12 July 2018 / Accepted 9 October 2018





# Using Giants as probes

Sankhyayan & Dabhade 2024 A&A

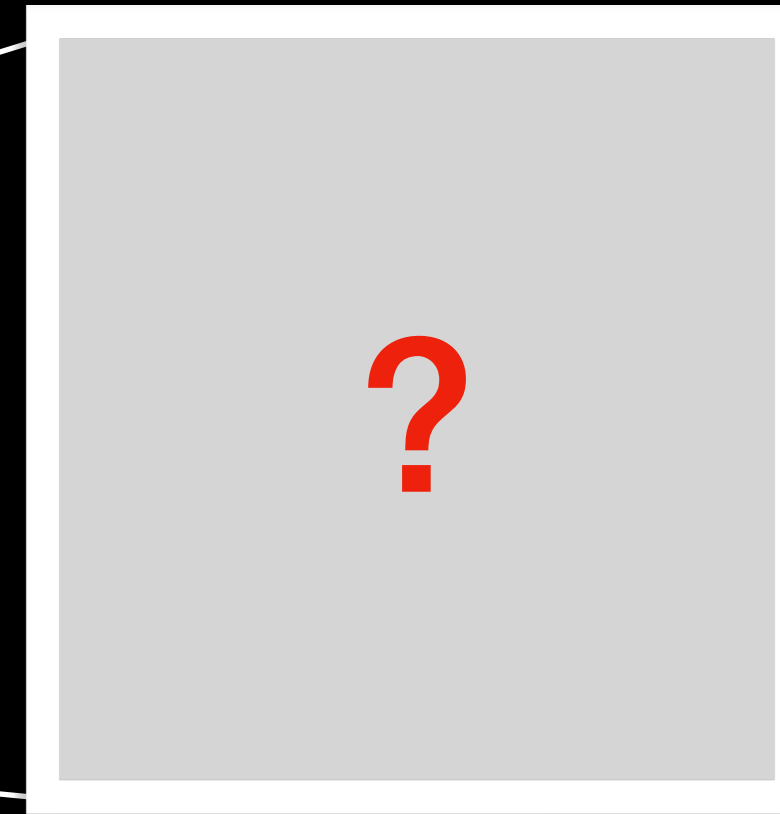
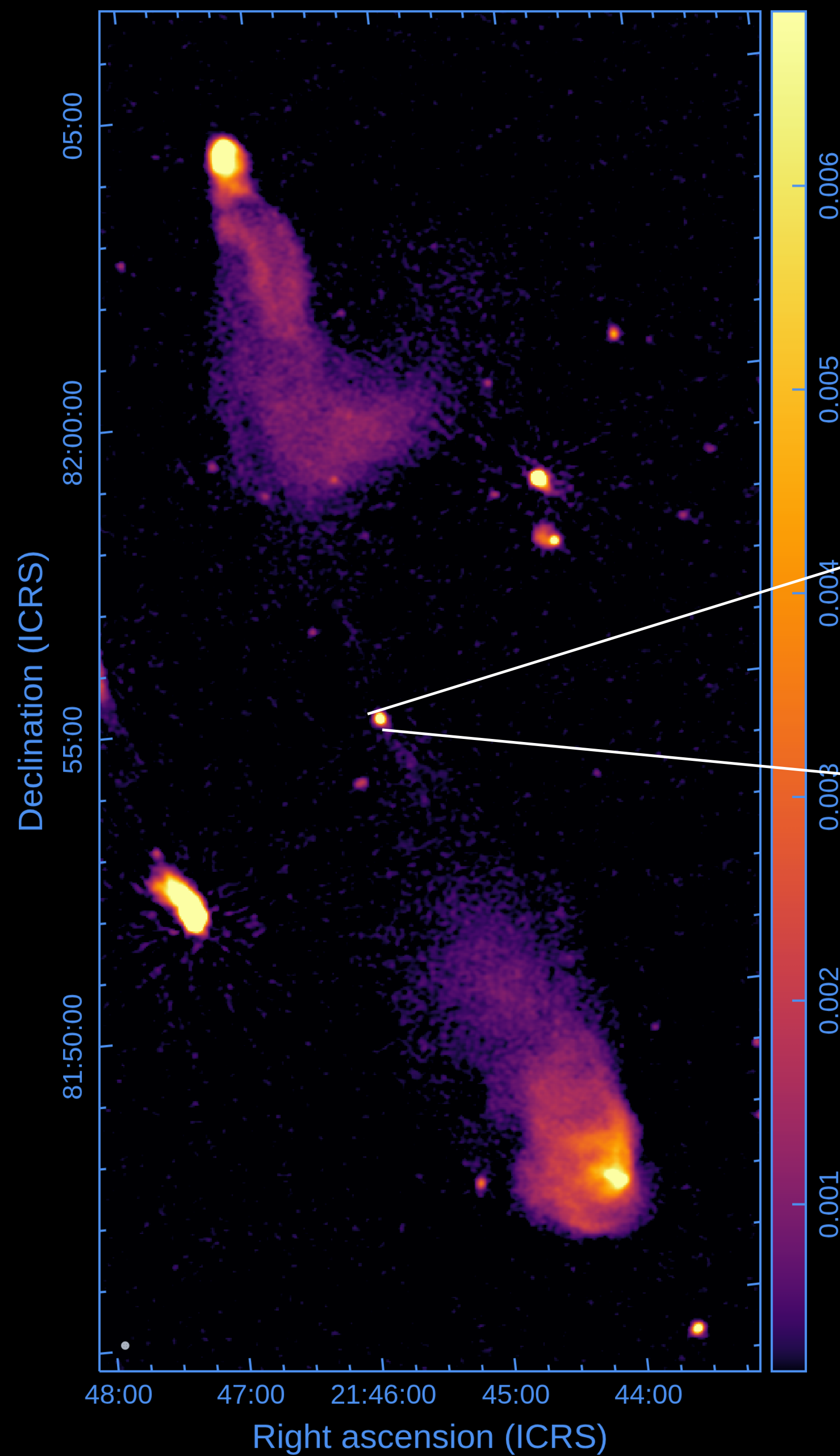


**Fig. D.1.** Polarised light propagation through the supercluster's magneto-ionic medium, illustrating the resultant Faraday rotation prior to detection by terrestrial telescopes (see Sect. 5).

Sub-micro gauss magnetic field in intra-supercluster medium !



# Probing Sub-kpc structure of core-jet with LOFAR-VLBI



See Sagar Sethi's talk  
on Wednesday

On-going work



# What have we learnt about GRGs?

**GRGs are no longer rare curiosities, they are a statistical population**

- Defined as radio galaxies/quasars with projected sizes  $>0.7$  Mpc
- They represent the **largest jet-driven structures produced by SMBHs**
- Known population has grown from a few dozen to  $>10^4$  candidates/confirmed systems in the LOFAR era
- Low-frequency surveys, especially **LOFAR Surveys**, revealed many faint, diffuse and low-surface-brightness giants
- Most GRGs are **FR-II-like**, but the population includes FR-I, hybrid, restarted, remnant and complex systems
- GRGs are associated with both **galaxies and quasars**, with GRQs generally tracing more powerful central engines
- Integrated spectral properties and black-hole masses are broadly similar to normal-sized radio galaxies
- GRGs do not require one preferred accretion mode: both **HERGs and LERGs** can grow to giant scales



# What drives giant growth?

## Giant size is not controlled by one parameter

- GRG growth likely requires a combination of:  
**jet power + lifetime/duty cycle + accretion state + environment**
- High-excitation GRGs tend to be **larger and more powerful**, with higher radio power, jet kinetic power and Eddington ratios.
- Sparse environments help jets expand to the largest sizes, especially for **>3 Mpc** systems
- GRGs can grow in dense environments: a significant fraction of GRGs are found in groups, clusters and superclusters
- Recent environmental work shows that **low-density environments are not a strict prerequisite** for luminous GRGs
- GRGs can therefore be regular members of the radio-galaxy population, not necessarily a special class with one unique formation path
- Their huge lobes make them useful probes of the **IGM, cosmic web, WHIM, feedback and large-scale magnetic fields.**



# Future outlook

**Main idea:** LOFAR Surveys have revealed thousands of giants.

*The next challenge is to build complete, uniform samples and turn them into physical measurements.*

**Key questions for the next phase:**

**-How many more GRGs are hidden in LoTSS DR3?**

Should enable the most complete northern-sky GRG search so far.

**-How many high-redshift GRGs exist?**

With full DR3 coverage, better host identification and deeper optical/IR data, we can test whether Mpc-scale jets were already common at earlier cosmic epochs.

**-Can we build a genuinely complete GRG sample & the GRG luminosity function?**

Uniform radio properties, host IDs, redshifts and selection limits can unlock the GRG luminosity function, size function, space density and cosmic evolution.

**-Can LOFAR-VLBI reveal the engines inside the giants?**

High-resolution LOFAR-VLBI can identify compact cores, young restarted jets, mini-doubles, DDRGs and ambiguous hosts, linking parsec/kpc-scale activity to Mpc-scale lobes.

**-Can GRGs become cosmic-web probes?**

Combining LoTSS DR3 with spectroscopy, photometric redshifts, clusters, filaments, RM grids and simulations will let us use GRGs to probe feedback, WHIM, magnetisation and environment.





Thank you