

RADIO GALAXIES IN ABELL 2255: INSIGHTS FROM LOFAR-VLBI

E. DE RUBEIS, UNIVERSITÀ DI BOLOGNA & INAF-IRA (BOLOGNA)

COLLABORATORS:

M. BONDI, A. BOTTEON, G. BRUNETTI, R. VAN WEEREN, ET AL.

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LOFAR AND LONG BASELINES

- 38 stations in the Netherlands
- 14 “international” stations, 3 in Poland



What can we achieve with long baselines?

- ✓ ~0.3" resolution at 150 MHz
- ✓ The IS cover a larger geographic area with respect to the CS and RS

But, it is not all sunshine and rainbows!



LOFAR-VLBI ISSUES AND SOLUTION

- Bad ionospheric effects, and different throughout the IS
- Offsets in clock values
- IS have different station beams with respect to CS and RS, limited FoV
- Dispersive delays introduced by the ionosphere
- Source structure of the calibrators
- Huge amount of data

And so, how can we use them?



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**Astronomy
&
Astrophysics**

Sub-arcsecond imaging with the International LOFAR Telescope

Special issue

Sub-arcsecond imaging with the International LOFAR Telescope

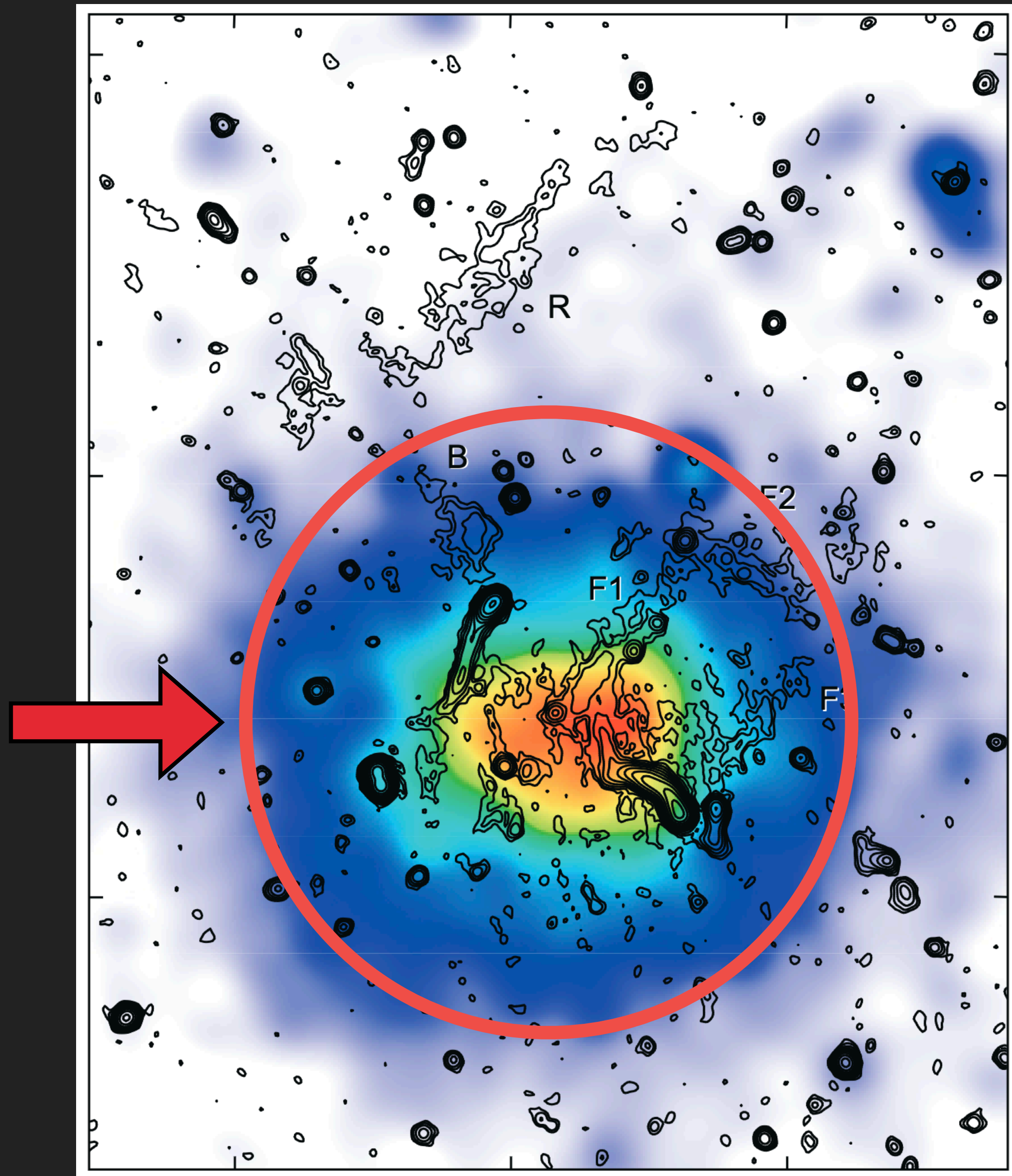
I. Foundational calibration strategy and pipeline

L. K. Morabito^{1,2}, N. J. Jackson³, S. Mooney⁴, F. Sweijen⁵, S. Badole³, P. Kukreti^{6,7}, D. Venkattu⁸, C. Groeneveld⁵, A. Kappes⁹, E. Bonnassieux¹⁰, A. Drabent¹¹, M. Iacobelli⁷, J. H. Croston¹², P. N. Best¹³, M. Bondi¹⁴, J. R. Callingham^{5,7}, J. E. Conway¹⁵, A. T. Deller¹⁶, M. J. Hardcastle¹⁷, J. P. McKean^{7,6}, G. K. Miley⁵, J. Moldon¹⁸, H. J. A. Röttgering⁵, C. Tasse^{19,20}, T. W. Shimwell^{7,5}, R. J. van Weeren⁵, J. M. Anderson^{21,22}, A. Asgekar^{7,23}, I. M. Avruch^{7,24}, I. M. van Bemmelen²⁵, M. J. Bentum^{7,26}, A. Bonafede^{27,14,28}, W. N. Brouw⁶, H. R. Butcher²⁹, B. Ciardi³⁰, A. Corstanje^{31,32}, A. Coolen⁷, S. Damstra⁷, F. de Gasperin^{28,14}, S. Duscha⁷, J. Eislöffel¹¹, D. Engels²⁸, H. Falcke³², M. A. Garrett^{3,5}, J. Griessmeier^{33,34}, A. W. Gunst⁷, M. P. van Haarlem⁷, M. Hoeft¹¹, A. J. van der Horst^{35,36}, E. Jütte³⁷, M. Kadler⁹, L. V. E. Koopmans⁶, A. Krankowski³⁸, G. Mann³⁹, A. Nelles^{40,41}, J. B. R. Oonk⁴², E. Orru⁷, H. Paas⁴³, V. N. Pandey⁷, R. F. Pizzo⁷, M. Pandey-Pommier⁴⁴, W. Reich⁴⁵, H. Rothkaehl⁴⁶, M. Ruiter⁷, D. J. Schwarz⁴⁷, A. Shulevski^{5,48}, M. Soida⁴⁹, M. Tagger³³, C. Vocks³⁹, R. A. M. J. Wijers⁴⁸, S. J. Wijnholds⁷, O. Wucknitz⁴⁵, P. Zarka^{50,34}, and P. Zucca⁷

(Affiliations can be found after the references)

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ABELL 2255

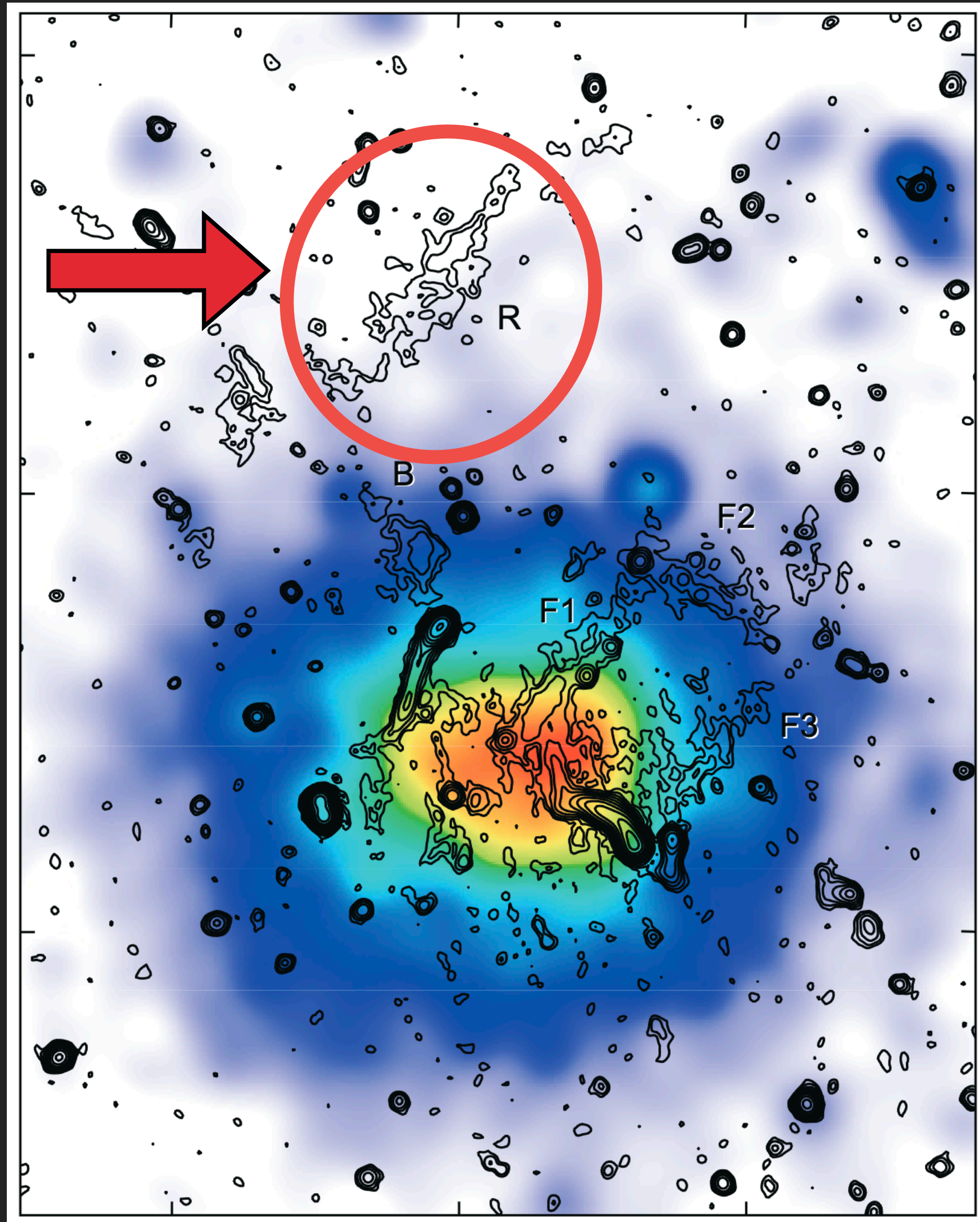


Abell 2255 is a nearby ($z=0.0806$) merging galaxy cluster

It shows a complex morphology from a radio point of view, with the presence of

- a **radio halo**

ABELL 2255

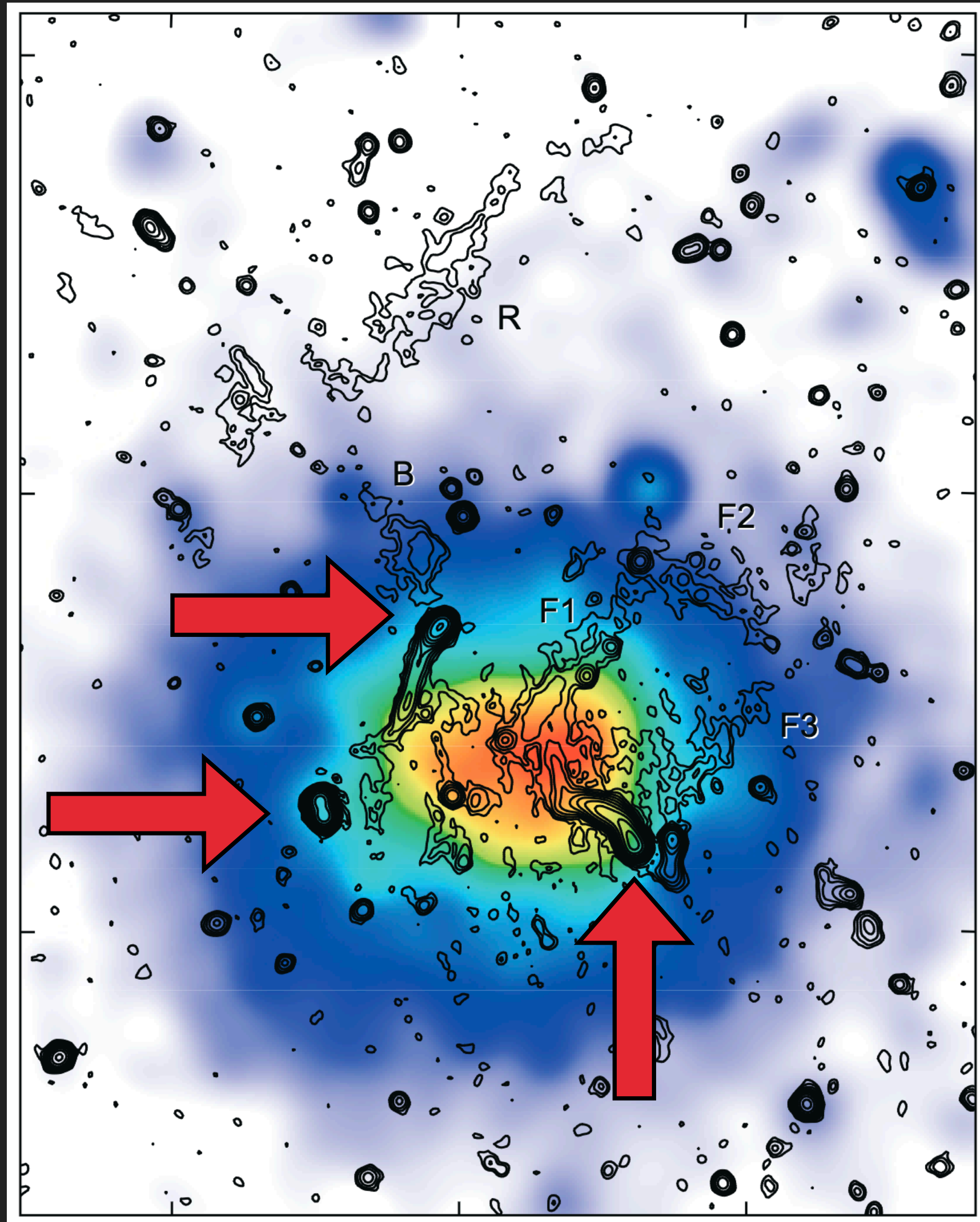


Abell 2255 is a nearby ($z=0.0806$) merging galaxy cluster

It shows a complex morphology from a radio point of view, with the presence of

- ▶ a **radio halo**
- ▶ a **radio relic**

ABELL 2255



Abell 2255 is a nearby ($z=0.0806$) merging galaxy cluster

It shows a complex morphology from a radio point of view, with the presence of

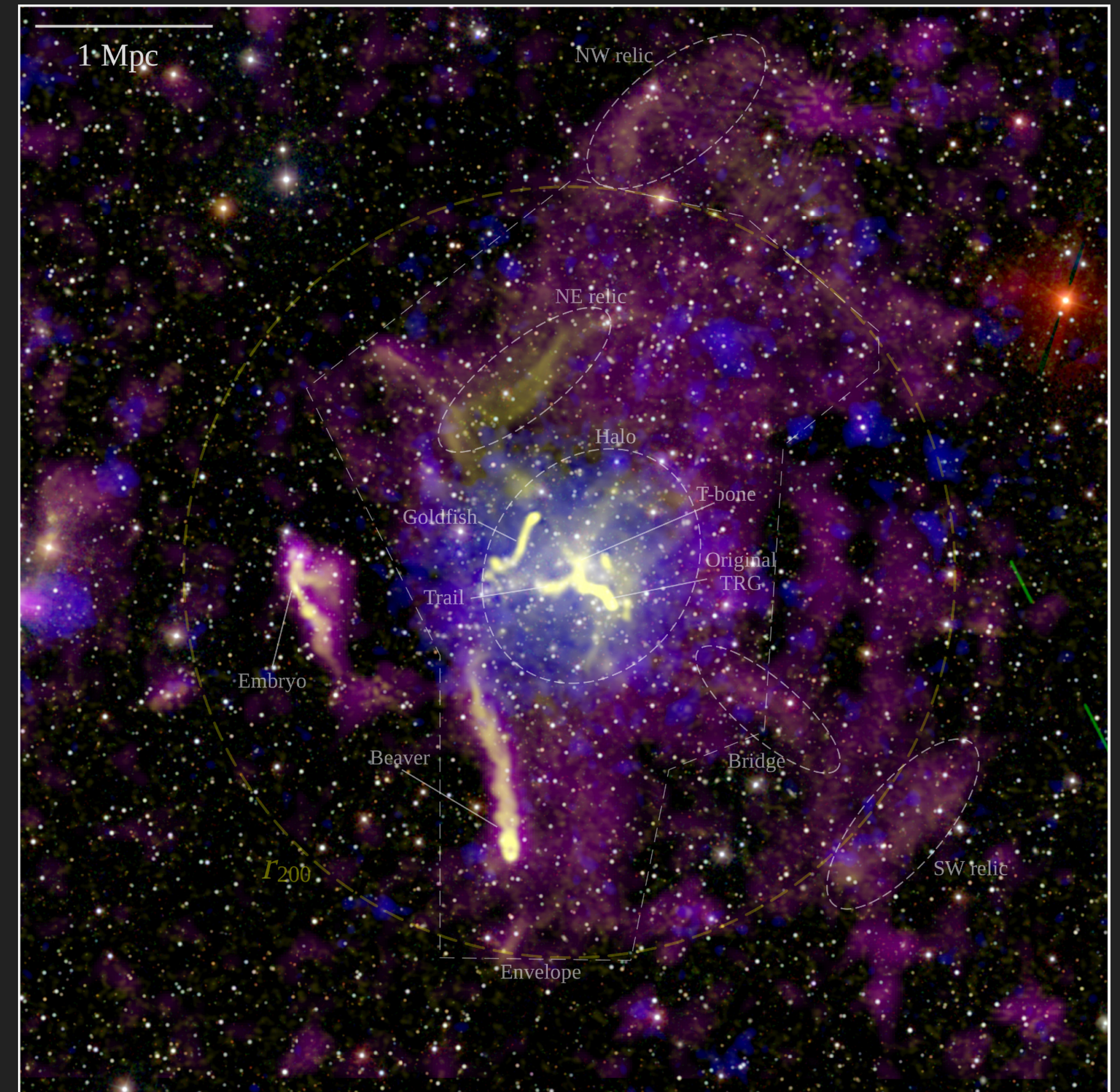
- ▶ a **radio halo**
- ▶ a **radio relic**
- ▶ **several radio galaxies** embedded in the cluster environment

ABELL 2255

Deep LOFAR observations made by Botteon et al. (up to **75h** in 2022) revealed

- ▶ High complexity of the radio emission on multiple scales
- ▶ Radio synchrotron emission distributed on at least 5 Mpc scales
- ▶ Additional relics detected in northwest and southwest peripheral regions

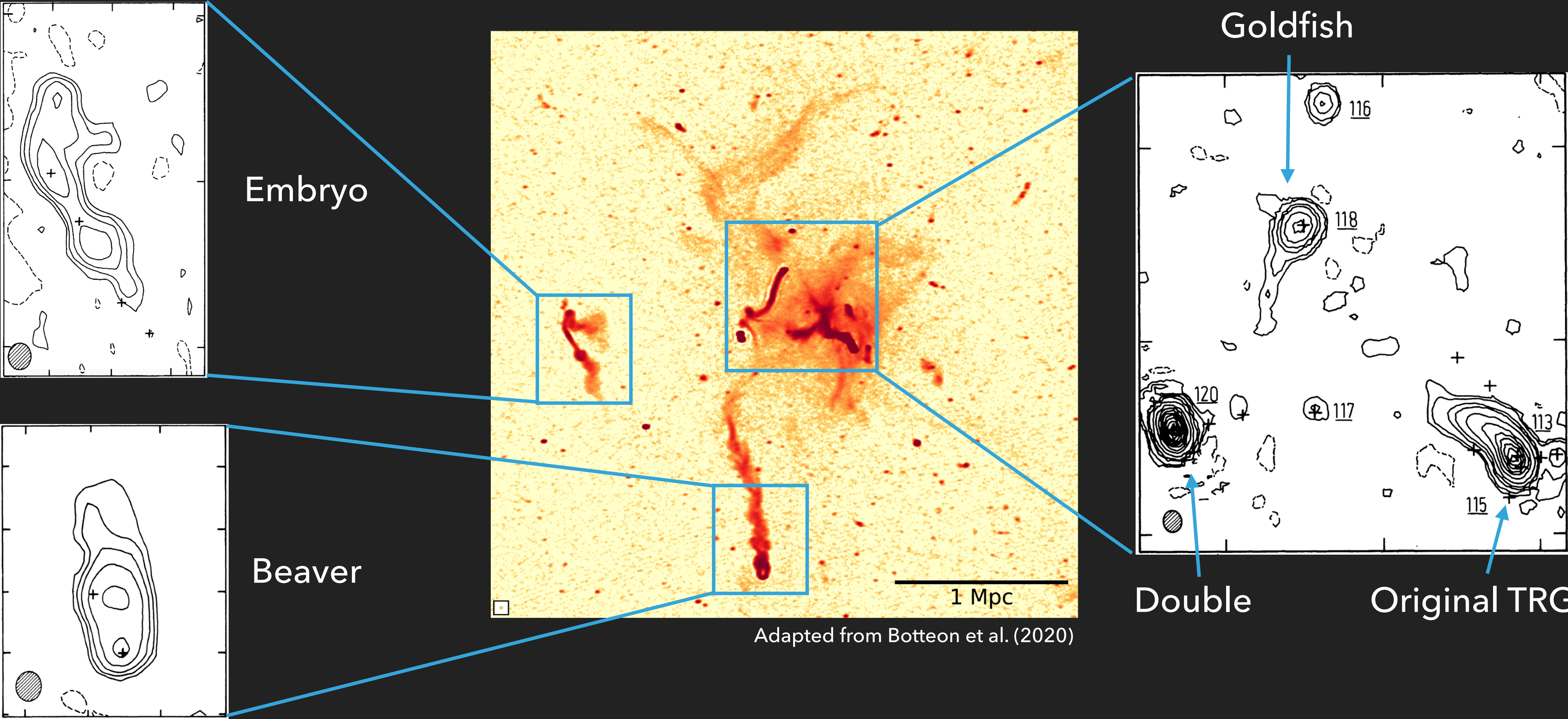
But what about radio galaxies?



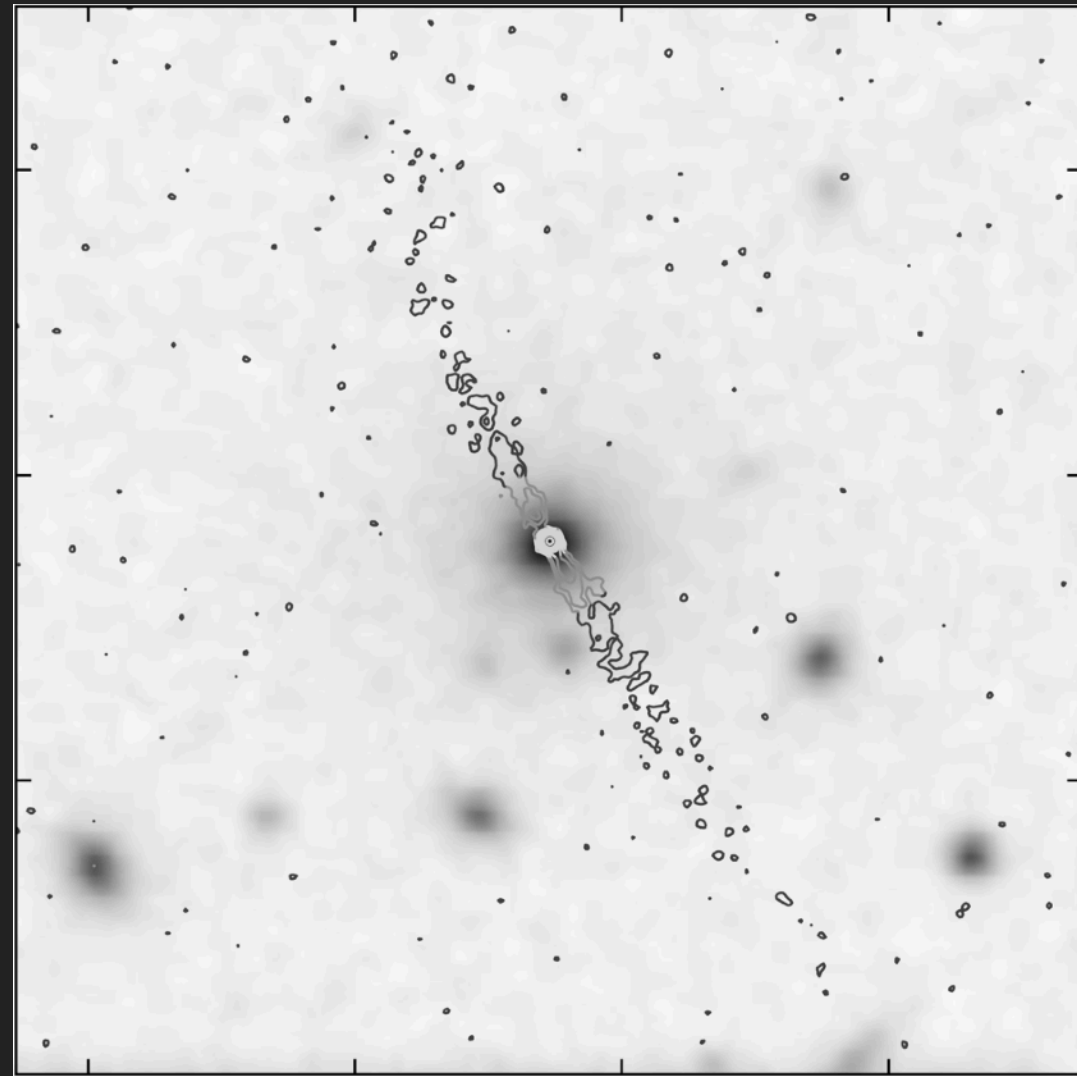
Adapted from Botteon et al. (2022)

ABELL 2255 – RADIO GALAXIES

1415 MHz maps of A2255 with WSRT at 25"x28"

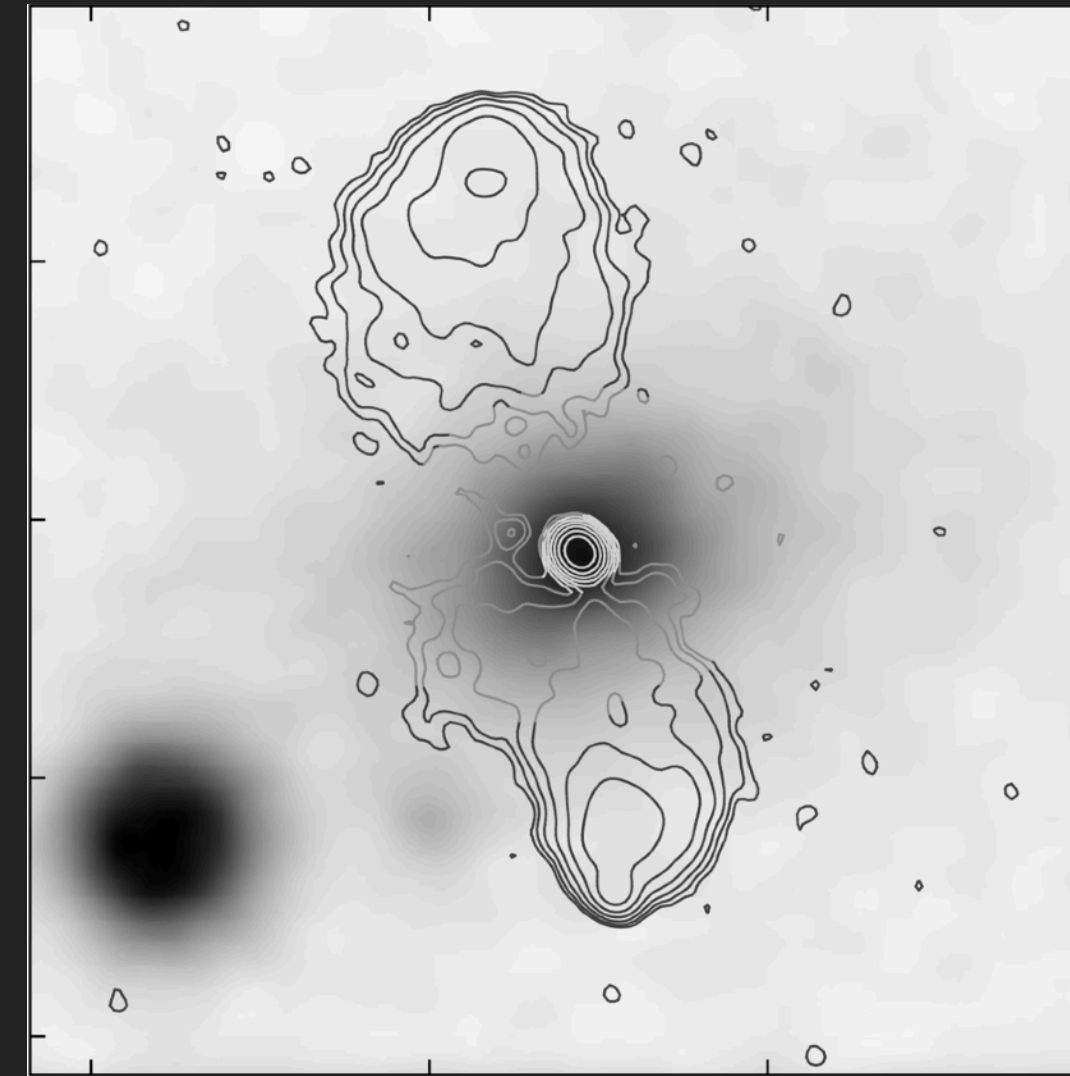
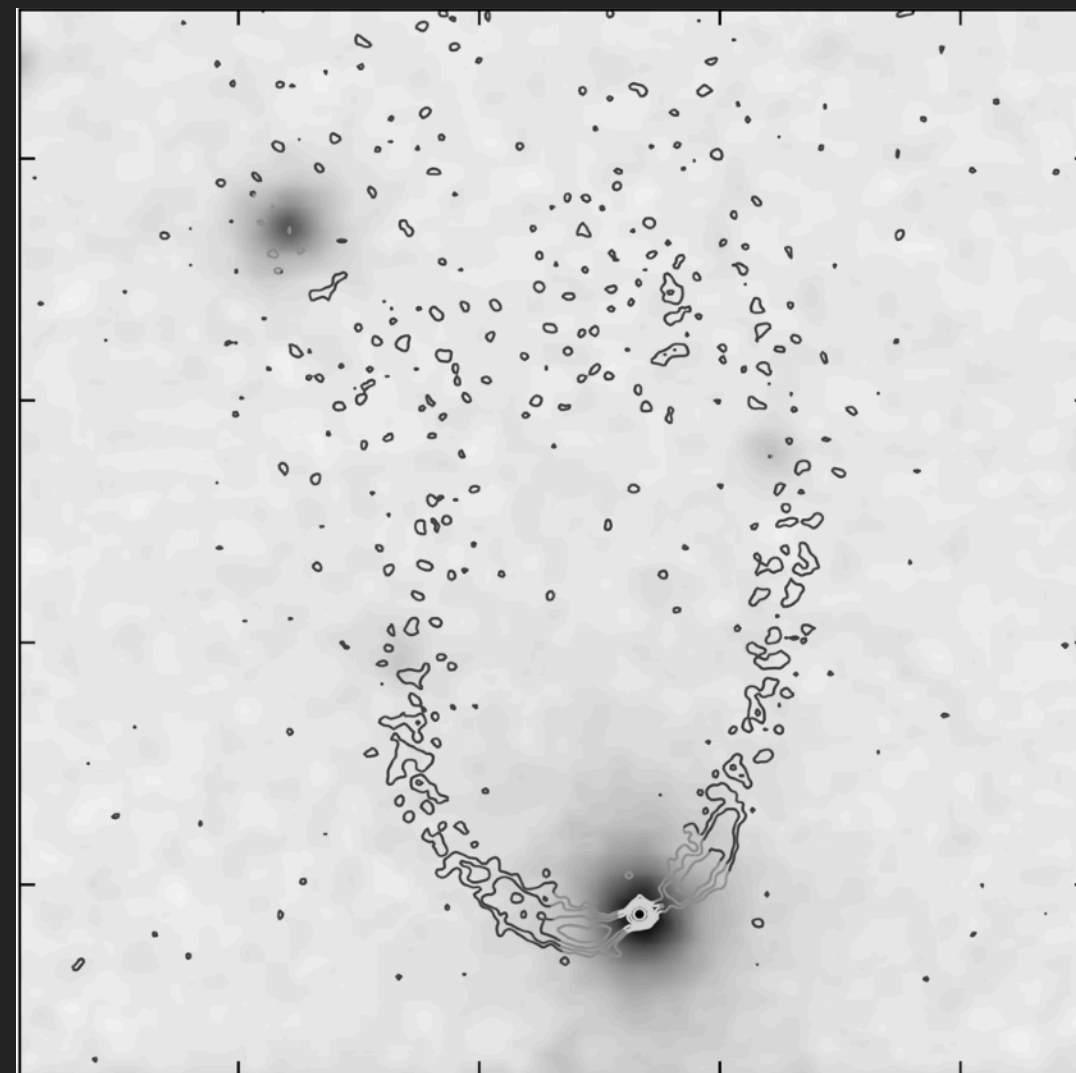


ABELL 2255 – RADIO GALAXIES



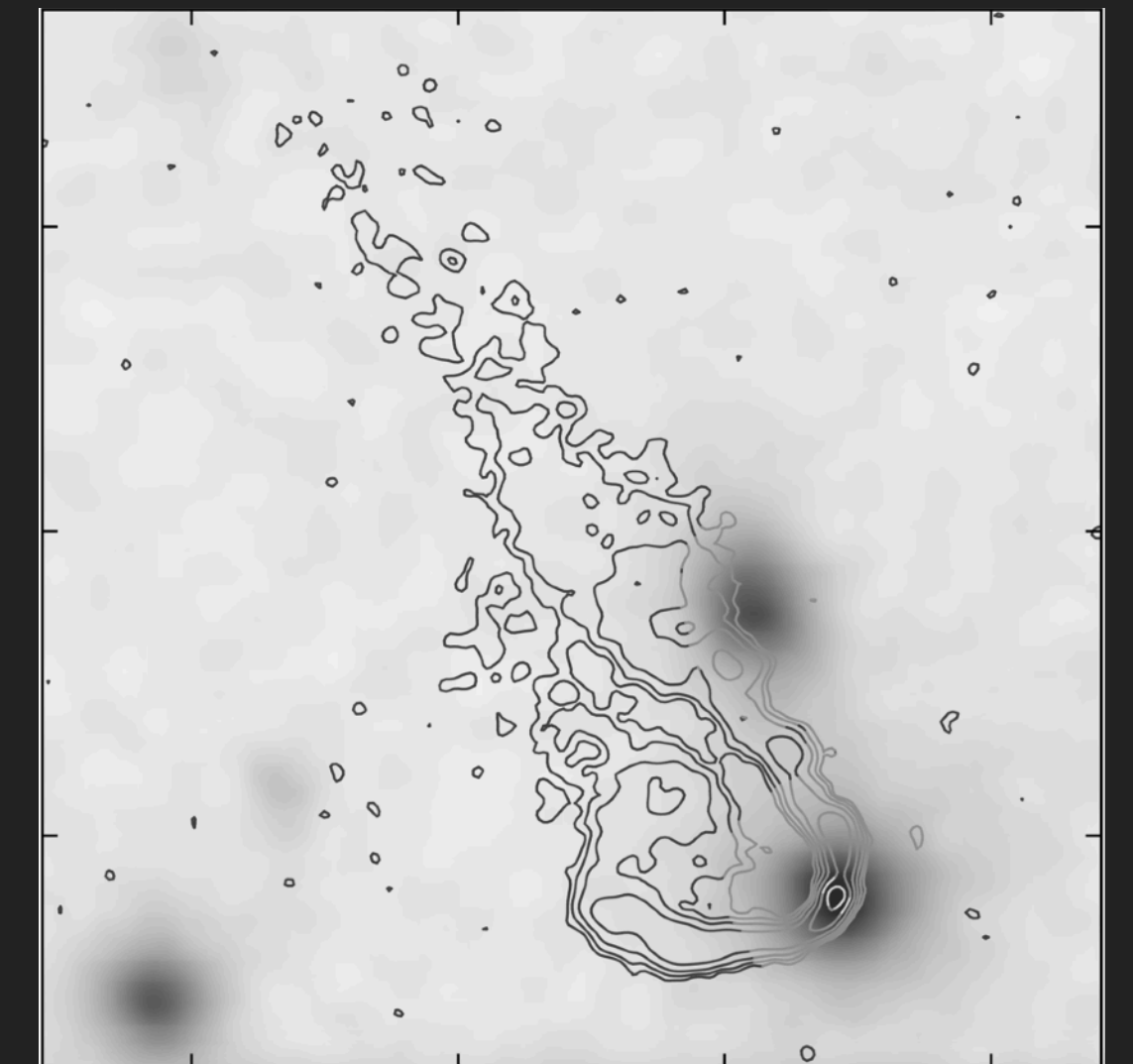
Embryo

Beaver



Double

Original TRG



3.6 cm contours of A2255 with VLA at 1"
 $\sigma = 13 \mu\text{Jy/beam}$

DATA CALIBRATION ...

We inspected **4x8h** nights (32h in total) with **LOFAR HBA** stations . For each night:

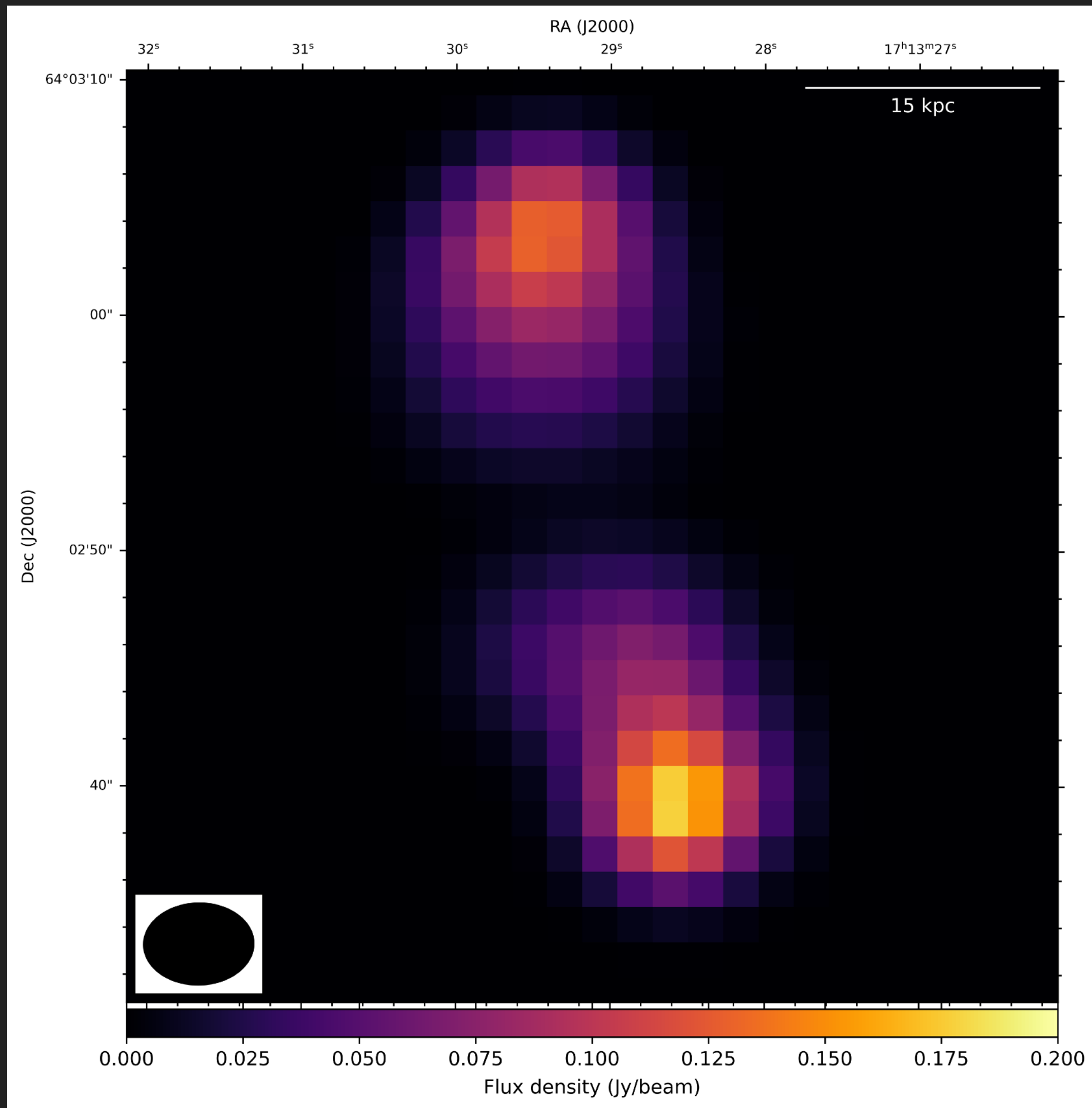
- ▶ PREFACTOR on calibrator and target for direction-independent effects
- ▶ DDF-PIPELINE for direction-dependent effects
- ▶ LOFAR-VLBI pipeline (Morabito et al., 2022)
 - Delay-Calibration.parset on the delay calibrator
 - Split-Directions.parset for each source that we want to image

... AND IMAGING

- ▶ The Original TRG and the Double were **self-calibrated** using the LOFAR_FACET_SELFCAL script from van Weeren et al. (2021), pre-applying the solutions found for the delay calibrator
- ▶ The other sources were not enough bright, so we just applied the solutions from the delay calibrator and imaged them with WSClean
- ▶ The four nights of observation per source are **put together directly at the self-calibration/imaging step**

We present here the **first sub-arcsecond resolution** images of the **5** aforementioned radio galaxies, with 32 hours of observation, obtained with **LOFAR-VLBI**, compared with the lower resolution observations taken from Botteon et al. (2022) with 75 hours

LOFAR-VLBI INSIGHTS: DOUBLE

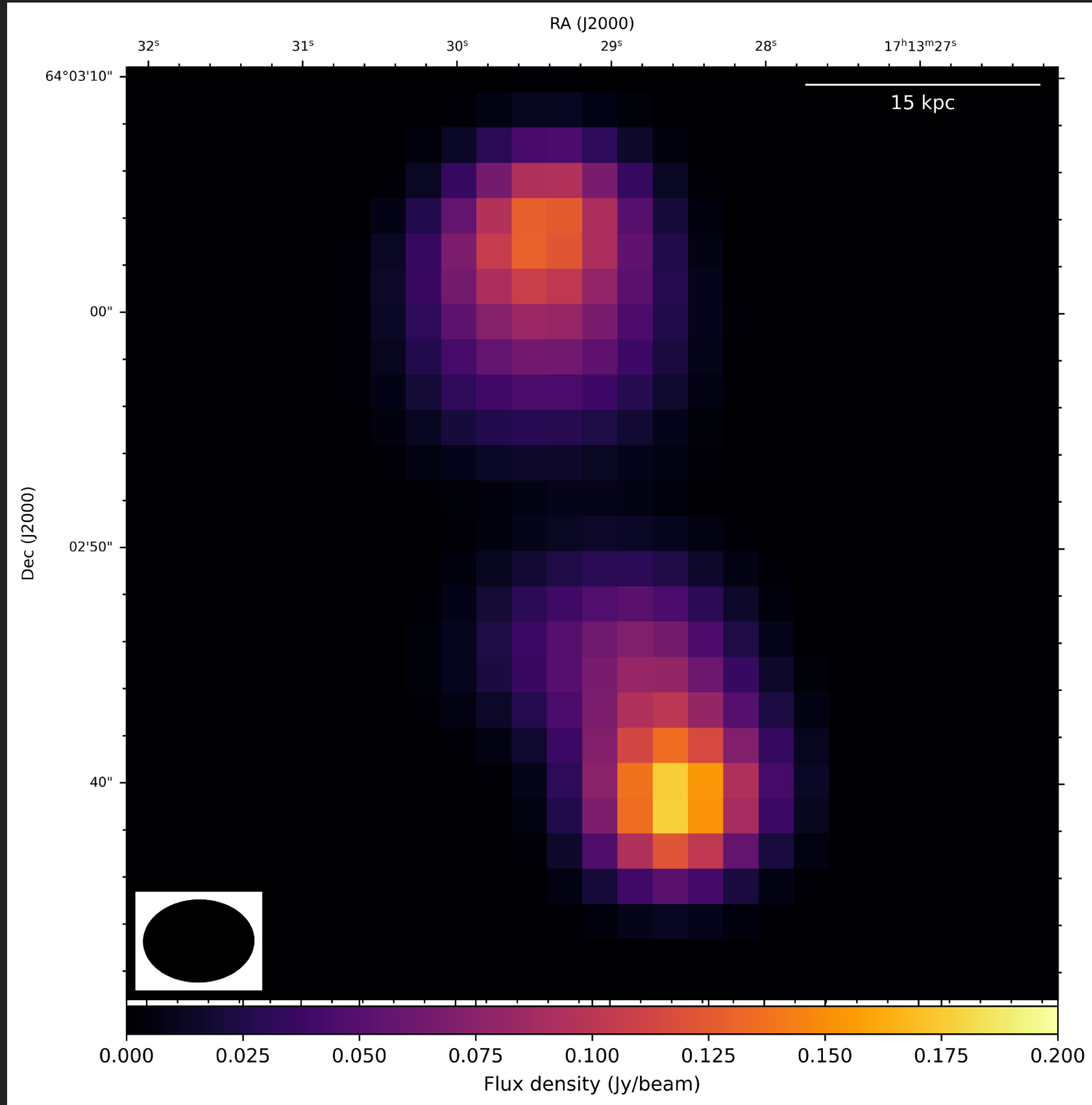


LOFAR 144 MHz image at **4.7"x3.5"**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)

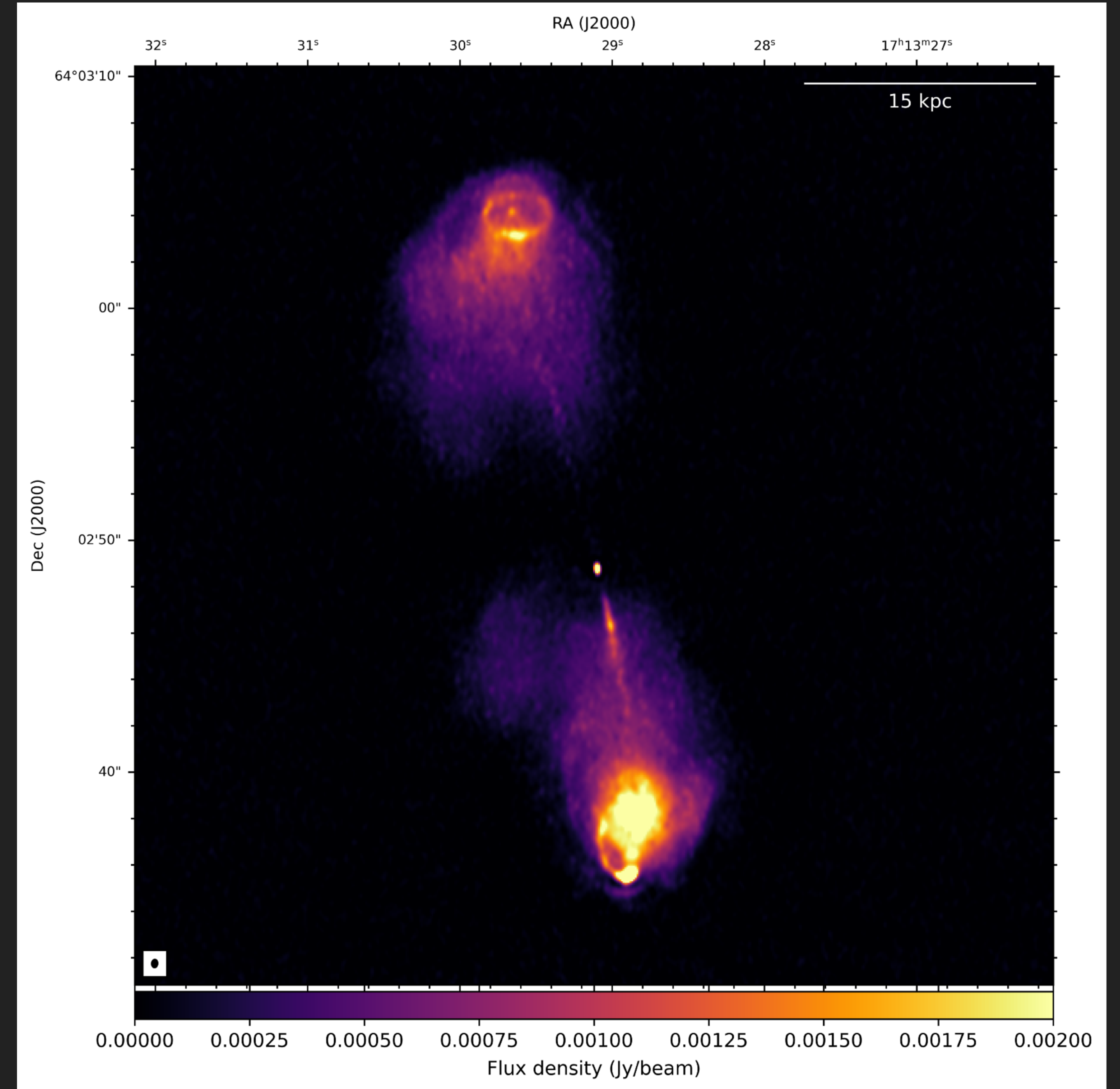
The "Double" is an FRII radio galaxy with a total extension of about 50 kpc

It is located near the cluster centre

LOFAR-VLBI INSIGHTS: DOUBLE

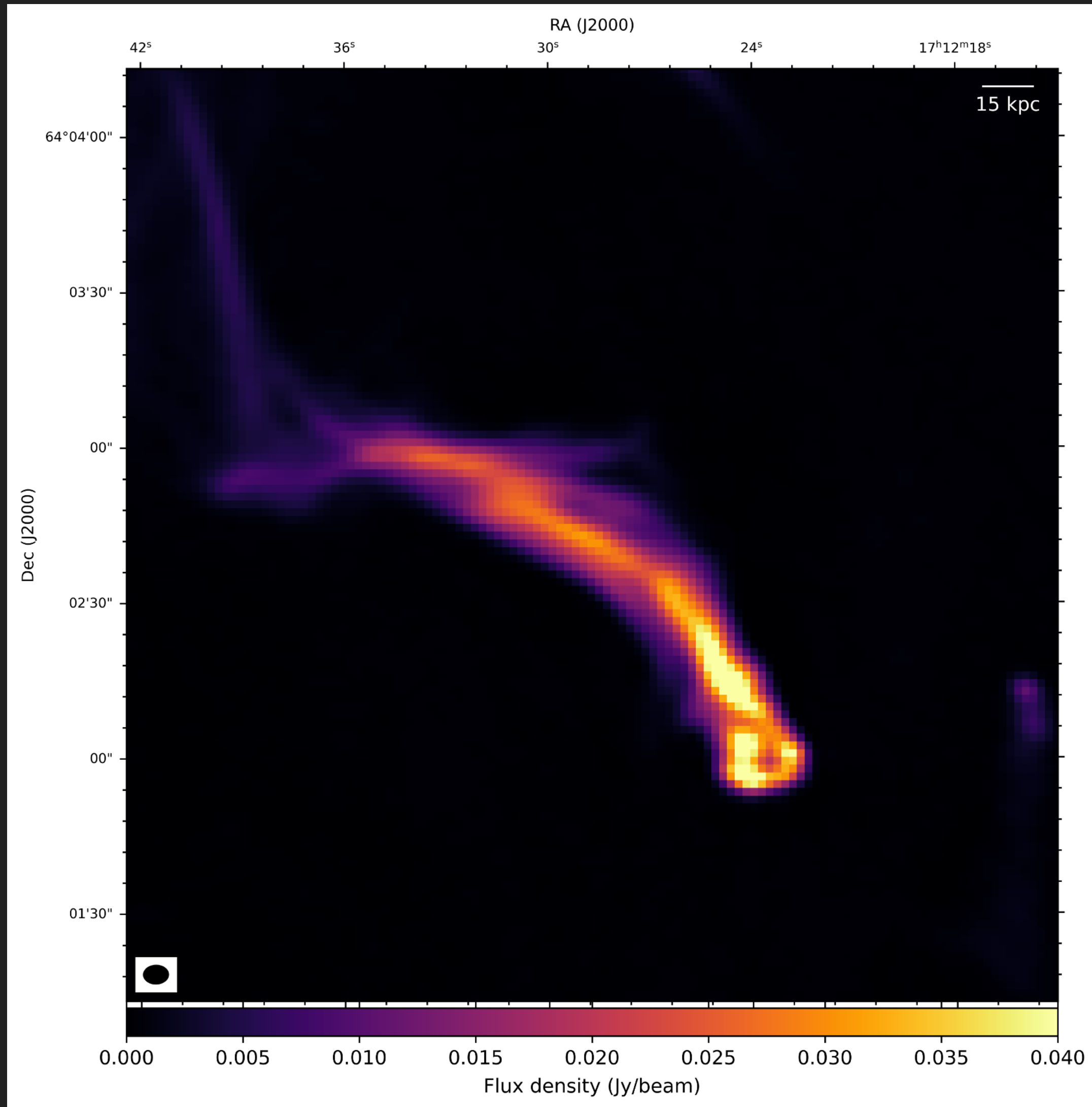


LOFAR 144 MHz image at **4.7''x3.5''**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)



LOFAR 144 MHz image at **0.33''x0.24''**, $\sigma = 26 \mu\text{Jy/beam}$

LOFAR-VLBI INSIGHTS: ORIGINAL TRG

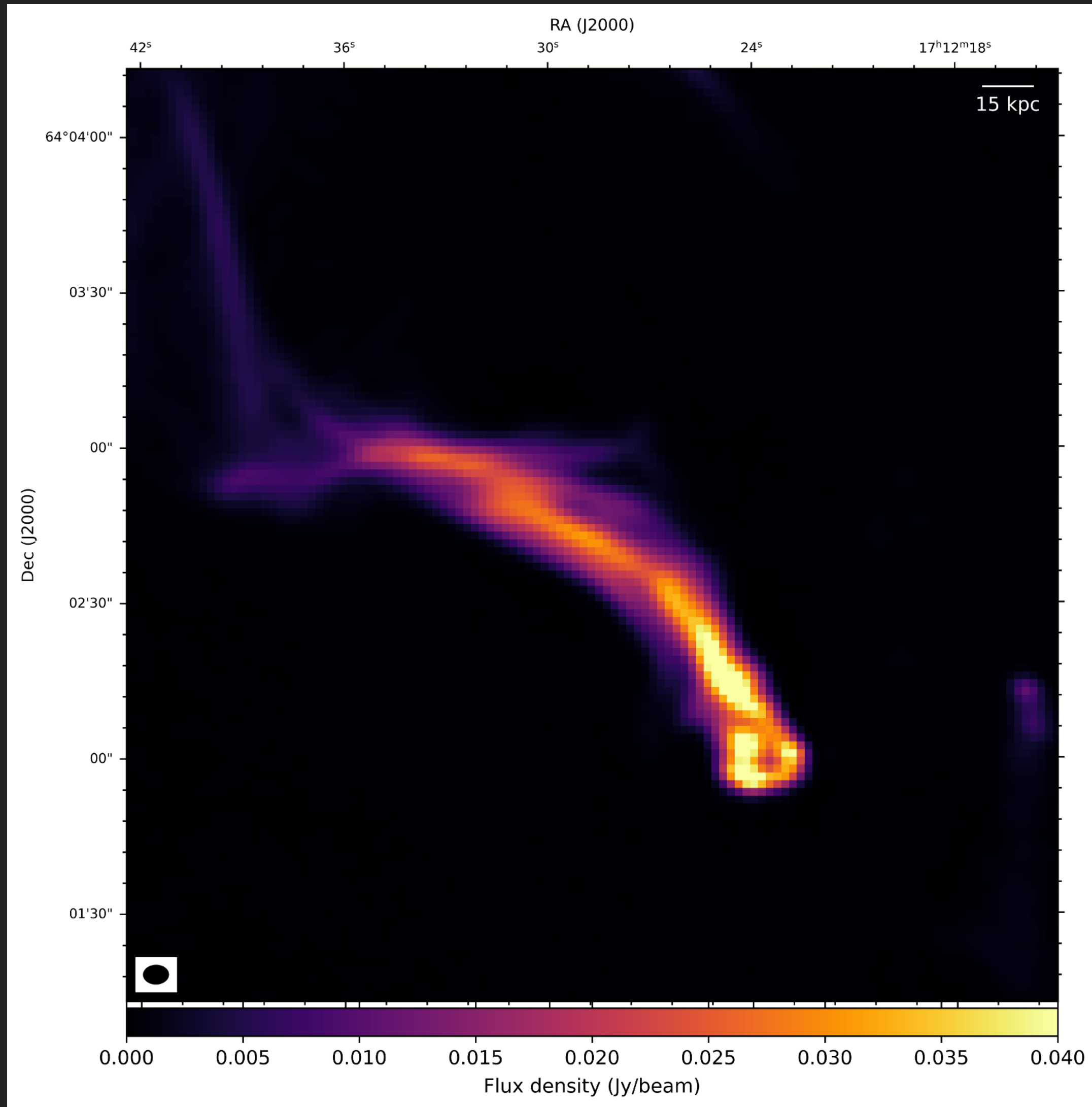


LOFAR 144 MHz image at **4.7" x 3.5"**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)

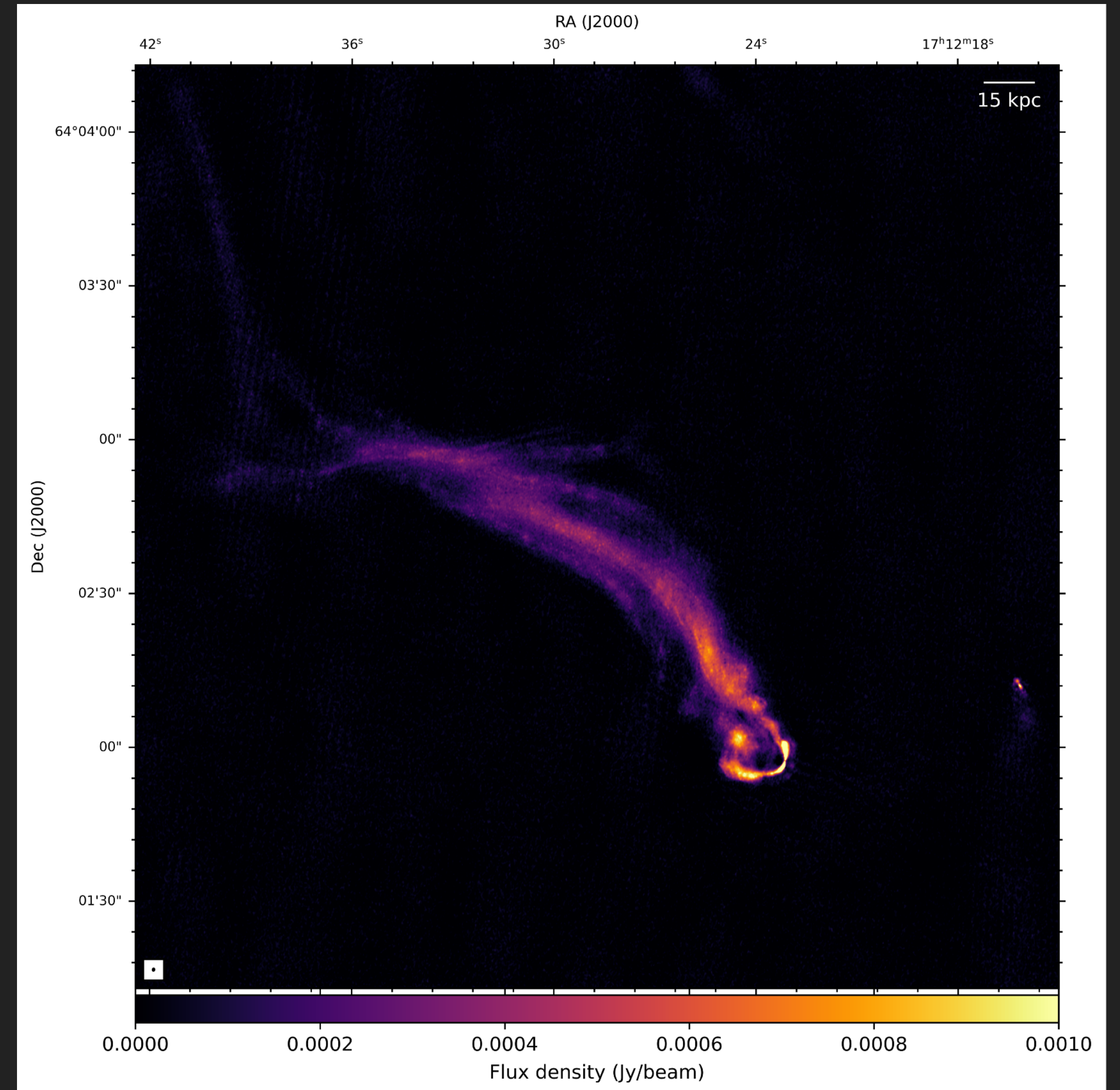
The "Original TRG" has a NAT structure and is located, in projection, quite near to the cluster centre

It is well extended in the N-E direction, and shows the presence of a tail with a complex structure that has been observed with LOFAR

LOFAR-VLBI INSIGHTS: ORIGINAL TRG

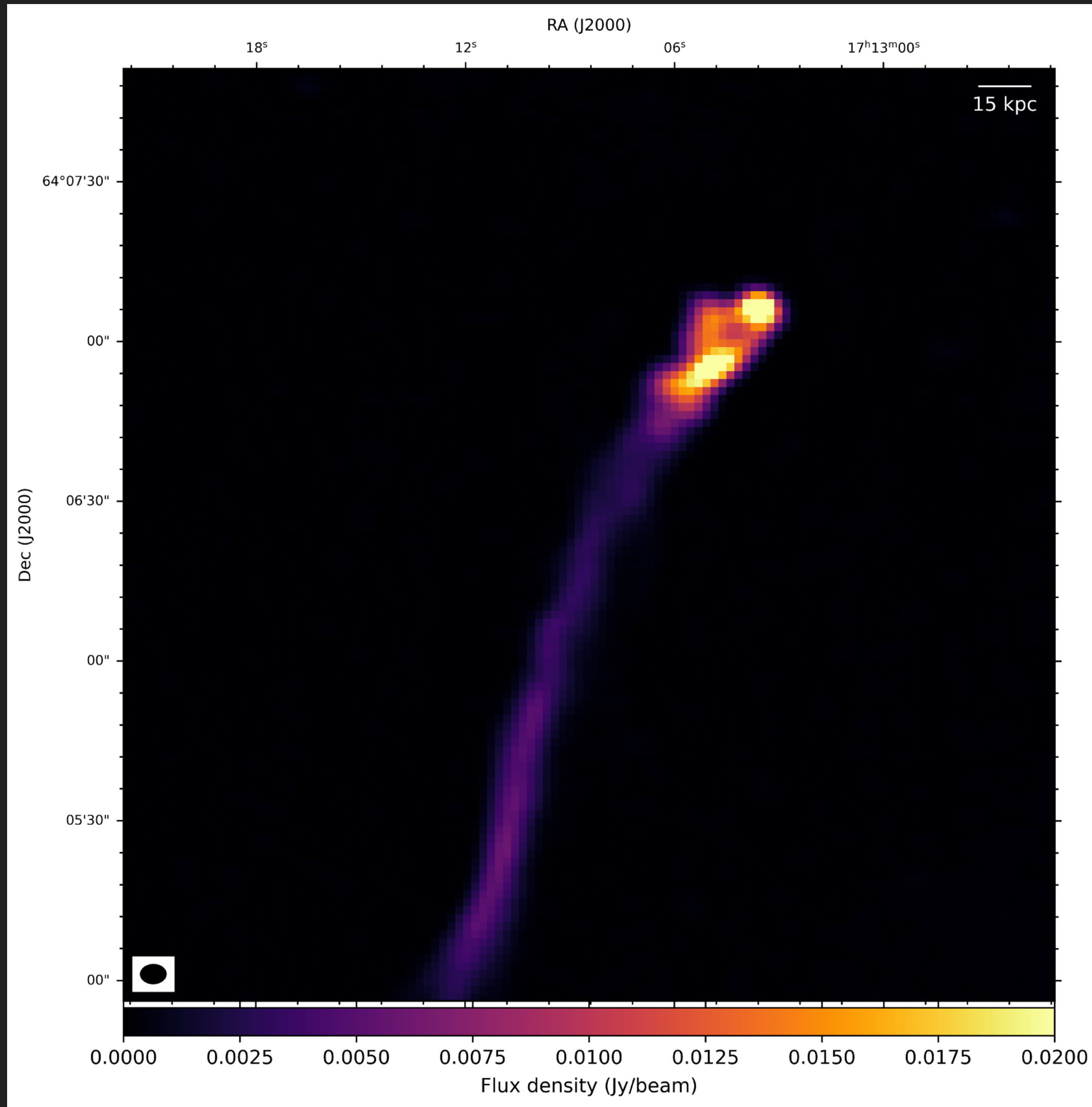


LOFAR 144 MHz image at **4.7''x3.5''**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)



LOFAR 144 MHz image at **0.45''x0.32''**, $\sigma = 26 \mu\text{Jy/beam}$

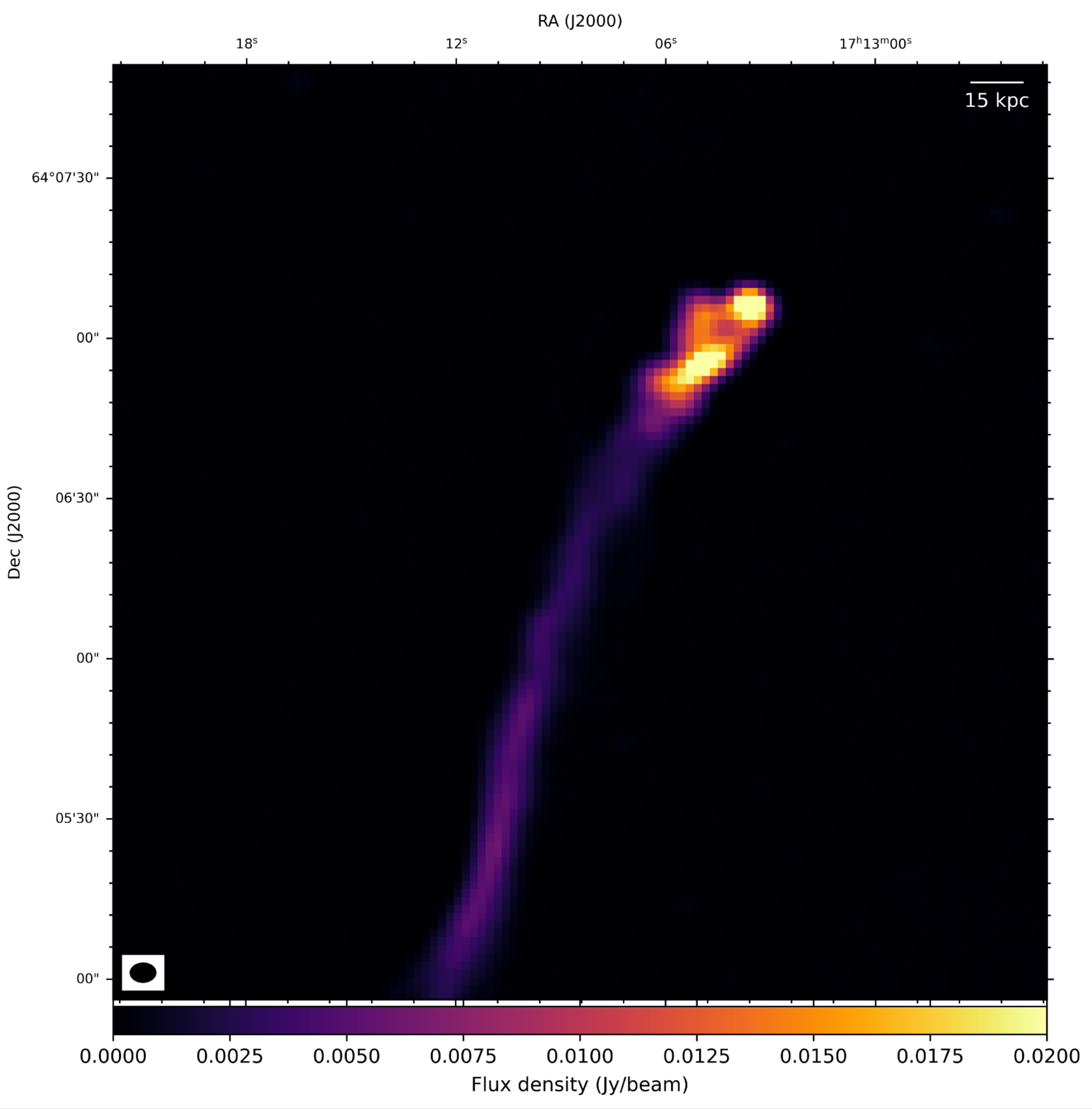
LOFAR-VLBI INSIGHTS: GOLDFISH



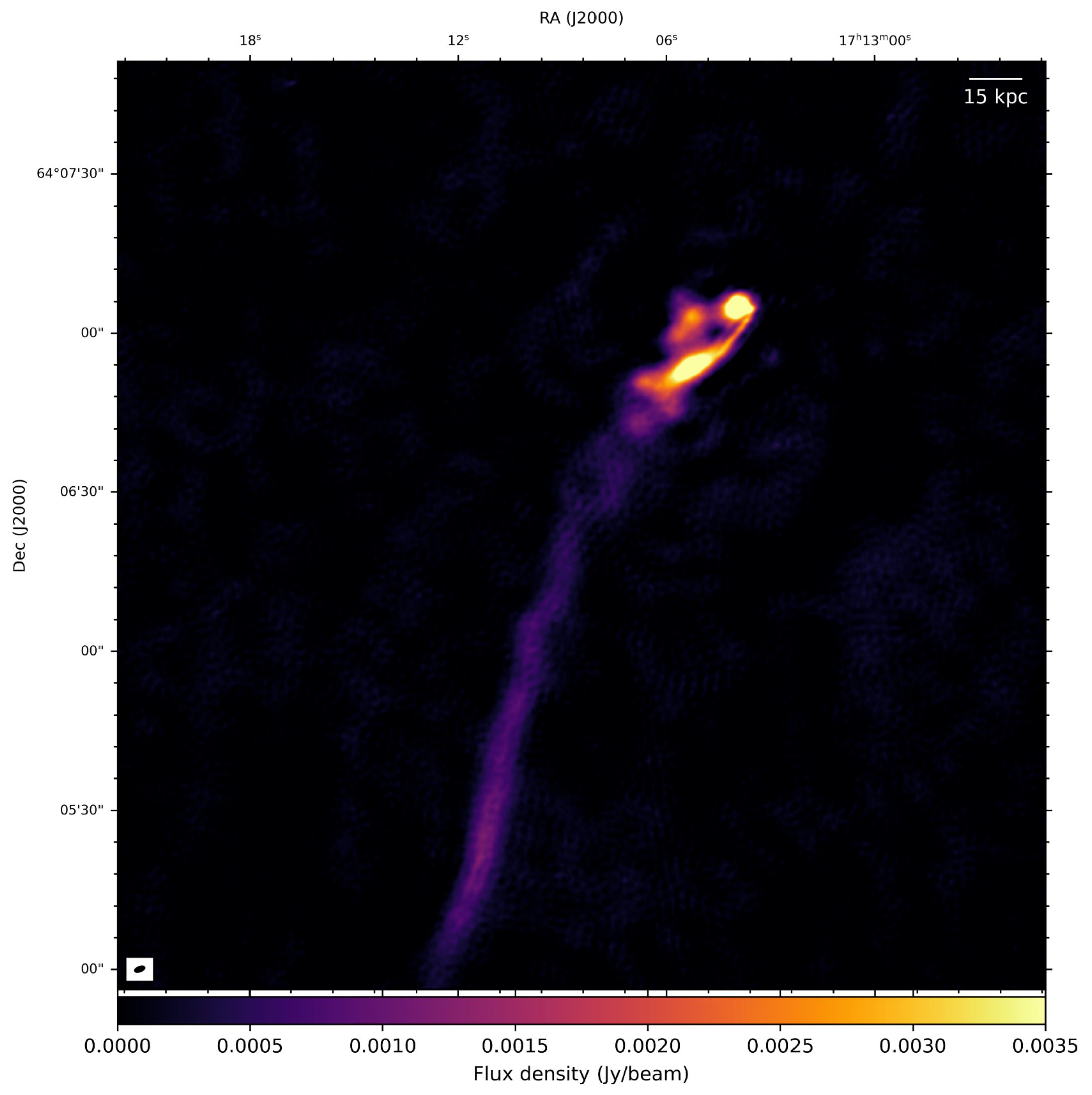
LOFAR 144 MHz image at **4.7"×3.5"**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)

The "Goldfish" is a NAT radio galaxy located just beside the "Original TRG".

LOFAR-VLBI INSIGHTS: GOLDFISH

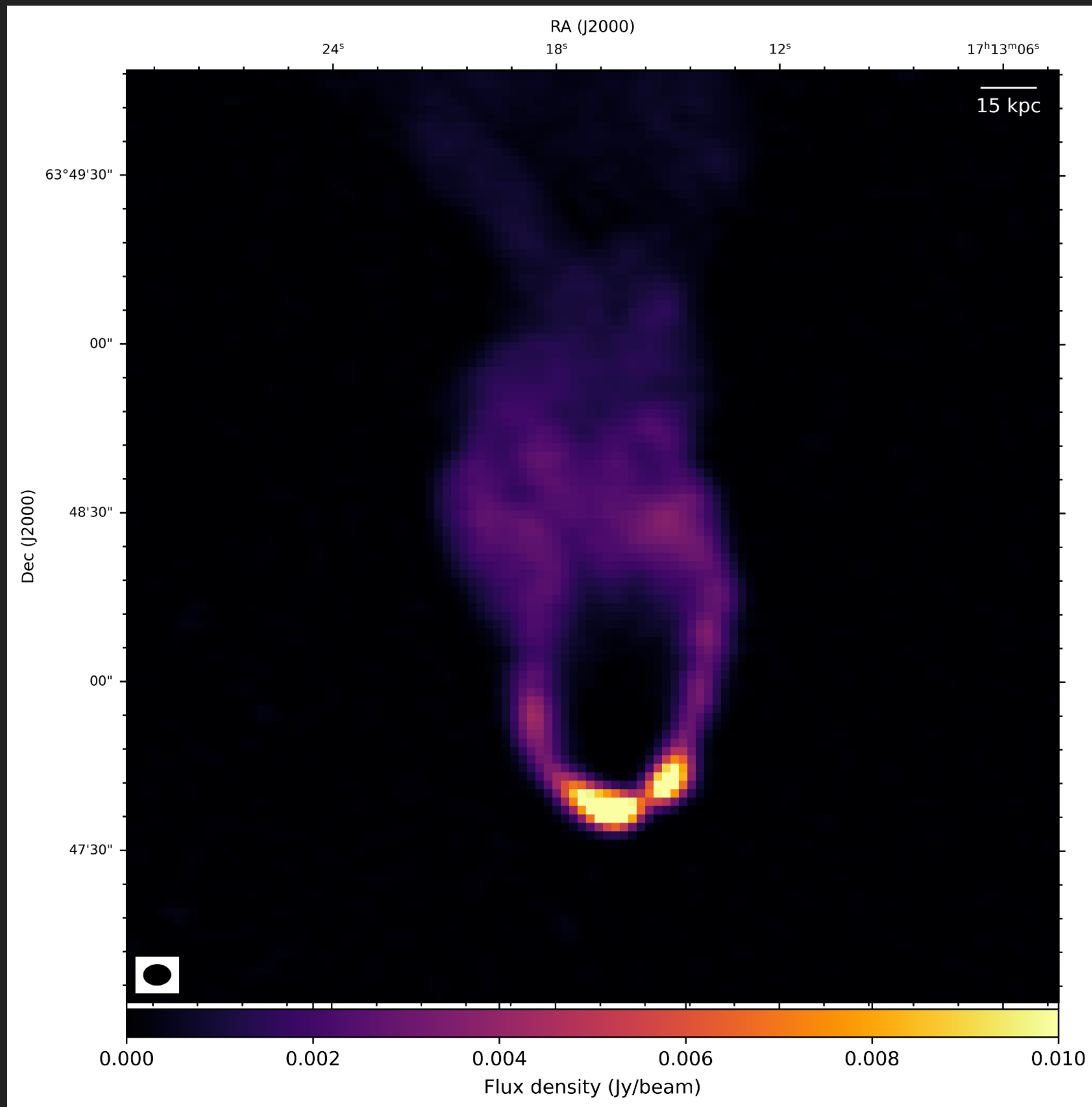


LOFAR 144 MHz image at **4.7''x3.5''**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)



LOFAR 144 MHz image at **1.89''x0.86''**, $\sigma = 75 \mu\text{Jy/beam}$

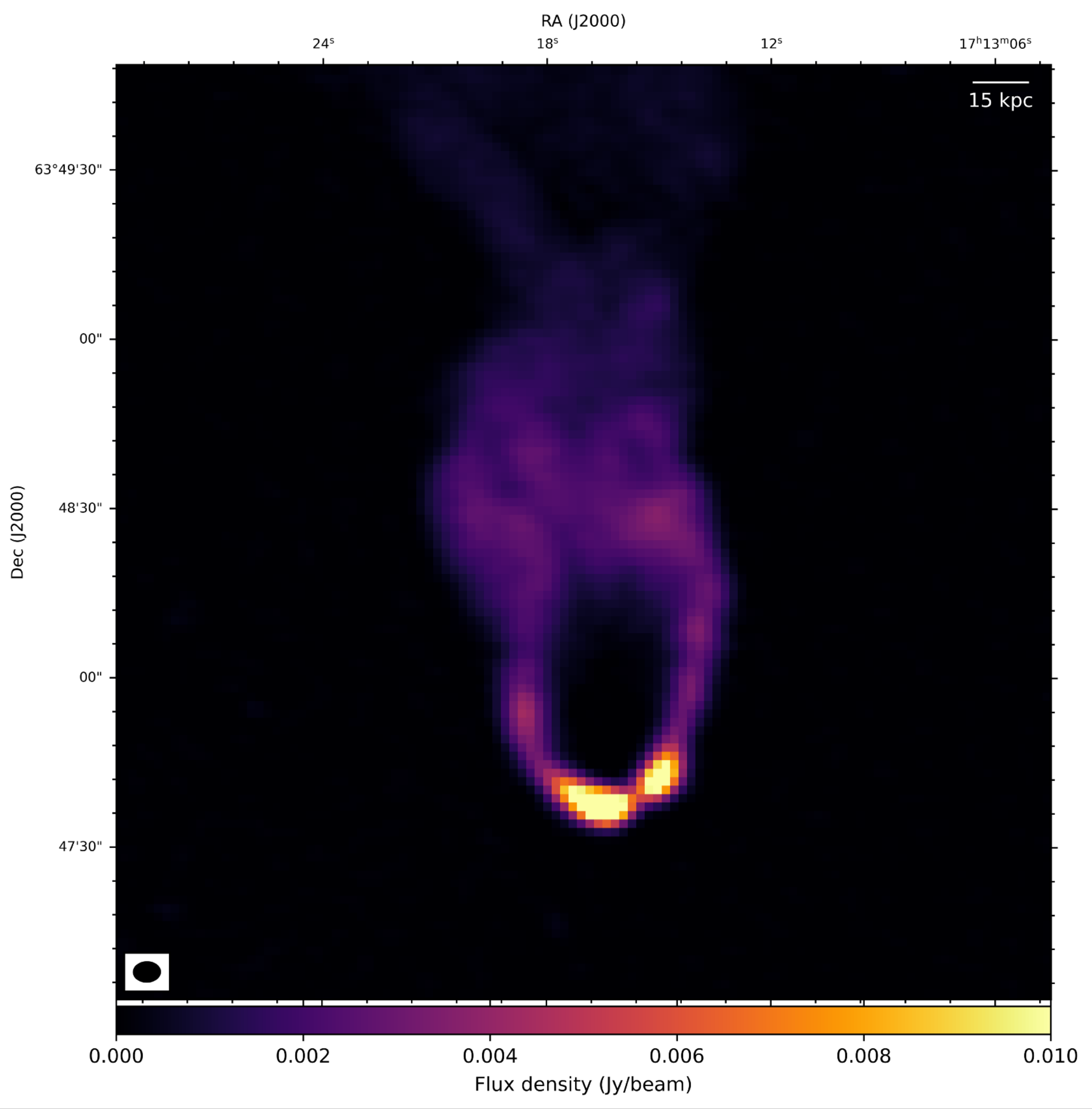
LOFAR-VLBI INSIGHTS: BEAVER



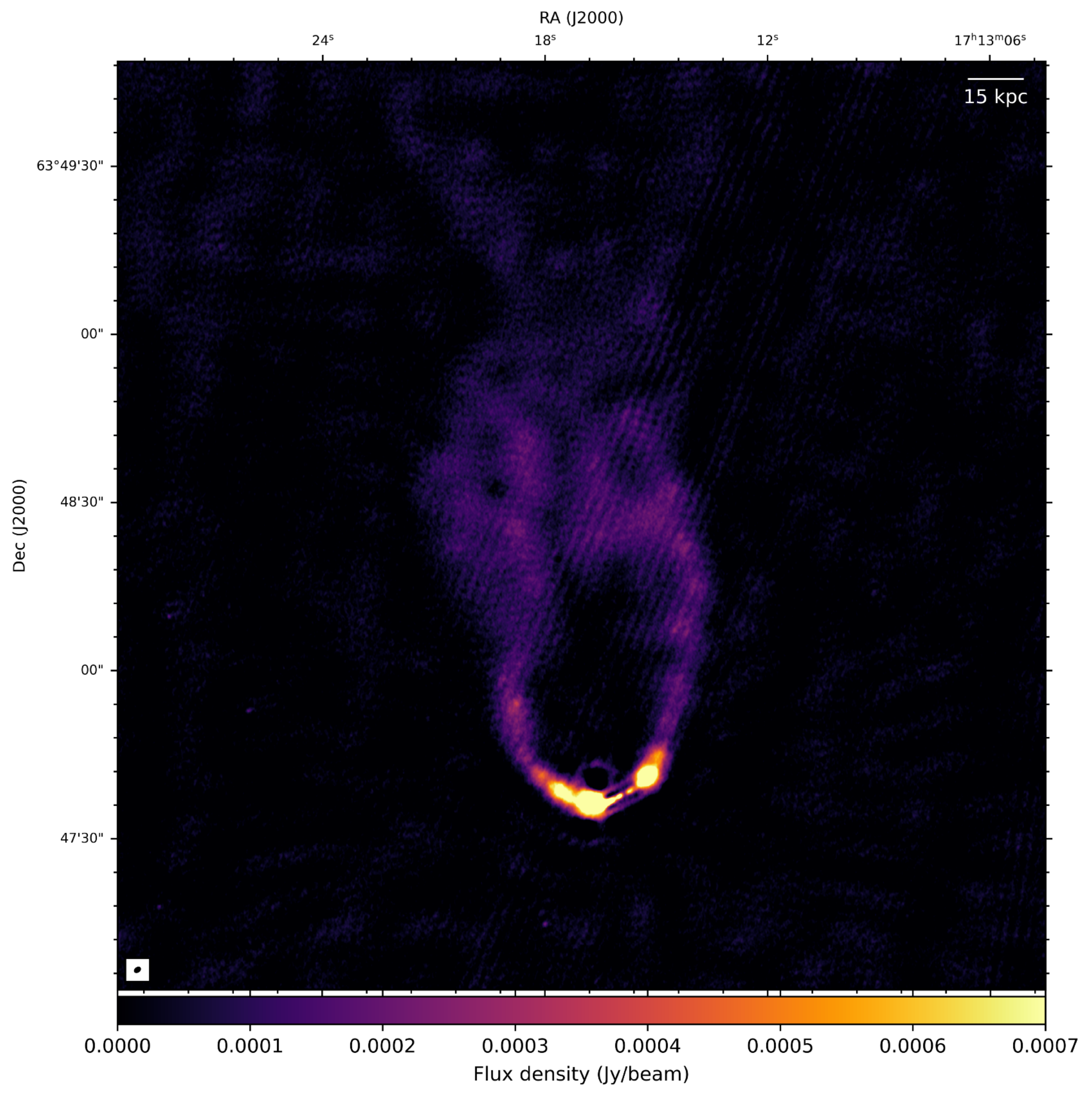
The “Beaver” is a NAT located in the southern part of the cluster, at ~ 1.6 Mpc from the cluster centre, with a tail that extends over a Mpc before fading into the cluster halo

LOFAR 144 MHz image at **4.7" x 3.5"**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)

LOFAR-VLBI INSIGHTS: BEAVER

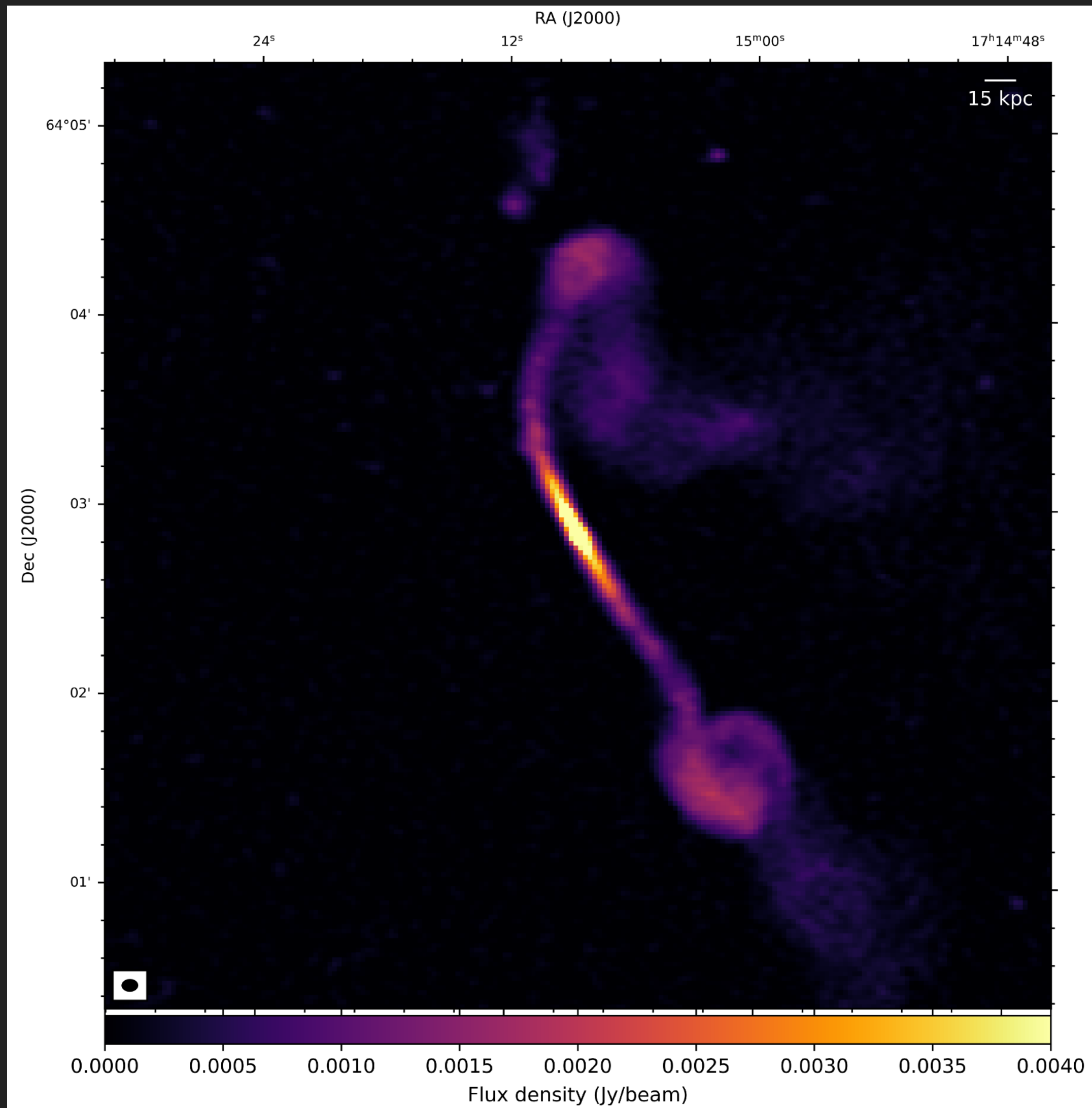


LOFAR 144 MHz image at **4.7''x3.5''**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)



LOFAR 144 MHz image at **1.05''x0.65''**, $\sigma = 33 \mu\text{Jy/beam}$

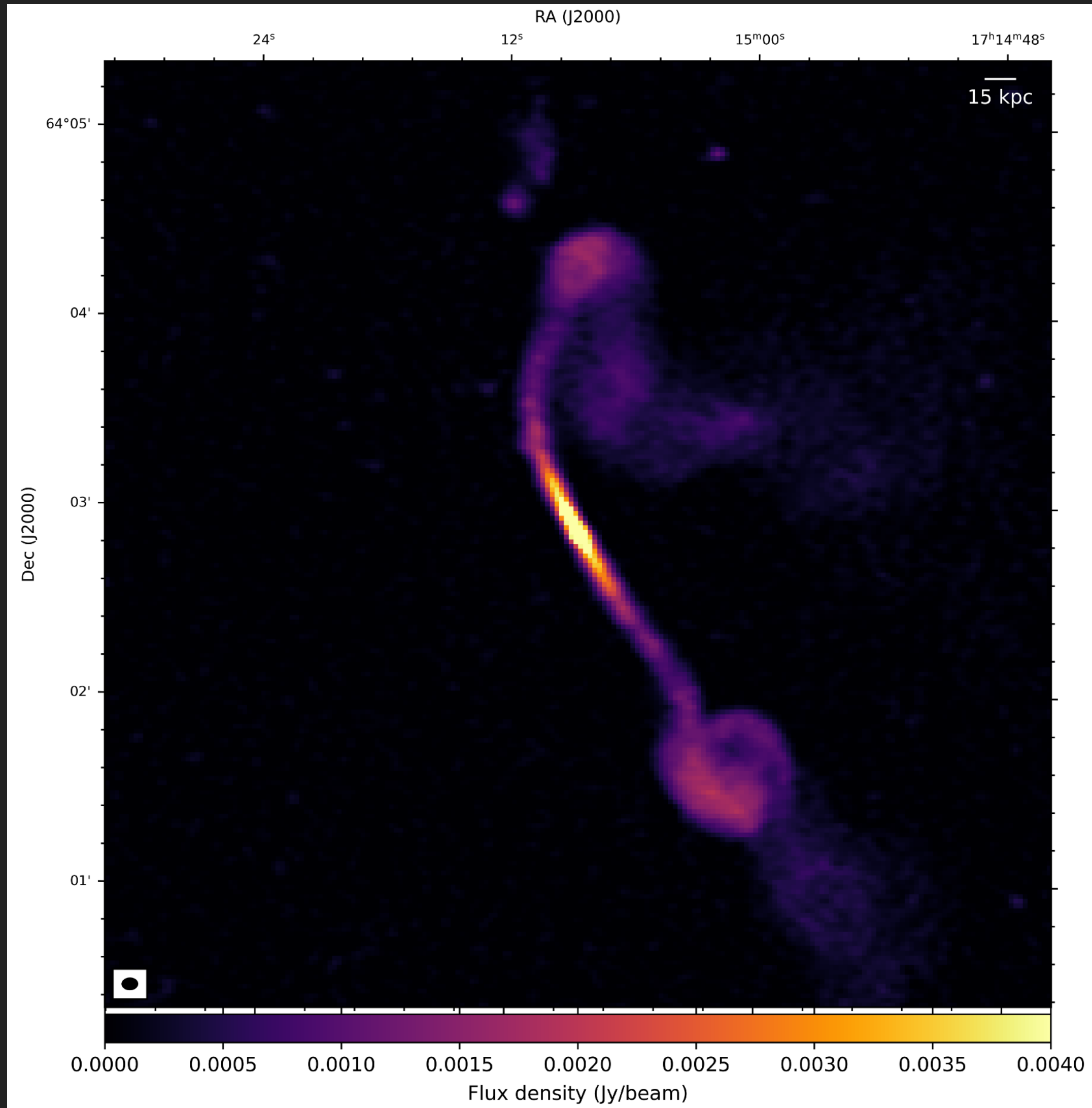
LOFAR-VLBI INSIGHTS: EMBRYO



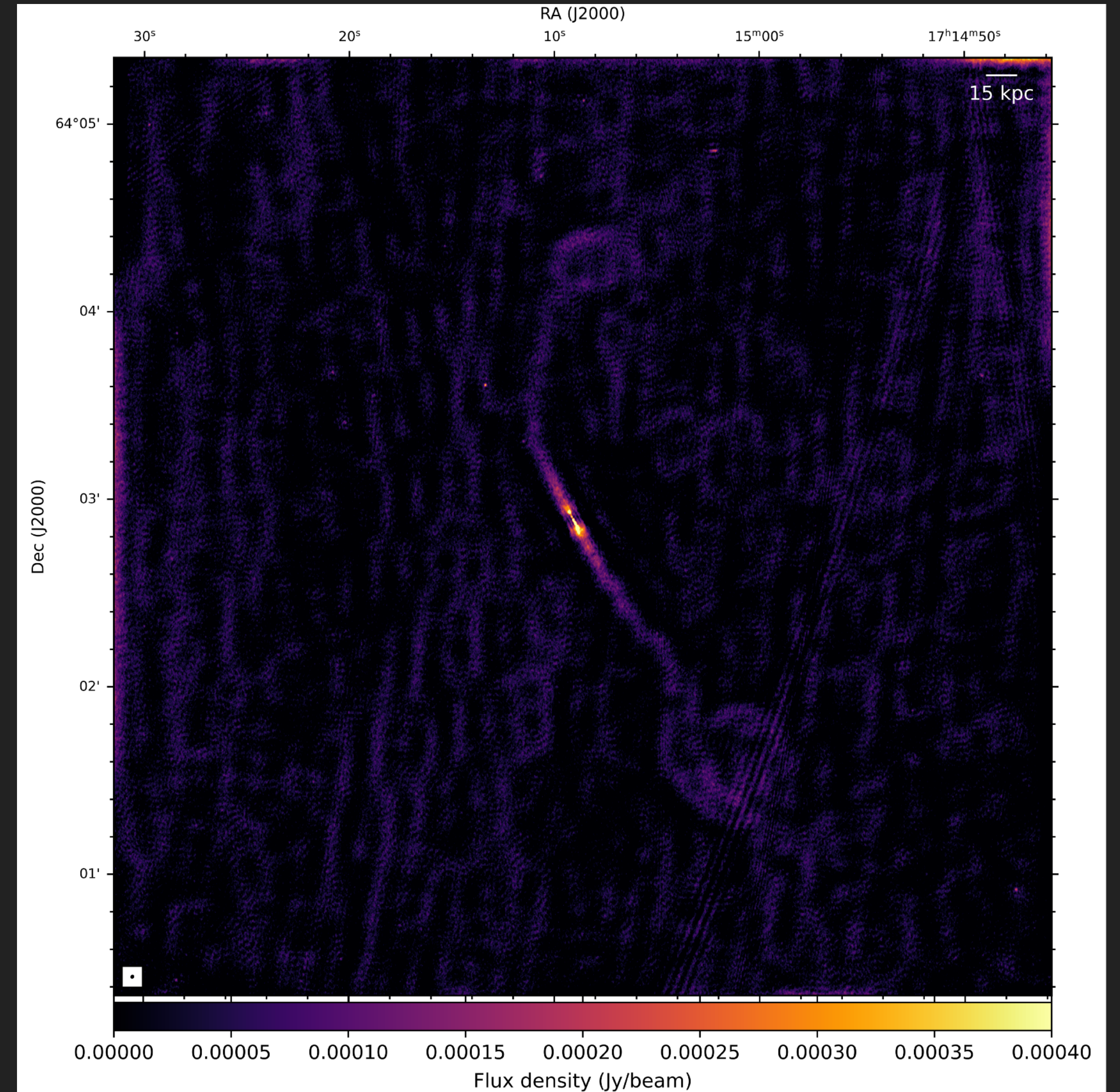
LOFAR 144 MHz image at **4.7"×3.5"**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)

The "Embryo" is a WAT radio galaxy that extends for around 290 kpc and is located in the western direction of the cluster, at around 1.5 Mpc from the centre

LOFAR-VLBI INSIGHTS: EMBRYO



LOFAR 144 MHz image at **4.7''x3.5''**, $\sigma = 55 \mu\text{Jy/beam}$
(adapted from Botteon et al., 2022)



LOFAR 144 MHz image at **0.68''x0.53''**, $\sigma = 26 \mu\text{Jy/beam}$

SUMMARY

- ▶ We want to focus on A2255 radio galaxies at sub-arcsecond resolution combining multiple nights of LOFAR observations
- ▶ 5 main cluster-member radio galaxies have been selected
- ▶ LOFAR HBA data have been calibrated for DIE and DDE
- ▶ LOFAR-VLBI pipeline by Morabito et al. (2022) for IS calibration
- ▶ Split direction for five cluster member radio galaxies
- ▶ We obtained **the first sub-arcsecond resolution images of 5 radio galaxies embedded in A2255** with 32h of observations

STILL A LOT OF WORK TO DO

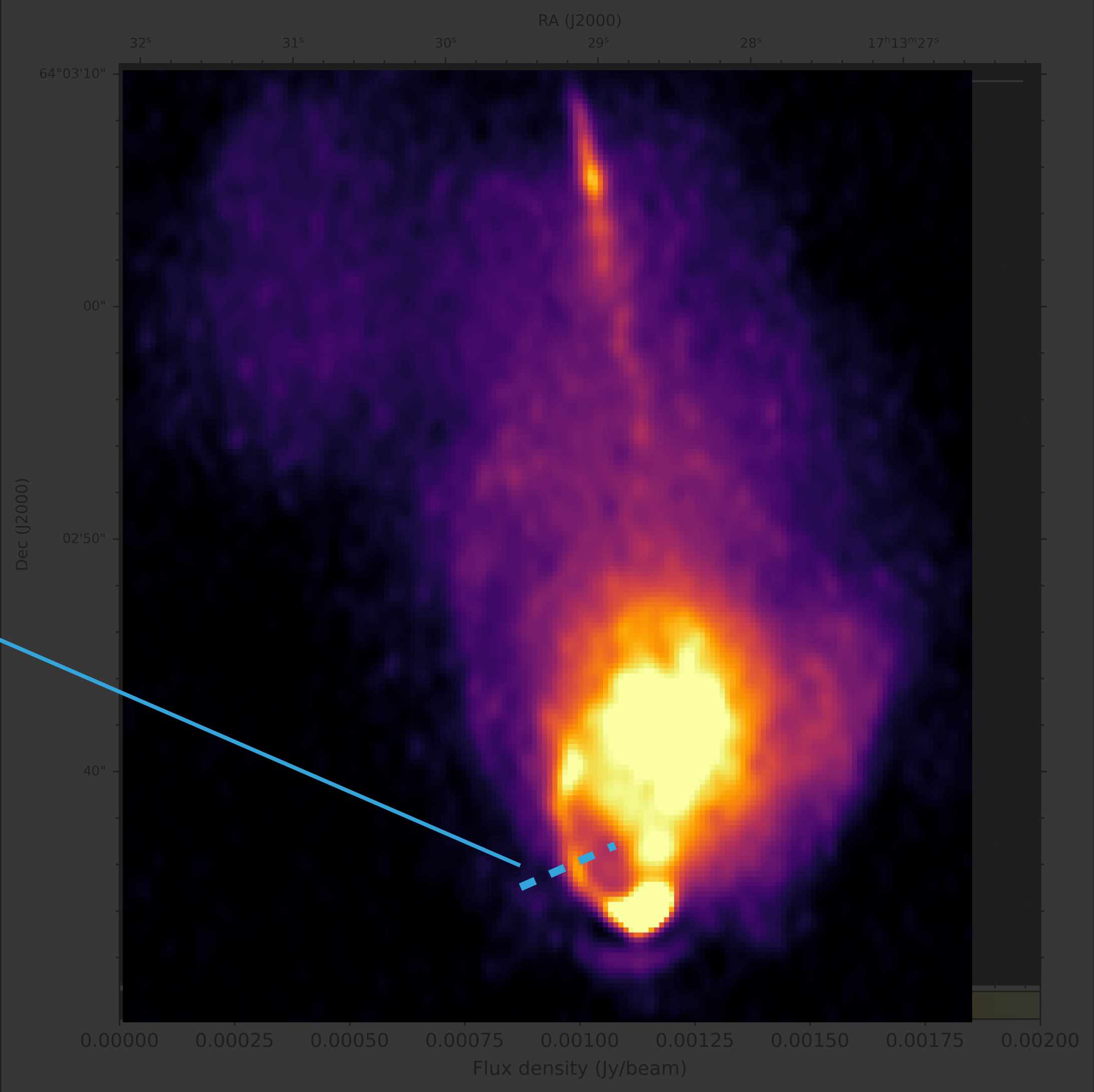
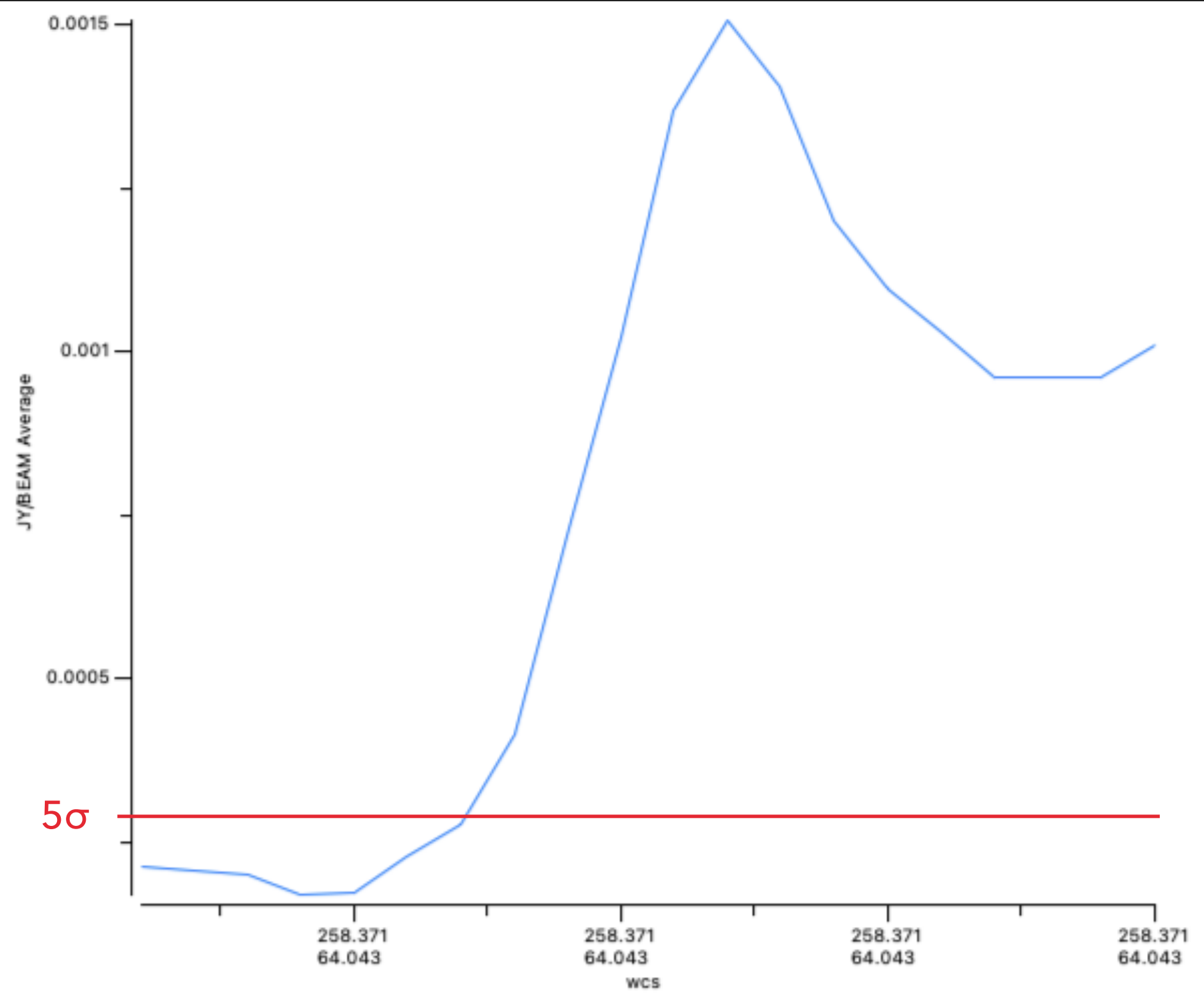
- ▶ These are “just” 32h: potentially we have **up to 300h** of LOFAR observations, in order to have a **unique deep vision** of these structures
- ▶ We want to investigate other interesting sources in the A2255 field, both active and non-active (like jellyfish galaxies, see Ignesti et al., 2023)
- ▶ Perform a spectral index analysis, using data at high resolution from JVL A (see Govoni et al., 2006)
- ▶ Comparison with models in order to explain the filaments observed in the “Original TRG”, as well as the hotspot morphology of the “Double”

Stay tuned!

SEE YOU SPACE COWBOY . . .

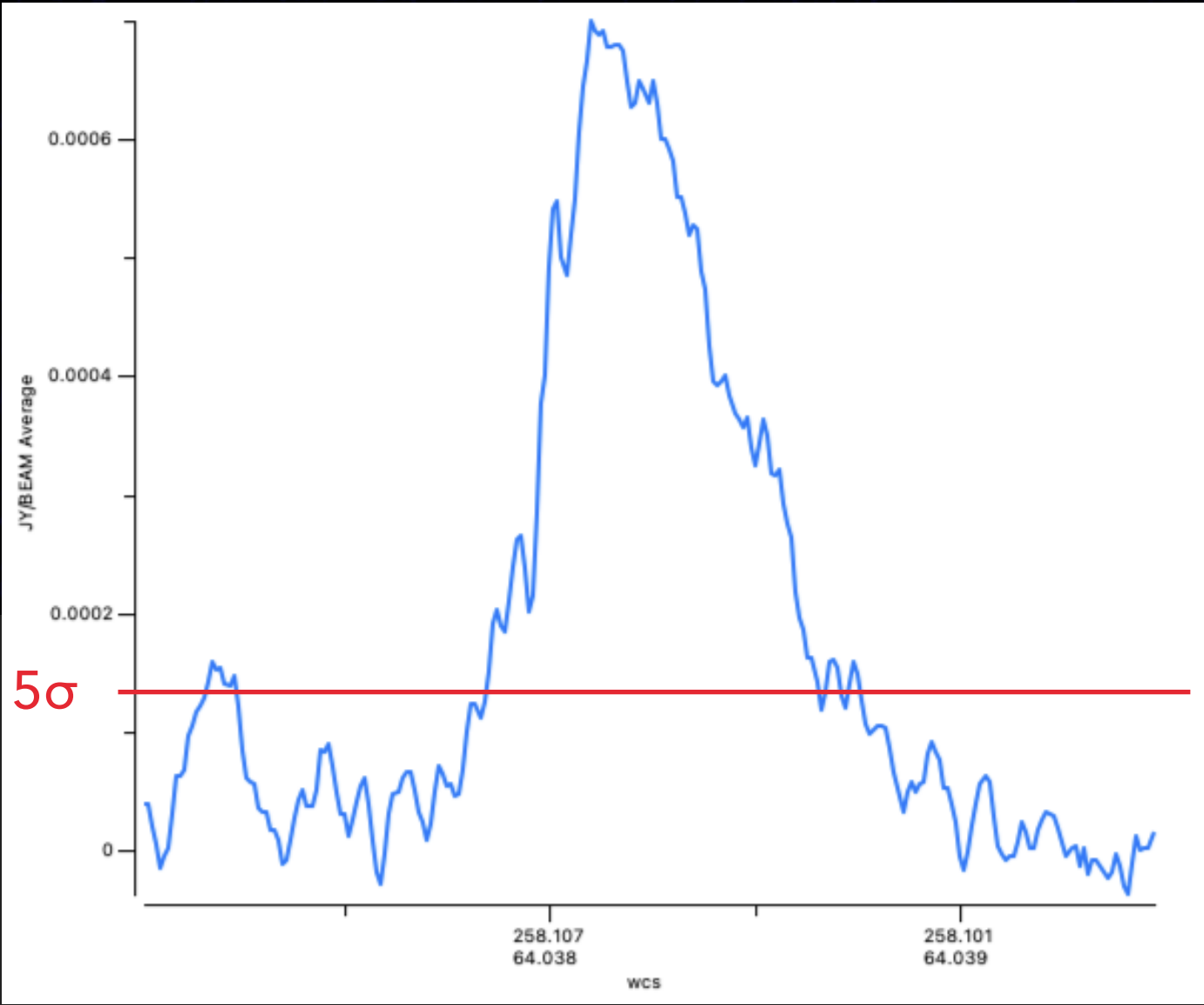
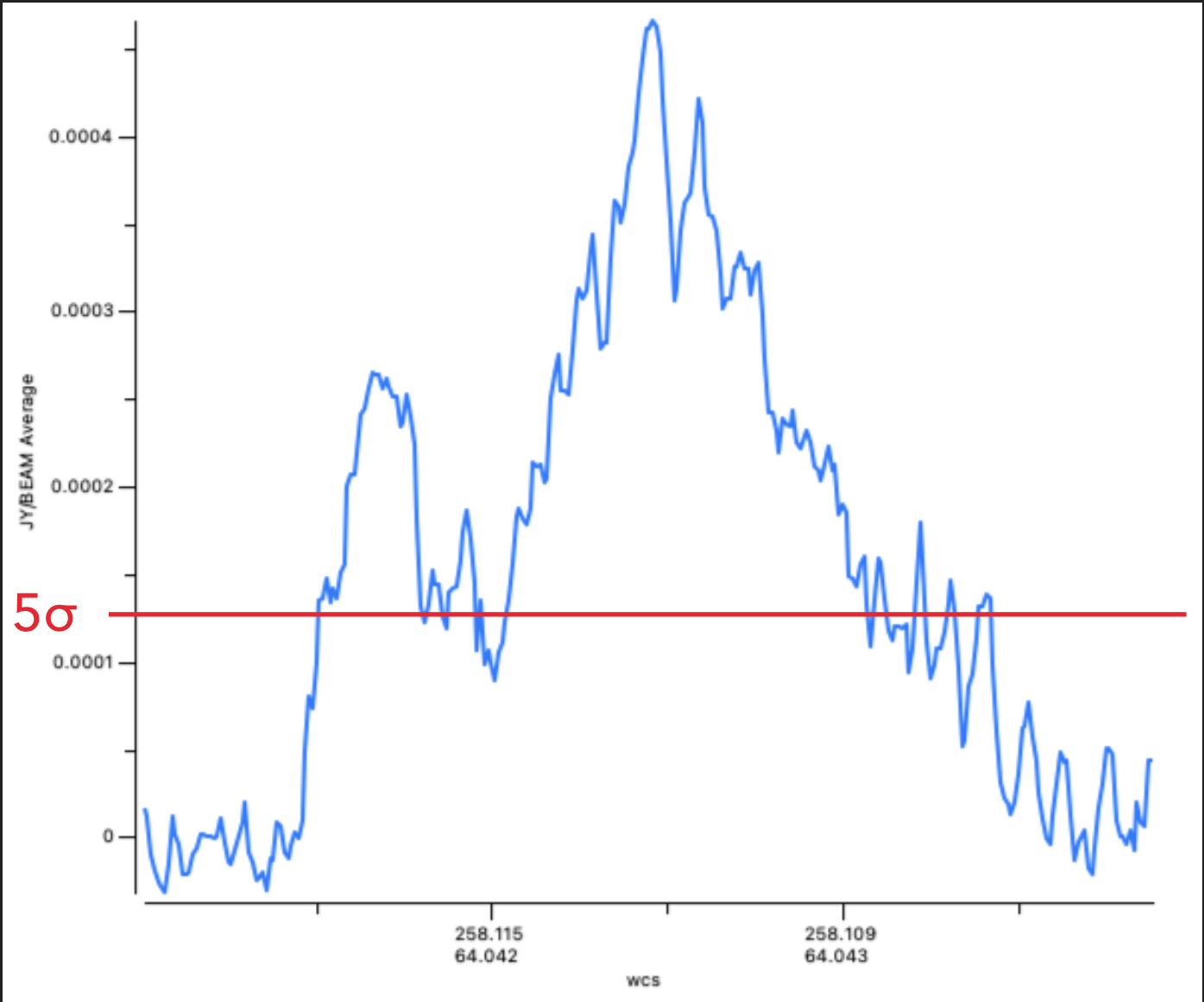
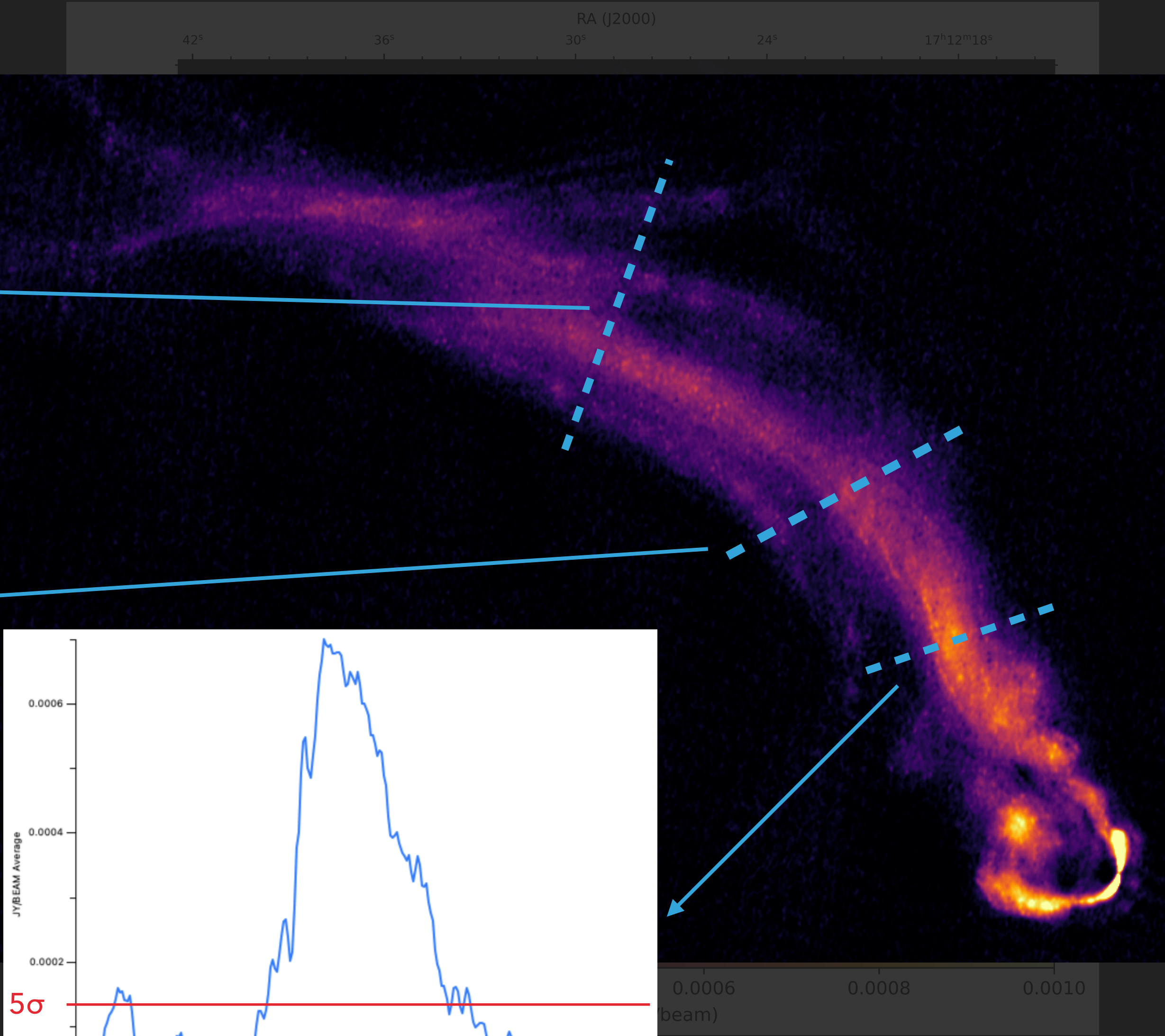
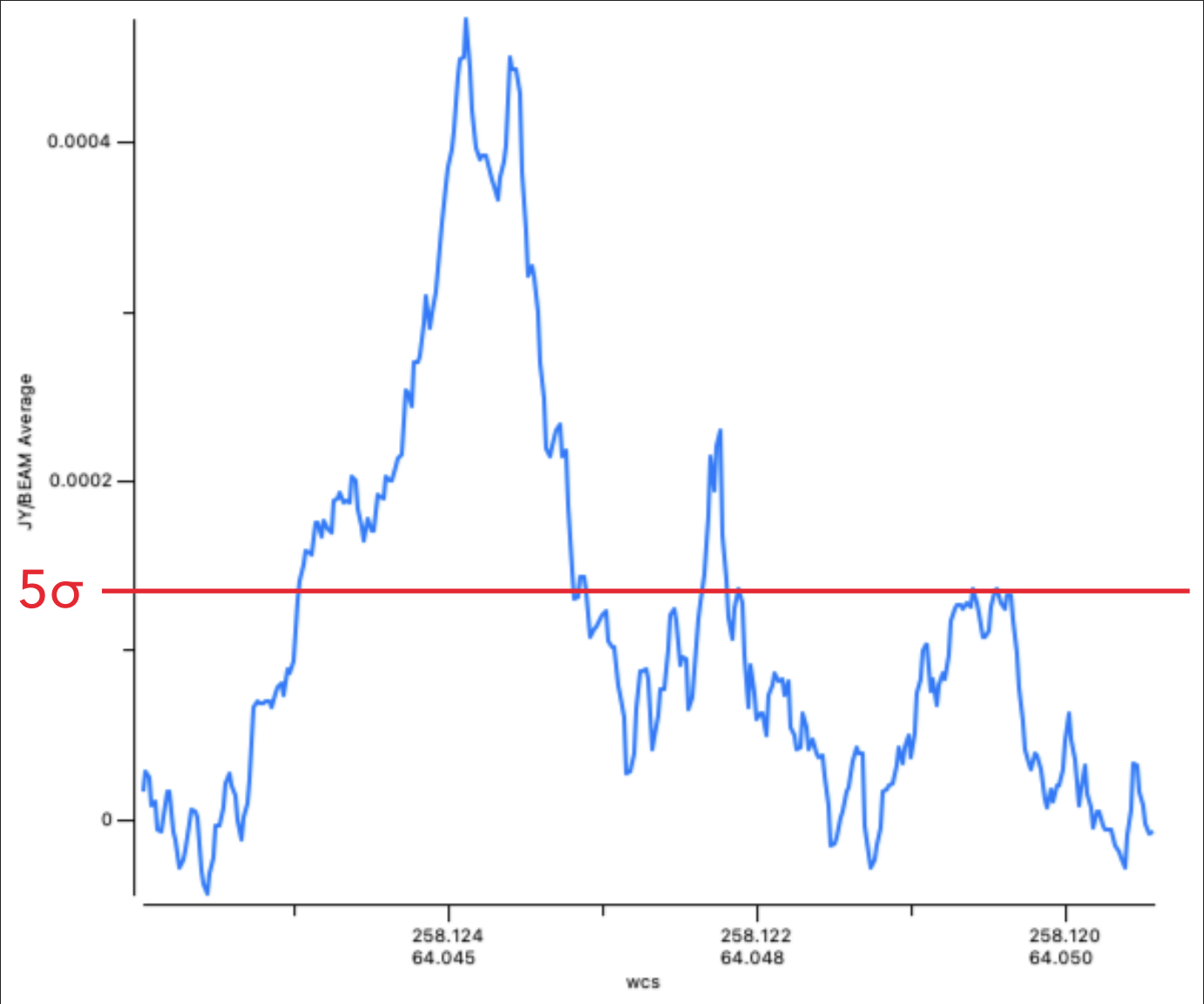


LOFAR-VLBI INSIGHTS: DOUBLE

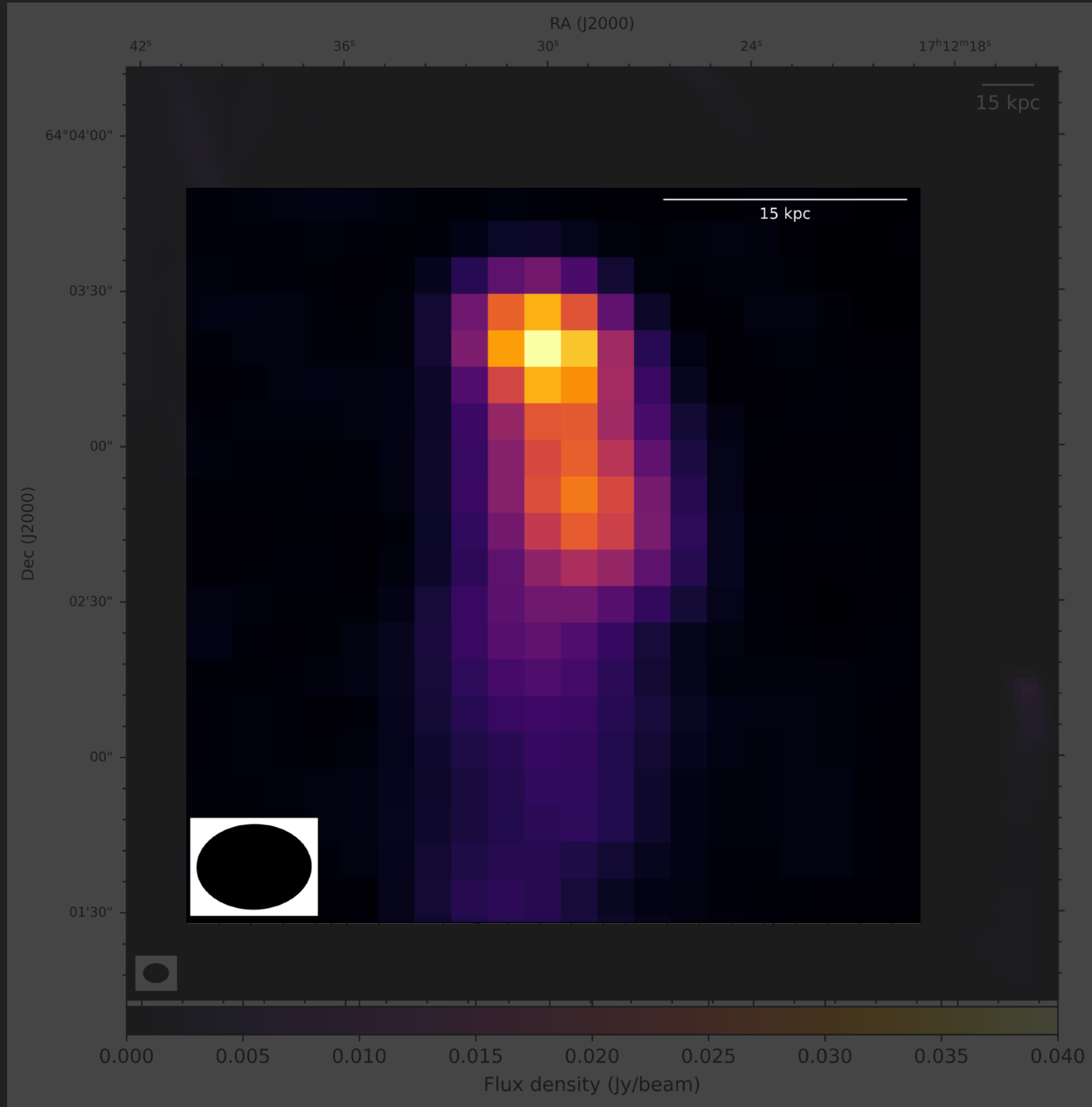


LOFAR 144 MHz image at **0.33"x0.24"**, $\sigma = 26 \mu\text{Jy/beam}$

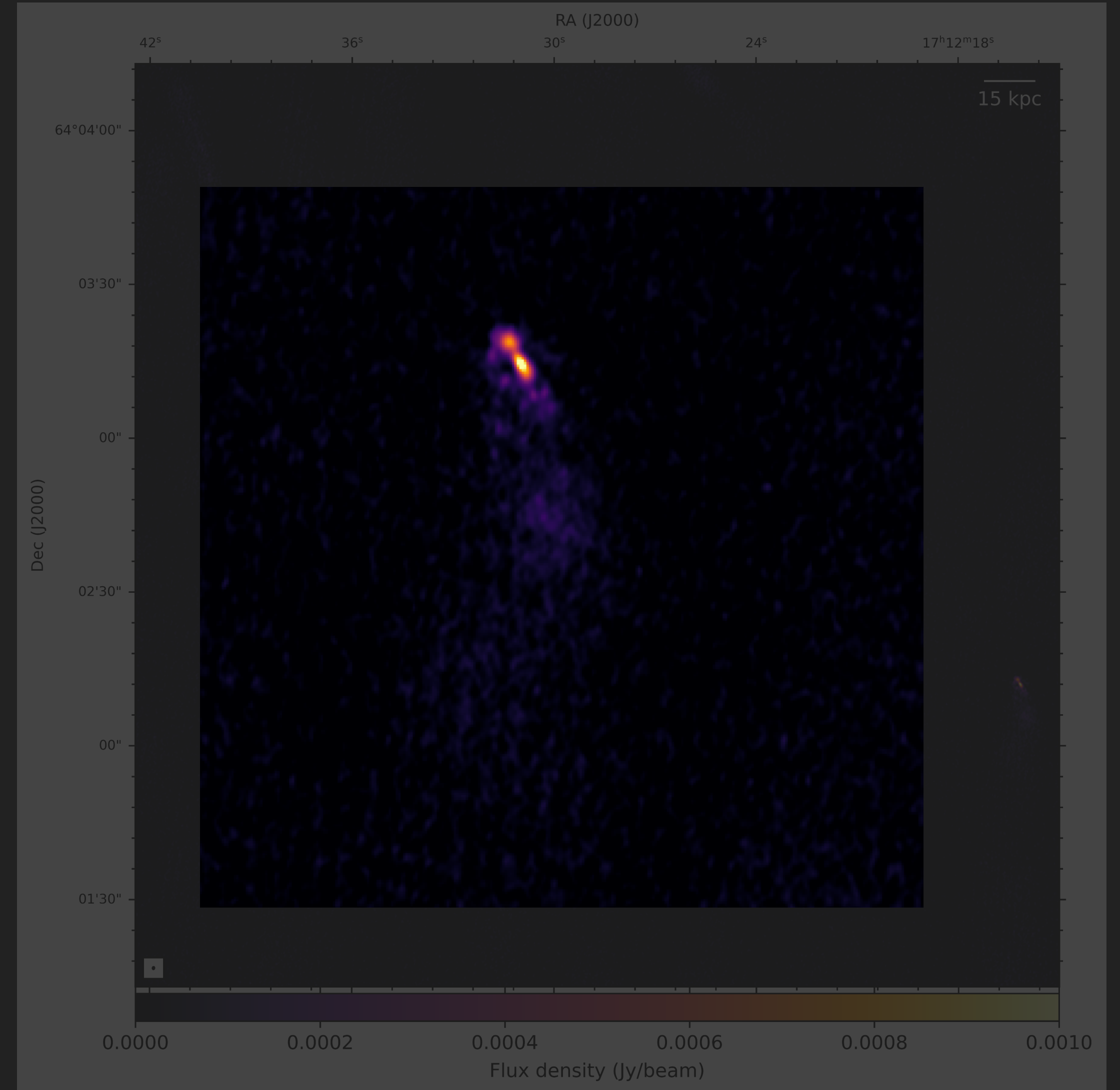
LOFAR-VLBI INSIGHTS: ORIGINAL TRG



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