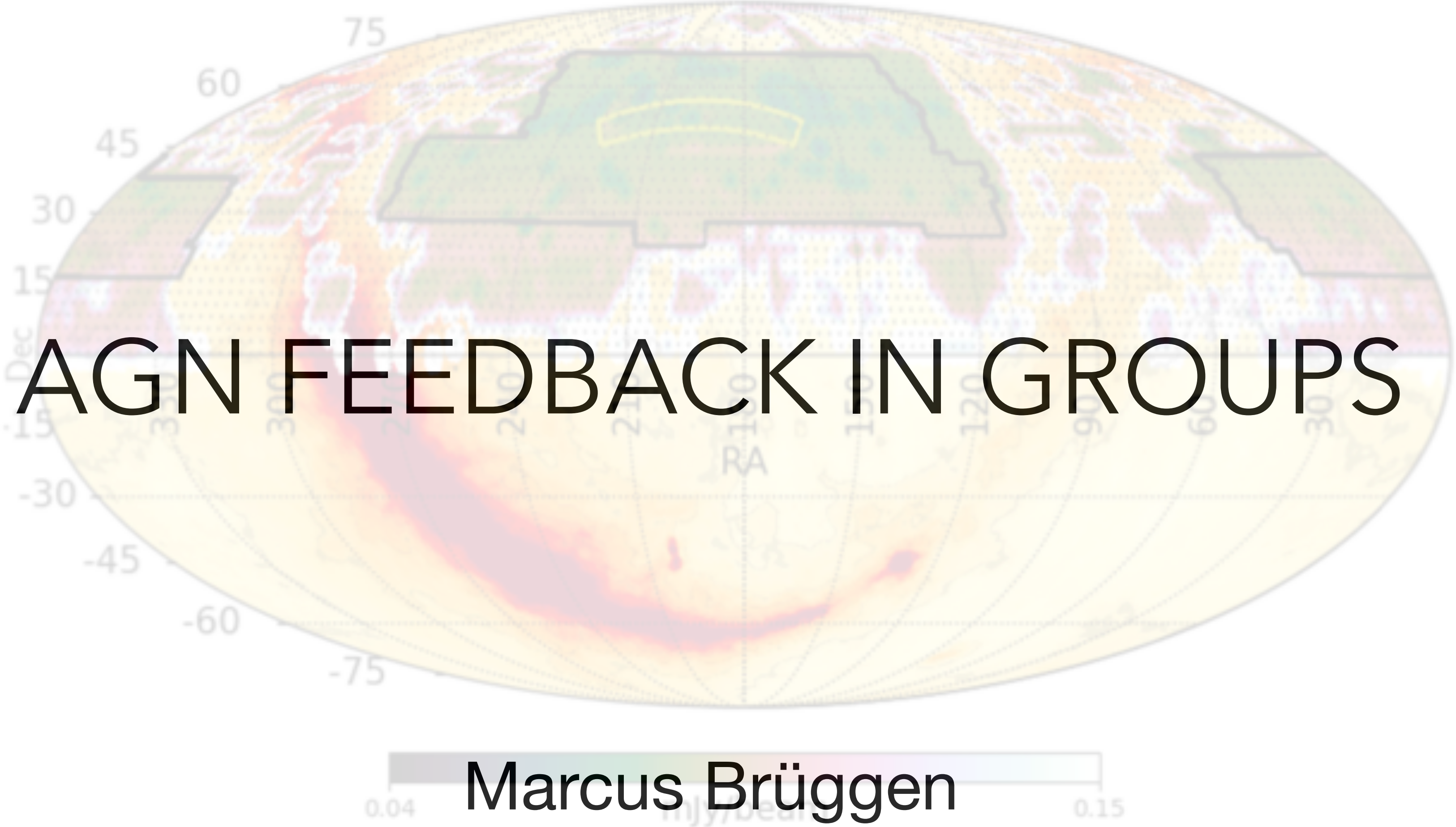


AGN FEEDBACK IN GROUPS

Marcus Brüggen
University of Hamburg

@HambObs

THE PLAN

① STATISTICS

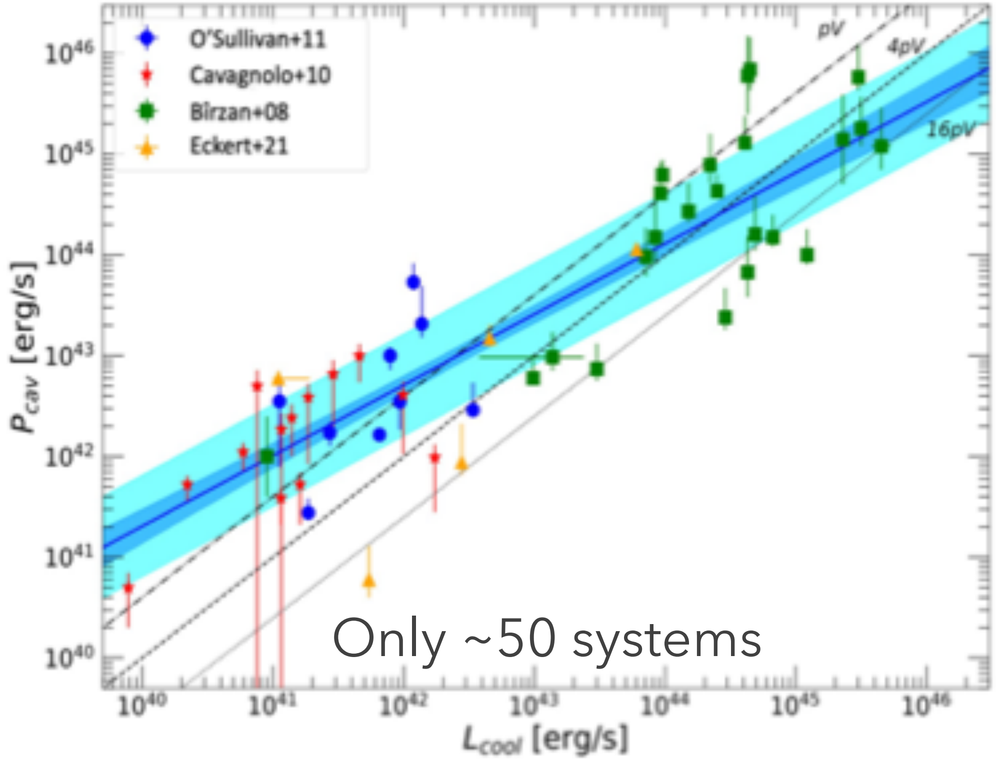
Is feedback effective over the entire mass range of clusters and groups?

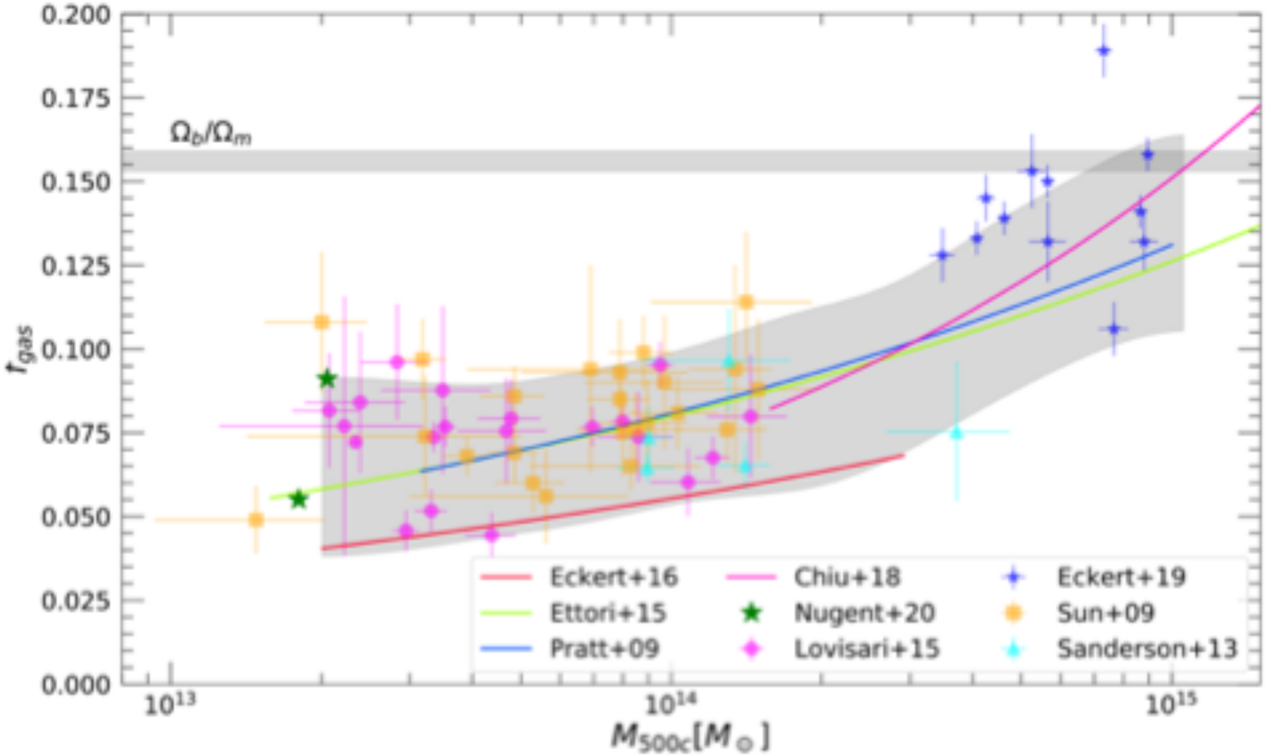
What happens if the AGN is not lying at the centre of the cooling region?

② INDIVIDUAL SYSTEMS

The emergence of filaments

CORRELATIONS





Eckert+ 2021

Not a clear threshold, we assume $10^{13} < M_\odot < 10^{14}$

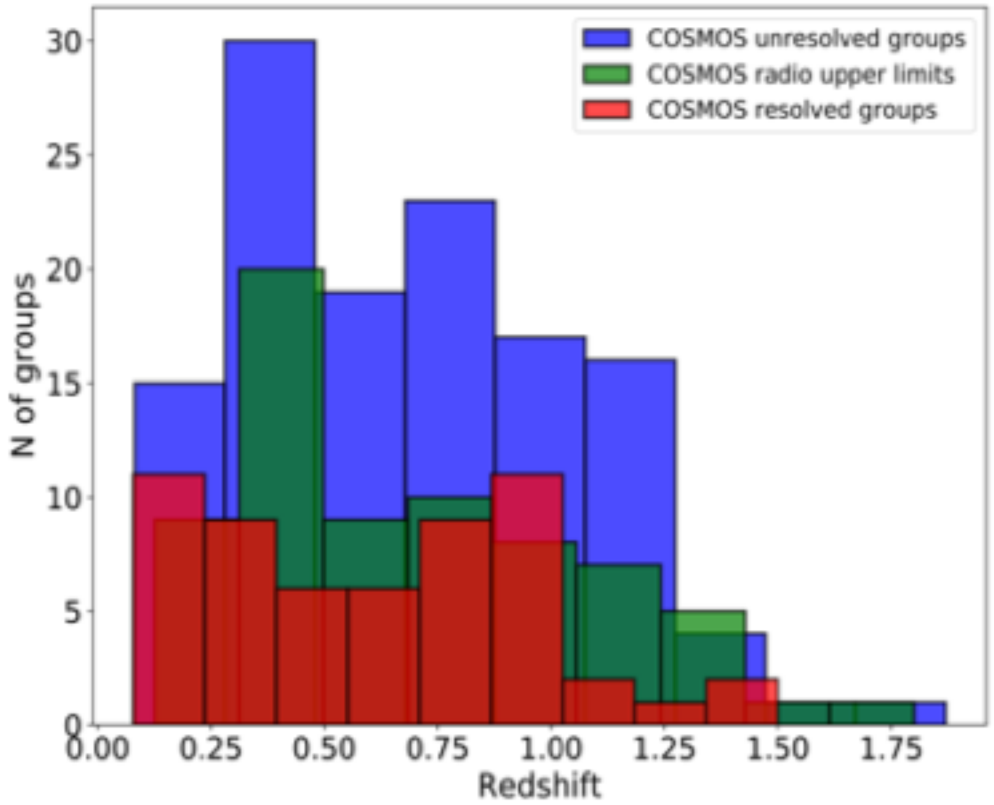
Lower temperature and lower density

Cooling dominated by line emission

Shallower grav. potential. Large scatter in closure radii

eROSITA is observing thousands of clusters and groups;

CENTRAL RADIO GALAXIES IN GROUPS



- Parent sample: 247 galaxy groups in COSMOS (Gozaliasl+19);

- Cross-match with VLA-COSMOS Deep Survey and MIGHTEE survey by MeerKAT;

- **174 detections (55 resolved)**
- **73 radio upper limits**

Pasini, Brüggen, de Gasperin + 2020

X-RAY VS RADIO

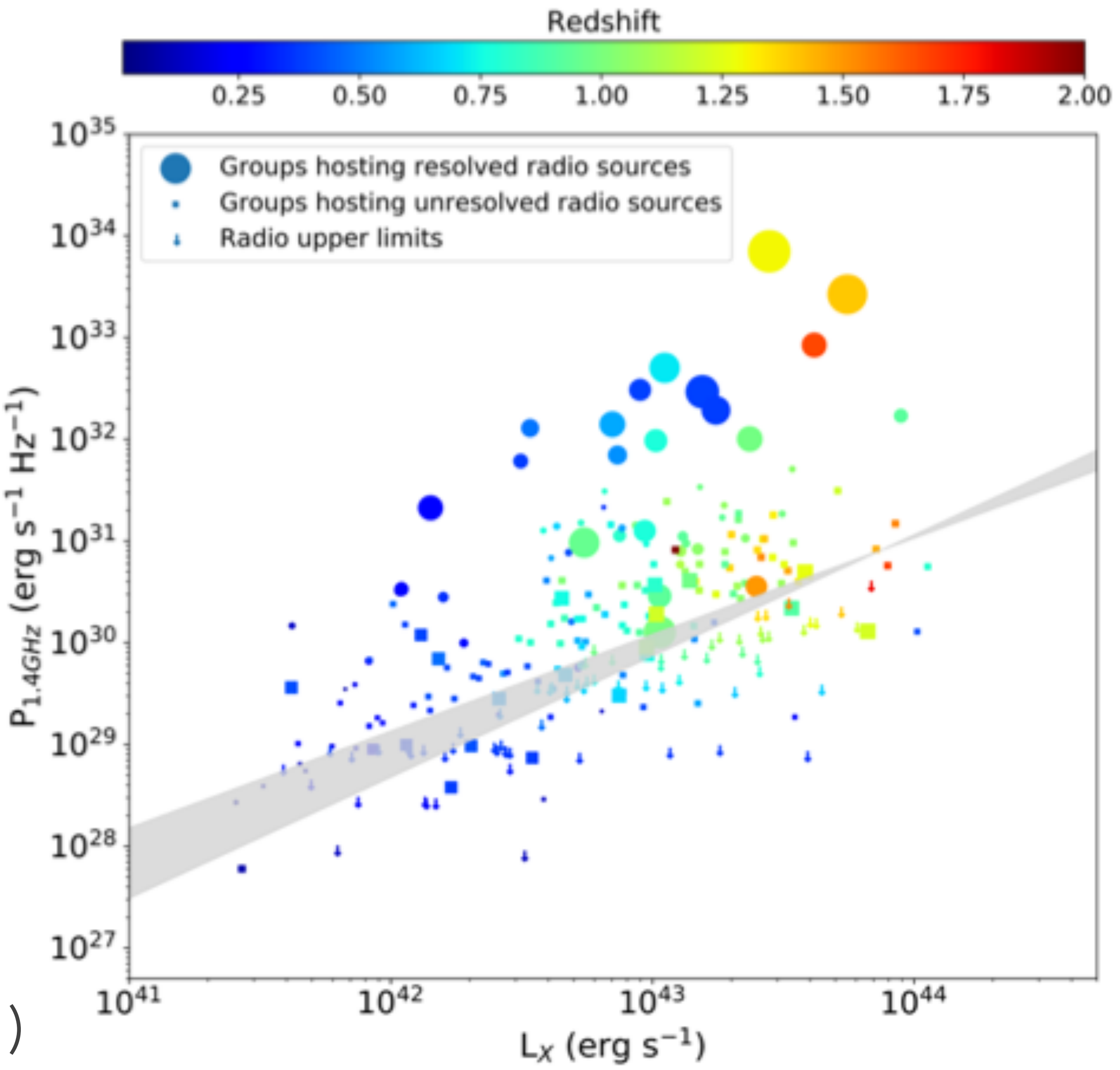
More luminous groups host stronger radio sources at their centres;

~15 outliers: systems that host very large radio galaxies;

Statistical tests to check the correlation and the contribution from upper limits.

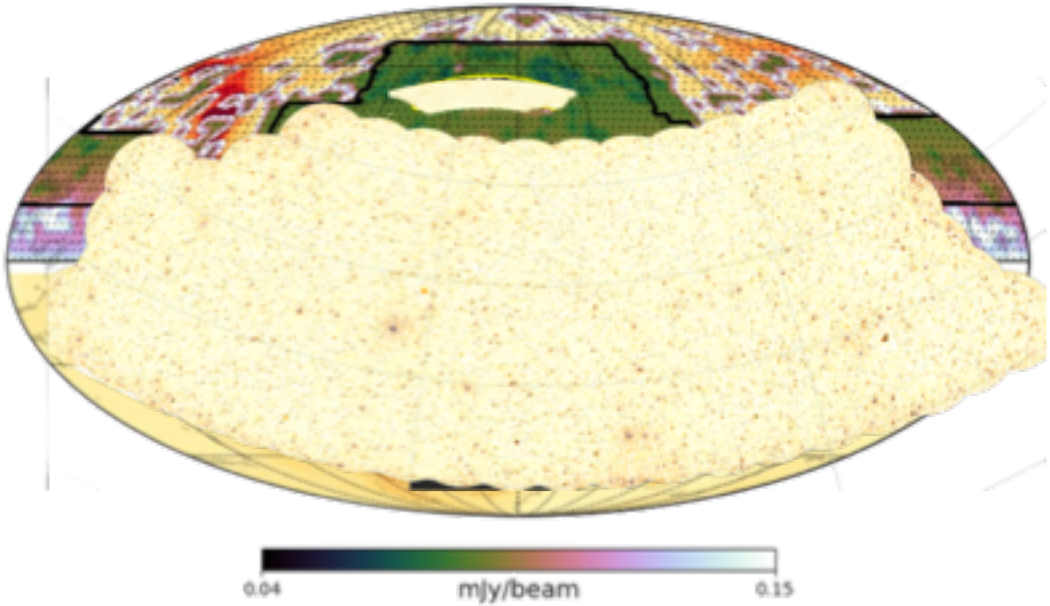
Correlation very similar to cluster samples

- ~85% of central radio sources are hosted in BCGs; same fraction is only 30% in groups;

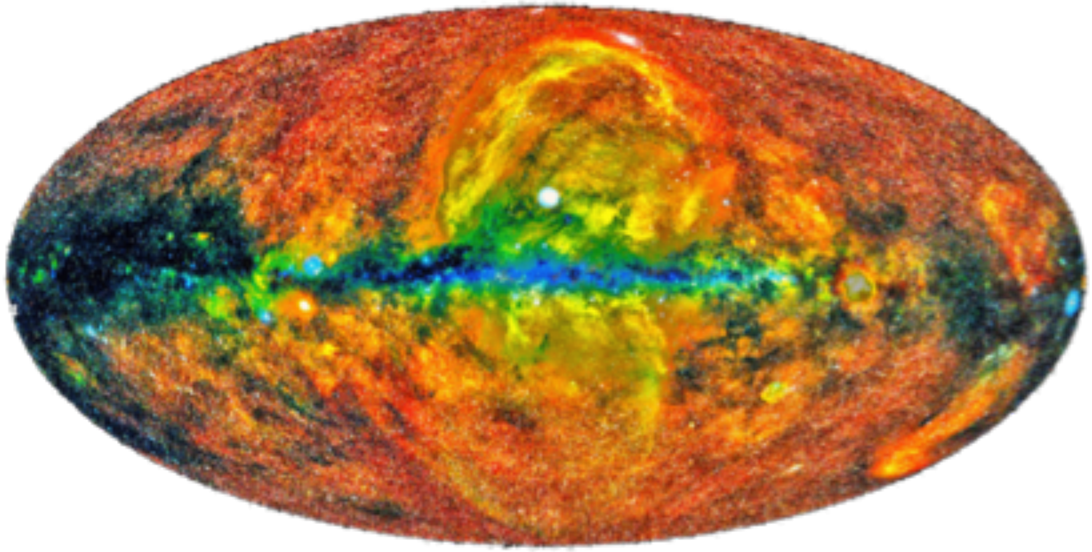


$$-\log L_R = (1.1 \pm 0.11) \log L_X - (15.9 \pm 5.1)$$

SURVEYS



LOTSS+LoLSS



eRASS

eROSITA advantages for galaxy clusters

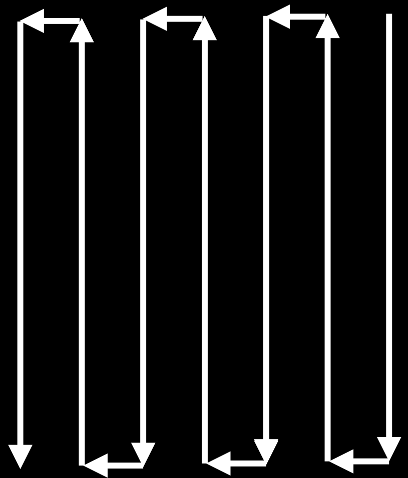
Moon diameter
30 arcmin

XMM-Newton
Field of view ~ 30 arcmin

Chandra
Field of view ~ 17 arcmin

eROSITA
Field of view ~ 65 arcmin

+

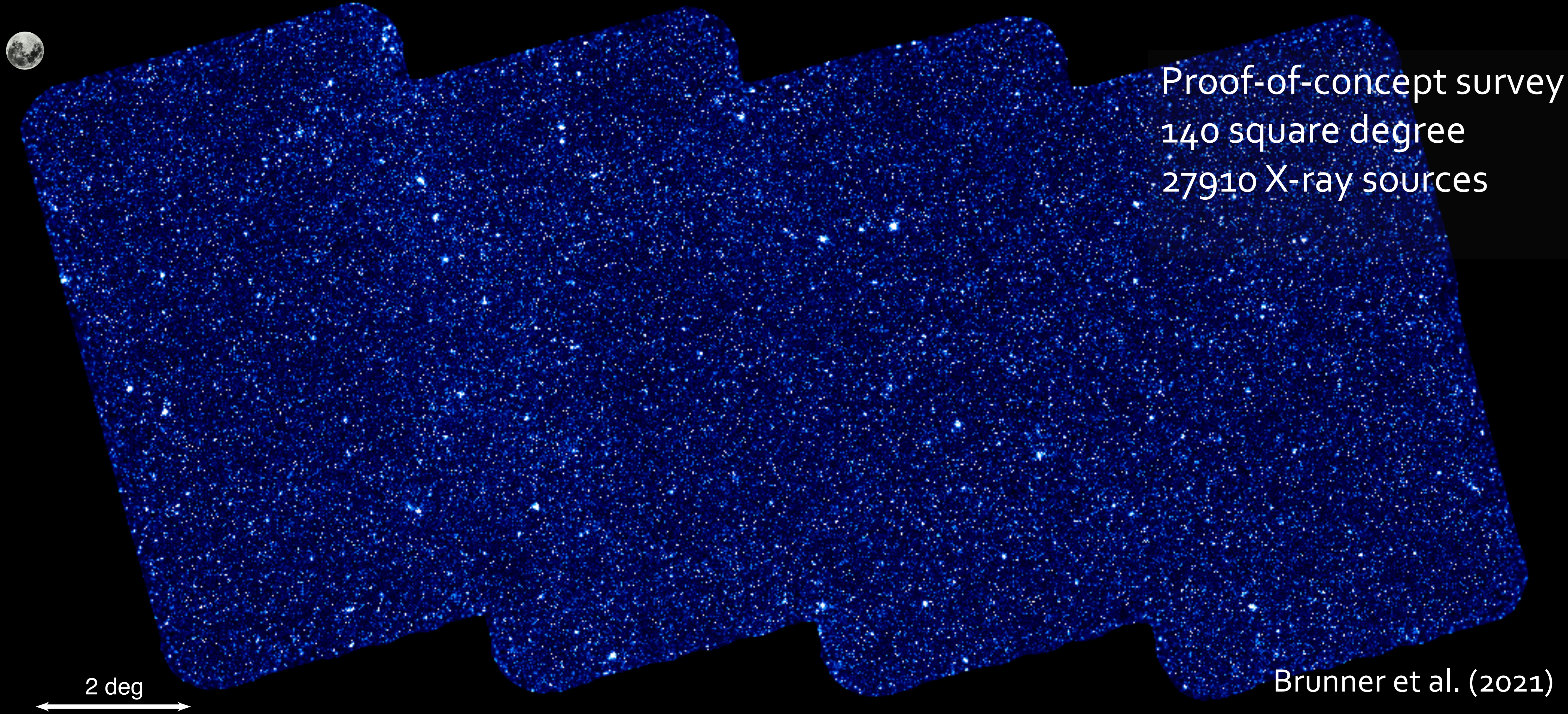


Scanning feature

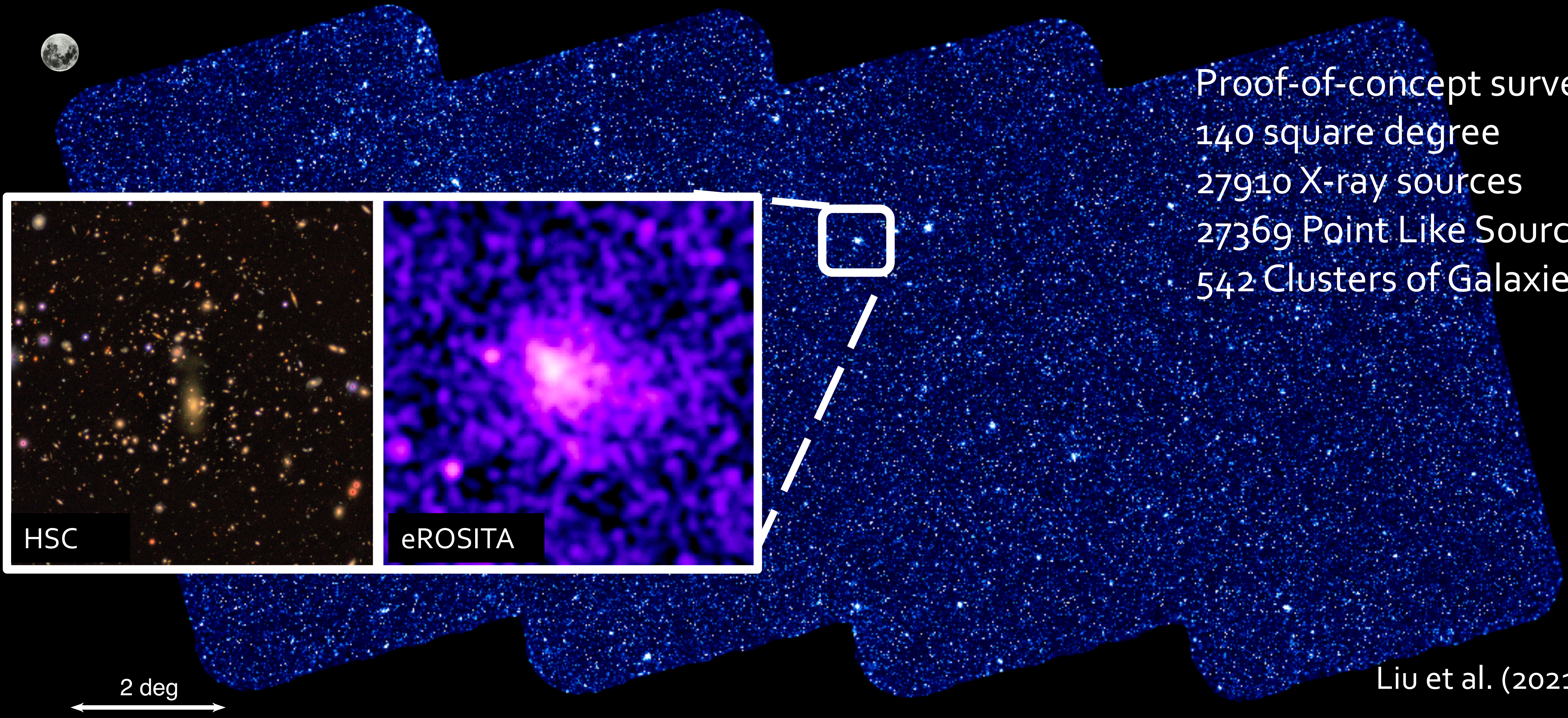
Grasp; FOV*Effective Area @1keV:
- 5×XMM-Newton
- 100×Chandra ACIS

Credit: M. Ramos-Ceja

eROSITA Final Equatorial Depth Survey

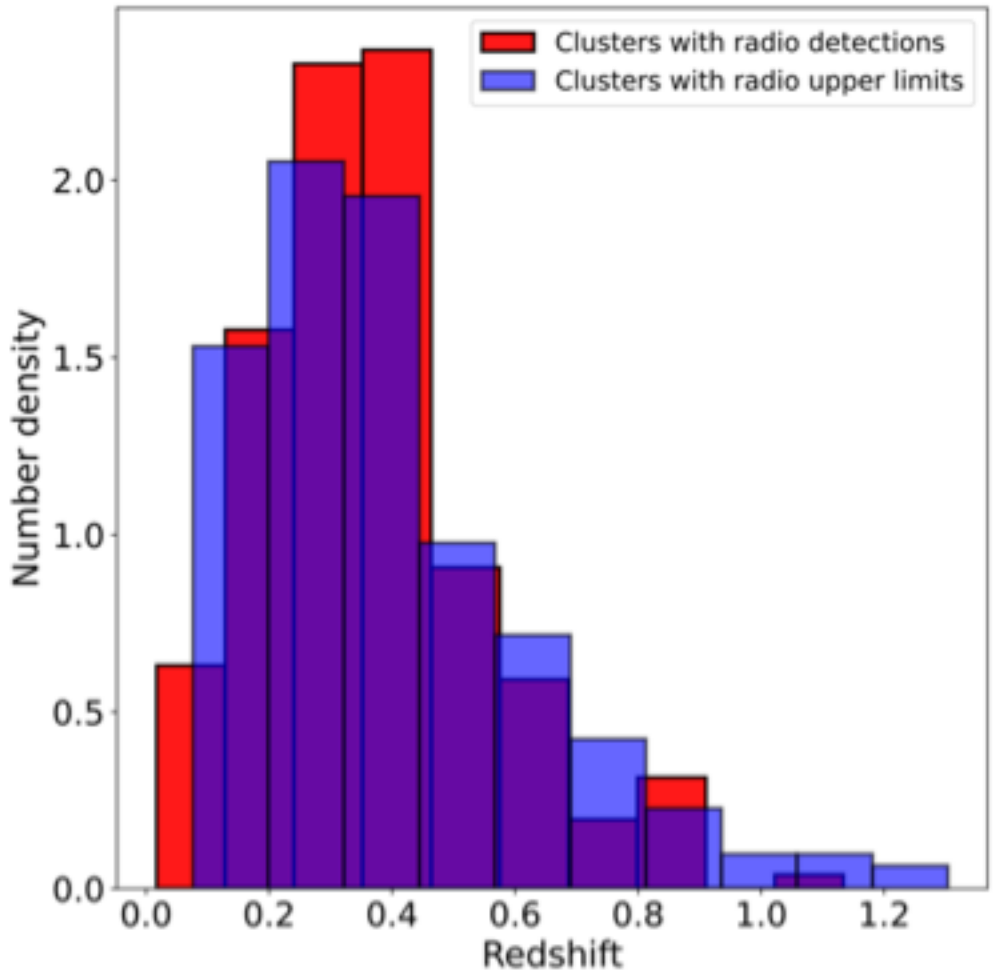


eROSITA Final Equatorial Depth Survey



eFEDS: eROSITA and LOFAR observations

- 542 galaxy clusters and groups detected in this field;
- 184 hours coverage by LOFAR (144 MHz), mean *rms* ~ 220 uJy/beam;
- Cross-match with BCG position;
- 227 BCGs show AGN radio emission
- 248 radio upper limits
- 67 excluded for contamination

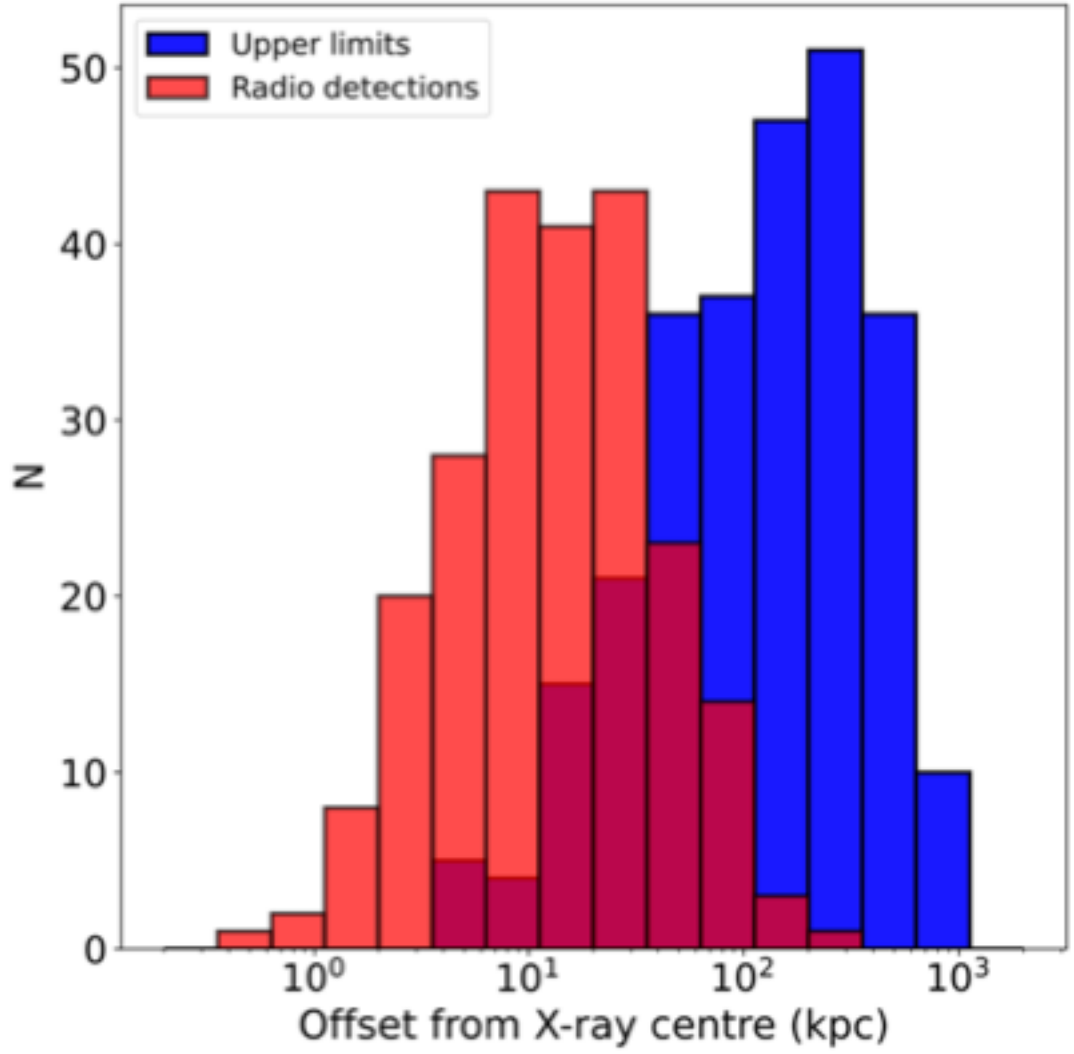


Pasini, Brüggen,Hoang +, MNRAS 2022

BCG offsets and link to radio emission

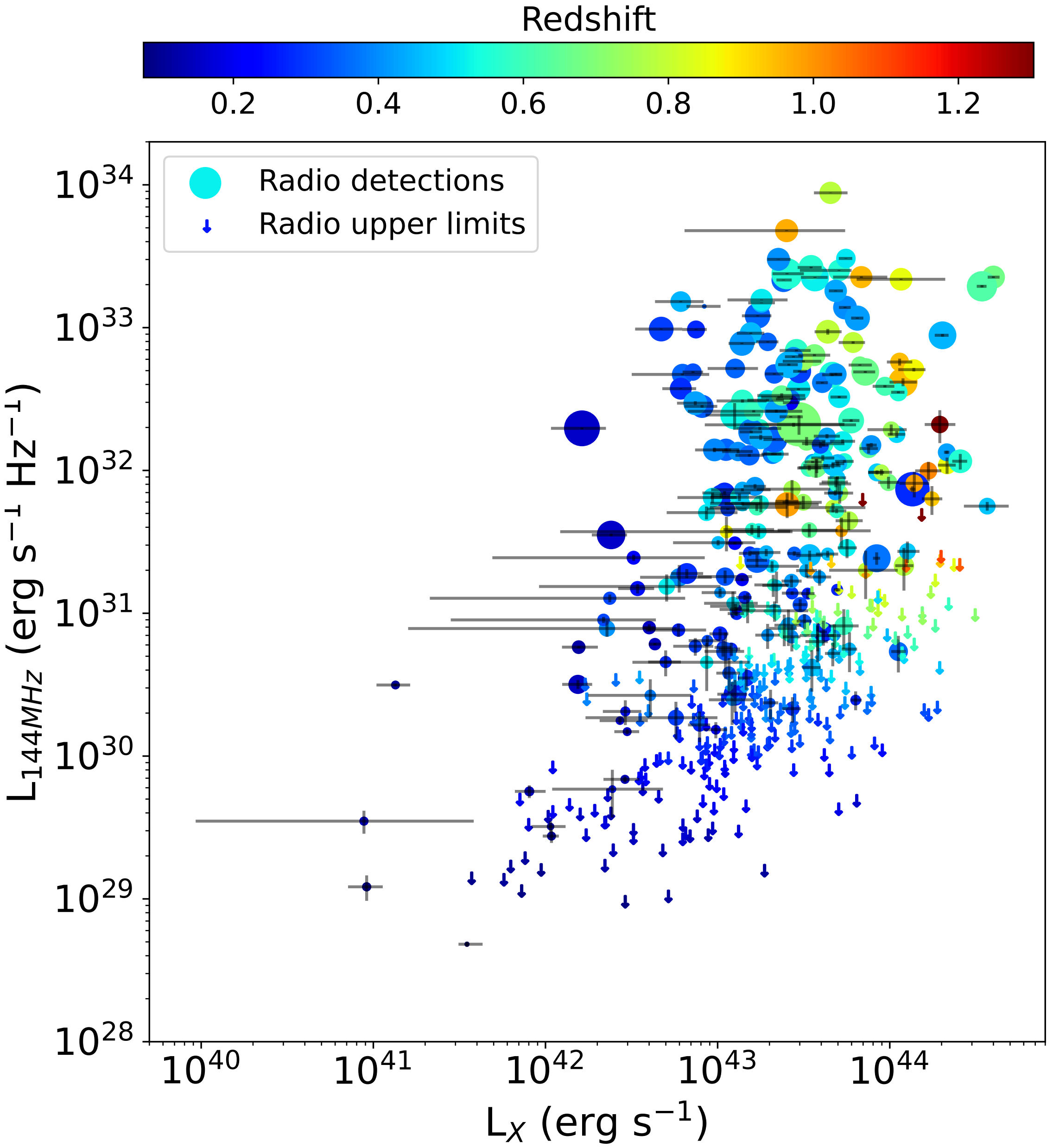
- ~84% of radio BCGs lie within 50 kpc from the cluster centre, with median ~15 kpc and dispersion ~30 kpc;

- In more central galaxies the accretion onto the central BH is boosted by the cooling in the cluster core (Shen+17, Pasini+21).



Pasini, Brüggen,Hoang +, MNRA 2022

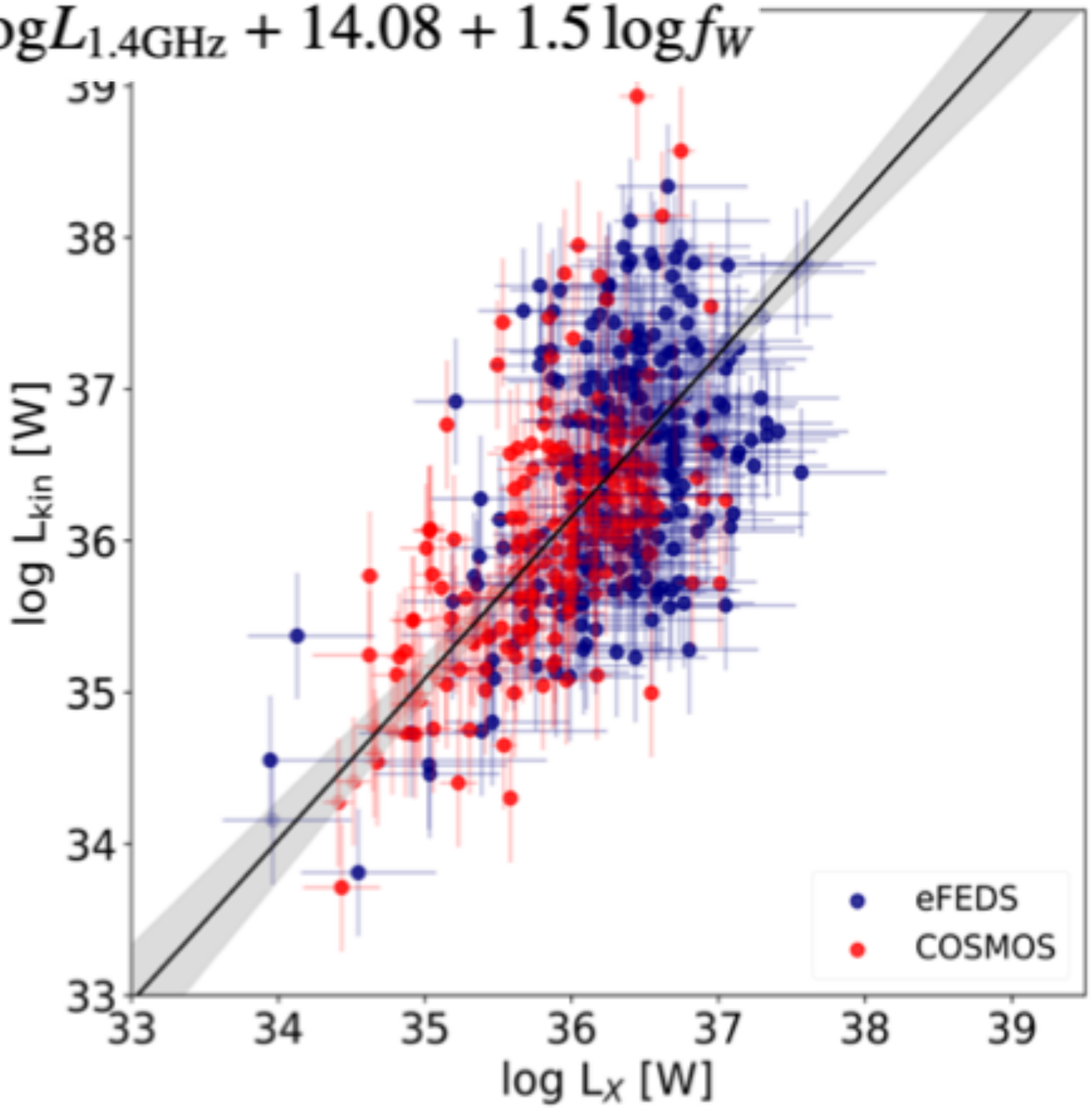
144 MHz radio vs X-ray



Pasini+ 2021

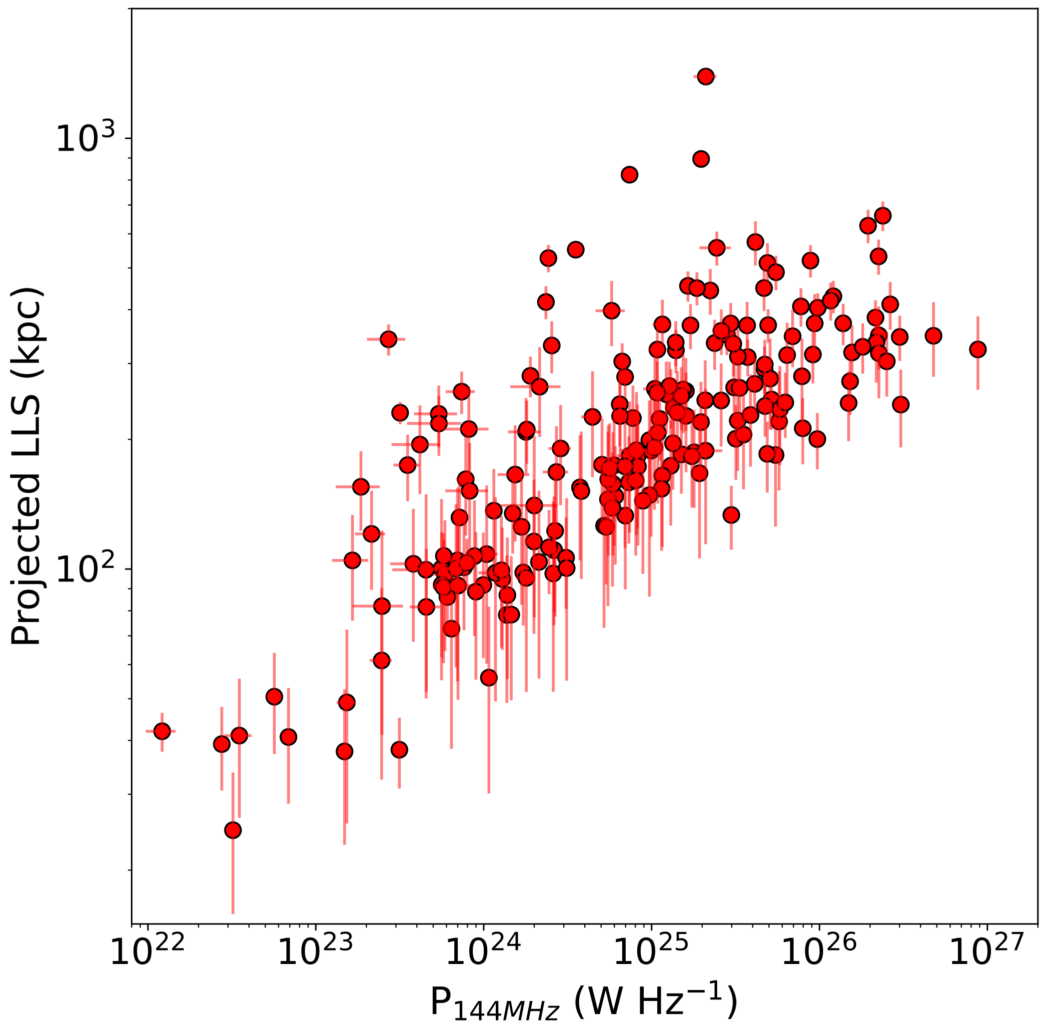
Kinematic luminosity

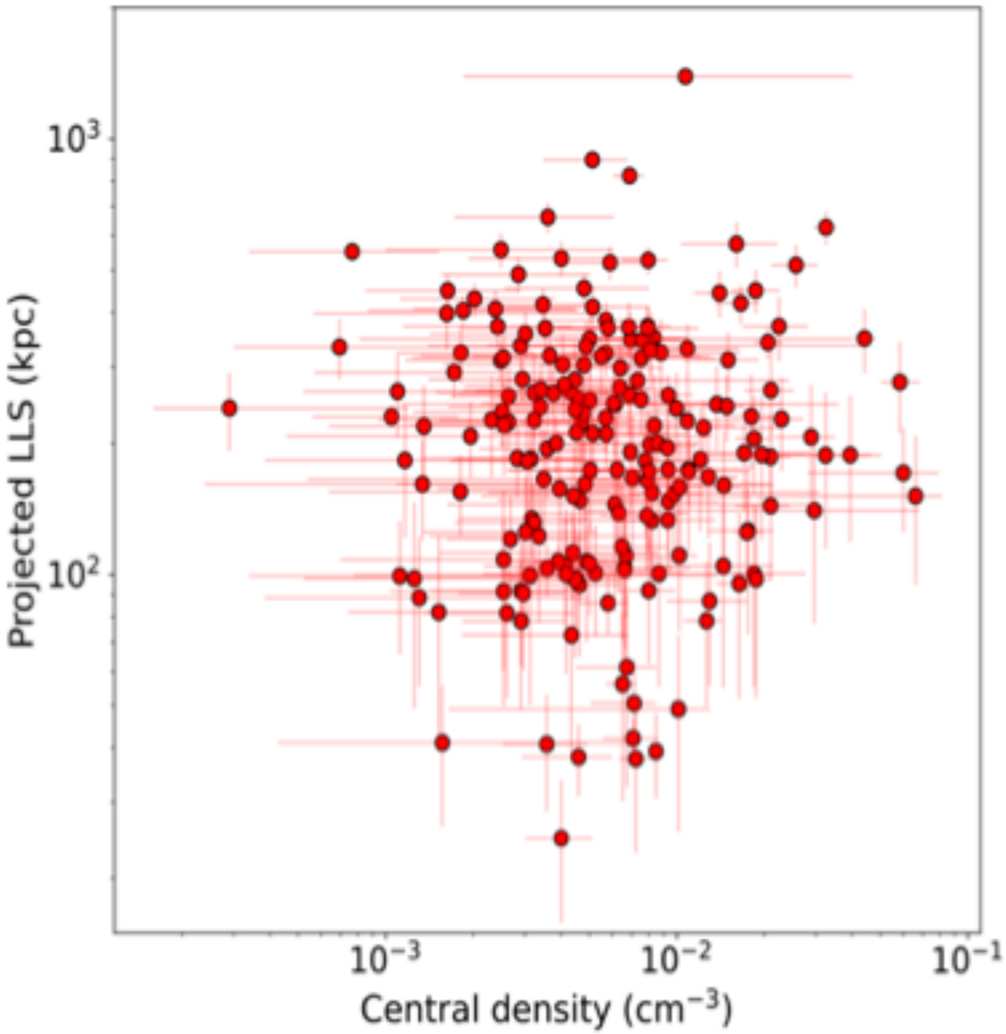
$$\log L_{\mathrm{kin,1.4GHz}} = 0.86 \log L_{\mathrm{1.4GHz}} + 14.08 + 1.5 \log f_W$$



Pasini+ 2021

LLS





Pasini+, MNRAS 2021

AGN Feedback in Groups

There is a clear relation between the group's X-ray luminosity and the 144 MHz radio power of the BGG.

No apparent link between largest linear size of the radio galaxy and the central density in the host group.

Radiative losses of the intracluster medium are in overall balance with the heating provided by the central AGN

BGGs with radio-loud AGN are more likely to lie close to the group centre than radio-quiet BGGs.

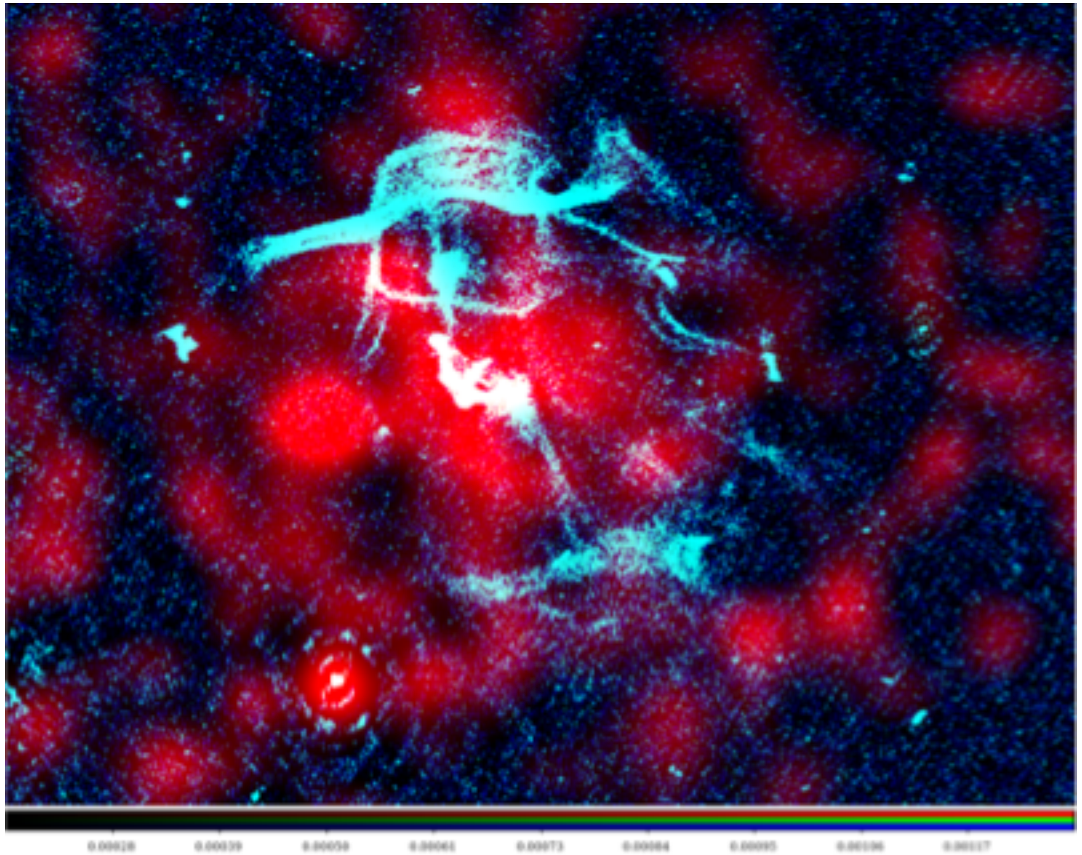
Pasini+, MNRAS 2021

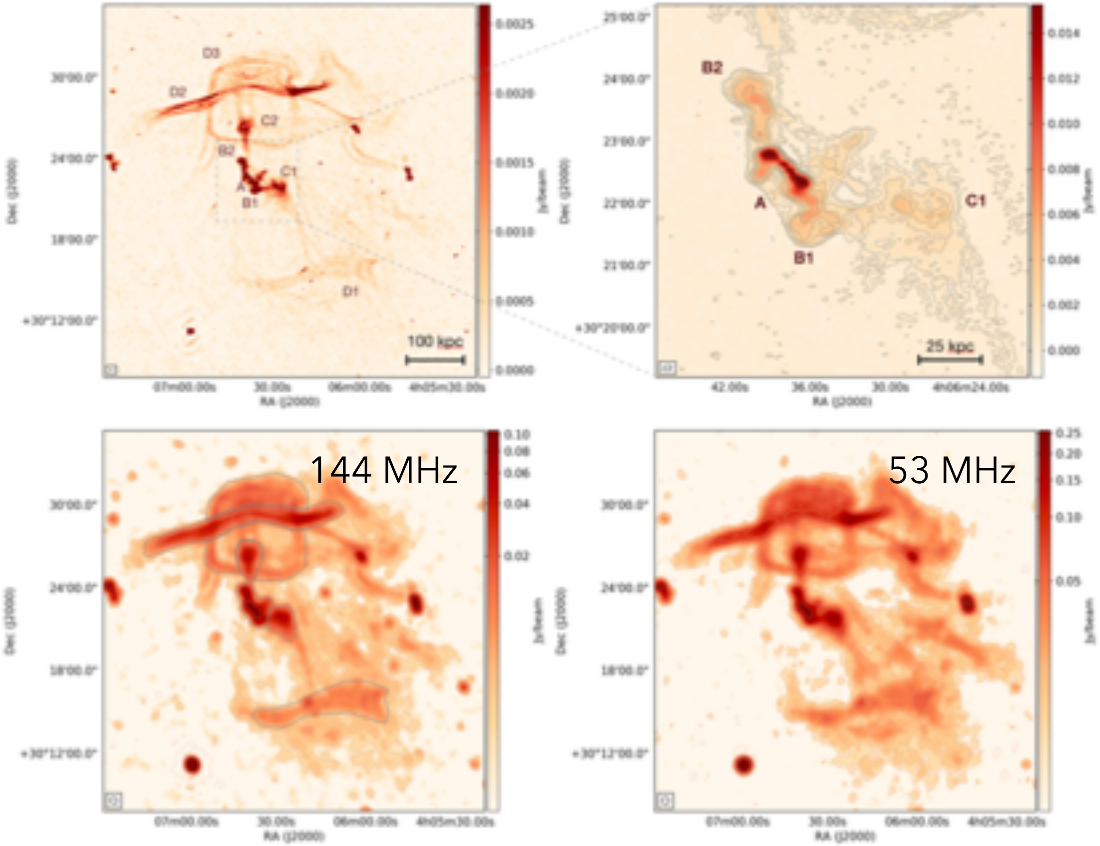
INDIVIDUAL SYSTEMS

GALAXY GROUP Nest200047

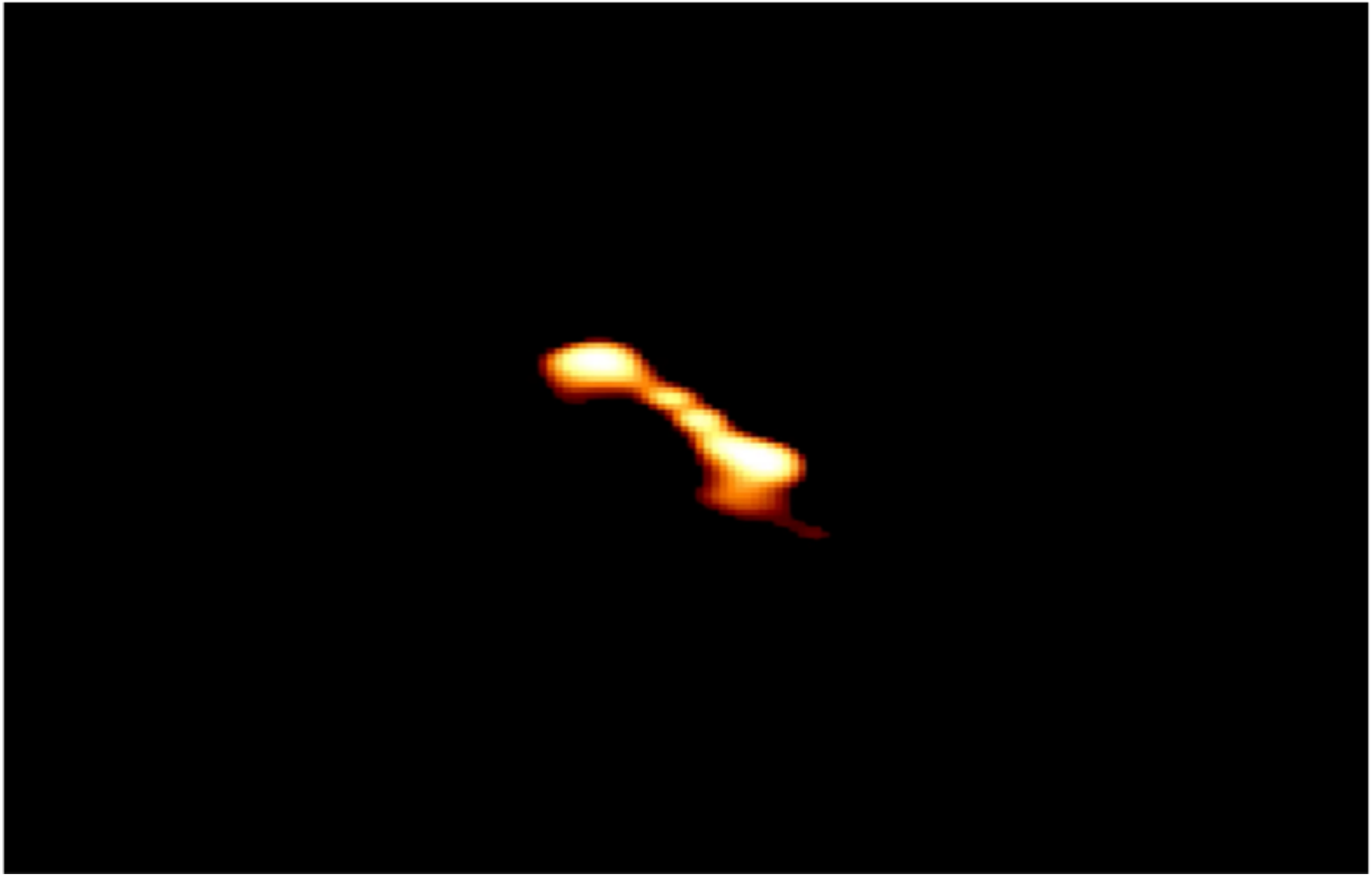
- We found a group with $M_{500}=3\text{-}7\times10^{13}$ Msun that appears as a low-mass equivalent of M87
- $t_{buoy} > t_{rad}$ re-acceleration?
- Magnetic tension may play an important role

0.5-2 keV eROSITA + LOFAR



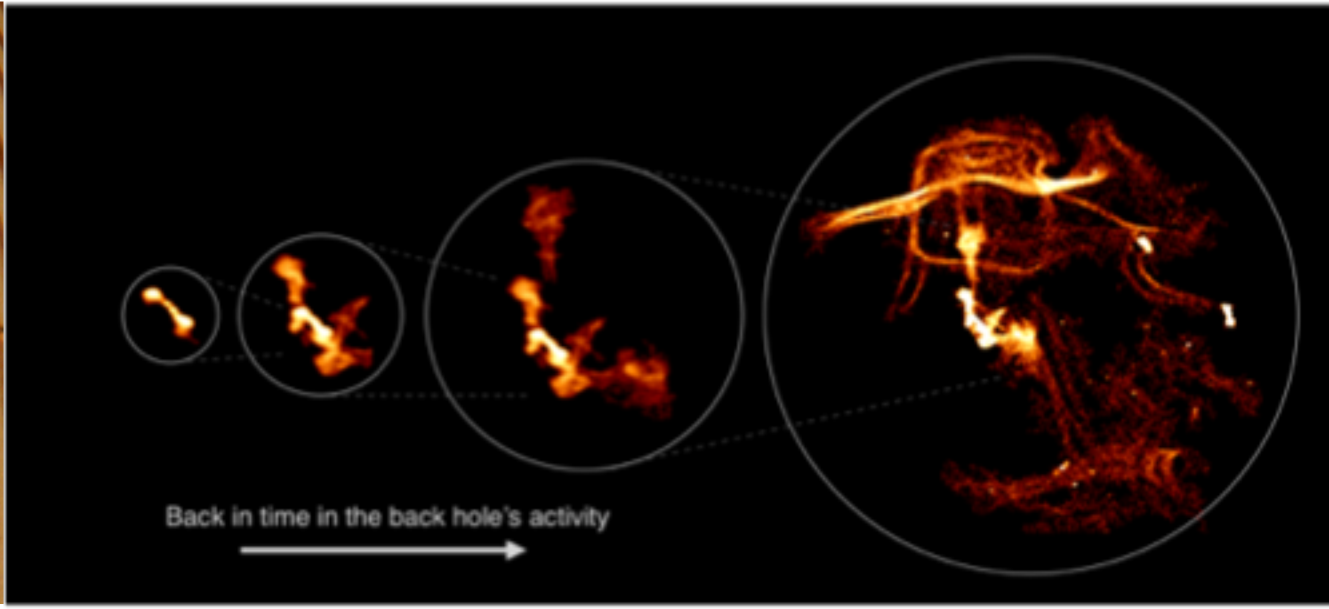


Brienza+, Nature Astronomy, 2021

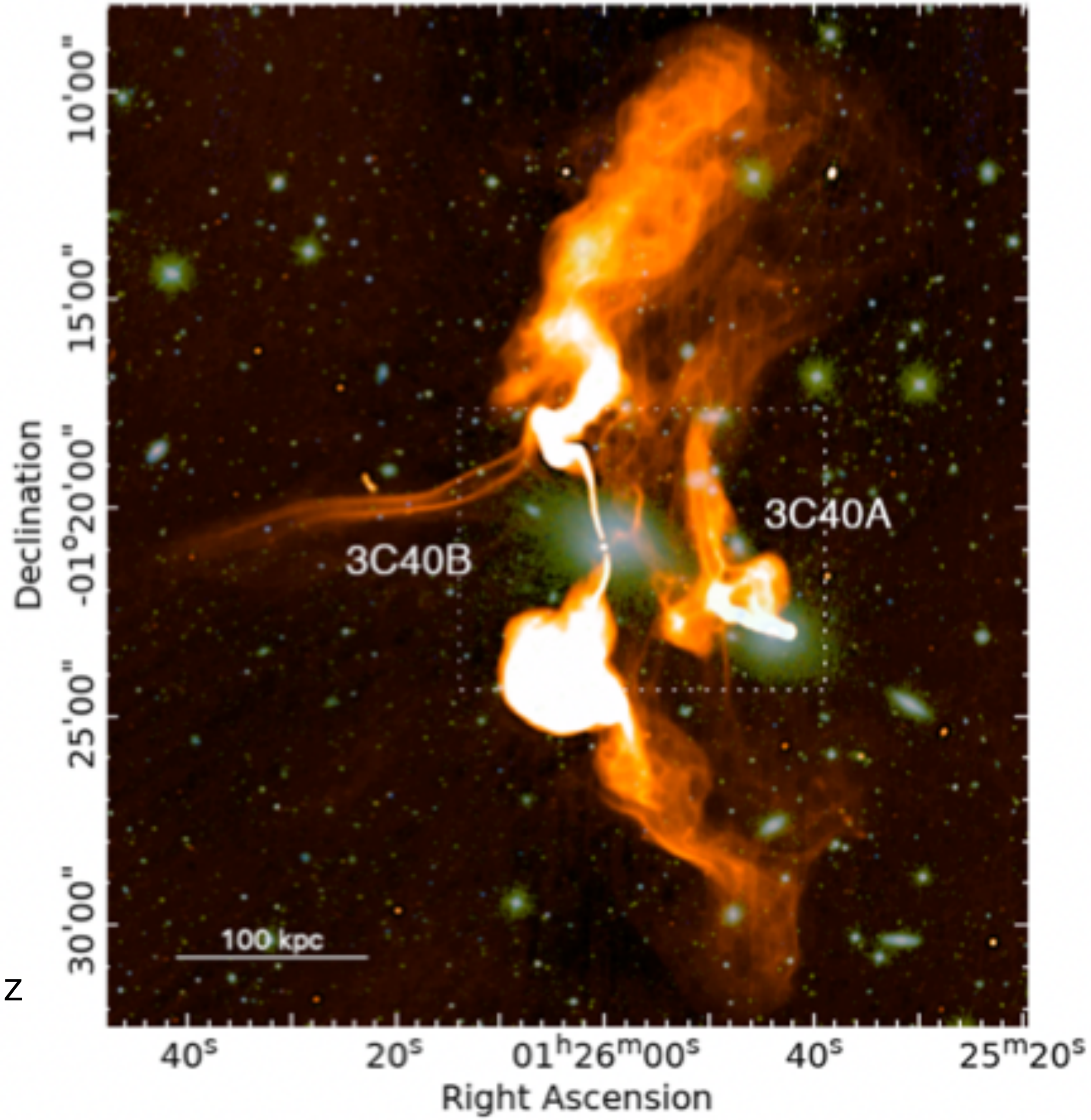


DENDROCHRONOLOGY

CRE-CHRONOLOGY



The curious case of 3C40B



MeerKAT 900–1670 MHz at 7.75''

Two radio galaxies in Abell 194

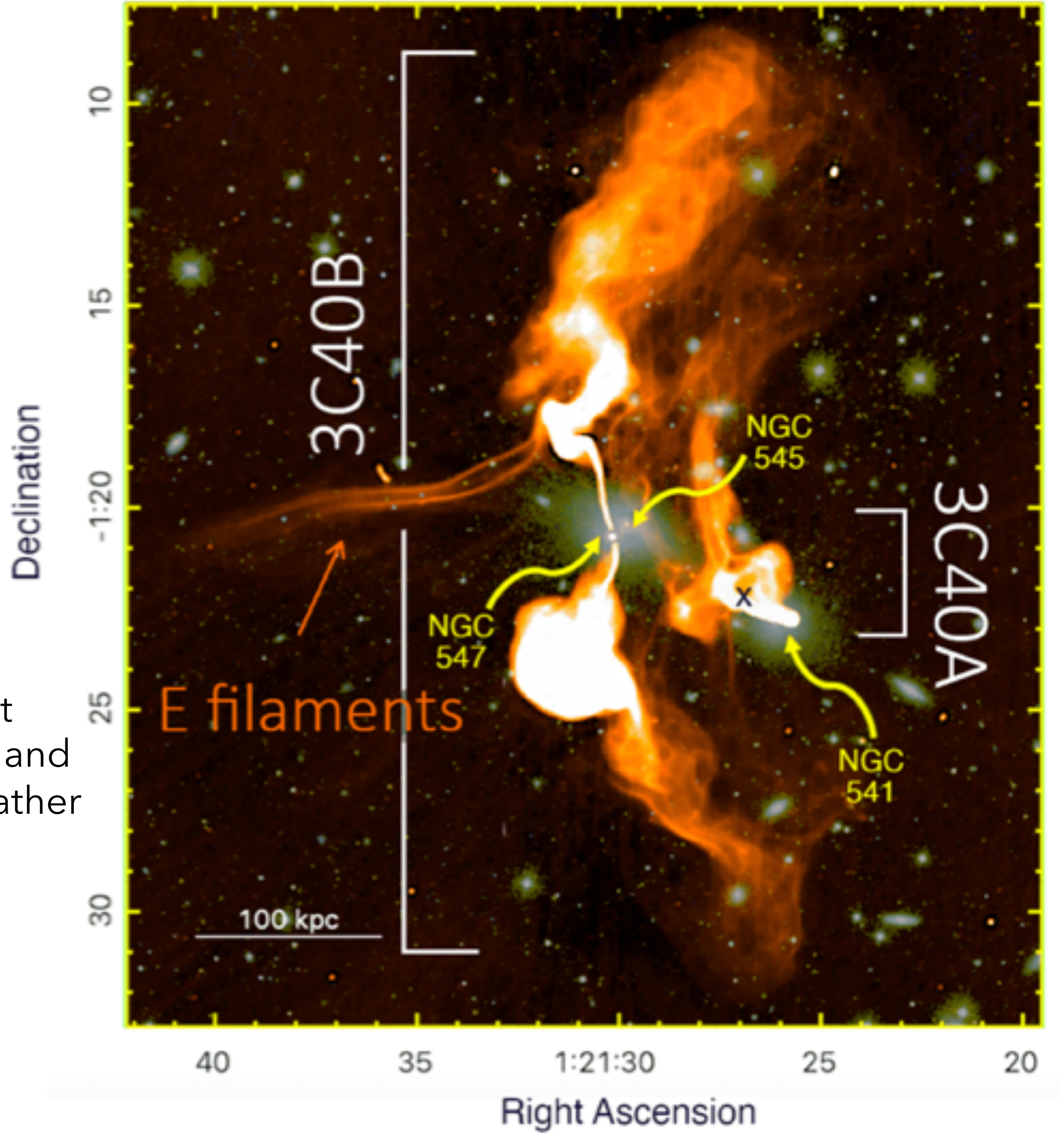
A194 has low X-ray luminosity ($7.1 \pm 0.7 \times 10^{42}$ ergs/s, 0.1 - 2.4 keV) and a low X-ray temperature (kT = 1.37 ± 0.04 keV), which is characteristic of an X-ray bright group.

Knowles+, MNRAS 2022
Rudnick, Brüggen + ApJ in press 2206.14319

The E-fils have narrow emission extending for 200 kpc and more diffuse emission extending ~300 kpc from the 3C40B jet, with narrow components ~3-8 kpc across and a broad component relatively constant at 12 kpc wide

There is a ~20% deficit in X-ray surface brightness at the position of the E-fils, consistent with an absence of X-ray emitting material in a ~35 kpc cylinder encompassing the radio structure.

The E-fils wrap around the northern jet of 3C40B as it abruptly turns to the west. The Faraday depths of jet and E-fils coincide at this point, -> physical interaction , rather than a chance superposition.



Rudnick, Brüggen + ApJ in press 2206.14319

THE EMERGENCE OF FILAMENTS

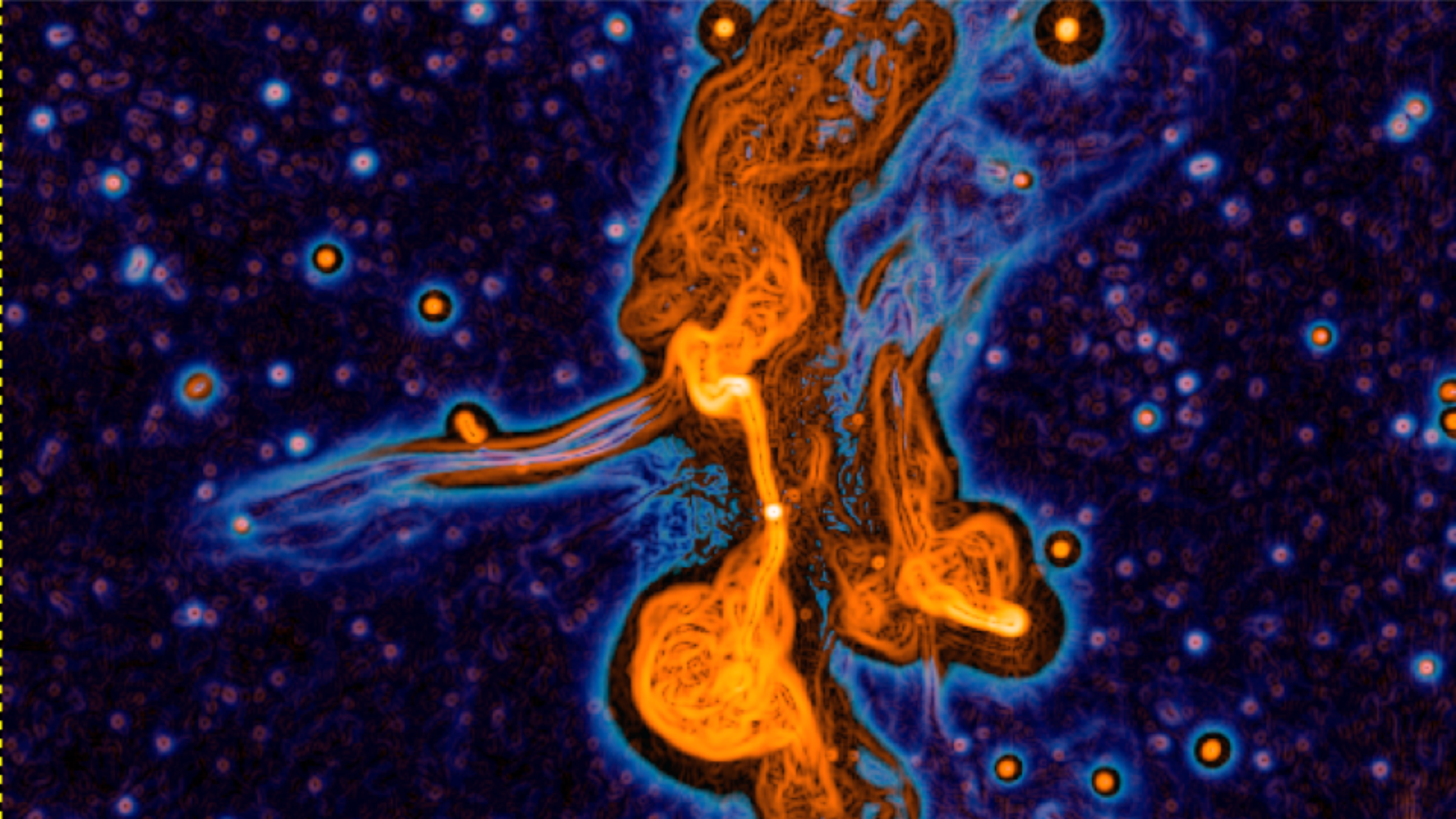
Pair of filamentary structures in Abell 194 show clear signs of interactions with the northern jet from 3C40B, associated with the BCG NGC 547.

Isolated filaments may provide another site for cosmic ray acceleration in clusters.

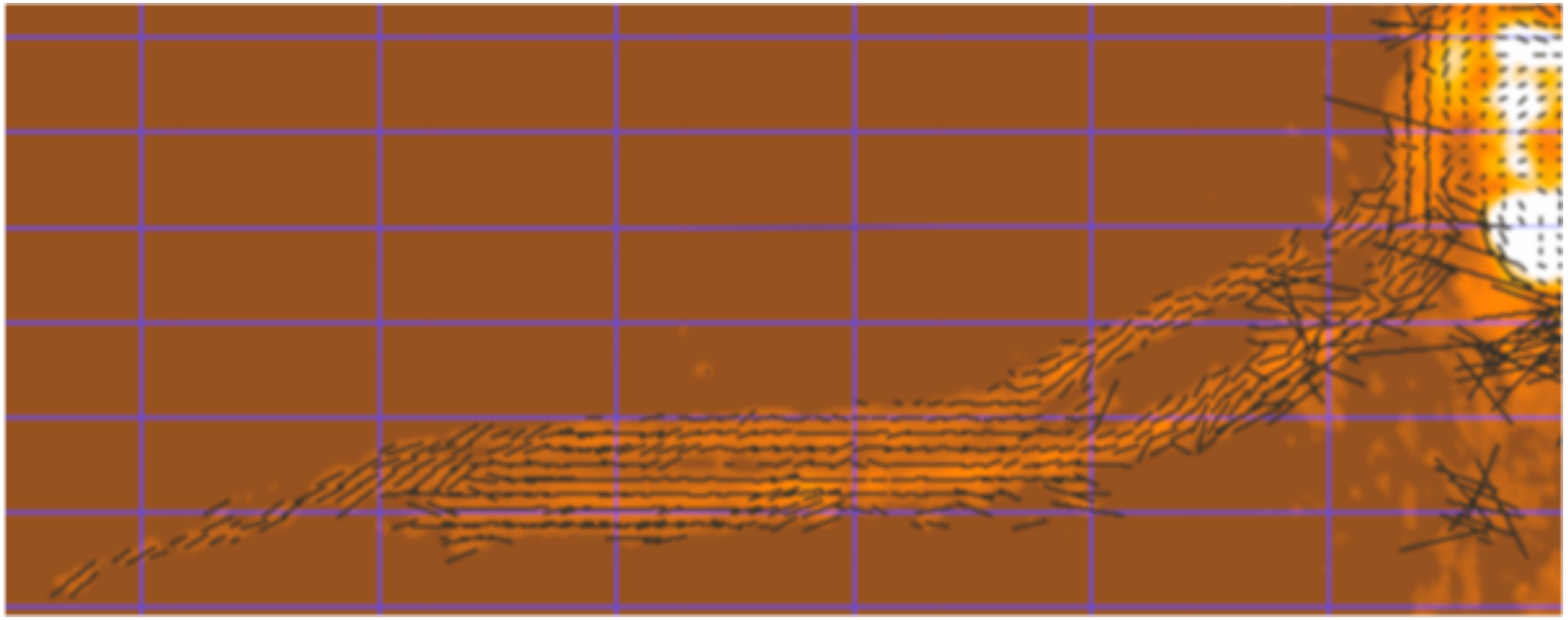
Filamentary structures are a natural consequence of turbulence in a high-β plasma.
Simulation: extended bundles of magnetic fields are ubiquitous in turbulent MHD flows, their lengths reflect the local driving scales of the turbulence.

Filaments are formed from the tearing of thin current sheets; they are then stretched until magnetic stresses approach dynamical turbulent stresses.

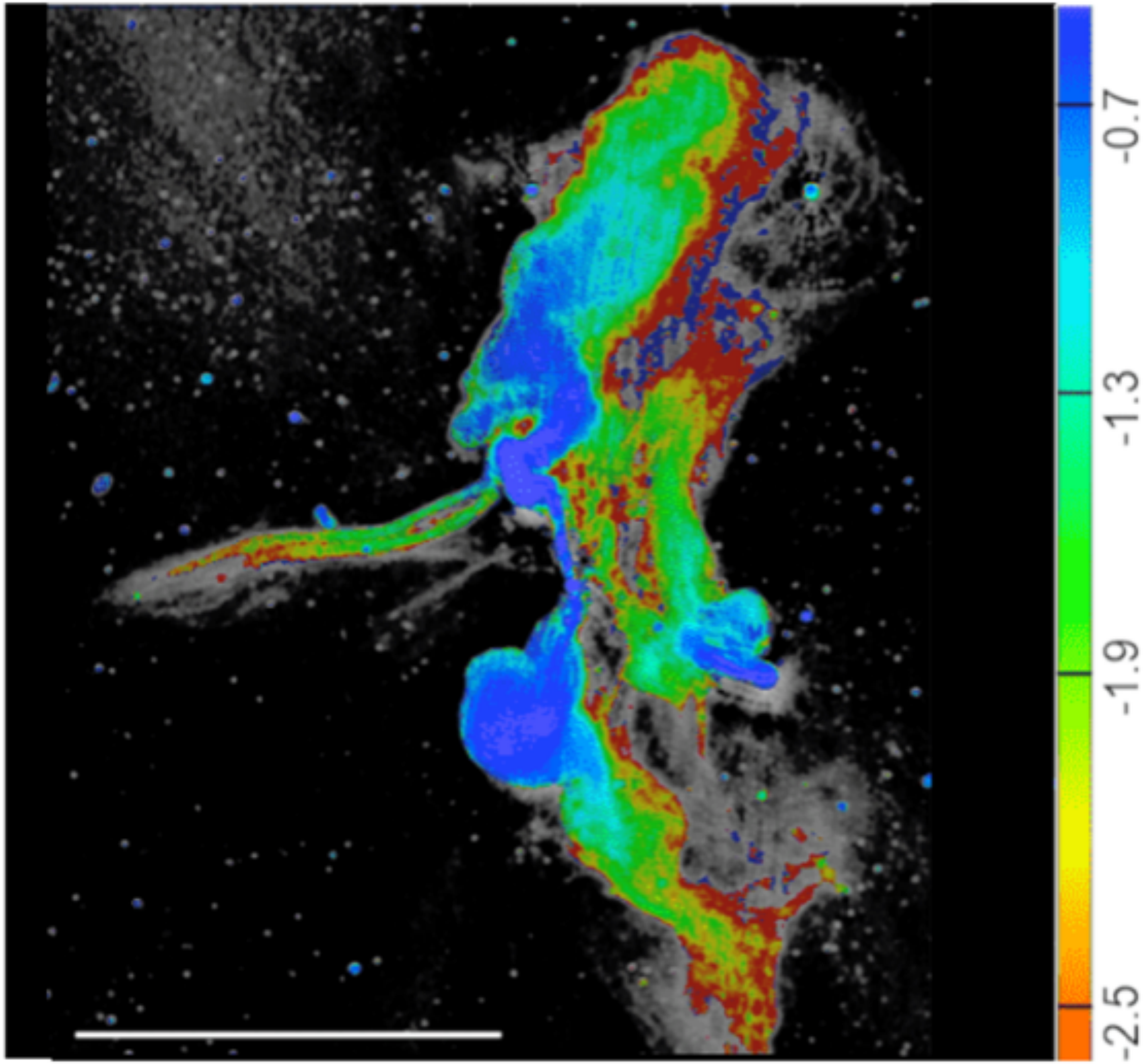
The lengths of filaments set by dominant physical scales in the kinematics of the plasmas;
the widths of the filaments are an important indicator of the physics/microphysics regulating their origin and evolution.



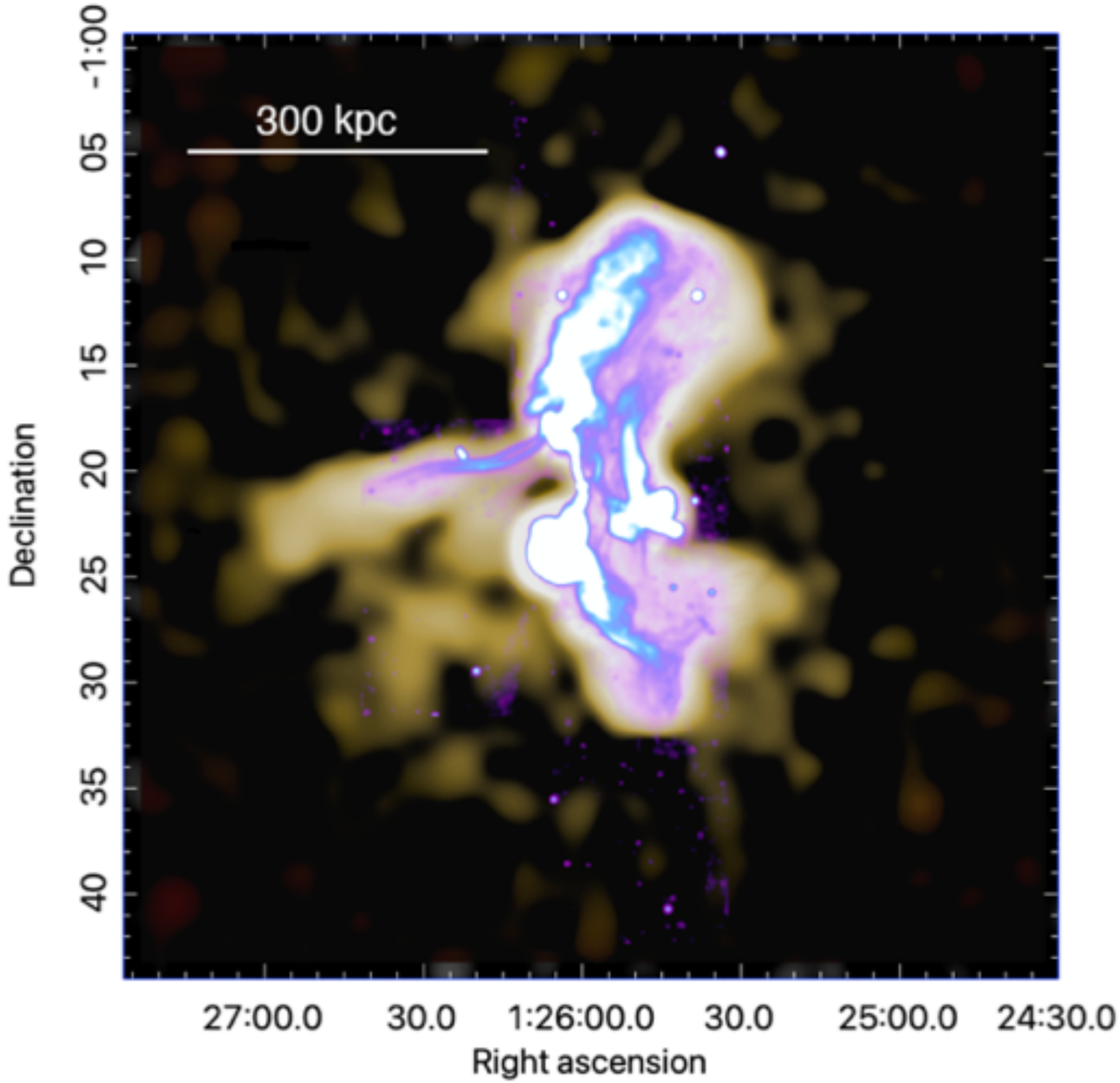
The E-fils are ~50% polarized



•The spectra of the E-fils steepen mostly monotonically with distance from 3C40B



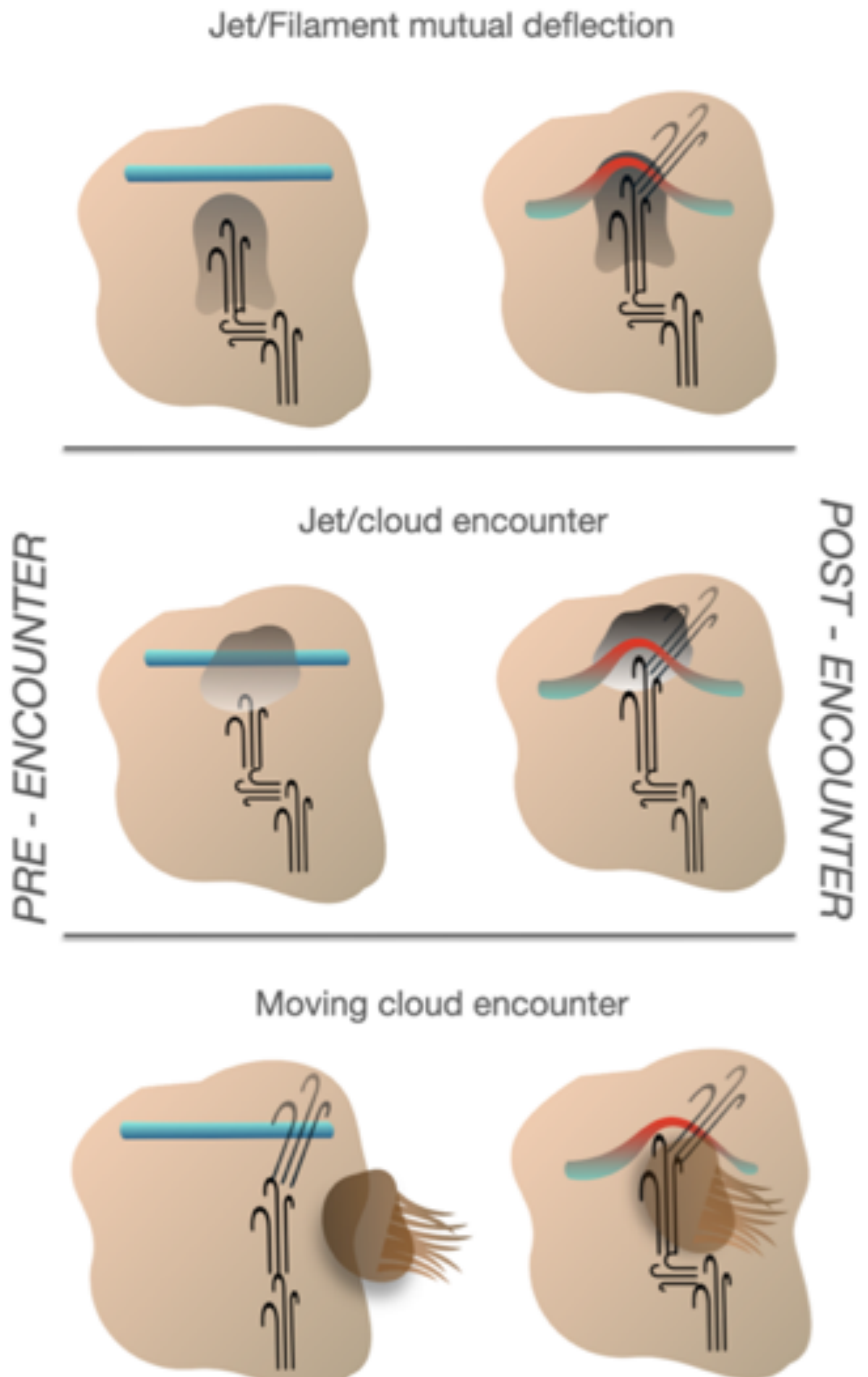
LOFAR


300 kpc
-1:00
05
10
15
20
25
30
35
40
Declination
27:00.0
30.0
1:26:00.0
30.0
25:00.0
24:30.0
Right ascension

Jet material will not be deflected significantly by interaction with the draped filament. In addition, this scenario provides no explanation for the earlier bends in the jet.

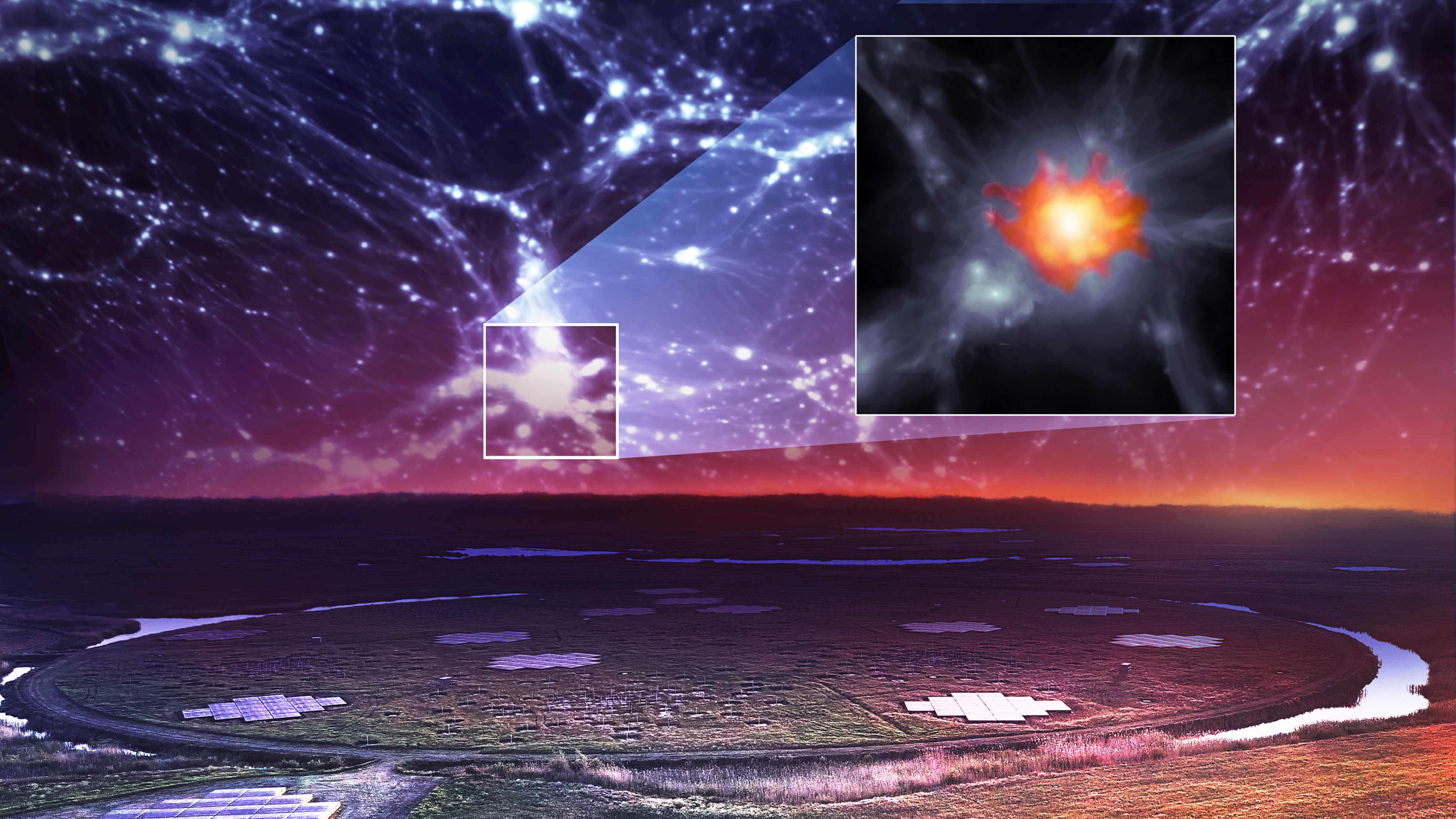
As jet momentum is deposited in the cloud, the outer portions of the cloud will be stripped away while the core of the cloud may acquire some bulk “re- coil” velocity v_c. Not clear whether that is enough

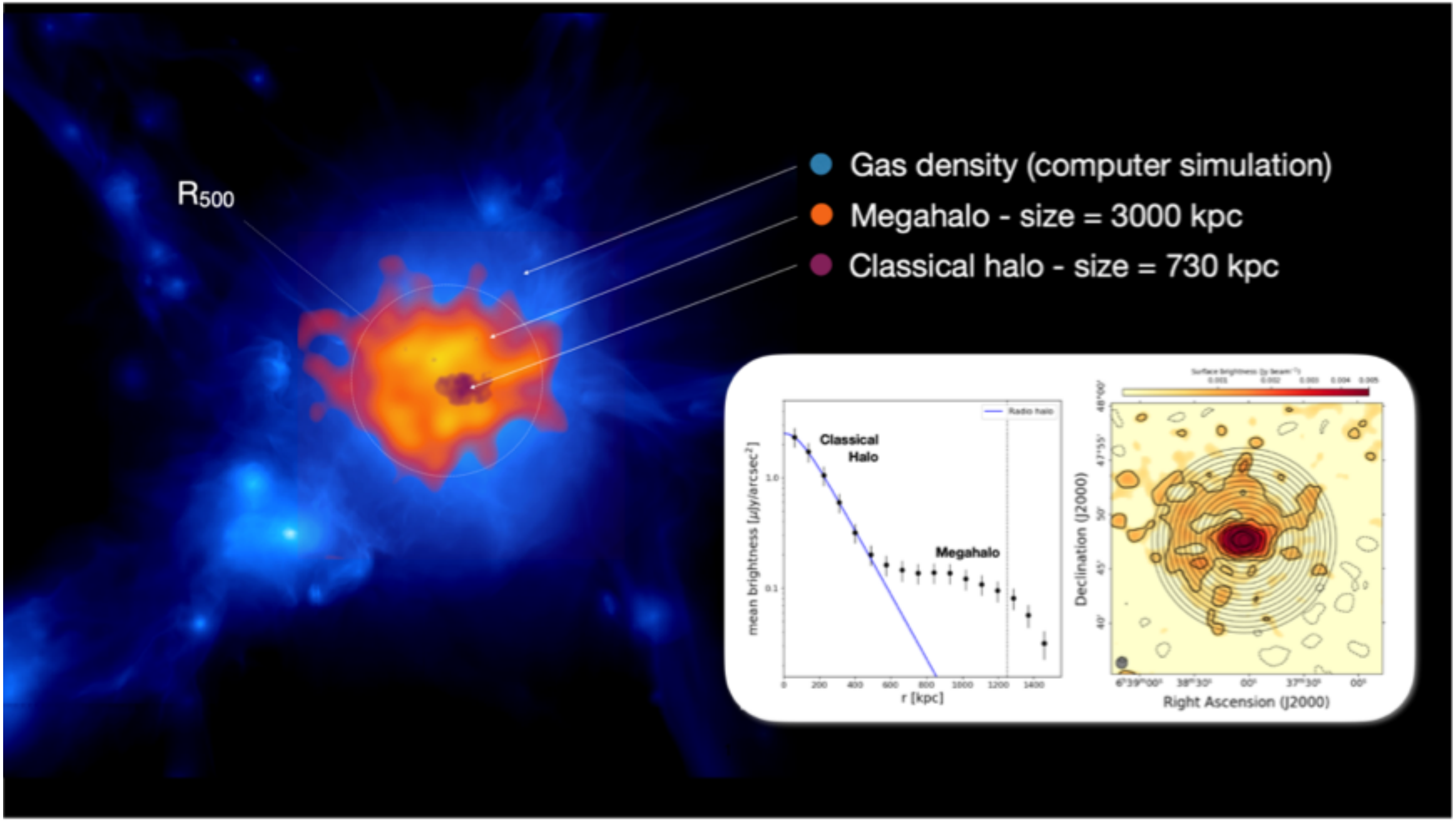
Possibly: dense moving cloud encounters the northern jet of 3C40B, bending it and the E-fils.



ONE MORE THING

TEASER: MEGAHALOS





MORE IN GIANFRANCO'S TALK

Cuciti, Brüggen + Nature in press

TAKE-HOME MESSAGES

- Relation between group's X-ray luminosity and the 144 MHz radio power of the BGG: similar to clusters
- BGGs with radio-loud AGN are more likely to lie close to the group centre than radio-quiet BGGs.
- Filaments will be be further stretched, and their magnetic fields amplified, by bulk motions in the ICM and by encounters with radio jets. The lengths of filaments set by dominant physical scales in the kinematics of the plasmas; the widths of the filaments are an important indicator of the physics/microphysics regulating their origin and evolution.
- Magnetic pressures in filaments can reach significant fractions of the ambient thermal pressures and together with accompanying cosmic rays, can expel the local thermal plasma.
- Either streaming of cosmic ray electrons from a radio galaxy or the (re-)acceleration of seed electrons from the ICM through betatron or other mechanisms, is required to illuminate the filaments.
- Look out for Megahalos

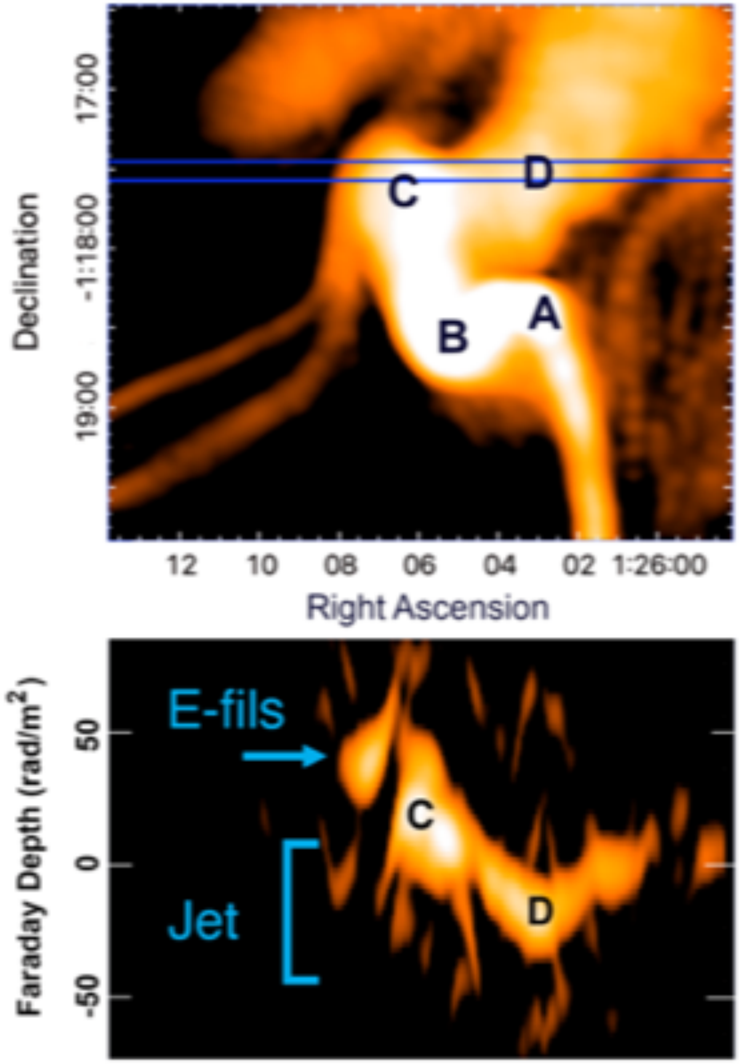
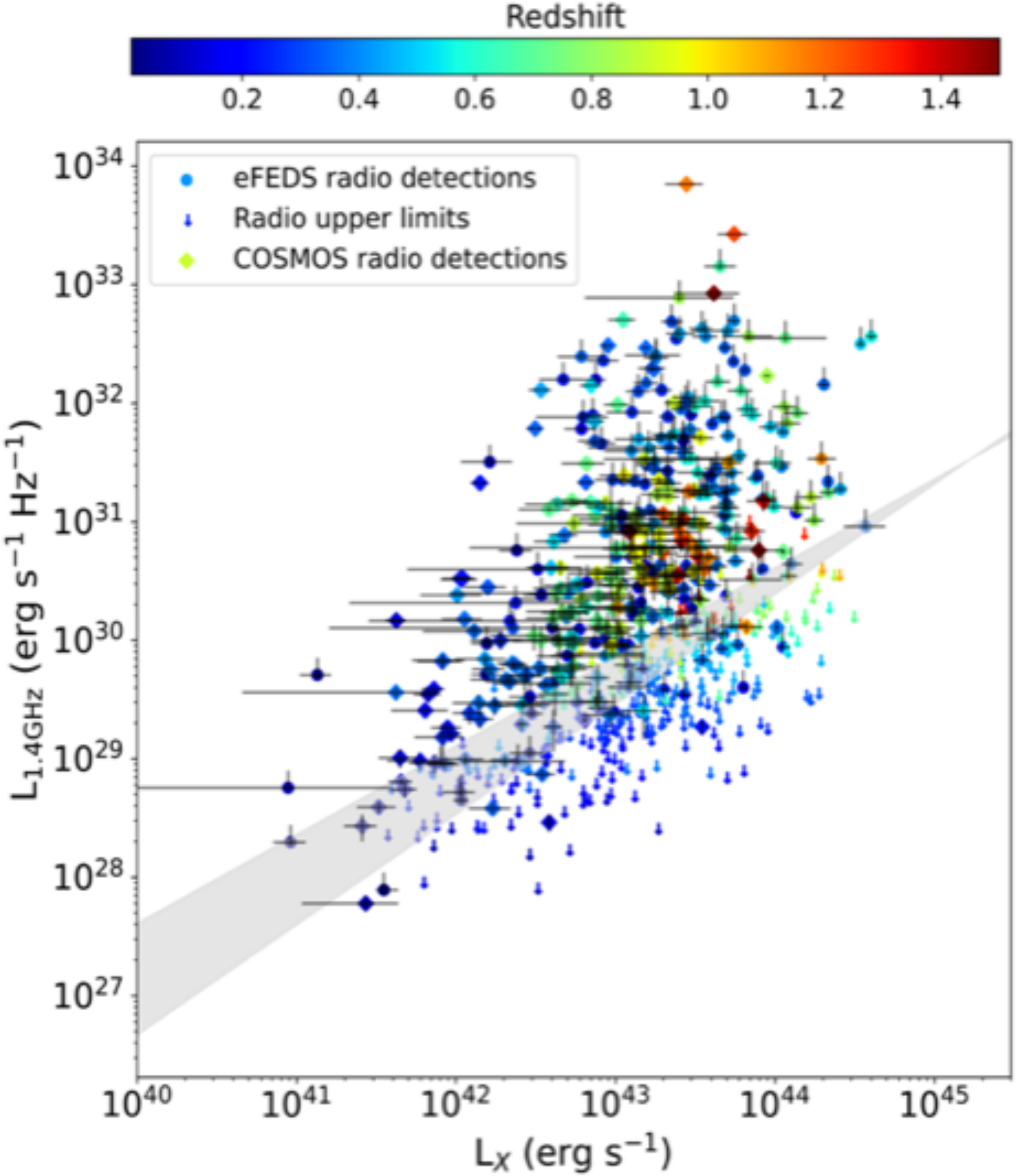
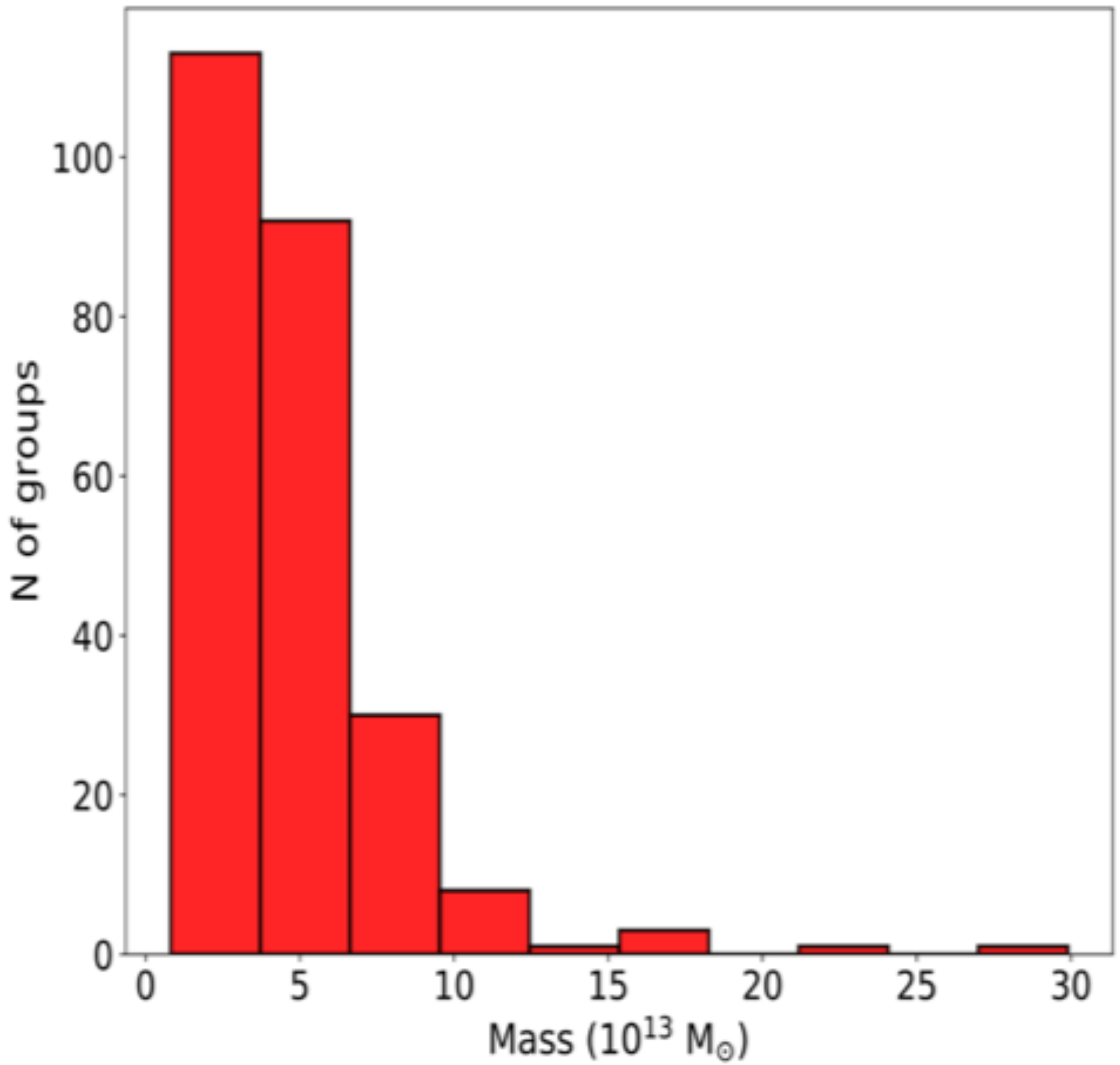
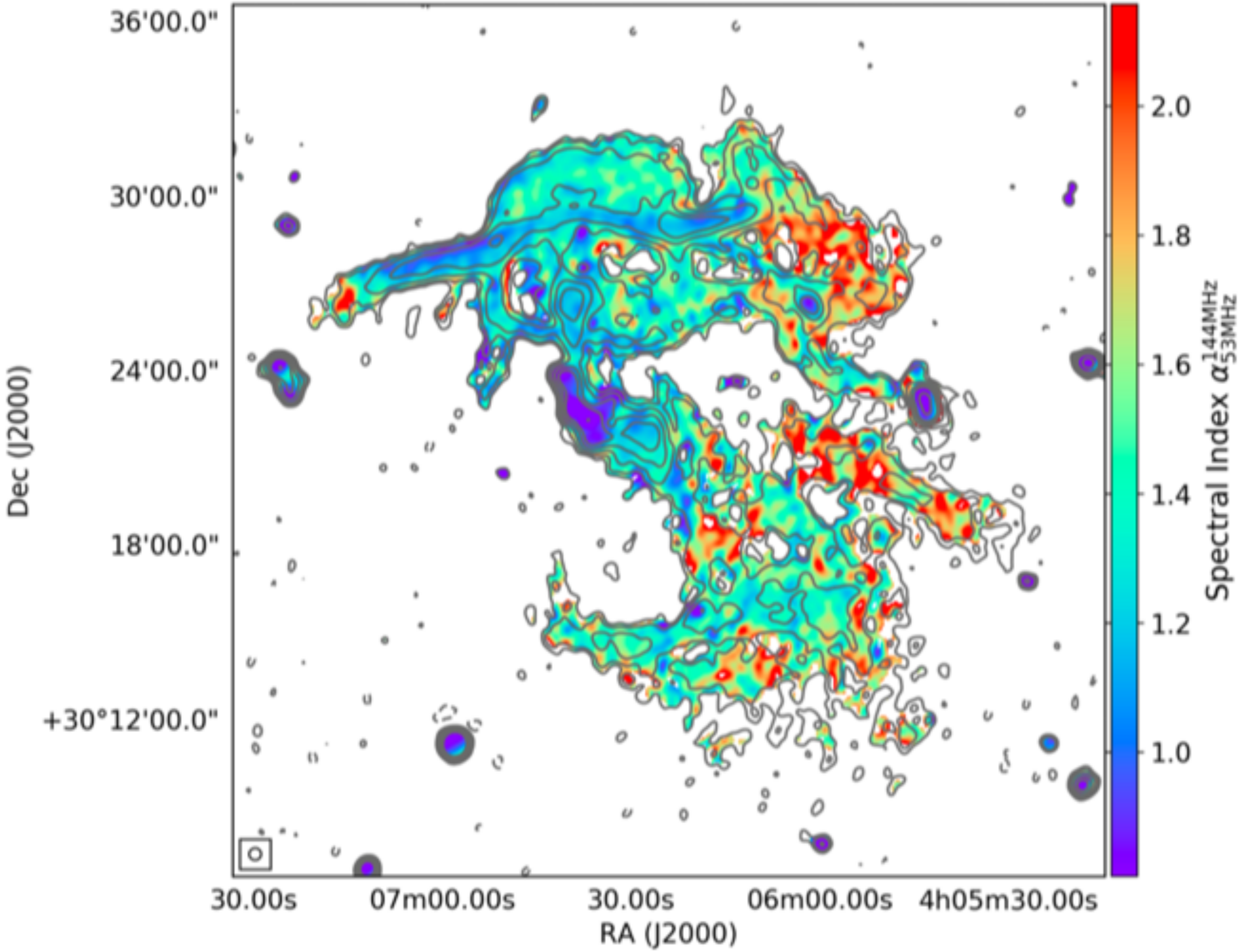


Figure 20. Top: MeerKAT total intensity of 3C40B in the region of the interaction with the *E-fils*. Letters mark the locations of bends in the jet. Bottom: Polarized intensity produced by the super-resolved cleaned Faraday spectrum. Plotted in the Faraday depth vs. RA plane, at the fixed declination marked by dark blue lines in the top panel. The cyan arrow shows the polarized emission from the *E-fils*, while the rest of the emission is from the jet.


Redshift
0.2
0.4
0.6
0.8
1.0
1.2
1.4
eFEDS radio detections
Radio upper limits
COSMOS radio detections
$L_{1.4GHz}$ (erg s^{-1} Hz^{-1})
10^{34}
10^{33}
10^{32}
10^{31}
10^{30}
10^{29}
10^{28}
10^{27}
10^{40}
10^{41}
10^{42}
10^{43}
10^{44}
10^{45}
L_X (erg s^{-1})

MASS DISTRIBUTION OF COSMOS SAMPLE





36'00.0"
30'00.0"
24'00.0"
18'00.0"
+30°12'00.0"
Dec (J2000)
30.00s
07m00.00s
30.00s
06m00.00s
4h05m30.00s
RA (J2000)
2.0
1.8
1.6
1.4
1.2
1.0
Spectral Index α_{53MHz}^{144MHz}