Searching for revived fossil plasma sources in galaxy clusters

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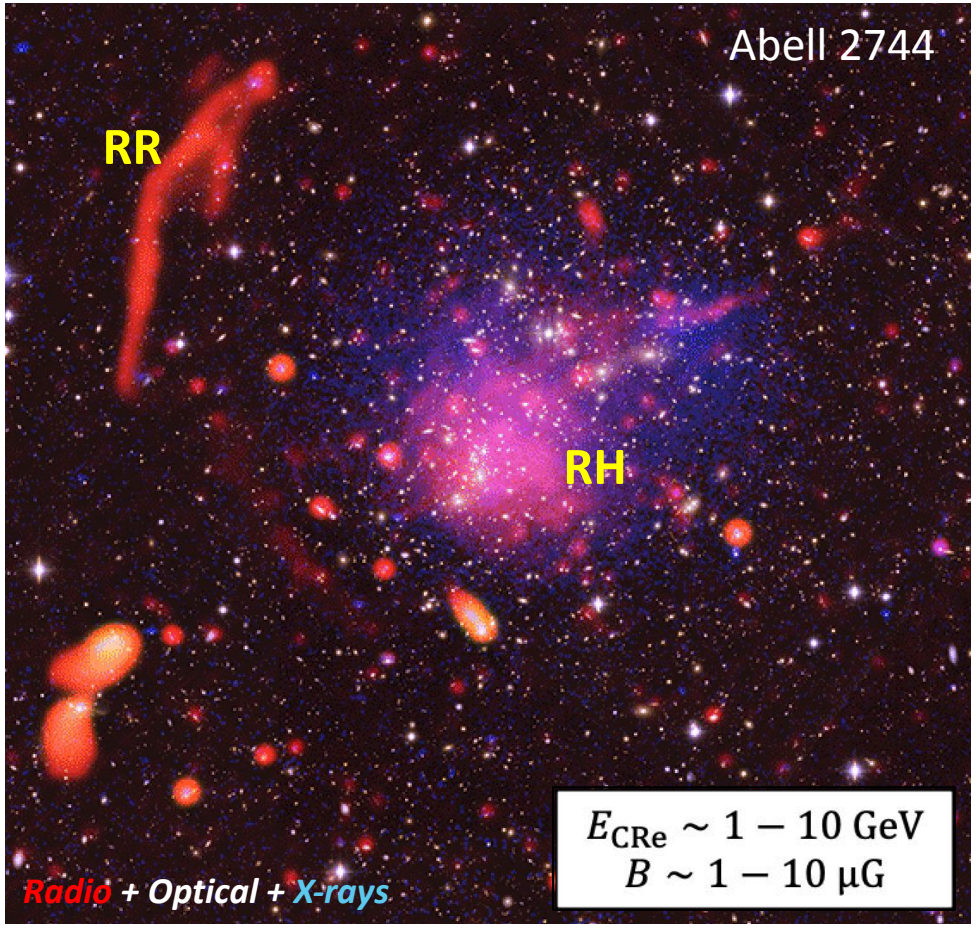
Diffuse radio sources in galaxy clusters: radio halos and relics

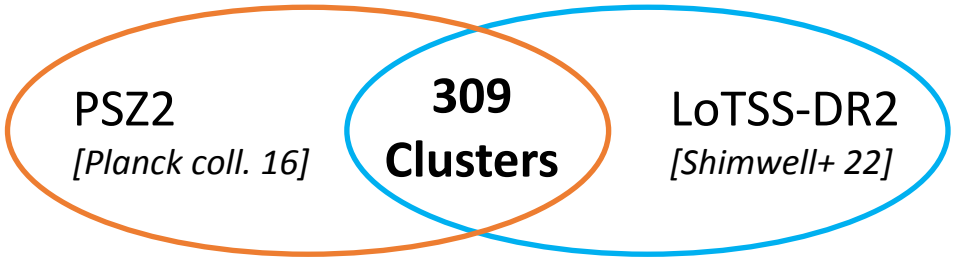


[Credits: Pearce et al.; Bill Saxton, NRAO/AUI/NSF; Chandra; Subaru; ESO]

	RH	RR
host state	disturbed	disturbed
location	centre	outskirts
morphology	roundish	elongated
LLS (Mpc)	∼0.3–2	∼0.3–2
α	∼1–1.5	∼1–1.5
origin	turbulence	shocks

[Reviews: Brunetti & Jones 14; van Weeren+ 19]

The *Planck* clusters in the LOFAR sky

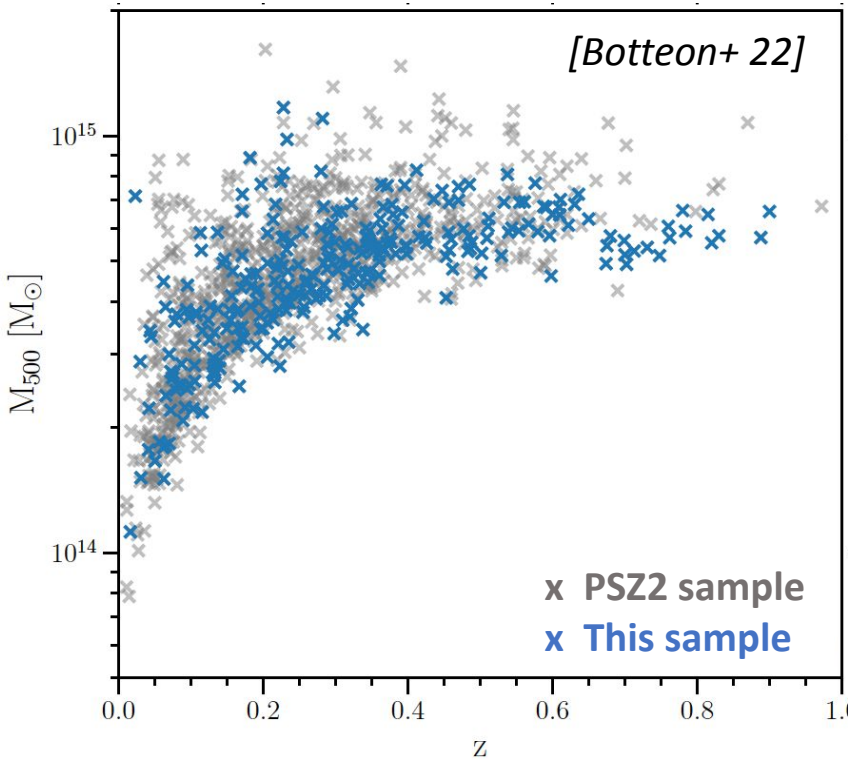


Statistical study of mass-selected clusters
to test theoretical models at low-ν

[Botteon+ 22; Bruno+ 23; Zhang+ 23; Cassano+ 23; Cuciti+ 23; Jones+ 23]

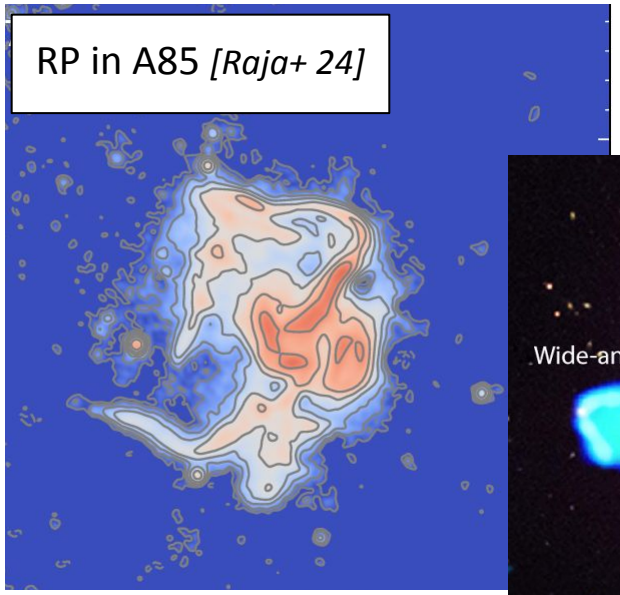
What can we learn ?

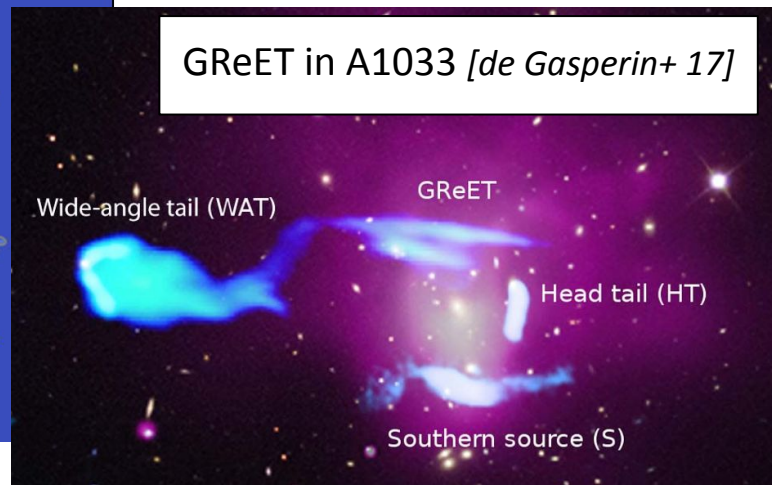
- ➔ Energy transfer mechanisms
- ➔ Origin of CR
- ➔ Cosmic magnetism
- ➔ Thermal/non-thermal interplay



Check the project website!

Revived fossil radio sources





	RP	GReET
host state	?	?
location	?	?
morphology	patchy/filamentary	elongated
LLS (kpc)	∼100–500	∼100-500
α	∼1.5–3	∼1.5–3
origin	shocks ?	turbulence ?

What can we learn ?

- ➔ Energy transfer mechanisms
- ➔ Origin of CR
- ➔ Cosmic magnetism
- ➔ Thermal/non-thermal interplay

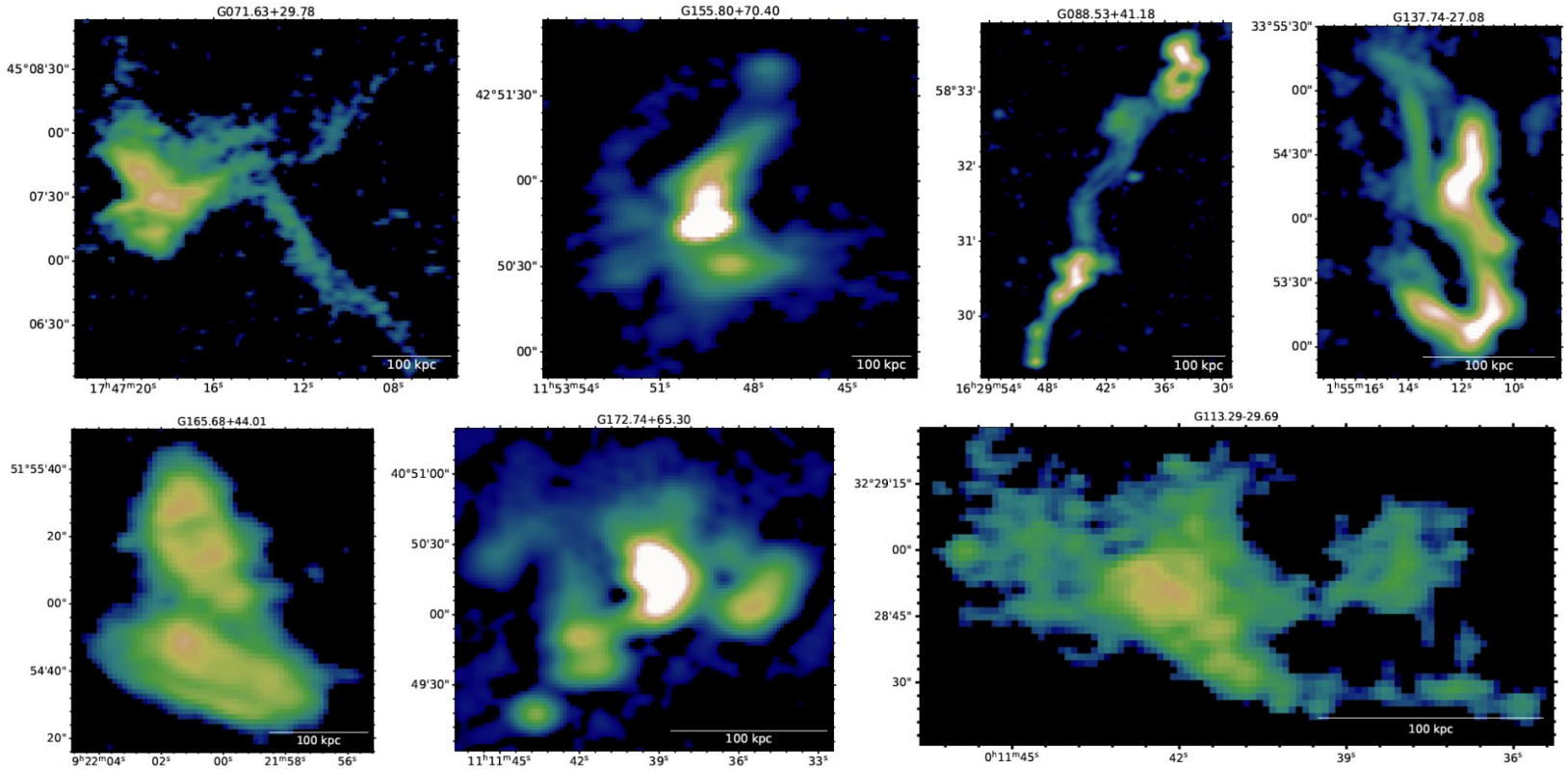
Not only RHs/RRs!

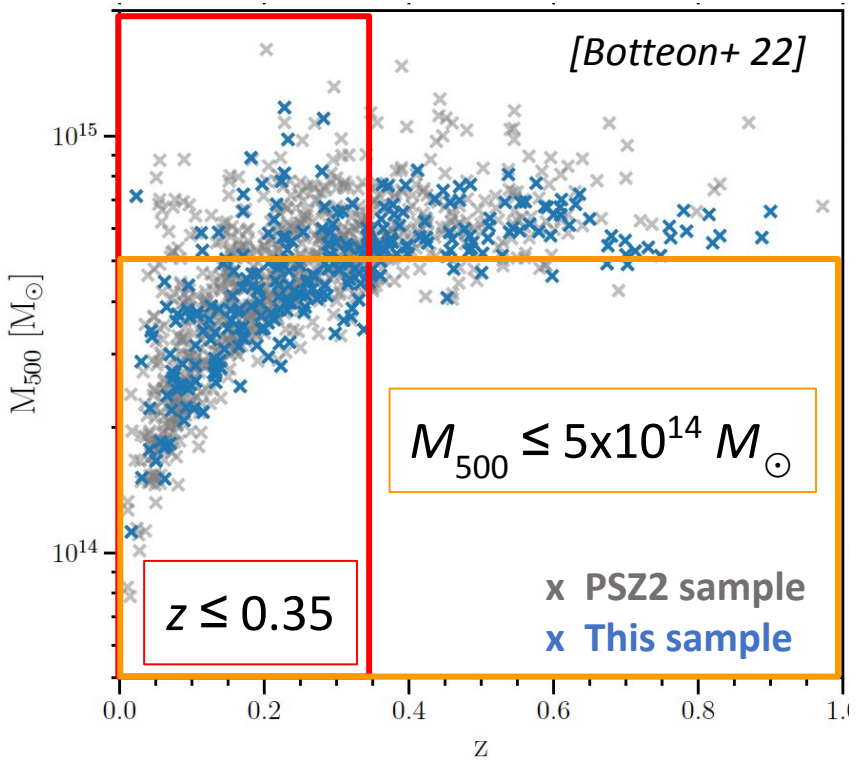
Fossil components from radio galaxies can be also revived by shocks and turbulence →

Radio phoenices and Gently Re-Energised Tails

The pilot sample from *Planck*/LoTSS-DR2

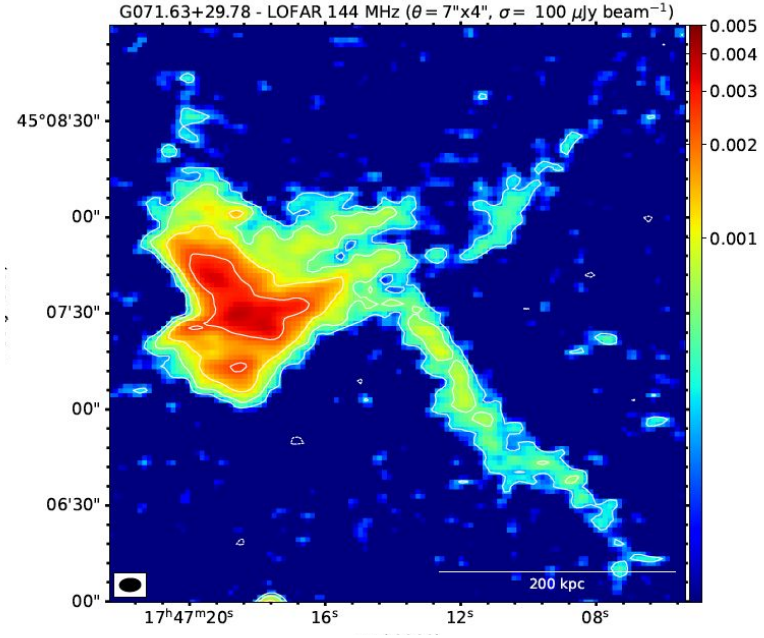
- 309 clusters → **92** without RR/RH in selected z-M_{500} ranges
- **Visual inspection: irregular/filamentary sources → 7 targets**
- **Follow-up → uGMRT at 300-500 MHz**





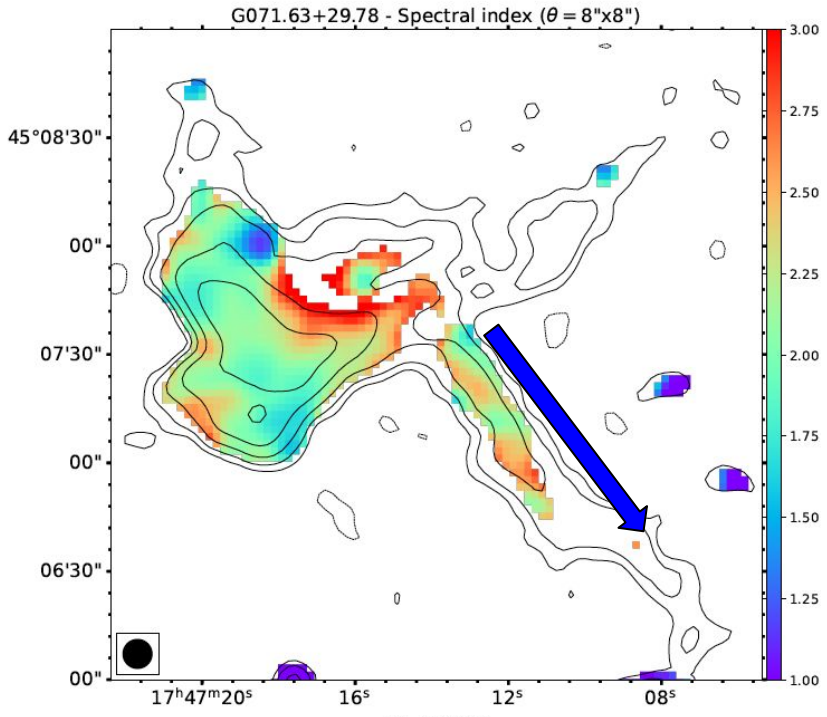
AIM

spectral study at high resolution (< 50 kpc) for classification

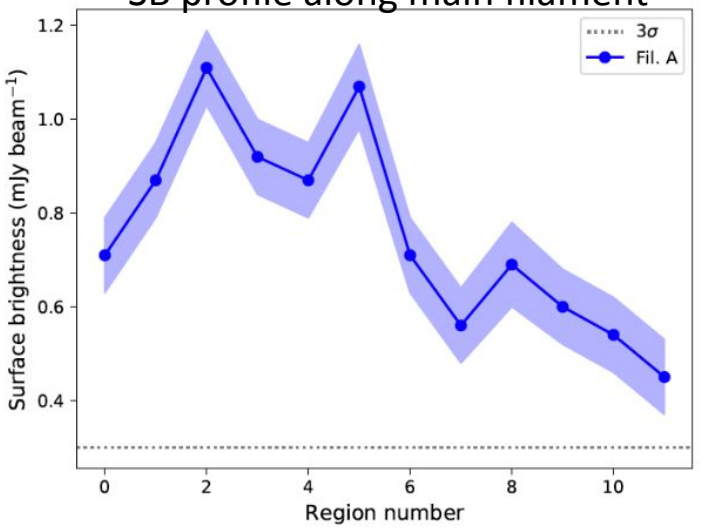


- uniform α∼2.3
- no obvious host
- sign of reacceleration along filaments

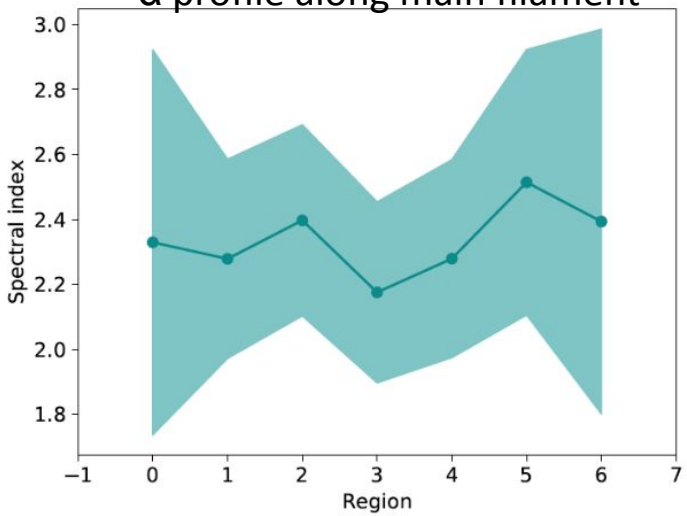
G071: Candidate RP

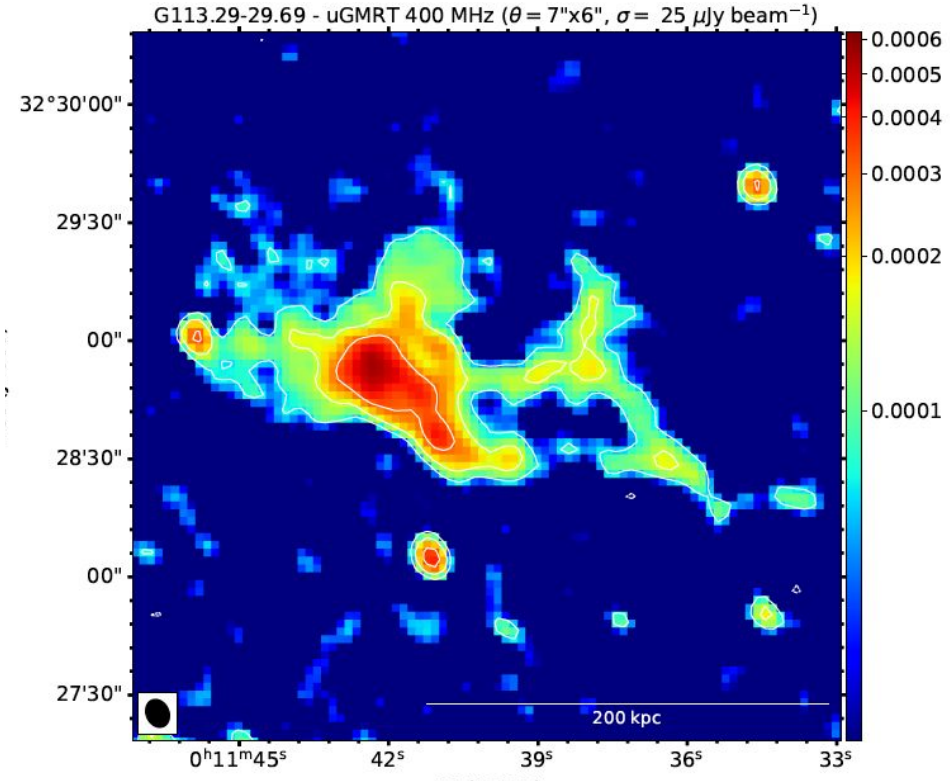


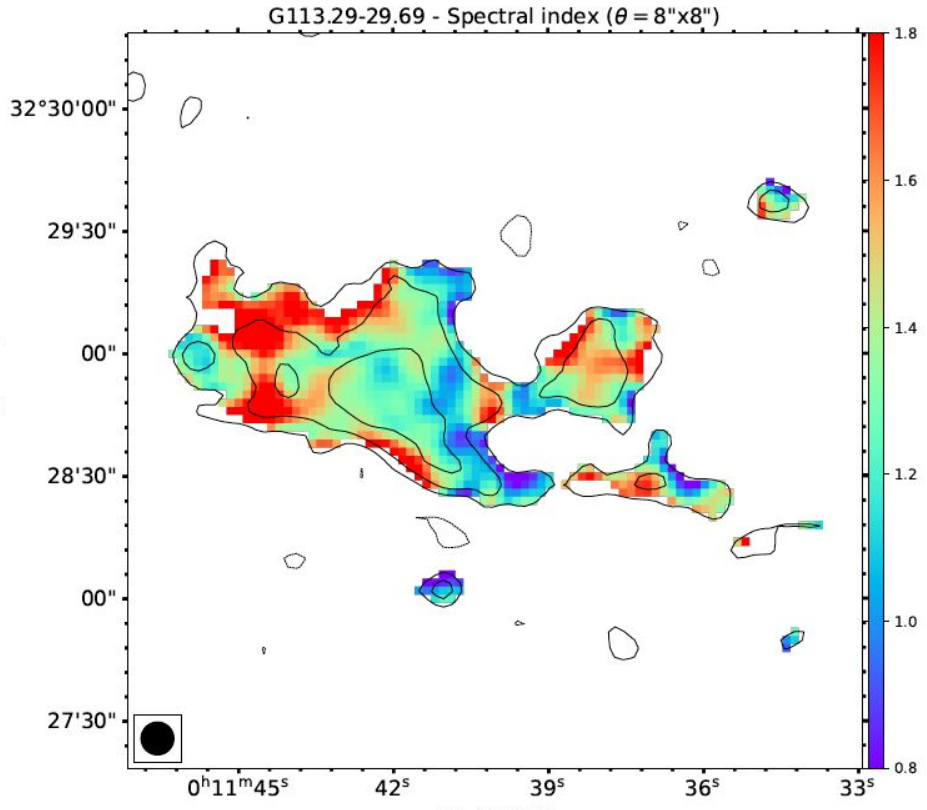
SB profile along main filament



α profile along main filament

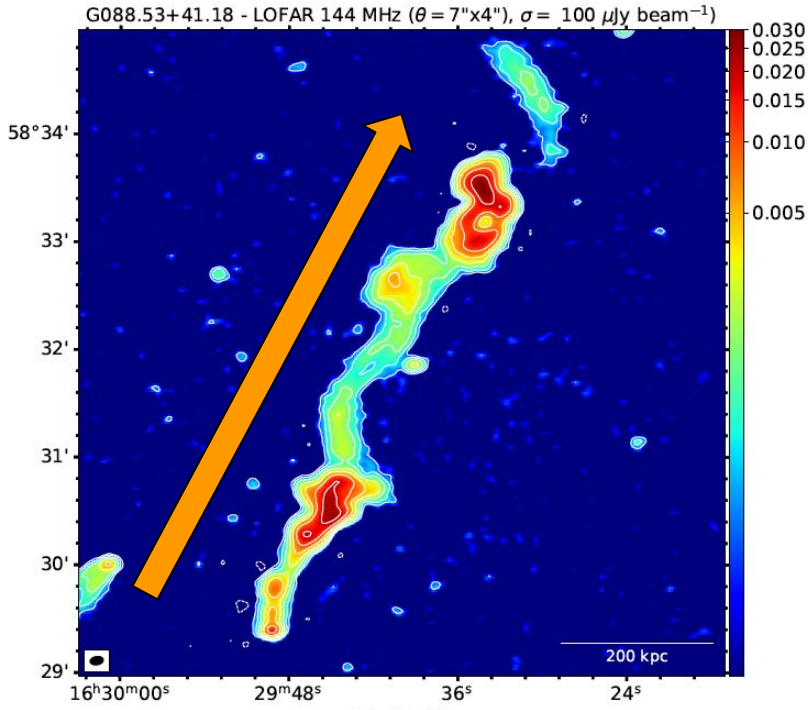


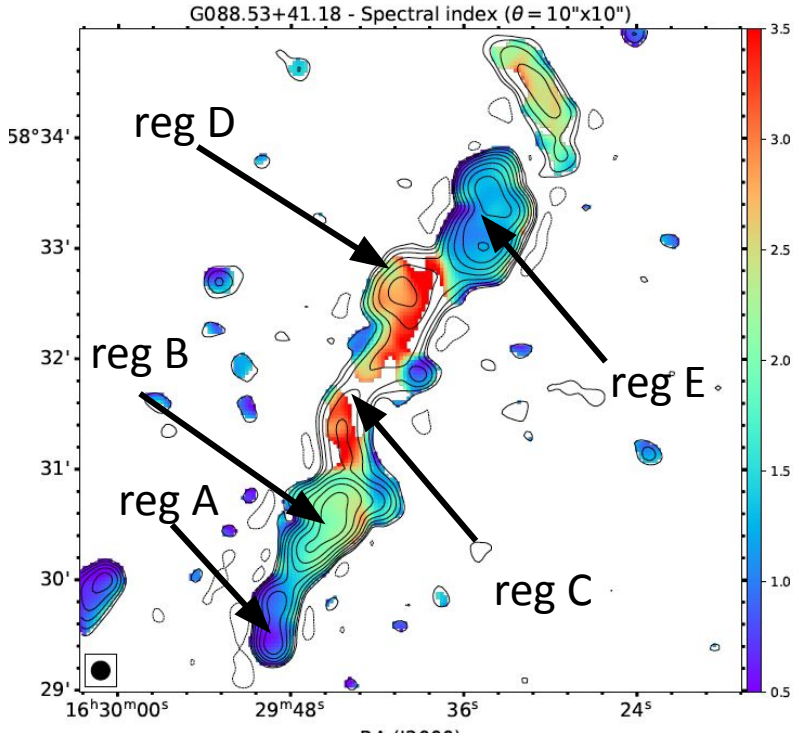


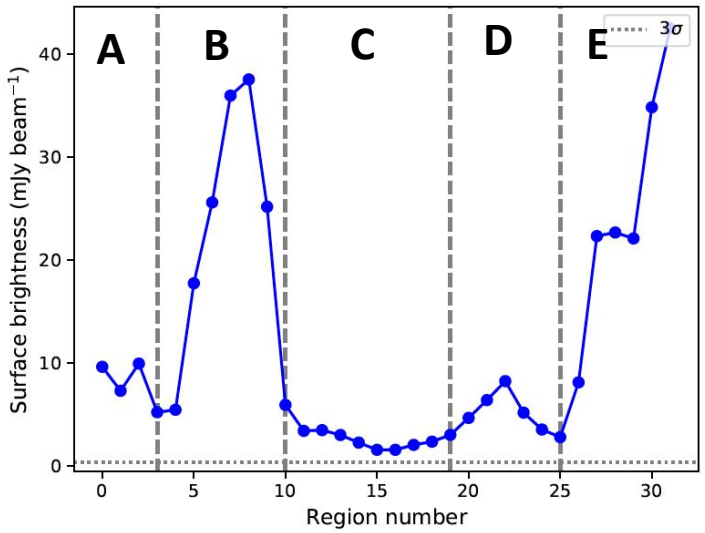


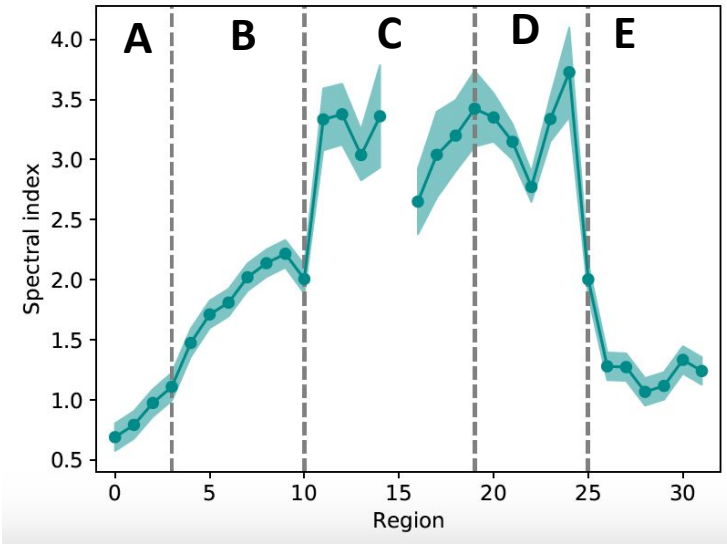
- α∼1.3, no gradients
- no obvious host
- similar to RP in G071
- no sign of reacceleration

G113: Remnant radio galaxy

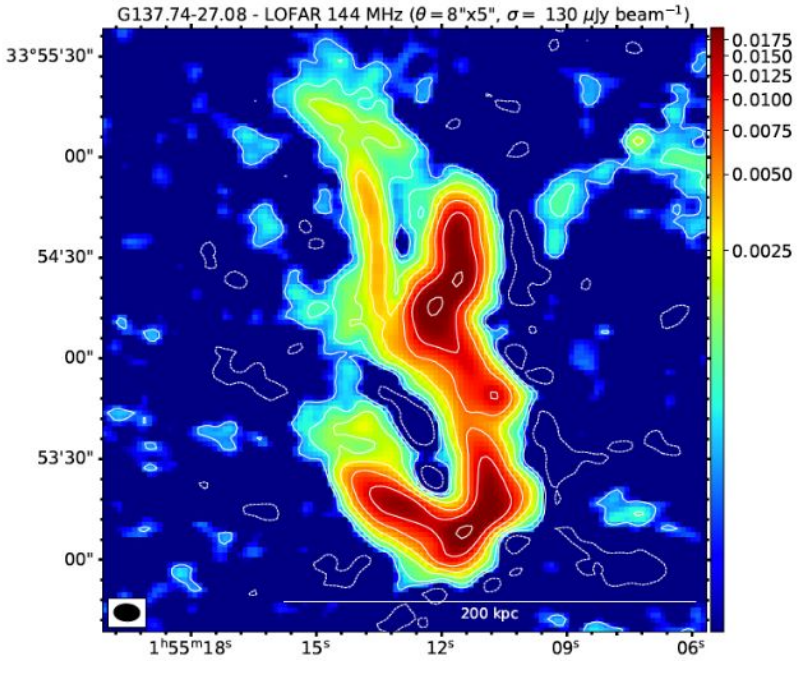


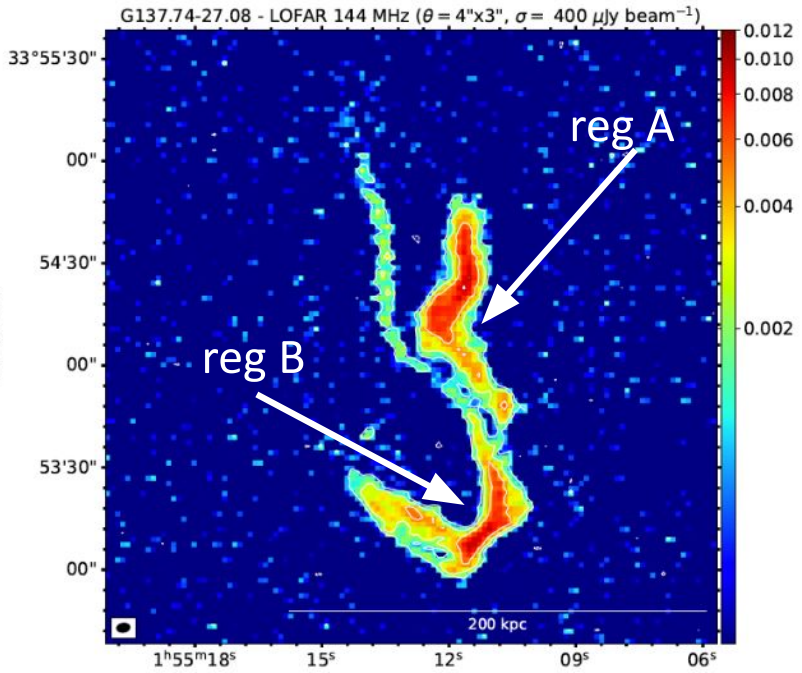


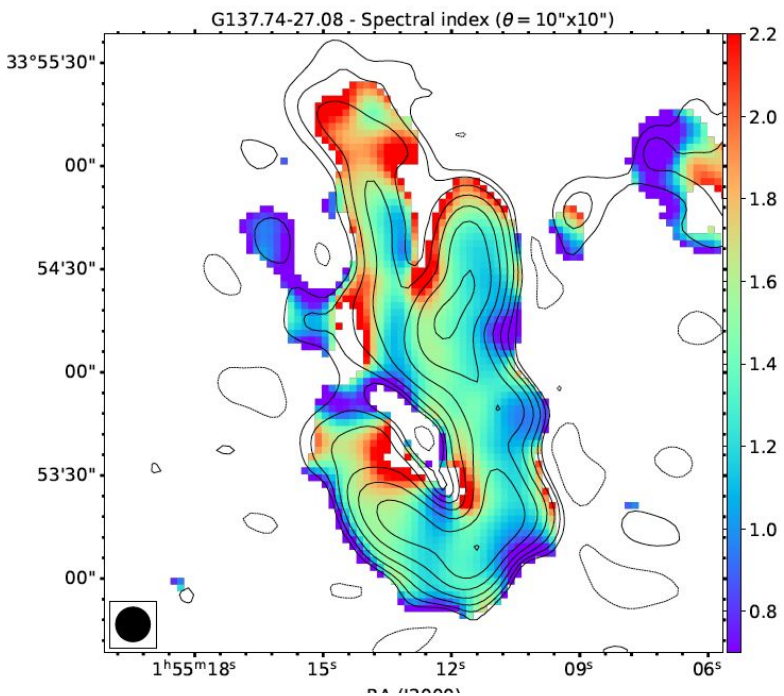


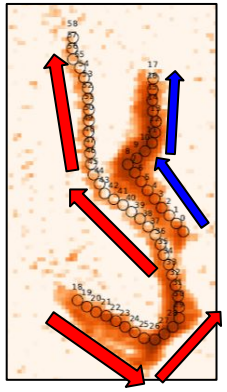


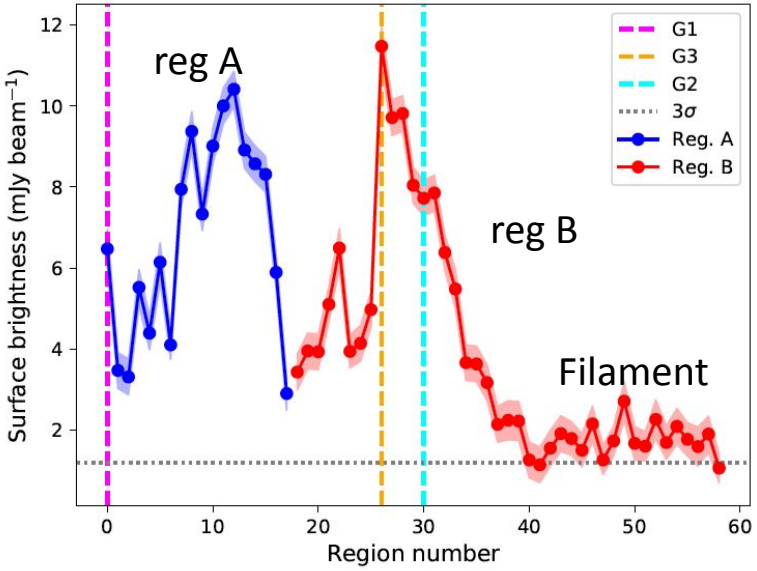
- Reg A+B ⟶ HT
- Reg C+D: constant α∼3 and SB ⟶ **G088**: Candidate GReET
- Reg E ⟶ ?





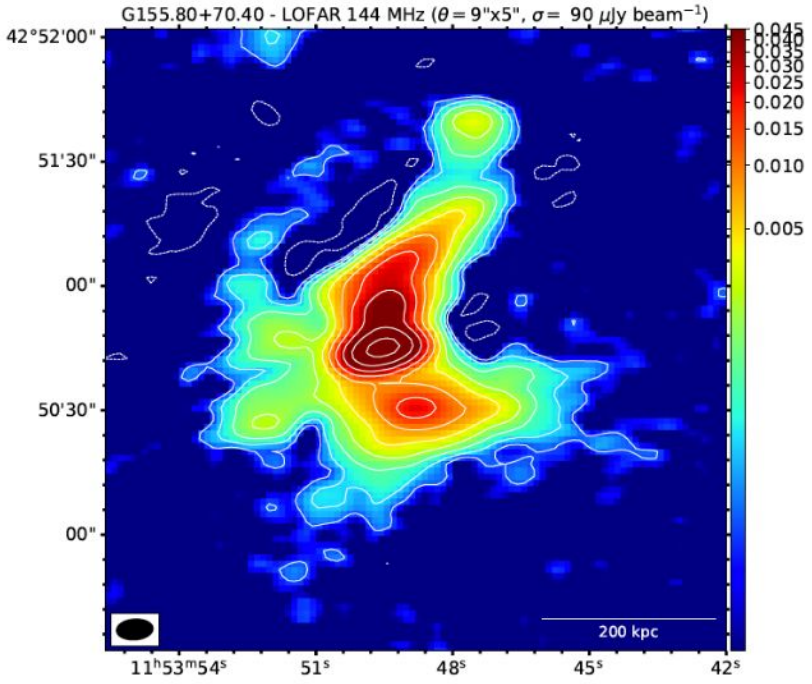


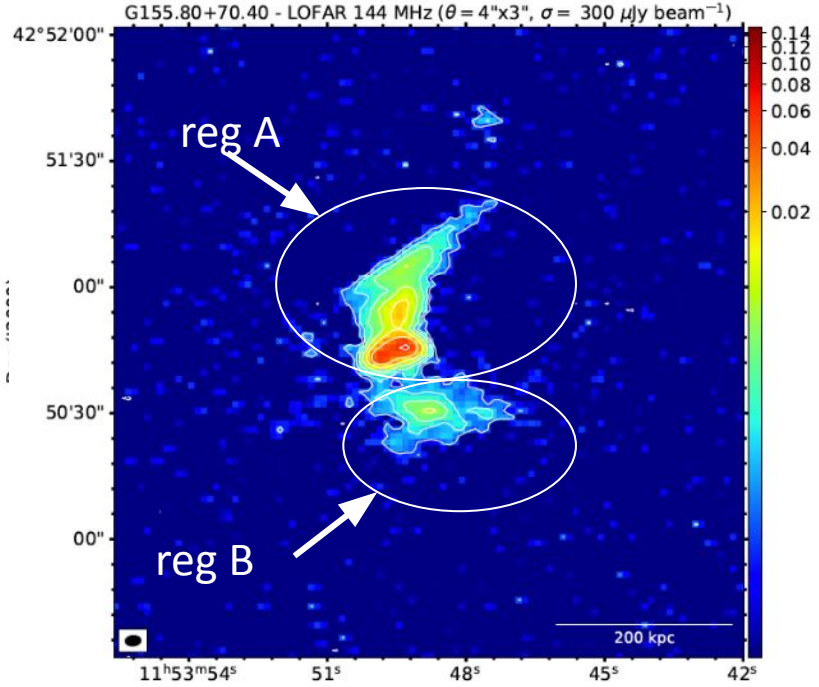


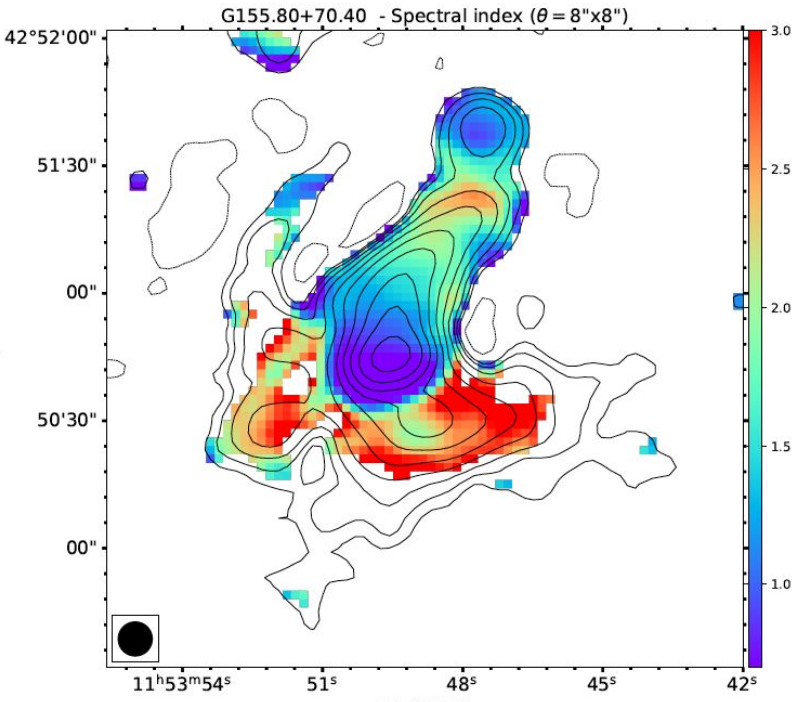


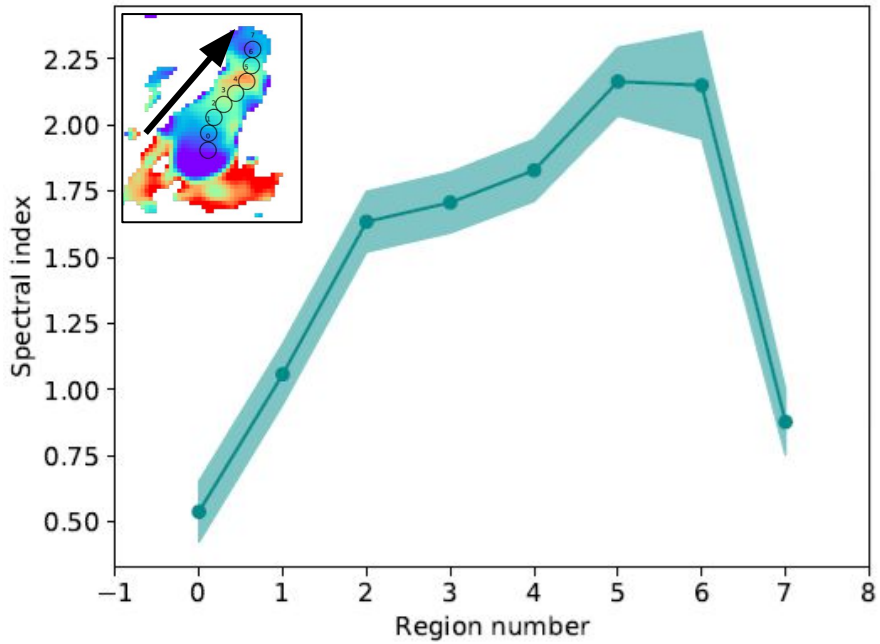
- Reg B → WAT with filament
- Reg A → HT ?
- Sign of reacceleration for both regions

G137: No simple classification as RP/GReET









- Reg A → HT, standard spectral steepening
- Reg B → remnant, α∼3

G155: No sign of reacceleration

Summary and conclusions

- ❑ Ultra-steep spectrum emission in all targets → **effective morphological selection of fossils**
- ❑ Avoid simplistic conclusions → **ultra-steep spectrum source ≠ revived source**
- ❑ High-resolution radio images → **high risk of misclassification**

Results

- ❑ Confirming reacceleration via X-ray data analysis
- ❑ Additional radio follow-ups

What's next

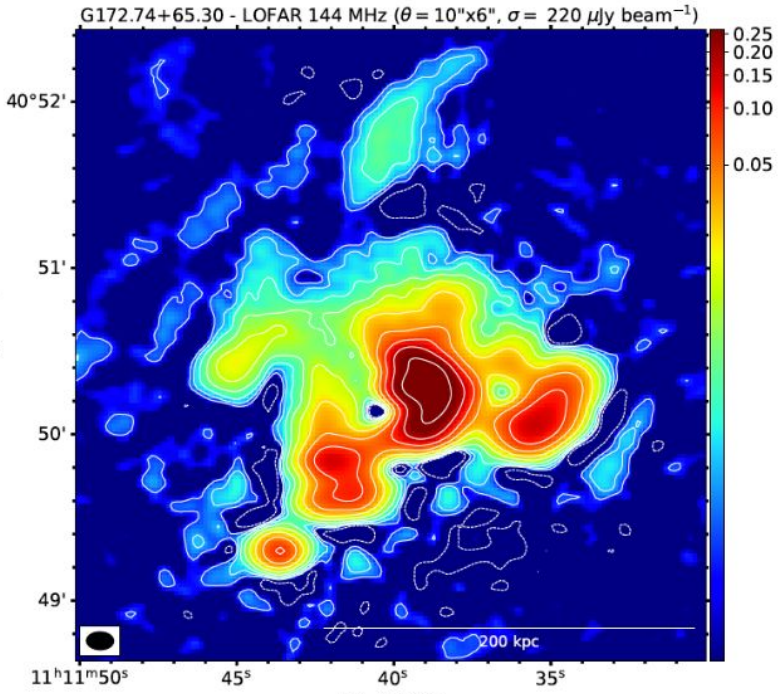
submitted!

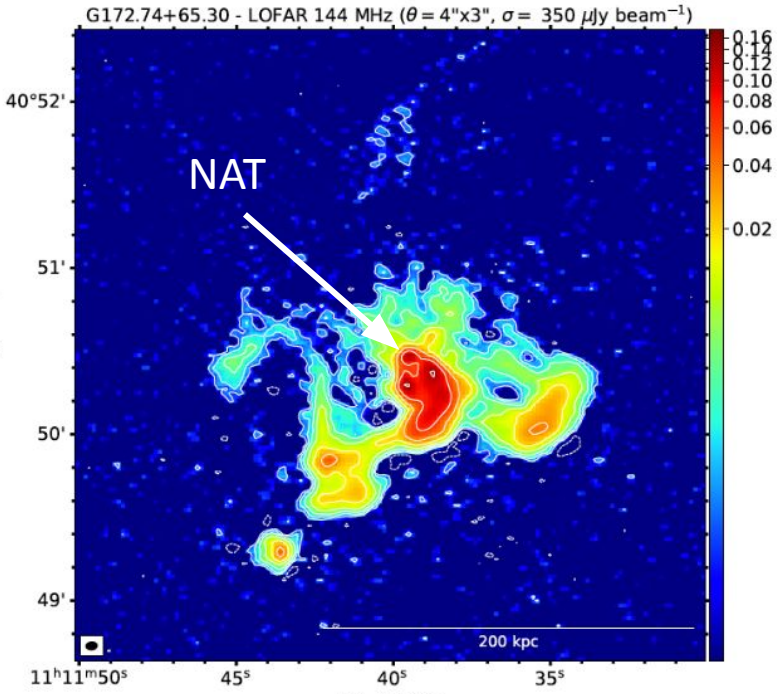
Resurging from the ashes: A spectral study of seven candidate revived radio fossils in nearby and low-mass galaxy clusters

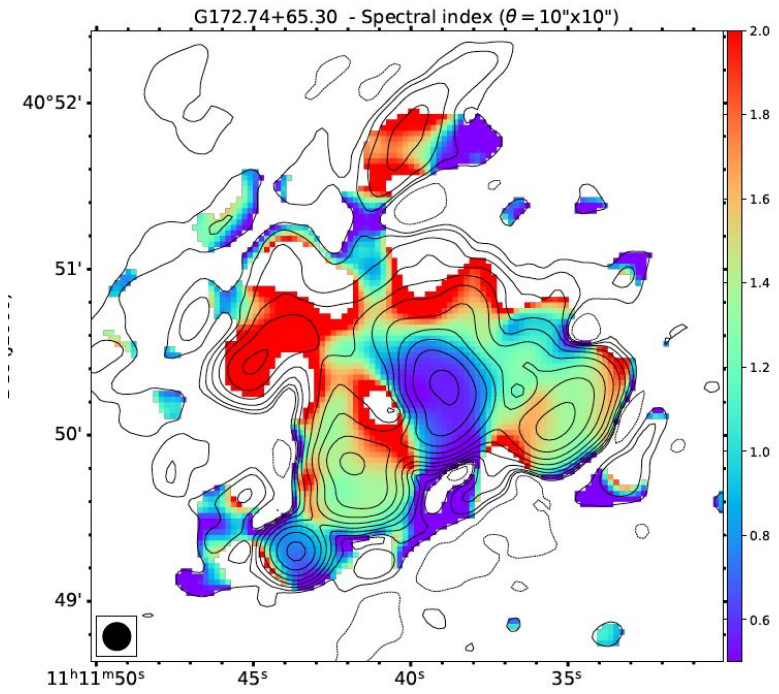
L. Bruno[1], A. Botteon[1], D. Dallacasa[2,1], T. Venturi[1,3], M. Balboni[2,4], N. Biava[5], M. Brienza[1], M. Brüggen[6], G. Brunetti[1], F. de Gasperin[1], E. De Rubeis[2,1], G. Di Gennaro[1], F. Gastaldello[4], A. Ignesti[7], T. Pasini[1], K. Rajpurohit[8], A. Shulevski[9,10,11,12], K. S. L. Srikanth[2,1], R. J. van Weeren[13], X. Zhang[14]

Thanks for your attention

… Questions?

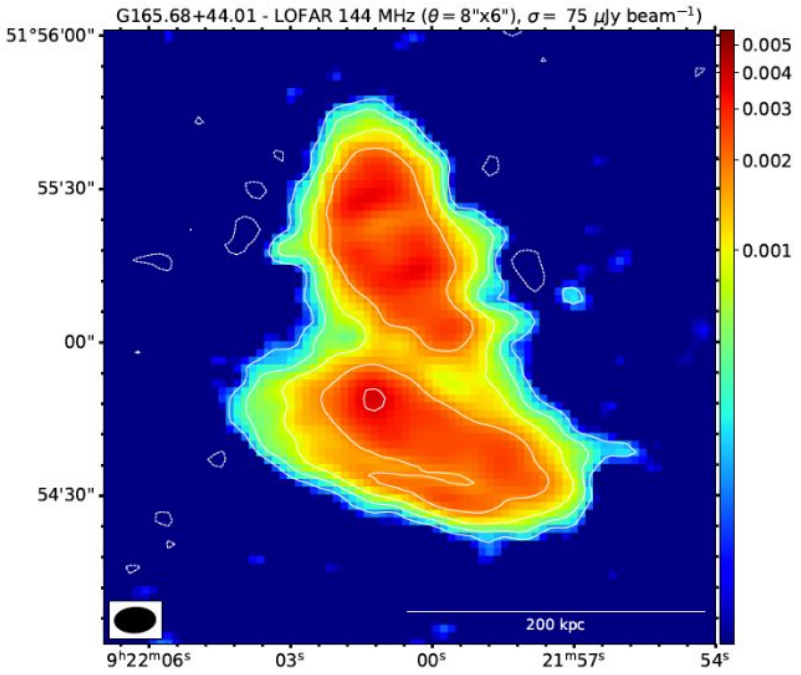


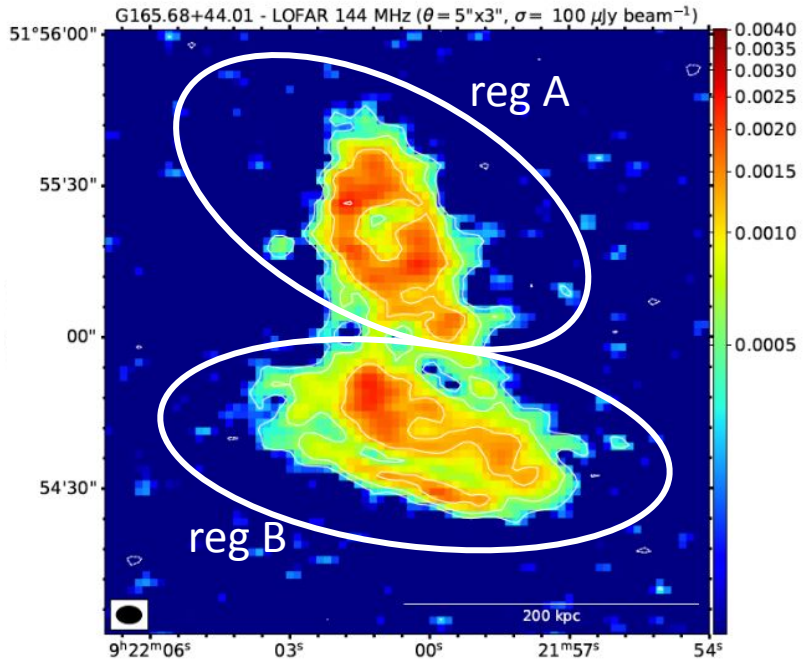


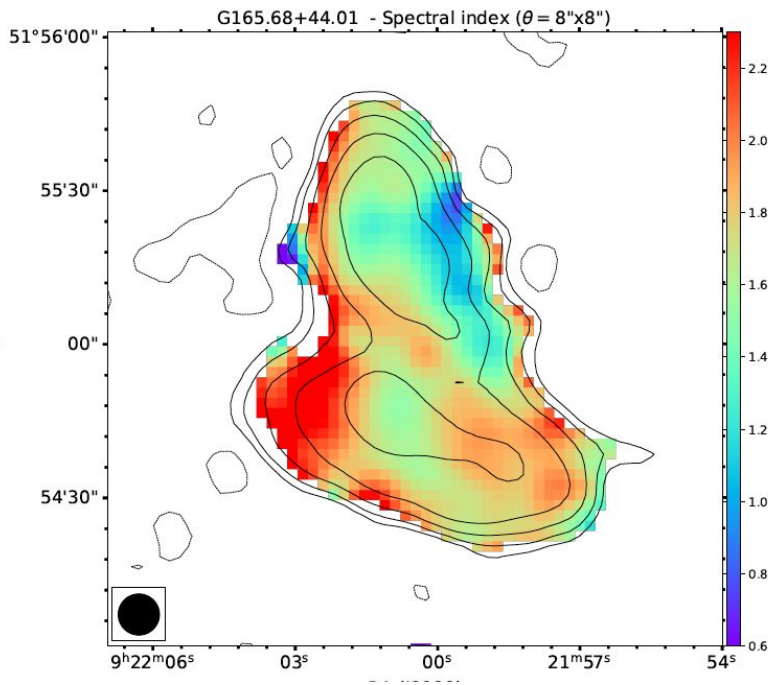


- Central NAT (twisting jets ?)
- Various diffuse steep-α components
- Fossil electrons spread by NAT + reacceleration ?

G172: Uncertain origin

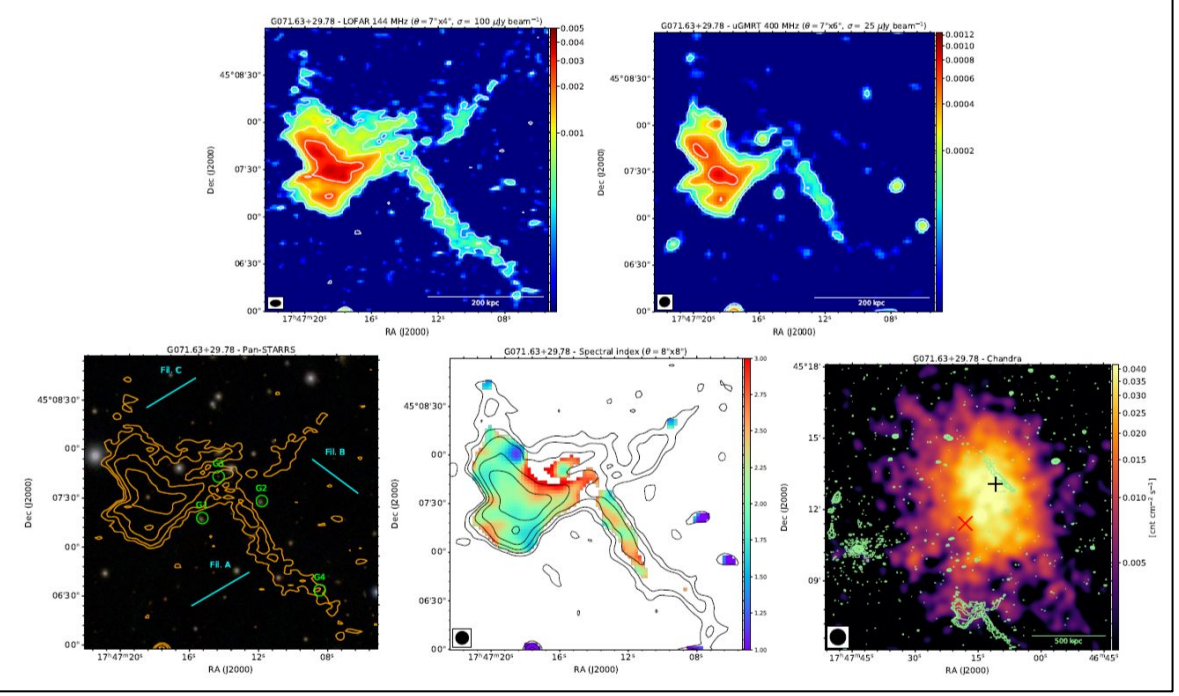


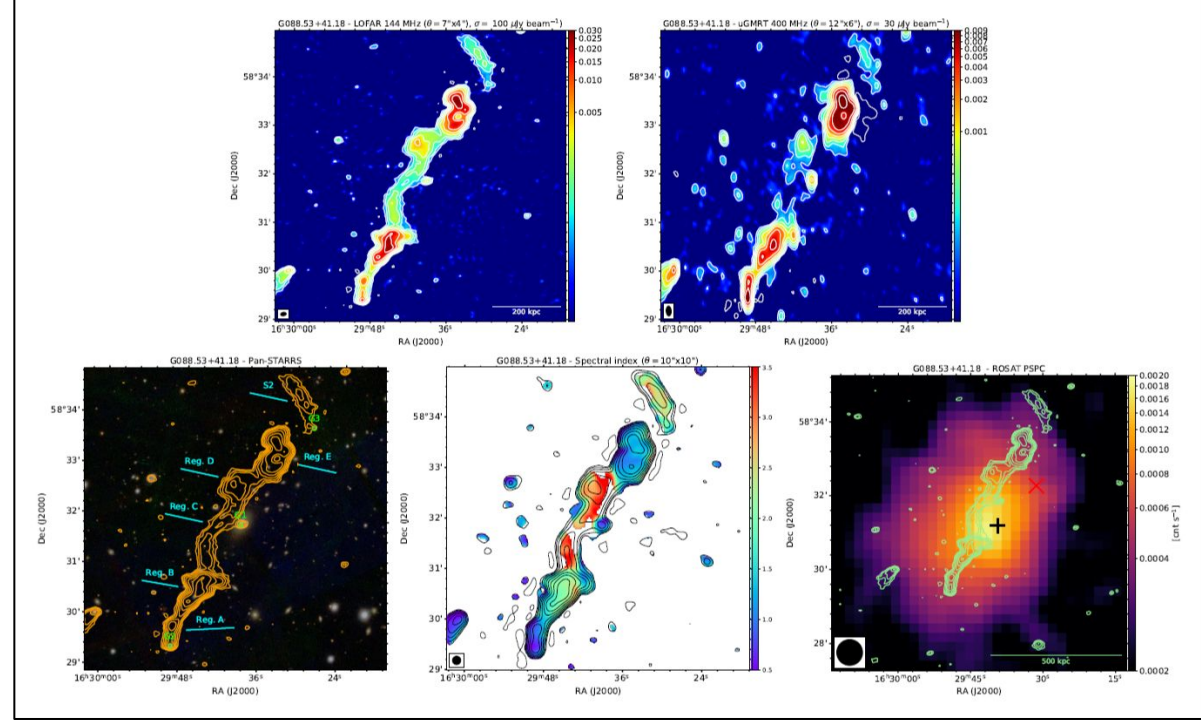


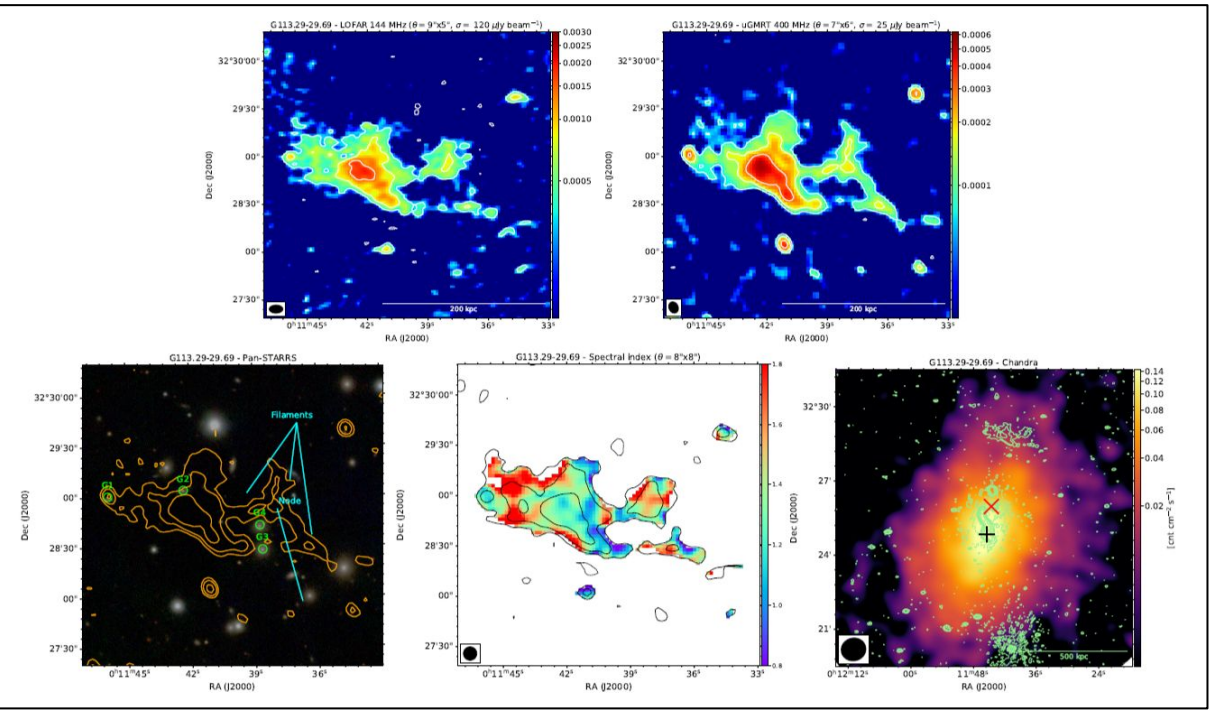


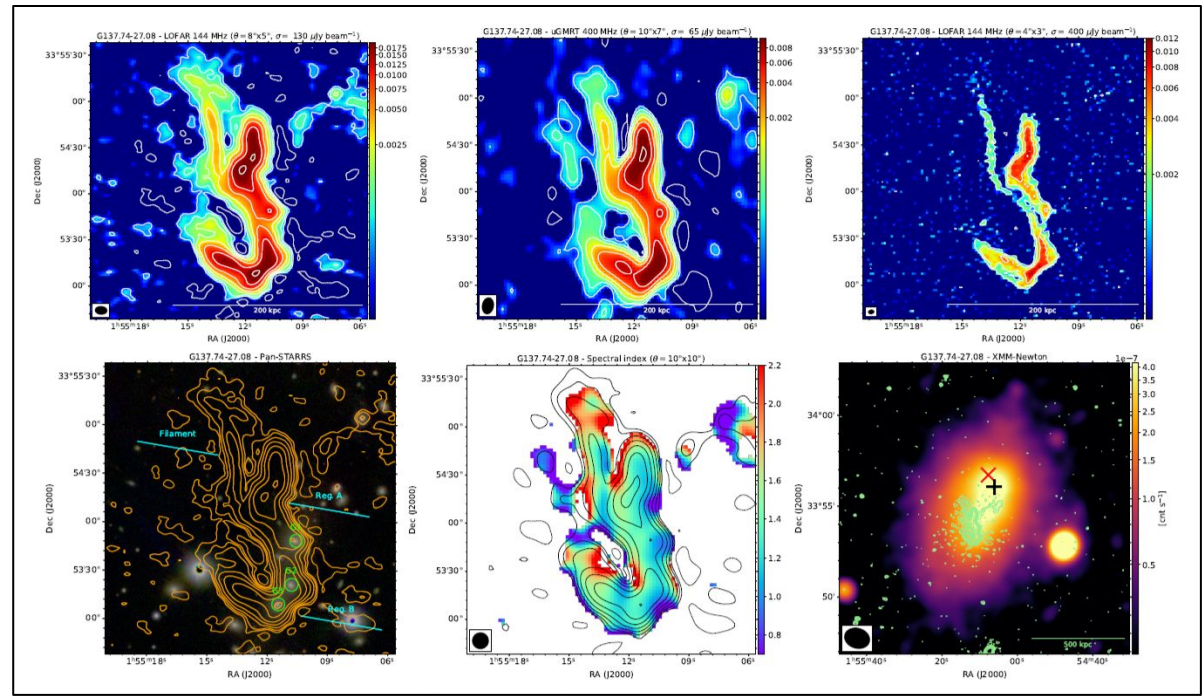
- Similar structures at low resolution
- Different internal structures at high resolution
- $\alpha \sim 1.5$

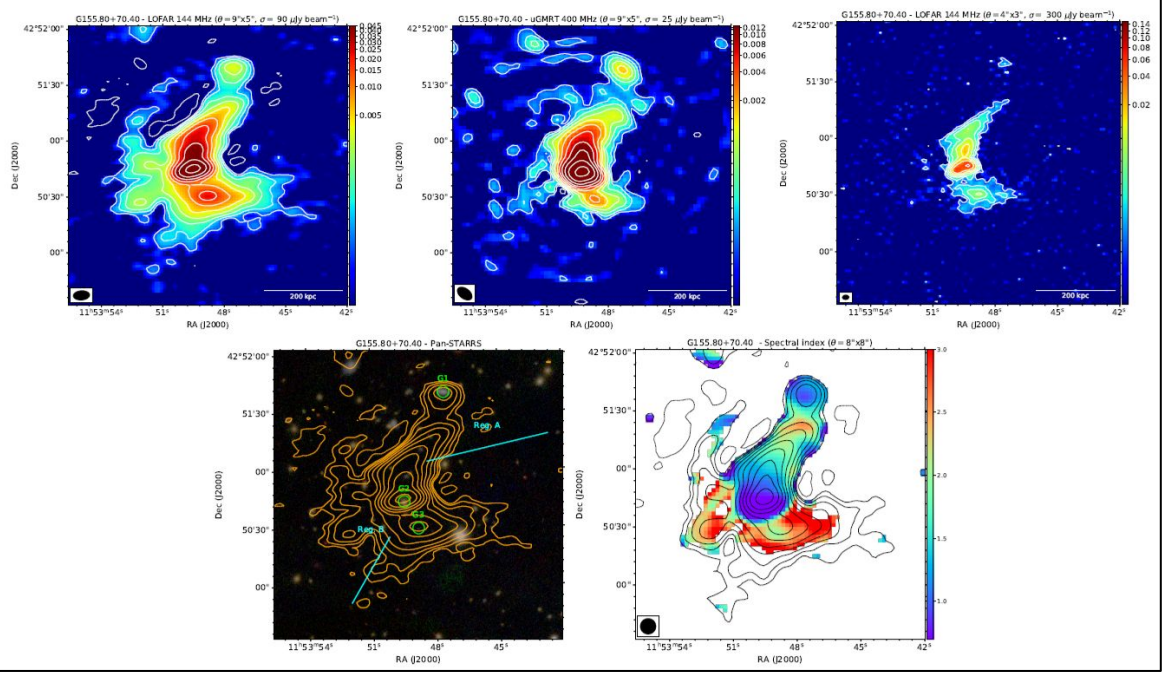
G165: Single/double remnant ?

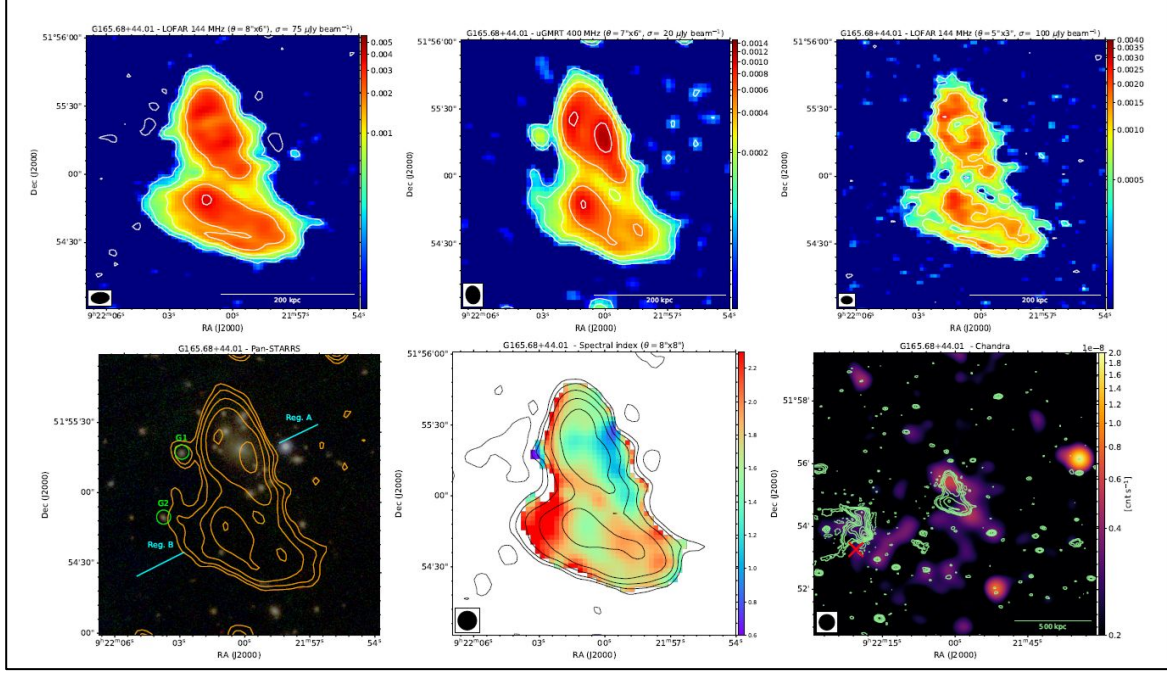

G071.63+29.78 - LOFAR 144 MHz (θ = 7"x4", σ = 100 μJy beam⁻¹)
G071.63+29.78 - uGMRT 400 MHz (θ = 7"x6", σ = 25 μJy beam⁻¹)
G071.63+29.78 - Pan-STARRS
Fil. C
Fil. B
Fil. A
G1
G2
G3
G4
G071.63+29.78 - Spectral Index (θ = 8"x8")
G071.63+29.78 - Chandra
RA (J2000)
Dec (J2000)
200 kpc
500 kpc

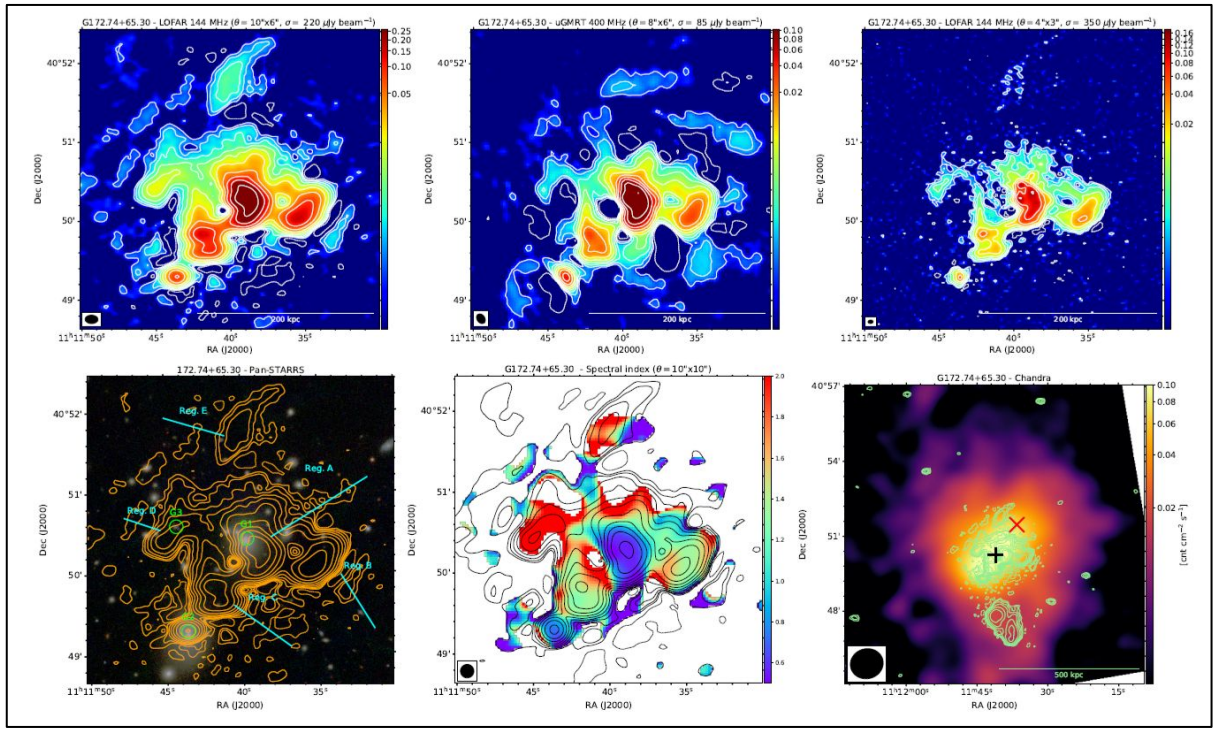

G088.53+41.18 - LOFAR 144 MHz (θ = 7"x4"), σ = 100 μJy beam⁻¹)
G088.53+41.18 - uGMRT 400 MHz (θ = 12"x6"), σ = 30 μJy beam⁻¹)
G088.53+41.18 - Pan-STARRS
S2
S3
Reg. D
Reg. E
Reg. C
Reg. B
Reg. A
G088.53+41.18 - Spectral Index (θ = 10"x10")
G088.53+41.18 - ROSAT PSPC
RA (J2000)
Dec (J2000)
200 kpc
500 kpc


G113.29-29.69 - LOFAR 144 MHz (θ = 9"x5", σ = 120 μJy beam⁻¹)
G113.29-29.69 - uGMRT 400 MHz (θ = 7"x6", σ = 25 μJy beam⁻¹)
G113.29-29.69 - Pan-STARRS
Filaments
Node
G1
G2
G3
G113.29-29.69 - Spectral Index (θ = 8"x8")
G113.29-29.69 - Chandra
RA (J2000)
Dec (J2000)
200 kpc
500 kpc

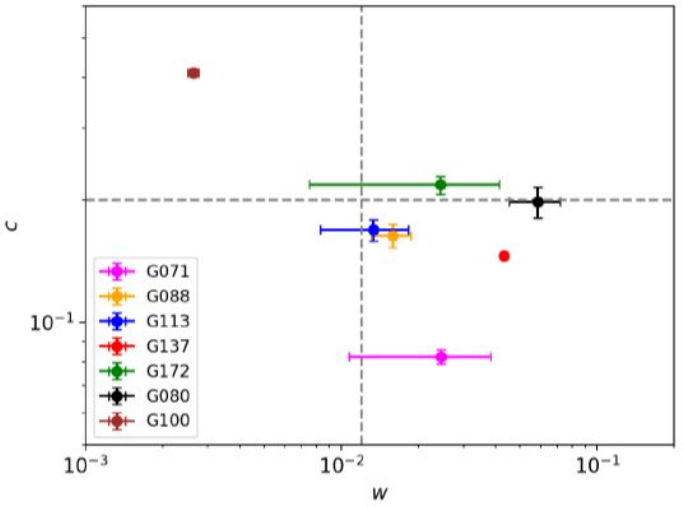

G137.74-27.08 - LOFAR 144 MHz (θ = 8"x5", σ = 130 μJy beam⁻¹)
G137.74-27.08 - uGMRT 400 MHz (θ = 10"x7", σ = 65 μJy beam⁻¹)
G137.74-27.08 - LOFAR 144 MHz (θ = 4"x3", σ = 400 μJy beam⁻¹)
G137.74-27.08 - Pan-STARRS
Filament
Reg. A
Reg. B
G137.74-27.08 - Spectral Index (θ = 10"x10")
G137.74-27.08 - XMM-Newton
RA (J2000)
Dec (J2000)
200 kpc
500 kpc


G155.80+70.40 - LOFAR 144 MHz (θ = 9"x5", σ = 90 μJy beam⁻¹)
G155.80+70.40 - uGMRT 400 MHz (θ = 9"x5", σ = 25 μJy beam⁻¹)
G155.80+70.40 - LOFAR 144 MHz (θ = 4"x3", σ = 300 μJy beam⁻¹)
G155.80+70.40 - Pan-STARRS
G155.80+70.40 - Spectral index (θ = 8"x8")
Reg. A
Reg. B
G1
G2
G3
200 kpc
RA (J2000)
Dec (J2000)


G165.68+44.01 - LOFAR 144 MHz (θ = 8"x6", σ = 75 μJy beam⁻¹)
G165.68+44.01 - uGMRT 400 MHz (θ = 7"x6", σ = 20 μJy beam⁻¹)
G165.68+44.01 - LOFAR 144 MHz (θ = 5"x3", σ = 100 μJy beam⁻¹)
G165.68+44.01 - Pan-STARRS
G165.68+44.01 - Spectral index (θ = 8"x8")
G165.68+44.01 - Chandra
Reg. A
Reg. B
G1
G2
200 kpc
500 kpc
RA (J2000)
Dec (J2000)


G172.74+65.30 - LOFAR 144 MHz (θ = 10"x6", σ = 220 μJy beam⁻¹)
G172.74+65.30 - uGMRT 400 MHz (θ = 8"x6", σ = 85 μJy beam⁻¹)
G172.74+65.30 - LOFAR 144 MHz (θ = 4"x3", σ = 350 μJy beam⁻¹)
172.74+65.30 - Pan-STARRS
G172.74+65.30 - Spectral index (θ = 10"x10")
G172.74+65.30 - Chandra
Reg. A
Reg. B
Reg. C
Reg. D
Reg. E
G1
G2
G3
200 kpc
500 kpc
RA (J2000)
Dec (J2000)

PSZ2 Name	Abell Name	RA_{J2000} (deg)	DEC_{J2000} (deg)	z	M_{500} (10^{14} $M_\odot$)	R_{500} (kpc)	Scale (kpc arcsec^{-1})
G071.63+29.78	—	266.8257	45.1899	0.157	4.13 ± 0.29	1080 ± 25	2.715
G088.53+41.18	A2208	247.3887	58.5338	0.133	2.56 ± 0.34	929 ± 42	2.363
G113.29-29.69	A7	2.9363	32.4325	0.107	3.71 ± 0.27	1060 ± 25	1.958
G137.74-27.08	A272	28.7835	33.9443	0.087	2.83 ± 0.28	975 ± 32	1.629
G155.80+70.40	—	178.4833	42.8600	0.333	4.42 ± 0.56	1036 ± 44	4.781
G165.68+44.01	—	140.5859	51.8876	0.21	3.76 ± 0.50	1027 ± 46	3.427
G172.74+65.30	A1190	167.9029	40.8574	0.079	2.45 ± 0.21	932 ± 27	1.493



Host	Reg.	Class.	D_c (kpc)	LLS (kpc)	A (10^3 kpc^2)	S_{144} (mJy)	S_{400} (mJy)	α	P_{150} (10^{24} W Hz^{-1})
G071	-	RP$^{(c,*)}$	920^{+}	580	78	197.8 ± 19.8	19.5 ± 1.2	2.3 ± 0.1	14.6 ± 1.5
G088	A, B	HT$^{(*)}$	290^{+}	275	29	431.1 ± 43.1	74.7 ± 4.5	1.7 ± 0.1	20.6 ± 2.1
G088	C, D	GReET$^{(c,*)}$	155^{+}	315	28	123.1 ± 12.3	6.1 ± 0.4	2.9 ± 0.1	6.5 ± 0.6
G088	E	Uncertain	390^{+}	215	21	432.1 ± 43.2	121.6 ± 7.3	1.2 ± 0.1	19.8 ± 2.0
G088	S2	Uncertain	535^{+}	210	14	24.6 ± 2.5	2.4 ± 0.2	2.3 ± 0.1	1.3 ± 0.2
G113	-	Remnant	580^{+}	210	21	48.4 ± 5.0	13.1 ± 0.8	1.3 ± 0.1	1.4 ± 0.1
G137	A	Uncertain$^{(*)}$	240^{+}	130	6	342.0 ± 34.2	86.0 ± 5.2	1.4 ± 0.1	6.3 ± 0.6
G137	B, Fil.	WAT$^{(*)}$	300^{+}	280	17	403.7 ± 40.4	99.7 ± 6.0	1.4 ± 0.1	7.4 ± 0.7
G155	A	HT	435^{x}	285	41	581.5 ± 58.2	254.0 ± 15.2	0.8 ± 0.1	195.2 ± 20.3
G155	B	Remnant	520^{x}	430	53	85.8 ± 8.6	5.6 ± 0.4	2.7 ± 0.1	46.0 ± 4.8
G165	A	Remnant	750^{x}	240	23	56.7 ± 5.7	12.1 ± 0.7	1.5 ± 0.1	7.6 ± 0.8
G165	B	Remnant	720^{x}	260	25	61.6 ± 6.2	9.5 ± 0.6	1.8 ± 0.1	8.6 ± 0.8
G172	A	NAT	40^{+}	90	7	4104.4 ± 410.4	2020.9 ± 121.3	0.7 ± 0.1	60.0 ± 6.0
G172	B, C, D	Uncertain	40^{+}	220	21	2116.1 ± 211.6	460.1 ± 27.6	1.5 ± 0.1	32.8 ± 3.2

Notes. Cols. 1-2: host cluster and considered region of the radio source. Col. 3: (tentative) classification; 'c' stands for 'candidate' and '*' indicates evidence of re-energising based on radio data only (not considering X-rays). Cols. 4-6: projected distance of target from the *Planck* centre (^{x}) or X-ray peak ($^{+}$), largest linear size, and area. Cols. 7-10: flux densities measured within regions encompassing the 3σ level of the 144 MHz image, integrated spectral index, and k-corrected radio power at 150 MHz.