

Searching for revived fossil plasma sources in galaxy clusters

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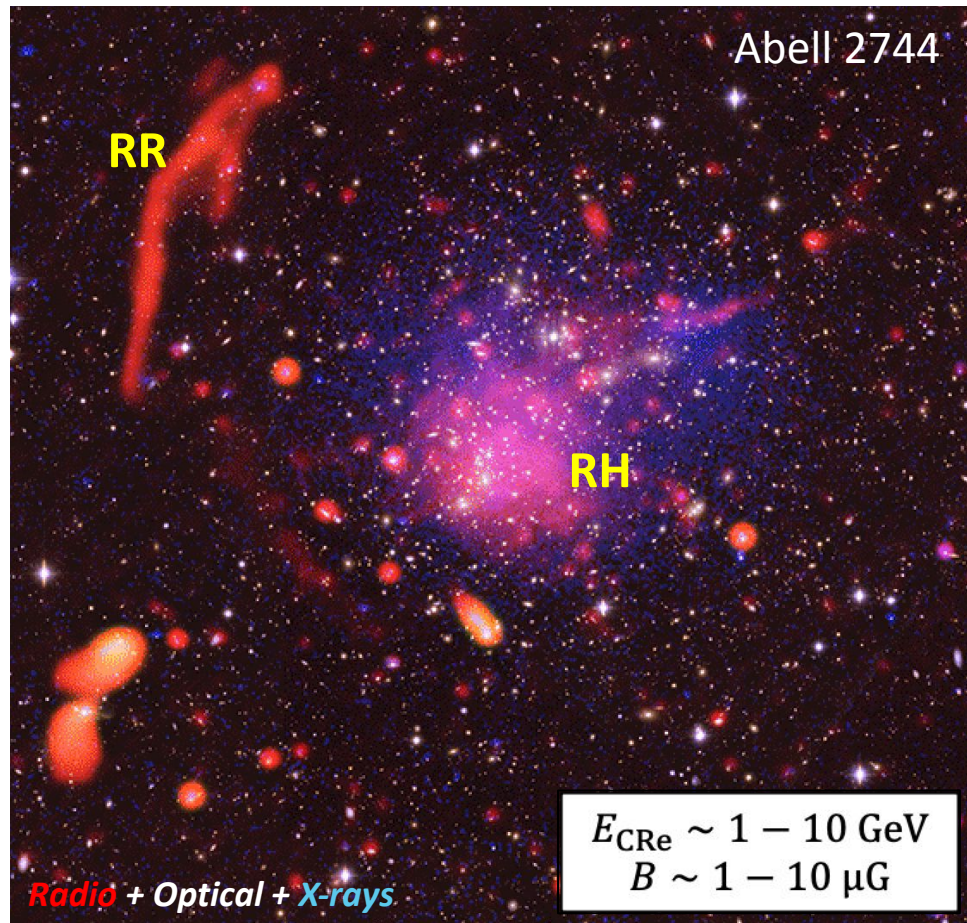
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Diffuse radio sources in galaxy clusters: radio halos and relics

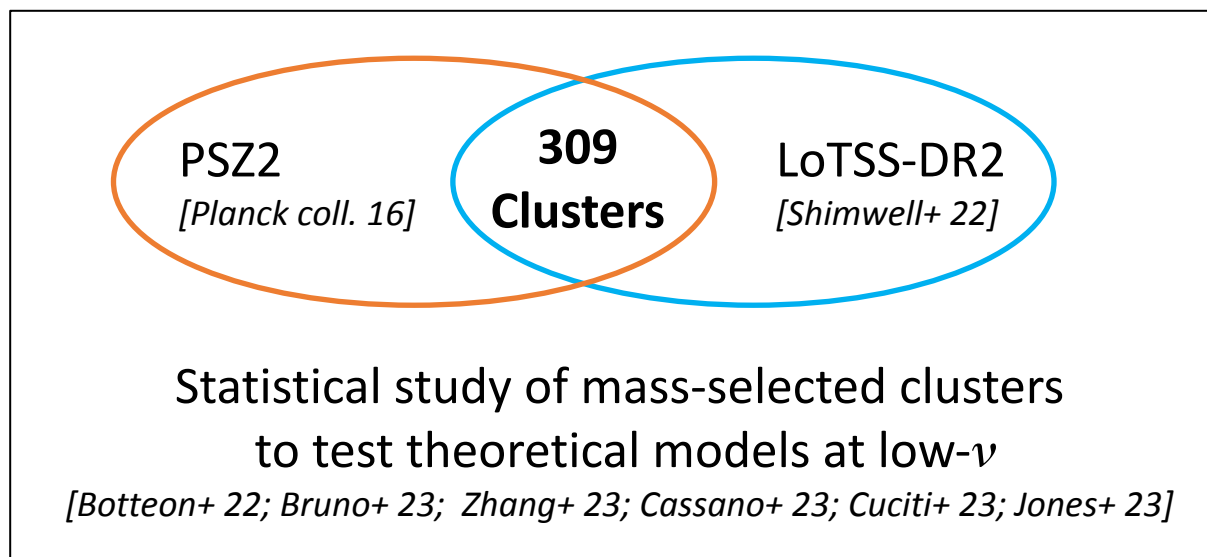


[Credits: Pearce et al.; Bill Saxton, NRAO/AUI/NSF; Chandra; Subaru; ESO]

	RH	RR
host state	disturbed	disturbed
location	centre	outskirts
morphology	roundish	elongated
LLS (Mpc)	$\sim 0.3-2$	$\sim 0.3-2$
α	$\sim 1-1.5$	$\sim 1-1.5$
origin	turbulence	shocks

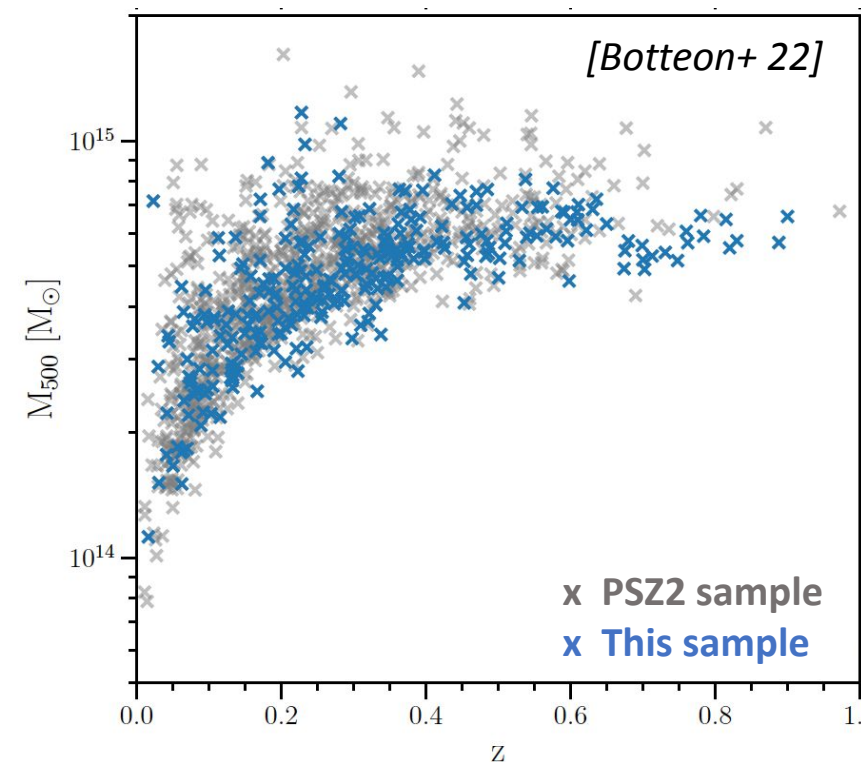
[Reviews: Brunetti & Jones 14; van Weeren+ 19]

The *Planck* clusters in the LOFAR sky



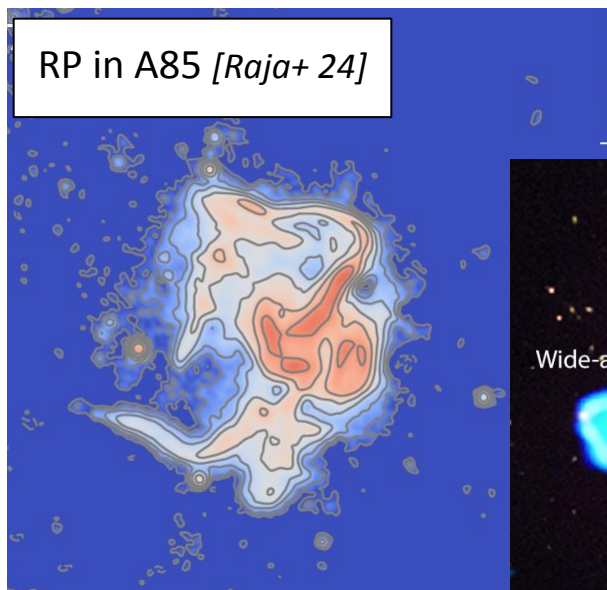
What can we learn ?

- 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 ?

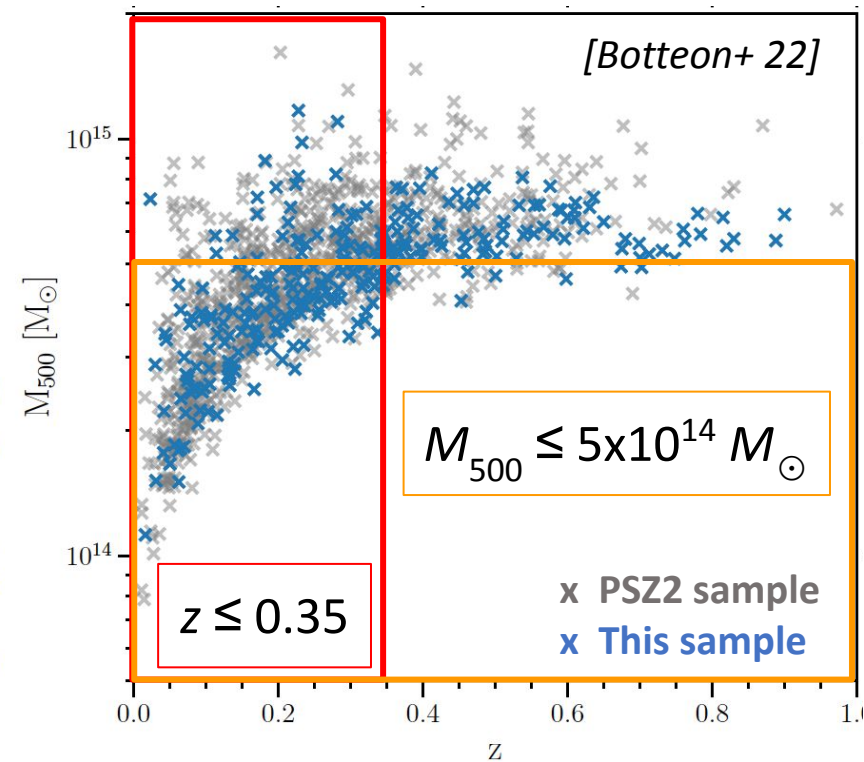
- Energy transfer mechanisms
- Origin of CR
- Cosmic magnetism
- Thermal/non-thermal interplay

Not only RHs/RRs!
Fossil components from radio galaxies can be also
revived by shocks and turbulence →
Radio phoenixes and Gently Re-Energised Tails

The pilot sample from *Planck*/LoTSS-DR2

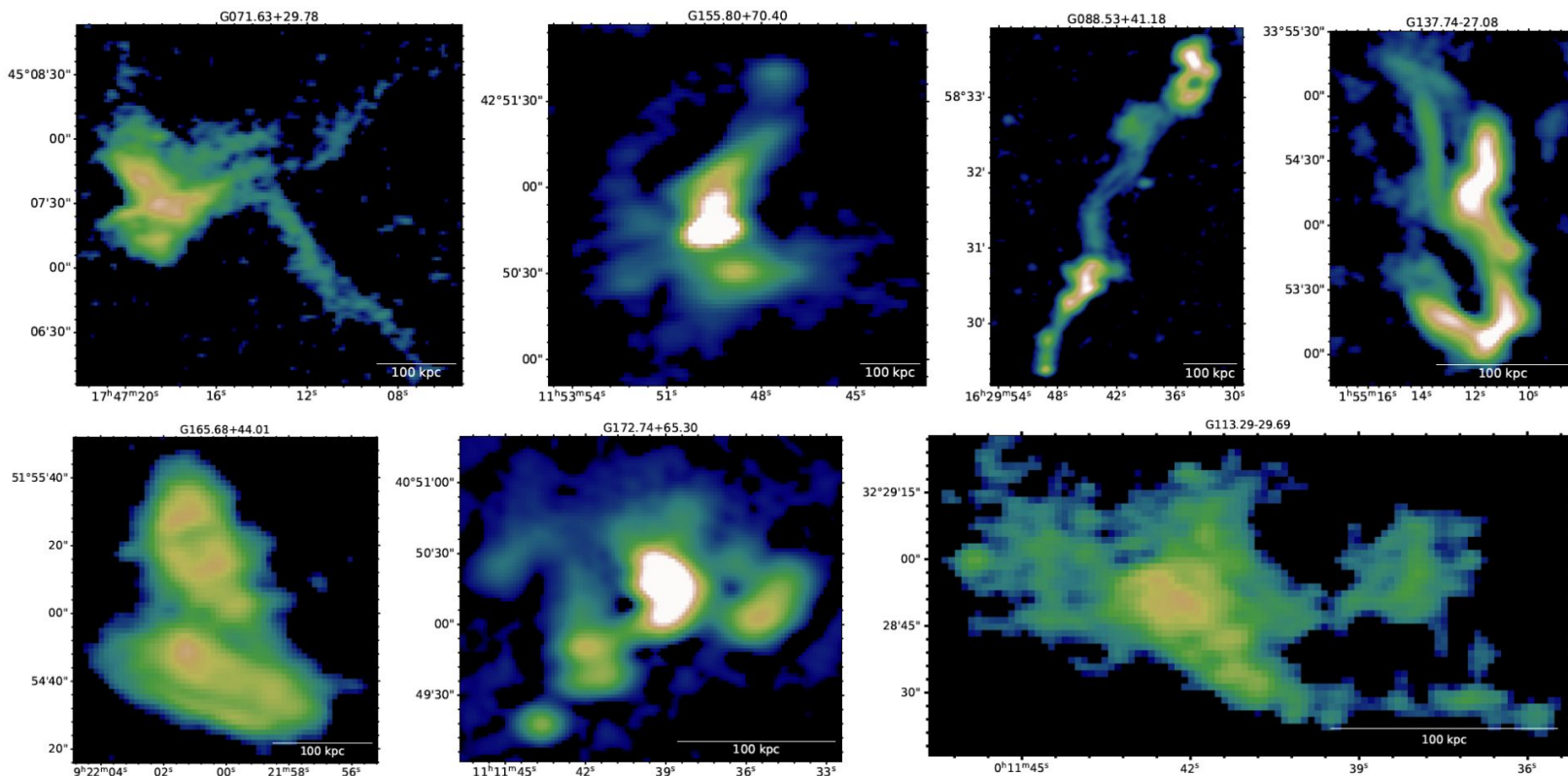
- 309 clusters → **92** without RR/RH in selected z - M_{500} ranges
- **Visual inspection: irregular/filamentary sources** → **7** targets
- **Follow-up** → **uGMRT at 300-500 MHz**

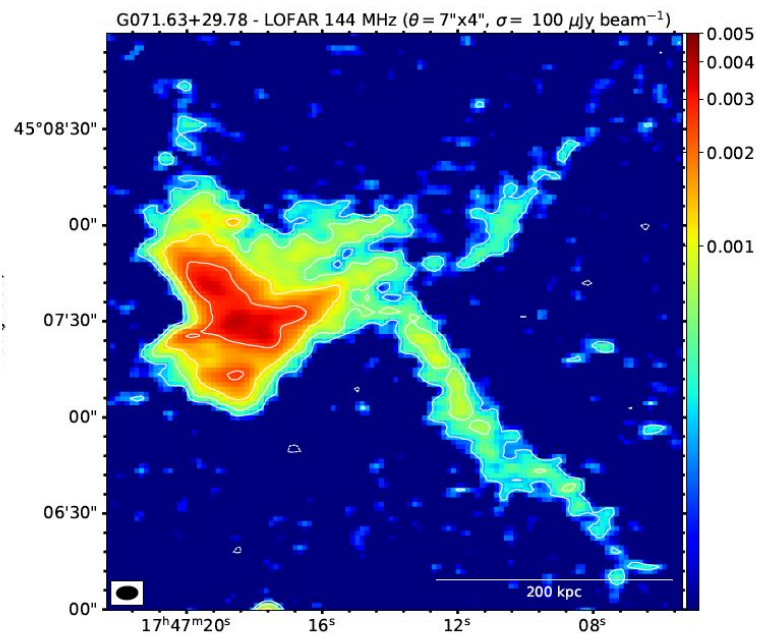
[Bruno+ 25]



AIM

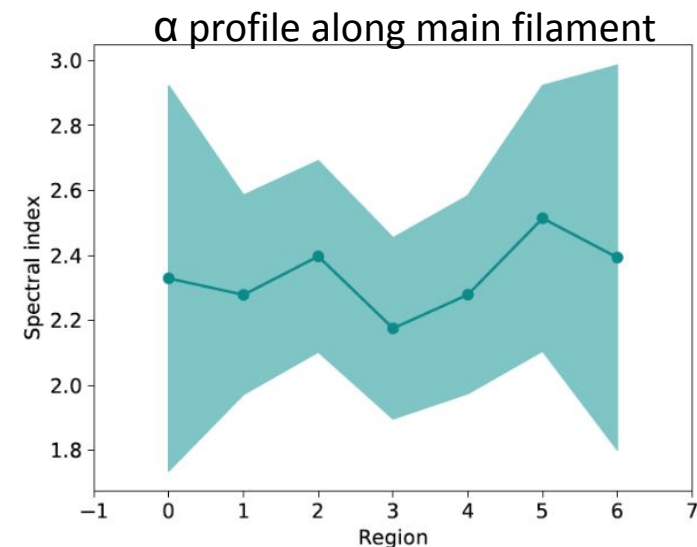
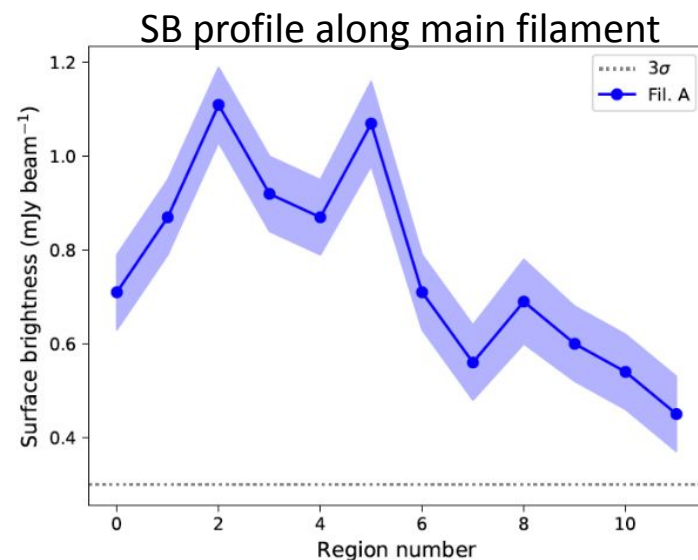
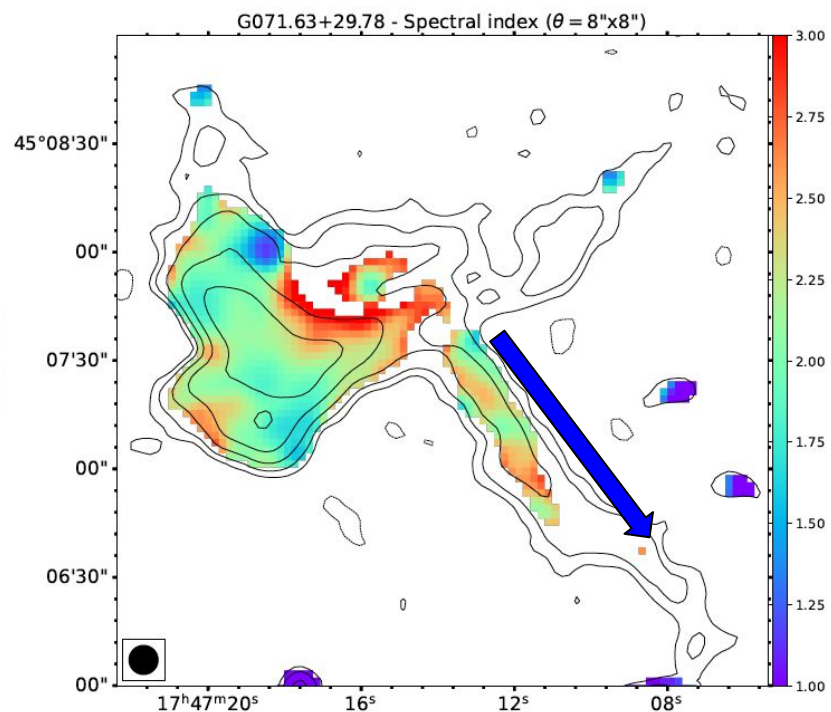
spectral study at high resolution
(< 50 kpc) for classification

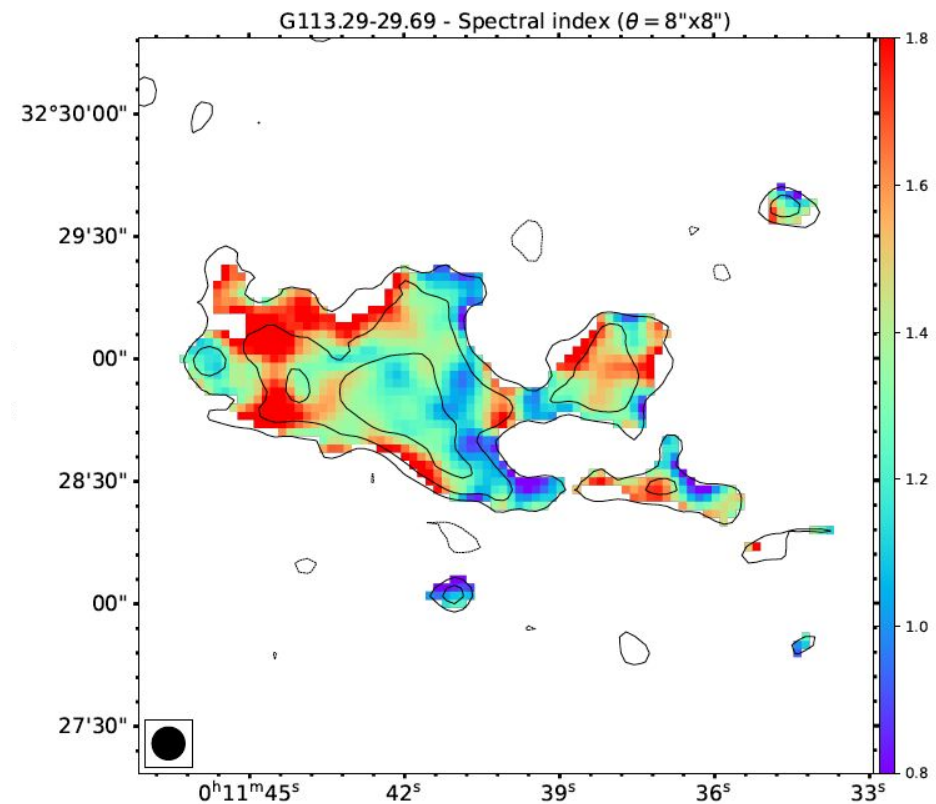
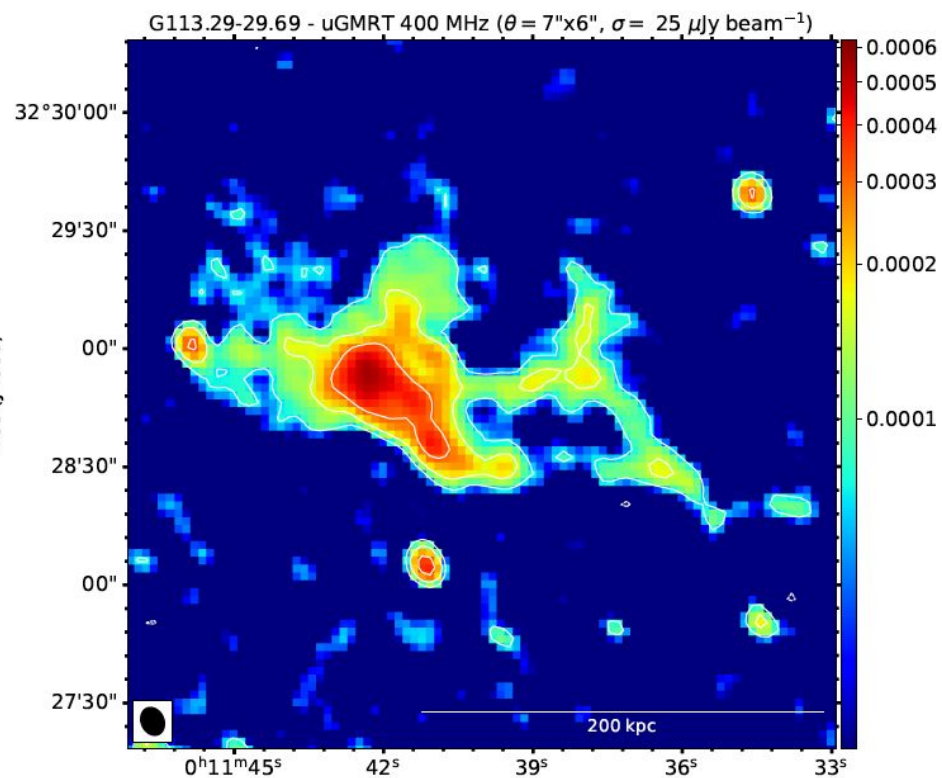




- uniform $\alpha \sim 2.3$
- no obvious host
- sign of reacceleration along filaments

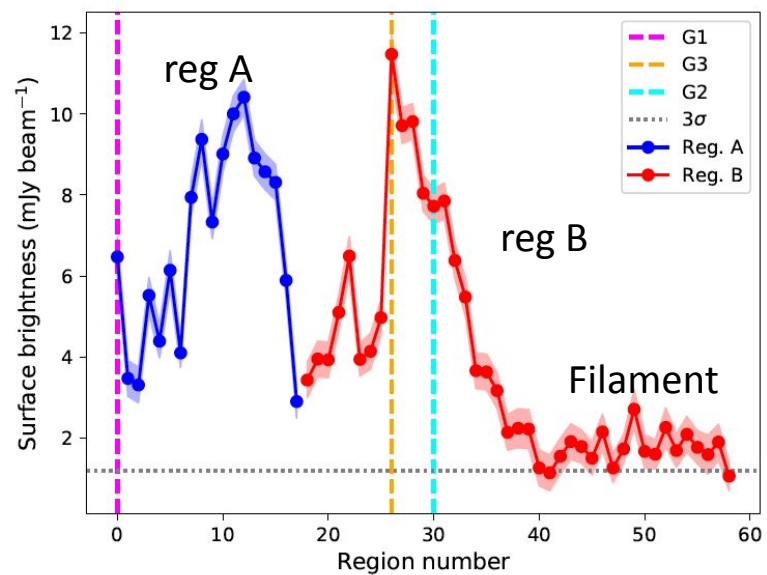
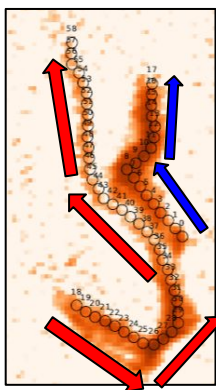
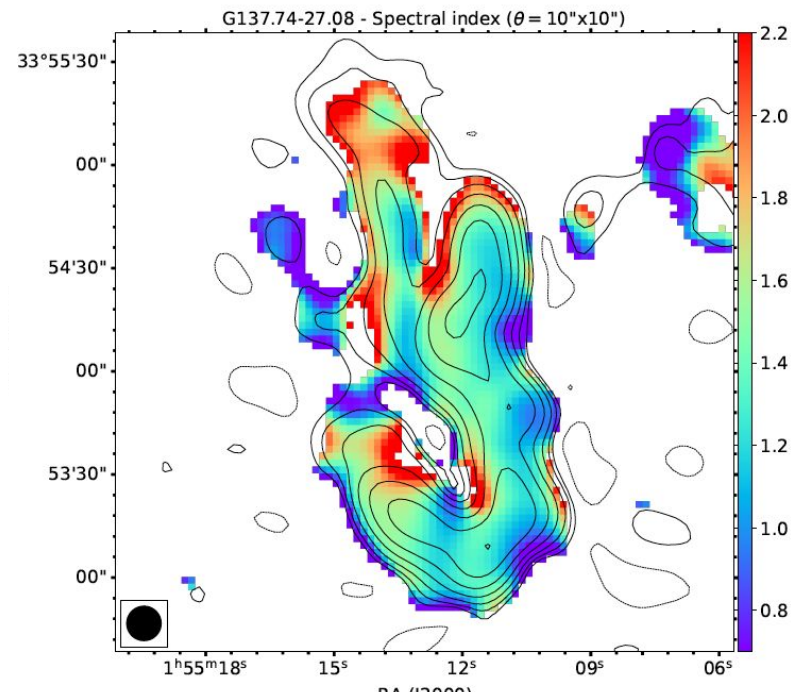
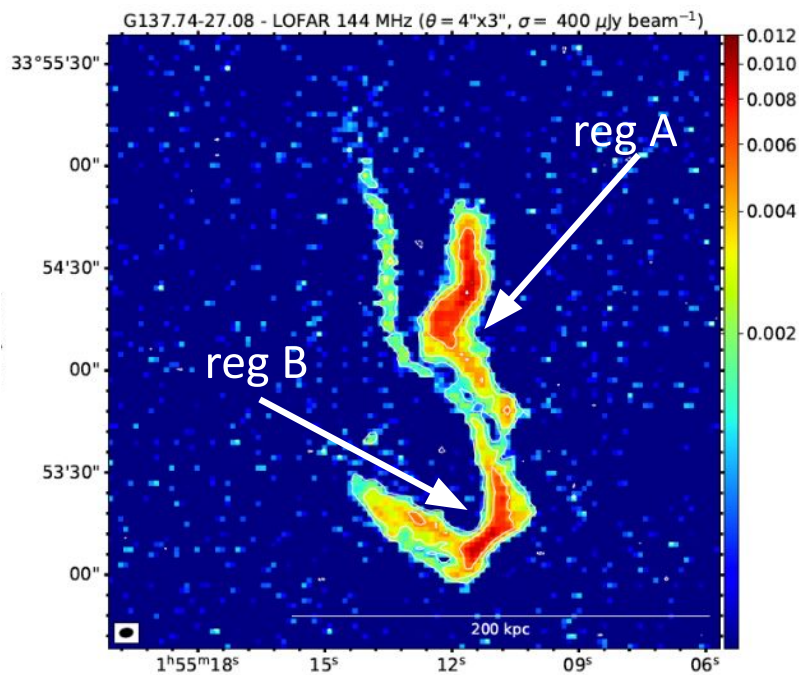
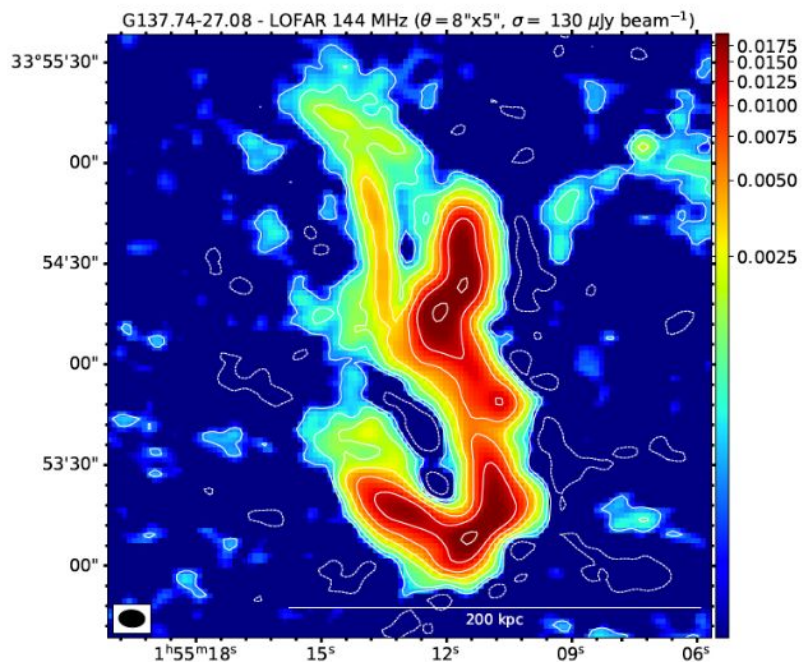
G071: Candidate RP





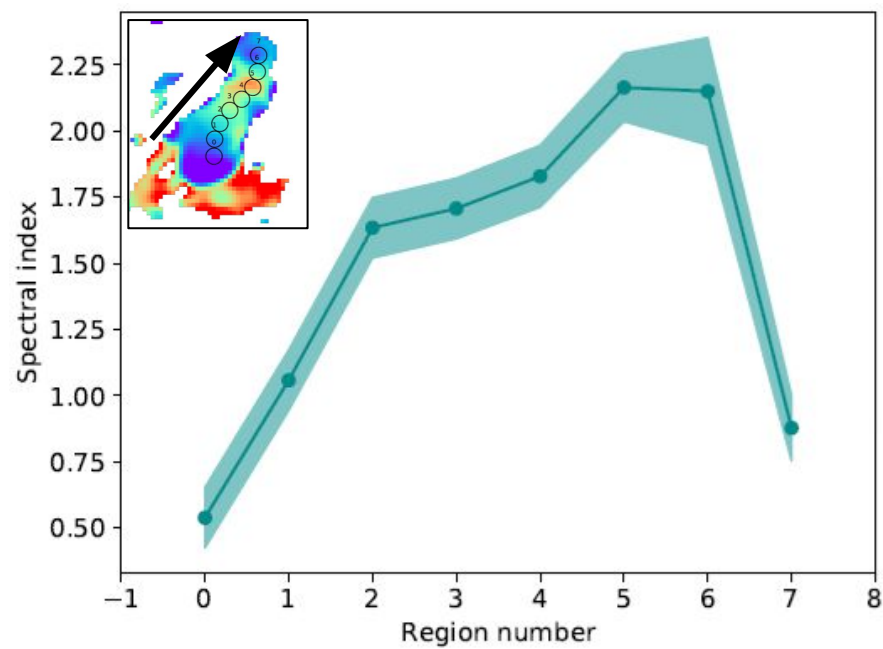
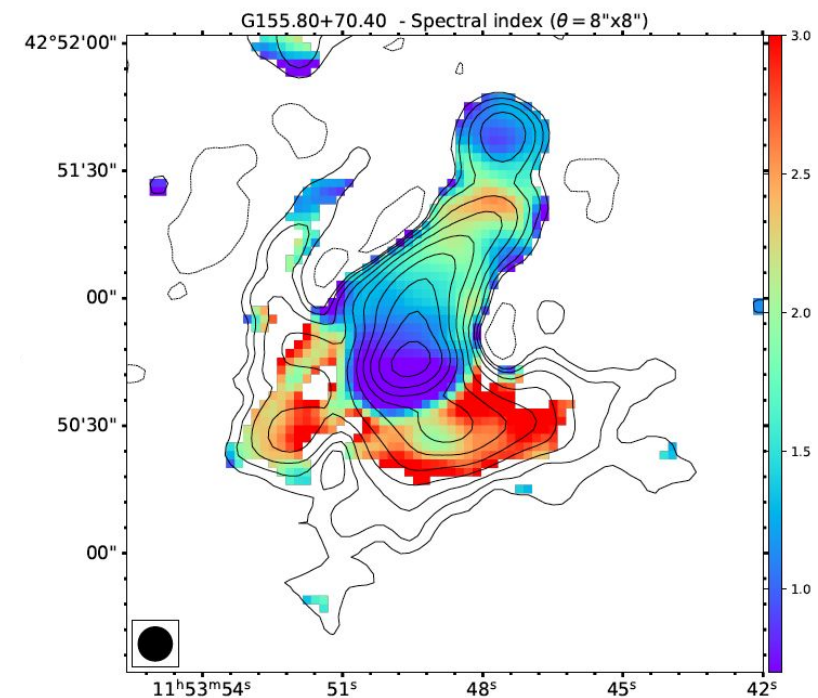
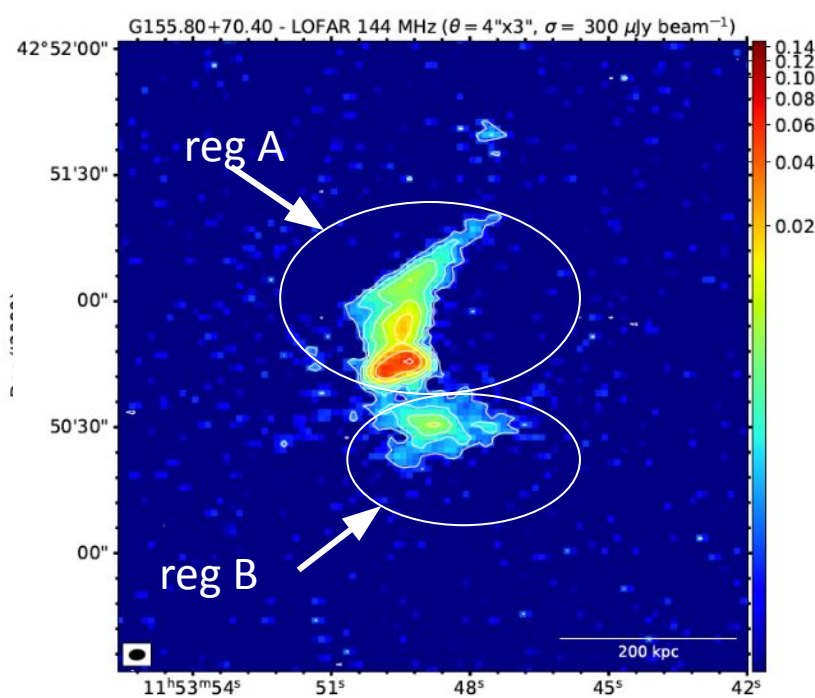
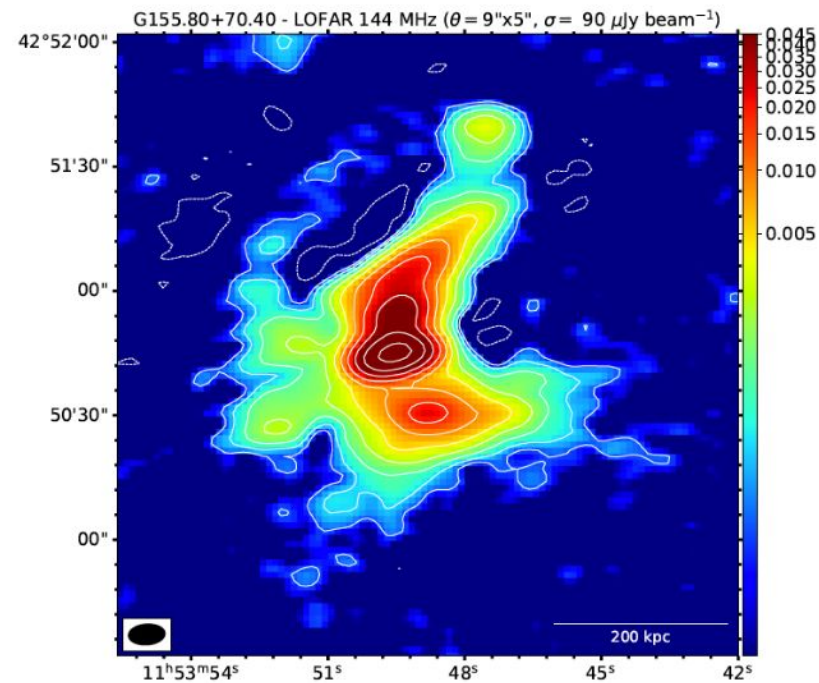
- $\alpha \sim 1.3$, no gradients
- no obvious host
- similar to RP in G071
- no sign of reacceleration

G113: Remnant radio galaxy



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

G137: No simple classification as RP/GReET



- Reg A \rightarrow HT, standard spectral steepening
- Reg B \rightarrow remnant, $\alpha \sim 3$

G155: No sign of reacceleration

Conclusions...

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

Results

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

What's next

Conclusions... and beginning of the SKA era

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

Results

➤ $\theta \sim 6''$, $\sigma \sim 20 \mu\text{Jy/b}$ @150 MHz (T=8 h)
x5 more sensitive than LOFAR

➤ $\theta \sim 6''$, $\sigma \sim 5 \mu\text{Jy/b}$ @300 MHz (T=6 h)
x5 more sensitive than uGMRT
(+ possibility of $\theta \sim 3''$!)



SKA-LOW 50-350 MHz

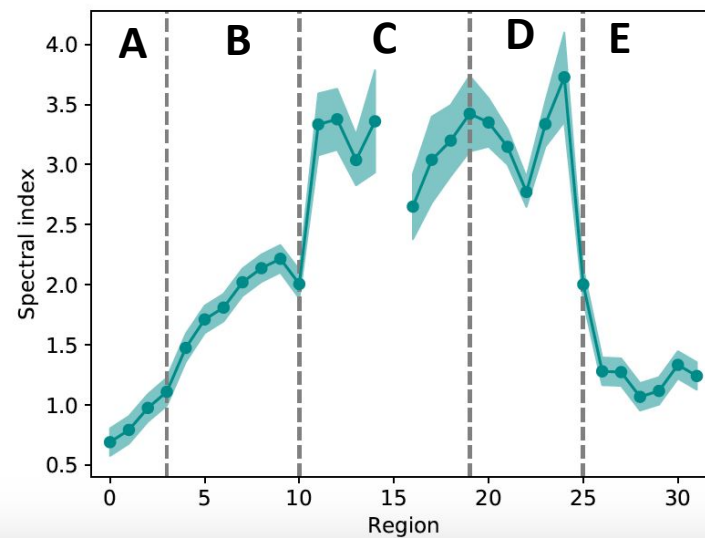
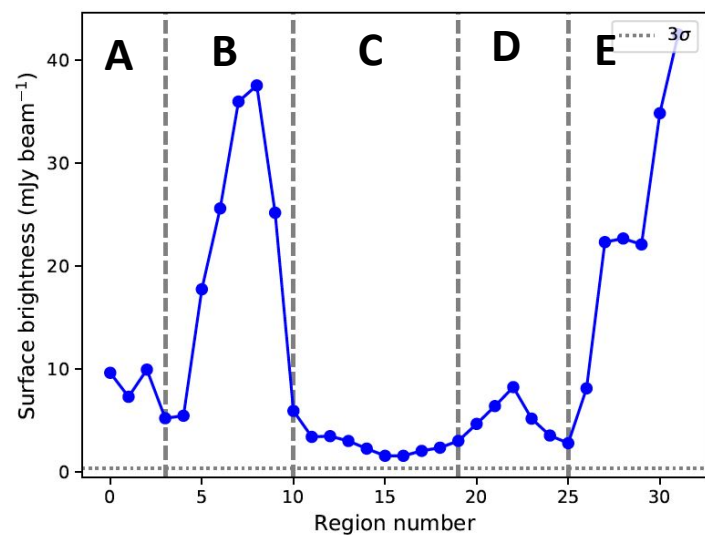
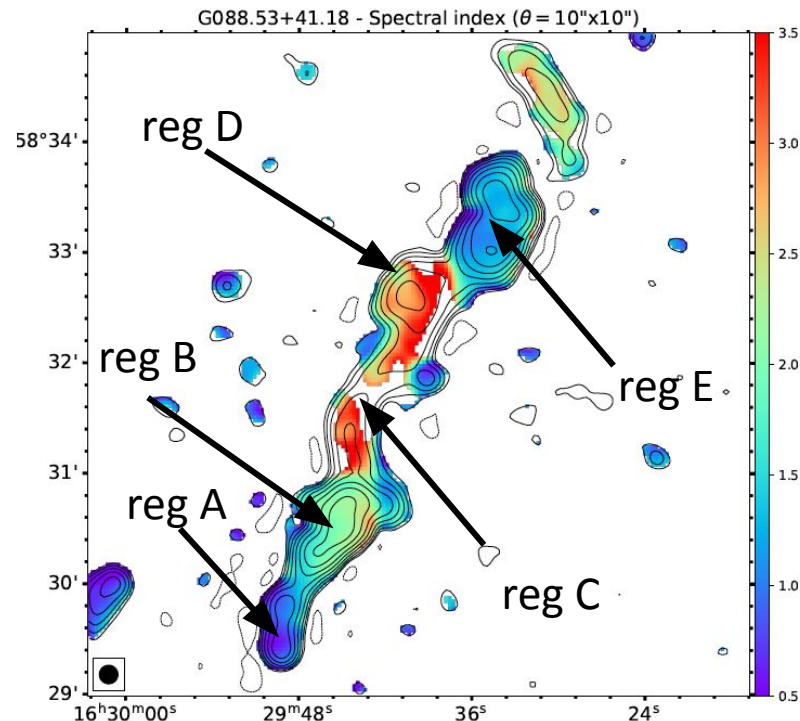
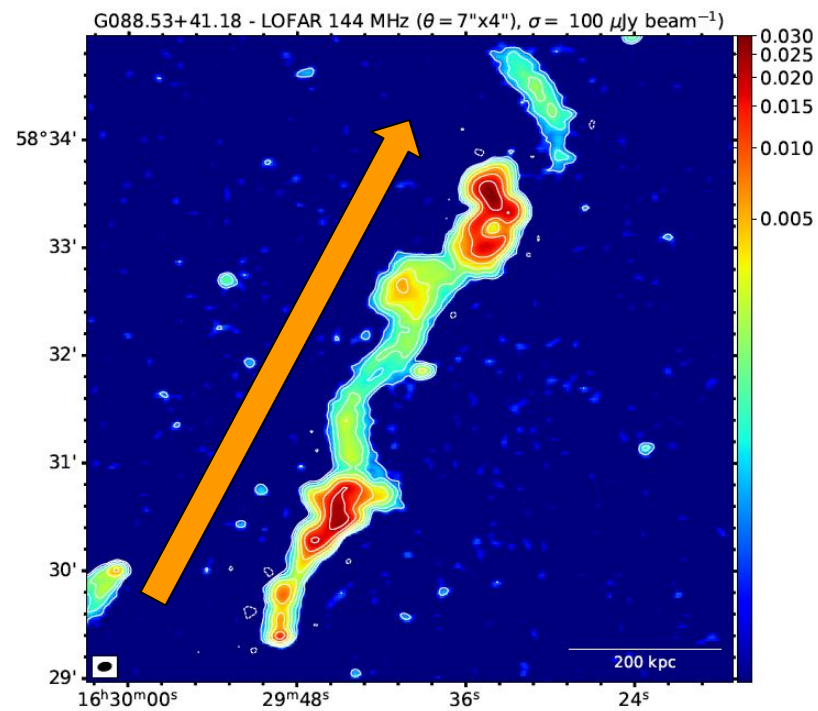
[based on *Braun+ 19*]

Take home messages

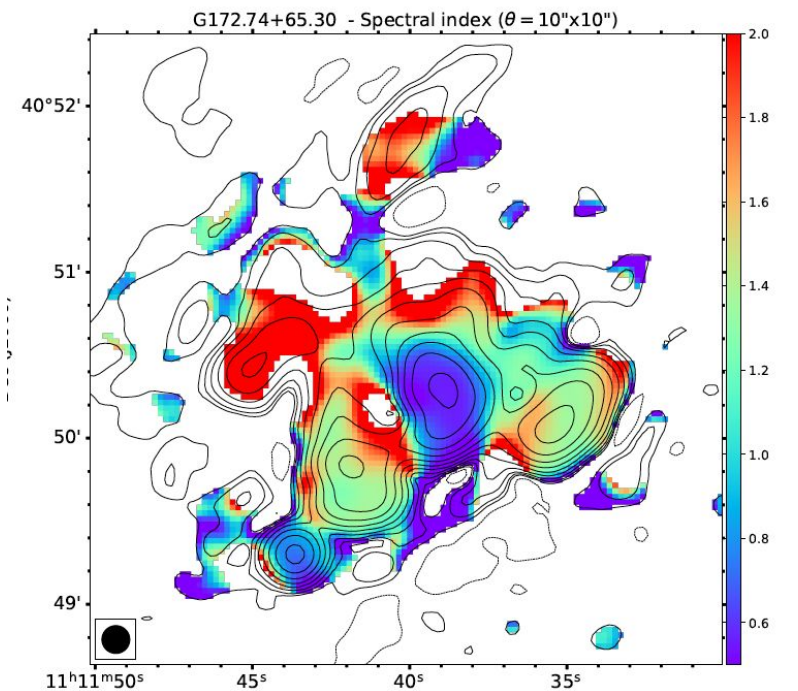
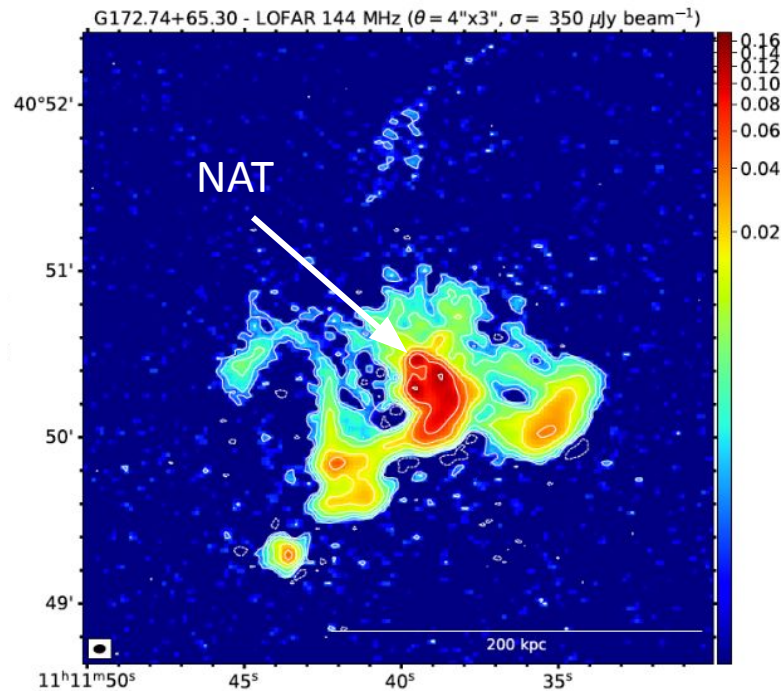
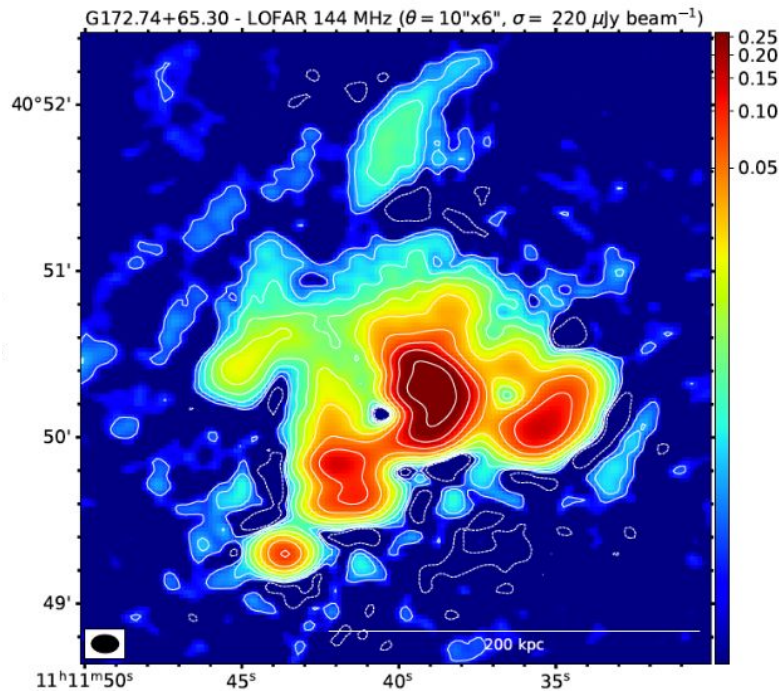
- ★ higher sensitivity → **systematic search and detections**
- ★ similar/better θ → **reduced misclassification**
- ★ in-band capability → **α with a single instrument**

→ **A bright future for science with revived fossil sources!**

Thanks for your attention!

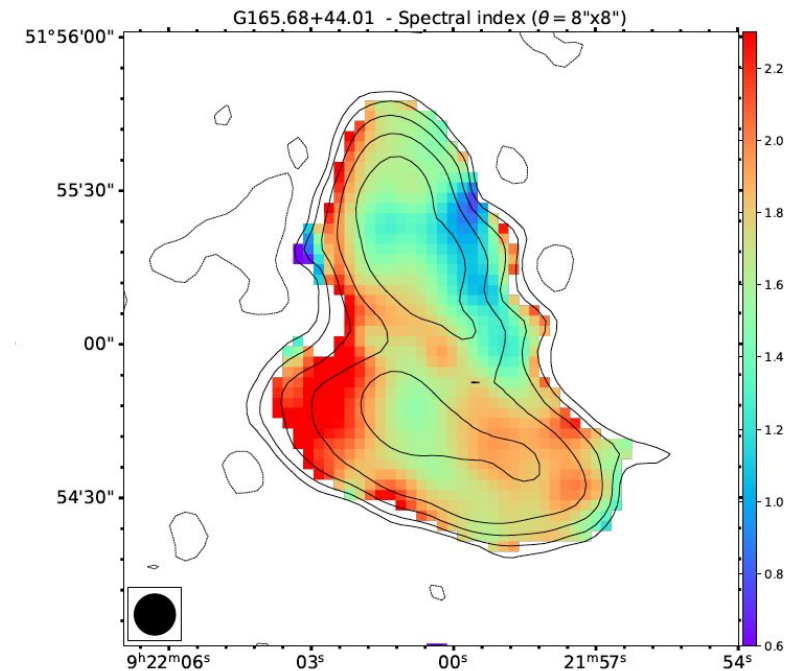
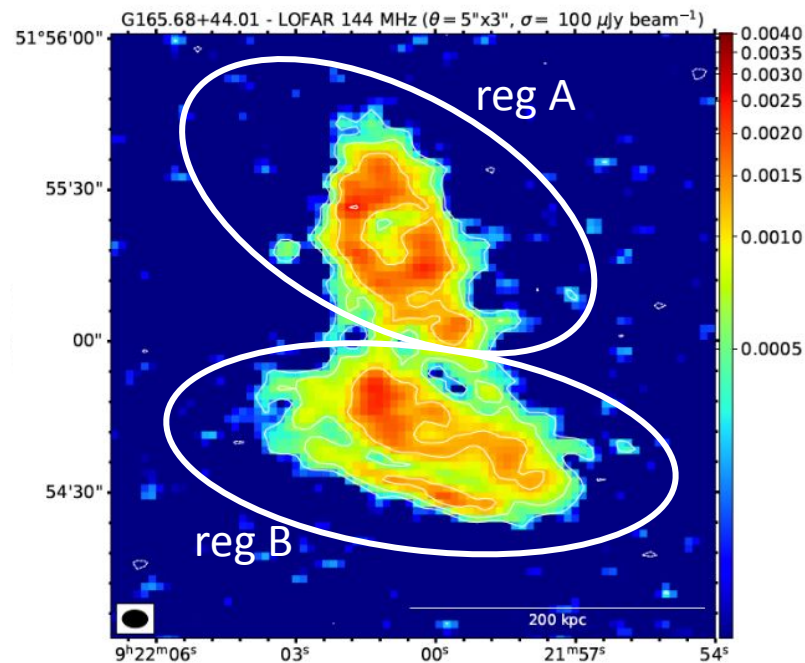
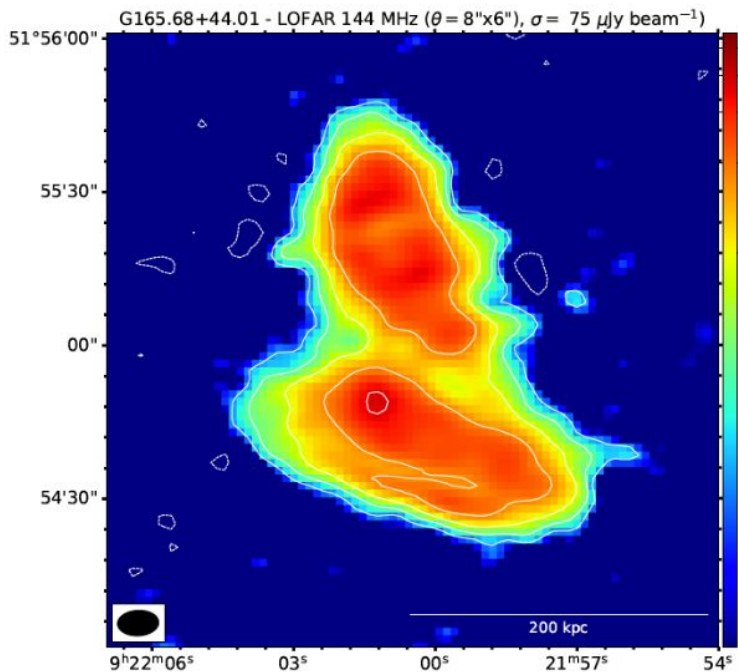


- Reg A+B \rightarrow HT
- Reg C+D: constant $\alpha \sim 3$ and SB \rightarrow **G088**: Candidate GReET
- Reg E \rightarrow ?



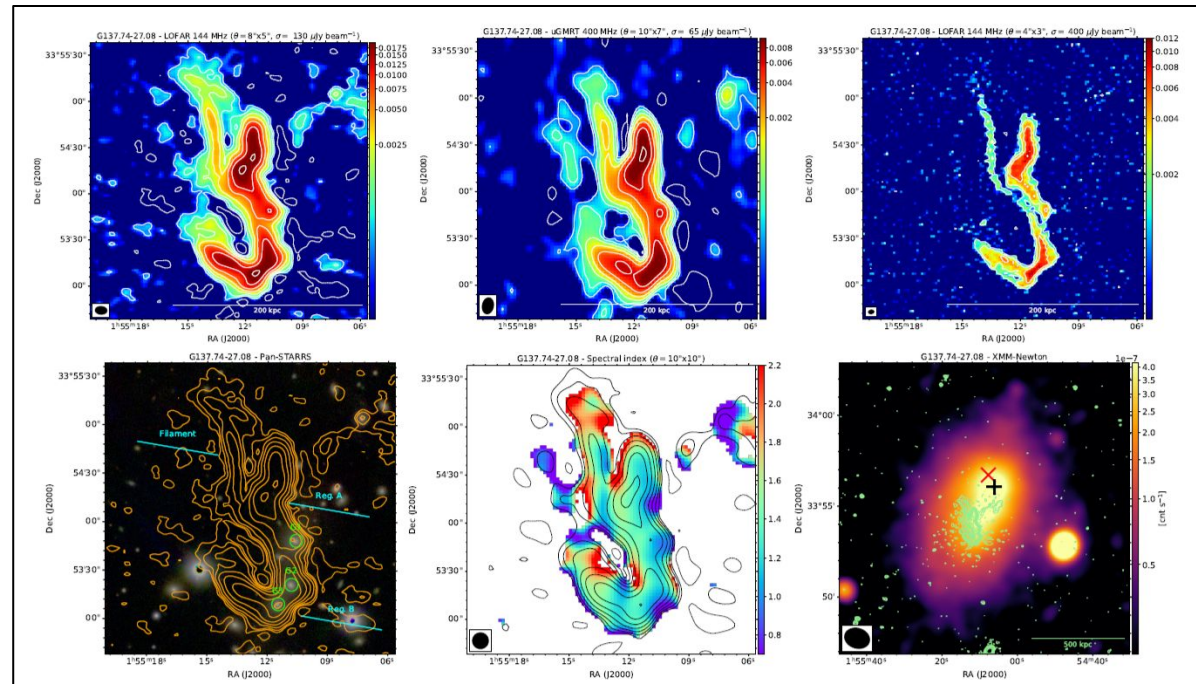
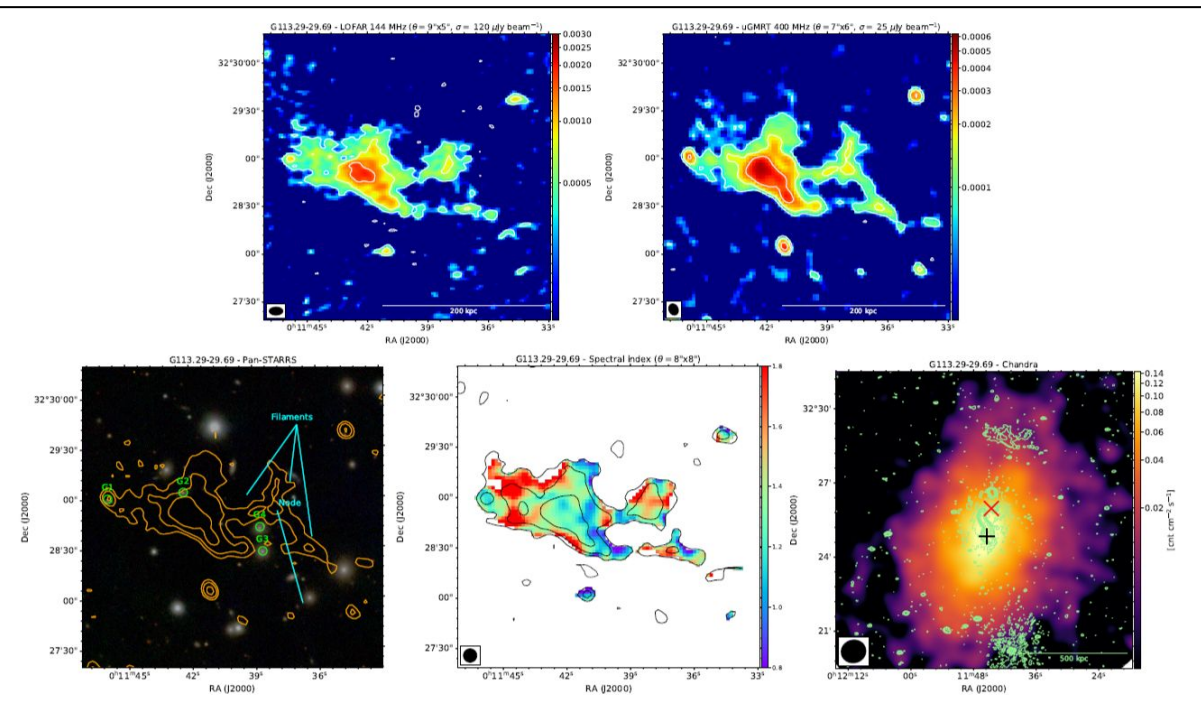
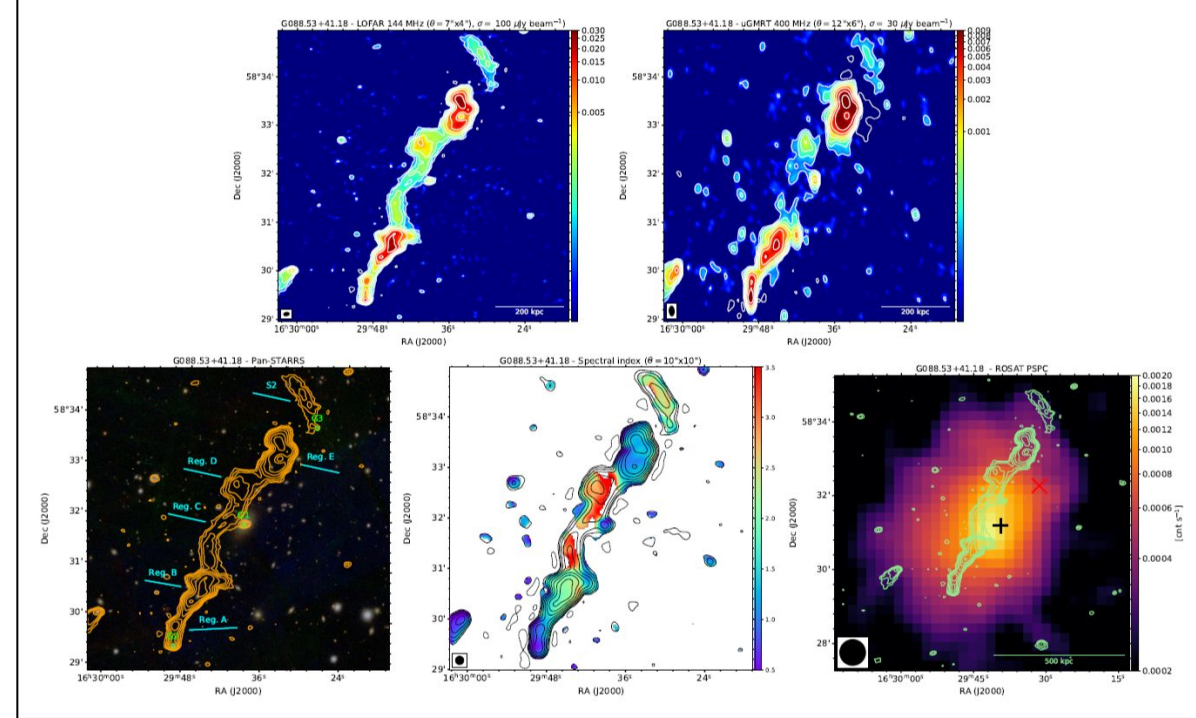
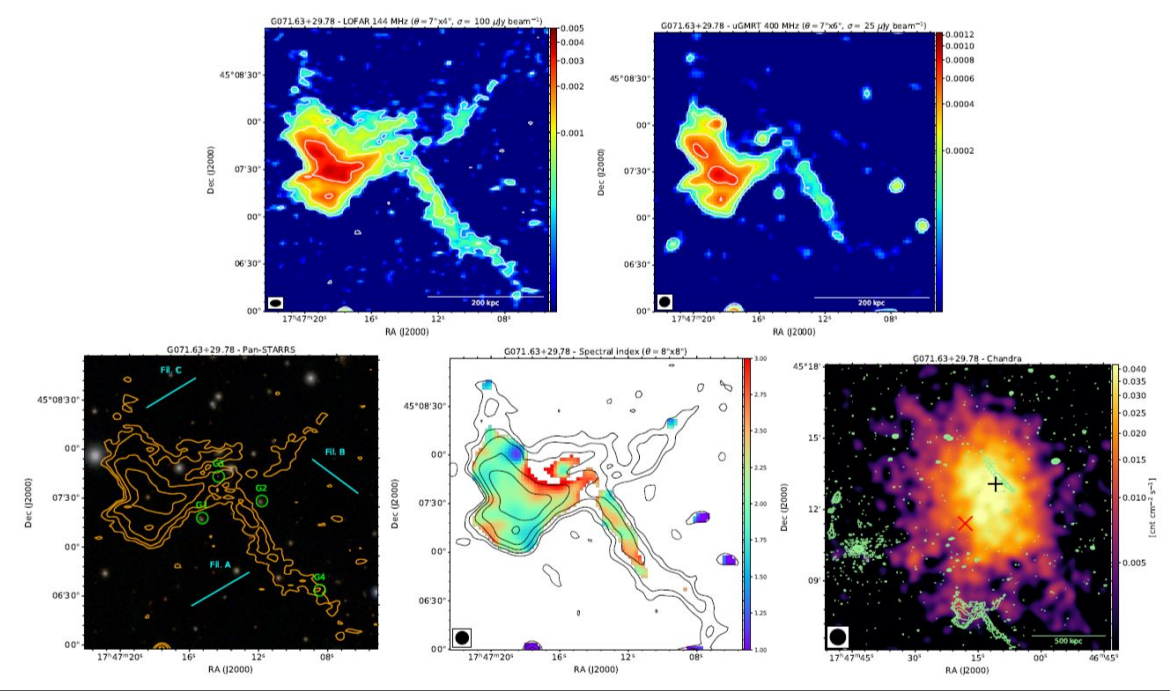
- Central NAT (twisting jets ?)
- Various diffuse steep- α components
- Fossil electrons spread by NAT + reacceleration ?

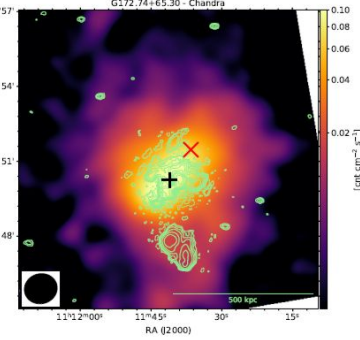
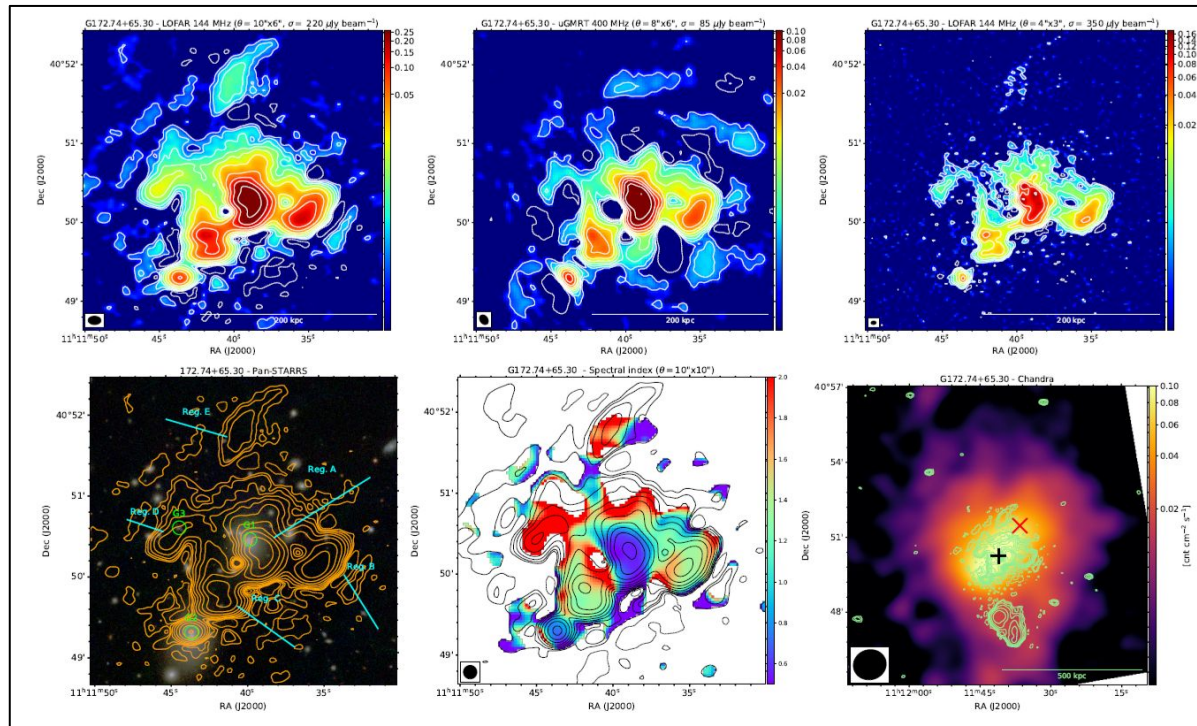
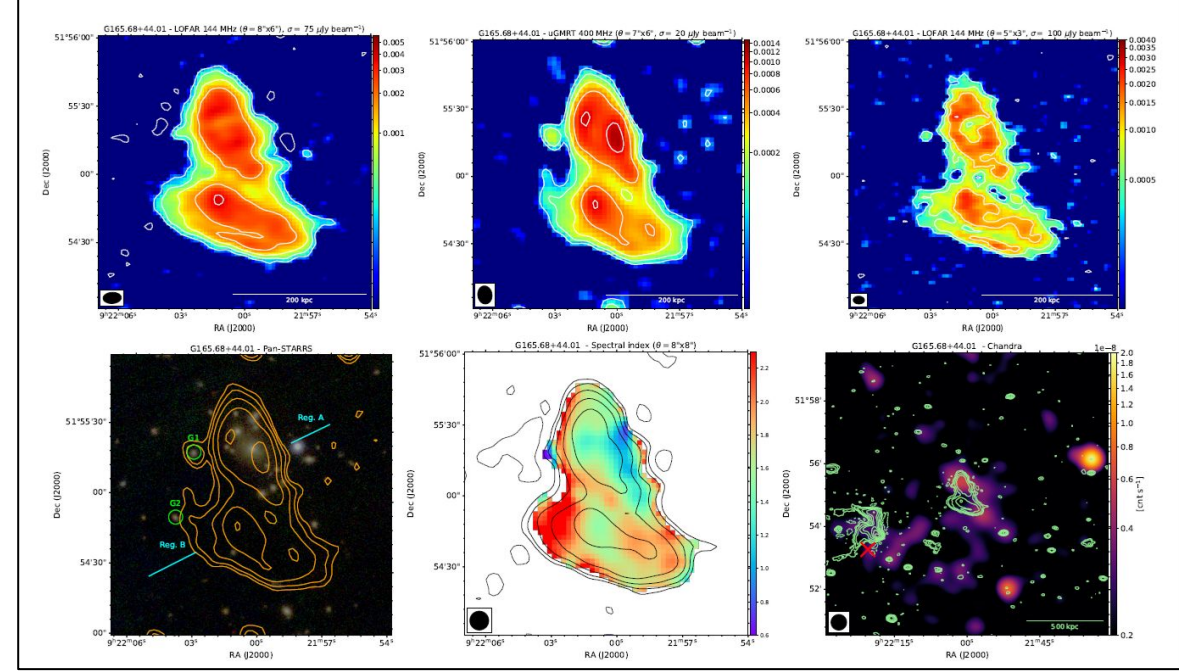
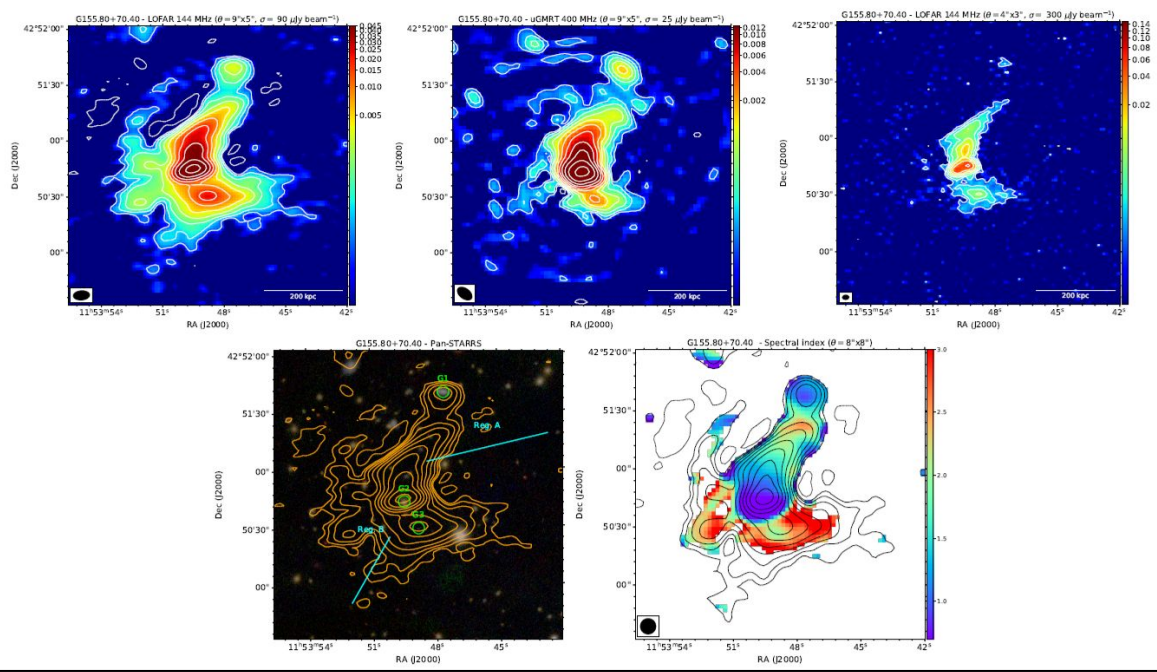
G172: Uncertain origin



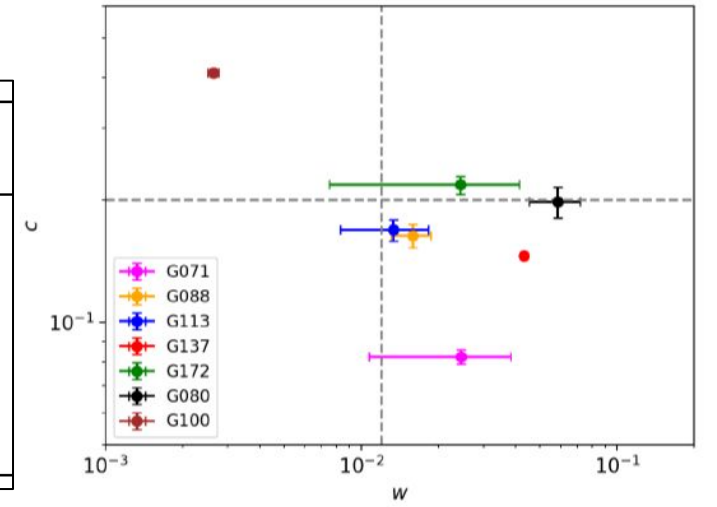
- Similar structures at low resolution
- Different internal structures at high resolution
- $\alpha \sim 1.5$

G165: Single/double remnant ?





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} ($10^{24} \text{ W Hz}^{-1}$)
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.