redshift. It appears to be a distorted bent-tail source whose features merge (in projection) with those of the western lobe of the assumed giant radio galaxy. Spectral index studies and redshift measurements will likely to be needed to disentangle such structures (Mhlahlo & Jamrozy 2021), which appear frequently in the MGCLS images, due to the high sensitivity to extended structures.

6. MGCLS diffuse cluster emission

A key aspect of radio observations of galaxy clusters is the detection of diffuse cluster-scale synchrotron emission, which carries information about the cluster formation history (see van Weeren et al. 2019; Brunetti & Jones 2014, for observational and theoretical reviews, respectively). There are several different categories of diffuse cluster radio emission, historically separated into three main classes: radio halos, mini-halos, and radio relics. All classes are characterised by low surface brightness and, typically, steep radio spectra ($\alpha \lesssim -1.1$).

Radio halos are diffuse sources that cover scales greater than 500 kpc, with many spanning megaparsec scales. They are typically seen to have morphologies closely linked to those of the X-ray emitting ICM. Both individual studies (e.g. Brunetti et al. 2001; Lindner et al. 2014) and statistical studies of large samples (Cassano et al. 2013; Kale et al. 2015; Cuciti et al. 2021a) have shown a strong link between radio halos and particle reacceleration following major cluster mergers, as well as correlations between source radio power and cluster mass and thermal properties.

Radio mini-halos are found in the central region of dynamically relaxed, cool-core clusters (see Giacintucci et al. 2017, for a recent update). They are defined to be smaller than radio halos, with projected sizes ranging from a few tens of to a few hundred kiloparsecs, usually confined within cold fronts at the cluster centre (Mazzotta & Giacintucci 2008). Mini-halo clusters always have a radio active brightest cluster galaxy (BCG), which is thought to provide at least a fraction of the seed electrons necessary to produce the diffuse emission (see e.g. Richard-Laferrière et al. 2020). Particle re-acceleration induced by gas sloshing is possibly the driving mechanism for mini-halos (e.g. ZuHone et al. 2011, 2013).

Radio relics are elongated megaparsec-scale structures located at the periphery of merging galaxy clusters. Their observed properties, which include a high degree of polarisation (see for instance the case of the Sausage cluster, van Weeren et al. 2010) are consistent with the idea that they are related to the presence of merger-induced shocks in the ICM. Double radio relics are found in a number of clusters, the prototype case being Abell 3667 (Rottgering et al. 1997), and in some cases a radio halo is detected as well (see e.g. Bonafede et al. 2012; Lindner et al. 2014). Radio phoenix sources are a subclass of relics thought to be related to revived fossil emission from radio AGN in the cluster region (van Weeren et al. 2019).

Radio halos and relics have been detected in an increasing number of merging clusters, over a broad range of cluster masses (see van Weeren et al. 2019; Cuciti et al. 2021b, for recent updates) and over a wide range of redshifts (Lindner et al. 2014; Di Gennaro et al. 2021). The detection of mini-halos, by contrast, remains limited, mainly due to observational constraints. In addition to the three main classes, more clusters with very steep-spectrum filaments have been detected recently (e.g. Abell 2034, Shimwell et al. 2016), requiring further investigation of the connection between the structures and particle reservoirs radio galaxies deposit into the ICM, and the effects of cluster merger events (see e.g. van Weeren et al. 2017; de Gasperin et al. 2017).

Of the 115 clusters observed in this Legacy Survey, 62 have some form of diffuse cluster emission, with several clusters hosting more than one diffuse source. Table 4 presents the list of all 99 diffuse cluster structures or candidates detected in the survey. Fifty-six of these are new. For each diffuse source we list the emission classification, as well as angular and physical projected sizes, and position relative to cluster centre (where relevant). Classifications are based on a combined interrogation of the full- and 15″ resolution MeerKAT data products, a 25″ resolution filtered image (see Sect. 4.3.1 for details), and any available optical and X-ray imaging. Candidate structures are those with either marginal detections or where the classification is uncertain. Where a diffuse source does not fit into any of the current classes, but is not clearly associated with an individual radio galaxy, we classify it as ‘unknown’. Our diffuse cluster emission detections can be summarised as follows: three new mini-halos and seven new mini-halo candidates, 27 halo detections and six candidates (of which 13 are new), 28 relics and 18 candidates (of which 26 are new), one known phoenix source and two new candidates, and nine diffuse sources, six of which are new, with ambiguous or unknown classifications.

The galaxy clusters observed in the MGCLS provide just a glimpse of the many diffuse cluster emission discoveries likely to be made in the Square Kilometre Array era. In the following, we present a few examples to show the much improved images compared to previous observations, opening up new areas of investigation, as well as discoveries highlighting specific interesting science issues. Flux densities for the diffuse emission in these systems have been measured by integrating the surface brightness within the 3σ contour in the 15″ resolution image and then subtracting the compact source contributions, which are determined from the full-resolution image. In some cases the 25″ resolution filtered image shows a greater extent to the diffuse structures than the 15″ resolution products; the flux densities quoted here may be considered as lower limits to the total amount of diffuse emission.

6.1. New insights into known sources

Twenty-eight of the MGCLS targets are hosts of previously known diffuse cluster emission. In many cases the MGCLS data provide an additional frequency or deeper detections of low-surface-brightness emission, yielding new insights into well-known sources (e.g. El Gordo, Abell 3376). Here we provide three examples.

6.1.1. Abell 85: A new type of halo?

The MGCLS multi-resolution view of the Abell 85 system, a cool-core cluster at $z = 0.0556$ and part of the Pisces-Cetus supercluster, is shown in the top panel of Fig. 8. We detect two diffuse sources: a complex phoenix or revived fossil plasma source south-west of the cluster centre (previously known) and a newly discovered elongated radio mini-halo that may be an example of a new class of sources that represents an evolutionary bridge between mini-halos and halos.

The newly detected diffuse source in Abell 85 surrounds the BCG, with contours shown in panel A of Fig. 8, and has a 1.28 GHz flux density of ~5.5 mJy measured from the 15″ resolution image. The 25″ resolution image, also shown in Fig. 8, reveals a much greater extent to this source, with a largest

Table 4. Catalogue of the 99 diffuse cluster radio sources detected in the MGCLS.

(1) Cluster name	(2) RA$_{\rm J2000}$ (deg)	(3) Dec$_{\rm J2000}$ (deg)	(4) z	(5) Class	(6) New?	(7) LAS (′)	(8) LLS (Mpc)	(9) Notes [Refs.]
Abell 13	3.384	−19.501	0.094	cR		3.0	0.32	W of centre; [8, 13, 17, 37]
Abell 22	5.161	−25.722	0.142	cH		2.7	0.41	[8]
Abell 85	10.453	−9.318	0.056	MH $^{(\dagger)}$	✓	4.0	0.26	
				Ph $^{(a)}$		5.6	0.36	SW of centre; [8, 18]
Abell 168	18.791	0.248	0.045	R		12.4	0.66	N of centre; [10]
Abell 209	22.990	−13.576	0.209	H		7.9	1.62	Embedded HT; [17, 19, 20, 41, 42]
Abell 370	39.960	−1.586	0.375	cH	✓	3.1	0.96	[44]
Abell 521	73.536	−10.244	0.248	R		6.0	1.40	SE of centre; [11, 15, 28, 41]
				H		5.3	1.23	[4, 6, 20, 28, 42]
				R	✓	4.0	0.93	NW of centre
Abell 545 $^{(b)}$	83.102	−11.543	0.154	H		4.7	0.75	[1, 17]
Abell 2645	355.320	−9.028	0.251	cH	✓	2.7	0.64	Irregular shape; [5]
Abell 2667	357.920	−26.084	0.232	H $^{(\dagger)}$		4.6	1.02	[16]
Abell 2744	3.567	−30.383	0.307	H		7.5	2.04	[8, 13, 17, 21, 32, 42]
				R		5.8	1.57	NE of centre; [8, 13, 21, 30, 32, 42]
				R		4.6	1.25	SE of centre; [32]
Abell 2751	4.058	−31.389	0.081	cPh	✓	0.9	0.08	NW of centre; [8] (says relic)
Abell 2811	10.537	−28.536	0.108	H		5.2	0.62	[8]
Abell 2813	10.852	−20.621	0.292	cH	✓	3.1	0.81	
Abell 2895	19.546	−26.973	0.228	cPh	✓	0.8	0.18	E of centre
Abell 3365	87.050	−21.935	0.093	R	✓	6.8	0.70	NE of centre; [45]
				R	✓	3.4	0.35	W of centre; [45]
Abell 3376	90.426	−39.985	0.047	R		28.1	1.55	E of centre; [2, 12, 23]
				R		18.8	1.04	W of centre; [2, 12, 23]
Abell 3558	201.978	−31.492	0.048	H		4.5	0.25	[7, 39]
Abell 3562	202.783	−31.673	0.050	H		11.5	0.67	[7, 14, 40]
				R		8.6	0.50	SW of centre; [40]
Abell 3667	303.140	−56.841	0.056	R		25.8	1.67	SE of centre; [22, 33]
				R		35.2	2.28	NW of centre; [22, 33]
Abell 4038	356.880	−28.203	0.030	cMH	✓	4.5	0.16	Embedded HT
Abell S295	41.400	−53.038	0.300	H		4.0	1.07	[46]
Abell S1063	342.181	−44.529	0.348	H		5.5	1.62	[44]
Abell S1121	351.284	−41.212	0.190	U		2.2	0.42	SE of centre
Bullet	104.658	−55.950	0.297	H		8.5	2.26	[26, 35]
				R		3.8	1.01	E of centre; [36]
El Gordo	15.719	−49.250	0.870	H		3.3	1.53	[3, 27]
				R		2.0	0.93	NW of centre; [3, 27]
				R		1.0	0.46	SE of centre; [3, 27]
				R		0.9	0.42	E of centre; [27]
PLCK G200.9−28.2	72.587	−2.949	0.220	R	✓	5.6	1.19	E of centre
				R	✓	2.7	0.58	SW of centre; [24]
				cR	✓	1.0	0.21	NW of centre

Notes. Several of the 62 MGCLS clusters in this catalogue are host to more than one diffuse cluster source. Columns: (1) Cluster name; (2) and (3) NED cluster position: J2000 RA and Dec; (4) Cluster redshift; (5) Diffuse source classification – mini-halo (MH), halo (H), relic (R), phoenix (Ph), candidate (c), unknown/unclear (U); see Sect. 6 for further details. Elongated halos/halo candidates with embedded bright AGN sources are indicated by (†); (6) Indicates whether or not the diffuse source is a new detection; (7) Largest angular size in arcminutes; (8) Largest physical linear size at the cluster redshift in Mpc; (9) Notes on the detection with references, in square brackets, to previous studies. HT – head-tail galaxy; WAT – wide-angle tail galaxy. $^{(a)}$Mixed classification in the literature (see Sect. 6.1.1). $^{(b)}$Diffuse emission from the Hα region in the Orion Nebula is also detected in this field. $^{(c)}$MACS J0257.6−2209 has a published detection of a giant radio halo (Giacintucci et al. 2017) but in the higher-quality MGCLS data, the reported giant halo looks like the blending of other sources. $^{(d)}$Diffuse emission in RXC J0520.7−1328 is complex and difficult to classify (see Sect. 6.1.2).

References. [1] Bacchi et al. (2003); [2] Bagchi et al. (2006); [3] Botteon et al. (2016); [4] Brunetti et al. (2008); [5] Cassano et al. (2013); [6] Dallacasa et al. (2009); [7] Di Gennaro et al. (2018b); [8] Duchesne et al. (2021a); [9] Dwarakanath et al. (2011); [10] Dwarakanath et al. (2018); [11] Ferrari et al. (2006); [12] George et al. (2015); [13] George et al. (2017); [14] Giacintucci et al. (2005); [15] Giacintucci et al. (2008); [16] Giacintucci et al. (2017); [17] Giovannini et al. (1999); [18] Giovannini & Feretti (2000); [19] Giovannini et al. (2006); [20] Giovannini et al. (2009); [21] Govoni et al. (2001); [22] Hindson et al. (2014); [23] Kale et al. (2012); [24] Kale et al. (2017); [25] Kale et al. (2019); [26] Liang et al. (2000); [27] Lindner et al. (2014); [28] Macario et al. (2013); [29] Macario et al. (2014); [30] Orrù et al. (2007); [31] Parekh et al. (2017); [32] Pearce et al. (2017); [33] Rottgering et al. (1997); [34] Sandhu et al. (2018); [35] Shimwell et al. (2014); [36] Shimwell et al. (2015); [37] Slee et al. (2001); [38] Stuardi et al. (2019); [39] Venturi et al. (2000); [40] Venturi et al. (2003); [41] Venturi et al. (2007); [42] Venturi et al. (2013); [43] Wilber et al. (2020); [44] Xie et al. (2020); [45] van Weeren et al. (2011b); [46] Knowles et al. (2021); [47] HyeongHan et al. (2020); [48] Feretti et al. (2005). We note that after our review of the literature, detections of diffuse emission in some of the clusters above are published by Duchesne et al. (2021b), Brüggen et al. (2021) and Duchesne et al. (2021c).

Table 4. continued.

(1) Cluster name	(2) RA_{J2000} (deg)	(3) Dec_{J2000} (deg)	(4) z	(5) Class	(6) New?	(7) LAS (′)	(8) LLS (Mpc)	(9) Notes [Refs.]
MACS J0257.6−2209 $^{(c)}$	44.412	−22.163	0.322	U		1.6	0.45	[16]
				cR	✓	1.4	0.39	SW of centre
MACS J0417.5−1154	64.394	−11.909	0.443	H $^{(\dagger)}$		4.9	1.68	[9, 31, 34]
				cR	✓	1.0	0.34	N of centre
				cR	✓	1.0	0.34	NW of centre
RXC J0510.7−0801	77.685	−8.020	0.220	cH $^{(\dagger)}$	✓	4.9	1.04	
				cR	✓	3.0	0.64	N of centre; possible WAT
RXC J0520.7−1328 $^{(d)}$	80.200	−13.502	0.336	cR		4.2	1.21	SE of centre; [29]
				U		7.1	2.05	SE of centre; bubble?; [29]
RXC J1314.4−2525	198.599	−25.256	0.244	H		4.7	1.08	[38, 48]
				R		4.7	1.08	W of centre; [38, 48]
				R		2.7	0.62	E of centre; [38, 48]
RXC J2351.0−1954	357.770	−19.913	0.248	cR		9.8	2.28	W of centre; [8]
				cR		5.5	1.28	E of centre; [8]
				cH	✓	4.0	0.93	[8]
J0027.3−5015	6.839	−50.251	0.145	cMH	✓	2.5	0.38	
J0145.0−5300	26.260	−53.014	0.117	H	✓	4.9	0.62	
J0145.2−6033	26.320	−60.565	0.181	cMH	✓	1.9	0.35	
J0216.3−4816	34.080	−48.273	0.163	cMH	✓	1.4	0.24	
J0217.2−5244	34.303	−52.747	0.343	cR	✓	1.5	0.44	N of centre
J0225.9−4154	36.478	−41.910	0.220	H	✓	2.4	0.51	
J0232.2−4420	38.070	−44.348	0.284	H		5.8	1.49	[25]
				cR	✓	3.3	0.85	S of centre
				cR	✓	1.8	0.46	E of centre
J0303.7−7752	45.943	−77.869	0.274	H	✓	3.8	0.95	
J0314.3−4525	48.583	−45.424	0.072	cMH	✓	2.4	0.20	
J0342.8−5338	55.725	−53.635	0.060	MH $^{(\dagger)}$	✓	5.2	0.36	
J0351.1−8212	57.787	−82.217	0.061	U	✓			See Sect. 6.2.2
J0352.4−7401	58.123	−74.031	0.127	R	✓	15.6	2.13	SE of centre
				H	✓	10.7	1.46	
				cR	✓	6.8	0.93	NW of centre
				R	✓	3.9	0.53	NNW of centre
				R	✓	5.0	0.68	N of centre
J0431.4−6126	67.850	−61.444	0.059	R	✓	9.7	0.66	SE of centre
				U	✓			Confused tail
J0510.2−4519	77.558	−45.321	0.200	cMH	✓	1.3	0.26	
J0516.6−5430	79.158	−54.514	0.295	H	✓	5.7	1.51	
				R	✓	5.7	1.51	N of centre
				cR	✓	2.3	0.61	S of centre
J0528.9−3927	82.235	−39.463	0.284	H		4.0	1.06	[46]
J0627.2−5428	96.810	−54.470	0.051	R	✓	5.4	0.32	W of centre
J0631.3−5610	97.836	−56.172	0.054	cR	✓	7.7	0.49	W of centre
J0637.3−4828	99.329	−48.478	0.203	U	✓	7.6	1.52	
				cR	✓	2.0	0.40	NW of centre
J0638.7−5358	99.694	−53.972	0.227	H $^{(\dagger)}$		6.4	1.40	[43]
J0645.4−5413	101.372	−54.219	0.164	H	✓	7.7	1.30	
				R	✓	3.5	0.59	SW of centre
J0745.1−5404	116.290	−54.079	0.074	U	✓	4.2	0.35	S of centre
J0820.9−5704	125.248	−57.080	0.061	U	✓			S of centre
J1130.0−4213	172.523	−42.230	0.155	cR	✓	2.1	0.34	NE of centre
J1423.7−5412	215.930	−54.203	0.300	U	✓			N of centre
J1539.5−8335	234.891	−83.592	0.073	MH	✓	2.8	0.23	
				cR	✓	2.2	0.18	W of centre
J1601.7−7544	240.445	−75.746	0.153	H	✓	5.9	0.94	
J1840.6−7709	280.155	−77.156	0.019	cMH	✓	2.5	0.06	
J2023.4−5535	305.852	−55.592	0.232	H		4.7	1.04	[47]
				R		2.9	0.64	[47]

angular size of 5.6′ (~370 kpc). This structure has not been detected in any of the low resolution radio data available in the literature at other frequencies (see Duchesne et al. 2021a, and references therein), possibly due to its low surface brightness (~1.1 μJy arcsec^{-2} in the diffuse emission filtered 25″ resolution image) and its proximity to the 27 mJy BCG and 13 mJy tailed source. Given its size and location in a cool-core system, we classify this new detection as a mini-halo. We note, however, that