Astrophysics Group

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Feedback and active nuclei in brightest cluster galaxies

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Mergers of elliptical galaxies are likely to create supermassive black hole binaries, with the most promising sites being the giant elliptical galaxies at the centers of clusters of galaxies. We have studied the brightest cluster galaxies (BCGs) in Abell 85 and 1775 in the radio with the JVLA, in the optical, and in the X-ray with Chandra to investigate whether the large cores of these BCGs are caused by supermassive binaries. We also describe what the configurations of the central radio sources reveal about feedback in these two prominent X-ray clusters.

The optical cores of some luminous elliptical galaxies appear unusually large relative to the overall galaxy size. This has been attributed to the dynamical effect of a central supermassive black hole binary (SBHB) scouring stars from its neighborhood and pumping them to larger galactocentric distances (Faber *et al.* 1997; Merritt 2006). Such SBHB may arise from mergers of giant galaxies at the centers of clusters.

We have shown that a particularly large such core is present in the BCG of Abell 85 (Holm 15a; López-Cruz *et al.*, 2014), and a second such large core has been suggested in the BCG of Abell 1775 (VV 195b). Both galaxies have unusually large cores (Fig. 1), and their host clusters have been well mapped in the X-ray by *Chandra.*

We investigated these two cores with high-resolution JVLA data to search for double central AGN in their known central radio structures, with *Chandra* to look at the central gas structure, and with ground-based optical imaging to look at the central isophotal structure and to allow astrometric comparisons to check for offsets.

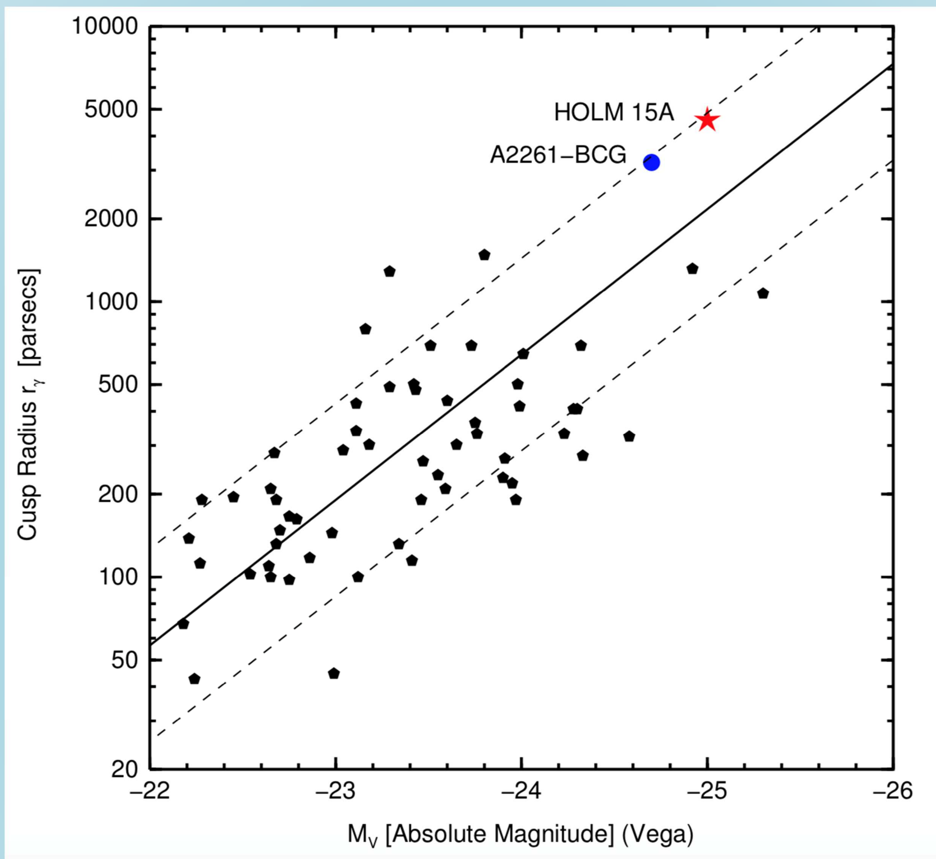

Figure 1. Cusp scale vs absolute V-band magnitude for core BCGs from Lauer et al. (2007), with the BGCs in Abell 2261 and Abell 85 (alias Holm 15a) marked. Holm 15a has the largest measured break radius, suggesting that the core has been expanded by the scouring effect of a central supermassive black hole binary, or some other dynamical heating. Figure from López-Cruz *et al.* (2014).

The scale of the cores of the BCGs that we studied were measured using the Nuker surface brightness law (Lauer *et al.* 1995), where r_γ is the "cusp radius", related to the break radius r_b discussed by Lauer *et al.*, but found to be better correlated with other galaxy properties by Carollo *et al.* (1997) and Lauer *et al.* (2007).

The cores of the BCGs in Abell 85 and Abell 1775 are both significant radio sources, perhaps as a result of recent episodes of feedback into the intracluster gas, but no significant star formation has been identified in either case at a level that could distort the light profile.

Confirmation of the extreme (but contested) nature of the large core in Holm 15a was provided by Mehrgan *et al.* (2019), who provided a new mass estimate of 2×10^{10} $M_\odot$ for the SMBH, consistent with the original estimate of López-Cruz *et al.* (2014).

The radio structures

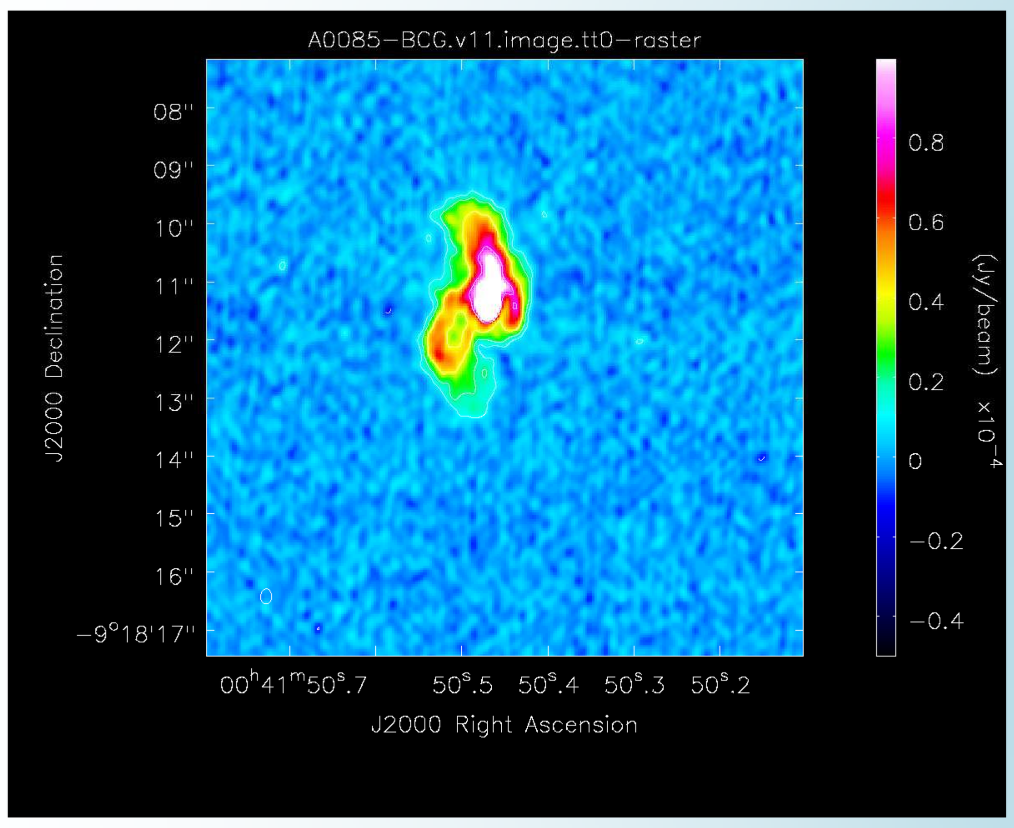

Figure 2: X-band (8 – 12 GHz) JVLA image of the core of Abell 85, showing the radio source in Holm 15a, its BCG. Only a single radio core is seen, but the extended structure has an exceptionally steep radio spectrum and a prominent loop to the S. At the redshift of Abell 85, 1 arcsec corresponds to a linear scale of 1.05 kpc.

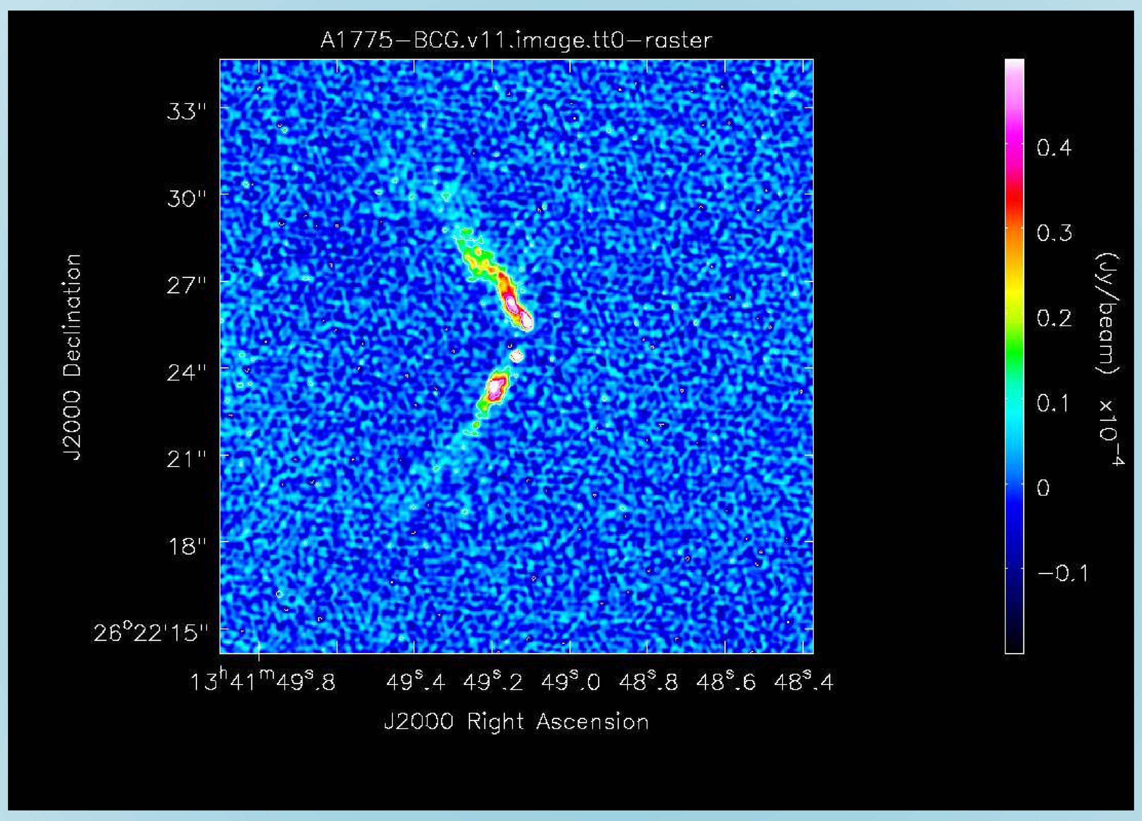

Figure 3: X-band JVLA image of the core of Abell 1775, showing the radio source associated with its BCG. Unlike the case of Abell 85, the BCG here shows a more typical FR I morphology, with double-sided radio jets emerging from a single core. At the redshift of Abell 1775, 1 arcsec corresponds to a linear scale of 1.35 kpc.

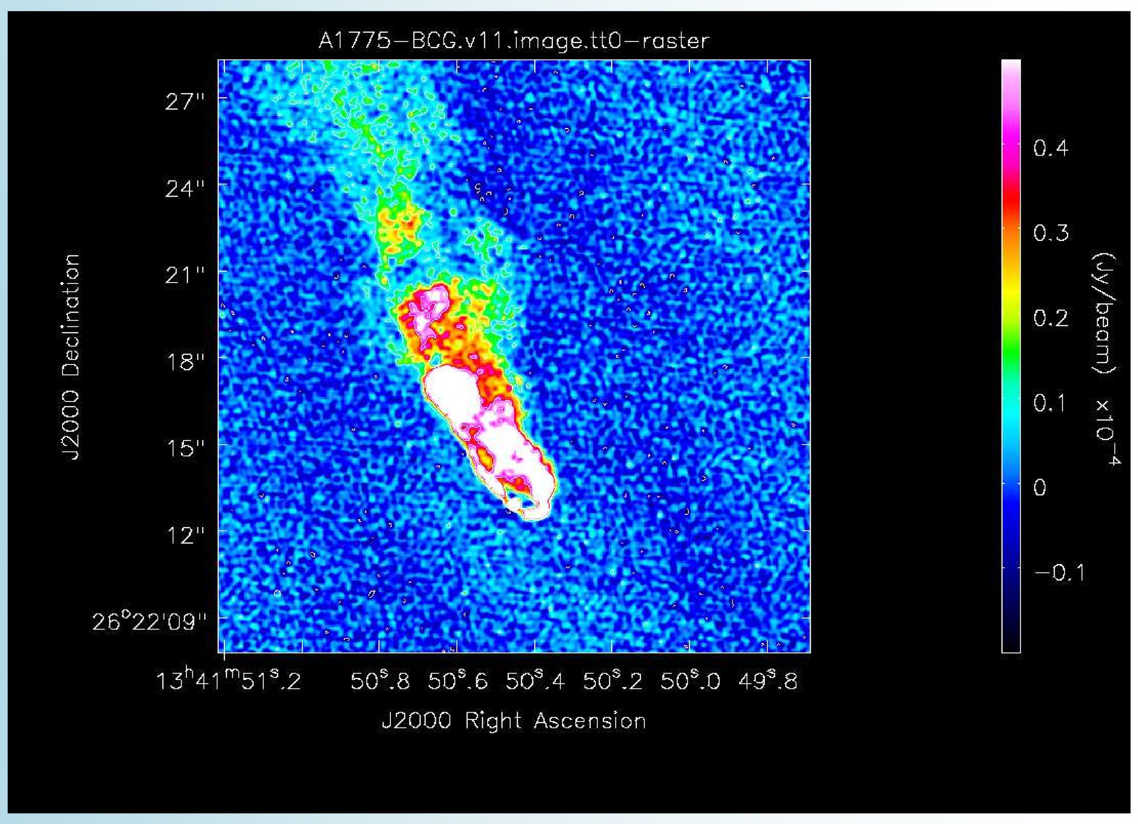

Figure 4: X-band JVLA image of a second bright radio galaxy in Abell 1775. Its radio core is 21 arcsec (28 kpc in projection) from the BCG's radio core and lies near the SE tip of the radio structure. Two bright jets emerge from the core and the SW jet is bent back on a scale of about 1 kpc to enter the long plume and tail.

Interpretation

The structures of the radio sources at the centres of the two BCG are shown in Fig. 2 and Fig. 3. Neither image shows a double radio core. Holm 15a in Abell 85 (Fig. 2) shows a dominant central core with a peculiar loop-like structure to the SE and a bar-like structure to the NW. The BCG of Abell 1775 shows a typical low-power, two-sided, radio jet of the wide-angle tail variety, as often seen in the BCGs of X-ray bright clusters.

Abell 1775 also hosts another prominent radio source (Fig. 4), which is a highly distorted radio trail source, so that its host galaxy, the second brightest in the cluster, is moving at high speed relative to the intracluster medium, and so suggesting that a large group has recently fallen into the cluster.

There are a number of peculiarities of the non-thermal structures in Holm 15a.

(1) The radio and optical centres are offset by 0.19 arcsec (200 pc), highly significant given the astrometric accuracy of the images; Chandra finds no AGN at the core, and the radio activity has created no detectable cavities - perhaps because of limited contrast.
(2) The radio spectrum of the radio core is normal, but that of the extended emission is very steep (spectral index > 1). The emission is unpolarised.
(3) The morphology of the radio structure is unusual, in displaying the loop to the SE.

It is possible that the unusual structure of Holm 15a relates to motion of the radio core around a second SMBH located at the mass centre of the galaxy, but if so that second object is radio quiet (< 20 μJy at 10 GHz) since no further compact core has been detected. An orbital period of about 1 Myr, consistent with the expected orbital period of an SBHB on the scale of the central offset and total mass as given by Mehrgan *et al.*, could create radio distortions on the scale of the loop and maintain the structure over multiple orbits.

Table 1: Selected BCGs

Priority	Abell number	Redshift	S_X mJy	size arcsec	dataset
1	85	0.0553	6.5	5.0	AR286
2	1775	0.0717	< 2.0	—	AB611

Table 1. Data for the two cluster BCGs in our study, with the best pre-existing VLA results as indicated. No radio detection at X band (8 GHz) was available from the AB611 observation. Little structure could be seen in the radio image of the BCG of Abell 85 from AR286.

References

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