The evolution of radio galaxies in Coma Cluster progenitors

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Abstract

Evolutionary studies of cluster radio galaxies provide a snapshot of AGN activity, which can affect the thermal history of the ICM. Guided by cosmological simulations, we select 22 clusters between $0.2<z<1.2$ that are predicted to end with X-ray properties similar to the Coma Cluster, a prototypical massive cluster in the present epoch. We use new and archival VLA L-band radio maps to identify cluster radio galaxies at $P_{20cm}>5\times10^{23}$ W Hz^{-1}. Contrary to previous studies, we find significant evolution of the radio luminosity function (RLF) of cluster radio galaxies with higher-power radio galaxies situated in lower-temperature clusters at earlier epochs. Our results suggest a 9-10 fold increase in the heat injected into high-z clusters by AGN compared to the present epoch.

Figure 1 (below): Predicted ICM temperature versus redshift of Coma Cluster progenitors. The model curves display the results of hydro-dynamical simulations of galaxy clusters predicted to evolve to masses similar to the present-day Coma cluster. For each cluster halo, the ratio of T_z/T_0 is normalized to the current ICM temperature of the Coma Cluster. The solid line shows the median value for this distribution, while the dashed lines represent the 25th and 75th percentiles. Our sample selection chooses pre-cursors of current-epoch rich clusters instead of precursors of extreme mass/luminosity. Notice how MS1054-03 falls above the "Road to Coma". This cluster would evolve into a more massive cluster than present-day Coma.

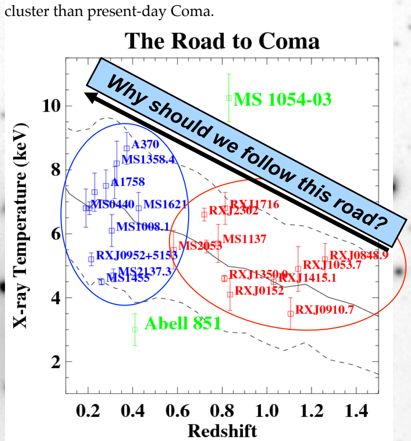


Figure 2: Histogram of radio galaxy powers in 21 clusters at $0.2<z<1.1$ (top panel) and of cluster BCGs only (bottom panel). The spread in the average radio powers for $z>0.4$ cluster radio galaxies suggest that some of them are more luminous than their low-z counterparts. The bottom panel shows some evidence that BCG radio sources have faded by about an order of magnitude from high-z to low-z. This is consistent with earlier results from samples that were selected differently (e.g., Harvanek et al. 2001).

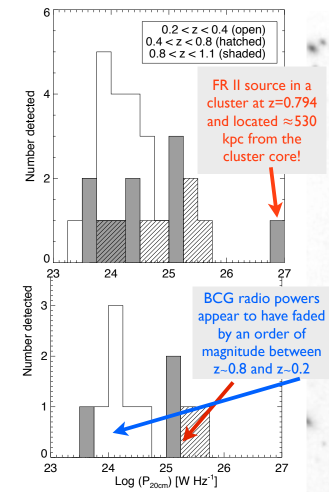


Figure 3 (right): The RLF of radio galaxies in Coma Cluster progenitors between $0.2<z<1.1$. The y-axis is the fraction of cluster red sequence (CRS) galaxies located within 1 Mpc of the cluster center that are detected as radio sources within the given radio power bin. In Coma Cluster progenitors the radio galaxy population at $\log(P_{1.4GHz})>25.0$ W Hz^{-1} evolves from $z\sim1.1$ to 0.2 with more powerful radio sources situated in less-massive clusters at earlier epochs (3.3σ significance).

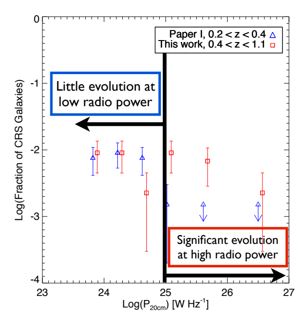
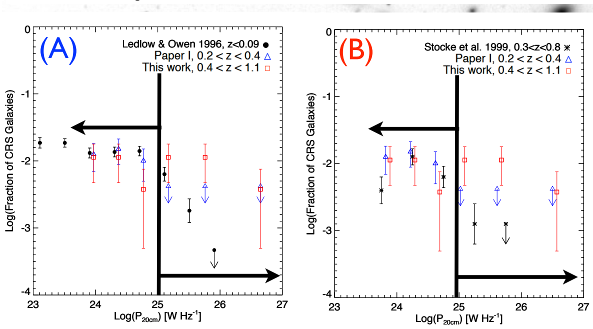


Figure 4 (below): (1) Panel A displays the RLF comparison between $z<0.09$ Abell cluster radio galaxies and our low-z and high-z cluster radio galaxies. Our low-z RLF is consistent with the radio galaxy populations in nearby Abell clusters (see Ledlow & Owen 1996). However, our high-z RLF ($z>0.4$) deviates from it at $\log(P_{1.4GHz})>25.0$ W Hz^{-1}. (2) Panel B displays the RLF comparison between $0.3<z<0.8$ EMSS radio galaxies and our cluster radio galaxy sample. Our low-z ($0.2<z<0.4$) RLF is consistent with cluster radio galaxies in the EMSS (Stocke et al. 1999). However, our high-z RLF deviates noticeably from the EMSS RLF at $\log(P_{1.4GHz})>25.0$ W Hz^{-1}, similar to our high-z radio source comparisons to the local Abell cluster radio sources. (Note: The y-axis is defined as the fraction of CRS galaxies located within 600 kpc of the cluster center.)



Conclusions

(1) The RLF for radio galaxies in Coma Cluster progenitors differs significantly at high-z (0.4<z<1.1) entirely at $\log(P_{20cm})\geq 25$ W Hz^{-1}.

We constructed optical color-magnitude diagrams to identify the cluster red sequence (CRS) and to calculate the number of $L\geq L^*$ CRS galaxies within 1 Mpc of the cluster core. The low-z and high-z RLFs of cluster radio sources as a function of CRS galaxies (i.e., passive galaxies) are consistent at $23.5 \leq \log(P_{20cm}) \leq 25$ W Hz^{-1}. However, a larger number of high-power radio galaxies at $\log(P_{20cm})>25$ W Hz^{-1} are situated in low X-ray temperature clusters at $z>0.4$. There is additional evidence that these cluster sources become more centrally concentrated compared to CRS galaxies over cosmic time (see Fig. 5 below).

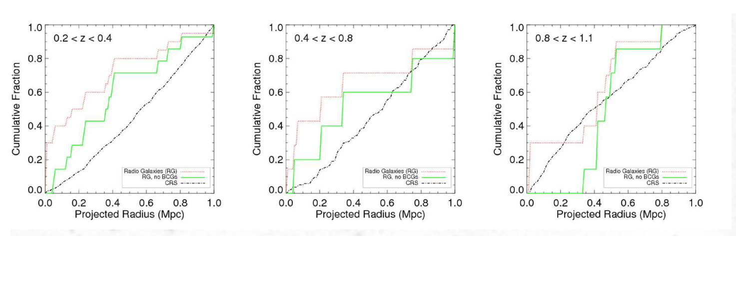
(2) Cluster sample selection does result in finding cluster AGN populations that differ.

The clear density and luminosity evolution of radio galaxies found in our sample of cluster AGN is quite different from the absence of evolution found by Stocke et al. (1999) using a flux-limited sample of EMSS clusters. We interpret this lack of agreement as support for our novel, physically-based method for selecting clusters for study, i.e., the "Road to Coma" concept. We suggest that Stocke et al. (1999) failed to find cluster AGN evolution because their high-z sample has very similar ICM properties to the low-z sample of Ledlow & Owen (1996), to which they compared AGN populations. Thus, the "no evolution" conclusion from Stocke et al. (1999) is consistent with our hypothesis that the RLF depends on the cluster sample selection.

(3) The increased number and luminosities of radio galaxies in high-z clusters suggest a substantial increase in the heat injected into the ICM at z>0.4 compared to the present epoch.

Using the recent scaling law between AGN jet power and radio luminosity suggested by Cavagnolo et al. (2010), $P_{jet} \propto L_r^{0.7}$, we determine that the excess power from luminous radio galaxies at $23<\log(P_{20cm})<27$ W Hz^{-1} is ≈26× higher in $0.4<z<1.1$ clusters than in $0.2<z<0.4$ clusters, which corresponds to 9–10 fold increase in the AGN jet power if FR II jets have similar kinetic energies to FR I jets. Therefore, a larger amount of heat can be deposited into the ICM at high-z.

Figure 5: The cumulative radial distribution of cluster radio galaxies within 1 Mpc of the cluster center as a function of redshift suggests that these sources become more centrally-concentrated with cosmic time.



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