Average AGN Heating Rate in Galaxy Clusters: Radio AGNs in 400 Square Degree Cluster Survey

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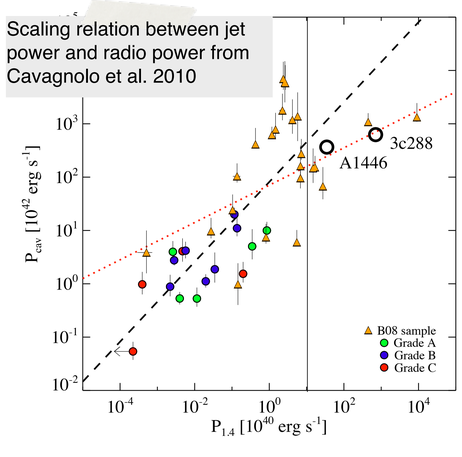
Abstract

We examine AGN heating in a carefully selected sample of distant X-ray clusters by cross correlating clusters selected from the 400 Square Degree X-ray Cluster survey with radio sources in the NRAO VLA Sky Survey. The jet power for each radio source was determined using scaling relations between radio power and cavity power determined for nearby clusters, groups, and galaxies with atmospheres containing X-ray cavities. We find no significant correlation between radio power, and therefore jet power, and the X-ray luminosities of clusters lying between redshifts 0.1 and 0.6. The incidence of radio AGN does not strongly correlate with the X-ray luminosity. The detection frequency of radio AGN in 400SD clusters in inconsistent with the presence of strong cooling flows. The average jet power of central radio AGN is approximately 2×10^{44} erg s^{-1}, while the average jet power may reach ~10^{45} erg s^{-1} when all (net) radio sources within 1Mpc of the clusters are included. The heating energy per particle is approximately 0.1-0.2 keV/particle from AGN within a 250 kpc radius, and 0.4-0.8 keV/particle within a 1Mpc radius. Assuming the current AGN heating rate is constant out to redshifts z=2, these figures are expected to increase by a factor of two. Therefore our results suggest that the integrated heating energy from radio AGN outbursts in clusters is significant, compared to the excess entropy found in the hot atmospheres of clusters that is needed to explain the breaking of self-similarity in cluster scaling relations. While it is unclear whether the AGN in 400SD clusters are maintained by a self-regulated feedback loop, they may play a significant role in preventing the development of strong cooling flows at early epochs.

Introduction

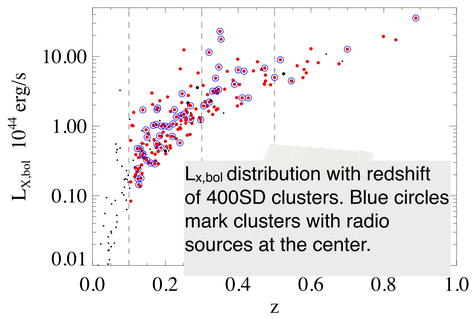
- The amount of released by AGN, on the order of 10^{62} $M_{BH}/[10^9 M_{sun}]$ erg s^{-1}, is more than enough to be the major heating source responsible for the two phenomena in clusters: cooling flow problem, and the deviation of L_X-T relation in the low mass end. Nevertheless, how and where the energy is distributed into the ICM remains an issue.
- A close correspondence between X-ray cavities and radio lobes argues that cavities are created when powerful jets from supermassive black holes in AGN inflate radio lobes, driving the hot ICM aside. The minimum energy required to create a cavity is its enthalpy, which has been used to estimate the energies injected by AGN into the ICM.



- A scaling relation between the power injected by the AGN and their 1.4GHz radio luminosity are found in e.g. Cavagnolo et al. 2010. The relation provides a practical way to estimate the jet powers without deep X-ray exposures.
- Using the scaling relation and the NRAO VLA Sky Survey data, we attempt to estimate the average AGN heating energy in "normal" clusters.

Data

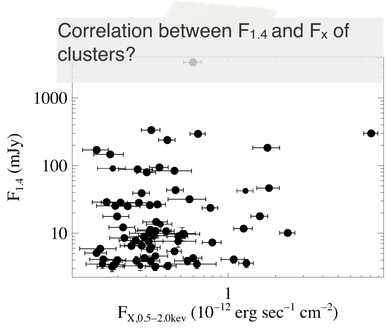
- We matched the coordinate of 196 clusters in 400 Square Degree survey with z>0.1 and covered by the NVSS survey with that of the NVSS sources.



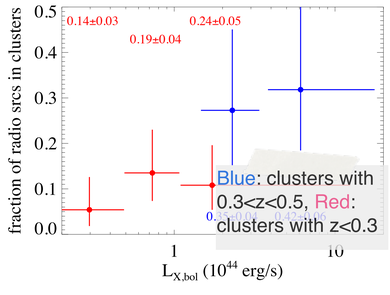
- 782 radio sources above a flux limit of 3mJy are located within 2Mpc of 166 clusters. Of these sources, 61 are located within a 250kpc radius of 56 clusters.
- Thus, roughly 30% of the 400SD clusters show radio emission within the central 250kpc that is presumably associated with the BCGs.

Results

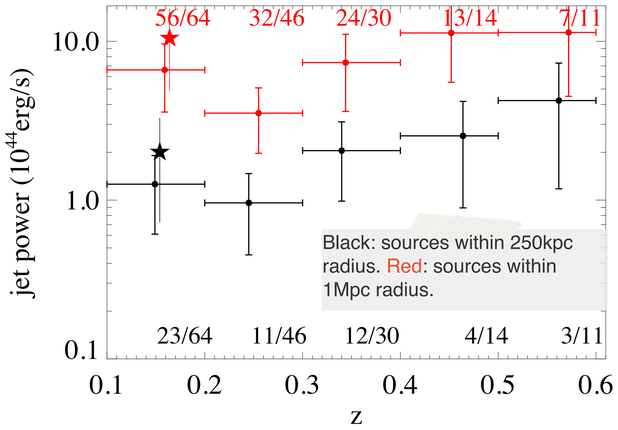
- We found no correlation between radio power and X-ray luminosity of the 400SD clusters.



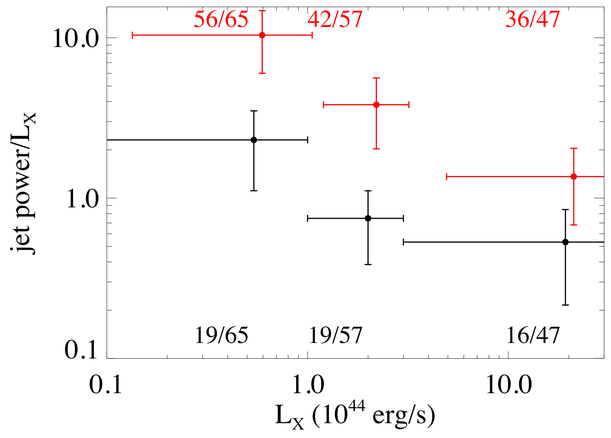
- We found no correlation between fraction of clusters with NVSS radio sources and X-ray luminosity of the 400SD clusters, either. Since the X-ray luminosity of a cluster correlates with its richness, this implies that richer clusters have fewer radio AGN per galaxy.
- We found only modest correlation between radio power and incidence of radio detection in 400SD clusters with redshift. Although it is difficult to completely rule out the bias in a flux-limited sample, our results are qualitatively consistent with redshift evolution of the radio AGN detection rate in clusters by e.g. Galametz et al. 2009.



- We have estimated the average jet power and the rate of AGN heating in clusters using the scaling relation. The average jet power is about 2×10^{44} erg s^{-1} for radio AGNs within 250 kpc radius of the 400SD clusters and about 10^{45} erg s^{-1} for sources within 1Mpc radius. We found that the average jet power and AGN heating rate do not correlate with total X-ray luminosity of the 400SD clusters. Therefore, the heating rate per particle will be larger in less massive systems.
- The AGN heating within the core of clusters can reach 0.2keV/particle for poor cluster with typical X-ray luminosities of 5×10^{43} erg s^{-1}. The AGN heating rate will



increase to 0.8keV/particle, if all radio sources within 1Mpc radius are considered. These numbers are calculated within the redshift range of our sample, i.e. 0.1<z<0.6. If we extrapolate the result to redshift z=2 ignoring the AGN evolution, the integrated AGN heating per particle will increase by a factor of 2.



Conclusion

If the heated gas is unable to cool quickly enough, the entropy of their hot atmospheres will rise above the values expected from gravitational heating alone. In fact, we found that the amount of AGN heating of the hot atmospheres is a significant fraction of the heating required to ``preheat" clusters (e.g. Wu et al. 2000). This so-called preheating phase is thought to occur during the epoch of galaxy formation at redshifts of 3 and beyond (Kaiser et al. 1991). Our results are consistent then with significant AGN heating of cluster atmospheres long after the epochs of galaxy and cluster formation, and throughout the formation history of clusters. Thus, the heating that apparently broke the self-similarity of cluster scaling relations appears to have occurred continuously, and not necessarily at a single epoch.

References:

Birzan et al. 2008, ApJ, 686, 859; Cavagnolo et al. 2010 ApJ, 720, 1066; Kaiser 1991, ApJ, 383, 104; McNamara et al. 2007, ARAA, 45, 117; Wu et al. 2000, MNRAS, 318, 889;