Average Heating Rate of Hot Atmospheres in Distant Clusters by Radio AGN: Evidence for Continuous AGN Heating

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We examine atmospheric heating by radio active galactic nuclei (AGN) in distant X-ray clusters by cross correlating clusters selected from the 400 Square Degree (400SD) X-ray Cluster survey with radio sources in the NRAO VLA Sky Survey. Roughly 30% of the clusters show radio emission above a flux threshold of 3 mJy within a projected radius of 250 kpc. The radio emission is presumably associated with the brightest cluster galaxy. The mechanical jet power for each radio source was determined using scaling relations between radio power and cavity (mechanical) power determined for nearby clusters, groups, and galaxies with hot atmospheres containing X-ray cavities. The average jet power of the central radio AGN is approximately 2×10^{44}\ergs. We find no significant correlation between radio power, hence mechanical jet power, and the X-ray luminosities of clusters in the redshift range 0.1 -- 0.6. This implies that the mechanical heating rate per particle is higher in lower mass, lower X-ray luminosity clusters. The jet power averaged over the sample corresponds to an atmospheric heating of approximately 0.2 keV per particle within R$_{500}$. Assuming the current AGN heating rate does not evolve but remains constant to redshifts of 2, the heating rate per particle would rise by a factor of two. We find that the energy injected from radio AGN contribute substantially to the excess entropy in hot atmospheres needed to break self-similarity in cluster scaling relations. The detection frequency of radio AGN is inconsistent with the presence of strong cooling flows in 400SD clusters, but does not exclude weak cooling flows. It is unclear whether central AGN in 400SD clusters are maintained by feedback at the base of a cooling flow. Atmospheric heating by radio AGN may retard the development of strong cooling flows at early epochs.

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