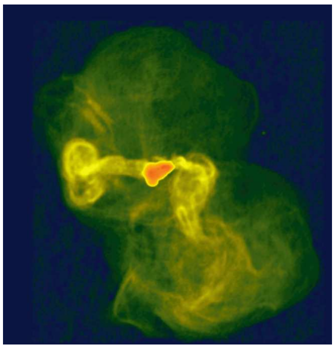

Radio Bubbles in Clusters: Relativistic Particle Content

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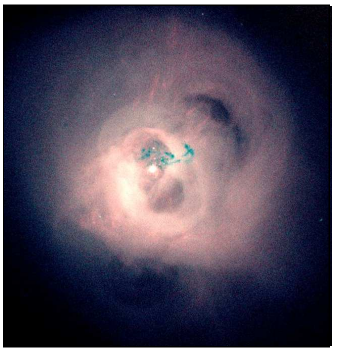

Introduction

As synchrotron radiation is observed from radio bubbles in clusters of galaxies, they contain magnetic fields and charged particles. Disentangling the pressure from each component is difficult; in the past equipartition (corresponding closely to the minimum energy condition) has been assumed. When the lobes are embedded in the thermal Intra-Cluster-Medium (ICM) the contribution from each component can be determined in the assumption of pressure balance.

Particle Content of Radio Bubbles

We determine k/f for a sample of radio bubbles, where k is the ratio of the total energy in particles to that in electrons emitting synchrotron radiation between $10\,\mathrm{MHz}$ to $10\,\mathrm{GHz}$ assuming that the bubbles are in pressure balance with the ICM, and f is the volume filling factor of the relativistic plasma. The ages of the bubbles are calculated assuming that they expand at the local sound speed, as no strong shocks are observed around the bubbles. If the bubble is completely filled by an electron-positron plasma emitting only between $10\,\mathrm{MHz}$ and $10\,\mathrm{GHz}$ then $k/f = 1$, however if the plasma is electron-proton then it is expected that $k/f \sim 2000$.

The ratio does not appear to depend on the physical parameters of the radio source or host cluster. It lies within the range $1 \lesssim k/f \lesssim 1000$, but there is no clear shape for the distribution.

The large spread in k/f maybe the result of a significant population of non-relativistic particles present in some of the bubbles. The variation of k/f, assuming $f \sim 1$, may be due to stochastic entrainment processes which may be highly dependent on the environment of the jet in the first few kpc around the radio source.

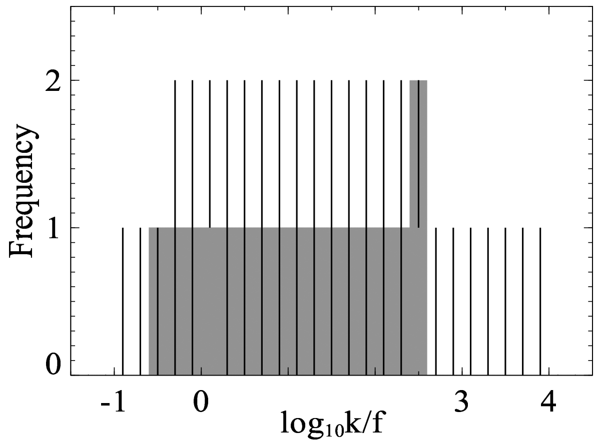

Fig. 1: The distribution of k/f shown by the grey bars. A Monte-Carlo algorithm has been used to estimate the errors on the bin values (vertical lines). This figure shows that there is a significant spread, but no clear choice for the underlying shape of the distribution.

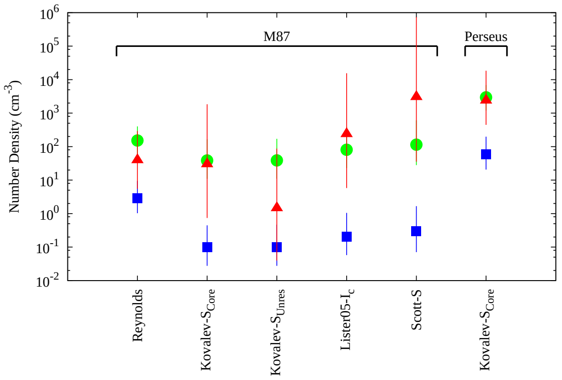

Fig. 2: The expected number densities for e^+e^- (Green circle) and e^-p^+ (Blue square) estimated from L_K. The minimum number density allowed from the Synchrotron emission from the jet base is shown as the Red triangle. All of the above measurements exclude e^-p^+ jets. For full details on the core fluxes see Dunn *et al.* (2006).

Jet Matter Content

We revisit the Synchrotron Self-Absorption (SSA) model from Reynolds *et al.* (1996) to place limits on how much of the material is intrinsic to the jet. Using the Synchrotron emission and absorption characteristics from the base of the jet we determine an upper limit on the magnetic field and a lower limit on the lepton number density present.

The bubble power, pV/t_bubble, is used as an estimator of the kinetic luminosity of the jet, L_K, assuming that all the jets' energy goes into creating the bubble. The kinetic luminosity of the jet depends on its matter content, and so predictions for the expected lepton number densities in the jet are derived for the two types of jet (e^+e^- and e^-p^+).

We have analysed M87 and the Perseus Cluster (Dunn et al., 2006). Most of the data analysed for M87 and Perseus are inconsistent with e^-p^+ jets. VLBI radio data for other clusters was of insufficient resolution to give meaningful limits on the jet matter content.

Conclusions

Radio bubbles must contain a significant fraction of non-relativistic particles to be in pressure balance with the ICM. The fraction varies between between $1 \sim 1000$ times the energy in particles inferred from the synchrotron emission alone.

The results on the jet matter content imply that the jets in M87 and Perseus are likely to be e^+e^-, and so these extra particles are not intrinsic to the jet, but may be entrained as it travels out through the ICM. The range in k/f implies that the process may be stochastic, depending on the initial environment of the jet.

For further details and full references see Dunn, R.J.H. and Fabian, A.C., 2004, MNRAS, **351**, 862; Dunn, R.J.H., Fabian, A.C., and Celotti, A, 2006, MNRAS, submitted and Dunn, R.J.H., Fabian, A.C., and Taylor, G.B., 2005, MNRAS, **364**. 1343