

OUTSTANDING QUESTIONS ABOUT MERGERS IN CLUSTERS OF GALAXIES

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Abstract

Based on the talks, posters, and discussions at this meeting, I list some important questions and lines of inquiry for the future study of the X-ray and radio connections in mergers in clusters of galaxies.

Questions

- 1) **Can we construct a rigorous quantitative definition of a “merging cluster”?** As the quality of the X-ray data improves, we need a better definition since most clusters show some evidence for the effects of mergers. It is unlikely that a simple bifurcation between merging and non-merging clusters is useful. We need a more continuous, quantitative measure or measures of the degree to which mergers affect the dynamics in each cluster. One simple example are the “power-ratios” developed by Buote.
- 2) **How is shock acceleration affected by the low Mach numbers in merger shocks?** Is the primary effect just the lower compression and steeper particle spectra predicted by kinematic theory? Or, is there a critical Mach number below which shock acceleration of electrons doesn’t occur?
- 3) **What is the source of the seed electrons for shock or turbulent acceleration in clusters?** Are they thermal, or low energy relativistic electrons from radio sources or previous mergers?
- 4) **Are cluster radio relic sources due to (re)acceleration of electrons by merger shocks? Or, are they produced by the compression of old radio sources (“radio ghosts”)?** How can we determine which is correct? One way would be to compare radio and X-ray images and spectra in detail. The X-ray images could show us the locations of the shocks. If the relics are due to shock acceleration, they should have sharper edges and flatter spectra on the shock side. Better radio images and spectral index maps are needed. In the X-ray, it is difficult to study the regions around relics as they are often in the outer parts of clusters where the X-ray surface brightness is very low.
- 5) **Are cluster radio halos due to turbulent acceleration? Since they are only present in merging clusters, does this mean that non-merging clusters have quiescent intracluster gas?** We can test this with ASTRO-E2 and other observations of turbulent motions in the the ICM.
- 6) **Why are radio halos and relics comparatively rare?** Are they really only found in merging clusters? Given the strong correlation between radio halo power and L_X or T_X for merging clusters, **is there a large population of fainter radio halos and relics?** Is so, they may be found with more sensitive searches with LOFAR, LWA, EVLA, and other instruments.
- 7) **Do all merging clusters have radio halos and/or relics?**
- 8) **How does fossil radio plasma from old radio sources get distributed in clusters?** Is it lifted buoyantly by radio bubbles? Does the fossil radio plasma mix with the thermal ICM, or does it remain in small or large discreet regions?
- 9) **How turbulent is the intracluster medium? Are merging clusters much more turbulent?** Hopefully, we will be able to measure turbulent velocities in the X-ray gas with ASTRO-E2.

- 10) **Which regions of clusters are turbulent?** Observations of cold fronts suggest the gas is laminar except in the wake.
- 11) Although the energy density in turbulence in clusters is probably smaller than the thermal energy density, **can turbulence heat the thermal ICM in some locations?** Is this heating important in cooling flows?
- 12) **What are the radio mini-halos in the centers of some clusters?** Are they related to cluster radio halos? Are they produced by particle acceleration in cooling flows, where they are often found? Or, are they simply due to some sort of leakage of relativistic electrons from the central radio sources in these cooling flows?
- 13) **What is the origin of the “sloshing features” seen in Chandra images of the central regions of many (particularly cooling flow) clusters of galaxies? Are they related to mergers?** Hydrodynamical simulations would be very useful to determine the origin and evolution of these sloshing features.
- 14) **A library of mergers from hydrodynamical simulations would be very useful.** Fairly complete suites of merger simulations, perhaps extracted from cosmological large scale structure simulation, are needed to study clusters.
- 15) Simple analytical techniques have been used to estimate kinematic parameters in simple merging clusters from X-ray observations. It is clear that more detailed hydrodynamical simulations are needed to study most cluster mergers. **Is there a simple way to find the relevant hydrodynamical model for an observed cluster?** We need an efficient technique to match simulations with the observations of a given cluster.
- 16) **Can we perform numerical simulations of cluster mergers with much better resolution and with more of the relevant physics (magnetic fields, cooling, turbulence, non-thermal particles, ...)?**
- 17) **Are the non-thermal particles in clusters dynamically important?** At present, I would say the answer is “probably not”, but we won’t really know until we can detect the relativistic protons in clusters.
- 18) **Are clusters of galaxies generally luminous γ -ray sources?** They are predicted to be by models for the relativistic particle populations in clusters. Will they be detected with AGILE and GLAST? Can TeV γ -rays be convincingly be detected with ground-based instruments like VERITAS? Will only merging clusters be detected (either at GeV or TeV energies)?
- 19) **What is the nature of the EUV/soft X-ray excesses observed toward clusters?** Are they real, and how commonly do they occur? Do they only occur in merging clusters? What is the spatial distribution of the soft excess? **In general, is the emission thermal or non-thermal?**
- 20) **What is the nature of the hard X-ray (HXR) excesses seen toward a few clusters with BeppoSAX and RXTE?** Are they real, and how commonly do they occur? Do they only occur in merging clusters? What is the spatial distribution of the soft excess? Better information of the hard X-ray excesses may come soon from observations with INTEGRAL, or eventually with future hard X-ray space missions. **Can we detect HXR excesses more easily in groups, where the thermal X-ray emission is softer?**
- 21) **What are the magnetic fields in clusters like?** Can we reconcile the low values of B found from the HXR with the larger values based on Faraday rotation? What is the spatial coherence length of the field? Is it really possible to characterize the magnetic field in any regions of a cluster by a typical value, or is there a (turbulent) spectrum with many values of B on different spatial scales? How do the properties of the field vary with radius in a cluster? How do magnetic fields vary with the merger state of the cluster?
- 22) **What is the source of cluster magnetic fields?** Are they generated from weak seed fields during cluster mergers and formation? Do they come from galaxies (probably not)? Are they amplified or produced by plasma instabilities?
- 23) **How do mergers disrupt cooling flows in cluster cores?** What is the detailed physical mechanism (or mechanisms)? How large a merger is required? How long does the disruption last?
- 24) **What, if anything, is the connection between mergers and the life cycles of cluster-core radio sources?**
- 25) **How do mergers affect the Sunyaev-Zeldovich (SZ) effect?** How are cosmological conclusions based on SZ measurements affected?
- 26) **Can we use SZ images to study outer merger shocks and accretion shocks in clusters, and determine the pressure variations due to mergers?** Since the SZ effect depends on pressure (and thus only linearly on

density), in principle SZ measurements could be more sensitive probes of shocks in the outer parts of clusters, particularly in regions where radio relics are found.

27) **Do mergers significantly increase the cross-section for strong lensing in clusters?**

28) **What are the correct rates for transport processes in clusters?** What is the correct value of the thermal conductivity? What is the correct value of the viscosity? How are transport processes affected by magnetic fields?

29) **Are clusters the (or an important or a) source of very high energy cosmic rays?**

30) **Can we extend the study of the thermal and non-thermal processes in clusters of galaxies to super-cluster, filaments, and also to groups of galaxies?**

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