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Accretion Shocks in Clusters of Galaxies and their SZ Signature From Cosmological Simulations

This paper examines the nature of accretion shocks in galaxy clusters first by using a simulation that "utilize[s] a discrete sample of well-resolved individual clusters"[1] and then by determining "the detectability of accretion shocks near the virial radius through the Sunyaev-Zel'dovich (SZ) effect."[2,3]

The simulation used a sample of ten galaxy clusters taken from AMR[4] simulations all located at z=0. To observe the accretion shocks in a physically meaningful way, spherical coordinates centered on the center of mass of the system were used. Shocks are identified by regions of large compression, as indicated by the large peaks in the bottom graphs of figure 2. So as not to waste resolution on areas where accretion shocks are either unlikely or likely to be incoherent, the authors took two measures to target their resolution. First, they removed pixels in the direction of filaments or sheets that represent overdense regions, since coherent accretion shocks are expected in lower-density diffuse gas. Second, since coherent accretion shocks rely on the gas falling nearly radially, in regions not already depixelated due to filamentary nature, pixels are selected so that –$V_{rad}/V \geq .85$.

The authors discovered that consistently, two shocks form in these galaxy clusters. The first of these shocks is an external shock, typically located around 3 R_{vir} and it consists of low-density diffuse gas freefalling into the cluster and slamming into a wall of dense material, resulting in a shock. The mach numbers for these shocks were initially thought to be on the order of 10^3-10^4, though as the authors point out UV background photons will heat the pre-shock gas, raising its mach speed which lowers these mach numbers. Nevertheless these shocks are easily recognized by pixels with mach numbers above 10. The second shock occurred at approximately 1.1 R_{vir} and as such is labeled the internal shock, because it takes place within the gas that has already been shocked by the initial external shock. These shocks typically have a much lower mach number (~3).

[1] 3
[2] ibid.
[3] The Sunyaev-Zel'dovich effect (often abbreviated as the SZ effect) is the result of high energy electrons distorting the cosmic microwave background radiation (CMB) through inverse Compton scattering, in which some of the energy of the electrons is transferred to the low energy CMB photons. (Wikipedia)
[4] Adaptive mesh refinement

The authors also ran a simulation using a sample of ten galaxy clusters from SPH simulations[5] (also located at z=0). In SPH the particles are treated as preheated to a temperature of 2keV, and using a dark matter simulation in a 366Mpc box to identify regions of cluster formation the simulation is further resolved to focus on these areas of clustering. Similar methods to the AMR simulation are used in shock identification, and this time internal/virial shocks are found at ~2.7 R_{vir}. Unlike the AMR simulation, however, this time the virial shock is the only shock observed. It is still called the virial shock, in spite of its being the only shock, because the shock converts kinetic energy to thermal energy to stabilize the system. At larger radii where external shocks would be expected, the SPH simulation's resolution is too poor to resolve any shock, and so this simulation does not analyze these shocks.

The primary purpose of the paper, the authors remind us, is to show that these predicted accretion shocks should be observable by *ALMA* due to the SZ effect. The SZ is the chosen indicative effect because it varies with density as opposed to density to some higher power, and therefore we see a less precipitous drop with radius. Using the gas models and temperature profiles, a signal-to-noise ratio (S/N)[6] was calculated to detect shocks near R_{vir}. Virial shocks are focused on, again, because the external shocks are located at radii for which *ALMA* would not be able to resolve a shock given the low SZ brightness. How much a shock affects SZ brightness depends largely on what proportion of the cluster's surface area is covered by shock, and this percentage depends on the angle at which we are viewing the cluster with respect to the plane containing the most filaments (referred to as the active filament plane). To minimize the effect of filament contamination, one can choose to view the cluster edge-on with the active filament plane[7]. Analyzing

[5] Smoothed particle hydrodynamics
[6] The difference in predicted surface brightness near the location of the shock, in the presence and absence of a strong discontinuity in gas pressure, divided by the instrumental noise.
[7] Edge-on approximately 50% of the surface area of a cluster is covered by shock. A non-optimized cluster is much lower, closer to 10%.

an edge-on cluster, the S/N ratio that indicates shock presence is given by $N_{pix1}^{1/2}(S/N)_1$, where N_{pix} is the number of independent pixels and $(S/N)_1$ is the S/N for one pixel. Other factors exist such as CMB lensing and thermal SZ contamination from unresolved clusters that may reduce significance, but the authors conclude that given the ratios required to recognize shocks, *ALMA* should be capable of resolving shocks with mosaic observations at R_{vir} if the cluster is sufficiently bright.