



PIC simulations of collisionless shock waves in clusters of galaxies

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Shock waves form during the hierarchical formation of the large-scale structure of the universe including clusters of galaxies. The gas in the intracluster medium (ICM) is in the form of hot tenuous plasma, and thus shocks in galaxy clusters are collisionless as in other astrophysical environments. The shocks induced as a consequence of major mergers in merging clusters are energetic enough to be observed in X-ray as well as in radio. Diffuse radio sources known as radio relics are explained by synchrotron-emitting electrons accelerated at the shocks, indicating vigorous acceleration of cosmic-rays (CR) electrons. Yet, the lack of observation of pion⁰ decay gamma-ray, produced by inelastic collisions of CR protons with ICM thermal protons, hints very little acceleration of CR protons at cluster shocks. As an effort

to comprehend this issue, we recently performed PIC (particle-in-cell) simulations for collisionless shock waves with parameters relevant to the galaxy cluster environment. In this talk, we present the results of these simulations along with implications for the observations of galaxy clusters.

References

Diffusive Shock Acceleration Simulations of Radio Relics, Kang, H., Ryu, D. & Jones, T. W. 2012, *The Astrophysical Journal*, 756, 97 (11pp).
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