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Effects of cosmological infall of galaxies: its discovery, plasma physical implications, and verification with ASTRO-H

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Clusters of galaxies are a system consisting of hundreds of galaxies that are gravitationally bound together. About 10% of the mass of each cluster is in the form of X-ray emitting hot plasmas, called Intra-Cluster Medium (ICM), that constitute the most dominant form of known baryonic components in the universe. The ICM is tenuous, hot, and magnetized, and is hence considered as the most ideal classical plasma ever known.

At central regions of many clusters, the ICM was considered to cool over the Hubble time by emitting X-rays, and lose its pressure. Then, the ICM would flow from outer to inner regions, and enhance the radiative cooling by raising the density. This catastrophy, called cooling flows, were long thought to be actually taking place, as X-ray observations kept discovering its evidence.(3) the energy is then transported to the cool ICM phase via Alfven waves and reconnection, (4) the two ICM phases are kept thermally stable by a mechanism known in Solar corona; and (5) the moving galaxies will gradually fall to the potential center as they transfer their dynamical energies to the ICM (Makishima et al., Publ. Astro. Soc. J. 53, 401, 2001). We have been striving to observationally enhance this novel scenario.

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Through observations of clusters of galaxies with the 4th Japanese X-ray satellite ASCA launched in 1993, we found that the cooling flows are not taking place anywhere, even though the ICM ubiquitously shows mild temperature decrease towards the cluster center: there must be some unknown plasma heating source. We have hence proposed a novel plasma physical scenario; (1) the central galaxy has a magnetosphere, where the cooler plasma is confined and insulated from the surrounding hot ICM; (2) other galaxies, all moving in the cluster space, will receive resistance from the ICM and excite MHD turbulence therein; (3) the energy is then transported to the cool ICM phase via Alfven waves and reconnection, (4) the two ICM phases are kept thermally stable by a mechanism known in Solar corona; and (5) the moving galaxies will gradually fall to the potential center as they transfer their dynamical energies to the ICM (Makishima et al., Publ. Astro. Soc. J. 53, 401, 2001). We have been striving to observationally enhance this novel scenario.

Recently, we have obtained crucial evidence supporting (5). That is, we studied 34 clusters with various redshifts (0.1-0.9) with X-ray and optical wavelength. Then, galaxies in nearby clusters were confirmed to be much concentrated than the ICM, while these two components are nearly co-spatial at distant clusters (Gu et al., Astrophys. J. 767, id 157, 2013). That is, galaxies in each luster have been falling, on the Hubble time scale, to the center. This result not only provides the long-sought heating mechanism of the ICM and strengthen our hypothetical view, but means the discovery of a very large energy flow that has not been known. Furthermore, it can explain many other puzzles with clusters of galaxies.

We are now developing, under an extensive international collaboration, the innovative X-ray satellite ASTRO-H, to be launched in 2015. With ASTRO-H, we will be able to detect X-ray Doppler effects which is caused when moving galaxies drag the ICM around them, and study possible particle acceleration phenomena as a consequence of energy loss by galaxies.

Keywords: galaxies and their clusters, intra-cluster medium, X-ray emission, magnetoplasma effects, ASTRO-H satellite