5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Evolution of galaxies driven by the Intra-Cluster plasma

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Among a variety of cosmic baryon components known to date, the most dominant one is Intra-Cluster Medium (ICM), i.e., X-ray emitting hot (T_e=$10^{7\text{-}8}$ K) and tenuous (n_e=$10^{2\text{-}4}$ m^{-3}) plasmas [1] associated with individual clusters of galaxies (CLGs). A CLG is a huge bound astronomical system, wherein a deep gravitational potential produced by Dark Matter (DM) confines the ICM, as well as $10^{2\text{-}3}$ galaxies. The galaxies move with typical velocities of ~10^3 km/s, which are transonic with respect to the ICM, and are comparable to the Virial velocity of the gravitational potential.

So far, it has been widely believed that the motion of galaxies within each CLG is governed solely by gravity, and hence the dynamical energy of each moving galaxy is approximately conserved. At the same time, the ICM was thought to cool, on cosmological time scales, by emitting the X-rays and gradually flow towards the center, thus producing so-called Cooling Flows [2]. In short, the two baryonic components, galaxies and ICM, were believed to evolve independently.

Through decades of X-ray observations, we have however confirmed that these two baryonic components in reality interact significantly with each other [3]. This is evidenced by the following facts, which have mostly been derived through imaging X-ray spectroscopy.

(1) In nearby (present-day) CLGs, it is widely known that galaxies are more concentrated, whereas the ICM is more extended, compared to the DM distribution.

(2) Galaxies have been found to fall towards the bottom of their CLGs on cosmological times scales [4,5].

(3) The theoretically predicted Cooling Flows have been found nowhere; by some unknown mechanisms, the ICM is heated against the radiative cooling [3,6].

(4) At core regions of many CLGs, hot and cool ICM components are seen to co-exist, typically keeping a factor of ~2 temperature difference [6,7,8].

(5) Heavy elements were found to distribute in the ICM very uniformly, and are more extended than the galaxies that must have supplied them [9].

(6) The ICM turbulence has been measured to be rather mild, with a velocity dispersion several times lower than the sound speed in the ICM [10,3].

The above facts altogether indicate that the galaxies, as they move through the ICM, eject heavy elements, and interact strongly with the ICM. As a result, the galaxies' dynamical energies are gradually transferred to the ICM. This on one hand suppresses the Cooling Flows in the ICM, and on the other hand causes the galaxies to fall towards the bottom of the potential [3]. The cooler plasma in the CLG core region is not the cooling portion of the ICM, but can be interpreted as a plasma confined in the magnetosphere of the central giant galaxy [3,6].

Our novel discovery is expected to provide paradigm shifts in several astronomical researches, including in particular the cosmological evolution of galaxies. There, a long-unsolved issue is so-called *environmental effects*; the fraction of spiral galaxies in a CLG decreases from higher to lower redshifts, and from the periphery to the center of each systen. Although this effect has so far been investigated mostly *by ignoring the presence of the ICM*, a natural and comprehensive explanation can be deduced by properly taking into account the galaxy-ICM interaction. That is; (i) The ram pressure of the inflowing ICM will remove gas from spiral galaxies and suppress their star formation. (ii) A spiral galaxies will launch helical Alfven waves, and dump its angular momentum onto the ICM, so as to change into an elliptical galaxy. (iii) When a pair of spiral galaxies are orbiting around each other, the drag force exerted to them from the ICM will accelerate their merger into a single elliptical. (iv) The drag force will also cause gas-rich spirals to fall to the center, where the increased galaxy number density will accelerate their mergers into elliptical galaxies. These predictions will be verified in near future through X-ray observations with enhanced spectroscopic capabilities.

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