X-ray observation of shocks within the plasma in clusters of galaxies

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Abstract

A cluster of galaxies hosts up to thousands of galaxies trapped in a dark matter halo with a size of Mpc and total mass reaching $10^{14\text{-}15}$ times Solar mass. In its gravitational well, a large amount of plasma heated up to a temperature of several keV is trapped and emits X-rays via thermal process. With the evolution of large-scale structure of Universe, clusters of galaxies grow up by attracting one another and merging together. In these events, shocks with low Mach numbers (M~1-5) are produced in the plasma, and convert the huge gravitational energy into plasma thermal energy, and non-thermal energies such as particle acceleration and magnetic field amplification.

With recent X-ray observations, we found that the cluster candidate catalogued as CIZA J1358.9-4750, which has been poorly studied because of its location near the Galactic plane, is a textbook-case of a merging together pair, exhibiting various plasma physical phenomena activated by low-Mach-number shocks. This object consists of two X-ray clusters of galaxies separated by 1.2 Mpc. The two X-ray peaks are connected by an X-ray bright region, which can be a signature of their interaction. We analyzed the X-ray surface brightness with Chandra, which has superior spatial resolution, and discovered for the first time a pair of parallel brightness jumps that run perpendicular to the axis connecting the two clusters. We also studied the temperature distribution of this system, with the Japanese X-ray satellite Suzaku which has high spectroscopy performance. Then, the two closer cores were observed to have a temperature of 4.6±0.2 keV and 5.6±0.2 keV, whereas the region between the two Chandra-detected jumps to have a significantly higher temperature of 9.2±1.6 keV. The positional coincidence between the brightness jumps and the temperature increase allows us to interpret these structures as a pair of shocks propagating in the opposite direction. Since the shock fronts are vertical to the merging axis, the two clusters are suggested to have similar masses, and are in the course of an almost head-on collision. Compared to previously known shocks in merging clusters, the shocks we discovered are located in a region with a higher plasma density, and hence have a much higher brightness. As a result, we were able to derive the Mach number accurately as M=1.3±0.2, from the temperature transition and the Rankine-Hugoniot equations. From this Mach number, together with the sound velocity estimated from the unshocked temperature and symmetry assumption, the shocks propagation velocity is calculated to be 1200 km/s each. Further considering the separation between the two shocks, we conclude that they were formed only 70 Myr ago, which is very young compared to the cluster merging timescale (several Gyr). In contrast, assuming only the Coulomb scattering, the proton-to-electron heat transfer is calculated to take place on a much longer time scale of τ_c=210 Myr. Therefore, the electron heating is suggested to be taking place ~3 times faster than in the classical view.