Hitomi observation of the Perseus cluster – temperature and elemental abundances –

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Abstract

The X-ray emitting hot intracluster medium (ICM) dominates the baryonic mass in clusters of galaxies, and hence the dynamics and physics of the ICM is crucial to understand the formation and evolution of the galaxies and clusters. Several clusters have dense cores (the so-called "cool cores") in which the radiative cooling time of the ICM is shorter than the age of the universe. However, the observed temperature at the core region is higher than expected, and moreover the star formation rate of the central galaxy is an order of magnitude lower than that estimated from the cooling rate. Therefore a heating mechanism is required to suppress the cooling of the central dense ICM. Several heating sources are proposed but further observations are necessary to constrain its origin. The metallicity of the ICM is also important because it stores the metals ever ejected from cluster galaxies. Measurements of metal abundances in the ICM provides a unique insight into the average star formation history in galaxies.

The Japan's sixth X-ray astronomy mission, Hitomi (formerly ASTRO-H), was launched on 17th February 2016. The non-dispersive Soft X-ray Spectrometer (SXS) on board Hitomi achieves spectral resolution of $E/\Delta E \sim 1200$ at 6 keV in orbits, which is about 30 times higher than that of X-ray CCDs. It provides the first opportunity to determine precise ionization sate, metal abundances, and turbulence velocity of the ICM utilizing emission line diagnostics. Even though the operation of Hitomi was discontinued on April 2016 because of the attitude anomaly, Hitomi observed the Perseus cluster for about 300 ks during its commissioning phase.

We obtained an excellent spectrum of the ICM in the 2.0-20 keV band (limited energy range is due to the closed gate valve in the commissioning phase). The He-like Fe Kα complex and the He-like Ni Kα lines nearby the He-like Fe Kβ lines are successfully resolved. The weak emission lines from He-like Cr and Mn are also clearly detected. The spectrum is almost represented by a single thin-thermal plasma model with the temperature of $\sim$4 keV. However, the ionization temperatures of Si, S, Ar, Ca, and Fe derived from detailed line diagnostics deviates from a single temperature assumption, and therefore multi-temperature or non-ionization equilibrium of the ICM is suggested. Indeed a two-temperature plasma model gives a better fit to the data. The precise plasma temperatures are under investigation because systematic effects due to the central AGN emission and the calibration uncertainty are not fully understood yet.

We also measured the abundance ratios of major elements to Fe assuming the single temperature plasma model. All of them are $\sim$1.0 relative to the solar values, while previous CCD observations reported the super-solar abundances of Fe-peaked elements (Cr/Fe, Mn/Fe, and Ni/Fe). The cause of this discrepancy is under discussion but we believe that our result utilizing the resolved Kα lines is reliable. The abundances of Fe-peaked elements also shows the diversity of the progenitor of the type Ia supernova.

Key words: galaxies: clusters: individual (Perseus) — galaxies: clusters: intracluster medium — X-rays: galaxies: clusters