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Discovery of non-equilibrium ionization plasma around the Fermi Bubble; new evidence of past activity of the Galactic center

Fermi bubbles are giant gamma-ray structure toward the Galactic center (GC) with symmetrical north-south extension perpendicular to the galactic plane. Such giant structures toward the GC are also observed in various wavelengths from radio to X-rays, such as WMAP haze, North Polar Spur (NPS), and most recently, eROSITA bubbles. We investigated the detailed plasma condition of the NPS/Loop I around Fermi bubble using archival $Suzaku$ data. In previous research collisional ionization equilibrium (CIE) have been assumed for plasma state, but we also assume non-equilibrium ionization (NEI) to check the plasma condition in more detail. We found that most of the plasma in the NPS/Loop I favors the state of NEI, and has the density-weighted ionization timescale of $n_e t \sim 10^{11-12}$ s cm^{-3} and the electron number density $n_e \sim$ a few $\times$ 10^{-3} cm^{-3}. The plasma shock age, t, or the time elapsed after the shock front passed through the plasma, is estimated to be on the order of a few Myr for the NPS/Loop I, which puts a strict lower limit to the age of the whole NPS/Loop I structure. We found that NEI results in significantly higher temperature and lower emission measure than those currently derived under CIE assumption. The electron temperature under NEI is estimated to be as high as 0.5~keV toward the brightest X-ray NPS ridge at $\Delta\theta = -20^\circ$, which decreases to 0.3 keV at -10°, and again increases to ~ 0.6 keV towards the outer edge of Loop I at $\Delta\theta \sim 0^\circ$, about twice the currently estimated temperatures.Here, $\Delta\theta$ is the angular distance from the outer edge of Loop I. We discuss the implication of introducing NEI for the research in plasma states in astrophysical phenomena.

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