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Probing the Origin of the NPS with Broadband Radio Observations: New Insights into Future X-ray and Gamma-ray Observations

The North Polar Spur (NPS) is a giant structure that is clearly observed in both radio and X-ray all-sky maps. Although half a century has passed since its discovery, two competing ideas are still being actively debated to postulate its origin: one considers a local super-bubble near the solar system,and the other is based on a remnant of AGN and/or starburst outflow from the Galactic Center (GC) over 10 Myr ago. In this context, the recent discovery of gamma-ray Fermi bubbles, as well as even larger X-ray eROSITA bubbles, may suggest a possible connection between the NPS and these large structures. In this study, we analyzed broad-band radio observations covering a range between 22 MHz (VLA) to 70 GHz (Planck) for the first time, to provide a systematic analysis of thermal/non-thermal emissions associated with the NPS. We show that the radio emission of the NPS is composed of (1) synchrotron radiation, (2) free-free radiation, and (3) dust emission, but the synchrotron emission dominates over other emissions at high galactic latitudes. In most regions, the electron spectrum indicates a power-low relationship with its index, s, of $N(\gamma) \propto \gamma^{-s}$ ($s \approx 2.2 - 3.0$), moderated by a high-energy turnover cutoff around $\gamma \sim 10^4$ ($E \sim 10$ GeV) ; this indicates that radio-emitting electrons are already cooled within the NPS. When assuming a typical magnetic field strength of $B \approx 5\ \mu G$, the resultant cooling time is ~ 10 Myr, which provides additional support that the NPS is a structure within the GC. We estimated the non-thermal energy stored in the NPS to be $\sim 2.6 \times 10^{55}\ [erg]$ in case of the GC. We also estimated that gamma-ray emission associated with the NPS, through inverse Comptonization of the CMB, peaks at approximately 100-1000 keV, with a flux of $\sim 10^{-9}\ [erg/cm^2/s/str]$, which may be a good candidate for future detection by the Athena X-ray observatory.

Primary authors: Mr IWASHITA, Ryoji (Faculty of Science and Engineering, Waseda University); Prof. KATAOKA, Jun (Facility of Science and Engineering, Waseda University); Prof. SOFUE, Yoshiaki (Institute of Astronomy, The University of Tokyo)

Presenter: Mr IWASHITA, Ryoji (Faculty of Science and Engineering, Waseda University)

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