Investigating Electron Energizations in Ion-scale Flux Rope Chain in Turbulent Plasma

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Abstract

Flux ropes in Earth's magnetotail are widely recognized as key structures in space plasma physics, playing a critical role in the transport, acceleration, and energization of particles. While both kinetic simulations and in situ spacecraft observations have shown that ions and electrons can be energized within flux ropes, the precise mechanisms responsible for particle energization remain an active area of investigation. In this study, we investigate a flux rope chain event observed by NASA's Magnetospheric Multiscale (MMS) mission. The chain consists of four ion-scale flux ropes embedded in a turbulent magnetotail plasma environment. We investigate a flux rope chain event in the magnetotail to better understand how electron energization operates in such systems. While individual flux ropes have been studied extensively, it remains unclear whether energization processes in a chain are governed by local conditions within each flux rope or by more global, collective effects across the chain. We utilized high-resolution magnetic field data from the Fluxgate Magnetometer (FGM) and higher-energy electrons in the 50–200 keV range using data from the Fly's Eye Energetic Particle Sensor (FEEPS), to analyze the spatial evolution of electron energization. The orientation and structure of the flux ropes were determined using Minimum Variance Analysis (MVA) and Maximum Directional Derivative (MDD), and electron phase space distributions were fitted with kappa and flat-top distribution functions to assess nonthermal features. We specifically examined the roles of Fermi acceleration, betatron acceleration, and direct acceleration by parallel electric fields within these structures. Our results show that Fermi acceleration is the dominant mechanism driving electron energization, with betatron acceleration also contributing significantly. Acceleration by parallel electric fields was found to be negligible. Additionally, although thermal electrons account for _˜90% of the number density, suprathermal electrons contribute _˜30% of the total energy density,underscoring their significant energetic contribution despite representing a small fraction of the population. These findings provide new insight into particle energization in dynamic flux ropes.

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