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Discovery of hidden EMIC wave branches: Evidence of molecular and metallic ion contributions in the inner magnetosphere

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The cold ion composition plays an important role in defining various wave branches in the dispersion relationship of electromagnetic ion cyclotron (EMIC) waves. EMIC waves are typically identified within three major wave branches: H-, He-, and O-band EMIC waves, which are associated with major ion species (H+, He+, and O+) in the Earth's magnetosphere. However, recent studies suggested that other ions (e.g., He++, N+, and O++) can contribute to creating additional wave branches depending on geomagnetic environments. Molecular ions can be supplied to the inner magnetosphere during the active solar period and/or high-speed solar wind conditions [Nagatani et al., 2024]. Sporadic E-regions or the lunar surface can be a candidate for supplying Fe+ in the inner magnetosphere [Lin et al., 2025]. While it is expected that molecular and metallic ion contributions have been hypothesized theoretically, their observational evidence has not been identified. From the point of view of observations, it is difficult to distinguish such low-frequency (LF) EMIC waves from typical ultralow-frequency (ULF) pulsations in the Pc 3-5 bands (2-100 mHz). In this study, we present the first satellite evidence of EMIC wave events observed below the gyrofrequencies of oxygen, molecular ions, and metallic ions observed by the Arase satellite. We investigated the characteristics of LF EMIC waves to discriminate from typical ULF waves. LF EMIC waves had left-handed and linear polarization sense with the field-aligned wave normal angles and non-zero Poynting vector in the ambient magnetic field direction, indicating similar wave properties as typical EMIC waves. We also found that LF EMIC waves used to be observed near the boundary between the tail lobes and the plasma sheet boundary layer (PSBL) on the nightside. They are also frequently detected on the dayside of the magnetosphere with a broad bandwidth. These waves sometimes show phase differences between the electric and magnetic fields of 45 or 135 degrees. If the observed waves can be categorized as EMIC waves, these LF events imply the presence of significant molecular and metallic ion populations in the inner magnetosphere. This finding contributes to the task of estimating the fraction of molecular and metallic ions in the inner magnetosphere using the dispersion relationship of EMIC waves. We discuss the underlying physical mechanism causing low-frequency EMIC waves and the possibility of LF EMIC wave-particle interactions, as well as the implications for cold ion compositions.