Harmonic spectral features of upstream whistler-mode waves near the Moon

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We report the presence of harmonic features in the spectra of the magnetic field observed by LMAG aboard Kaguya. The frequency intervals of the harmonic emissions correspond to the frequency of the fundamental waves, which is about 1 Hz. We find the signature of steepening waves in the waveform, particularly in the longitudinal component with respect to the ambient magnetic field direction. The wave amplitude of the fundamental waves is in the range from 10 % to 40 % of the background magnetic field intensity, and the wave normal angles of the waves are estimated to be larger than 40 degree.

The fundamental waves are similar to '1 Hz waves', which have been observed in the upstream regions of planetary bow shocks [e.g., Orlowski et al., 1995; Russell, 2007] and near the Moon [Farrell et al., 1996; Nakagawa et al., 2003; Halekas et al., 2008; Tsugawa et al., 2011] in the solar wind. The 1 Hz waves are whistler-mode waves propagating against the solar wind whose group velocity approaches to the solar wind velocity and phase velocity is smaller than the solar wind velocity to be observed left-hand polarized in the spacecraft frame. Large amplitude and large propagation angle of the fundamental waves indicate that difference of the phase velocity in the wave phase makes nonlinear steepening on the longitudinal component.

In contrast with the lunar case, 1 Hz waves observed by Geotail in the upstream region of the Earth's bow shock do not have its harmonics, nor are steepened. This could be explained by the conditions around the Earth's bow shock that oblique whistler-mode waves are difficult to be observed far from the shock because of large damping rates for the large propagation angle and that the waves generated around the Earth's bow shock are mostly propagating parallel to the background magnetic field. In addition, the steepened waves are frequently observed in the specific locations near the lunar magnetic anomalies or the terminator region. This localization suggests that additional conditions such as magnetic field and plasma inhomogeneities around the anomalies or the terminator region are necessary to maintain the waves to be steepened. Since the waves would modify the velocity distributions of particles significantly, it is important to investigate the wave generation for understanding whole picture of the solar wind interaction with the Moon.