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Similarities of upstream whistler-mode waves observed in the solar wind

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Narrowband whistler-mode waves whose frequencies close to 1 Hz have been observed near the Moon by WIND [Farrell et al., 1996], Geotail [Nakagawa et al., 2003], Lunar Prospector [Halekas et al., 2006, 2008], and Kaguya spacecraft [Tsugawa et al., 2011]. These waves are propagated upstream against the solar wind and Doppler-shifted in the spacecraft frame to be left-hand polarized. Similar waves have been observed in the upstream regions of many solar system bodies over four decades and have been called '1 Hz waves' [e.g., Heppner et al., 1967; Russell et al., 1971; Fairfield, 1974; Orlowski et al., 1990, 1995; Brain et al., 2002]. However, some unclear issues in their propagation and generation processes have not been solved, such as required condition to observe the waves, spectral formation mechanism, and the frequency dependences of the processes.

In the present study, we compare the waves in different regions to answer the issues. We investigate common properties of the waves observed by Kaguya at 100 km altitude of the Moon and by Geotail in the upstream region within 20 R_E from the Earth's bow shock. Group velocity vectors of the waves in both regions are going to cancel the solar wind velocity vector. This condition is required to observe the waves and would make the narrowband spectra. We suggest that the wave frequency is determined so as to satisfy the condition. We reveal that the wave propagation angles in the upstream region of the Earth's bow shock are typically in the range of 20?40 degrees and are smaller than those near the Moon which are in the range of 20?70 degrees. This result suggests differences of the wave generation and damping processes.