

Classification of ULF waves observed by ARTEMIS around the Moon in the solar wind

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Electromagnetic waves in the ULF band have been observed around the Moon in the solar wind by Explorer 35 [Ness, 1969], WIND [Farrell et al., 1996], Geotail [Nakagawa et al., 2003], Lunar Prospector [Halekas et al., 2006, 2008], Kaguya [Nakagawa et al., 2011, 2012; Tsugawa et al., 2011, 2012], and ARTEMIS [Halekas et al., 2013]. It has been suggested that these waves originate from the solar wind interaction with the Moon, e.g., particle reflections by the lunar magnetic anomalies or surface, temperature anisotropies through the surface absorption, or plasma instabilities at the lunar wake boundary. However, it has been difficult to establish the energy sources and the propagation processes of the waves by a single spacecraft observation. Their phase velocities comparable to or smaller than the solar wind velocity also make it difficult to identify the characteristics of the waves because of large Doppler-shift by the solar wind. We investigate the dataset of ARTEMIS which is a two-spacecraft (P1 and P2) complement in order to reveal natures of the ULF waves.

The two probes are orbiting around the Moon in the ecliptic plane at selenocentric distances~1.1-12 lunar radii since July 2011. We analyze the time series of the magnetic field vectors sampled in 4 Hz by the fluxgate magnetometer (FGM) in the fast survey mode. In consequence of comprehensive analyses, we identify four types of ULF waves: 1) broadband electromagnetic noise, 2) 1 Hz whistlers, 3) 30 s waves, and 4) wake front perturbation <0.01 Hz. The electromagnetic noise is caused by currents or drift driven instabilities in the dayside and wake boundary. 1 Hz whistlers also originate from the instabilities but propagate and group-standing in the Moon frame. 30 s waves of terrestrial ion foreshock are frequently observed around the Moon even 60 R_E upstream from the Earth when the interplanetary magnetic field (IMF) connects to the bow shock. 30 s waves are also occasionally generated by the ions reflected from the Moon when IMF is parallel to the solar wind. The wake front perturbation is observed with right-hand and left-hand polarizations at inbound and outbound the wake, respectively. These features suggest that they are phase-standing whistler perturbation outward the wake edge Doppler-shifted by the spacecraft velocity.