Plasma and wave observations in the deep lunar wake

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Abstract

The near-Moon space environment is characterised by formation of a plasma cavity region on the night side along the solar wind flow, which is called the lunar wake. Because the Moon obstructs the solar wind flow on the dayside, the wake region is much more tenuous than the ambient (unperturbed) solar wind region. Before the SELENE (Kaguya) measurement in orbit around the Moon, the plasma environment of the lunar wake was considered as follows; Only high-energy solar wind electrons can easily access the lunar night-side region along the interplanetary magnetic field (IMF) while protons cannot, and thus no significant wave activities were anticipated.

Recently, a Japanese lunar orbiter SELENE (Kaguya) performed comprehensive measurements of the plasma and electromagnetic environment around the Moon at ~100 km altitude. Our study using SELENE data revealed that so-called type-II (T2) entry of the solar wind protons into the near-Moon wake occurs when the IMF is dominated by the non-radial components (i.e. B_Y and/or B_Z in the SSE or GSE coordinate system). Under this condition a part of the solar wind protons scattered/reflected at the lunar dayside surface subsequently enters the deepest wake after a large-scale cycloid motion. As the T2 proton entry takes place, solar wind electrons are attracted into the wake along the interplanetary magnetic field that is considered to be detached from the lunar surface. In addition, excitation of broadband electrostatic noises (BENs), which can be attributed to the two-stream instability of electrons, is accompanied by the T2 proton entry.

Meanwhile, the situation handled in the previous studies mentioned above is that the relevant magnetic field line is detached from the lunar surface, leaving a possibility of the T2 entry under magnetic connection left open. Here we report that the protons can access the central wake region that is magnetically connected to the lunar nightside surface, which we categorize into the T2 entry with magnetic connection to the lunar surface (T2MC). Furthermore we show that both the energy of the electron beams and the strength of the BENs induced by the proton entry into the wake depend on the magnetic connectivity. Strong electron acceleration (up to several hundred eV to 1 keV) along the magnetic field and strong BEN signals associated with the T2 entry are prominent when the field line has its both ends in the solar wind, that is, when the magnetic field is detached from the lunar surface (i.e. the previously-reported T2 entry that we rename to T2MD). On the other hand, no significant electron acceleration and weaker BEN are found in the T2MC cases, although an enhancement of the electron flux associated with the T2 proton entry is evident. We also report that the T2 entry process takes place even under radial (B_X-dominated) IMF condition, while the strength of BENs is much weaker than the T2MD cases (or not detected at all). Our results indicate that, while the T2 entry of solar wind protons into the wake itself does not require a special IMF condition but is a rather general phenomenon, the characteristic energy of associated electrons and the strength of BENs do show a strong dependence on the magnetic connectivity to the lunar surface.

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