THE LUNAR WAKE AS A UNIQUE PLASMA PHYSICS LABORTORY. W.M. Farrell[1], J. S. Halekas[2], T. J. Stubbs[1], R. R. Vondrak[1], G. T. Delory[2], S. D. Bale, and R. P. Lin[2], [1]NASA/GSFC, Greenbelt, MD 20771 (William.Farrell@gsfc.nasa.gov), [2] Space Science Laboratory, University of California at Berkeley, Berkeley, CA, 94720.

Introduction: The Moon is an obstruction in the outward flowing solar wind, leaving trailing solar wind plasma void in the anti-sunward direction. This trailing disturbance is called the lunar wake. Solar wind plasma incident on the lunar dayside is absorbed, and the region anti-sunward of the Moon contains a near vacuum, with anomalously low plasma densities. The solar wind eventually fills-in the void, but the exact process by which the near vacuum is replenished is still being studied and understood. As such, the lunar wake is an excellent basic plasma physics laboratory for understanding the general process of plasma expansion into a vacuum.

Originally, the wake was considered primarily a magnetosonic disturbance, filling in the plasma void via a large-scale fluid structure that closes on itself near 5 lunar radii [1]. However, more recent observations of the wake with Wind and Lunar Prospector (LP) suggest a very different view of the wake as a kinetic (i.e., electron-scale) ion sonic disturbance [2]. The evidence for the change in view includes the following: 1) counter streaming, cross-tail ions beams observed within the wake tail consistent with the presence of an ambipolar E-field near the wake flanks [3], 2) a magnetic disturbance that is consistent with a diamagnetic current along the wake boundary [4], and 3) intense electrostatic wave activity detected in the central region of the lunar wake [5]. The ion beams, ambipolar E-fields, and electrostatic waves are not included in the older magnetosonic/hydrodynamic viewpoint of the wake [1] and thus some other framework is required to incorporate these important electron-scale phenomena. The ion sonic-driven/self-similar plasma expansion appears to best explain the Wind and LP observations most completely.

Figure 1 shows the plasma expansion/lunar wake from a particle-in-cell code [6] that incorporates electron scale phenomena including the ambipolar E-fields and wave activity. Note that the ion density wake extends over 30 lunar radii in the anti-sunward direction consistent with Wind observations of the disturbance at > 20 lunar radii. Also note the formation of the ambipolar E-field (strongest near the Moon) and downstream plasma wave activity.

A New Description of Plasma Expansion into the Wake: The new view of the plasma expansion into the wake void is illustrated in Figure 2. The streaming solar wind is absorbed on the lunar frontside, leaving a trailing void antisunward of the Moon. Along the "sidewall" or flank of the wake, solar wind electrons with thermal velocities greater than the more massive ions migrate into the void ahead of the ions, breaking plasma quasi-neutrality [3]. In doing so, they form an inward-propagating electron "cloud". However, an electrostatic field (ambipolar E-field) quickly forms quasi-normal to the wake flank to retard the electron migration and to accelerate ions. The accelerated ions are in the form of ion beams directed toward

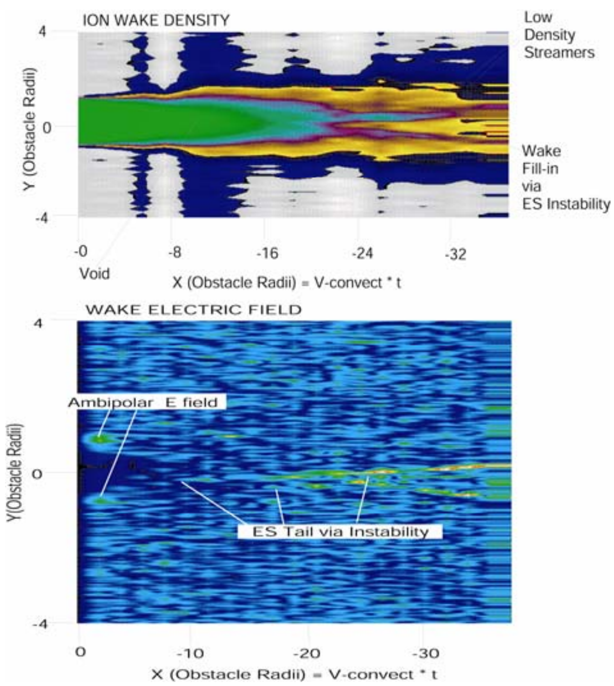
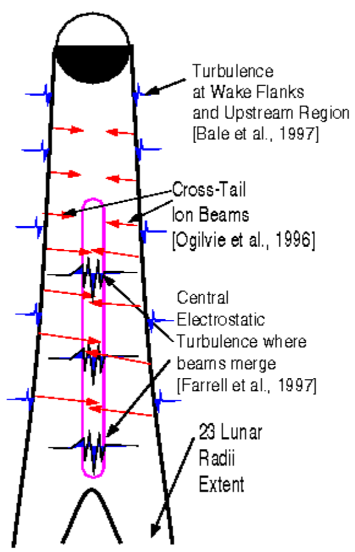


Figure 1 –A simulation of the lunar wake [6] showing the (a) ion density depletion behind the Moon and (b) E-fields including the ambipolar field near the Moon and electrostatic wave activity created downstream in the central tail. The wave activity is a result of the ion-ion beam instability that causes the flank-emitted ion beams to stop. The process thereby refills the void.

the central wake. These beams are generated from along the entire cylindrical wake edge. The flank-emitted ion beams merge in central wake at a distance downstream from the Moon of about 5-10 lunar radii. In the merging regions, the counterstreaming beams are unstable to the classic ion-ion beam plasma instability, and the beams are slowed and eventually stopped via instability-related wave energy losses via the ion acoustic mode [6]. Hence, the observation of plasma wave activity in the central wake by the Wind spacecraft (and modeled in the simulation in Figure 1b) is a direct pointer of this radiation "braking" or stopping of the ion beams. The wake thus replenishes itself (the void fills in) via the instability that causes the ion beams to stop in the central region.



Science Objective for Exploration: Lunar orbiting spacecraft will have a unique opportunity to further test and elaborate upon the process of plasma expansion into a void, especially those in low altitude orbits passing through the terminator region where the ambipolar E-field first forms and will be most intense [6]. This ambipolar E-field may also be relevant to the lunar dust problem, with the fields possibly involved in terminator dust lifting and acceleration detected by the Apollo 17 Lunar Ejecta and Meteorite (LEAM) system [7]. Such wake-related ambipolar E-fields may also be present within Shackleton crater, creating accelerating dust at the region of NASA's proposed lunar base.

Figure 2- An illustration of the expansion of plasma in the trailing lunar void/wake.

Applications of this basic plasma physics study include the wake following any large object in LEO, including the space shuttle, the ISS, and HST, and the replenishment of plasma voids in plasma torus regions surrounding the Earth, Jupiter, and Saturn. The plasma expansion problem is applicable to any airless body in a high-Beta plasma flow.

The plasma instrumentation required to further the basic study includes a quasi-DC E-field system, plasma wave system, magnetometer, and ion & electron plasma spectrometers. Such hardware currently exists and is already flying on spacecraft like THEMIS to measure the magnetosphere plasma during solar storms. A dedicated THEMIS-like spacecraft, called LEEAH, has been proposed to be placed in low altitude orbit about the Moon, and the instrumentation onboard would be capable of making new advances in the formation of the lunar wake. A surface magneto-plasma package passing directly through the terminator would be also invaluable to study the basic plasma processes created directly at the wake origin.

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