# Measuring Ionospheric Electric Field Gradients with the International Space Station Floating Potential Probe


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The International Space Station (ISS) operates in the Earth's ionosphere – an electrically conductive ionized gas or plasma. The station's electrical power systems and metallic structures interact with the ionospheric plasma and with Earth's magnetic field to produce an electric charge on the structure that changes as the vehicle orbits the Earth. This charge is measured by the floating potential measurement unit (FPMU) instruments now attached to ISS. One of these instruments is a floating potential probe comprised of a high-impedance voltmeter that measures the difference in voltage between the ISS structure and its surrounding electrically conductive plasma environment.

We are interested in the ISS floating potential because of its impact both on crew safety and possibly on vehicle performance. Figure 1 shows measurements from the FPMU. The floating potential in the upper panel illustrates variation in the vehicle's voltage, measured with respect to the surrounding ionospheric plasma, as the station orbits the Earth.

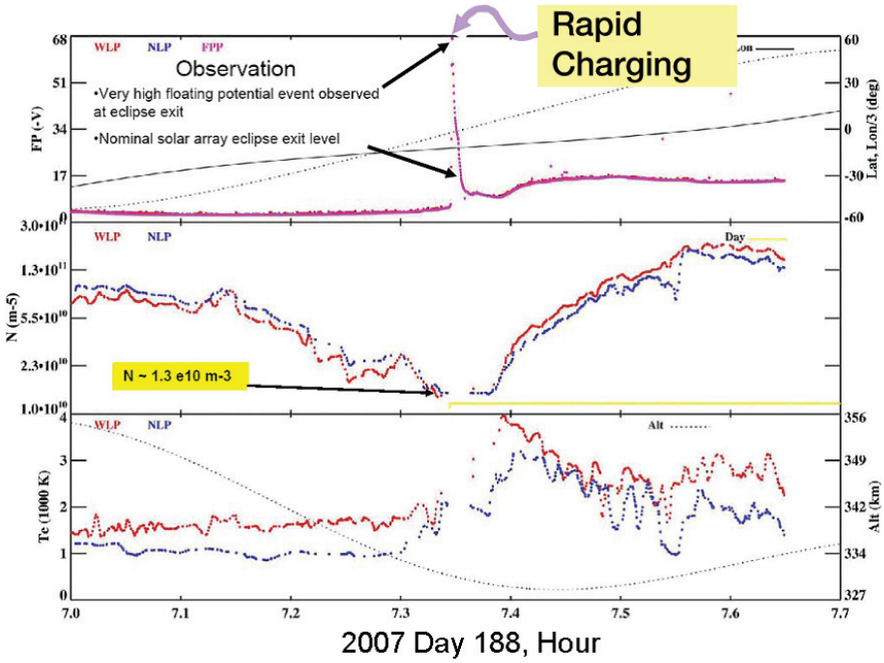


***Fig. 2.*** *Rapid charging observed at low latitude.*

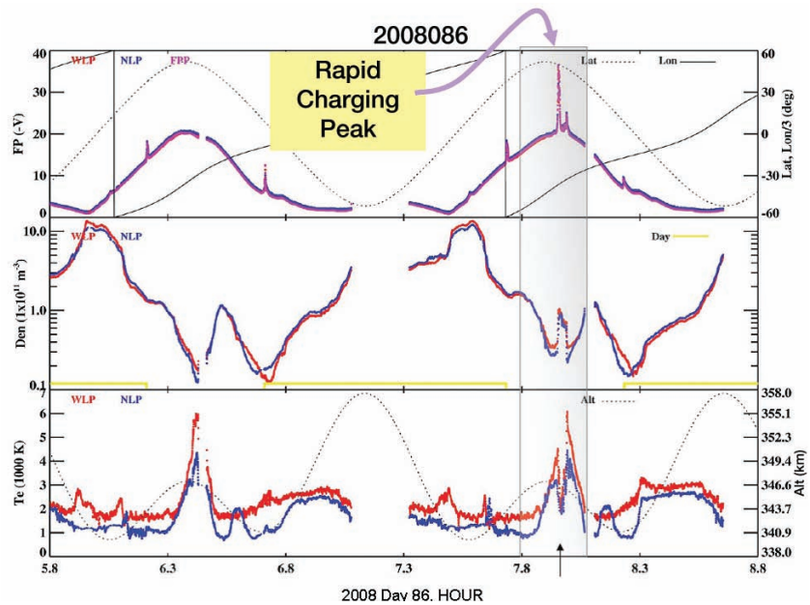


***Fig. 1.*** *FPMU measurements of plasma floating potential, density, and temperature in the ISS environment.*

The charge on ISS is controlled naturally by electron collection at positively charged surfaces and by ion flux removal of electrons at negatively charged surfaces. These physical principals are used in a numerical model, the Plasma Interaction Model (PIM), developed by NASA and The Boeing Company, Chicago, Ill., to predict and control, through use of artificial plasma sources, the ISS floating potential.

Many features of the floating potential (e.g., its broad increase and decrease during each orbit) are well understood

and were accurately predicted by PIM. However, within the past couple of years, analysis of data from the FPMU has revealed rapid and anomalous vehicle charging peaks not captured by PIM physics. One of these peaks is identified in figure 1 and another in figure 2. NASA and Boeing have now established that these anomalous charging peaks are related to voltage gradients in Earth's ionosphere along the ISS flight path as the station orbits the Earth rather than to changes in electron and ion collection by ISS electrical power systems or structural components. In fact, these anomalous rapid charging peaks are only observed in connection with the unusually low ionospheric plasma densities associated with the minimum of the 11-year solar cycle.

We have discovered through this study that the ionospheric reference potential is changing rapidly as the ISS transits geographic regions of high and low potential. As a result of the large size and unprecedented electrical capacitance of the vehicle, these geographic variations in potential appear as observed changes in vehicle floating potential measured with respect to the ionospheric plasma.

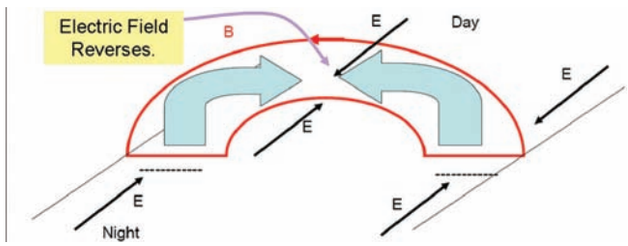


***Fig. 3.*** *Diagram showing reversal of geophysical electric field, often occurring at low latitude when the ISS exits darkness and associated with anomalous rapid charging of the vehicle for several seconds.*

Our NASA/Boeing team identified two immediate sources of geographic variability. One appears at low latitude when the ISS exits darkness and the other appears at high latitude. At low latitude, a condition of reversed electric field often occurs in the natural ionosphere. Figure 3 illustrates this so-called pre-reversal enhancement (PRE). The PRE has long been recognized by the geophysical sciences, and has been observed on many science satellite missions.

The high-latitude, rapid-charging events are associated with geophysical mechanisms that provide a varying electric potential. However, for these high-latitude cases, the mechanism has more to do with solar-wind-driven electric fields that penetrate vertically from high altitudes in the polar zones and then turn horizontally.

These penetration electric fields are illustrated in figure 4. As the ISS transits regions of different electric field orientation, the potential can change rapidly and is responsible for the spike-like events seen in figure 1.

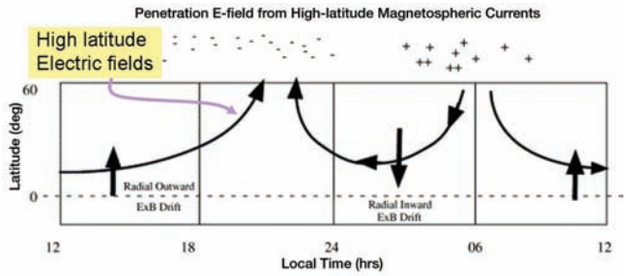


***Fig. 4.*** *Diagram showing vertically oriented electric fields that occur at high latitude and contribute to rapid charging events.*

The electric potential difference for penetration fields is governed by solar wind processes occurring at very high altitude in the interplanetary medium. These processes involve solar wind speed and interplanetary magnetic field orientation, which affect the currents and fields in the Earth's polar and high-latitude regions.

NASA, with support from The Boeing Company, is identifying and managing charging risks on the ISS by monitoring the space environment through FPMU data, analyzing and interpreting FPMU data with the PIM, and innovatively applying well-known geophysical principles. In particular, we have now identified previously unsuspected spacecraft charging mechanisms with variable electric potential in the ionospheric environment that can be attributed to previously known geophysical processes. The subject charging processes can be readily observed only on a spacecraft as large as ISS.



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