Incoherent Scatter Measurements of Aurora–Like Ion Beam Distributions and Ionospheric Holes Produced by the Space Shuttle Flying over the Radars at Jicamarca, Kwajalein, and Arecibo

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In October 1997 and July 1999 during the STS–86 and STS–93 flights of the Space Shuttle, the crew performed experiments with controlled ion injections over the incoherent scatter radar (ISR) facilities located at Arecibo, Puerto Rico; Jicamarca, Peru; and Kwajalein, Marshall Islands. Ion beams were formed by charge exchange in the ionosphere of the high velocity neutral molecules exhausted by the Orbital Maneuver Subsystem (OMS) engines on the Space Shuttle. Pick–up ions were produced with energies between 2 and 10 eV depending on the orientation of the OMS engines relative to the vehicle orbit. The ions eventually recombined with electrons yielding electron density depressions or holes.

On the STS–93 Mission, the first ISR spectra were measured by reflection from electrons in the presence of the high–speed ions. The non–equilibrium ion distributions produced atypical ion–line spectra. Bernhardt et al. [1998] predicted these spectra. Numerical fitting procedures were used to extract the ion beam parameters from the measured ISR spectra. The analysis shows relaxation from ring–beam distribution to a thermal distribution in the period of 30 seconds. The analysis of the spectra also indicates that collisional heating by the ion beams yields elevated temperatures in the background ions leading to enhanced radar echoes. Beam driven instabilities involving ions in the OMS plume may produce turbulence that yields enhanced radar backscatter. This region of enhanced turbulence was postulated by Bernhardt et al. [1995] but has not been observed in the radar data for the 2eV ion beam injections over Arecibo and Jicamarca. The 10 eV beam injections over Kwajalein may show the effects from irregularities produced by beam driven instabilities. These observations open up the possibility of conducting a new series of ion–beam instability and heating experiments using the Space Shuttle OMS engines as plasma beam generators.

One the STS–86 Mission, the Jicamarca ISR recorded the reduction in density on a modified magnetic flux tube. The refilling process occurred much more rapidly than can be duplicated with ambipolar diffusion along magnetic field lines. An electron density depression was produced at 359–km altitude on the mid–point of a magnetic field line. The experiment was scheduled when there were no zonal drifts of the plasma so the modified field–line remained fixed over the 50 MHz, Jicamarca radar. The density depression was filled in by plasma flowing along the magnetic field line with a time constant of 4.5 minutes. The density perturbation has completely vanished 20 minutes after the engine burn. The experimental measurements were compared with a model of field–aligned transport by ambipolar diffusion. The recovery time was computed to be much longer than observed. The theory of ambipolar diffusion currently used in ionospheric models is inadequate to describe these observations. Several possible sources for this discrepancy including (1) ion and electron inertia, (2) cross–field diffusion, and (3) convection of the modified plasma out of the radar beam. At this stage, no explanation has been found for the rapid refilling of the ionospheric hole.