Radio Sounding From IMAGE: New Perspectives on Field Aligned Density Irregularities, Z and Whistler Mode Diagnostics, and Proton Cyclotron Harmonic Echoes

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The operating frequency of the Radio Plasma Imager (RPI) instrument on the IMAGE satellite extended from 3 kHz to 3 MHz. This wide range made possible free-space O and X mode sounding from altitudes on both sides of the plasmasphere boundary layer (PBL) while also making possible wave injection in the whistler-mode and Z-mode domains at altitudes less than ≈ 10,000 km. We briefly review new findings in four areas: (i) density irregularities in the PBL and within the plasmasphere; (ii) upward Z-mode probing along geomagnetic field lines from within a Z-mode propagation 'cavity'; (iii) downward probing from 4500-7000 km altitude using whistler-mode waves that undergo two fundamentally different types of reflection; (iv) strong coupling of RPI pulses to the local proton plasma

Radio sounding from outside the plasmasphere boundary layer revealed an irregular plasmasphere 'surface' and the regular presence of field aligned density irregularities in the outer plasmasphere. Free-space mode-waves that were not guided along the **B** field showed evidence of scattering from density irregularities with scale size from ~200 to 800 meters. Inversion of the often diffuse frequency-versus-time properties of these 'unguided' echoes, in combination with the (already successful) analysis of simultaneously propagating guided echoes, could be developed as a tool for remotely mapping large meridional sections of the plasmasphere.

The Z-mode cutoff frequency is strongly dependent upon the ratio of the local plasma and gyro frequencies, such that the cutoff develops a minimum with altitude (or 'cavity') between 1500 and 5000 km altitude, where the ratio tends to drop from high ionospheric values toward or below unity before increasing again. A radio sounder operating near this minimum can in principle receive echoes from both above and below the satellite. As in the case of O and X mode sounding on IMAGE, the Z-mode echoes were both discrete and diffuse, in the discrete cases showing clear evidence of echoing back and forth between upper and lower reflection points along a field-aligned path passing through the satellite. Inversion of the frequency-vs-time properties of the Z echoes can provide information on the plasma density profile along the field lines above and below the sounder, while the altitude of the Z cavity itself appears to be sensitive to ion composition in the transition region from the ionosphere to the region above.

When RPI operated below ≈ 4500 km altitude at frequencies between ~ 6 and ~14 kHz, it regularly detected echoes resulting from so-called "magnetospheric (MR) reflections" near locations where the wave frequency matched the local lower hybrid resonance frequency. Because of this matching, the MR echo provided information on the "effective mass" of the plasma in the important transition region between the heavy-ion dominated lower ionosphere and the light-ion dominated region at higher altitudes. These echoes also provide an integral measure of the electron density between IMAGE and the altitude at which magnetospheric reflection occurs. In addition, RPI soundings regularly exhibited echoes interpreted as having reflected from the steep density gradients at the bottom side of the ionosphere. Such echoes provided an integral measure of the electron density between IMAGE at ≈ 7000 km and the ionosphere at ≈ 100 km, and thus represented a constraint on the density/plasma composition model that was found most consistent with an MR event on the same record.

At altitudes ranging from ≈ 1500 km to 20,000 km in the plasmasphere, the RPI instrument on IMAGE was found to couple strongly to protons in the immediate vicinity of the satellite as it transmitted 3.2-ms pulses and scanned from 6 to 63 kHz or 20 to 326 kHz. Those soundings also gave rise to a new resonance at a frequency ≈ 15% above the electron cyclotron frequency. The coupling to protons was revealed in echoes that arrived at multiples of the local proton cyclotron period. Lower-altitude (< 4,000 km) versions of several of these proton cyclotron (PC) echo forms were observed in the topside ionosphere by sounders in the ISIS satellite era.

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