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Visualizing the Invisible and Other Wonders of Saturn' s Magnetosphere

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New measurement capabilities on exploratory missions always make new discoveries and reveal new phenomena, even when earlier planetary encounters had sketched out the broad features of a planet' s environment. And so it is with the Cassini-Huygens intensive study of the Saturn system, even though the reconnaissance of the planet had already taken place first with Pioneer-11 in 1979 and then Voyager-1 and -2 in 1980 and 1981, respectively. Thus, the inclusion in the payload of the Ion and Neutral Camera (INCA) to perform energetic neutral atom (ENA) imaging, plus an instrument that could measure ion charge state (CHEMS) and, in addition, state-of-the-art electron and ion sensors (LEMMS) provided the tools for a plethora of new and unique observations. These include, but are not limited to: (1) explosive large-scale injections appearing beyond 12 R_S in the post-midnight sector, propagate inward, are connected to auroral brightening and SKR emissions, and apparently local injections as far in as 6 R_S in the pre-midnight through post-midnight sector with a recurrence period around 11h that appear to corotate past noon; (2) periodicities in energetic charged particles in Saturn' s magnetosphere, including "dual" periodicities, their slow variations, periodic tilting of the plasma sheet, , and the possible explanation of these periodicities by a "wavy" magnetodisk model and the existence of the solar wind "driver" periodicity at $\sim$26 days; (3) dominance of water group (W^+) and H^+ with a healthy dose of H_2^+ ions in the energetic particle population throughout the middle magnetosphere, plus minor species such as O_2^+ and $^{28}M^+$ of unknown origin, all with relative abundances varying with the solar cycle and/or Saturn' s seasons; (4) sudden increases in energetic ion intensity around Saturn, in the vicinity of the moons Dione and Tethys, each lasting for several weeks, in response to interplanetary events caused by solar eruptions.; (5) a uniform electric field of around 0.11-0.18 mV/m within 4.4-7.0 R_S oriented roughly from noon to midnight, that explains the persistent radial offsets of satellite electron microsignatures from their expected positions; (6) determination that the ring current pressure in the outer magnetosphere is dominated by superthermal ions heavier than protons; (7) detection of magnetic-field-aligned ion and electron beams (offset several moon radii downstream from Enceladus) with sufficient power to stimulate detectable aurora, and the subsequent discovery of Enceladus-associated aurora in a few per cent of the scans of the moon' s footprint. These and many other observations have revealed fundamental plasma processes operating in Saturn' s magnetosphere such as magnetotail reconnection, centrifugal interchange instability, ion and electron acceleration, convection/diffusion, charge exchange, and magnetosphere/ionosphere coupling, among others.