Why do Saturn's energetic particle profiles look as they do?

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Summary: The combined MIMI/LEMMS&CHEMS instruments onboard the Cassini spacecraft measure ions and electrons between 1keV and 10MeV. Their mission-averaged phase space density profiles show a general decrease towards Saturn (Fig. 1). Origin and fine-structure of the profiles are discussed here. The overall decrease might be caused by losses close to the planet. Since the slopes depend on pitch angle, the common explanation that uses radial diffusion alone does not work. Kinks in the profiles are caused by the icy moons (Fig. 2). Only at low energies (<100keV), losses in the gas cloud are relevant (Fig. 3+4).

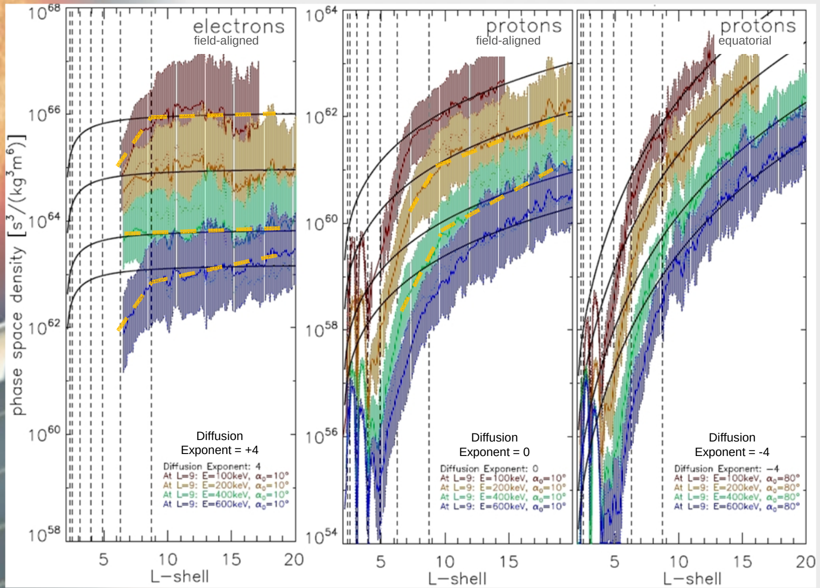

Figure 1
SHAPE OF THE PROFILES
Phase space densities for different 1st and 2nd adiabatic invariants.

- *Black lines:* Fits for L>9.5 assuming radial diffusion with a coefficient ~L^n, exponents n as stated in legend. Profiles of equatorial protons are steeper than field-aligned ones → inconsistent with the usual theory of diffusion.
- *Orange lines* to guide the eye. Gradients change approximately at the orbits of the icy moons (dashed lines). Explanation in Fig. 2.

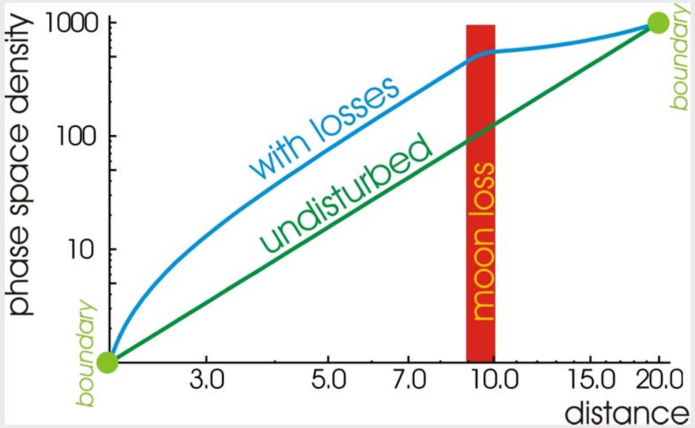

Figure 2
ROLE OF MOON LOSSES
Green line: Phase space density profile assuming radial diffusion and processes enforcing boundary conditions *(light green dots).* *Blue line:* Includes loss from a moon *(red column).* Diffusion causes a localized loss to modify the entire profile.

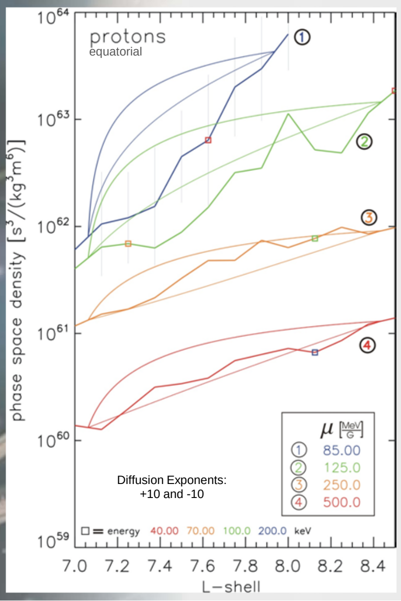

Figure 3
ROLE OF GAS LOSSES
Scattered lines: Phase space density of low energy protons. *Smooth lines:* Fits assuming only radial diffusion. Upper lines use diffusion exponent n=+10 (realistic), lower lines n=-10. Only at lowest energies *(blue lines)*: no match → losses from charge exchange (not from energy loss in gas or ice, Kollmann et al. 2011 JGR).

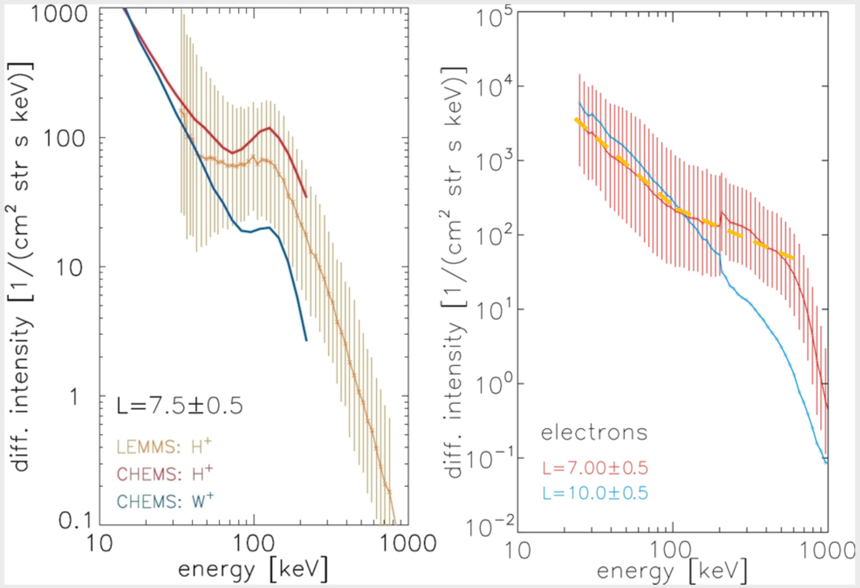

Figure 4
FEATURES IN RADIAL PROFILES APPEAR IN ENERGY SPECTRA

- Left: Spectra of protons *(red and orange)* and water group ions *(blue)*. In the dense gas cloud, losses occur for <100keV ions. Equivalent to blue line in Fig. 3
- Right: Electron spectra outside *(blue)* and inside *(red)* of moon orbit. Orange lines indicate a kink equivalent to Fig. 1.

Comments

- Our use of adiabatic invariants implies *adiabatic heating*. A radial profile falling with L-shell (Fig. 1) is equivalent to a spectrum falling with energy (Fig. 4). Different slopes arise because heating is *pitch angle* dependent, not from pitch angle distribution (mission-average is mostly isotropic).
- *Distributed source* might explain the pitch angle depending slopes (Fig. 1). Source could be injection events, CRAND and/or local acceleration?
- Falling profile can exist without distributed losses from gas (Fig. 2). Inner *boundary condition* from strong losses at main rings? Outer boundary approximates distributed source?
- *Diffusion exponent* >0 means diffusion is strongest at large distances, where EM-fields are weak (Fig. 1+3).
- *Energy spectra* for large L are mostly a power law (Fig. 4) . Why?