Characteristics of the neutral influx from Saturn's rings

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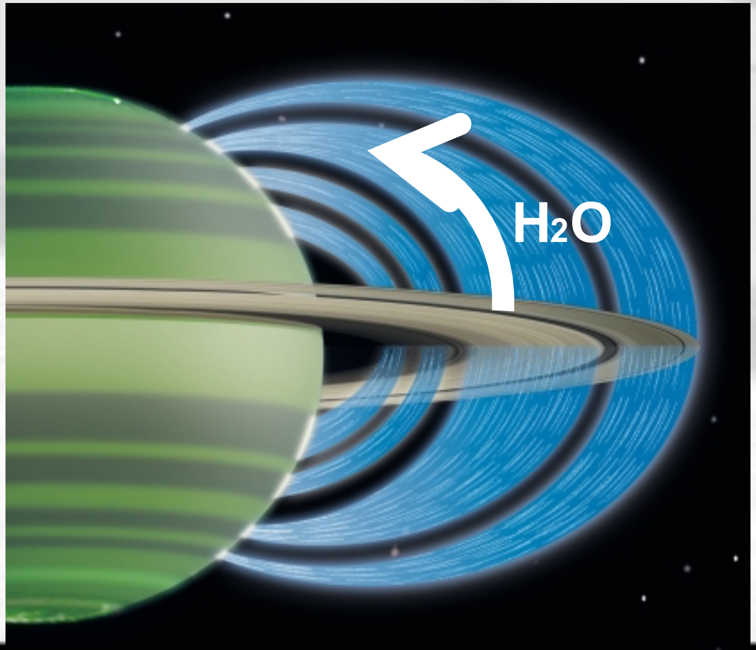
Major findings

1. Two processes bring material into Saturn.
2. The huge flux of material from the rings into Saturn.
3. Atmospheric drag preferentially acts on smaller particles.

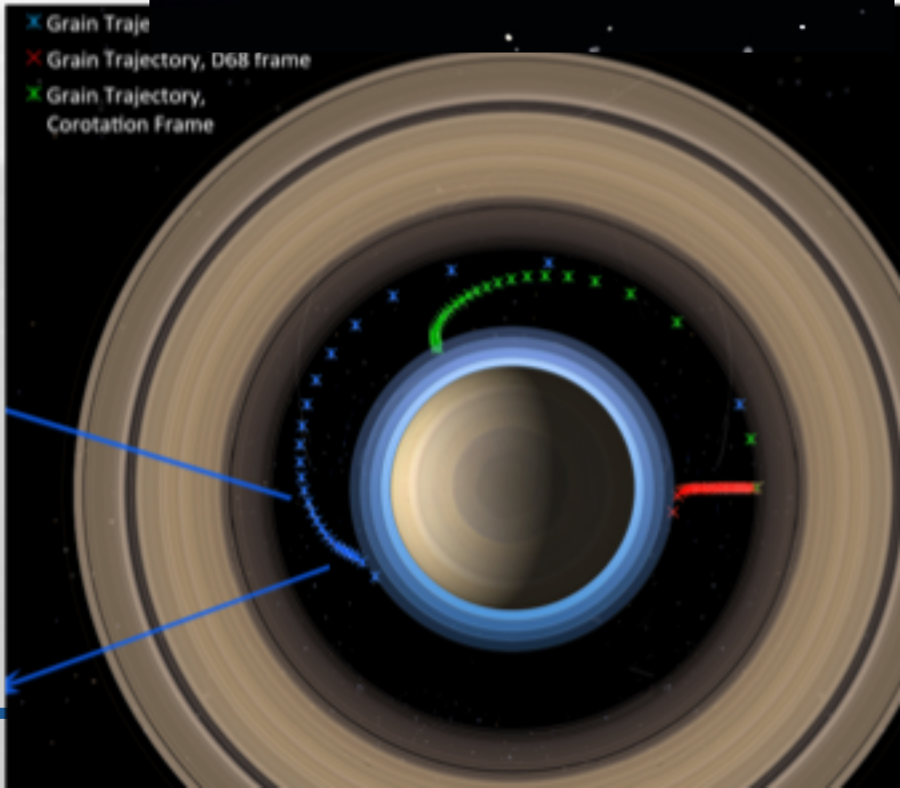
- Some frequently asked questions related to these findings
  - How is mass flux calculated?

- Questions that can be answered by comparing observations to high-fidelity simulations:
  - How does atmospheric drag disperse material laterally?
  - What is the density of atomic hydrogen in Saturn's exosphere?
  - How quickly does material enter the atmosphere

1.Two processes bring material into Saturn

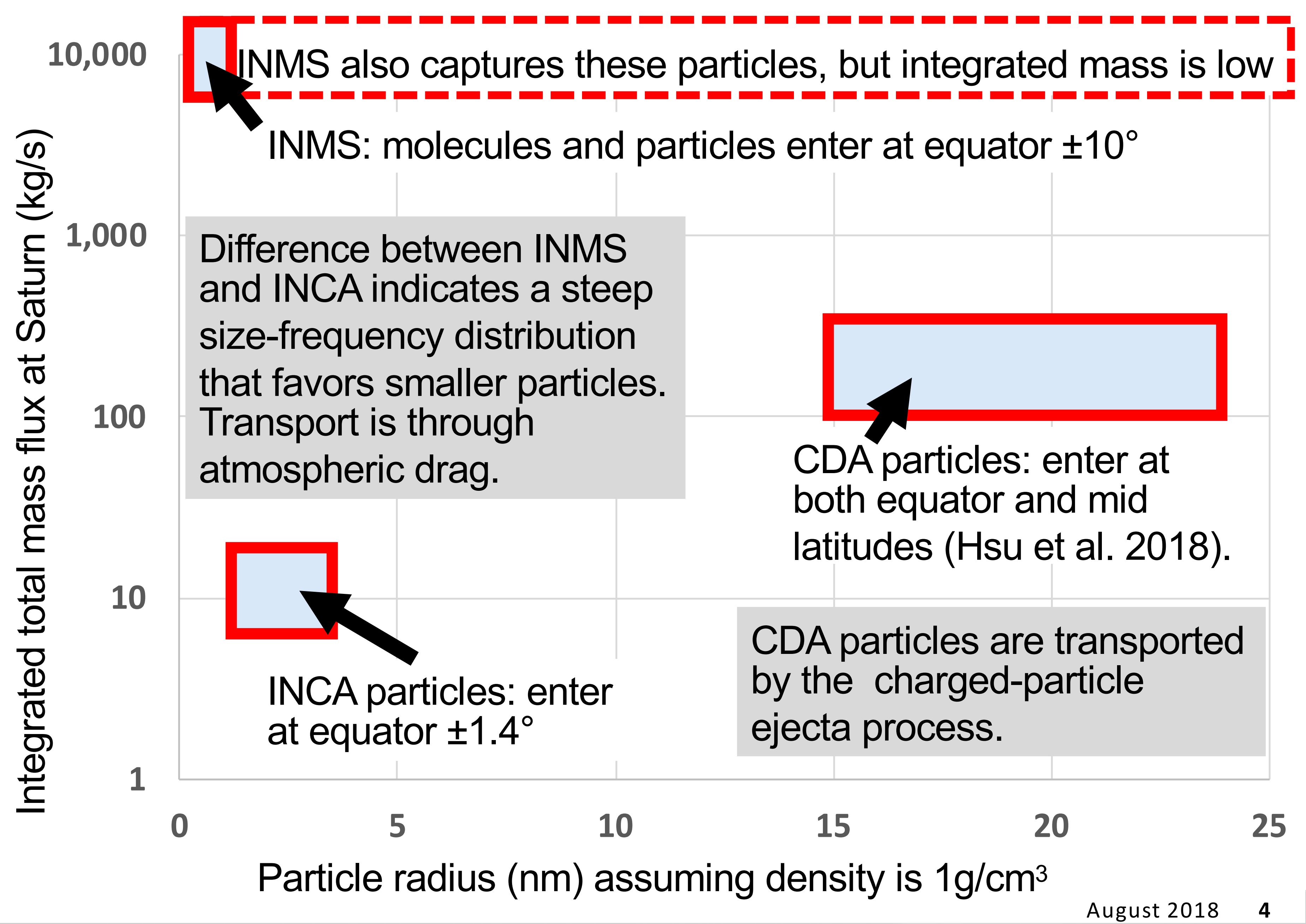


1. **Charged** particles and ions flowing along magnetic field lines; previously “Ring rain”
   - Connerney and Waite 1984, Northrup and Connerney 1986, Hsu et al. 20018, Ip et al 2016.
   - Enters Saturn primarily at mid latitudes, but some at equator, also.
   - CDA measurements and the modeling by Hsu confirmed this process.
2. Small, **neutral** material enters along ring plane due to atmospheric (exosphere) drag.
   - Material orbiting at the inner edge of the D ring collides with atoms in the extended exosphere (atomic hydrogen) and deorbits.
   - Affects small particles, which cannot be observed with remotely.



2. Mass flux into Saturn 1-20x10⁴ kg/s

- Three independent calculations agree.
- INMS flux at INCA altitudes (3,000 km) and at low altitude (1,800 km) are the same within uncertainty.
- The high flux measured by INMS indicates a steep size-frequency distribution.
- Dip reflects two processes



3. The influx is dominated by small (<2nm) particles

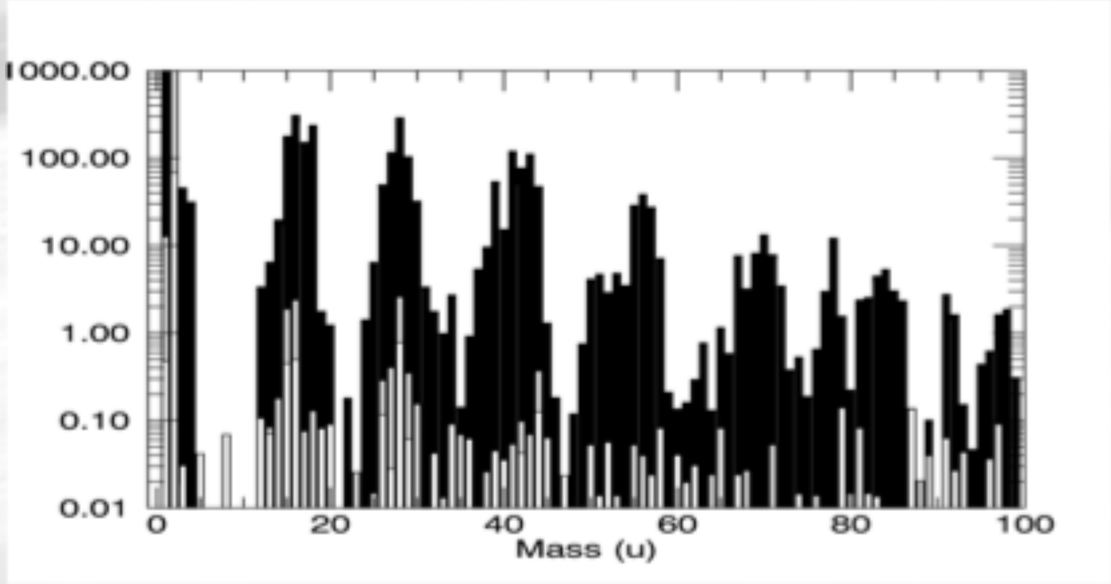
- Evidence: INMS mass flux compared to INCA mass flux.
- Two aspects of the transport process preferentially extract small particles:
  - Smaller particles remain neutral longer than larger particles.
    - Charging time is proportional to area and can be days for r = 1nm.
    - Once ionized, they are controlled by the magnetic field and not susceptible to atmospheric drag.
  - Smaller particles deorbit faster than larger particles.
    - Larger particles (> 20,000u) require tens of thousands of collisions; small particles (100u) less than 100.
    - Deorbit time depends on exosphere density of atomic hydrogen.

Quote from our GRL paper:

"The authors acknowledge the massive, unexpected, and unsustainable size of this flux. Multiple diligent, careful reviews of the data, analyses, and instrumental effects were unable to reduce the flux below 10^4 kg/s. In fact, a flux ten times larger is consistent with the data."

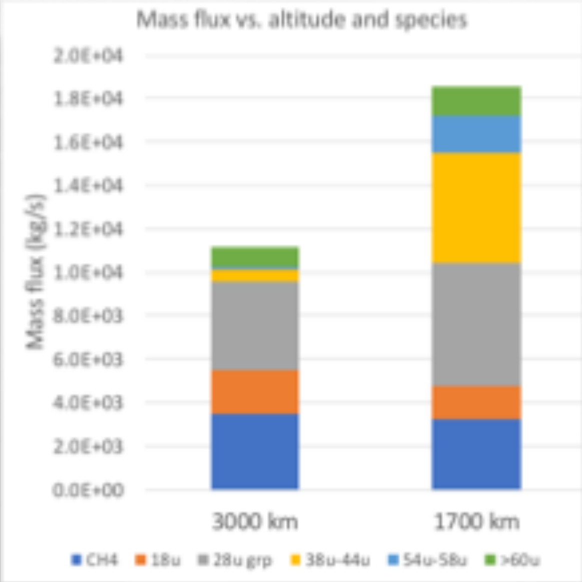
FAQ: How is mass flux calculated?

- Sum all the material that INMS measures at a given altitude.
- Calculate the vertical velocity of the material based on the atmospheric density.
  - Several different methods (e.g., maximum diffusive velocity, terminal velocity, modeling, etc.) all agree
  - Altitude-independent concentration is confirmation.
- Multiply total mass by the velocity
  - Higher accuracy if adjust velocity for the mass of the molecule.
  - For total flux, include latitude range of influx.
- Cross check by repeating calculation at different altitudes.
- Mass is conservative (low).
  - Most-likely adjustments increase the flux.



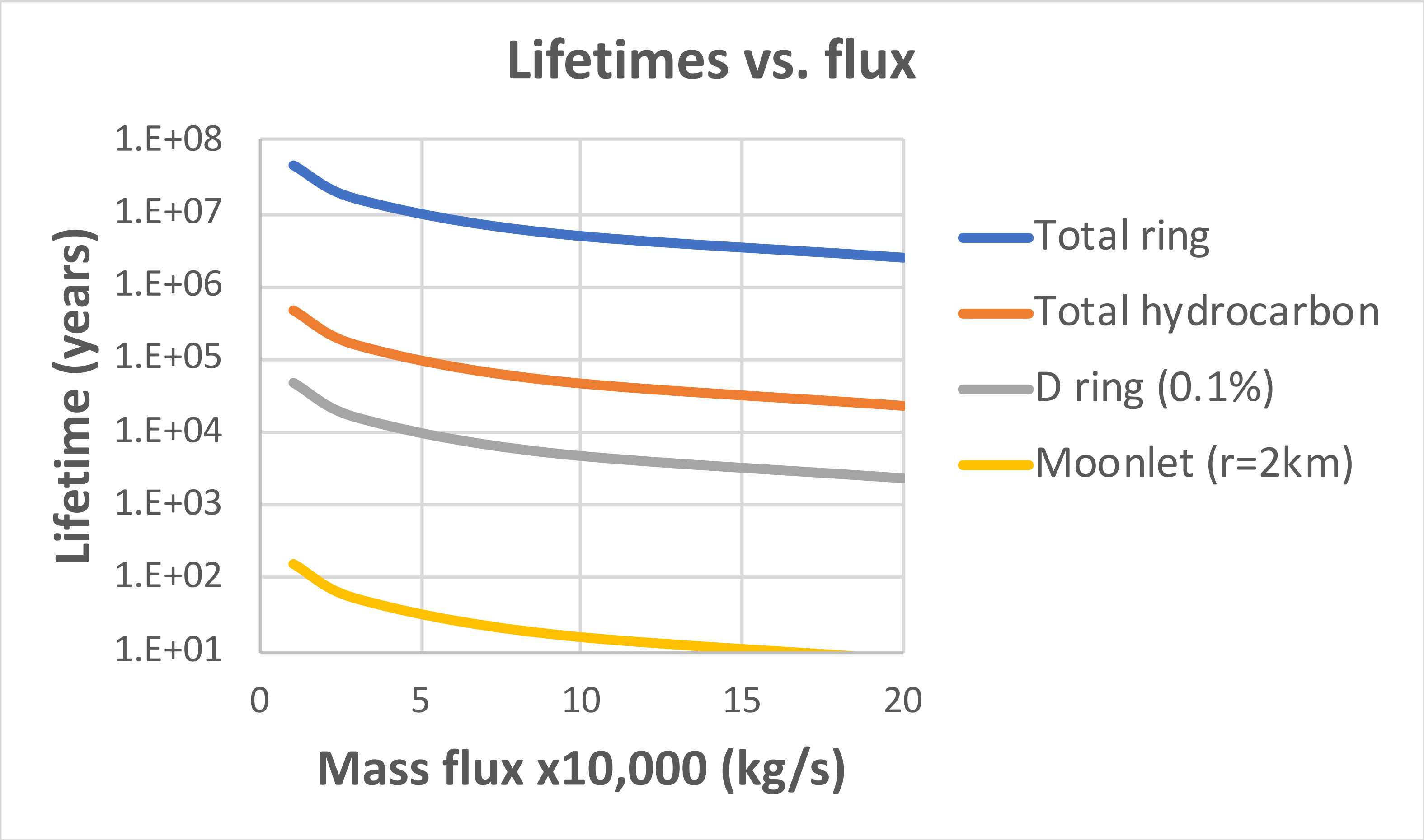
$$v_s = \frac{0.36\rho_p g(2a)}{m_{H2} n_{H2} v_{H2}}$$

$$v_m = \frac{D}{H}\left(1 - \frac{m}{m_{H2}}\right)$$

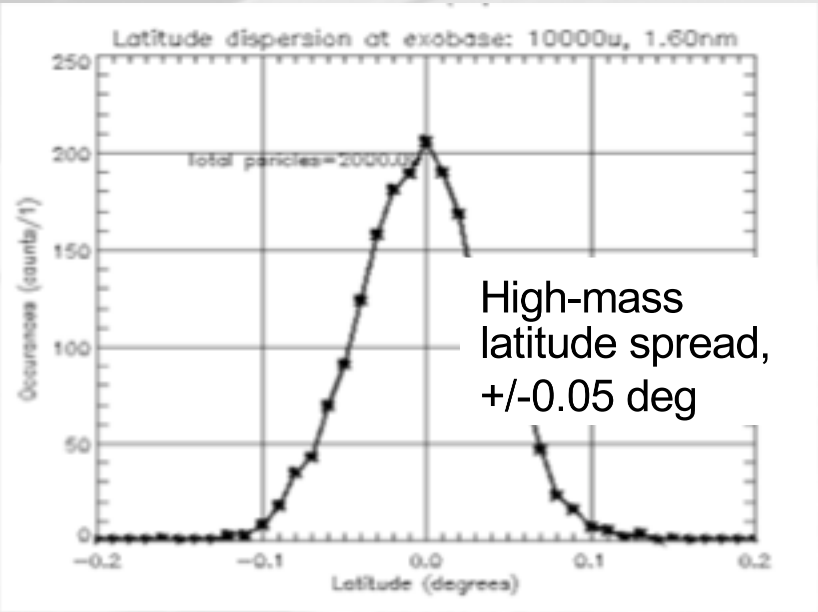


FAQ: Ring-lifetime calculations

- Current flux cannot be the average flux over the life of the rings.
- Working theory: flux has recently increased due to disruption of the D68 ringlet in 2015.

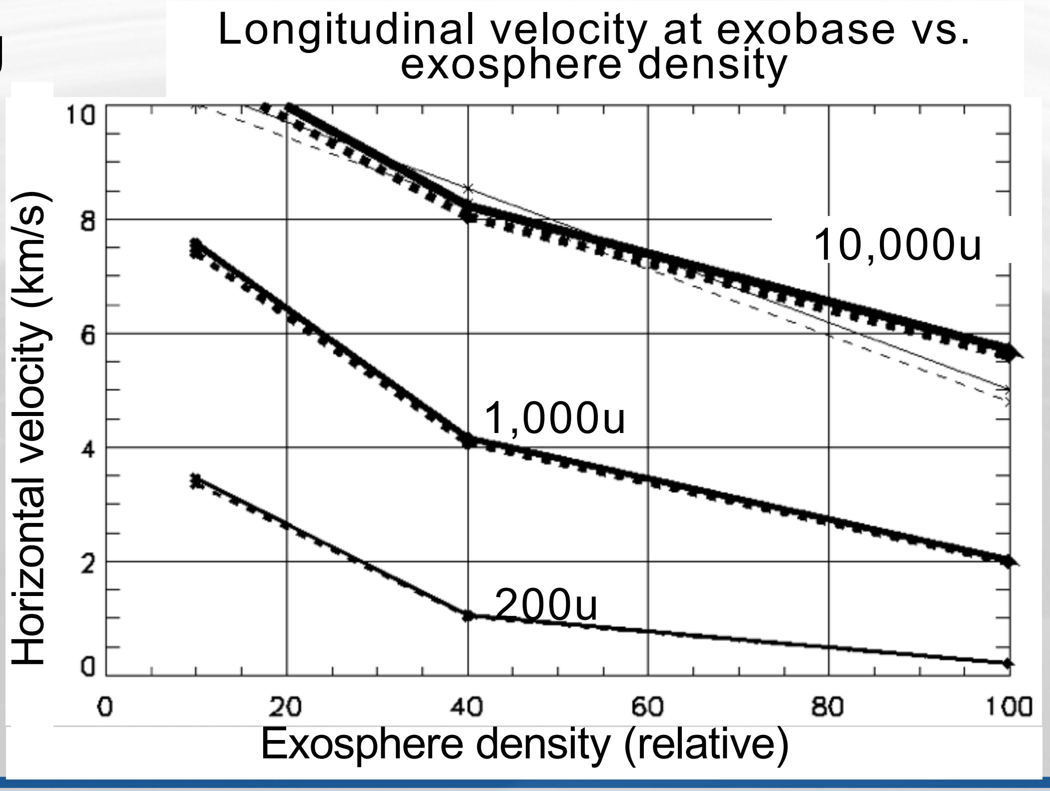


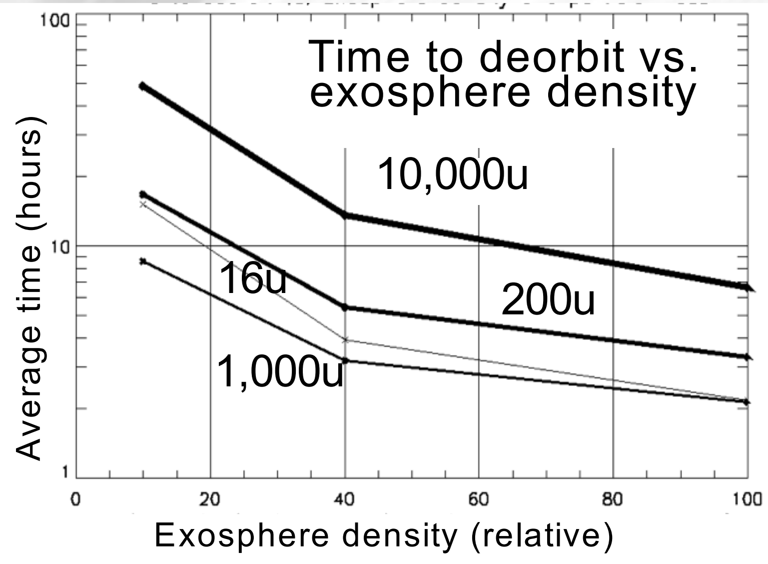
Insights from the high-fidelity Monte Carlo model



- Atmospheric drag does not provide the observed dispersion in latitude (±1.4° for 10,000 u).
- Options for additional dispersion mechanisms:
  - Broad distribution at source
  - Low-exosphere charging

Compare these results to velocity derived from INCA data.





Use to calculate delay and offset from source at D68

Major findings

1. Two processes bring material into Saturn.
2. The atmospheric drag brings more than ten tons per second
3. Atmospheric drag preferentially drags smaller particles, so the primary mass influx is comprised of nanograins with $r < 2$ nm.

- Some frequently asked questions related to these findings
  - How is mass calculated?

- Questions that can be answered by comparing observations to high-fidelity simulations of atmospheric drag:
  - How does atmospheric drag disperse material laterally?
  - What is the density of atomic hydrogen in Saturn's exosphere?
  - How quickly does material enter the atmosphere

Thank you

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