Mathematical Approaches and Processes Relevant to the Escape of Planetary Gases and Plasmas

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Outline

• Ion Escape
• Neutral Polar Wind
• Escape Spatial Structure
• Escape Processes
• Non-Maxwellian Escape
• Mathematical Approaches
Continuous Loss Due to Ion & Neutral Outflow

Schunk & Sojka (1997)
1. Macroscopic PIC Polar Wind Model

- Fluid Code: 90 - 1200 km
- PIC Code: 1200 km - 8 $R_E$
- 1000 Convecting Flux Tubes
- 1 Million Particles Per Flux Tube
- Total of 1 Billion Particles

Barakat and Schunk (2006)
• 1000 Convecting Flux Tubes for Background Plasma
• 130-200 km Horizontal Resolution in Polar Cap (70°-90°)
• 3 UT --> All Processes Included, 1 Billion Particles
Processes Included

• Low-Altitude Auroral Energization
• Gravity, Electrostatic Field, Magnetic Mirror Force
• Ion - Ion Collisions
• Wave - Particle Interactions
• Hot Magnetosphere Electrons
• Centrifugal Acceleration

Barakat and Schunk (2006)
$O^+ / H^+ $ Density

Before Storm

Barakat and Schunk (2006)
During Storm

O⁺/H⁺ Density

Barakat and Schunk (2006)
2. Neutral Polar Wind

Neutral Polar Wind

$H_S$ Escape Flux = $10^9$ cm$^{-2}$ s$^{-1}$

Gardner & Schunk (2005)
3. Polar Wind Structures

- Propagating Jets
- Stationary Jets
- Localized Holes
- Upward Propagating Holes
- Gusty Outflows
- Pulsating Outflows
End of Main Phase

Winter - Solar Maximum

Demars & Schunk (2003)
End of Main Phase

Winter - Solar Maximum

Demars & Schunk (2003)
4. Shocks in the Polar Wind
Forward-Reverse Shock Pair in Auroral Oval
Hot-Cold Electron Interaction

Contact Potential

$T_h/(T_c)_a = 300$
5. Escaping Ion Velocity Distributions

- Beams
- Bi-Maxwellian
- Asymmetric with Elongated Tails
- Double-Peak
- Conic
- Counter-streaming Ions
6. Model Types

- **Hydrodynamic**
  - Single stream per ion
  - Multi-stream per ion
- **Hydromagnetic**
- **Generalized Transport**
  - Maxwellian based
  - Bi-Maxwellian based
  - Toroidal based
- **MHD**
  - Ideal
  - Hall
  - Two-temperature
  - Multi-ion
- **Kinetic**
  - Maxwellian based
  - Bi-Maxwellian based
- **Semi-Kinetic**
- **Monte Carlo**
- **Particle in Cell (PIC)**