How do solar wind and ionospheres interact via reconnection?

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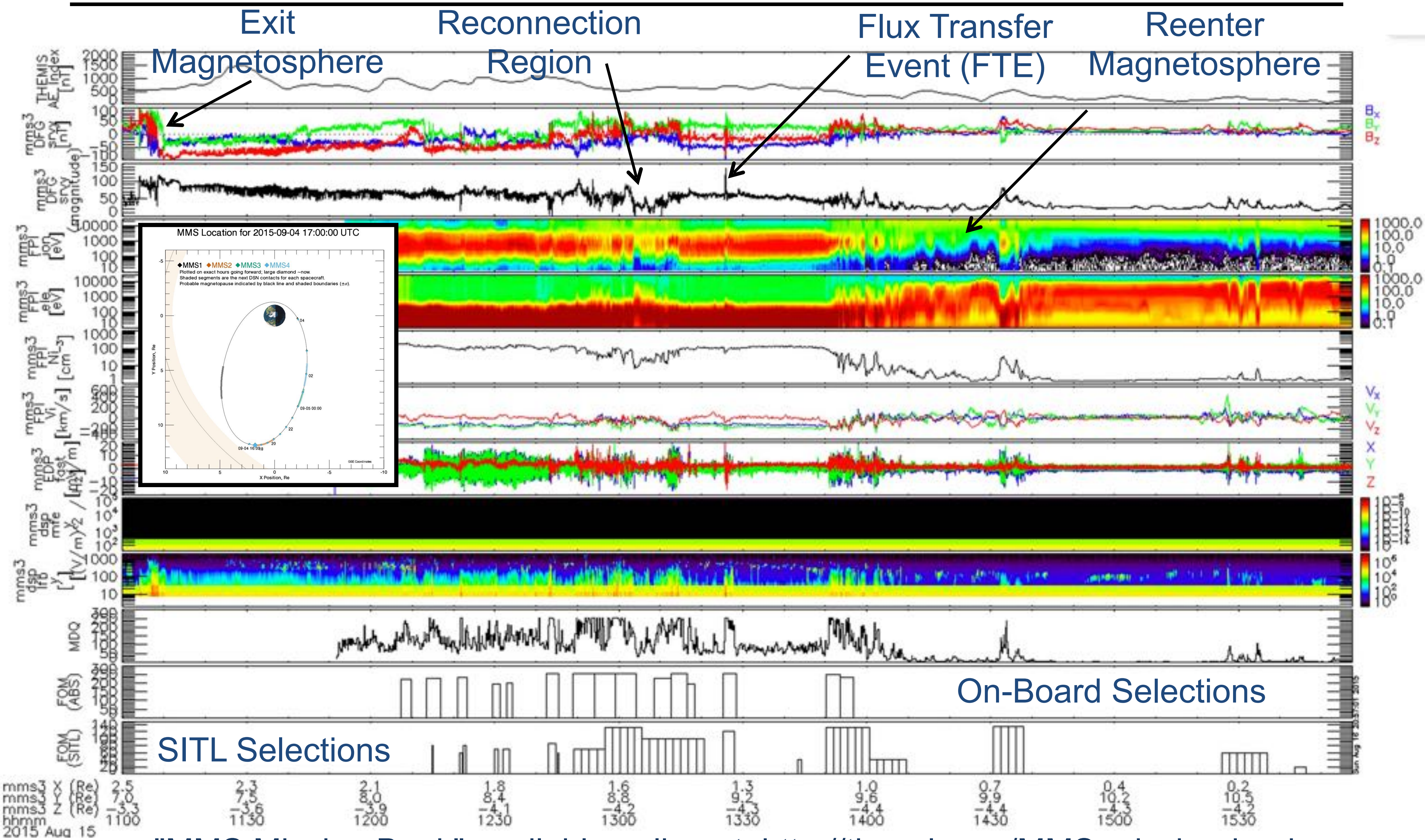
Unsolved Problems in Magnetospheric Physics
Scarborough, UK
7 September 2015

Short Answer

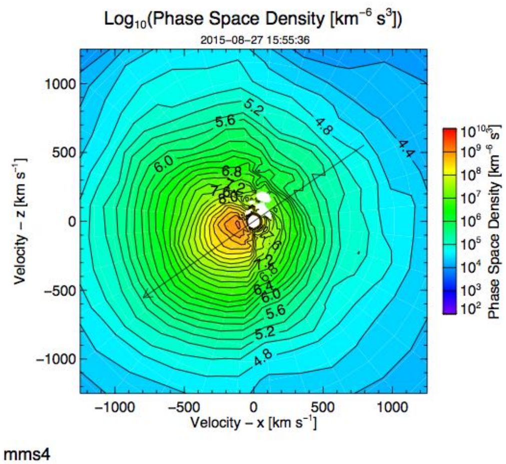
- Reconnected flux tubes pick up ions from a gravity trap

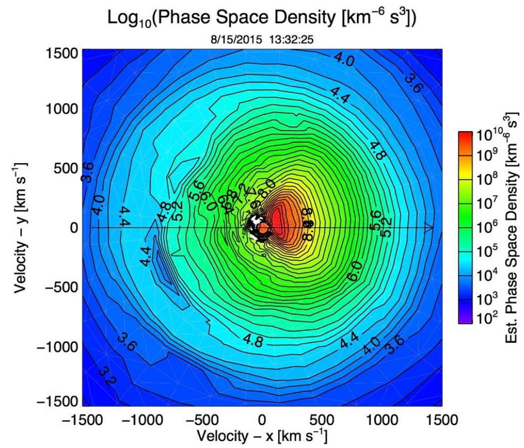
First Encounter with Reconnection Region

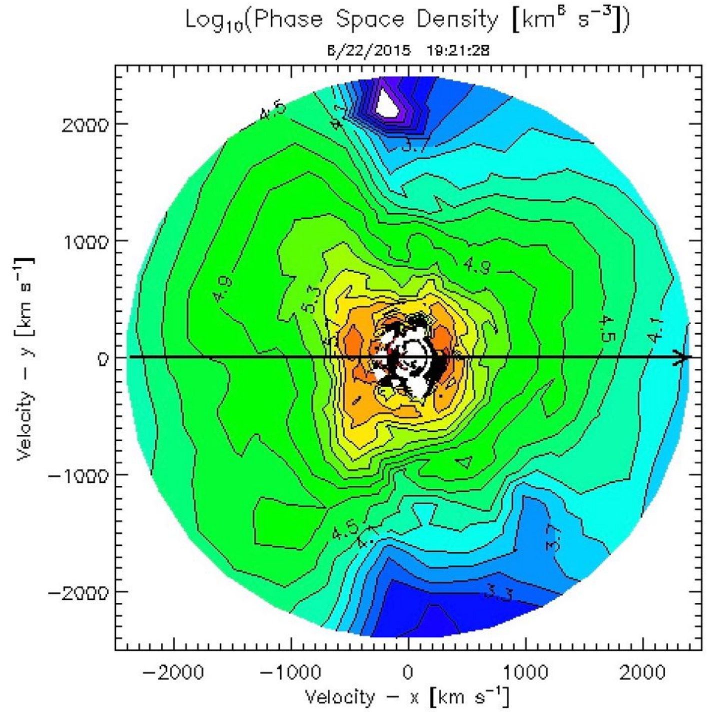


"MMS Mission Book" available online at: http://tinyurl.com/MMS-mission-book

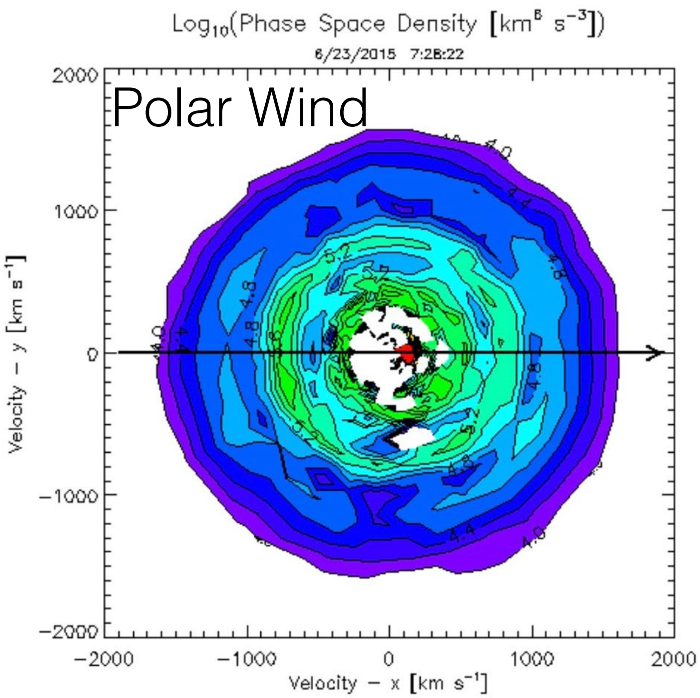
Magnetosheath Flows



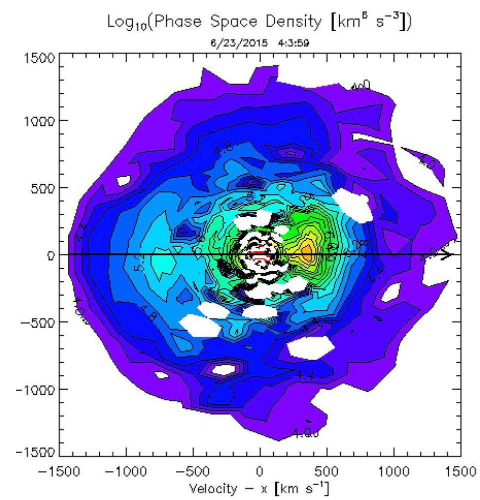




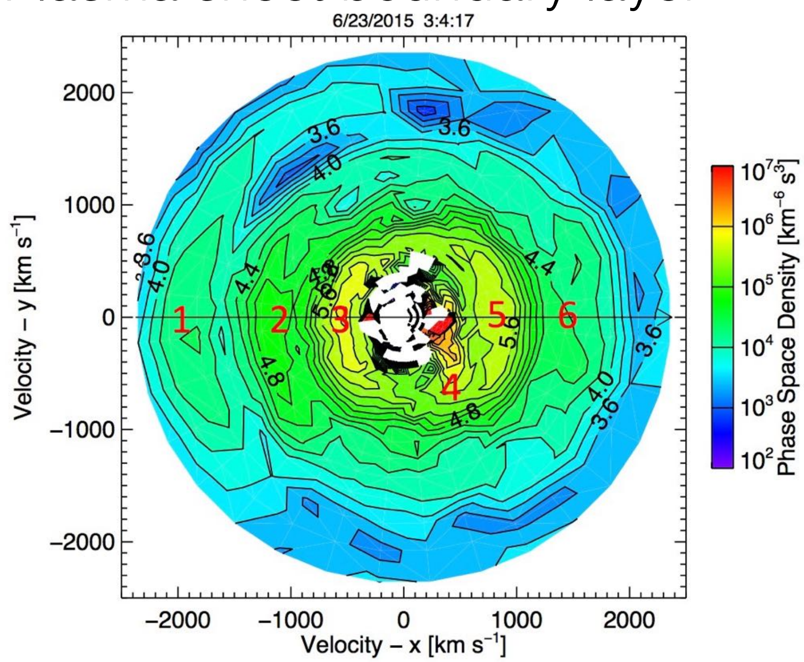
Polar Wind



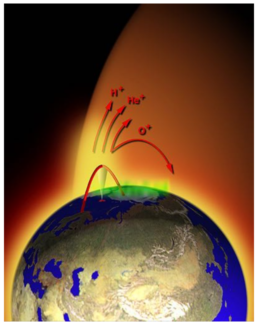
Auroral Wind

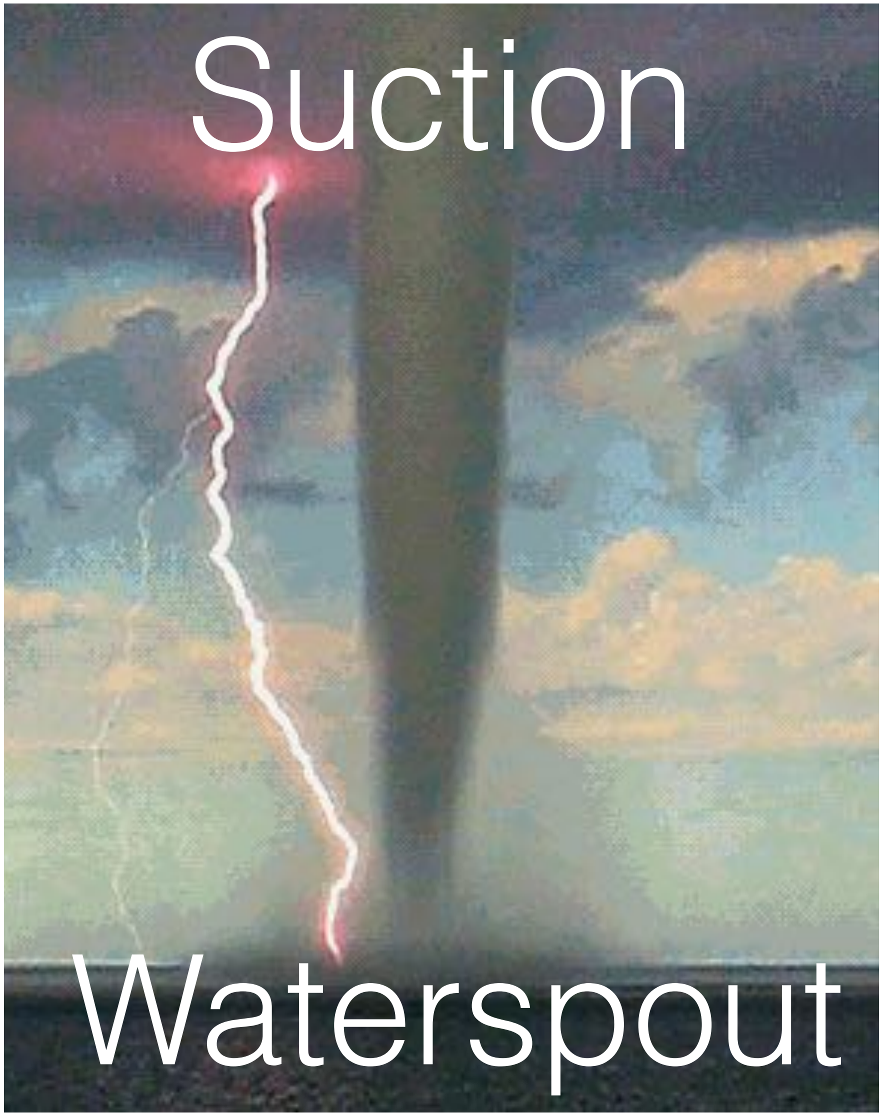


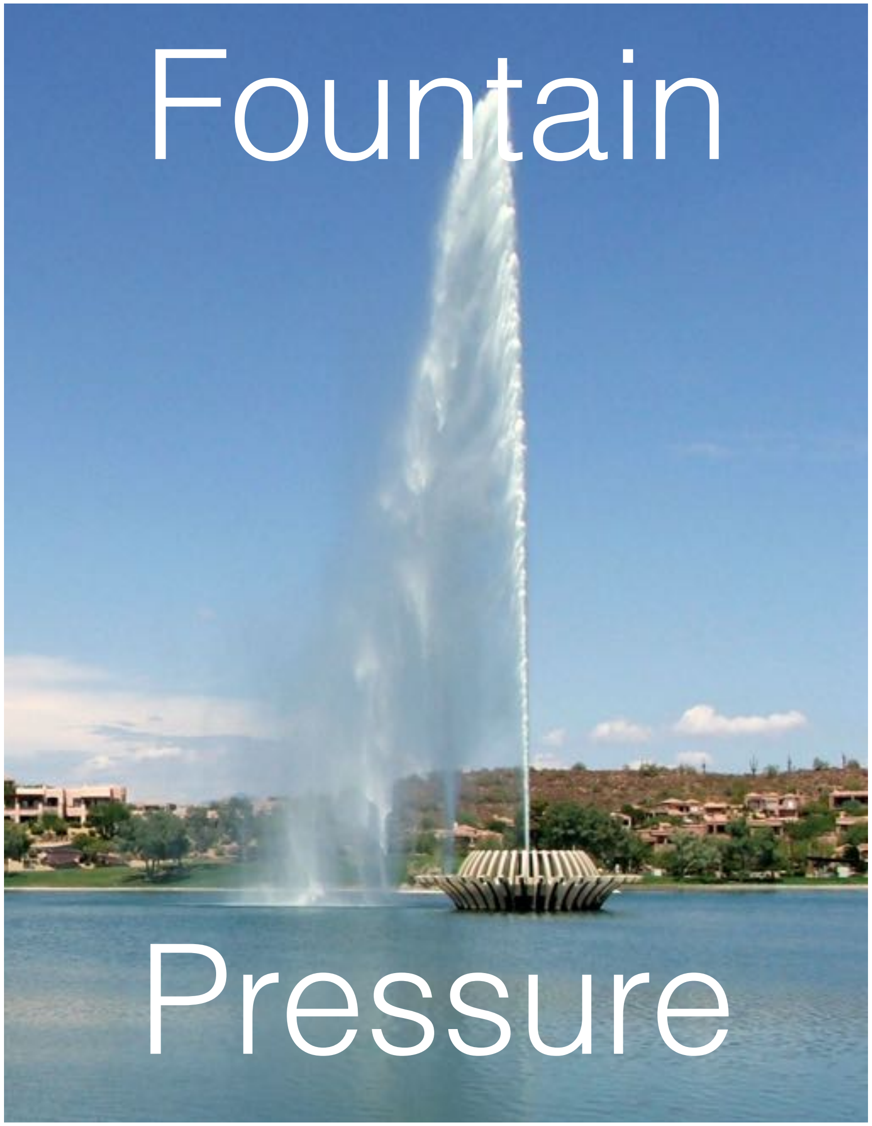
Plasma sheet boundary layer



What produces the mass flux?
Vacuum Cleaner or Fountain?







Fundamental Problem?

- How get enough of ion velocity distribution up above escape speed?
- 1. Lower escape speed
- 2. Raise ion speeds

Observing Outflow Origins

EISCAT Radar Discoveries

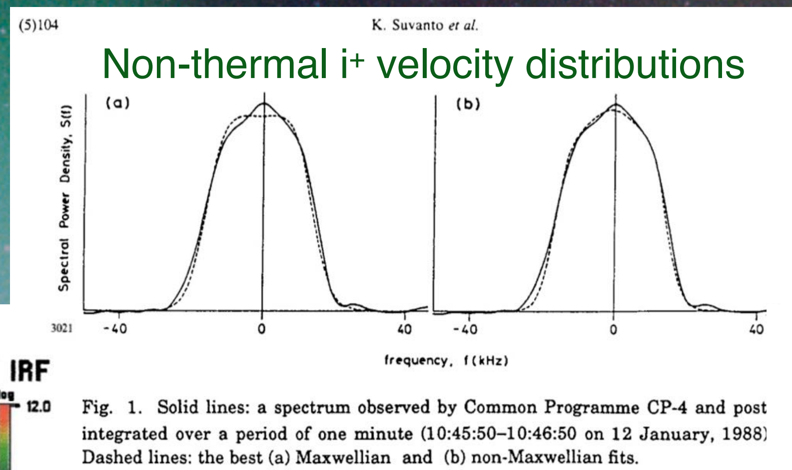
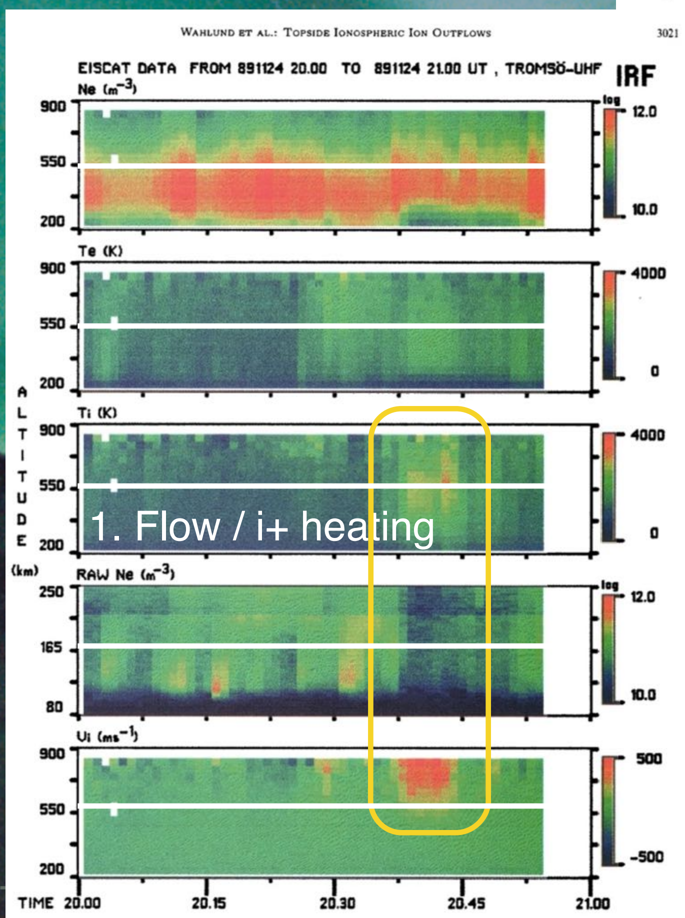
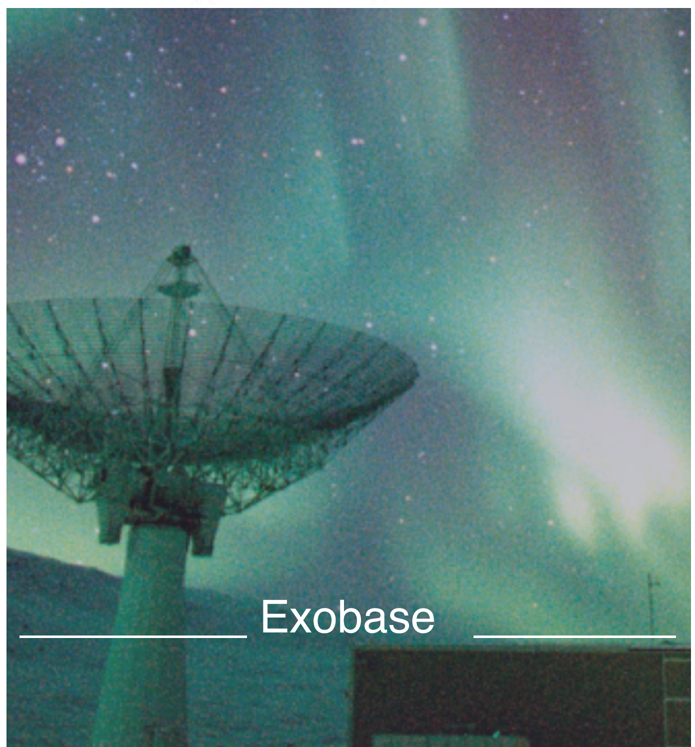


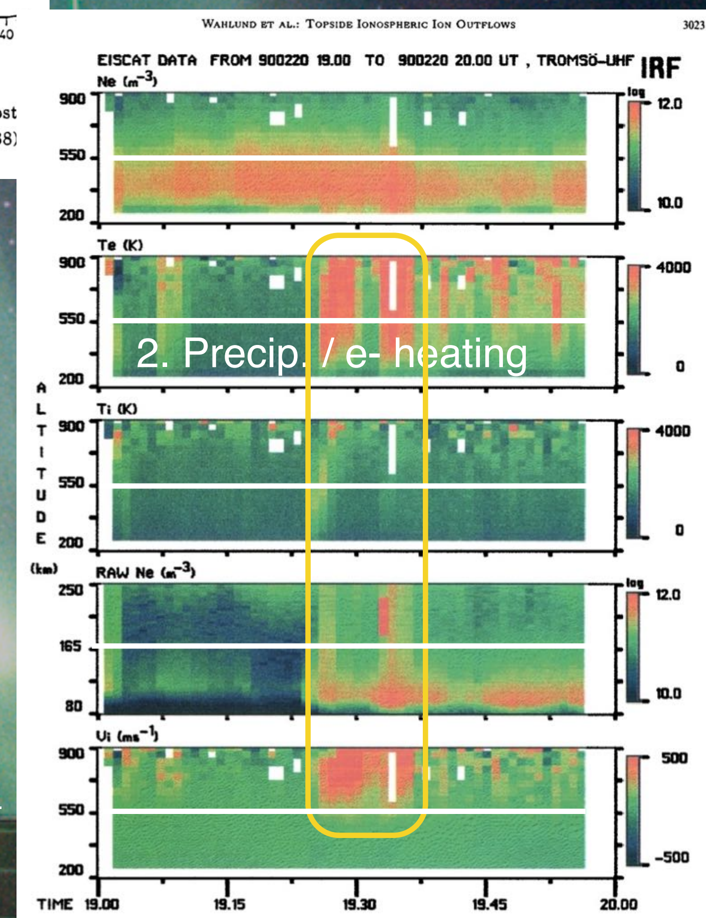
Fig. 1. Solid lines: a spectrum observed by Common Programme CP-4 and post integrated over a period of one minute (10:45:50–10:46:50 on 12 January, 1988) Dashed lines: the best (a) Maxwellian and (b) non-Maxwellian fits.

Type 1 Upflows
Ion Heating





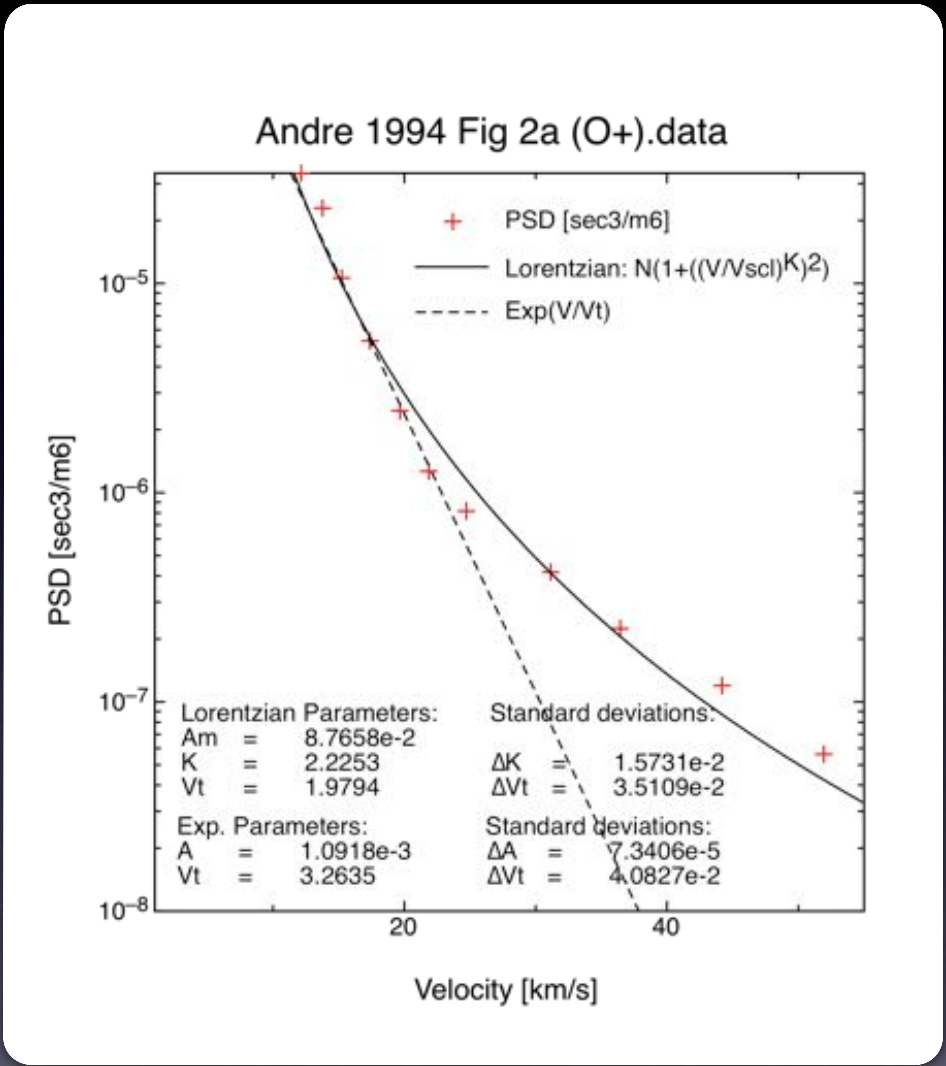
Type 2 Upflows
Electron Heating

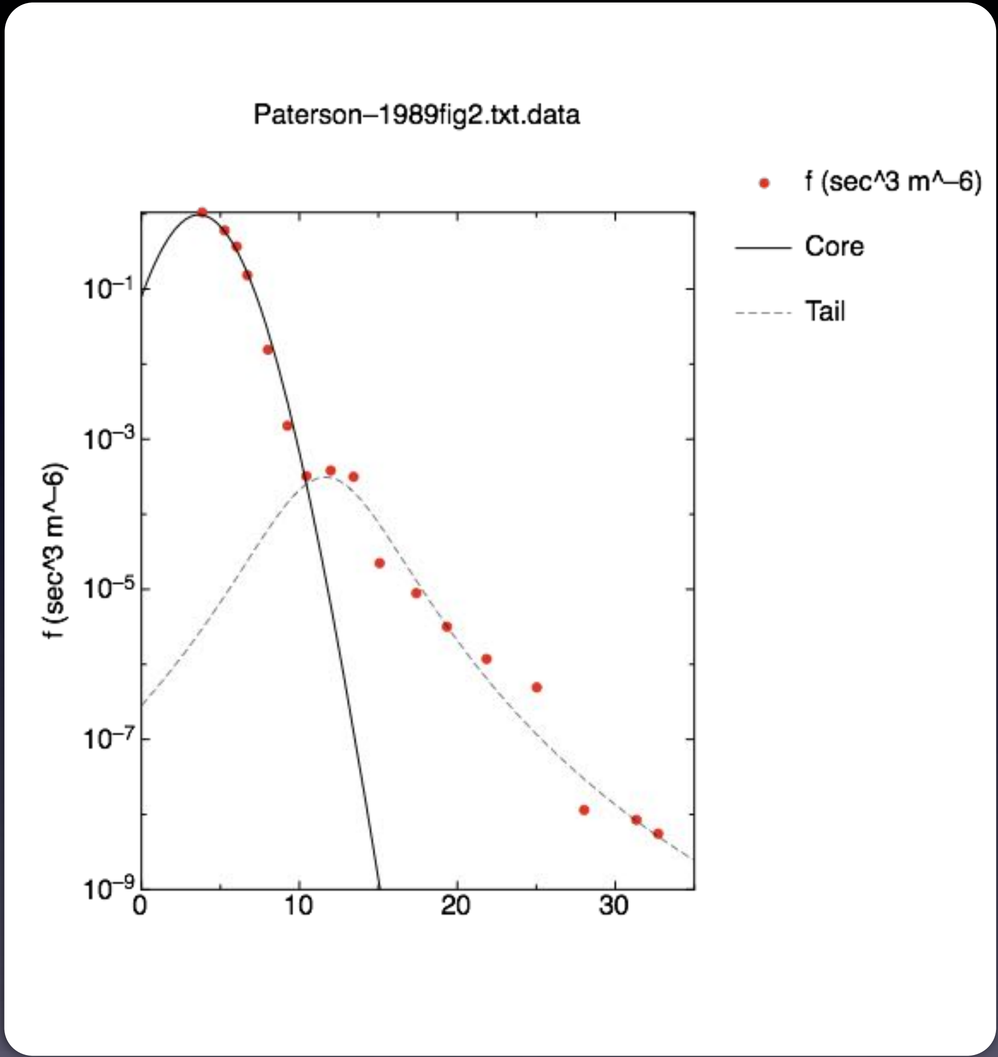


Energy Pathways

- Kinetic energy in electrons:
  - Ambipolar potential drop ~ 10-20 V reduces escape velocity
- EM energy moving ions
  - Fast ion pick-up, thermalization increase ion velocities

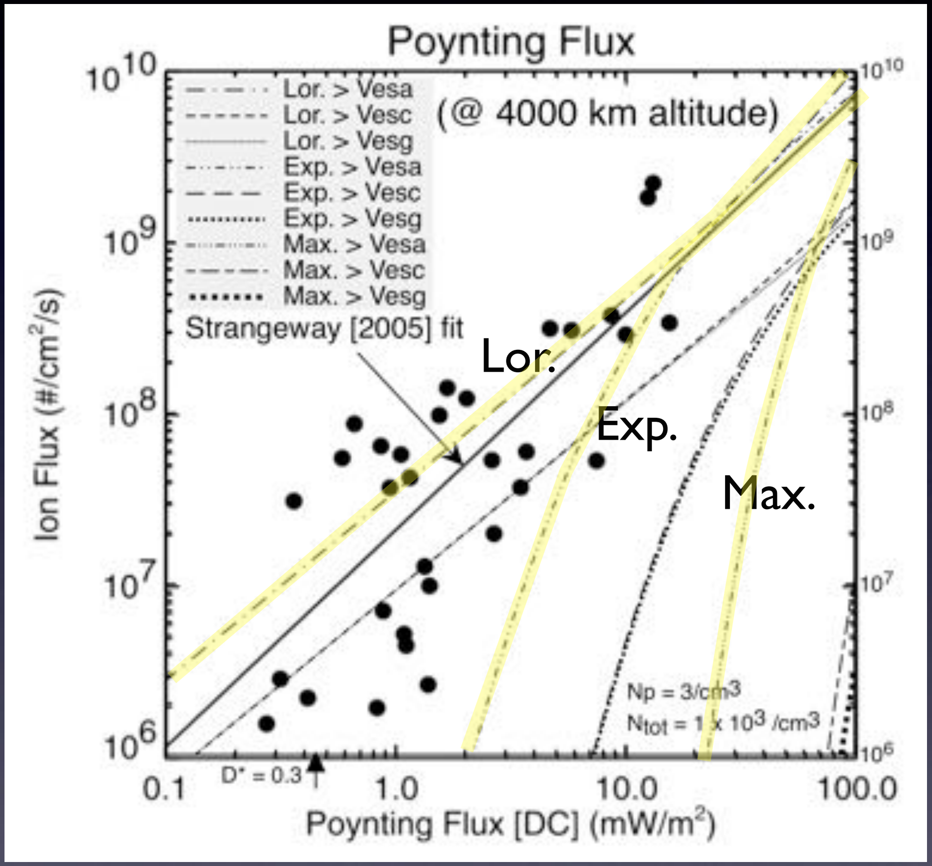
Transversely Accelerated Ions





Natural TAI and STS hot ions have power law tails

Generalized Jeans' Escape



- Jeans' ion escape in ambipolar potential with centrifugal force
- Consider three velocity forms
- Power law form most realistic

Observed outflow => power law tails [Moore & Khazanov 2010]

Hasegawa Hypothesis

- Assume presence of plasma turbulence
- Velocity dependent velocity diffusion $\sigma \sim v^2$
- => power law tails
- What is origin of turbulence?

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Plasma Distribution Function in a Superthermal Radiation Field

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and

longer proportional to the friction coefficient. In this Letter, we show that the proportionality constant is then given by the square of the test-particle velocity in the high-energy regime. This leads to a multiplicative stochastic process[2] in the velocity-space diffusion, and a power-law distribution function originates at the high-energy tail. The overall distribution function resembles the κ distribution[3] which is often used to fit the particle distribution function observed in space plasmas.[4]

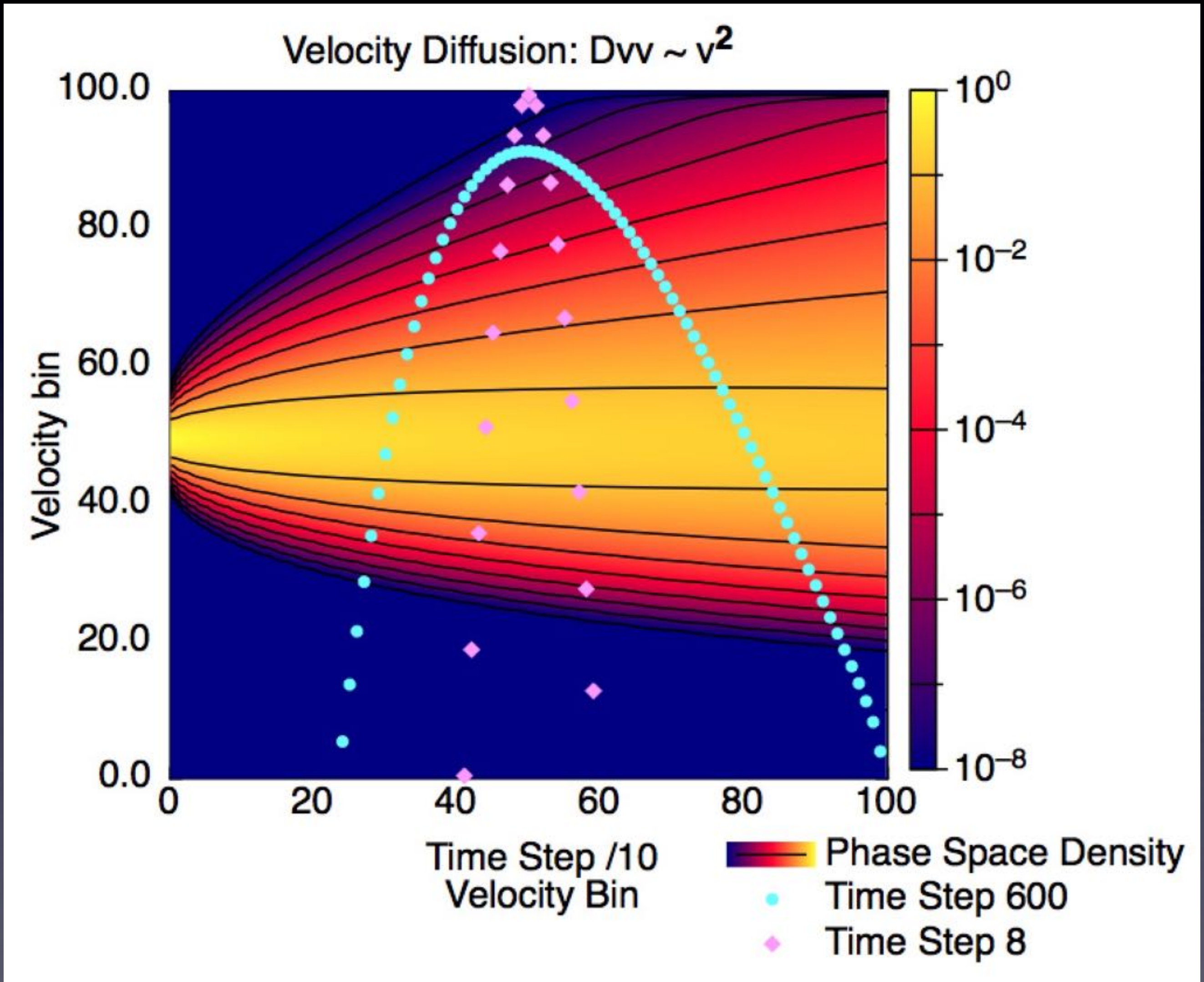
We consider the Fokker-Planck equation to describe the evolution of the distribution function in the Coulomb field[5]:

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial \mathbf{v}} \cdot \left[\frac{1}{2} \mathbf{D}(\mathbf{v}) \cdot \frac{\partial f}{\partial \mathbf{v}} - \mathbf{v}\gamma(\mathbf{v}) f \right], \quad (1)$$

where the diffusion tensor is given by

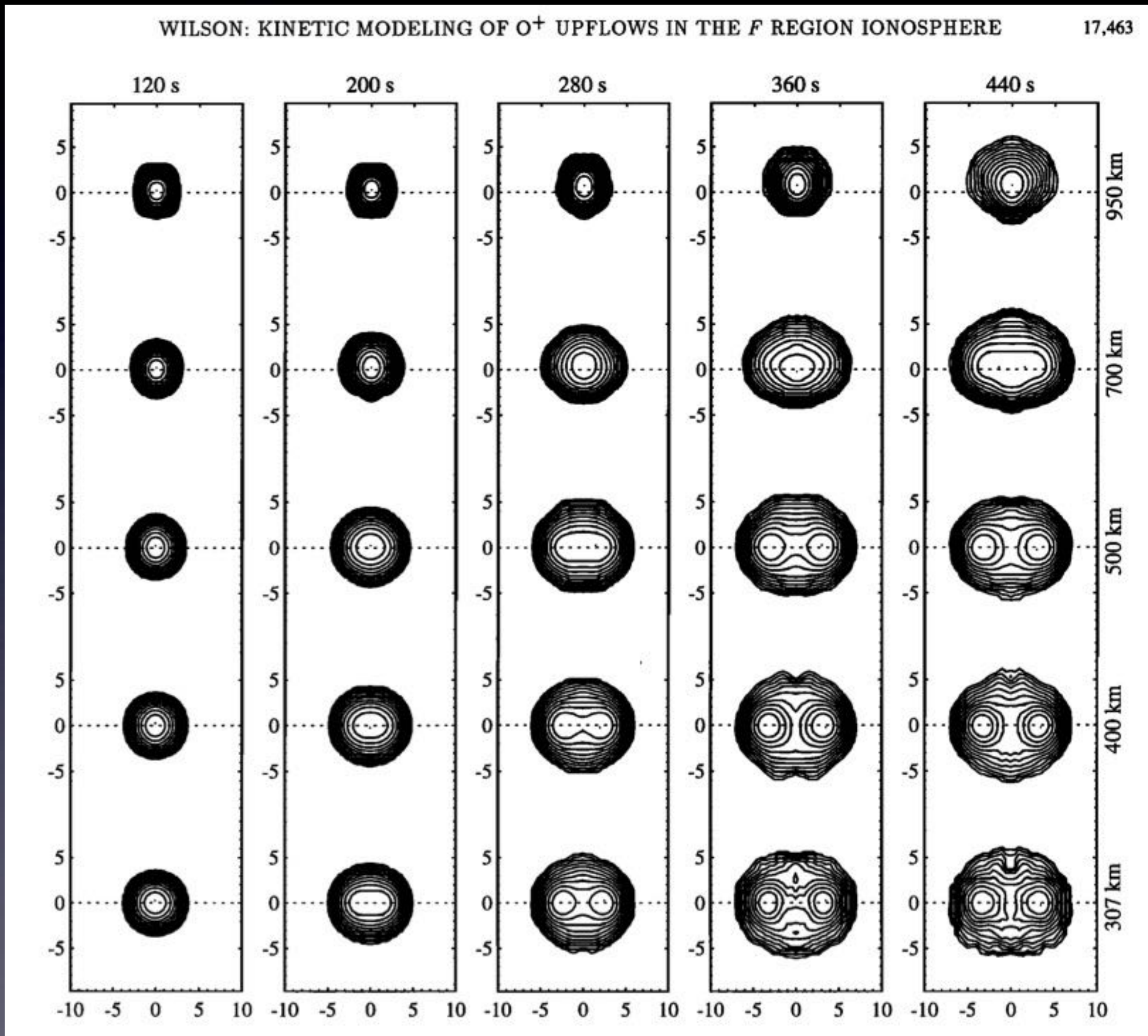
$$\mathbf{D} = D_{\parallel} \mathbf{I} + D_{\perp}(\mathbf{I} - \mathbf{v}\mathbf{v}/v^2).$$

Velocity Diffusion $\sigma_{vv} \sim v^2$

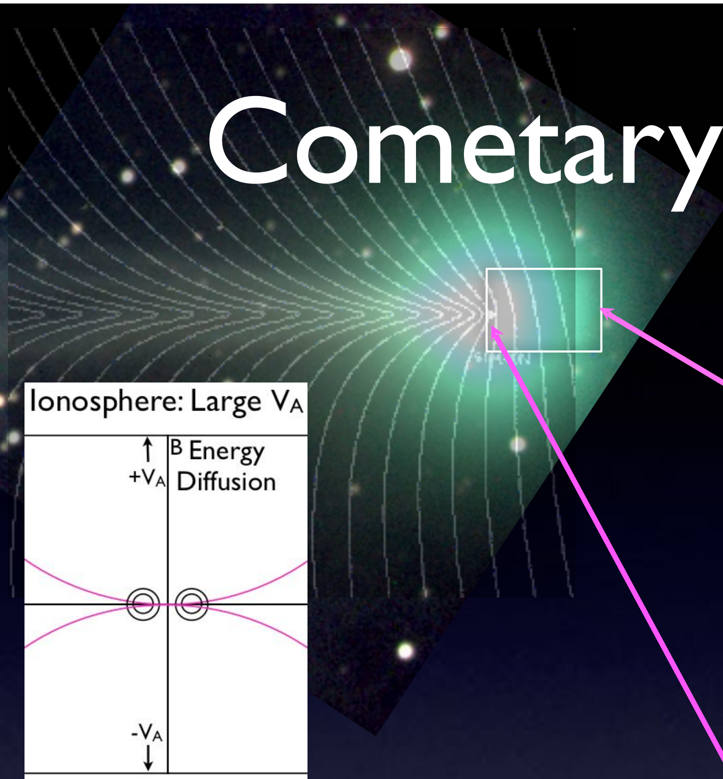


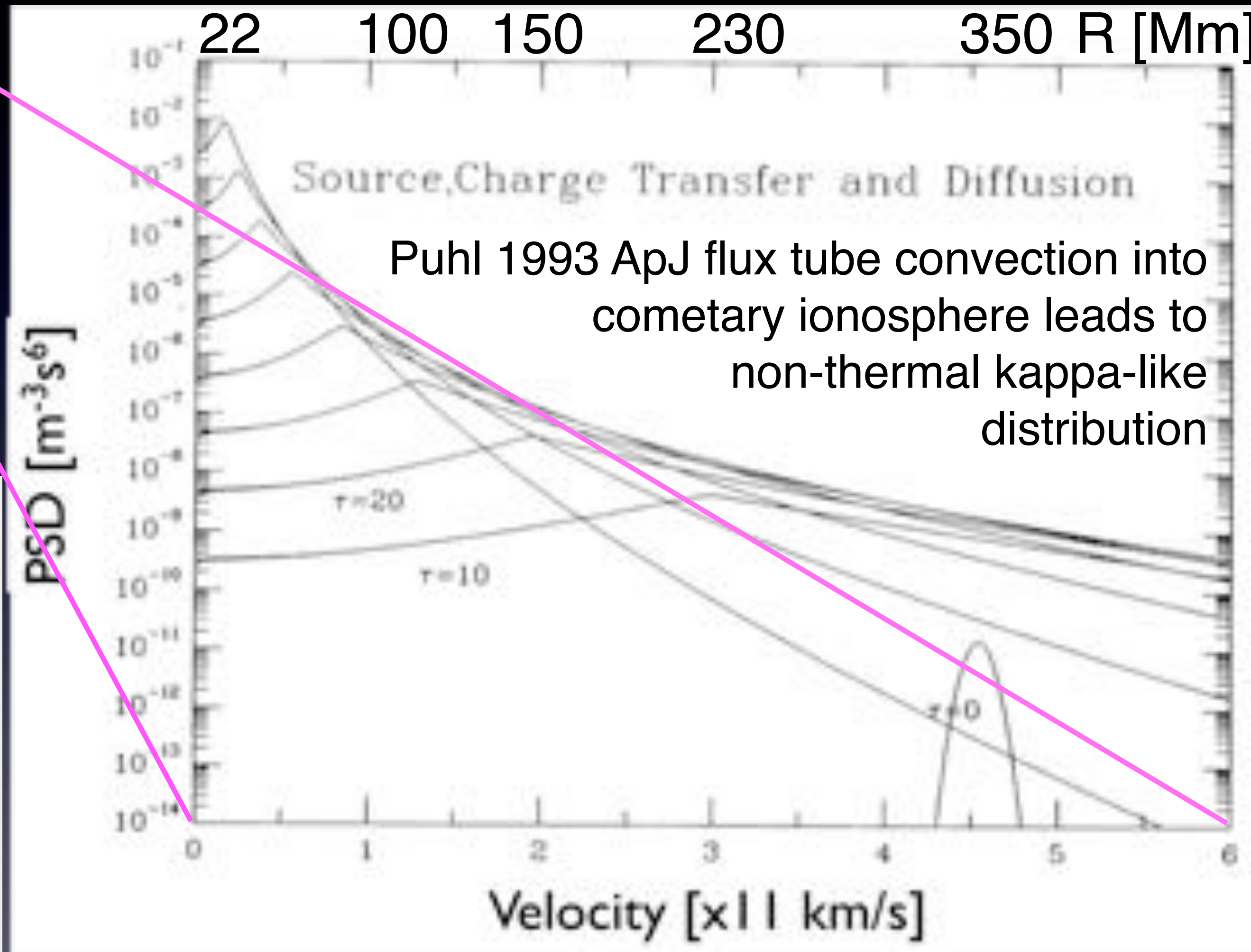
Velocity diffusion $\sim v^2$ generates power law tail

Classical physics generates plasma physics



Cometary Pick Up Ion Relaxation



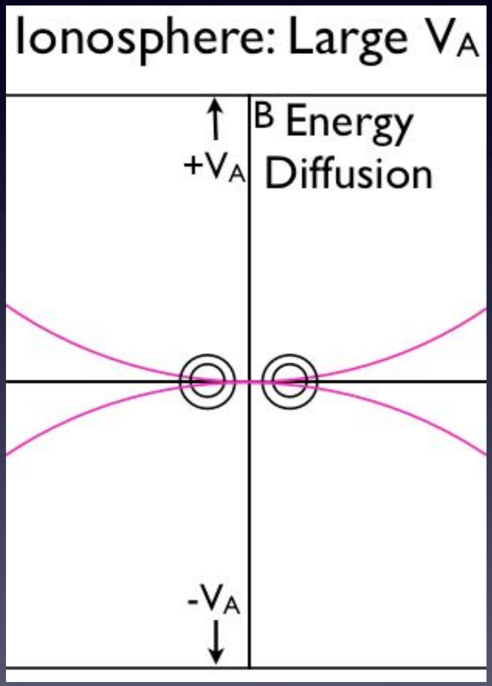


Pick Up source of ubiquitous Kappa distrib's?

Pick Up A Solved Problem?

- For flow speeds >> than V_A pure pitch angle diffusion => bispherical shell
- What if flow speeds << V_A?
- Spherical shell diffusion is then transverse to B
- Just as observed for auroral wind outflows

Pick Up Ions in limit of small V/V_A



=> perpendicular energy diffusion

Isenberg&Vasquez 2007 ApJ

An Outstanding Problem of Space Plasma Physics

- How do pick up ions thermalize their pick up energy (where $V > V_{Ti}$)
- Does thermalizing turbulence create power law tails (Kappa distributions) per Hasegawa?
- Pick-Up Ion (PUI) physics is as fundamental as the auroral electron bump-in-tail instability
- General quasilinear theory solution has not been accomplished
- Smart money on better observations and simulations