Shock-Generated Energetic Particle Populations & Their Effects in the Foreshock Region

Eberhard Möbius **& H. Kucharek**

Space Science Center and Department of Physics

University of New Hampshire

***Thanks to all our collaborators**, especially:*

M. Scholer, R. Behlke

L. Kistler, B. Klecker, C. Mouikis,

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9/30/2005

Shock-Generated Energetic Particle Populations & Their Effects in the Foreshock Region

- *Introduction and Motivation*
- *Reflection at the Quasi-Perpendicular BS*
- *Beam Effects Upstream*
- *Diffusion and Gradients at the Quasi-Parallel BS*
- *Effects Upstream (SLAMS)*

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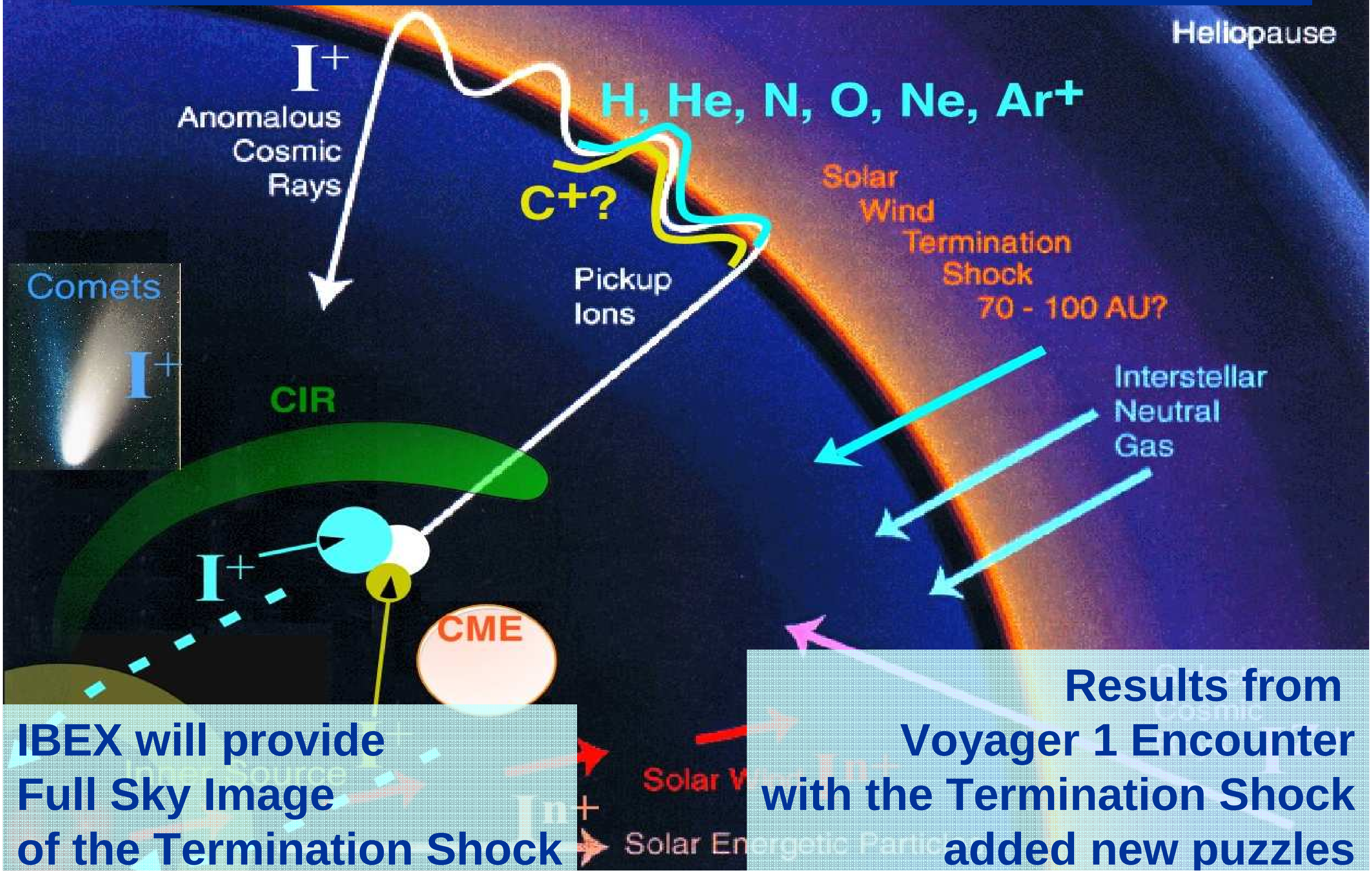
Shocks are Powerful Astrophysical Accelerators

- **Supernova Shocks thought to generate Cosmic Rays**
- **Shocks are also found around stellar and galactic winds**
- **Shocks also accelerate particles in the heliosphere**
- ***And thus can be studied locally!***

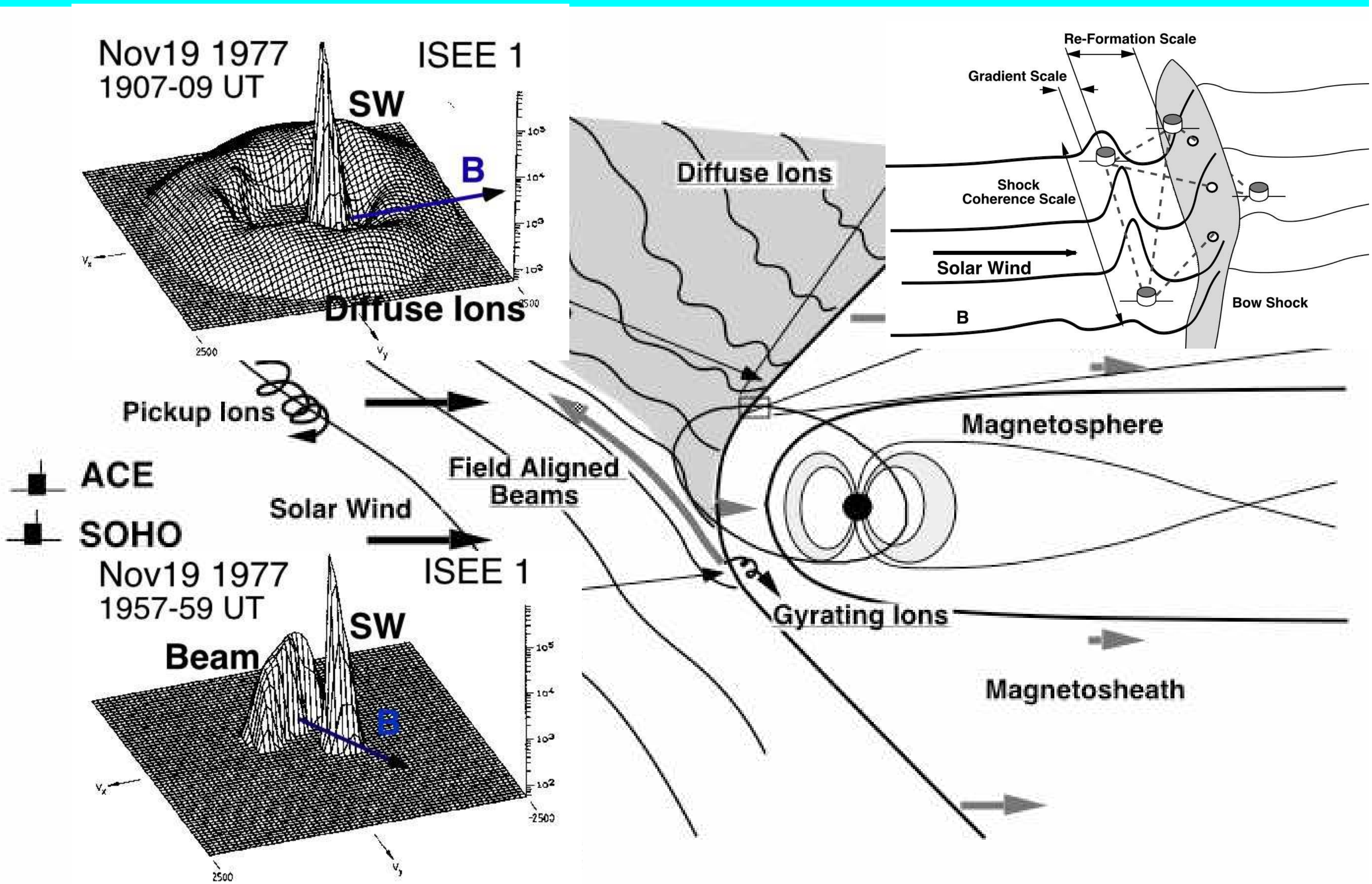
Let's get the details at the Bow Shock With Cluster!



IBEX will provide Full Sky Image of the Termination Shock

Results from Voyager 1 Encounter with the Termination Shock added new puzzles

Bow Shock Configurations



Ion Populations at the Quasi-Perpendicular Shock

- **Gyrating Ions Convected Downstream**
  - turn into anisotropic distribution (low M_A)
  - turn into isotropic distribution (high M_A)

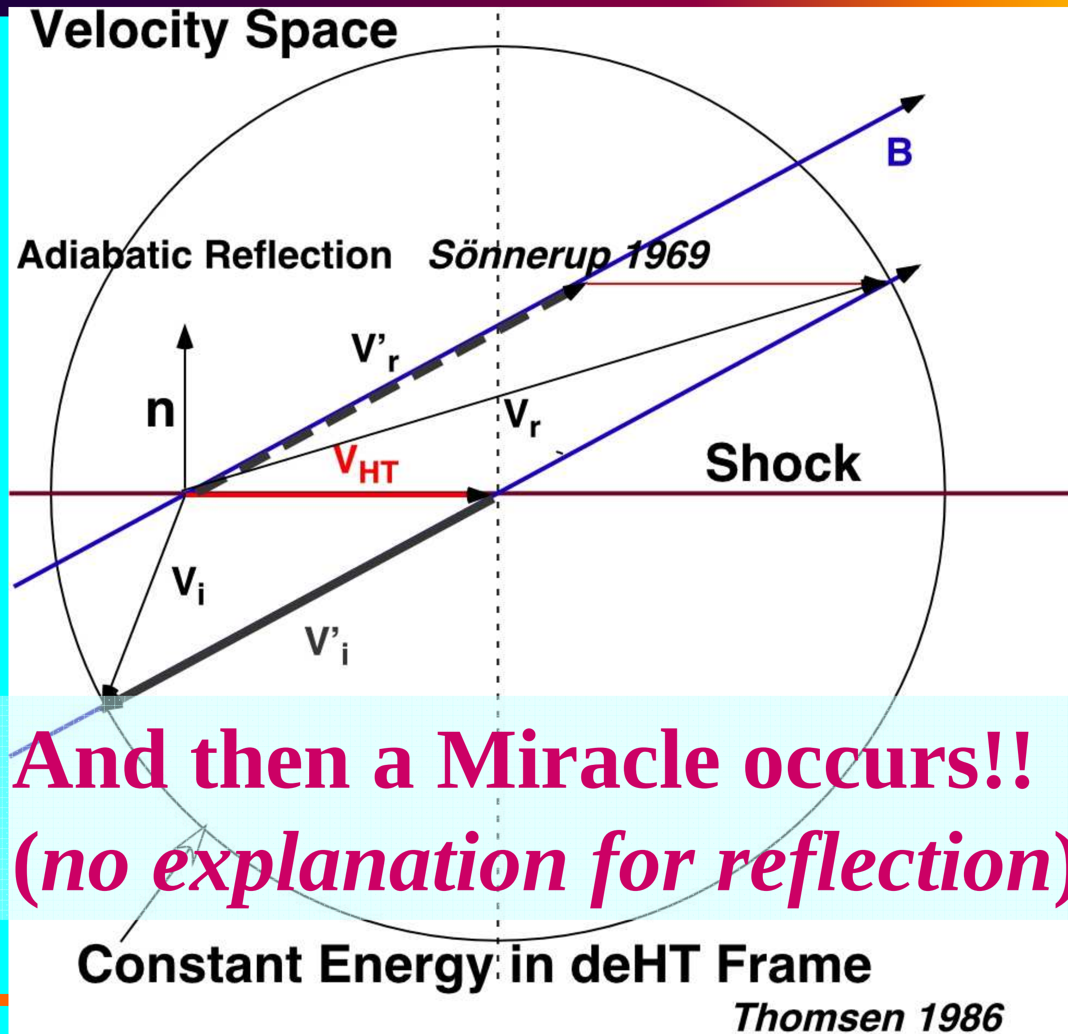
  Sckopke et al., 1983, 1990
- **Reflected Ion Beam along the Magnetic Field**
  - Energy condition in DeHofman-Teller Frame

  Paschmann et al., 1980
  - Usually with very few α-Particles

  Ipavich et al., 1988; Fuselier, 1994

Adiabatic Reflection (Sönnerup 1969)

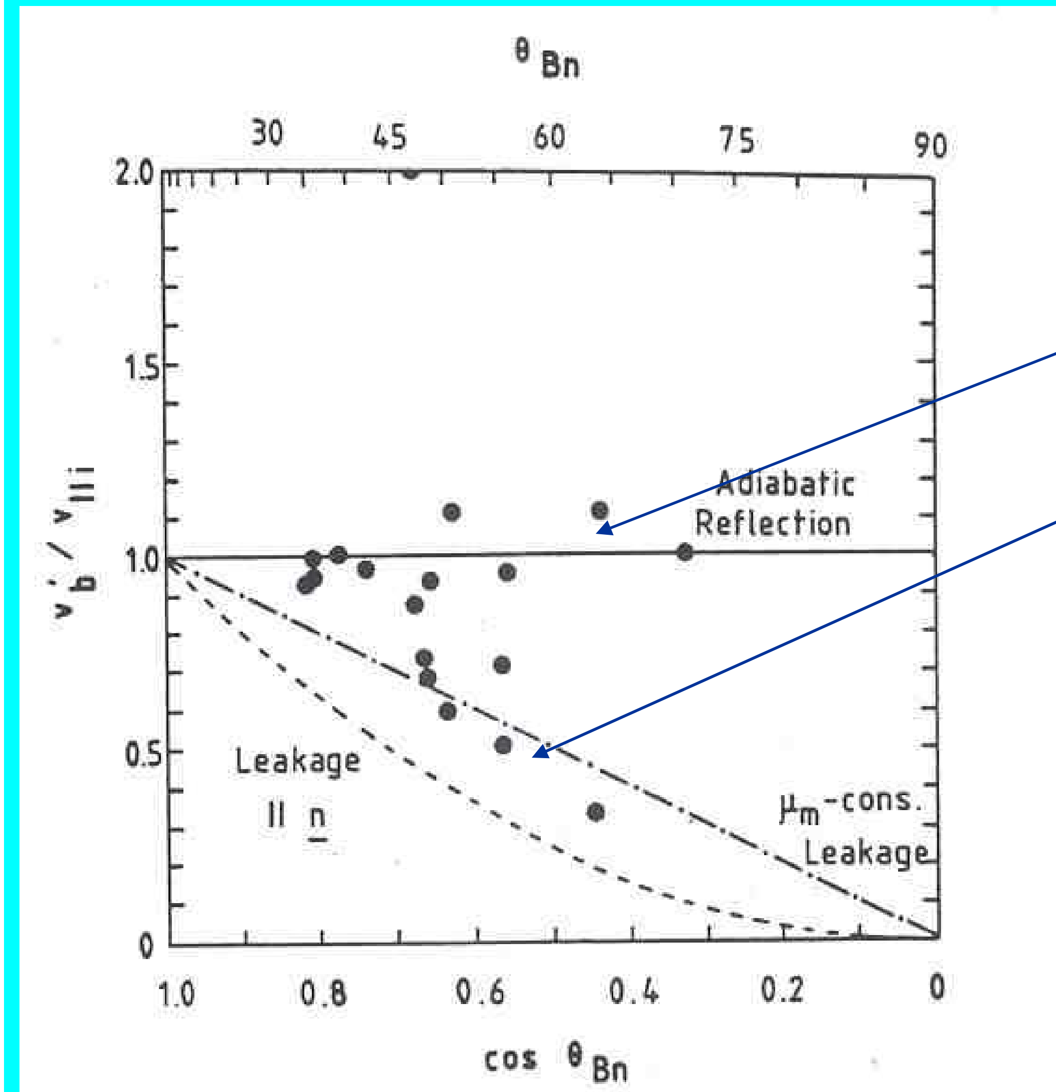
- $V'_{r||} / V_i = \dfrac{\cos\Theta_{Vn}}{\cos\Theta_{Bn}}$



And then a Miracle occurs!!

(*no explanation for reflection*)

Source of Field-aligned Beams Theoretical Considerations



Evidence for generation through Adiabatic Reflection of solar wind and through Leakage of heated magnetosheath ions

Schwartz and Burgess 1984

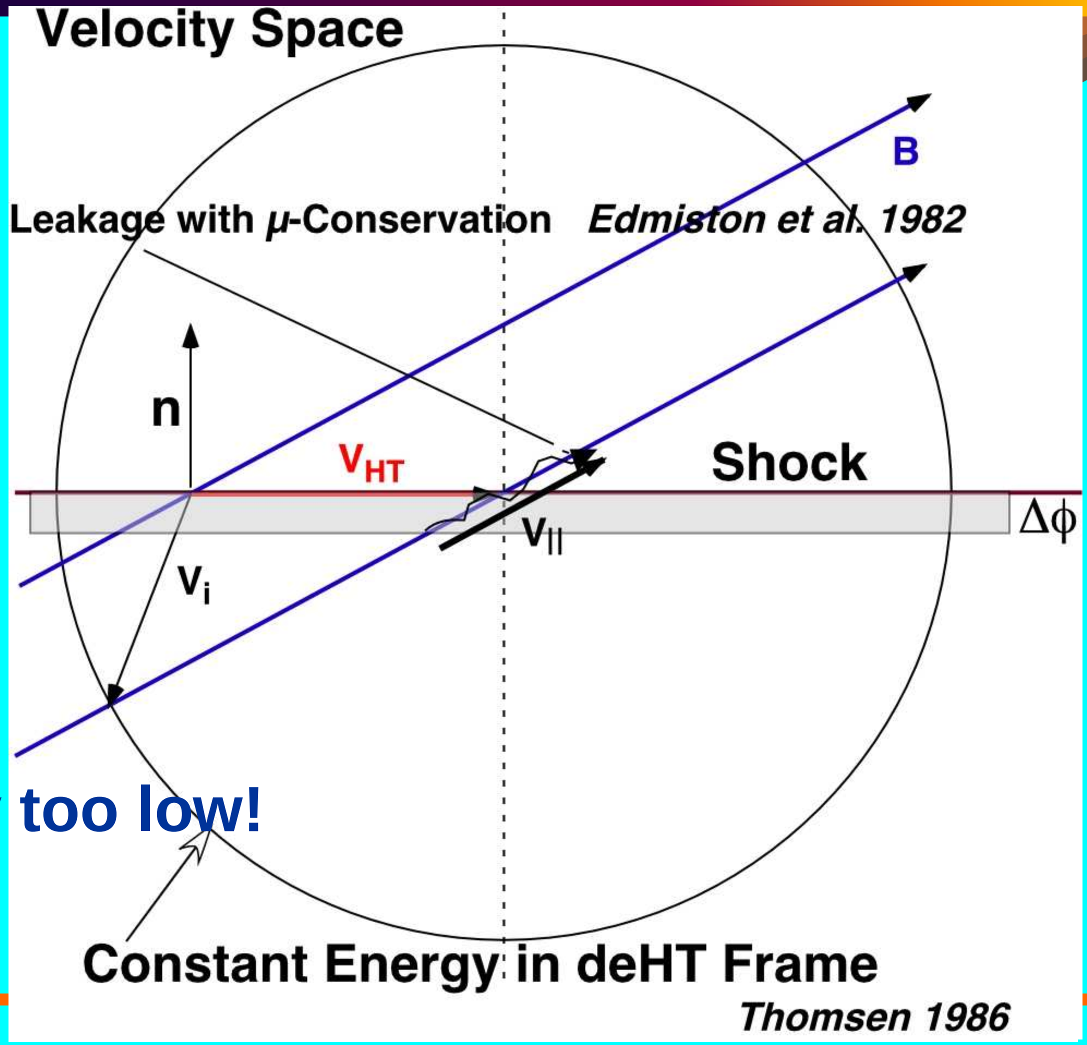
<u>Assumptions:</u>

- Planar shock

- DeHofmann Teller frame proper reference frame

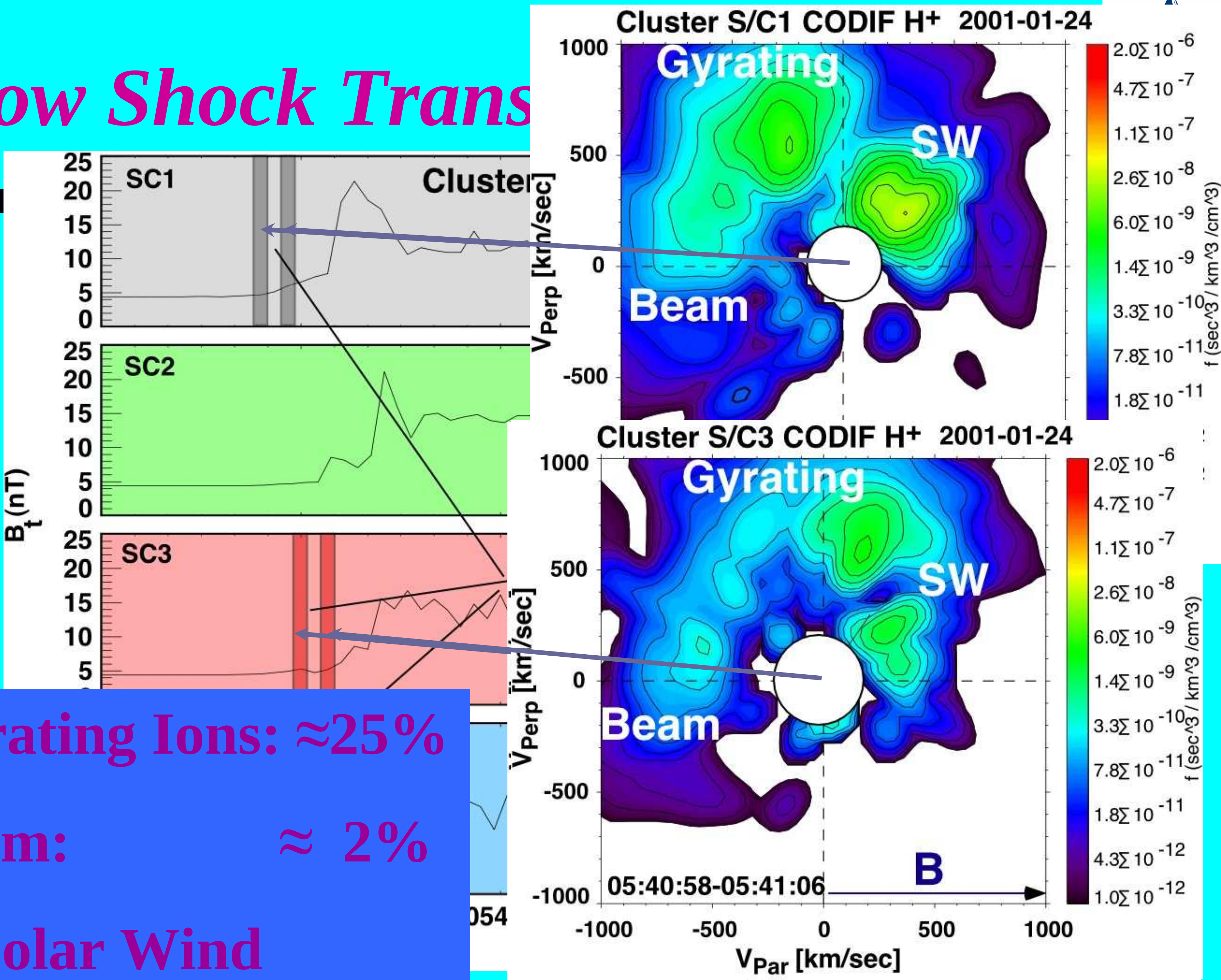
Leakage ||B from the Magnetosheath

- $V'_{r||} / V_i = \cos\Theta_{Vn}$



Beam Mostly Energy too low!

Bow Shock Trans



Gyrating Ions: ≈25%

Beam: ≈ 2%

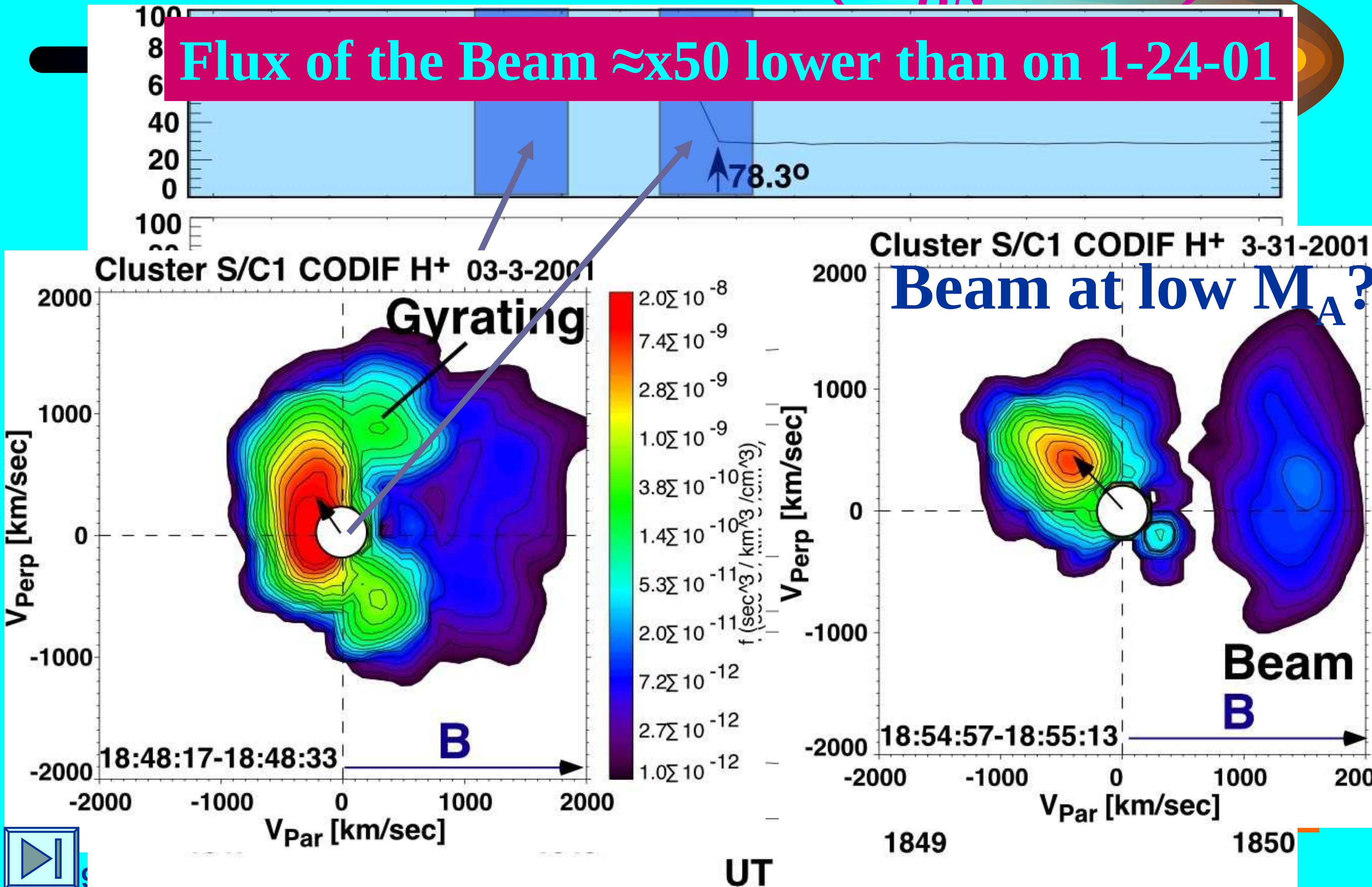
of Solar Wind

Beam Generation:

Thermalization vs. Immediate Scattering

- **Thermalization in the Downstream Region and leakage upstream along B, where Θ_{BN} small enough to allow escape (Max. Θ_{BN})**
  Edmiston et al., 1982, Tanaka et al., 1983
- **Reflection in the Ramp and <u>immediate scattering</u> by Alfvén waves; Ions ||B can escape along B *Scholer et al., 2000* (Scattering depends on M_A)**
  <u>Multiple encounters</u> *Burgess;Oka et al. 2005*

BS Transition 3-31-01 (Θ_{BN} = 78º)

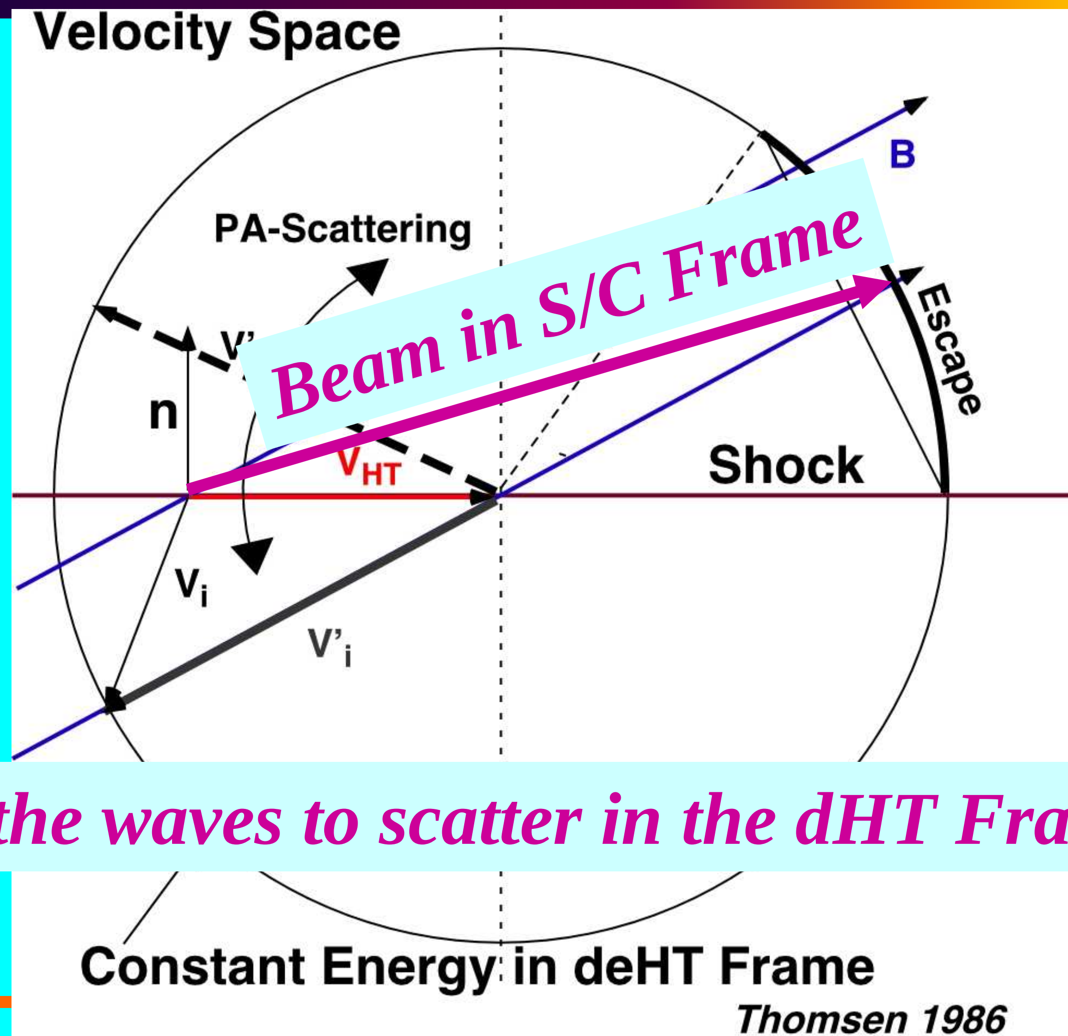


New Understanding of Field-Aligned Beams

- **At Quasi-Perpendicular Shocks Ion Beams Emerge from Reflected Gyrating Ions**
  - Scattering appears to happen immediately in the shock ramp
  - Thermalization downstream of the shock does <u>not seem to</u> play a role
- **How Does that Lead to the Energy Condition Observed by *Paschmann et al. 1980*?**
  - Direct reflection in dHT frame not viable

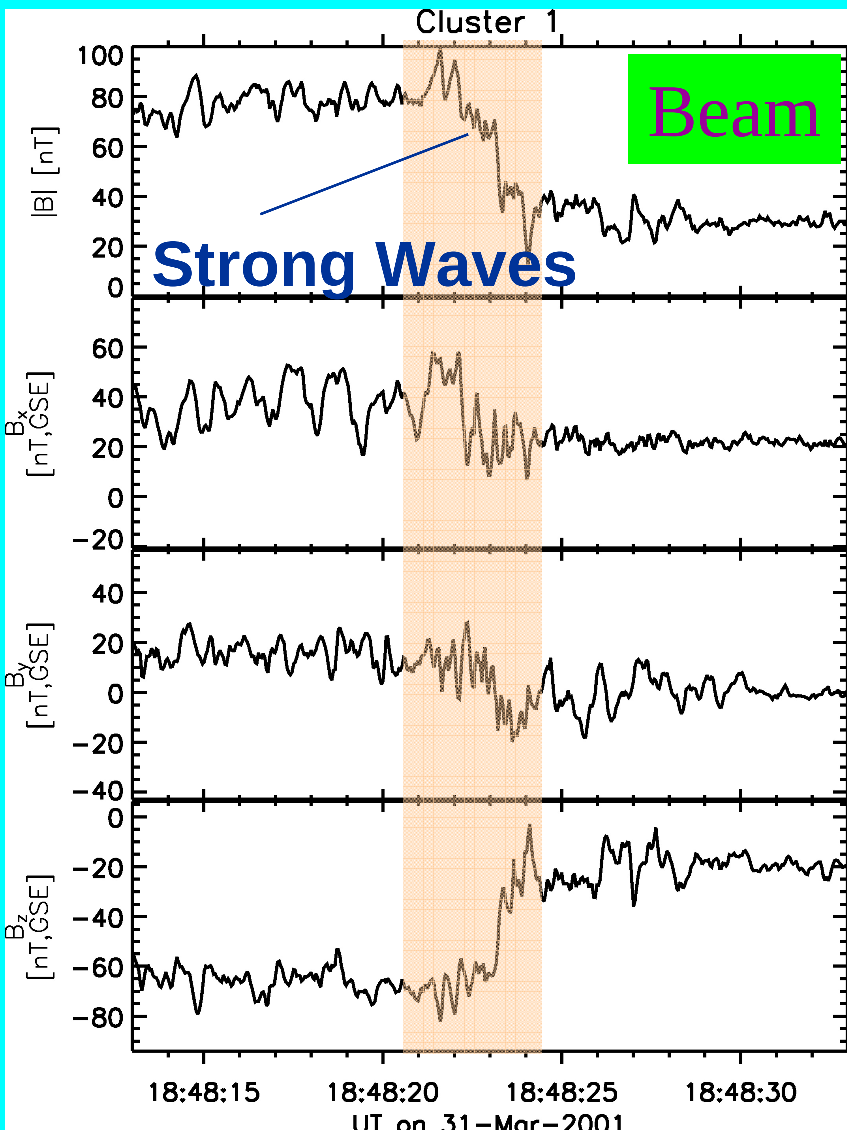
Specular Reflection (as for gyrating ions +scattering)

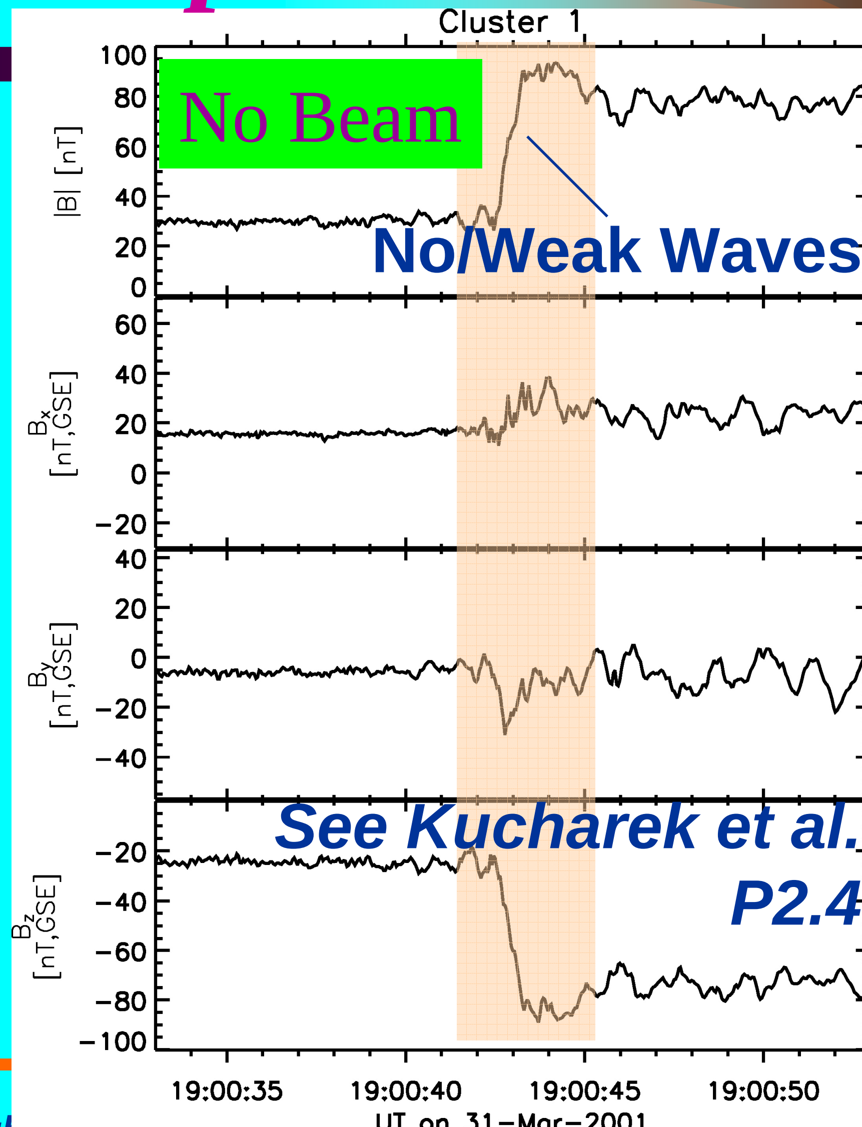
- $$\frac{V'_{r\|}}{V_i} \leq \frac{\cos\Theta_{Vn}}{\cos\Theta_{Bn}} * (2\cos^2\Theta_{Bn} - 1)$$



Problem: ***What tells the waves to scatter in the dHT Frame?***

Are Beams Tied to Waves in the Ramp?

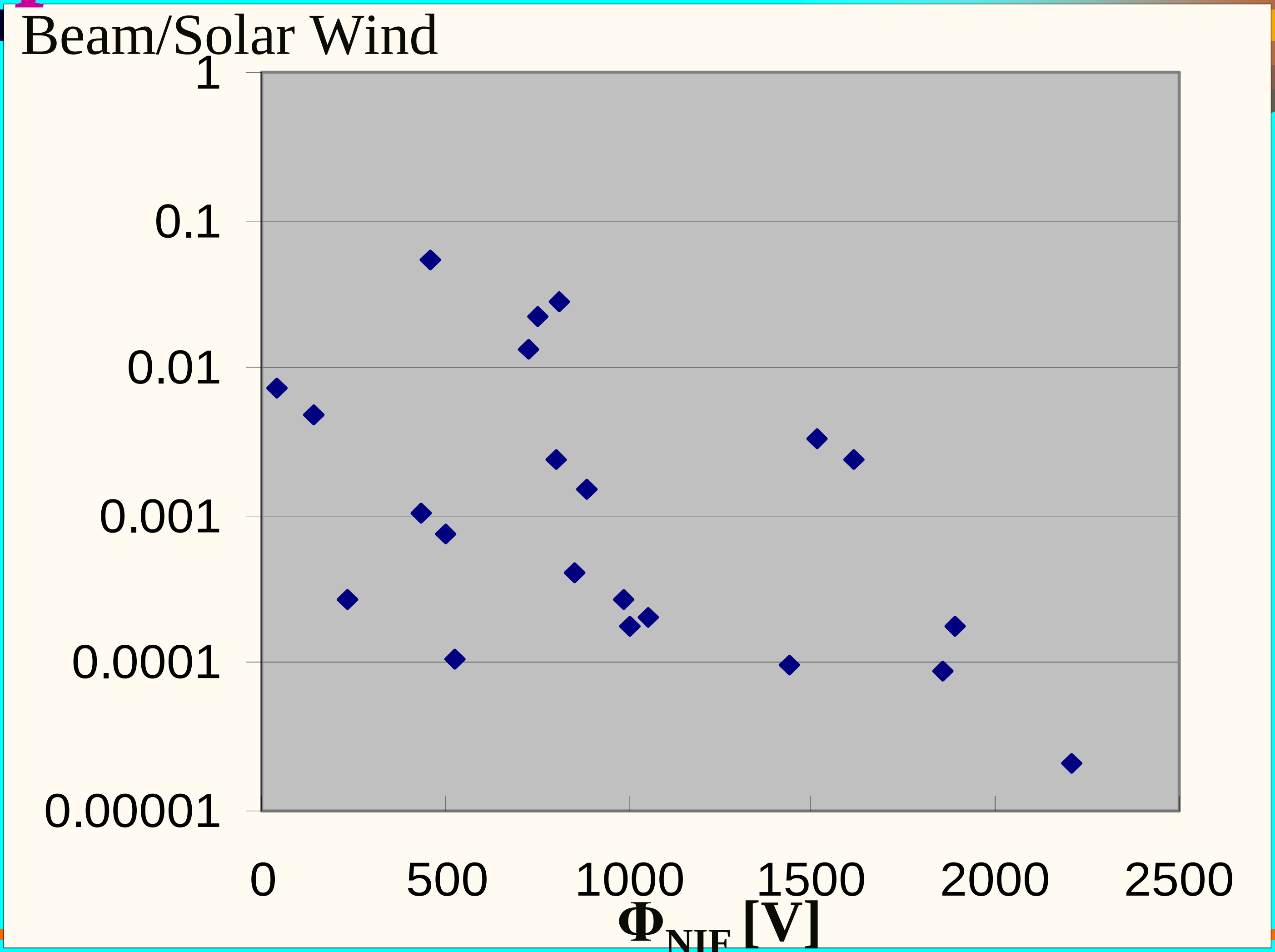




Ion Beam Observations To Be Performed/In Progress!

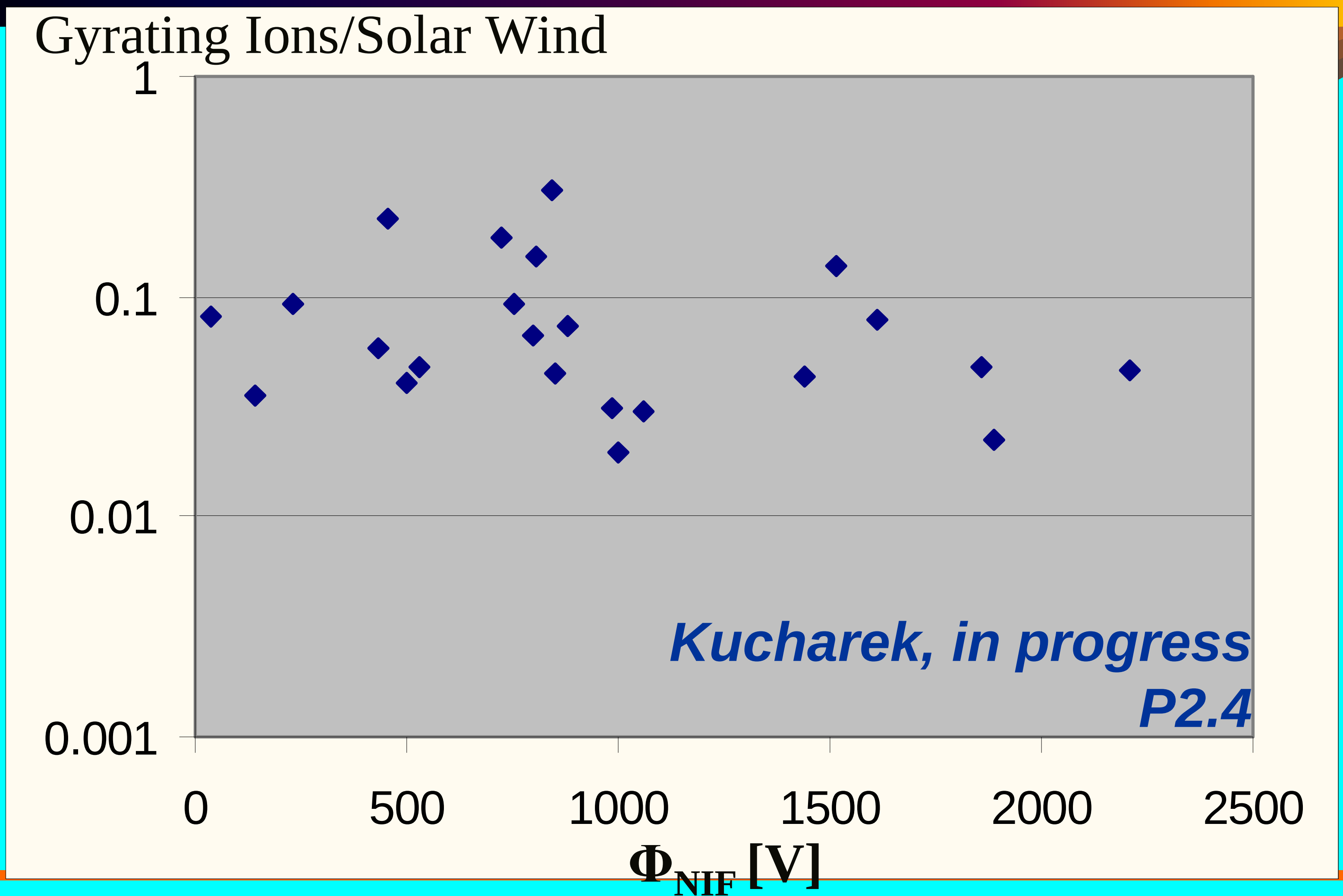
- **Energies:**
  Peak, Minimum, Maximum in Spectra
  How effective is the energy transfer?
- **Pitch-Angle Distribution**
  Consistent with Escape Condition?
- **Angle of Peak**
  Is it ||B or offset according to Transformation?
- **Shock Dynamics**: ***Changes Transformation Condition***
  Graduate Student Work (Bin Miao)
- **All as Function of**: Θ_{Bn}, Θ_{Vn}, M_A, β, $\Delta\Phi$ +…

First Crack at Dependence on Shock Potential

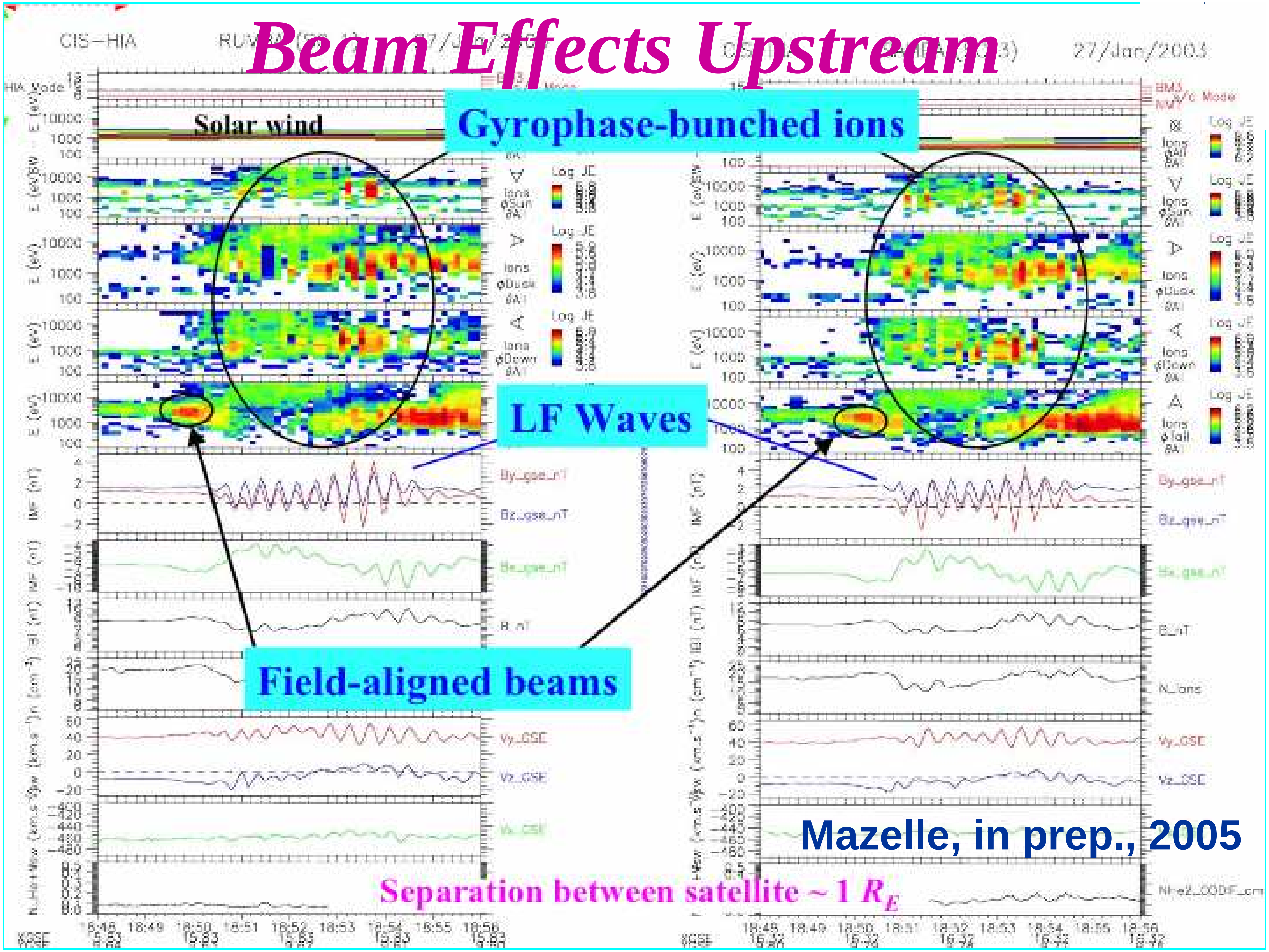


Kucharek, in progress

First Crack at Dependence on Shock Potential

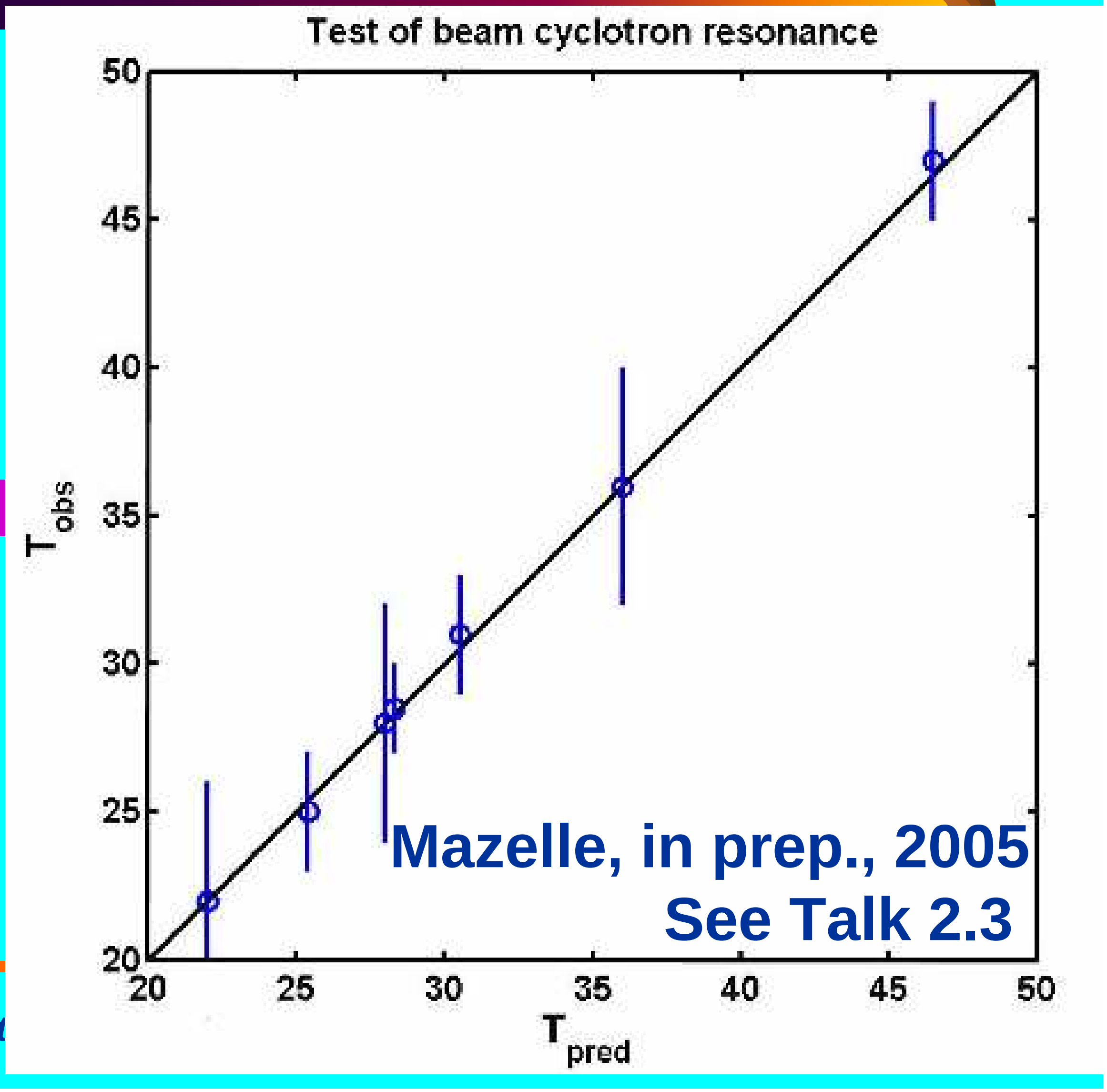


Beam Effects Upstream



Waves & Particles Obey Gyro-Resonance Condition

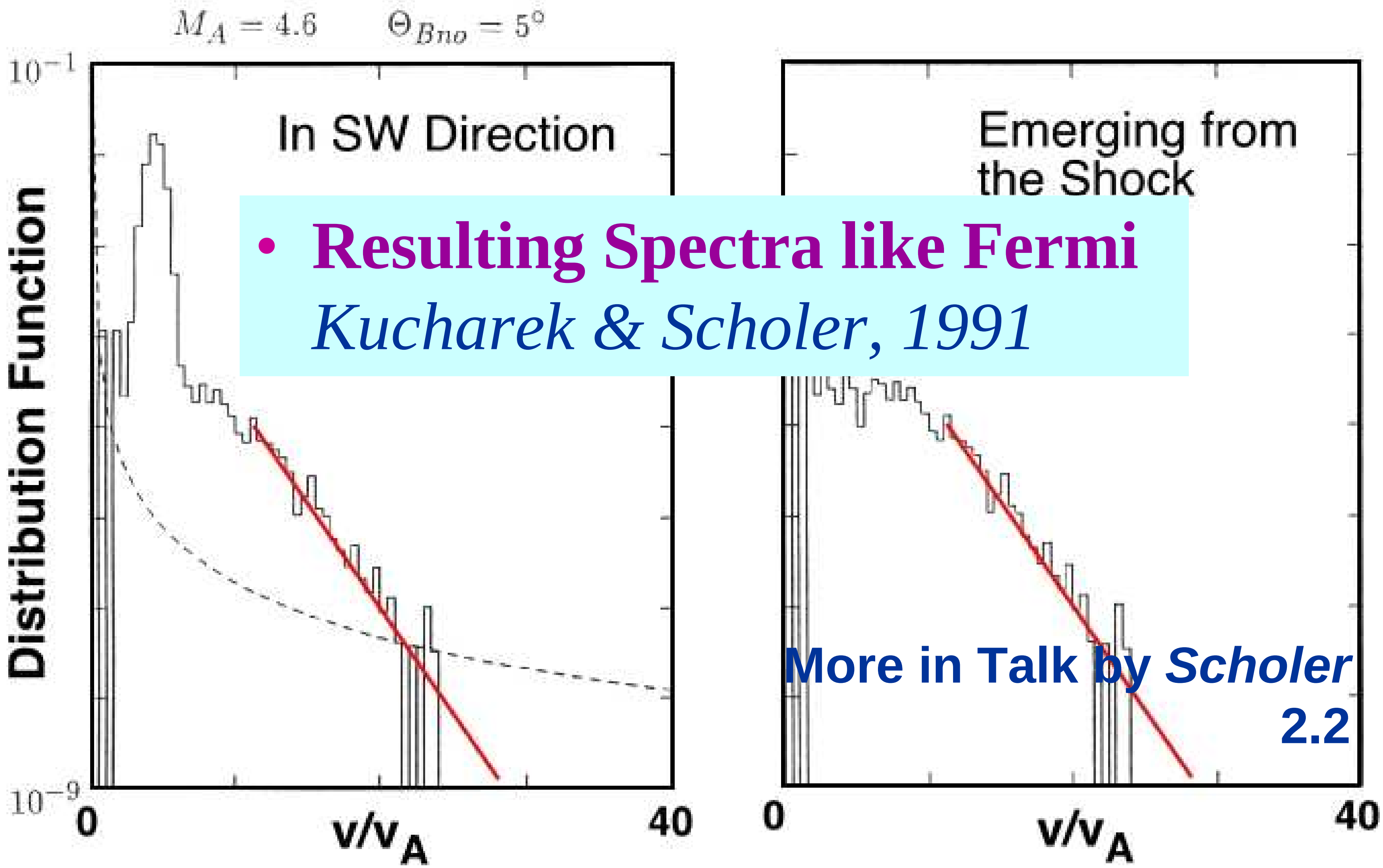
- $\omega - k_{||}v_{||} + \Omega_p = 0$
- Energy of original beam conserved
- However, switch between Beam and Waves + Gyro-Phase Bunching not fully understood!



Is the Quasi-Parallel Shock Simpler?

- Here is where 1st Order Fermi Acceleration is supposed to work?
- Ions easily cross the shock repeatedly along the field lines
- But: How to get Particles with already some energy relative to SW?

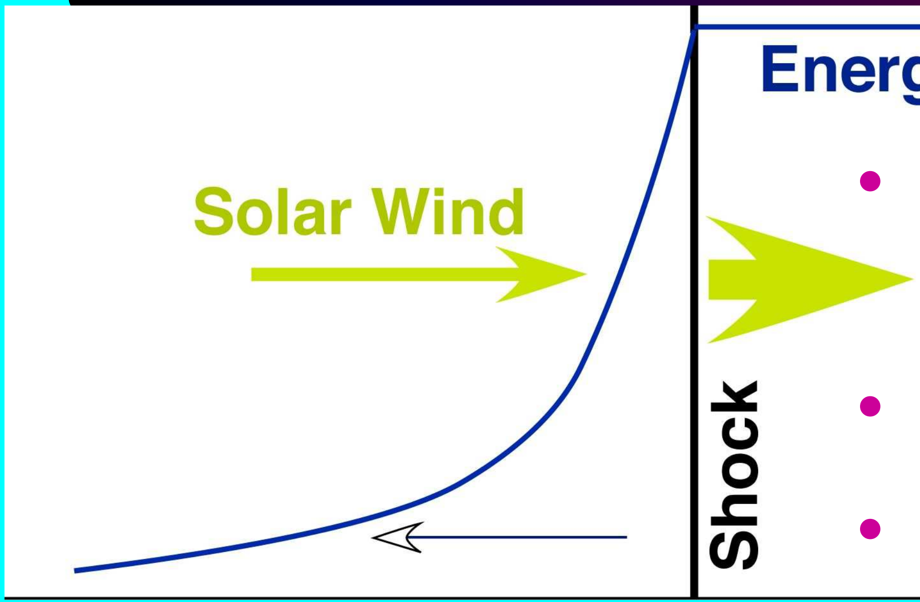
Quasi-Parallel Shock



- **Resulting Spectra like Fermi**
  Kucharek & Scholer, 1991

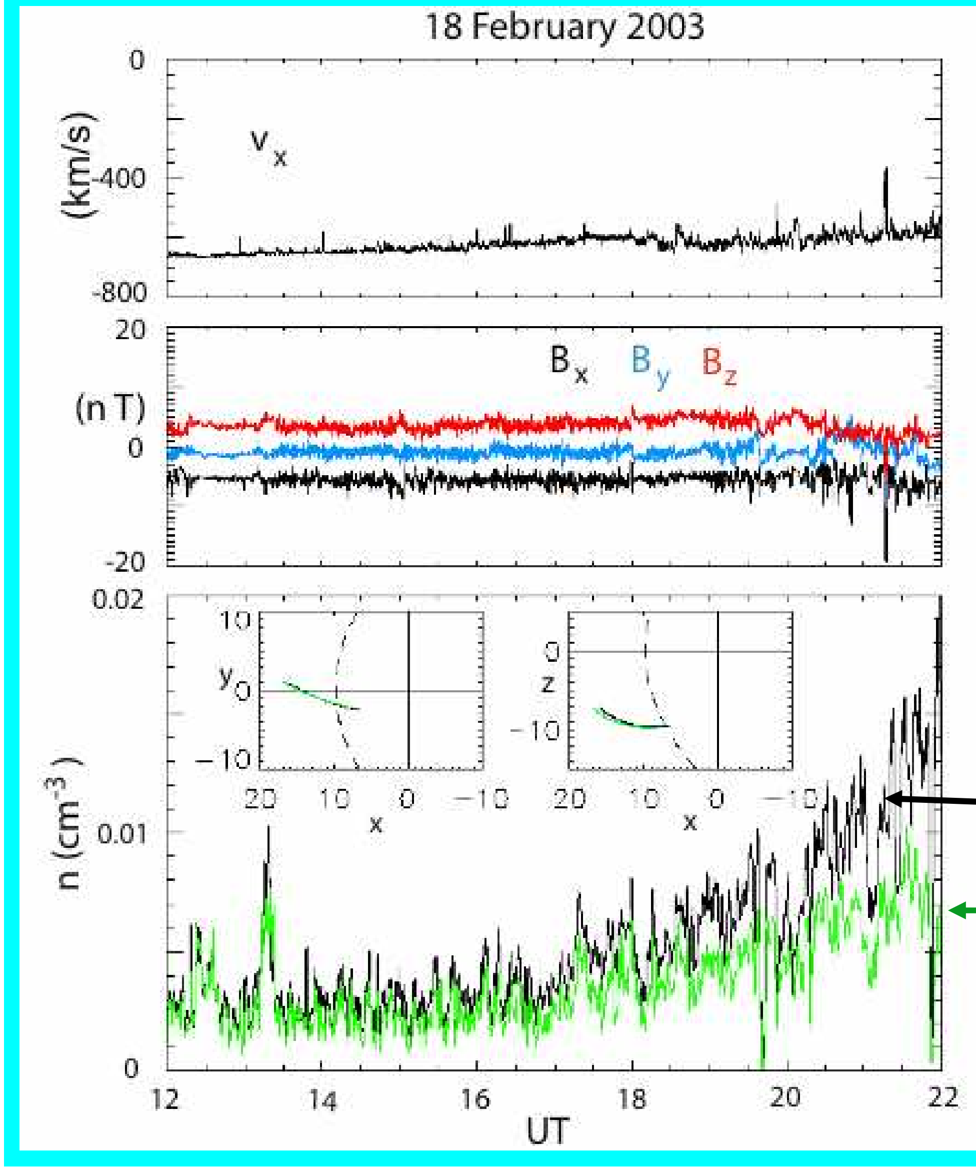
More in Talk by *Scholer* 2.2

Quasi-Parallel Shock



- Energetic Ion Flux should Produce Waves
- Waves should Scatter Ions
- Diffusion should Build up Gradient of Upstream Ions
  $L(E) = \kappa(E)/v_{SW}$
- Then the Fermi Process should Work!

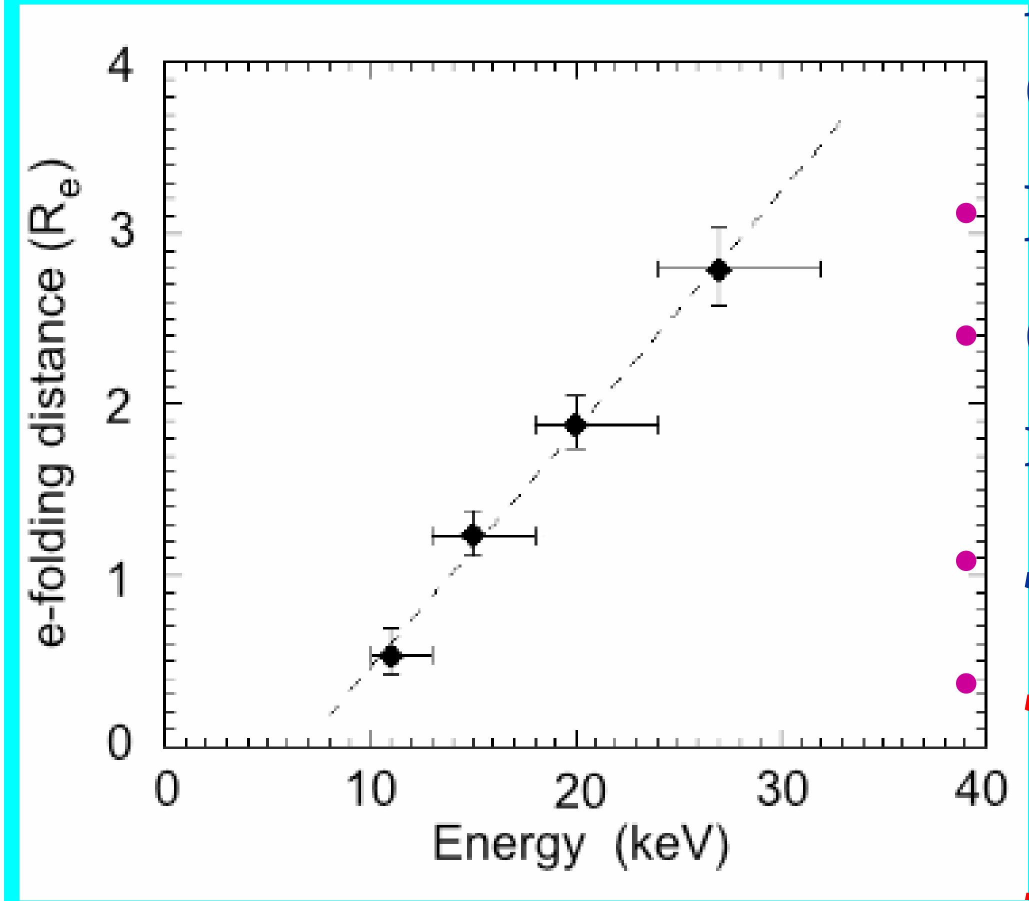
Ion Gradient at the Quasi-Parallel Shock



- **Cluster allowed first direct observation of the Upstream Ion Gradient**
- **Visible on inbound orbit, but measured between S/C 1 and 4**

Kis et al. 2004

Ion Gradient at the Quasi-Parallel Shock



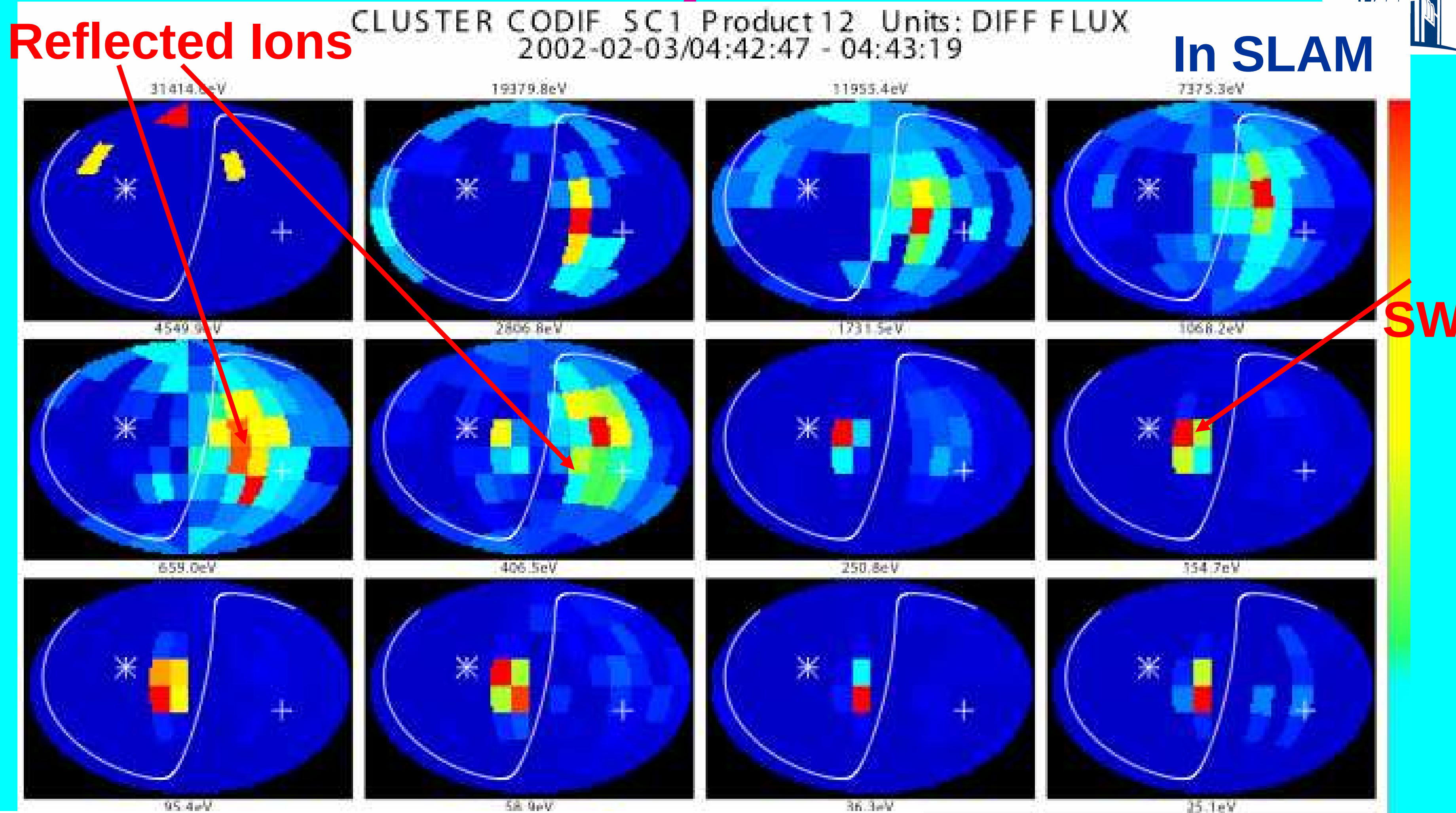
- **Exponential Density Gradient**
- **E-folding: ≈ 0.5-3 R_E**
- **Generally Shorter than in Statistical Study**
- ***Statistics Smoothes!***
- ***Subsolar location ideal! With radial B (ISEE!) -> Next years of Cluster!***

Parallel Shocks are Messy

- **Often Short Large Amplitude Magnetic Structures (SLAMS) are strewn across the Shock's staging area**
- **They show many features of the shock, but are not the shock just yet**
- **Cluster allows detailed view into their evolution, 3D field and particle structure**

see Talk by *Lucek et al.* (3.1)

SLAMS Influence Ions



But: What generates the SLAMS?
Particles; Waves?
A Hen and Egg Question!

Behlke et al., 2005
See P2.2

Let’s Conclude with "Rock Around the Bow Shock"

- **Quasi-Perpendicular Shock**
  - Beams come from Ramp and not Downstream
  - Unified view of Gyrating Ions and Beams: Beams evolve from Reflected Gyrating Ions
  - Waves in the Ramp seem to play a role
  - Beams generate Wave-Particle interaction
- **Quasi-Parallel Shock**
  - Scattering of Diffuse Ions establishes gradient: Fermi process necessary consequence
  - Upstream of the BS can be choppy: SLAMS decelerate and heat SW, reflect Ions