Measuring, Correcting, and Analyzing Ion Moments

Why you shouldn't blindly trust particle velocity moments…

Lynn B. Wilson III

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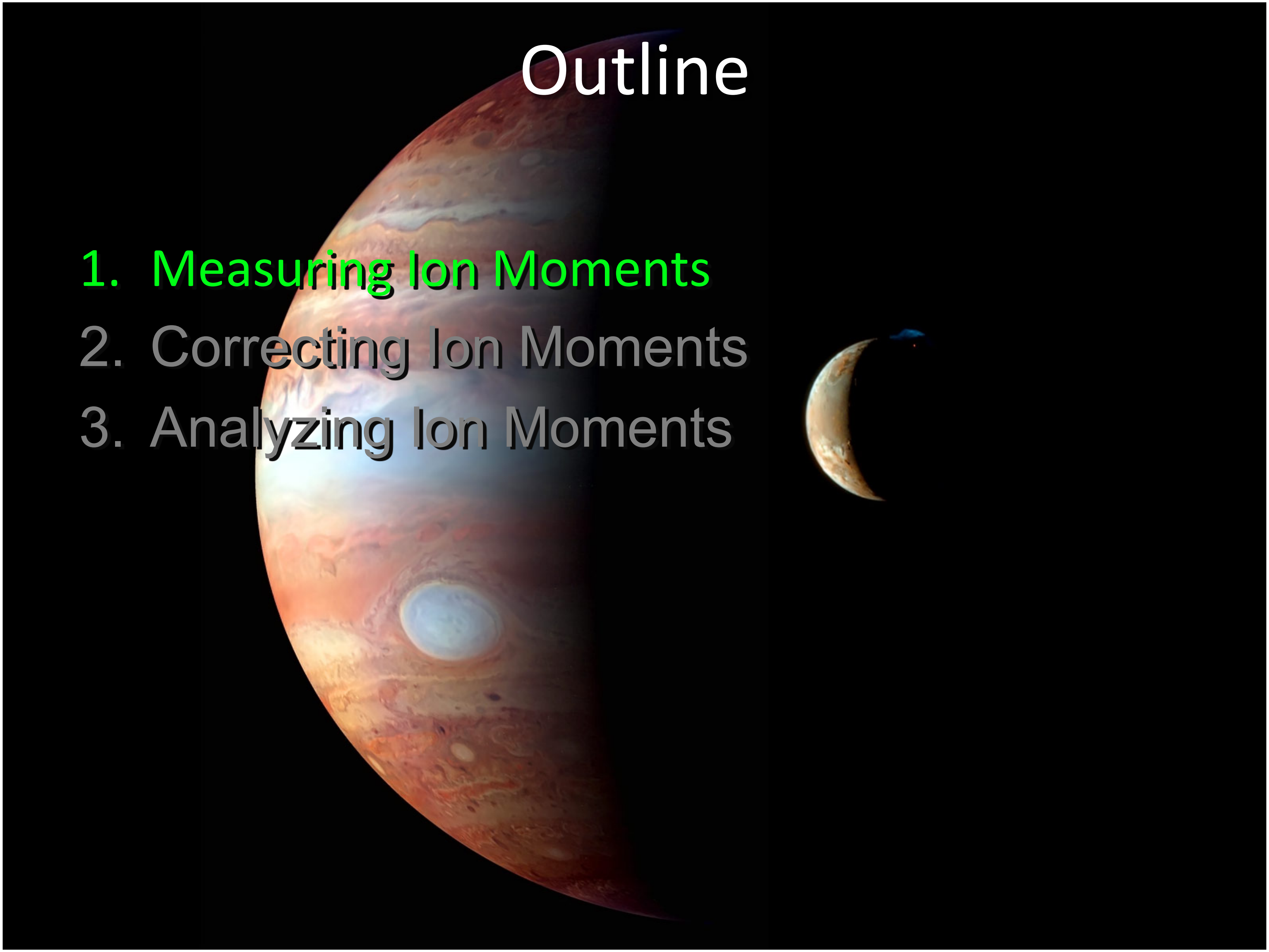
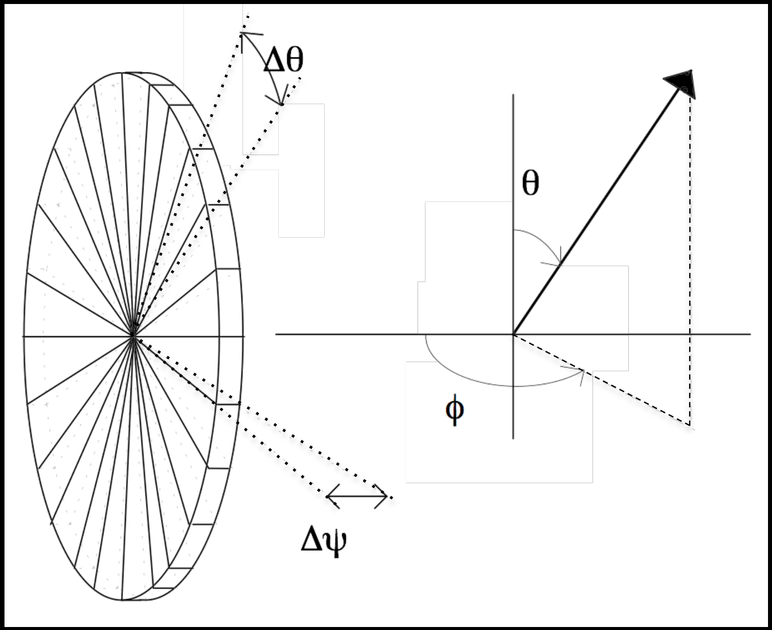

Outline
1. Measuring Ion Moments
2. Correcting Ion Moments
3. Analyzing Ion Moments

Part 1: Measuring Ion Moments

Electrostatic Analyzers: Measurements

1. measure energy (E) per charge (q) for each spherical coordinate (θ, ϕ)
2. these detectors typically sweep through an energy range logarithmically, where by design, $\Delta E/E \sim$ constant
3. each point (E_i, θ_j, ϕ_k) is measured in one accumulation time, τ_{acc}
4. typically, these detectors are mounted on spinning spacecraft

Paschmann et al., [1998]



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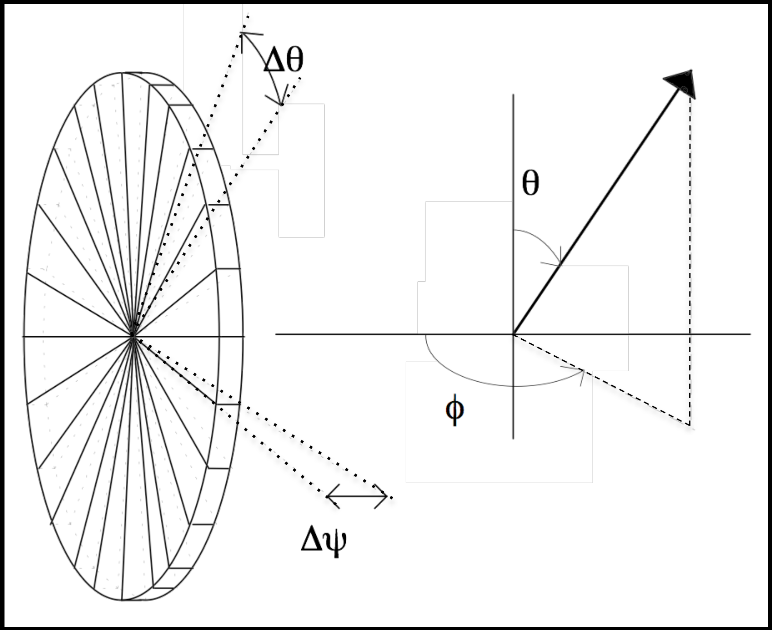
Electrostatic Analyzers: Measurements

5. thus, each data point subtends an angle, $\Delta\phi_{acc}$, in time τ_{acc}
6. the total accepted azimuth is $= \Delta\psi + \Delta\phi_{acc}$
7. as the spacecraft rotates, the detector eventually covers nearly all 4π steradian

Paschmann et al., [1998]



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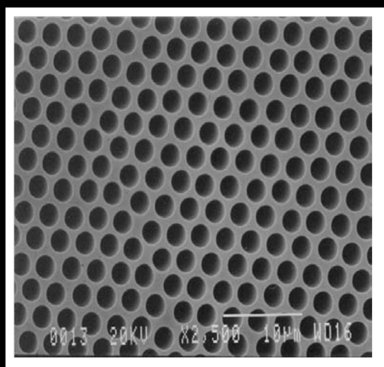
Electrostatic Analyzers: Microchannel Plates (MCPs)



Wüest et al., [2007]

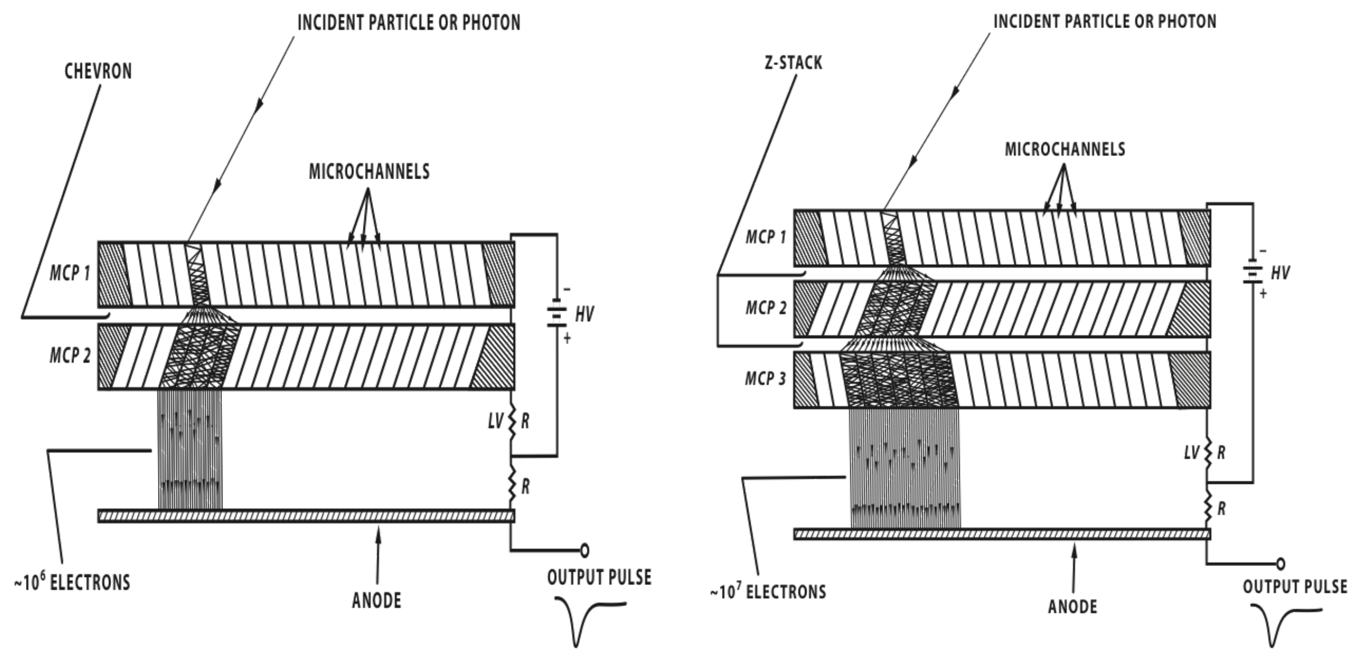
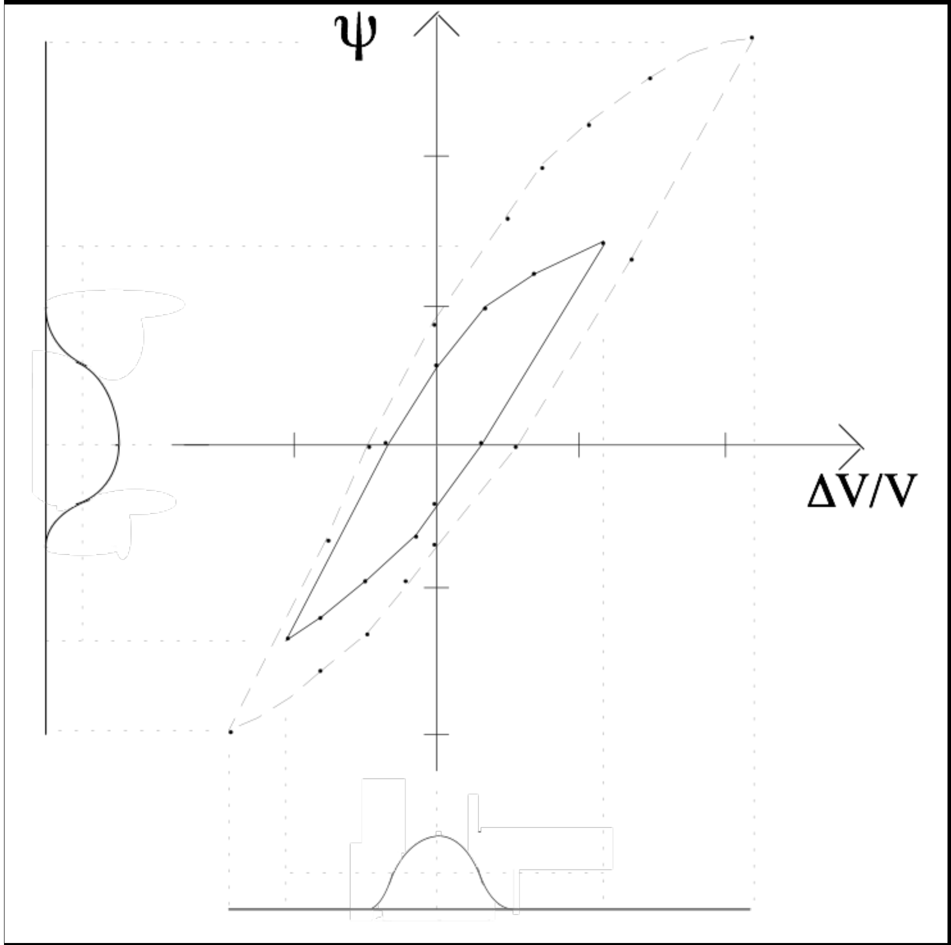


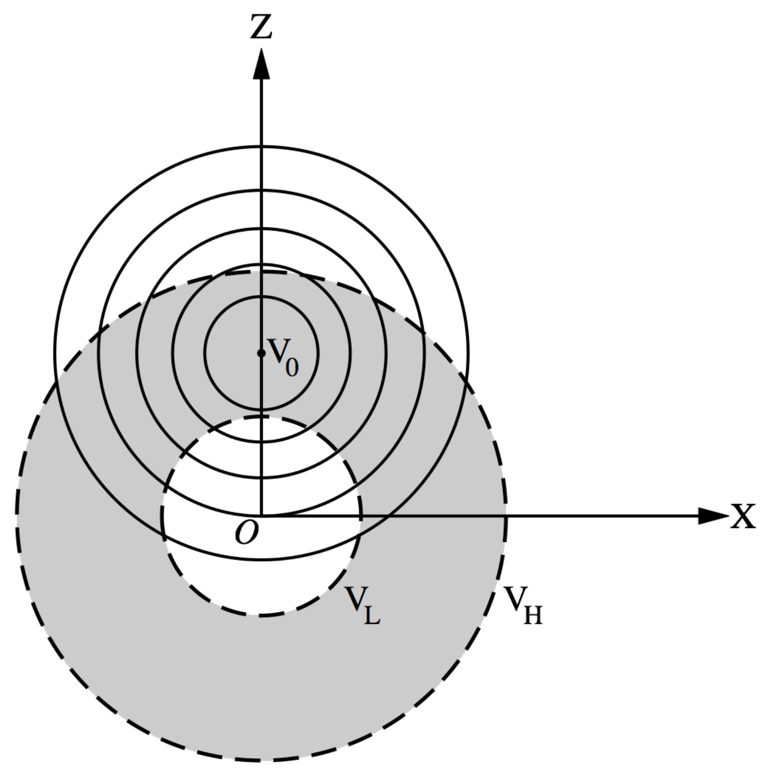
Figure 2.9: Schematic drawing of MCPs in chevron (left) and Z-stack (right) configuration. The LV next to the resistor between the back of MCP and anode is to indicate that the voltage drop across this resistor is small. Generally, the potential difference between anode and the back of the MCP is desired to be 50–100 V). The resistance is only about 2–4 % of the MCP resistance. Nearly all the MCP current flows through this resistor. The resistor from the anode to the HV carries only a tiny current from the charge pulses and has virtually no voltage drop. The anode resistor bleeds off the current since the preamplifier is generally capacitively coupled.

Electrostatic Analyzers: Instrument Response



1. azimuthal acceptance angle = ψ
2. energy response = $\Delta v/v$
3. detector unavailable during time, τ_{dead}, or the detector *dead time*
4. dead time due to electronics and metallurgic recovery
5. τ_{dead}, angular acceptance, and the efficiency, ε, of the detector are all used to estimate the geometry factor, G

Electrostatic Analyzers: Instrument Response



1. energy range relative to observed distribution can adversely affect the accuracy of particle moments
2. Incomplete coverage requires extrapolation to estimate particle velocity moments

$E_s < E_{min}$	$E_s > E_{max}$
n_s & P_s : too low (n_s more so than P_s)	n_s & P_s : too low (P_s more so than n_s)
T_s & $\lvert \mathbf{V}_{os} \rvert$: too large	T_s & $\lvert \mathbf{V}_{os} \rvert$: too small
$\mathbf{V}_{os}/\lvert \mathbf{V}_{os} \rvert$ ~ okay unless distribution is very anisotropic	false anisotropies introduced in bulk-flow rest frame

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Electrostatic Analyzers: Conversion to Physical Units

1. measure f_{ijk} α $C(E_i, \theta_j, \phi_k)\, V_{ijk}{}^4$, where $C(E_i, \theta_j, \phi_k)$ is the count rate
2. differential volume : $d^3V = v^2\, dv\, \sin\theta\, d\theta\, d\phi$
3. since $\Delta E/E \sim$ constant => $v^2\, dv = v^3\, dv/v \sim$ constant * v^3
4. the number flux, F_γ, α v, therefore the count rate $\alpha\, v^4$

Cartesian Unit Vector

$$\hat{r} \equiv \left(\cos\theta\, \cos\phi\right)\hat{x} + \left(\cos\theta\, \sin\phi\right)\hat{y} + \left(\sin\theta\right)\hat{z}$$

Electrostatic Analyzers: Conversion to Physical Units

1. the spacecraft has a net potential, ϕ_{sc}
2. thus, the energy of a particle brought in from infinity : $E_{inf} = E + \phi_{sc}$ (> 0)
3. therefore, the differential distribution function, δf, is an *i x j x k* element array

$$\delta f_{ijk} = \left(\frac{\delta v_i}{E_i}\right)\left(\frac{\delta E_i}{E_i}\right) df_{ijk} \left(\sin\theta_j \, d\theta_j \, d\phi_k\right)$$

$$df_{ijk} \equiv data\,[energy\ \ flux] = f\left(E_i, \theta_j, \phi_k\right)$$

$$\delta v_i \equiv \sqrt{\left(E_{\mathrm{inf}}\right)_i}$$

$$\delta E_i \equiv energy\ resolution$$

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Electrostatic Analyzers: Conversion to Physical Units

$$F_{\alpha,ijk} = \delta f_{ijk}\left(\hat{r}_\alpha\right)\left(\frac{\left(E_{\inf}\right)_i}{E_i}\right) \equiv number\ \ flux$$

$$V_{\alpha,ijk} = \left(\frac{F_{\alpha,ijk}}{N_s}\right) \equiv bulk\ \ flow\ velocity$$

$$\Gamma_{\alpha\beta,ijk} = \sqrt{M_s}\ \delta f_{ijk}\left(\hat{r}_\alpha \hat{r}_\beta\right)\left(\frac{\left(E_{\inf}\right)_i^{3/2}}{E_i}\right) \equiv momentum\ \ flux$$

$$P_{\alpha\beta,ijk} = \Gamma_{\alpha\beta,ijk} - M_s\left(V_{\alpha,ijk}\, F_{\alpha,ijk}\right) \equiv pressure\ tensor$$

$$\{\hat{r} \equiv \left(\cos\theta\, \cos\phi\right)\hat{x} + \left(\cos\theta\, \sin\phi\right)\hat{y} + \left(\sin\theta\right)\hat{z}\}$$

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Electrostatic Analyzers: Conversion to Physical Units

$$T_{o,ijk} = \sum_{\alpha} \sum_{\beta} \left(\frac{P_{\alpha\beta,ijk} \, \delta^{\alpha\beta}}{N_s} \right) \equiv Avg.Temperature$$

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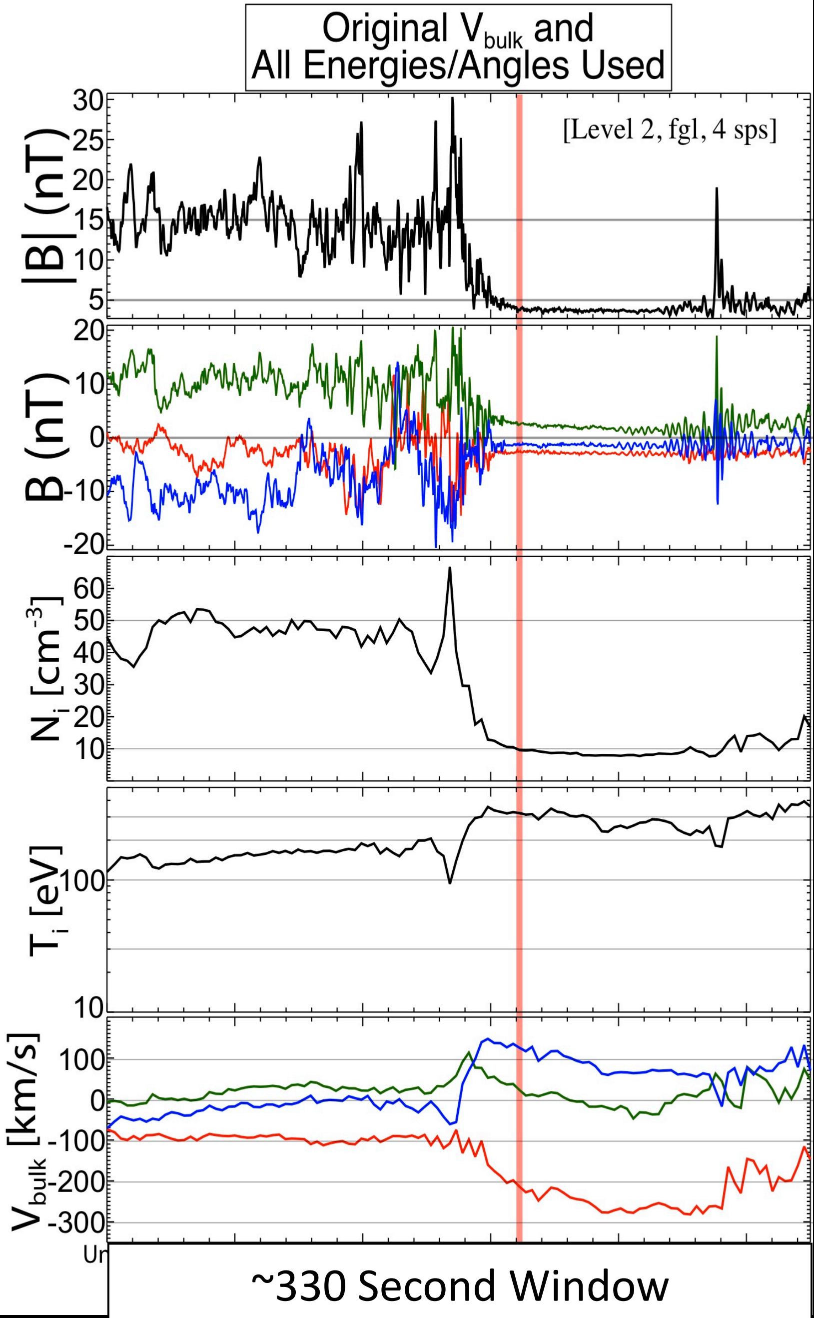
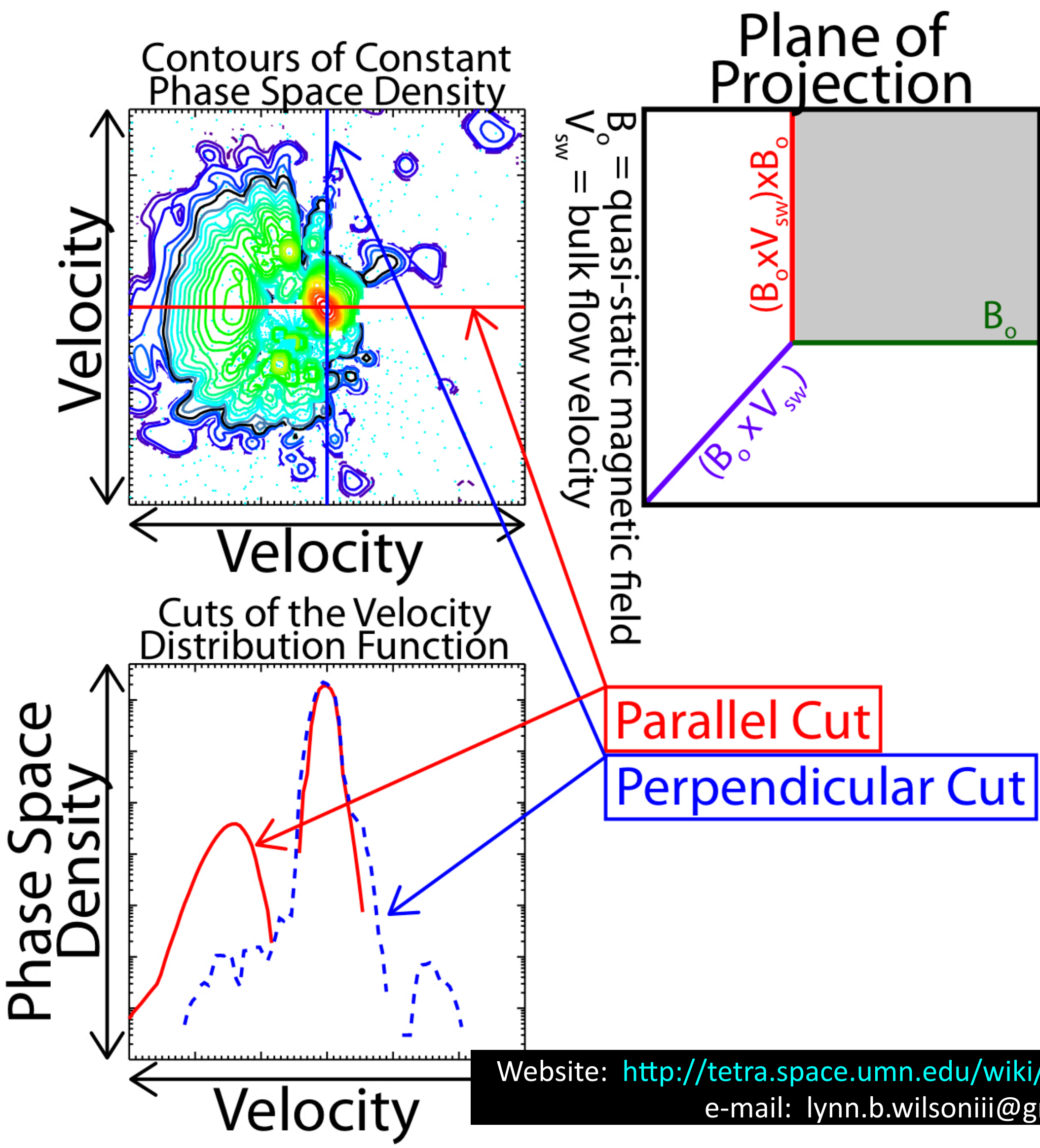
Part 2: Correcting Ion Moments



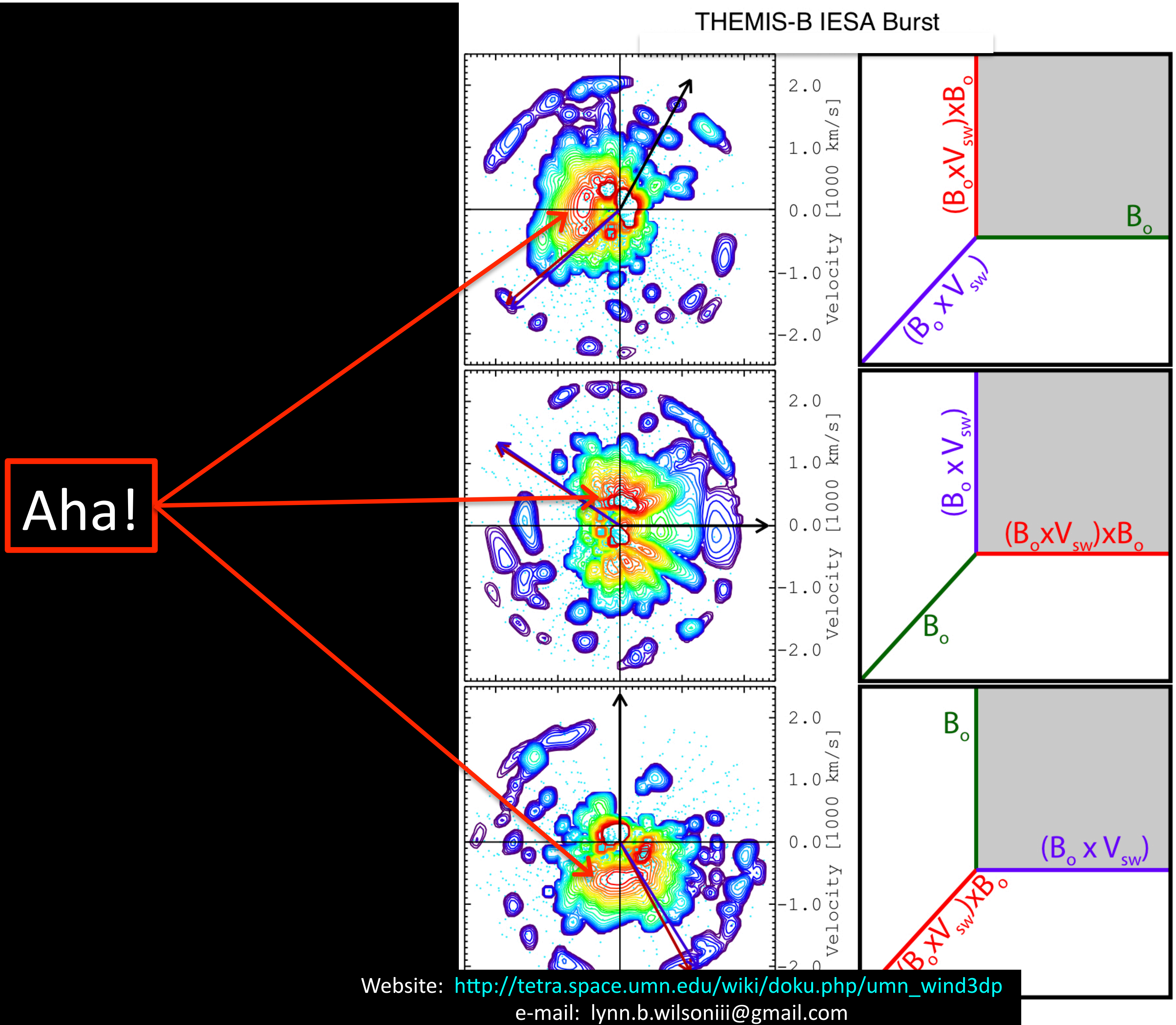
The Problem

T_i decreases across the shock ramp?

Examine Phase (Velocity) Space Distributions



Plot in 3 Planes



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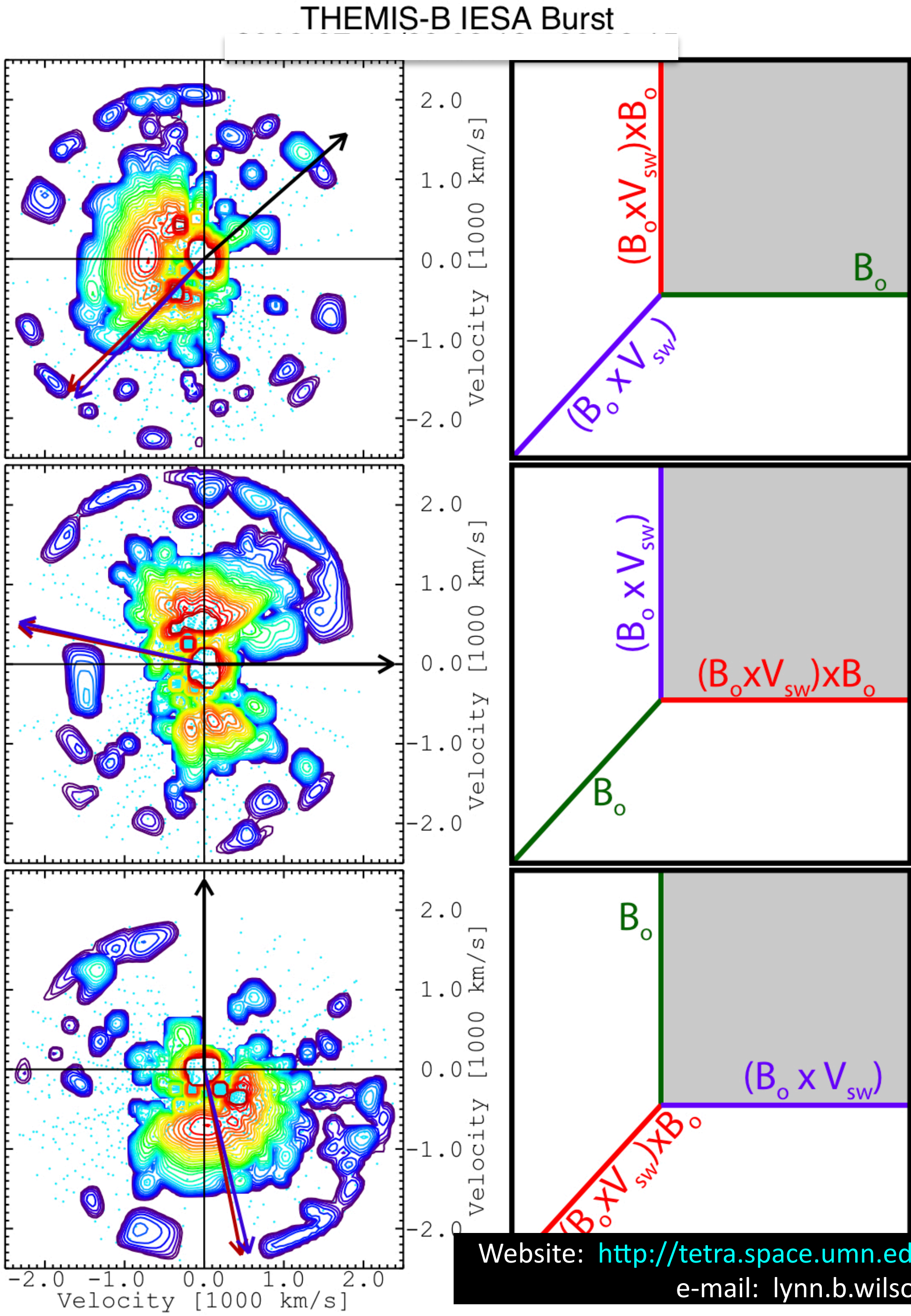
Correct Bulk Flow Velocity



Now the peak is centered
In the bulk flow rest frame

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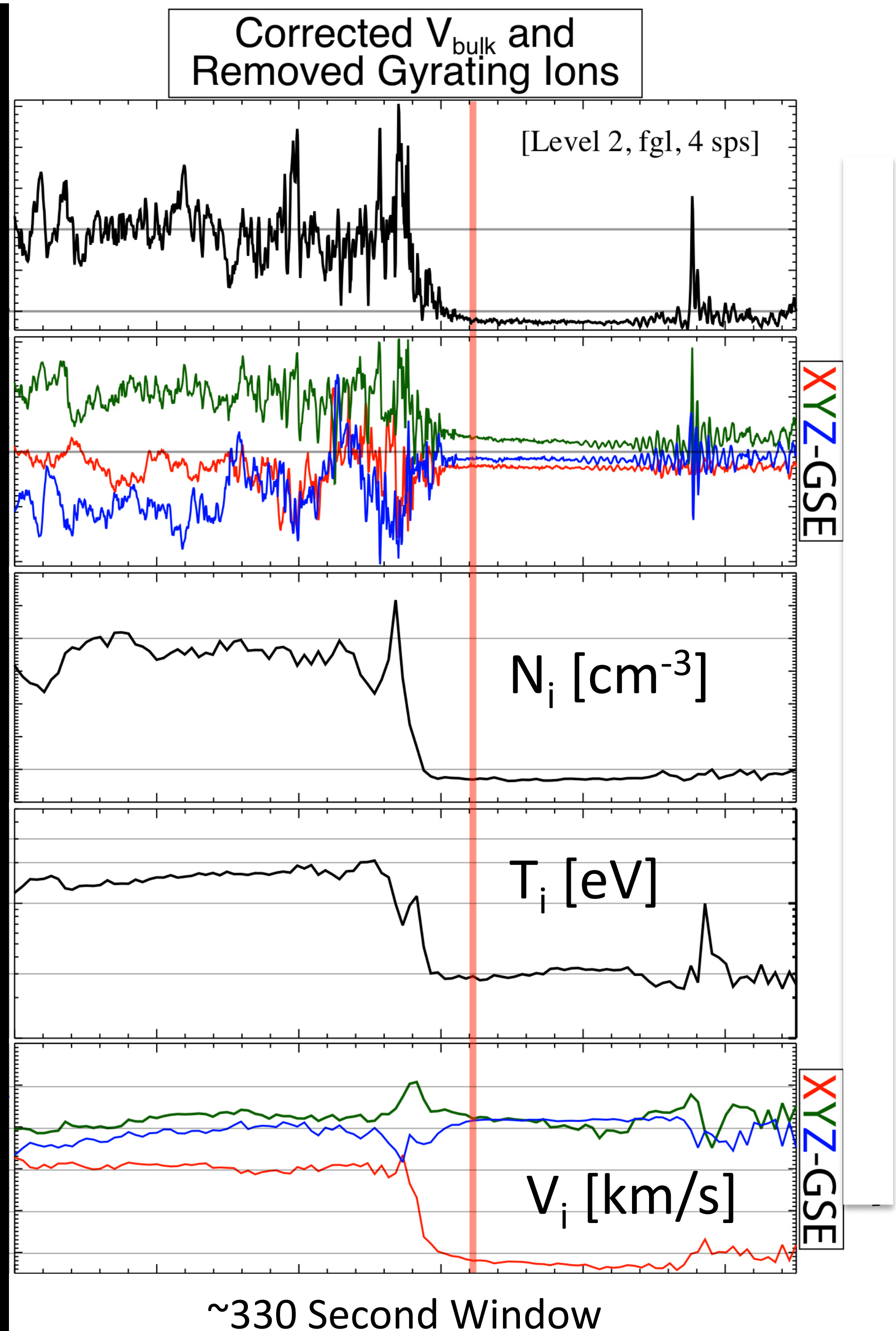
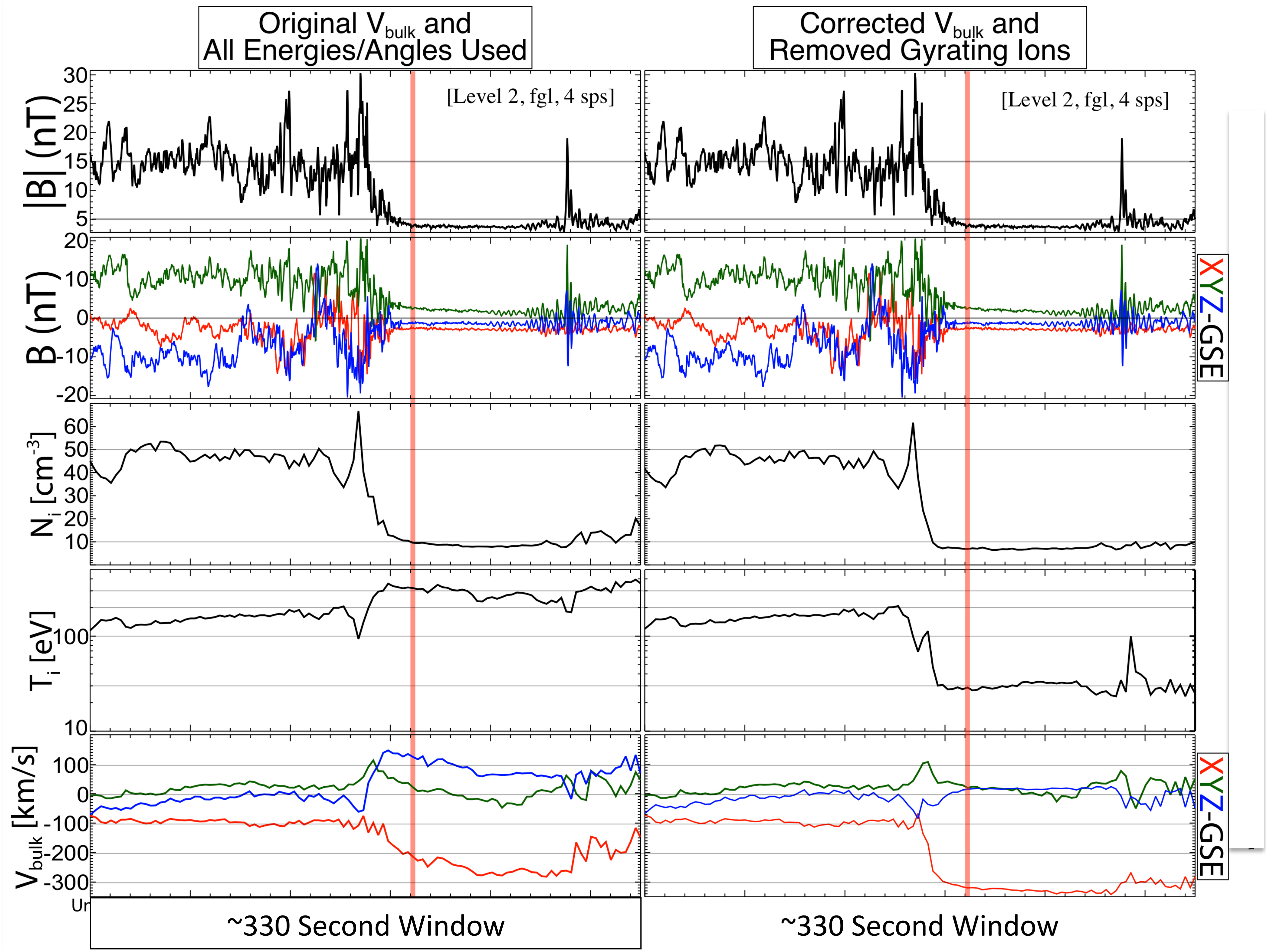
Use a "mask"

1. Use a mask to isolate the "core" of the distribution
2. Remove spurious data due to UV contamination and beam components
3. Re-calculate velocity moments

Implications for Velocity Moments?

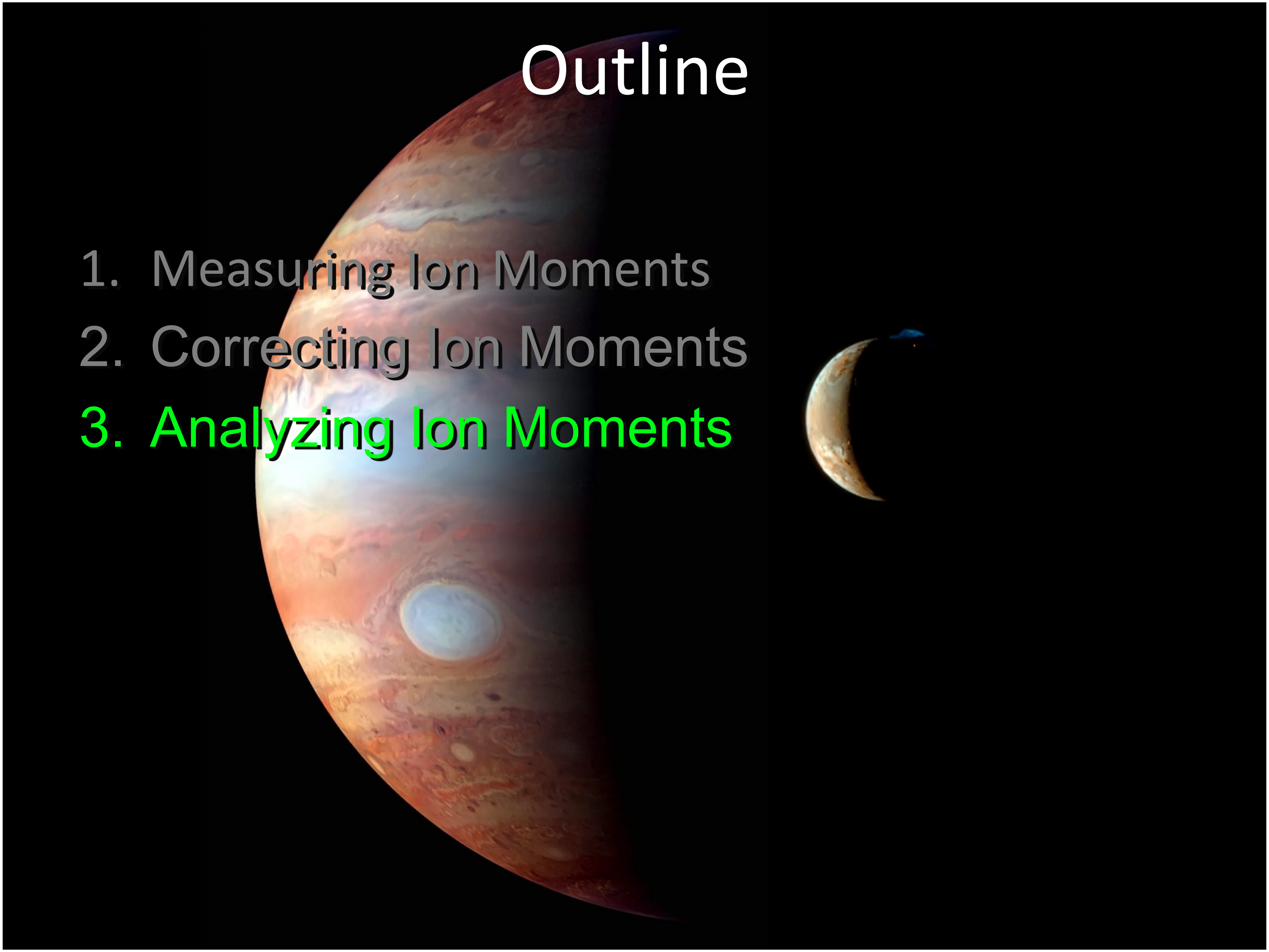
Now Ti increases across the shock ramp
(as any self-respecting temperature should)





Original V_{bulk} and
All Energies/Angles Used
Corrected V_{bulk} and
Removed Gyrating Ions
[Level 2, fgl, 4 sps]
|B| (nT)
B (nT)
XYZ-GSE
N_i [cm^{-3}]
T_i [eV]
V_{bulk} [km/s]
~330 Second Window
~330 Second Window

Outline



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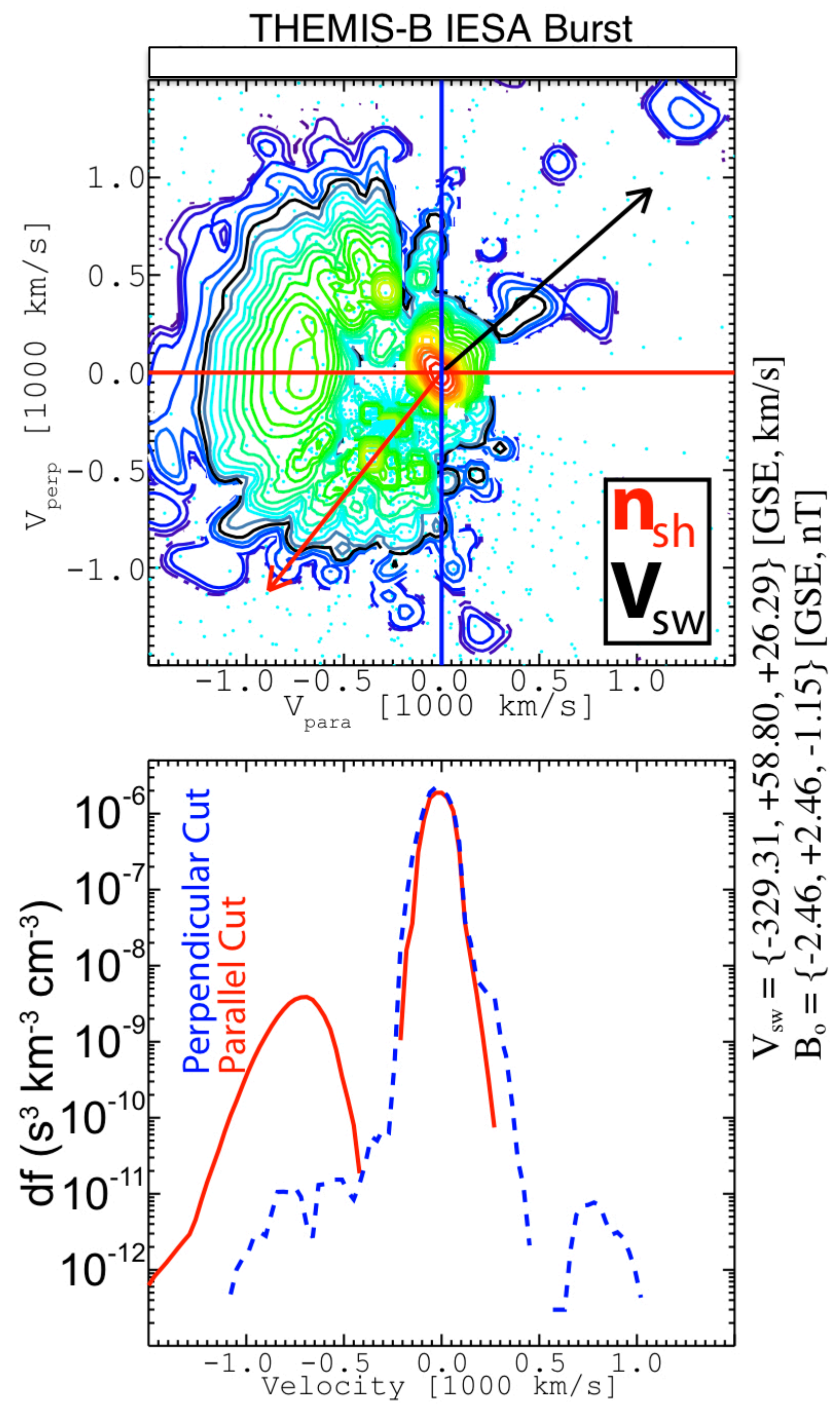
Part 3: Fit bi-Maxwellians to Ion Beams

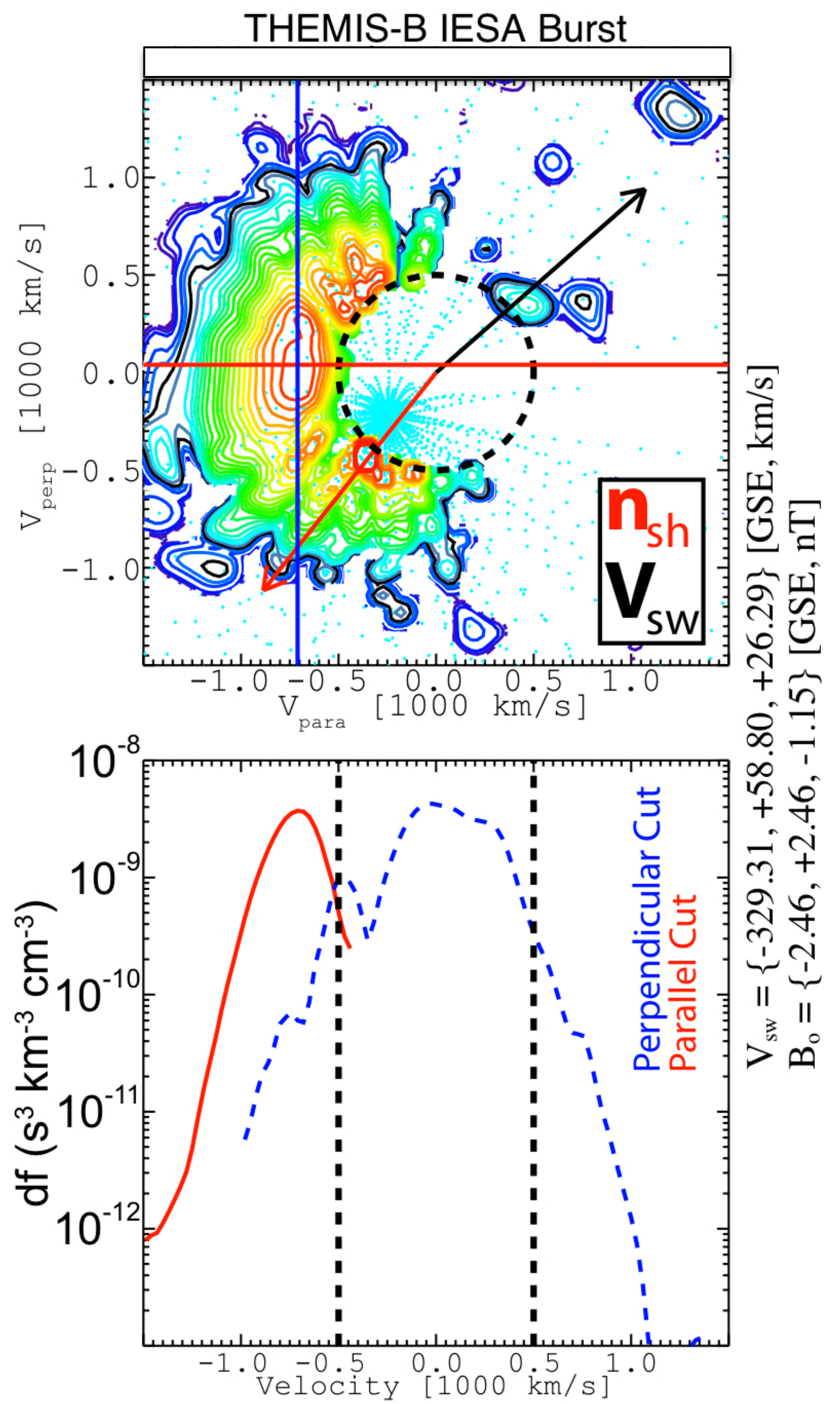
1. Plot using corrected bulk flow velocity

A. The peak is centered
In the bulk flow rest frame
B. Ion beam anti-parallel to the quasi-static magnetic field



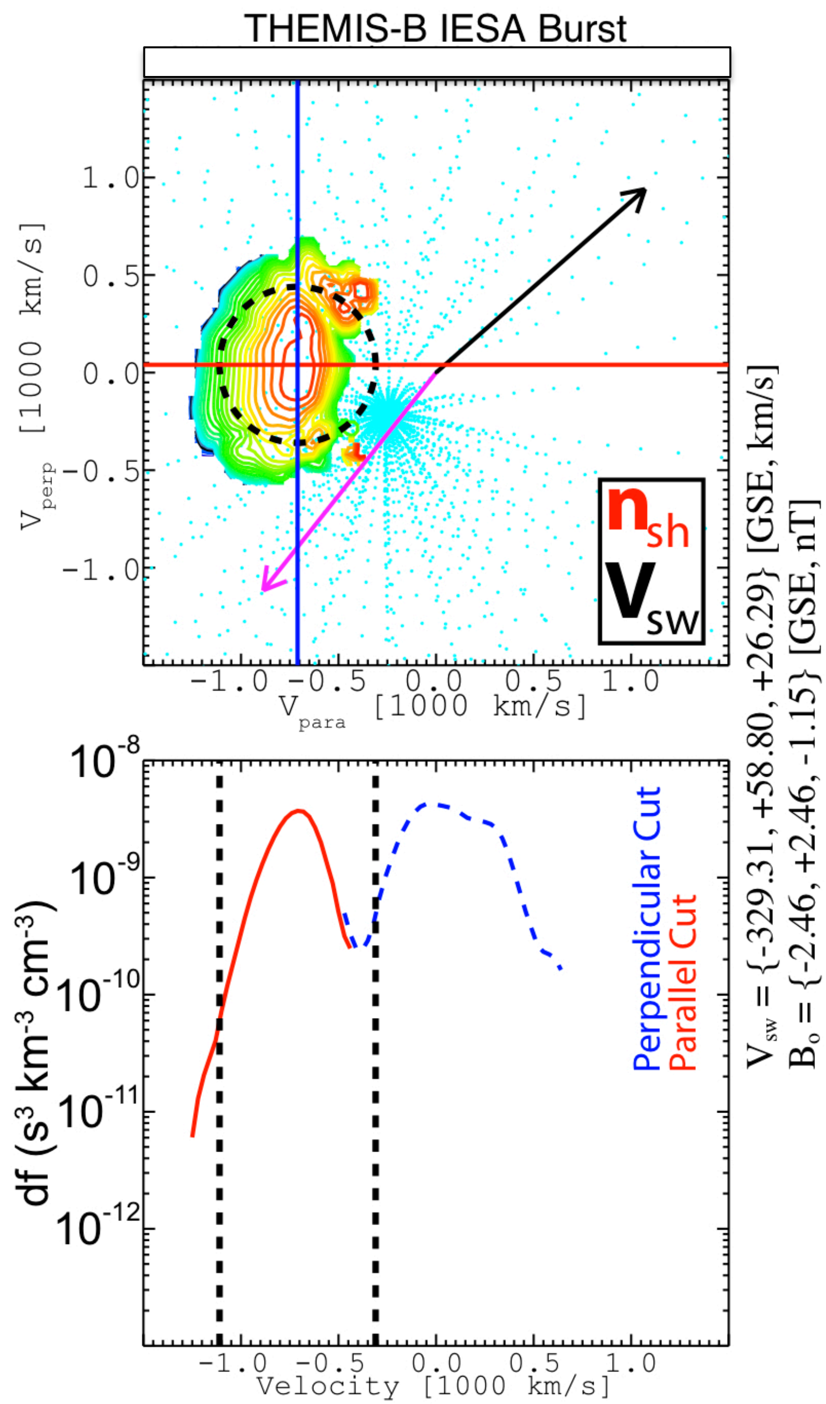
2. Use mask to remove core and UV

A. The plot ranges have changed causing the color scale to change
B. Now we shift the crosshairs to the center of the beam peak



3. Use mask to isolate beam peak

A. The plot ranges have not changed
B. Now we can fit this peak to a bi-Maxwellian



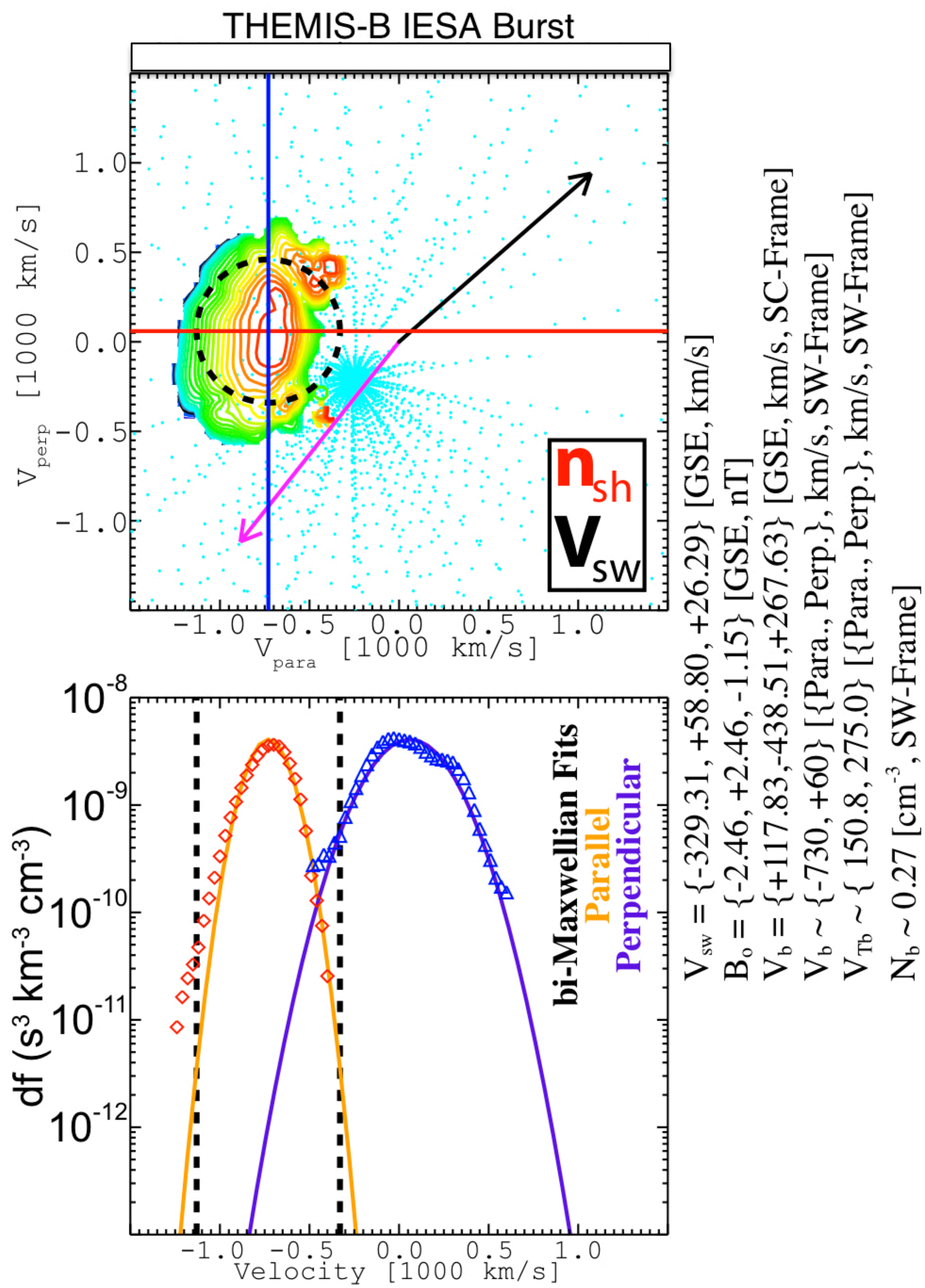
4. Fit beam peak to bi-Maxwellian: Fit Options

A. Limit the range of any of the following: N_b, V_{Tb_k}, V_{ob_k} {k = para or perp}
B. Constrain any parameter to specified value
C. Tie the density to the peak amplitude and thermal speeds
D. Change the range of data used in each fit

Tie density to thermal speeds:

$$n_o \Leftrightarrow A_o \pi^{3/2} V_{T_{//}} V_{T_\perp}{}^2$$

4. Fit beam peak to bi-Maxwellian: Results



Summary

1. Software available at link shown at bottom of slides
2. My software has detailed comments and I include crib sheets for examples
3. My software is free of obligations (i.e., no need to add me as co-author). However, if you find errors/bugs, please inform me. I would also appreciate it if you informed me whether you found the software useful/helpful.