The effect of high latitude distorted ion velocity distributions on radar and satellite observations

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Outline

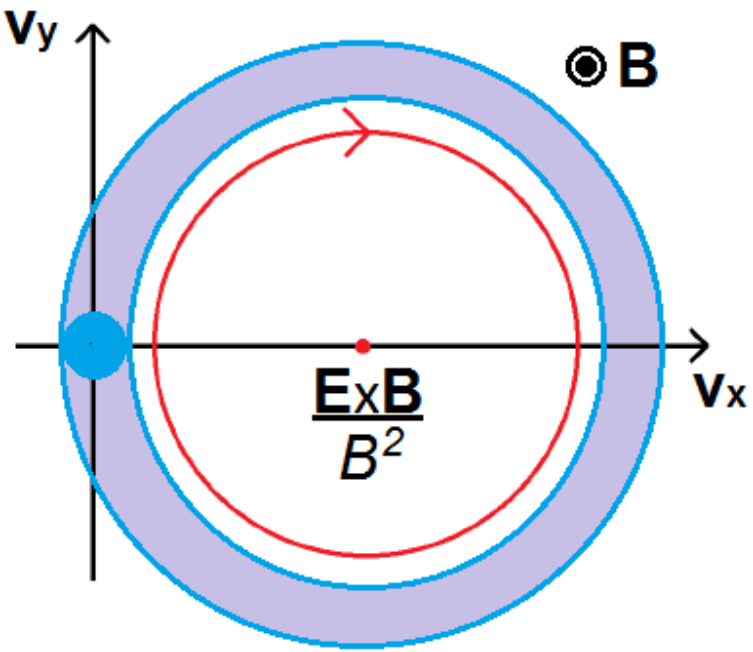
From St-Maurice and Schunk [Planet. Space Sci., 1977]:

$$\frac{d\mathbf{v}}{dt} = \Omega\frac{\mathbf{E}}{B} + \mathbf{v}\times\tilde{\mathbf{\Omega}}$$

$$\frac{d}{dt}\left(\mathbf{v} - \frac{\mathbf{E}\times\mathbf{B}}{B^2}\right) = \left(\mathbf{v} - \frac{\mathbf{E}\times\mathbf{B}}{B^2}\right)\times\mathbf{\Omega}$$

or, letting $\mathbf{c} = \mathbf{v} - \dfrac{\mathbf{E}\times\mathbf{B}}{B^2}$

$$\frac{d\mathbf{c}}{dt} = \mathbf{c}\times\mathbf{\Omega}$$



Torodial Velocity Distributions

- In 3D space, the ring O^+ velocity distributions becomes a toroid.
- The distortions introduce different temperatures parallel and perpendicular to the magnetic field.
- Monte-Carlo simulations (*Winkler et. al.*, 1992) are needed for a more precise determination of the ion velocity distribution.

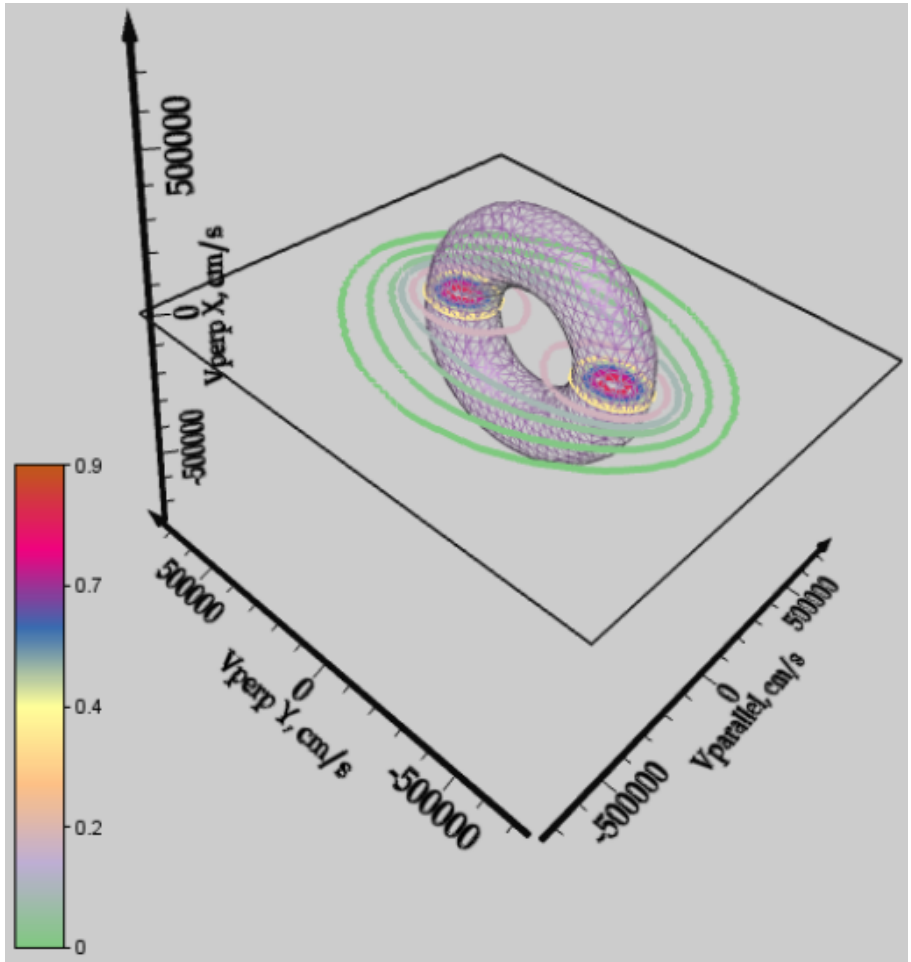


Figure: Exaggerated O^+ velocity distribution subject to O collisions in a 150 mV/m electric field.

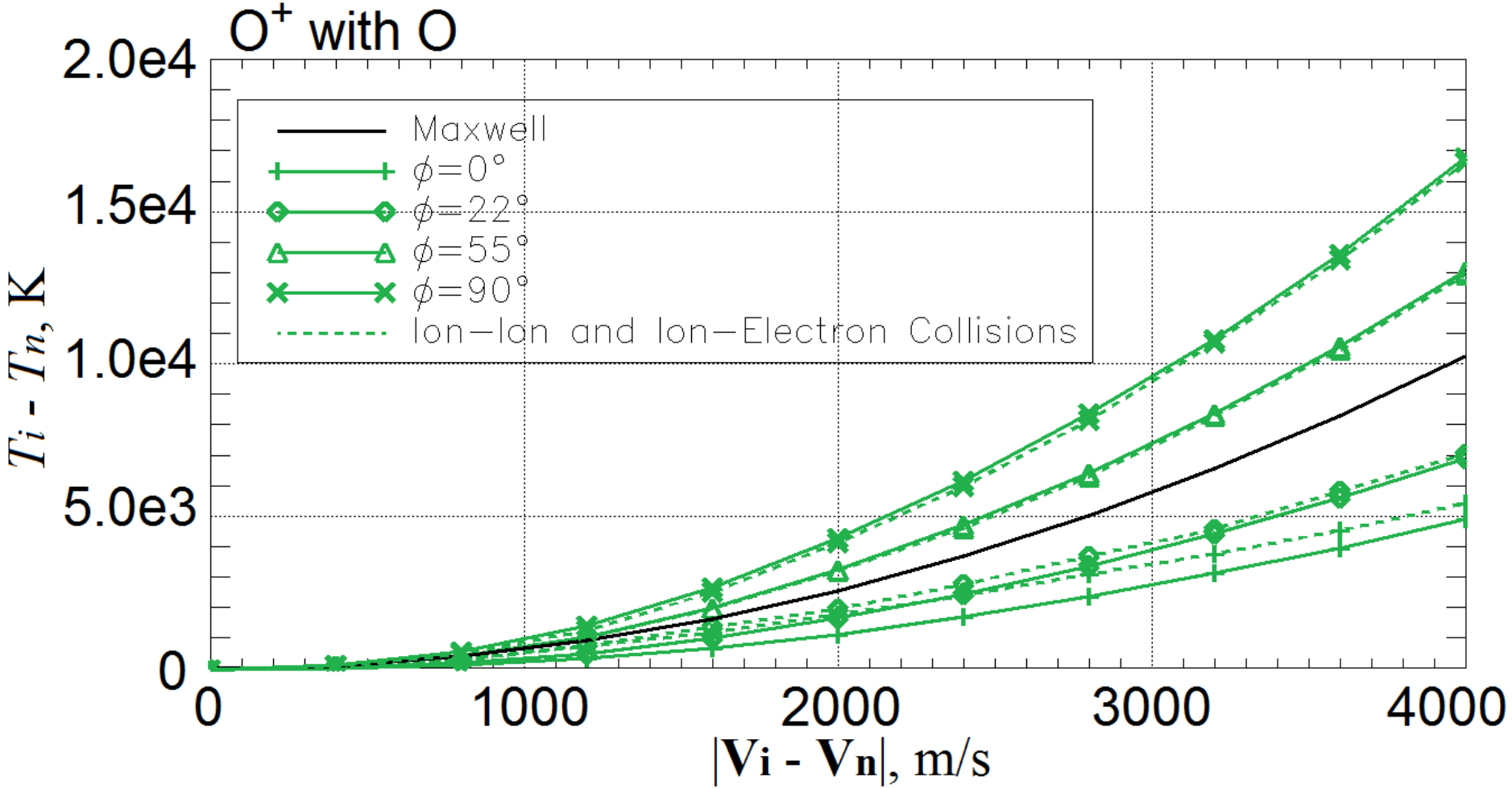
More Recent Modifications

- The improvements over previous work:
  - A much higher number of collisions used to reduce statistical noise.
  - Improved fitting techniques are used to smooth out the velocity distributions.
  - New suggestion for O^+-O collisional cross-section.
  - Collisions with other charged particles included in the calculation.
    - $\nu_T f_i = \nu_{in} f_{in} + \nu_{ii} f_{i1} + \nu_{ie} f_{i2}$, where $\nu_T = \nu_{in} + \nu_{ii} + \nu_{ie}$

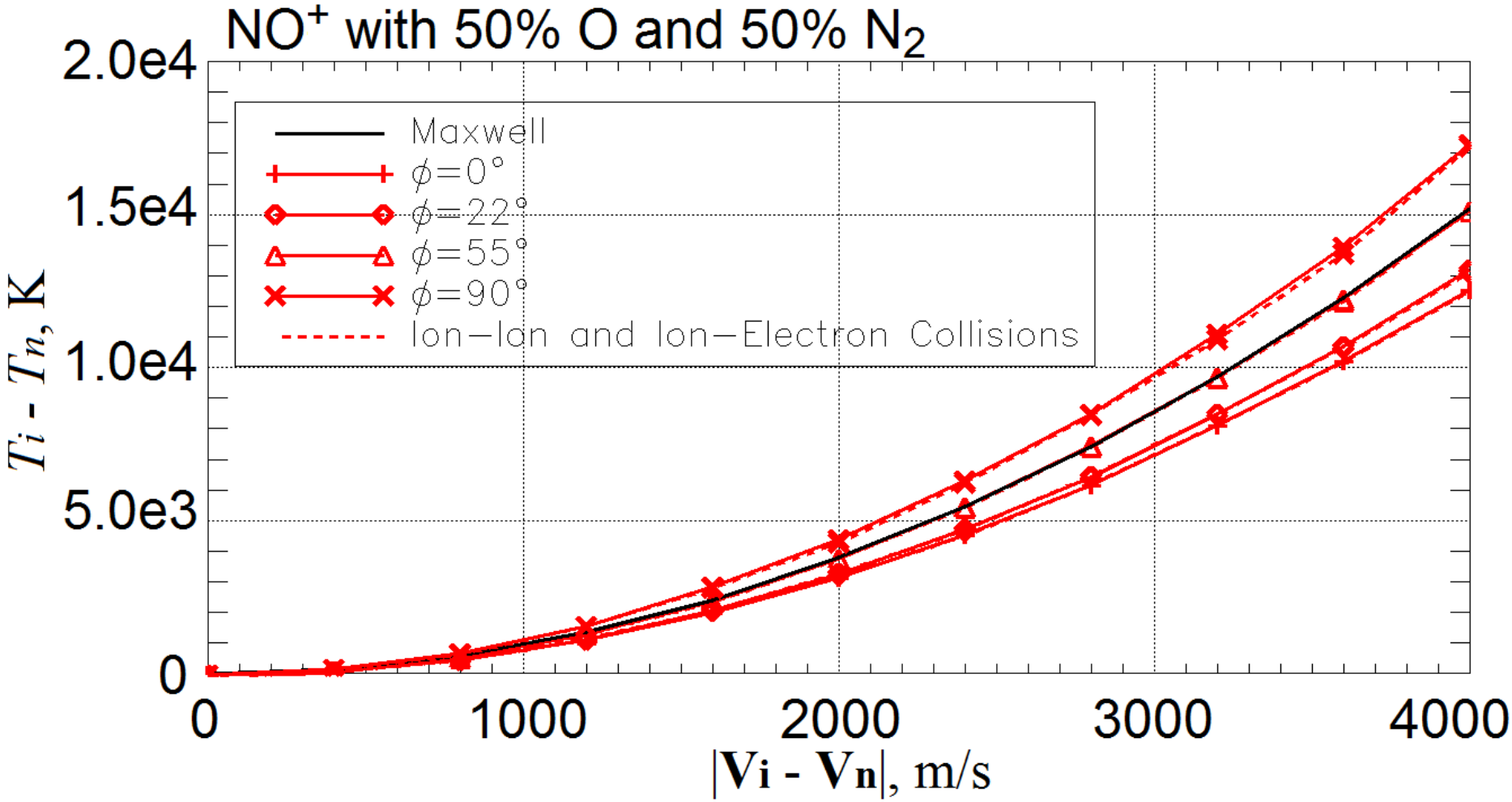
Challenges Arising from Torodial Velocity Distributions

- The analysis of spectral shapes obtained by Incoherent Scatter Radars (ISR) and satellite images of the velocity distribution must be handled with care.
  - Current ISR spectral fitting techniques assume that the ion velocity distribution to be Maxwellian
  - Satellite observations of velocity distributions require careful understanding of the distribution function.

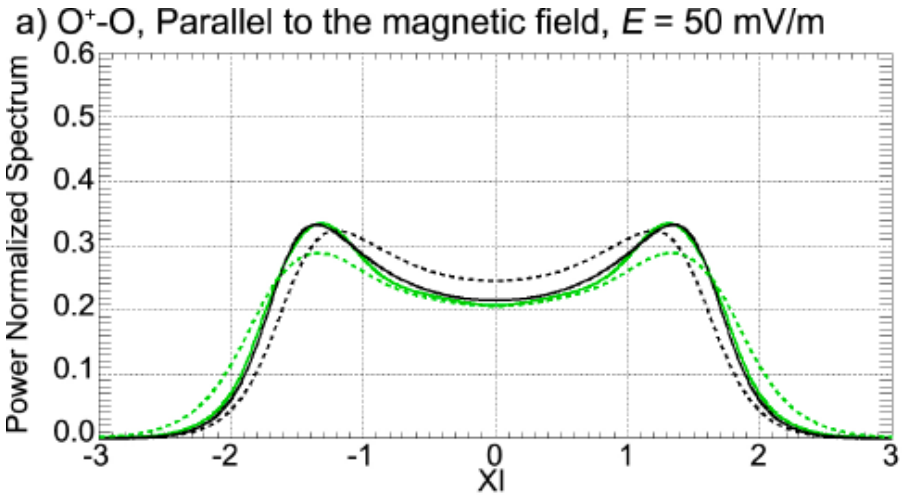
O^+ Temperature Anisotropy Resulting from Simulated Velocity Distributions

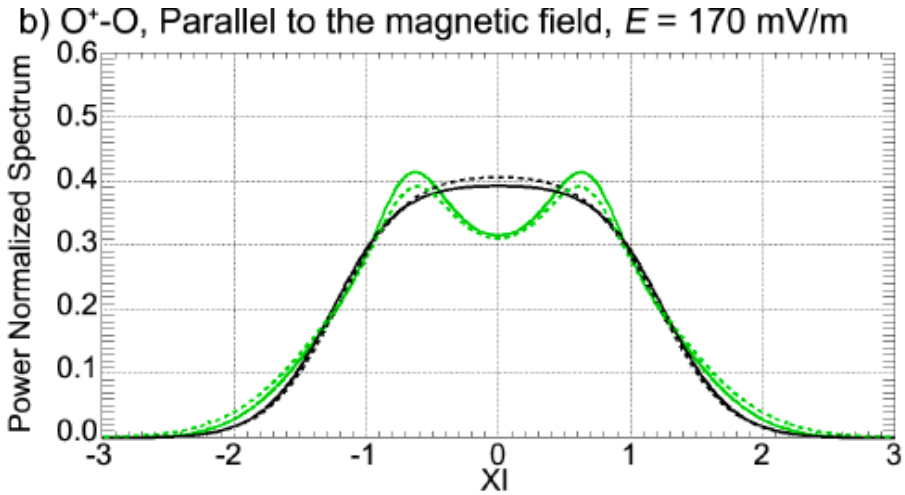


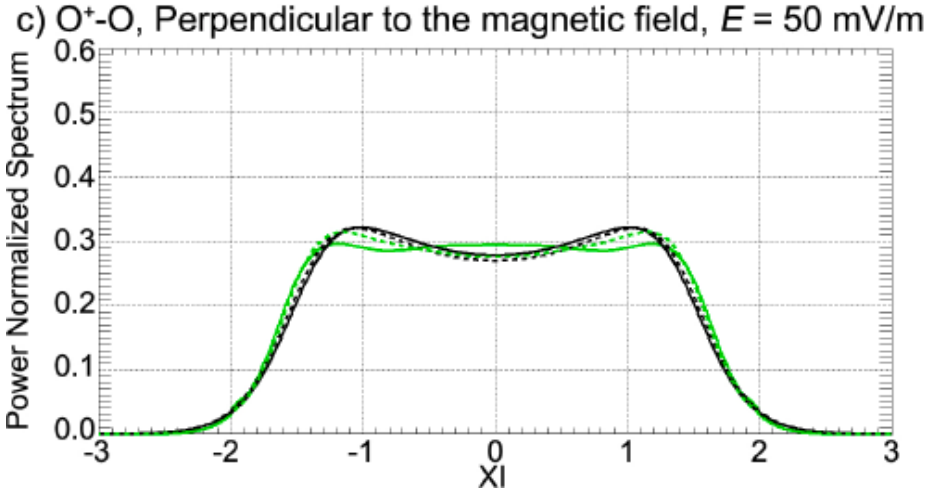
NO^+ Temperature Anisotropy Resulting from Simulated Velocity Distributions

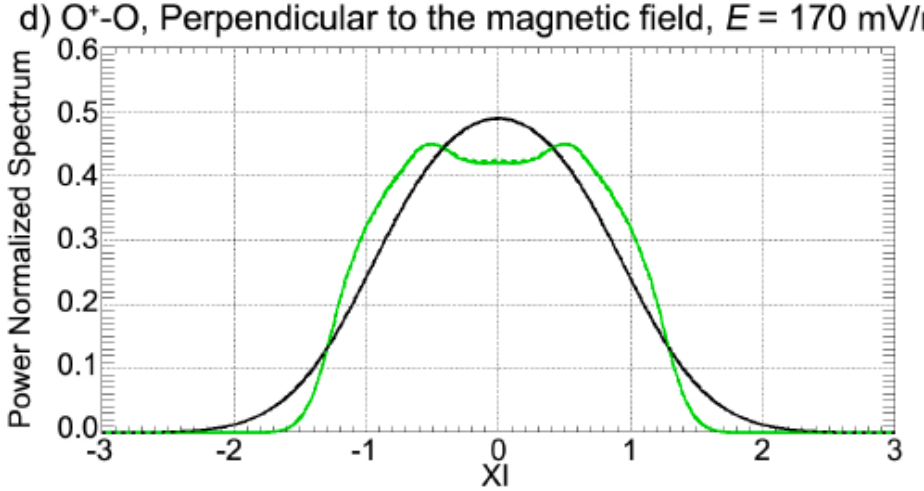


O^+ Spectra: More than just anisotropies



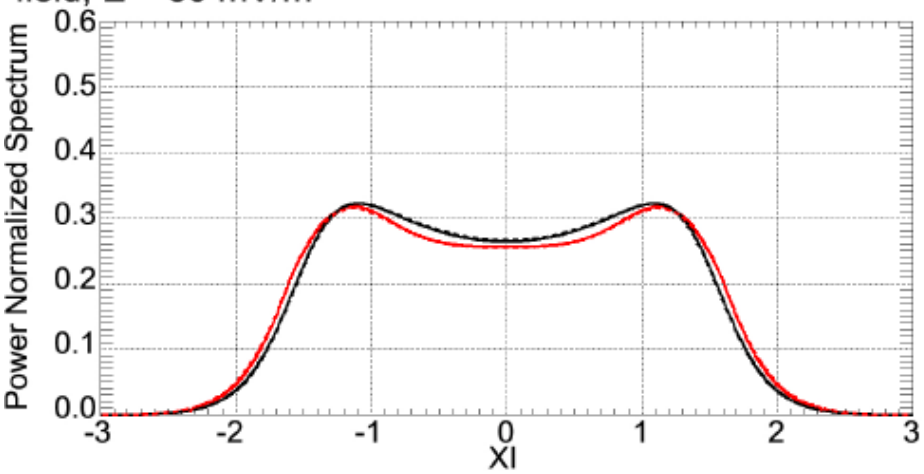




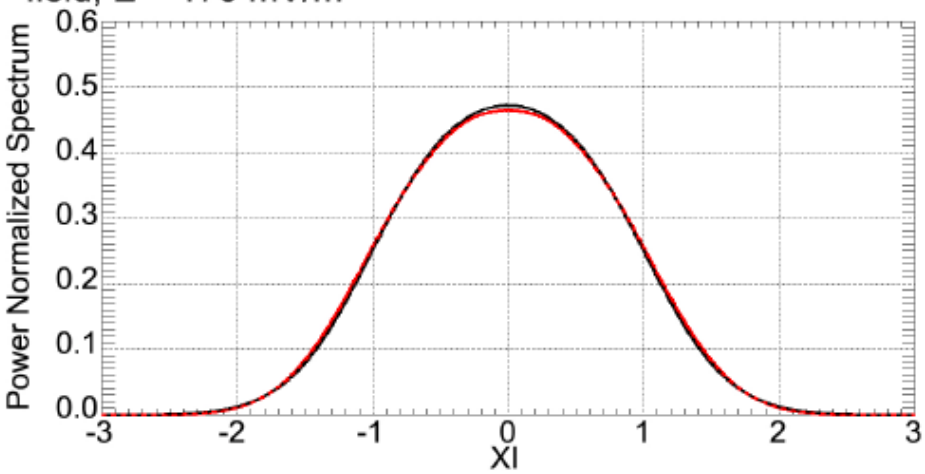


NO^+ Spectra: More than just anisotropies

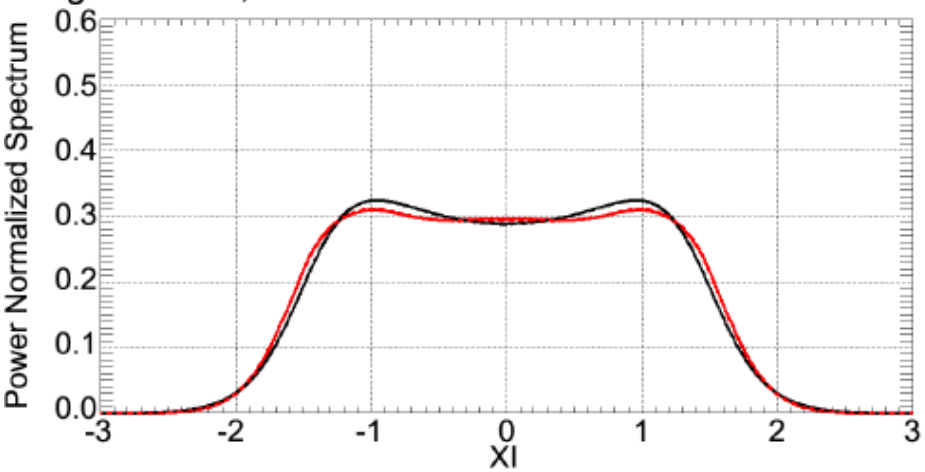
e) NO^+ with 50% O and 50% N_2, Parallel to the magnetic field, E = 50 mV/m



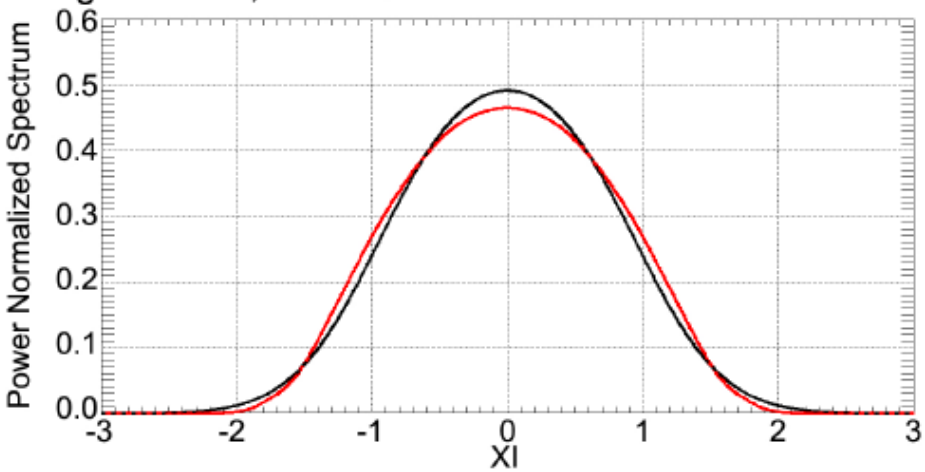
f) NO^+ with 50% O and 50% N_2, Parallel to the magnetic field, E = 170 mV/m



g) NO^+ with 50% O and 50% N_2, Perpendicular to the magnetic field, E = 50 mV/m



h) NO^+ with 50% O and 50% N_2, Perpendicular to the magnetic field, E = 170 mV/m



Applications to Satellite Images Above the Collisional Region (Sample Run)

- After maintaining a steady, E=0 mV/m ion velocity distribution at the boundary layer, the boundary electric field is linearly increased by 1 mV/m per 1 second to 100 mV/m and then decreased at the same rate.

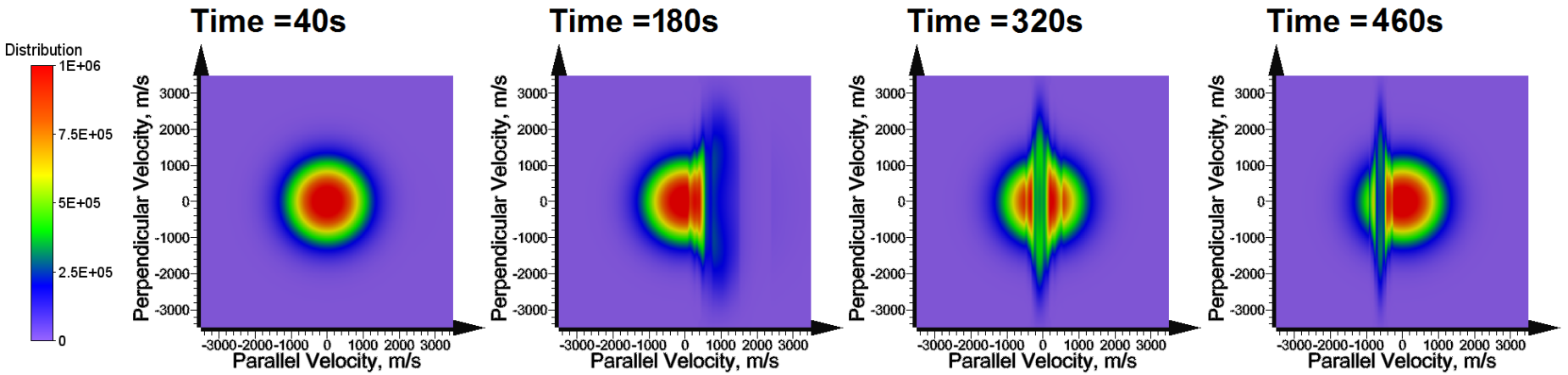


Figure: The velocity distribution 100 km above the boundary layer at 40s, 180s, 320s, and 460s.

Simulating Swarm Satellite Observations (Sample Run)

- In the sample run, anisotropic ion temperatures are found, as well as an increase and decrease in density, and a sharp upflow followed by a smaller, short downflow.
- These results agree with Swarm data seen in *Archer et al.* [2015]

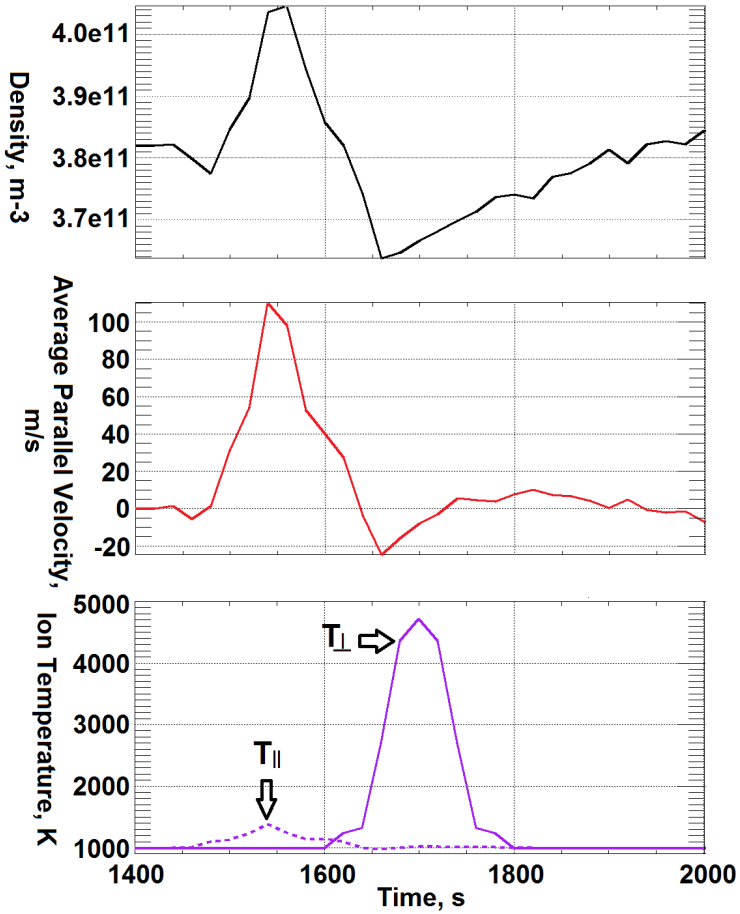


Figure: Velocity distribution moments calculated from the simulation featured previously.

Summary

- I used Monte-Carlo simulations to examine the effects of distorted velocity distributions on ISR and on satellite observations.
- ISR interpretations must incorporate ion-ion and ion-electron collisions, particularly near the magnetic field direction.
  - This is the only way to explain the temperature observations seen in ISR.
- The interpretation of the radar spectra is seriously affected by the shape of the velocity distribution during strong frictional heating events, even along the magnetic field direction.
  - O^+ spectra parallel to the magnetic field lead to erroneous electron temperature interpretations.
- The distributions mapped into relatively collisionless regions agree with Swarm observations.

Future Work

- The temperature anisotropy and spectral shapes obtained in this work are being compared to ISR observations.
- For satellite images the semi-collisional transition regions and polarization electric fields are being incorporated in the velocity distribution model of the collision-less ionosphere. Comparisons to Swarm data are underway.

References

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