Revealing the role of “hidden heavy ions” component in the terrestrial polar wind outflow

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Abstract

The roles of heavy ions have long been an important subject in the magnetospheric physics since the first discovery of O+ ions in the magnetosphere as it hinted to the connection between the ionospheric and magnetospheric plasma. Albeit limited, several observations show the importance of ionospheric N+ and molecular ions, including NO+, N2+ and O2+, in the high-altitude ionosphere and magnetosphere. However, the mechanisms responsible for accelerating the ionospheric heavy ions from eV to keV energies are still largely unknown. Developed from the Polar Wind Outflow Model (PWOM), the Seven Ion Polar Wind Outflow Model (7iPWOM) solves the gyrotropic transport equations for all relevant species (e-, H+, He+, N+, O+, N2+, NO+ and O2+) along open magnetic field lines and therefore, has the capability to assess the role of heavy ions in the supersonic ionospheric outflow. However, the hydrodynamic approach is limited to the region where collisions are important. For the altitudes above the collision-dominated region, the hydrodynamic solution becomes increasingly inadequate. Thus, the 7iPWOM applies a kinetic particle-in-cell (PIC) approach that enables the inclusion of wave-particle interactions (WPI) and Coulomb collisions. The simulation results showed that the N+ ions play a key role in the polar wind solution under all conditions. The mechanisms responsible for the energization of outflowing N+ ions are different than those of O+, not only in the collision-dominated region but also at high-altitudes. This means that the local heating sources to O+ and N+ in the polar wind, even in small amounts, can lead to plasma instability and could possibly affect the large-scale transport properties. In addition, the relative abundance of molecular ions, and how they change the polar wind solution, reveals the link between lower thermosphere and the ionosphere. Therefore, tracking the molecular ions helps understand how the “fast ion outflow” acquires sufficient energy in such a short time scale, compared with the dissociative recombination lifetime of the molecular ions, and assess the role of molecular ions in the overall dynamics of the polar wind outflow.

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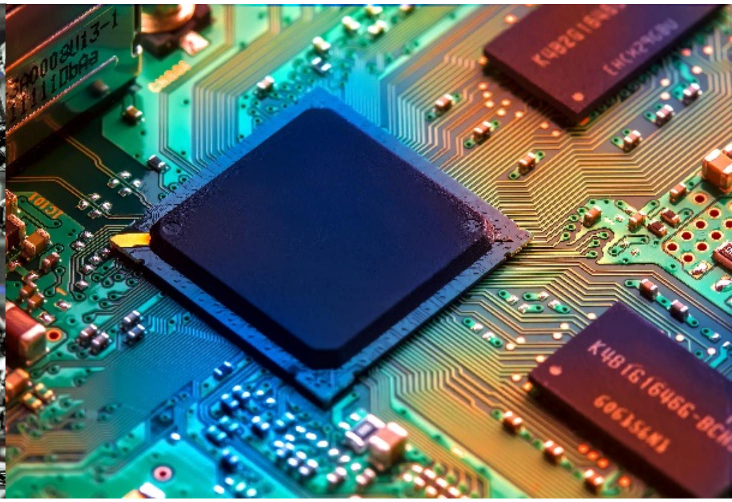

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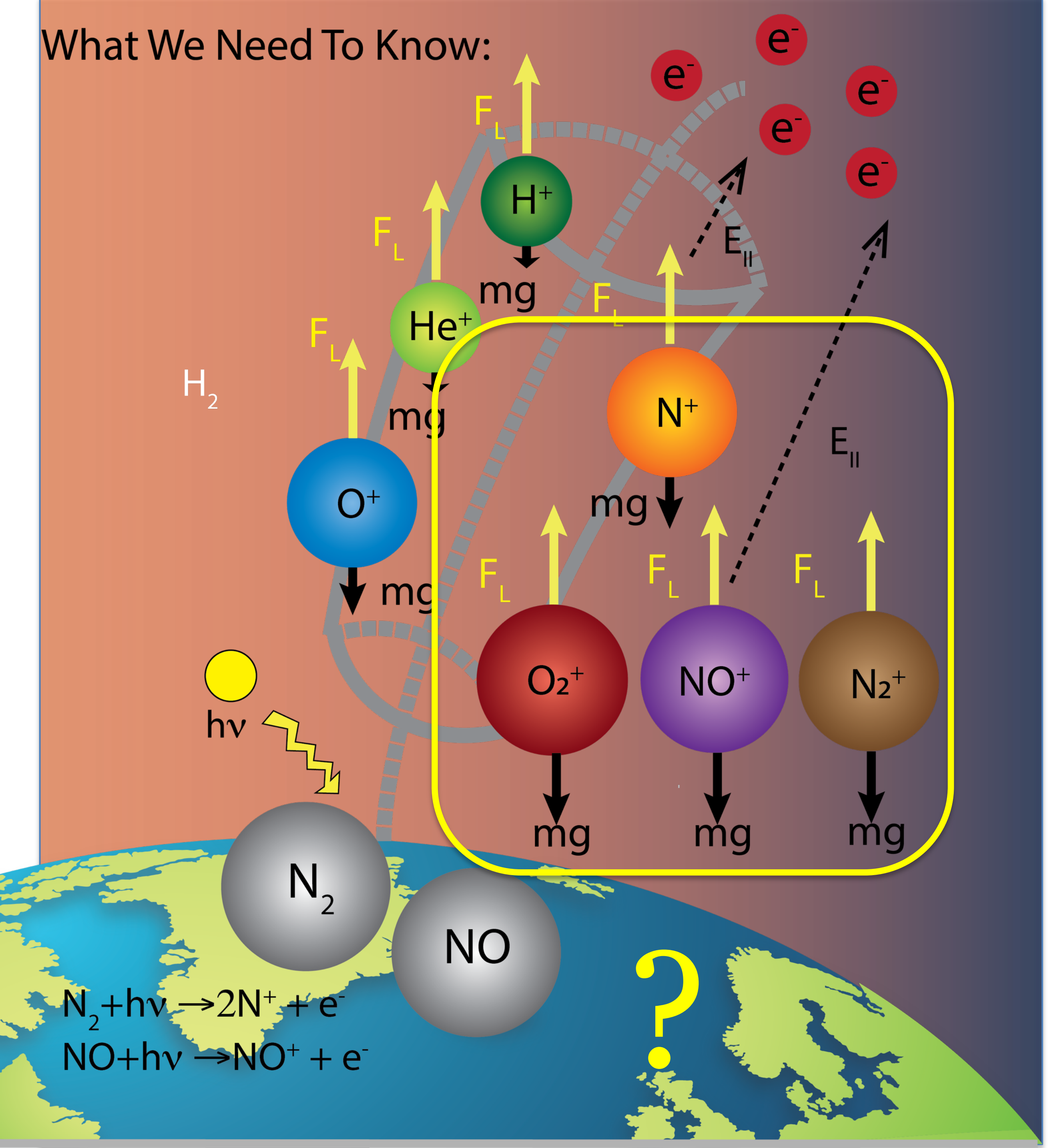
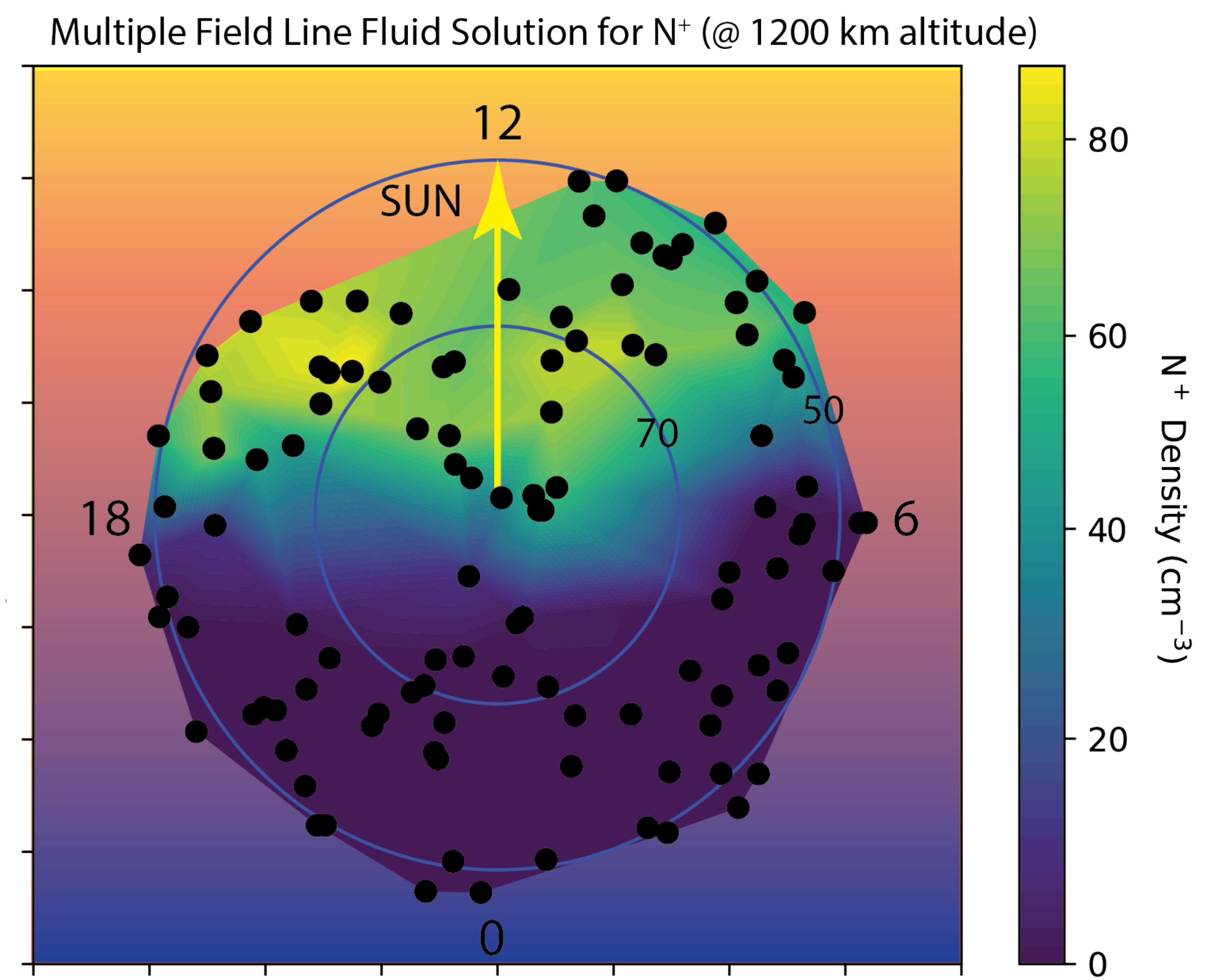
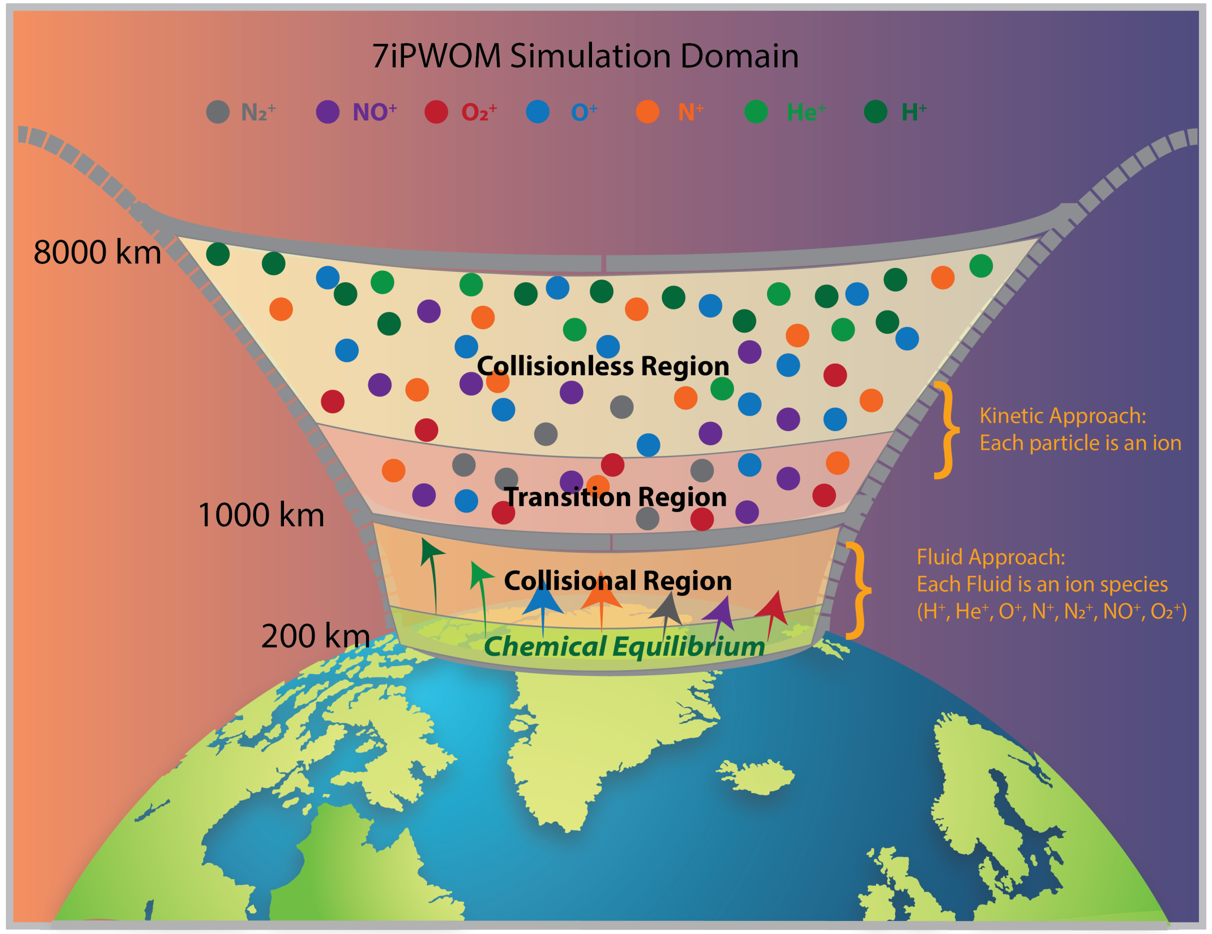
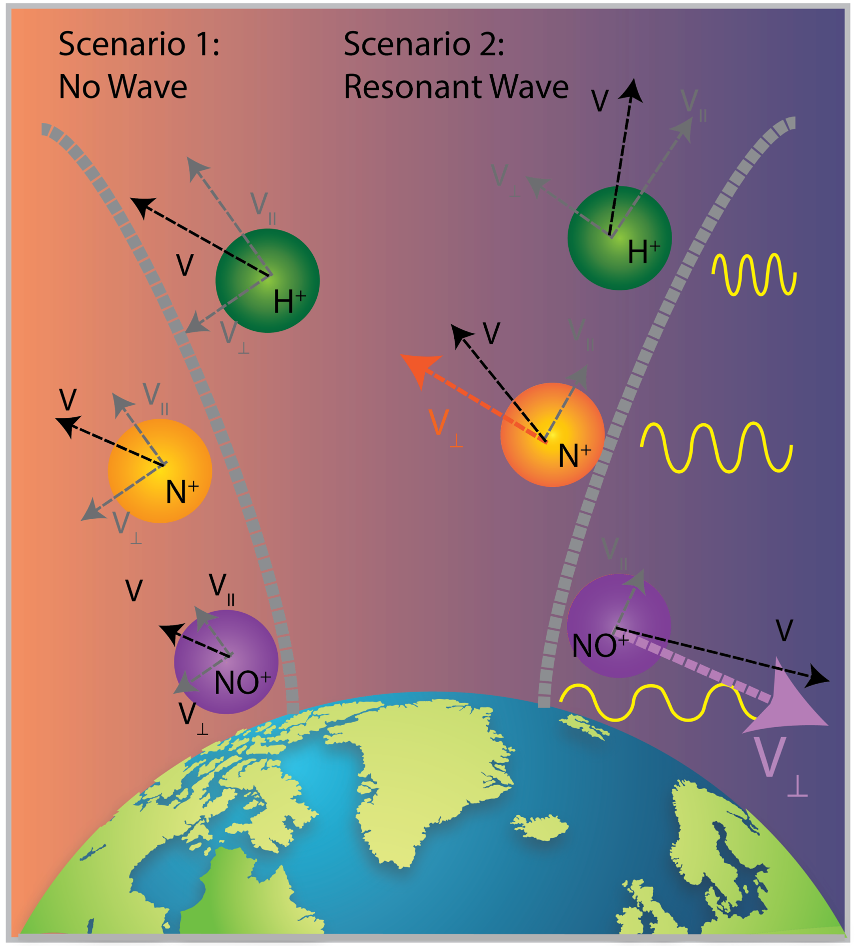


~ 2500 lbs of N^+ lost a day



Seven Ion Polar Wind Outflow Model (7iPWOM)





WPI increase $V_\perp$

↓

Ions move up ($V_\parallel$) along B

↓

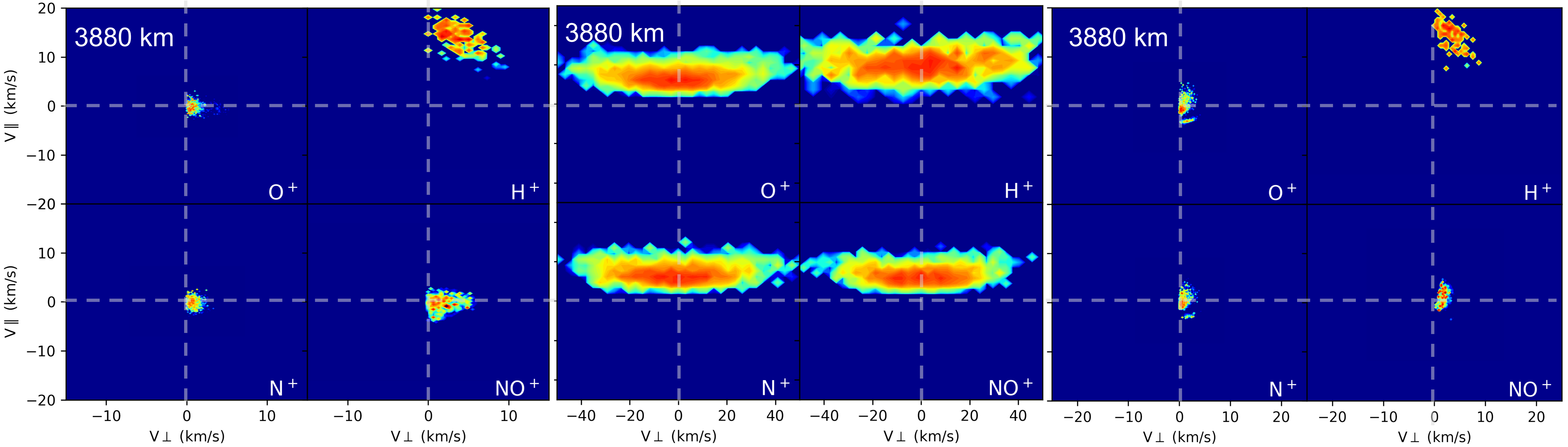
Form ion conic in velocity space

- Developed from PWOM (Glocer et al., 2018), 7iPWOM solves H^+, He^+, N^+, O^+, N_2^+, NO^+, O_2^+ with fluid approach below 1000 km altitude and kinetic approach beyond.
- Heavy ions, especially molecular ions, are expected to be preferentially heated.

(Glocer et al., [2018], *JGR*)

Effect of Wave Heating

- **N^+ ions are a key species** in the ionospheric outflow.
- Preliminary simulations show that **molecular ions can acquire sufficient energy via WPI** to escape from the high latitude ionosphere.



Steady State (T = 0) | Turn on wave heating (T =15 min) | Turn off wave heating (T = 100 min)

- Few NO^+ ($n < 10^{-5}$ cm^{-3}) existed during the steady state. However, after turning on wave, n(NO^+) increase to 10^{-1} cm^{-3} and the average $V_{\parallel}$ is ~ 10 km/s (> escape velocity).
- The presence of molecular ions upflows provides an important framework to understand wave heating mechanisms in the polar wind.