N+: Journey to the Dark Side

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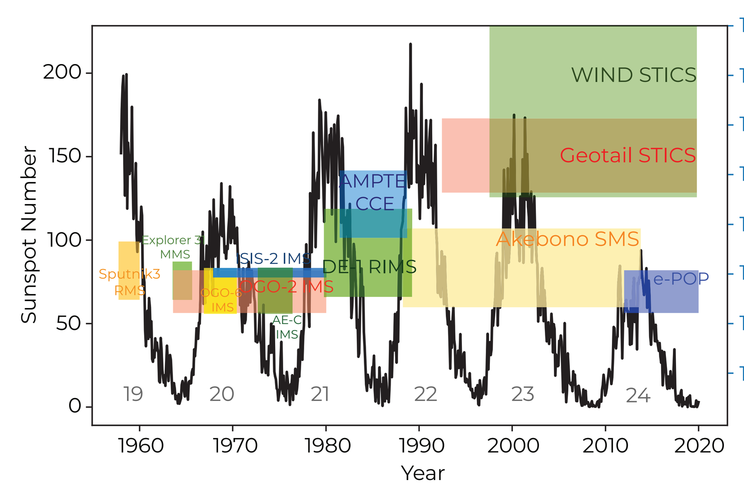
view animations on
https://hsinjuchen.web.illinois.edu/VGEM21.html

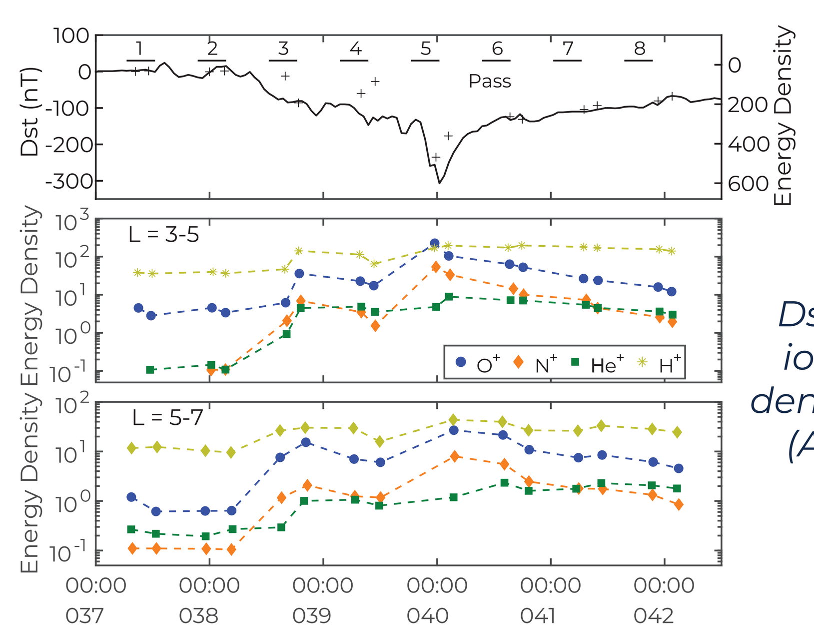
MOTIVATION

The dynamics of N^+ ions in the ionosphere-magnetosphere system are not yet understood despite being observed in ionospheric outflow & the magnetosphere for 60+ years.

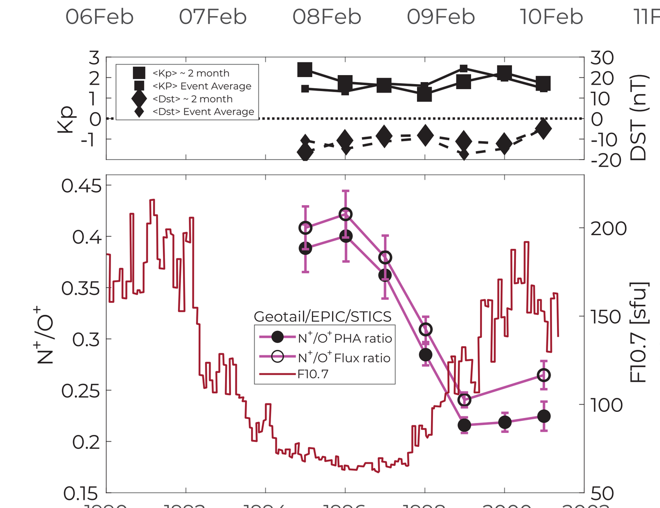
- What determines the spatial & temporal variations in heavy ion composition on timescales comparable to the ion drift periods?
- How does n_{N^+}/n_{O^+} change during solar storms?



operating altitude & lifetime of nitrogen-measuring missions



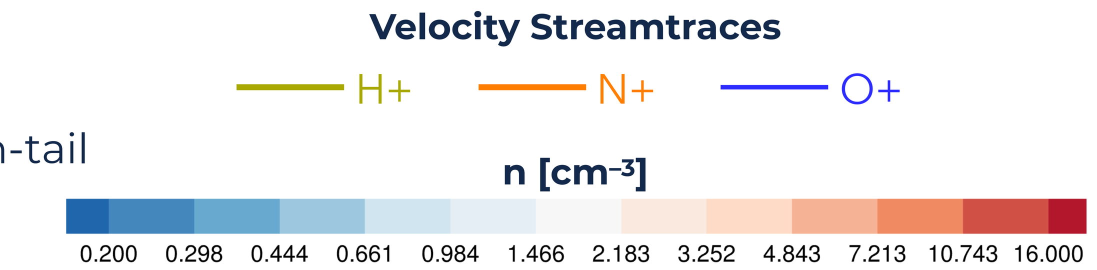
Dst index & ion energy density trends (AMPTE in 1986)



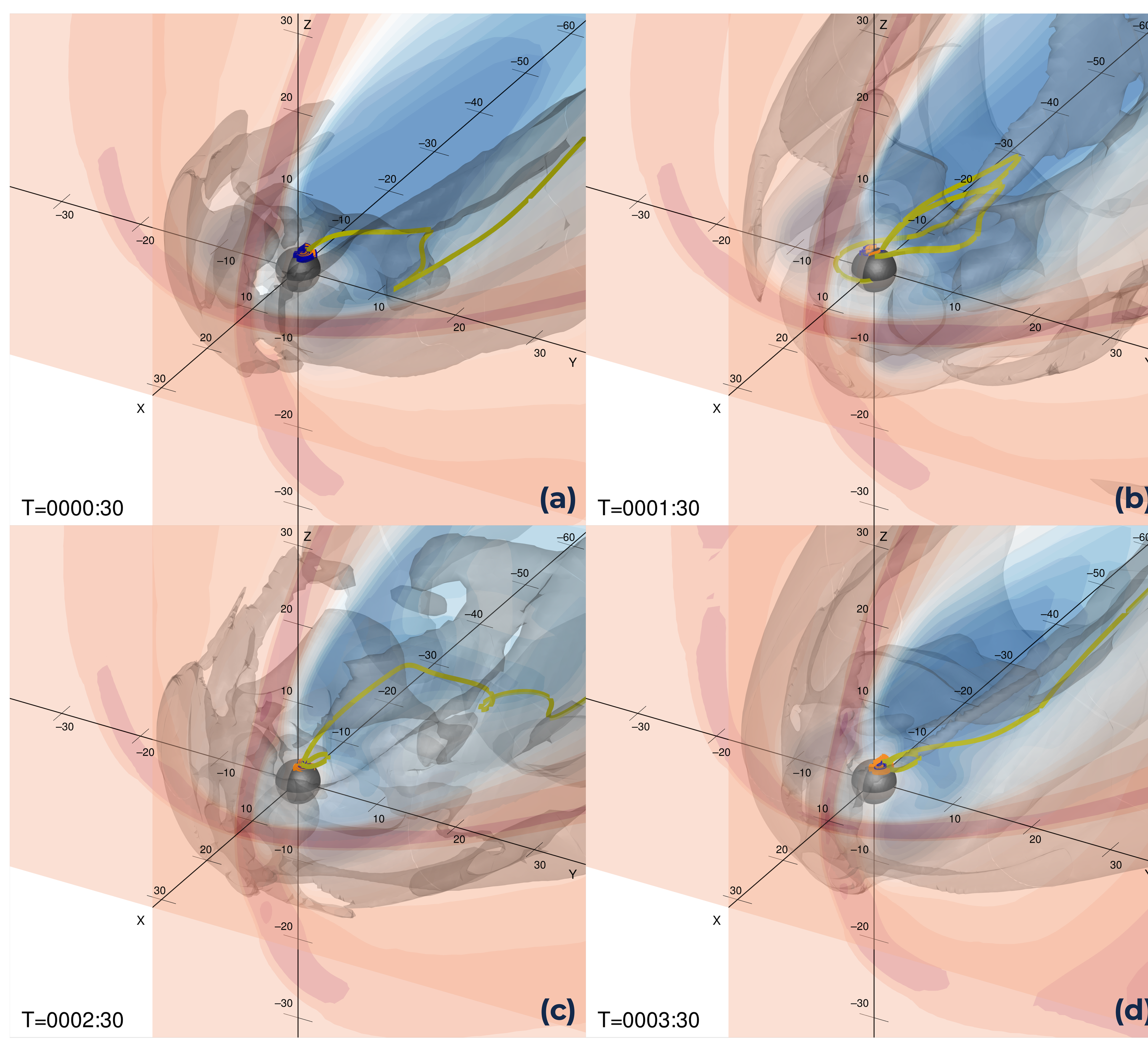
solar activity & N+/O+ ratio trends (Geotail, from 1990 to 2002)

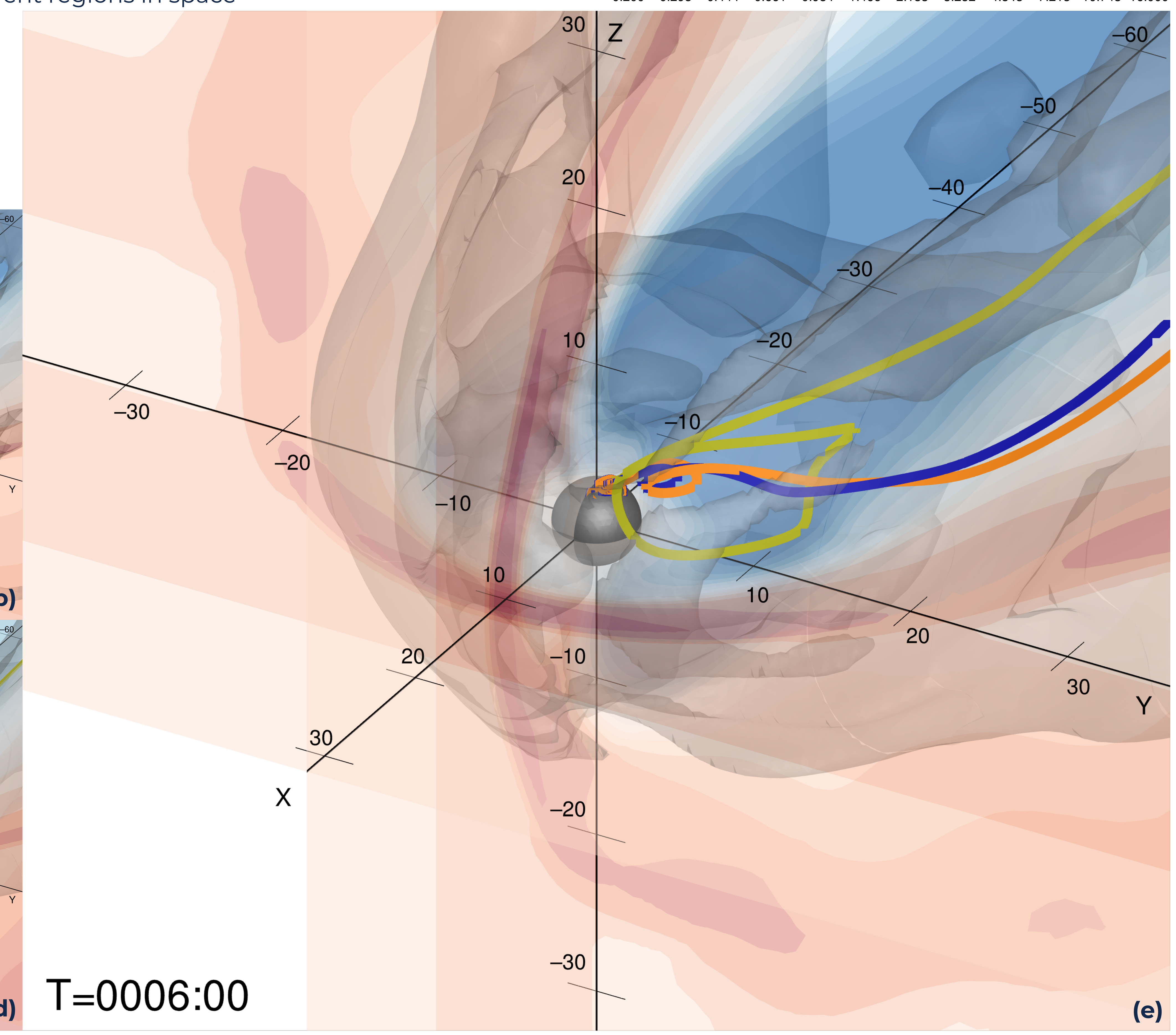
PATHWAY DIFFERENCE BETWEEN N⁺ AND O⁺

- Pathways
  - **(a)–(d)**: steady convection
    N^+ & O^+ ions tend to follow similar pathways as they are transported from the inner boundary (2.5 R_E, dark gray sphere) down-tail
  - **(e)**: increased dynamics where the simulation is driven by a sinusoidal wave in solar wind density
    the pathways of N^+ & O^+ start to diverge, allowing these ions to access different regions in space
- Isosurface ($n_{N^+} = n_{O^+}$, light gray)
  - The dynamic behavior of isosurfaces of equal N^+ and O^+ densities suggest that the local n_{N^+}/n_{O^+} ratio changes fast in response to solar driving.



velocity streamtraces footpoint @ latitude 70°N, 21 MLT





METHODOLOGY

Space Weather Modeling Framework (SWMF)

- Global Magnetosphere (GM) & Ionospheric Electrodynamics (IE) Coupling: Block-Adaptive Tree Solarwind Roe-type Upwind Scheme (BATS-R-US) & Ridley Serial
- Multi-Fluid Magnetohydrodynamics (MHD) [Tóth et al., 2012]

$$\frac{\partial \rho_s}{\partial t} + \nabla \cdot (\rho_s \mathbf{u}_s) = S_{\rho_s}$$

$$\frac{\partial \rho_s \mathbf{u}_s}{\partial t} + \nabla \cdot (\rho_s \mathbf{u}_s \mathbf{u}_s + I p_s) = n_s q_s (\mathbf{u}_s - \mathbf{u}_+) \times \mathbf{B} + \frac{n_s q_s}{n_e q_e}(\mathbf{J} \times \mathbf{B} - \nabla p_e) + S_{\rho_s \mathbf{u}_s}$$

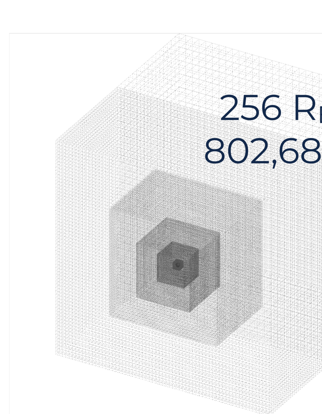
$$\frac{\partial \mathbf{B}}{\partial t} + \nabla \times \left(-\mathbf{u}_e \times \mathbf{B} - \frac{\nabla p_e}{q_e n_e} \right) = 0$$

$$\frac{\partial p_s}{\partial t} + \nabla \cdot (p_s \mathbf{u}_s) = -(\gamma - 1) p_s \nabla \cdot \mathbf{u}_s + S_{p_s}$$

$$\frac{\partial p_e}{\partial t} + \nabla \cdot (p_e \mathbf{u}_e) = -(\gamma - 1) p_e \nabla \cdot \mathbf{u}_e + S_{p_e}$$

$$\mathbf{u}_+ = \frac{\sum_s q_s n_s \mathbf{u}_s}{q_e n_e}$$

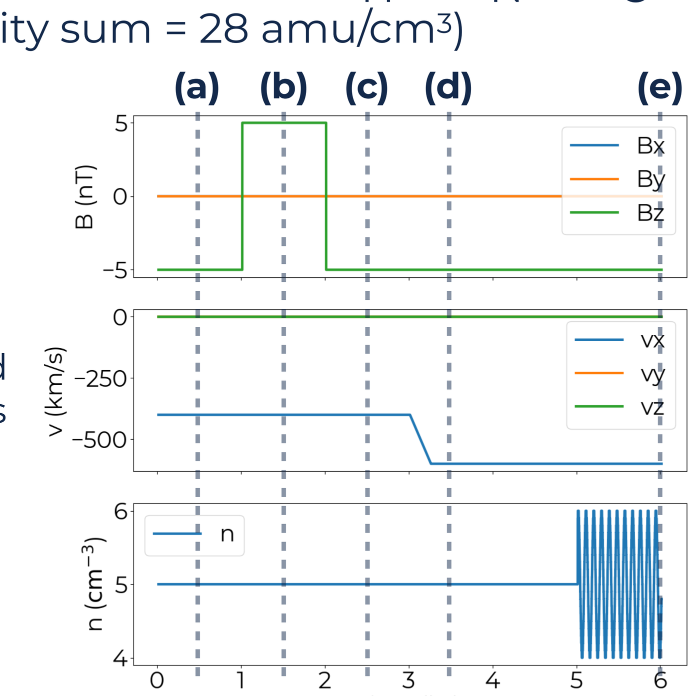
$$\mathbf{u}_e = \mathbf{u}_+ - \frac{\mathbf{J}}{q_e n_e}$$

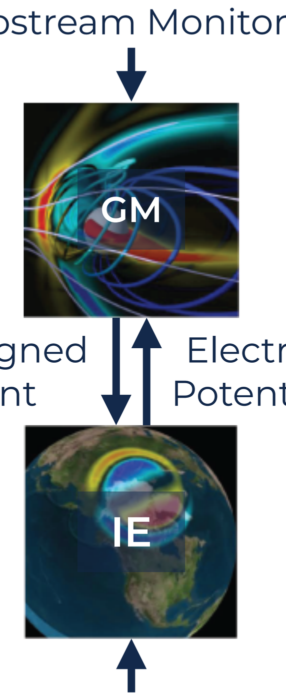


Mesh
256 R_E cube
802,688 cells

- Outflow Ion Density Setup: $n_{H^+} = n_{N^+} = n_{O^+} = 0.90$ /cm³
  (mass density sum = 28 amu/cm³)

Solar Wind Conditions





CONCLUSION

Preliminary results based on multi-fluid simulations that solve for the transport of N^+ in addition to that of O^+ and H^+, indicate that under steady convection, N^+ and O^+ ions tend to follow similar pathways as they are transported from the inner boundary (2.5 R_E) down-tail but diverge during increased dynamics in solar wind density.

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