# The Role of N+ in the Magnetosphere Dynamics: A Multifluid MHD Study

Hsinju Chen (hsinjuc2@illinois.edu) and Raluca Ilie

Heliophysics Research and Applications (HeRA), Department of Electrical & Computer Engineering, University of Illinois at Urbana-Champaign

view animations at hsinjuchen.web.illinois.edu/GEM22.html

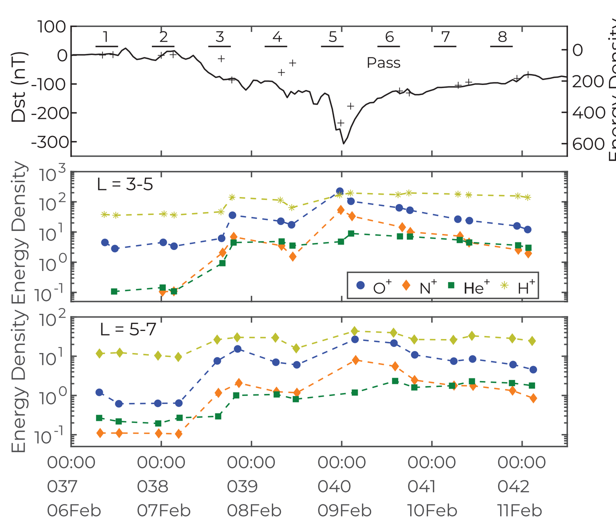
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

HeRA HELIOPHYSICS RESEARCH & APPLICATIONS

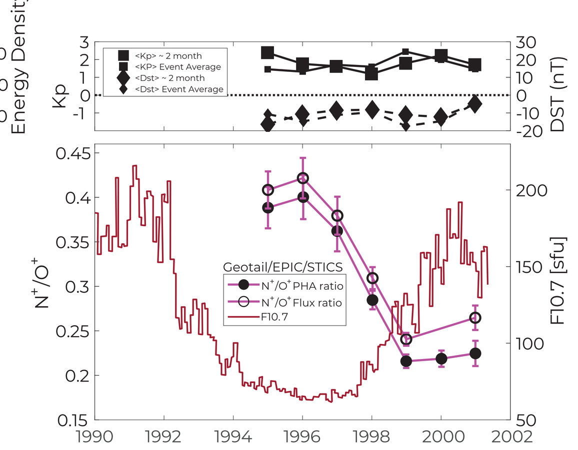
## MOTIVATION

- N+ ions have been observed in the ionosphere & magnetosphere for 60+ years, but their dynamics in the ionosphere–magnetosphere system remain unknown. [Lin & Ilie, 2022]

- What is the differential transport of $N^+$ and $O^+$ ions throughout the global magnetosphere?
- What is the effect of magnetospheric ion composition on the global system dynamics?




AMPTE in 1986 (digitized from Hamilton et al., 1988)




Geotail from 1990 to 2002 (digitized from Christon et al., 2002)

## METHODOLOGY

- Space Weather Modeling Framework (SWMF)
- Global Magnetosphere (GM) & Ionospheric Electrodynamics (IE) coupling: Block-Adaptive Tree Solar wind Roe-type Upwind Scheme (BATS-R-US) & Ridley Ionosphere Model (RIM)
- Multifluid Magnetohydrodynamics (MHD) [Tóth et al., 2012]

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

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

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

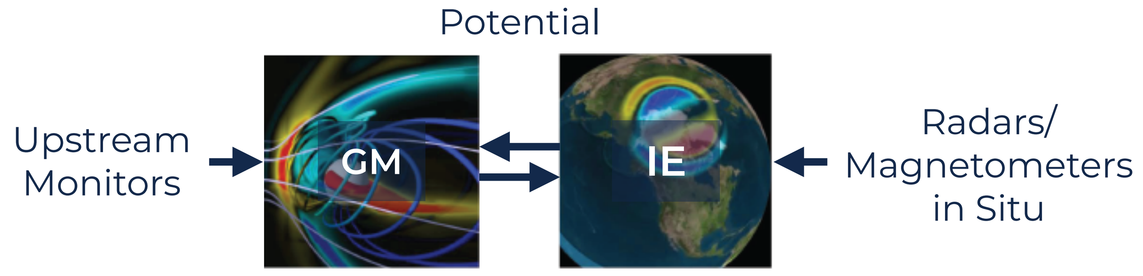
$$\frac{\partial p_e}{\partial t} + \nabla \cdot (p_e \mathbf{u}_e) = -(\gamma - 1) p_e \nabla \cdot \mathbf{u}_e + S_{p_e}$$

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

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

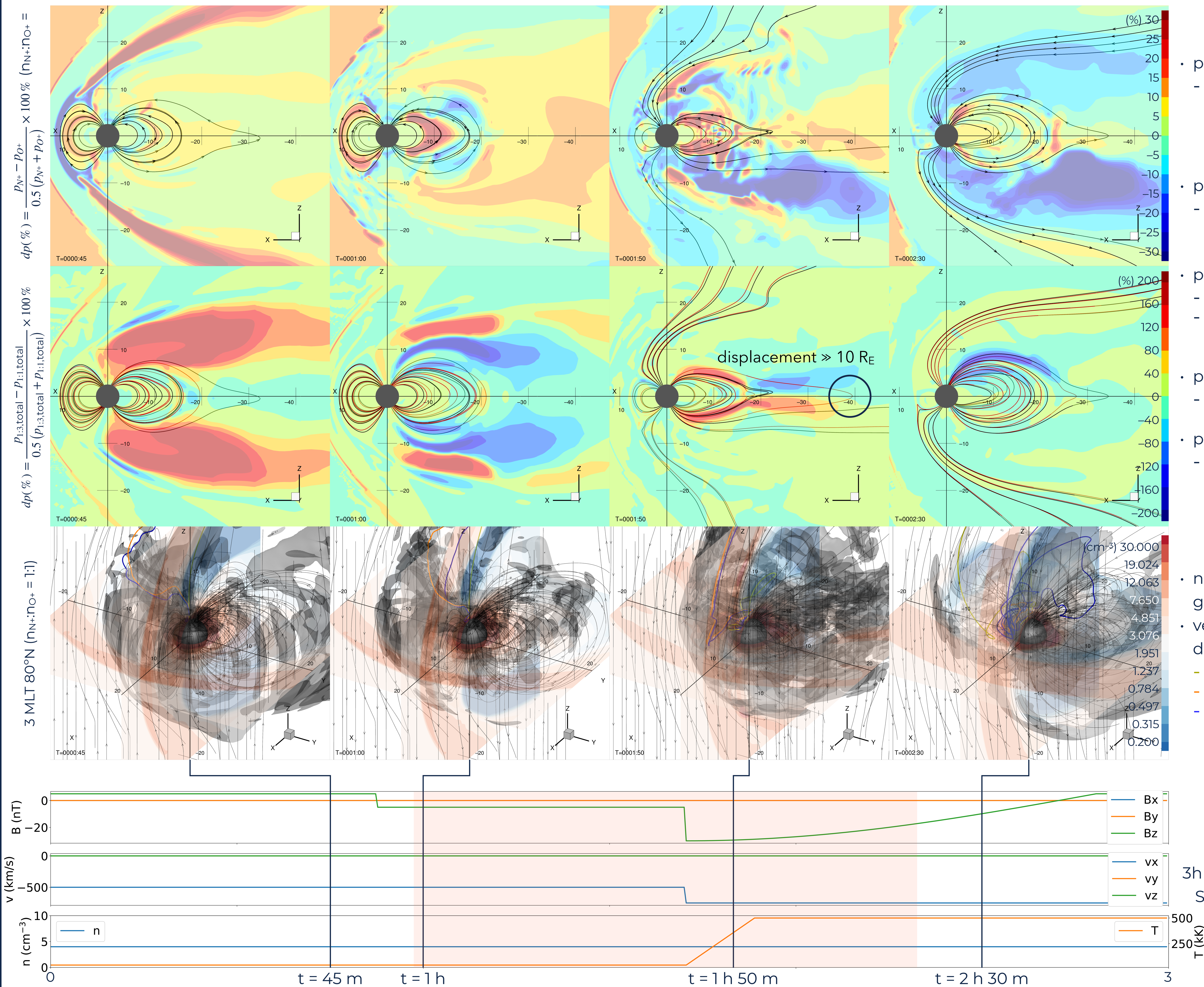
$$\mathbf{u}_e = \mathbf{u}_+ - \frac{\mathbf{J}}{q_e n_e}$$

- Inner Boundary Ion Density Setup ($\Sigma_i \rho_i = 28\ cm^{-3}$):
  - **[$n_{N+}:n_{O+}$ = 1:1]** 80% $H^+$, 10% $N^+$, 10% $O^+$
  - *vs.* **[$n_{N+}:n_{O+}$ = 1:3]** 80% $H^+$, 5% $N^+$, 15% $O^+$ @ 2.5 $R_E$
- 292 $R_E$ × 256 $R_E$ × 256 $R_E$: ~22M cells




## ION PRESSURE VARIATION UNDER DIFFERENT N+/O+ COMPOSITION RATIOS

magnetic field line footpoints @ 2.5 $R_E$ 55°, 60°, 65°, 70° N & S




- $p_{N+} > p_{O+}$
  - main & recovery phases: nightside near-Earth plasma & plasmasheet ($p_{N+} \gg p_{O+}$ @ L ≈ 7 – 15 during main phase)
- $p_{N+} < p_{O+}$
  - recovery phase: lobes

- $p_{[nN+:nO+ = 1:3]} > p_{[nN+:nO+ = 1:1]}$
  - initial phase: lobes
  - main phase: nightside closed field lines (L ≈ 15 – 20)
- $p_{[nN+:nO+ = 1:3]} \approx p_{[nN+:nO+ = 1:1]}$
  - recovery phase: most of nightside
- $p_{[nN+:nO+ = 1:3]} < p_{[nN+:nO+ = 1:1]}$
  - recovery phase: northern closed field lines in the nightside (L ≈ 30)

- $n_{N+} = n_{O+}$ isosurface (light gray): dynamic
- velocity streamtraces diverge
  - H+
  - N+
  - O+

3h storm condensed from Sept. 8, 2017 storm (9h)

## CONCLUSIONS

- Under equal $n_{N+}$ & $n_{O+}$ on the inner boundary of BATS-R-US:
  - Larger $p_{N+}$ (compared with $p_{O+}$) in the nightside near-Earth plasma and plasmasheet regions.
  - Larger $p_{O+}$ in the lobes.
  - $n_{N+} = n_{O+}$ isosurface is dynamic & ion pathways diverge.
- The effects of $n_{O+} > n_{N+}$ in ionospheric outflow:
  - Shorter magnetotail; altered magnetic topology.
  - Larger pressure along nightside closed field lines during main phase.
  - Smaller pressure in the lobes during main phase and in northern closed field lines in the nightside @ L ≈ 30 during recovery phase.

## ACKNOWLEDGMENTS

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