Ion Acceleration by Different Electric Field Terms in an Induced Magnetosphere

Xiao-Dong Wang, Shahab Fatemi

Swedish Institute of Space Physics (IRF)
Kiruna, Sweden

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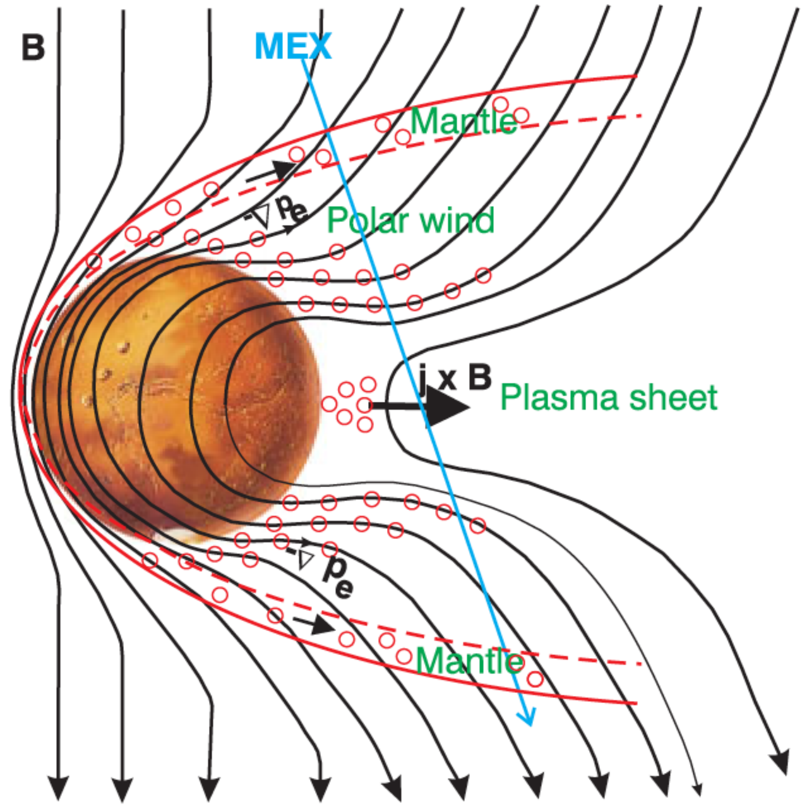
INDUCED MAGNETOSPHERE

- Exists at non-magnetized, atmospheric bodies
  - Mars, Venus, Titan, etc..
- Produced by solar wind/surrounding plasma interactions
  - Super/subsonic plasma flow
  - Conductive ionosphere => induced magnetic field
- Governs the acceleration and escape of planetary ions



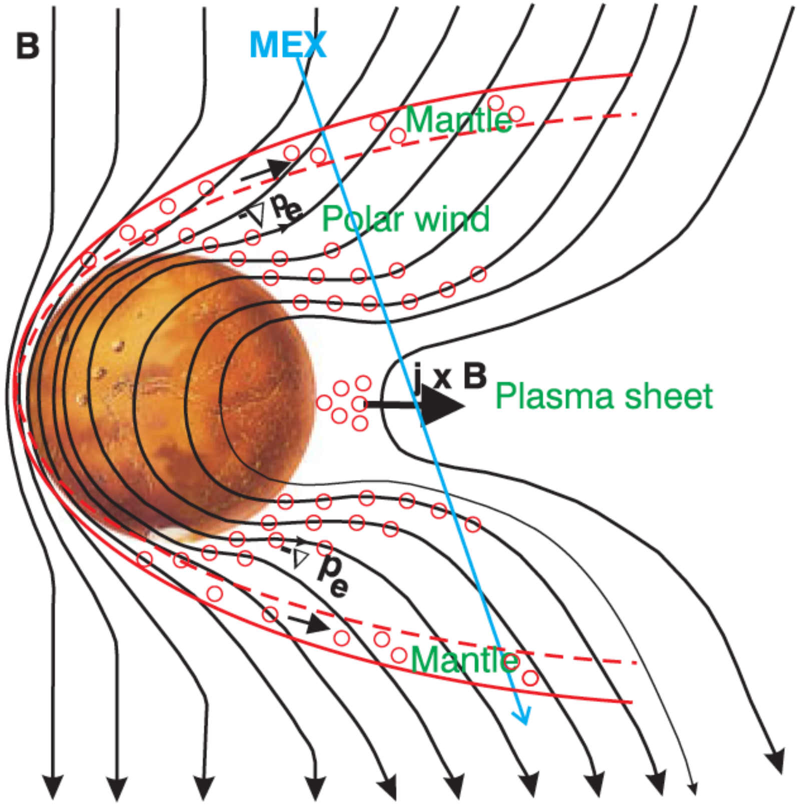
[Dubinin+11]

ELECTRIC FIELD ACCELERATES IONS

- **B** does not directly accelerate ions, only **E** does
- **E** expressions felt by an ion

$$\boldsymbol{E} = \boxed{-\sum_i \frac{n_i}{n_e} \boldsymbol{V}_i \times \boldsymbol{B}} - \boxed{\frac{\nabla P_e}{n_e e}} + \boxed{\frac{\boldsymbol{j} \times \boldsymbol{B}}{n_e e}}$$

  - Motional term
  - Electron pressure gradient term
  - Hall term
- Different acceleration mechanisms
- Explains the ion acceleration and escape by physics instead of statistics



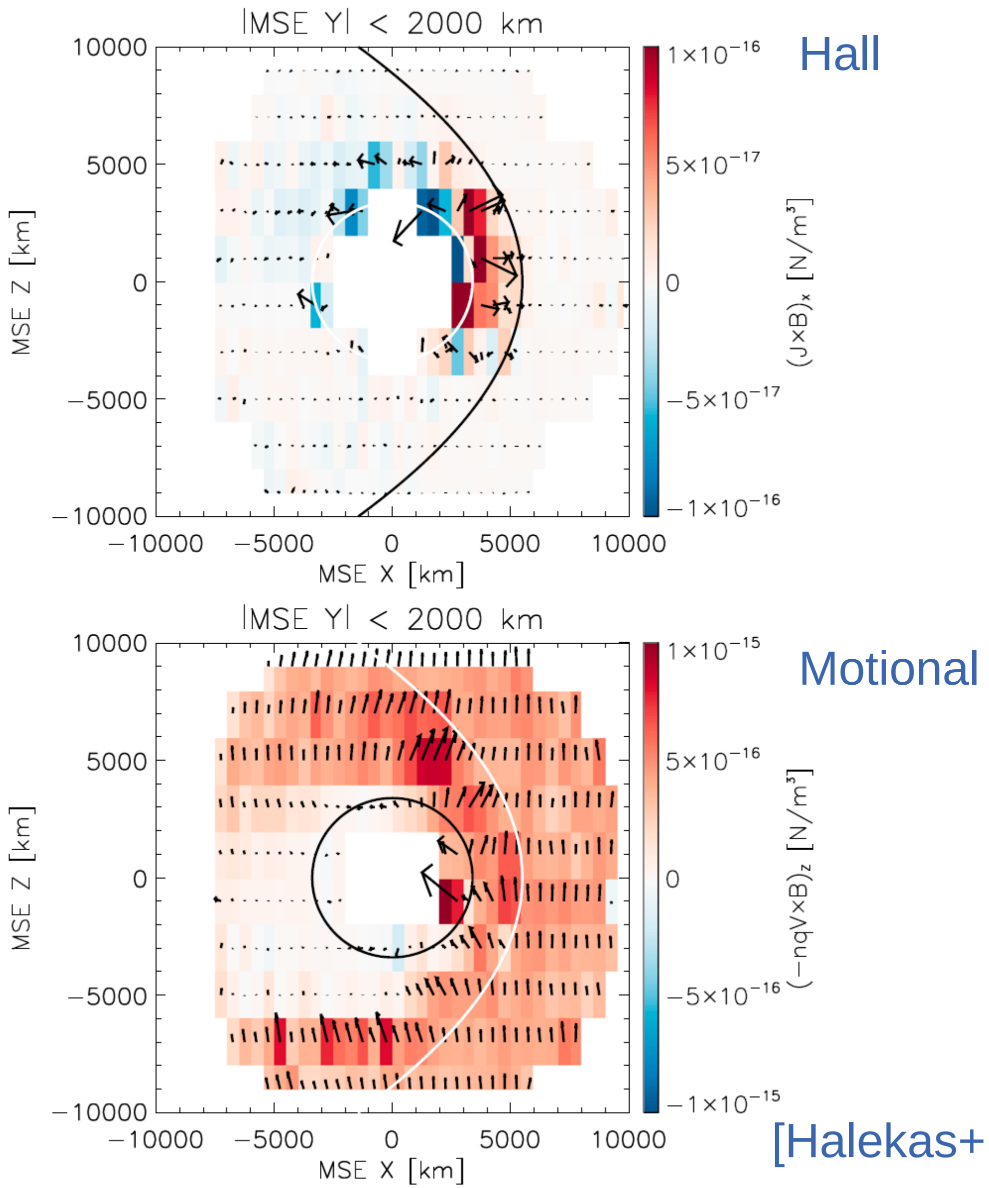
[Dubinin+11]

FIRST OBSERVATION OF EF TERMS

- MAVEN observations
- Motional term and Hall term deduced
- Motional term dominates

- Averaged picture
- Underestimation due to averaging before differentiation

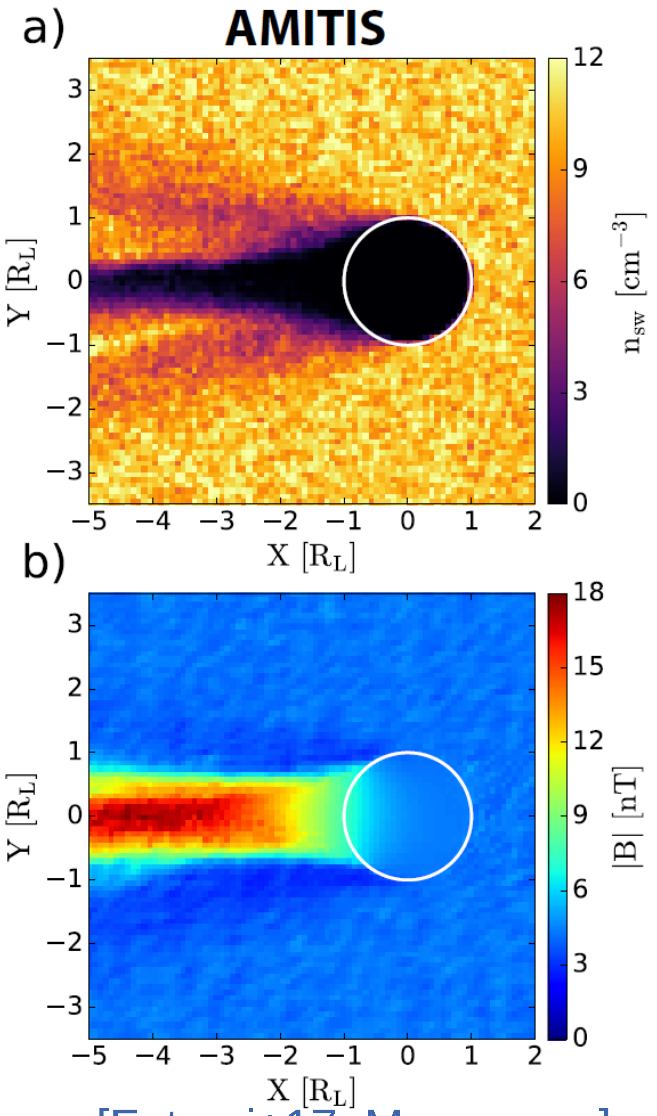
- What role do they play in ion acceleration?



[Halekas+17]

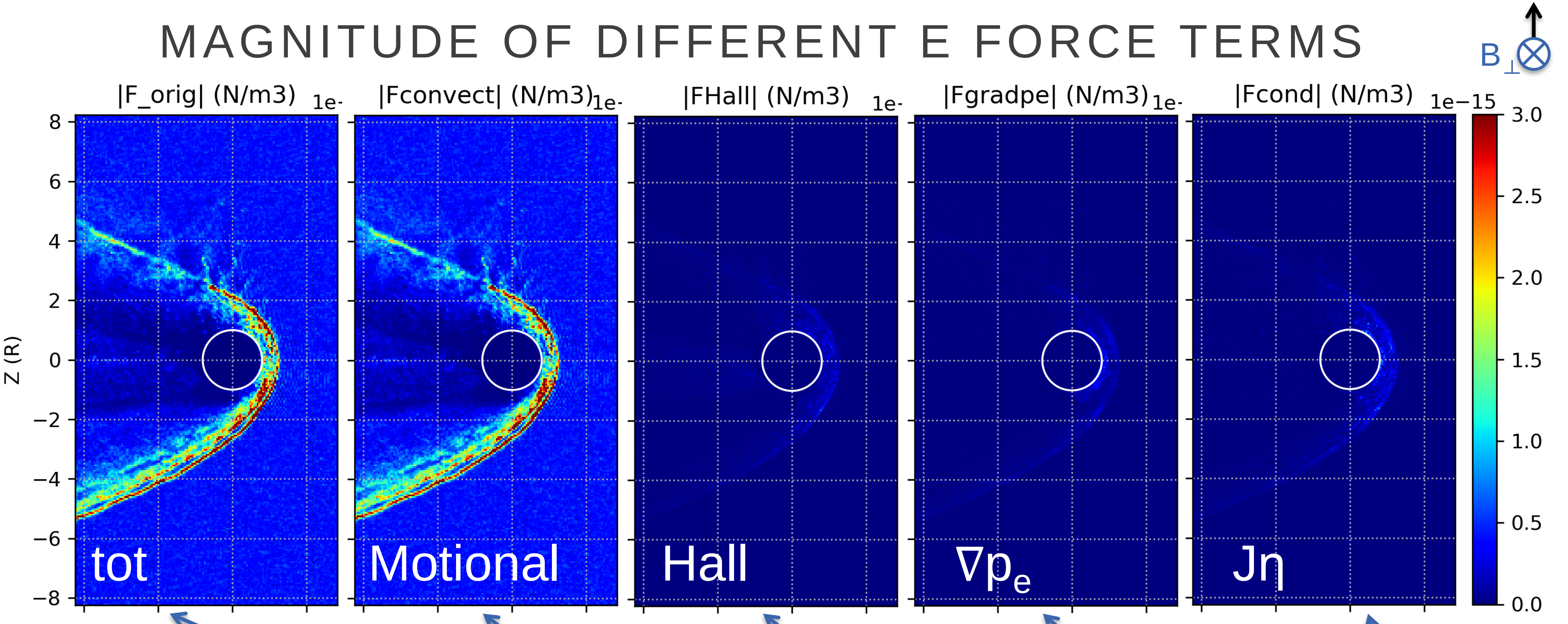
HYBRID SIMULATION: AMITIS

- AMITIS: A 3-D GPU-based hybrid particle-in-cell model for space and plasma physics.
- Particle ions, fluid electrons, field on cell
  - Can trace individual particles
- Can handle very low densities/vacuum
  - Applicable in the wake
- Efficient



[Fatemi+17, Moon case]

MAGNITUDE OF DIFFERENT E FORCE TERMS

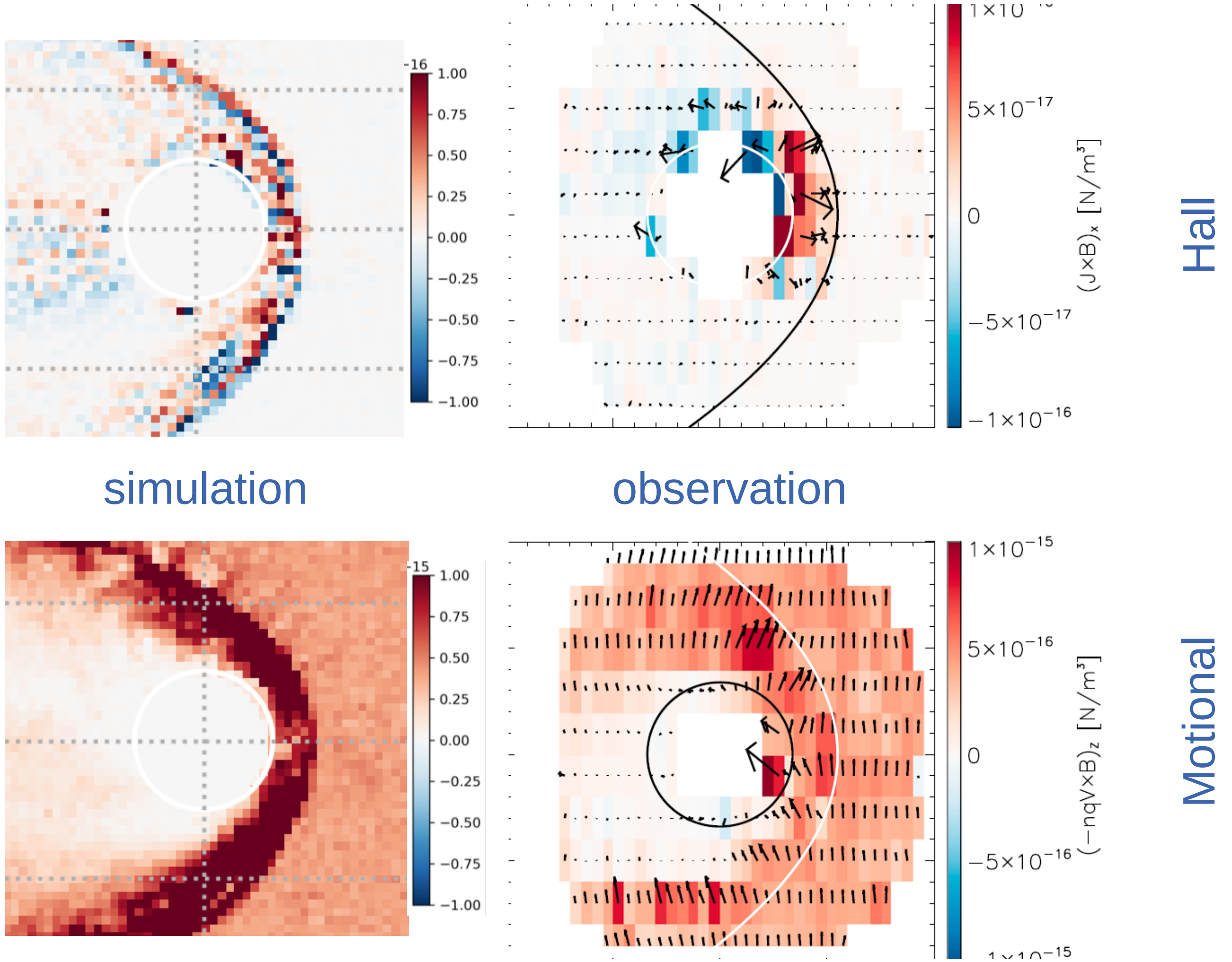


n_{sw} = 2 cm^{-3}
v_{SW} = (-400, 0, 0) km/s
B = (-1.634, 2.516,0) nT
Only O^+ launched,
Chapman production
profile in dayside

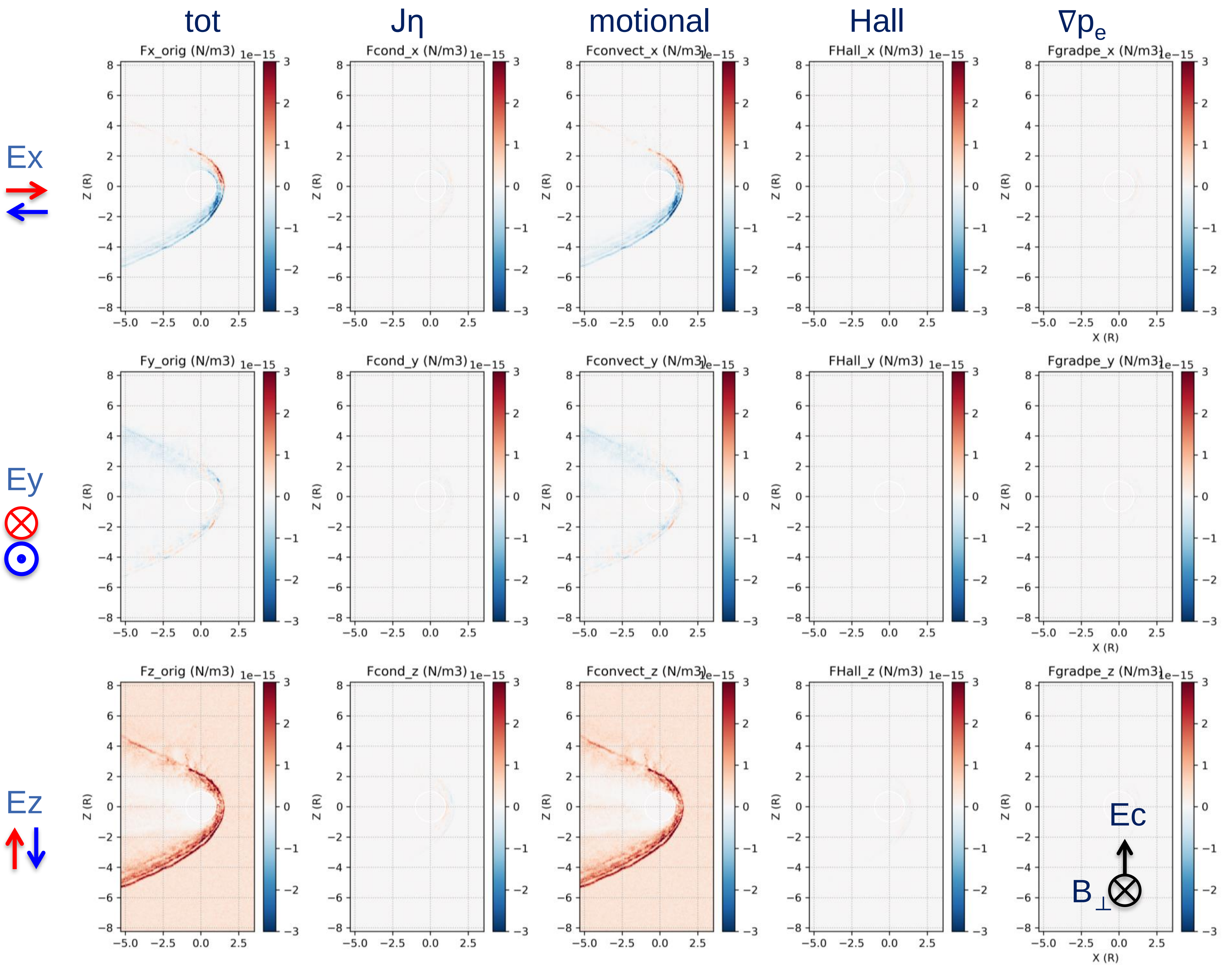
$$\mathbf{F_I} = -\mathbf{J_I} \times \mathbf{B} + \frac{1}{\mu_0}(\nabla \times \mathbf{B}) \times \mathbf{B} - \nabla p_e + \rho_I \frac{\eta}{\mu_0} \nabla \times \mathbf{B}$$

COMPARISON WITH OBSERVATIONS

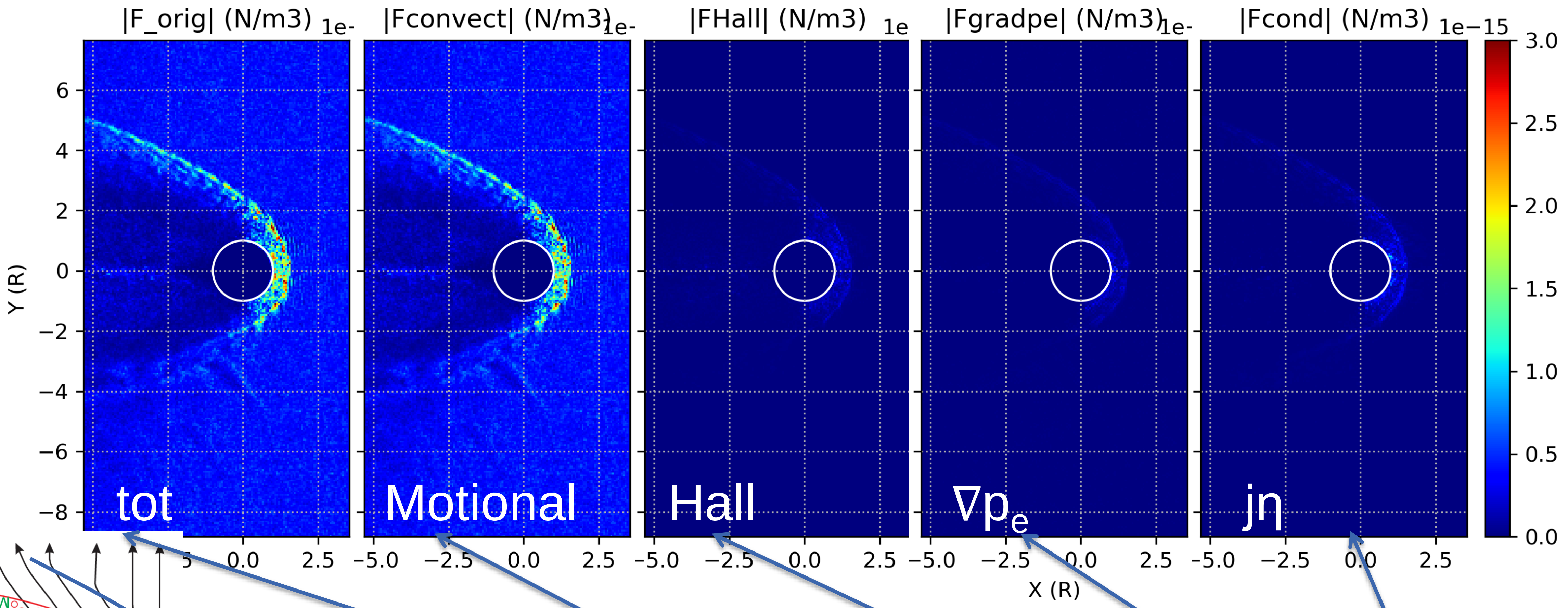
- E plane
- Agreement
  - Domination of the motional term
  - Hall term magnitude
- Discrepancy
  - Motional term magnitude

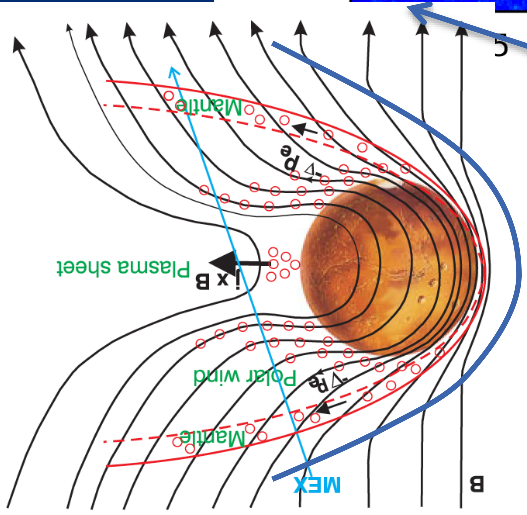


E PLANE: COMPONENTS



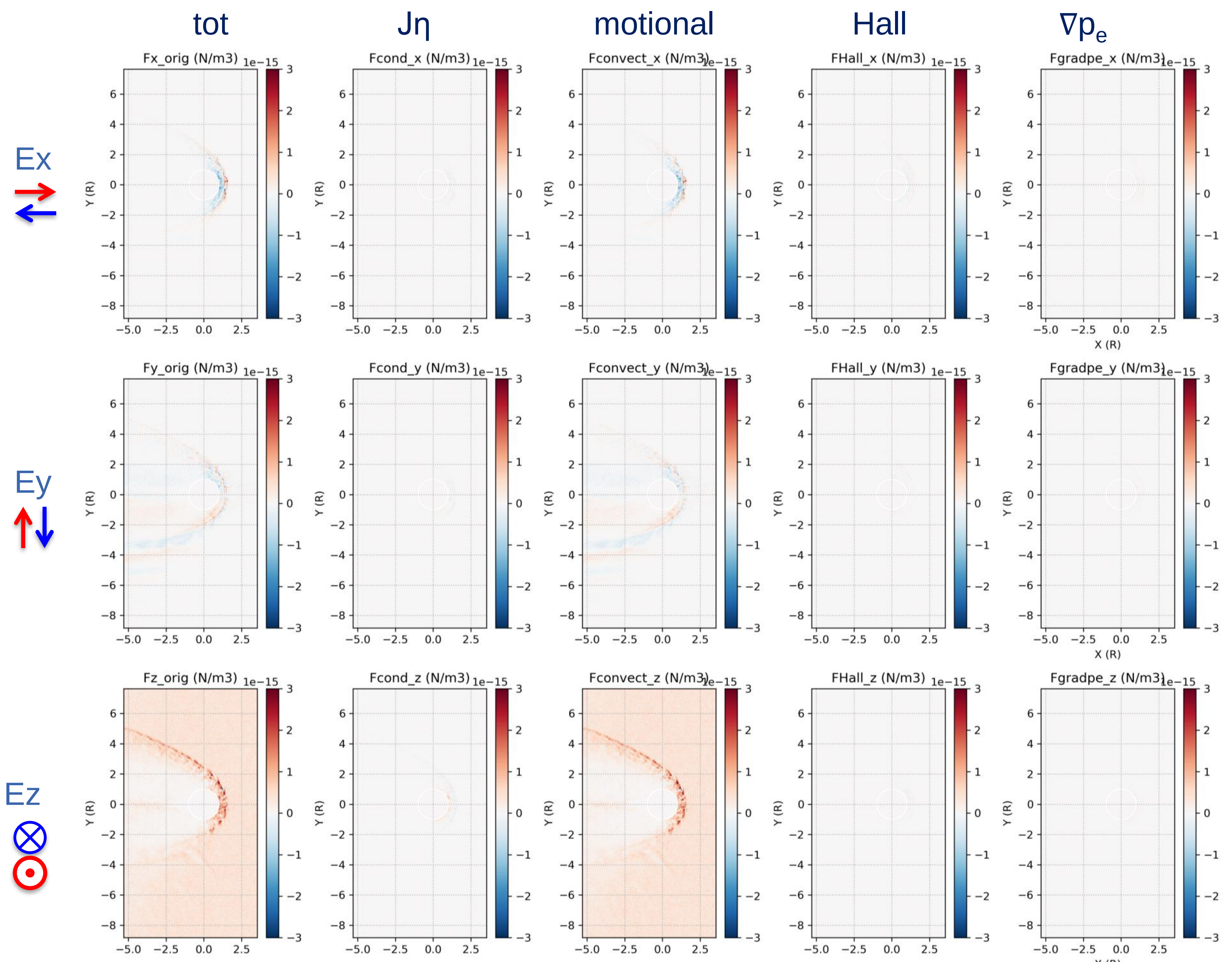
MAGNITUDES IN B PLANE





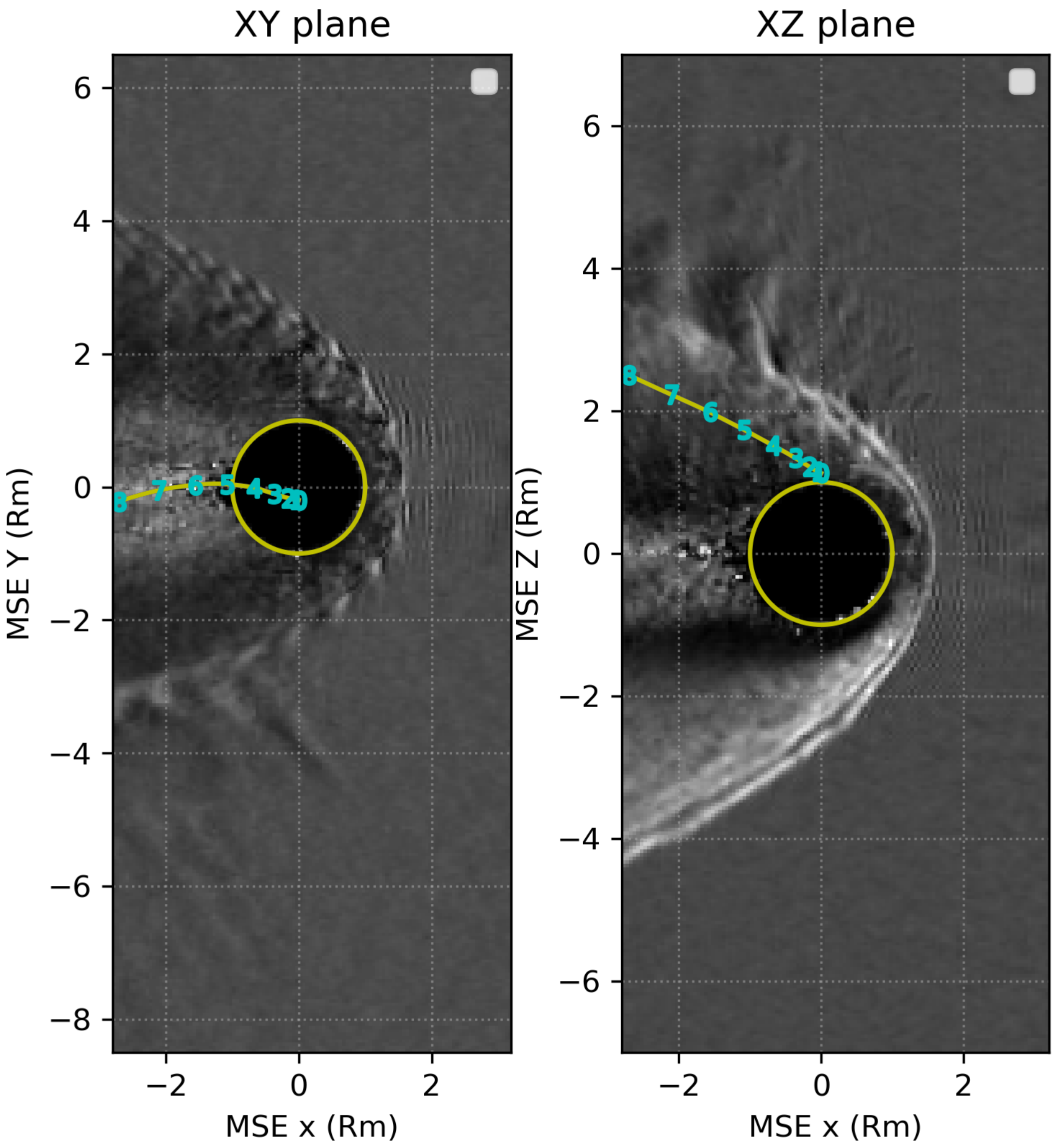
$$\mathbf{F_I} = -\mathbf{J_I} \times \mathbf{B} + \frac{1}{\mu_0}(\nabla \times \mathbf{B}) \times \mathbf{B} - \nabla p_e + \rho_I \frac{\eta}{\mu_0} \nabla \times \mathbf{B}$$

B PLANE: COMPONENTS



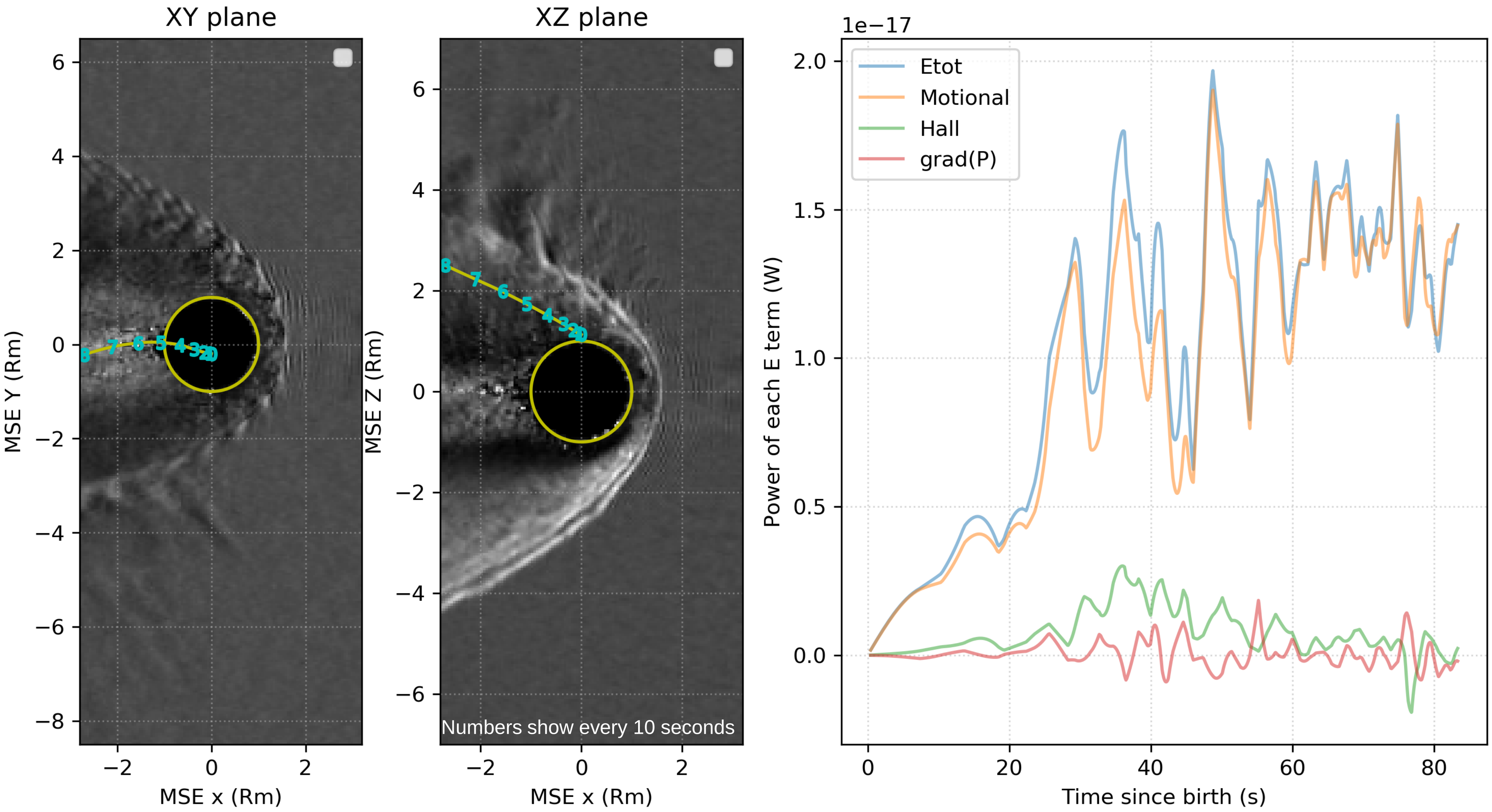
HOW DOES THE FIELD ACCELERATE IONS?

PARTICLE TRACING IN THE FIELD



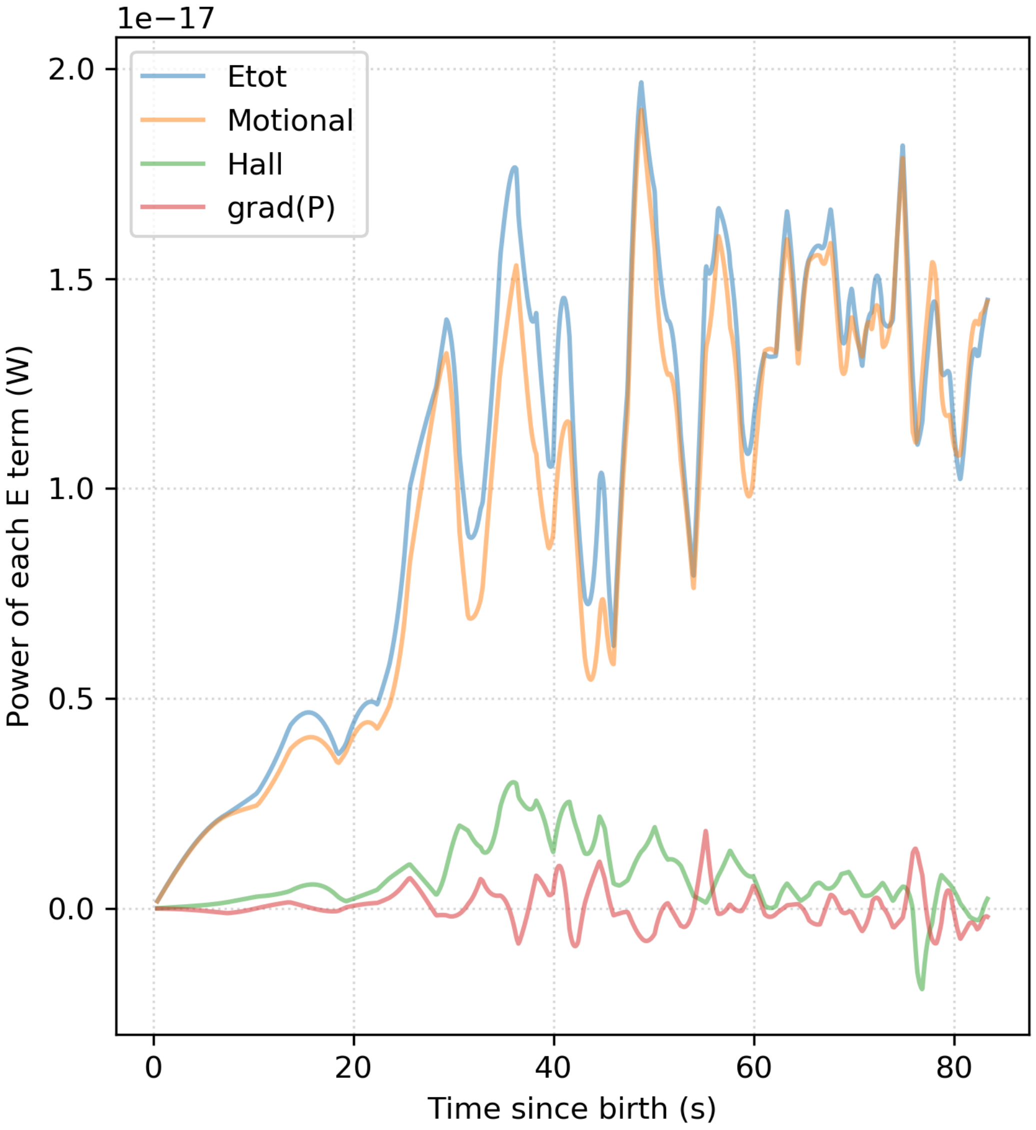
- Field of steady state
- Launch particles from dayside at different altitude
- Trace ion trajectory in the total E field
- Calculate power of different EF terms along the trajectory
- Explore the acceleration history of each ion

TYPICAL ACCELERATION HISTORY

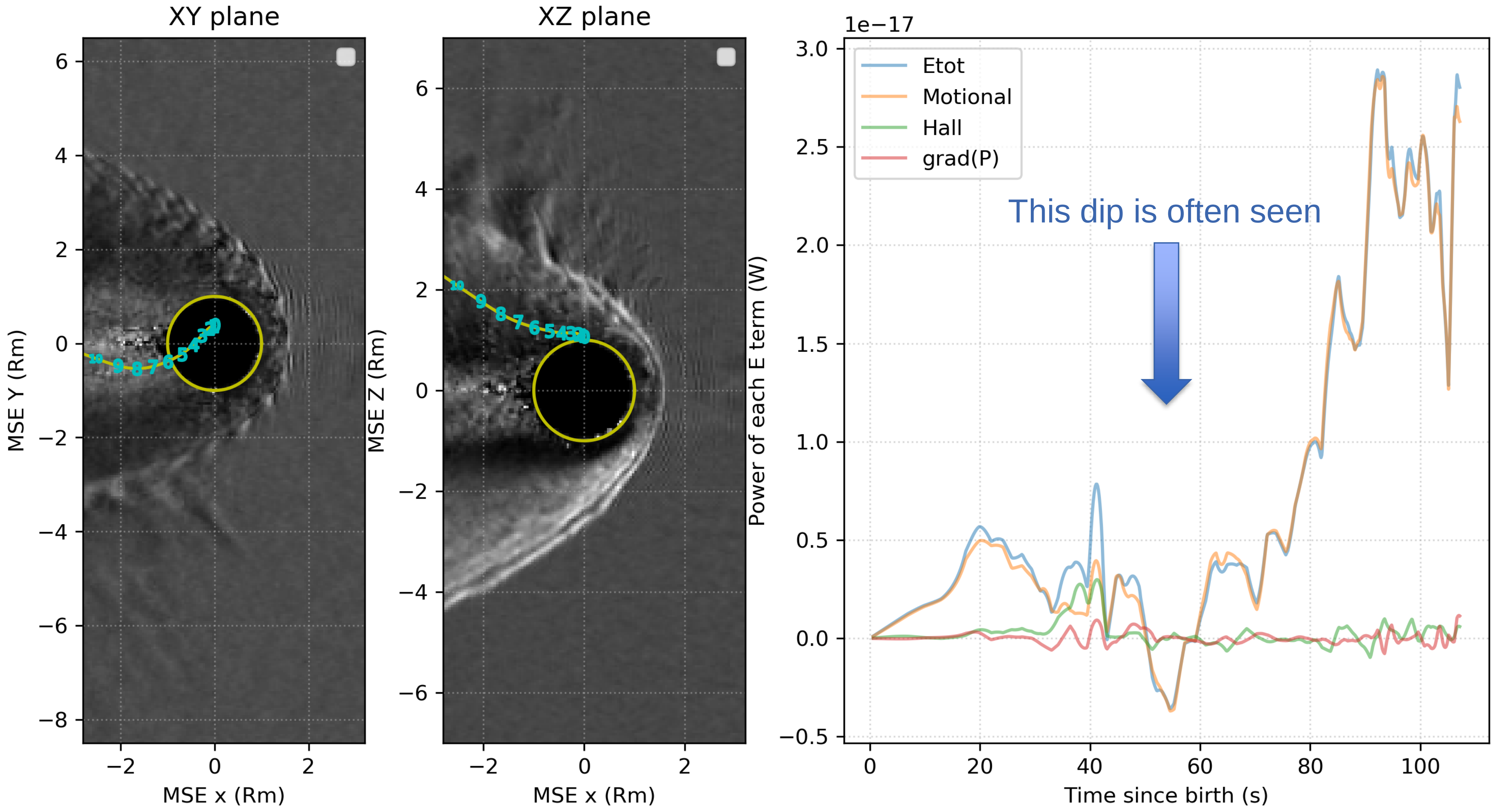


TYPICAL ACCELERATION HISTORY

- Ions may or may not escape
- Motional term governs the acceleration in general
- Power of acceleration is fluctuant
- Total power always positive in this case

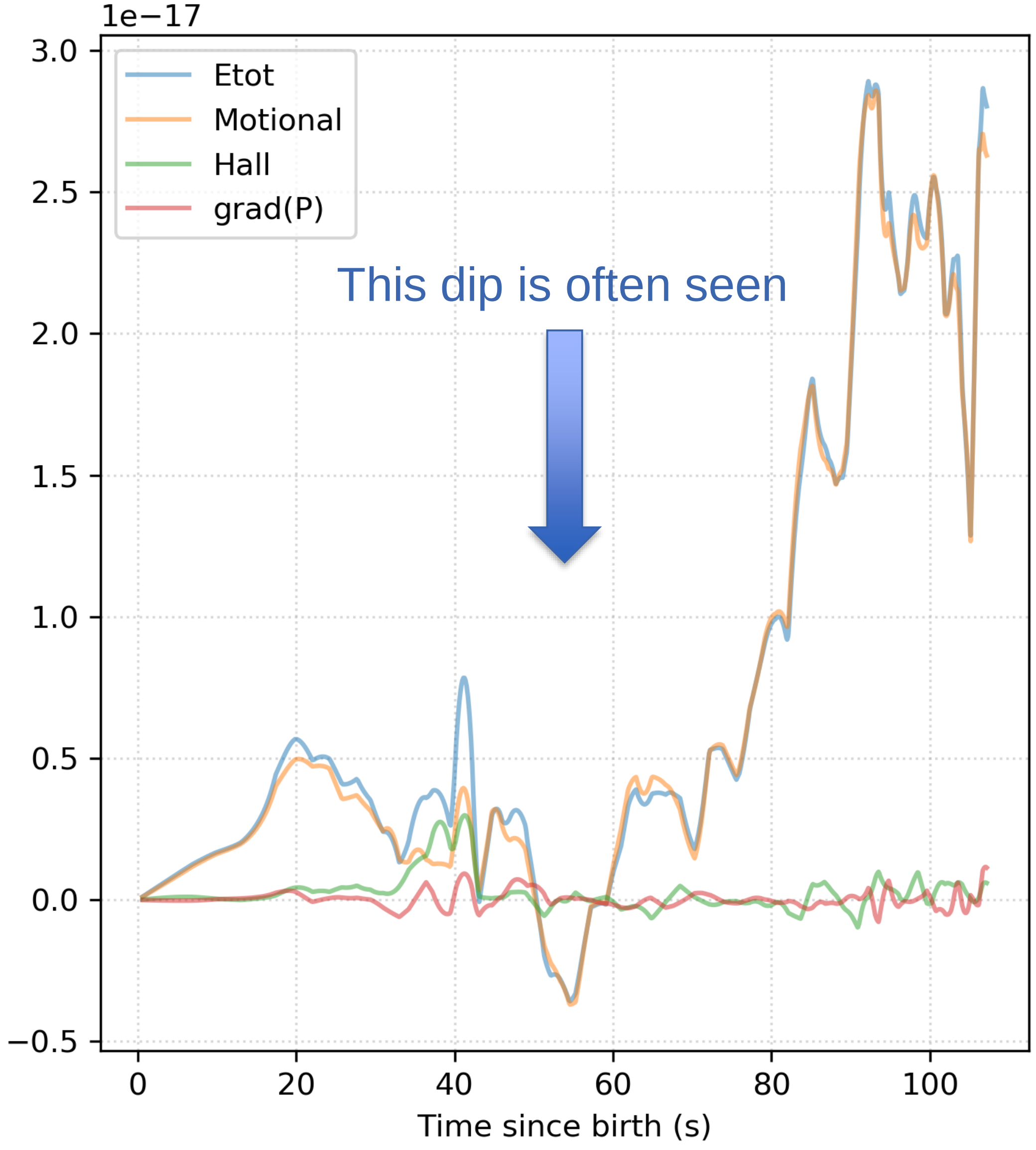


NOT ALWAYS ACCELERATED



NOT ALWAYS ACCELERATED

- Deceleration often seen at the bottom of the ion plume or the center of plasma sheet
- Possibly related to the curvature of MF lines



SUMMARY

- Different E field terms in an induced magnetosphere separated. In general consistent with MAVEN observations where comparable.

- Motional E term dominant in most of the induced magnetosphere and magnetosheath.

- The work of each E term depends on the trajectories of individual ions.