Quasi-static Acceleration Regions as the source of Bi-Directional Electron Beams at Jupiter

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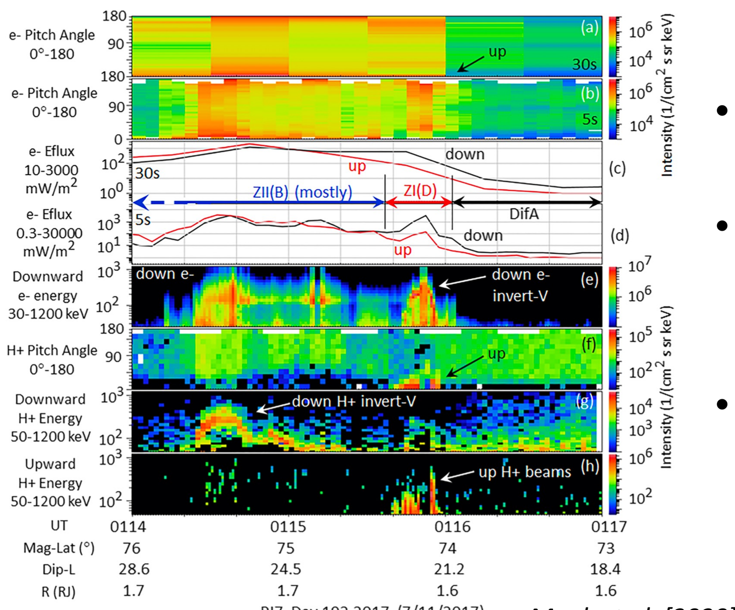
Introduction to Quasi–Static Acceleration Regions (QSARs) & Double Layers (DLs)

What is a Double Layer (DL)?

- Local region in plasma that sustains a quasi-static potential difference
- Two plasma layers of equal & opposite charge
- Particles accelerated across potential difference
- Stability of DL depends on charge separation, pressure balance, instabilities
- Detected at Earth by FAST, Polar, Cluster (e.g. *Ergun at al. [1998], Marklund et al. [2011]*)



Mauk et al. [2020]

Double Layers at Jupiter

- Expected to be acceleration mechanism for main auroral electrons (e.g. *Cowley & Bunce [2001]; Ray et al. [2009]*)
- *Ray et al. [2009]* modelled Io flux tube accel. region
  - Located at minimum of gravitational & centrifugal potentials, ~2-3 R_J jovicentric
- Juno has *not* measured as many double layers as expected (e.g. *Mauk et al. [2017, 2020]*)
  - Double layers observed in upward & downward zones with particle energies up to 400 eV

Open Questions:

What are the potential and plasma profiles along auroral field lines?

How is the stability of quasi-static acceleration structures affected by plasma dynamics?

What are the energy profiles of precipitating populations?

Time-Dependent Vlasov Model

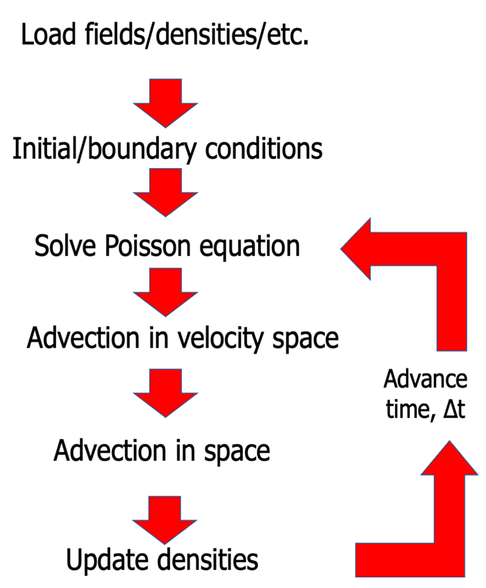
Model Heritage and Key Features

- Terrestrial model developed by *Gunell et al. [2013]*
- Adapted to include centrifugal forces for jovian system
- Describes plasma evolution along 1-D magnetic field line
- Solves 1-D spatial, 2-D velocity space Vlasov equation
  - $v_{parallel}$, μ space
- Employs non-uniform mesh along field
- Fully kinetic, time-varying description of plasma

$$\frac{\partial f}{\partial t} + v_s\frac{\partial f}{\partial s} + \frac{1}{m}\Big(\underbrace{qE}_{\text{Electric field}} - \overbrace{\mu\frac{dB}{ds}}^{\text{Magnetic Mirror}} + \underbrace{ma_g}_{\text{Gravity}} + \overbrace{\frac{1}{2}m\Omega^2 r^2}^{\text{Centrifugal force}}\Big)\frac{\partial f}{\partial v_s} = 0$$

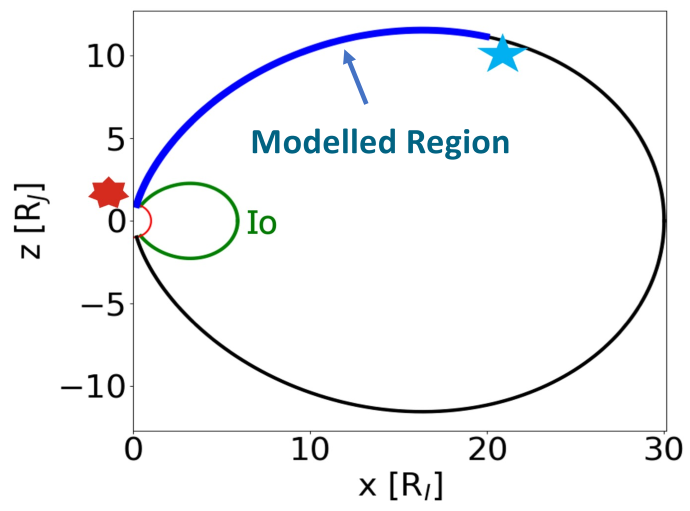
Numerical Scheme

- Assume plasma at boundaries
- Impose magnetic field structure
- Set potential drop across the domain
- Iterate towards quasi-neutrality at each spatial location
- Advance in time
- Refine spatial & temporal grid as stability is obtained

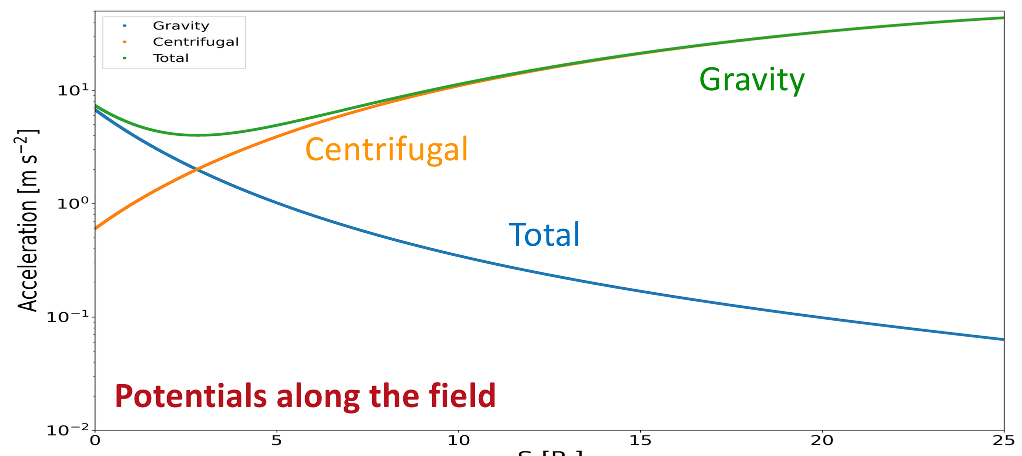


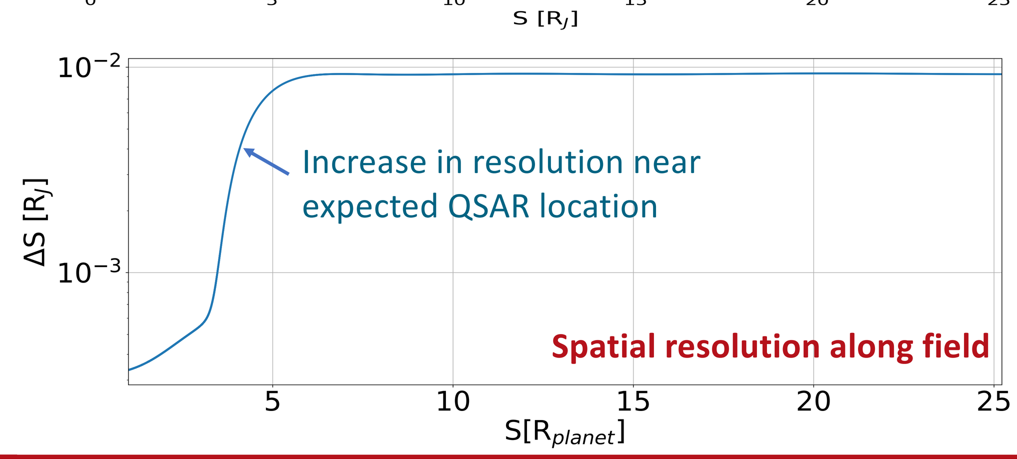
Exploring the L = 30 Auroral Flux Tube

- Large mirror ratios along field line
  - Spatial step resolution increases towards ionosphere
  - Examine reduced section of field line for computational feasibility
- Ionospheric potential fixed at 150 kV
- Magnetospheric ions determined by propagating *Dougherty et al. [2017]* values to mid-latitudes
- Use scale height from *Bagenal & Delamere [2011]*
- Hot electrons from *Mauk & Saur [2008]*
- Ionospheric population from *Strobel & Atreya [1983]*



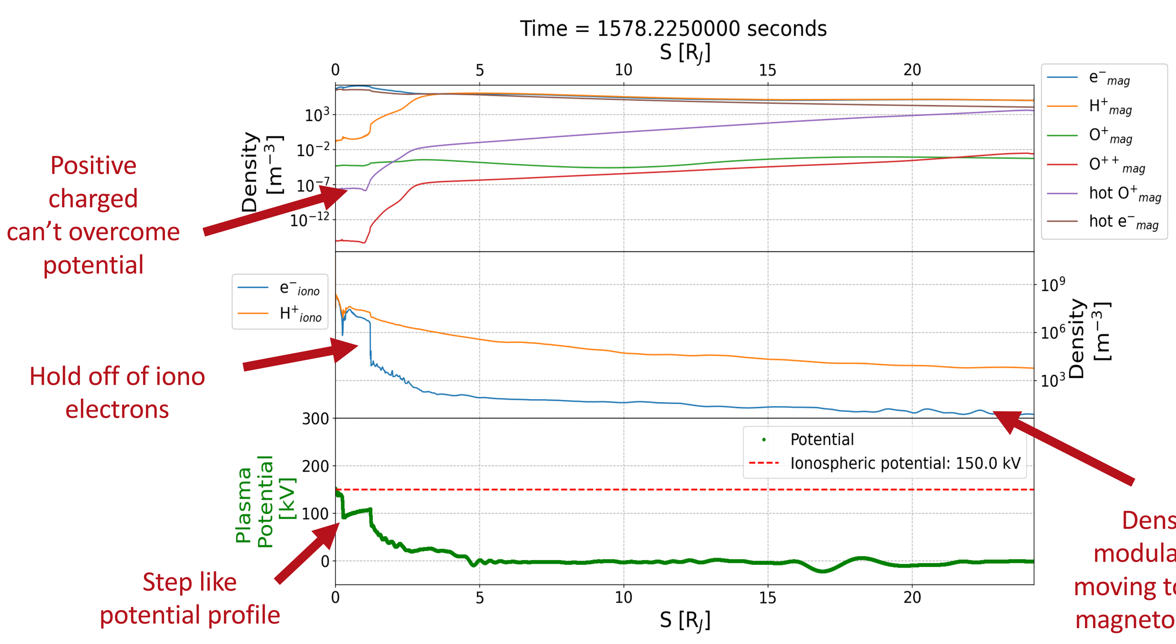
	★ Magnetospheric		Ionospheric [Strobel & Atreya, 1983]	
Species	**Density (m^{-3})**	**Temp. (eV)**	**Density (m^{-3})**	**Temp. (eV)**
e^-	2.4×10^5	1000	2×10^{11}	0.31
H^+	2.4×10^3	250	2×10^{11}	0.31
e^- (hot) [Mauk & Saur 2008]	1.2×10^4	25,000		
O^+	1.1×10^{-3}	250		
O^{++}	5.6×10^{-3}	550		
O^+ (hot)	6.8×10^3	2,500		



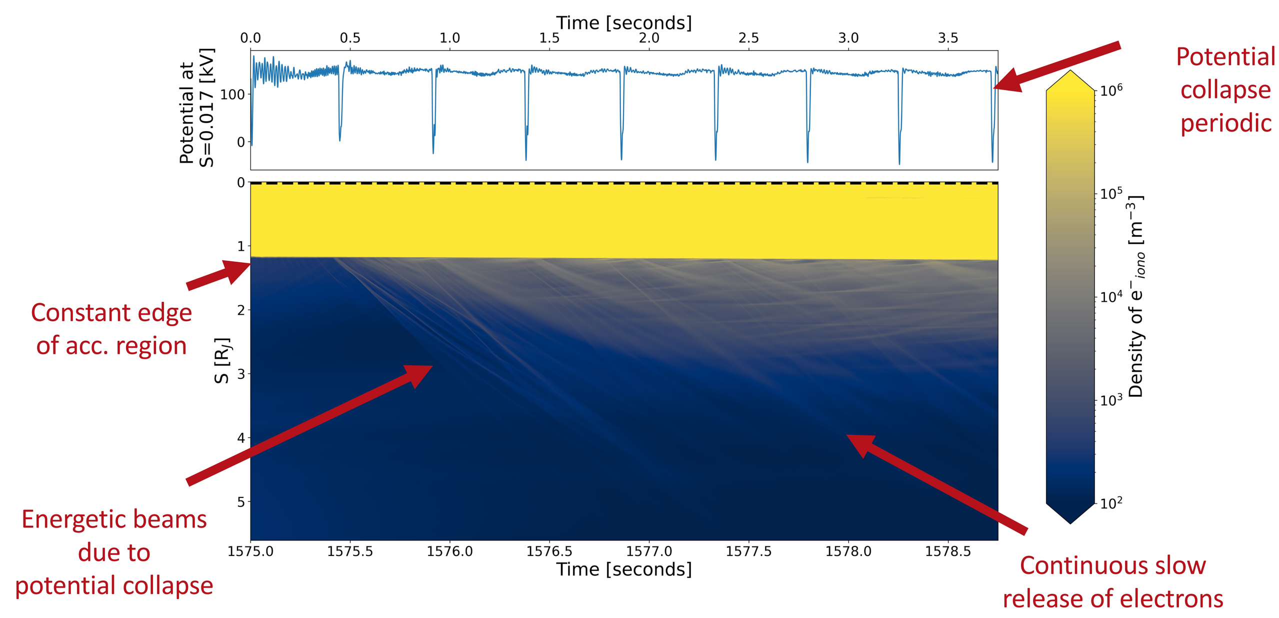


Results

1. Stable density & potential structure:



2. Evidence of outgoing ionospheric e^- beams:



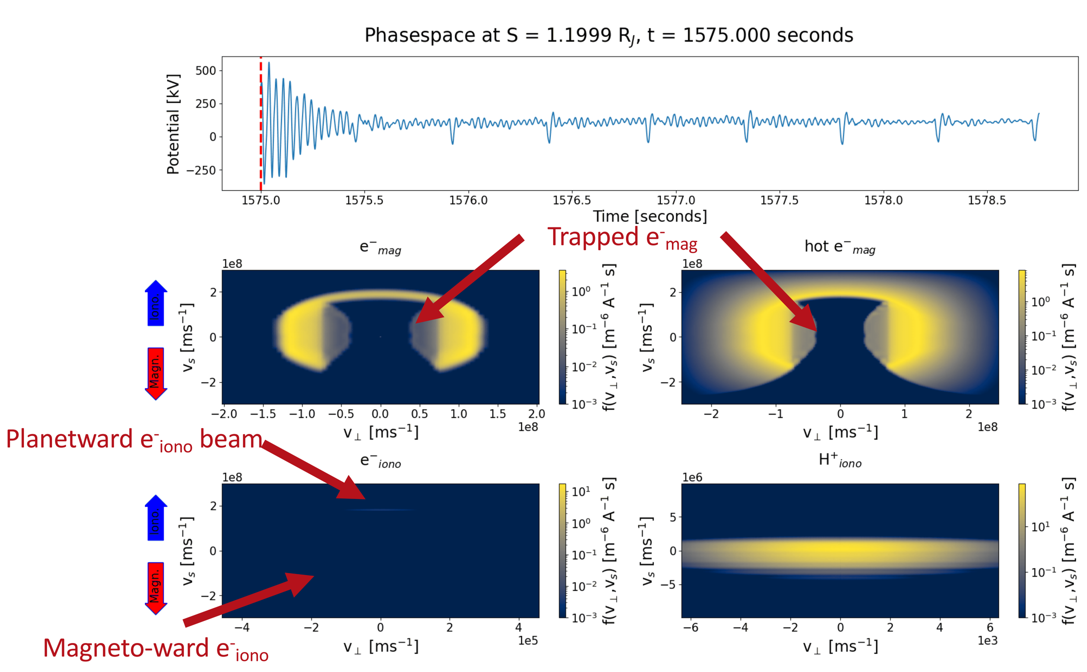
Model Parameters for 'final' results

N_s	16320
Δt (μs)	37.5
ϵ_r	8.96×10^5
Iterations	100,000
V_{iono} (kV)	150

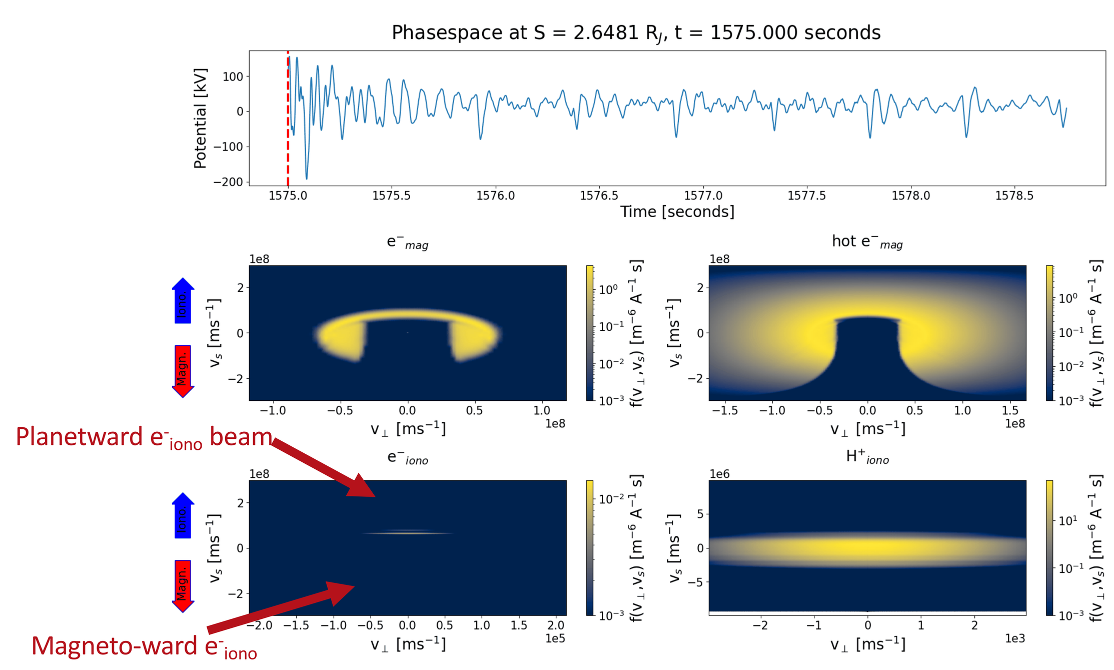
ϵ_r is artificial relative dielectric constant

- $\varepsilon = \varepsilon_0\varepsilon_r$ allows for computationally manageable spatial grid and time steps
- $\lambda_D \sim \varepsilon_r^{1/2}$ and $\omega_p \sim \varepsilon_r^{-1/2}$
- ε_r reduced with increases in spatial resolution and shorter time steps

3. Phasespace at QSAR edge contains trapped e^-

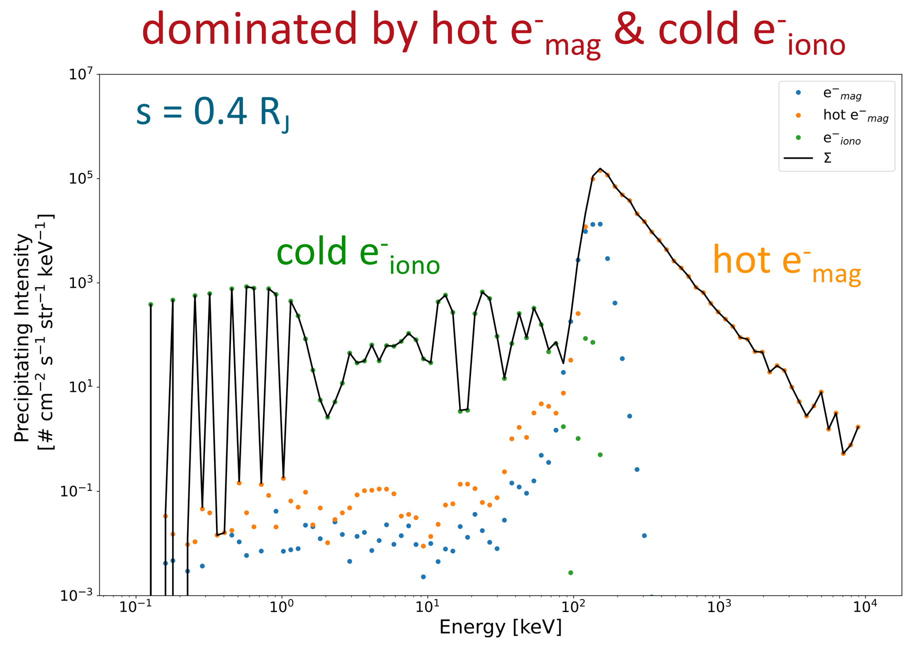


4. Phasespace outside QSAR shows e^- beams

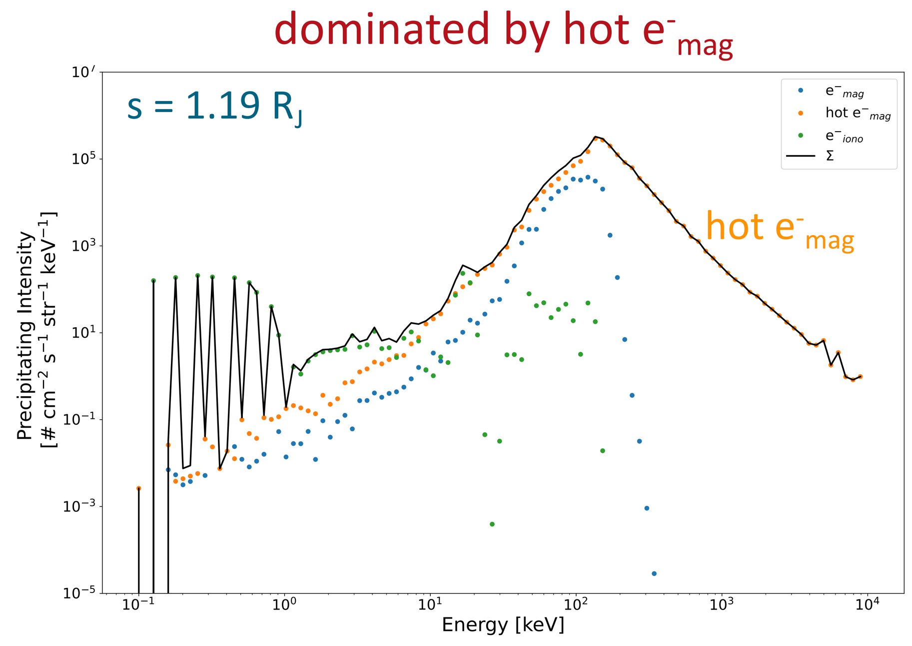


See movies for 4 & 5 on laptop!

5. Precipitating electron profile inside QSAR dominated by hot e^-_{mag} & cold e^-_{iono}



5. Precipitating electron profile at QSAR edge dominated by hot e^-_{mag}



Conclusions

- First time-dependent Vlasov model of Jupiter's QSAR
- Simulation shows sharp potential drop ~1.2 R_J along field (2.2 R_J jovicentric) from inner boundary
- Predicts electron beams sourced from ionospheric and magnetospheric populations
- Electrons trapped within 2.2 R_J jovicentric
- Upward travelling electron beams linked to periodic collapse of QSAR
  - QSAR are less static than expected

Future Steps

- Investigate downward current region
- Extract pitch-angle information to directly compare with Juno measurements
- Implement non-dipolar magnetic field structure