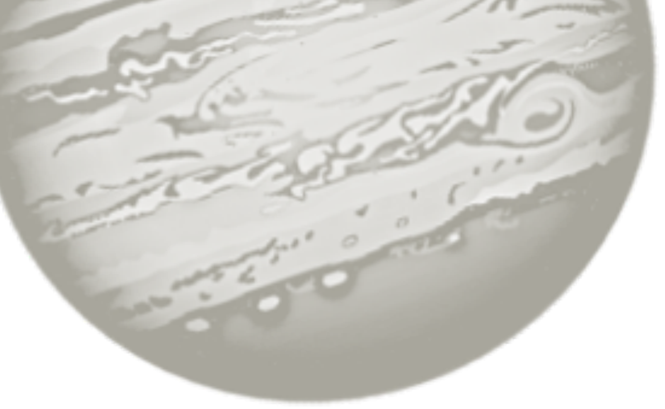

1-D Hybrid Kinetic/Fluid Modelling of the Jovian Magnetosphere

Space & Planetary Physics | Lancaster University

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① Introduction & Model Overview

Open questions

- What is the quasi-static potential structure along auroral field lines in Jupiter's middle magnetosphere, ~30R_J?
- How is plasma distributed along field?
- What is the energy deposited in to the atmosphere by precipitating field-aligned currents?

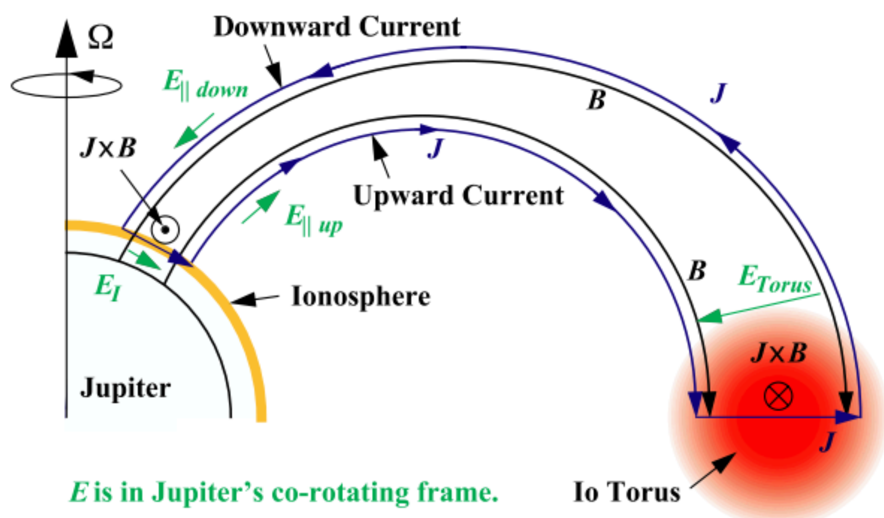

Fig. 1 – Field aligned currents in the Jupiter-Io system [Ray+ 2009].

Finding answers?

$$\frac{\partial f}{\partial t} + v_s\frac{\partial f}{\partial s} + \frac{1}{m}\left(qE - \mu\frac{dB}{ds} + ma_g + \frac{1}{2}m\Omega^2 r^2\right)\frac{\partial f}{\partial v_s} = 0$$

- Solve time-dependent, 1-D spatial, 2-D velocity Vlasov equation along field.
- Couples ionosphere and middle magnetosphere.
- Fully kinetic, time-varying description.
- Non-uniform grid allows fine resolution in acceleration region.
- No collisions considered.
- Examine limited region of L=30 flux tube.

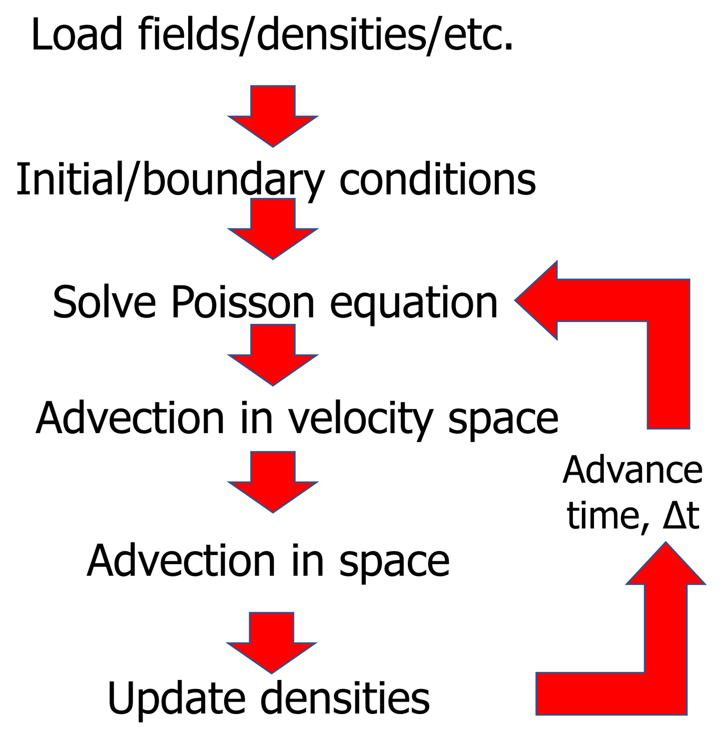

Fig. 2 – Model flow diagram.

Previous work

- Confined to Io flux tube [Su+ 2003, Ray+ 2009, Mastuda+ 2010].
- No time-variation considered.
- Quasi-static acceleration region identified ~1-3 R_J.

Challenges

- Computationally intensive – HPC required.
- Choice of boundary conditions non-trivial.
- Large scale sizes and mirror ratios.
- Centrifugal forces.

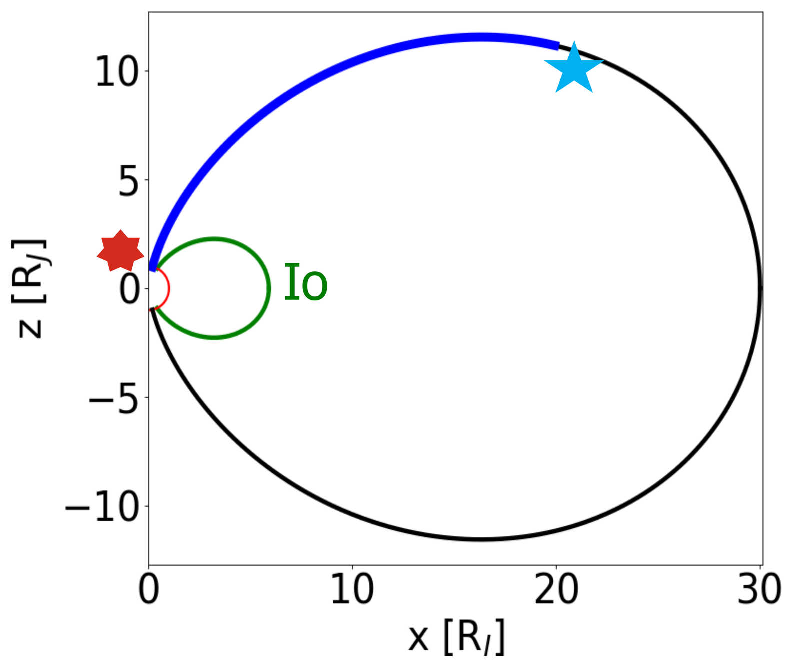

Fig. 3 – Relevant dipole field lines in the Jovian system.

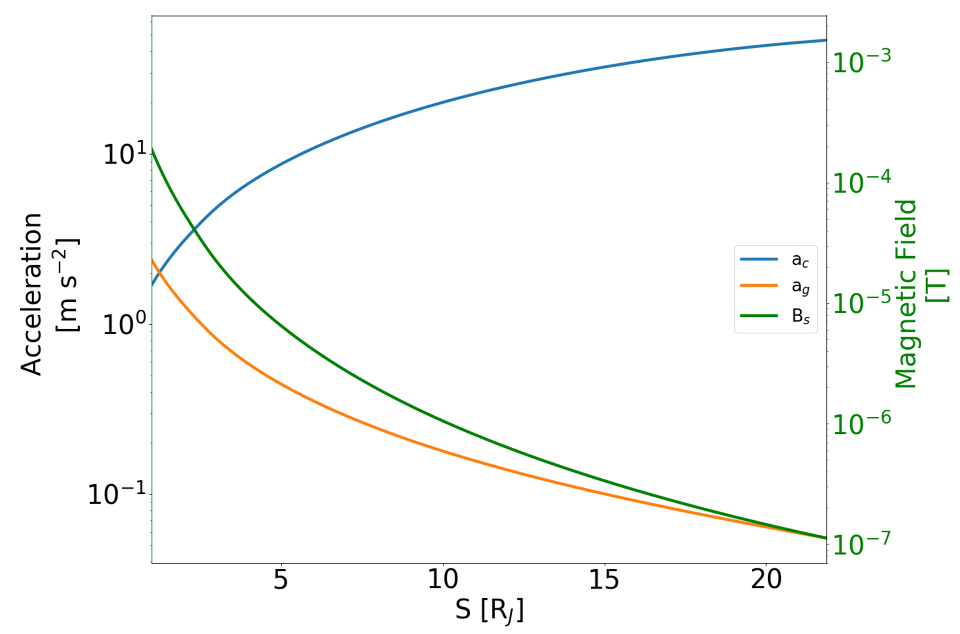

Fig. 4 – Centrifugal and gravitational forces in model, L=30 flux tube.

② Boundary & Initial Conditions

- Equatorial densities [Bagenal & Delamere 2011] translated with scale height.
- Heavier species confined to equator.
- Bulk flux tube temperature, 0.01 eV.
- Bulk densities two orders less than BC.
- Maxwellian distribution function for all species.
- Positive velocities planetward; negative velocities equatorward.

Species	★ Magnetospheric Density (m^{-3})	★ Magnetospheric Temp. (eV)	Ionospheric [Strobel & Atreya, 1983] Density (m^{-3})	Ionospheric [Strobel & Atreya, 1983] Temp. (eV)
e^-	2.89x10^2	100	2x10^{11}	0.31
H^+	2.88x10^2	100	2x10^{11}	0.31
e^- (hot) [Mauk & Saur 2008]	1.44x10^1	25,000		
O^+	1.02x10^0	550		
S^+	4.3x10^{-4}	550		

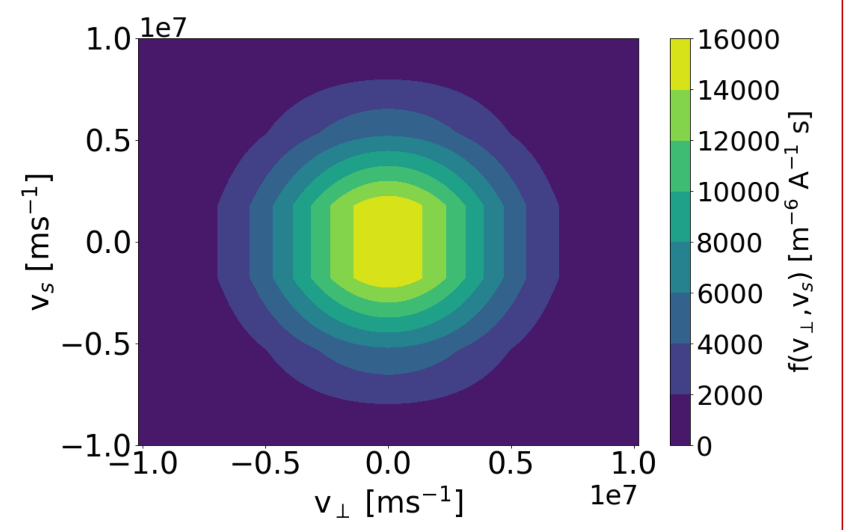

Fig. 5 – Boundary condition of hot electron population.

③ Model Results

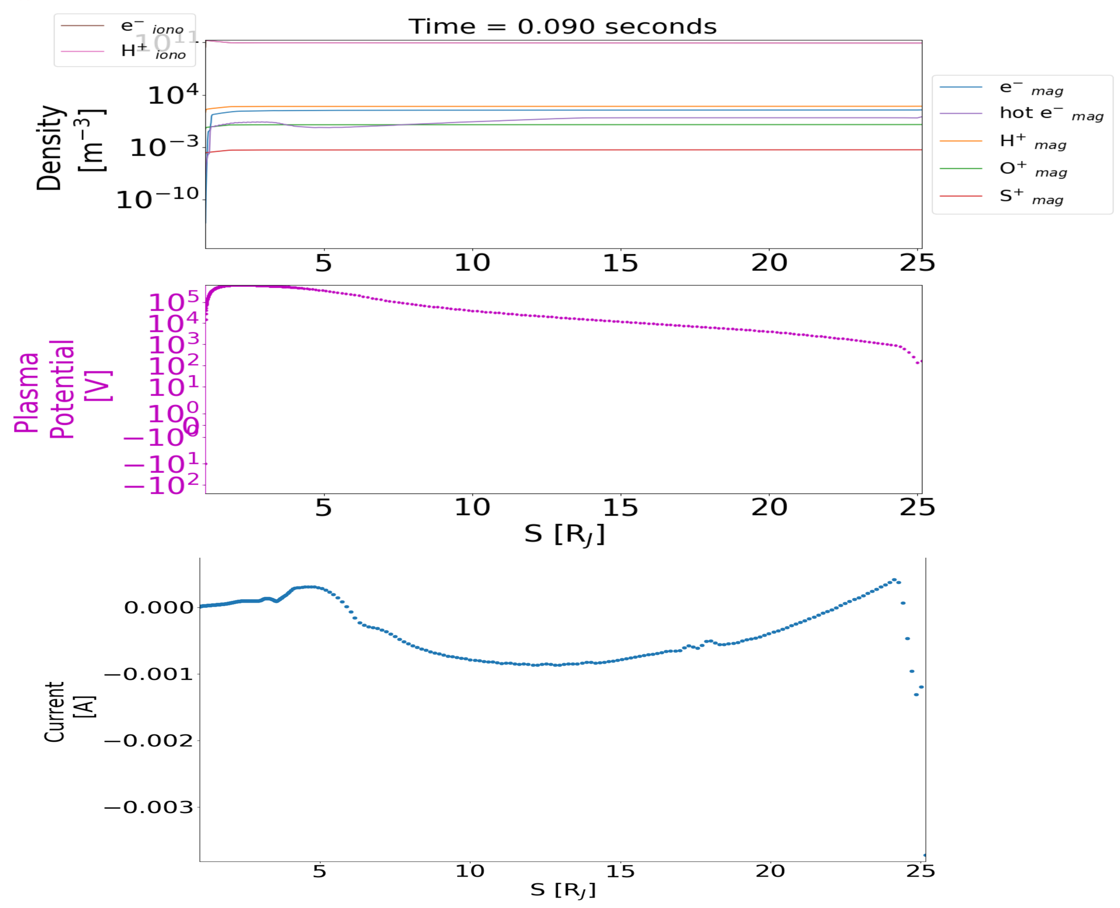

Fig. 6 – Plasma densities, potential structure & current flow, t=0.09 s.

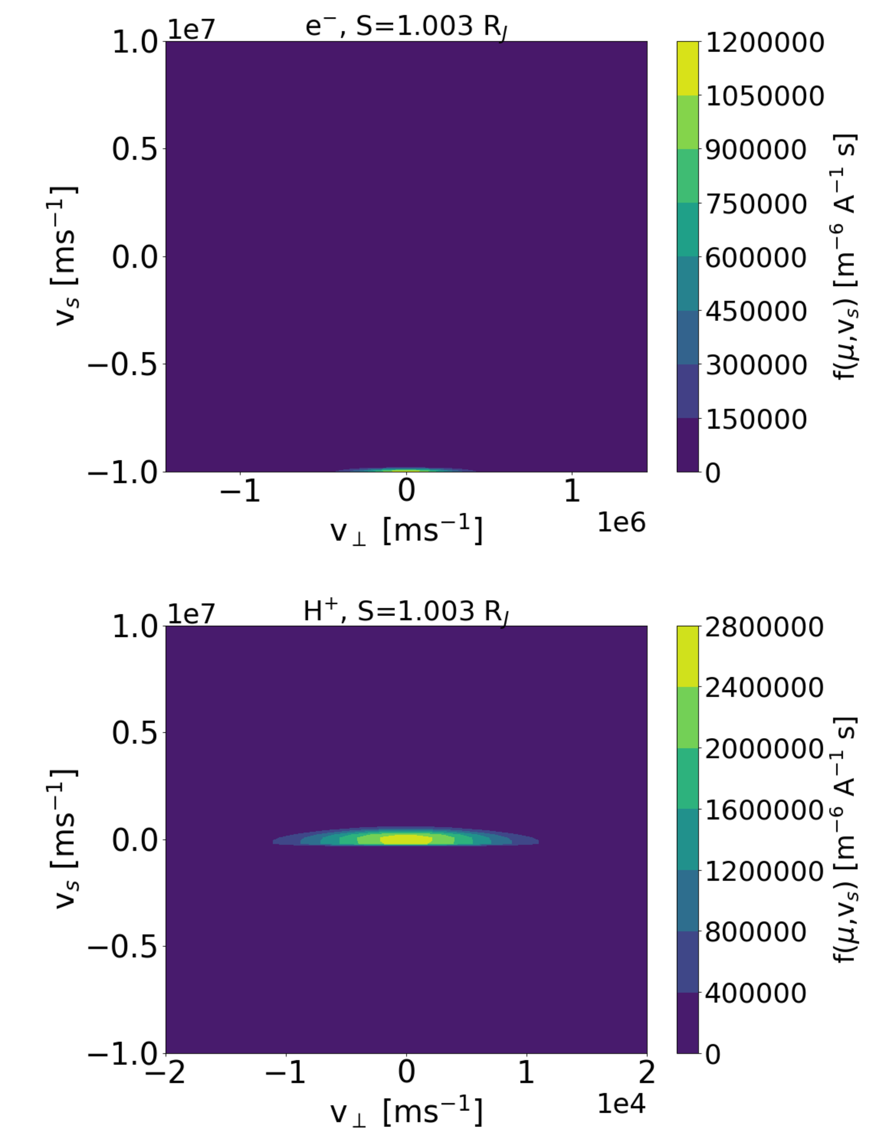

Fig. 7 – Distribution func. for ionospheric sources, t=0.09 s.

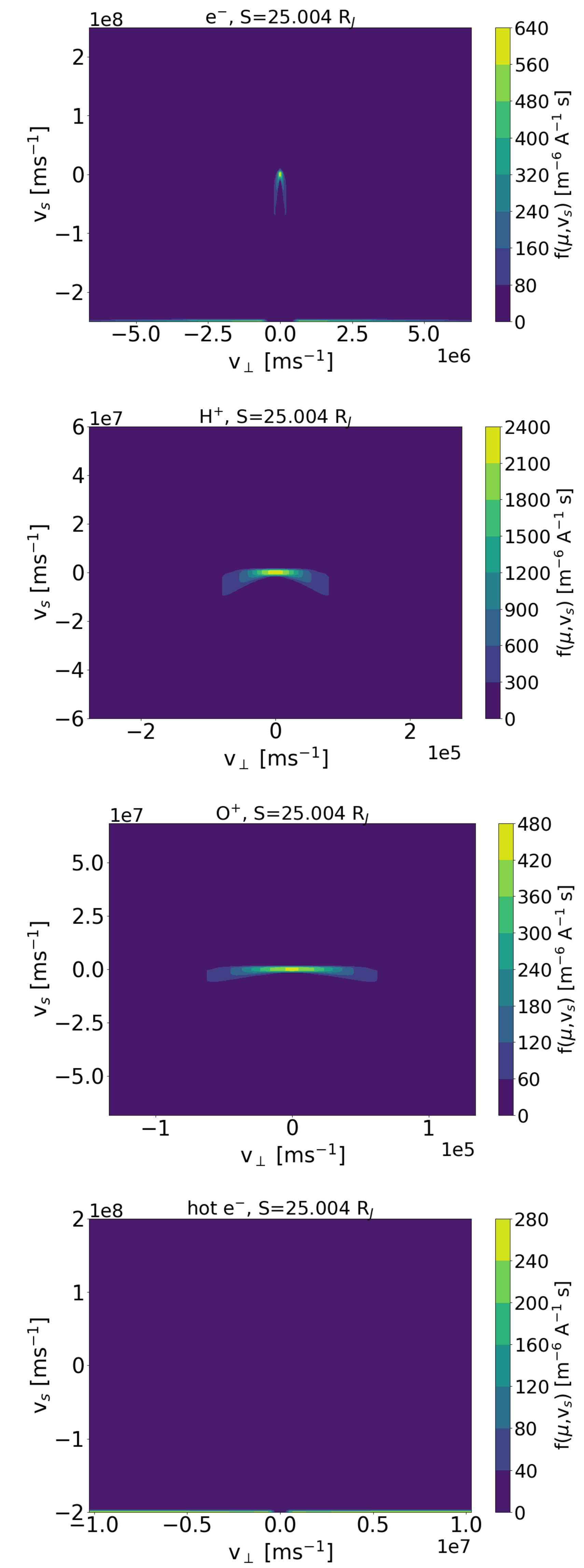

Fig. 8 – Distribution func. for magnetospheric sources, t=0.09 s.

④ Future Improvements

Fluid treatment of species

- Improves computational times.
- Tested on low-resolution Terrestrial case.
- No centrifugal forces, only 4 species.

	All kinetic	Kinetic elec. & fluid ions.	%age Change
Advection in vel. space (seconds)	13,220	14,473	+9.5%
Advection in space (seconds)	31,421	20,103	-36.0%
Update densities (seconds)	194	33	-83.0%
Poisson eq. (seconds)	0.30	0.27	-10%
Advection fluids (seconds)	0	40	
Total run-time (seconds)	71,735	54,730	**-23.7%**

Realistic densities/temperatures in flux tube

- Filling flux tube takes significant computational time.
- Option 1: data from Juno/JADE [Huscher+ 2019].
- Option 2: diffusive equilibrium model [Bagenal & Sullivan 1981; Dougherty+ 2017].

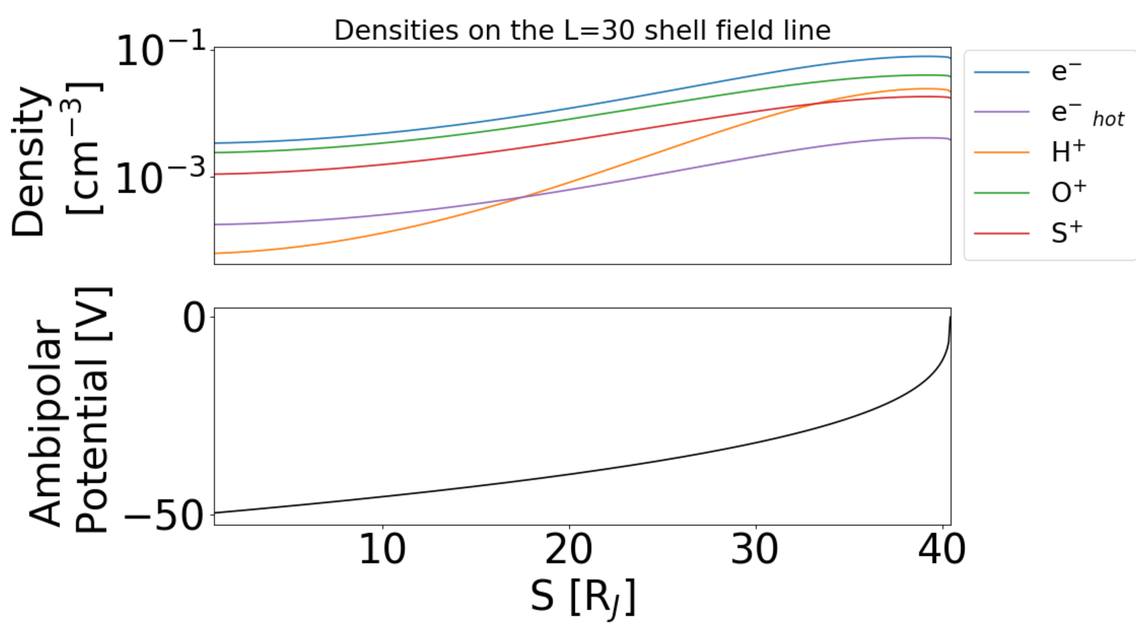

Fig. 9 – Density & ambipolar potential profiles from diffusive equilibrium model.