Ionospheric energization, field-aligned transport, and escape at Jupiter

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Abstract

While Jupiter's gravity strongly binds the neutral atmosphere to the planet, energization in the auroral region can lead to field-aligned upward transport and escape of electrons and ions. This field-aligned transport mechanism provides a way for heavier ions like H2+ and H3+ to enter Jupiter's magnetosphere. Formation of H3+ from H2+ occurs quickly in the collisional ionosphere, so rapid field-aligned transport of H2+ is the most likely mechanism for H2+ ions present in Jupiter's high-latitude ionosphere and magnetosphere. We model these processes using the PWOM model for ionospheric field-aligned transport and J-GITM providing the neutral atmosphere and lower ionospheric boundary. The ionosphere is formed and heated by a combination of solar EUV flux and electorn precipitaiton. The effects of energization from electron precipitation and resonant wave heating are also accounted for. We show the energy input that is needed to produce ion escape in both the fluid and kinetic regimes, and we show the formation of ion conics in the kinetic PWOM model. We discuss what observations from JUNO are needed to allow us to constrain and test our model results.

Ionospheric energization, field-aligned transport, and escape at Jupiter

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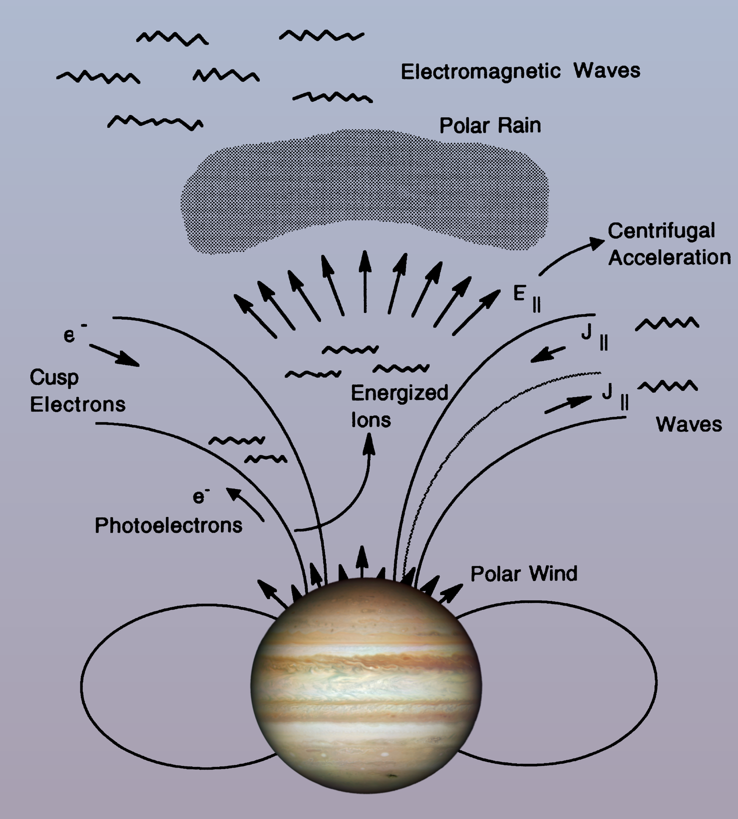
Background

Recent JUNO results show ion conics escaping from Jupiter's polar ionosphere *[Clark et al., 2017]* that indicate perpendicular ion acceleration leading to field-aligned upward transport and escape.

These processes at Earth allow ionospheric-origin ions to affect the composition of magnetospheric plasma and modify space weather processes in Earth's magnetosphere.

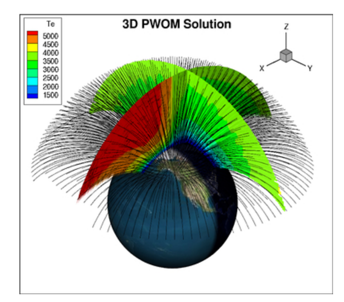
At Jupiter, field-aligned transport and escape provides a way for heavier ions like H2+ and H3+ to enter the magnetosphere. Formation of H3+ from H2+ occurs quickly in the collisional ionosphere, so rapid field-aligned transport of H2+ is the most likely mechanism for H2+ ions present in Jupiter's upper ionosphere and magnetosphere.



adapted from Schunk & Sojka, 1997

Polar Wind Outflow Model (PWOM)

Originally developed for Saturn and Earth



Solves the field-aligned gyrotropic transport equations for multiple ion species along convecting field lines. *[Glocer et al., 2007, 2012]*

continuity

$$\frac{\partial}{\partial t}(A\rho_i) + \frac{\partial}{\partial r}(A\rho_i u_i) = AS_i$$

momentum

$$\frac{\partial}{\partial t}(A\rho_i u_i) + \frac{\partial}{\partial r}\left(A\rho_i u_i^2\right) + A\frac{\partial p_i}{\partial r} = A\rho_i\left(\frac{e}{m_i}E_{\parallel} - g\right) + A\frac{\delta M_i}{\delta t} + Au_iS_i$$

energy

$$\frac{\partial}{\partial t}\left(\frac{1}{2}A\rho_i u_i^2 + \frac{1}{\gamma_i - 1}Ap_i\right) + \frac{\partial}{\partial r}\left(\frac{1}{2}A\rho_i u_i^3 + \frac{\gamma_i}{\gamma_i - 1}Au_ip_i\right) = A\rho_i u_i\left(\frac{e}{m_i}E_{\parallel} - g\right) + \frac{\partial}{\partial r}\left(A\kappa_i\frac{\partial T_i}{\partial r}\right) + A\frac{\delta E_i}{\delta t} + Au_i\frac{\delta M_i}{\delta t} + \frac{1}{2}Au_i^2S_i$$

ambipolar E-field

$$E_{\parallel} = -\frac{1}{en_e}\left[\frac{\partial}{\partial r}\left(p_e + \rho_e u_e^2\right) + \frac{A'}{A}\rho_e u_e^2\right] + \frac{1}{en_e}\frac{\partial}{\partial r}\left(\sum_i \frac{m_e}{m_i}\left[\left(u_e - u_i\right)S_i - \frac{\delta M_i}{\delta t}\right] + \frac{\delta M_e}{\partial t}\right)$$

[Gombosi & Nagy, 1989]

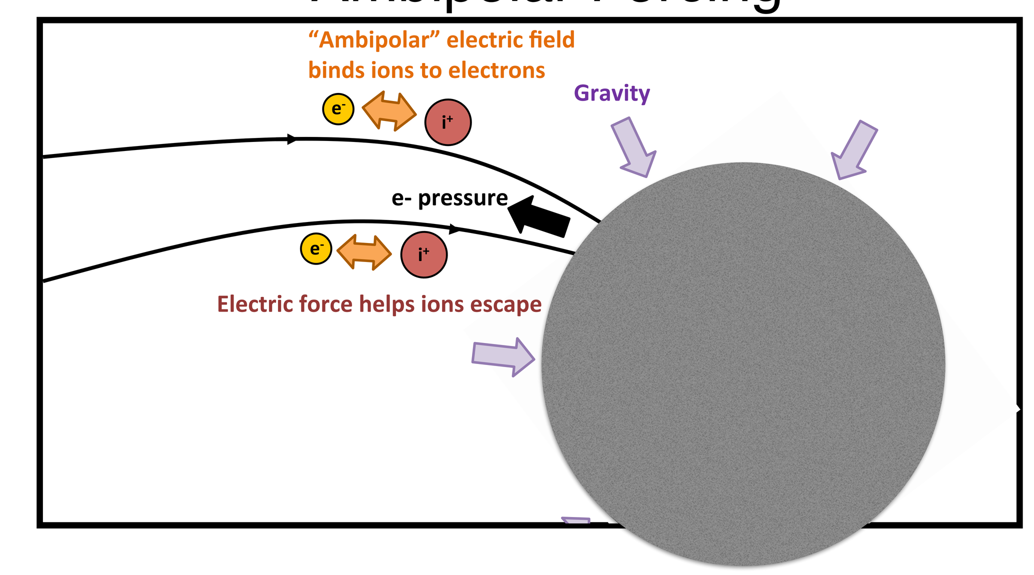
GLOW Two-Stream Electron Transport Model

Field-aligned superthermal electron transport model by *Solomon et al. [1988].*

Coupled with PWOM through electron fluid equations and self-consistent ambipolar E-field.

[Glocer et al., 2014]

Ambipolar Forcing

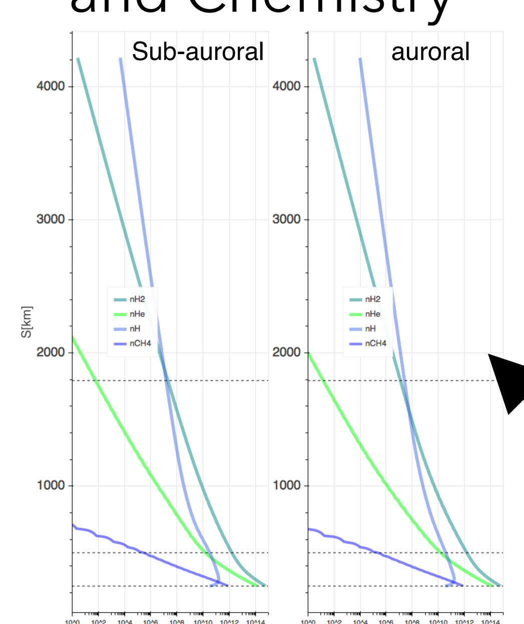


courtesy of G. Collinson

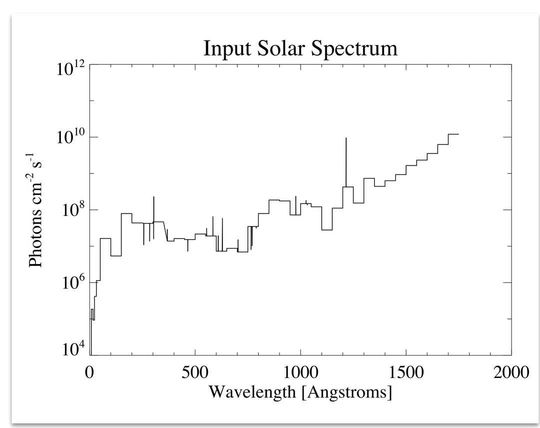
Magnetic field-aligned transport is driven by pressure gradients and enhanced by the electric fields set up by electron pressure.
Additional forces such as wave heating will be added in future work.

Photo-Production

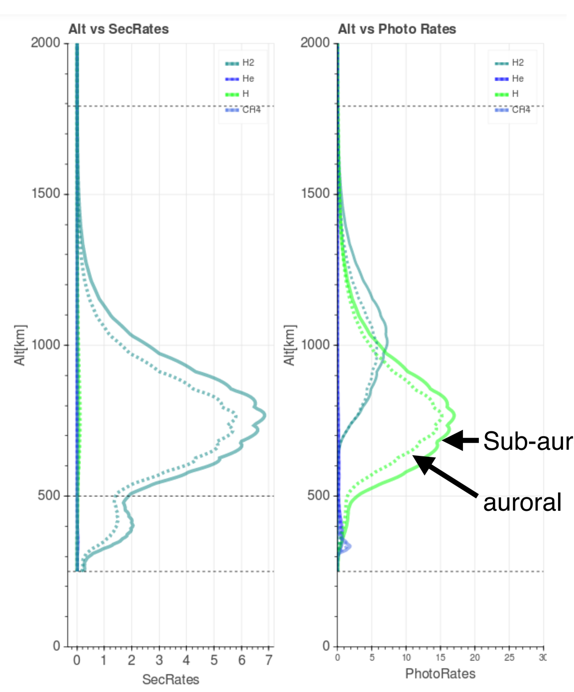
Neutral Atmosphere and Chemistry + Stellar EUV Flux → Photo Production and Secondary Production → Superthermal Electrons → Ion Transport

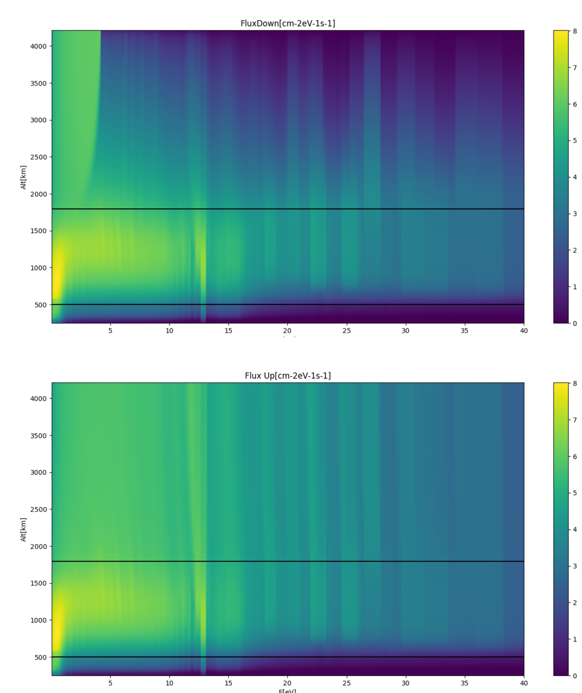


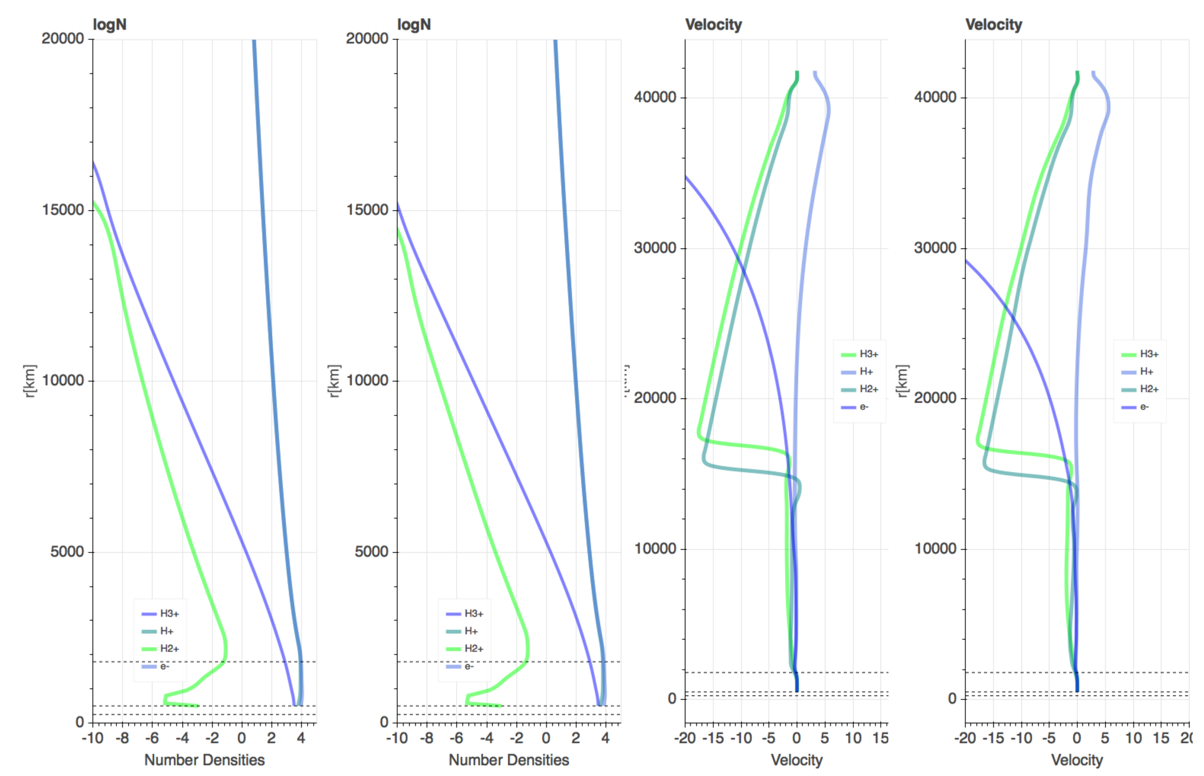
neutral profiles from J-GITM [*Bell et al., 2013*]



Reaction	Reaction Rate	Reference
$H_2 + h\nu \rightarrow H^+ + H + e^-$	$1.9 \times 10^{-11} s^{-1}$	[*Moses and Bass*, 2000]
$\rightarrow H_2^+ + e^-$	$9.9 \times 10^{-10} s^{-1}$	[*Moses and Bass*, 2000]
$H + h\nu \rightarrow H^+$	$1.0 \times 10^{-9} s^{-1}$	[*Moses and Bass*, 2000]
$H^+ + H_2(\nu \geq 4) \rightarrow H_2^+ + H$	see text	-
$H_2^+ + H_2 \rightarrow H_3^+ + H$	$2.0 \times 10^{-9} cm^3 s^{-1}$	[*Nagy*, 1987], [*Anichich*, 1994]
$H^+ + H_2 + M \rightarrow H_3^+ + M$	$3.2 \times 10^{-29} cm^6 s^{-1}$	[*Capone et al.*, 1977]
$H^+ + CH_4 \rightarrow CH_3^+ + H_2$	$3.69 \times 10^{-9} cm^3 s^{-1}$	[*Kim and Fox*, 1994]
$\rightarrow CH_4^+ + H$	$0.81 \times 10^{-9} cm^3 s^{-1}$	[*Kim and Fox*, 1994]
$H_3^+ + CH_4 \rightarrow CH_5^+ + H_2$	$2.4 \times 10^{-9} cm^3 s^{-1}$	[*Anichich*, 1994]
$H^+ + e^- \rightarrow H + h\nu$	$1.91 \times 10^{-10} T_e^{-0.7} cm^3 s^{-1}$	[*Kim and Fox*, 1994]
$H_3^+ + e^- \rightarrow H_2 + H$	$7.62 \times 10^{-7} T_e^{-0.5} cm^3 s^{-1}$	[*Kim and Fox*, 1994][a]
$\rightarrow H + H + H$	$9.7 \times 10^{-7} T_e^{-0.5} cm^3 s^{-1}$	[*Kim and Fox*, 1994][a]



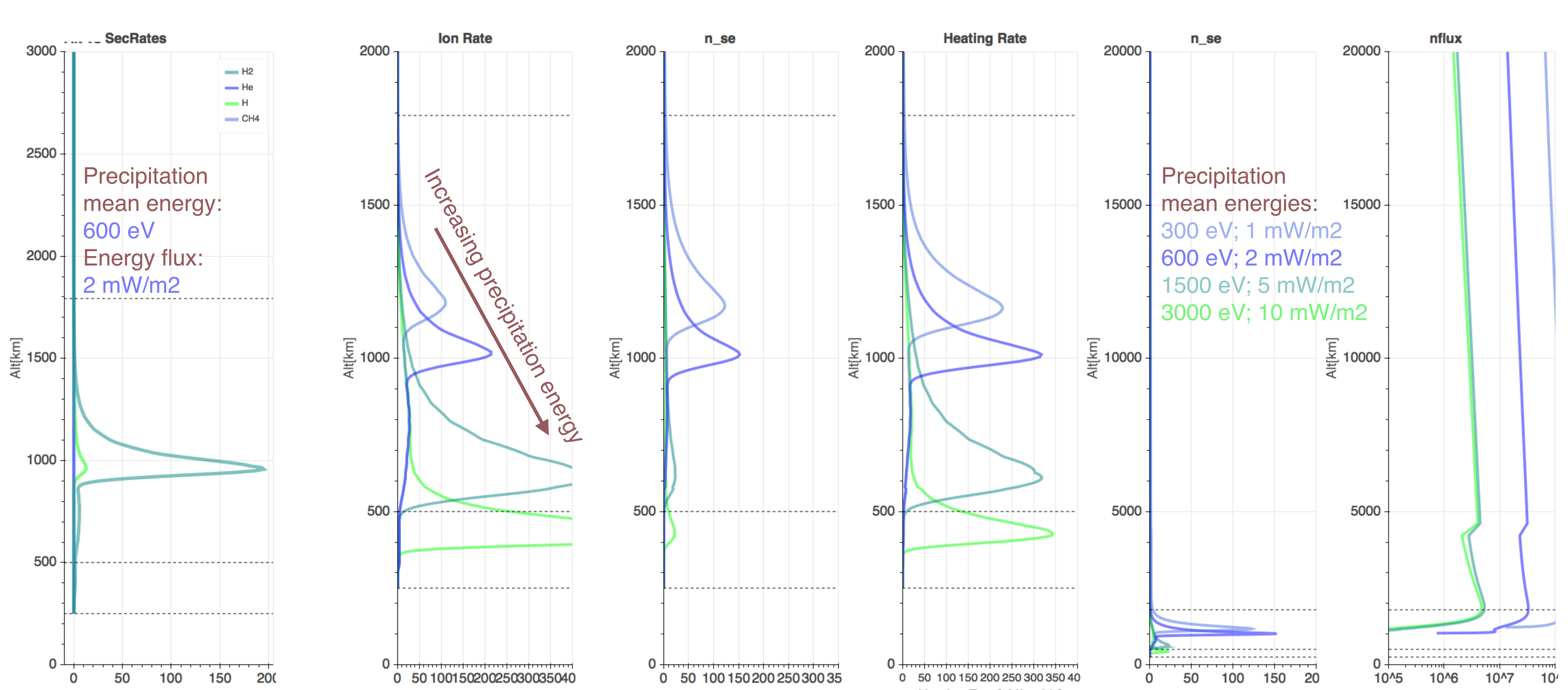




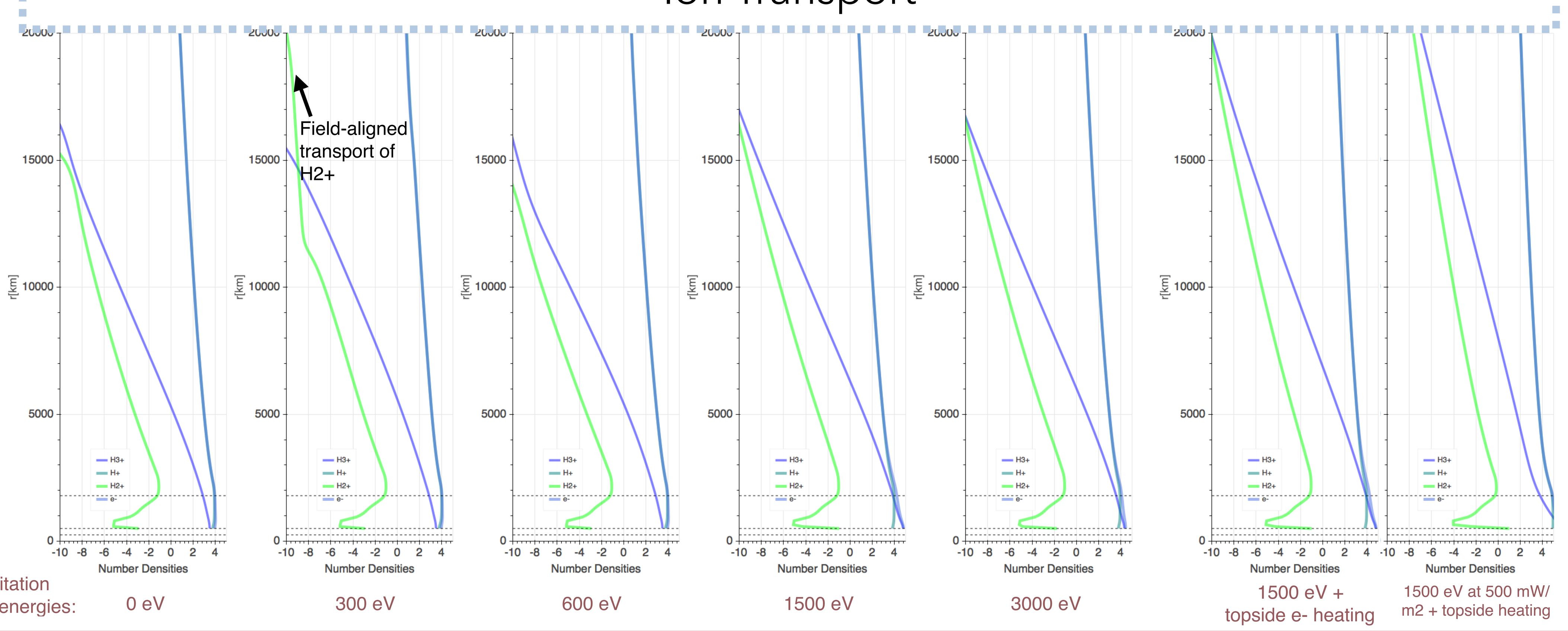
Thermospheric changes at sub-auroral vs auroral latitudes have little effect compared to the effects of photoionization.

Electron Precipitation

Electron Production and Transport



Ion Transport



Conclusion

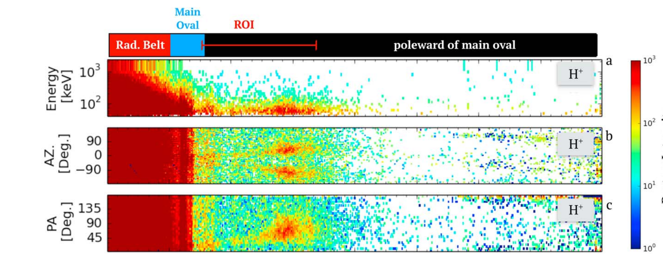
We can self-consistently model magnetic field-aligned ion and superthermal electron transport at Jupiter.

Escape from EUV alone is not enough to explain observations of H2+ and H3+ in Jupiter's magnetosphere that indicate a planetary source of plasma (e.g. *Hamilton et al., 1980*).

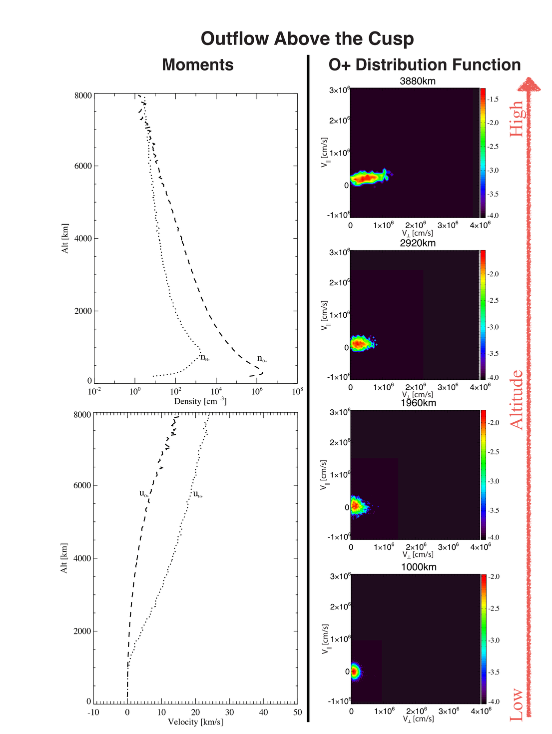
Electron precipitation and topside heating transport ions to higher altitudes but are still not enough to produce escape.

Future Work

Add wave heating that can produce ion conics (already done at Earth).



Observations of ion conics with JUNO *[Clark et al., GRL, 2017]*



Results of Kinetic PWOM at Earth show the formation of ion conics. *[Glocer et al., 2017]*

JUNO observations JADE-E can help us constrain, and JADE-I and JEDI can help us test the model results.