Connecting Uranus' magnetosphere and upper atmosphere via electron precipitation

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Abstract. The precipitation of electrons is a key process through which significant energy is transferred from Uranus' magnetosphere to its upper atmosphere. These electrons drive atmospheric ionization, thermospheric heating, and auroral emission at Uranus, and their properties are critical to address Uranus' energy crisis as well as auroral phenomena. We combine measurements of auroral precipitation at Earth, Saturn, and Jupiter, with relevant Voyager 2 observations to estimate the properties of precipitating electrons at Uranus. In order to produce the measured aurora, energy fluxes of ~0.1mW/m^2 are required with energies of ~5keV. The acceleration of particles between the magnetosphere and thermosphere is predicted to be Earth-like, but with significantly lower overall energy flux and field aligned currents due to Uranus' sparser magnetosphere. The height-integrated Joule heating rates of ~0.2 mW/m^2 are an order of magnitude lower than Earth.

From Knight,[1975] and Cowley and Bunce, [2001], the energy flux and field aligned current density at the top of the ionosphere can be expressed as a function of a potential drop and the properties of magnetospheric electrons:

$$j_{||i}(0) = eN\left(\frac{W_{th}}{2\pi m_e}\right)^{1/2}$$

$$E_f(0) = 2NW_{th}\left(\frac{W_{th}}{2\pi m_e}\right)^{1/2}$$

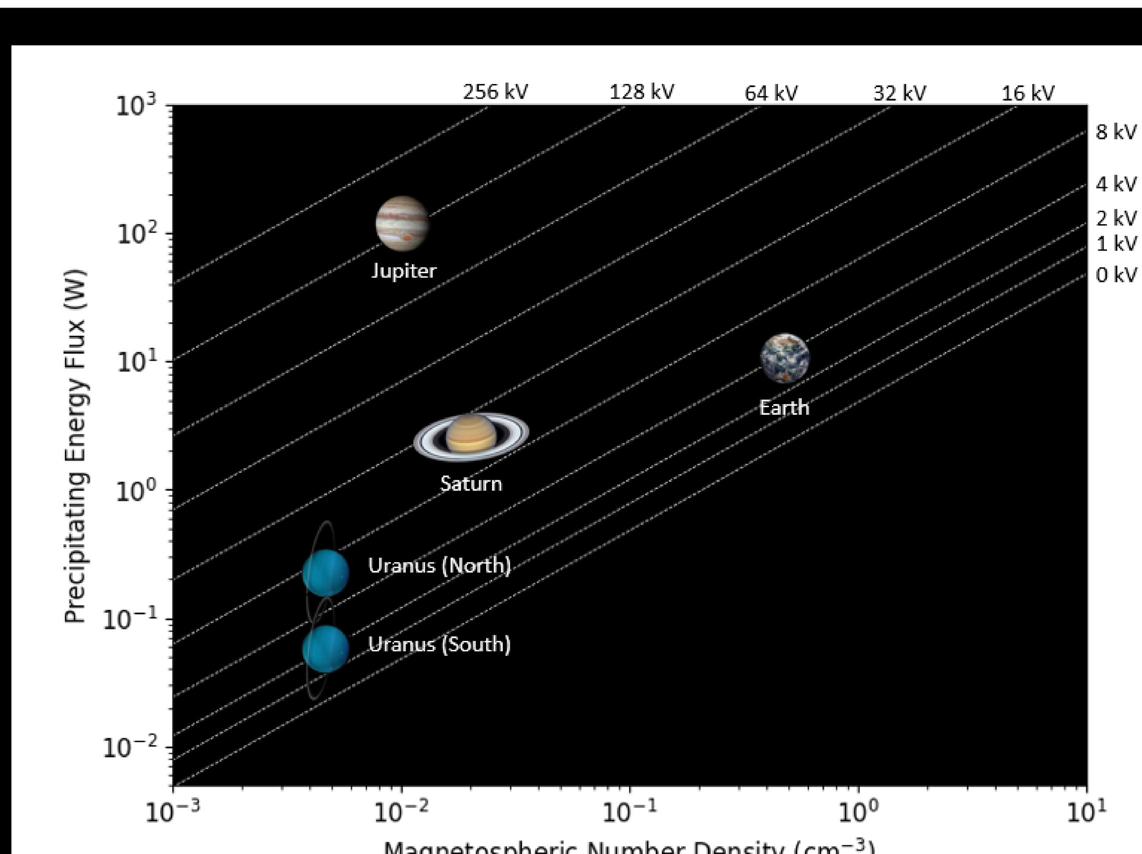
$$j_{||i_{max}}(\Phi) = j_{||i}(\Phi, R_B \to \infty) = j_{||i}(0)\left(1+\left(\frac{e\Phi}{W_{th}}\right)\right)$$

$$E_f(\Phi, R_B \to \infty) = E_f(0)\left[1+\left(\frac{e\Phi_{min}}{W_{th}}\right)+\frac{1}{2}\left(\frac{e\Phi_{min}}{W_{th}}\right)^2\right]$$

The relationships between the height-integrated conductivity (Σ), joule heating rate (q), electric field (E), and field-aligned current density ($j_{||}$) can be approximated as:

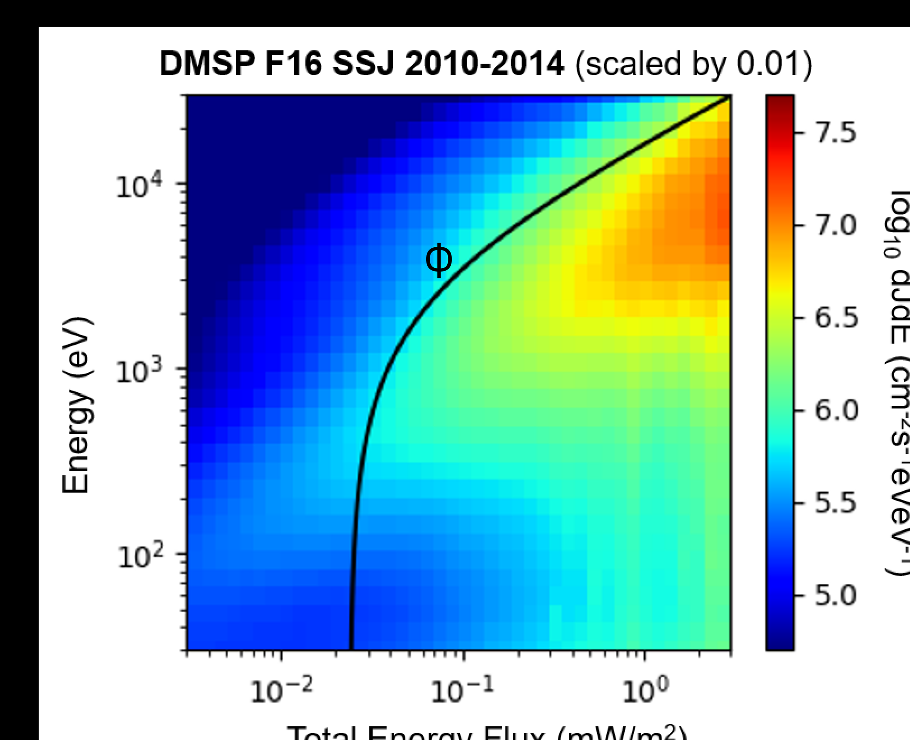
$$j_{||} \approx -\nabla(\Sigma E) \qquad q \approx \Sigma E^2$$

e.g., Smiddy et al. [1980], Weimer et al. [1987], Gjerloev and Hoffman, [2000], Robinson and Zanetti, [2020], Gianattsio et al. [2022])



By using auroral emission and magnetospheric electron properties observed at different planetary bodies, we estimate the precipitating electron energy flux and corresponding potential drop using the equations above and the approximation of 1 kR ~ 0.1mW/m^2

The potentials predicted for Uranus are Earth-like (i.e., several kV) and likely exhibit a strong North-South asymmetry



With an estimated heigh-integrated conductivity and precipitation properties at each planet, we can estimate electric field and joule dissipation rates at the aurora. We take a ~1° gradient scale size to calculate E and q

Global values are much more complicated to estimate given limited observations

Planet	L/M-shell of Auroral Emission	Magnetospheric Electron Properties Mapped to Auroral Field Lines	Auroral Emission Intensity (kR)	Magnetic Latitude of Emission (°)	Height Integrated Conductivity (mho)	km/°	Knight Potential (kV)	$J_{\|\|}$ (μA/m^2)	E_f (mW/m^2)	E (mV/m)	q (mW/m^2)
Earth	9-12	0.5 cm^{-3} 2000 eV [Lee et al. (2011)]	100 [Clarke, (2013)]	65	10 [Robinson et al. (1987); Gerlov et al. (2000)]	111	4	1.8	12	20	4
Jupiter	20-50	0.01 cm^{-3} 2.5keV [Scudder et al. (1981); Bagenal et al. (2016)]	1300 [Clarke, (2013)]	55	2 [Badman et al. (2015)]	1220	128	0.78	101	476	452
Saturn	9-20	0.02 cm^{-3} 2keV [Bunce et al. (2008)]	25 [Clarke, (2013)]	75	1 [Bunce et al. (2003); Bunce and Cowley (2003)]	1016	10	0.14	18	142	20
Uranus	6-9	0.005 cm^{-3} 2keV [Sittler Jr et al. (1987)]	2 N 0.7 S [Herbert and Sandel, (1994); Herbert (2009)]	75 N 85 S	0.4 [McNutt Jr et al. 1987]	442	6 N 2 S	0.024 N 0.012 S	0.2 N 0.06 S	27 N 13 S	0.28 N 0.07 S

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