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MI coupling impact of superthermal electrons on diffuse aurora precipitation and ionospheric conductance: Missing piece in the global MHD models

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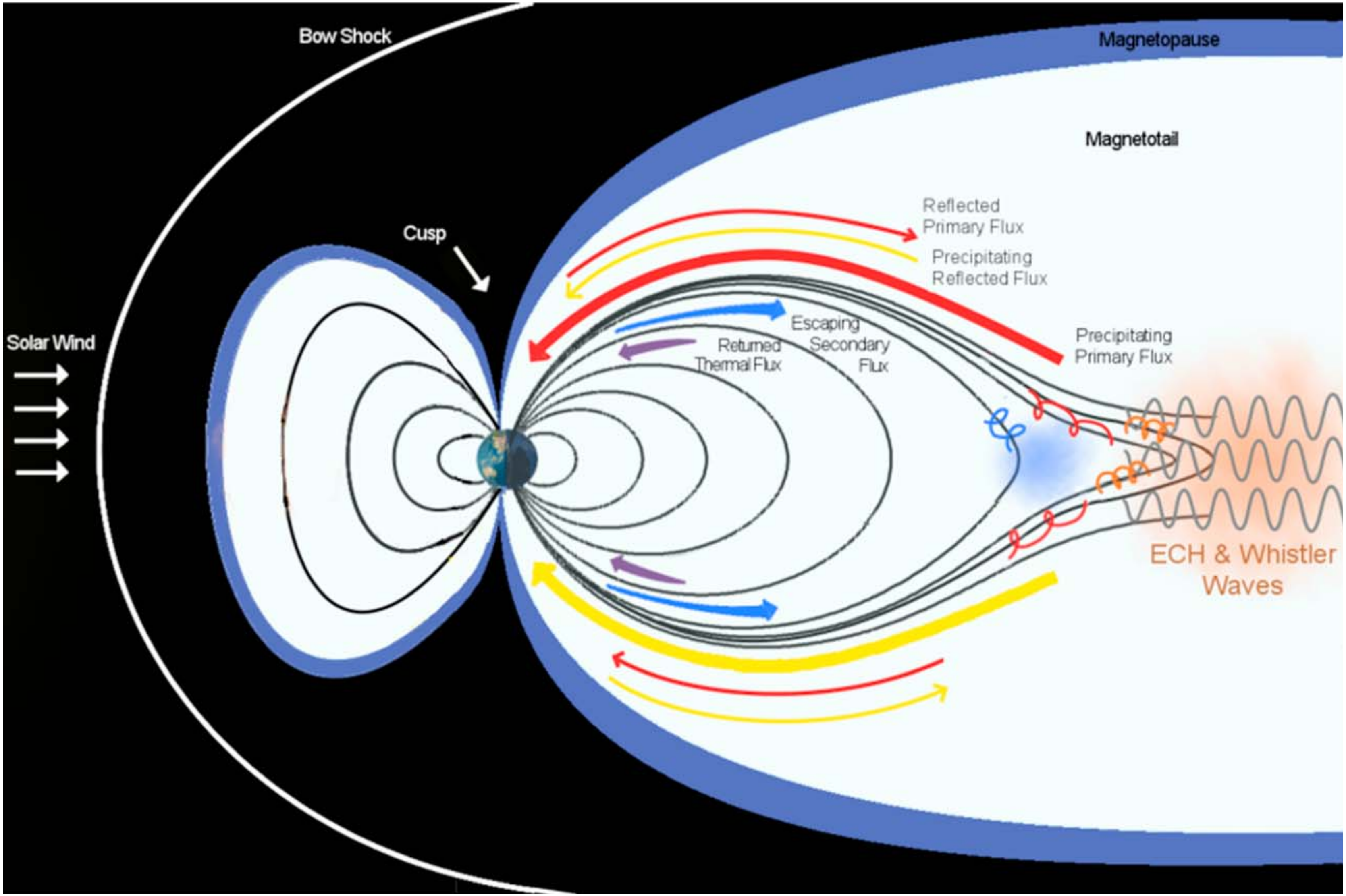
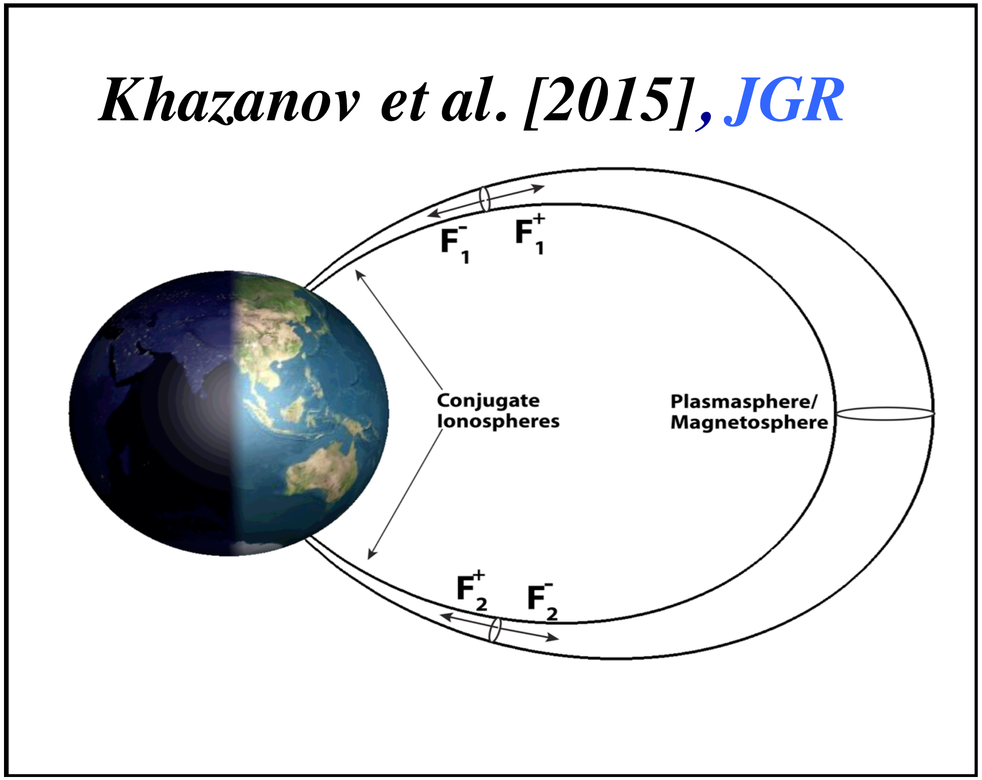
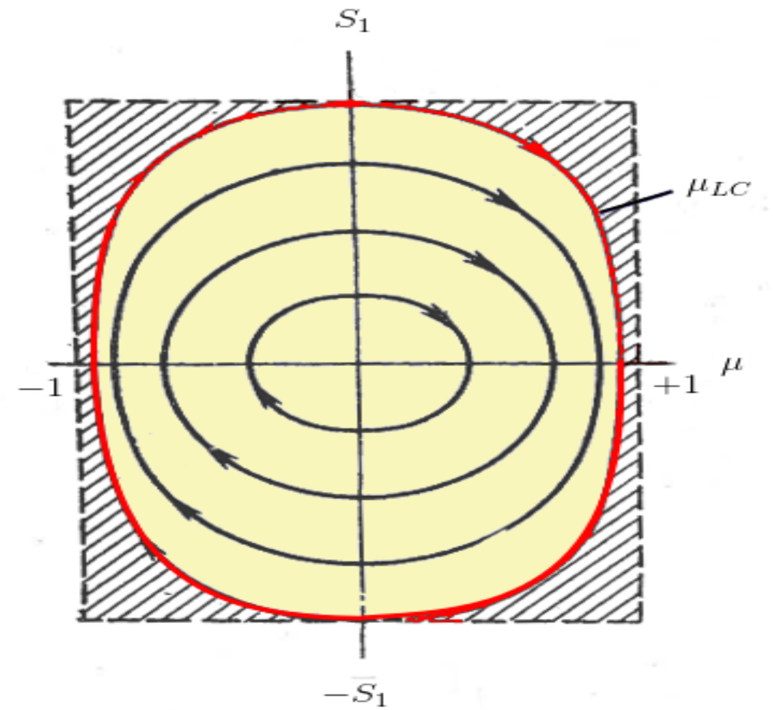
MI coupling processes in diffuse aurora regions



Khazanov et al. [2015]

SuperThermal Electron Transport (STET) Code

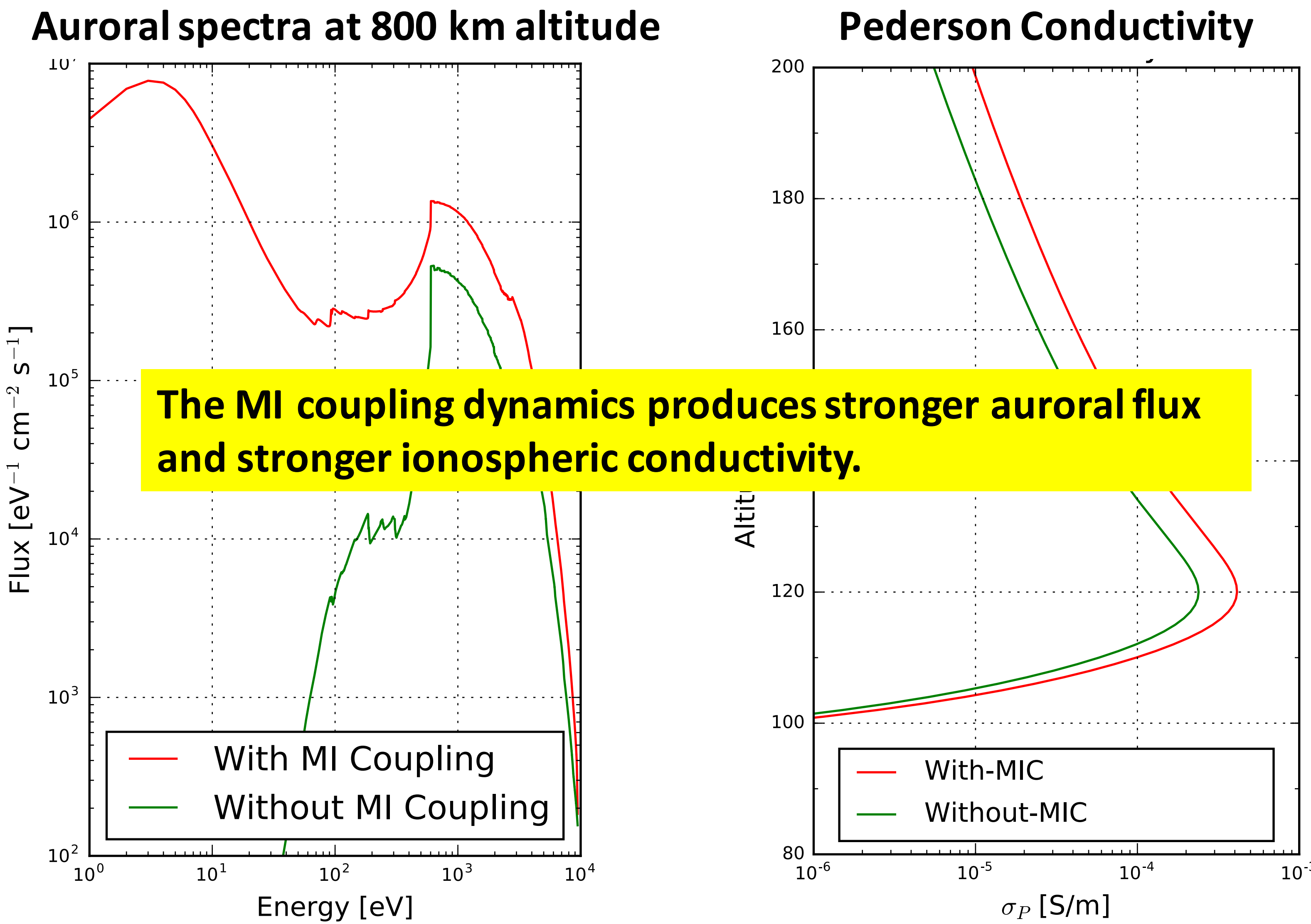




$$\frac{\beta}{\sqrt{E}}\frac{\partial\phi}{\partial t}+\mu\frac{\partial\phi}{\partial s}-\frac{1-\mu^2}{2}\left(\frac{1}{B}\frac{\partial B}{\partial s}-\frac{F}{E}\right)\frac{\partial\phi}{\partial\mu}+EF\mu\frac{\partial}{\partial E}\left(\frac{\phi}{E}\right)=Q+\bar{S}$$

$$\bar{S} = \langle S_{ee}\rangle + \langle S_{ei}\rangle + \langle S_{en}^{*}\rangle + \langle S_{en}^{+}\rangle + \langle S_{ew}\rangle$$

STET results with/without MI coupling



Reproduced from Khazanov et al. [2015]

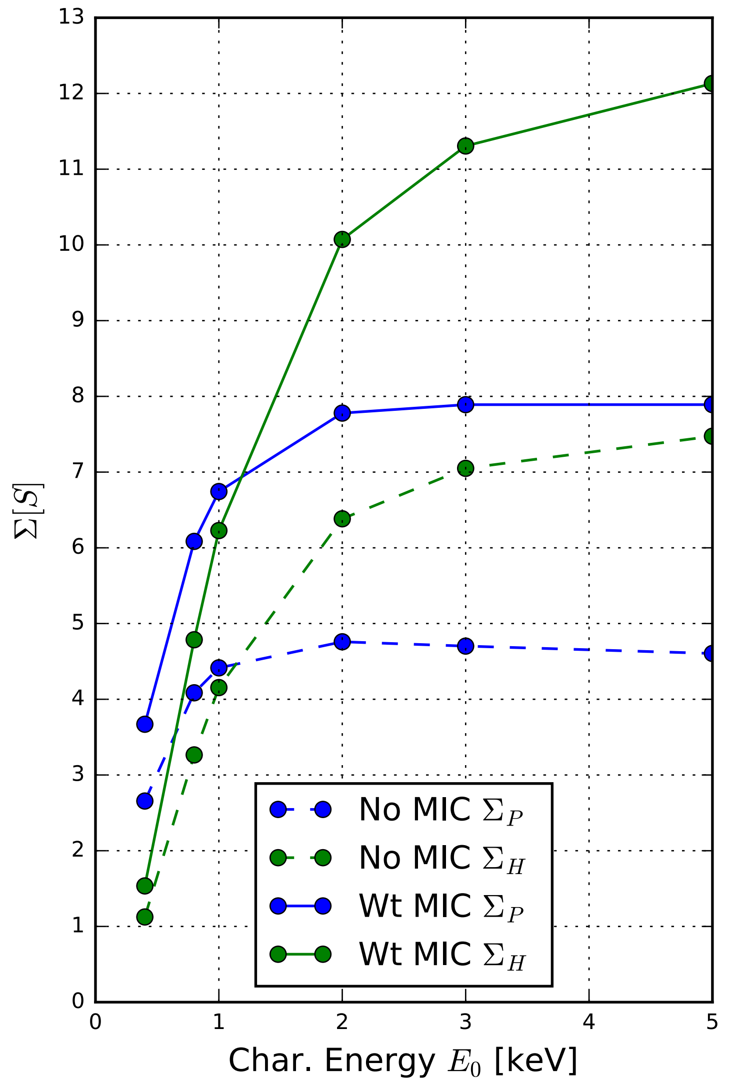
MI coupling impact on ionospheric conductance for various initial auroral spectra

We input 6 initial auroral spectra to STET :

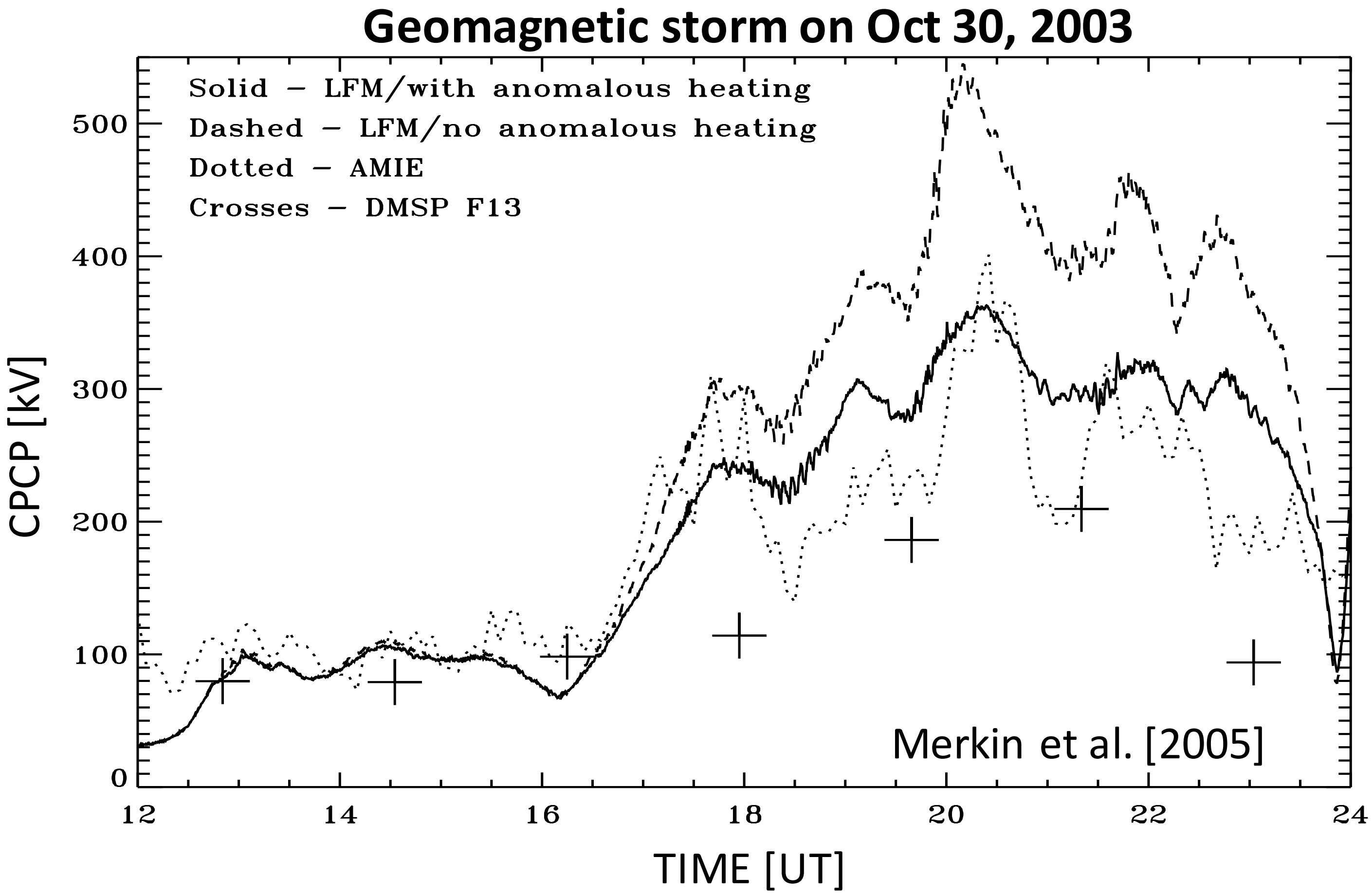
1. Maxwellian distribution
2. Total auroral energy flux at 1 mW/m^2
3. 6 auroral char. energies (400eV – 5keV)

The MI coupling processes can increase the height-integrated conductance up to 35 – 70%.

MI coupling impact can be significant during geomagnetic storm when the total auroral energy flux can go over 50 mW/m^2.



Global MHD models' CPCP



The MI coupling dynamics of superthermal electrons can be the physics mechanism to solve the CPCP problem by increasing ionospheric conductance.

Summary

- We examine magnetosphere – ionosphere energy interchange in the diffuse aurora region using SuperThermal electron transport code.

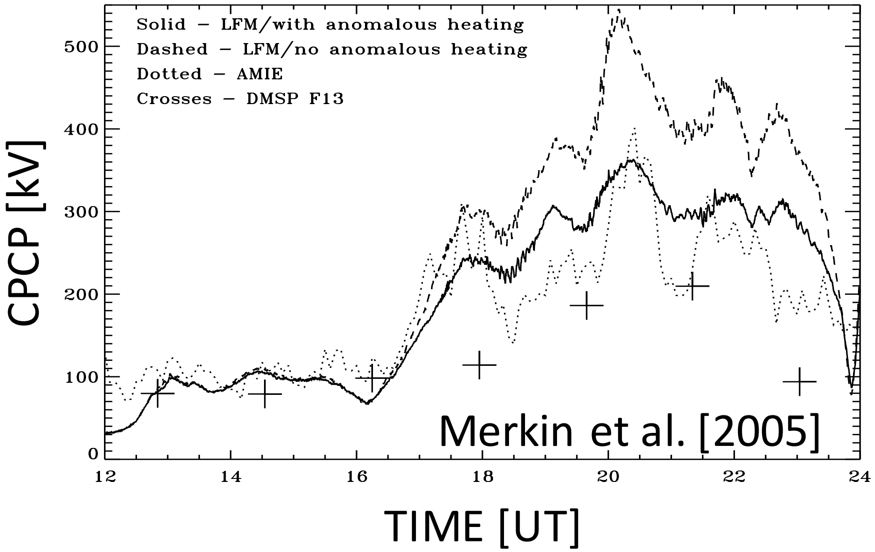
- Our study showed that the MI coupling processes of superthermal electrons produce stronger auroral precipitation and increase height-integrated conductance up to 35 – 70%.

- Note that we introduce 1mW/m^2 of total aurora flux. Geomagnetic events can produce over 50mW/m^2 of total auroral flux, indicating more significant MI coupling impact during storm times.

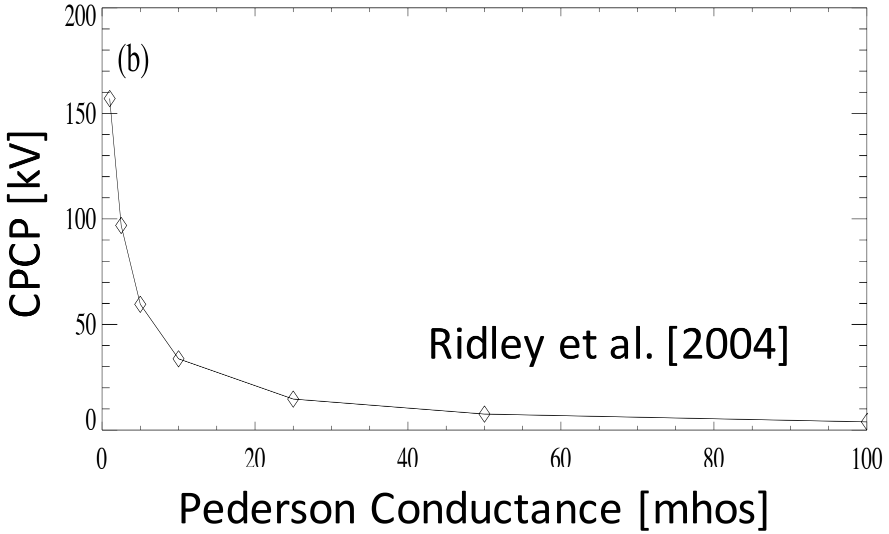
- The MI energy interchange of superthermal electrons can solve a strong transpolar cap potential problem of the global MHD models by increasing ionospheric conductance and thus decreasing the ionospheric electric potentials via a current continuity equation.

Global MHD models' CPCP problem

[A] Model-data comparison of CPCP during a geomagnetic storm



[B] The relation between CPCP and conductance in a global MHD model



The MI coupling dynamics of superthermal electrons can be a physics-based reason to increase ionospheric conductance and thus solve the CPCP problem.

Parameterization of the MI coupling impact on the ionospheric conductance

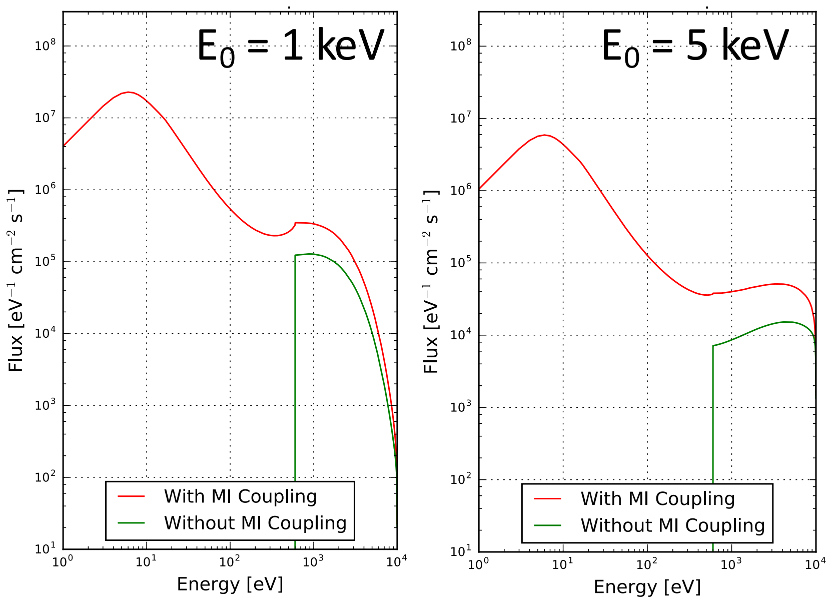
- We investigate the MI coupling impact of superthermal electrons on the height-integrated ionospheric conductance as a function of the auroral characteristic energies (E_0).

- The following input conditions are introduced to a STET code.
  1. Isotropic Maxwellian energy distribution of auroral electrons.
  2. 1 mW/m^2 of total energy flux (Q_0) at 800km altitude
  3. 6 different characteristic energies (E_0 = 400eV – 5keV)

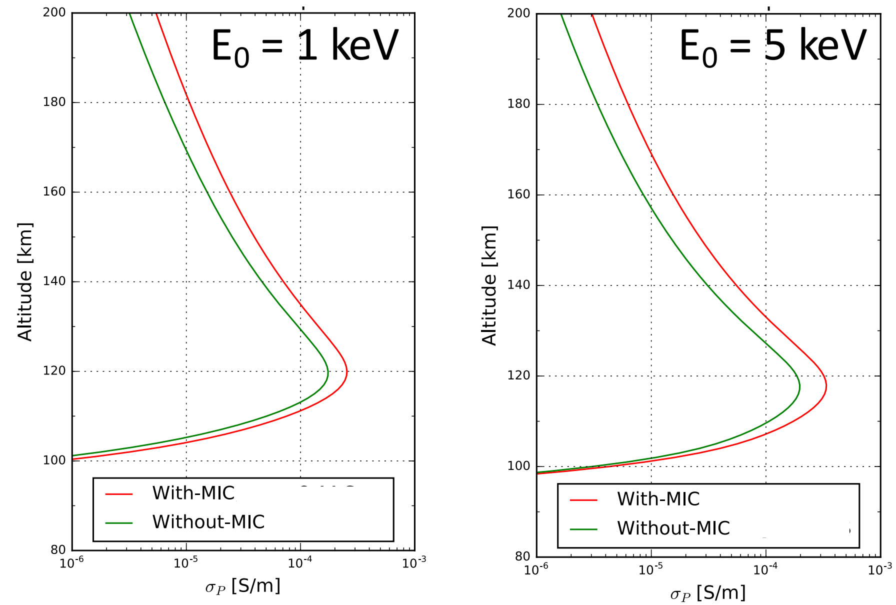
- We conduct 12 simulations by turning on and off the MI coupling effect inside a STEP code.

MI coupling impact for various auroral characteristic energies (E_0)

STET diffuse aurora energy spectra



Pederson ionospheric conductivity



The MI coupling dynamics of superthermal electrons in the diffuse auroral regions produces stronger auroral energy flux and thus increases ionospheric conductivity throughout the whole altitude.

References

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Appendix: Ionospheric Conductance Calculation Details

Methodology

1. Energy distribution of precipitating electrons

Robinson [1987] assumed Maxwellian distribution:

$$\phi(E) = \frac{Q_0}{2E_0^3} E \exp\left(-\frac{E}{E_0}\right)$$

where Q_0 : Total energy flux [keV cm^{-2} s^{-1}], E_0: Characteristic energy [keV]

2. Ionization rate calculation

$$q_{tot} = \frac{Q_0}{2\Delta\epsilon} \frac{1}{H} f$$

where $\Delta\epsilon$: Mean energy loss per ion pair production (0.0035 keV)

H : Scale height [cm]

f : Energy deposition function from Fang et al. [2010]

Fang et al. [2010] parameterize the energy deposition function based on sophisticated first principal models, providing more accurate calculation for any incident auroral energies between 100 eV – 1 MeV, while Robinson et al. [1987] used the energy deposition function from Rees [1963] that is applicable for 5 – 54 keV auroral energies.

3. Electron density calculation

Robinson [1987] assumed steady state conditions and neglected transport. Then, the electron continuity equation becomes:

$$\frac{\partial n}{\partial t} = q - \alpha n^2 + \nabla \cdot (n\mathbf{V}) \longrightarrow n = \sqrt{\frac{q}{\alpha}}$$

where n : electron density [cm^{-3}], q : ionization rate [cm^{-3} s^{-1}],

V : ionospheric plasma velocity

$\alpha = 2.5 \times 10^{-6} e^{-\frac{H}{51.2}}$: effective recombination coefficient [cm^3 s^{-1}]

4. Ionospheric conductance calculation

Robinson [1987] neglected electron-neutral collisions. Then, Pederson and Hall conductivities are:

$$\sigma_P = (ne/B)[\Omega_i \nu_i/(\Omega_i^2 + \nu_i^2)] \qquad \sigma_H = (ne/B)[\nu_i^2/(\Omega_i^2 + \nu_i^2)]$$

where n : electron density, e : electrical charge, B : magnetic field strength,

$\Omega_i = eB/m_n$: ion gyrofrequency,

$v_i\ [s^{-1}] = 3.75 \times 10^{-10}\ n_n[cm^{-3}]$: ion-neutral collision frequency

m_n : mean molecular weight, n_n : total neutral number density

We use NRLMSIS thermosphere model instead of Banks and Kockarts [1973] thermosphere model that Robinson [1987] used.