On Wind-Driven Electrojets at Magnetic Cusps in the Nightside Ionosphere of Mars

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Outline

Summary

Martian Magnetic Fields and Cusps

Martian Ionospheric Dynamo

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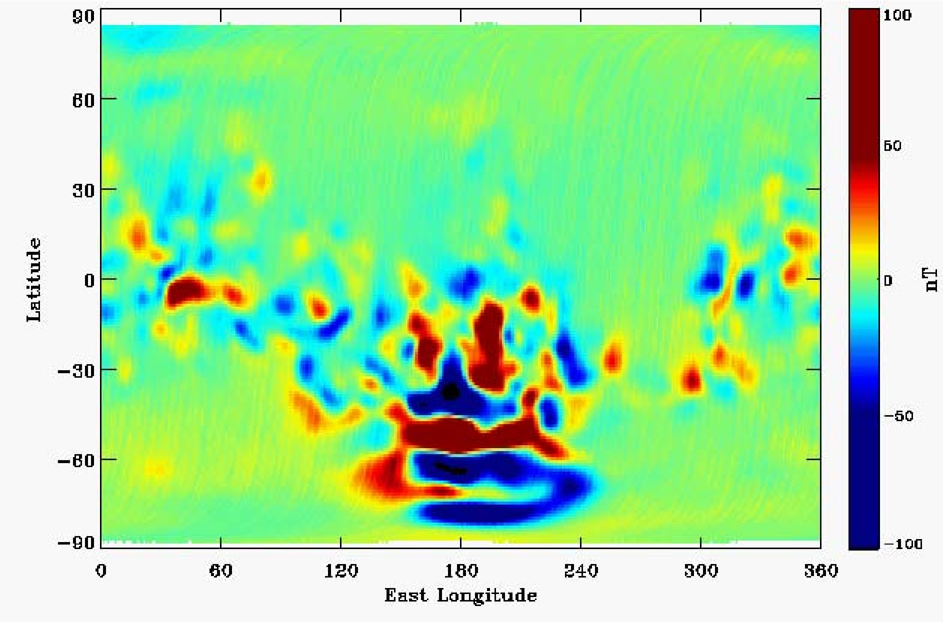
- The complex magnetic topology at Mars allows solar wind (and accelerated) electrons to ionize the nightside atmosphere in limited regions (cusps) forming a patchy nightside ionosphere
- Neutral winds drive ionospheric currents at altitudes where ions are collisionally coupled to the neutral atmosphere while electrons are magnetized → **dynamo region**
- Inhomogeneities in the ionospheric conductivity lead to polarization electric fields and secondary ionospheric currents – secondary currents can reinforce original currents forming **electrojets**
- The magnetic signatures of electrojets can be measured from orbit and from the surface

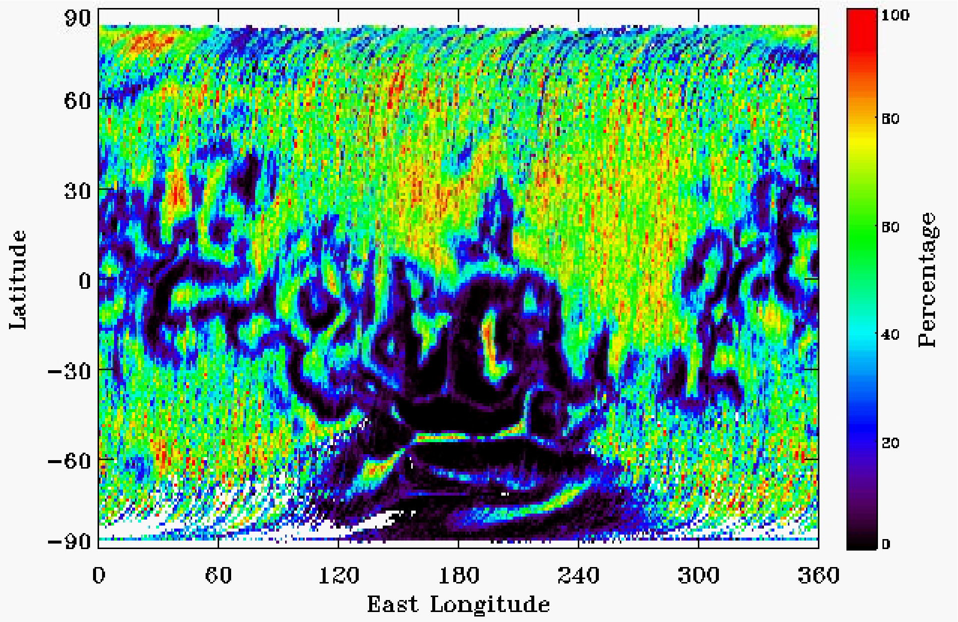
Martian Magnetic Fields and Cusps

- No global magnetic field ***but*** strong crustal fields
- Cusps form where radial crustal fields connect to the IMF → solar wind has access to the atmosphere → ionization
- Non-uniform global distribution of cusps and ionization
- Accelerated electrons, ionospheric structure, and aurora associated with cusps

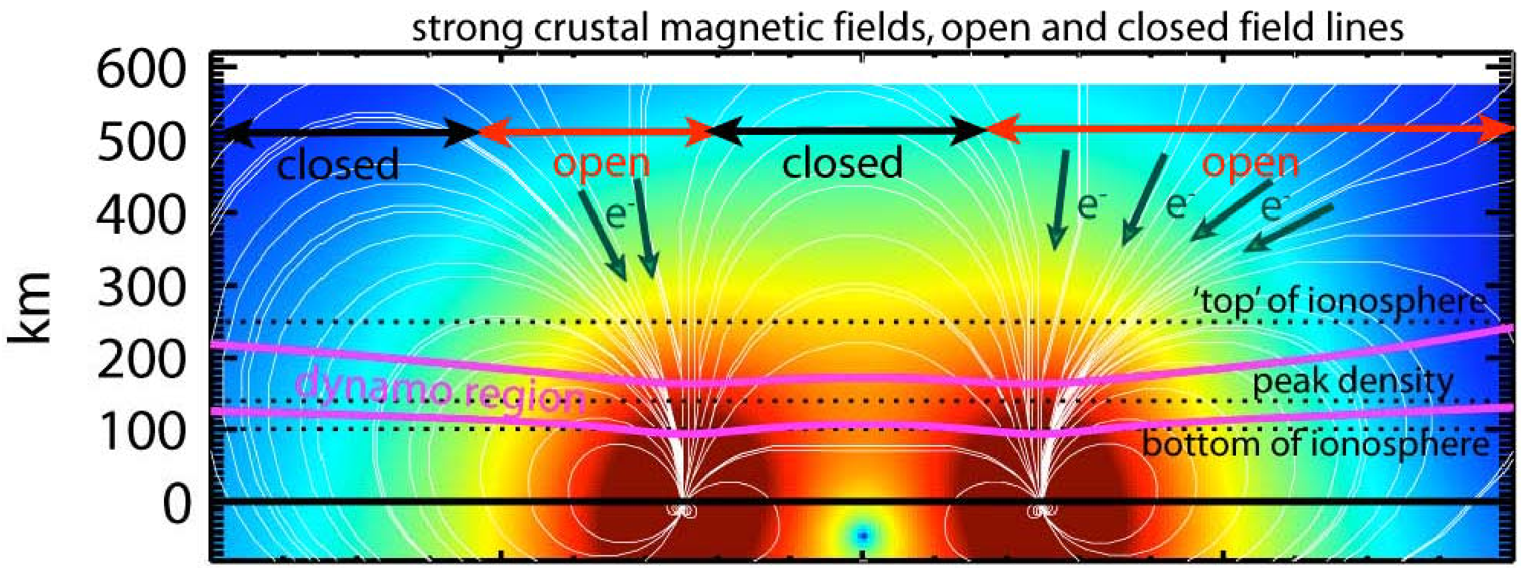
Radial component of B



Probability of observing loss cones on the nightside



Martian Ionospheric Dynamo

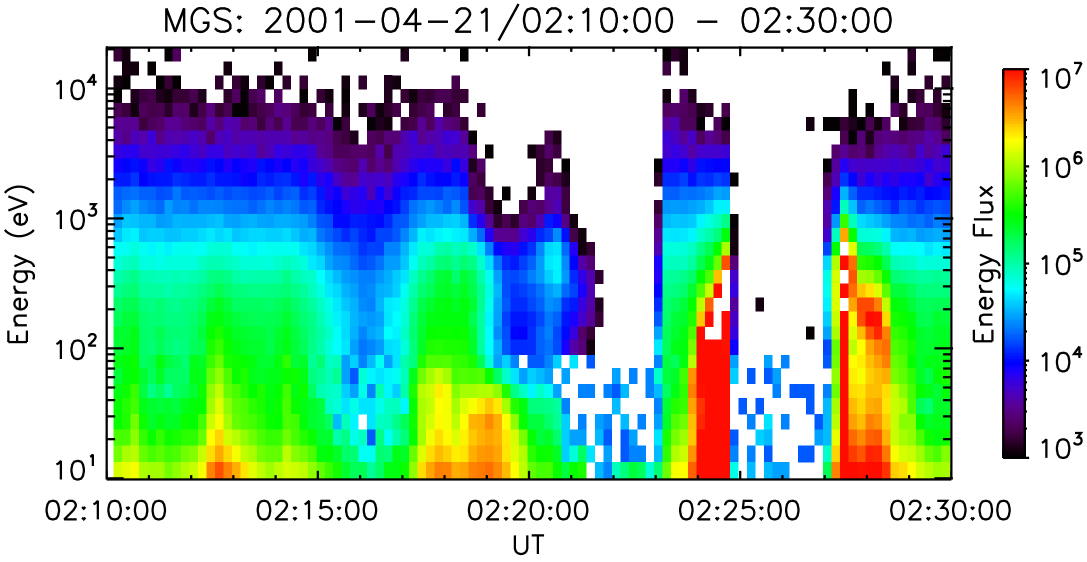


- Ionospheric currents exist where ions are collisional ($\Omega_i < \nu_{in}$) but electrons are magnetized ($\Omega_e > \nu_{en}$) → **dynamo region**
- Crustal magnetic fields alter the ionospheric electrodynamics
- The altitude of the dynamo is geographically dependent
- Currents vary on the same spatial scales as the crustal fields do at ionospheric altitudes (~ 100 – 600 km)

Martian Ionospheric Currents

(see Fillingim *et al.* (2010), *Icarus*, *206*(1), pp. 112-119.)

1. Start with observed electron energy spectra



Electron spectrogram observed by Mars Global Surveyor on the nightside at 400 km

Regions of accelerated electrons (at cusps) & “voids” of few electrons

Martian Ionospheric Currents

(see Fillingim *et al.* (2010), *Icarus*, *206*(1), pp. 112-119.)

1. Start with observed electron energy spectra

2. Calculate ionization rate

→ neutral atmosphere (MTGCM) of Bougher *et al.* [2009]
→ electron transport code of Lummerzheim & Lilensten [1994]
→ magnetic field model of Cain *et al.* [2003] (path length)

Martian Ionospheric Currents

(see Fillingim *et al.* (2010), *Icarus*, *206*(1), pp. 112-119.)

1. Start with observed electron energy spectra

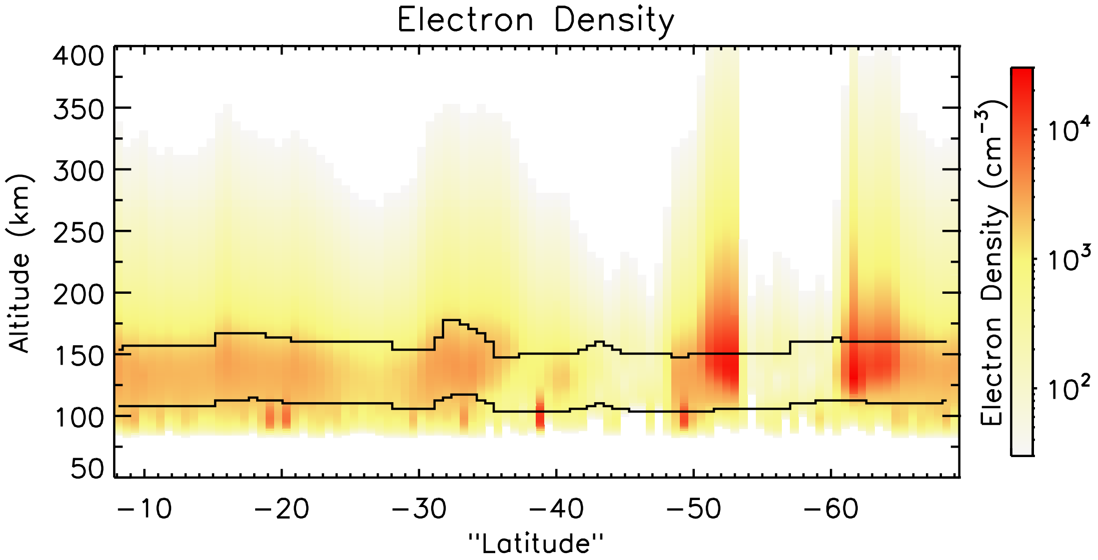
2. Calculate ionization rate

3. Compute resulting electron density, n_e

→ assume photochemical equilibrium, i.e., $n_e(z) = \sqrt{P(z)/\alpha_{eff}(z)}$

→ assume all ions are O_2^+, $\alpha_{eff}(z)$ is O_2^+ recombination rate

→ electron temperature, T_e, is equal to measured daytime T_e



Computed n_e versus altitude and latitude

Black lines bound dynamo region → currents coincide with ionospheric peak

Martian Ionospheric Currents

(see Fillingim *et al.* (2010), *Icarus*, *206*(1), pp. 112-119.)

1. Start with observed electron energy spectra
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4. Add external force → neutral winds (u_X = 100 m/s northward)

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5. From equations of motion, calculate particle velocities, $\mathbf{v}_{\mathbf{i,e}}$

$$-1/n_{i,e}\,\nabla(n_{i,e}kT_{i,e}) + m_{i,e}\mathbf{g} + q(\mathbf{E} + \mathbf{v}_{i,e} \times \mathbf{B}) - m_{i,e}\nu_{in,en}(\mathbf{v}_{i,e} - \mathbf{u}) = 0$$

pressure gradient	gravity	electric field	magnetic field	collisions with neutrals

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* Assume $\mathbf{B} = B_Z$ and $\mathbf{u} = u_X$

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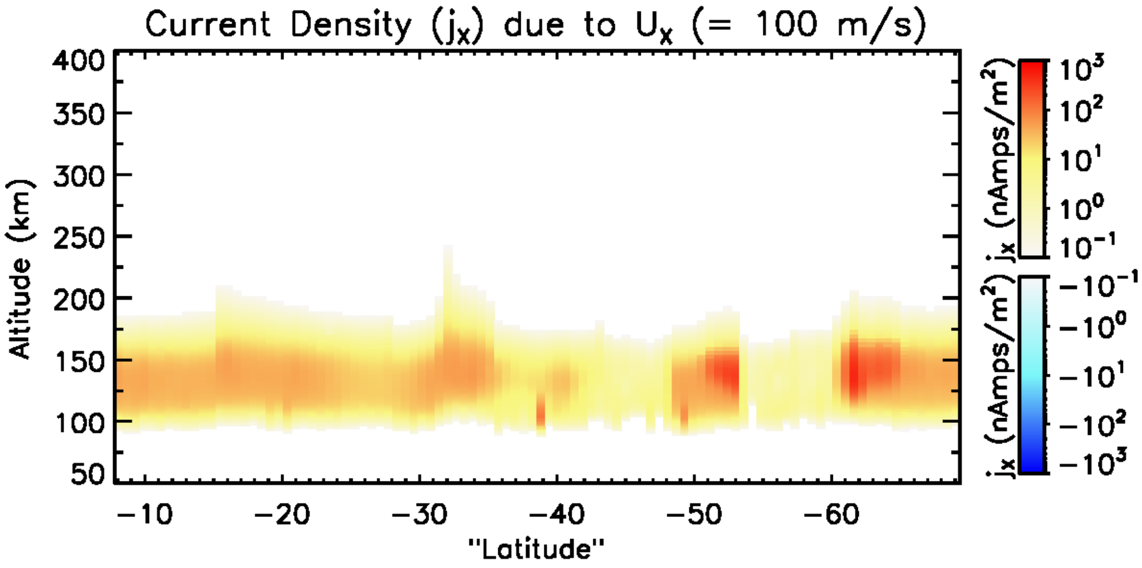
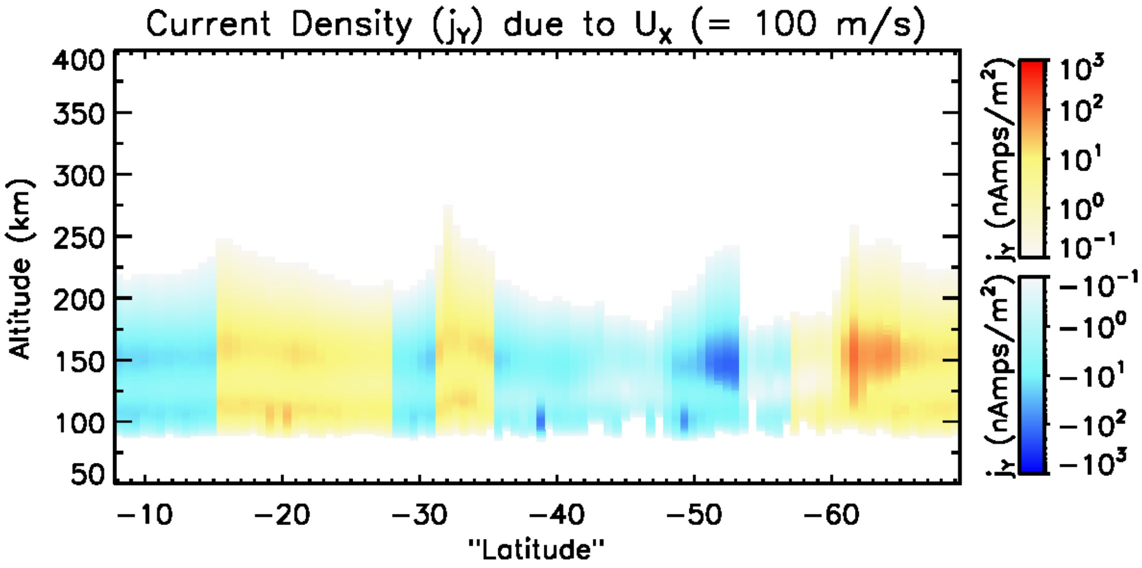
5. From equations of motion, calculate particle velocities, $\mathbf{v}_{\mathbf{i,e}}$
6. Calculate currents: $\mathbf{j} = nq(\mathbf{v}_{\mathbf{i}} - \mathbf{v}_{\mathbf{e}})$

Martian Ionospheric Currents





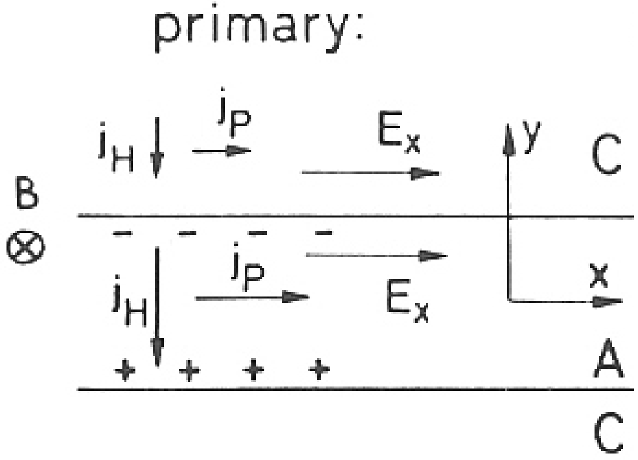
X- (north) and Y- (west) components of currents driven by a uniform northward neutral wind; $u_X = +100$ m/s

Collisional ions carry northward currents, j_x

East-west currents, j_y, carried by magnetized electrons as they drift in the –**F** × **B** direction where $\mathbf{F} = F_x = m_e \nu_{en} u_x$

What about **secondary effects**…?

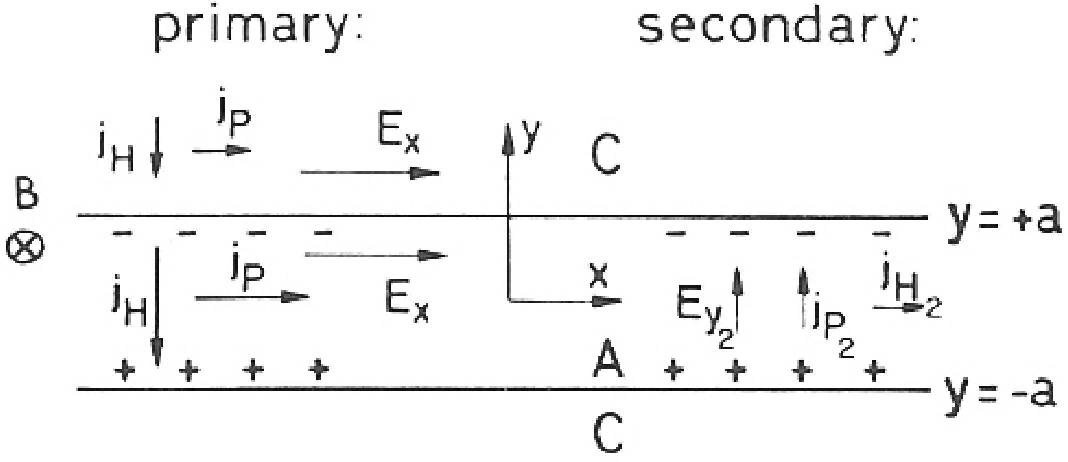
Terrestrial Auroral Electrojets



[from Carlson and Egeland, 1995]

- Particle precipitation (i.e., aurora) can create a channel of enhanced ionization and enhanced conductivity, σ (region A)
- An external force (electric field, **E**,) drives ionospheric currents
- Collisional ions carry current parallel to **E**: Pedersen current, j_P
- Magnetized electrons carry current perpendicular to both **E** and **B**: Hall current, j_H
- Currents in region A are stronger due to higher conductivity → difference in j_H leads to charge accumulation at the edges of A

Terrestrial Auroral Electrojets



[from Carlson and Egeland, 1995]

- Charge separation creates a secondary electric field, E_{y2}, which drives secondary Pedersen and Hall currents, j_{P2} and j_{H2}
- j_{P2} partially cancels j_H in region A
  → current continuity in y-direction across A-C boundary
- j_{H2} adds to j_P enhancing original current → **electrojet**
- Can an analogous situation occur in the nightside ionosphere of Mars…?

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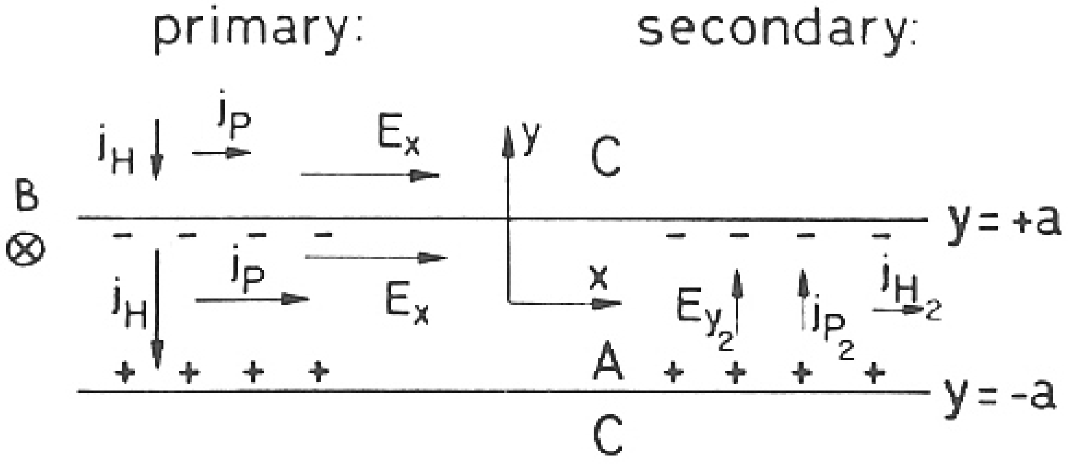

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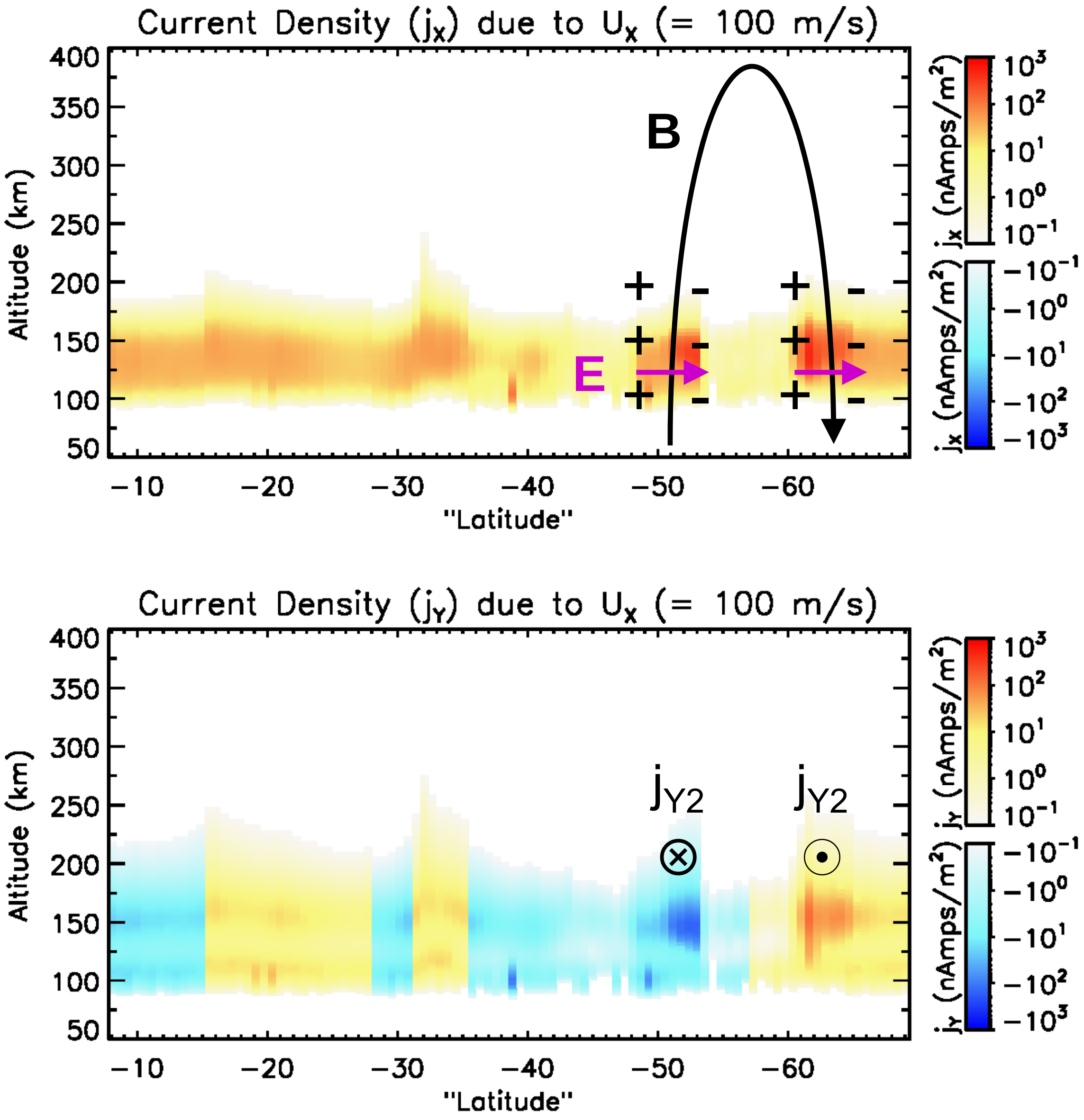
- Can an analogous situation occur in the nightside ionosphere of Mars…?
- **Yes – in magnetic cusps!**

Martian Auroral Electrojets



Variations in spectra of precipitating electrons

→ variations in n_e

→ variations in σ

→ variations in j

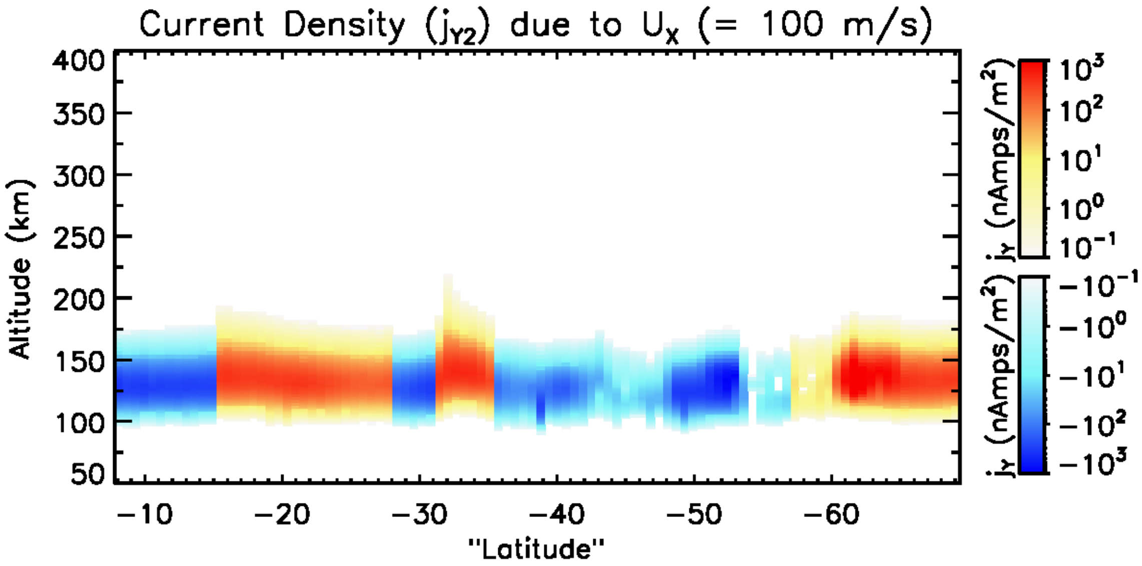
Neglecting parallel currents, j_X must be continuous (and small)

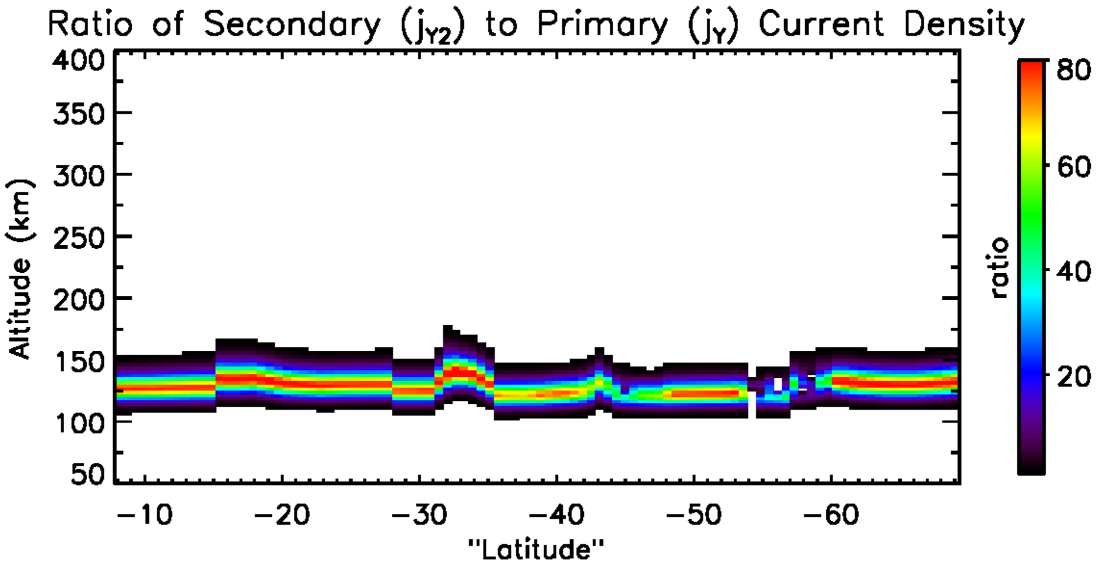
Charge accumulates at edges of high σ cusps

→ creates southward **E**

E drives secondary Hall currents, j_{Y2}, enhancing original j_Y

Martian Auroral Electrojets


Current Density (j_{Y2}) due to U_X (= 100 m/s)


Ratio of Secondary (j_{Y2}) to Primary (j_Y) Current Density

Secondary east-west Hall current, j_{Y2}, calculated assuming j_X continuous and = j_X^{min}

$$E_X = (j_X - j_X^{min})/\sigma_P,$$

$$j_{Y2} = E_X\sigma_H \approx j_X\, \sigma_H/\sigma_P$$

Current increase, j_{Y2}/j_Y

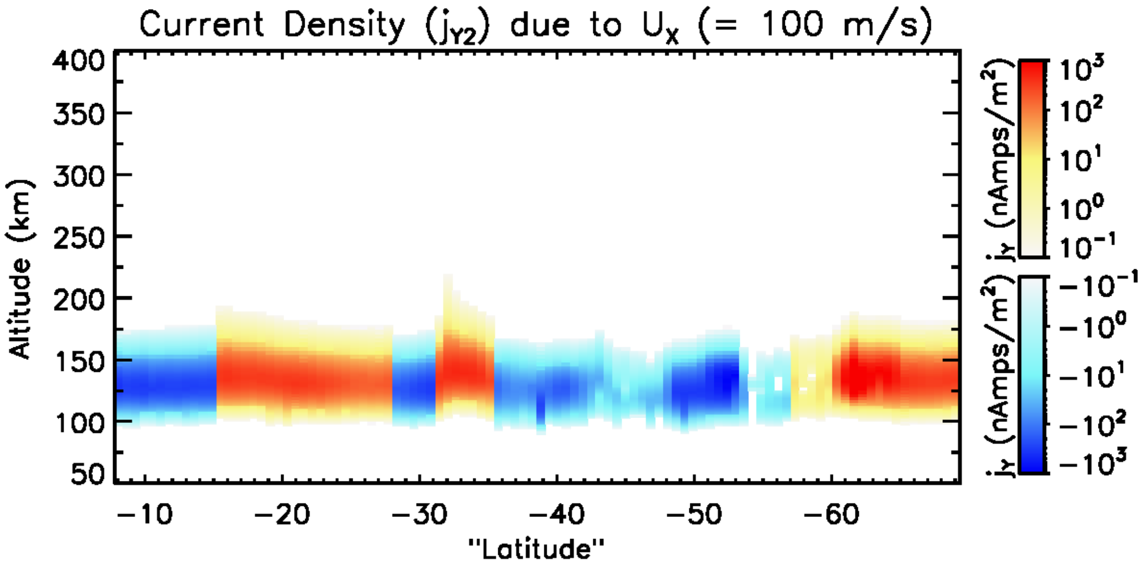
$$j_{Y2}/j_Y \approx j_X/j_Y\, \sigma_H/\sigma_P$$

$$\approx [\sigma_H/\sigma_P]^2$$

Factor of ~ 80 increase → **electrojets**

Large j_X, large increase

Martian Auroral Electrojets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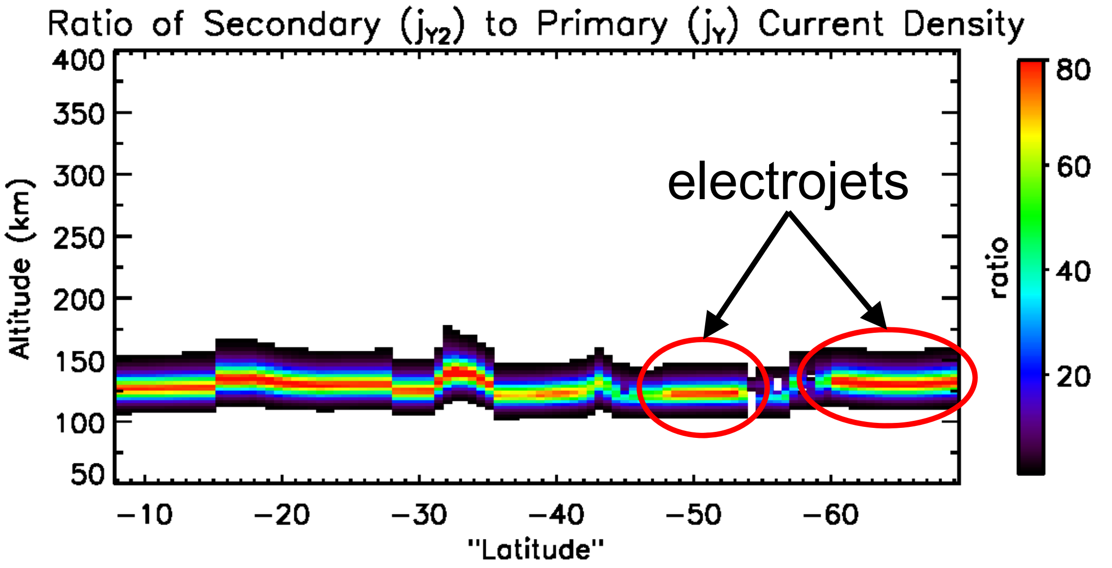
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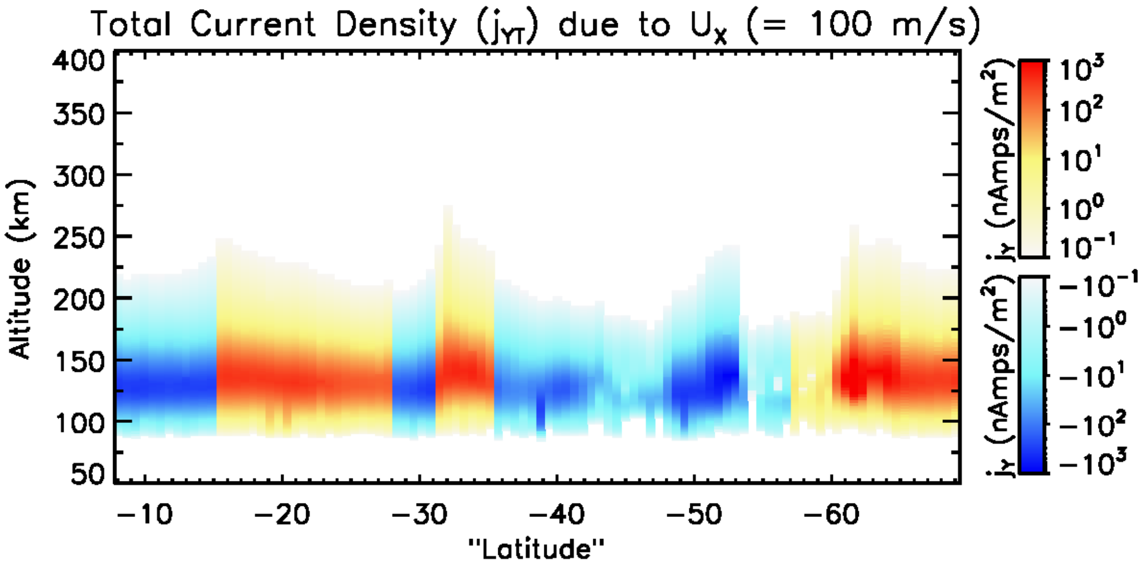

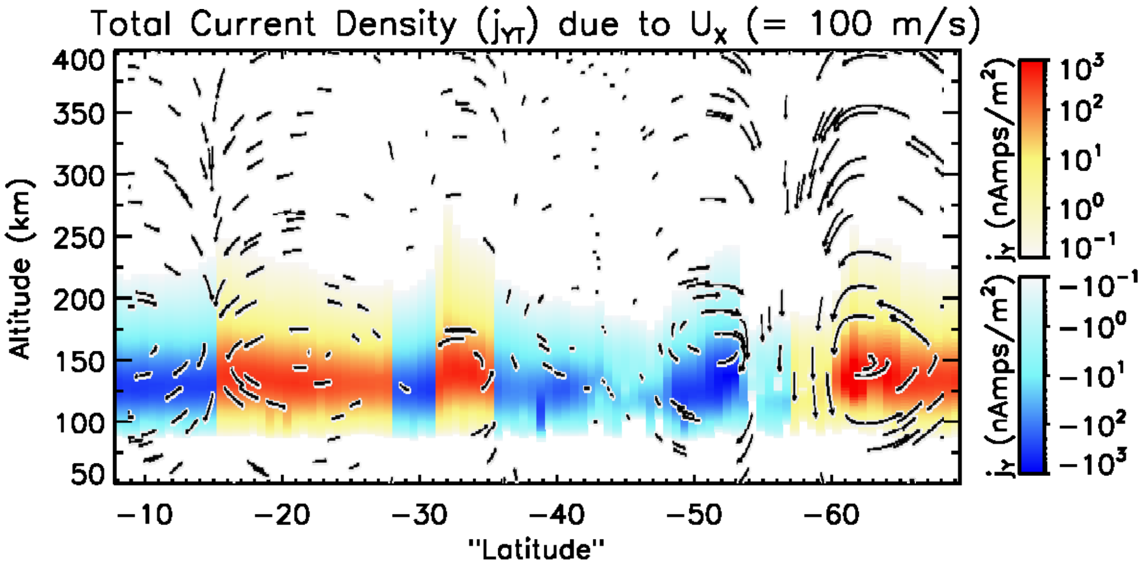

Total current density

$j_{YT} = j_Y + j_{Y2}$

Solve Biot-Savart Law to find ΔB due to j_{YT}

Max j_{YT} at -50 & -65°; max ΔB in region between -50 – -65°

at 400 km, ΔB ≈ 10 nT, $B_{ambient}$ ≈ 100 nT (10%)

at 150 km, ΔB ≈ 50 nT, $B_{ambient}$ ≈ 500 nT (10%)

at surface, ΔB ≈ 10 nT, $B_{ambient}$ > 1000 nT (1%)

Variability

- Wind driven electrojets are variable; periodic changes in **conductivity gradients** and neutral wind **speed** and **direction** affect intensity of electrojets
- **Diurnal**:
  - In **sunlight**, conductivity gradients are weaker (solar EUV) → j_X is "more continuous" → weaker electrojets
  - Wind patterns change with **local time** [Bougher *et al.*, 2000] northward winds in southern hemisphere pre-midnight; westward wind post-midnight → weaker electrojets
- **Seasonal**:
  - Nightside wind patterns also change with **season** northward winds at equinox and southern summer solstice; eastward winds at northern summer solstice → weaker EJ

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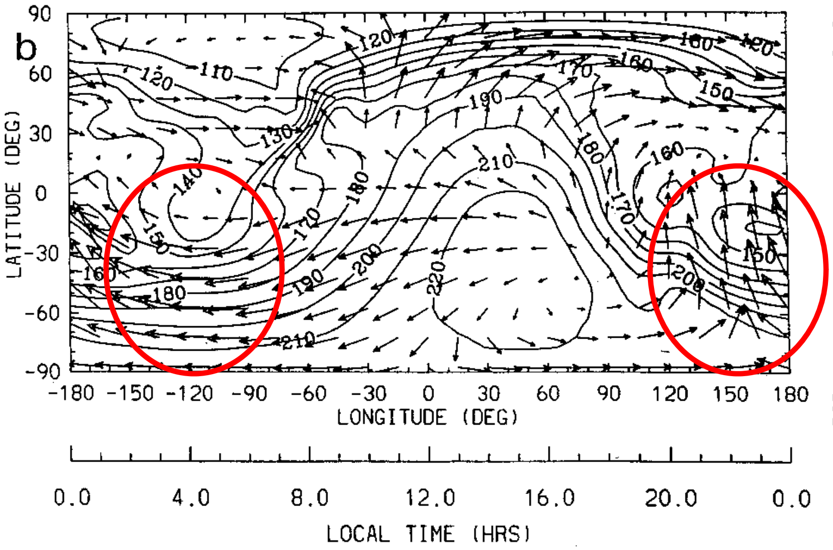

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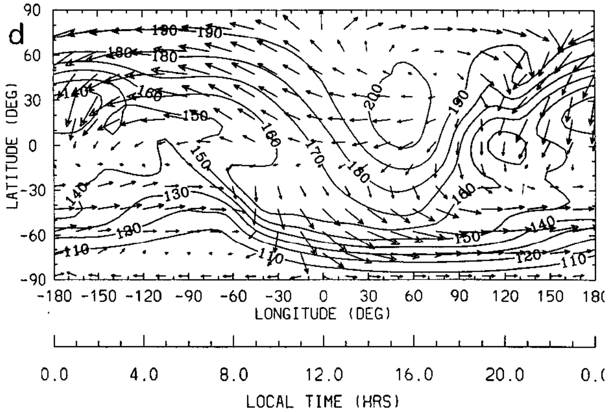
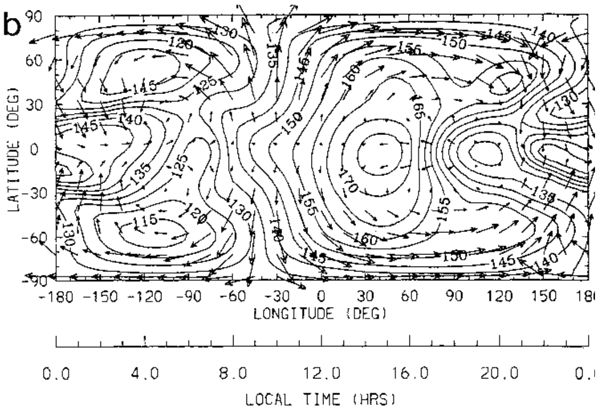
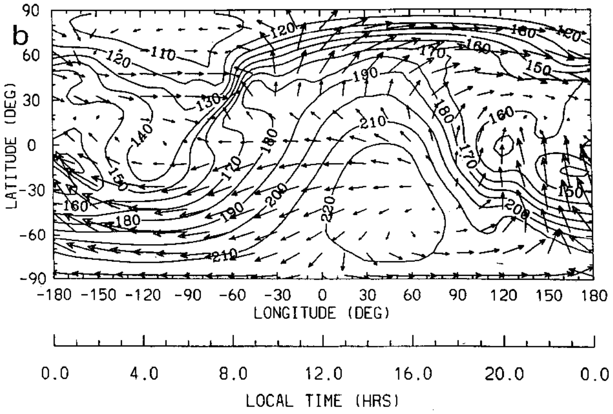
Northern Summer Solstice



Equinox



Southern Summer Solstice



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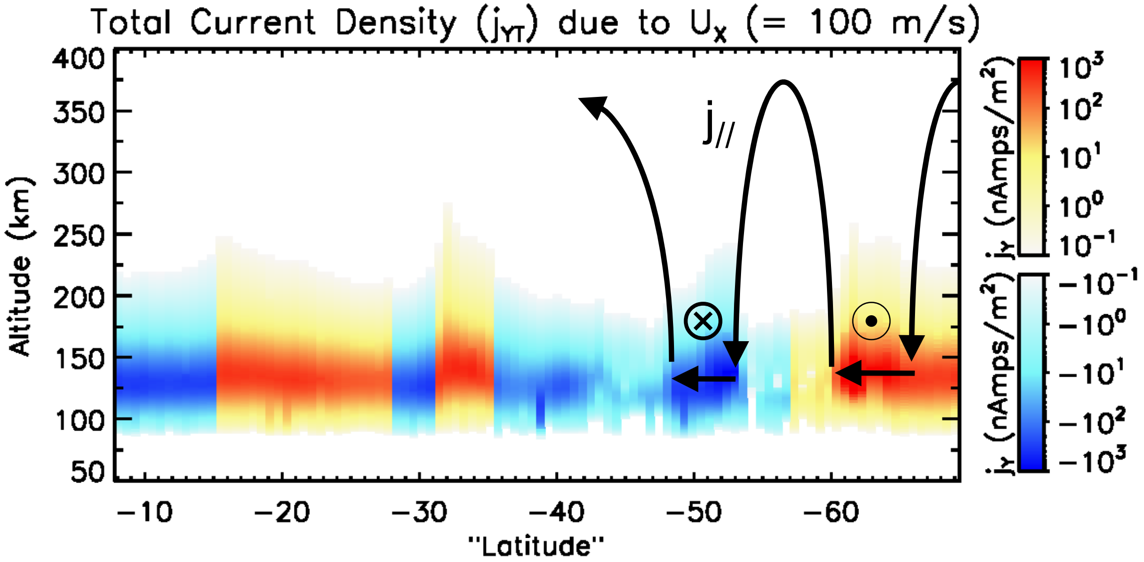
Caveats/Assumptions/Simplifications

- Electron transport code does not include magnetic gradients: straight field lines with constant magnitude and dip angle
  → Bad assumption for anisotropic electrons (Lillis *et al.*, 2009)
- For current calculations, use unrealistic geometry → **B** = B_Z
- Neglect effects of external (magnetospheric) electric fields
- Ignore (observed) parallel currents: $j_{//} \sim 0.5 – 1\ \mu A/m^2$
  [Brain *et al.*, 2006; Halekas *et al.*, 2006]
  $j_{//}$ will decrease – but not nullify – magnitude of electrojets
  → 3-D current system analogous to Earth's auroral region
- Currents modify magnetic field (which modify currents…)
- What is needed to more adequately address these problems?
  → Geometrically accurate, self-consistent, 3-D model of the electrodynamics of the Martian ionosphere (see Poster 41)

Cavea ations



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