The unusual electrodynamics of the ionosphere of Mars

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Martian Patchy Fields

Arkani-Hamed model
Martian Field Lines

Brain et al. 2003

Mendillo and Withers, 2008
Earth’s Field Lines

http://www.windows2universe.org/glossary/particle_motion.html

http://core2.gsfc.nasa.gov/terr_mag/core.html
Effect of Crustal B on Ionosphere

Nielson et al. 2007a, from Fig 1

Nielson et al. 2007a Fig 5
More effects of Crustal B

- Ion densities
- Electron Densities
- Temperatures
- Neutral Atmosphere

Duru et al., 2006, Fig 4
Withers 2005a, Fig 2
Theory (Withers, 2008)

\[ \frac{\partial N_j}{\partial t} + \nabla \cdot (N_j \nu_j) = P_j - L_j \]

\[ 0 = m_j g - \frac{1}{N_j} \nabla (N_j k T_j) + q_j E' + q_j B \Lambda \ w_j - m_j \nu_{jn} w_j \]

\[ w_j = \left( m_j \nu_{jn} I - q_j B \Lambda \right)^{-1} \left( m_j g - \frac{1}{N_j} \nabla (N_j k T_j) + q_j E' \right) \]

\[ w_j = \frac{1}{m_j \nu_{jn}} \left( I - \kappa_j \Lambda \right)^{-1} \left( m_j g - \frac{1}{N_j} \nabla (N_j k T_j) + q_j E' \right) \]

\[ w_j = \frac{1}{N_j q_j} \left( Q_j + S_j E' \right) \]

\[ J = \sum_j N_j q_j w_j \quad \text{---------} \quad J = Q + S \ E' \]
Traditional Conductivity Tensor

\[ J = \frac{\sigma}{\sigma} E' \], where

\[ \sigma = \begin{pmatrix} \sigma_P & -\sigma_H & 0 \\ \sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_0 \end{pmatrix} \]

\[ \sigma_P = \sum_{j=1}^{M} \frac{N a_j}{B} \frac{v_j/\omega_j}{1 + (v_j/\omega_j)^2} \]

\[ \sigma_H = \sum_{j=1}^{M} \frac{N a_j}{B} \frac{1}{1 + (v_j/\omega_j)^2} \]

\[ \sigma_0 = \sum_{j=1}^{M} \frac{N a_j}{B} \frac{\omega_j}{v_j} \]

(Forbes, 1981)
General Conductivity Tensor:

\[ S = \sum_j \frac{N_j q_j^2}{m_j \nu_{jn}} \begin{pmatrix} \frac{1}{1 + \kappa_j^2} & \kappa_j \frac{1}{1 + \kappa_j^2} & 0 \\ -\kappa_j \frac{1}{1 + \kappa_j^2} & \frac{1}{1 + \kappa_j^2} & 0 \\ 0 & 0 & 1 \end{pmatrix} \]

(Withers, 2008)
Determining Ion Velocities

- Continuity Equation
- Momentum Equation
- Maxwell’s Equations
- $N_i(z)$
- Etc…

$\Rightarrow v_i(z)$
More Theory

(Withers, 2008)
Application of General Conductivity

(Withers, 2008: Figures 7 and 9)
Next, a 2D Model:

- Objective is to model, as accurately as possible, the generation of 5 major ions in the Martian ionosphere between 80-400 km.

- Then to analyze this model as input parameters change (location over surface, surrounding magnetic environment, etc...)
2D Model Methodology

- PC Production
- PC Loss
- Transport
- Calculation of 2D ion velocities
2D Model, Preliminary Results

Noon densities, \(I = 90^\circ\), PC

Noon densities, \(I = 90^\circ\), PC+Diff
More Preliminaries

Noon densities, $I = 0^\circ$, PC

\begin{align*}
\text{Altitude (km)} & \quad 400 & \quad 350 & \quad 300 & \quad 250 & \quad 200 & \quad 150 & \quad 100 \\
\text{Number Density (cm}^{-3}) & \quad 10^{-6} & \quad 10^{-4} & \quad 10^{-2} & \quad 10^{0} & \quad 10^{2} & \quad 10^{4} & \quad 10^{6} \\
\end{align*}

\begin{align*}
[\text{O}^{2+}] & \quad [\text{O}^{+}] & \quad [\text{CO}^{2+}] & \quad [\text{N}^{2+}] & \quad [\text{NO}^{+}] \\
\end{align*}

Noon densities, $I = 0^\circ$, PC+Diff

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\end{align*}
More 2D Model Preliminaries

Difference between PC only and PC with Diffusion densities for $I_B=90^\circ$

Difference between PC only and PC with Diffusion densities for $I_B=0^\circ$
Conclusions

- Martian crustal fields generate effects on the ionosphere that have been measured and modeled (1D).

- The most general representations of underlying physics apply to the regions of Martian ionospheres that should not be generalized for terrestrial-like cases.

- Further study and modeling (2D) is required to improve our understanding of the phenomena governing such regions.