Integration of MAVEN neutral and plasma observations
(or, Testing basic ionospheric predictions and seeing where they fail)

Paul Withers (withers@bu.edu)
MAVEN Participating Scientist
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Several predictions can be properly tested for the first time

What topside scale height?

What altitude or pressure at the peak?

What density at the peak?

MGS radio occultation electron density profile
Where is the peak?

- $\tau$ at peak = ?
Where is the peak?

- $\tau$ at peak = 1
- $\int n \sigma \, dl = 1$
Where is the peak?

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- $\int n \sigma \, dl = 1$
- $\int n \sigma \, dz = 1$ (subsolar)
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- \( \int n \sigma \, dl = 1 \)
- \( \int n \sigma \, dz = 1 \) (subsolar)
- \( n \sigma H = 1 \)
Where is the peak?

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- $\int n \sigma \, dl = 1$
- $\int n \sigma \, dz = 1$ (subsolar)
- $n \sigma H = 1$
- $(p/kT) \sigma (kT/mg) = 1$
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- $p \sigma / mg = 1$

- Neutral pressure at peak is $mg / \sigma$
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- $p \sigma / mg = 1$

- Neutral pressure at peak is $mg / \sigma$

- Find peak plasma density with LPW
  - Langmuir probe instrument, Ne and Te

- Find pressure with NGIMS
  - Neutral/ion mass spectrometer
  - Hydrostatic equilibrium
What is the peak density?

• \( \frac{\partial N}{\partial t} = P - L \)
• (neglecting transport)
What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F \cap \sigma$
What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F \cap \sigma$
- Check dimensions
- cm$^{-2}$ s$^{-1}$ . cm$^{-3}$ . cm$^2$
- cm$^{-3}$ s$^{-1}$ OK
What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F \, n \, \sigma$
- Subsolar and at $\tau=1$...
- $F = F_0/e$ and $n\sigma H = 1$
What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F \, n \, \sigma$
- Subsolar and at $\tau=1$...
- $F = F_0/e$ and $n_0H = 1$
- $P = F_0/eH$
What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F n \sigma$
- At peak, $P = F_0/eH$

- $\text{CO}_2 + \text{hv} \rightarrow \text{CO}_2^+ + e$
- $\text{CO}_2^+ + \text{O} \rightarrow \text{O}_2^+ + \text{CO}$
  - fast
  - $\text{CO}_2^+$ is not main ion

- $\text{O}_2^+ + e \rightarrow \text{O} + \text{O}$
  - slow
  - produces hot O, which escapes
What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F n \sigma$
- At peak, $P = \frac{F_0}{eH}$
- $L = \alpha(Te) N^2$

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What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F \pi n \sigma$
- At peak, $P = \frac{F_0}{eH}$
- $L = \alpha(Te) N^2$
- $\frac{F_0}{eH} = \alpha(Te) N^2$

- $\text{CO}_2 + \text{hv} \rightarrow \text{CO}_2^+ + \text{e}$
- $\text{CO}_2^+ + \text{O} \rightarrow \text{O}_2^+ + \text{CO}$
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What is the peak density?

- $\frac{\partial N}{\partial t} = P - L$
- $P = F \, n \, \sigma$
- At peak, $P = \frac{F_0}{eH}$
- $L = \alpha(Te) \, N^2$
- $\frac{F_0}{eH} = \alpha(Te) \, N^2$
- Find $F_0$ with UV instruments
- Find $H$ with NGIMS neutral mass spectrometer
- Find $Te$ and $Ne$ with LPW Langmuir probe
Topside structure – No transport

• $P = L$
Topside structure – No transport

- $P = L$
- $P = F \cap \sigma$
- $L = \alpha(Te) N^2$
Topside structure – No transport

- $P = L$
- $P = F \cdot n \cdot \sigma$
- $L = \alpha(Te) \cdot N^2$
- $F \cdot n \cdot \sigma = \alpha(Te) \cdot N^2$
- $\uparrow \uparrow \uparrow$ constant
Topside structure – No transport

- $P = L$
- $P = F \, n \, \sigma$
- $L = \alpha(T_e) \, N^2$
- $F \, n \, \sigma = \alpha(T_e) \, N^2$
- Constant
- $n_0 \exp(-z/H)$ proportional to $N^2$
- $N$ proportional to $\exp(-z/2H)$
- $H_p = 2Hn = 2kT/mg$
Topside structure – No transport

- $P = L$
- $P = F \cdot n \cdot \sigma$
- $L = \alpha(Te) \cdot N^2$
- $F \cdot n \cdot \sigma = \alpha(Te) \cdot N^2$
- $\uparrow \uparrow \uparrow$ constant

- $n_0 \cdot \exp(-z/H)$ proportional to $N^2$
- $N$ proportional to $\exp(-z/2H)$
- $Hp = 2Hn = 2kT/mg$

- Predict $Hp = 20$ km
- $ Hp $ from LPW Langmuir probe electron densities
- $Hn$ from NGIMS mass spectrometer neutral densities
Topside structure – Transport

• $\frac{\partial N}{\partial t} + \nabla \cdot (N \mathbf{v}) = P - L$
Topside structure – Transport

\begin{itemize}
  \item \( \frac{\partial N}{\partial t} + \nabla \cdot (N\nu) = P - L \)
  \item \( 0 = m_i g - \frac{1}{N} \nabla (NkT_i) + eE - m_i \nu_{in} \nu_i \)
  \item \( 0 = m_e g - \frac{1}{N} \nabla (NkT_e) - eE - m_e \nu_{en} \nu_e \)
\end{itemize}
Topside structure – Transport

- \( \partial N / \partial t + \nabla \cdot (N \nu) = P - L \)
- \( 0 = m_i g - \frac{1}{N} \nabla (N k T_i) + eE - m_i \nu_{in} \nu_i \)
- \( 0 = m_e g - \frac{1}{N} \nabla (N k T_e) - eE - m_e \nu_{en} \nu_e \)
- One eigenfunction has \( \nu \rightarrow 0 \), other has \( \nu \rightarrow \infty \) (guess which one I will pick)
Topside structure – Transport

• \( \frac{\partial N}{\partial t} + \nabla \cdot (N \nu) = P - L \)
• \( 0 = m_i g - \frac{1}{N} \nabla (N k T_i) + eE - m_i \nu_{in} \nu_i \)
• \( 0 = m_e g - \frac{1}{N} \nabla (N k T_e) - eE - m_e \nu_{en} \nu_e \)
• \( 0 = m_i g - \frac{1}{N} \nabla (N k (T_i + T_e)) \)
Topside structure – Transport

\[ 0 = m_i g - \frac{1}{N} \nabla (N k T_i) + e E - m_i v_{in} v_i \]
\[ 0 = m_e g - \frac{1}{N} \nabla (N k T_e) - e E - m_e v_{en} v_e \]
\[ 0 = m_i g - \frac{1}{N} \nabla (N k (T_i + T_e)) \]
\[ m_i g = -k (T_i + T_e) d (\ln N)/dz \]
Topside structure – Transport

- \( 0 = m_i g - \frac{1}{N} \nabla (NkT_i) + eE - m_i v_{in} v_i \)
- \( 0 = m_e g - \frac{1}{N} \nabla (NkT_e) - eE - m_e v_{en} v_e \)
- \( 0 = m_i g - \frac{1}{N} \nabla (Nk(T_i + T_e)) \)

- \( m_i g = - k (T_i + T_e) \, d (\ln N)/dz \)
- \( N \) proportional to \( \exp(-z/H_p) \) where
- \( H_p = k (T_i + T_e) / m_i g \)
- \( H_p = 200 \text{ km} \) (not 20 km)
• Such diverse topside structures do exist!
• \( \text{Hp} \approx 20 \text{ km} \rightarrow \) Consistent with no transport
  – Strong horizontal magnetic field
• \( \text{Hp} \approx 200 \text{ km} \rightarrow \) Consistent with diffusive equilibrium
  – Strong vertical magnetic field or no field

A+ B – MEX radio occultation profiles
Summary

• MAVEN will measure:
  – Background neutral atmosphere,
  – Driving solar conditions, and
  – Ionospheric response
  – Simultaneously

• Great opportunity to determine how the ionosphere functions

• Failures of canonical predictions will show where interesting physics can be found