The ionosphere of Mars prior to the arrival of MAVEN

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This hazy region contains the atmosphere and ionosphere of Mars

NASA
This is Mars

0.5 x R-Earth

1.5 AU from Sun

Same rotation rate as Earth

Carbon dioxide atmosphere

100x smaller surface pressure

Target of many spacecraft in last 15 years
What is an ionosphere?
What is an ionosphere?

An ionosphere is a weakly ionized plasma embedded within an upper atmosphere, often produced by photoionization.
What does that actually mean?

<table>
<thead>
<tr>
<th></th>
<th>Atmosphere</th>
<th>Ionosphere</th>
<th>Space physics</th>
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<tbody>
<tr>
<td>Chemistry</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Gravity</td>
<td>✓</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Sunlight</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Magnetic fields</td>
<td>✗</td>
<td>✓ and ✗</td>
<td>✓</td>
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<tr>
<td>Composition</td>
<td>Neutrals</td>
<td>Ions, electrons, and neutrals</td>
<td>Protons and electrons</td>
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</tbody>
</table>
Typical electron density profile

Withers et al. (2009) – Radio occultation observations
Peak electron density and SZA

\[ n_0 = 1.58 \times 10^5 \text{ cm}^{-3} \pm 0.01\% \]

Morgan et al. (2008) – Radar sounder observations
Peak altitude and SZA

Peter et al. (2014) – Radio occultation observations
Overall shape

Radio occultation observations
Predictions of simple theory

\[ N = N_m \exp \left( \frac{1}{2} \left( 1 - \frac{(z - z_m)}{H} \right) - \exp \left( \frac{(z - z_m)}{H} \right) \right) \]

\[ N_m = \frac{N_0}{\sqrt{C'h(SZA)}} \quad N_0^2 = \frac{F_0}{\alpha \exp(1) H} \]

\[ z_m = z_0 + H \ln C'h(SZA) \quad \sigma_n(z_m) H C'h(SZA) = 1 \]

\[ C'h(SZA) = \frac{1}{\cos(SZA)} \text{ for small SZA} \]

This is Chapman theory

Neutral atmosphere has single constituent and fixed scale height
Each ionization event instantly produces one molecular ion
Molecular ions are lost by dissociative recombination with an electron
The ionosphere of Mars

Neutral atmosphere is mainly CO$_2$, O becomes significant at high altitudes

O$_2^+$ is main ion at all altitudes

Solar EUV photons responsible for main M2 layer

Soft X-ray photons and secondary ionization responsible for lower M1 layer

Does transport, which is ignored by Chapman theory, affect plasma densities anywhere?

Withers (2011)
Peak electron density and SZA

Peak density does not always depend smoothly on SZA

\[ N_m = \frac{N_0}{\sqrt{Ch(SZA)}} \]
Unique magnetic field is responsible

Earth magnetic field

Mars magnetic field

www.windows2universe.org

Brain (2002)
Peak electron density and SZA

Enhancements seen over strong and vertical crustal magnetic fields

Nielsen et al. (2007)
Peak altitude and SZA

Peak altitude does not always depend on SZA in the usual manner

\[ z_m = z_0 + H \ln C h \ (SZA) \]

Peter et al. (2014)

Hantsch and Bauer (1990)
Mars • Global Dust Storm

June 26, 2001

Hubble Space Telescope • WFPC2

NASA, J. Bell (Cornell), M. Wolff (SSI), and the Hubble Heritage Team (STScI/AURA) • STScI-PRC01-31

September 4, 2001
Shape is often not Chapman-like

\[ N = N_m \exp \left( \frac{1}{2} \left( 1 - \frac{(z - z_m)}{H} \right) - \exp \left( -\frac{(z - z_m)}{H} \right) \right) \]

Withers et al. (2012)
Radio occultation data
Odd features at slightly higher altitudes

Withers et al. (2012) – Radio occultation observations
How does the topside behave?

Withers et al. (2012) – Radio occultation observations

Consistent with no transport

Consistent with diffusive equilibrium
Where’s the ionopause?

Withers et al. (2012) – Radio occultation observations
Why is it so hard to predict ionospheric characteristics?

Consider existing data on

- Neutral composition
- Neutral dynamics
- Plasma composition
- Plasma dynamics
- Plasma energetics
Neutral composition
Neutral dynamics
Plasma composition
Plasma dynamics
Plasma energetics
The $500M MAVEN mission was sent to Mars to collect more data for my ionospheric research
MAVEN Will Allow Us to Understand Escape of Atmospheric Gases to Space

- MAVEN will determine the present state of the upper atmosphere and today’s rates of loss to space.
- Measurements will allow determination of the net integrated loss to space through time.
MAVEN instruments

- EUV – Several sensors for EUV fluxes
- IUVS – UV spectrometer
- LPW – Langmuir probe
- MAG – Magnetometer
- NGIMS – Neutral and ion mass spectrometer
- SEP, STATIC, SWEA, SWIA – Electron and ion spectrometers
MAVEN Mission Architecture

Launched on 18 Nov. 2013, first day of its 20-day launch period

Ten-Month Ballistic Cruise to Mars

Orbit Insertion: 22 Sept 2014

One Year of Science Operations

Orbit shown to scale
MAVEN Observes All Regions Of Near-Mars Space Throughout The Orbit
Elliptical Orbit Allows Measurement of All Relevant Regions of Upper Atmosphere

- Nominal periapsis near 150 km.
- Five “deep-dip” campaigns with periapsis near 125 km.
- Provide coverage of entire upper atmosphere
MAVEN Orbit During Primary Science Mission

- Elliptical orbit to provide coverage of all altitudes
- The orbit precesses in both latitude and local solar time
- One-Earth-year mission allows thorough coverage of near-Mars space
Early media releases

http://www.nasa.gov/sites/default/files/thumbnails/image/ozone_justin2.png
Early media releases

Hydrogen  Oxygen  Reflected Sunlight  Composite

http://lasp.colorado.edu/home/maven/files/2014/09/IUVS-final-image.jpg
Early media releases

Three views of an escaping atmosphere

http://www.nasa.gov/sites/default/files/thumbnails/image/justincombined.png
Conclusions

• Simple theory explains some ionospheric characteristics…
• …But lots of observations exist that conflict with simple theory
• Explaining them will require data on solar flux, magnetospheric conditions, neutral atmosphere, and ionospheric response
• MAVEN will provide abundant and comprehensive data for space physics at Mars