TRANSIENT UPPER LAYERS AND ASSOCIATED CURRENT SHEETS IN THE IONOSPHERE OF MARS

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A SECOND TOPSIDE IONOSPHERIC LAYER

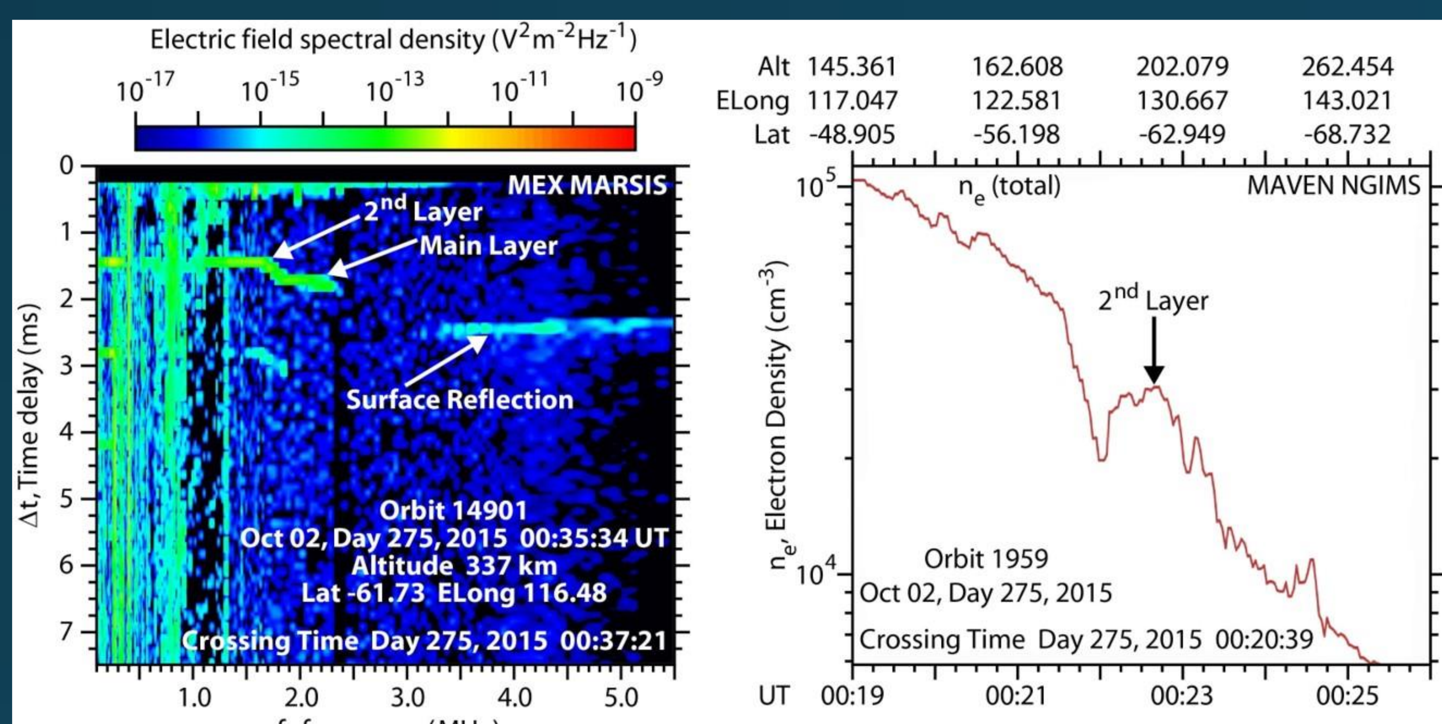
The first report of a topside ionospheric layer was made by *Gurnett et al.* [2008]. This study revealed that a layer regularly appeared at an altitude well above the 130-140 km altitude of the photo-ionization peak. This "transient layer" was analyzed in detail by *Kopf et al.* [2008], who determined, among other things, that the layer:

- Is at an altitude near 200 km
- Has a density between roughly 2-5 x 10^4 cm^{-3}
- Is seen more prominently at low solar zenith angles, away from the terminator

Due to the high-altitude orbit of Mars Express (MEX), no in situ measurements could be made, limiting the ability to define the structure and origin of the layer.

MAVEN allows for near-simultaneous measurements of the ionosphere with Mars Express. Their orbital paths cross twice per orbit, allowing for correlated observations of the ionosphere. In order to identify useful crosses, a series of criteria were imposed.

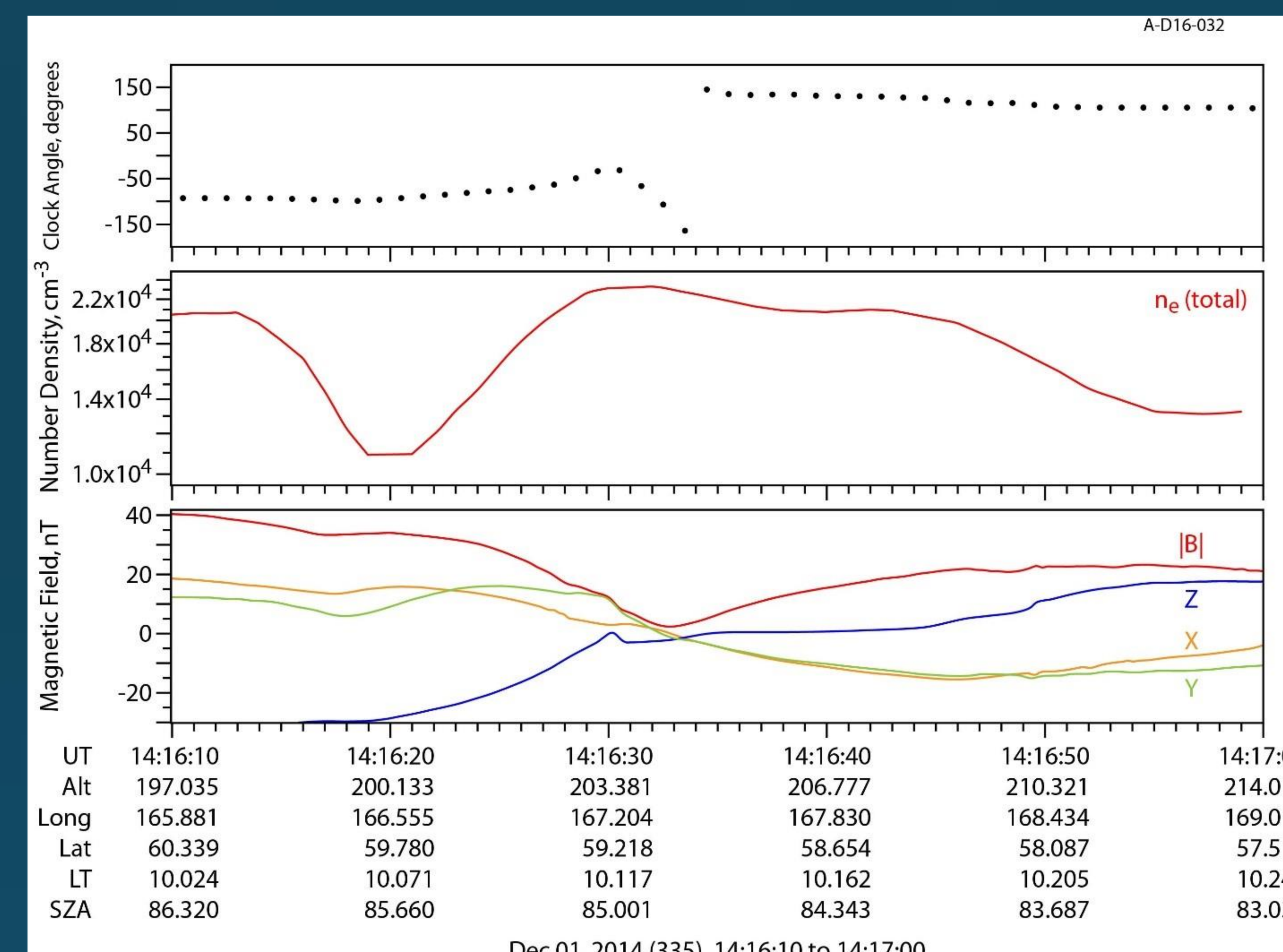
- The orbits cross on the day side of Mars to allow for MEX-MARSIS observations.
- MAVEN is in the ionosphere, at an altitude less than 400 km.
- MARSIS is in Ionospheric Sounding mode, with MAVEN-NGIMS measuring ions.



On October 2, 2015, the spacecraft observed nearly the same area of the ionosphere 13 minutes apart. The left panel shows remote sounding from MARSIS, which reveal the second layer by a sharp change in the slope of the echo at 1.7 MHz. The right panel displays the density profile from in situ observations by NGIMS. This profile contains a peak in the density when MAVEN is at an altitude of about 190 km. This local density peak is well above the main ionospheric peak, which NGIMS approached at its periapsis altitude of 145 km at 0:18:20 UTC, outside the time range of the figure.

KEY POINTS

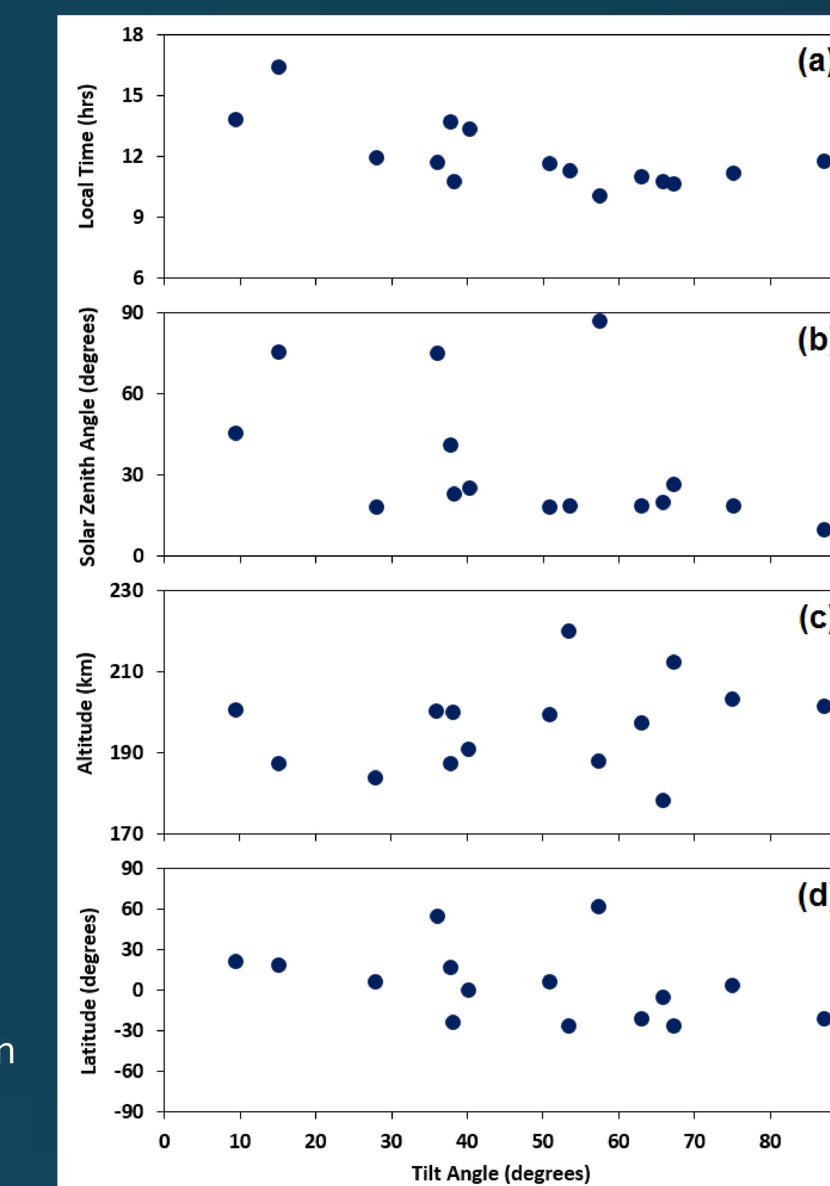
1. **MAVEN observed a transient peak in the density profile near 200 km altitude**
2. **This correlates with the upper layer discovered remotely in previous work**
3. **A current sheet associated with the second layer has been discovered**



A CORRESPONDING CURRENT SHEET

Results from the magnetometer (MAG) aboard MAVEN revealed that the enhancement in the density was accompanied 88% of the time by a local minimum in the overall magnetic field strength at the same altitude, with a rotation in one or more of the field components. The middle panel above gives the overall electron density, calculated by a sum of the individual ion species and assuming charge neutrality. The bottom panel displays the magnetic field strength and components obtained from the MAG measurements. A 30 nT decrease in the magnetic field magnitude coincides with the peak of the density enhancement in the middle panel. A rotation in the magnetic field, due to the x and y components changing from a positive orientation to a negative one, or vice versa, indicates the presence of a current in this region.

CORRELATIONS WITH THE CURRENT SHEET



18 of the 48 detections were selected to undergo Minimum Variance Analysis (MVA), in order to identify the normal direction of the current sheet.

The orientation of the current sheet is highly variable. A stable layer might be expected to produce a current that is horizontally stratified with respect to the planet, but the current sheet associated with this layer varies widely, from less than 10 degrees to nearly 90 degrees off horizontal, thus nearly perpendicular to the surface in some cases. Also, there is no relation between this orientation and the layer's altitude, solar zenith angle, or latitude. We see considerable variability in the current sheet's orientation, with no correlation to the conditions above.

There is a correlation between the orientation and the local time where the observation was made. A decreasing trend exists between the tilt of the current sheet as the spacecraft moves from dawn to dusk, suggesting the current becomes more horizontally stratified, and thus perhaps more stable, over the course of increasing daylight hours on Mars (0600-1800 UTC). This trend is shown in panel (a) of Figure the figure above. Other correlations are also plotted in the other panels, but the data were not well organized. This suggests a possible solar connection to the stability of the current, and perhaps to its origin as well.

One related important aspect is the influence of the crustal magnetic fields. While *Kopf et al.* [2008] found no correlation between the crustal fields and the detection of the second layer, a result supported by a larger study [*Kim et al.*, 2012], the limited time range and indirect nature of that early study left room for a possible connection on a broader scale.

Analysis here is consistent with previous findings. Although a handful of the MAVEN cases are along or near strong crustal fields of 100 nT or larger, the vast majority are in regions where the field strength is significantly smaller, and in some cases virtually nonexistent. On average, the layer appears in a region where the crustal field strength is less than 50 nT, about one third of the average peak strength during each orbit.

SOME POSSIBLE EXPLANATIONS

- **Kelvin-Helmholtz Instability** – This process occurs where a velocity shear exists between two fluids or plasmas. However, cases analyzed so far show no conclusive evidence of any velocity gradient, and it is unclear why such a shear would exist at this altitude. MAVEN could observe this current at several orientations at the same vortex, depending on its position. The observations could be a result of how close MAVEN flew to any particular peak.

- **Flux Ropes** – A few features do not fit the observations of this layer. A rotation is seen, as expected, but an axial field should also be present, causing an increase in magnetic field. MAG instead observes a decrease. Also, MVA should have yielded a minimum field eigenvector with a magnitude close to zero if MAVEN neared the center of a flux rope, which was consistently not the case. Finally, the size here is far smaller than other flux ropes observed at Mars. Flux ropes are thus unlikely to be the solution here.

- **Magnetic Reconnection** – The magnetism of this layer implies an interaction in the upper ionosphere. However, the current sheet alone does not directly imply reconnection. Plasma should be ejected at the Alfvén velocity following reconnection, but no discernable flow has been detected to date. Still, MAVEN is only able to observe flow within a limited angular field, so it could elude the instrument's detection. It is possible that these are magnetized plasma parcels downstream from a more sub-solar reconnection point.

- **Magnetic Field Convection** – The solar wind magnetic fields drape around Mars. Regions with different field orientation will form a current layer between them. This layer will be transient, and most prevalent near the subsolar point. Mars Express, in a polar orbit, would frequently cross these draped field lines. However, this model suggests a horizontal current which is not consistent with our analysis. The solar wind field also may not rotate regularly enough, and on short enough time scales, to account for the MARSIS observations.

REFERENCES and ACKNOWLEDGEMENTS

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MARSIS data are available through the Geosciences Node of NASA's Planetary Data System (PDS) at http://pds-geosciences.wustl.edu. MAVEN data are available via the Planetary Plasma Interactions node of the PDS at http://ppi.pds.nasa.gov. We also wish to thank Majd Mayyasi and Mehdi Benna of the MAVEN team for fruitful discussions related to this research.