Eclipse-Induced Changes to Topside Ion Composition and Interhemispheric Ion Flows in the August 2017 Solar Eclipse: Swarm-E (e-POP) Observations

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Abstract

We present in-situ ion composition and velocity measurements from the Enhanced Polar Outflow Probe during the August 2017 solar eclipse, which crossed the path of totality at ˜640 km altitude within 10 minutes of totality passing. These measurements reveal two distinct H+ ion populations, and show a ˜40% decrease in topside plasma density, a similar drop in upward but not downward H+ ion flux, and a downward O+ ion velocity of ˜100 m/s. These features are directly linked to changes in the H+/O+ composition and field-aligned or interhemispheric light ion flow, and reduction in the negative spacecraft potential. These observed features were absent on the preceding, non-eclipse days, and corroborate the reduction in F-region plasma density and topside Total Electron Content (TEC) observed by the Global Position System (GPS) receivers onboard. They are attributed to the temporary reduction of photoionization in the eclipsed F-region.

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Summary

- Swarm-E (e-POP) ion composition and velocity measurements during August 21, 2017 solar eclipse, at ~640 km altitude in eclipse region
- Eclipse-induced decrease in ion density and changes to H^+/O^+ ratio and field-aligned H^+ flows observed within 10 minutes after totality
- Eclipse-induced decrease in only upward (but not downward) H^+ flux, accompanied by downward O^+ flow
- Observed ion density decrease (~40%) a factor of ~2 larger than SAMI-3 prediction; corroborates radio-occultation measurements of F-region plasma density (15-35% depletion) and topside Total Electron Content decrease (44-56%, 0.8-0.9 TECU decrease)

August 21, 2017 Total Eclipse - Swarm-E Ion Composition Observation

The solar eclipse traversed the continental United States, from 15:46 UT over the Pacific Ocean to 21:04 UT over the Atlantic. During the total eclipse (16:49-20:02 UT), Swarm-E (e-POP) crossed the totality path over Idaho at 17:36:56 UT at 44.3°N, 116.1°W, and 640 km altitude, 9.33 minutes after totality passing (***Figure 1***), and made in-situ ion composition and other measurements over a range of ~6000 km.

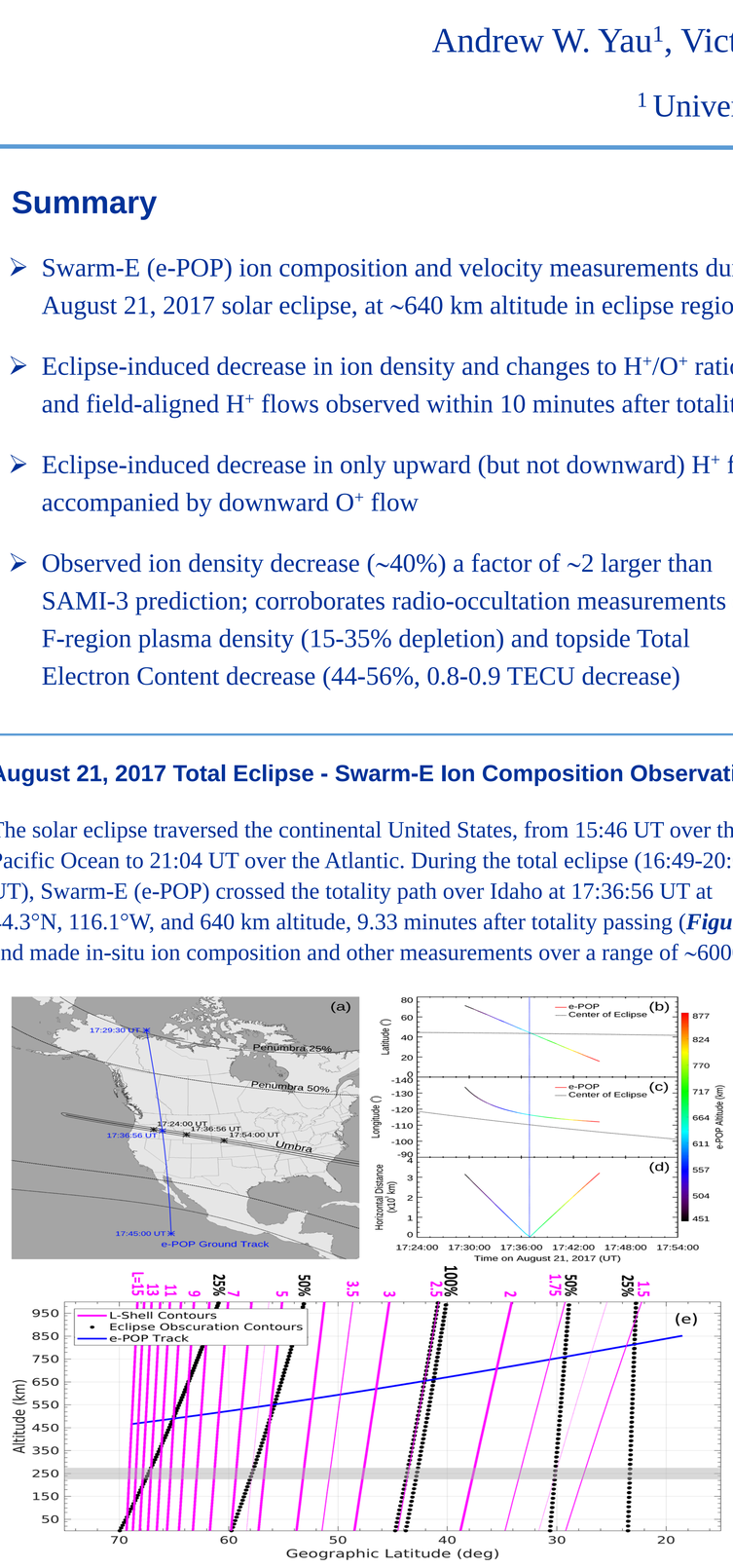

Figure 1. Swarm-E (a) ground track, (b) altitude, (c) latitude, (d) longitude, (e) distance from totality path, (e) orbit across the eclipse and L-shells; totality crossing at 17:36:56 UT, at 44.3°N, 116.1°W

The observed O^+ (***Figure 2***, *right*) in the ram direction indicates:

(*i*) cold, ambient ions and a negative spacecraft potential ($V_{s/c}$<0);

(*ii*) eclipse-induced decrease in ion density and accompanied decrease in $V_{s/c}$.

The observed H^+ (***Figure 2***, *left*) in the upward and downward directions indicates:

(*i*) two distinct ion populations or components: one upward from below the spacecraft, one downward from higher altitudes or the opposite hemisphere;

(*ii*) eclipse-induced decrease in (only) upward (but not downward) flux.

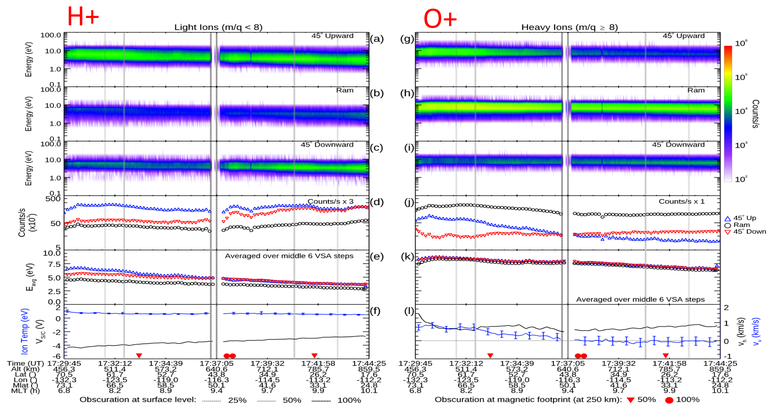

Figure 2. Observed H^+ and O^+ distributions show decreased count-rates and two distinct H^+ components in eclipsed region: (*a-c*, *g-i*) count-rate vs. energy, time; (*d-e*, *j-k*) upward, ram, downward count rate and energy (inside spacecraft sheath); (*f*, *l*) ion temperature, spacecraft potential, upward and southward O^+ velocity

Figure 3 captures the changes in ion density, composition and angular distributions:

(*i*) a decrease in O^+ density of up to ~40%,

(*ii*) a decrease in H^+ upward flux and in upward/downward flux ratio, due to a decrease in H^+ production via H/O^+ charge-exchange in the eclipsed region.

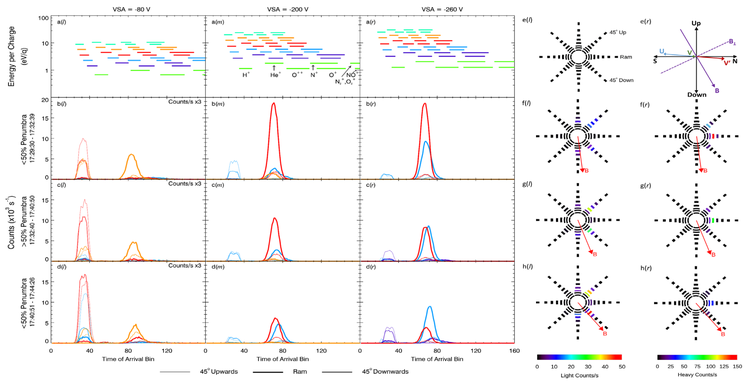

Figure 3. (*a-d*) Ion time-of-arrival (TOA) spectra show density reduction and changes in H^+/O^+ and up/down H^+ ratios in eclipsed region: (*a*) ion energy-per-charge (*E*/*q*) and TOA ranges for each (*M*/*q*) species; (*b-d*) upward, ram, downward ion count-rates in each detector-pixel (*b*) prior to, (*c*) during, and (*d*) after eclipse (transit through 50% obscuration lines); (*e-h*) detector pixel maps of H^+ and O^+ count rates

Figure 4 compares the eclipse data with those on non-eclipse days (August 18-20):

(*i*) O^+ had a lower count-rate and a downward shift in velocity (~100 m/s);

(*ii*) H^+ exhibited a 3× decrease in upward count-rate at the lowest latitudes - and a resulting ~50% decrease in up/down H^+ ratio and 2× increase in H^+/O^+ ratio.

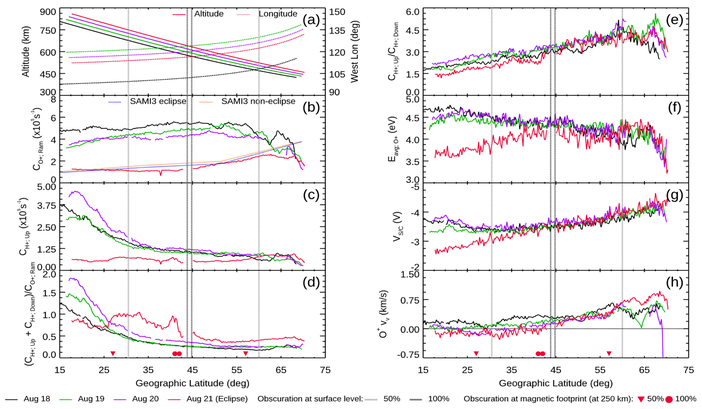

Figure 4. Observed ion composition and velocity during eclipse (Aug 21) and non-eclipse (Aug 18-20) orbits: (*a*) e-POP altitude, longitude; (*b-e*) count-rate: (*b*) ram O^+, (*c*) upward H^+, (*d*) (upward + downward) H^+ to ram O^+ ratio, (*e*) upward/downward H^+ ratio; (*f-h*) O^+ ion energy, spacecraft potential, upward O^+ velocity

The observed density decrease (~40%) corroborates the TEC measurements with the Swarm-E GPS receivers (GAP-O) and retrieved densities (***Figure 5***; *cf*. SA14A-07):

(*i*) 0.8-0.9 TECU (44-56%) depletion above spacecraft, within minutes of totality

(*ii*) 15-35% lower F-region density, 10-35 km lower height (w/n 15 min of totality)

(*iii*) TEC perturbations of 0.2-0.3 TECU in topside F-region within lunar penumbra, indicating the presence of medium-scale (100-200 km) plasma irregularities.

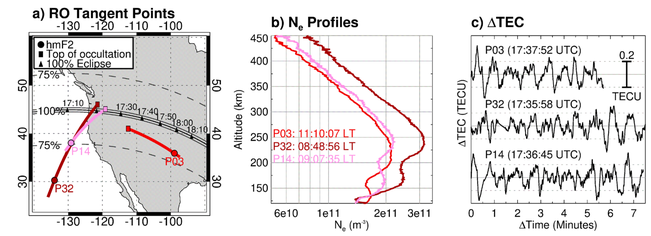

Figure 5. (a) GAP-O radio occultation tangent points at top of each occultation (□) and hmF2 (○); (b) vertical density profiles, local times at hmF2; (c) detrended TEC (above 270 km), starting UTC

Conclusion: The in-situ ion composition measurements clearly showed several direct effects of the eclipse on the mass composition and plasma density of the topside ionosphere and the resulting field-aligned light ion flow: (1) ~40% decrease in topside plasma density, (2) similar drop in upward H^+ ion flux that was absent in the downward H^+ flux, (3) downward shift in O^+ ion velocity of ~100 m/s, (4) a resulting 100% increase in observed H^+/O^+ ratio and (5) change in field-aligned (up/down) light ion flow ratio, and (6) reduction in spacecraft potential.

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