# Minor Pick-up Ions from the Martian Corona

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## Abstract:

The SupraThermal and Thermal Ion Composition (STATIC) instrument onboard the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft measures angular, energy, and mass distributions of suprathermal ions over a range of altitudes near Mars. We study pick-up ions that are created and escape when neutrals in Mars' exosphere get ionized and accelerated by the solar wind's motional electric field. We analyze mass-energy spectra to identify minor species of pick-up ions, i.e. ions other than O+ and H+. For this project, we analyze time intervals when the spacecraft was in the solar wind and exclude ions that are co-moving with the solar wind. We report a successful detection of several minor pick-up ion species, determined through statistical analysis for signal significance, as well as their spatial locations and abundances. The prevalence of these minor pick-up ions constrains the ongoing escape of Mars' upper atmosphere and its evolution over time.

## Introduction:

- Mars' atmosphere is composed of 95% $CO_2$, 2.8% N, 2% Ar, and lesser He.
- The upper atmosphere is actively escaping, creating a neutral exosphere composed of H, O, as well as C and other minor species.
- H and O coronae dominate over C in the exosphere (Figure 2).
- Neutrals from the upper atmosphere get ionized and accelerated by the **electric field** of the solar wind at ~450 km/s,
- The pick-up ions drift with the solar wind in a cycloidal motion.
- Minor ion species are characterized by low chemical abundance.
- The minor species are more likely seen at high energies ranging from 10 keV to 30 keV.

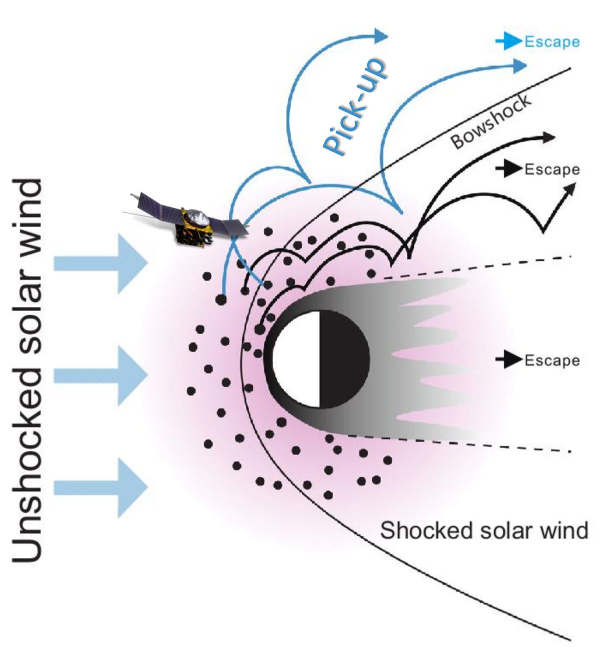


Figure 1: Illustration of pick-up ion trajectories at an unmagnetized planet (Y. Wei et al. 2017)

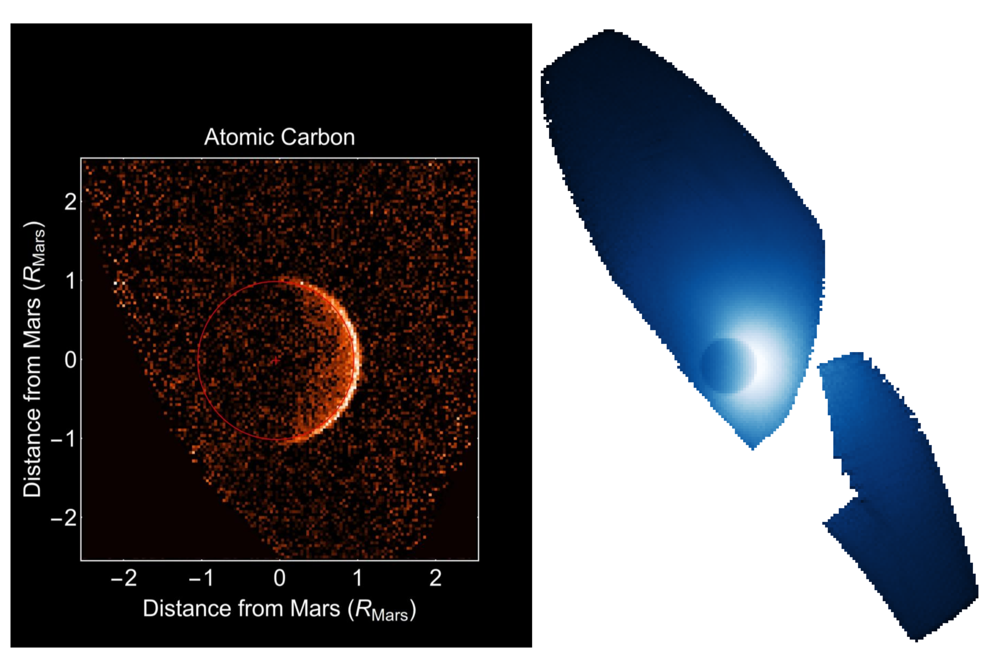


Figure 2: Neutral C and H corona imaged in UV by MAVEN(NASA/GSFC 2015)

- $O^+$ and other heavy-ion measurements and behavior studies with STATIC have been made by McFadden et al. (2015).
- We surveyed pick-up ion observations during high solar activity to search for minor ion species that are seen escaping the exosphere, excluding the common $H^+$ and $O^+$ (Rahmati et al. 2017).
- For this project it was essential to distinguish real pick-up ions from solar wind particles ($H^+$, $He^{++}$), instrument noise and ionospheric molecular ions.

## Method:

The STATIC instrument measures thermal ion flux and their **mass-energy distributions** (McFadden 2015). Pick-up ions enter the instrument, where it measures the ion's time-of-flight (TOF) to characterize species by atomic mass per charge.

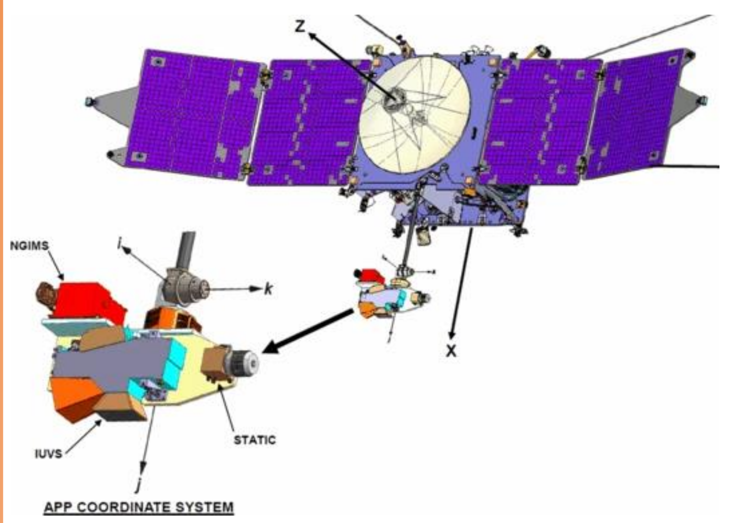


Figure 3: MAVEN and STATIC location (McFadden 2015)

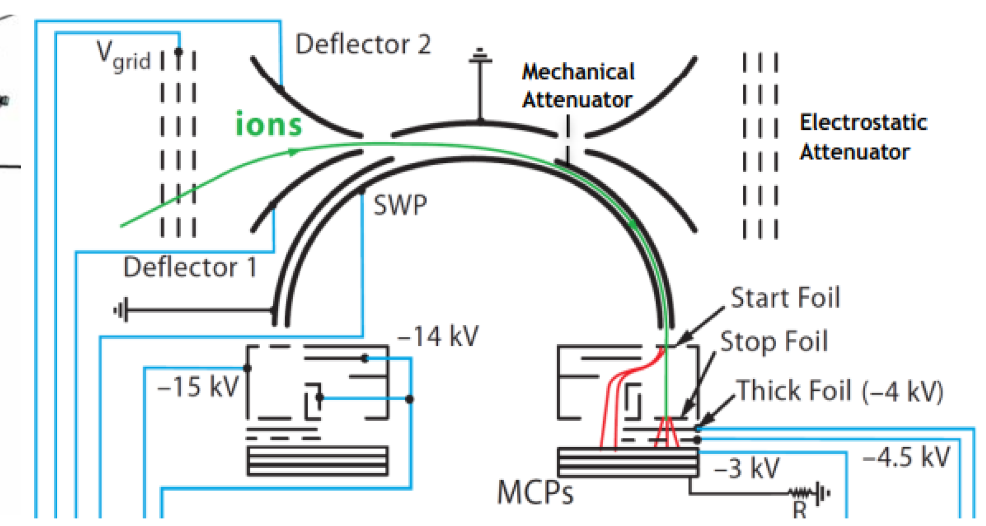


Figure 4: STATIC cross-section (McFadden 2015)

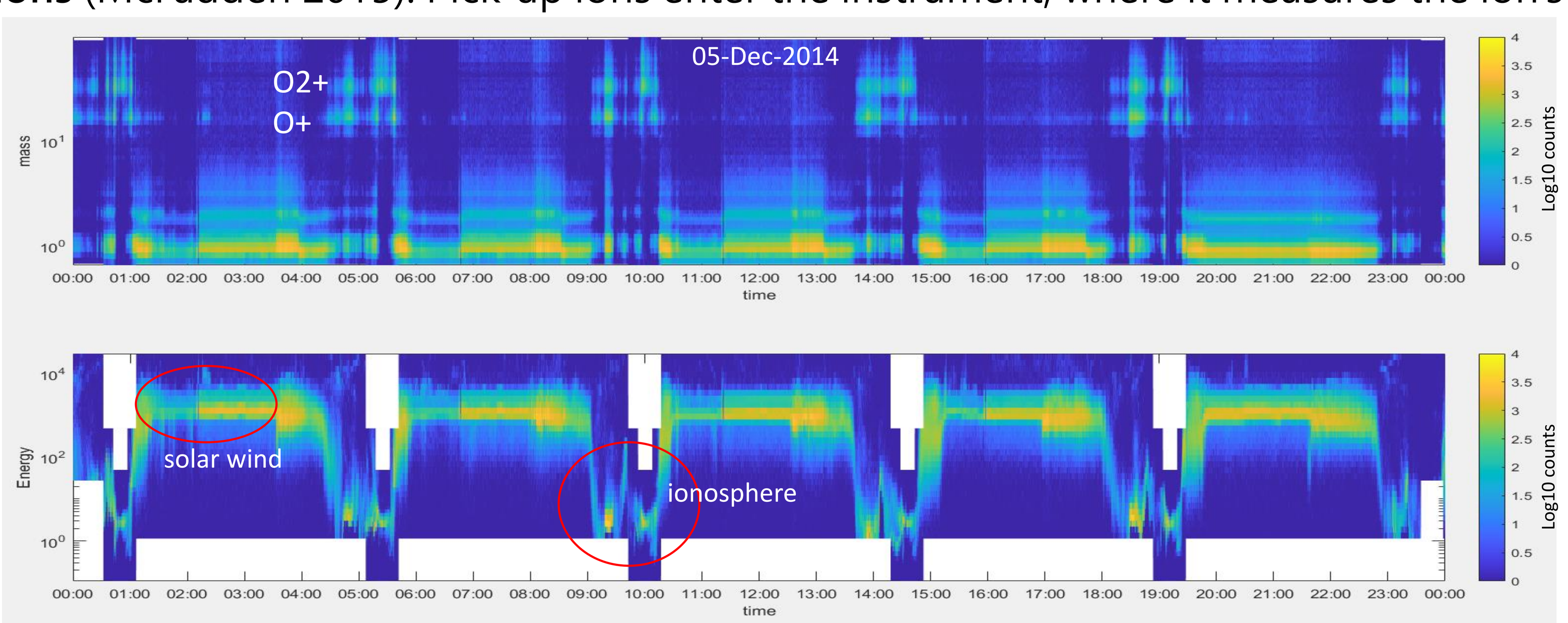


Figure 5: Time vs mass (Panel 1) and Time vs energy (Panel 2) 05-Dec-2014

To avoid noise caused by the instrument or alpha particles, we looked at energies > 10 keV and researched instrument calibrations. We determined that the best time to analyze was at solar maximum 2014, and at time intervals when the spacecraft was in the solar wind. Using the C6 (64 mass x 32 energy) dataset from STATIC provides high-mass resolution for in-depth analysis. Figure 5 shows the time plot vs mass and energy distributions of December 5th, 2014, chosen after analyzing ~35 orbits and identifying various mass per charge peaks. We made mass-energy spectrograms and extracted mass spectra for energy bins of 15 keV, 20 keV, and 30 keV.

## Results:

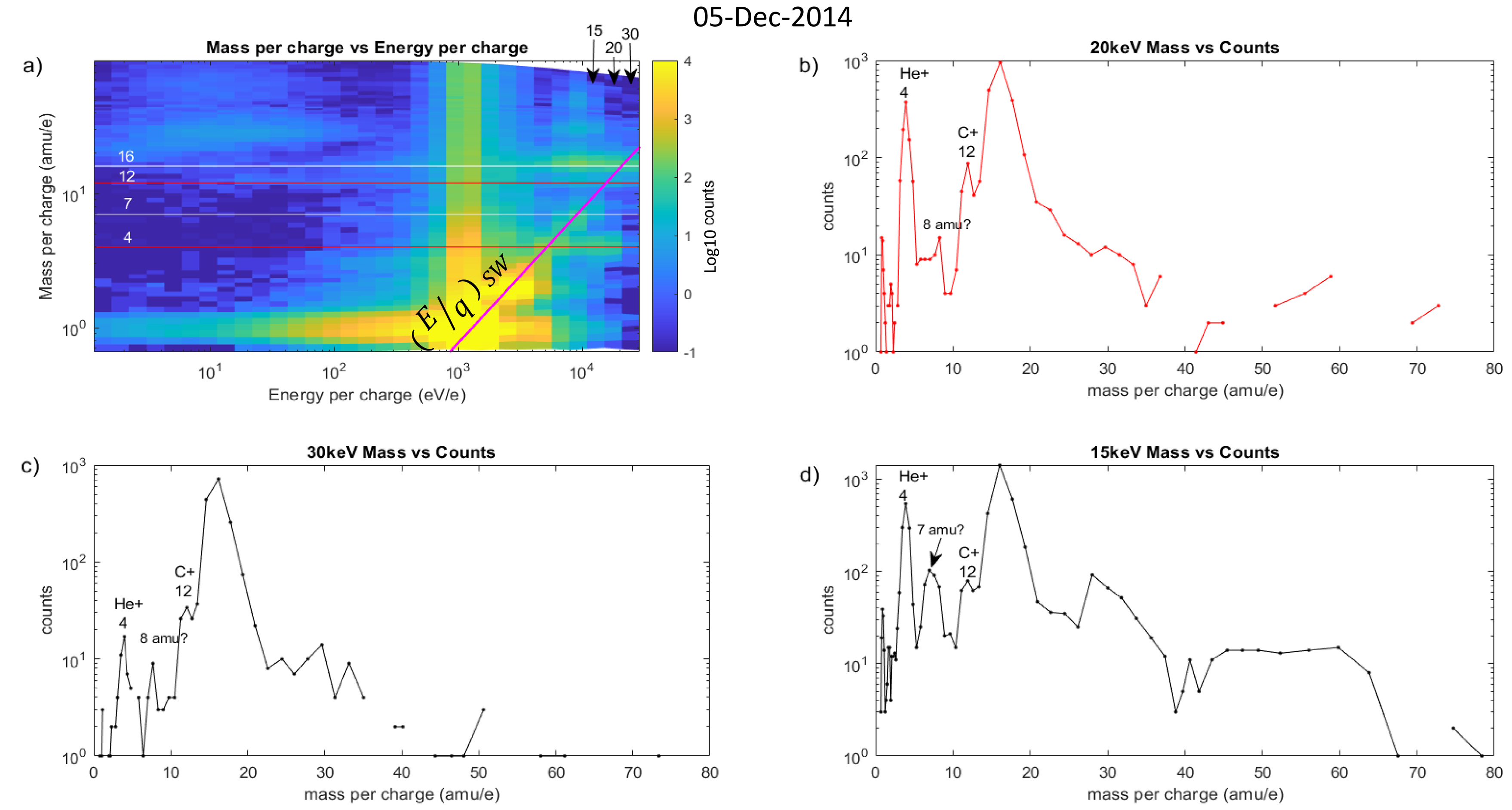


Figure 7: Mass-Energy Spectrogram (a) and Mass vs Count plots (b,c,d) 05-Dec-2014

$$\left(E/q\right)_{sw} = \left[\frac{(m_p \cdot v_{sw}^2)}{2q}\right]$$

**Equation 1:** Solar Wind line
$m_p$ = *proton mass (1 amu)*
$v_{sw}$ = *solar wind velocity*
*q= charge (1)*

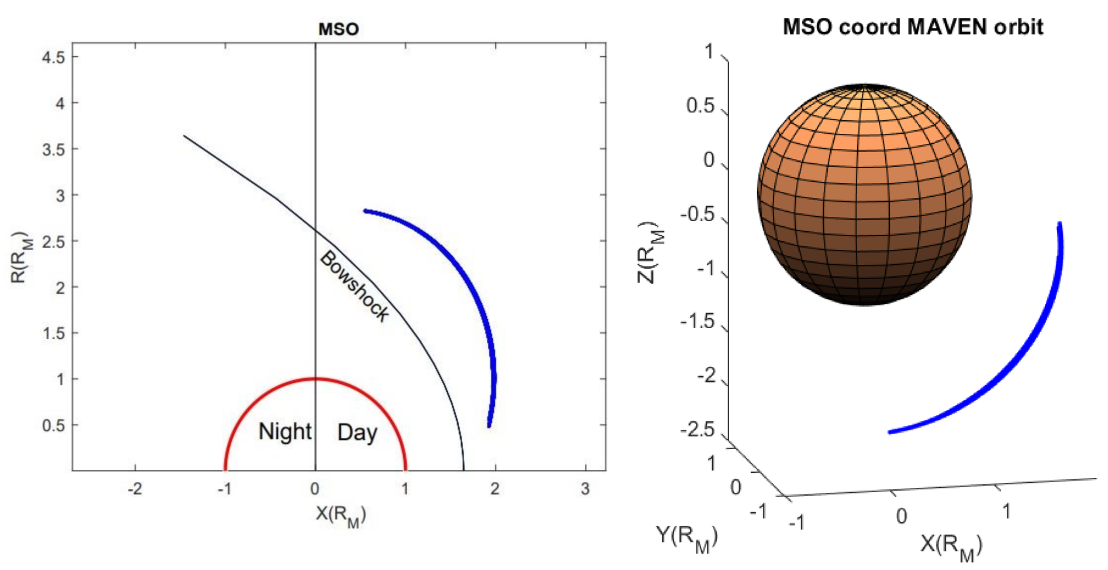


Figure 8: 2D and 3D MAVEN Trajectory

- To distinguish pick-up ions from solar wind ions, we modeled a "solar wind line" using Equation 1 in Figure 7; ion species that fall on this diagonal are co-moving with the solar wind.
- There are two significant mass peaks at 4 amu and 12 amu: $He^+$ and $C^+$.
- High $He^+$ counts were mostly at 15keV and 20keV, while $C^+$ energies ranged throughout the five highest energy bins.
- Figure 8 shows MAVEN's upstream orbit path where pick-up ions were seen.
- Uncommon peaks at masses 8 and 28 amu/e behave as pick-up ions.
- Peaks at mass per charge ~7 amu/e are solar wind ions

## Conclusion:

- We successfully identified two minor pick-up ion species: $C^+$ and $He^+$.
- Interestingly, $He^+$ appeared more abundant than $C^+$.
- The minor ion species were detected upstream (Figure 8).
- There are two peaks in Figure 9 at mass 8 amu/e and 28 amu/e that behave as pick-up ions in the mass-energy spectrograms, which could be unknown ion species or sporadic counts of other well-known species, such as $O_2^+$ for the 28 peak.

## Future Work:

- More research needs to be done to understand the nature of the 8 amu/e and 28 amu/e ions, as well as the origin of $He^+$ (corona or interstellar pick-up).

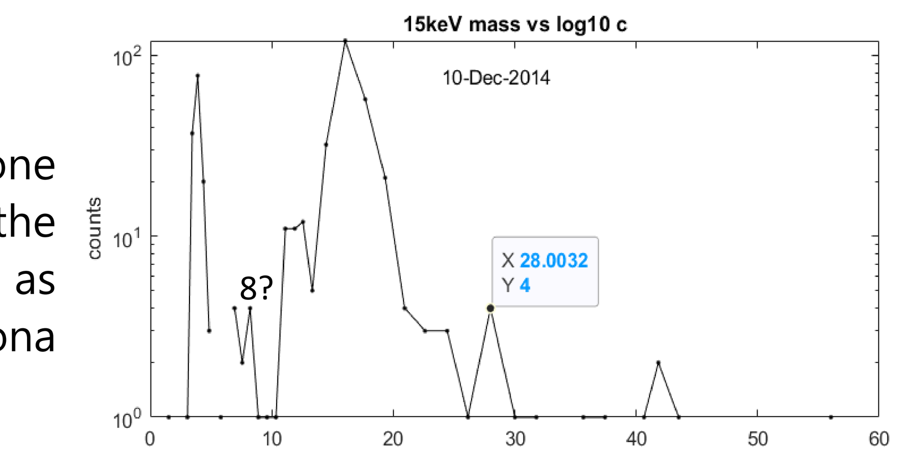


Figure 9: Mass vs Counts (10-Dec-2014)

## References:

1 McFadden, J.P., Kortmann, O., Curtis, D. *et al.* MAVEN SupraThermal and Thermal Ion Composition (STATIC) Instrument. *Space Sci Rev* 195, 199–256 (2015).
2 Rahmati, A., et al. (2017), MAVEN measured oxygen and hydrogen pickup ions: Probing the Martian exosphere and neutral escape, J. Geophys. Res. Space Physics, 122, 3689–3706, doi:10.1002/2016JA023371.
3 Wei, Y. *et al.* Ablation of venusian oxygen ions by unshocked solar wind – *researchgate* Available: https://www.researchgate.net/publication/322401287_Ablation_of_Venusian_oxygen_ions_by_unshocked_solar_wind.

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