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Signature of Metallic ion in the upper atmosphere of Mars following the passage of comet C/2013 A1 (Siding Spring)

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Abstract

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission made the first in situ detection of metal ions in the upper atmosphere of Mars. These ions result from the ablation of dust particles from comet Siding Spring. This detection was carried out by the Neutral Gas and Ion Mass Spectrometer (NGIMS) on board the MAVEN spacecraft. Metal ions of Na, Mg, Al, K, Ti, Cr, Mn, Fe, Co, Ni, Cu, and Zn, and possibly of Si, and Ca, were identified in the ion spectra collected at altitudes of ~185 km. The measurements revealed that Na^+ was the most abundant species, and that the remaining metals were depleted with respect to the CI (type 1 carbonaceous Chondrites) abundance of Na^+.

1. Introduction

The close passage of comet Siding Spring (C/2013 A1, CSS) provided a unique opportunity to observe the close interaction between the dusty coma of a comet and a dense planetary atmosphere. During this event, the MAVEN spacecraft was ideally located and equipped to measure the response of the upper atmosphere of Mars to a strong and rapid cometary mass and energy disposition, and to assess the mechanisms by which the atmospheric system returns to equilibrium. It also offered the rare opportunity for direct characterization of cometary material being freshly delivered into the upper atmosphere and ionosphere of Mars.

2. Observations

Data of neutrals and ions were collected by NGIMS from 18 October to 22 October 2014 as part of the MAVEN Siding Spring observation campaign that took place immediately before and after the comet's encounter with the planet. During this campaign, NGIMS carried out 19 sets of special observations. This special observation sequence devoted the majority of the instrument's observing time to a select set of atmospheric neutrals and ions but included 10 ion "survey" scans that were conducted at various altitudes. Each survey scan covered the full 2–90 Da mass range at a unit mass resolution. The NGIMS activities were conducted at regularly spaced intervals (orbits #108-128), interrupted only by a 10 h period at the peak of the cometary dust flux, when the instrument was temporarily turned off to minimize risk to the hardware.

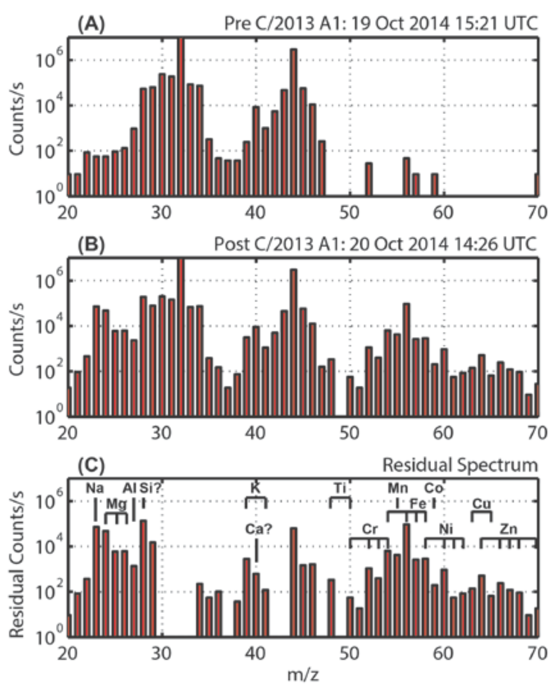

Figure 1: Comparison between two spectra collected (a) 5 h prior to and (b) 19 h following the time of maximum dust flux of CSS. (c) The residual spectrum reveals the emergence of 14 spectral lines characteristic of metal ions.

Figure 1 depicts the spectral signatures of ions before and after the passage of CSS in two ion survey spectra collected at the same altitude (185–189 km). The difference between these two spectra reveals the emergence of several mass peaks that are characteristic of metal ions in the few hours that followed the CSS encounter. These ions were identified as Na^+, Mg^+, Al^+, K^+, Ti^+, Cr^+, Mn^+, Fe^+, Co^+, Ni^+, Cu^+, and Zn^+, and possibly Si^+, and Ca^+. The identity of most of these species was established unambiguously by comparing measured isotope ratios to their relevant natural relative abundances.

3. Inferred abundances

Figure 2 shows that the relative NGIMS ion abundances are depleted with respect to Na^+ in primitive CI carbonaceous chondrites [1]. As an example, Fe^+ and Mg^+ are depleted by factors of 44 and 24, respectively. There are three reasons to why Fe^+ and Mg^+ could be depleted relative to Na^+ at 185 km.

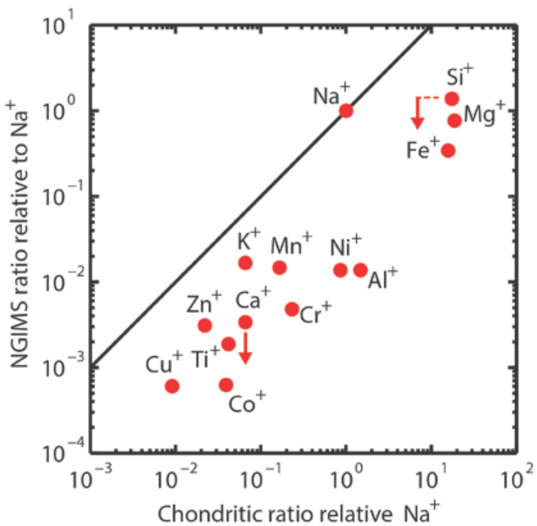

Figure 2: Comparison between relative NGIMS ion abundances and those of primitive CI carbonaceous chondrites. All abundances are normalized to that of Na^+. The relative abundances of Si^+ and Ca^+ reflect upper limit values.

First, a significant fraction of the ablating elements would have been ionized by hyperthermal collisions with CO_2 molecules on entry. At the speed of incoming meteoroids, Na is more than twice likely to be ionized than Fe or Mg. Second, during transport from the ablation region below 120 km up to the height of the NGIMS measurements, neutral metal atoms will be ionized by charge transfer with ambient O_2^+ ions. The rate coefficient for charge transfer with Na is about 2.5 times faster than for Fe or Mg [2, 3] leading to an excess in relative abundance of Na^+. Third, neutralization of the metal ions involves clustering with CO_2, followed by dissociative recombination with electrons [3]. The rates of these clustering reactions increase by a factor of ~3 from Na to Fe.

4. Summary and Conclusions

The identification of metal ions in the ionosphere of Mars following the passage of CSS is a first-of-its-kind measurement conducted on another planet of the solar system. The characterization of the metal content in the CSS dust particles that ablated in the Martian atmosphere will require untangling the effects of the various mechanisms that interplayed to produce the signatures of metals observed by NGIMS. More importantly, these measurements paved the way to a systematic long term survey of metals in the ionosphere of Mars which led to the detection of a continuous presence of an ablation metal ion layer at lower altitudes [4].

Acknowledgements

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