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Four years of upper atmospheric exploration at Mars with MAVEN and IUVS

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Abstract

1. MAVEN's Imaging UltraViolet Spectrograph (IUVS)

The Mars Atmosphere and Volatile EvolutioN mission (MAVEN) is a Mars orbiter equipped with instruments to study the current state of the Mars atmosphere, atmospheric loss processes, and their fundamental drivers. Most instruments make *in situ* measurements of particles and fields in the Mars environment and upper atmosphere. IUVS is the only remote sensing instrument for the study of Mars' atmosphere and its interaction with the plasma environment [8]. The instrument has two main channels for the study of the upper atmosphere at far-UV and Mid-UV wavelengths, plus an echelle channel capable of spectrally resolving hydrogen and deuterium Lyman alpha lines to measure the D/H ratio [1]. The instrument uses a scan mirror to obtain limb scans or disk maps and is mounted on an Articulated Payload Platform (APP) which maintains Mars pointing while the spacecraft bus and solar arrays maintain sun-pointing. The spacecraft travels on an elliptical orbit allowing limb scans to be obtained at periapse and full-disk imaging at apoapse, and scans of Mars corona in between [3]. Thanks to the scan mirror, APP, and routine planning, the instrument observes with >50% duty cycles in a variety of repeating modes. On a bimonthly basis, the instrument performs two-day stellar occultation campaigns [5] to probe atmospheric structure.

2. Key science results

By virtue of broad instrument capabilities and extensive observations, IUVS has observed the vast majority of phenomena discovered by prior UV instruments, and revealed a significant number of new phenomena as well. Observations of different phenomena can be individually optimized for spectral and two-dimensional resolution (through binning), as well as for sensitivity on daytime vs. night-time phenomena.

2.1 Dayglows and Nightglows

MAVEN/IUVS dayglow observations build on a rich history of prior UV studies by the Mariner missions and the SPICAM instrument on Mars Express. The dominant MUV emissions derive from solar excitation, ionization and dissociation of CO_2, and subsequent ionization and dissociation products. The brightest FUV emissions are atomic emissions from the constituent atoms of CO_2 and H_2O, plus additional molecular bands originating with CO_2 and its breakdown products. In addition to all spectral features observed by prior missions, IUVS has unambiguously observed and mapped the N_2 Vegard Kaplan bands [4, 11], and observed and mapped Mg^+ from meteor ablation [2]. The instrument also recorded the aftermath of the most intense meteor shower observed with scientific instrumentation, after the close passage of Comet Siding Spring past Mars in October 2014 [9]. Limb scan dayglow observations have been powerful studies of spatial, seasonal and short-term variations in the thermosphere [6]. Longitudinal non-migrating tides have been observed in the peak emission altitudes [7].

The primary form of nightglow observed by IUVS is nitric oxide chemoluminescence. Nitrogen and oxygen atoms are liberated through molecular photodissociation on Mars' dayside. The atoms are then carried by thermospheric and mesospheric circulation patterns towards the winter pole, where they recombine and emit in the gamma and delta band of NO. IUVS limb scan observations [13] confirmed the basic geographic and seasonal emissions distribution predicted by modelling and observed by MEX/SPICAM. These observations also showed that the observed latitudinal emission distribution was not as sharply peaked at the winter poles as in models, an indication the circulation models may be missing important processes. Wave-3 tides were observed in equatorial regions at some seasons. Further apoapse imaging work with broader local time coverage is likely to distinguish between migrating, nonmigrating and stationary waves, offering further insights on their origin.

2.2 H and D observations above the exobase

The MAVEN IUVS instrument contains an echelle spectrograph channel designed to measure D and H Ly α emissions from the upper atmosphere of Mars. This channel has successfully recorded both emissions, which are produced by resonant scattering of solar emission, over the course of most of a martian year. The fundamental purpose of these measurements is to understand the physical principles underlying the escape of H and D from the upper atmosphere into space, and thereby to relate present-day measurements of an enhanced HDO/H_2O ratio in the bulk atmosphere to the water escape history of Mars. Variations in these emissions independent of the solar flux reflect changes in the density and/or temperature of the species in the upper atmosphere. The MAVEN measurements show that the densities of both H and D vary by an order of magnitude over a martian year, and not always in synch with each other. This discovery has relevance to the processes by which H and D escape into space. One needs to understand the controlling factors to be able to extrapolate back in time to determine the water escape history from Mars at times when the atmosphere was thicker, when the solar flux and solar wind were stronger, etc. Further measurements will be able to identify the specific controlling factors for the large changes in H and D, which likely result in large changes in the escape fluxes of both species [16].

2.3 Stellar occultations

Stellar occultations are a well-established tool for retrieving vertical profiles of density, temperature and composition in Earth and planetary atmospheres. As stars rise or set behind a planet's atmosphere, gases (and aerosols, if present) absorb light with their individual spectroscopic signatures. CO_2 and O_3 are the two gases readily identified in the IUVS wavelength range [5]. Thousands of occultation events have been observed by SPICAM on Mars Express [14] and vertical profiles have been used to understand and constrain models of the middle atmosphere [15]. To first order the vertical profile can reveal how the mesosphere has been raised, lowered or stretched out by heating or cooling processes. Statistically significant variations in the profiles are evidence of waves, tides or other perturbations.

IUVS has acquired data on Mars for more than one Martian year. During this time, beginning with March 2015 reported in [5], hundreds of stellar occultations have been since observed, during 12 dedicated occultation campaigns, executed on average every two to three months. The occultations cover the latitudes from 80°S to 75°N and the full range longitude, and local times with relatively sparse sampling. From these measurements we retrieve CO_2, O_2, and O_3 number densities as well as temperature profiles in the altitude range from 20 to 160 km, covering eight orders of magnitude in pressure from $\sim 2 \times 10^1$ to $\sim 4 \times 10^{-7}$ Pa. These data constrain the composition and thermal structure of the atmosphere. The O_2 mixing ratios retrieved during this study show a high variability from 1.5×10^{-3} to 6×10^{-3}; however, the mean value seems to be constant with solar longitude. We detect ozone between 20 and 60 km. In many profiles there is a well-defined peak be- tween 30 and 40 km with a maximum density of $1 - 2 \times 10^9$ cm^{-3}. Examination of the vertical temperature profiles reveals substantial disagreement with models, with observed temperatures both warmer and colder than predicted. Examination of the altitude profiles of density perturbations and their variation with longitude shows structured atmospheric perturbations at altitudes above 100 km that are likely non-migrating tides. These perturbations are dominated by zonal wavenumber 2 and 3 with amplitudes greater than 45 %.

2.4 Ozone mapping

While ozone is mostly found closer to the surface of Mars, it also supplies information about the large-scale circulation phenomena that extends deep in the mesosphere. At every apoapsis, IUVS activates its built-in scan to assemble a global mosaic of Mars in the MUV range where ozone can be retrieved for each individual FOV. This permits an acute characterization of ozone longitudinal and latitudinal behavior, providing unique insights into the short-term dynamical chemical processes at work in the ozone annual cycle.

3. Data Access

All data, including higher-level products are archived for public use at NASA's Planetary Data System (PDS). All team publications indicate the data types used and reference the time period(s) utilized in the analysis. An instrument description and data format document ("Software Interface Specification) is also provided at the PDS.

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