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Ozone on Mars and Venus

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Abstract

Cross-hemispheric circulation of the atmosphere is a major feature of the Martian troposphere and Venusian thermosphere. On Mars, it is driven by the latitudinal gradient of insolation at the surface, which generates a global summer-to-winter Hadley cell reversing orientation during equinoxes and maximizing intensity at solstices. On Venus, it is driven by a longitudinal gradient between the dayside and the nightside and takes place above the super-rotating mesosphere and troposphere. This subsolar-to-antisolar (SSAS) circulation is known to induce major observational features, such as the vast O_2 and NO emission zones observed close to midnight. Recently, SPICAV onboard Venus Express has detected for the first time the presence of ozone on Venus, accounting for a thin thermospheric layer at about 100 km. Concomitantly, a similar feature was recently identified on Mars with SPICAM, with the presence of a >10 km thick ozone layer in the southern winter hemisphere near the pole.

1. Introduction

Ozone is a molecule of fundamental photochemical and exobiological interest. Its absorption continuum in the spectral region between 200 and 300 nm, also known as the Hartley band, is a remarkable spectroscopic ultraviolet (UV) feature in the family of basic chemical compounds. For this reason, the presence of ozone in a given atmosphere provides efficient filtering of the energetic ultraviolet radiation that reaches the top of the atmosphere. On Earth, stratospheric ozone plays a critical role for Earth habitability, reducing ultraviolet to doses acceptable for life development and maintenance. Its formation is controlled by the following reactions:

(1) $O_2 + h\nu \rightarrow O + O$

(2) $O_2 + O \rightarrow O_3$

where (2) is the sole reaction producing ozone. O_3 production is therefore uniquely dictated by the availability of oxygen molecules. Ozone has also Earth, molecular oxygen built up subsequently to the emergence of micro-organisms [1], the source of Martian O_2 comes essentially from the photolysis of CO_2, limiting O_2 to a minor fraction (0.1%) of the atmospheric inventory. Ozone abundance is consequently low on Mars (< 10 µm-atmosphere), typically 300 times less than on the Earth. In spite of its scarcity, Martian ozone is a key tracer of the photochemistry that regulates the composition of Mars atmosphere. By reacting with HOx radicals, it appears closely tied to the photochemistry of water and exhibits a strong temporal and spatial anti-correlation with gaseous H_2O, as evidenced by SPICAM onboard Mars Express [2] consistently with model predictions [3].

2. Methods and Results

The observations reported here were made with the SPICAM and SPICAV instruments. Both are remote-sensing spectrometer scovering three distinct spectral regions from ultraviolet to mid-infrared. The ultraviolet part probes the 110-320 nm range with a spectral resolution of 1.5 nm. The present work is based on the results of stellar occultations which have been discussed in the case of Mars with SPICAM [4], and which have been already presented for Venus [5]. Stellar occultation allows to infer vertical profiles of aerosols and CO_2 density (the main atmospheric constituent, see Figure1).

Different from the ozone layer otherwise observed on Mars which extends from the surface and is controlled by reaction with HOx radicals, a new type of layer has been recently identified that is only observed at the winter poles of Mars. This layer is located at 50 km and is confined to the deepest polar regions, typically poleward of 60° (Figure 2). Due to the asymmetric coverage of SPICAM occultations between the two hemisphere, it was not possible to probe the north polar region as deeply as in the south. This polar ozone layer follows a distinct seasonal evolution, only existing during southern fall/winter in the south (and conversely in the north), and peaking in abundance around solstices. Such seasonal circulation whose typical pattern around solstices is dominated by a single Hadley cell extending from the summer mid-latitudes to the winter polar regions. We hypothesize that this layer is related to O atoms produced in the summer hemisphere and carried via global circulation towards the polar night where they can recombine, yielding the newly detected O_2 emission feature evidenced by OMEGA, showing an O_2 production zone at around 45 km. The transport of O atoms allows further recombination of O_2 molecules with O, resulting in a local source of ozone.

For Venus, A detailed inspection of the complete SPICAV dataset allowed to visually identify ozone UV absorption from a stellar occultation sequence during orbit #348 at an altitude of 103 km (Figure 1). The ozone signature emerges as a moderate, yet distinct reduction of the atmospheric transmission between 220 and 280 nm, with a maximum around 250 nm, consistently with the Hartley band structure. In this spectrum, absorption by ozone absorbs 4% of the stellar signal at the band center (Figure 1), produced by a slant density of $8.2\mathrm{x}10^{15}$ molecules of ozone.cm^{-2} along the line of sight. A factor of ~1/50 must be applied to convert tangentially integrated densities to vertically integrated densities. A positive ozone identification is established when the sum of squared residuals in the 220-280 nm range is decreased by a factor of two when ozone Hartley band is included in the retrieval, yielding a >5-σ confidence level. For orbit #348, ozone signature at 103 km is not firmly identified in the adjacent spectra recorded 5 km below and 5 km above the detection altitude. This implies that ozone exists as a discrete layer confined within five to ten kilometers of altitude. This vertical layering is generally verified for the 28 other orbits where ozone has been detected. The ozone layer is even more prominent in the local concentration profiles that are obtained after vertical inversion of the integrated abundance. The conversion from slant integrated abundances to local concentrations of ozone is performed via standard onion-peeling procedure. On a few orbits, several consecutive spectra exhibit a firm ozone signature: four detections spanning the 92 to 105 km range are made on orbit #204, resulting in a O_3 local concentration peak of $6\mathrm{x}10^7$ molecules.cm^{-3} at 92 km. Here, the layer is characterized by a factor of two decrease of ozone concentration 5 km below and 5 km above the peak. On average, the retrieved local concentrations range between 10^7 and 10^8 molecules.cm^{-3} at a pressure of 1 μbar, yielding 0.1 to

3. Figures

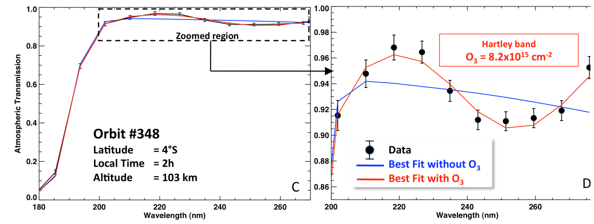

Figure 1: SPICAV spectra. Right Plot is a zoomed version of the 200 to 280 nm range of left plot to emphasize the prominent ozone signature. Data inversion without ozone is shown in blue.

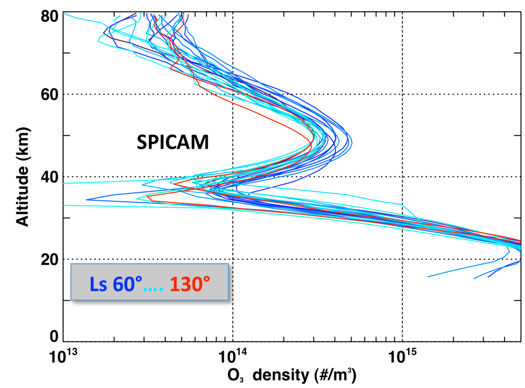

Figure 2: A subset of SPICAM ozone concentrations (molecules/m^3) profiles collected near 75°S between Ls 60° and 130°. The layer of interest appears distinctly between 40 and 60 km.

4. Conclusions

The direct relation between ozone and molecular oxygen makes ozone a unique proxy for estimating O_2 abundance in planetary atmospheres, which is otherwise impossible to detect directly. In the field of exoplanets, the O_3-CO_2-H_2O triplet detection is considered to be a robust biomarker signature that can be used to distinguish between abiotic and biotic production of oxygen[6]. The cases of Venus and Mars show that despite the positive identification of this triplet, a biological activity does not exist on these planets. The Venusian ozone layer that is reported here appears too tenuous (>0.02 Dobson Units, or 0.1-1 μm-atmosphere) to efficiently filter out UV radiation and protect organisms if they were to develop below. The specifics of the Earth held in the ability of the emerging life to modify its environment, disrupting chemical equilibrium in a sustainable manner: oxygen photosynthesized by cyanobacteria eventually led to the formation of an optically thick and thus protective layer of ozone. Such positive feedback has not occurred on Venus or Mars, or if it has, eventually vanished.

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