

Survey of the nitric oxide ultraviolet emissions by Mars Express and implications for the Martian upper atmosphere dynamics

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Abstract

We present **ten years of Martian NO nightglow** SPICAM observations in limb and stellar occultation modes.

The NO nightglow is used as a **tracer of the summer-to-winter hemispherical circulation** in the upper atmosphere of Mars.

We present **maps of the brightness of the NO emission peak**. Its variability, an important factor that can reach up to 50% of the emission and is not reproduced by average brightness model maps.

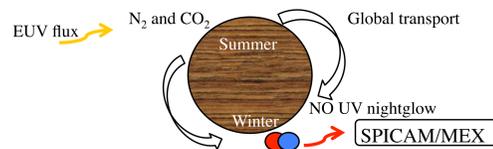
The NO nightglow distribution roughly follows the curve **latitude = -80 x sin(solar longitude)**, with deviations. We find that the **peak brightness is 5 ± 4.5 kR, situated at 72 ± 10.4 km**. It ranges from 0.23 to 18.51 kR and from 42 to 97 km.

Results presented in this study lead to future comparisons with global Martian atmospheric models and observational targets for the IUVS-MAVEN instrument. This work was recently submitted to GRL for publication.

Background

In the dayside atmosphere of Mars, the extreme ultraviolet (EUV) solar radiations photodissociate CO₂ and N₂ molecules. O(³P) and N(⁴S) atoms are then carried by the summer-to-winter hemispheric transport in the upper atmosphere of Mars.

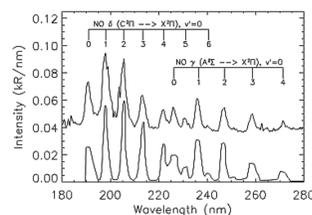
They recombine to form NO(C²Π) excited molecules that directly emit the UV δ and γ bands. These emissions are indicators of the N and O atom fluxes transported by the summer-to-winter dayside to nightside Hadley cell.



The first detection of the nitric oxide UV airglow on Mars nightside was reported by Bertaux et al. (2005) using the SPICAM (Spectroscopy for Investigation of Characteristics of the Atmosphere of Mars) spectrograph on board Mars Express (MEX). This emission has been then studied through SPICAM observations in two different observing modes: tangential limb (Cox et al., 2008) and stellar occultation (Royer et al., 2010; Gagné et al., 2013).

Bertaux et al. (2005) observed an emission peak reaching **2.2 kR located at 70 km**. The limiting factor for this emission is the nitrogen atom flux descending towards the atmospheric layer where N atoms recombine with O to produce NO*. They estimated this downward flux to be 2.5×10^8 atoms cm⁻² s⁻¹, which is about a third of the production of N atoms by EUV photodissociation of N₂ molecules on the dayside.

Cox et al. (2008) looked for possible correlations between the emission peak brightness and altitude with several factors that may affect the emission rates, such as: latitude, local time, magnetic field and solar activity. They noticed that **none of these factors seems to control** the emission that experiences large variations. The dataset used by Cox et al. (2008) included 21 airglow detections between August 2004 and May 2006. The altitude of the maximum nitric oxide nightglow shows variations, ranging from 55 to 92 km, with a mean value of **73 ± 8.2 (1-σ standard deviation) km**. The brightness of the emission peak varies by nearly two orders of magnitude, from 0.2 to 10.5 kR, with a mean value of **1.2 ± 1.5 kR**.



Top: SPICAM spectrum from Cox et al. (2008)
Bottom: Synthetic spectrum from Groth et al. (1971)

Gagné et al. (2013) used three Martian years (MY 27 to 29) of stellar occultations performed by SPICAM, containing 2275 observations between June 2004 and September 2009, to analyze **128 detections** of the nitric oxide UV nightglow. They noticed an interannual variability of the number of detection of the emission, linked to changes in the solar flux during the time period when their dataset was accumulated. They claimed that **the number of detections increases with the solar flux**, in agreement with the paradigm of production of N(⁴S) on the dayside.

Gagné et al. (2013) also analyzed the peak intensity and altitude of the NO emission. They found that the peak altitude ranges from 40 to 130 km, with a mean value of **83 ± 24 km**, and an associated brightness of **4 ± 3.5 kR**.

They explained that the mean brightness they observed is higher than the value found by Cox et al. (2008) as the result of two factors: the dataset they used is larger than the dataset of Cox et al. (2008) and it contains observations in various seasons covering three Martian years. The observations they analyzed were obtained in a large part at higher solar activity.

Gagné et al. (2013) also noticed that the **peak altitude is statistically lower in the southern hemisphere**. This hemispheric asymmetry was not reproduced by the LMD model described by González-Galindo et al. (2009) and Lopez-Valverde et al. (2011).

In agreement with the LMD results, the detections of the nitric oxide δ and γ bands are roughly located along the curve **latitude = -80 sin(solar longitude)**, with some outliers (detections outside of the region defined by the curve) and non-detections (observations without a detectable NO emission) along the curve. These discrepancies are apparently more frequent at equinox conditions.

The LMD model also predicts a brightness at the winter poles exceeding 100 kR. No such bright airglow was detected.

Finally, Gagné et al. (2013) pointed a last discrepancy between the data and the model: the large variability for the altitude of the peak is not charted by the LMD model.

Observations

We here use detections and non-detections of the NO δ and γ bands by SPICAM to investigate the dynamics of the nightside upper atmosphere of Mars. The dataset used in this study covers the **years 2003-2013, almost a full solar cycle**. Results showed in this study will provide comparative information useful for the future observations of the Martian UV nightglow by the Imaging UltraViolet Spectrograph (IUVS) on board the MAVEN spacecraft.

The Mars Express spacecraft travels along a nearly polar eccentric orbit with a period of 6.72 hour, a periaapsis of about 300 km and an apoapsis of 10,100 km.

The SPICAM instrument on board Mars Express is composed of both an UV and an infrared spectrometer. The UV spectrometer covers the range from 118 to 320 nm that includes the totality of the NO δ and γ bands, from 190 to 300 nm.

In this study, we use measurements from the UV spectrometer SPICAM in limb profile mode. A typical observation lasts 20 minutes with one spectrum recorded every second in each of the 5 spatial bins (adjacent segments of the CCD) of the instrument. A spectrum can be collected after light travels through a small (50 μm) or a wide (500 μm) slit, providing a spectral resolution of 1.5 and 6 nm respectively. The spatial vertical resolution depends on the distance between the spacecraft and the atmosphere of Mars, and may be as small as a few kilometers when the spacecraft is close to the planet. The field of view of a single SPICAM pixel is 40x40 arcsec.

This study also includes the SPICAM observations performed in stellar occultation mode. A stellar occultation observation proceeds similarly to a limb-viewing observation with the difference that in the stellar occultation mode, the spacecraft pointer is directed to a star, hence providing an absolute calibration of the emission by subtracting the known star brightness. The technique used to retrieve the NO emissions from stellar occultations was first described by Royer et al. (2010), which was developed to study the nitric oxide emissions in the upper nightside atmosphere of Venus.

These two techniques provide a wide dataset of **5000 observations** among which more than **200 present an identifiable NO emission**. In the limb viewing mode, 700 observations present solar contamination where the solar illumination is orders of magnitude higher than the nitric oxide emission and have therefore been ignored in the data analysis. 111 observations do not allow defining the peak brightness and altitude because of very low emissions (typically under 0.2 kR) and 1789 observations show no detectable NO emission.

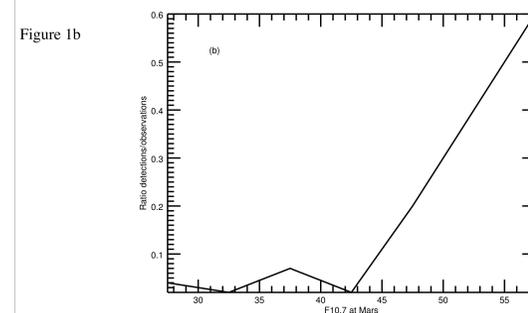
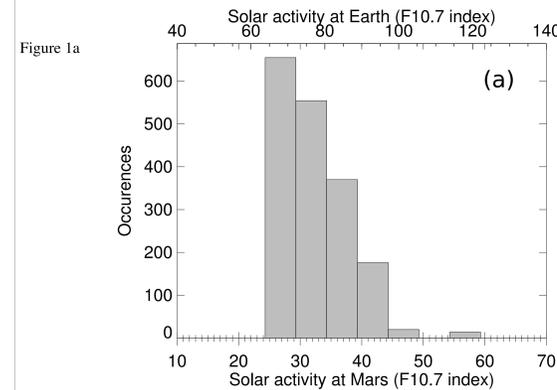
This limb observations dataset contains the smaller dataset used by Cox et al., (2008). We also use the 2215 occultations processed by Gagné et al. (2013), from which 128 observations produced a detectable NO emission.

Results

We here analyze the possible correlations between the peak characteristics (brightness and altitude) and factors such as geographical location and solar flux influence.

A large inhomogeneity appears in the detection of the nitric oxide δ and γ bands. Figure 1 shows the distribution of the observations (panel a) and ratio of the number of positive detections by the number of observations (panel b) performed by SPICAM in the limb viewing mode for different F10.7 indices encountered during the 2003-2013 period.

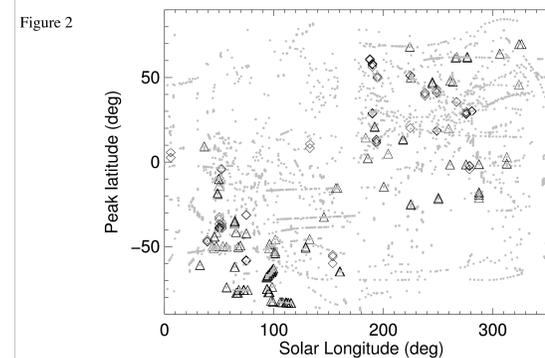
Gagné et al. (2013) claimed that the number of detections increases with the solar flux. This result was reproduced by LMD simulations. We statistically confirm this long term variability. Figure 1 panel a shows a decrease in the number of observations as the solar flux increases. We show in Figure 1b the ratio between the number of positive detections of the NO airglow and the total number of detections, for increasing solar fluxes. This is an indicator of **more numerous positive detections for higher solar activity conditions**.



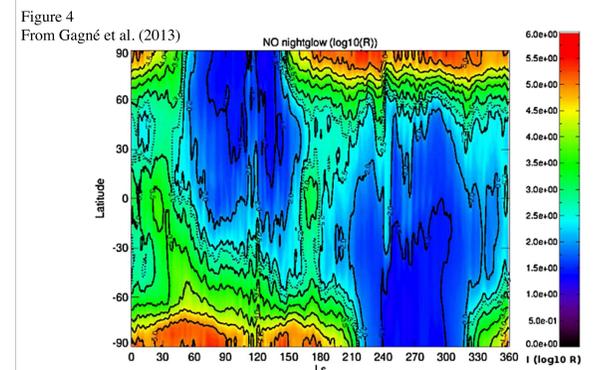
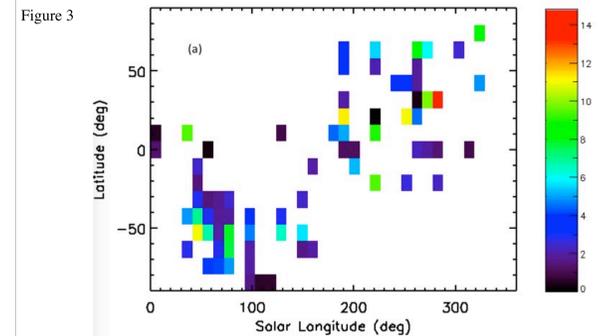
The mean peak brightness and altitude of the NO emission is 1.2 ± 1.5 kR at 73 ± 8.2 km and 4 ± 3.5 kR at 83 ± 24 km from the studies of Cox et al. (2008) and Gagné et al. (2013), respectively. We now found a statistical peak of the nitric oxide δ and γ bands of **5 ± 4.5 kR** located at **72 ± 10.4 km**, consistent with both former studies.

The peak brightness and altitudes range from **0.23 to 18.51 kR** and from **42 to 97 km**. The emission layer (from 40 to 100 km) is larger than the one predicted by the LMD model, but in good agreement with the results obtained from stellar occultations.

Both SPICAM stellar occultations and limb viewing observations of the nitric oxide nightglow are represented in a latitude/solar longitude map in Figure 2. **Dots** show the locations of the **non-detections** of the nitric oxide nightglow. **Triangles** represent the detections while SPICAM observes in **stellar occultation mode** while **diamonds** are detections made by SPICAM in **limb viewing mode**.



The analysis of the brightness at different latitudes and seasons is presented in Figure 3. In figure 3, all observations (regardless of the observation mode, stellar occultation or limb viewing) are combined to construct an extensive dataset of 200 detections. Figures 2 and 3 are useful to summarize all observations and compare with the outputs from the LMD model (Gagné et al., 2013, Figure 4). The model provides a good first order prediction of the global picture of the nitric oxide emission. It roughly reproduces the location where the NO nightglow is detected, following the curve **latitude = -80 x (solar longitude)** (Gagné et al., 2013). There are however **many non-detections within regions where the NO airglow is predicted to be bright in the model**, such as the dots in Figure 2 in the winter polar regions. Similarly interesting, **detections have been made in regions of very low model-predicted NO intensity**, for example, in the equatorial region. Figure 3 allows to analyze the variability of the emission. The **LMD model reproduces well the mean brightness of the emission**. The variability can reach 8 kR, slightly under 50% of the peak brightness of the brightest profiles. This variability cannot be reproduced in averaged LMD simulations as shown by Gagné et al. (2013), figure 4. We note however that it is an important constraint for future developments of atmospheric models.



Conclusion

The SPICAM instrument on board Mars Express spacecraft has observed the **nitric oxide emission** in two different viewing modes: tangential limb and stellar occultations. We merged the two dataset to build up an **extensive survey of the nitric oxide nightglow for almost a full solar cycle (2003-2013)**.

The nitric oxide nightglow is a **tracer of the dynamics of the upper atmosphere of Mars**, especially useful to constrain the **summer-to-winter hemispherical transport**.

We show that the **number of detections increases with the solar activity**, despite a lack of correlation between the F10.7 index and the brightness of the NO nightglow.

The detections are also higher in specific regions: they are more frequent closer to the winter pole. The detections seem to be roughly distributed along a **latitude = -80 x (solar longitude)** curve, in agreement with LMD simulations.

The characteristics of the emission peak are analyzed and no correlation with geographical or solar flux related factors is found. We find the peak of the nitric oxide δ and γ bands vertical profiles of **5 ± 4.5 kR situated at 72 ± 10.4 km**. The peak brightness and altitudes range from **0.23 to 18.51 kR and from 42 to 97 km**.

We build maps of the brightness of the nitric oxide emission and its variability, which show that the emission is highly variable, even for similar conditions, with variations that may reach 50% of the brightest profiles. This is an indicator of variations in the N fluxes at time scales shorter than a Martian year. Similarly, discrepancies in the regions of the detections between the data and the model are indicators of short-term variations of the N flux or the circulation pattern.

These questions will be investigated in future **comparisons between the data and the atmospheric models** such as the LMD and the M-GITM. This study also leads to future work using the **IUVS-MAVEN** measurements of the nitric oxide nightglow.

Acknowledgement and References

The authors thank the SPICAM and the Mars Express teams for the excellent quality of their work. A. Stiepen was supported by the PRODEX program of the European Space Agency (ESA) managed with the help of the Belgian Space Policy Office (BELSPO), Belgian American Educational Foundation (BAEF) and Rotary District 1630. Data used in this study are available from ESA planetary science archives (http://www.rssd.esa.int/index.php?project=MARSEXPRESS&pages=file_tracker&reversed=on)

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