# TWINKLING LIGHTS IN THE NIGHTSIDE ATMOSPHERE: HOW NIGHTGLOW CONTRIBUTES TO OUR UNDERSTANDING OF GLOBAL DYNAMICS

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**Introduction:** Atmospheres of planets continuously emit photons in the UV, Visible, and IR regions of the electromagnetic spectrum. Some of these emissions are classified as airglow, which includes dayglow and nightglow. There are several mechanisms to create these emissions, but nightglow emissions resulting from photochemistry of neutral components will be the main focus. More specifically, these neutral components in Venus and Mars' atmosphere originate on the dayside and are transported from the dayside to the nightside of a planet, where they subsequently undergo chemical reactions yielding nightglow emissions. Nightglow emissions serve as effective tracers for planetary atmosphere global wind systems due to their variable peak brightness and spatial distributions. Understanding the global wind systems of planets provides accessibility to other atmospheric or surface regions of the planet (i.e. mission planning). Mars and Venus will be focused upon in detail due to the similar chemical constituents which populate their atmospheres.

**Mars:** It has been determined through observations and modeling, the Martian middle and lower atmosphere meridional circulation can be described as a Hadley cell(s) (e.g. [1], [2], [3], [4], [5], [6], [7]). The Hadley cell consists of rising motion near the sub-solar point from the lower atmosphere to the middle atmosphere, upper-level movement towards either one or both poles, and sinking motion at higher latitudes. At the equinoctial seasons, two cells exist with the rising branch in the tropics and a descending branch in each hemisphere. At the solstitial seasons, one larger cell is present with the rising branch in the summer hemisphere and the descending branch in the winter hemisphere. The descending branch near the poles transports chemical species to a region optimal for recombination and subsequent de-excitation (i.e. nightglow emission) to occur. Currently, $O_2$ IR and NO UV nightglow have been observed and are discussed in this report.

The Martian NO UV nightglow has been observed by Mars Express (MEx) instrument Spectroscopy for Investigation of Characteristics (SPICAM) ([8], [9], [10], [11]) and by the Mars Atmosphere and Volatile Evoltion (MAVEN) instrument Imaging Ultraviolet Sprectrograph Mars Atmosphere (IUVS) [12]. The mean peak nightglow emission has been observed near 72 km altitude with a range of 42 – 97 km and peaks near the winter pole. Moreover, the detections of the nightglow have been following a sinusoidal curve dependent on latitude and solar longitude (Ls) (latitude = -80sin(Ls)) [11] therefore nightglow emissions have occurred near the equator as well as the poles. The mean peak intensity was 5 Kilo-Rayleigh (kR) (Rayleigh = $10^6$ photons $cm^{-2}s^{-1}$ in 4Π sr) with a range of 0.23 – 18.51 kR [11]. From the SPICAM observations, few correlations between the observations and nightglow intensity have been determined to help identify processes responsible for any variability. Currently, no correlation with altitude or solar activity has been found and the nightglow emissions have been more intense towards the higher latitudes in the winter pole. The MAVEN IUVS observations will help augment the current observations and correlations. To help interpret observations and provide a global context, three-dimensional circulation models has been utilized. The Laboratoire de Météorologie Dynamique Mars General Circulation Model (LMD-GCM) (e.g. [5], [13]) has been utilized in the observation papers for comparisons. The LMD-GCM mostly reproduces the Ls and latitudinal location of the nightglow, and the mean brightness. However, the model predicts two maxima at equinox which is not observed and does not capture the observed altitude variations.

The $O_2$ IR nightglow emission has only been recently observed due to its low intensity compared to Venus and Earth and has been observed less than the NO UV nightglow. MEx instruments OMEGA (infrared mineralogical mapping spectrometer) and SPICAM [14], [15], [16] and Mars Reconnaissance Orbiter (MRO) instrument Compact Reconnaissance Imaging Spectral Mapping (CRISM) [17], [18] have observed the $O_2$ IR nightglow. The nightglow emission has been observed from 40-60 km altitude and strictly in the poles (70° - 90° N/S). The mean intensity is ~0.3 kR, but has ranged from 0.15 – 0.4 kR [18]. The observations suggest the most intense nightglow emission occurs closest to the winter poles. Due to the minimal amount of observations, correlations are difficult to determine. The LMD-GCM was utilized for comparisons with observations, but not in a detailed study. The model over predicts the observed emission intensity by ~25% on average. Furthermore, the modeled peak emission layer is vertically broader than observed.

Overall, the observed difference of location for the NO UV and the $O_2$ IR nightglow suggests that different forces are acting upon the mean meridional circulation (i.e. thermal and /or mechanical forces).

Observations suggest the meridional circulation is weaker than what is simulated by the LMD-GCM. Lastly, detailed numerical studies utilizing the nightglow emission as further information constraining the meridional circulation have not been done due to the lack of observations.

**Venus:** It is understood that Venus has a unique two part zonal circulation pattern within its atmosphere (e.g. [19], [20], [21], [22]). One part occurs in the region between the surface and the top of the cloud deck (~70 km). This region is dominated by a stable wind pattern flowing in the direction of the planet's spin and is faster than Venus' rotation; known as a retrograde superrotating zonal flow (RSZ). The second part occurs above ~120 km and is a relatively stable mean subsolar-to-antisolar flow (SS-AS). Venus has inhomogeneous heating in the upper atmosphere by solar radiation (EUV, UV, IR) thus providing huge pressure gradients to generate the dominant SS-AS flow pattern (e.g. [23], [22], [19], [20]). Between these defined patterns is a "transition region" (~70-120 km) where the two flow patterns are superimposed. The "transition region" typically has large variations on short timescales and varies as a function of altitude, which reflects the changing importance of underlying drivers and solar cycle variations. The chemical species are transported by these zonal flow patterns and produce nightglow emissions on the nightside. These nightglow emissions offer further insight into the mean zonal circulation.

The Venusian NO UV nightglow has been observed since 1980 by the Pioneer Venus Orbiter (PVO) instrument OUVS (ultraviolet spectrometer) (e.g. [24], [25], [26]) and then later by Venus Express (VEx) instrument Spectroscopy for Investigation of Characteristics (SPICAV) (e.g. [27], [28], [29]). The observed mean location of the nightglow emission is 115 km altitude, near the equator, and a few hours after midnight (0200 local time). The peak emission intensity is 8.4 kR with the hemispheric average emission intensity at 1.9 kR. The majority of the peak emission brightness occurs between 110 – 120 km altitudes, while the lower peak emission altitudes occur at higher latitudes [28], [29]. The Venus Thermospheric General Circulation Model (VTGCM) had been specifically exercised to simulate the NO UV nightglow emission and provide insight into what controls the emissions variability [30]. The VTGCM under predicted the vertical location (106 km) and peak intensity (1.83 kR), while the hemispheric average (0.7 kR) and horizontal location was comparable to the observations.

The $O_2$ IR nightglow has been more extensively observed through ground-based observations (e.g. [31], [32], [33], [34], [35]) and VEx instrument visible and infrared thermal imaging spectrometer (VIRTIS) observations (e.g. [36], [37], [38], [39], [40],[41]). The $O_2$ IR nightglow emission is observed on average at 97 km altitude, near the equator, and at midnight local time. The peak intensity is 1.6 Mega-Rayleigh (MR) with the hemispheric average emission intensity at 0.5 MR [39]. The emission seems to be brightest at lower latitudes and near midnight local time. As with the NO UV nightglow emission, the VTGCM was also utilized in simulating the $O_2$ IR nightglow emission and its variability [30]. The model results were in good agreement with the observations, such that the simulated location is 100 km altitude, near the equator, and at midnight. Moreover, the simulated peak intensity is 1.7 MR with the hemispheric average of 0.5 MR.

Overall, the NO UV and $O_2$ IR nightglow emissions occur in the transition region and have helped further our knowledge of this region. From the spatial location and intensity of the two nightglows emission, it is discerned the RSZ winds are minimal from ~80 km to 110 km altitude followed by a rapid increase in speed (~ 50 $ms^{-1}$) between 110 km and 130 km. Above 130 km, the RSZ is constant around ~40 $ms^{-1}$ and 60 $ms^{-1}$. The VTGCM simulations have shown the variability of the two nightglow emission intensity is driven differently by at least two different processes. The NO UV nightglow emission intensity is controlled by the vertical winds, while the $O_2$ IR emission intensity is controlled by eddy diffusion. Both emission layers (vertical location) are controlled by the both eddy diffusion and the global wind system. Furthermore, there is ongoing work to determine the impacts waves and tides have upon the nightglow emissions.

**Conclusion:** Venus and Mars have distinctly different dominating circulation patterns in the middle/upper atmosphere as indicated by the observed nightglow emissions location (latitude, local time, and altitude) and intensity (see Table 1 for mean values related to the nightglow emissions). For both planets and their nightglow emissions, observations show a lot of variability which make the nightglow intensity and location vary sporadically (i.e. twinkling lights). Moreover, the variability of the nightglow emissions seems to be driven differently on each planet. Model implications for both nightglows on both planets can and are providing valuable insight and understanding of the dynamical and chemical processes creating the nightglow emission variability; modeling work needs to be continued in connection with observations. Lastly, the nightglow emissions have proven observationally and numerically to be a useful tracer of the atmospheric circulation for any planet.

| $O_2$ IR (observed) | Mars[18] | Venus[39] |
|---|---|---|
| Peak Intensity | 3 kR | 1.6 MR |
| Peak Altitude | 40 – 60 km | 97 km |
| Peak Latitude | Poles | Equator |
| **NO UV (observed)** | **Mars[11]** | **Venus[28][29]** |
| Peak Intensity | 5 kR | 8.4 kR |
| Peak Altitude | 72 km | 116 km |
| Peak Latitude | Winter Poles | Near Equator |

Table 1: Mean values of the observed nightglow emissions for the $O_2$ IR nightglow and the NO UV nightglow emissions for Mars and Venus.


**Bibliography:**
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