Planetary and Space Science 85 (2013) 243–249

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Night and day airglow of oxygen at 1.27 μm on Mars

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ARTICLE INFO

Article history:
Received 2 February 2013
Received in revised form
13 June 2013
Accepted 19 June 2013
Available online 28 June 2013

Keywords:
Mars
Airglow
Seasonal and latitudinal variations

ABSTRACT

An attempt has been made to detect the O_2 nightglow at 1.27 μm at low latitudes on Mars using ground-based high-resolution spectroscopy. The observed intensity is 10 ± 32 kR, that is, less than 40 kR with a probability of 83%. The current models give the O_2 nightglow intensity from 13 to 100 kR. Continuation of the ground-based observations of the O_2 dayglow at 1.27 μm in the last 3 martian years results in interannual variations of the dayglow at $L_S \approx 15°$, 65°, and 110°. According to the observations, these variations are typically ~20% in northern spring and summer. Our long-term observations of the O_2 dayglow are presented as a seasonal-latitudinal map that is compared with models by Krasnopolsky (2009) and Gagne et al. (2012). While the models correctly reproduce the general behavior of the dayglow, there are some differences that are briefly discussed.

1. Introduction

Nightglow is a fascinating phenomenon that reflects atmospheric chemistry and dynamics. The first attempt to detect nightglow on Mars was made in the visible range from the Mars 5 orbiter (Krasnopolsky and Krysko, 1976) and resulted in upper limits of 50 R for individual emission lines in the nadir and limb observations. (One Rayleigh is an emission of 10^6 photons per (cm^2 s 4π sr).) After the discovery of the Venus nightglow in the visible range (Krasnopolsky et al., 1976; Krasnopolsky, 1983) and in the $O_2(a^1\Delta_g \rightarrow X^3\Sigma_g^-)$ band at 1.27 μm (Connes et al., 1979), it became clear that the O_2 band at 1.27 μm is the strongest nightglow feature on the terrestrial planets. This nightglow is excited by the termolecular association of O_2 with a high yield of ~0.7 (Krasnopolsky, 2011).

The O_2 band at 1.27 μm was detected in the martian dayglow by Noxon et al. (1976) and then observed by Traub et al. (1979). This band is excited by photolysis of ozone with a yield close to one and then either emitted or quenched by CO_2 below ~20 km. Clancy and Nair (1996) argued that ozone at and above ~20 km is even more sensitive to variations of the martian photochemistry at low and middle latitudes than the column ozone. Therefore Krasnopolsky (1997) proposed ground-based observations of the O_2 dayglow at 1.27 μm as a substitute for the high-altitude ozone to monitor variations of Mars photochemistry and dynamics. The observations were made by Krasnopolsky and Bjoraker (2000), Novak et al. (2002), and Krasnopolsky (2003, 2007).

A bright O_2 1.27 μm airglow of 2.2 MR was observed 0.6 arcs off the martian nightside limb at 70°S and $L_S = 173°$ (Krasnopolsky, 2003). That was probably a detection of the polar nightglow on Mars. However, Krasnopolsky (2003) pointed out contributions from three possible sources: a true nightglow, a nightside tail of the dayglow with the lifetime of 1.2 h, and a tail of the instrument response function.

The Mars Express orbiter started science observations in 2004, and two instruments, SPICAM-IR and OMEGA, have capabilities to observe the O_2 airglow at 1.27 μm. The SPICAM-IR observations for a full martian year are discussed by Fedorova et al. (2006). The results are in excellent agreement with those from the ground-based observations by Krasnopolsky (2003, 2007), especially after correction for variations with local time. Some detailed maps of the dayglow were observed by OMEGA (Altieri et al., 2009) in the subpolar regions in seasons, when the dayglow was very bright.

SPICAM-UV observations discovered an aurora (Bertaux et al., 2005a) and the NO UV nightglow (Bertaux et al., 2005b; Cox et al., 2008) that is similar to those observed on the Earth and Venus and excited by the radiative association of the NO molecule.

Recently three independent teams (Bertaux et al., 2012; Fedorova et al., 2012; Clancy et al., 2012a, 2012b) revealed a very bright emission of O_2 at 1.27 μm from winter polar night regions. The observations were made using OMEGA and SPICAM-IR at Mars Express and CRISM at the Mars Reconnaissance Orbiter (MRO), respectively. The polar nightglow intensity has a peak of ~10 MR at ~55 km on the limb with a mean vertical intensity of ~250 kR.

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0032-0633/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.pss.2013.06.018

The polar night conditions appear at latitudes exceeding 70° during winter. The observed polar nightglow agrees with simulations by the LMD general circulation model that are reproduced in the cited publications. The bright polar nightglow is excited by the termolecular association of O_2 in a descending flow of air in the Hadley circulation. This air is transported from the low and middle latitudes and enriched with atomic oxygen.

However, the polar night conditions are extreme and very different from the mean nighttime conditions on Mars. Here we will describe our attempt to detect the O_2 nightglow at 1.27 μm at low latitudes and then discuss a continuation of our observations of the O_2 dayglow for the last 3 martian years.

2. Search for O_2 nightglow at low latitudes on Mars

Our observations were conducted at the NASA Infrared Telescope Facility (IRTF) on Mauna Kea (Hawaii). The telescope diameter is 3 m, and its elevation is 4.2 km with atmospheric pressure of 0.6 bar. We applied the CSHELL spectrograph (Greene et al., 1993) that covers an interval of $0.0023\nu_0$ with resolving power $\nu/\delta\nu = 4\times10^4$. Here ν_0 is the central wavenumber that may be chosen in a range of 1800–9000 cm^{-1} (5.5–1.1 μm). The instrument detector is an InSb array of 256 × 150 pixels cooled to 30 K. The pixel size is $9\times10^{-6}\,\nu_0$ in the dispersion and 0.2 arcs in the aspect direction. Each exposure gives a frame of 150 spectra along the slit of 30 arcs with 256 pixels in each spectrum.

The observations were made on May 10, 2012, when Mars was at 1.631 AU from the Sun and 1.016 AU from the Earth. Its angular diameter was 9.2 arcs (46 pixels) and geocentric velocity was 14.0 km s^{-1}. This velocity results in a Doppler shift of −0.37 cm^{-1} at 7900 cm^{-1}. Position of Mars in the celestial coordinates is shown in Fig. 1. Mars was near the peak of northern summer with $L_S = 110°$ that corresponds to July 11 in the terrestrial calendar.

The night crescent of Mars is always small and poorly seen from the Earth. Its width was 0.9 arcs in our observations. The night crescent was morningside, and this rules out the O_2 dayglow tail caused by the long dayglow radiative time. We acquired two 8 min and one 20 min exposures to observe the nightglow at the nightside limb and ~0.5 arcs below and above the limb (Fig. 1). Spectra of dark current and flat field using a continuum source were observed as well, and the dark current was subtracted from the martian and flat field spectra. Then bad pixels in their ratio were replaced by mean values from their neighbors, and 21 spectra in each of three observing frames were summed up to improve signal-to-noise ratio. These 21 spectra are closest to the terminator and therefore brightest. Signals at the edges of these intervals of 21 aspect pixels are smaller than those in the centers typically by a factor of 2.

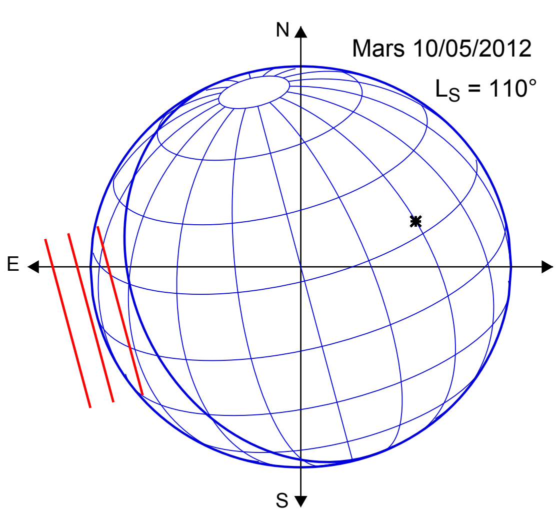

Fig. 1. Mars in the celestial coordinates during the O_2 nightglow observations. Its diameter is 9.2 arcs (46 pixels). Positions of the subsolar point, terminator, and three slits for the nightglow exposures are shown. 21 pixels were used for the nightglow measurements, and the slit length is 21 pixels in the figure. Local time at the nightside limb is 03:20.

The observed spectra at three slit positions are shown in Fig. 2. Bright continuous radiation from the dayside disk of Mars dominates in all spectra, because the dayside disk is off the instrument field of view by just a few arc seconds. Each spectrum includes eight telluric O_2 absorption lines that are identified in the lower panel. One strong line is solar, and there are some weak solar lines and lines of the martian CO_2 in the spectra. The spectra look rather similar, though that in the lower panel is weaker than that in the upper panel by a factor of 6.5.

Absolute calibration of the spectra was made observing a standard infrared star. The spectral frame for the star was also used to derive the instrument line spread function (LSF). The star continuum spectrum would be just a thin line in the spectral frame for an ideal instrument. The observed spectrum has a finite width, and its distribution in the aspect direction is the instrument LSF (Fig. 3). Generally, a point spread function may be obtained from the observed LSF, but we do not need it.

Our observations of the O_2 dayglow along the central meridian on the same date will be discussed in the next section. Using the measured continuum brightness and assuming the Lambert reflection of the solar light from the surface and lower atmosphere, we calculated brightness distribution along the martian disk. We convolved this distribution using the observed LSF and obtained a brightness distribution seen by our instrument off the terminator. Comparing the calculated distribution with the observed spectra in Fig. 2, we got more accurate positions of the slits during the observations than those extracted from the telescope data. They are shown in Fig. 1. The O_2 nightglow is expected at 50–65 km at low latitudes on Mars. Absorption by dust and haze is weak at these altitudes and may be safely neglected.

All telluric O_2 lines show some asymmetry and excess on the left shoulder that is due to the Doppler shifted martian emission. We choose four lines to extract the martian airglow. They are marked red in Fig. 2. The other four lines are either contaminated or weak. Our technique of the martian O_2 airglow extraction is similar to that used in our previous observations (Krasnopolsky, 2003). The observed line shape is fitted by a sum of Gaussian and parabola (Fig. 4). Five pixels that are centered at the expected Doppler-shifted position of the martian airglow line are not involved in the fitting, and a difference between these pixels and the calculated fit gives the airglow line intensity.

The radiative lifetime of $O_2(a^1\Delta_g)$ is long, and rotational temperature of the O_2 nightglow at 1.27 μm should be similar to the ambient temperature of the atmosphere. We will see below that the O_2 dayglow from the dayside disk of Mars at tail of LSF dominates in the extracted O_2 emission lines. Its mean temperature is

$$T = \frac{\int_0^\infty T(h)i(h)dh}{\int_0^\infty i(h)dh}$$

where $i(h)$ is the O_2 dayglow volume emission rate, and the data from our model at $L_S = 112°$ and 20°N (Krasnopolsky, 2006, figure 10) result in $T = 172$ K.

Line intensity is proportional to $Ag_u e^{-\alpha(E_0+\nu)/T}$, where A is the line transition probability, g_u is the statistical weight of the upper state, $\alpha = 1.4388$ cm K, E_0 is the lower state energy in cm^{-1}, and ν is the line wavenumber. All these values may be found in HITRAN 2008 (Rothman et al., 2009). According to this relationship, the chosen O_2 lines at 7888.06, 7893.53, 7895.48, and 7900.83 cm^{-1}