



ELSEVIER

Contents lists available at ScienceDirect

## Planetary and Space Science

journal homepage: [www.elsevier.com/locate/pss](http://www.elsevier.com/locate/pss)

## Measurements of the helium 584 Å airglow during the Cassini flyby of Venus

J.-C. Gérard<sup>a,\*</sup>, J. Gustin<sup>a</sup>, B. Hubert<sup>a</sup>, G.R. Gladstone<sup>b</sup>, L.W. Esposito<sup>c</sup><sup>a</sup> Laboratoire de Physique Atmosphérique et Planétaire, Université de Liège, 17, allée du 6 août, B5c, B-4000 Liège, Belgium<sup>b</sup> Southwest Research Institute, P.O. Drawer 28510, 6220 Culebra Road, San Antonio, TX 78238-5166, USA<sup>c</sup> Laboratory for Atmospheric and Space Physics, University of Colorado, Campus Box 392, Boulder, CO 80309-0392, USA

## ARTICLE INFO

## Article history:

Received 24 February 2011

Received in revised form

17 June 2011

Accepted 21 June 2011

Available online 7 July 2011

## Keywords:

Venus

Helium density

Airglow

Cassini

Flyby

Radiative transfer

## ABSTRACT

The helium resonance line at 584 Å has been observed with the UltraViolet Imaging Spectrograph (UVIS) Extreme Ultraviolet channel during the flyby of Venus by Cassini at a period of high solar activity. The brightness was measured along the morning terminator up to the bright limb near local noon. The mean disk intensity was  $\sim 320$  R, reaching  $\sim 700$  R at the bright limb. These values are slightly higher than those determined from previous observations. The sensitivity of the 584 Å intensity to the helium abundance is analyzed using recent cross-sections and solar irradiance measurements at 584 Å. The intensity distribution along the UVIS footprint on the disk is best reproduced using the EUVAC solar flux model and the helium density distribution from the VTS3 empirical model. It corresponds to a helium density of  $8 \times 10^6 \text{ cm}^{-3}$  at the level of where the  $\text{CO}_2$  is  $2 \times 10^{10} \text{ cm}^{-3}$ .

© 2011 Elsevier Ltd. All rights reserved.

## 1. Introduction

Helium atoms in the Venus atmosphere originate from outgassing following radioactive decay of uranium and thorium in the planetary crust or from the capture of solar wind  $\alpha$ -particles. The helium budget on Venus has been discussed by Pollack and Black (1982), Prather and McElroy (1983), Chassefière et al. (1986), and Krasnopolsky and Gladstone (2005). The thermal escape rate is negligibly small and the main loss process is ionization of helium atoms above the ionopause followed by interaction with the solar wind sweeping out  $\text{He}^+$  ions. The efficiency of this loss process depends on the helium density in the upper atmosphere. Krasnopolsky and Gladstone (2005) derived a mixing ratio of  $9 \pm 6$  ppmV in the middle and lower atmosphere and concluded that the efficiency of the solar wind  $\alpha$ -particles capture is 0.1. Barabash et al. (2007) detected with the Aspera-4 instrument on board Venus Express the presence of  $\text{He}^+$  ions escaping through the planetary plasma wake. They measured an unexpectedly high  $\text{He}^+$  relative abundance, possibly due to an effective acceleration of the ions caused by the polarization field. The importance of the knowledge of the helium density is linked to the planetary evolution since the present helium abundance

depends on the relative rates of the outgassing and  $\text{He}^+$  capture sources during the evolution of the planet.

The first detection of helium in the Venus atmosphere was made with the ultraviolet spectrometer on board Mariner 10. From the bright limb profile of the  $\text{HeI}$  resonance line at 584 Å, Kumar and Broadfoot (1975) derived a helium density of  $(2 \pm 1) \times 10^6 \text{ cm}^{-3}$  at the altitude where the  $\text{CO}_2$  density is  $2 \times 10^{10} \text{ cm}^{-3}$ . Following Krasnopolsky and Gladstone (2005), we adopt this altitude where the  $\text{CO}_2$  density is  $2 \times 10^{10} \text{ cm}^{-3}$  as the reference level for comparison of the various measurements. It is located near 145 km according to the VTS3 empirical model (Hedin et al., 1983) and corresponds to a vertical optical depth at 584 Å of  $\sim 0.5$ . If a more realistic thermospheric temperature of 275 K than the 350 K used in the original analysis is adopted, the density must be increased by a factor of 1.8 (von Zahn et al., 1983) and the Mariner 10 observations correspond to a helium density of  $3.6 \times 10^6 \text{ cm}^{-3}$  at the reference level. Further observations of the  $\text{HeI}$  584 Å emission were made with the EUV spectrometers carried by the Venera 11 and Venera 12 spacecraft during their Venus flyby in December 1978. A description of the instrument and a preliminary analysis was given by Bertaux et al. (1981). The observed intensity, following background subtraction, reached a peak value of 280 R. A detailed analysis by Chassefière et al. (1986) based on the shape of the scans of the illuminated disk concluded that the optical thickness of the 584 Å emission above the  $\text{CO}_2$  absorption level was  $3.5 \pm 1.5$ , independently of the instrumental calibration. This optical depth corresponds to a helium density of  $(2.6 \pm 1.2) \times 10^6 \text{ cm}^{-3}$  at the reference level. Krasnopolsky and Gladstone (2005) observed the 584 Å line with the Extreme

\* Corresponding author. Tel.: +32 4 3669775; fax: +32 4 3669711.

E-mail addresses: [jc.gerard@ulg.ac.be](mailto:jc.gerard@ulg.ac.be) (J.-C. Gérard),[J.Gustin@ulg.ac.be](mailto:J.Gustin@ulg.ac.be) (J. Gustin), [randy.gladstone@swri.org](mailto:randy.gladstone@swri.org) (G.R. Gladstone), [larry.esposito@lasp.colorado.edu](mailto:larry.esposito@lasp.colorado.edu) (L.W. Esposito).

**Table 1**

Values of the helium density measured at the reference level<sup>a</sup> in the Venus lower thermosphere.

Spacecraft	He density (in $10^6 \text{ cm}^{-3}$ )	Reference
Mariner 10	$2 \pm 1$	Kumar and Broadfoot (1975)
Mariner 10 <sup>b</sup>	3.6	von Zahn et al. (1983)
Venera 11 and 12	$2.6 \pm 1.2$	Chassefière et al. (1986)
EUV Explorer	$4.3 \pm 1.9$	Krasnopolsky and Gladstone (2005)
Pioneer Venus bus	7.0	von Zahn et al. (1980)
Cassini flyby <sup>c</sup>	$8.0 \pm 4$	This work

<sup>a</sup> Where  $[\text{CO}_2] = 2 \times 10^{10} \text{ cm}^{-3}$ .

<sup>b</sup> With corrected temperature profile.

<sup>c</sup> Value deduced using the EUVAC solar flux model.

Ultraviolet Explorer (EUVE) satellite during an accumulated 16,000 s period in April 1998. During these observations, the sunlit fraction of the Venus disk was 55.5% and the solar activity was moderate (F10.7 index = 113). The observed integrated disk brightness at 584 Å was  $144 \pm 32 \text{ R}$ . They inferred a helium density of  $(4.3 \pm 1.9) \times 10^6 \text{ cm}^{-3}$  at the reference level. Using a radiative transfer model, they calculated the He 584 Å brightness distribution over the Venus sunlit disk for the conditions of the EUVE observations. It shows a significant limb brightening along the subsolar meridian and a continuous increase from the morning terminator to the subsolar meridian. Chassefière et al. (1986) analyzed how the presence of a limb brightening depends on the interplay between the optical thickness of the 584 Å emission and the level of CO<sub>2</sub> absorption. They showed that for a helium optical thickness of  $\sim 1$  above the CO<sub>2</sub> absorption level, a clear center to limb brightening is present. Instead, for  $\tau = 7.56$ , a limb darkening was predicted by their model. The calculated 584 Å intensity increased everywhere on the disk as the helium optical thickness increased.

In situ measurements of the helium density were also performed during the Pioneer Venus mission. The bus carrying a mass spectrometer entered the atmosphere on the morning side where the solar zenith angle was close to 60° and measured the chemical composition down to 130 km (von Zahn et al., 1980). The measured helium density at the reference altitude was  $6.8 \times 10^6 \text{ cm}^{-3}$ . The neutral mass spectrometer (ONMS) on board the Pioneer Venus orbiter provided He density measurement down to  $\sim 145 \text{ km}$  at all solar times in a region confined to low latitude (Niemann et al., 1980). The measurements showed little variation as a function of local time on the dayside, but indicated the presence of a pronounced bulge centered near 4:30 LT. This bulge was interpreted as a consequence of the subsolar to antisolar circulation and the presence of superrotation in the upper atmosphere of the planet. The VTS3 model, which is mainly driven by the ONMS measurements, predicts equatorial helium density at the reference level varying from  $1.8 \times 10^7 \text{ cm}^{-3}$  at 0600 LT to  $8 \times 10^6 \text{ cm}^{-3}$  during daytime. These helium density values derived from earlier measurements are summarized in Table 1.

## 2. The observations

The Cassini spacecraft flew by Venus on 24 June 1999 on its way to Saturn, reaching a closest altitude of 602 km. A series of simultaneous FUV and EUV spectra were collected with the UltraViolet Imaging Spectrograph (UVIS) (Esposito et al., 2004). The UVIS line of sight was oriented nearly perpendicular to the Sun-spacecraft line, so that the phase angle remained close to 90°.

During the observations, 55 records of 32 s each were obtained, 25 of which were recorded while the instrument scanned the sunlit disk of Venus from the morning terminator to sunlit limb in the vicinity of the subsolar point. The latitude of the UVIS slit footprint on the planet varied from 24° north to 5° south. Figure 1 and Table 1 by Gérard et al. (2011) show the foot track geometry and describe the variation of the solar zenith angle (SZA) and emission angle (the angle between the line of sight and local zenith at the altitude of airglow emission) at each record. At this period, solar activity was rising, and reached a F10.7 solar index of 212 at Earth distance, accounting for the difference in solar longitude between the Earth and Venus. Observations in the FUV and in the EUV down to 834 Å made with UVIS during the Cassini flyby have been described and analyzed by Hubert et al. (2010) and Gérard et al. (2011).

The bandpass of the UVIS EUV channel covers the range 563–1182 Å. The two-dimensional CODACON detector allows spectral and one-dimensional spatial coverage as the footprint of the instrument scans the planetary disk. The UVIS slit image on the detector is composed of 1024 pixels in the dispersion direction and 64 pixels in the spatial direction. The slit was oriented nearly perpendicular to the ecliptic plane. The full spectral resolution has been used during the Venus observations, providing spectra at a resolution of  $\sim 3.7 \text{ Å FWHM}$ . The spatial direction has been rebinned over 16 pixels, leaving a resolution of 4 pixels along the spatial direction. Each record presented here is the sum of the two central spatial pixels in order to increase the signal/noise ratio. The EUV field of view along the slit is 59 mrad, corresponding to  $\sim 415 \text{ km}$  projected on the planet surface from an altitude of 7000 km. Consequently, only a small fraction of the disk is seen during each record, causing negligible smoothing, except in the vicinity of the planetary limb. The spacecraft moved  $\sim 500 \text{ km}$  during the 32 s integration period of each record.

The EUV channel was initially calibrated following the pre-flight laboratory measurements described by Esposito et al. (2004). The primary standards used for determining the UVIS absolute radiometric sensitivity were photodiodes provided by the National Institute for Standards and Technology (NIST). Measurements of the star Alpha Virginis (Spica) obtained during cruise in January 1999 agreed with previous results to within 10% for both EUV and FUV channels, validating the UVIS laboratory results. An empirically derived background noise level of  $4.5 \times 10^{-4} \text{ count s}^{-1} \text{ pixel}^{-1}$  originating from the radioisotope thermoelectric generators has been removed and a flat-field correction derived from observations of Spica (Steffl et al., 2004) has been applied. A contaminating source also affects wavelengths below 920 Å (known as “the mesa”). It is caused by a small light leak allowing undispersed interplanetary Lyman- $\alpha$  photons to reach the portion of the EUV detector corresponding to short wavelengths. The signal associated with the Lyman- $\alpha$  leak smoothly rises from  $0.063 \text{ count s}^{-1} \text{ pixel}^{-1}$  at 560 Å to  $0.125 \text{ count s}^{-1} \text{ pixel}^{-1}$  at 920 Å, rapidly dropping to zero at 1020 Å. Consequently, the residual spectrum in this region is quite noisy, preventing reliable detection of weak emissions below 930 Å, with the exception of the bright He I emission at 584 Å. This background signal has been manually subtracted from each individual spectrum to determine the brightness of the 584 Å line across the disk. The average signal of the 584 Å emission is about 60 counts/spectrum, to be compared with the 135 counts/spectrum from the Lyman- $\alpha$  leak. The count rate has been converted into physical units using the latest UVIS calibration routines. Fig. 1 shows the intensity distribution of the 584 Å line measured along the slit scan of the Venus disk during the flyby. The statistical 1- $\sigma$  error bars are indicated for each record. The main source of uncertainty comes from the subtraction of the signal due to the Lyman- $\alpha$  leak.

Download English Version:

<https://daneshyari.com/en/article/10705296>

Download Persian Version:

<https://daneshyari.com/article/10705296>

[Daneshyari.com](https://daneshyari.com)