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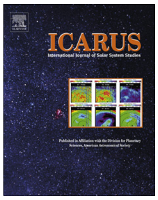

Observations of the nightside venusian hydrogen corona with SPICAV/VEX

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ABSTRACT

Observations of the venusian hydrogen corona on the nightside (8 PM local time) have been performed with SPICAV instrument on board Venus Express from 12 to 15 October 2011. These observations were associated with interplanetary observations obtained at apoapsis to subtract the interplanetary contribution. The observed brightness variation with altitude on the disk and above the limb shows that one part of the interplanetary emission is scattered out of the line of sight by the venusian hydrogen atoms above the CO_2 absorption limb. The emission of the H corona beyond the cylindrical shadow is also scattered in the same way. Taking into account the geometry of the line of sight and this scattering in a radiative transfer model allows us to retrieve for the first time the vertical profile of the hydrogen density on the nightside of Venus from Lyman-α measurements. The derived cold hydrogen density at the exobase is $\sim$40 times larger than the dayside hydrogen density derived by the same instrument, showing an evening bulge in agreement with *in situ* measurements of Pioneer Venus. The hot hydrogen density derived at the nightside is $\sim$5 times larger than the average dayside hot hydrogen density found previously with SPICAV/Venus Express. A decrease of the hot hydrogen content by a factor $\sim$2 is observed during these three days of observations. This decrease could be explained by a decrease of the hot hydrogen production rate on the nightside driven by a variation of the dayside ionosphere.

1. Introduction

Venus is very dry compared to the Earth, the high deuterium to hydrogen ratio measured (Donahue et al., 1982; De Bergh et al., 1991; Encrenaz et al., 1995; Bertaux et al., 2007a; Fedorova et al., 2008; Krasnopolsky et al., 2013) suggests that a large part of its water escaped in the interplanetary medium over geologic times (Watson et al., 1981; Kasting and Pollack, 1983; Donahue and Hodges, 1992; Chassefière, 1996; Chassefière and Leblanc, 2004; Kulikov et al., 2006). Currently, several processes can lead to a net loss of hydrogen from Venus: The planetary protons produced by photoionization, solar wind electron impact or charge exchange with solar protons can be accelerated by the motional electric field of the solar wind and escape. Barabash et al. (2007) estimated a first lower limit for the net loss by such processes of 10^{25} protons s^{-1} from ASPERA-4 measurements. Later, values between 7.1 and 39.0 × 10^{24} s^{-1} have been reported (Fedorov et al., 2011; Lundin, 2011) for solar minimum conditions from ASPERA-4. The more recent estimate from this instrument is $14.0 \pm 2.6 \times 10^{24}$ s^{-1} (Nordström et al., 2013). Momentum transfer from energetic planetary protons and thermospheric hydrogen atoms leads to the formation of a suprathermal hydrogen population leading to neutral escape (Hodges, 1999). This suprathermal population was first inferred from the two scale heights brightness profile of the Lyman-α emission and confirmed by several other missions (Barth et al., 1967; Barth, 1968; Wallace, 1969; Broadfoot et al., 1974; Anderson, 1976; Bertaux et al., 1978, 1981, 1982; Takacs et al., 1980; Paxton et al., 1988; Chaufray et al., 2012). A Lyman-α observation crossing the venusian shadow was performed during the Mariner-5 Venus flyby (Wallace, 1969). These authors observed a decrease of the brightness at the dark limb. This decrease was equal to the interplanetary emission only, while an additional decrease by 2 of the venusian signal would have been expected for an optically thin nightside hydrogen corona when the line-of-sight (LOS) intercepts the altitude (125 ± 5 km) at which the Lyman-α emission is absorbed by CO_2. Wallace (1969) deduced from this observation that the nightside venusian exosphere was optically thick and the signal from the far side beyond

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the cylindrical shadow was extinguished by the hydrogen atoms in the shadow. This observation was first interpreted as the effect of a hydrogen bulge at the venusian nightside by Kumar et al. (1978) who modeled the transport of atomic hydrogen and found an important net transport from the dayside to the nightside due to strong thermospheric winds. A similar effect had been proposed to explain the terrestrial winter helium bulge (“Johnson pump”) (Johnson and Gottlieb, 1969). Similar bulges have been predicted for atomic oxygen (Valeille et al., 2009) and hydrogen (Chaufray et al., 2015) on Mars. Several observations done by Pioneer Venus Orbiter later confirmed the large variations of the cold hydrogen density with local time and the presence of a hydrogen density bulge at the nightside near 3 AM (Hartle et al., 1996; Grebowsky et al., 1996). However, the *in situ* Pioneer Venus Orbiter observations are only indirect: the neutral H density was derived from the combination of H^+, O^+ and O measurements and the assumption of a fast local chemical equilibrium from the charge exchange reaction between H and O ions and neutrals (Brinton et al., 1980). Paxton et al. (1985, 1988) and Chaufray et al. (2012) find a strong morning/evening asymmetry in the Lyman-α brightness from PVO UVS and SPICAV/VEX respectively as expected from variations of the hydrogen density with local time. Chaufray et al. (2012) found that the density reported by Brinton et al. (1980) at the morning side leaded to a Lyman-α brightness larger than the observed brightness by SPICAV on Venus Express and suggested a lower hydrogen bulge density at the morning side.

While it is relatively easy to determine the neutral H density distribution in the fully Sun-illuminated parts of the Venus H corona from photometric Lyman-α measurements, it becomes very uncertain to determine the H density distribution on the night side with the same method. The reason is that within the shadow cylinder of Venus, H atoms are only weakly illuminated by multiple scattering transport of photons from the day side to the night side. For instance, when the observer and the LOS are fully in the night and looking to the planet, only an estimate of the total H content (above the CO_2 cut-off altitude) may be retrieved, but not a vertical distribution. When the LOS is partially in the shadow, the situation is even more complicated. A full radiative transfer model has to be used to compare to the measurements.

We reported earlier day-side Lyman-α measurements (Chaufray et al., 2012) from SPICAV instrument on board Venus Express (Bertaux et al., 2007b). A distribution of temperature and density at the exobase level (250 km) was determined for the day side, with some indications that the night side hydrogen bulge could be smaller than reported by PVO (Brinton et al., 1980) (the night side exospheric hydrogen is somewhat transported to the day side by “lateral transport”, an expression designating the ballistic flight of hydrogen atoms through the collision-less exosphere, e.g. Hodges and Johnson, 1968). One additional difficulty for the study of the H corona of Venus is the existence of two populations of H atoms: the normal, “cold” population with the temperature of the upper thermosphere, and a hot component of non-thermal origin.

In the following are reported four observations made with SPICAV/Venus Express conducted to explore the Venus H thermosphere/exosphere made in October 2011 on the night side of the terminator.

2. Observations

The geometry of observations is sketched on Fig. 1. The orbit of Venus Express is extremely eccentric (periapsis ~ 300 km, apoapsis ~ 66,000, km, period 24 h) (Fig. 1b). The periapsis is near the north pole of Venus, the orbit is almost polar, and fixed in inertial space, therefore at a constant local time, drifting from one orbit to the next. The present observations were made with a LOS fixed in inertial space, looking toward the south ecliptic pole, in the orbital plane (blue line on Fig. 1a). All H atoms along the LOS are conveniently at a constant Local Time (~20.00). Observations were started when the spacecraft was behind the terminator w.r.t. the Sun (position A). Venus Express (VEX) was never in the shadow and a substantial portion of the LOS was always outside of the shadow (Fig. 1a). Therefore, atoms of the both the hot and the cold component (dominating up to ~2000 km) near the evening bulge are directly illuminated by the Sun, and emit Lyman α. The dark CO_2 limb was crossed at position B, and between B and C (altitude of the tangent point ~1600 km) a part of the LOS was in the shadow. Between C and D the LOS was entirely illuminated.

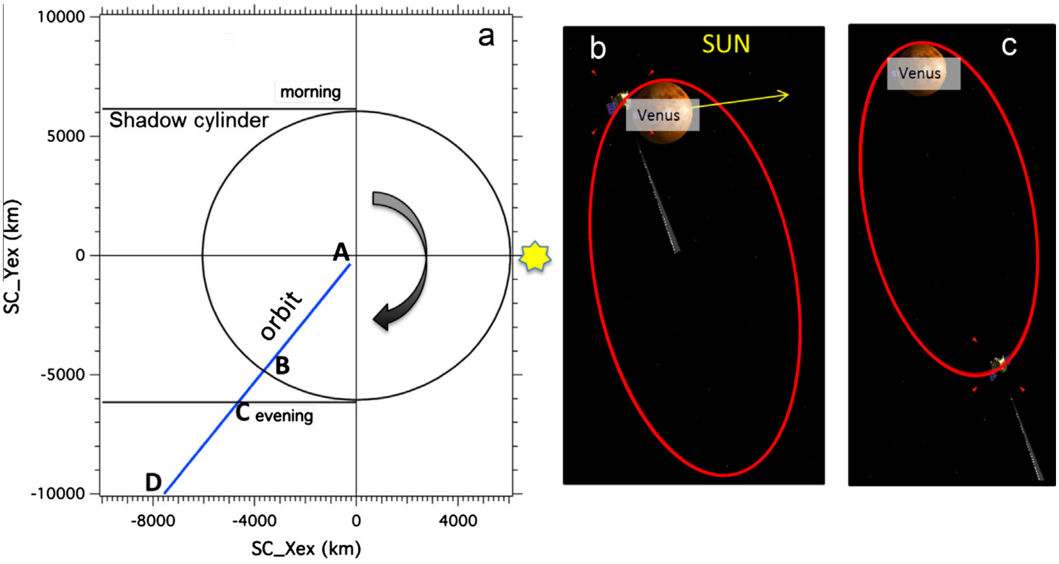

Fig. 1. (a) Geometry of VEX orbit 2000 during the SPICAV exosphere observation A04. The Sun is on the right, toward X_{ex}. The $+Ze_x$ axis is to the North ecliptic pole. The orbit projection on the equatorial plane of Venus $X_{ex} - Y_{ex}$ is in blue and is at a constant LT~20:00. The LOS was oriented to the south ecliptic, therefore the blue line is also the track of the LOS. Measurements began with the LOS near the center of Venus at position A., moving outward. B is limb-crossing, C is when the LOS is fully out of the shadow, and D is the end of observations. (b) Venus Express orbit (red line) and observations during the scan of the venusian shadow (blue line) near the Venus Express periapsis, close to the venusian north pole. The Sun direction is indicated by the yellow arrow. (c) Same as (b) but for the interplanetary medium observation near the Venus Express apoapsis. (b and c) were performed using the Celestia software. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)