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Venus' winds measured with visible imaging-spectroscopy at the THEMIS observatory

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Abstract

The objective of the present work is to measure the global properties of Venus' atmospheric dynamics, through the obtention of a complete radial-velocity map of Venus at the altitude of the uppermost cloud layer. Our results are based on high-resolution spectroscopic observations of Venus performed in the visible domain with the long slit spectrometer of the solar telescope THEMIS (Spain). We present the first instantaneous "radial-velocity snapshot" of any planet of the solar system in the visible domain, i.e., a complete RV map of the planet obtained by stacking data on less than 10 % of its rotation period. From this, we measure the properties of the zonal and meridional winds, which we unambiguously detect. We identify a wind circulation pattern that significantly differs from what we know about Venus. The zonal wind displays a "hot spot" structure, featuring about 200 m s^{-1} at sunrise and 70 m s^{-1} at noon in the equatorial region. Regarding meridional winds, we detect an equator-to-pole meridional flow peaking at 45 m s^{-1} at mid latitudes, i.e., which is about twice as large as what was reported so far.

1. Context

Venus' atmosphere is well known for rotating in a retrograde direction (from east to west), contrarily to all other bodies in the solar system, with the notable exception of Saturn's moon Titan. First evidenced from the ground, the atmospheric super-rotation has been extensively studied both from space and ground-based telescopes (e.g., Gierasch et al. 1997). The cloud top region is important as it constrains the global mesospheric circulation in which zonal winds generally decrease with height while thermospheric sub-solar to anti-solar winds increase (e.g., Lellouch et al. 1997). It also shows important spatial and temporal variability (e.g., Sánchez-Lavega et al. 2008; Khatuntsev et al. 2013).

In 2007, a significant international effort was organized to support the atmospheric observations of Venus by ESA mission VEx (Lellouch & Witasse 2008). The objective was to measure the atmospheric circulation using different spectral ranges, to probe different altitudes in the Venus mesosphere. Significant results on the upper mesospheric dynamics were obtained using mid-infrared heterodyne spectroscopy (e.g., Sornig et al. 2012), millimeter and submillimeter wave spectroscopy (e.g., Moullet et al. 2012), and visible spectroscopy (e.g., Machado et al. 2017, and refs. therein).

Back in 2007, we proposed to use the THEMIS solar telescope to get Doppler maps of Venus by scanning the planet in the visible with the 100-arcsec long slit spectrometer MulTiRaies (MTR) at a resolution of 100,000. We present the extensive analysis of the observation campaign we led in September 2009.

2. Results

In this presentation, we present the first complete Doppler snapshot of a planet in the visible domain: the map obtained on September 14th, 2009 is the result of integrating eight hours of data, which represents about 10 % of the rotation period at the cloud-top altitude (Fig. 1). Despite poor atmospheric seeing conditions ($\approx$ 3 arcsec), we unambiguously detect a clear retrograde rotation and meridional component.

From a technical point of view, this paper makes use of an innovative and sophisticated method to measure and analyze the radial velocities of planetary atmosphere (Gaulme et al. 2018), which is has also been applied to Jupiter (see abstract by Gonçalves et al.). It involves the consideration of biases caused by atmospheric seeing on radial velocities, as well as the development of a dedicated MCMC routine to model the data.

The first main result confirms what was expected from both cloud-tracking and recent spectroscopic observations: solid body rotation alone is not sufficient to model observations, and equator-to-pole meridional circulation is needed. However, we find amplitudes of zonal and meridional winds to be larger that previously measured. It is hard to compare the zonal wind values because we identify a strong longitudinal and latitudinal variation, however, no observations have indicated winds as large as 200 m s^{-1} at the morning terminator, so far. As regards meridional winds, we find an amplitude about twice larger than expected (about 45 instead of 20 m s^{-1} at mid latitudes).

The second main result is a "hot-spot" structure of the atmospheric circulation (see Fig. 2) of the zonal component, which had never been suggested that clearly so far. Cloud tracking measurements and Doppler spectroscopic measurements indicated possible longitudinal variations of the wind as function of local time, with faster circulation towards the terminator (e.g., Khatuntsev et al. 2013). However, no such *hot-spot* pattern had been identified. We conclude the presentation on observational prospects with the new instrument project JOVIAL/JIVE, specially designed for measuring atmospheric dynamics of planets with radial velocities in the visible (Gonçalves et al. 2016).

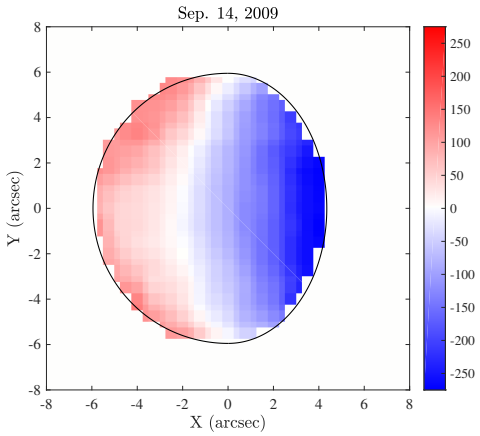

Figure 1: Radial velocity map obtained with the MTR/THEMIS long-slit spectrometer.

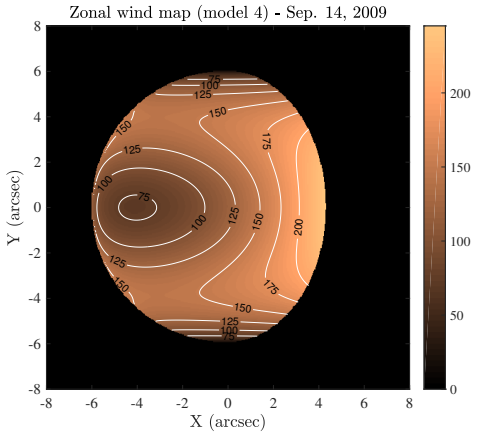

Figure 2: Map of zonal winds corresponding to the best-fit model of the data displayed in Fig. 1.

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