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First measurements of the Jovian zonal winds profile through visible Doppler spectroscopy

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Abstract

We present the first measurements of Jupiter's wind profile obtained from radial-velocity measurements. Radial velocity measurements of wind are rather difficult, but can be very interesting as they measure the actual speed of cloud particles instead of the motion of large cloud structures. Here we present the first scientific results of the Doppler spectro-imager JOVIAL-JIVE, dedicated to giant planets' seismology and atmospheric dynamics. The instrument provides instantaneous velocity maps in the mid-visible domain by monitoring the Doppler shift of solar Fraunhofer lines reflected in the planets' upper atmosphere thanks to an imaging Fourier transform spectrometer. We present profiles of the zonal wind speed of Jupiter as function of latitude from observations obtained between 2015 and 2017. Our results are compared with wind profiles obtained by cloud tracking from HST images at the same epoch. We point out comparable results from both techniques except at the latitude of the hot spots in the northern equatorial band ($\approx 5^\circ$ N) where we find a much lower wind speed.

1. Introduction

The *Juno* NASA spacecraft, which has been orbiting Jupiter since July 2016, aims at investigating the internal structure below the surface of the planet by measuring the gravitational moments. Very accurate values have been obtained so far [1]. However, interpreting these measurements depends on our ability to correctly model the dynamics of the surface layers, as the moments are sensitive to both local composition gradients and to underlying differential rotation, which are not easy to disentangle. Thus, accurate measurements of the dynamics of Jupiter's upper atmosphere are fundamental for interpreting *Juno*'s data.

In this paper, we present the first measurements of Jupiter's atmospheric zonal winds obtained with Doppler imaging spectroscopy in the visible domain. As we discuss in the next section, measuring atmospheric winds with radial-velocity techniques brings unique information, complementary to the traditional cloud tracking results.

2. Observations and results

2.1. Instrumental concept

The Doppler Spectro-Imager (DSI) is an instrument that produces radial velocity maps of extended objects. The instrument is a compact Mach-Zehnder (MZ) interferometer with a fixed Optical Path Difference (OPD) which provides four interferograms, whose fringes phase measures the Doppler shift of Fraunhofer lines between 519 and 520 nm. Its concept and performances are described in [2]. The instrument was developped in the context of the JUICE mission and a prototype was realized in this goal, which was tested on the sky in 2013. A new joint project (JOVIAL-JIVE) started in 2014 to set-up a network of three instruments around the Earth for continuous ob-

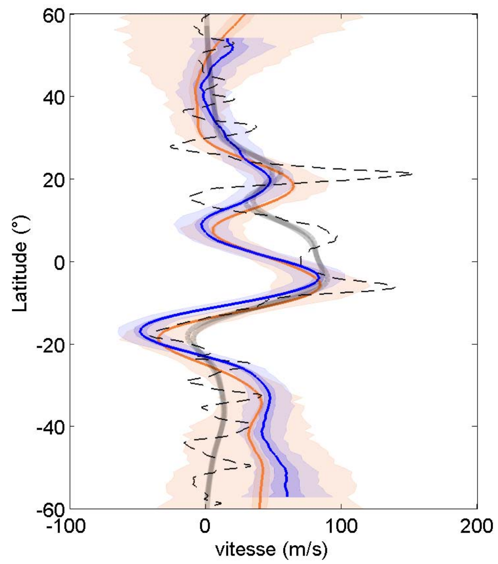

Figure 1: Zonal winds profile of Jupiter obtained with the Doppler Spectro Imager in 2016 (orange) and 2017 (blue) as compared with cloud-trancking measurements from HST data in 2016 (dashed line). For a better comparaison, we simulated a degraded wind profile from cloud-tracking using the same PSF as the DSI observations and shown here as gray lines.

servations. Here, we report observations carried out with the JOVIAL-JIVE instrument at the C2PU 1m telescope at Calern observatory near Nice. Observations were obtained near Jovian's opposition in Mars 2016 and April 2017.

2.2. Results

We show here the result from about 10 nights in 2016 and only one night in 2017. Images were obtained at a rate of two per minutes. The phase of the interferometric fringes is corrected from the instrumental phase, obtained on the diffused solar light during the day to produce a velocity map. A solid rotation model is first applied, then a linear fit along each line parallel to the equator on the remaining velocity map gives the mean zonal velocity as a function of the latitude. The spatial resolution is limited by the atmospheric seeing around 2 to 3 arcsec. The dispersion of these measurements is displayed in light color for each year, and compared to the theoretical photon noise in darker color.

Our zonal winds estimates are in complete agreement each year. We compare them with simulated Doppler measurements using the same angular resolution as DSI observations assuming that the actual velocity corresponds to cloud-tracking wind profile from HST observations [3]. Zonal profile from Doppler imaging are compatible with cloud-tracking zonal velocity profile, except in the northern equatorial band, between 0 and 15 degrees north, where a significative discrepancy can be seen. Several hypothesis can be formulated to explain this difference. Either the Doppler measurements can be sensitive to other components of the wind [4], or we are looking at different altitude, or the cloud-tracking itself doesn't reflect the actual particle speed. It has to be noticed that the northern equatorial band is known to exhibits almost periodic hotspots. These hotspots have been interpreted as the effect of Rossby waves, travelling westward upon faster jets [5]. Our measurements are apparently in contradiction with this interpretation but more has to be done to confirm our observations. We foresee new observations with a better angular resolution. However, it would be interesting to look for an interpretation of the Juno's data assuming a surface wind velocity compatible with our results.

Acknowledgements

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