EPSC Abstracts
Vol. 13, EPSC-DPS2019-1613-2, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Jupiter atmospheric dynamics from ground-based Doppler imaging

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Abstract

The JOVIAL/JIVE project aims at measuring motions at the surface of gaseous planets and to detect their acoustic oscillations using a series of dedicated Doppler spectro-imagers. The instruments detect small Doppler shifts of a set of optical solar lines reflected by the top of the giant planets clouds to infer the projected velocity at each point of the planetary surface. We focus here on retrieving new information on atmospheric dynamics of the giant planets and show how planetary rotation can be used to reconstruct velocity maps from ground-based observations [2]. Based on observations of Jupiter performed in 2018 at the Dunn Solar Telescope, we provide for the first time a Doppler zonal velocity map including longitudinal structure such as the Great Red Spot. We show that the method can provide vertical and meridional circulation as well. Preliminary analysis points to detectable vertical motion at the limit between the equatorial belts and the tropical zones of Jupiter.

1. Introduction

The atmosphere of giant planets, and in particular of Jupiter, is subject to strong winds and huge dynamical processes. Juno has revealed new behavior about this dynamics, and in particular the fact that the zonal flow observed by cloud-tracking and the asymmetry between the Northern and Southern hemispheres extends to about 3000 km depth [4]; [3]. However, cloud-tracking can only give a 2D view of the motion at the surface, and can be biased by the presence of waves controlling the shape of the clouds. Doppler spectroscopic measurements can reveal complementary components of the winds, in particular by providing the velocity along the line-of-sight. Such observations are very difficult both to measure and to interpret. In this presentation, we will summarize the observations that were conducted with a dedicated Doppler imaging instrument (JIVE-JOVIAL) and the main results that were obtained after a careful data processing. We will in particular present maps of zonal and vertical components of the winds.

2. Observations

In paper [2], we explained the principle of the JOVIAL Doppler imager and described its performances on observations carried out of Jupiter in 2016 and 2017. In the present paper, we use observations obtained with the same instrument at the Dunn Solar Telescope at Sunspot, New Mexico, between May 4th and May 30th, 2018. A total of 110 hours were obtained over 16 nights. Unlike previous observations, the seeing quality was quite good, 1 arcsec in average. The calibration and data processing is described in [2]. One improvement of the measurements came from the telescope configuration [5] where the whole focus room can rotate around the azimuthal axis, allowing us to take images with different orientations of the instrument in order to calibrate the instrumental effects linked to the alignment of the images on the detector.

2.1. Reconstruction of the 2D maps

In the previous work, we mainly derived a zonal wind profile from the individual velocity images. Here, we tried to reconstruct full velocity maps on planispheres. In order to do so, we first corrected the Doppler images from the effect of the PSF, as explained in [1]. We use then the projection factor corresponding to the different components of the wind to deproject the Doppler data onto a planisphere of Jupiter. In principle, Doppler images are insensitive to zonal velocities on the central meridian of the planet, as the motion is perpendicular to the line-of-sight at that location. Due to Jupiter's rotation over the course of one night, each image corresponds to a different central longitude on Jupiter, and therefore will be projected on the map at different positions and averaged together. At a given longitude of the planisphere, many different images will be averaged with a weight corresponding to their SNR. This results in a complete planisphere for each velocity components. The meridional component is still affected with a high noise level near the equator, as all observations are obtained from the Earth, almost in the equatorial plane. To the contrary, the vertical component is well recovered around the equator.

2.2. Results

We display here the zonal component map. A comparison was made with OPAL observations of Jupiter with HST, obtained at the same epoch. The zonal map is very similar to what can be obtained from cloud-tracking. In [2], we noticed a lower velocity in the north of the Equatorial Zone. In these new measurements, we still observe a reduction of the velocity in this region, but smaller. We see the presence of the Great Red Spot, which is visible as a shear in the zonal velocity above and below the GRS. After removal of the systematics errors, the noise level on the map is of the order of a few m/s.

We can also produced vertical and meridional components maps. The vertical component and the meridional component maps only differ by a factor depending of the planetocentric latitude [1].We observe a vertical downflow or meridional motion at the limit between the Equatorial Belt and the Tropical Zone. There is no way to distinguish between both components, as all measurements are obtained in the equatorial plane. The interpretation of these maps requires complementary measurements as can be obtained by cloud-tracking and careful modeling, before we can conclude on the existence of vertical motion.

3. Summary and conclusion

We have shown that Doppler imaging can provide precise information, complementary to cloud-tracking, about atmospheric dynamics of gaseous planet. In the case of Jupiter, we can produce velocity maps for different velocity components by combining images obtained from a complete rotation of the planet. We show a full map of the zonal wind that can be compared with cloud-tracking images. The techniques allow us to study also vertical motions. The observations were limited by the terrestrial atmospheric turbulence. The quality of the results could be improved by using simultaneously an Adapted Optics system, which will be developed for that purpose. Ultimately, a dedicated space mission around the planet would provide much more precise data and would allow to recover the whole dynamical structure.

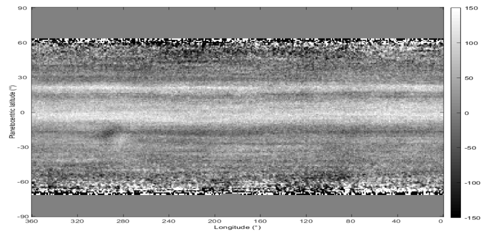

Figure 1: Map of the zonal component of the wind, obtained from 16 nights of observations. The colorscale is in m/s, brighter for prograde velocity (eastward)

Acknowledgements

This work was possible thanks to the ANR JOVIAL and the JIVE in NM NASA EPSCOR programme. Ivan Gonçalves was supported by OCA.

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