Wind measurements in Saturn’s atmosphere using Doppler velocimetry techniques from ground-based observations


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Observations

- Our team’s 2004 ESO proposal with VLT’s UVES spectrograph
- Almost coordinated observations with Cassini’s arrival at Saturn in April 2004
- Applied to the backscattered solar Fraunhofer lines present in high resolution spectra in the 478-680 nm range.

![Image](image.jpg)

**Figure 3.12:** Geometry of the slit positions at the observation days. Saturn’s diameter is 17.4”, and the slit aperture is 0.3⁰×23⁰. The aperture offset between consecutive exposures is 1”. The sub-terrestrial point is at 26.1°S.

<table>
<thead>
<tr>
<th>Night of observations</th>
<th>Seeing (min - max)</th>
<th>Airmass (min - max)</th>
<th>Latitudes (on central meridian)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-04-2004</td>
<td>1.02 - 1.64</td>
<td>1.82 - 2.20</td>
<td>69S - 38N</td>
</tr>
<tr>
<td>19-04-2004</td>
<td>0.57 - 0.90</td>
<td>1.87 - 2.28</td>
<td>69S - 38N</td>
</tr>
<tr>
<td>20-04-2004</td>
<td>0.47 - 1.00</td>
<td>1.87 - 2.29</td>
<td>90S - 16N</td>
</tr>
<tr>
<td>21-04-2004</td>
<td>0.56 - 0.96</td>
<td>1.94 - 2.50</td>
<td>90S - 16N</td>
</tr>
<tr>
<td>29-04-2004</td>
<td>1.31 - 1.86</td>
<td>1.90 - 2.21</td>
<td>60S - 65</td>
</tr>
<tr>
<td>01-05-2004</td>
<td>0.69 - 1.09</td>
<td>1.89 - 2.07</td>
<td>60S - 65</td>
</tr>
</tbody>
</table>

**Table 3.1:** Summary of Saturn’s main observations.

**Table 3.3:** Specifications of the UVES’s ccd detectors.
Spectra Analysis

- Dynamical regime of differential rotation in latitude ("Systems" I, II and III)
- Telluric Lines
- Planetary Contribution
- Fraunhofer Lines (with an eco-Doppler)
- Bands of methane, ammonia and hydrogen molecules (single Doppler)

Credits: A. Sánchez-Lavega
Figure 2.8: Visible spectra of the gas giants. Here we can see the prominent absorption bands from methane. We can find that a small absorption band from methane is in the range of the wavelengths covered by UVES in this work, which will affect considerably the retrieved Doppler velocities. (Courtesy of Sánchez-Lavega, June 2016)
Slit' active window

<table>
<thead>
<tr>
<th>Slit position</th>
<th>No of pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>51</td>
</tr>
<tr>
<td>5</td>
<td>81</td>
</tr>
<tr>
<td>6</td>
<td>81</td>
</tr>
<tr>
<td>7</td>
<td>91</td>
</tr>
<tr>
<td>8</td>
<td>97</td>
</tr>
<tr>
<td>9</td>
<td>97</td>
</tr>
<tr>
<td>10</td>
<td>97</td>
</tr>
<tr>
<td>11</td>
<td>91</td>
</tr>
<tr>
<td>12</td>
<td>81</td>
</tr>
<tr>
<td>13</td>
<td>81</td>
</tr>
<tr>
<td>14</td>
<td>51</td>
</tr>
<tr>
<td>15</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 3.2: Number of pixels of the slit's active window at each position.
Doppler Velocimetry Basis

\[
\frac{\delta V_n}{c} = \frac{\delta \lambda}{\lambda} \quad \text{and} \quad I_n - I \approx \frac{\partial I}{\partial \lambda} \delta \lambda
\]

\[
\frac{\delta V_n}{c} = \frac{I_n - I}{\lambda(\frac{\partial I}{\partial \lambda})_{\lambda=\lambda(i)}}
\]

\[
\delta v_i = \frac{c}{\lambda(i)} \delta \lambda_i = \frac{I(i) - I_0(i)}{\lambda(i) (\frac{\partial I}{\partial \lambda})_{\lambda=\lambda(i)}}
\]

\[
\delta v = \frac{\sum \delta v_i \omega_i}{\sum \omega_i} \quad \text{where} \quad \omega_i = \frac{1}{\sigma^2[\delta v_i]}
\]

\[
\sigma[\delta v] = \frac{1}{\sqrt{\sum \omega_i}}
\]

Figure 3.10: Algorithm for obtaining the radial velocity using only a single spectral line shift. (Luz et al. 2009).
Spurious Contributions for wind velocity retrieval

1. Orbital shift (OS) induced by Earth-target orbital motion.
\[ \Delta V = F \cdot V + Y + OS. \]

2. Young effect
\[ Y = 3.2 \tan(SZA) \]

3. Geometric projection factor, due to the spherical geometry
\[ F \cdot V = V \cdot \cos(\phi/2) \sin(\phi - \phi/2) \cos \beta \]
**Doppler Shifts**

- Doppler shift vs pixel position
- Navigation of the images (attribution of planetocentric coordinates)
- De-project from the line of sight
- Subtract the planetary rotation velocity (System III)

![Figure 3.15](image1.jpg): Retrieved relative Doppler shift for each pixel surveying the long slit, with the central pixel passing on the planetary equator. EEV detector on blue and MIT detector on red in the figure. The measured Doppler shifts are along the line-of-sight from Earth.

![Figure 3.16](image2.jpg): This figure shows the Doppler shifts obtained in the previous step, but now as a function of the sub-Earth longitude of Saturn. The correspondence pixel-longitude was made based on the spherical geometry of Saturn. In one of the scripts (for Figure 3), I used the specific observations' geometry for yielding the correspondence between each detector's pixel (along the slit) at each offset, in order to calculate the latitude and sub-Earth longitude of each pixel upon the planetary disk. The zero longitude is by convention at the sub-Earth point meridian; that is in the middle of the disk.

![Figure 3.17](image3.jpg): Overall planetocentric Doppler shifts for each CCD detector, de-projected from the line-of-sight. EEV detector on blue and MIT detector on red in the figure.
Doppler velocities
Key Adjustments/Calibrations

- Removal of MIT spectral orders affected by methane bands
- Exposure Time -> Excess velocity
- Disentangle the planetary contribution from the back-scattered solar radiation
Rings

Cannot survey latitudes above 22° N
Pressure Levels and Altitudes

Figure 4.1: Saturn transmission at visible wavelengths with the respective atmospheric pressure levels through the visible and near-infrared wavelengths. (Source: Patrick Irwin (Oxford University), private communication)

<table>
<thead>
<tr>
<th>CCD</th>
<th>Number of spectral orders</th>
<th>Wavelength coverage (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIT</td>
<td>16</td>
<td>478-575</td>
</tr>
<tr>
<td>EEV</td>
<td>23</td>
<td>584-680</td>
</tr>
</tbody>
</table>

Table 3.3: Specifications of the UVES's ccd detectors

Courtesy of P. Irwin
Latitudinal Profile

![Graph showing wind velocity vs. latitude](image)

- **Wind Velocity (m/s)**
- **Latitude (degrees)**

**Legend:**
- Doppler Winds - VLT/UVES 2004

**Rings**

**M. SILVA**

Riga 20 Sep 2017
Latitudinal Profile
Data Comparison

![Data Comparison Diagram]

- Doppler Winds - VLT/UVES 2004
- CB2 CT Cassini2014 350-750 mbar

Latitude (degrees)

Wind Velocity (m/s)
Data Comparison
Data Comparison
Data Comparison

![Graph showing zonal velocity vs. planetocentric latitude](image)
Prospects

Retrieve the velocity associated to the planetary contributions while sounding different pressure levels.

Adapt the method to Jupiter’s atmosphere with a collaboration with the JUNO mission.

Adapt our Doppler velocimetry technique to the near-infrared wavelengths with data from CARMENES.
Thank you for your kind attention