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

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EPSC – Riga, September 20th, 2017

Observations

- Our team’ 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.

CCD	Number of spectral orders	Wavelength coverage (nm)
MIT	16	478-575
EEV	23	584-680

Table 3.3: Specifications of the UVES’s ccd detectors

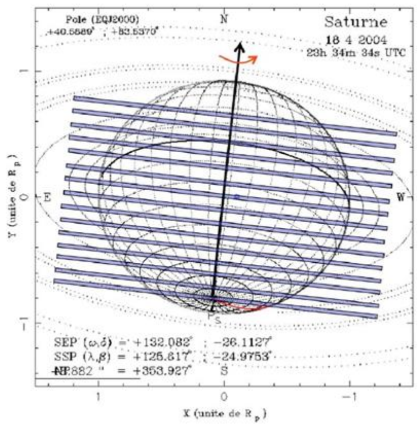


Figure 3.12: Geometry of the slit positions at the observation days. Saturn’s diameter is 17.4", and the slit aperture is 0,3"×25" . The aperture offset between consecutive exposures is 1". The sub-terrestrial point is at 26.1°S.

Night of observations	Seeing (min - max)	Airmass (min - max)	Latitudes (on central meridian)
18-04-2004	1.02 - 1.64	1.82 - 2.20	69S - 38N
19-04-2004	0.57 - 0.90	1.87 - 2.28	69S - 38N
20-04-2004	0.47 - 1.00	1.87 - 2,29	90S - 16N
21-04-2004	0.56 - 0.96	1.94 - 2.59	90S - 16N
29-04-2004	1.31 - 1.86	1.90 - 2.21	60S - 6S
01-05-2004	0.69 - 1.09	1.89 - 2.07	60S - 6S

Table 3.1: Summary of Saturn’s main observations.

Spectra Analysis

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

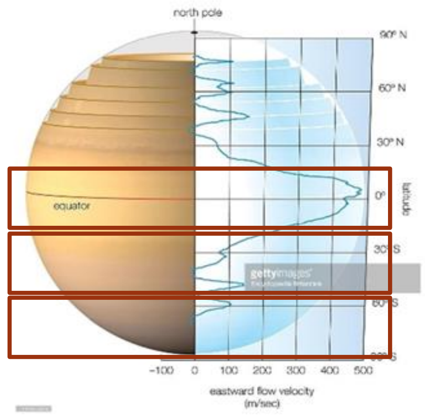
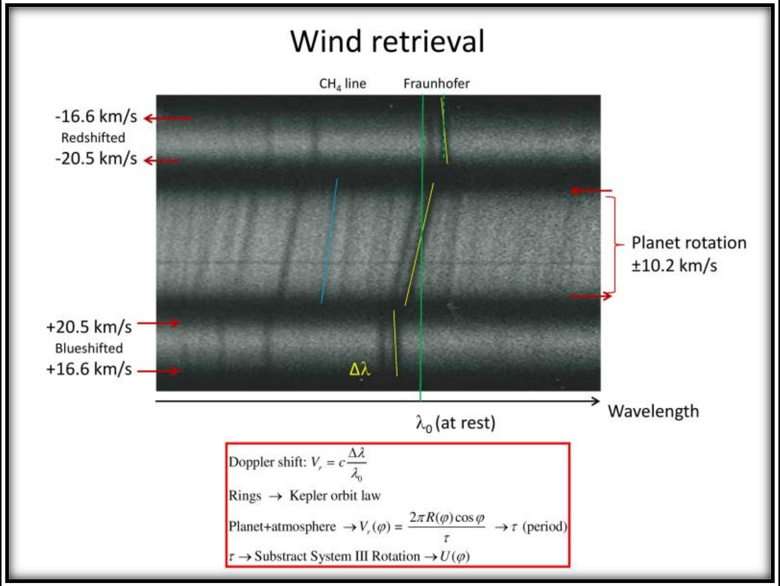


Figure 2.4: Approximation of the latitudinal profile of the wind speeds in the Saturn’s atmosphere. (Source: http://www.gettyimages.pt/fotos/saturn-wind-speed)



Credits: A. Sánchez-Lavega

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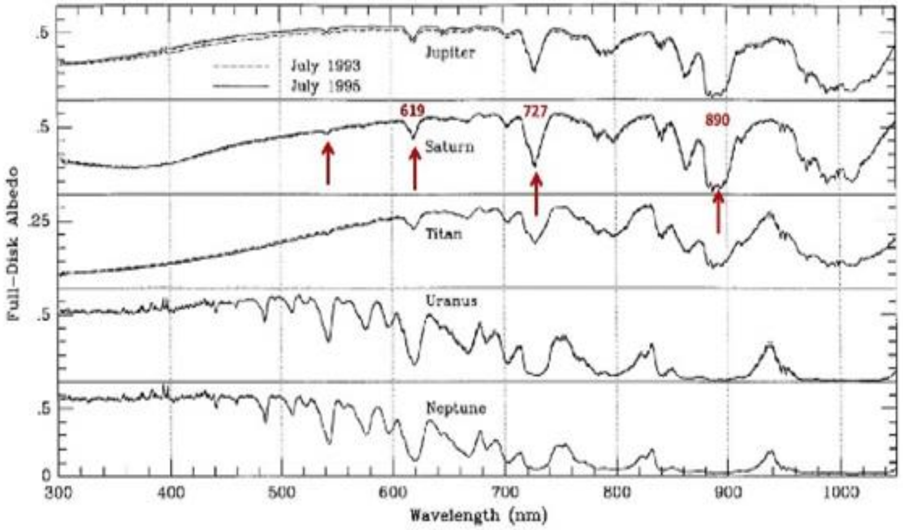

Figure 2.8: Visible spectra of the gas giants. Here we can see the prominent absorption bands from methane. We can find that a small absorption band from methane is in the range of the wavelengths covered by UVES in this work, which will affect considerably the retrieved Doppler velocities. (Courtesy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

Methane bands

Band	Range
460 nm	458-463 nm
470 nm	463-479 nm
486 nm	479-490 nm
496 nm	490-502 nm
509 nm	502-514 nm
516 nm	514-518 nm
523 nm	518-527 nm
543 nm	527-552 nm
557 nm	552-564 nm
576 nm	564-586 nm
596 nm	586-605 nm
619 nm	605-633 nm
667 nm	633-678 nm
683 nm	678-691 nm
703 nm	691-711 nm
727 nm	711-748 nm
790 nm	748-831 nm
841 nm	831-850 nm
864 nm	850-875 nm
890 nm	875-941 nm

523 nm + 543 nm
596 nm + 619 nm
703 nm + 727 nm
841 nm + 864 nm + 890 nm

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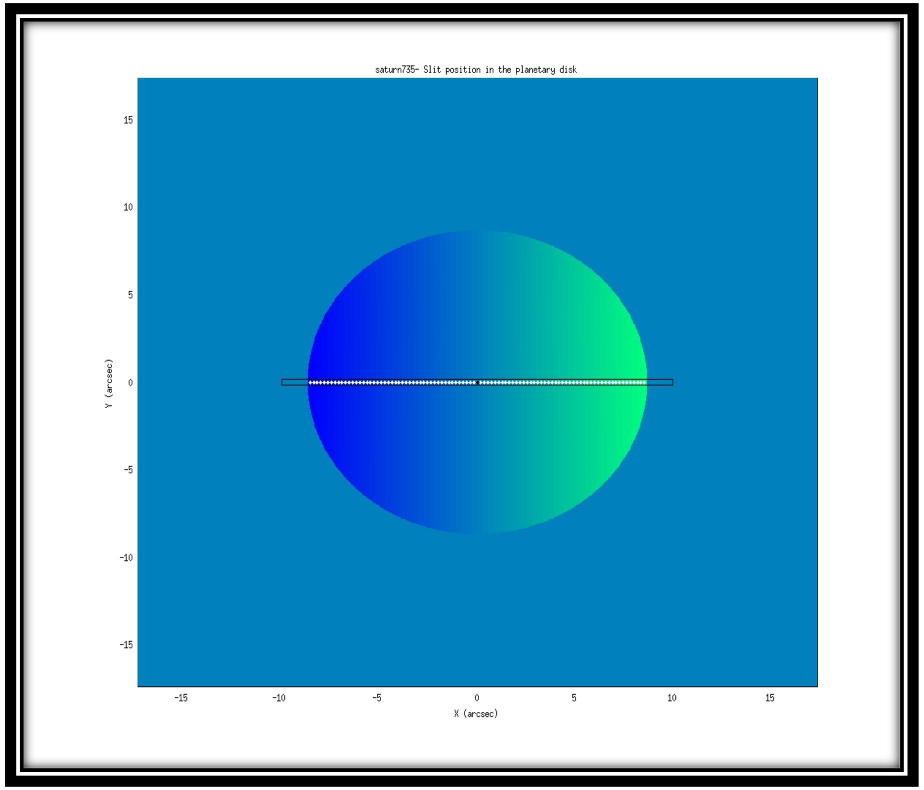
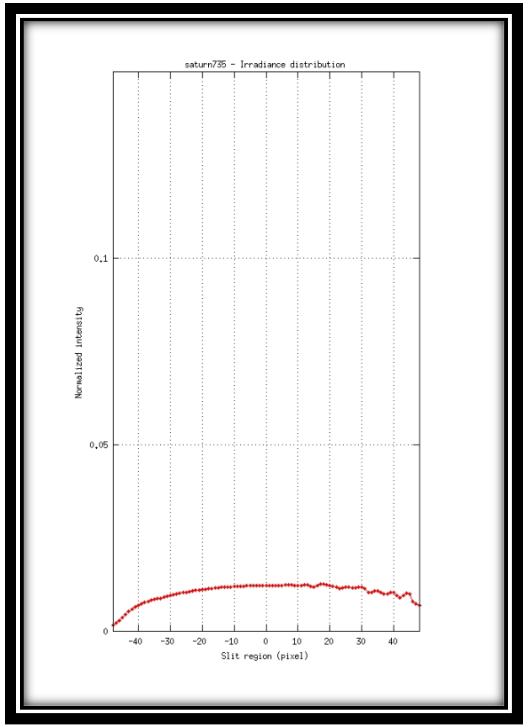
Slit' active window





Slit position	No of pixels
4	51
5	81
6	81
7	91
8	97
9	97
10	97
11	91
12	81
13	81
14	51
15	41

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

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Doppler Velocimetry Basis

$$\frac{\delta V_n}{c} = \frac{\delta\lambda}{\lambda}$$

$$I_n - I \approx \frac{\partial I}{\partial \lambda}\delta\lambda$$

$$\frac{\delta V_n}{c} = \frac{I_n - I}{\lambda \frac{\partial I}{\partial \lambda}}$$

$$\delta v_i = \frac{c}{\lambda(i)}\delta\lambda_i = \frac{I(i) - I_o(i)}{\frac{\lambda(i)}{c}\left(\frac{\partial I_o}{\partial \lambda}\right)_{\lambda=\lambda(i)}}$$

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

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

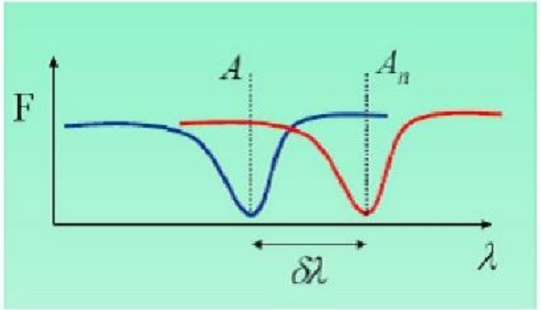

Figure 3.10: Algorithm for obtaining the radial velocity using only a single spectral line shift. (Luz et al. 2009).

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

$$F \cdot V = V \cdot 2\cos(\Phi/2)\sin(\varphi - \Phi/2)\cos\beta$$

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)

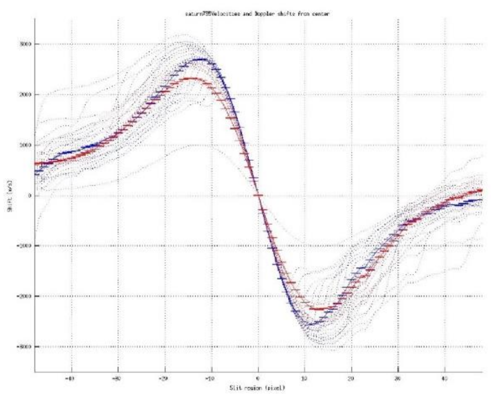

Figure 3.15: Retrieved relative Doppler shift for each pixel surveying the long slit, with the central pixel passing on the planetary equator. EEV detector on blue and MIT detector on red in the figure. The measured Doppler shifts are along the line-of-sight from Earth.

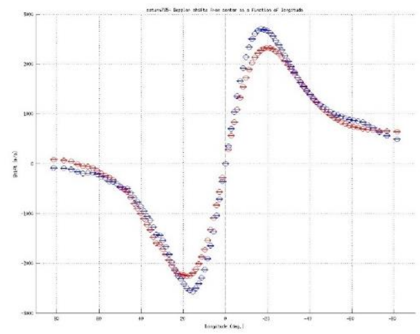

Figure 3.16: This figure shows the Doppler shifts obtained in the previous step, but now as a function of the sub-Earth longitude of Saturn. The correspondence pixel-longitude was made based on the spherical geometry of Saturn. In one of the scripts (*getlatton.m*) I used the specific observations' geometry 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.

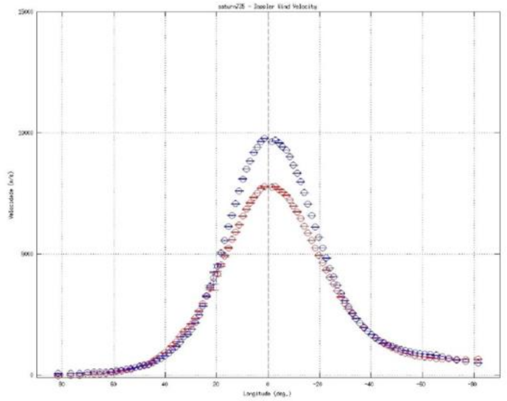

Figure 3.17: Overall planetocentric Doppler shifts for each CCD detector, de-projected from the line-of-sight. EEV detector on blue and MIT detector on red in the figure.

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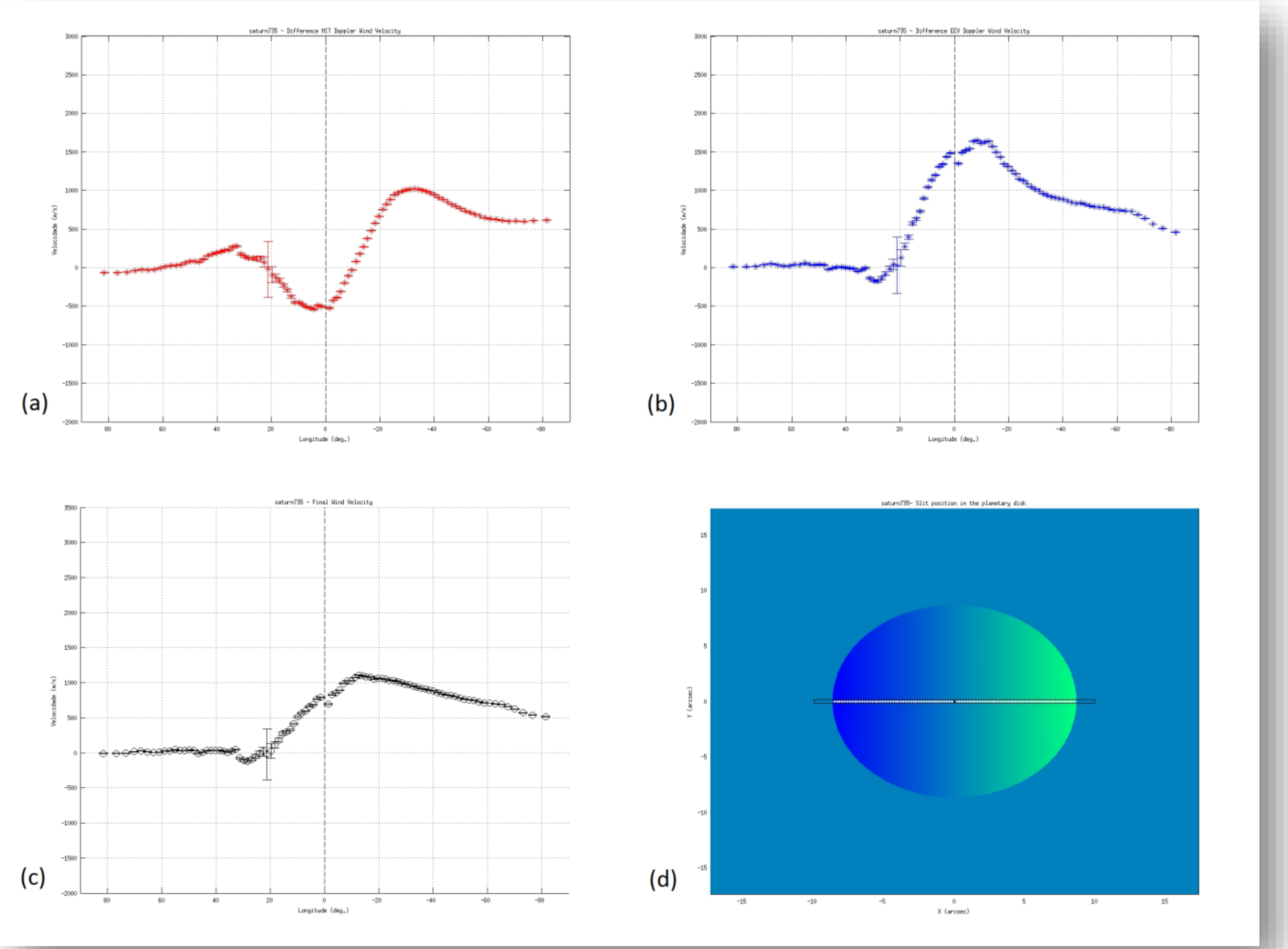
Doppler velocities



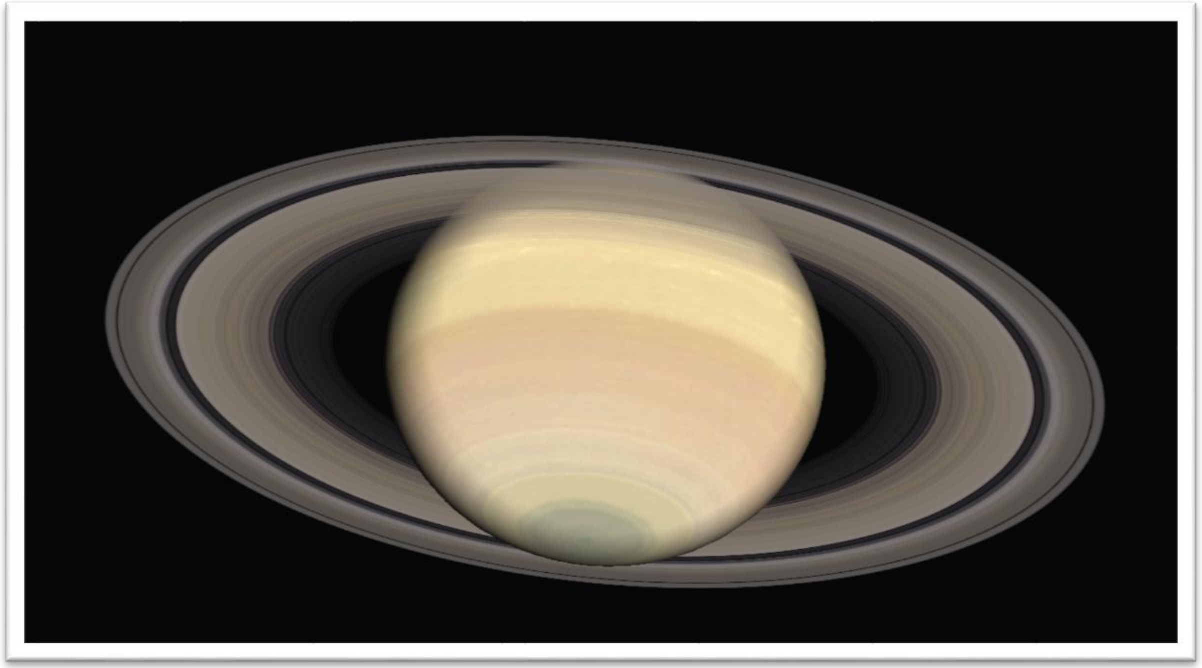
Key Adjustments/Calibrations

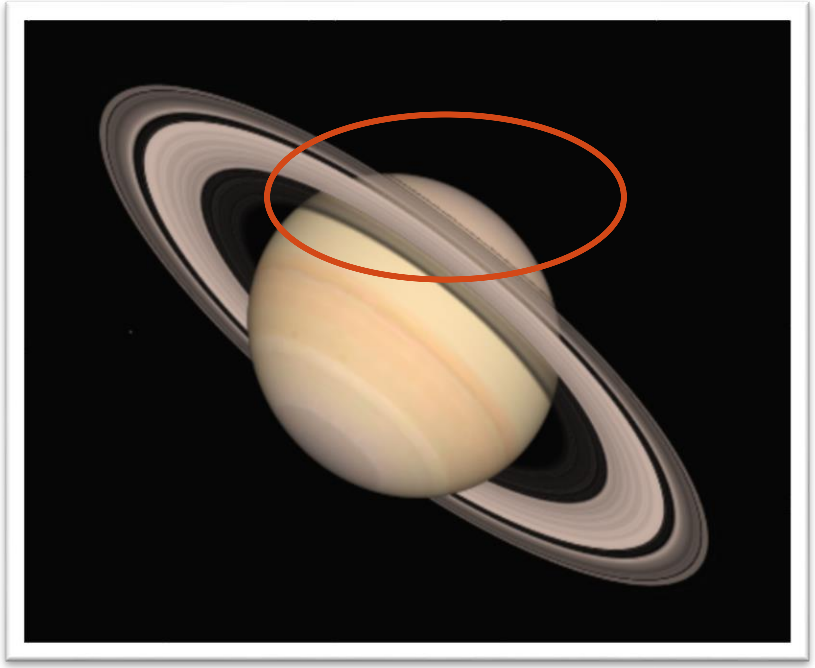
Removal of MIT spectral orders affected by methane bands

Exposure Time -> Excess velocity

Disentangle the planetary contribution from the back-scattered solar radiation

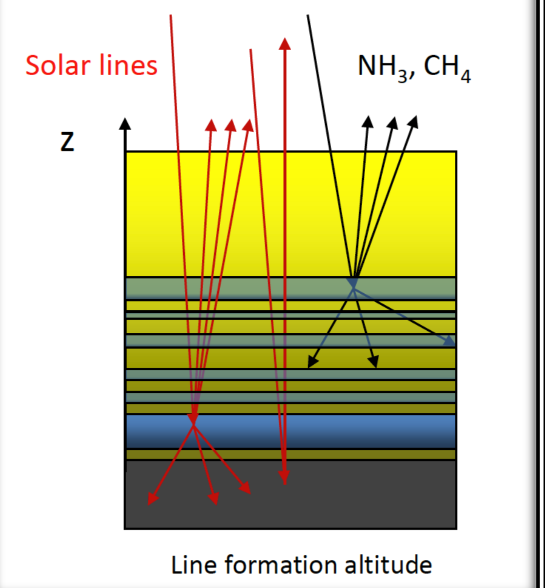
Rings





Cannot survey latitudes above 22° N

Pressure Levels and Altitudes



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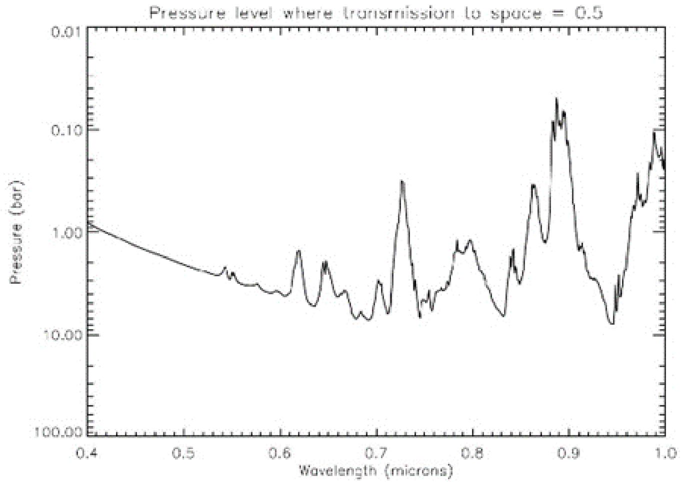
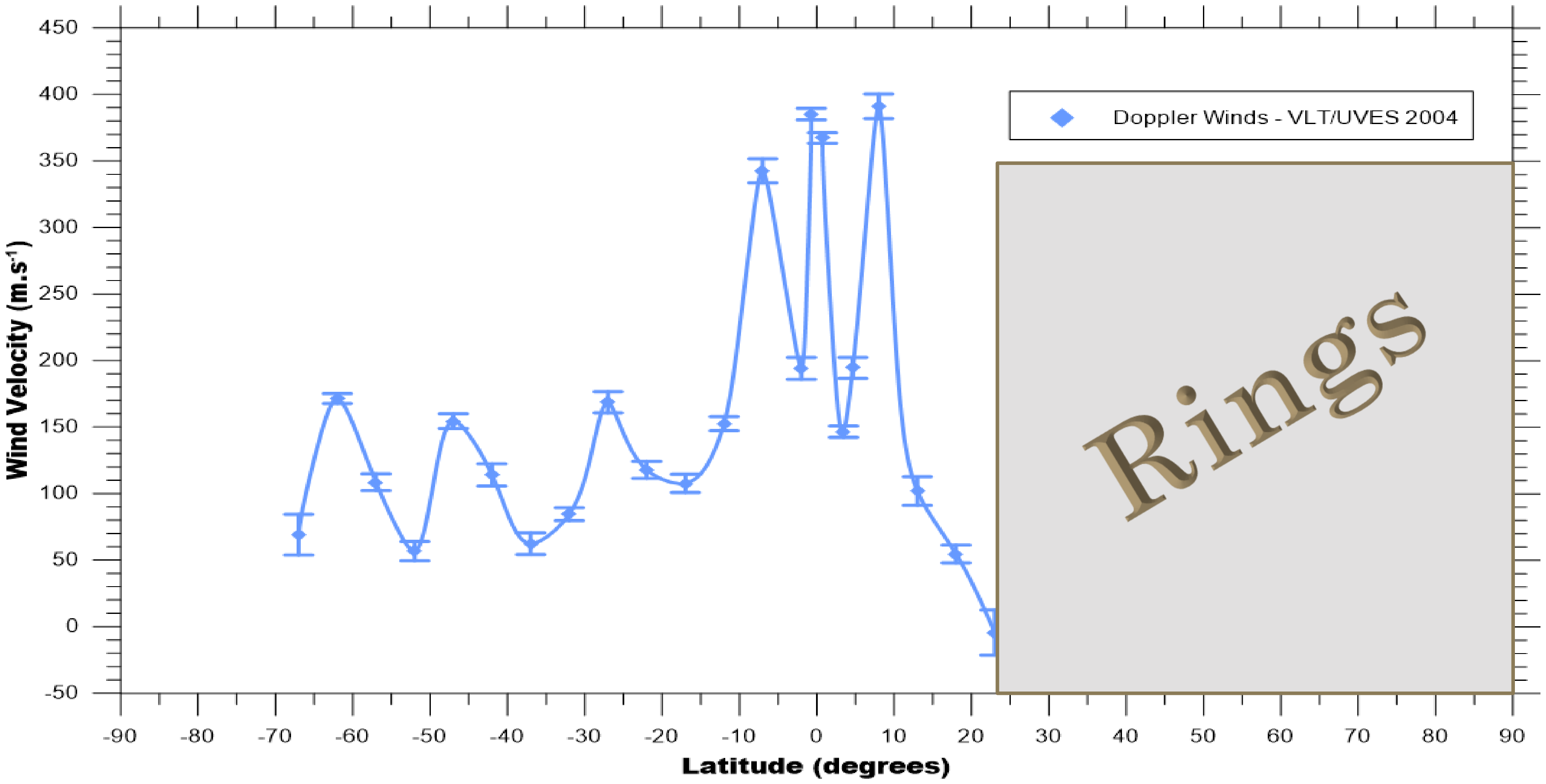


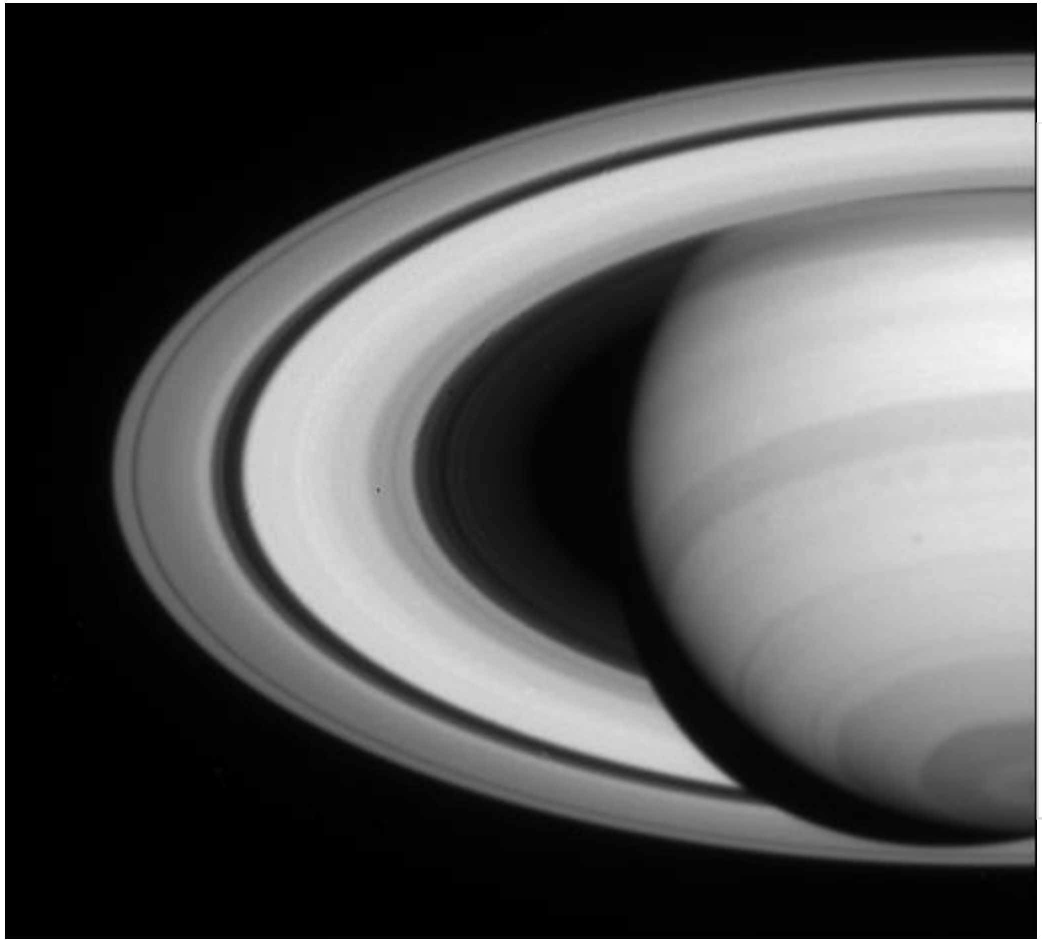
Figure 4.1: Saturn transmission at visible wavelengths with the respective atmospheric pressure levels trough the visible and near-infrared wavelengths. (Source: Patrick Irwin (Oxford University), private communication)

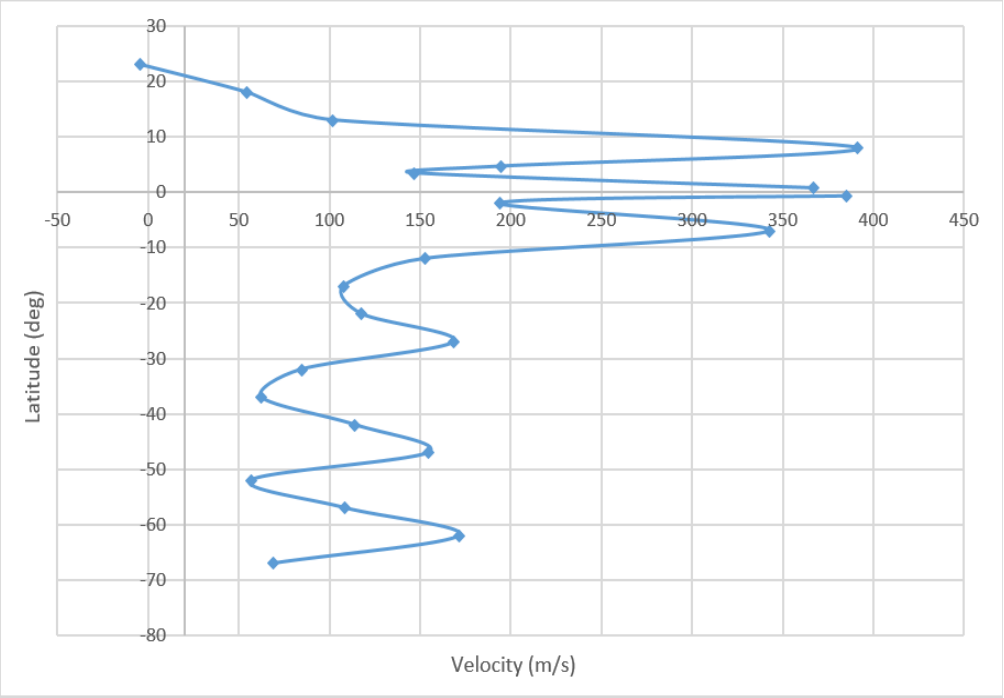
Courtesy of P. Irwin

Latitudinal Profile



Latitudinal Profile





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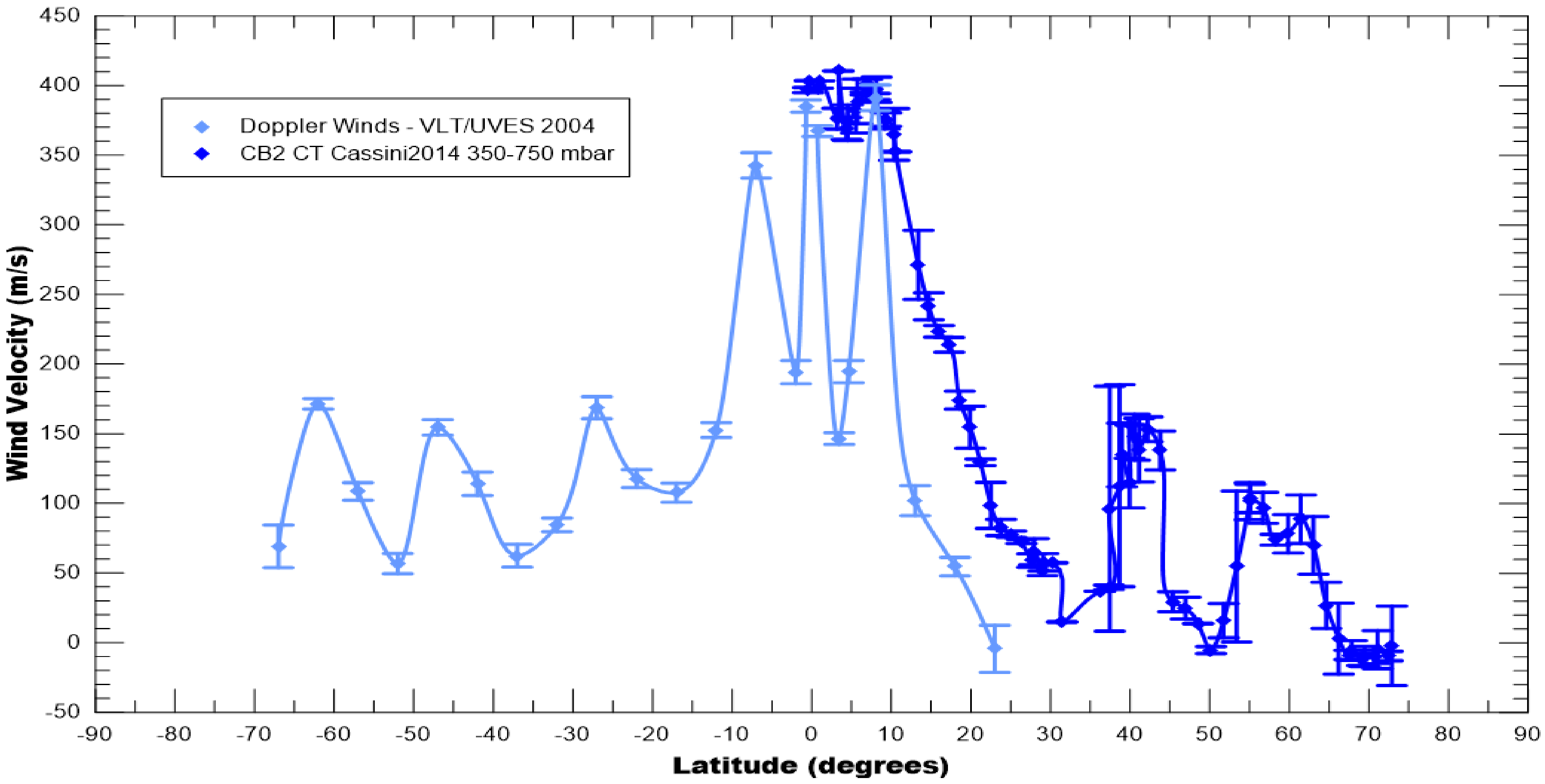
Data Comparison



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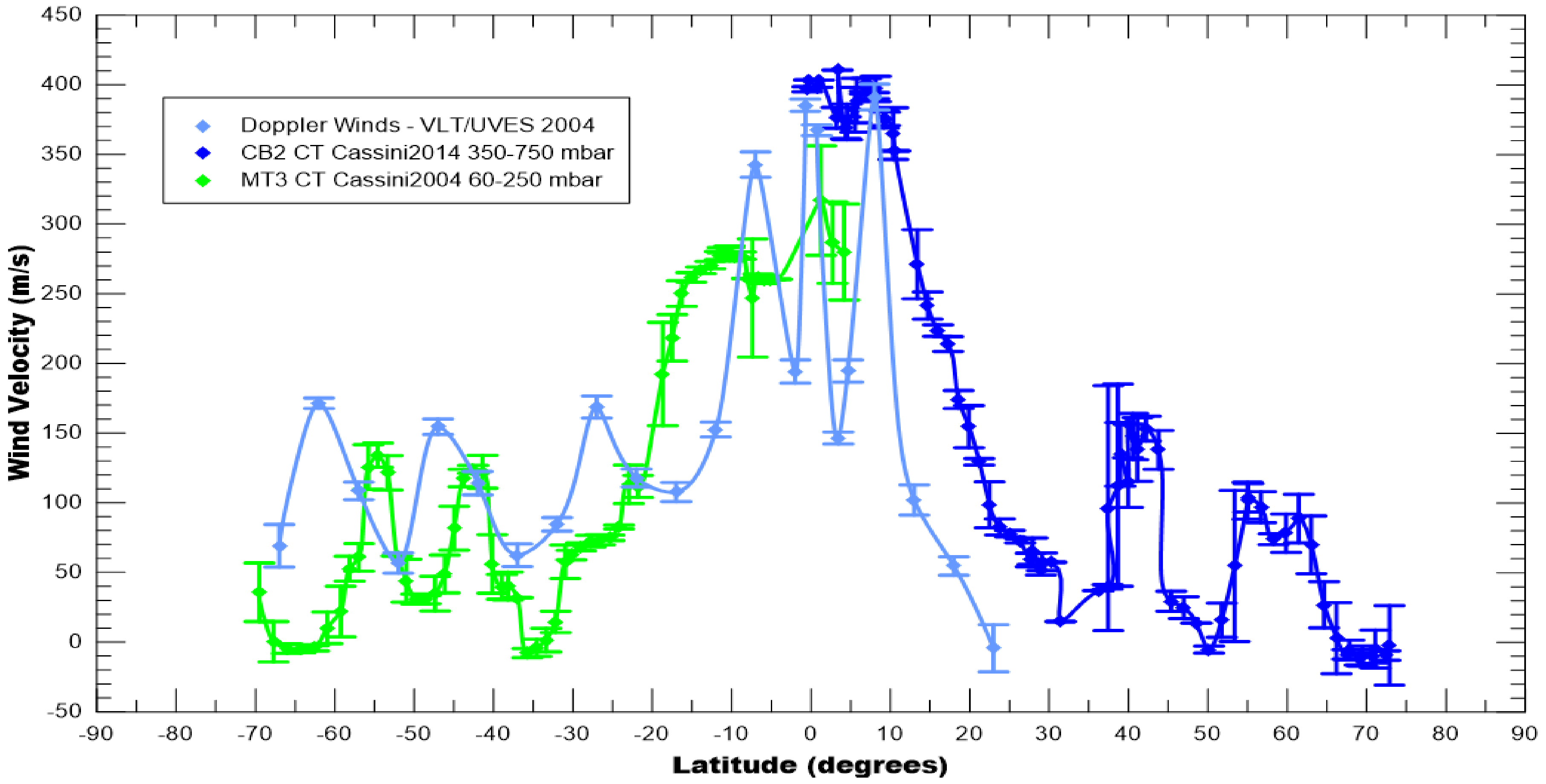

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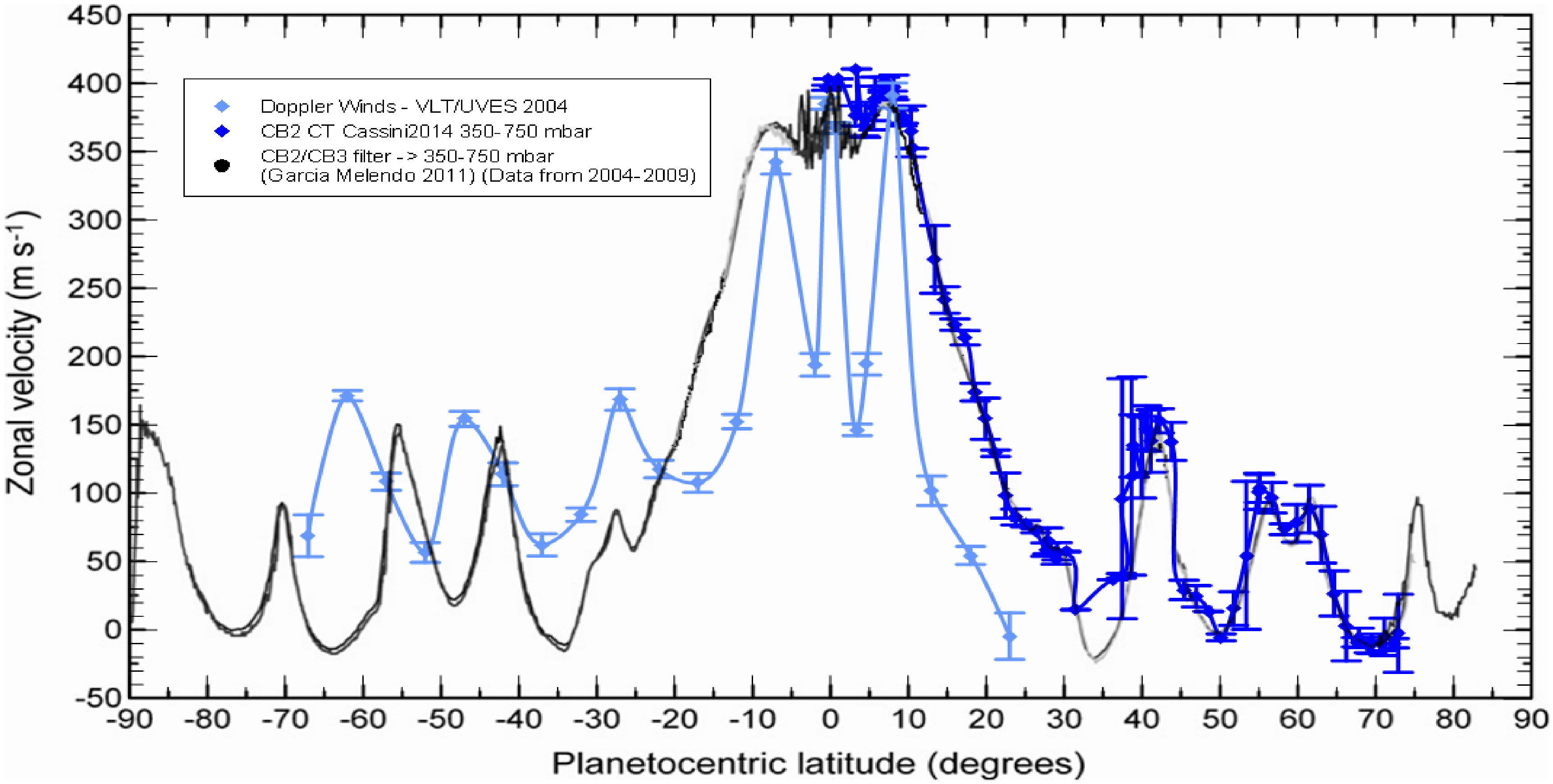

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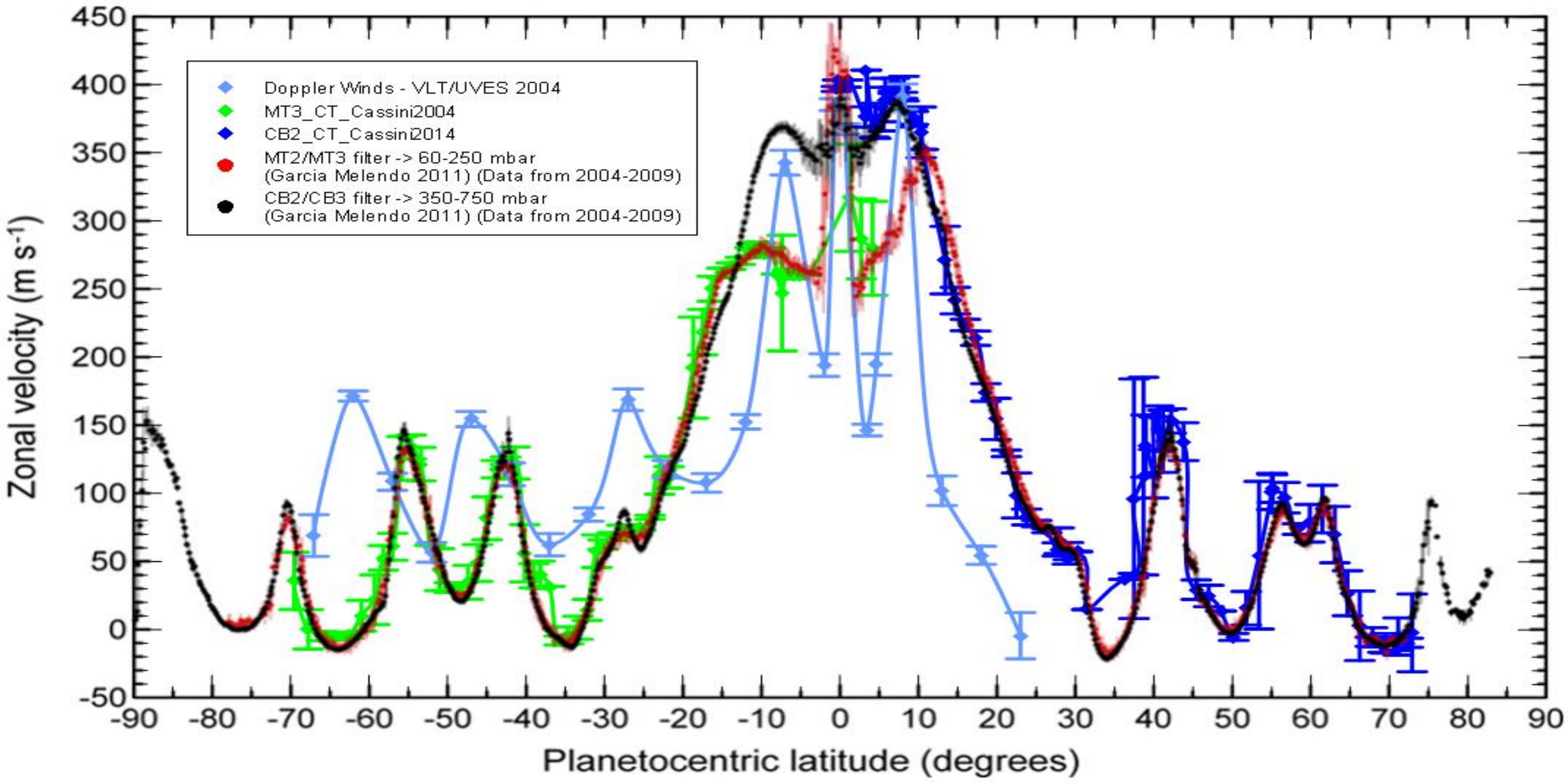
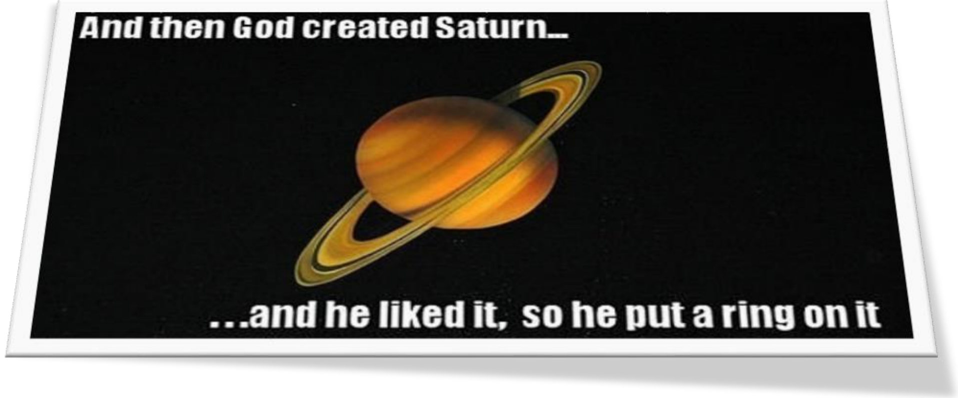


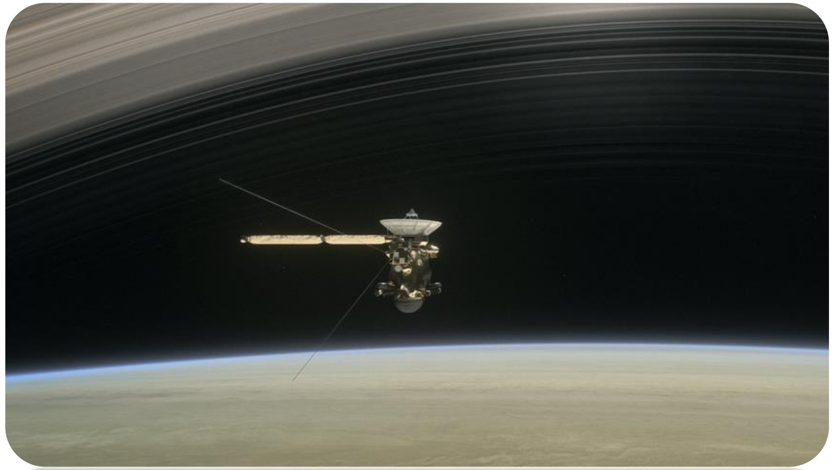
Prospects

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 atention