Temporal variations in spectral reflectivity and vertical cloud structure of Jupiter's Great Red Spot and its surroundings

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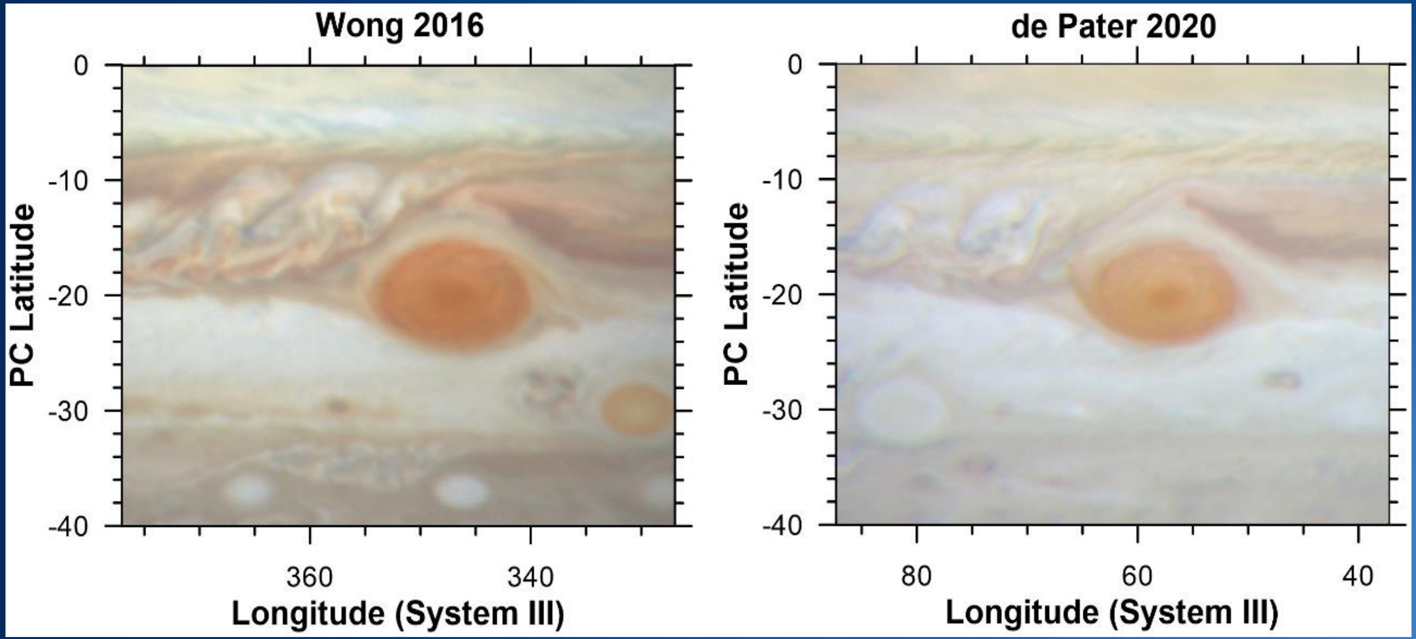
1. HST/WFC3 DATA

- We use HST/WFC3 images obtained between years 2015 and 2021. The images were photometrically calibrated in absolute reflectivity *I*/*F* and projected into planispheres with 0.1°/pixel resolution.

- The wavelength range spans from the UV to the near IR, with two methane bands of different depths

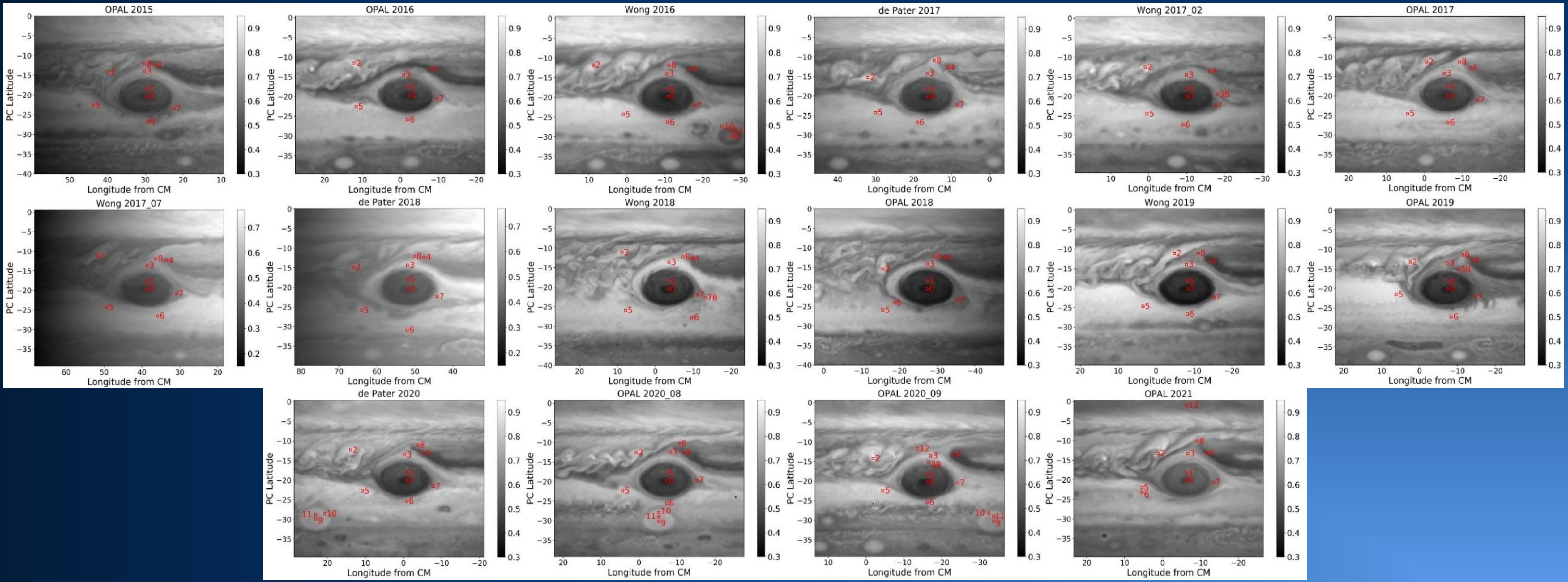
- All the planispheres in which the GRS is present were cropped covering the same region around it. The cropped planispheres have a latitudinal extent of 40° (400 pixels) and a longitudinal extent of 50º (500 pixels), and as the GRS is almost constantly located at 20°S, the planispheres cover latitudes from 0 to 40°S.



2. ANALYSIS

Region selection

- We study 13 regions in the GRS area. We choose the ones of greatest interest from the dynamical point of view or are morphologically outstanding.
- Worthy of note is oval BA, which suffered a color change from red to white in 2018-2019. We pick 3 regions in the oval: 1) the nucleus, 2) periphery of white clouds and 3) interior annulus in which the color change was most significant.



Color analysis

- We use the technique introduced by Sánchez-Lavega et al. (2013) by obtaining two different reflectivity ratios that provide a relative measure of color and altitude/opacity, and are thus called Color Index (CI) and Altitude/Opacity Index (AOI)

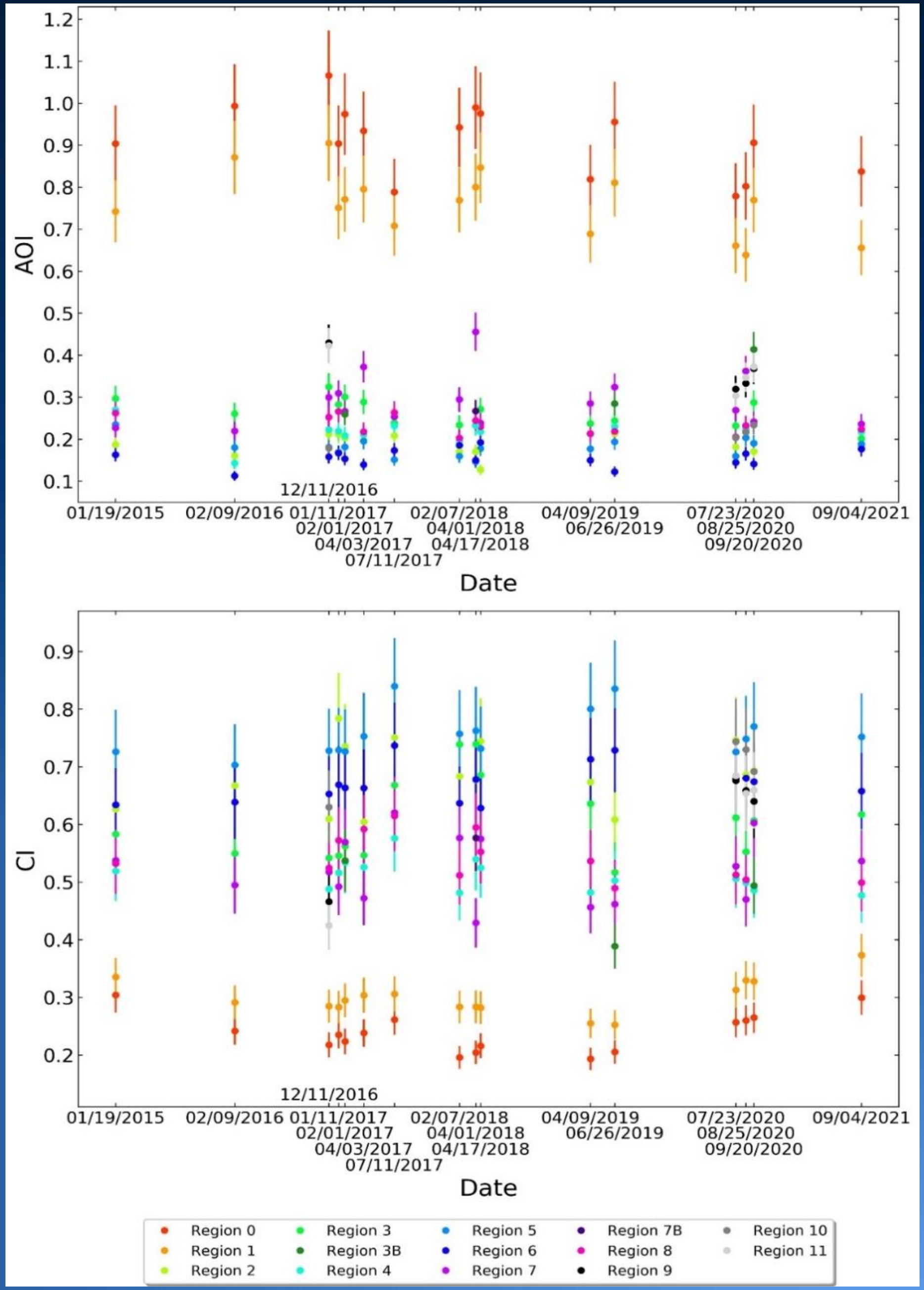
$$CI = \frac{I/F(F395N)}{I/F(F631N)}$$

$$AOI = \frac{I/F(FQ889N)}{I/F(F275W)}$$

- The AOI indices for the GRS nucleus and interior indicate a decrease in altitude/opacity from 2016 to 2021. On the other hand, the CI values for those regions increase, indicating that the GRS became less reddish in recent years.

- The AOI values for oval BA nucleus and ring also show a slight decrease from 2016 to 2020, whilst its periphery shows no major temporal differences. The CI values of these regions, however, show an overall increase from 2016 to 2021, with the most noticeable change in the nucleus and interior ring.

- The high variability in some other regions, such as regions 2, 3, 7 and 8, is due to the fact that they are highly dynamical and may change abruptly in a short time span.

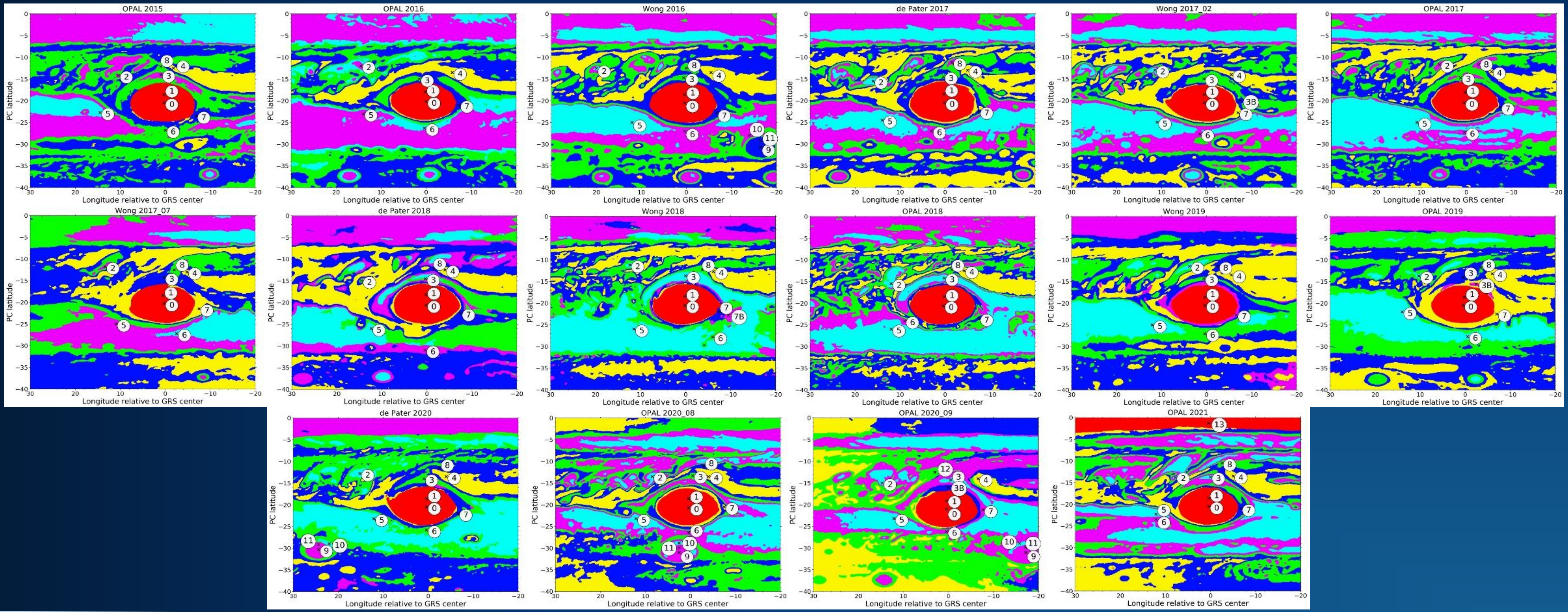


Spectral clustering

- Combining planispheres of all filters we get a spectrum per pixel. Then, all the pixel spectra are classified in the specified number of clusters, which was chosen to be 6 by visual inspection of the result. The clustering is performed using the *k*-means algorithm (Pérez-Hoyos et al., 2012).

- The red oval is classified in a spectral group that is independent from the rest of regions, as expected from the color analysis. The only exception is the Equatorial Zone in year 2021, which showed a reddish coloration.

- This clustering allows to make maps of properties that are deduced from spectra.



3. MODEL ATMOSPHERE

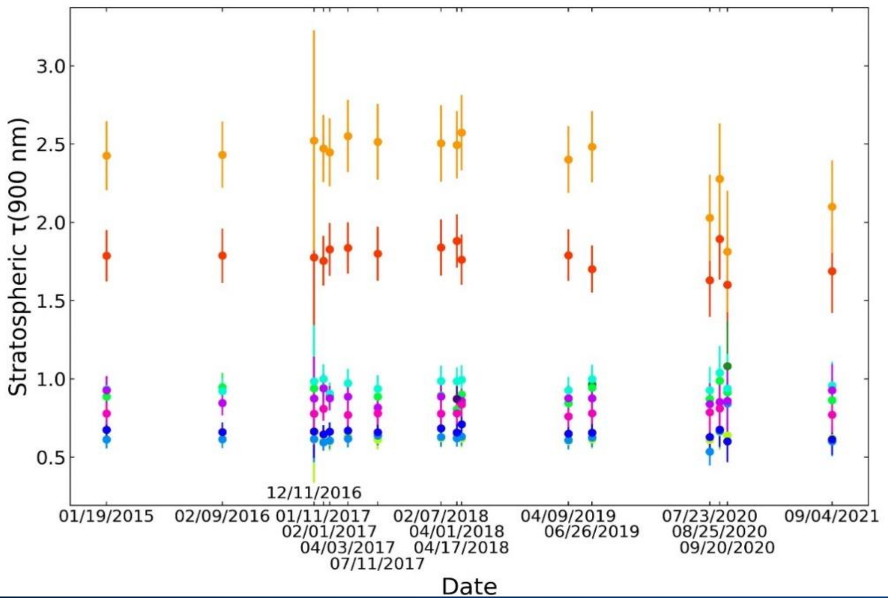
- **We use the Nemesis Radiative Transfer code (Irwin et al., 2008) to retrive some key properties of the clouds/hazes for P > 1 bar by fitting our spectra.**

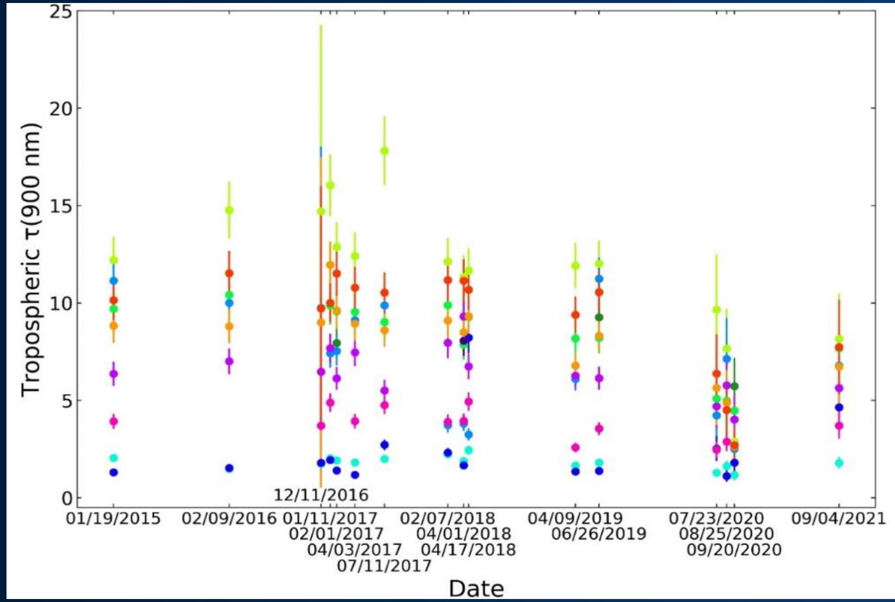
- **For each selected region, we use as *a priori* parameter values the ones retrieved for the analogous region in visit Wong 2016, which is the visit studied in Anguiano-Arteaga et al. (2021). This was done for two main reasons:**

  - ❖ **This procedure allowed reducing the retrieved errors to more constrained values, since they depend on the input errors and these were now smaller.**

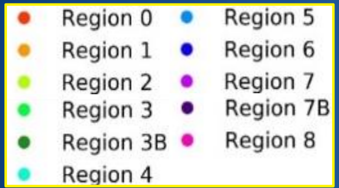
  - ❖ **This approach helped to avoid other family of solutions that also provided marginally acceptable fits but was not supported in cases with stronger limb-darkening constraints and lacked self-consistency when comparing the whole time period in this work.**

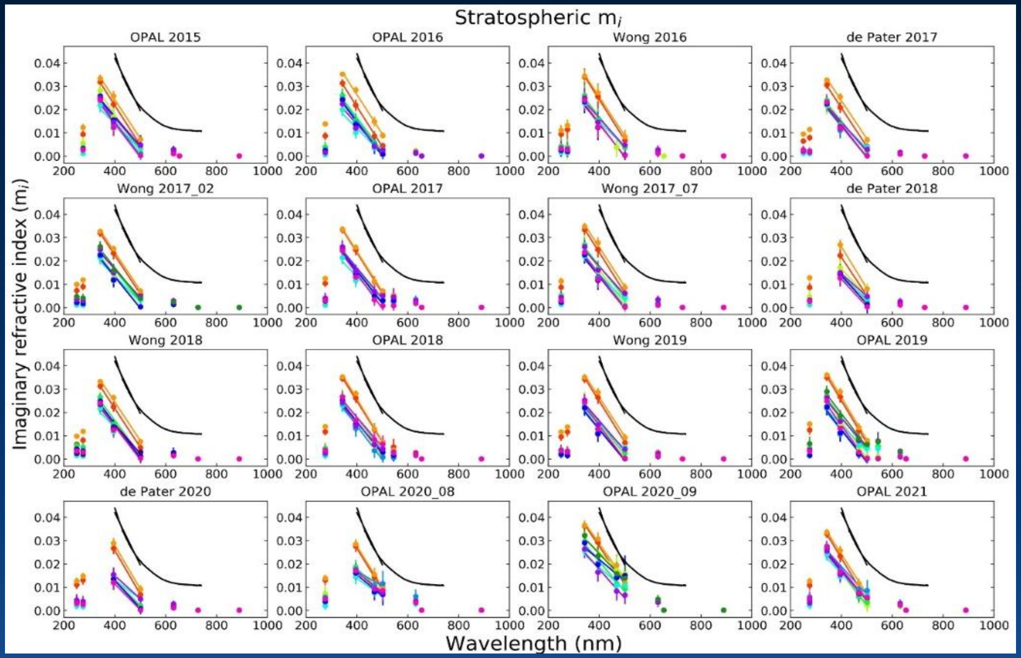
4. RESULTS: General overview

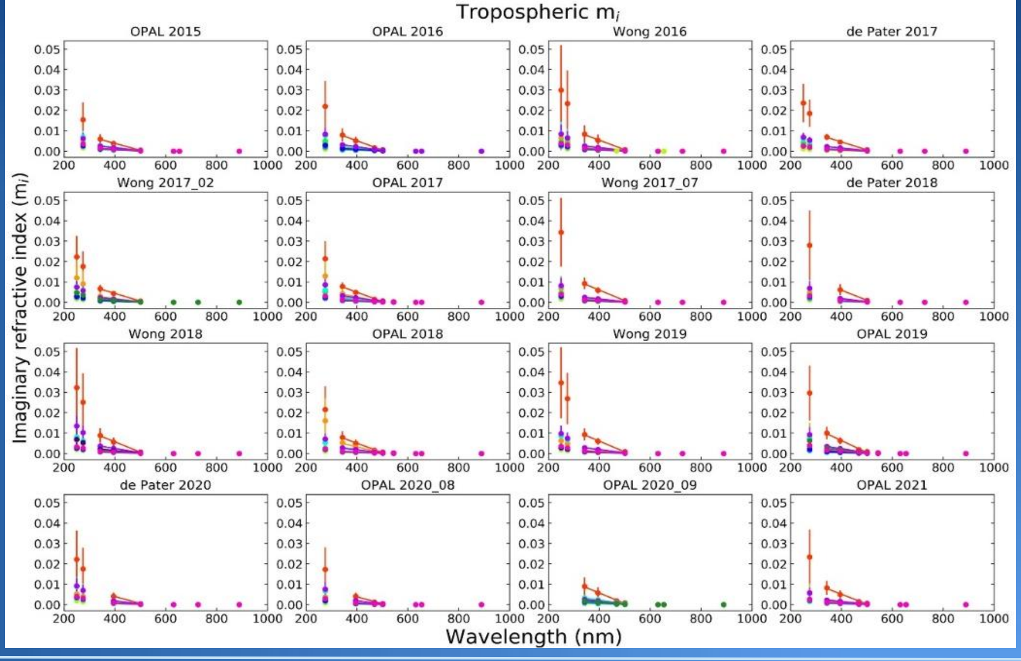




- For the GRS nucleus and interior, we find a slight decrease in the stratospheric optical depth
- Steeper changes are found in the tropospheric optical depth. However, the tropospheric haze shows a relatively weak absorption in the visible, and thus these changes are not coupled with color changes
- The imaginary refractive indices do not suffer major variations, indicating that the absorbing nature of the hazes is unchanged

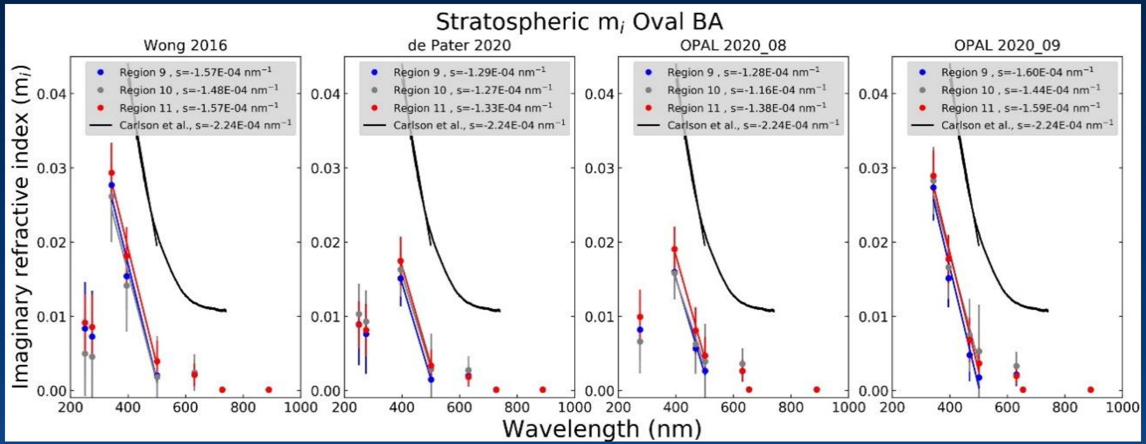


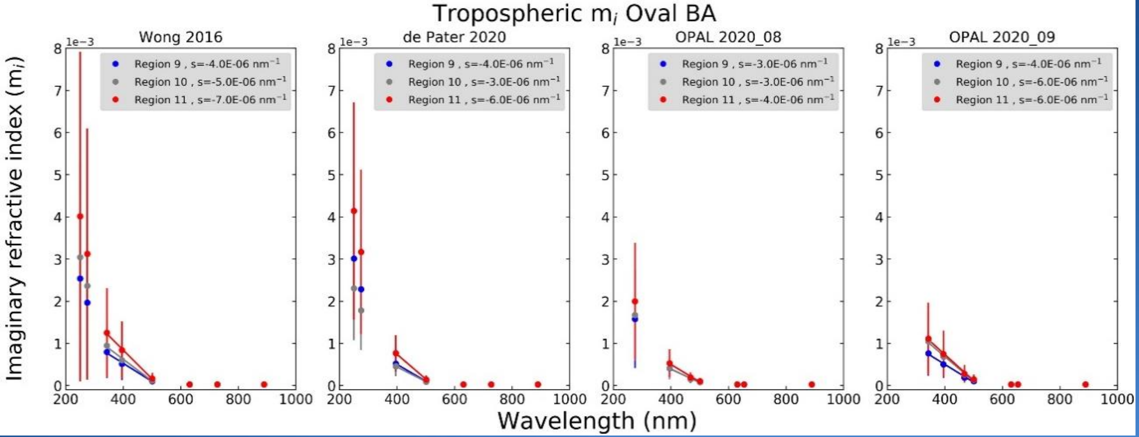




4. RESULTS: Oval BA

- Changes in cloud top altitude are not conclusive
- The absorbing nature of the hazes do not seem to have changed significantly either
- The color change, which is most prominent in region 11 (interior ring), is related to a decrease in the stratospheric optical depth.
- The tropospheric optical depths for regions 9 and 10 shown in the table below are not coupled with a more pronounced color change





Optical depths at 900 nm

	Region 9		Region 10		Region 11	
	τ_{str}	τ_{trop}	τ_{str}	τ_{trop}	τ_{str}	τ_{trop}
2016	0.8 ± 0.5	4 ± 5	0.6 ± 0.3	5 ± 6	1.2 ± 0.5	3 ± 3
2020	0.66 ± 0.02	2.3 ± 0.2	0.65 ± 0.01	2.3 ± 0.3	0.91 ± 0.05	2.6 ± 0.9

5. CONCLUSIONS

- The stratospheric imaginary refractive index curves seem to be compatible with the chromophore proposed by Carlson et al. (2016). The lower values found may be due to the mixture of the chromophore with non-absorbing compounds.

- The variations of the stratospheric and tropospheric imaginary refractive indices among the different regions could also be explained by various degrees of abundance and mixing with non-absorbing compounds. If this were true, it would support the universal chromophore scheme proposed by Sromovsky et al. (2017), but with the addition of a new coloring species at tropospheric levels

- We find a decrease in the stratospheric and tropospheric optical depths inside the GRS red oval (i.e., regions 0 and 1), starting in 2019. The change between 2018 and 2020 in stratospheric haze optical depth is about 10% and 30% for regions 0 and 1, respectively. For the tropospheric haze optical depth, the decrease is approximately of 50% and 40% for those regions. This seems to explain the decreasing altitude/opacity and redness indicated by the AOI and CI temporal curves

- Our model explains the color change from reddish to white suffered by oval BA in terms of a decrease in the stratospheric optical depth. The biggest decrease occurs in region 11 (i.e., the ring surrounding the nucleus that changed from red to white), with a decrease of 25%. We also find a decrease of 17.5% in the stratospheric optical thickness of the oval nucleus, and practically no change in the periphery of white clouds

6. REFERENCES

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