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# Titan's polarization phase curves with Cassini/ISS

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## Abstract

The sunlight reflected by Titan's atmosphere is strongly polarized at phases near quadrature. This Rayleigh-like behavior has provided key clues towards the understanding of the aggregate nature of Titan's ubiquitous haze [1, 2]. We are compiling the polarization phase curves of Titan with data collected with Cassini's Imaging Science Subsystem (ISS). The ISS dataset covers the spectrum from the UV to the NIR, and phase angles from nearly zero degrees (full illumination) to 150 degrees, thereby extending the observations made by the Voyager and Pioneer spacecraft decades ago. The ISS dataset confirms the older trends in Titan's polarization, i.e. high fractional polarizations at quadrature that increase towards the shorter wavelengths. The ISS dataset also shows new insight thanks to the relatively good phase sampling and to the availability of data at wavelengths affected by methane absorption. Since we have spectrally-resolved phase curves in both brightness and polarization, we are investigating the optimal way to combine that information towards the optimal characterization of Titan's atmosphere.

## 1. Introduction

Ref. [3] discusses Titan's brightness phase curves obtained from images taken with ISS's Narrow Angle Camera (NAC) and non-polarizing filters. We are currently extending that analysis to include images taken with the Wide Angle Camera (WAC) as well as with polarizing filters. Figure 1 shows a brightness phase curve obtained with four instrument configurations an the CB2 filter. The configurations are: ***i)*** NAC without polarizing filters (*Photometric Data (NAC)* in the Legend); ***ii)*** NAC with 3 polarizing filters offset by 60 deg (*Polarimetric Data (NAC)*); ***iii)*** WAC without polarizing filters (*Photometric Data (WAC)*); ***iv)*** WAC with two polarizing filters at right angles (*Polarimetric Data (WAC)*).

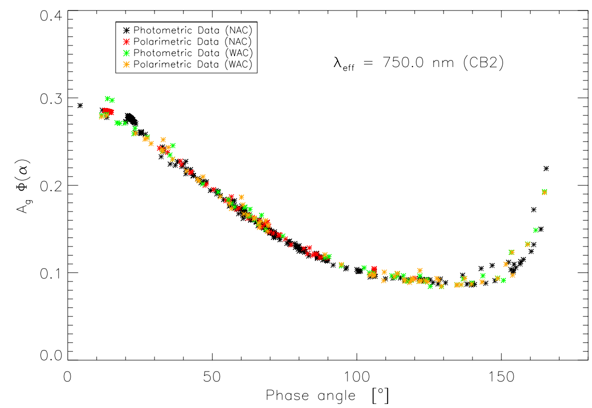



*Figure 1. Cassini/ISS brightness phase curve of Titan taken with the CB2 filter (effective wavelength of ~750 nm). The four datasets correspond to measurements done with: NAC without polarizers; NAC with 3 polarizing filters; WAC without polarizers; WAC with 2 polarizing filters.*

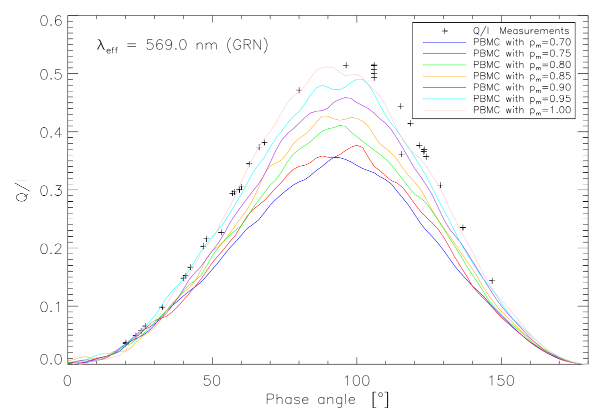



*Figure 2. Titan's fractional polarization measured with the NAC and the green filter (effective wavelength of ~570 nm). NAC measurements result in the two elements of the Stokes vector for linear polarization, Q and U, referred to the camera axes. To produce the phase curve in the graph, we have rotated the reference plane for each datapoint so that the rotated Stokes elements U≡0 and Q>0. The solid curves are models calculated with a Monte Carlo algorithm that solves the multiple scattering problem in Titan's atmosphere [4]. The models assume that the normalized elements of the scattering matrix $F_{ij}/F_{11}(\theta)$ are Rayleigh-like, meaning that $F_{ij}/F_{11}(\theta)|_{aerosol} \propto F_{ij}/F_{11}(\theta)|_{Rayleigh}$. $p_m$ parameterizes the maximum single-scattering polarization in $F_{12}/F_{11}(\theta)|_{aerosol}$, which occurs for $\theta$=90 deg. The model simulations suggest that values of $p_m$~1 are required to reproduce the observations. The wiggles in the synthetic phase curves are due to poor statistics in the Monte Carlo simulations, which for these exploratory examples are run with $10^5$ photons.*

Figure 2 shows the fractional polarization Q/I obtained with the NAC and the green filter (effective wavelength of ~570 nm). The fractional polarization is obtained from the ratio of Q and I. Figure 3 shows the corresponding curve for Q.

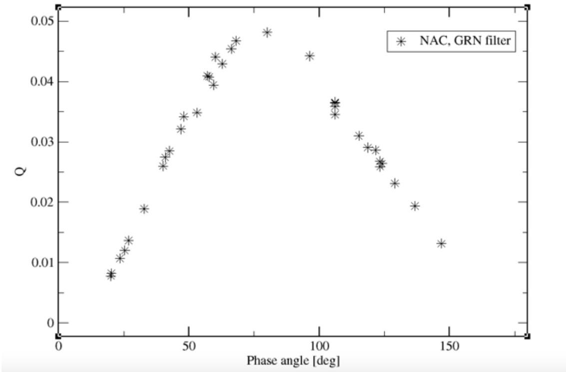



*Figure 3. Phase curve for Q, obtained with the NAC and the green filter.*

Figures 2-3 show that the sampling in phase angle is quite complete, and allows to trace the polarization behavior up to phase angles of 150 deg. At this wavelength, Titan reaches a maximum fractional polarization of 50 percent. This value is representative of the haze optical properties over the entire atmosphere and within less than one optical depth from the atmospheric top. Figure 4 compiles some images of Titan's disk and shows the orientation of the emergent electric field.

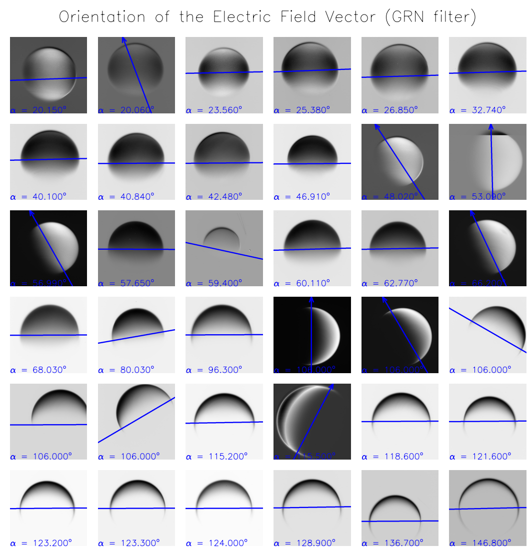
We are currently addressing the interpretation of the polarization curves with a Monte Carlo model that solves the multiple scattering problem in the atmosphere [5]. For the time being, we have assumed that the scattering matrix of the aerosols can be described in the form $F_{ij}/F_{11}(\theta)|_{aerosol} \propto F_{ij}/F_{11}(\theta)|_{Rayleigh}$. In particular, for $F_{12}/F_{11}(\theta)|_{aerosol} = p_m F_{12}/F_{11}(\theta)|_{Rayleigh}$, where $p_m$ is a user-defined parameter that represents the maximum polarization for single scattering.

The comparison of models to observations should result in valuable constraints on the aerosol sizes near the top of the atmosphere. Our initial exploration suggests that the haze layer to which the measurements are sensitive is strongly polarizing, with nearly full polarization in single scattering ($p_m$~1, Fig. 2). Our analysis complements the linear polarization investigation of Titan's atmosphere during the DISR descent [6], which is probably relevant to lower altitudes than those probed by the phase curves here.

# Summary and future work

The Cassini/ISS polarization phase curves that we are preparing represent a valuable dataset for the characterization of Titan's aerosols. This emphasizes the diagnostics possibilities offered by polarimetry, which complements other remote sensing techniques. The next steps include the interpretation of the phase curves with multiple scattering models.

Figure 4. Orientation of the electric field in images taken with the NAC and the green filter. In these images, it is possible to infer all three I, Q and U elements of the Stokes vector.

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