MAPPING VIMS SPECULAR REFLECTIONS ON TITAN'S SURFACE DURING THE CASSINI MISSION.

B. Seignovert[1], C. Sotin[1], K.J. Lawrence[1] and M.F. Heslar[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [2]Department of Physics, University of Idaho, Moscow, ID, USA.

Introduction: Besides the Earth, Titan, the largest moon of Saturn, is the only body of the Solar System with a dense atmosphere hiding lakes and seas at its surface. In 2009, during the T58 flyby, the Visual and Infrared Mapping Spectrometer (VIMS), onboard the Cassini orbiter, recorded 4 spectral cubes containing a very unusual signature presenting a very high I/F infrared peak around $5\,\mu\mathrm{m}$ in a specular geometry [1]. This observation, located on a radar smooth area [2] is the first confirmation of the presence of large hydrocarbon liquids in Titan's North Pole.

Between 2010 and 2014, a dozen of new specular signatures were recorded by the VIMS instrument above different lakes and Mares (Kraken, Jingpo, Punga). By modeling the shape of these unique signals and their spread on the surface, it was possible to derive the refractive index of the lakes [3], the methane-ethane ratio [1], the transmission spectrum of Titan's north polar atmosphere [4] and even the roughness of the lake and the height of waves [5, 6]. More recently, sun glitter, close to specular observations, provided new constraints on tidal and wind waves [7].

Up to now, the detections of the specular points in the VIMS dataset were conducted manually on the cubes recorded above the North Pole containing a significantly high signal at $5\,\mu\mathrm{m}$. The purpose of this study is to generalize specular detections and create a global database of all specular pixels across the entire mission (2004 - 2017). This will allow us to map the spatial distribution of these points and identify the variability of their spectral signature.

Method: Based on Snell-Descartes optical laws, the reflection of a point light source on a perfect flat mirror is located on the mid-plane between the source and the observer for which the incidence angle is equal to the emergence angle. This point is known as a specular point. More generally, any surface will produce a peak of intensity (I/F) when the incidence and emergence angles are equal and aligned. If the surface is smooth enough, the I/F peak can be larger than 1 and it highly depends on the surface properties where the reflection occurs.

In the case of an orbiter observing the surface of a planet, the location of the specular point is not trivial but is a solution to the antique *Alhazen's problem* of light reflection on a spherical mirror. The specular angle (when it exists) is one of the roots of a quartic polynomial (Fig. 1).

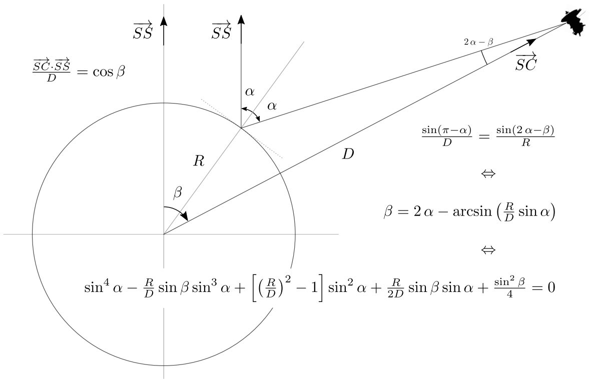

Figure 1: Alhazen's problem of the reflection location of a light source on a sphere seen by an observer at finite distance. The only unknown is the specular angle α.

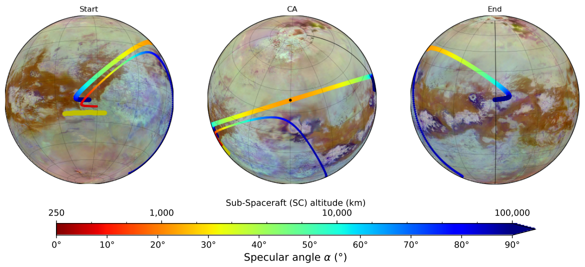

Figure 2: Locations of the sub-solar point (yellow line), sub-spacecraft point (thick colored line) and specular point (thin colored dots) during TA flyby (Oct 2004) $\pm 16\,\mathrm{h}$ around closest approach (black dot). Background: Titan VIMS-ISS mosaic [9].

For each Titan flyby, we use the SPICE kernels [8] to extract the location of Cassini (SC) and the position of the Sun (SS) in Titan's frame before and after close-approach. Then, we check the presence of the specular point and we calculate its expected location as function of time (Fig. 2). Finally, we searched in all the VIMS cubes acquire by Cassini, when the pixel footprint (IFOV) contains the specular point. Because the VIMS-IR and VIMS-VIS IFOVs are not the same, only the VIMS-IR specular pixels are reported in this study.

Results: Between 2004 and 2017, Cassini acquired 24,879 resolved cubes on Titan. We found that 7751 cubes contain at least one specular point. Due to its two dimensional scan design and the motion of the Cassini spacecraft during acquisition, VIMS-IR IFOV can overlap one another. This represent a collection of 7892 specular spectra.

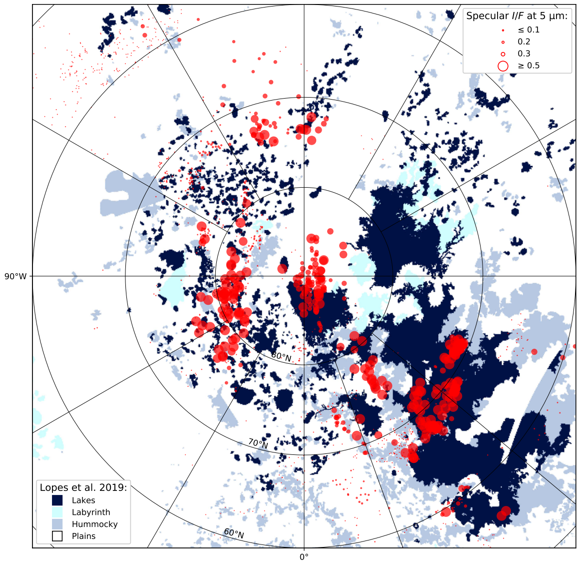

Figure 3: Location of all the VIMS-IR specular points (red circles) around Titan's North Pole. The size of the circle is proportional to the mean I/F spectra at 5 µm. Background: Titan geological map [10]

Fig. 3 summarizes the location of all the specular pixels observed around the northern latitudes. We counted at least 238 specular points above known lakes [10]. And 176 specular points have an I/F peak larger than 0.5 in the 5 µm window [11]. Most of the pixels with a strong peak at 5 µm are located on Kraken Mare (between 30°E, 65°N and 75°E, 75°N), on Punga lacus (≥85°N) and in lake district (75°W, 80°N). Due to the orbit constraints, no specular pixel were acquired on Ligeia Mare (second largest lake on Titan and located at 110°E, 80°N).

Discussion All the specular pixels analyzed by previous studies [1, 3–6] are reported in our database. In the present study, all the specular pixels are considered, independently of their spectral signature. This allows us to notice that many specular pixels which do not present a strong peak at 5 µm are located on plains. This confirms that the presence of a 5 µm specular peak is highly correlated with the presence of liquid lakes. However, in some cases, we do not observe an I/F peak at 5 µm above known lakes (e.g. in the south of Kraken). This could be correlated with higher surface roughness due to waves.

Conclusions and perspectives Tracking specular reflection on the surface of Titan provides many opportunities to probe its surface hidden by its thick hazy atmosphere. We show that the VIMS dataset contains approximately 30 % of cubes with at least one pixel in a specular geometry. This represent a large collection of spectra that could help us to better determine the surface and atmospheric properties, the lake content and behavior and bring new insights on the morphology and composition of the surrounding geological units.

This new dataset provides a unique and complete collection of all the cubes of interest in a specular geometry. The spectra of these pixels need to be analyzed with radiative transfer models to determine precisely the properties of the surface on the different reflection area. In some cases, like on Kraken Mare, the number of detections is high enough to make statistical analysis of the temporal variability of the surface. Moreover, by comparing the peak intensity with the direct surrounding pixels, we should be able to provide information on the transmission of the atmosphere and the amount of haze on the line of sight.

Finally, as previous studies already reported [6, 7, 12], bright off-specular pixels play a key role in the detection of wet surfaces and are required to estimate the wave amplitude of the surrounding lakes. The extraction of these pixels is currently not implemented but could be achieved with our current tools.

Acknowledgments: This work has been partly performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA.

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