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UNDERSTANDING THE COMPOSITION OF TITAN'S SURFACE FROM REMOTE SENSING DATA

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ABSTRACT

The Cassini spacecraft investigated the nature of the second largest satellite of our solar system, Saturn's Titan, for 13 years, ending its mission in 2017. In addition to Cassini's remote sensing monitoring of Titan, valuable data was acquired *in situ* from the surface by ESA's Huygens probe in 2005. Cassini carried 12 instruments of which 3 were dedicated to the investigation of its geology by studying its surface globally in the visual, infrared, and radar wavelength ranges. We present an overview of major results for the chemical composition of Titan's surface as derived by Cassini's remote sensing instruments.

Index Terms— Titan, icy moons, outer solar system remote sensing, surface composition

1. INTRODUCTION

The surface of Titan is considered one of the most Earth-like ones in our solar system even if the chemistry (ice vs. silicate) and temperature (-180 °C vs. 15 °C) differ significantly. The presence of surface features such as mountains, dunes, drainage networks, lakes, alluvial fans, craters in addition to processes such as aeolian, fluvial, karstic, and lacustrine make this sedimentary world resemble Earth in some respects.

The remote sensing capabilities of the Cassini spacecraft's instruments provided a wealth of data that revolutionized our knowledge and understanding of this unique moon. However, a number of challenges were identified over the course of the Cassini's Titan flybys affecting our understanding of both the morphology and chemical composition of the surface. For instance, the thick and hazy atmosphere prevents the identification of surface compounds by classic spectroscopy. Due to those challenges and the world's natural complexity, the surface chemical

composition of Titan remains uncertain even after 13 years of Cassini exploration. Nonetheless, remote sensing data was able to identify the presence of large amounts of solid hydrocarbons and nitriles as both surface deposits and as lake liquids that are made of liquid methane-ethane-nitrogen. Some of the crucial chemical composition questions that remain concern the extent of exposed water-ice and its locations, and the specific composition of the organics. Fortunately, the Cassini instruments recorded a great amount of data and measurements, and the analyses and investigations are still ongoing.

The identification and thorough understanding of Titan's surface composition is essential in order to further understand the origin and evolution of the outer solar system satellites and planets and the potential for life elsewhere.

2. CASSINI VIMS AND COMPOSITION

The Cassini Visual and Infrared Mapping Spectrometer (VIMS) was the instrument dedicated to the study of Titan's lower atmosphere and surface composition. It functioned at visible and near-infrared wavelengths ranging from 0.85 to 5.1 μm and a spectral resolution of 16.6 nm [1]. Using its near-IR channel, VIMS acquired spectro-imaging cubes of sizes up to 64x64 pixels with spatial resolutions varying from a few hundreds of meters to hundreds of kilometers per pixel. Cassini performed 127 dedicated flybys over its 13 year mission and acquired more than 60,000 hyperspectral cubes of Titan and successfully imaged about 60% of Titan's surface with a spatial resolution better than 15 km/pixel, 20% at better than 10 km, and 5% with a spatial resolution better than 6 km/pixel [2]. Early in the analysis of VIMS data, three primary spectral/compositional units were identified, the so-called "blue", "brown", and "5- μm -bright" units, which were attributed to areas potentially elevated in H₂O ice, organic materials, and CO₂ frost respectively [e.g., 3;4] (Figure 1).

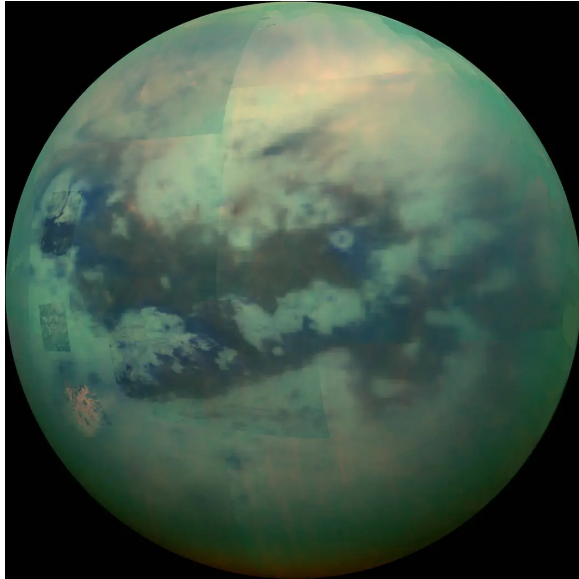


Figure 1. False-color RGB VIMS image of Titan acquired during the T114 flyby on Nov. 13, 2015. image of Titan with R=5.0 μm , G=2.0 μm , B=1.3 μm . Image credit: NASA/JPL/University of Arizona.

From the beginning of the VIMS data analysis, the challenges in uniquely identifying the composition were noted and were attributed in part to the issue of determining the opacity of the

atmosphere. Titan's atmosphere contains both methane and aerosols, and methane absorbs in the infrared, while aerosols are absorbing in the visible and scattering more in the infrared. Hence, the optical effects of both haze and gas species are important even at specific wavelengths where the methane absorption is less, namely the 'methane windows'. Several correction techniques, atmospheric simulations, RT codes, and mixing models are being used to sufficiently analyze VIMS data and extract meaningful results [5;6;7;8;9;10].

Starting in 2014, we began analyzing VIMS data using a radiative transfer technique [11;12] and a mixing model [13;14] yielding compositional constraints on Titan's optical surface layer. Figure 2 shows the current state of the chemical composition map for Titan. The colors represent suggestions for the major components including water-ice (blue), tholin-like materials (orange), and dark organic materials (magenta) as derived from the extracted surface albedo using the radiative transfer code and the mixtures of candidate Titan materials that best fit the albedos. Furthermore, the combination of the geomorphological characterization of regions, as presented in the first global geomorphological Titan map by [15] and the constraints of their chemical composition help with the formulation of hypotheses on the origin and evolution of Titan's regional geology.

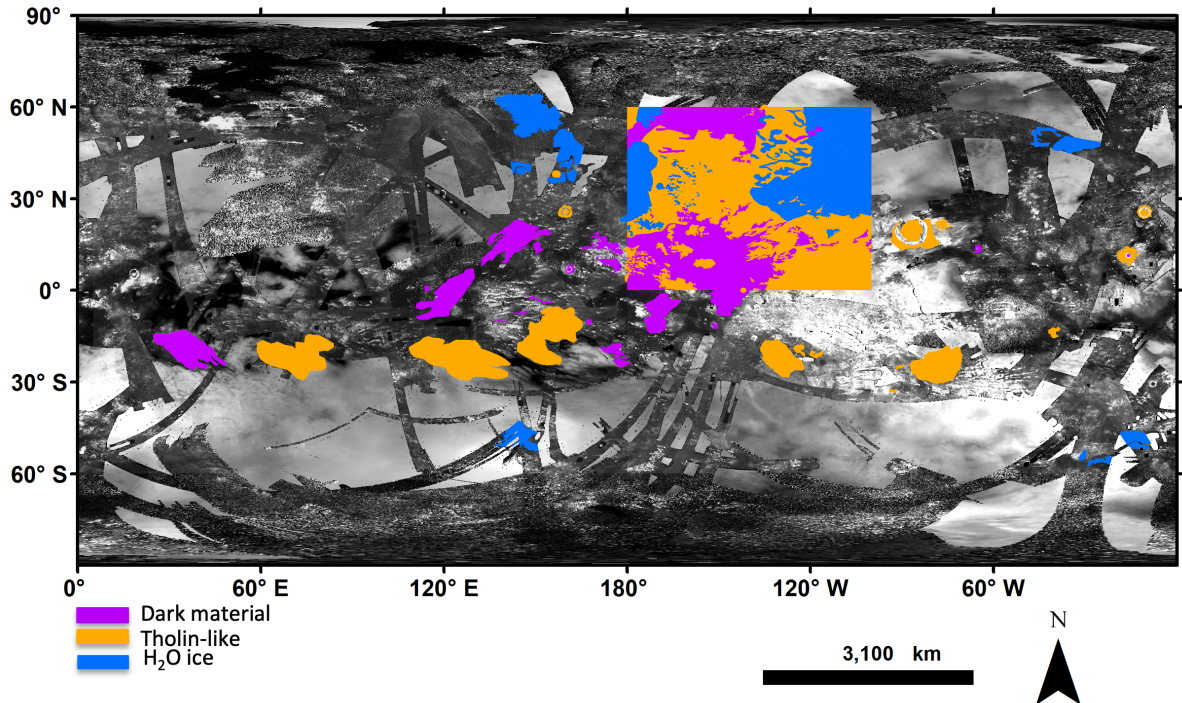


Figure 2. Implications on the major constituents of Titan regions. The background constitutes of the Imaging Science Subsystem global map (NASA/JPL/Caltech/PIA14908) and SAR swaths for context. The blue-colored regions correspond to regions where the major constituent in the mixture is an OH-bearing constituent, the magenta is an unknown dark material, and the orange is a tholin-like material. [Adapted from 13].

3. CASSINI RADAR AND COMPOSITION

Titan's surface has been observed by radar and microwave radiometers from both ground-based [16] and Cassini instruments [17], namely the RADAR instrument which operated in 4 modes (Synthetic Aperture Radar, scatterometer, radiometer, and altimeter). The RADAR in its different modes, both passive and active, helped tremendously in the unveiling of Titan's geomorphology and topography, while also providing insights into the composition through the measurements of dielectric constant (ϵ) and the estimate of the degree of volume scattering in the near-subsurface.

Figure 3 shows the global emissivity map of Titan as presented by [18]. The map shows distinctly 'hot' (reddish) and 'cold' (bluish) areas, corresponding to high and low emissivity respectively. Xanadu, the large region centered at 100°W is a distinct example of a low emissivity area correlated with highly fractured water ice bedrock [18;19].

The combination of Cassini VIMS and emissivity results has proved to be very useful in better understanding the surface composition of Titan, since the RADAR emissivity values provide information for the composition of the near-subsurface (up to 1 m deep) and VIMS for the very top (microns thick) layer of the optical surface [10].

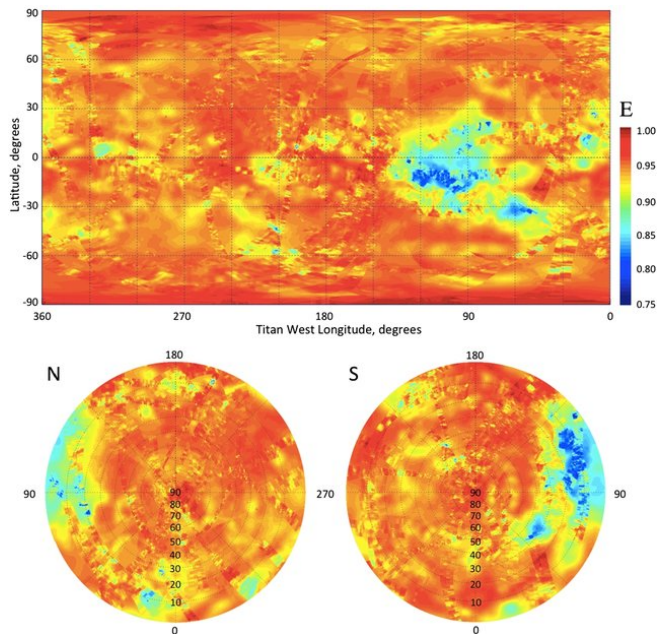


Figure 3. Global mosaic of emissivity of Titan at the 2-cm wavelength of the Cassini RADAR [18].

4. COMPOSITION OF LIQUID AND SOLID SURFACES

After 13 years of Cassini exploration, the liquid bodies of Titan are better understood in terms of chemical composition than the solid surfaces. The lakes and seas mainly consist of methane, ethane, and nitrogen while small amounts of propane and possibly 1-butene may be present in southern lakes [1;20;21]. For the solid surfaces, where the most mystery lies, it is widely accepted that Titan is a sedimentary world where its surface composition correlates with the surface's active geological processes, primarily aeolian, fluvial and sediment depositional processes [15]. Two classes of materials seem to be present, organics and water-ice (e.g., 22;13;3; 23]. Latitudinal trends suggest a correlation with the optical chemical composition, with the mid-latitudes being more abundant in water-ice and the equatorial zones being more abundant in organics [13], suggesting a strong correlation between geological processes and composition. Interestingly, microwave emissivity consistently indicates to the presence of organics at depth in the midlatitudes.

5. CONCLUSION

The remote sensing capabilities offered by the Cassini mission have dramatically improved our knowledge of this exotic and unique world and identified it as a privileged target for future missions. The need for identifying Titan's surface composition is directly connected to the assessment of its habitability potential and the understanding of the conditions that contributed to the emergence of life on Earth and potentially places of our outer solar system.

The current state of knowledge of Titan's composition derives primarily from Cassini's surface remote-sensing instruments and their data and measurements. Cassini's discoveries have pointed to the need for new missions to return to Titan carrying advanced technologies and remote sensing instrumentations with enhanced capabilities.

The next planned mission to Titan, the Dragonfly mission, will not carry remote sensing instruments but is a relocatable lander capable of acquiring samples from compelling areas with a diverse geology. This will significantly transform our knowledge about the surface. In addition to Dragonfly, a plethora of mission concepts (orbiters and landers) have been suggested to both NASA and ESA for future Titan exploration that include remote sensing instrumentation [24;25;26;27].

6. REFERENCES

- [1] R. H. Brown, et al., (2004), The Cassini visual and infrared mapping spectrometer (VIMS) investigation, *Space Sci. Rev.*, 115, 111–168.

- [2] S. Le Mouélic, Cornet, T., Rodriguez, S., et al., (2019), *Icarus*, 319, 121.
- [3] L.A. Soderblom, et al., (2007). Correlations between Cassini VIMS spectra and RADAR SAR images: implications for Titan's surface composition and the character of the Huygens probe landing site. *Planetary and Space Science*. 55, 2025–2036.
- [4] T.B. McCord, et al. (2008), Titan's surface: Search for spectral diversity and composition using the Cassini VIMS investigation, *Icarus*, 194, 212–242.
- [5] B. Hapke, (1993). Combined theory of reflectance and emittance spectroscopy. Cambridge University Press.
- [6] C.A. Griffith, Owen, T., Geballe, T.R., Rayner, J., Rannou, P., (2003). Evidence for the exposure of water ice on Titan's surface. *Science*, 300, 628–630.
- [7] S. Rodriguez, Le Mouélic, S., Sotin, C., Clénet, H., Clark, R.N., Buratti, B., Brown, R.H., McCord, T.B., Nicholson, P.D., Baines, K.H., and the VIMS Science Team, (2006). Cassini/VIMS hyperspectral observations of the Huygens landing site on Titan. *Planet. Space Sci.* 54 (15), 1510–1523.
- [8] S. Le Mouélic, Cornet, T., Rodriguez, S., Sotin, C., Barnes, J.W., Baines, K.H., Brown, R.H., Lefèvre, A., Buratti, B.J., Clark, R.N., Nicholson, P.D., (2012). Global mapping of Titan's surface using an empirical processing method for the atmospheric and photometric correction of Cassini/VIMS images. *Planet. Space Sci.*, 73 (1), 178–190. <https://doi.org/10.1016/j.pss.2012.09.008>.
- [9] M. Hirtzig, et al. (2013). Titan's surface and atmosphere from Cassini/VIMS data with updated methane opacity. *Icarus*, 226, 470–486.
- [10] A. Solomonidou, A., Neish, C., Coustenis, A., Malaska, M., Le Gall, A., Lopes, R., Werynski, A., Markonis, Y., Lawrence, K., Altobelli, N., Witasse, O., Schoenfeld, A., Matsoukas, C., Baziotis, I., Drossart, P., (2020). The chemical composition of impact craters on Titan I. Implications for exogenic processing. *Astronomy & Astrophysics*, 641, A16.
- [11] A. Solomonidou, Hirtzig, M., Coustenis, A., Bratsolis, E., Le Mouélic, S., Rodriguez, S., et al. (2014). Surface albedo spectral properties of geologically interesting areas on Titan. *Journal of Geophysical Research: Planets*, 119, 1729–1747.
- [12] Solomonidou, Coustenis, A., Hirtzig, M., Rodriguez, S., Stephan, K., Lopes, R. M. C., et al. (2016). Temporal variations of Titan's surface with Cassini/VIMS. *Icarus*, 270, 85–99.
- [13] A. Solomonidou, A. Coustenis, R. Lopes, M. Malaska, S. Rodriguez, P. Drossart, C. Elachi, B. Schmitt, M. Janssen, M. Hirtzig, S. Wall, C. Sotin, K. Lawrence, N. Altobelli, N. Bratsolis, J. Radebaugh, K. Stephan, R. Brown, S. Le Mouélic, A. Le Gall, E.V. Villanueva, J.F. Brossier, A.A. Bloom, O. Witasse, C. Matsoukas and A., Schoenfeld (2018). The Spectral Nature of Titan's Major Geomorphological Units: Constraints on Surface Composition. *J. Geophys. Res.*, 123, 2, 489-507.
- [14] A. Solomonidou, A., Le Gall, A., Malaska, M., Birch, S., Lopes, R., Coustenis, A., Rodriguez, S., et al. (2020). Spectral and emissivity analysis of the raised ramparts around Titan's northern lakes. *Icarus*, 344, 113338.
- [15] R.M.C. Lopes, M.J. Malaska, A. M. Schoenfeld, A. Solomonidou, S.P.D. Birch, M. Florence, A.G. Hayes, D.A. Williams, J. Radebaugh, T. Verlander, E.P. Turtle, A. Le Gall, S. Wall, and the Cassini RADAR Team, (2020). A Global Geomorphologic Map of Saturn's Moon Titan. *Nature Astronomy*, 4, 228-233.
- [16] D.B. Campbell, Black, G.J., Carter, L.M., Ostro, S.J., (2003). Radar evidence for liquid surfaces on Titan. *Science*, 302, 431–434.
- [17] C. Elachi, Allison, M. D., Borgarelli, L., Encrenaz, P., Im, E., Janssen, M. A., et al., (2004). Radar: The Cassini Titan radar mapper. *Space Science Reviews*, 115(1), 71–110. <https://doi.org/10.1007/s11214-004-1438-9>
- [18] M. A. Janssen, Le Gall, A., Lopes, R. M., Lorenz, R. D., Malaska, M. J., Hayes, A. G., et al. (2016). Titan's surface at 2.18-cm wavelength imaged by the Cassini RADAR radiometer: Results and interpretations through the first ten years of observation. *Icarus*, 270, 443–459.
- [19] R.M.C. Lopes, et al., (2019). Titan as revealed by the Cassini radar. *Space Sci. Rev.* 215(4), 33.
- [20] J.W. Barnes, et al. (2011). Organic sedimentary deposits in Titan's dry lakebeds: Probable evaporite. *Icarus*, 216, 136–140.
- [21] A.G. Hayes, (2016). The lakes and seas of Titan. *Annu. Rev. Earth Planet. Sci.* 44, 57–83.
- [22] J.W. Barnes, et al. (2008). Spectroscopy, morphometry, and photoclinometry of Titan's dunefields from Cassini/VIMS, *Icarus*, 195, 400–414.
- [23] C.A. Griffith, Penteadó, P.F., Turner, J.D., Neish, C.D., Mitri, G., Montiel, N.J., Schoenfeld, A., Lopes, R.M.C., (2019). A corridor of exposed ice-rich bedrock across Titan's tropical region. *Nature Astronomy*, 3, 642-648.
- [24] A. Coustenis, et al., (2009). *Experimental Astronomy*. 23(3), 893–946.
- [25] J.W. Barnes, et al. (2012). *Experimental Astronomy*. 33(1), 55–127.
- [26] A.Sulaiman, et al., (2021). Enceladus and Titan: emerging worlds of the Solar System. *Experimental Astronomy*.
- [27] S. Rodriguez, et al., (2022). Science goals and new mission concepts for future exploration of Titan's atmosphere, geology and habitability: Titan Polar scout/orbitEr and in situ lake lander and DrONE explorer (POSEIDON). *Experimental Astronomy*, <https://doi.org/10.1007/s10686-021-09815-8>