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The evolution of the atmosphere and surface of Titan from Cassini infrared observations

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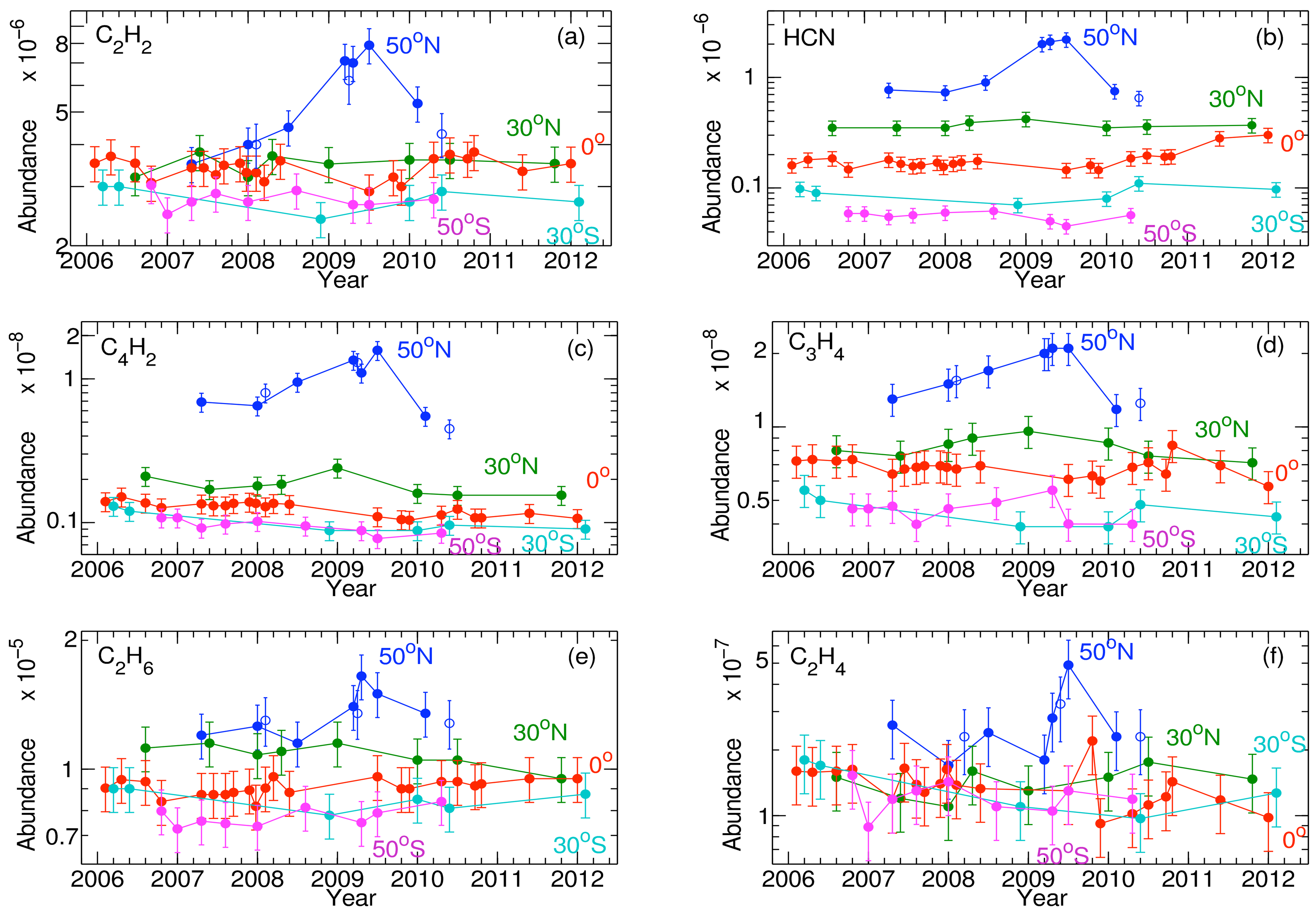
Saturn's Earth-like satellite Titan has a thick and dense atmosphere consisting of nitrogen (98.4%), methane (1.6%) and trace gases such as hydrocarbons and nitriles [1]. The condensed organics are deposited on the surface and the atmosphere-surface-interior interactions shape the ground. In particular, Titan's methane cycle, similarly to the Earth's hydrologic cycle, plays an important role in these exchanges by transporting methane at all layers. By applying our radiative transfer code (ARTT) to Cassini/CIRS data taken during Titan flybys from 2004-2010 and to the 1980 Voyager 1 flyby values inferred from the re-analysis of the Infrared Radiometer Spectrometer (IRIS) spectra, as well as to the intervening ground- and space- based observations (such as with ISO), we study the stratospheric evolution over a Titanian year (V1 encounter Ls=9° was reached in mid-2010) [1,2].

CIRS nadir and limb spectral [1-4] show variations in temperature and chemical composition in the stratosphere during the Cassini mission, before and after the Northern Spring Equinox (NSE) and also during one Titan year. We will present the findings.

Furthermore, we analyse spectro-imaging data (0.8-5.2 μm) from Cassini/VIMS to study Titan's surface consisting of a multivariable geological terrain. We study in particular Tui Regio, Hotei Regio and Sotra Patera, suggested as volcanic-like candidates [e.g. 5-8]. We find albedo changes with time for Tui Regio from 2005-2009 (darkening) and Sotra Patera from 2005-2006 (brightening) at all wavelengths [8]. Such variations may be indicative of cryovolcanism, which would bring methane into Titan's atmosphere and account for its replenishment.



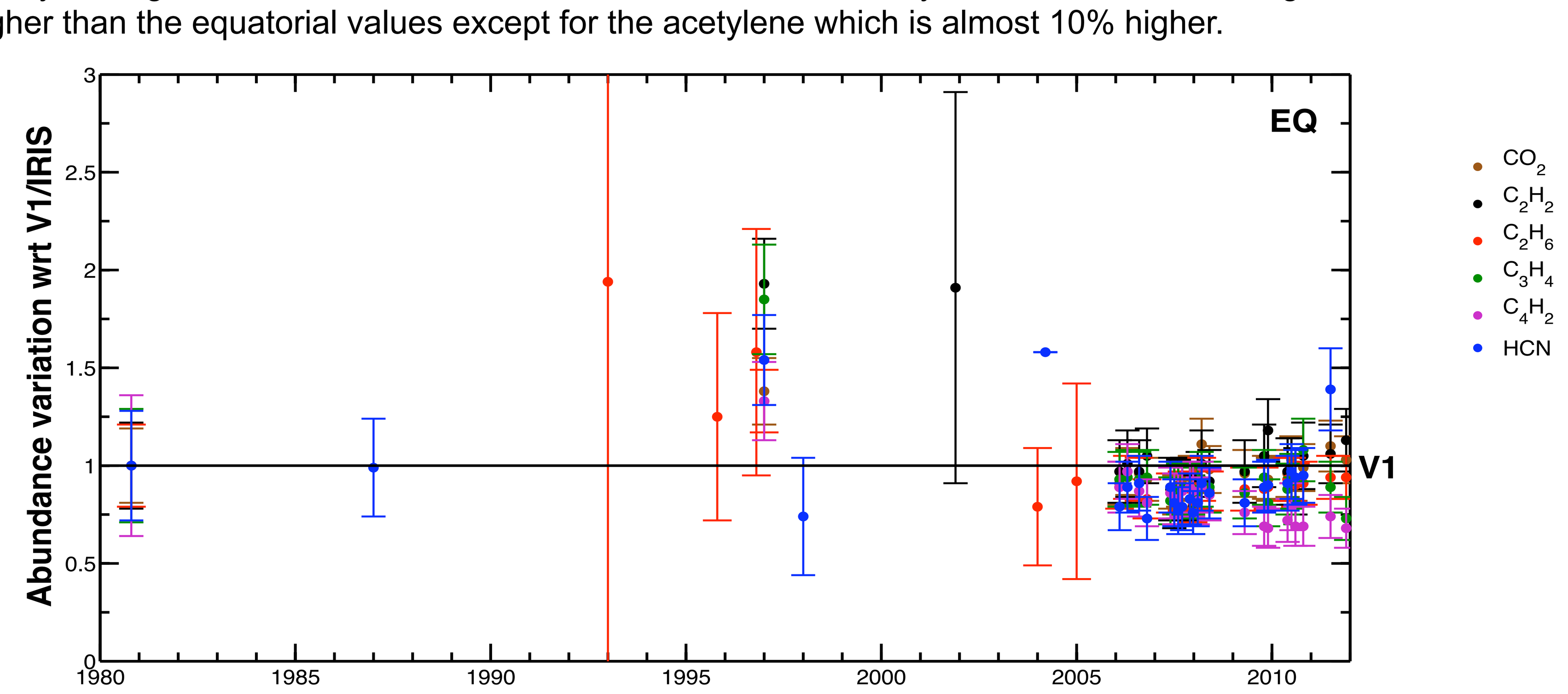
<u>Latitudinal chemical evolution during the Cassini-Huygens mission</u> [2]

We found a definitive trend for increased gaseous content in the stratosphere when moving from the south to the north, and, in addition, significantly enhanced abundances during the whole mission duration at northern latitudes, observed in most cases at latitudes higher than 30°N.

At 50°N, we find indication for an increase in abundance from 2006 to mid-2009 for almost all molecules (the exceptions are propane and carbon dioxide which do not seem to vary in time at any latitude, lower double panel of Fig. 2). **We detect a maximum around the time of the Northern Spring Equinox (NSE, 15 August 2009) in mixing ratios with increases in abundances by about 30-40% for C_3H_4 and C_2H_6, 60-70% for C_2H_2 and C_4H_2 and about a factor of 2 for HCN and C_2H_4 (albeit with higher uncertainties) relative to the adjacent time periods in 2008 and 2010.** Ethane shows variations with time only at this higher latitude.

The observed increase in abundance for some molecules is followed by a strong decrease which reduces considerably the observed enhancement by 2010. This decrease settles in quickly, within 1-2 terrestrial years and brings the abundances back to their levels prior to the ascent. Admittedly we have so far only one high-resolution nadir selection after the NSE and one in lower resolution confirming this result, so that the finding probably requires further verification. However, both high and low-resolution nadir data taken in the 2010-2012 period seem to support the increase and follow-up decrease.

At southern (50°S and 30°S) and equatorial latitudes the abundances of the gaseous trace constituents remain rather constant-in-time during the Cassini mission within the error bars. Except for C_2H_4 and C_3H_8, the equatorial data yield higher abundances than the 30 or 50°S inferences by about 20%. The mixing ratios at 30°N are 20% higher than the equatorial values except for the acetylene which is almost 10% higher.



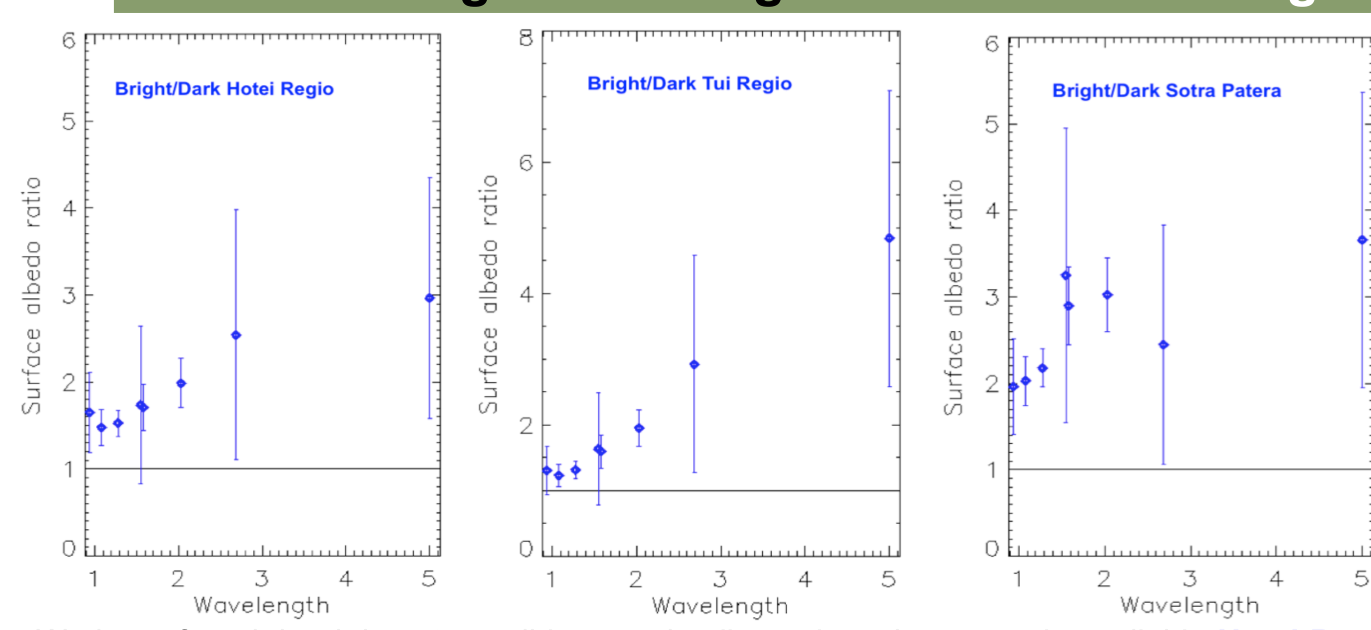
Equatorial temporal variations of the stratospheric Titan abundances within a Titanian year ratioed to their respective V1/IRIS values at the same latitude. Some ISO and ground-based data have been added [1]. These data show that some of the constituents increased with time toward the autumnal equinox (1997) and then decreased afterwards at the time of the Cassini mission. After one Titan year, there is a return to the values observed at the time of the Voyager encounter in 1980.

Surface variations

The Cassini-Huygens mission measurements suggest that several of the Saturnian satellites could be geologically active and support tectonic processes. Titan, for example, possesses a complex and dynamic geology as witnessed by its varied surface that is modified by aeolian, fluvial, tectonic and probably cryovolcanic processes. We present a study on Titan's possibly cryovolcanic and varying regions as suggested from previous studies [5-9 and references within]. These regions, which are potentially subject to change over time in brightness and are located close to the equator, are Tui Regio (20°S, 130°W), Hotei Regio (26°S, 78°W), and Sotra Patera (15°S, 40°W –Formerly Sotra Facula).

We use VIMS spectro imaging data that include both the Titan atmospheric and the surface contribution. We focus on retrieving the spectral differences (with respect to the Huygens landing site albedo) with time focusing at a specific Region of Interest (RoI) at each datacube. We have pre-selected one RoI for Tui Regio,one for Hotei Regio and one for Sotra Patera using **the Principal Component Analysis (PCA) [7] method that distinguishes heterogenic units that correspond to units of diverse spectral response; in this case we use the brightest RoI [7].** Using these RoIs we then apply a radiative transfer code (RT) [6] in order to retrieve their surface albedo and study the temporal surface variations of the three areas [8].

Hotei Regio – Tui Regio – Sotra Patera Bright Vs Dark regions



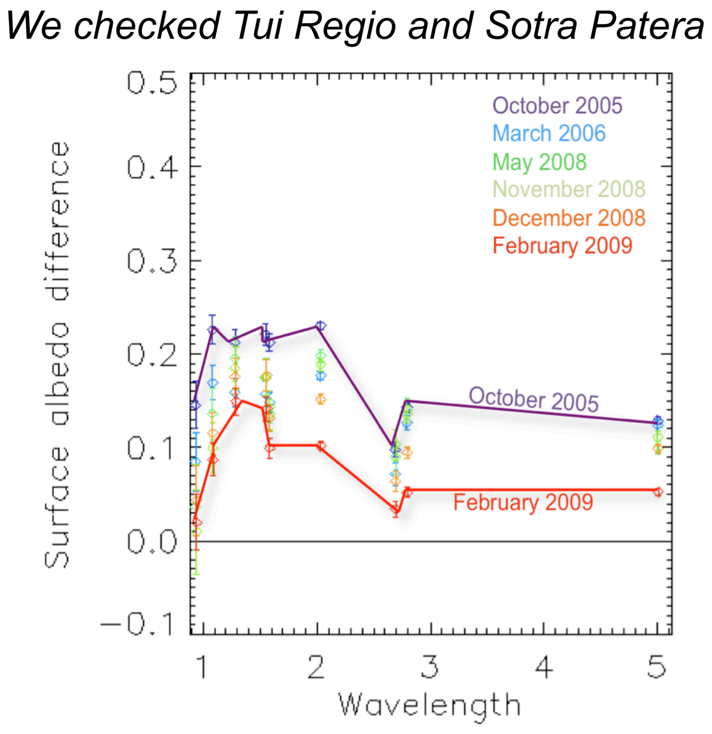
Surface albedo ratio of the bright region with respect to the dark region of regions of interest. The bright regions correspond to Hotei and Tui Regios and Sotra Patera features and the dark to the surrounding regions as selected with PCA from three individual VIMs datacubes.

We have found that it is not possible to optimally analyze the currently available **Hotei Regio** data where our inferences suffer from high uncertainties [7]. For **Tui Regio**, we find significant differences, especially at the longer wavelengths, mainly at 2.79 μm and 5 μm. This could mean that Tui's bright region contains a surface component which is significantly brighter at 2.79 and 5 μm [7]. The bright **Sotra Patera** spectrum presents increased values of surface albedo at all wavelengths with respect to the dark spectrum, especially after 1.6 micron, where a plateau with factors of increase of 3-4 is reached. This indicates that any differences in composition of the surface in this area again concern mainly the longer wavelengths, but from 1.6 and beyond, rather than only at 3-5 μm as for Tui Regio [7].

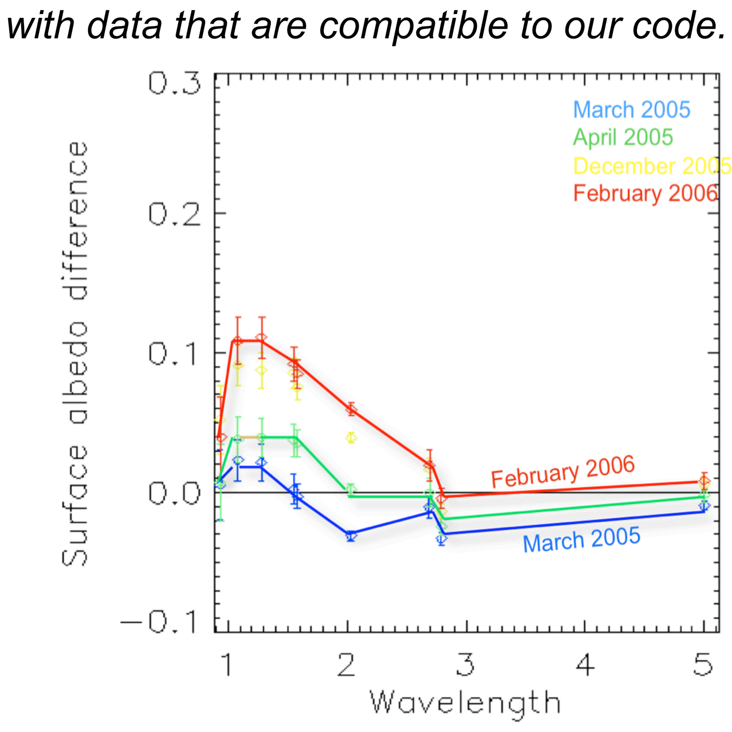
Tui Regio – Sotra Patera Temporal variations

Hotei Regio is the first Titan area that has been reported to **exhibit changes in brightness with time from July 2004 until March 2006 [9]. With our analysis [8] we have witnessed no change in surface albedo from 2004-2009. However, for this area we cannot infer reliable results since** the observing geometry of the data studied in Nelson et al. (2009) and further until 2009 reach the limit of compatibility with our plane-parallel code (close to both the limb and terminator, therefore with incidence angles greater than 60 degrees). We prefer to assume that our RT and the data for Hotei Regio are not adequate for retrieving any information at this point. This could be remedied in the future with better quality observations of this area, or with a more sophisticated code [8].

We checked Tui Regio and Sotra Patera temporally with data that are compatible to our code.



From 2005 – 2009 Tui Regio appears darker by about 20-50%. The decrease is highest at 1.08 m by about 50% and smaller but significant in other wavelengths [8].



Sotra Patera appears to have increased in brightness within a year by a factor of 2 [8].

In order to validate our code and confirm that the area of Tui Regio changed with time as an isolated area and not due to changes that affected the whole globe or massively a large part of it, we applied our code to a test case area far away from Tui Regio that corresponds to a dunes field at 145°W, 9.5°S for approximately the same time period [8]. We did the same comparison for Sotra Patera with another dunes field at 172°W-7.5°S. Both test cases did not present any change in surface albedo with time [8].

Conclusion:

Atmosphere : variations in chemical composition during the Cassini mission are found, with a maximum at the North Spring Equinox. On the long-term, after one Titan year there is a return to the same abundances as in 1980, with some few exceptions.

Surface: We study the temporal surface variations of Tui Regio, Hotei Regio and Sotra Patera with respect to test case areas [8]. Our findings indicate a significant darkening for Tui Regio from 2005-2009 (at all wavelengths). For Sotra Patera a brightening is observed from 2005-2006. On the contrary, the dunes fields' test cases did not change with time. Hotei Regio has been previously suggested to present brightness variations over a two-year period (2004-2005) [9]. However, we find that to-date available observations of that region present issues (e.g. geometry) prevent an accurate application of our RT model to infer surface information with the desired accuracy [8]. The surface albedo variations together with the presence of volcanic-like morphological features suggests that the cryovolcanic candidate features are connected to the satellite's deep interior, which could have important implications for the satellite's astrobiological potential. This idea has been recently augmented by the construction of new interior structure models of Titan and corresponding calculations of the spatial pattern of maximum tidal stresses [10].

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