CASSINI EVIDENCE FOR ACTIVE CRYOVOLCANISM ON SATURN'S MOON TITAN. Robert M. Nelson[1], Lucas W. Kamp[1], Rosaly M. C. Lopes[1], Dennis L. Matson[1], Randolph L. Kirk[2], Bruce W. Hapke[3], Mark D. Boryta[4], Frank E. Leader[1], William D. Smythe[1], Karl L. Mitchell[1], Kevin H. Baines[1], Ralf Jaumann[5], Christophe Sotin[1], Roger N. Clark[6], Dale P. Cruikshank[7] , Pierre Drossart[8], Jonathan I. Lunine[9], Michel Combes[10], Giancarlo Bellucci[11], Jean-Pierre Bibring[12], Fabrizio Capaccioni[11], Pricilla Cerroni[11], Angioletta Coradini[11], Vittorio Formisano[11], Gianrico Filacchione[11], Yves Langevin[12], Thomas B. McCord[13], Vito Mennella[14], Phillip D. Nicholson[15] , Bruno Sicardy[8], Patrick G. J. Irwin[16] ,John C. Pearl[17]

1-JPL, 4800 Oak Grove Drive, Pasadena CA 91109;2-USGS, Flagstaff; 3-U Pittsburgh; 4-Mt. San Antonio College; 5-DLR, Berlin;6-USGS Denver; 7-NASA AMES; 8-U Paris-Meudon; 9-U Arizona; 10- Obs de Paris; 11-INAF-ISAF Rome; 12-U Paris –Sud. Orsay; 13-Bear Flt Cntr Winthrop WA;14-Obs Capodimonte Naples; 15-Cornell U.; 16-Clarendon Laboratory, Oxford, UK

Robert.m.nelson@jpl.nasa.gov, lkamp@jpl.nasa.gov, rosaly.lopes@jpl.nasa.gov, dennis.l.matson@jpl.nasa.gov, rkirk@usgs.gov, hapke+@pitt.edu, mboryta@mtsac.edu, frank.e.leader@jpl.nasa.gov, william.d.smythe@jpl.nasa.gov, Karl.l.mitchell@jpl.nasa.gov, blueskies4321@yahoo.com, ralf.jaumann@dlr.de, christophe.sotin@jpl.nasa.gov, rclark@usgs.gov, dcruikshank@mail.arc.nasa.gov, Pierre.Drossart@obspm.fr, jlunine@lpl.arizona.edu, michel.combes@obspm.fr, giancarlo.bellucci@ifsi.rm.cnr.it, bibring@ias.fr, capaccio@rm.iasf.cnr.it, priscio@rm.iasf.cnr.it, coradini@rm.iasf.cnr.it,

Introduction: We report evidence for surface morphology changes on the surface of Saturn's satellite Titan from information returned by the Visual and Infrared Mapping Spectrometer (VIMS) aboard the Cassini Orbiter spacecraft. Titan's atmosphere is opaque at visual wavelengths due to methane, but VIMS is able to image the surface through "windows" at infrared wavelengths where the methane is relatively transparent. We have previously reported evidence for brightness fluctuations at two locations on Titan's surface [1,2]. Cassini radar images show that one of these regions exhibits lobate flow morphology consistent with volcanic terrain [3]. Here we report lobate "flow" patterns on Titan's surface at (26S,78W), based on VIMS data from recent close flybys by Cassini. This is a region which was found to be photometrically variable in more distant images[1]. Significantly, we also observe a change in the morphology of the scene, in addition to the brightness change, between different epochs. This region is often called *Hotei Arcus*.

The Observations: Cassini encountered Titan at very close range on 2008-11-19-13:58 and again on 2008-12-05-12:38. These epochs are called T47 and T48. The slant distance from the spacecraft to *Hotei Arcus* was 27,051 and 31,787 km. for T47 and T48 respectively. In this study we report changes that occurred since the T5 flyby (2005-04-16-13:17; range 117042 km.) In our previous work, VIMS was able to report brightness changes but not morphological change. In our earlier work on brightness changes, the slant distance was 402,000 km (closer encounters were degraded to the minimum spatial resolution of flybys we compared), precluding our detection of changes in surface morphology. Comparisons of earlier higher-resolution data (T5) with the recent T47 and T48 data reveal changes to the surface morphology in the Hotei region. The location of Hotei Arcus as it appeared during the T5 flyby on Titan's surface is shown as a box in the upper left of Fig 1. The T5, T47 and T48 enlargements of *Hotei Arcus* are shown on the right panel of Fig. 1. The T47 and T48 images were degraded in resolution to appear as they would from the distance of the T5 flyby, enabeling a direct comparison of the three flbybys.

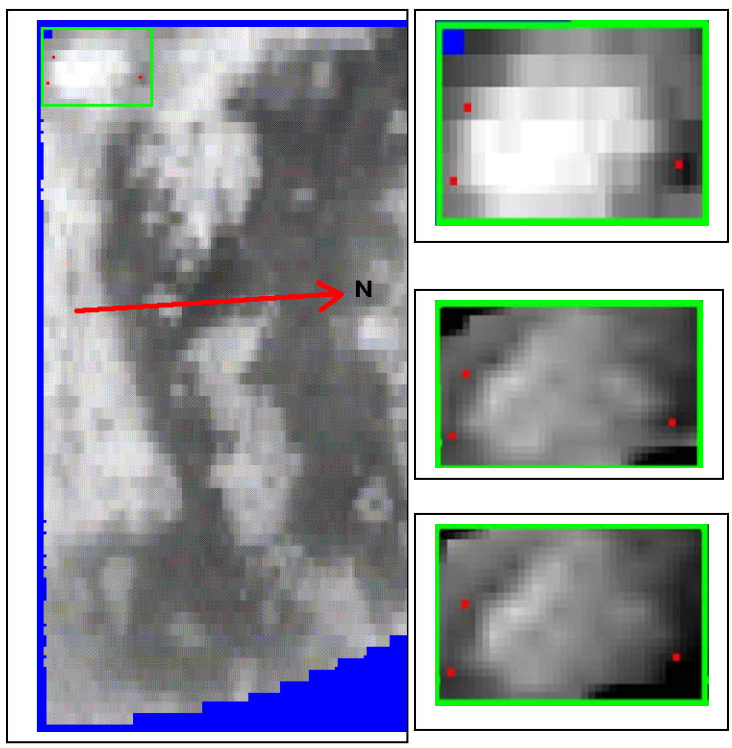

Fig. 1 VIMS images of Titan λ=2.02µm. *Left*: T5 image. *Hotei Arcus* is region shown in box on upper left. *Right (Top to bottom)*: T5, T47 and T48 images, all at the same spatial resolution as the T5 image. The length of the arrow is ~1200 km. The brightness and contrast of all three images are calibrated relative to the three photometric control points in each image (red dots). We find that *Hotei Arcus* was a factor of 1.45 more reflective at T5 than it was at T47 and a factor of 1.59 more than at T48.

Photometric changes: The images in Fig 1 are all scaled to the same spatial resolution. They are also scaled to the same I/F as three control points shown in red in the image. It is obvious from visual inspection of Fig. 1 that *Hotei Arcus* was more reflective at the time of the T5 flyby than it was at the time of the T47 and T48 flybys. In our previous work [1,2] we compared the I/F from *Hotei Arcus* to the I/F of a set of photometric reference points that surround it. The result is consistent with the changes that we previously reported.

Morphology at *Hotei Arcus*: The T47 and T48 flybys were at smaller distances from the surface. Hence, the spatial resolution is improved by an order of magnitude than T5. In Fig. 1 we show the T47 and T48 data at the resolution of the T5 flyby. In Fig 2. we show the same images at the improved spatial resolution. Three lobate features are identified as F1, F2 and F3 and appear to be consistent with flow fronts.

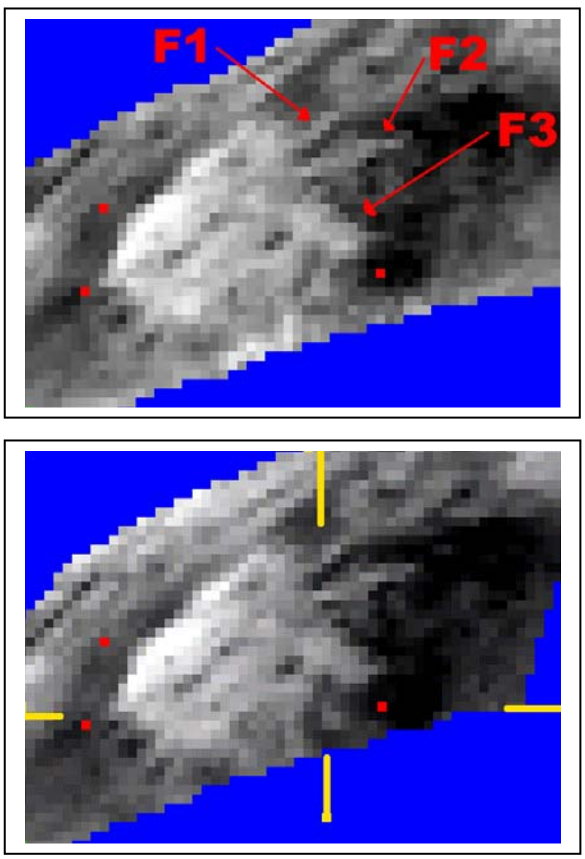

Fig 2. VIMS high resolution images of *Hotei Arcus* at λ=2.02 µm. *Upper*: T47 flyby image indicates three apparently lobate flow features consistent with cryovolcanic activity. These may have changed slightly from T47 to T48 suggesting activity between the two flybys. *Lower*: T48 flyby image. The fiducial marking indicate one location where photometric changes are observed. The area indicated by the markings changed relative to the photometric control point just to the right between the two flybys suggesting activity between the two flybys.

Discussion: This is the first evidence from VIMS that suggests *Hotei Arcus* has morphology consistent with volcanic terrain. The high resolution images also suggest that changes in brightness and morphology occurred between the T47 and T48 flybys. Furthermore, between T47 and T48 we find changes in I/F at *Hotei Arcus* at other wavelengths where VIMS is able to image Titan's surface through the hazy methane atmosphere. It is conceivable that thermal changes may be apparent in these data, although spectral reflectance changes might also explain the data. In either case, the evidence for surface activity is more compelling.

Hotei Arcus has exhibited photometric changes detected by VIMS during the Cassini orbital tour. At times when it appears highly reflective it exhibits a spectral signature consistent with ammonia [1]. Wye *et al.* have also provided evidence consistent with NH_3 on Titan's surface using an different avenue of investigation[3]. The presence of NH_3 has been offered as evidence supporting cryovolcanic activity. Wall *et al.* have recently reported that Cassini rader images of *Hotei Arcus* where VIMS reports brightness changes are found in SAR images to exhibit lobate morphology consistent with cryovolcanic flows. The Radar and VIMS instruments image Titan's surface at very different wavelengths. The difference in effective penetration depth of the two instruments offers the possibility of examining a series of flows from *Hotei Arcus* that may overlie one another. The matetial in the VIMS images may be more recent than the SAR images. This also suggests that *Hotei* may have recurrent activity.

Conclusion: These observations provide further evidence for currently active volcanic processes on Titan's surface. Thus, Titan may now join Earth, Io, Triton, Enceladus, and probably Venus, as the small community of planetary objects in the solar system that have active volcanism. Pre-Cassini, Titan was thought of as frozen pre-biotic earth. Cassini VIMS observations of Titan now suggest that we have evidence for a rapidly evolving object.

Lastly, the participation of two species (CH_4 and NH_3), as active components of Titan's surface-atmosphere interactions, and which are also associated with pre-biological chemistry, is obviously significant. However, care should be taken to avoid premature conclusions. However, this raises for discussion the following question. Are the chemical processes happening on Titan today are the best approximation among the planets to those under which life evolved on Earth?

References: [1]R. M. Nelson *et al.*, 2008a accepted in Icarus [2]R. M. Nelson et al., 2008b accepted in GRL. [3]S. D. Wall *et al.* 2009 accepted in GRL. [3] L. Wye *et al*. DPS and AGU 2008.