CLOUD ACTIVITY ON TITAN DURING THE CASSINI MISSION. E. L. Schaller[1], M. E. Brown[1], H. G. Roe[1], A. H. Bouchez[2], C. A. Trujillo[3], [1]California Institute of Technology, Division of Geological & Planetary Sciences, Pasadena, CA 91125, *emily@gps.caltech.edu*, [2]W.M. Keck Observatory, Waimea, HI 96743, [3]Gemini Observatory, Hilo, HI, 96720.

Introduction: Ground-based observations and recent Cassini images through narrow methane windows have revealed Titan's surface features [1-4] and variable tropospheric clouds [5-10]. Clouds have been regularly observed near Titan's south pole since their discovery [7,8] and typically contribute about 1% of the total brightness of Titan's disk [6,9]. Until the recent discovery of clouds at midlatitudes [10], clouds were only observed at far southern latitudes – the current area of maximum solar insolation. In addition to these daily clouds, Titan also occasionally experiences large cloud outbursts. These were first observed spectroscopically by Griffith et al. [5] who saw a dramatic brightening of Titan in atmospheric windows corresponding to cloud cover of 7-9% of Titan's disk. More recently, a dramatic brightening of the south polar clouds was observed in October 2004 with Keck adaptive optics images (Figure 1).

While infrequent observations from large telescopes and from Cassini flybys are useful for studying the morphologies of clouds and occasional cloud outbursts, only a continuous monitoring project can provide the type of dataset necessary to begin to determine the frequency and duration of these outbursts. This study focuses on quantifying the attributes of these large cloud outbursts and placing the Cassini observations into the broader context of the full range of cloud activity on Titan.

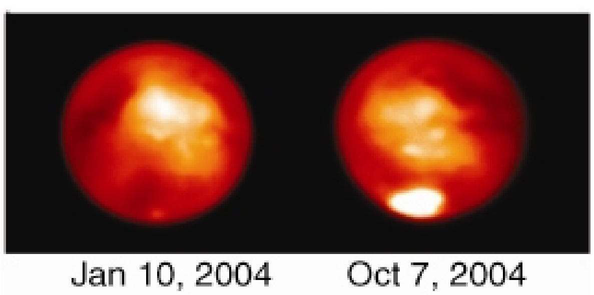

Figure 1. Keck adaptive optics images of Titan taken through the K' filter. The January 10, 2004 image has only a small cloud at the south pole while the October 7, 2004 image shows a large cloud outburst at the south pole. The bright region near the equator is the Xanadu surface feature.

Observations: In order to determine the daily cloud activity on Titan, we observe nightly with a 14-inch Celestron located at New Mexico Skies Observatory. We perform whole disk photometry of Titan through two filters that probe to different levels in Titan's atmosphere in the visible region of the spectrum. We take the ratio of the total flux of Titan in a methane window, which probes to the surface and troposphere, to the flux in a methane absorption region, which probes only to the stratosphere. This technique is self-calibrating and provides a highly efficient and precise observing method. The particular power of this technique is that even through light but variable cirrus or other changing atmospheric conditions on Earth, rapid switching between filters can still give a precise calibration of the relative albedo of Titan in the methane window. We continuously image Titan throughout the night allowing us to obtain extremely small errors on the average of the flux ratio for a given night. We also perform this filter ratioing on a star with similar magnitude and location in the sky to Titan to check for systematic errors.

The phase and approximate magnitude of Titan's lightcurve that we measure in the visible corresponds very precisely to that measured in the infrared. We find that this technique is capable of reproducing the known light curve to high accuracy. By subtracting out this lighcurve from the flux ratio we are able to detect changes due to clouds in the troposphere. As expected, the flux ratio of the star shows no correlation with Titan phase.

We began this project in November of 2003 and observed nightly through April of 2004. We resumed observing for a second season in October 2004 and are continuing to observe every night. Since November 2003, we have also obtained numerous Keck and Gemini adaptive optics images of Titan. Keck and Gemini images from November 11-18, 2003 and October 2-8, 2004 show dramatically increased cloud activity at the south pole of Titan. These large cloud outbursts are clearly recorded by the small telescope monitoring project.

Results: The October 2004 Cassini flyby of Titan (Ta) occurred immediately following the largest cloud outburst we have yet observed. The actual flyby occurred as the outburst was in the process of decaying back to the nominal value. However, several days after the flyby, cloud cover again increased. Keck images taken immediately before and after the flyby confirm these varying levels of cloud activity recorded by the small telescope monitoring project (Figure 2).

The December 2004 Cassini flyby (Tb) occurred in a relatively quiescent period of cloud activity that began in mid-November. The small increase over the nominal lightcurve on the day of the flyby may be due to the midlatitude clouds that were observed in Cassini images.

By analyzing the complete small telescope dataset, we are able to place constraints on the timescales of large cloud formation and on the duration of these events. We find that there were at least four large deviations from the lightcurve during the five months we observed during the 2003-2004 Titan season and one large cloud outburst followed by a period of increased cloud activity lasting until mid-November so far in this Titan season. The October 2004 outburst was larger than anything seen in the previous season and is the largest ever observed with the Keck telescope. Cloud outbursts typically have durations ranging from five to twenty earth days. We find that there tend to be periods lasting up to several months during which large variations in cloud activity are observed followed by more quiescent periods. In addition, we find that these large cloud outbursts often display sudden onset – increasing to full value in less than two earth nights.

Summary: Small telescope photometry of Titan combined with Keck and Gemini adaptive optics images provide important context for the interpretation of high resolution images of clouds seen during Cassini flybys. Cloud formation and evolution in the troposphere of Titan is currently not well understood. Understanding the frequency and duration large cloud outbursts is important for determining how and why they occur. In the coming years, as Titan moves away from southern summer solstice, the small telescope monitoring project will allow us to determine how cloud activity changes with Titan season. In the coming months, this project will be useful for providing context for the Huygens entry and future Titan flybys.

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References: [1] Lemmon, M.T. et al. (1995) *Icarus 113*, 27-38. [2] Noll, K.S. et al. (1996) *Icarus, 124*, 625-631. [3] Smith, P.H. et al. (1995) *Icarus, 119*, 336-349. [4] Coustenis, A., et al. (1995) *Icarus, 118*, 87-114. [5] Griffith, C.A., et al. (1998) *Nature, 395*, 575-578. [6] Griffith, C.A., et al. (2000) *Science, 290*, 509-513. [7] Brown, M.E., et al. (2002) *Nature, 420*, 795-797. [8] Roe, H.G., et al. (2002) *ApJ, 581*, 1399-1406. [9] Bouchez, A.H. and Brown, M.E. (2005) *ApJ, 618*, L53-L56. [10] Roe, H.G., et al. (2005) *ApJ, L49-L52*.

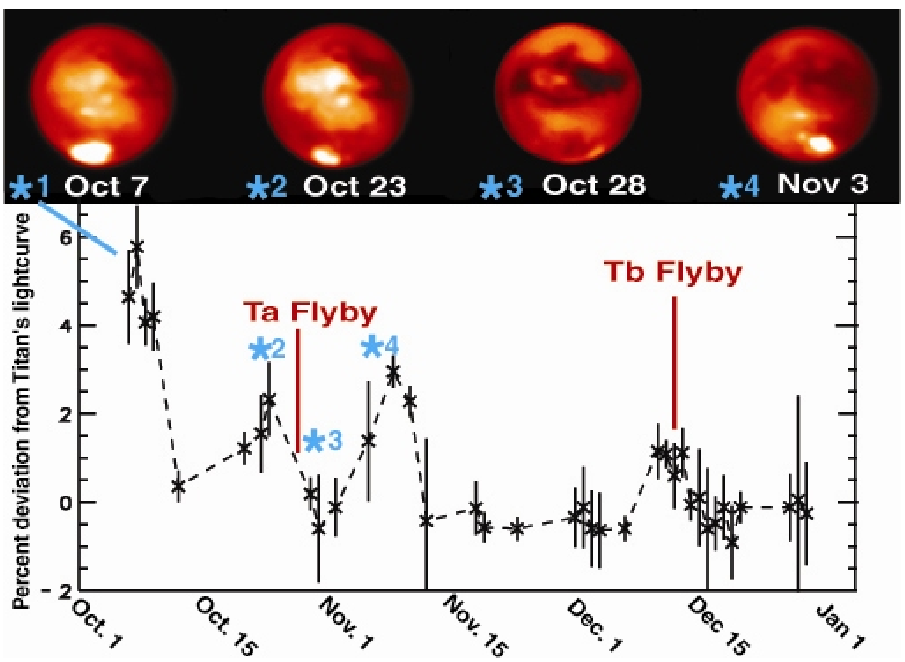

Figure 2. Small telescope lightcurve-subtracted photometry points plotted vs. time for the 2004-2005 season. Large values indicate increased cloud activity. The Ta flyby occurred as cloud activity was rapidly decreasing on Titan. This is evident in the photometry data points and by the two Keck images from Oct 23 and Oct 28 that bracket the flyby date. In addition, the small telescope photometry project recorded an increase in cloud activity seen in the November 3, 2004 Keck image. The Tb flyby occurred during a relatively quiescent period of cloud activity confirmed by Cassini images from the flyby.