**MONITORING TITAN'S ATMOSPHERIC ACTIVITY WITH KEPLER/K2.** S. M. Hörst[1], A. H. Parker[2], C. A. Howett[2], E. L. Ryan[3], [1]Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD, [2]Southwest Research Institute, Boulder, CO [3]SETI Institute, Mountain View, CA.

**Titan's dynamic atmosphere:** Titan has a very dense $N_2$-dominated atmosphere that is rendered nearly opaque by photochemically-generated organic aerosols composed of hydrocarbons and nitriles (see e.g., [1]). Titan's atmosphere drives the only known extant hydrological cycle aside from the Earth's, with a precipitable column of methane in Titan's atmosphere far larger than that of water in the Earth's atmosphere [2]. The global dynamics and chemistry of Titan's atmosphere are complex: the atmosphere is highly stratified [3], at altitude it rotates much faster than the moon's surface (see e.g., [4]), and it supports both short- and long-lived storm systems [5], and some of its molecular constituents result from exogenic sources [6]. From a photochemical standpoint, Titan's atmosphere is a frozen analog to the early Earth's, and understanding the processes that govern its atmosphere are of great astrobiological interest.

**Searching for clouds and haze variation on Titan:** Earth-based monitoring programs have used variability of Titan's brightness in and out of a methane spectral absorption band to identify the onset of storms on Titan and trigger subsequent follow-up from large observing facilities (eg., [7]). We used K2 to perform a similar monitoring campaign, without the same spectral information but with high absolute photometric precision. This campaign allowed us to observe Titan on temporal scales that had not been previously explored. While the estimated precision of Kepler/K2 Long Cadence observations of an isolated, stationary source as bright as Titan is of order ~20 ppm, Titan's motion through the field and through the time- and spatially-variable PSF of Saturn results in a substantial reduction in deliverable precision, to approximately 0.5% - 1%. Similar or greater reductions in precision are seen for other Kepler/K2 satellite observations (e.g., Nereid). We model the effective "sky" under Titan's aperture using a radial basis interpolant with a center defined on Saturn's predicted location in the focal plane, which proved to be very effective in reproducing Saturn's PSF across the spatial scale of the aperture.

In 2001, transient clouds were witnessed daily over a 16-night observing program, and they varied on timescales as short as 3 hours [7] a timescale very well sampled by K2 Long Cadence observations. The K2 observations we obtained span the period of December 3, 2016 to December 7, 2016, sampled at a continuous cadence of 1 integration per 30 minutes. Over the span of these observations, Titan did not vary in broadband brightness by more than 1%. This rules out variability of the global broadband optical geometric albedo due to haze layer variations or cloud emergence and disappearance to similar values. Further long-term, high-precision absolute photometry of Titan may provide a valuable means to constrain the long-term evolution of Titan's haze layers over the course of Titan's seasons and as environmental factors vary (e.g., the Solar FUV output).

**Comparison to Cassini observations:** During the period of the K2 observations, there were no observations of Titan from the Cassini Spacecraft. However, clouds were observed prior to our observations (on November 14$^{th}$ and November 29$^{th}$) and after our observations (on December 18$^{th}$ and December 30$^{th}$) in Cassini Imaging Science Subsystem (ISS) and Visible and Infrared Mapping Spectrometer (VIMS) measurements indicating that this was a period of frequent cloud activity in Titan's atmosphere [8]. In these ISS observations

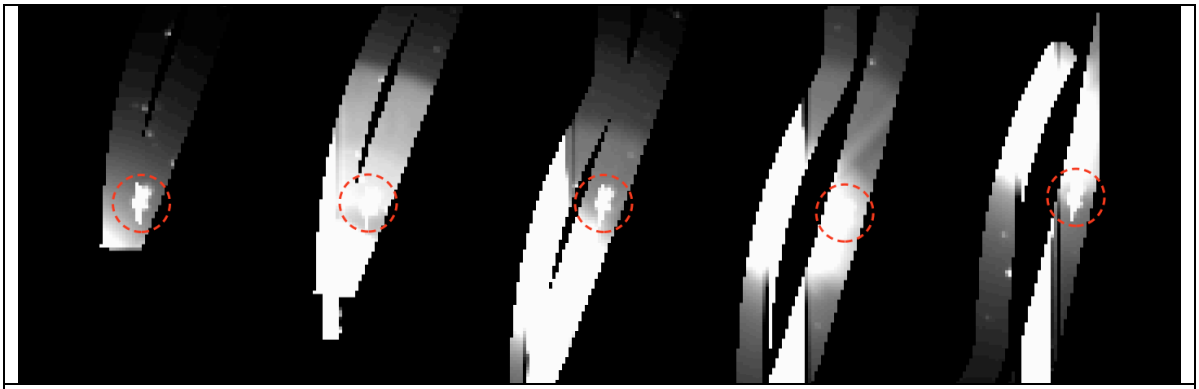

Figure 1: A selection of epochs from the Kepler/K2 sequence of Titan and Saturn. Red dashed circle shows the location of Titan in each frame. Stretch in each frame is identical. Extreme background variation due to scattered light from Saturn varying as a function of focal plane position is clearly evident.

these clouds are reported as “streaks” and were therefore not the large, presumably convective, methane cloud systems seen in ground based observations like those of [7].

**References:** [1] West, R., Lavvas, P., Anderson, C., & Imanaka, I. (2014). Titan’s Haze. *Titan. 1st ed. Cambridge University Press, Cambridge*, 285-321. [2] Atreya, S. K., E. Y. Adams, H. B. Niemann, J. E. Demick-Montelara, T. C. Owen, M. Fulchignoni, F. Ferri, and E. H. Wilson (2006). Titan’s methane cycle. *Planet. Space. Sci.,* 54, pp. 1177–1187. [3] Strobel, D. F., S.K. Atreya, B. Bézard, F. Ferri, F. M. Flasar, M. Fulchignoni, E. Lellouch, and I. Müller-Wodarg. (2009). “Atmospheric structure and composition." In *Titan from Cassini-Huygens*, pp. 235-257. [4] Lebonnois, S., Flasar, F. M., Tokano, T., & Newman, C. (2014). The General Circulation of Titan's Lower and Middle Atmosphere. *Titan: Interior, Surface, Atmosphere and Space Environment*, 122-157. [5] Griffith, C. A., Rafkin, S., Rannou, P., & McKay, C. P. (2014). Storms, clouds, and weather. *Titan: Interior, surface, atmosphere, and space environment, Cambridge University Press*. [6] Hörst, S.M., Vuitton, V. and R.V. Yelle. (2008). Origin of oxygen species in Titan’s atmosphere. *J. Geophys. Res.* 113, E10, E10006. [7] Bouchez, A. H. & Brown, M. E. (2005). Statistics of Titan’s south polar tropospheric clouds. *ApJL, 618*(1), L53. [8] Turtle, E.P., J.E. Perry, J.M. Barbara, A.D. Del Genio, S. Rodriguez, S. Le Mouélic, C. Sotin, J.M. Lora, S. Faulk, P. Corlies, J. Kelland, S.M. MacKenzie, R.A. West, A.S. McEwen, J.I. Lunine, J. Pitesky, T.L. Ray, & M. Roy (2018) Titan’s Meteorology Over the Cassini Mission: Evidence for Extensive Subsurface Methane Reservoirs. *GRL*, 45, 5320-5328.