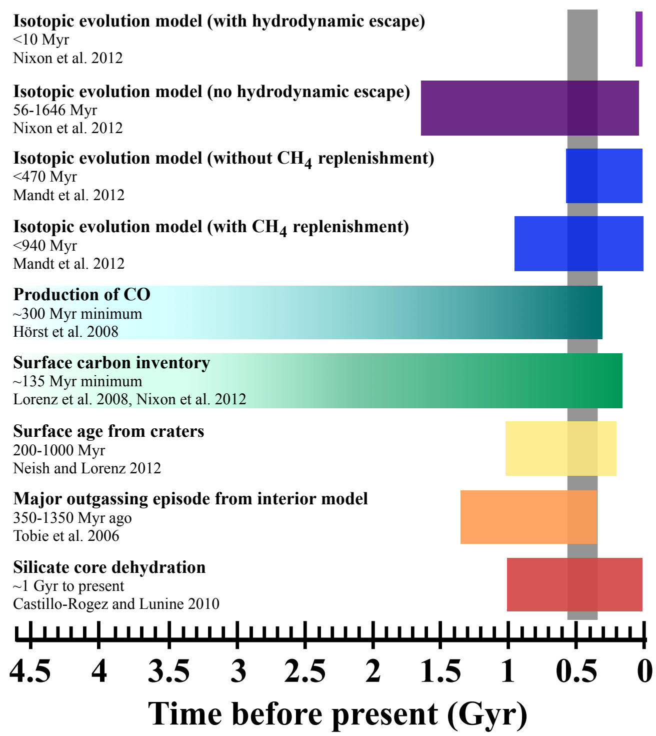
TITAN'S ATMOSPHERE AND CLIMATE: UNANSWERED QUESTIONS S.M Hörst[1], [1]Johns Hopkins University, sarah.horst@jhu.edu

Introduction: Titan is unique in our solar system: it is the only moon with a substantial atmosphere, the only other thick N_2 atmosphere besides that of Earth, the site of extraordinarily complex atmospheric chemistry that far surpasses any other solar system atmosphere, and the only other solar system body that currently possesses stable liquid on its surface. Titan's mildly reducing atmosphere is favorable for organic haze formation and the presence of some oxygen bearing molecules suggests that molecules of prebiotic interest may form in its atmosphere. The combination of liquid and organics means that Titan may be the ideal place in the solar system to test ideas about habitability, prebiotic chemistry, and the ubiquity and diversity of life in the Universe.

Since the Voyager era, we, as a community, have made significant progress in understanding Titan's atmosphere and climate; we have transformed Titan from an enigmatic moon into a dynamic world. This transformation required the persistent and sustained effort of an international, multidisciplinary community that leveraged ground and space based observing, spacecraft measurements, laboratory experiments, and models in pursuit of one overarching goal: to understand Titan as a world. In the process, we have pushed our understanding of terrestrial processes like fluvial and aeolian erosion into completely new phase space allowing us to begin to determine the underlying fundamental physics and chemistry that drive a number of planetary processes. We unveiled a beautiful world that holds so many pieces to the puzzle of how planets form and evolve. We revealed atmospheric organic chemistry that is so complex we are forced to rethink our ideas about how atmospheres work.

Unanswered questions: As with any wildly successful mission, we enter the post-Cassini-Huygens era with new questions, in addition to some long standing questions that continue to evade our understanding. These questions include [1]:

1. What are the very heavy ions in the ionosphere, how do they form, and what are the implications for complexity of prebiotic chemistry?
2. What is the connection between the plumes of Enceladus and Titan's atmosphere?
3. What is the composition of the haze and how does it vary spatially and temporally?
4. How do the organic compounds produced in the atmosphere evolve once reaching the surface?
5. What are the dynamics of Titan's troposphere and how does that affect the evolution of the surface?
6. How variable is Titan's weather from year to year and how variable is the climate over longer timescales?
7. How old is Titan's current atmosphere?



Constraints on the age of Titan's atmosphere from various measurements and models [1]

8. What happened on Titan 300-500 Myrs ago?
9. Is Titan's atmosphere cyclic and if so, what are the implications for habitability?
10. Where is the origin of Titan's methane and what is the fate of the photochemically produced ethane?
11. What is controlling Titan's H_2 profile and potential spatial variations?
12. What is the composition of the surface and on what scales is it spatially variable?
13. What is the composition of the dune particles and how are they produced?
14. Does cryovolcanism occur on Titan?

Answering many of these questions definitively will require future missions, but in all cases there are necessary technology and laboratory needs, discussed below, before we can

Technology investments: One particularly vexing challenge for studying Titan is the need for analysis of extremely chemically complex samples at cryogenic temperatures while minimizing the possibility of sample chemical alteration during acquisition and analysis. This challenge is not unique to Titan and many of the technology challenges that must be overcome to truly explore and understand Titan are also present for exploration of other Ocean Worlds such as Europa and Enceladus. In particular, there is a need for:

1. Sample acquisition systems that minimize chemical alteration of samples (in particular that minimize and/or eliminate heating and contamination of samples)
2. Cryogenically capable sample handling systems
3. Analytical techniques that measure chemical composition and structure for a large range of concentrations (from major to trace constituents), are capable of discerning between and identifying species of the same nominal mass (isobars), and can do so for solids, liquids, and gases
4. For Titan in particular, solutions to 1-3 must minimize power requirements due to the limited energy available on Titan's surface.

Need for dedicated laboratory facilities: Many of our outstanding questions about Titan stem in part from a lack of laboratory measurements of material properties, reaction rates, etc. at relevant temperatures. Titan's complex atmospheric chemistry combined with cryogenic temperatures results in the production of materials that can be challenging to handle safely and in a scientifically rigorous way in Earth laboratories. This presents an additional challenge for developing and testing sampling and sample handling systems and raising the TRL of instruments (the need for which is discussed above). NASA should invest in maintaining laboratories capable of these types of investigations, fund them at stable levels necessary to produce information required by the scientific community and support of flight development, and ensure that students have access to such facilities to ensure that future generations receive necessary training and experience (whether at a university, institute, or at a NASA center).

Equity and Inclusion in Planetary Science: Our mission teams, mission leadership, and full professors do not reflect the demographics of our field [2-4] and the demographics of our field do not reflect the demographics of the US population [4]. This is unacceptable and hinders our ability to attract, train, and retain the scientists and engineers required for the most innovative, creative, and visionary thinking, which is required to solve the challenges we face. Despite numerous studies demonstrating the barriers faced by minoritized groups (see e.g., [5,6]), our institutions remain slow to respond to these issues or in some cases even acknowledge that they exist. For example, at the same rate of change over the past ~20 years, our field will not reach gender parity until nearly 2050. Any vision for Planetary Science in the next 3 decades must acknowledge the existing barriers to equity and inclusion and actively work to dismantle them. The abstract submitted by Rathbun et al. for this workshop includes a much more detailed discussion of these issues and presents a number of suggested starting points.

References: [1] Hörst, S.M. "Titan's Atmosphere and Climate" Submitted to JGR Planets, 2016. [2] Rathbun, J. A., et al. (2015) DPS, 312.01 [3] Rathbun, J. A. (2016) DPS, 332.01 [4] White, et. al. 2011 (http://lasp.colorado.edu/home/mop/files/2015/08/Report.pdf). [5] Richey, C. (2015) DPS, 406.01 [6] Diniega, S., J. Tan, M. S. Tiscareno, and E. Wehner (2016), Senior scientists must engage in the fight against harassment, *Eos, 97,* doi:10.1029/2016EO058767.