Trajectory Design For A Titan CubeSat Mission

Sabrina N. Thompson
NASA Goddard Space Flight Center, Navigation and Mission Design Branch, Code 595, Greenbelt, MD, 20771

Introduction

As their capabilities continue to grow, CubeSats are being used more often for challenging space missions. In addition to their use for technology demonstrations in Low-Earth-Orbit (LEO), a growing number of NASA CubeSat missions are being proposed for science investigations beyond Earth orbit. In March of 2017, NASA selected ten studies under the Planetary Science Deep Space SmallSat Studies (PSDS3) program, to develop mission concepts using small satellites to investigate Venus, Earth's moon, asteroids, Mars and the outer planets. Using CubeSats to explore the outer solar system provides a compact, low-cost alternative to traditional planetary missions[1].

Science Goals

As a result of the Cassini mission, a great deal of knowledge about Saturn and its many moons has been gained from the data collected by Cassini and the Huygens probe. Cassini's imaging radar enabled scientists to see past Titan's thick and hazy atmosphere and revealed methane lakes and hydrocarbon sand dunes.

As it is said to be the most Earth-like body in our solar system because of its surface lakes and active weather system, Titan's atmosphere is comprised of extremely complex chemical processes. However, at Titan's frigid surface temperature (roughly -292 ºF) liquid methane and ethane, rather than water dominates Titan's hydrocarbon equivalent of Earth's water [2]. Two forms of methane- and ethane-filled depressions have been identified by Cassini. These depressions create distinctive features near Titan's poles. It is assumed the lakes are filled via rainfall and from liquids forming underground, since there are no rivers associated with the lakes. At this point, the origins of the depressions hosting the lakes is unclear. Therefore, a feasible science mission to Titan using CubeSats could consist of sending probes into Titan's northern hemisphere for deeper study of its atmospheric chemical composition above the methane lakes. For this reason, the goal of this study is to generate a baseline trajectory design to send 4 CubeSat-sized probes into Titan's northern hemisphere. The mission requirements include the following:

- Carrier-probe separation occurs approximately 2-3 weeks before the probe reaches the entry point
- Carrier reaches entry point at least 4-hours after the probe
- Carrier altitude range at entry point: 1500 km – 5000 km

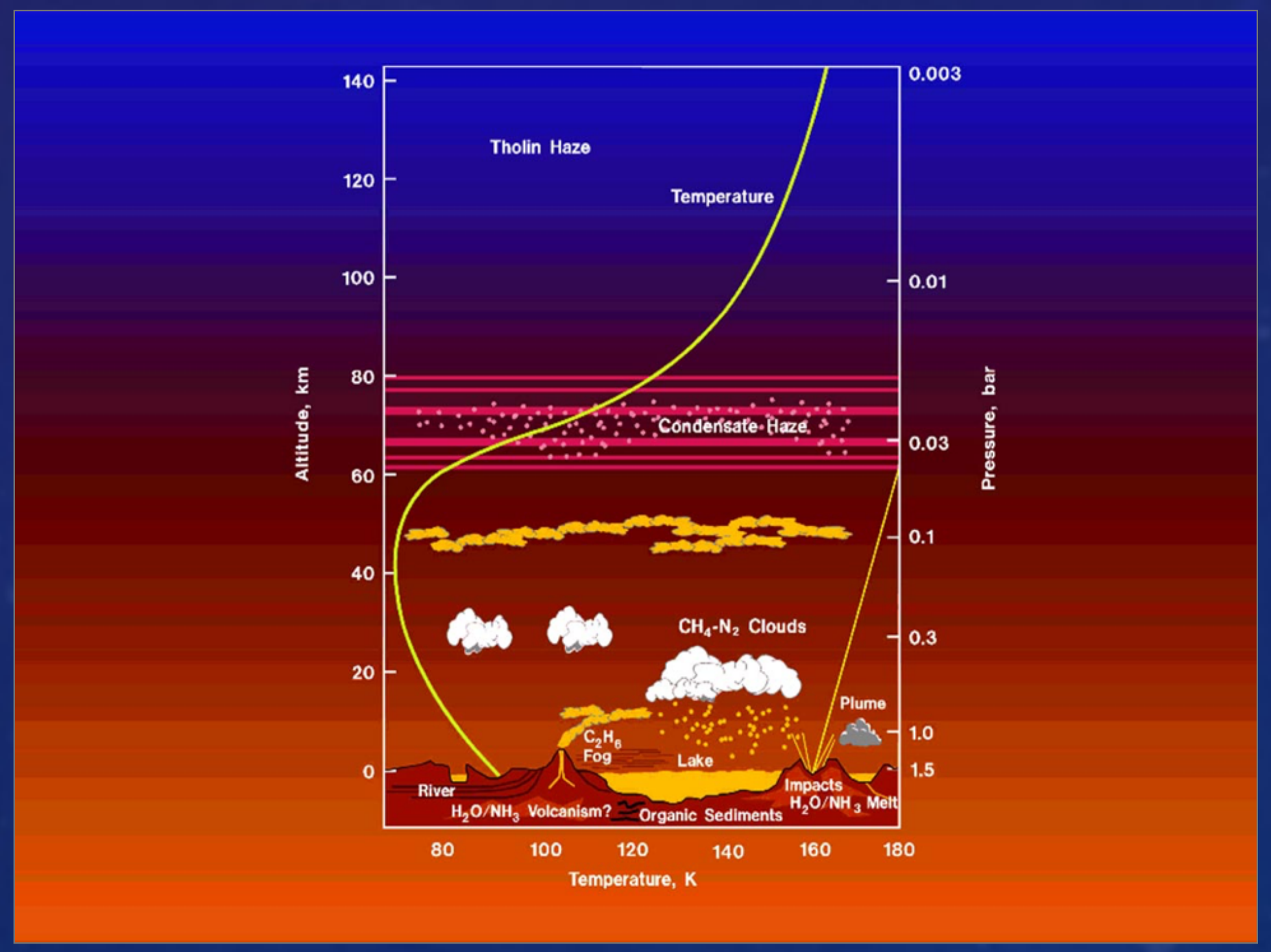

Figure 1. The atmosphere above Titan lakes/seas. Credits: JPL/NASA
.

Interplanetary Trajectory Design

For this study, four 3-U probes are housed in a 24-U carrier. In the final mission concept, the probes will be released in pairs. However, the deployment of only one probe is included in this baseline trajectory design. It is assumed, once deployed, the probe(s) will be able to navigate to the required location in Titan's hemisphere.

Table 1: Mission Assumptions

Launch Date	August 2025
Launch Vehicle	Atlas V Class
Launch C3	50.2 km^2/s^2
Launch Location	Cape Canaveral (KSC)
Arrival Date	May 2034
Flight Time	~ 9 years

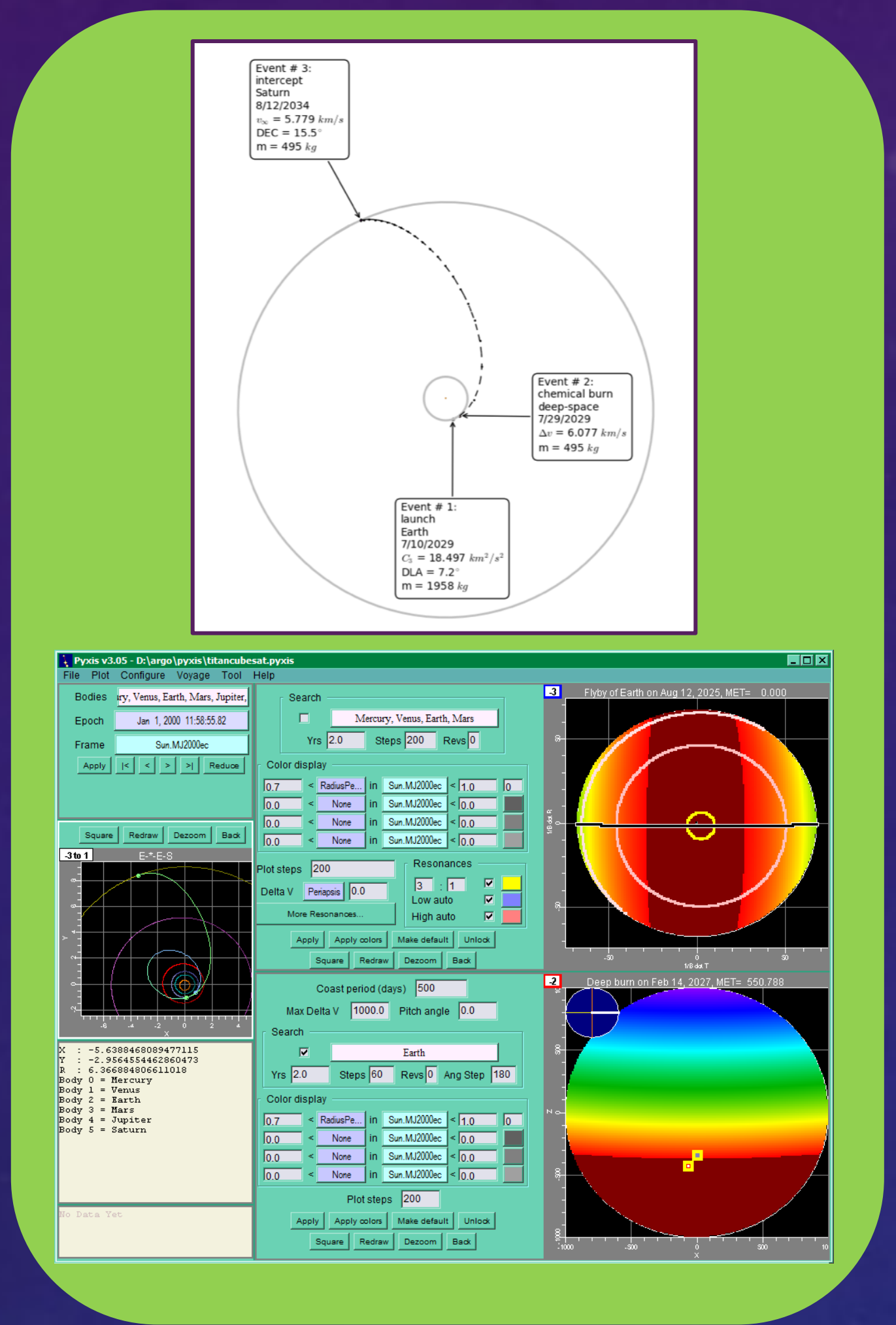

Figure 2. Preliminary Saturn intercept trajectory design using EMTG and Pyxis.

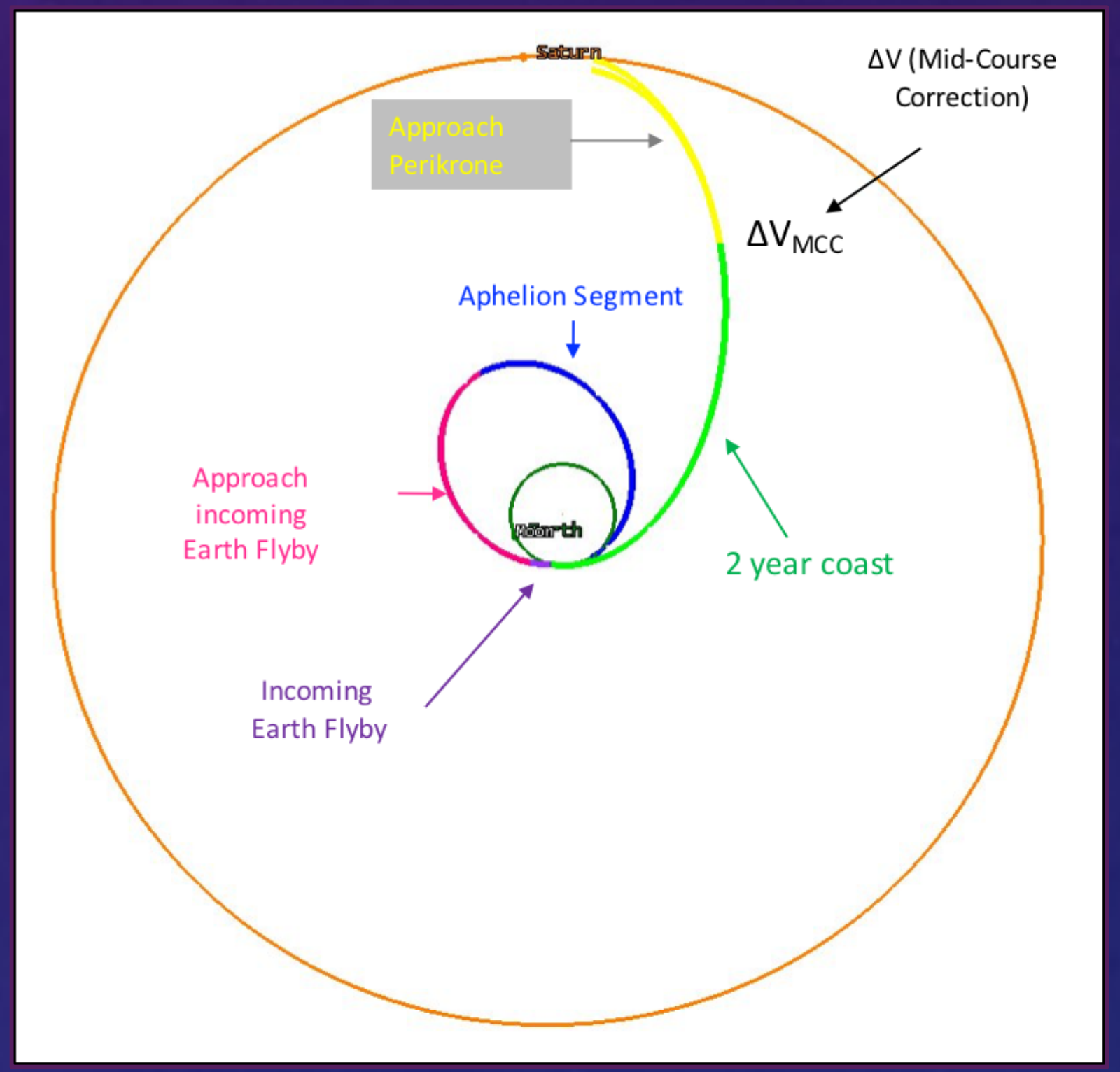

Figure 3. High-fidelity Earth-to-Saturn trajectory with Earth flyby (created using STK) .

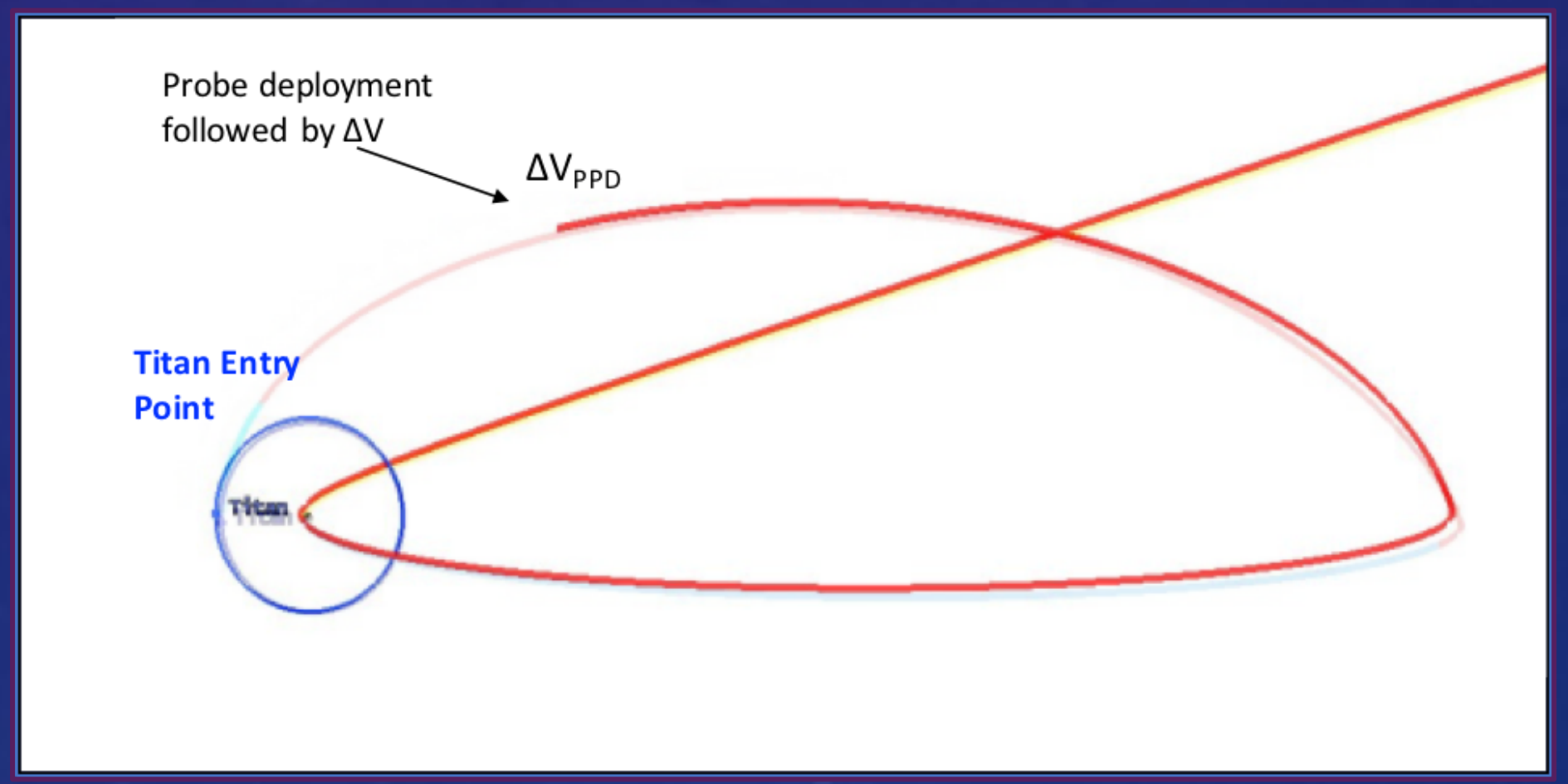

Figure 4. Probe deployment followed by a delta-v maneuver, enabling carrier to lag behind probe(s).

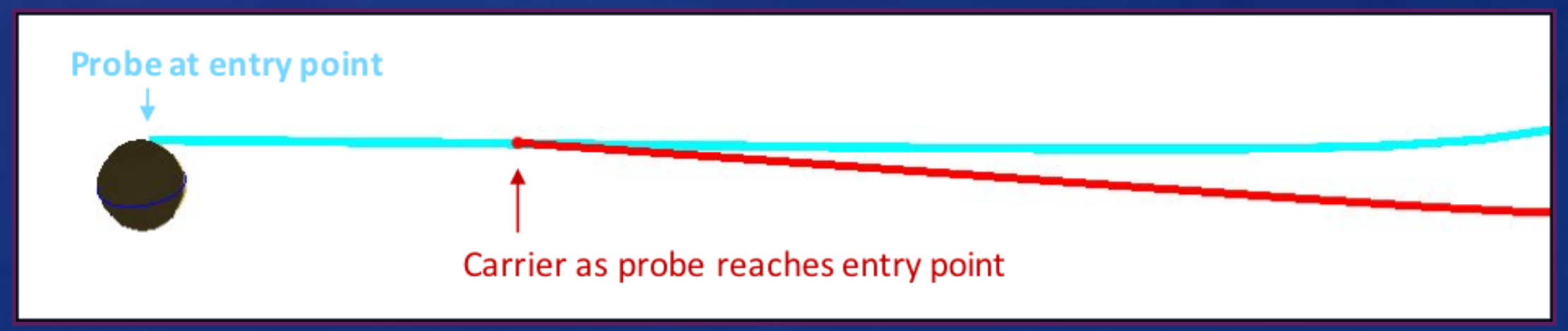

Figure 5. Carrier position as probe reaches Titan entry point.

Acknowledgements:

Conor Nixon (Code 693)
John Downing (Code 595)
David Folta (Code 595)
Kyle Hughes (Code 595)
Jeremy Knittel (Code 595)

Table 2: Mission Maneuver Summary (Impulsive Design)

Launch C_3	**50.3 km^2/s^2**
Primary Spacecraft Maneuvers	
DSM	591 m/s
MCC	290 m/s
Saturn Capture	525 m/s
PC and PRM	514 m/s
Total Primary Delta-V	**1920 m/s**
Carrier maneuver Delta-V	**33 m/s**

Propulsion Considerations

For this mission study, an impulsive maneuvering scheme was employed. However, as secondary payloads, CubeSat propulsion systems are prohibited from using pyrotechnics or hazardous materials. In addition, limits are set on the pressure at which fluids are kept and the total chemical energy that they store[6]. For these reasons and more, propulsion systems using solar sails, as well as, electrical means are being proposed and developed, as they provide low cost, low-thrust options. In addition, there is mention of the possibility of using the Evolved Expendable Launch Vehicle (EELV) Secondary Payload Adapter (ESPA) Ring as a "shepherding spacecraft" with an on-board propulsion system. While the EELV ESPA Ring has been used primarily to mount and deploy auxiliary payloads, Moog Space and Defense has performed multiple studies promoting the use of a family, of what they call, ESPA-based Orbital Maneuvering Vehicles (OMVs). The OMVs can offer small, rideshare payloads an option for orbit optimization, accelerated constellation deployment or a way to reach orbits not traditionally accessed by primary payloads[7].

Conclusions

While CubeSats provide a compact, low-cost alternative to traditional planetary missions, deep space travel is no easy task. CubeSats are limited by power and propulsion requirements needed to reach the outer planets on their own. Therefore, upcoming planetary CubeSat missions are taking advantage of rideshare opportunities. Rideshares provide low-cost transportation services to orbit, however, there are tradeoffs. Some of these tradeoffs include relying on a more expensive mission, having little or no control over launch and arrival date/time, as well as, limited tracking during the mission, as rideshares are often comprised of many other CubeSats. In addition, with the increased technological advancements, as well as, innovation surrounding propulsion system development, exploring the outer planets, such as Titan, using CubeSats is becoming more feasible. The trajectory design proposed in this study can be used as a baseline for such a mission.

References:

[1] "NASA Selects CubeSat, SmallSat Mission Concept Studies", https://www.nasa.gov/feature/nasa-selects-cubesat-smallsat-mission-concept-studies
[2] "The Mysterious 'Lakes' on Saturn's Moon Titan", https://www.nasa.gov/feature/the-mysterious-lakes-on-saturns-moon-titan
[3] "Tiny Cubesats Set to Explore Deep Space", http://www.space.com/29306-cubesats-deep-space-exploration.html
[4] "10 things we've learned from Cassini-Huygens", http://www.stfc.ac.uk/news-events-and-publications/features/10-things-we-ve-learned-from-cassini-huygens/
[5] Englander, J., "Rapid Preliminary Design of Interplanetary Trajectories Using the Evolutionary Mission Trajectory Generator", 2016.
[6] Barbee, B., "Interplanetary Mission Design" lecture note, Aerospace Engineering: ENAE741, University of Maryland, College Park, 2015.
[7] Martin-Mur, T., Gustafson, E., and Young, B., "Interplanetary CubeSat Navigational Challenges", 2015.
[8] Stender, M., Pearson, C., Maly, J., Loghry, C., "Mission Case Studies using the Rideshare Enabling Orbital Maneuvering Vehicle", Aerospace Conference, 2015 IEEE, March 2015.