SMALL SPACECRAFT EXPLORATION OF URANIAN MOONS. B. Badders[1], T. Hill[1], J. Straub[2], J. Berk[1], N. J. Long[1], J. Schiralli[1], [1]Department of Space Studies, University of North Dakota, 4149 University Avenue Stop 9008, Grand Forks, ND 58202, brian.badders@my.und.edu, tyler.n.hill@my.und.edu, joshua.berk@my.und.edu, nicholas.j.long@my.und.edu, jonnathan.schiralli@my.und.edu, [2]Department of Computer Science, University of North Dakota, 3950 Campus Road Stop 9015, Grand Forks, ND 58202, jeremy.straub@my.und.edu.

Introduction: Exploration of the Uranian Moon system remains of high interest, as current knowledge emanates from a limited set of data, gathered during a single fly-by the Voyager spacecraft. The five major moons, Miranda, Ariel, Umbriel, Titania and Oberon, are of particular interest to answering fundamental questions of planetary science related to the formation and composition of the 'icy-giant' systems. Due to the limitation the extreme distance of these moons poses to Earth based observatories and the limited duration of the one fleeting encounter made by Voyager, not much data has been recorded about the Urianian system. Voyager provided tantalizing pictures and recorded some data for a handful of Uranus's moons but more close-proximity information is needed to validate or refute unresolved theories about Uranus, its moons and the evolution of the system. Such a mission is presently achievable via a pristine spacecraft that serves as a relay for daughter small spacecraft dispatched to candidate moons.

Under this exploration mission concept the parent, solar electric powered (SEP), spacecraft will orbit Uranus conducting relevant planetary research. The large spacecraft will serve as a relay platform for four deployable small spacecraft. The small craft will be dispatched to a moon, for gravity mapping and multispectral imaging of the Urianian satellites.

Projected Scientific Benefits of Small Spacecraft: The National Research Council's, planetary decadal survey listed Uranus exploration as the third highest priority exploration target for flagship exploration in the 2013-2022 timeframe [1]. Flagship missions to the outer planets occur only once every several decades. To take advantage of a rare opportunity to make detailed observations of Unaranian moon, small spacecraft will be deployed from the primary spacecraft to collect information on multiple Uranian satellites.

The four spacecraft will be split into two teams of two. A pair of daughter satellites will be deployed to moons within the energy and propellant budgets of the craft. The spacecraft will fly in formation to make high-resolution gravity field models, using RF transmissions to make orbit perturbation measurements, as has been done on the NASA GRAIL (Ebb and Flow) spacecraft [2].

Due to limited power and volume and data bandwidth restrictions the second primary science instrument will be a multi-spectral imager. Producing mid-resolution imagery for Uranian moons has been deemed to be the most productive use of these limited resources. It will help constrain the petrology and geology of Uranian moons.

Enabling Technologies: The scientific mission is enabled by the ability to control a constellation of four satellites, divided into two groups of two, to produce a multispectral mosaic of the surface and an internal mass model of each body. The payload onboard these small satellites will be a multispectral imager with an optics package that will record detailed image data for each moon. The communications delay between Earth and Uranus poses significant challenges to any technique which requires intervention by a ground controllers. A high level of autonomy is thus required.

The spacecraft will be utilize a 6U CubeSat form factor and include deployable solar panels. The ability to operate at this distance is enabled by a recent high efficiency solar cell concept promulgated by the University of Delaware (with support from DARPA). This project has a stated aim of achieving a 50% level of efficiency; current work has reached an efficiency of 42% [3]. The reverse side of the deployable solar panels doubles, based on work presented in [4], as a phased array antenna, significantly increasing communications gain levels. In addition to enabling inter-satellite communication, the communications system will be used to perform inter-spacecraft ranging to monitor changes in distance. This technique, used by GRAIL and GRACE [5, 2], allows minute changes in the body's gravitational field to be detected and an internal mass model to be created.

Mission Operations Plan: At a distance from the sun of approximately 20 AU, solar flux is 3.4 w/m^2. With a deployable solar array with the dimensions 20 cm x 130 cm and a surface area of 2,600 cm^2 (or 2.6 m^2) and a projected solar panel efficiency of 48%, based on [], a projected power generation level of 4.24 W is possible.

This limited power generation capability necessitates that the mission conserve power via a control cycle that limits communications to short bursts, when the batteries are fully (or nearly fully) charged. The camera and onboard flight computer will operate continuously; however, the payload processing computer will operate in short bursts and analyze and prioritize the data for transmission, during appropriate transmission windows.

The small spacecraft will utilize ion electrospray propulsion, a low-power, scalable engine with 2000 – 3500 seconds of impulse. [4] When a pair of spacecraft complete an investigation at one moon, they may be re-stationed when batteries are fully charged and the orbital mechanics permit re-deployment. Upon arriving at the new target the craft will be permitted to fully recharge before the onboard flight computer engages the science sensors and any other non-vital systems.

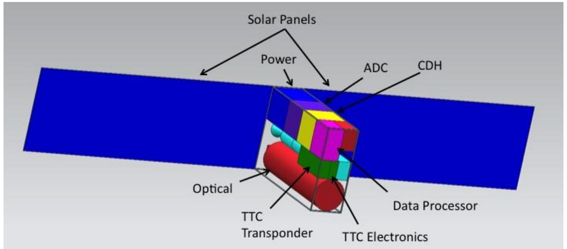
Mission Data Operations: A key component of facilitating this low-cost add-on mission is the autonomous operations of the mission craft. The model-based transmission reduction (MBTR) approach [9, 10] and autonomous cluster operations [11] will be utilized to maximize the value of the limited communications bandwidth available, via limiting transmission to important data. MBTR compares in-situ collected data to an a priori shared model and transmits important differences back to Earth-based controllers. Autonomous cluster operations maintain spacecraft separation to ensure that the data collected has the appropriate characteristics for the science being performed (e.g., imaging of the same areas for super-resolution or separation and overlap for mosaicking).

The data transmission capabilities of the small spacecraft are insufficient to send even the model-driven differences back to the Earth. Because of this, it is expected that data will be relayed via the primary spacecraft. The primary spacecraft will combine and prioritize, based on the scientific importance of the data or operational importance of other messages, data for transmission. Data will be transmitted by the primary spacecraft during communications windows with Earth.

Because of this relay mechanism, there will be four modes of operation, relative to the availability of Earth controllers. In mode 1, controllers are available, however, their utility for problem solving and mission command is limited by the round-trip communications delay. In mode 2, the small spacecraft are not in communications with the primary spacecraft (e.g., if the moon they are studying or Uranus is in the way); however, the primary spacecraft is in contact with ground controllers. In mode 3, the small spacecraft are in contact with the primary spacecraft; however, the primary spacecraft is not in contact with ground controllers. Finally, in mode 4, communications are not possible between the small and primary spacecraft and between the primary spacecraft and ground controllers. The precise time that the mission spends in each of the aforementioned will be a function of the orbits chosen and mission plan. However, the above illustrates the need for autonomous operations and a robust autonomous system that is capable of handling almost any issue that might arise.

Conclusions and Future Work: The above describes a multi-phase mission to three moons in orbit of Uranus utilizing a constellation of small spacecraft deployed from a larger spacecraft that will study the planet. This approach demonstrates the 'hitchhiker' approach to planetary science, described by and maximizes the value of the base mission by allowing the performance of secondary science (related to the moons) at minimal additional mission cost. This mission, thus, in addition to providing important information about three interesting targets also demonstrates a new paradigm for prospective future missions.

Figure 1. Diagram of 6U CubeSat with Deployable Solar Panels [b]



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