FLYBY AND IMPACT OF CHARIKLO: A NEW FRONTIERS CLASS CENTAUR RECONNAISSANCE MISSION CONCEPT FROM THE 2017 NASA-JPL PLANETARY SCIENCE SUMMER SEMINAR. M. C. Bouchard[1], S. M. Howell[2], L. Chou[3], M. Thompson[4], S. Cusson[2,5], M. Marcus[6], H. Brodsky Smith[7], S. Bhattaru[8], J. J. Blalock[9], S. Brueshaber[10], S. Eggl[2], E. R. Jawin[11], K. E. Miller[12], M. Rizzo[13], K. Steakley[14], N. H. Thomas[15], K. Trent[5], M. Ugelow[16], C. J. Budney[2] and K. L. Mitchell[2]. [1]Washington Univ. in St Louis, St. Louis, MO, [2]JPL, Cal-Tech, Pasadena, CA (PI: samuel.m.howell@jpl.nasa.gov), [3]Univ. Illinois at Chicago, Chicago, IL, [4]NASA JSC, Houston, TX , [5]Univ. Michigan, Ann Arbor, MI , [6]Univ. Maryland College Park, College Park, MD , [7]ASU, Tempe, AZ, [8]MIT, Cambridge, MA, [9]Hampton Univ., Hampton, VA, [10]Western Michigan Univ., Kalamazoo, MI, [11]Brown Univ., Providence, RI, [12]SwRI, San Antonio, TX, [13]NASA GSFC, Greenbelt, MD, [14]New Mexico State Univ. Main Campus, Astronomy, Las Cruces, NM, [15]CalTech, Pasadena, CA, [16]Univ. Colorado at Boulder, Boulder, CO

Introduction: The mission concept detailed here was developed as part of the 2017 Planetary Science Summer Seminar (PSSS) hosted by the Jet Propulsion Laboratory (JPL) and supported by the National Aeronautics and Space Administration (NASA) [1]. The PSSS seeks to foster the next generation of solar system explorers by bringing early-career professionals in space science and engineering together to teach them about the space mission life cycle, roles and responsibilities of scientists and engineers working on missions, as well as the concurrent engineering and trade-off decision making involved in mission planning. The PSSS participants designed a pre-phase-A mission concept based on the requirements outlined in NASA's 2016 New Frontiers 4 Announcement of Opportunity (AO) [2].

Target and Science Rationale: New Frontiers missions provide the ideal opportunity to explore previously unexplored planetary bodies such as the Centaurs, a population of small bodies and minor planets that have unstable orbits between Jupiter and Neptune (5-30 AU). The unstable orbits of these hybrid bodies have dynamic lifetimes of a few million years [3]. While their origin is unknown it has been suggested that some Centaurs originated from Kuiper Belt objects [4], though this interpretation has been challenged [5].

Centaurs include some of the reddest bodies in the solar system and have a bimodal color distribution ranging from near-neutral to red. Possible origins for this color distribution include surface reddening due to solar irradiance and differences in primary ice and tholin compositions [6-11].

Chariklo is the largest observed Centaur with a diameter of ~330 km, and with two distinct rings, it is one of the smallest bodies in the solar system with a confirmed ring system [12-13]. Chariklo was selected as the target Centaur because a mission to this body would address several high priority themes of the most recent Planetary Science Decadal Survey, Visions and Voyages (V&V) [14].

Our proposed robotic mission to Chariklo would: (1) determine if exogenic processes dominate the current geologic state of the Centaur surface, including corresponding spectral and morphologic characteristics (V&V Theme 1, 10), (2) determine formation mechanism of the Chariklo system (rings, outgassing, and binary objects) to inform an understanding of ring formation for other planets (V&V Theme 3, 10), and (3) determine the formation location of Centaurs within the solar system (V&V Theme 1, 3, 4, 8, 10). These science goals are further delineated as objectives:

Science Objective 1.1: Determine if the present surface of Chariklo closely resembles that of other outer solar system bodies by investigating the near-surface presence and abundance of ices and minerals (including H_2O, CH_3OH, CO_2, CO, CH_4, N_2, NH_3, HCN) and by identifying surface temperature and geologic features (impact craters, flow features, mass wasting, and tectonic features).

Science Objective 1.2: Determine if differences in color on Centaurs are a result of the cumulative effect of impacts, outgassing activity, or other processes, by correlating color to the relative age of the surface.

Science Objective 2.1: Determine whether Chariklo's rings are a product of a) outgassing activity (with the same volatile composition as the surface), b) material ejected through impacts (same bulk composition as the upper crust), or c) captured external material (unique ring composition).

Science Objective 2.2: Determine ring formation processes by measuring the physical properties of Chariklo and observing if an induced impact plume changes the physical properties of the rings.

Science Objective 3.1: Constrain Centaurs' original reservoir by measuring composition, speciation, and isotopic ratios (D/H, O, N, and C) of near-surface material on Chariklo and comparing these measurements to those made at other bodies and with models of solar system formation.

Science Objective 3.2: Determine non-gravitational effects on Chariklo's historical trajectory.

Mission Design and Science Payload: In order to execute an outer solar system mission capable of answering these questions, a flyby mission with a remote sensing payload and a kinetic impactor was designed. Modeling the orbital dynamics of the target and the New Frontiers 4 launch window resulted in the primary mission profile shown in Figure 1. Utilizing four plane-

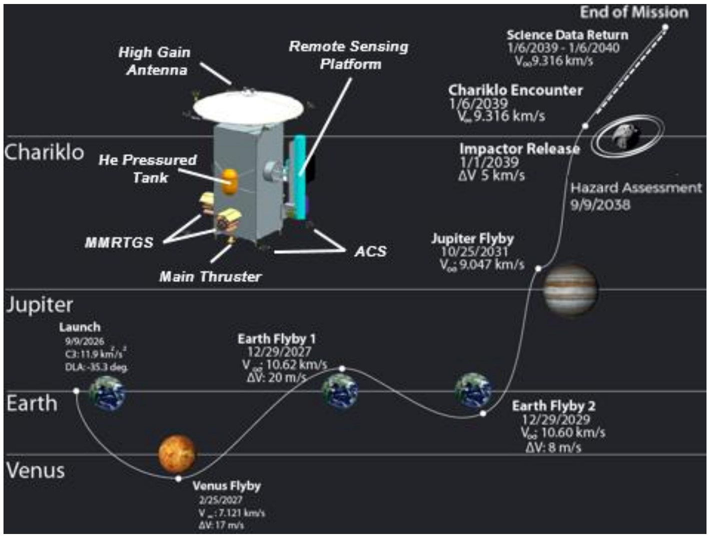

Figure 1: Concept of operations for a Centaur Reconnaissance mission with planetary encounter dates and delta velocity. Inset shows spacecraft configuration with labeled subsystems including: Multi-Mission Radioisotope Thermoelectric Generators (MMRTGs) and Attitude Control System (ACS).

tary flybys and a delta-v <0.4 km/s provides an ample six month launch window. The entire 14 year mission will culminate in a <12 hour flyby event.

The mission's primary science goals and objectives can be addressed with a moderate payload, which includes a remote sensing package on an articulated scanning platform that will image Chariklo's surface and rings on approach, as well as the surface, rings, and impact plume on departure. Occultation science will be performed on the rings after the flyby as well. This instrument package includes:

CAMIS – Centaur Advanced Multi-wavelength Imager and Spectrometer: high resolution camera and multi-wavelength spectrometer that allows for spectral features to be spatially associated with geologic features, and facilitates mapping of spatial distribution of geologic features.

HALBERD – Impactor: 100 kg tungsten sphere that will detach from the spacecraft and impact the surface, creating a plume of subsurface material whose composition and isotope ratios can be measured.

SMART – Sub-mm Articulated Reconnaissance Telescope: microwave instrument that can measure isotope ratios in the impact plume (H_2O, NH_3, and CO) and map thermal characteristics of the surface. SMART's optics are co-aligned with CAMIS, allowing for concurrent and comparable observations.

COEUS – Centaur Occultation Ejecta Ultraviolet Spectrometer: will be pointed at Chariklo's rings and the impact ejecta, and will measure Ar, Ne and ice/carbon species (CO, CO_2, CH_4, H_2O) and abundances. COEUS will also track the rings particle size and phase functions and observe the fate of the impact ejecta plume.

CERSE – Centaur Radio Science Experiment: will utilize the telecommunication system to determine Chariklo's mass distribution (J2), ring/plume occultation characteristics, and constrain ring/plume particle size and density.

Descope Considerations: To account for the risk of a malfunction with the impactor release mechanism and timing, all threshold science will be completed during the approach phase with the impact experiment and ring occultation science contributing to the baseline science of the mission.

Phases A-D of this mission concept can be accomplished within a budget of $760 million, under the New Frontiers 4 mission cost cap of $850 million (FY 2015 dollars).

The participants performed a high-level cost evaluation to determine if this mission could be completed within the $450 million Discovery cost cap. Assuming a credit for reduced launch vehicle performance, donated MMRTGs, and a descoped science payload (no Sub-mm spectrometer), the mission profile was 16% over budget and did not close on a power solution. However, due to conservative assumptions from the New Frontiers design, a more thorough analysis may yield a Centaur mission within the Discovery cap.

Summary: This conceptual mission design shows that it is possible for a mission with aspects of both a New Horizons flyby and Deep Impact impactor to visit a Centaur on a New Frontiers budget and address a preponderance of science questions about these unique and primitive solar system bodies.

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