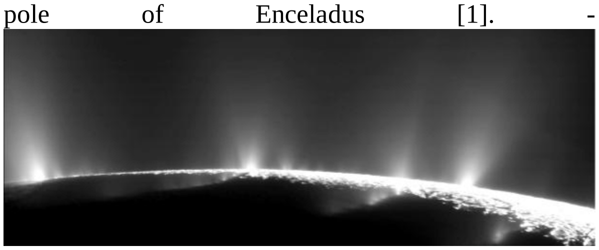
LIFE - Enceladus Plume Sample Return via Discovery Peter Tsou[1], Ariel Anbar[2], Kathrin Atwegg[3], John Baross[4], Donald Brownlee[4], Richard Dissly[5], Daniel Glavin[6], Christopher Glein[7], Isik Kanik[8], Christopher McKay[9], Carolyn Porco[10], Yasuhito Sekine[11], Ken Takai[12], Yoshinori Takano[12], Peter Williams[2], and Hajime Yano[13], [1]Sample Exploration Systems, [2]Arizona State University, [3]University of Bern, [4]University of Washington, [5]Ball Aerospace, [6]NASA Goddard Space Flight Center, [7]Carnegie Institution of Washington, [8]Jet Propulsion Laboratory California Institute of Technology, [9]Ames Research Center, [10]Cassini Imaging Central Laboratory for Operations, [11]University of Tokyo, [12]Japan Agency for Marine-Earth Science and Technology,[13]Japan Aerospace of Exploration Agency, Institute of Space and Astronautical Science. Email: tsou.peter@gmail.com.

Introduction: One of the most significant discoveries made by the Cassini Mission in 2005 was finding salt bearing ice particles and organic compounds in the 200 km cryovolcanic plume emanating from the south pole of Enceladus [1]. -



In the first half century of space exploration, samples have been returned from the Moon, comet Wild 2, the Solar Wind and the asteroid Itokawa. The in-depth analyses of these samples in terrestrial laboratories have yielded pivotal knowledge based upon incredibly detailed chemical information that would have been impossible to obtain without the returned samples. Now the geysers on Enceladus offer both exceptional cost effective opportunity and strong scientific rationale for repeating another successful low-cost flyby sample return mission. The earliest possible flight opportunity is the next Discovery Mission [2].

Plume Discoveries: While Voyager provided evidence for geologically young regions on Enceladus, its plumes, active tectonics, and high heat flux were discovered by Cassini. The confirmation of these geysers on Enceladus opens the possibility of a flyby sample return without the necessity of landing or surface contact, similar to the Stardust and Hayabusa I missions. Based on Hubble observations, it was recently announced that Europa also intermittently puffs water some 200 km from its south pole [3]. Future analyses of the Europa plume material may offer yet another opportunity to expand our search for life within our Solar System. LIFE becomes the pathfinder in these outer planet life search missions. Yet, Enceladus sample return should be done first because we can be better prepared for this mission using the more detailed in situ data from Cassini.

Cassini In Situ Findings: Cassini has made many key discoveries of the Saturn system, especially the fragmentation of relatively heavy organics from the plumes of Enceladus. Based on meeting the four prime criteria for habitability as we know it: liquid water, an energy source, organics, and nitrogen, Enceladus has been determined to be habitable [4]. Out of all the NASA-designated habitability targets, Enceladus is the single body that presents the clearest evidence for all four criteria. Significant advancement in assessing the biological potential of Enceladus can be made on returned samples in terrestrial laboratories where the full power of state-of-the-art laboratory instrumentation and procedures can be utilized, without serious limits on power, mass or cost. Terrestrial laboratories provide the ultimate in analytical capability, adaptability, reproducibility, reliability, and synergy amongst scientists.

Some Key Questions for Returned Samples: Samples collected from the Enceladus plume will enable a thorough and replicable search for possible extraterrestrial organisms and biosignatures [5], which would propel our understanding of the habitability of the subsurface ocean of Enceladus. By searching for amino acids, peptides, nucleotides, and other organic compounds, by determining the sequences of any oligomers, by measuring chirality, chemical disequilibrium, and compound specific isotope ratios, we can formulate a new set of hypotheses to address many of the most critical science questions required for investigating the stage of extraterrestrial life at Enceladus beyond the initial four factors of habitability. At a broader level, Enceladus offers us a unique opportunity to search for new insights into the puzzling transition between the ubiquitous prebiotic chemistry of asteroids and comets, and the biochemistry at the root of all known life. There is also much to be learned about the geochemistry of oceans inside icy worlds as a general phenomenon by studying Enceladus as a test case.

Criticality of Laboratory Analyses: For extraterrestrial organic compound analyses such as chirality and compound-specific isotope ratio determination, the repeatable robustness of laboratory measurements is essential. In general, these analyses require a variety of wet chemical extraction and derivatization steps prior to analysis that are adapted to the sample and procedures that can be modified according to the results obtained. The Stardust mission is an excellent example of the challenges in the analysis of organics. Final confirmation of the cometary origin of the amino acid glycine from comet Wild 2 was obtained over 3 years after the samples were returned to Earth. This long period of laboratory testing and development allowed several modifications to the extraction protocol, involving multiple analytical techniques and instrumentation.

In Situ Measurement: The most recent Cassini INMS data suggest the existence of heavy organic molecules with intriguing astrobiological possibilities in the Enceladus jets. The proposed LIFE payload would help to identify these molecules by including a mass spectrometer (CHIMPS, an upgraded ROSINA on Rosetta) with a significantly higher mass range (>300 amu) than the Cassini INMS (99 amu). We would also carry a camera for Optical Navigation shared with science to observe the dynamics of the jets and a dust counter to record the flux of the jet particles encountered by the collectors. In situ measurements provide essential upgrades to follow up on Cassini observations and resolve some of the instrumental issues while providing valuable early science return. However, the in situ measurements cannot replace the returned samples, because the most astrobiologically "interesting" organics (e.g., amino acids) would not be detectable by in situ mass spectrometry because they are highly water soluble and nonvolatile, which means that they would be trapped in the ice grains (i.e., frozen ocean water) rather than in the plume gas. Thus in situ and samples are complementary by providing different types of information (e.g., gas vs. solids).

Urgency of Returning Samples: The size of the Saturn's E ring suggests that the Enceladus' plume has existed for about three centuries [6]. This does not mean, however, that the geysers have been continually active, or that they would continue to persist in the foreseeable future. We know the jetting exhibits both seasonal and diurnal variations [7] but we do not know how long the jets are continuously active; it is therefore extremely important to sample them as soon as practically possible. If the plume becomes intermittent or ceases, further study would require a costly and risky operation, involving a lander that would have to locate and then drill through the icy crust (estimated to be at least several km thick) to reach the liquid reservoir that feeds the geysers, a mission which may not be fiscally or even technically possible in the near to distant future. The earliest flight opportunity in NASA would be the next Discovery Mission.

Mission Challenges: An ambitious goal of LIFE is to search for microorganisms that might have existed or are presently living in the Enceladus ocean. As a result, we must be prepared both to protect Enceladus from potential terrestrial contaminants and to protect the Earth's biosphere from samples collected from Enceladus. There are considerable geochemical differences between Mars and Enceladus (e.g., dry, oxidized vs. wet, reduced), it may be sensible to formulate new, possibly more relaxed baseline planetary protection requirements for Enceladus sample return because putative life in the Enceladus ocean may lack adaptations that would allow them to survive desiccation during the return cruise, and exposure to Earth's O_2-rich atmosphere. Since LIFE may be the first sample return mission that might actually bring "life" back to Earth, it is imperative that we develop the planetary protection implementations for a Discovery class missions.

A novel concept for acquisition and processing of the returned samples from Enceladus has been developed by the Japan Agency for Marine-Earth Science and Technology: construct a Bio Safety Level 4 facility on the research ship *Chikyu* [8]. They would operate the BSL 4 facility as part of their search for life in Earth's oceans. In much the same way, the facility can be used for processing samples from extraterrestrial oceans. This collaboration will bring forward to LIFE an extended insight and experience in search for life and a large number of seasoned scientists and engineers in the field of oceanography. In fact, the two exploration endeavors are complimentary, and LIFE would benefit tremendously from this collaboration. The onboard helicopter landing accommodation on *Chikyu* would also provide transport to anywhere on land.

Collaborations: STARDUST and Hayabusa I returned samples from comet Wild-2 [9] and contemporary Interstellar dust in 2006 and asteroid Itokawa in 2010 [10]. Both institutions would join to implementation LIFE: Ball Aerospace to build the spacecraft and JAXA/ISAS to developing and providing the Integrated Sampling Subsystem (to include the sample collection mechanisms, sample canister and Earth return capsule). As with STARDUST, the sample instrument team will supply the capture media. Due to the higher Earth reentry speed, NASA Ames' Heatshield for Extreme Entry Environments Technology would provide the advanced Earth reentry thermal protection system. To realized institutional advantages, JAXA/ISAS would also support the flight operations. The University of Bern would contribute CHIMPS and its associated engineering and science teams.

The in situ data would be deposited at the NASA Space Science Data Center after the designated processing time. The returned sample would be deintegrated within one year with a three-year preliminary examination. The remaining samples would be distributed to collaborators according to the amount of equivalent mission contributions including the STARDUST model open to all world's qualified analysts.

References: [1] *JPL Status Report*, December 2005, [2] Tsou et al., Astrobiology 2012, [3] Roth et al., 2013, [4] McKay et al. Astrobiology submitted 2014. [5] Glavin et al., LPSC, #5002, 2011, [6] Feibelman 1967, [7] Porco et al., 2013, [8] Takano et al., Adv Space Res., 2014. doi: 10.1016/j.asr.2013.12.041, [9] Brownlee et al, Science, 2006, [10] Nakamura et al, AGU #P42A-02 2011.