TECHNOLOGIES FOR MISSIONS TO OCEAN WORLDS

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Background

- Technology development roadmaps in several areas that are important to exploring Ocean Worlds have been developed with the understanding that low temperature electronic and actuator/mechanisms components will be required for these subsystems.
- We summarize here three subsystem-level technologies (precision landing; ice penetration and sampling; ice sample return). Precision landing for airless bodies is being addressed as part of Europa-focused development, so only the unique requirements for Titan are addressed here.

Key Environment Data

- Europa
  - Surface temperature ~ 110 K at equator, ~ 50 K at poles. High radiation; airless.
- Enceladus
  - Surface temperatures from ~ 33 K to 145 K. Low radiation; airless.
- Titan
  - Surface temperature ~ 94 K. Low radiation; deep, dense, hazy atmosphere; high zonal winds at high altitudes that vary with season and latitude.

Precision Landing on Titan

Current State of the Art

- Unguided entry and parachute descent 3σ landing ellipse ellipse major axes are estimated to be ~ 100 to 500 km, depending on season and latitude, due to high zonal winds at high altitude [1].

Technical Goals

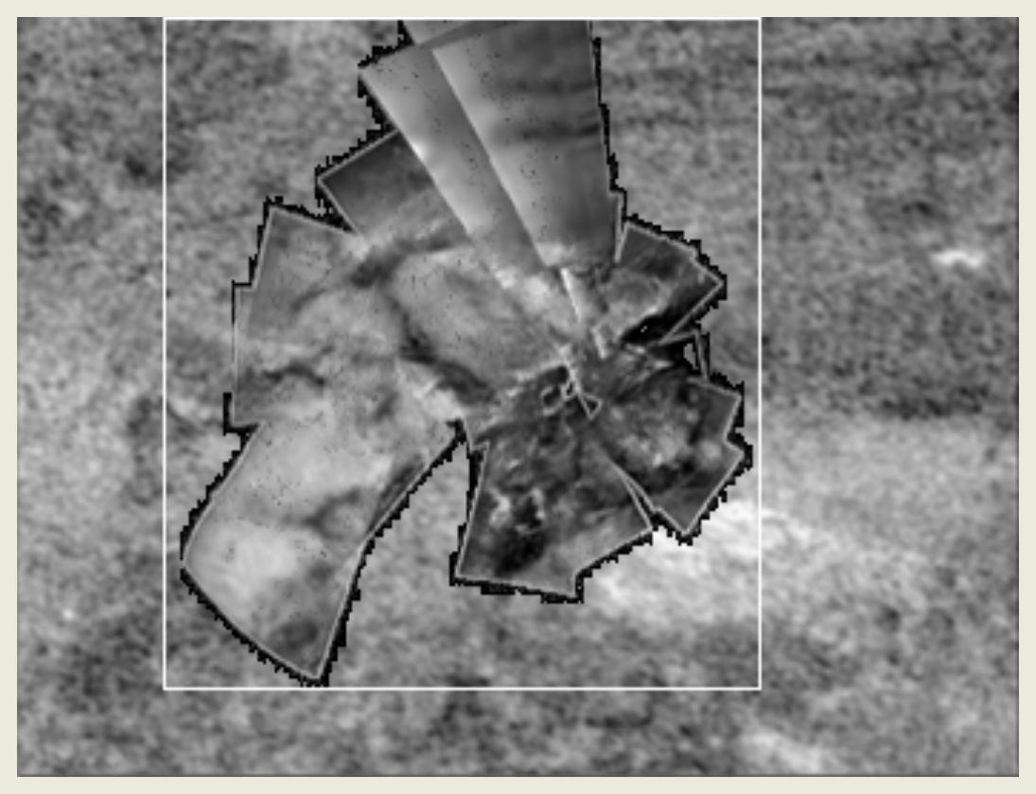
- Based on characteristics of scientifically valuable landing sites and technical challenges, enable progressive improvement:
  - *Class 1: smaller ellipses (e.g. 3σ major axis < 100 km) landing anywhere in the ellipse.*
  - *Class 2: "multi-target" precision landing near small targets (e.g. < 100 m error) that are widely distributed in any size ellipse; analogous to approach to Mars precision landing.*
  - *Class 3: single target precision landing at specific sites.*
- Technology advances required in:
  - *Aeroshell design allowing useful lander geometry and rapid descent to low altitude to minimize wind effects.*
  - *Guidance and control (G&C) to fly out targeting error.*
  - *Terrain-relative navigation (TRN) to provide adequate position, velocity, and altitude knowledge for G&C during long descents.*

Potential Mission Applications

- Class 1: landing in southern hemisphere lakes (with more diverse chemistry than northern seas) and dry lakebeds (access to probable evaporite deposits, sediment coring).
- Class 2: landing between dunes, near shores, or in river valleys, allowing sampling of a wide range of organic terrain and studying geologic/climate history.
- Class 3: landing in river deltas or at specific sites for sampling.

Technical Status

- TRN achieving position error < 40 m is at TRL 6 for Mars using onboard registration of descent imagery with orbiter imagery in the same spectral band, but needs major further development given the much lower resolution and different spectral bands of Titan orbiter imagery (see figure below).
- Guided entry is at TRL 9 for Mars, but would not address the biggest error source for Titan. Guided parachutes/parafoils are at TRL 9 on Earth with GPS navigation and should be quite tractable for Titan, but these and other forms of control authority have not be carefully studied for Titan.



Automatic registration of descent image mosaic from Huygens probe to Cassini radar image replicates best manual alignment and has potential for onboard operation in TRN for Titan precision landing [2]

References:

[1] Lorenz, R. D. and Newman, C. E., (2015), Adv. in Space Research 56:190-204.

[2] Ansar, A. and Matthies, L., (2009), IROS Conference.

Ice Penetration and Sampling

Current State of the Art

- The Europa Lander Concept Study is evaluating methods to sample at depths of at least 10 cm.

Technical Goals

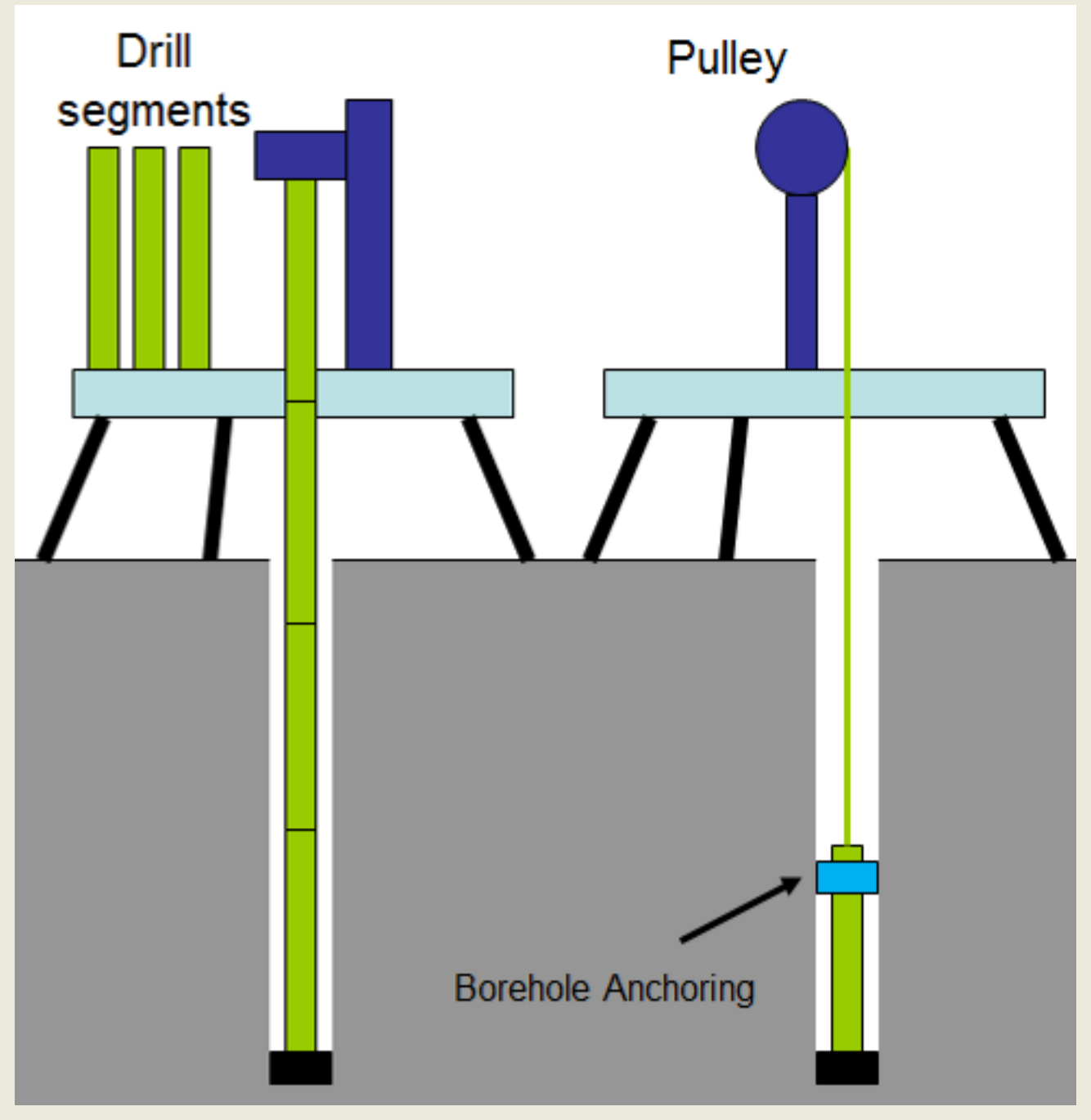
- Develop system-level ice penetration and sampling capability that enables three classes of ice exploration:
  - *Class 1: depths of 0.2 to 10 meters.*
  - *Class 2: depths of 10 meters to ~ 1 km*
  - *Class 3: depths > 1 km, down to liquid water ocean*
- Major hurdles to overcome are to stay within plausible mass, power, and volume constraints of near-term landed missions while meeting COSPAR requirement that probability of forward-contamination of the ocean be < 10^{-4} per mission. Technology advances are required in:
  - *Low-power, low-mass excavation.*
  - *Sample handling and transport.*
  - *Sterilization as needed to prevent forward-contamination.*

Potential Mission Applications

- Class 1 enables sampling of pristine material, e.g. almost entirely unaffected by the radiation environment of Europa.
- Class 2 enables sampling of possible layered terrain on Titan, and completely unaffected by radiation (including galactic cosmic rays)
- Class 3 enables sampling of liquid water from the oceans or in convecting ice that has been in contact with the liquid oceans in the geologically recent past.

Technical Status

- Many approaches exist for sampling between 0.2 and 2 meters: circular or chain saws, heated blades, etc. [1].
- Wireline drills allow open-hole drilling or coring without lining the hole in formations where mechanical properties allow a hole to remain open without lining [3].
- Novel approaches to melt probes (e.g. putting heat source in a Dewar to eliminate horizontal heat leak) may allow deep penetration within mass/power/volume limits [4].



Conventional approach

Wireline approach

References:

[1] Zacny, K. et al, (2016) *in Low Temperature Materials and Mechanisms*, Y. Bar-Cohen (ed.).

[3] Zacny, K. et al, (2016), ASCE Earth and Space Conference.

[4] Wilcox, B. H. et al., (2017), IEEE Aerospace Conference.

Ice Sample Return

Current State of the Art

- No prior mission has returned ice samples from a solar system body.

Technical Goals

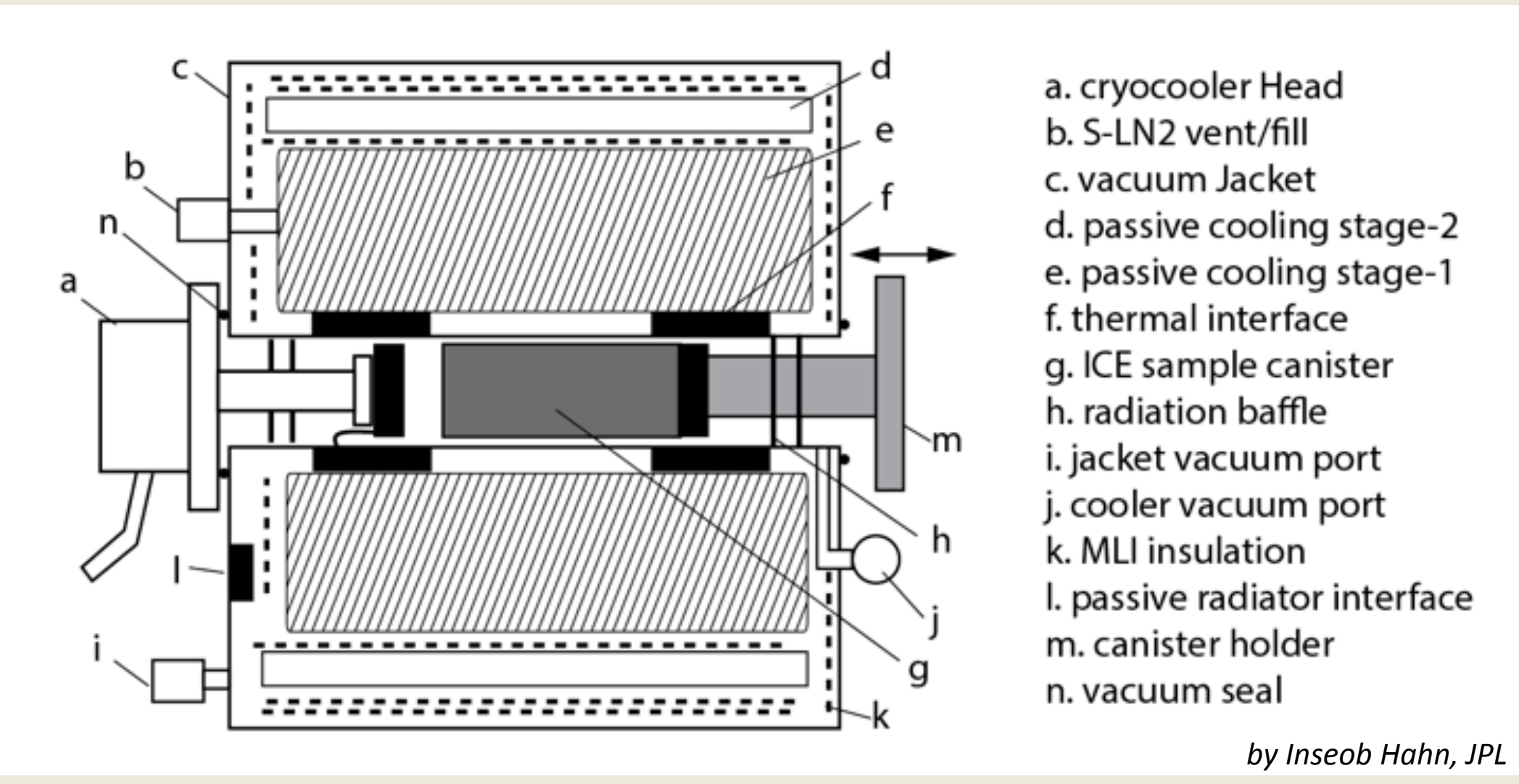
- Subsystem capabilities to preserve an ice sample during return to Earth's surface for three classes of missions:
  - *Class 1: sample kept between 100K to 150K*
  - *Class 2: sample kept between 65K to 100K*
  - *Class 3: sample kept < 65K*
- Two classes of technology must be developed to enable such missions, with each class requiring increasing complexity for lower return temperatures:
  - *Integrated Cryogenic Chamber (ICC) to keep samples at cryogenic conditions during transit to Earth and to Earth's surface.*
  - *Back Planetary Protection (BPP) resulting in a probability < 10^{-6} of releasing alien material into the Earth biosphere.*

Potential Mission Applications

- Class 1:
  - *Europa Lander Sample Return Concept*
- Class 2:
  - *Enceladus Plume Sample Return Concept*
  - *Enceladus Lander Sample Return Concept*
  - *Europa Lander Sample Return Concept*
- Class 3:
  - *Same missions as class 2, but with better preserved sample*
- Also, a Comet Nucleus Sample Return (CNSR) mission concept is enabled by 65K to 100K ICC technology, but would not need BPP. The < 65K ICC technology would enable a CNSR mission with a better preserved sample.

Technical Status

- No prior mission has actively cooled a sample returned to Earth, so no ICC technology has been developed; however, a relevant thermal architecture was described in the CNSR concept study [1]. One such concept is illustrated below.
- Mars Sample Return concept studies are developing BPP [2], but without maintaining samples at cryogenic temperatures; new methods are needed for cryogenic BPP.



by Inseob Hahn, JPL

References:

[1] Veverka, J., tech report NASA SDO-12367.

[2] Bao, X. et al., (2015), in *Proc. SPIE Symposium 9435*.