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Technology Challenges and Readiness Levels for a Cryogenic Comet Nucleus Sample Return Mission

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Outline

- Mission concept architectures and sampling options
- Cryogenic chamber

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Mission Architectures - Lander

- Selected mission architecture is likely to be determined by how deep you want to sample.
- Land, anchor, drill.
  - Limited on number of landing and sampling attempts by number of times you can anchor and release.
  - Allows for extended time for the sampling process: hours, days.
  - Allows for deepest sampling, e.g. to 2+ meters to ensure acquisition of amorphous ice (I'm assuming a CNSR mission would require return of unmodified amorphous ice).
  - Would need the long time, stable anchoring, for drilling to depth.

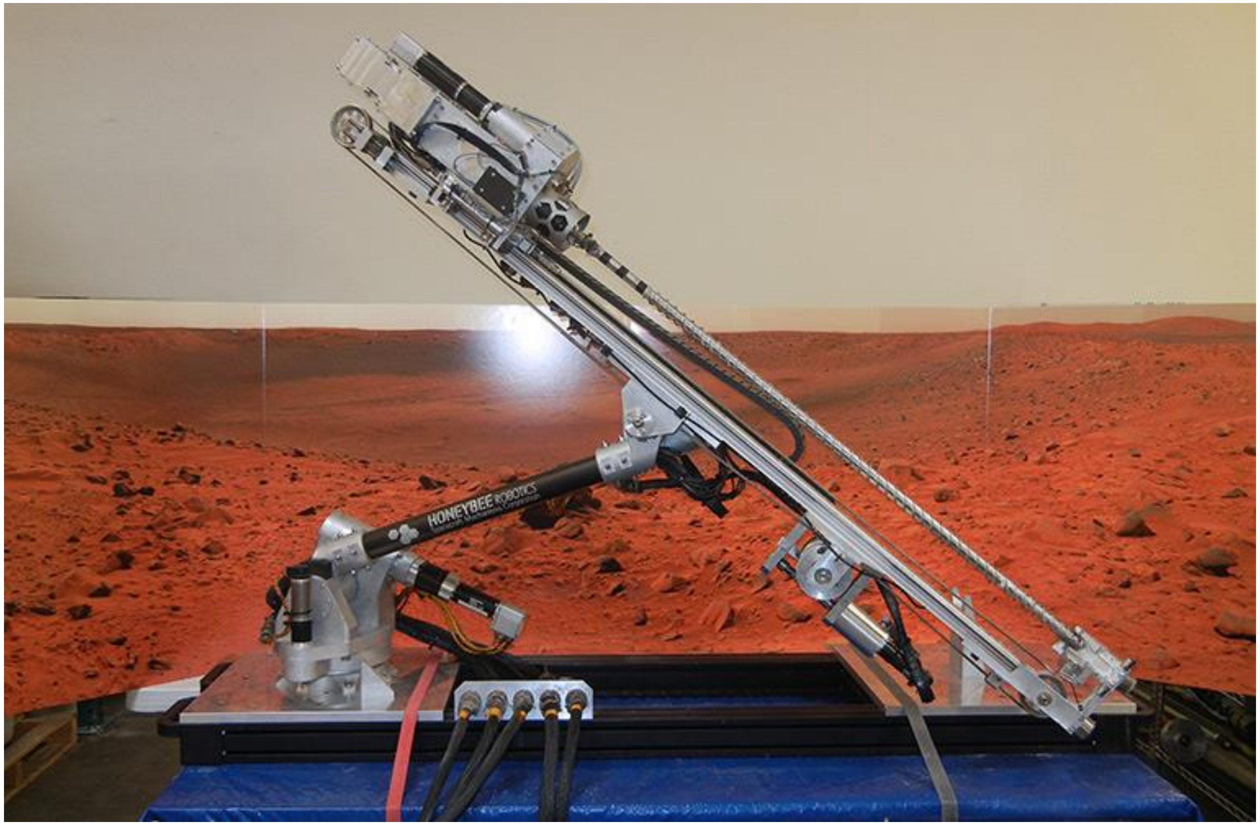
➢ A lander mission might be the only feasible mission architecture that would assure acquisition of amorphous ice due to the depth requirement (assumed to be about 2m).

➢ A lander mission is likely to be the most expensive mission architecture option.

Honeybee Robotics 1-2m Drill

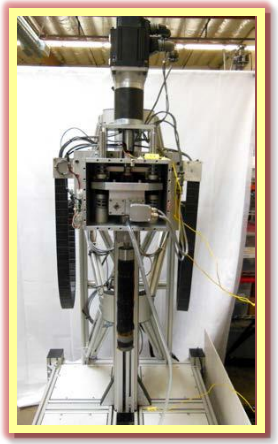
- "Icebreaker has completed field testing in harsh environments, including the Dry Valleys of Antarctica, to simulate penetrating into the Martian ice and permafrost. The drill has also performed to specifications in Honeybee's 3.5-meter-tall vacuum chamber, which simulates the Martian environment".

Produces cuttings, not core



Honeybee Robotics 1-2m Drill

SONIC

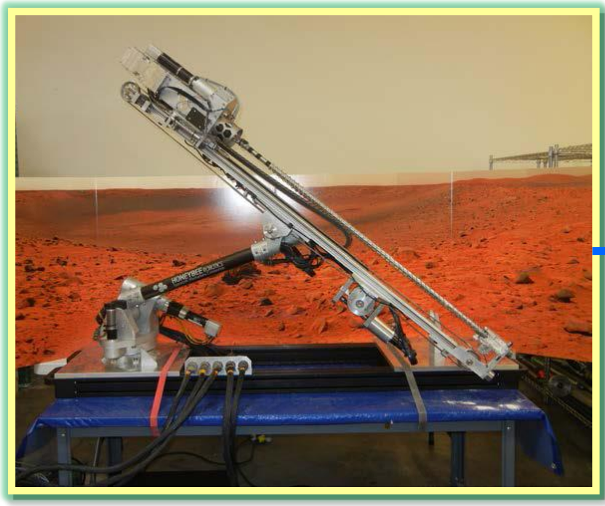


ULTRA SONIC

PERCUSSIVE

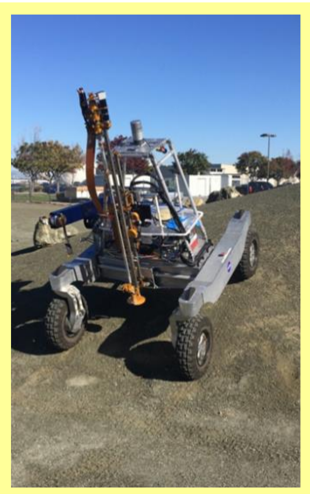
ROTARY

TRL 4 (Rot Perc)



TRL 5 (Rot Perc)

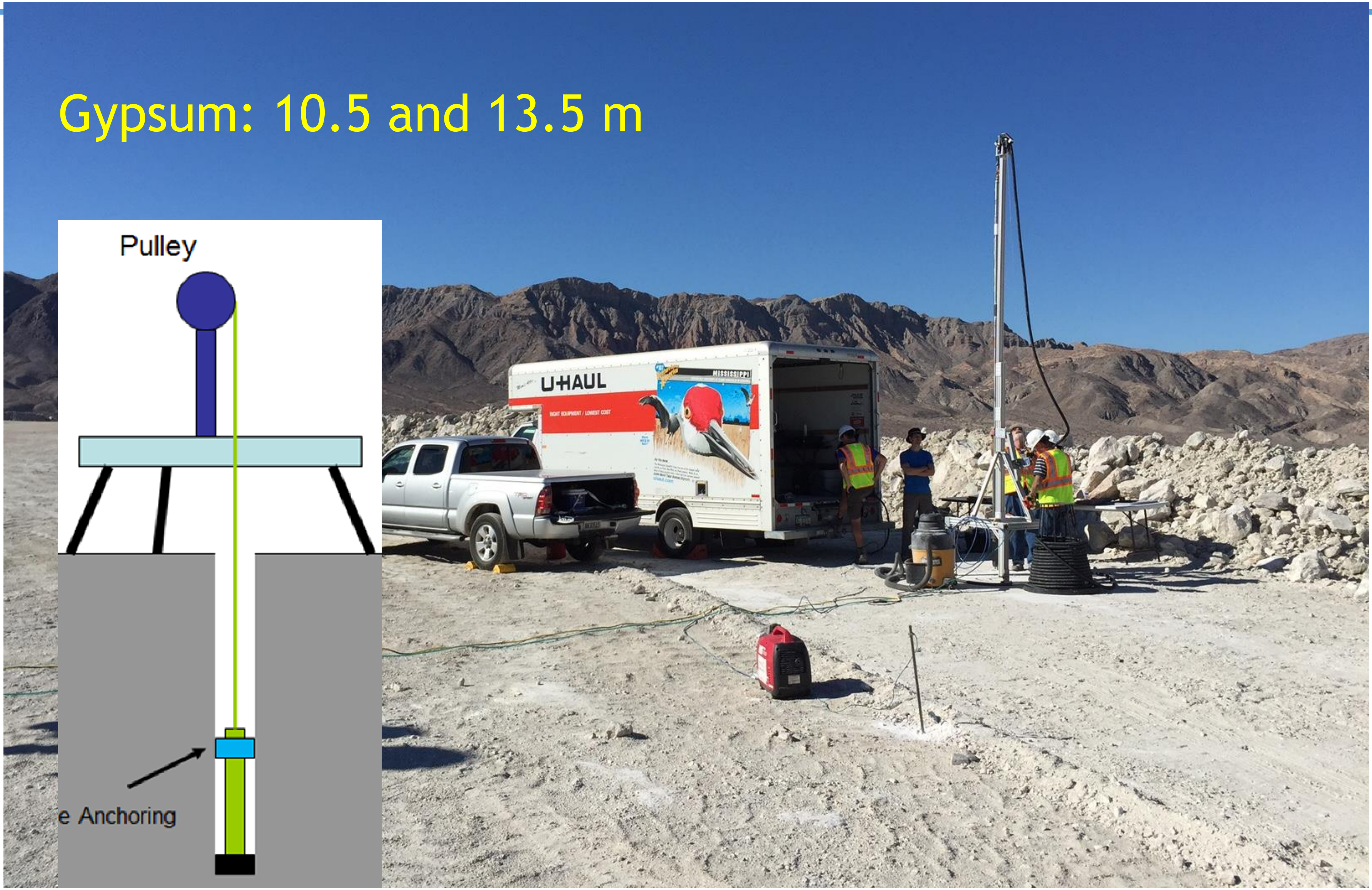
TRL 6 (Rot Perc)



Honeybee Icebreaker Drill

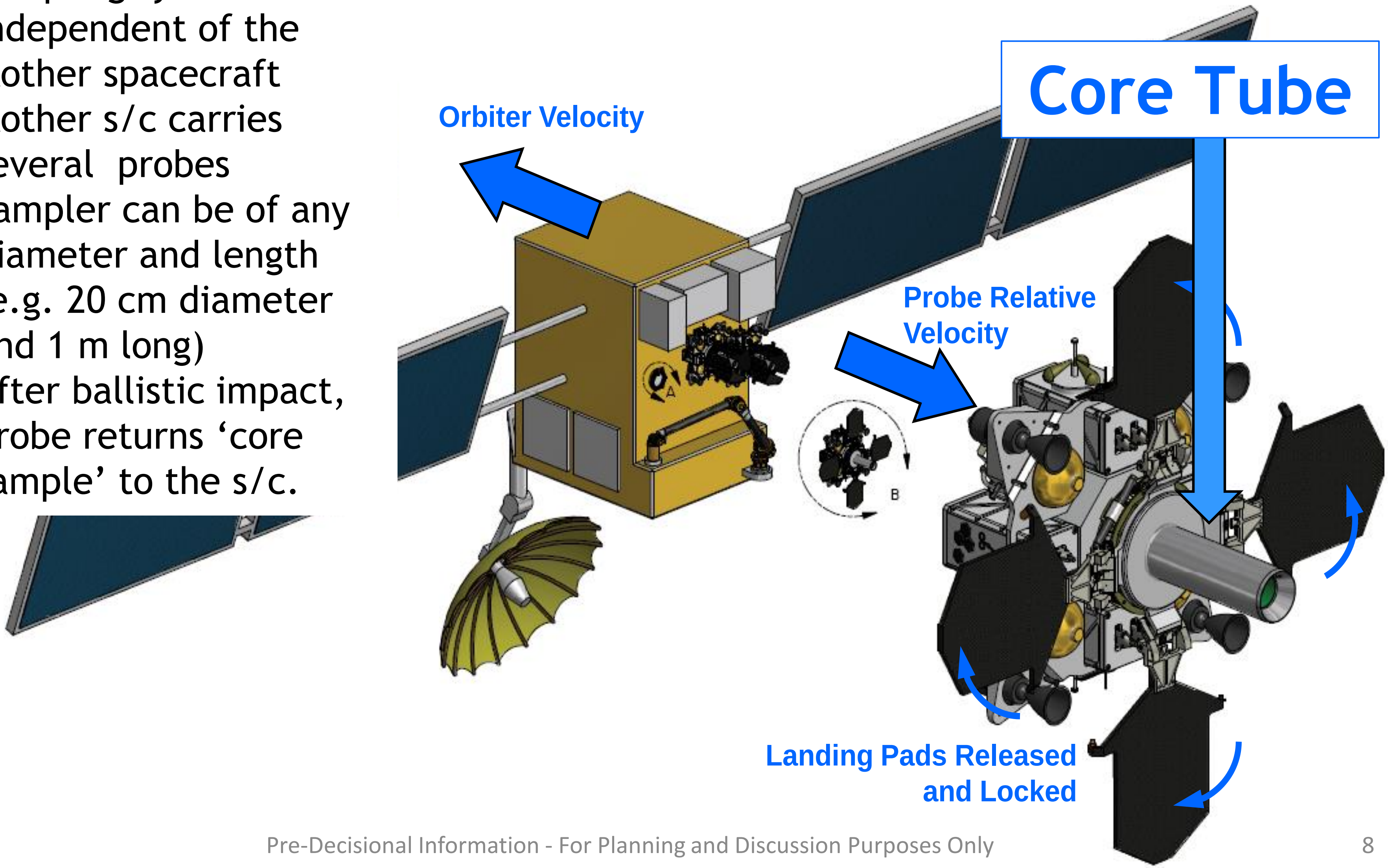
- **Antarctic Massive Ice**
- **Power: ~100 Watt**
- **Penetration Rate: ~ 1 m/hr**

Honeybee: Wireline drill (> 5m depth)



Honeybee Stinger System

- Sampling system independent of the Mother spacecraft
- Mother s/c carries several probes
- Sampler can be of any diameter and length (e.g. 20 cm diameter and 1 m long)
- After ballistic impact, probe returns 'core sample' to the s/c.



Drill Issues

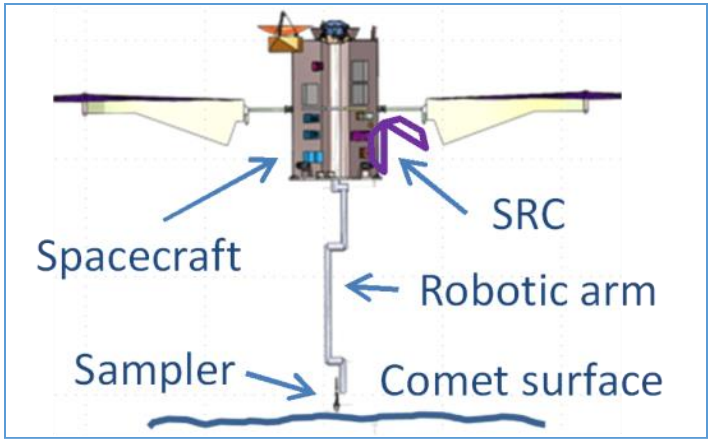
- Have to anchor the lander in order to provide reaction force for sampling – is that feasible?
  - Probably anchor with harpoons, one to anchor and one for redundancy for each drilling attempt.
  - So, two drilling attempts (would you risk your mission on one drilling location?), and four+ harpoons.
  - Each drilling attempt would be at a different location on the comet, meaning, ascent, replan, descend, land, sample.
- Depth:
  - Single string will simplify design: < length of spacecraft.
- Probably drill with rotary percussion.
  - Rotary to eject cuttings.
  - Percussion to reduce cutting energy (and heating of sample).
- Corer: As with all open-faces samplers:
  - Requires multi-wall system so face cut-off mechanisms are in walls, so thick wall translating into extra excavated material and sampling energy to convert to heat that could raise sample temperature.
  - How to cut off front face.
  - How to remove sample from drill? Drill down, pull drill out, transfer sample – how?
- Auguring: Simpler possibly, but is heating sample a problem?
- Heating issue:
  - What rate of penetration is possible that does not heat up the sample beyond acceptable cryogenic temperature? Is this even possible? How do we prove feasibility?

Segue: What Makes CNSR Sampling Hard?

- Sampling a comet for a CNSR mission is difficult for many reasons including:
  - The scientists want the sample that has not changed since the formation of the solar system.
  - The sample is about 2m depth or deeper (deeper than length of spacecraft makes it much more difficult.)
  - The potential range of surface strengths is currently quite wide, possibly 50kPa – 10 MPa. In engineering speak: the strength range that the scientists can't prove can't exist.
  - The sample must not be contaminated with earth-source contaminants.
  - The sample must be kept at cryogenic temperatures during sampling, handling, and sample transfer to cryogenic chamber.

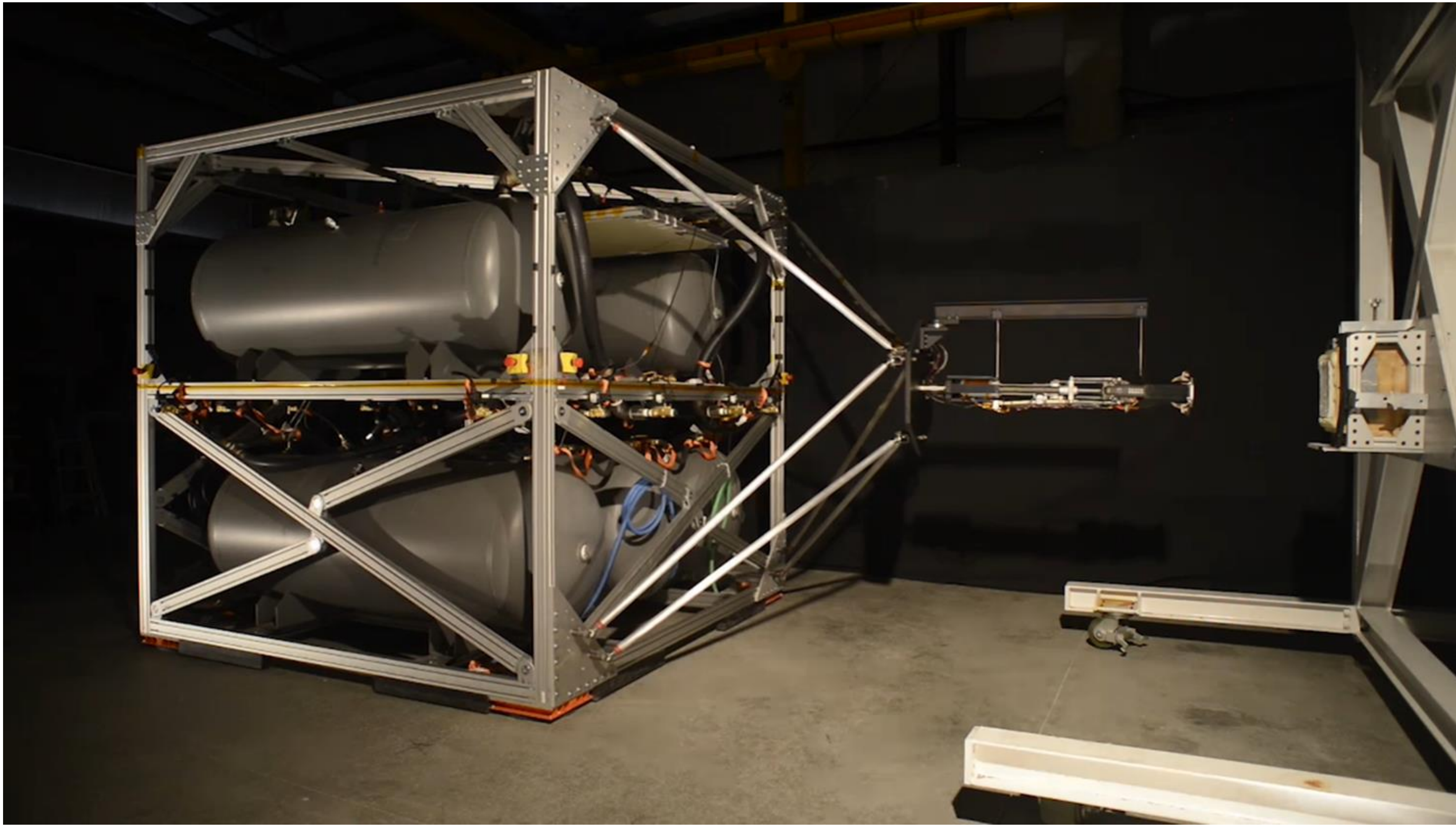
Mission Architectures – Touch-and-Go

- In a Touch-and-Go (TAG) mission concept, the spacecraft flies down to the surface of the comet and upon contact, quickly acquires a sample, then ascends.
- Examples: Hayabusa, OSIRIS-REx.
- Sampling limitation:
  - Likely the sampling depth would be limited to a few 10s of cm.
- Benefit: Cost and risk. A TAG mission could be the lowest cost mission architecture, and lowest risk since it has been used in prior missions.



Example TAG mission

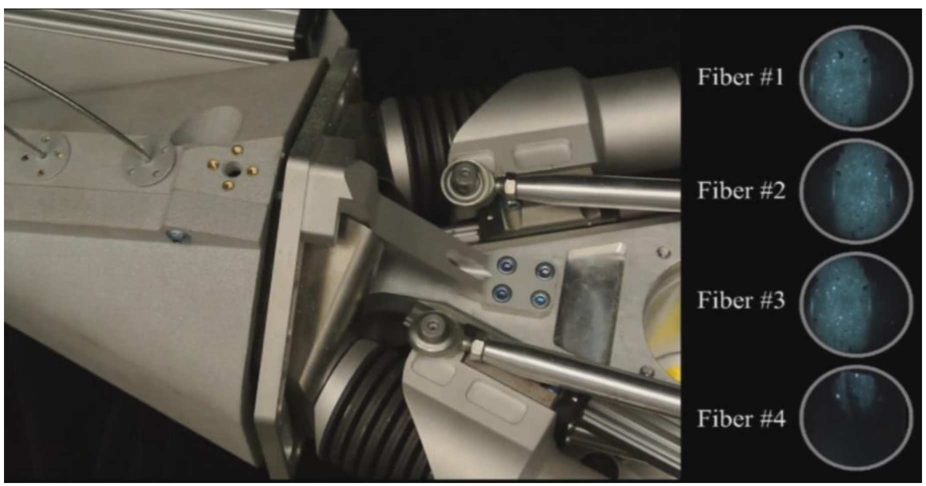
Mission Architectures – Touch-and-Go: BiBlade



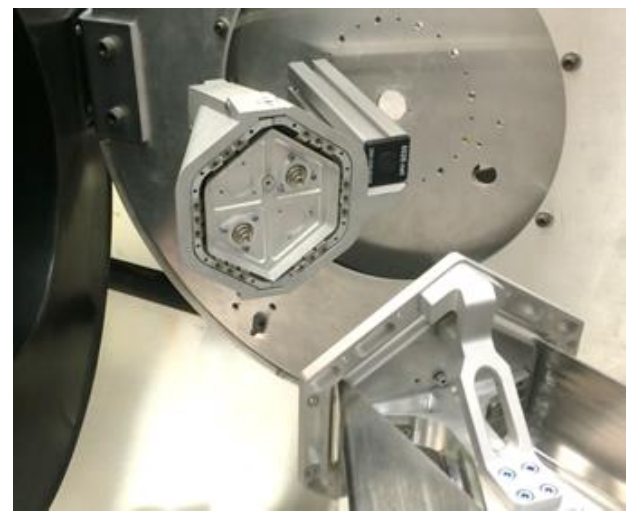
Mission Architectures – Touch-and-Go: BiBlade

Pull blades back compressing springs (one actuator for all operations)

Sample in ~ 30 ms (fast) and retract (tapered blades prevent binding)



Insert into sample measurement station and image with 9 fiberscopes



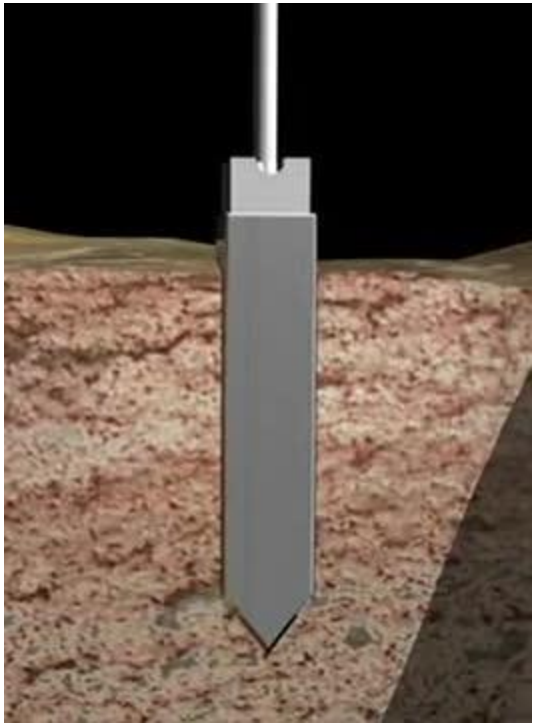
Insert into SRC and release lid via frangibolt (repeat for second sample)

Mission Architectures – Touch-and-Go: BiBlade

- BiBlade:
  - Solve front face encapsulation problem: Sampling also closes off the front of the sample.
  - Solve the sample heating problem: thin blades push through material, minimizing cutting area and heat generated.
  - Solve the mechanical complexity problem: only one motor and two frangibolts (release lids).
  - Solve the sample transfer problem: pull blades back to release the sample.
  - Solve the sample measurement problem: pull the blades back slightly to expose sample in slits for analysis (measurement and in-situ instruments).
  - BUT: How deep could you go? Probably not 2+m.

Harpoon Concept: Example: GSFC Harpoon

- NASA Goddard Space Flight Center developed the RApid SAmple Retrieval System (RASARS).



Dual-walled projectile: outer sheath stays in comet, inner sheath is pullout back.

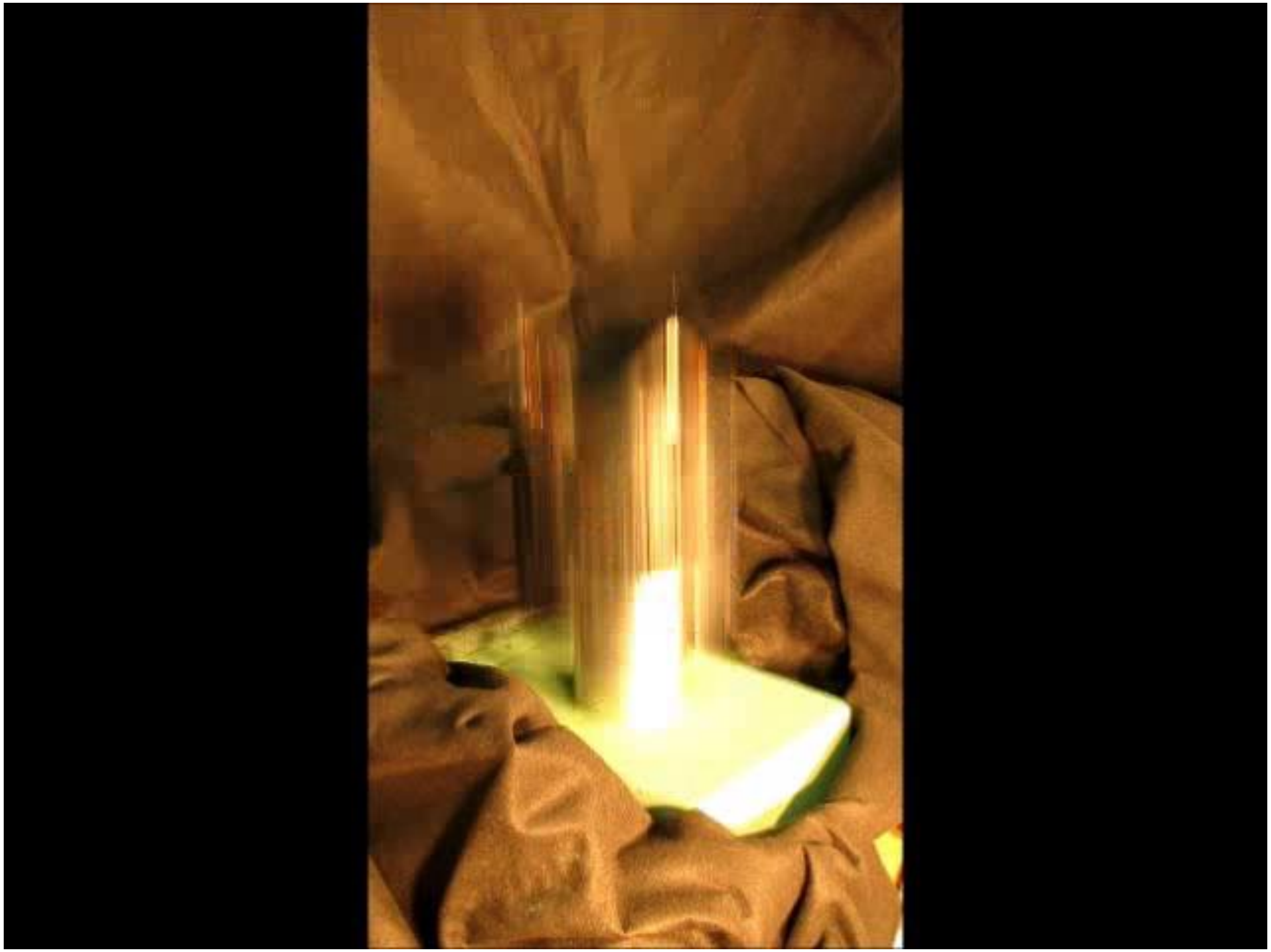
Mission Architectures – Harpoon

- In a harpoon mission concept architecture:
  - The spacecraft maneuvers to near the comet surface, perhaps 2m to 20m away,
  - Then fires a sampler to the surface that is connected to the spacecraft with a tether, and the sampler embeds into the comet surface, forcing material into the sampler body.
  - A decelerator plate decelerates the sampler at full sampling depth for weaker material.
  - The inner sample canister is ejected out the back of the sampler.
  - The sample canister is reeled in back to the spacecraft where it docks and the sample is transferred.
- Challenges:
  - The wide range of potential surface strengths makes it difficult to find a feasible kinetic energy to fire the sample with. Too little energy and it might not penetrate. Too much energy and it might sink too deep into the comet.
  - Tether management would be difficult, including paying out the line fast, and handling the swinging sampler as it is reeled in (or special tether does not swing).
  - It would be difficult to ensure a satisfactory angle-of-attack (angle between long axis and velocity vector) and angle-of-incidence (angle between velocity vector and surface normal). This could be mitigated by firing when closer to the surface, e.g. 2m, but then there is the problem of ejecta spraying back and covering spacecraft optical surfaces. If you're that close, why not land?
  - The sampler could return to the spacecraft as a projectile, so there would be a complicated design space of spacecraft surface offset distance, projectile problem, sampler swinging, etc. (Unless that is solved with a stiffened tether.)

GSFC Harpoon Concept

- TRL: Being proposed in a New Frontiers program CSSR proposal.
- Similar challenges to any open-faced sampler:
  - How to reliably cut off front of sample.
  - Increased required sampling energy (converts to heat) due to thick walls from multi-walled system.

Mission Architectures - Dart:
JPL Dynamic Acquisition and Retrieval Tool



Mission Architectures – Dart

- In a Dart mission concept architecture:
  - Spacecraft maneuvers to proximity of comet.
  - Untethered sampler is released that flies and impacts the comet.
  - Impact (kinetic energy) with comet drives sample into a sample tube.
  - Sample canister is closed off at the front.
  - Inner sample canister is ejected out back of sampler at > escape velocity, leaving outer casing behind.
  - Spacecraft tracks and rendezvous with the sample container.

Challenges:

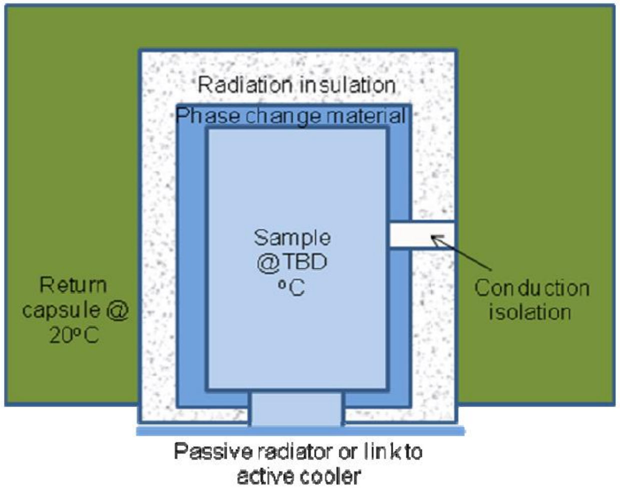
- It would be new technology to track and rendezvous with the sample canister.
- Difficult to ensure angle-of-attack and angle-of-incidence.
- Autonomous avionics in Dart.
- Multi-walled sampler meaning much energy for sampling that can covert to heat which would violate sample temperature requirement.

Integrated Cryogenic Chamber

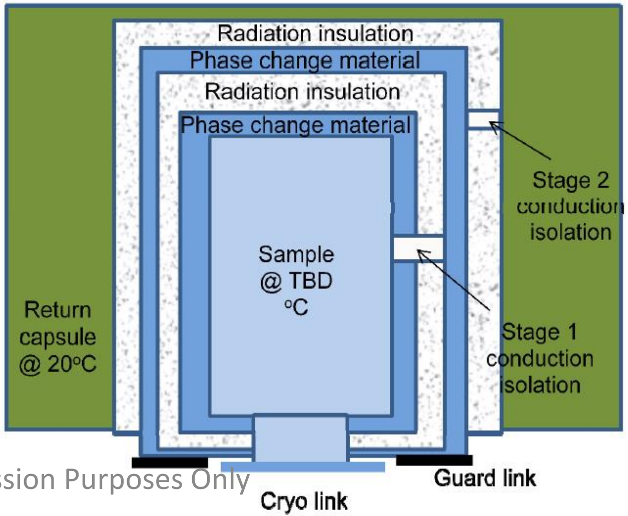
- An Integrated Cryogenic Chamber (ICC) would house the sample and keep it at cryogenic temperature through return to the Earth's surface.
- No ICC has been developed to date, since no sample has been returned to Earth at cryogenic temperatures.
- Veverka, et al. proposed a concept in their supplemental report for the NASA 2012 Decadal Survey, "Cryogenic Comet Nucleus Sample Return (CNSR) Mission Technology Study"
- Various designs are possible, depending on necessary sample temperature and mission architecture.

Veverka study concepts

1 stage system

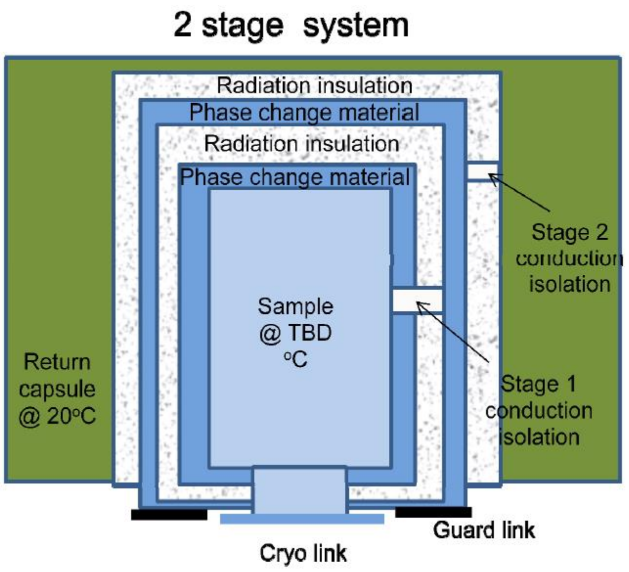


2 stage system



Integrated Cryogenic Chamber

- EEV: It is assumed that the sample would return to Earth in an Earth Entry Vehicle. The ICC would be in the EEV. Would an active cryogenic cooler be in the EEV? Depends on the temperature requirement.
- Passive thermal radiator (PTR) could be used for when radiator is pointing into cold deep space.   But would need an efficient heat switch to isolate the heat path for when the radiator is pointing at warm object like the sun when spacecraft maneuvers.
- Active cryocooler: various cryocoolers are currently available. But they generally cool small instruments, smaller than the thermal mass of a CNSR sample.
- Existing cryocoolers do not have the cooling capacity needed for a <65K mission, so might need multiple cryocoolers.



Integrated Cyrogenic Chamber

- Phase Change Material
  - Argon: melting temperature 83K, so feasible for <150K and perhaps <100K mission.
  - Nitrogen: melting temperature 63K, so feasible for <100K and perhaps <65K missions.
  - Colder?
- Veverka study: suggests active cryocooler in EEV running on batteries for <125K mission in addition to PCM. Another active cryocooler running off spacecraft power during return cruise and before EEV separation.

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Summary

- Science requirements will drive the trade-space decisions on mission concept architecture and sampling approach.
  - Depth of sample.
  - Potential range of strength of material to penetrate and sample – low and high.
  - Temperature sample must be kept below through delivery to curation facility.
- Examples:
  - Sample depth:
    - 25 cm: TAG, harpoon, dart, lander; various tool options
    - 1+m: lander and drill (can drill keep sample < required temperature?)
  - Sample return temperature:
    - <150K sample return: passive cooling may be possible, active cryocooler possibly external to EEV.
    - <100K sample return: active cryocooler; unclear whether need cryocooler internal to EEV, larger EEV.
    - <65K sample return: multiple active cryocoolers, cryocooler internal to EEV; even bigger EEV.
- Reduce range of surface mechanical properties by carrying sufficient instruments to characterize sampling site.

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