Cryobot Thermal Drills in the NPLD

Scout Proposals:

- 2007 launch opportunity: Cryoscout (PI: Frank Carsey)
- 2013 launch opportunity: Chronos (PI: Mike Hecht)

2005 Vision Study: PalmerQuest (PI: Frank Carsey)

…none were successful ☹

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Cryoscout

- ~ 80 m into the North PLD
- 6 instruments:
  - IceCam to record the visible stratigraphy
    - 1-mm vertical resolution in nephelometer mode
    - full-color stereo images at 10–5 m per pixel
  - Mars Inorganic Chemistry Analyzer (MICA) to determine salt composition and abundance
    - analyze meltwater with a suite of electrochemical sensors
  - Mars Isotopic Laser Hygrometer (MILH) to measure variations in relative H and O isotopic abundance in meltwater
  - Distributed Temperature Sensor (DTS) is fiber thermometer incorporated into the tether
    - Time dependent ice temperature profile, including the thermal wave penetration in the top ~20 m and geothermal heat flux below.
    - determine both conductivity and diffusivity.
  - Stereoscopic Surface Imager (SSI) studies dynamics of polar surface with imaging, including atmospheric opacity and surface albedo
  - surface version of MILH to record the movement of water vapor, provide a baseline measurement of isotopic ratios, and monitor basic meteorology.

Hecht and Saunders, 3rd Mars Polar Conf, #8079, 2003
Zimmerman et al, Aerospace Conference Proceedings, IEEE, 2002.

Thermal Drill:
Active water-jetting system

- **Nose**
  - Waterjet nozzle
  - Acoustic imaging system
  - Four quadrant passive resistance heaters
- **Pump bay**
  - Melt-water pump
  - Meltwater reservoir
  - Immersion heaters (2)
  - Water-jet plumbing
- **Pressure Vessel**
  - Control electronics/cabling
  - Science instruments
  - Imager/UV laser window
  - Primary tether connector
  - Shell heaters (4)
- **Tether bay**
  - Copper fiber-optic power and com tether (0.100-in diameter, 300 m long)
  - Tether brake and encoder

- kilowatt magnitude power input ➔ formation of a 1-mm meltwater jacket around the probe.
- In the worst case, the rear 20-30 cm of the probe starts to refreeze at the end of 2 hours, requiring activation of the rear shell heaters to heat the probe.

Hecht and Saunders, 3rd Mars Polar Conf, #8079, 2003
Zimmerman et al, Aerospace Conference Proceedings, IEEE, 2002.

PALMER QUEST: A FEASIBLE AND VALUABLE VISION MISSION TO THE MARS POLAR CAPS

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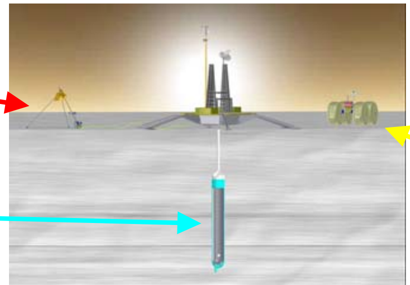
Surface Station: Unique, small surface-atmosphere observation platform

Cryobot: Nuclear fission powered thermal probe



FRAM Rover: Long-range inflatable, powered by RPS

PQ Mission Architecture

Mission Design	
Launch and trajectory	
Launch vehicle	Delta 4050H-19
Injection C3	22 m^2/s^2
Trajectory	Type II
Launch date	August 2022
Arrival date	June/July 2023
Arruval V_{inf}	2.39 km/s
Target landing site	83 deg N, 4 deg E
EDL	
Landing method	Powered descent
Parachute	Mach 1.8
Telecommunications	
Data transmission	UHF relay via MTO (8 kbps downlink, 128kbps uplink
Surface/sub-surface operations	
Surface mission duration	5 Earth years
Cryobot fission power output	1100We
Rover RPS power output	120We

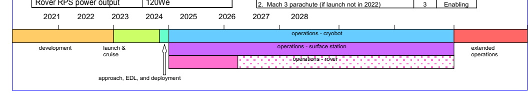
Spacecraft Elements	Mass (kg)
Payload Mass	
Cryobot	1457
Rover	222
Instrument Sled	125
Total Payload mass	**1804**
Landed Mass	
Pallet Lander	1392
Total landed mass	**3196**
Mars Entry Mass	
Aeroshell	1069
Total entry mass	**4265**
Launch Mass	
Cruise Stage	597
Wet Launch Mass	**4862**

* Preliminary masses based on Team X studies, 30% contingency included

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Nathaniel Brown Palmer

Technologies:	TRL	Type
1. 1500kWt HOMER-15 fission reactor	4	Enabling
2. Mach 3 parachute (if launch not in 2022)	3	Enabling



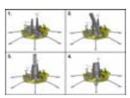
Palmer Quest mission goals

- **Determine the presence of amino acids, nutrients, and geochemical heterogeneity in the ice sheet.**
- **Quantify and characterize the provenance of the amino acids in Mars' ice.**
- **Assess the stratification of outcropped units for indications of habitable zones.**
- **Determine the accumulation of ice, particulate matter, and amino acids in Mars ice caps over the present epoch.**

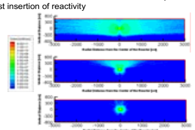
Reactor Startup

•Period of Reactor Startup is critical as a result of radiation dose to surroundings and lander avionics

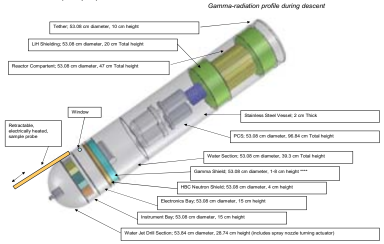
•A detailed startup scenario has been devised that would have the reactor started at low power and the cryobot fully submerged within 26 hours of first insertion of reactivity



Cryobot deployment sequence (conceptual)



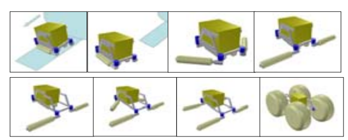
Gamma-radiation profile during descent

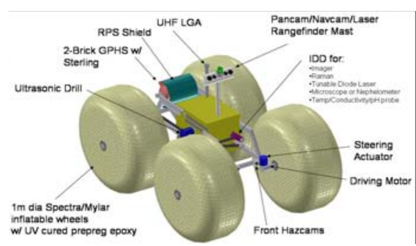


Cryobot Science Goals and Measurements

1. Characterize the biologic potential of the Basel layer.
   1. Identify and quantify organic material at the Basel layer, including determination of amino acid chirality
   2. Measure energy sources available for sustaining of life
   3. Identify nutrients available for life at the boundary layer.
   4. Image any potential microorganisms present in the melt water around the stationary cryobot.
2. Characterize the chemical composition of the Martian northern polar cap during descent
   1. Identify and quantify organic material, including determination of amino acid chirality
   2. Measure inorganic material present in the ice
   3. Measure isotopic ratio of H/D, C12/C13, and O16/O18 of material through the cryobot descent
3. Characterize the properties of solid material in the ice sheet.
   1. Determine chemical and mineralogical composition of particulate matter present in ice sheet
   2. Continually image ice sheet to determine past impacts/volcanism through particulate layers.

Rover Deployment

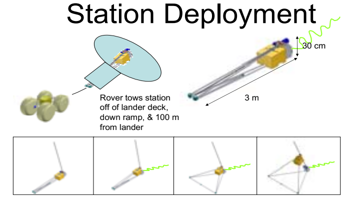


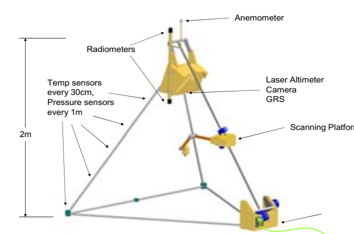


FRAM Rover Science Goals and Measurements

1. Characterize the Basal Unit (BU)
   1. Determine the characteristics of the Basal Unit including the mineralogy, chemistry, and ice component inventory
   2. Characterize the transition between the PLD and BU
   3. Identify the sedimentary structures and nature of material derived from the BU
2. Characterize the stratigraphy of the Polar Layer Deposits (PLD)
   1. Determined the relative proportions of ice and dust
   2. Identify the layers size distributions.
3. Investigate the PLD formation
   1. Identify relative proportions of ices and dusts
   2. Determine ice characteristics and grain sizes with depth
   3. Characterize pole-face and equatorial facing troughs
4. Identify PLD modification mechanisms
   1. Image the morphology and structure of the surface expression of different layers of the stratigraphy
   2. Measure H_2O vapor pressure with Altitude

Station Deployment





Surface Station Science Goals and Measurements

1. Associate the internal properties of the PLD with mass accumulation at the surface
   1. Determine rates of accumulation of accumulation/ablation of CO_2, H_2O and Dust.
   2. Estimate annual net CO_2, H_2O and Dust accumulation/ablation
   3. Determine fine-scale structure and morphology of seasonal frost layer
   4. Relate fine-scale morphology and structure to current polar climate.

Acknowledgement
The research described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology.

Carsey et al, 36th LPSC, #1844, 2005

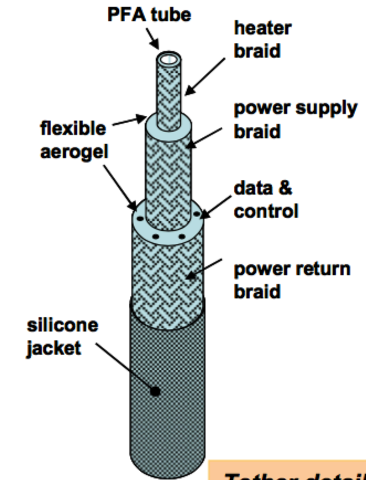
- Thermally drill from 10 to 75 m into the north polar ice cap and:
  - Image visible stratigraphy as an indicator of ice and dust deposition rates.
  - Measure the concentration of dust as a function of depth.
  - Measure H_2O and CO_2 isotopic ratios.
  - As a function of depth, analyze the inorganic ionic species in the meltwater.
  - Image the surface topography and morphology of the ice.
  - On the surface, measure humidity, T, P, and wind velocity.
  - Determine the geothermal gradient in the layers.
  - Constrain the internal structure of Mars from ice sheet response to seismic activity

Hecht et al, 4th Mars Polar Conf, #8096, 2006

Thermal Drill: Passive System

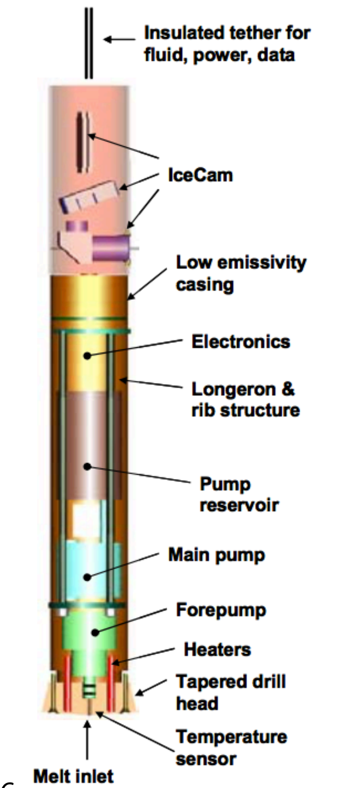
Table D3-1: Thermal Drill Specifications

Drill body	
Mass (CBE)	4.1 kg for each drill
Size	7.5 cm diameter
Power (drill system)	310 W (387 w/ cont.) at 100V
Descent Rate	20–45 cm/hr (163 K ice)
Flow Rate	0.8-1.8 l/hr
Pump pressure	2.8–10 bar
Sensors	Temperature, flow rate, load cell, 3-axis inclinometer



Tether detail

- Shallow drill: 10 m tether
- Deep drill: 75 m tether
- 7.5 cm borehole
- Tether transfers power, data, and meltwater between the lander and the drill head
- The nose is a heated copper disk that melts the ice ahead of the drill
- Small forepump delivers water to the top of a small reservoir, where air bubbles are allowed to separate
- Particles larger than 15µm filtered out by a screen
- Smaller particles stay in suspension during transport to the surface, traveling at the same speed as the liquid
- The water is gravity fed into the main pump which pressurizes it for delivery to the surface



Drill components

Hecht et al, 4rd Mars Polar Conf, #8096, 2006
Cardell et al, 4rd Mars Polar Conf, #8088, 2006
Smith et al, 4rd Mars Polar Conf, #8095, 2006

Science instruments

Payload Element	Performance	Data Products	Derived Results	Responsible Co-I
Thermal Drills (deep & shallow)	7.5 cm borehole, 10m and 30-75m deep, at a rate of up to 1m/sol, returning meltwater to the surface with mixing on order 1 cm.	▪ Depth to 0.1% accuracy ▪ Ice temperature to 0.1K	No required products, but may be possible to estimate ice density and thermal properties	Cardell
IceCam	24-µm resolution RGB imager w/ polarizing filters. As nephelometer, 1% accuracy with <0.1 mm vertical resolution.	▪ 2.5 cm wide, 4-color images of sidewall w/ 50% overlap for stereo ▪ 3 mm wide nephelometer images for each of 3 lasers	▪ Dust density vs. depth below surface, <1mm res'n ▪ RGB stereo image strip linked to MICA and MILS results, <0.1 mm res'n	Herkenhoff
Mars Isotopic Laser Spectrometer (MILS)	cm-scale variations in $^{18}O/^{16}O$ ratio in the ice to $\delta(^{18}O)<2‰$, D/H to $\delta(D)<10‰$.	1 measurement of each quantity per centimeter of travel	▪ Historical T & RH variation ▪ Measure of H_2O exchange between atmospheric, surface, and subsurface	Webster
Mars Inorganic Chemistry Analyzer (MICA)	▪ Conductivity .001–10 mS/cm ▪ pH 1–10 ± 0.5, Eh -1–+1V ▪ $Na^+, K^+, Mg^{2+}, Ca^{2+}$, to 10^{-5} M ▪ Cl^-, SO_4^- to 10^{-5}M ▪ Oxidants (CV)	Profile of pH, conductivity, redox potential, cations and anions of common salts, cyclic voltammetry	Composition, solubility, and chemical reactivity of embedded particles	Kounaves
MET (contributed)	Relative humidity to 1%, pressure to 0.1 mbar, temperature to 1K, wind speed to 20%.	Temperature, pressure, RH, wind every 10 minutes	Net flux of water to/from surface.	Lange (Liaison: Bass)
CanCam (contributed)	Camera & filter wheel with 0.975 mrad/pixel resolution. FOV 360° az, +90° to -67° el. 0.5m-infinity focus, <4 mrad pointing.	Panoramas and thumbnails of albedo, opacity	Local topography and morphology; surface to atmosphere thermal balance and water exchange.	Lange (Liaison: Smith)
Mars Miniature Seismometer (MMS) (contributed)	3-axis seismometer, 90 sols, noise floor below 1ng/√Hz, strongly coupled to ice to separate ground motion from wind.	Record events with moments $>10^{14}$ N-m Detect seismic signals from 0.04 to 200 Hz	Wave directionality, angle of emergence, and polarization Density & wave speed Depth profile of Mars' interior.	Pike (Liaison: Aharonson)

Frequently Asked Questions

Q: Can you make liquid water on the polar cap? Won't it sublimate first?

Even on the north polar cap the atmospheric pressure is above the triple point of water, so ice will melt before sublimating. The sublimation rate is faster than on Earth, but still much slower than the drill's melting rate.

Q: What keeps the water from freezing while it is being transported to the surface?

The core of the tether is heated and insulated.

Q: The boiling point is very low. How about vapor lock?

Temperature is carefully controlled at the pump inlet to prevent boiling. The tube itself is pressurized, and water temperature can increase up to 50°C without boiling.

Q: What keeps the borehole from collapsing?

On Earth, an open borehole in ice is stable to about 300m. In Mars' lower gravity and at typical PLD temperature, a borehole would be stable all the way to the base.

Q: With so little atmospheric pressure, how do you prime the pump?

A small forepump is kept below the water level by allowing a small amount of water to rise up the sides of the drill.

Q: What keeps the drill going straight?

Tether tension is controlled, the drill is always hanging.

Q: Won't the tether bind in the hole?

The tether materials were selected for their low memory and high flexibility at low temperature.

Q: What happens if the drill encounters dusty ice?

Dust simply moves into suspension and is pumped away. If the drill encounters highly desiccated layers it briefly slows until ice below the blockage begins to melt. A filter removes larger aggregates

Q : What if the drill hits a rock?

The chance of hitting even a 10-50g meteorite is 1 in 10^6. Encountering rocks would be a sensational finding.

Q: Does the camera lens frost over?

Lenses and other critical components will be equipped with heaters. We don't expect frost because the extremely cold borehole wall is a natural sink for water vapor.

Q: What happens to water in the lines at night?

The tube, pumps, and valves can all withstand freezing. Thawing takes less than 4 minutes.