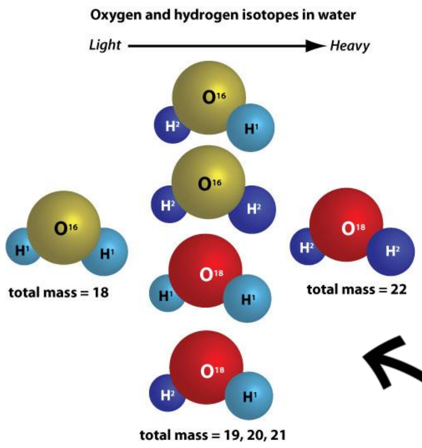
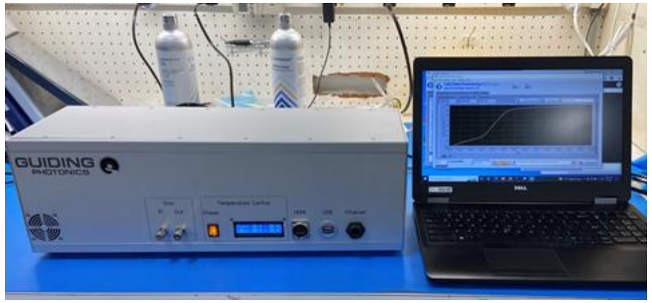
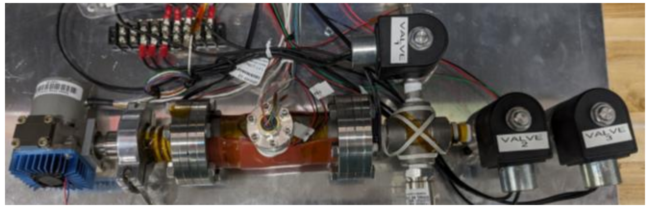
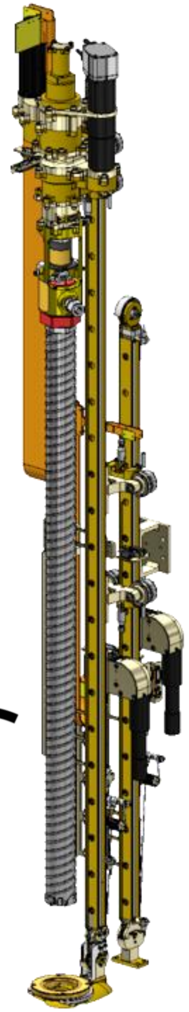








Results from End-to-End Testing with PVEx and the Lunar Capillary Absorption Spectrometer (LuCAS)

Isabel King, Sr. Research Engineer

6/2/2026

Lunar Volatiles

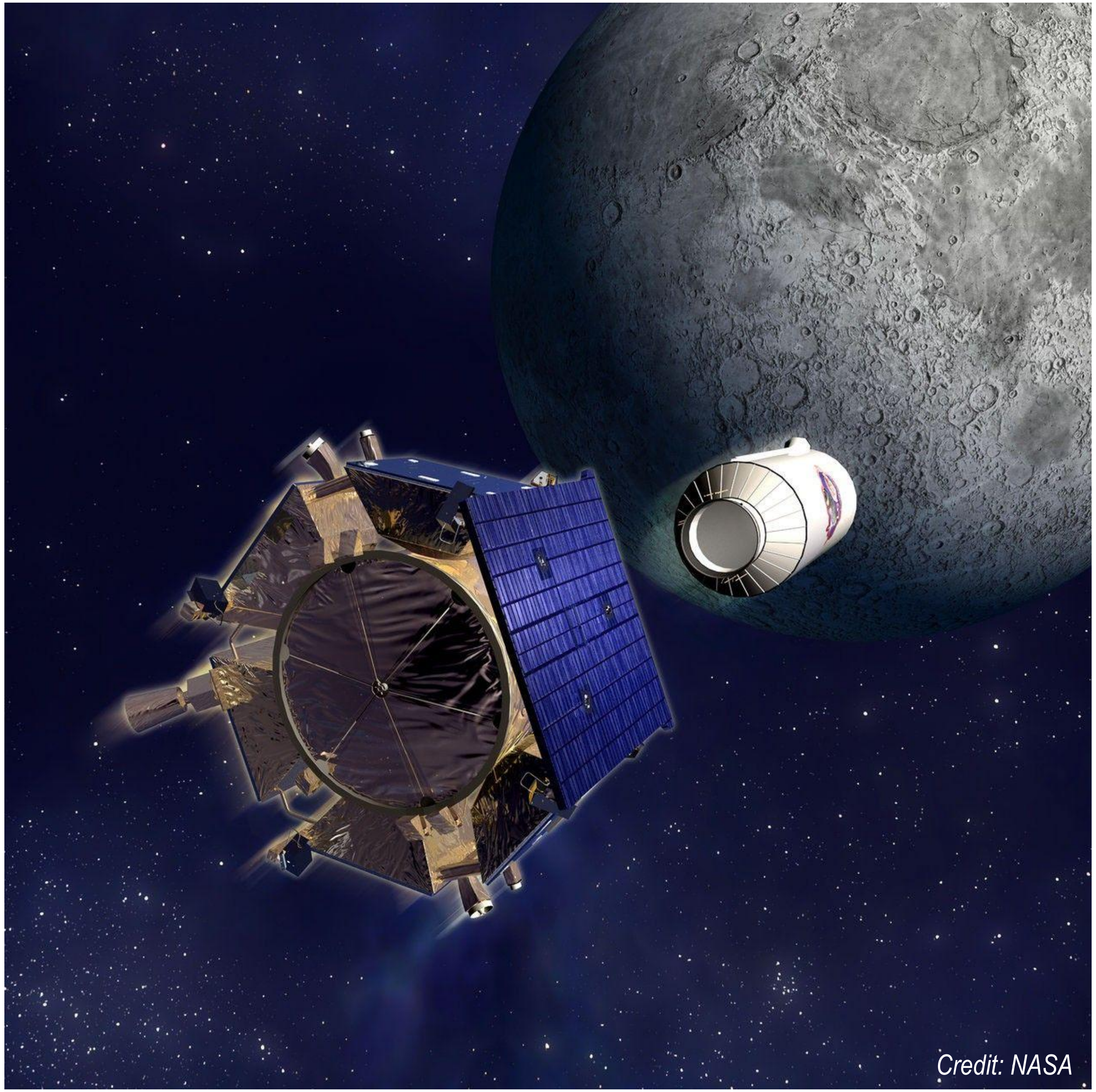


Table 2. Abundances derived from spectral fits shown in Fig. 3. The uncertainty in each derived abundance is shown in parenthesis [e.g., for H_2O: 5.1(1.4)E19 = $5.1 \pm 1.4 \times 10^{19}$ cm^{-2}] and was derived from the residual error in the fit and the uncertainty in the radiance at the appropriate band center.

Compound	Molecules cm^{-2}	% Relative to $H_2O(g)$*
H_2O	5.1(1.4)E19	100.00%
H_2S	8.5(0.9)E18	16.75%
NH_3	3.1(1.5)E18	6.03%
SO_2	1.6(0.4)E18	3.19%
C_2H_4	1.6(1.7)E18	3.12%
CO_2	1.1(1.0)E18	2.17%
CH_3OH	7.8(42)E17	1.55%
CH_4	3.3(3.0)E17	0.65%
OH	1.7(0.4)E16	0.03%

*Abundance as described in text for fit in Fig. 3C.

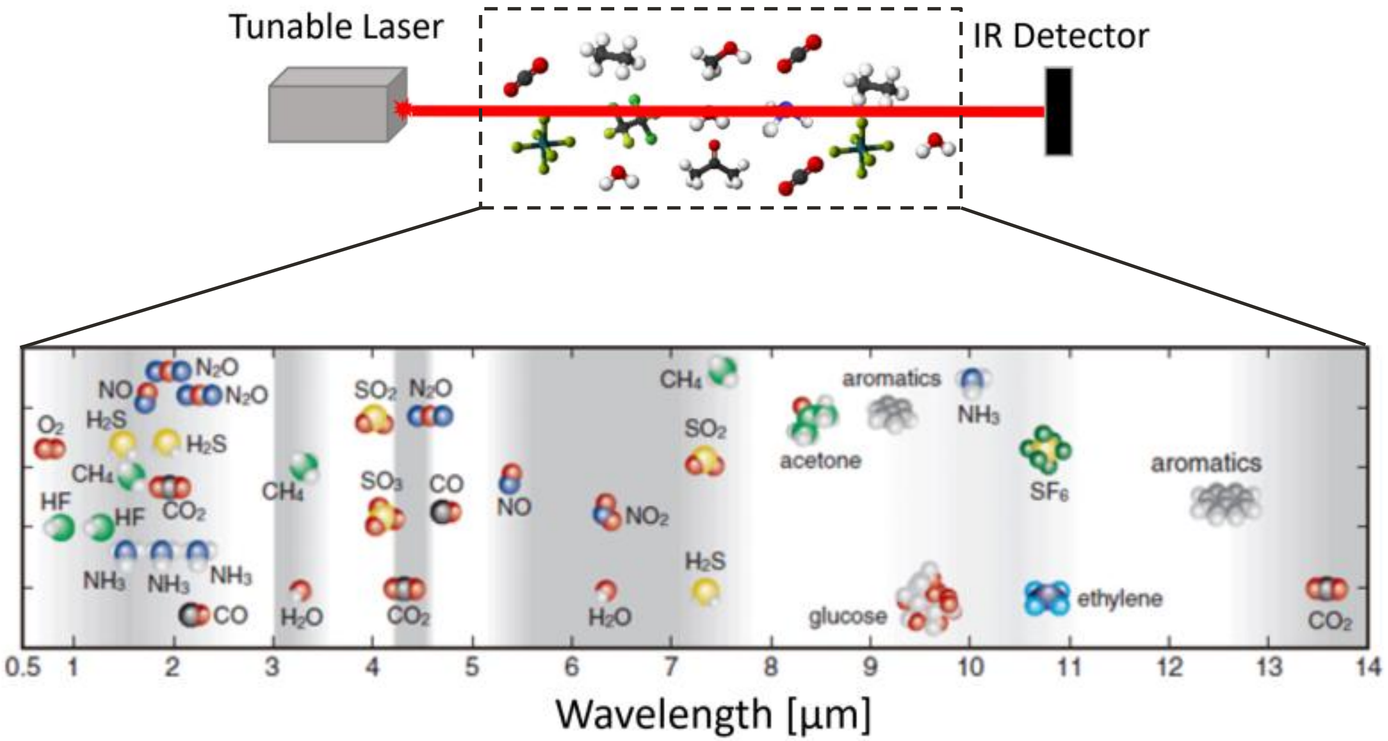
Colaprete, et al. (2010)

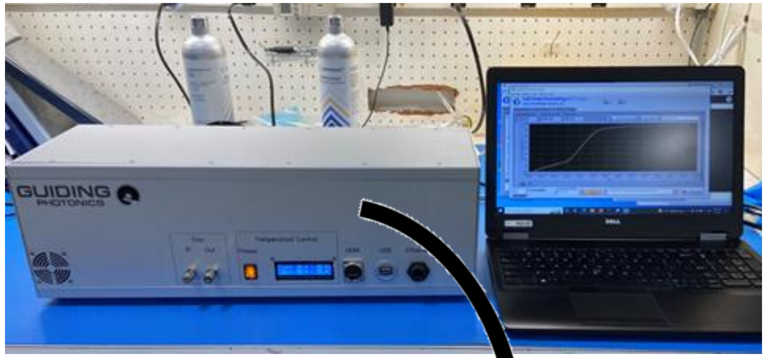
- Lunar volatiles are more than just water ice
- Characterizing composition and abundance is important to building ISRU systems
- Isotopic ratios of these molecules tell us about their origin, which can inform our understanding of key parameters like spatial distribution and texture

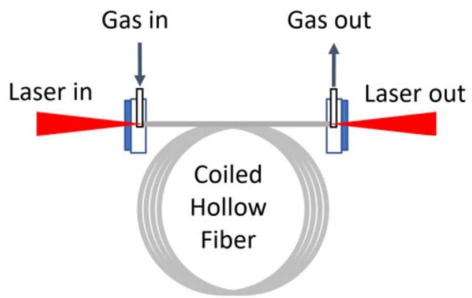
Capillary Absorption Spectrometer (CAS)

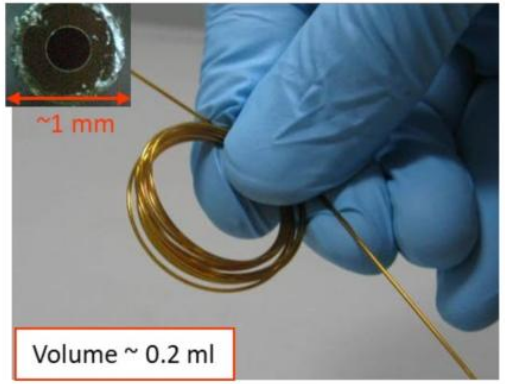
- Trace gas and isotope analyzer utilizing a low-volume (~1 mL) compact gas cell
- Mid-IR wavelength range enables unique identification of molecules, differentiating both species and isotopologues – e.g. differentiating HDO and $H_2{}^{17}O$, both mass 19
- Identifies abundance of key volatiles of interest for the lunar surface – notably H_2O, H_2S, CO_2, SO_2 (and/or others depending on wavelengths selected)

Intelligent. Adaptive. Integrated.









Kriesel, et al. (2023)

Planetary Volatiles Extractor (PVEx) Overview

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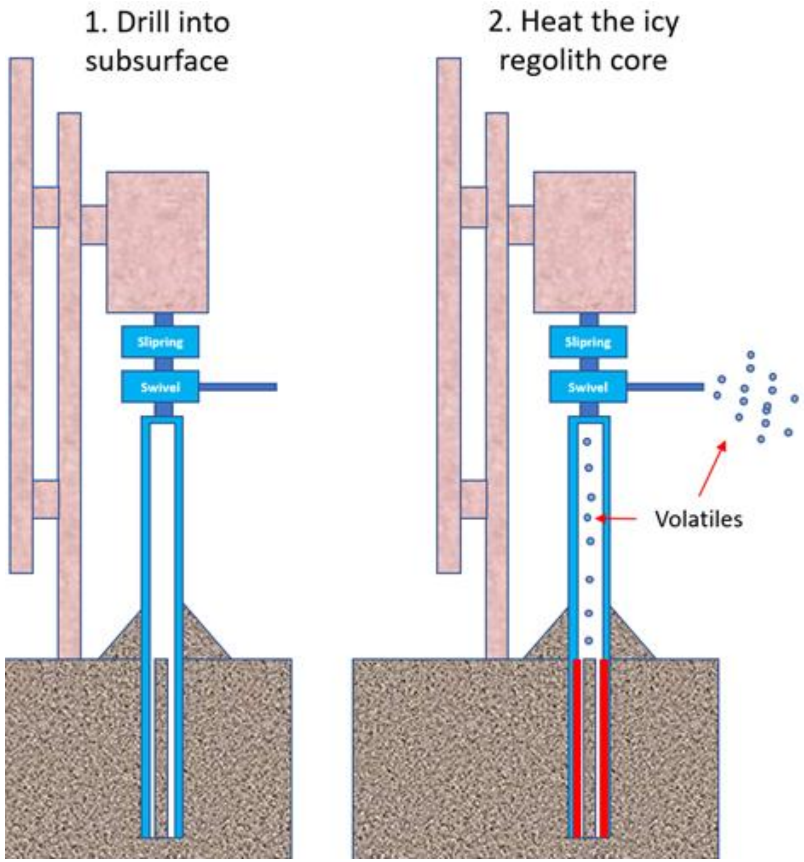
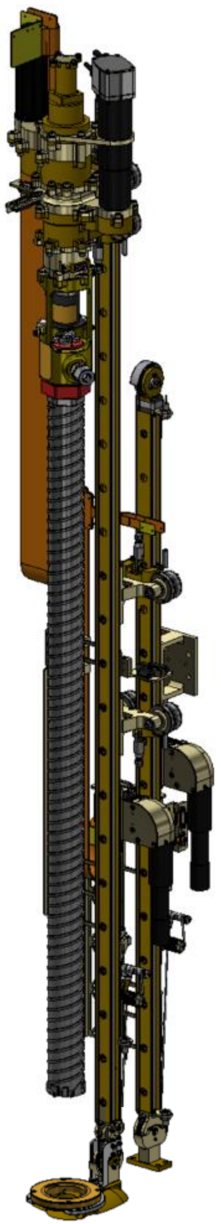
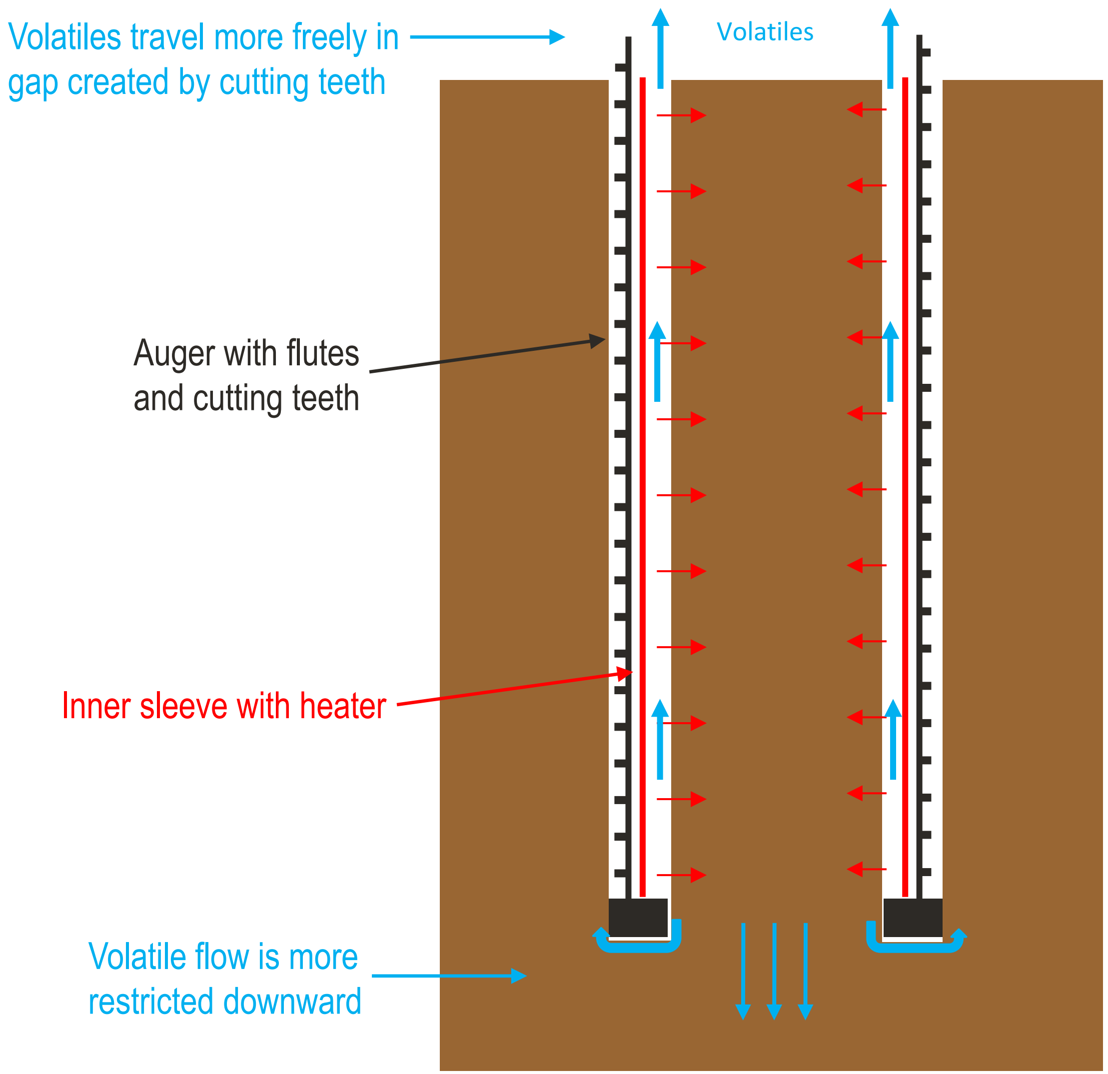
A BLUE ORIGIN COMPANY

- 1-meter rotary percussive “coring” drill
- Auger contains a heater to volatilize ices in-situ
- Volatilized gas flows up through the drill string to a cold trap where it is collected





Volatile Extraction Concept



Lunar Capillary Absorption Spectrometer (LuCAS)

OKSI
Intelligent. Adaptive. Integrated.

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NASA Goddard Space Flight Center

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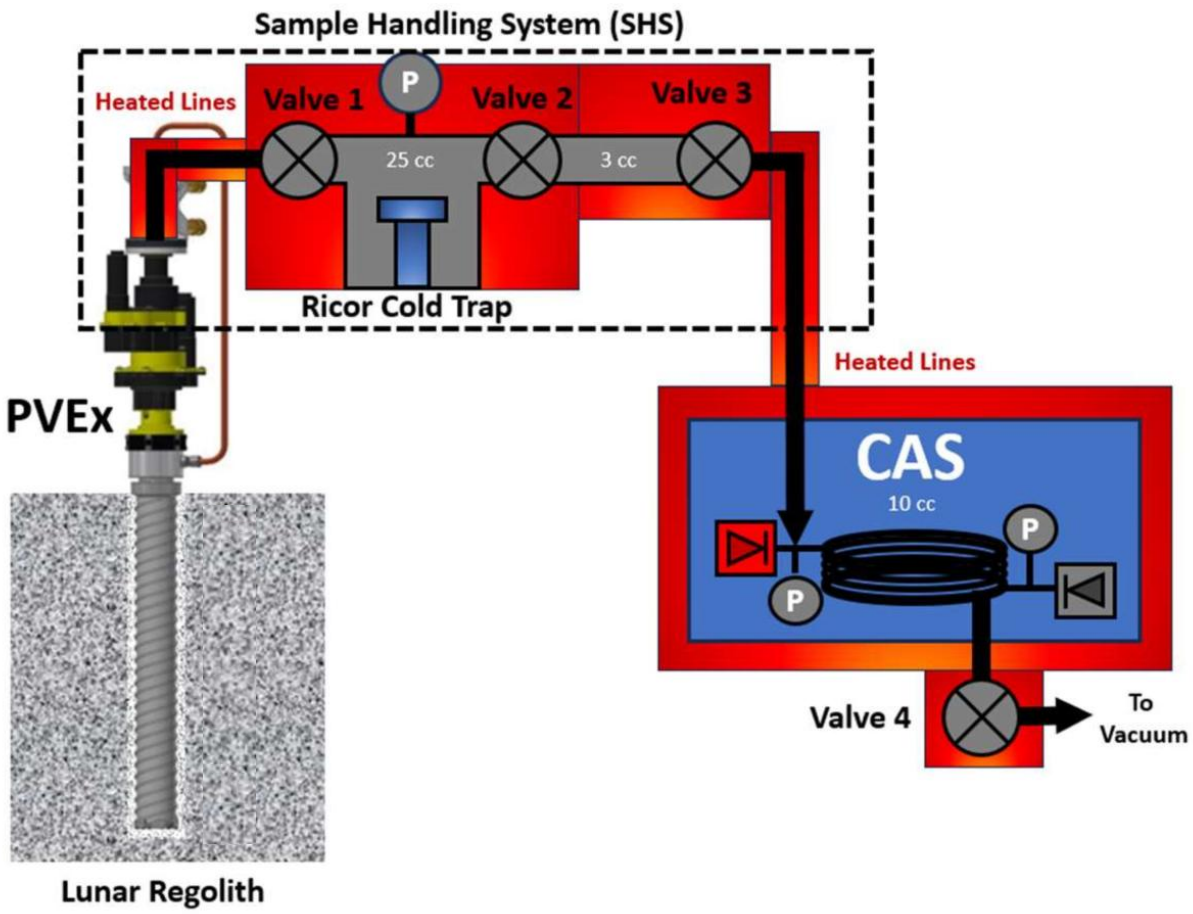
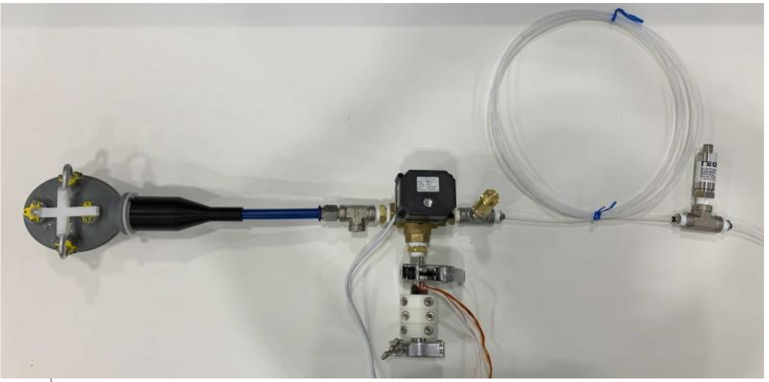
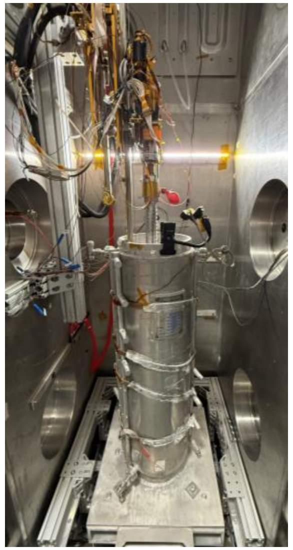
LuCAS is an end-to-end system for volatile extraction, collection, metering, and analysis on the lunar surface

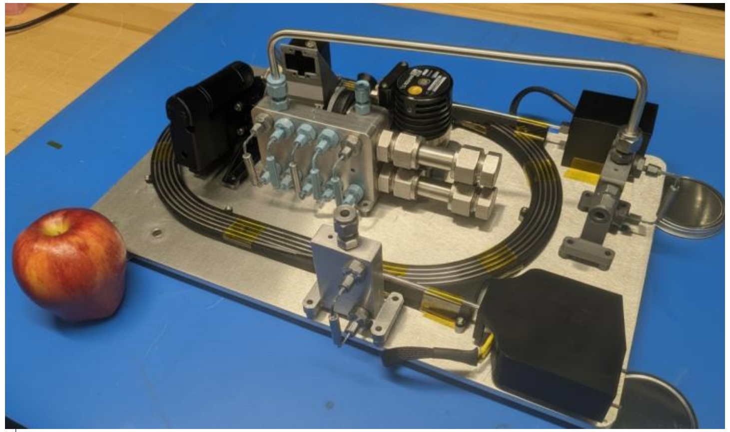


LuCAS Development Timeline



SBIR Phase I





LuCAS DALI

2021

2022 – 2024

2024-2027

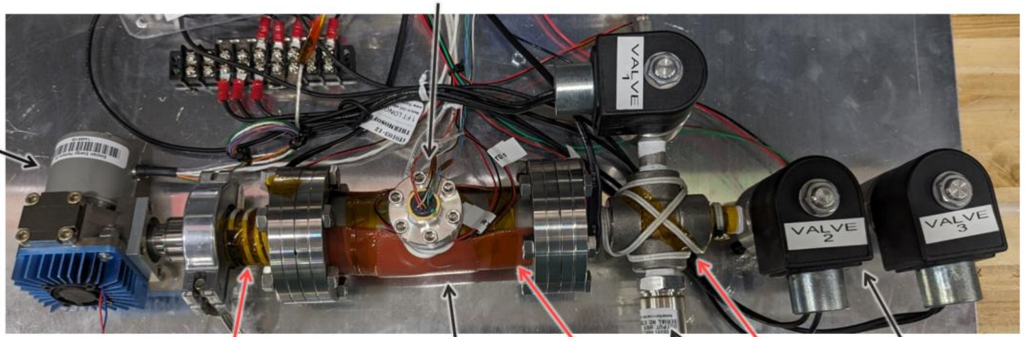
SBIR Phase II

2.0" ID
0.5 m long

LuCAS PVEx drill

1.5" ID
1.0 m long

0.76" ID
1.0 m long



LuCAS Development Timeline

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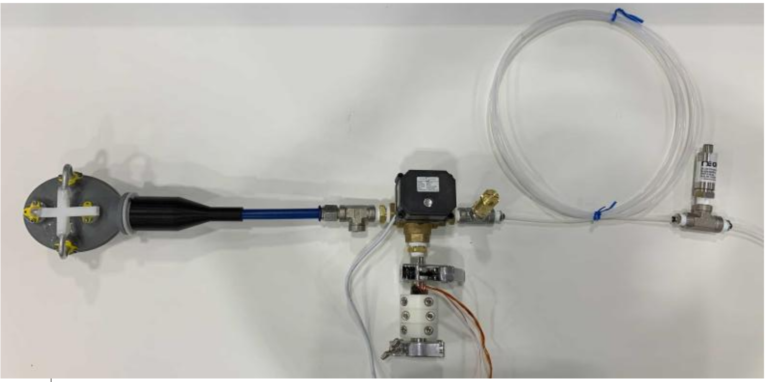
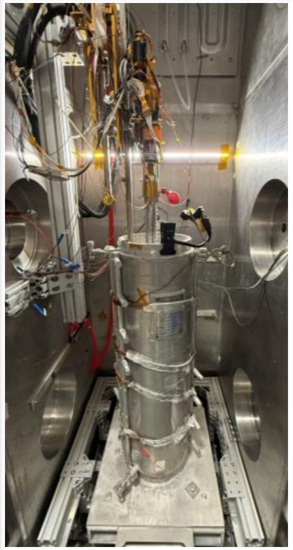
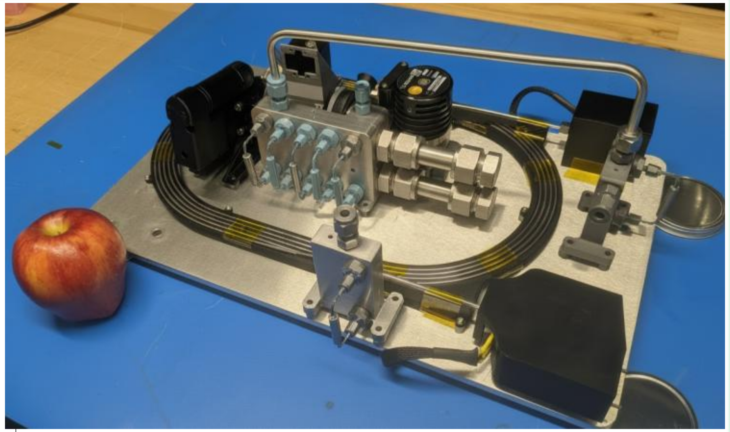


SBIR Phase I





LuCAS DALI

- ☑ TRL 5 Testing
- ☑ TRL 6 Design
- ☐ TRL 6 Qualification

2021 | 2022 – 2024 | 2024-2027

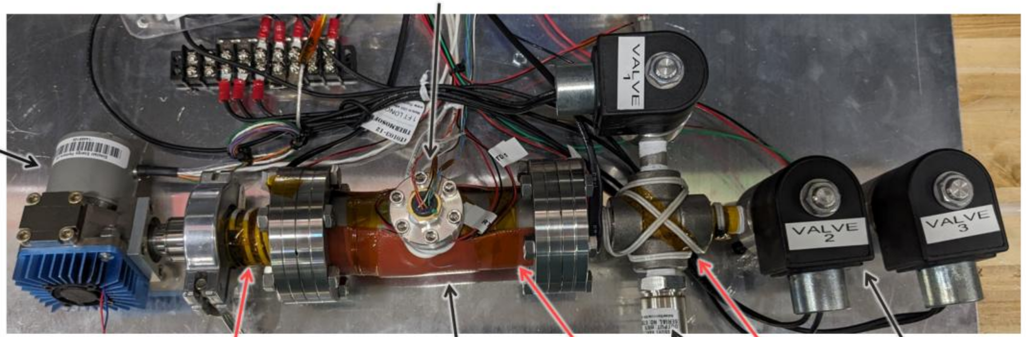
SBIR Phase II

2.0" ID
0.5 m long

LuCAS
PVEx
drill

1.5" ID
1.0 m long

0.76" ID
1.0 m long



TRL 5 Sample Handling System

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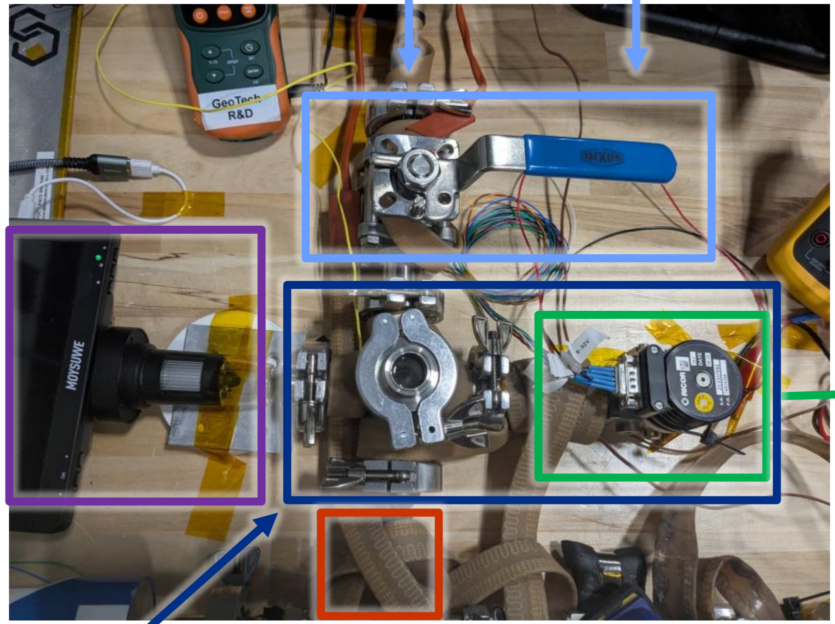
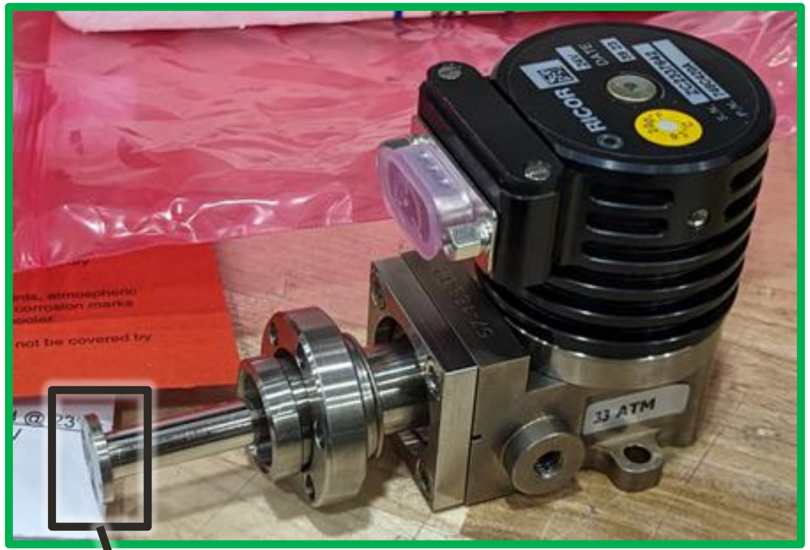
Volatiles in from PVEx

Gate Valve

SnowCam



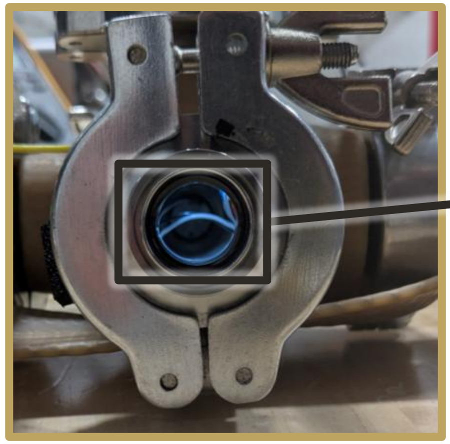
Ricor K508 Cryocooler

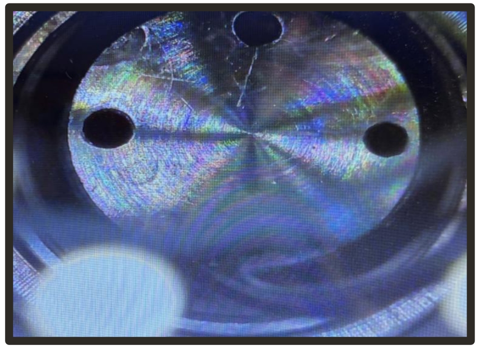


Primary Volume

Secondary Volume

Cold finger head





View from SnowCam of cold finger head inside TRL 5 system

Cold Trap Surface Area Study

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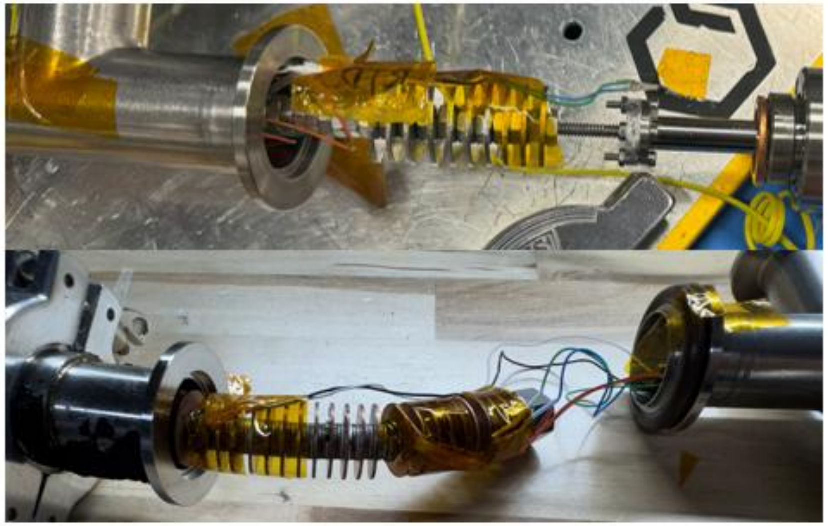
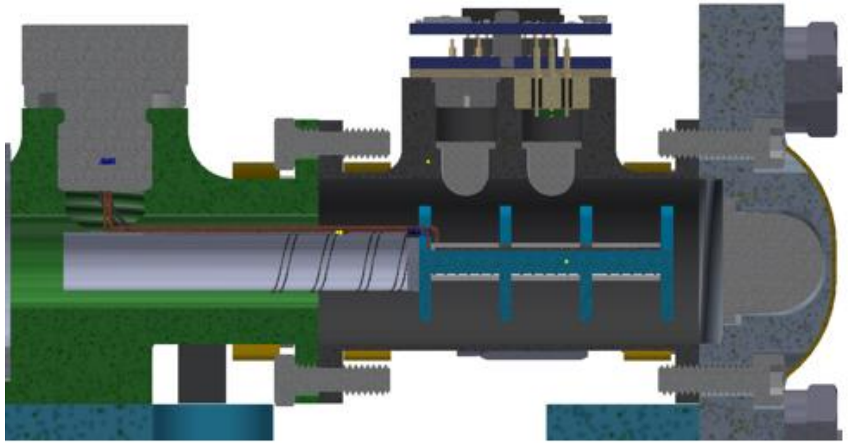
- To maximize volatile collection, the cold trap should (1) minimize surface temperature and (2) maximize surface area
- Bench top testing was performed to inform cold trap design and characterize minimum achievable temperature

Cold Trap Surface	Min. Temp Achieved
None – Cold Finger Only	-110 C
Extender (shown right)	-10 C

- Adding thermal mass to the cold trap dramatically reduced thermal performance, opted to proceed with TRL 5 testing with cold finger alone



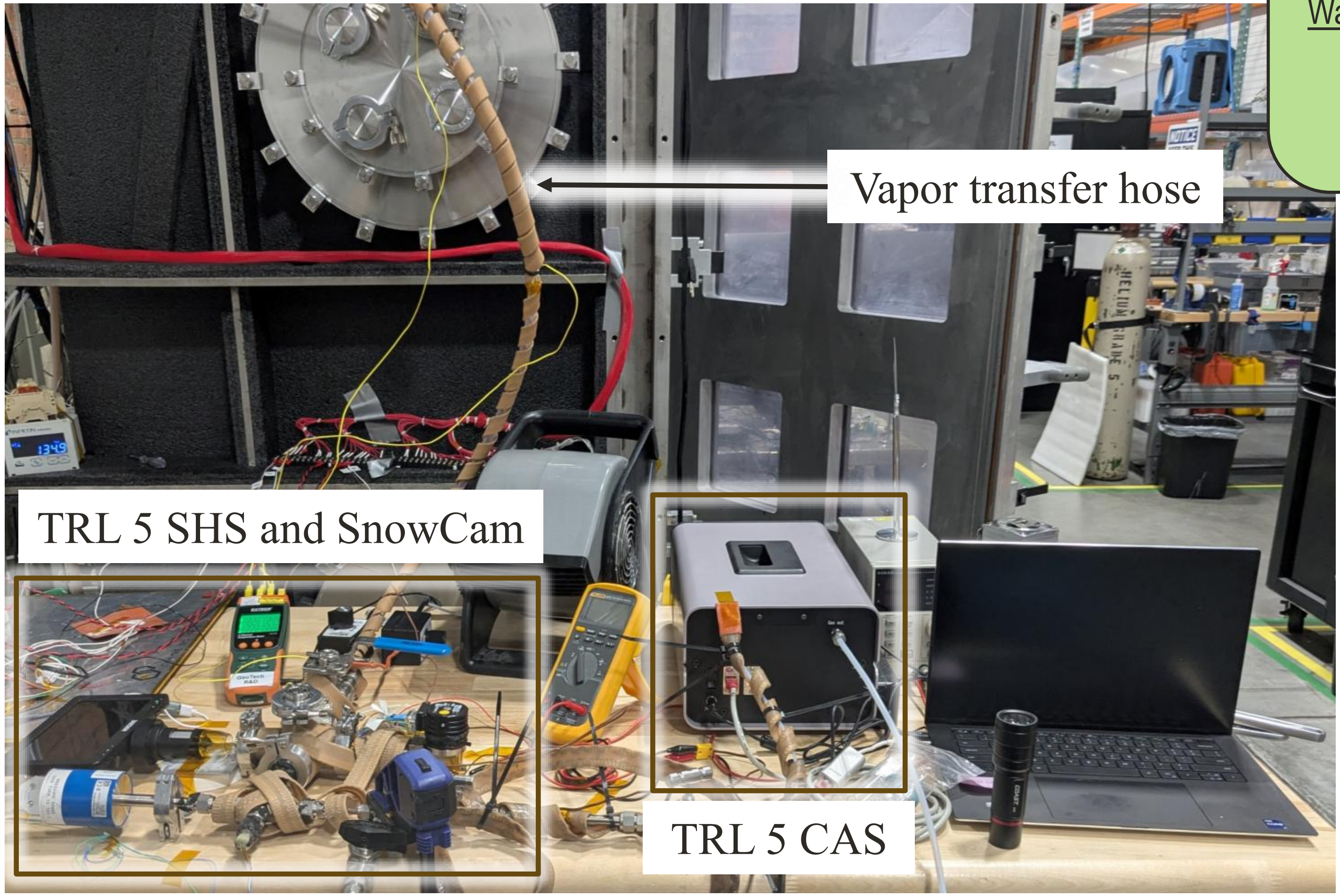
TRL5 Cold Trap Designs



TRL6 SHS Conceptual Layout

Test Plan: Test Bed Overview

- Utilize TRIDENT/VIPER lunar TVAC testbed for PVEx + simulant
- TRL 5 sample handling and CAS subsystems connected via vapor transfer hose



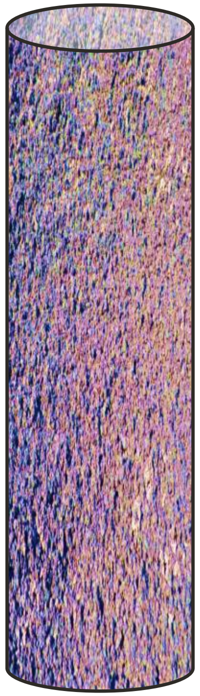
Test Specs at a Glance

Simulant: LSP-2

Water Content: as low as possible

Pressure: ≤1E-2 torr

Temperature: ≤200K



Test Sample
1 m column of uniform water ice distribution

TRIDENT/VIPER Testbed

Test Plan: Simulant Preparation

- Literature suggests as much as ~100 ppm adsorbed water can be found even at equatorial locations on the lunar surface

Article | Open access | Published: 22 September 2025

Lunar surface and subsurface water revealed by Chang'e-6

Bin Liu, Xingguo Zeng, Rui Xu, Shuai Li, Jianjun Liu, Lin Guo, Xin Ren, Dawei Liu, Wei Yan, Wangli Chen, Jinning Li, Zhiping He & Chunlai Li

Nature Astronomy **9**, 1776–1784 (2025) | Cite this article

which are driven by the redistribution of fine regolith. The average water content of the exposed fine regolith of the shallow subsurface is ~76 ppm, which is lower than the surface abundance of ~105 ppm measured at the surface. The Chang'e-6 landing site also contains on

- Baked out regolith simulant in oven at 200C for ~4 hrs to get as dry as possible to inform end-to-end LuCAS limit of detection – **no water added for most tests**
  - Lowest achievable water content was 0.2 wt. %
  - In prior development work, lowest water content tests performed with PVEx were ~4 wt. %

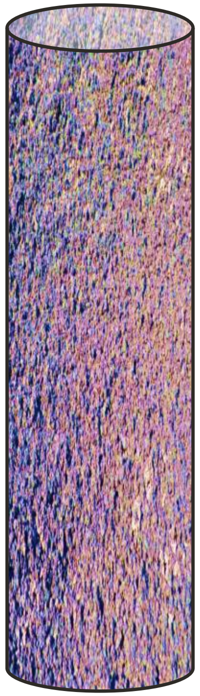
Test Specs at a Glance

Simulant: LSP-2

Water Content: From. 0.2-2 wt. %

Pressure: ≤1E-2 torr

Temperature: ≤200K



Test Sample

1 m column of uniform water ice distribution

Volatile Accumulation Monitoring

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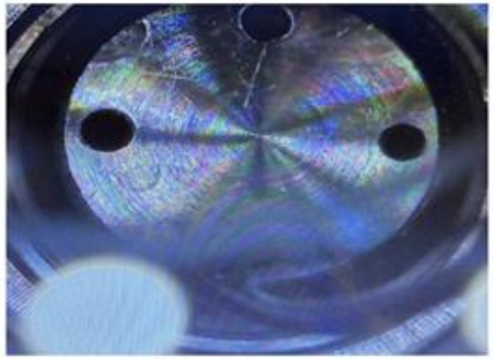
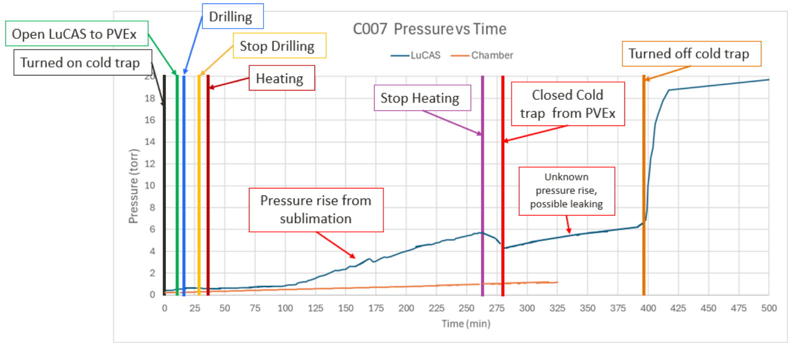
A BLUE ORIGIN COMPANY

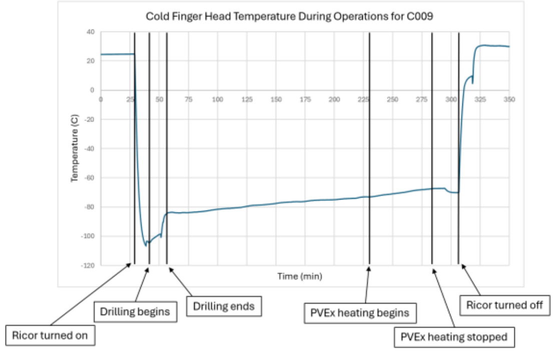
1 Image cold trap using SnowCam



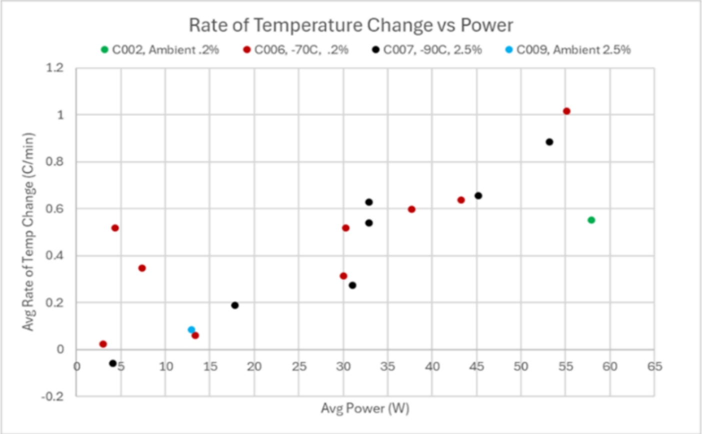
2 Monitor pressure in primary chamber



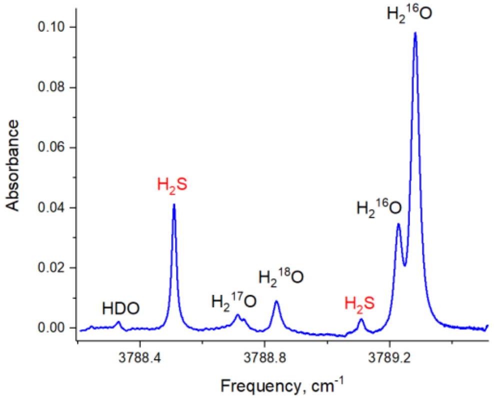
3 Monitor temp change of cold trap



4 Observe PVEx rate of temp change



5 Open to CAS for analysis



Test Results: Primary Chamber Pressure

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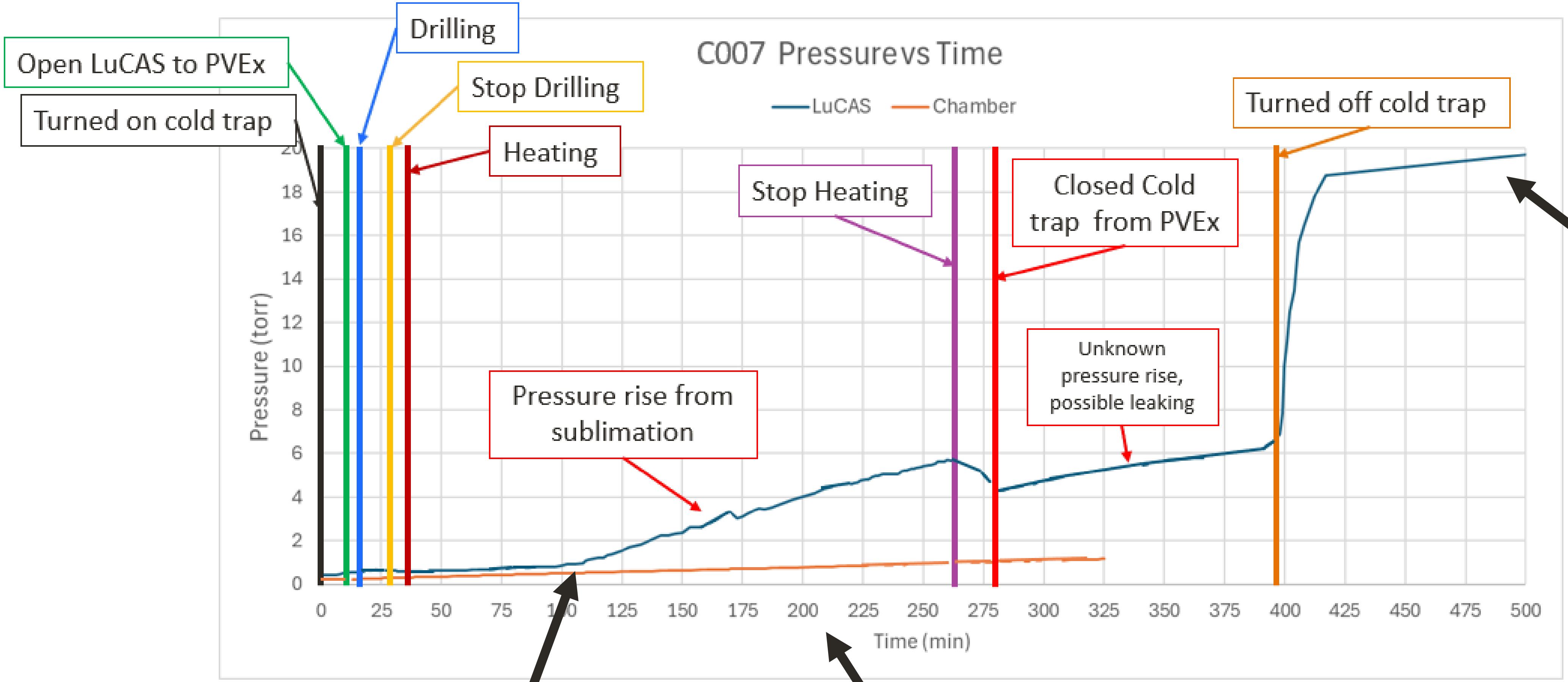
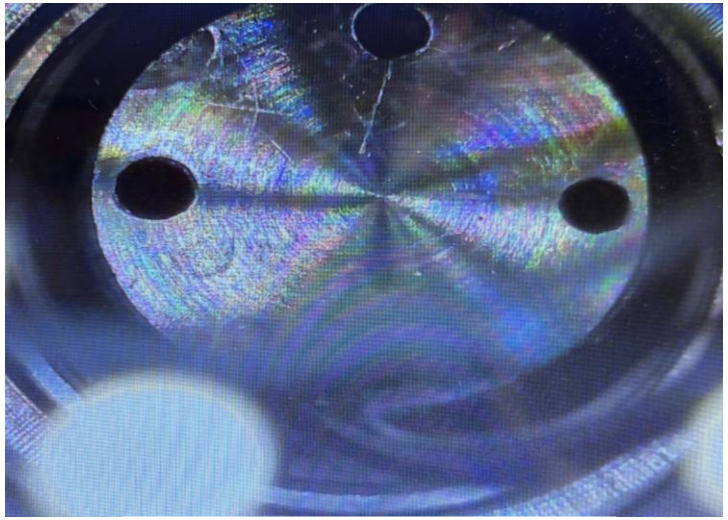


After re-heating, reach vapor pressure of water, meaning we have at least 1.1 mg of water and likely condensation

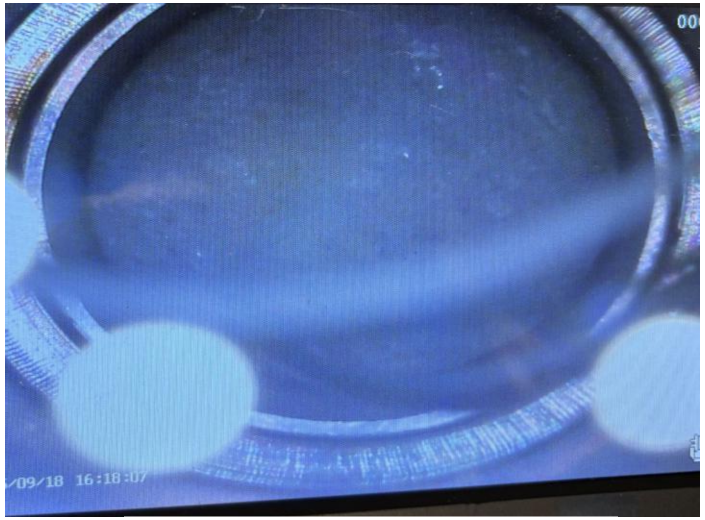
Takes time to begin phase change

Water accumulation over 4 hours

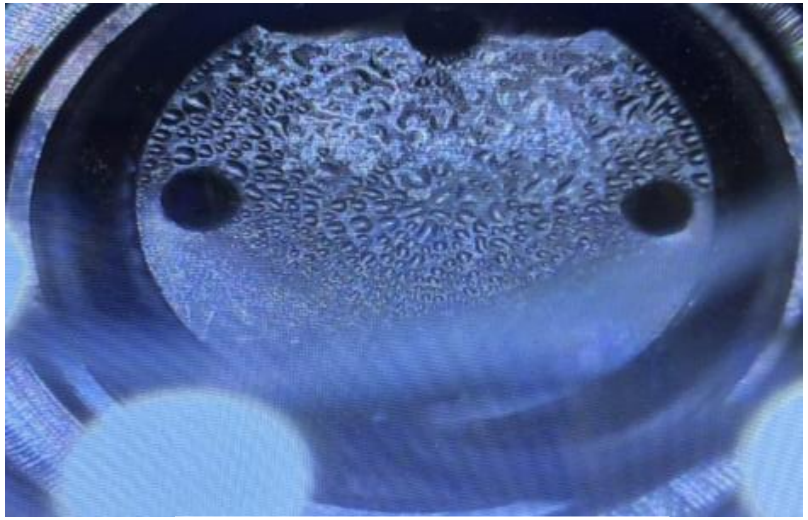
Test Results: SnowCam Images



Before Collection:
-110C cold trap



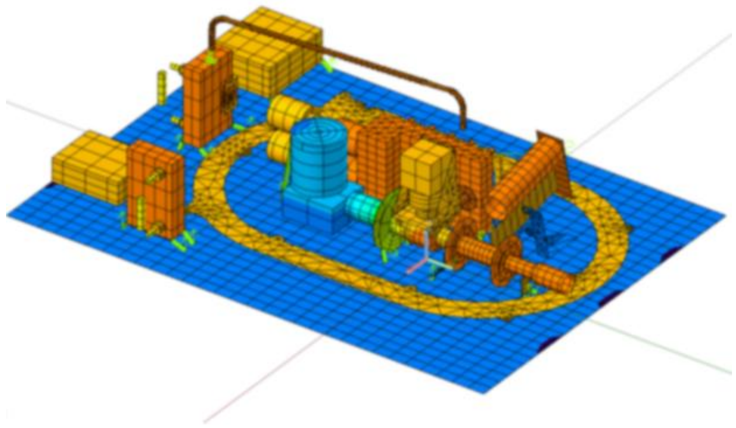
During Collection:
-70C cold trap

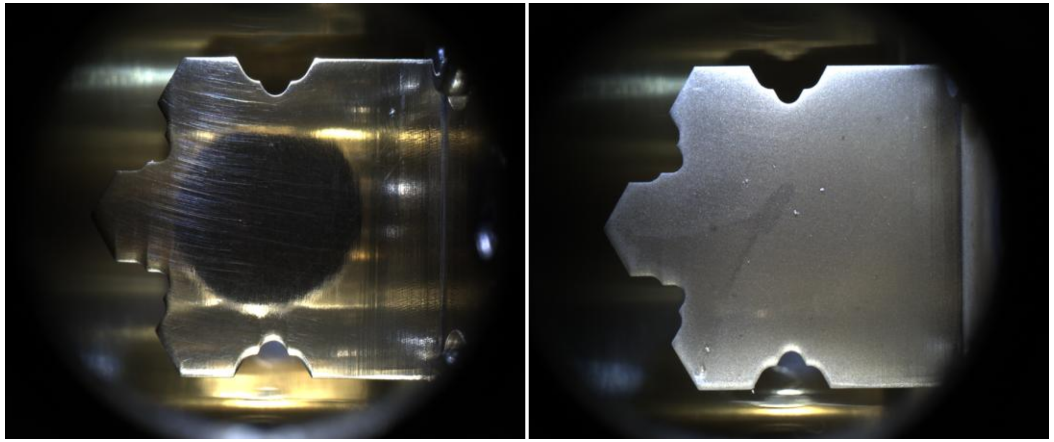


After Collection:
+22C cold trap

Lessons Learned for TRL 6 Design

- **Thermal design is crucial to the success of LuCAS**
  - Reduce parasitic loads to the cold trap to maximize power efficiency (e.g. spend available power to get as cold as possible)
  - Most interior surface area must be kept hot to avoid isotopic fractionation of the sample
  - Laser assembly has tight operational temperature and stability requirements
  - Cryocooler must be able to efficiently reject heat for best performance
- Can successfully use multiple data sources, including opportunistic measurements, to inform volatile extraction status. Tests also informed anticipated duration of each step, which matures power and energy consumption estimates
- SnowCam images provide valuable context - changes can be subtle and we don't know what to expect on the Moon!





Ongoing Work – TRL 6 Development

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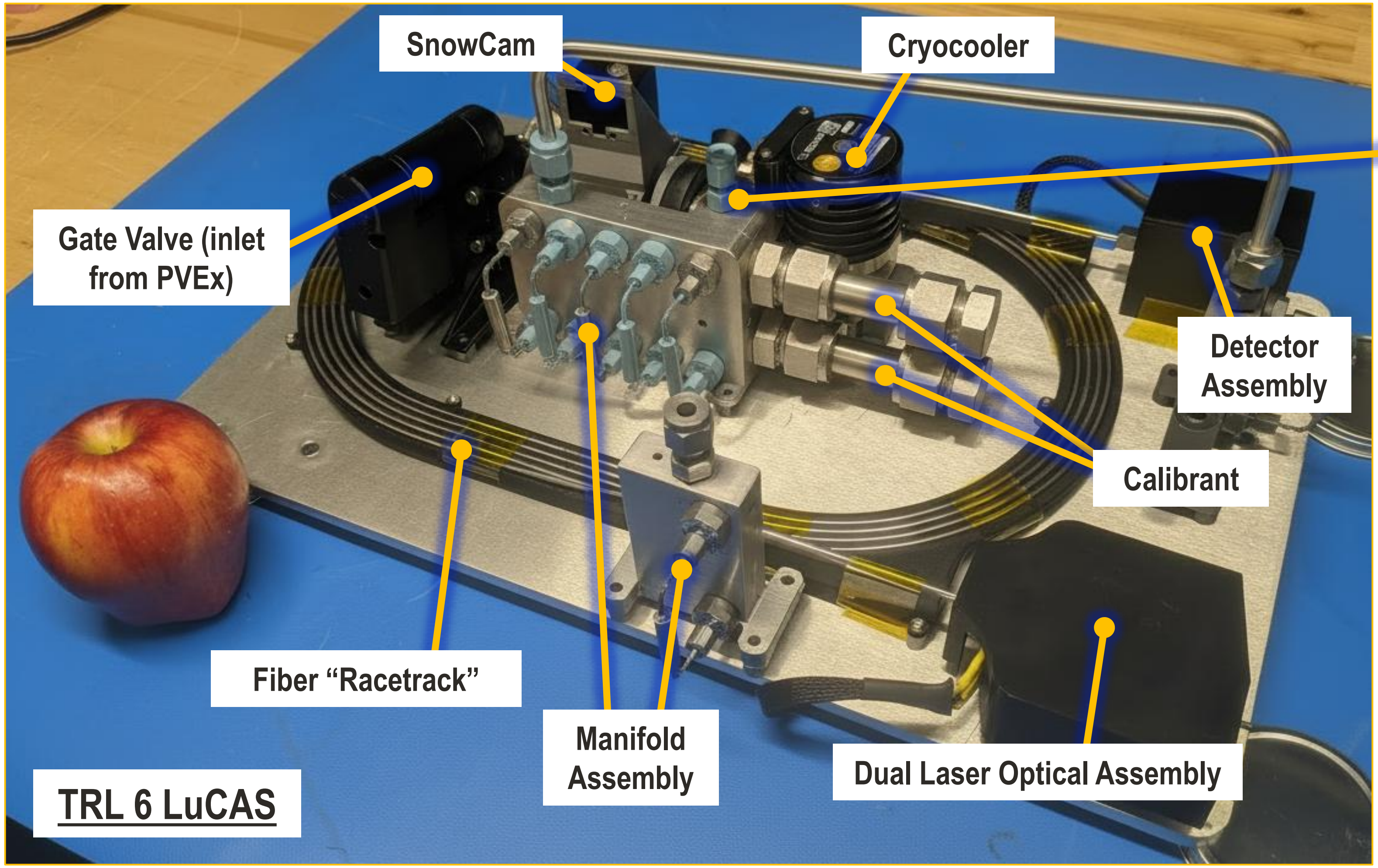
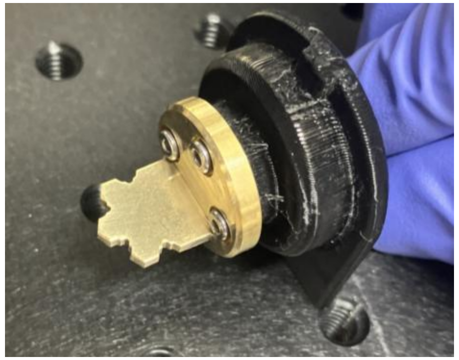
- Lessons learned from TRL 5 testing informed TRL 6 hardware design, CDR held in January
- TRL 6 hardware build is ongoing, end-to-end TVAC tests, thermal stress tests, and vibe test campaign taking place this summer



Cold finger extender designs



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