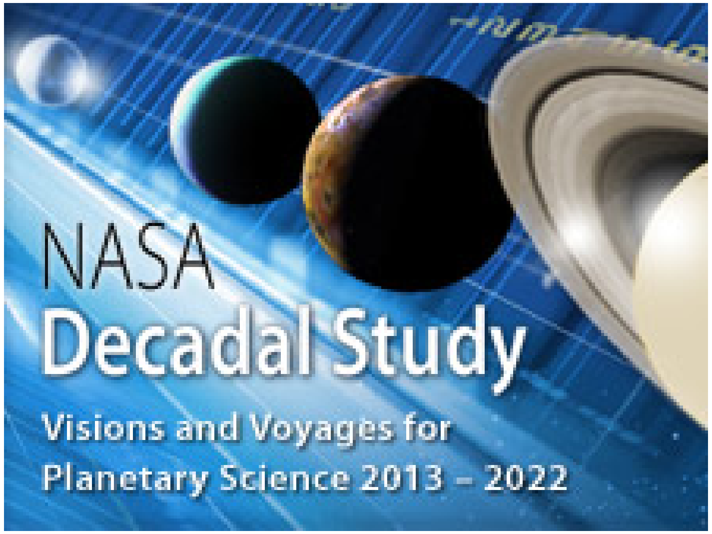
National Aeronautics and Space Administration

Instrumentation for Lunar Volatile Analysis

WAVE, MSolo PI- Janine Captain, Ph.D., KSC

Visions & Voyages NASA Decadal Study



Decadal Study posed these questions about lunar polar volatiles:

1. What is the lateral and vertical distribution of the volatile deposits?
2. What is the chemical composition and variability of polar volatiles?
3. What is the isotopic composition of the volatiles?
4. What is the physical form of the volatiles?
5. What is the rate of the current volatile deposition?

Basis for Resource Need

Defining Case for Requirement Development

To develop mission requirements defined a “Basis of Need”, a case study for ore body quality, quantity and recovery efficiency

Need Case Assumed:

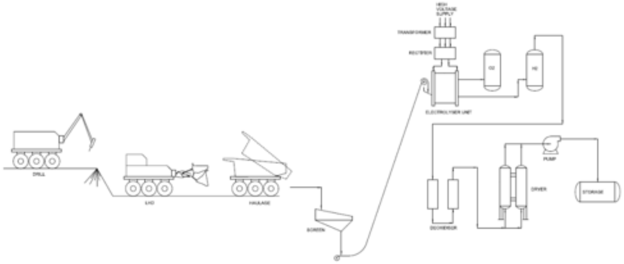
- 1000 kg of O_2 per year for Crew support (Based on Constellation studies)

Processing Assumptions:

- Distribution: **0.5%** water ice with **0.5 meter dry over burden**
- Excavation to 1m deep
- Capture efficiency: **10%**, including mining/acquisition, extraction, transportation, processing and storage

The need with these assumption requires an approximately **2500 m^2** area to be excavated to **1 meter deep**

This model acts as the basis for Level 2 requirements, including sensitivity and spatial extent

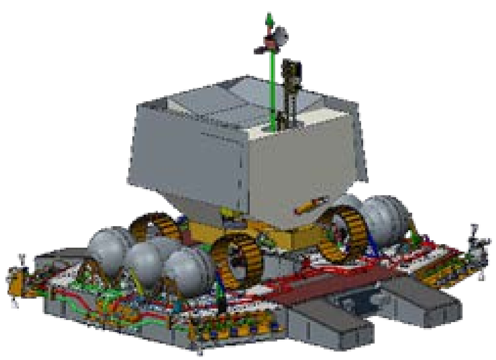


Boucher, 2016

Prospecting tools– The Tool Box

Mobility

Rover
- Mobility system
- Cameras
- Surface interaction



Prospecting

Neutron Spectrometer System (NSS)
- Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth

NIR Volatiles Spectrometer System (NIRVSS)
- Surface H_2O/OH identification
- Near-subsurface sample characterization
- Drill site imaging
- Drill site temperatures

Sampling

Drill
- Subsurface sample acquisition
- Auger for fast subsurface assay
- Sample transfer for detailed subsurface assay

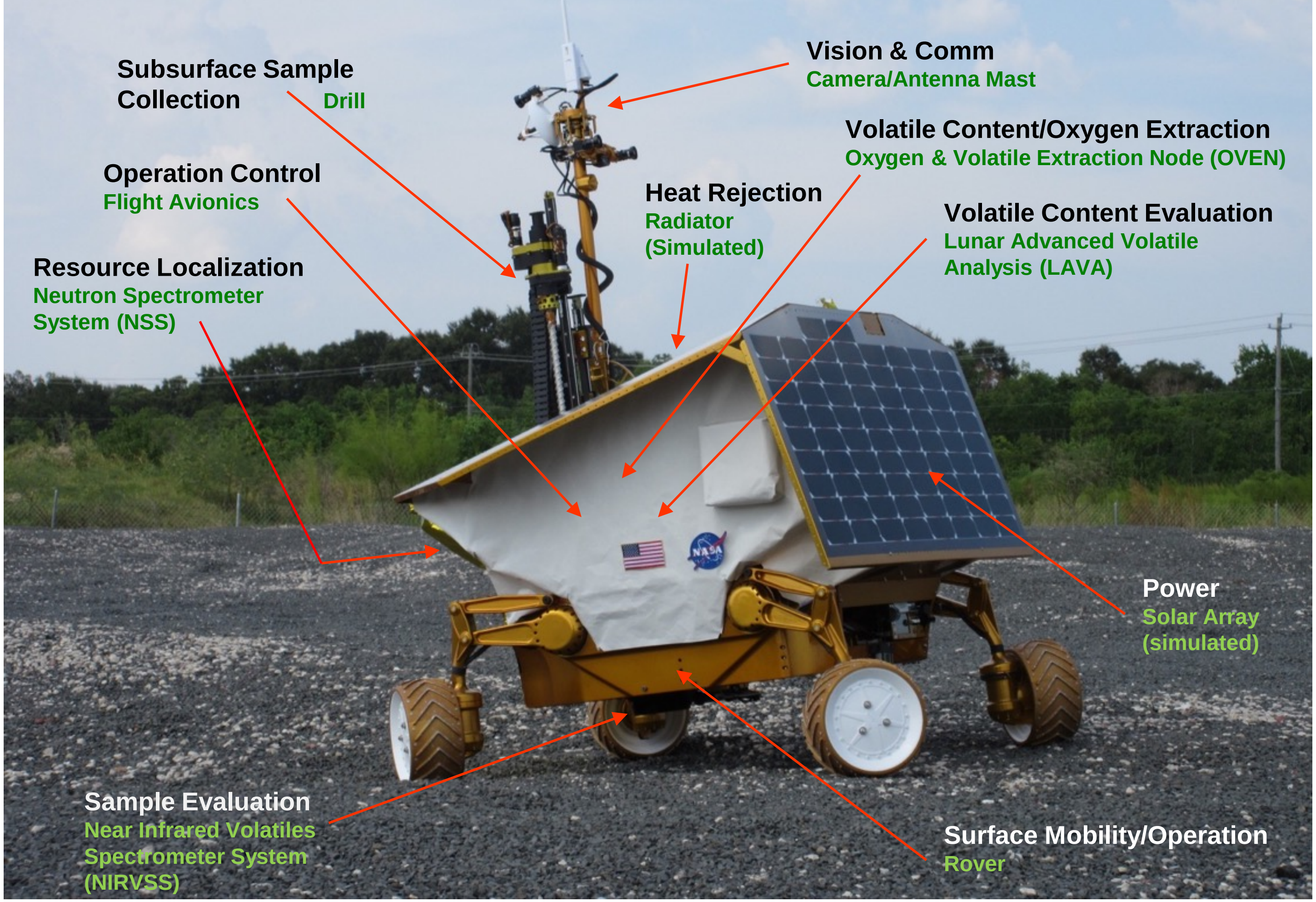
Processing & Analysis

WAVE

Oxygen & Volatile Extraction Node (OVEN)
- Volatile Content/Oxygen Extraction by warming
- Total sample mass

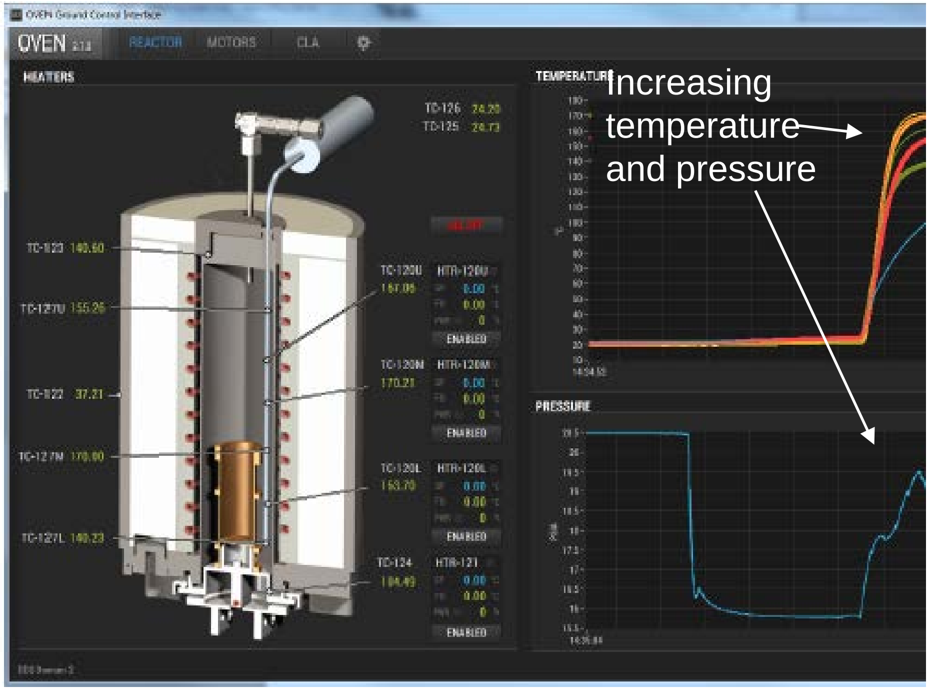
Lunar Advanced Volatile Analysis (LAVA)
- Analytical volatile identification and quantification in delivered sample with GC/MS
- Measure water content of regolith at 0.5% (weight) or greater
- Characterize volatiles of interest below 70 AMU

RP15: Surface Segment (Payload/Rover)

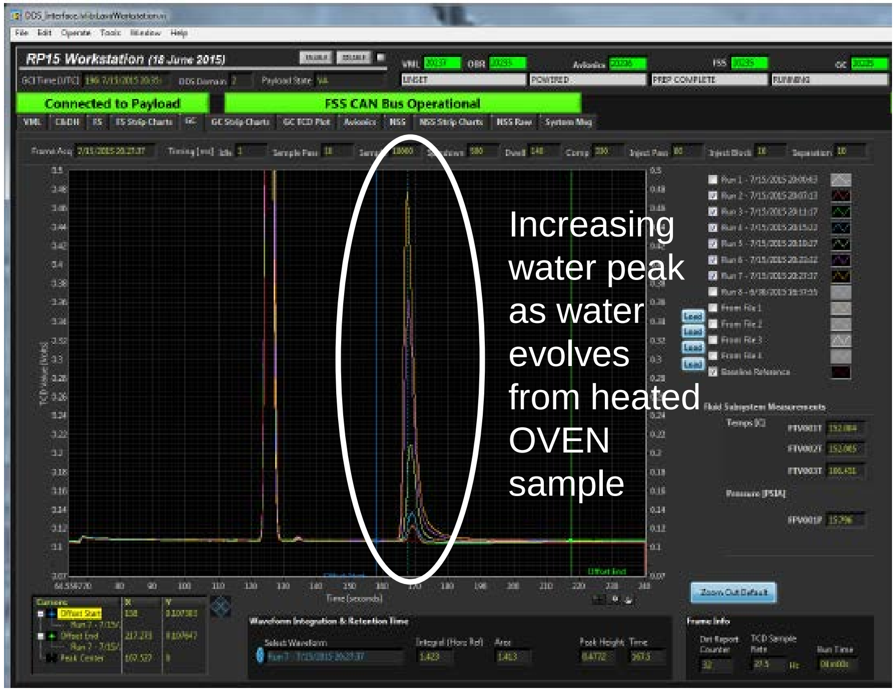


OVEN-LAVA Operation during RP-15 Volatile Analysis

Volatile analysis demonstration measured increasing water concentration as simulant sample temperature increases



OVEN User Interface

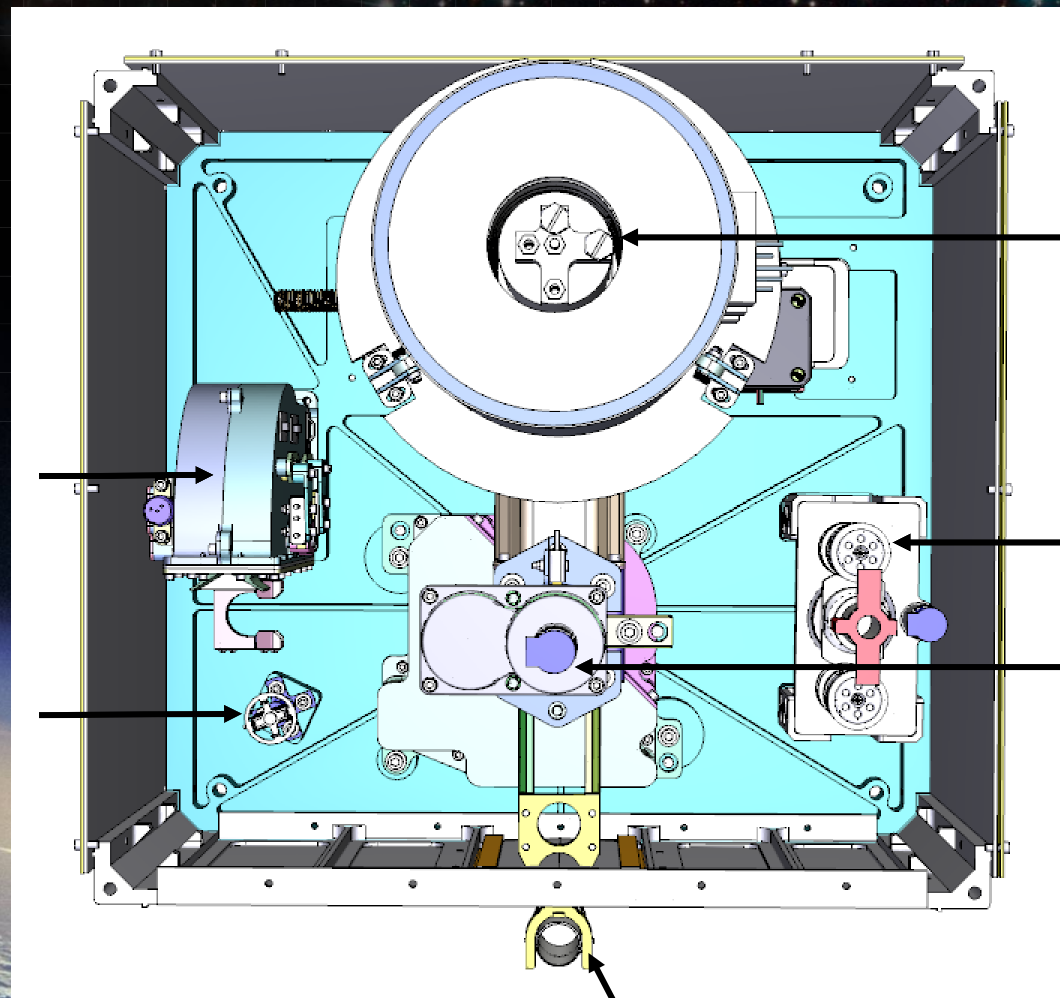


LAVA GC User Interface

OVEN (Oxygen and Volatile Extraction Node)

Multiple functions

- Receive sample from drill
- Confine sample to a known volume
- Weigh sample
- Heat sample, build pressure from volatiles
- Transfer volatile sample to LAVA Subsystem
- Discard sample



SAMPLE REMOVAL STATION
Inverts crucible to remove sample

WEIGH STATION
Measures mass of sample

REACTOR STATION
Seals and heats sample up to 450 º C

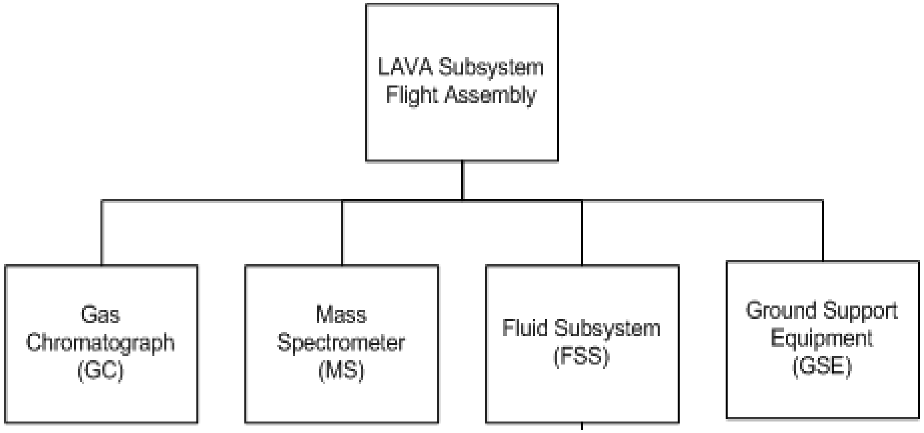
STORAGE STATION
Locks two crucibles in place during launch

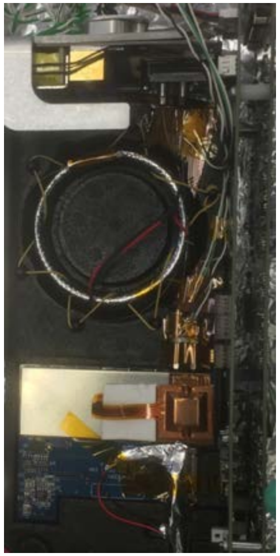
ARM
Has three degrees of freedom to move crucible to different stations

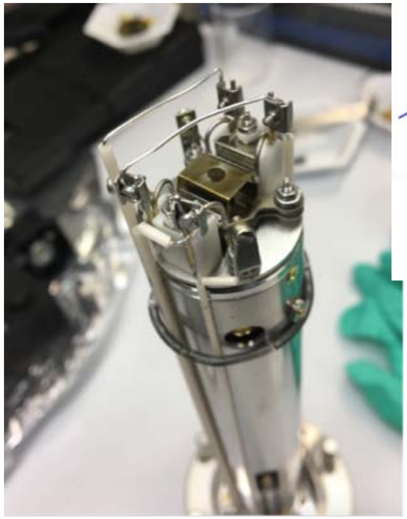
CRUCIBLE **(Shown at sample acceptance location)**
Holds 12 ccs of sample delivered from drill

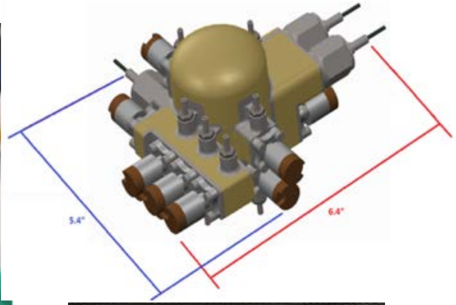
Lunar Advanced Volatile Analysis (LAVA)

- Purpose: Identify and quantify water as well as other low molecular weight species of interest to ISRU and Science community
  - Volatiles are transferred from the OVEN reactor to the LAVA Surge Tank where the pressure & temperature are measured
  - Gas sample is diluted and analyzed by GC-MS to identify and quantify constituents.
  - Gases of interest are H_2O, CO, CO_2, H_2, H_2S, NH_3, SO_2, CH_4, and C_2H_4 (1-70 amu)
  - Water that is evolved will be condensed and photographed, demonstration of resource storage (as well as public engagement).









Volatile Identification and Quantification

Drill and Regolith Transfer

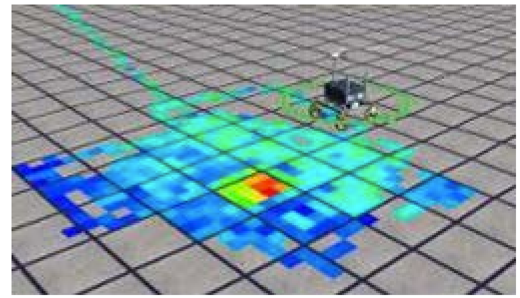
- Near Surface Assay located sample of interest
- Regolith from depth captured on drill flutes and transferred into OVEN crucible

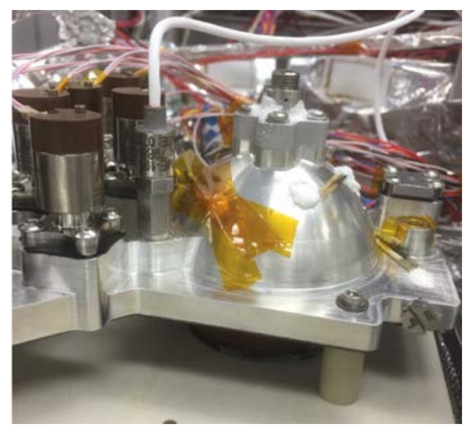
Seal and Heat

- Regolith filled crucible manipulated in OVEN and sealed in reactor station
- Crucible is heated to user defined setpoints to drive volatiles into gas phase

Quantify and Identify

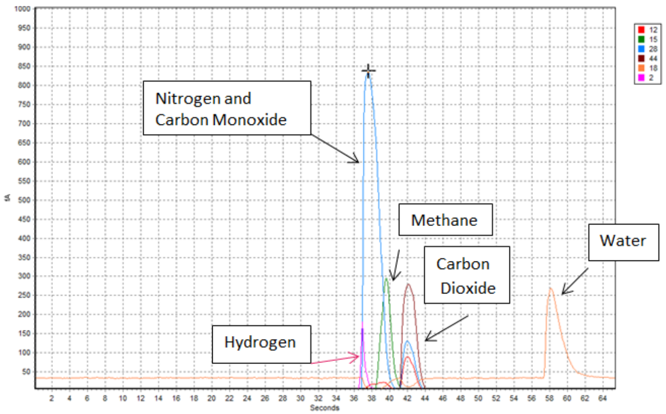
- Gas phase volatiles transferred to known volume held at temperature to prevent condensation, number of moles calculated with ideal gas law
- Gas sample diluted and analyzed with GC-MS for species identification and quantification





RP LAVA GC-MS Summary

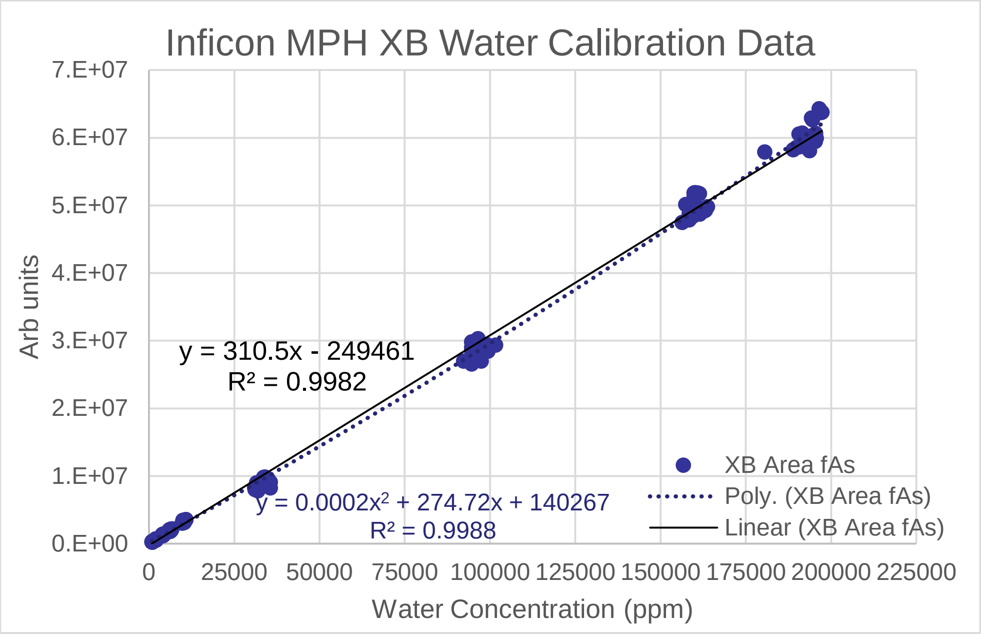
- Inficon Fusion MicroGC module
  - Single Plot-Q column (8m), separate inert components from CO_2 and H_2O
  - Isothermal operation, ~2min runtime
  - microTCD with auto-ranging capability



- Inficon Transpector MPH
  - Quadrupole mass spectrometer
  - Open ion source and cross beam ion source configurations
  - ~3.5kg, ~20W

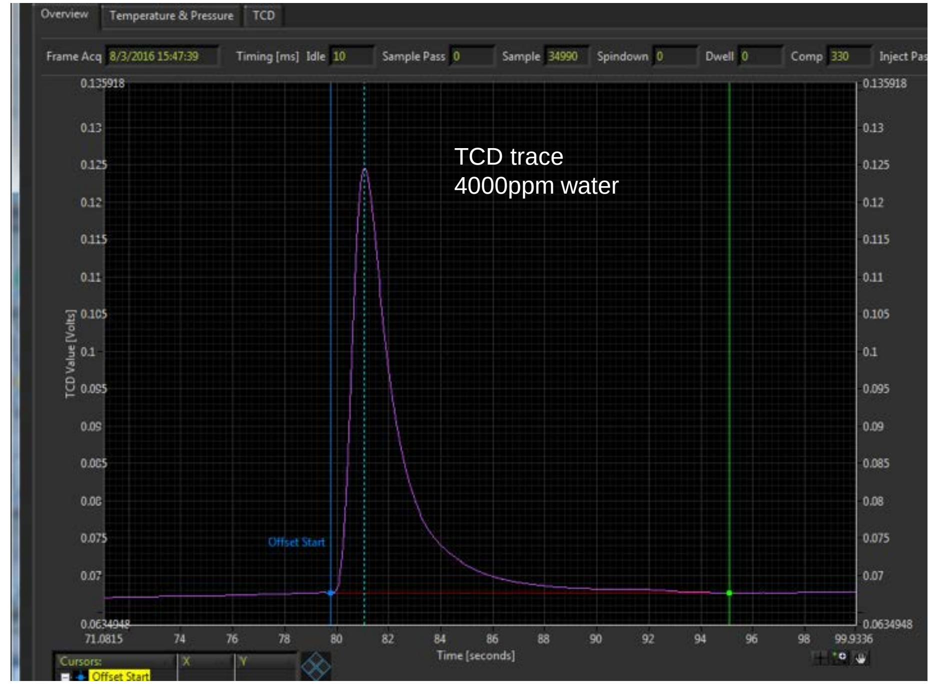
	Factor	Requirement
1.1	Scan rate	Collect 1-70 amu at 6Hz
1.2	Water detection limit	1000ppm at above scan rate

	Integrated System
Low water range average uncertainty	70 ppm
High water range average uncertainty	1725 ppm



Detection Limits for Water

- Detection limit for water with worst case assumptions is 1.3% water in the vapor phase
- Instruments have demonstrated detection limits of 1000ppm
- Lower limit of detection required for isotope analysis, this work is still in progress

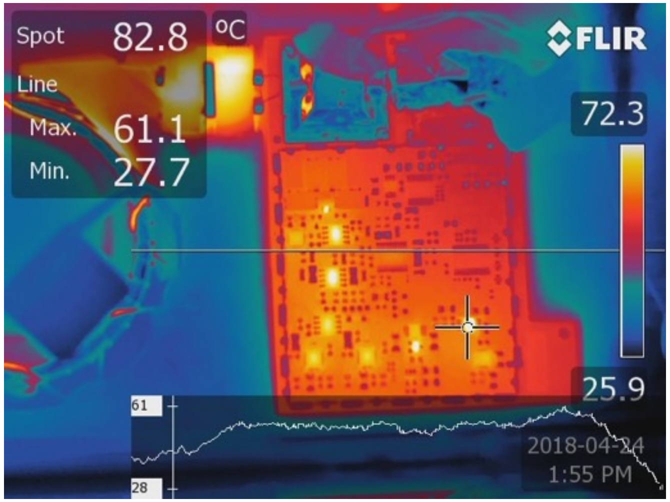


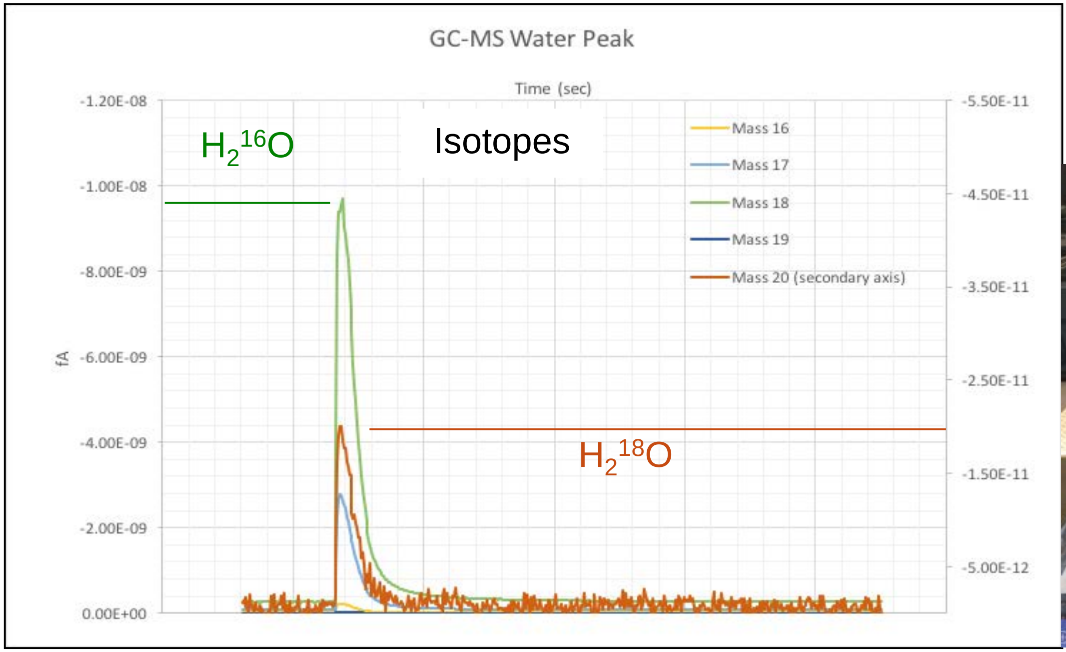
Assumptions

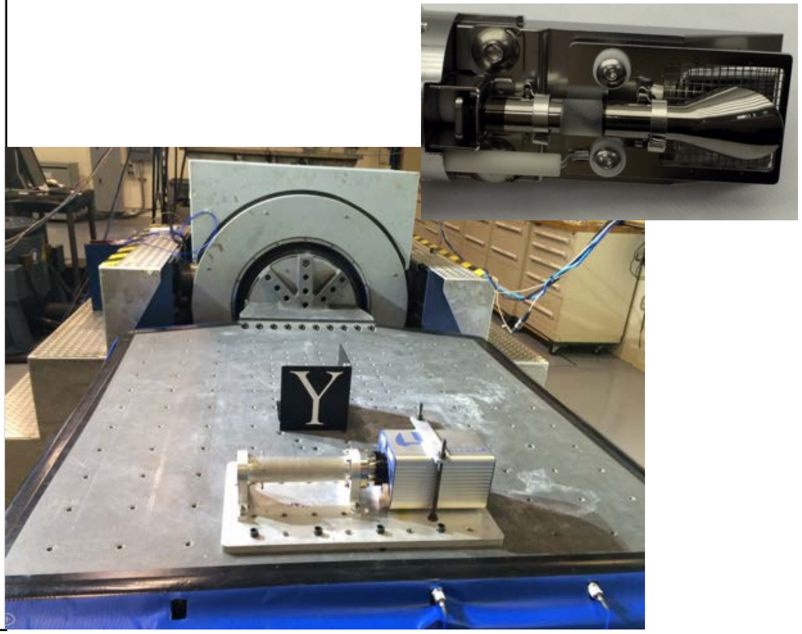
- 12g lunar regolith sample (lowest density sample)
- 50% loss of water ice due to sublimation during drilling
- OVEN and LAVA volumes were volatiles are generated are 100cc each
- SDS dilution is 1:5 (sample to helium diluent) based on the assumption that the sample is all water (worst case assumption)
- Total pressure generated by water and other volatiles is 65psia (max operational pressure with current concept of operations)
- All of the water present in the sample is in the vapor phase
- Gas temperature is 150C (423K), i.e. the temperature of the LAVA system

Modified commercial off the shelf approach

- In line with Space Policy Directive 1 to engage commercial vendors
- Radiation, thermal and vibration testing for appropriate environment to make informed modifications ideally in collaboration with the vendor







Flight forward design – modified Commercial Off the Shelf (COTS)

- Modification areas for flight driven by environment
  - Thermal considerations
  - Vibration considerations
  - Radiation considerations
  - Command/control interface

- Utilize components from other missions where possible within schedule/cost (valves, port connectors)

- Testing in thermal vacuum chamber and radiation testing of avionics