National Aeronautics and Space Administration

Characterizing Lunar Water

Resource Prospector: A rover mission to the Lunar polar region

Ted L. Roush

NASA Ames Research Center

Moffett Field, CA USA

June 2017

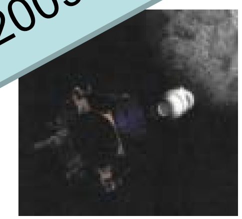
Outline

1. History of Water on the Moon (2)
2. Mission History (8)
3. Near-Infrared Volatile Spectrometer System (NIRVSS) (9)
4. Future (2)

History of Water on the Moon

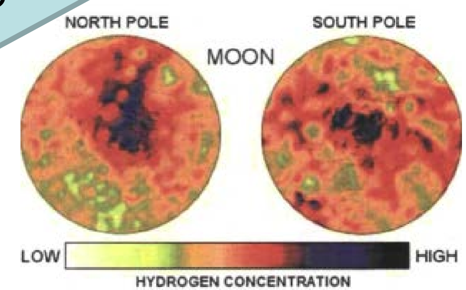
Integrated data from instruments on LRO support large quantities of water ice in PSRs and partially sunlight regions

Chandrayaan-1 radar data consistent with water ice in PSRs and M^3, Deep Impact HRIIR, and Cassini VIMS data indicate presence and variability of surface OH/H2O



Clementine bi-static radar suggests water ice in polar permanently shadowed regions (PSRs)

1961 1970 1994 1998 2008 2009 2010 …



Lunar Prospector Neutron Spectrometer detects elevated hydrogen levels correlated with PSRs

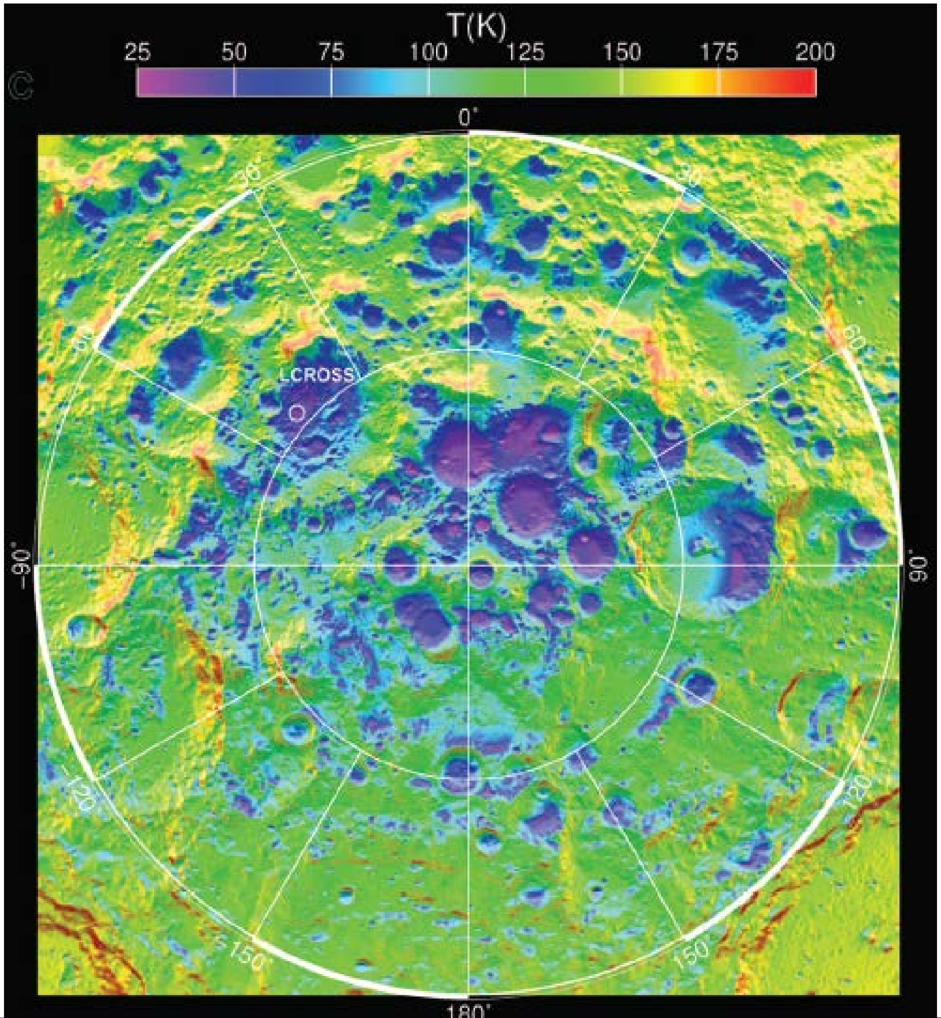
LCROSS impacts Cabeus A and detects significant quantities of water in the ejecta

1961 - Watson, Murray & Brown theorize Lunar cold traps may contain water ice

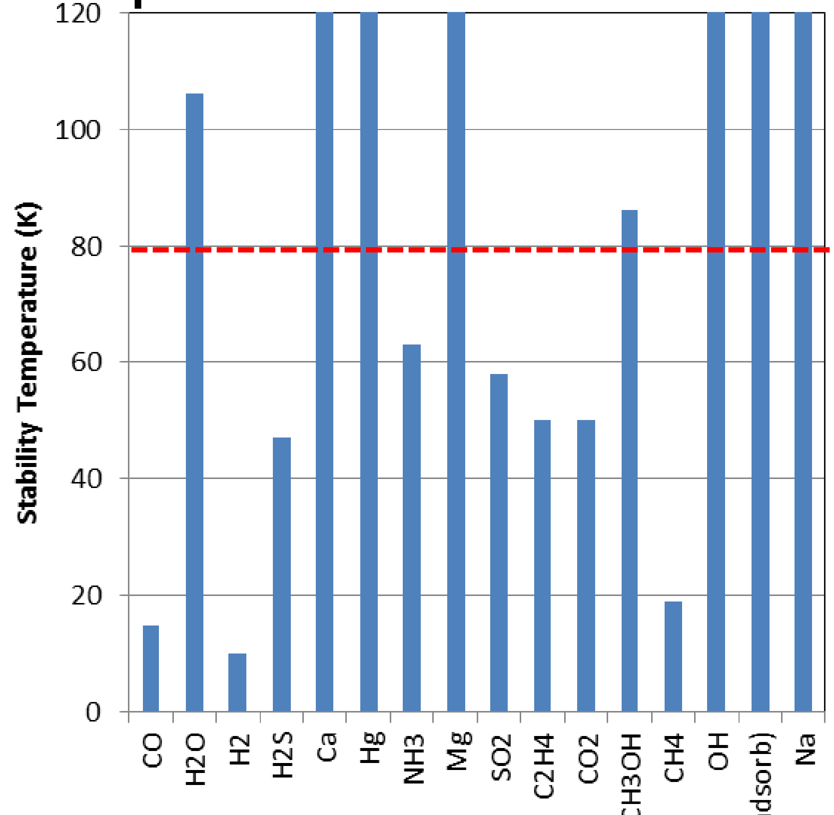
1969-1972 Apollo samples suggest a dry moon

Polar Temperatures and Volatiles

Modeled annual mean temperature



Long-term vacuum stability temperatures for observed volatiles



Only volatiles with T>80 K (above red dashed line) expected below surface in sunlight regions

Moving Forward – What Must Be Done

National Aeronautics and Space Administration

Given: There are potentially substantial hydrogen rich resources on the Moon…

Then: We must gain the necessary knowledge to guide future mission architectures to allow effective utilization of in-situ resources to their fullest extent and optimum benefit.

- Understand the resources – Resource Prospector (RP)
  - What resources are there (minerals, volatiles, water/ice)?
  - How abundant is each resource?
  - What are the areal and vertical distributions and hetero/homogeneity?
  - How much energy is required to locate, acquire and evolve/separate the resources?
- Understand environment impact on extraction and processing hardware
  - What is the local temperature and illumination environment?
  - What are the physical/mineralogical properties of the local regolith?
  - Are there extant volatiles that are detrimental to processing hardware or humans?
  - What is the impact of significant mechanical activities on the environment?
- Design and use hardware to the maximum extent practical that has applicability to follow-on ISRU missions
  - Can we effectively separate and capture volatiles of interest?
  - Can we execute repeated processing cycles (reusable chamber seals, tolerance to thermal cycles)?

RP - “Big Picture”

RP is being pursued within NASA to prospect for volatiles in the polar regions of the Moon.

RP addresses using lunar resources to produce oxygen and propellants that enable new mission architectures for human exploration

RPM is targeted for launch in 2021/22.

Mission elements include:

Launch vehicle – TBD, Potentially SLS, EM-2

Lunar lander

- Commercial
- International Cooperation, possibly Taiwan

Rover - NASA

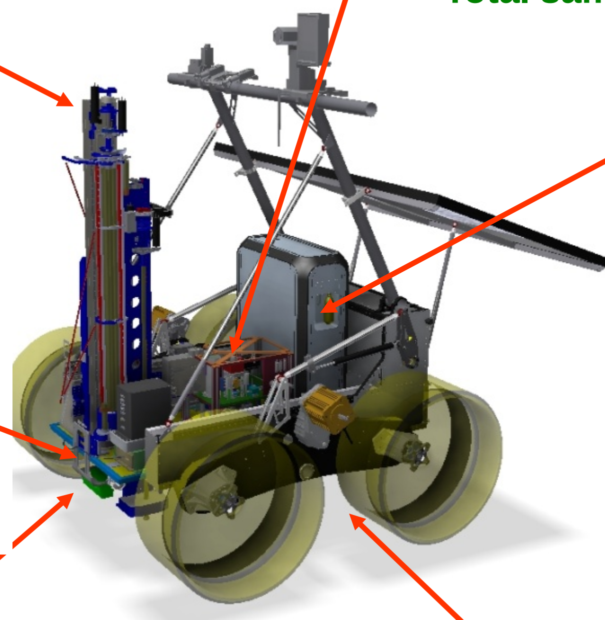
Payload – NASA

- **Surface and sub-surface characterization**
  - neutron spectrometer – sub-surface
  - near-infrared spectrometer, camera, radiometer – surface & sub-surface
- **Sample collection, delivery, analysis**
  - drill - collect and deliver sample(s)
  - oven - heats sample(s)
  - gas chromatograph / mass spectrometer - characterizes sample volatiles

RP– The Tools

Drill
- Subsurface sample acquisition
- Near-surface assay
- Detailed subsurface assay

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



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

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

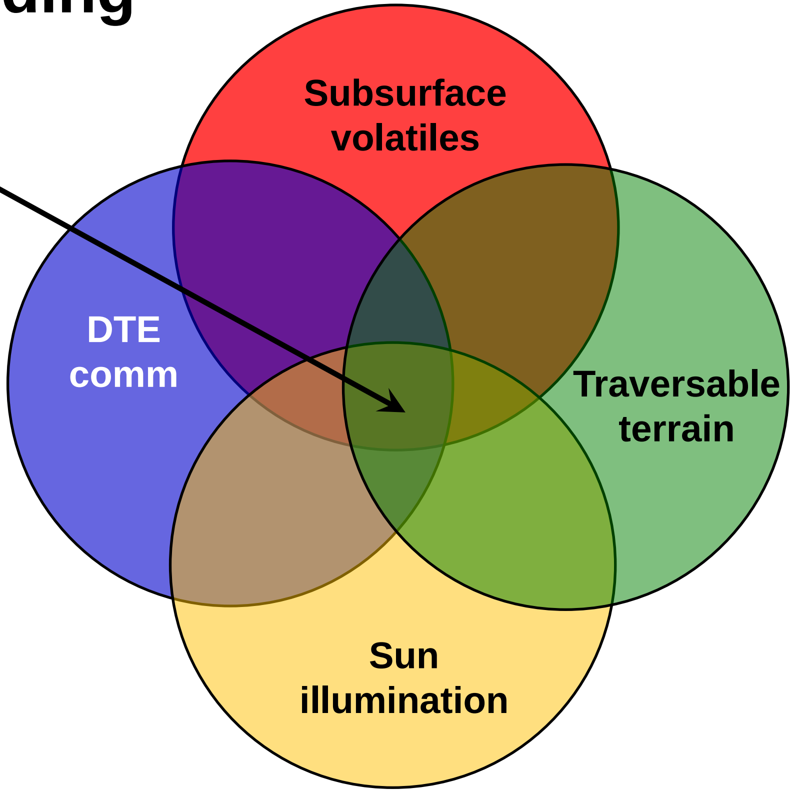
Neutron Spectrometer System
- Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth

Rover
- Mobility system
- Cameras
- Surface interaction

RPM Polar Landing

Must meet the following four criteria

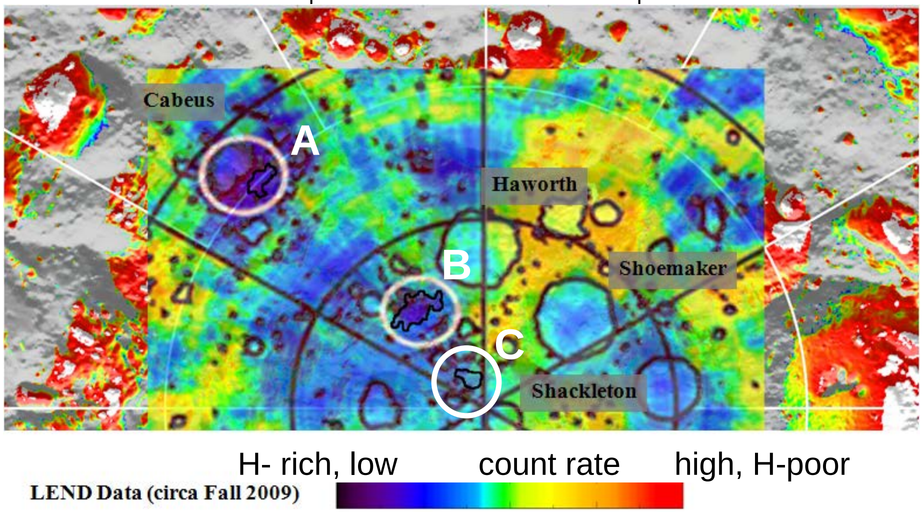
1. **Surface/Subsurface Volatiles**
   - High hydrogen content (LRO LEND & LPNS instruments)
   - Constant <100 K temperatures @ 10 cm below surface (LRO Diviner instrument)
   - Surface OH/H_2O (M^3, LRO LAMP & Diviner)
2. **Reasonable terrain for traverse**
   - Slopes < 10°
   - Limited density of rocks
3. **Direct Earth view for communication (DTE)**
4. **Sunlight for duration of mission for power**



8

A Potential S. Pole Landing Sites

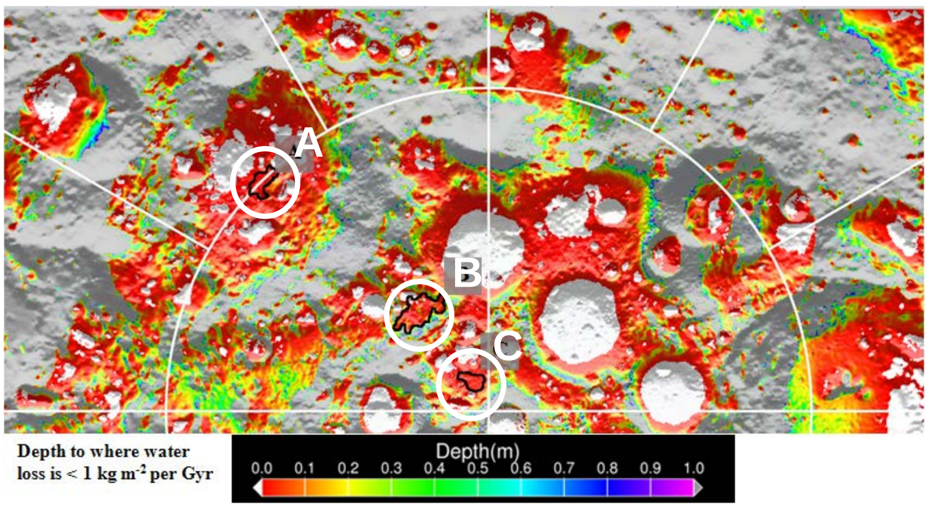
LEND Results



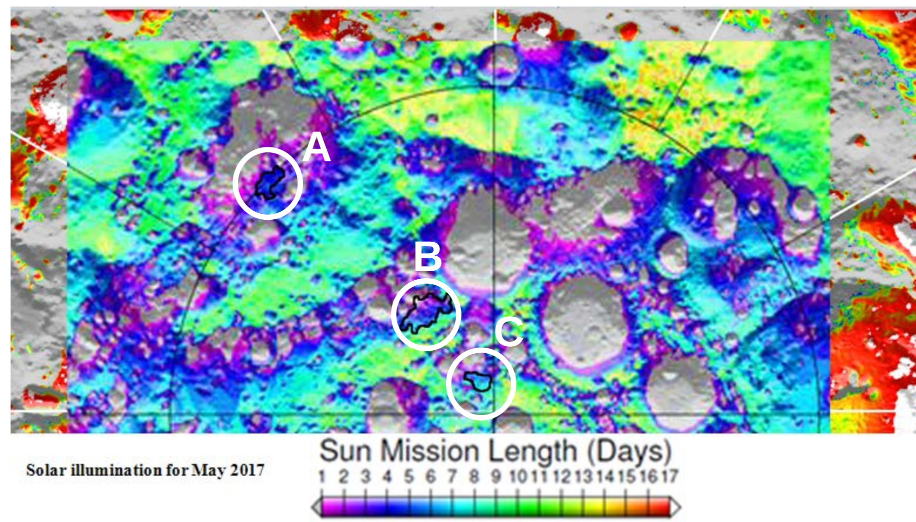
Site Analysis

Site:	A	B	C
Shallow "Frost Line"	<0.1 m	<0.2 m	<0.1 m
Slopes	<10°	<15°	<10°
Neutron Depletion	4.5 cps	4.7 cps	4.9 cps
Temporary Sun*	4 days	2-4 days	5-7 d
Comm Line of Sight*	8 days	17 days	17 days
* may not coincide			

Very short duration mission



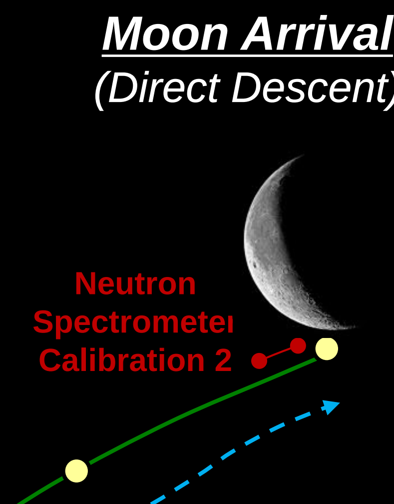
Predicted Volatile Stability



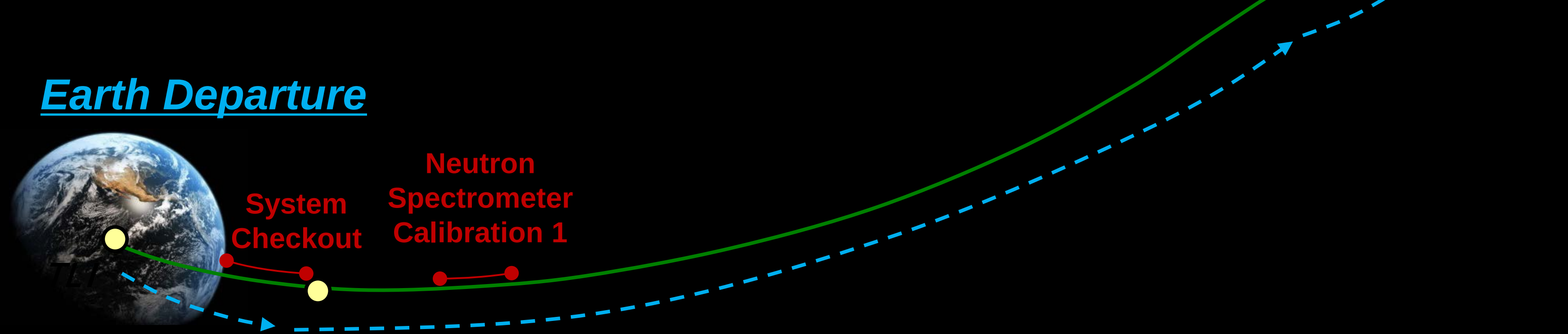
Solar Power Potential

Step #1: Get there…

- Cruise Phase (Depends on launch vehicle):
  - 5-day direct Earth to Moon transfer w/DSN S-band
  - Spin up to 1 rpm using Attitude Control System (post-TLI)
    - No de-spin during TCMs
  - Perform system checkout
  - Perform two TCMs (nom.)
  - Perform two Neutron Spec calibrations (nom.)

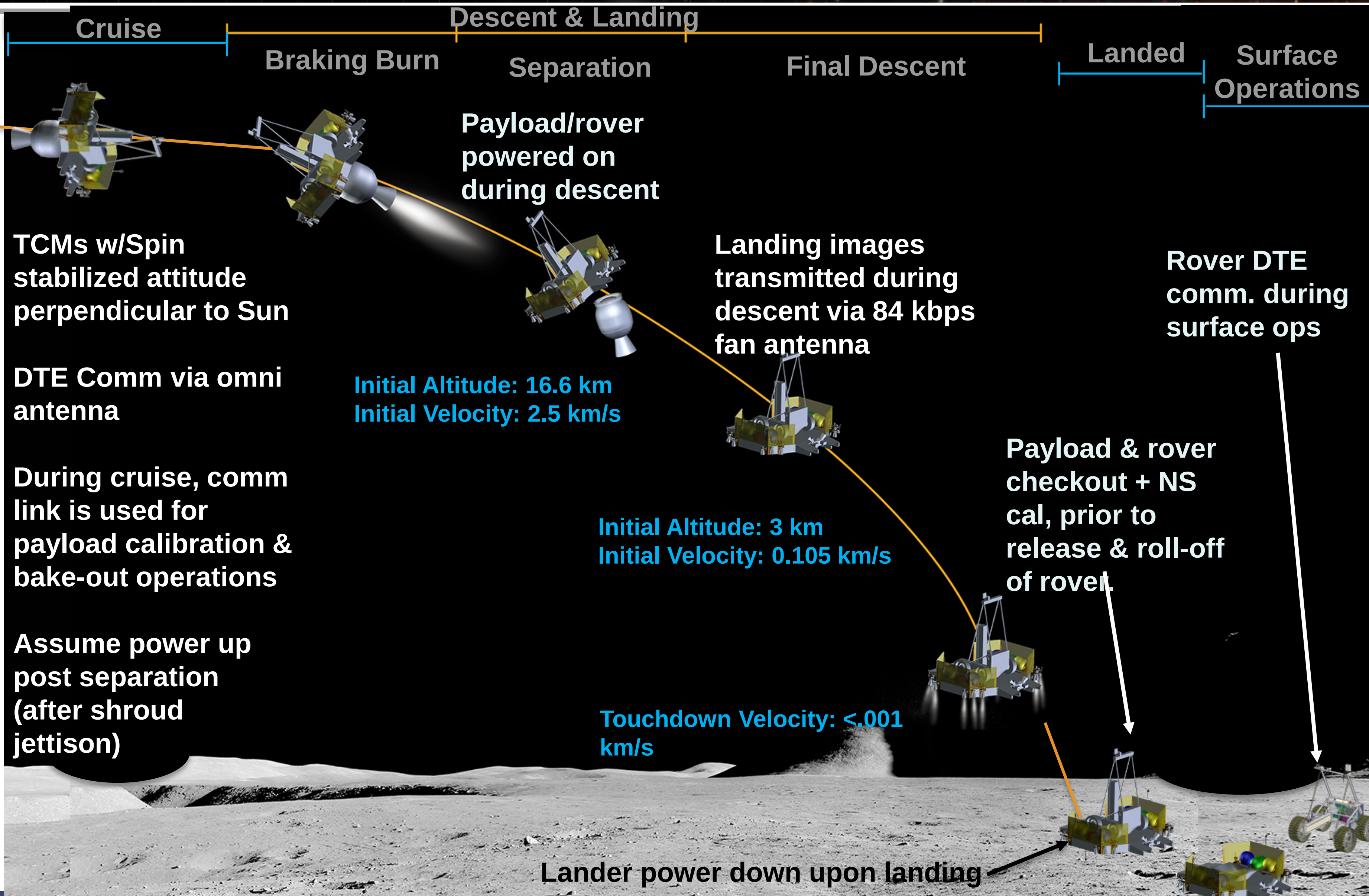


- Contingency / Off nominal
  - Allows for two (2) additional TCMs
  - Propellant margin for spin / de-spin for thermal anomalies

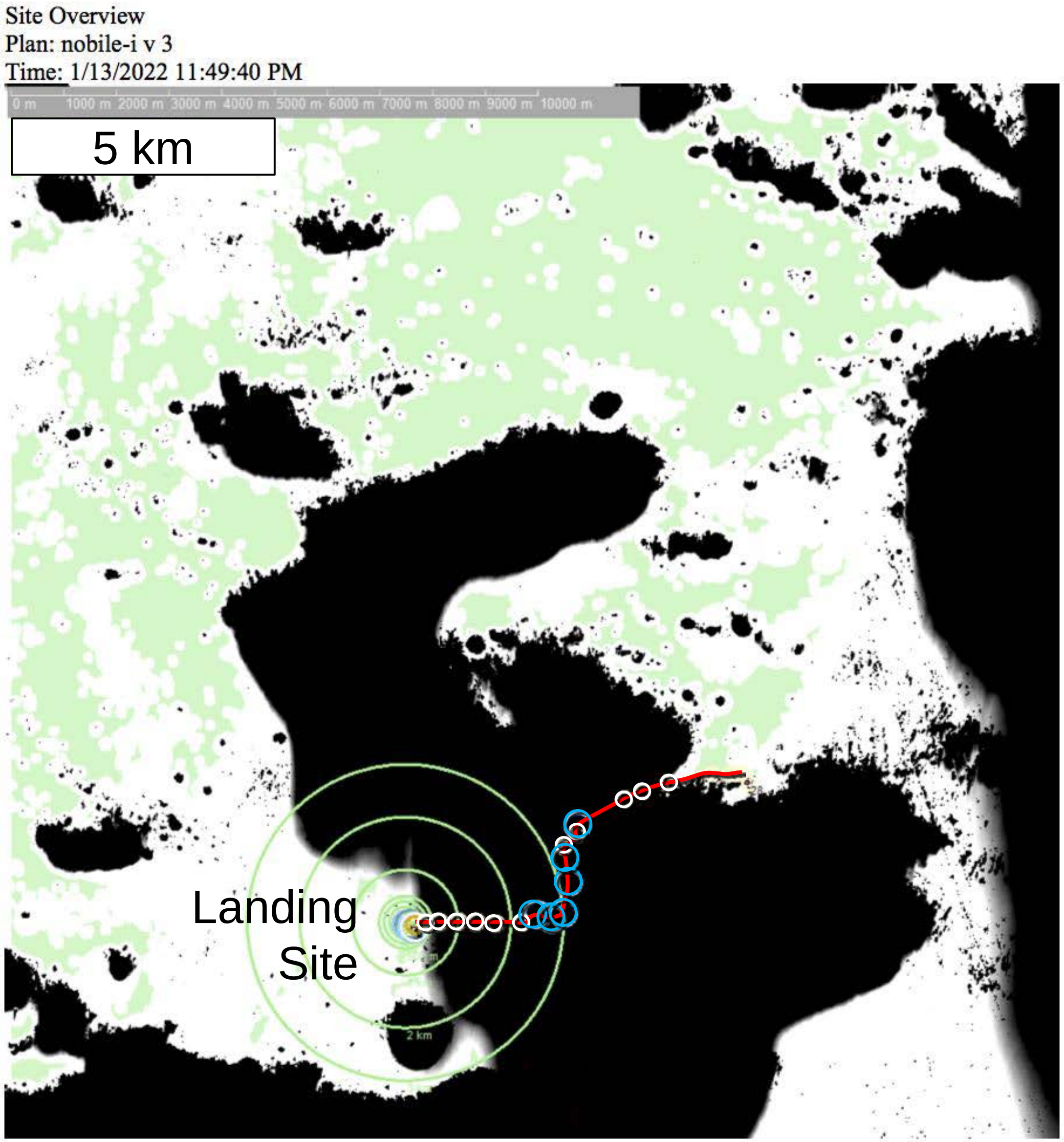


Step #2: Land there…

Details depend on launch vehicle)



Step #3: Prospect & Excavate there…



Landing site candidate areas (**green**):

- No slopes > 15° in 200 m diameter landing ellipse
- Must have sun & communication for 48 hrs
- Must have lit terrain on approach during powered descent

Traverse path:

No slopes > 15° (using 20-m LOLA gridded product)

Sun/comm corridors with margin

White circles near surface assay

blue circles deep, 1m, drilling

12

Science Goals

1. **Monitor** the surface during rover traverses and at excavation sites for water and other volatiles.
    - Identify surface bound H_2O/OH
    - constrain mineralogical/geological context
    - measure surface temperatures
2. **Observe** the immediate vicinity of the drill site before and during drill operations to look for real-time changes in the properties of the materials exposed during drilling.
    - Identify volatiles, including water form (e.g., ice vs. bound) at all depths drill exposes at surface
    - Constrain the volatile presence in top ~20-30 cm of regolith: provides constraints on NSS measurements of hydrogen abundance
    - Constrain surface/subsurface temperatures

13

NIRVSS

Spectrometer Box

- Two spectrometers to achieve wavelength range and resolution to identify key volatiles (solids)
- Shortwave (SW): 1590-2400 nm
- Longwave (LW): 2300-3400 nm

Bracket Assembly

Lamp - Enables spectral observations in illuminated and shadowed terrain

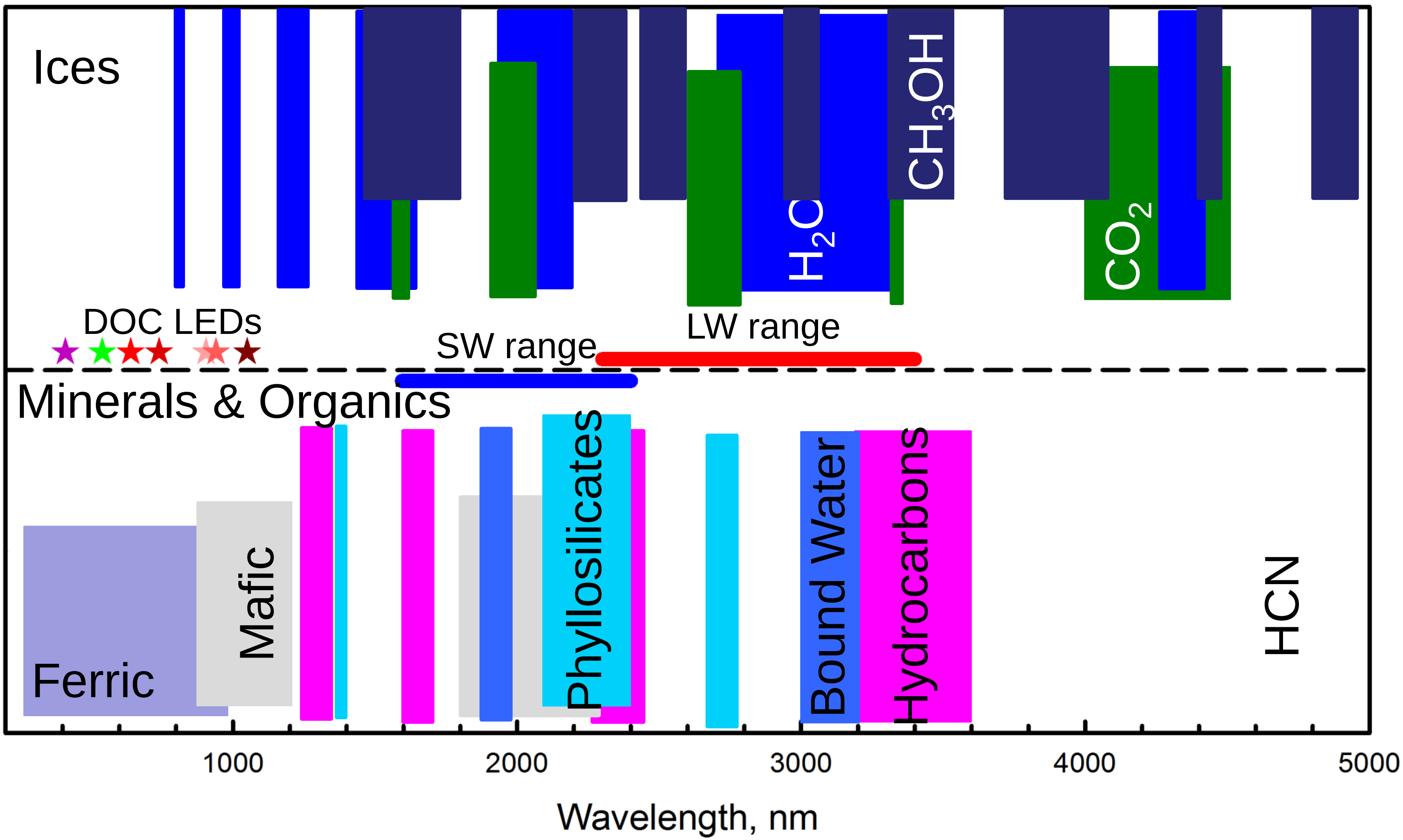
Drill Observation Camera (DOC) & LEDs

- Image drill area with sufficient FOV to observed ~20 cm of tailings
- Sufficient resolution to identify regolith structure at scales ~500 μm
- Using multiple-wavelength LEDs for surface mineral composition

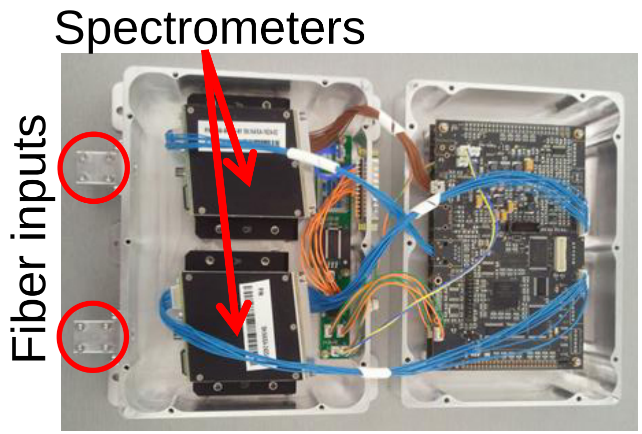
Longwave Calibration Sensors (LCS), 7.8, 10.6, 14, and 25 μm

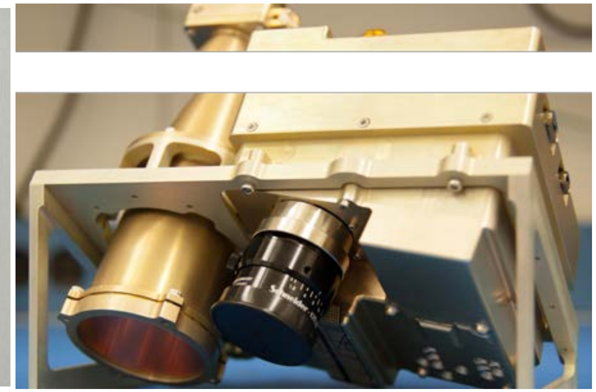
- Surface temperatures
- correct thermal emission contamination in 3 μm band ➔ required for determining concentrations of OH/H2O

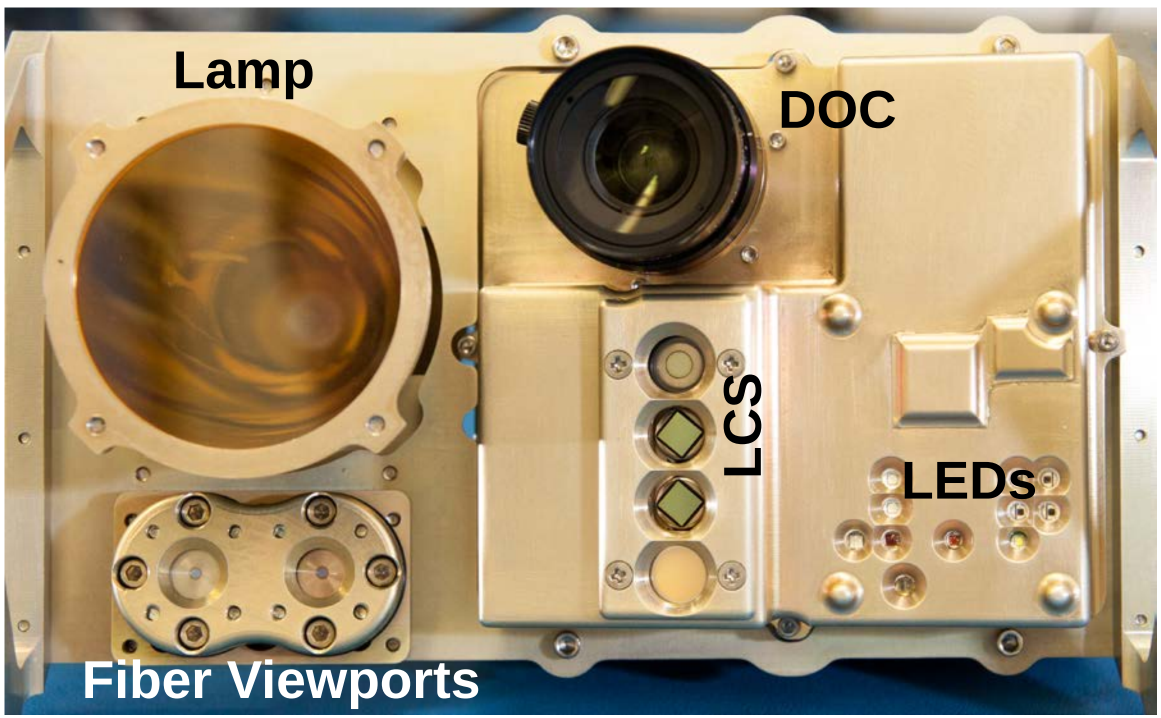
NIRVSS designed for minerals and ices



NIRVSS Components



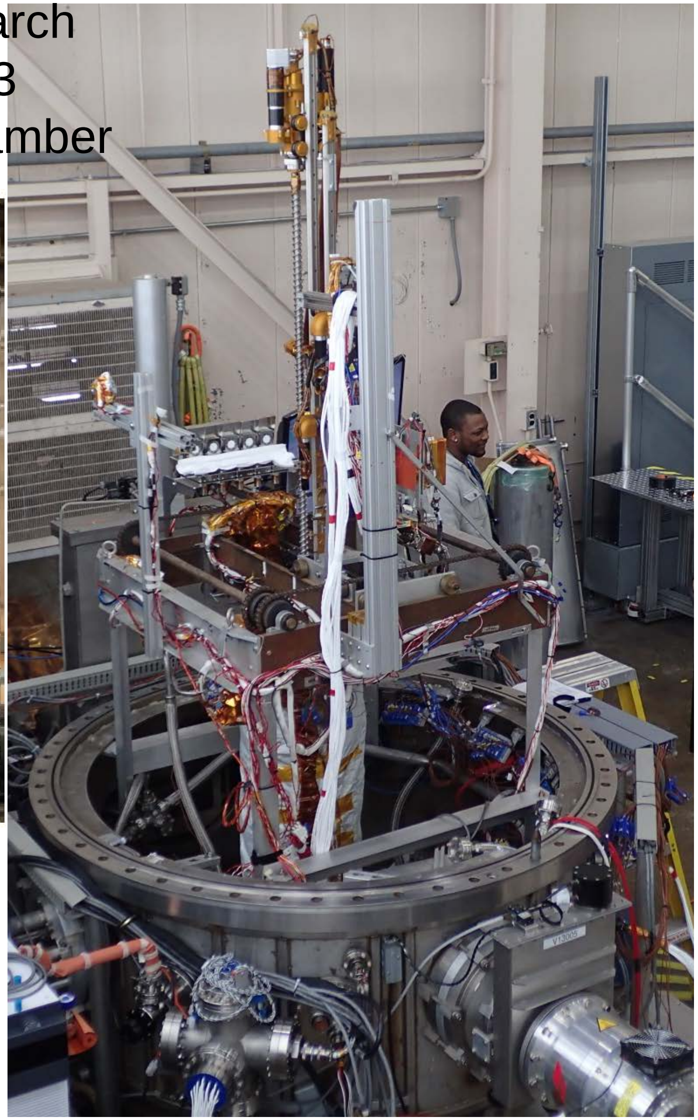


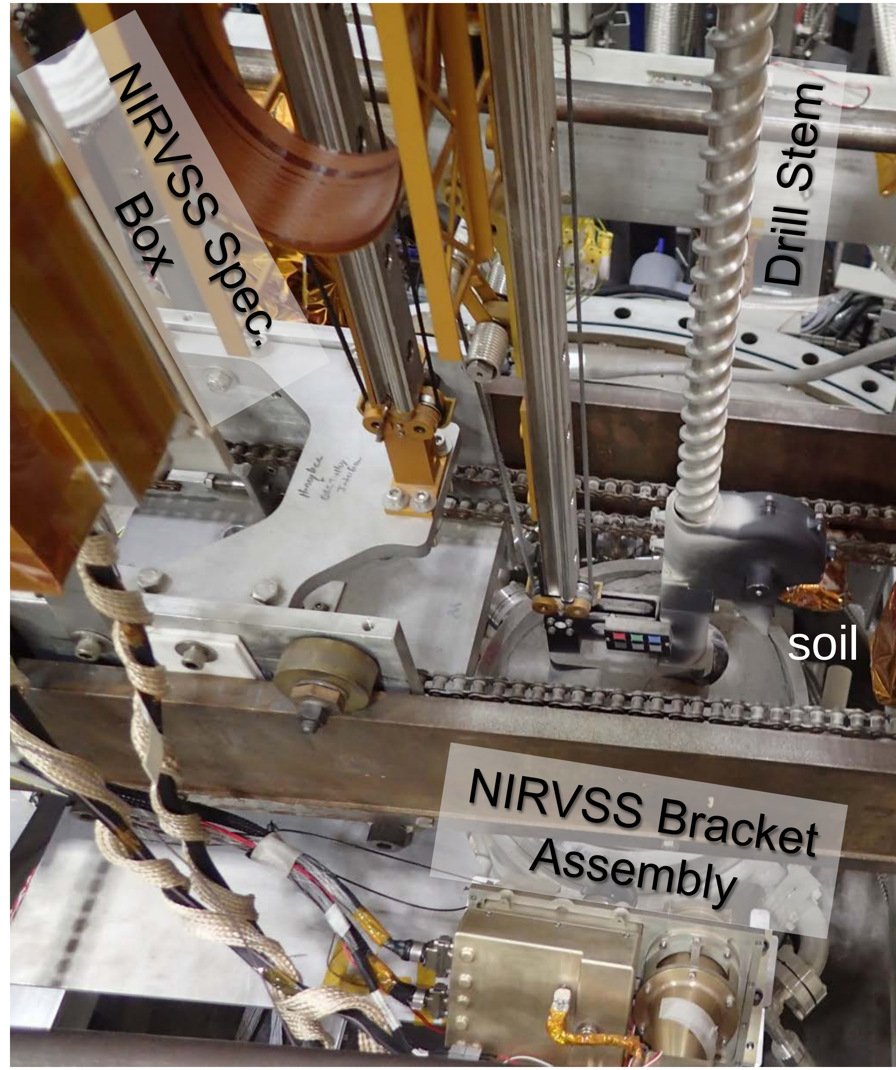


16

NIRVSS Testing

Glenn Research Center VF-13 Vacuum Chamber

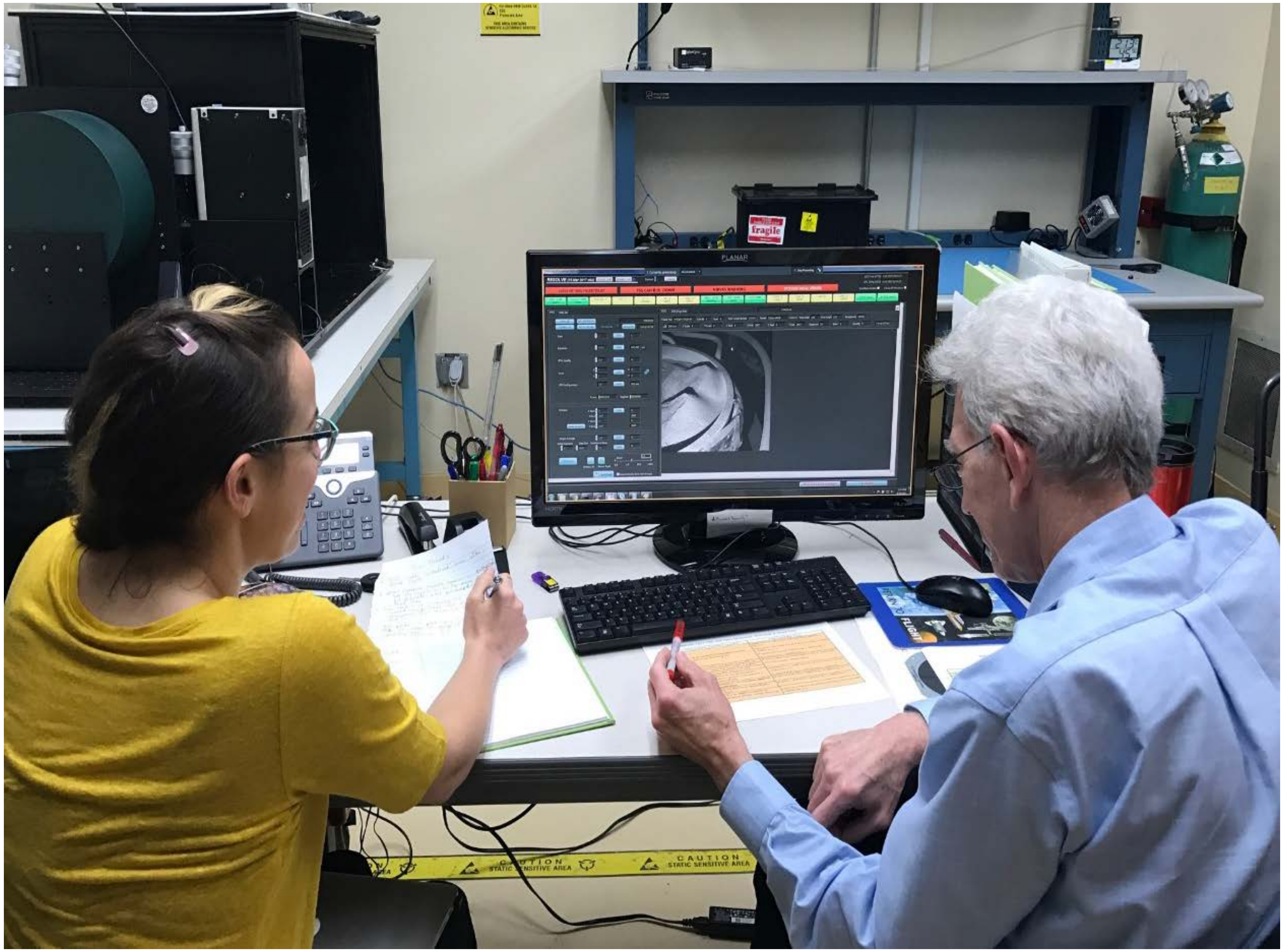




17

NIRVSS Testing

From Ames we command data collection by NIRVSS and monitor DOC imaging and spectral data

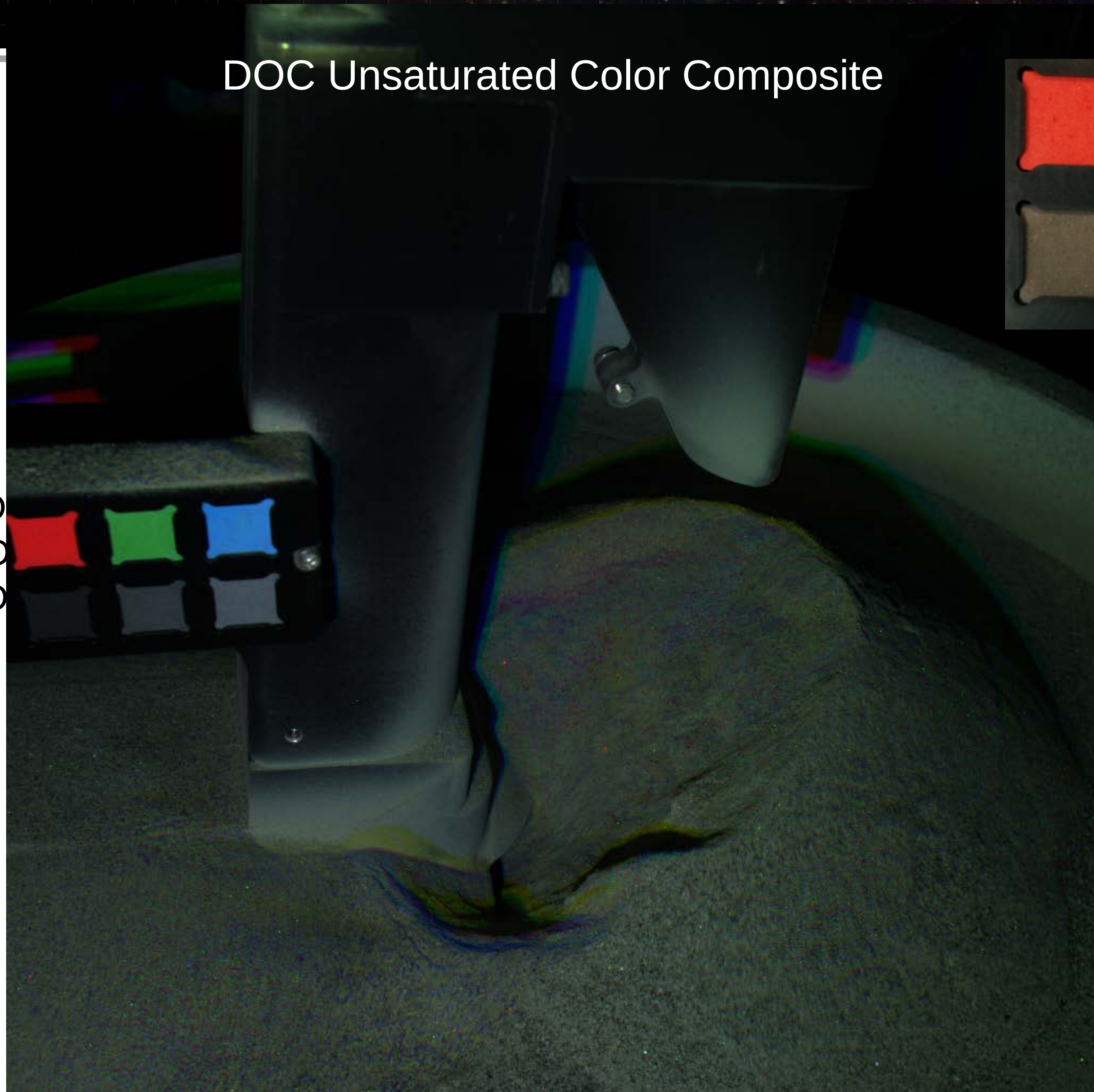


18

NIRVSS Testing

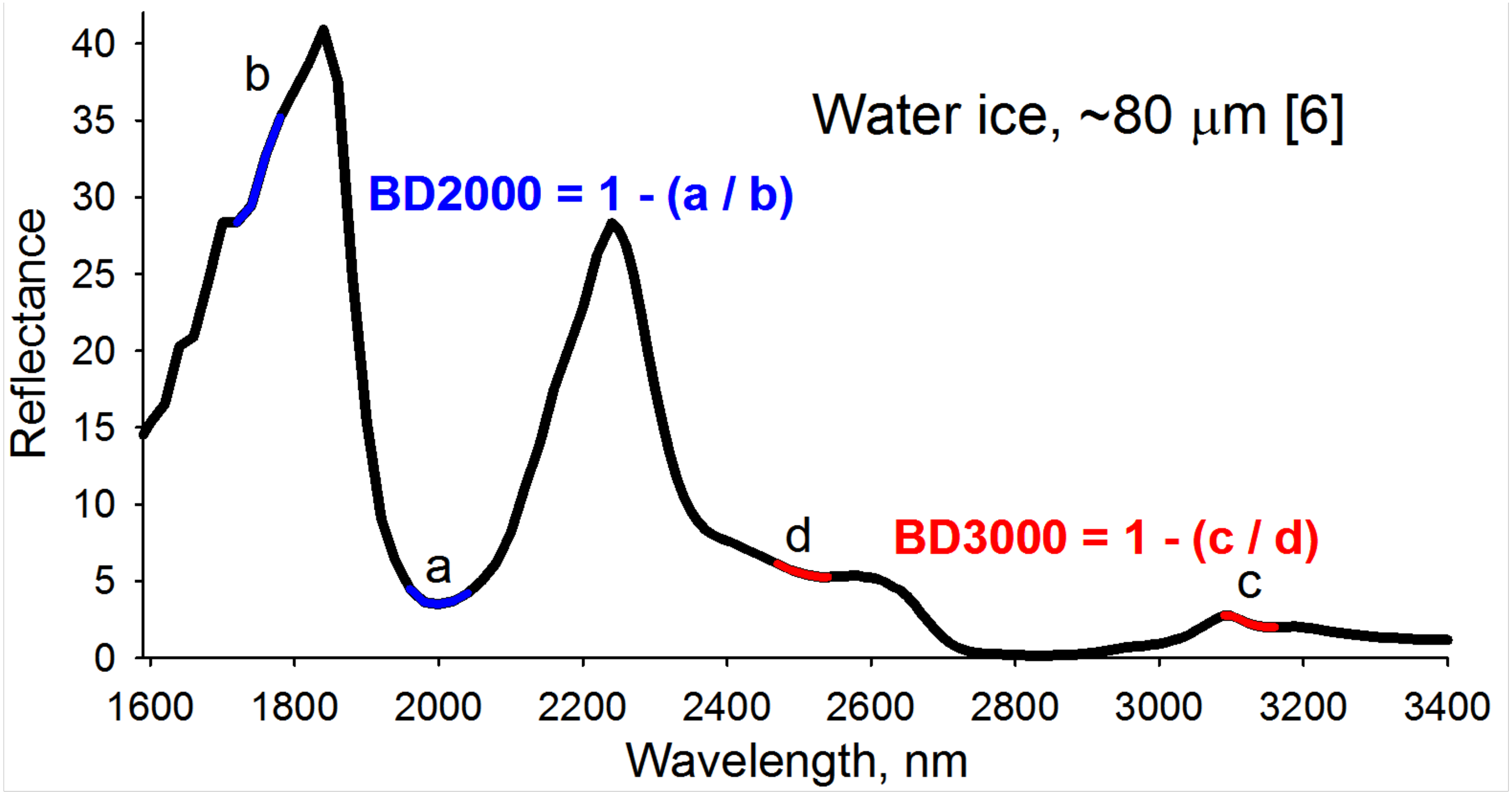
DOC Unsaturated Color Composite

scale = 1
B = 410 nm LED
G = 540 nm LED
R = 650 nm LED



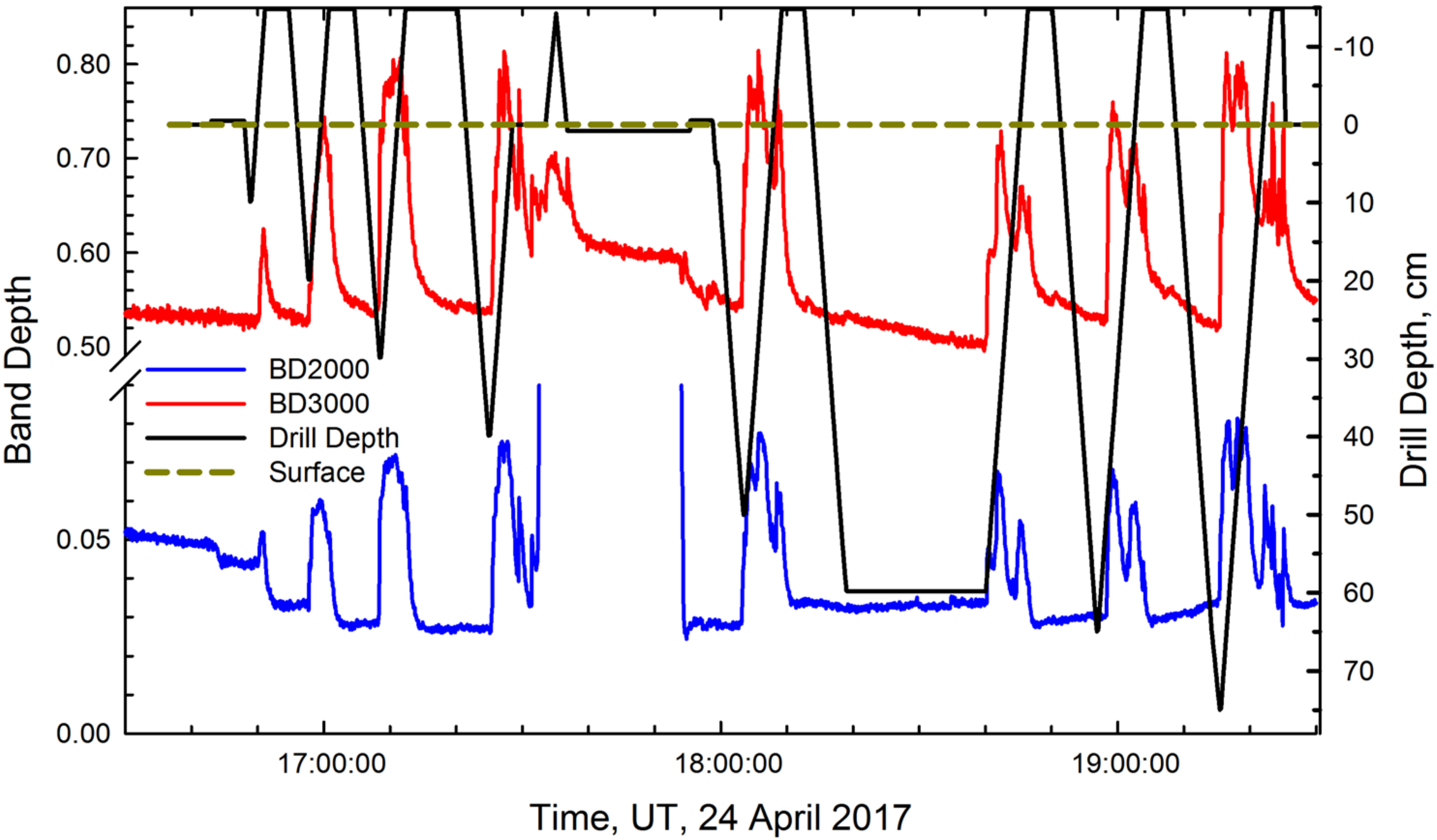
Phone camera Image during assembly, color not correct bottom row are gray scales 10, 20, 30 percent reflectance

Spectral parameters to monitor water ice during drilling



Monitor band parameters as drilling progresses

BD2000 and BD3000 ↑ as drilling proceeds



Show the movie

22