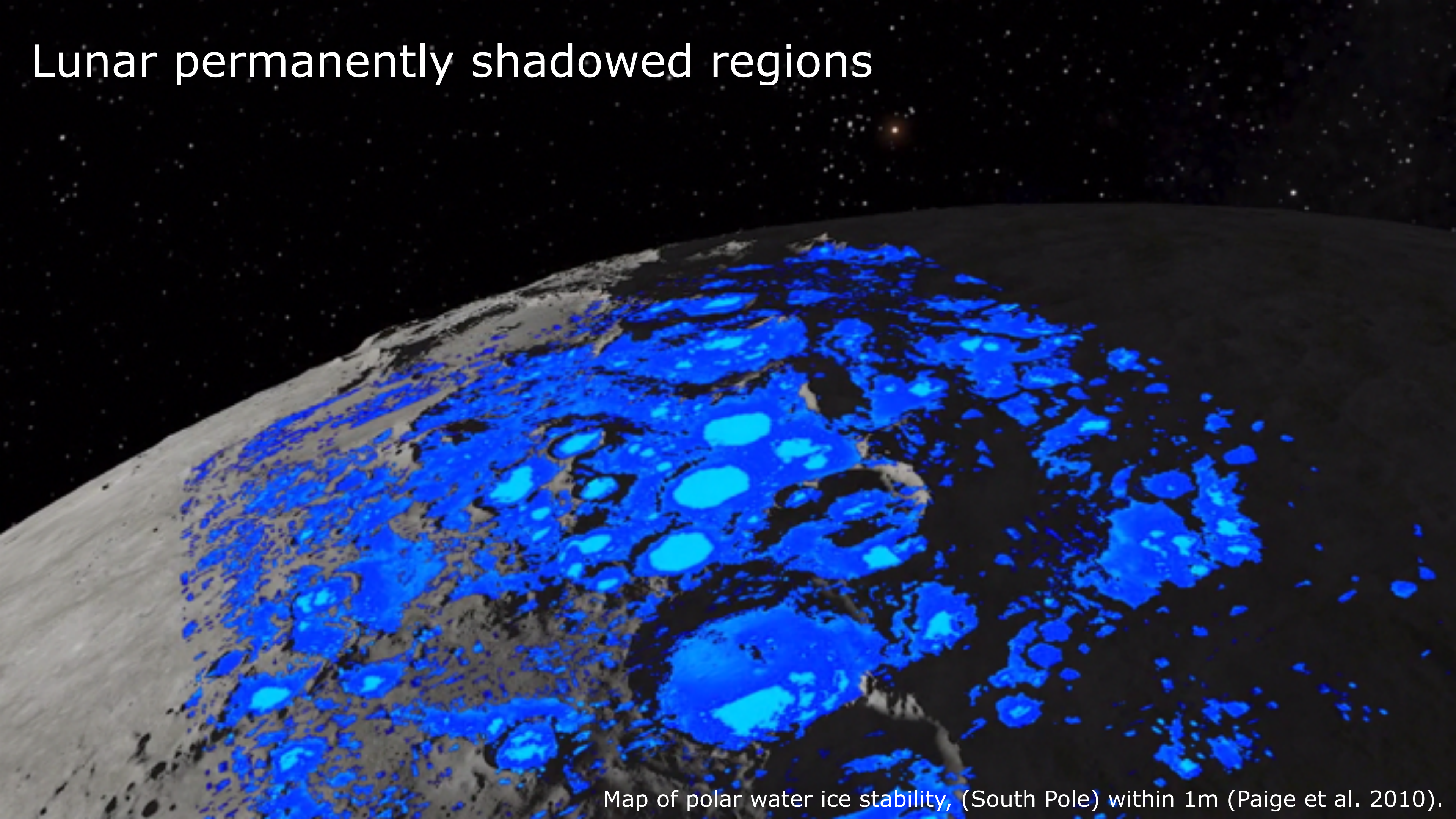
PROSPECT: ESA's **P**ackage for **R**esource **O**bservation and In-**S**itu **P**rospecting for **E**xploration, **C**ommercial Exploitation and **T**ransportation

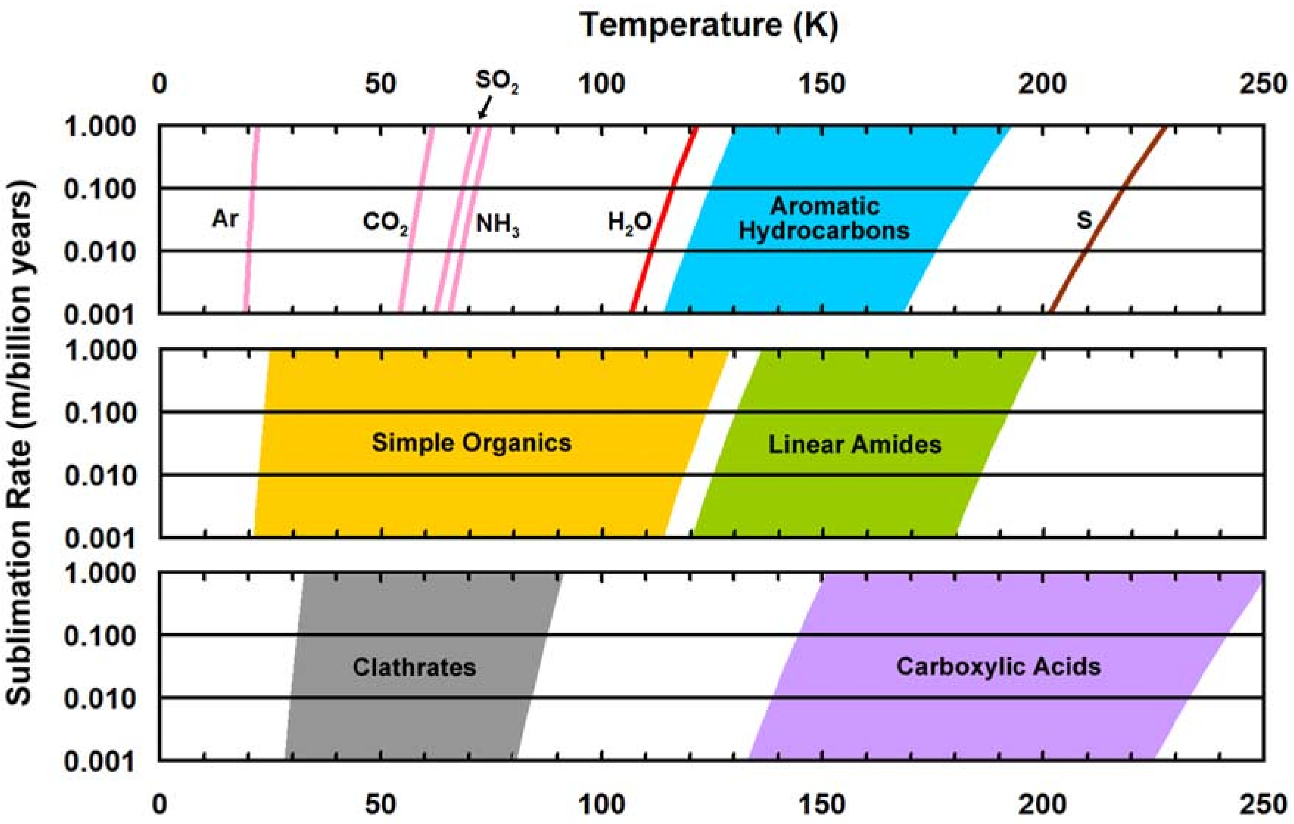
E. Sefton-Nash, J. Carpenter and the PROSPECT Team

Lunar permanently shadowed regions



Map of polar water ice stability, (South Pole) within 1m (Paige et al. 2010).

Volatile stability in permanently shadowed lunar polar regolith



Zhang and Paige (2009), *Geophysical Research Letters*

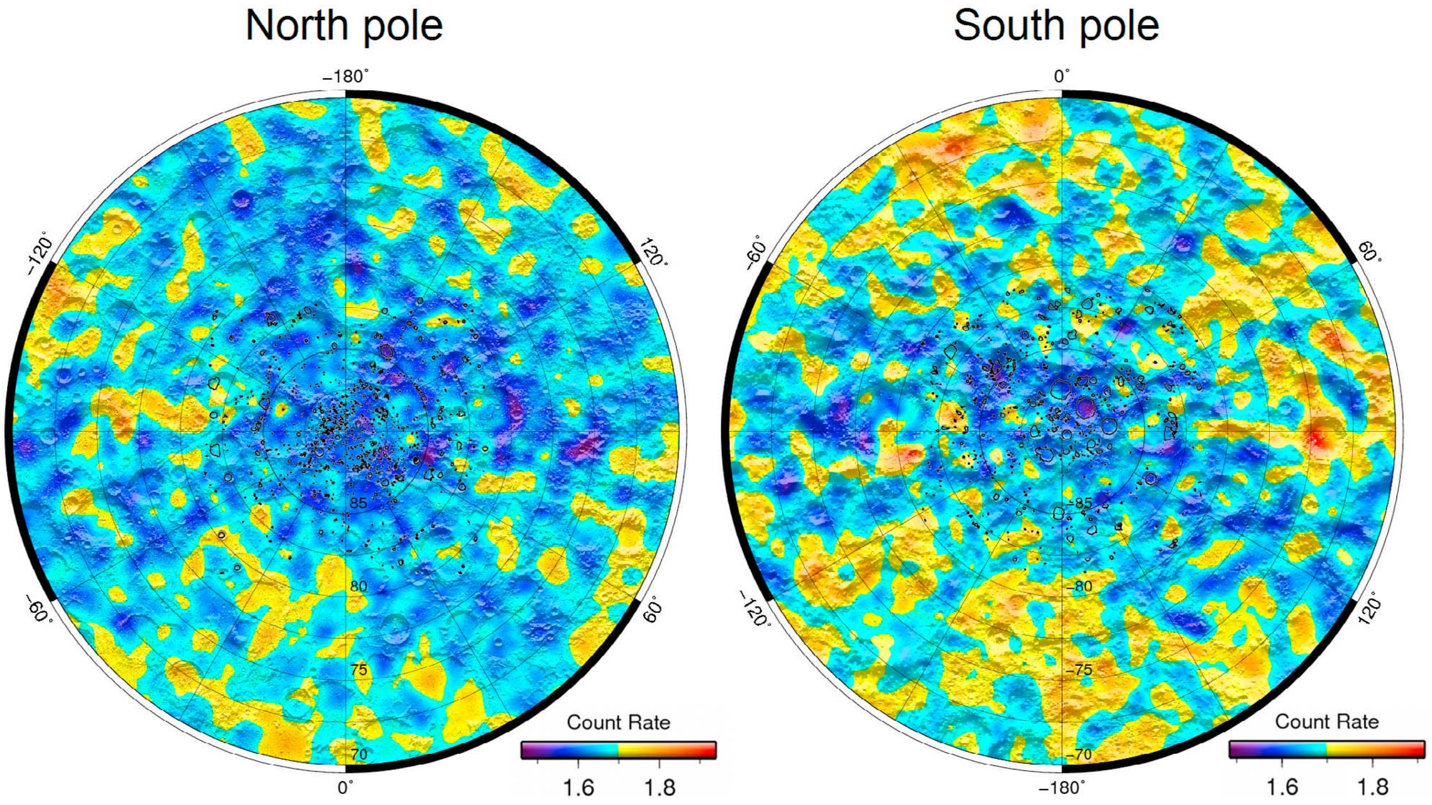
Volatiles buried in permanently shadowed polar regolith

- Volatiles in LCROSS plume ejected from Cabeus Crater impact (9th Oct. 2009)

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%

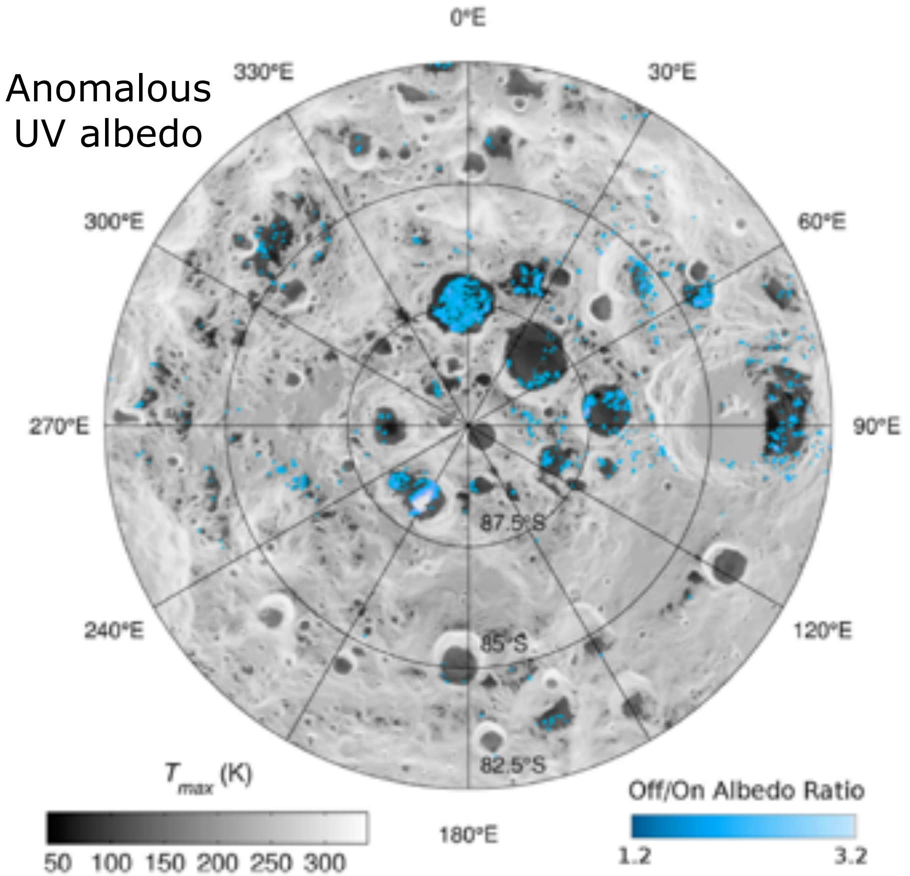
Colaprete et al. (2010), *Science*

Epithermal neutron suppression by buried H

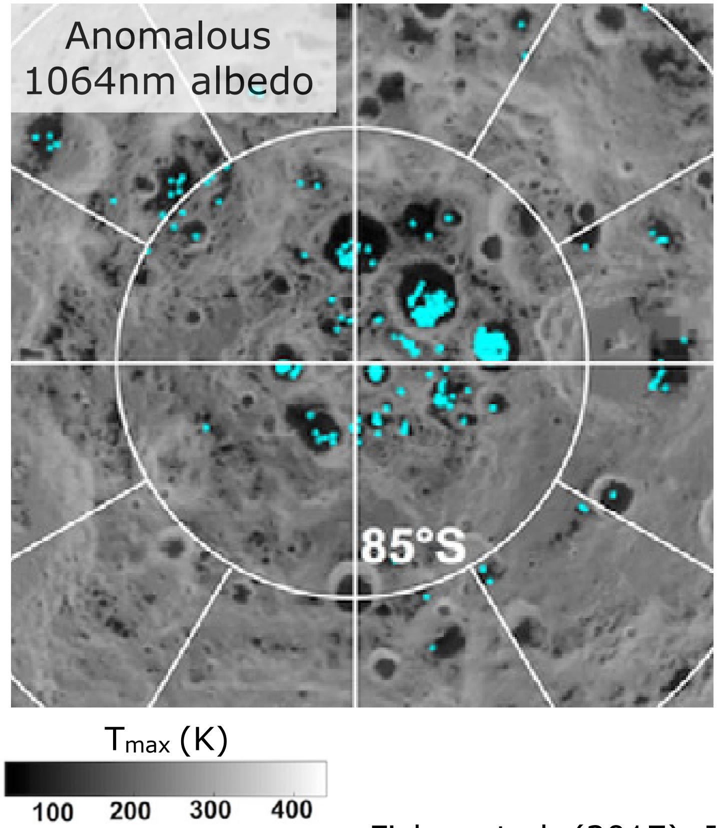


Mitrofanov et al. (2012), JGRP

Evidence for surface water frost in lunar south pole cold traps

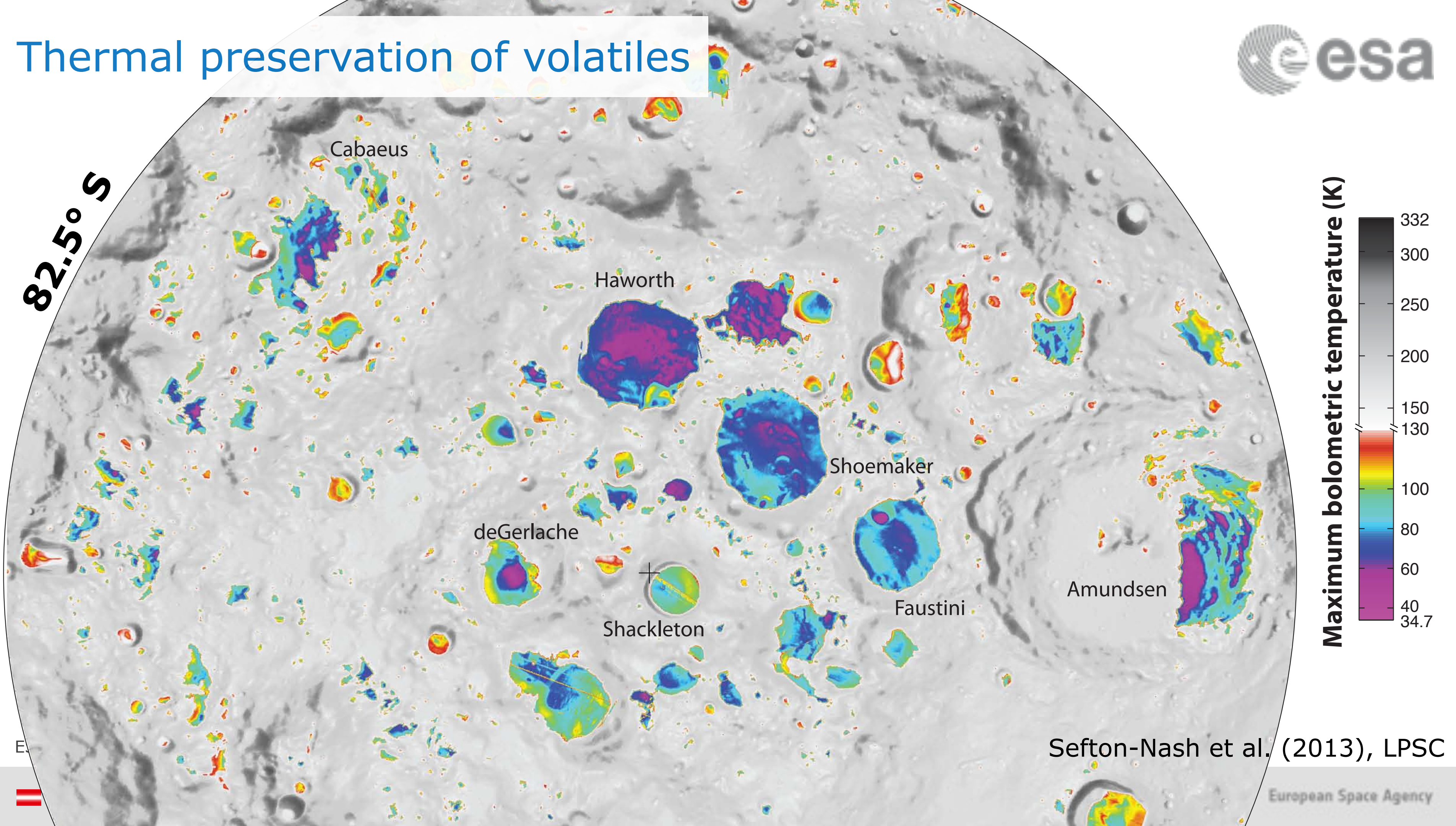


Hayne et al. (2015), Icarus

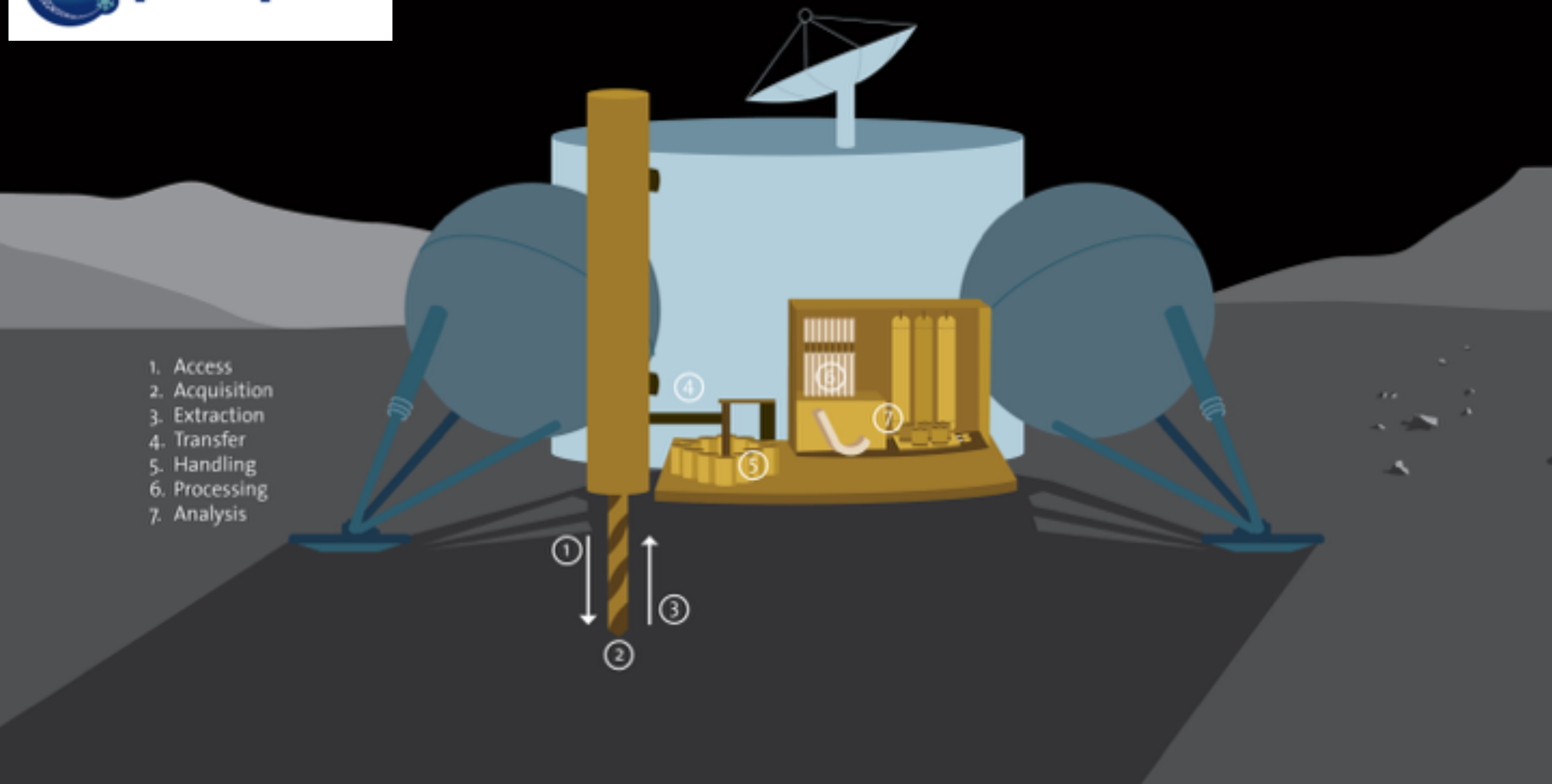


Fisher et al. (2017), Icarus

Thermal preservation of volatiles

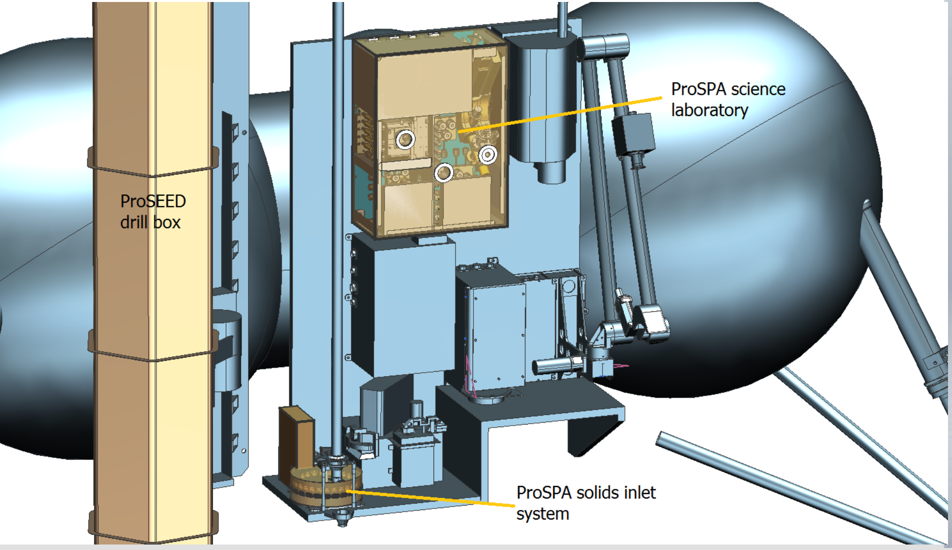


Sefton-Nash et al. (2013), LPSC

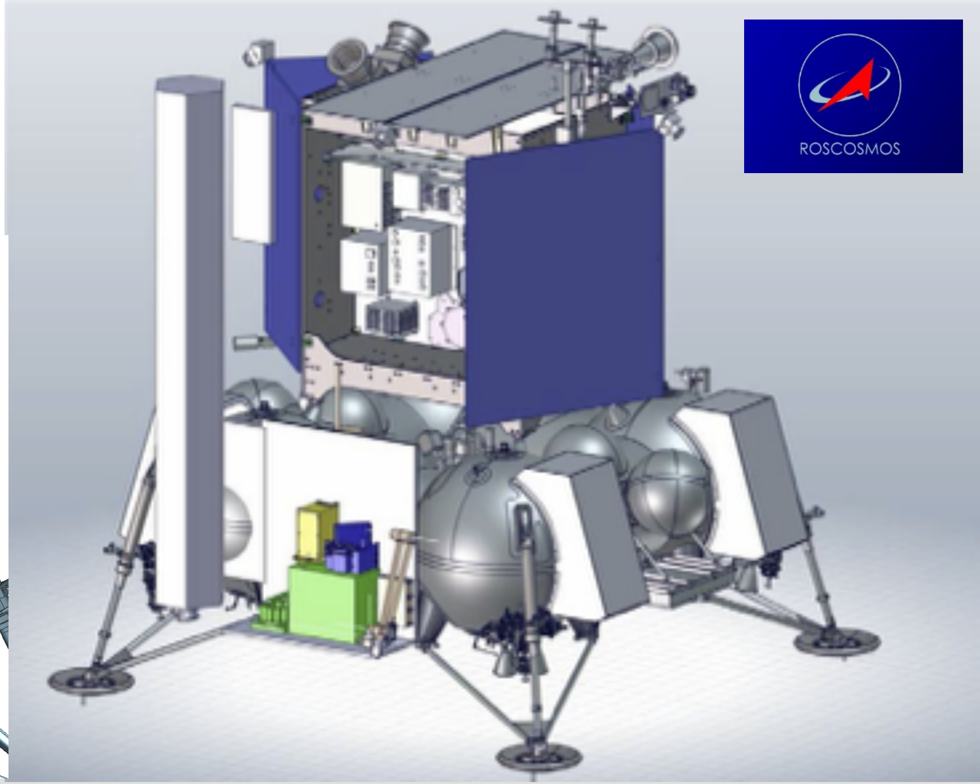

1. Access
2. Acquisition
3. Extraction
4. Transfer
5. Handling
6. Processing
7. Analysis

PROSPECT on Luna 27 (launch 2022)

PROSPECT =
ProSEED drill
+ ProSPA analysis package

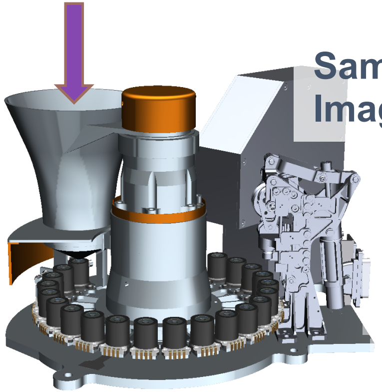


Luna 27



ProSPA: 3 science questions and analysis modes

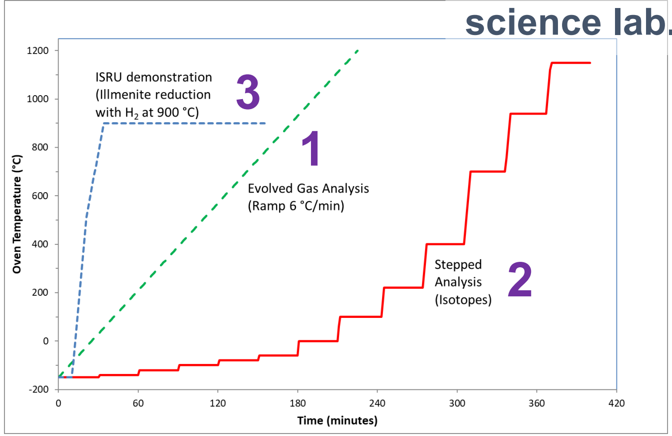
Sample from drill



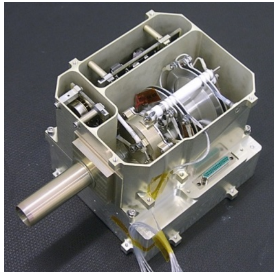
Sample Imaging

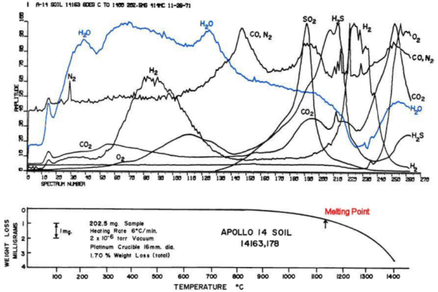
Sample Sealing/ Heating

Evolved gas to science lab.



1: Is water released and how much? What else?

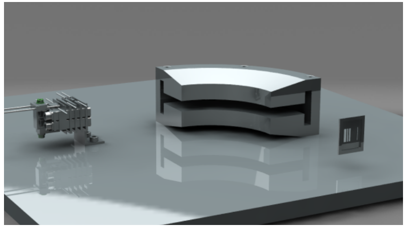


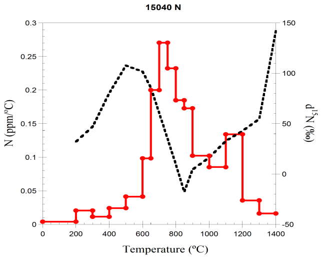


L: Rosetta Philae Ptolemy ion trap mass spectrometer 10 x 10 x 10 cm; for ProSPA: 2-200 amu; ~500 gram

R: Thermal release of volatiles from Apollo 14 soil. Gibson E.K., Jr. et al. (1972) Proc. Lunar Sci. Conf. 2029-2040

2: Where did it come from? Comets? Asteroids? etc





L: Magnetic sector CAD

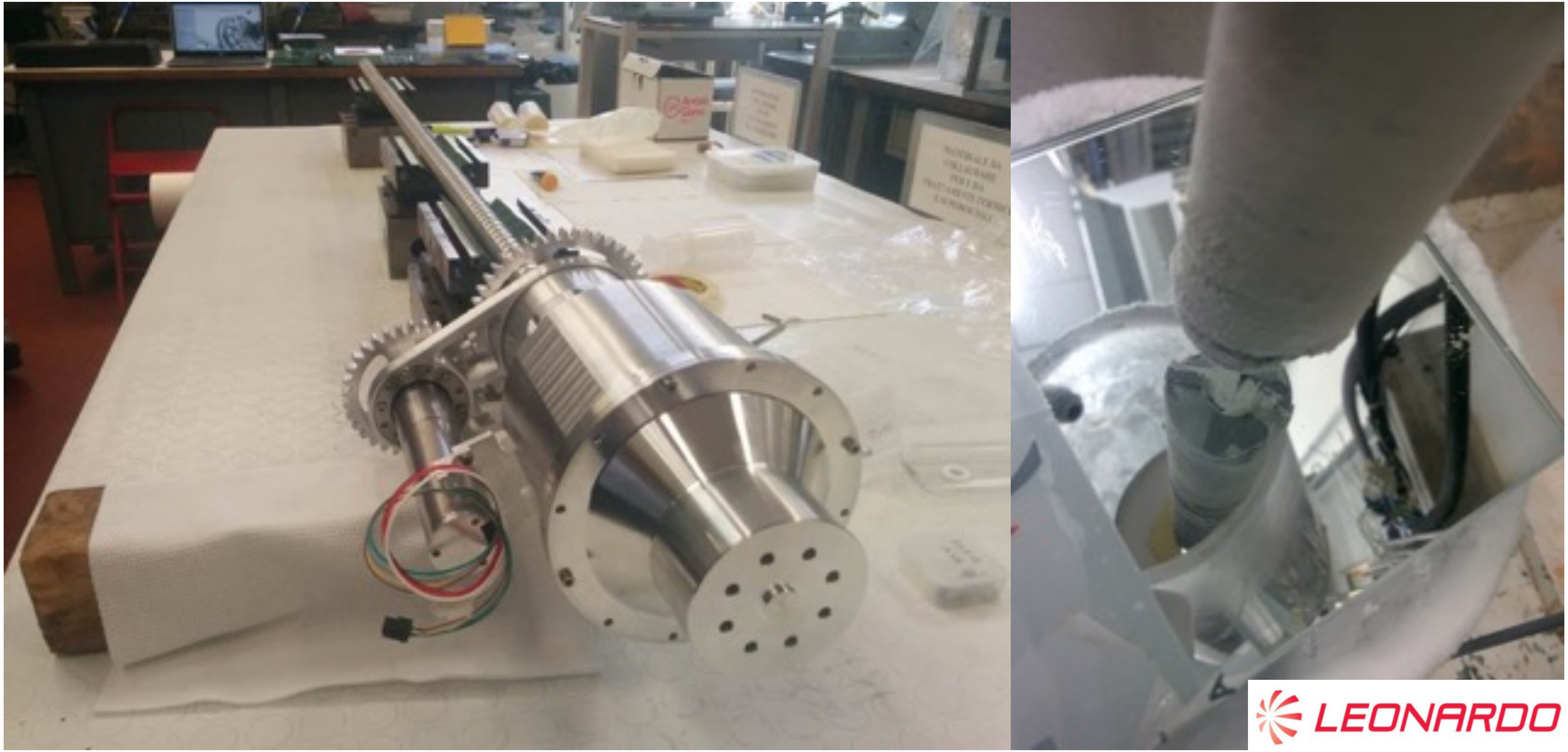
R: Preliminary ProSPA breadboard data (A Verchovsky, F Abernethy, J Mortimer)

3: Can we extract it to support exploration / ISRU?

$$FeTiO_3 + H_2 \rightarrow Fe + TiO_2 + H_2O$$

Courtesy of S. Barber (OU)

Drilling and Sampling



Drill testing

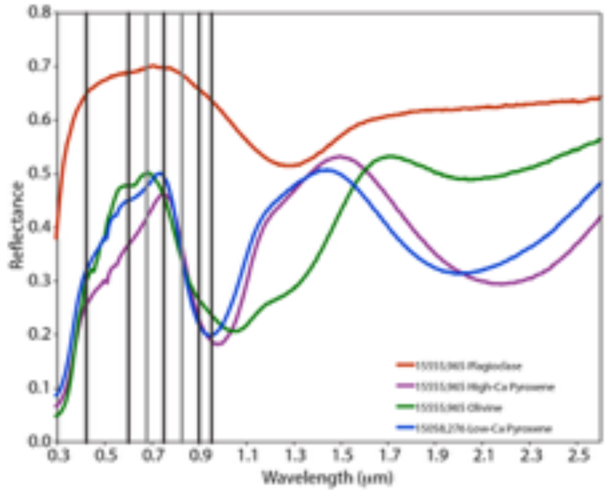
Two variants of lunar highland simulant NU-LHT-2M from USGS (right) and Zybek (Left) with very different mechanical properties (image Leonardo, Italy)

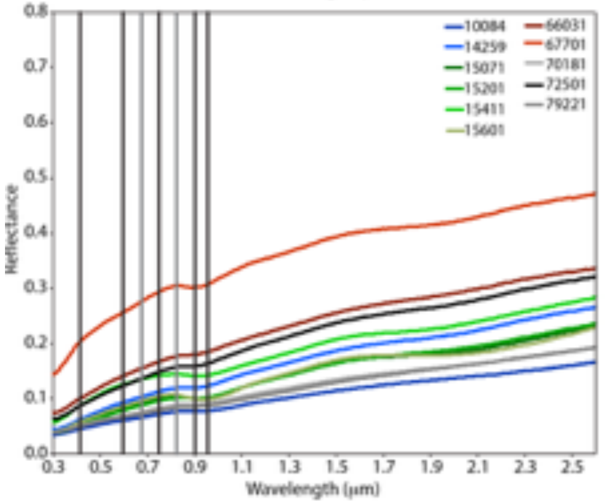
Significant differences in particle properties observed (K. Donaldson Hanna Oxford and D. Martyn & K. Joy (Manchester)

Currently assessing new ESA simulant EAC-1 as a mechanical simulant for testing

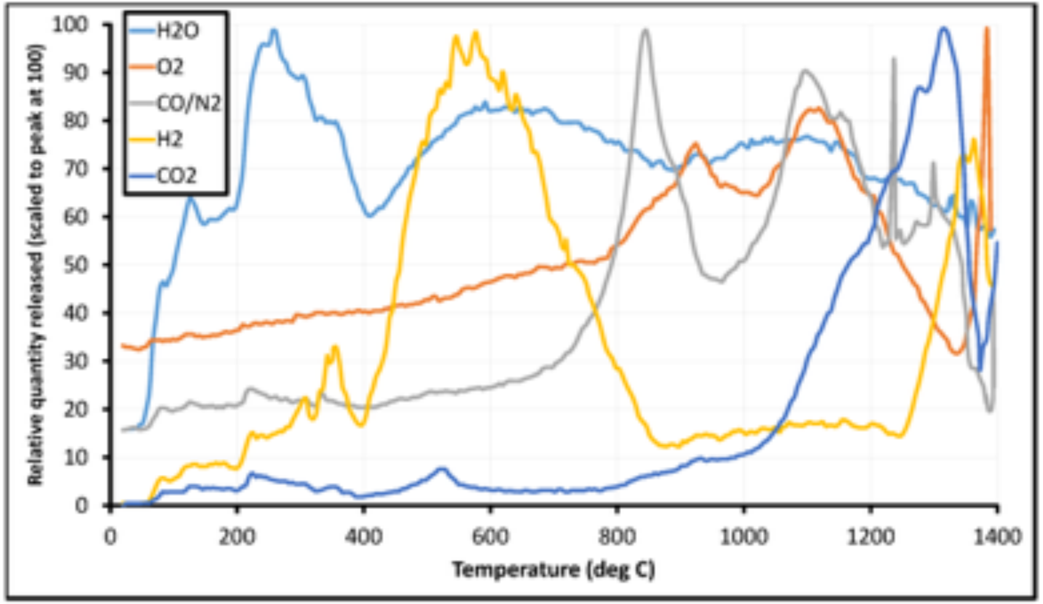
Imaging

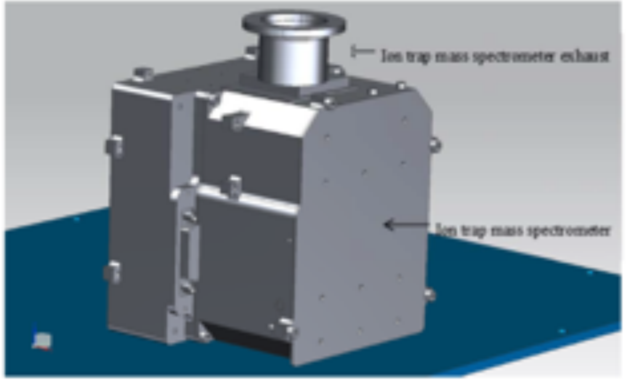
- Monitor drilling and transfer operations
- Estimate sample quantity in ovens
- LED emission spectra to maximise opportunistic science
- Selected band passes centered at 415, 675, 750, 825, 900, 950 nm
- (Upper) RELAB reflectance spectra of common lunar minerals and (lower) a suite of lunar soils of varying maturities (N. Schmitz and K. Donaldson-Hanna)





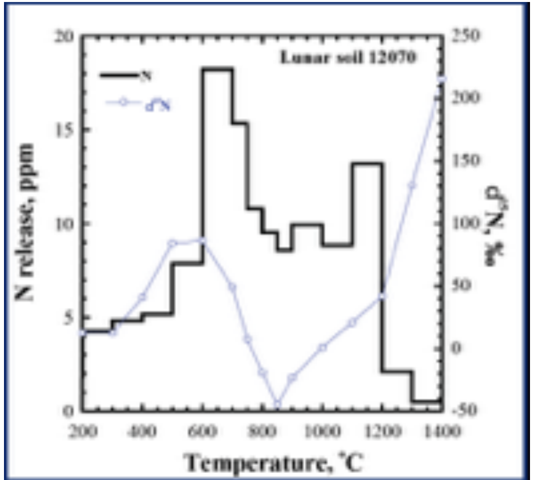
Extraction and chemical analysis





Soil 69961,33 data courtesy of E. Gibson
Digitised by Spaceship EAC – database of release curves available

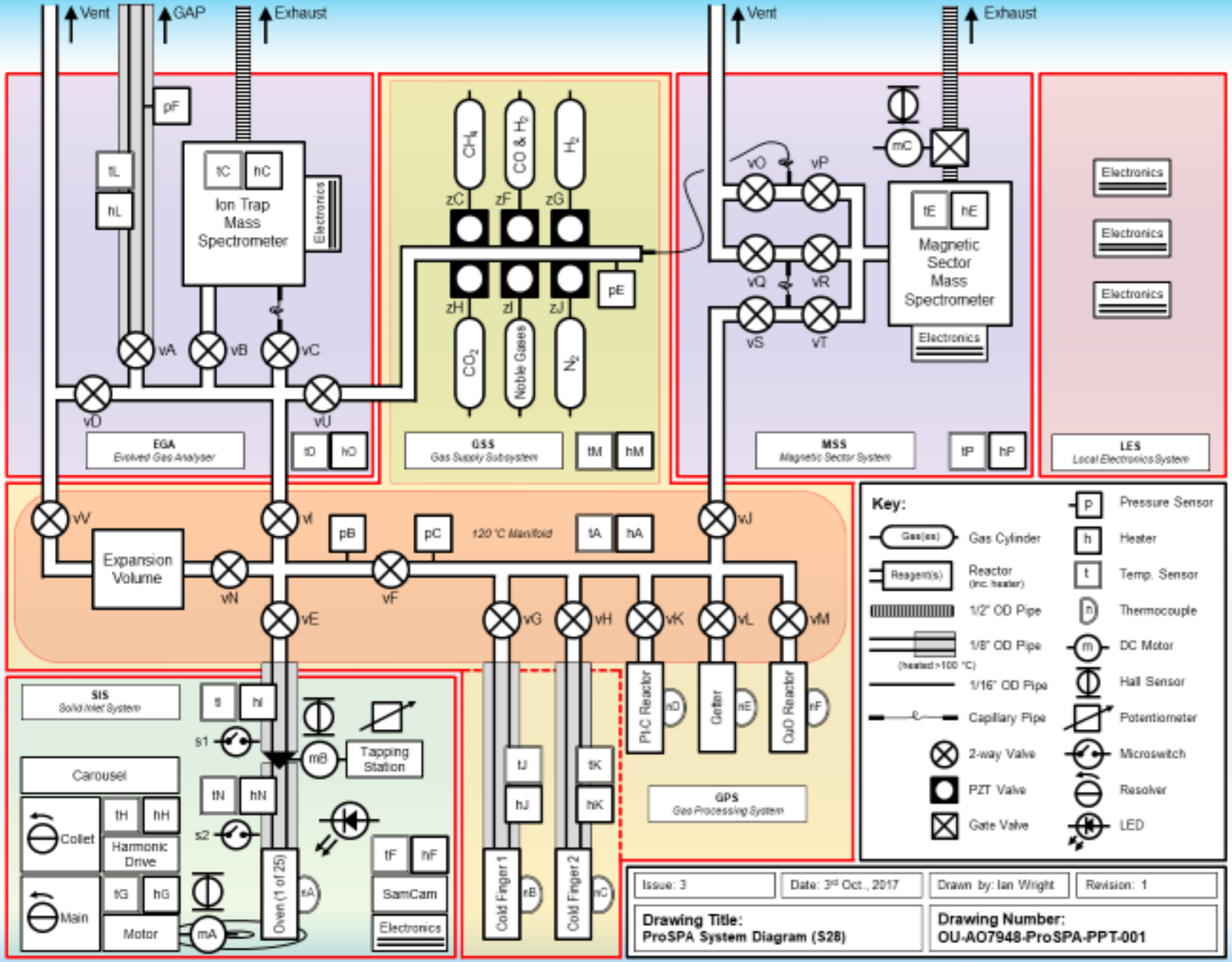
Isotopic Analysis

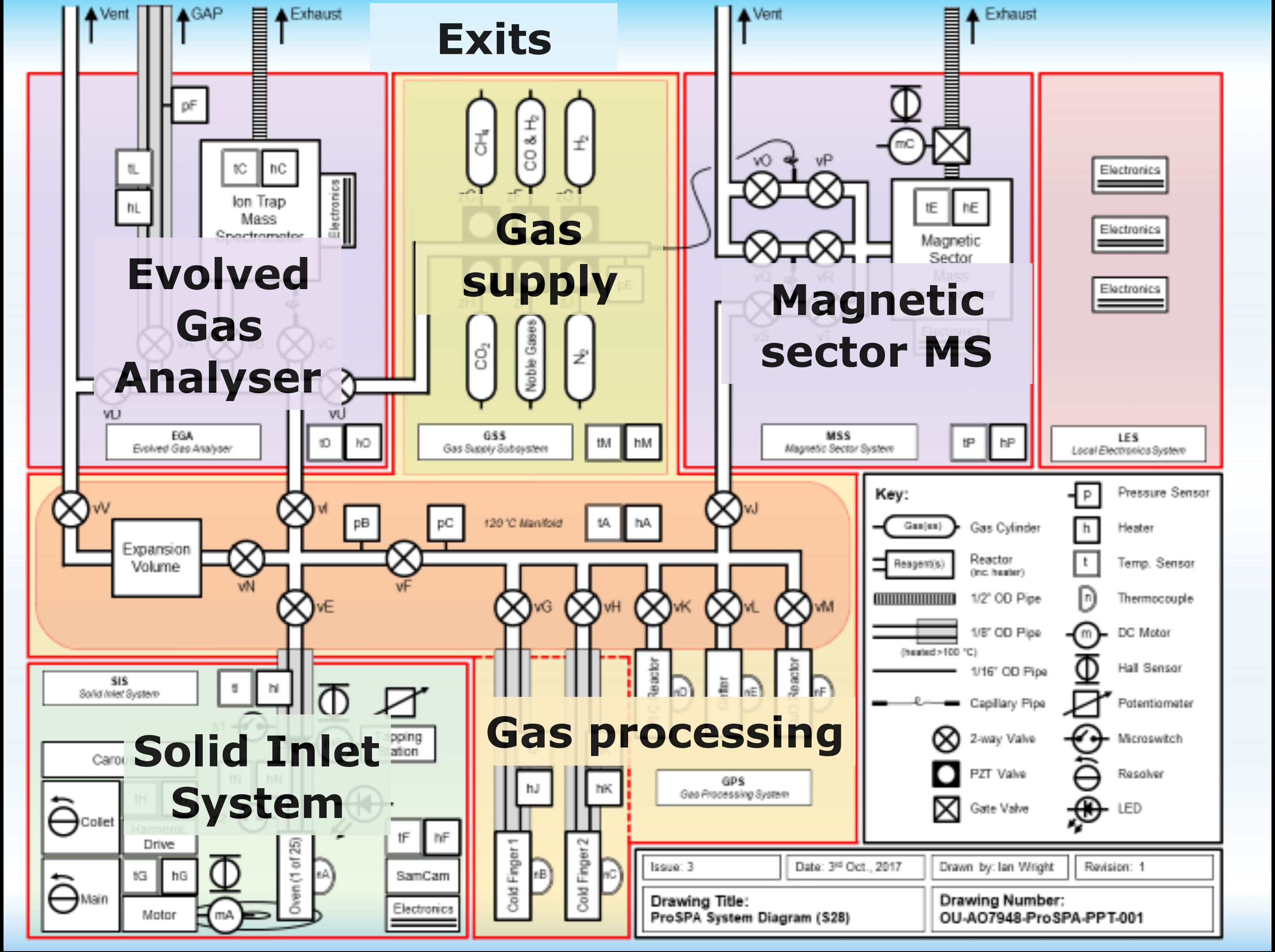


↑ Illustrative nitrogen isotopic analysis (from Mortimer, J.; Verchovsky, S. and Anand, M. (2016). Predominantly Non-Solar Origin of Nitrogen in Lunar Soils. Geochimica et Cosmochimica Acta, 193 pp. 36-53.)

Isotopic ratio	Associated molecular species	Expected precision
δD	H_2,H_2O, -OH, hydrocarbons	10‰
$δ^{13}C$	CO, CO_2, hydrocarbons	0.1 - 1‰
$δ^{15}N$	N_2, NH_3, nitrogen oxides	0.1 - 1‰
$δ^{18}O$	H_2O, CO and CO_2	0.1‰

↑ Expected isotopic measurement performance of the PROSPECT chemical laboratory


Vent
GAP
Exhaust
Vent
Exhaust
pF
tL
hL
tC
hC
Ion Trap Mass Spectrometer
Electronics
vA
vB
vC
vD
vU
EGA
Evolved Gas Analyser
tO
hO
CH4
CO & H2
H2
zC
zF
zG
zH
zI
zJ
CO2
Noble Gases
N2
pE
GSS
Gas Supply Subsystem
tM
hM
vO
vP
vQ
vR
vS
vT
mC
tE
hE
Magnetic Sector Mass Spectrometer
Electronics
MSS
Magnetic Sector System
tP
hP
Electronics
Electronics
Electronics
LES
Local Electronics System
vV
vI
vJ
pB
pC
120 °C Manifold
tA
hA
Expansion Volume
vN
vF
vE
vG
vH
vK
vL
vM
SIS
Solid Inlet System
tI
hI
s1
mB
Tapping Station
Carousel
tN
hN
s2
tH
hH
Collet
Harmonic Drive
tG
hG
Main
Motor
mA
Oven (1 of 25)
tA
tF
hF
SamCam
Electronics
Cold Finger 1
tJ
hJ
tB
Cold Finger 2
tK
hK
tC
PtC Reactor
tD
Getter
tE
CuO Reactor
tF
GPS
Gas Processing System
Key:
Gas Cylinder
Reactor (inc. heater)
1/2" OD Pipe
1/8" OD Pipe
(heated >100 °C)
1/16" OD Pipe
Capillary Pipe
2-way Valve
PZT Valve
Gate Valve
Pressure Sensor
Heater
Temp. Sensor
Thermocouple
DC Motor
Hall Sensor
Potentiometer
Microswitch
Resolver
LED
Issue: 3
Date: 3rd Oct., 2017
Drawn by: Ian Wright
Revision: 1
Drawing Title:
ProSPA System Diagram (S28)
Drawing Number:
OU-AO7948-ProSPA-PPT-001



Exits
Evolved Gas Analyser
Gas supply
Magnetic sector MS
Solid Inlet System
Gas processing
Vent
GAP
Exhaust
Vent
Exhaust
Ion Trap Mass Spectrometer
Electronics
Magnetic Sector
EGA
Evolved Gas Analyser
GSS
Gas Supply Subsystem
MSS
Magnetic Sector System
LES
Local Electronics System
Electronics
Electronics
Electronics
Expansion Volume
120 °C Manifold
SIS
Solid Inlet System
Collet
Main
Drive
Motor
SamCam
Electronics
Cold Finger 1
Cold Finger 2
GPS
Gas Processing System
Key:
Gas Cylinder
Reactor (inc. heater)
1/2" OD Pipe
1/8" OD Pipe
(heated >100 °C)
1/16" OD Pipe
Capillary Pipe
2-way Valve
PZT Valve
Gate Valve
Pressure Sensor
Heater
Temp. Sensor
Thermocouple
DC Motor
Hall Sensor
Potentiometer
Microswitch
Resolver
LED
Issue: 3
Date: 3rd Oct., 2017
Drawn by: Ian Wright
Revision: 1
Drawing Title:
ProSPA System Diagram (S28)
Drawing Number:
OU-AO7948-ProSPA-PPT-001

ISRU Roadmap, increasing lunar habitability

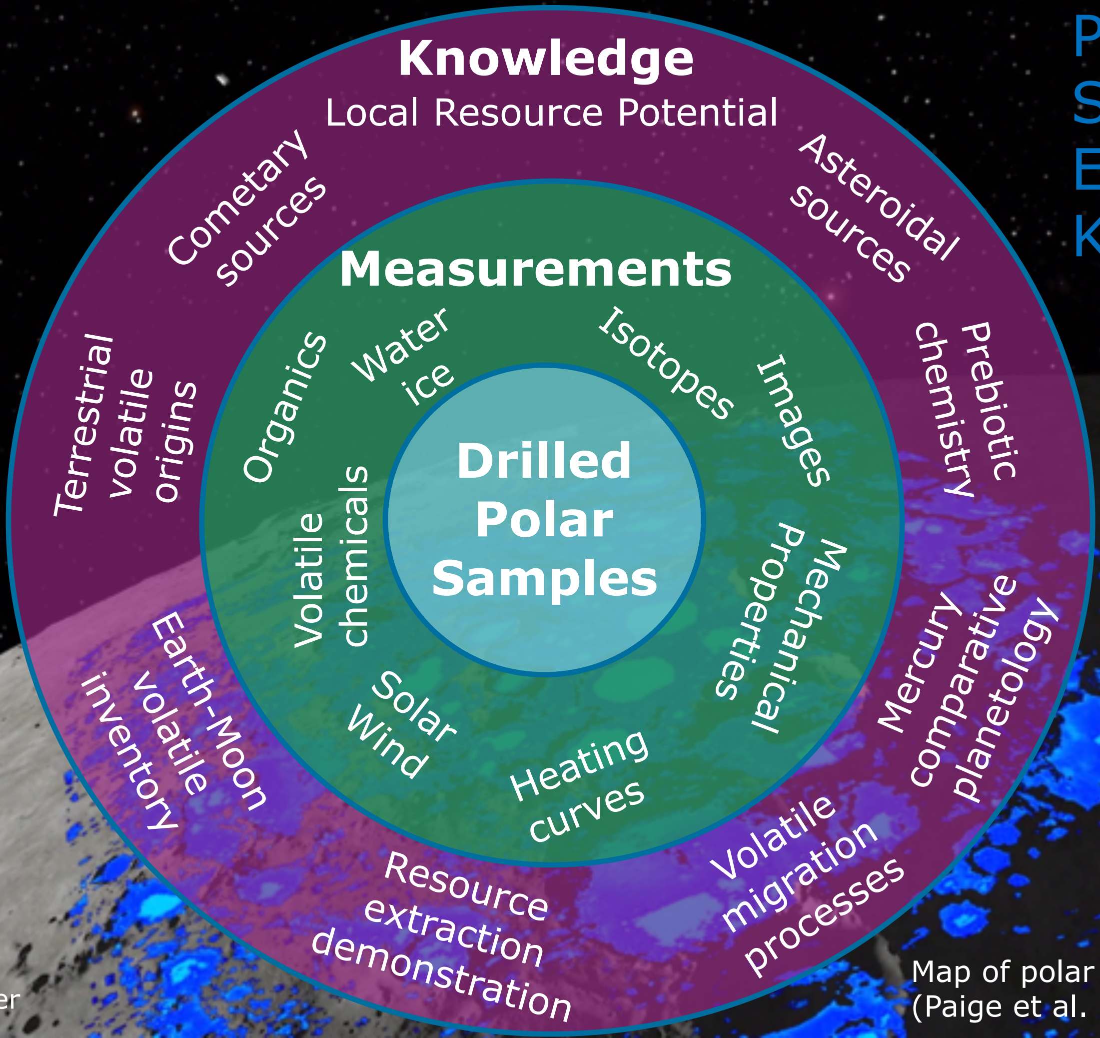
PROSPECT on Luna-27, embedded in international strategy, 2022

Prospecting and validation of key process steps and assumptions

ISRU technology and end-to-end Process demonstration and validation on Earth	→	Flight demonstration and qualification of critical ISRU technologies and end-to-end process	→	In-situ and fully scalable pilot plant providing "useable" resources	→	Full ISRU system in support of human lunar surface exploration
Terrestrial ISRU system demonstrator by 2020		ISRU demonstration mission by 2025		Human lunar surface campaign by 2030		Sustained human lunar operations by 2040

Courtesy of J. Carpenter

PROSPECT Science & Exploration Knowledge Gain



Map of polar water ice stability within 1m (Paige et al. 2010.)

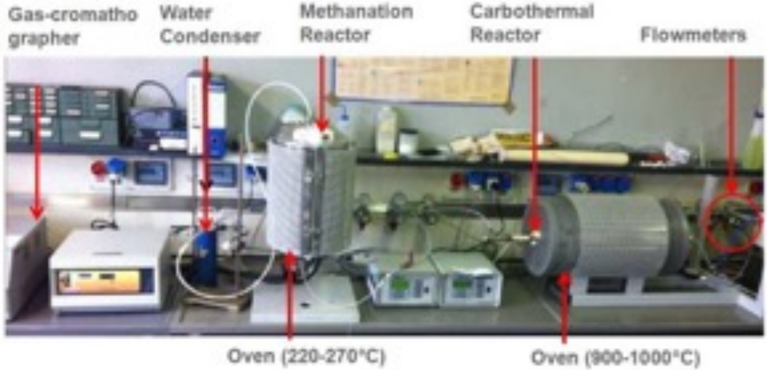
Courtesy of J. Carpenter

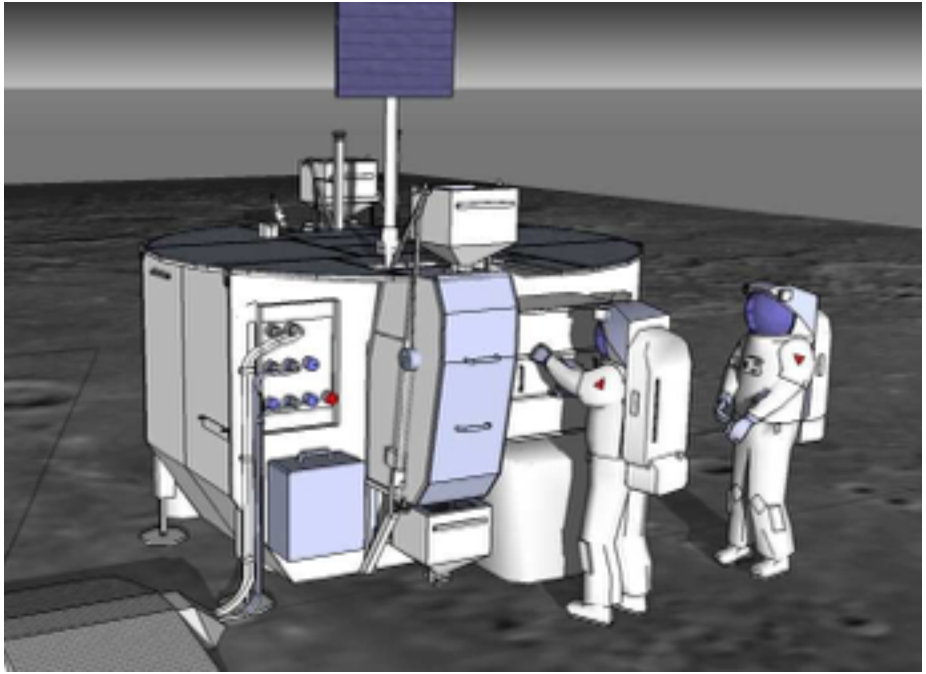
Future ISRU systems

Compatible with Human Precursor mission architecture from Deep Space Gateway

ESA IRSU system study + technology led by OHB-CGS with Poli. Di Milano

Solid-gas phase carbothermal reduction





Courtesy of J. Carpenter