

REGOLITH SIMULANTS

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DEVELOPING TECH FOR SPACE RESOURCES

Harvesting space resources requires unique hardware & processes that must be tested before going to the Moon or Mars or asteroids.

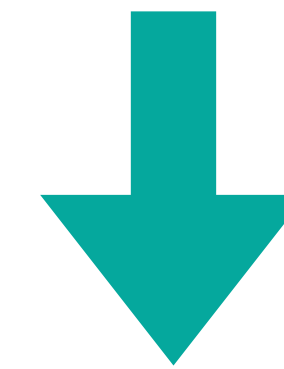
As we've seen in the course, the environments on other planetary bodies are unlike Earth. To some extent, these can be replicated using vacuum chambers, zero-G flights, etc.

But what about the materials?

Planetary materials share many similarities with terrestrial rocks, but there are many unique features as well.

For example:

- Lunar regolith is very fine grained with angular particles, agglutinates, nanophase iron, dangling bonds.
- Martian regolith very iron-rich, replete with amorphous phases, minor perchlorates, etc.
- Carbonaceous asteroids have incredibly fine-grained matrix (< 1 micron particles), carbon-rich.



WHAT'S AVAILABLE TO USE?

One might ask why we don't just test on the real thing: Apollo astronauts brought back loads of samples from the Moon, and we have asteroid sample return missions.

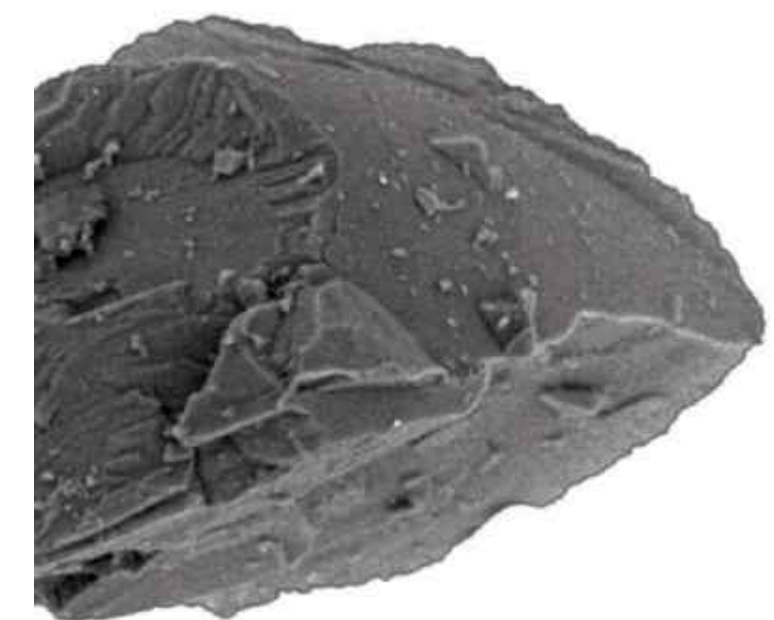
BUT, the actual mass is very limited, these are the most precious and carefully curated materials that exist.

Material	Collection mass (kg)
CI chondrites	21.5
Apollo samples	382
Luna samples	0.3
Asteroid regolith	~1500 grains (micron-size)

Mining techniques are highly destructive, and vehicle testing requires huge amounts of material. Need another solution.



RA-QD02-0057



20 μ m

SIMULANTS

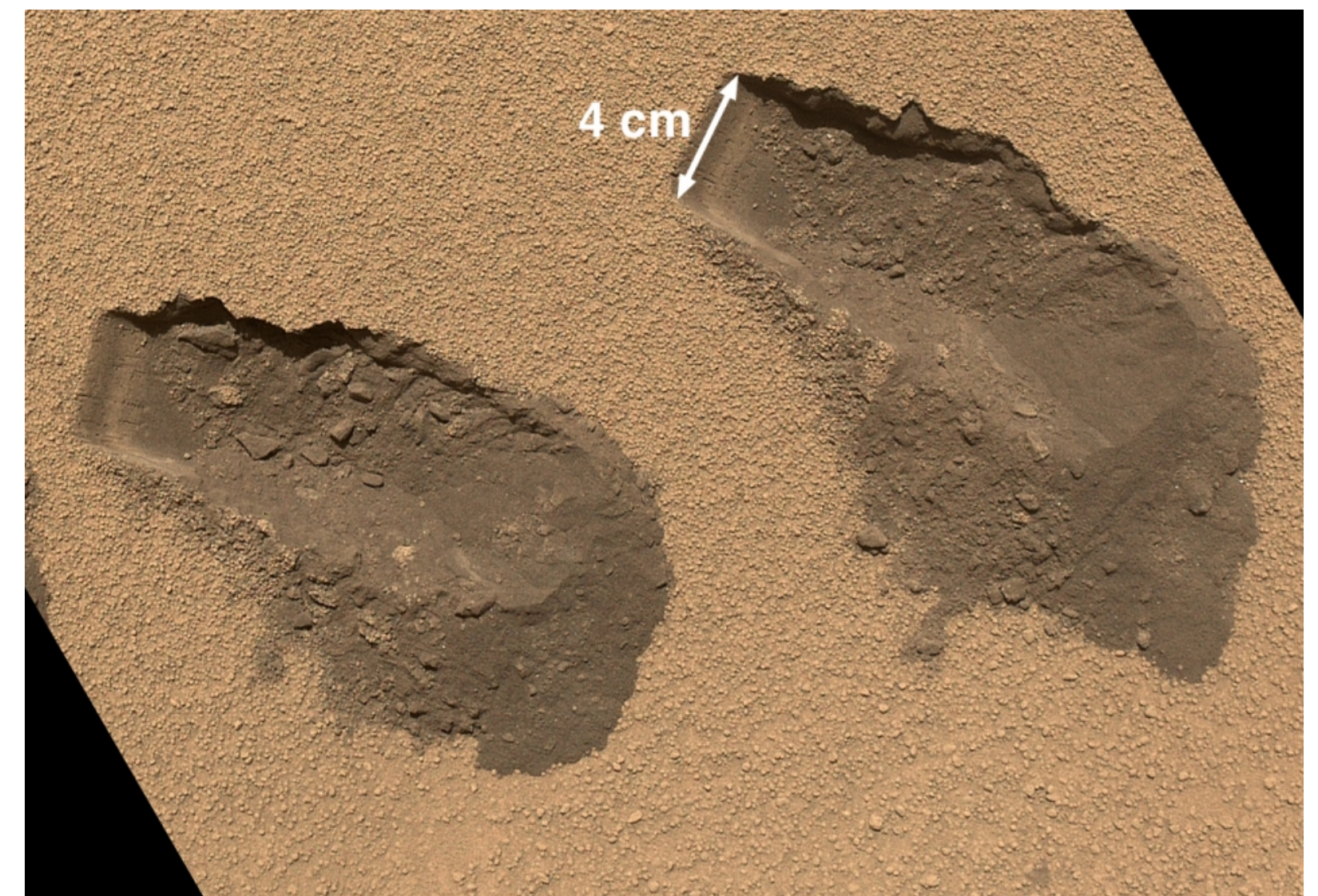
A **simulant** is a material that replicates one or more features of extraterrestrial materials.

More specifically, a **regolith simulant** aims to replicate the features of unconsolidated regolith.

Simulants actually pre-date Apollo: different rocks were ground into powders in anticipation of what astronauts would encounter.

Some questions to ponder:

- Which properties of planetary materials should we aim to re-produce with simulants?
- How faithfully should the simulants mimic the real thing in order for results to be valid?
- How much time and money will it take to achieve that level of realism?



SIMULANT INFORMATION FLOW

Low-fidelity simulant based on incomplete info



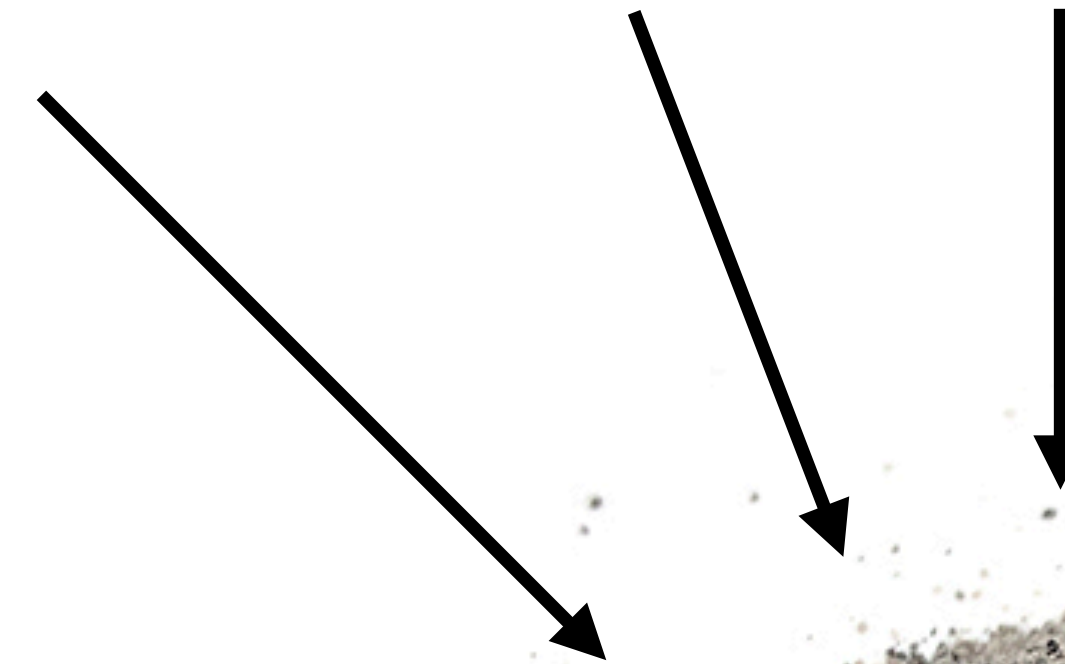
enables

Orbital and landed missions to collect better data



enables

Better simulants created based on new data



Information
flows
this
way



ISSUES WITH MANY HISTORIC SIMULANTS

Two main issues have plagued simulant efforts, most notably during the Constellation era:

1. Many simulants were low fidelity and simply consisted of a single terrestrial rock type ground into a powder. As an excuse, these were called “geotechnical simulants” even if they weren’t altered to have accurate geotechnical properties.
2. Nobody came up with a good way to distribute simulants to those who needed them.

SOLUTION #1: MINERAL-BASED SIMULANTS

Minerals are the basic building blocks of planetary materials.

Most properties (physical, thermal, optical, etc.) are a function of the mineralogy much more so than chemistry.

PSD-XRD of chondrites allows for accurate mineralogy of asteroid simulants, CHEMIN on Mars for martian simulants.



Mineral	Wt.%
Mg-serpentine	51.3
Magnetite	10.0
Vermiculite	9.6
Olivine	7.0
Pyrite	7.0
Attapulgite	5.3
Sub-bituminous coal	5.0
Ferrihydrite	4.8

X-ray diffraction



MINERALOGY VS. CHEMISTRY

Elements

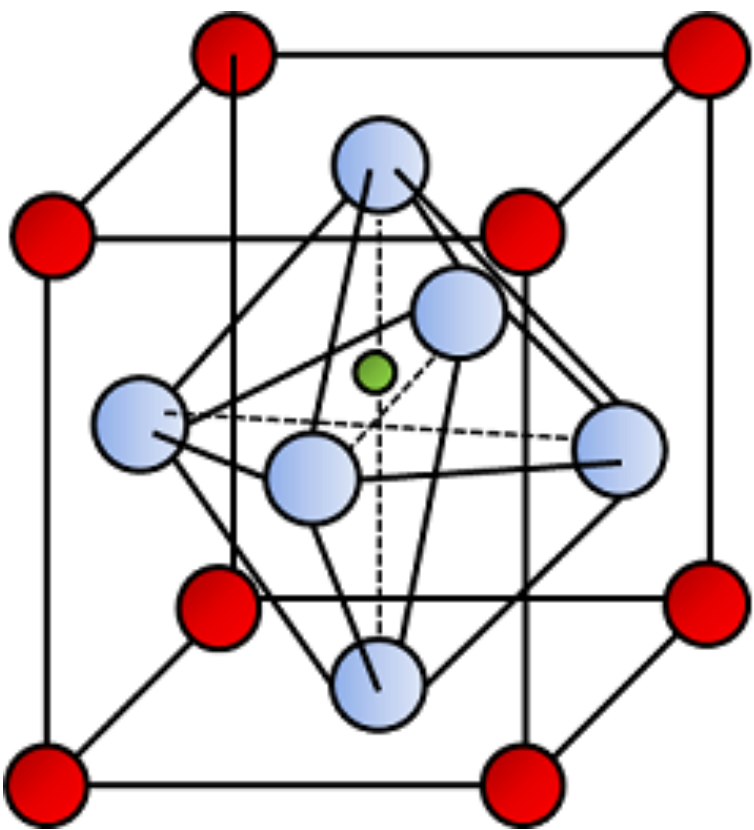


Minerals

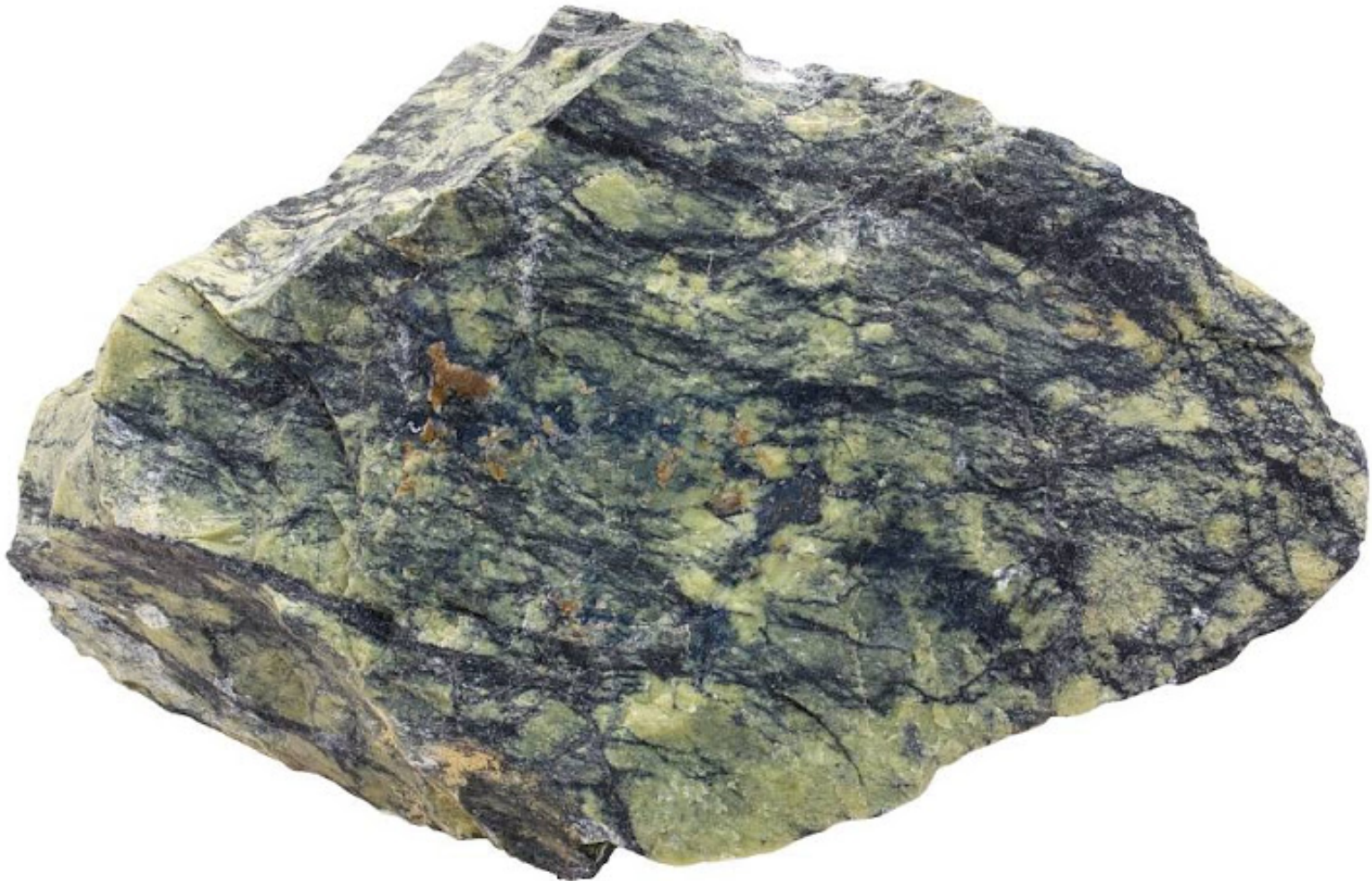


Rocks

1A	2A																		
1 1.008 H Hydrogen	3 6.941 Li Lithium	4 9.012 Be Beryllium																	
ATOMIC NUMBER		ATOMIC MASS																	
		He Helium																	
		ELEMENT SYMBOL																	
CHEMICAL NAME																			
11 22.990 Na Sodium	12 24.305 Mg Magnesium	3B	4B	5B	6B	7B	8B		1B	2									
19 39.098 K Potassium	20 40.078 Ca Calcium	21 44.956 Sc Scandium	22 47.88 Ti Titanium	23 50.942 V Vanadium	24 51.996 Cr Chromium	25 54.938 Mn Manganese	26 55.933 Fe Iron	27 58.933 Co Cobalt	28 58.693 Ni Nickel	29 63.546 Cu Copper	30 65.39 Zn Zinc								
37 84.468 Rb Rubidium	38 87.62 Sr Strontium	39 88.906 Y Yttrium	40 91.224 Zr Zirconium	41 92.906 Nb Niobium	42 95.95 Mo Molybdenum	43 98.907 Tc Technetium	44 101.07 Ru Ruthenium	45 102.906 Rh Rhodium	46 106.42 Pd Palladium	47 107.868 Ag Silver	48 112.411 Cd Cadmium								
55 132.905 Cs Cesium	56 137.327 Ba Barium	57-71 Lanthanides	72 178.49 Hf Hafnium	73 180.948 Ta Tantalum	74 183.85 W Tungsten	75 186.207 Re Rhenium	76 190.23 Os Osmium	77 192.22 Ir Iridium	78 195.08 Pt Platinum	79 196.967 Au Gold	80 200.59 Hg Mercury								



- Ca²⁺
- O²⁻
- Ti⁴⁺



Fe

Si

Mg

O



SOLUTION #2: A BETTER DISTRIBUTION SYSTEM



Profit margins on simulants are negligible. Many companies have tried to sell them for-profit and have failed.

CLASS Exolith Lab: not-for-profit entity, set up under UCF Research Foundation.

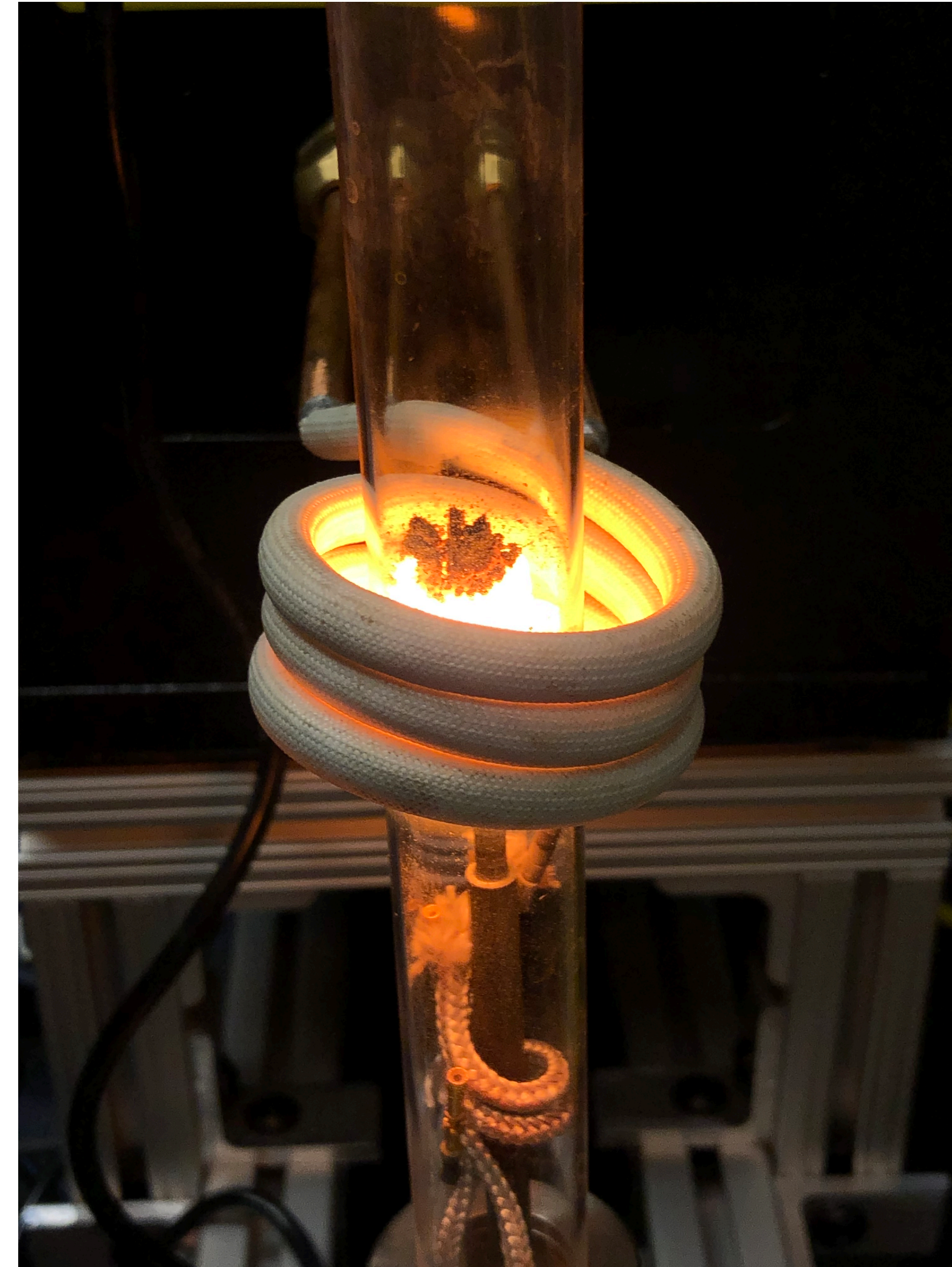
Full suite of asteroid, lunar, and martian regolith simulants.

Manufactures & distributes simulants worldwide to researchers, space agencies, private companies, STEM education.

SIMULANT APPLICATIONS: HOME-GROWN EXAMPLES



Simulated C-type asteroid for TransAstra's Mini Bee orbital flight demo mission



Lunar mare simulant being tested with HELIOS's molten regolith electrolysis methods to extract oxygen from lunar regolith

PLANETARY SIMULANT DATABASE

<https://simulantdb.com>

Planetary Simulant Database

Free Resource for Regolith Simulant Information

Changelog

03/20/20 — Simulant DB website launched (migrated from UCF server). All simulants now contained in an actual database with filtered search capabilities.

Recent Simulant Research

Godin et al., [Laboratory investigations of Lunar ice imaging in permanently shadowed regions using reflected starlight](#)

Zocca et al., [Investigation of the sintering and melting of JSC-2A lunar regolith simulant](#)

Zheng et al., [Mechanical behavior of the metal parts welded with extraterrestrial regolith simulant by the solar concentrator in ISRU & ISRF application](#)

[View archive](#)

Simulant Availability

The UCF Planetary Simulant Database maintains up-to-date information on currently available planetary simulants. If you would like a simulant added to the database, or can provide missing information, please email Kevin Cannon (cannon@ucf.edu). Note that **we do not keep physical samples in the database.**

The listing of simulants below was last updated on March 25, 2020. A [downloadable spreadsheet](#) is available with the listing of the simulants and their bulk chemistry.

We also offer complimentary consulting on all simulant-related matters (cannon@ucf.edu).

Database Filters

[Reset](#)

- | | | |
|--|--|---|
| <input checked="" type="checkbox"/> Moon (highlands) | <input checked="" type="checkbox"/> Not Available | <input checked="" type="checkbox"/> Basic |
| <input checked="" type="checkbox"/> Moon (mare) | <input checked="" type="checkbox"/> May Be Available | <input checked="" type="checkbox"/> Standard |
| <input checked="" type="checkbox"/> Moon (other) | <input checked="" type="checkbox"/> Available | <input checked="" type="checkbox"/> Enhanced |
| <input checked="" type="checkbox"/> Mars | | <input checked="" type="checkbox"/> Specialty |
| <input checked="" type="checkbox"/> Asteroid | | |
| <input checked="" type="checkbox"/> Other | | |

Filter

Acronym	Name	Body	Country
C2	C2 Carbonaceous Chondrite Simulant	Asteroid	Un

Database Filters

[Reset](#)

- | | | |
|--|--|---|
| <input checked="" type="checkbox"/> Moon (highlands) | <input checked="" type="checkbox"/> Not Available | <input checked="" type="checkbox"/> Basic |
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| <input type="checkbox"/> Mars | | <input checked="" type="checkbox"/> Specialty |
| <input type="checkbox"/> Asteroid | | |
| <input type="checkbox"/> Other | | |

Filter

Acronym	Name	Body	Country
CHENOBI		Moon	Canada
LHS-1	Lunar Highlands Simulant	Moon	United States
MLS-2	Minnesota Lunar Simulant	Moon	United States
NAO-1	National Astronomical Observatories	Moon	China
NU-LHT	NASA/USGS Lunar Highlands Type	Moon	United States
OB-1	Olivine Bytownite	Moon	Canada
OPRH2N/H2W/H3N/H3W	Off Planet Research Highlands Simulant	Moon	United States
TUBS-T	TU Braunschweig Base Simulant Terrae	Moon	Germany

FINAL THOUGHTS

At the end of the day, simulants are just crushed up rock.

It's probably not worth putting a significant amount of time, brainpower, and money into simulants (80:20 rule), or studying the simulants in and of themselves.

The goal of using simulants should be to create a future where they aren't needed anymore.