Stuff We Take Care of, How We Store it, and Why it's Hard to Plan for Everything

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NASA – Johnson Space Center

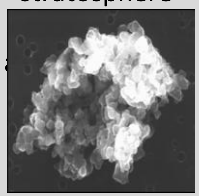
JSC's Astromaterials Acquisition & Curation Office

Our Past 50 years – planning for and curating multiple collections

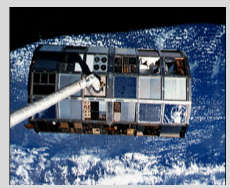
Lunar
(1969)
Apollo program lunar rocks and soils; Luna samples

Meteorite
(1977)
Antarctic Search for Meteorites (ANSMET) program

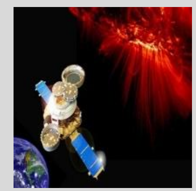
Cosmic Dust
(1981)
Cosmic dust grains from Earth's stratosphere



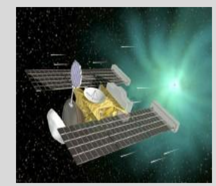
Microparticle Impact Col.
(1985)
Space exposed hardware from spacecraft



Genesis
(2004)
Genesis solar wind samples at Earth-Sun L1 point



Stardust
(2006)
Cometary and interstellar samples from Comet Wild 2



Hayabusa
(2012)
Samples collected from JAXA asteroid mission to Itokawa

Our Near Future . . .

Hayabusa II
(2020)
Subset of samples collected from JAXA asteroid mission to (162173) 1999

OSIRIS-REx
(2023)
Asteroid sample return from 101955 Bennu

OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION

Our More Distant Future . . .

Moon
(2020s)
Non-volatile-rich farside/polar sample return

Next New Frontiers Call

Comet
(2020s)
Cold curated (?) surface sample return from a comet

Next New Frontiers Call

Phobos
(2020s)
10% of a JAXA mission to bring back Phobos material

JAXA sample return mission

Mars
(~2030+)

Various Mars Sample Return

Over 50 years in the planning (est. 1964)

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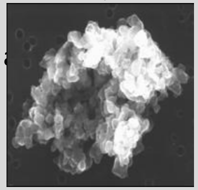

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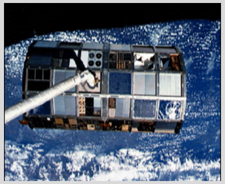

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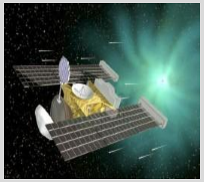

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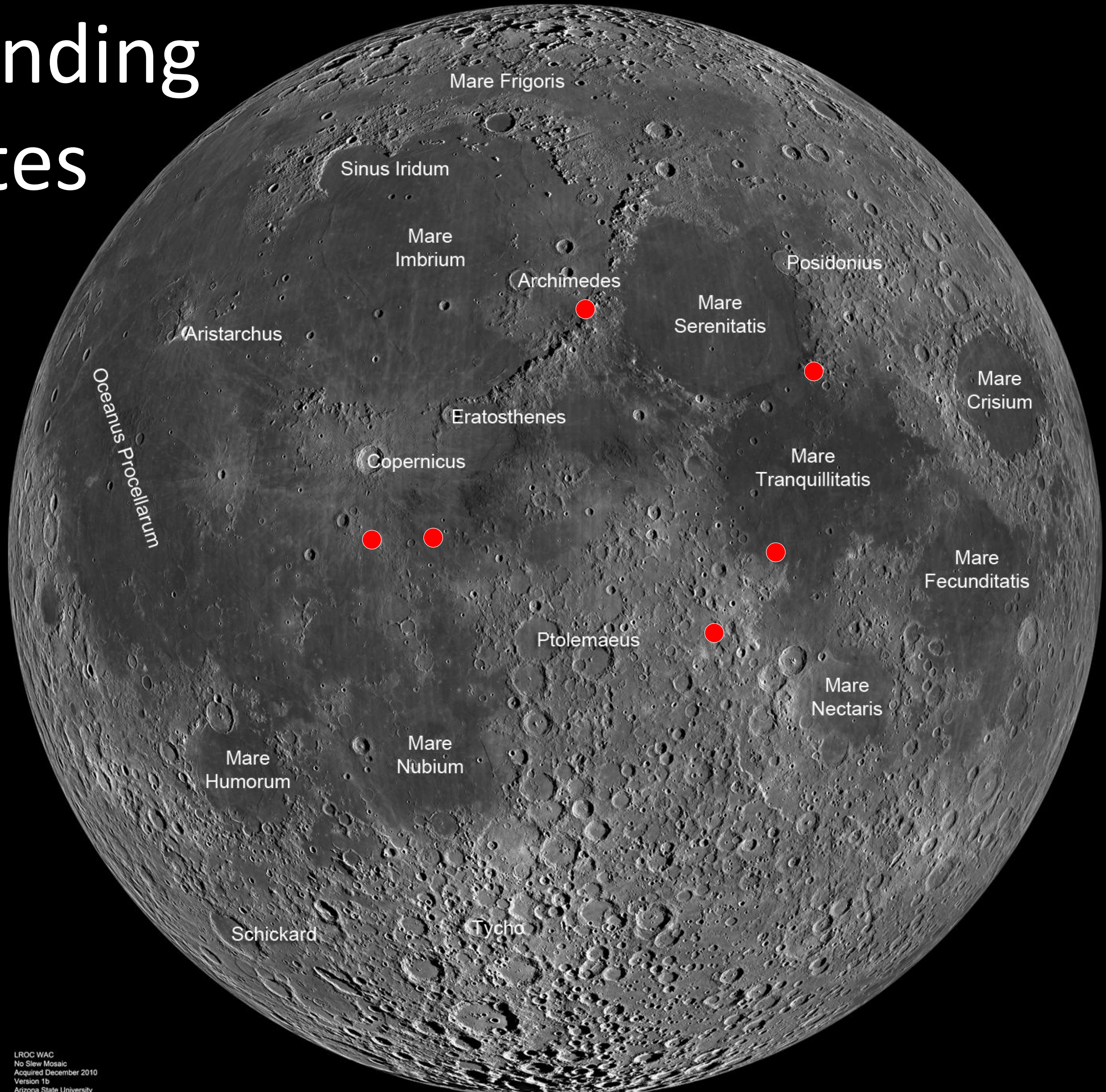
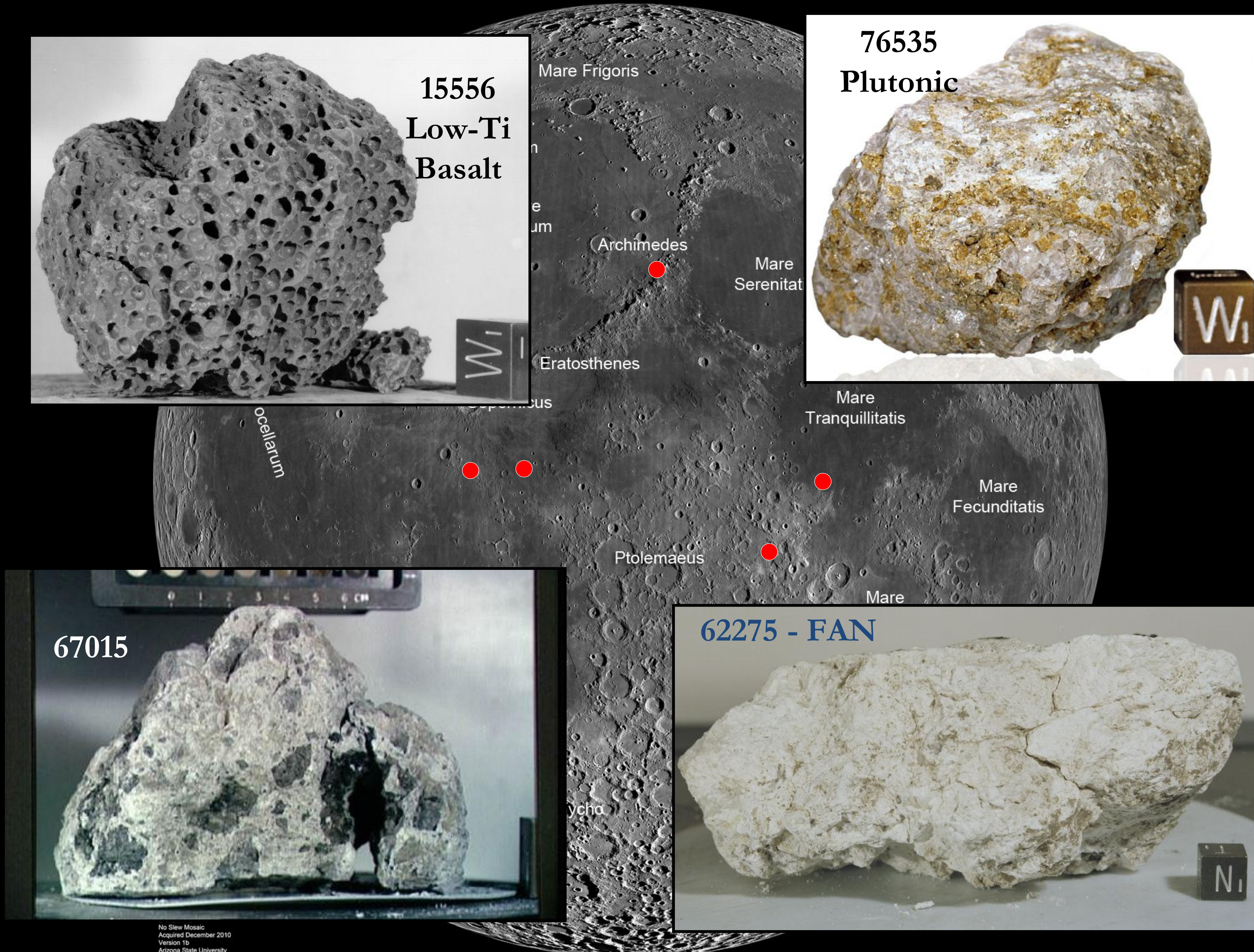
Overview

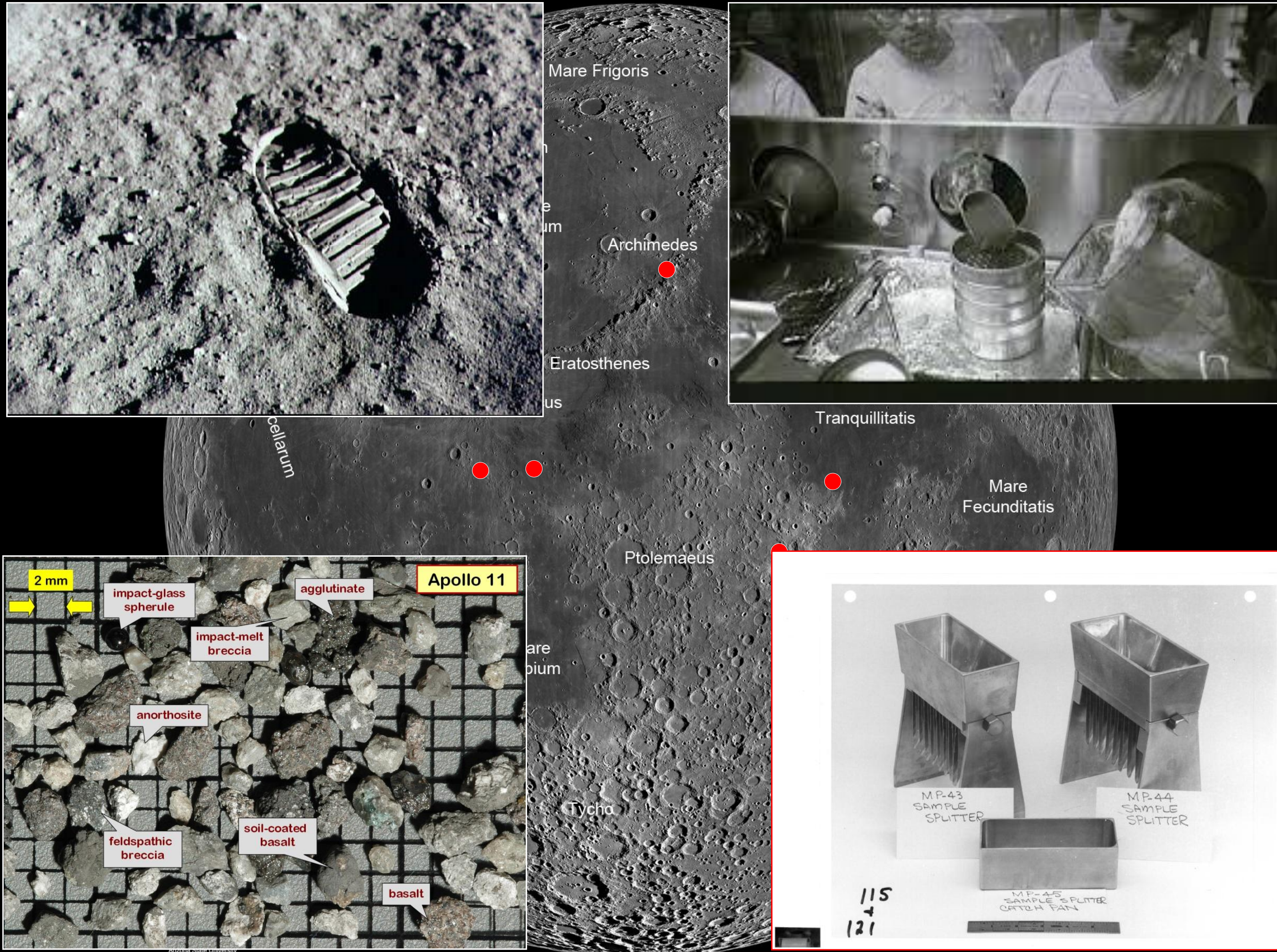
- Talk to you today about 4 main topics:
    1. Quick review of the Apollo samples – Variety of sample types.
    2. Brief Look at where the samples were originally stored – the Lunar Receiving Lab (LRL)
    3. Look at the building/laboratories that the samples are currently stored in – Lunar Curatorial Facility
    4. A discussion of the variety of research conducted on lunar samples in the past 5 years – illustrative of the challenges in designing a new facility.

Landing Sites





15556
Low-Ti
Basalt
76535
Plutonic
67015
62275 - FAN
Mare Frigoris
Archimedes
Mare
Serenitat
Eratosthenes
Mare
Tranquillitatis
Mare
Fecunditatis
Ptolemaeus
Mare
0 1 2 3 4 5 6 cm
No Slew Mosaic
Acquired December 2010
Version 1b
Arizona State University


Mare Frigoris
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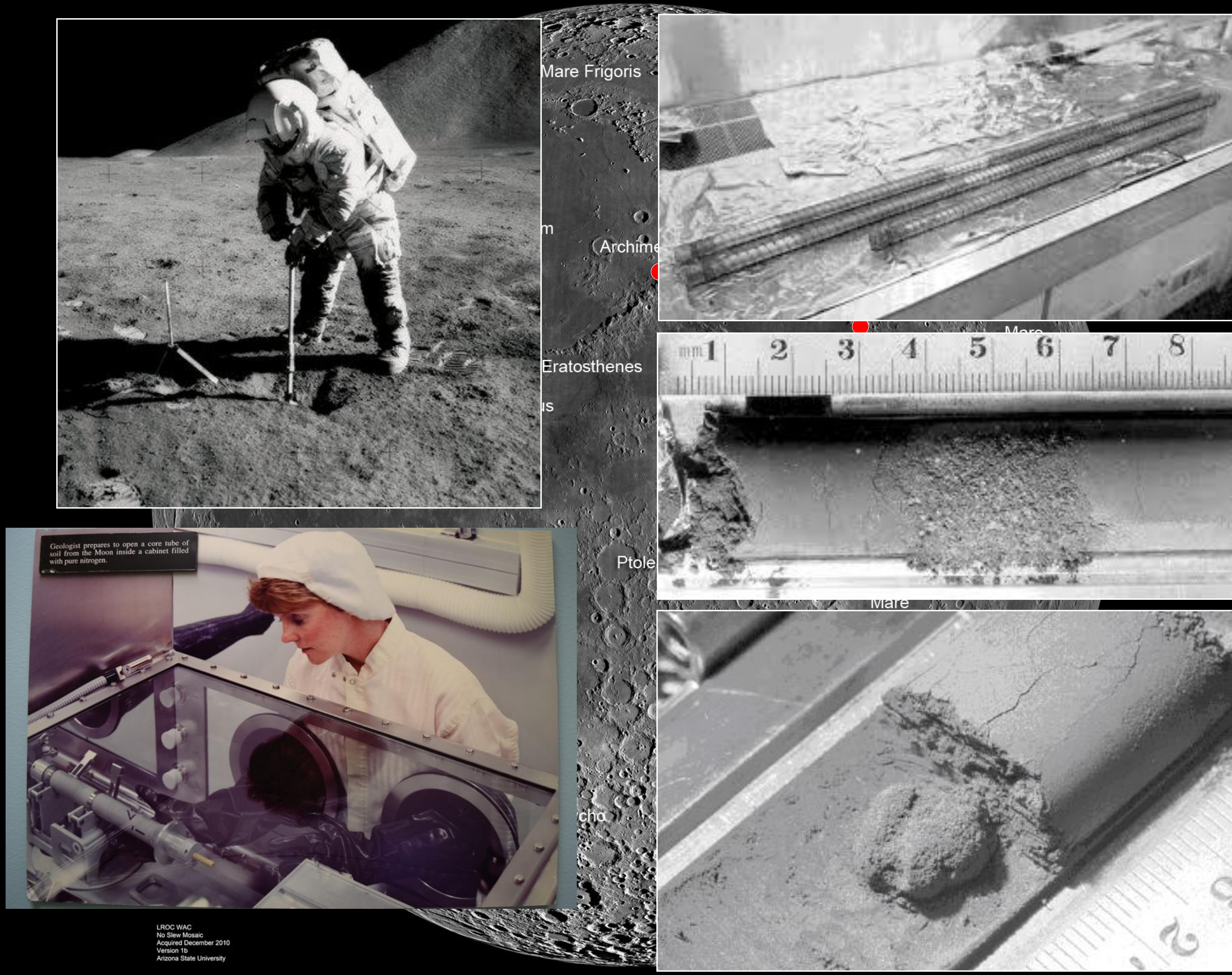
Mare
Fecunditatis
Ptolemaeus
Tycho
2 mm
Apollo 11
impact-glass
spherule
agglutinate
impact-melt
breccia
anorthosite
feldspathic
breccia
soil-coated
basalt
basalt
MP-43
SAMPLE
SPLITTER
MP-44
SAMPLE
SPLITTER
MP-45
SAMPLE SPLITTER
CATCH PAN
115
+
121


Mare Frigoris
Eratosthenes
Geologist prepares to open a core tube of soil from the Moon inside a cabinet filled with pure nitrogen.
mm 1 2 3 4 5 6 7 8
LROC WAC
No Slew Mosaic
Acquired December 2010
Version 1b
Arizona State University

Lunar Receiving Lab (LRL) – 1969-1972

- As early as 1964, the need for a dedicated facility to house the Apollo samples was recognized (finished in 1967).

Designed as a Quarantine Facility

Efforts to work under vacuum

Lunar Receiving Lab (LRL) – 1969-1972

- Samples were initially described, classified, and cataloged (PET), and disseminated for additional study.

Designed as a Quarantine Facility

Efforts to work under vacuum

Lunar Curatorial Facility – 1979 to present

- Specifically designed to be the long term home of the Apollo samples – Focus on physical security and cleanliness

Designed to with-stand a Cat 4 Hurricane

Designed with sign. community input to the plan

Lunar Curatorial Facility – 1979 to present

- Pristine Lab + Vault are ISO 6.
- Samples handled in stainless steel (316L) cabinets.
- Limited materials allowed within the cabinets:
  - Stainless (304L), Aluminium (6160), Teflon
- Specialty cabinets for cores and band-sawing samples.
- Atmosphere in the cabinets is dry N2 gas.
- Separate vault and labs for return samples (ISO 7).

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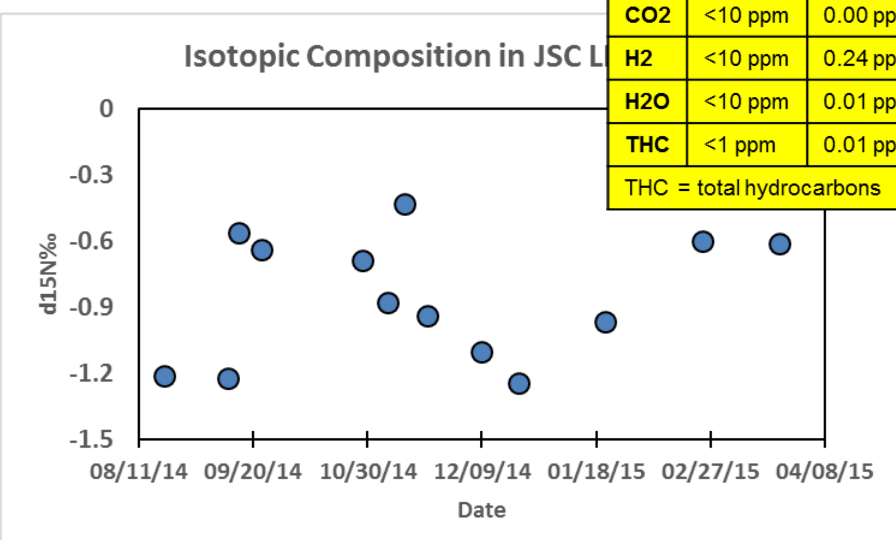
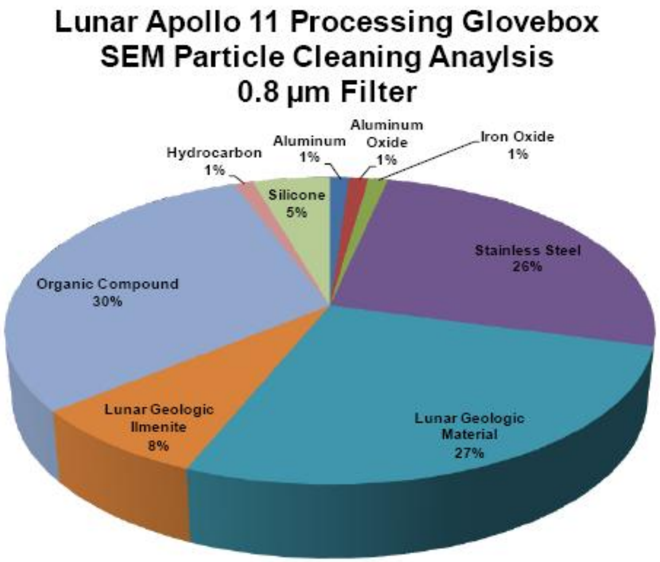
Monitoring Laboratory Cleanliness

	Max	Meas.
Ar	<20 ppm	4.20 ppm
O2	<10 ppm	0.14 ppm
CO	<10 ppm	0.96 ppm
CO2	<10 ppm	0.00 ppm
H2	<10 ppm	0.24 ppm
H2O	<10 ppm	0.01 ppm
THC	<1 ppm	0.01 ppm
THC = total hydrocarbons		



- Daily monitoring of the UPW sys.
- Weekly particle counts in labs.
- The composition of each delivery of N_2 is measured.
  - Delivery is refused if outside of spec.
- The O_2 + H_2O in the lunar cabinets is measured 4x hour
  - Cycles through all cabinets.
- The isotopic composition of the N_2 gas is measured monthly.
- Periodically we analyze the composition of particles when the cabinets are cleaned.
- Periodically we measure the total organic hydrocarbons in the labs.

Monitoring Laboratory Cleanliness



Lunar Glovebox SEM Particle Cleaning Anaylsis - Fine Filter				
Possible Identified Material Groups	Particle Count	Particle %	Size Range (µm)	Average Size (µm)
Aluminum	1	1.12%	25	25
Aluminum Oxide	1	1.12%	12	12
Iron Oxide	1	1.12%	5	5
Stainless Steel	23	25.84%	2 to 10	5
Lunar Geologic Material	24	26.97%	2 to 15	6
Lunar Geologic Ilmenite	7	7.87%	3 to 8	8
Organic Compound	27	30.34%	2 to 100	16
Hydrocarbon	1	1.12%	10	10
Silicone	4	4.49%	4 to 8	6

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Monitoring Laboratory Cleanliness

Lunar Curation Glovebox			
Hydrocarbons	Control Wafer (ng/cm²)	Vertical Exposure (ng/cm²)	Surface Exposure (ng/cm²)
Low boilers C7-C10	*	*	0.2
Medium boilers >C10-C20	*	1.8	2.5
High boilers >C20	*	0.1	0.2
Sum >= C7	*	1.9	2.9
Identified Compounds			
Diethylformamide	*	*	*
Diethylacetamide	*	*	*
Alkyl amine	*	*	*
2-Butoxyethyl acetate	*	*	*
Octafluoropentanal(m/z:51,69,100,131,151,181,200,231,281)	*	*	*
2-Cyclohexen-1-one, 3,5,5-trimethyl-	*	0.3	0.3
Dibutylformamide	*	0.2	0.2
Cyclo(Me2SiO)6	*	0.2	0.2
2,6-di-tert-Butylquinone	*	*	*
Cyclo(Me2SiO)7	*	*	*
Cyclo(Me2SiO)8	*	*	0.1
Cyclo(Me2SiO)9	*	0.2	0.3
Dibutyl phthalate	*	*	0.1
Cyclo(Me2SiO)10	*	0.1	0.2
Siloxane	*	0.1	0.1
* Recording Limit = < 0.1 ng/cm²			

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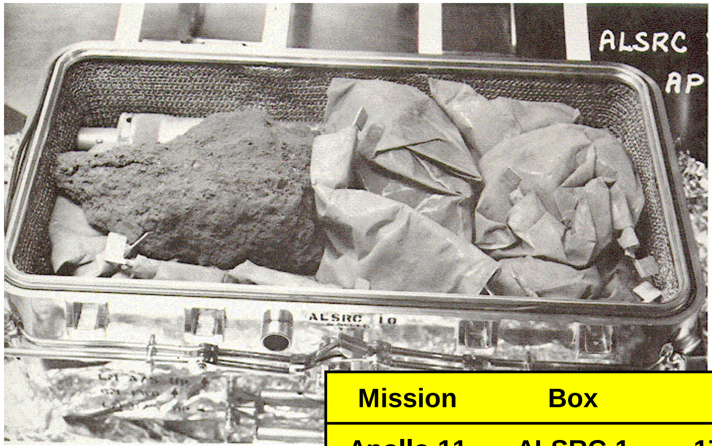
Apollo Sample Level of Pristinity

- What levels of alteration have occurred over the past 40+ years.
  - The rock boxes didn't all leak
- Numerous studies of indigenous water in lunar samples; isotopic evidence it is not contamination.
- TEM studies of small lunar particles show Fe^0 metal within nanometers of the surface.
  - There is evidence for Fe^{3+} in the outermost angstroms of soil grains
- Recent studies of organics in Apollo samples show evidence for prebiotic molecules in lunar soils



Mission	Box	Pressure
Apollo 11	ALSRC 1	170 microns
Apollo 11	ALSRC 2	170 microns
Apollo 12	ALSRC S	40-60 microns
Apollo 12	ALSRC D	1/2 atm
Apollo 14	ALSRC 6	60 microns
Apollo 14	ALSRC 7	1 atm
Apollo 15	ALSRC 1	35 microns
Apollo 15	ALSRC 2	1 atm
Apollo 16	ALSRC 1	1 atm
Apollo 16	ALSRC 2	83 microns
Apollo 17	ALSRC 1	175 microns
Apollo 17	ALSRC 2	28 microns

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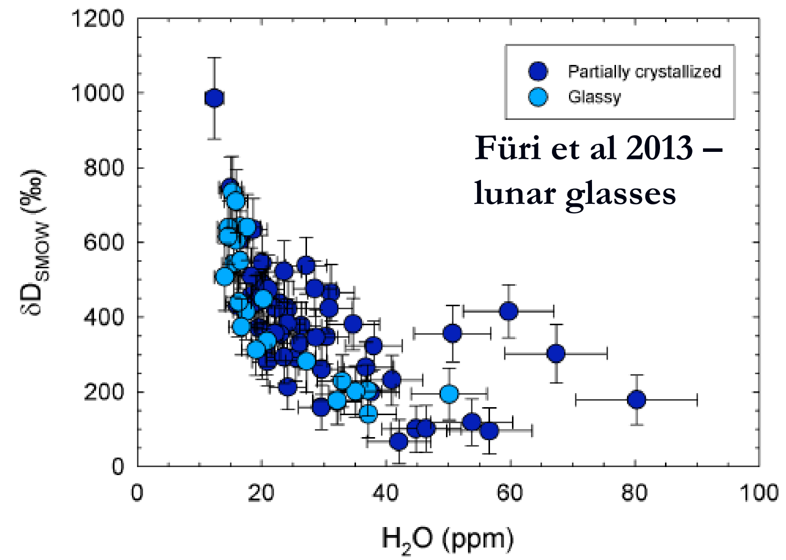

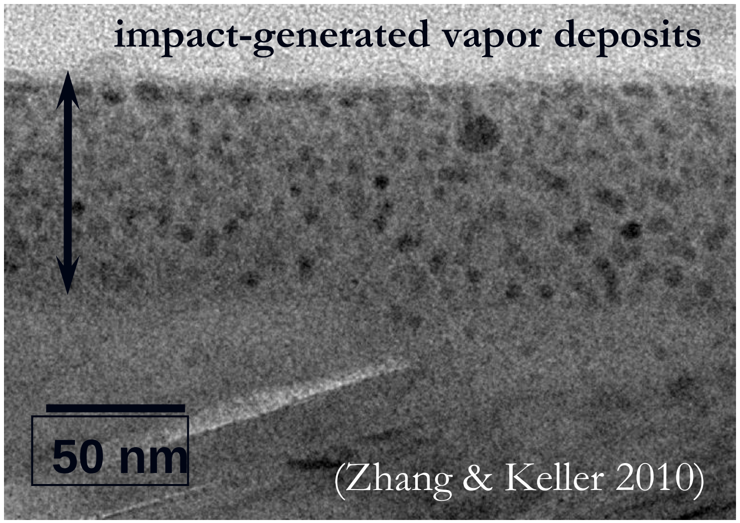

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Table 1. Lunar samples investigated in this study

Sample	Is/FeO ratio [6] (maturity)	Masses analyzed (g)
73131	16, immature	0.33[c]
73241	18, immature	0.27[c]
78501	36, submature	0.46
70011[a]	54, submature	0.27[c], 0.49[d], 9.28
72501[b]	81, mature	0.29[c], 9.84
78421	92, mature	0.25[c]
69961	92, mature	11.82

[a]Collected beneath lunar module (LM) as exhaust-exposed sample; [b]Collected 6.5 km from LM as exhaust control; [c]Both hydrolyzed and unhydrolyzed extracts analyzed; [d]Subsection of larger sample analyzed separately

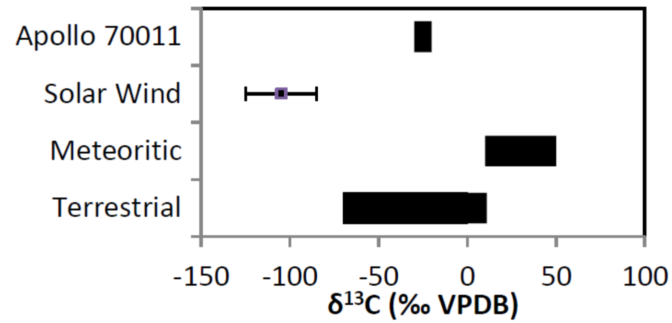

Figure 1. Range of carbon isotopic ratios measured for Apollo 70011 amino acids compared with solar wind, carbonaceous chondrites, and terrestrial biological sources.

Hard to plan for everything

- An incredible amount of foresight and planning went into each of the Apollo Sample Storage Facilities
  - Included panels of “outside” experts
- Ultimately, very difficult to plan for the unknown:
  - I suspect if you’d have told the committee in 1978 that Zn, Se isotopes (as an example) were going to be studied, they’d have been skeptical
  - Similar if the 1964 group needed to worry about ppt/b levels of organic contamination

Hard to plan for everything

- In the past 4 years, I've had requests to do the following:
  - Stable isotope studies – H, He, Li, C, N, O, Ne, Mg, Si, Cl, Ar, Ca, Ti, V, Fe, Ni, Cu, Zn, Se, Kr, Rb, Sr, Mo, Ru, Cd, In, Sn, Xe, Ba, Hf, W, Os (32)
  - Radiogenic isotope studies – K-Ca, K-Ar, Ar-Ar, Rb-Sr, Cs-Ba, Sm-Nd, Sm-Nd, Lu-Hf, Hf-W, Re-Os, Pb-Pb, Th-Pb, U-Pb, U-Th/He, U-Th disequil (15).
  - Organics – Amino Acids, Soluble organics, perchlorates, life toxicity (ppt)
  - Highly and Moderately Siderophile Elements – low ppb levels
  - Volatile elements – ppm level measurements of H, OH, H_2O, F, Cl, Br
  - Physical characteristics – Density, porosity, size distribution, particle shapes, magnetics, superconductivity
  - Cosmic studies – GCR flux variability, solar wind interactions, space weathering, D-production rates, life detection around extrasolar planets
  - Analog – Requested as an analog for Mercury, NEOs, Phobos; also as ground truth for orbital measurements
  - Outreach and Goodwill samples – Significant mass and numbers