Exploring Space through Sample Return Missions:

How, Where, and What Do We Do with the Rocks?

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Exploring Space through Sample Return Missions:

The Vital Role of Curation

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Geologist by training in analytical geochemistry

Ph.D. in France on meteorite terrestrial ages

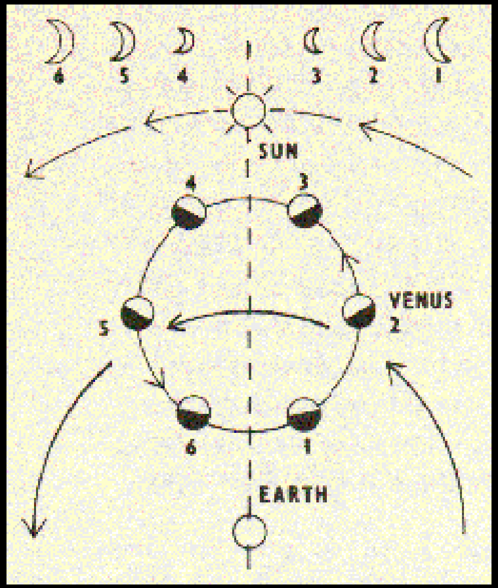
Post-doc in Austria on the ideal curation facility for astromaterials

Now Visiting Scientist at the Curation Office, NASA JSC (Houston, Texas) on contamination control and knowledge and material suitability.

Outline

- Where have we been so far?
- Exploration of the Solar System: why do we need sample return missions?
- NASA Astromaterials Acquisition and Curation Office
- Upcoming sample return missions and needed facilities
- Where do we want to go next
- How curation should adapt to new challenges

Looking above



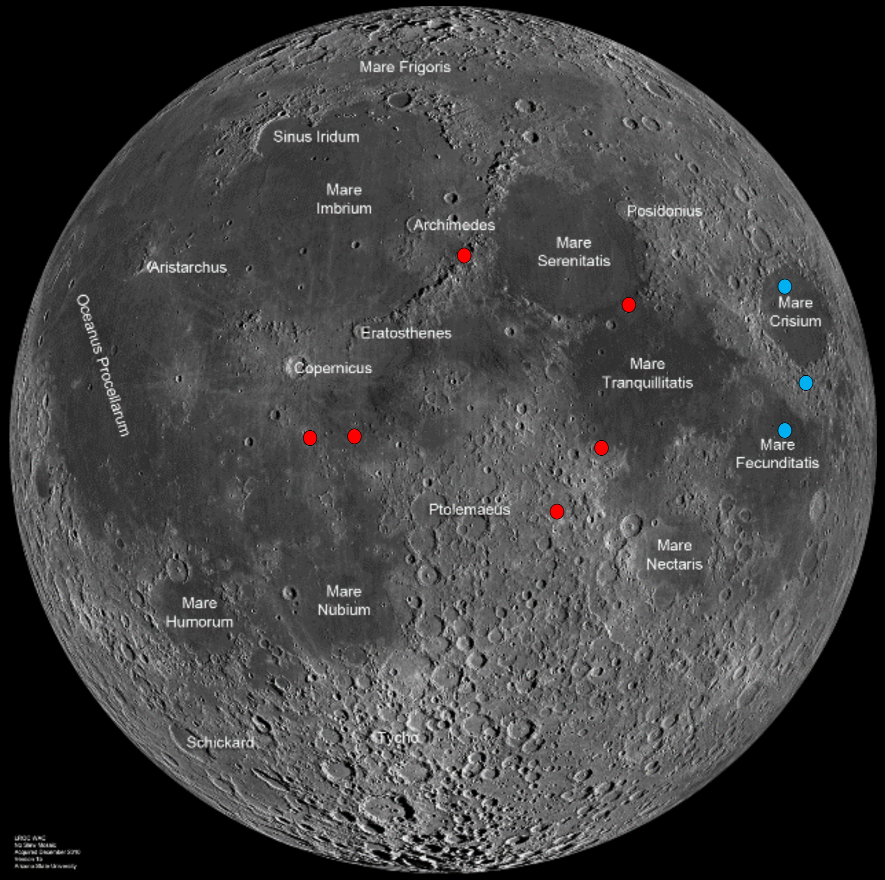
Early observations of moons and planets

Remote and in-situ missions (1950's)

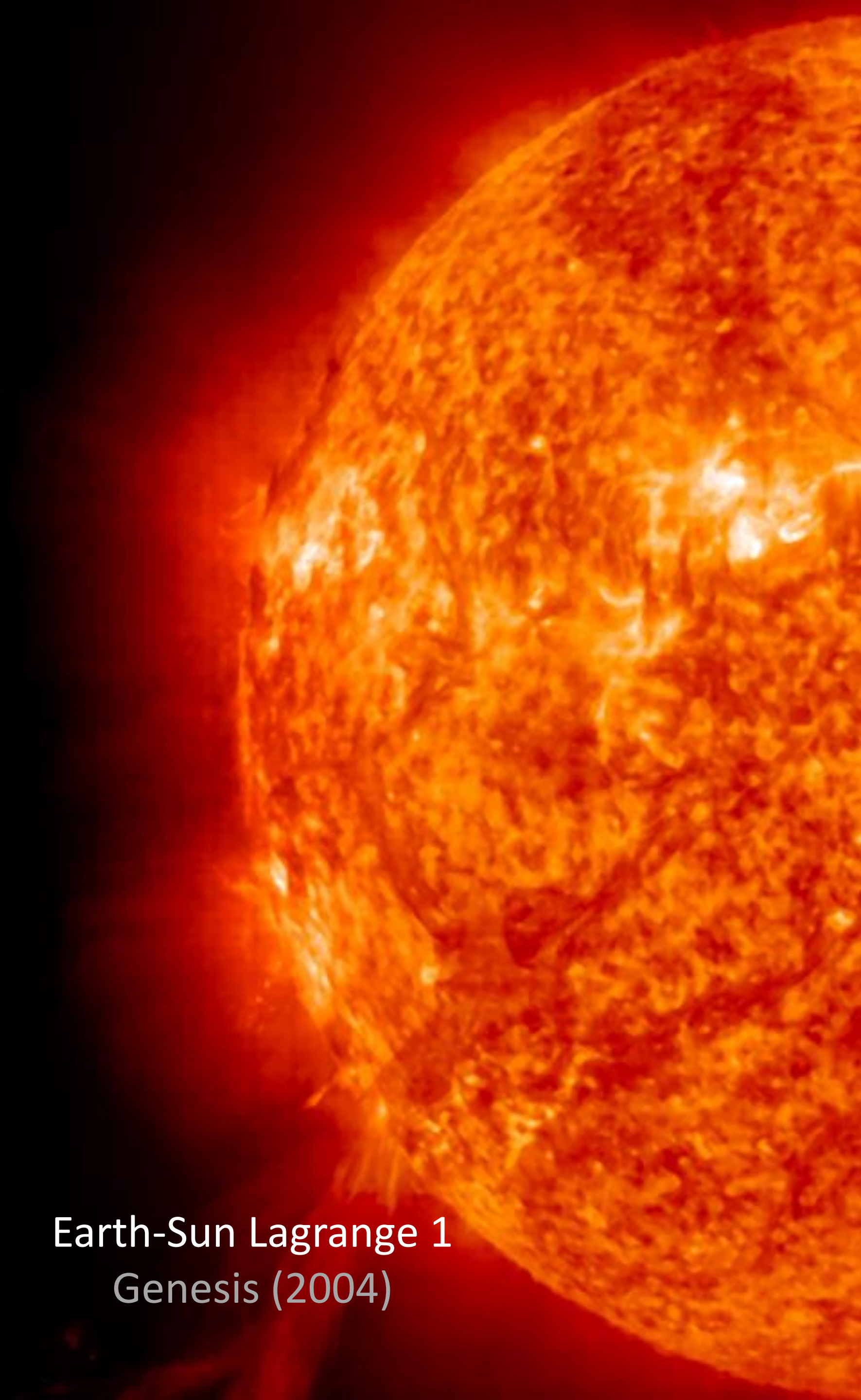
Where have we been so far?

Itokawa
Hayabusa (2010)

Comet 81P/Wild
Stardust (2006)



Moon
Apollo 11 to 17 (1969-1972)
Luna 16, 20, 24 (1970-1976)

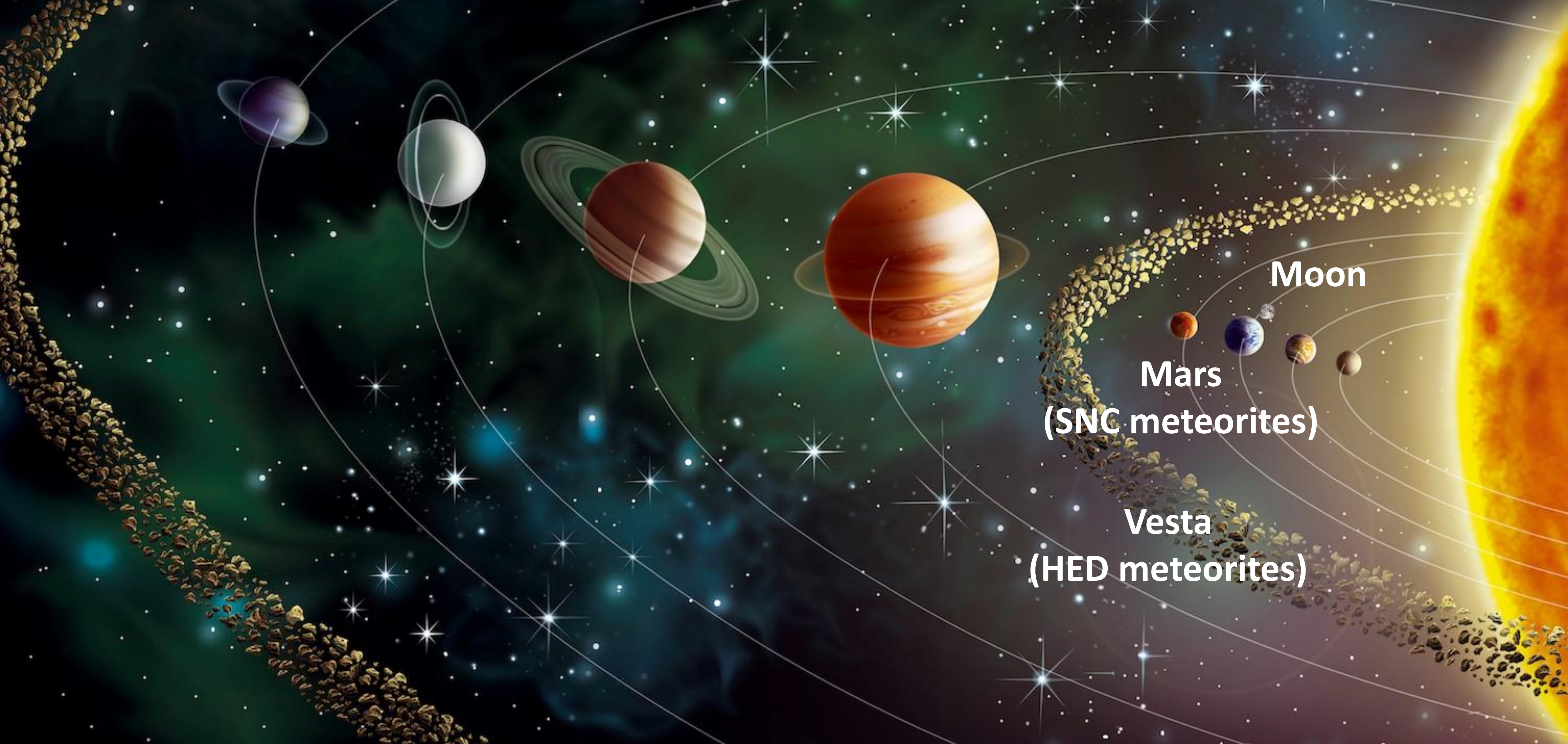


Earth-Sun Lagrange 1
Genesis (2004)

Falling from above

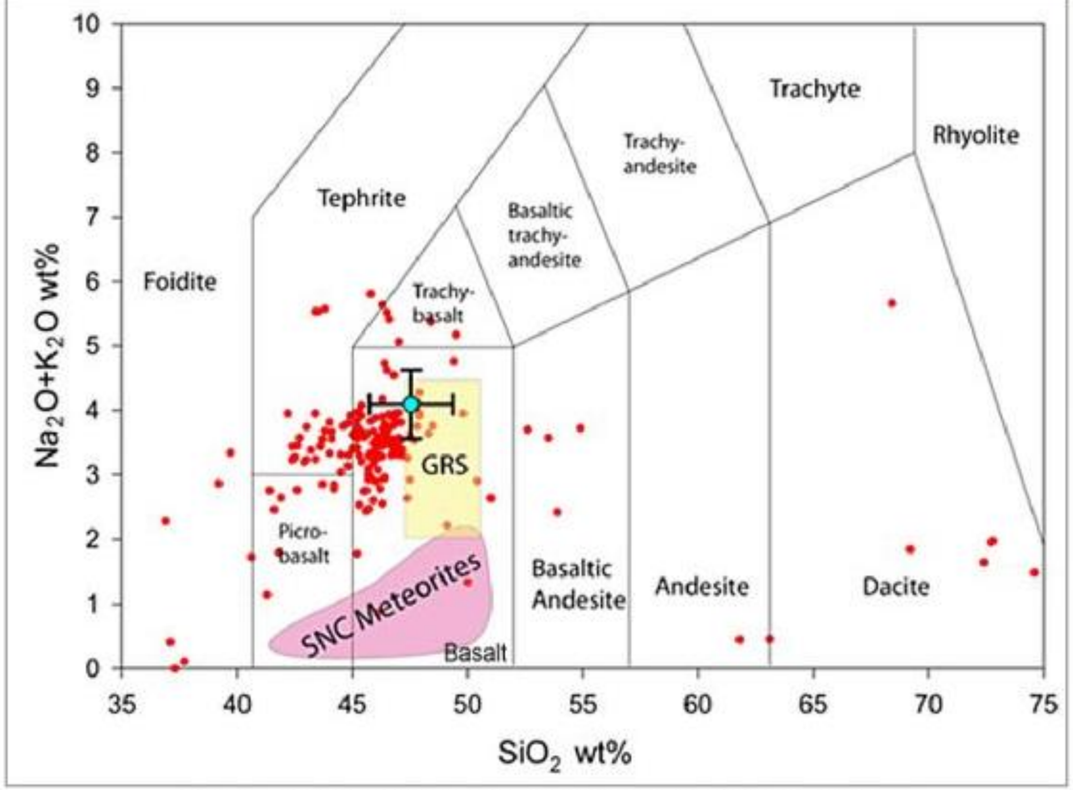
Meteorites are from space (1794)

Where have we been so far (sort of)?



Why sample return missions?

- Meteorite studies have limitations:
  - Rock types and ages
  - Geological context
  - Alteration via ejection and trip back to Earth
- Fabulous new discoveries from in-situ and remote studies have raised questions that require complementary analyses.
- Preparation techniques in terrestrial laboratories allow for analyses at higher spatial resolution and precision.
- Analytical instrumentation and techniques on Earth are more flexible and constantly innovating.



(From Agee, *et al.*, (2013) *Sciencexpress*, doi: 10.1126/science.1228858.)

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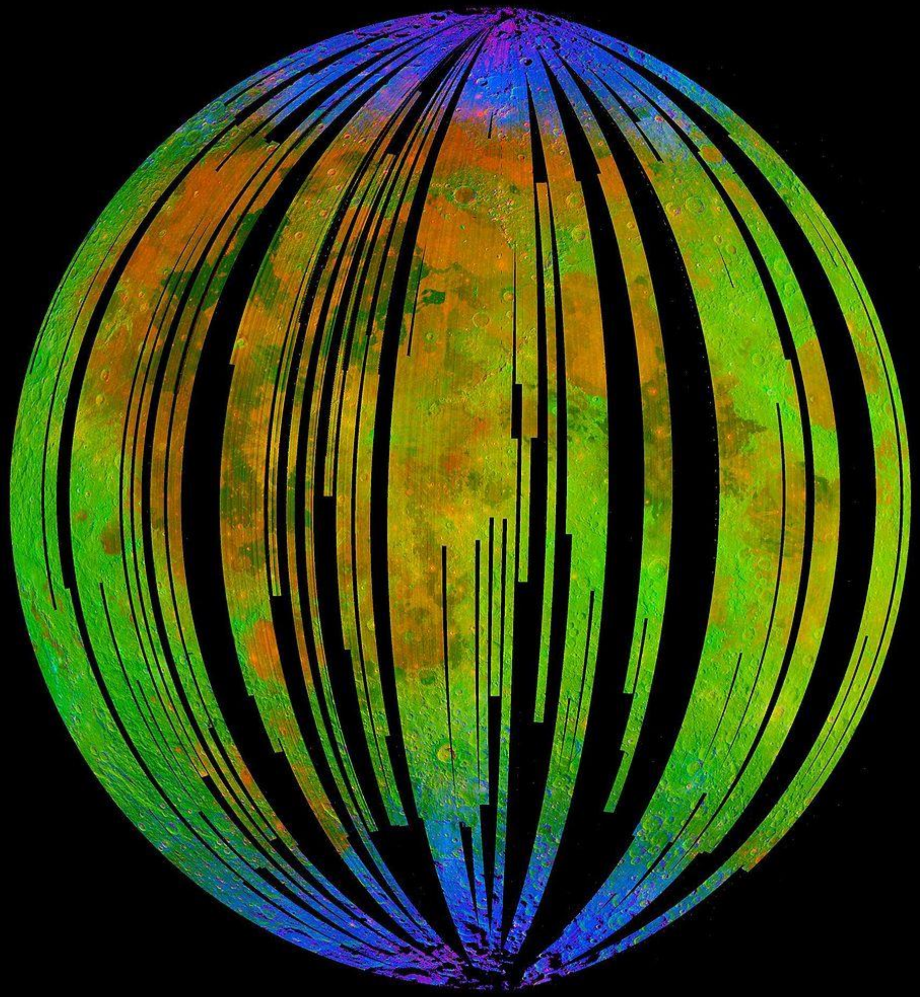

Moon Mineralogy Mapper data

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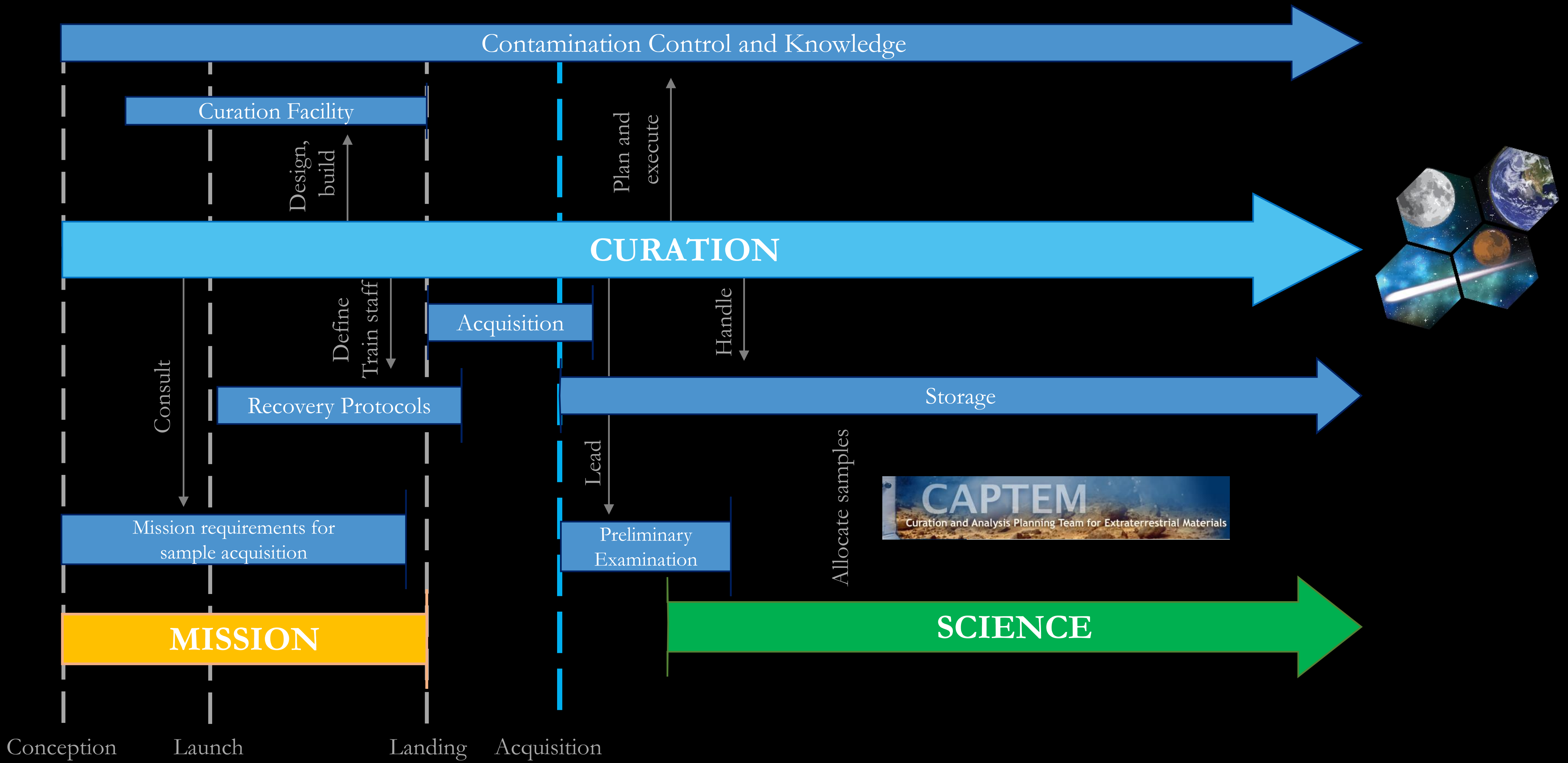
"The instrument suite of a sample return mission is the entire Earth"
–Steve Squyres, Cornell University

What is curation?



JSC's Astromaterials Acquisition & Curation Office

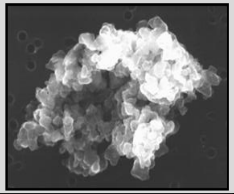
JSC's Astromaterials Acquisition & Curation Office

Our Past 50 years – planning for and curating multiple collections

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

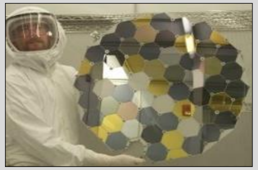
Meteorite
(1977)
Antarctic Search for Meteorites (ANSMET) program

Cosmic Dust
(1981)
Cosmic dust from Earth's stratosphere by high alt. aircraft

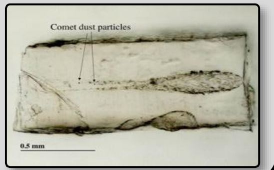


Microparticle Impact Col.
(1985)
Space exposed hardware from spacecraft

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



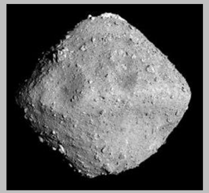
Stardust
(2006)
Cometary and Interstellar Particles from Comet Wild 2



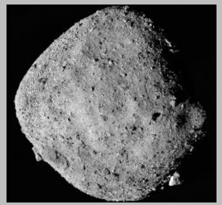
Hayabusa
(2012)
Samples collected from JAXA mission to asteroid Itokawa

Our Near Future . . .

Hayabusa2
(2020)
Subset of samples collected from JAXA mission to asteroid Ryugu

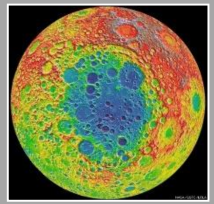


OSIRIS-REx
(2023)
Asteroid sample return from asteroid Bennu



Our More Distant Future . . .

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



Phobos
(2028)
MMX mission by JAXA mission to Phobos

Mars
(2029)
Diff. Mars Sample Return e. g. Mars2020, HAMSR, SCIM

Comet
(2038)
Cold curated surface sample return from a comet

Current curation setup at JSC

All curation activities are in cleanrooms (ISO 7 to ISO 4)

- Differential pressure, T, RH controlled.
- Weekly particle counts in labs.

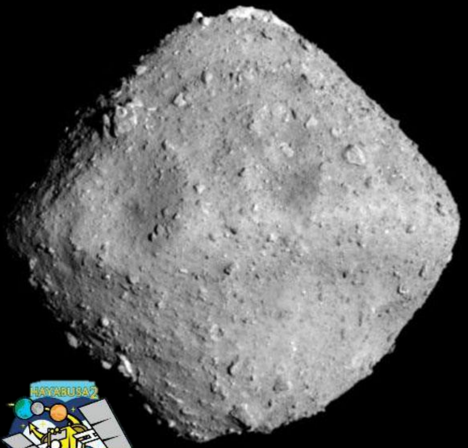
ISO Class suitable gowning is used and daily housekeeping.

Most samples are kept in inert environment (as opposed to vacuum or indigenous)

Contamination Control and Knowledge protocols (next talk)

Lunar curation laboratory

New samples upcoming!



Hayabusa2: (JAXA led) >100 **mg** of pristine carbonaceous regolith from asteroid **Ryugu** (1999 JU3).

OSIRIS-REx >60 **g** of pristine carbonaceous regolith from asteroid **Bennu** (1999 RQ36).

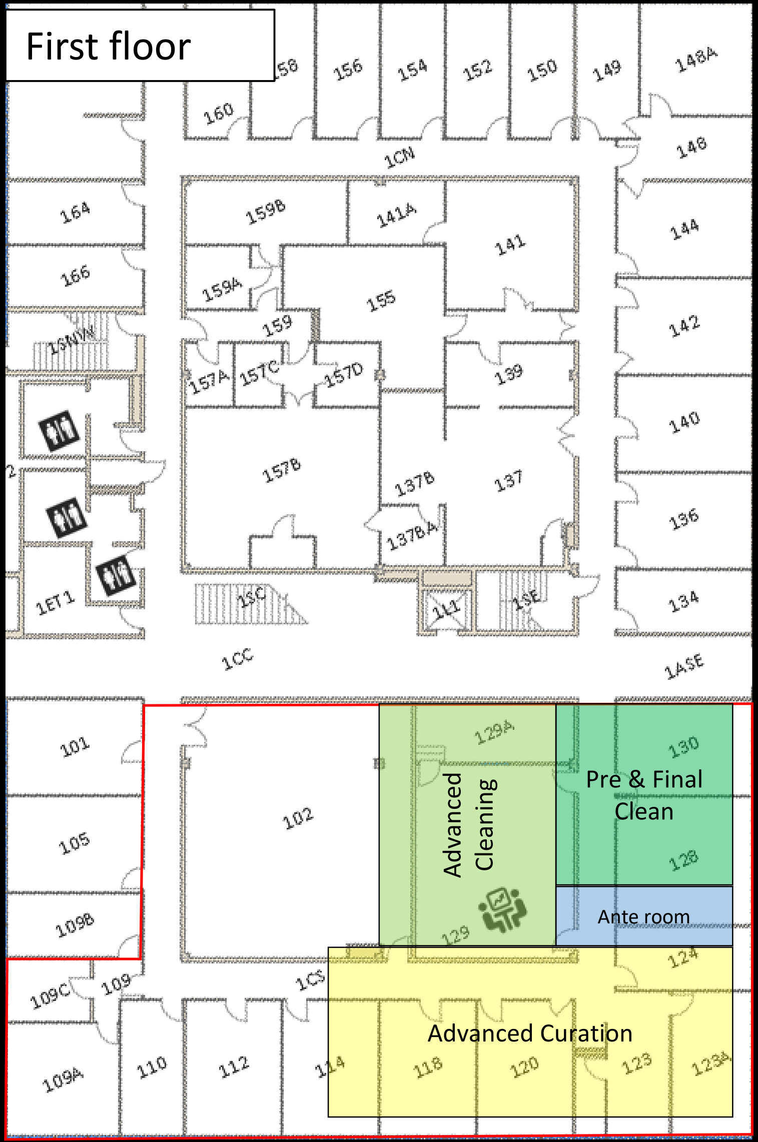
Moon

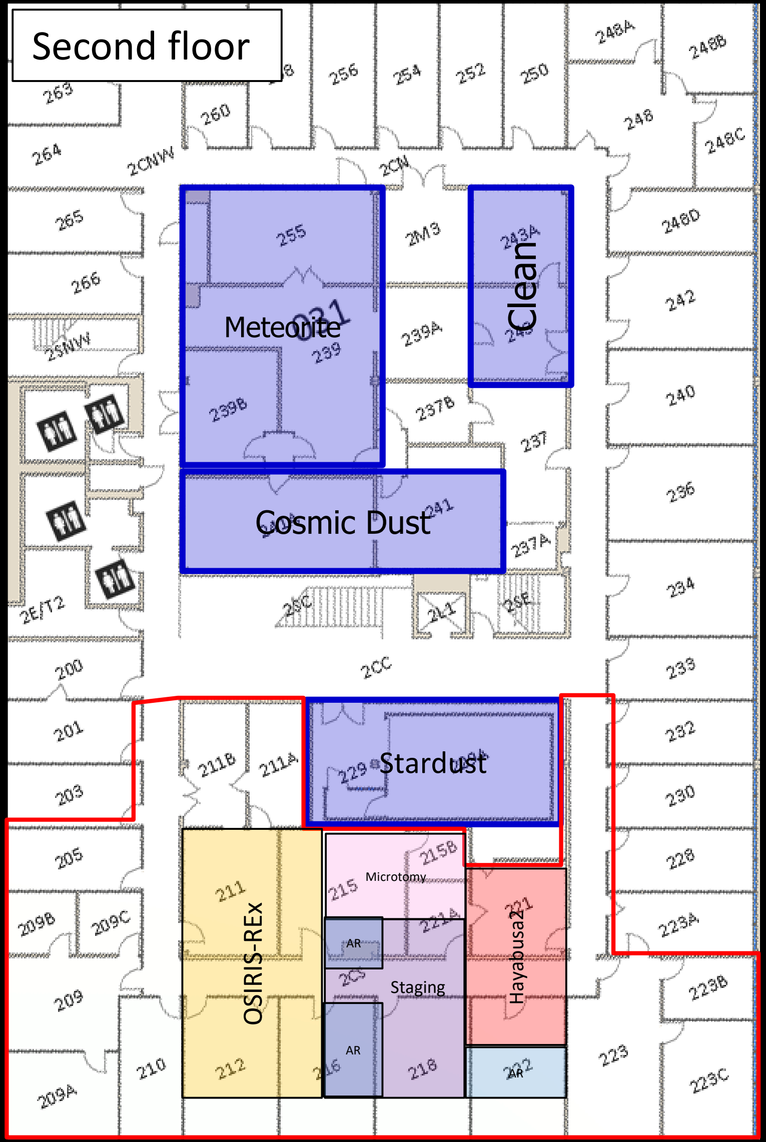
ARTEMIS

Phobos

Mars

New collections need new facilities



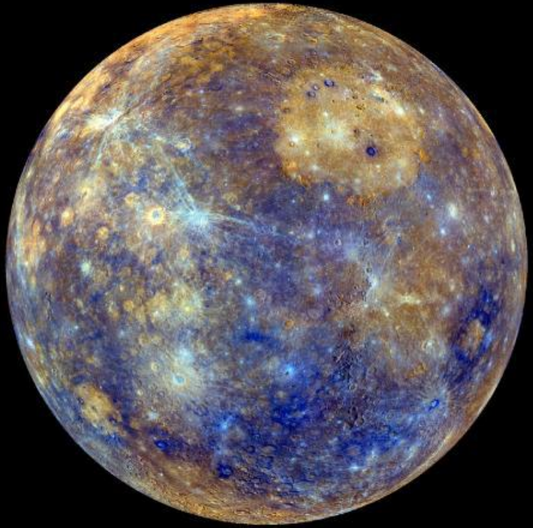


Construction of two new curation facilities, advanced curation and cleaning laboratories (ISO 7 to ISO 5).

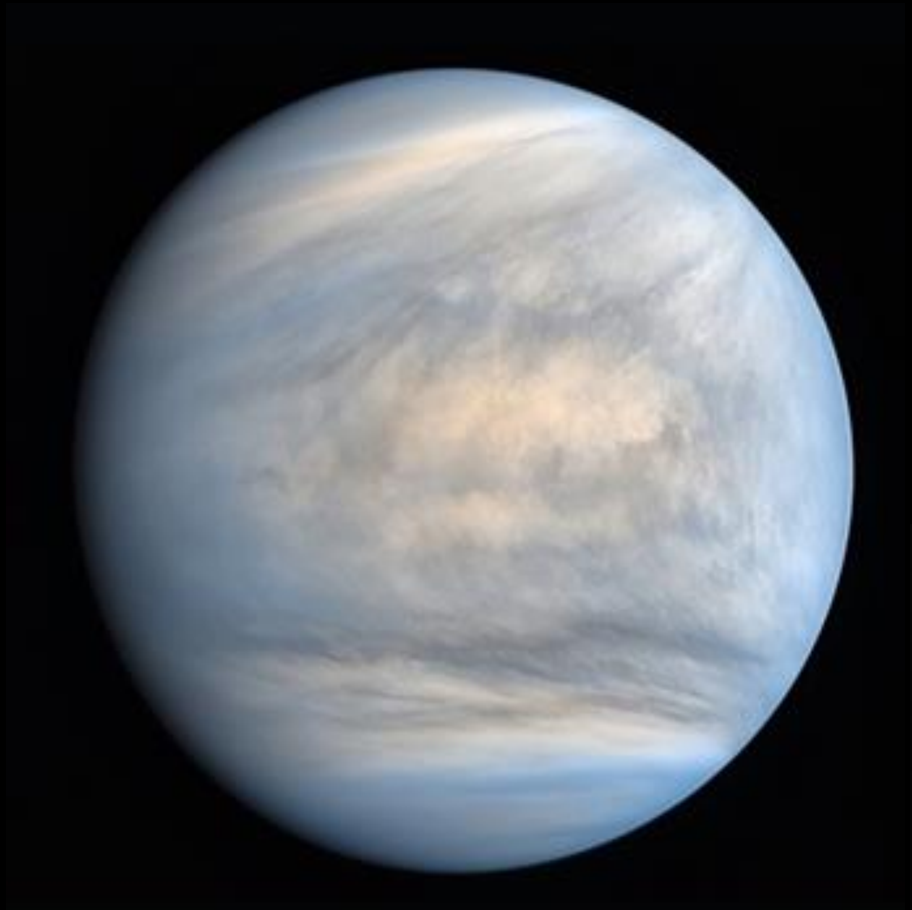
Materials are low-outgassing.

Started March 2019 for about 14 months.

Where could we go next?

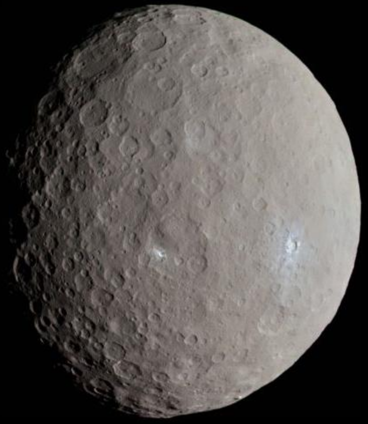


Mercury

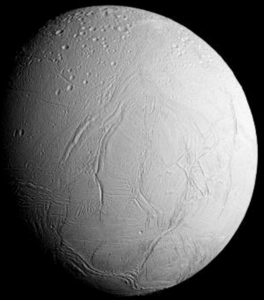


Venus

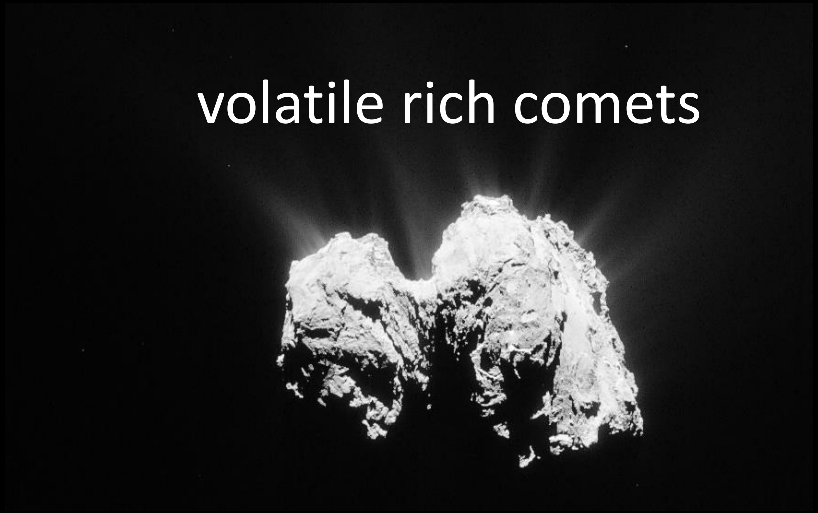
icy and ocean worlds



Ceres

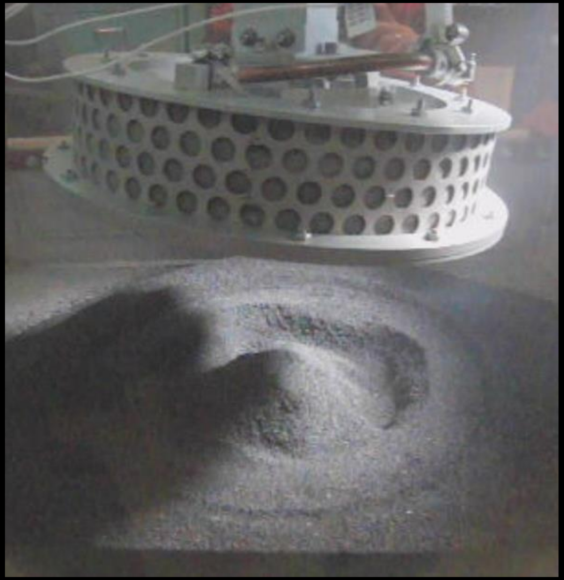


Enceladus



Challenges during mission

- Larger mass of samples (development of ascent vehicles…)
- More flexible sample catching mechanisms (or humans, but brings other issues)

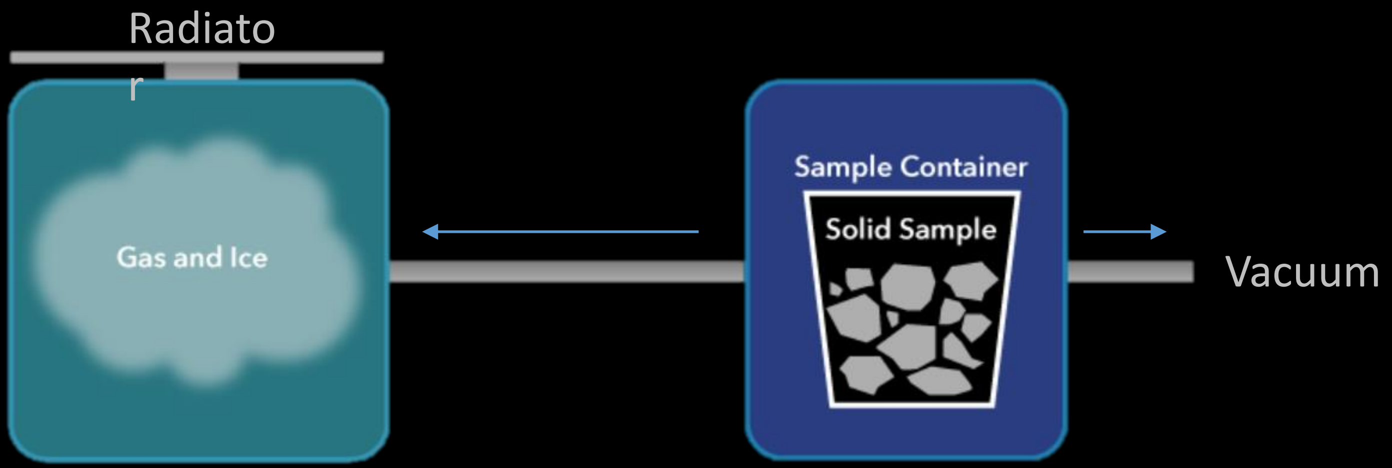


Expectation

Reality

Challenges during mission

- Keep volatile-rich sample pristine (cryogenic or separation of gas and solid)
- Protect samples during journey and landing (heat, radiation, shock…)



Gas reservoir

Sample Containment System

Future needs in storage, processing and handling

- Small particle handling (microscale): routine in laboratory environment…but need to make progress in gloveboxes, vacuum…

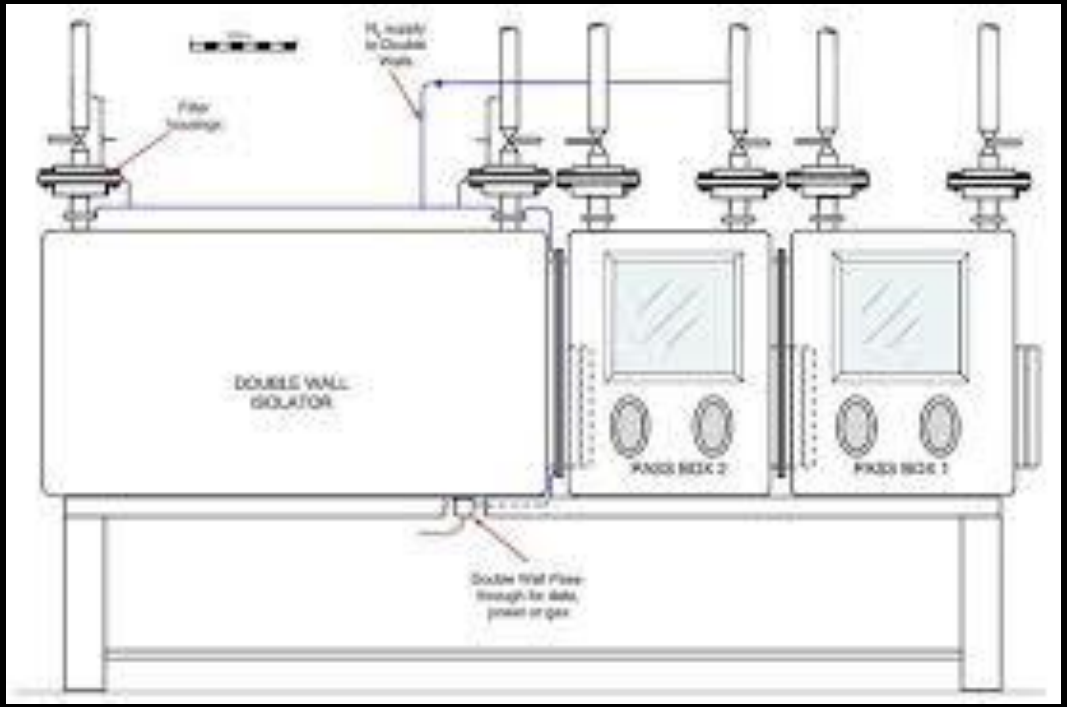
- Organic-rich samples at room temperature (OSIRIS-REx and Hayabusa2)

Future needs in storage, processing and handling

- Cold curation (Lunar missions)
  - <-20°C for handling
  - <-40°C for storage
  - -80°C to -196°C for biological samples

- Cryogenic curation (<180°C) for volatile-rich samples (polar samples from the Moon, and comets)

- Remote manipulation and robotics (cryogenic and biohazardous samples)



Double-walled isolator needs robotic manipulators (EURO-CARES, TAS)

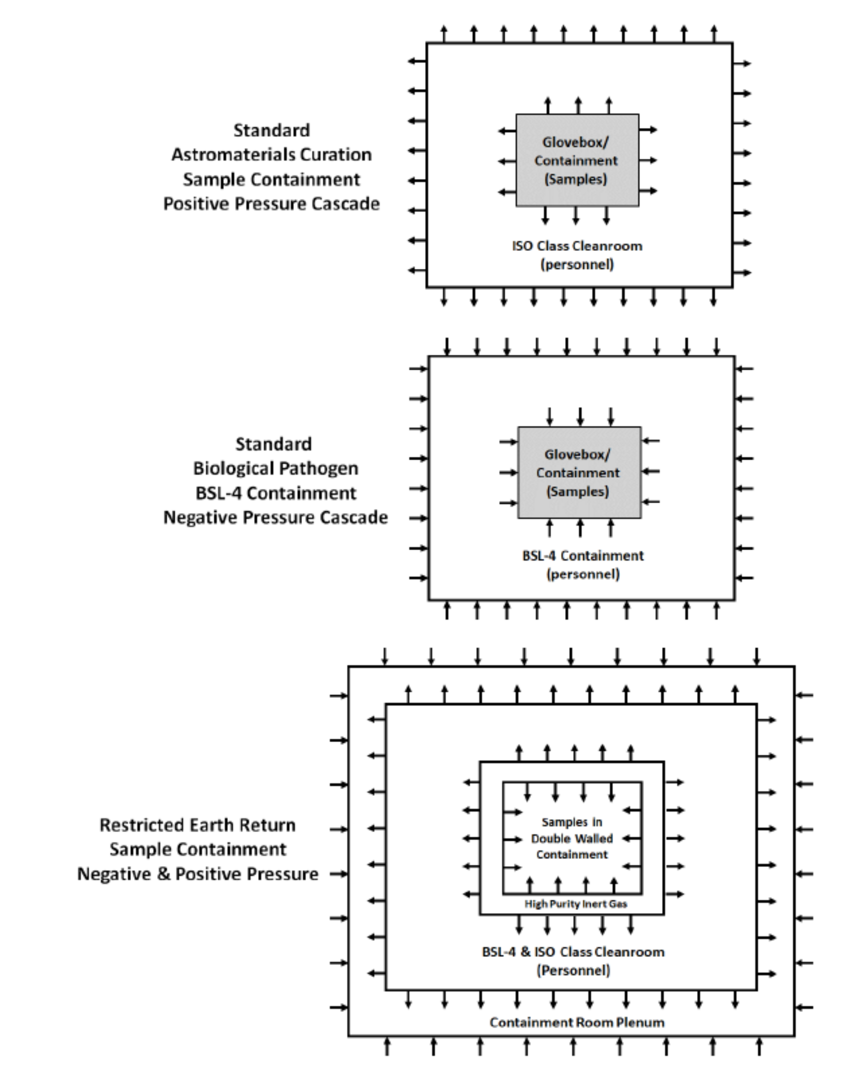
Future needs in storage, processing and handling

- Restricted SRM: contained AND pristine
  - BSL-4 equivalent
  - Proper pressure differentials

…and all the previous challenges

- A curation facility!

EURO-CARES, 2017



Final thoughts

Sample return missions are a necessary addition to remote sensing and in-situ data.

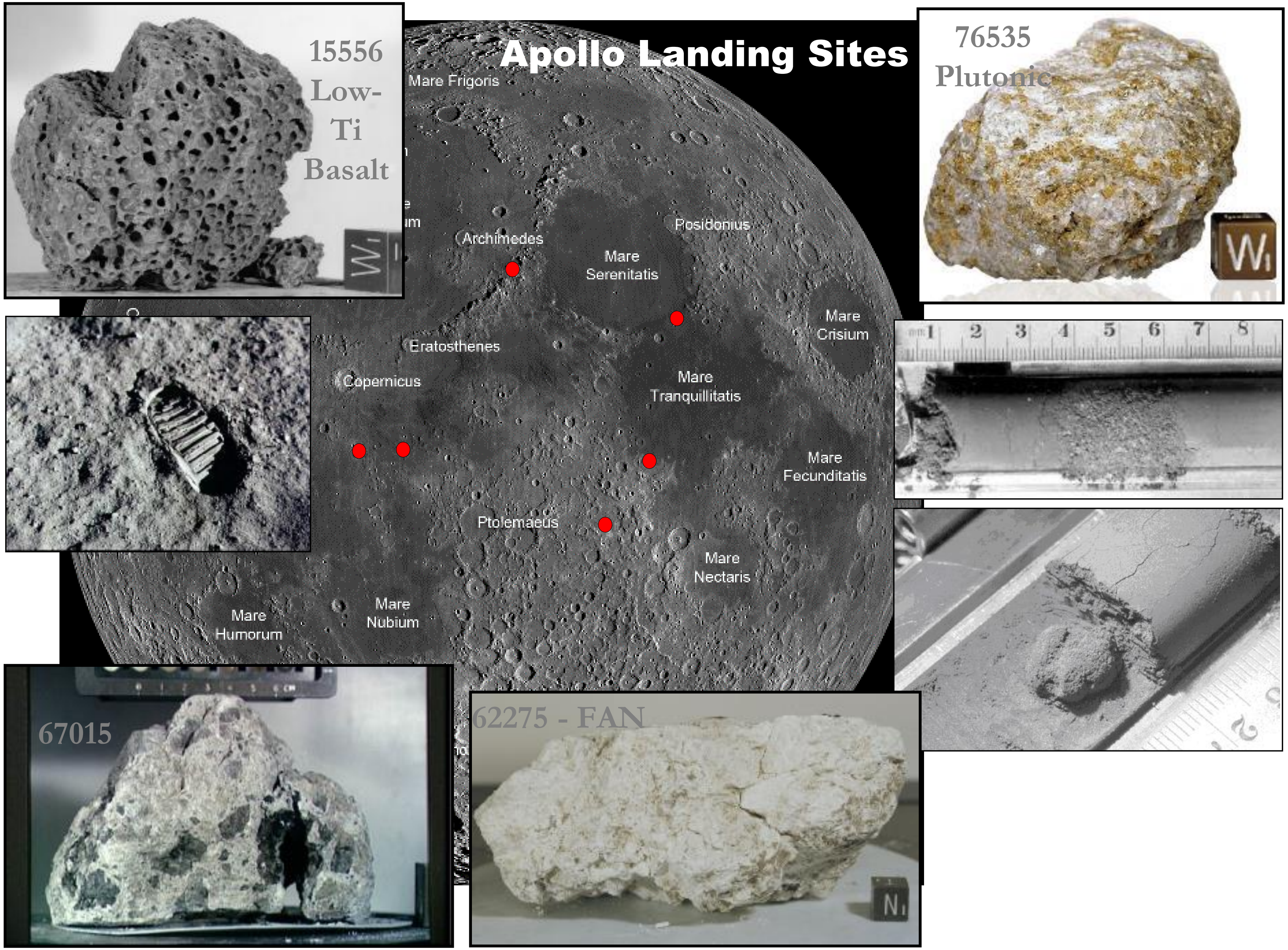
The community is currently getting ready for upcoming returns. Most of the agencies list sample return missions as a high priority in their medium-term plans.

Curation has to be involved from the beginning of a mission design.

Advanced curation must be interdisciplinary, and find novel approaches to limit and quantify contamination.

Apollo Sample Collection 1969-1972

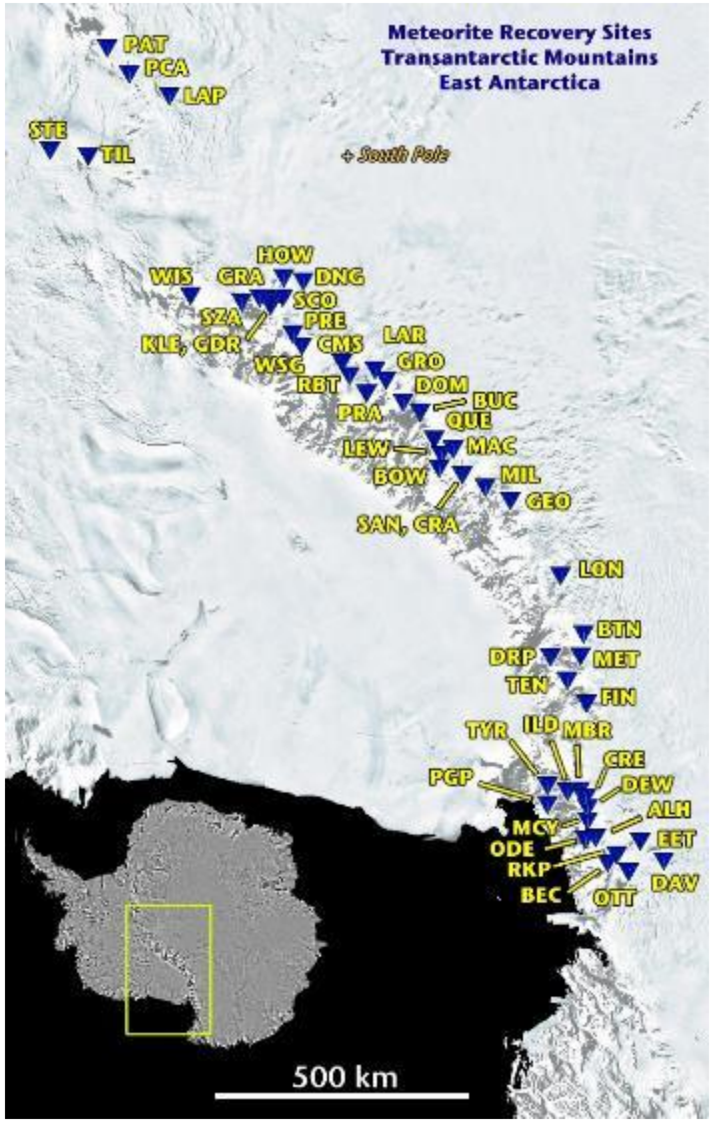
- The Apollo missions collected 382 kg (2200 samples) of rock, soil, and cores from 6 geologically diverse locations on the Moon
- Only sample suite collected by astronauts, and the only suite collected with geologic context.


Apollo Landing Sites
15556
Low-
Ti
Basalt
76535
Plutonic
Mare Frigoris
Archimedes
Mare
Serenitatis
Posidonius
Mare
Crisium
Eratosthenes
Copernicus
Mare
Tranquillitatis
Mare
Fecunditatis
Ptolemaeus
Mare
Nectaris
Mare
Humorum
Mare
Nubium
67015
62275 - FAN

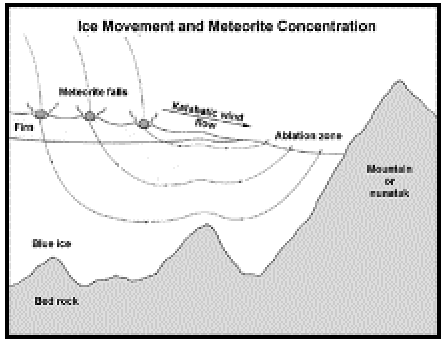
Apollo Sample Collection 1969-1972

- The Apollo missions collected 382 kg (2200 samples) of rock, soil, and cores from 6 geologically diverse locations on the Moon
- Only sample suite collected by astronauts, and the only suite collected with geologic context.
- Lunar lab complex is our largest suite of clean rooms and ancillary labs (ISO 6-7). Samples handled and stored in designated GN2 gloveboxes.

Antarctic Meteorite Collection 1977-Present



- For 40 years, teams of scientists have collected meteorites in the Trans-Antarctic Mountains
- Collection locations are blue ice fields where meteorites entrained in glaciers have been exposed by sublimation.
- Samples found by systematic searches of open ice fields and moraines.
- Meteorite lab complex is similar to the lunar labs (ISO 7, operating at ISO 6), but only “special” meteorites are worked on in cabinets, others are processed in air.



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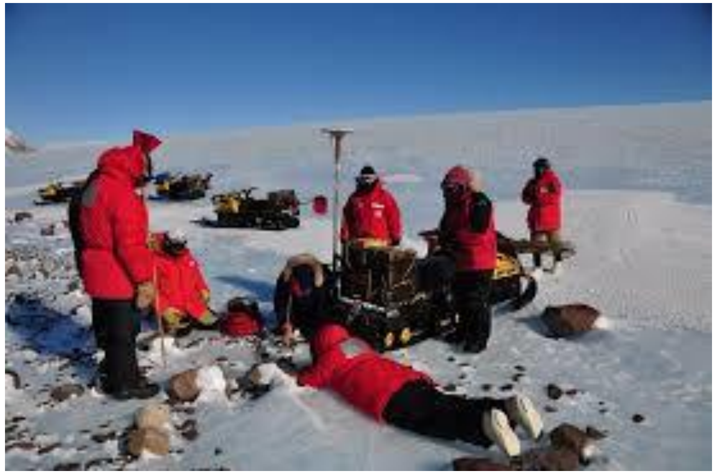

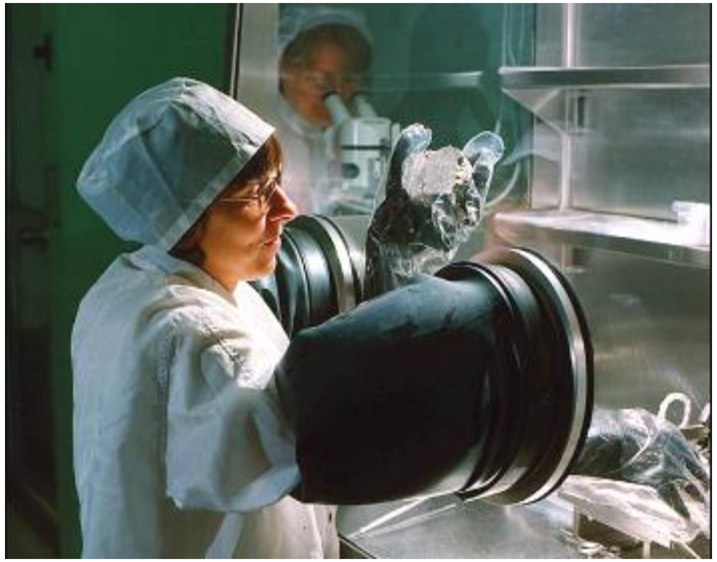

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Cosmic Dust from the Stratosphere 1981-Present

- NASA collects atmospheric dust with collectors on "high altitude reconnaissance aircraft"
- Most collections are with silicone oil collectors of random materials
  - Dry collections attempts.
  - Target comet streams (Giabobini-Zinner).
- Laminar flow clean room (ISO 5) and specialized sample handling techniques allow isolation and preservation of micron scale samples from comets, asteroids, and interstellar dust.

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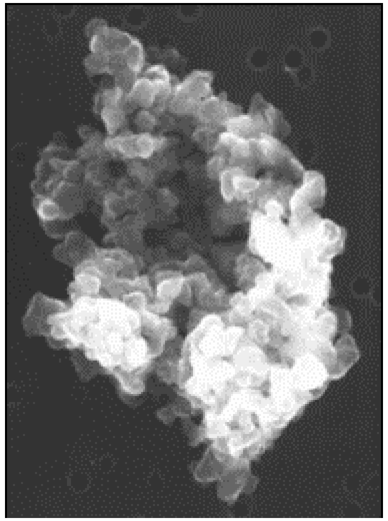

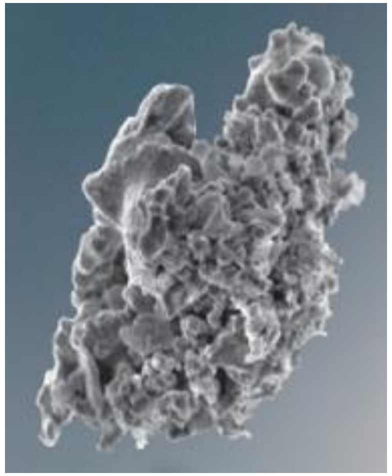

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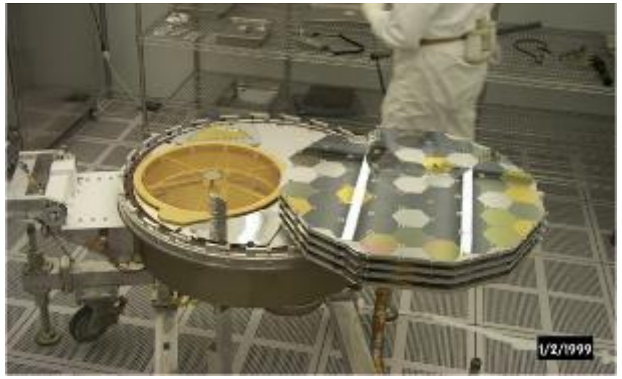
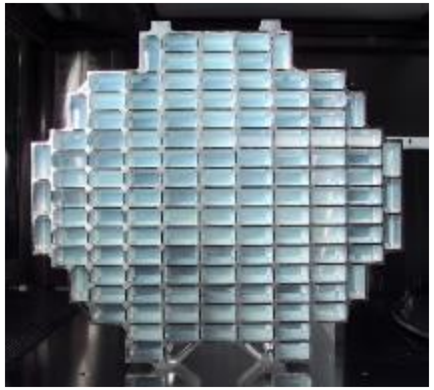
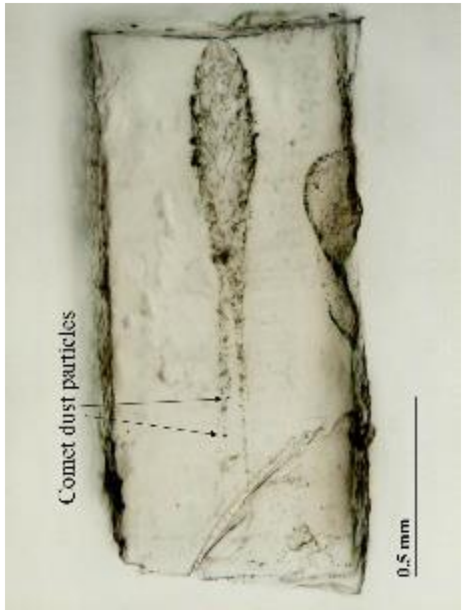
Genesis Solar Wind Samples 2004



- NASA mission that collected solar wind at Earth-Sun L1 location for 28 months.
  - Multiple detector arrays to sample different solar wind regimes
- Had an "off nominal" landing
  - Resulted in the world's worst jig saw puzzle.
  - Highlighted the importance of advanced planning for worst case scenarios.
- Assembled and curated in JSC curation's best clean room (ISO 4).
- Ultimately "every" science result was achieved.

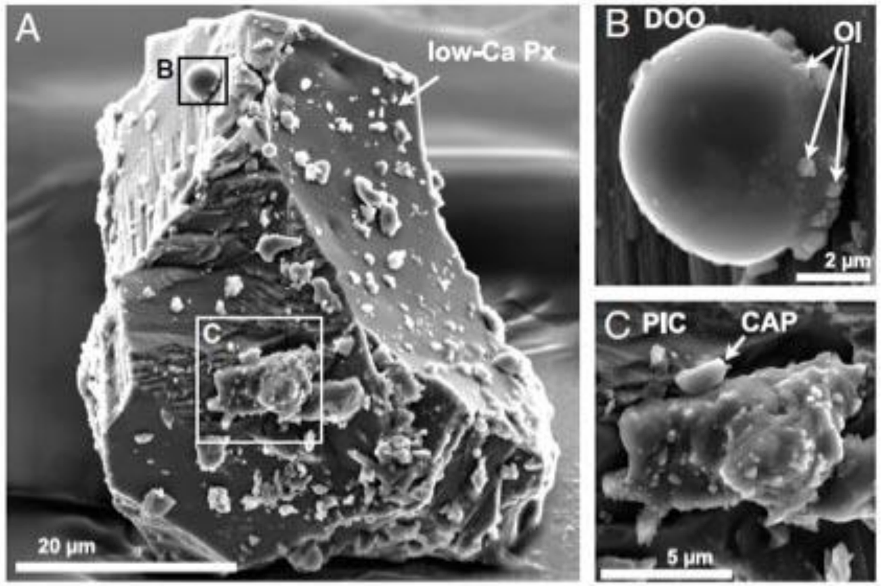
Stardust Comet + Interstellar Grains 2006





- NASA mission that collected particles from the coma of comet Wild 2; interstellar particles were collected during the cruise phase of the mission.
    - Estimated that many 1000s of comet particles were collected; 100s of interstellar particles
- Particles were captured by impacts into silica aerogel.
- Stored in a dedicated ISO 5 clean room.
- New sample handling techniques developed to extract the tracks.

Hayabusa Asteroid Samples 2012



- JAXA mission to study Itokawa, an S-type asteroid (535 meters long).
- Part of the mission involved surface sample collection of small particles by firing a projectile at the surface and flying through the debris.
  - Collection mechanism didn't quite work as intended, but thousands of particles returned in the 10-100 micron size range
- Particles handled in GN2 glovebox in ISO 5 cleanroom.

Allocations - CAPTEM

CAPTEM
Curation and Analysis Planning Team for Extraterrestrial Materials

Proposal reviewed by CAPTEM - allocations approved by NASA

Over 19,000 samples currently on loan to >430 investigators in 24 countries