National Aeronautics and Space Administration

# Advanced Curation activities to address knowledge gaps for curation of returned Martian samples

Francis M. McCubbin

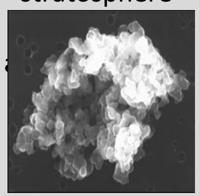
EXPLORATION INTEGRATION AND SCIENCE DIRECTORATE

# NASA Astromaterials Collections

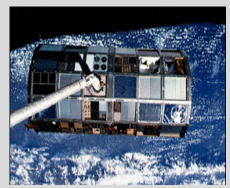
**Lunar**
(1969)
Apollo program lunar rocks and soils; Luna samples

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

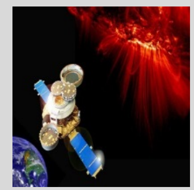
**Cosmic Dust**
(1981)
Cosmic dust grains from Earth’s stratosphere



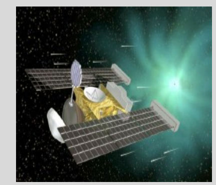
**Space Hardware**
(1985)
Space exposed hardware from spacecraft



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



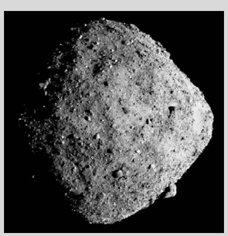
**Stardust**
(2006)
Cometary and interstellar samples from Comet Wild 2



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


**Hayabusa II**
(2020)
Subset of samples collected from JAXA asteroid mission to Ryugu

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



**Artemis**
(2020s)
There are new Lunar Exploration initiatives at NASA

**MMX**
(2029)
Sample return from Phobos

**Mars**
(2030s)
Jezero Crater

Mars 2020 is the first leg in MSR campaign

# What is Advanced Curation, and what is its purpose?

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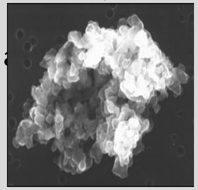

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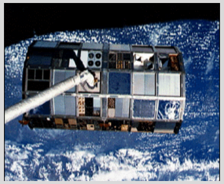

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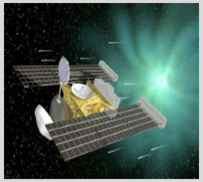

**Hayabusa**
(2012)
Samples collected from JAXA asteroid mission to Itokawa


Advanced Curation at NASA aims to improve and enhance the science returns of the collections that we already have by developing better methods of cleaning, sterilization, cleanliness monitoring, sample processing, and, for the collections that are still growing (i.e., meteorite and cosmic dust), new and innovative ways to collect samples.

# What is Advanced Curation, and what is its purpose?

Advanced Curation also includes the R&D activities needed to fill knowledge gaps for curating, processing ,and allocating the types of samples that are not already in our collections but that we anticipate collecting in the coming 1-2 decades.

These activities are critically important so that we are prepared to “hit the ground running” when samples arrive at the curation facility.

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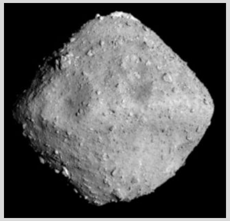
(2020)
Subset of samples collected from JAXA asteroid mission to Ryugu



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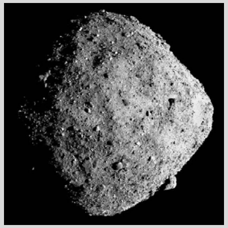

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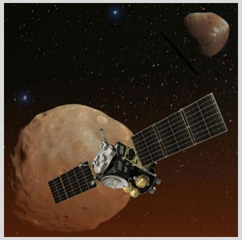


**Mars**
(2030s)
Jezero Crater

Mars 2020 is the first leg in MSR campaign

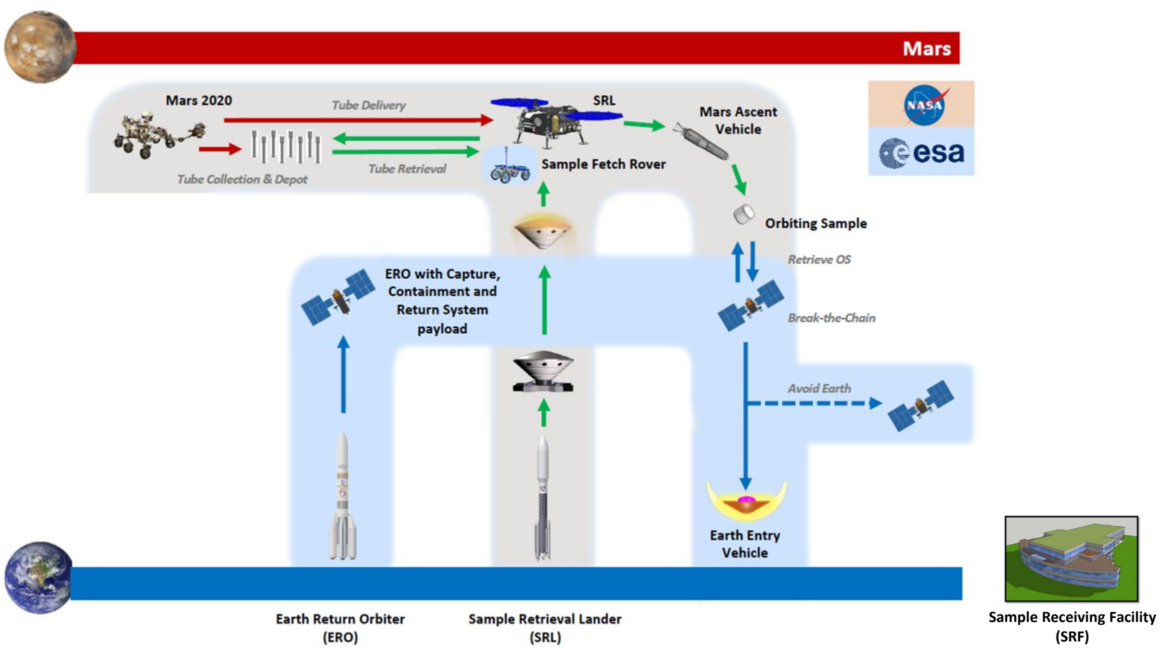
# Topics I was asked to cover in this presentation

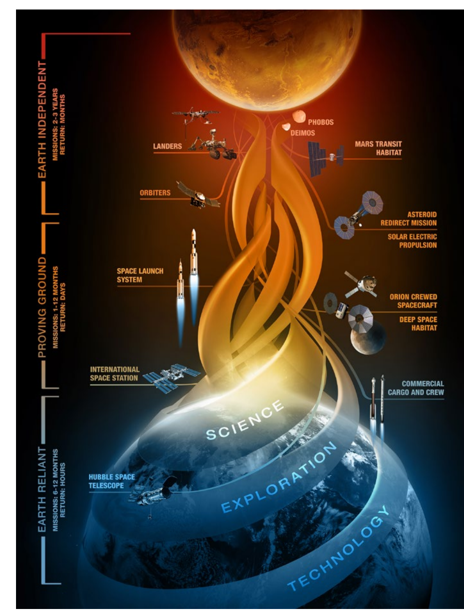
Advanced curation with a specific emphasis on returned Mars samples including ice

Any gaps or concerns you perceive regarding receiving and processing samples from the Mars Sample Return mission.

**Mars**
(2030s)
Jezero Crater

Mars 2020 is the first leg in MSR campaign



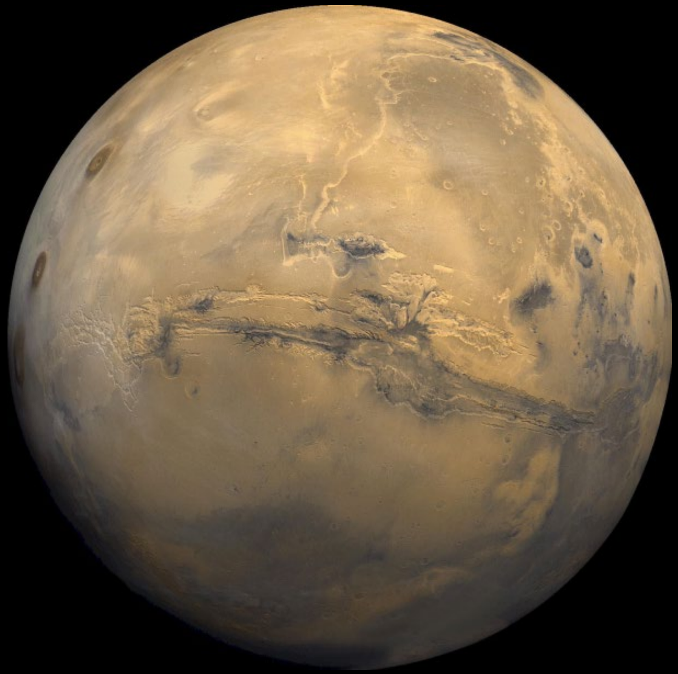



# Regarding Ice in returned Martian samples

An important aspect of advanced curation involves becoming prepared for curation and processing of returned cold samples (including ices). Although we anticipate a need to be ready for this in the near term with Artemis and possibly a comet sample return mission (one of the NF5 options), it is unlikely that ice will be a component of the first MSR campaign currently in progress.

Nonetheless, ice would have value to both science and human exploration, and preparing for the eventual return of martian ice in a subsequent sample return mission would be a valuable aim of future advanced curation studies.

# MSR will enable transformative science and provide unique challenges



- **Implementation of planetary protection requirements and contamination control requirements in a single curatorial infrastructure**

- **Sample safety assessment and possible sterilization of samples**

- **Instrumentation to use for basic characterization and preliminary examination to construct a useful sample catalog**

**The nominal plan is to return samples to Earth in the early 2030's, which gives us about 10 years (less in some cases) to work out unknowns**

**There are experiments and studies we can do now (some are in progress) to prepare for MSR and be ready to hit the ground running**

**The activities needed to prepare will require participation from government agencies and the broader scientific community**

# Planetary Protection requirements for class V Restricted Earth-Return

**NASA Interim Directive**
**NID 8020.109A**
**Planetary Protection Provisions for Robotic Extraterrestrial Missions**
Effective Date: March 30, 2017

***Category V, Restricted Earth Return (Noted Summary Requirements): "***Impact avoidance and contamination control including: clean room assembly, microbial containment of sample, breaking chain of contact with target planet, sample containment and biohazard testing in receiving laboratory (continuing monitoring of project activities, preproject advanced studies and research, as needed)."

"2.3.3 For PP Category V missions designated as "Restricted Earth Return," an extensive set of additional documentation, detailed in section 2.7, shall be required. The associated activities and reviews are intended to ensure that the Earth's biosphere is not adversely affected by the introduction of material from returned samples.

2.3.3a The highest degree of concern is expressed by the prohibition of destructive impact upon return, the need for containment throughout the return phase of all returned hardware which directly contacted the target body and/or any unsterilized material from the body, and the need for containment of any unsterilized sample collected and returned to Earth.

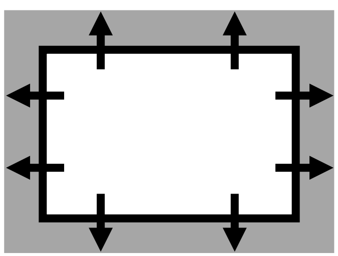
2.3.3b After the flight mission there is a need to conduct, under strict containment and using approved techniques, timely analyses of the unsterilized sample collected and returned to Earth. If any sign of a non-terrestrial replicating entity is found, the returned sample must remain contained unless treated by an effective sterilizing procedure."

# PP and CC requirements?

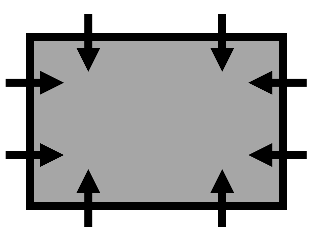
## Curation of Martian Samples

- **ISO Class Cleanroom facility** is required to work with Martian samples in order to prevent terrestrial contamination of samples.
- **Biosafety Level 4 (BSL-4)** is required for work with dangerous and exotic agents that pose a high individual risk of aerosol-transmitted laboratory infections and life-threatening disease that is frequently fatal, for which there are no vaccines or treatments, or a related agent with unknown risk of transmission (*e.g.*, unknown viable life on extraterrestrial geologic material or flight hardware).
- There are two models for BSL-4 laboratories:
  - Cabinet Laboratory — Manipulation of agents must be performed in a Class III Biosafety Cabinet (BSC); *i.e.,* glovebox
  - Suit Laboratory — Personnel must wear a positive pressure supplied air protective suit.
- Negative Pressure BSL-4 cabinet and suit laboratories have special engineering and design features to prevent microorganisms from being disseminated into the environment.
- **Integrating the BSL-4 and ISO Class cleanroom environments is integral for Planetary Protection and Contamination Control.**

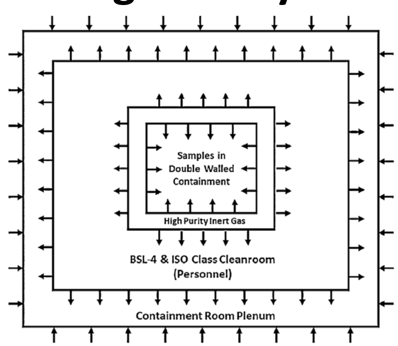
**ISO Cleanroom**



**BSL-4**



**Integrated System**




USAMRIID – Fort Detrick
BSL-4 Pressurized Suit Laboratory

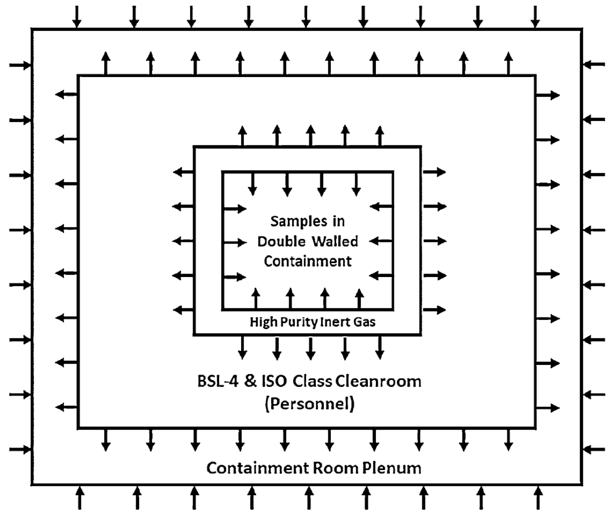
USAMRIID – Fort Detrick
ABSL-4 BSC Class III (Glovebox) Laboratory

# PP and CC requirements?

## Actions needed over next decade

- Existing BSL-4 labs are not designed to host cleanrooms
- There needs to be engineering studies on how to integrate both functions in a single infrastructure, which first requires funding studies to work out the options and trade space (e.g., sharing space at an existing BSL-4 lab, building a permanent brick and mortar facility, building a temporary/semi permanent modular facility)
- Once an implementation is determined and selected, there are many steps and approvals needed for building the facility and verifying BSL-4 requirements to the point where it is “hot”. This process can take about 10 years from start to finish
- The workforce needed to work in both BSL-4 and cleanroom environments does not exist and would need to be developed and trained over this same period of time
- For Class V Restricted Earth Return missions, space agencies are not the only government stakeholders involved. Public health officials and other regulatory agencies play an important role and will have a say in implementation.
- May need development of tools and infrastructure that can optimize sample curation under combined BSL-4/cleanroom conditions (e.g., ESA has funded the study and development of a double-wall isolator). We may need to develop sample isolation containers for each of the sample tubes, and we may need a mobile BSL-4 facility to deploy at the landing site.

### Integrated System




# Life detection testing and Preliminary Examination

**NASA Interim Directive**
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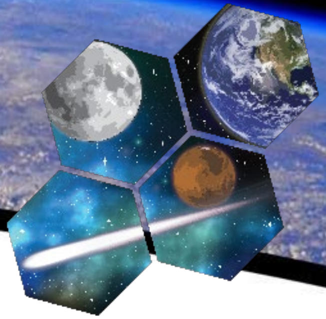
**Planetary Protection Provisions for Robotic Extraterrestrial Missions**
Effective Date: March 30, 2017

2.7.4.5 Sample Pre-Release Report
Before an extraterrestrial sample is released to the general scientific community for investigation, a "Sample Pre-Release Report“ shall be prepared certifying that, if released, the sample will not harm the Earth's biosphere. This report verifies that biohazard and life detection protocols have been executed and that samples are free of hazard to the Earth's biosphere and are, therefore, safe for release.

2.3.3b
After the flight mission there is a need to conduct, under strict containment and using approved techniques, timely analyses of the unsterilized sample collected and returned to Earth. If any sign of a non-terrestrial replicating entity is found, the returned sample must remain contained unless treated by an effective sterilizing procedure.

# Sample Safety Assessment



## Sample Safety Testing

NASA/CP—2002–211842

# A DRAFT TEST PROTOCOL FOR DETECTING POSSIBLE BIOHAZARDS IN MARTIAN SAMPLES RETURNED TO EARTH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October 2002


Mars Extant Life: What's Next? 2019 (LPI Contrib. No. 2108) 5028.pdf


**Planetary Protection: Updating the Draft Test Protocol in the light of almost two decades of research.** M. M. Grady[1] and the COSPAR SSAP WG[2], [1]School of Physical Sciences, The Open University Milton Keynes MK7 6AA, UK (monica.grady@open.ac.uk), [2]Sample Safety Assessment Protocol Working Group.

**Introduction:** The return of samples from Mars has been an international scientific priority for several decades – and it now seems that it actually might take place in the next decade (or so). But, we need to be prepared for materials to come back to Earth. There are top-level technical and governance issues that must be solved, including: where will the samples be received? How will they be curated? Where and how will they be studied? How will they be distributed? etc. Before any of these questions, though, must come consideration of planetary protection.

To date, all missions that have landed on Mars have been subject to planetary protection requirements that ensure that forward contamination is kept to a minimum, i.e., the microbial burden carried by spacecraft is reduced as far as possible by implementing bioburden control measures. Now that we are considering bringing material back to Earth, it is essential to consider the problem of backward contamination, the possible contamination of Earth by martian organisms. A Draft Test Protocol, drawn up in 2002, lays out the requirements for "sample materials to be assessed for biological hazards and examined for evidence of life (extinct or extant), while safeguarding the samples from possible terrestrial contamination" [1]. Since this protocol was produced, there has been a growth in our understanding of Mars through results from successful lander and rover missions, as well as from a greater variety of martian meteorites. Understanding of microbiology, the conditions under which microorganisms survive and the techniques for identifying and sequencing them has also increased.

It has been recognized by iMars II [2] and COSPAR that it is now time to update the Draft Test Protocol, enabling the community to prepare for Mars Sample Return (MSR) using the most recent and relevant information. To this end, COSPAR established in September 2018 a Sample Safety Assessment Protocol Working Group (SSAP WG) to provide a mechanism by which the international community could meet to discuss and update the Draft Test Protocol [1]. It is not intended that the SSAP Working Group would cover aspects of a MSR programme that deals with implementation of the protocol (e.g., sterilisation of material from Mars, environmental and health monitoring, containment elements, contingency planning, management elements, etc.).

**SSAP WG tasks:** Following review and assessment of all relevant documentation, in particular the Draft Test Protocol [1], the Life Detection Workshop Report [3] and various MEPAG-sponsored reports [3-6], the WG will undertake the following tasks concerning the biohazard determination of the returned samples:

- Define type of sample preparation, measurements and associated instrumentation
- Define the sequence of measurements
- Define what constitutes a representative sample for this assessment in terms of type and mass
- Define the statistical approach for sample selection and data analysis
- Define a decision tree to evaluate the safety status of the material from Mars
- Define success/no-success criteria to determine the safety status of the material from Mars, taking into account the sensitivity of this determination on terrestrial contamination in the analysed material
- Estimate the time necessary to execute the protocol
- Ensure throughout the process the highest degree of harmonisation feasible with the scientific analysis of the material from Mars (safety assessment benefitting from science analysis and vice versa).

The tasks will be undertaken through a series of workshops taking place through 2019; the final report will be presented to the 2020 COSPAR Scientific Assembly. The WG is working in parallel, but in contact with, the MSR Science Planning Group (MSPG). The MSPG is a joint NASA-ESA panel established to consider issues around scientific analysis of the returned material. The SSAP WG and the MSPG have several members in common, and at least one of the workshops will be held jointly.


**References:** [1] Rummel J. et al. (2002). [2] Haltigin T. et al. (2018). *Astrobiology 18* S-1-S-131; [3] Kminek G. et al. (2014). *Life Sciences in Space Research 2*, 1–5; [4] McLennan S. M. et al. (2012). *Astrobiology 12*, 175–230; [5] Beaty D. W. et al. (2008). Retrieved from https://mepag.jpl.nasa.gov/reports/iMARS_FinalReport.pdf; [6] Beaty D. W. et al. (2018). Retrieved from https://mepag.jpl.nasa.gov/reports/iMOST_Final_Report_180814.pdf

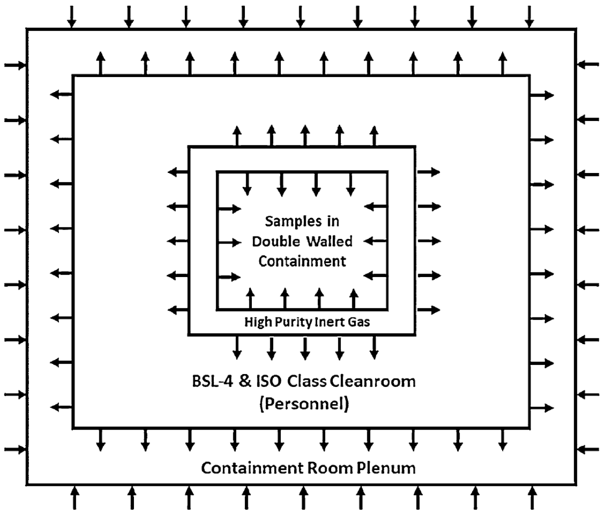

- **Previous groups have been trying to develop requirements for sample safety assessment of returned martian samples. Current group is the COSPAR Sample Safety Assessment Protocol Working Group**

# Sample Safety Assessment

## Actions needed over next decade

- Sample Safety assessment, basic/preliminary characterization, & time sensitive scientific investigations will be happening in the SRF in tandem which will require a management structure equipped to assess competing interests and requirements
- Improvements in life detection capability along with improvements in detection sensitivity of organic molecules that are of biological importance or significance would improve our ability to conduct a sample safety assessment
- Prior to the completion of a sample safety assessment, any scientific investigations on unsterilized martian samples will need to occur within containment in the SRF. Any samples sent out of the facility to PI labs will need to be sterilized
- Additional work on effective sterilization techniques for samples that will minimize the number of scientific questions that would be compromised by implementation of that sterilization technique would be useful.
- For Class V Restricted Earth Return missions, space agencies are not the only government stakeholders involved. Public health officials and other regulatory agencies play an important role and will have a say in implementation.

Integrated System

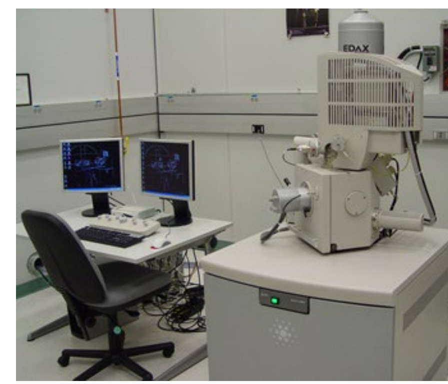



# Sample processing, BC, PE, and time-sensitive analyses

**Initial processing steps**

The purpose of BC is to collect basic information for every sample that will inform subsampling for PE, SA, and t-sensitive science.

The aim of Preliminary Examination is to produce a sufficiently detailed sample catalog from which scientists can make requests for materials for scientific investigations.

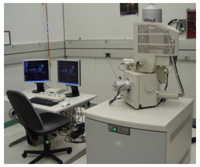



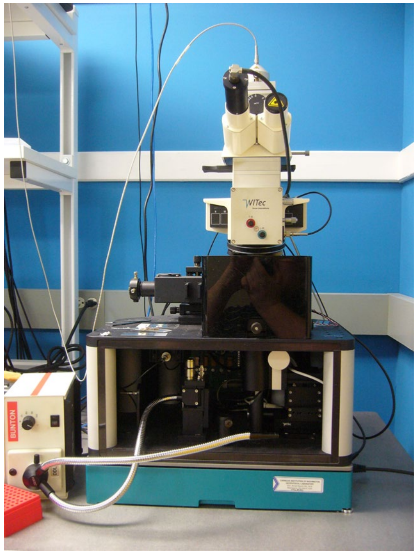

Some time-sensitive analyses would need to happen before BC like XCT and some magnetic measurements where the context of the materials within the core before opening is critical. We need to understand what changes these techniques (and other BC/PE techniques) will have on the samples

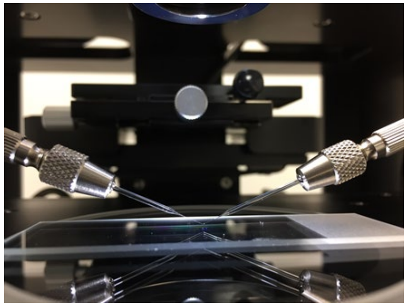
# Sample processing, BC, PE, and time-sensitive analyses

## Open questions that need answers in the next decade

- If we subject the returned samples to XCT, in what ways could other scientific investigations be compromised? In particular, what is the effect of XCT on organics that are of biological significance? Are there beam conditions that would yield minimal effects and sufficient resolution to be useful?
- What kinds of non-destructive measurements can be conducted during BC through the viewports of an isolator or glovebox?
- What kinds of information and analytical instrumentation will be needed during PE to build a sufficiently detailed sample catalog from which scientists can make informed sample requests?
- What types of measurements must be made prior to the tubes being opened because opening the tubes would compromise the measurement?
- What MSR scientific investigations have a limited "shelf life" that warrant doing the primary science early within the SRF?
- What materials should be used to comprise sample containers, isolators, and tools? What atmosphere should be chosen to fill the pristine isolators?





# Summary

To prepare for curation and processing of returned martian samples will require both directed studies (directed by NASA/ESA) and research (solicited proposals funded through R&A programs like LARS or Planetary Protection Research) to fill existing knowledge gaps.

Time is of the essence. There is a lot to learn about combining cleanroom and BSL-4 infrastructure, and there is a long lead time for building and approving BSL-4 facilities. With the existing MSR timeline, the schedule may be tight for facility completion prior to return of samples.

NASA and ESA are already moving forward with planning for the MSR ground element with the establishment of MSPG2, SSAP, and other similar groups. Furthermore, LARS already includes MSR as "in scope" within its AO. There is a lot of work ahead in the coming decade, and it will take a ramped effort on the part of government agencies and the scientific community to hit the ground running once samples are returned.