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CONSENSUS STUDY REPORT

STRATEGIC INVESTMENTS IN INSTRUMENTATION  
AND FACILITIES FOR EXTRATERRESTRIAL  
SAMPLE CURATION AND ANALYSIS

**Roberta L. Rudnick** (Chair), UC Santa Barbara  
**George Cody**, Geophysical Lab, Carnegie Inst. Sci.  
**James H. Crocker**, Lockheed Martin Space Systems  
Company, Ret.

**Vinayak P. Dravid**, Northwestern University  
**John M. Eiler**, California Institute of Technology  
**Abby Kavner**, University of California, Los Angeles  
**Timothy J. McCoy**, Smithsonian Institution  
**Clive R. Neal**, University of Notre Dame  
**Hanika Rizo**, Carleton University  
**Kimberly T. Tait**, Royal Ontario Museum

Staff:

**Abigail Sheffer**, Study Director  
**Sarah Brothers**, Associate Program Officer  
**Anesia Wilks**, Senior Program Assistant  
**Carson Bullock** and **Jonathan Lutz**, Lloyd V.  
Berkner Space Policy Interns

# Chapters

1. Introduction
2. Previous sample return missions
3. Current and near-future missions
4. Current labs and facilities
5. Current and future instrumentation and investments for extraterrestrial sample analysis

# Curation recommendations

**Recommendation:** NASA Planetary Science Division should **increase support for Johnson Space Center** to develop appropriate curatorial and characterization facilities relevant to and **necessary for future sample returns of organic matter, ices, and gases.**

**Recommendation:** NASA Planetary Science Division should **accelerate planning for curation of returned martian samples**, seeking partnerships with other countries, as appropriate.

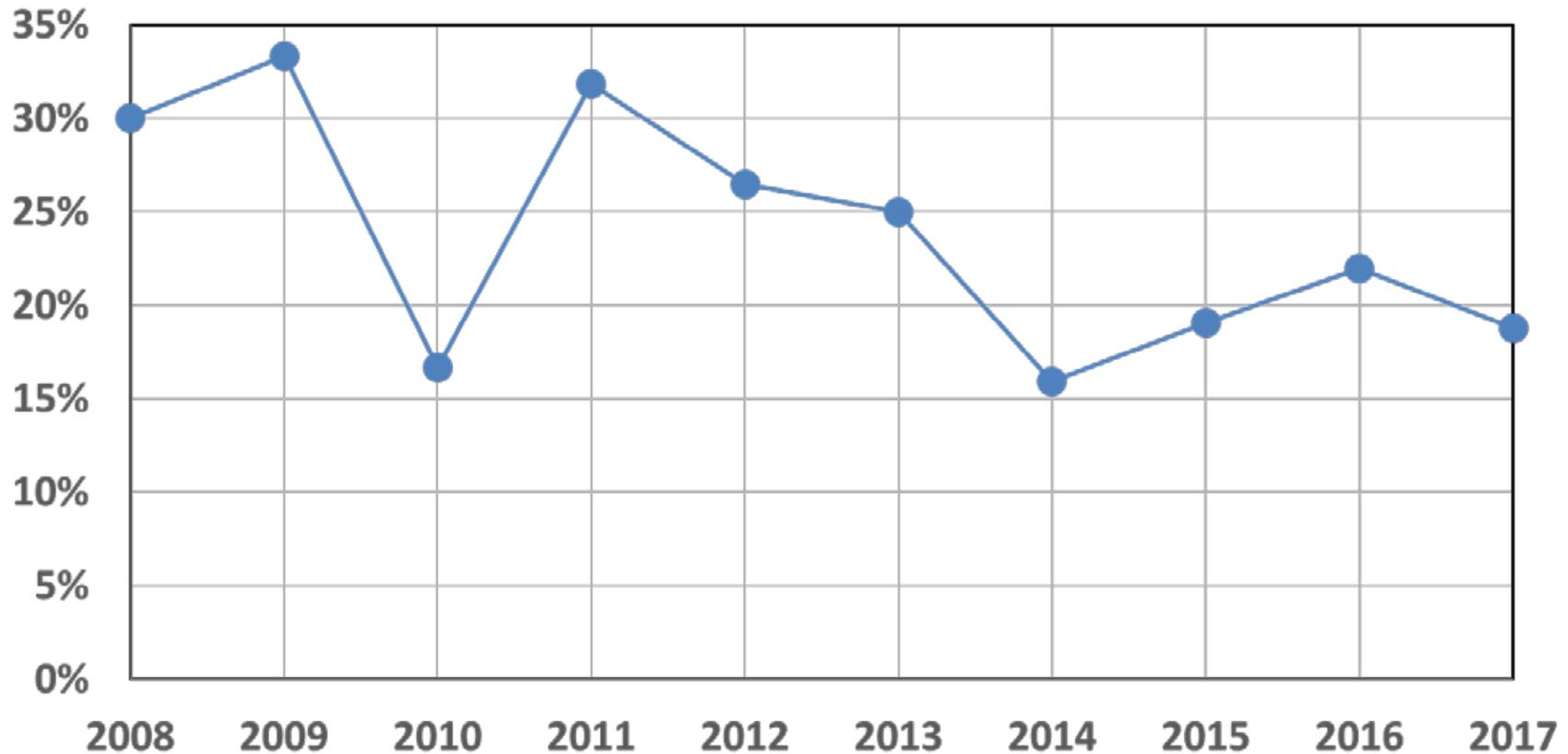


# Instrumentation conclusions

- **Conclusion:** The committee's analysis of analytical equipment available at U.S. laboratories indicates that there is a wide range of instrumentation that is currently accessible for returned sample analyses. **There are no obvious gaps in instrumentation for analysis of returned rocks, glasses, minerals, and the current inventory of organic materials.**
- **Conclusion:** Missions in flight will not return samples for at least five years, therefore, **some of the current analytical capabilities will be decommissioned before the samples are available.**
- **Conclusion:** Future sample return missions are focused on returning and analyzing **more challenging materials** (e.g., gases, ices, organic compounds, see Chapter 3) and **will require investment in technologies that are not currently widely utilized by the sample return community.**

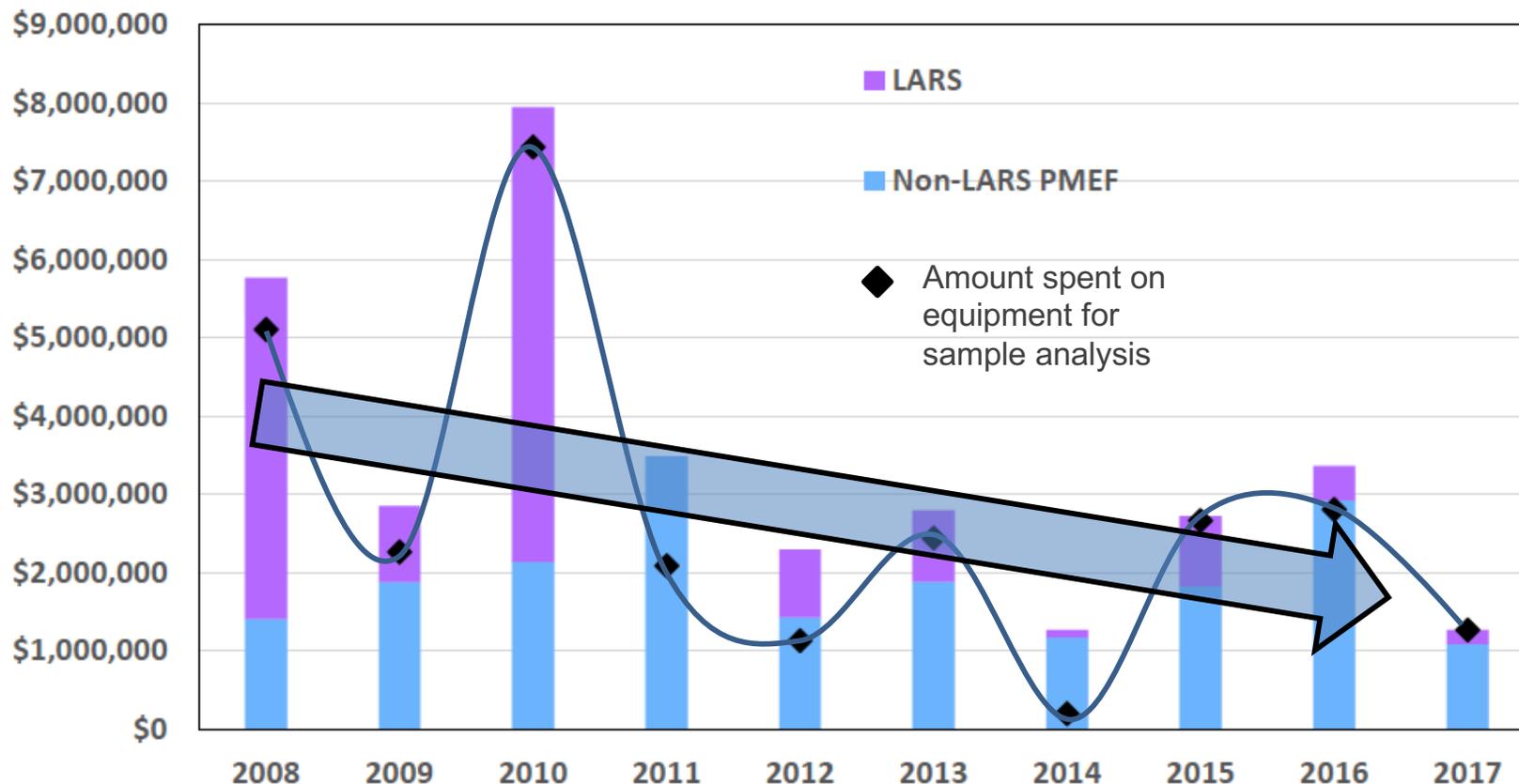
# Investment considerations

## PMEF proposal funding rate\*



\*2017 numbers incomplete; excludes LARS proposals with integrated equipment

# Investments\* in major equipment: PMEAF & LARS



\*2017 numbers incomplete

# Investment outcomes

- If funding for instrumentation is **flat or decreased**, labs will need to be cut in order to develop new capabilities.
  - mitigate by funding regional or national facilities?
- If **modest funding increase**, could support current labs and new capabilities, but developing methods for new materials (e.g., ices, gases) would be challenging.
- If **significant funding increase**, maintains current capabilities; allows pursuit of new capabilities, funding tech staff; spurs innovation.



# Investment considerations

**Conclusion:** If future instrument funding decisions must be made under the constraint of **flat or decreasing overall funding levels**, then the several competing demands of sample return science **will likely exceed available resources**, necessitating a focus on a few highest priority needs.



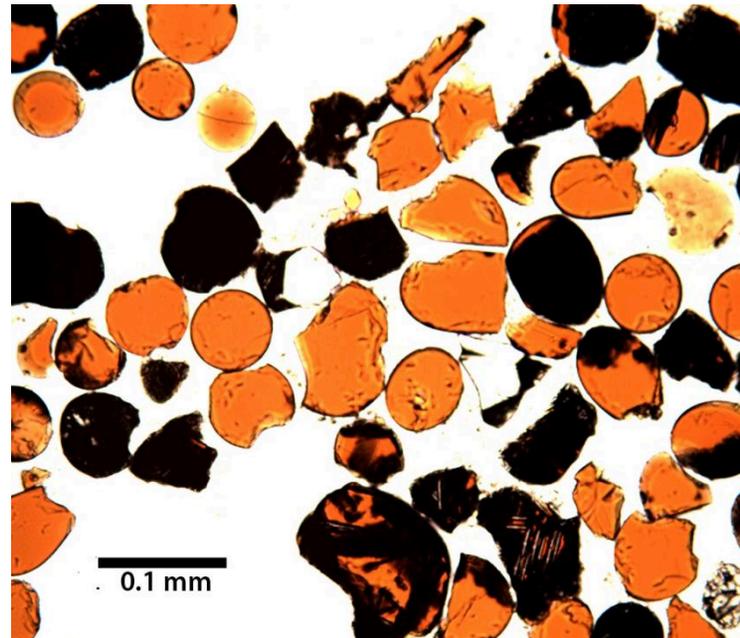
# Investment recommendations

- Prioritize support for instrumentation, technical staff and equipment maintenance
- Need to replace existing capacity & *develop new capabilities*

**Recommendation:** NASA Planetary Science Division should place **high priority on investment in analytical instrumentation** (including purchase, maintenance, technical oversight, and development) and curation (facilities and protocols) sufficient to provide **for both replacement of existing capacity and development of new capabilities**. This will maximize the benefit from the significant investment necessary to return samples for laboratory analysis from asteroids, comets, the Moon, and eventually Mars and outer solar system moons.

# Investment strategies: LARS program

**Recommendation:** NASA Planetary Science Division should consider opening the Laboratory Analysis of Returned Samples (LARS) grant program to all mission returned extraterrestrial samples.



*Apollo 17 orange glass where indigenous lunar water was first detected by Saal et al., 2008*

# Funding technical support is challenging

**Finding:** U.S. extraterrestrial sample analysis laboratories are experiencing increased difficulty finding and retaining good technical support staff because of the soft money funding model.

**Conclusion:** Having laboratories dependent on recharge to pay technical support staff and maintain instruments suggests that **NASA's investment in analytical facilities is not being maximized.**

**Conclusion:** NASA's **investment in analytical facilities could be enhanced by providing sustained funding for technical support staff**, so that the analytical work undertaken by a laboratory remains focused on extraterrestrial sample analyses.

**Recommendation:** NASA Planetary Science Division should provide means for longer term (e.g., 5-year) technical staff support for analytical instrumentation.



# Training the next generation

**Conclusion:** A highly-qualified workforce that is able to perform both routine, and state-of-the-art laboratory analyses, as well as develop the instruments of the future, is necessary to fulfill NASA's goals for the characterization and analysis of future returned samples.



# Training the next generation

**Recommendation:** NASA Planetary Science Division should encourage principle investigators to specifically address in their research proposals **how the work will contribute towards training** future generations of laboratory-based planetary scientists.



# Technology Development

- Invest in developing novel instrumentation
- Especially for non-traditional samples

**Recommendation:** NASA Planetary Science Division should **make appropriate investments in the technological development** of novel instrumentation and unconventional analytical techniques, specifically for curation, as well as characterization and analysis of non-traditional samples that are expected to be returned from future missions. These would likely include **gases, ices, and organic matter**, including volatile organic compounds (VOCs) and related hybrids and complexes.



# Collaborations and Sharing Knowledge

**Recommendation:** NASA Planetary Science Division should **continue to engage in strategic relationships with international partners** to ensure that the best science possible is extracted from extraterrestrial samples with the limited resources available to all space agencies.

- Examples of unique international labs: Argus collision cell, Bristol; RELAX instrument, Univ. Manchester; Cosmorbitrap, Univ. d'Orléans.

**Recommendation:** NASA Planetary Science Division should consider ways to facilitate the **dissemination of information** about present and future international, state-of-the-art facilities relevant to sample analysis. This could, for example, include organizing workshops to be held with existing international conferences.

# Concluding thoughts





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# Statement of Task

To prepare for the analysis of diverse extraterrestrial samples in the coming decade, NASA requires information on the **current** capabilities of the planetary science community's **analytical laboratory facilities**, their **future requirements**, and any **associated challenges**. Therefore, the National Academies of Sciences, Engineering, and Medicine will assemble a committee to perform a study addressing the following questions:

- What **laboratory analytical capabilities** are required to support the NASA Planetary Science Division's (and partners') analysis and curation of existing and future extraterrestrial samples?
  - Which of these capabilities currently exist, and where are they located (including international partner facilities)?
  - What existing capabilities are not currently accessible that are/will be needed?
- Whether the current sample **laboratory support infrastructure and NASA's investment strategy** meets the analytical requirements in support of current and future decadal planetary missions.
- How can NASA ensure that the science community can stay **abreast of evolving techniques** and be at the forefront of extraterrestrial sample analysis?

# Investment recommendations

**Recommendation:** NASA Planetary Science Division should continue to engage in and **encourage cost-sharing** arrangements for laboratory analytical equipment with other funding sources.

**Recommendation:** NASA Planetary Science Division should continue to invest in **both multi-user facilities and individual principal investigator labs.**

# Collaborations

- Explore collaborations with ‘adjacent’ communities, other federal agencies and national labs
- Especially for organic matter analysis

**Recommendation:** With the rapid developments in related fields such as molecular biology, and concomitant advances in bio-organic analytical methodologies, NASA should consider **partnerships with relevant federal agencies (e.g., DOE and NIH) and laboratories** (e.g., the National Laboratories). NASA should implement **information exchange activities** (e.g., joint workshops) to enhance cross-fertilization and cooperative development of analytical instrumentation and methods, specifically **to enhance analysis of organic matter** (both macromolecular/polymeric and molecular-moderate molecular masses, as well as volatiles-low molecular weight compounds), in the study of extraterrestrial returned samples.

# Instrumentation

Types of Analysis Types of Facilities	A. Sample & specimen preparation	B. Physical or Structural Analysis	C. Chemical or Compositional Analysis
1. Commonly available at most institutions—broadly accessible	1A e.g., cutting, grinding, thin section preparation	1B E.g., optical microscopy—zoom and petrographic microscopes	1C E.g. general analytical chemistry equipment
2. Multiple regional facilities—limited access*	2A E.g., scanning electron microscope (SEM) equipped with Focused Ion Beam (FIB) technology	2B E.g., X-ray tomography laboratories; M <sup>3</sup> EGA Laboratory, JSC	2C E.g. many mass spectrometry laboratories  Tabletop FTIR and Raman spectroscopy systems
3. Multiple regional facilities—with access open to users**	3A E.g., neutron activation sources	3B E.g., national Center for Electron microscopy	3C E.g. national ion microprobe centers
4. Unique facility—Limited access*	4A E.g., Creek Road Cryogenic Complex, NASA Glenn Research Center	4B E.g. shockwave laboratories, specialized laboratories at national labs and related research centers	4C E.g. MegaSIMS (UCLA), CHILI (University of Chicago)
5. Unique Facility—access open to users***	5A E.g., Molecular Foundry, Lawrence Berkeley National Laboratory	5B E.g. synchrotron-and/or neutron- based diffraction and or tomography techniques	5C E.g. synchrotron and/or neutron based spectroscopy techniques

# Instrumentation

<b>Mission Relevance Classifications</b>  (Additional mission-specific information is provided in comments in Table 4.2, where applicable)	<b>MR I</b> Fundamental tools relevant for all sample return missions.	<b>MR II</b> More specialized tools, required for rock and metal samples	<b>MR III</b> More specialized tools, required for organic, volatile, and other low temperature materials	<b>MR IV</b> Direct mission relevance not established; however, technique may generate unique data relevant to specific missions
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Method	Purpose	Availability and Access and Mission Relevance (see Table 4.1)	Comments on Relevance to Extraterrestrial Materials and Sample Return Missions
<b>Microscopy, Tomography, and Diffraction Techniques</b>			
<i>Light Microscopy</i>			
Optical microscopy techniques: binocular, optical, reflected, polarized petrographic scopes	Non-invasive imaging, spectroscopy, depth and through-thickness analysis.	1B MR I	
Specialized and unconventional light-optical techniques: e.g., second harmonic generation (SHG), waveguide- and near-field techniques	Non-invasive, optical and structural measurements; typically via light-optical response of the materials.	2B, 3B MR IV	
Computed and Computer-Aided Tomography (CT/CAT)	Radiation-based 3D (4D reconstruction) of objects/structures, down to submicrometer resolution.	4B, 5B MR I	Laboratory based X-ray tomography and synchrotron-based X-ray tomography
<i>Electron Microscopy</i>			
Scanning electron microscopy (SEM), including field emission SEM	Imaging the surface of materials at the nano- to micrometer scale; capable of wavelength and energy dispersive spectrometry, cathodoluminescence, and SEM-based Raman; low vacuum and environmental chamber SEMs can be used for unprepared surface observation of non-conductive materials.	1B MR I, MR III	Capable of characterizing both hard and soft materials.
Electron probe microanalysis (EPMA), including field emission EPMA	In situ major and trace element analyses; quantitative microchemical measurements, typically by wavelength-dispersive spectrometry (WDS), but electron-dispersive spectrometry (EDS) also possible, as is concomitant CL spectral acquisition. Combined WDS-EDS mapping for trace and major element composition at the micro-scale.	1C, 2C MR I	

Method	Purpose	Availability and Access and Mission Relevance (see Table 4.1)	Comments on Relevance to Extraterrestrial Materials and Sample Return Missions
<b>Spectroscopy Techniques</b>			
<i>Light Spectroscopy Techniques</i>			
Laser-based Raman Spectroscopy	Non-destructive method for phase identification and estimates of pressure (for inclusions within minerals)	2B, 2C MR I	First-line characterization for curating most ET materials
Synchrotron-based X-ray Raman Spectroscopy	Non-destructive method for phase identification and estimates of pressure (for inclusions within minerals)	5B, 5C MR IV	Specialized phase identification in fine-grained mixed solids
Laboratory-based Infrared, UV-Vis, multiphoton/related spectroscopy	Vibration, absorption and electronic structure determination of structures, suspensions, gases and hybrids	2B, 2C 3B, 3C MR I	Identification of water and volatiles within small samples
Synchrotron-based Infrared, UV-Vis, multiphoton/related microscopy, spectroscopy	Characterization of absorption features of materials for comparison with remote sensing IR spectra, identification of organic C-H and C-O features. High spatial and energy resolution.	5B, 5C MR II, MR III	Identification of water and volatiles within small samples
Nuclear magnetic resonance (NMR) and related magnetic techniques,	Non-invasive, sub-surface imaging, spectroscopy, and tomography (e.g., MRI imaging).	2B, 3B MR II	Provides a quantitative analysis of functional groups in organic solids. Sensitive detection of hydrogen in inorganic solids.