EXMAG Outlook on Sample Science in the era of sample return from the Moon and other solar system bodies

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Sample science is Solar System science

- The sample analysis community works over the full timescale and physical extent of the solar system (and before) - sample analysis transcends disciplinary boundaries,
- Sample analysis isn't just "my pet rock" – the data we deliver bounds models, provides physical constants, and puts planetary processes in order
- Sample analysis plays a role in missions beyond just sample-return missions – we use samples on Earth to understand and calibrate what we see on the surfaces of other bodies
- PSD portfolio should contain a sustained investment in sample research and analysis, analysis facilities, technique development, workforce development, collections expansion, and curation of samples – all of which have challenges
- ExMAG White papers on these topics:
  - Strategic Investment in Laboratory Analysis of Planetary Materials as Ground Truth for Solar System Exploration – Stroud et al.
  - Terrestrial Recovery of Extraterrestrial Materials – Ishii et al.
  - Advanced Curation of Astromaterials for Planetary Science Over the Next Decade – McCubbin et al.

Sample science is Solar System science

- Current and upcoming collections: Apollo lunar samples, Antarctic meteorites (ANSMET), Cosmic Dust, STARDUST cometary and interstellar dust, Genesis solar wind samples, Hayabusa Itokawa asteroid regolith grains and OSIRIS-REx and Hayabusa2 samples of asteroids Bennu and Ryugu. Planning for new lunar samples, and possibly the first samples from the surface of Mars.
- Community-contributed white papers to the 2023 Decadal Survey highlight the sustained interest in acquiring and analyzing new samples from across the Solar System in the upcoming decade
  - **Mercury** Mercury sample return to revolutionize our understanding of the solar system (K. Vander Kaaden)
  - **Moon** High Priority Returned Lunar Samples (S. Valencia); Sample Return from the Moon's South Pole-Aitken Basin (B. Jolliff)
  - **Mars** Why Mars Sample Return is a Mission Campaign of Compelling Importance to Planetary Science and Exploration (H. McSween); Mars, The Nearest Habitable World, A Comprehensive Program For Future Mars Exploration (B. Jakosky); Scientific value of returning an atmospheric sample from Mars (B. Jakosky); The importance of the study of igneous rocks and compositions to constrain the martian planetary evolution (A. Udry)
  - **Outer Planets** Returning Samples from Enceladus for Life Detection (M. Neveu); Volatile Sample Return in the Solar System (S. Milam)
  - **Small Bodies** Cryogenic Comet Sample Return (A. Westphal); The Case for Non-Cryogenic Comet Nucleus Sample Return (K. Messenger); Small Bodies Tell the Story of the Solar System: A Rationale for a Small Body Sample Return Program including Laboratory Analysis of Returned Samples(S. Jacobsen); Ceres sample return PMCS (J. Castillo-Rogez)
  - **Solar System** Interplanetary and interstellar dust as windows into solar system origins and evolution (M. Horanyi)

Core research capabilities

- R&A programs are the lifeblood of the planetary materials analysis community.
- These investments are not only important for continued sample science that underpins and helps advance space exploration, but are also needed to support analysis of samples returned by ongoing and future space missions.
- Basic Research and Analysis
  - Examine investments in R&A programs (primarily EW and SSW) and outcomes, are we maintaining a robust community?
  - What are the pressures for sample-related research? Are proposal costs higher than average? Are they being selected at a comparable rate? What is the size of the community that can be sustained with current R&A levels? (see discussion on the Steering Committee, March 5)
- Investment in laboratory personnel
  - Maintain core expertise and health of facilities
  - Develop new analytical techniques and hardware
- Training the next generation
  - Broad engagement of young researchers across discipline and demographic boundaries is needed to invent, test, and carry out the necessary sample processing and curation procedures, and to share knowledge of sample analyses with the larger planetary science community.
  - Engaging students in research on terrestrially-recovered extraterrestrial materials using state-of-the-art tools is a primary means of motivating and educating the next generation of planetary scientists. Low selection rates mean we as a community need to market lab-based skills to industry.

Sample analysis facilities & techniques

- Facilities come in a range of sizes from single investigator labs to telescopes. There is no one funding approach that works for all. Although some instruments are expensive on the scale of R&A budgets, they are order of magnitude lower that mission budgets.
- Facilities support must encompass keeping older facility investments available and investing in new ones
- "A well-coordinated and integrated program for development of the next generation of laboratory instruments" was recommended in Visions and Voyages and expanded upon by a NASA-commissioned National Academies report (2019)*
- NASA maintains Planetary Major Equipment (PME) requests as supplements to R&A programs, and initiated the the Laboratory Analysis of Returned Samples (LARS) program to support sample analysis, technique development and targeted facilities investment for upcoming mission support
- PME and LARS statistics (expected ~$260k/awardee in ROSES21)
  - ROSES 2018: PMEF $2M (1 selected/8 submitted) // LARS $2.6M (12 selected/26 submitted)
  - ROSES 2019: PMEF (standalone not solicited) // LARS $2.6M (7 selected/23 submitted)
  - ROSES 2020: PMEF $1.5M (5-9 awardees, not yet announced) // LARS $2.6M (7 selected/30 submitted)
  - ROSES 2021: PMEF $1.5M (~5-9 awardees, supplement by other programs possible) // LARS $2.6M (~10 awardees)
- Additional investment has been under discussion by PSD and the PAC but so far has not been able to be realized
- Some related discussion points that ExMAG is considering
  - What has been funded through LARS and PME and what have the output/outcomes/impact on the community been?
  - What state are older instruments (funded 10+ years ago under cosmochemistry) in now and how are they maintained?
  - Maintenance of NASA-funded facilities is still in the competitive R&A pool. How can the community ensure continued access and utility?
  - How can facility investments made by missions be adapted and made available for use by other teams?
  - Could ISFM or internal funding be used to open NASA facilities to the wider community?

- *Strategic Investments in Instrumentation and Facilities for Extraterrestrial Sample Curation and Analysis (2019) https://www.nap.edu/catalog/25312/strategic-investments-in-instrumentation-and-facilities-for-extraterrestrial-sample-curation-and-analysis

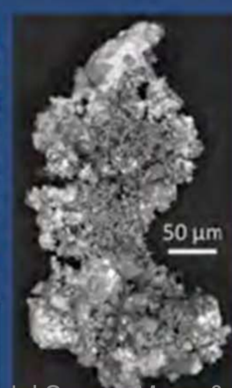
Sample-return missions

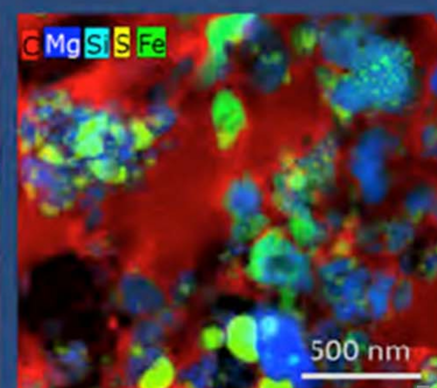
- Sample-return missions take advantage of the combined analytical power of terrestrial laboratory instrumentation, which vastly exceeds that of the weight and power-constrained spacecraft and rover instrumentation that has already and can be flown this decade.
- Proposed mission concepts envision sample return from the plumes of Enceladus, the nucleus of a comet, and the cold traps of the Moon. ExMAG encourages the Decadal Survey to consider robust sample-related missions among their candidates.
- Future returned samples are likely to include not only rocks, but also volatiles, ices, liquids, and labile materials that would enable key scientific investigations, but which would also require specialized sampling, curation, and manipulation capabilities to minimize losses and alteration and enable long-term preservation.
- Technology investments are needed in sample acquisition, sample handling, and sample return
  - Drills, scoops, pneumatics hardware, coring
  - Robotics, autonomy, teleoperation, and virtual presence
  - Extreme conditions: Temperature, volatile retention, organics
  - Contamination knowledge and control

- ***Visions and Voyages***: "every sample return mission flown by NASA should explicitly include in the estimate of its cost to the agency the full costs required for appropriate initial sample curation"
- ***Decadal Midterm***: Discovery and New Frontiers Missions require early planning and coordination for sample return missions. The actual costs for all aspects of curation, from planning through distribution and storage, including all required laboratory construction or modification, are required to be borne by the mission from inception to 2 years following sample return. Therefore, curation activities (and their associated costs) during phases A-D fall under the AO cost cap and activities during phase E fall under the PI-managed mission cost (but not the AO cost cap). Whereas long cruise missions can defer such costs to phase E, this situation penalizes short missions that have to include curation and laboratory costs in phases B-D.
- ***Recommendation***: NASA should consider the budget for curation by sample return missions, as developed in the announcement of opportunity-required curation planning documents, a phase E cost, regardless of the phase in which the costs are actually incurred. This would ensure that sample return missions are on equal footing with other mission proposals and discourage unrealistically low budgets for sample curation.

Terrestrial samples

- Extraterrestrial samples recovered on Earth (meteorites, micrometeorites, and cosmic dust particles) are critical to small body and planetary missions
  - they motivate and inform preparations for, analyses during, and context following missions
  - provide samples of bodies that are not accessible by sample return, e.g., the icy Kuiper Belt bodies
- For example, the ~412 lunar meteorites (ignoring pairing) recovered on Earth provide more global information about the Moon by enabling study of locations other than Apollo and Luna sites
  - New lunar sample return missions use this expanded library of geologic compositions to select sampling sites that promote understanding of lunar geochemical evolution
  - Currently, three lunar meteorites may come from the South Pole Aitken basin and help refine New Frontiers mission proposals to understand the Lunar Cataclysm Hypothesis which, in turn, can inform us about early Solar System orbital dynamics; lunar mantle compositions and heterogeneity; and polar volatile deposits (e.g Artemis)

Sample curation

- **Samples are the ”gifts that keep giving.”** Proper curation makes samples available to the community as new analysis methods are developed (e.g., ANSGA)
- **Visions and Voyages***: “Sample curation facilities are critical components of any sample return mission, and must be designed specifically for the types of returned materials and handling requirements. Early planning and adequate funding are needed so that an adequate facility is available once samples are returned and deemed ready for curation and distribution.”*
- ExMAG reaffirms the importance of curation for the current collections and investment in advanced curation
  1) supporting efforts to build contamination knowledge collections as part of sample return missions, which requires curation involvement from the earliest stages of sample return mission planning
  2) supporting Earth-based astromaterials collection campaigns of meteorites and cosmic dust as they represent relatively inexpensive sample acquisition activities that continue to grow NASA’s astromaterials collections and enable new discoveries
  3) preparing to curate and process samples under “cold” conditions to enable return of samples from volatile-rich Solar System targets like permanently shadowed regions on the lunar surface or comets
  4) determining how best to combine clean room technology and biosafety technology into one infrastructure to support curation of samples from bodies designated as Category V: Restricted Earth Return
  5) supporting real-time monitoring and testing of curation labs to verify that sample processing environments remain clean from the standpoint of inorganic, organic, and biological contamination

Human lunar exploration

- NASA is implementing the Artemis program for a set of human mission to the lunar surface, near the South Pole. The first landed mission would be Artemis III.
- Artemis III Science Definition Team (SDT) formed in Fall 2020. Recommended a candidate set of activities built on field geology, sample collection and return, *in situ* and field science, and deployed experiments
- Community contributed white papers to the SDT show intense interest in samples https://www.lpi.usra.edu/announcements/artemis/whitepapers/ (n=16)
  - Maximizing scientific opportunities through the careful selection, collection, storage, curation, and analysis of samples from the Artemis program. (Gross, J.)
  - Volatile Sample Return by Artemis III. (Gerakines, P. A.)
  - Science Priorities for Sample Return for Artemis Missions to the Lunar South Pole. (Jolliff, B. L.)
  - Artemis III EVA Opportunities along a Ridge Extending from Shackleton Crater towards de Gerlache Crater. (Kring, D. A.)
  - Artemis III EVA Opportunities on the Rim of de Gerlache Crater. (Kring, D. A.)
  - Alternative Artemis III EVA Opportunities near de Gerlache Crater. (Kring, D. A.)
  - Artemis III EVA Opportunities on the Lunar Farside near Shackleton Crater. (Kring, D. A.)
  - Artemis III EVA Opportunities on Malapert and Leibnitz Beta Massifs. (Kring, D. A.)
  - Artemis Iii Science and Tools Exploration Science for a Near South Pole Crewed Landing. (Schmitt, H. H.)
  - Sample Return of Pristine Lunar Dust to Enable the Design of New Simulants and Activation Protocols for Astronaut Health. (Corazzari, I.)
  - Science Strategy for Understanding Regolith Development and Space Weathering with Artemis III. (Denevi, B. W.)
  - Core Samples Recollection of Ice-Bearing Regolith in the PSR¥s of the Moon South Pole. (Suarez, J. E.)
  - Sample Return of Permanently Shadowed Regions for Space Weathering Investigations. (Burgess, K. D.)
  - Lunar Glass Sampling by the Artemis Crew: Big Science from Small Samples. (Zellner, N. E. B.)
  - Next-Generation Lunar Magnetism by Artemis. (Tikoo, S. M.)
  - Artemis Search for Supernova Isotopes in the Lunar Regolith. (Fields, B. D.)

Human Lunar Exploration

- ExMAG endorses the sample-related findings and recommendations for the Artemis program, including:
  - The collection of a diverse set of sample types, from geographically diverse locations broadly representative of the complex geology of the south polar region
  - A total returned sample mass from the Artemis III south polar site exceeding the average return mass for the Apollo missions – *this is not currently the baseline*
  - The ability to conduct cryogenic sample return from the Moon, at temperatures low enough to preserve water ice and other low temperature volatiles in the solid state throughout the entire journey from the lunar surface to Earth-based laboratories - *this is not currently the baseline*
  - The ability to return hermetically sealed volatile bearing samples from the lunar south polar region to preserve lunar volatile signatures within the sample containment system and prevent gas-exposure hazards in the crew cabin
- Opportunities exist for NASA's Human Exploration program to materially advance Decadal science goals, but … remember that in the last Decadal, we had Lunar Quest / Constellation. That was canceled and now we have CLPS / Artemis.
- Competed and directed SMD missions, HEO partnerships, pay-for-data or pay-for-delivery commercial models, public/private partnerships, and philanthropic spaceflight are all acquisition methods. The Decadal Survey should reaffirm the ***science goals*** (including those met by sample return) to be accomplished using those methods.

Recommendations

- The scientific payoff of sample collections grows over time with the advancement of analytical instrumentation only if there is systematic investment in sample curation, instrument development, analytical facilities, and development of the experienced workforce. Therefore ExMAG recommends:
- A robust commitment to Research and Analysis on planetary materials
- Targeted expansion of sample collections by missions and terrestrial collection
    - Joint support with NSF for Antarctic meteorite recovery (ANSMET)
    - Continued international collaboration for US researchers in international missions such as Hayabusa-2, MMX, and Mars Sample Return
    - Consider Curation costs as Phase E mission costs
    - Lunar sample return (and lunar science in general) stands separate from Human Exploration efforts
- Technology investment for future missions in sample acquisition, sample handling, and sample return
- Commitment to Curation and Advanced Curation research
- Investment in existing and new facilities and analysis methods
    - Commitments to maintain and expand PME and LARS for instruments, technique development, and personnel
- Training of the next generation of planetary materials analysts and placing them within and outside the NASA economy