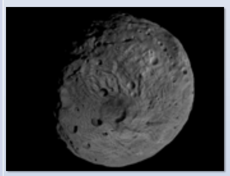
In Situ Geochronology for the Next Decade: A Planetary Mission Concept Study

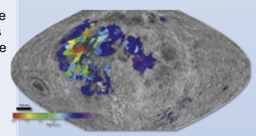
PI: Barbara A. Cohen, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA (Barbara.A.Cohen@nasa.gov)

Our Science Definition Team comprises a diverse team of geologists and geochronologists with expertise across the Moon, Mars, and small bodies to represent inner Solar System science.: Kris Zacny, Honeybee Robotics; Kelsey Young, NASA Goddard Space Flight Center; R. Aileen Yingst, Planetary Science Institute; Tim Swindle, University of Arizona; Stuart Robbins, Southwest Research Institute; Jennifer Grier, Planetary Science Institute; John Grant, Smithsonian Institution; Caleb Fassett, NASA Marshall Space Flight Center; Ken Farley, California Institute of Technology; Bethany Ehlmann, California Institute of Technology; Darby Dyar, Planetary Science Institute; Carolyn van der Bogert, University of Münster; Ricardo Arevalo, University of Maryland; F. Scott Anderson, Southwest Research Institute

Major advances in understanding formation and evolution of the inner solar system can be driven by absolute geochronology in the next decade: calibrating body-specific chronologies and creating a framework for understanding Solar System formation, the effects of impact bombardment on life, and the evolution of planets and interiors.

Science Drivers	Moon (SCEM/ASM-SAT)	Mars (iMOST)	Small Bodies (SBAG)	Potential solutions (illustrative, not definitive)
Impacts and Solar System dynamics	1a. Determinethe age of lunar basins; 1b. Anchor the early Earth-Moon impact flux curve by determining the age of SPA Basin; 1d. Assess the recent impact flux.	3. Determine the evolutionary timeline of Mars.	1.2.3. Use the distribution of compositions and ages of small bodies to make testable predictions about observable parameters in forming planetary systems.	Absolute ages of large planetary basins (e.g. South Pole-Aitken, Nectaris, Isidis, Caloris, Rheasilvia)
Igneous evolution and interior processes	5b. Determine the age of the youngest and oldest mare basalts; 5d. Determine the flux of lunar volcanism and its evolution through space and time.	1.5 Determine the petrogenesis of martian igneous rocks in time and space.	1.4.3. Determine the evolution of the interiors of small bodies, including differentiation and melting, metamorphism, and fragmentation/ reaccretion.	Correlate crystallization age of igneous rocks from a wide range of geographic locations with petrology, mineralogy, and composition.
Habitability and delivery of volatiles	4b. Determine the source(s) for lunar polar volatiles. 7c. Understand regolith modification processes, particularly deposition of volatile materials.	4.0 Constrain the inventory of martian volatiles as a function of geologic time and determine the ways in which these volatiles have interacted with Mars as a geologic system.	1.3.4. Use ages of meteorites and returned samples to determine the most recent dynamical history of these objects.	Determine the radiometric ages of unhydrated primary materials and hydrated secondary materials. Determine the timescales of delivery of volatile-bearing materials.
Calibrating absolute ages across the Solar System	1c. Establish a precise absolute chronology.	5.0 Reconstruct the history of Mars as a planet, the origin and modification of the crust, mantle and core.	1.2.2. Determine the timing of events in the early Solar System, using meteorites and returned samples	Calibrate the cratering chronology across multiple bodies by dating surfaces with well-defined cratering statistics.





The aim of this study is to give the next Decadal Survey panel a viable alternative or addition to sample return missions to accomplish longstanding geochronology goals within a New Frontiers envelope.

- Absolute ages for multiple worlds are a desire in both the 2003 and 2013 Planetary Science Decadal Surveys, but in these two decades, only sample return was considered a viable method for geochronology. The Decadal Surveys recommended mission lists reflect the reality for those decades that sample return is the only way to yield reliable and interpretable geochronology.
- In the last two decades, NASA has invested in the development of *in situ* dating techniques, increasing the maturity of instruments using complementary radiogenic isotopic systems (K-Ar and Rb-Sr) to TRL 6.
- The time is right to consider how the precision achievable with *in situ* geochronology can advance important science goals for the next Decadal Survey

Element	Objective	Heritage	Mass (kg)	Power (W)	Current TRL
KArLE	K-Ar geochronology	PIDDP and DALI	25	65 (peak)	6*
CDEX	Rb-Sr geochronology	PIDDP and MatISSE	50	180 (peak)	6*
ICP-MS	Trace-element geochemistry	PIDDP	25		3
Point or imaging spectrometer	Sample selection and characterization, geologic context	MicrOmega (ESA), NIRVSS (NPLP)	2 to 3	24	6*
Cameras	Geologic context, workspace documentation, sample characterization	MER MI/Pancam, MSL MAHLI/Mastcam, WATSON	2 (for 2)	4	9 for Mars and asteroids
PlanetVac	Acquire and sort regolith samples	MMX			6 for asteroids
Sample triage and analysis carousels	Introduce samples to analysis instruments	SAM carousel (MSL)	10	TBD	9 for Mars
Total			105	180 (peak)	

**these instruments are currently funded for development to TRL 6 through NASA and ESA instrument development programs; no additional costs would be required to achieve this TRL rating. MatISSE - Maturation of Instruments for Solar System Exploration, DALI - Development of Advanced Lunar Instrumentation, NPLP - NASA-Provided Lunar Payloads*

This study will formulate and cost a medium- or flagship-class mission for Solar System chronology

- Science Definition Team (SDT) will identify the most important science questions that can be answered in the next decade using the first generation of in situ dating techniques and examine mission-level requirements, trades, and instrumentation for answering these questions
- Notional payload includes two geochronology techniques (Rb-Sr and K-Ar), sample acquisition and handling, and contextual measurements
- Mission trades include mobility, number of samples and sites required, operations timelines, and mission architecture choices. Going-in positions for this study are in **bold** but could change in concert with the Mission Design activity.

Topic	Trades
Destination	. **Moon - Pre-Imbrian basin impact melt, youngest basalt** . Mars - Noachian potentially habitable crust , keystone Hesperian lava flow . Vesta - Rheasilvia and Veneneia basins
Sampling	Regolith/pneumatic vs rock/drill design; sample handling and presentation pathways; amount of workspace required
Landing	. Passive . Terrain-relative navigation (identify existing map products) . **Active hazard avoidance**
Mobility	. Local - single lander . Regional – rover . **Global - multiple landers and/or a hopper**
Operations	Sample acquisition and delivery operations run with ground in the loop or autonomously, fault tolerance for sample acquisition and delivery, sample analysis decision rules (e.g., geochronology systems not agreeing or converging)
Mission	Sizing of lander, power (solar + battery vs nuclear), common elements (C&DH, comm, etc.)