In-situ Geochronology

Discussion for A Science Strategy for the Human Exploration of Mars: Panel on Astrobiology

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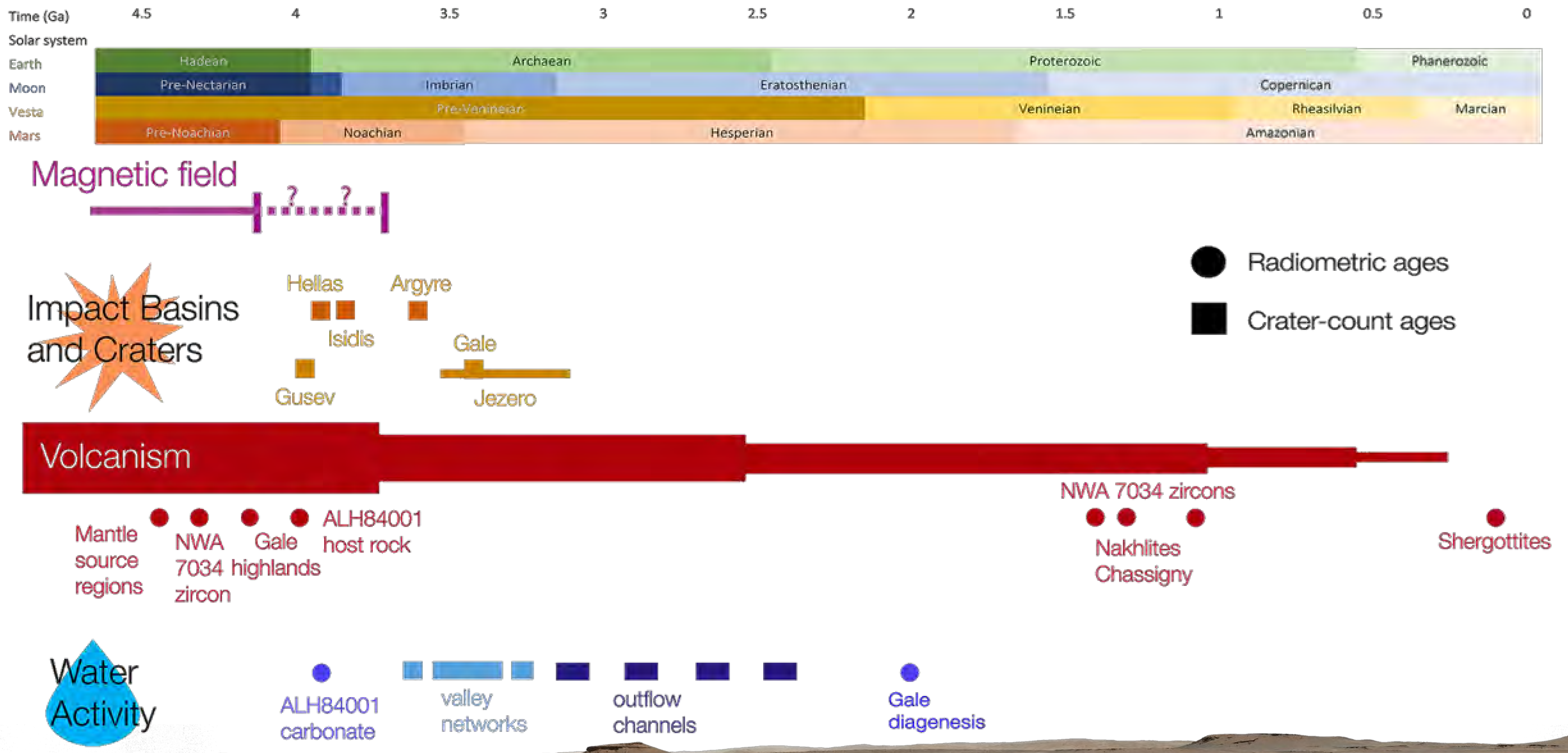
Planetary History

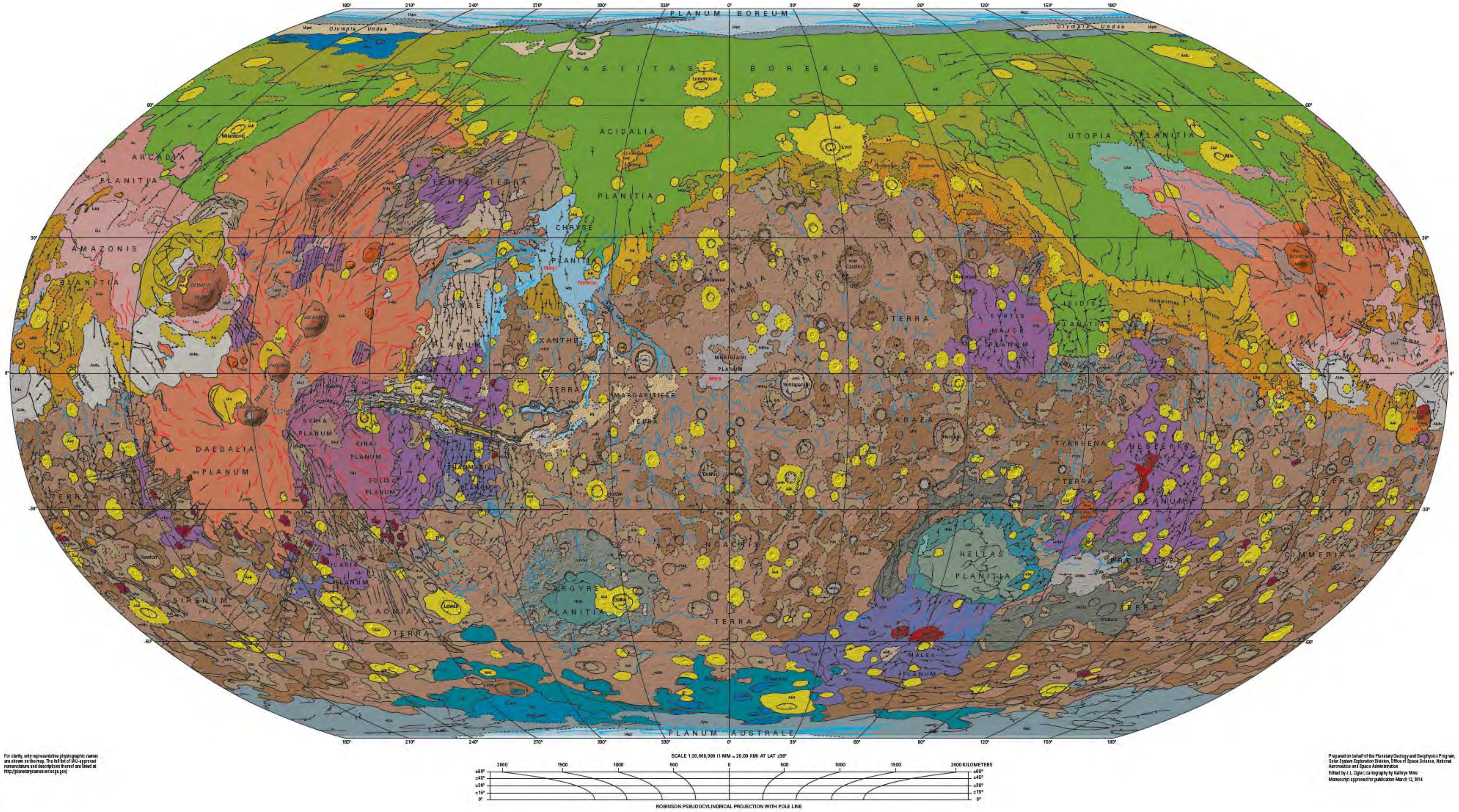
- Every rock is a page in the book of a planet's history
  - the grain size of a sediment tells us how far the particles were transported
  - the trace elements in igneous rock tell us what the magma source was
  - the mineralogy of a metamorphic rock tells us how much pressure it endured.
  - A rock tells us whether an area was wet or dry, whether the fluids percolating through it were warm or cool, whether the surface was disturbed by impact breakup or tectonic folding.
- ***Geochronology*** is what puts the pages in order. It is the study of when rocks and minerals were affected by geologic events. That allows us to put planetary events in order and also ties them to other events in the solar system.
- ***An age is an interpretation of an event, requiring both accurate and precise measurement and adequate knowledge to interpret that measurement***

History of Mars in the Framework of the Solar System



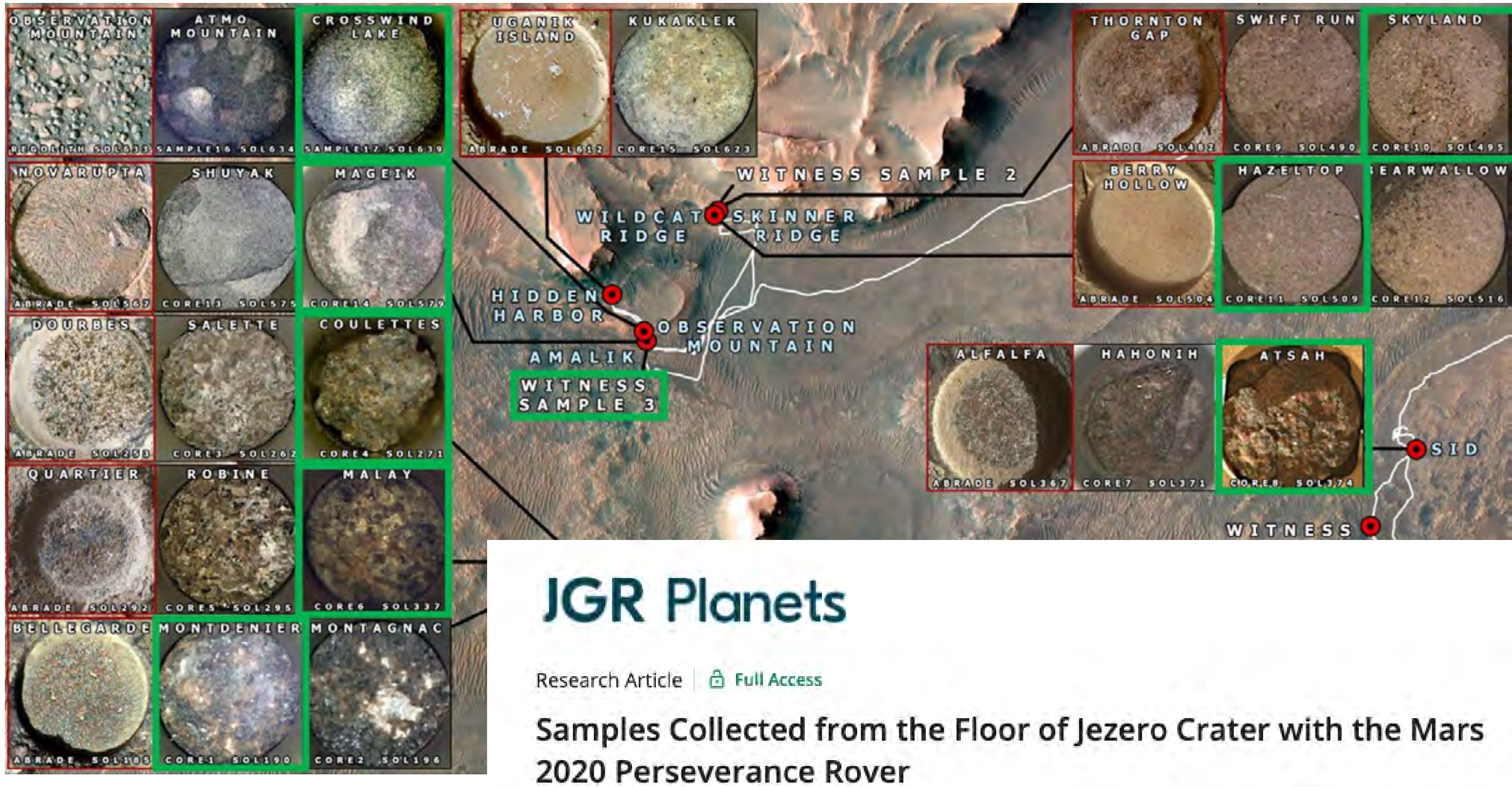
Martian relative history

- Absolute ages of Martian surface units are uncertain by a factor of two or more ☹
  - The lunar crater record conveys a roughly billion-year uncertainty during the Hesperian (Bottke and Norman, 2017; Robbins, 2014)
  - Persistent volcanism and fluvial and aeolian weathering degrade and erase impact craters (Hartmann et al., 2000; Malin, 1988; Tanaka, 1986).



Sample Return

- Sample-return missions take advantage of the combined analytical power of terrestrial laboratory instrumentation and the research community
- Multiple analysis, replicates, different techniques (see for example, ALH84001)
- Returning samples to earth enables us to address questions we don't know to ask using instruments that haven't been invented by researchers who haven't yet been born (*J. Dworkin*)



JGR Planets

Research Article | Full Access

Samples Collected from the Floor of Jezero Crater with the Mars 2020 Perseverance Rover

J. I. Simon, K. Hickman-Lewis, B. A. Cohen, L.E. Mayhew, D.L. Shuster, V. Debaille, E. M. Hausrath, B.P. Weiss, T. Bosak, M.-P. Zorzano, H. E. F. Amundsen, L.W. Beegle, J.F. Bell III ... See all authors

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OK! Let's date all the rocks!

- Sample return from everywhere in the solar system! Unlikely.
- *In situ* radiometric dating is strategically aligned with the Decadal Survey science goals and OCT roadmap for science instruments

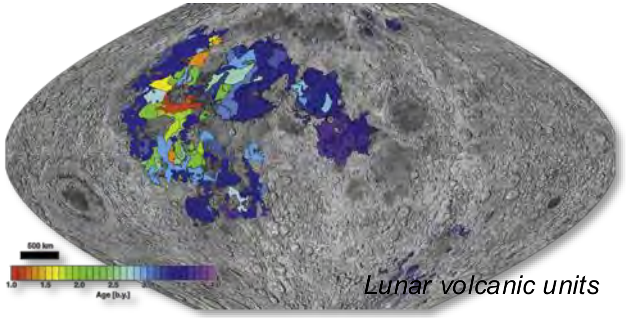
How do we go from this…… *to this?*

PMCS Study

- Motivation: Major advances in planetary science can be driven by absolute geochronology in the next decade, calibrating body-specific chronologies and creating a framework for understanding Solar System formation
  - Traceable to 2014 NASA Science Goals, p.61; Planetary Science Decadal Survey: p.151, p.143; LEAG, MEPAG, and SBAG goals documents
- Why Now? In the last two decades, NASA has invested in the development of in situ dating techniques; K-Ar and Rb-Sr instruments will be TRL 6 by the time of the next Decadal Survey
- Study Goals:
  - Assess how in situ geochronology could be accomplished in the inner solar system (Moon, Mars, and asteroids) – multiple CML 3-4 studies
  - Give the next Decadal Survey panel a viable alternative – or addition to – sample return missions to accomplish longstanding geology and geochronology goals within a New Frontiers envelope
- https://science.nasa.gov/files/science-pink/s3fs-public/atoms/files/Geochronology%20Report.pdf


Rheasilvia basin, Vesta


Ancient Martian Crust, Syrtis Major


Lunar volcanic units

Science Traceability Matrix

Science Objectives	Measurement Goals	Measurement Requirements	Mission Support
Determine the chronology of basin-forming impacts and constrain the time period of heavy bombardment in the inner solar system Constrain the 1 Ga uncertainty in solar system chronology from 1-3 Ga, informing models of planetary evolution Establish the history of habitability across the Solar System	Measure the age of the desired lithology with precision ±200 Myr	Use Rb-Sr radiometric chronology to directly measure the age of samples derived from the target lithology	Collect, triage, and analyze 10 0.5-2 cm sized samples at each site * see additional information on sampling statistics Conduct sample analysis at 2 different sites on each body ** see additional information on sites Remotely sense the workspace around the landing legs to provide sample context and of landing site at low and high sun angles to create spatially contiguous maps
		Use K-Ar radiometric chronology to directly measure the age of samples derived from the target lithology	
	Contextualize the desired lithology using petrology, mineralogy, and/or elemental chemistry	Measure the major- and trace-element geochemistry of the samples to establish parentage and evolution of lithologies	
		Identify the mineralogy by mapping abundances of olivines, pyroxenes, oxides, plagioclases; Identify aqueous alteration minerals including phyllosilicates, sulfates, carbonates, and other hydrated salts	
		Image the samples at the microscale to determine grain size, petrology, etc.	
		Determine the composition of the surface unit to place the lithologies into a regional and global context	
	Relate the measured lithology age to crater counting of the lithology's terrain	Determine the geology of the landed site and map discrete lithologic units to relate them to maps and crater counts determined from remote sensing	

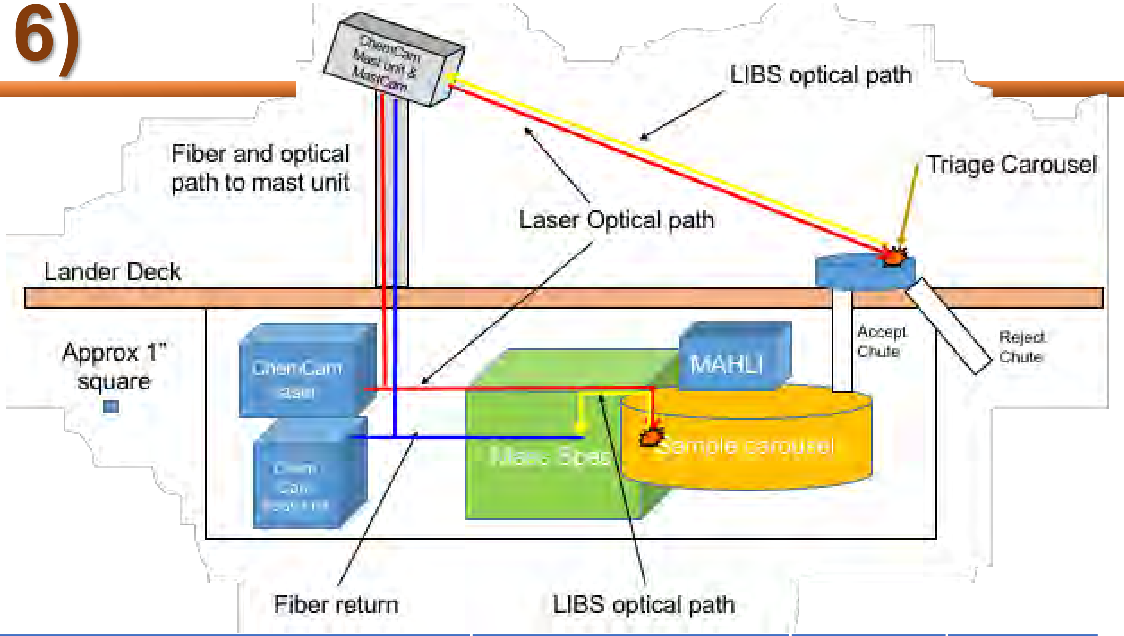
Payload concept

- Measurement requirements for all goals and objectives are met by carrying a single payload
- Study payload comprises representative instruments - generalizable to any suite of instruments that can accomplish the Measurement Requirements
- TRL in 2023 (start of next Decadal) - no additional costs or technology will be required

Measurement Requirement	Measurement	Payload Element	Element Lead	TRL in 2023
Geochronology	Rb-Sr geochronology	CDEX	Scott Anderson / SWRI	6 (MatISSE)
	K-Ar geochronology	KArLE	Barbara Cohen / GSFC	6 (DALI)
Sample & site context	Trace-element geochemistry	ICPMS	Rick Arevalo / UMD	4 (PICASSO) – *6 (DALI or MatISSE*)
	Mineralogy	UCIS-Moon	Bethany Ehlmann / JPL	6 (DALI)
	Visible/color imaging and micro-imaging	Panoramic and microimagers	Aileen Yingst / MSSS	9 (MSL / CLPS)
Sample Handling	Acquire, prepare, and introduce samples to analysis instruments	PlanetVac	Stephen Indyk / Honeybee Robotics	9 (CLPS / MMX)

K-Ar geochronology with KArLE (TRL 6)

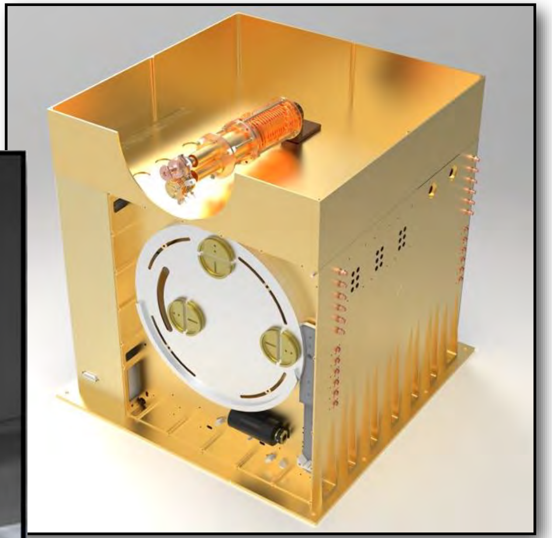
- Cohen et al. (GSFC)
- Validated on meteorites
- Mass ~50 kg

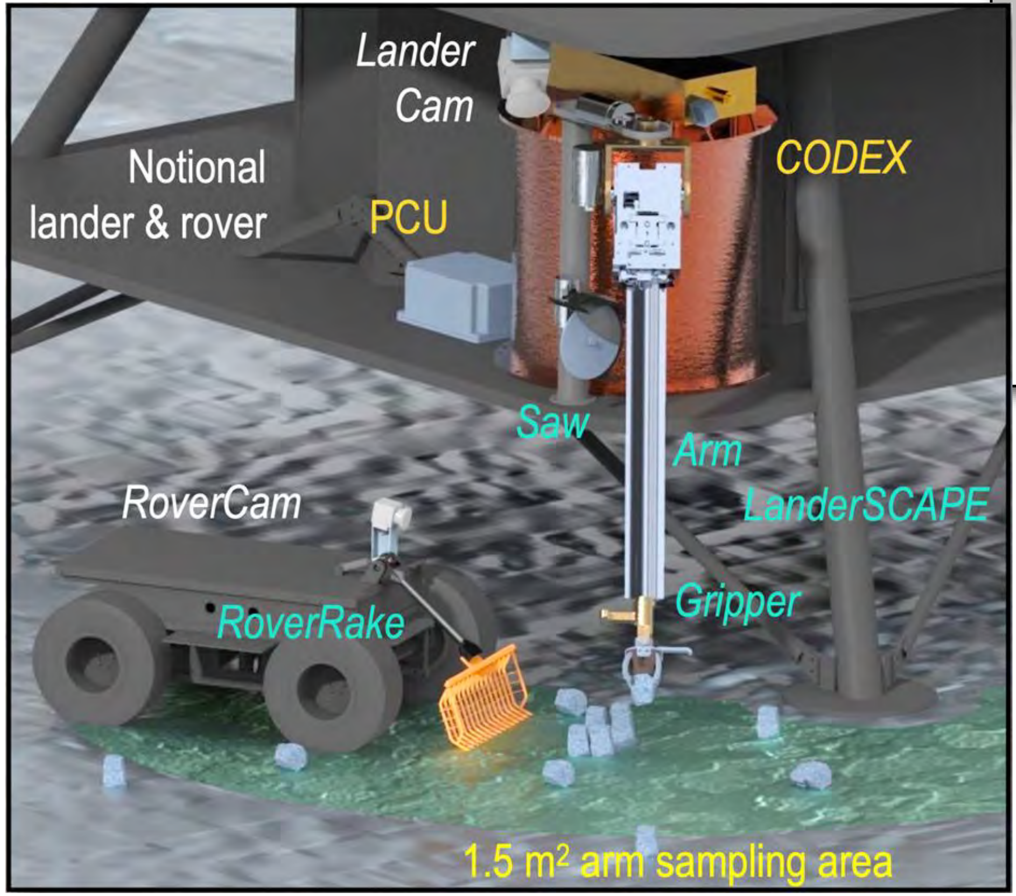


KArLE Element	Objective	Heritage	Mass (kg)	Power (W)
Sample handling system	• Present rocks to LIBS and MI for triage • Introduce individual rocks to analysis chamber	SAM carousel (MSL)	10	TBD
LIBS	• Characterize and prioritize samples • Determine K for geochronology	ChemCam (MSL), SuperCam (Mars 2020)	10	65
Gas Handling System	• Clean gas and concentrate noble gas species	SAM (MSL), MOMA (ExoMars), etc.	5	
Mass Spectrometer	• Determine Ar for geochronology • Measure volatile compounds in the regolith	RELL on ISS	10	40
Metrology	• Volume of LIBS pits for geochronology	ISS	5	

Rb-Sr geochronology with CODEX (TRL 6)

- CODEX, the Chemistry, Organics, and Dating Experiment (Anderson et al. SwRI)
- Validated CODEX with a variety of meteorites
- Flying to Ina-D on the Moon with CLPS in 2028!
  - Mass 50 kg
  - runs autonomously
  - precision of ±375 million years





Conclusions and Recommendations

- Mars is a complex planet
  - Formed from terrestrial building blocks 4.6 Ga
  - Differentiated into a crust, mantle and core very early
  - Bombarded to make big basins
  - Persistent volcanism
  - Evolving surface and subsurface water cycle
- But the detailed history of Mars using absolute ages is still being worked out
- Both *in situ* dating and returned samples have enormous utility in constructing an absolute age framework for Mars that informs Martian history and solar system commonality
- *In situ* geochronology is a feasible way to address or complement cross-cutting, big-picture, community-identified science goals at Mars, the Moon, and Vesta
- Geochronology measurements may be flexibly accomplished on dedicated missions or as part of "normal" geology missions, by sample return or *in situ* measurements, depending on the science question and need