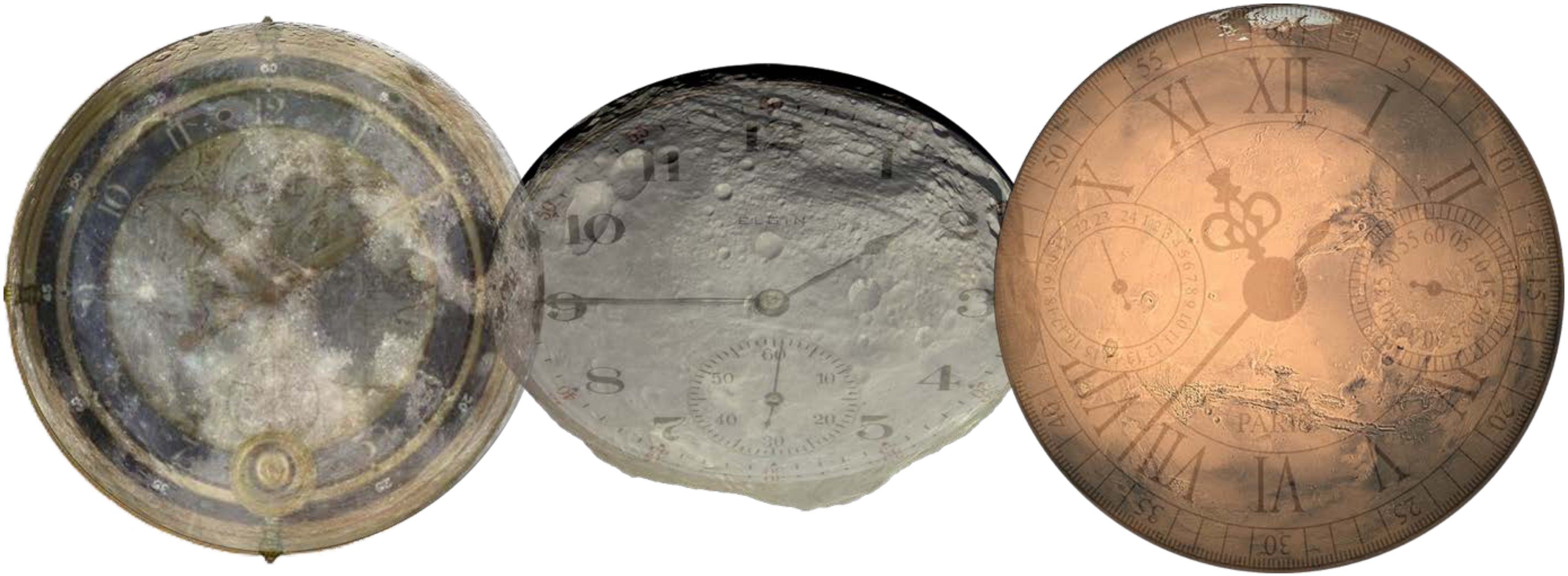


Geochronology for the Next Decade

A Planetary Mission Concept Study for the 2023 Decadal Survey

PI: Barbara Cohen, NASA GSFC (barbara.a.cohen@nasa.gov)

Geochronology PMCS Science Definition Team

Person	Institution	Research expertise
Barbara Cohen (PI)	GSFC	Geochronology, mission operations
Kelsey Young (DPI) *	GSFC	Geochronology, human missions
Nicolle Zellner	Albion College	Geochronology
Kris Zacny	Honeybee Robotics	Sample acquisition and handling
R. Aileen Yingst	PSI	Imaging, mission operations
Ryan Watkins *	PSI	Remote sensing
Sarah Valencia *	GSFC	Lunar samples
Tim Swindle	U of Arizona	Geochronology
Stuart Robbins *	SwRI	Crater chronology
Noah Petro	GSFC	Site analysis, remote sensing
Dan Moriarty *	GSFC	Remote sensing
Katherine Joy	Manchester University	Geochronology
Stephen Indyk	Honeybee Robotics	Sample acquisition and handling
Juliane Gross	Rutgers University	Lunar samples, petrology
Jennifer Grier	PSI	Crater chronology, EPO
John Grant	Smithsonian	Geology, mission operations
Caleb Fassett	MSFC	Geomorphology, crater chronology
Ken Farley	Caltech	Geochronology, mission operations
Bethany Ehlmann *	Caltech	Geology, spectroscopy, habitability
Darby Dyar	PSI	Spectroscopy, sample analysis
Natalie Curran *	GSFC	Lunar samples
Carolyn van der Bogert	University Westfalische	Crater chronology
Ricardo Arevalo *	U of Maryland	Mass spectrometry, trace elements
Scott Anderson	SwRI	Geochronology

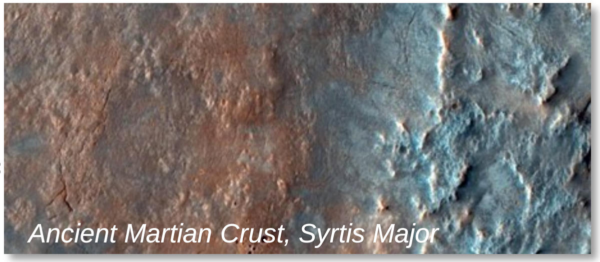
*early-career

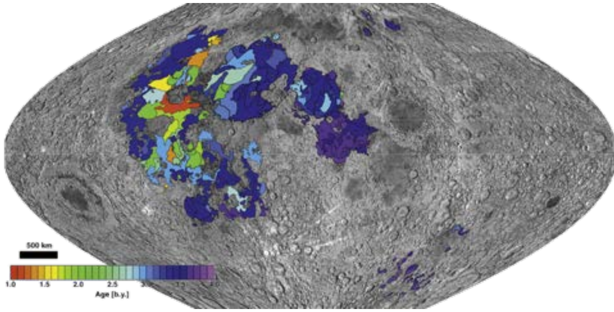
Geochronology: More than just rock ages

- 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, the effects of impact bombardment on life, and the evolution of planets and interiors
  - *When* did the outer planets migrate and *what was the flux* of early bombardment?
  - *When* was Mars warm and wet? *How much time* did organisms have to thrive in this environment?
  - *How long* were planetary heat engines active?
  - *How long* have surfaces been exposed to (and possibly changed by) the space environment?
- 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
- For this Planetary Mission Concept Study, we will investigate how Solar System chronology missions can be accomplished in the inner solar system (Moon, Mars*, and asteroids)
- 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

***Focusing on Mars case for this talk, of course!**


Rheasilvia basin, Vesta


Ancient Martian Crust, Syrtis Major


Lunar volcanic units

Science Goals, Objectives, and Measurements

Science Goal: Determine the history of major events in the Inner Solar System and broader solar system chronology.

- Traceable to 2014 NASA Science Goals, p.61; Planetary Science Decadal Survey: p.151, p.143; LEAG, MEPAG, and SBAG goals documents

Science Objectives:

- 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 from 1-3 Ga, informing models of planetary evolution including volcanism, volatiles, and habitability
- Constrain the history of hydration and habitability across the Solar System.

Measurements:

- **Measure the age** of the desired lithology with precision ±200 Myr
- **Contextualize** the desired lithology using petrology, mineralogy, and/or elemental chemistry.
- **Relate** the measured lithology age to crater counting of the lithology's terrain

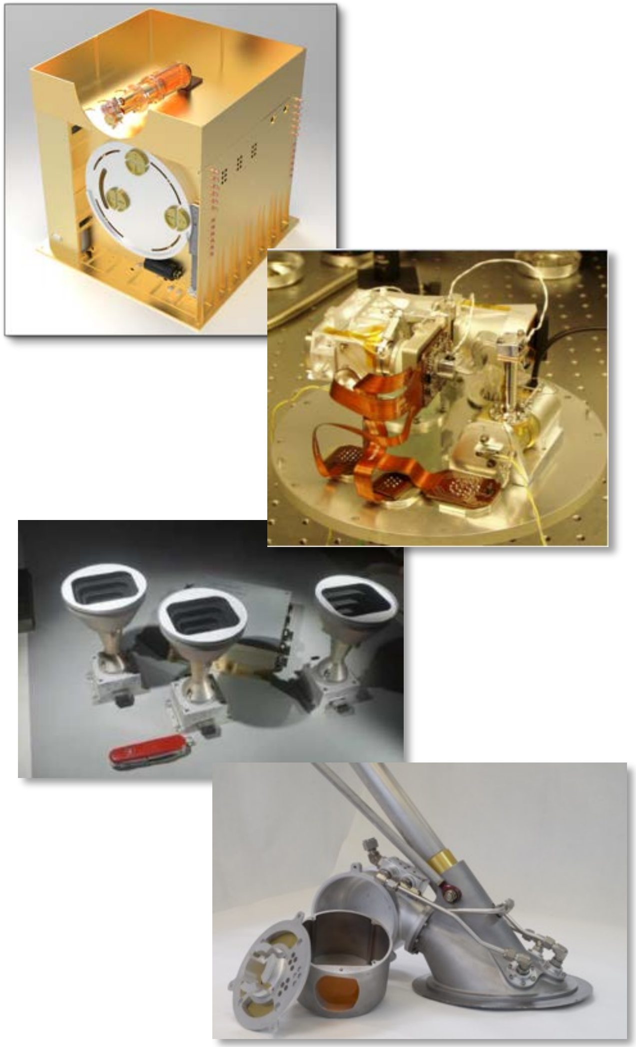
Driving Mission Requirements:

- **Payload**: Collect, characterize, and date at least ten 0.5-2 cm sized samples of lithologies that address the science objectives
- **Mobility**: Conduct sample analysis at 2 different sites on each body to address different objectives

Payload concept

- Mission goals for all destinations are met by carrying an identical payload
- This is a mission concept study, therefore we are using representative instruments - generalizable to any suite of instruments that can accomplish the Measurement Requirements

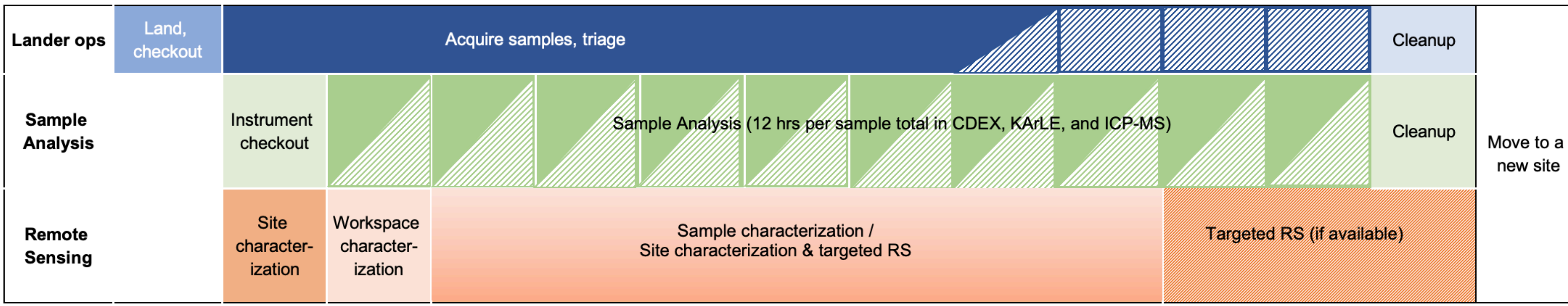
Measurement Requirement	Measurement	Straw payload instrument	Mass	Power	TRL in 2023
Geochronology	Rb-Sr geochronology	CDEX	55	140	6*
	K-Ar geochronology	KArLE	23	100	6*
Sample & site context	Trace-element geochemistry	ICPMS	9.5	102	6*
	Mineralogy	UCIS-Moon	5	30	4-6**
	Visible/color imaging and micro-imaging	Cameras	5	15	9 +
Sample Handling	Acquire, prepare, and introduce samples to analysis instruments	PlanetVac, triage station, arm	31.5	30	from 6 to 9 +
Payload drivers			129 / **167 (30%)**	140 / **180 (30%)**	**6**



*currently funded for development to TRL 6 through NASA MatISSE and DALI development programs
**Currently funded through TRL4 via PICASSO, would need a followup MatISSE or DALI
+ Will have flight heritage via CLPS payloads

Surface Operations

- Sample acquisition, triage, and analysis run in parallel
- Onboard decision rules and prioritization may be assisted software to route easy samples while science team considers others
- 1 sample analyzed per 24 terrestrial hours, *running in serial*



- How many rocks?
  - Science requires 3-5 ages of the lithology of interest to get a reliable age
  - Allow for some rocks being uncooperative = 10 samples analyzed
  - Allow for some rocks at the site being not what we want = 30 samples acquired/triaged

Mobility Requirement

- Constrain Martian habitability and volcanic activity by investigating **both** ancient but potentially habitable (Noachian) crust and young (Hesperian) lavas that are geologically well-constrained.
- Take advantage of significant engineering and scientific research expended on potential landing sites for previous, current and future landed missions – sites are landable and traversable

Nili Fossae Trough

- Provides access to representative sections of widely distributed units.
- High confidence in interpretation of relationships
- Ability to place into context via geochronology dating
- Ellipse was proposed and vetted for Mars 2020 Landing Site selection.

NE Syrtis

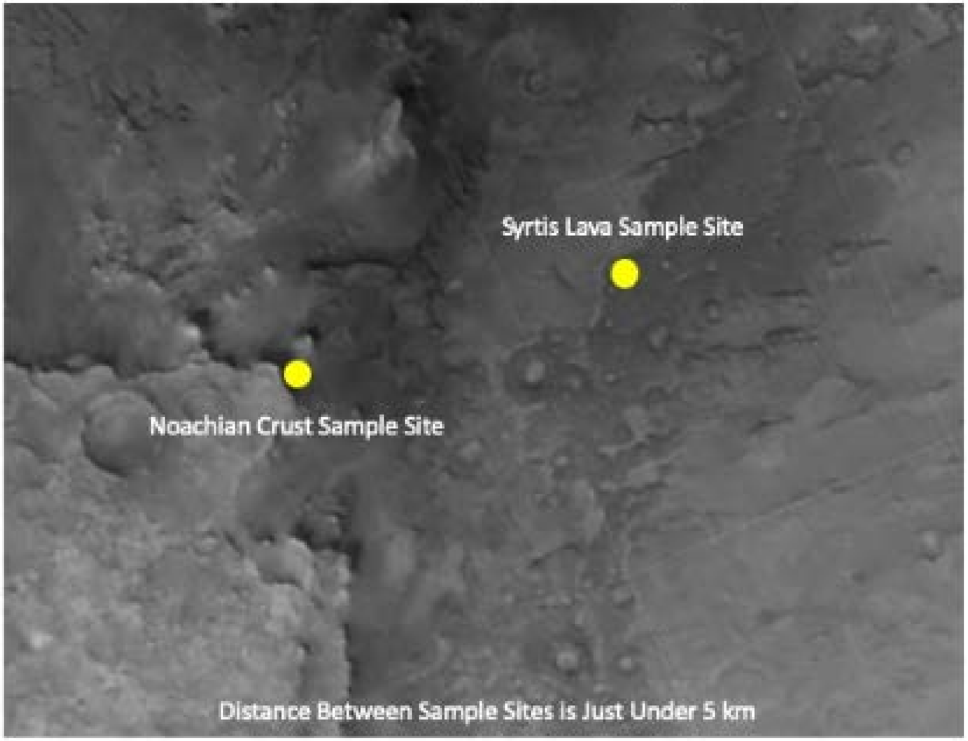
- Access to a broad range of materials that may represent comparable units
- Distance between the two most interesting units (Hesperian lava and Noachian crust) is 30 km, too far for a rover traverse.
- Mafic cap at NE Syrtis, but uncertain relationship to the Syrtis lavas

Mawrth Vallis

- Context and physical character is well-understood
- Access to widespread Noachian crustal materials but with uncertain origin
- Hesperian dark mantling materials that cap the section may or may not be volcanic

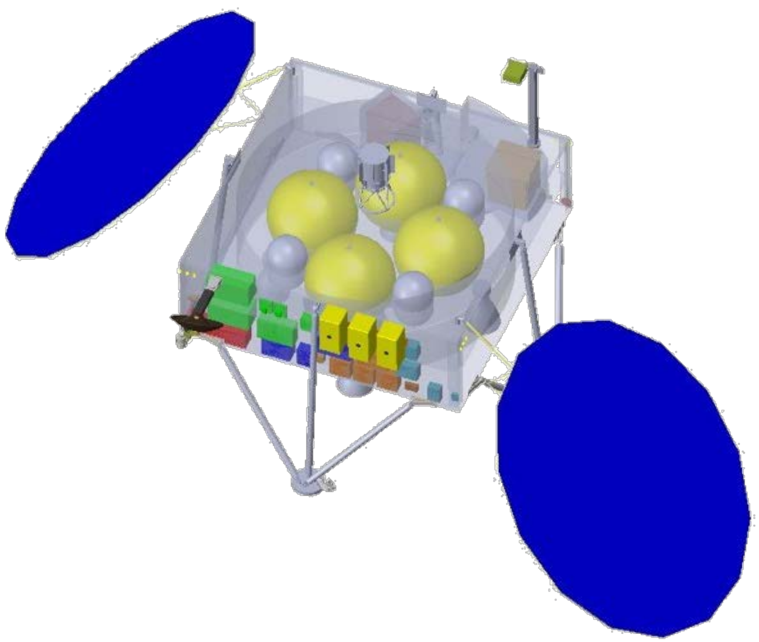
Lots of other sites globally that are interesting!

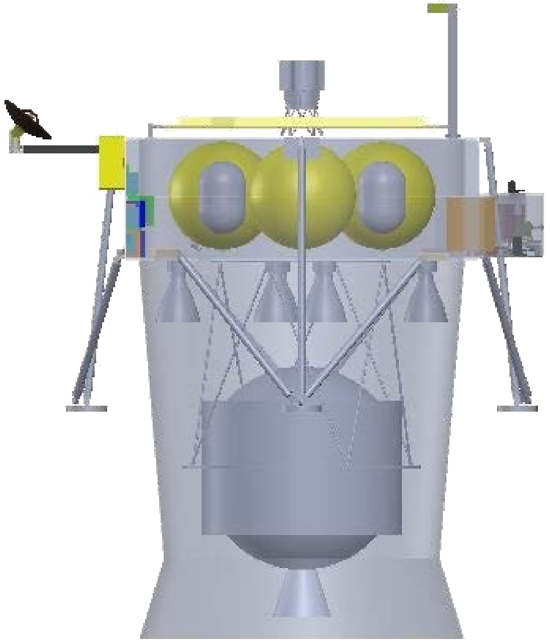
CTX of Candidate Sample Sites in Nili Trough:



Lunar architecture

- We conducted a full Mission Design Lab (MDL) at GSFC March 9-13
- Focused on a lunar case – full payload and mobility to widely-separated sites (100's of km) – large lander/hopper
- F9 Heavy 5.2-meter fairing gives us 13000 kg wet mass lander
  - 11641 kg of propellant
  - 1359 kg of everything else, including payload, structure to hold all that propellant, and power (battery+MMRTG) to heat liquid prop thru a lunar night
- It takes a lot of fuel to hop
  - The Moon is a marginal case for hopping. We didn't get a design to close yet.
  - Hopping works on Vesta – lower gravity = less fuel, less severe day/night cycle = less heating
  - Hopping isn't going to work on Mars





Mars architecture assessment

Mission	Cost Class	Payload (kg)	Mobility	Geochron Score	*References*
MER	Discovery * (for one)	5	Y	Poor - payload capacity too small	*Minitti et al. & Blake et al.(this meeting)*
Huoxing-1	?	MER-class	Y		*Fantino et al. (2017), Barba et al. & Kaufman et al. (this meeting)*
Small landers	SIMPLEX	5	Y		
Phoenix	Discovery *	59	N	Good - one instrument to one location	
Insight	Discovery *	50 (lander) + 30 (MarCO)	N		
Icebreaker	Discovery	Phoenix-class	N		*McKay et al. (various)*
Mars Geoph. Network	New Frontiers	55	2 landers		
Rosalind Franklin	Flagship	26 (rover) + 45 (lander)	Y		
Curiosity / Perseverance	Flagship	75	Y	Excellent - full payload and mobility possible	
MSR lander	Flagship	77 (lander) + 157 (rover)	Y		
Red Dragon	Discovery *	tons	Y		*Heldmann et al. (2017), Gonzales et al. (2015)*
Geochronology	New Frontiers	150 baseline / 75 threshold	Y baseline / N threshold	Advances in EDL, small spacecraft technologies	*Fraeman et al., Edwards et al., D'Souza et al., Beck et al.., (this meeting)*

Mars architecture assessment

Mission	Cost Class	Payload (kg)	Mobility	Geochron Score	*References*
MER	Discovery * (for one)	5	Y	Poor - payload capacity too small	*Minitti et al. & Blake et al.(this meeting)*
Huoxing-1	?	MER-class	Y		*Fantino et al. (2017), Barba et al. & Kaufman et al. (this meeting)*
Small landers	SIMPLEX	5	Y		
Phoenix	Discovery *	59	N	Good - one instrument to one location	
Insight	Discovery *	50 (lander) + 30 (MarCO)	N		
Icebreaker	Discovery	Phoenix-class	N		*McKay et al. (various)*
Mars Geoph. Network	New Frontiers	55	2 landers		
Geochronology	New Frontiers	150 dream 75 need	Y dream N need	Advances in EDL, small spacecraft technologies	*Fraeman et al., Edwards et al., D'Souza et al., Beck et al.., (this meeting)*

A compelling, feasible New Frontiers-class mission could be a capable instrument payload, including geochronology, to a single, well-characterized site to link absolute ages to Mars crater counting.

Your ideas on how to achieve this are most welcome!
(barbara.a.cohen@nasa.gov)

Backup

- Surface operations timeline

Surface Ops Timeline