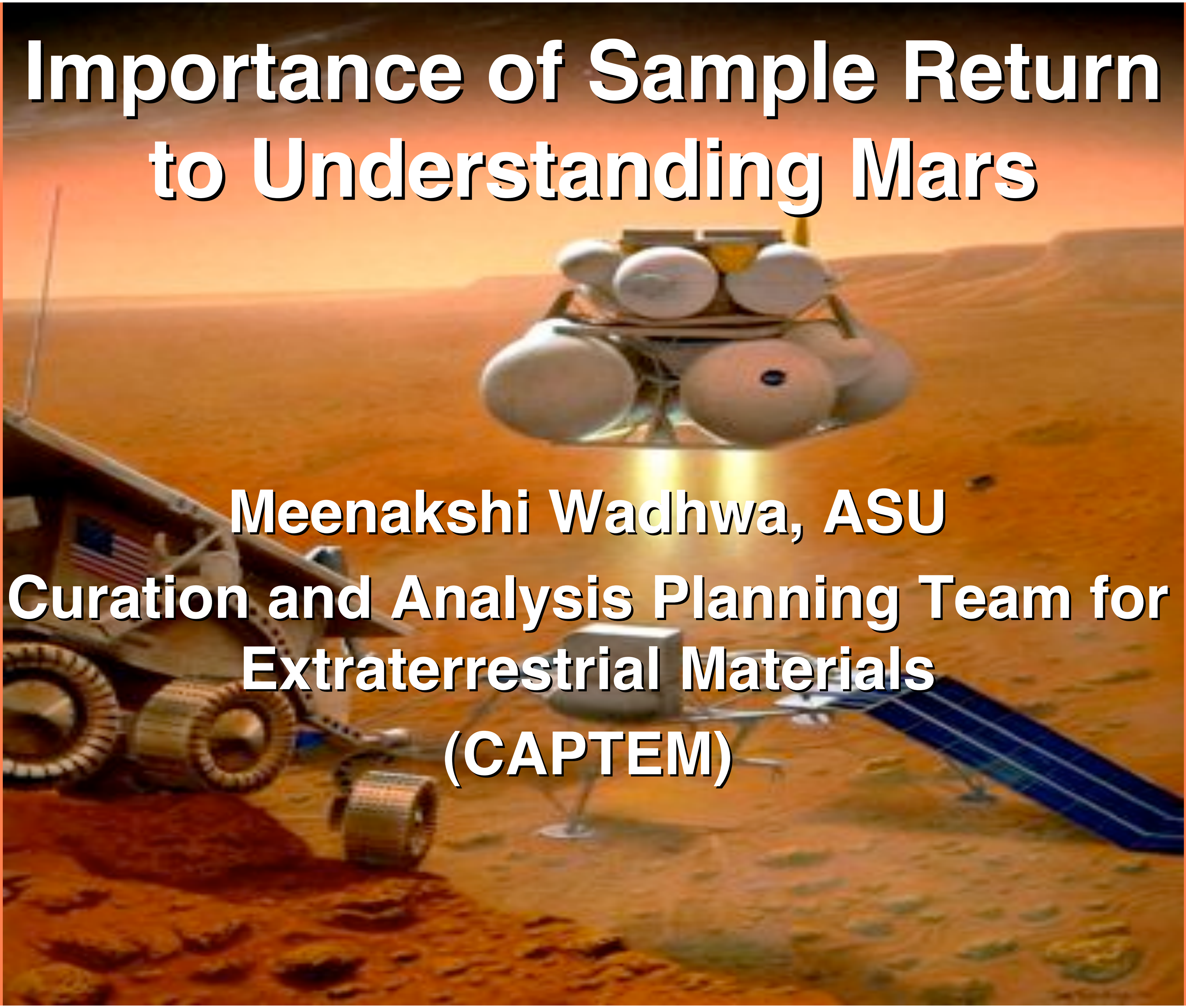
Importance of Sample Return to Understanding Mars



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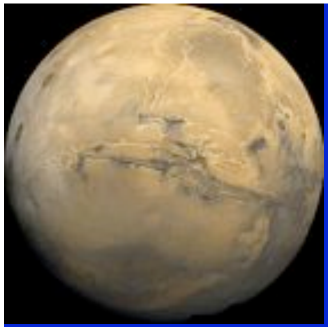
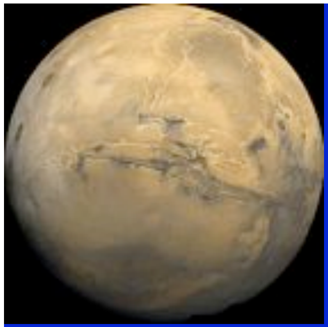
Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM)



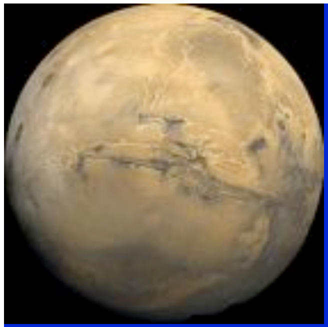
Outline

- General Principles for Planetary Missions
- Importance of Returned Samples
- Sample Return from Mars: Why and How?
- Conclusions



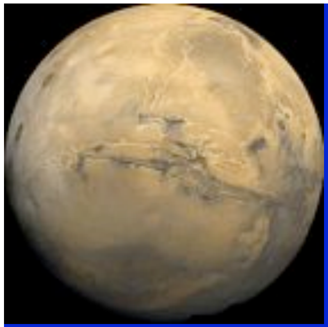
General Principles

- The most scientifically significant missions are those that provide a giant leap in type or quality of data:
  - New type of data (e.g., abundances of trace species in planetary atmospheres, sample returns)
  - Huge increase in data quality (e.g., factor of ten increase in spatial resolution, better detection limits for elements and minerals)



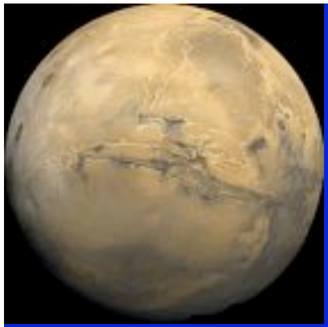
General Principles

- Sample return missions are essential but cannot be the sole component of a program for planetary exploration
  - They are one way to explore the planets (although some questions can only be adequately answered by sample return)
  - They complement other types of missions
- Sample-return missions require:
  - Investments in <u>sample curation</u>
  - Investments in <u>laboratory equipment</u>



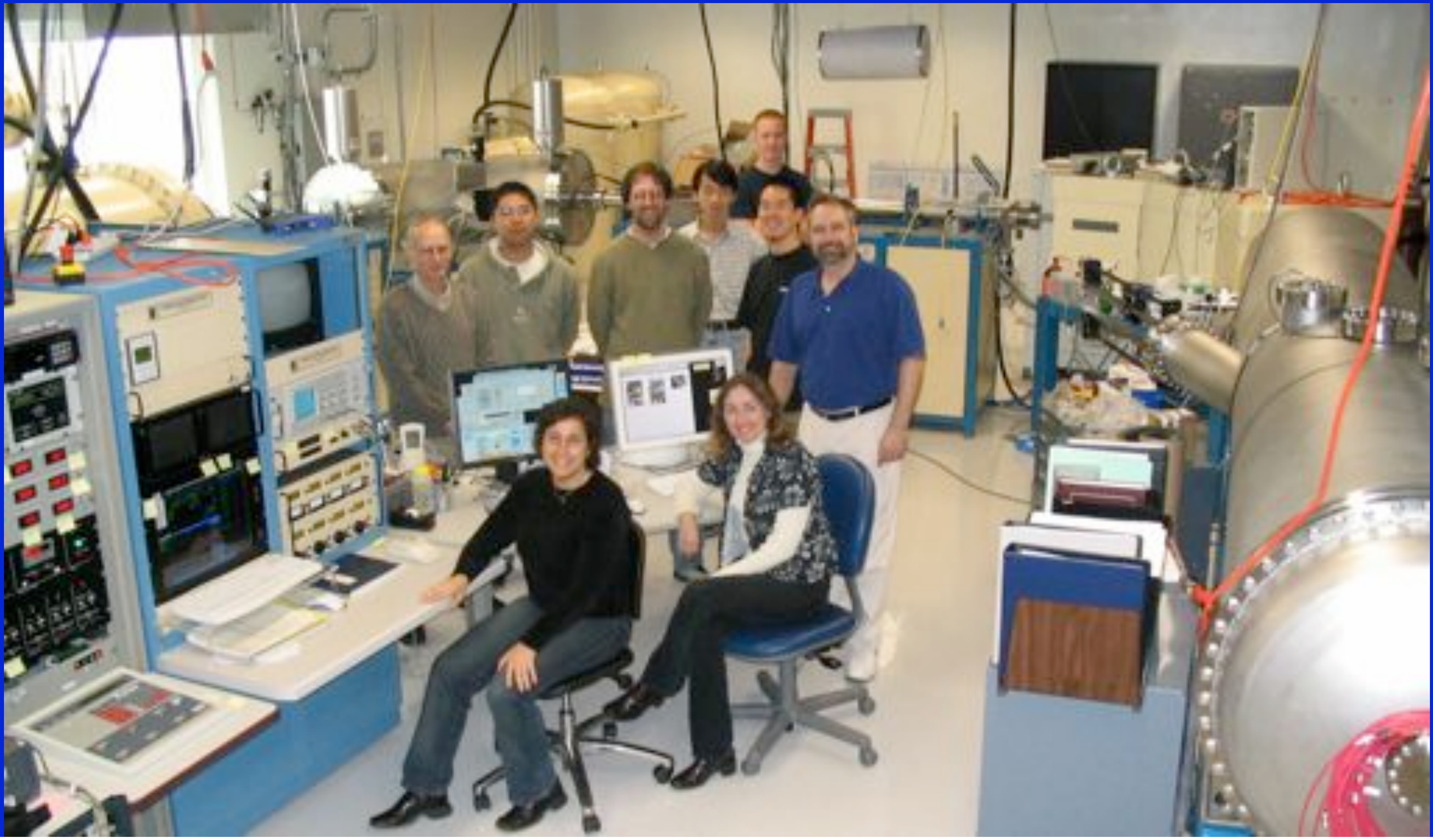
Investment in Sample Curation

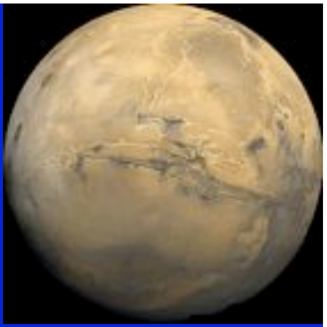
- Curation of valuable returned samples ensures:
  - that information recorded in samples is not compromised
  - availability of samples for analyses by future generations of scientists and instruments

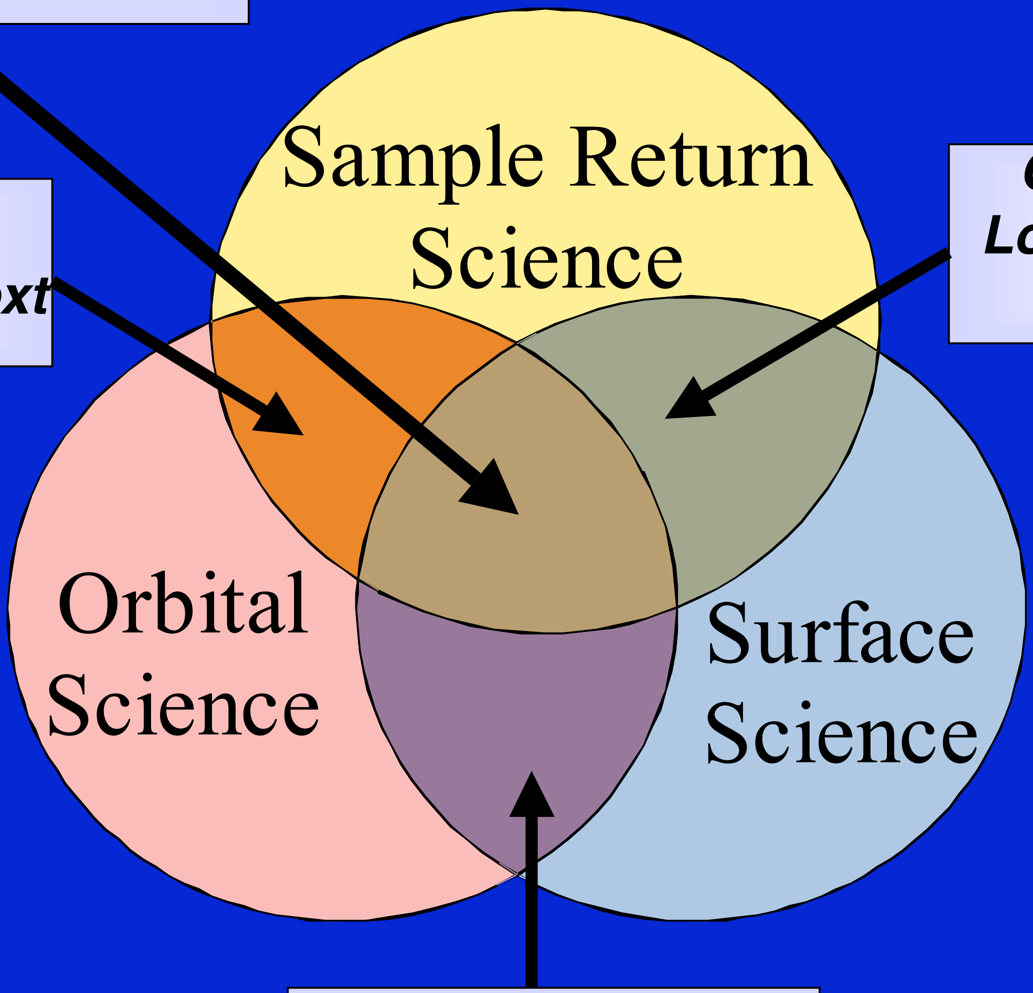


Investment in Analytical Development

- Analytical development is necessary to get the most information from returned samples







Richer Understanding of Planetary Formation & Evolution

Sample Return Science

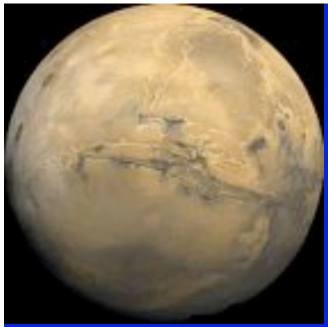
Ground Truth, Planetary Context

Ground Truth, Local “Geologic” Context

Orbital Science

Surface Science

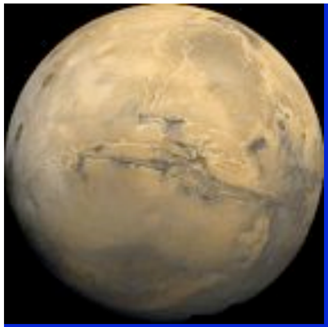
Surface Conditions, Planetary Context



Importance of Returned Samples

Samples Provide a Unique Perspective

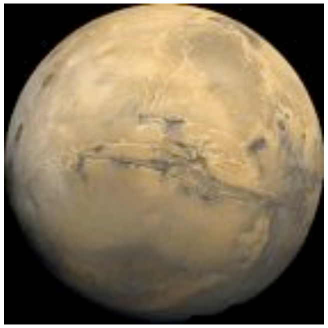
- Relatively small samples often record planetary- and solar system-scale processes.
- Establishes ground truth for remote and surface measurements.
- Provides a unique perspective based on high spatial resolution and high analytical precision.
- Large numbers of scientists can usefully participate, bringing a diversity of experience and expertise.



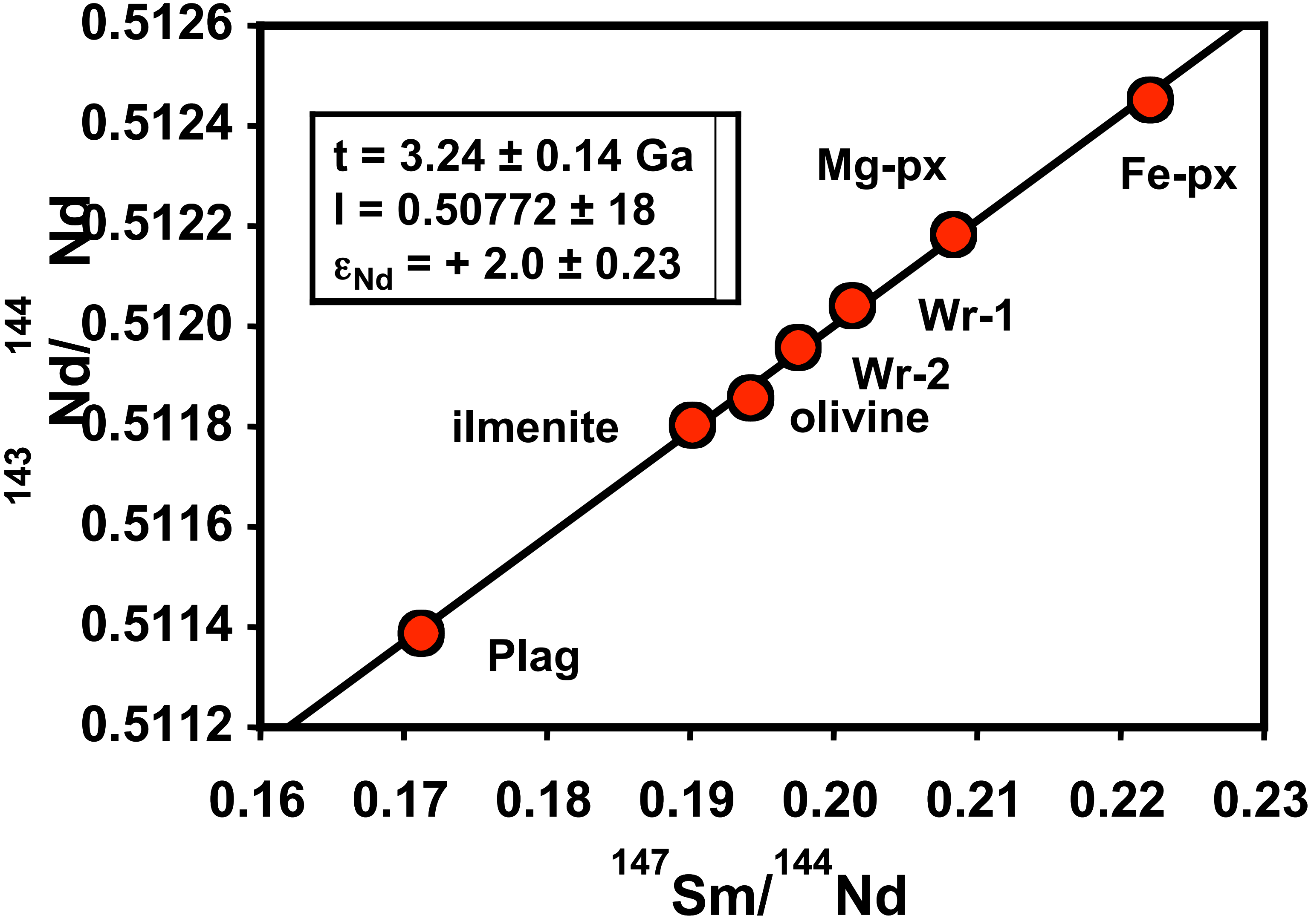
Importance of Returned Samples

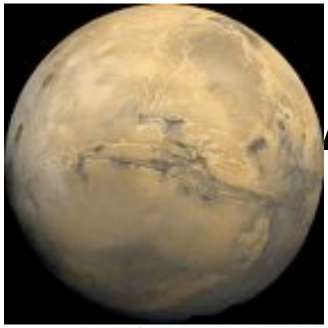
Analyses in a Lab will <u>Always</u> be Better

- The <u>best instruments and methods</u> (current and future!) can be used to analyze returned samples, not the best available at the end of mission design reviews.
- Instrumentation is <u>not limited</u> by mass, power, reliability, data rate, the requirement to work autonomously, etc.
- Analysis is <u>iterative</u> and not limited by preconceived ideas.
- Offers a high degree of <u>sample manipulation and multiple analytical approaches</u>.
- Unexpected or ambiguous results can be tested with additional measurements or modified experiments.
- <u>Flexibility</u> in the ability to modify experiments as logic and technology dictate over an extend period of time.

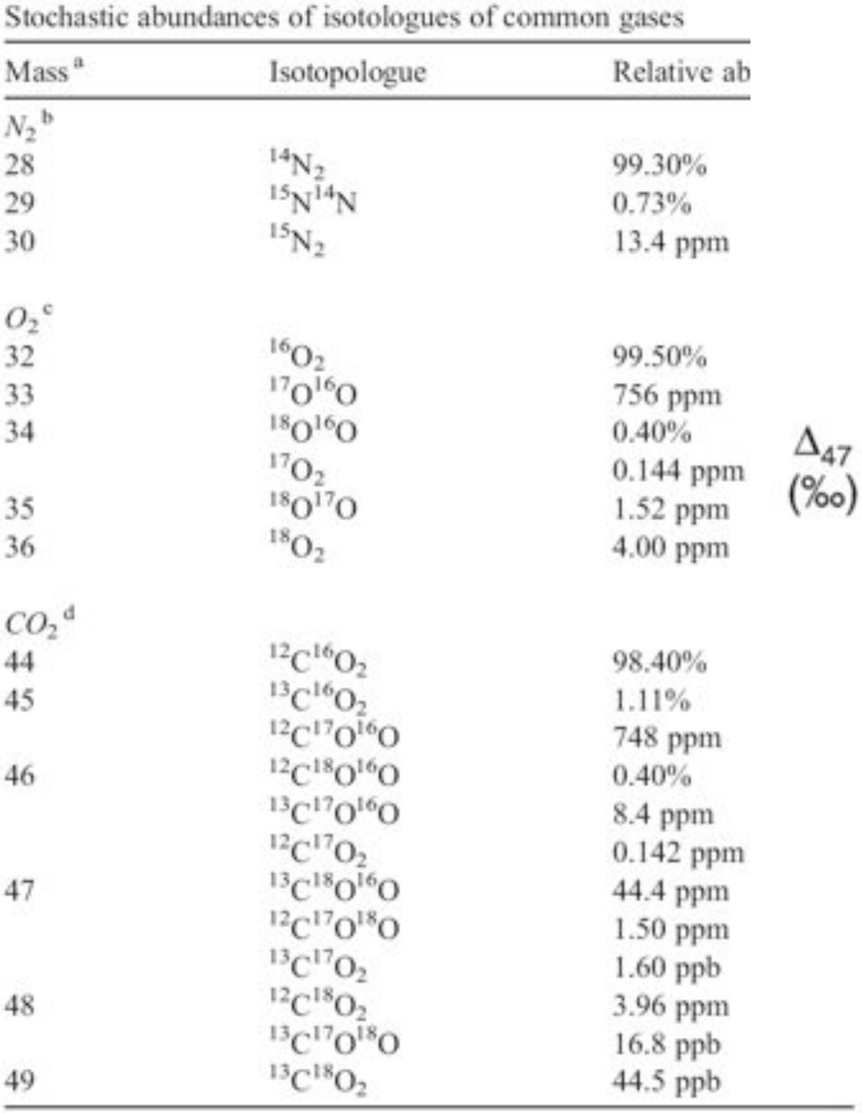


An Example: High Precision Radiometric Dating



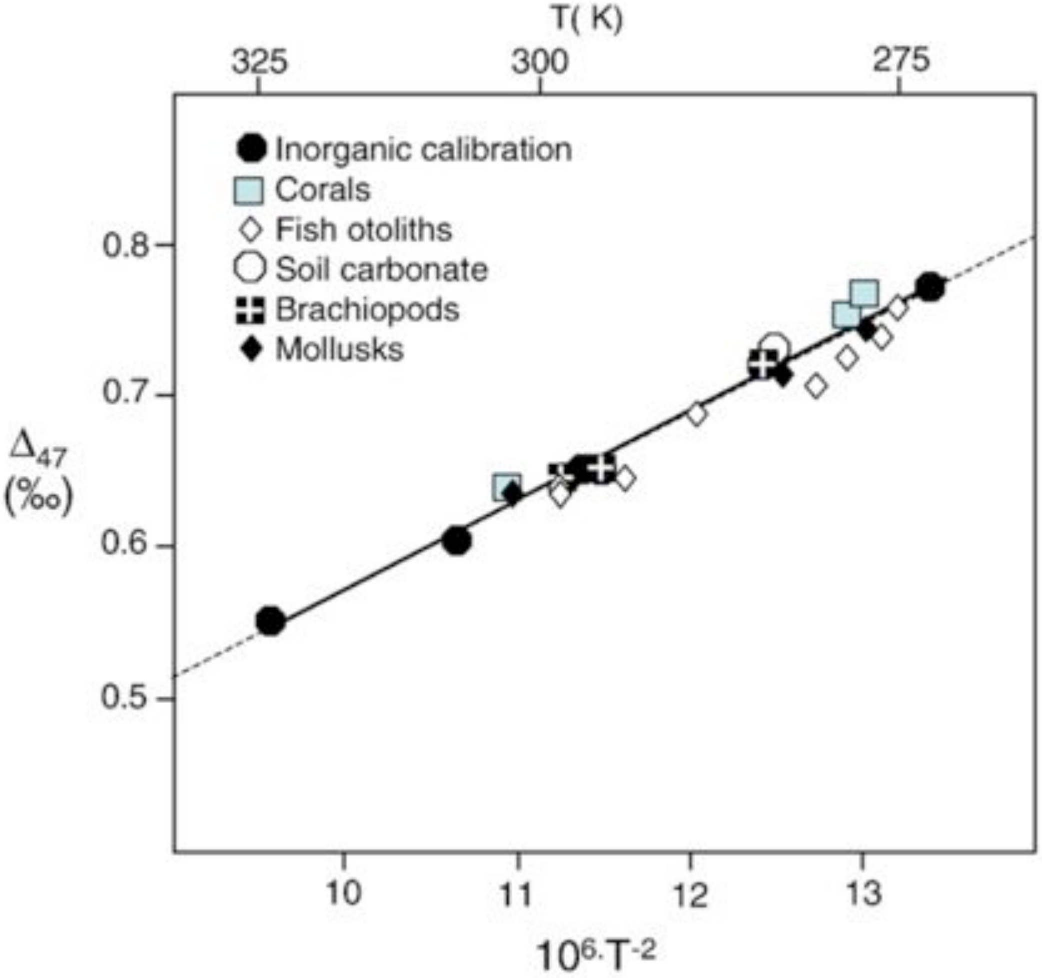


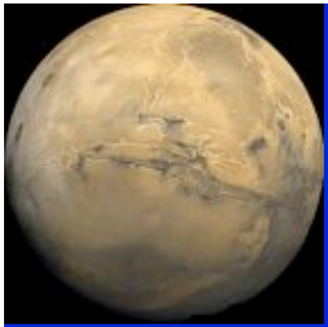
An Example: “Clumped Isotope” Paleothermometry



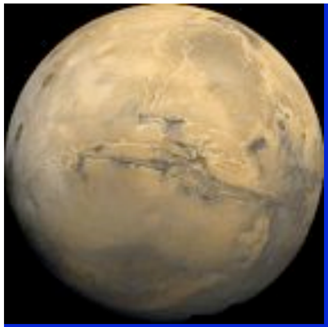
Stochastic abundances of isotologues of common gases

Mass [a]	Isotopologue	Relative ab
N_2 [b]		
28	$^{14}N_2$	99.30%
29	$^{15}N^{14}N$	0.73%
30	$^{15}N_2$	13.4 ppm
O_2 [c]		
32	$^{16}O_2$	99.50%
33	$^{17}O^{16}O$	756 ppm
34	$^{18}O^{16}O$	0.40%
	$^{17}O_2$	0.144 ppm
35	$^{18}O^{17}O$	1.52 ppm
36	$^{18}O_2$	4.00 ppm
CO_2 [d]		
44	$^{12}C^{16}O_2$	98.40%
45	$^{13}C^{16}O_2$	1.11%
	$^{12}C^{17}O^{16}O$	748 ppm
46	$^{12}C^{18}O^{16}O$	0.40%
	$^{13}C^{17}O^{16}O$	8.4 ppm
	$^{12}C^{17}O_2$	0.142 ppm
47	$^{13}C^{18}O^{16}O$	44.4 ppm
	$^{12}C^{17}O^{18}O$	1.50 ppm
	$^{13}C^{17}O_2$	1.60 ppb
48	$^{12}C^{18}O_2$	3.96 ppm
	$^{13}C^{17}O^{18}O$	16.8 ppb
49	$^{13}C^{18}O_2$	44.5 ppb

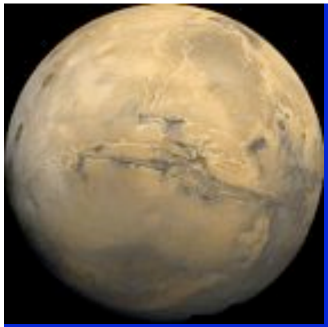




Samples are
“gifts that keep on giving”

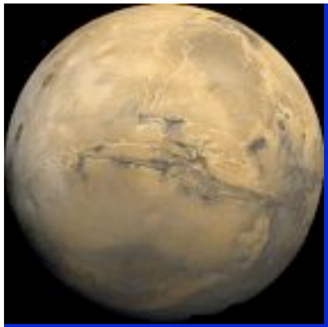


But….if we already have Mars samples (SNC meteorites), <u>why</u> do we need sample return from Mars???

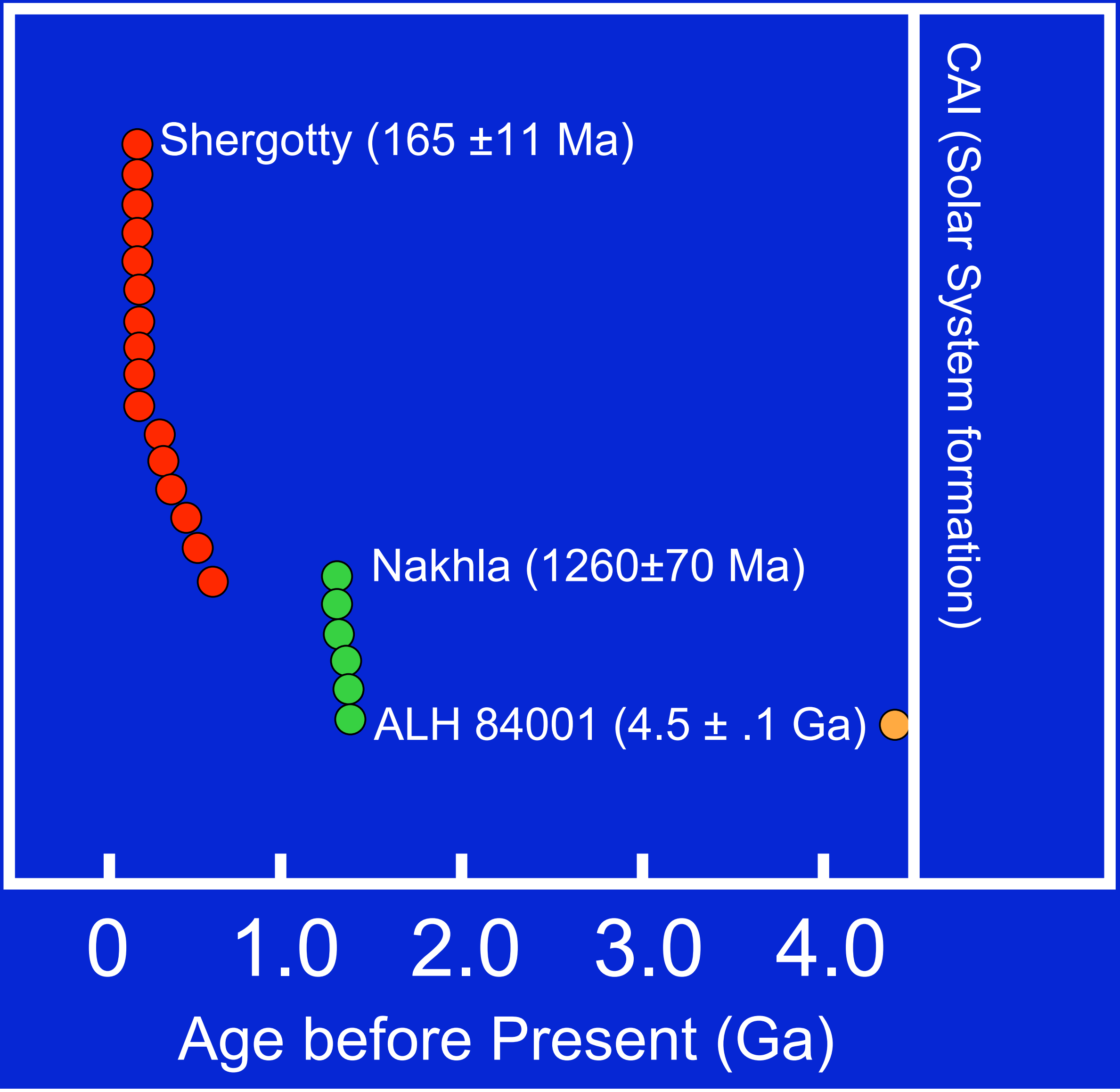


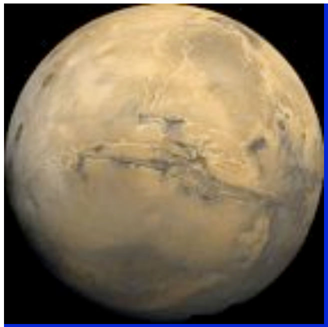
Martian Meteorites

- Approximately 4 dozen or so unpaired meteorites are acknowledged as samples derived from Mars.
- The total mass of these samples exceeds ~85 kg. All are of igneous origin and formed by the crystallization of basaltic magmas on or near the martian surface. All (expect one) are younger than 1.3 Ga.
- With such a large mass in hand, why is it critical to return additional material from Mars?



Ages of Martian Meteorites

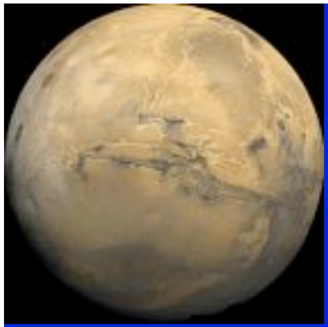




What has been learned from martian meteorites?

- Mars has been geologically active into the recent past (& may still be), but no evidence for active and sustained plate tectonics
- Early and rapid accretion and differentiation
- Presence of an early dynamo
- Possible that significant inventory of water and volatiles was delivered from interior to surface by volcanism
- An active groundwater cycle; but episodic, short-lived surface water reservoirs

⇒ Dynamic and evolving atmosphere and hydrosphere! Possibility of crustal hydrothermal systems.

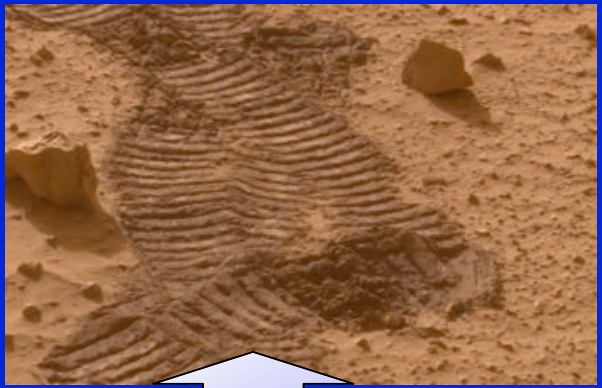


Some questions posed by the martian meteorites?

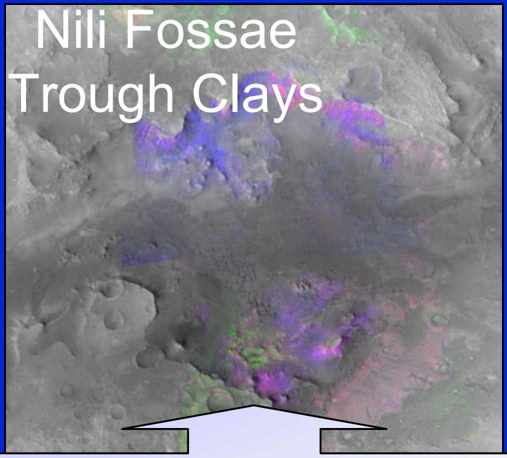
- What is the abundance of volatiles (C, H, S) in the martian mantle and was it a significant source of volatiles in the atmosphere and surface?
- What is the composition of the martian crust? Is martian magmatism essentially basaltic in composition, or are more evolved compositions common on Mars?
- How well do the low-temperature phases in the martian meteorites record aqueous alteration processes on Mars?
- Is there evidence of life (extinct or extant) on Mars?

Martian meteorites present a biased view of Mars

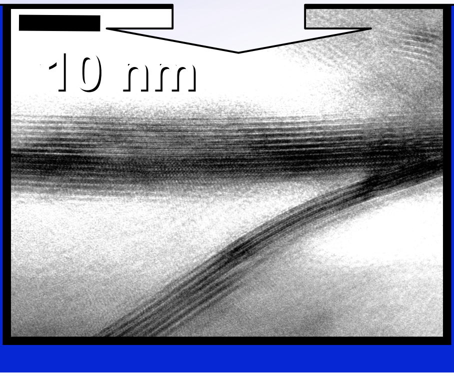
Orbital and surface missions have revealed that Mars has a plethora of distinct environments not represented in the meteorite collection.



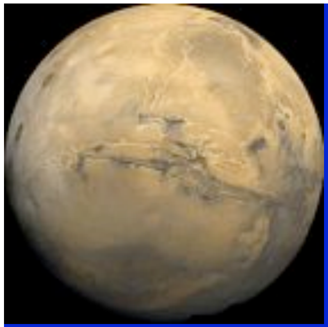
Regolith



Sheet silicates



Br-,Cl-,S-rich samples



What is the value of MSR?

Martian meteorites provide a highly biased view of Mars, and lack geologic context.

- Need MSR to provide samples with geologic context for ground truthing of orbital and surface science data sets. Important for addressing the MEPAG goals of “Geology” and “Climate”.
- Furthermore, MSR will be critical for addressing the MEPAG goals of “Life” and “Human Exploration”.

Candidate Scientific Objectives for MSR Missions (1 of 2)

NOTE: No single site on Mars will support all of these.

Ref.	Goal	Draft Objective	Nickname	Relative Priority
1	I	Characterize the reservoirs of carbon, nitrogen, sulfur, and other elements with which they have interacted, in chemical, mineralogical, isotopic and spatial detail down to the submicron level, in order to document any processes that can sustain habitable environments, both today and in the past.	**Habitability**	**H**
2	I	Assess the evidence for pre-biotic processes and/or life at one location by characterizing any signatures of these phenomena in the form of organic molecular structures, biominerals, isotopic compositions, morphology, and their geologic contexts.	**Pre-biotic, life**	**H**
3	III	Interpret the conditions of water/rock interactions through the study of their mineral products.	**water/ rock**	**H**
4	III	Constrain the absolute ages of martian geologic processes, including sedimentation, diagenesis, volcanism/plutonism, regolith formation, hydrothermal alteration, weathering, and cratering	**Geochronology**	**H**
5	III	Understand paleoclimates, paleoenvironments, and fluid histories by characterizing the clastic and chemical components, depositional processes, and post-depositional histories of sedimentary sequences.	**Sedimentary record**	**H**
6	III	Constrain the mechanisms and determine the characteristics of early planetary differentiation and the subsequent evolution of the core, mantle, and crust	**Planetary evolution**	**M**

Candidate Scientific Objectives for MSR Missions (2 of 2)

NOTE: No single site on Mars will support all of these.

7	III	Understand how the regolith is formed and modified and how it differs from place to place.	**Regolith**	**M**
8	IV	Substantiate and quantify the risks to future human explorers through characterization of biohazards, material toxicity, and dust/granular materials, as well as demonstrate the potential utilization of in-situ resources to aid in establishing a human presence.	**Risks to human explorers**	**M**
9	I	For the present-day Martian surface and accessible shallow subsurface environments, determine the state of oxidation as a function of depth, permeability, and other factors in order to interpret photochemical processes in the atmosphere, the rates and pathways of chemical weathering, and the potential to preserve chemical signatures of extant life and pre-biotic chemistry.	**Oxidation**	**M**
10	II	Utilize precise isotopic measurements of martian volatiles in both atmosphere and solids to interpret the atmosphere's starting composition, the rates and processes of atmospheric loss and atmospheric gain from interior degassing and/or late-stage accretion, and atmospheric exchange with surface condensed species.	**Gas Chemistry**	**M**
11	II	Determine the relationship between climate-modulated polar deposits, their age, geochemistry, conditions of formation and evolution through detailed examination of the composition of water, CO2, and dust constituents, isotopic ratios , and detailed stratigraphy of the upper layers of the surface .	**Polar**	**M**

Sample Acquisition System Priorities

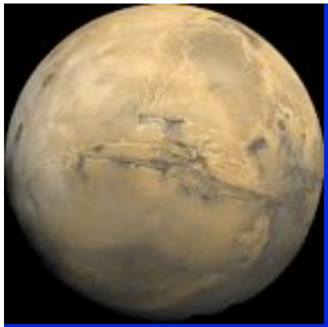
		Acquisition System Priority					
Sample Type	Mechanical	Mini-Corer	Big drill	Scoop	Tongs	Rake	Other
Sedimentary suite	rock	H		L		L	
Hydrothermal suite	rock	H		L		L	
Low-T W/R suite	rock	H		M	M	M	
Igneous Suite	rock	H		L	L	M	
Depth-Resolved Suite	rock or reg.		H				
Regolith	granular	H	H	H		H	
Dust	granular			H			M
Ice	ice or liquid						H
Atmospheric Gas	gas						H
Other	rock	H		L	M	M	

Envisioning the First MSR Mission: Parameters in the Trade Space

Attribute judged to improve science value of MSR	Range of Parameter	Preliminary Impact on Mission Engineering	Yugo	Chevy	Lexus
Sample size	**8 to 10 g**	**Minimal**	**HIGH:** *8*	**HIGH: 10**	**HIGH: 10**
Number of rock samples	**16 to 30**	**Moderate**	**HIGH:** *16*	**HIGH: 20**	**HIGH: 30**
Samples encapsulated	**yes/no**	**Moderate**	**HIGH**	**HIGH**	**HIGH**
Mobility	**2 to 10 km**	**Major**	**HIGH:** *2*	**HIGH:** *6*	**HIGH:** *10*
Mini-corer?	**yes/no**	**Moderate**	**HIGH**	**HIGH**	**HIGH**
Avoid heat sterilization	**yes/no**	**Major**	**HIGH**	**HIGH**	**HIGH**
Option A Instruments (new site)	**number: 3 to 5**	**Moderate**	**HIGH:** *3*	**HIGH: 5**	**HIGH: 5**
Option B Instruments (revisit site)	**number: 2 to 3**	**Moderate**	**HIGH: 2**	**HIGH: 2**	**HIGH:** *3*
Sample acquisition time	**6 to 18 months**	**Major**	**HIGH: 6**	**HIGH: 12**	**HIGH:** *18*
Sample acquisition time (get cache)	*6 to 12 months*	**Major**	**HIGH:** *6*	**HIGH:** *12*	**HIGH:** *18*
Sample Temperature < +20°C	**yes/no**	**Minimal**	*MED*	**HIGH**	**HIGH**
Samples from known context?	**yes/no**	**Major**	*MED*	**HIGH**	**HIGH**
solated gas sample	**compressed**	**Moderate**	**LOW**	**MED**	**HIGH**
Sample Temperature < -20°C	**yes/no**	**Major**	**LOW**	**LOW**	**HIGH**
Sample orientation known	**yes/no**	**None**	**LOW**	**LOW**	**HIGH**
Two landers?	**yes/no**	**Major**	**LOW**	**LOW**	**HIGH**
Option to visit special region	**yes/no**	**Major**	**LOW**	**LOW**	**MED**
Acquire previous cache	**yes/no**	**Major**	*TBD*	*TBD*	*TBD*
Deep drill	**yes/no**	**Major**	*TBD*	*TBD*	*TBD*

KEY: *ITALICIZED FONT* indicates consensus is TBD

Pre-decisional draft for discussion purposes only: Subject to Revision



Search for Life on Mars: An Integrated and Iterative Strategy

- Life and the history of life is inextricably connected with the physical factors of its environment, planetary composition, formation and evolution.

- The study of Mars as a possible home for life is a laudatory first step for the search for life during an initial sample return mission.

- An iterative (rather than linear) exploration strategy:
  a) Observations from orbit
  b) In-situ analyses by landed missions
  c) Sample return from previously characterized site
  d) Rinse and repeat…

Some random (but key) thoughts on MSR: The CAPTEM perspective

- MSR was accorded high priority in the 2003 decadal survey - interim orbital and surface science missions have only served to highlight the importance of MSR to addressing the important science goals of the Mars exploration program.
- MSR should NOT be viewed as the “end point” or culmination of the Mars program! It must be integrated into an iterative strategy involving both orbital and surface science towards addressing the MEPAG goals.
- Need to think creatively, and out of the box for MSR - to expect a single (and necessarily highly complex) MSR mission to meet ALL science “desirements” is unrealistic and untenable!
- Need to be thinking of MSR in terms multiple smaller missions rather than a single big mission - a first logical step of which could be “groundbreaking MSR” from a previously characterized site (e.g., n=3: MER-A,B and MSL).

Conclusions

Samples will provide a unique data set that will be critical
(the next giant leap!) for understanding Mars as a planet
(differentiation history, geologic evolution, climate and habitability) and
For paving the way to future human exploration -
will address all 4 high level MEPAG goals!

Sample return science must be an important component (along with orbital and surface science investigations) of a robust program for Mars exploration.

Sample return must not be viewed as the “end point” or culmination of a linear trajectory in the Mars exploration program - must be integrated into an iterative strategy involving orbital and surface science.

The above may imply thinking in terms of a multiple MSR components, first logical step of which could be a “groundbreaking MSR”.

Investment in curation facilities (and sample quarantine) as well as development of analytical instrumentation will be essential for getting the most from sample return.