Changing Planetary Environments & the Fingerprints of Life

The SETI Institute NAI Team

ASU, PNNL, University of Montan, University of Tennessee, CMU Robotics Institute, Georgia Tech., Honeybee Robotics, CAB (Madrid)

NASA Ames, DWD and University of Erlangen (Germany), McGill (Canada)

The SI Research Program (Quick Facts)

- 20 Co-Is (12 from the SETI Institute).
- 7 Collaborators
- 14 Institutions
- 5 countries (USA, Canada, Spain, Chile, Germany).
- 4 Integrated Research Areas.
  - 8 Focus Areas.
    - 23 Investigations.

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Janice Bishop (SI)

Adrian Brown (SI)

Sherry Cady (PNNL)

Alfonso Davila (SI)

Edna DeVore (SI)

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Virginia Gulick (SI)

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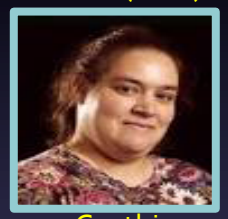
Jeffrey Moersch (UTK)

Victor Parro (CAB)


Cynthia Phillips (SI)

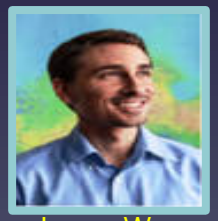
Richard Quinn (SI)

Philippe Sarrazin (SI)

Pablo Sobron (SI)

David Summers (SI)

David Wettergreen (CMU)

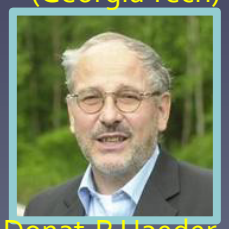

James Wray (Georgia Tech)

Kris Zackny (Honeybee)

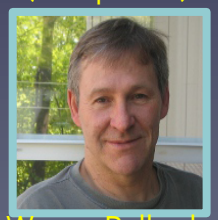
Cristian Tambley (Campoalto)

David Blake (NASA Ames)

Uwe Feister (DWD)


Donat-P Haeder (U. Erlangen)

Richard Leveille (McGill)


Wayne Pollard (McGill)

A Roadmap to Biosignature Exploration on Mars

SETI Institute

- Support to life-seeking missions to Mars (SDT Recommendations, Mustard et al. 2013), starting with 2020 (traces of ancient life) and leading to Mars Sample Return.
- A central question:

How to identify and cache the most valuable samples?

- Sub-elements to the central question:

Where to search?

What to search for?

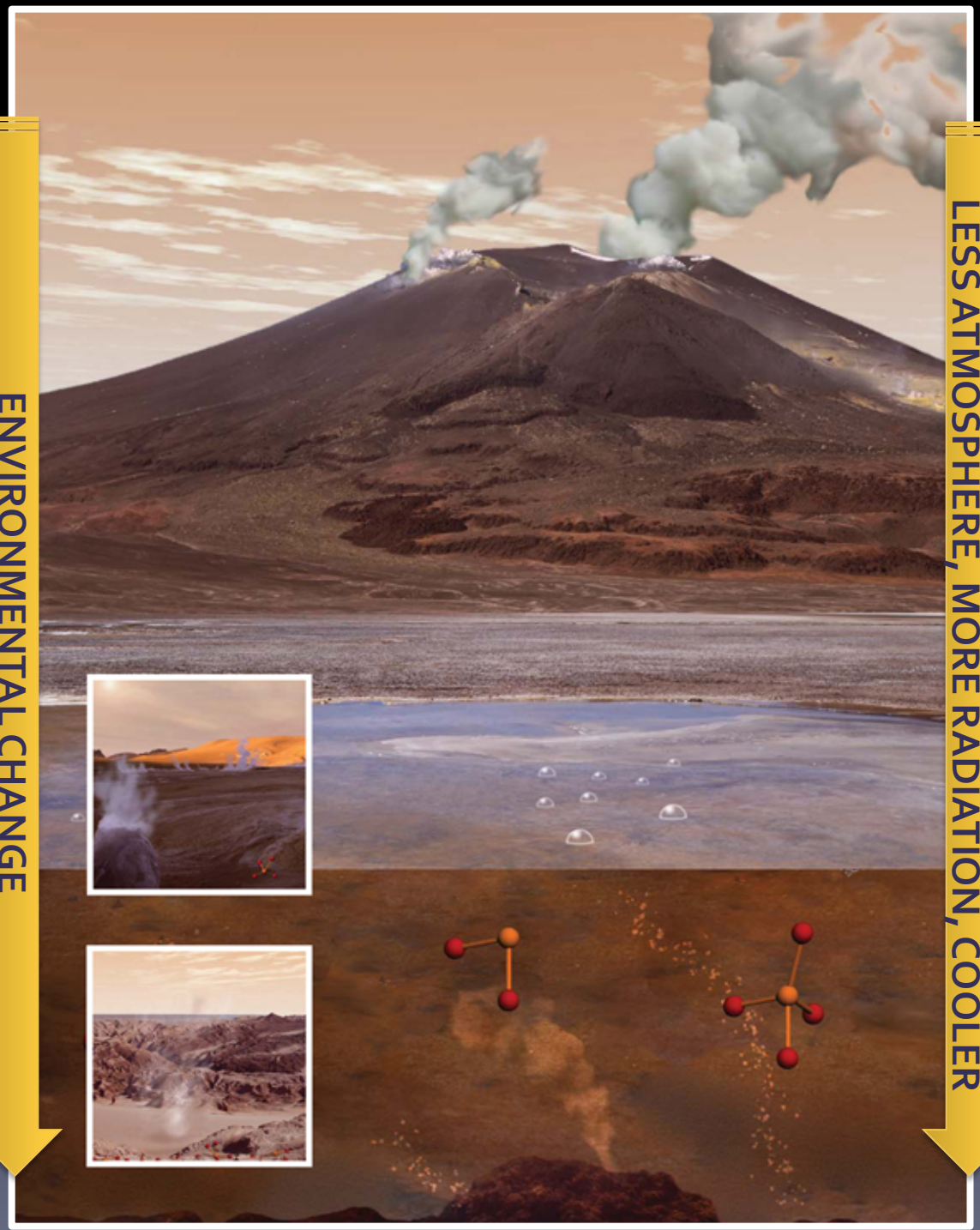
How to search?

NOACHIAN

HESPERIAN

PRESENT

ENVIRONMENTAL CHANGE



LESS ATMOSPHERE, MORE RADIATION, COOLER

HABITABILITY & LIFE POTENTIAL

BIOSIGNATURE PRESERVATION POTENTIAL

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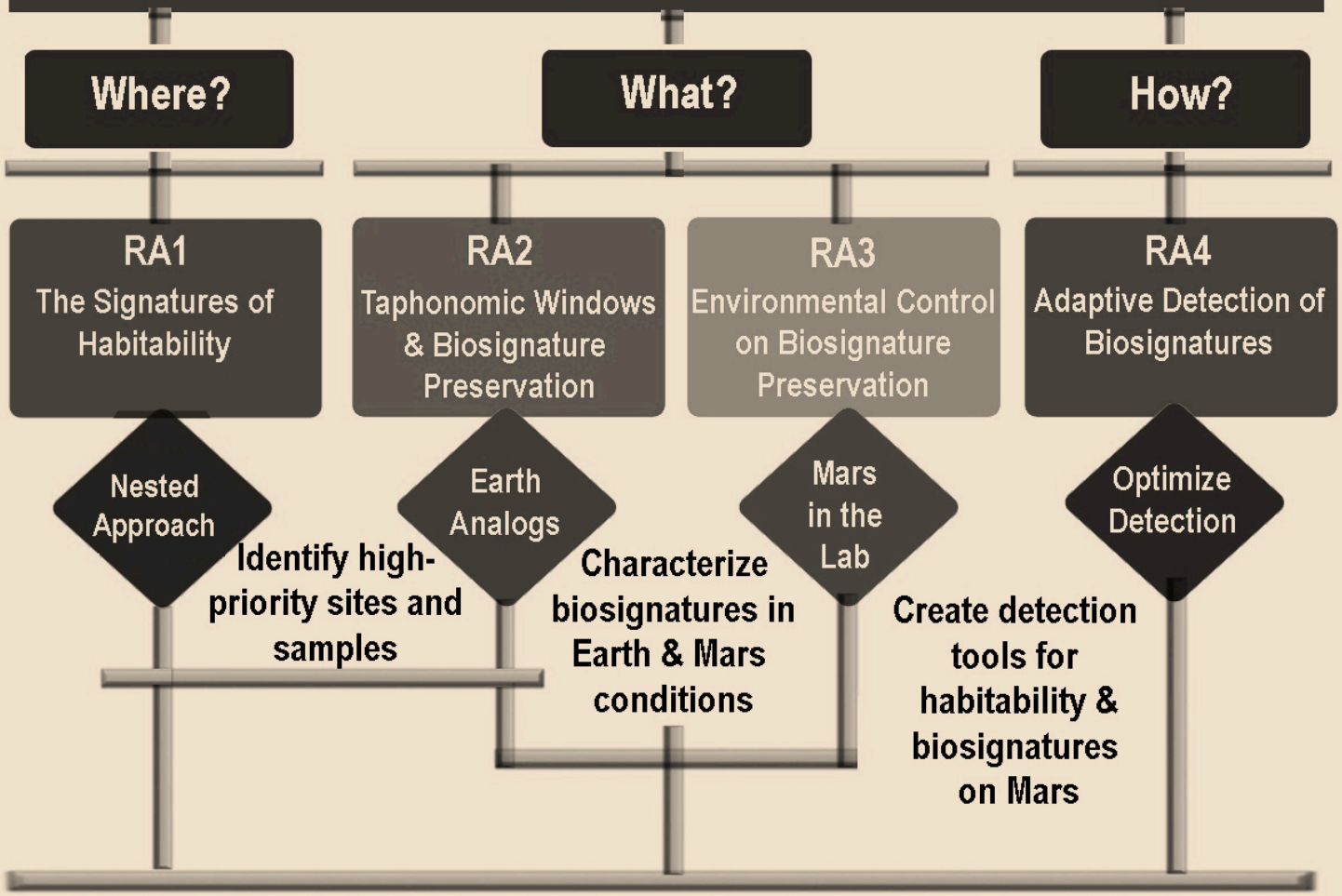
How to Cache the Most Valuable Samples on Mars?
The SI Team Roadmap



Improve Sample Scientific Documentation & Biosignature Detection Potential

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Changing Martian Environments: transitions in aqueous mineralogy and chemistry

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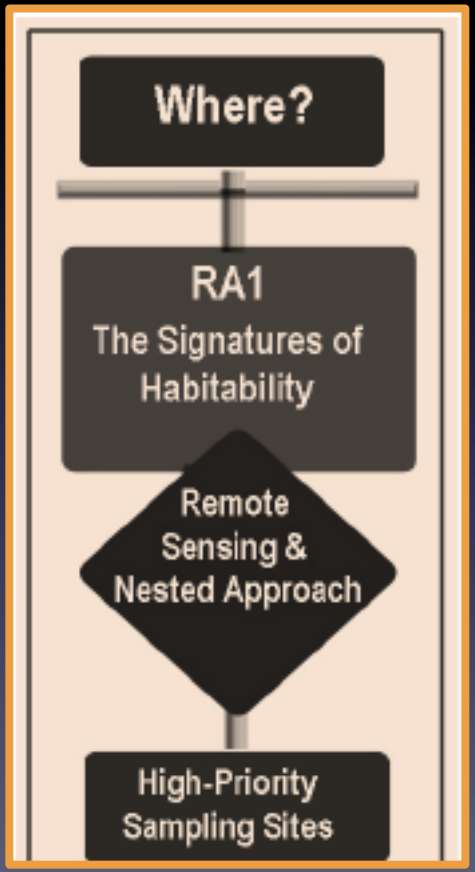
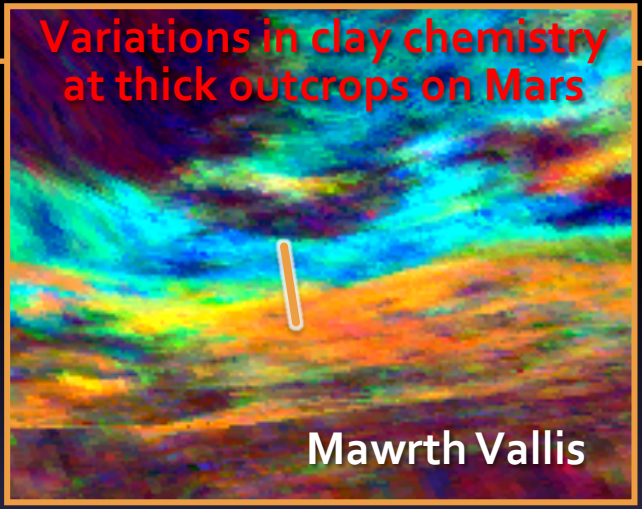
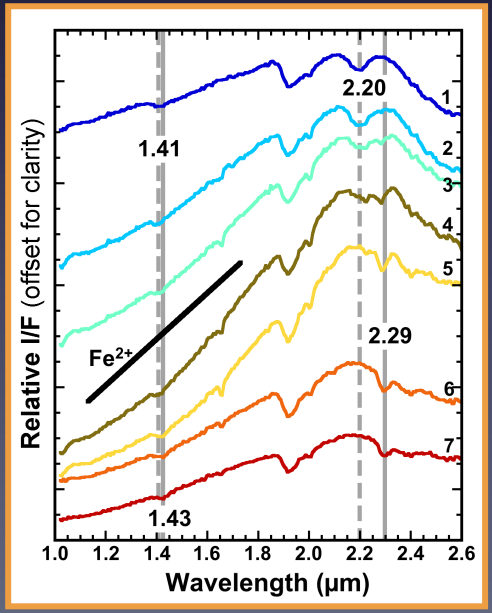


Variations in clay chemistry at thick outcrops on Mars





Variations in carbonate chemistry across Mars

Bridging Knowledge Gaps

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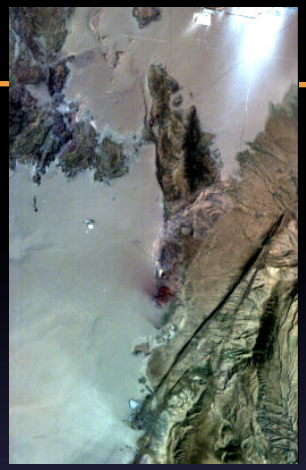
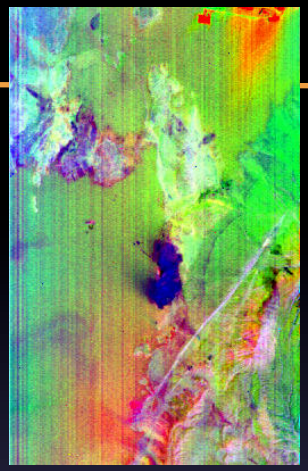
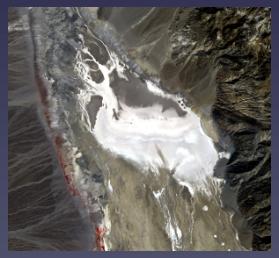
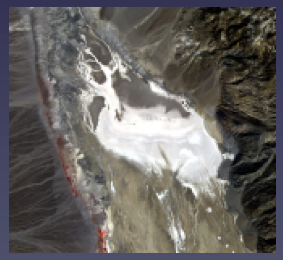


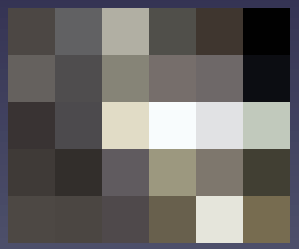


Regional-scale compositional mapping of field sites using orbital multi- and hyperspectral images, to set geologic context.

Low-altitude aerial observations from UAVs to create cm-scale orthophotomosaics and digital elevation maps of selected field sites.







Multi-scale assessment of orbital and aerial datasets to establish critical thresholds of detectability in spatial resolution for key habitable environments.

"Ground-truthing" of remote observations – calibration and validation of orbital and aerial results using portable field spectrometer and sampling for lab analyses.

Instruments and Datasets

SETI INSTITUTE

- Orbital Imagery - NASA EOS mission datasets: C. Phillips
- Aerial Imagery: Octokopter - Vis/FLIR: J. Moersch
- Context Imagery: Stereo Camera: D. S. Wettergreen
- Context Mineralogy : ASD/VNIR: J. Moersch
- Fine Scale Context & Mineralogy (MMI): J. D. Farmer
- Fine Scale Mineralogy & Geochemistry (Terra/CheMin): P. Sarrazin & D. Blake.
- Fine Scale Mineralogy & Biomarkers (LRS/LiBS): P. Sobron.
- Molecular Biomarkers (SOLID, In situ Life Detection): V. Parro.
- Radiation Environment (Micro-Eldonet): N. A. Cabrol
- Subsurface Access (SLOT and Preview Core Drill with acquisition window): K. Zacny.

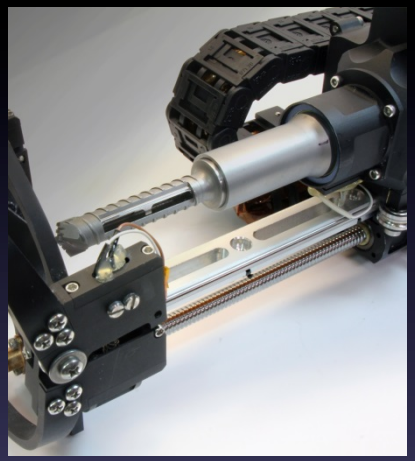
In Situ

HoneyBee Robotics Preview Core Drill System

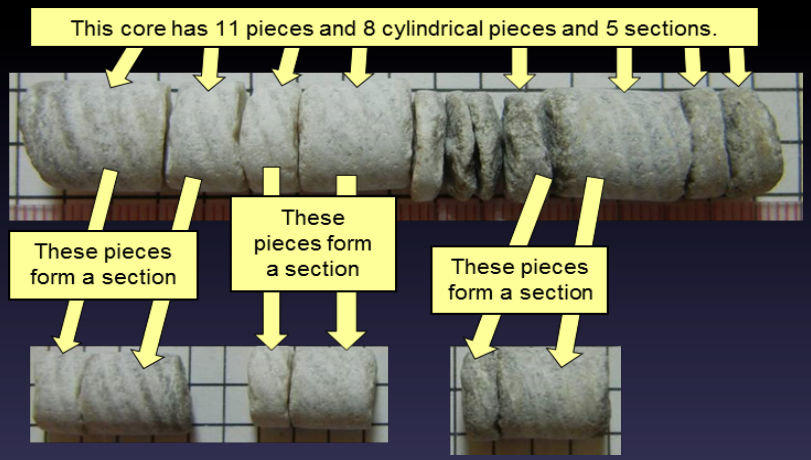
SETI INSTITUTE

1 m drill

Powder Bit



Core quality assessment



Sealing/Caching

SLOT Bit

Summary RA1 Focus Areas (FAs) and Investigations

SETI INSTITUTE

- FA-A: Transitions in Mars Ancient Mineral Record
  - Inv.1: Changes in aqueous chemistry over time on Mars (Bishop Lead);
  - Inv. 2: Global differences in Fe/Mg-Phyllosilicates on Mars (Bishop Lead);
  - Inv. 3: Global variations in carbonate chemistry on Mars (Wray, Brown Leads);
  - Inv. 4: Duration of ancient aqueous environments on Mars (Gulick Lead).

Summary RA1 Focus Areas (FAs) and Investigations

SETI INSTITUTE

- FA-B: From Habitability to Biosignature
  - Inv. 5: Connecting orbital and *in situ* data (Phillips Lead);
  - Inv. 6: Bridging knowledge gaps (Moersch Lead)
  - Inv. 7: *In situ* correlated measurements (all *in situ* instruments PIs, and integration with Inv. 5-6.

RA2: Taphonomic Windows & Biosignature Preservation - Terrestrial Analogs

- Mars Space-for-Time Substitution Experiment
  - (Lakes to evaporitic basins: Arctic-Andes-Atacama) + Seasonal and Permanent high UV.
- Biosignature Preservation in volcanic, hydrothermal environment, cold springs, desert.
- Microbialites in times:
  - Oldest Fossils (Pilbara, Australia);
  - Recent Fossils (Altiplano, ~11,000 yr)
  - Modern, Active (High Arctic)

Terrestrial Analogs

High Andes Volcanic - Hydrothermal Systems in Extreme UV

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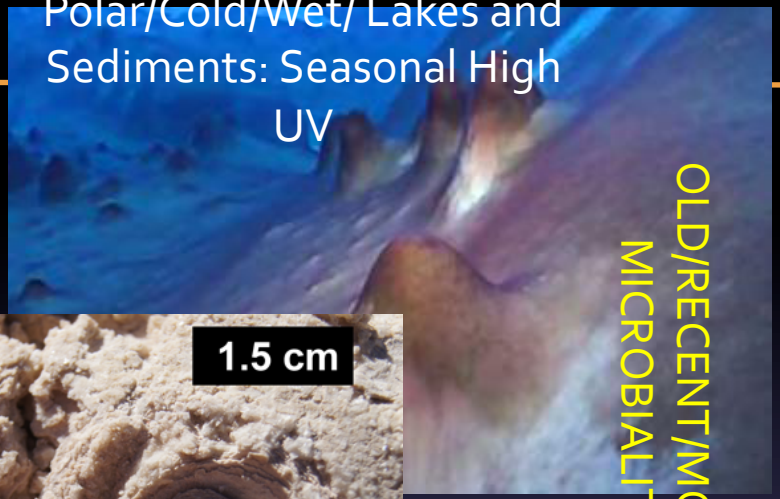
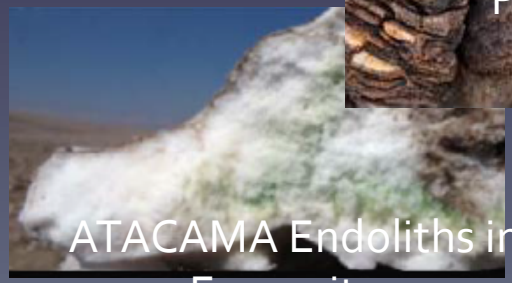
Polar/Cold/Wet/ Lakes and Sediments: Seasonal High UV



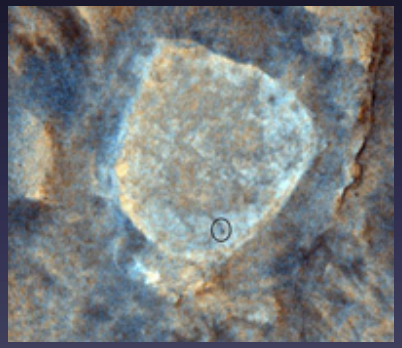
OLD/RECENT/MODERN MICROBIALITES

ALTIPLANO

PILBARA



ATACAMA Endoliths in Evaporites



MARS

Arctic Cold Springs

El Tatio/Yellowstone

High Andes: Lakes and Sediments in Cold/Dry/ Permanent Extreme UV Environment

Ground-Truth/ Exploration Templates and Metrics

- (1) Advance the understanding of instruments providing data on threshold and baseline measurements requested by the Mars 2020 SDT to satisfy the documentation of high-priority samples, and
- (2) Evaluate their individual and combined diagnostic power on key Mars analog materials.

Samples Returned to the Labs

SETI Institute
NASA Ames
ASU
Georgia Tech
Honeybee
PNNL
University of Montana
University of Tennessee
CAB Spain

RA2: Lab Instruments and Techniques

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- Core, Hand, Powder, Synthetic Samples will be made Available to the other NAI teams for additional/complementary analyses.
  - ESI FTMS
  - LA ICPMS
  - Mars Simulation Chambers (ARC, Univ. Maryland)
  - Macromorphology and/or Stereomicroscopy
  - Focused Ion Beam Sectioning
  - Helium Ion Microscopy
  - X-Ray Photoelectron Spectroscopy
  - Analytical High-Resolution Transmission Electron Microscopy
  - Time-of-Flight Secondary Ion Mass Spectroscopy
  - NanoSIMS
  - Nano Emission X Fluorescence Spectroscopy
  - Lab Raman

Summary RA2 Focus Areas (FAs) and Investigations

SETI INSTITUTE

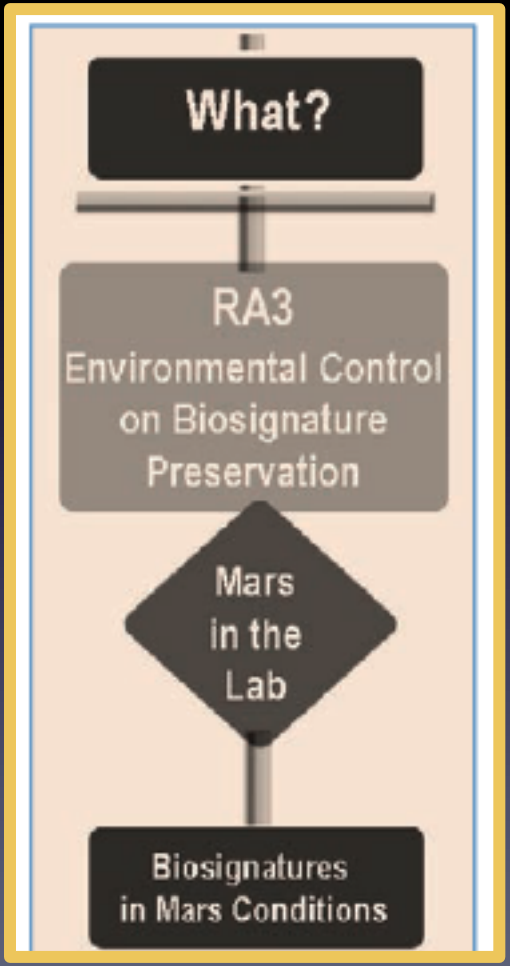
- FA-C: Volcanic/Hydrothermal Environments
  - Inv. 8: Hyperthermophilic chemotrophic biofilms (Cady Lead T1/ T2; Co-Lead Cabrol T3). (T1) Nature and distribution of organic biosignatures in silica sinters; (T2) Synthesis of primary opaline silica precipitated under controlled abiotic conditions; (T3) Impact of extreme UV and volcanic activity on silica sinter preservation potential.
  - Inv. 9: Impact of Reactive Oxygen Species on Biosignature Preservation (Hinman, Lead).
  - Inv. 10: Biosignature preservation in subsurface volcanic environments (Farmer Lead).

Summary RA2 Focus Areas (FAs) and Investigations

SETI INSTITUTE

- FA-D: Lake Sediment Habitats
  - Inv. 11: Lake habitability and sediment biosignatures (Cabrol and Andersen Co-leads, polar and andean lakes).
  - Inv. 12: Comparison of stromatolite environments and signatures in Australia, Andes, Antarctica (Brown lead).
- FA-E: Evaporitic Environments
  - Inv. 13: Spectroscopic and morphologic comparison of salars in the Atacama with chloride-bearing deposits on Mars (Bishop lead).
  - Inv. 14: Biosignature preservation in evaporitic crusts (Davila lead).
  - Inv. 15: Taphonomic processes and preservation modes (Farmer lead).
- FA-F: Perennial Cold Springs
  - Inv. 16: Characterization of habitability and biosignature preservation in cold springs (Andersen lead).

RA3: Environmental Controls on the Survival & Preservation Potential of Organic Molecules



Biogeomaterials (field samples and synthetic samples exposed to changing early Mars conditions in the lab to understand biomarker stability, preservation potential, and detection.

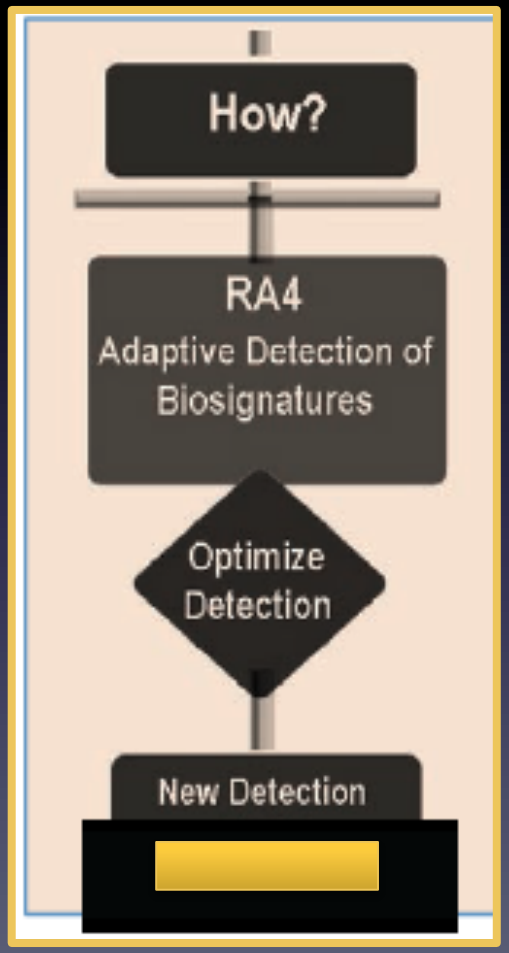
(1) The role that changes in water availability have played in time in the chemical evolution of ancient organic biomarkers;
(2) The role of mineral and soil matrices in the sequestration and preservation of organics;
(3) The impact of radiation in the generation of oxidants and alteration of organics;
(4) The role these three variables play in the formation of spatial distributions of biosignatures within microenvironments.

Summary RA3 Focus Areas (FAs) and Investigations

SETI INSTITUTE

- FA-G: Environmental Controls on Biosignatures
  - Inv. 17: The role of water availability on preservation (Summers lead).
  - Inv. 18: Minerals, soils, and the preservation of organic matter. Exposure of organics to extreme UV in the lab and in the field (Ertem lead lab; Cabrol lead field).
  - Inv. 19: UV radiation and the preservation of organic matter (Hinman lead).
  - Inv. 20: Alteration of minerals & organics by ionizing radiation (Quinn lead).

RA4: Adaptive Detection of Biosignatures



To be conclusive, proof of life will need to be confirmed by multiple lines of evidence, i.e., various means of measurement and scales.

Ra4 will augment detection effectiveness by applying science autonomy and adaptive science:

(1) data fusion – (integrated/nested exploration)
(2) novelty detection
(3) autonomous detection of biogenicity across the multi-scale, multi-resolution datasets produced by RA1-RA3.

Summary RA4 Focus Areas (FAs) and Investigations

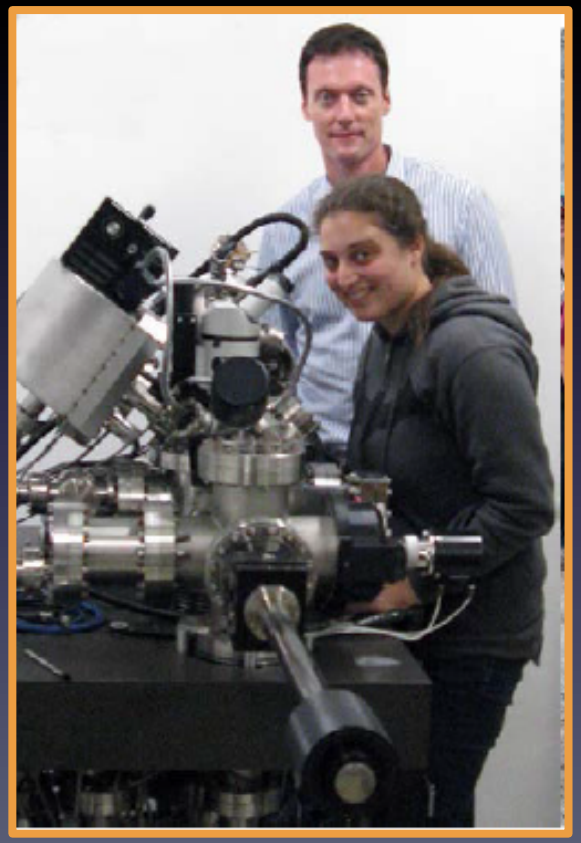
SETI INSTITUTE

- FA-H: Data Fusion and Automated Detection
  - Inv. 21: Detection of Biosignatures : (T1) Multi-resolution data analysis; (T2) Novelty detection, (Wettergreen lead).
  - Inv. 22: Automated prediction of biogenicity in laminated sediments: (T1) Biogenicity metrics development; (T2) Mars analog sediment detection tests (Cady lead).
  - Inv. 23: Image and Raman spectral library: (T1) Sample analysis and library development; (T2) Autonomous sedimentary mineral and biosignature classifiers (Gulick lead).

Focus Groups (?)

- Contribute to the Mars Focus Group:
  - *Identify scientific goals, objectives, and investigations for the astrobiological exploration of Mars, and to help define priorities.*
- Create a Biosignature Exploration Focus Group:
  - *Create novel strategies and detection tools for the exploration of planetary habitability and biosignatures in the Solar System.*

Participation of Students & Young Researchers



- The SI Board of Trustees committed to $1.2M total to support the creation of a SETI Institute Postdoc Program (starting Yr. 2).
- Programmed: Students from the Research Experiences for Undergraduates – REU, and California-Arizona Minority Partnership for Astronomy Research and Education CAMPARE programs); URSA (?).
- US Embassy, Santiago (Chile): E/PO during field deployments in Chile. Long-term collaboration with the PI is now extended to the NAI. The US Embassy has allowed us to mention this collaboration in official documents for the project if need be. They are ready to assist us.
- NAI-Supported SI E/PO Program (?)

Opportunities for Collaborations Within the NAI

- Sharing Samples and Spectra Library through team's archive & Sharing Analytical Methods.
- Collaborative Fieldwork and Test of Exploration Strategies.
- Bridging Research Areas.
  - Focus Groups, Other.
- Student Research Projects.
  - Fieldwork, Other.

Science Summary

SETI Institute

- (1) Characterize terrestrial analogs to high-priority environments and biogeomaterials essential for identifying traces of ancient life on Mars.
- (2) Define the habitability potential of these environments, taphonomic windows, potential for biosignatures and their preservation through the analysis of the physical, biomolecular, and metabolic records of life.
- (3) Investigate the impact of changing early martian conditions on the preservation of biosignatures.

Technology Summary

SETI INSTITUTE

Concurrently

- (1) Advance the understanding of instruments providing data on threshold and baseline measurements requested by the Mars 2020 SDT to satisfy the documentation of high-priority samples, and
- (2) Evaluate their individual and combined diagnostic power on key Mars analog materials.

Method Summary

SETI INSTITUTE

- (1) Synergistically investigate environments and biogeomaterials at multiple scales and resolutions to support, ground-truth, and validate results every step of the way.

Table 5A. Roles and Responsibilities				
Name	**Institution**	**Role**	**Research Focus/ Program Responsibility**	**Res. Area***
Cabrol, Nathalie	SETI Institute	PI	UV, Mars Habitability, Lake Sedimentology, Exploration	2, 3, 4
Andersen, Dale	SETI Institute	Co-I	Permafrost, Stromatolite, Perennial Spring, Biomarkers	2, 4
Bishop, Janice	SETI Institute	Co-I	Mars, Remote Sensing, Mineralogy	1, 2
Brown, Adrian	SETI Institute	Co-I	Hydrothermal Zones, Stromatolites, Mineralogy	1, 2, 4
Cady, Sherry	Portland State Univ.	Co-I	Biosignatures, Biogenicity, Stromatolites	2, 4
Davila, Alfonso	SETI Institute	Co-I	Evaporites, Biomarkers, Life	2, 1
DeVore, Edna	SETI Institute	Co-I	**Lead, Education and Public Outreach**	
Ertem, Gözen	SETI Institute	Co-I	Organic Molecule Survival, Cosmic Rays, Minerals	3, 2
Farmer, Jack	Arizona State Univ.	Co-I	Habitability, Taphonomy, Fossil Biosignatures	2, 1
Gulick, Virginia	SETI Institute	Co-I	Mars Imaging, Raman Spectroscopy	4, 1
Hinman, Nancy	Univ. Montana	Co-I	Geochemistry, ROS, Aqueous Speciation	2, 3
Moersch, Jeffrey	Univ. Tennessee	Co-I	Remote Sensing, Mineralogy, Spectroscopy	1, 3
Parro, Victor	CAB-INTA-CSIC	Co-I	Life Detection, Biomarker Identification, Extremophiles	2, 3
Phillips, Cynthia	SETI Institute	Co-I	Remote Sensing, Spectroscopy, Image Analysis	1, 4
Quinn, Richard	SETI Institute	Co-I	Perchlorate, Redox Chemistry, ionizing Radiation	3, 1
Sarrazin, Philippe	SETI Institute	Co-I	Mars Instruments (Terra), XRD/XRF, Sample Analysis	1, 2
Sobron, Pablo	SETI Institute	Co-I	In Situ Characterization, Laser-Based Spect. Data Fusion	1, 2, 4
Summers, David	SETI Institute	Co-I	Biomarker Preservation, Biomarker Alteration Products	3, 1
Wettergreen, David	CMU-Robotics Inst.	Co-I	Data Fusion, Automated Analysis, Biosignature Detection	4, 1
Wray, James	Georgia Tech	Co-I	Mars Spectroscopy, Stratigraphy	1, 2
Zacny, Kris	Honeybee Robotics	Co-I	Drilling, Sample Acquisition, Core Quality	2, 1
Blake, David	NASA Ames	Coll	Mineralogy, In Situ Instrument, Habitable Environment	1, 2
Feister, Uwe	DWD, Germany	Coll	UV Radiation, Spectral Irradiance at High Altitude	2
Grin, Edmond	SETI Institute	Coll	Physical Environment, Climate	2
Häder, Donat-P	Univ. Erlingen	Coll	Solar UV radiation, Ozone Depletion, UVB Effects	2
Leveille, Richard	McGill, Canada	Coll	Biosignature Detection, Geochemistry, Mineralogy	1
Pollard, Wayne	McGill, Canada	Coll	High Arctic Physical Environment	2