International Collaboration for Future Mars Missions

Report from the Mars International Collaboration Science Analysis Group (MIC-SAG)

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Outline

I(a): Mars International Collaboration Science Analysis Group (MIC-SAG) Terms of Reference

Accepted November 11, 2016

The next orbiter mission to Mars may be extremely cost constrained and could be limited in the number of U.S. instruments that can be selected.

Goal – To increase participation and coordination in contributed and selected instruments during design, development and operations of the next orbiter mission to Mars and, by doing so, to ensure that the science objectives will be met and that the international Mars science community will be maintained and enhanced.

The Mars International Collaboration Science Analysis Group (MIC-SAG) will consider the process of selection and the roles of science team members of an orbiter team to design, develop, integrate, and operate payload elements, the majority of which may be provided by international and/or commercial partners reducing significant costs to NASA.

The significant challenges that the study group will address include:

- How to organize an international team so that high-priority science is conducted to advance the goals of NASA and MEP, and be consistent with recommendations of the Decadal Survey, guided in part by the Next Mars Orbiter Science Analysis Group report (2015);
- How to craft opportunities for U.S. scientists while forming collaborations with international and commercial partners;
- How to select an effective science team that preserves the science integrity of the mission through design, development and mission operations, perhaps including phasing of its members.
- How to capture different modes of scientist participation to compare and contrast.

The MIC-SAG is requested to develop different models for scientists’ participation in the mission and delineate the pros and cons of the different approaches.

MIC-SAG membership

MIC-SAG members	
Bruce Jakosky	University of Colorado, Boulder; *Chair*
Jim Bell	Arizona State University
Barbara Cohen	Goddard Space Flight Center
Joy Crisp	Jet Propulsion Laboratory
Frank Eparvier	University of Colorado, Boulder
Don Hassler	Southwest Research Institute
Alfred McEwen	University of Arizona
Kim Seelos	Johns Hopkins University Applied Physics Laboratory
Roger Yelle	University of Arizona
MIC-SAG Ex Officio	
Rich Zurek	Mars Program Office, Jet Propulsion Laboratory; *Lead*
Serina Diniega	Mars Program Office, Jet Propulsion Laboratory
Jeffrey Johnson	Johns Hopkins University Applied Physics Laboratory; *MEPAG Chair*
Michael Meyer	NASA Headquarters; *MEP Lead Scientist*

I(b): MIC-SAG inputs and discussion

- Community input was solicited.
  - Online survey was open from early December to mid January.
  - Survey was advertised in standard newsletters to the Planetary Science community (i.e., the Mars Science newsletter, PEN – few thousand recipients) and the Young Planetary Scientists for Exploration Facebook group (~2000 "members").
  - 14 inputs from individuals + 2 white papers were submitted.
  - Comments were offered from U.S. and (2) foreign scientists and instrument providers, from a range of career levels.
- Five telecons were held November 2016-January 2017, exploring a range of perspectives & experiences related to different science mission collaboration models.
  - Presentations were by invited speakers as well as MIC-SAG members.
  - Topics included issues and advantages within past and ongoing missions in Planetary, Earth, and Heliophysics Science (at both mission and investigation levels), as well as potential future collaborations with Commercial providers. Presentations included U.S. instrument providers collaborating with a foreign mission and U.S. mission management who have been or are collaborating with foreign partner(s), within a joint mission or with more focused contributions. ITAR/EAR concerns were also discussed.
- Input was treated as confidential to the committee and will not be presented here.
- All input was used to identify key community concerns. These concerns fed into our generation of Guiding Principles and consideration of different mission collaboration models.

II. MIC-SAG Findings

a) Consensus Guiding Principles
b) Benefits and Risks of International Participation
c) Science-Teaming Summary
d) Recommendations for a Future Mars Mission

II(a): Guiding Principles (Mission & Project-level)

- Agreement is needed up front by all stakeholders (e.g., science community, NASA mission directorates, international, and/or commercial partners) on the definition of all science objectives and technical, managerial, and financial requirements of the mission.
  - This can be accomplished via: Mission Definition Team, negotiated contracts, formal international agreements, etc.
  - Reconciliation is needed of the often different approaches to requirements development by NASA directorates and other partners.
  - This should include an expectation of open sharing and archiving of data.
- Clear lines of authority and responsibility are required within the project, across all partners.
  - Communications must be open (especially at the beginning) and continuous throughout the mission, with minimal firewalling among parties.
- Individual national interests, including fostering robust planetary science programs, need to be considered in international missions.
  - Retention and/or development of key science and engineering capabilities within each community.
  - Training and mentoring the next generation of project personnel for extended and future mission(s).

II(a): Guiding Principles (Investigation-level)

- *Throughout this report, reference to investigations includes instruments and interdisciplinary scientists.*
- Open investigation competition is important for enabling the best science to be achieved.
- Ownership of an investigation by an individual leading a team to develop and operate the instrument and fully achieve the science goals has been demonstrated to yield excellent results in planetary science and to reduce risk.
- Participation of key personnel and continuity of science, engineering, and operations expertise and knowledge is required through all stages of mission.
- Increased opportunities for U.S.-provided science investigations—for example, by seeking externally contributed spacecraft subsystems—can make more science funds available within a fixed budget.
- Adequate funding for U.S. scientists collaborating on contributed investigations is needed.

All of these guidelines can be met within different instrument-provision models (e.g., PI-led, facility instrument – defined on slide 24), as long as appropriate care is taken in developing interactions and plans among all stakeholders.

II(b): Benefits and Risks of International Participation: Background

- Planetary Science is by nature international. U.S. scientists collaborate with scientists around the world because of shared interests and complementary expertise.
- There are many strong examples of successful international cooperation at the Project level (such as Cassini/Huygens, Rosetta, MSL).
- All recent NASA and ESA missions have included participation by foreign nationals at least at the level of members of science teams.
- There is a long history of successful joint international development and operation of spaceflight instrumentation.
- International partnerships and collaborations are best done as part of a long-term relationship that, in the long run, provides for an equitable partnership.

II(b): Benefits of International Participation

- Interactions between scientists from different countries with different backgrounds, experience, and points of view and skill sets, are of high value and often lead to improved results.
- Sharing of cost among two or more countries may lead to lower costs for each country while achieving the same science. This may enable missions that are not otherwise affordable by an individual country.
- Expanding the pool of potential participants, especially instrument providers, may lead to strong investigations in the future.

II(b): Risks of International Participation

- Overly high reliance on foreign-provided instruments may risk the health of the U.S. planetary instrumentation and science analysis communities.
  - Support for U.S. instrument builders enables maintenance and enhancement of U.S. technological capabilities.
  - Mission support is a crucial component of support for the U.S. planetary science community, and provides a level of stability/continuity beyond that provided by R&A programs.
- Lines of authority within a project may weaken as they cross national boundaries. This poses a challenge to project/investigation management. The danger is that mission/investigation performance will not achieve science objectives.
- Communication issues often arise with multiple stakeholders. Resolution of such issues can be more difficult across national boundaries, different cultures, institutes, contractors, and agencies.
- Involvement of two or more funding agencies adds complexities and raises the risk that funding problems will adversely affect the mission through delays or descoping of capabilities. The risk to schedule is especially important.
- There is a chance that a partner may withdraw from the project, mid-project.

II(c): Science-Teaming Summary

- International collaboration can be done successfully with PI-led or Facility investigations, and with U.S.-led or foreign-led investigations.
  - *Participation of key personnel and continuity of science, engineering, and operations expertise and knowledge is required through all stages of mission.*
- Procuring foreign-led investigations can allow greater science return within the available budget, but, by virtue of displacing U.S.-provided instruments, may be detrimental to U.S. science capabilities.
- Competition, open to both U.S. and foreign investigations, is strongly preferred over directed selection.
  - *International participation and collaboration should be a formal part of the evaluation and selection criteria.*
- International science-team participation should be incorporated into investigations, whether foreign- or U.S.-provided, early enough to allow significant interaction through concept and design stages.
  - *NASA needs to provide adequate funding to U.S. investigators to support an appropriate level of interaction.*
- Especially with international partnering, clear and well-defined lines of authority and responsibility are required, both within the project as a whole and within individual investigations.

II(d): Recommendations for a Future Mars Mission

- An appropriately constituted Mission Definition Team should prioritize objectives, including science, within a well-defined resource box.
  - *This Mission Definition Team starts with Decadal Survey and NASA priorities including refinement of those objectives from MEPAG SAGs (e.g., NEX-SAG), as appropriate.*
  - *If significant foreign participation is anticipated, the Mission Definition Team composition and scope should reflect that.*
- <u>The payload should be openly competed</u>, with full consideration of U.S. & foreign provided proposals.
- <u>If resources or other factors do not permit open competition</u> of all investigations, NASA should:
  - *Form an Instrument Definition Team(s) to assess with rigor comparable to a selection review whether the contributed and/or directed investigation(s) will meet the mission objectives.*
  - *Recognize that increased international contribution may greatly impact future U.S. capabilities and so actively seek to increase U.S. instrument and team member opportunities:*
    - Consider foreign contributions to spacecraft subsystems (e.g., telecom) instead.
    - Fund U.S. investigators on foreign (or commercial) contributed teams to augment capabilities, including working U.S. interfaces (e.g., PDS archive).
    - There should be comparable opportunities for foreign Co-I's on U.S. provided investigations.
  - *This could be done under either the PI-led or Facility investigations, but continuity of expertise and knowledge is needed through investigation design, build, & operations.*
  - *International collaboration integrated within investigation teams is strongly recommended.*
- NASA should plan funded opportunities for Guest Investigators or Participating Scientists to broaden participation in the mission and thereby enhance overall scientific return.

Key Take-Away Points

- International collaboration on missions has high science value, by bringing in new and innovative ideas and engaging a larger community, and forging international ties.
- However, decreasing opportunities for U.S. instrument builders may lead to a loss of key U.S. capabilities.
- Open competition (or equivalent review) for providing investigations is the best approach for obtaining the highest-quality science results.
- If foreign investigations are included on a U.S. mission, U.S. science participation can be enhanced by including scientists on foreign teams; U.S. science participants need to be included from very early in development, in order to have substantive input into science objectives, design, etc.
- Foreign science participation should be encouraged in US-led investigations as well.
- U.S. and foreign scientists should have well-defined roles and responsibilities in their respective investigations, and should receive funding commensurate with those roles.
- Well-defined lines of authority and responsibility are needed within a Project for overseeing and integrating foreign-provided instruments into a U.S. mission.

III. Details of Implementation Discussion

a) Project Implementation
b) Investigation Implementation
c) Science Team Implementation

III(a): Project Implementation (1 of 3)

Mission Definition

- Science and additional objectives for an international mission need to be developed and agreed to in advance by the Mission Definition Team (e.g., a SDT or ORDT).
  - The Mission Definition Team should have relevant community representation and international participation.
  - Objectives should be identified for the mission as a whole, and investigations should be chosen based on those objectives and not only on provision of a free instrument.
- Agreement is needed up front by all stakeholders on the requirements of the mission.
- Agency/International agreements should be specific enough that the Project can ensure that all elements will meet Level-1 requirements.

III(a): Project Implementation (2 of 3)

Project Management

- There need to be clear lines of authority and responsibility within the project, especially across institutional and international boundaries, and through all phases of the project.
- There needs to be open communications within the project and between the project and the stakeholders.
- There needs to be an agreement from each funding agency to provide the resources required to ensure that their contributed instrument is delivered on time and will meet requirements, to provide additional resources as necessary, and to support instrument anomaly resolution, data analysis, and data archiving.
- All instruments require appropriate project-level oversight and authority during development, and science oversight during all stages of development, to ensure that the instrument will be able to meet the science objectives and requirements.

III(a): Project Implementation (3 of 3)

ITAR/EAR issues

- ITAR/EAR types of regulations and concerns need to be addressed in a comprehensive way from the very beginning, rather than being added in to the project later in the process.
- The regulations and processes for compliance need to be revisited throughout lifetime of mission, as new issues may come up as the project develops or as legal requirements evolve.
- The instrument teams need to be able to have substantive discussions with the project and spacecraft provider about accommodation or resource requirements. All instrument teams need to be able to have substantive discussions with all partners, as appropriate.

III(b): Investigation Implementation

There are different approaches to investigation implementation. The next few slides will define and elaborate on the strengths/weaknesses of these scenarios:

- **Types of International Investigation Collaborations**
  - U.S.-provided investigation (i.e., U.S. hardware and/or science; foreign scientist participation only)
  - U.S.-led investigation (w/ some foreign hardware contribution and scientist participation)
  - Foreign-led investigation (w/ some U.S. hardware contribution and scientist participation)
  - Foreign-provided investigation (U.S. science participation only)
- **Types of Investigation Management**
  - PI-led
  - Facility
  - Observatory

III(b): Types of International Collaborations (1 of 4)

U.S.-provided investigation (i.e., U.S. hardware and/or science; foreign scientist participation only)

- Strengths:
  - Maximum end-to-end control to ensure scientific success on schedule & within budget
  - Strong U.S. science & engineering engagement
  - Opportunity for some international scientist involvement
  - Quickest response to challenges/anomalies
  - Maximum control of risk mitigation/resolution
  - Depending on the nature of the collaboration, ITAR/EAR requirements may not be involved
  - Full control of data pipeline & archiving
- Weaknesses:
  - Most expensive to the U.S.
  - Limited access to non-U.S. hardware expertise
- *Examples of Successful Implementation*
  - *MRO: HiRISE*
  - *MAVEN: IUVS*

III(b): Types of International Collaborations (2 of 4)

U.S.-led investigation w/ some foreign hardware contribution and scientist participation

- Strengths:
  - Reduced U.S. cost
  - More end-to-end control to ensure scientific success on schedule & within budget
  - Strong U.S. science & engineering community engagement
  - Opportunity for some international involvement
  - Quick response to challenges/anomalies
  - More mechanisms for risk mitigation/resolution
  - Majority of control over data pipeline & archiving
- Weaknesses:
  - More expensive than fully foreign-contributed
  - Substantial ITAR/EAR requirements and potential issues
- *Examples of Successful Implementation*
  - *MSL: ChemCam, SAM, RAD*
  - *MAVEN: SWEA*

III(b): Types of International Collaborations (3 of 4)

<u>Foreign-led investigation w/ some U.S. hardware contribution and scientist participation</u>

- Strengths:
  - Reduced U.S. cost
  - Some U.S. science & engineering community engagement
- Weaknesses:
  - Decreased NASA end-to-end control to ensure scientific success
  - Limited NASA visibility to challenges/anomalies
  - Fewer mechanisms for risk mitigation/resolution
  - Potentially significant ITAR/EAR requirements and issues (e.g., instrument/component interface)
  - Potential data archiving and distribution issues
- *Examples of Successful Implementation*
  - *Mars Express: SPICAM, MARSIS*

III(b): Types of International Collaborations (4 of 4)

<u>Foreign-provided investigation onto a U.S. spacecraft (U.S. scientist participation only)</u>

- Strengths:
  - Minimal U.S. cost (IF no major schedule delays)
  - Opportunity for some U.S. science involvement
  - Development of expertise and contribution to foreign national goals
- Weaknesses:
  - Limited U.S. science involvement, and no engineering involvement
  - Minimum NASA end-to-end control to ensure mission scientific success
  - Limited NASA visibility to challenges/anomalies
  - Few NASA mechanisms for risk mitigation and resolution
  - Significant ITAR/EAR requirements and potential issues (i.e., spacecraft interface)
  - Potential data archiving and distribution issues
- *Examples of Successful Implementation*
  - *MRO: SHARAD*
  - *MSL: APXS*

III(c): Types of Investigation Management (1 of 4)

- **PI-led Investigation** *(Example - MSL: ChemCam)*
  - There is a single individual (PI) responsible for end-to-end development & complete success of full scientific investigation.
  - Typically competed & selected based on scientific & technical merit.
  - PI has responsibility over the investigation team; investigation team is selected as part of the investigation proposal.
- **Facility Investigation** *(Example - ODY: GRS)*
  - Project Manager is responsible for successful development, delivery & initial performance of the instrument. The PM and development team are not necessarily involved with operations.
  - Instrument is built under institutional responsibility (i.e., not built solely under the direction of a PI or science team).
  - Science team members, including the science Team Leader, are selected competitively and collectively comprise the Facility Science Team.
  - The science team operates the instrument, processes and archives the data, and does science analysis.
- **Observatory-Mode Investigation (can be within either PI-led or Facility)** *(Example - HST instruments)*
  - Instrument development & build could be implemented under either Facility or PI-led paradigm.
  - Most science investigations transition to those proposed by scientists external to instrument development, and are selected as individual investigations or observing proposals.
  - The science investigations are not necessarily connected to each other and are not linked within a higher-level set of mission objectives.
  - Data pipeline & archiving done by operations team that is distinct from science observers.

III(c): PI-led Investigation (2 of 4)

- Strengths:
  - PI has clear end-to-end responsibility.
  - Because Mars science is often discovery driven, investigations are likely to be complex and specifically adapted for a specific objective(s) – this makes them more amenable to PI-led investigations.
  - Personal investment & pride of accomplishment facilitates achievement of science objectives.
  - Having a scientist as a PI enhances the ability to make science and engineering trades and to respond to development, build, and operation challenges to optimize science.
  - Typically competed, usually leads to proposal and selection of innovative investigations.
- Weaknesses:
  - Competitive AO requires time and expense.
  - Risk of limited opportunities for scientists outside of selected team.

III(c): Facility Investigation (3 of 4)

- Strengths:
  - Broadens participation as NASA selects individual members of the science team (as opposed to teams defined within PI-led proposal).
  - Has possibility of quicker selection & project start for hardware build.
  - Can assign instrument build to institution with desired expertise.
- Weaknesses:
  - There is a decreased ability to make trades and respond to development, build, and operations challenges while optimizing science.
  - Not competed, so less opportunity to select best or innovative investigations.
  - Team cohesion can be an issue as NASA selects individual members to the science team.
  - Potentially less “ownership” of the science and instrument within the team.
  - Less integration of engineering & science throughout the mission.

III(c): Observatory Mode of Operation (4 of 4)

- *Either a PI-led or Facility instrument can be partly used within this mode.*
  - *For example: Mars landing site characterization uses MRO HiRISE and ODY THEMIS as the functional equivalent of facility instruments*
- Strengths:
  - Broadest opportunity for involvement of the science community.
  - Wider range of scientific topics can be addressed.
- Weaknesses:
  - Larger (and therefore more expensive) team needed to support a large and diverse user community who can be unfamiliar with the instrument.
  - Collection of individual proposals may not address the overarching science objective.
  - Lack of an integrated science team hinders design and execution of comprehensive science plans.
  - Instrument may not be optimized for overarching science objectives.
  - Over time, corporate memory is lost on, e.g., calibration, less-used operations modes, and potential workarounds when issues arise or a new type of dataset is desired.
  - Inadequate funding for the support of guest observers during data collection and analysis can lead to underutilization.

III(d): Science Team Implementation (1 of 2)

- There should be strong U.S. representation in the science teams of any foreign-led investigations throughout all Phases.
  - This helps provides a science-conduit between the instrument and the Project.
  - U.S. participants can assist when there are export compliance issues.
  - This helps maintain U.S. scientist capability and participation.
  - U.S. participants in a foreign instrument have to be selected early enough to be able to have meaningful participation in instrument concept and design.
- U.S. participants must have formally defined roles and meaningful responsibilities within the science teams.
  - For foreign-contributions, U.S. participation on the instrument science teams should be a formal and well-defined criterion within the investigation selection. Team member composition, roles, and expertise should be considered.
- NASA funding to U.S. participants must be commensurate with their defined roles and responsibilities, to enable meaningful contribution and collaboration.
- *Recent Planetary Examples:*
  - *MRO: SHARAD*
  - *The original joint selection process used for ExoMars TGO*
  - *Cassini: MAG (foreign instrument w/U.S. participation), RADAR (U.S. instrument w/foreign participation)*

III(d): Science Team Implementation (2 of 2)

- Codify rules of team-member interaction, e.g., through "Rules of the Road."
  - This sets clear expectations and responsibilities at mission and investigation levels.
  - Establish rules for publications and data sharing between investigations, with the science community/public, and with special expert consultants.
    - Data, analysis tools, and preliminary results should be openly shared between investigation teams to facilitate greater overall science return.
    - Rapid PDS data release should be required from all investigation teams.
  - To the extent necessary, roles and responsibilities of scientists participating in operations (e.g., working group chairs or long-lead planners) should be defined within an official Project document.
- There should be opportunities for phased participation, such as through Participating Scientist or Guest Observer (or comparable) programs that bring on people throughout the mission. Such programs:
  - Increase diversity of people, expertise, and ideas;
  - Increase community involvement, particularly of early career scientists;
  - Need to come with commensurate funding, and be budgeted for as early as possible.

IV. Commercially Provided Access Models

We discussed some proposed commercial models, but this area requires additional investigation as opportunities are evolving.

- **Data Buy:** NASA contracts with commercial entity to provide instrument, pays set price for some or all data collected. Examples can be found within Earth Science, weather models, insurance companies, etc. *This has not yet been implemented for a Planetary mission.*
  - Pros: Provides potential cost savings over the full cost of an investigation. Can put a different phasing into the funding profile.
  - Cons: Requires firm grasp of requirements in advance, does not necessarily advance science/instrument community involvement. Science community may have less influence on types or fidelity of data collected.
- **Hosted payload:** Entities (commercial, university, etc.) provide hardware at no cost to NASA, conduct their own investigations. *This has not yet been implemented for a Planetary mission, but ARM recently issued a solicitation.*
  - Pros: Provides potential cost savings to NASA over the full cost of an investigation, may broaden opportunities for innovation or creative science investigations.
  - Cons: May be difficult to meet mission-level requirements / science goals; limited provider pool.
- **Paid accommodation:** Pay per kg to fly NASA-developed instrument aboard commercial vehicle. *This has not yet been implemented for a Planetary mission.*

Commercially-provided components, hardware, and/or instruments must follow the same best practice guidelines as international contributions, though the contracting mechanisms may differ.

Appendix 1 - Acronyms

AO	Announcement of Opportunity
APXS	Alpha Particle X-Ray Spectrometer (on MSL)
ARM	Asteroid Redirect Mission
ASI	Agenzia Spaziale Italiana
ChemCam	Chemical Camera (on MSL)
Co-I	Co-Investigator
EAR	Export Administration Regulation
ESA	European Space Agency
GRS	Gamma Ray Spectrometer (instrument and instrument suite on ODY)
HiRISE	High Resolution Imaging Science Experiment (on MRO)
HST	Hubble Space Telescope
ITAR	International Traffic in Arms Regulations
IUVS	Imaging Ultraviolet Spectrograph (instrument on MAVEN)
MAG	Dual Technique MAGnetometer (instrument on Cassini)
MARSIS	Mars Advanced Radar for Subsurface and Ionosphere Sounding (on Mars Express)
MAVEN	Mars Atmosphere and Volatile Evolution Mission
MDT	Mission Definition Team (e.g., SDT or ORDT)
MEP	Mars Exploration Program
MEPAG	Mars Exploration Program Analysis Group
MIC-SAG	Mars International Collaboration Science Analysis Group
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
NASA	National Aeronautics and Space Administration
NEX-SAG	Next Mars Orbiter Science Analysis Group
ODY	Mars Odyssey mission
ORDT	Objectives & Requirements Definition Team
PDS	Planetary Data System
PI	Principal Investigator
RAD	Radiation Assessment Detector (on MSL)
RADAR	Radar (on Cassini)
SAM	Sample Analysis at Mars instrument suite (on MSL)
SDT	Science Definition Team
SHARAD	Shallow Radar sounder (on MRO)
SPICAM	Spectroscopy for Investigation of Characteristics of the Atmosphere of Mars (on Mars Express)
SWEA	Solar Wind Electron Analyzer (on MAVEN)
U.S.	United States of America

Appendix 2: NEXT ORBITER SAG: Science Objectives

http://mepag.jpl.nasa.gov/reports/NEX-SAG_draft_v29_FINAL.pdf

In addition to relay, reconnaissance, and progress on future Sample Return, compelling new objectives for science are:

A. Map and quantify **shallow ground ice deposits** across Mars to better understand the global water inventory and atmospheric exchange today and how ground ice records climate change on longer time scales (e.g., obliquity variation). [see Findings #3-6]

B. Detect and characterize areas of **possible brine flow**, and link these observations with ground ice, temperature, and atmospheric properties to understand the distribution and potential for habitability of volatile reservoirs; representative coverage at different times of day is key. [#7-8]

C. Characterize **dynamic atmospheric processes and transport**, to understand current climate, water, and dust cycles, with extrapolation to past climates. [#9-12]

D. Characterize the **occurrence and timing of major environmental transitions** recorded in compositional stratigraphic records, such as discrete hydrated mineral assemblages, sedimentary bedding, and shallow polar cap layering. [#13]

E. In SEP missions, carry out high-value, close-approach **investigations of Phobos and Deimos.** [#14]

App. 2 – NEX-SAG Proof-of-Concept Instrument Specs

Proof-of-Concept Instrument	Purpose	Wavelength	Spatial Resolution	Potential Payload Combinations *(to address Obj. defined on previous slide)*
Visible Imager (camera)	Science & site certification **Required:** high-res, high SNR images and stereo (for DTM generation)	**Required:** Multiple visible/NIR bands (min. 2). **Highly desired:** ≥3 color bands.	**Required:** ≤ 0.3 m/pixel, including color, with high SNR (≥100) **Desired:** 10-15 cm/pixel at high SNR	With any/all payload Combinations A, B, C
Polarimetric Synthethic Aperture Radar (PSAR)	Detect and map relatively pure shallow water ice for science and resource utilization	**Required:** 20<λ<100 cm in free space, dual circular polarization. **Highly Desired:** λ~60 cm in free space, full polarization.	**Required:** Detection of ice within 5-10 m of the surface. 30 m/pixel horizontal resolution. **Highly Desired:** Detection of ice layers within 2 m of the surface. ~15 m/pixel horizontal resolution. **Desired:** Sounding mode (single received polarization OK)	Combination A
Wide Angle Imager (weather camera)	Ability to create daily global maps of Mars weather	**Required:** Visible bands. **Desired:** Additional UV band for Ozone; SWIR bands for frost.	**Required:** ~1 km /pixel, wide FOV for daily global maps	Combination B Can be packaged with others.
Microwave Radiometer	Water vapor & temperature profiles. Highly Desired: Wind profiles.	**Required:** Minimal sensitivity to atmospheric dust and ice particles. Likely requires operation at microwave to sub-mm wavelengths.	**Required:** ~10 km vertical resolution from 0-50 km. **Highly Desired:** ~5 km vertical resolution of profiles from 80 km to within 5 km of surface. **Highly Desired:** Wind profiles with accuracy of ≤ 20 m/s below 50 km and vertical resolution ≤ 10 km.	Combination B Should be flown with an aerosol mapper (e.g., IR Sounder).
IR Sounder (Atmosphere)	Atmospheric temperature & aerosol vertical profiles. **Highly Desired:** Water vapor profiles at similar vertical resolutions	**Required:** Thermal IR channels; selected bands or spectrally resolved channels for temperature and water ice. **Highly Desired:** Thermal IR channels to profile water vapor.	**Required:** ~10 km vertical resolution from 0 - 50 km. **Highly Desired:** ~5 km vertical resolution of temperature & aerosol profiles from 80 km to within 5 km of surface. Water vapor ≤ 30 km.	Combination B
IR Mapper Radiometer/Spectrometer (Surface)	Map thermal inertia at high spatial resolution	**Required:** Thermal IR channels to measure ground temperatures.	**Required:** ≤ 30 m/pixel. **Highly Desired:** ~15 m/pixel.	Combinations A, C
SWIR Spectrometer	Detection of aqueous minerals for science & resource utilization	**Required:** SWIR (solar reflected) bands or spectrum in the 1-4 μm needed to detect aqueous minerals (e.g., hydrated sulfates, phyllosilicates, carbonates). **Desired:** Spectral resolution adequate to detect both primary and secondary minerals, salts & ices (≤10 nm).	**Required:** ~6 m/pixel; good SNR at various times of day (light)	Combination C