Possibilities for Cooperative Science Using Two Rovers at the Same Site

Report of the MEPAG 2R-iSAG committee

March 17, 2010

This report is a draft intended to generate discussion and feedback. Oral or written comments may be conveyed to any of John Grant (grantj@si.edu), Frances Westall (westall@cnrs-orleans.fr), Dave Beaty (David.Beaty@jpl.nasa.gov), and Jorge Vago (jorge.vago@esa.int).

Charter: 2R-iSAG

Assume: The proposed MAX-C and ExoMars rovers are delivered to the same landing site.

The science of the proposed MAX-C and ExoMars rovers has been discussed separately, and we provide the first analysis of possible exploration strategies, priorities, and cooperative scientific objectives involving their potential joint operation.

Requested Tasks

1. Given the ExoMars and MAX-C rovers as they are currently proposed, what cooperative science could be done?
2. Given some leeway with changes to the scientific capabilities of MAX-C, and with lesser leeway of ExoMars, what additional cooperative science could be done?

Deliverables

- A mid-term status presentation, in PPT format, is requested by Jan. 31, 2010.
- A presentation on final results is to be given at the MEPAG meeting of Mar. 17-18, 2010 (Monrovia, CA).
- A text-formatted final report, that summarizes the essential messages and that incorporates the feedback from the MEPAG discussion

2R-iSAG Team Roster

Name	Technical Interest	Organization
European scientists:		
Frances Westall (Co-Chair)	Paleo biosignatures	CNRS, Orléans (F)
Mark Sephton	Organics extraction and analysis	Imperial College, London (UK)
Gian Gabriele Ori	Geology	IRSPS, Pescara (I)
Angioletta Coradini	TC (PI) for drill spectrometer	INAF, Rome (I)
Fred Goesmann	TC (PI) for MOMA	MPI for Solar Sys. Res., Lindau (D)
Valérie Ciarletti	TC (PI) for WISDOM ground penetrating radar	LATMOS-IPSL, Velizy (F),
U.S. scientists:		
John Grant (co-chair)	GPR, surface geology, rover operations, landing site considerations	Smithsonian Institution
Mike Carr	Water on Mars, general Mars geology	U.S. Geological Survey (ret)
Danny Glavin	Astrobiology, member of the SAM team on MSL	Goddard Space Flight Center
Roger Phillips	General geophysics. MARSIS and SHARAD.	Southwest Research Institute
Sherry Cady	Editor of Astrobiology. Biosignature formation and preservation	Portland State University
Joel Hurowitz	Sedimentary rock geochem, MER science team	JPL/Caltech
Engineering		
Anders Elfving	ExoMars Rover Manager	ESA
Marguerite Syvertson	MAX-C pre-project systems analyst	Mars Prog. Off., JPL/Caltech
Chris Salvo	MAX-C pre-project study lead	Mars Prog. Off., JPL/Caltech
Ex Officio:		
Jorge Vago	EXM project scientist	ESA
Dave Beaty	cat herder	Mars Prog. Off., JPL/Caltech

Initial Idea Generation

- **For the purpose of initial idea generation, the team organized itself into four functional subteams:**
  - Astrobiology (Sherry Cady, Team Leader);
  - Geology (Mike Carr, TL);
  - Geophysics (Valérie Ciarletti, TL);
  - Engineering (Chris Salvo + Marguerite Syvertson, TL).

  - **Each sub-team produced a PPT report summarizing opportunities in its area for cooperative science.**

  - **By early Jan. 2010, the team recognized that it could more effectively work with a single integrated list; we shifted into EXCEL mode.**

Review for Completeness

The preliminary list of ideas was reviewed for clarity and completeness during the week of Jan. 21 by:

- MRR-SAG leadership team;
- ExoMars project leadership;
- ExoMars science working group;
- MOMA instrument science colleagues;
- Mars Program Office science team;
- ~8-10 MER scientists;
- Professional colleagues of several team members.

Results:

- ~6 new ideas added to the list;
- Multiple suggestions for clarifying and amplifying the descriptions;
- Revised list of 2-rover science possibilities prepared (see Slides #8-9), organized into two groups (no change; change).

Science Priority Assessments

- **Science value prioritization of early list using three ratings to help focus discussions:**
  1. Degree of (positive) impact on the proposed EXM scientific objectives;
  2. Degree of (positive) impact on the proposed MAX-C scientific objectives;
  3. Collective science value added.
  - Several initial differences between European and N. American perceptions of priorities were observed. We talked through these differences, and in the next prioritization there was higher convergence.
  - Good community feedback received on these preliminary priorities.
- **Revised the science value prioritization using the reviewed and edited list.**
  - Please see Slides #8-9 of this package.

Analysis of Engineering Impact

- **Possible dual rover operations assessed in three areas:**
  - **Cost**
    - Instrument Hardware, Other Hardware, Workforce;
  - **Resources**
    - Mass, Power, Data, Workforce, Schedule;
  - **Risk**
    - Complexity, Technology, Testing/V&V, Rover Interactions.
  - **The cost and resource impacts on the two proposed rovers were estimated separately.**
- **Each area was assigned a qualitative rating:**
  - Minor (low cost, minor schedule changes, etc.);
  - Medium (noticeable changes to budget, schedule, or new subsystems, etc.);
  - Major (live pallet, rover-to-rover contact, significant cost or schedule impacts).

For definition of terms, see slides in Backup

2-Rover Cooperative Science: No change

Ref.	Nickname	Value	Dist.
1	EXM instruments applied to MAX-C discovery	H	Near
2	MAX-C acquires second sample after EXM discovery	H	Near
3	MAX-C instruments applied to EXM discovery	H	Near
4	Use complementary capabilities for efficient site search	H	Open
5	MAX-C does site characterization around EXM discovery	H	Near
6	EXM helps MAX-C pick analysis/cache samples	H	Mid
7	EXM and MAX-C split up to improve spatial coverage	H	Far
8	MAX-C surface geology extends EXM GPR ground truth	H	Mid
9	Trailing rover examines materials disturbed by leading rover looking for temporal effects	M	Mid
10	Cross-calibrate instruments by analyzing same samples	M	Near
11	Cross-calibrate cameras on same scene	M	Open
12	Two-rover long-baseline stereo imaging for path planning	M	Open
13	Rovers image each other for PR value	L	Near
14	Rover 1 images Rover 2 to help with mobility issues	L	Near
15	Cross-monitoring to avoid hazards and reduce risk	L	Near
17	Imagers/spectrometers examine same target at different angles for photometry	L	Mid
16	Provide a better color image	L	Open
18	Calibrate elevation measurements by using known height on other rover	L	Mid

Within groups, elements are listed in approximate priority order

2-Rover Cooperative Science: With Change

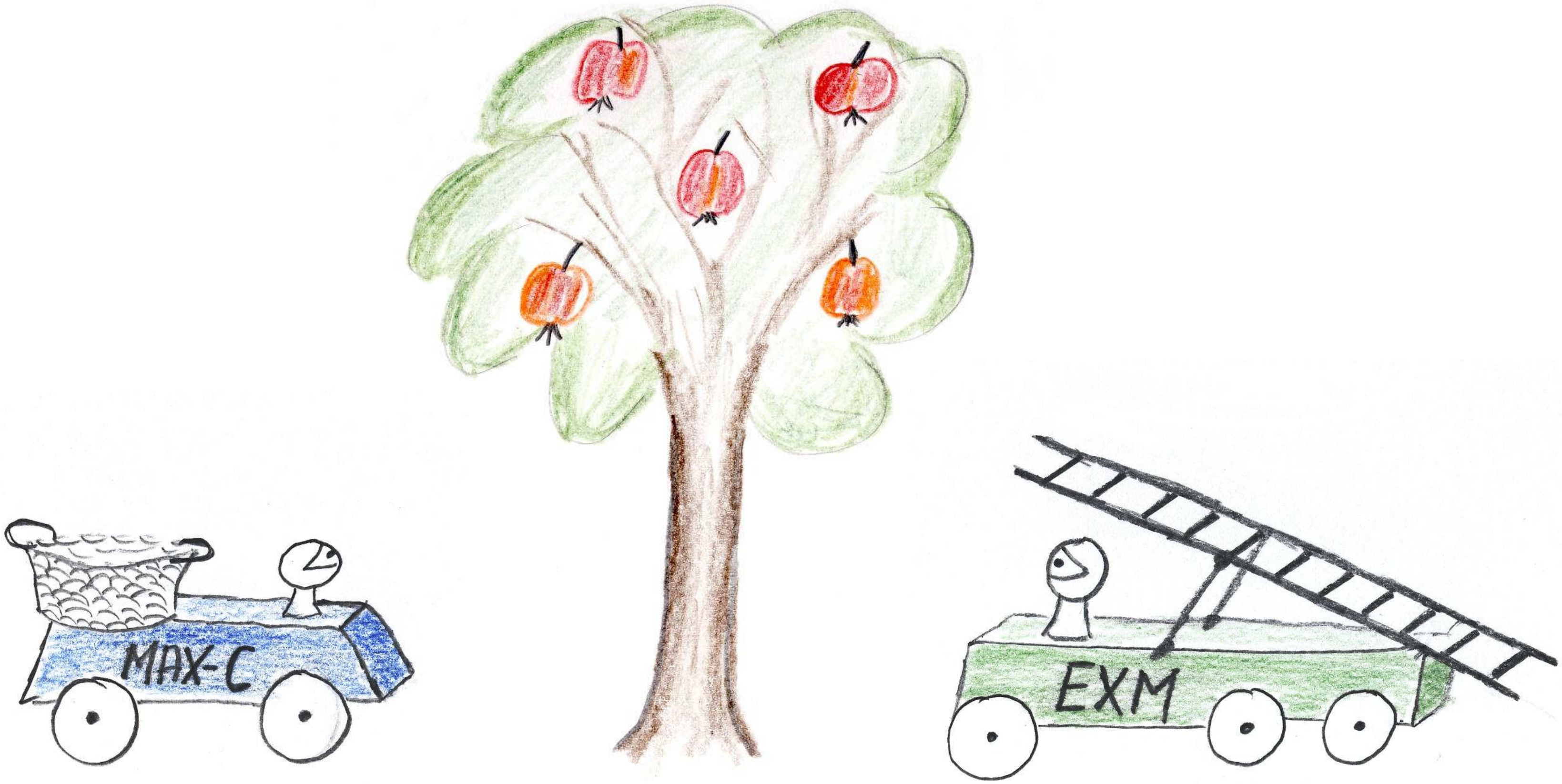
Ref.	Nickname	Value	Dist.
1	EXM-collected sample returned to Earth	H	Near
2	Recon. tools added to MAX-C to improve its scouting for EXM	H	Open
3	MAX-C measures methane concentration in EXM drill holes	H	Near
4	Max-C analyzes/caches separated drill cuttings from EXM	H	Near
5	Add hazard avoidance to the landing system to improve geologic access	H	Open
6	UHF communication link between rovers adds 2nd uplink capability for each	H	Open
7	GPR added to MAX-C improves subsurface picture	H	Near
8	Ar detrmination for age measurements and cosmogenic effects	M	Open
9	Solar panel cleaning mechanism on rovers	M	Contact
10	Lower frequency (VHF) antennas on both GPRs gets high-value bistatic measurements	M	Mid
11	LOS atmospheric measurements constrain trace gas variations	M	Mid
12	Max-C arm camera for better characterization of rover anomalies	M	Near
13	Precise dist. measurements between rovers improves traverse reconstructions	L	Mid
14	Deep (HF) sounding to km with Tx on landing platform	L	Open
15	Meteorological stations on 2 of 3 platforms characterize weather fronts	L	Open
16	Seismic sensor uses drill signal source to map shallow subsurface	L	Open
17	Rover "towbar" extricates the other, stuck rover	L	Contact
18	IP or DS instrument constrains subsurface composition (e.g., clays)	L	Open

Within groups, elements are listed in approximate priority order

Potential 2R Cooperation: Summary of Highest Science Priorities

1. **Group 1 (no change) highest priority science:**
    1. Use MAX-C to scout for drill locations for EXM.
    2. Several variations on following up on either rover's discovery of interesting or contentious samples using the other rover.
    3. Send the rovers in different directions to improve spatial coverage.
2. **Group 2 (some change) highest priority science:**
    1. Return an EXM-acquired sample to Earth via a possible future MSR.
    2. Several different kinds of instruments considered for addition to the proposed MAX-C payload (additional recon tools, methane sensor, GPR).
    3. Improve ability to land in rough terrain—this would allow for landing sites that are better suited to both rovers.
    4. Telecommunications. Solve telecom bottleneck.

The Apple Orchard



An analogy constructed based on two children picking apples in an orchard.

1.1. Use Proposed MAX-C to scout for drill locations for EXM

Full Description

Take advantage of the proposed MAX-C's higher mobility, faster measurement capability, and much higher limit on number of samples that could be interrogated to serve as a scout to help identify and prioritize drilling locations for ExoMars. We refer to this as the Thunderbird approach.

Strategy was used in the 1960's British action/sci-fi adventure series Thunderbirds

One looking for apples, the other picking them

Benefit considerations

This could significantly improve the chances that ExoMars would acquire the samples needed to achieve its objectives, with the additional potential that those samples could be contributed to a possible future MSR (thereby supporting MAX-C's proposed objectives).

Impact considerations

Cost		Resource		Risk
EXM	MAX-C + pallet	EXM	MAX-C + pallet	
Minor	Minor	Minor	Minor	Minor

1.2. Follow up on one rover's discovery using the other's instruments

Have a 2nd opinion on your best apple

Description of possibilities

- ExoMars instruments applied to MAX-C discovery;
- MAX-C instruments applied to ExoMars discovery;
- MAX-C does site characterization around ExoMars discovery.

Benefit considerations

- Provide, with ExoMars, better organic chemistry characterization of a possible MAX-C discovery;
- MAX-C improves contextual characterization of ExoMars rocks for accurate determination of the formation environment —essential for interpreting eventual artifacts, alterations, etc.

Impact considerations

Cost		Resource		Risk
EXM	MAX-C + pallet	EXM	MAX-C + pallet	
Minor	Minor	Minor	Minor	Minor

1.3. Send proposed rovers in different directions to improve spatial coverage

Are the apples better on different trees?

Description of Option

Have the two rovers use their combined mobility to amplify the spatial coverage of the landing site. For example, they could simultaneously traverse up and down a section, characterizing the different kinds of geologic terrane and stratigraphic units present at the landing site.

Benefit considerations

This could lead to significantly improved geologic interpretation, better path planning, and better sample diversity within the samples potentially to be returned.

Impact considerations

Cost		Resource		Risk
EXM	MAX-C + pallet	EXM	MAX-C + pallet	
Minor	Minor	Minor	Minor	Minor

2.1. Return an EXM-acquired sample to Earth via a potential future MSR.

Description of Option

Follow-up on a compelling discovery by the ExoMars analytic instruments in a sample acquired by the ExoMars drill by having ExoMars collect a second sample, either from deeper in the same drill hole, or from a second, adjacent drill hole; and have the capability to potentially return that sample to Earth by means of a future MSR mission. There are several possibilities involving the proposed MAX-C, ExoMars, the landed platform, and the projected MSR Lander for how this sample could be managed, and the pathway by which it would end up on a potential MSR.

Give your best apple to your friend to take to town

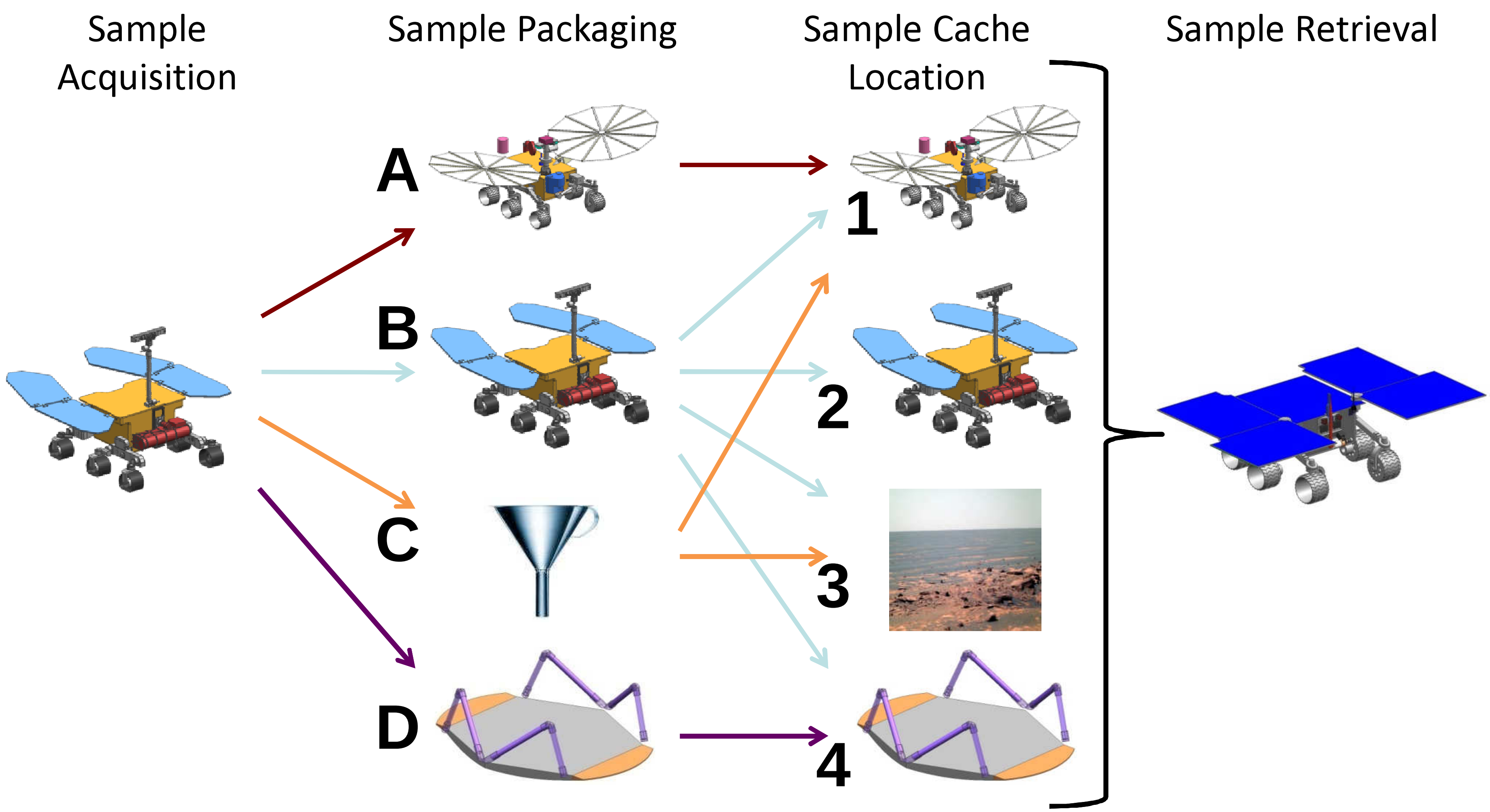
Benefit considerations

The current EXM payload has a robust organic detection capability. Using EXM to screen for organics would maximize the science value for a potential MSR.

Impact considerations

Cost		Resource		Risk
EXM	MAX-C + pallet	EXM	MAX-C + pallet	
Medium	Medium	Medium	Medium	Major

Returning an ExoMars Sample: Analysis



These potential pathways have different implications for risk (and different kinds of risk), sample integrity, 2018 hardware changes, and operations by the proposed MSR fetch rover. NEEDS COMPARATIVE ANALYSIS.

2.2. Recon. tools added to proposed MAX-C to improve selection of ExoMars drill sites

Description of Possibilities

•Proposed MAX-C would map variation in concentration of methane (and/or other trace gases) in the area of surface operations;

•GPR added to proposed MAX-C would improve subsurface picture;

•Other instruments also considered.

Scouting to help choose the best trees to pick.

Benefit considerations

•Better characterization of the geological context *in situ*;

•Possible link between methane production and organics detected by ExoMars in drilled materials;

•More complete subsurface picture could help choose drill site for ExoMars.

Impact considerations

Cost		Resource		Risk
EXM	MAX-C + pallet	EXM	MAX-C + pallet	
Minor	Medium	Minor	Minor/ Medium	Medium

Recon Tools Added to Proposed MAX-C: Analysis

Introduction

It is possible that adding additional recon tools to the proposed MAX-C rover would improve decision-making for deciding where to locate the ExoMars drill holes, thereby improving its odds of making a compelling discovery.

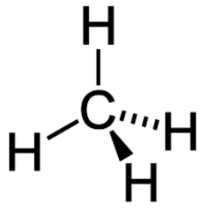
- Multiple measurement types considered, with **the two mentioned below having greatest potential;**
- We **do not have consensus** that the value of either is worth the cost.

Methane (or other trace gases)

•Measurement could be made either by a point detector, or by line of sight.

•This measurement has no recon value unless there is heterogeneity in gas chemistry at the scale of surface operations (and we don't know this).

– We will get information about this from MSL.



GPR

•Constraining the setting could be key to evaluating where to sample.

•Important input for understanding the relationship of separated outcrops.

•2-rover GPR would give far better coverage, interpretations than 1-rover GPR.

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2.3. Improve ability to land in rough terrain

Make sure not to run into the trees

Description of Option

•Add hazard avoidance to the common landing system. This might allow landing in more geologically diverse landing sites than otherwise possible.

•It is assumed that this improvement would also be implemented in a potential MSR mission.

Benefit considerations

•Would allow landing in sites better suited to both rovers' science.

•Potentially extremely significant for both ExoMars scientific objectives (since ExoMars would have limited range), and for joint operations.

•Useful feed forward technology for a future MSR mission.

Impact considerations

Cost		Resource		Risk
EXM	MAX-C + pallet	EXM	MAX-C + pallet	
Minor	Medium	Minor	Medium	Medium

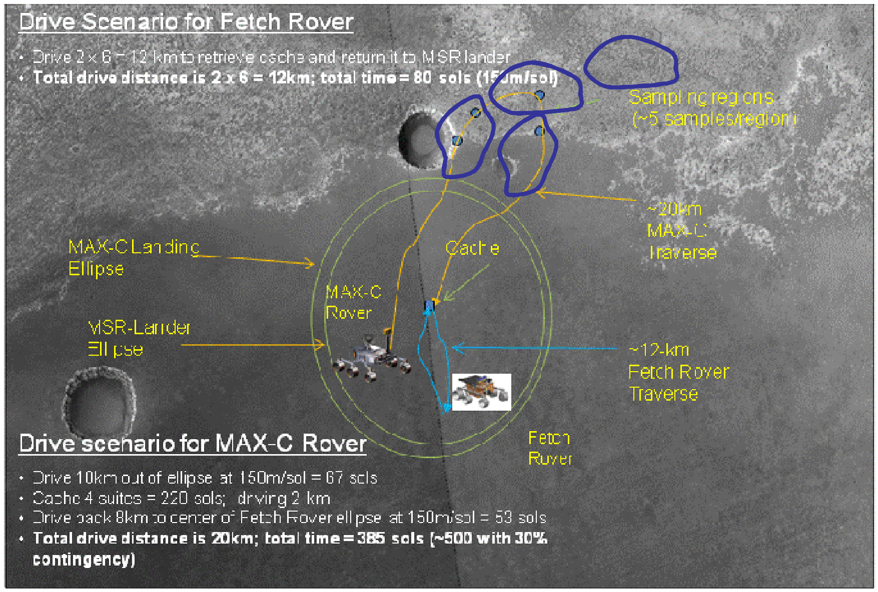
Summary of Benefit vs. Impact

Impact (Money/ Time/ Risk)	Science Benefit: Low		Science Benefit: High
Low	*MULTIPLE LOW-COST, LOWER-VALUE IDEAS*	• MAX-C scouts for drill locations for EXM • Send the rovers to different targets to improve spatial coverage	
	A FEW IDEAS	• Additional recon instruments added to MAX-C	• Follow up on either rover's discovery of interesting samples using the other rover. • Telecommunications
High		*A FEW IDEAS*	• Return an EXM-acquired sample to Earth via MSR. • Improve ability to land in rough terrain

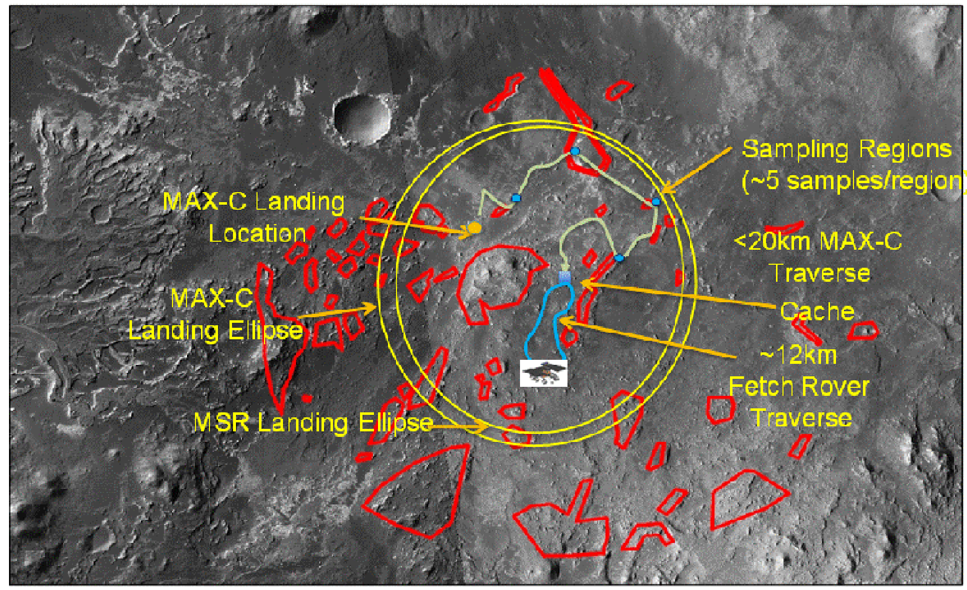
Science Benefit

Realizing 2-Rover Benefits Depends on Type of Landing Site

“Go-to” site example



“Mixed Terrain” site example



- The traverse distance for the proposed MAX-C rover depends on landing site:
  - A “Go-to” site would require up to 20-km traverse: it must include bringing the sample back to near the center of the landing ellipse (safe site);
  - “Sample-locally” site would require less than 20-km traverse;
- The Fetch Rover would be required to traverse up to ~14km.

2-Rover Separation

1. The two rovers by definition would begin their journeys on the Martian surface together. Once the MAX-C cache is complete, it would need to be driven to a safe landing area for MSR-L. There is no reason for ExoMars to perform this drive. Thus, we assume the rovers would end their lives separated.
2. There are multiple pathways in between that involve independent and cooperative activity.
3. Each rover team would need an early independent phase to learn how to operate its vehicle

Some operational implications:

- For a site with multiple accessible targets, the best approach would be to have the rovers drive to different first targets.
- For a go-to site, the site logic would likely to cause both rovers to head for the same first target, but likely arrive at different times.
- After initial independent work, if one rover makes a good discovery, cooperative follow-up activities could be planned.

2-Rover Scenario Planning

<table>
<tr><th>Scenario</th><th>Phase 1 Checkout</th><th>Phase 2 Travel</th><th>Phase 3 1st target</th><th>Phase 4 What's next?</th><th></th><th>Phase 5 Cache</th><th>Phase 6 Ext. Mission</th></tr>
<tr><td>1</td><td rowspan="7">Checkout systems and calibrations (~4 wks)</td><td rowspan="5">Travel to Same 1st Target Area (0-6 months)</td><td rowspan="3">Independent Exploration</td><td>Cooperate at discovery site</td><td rowspan="7">Repeat n times</td><td rowspan="7">Cache Delivery via MAX-C from discovery site</td><td rowspan="7">TBD</td></tr>
<tr><td>2</td><td>Travel, scout next site</td></tr>
<tr><td>3</td><td>Independent Exploration</td></tr>
<tr><td>4</td><td rowspan="2">Coop. Explor.</td><td>Travel, scout next site</td></tr>
<tr><td>5</td><td>Independent Exploration</td></tr>
<tr><td>6</td><td rowspan="2">Drive to different 1st targets</td><td rowspan="2">Independent Exploration</td><td>Cooperate at discovery site</td></tr>
<tr><td>7</td><td>Independent Exploration</td></tr>
</table>

"Baseline" scenarios (for "go-to" and "mixed terrain" sites), assuming a discovery is made that requires 2-rover cooperation

Cooperate

Independent

The Cost of Getting Married

Getting married (i.e. the proposed 2-rover scenario) inevitably leads to benefits in some areas, and costs in others.

<u>Consequences</u>: The BIG PICTURE

Identified impacts fit into 3 major classes:

1. **<u>Time</u>**. The two proposed rovers have independent objectives to meet that require time to achieve. Cooperation would require extra time, and may imply surface schedule restrictions.
2. **<u>Landing Site</u>**. Sharing a landing site has multiple implications (see next slide) that would require compromises.
3. **<u>Contamination</u>**. Sharing a volume during launch, cruise to Mars, and EDL means that the two rovers would have some common contamination considerations.

Common Landing Site: Some Issues

- **Latitude**. The proposed rovers would have different power/thermal designs, which would lead to different latitude limitations.
- **Trafficability**. The rovers would have different trafficability capabilities. The two proposed rovers are not being designed to traverse over/among the same obstacles. This would further constrain the landing site selection.
- **Telecommunications**. Placing the rovers at the same place would result in a relay communications bottleneck due to sharing the same orbiter overflight opportunities.
  - The UHF relay orbiter(s) would be in view of both rovers at the same time. This would force some sort of time-sharing of the available passes, or require enhancements to the orbiter's UHF system to communicate with both rovers simultaneously. This is important for science operations.
- **Science objectives**. The proposed rovers would not have the same scientific objectives. This would lead to different priorities regarding the desired and required geological attributes of the landing site.

Landing Site Requirements: DRAFT

		LANDING #1		LANDING #2
No	Criterion	MAX-C	ExoMars	MSR-L
1	Safe landing	Essential	Essential	Essential
2	Large geological variability (to support multiple MSR objectives)	Important, but hard/ impossible to define	Desired, but must also include sedimentary deposits	Not Relevant
3	Ancient habitability hypothesized	Required	Required	Not Relevant
4	Modern habitability hypothesized	Might be precluded	Desired?	Might be precluded
5	Preservation potential for >1 biosignature	Required	Required	Not Relevant
6	Potential for organic preservation	Desired	Required	Not Relevant
7	Access to extensive outcrop	Required	Desired; but many small outcrops also OK	Not Relevant
8	Interesting regolith	Acceptable, but currently not required	Acceptable, but currently not required	Required
9	Science targets within landing ellipse	Acceptable, and lower science risk than #10	Currently required	Not Relevant
10	Go-to capability (traverse out of landing ellipse)	Might be necessary to achieve all of the above	Requires investigation to determine how capable ExoMars would be	Not Relevant

Conclusions (1 of 2)

1. Landing the proposed MAX-C and ExoMars rovers together would create interesting options for cooperative science that could increase the collective science return without change to either rover. More valuable cooperative science would require some changes: e.g.
   a) Use 2 rovers to make a discovery;
   b) Use 2 rovers to follow up on a discovery made by one.

2. The most obvious ways in which significant science benefits have the potential to exceed/justify the costs:
   a) Use the proposed MAX-C rover as an advance scout to help decide the ExoMars rover's drill hole locations.
   b) Complementary instruments and sampling devices could be used on compelling discoveries.
   c) Allow an ExoMars-acquired sample to be returned to Earth via a potential future MSR.

Conclusions (2 of 2)

3. Realizing the benefits of the proposed 2-rover scenario would have three primary consequences:
   a) Cooperative, two-rover time use on the martian surface would reduce the time available for each rover's independent objectives.
   b) The need to share a landing site would involve certain compromises: e.g. safe (?boring?) site for skycrane and pallet, ExoMars restrictions for a "go-to" site, need for hazard avoidance.
   c) Costs associated with hardware change.
4. The most obvious recommended hardware changes:
   a) Landing hazard avoidance, to allow a mixed-terrain site "with character."
   b) Improvements to ExoMars and MAX-C sample transfer systems to allow a subsurface ExoMars sample to be returned to Earth.
   c) Increase telecommunication sessions to twice per sol for each rover. This is important for efficient surface science operations.
   d) Extend ExoMars roving capabilities to ~10 km, and its nominal life time from 180 to 360 sols.

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BACKUP SLIDES

Relation to MEPAG Goals

SCIENCE OBJECTIVE	SCIENCE INVESTIGATION	REQUIRED MEASUREMENTS	PLANNED MEASUREMENT APPROACH	MEPAG Goal, Objective, Investigation
O1: Search for signs of past and present life	**I1**: Search for complex organic molecules at depth	**M1:** Detect the presence of C-C, C-H, C-N, and N-H bonds	**A1:** Determination of the Raman spectra of subsurface samples **A2**: IR spectral analysis of subsurface samples **A3:** IR spectral analysis performed in drill borehole	I, B, 1 I, B, 2
		M2: Detection of amino-acids, PAHs, and other organic material	**A1:** Laser-desorption detection of organic material from subsurface samples **A2**: Heat evolved detection of aminoacids and other organics **A3:** Spectral identification of pigments and fluorescense signature of organics	I, C, 1 I, C, 4
		M3: Identify specific organic biomarkers	**A1:** Ppb-level mass determination of organic fragments released from drilled material **A2:** Spectral identification of specific pigments **A3:** Liquid extraction and detection of specific biomarkers	I, C, 1 I, C, 4
	I2: Identify bio-mediated processes in rocks	**M1:** In situ assessment of the presence of fossils and/or biofabrics in rocks and soils	**A1:** Target characterisation at panoramic scale, with sub-mm texture observations **A2**: Spectral signatures of surface rocks **A3.** Determine the oxidation state of rocks by measuring Fe0, Fe2+, Fe3+	I, C, 2 I, C, 3 I, C, 4
	I3: Search for complex organic molecules on surface targets	**M1:** Detect the presence of C-C, C-H, C-N, and N-H bonds	**A1:** Determination of the Raman spectra of samples obtained from oucrops **A2**: IR spectral analysis of outcrop samples	I, B, 1 I, B, 2
		M2: Detection of amino-acids, PAHs, and other organic material	**A1:** Laser-desorption detection of organic material from surface samples **A2**: Heat evolved detection of aminoacids and other organics **A3:** Spectral identification of pigments and fluorescense signature of organics	I, C, 1 I, C, 4
		M3: Identify specific organic biomarkers	**A1:** Ppb-level mass determination of organic fragments released from drilled material **A2:** Spectral identification of specific pigments **A3:** Liquid extraction and detection of specific biomarkers	I, C, 1 I, C, 4
	I4: Search for atmospheric signatures of possible biological significance	**M1:** Detect atmospheric trace gases of possible biological relevance	**A1**: Measurement of atmospheric trace gases	I, A, 3 II, A, 2, 3
	I5: Determine geological context of explored sites	**M1:** Field geologic mapping and correlation with analytical laboratory measurements	**A1**: Site characterisation at panoramic scale, with observations down to sub-mm scale **A2:** Subsurface soundings to establish stratigraphy **A3:** Analysis of surface outcrop samples	III, A, 1,2,4,5,6,8
	I6: Establish organic cleanliness of sample path	**M1:** *In-situ* verification of abscense of Earth organic contaminants	**A1**: Ppb-level organics investigation on mission blanks	I, C, 1 I, C, 4

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Relation to MEPAG Goals

SCIENCE OBJECTIVE	SCIENCE INVESTIGATION	REQUIRED MEASUREMENTS	PLANNED MEASUREMENT APPROACH	MEPAG Goal, Objective, Investigation
O2: Characterise the water/geochemical environment as a function of depth in the shallow subsurface (0–2 m depth)	**I1:** Detect the presence of water	**M1:** Detect water in the subsurface	**A1:** Subsurface sounding down to 3 m at cm-scale resolution along the rover path **A2:** Possible deeper sounding of the subsurface **A3:** Search for water by GC-MS analysis. **A4:** Search for H_2O spectral signatures in drill samples	I, A, 1 III, A, 1,2,4,8
	I2: Search for water-bearing minerals at different depths	**M1:** Identification of rocks and borehole material	**A1:** Wide angle + high resolution images **A2**: Measure spectral signature of OH and H_2O	III, A, 1,2,4,5,6,8
		M2: Mineralogic composition of drilled samples	**A1:** Spectral analysis of drilled samples at the mineral grain size level **A2**: Elemental analysis of drill samples **A3**: Analysis of gases released by heating	I, A, 1 I, B, 3 III, A, 1,2,4,5,6,8
	I3: Degree of subsurface layering and mineralogy	**M1:** Physical characteristics/ mineralogy/ stratigraphy of the subsurface	**A1**: Subsurface sounding down to 3 m at cm-scale resolution along the rover path **A2:** Possible deeper sounding of the subsurface	III, A, 1
		M2: Mineralogy/chemistry/biochemistry of the drilled samples	**A1**: Spectral analysis of drill samples at the grain size level **A2**: Elemental analysis of drill samples **A3:** Analysis of borehole as a function of drilling depth **A4**: Search for biominerals by step heating	I, A, 1 I, B, 3 III, A, 1,2,4,5,6,8
	I4: Record preservation state as a function of depth	**M1**: Determine the chemical nature and reactivity of oxidants (and free radicals) **M2:** Estimate ionising radiation effects	**A1**: Detect iron-bearing minerals **A2**: Search for H_2O_2 and other GC-MS analysable oxidants **A3:** Characterise cosmic ray dose	I, B, 4

Expanded info for the rover mission objectives available in Excel file.

MAX-C Overall Proposed Scientific Objectives

Primary Scientific Objectives:

1. At a site interpreted to represent high habitability potential, and with high preservation potential for physical and chemical biosignatures:

- Evaluate paleoenvironmental conditions;
- Characterize the potential for the preservation of biotic or prebiotic signatures;
- Access multiple sequences of geological units in a search for possible evidence of ancient life and/or prebiotic chemistry.

2. Samples necessary to achieve the proposed scientific objectives of the potential future sample return mission would be collected, documented, and packaged in a manner suitable for potential return to Earth.

Secondary Scientific Objective:

3. Address the need for long-term atmospheric pressure data from the martian surface.

1. Cost

- **Estimated increased dollar cost to the mission**
  - Instrument Hardware
    - Minor = < $5 million
    - Medium = $5 - $25 million
    - Major = > $25 million
  - “Ripple” Hardware
    - “Ripple” would be any other system or subsystem that would incur a cost as a result of the added instrument or capability: arm development, sampling system changes, pallet development.
    - Minor = < $10 million
    - Medium = $10 - $75 million
    - Major = > $75 million
  - Workforce to support instrument, added hardware, V&V
    - Minor: a few added people within a team or two
    - Medium: new science instrument team or added subsystem team
    - Major: system level team

2. Resources

- **Resources are limited items in the project**
  - Mass, power, data on the rover or mission
    - Minor: (example) small subsystem added to rover directly
    - Medium: (example) added arm/mast instrument ripples to 5-6x mass
    - Major: (example) live pallet
  - Workforce
    - (see previous slide)
  - Schedule/time
    - Minor: very little impact (development parallels existing schedules)
    - Medium: a few weeks added to critical path
    - Major: complex testing requiring several weeks added, new technology development required; long campaign on surface

3. Risk

- **Risk increases with complexity (new systems, new technology, more complex testing) and schedule items that affect critical path; levels of interaction between rovers**
  - Minor: Added complexity to single subsystem, technology development for subsystem not currently funded, added testing for subsystem on single rover
  - Medium: Multiple subsystem complexity on single rover, coordinated V&V between both rovers, new unplanned instrument technology development, close proximity operations (camera placed under other rover)
  - Major: Complexity for both proposed rovers, new rover technology, significant V&V between rovers, rover-to-rover contact

Draft Results by Perspective

PHASE 2 PRIORITIZATION, 2R-iSAG		Collective science value added						
Ref.		**TOTAL**	EU perspective	USA perspective	astrobiologists	geologists	geophysicists	Program
Group 1: Assume proposed ExoMars and Max-C remain as currently configured.								
1A-2a	**EXM instruments applied to MAX-C discovery**	**1**	2	1	2	1	1	1
4A	**MAX-C acquires second sample after EXM discovery**	**2**	1	3	1	1	1	5
1A-2b	**MAX-C instruments applied to EXM discovery**	**3**	5	2	2	3	1	6
5A	**MAX-C scouts for EXM drill sites**	**4**	3	5	2	5	4	3
1GP	**MAX-C does site characterization around EXM discovery**	**5**	5	5	5	3	N.A.	3
1GE/2A	**EXM helps MAX-C pick analysis/cache samples**	**6**	3	7	5	5	4	7
4GE	**EXM and MAX-C have complementary spatial coverage**	**7**	7	4	7	7	4	1
Group 2: Assume a change somewhere in the system is made relative to the current configuration.								
OLD1	**EXM-collected sample returned to Earth**	**1**	2	1	2	1	1	1
6A	**Recon. tools added to MAX-C to improve its scouting for EXM**	**2**	1	3	1	5	N.A.	1
8A	**MAX-C measures methane concentration in EXM drill holes**	**3**	4	3	3	4	7	6
10GE	**Max-C analyzes/caches separated drill cuttings from EXM**	**4**	5	2	8	2	2	7
OLD2	**Add hazard avoidance to the landing system to improve geologic access**	**5**	2	N.A.	7	5	N.A.	3
1E	**UHF communication link between rovers adds 2nd uplink capability for each**	**6**	7	7	6	N.A.	8	4
6GP	**GPR added to MAX-C improves subsurface picture**	**7**	8	8	N.A.	8	4	4