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*News & Views*

## Rationale and Proposed Design for a Mars Sample Return (MSR) Science Program

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## Abstract

The Mars Sample Return (MSR) Campaign represents one of the most ambitious scientific endeavors ever undertaken. Analyses of the martian samples would offer unique science benefits that cannot be attained through orbital or landed missions that rely only on remote sensing and *in situ* measurements, respectively.

As currently designed, the MSR Campaign comprises a number of scientific, technical, and programmatic bodies and relationships, captured in a series of existing and anticipated documents. Ensuring that all required scientific activities are properly designed, managed, and executed would require significant planning and coordination. Because there are multiple scientific elements that would need to be executed to achieve MSR Campaign success, it is critical to ensure that the appropriate management, oversight, planning, and resources are made available to accomplish them. This could be achieved *via* a formal MSR Science Management Plan (SMP).

A subset of the MSR Science Planning Group 2 (MSPG2)—termed the SMP Focus Group—was tasked to develop inputs for an MSR Campaign SMP. The scope is intended to cover the interface to the Mars 2020 mission, science elements in the MSR flight program, ground-based science infrastructure, MSR science opportunities, and the MSR sample and science data management.

In this report, a comprehensive MSR Science Program is proposed that comprises specific science bodies and/or activities that could be implemented to address the science functionalities throughout the MSR Campaign. The proposed structure was designed by taking into consideration previous management review processes, a set of guiding principles, and key lessons learned from previous robotic exploration and sample return missions.

## Executive Summary

The Mars Sample Return (MSR) Campaign represents one of the most ambitious scientific endeavors ever undertaken. Analyses of the martian samples would offer unique

science benefits that cannot be attained through orbital or landed missions that rely only on remote sensing and *in situ* measurements, respectively.

Ensuring that all required scientific activities are properly designed, managed, and executed would require significant planning and coordination. As currently designed, the MSR Campaign comprises a number of scientific, technical, and programmatic bodies and relationships, captured in a series of existing and anticipated documents.

Because there are so many scientific elements that would need to be executed to achieve MSR Campaign success, it is critical to ensure that the appropriate management, oversight, planning, and resources are made available to accomplish them. To date, however, no dedicated budget lines within NASA and ESA have been made available for these purposes, and no formal MSR Science Management Plan (SMP) has yet been established. It is thus evident that:

***A joint ESA/NASA MSR Science Program, along with the necessary funding and resources, will be required to accomplish the end-to-end scientific objectives of MSR.***

To aid in planning, the MSR Science Program requires an overarching SMP to fully describe how it could be implemented to meet the MSR scientific objectives and maximize the overall science return.

A subset of the MSR Science Planning Group 2 (MSPG2)—termed the SMP Focus Group—was tasked to develop inputs for the MSR Campaign SMP. The scope covers the interface to the Mars 2020 mission, science elements in the MSR flight program, ground-based science infrastructure, MSR science opportunities, and the MSR sample and science data management. Some of the required bodies and activities already exist; the remainder require definition.

In this report, a comprehensive MSR Science Program is proposed, comprising specific science bodies and/or activities that could be implemented to address the science functionalities throughout the MSR Campaign. The proposed structure was designed by taking into consideration previous management review processes, a set of guiding principles, and key lessons learned from previous robotic exploration and sample return missions.



While we acknowledge that the proposal is non-unique, that is, other implementations could meet the overall needs of the MSR Campaign, we have striven to optimize efficiencies and eliminate unnecessary overlap wherever possible to reduce the potential cost and complexity of the MSR Science Program.

Many elements of the proposed Science Program are interdependent, as the decision to trigger certain bodies or activities depend on reaching key milestones throughout the MSR Campaign. Although the timing of certain elements may be flexible depending on the anticipated date of samples arriving on Earth, it is crucial that others are implemented as soon as is feasible.

As a first step, formalizing the Science Program's management structure by the end of 2021 would ensure that impending time-sensitive trades are conducted, and the resulting decisions are made with adequate scientific input.

### Summary of Findings

**FINDING SMP-1:** A joint science management structure and documented agreements among the MSR Partners are required to coordinate the MSR Science Program elements that are not currently defined in existing structures or documents.

**FINDING SMP-2:** A long-term ESA/NASA MSR Science Program, along with the necessary funding and human resources, will be required to accomplish the end-to-end scientific objectives of MSR.

**FINDING SMP-3:** The MSR Science Management Plan should be linked to, but not encompass, other required functionalities within the MSR Campaign. Input will be needed to produce formal plans for (at a minimum) curation, planetary protection, data management, and public engagement.

**FINDING SMP-4:** The guiding principles proposed in the MSR Science Planning Group (MSPG) Framework document (2019c) remain appropriate and relevant and should be utilized in drafting the MSR Science Memorandum of Understanding (MOU) and Science Management Plan.

**FINDING SMP-5 (a):** MSR scientific return would be maximized if participation in the MSR Science Program is not limited to scientists sponsored by existing MSR Partners; rather, opportunities should be provided to scientists from around the world. **(b)** All programmatic decision-making power (*e.g.*, selection of competitive proposals) would still rest with the Partners.

**FINDING SMP-6:** At the implementation level, the MSR Science Program should, wherever possible, leverage structures, programs, and lessons-learned from previous mission organization to benefit from their experiences to engender familiarity among both decision-makers and the science community.

**FINDING SMP-7:** The MSR Science Program requires the establishment of scientific bodies to meet management, science operations, and public participation needs. These bodies require dedicated funding, addressing scientific functionalities that span the entirety of the MSR Campaign.

**FINDING SMP-8:** Some elements of the MSR Science Program cannot be delayed in the event of an MSR Program schedule delay, as they are linked to key decisions or operations of the Mars 2020 mission.

## 1 Introduction

### 1.1 Context

In October 2020, the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) signed a Memorandum of Understanding (MOU) (RD-01) to return scientifically selected samples from the surface of Mars. The Mars Sample Return (MSR) Program outlined in the MOU consists of multiple flight missions to retrieve and deliver to Earth samples collected by NASA's Mars 2020 (M2020) mission. The returned samples would be carefully managed and made available to the international community for scientific investigation.

A number of scientific functionalities must be successfully defined, established, and executed throughout the end-to-end sample return effort. To aid in preparing for the scientific elements of MSR, ESA, and NASA had jointly chartered the MSR Science Planning Group (MSPG) in 2018. This group produced a series of technical reports (MSPG 2019a,b) and a Framework for Returned Sample Science Management ("the Framework"; MSPG 2019c), delivered in late 2019.

To build upon the findings of MSPG, the MSPG2 was jointly chartered by ESA and NASA in 2020. Among other deliverables, the MSPG2 Terms of Reference specifically requested:

- *"Inputs to the Science Management Plan. The MSPG-2 is expected either to adopt the MSPG recommendations, or to propose suitable alternatives, regarding science management planning issues. The scope of this task could include, but not necessarily be limited to, the following:*
  - *Amplify the planning descriptions of the bodies & processes described in the Framework document, Section 4.*
  - *Define the interface, organizational relationships, and communication pathways between science, curation, Mars 2020, facilities planners, and planetary protection."*

A subset of MSPG2—the Science Management Plan (SMP) Focus Group (FG)—was assigned to this task, aiming to propose a plan that describes the functionalities and implementation of an MSR Science Program. The present document provides the outputs

of the SMP-FG deliberations and could be used by ESA and NASA management as input to the eventual SMP.

## 1.2 Scope

The MSR SMP will describe the MSR Science Program and how it should be implemented to meet the MSR scientific objectives and maximize the overall science return. The scope should cover the interface to the Mars 2020 mission, science elements in the MSR flight program, ground-based science infrastructure, MSR science opportunities, and the MSR sample and science data management. Some of the required bodies and activities already exist; the remainder require definition.

Upon direction of the MSPG2 leadership, a number of elements described in the Framework were excluded from consideration. Specifically, the facilities planning groups and long-term sample management beyond the first round of objective-driven science are not part of this report.

There is considerable overlap between the scientific activities undertaken during the MSR Campaign and other aspects of sample handling and management, including umbrella agreements between the MSR partners, MSR Program flight elements, sample curation, sample safety assessment, and sample allocation and management procedures, and public engagement. The relationship between the SMP and companion documents is provided in Section 3.4.

Defining the interface with the M2020 mission is of particular importance. While M2020 is clearly a critical component of MSR, it is not managed jointly between the MOU partners. Rather, M2020 is managed exclusively by NASA's Science Mission Directorate (SMD) and as such has been assigned responsibility for a number of important tasks that will contribute to the MSR effort (see Section 3.4). The proposed science bodies and activities described in this report were designed to ensure that authorities already assigned to M2020 are respected.

Moreover, as the SMP would cover the timespan from 2021 until nominally two years after sample arrival on Earth, future updates are expected. The present document serves as a starting point for developing an overarching MSR Science Program.

### 1.3 Definition of terms

For the reader's clarity, a number of key terms used throughout this report are defined here:

- **MSR Partners:** signatories of the MSR MOU (RD-01) and any subsequent modifications.
- **MSR Program:** the flight missions and elements—the Sample Retrieval Lander (SRL), Sample Fetch Rover (SFR), the Earth Return Orbiter (ERO), and Capture, Containment and Return System (CCRS)—required to return samples collected by M2020.
- **MSR Campaign:** collectively, all of the flight missions (M2020 + the MSR Program) and the subsequent ground-based infrastructure to collect, return, curate, and investigate the samples.
- **MSR Science Program:** the science management with associated bodies and activities that will be required to successfully plan and execute the scientific elements of the MSR Campaign.

### 1.4 MSR Science Program structure

Ultimately, the SMP will provide a plan as to how the MSR Partners develop and manage the MSR Science Program. In doing so, the SMP-FG has produced its report with an intended structure that represents target groups at various levels (Figure 1):

- **MSR Partners:** decision-makers responsible for ensuring sufficient budget and programmatic coverage needed to successfully complete the MSR Campaign.
- **MSR Campaign Scientific Leadership:** senior scientists and science managers responsible for enabling and implementing the SMP (see Section 0).
- **MSR Campaign Science Investigations:** activities conducted by competitively selected scientists responsible for performing the data collection and analyses required to achieve the scientific objectives of the MSR Campaign (see Section 0).
- **Broader Scientific Community:** all members of the MSR scientific community, whether selected through a competitive process or not (see Section 4.4).

### 1.5 Document overview

The SMP-FG report is structured and reported as follows:

**Section 2** provides background and context for the MSR Campaign, outlining the scientific rationale and overarching science objectives for returning samples from Mars, and introducing the range of activities that are being planned.

**Section 3** describes the approach that shaped the SMP-FG deliberations, including an overview of currently existing documents and management bodies, a review of the MSPG Framework guiding principles, a definition of the core MSR Campaign functionalities that will need to be covered by the SMP and be managed outside of the SMP, and a collection of lessons-learned from previous planetary exploration missions.

**Section 4** presents the overall proposed science management structure, introducing the roles and responsibilities, selection processes, timelines, and outputs for the various scientific entities that may exist during the MSR Campaign.

**Section 5** discusses the management of data products generated by the MSR Campaign, including information collected and produced by all flight mission elements and by ground-based curatorial and scientific investigations.

**Section 6** provides the overall MSR Campaign schedule and integrated timeline, presenting a list of key decision points and the timing of selected science management-related activities.

**Section 7** summarizes the report's findings and demonstrates its response to the statement of task.

## 2 The MSR Campaign

### 2.1 MSR Science Benefits

A successful MSR Campaign would provide scientific value of the highest order in understanding martian geologic processes and other foundational aspects of its evolution and present state, including whether the near surface of Mars hosts, or has ever hosted, life.

The MSR Campaign offers unique science benefits that cannot be attained through orbital or landed missions that rely only on remote sensing and *in situ* measurements. Like previous sample return missions such as Apollo, Genesis, Stardust, Hayabusa 1 and 2, and the current OSIRIS-REx mission, MSR plans to deliver to Earth samples that can be studied in the world's best laboratories for decades to come.

In many cases, the samples can be studied with no time limitation (see Tosca *et al.*, 2021) and can be preserved for future generations of researchers and technologies and held in curation facilities for posterity (see Tait *et al.*, 2021). In contrast to *in situ* studies on Mars, returned sample studies and instruments have no practical limitations on power, size, weight, data rates, consumables, component life, or the ability to modify sample preparation procedures and analytical methods in response to new discoveries.

Martian samples can be analyzed by using elaborate and delicate preparation techniques to maximize science yield. These studies can characterize the Mars samples down to the micrometer, nanometer, and atomic scale. Studies of Mars samples in Earth-based laboratories offer the ability to design experiments iteratively and in real time as sample characteristics are revealed. With no requirement to prejudge what we could find in the samples, the dilemma of deciding which instruments to fly on a Mars mission is avoided since every possible technique on Earth would be available when the samples arrive.

The MSR Campaign also benefits from the M2020 Perseverance rover's ability to acquire a scientifically selected set of samples with geological diversity and context. A coherent *in situ*-characterized suite of geologic samples can help realize the full scientific potential of samples returned from Mars. The suite of samples offers one of the main aspects lacking in the world's martian meteorite collection: geologic context. For example, without locality information and geologic context radiometric dating cannot provide a robust martian geologic timescale.

Another valuable aspect of a carefully selected sample suite is the ability to collect a diversity of martian rock types guided by *in situ* environmental observations and scientific considerations. In particular, Perseverance can collect, and prepare for return, fragile sedimentary rocks that would never survive the impact ejection processes that deliver

meteorites from Mars to Earth. Carefully preserving the samples in sealed containers would also minimize the potential effects of terrestrial contamination and alteration commonly affecting meteorites.

Thus, it is likely that the Mars sample return cache would have within it martian rock types distinct from martian meteorites that we have never seen before in Earth-based laboratories. These precious martian sediments, and other constituents contained within them, may even hold clues to answering the age-old question “Was there ever life on Mars?”.

## 2.2 MSR scientific objectives

The overarching research objectives of the MSR campaign have been adopted from the International MSR Objectives and Samples Team’s (iMOST) final report (Beaty *et al.*, 2019). The iMOST report offers guidelines for decision making with regard to future investigations and in support of the efforts of the M2020 mission to acquire and select for return the most suitable samples necessary to reach the MSR scientific research objectives.

An educated strategy of acquisition, caching, and selection for return will be essential because M2020’s Perseverance rover is able to store more sample tubes than the subsequent MSR Program elements would be able to return. The geological and environmental context of all returned samples, which will include rocks, regolith, dust, and atmosphere, will be defined thoroughly *via* data and images acquired by the instruments onboard Perseverance and multiple spacecraft investigating Mars. Sample diversity necessary to achieve the following broad range of research goals would be enabled by the comparably large number of sample tubes to be returned, which will include a variety of distinct relevant geological and geochemical features.

The scientific objectives and sub-objectives of MSR are reproduced below as originally presented in Beaty *et al.*, 2019:

- **Objective 1 (Geology):** Interpret the primary geologic processes and history that formed the martian geologic record, with an emphasis on the role of water
  - *Sedimentary system:* Characterize the essential stratigraphic, sedimentologic, and facies variations of a sequence of martian sedimentary rocks.



- *Hydrothermal*: Understand an ancient martian hydrothermal system through study of its mineralization products and morphological expression.
- *Deep subsurface groundwater*: Understand the rocks and minerals representative of a deep subsurface groundwater environment.
- *Subaerial*: Understand water/rock/atmosphere interactions at the martian surface and how they have changed with time.
- *Igneous terrane*: Determine the petrogenesis of martian igneous rocks in time and space.
- **Objective 2 (Life)**: Assess and interpret the potential biological history of Mars, including assaying returned samples for the evidence of life
  - *Carbon chemistry*: Assess and characterize carbon, including possible organic and pre-biotic chemistry.
  - *Biosignatures—ancient*: Assay for the presence of biosignatures of past life at sites that hosted habitable environments and could have preserved any biosignatures.
  - *Biosignatures—modern*: Assess the possibility that any life forms detected are still alive or were recently alive.
- **Objective 3 (Chronology)**: Quantitatively determine the evolutionary timeline of Mars.
- **Objective 4 (Volatiles)**: Constrain the inventory of martian volatiles as a function of geologic time and determine the ways in which these volatiles have interacted with Mars as a geologic system.
- **Objective 5 (Interior)**: Reconstruct the processes that have affected the origin and modification of the interior, including the crust, mantle, core and the evolution of the martian dynamo.
- **Objective 6 (Environment)**: Understand and quantify the potential martian environmental hazards to future human exploration and the terrestrial biosphere.

- **Objective 7 (Resources):** Evaluate the type and distribution of *in situ* resources to support potential future Mars exploration.

*These generic MSR science objectives were produced prior to Jezero Crater having been selected as the M2020 landing site. Refined objectives will be tailored to match the specifics of the scientific discoveries of the M2020 science team and the sample cache(s) collected by Perseverance.*

### 2.3 MSR Campaign overview

The planned MSR Campaign spans multiple flight missions and one ground element (These generic *MSR science objectives were produced prior to Jezero Crater having been selected as the M2020 landing site. Refined objectives will be tailored to match the specifics of the scientific discoveries of the M2020 science team and the sample cache(s) collected by Perseverance.*

), described briefly below. For a detailed summary of activities, please see Meyer *et al.* (2021) and references therein:

- (1) **M2020:** Launched on July 30, 2020, and successfully landed the Perseverance rover in Jezero Crater on February 18, 2021.
- (2) **NASA Sample Retrieval Lander (SRL):** Includes the Mars Ascent Vehicle (MAV), the Orbiting Sample container (OS), and the ESA Sample Fetch Rover (SFR).
- (3) **ESA Earth Return Orbiter (ERO):** Includes the NASA Capture, Containment, and Return System (CCRS) that includes the Earth Return Vehicle (ERV) that would land in the United States.
- (4) **Mars Returned Sample Handling (MRSH):** Upon landing on Earth, the ERV would be recovered and transported to a Sample Receiving Facility (SRF) where the samples would be stored temporarily and prepared for the initial sample science investigations.

Under the anticipated schedule at the time of this writing, the NASA-led SRL mission, including an ESA-led SFR, would launch in 2026 and arrive at Mars in late August/early September 2028. Note that the MSR Program will also have a viable backup option to

launch the ERO and SRL missions in 2028 with sample return to Earth in late 2033.

Descriptions of the essential timing aspects of the MSR Campaign that influence the science management planning are provided as follows.

#### 2021

- **M2020:** Landing and sample collection begins in Jezero Crater, Mars.
- **SRL and ERO:** Requirements definition and preliminary design work.
- **MRSH:** Early planning. Identify SRF types for subsequent options analysis.
- **Sample collection / information:** Some samples will be acquired; some future sampling opportunities will have been identified; relevant sample information including the surface wind, temperature, pressure, and relative humidity during and after sampling will be documented in a Sample Dossier (see Section 5.3).

#### 2021–24

- **M2020:** Initial phase of sample collection. The Perseverance rover has a nominal prime mission lifetime of 1 Mars year (2 Earth years) with a qualified lifetime of 1.5 Mars years (3 Earth years). The rover has the capability to acquire 20 samples within the prime mission lifetime.
- **SRL and ERO:** Detailed design work and construction.
- **MRSH:** SRF preliminary planning, culminating in site selection.
- **Sample collection / information:** It is likely that one set of samples will have been placed in a cache depot; some additional future sampling opportunities will have been identified.

#### 2024–26 (or 2024–28)

- **M2020:** Extended phase of sample collection. Rover health permitting, focus is likely to be on an extended phase of sample collection; at least most, and potentially all, of the samples that are candidates for Earth return will have been collected.

- **SRL and ERO:** Construction, verification requirements, and preparation for launch.
- **MRSH:** SRF site-specific design, and onset of construction.
- **Sample collection / information:** Most of the samples that may be brought to Earth will have been collected; initial sample prioritization workshop(s) (see Section 4.4.3); the preliminary surface sample recovery plan will have been formed and iterated.

2027 (or 2028–29)

- **M2020:** Extended phase of sample collection. Rover continues collecting samples if it is able to do so.
- **SRL and ERO:** ERO completes MOI, and SRL landing on Mars. The landing site for SRL will be known several months in advance of landing for trajectory planning purposes. There is a need for coordinated planning involving the positioning of Perseverance, SRL landing site selection, and the traverse planning for SFR.
- **MRSH:** SRF construction continues, analytical instrument selection process completed.
- **Sample collection / information:** Final sampling completed; sample prioritization workshop process completed; the plan for which samples will make up the return collection will have been finalized.

2028–29 (or 2030–31)

- **M2020:** May contribute to sample delivery to SRL. Rover continues collecting samples if it is able to do so; may execute option to drop sample tubes in a sample tray on SRL that can be picked up by the robotic arm on SRL and loaded into the OS.
- **SRL and ERO:** SRL/SFR carry out surface sample recovery operations. A selected set of samples collected by M2020 and left at a depot would be collected by the SFR and returned to SRL where the tubes would be transferred to the OS inside the MAV.
- **MRSH:** SRF instrument and critical hardware (*e.g.*, sample isolator) installation.

- **Sample collection / information:** Identity of the samples that have been successfully loaded into the OS will be known, along with metadata collected with the samples.

2029 (or 2031)

- **M2020:** No longer relevant to MSR Campaign.
- **SRL and ERO:** The MAV launches from Mars's surface and releases the sample-bearing OS into low Mars orbit. The ERO captures the OS in orbit.
- **MRSH:** SRF commissioning process.
- **Sample collection / information:** Returned sample collection known with 100% certainty.

2031 (or 2033)

- **M2020 and SRL:** No longer relevant to MSR Campaign.
- **ERO:** Jettisons the Capture and Containment Module (CCM), leaves Mars orbit, and returns to Earth. The ERO releases the EEV (Earth Entry Vehicle) for a ballistic reentry through the Earth's atmosphere and then proceeds to a heliocentric orbit to prevent impact with Earth per Planetary Protection requirements.
- **MRSH:** SRF certified to receive and process the Mars samples.
- **Sample collection / information:** Returned sample collection known with 100% certainty.

2031–32 (or 2033–34)

- **M2020, SRL, and ERO:** No longer relevant to MSR Campaign.
- **MRSH:** Upon successful ERV landing and recovery in the United States, the contained ERV is transferred to the SRF. Activities conducted within the SRF will include (but are not limited to) hardware de-integration, archiving and analyses of the flight hardware, dust removal and analyses from the OS and the tube exteriors, sample tube headspace gas extraction and analyses, extraction of samples from the tubes, processing of witness materials, completion of sample safety assessment,

scientific investigations that are time-sensitive, scientific investigations sensitive to sample sterilization, and preparation of samples for investigations to be conducted in external laboratories.

- **Sample collection / information:** Sealed sample tubes will be opened and returned sample science will begin.

2032–TBD (or 2034–TBD)

- **M2020, SRL, and ERO:** No longer relevant to MSR Campaign.
- **MRSB, Sample collection / information:** Sample scientific investigation.

#### 2.4 MSR sample science investigations: Objective-driven vs. opportunity-driven

After delivery of the samples to the SRF, scientific investigations would commence concurrently with the initial characterization of the samples. Teams of investigators competitively selected years in advance will conduct a variety of studies that will address the MSR objectives (“objective-driven investigations”). During this period, there would be considerable overlap with curation activities and sample safety assessment, which will require appropriate coordination to optimize the use of sample material and maximize the scientific return.

Two types of investigations would be conducted within the SRF itself: (i) those that require time-sensitive measurements (*i.e.*, characterizing physical or chemical properties that may change rapidly after sample tube opening) (Tosca *et al.*, 2021) and (ii) those that require measurements that are sensitive to sample sterilization processes and have an element of time-criticality (Velbel *et al.*, 2021). Other studies may be conducted outside the SRF after samples have either been deemed to be safe or rendered so.

As with other sample return missions, it is envisioned that scientific investigations would continue for decades to come after the objective-driven investigations are complete. However, such “opportunity-driven” investigations are not included within the scope of the SMP and are thus not discussed further in this document.

### 3 Approach to Developing an MSR Science Management Plan

#### 3.1 Current MSR management bodies and documentation

The end-to-end MSR Campaign as currently designed comprises a number of scientific, technical, and programmatic bodies and relationships captured in a series of existing and anticipated documents. The following represents the overall MSR Campaign management structure as it exists at the time of writing:

- **M2020:** although a crucial element of the MSR Campaign, M2020 is managed entirely by NASA's SMD outside of the NASA-ESA MSR agreement. M2020 is led by a PSG (Figure 4a) and is governed by its own Science Team Guidelines (RD-02) and Curation Plan (RD-03). Within NASA, high-level coordination between M2020 and the MSR Program is defined in the Mars Exploration Program (MEP) / MSR Program Memorandum of Agreement (MOA) (RD-04).
- **MSR Program:** consisting of the SRL and ERO flight missions, the MSR Program is jointly managed by ESA and NASA. A simplified organizational chart providing an overview of the management structure under the Program is shown in Figure 3b. The high-level binding agreement between ESA and NASA for the MSR Program is the Flight Element MOU (RD-01), which details each agency's respective roles and responsibilities under the Program. The Joint Management Implementation Plan (JMIP) (RD-05) serves as the guiding document that provides further detail for Partners' execution of the Program, overseen by the Joint Steering Board (JSB) that consists of agency-appointed project managers, engineers, and scientists.
- **MRSH:** the NASA MEP/MSR MOA (RD-04) notes that MEP is responsible for (among other responsibilities) managing curation of the samples, defining Mars science requirements, and directing science activities within an SRF. While the goal to have a jointly managed facility was indicated in the original MSR Statement of Intent between NASA and ESA, ESA's roles in MRSH management have yet to be formally defined and no overarching science bodies or documentation have yet been developed that define NASA/ESA interaction on science activities.

M2020 is currently operating on the martian surface and is managed effectively by NASA's MEP. The MSR Program element is largely engineering-driven, focused solely on the flight missions' requirement to return the samples collected by M2020 back to Earth. However, there is a need to develop sample integrity science requirements and monitor their implementation on the various MSR Program elements.

Given that the overall MSR science benefits are intended to be shared among the MSR Partners, it will be crucial to develop a joint science management structure that covers scientific aspects of the end-to-end Campaign to ensure that the MSR science objectives can be successfully achieved.

**FINDING SMP-1:** A joint science management structure and documented agreements among the MSR Partners are required to coordinate the MSR Science Program elements that are not currently defined in existing structures or documents.

Jointly managing the MSR Science Program will require a series of international agreements. At the time of writing, it is expected that two critical documents will be produced in the coming year:

- **MSR Science MOU:** outlining each agency's roles and responsibilities for the MSR Science Program, and;
- **MSR SMP:** describing the detailed joint implementation of the MSR Science Program.

To provide inputs for the Science MOU and SMP, the MSPG2 SMP-FG has developed a strawman MSR Campaign science management structure, described in detail throughout Section 4. The following sections provide the context with which we developed the proposed structure, incorporating previous management review processes, identifying both the science functionalities that are, and are not, managed within the SMP, outlining the principles by which the structure could be designed and integrating key lessons learned from previous robotic exploration and sample return missions.



### 3.2 MSR Independent Review Board findings

In August 2020, NASA chartered an MSR Independent Review Board (IRB) to evaluate the technical progress on its early concepts for contributions to the MSR Program. Noting that MSR is one of the most technically challenging undertakings ever attempted, ultimately the IRB concluded that the Agency is ready to proceed.

The IRB's final report in November 2020 provided 43 recommendations for both programmatic and technical elements of MSR preparations, to which NASA has provided an initial response (NASA SMD, 2021). The IRB stated explicitly the importance of close coordination in all scientific elements of M2020 and MSR, issuing three such recommendations in particular:

- **B-1:** A scientific advisory team (or dedicated subgroup) for both M2020 and MSR should be formed immediately and integrated into operations planning. The membership of this team should include leading sample analysis and mission operations experts.
- **B-2:** Science operational decisions for M2020 after its landing should reflect sample acquisition as the dominant science priority.
- **B-4:** Campaign-level baseline and threshold success criteria for sample return (including number of sample tubes and diversity of sample types) should be documented.

Wherever possible, the SMP-FG attempted to develop findings consistent with the above recommendations that NASA and ESA management could incorporate into its planning.

### 3.3 MSR Campaign: Required science functionalities

Under our definition, the MSR Science Program would encompass all scientific activities conducted during the MSR Campaign, noting that the M2020 mission is independently managed. As such, we envision a variety of scientific bodies or entities to be required, categorized broadly under the themes of:

- **Science Program Management:** Appointed and competed representatives responsible for overall Science Program design and implementation, serving as the interface between the MSR Partners and the broader scientific community.
- **Science Operations and Investigations:** Competitively selected teams and individuals responsible for the science activities required to meet the MSR Campaign's scientific objectives.
- **Participation of the wider scientific community:** Opportunities for members of the broader scientific community to provide input into the decision-making processes of key Science Program activities.

NASA's MEP/MSR MOA (RD-04) provides an initial breakdown of specific science and other tasks required throughout the MSR Campaign, along with relative decision-making authority within NASA. We have also identified a variety of other specific tasks that would benefit from joint definition and oversight.

Table 1 outlines a list of envisaged functionalities that may be carried out under the MSR Campaign, indicating which are already listed explicitly within the MEP/MSR MOA (RD-04). Note that only NASA responsibilities have been indicated in the table. However, the MSR Science Program will be jointly managed with the respective ESA decisional authorities that will be indicated when they are formalized.

The MEP/MSR MOA also stipulates that MEP is responsible for coordination between NASA and ESA for M2020 surface operations and sample collection. Because there are so many scientific elements required to achieve MSR Campaign success, it is critical to ensure that the appropriate management, oversight, planning, and resources are made available to accomplish them. To date, however, no dedicated budget lines within NASA and ESA have been made available for these purposes, and no formal MSR science program plan has been established.

**FINDING SMP-2:** A long-term ESA/NASA MSR Science Program, along with the necessary funding and human resources, will be required to accomplish the end-to-end scientific objectives of MSR.

Given that the MSR Campaign science activities have already commenced with M2020, the MSR Science Program should be initiated and funded as soon as is feasible and should run through the end of the “objective-driven” investigations that directly address the MSR science goals.

### 3.4 Functionalities managed outside of the SMP scope

The SMP will describe the overall structure of the MSR Science Program and detail how it will be implemented to meet the MSR science objectives and maximize the overall scientific return of the MSR Campaign. Because science is intrinsically linked with other aspects of sample handling and interrogation, clear decisional boundaries are also required for elements of sample handling after return. As such, the SMP will serve as a reference document to (as examples) the following anticipated documents:

- **Curation Plan** would describe archiving of spacecraft and witness materials, sample recovery and transport, ERV de-integration procedures, initial sample characterization, the policies and procedures surrounding sample requests, application reviews, allocations, distribution, and user guidelines.
- **Interagency Planetary Protection Plan** would define the organizational and decisional relationships between NASA, ESA, and other US national and international departments, sample safety assessment protocols, and hazard assessments.
- **Communications and Public Engagement Plan** would outline key messages and strategies for communicating with the general public and media.

Undoubtedly, scientific input will be required to produce each of the above. However, the specific objectives of each of these documents is considered distinct from the SMP and will thus be managed separately.

In addition, the SMP will be required to set boundary conditions for one other critical document:

- **Science Data Plan** would provide expectations for all MSR data archiving and dissemination.

Though technically outside the scope of the SMP itself, the Science Data Plan would be a subordinate document to the SMP, owned by MSR Campaign Science Program management bodies (see Section 4.2).

**FINDING SMP-3:** The MSR Science Management Plan should be linked to, but not encompass, other required functionalities within the MSR Campaign. Input will be needed to produce formal plans for (at a minimum) curation, planetary protection, data management, and public engagement.

### 3.5 MSR Campaign science management: Guiding principles

Five guiding principles have served as the foundation of the SMP-FG deliberations, drawn directly from the SMP Framework document (MSPG 2019c). These principles were formulated upon previous science management recommendations, leveraging experience from other major international science partnerships and sample return missions.

Summarized below, they aim to balance the need of MSR partners to achieve a return on their investment with the need to engage many international scientists to meet the MSR scientific objectives:

- **Accessibility:** International scientists should have multiple opportunities to participate throughout the MSR Campaign in a variety of capacities (*e.g.*, sample management, sample analysis), whether through competed opportunities or through publicly accessible activities.
- **Transparency:** Access to MSR Campaign scientific activities and the processes that define participation in scientific activities should be as transparent as possible.
- **Science maximization:** The management and sample-related processes should be designed to maximize sample science and optimize the productivity of the investigation team.
- **Return on investment:** The MSR Partners should receive demonstrable benefits in return for having provided the resources required to conduct the MSR Campaign.

- **One return canister / One collection:** The returned martian samples and associated blanks and archived contamination knowledge materials should be managed as a single collection even if the materials are physically housed in different facilities over time.

Once drafted, the official SMP, the Science MOU, and any future modifications to either document should ensure consistency with these principles.

**FINDING SMP-4:** The guiding principles proposed in the MSR Science Planning Group (MSPG) Framework document (2019c) remain appropriate and relevant and should be utilized in drafting the MSR Science Memorandum of Understanding (MOU) and Science Management Plan.

### 3.6 *Science Program element eligibility*

The MSR Science Program is an ambitious effort and, as such, will draw immense interest from the international science community. While ensuring alignment to the Guiding Principles outlined above, the SMP-FG has aimed to develop a Science Program to address both community and MSR Partner needs as follows:

- **Open worldwide competitions:** Numerous opportunities will be developed for both science management and scientific activities throughout the MSR Campaign. Wherever possible, these opportunities will be populated on a competitive basis or will be freely open to the entire scientific community. Competitive opportunities are not restricted to scientists represented by MSR Partners but rather will be open internationally to ensure the most qualified scientists are selected for the roles.
- **Decision-making:** Sample ownership will not be pro-rated based on relative Partner investment levels. Rather, Partners are granted final decisional authority over all Science Program selection processes, infrastructure, and operational activities.

**FINDING SMP-5 (a):** MSR scientific return would be maximized if participation in the MSR Science Program is not limited to scientists sponsored by existing MSR Partners; rather, opportunities should be provided to scientists from around the world.

**FINDING SMP-5 (b):** All programmatic decision-making power (*e.g.*, selection of competitive AOs) would still rest with the Partners.

### 3.7 Management and scientific precedents from previous missions

In many ways, the MSR Campaign is unprecedented with regard to technical and managerial perspectives. It involves multiple flight missions coordinated by two space agencies leveraging a science mission managed exclusively by only one of those agencies and adds a ground segment that may rival the complexity of a flight effort. As such, attempting to develop an overarching, cohesive Scientific Program may appear daunting.

However, multiple decades of mission experience (*e.g.*, Longobardo 2021 and papers therein) have provided significant lessons directly applicable to MSR, from which NASA and ESA managers can base their planning. Prior sample return missions, including Stardust (Brownlee, 2014), OSIRIS-REx (Lauretta *et al.*, 2017), Hayabusa (Yoshikawa *et al.*, 2015) and Hayabusa2 (Tsuda *et al.*, 2013), Mars exploration missions such as the Mars Science Laboratory (MSL) (Grotzinger *et al.*, 2012), and the ExoMars rover (Vago *et al.*, 2017), and sample analysis efforts such as the Apollo Next Generation Sample Analysis (ANGSA) program (RD-06) have helped shape our rationale in developing recommendations for the MSR Science Program, as reported below.

**FINDING SMP-6:** At the implementation level, the MSR Science Program should, wherever possible, leverage structures, programs, and lessons-learned from previous mission organization to benefit from their experiences to engender familiarity among both decision-makers and the science community.

#### 3.7.1 Long-term planning

- **Sample analysis objectives should be clearly defined (OSIRIS-REx):** A science traceability matrix should be developed to provide clear and detailed traceability between the mission goals and science objectives to the required laboratory measurement capabilities and sample requirements. Such requirements will be invaluable to help guide selection of sample investigations.

- **Specialized equipment for sample analysis may require up to seven years of development time (Stardust):** The instruments that will be required to carry out the sample investigations may be in various states of readiness at the time of the initial Announcement of Opportunity (AO). They may be already existing, though in need of upgrade or modification, commercially available, or requiring customized development. As a result, the MSR investigation AO(s) would need to occur early enough to account for long-lead development.

### 3.7.2 Science team selection

- **Mission science teams are selected many years in advance of operations (MSL, M2020, OSIRIS-REx, Stardust, Hayabusa, and Hayabusa2):** Formation of a core science team that is trained well in advance of sample receipt, facilitates acknowledgment of the limitations of instruments and their calibration, and promotes fast and accurate analysis of observations and timely decisions during operation.
- **Consortia bids should be encouraged (ANGSA):** Consortia bids should be encouraged to maximize science return and optimize sample usage. Additionally, natural consortia may form after individual investigations are selected and a broader team is formed.
- **The curation function should be complementary to science (ANGSA):** Curation team members cannot be a PI or Co-I on research proposals but can be co-authors of research publications if a substantive contribution is made.

### 3.7.3 Science team composition

- **Mission Science Teams require formal science leadership (MSL and M2020 Project Science Group; OSIRIS-REx Science Executive):** A relatively small (10–20 person) group ensures alignment of science team activities to achieving the mission's objectives.
- **The formation of thematic working groups promotes collaboration and increases science return (Stardust, OSIRIS-REx, Hayabusa2):** Working groups organized around general themes (*e.g.*, organics, mineralogy and petrology, elements and

isotopes, biology/paleobiology, sample data management and archiving, curation, contamination knowledge, etc.) can be an effective way to organize the selected team and help facilitate coordination of measurements and development of the sample analysis and publication plans.

#### 3.7.4 Preparatory activities

- **A sample analysis readiness test should be conducted well in advance of the samples being returned to Earth (OSIRIS-REx):** The samples returned from Mars will be among the most precious materials ever collected. Ensuring the science team's readiness by performing respective critical analyses on "dummy" samples will be crucial for developing a revised protocol and applying lessons-learned on the actual samples after return.

#### 3.7.5 Involvement of the broader science community

- **Openly accessible processes promote community engagement (e.g., landing site workshops for MSL and M2020):** Early engagement of the scientific community through workshops and AOs would maximize the scientific exploitation and the quality and impact of mission data analysis. This would promote transparency, documentation and internationalization, and generate a sense of community. Moreover, early engagement may also help researchers publish refereed work and seek funding, and it may help to generate a community that develops the tools and the hypotheses well in advance, even before landing.
- **Being open to new science team members maximizes opportunity (e.g., MSL, M2020):** Defining a dynamic program where some scientists and technicians join over time, all agreeing to a Rules of The Road document (Section 4.2.1), would facilitate incorporation of excellent candidates and new ideas, distribute costs, enhance cooperation, and reduce friction or disagreements.

#### 3.7.6 Accessibility of data products

- **Delivery of data to public archives (e.g., PDS/PSA for all Solar System exploration missions):** Allowing online access to archived data would facilitate scientific



exploitation, promote internationalization, and allow for future re-evaluation of analysis in view of new data.

## 4 Proposed MSR Science Management Structure and Science Bodies

### 4.1 Overview

We have developed a design reference program comprising specific science bodies and/or activities that could be implemented to address the science functionalities outlined in Section 3.3. While we acknowledge that the proposal is non-unique, that is, other implementations could meet the overall needs of the MSR Campaign, we have striven to optimize efficiencies and eliminate unnecessary overlap wherever possible to reduce the potential cost and complexity of the MSR Science Program.

Each of the proposed bodies or activities is organized and reported around the following headings:

- **Rationale:** Why the particular body or activity is required.
- **Roles & Responsibilities:** Specific tasks that the body would carry out.
- **Selection Process and Composition:** Procedure by which, and rationale for how, the body could be populated.
- **Dependencies:** Critical milestones or deliverables to which the activity would be tied.
- **Key Outputs:** Major deliverables and/or decisions that arise from the activity.
- **Timeline:** Proposed commencement and duration of each body, wherever possible reported as being relative to key MSR Campaign milestones to maintain flexibility in the event of high-level schedule changes.

Broadly, the ESA and NASA MSR lead scientists would largely manage the preparation and implementation of the MSR Science Program, including the science input necessary for ground-based infrastructure. As a complement, the following sections represent a cohesive, integrated set of initiatives that respective ESA and NASA managers could put in place to address the scientific needs of the MSR Campaign and, in some cases, respond to

the IRB recommendations presented in Section 3.2. A summary of the functionalities and proposed decisional authorities is presented in Table 2.

**FINDING SMP-7:** The MSR Science Program requires the establishment of scientific bodies to meet management, science operations, and public participation needs. These bodies require dedicated funding, addressing scientific functionalities that span the entirety of the MSR Campaign.

## 4.2 Science Program management

### 4.2.1 MSR Campaign Science Group (MCSG)

#### *Rationale*

Oversight and guidance will be required at the highest level of the MSR Science Program. The proposed MSR Campaign Science Group (MCSG) would assist in the execution of the SMP, operating in two phases:

- **Phase 1 (MCSG-1):** The focus of Phase 1 is the MSR science planning, which interfaces with the flight elements and ground-based science infrastructure to generate opportunities for the science community.
- **Phase 2 (MCSG-2):** The focus of Phase 2 is the implementation of the objective-driven science to be carried out on the samples from Mars.

Development of such a body would result in a similar structure of processes and envisaged documentation for both the engineering and science elements of MSR (see Figure 5).

Serving as the interface between the MSR Partners and the science community, the MCSG would represent many of the functions of a traditional PSG for NASA flight missions or Science Working Teams (SWT) for ESA flight missions and provide overall guidance for the long-term strategic science planning and the day-to-day management of the Science Program.

Ultimately, the MCSG members act as the stewards of the Science Program and are focused on the entirety of the MSR Campaign's end-to-end scientific activities. As such, it

will represent MSR science to the MSR Partners, international science community, and the public.

#### *Roles and responsibilities*

The MCSG would be required for a number of tasks that may vary over time. In the immediate term, it could be responsible for the following:

- Support the oversight process from NASA and ESA management in the execution of the Science Program.
- Provide a research and development (R&D) roadmap.
- Review Level 1 science requirements.
- Draft and maintain the SMP and the Data Management Plan.
- Approve the Terms of Reference for *ad hoc* and standing working groups and committees within the frame of the Science Program.
- Develop and maintain strategic decision guidelines to inform M2020 Science Team sample caching strategy.
- Define engineering data products required to trace sample history.
- Manage the scientific side of the interfaces between the MSR Science Program and M2020, Sample Curation, and Planetary Protection.
- Provide scientific input into M2020 and MSR Program operational activities.
- Establish formal MSR sample science objectives and MSR Campaign success criteria.
- Develop and maintain, once M2020 samples have been acquired, a Science Traceability Matrix between sample science objectives and specific measurement requirements to meet them.
- Oversee scientific elements and instrumentation for SRF planning.
- Participate as needed in the public outreach process, especially in the U.S. and in Europe.

Over the longer term, responsibilities in addition to those listed above could include the following:

- Provide day-to-day leadership of the Science Program’s technical activities.
- Work with the MSR engineering implementation office.
- Provide progress reports to advisory bodies.
- Ensure that any advance long-lead planning for the receipt of the samples, and their proper analysis, is provided for.
- Engage the broader science community through regular workshops, conferences, and community events.
- Establish a scientific publication plan.
- Facilitate conflict resolution among science team members.

#### *Selection process and composition*

The MCSG would be co-chaired by NASA and ESA MSR lead scientists, with the remainder of members selected as follows:

- **Phase 1 (MCSG-1):** NASA and ESA management would jointly evaluate and select members for the MCSG Phase 1 on the basis of an open competitive AO and may appoint additional *ex officio* members. The group will represent the science community, covering subject matter expertise relevant to sample collection and analysis. Additional expertise of some of the scientists in curation and data management is required. It is expected that the group would be selected to ensure that the major science domains are covered by more than one person.
- **Phase 2 (MCSG-2):** Competed concurrently with the objective-driven investigation AO, NASA and ESA would jointly evaluate and select members for the MCSG-2 on the basis of an open competitive AO, who along with selected PIs would form the core of the MCSG-2. NASA and ESA may appoint additional *ex officio* members.

The selection of MCSG members would take into account Equity, Diversity, and Inclusion (EDI) along with diversity in career stage as considerations.

To avoid real or perceived conflict of interest, sitting MCSG-1 members should not be eligible to be PIs or Co-Is of objective-driven investigations at the time of proposal submission; any MCSG-1 member wishing to propose an investigation would step down at that time. After investigations have been selected, additional members could be added (*e.g.*, science theme group leads).

Appointments for the competitively selected (*i.e.*, *non-ex officio*) members of the MCSG would be made nominally for a duration of 4 years, after which the positions could be open for re-competition to allow for adjustments in expertise to react to new findings.

### *Dependencies*

Formation of the MCSG would represent the *de facto* initiation of the Science Program. In the immediate term, MCSG Part 1 should be populated as soon as is feasible given that MSR Campaign activities have already commenced. Specific scientific inputs on behalf of the Science Program are required already, including interfacing with M2020 operations, technical planning of the SRF, and formalization of MSR science objectives and traceability. In the longer term, MCSG Part 2 would be tied to the AO(s) for objective-driven sample investigations, nominally up to seven years before samples are returned to Earth (see Section 6.1.4).

### *Key outputs*

The MCSG would serve as the integrating body for scientific elements of the MSR Campaign and would provide critical inputs into MSR Campaign-level reviews and overall Science Program management.

Establishing the MSR Campaign's formal science objectives, Level 1 science requirements, and success criteria are of critical importance to maximize the MSR Campaign's scientific return. These products will be developed and maintained by the MCSG along the following schedule:

- **Initial Release:** Mid- to late-2022, identified as one of the earliest and highest-priority tasks after MCSG formation.
- **Revision 1:** Early 2024; reflects updates based on samples stored within the first cache on Mars and lessons learned from the M2020 and ExoMars rover missions

along with definition of a preliminary STM, which would be used as the basis for the objective-driven investigation competition.

- **Final:** Based on final decision of what samples will be retrieved (date may be flexible depending on MSR Program element development).

Beyond the products described above, the MCSG would also generate the following:

- The MSR Data Management Plan.
- Strategic decision guidelines to inform the M2020 Science Team sample caching strategy.
- Definition of engineering data products required to trace sample environmental history.
- Technical reports feeding SRF planning and other elements where scientific input is required.
- Inputs for the objective-driven investigation AO(s).
- Reports for advisory committees, as needed.
- Rules of the Road document governing expected behaviors and interactions of the MSR Sample Science Team (MSST, Section 4.3.6).
- Initial draft and maintenance of the Sample Dossiers produced by M2020 (Section 5.3).

### *Timeline*

Engineering developments for the MSR Program and the MSR Campaign are well underway, and scientific input is required immediately to ensure that the MSR Program technical requirements will meet the needs of the Science Program. As such, the MCSG should be put in place at the earliest possible opportunity. Given its importance in overall Science Program leadership, it should remain in place throughout the MSR Campaign and would be closed upon completion of the objective-driven investigations and the declaration of mission success (nominally two years after return).

### 4.3 *Scientific operations and investigations*

#### 4.3.1 M2020 Science Team

##### *Rationale*

The M2020 mission goal is to develop a scientific understanding of the geology of Jezero Crater, identify ancient habitable environments, locate rocks with a high probability of preserving biosignatures, and use the rover's instruments to look for potential biosignatures within those rocks. M2020 will select and collect the samples intended for Earth return.

##### *Roles and responsibilities*

The M2020 Science Team is responsible for the science operations of the Perseverance rover and is structured and managed outside the scope of the SMP. Roles and responsibilities are described in (RD-02). A group of 15 M2020 Returned Sample Science Participating Scientists (RSS-PS) were competitively selected by ESA and NASA to join the Perseverance science team and provide advice on the selection of samples to be cached.

##### *Selection process and composition*

The M2020 Science Team was selected through a NASA competitive process outside the scope of the SMP. Investigations were bid to a competitive AO and selected on a combination of science merit and technical feasibility. The team was subsequently supplemented through competitive processes for Returned Sample Science Participating Scientists (RSS-PS) in 2018 and general Participating Scientists in 2020.

##### *Dependencies*

The launch of M2020 represents the beginning of the MSR Campaign and (in principle) represents the start of the MSR Science Program activities.

##### *Key outputs*

The M2020 Science Team is responsible for collecting and depositing the sample cache at Mars and will begin development of the Sample Dossiers (Section 5.3) that outline the end-to-end environmental history of each sample.

### *Timeline*

M2020 launched on July 30, 2020, landed safely on Mars on February 18, 2021, and is currently active. Its nominal mission lifetime is one Mars year, with the possibility for extension subject to rover health and sufficient budget.

#### 4.3.2 Caching Strategy Steering Committee (CSSC)

##### *Rationale*

The retrieval of samples cached by M2020 requires transport by one of two pathways: (1) retrieval of the samples by the SFR and delivery to the SRL or (2) delivery of the samples to the SRL by M2020's Perseverance Rover.

Which strategies are actually implemented will depend on the nature and perceived value of each sample, the diversity of the samples at a depot, landing site accessibility for SRL, the capabilities of Perseverance and SFR, lifetime projections for Perseverance and SFR, and the projected risk of rover survivability and navigability of the terrain encountered.

As there are multiple options to the sample caching strategy, expert input was required to inform operational decisions for M2020 and future MSR systems (*e.g.*, SRL, SFR). Note that the CSSC was established on an *ad hoc* basis by NASA and ESA; such a role would be taken over in the future by the MCSG.

##### *Roles and responsibilities*

The CSSC was responsible for the following:

- Reviewing options for decisional guidelines to inform Perseverance's sample caching strategy.
- Planning and implementing a virtual workshop to discuss and provide feedback on the options.
- Providing a final report based on the workshop findings.

Workshop structure and findings are described in Section 4.4.1.



### *Selection process and composition*

Members of the CSSC were appointed by the MSR Partners. Chaired by NASA and ESA MSR science representatives, CSSC membership comprised representation from key MSR Campaign knowledge domains including:

- MSR Partner science leadership
- M2020 science and operations
- MSR Program management and operations
- MSR Campaign science
- the academic science community

Logistics were provided by the MSR Program Office at the Jet Propulsion Laboratory (JPL). The team's primary function was specifically to organize and execute the Sample Caching Strategy Workshop (Section 4.4.1) but may be called upon again for specific needs.

### *Dependencies*

The sample caching workshop was required prior to the Perseverance landing to inform future operational decisions for the M2020 science team.

### *Key outputs*

The CSSC delivered its final report in March 2021 (CSSC, 2021), outlining a variety of strategic intents and decision guidelines.

### *Timeline*

The CSSC was chartered in December 2020 and was disbanded in March 2021 following the acceptance of the final report.

### 4.3.3 Research and Development (R&D) activities

#### *Rationale*

With MSR Campaign activities already underway, there remain a number of open engineering and scientific trades that require dedicated R&D activities to address. As

highlighted throughout the MSPG2 technical reports (MSPG 2021a, b), near-term effort is needed to advance technical requirements and reduce risk for future MSR Campaign element design and operations.

#### *Roles and responsibilities*

The R&D roadmap generated by the MCSG would serve as the guideline defining the critical open trades to which teams from the scientific community would submit proposals. Selected teams would be tasked to conduct the necessary experiments and formulating results so that information can be delivered to the MSR Partners to inform necessary trades.

#### *Selection process and composition*

Wherever possible, existing ESA and NASA competitive processes could be leveraged. In the US, for example, the Mars Data Analysis Program (MDAP) and/or Laboratory Analyses of Returned Samples (LARS) programs could have specific research priorities identified and supported in ongoing calls. In instances where existing programs do not or cannot encapsulate the research priority, a dedicated MSR R&D budget line should be considered, as could *ad hoc* opportunities sponsored by the MSR Partners.

#### *Dependencies*

Many of the open trades can have an impact on the design of the SRF or of the flight elements. As such, early high priority projects should aim to be completed before crucial design trades are closed.

#### *Key outputs*

It is expected that selected research programs would produce a number of peer-reviewed publications for the literature. In cases where specific answers are required to inform engineering trades, short technical reports may also be required as deliverables to the Partners.

#### *Timeline*

Given that SRF and MSR Program element requirements are presently being developed, it is crucial to commence the R&D program as soon as possible. The research

community must be given adequate time to conduct their experiments and provide meaningful results that can be incorporated into the facility or hardware design where possible. The MSR R&D program would be required until the initial sample investigations are completed and selected and the MSST (see Section 4.3.6) is formed.

#### 4.3.4 MSR Program element science teams

##### *Rationale*

Although the SRL, SFR, and ERO are not planned to be equipped with dedicated scientific payloads, they will be functional vehicles operating on or in the vicinity of Mars. As such, they will provide invaluable opportunities for ancillary science by using existing engineering sensors, even if tasked (*e.g.*, primarily or strictly) sample retrieval functions. This is even more relevant after the samples will have been delivered to the MAV, when the SFR would be free to perform scientific, post-delivery activities. Data from engineering sensors and modeling will be required to document the environmental histories of the returned samples.

##### *Roles and responsibilities*

To exploit the scientific, engineering, and public engagement opportunities (*e.g.*, during the MAV launch) of the MSR Program flight elements, a small team or teams of dedicated scientists would be responsible for the following:

- Developing opportunistic scientific objectives that can be met on a no-interference basis with engineering tasks.
- Participating in operations planning of the vehicle(s).
- Collection of relevant data products.
- Planning and acquisition of data and development of models to contribute to sample environmental history knowledge.
- Planning of atmospheric and/or dust sample(s) acquisition (should engineering constraints permit).
- Publishing scientific findings in relevant journals.

- Delivering scientific data products to the appropriate archives.
- Participating in public engagement activities.

#### *Selection process and composition*

Program element (*i.e.*, ERO, SRL, SFR) science teams would be competed internationally. Applicants could be recommended by the MCSG and selected by the Partners, assigned within the following roles:

- **[Program Element] Project Scientist (*e.g.*, SFR Project Scientist):** Responsible for overall team leadership.
- **[Program Element] Co-Investigator:** Responsible for operations planning, data collection, interpretation, archiving, and publication.

#### *Dependencies*

Population of the element science team(s) would be tied to the respective launch dates. Planning of competitive AOs would thus need to be reactive to any change in the high-level MSR Program schedule. If such teams are formulated, individual element SMPs would likely be required, produced by the MCSG, and be daughter documents to the overarching MSR SMP.

#### *Key outputs*

The element Science Team would be responsible for collecting, analyzing, and archiving scientific data using available onboard sensors, and contribute to the Sample Dossiers (Section 5.3) that outline the end-to-end environmental history of each sample.

#### *Timeline*

Because no dedicated scientific instruments are onboard, these teams could be composed relatively late in the development process. Competitions could take place after NASA Key Decision Point D (KDP-D) of the respective element (*e.g.*, SRL, ERO) has been completed, at launch, or perhaps even during cruise. The teams would remain in place until a minimum of six months after its last opportunistic science measurement has been collected and the relevant data delivered to the appropriate archive.

#### 4.3.5 Curation team

##### *Rationale*

Upon return to Earth, the samples will be transported to the SRF for their initial characterization (MSPG 2021a, b). While the curation function will encompass numerous responsibilities, one of the major aims at this preliminary step is to produce a sample catalog, with relevant information on the physical, chemical, and mineralogical characteristics of the samples to enable allocation of the most appropriate materials without degrading the sample characteristics. The initial sample characterization in the SRF needs to be broken into three phases (**Error! Reference source not found.**) (MSPG 2021d), described briefly below. A joint NASA and ESA Curation Team is required to carry out these activities under the guidance and decisional authority of the MCSG.

##### *Roles and responsibilities*

At this stage, the Curation Team will be responsible for all examinations necessary to create a descriptive sample catalog, including (but not limited to):

- Sample tube weighing, imaging, and initial observations.
- Imaging and measurements conducted through sample tubes.
- Headspace gas extraction, seal quality check, and atmospheric composition analysis.
- Sample extraction, secondary imaging.
- Selected targeted analyses.

The Curation Team would also be required to support the science investigations (see Section 4.3.6) with the following:

- Preparation of samples for PI-led, competitively selected research within the SRF, including time-sensitive and sterilization-sensitive measurements.
- Preparation of samples allocated to PIs for competitively selected research outside the SRF.

Each of the above will involve a wide range of scientific and/or technical experts whose priority is to maintain the scientific integrity of the samples and work closely with the selected MSR Sample Science Teams (see Section 4.3.5) to maximize the scientific value and utility of the samples.

#### *Selection process and composition*

The Curation team would be composed of joint ESA and NASA staff members to satisfy two required sets of expertise: (i) intellectual guidance to plan the measurements that will be conducted and (ii) physical manipulation of equipment and samples to collect the measurements. Some positions may be staffed through competitive opportunities.

#### *Dependencies*

Examinations on the samples are tied exclusively to the sample return date. Flexibility in planning for the Curation Team should be made to accommodate the MSR Program flight schedule.

#### *Key outputs*

The principal output of the initial sample characterization process will be the MSR sample catalog (MSPG 2021d). The catalog is expected to be a *living-document* with updates made as new measurements are collected for each sample. In the long-term (and beyond the scope of the SMP) catalog data would also enable future researchers to submit sample access proposals for investigations; design of consortium sample studies; and a sample allocation committee would be established to make informed decisions about the best use of limited, high-value, and irreplaceable sample mass.

#### *Timeline*

To provide sufficient time for preparation and training, the team should be selected four years in advance of the samples returning to Earth. It is recommended that the team stays intact until initial characterization has been performed on all eligible samples and the sample catalog has been delivered (nominally two years after sample receipt).

#### 4.3.6 MSR Sample Science Team (MSST)

##### *Rationale*

Ultimately, MSR is being conducted to answer fundamental research questions about Mars and the solar system through scientific analyses of the samples. An MSR Sample Science Team (MSST) composed of international scientists would be populated to design and conduct the investigations to address the objectives outlined in Section 2.2. It would serve as an equivalent of a NASA or ESA flight mission science team, whereby individual investigations (including personnel and instruments, whether inside or outside the SRF) are competed and then combined to form a broader team. Overall leadership would be provided by the MCSG Phase 2.

Sample allocations for scientific investigations should be managed and decided jointly by NASA and ESA. A dedicated Sample Handling & Management Plan needs to be developed and maintained under the authority of the MCSG.

##### *Roles and responsibilities*

After formation, the MSST would:

- Develop Campaign-level thematic groups to establish integrated scientific investigations addressing high-level MSR science objectives.
- Provide advice and participate in the design, implementation, and/or calibration of scientific instrumentation to be located within the SRF (Carrier *et al.*, 2021).
- Provide scientific input to the exercise prioritizing the order in which the sample tubes will be opened and interrogated.
- Provide scientific input to the exercise for prioritizing the order in which the sample analyses will be conducted.
- Participate in the planning, rehearsal, and execution of scientific operations, including timing, duration, and selection of measurements to be collected.
- Support the Pre-BC, BC, and PE processes (see Tait *et al.*, 2021 for details) in an advisory role or by performing some of the investigations as part of their science plan.

- Perform the scientific investigations on the allocated samples, including elements of the sample safety assessment.
- Interpret data products to make scientific observations and conclusions.
- Publish the results in peer-reviewed journals.
- Deliver scientific data products to the appropriate archives.
- Participate in public engagement activities.

Individual PIs and/or thematic team leads would represent the MSST in the MCSG Phase 2.

#### *Selection process and composition*

Much like MSL or M2020, the MSST would be competitively selected through an open international AO. Proposal teams would self-organize and propose full investigations to address the MSR science objectives, including research questions, team members, and instrumentation. Teams may propose the use of existing instruments, upgrades to existing instruments, new off-the-shelf instruments, or new customized instruments, all of which may be proposed for installation and use inside or outside the SRF. To maximize potential scientific utilization of the samples, bids from consortia would be encouraged.

Proposed investigations should define members in the following roles:

- **Principal Investigator (PI):** The individual responsible for overall team leadership and scientific direction.
- **Deputy PI (D/PI):** The individual identified as the backup for the PI.
- **Co-Investigator (Co-I):** Active participant in all elements of the investigation, including measurement planning, execution, data processing and interpretation, and scientific publication.
- **Collaborator:** Team member who works in support of team activities, typically associated with an individual Co-I, brought onto the team for a specific timeline and set of tasks.



Collectively, selected teams will comprise the MSST. Subsequently, the MSST could be complemented through a separate AO for:

- **Participating Scientists (PS):** Individuals proposing novel research investigations unique from those being performed by PI-led teams, but that will contribute to overall MSR science objectives.

PSs would be granted full MSST status for the duration of their activities, including all publications and delivery of any required data products.

Following guidelines from ANGSA (RD-06), members of the Curation Team would be granted MSST membership and would be subject to its guidelines but would not be eligible to be PIs or Co-Is on the objective-driven investigations.

#### *Dependencies*

Understandably, formation of the MSST is tied strictly to the return date of the samples. Building on lessons learned from previous sample return missions, it is recommended to hold the AO up to seven years in advance of sample receipt to allow for instrument development, preparatory research activities, sample measurements protocol development, Biosafety level 4 (BSL-4) training (where appropriate), and operational rehearsals prior to conducting investigations on the Mars samples.

#### *Key outputs*

The MSST would be the primary source of science dissemination for the Campaign. The team would produce peer-reviewed publications and conference presentations to add to the literature. Moreover, they would also be required to participate in a variety of public engagement activities, as results stemming from sample science will undoubtedly generate immense public interest.

#### *Timeline*

Assuming a competitive AO up to seven years in advance of sample receipt, the team would need to be in place until completion of the objective-driven investigations (nominally two years after receipt). Team extensions could be considered at that time for ongoing investigations. Following from previous mission experience, we recommend

holding the PS AO up to two years in advance of sample receipt to allow for proper integration into the broader team and to increase readiness to conduct their proposed investigations.

#### 4.4 *Participation open to the entire science community*

##### 4.4.1 Sample Caching Strategy Workshop

###### *Rationale*

As outlined in Section 4.3.2, the CSSC was tasked with organizing and executing the MSR Sample Caching Strategy Workshop to consider the strategy for caching samples on Mars as a key element in planning their return to Earth. It provided a forum for mission planners and the broader science public to help define Scientifically Return Worthy (SRW) caches and determine an optimal caching strategy. An SRW cache is currently defined as (i) distinct sample suites or individual samples selected to represent the diversity of the exploration area and address the MSR Campaign science objectives (Section 2.2), including the history and evolution of Jezero Crater; (ii) available *in situ* data and other information to understand the geological history of the samples; and (iii) inclusion of one or more witness blanks (CSSC, 2021).

###### *Roles and responsibilities*

Workshop participants were encouraged to provide feedback to the CSSC on the various sample caching options available to the M2020 team through real-time comments and email communication.

###### *Selection process and composition*

Workshop participation was completely open to the public and was advertised through a variety of channels to maximize participation.

###### *Dependencies*

Scheduling of the workshop was required prior to M2020 landing to provide sufficient time to provide input to Perseverance operational planning.

### *Key outputs*

Workshop findings were provided to the CSSC and ultimately delivered to the Partners in the form of a Workshop Report (CSSC, 2021). Key recommendations included (i) creation of an initial depot within Jezero Crater; (ii) collection of a second sample set if Perseverance health permits; and (iii) maintenance of multiple sample delivery pathways to the SRL. These findings are being incorporated into M2020 operations.

### *Timeline*

The workshop was organized in late 2020 and held on January 21, 2021.

#### 4.4.2 Sample Depot Workshop

### *Rationale*

A future Sample Depot Workshop or Workshops would be another forum for community discussions, providing input to depot location(s) and strategy after Perseverance has collected a suite of samples. Members of the science community would be given the opportunity to present rationale for determining whether the sample caches remain onboard Perseverance or are deposited on the ground. If the latter, input would also be sought to select a specific location for the cache.

### *Roles and responsibilities*

Workshop participants would be encouraged to provide feedback to the MCSG on the preferred strategies based upon operational knowledge gathered by the M2020 Science Team over its prime mission and any orbital data collected between now and then.

### *Selection process and composition*

Workshop participation would be completely open to the entire worldwide science community.

### *Dependencies*

Workshop recommendations would be required prior to M2020 reaching its baseline mission timeline of one Mars year.

### *Key outputs*

The primary output of the Sample Depot Workshop would be a recommendation to the MCSG for final consideration, with ultimate decision-making power resting with the MSR Partners.

### *Timeline*

Assuming continuing health of Perseverance, the initial workshop would need to take place in late 2022 or early 2023. A second workshop could be envisaged if a second SRW cache is collected by M2020.

#### 4.4.3 Sample Prioritization Workshop(s)

### *Rationale*

One or several Sample Prioritization Workshops could be held if more samples are collected by Perseverance than can be returned by the MSR Program. This (these) workshop(s) would aim to provide recommendations on which samples should be prioritized by the SFR.

### *Roles and responsibilities*

Community groups would be invited to develop information packages to present at the workshop(s), which would provide recommendations on which samples should be prioritized by the SFR based on engineering constraints and science maximization (*i.e.*, which samples would best meet the objectives).

### *Selection process and composition*

Workshop participation would be completely open to the entire worldwide science community.

### *Dependencies*

Workshop recommendations will influence the SFR landing site, and thus the workshop(s) must take place after the launch of the SFR but must finalize landing site recommendations no less than 9 months prior to SFR arrival.

*Key outputs*

Discussions during the workshop would be collated and deliberated upon by the MCSG, ultimately submitted for final decision by the Partners.

*Timeline*

Specific scheduling of the workshop would be relative to the MSR Program schedule.

## 5 MSR Campaign Science Data

### 5.1 Overview

In providing accurate, timely, and public access to the MSR Science Program data, the MSR Campaign would (i) improve the quality and quantity of the scientific return of the sample collection; (ii) generate a long-term, documented archive for future analyses of the samples and reinterpretations and comparisons with new observations; and (iii) demonstrate the transparency of the full program.

Such an open policy may also offer an unprecedented opportunity for education and public engagement. Following the example of previous successful missions to Mars, data should be released in user friendly, web-based tools, ideally together with a consistent outreach program that can be used to engage the public's interest in this unique initiative.

Online access to MSR science data should be the primary method for data distribution, using existing archives such as the NASA Planetary Data System (PDS) and the ESA Planetary Science Archive (PSA), ideally with the latest data archive standard PDS-4 or any other dedicated, online archive.

Broadly, MSR science data deliverables can be divided into two elements (Figure 6):

- **Engineering data products:** produced from the various flight project elements (M2020, ERO, SRL, SFR) and ground elements (EEV recovery and transport) to cover the environmental history of the sample tubes from hardware integration through sample acquisition on Mars until sample handling on Earth.
- **Science data products:** data from the M2020 science instruments and form the objective-driven science investigations.

While specifics of the overall data management approach will be described in the Data Management Plan, high level considerations may include:

- All scientific datasets of the selected objective-driven science investigations are shared with the entire MSST.
- Each scientific dataset has a well-defined owner (*i.e.*, a PI).
- Within the proprietary period, scientific datasets can only be used by members of the MSST for publication after agreement provided by the owner of the scientific dataset.
- After a proprietary period of X years (TBD), all standard scientific datasets become publicly available at the NASA PDS and ESA PSA archives.
- Defined engineering datasets of the MSR program flight elements to support the scientific analyses and interpretation of the scientific datasets will be available to the MSR CSG.
- All defined engineering datasets of the MSR flight elements will become publicly available within six months of acquisition through the NASA PDS and ESA PSA archives.

The aim should be to coordinate global scientific publications and conference abstracts to (i) help focus effort and attention in key areas and ensure that the entire scientific community has an opportunity to contribute; (ii) minimize duplication of effort or misuse of samples; (iii) ensure that appropriate credit is properly attributed; and (iv) make a long-term plan for the sample release that allows for new techniques to be developed and new resolutions/accuracies of the instrumentation in the future.

This coordination will require specific procedures for the MSST to follow as they develop abstracts and manuscripts that describe scientific data. Instructions for seeking MCSG approval, procedures for communicating with the MSST about the dissemination of science results, and authorship guidelines should be described in the MSST Rules of The Road when it becomes available. In parallel, the appropriate data (as will be described in

the Data Management Plan) should be released and archived at the PDS/PSA or equivalent online archive in a timely manner.

### 5.2 *M2020 science data*

Scientific data produced by the M2020 mission are managed outside the scope of the MSR SMP. Details for its handling and dissemination can be found in the M2020 Science Team Guidelines (RD-02).

### 5.3 *M2020 Sample Dossiers*

The overarching goal for M2020 is to document as much auxiliary information (metadata) as possible about each sample in a readable manner, beginning from well before the sample is collected until the sample is placed in a depot or transferred to the SRL.

For each sample, an initial dossier (or field notebook) will be prepared. As the information contained within will be of interest to the public and will influence future proposals for sample investigations, we recommend that the dossiers are released as soon as possible after sample collection. This initial dossier would be a public release by M2020 project science and could include the science rationale for collecting the sample(s) as follows: limited, though important, engineering data; volume assessment; and initial evaluation of the *in situ* science that led to sampling.

Subsequently, a full “Pathway to Sampling Package” (PSP) document should be produced, led by one of the M2020 RSS-PS for each sample. This document is designed to start from the notional proposal for collecting a sample long before collection, including rationale for targeting that type of sample, and would trace the entire target selection process from outcrop to selection of the abrasion target to selection of the actual cored sample. This package would also need to include the PDS reference of all the raw data of each instrument used to characterize the setting. The PSP may be updated with later additions, such as orbital observations, or observations from the fetch rover.

Data to be collected include the following:

- **Engineering data:** Sample acquisition and rover data including rover position, day and time of day, number of coring bit used for the sampling, coring bit orientation,

angle of drill bit relative to vector gravity and azimuth with respect to North, total time from first contact of the drill with the surface to sample tube sealing in M2020's Adaptive Caching Assembly (ACA), drill resistance, estimate of maximum sample temperature, images of the atmospheric opacities, images of the coring and tube caching process and other relevant documentation of any anomalies during the coring and caching process.

- **Environmental data:** Surface and air temperature, pressure, air humidity (and derived surface humidity), atmospheric opacity, UV incident irradiance, and wind speed (especially relevant to interpret dust) determined by using Mars Environmental Dynamics Analyzer (MEDA) instrument (Rodriguez-Manfredi *et al.*, 2021) to be recorded.
- **Sample tube sealing engineering data:** Temperature of the sample tube sealing environment (closest temperature sensor), tube sealing force estimate (*e.g.*, by motor currents) when the samples are encapsulated, and any other available relevant engineering/health-check data of the “sealing” process (to establish whether any volatile contaminant could have been released within the rover at the time of sealing), ACA filling station data, ACA vision station data, and pictures pre- and post-seal application.
- **Science data:** Site context and documentation from an orbital scale to ground imaging and remote science of the area, to workspace outcrop documentation imaging, spectroscopy, and proximity science data for the outcrop, and all the same data for the nearby surrogate target(s) (see below).
- **Surrogate targets and coring target(s):** The notional plan for M2020 prime mission is to have at least three targets on a unit that may be sampled. Detailed rock evaluation would be done on a “surrogate” target(s) that would include imaging, remote and proximity science on an abraded surface to ensure a high-quality chemical and mineralogical characterization. If these data lead to the decision to sample the outcrop, another nearby spot would be selected for sampling, due to the desire to collect a sample that is as pristine as possible and has not been subject to abrasion and laser pitting. Following collection, proximity science and



images would be taken of the drill hole and tailings as another proxy for the sample itself.

The field notebook should adhere as much as possible to the standard format recommended for data submissions to the PDS and PSA (NASA 2020).

#### 5.4 *Sample environmental history*

The MSR Campaign will be capable of delivering the samples to Earth, avoiding environmental extremes that would compromise the scientific integrity of the samples and providing knowledge of the environmental conditions that the samples experienced until recovery. It is of great scientific importance to document the environmental histories of the returned samples from collection through storage within the SRF to aid in interpretation of scientific results and provide recommendations for the engineering data and models that should be made available to the MSST prior to scientific investigations of the samples.

It is extremely important to maintain the scientific integrity of the samples to the highest degree. When possible, all sample environmental history data and associated models and relevant results from ground testing of flight elements should be published in the PDA/PSA or in peer-reviewed scientific journals as appropriate.

The data products most critical for interpreting data collected from the returned samples include the following:

- **Temperature history:** Both the peak temperature and the average temperature can affect the preservation of the chemical, mineralogical, isotopic, and other attributes of the samples.
- **Exposure to magnetic fields:** Exposure to magnetic fields and increased pressure can affect interpretation of the intensity and direction of Mars's ancient magnetic field.
- **Contamination knowledge:** Characterization of all sources of potential contamination of flight hardware will be important for interpreting the origin of any complex organic molecules detected within the samples.

These data products will be produced *via* combination of direct measurement by M2020 science instruments, Program element engineering sensors, data from orbiters, and numerical modeling efforts. The data should be added to the M2020 Sample Dossiers that will consist of all rover engineering data related to sample acquisition and caching, all relevant science data for documentation of the geological context of the sampling sites and collected samples, and all relevant environmental data at the time of sampling including outside temperature, pressure, humidity, and atmospheric opacity.

### 5.5 *Sample initial characterization data*

The primary output of the initial characterization process is a detailed sample catalog that documents the results of the measurements collected during Pre-BC, BC, and PE (MSPG 2021d). The goal of the catalog will be to provide sufficient information such that researchers can have a detailed enough understanding of material within the collection to base future allocation requests for investigation.

Any given measurement during this process may be needed for several purposes as follows: (i) to contribute to sample catalog production; (ii) to satisfy the SSAP; and/or (iii) be included in a scientific investigation. To ensure proper scientific usage, all PE data products should first be reviewed by the MCSG and MSST to evaluate whether they are considered sensitive to a given investigation. If so, the data would be treated under the proprietary period described in Section 5.7 and utilized for the target publication. If not, data can immediately be placed into the catalog (Figure 7).

As a living document, the catalog would be maintained as new information becomes available about a given sample. For example, higher order data products (*e.g.*, CT scans that users can manipulate) may be added to the catalog after initial characterization is complete.

### 5.6 *Science data from program elements and objective-driven investigations*

Treatment of any scientific data collected by MSR Program elements or *via* objective-driven investigations should be described clearly in their respective Rules of the Road document(s) (Section 4.2.1). The following data management considerations could be included by using the M2020 Science Team Guidelines as a model:

- **Science Dissemination:** The primary responsibility is to convert measurements, observations, discoveries, and conclusions into scientific products and publications.
- **Collaboration:** All data are immediately available to the entire MSST.
- **Permissions:** Team members who wish to use unreleased data would consult with the respective investigation lead or their delegate.
- **Coordination:** The publication plan is managed by the MCSG.
- **Public access:** Data are to be delivered to the PDS and the PSA no later than six months after collection.
- **Embargo:** Under mutual concurrence by the Partners, certain data products may be subject to short-term embargoes, though such instances are expected to be exceptional.

### 5.7 *Publication rights*

The approach to publication of scientific data from Program element efforts or from ground-based sample investigations will also be crucial to define clearly. As with science data considerations, policies and procedures should be defined explicitly with the respective Rules of the Road documents.

While the full details will be developed later, significant guidance can again be sought from the M2020 Science Team Guidelines, which state that publications may include conference abstracts, presentations, and peer-reviewed articles in scientific journals. Specific processes and procedures could include the following considerations:

- **Publication Plan:** A draft publication plan including lead authors, co-authors, proposed manuscript titles and target journals, and links to scientific hypotheses outlined in the STM, should be developed after selection of the MSST and prior to sample analysis.
- **Notification and approval:** Any MSST team member wishing to create a publication would notify the MCSG.

- **Lead Authorship:** A lead author would be proposed as part of the publication plan and approved by the MCSG; members of the Curation Team are excluded from lead authorship.
- **Co-Authorship:** A co-author would be offered to any MSST member who asks to be a co-author and can demonstrate a substantive contribution, including data collection, processing, or interpretation; co-authorship can also be considered for non-MSST members who have made substantive technical or engineering contributions and for Curation Team members.
- **Dispute Resolution:** Disputes about authorship shall be decided upon by the MCSG.
- **Data Delivery:** Raw data and interpreted data would be delivered as an appendix or supplemental file for any peer-reviewed publication.

Building from the Apollo model, initial publications from the objective-driven investigations could be held under embargo for a TBD period of time, nominally one year. At that stage, articles would be released simultaneously and considered contemporaneous, which would prevent inter- or intra-team competitiveness or “scoops” in racing to be the first results published.

## 6 MSR Science Program Schedule

### 6.1 *Timing of opportunities relative to key decision points and milestones*

Many elements of the proposed MSR Science Program are interdependent, as the decision to trigger certain bodies or activities depends on reaching key milestones throughout the MSR Campaign. Broadly, there are four categories of schedule dependencies, in that the timing of events is measured relative to the following:

- **MSR Campaign commencement:** Activities that are linked to early Science Program management or to M2020 operations. These cannot be delayed in the event of a schedule slip in the Program.
- **M2020 operations milestones:** Activities linked to key achievements of the M2020 mission and thus are independent of MSR Program schedule modifications.

- **MSR Program milestones:** Activities that are linked to specific events or achievements of the MSR Campaign's flight missions. Specific timing of these events is dependent on the Program schedule.
- **Samples' arrival at Earth:** Activities that are relatively insensitive to specific timing of Program flight elements, but rather are tied specifically to the expected return date of the samples. These events are thus dependent on the overall MSR Program timeline.

A brief description of each is provided immediately below, with notional dates indicated in parentheses.

**FINDING SMP-8:** Some elements of the MSR Science Program cannot be delayed in the event of an MSR Program schedule delay, as they are linked to key decisions or operations of the Mars 2020 mission.

#### 6.1.1 Activities relative to MSR Campaign commencement

- **Science MOU finalization (late 2021):** Signifies the formal commencement of the MSR Science Program, required to initiate the MSR science management timeline.
- **MCSG formation (late 2021):** Allows for high-level Science Program coordination and is required for day-to-day management of the MSR Science Program.

#### 6.1.2 Activities relative to M2020 operations milestones

- **Initial cache in place (late 2023):** Necessitates a draft of the STM, as this will be the first opportunity to map science objectives and measurements against a known sample suite.
- **Second cache successfully collected (mid 2025):** Creates need for formal decision process of which samples should be retrieved and delivered to the SRL.

### 6.1.3 Activities relative to MSR Program milestones

- **Finalize Sample Integrity/Quality Science Requirements (System Requirements Review, likely 2022):** Ensures that requirement implementation can be appropriately monitored during project development.
- **Program Flight Elements Launch (2026 or 2028):** Triggers AO for formation of Element Science Team(s).
- **Sample retrieval strategy finalized (no later than nine months prior to SRL arrival):** Allows the MCSG to finalize STM, objectives, and success criteria.
- **Samples captured by ERO (three years post ERO launch):** Confirms that samples will be returned to Earth, triggering the Participating Scientist AO.

### 6.1.4 Activities relative to sample arrival at Earth

- **Curation Team appointments (four years before return):** The Curation Team must be given sufficient time to be trained on procedures and measurements conducted within the SRF.
- **Objective-driven investigation AO (up to seven years before return):** A competitive AO must occur early enough to allow for instrument development and ensure the team's scientific and technical readiness to conduct their analyses on the martian samples. The objective-driven investigation AO also coincides with the formation of the MCSG-2.

## 6.2 Integrated timeline

A graphical representation of the overall Science Program Timeline is presented in Figure 8, providing key information for:

- **MSR Partner management:** To plan adequately for funding, schedule, and resources required to execute the Science Program.
- **Science community:** Allowing international scientists to identify timing of opportunities to participate in the Science Program.

The schedule is derived from the two master timelines from the work of Meyer *et al.* (2021). In both of those versions, most sample collection at Mars is presumed to take place in the period 2021 to ~2026, but they differ in that samples arrive at Earth in 2031 and 2033, respectively. The analysis in the present report concludes that because some of the early MSR science planning constraints are driven by sampling activity and later activity by receiving-related activity, the timeline has an “accordion-like” aspect to it (see saw tooth line) that is driven by what is happening around it. As such, later years in the timeline are measured relative to the year of the sample receipt at Earth (R-0).

## 7 Summary and Conclusions

### 7.1 Summary of Findings

The key report findings are summarized below for the convenience of the reader.

**FINDING SMP-1:** A joint science management structure and documented agreements among the MSR Partners are required to coordinate the MSR Science Program elements that are not currently defined in existing structures or documents.

**FINDING SMP-2:** A long-term ESA/NASA MSR Science Program, along with the necessary funding and human resources, will be required to accomplish the end-to-end scientific objectives of MSR.

**FINDING SMP-3:** The MSR Science Management Plan should be linked to, but not encompass, other required functionalities within the MSR Campaign. Input will be needed to produce formal plans for (at a minimum) curation, planetary protection, data management, and public engagement.

**FINDING SMP-4:** The guiding principles proposed in the MSR Science Planning Group (MSPG) Framework document (2019) remain appropriate and relevant and should be utilized in drafting the MSR Science Memorandum of Understanding (MOU) and Science Management Plan.

**FINDING SMP-5 (a):** MSR scientific return would be maximized if participation in the MSR Science Program is not limited to scientists sponsored by existing MSR Partners; rather, opportunities should be provided to scientists from around the world. **(b)** All programmatic decision-making power (*e.g.*, selection of competitive proposals) would still

rest with the Partners.

**FINDING SMP-6:** At the implementation level, the MSR Science Program should, wherever possible, leverage structures, programs, and lessons-learned from previous mission organization to benefit from their experiences to engender familiarity among both decision-makers and the science community.

**FINDING SMP-7:** The MSR Science Program requires the establishment of scientific bodies to meet management, science operations, and public participation needs. These bodies require dedicated funding, addressing scientific functionalities that span the entirety of the MSR Campaign.

**FINDING SMP-8:** Some elements of the MSR Science Program cannot be delayed in the event of an MSR Program schedule delay, as they are linked to key decisions or operations of the Mars 2020 mission.

## 7.2 *Response to Statement of Task*

In providing inputs to an eventual MSR Science Management Plan, we were requested to either adopt or propose suitable alternatives to elements originally proposed in the MSPG Framework document (MSPG 2019c). We have tabled specific findings and proposals for the MSR Partners to now develop an integrated MSR Science Program, responding to our tasks as follows:

- **Amplify the bodies and processes described in the Framework:** In all cases, we have maintained fidelity to the original rationale for each of the bodies and activities proposed in the Framework. However, we have provided updates to many of the original proposals based on overall technical and programmatic changes that have occurred since Framework's release, as well as reconsideration of various timeline dependencies (Table 3A).
- **Define key interfaces and communication pathways:** As has been noted for years, there is considerable overlap between MSR scientific activities and those envisaged for M2020 in particular with regard to facility planning, curation, and planetary protection. Our work has identified a number of areas where coordination will be critical (Table 3B).



### 7.3 *Response to MSR Independent Review Board recommendations*

Noted in Section 3.2, three MSR IRB recommendations had direct bearing on our work. Where applicable, we have provided options for NASA and ESA management to provide responses to the recommendations through the following actions:

- **B-1 (Formation of a Scientific Advisory Team):** We have proposed the immediate formation of an MSR Campaign Science Group (MCSG) to facilitate science planning with M2020, the MSR Program, and MRSH.
- **B-2 (Prioritizing Sample Acquisition for M2020):** The proposed MCSG would serve as an important interface between M2020 and the Science Program, providing support to M2020 where appropriate to ensure that the sample science objectives targeted samples could be met with the available samples that are returned.
- **B-4 (Definition of Success Criteria):** Defining baseline and threshold success criteria would allow for the formalization of returned sample science objectives. Clear objectives are required, as the derived science traceability matrix will influence measurement requirements on the MRSH analytical instruments and will set overall goals for the MSR Science Program.

### 7.4 *Adherence to guiding principles*

The SMP-FG worked extremely hard to ensure that the proposed MSR Science Program is consistent with the guiding principles first outlined in the Framework:

- **Accessibility:** We have defined a number of opportunities throughout the MSR Campaign whereby international scientists can participate through competed opportunities (*e.g.*, MCSG, MSST, Participating Scientists) or through publicly accessible activities (community workshops).
- **Transparency:** In nearly all cases, access to MSR Campaign scientific activities and the processes would be done through openly competed AOs, with the number of directly appointed positions being kept to a minimum.

- **Science maximization:** By opening the MSST competition worldwide and not restricting to only Partner countries, the Science Program has been designed to optimize the scientific productivity of the samples.
- **Return on investment:** The MSR Partners retain full decision-making power throughout the MSR Campaign for all competitive selections and a number of operational decisions.
- **One return canister / One collection:** By not pro-rating sample ownership, it is ensured that the Science Program can be executed, and decisions can be made around a single collection.

Moving ahead, these principles lend themselves well to the development of both the Science MOU and the eventual SMP document itself. We offer them to ESA and NASA management for consideration and hope they can be used in the development and any subsequent modification of the Science Program documentation.

### 7.5 *Scientific risk mitigation*

The proposed Science Program outlined in this document represents a flexible structure that focuses on the samples themselves and on preserving the integrity and quality of work done on and with them. We have designed the plan to minimize the impact of certain risks as follows:

- **Schedule:** The plan is reactive to potential changes to the MSR Program timeline, aiming to minimize running costs for science bodies and activities where possible.
- **Environmental history:** Monitoring the sample environmental history aims to provide sufficient context for scientists to interpret any compositional changes to the samples after collection.
- **Preparedness:** Early formation of the MSST ensures that the team would be fully prepared to perform exceptional science on the samples immediately upon their return to Earth.
- **Sample utilization:** Promotion of consortia investigations was implemented to minimize consumption of the precious sample material.

- **Coordination with other MSR Functionalities:** Key interfaces between the Science Program, curation, and planetary protection elements were defined early on to allow for greater coordination of overall MSR Campaign activities.
- **Public Engagement:** Rapid data release and information sharing by well-prepared scientific spokespeople would increase public interest and understanding about the purpose and meaning of MSR results, and likely reduce the potential for negative outcomes due to misinformation or speculation.

Moving forward, it will be crucial that NASA and ESA management develop a formal risk matrix for scientific elements of the Program that are tracked closely and mitigated.

### 7.6 *The need for an integrated MSR Science Program*

MSR is one of the most complex endeavors ever attempted by the international planetary exploration community. While this is certainly true from the scientific and technical standpoints, it is no less complex from a management perspective. Ensuring that all required scientific activities are properly designed, managed, and executed will require significant planning and coordination.

This report has listed a range of science functionalities required to satisfy the goals of MSR and has proposed bodies and activities that could be organized to do so. While we acknowledge that other end-to-end solutions may exist, it is evident that:

***A joint ESA/NASA MSR Science Program, along with the necessary funding and resources, will be required to accomplish the end-to-end scientific objectives of MSR.***

As a first step, formalizing the Science Program's management structure (*via* the MCSG) within the next year would ensure that shortly upcoming time-sensitive trades are conducted, and the resulting decisions are made with adequate scientific input. The MSR Campaign's engineering elements have already been sufficiently developed and funded; it is imperative that the same be achieved for science.

## Appendix A: Unpublished Reference Documents

**RD-01:** Memorandum of Understanding between the National Aeronautics and Space Administration and the European Space Agency Concerning the Flight Elements of the Mars Sample Return Campaign (2020).

**RD-02:** M2020 Science Team Guidelines. Internal document to M2020 mission.

**RD-03:** M2020 Curation Plan. Internal document to M2020 mission.

**RD-04:** Memorandum of Agreement: Mars Exploration Program & Mars Sample Return Program (2021).

**RD-05:** MSR Program (2020) NASA and ESA Mars Sample Return Joint Management Implementation Plan (JMIP) JPL D-101373.

**RD-06:** Apollo Next Generation Sample Analysis Science Team Rules of the Road. (2020) NASA Internal Document. Unpublished.

## Acknowledgments

The decision to implement Mars Sample Return will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is being made available for planning and information purposes only.

## Disclosure Statement

No competing interests.

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**Acronyms Used**

AA	Associate Administrator
ACA	Adaptive Caching Assembly
AO	Announcement of Opportunity
BC	Basic Characterization
BSL	Biosafety Level
CCM	Capture and Containment Module
CCRS	Capture, Containment, and Return System
Co-I	Co-Investigator
CSSC	Caching Strategy Steering Committee
D/HRE	Director of Human and Robotic Exploration (ESA)
D/PI	Deputy Principal Investigator
EDL	Entry, Descent, and Landing
EEV	Earth Entry Vehicle
ERO	Earth Return Orbiter
ERV	Earth Return Vehicle
ESA	European Space Agency
FG	Focus Group
iMOST	International MSR Objectives and Samples Team
IRB	Independent Review Board
JMIP	Joint Management Implementation Plan
JPL	Jet Propulsion Laboratory
JSB	Joint Steering Board

KDP	Key Decision Point
LARS	Laboratory Analyses of Returned Samples
M2020	Mars 2020
MAV	Mars Ascent Vehicle
MCSG	Mars Sample Return Campaign Science Group
MDAP	Mars Data Analysis Program
MEDA	Mars Environmental Dynamics Analyzer
MEP	Mars Exploration Program
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MRSR	Mars Returned Sample Handling
MSR	Mars Sample Return
MSST	MSR Sample Science Team
NASA	National Aeronautics and Space Administration
OS	Orbiting Sample Container
PCV	Primary Containment Vessel
PDS	Planetary Data System
PE	Preliminary Examination
PI	Principal Investigator
PLT	Project Leadership Team
PS	Participating Scientist
PSA	Planetary Science Archive
PSG	Project Science Group

PSP	Pathway to Sampling Package
PSS	Participating Sample Scientist
RSS	Returned Sample Science
SCV	Secondary Containment Vessel
SFR	Sample Fetch Rover
SMD	Science Mission Directorate (NASA)
SMP	Science Management Plan
SRF	Sample Receiving Facility
SRL	Sample Retrieval Lander
SRW	Scientifically Return Worthy
SSAP	Sample Safety Assessment Protocol
STM	Science Traceability Matrix
SWT	Science Working Team
TBC	To Be Confirmed
TBD	To Be Determined



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**Table 1.** Preliminary list of science functionalities to be addressed during the MSR Campaign. Column 1 provides a brief description of the task. Note that the respective ESA decisional authorities are not indicated as they have yet to be formalized. The reader can consider that items indicated at the NASA SMD AA level would go to the ESA Director of Human and Robotic Exploration. Column 2 indicates whether that task has been included in the NASA MEP/MSR MOA document. Column 3 indicates the decisional authority within NASA for the given tasks identified in the MOA. [MEP: Mars Exploration Program; SMD AA: Science Mission Directorate Associate Administrator; MSR: Mars Sample Return Program; PSD: Planetary Science Division]. Black shaded cells represent tasks that are the sole responsibility of the M2020 Science Team.

Functionality/Task	In MOA?	NASA Decisional Authority
<b>Science Program Management</b>		
Science Program oversight	N	
Day-to-day management and implementation of the Science Program	N	
Recommendations to the SMD AA for any Level 1 science requirements on MSR	Y	MEP
Definition of formal scientific objectives for MSR investigations	N	
Assessment of science traceability between objectives and required measurements	N	
Establishment of an MSR publication plan	N	
Coordination of MSR public engagement activities	N	
<b>Science Operations and Investigations</b>		
<b>M2020 Surface Operations</b>		
	Y	MEP
Development of sample caching strategy	Y	MEP

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 This paper has been peer-reviewed and accepted for publication, but has yet to undergo copyediting and proof correction. The final published version may differ from this proof.

Determination of samples to be collected	Y	MEP ( <i>via</i> Mars 2020 Science Team)
Determination of which samples are to be retained on Mars 2020 and how long to wait prior to establishing a depot for risk mitigation	Y	MEP ( <i>via</i> Mars 2020 Science Team)
Determination of location(s) for samples to be cached and placed in a depot (candidate landing sites)	Y	SMD AA, based on inputs from MEP and MSR
Determination of MSR landing site	Y	SMD AA, based on inputs from MEP and MSR
Determination of future Mars 2020 excursions (after each of the depots of samples has been established)	Y	MEP, in coordination with MSR
Establishment of Mars 2020 plan and timeline to move to MSR landing site	Y	MEP, in coordination with MSR
Direction to begin the traverse of Perseverance to the planned MSR landing site	Y	SMD
Determination of which samples from the collection are loaded into the OS for return	Y	MEP
MSR Surface Operations	Y	MSR
Conducting opportunistic science investigations with Program vehicles	N	
Establishment of timing for collection of atmospheric and/or dedicated dust sample(s) (TBC?)	N	
Directing the SRF science activities	Y	MEP (likely <i>via</i> the PSD Astromaterials Curation program)

Coordinating science activities with curation activities within SRF	N	
Determination of order of sample tube opening and analyses	N	
Determination of order of sample analyses	N	
Execution of sample investigations	N	
<b>Public Participation</b>		
Input to sample caching strategy	N	
Input to sample depot strategy	N	
Input to determining which samples are loaded for return	N	

**Table 2.** Scientific functionalities required throughout the MSR Campaign and proposed decisional authorities for each. Descriptions of each authoritative body are described in Sections 4.2-4.4. As with Table 1, note that the respective ESA decisional authorities are not indicated as they have yet to be formalized. The reader can consider that items indicated at the NASA SMD AA level would go to the ESA Director of Human and Robotic Exploration. Black shaded cells represent tasks that are the sole responsibility of the M2020 Science Team.

Functionality	Proposed Authority
<b>Science Program Management</b>	
Science Program oversight	MCSG
Day-to-day management and implementation of the Science Program	MCSG
Recommendations to the SMD AA for any Level 1 science requirements on MSR	MCSG
Definition of formal scientific objectives for MSR investigations	MCSG
Assessment of science traceability between objectives and required measurements	MCSG
Establishment of an MSR publication plan	MCSG
Coordination of MSR public engagement activities	MCSG
<b>Science Operations and Investigations</b>	
<b>M2020 Surface Operations</b>	<b>M2020 Science Team</b>
Development of sample caching strategy	CSSC
Determination of samples to be collected	M2020 Science Team
Determination of which samples are to be retained on Mars 2020 and how long to wait prior to establishing a depot for risk mitigation	M2020 Science Team
Determination of location(s) for samples to be cached and placed in a depot (candidate landing sites)	SMD AA, with inputs from MCSG and M2020
Determination of MSR landing site	SMD AA, with inputs from

	MSR, MCSG, and Sample Prioritization Workshop
Determination of future Mars 2020 excursions (after each of the depots of samples has been established)	M2020 Science Team, with input from MSR and MCSG
Establishment of Mars 2020 plan and timeline to move to MSR landing site	M2020 Science Team, with input from MSR and MCSG
Direction to begin the traverse of Perseverance to the planned MSR landing site	M2020 Science Team, with input from MCSG
Determination of which samples from the collection are loaded into the Orbiting Sample for return	MCSG, with input from Sample Prioritization Workshop
MSR Surface Operations	MSR, with input from MSR Program Element Science Team(s)
Conducting opportunistic science investigations with Program vehicles	MSR Program Element Science Team(s), with input from MSR
Establishment of timing for collection of atmospheric and/or dedicated dust sample(s) (TBC)	MSR Program Element Science Team(s), with input from MSR
Directing the SRF science activities	MCSG, with input from MSST
Coordinating science activities with curation activities within SRF	MCSG, with input from MSST and Curation Team
Determination of order of sample tube opening and analyses	MCSG, with input from MSST and Curation Team



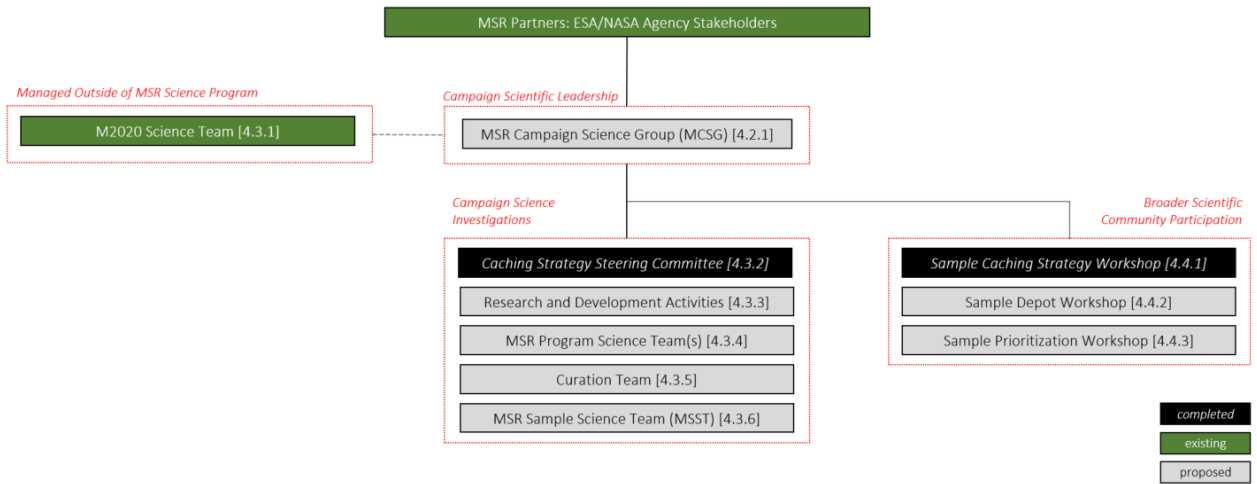
Determination of order of sample analyses	MCSG, with input from MSST and Curation Team
Execution of sample investigations	MSST
<b>Public Participation</b>	
Input to sample caching strategy	MCSG <i>via</i> Sample Caching Workshop
Input to sample depot strategy	MCSG <i>via</i> Sample Depot Workshop
Input to determining which samples are loaded for return	MCSG <i>via</i> Sample Prioritization Workshop(s)

**Table 3.** Response of MSPG-2 SMP-FG work to its statement of task described in Section 1.1: (A) Comparison of proposed science bodies and activities to those proposed in the MSPG Framework document (MSPG, 2019c). The “Section” column refers to the section of this report where the science body or activity is described; (B) Identification of potential areas of overlap between the MSR Science Program bodies and other key MSR functionalities managed outside the scope of an SMP.

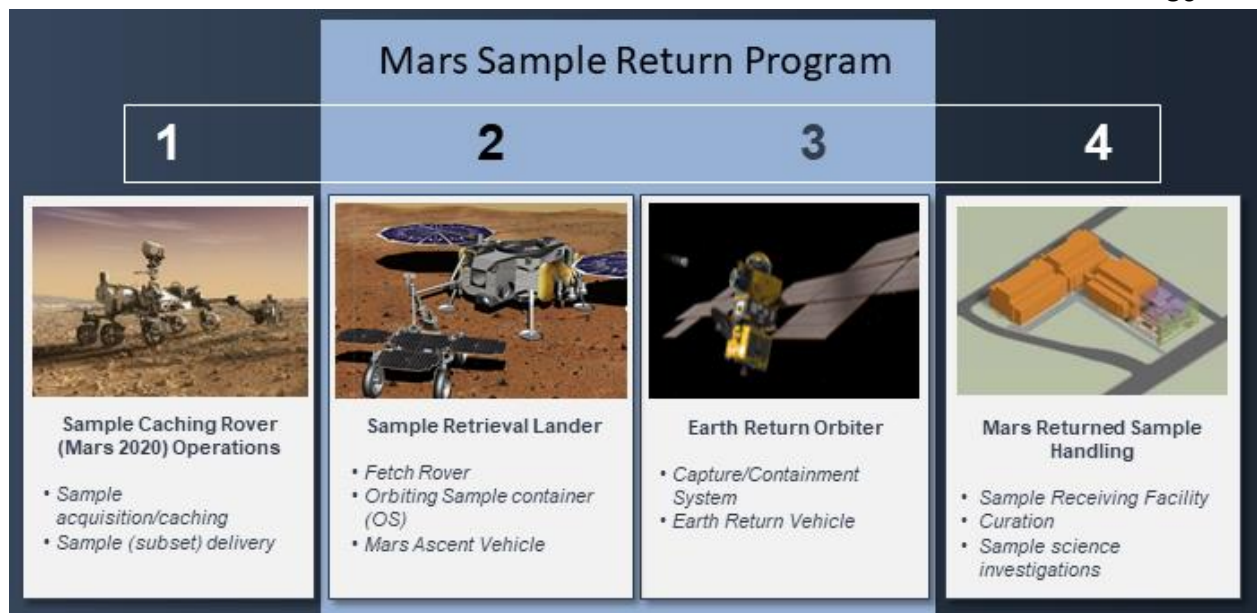
<b>A. Comparison of SMP-FG proposed science bodies / activities with those defined in the Framework document</b>				
<b>Science Activity</b>	<b>Body /</b>	<b>Section</b>	<b>Framework Precedent</b>	<b>Key Modification</b>
MSR Science (MCSG)	Campaign Group	4.2.1	MSR Council, Project Leadership Team (PLT)	The Council was originally envisaged to contain both engineering and science elements. Given the emergence of a separate MSR engineering structure, we propose that the MCSG serve as the primary science management body and adopts all the roles & responsibilities of the PLT.
M2020 Team	Science	4.3.1	M2020 Science Team	None. M2020 is managed outside the scope of the SMP.
Caching Steering Committee (CSSC)	Strategy	4.3.2	None	The various sample caching options had not been defined at the time of Framework development, and as such was not required.
R&D Activities		0	Future Work	The Framework identified major open technical issues, many of which could be addressed by an R&D program.
MSR Program		4.3.4	None	The Framework only considered

Element Science Team(s)			elements associated with returned sample science. Here, we consider all scientific elements of the MSR Campaign.
Curation Team	4.3.5	Preliminary Examination Team	Preliminary examination data are now considered directly as scientific measurements rather than as an independent curatorial process.
MSR Sample Science Team (MSST)	4.3.6	MSR Analysis Planning Team (MAPT); Objective-Driven PIs	Critically, we have identified the need to hold the MSST AO much further in advance than originally proposed in the Framework. Doing so will allow the MSST to assume responsibilities of the MAPT as well as those of the Objective-driven PIs.
Sample Caching Strategy Workshop	4.4.1	None	The various sample caching options had not been defined at the time of Framework development, and as such was not required.
Sample Depot Workshop	4.4.2	None	The various sample depot options had not been defined at the time of Framework development, and as such was not required.
Sample Prioritization Workshop	4.4.3	Sample Prioritization Workshop	No substantive modifications were made.

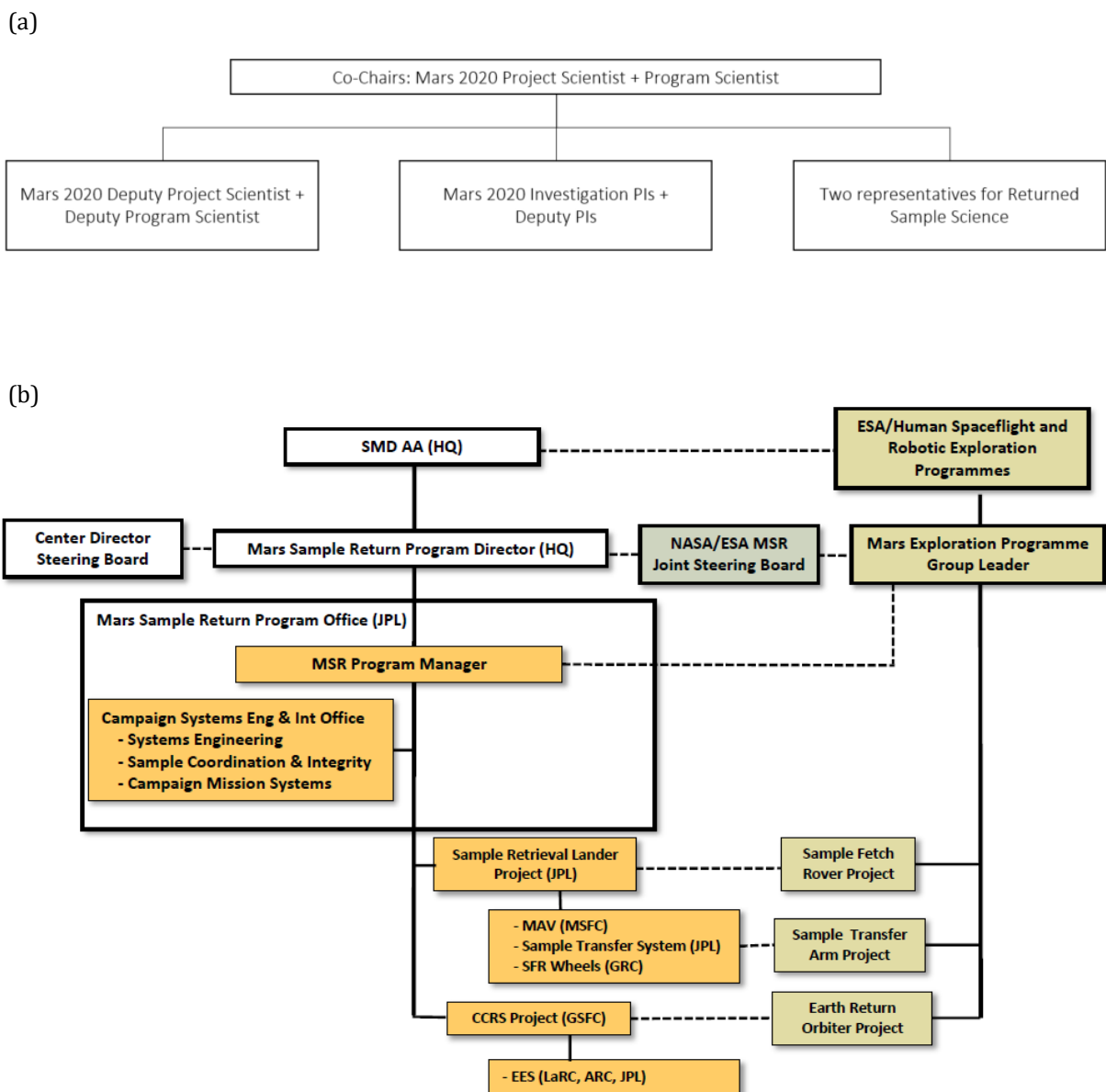
<b>B. Interfaces between the proposed Science Program and other core MSR functionalities</b>	
<b>MSR Functionality</b>	<b>Areas of overlap with proposed Science Program elements</b>
M2020	M2020 Science Team retains decisional authority on Perseverance surface operations and sample selection and collection; M2020 Sample Dossier inherited and expanded upon by Program Element science teams and MSST
Facility Planning	MSST competed early enough (seven years prior to sample arrival on Earth) to ensure that instrumentation for investigations within the SRF can be implemented and tested
Curation	All data from initial sample characterization are provided to MSST immediately upon collection for potential inclusion in scientific publications
Planetary Protection	As with initial sample characterization, data collected for sample safety assessment are provided to MSST immediately



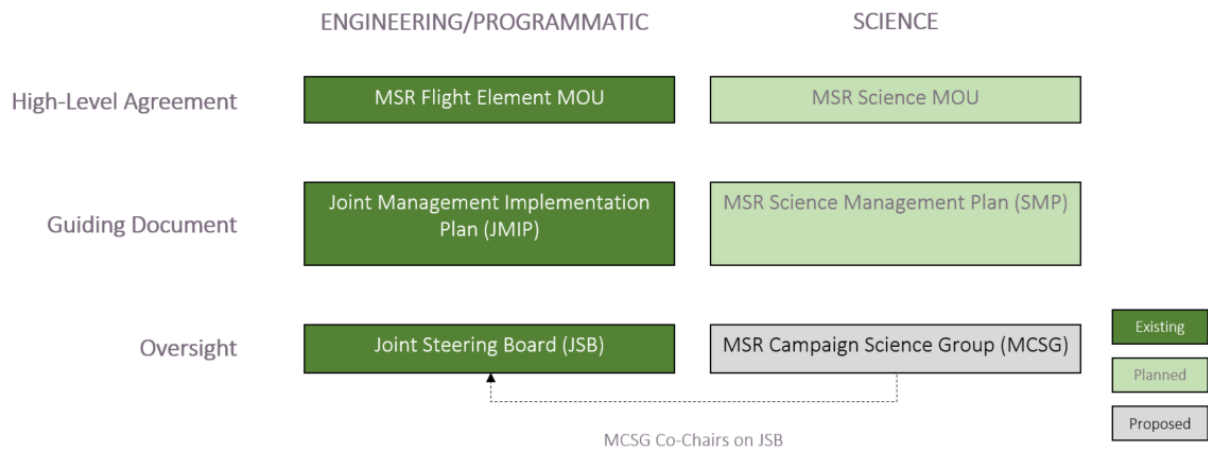
**Figure 1.** Graphical representation of the proposed MSR Science Program, illustrating relationships among the MSR Partners and other Science Program stakeholders. Numbers in parentheses indicate the report section where the proposed body or activity is described.



**Figure 2.** Overview of the planned MSR Campaign showing the current “3+1 architecture” outlining the three flight and one ground elements designed to collect samples on Mars and safely return them to Earth. The MSR Program refers to the 2-Sample Retrieval Lander (SRL) and 3-Earth Return Orbiter (ERO) missions. In its entirety, the collection of missions and ground segment (1-4 below) is referred to as the “MSR Campaign” (from Gramling and Braun, 2021).

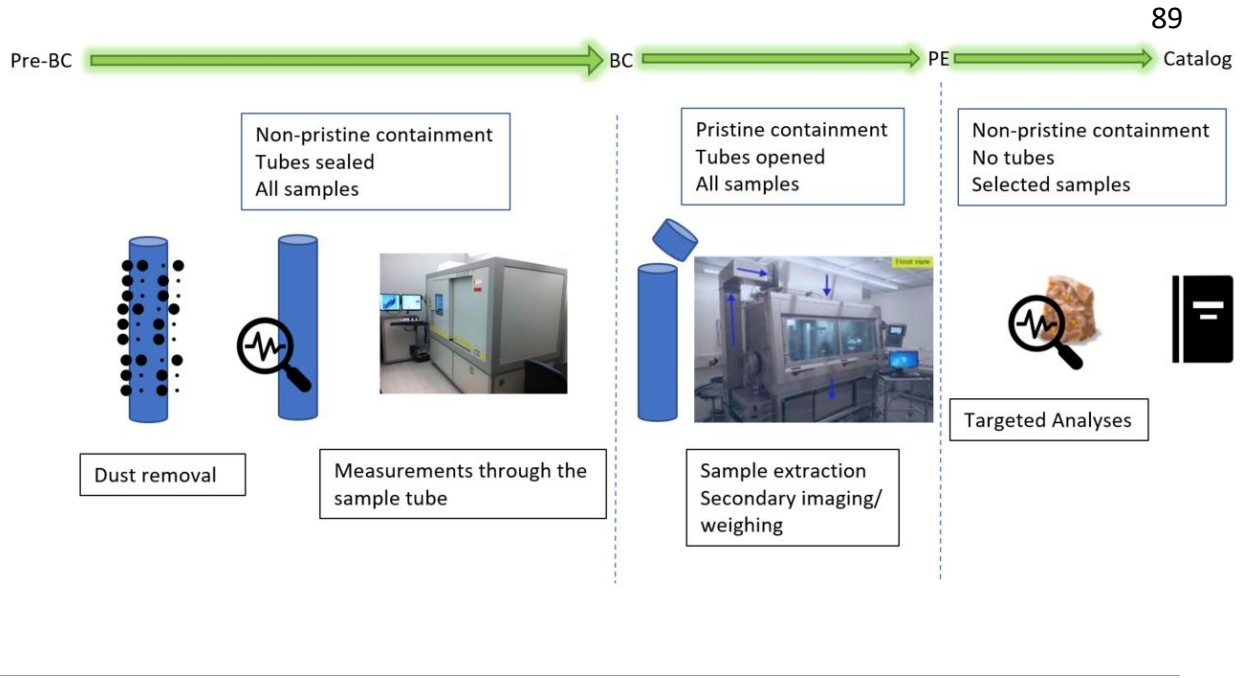


**Figure 3.** (a) Organizational chart of the M2020 PSG; (b) Simplified MSR Program interface map between NASA and ESA for the flight segments. Solid lines represent hierarchical relationships, while dashed lines represent functional relationships. Orange boxes are managed by NASA, beige boxes are managed by ESA, and the green box is jointly managed by NASA and ESA. (ARCL Ames Research Center; EES: Earth Entry System; GSFC: Goddard Space Flight Center; GRC: Glenn Research Center; LaRC: Langley Research Center; MSFC: Marshall Space Flight Center)

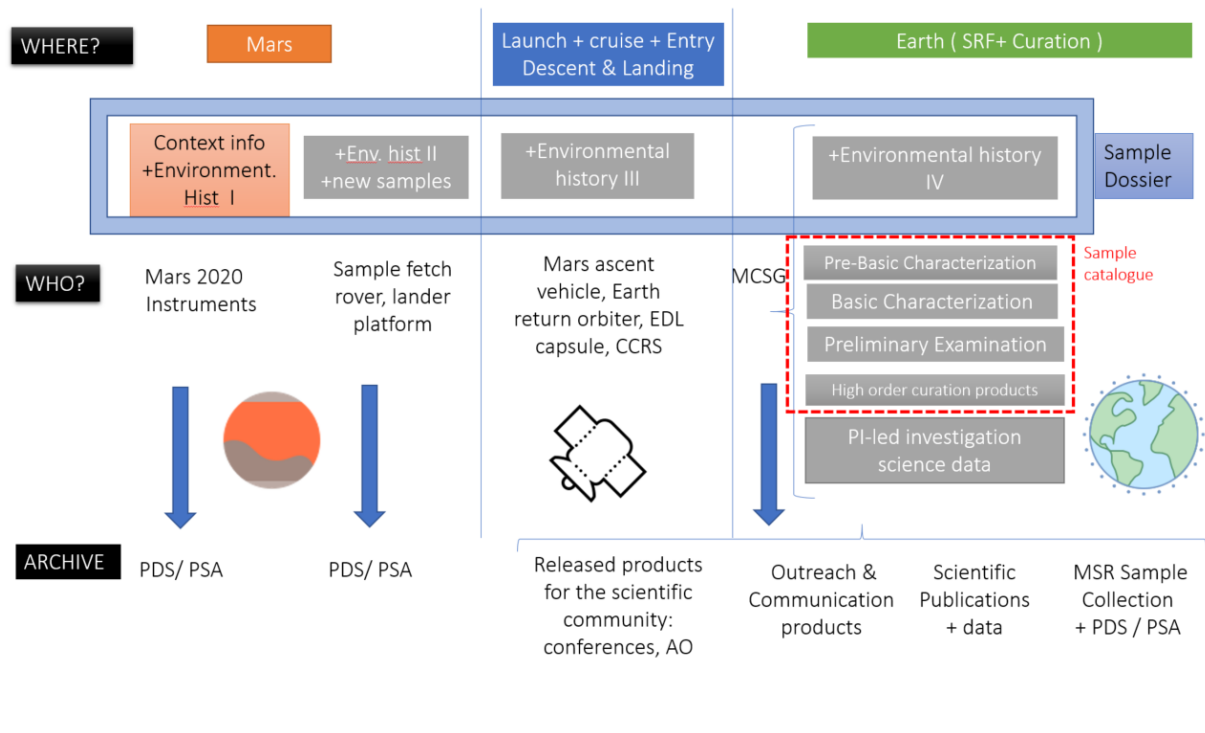


**Figure 4.** Proposed science management structure and documentation that are designed to mirror the existing structure for engineering elements of the MSR Program. Note that the Engineering/Programmatic column pertains to the MSR Program (*i.e.*, flight elements) only.

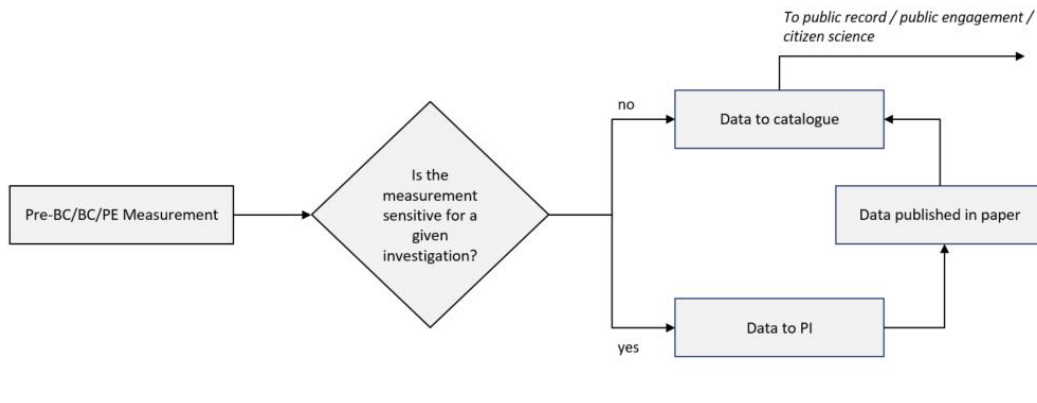




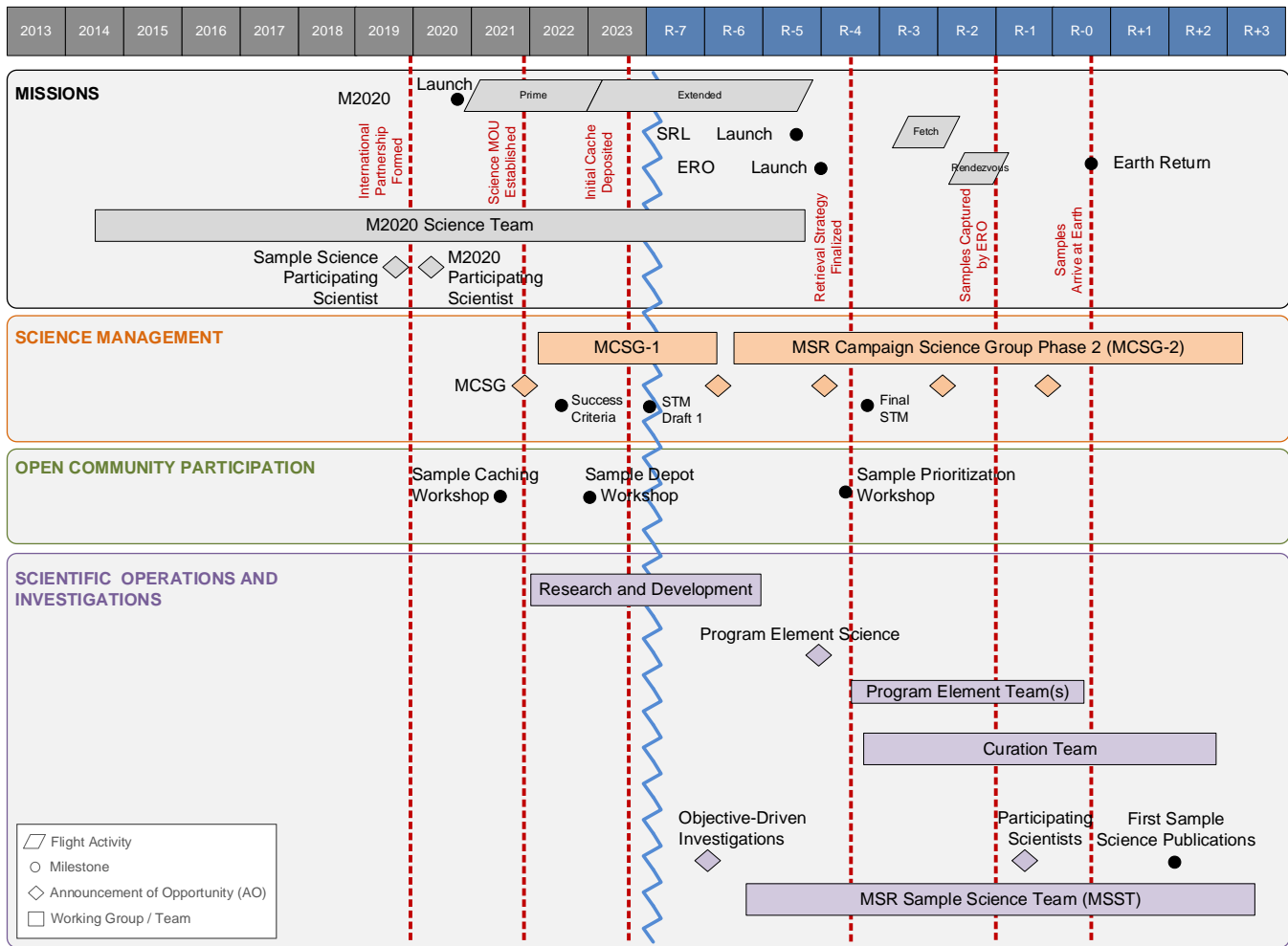
**Figure 5.** Proposed timeline of activities within the Pre-Basic Characterization, Basic Characterization, and Preliminary Examination (from Tait *et al.*, 2021).



**Figure 6.** Overview of data deliverables produced during different stages of the MSR Campaign.



**Figure 7.** Decision tree to be applied to all measurements collected during the initial stages of sample interrogation. If the measurement is crucial to a given investigation and release could impact the ability to publish the study, it is first provided to the investigation PI for proprietary usage prior to entry into the public catalog.



**Figure 8.** Integrated timeline of proposed MSR Science Program activities. Specific years are indicated up to 2023, after which years are measured relative to the year of the sample arrival at Earth (R-0).