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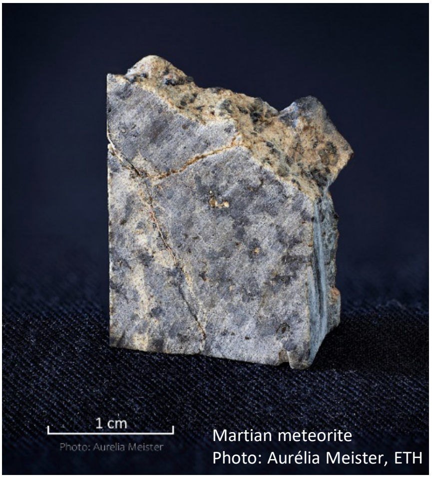
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

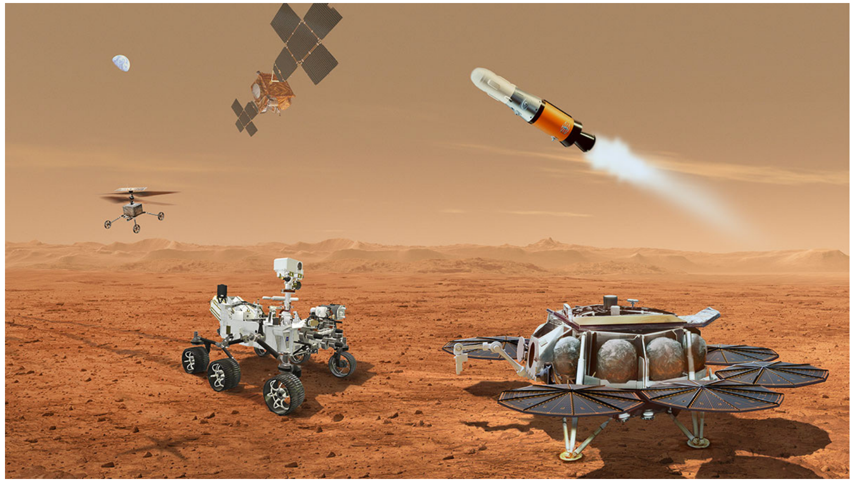
Mars Sample Return (MSR)



Martian meteorite
Photo: Aurélia Meister, ETH

H. Busemann
=> M. Schönbächler

Inst. of Geochemistry & Petrology, ETH Zürich



Mars Sample Return Campaign:

NASA & ESA led, based on **recommendations of the international science community**

“A particular challenge throughout the entire process is for the samples to be **securely contained**, and “breaking the chain” with Mars, **until determined to be safe for distribution outside of biological containment**.”

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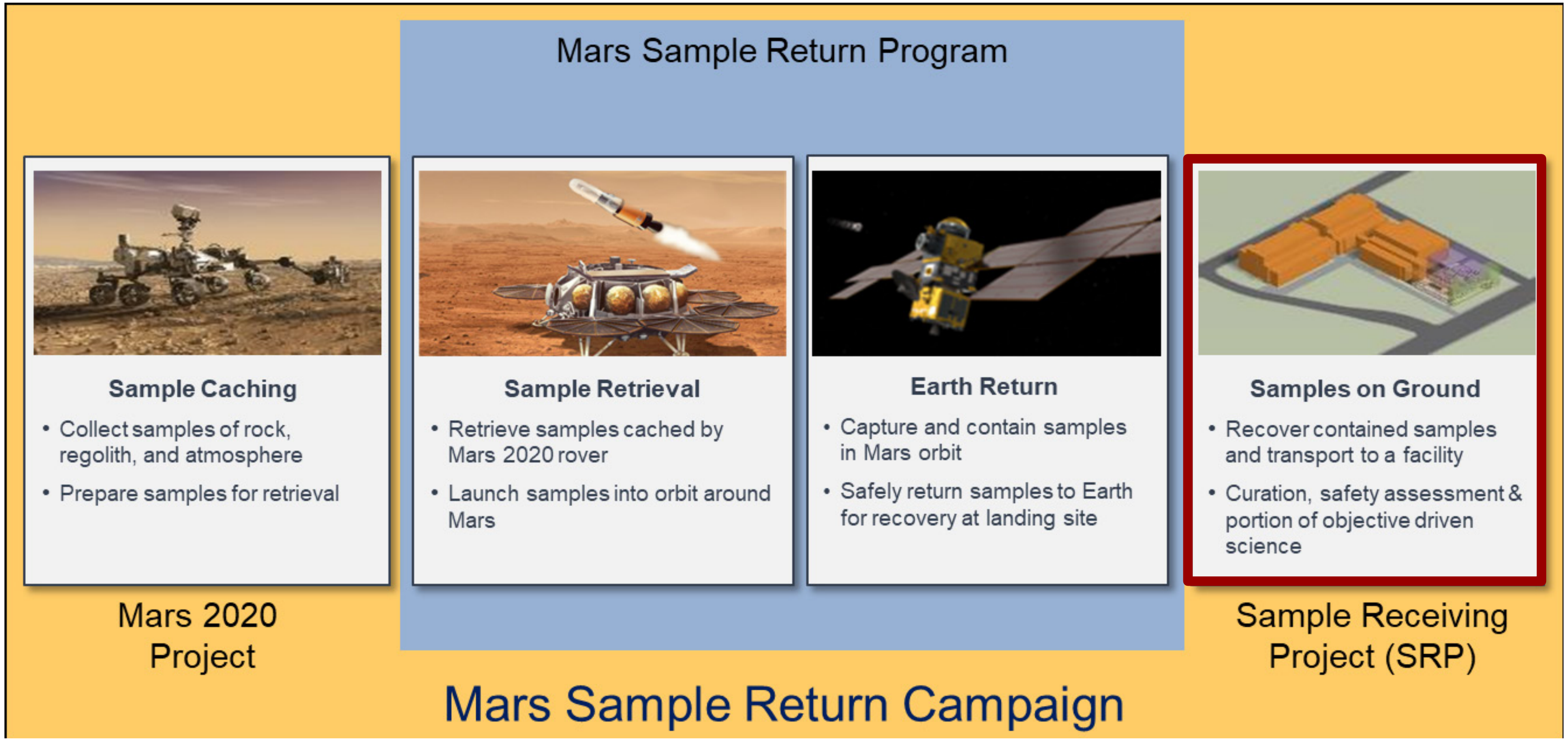
1. MSR campaign status



1. **context** development and **acquisition of scientifically selected samples** by Perseverance rover
2. **transit** through flight elements of MSR Program
3. **retrieval on Earth** for curation
4. **analysis** by the world's scientific community

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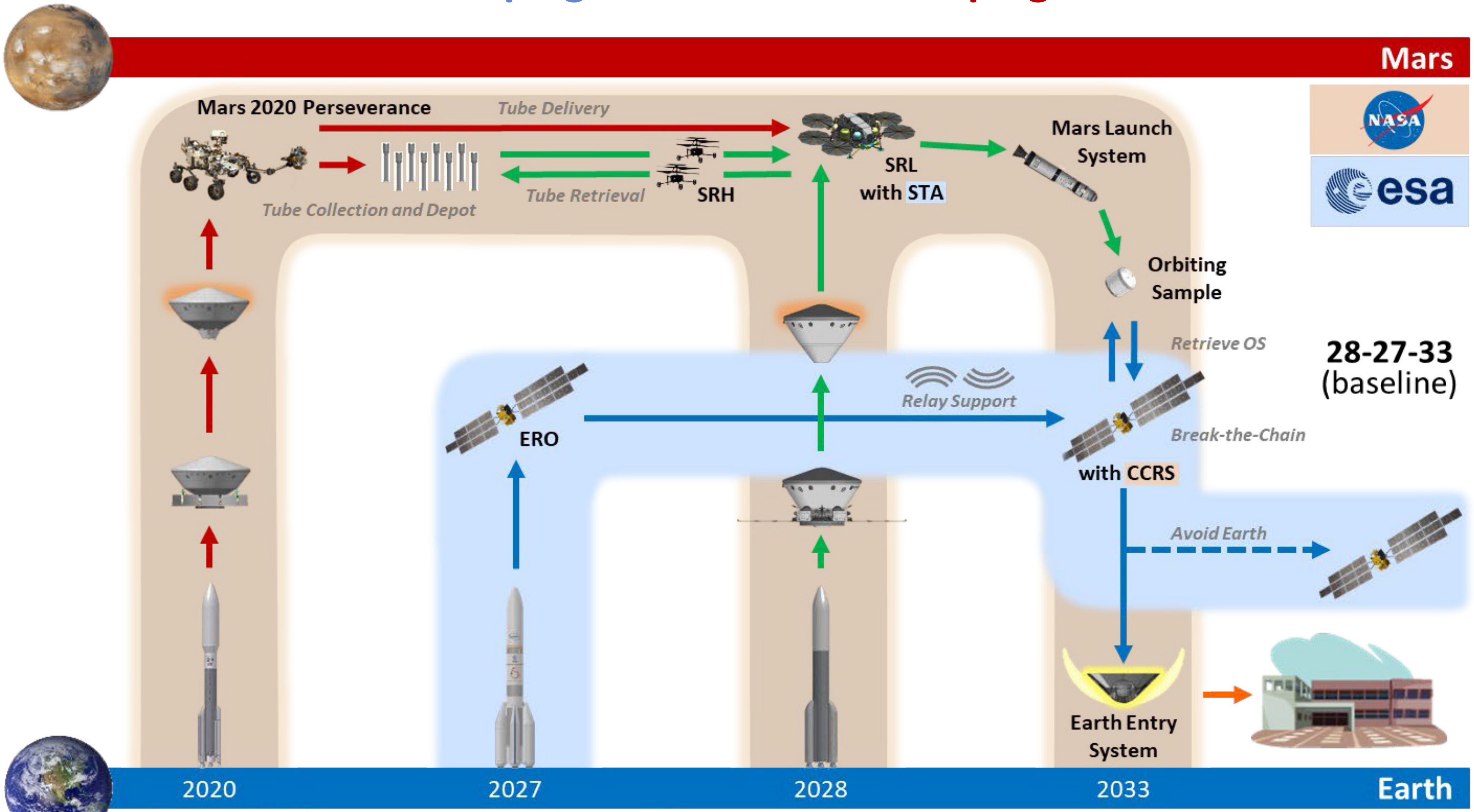
1. MSR campaign status – MSR campaign architecture



Mars 2020 (*JPL*)	Earth Return Orbiter (ERO) (*ESA*), with Capture, Containment, and Return System (CCRS) (*GSFC*)	Sample Retrieval Lander (SRL) (*JPL*), with Sample Transfer Arm (STA) (*ESA*), Mars Ascent Vehicle (MAV) (*MSFC*), and Sample Recovery Helicopter(s) (SRH) (*JPL*)	Sample Receiving Project (SRP) (*NASA/ESA*)

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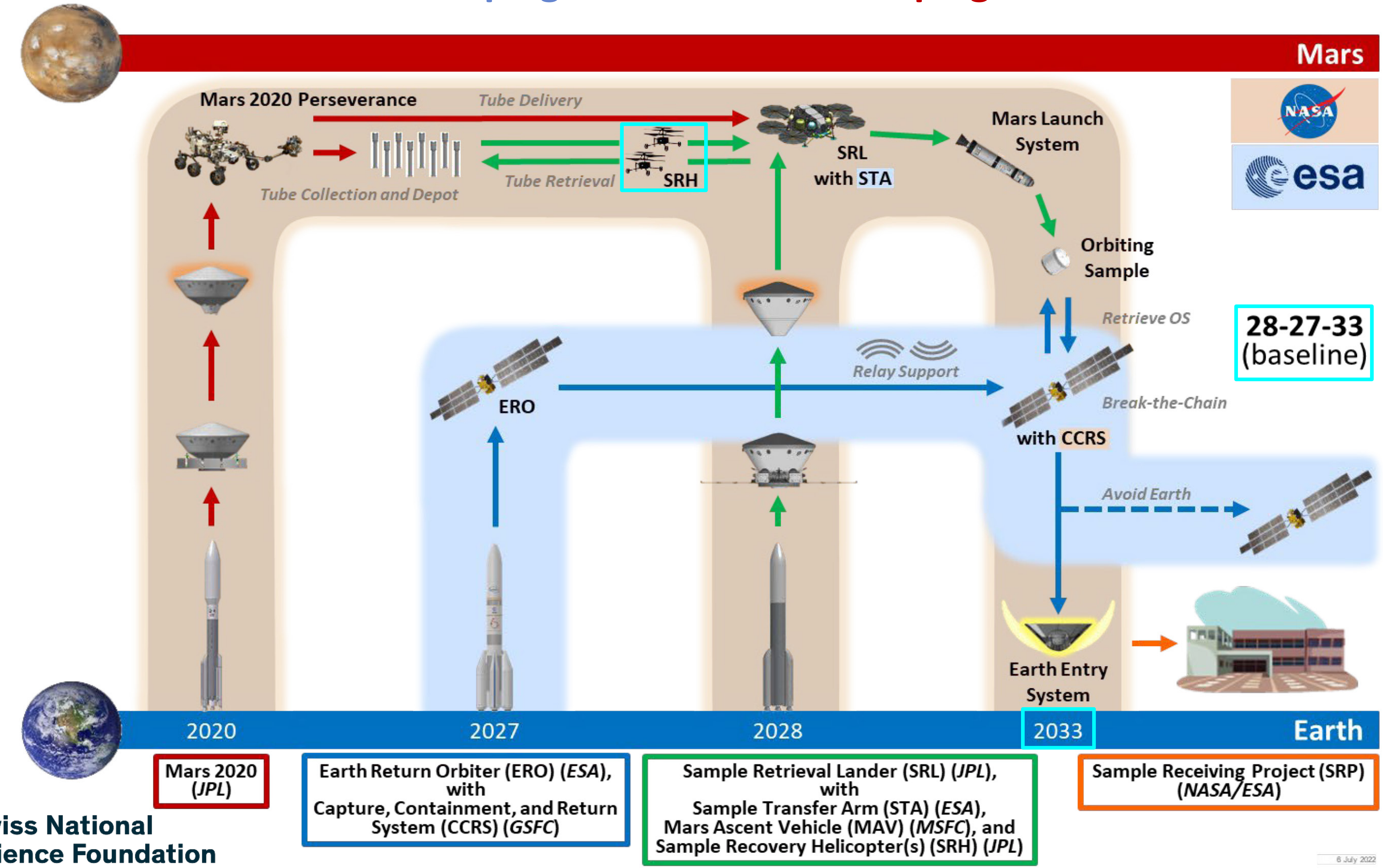
6 July 2022

1. MSR campaign status – MSR campaign architecture



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1. MSR campaign status – Science Program

The MSR Science Program four key milestones

1. Selecting samples for depot(s) and Earth return, linked to the ongoing operation of the M2020 mission on Mars
2. Finalizing the science input for the Sample Receiving Project (SRP) in 2024 to account for (a) curation, (b) safety assessment, (c) time- & (d) sterilization-critical objective-driven science
3. The first open, competitive Announcement of Opportunity (AO) in 2026 for MSR objective-driven science investigations on the samples
4. Begin conducting the MSR objective-driven science investigations once the samples are on Earth, planned for 2033

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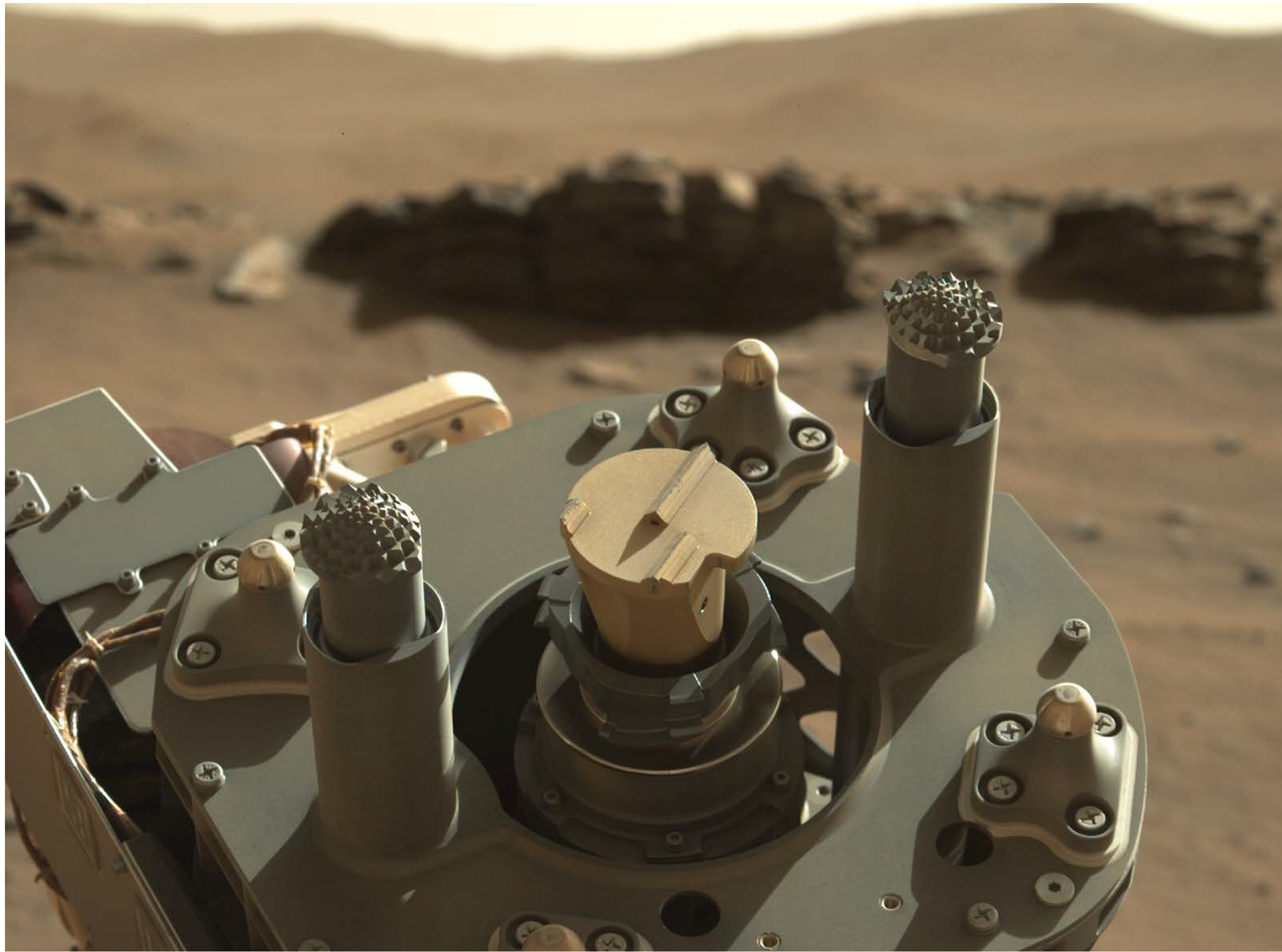
2. Scientific background & current steps



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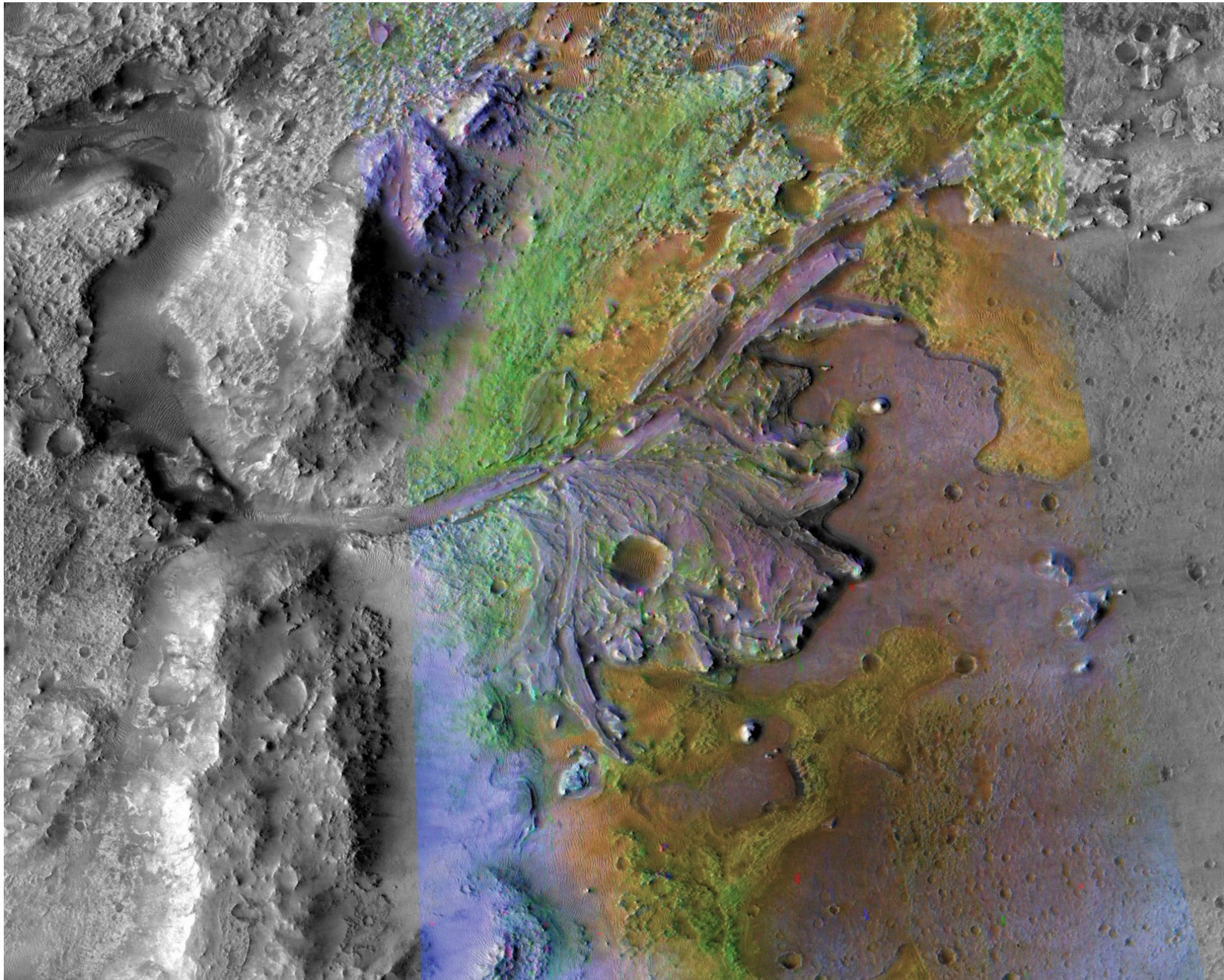
2. Scientific background & current steps – Field overview

- Launch Jul 30th, 2020
- Lands Feb 18th, 2021 in Jezero crater
-
- Jezero crater: 49 km diameter
  (in "Isidis Basin"), once water-filled?
- **expected: clays, sediments, regolith, basalts, "real" rocks**
- project scientist K. Farley



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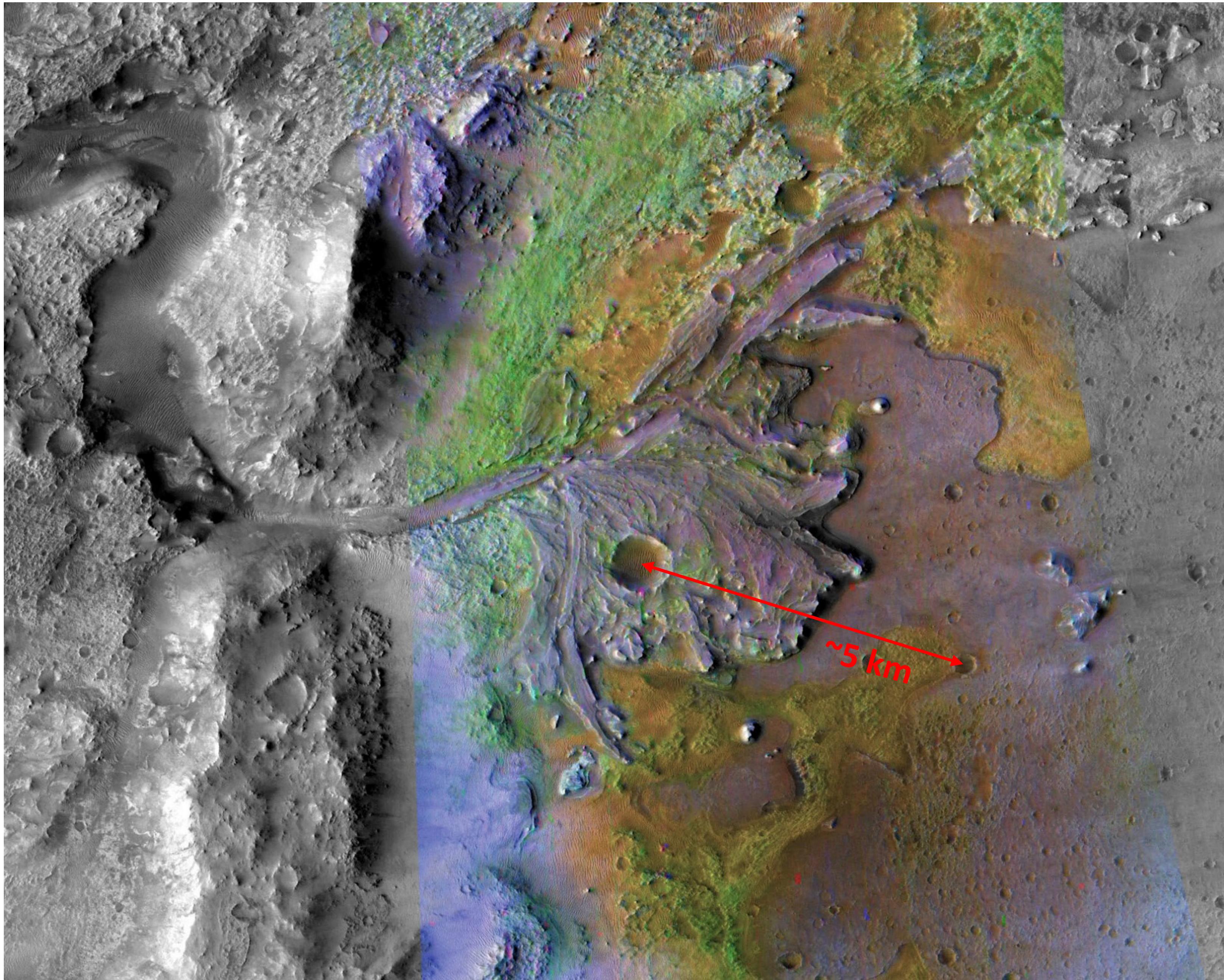

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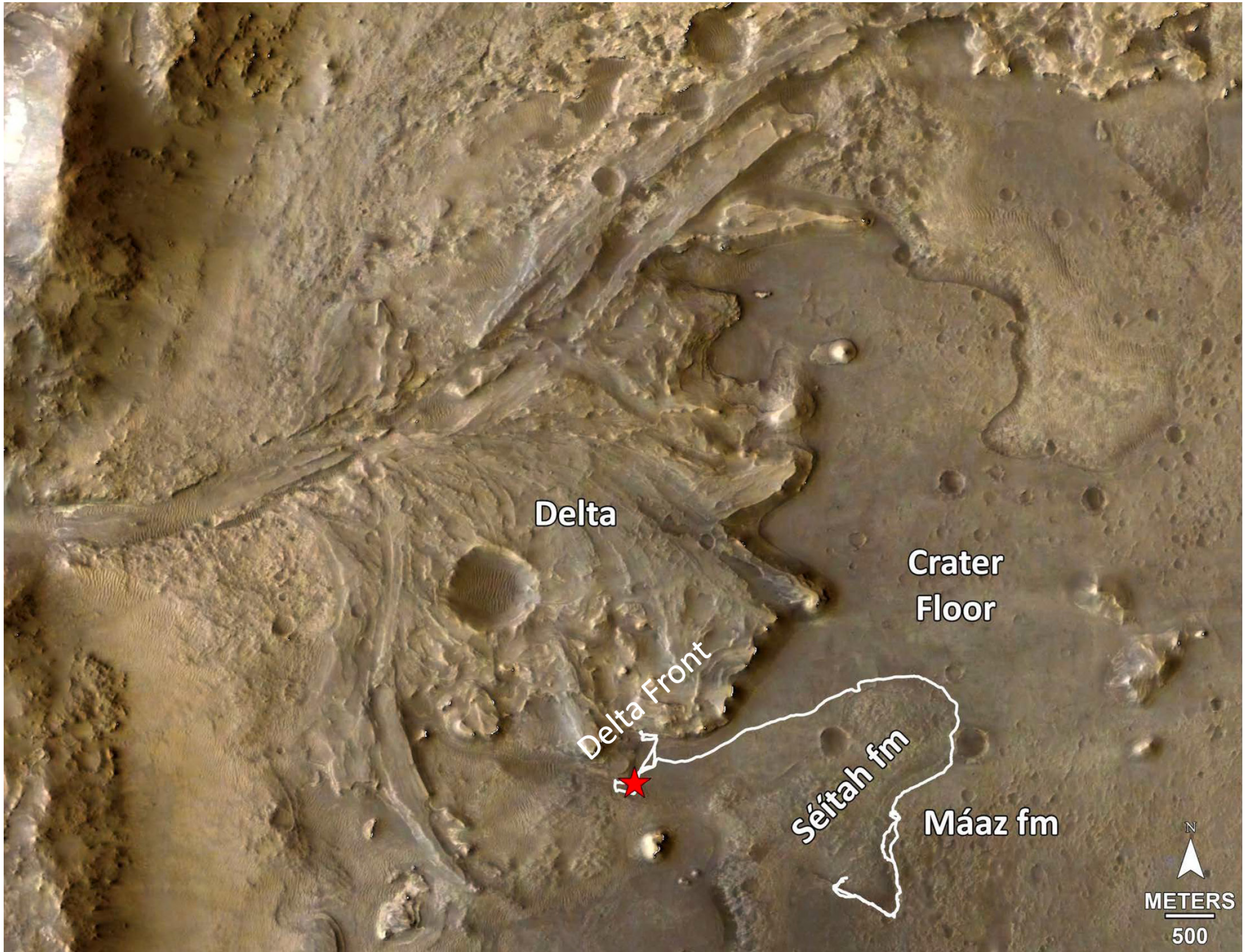
2. Scientific background & current steps – Field overview



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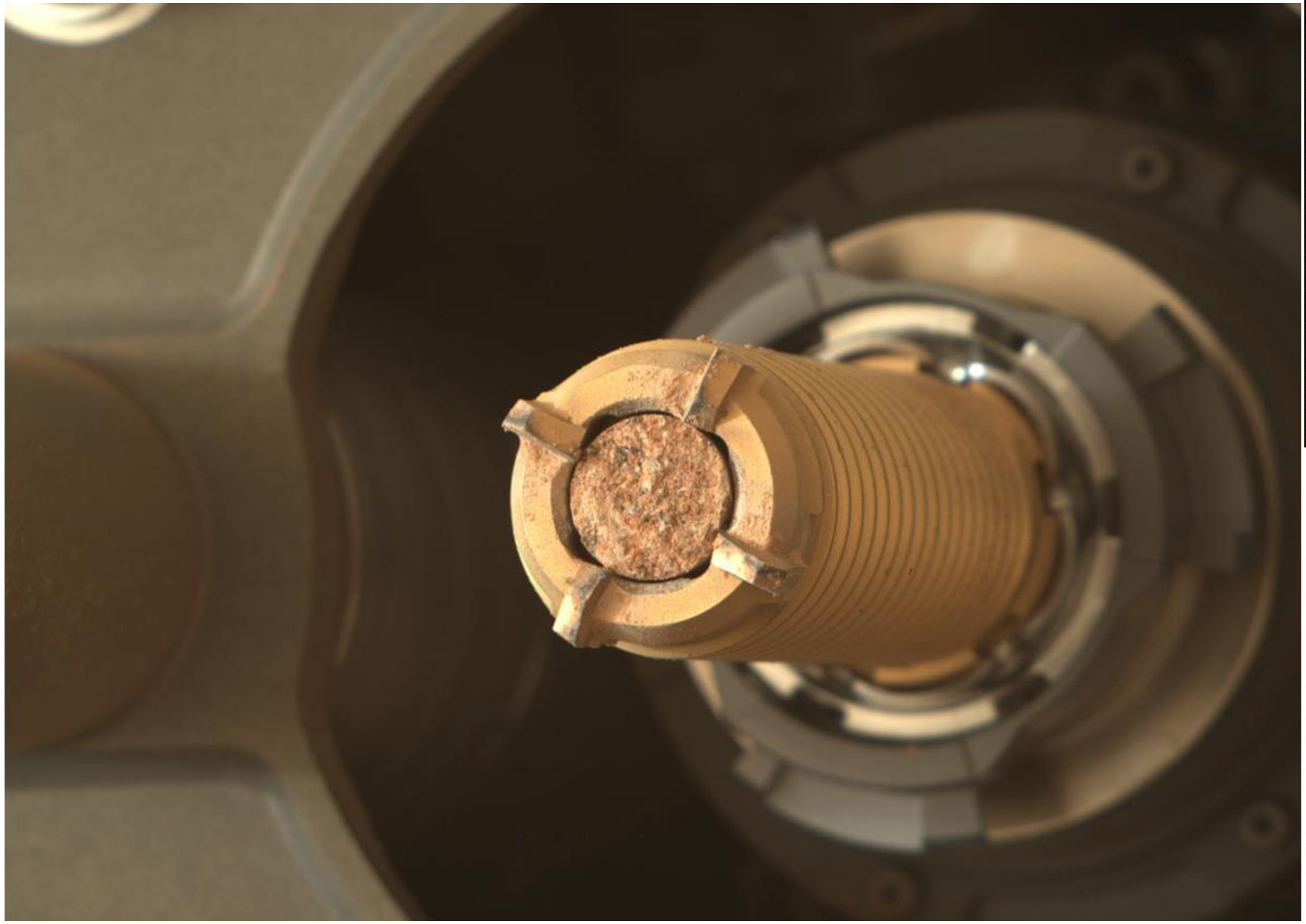
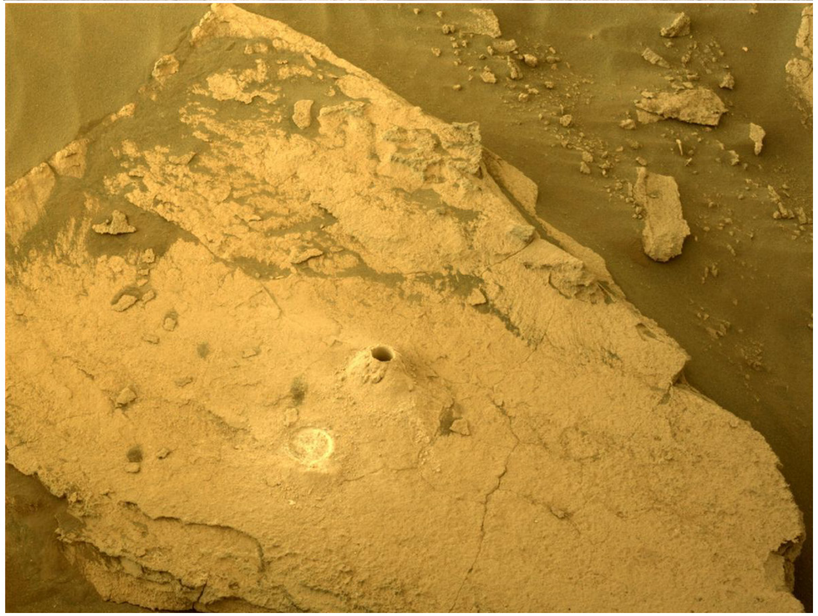
2. Scientific background & current steps – Drill cores

First samples from Delta Front Campaign





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2. Scientific background & current steps – Samples

Sampling campaign

- "scientific benchmark" => Beaty et al. 2019 **iMOST report**

- **Depot WS on Sept. 28+30, 2022** (>100 scientists + M2020 team)

2. Scientific background & current steps – Samples

Sampling campaign

- "scientific benchmark" => Beaty et al. 2019 **iMOST report**

- **Depot WS on Sept. 28+30, 2022** (>100 scientists + M2020 team)
- Sampled:
  - **Igneous rocks** (crater floor, absolute unit ages, anchor to Martian epochs, magmatic evolution, calibrate crater counting ages)
  - **Sedimentary rocks** (from delta front, promising to search for evidence of ancient life)
  - **Aqueous alteration products** (history of near-surface water)
  - **Organic compounds** (origins: biogenic vs. abiogenic)

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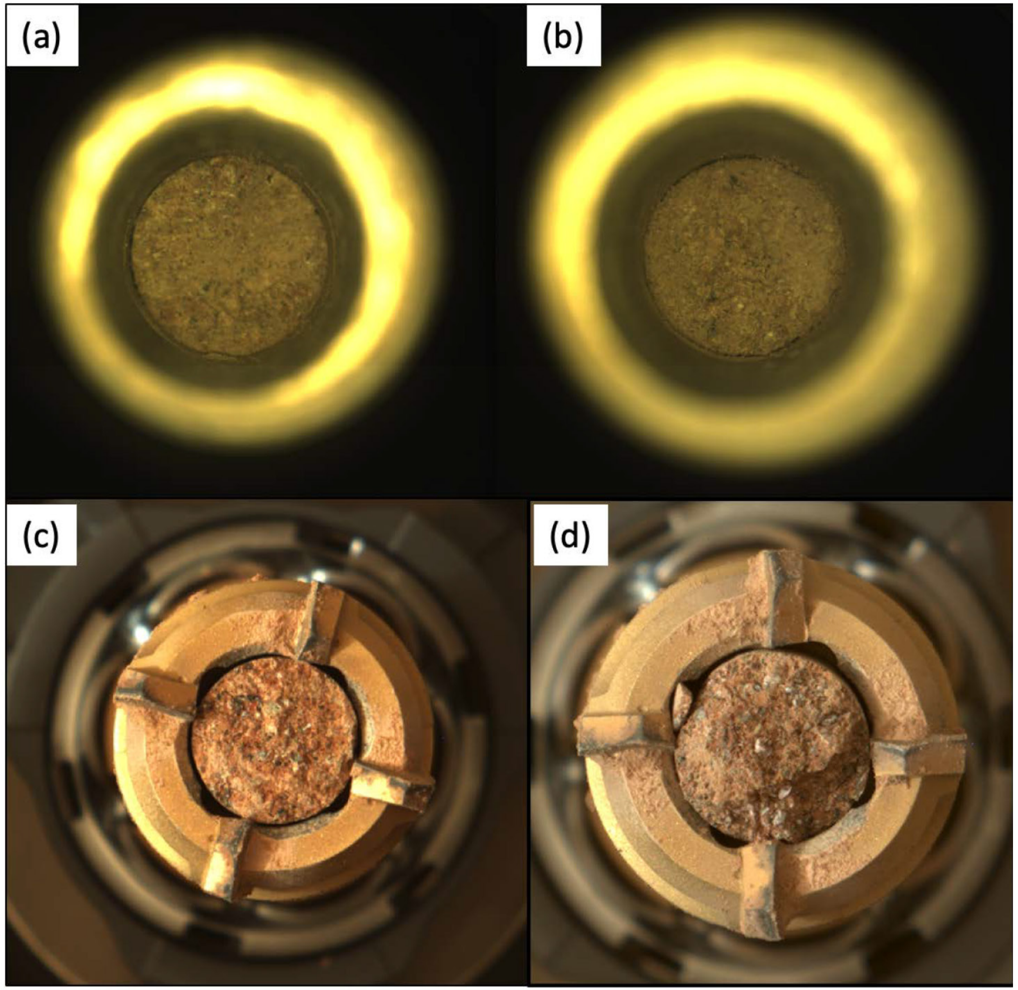
2. Scientific background & current steps – Samples

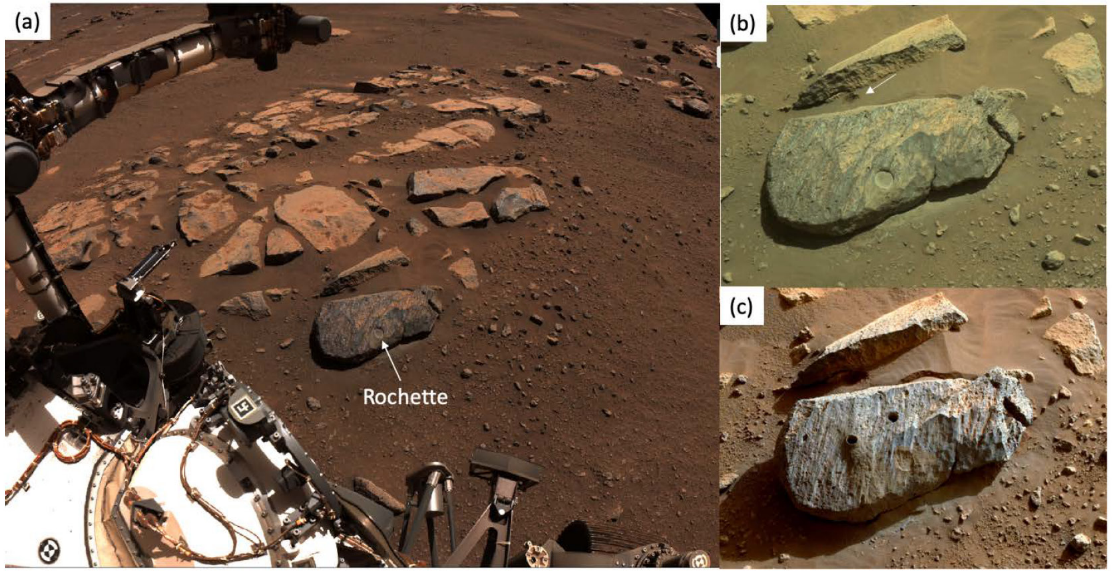
All rock cores have been paired

-same lithology/outcrop
-separation < 50 cm in all cases
-intention is to have one of the pair go into first depot, the other to remain on Perseverance

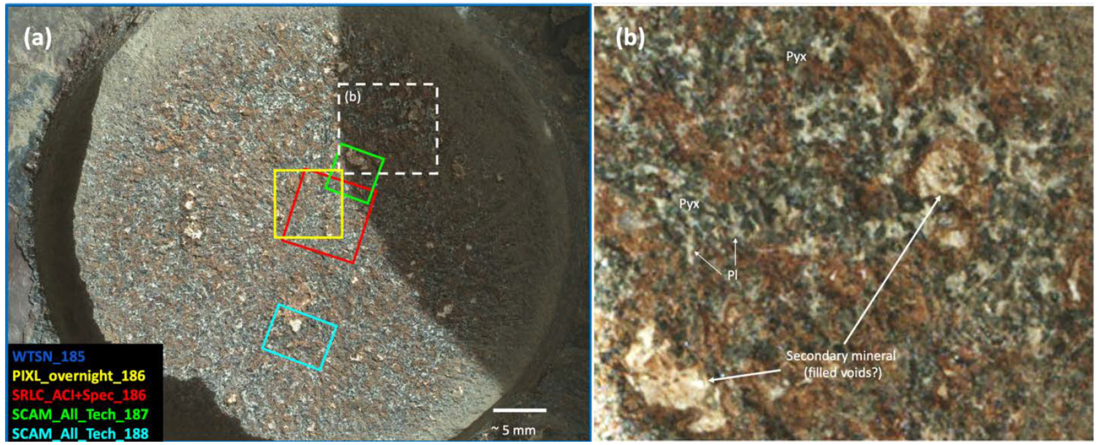


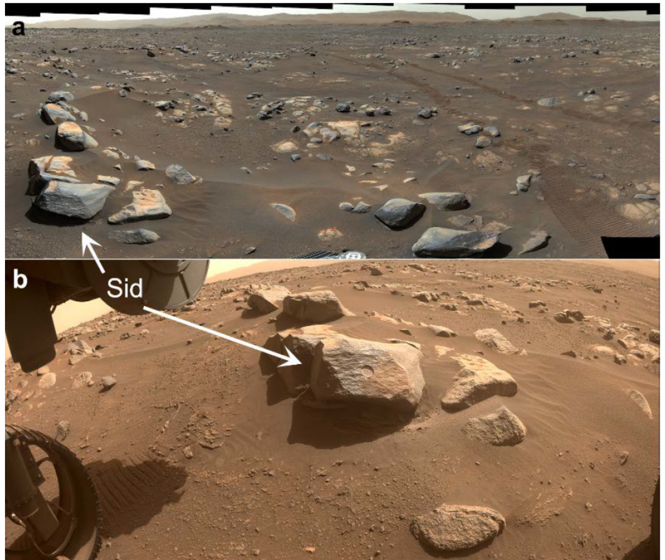
2. Scientific background & current steps – Samples

Máaz Formation: igneous, possible basaltic lava flows + aqueous alteration and salts

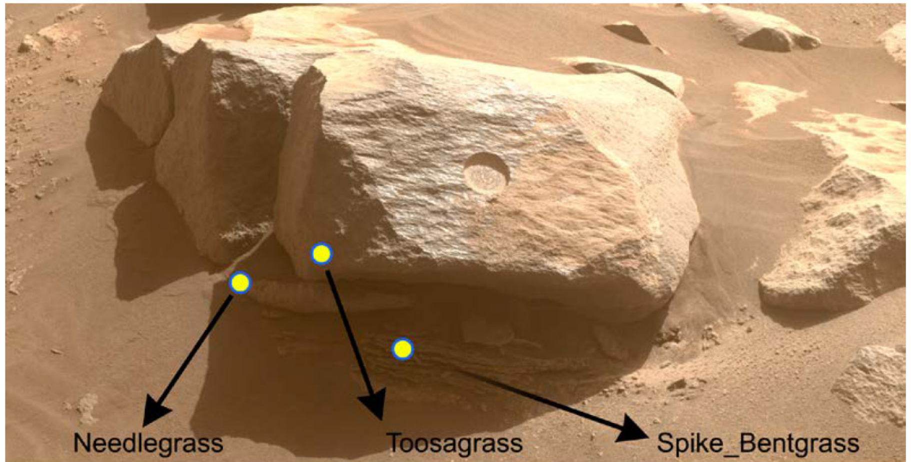


Montdenier, Montagnac



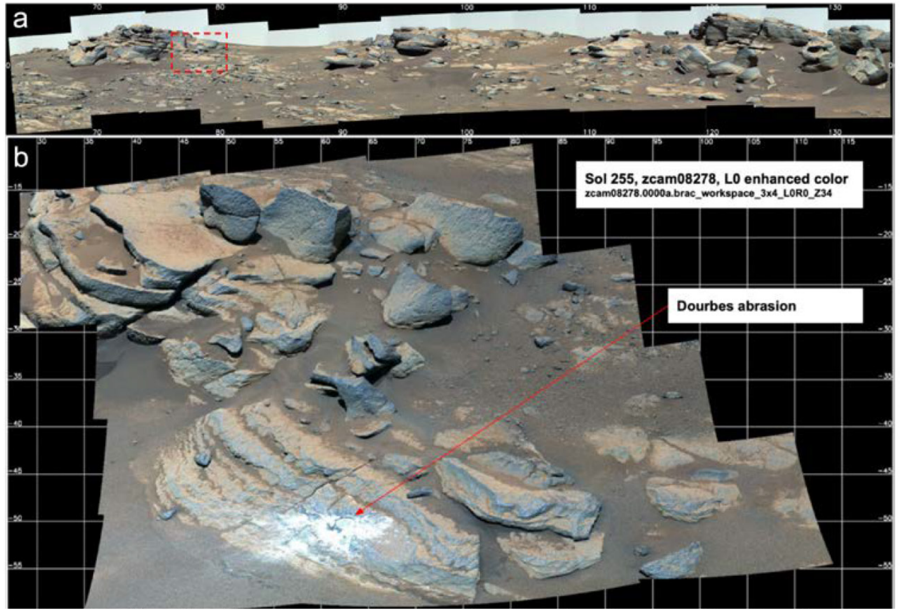


Hahonih, Atsah

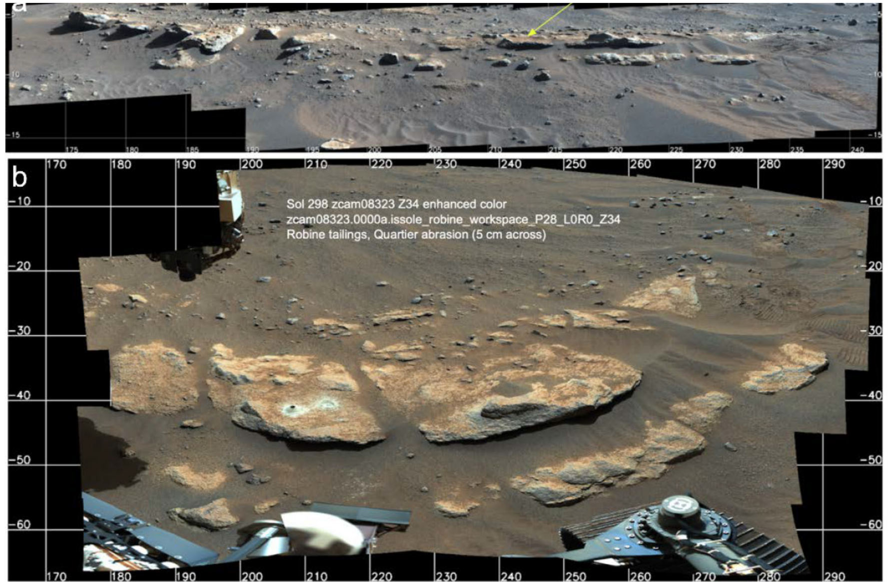


2. Scientific background & current steps – Samples

Séitah Formation: igneous, poikilitic olivine cumulates, possible layered intrusion; + carbonate and salts



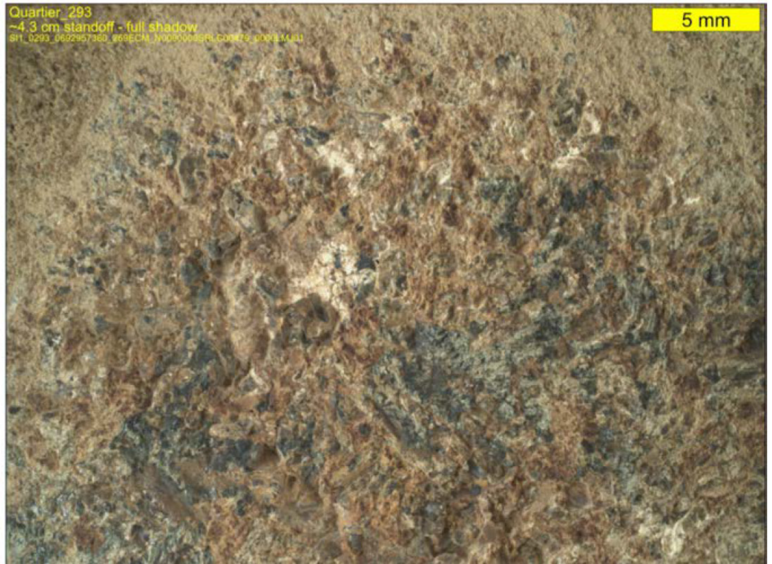
Salette, Coulettes



Malay, Robine

Instrumentation

- **SuperCam** (2 lasers, spectrometers, LIBS, Raman) images, chemical composition, minerals in rocks and regolith from a distance, audio
- **SHERLOC** (UV Raman) images, minerals, organics
- **PIXL** (X-ray fluorescence), images, fine-scale chemical composition



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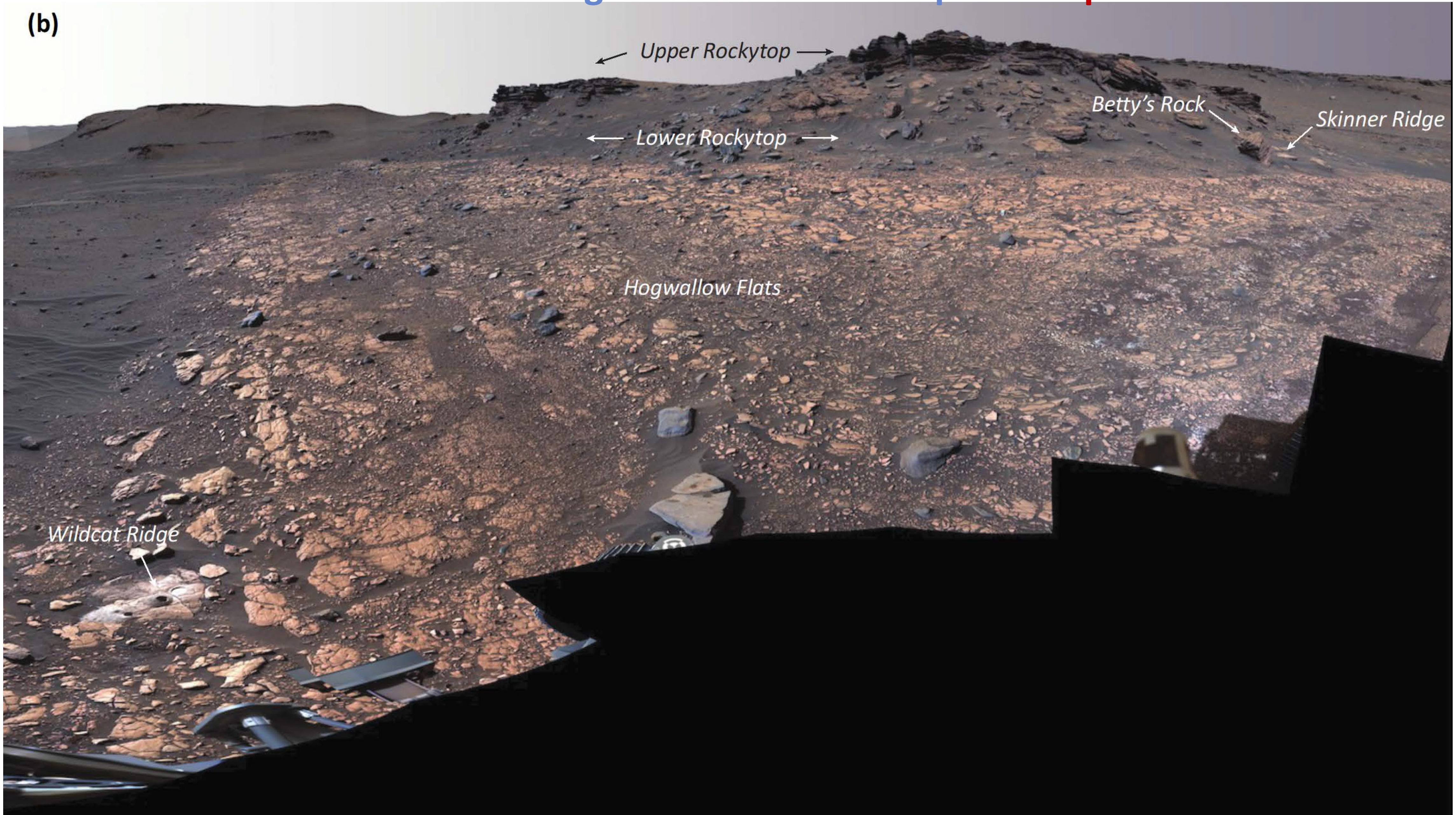
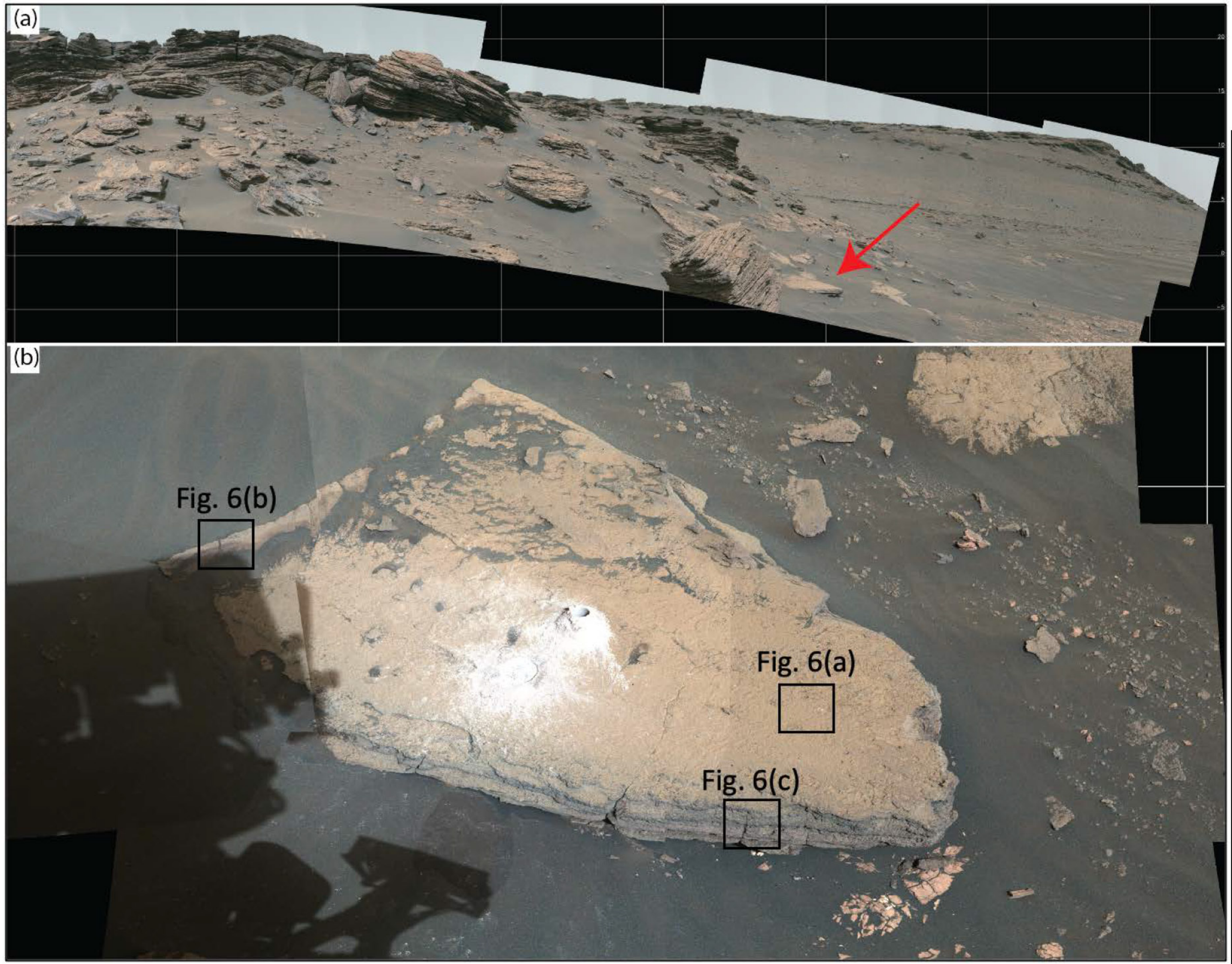
2. Scientific background & current steps – Samples



2. Scientific background & current steps – Samples

Skinner Ridge: Fine/medium-grained, poorly-sorted sandstone



Skyland, Swift Run

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2. Scientific background & current steps – Samples

Wildcat Ridge: sulfate-rich mudstone

Hazeltop Bearwallow

2. Scientific background & current steps – Samples

Additional tubes already acquired:

WB1 - Bit Carousel Witness Tube
WB2 - Ordinary Witness Tube

Roubion - atmospheric sample (~4.9 umol of martian air)

Tubes expected to be acquired before cache deployment:

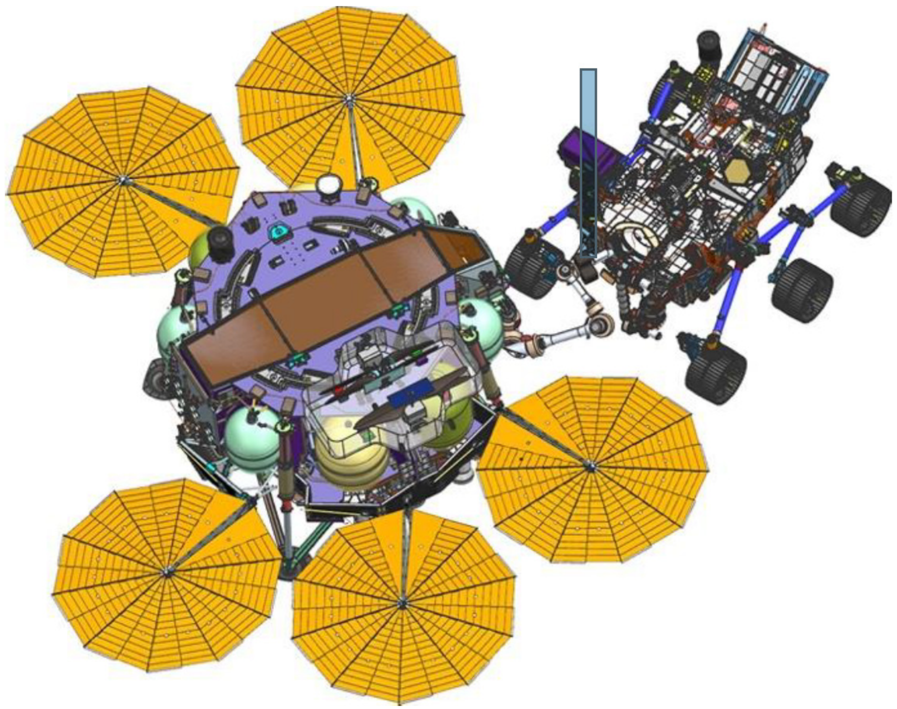
Amalik Outcrop- gray mudstone(?) - *Pair*
Regolith - *Pair*
WB3 -Ordinary Witness Tube

2. Scientific background & current steps – Storage in 1^{st} depot

Sampling campaign

- if Perseverance degrades & cannot transfer tubes to SLR =>

traverse to nearest suitable site to place **2^{nd} depot**



Scenario #1: Direct Delivery from Perseverance

- If Perseverance is still healthy during the SRL cruise phase, SRL will target a landing site near Perseverance to support direct tube transfer from the rover.

  In this scenario, SRH would not be used to retrieve sample tubes, and no sample tubes other than those in the initial depot would be placed on the Mars surface by Perseverance.

  This is the primary approach to sample tube delivery to SRL.

=> new, unknown samples available

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2. Scientific background & current steps – Storage in 1st depot

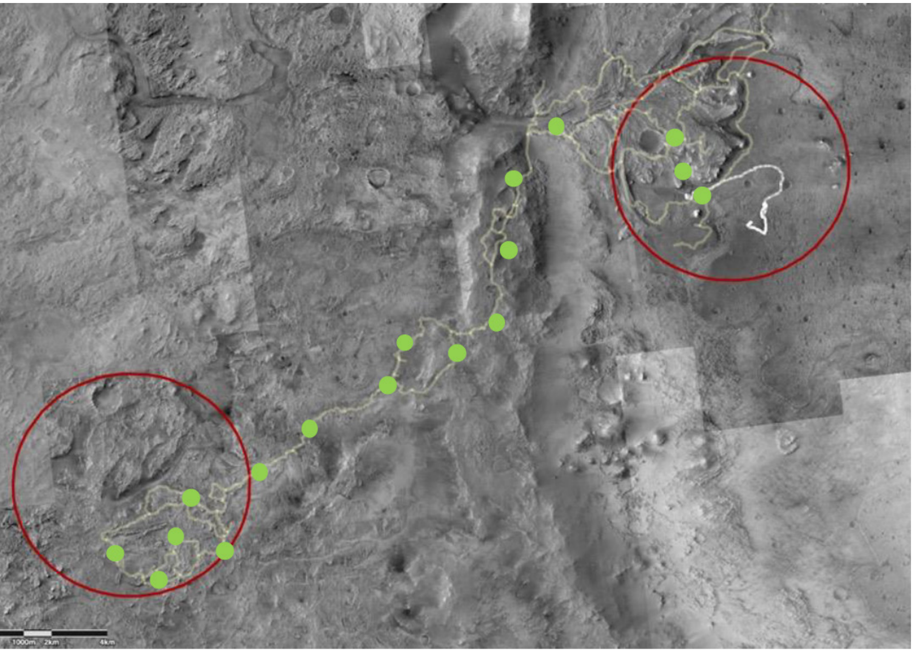
Sampling campaign

- if Perseverance degrades & cannot transfer tubes to SLR =>

traverse to nearest suitable site to place **2nd depot**

Scenario #2: SRH Delivery from Final Depot

- In the event of a degradation in Perseverance state of health that threatens the ability to directly deliver samples to SRL, Perseverance will attempt to traverse to the nearest suitable Campaign site and place a second depot.
  - Candidate Campaign sites (landing site and depot) have been identified along the M2020 strategic traverse route.
- In this scenario, SRH is used to retrieve sample tubes from the depot.
- A hybrid approach with some tubes coming from SRH and some coming from Perseverance is not required, but there are no technical reasons why this is precluded.



● Represents a candidate Campaign site (sample depot and landing circle)

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2. Scientific background & current steps – Storage in 1st depot

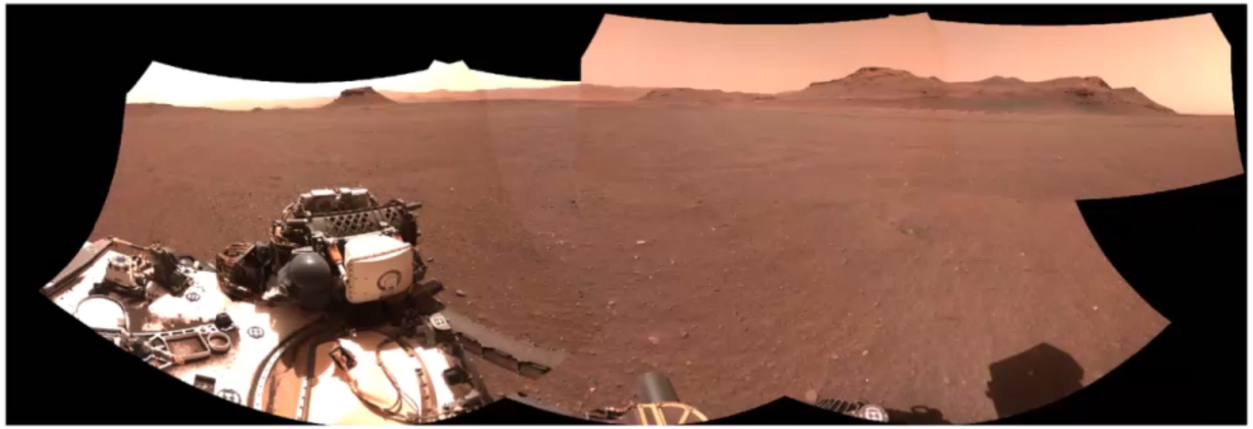
Sampling campaign

- if Perseverance degrades & cannot transfer tubes to SLR =>

traverse to nearest suitable site to place **2nd depot**

Scenario #3: SRH Delivery from Initial Depot

- Perseverance will drop a subset of sample tubes before the end of its qualified lifetime in an initial depot planned to be at Three Forks.
- This is to guard against sudden failure of Perseverance and ensures that MSR can return a scientifically return-worthy set of samples.
- SRH is used to retrieve sample tubes from the initial depot.
- Perseverance is not operational in this scenario.



M2020 sol 409 Navcam panorama taken inside the Three Forks landing circle

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2. Scientific background & current steps – Storage in 1st depot

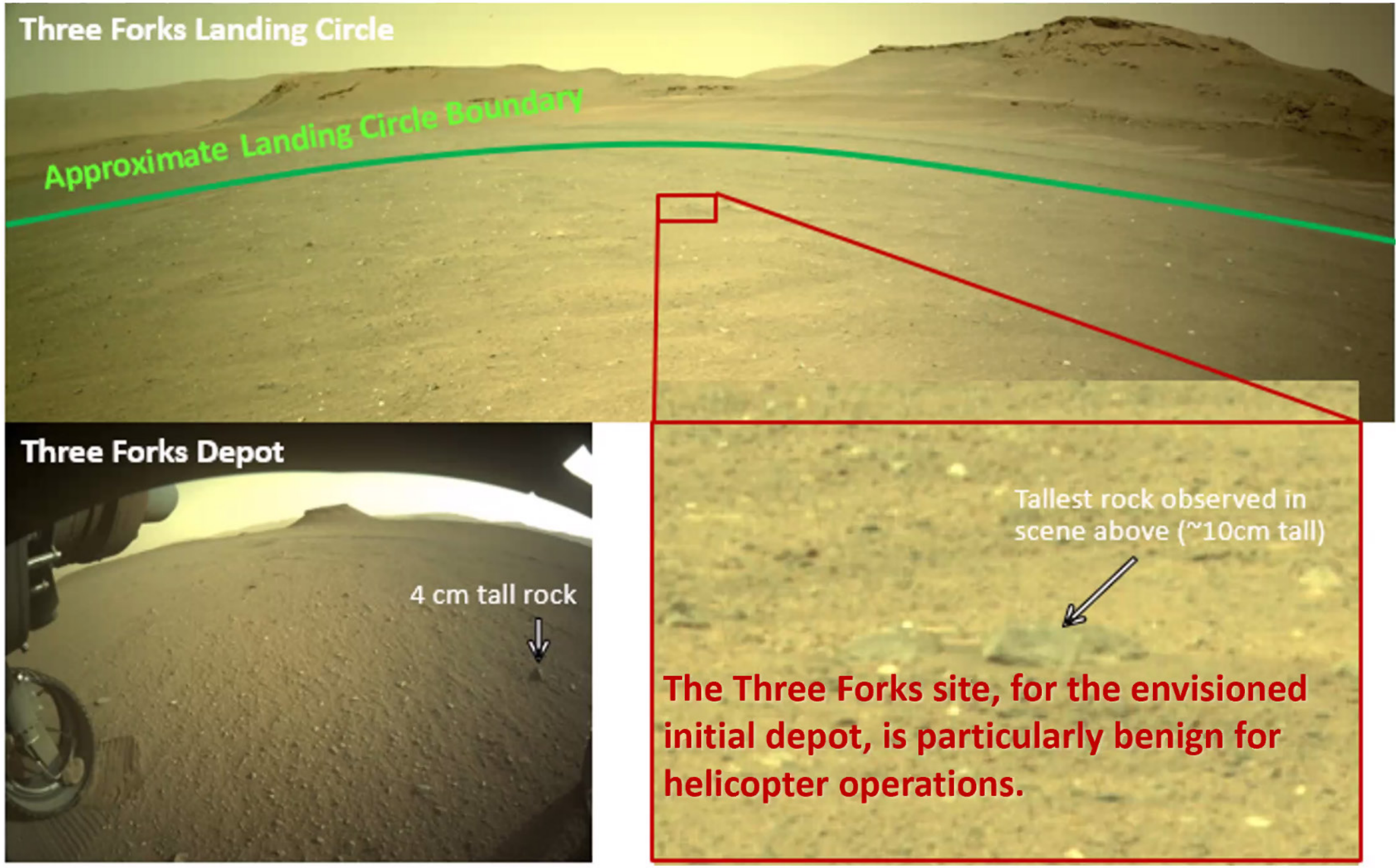
Sampling campaign

- 1st depot at "**Three Forks Site**" with **scientifically return-worthy collection**
- **risk hedge against rover failure** (before Perseverance reaching qualified lifetime (1.5 Mars yrs, 20 km traverse)

- **shorter of each pair in depot**, longer sample remains on rover cache

=> 10 samples: 7 rock samples, 1 regolith, 1 atmospheric sample, 1 witness sample

=> covers partially or fully all iMOST scientific objectives



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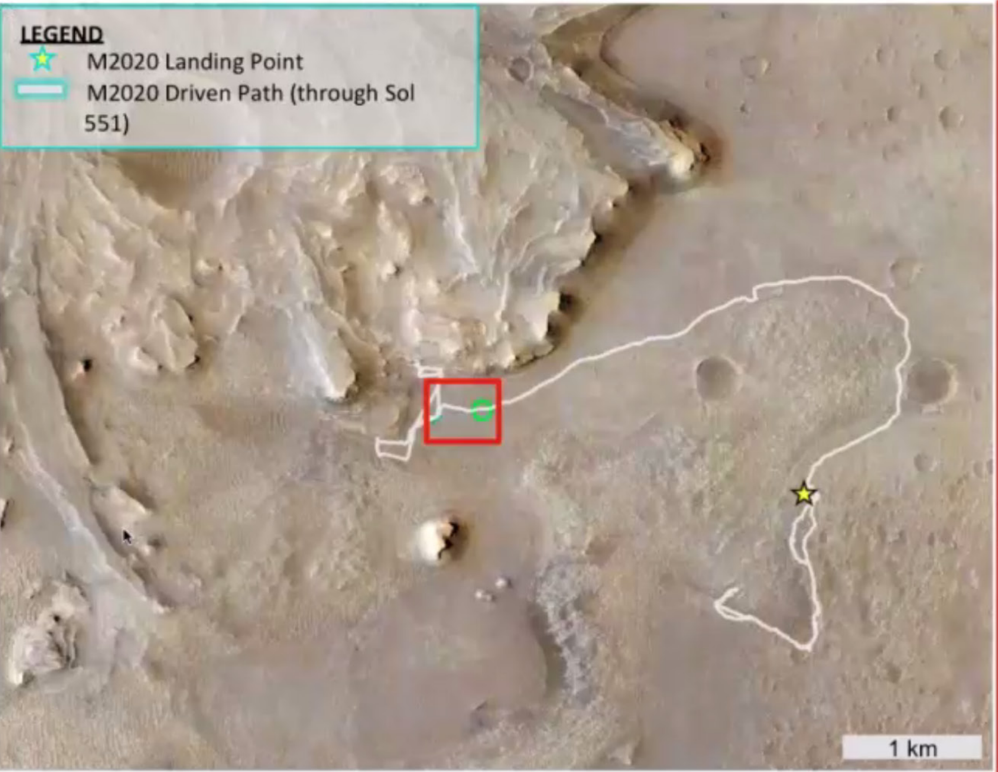
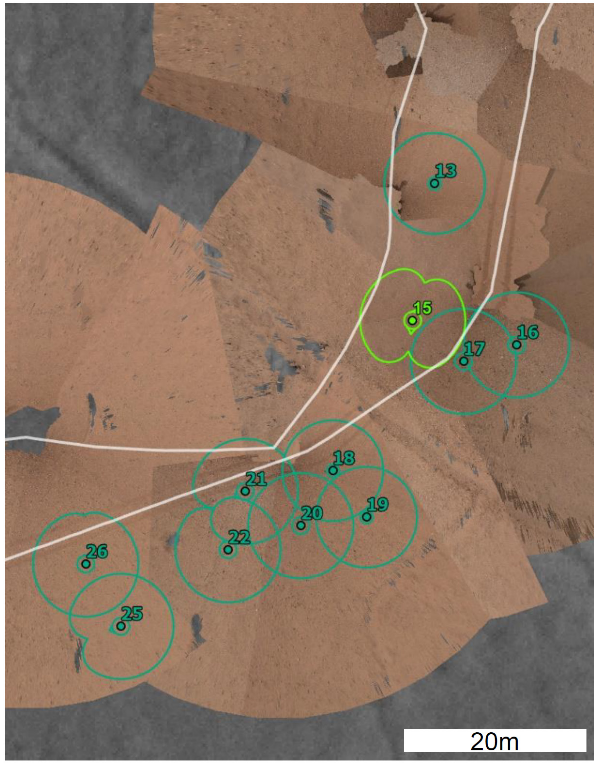
2. Scientific background & current steps – Storage in 1st depot

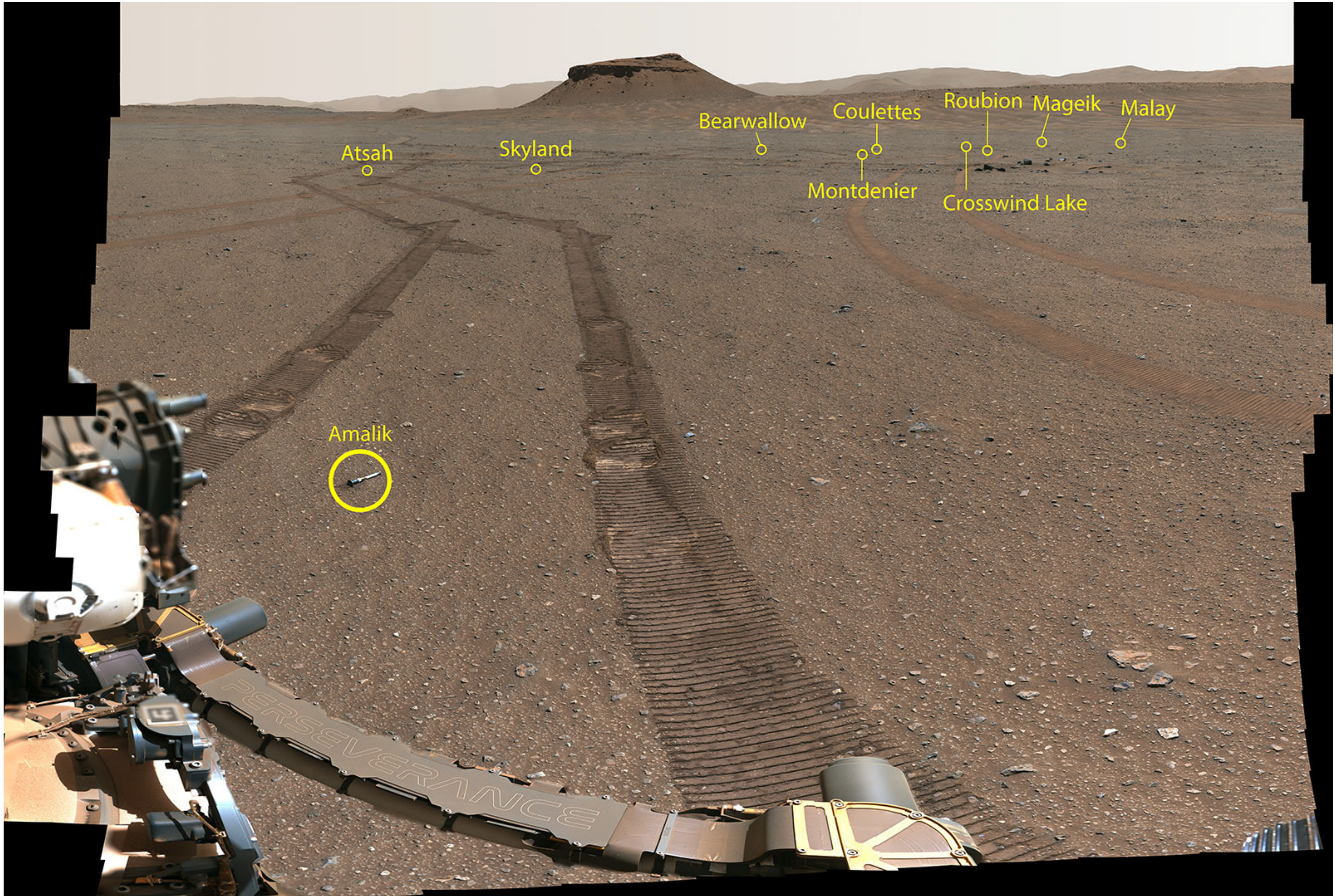
- most benign terrain, minimum landing risk
- soon certainty for a sample cache to return
- landing site could be within 200-400 m
- certification performed

Three Forks Campaign Site

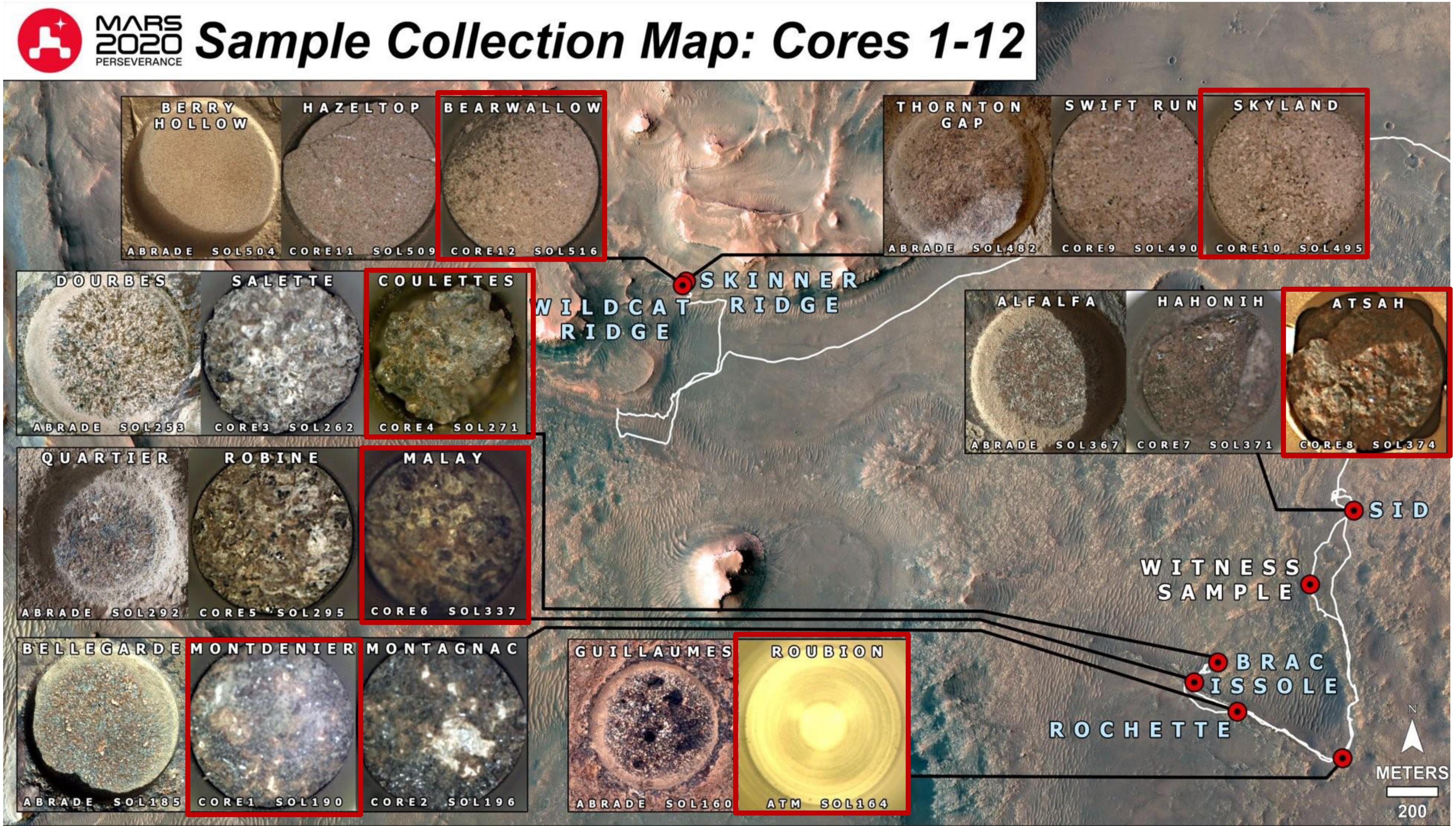




2. Scientific background & current steps – Storage in 1st depot



2. Scientific background & current steps – Samples (Cores & abraded patches)



2. Scientific background & current steps – MSR objectives

IMOST Objectives (1/2)

MSR Campaign Science Group

Proposed Objectives		
	Shorthand	**Full Statement of Objective**
Objective 1	*Geological environment(s)*	Interpret the primary geologic processes and history that formed the martian geologic record, with an emphasis on the role of water.
Sub-Obj. 1.1	*Sedimentary System*	Characterize the essential stratigraphic, sedimentologic, and facies variation of a sequence of martian sedimentary rocks.
Sub-Obj. 1.2	*Hydrothermal*	Understand an ancient martian hydrothermal system through study of its mineralization products and morphological expression.
Sub-Obj. 1.3	*Deep subsurface groundwater*	Understand the rocks and minerals representative of a deep subsurface groundwater environment.
Sub-Obj. 1.4	*Subaerial*	Understand water/rock/atmosphere interactions at the martian surface and how they have changed with time.
Sub-Obj. 1.5	*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.
Sub-Obj. 2.1	*Carbon chemistry*	Assess and characterize carbon, including possible organic and pre-biotic chemistry.
Sub-Obj. 2.2	*Biosignatures-ancient*	Assay for the presence of biosignatures of past life at sites that hosted habitable environments and could have preserved any biosignatures.
Sub-Obj. 2.3	*Biosignatures-modern*	Assess the possibility that any life forms detected are still alive, or were recently alive.

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2. Scientific background & current steps – MSR objectives

IMOST Objectives (2/2)

MSR Campaign Science Group

Proposed Objectives		
	Shorthand	Full Statement of Objective
Objective 3	*Geochronology*	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	*Planetary-scale geology*	Reconstruct the history of Mars as a planet, elucidating those processes that have affected the origin and modification of the crust, mantle and core.
Objective 6	*Environmental hazards*	Understand and quantify the potential martian environmental hazards to future human exploration and the terrestrial biosphere.
Objective 7	*ISRU*	Evaluate the type and distribution of in situ resources to support potential future Mars Exploration.

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Metrics for Evaluating Samples

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I. Estimated Sample Recovery Mass

Igneous Rock Density (g/cm^3)	Sedimentary Rock Density (g/cm^3)
2.9 ~Basalt	2.2 ~Mudstone

Sample Name		Core Length (cm)	Core Volume (cm^3)**	Core Length comp (length of shorter core is X% length of longer core)	Mass Estimates (g)
Montdenier	Igneous	5.98	8.4	97%	24.3
Montagnac	Igneous	6.14	8.7		25.2
Salette	Igneous	6.28	8.9	53%	25.8
Coulettes	Igneous	3.3	4.7		13.6
Robine	Igneous	6.08	8.6	50%	24.9
Malay	Igneous	3.07	4.3		12.5
Ha'ahóni (aka "Hahonih")	Igneous	6.5	9.24	96%	26.8
Atsá (aka "Atsah")	Igneous	6	8.46		24.5
Swift Run	Sedimentary	6.69	9.46	93%	20.8
Skyland	Sedimentary	5.85	8.27		18.2
Hazeltop	Sedimentary	5.97	8.44	98%	18.6
Bearwallow	Sedimentary	6.24	8.82		19.4

** Sedimentary Rock Volume Estimates are not from initial Mars 2020 reports. Purely estimates based on previous samples and used as a proof of concept

MCSG Perspective on Paired Samples

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Sample Mass Difference

MCSG experience with extraterrestrial samples (e.g. SNC meteorites, Tissint) terrestrial samples, and modified from the E2E-iSAG report

	Objective	Technical notes	*Conservative Mass Estimate (g)
Planetary Protection	Assess life and biohazard		1.5
Bulk Geochemistry	Major, minor, trace elements	A generous mass estimate and residual can likely be used for other analysis.	3
Mineralogy	Quantitative mineralogy; discrete clay mineral identification, amorphous component estimates	A generous mass estimate and residual can likely be used for other analysis.	1
Organics	Soluble and insoluble	Mass may be supplemented from other analysis	2
Petrology	Thin section of polished surface	Sedimentary point counts, framework grains, matrix and cement, and texture. Igneous texture, inclusions, zoning.	1.85
Isotopes	Element partitioning, mass dependent fractionation, etc.	Mass likely depends on the system (e.g., Ru vs. Ar)	2
Microanalysis	Microanalysis of individual subsamples	High resolution analysis of inorganic and organic chemistry, mineralogy, petrology, and isotope geochemistry	0.15
SUM			11.5

*Note, this mass is exaggerated to represent a conservative estimate. A scientifically compelling investigation can be made with far less *(e.g., Tissint studies used ~1.9 g)*

Take Home Message: All samples have plenty of material available to run traditional analyses on Earth and projecting into a new decade of instrument development, more sophisticated techniques will require less sample mass. Thus, ALL samples, regardless of which one "ranks" higher are scientifically return worthy and will provide ample sample for future interrogation.

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3. Next steps in the program – Your Chance!

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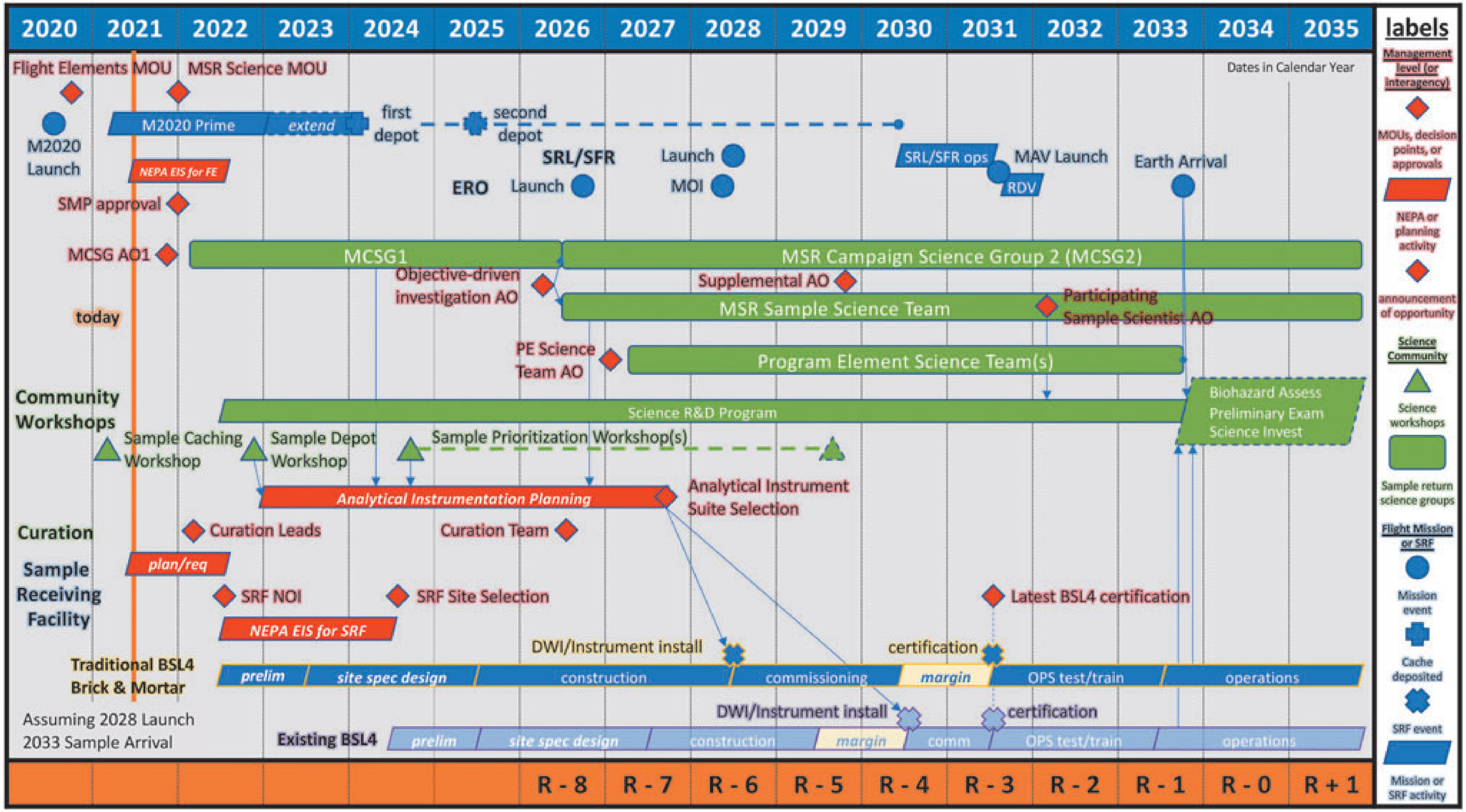
3. Next steps in the program – Timeline (2028-33)

MSPG2

return 2033

b



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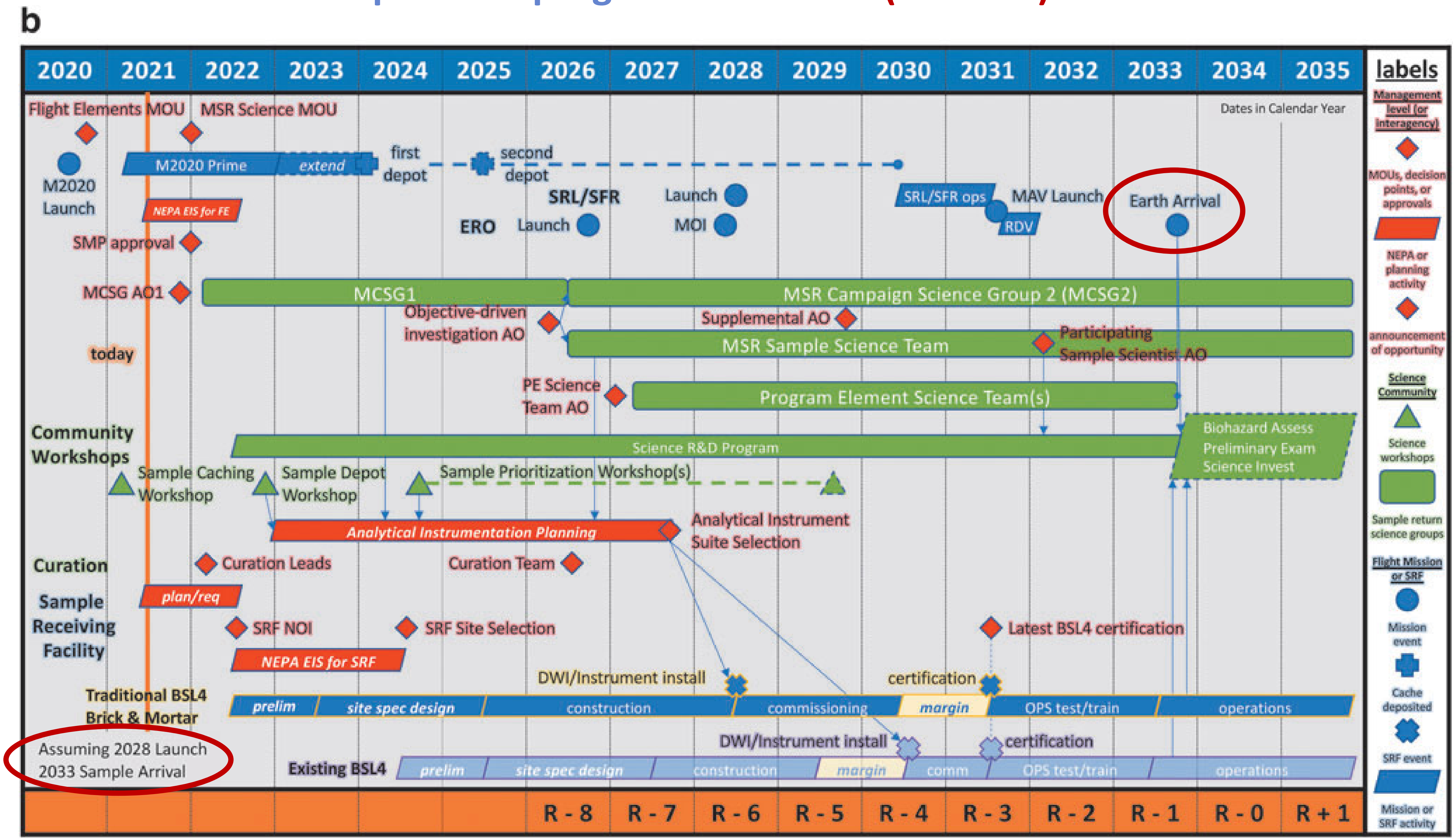
3. Next steps in the program – Timeline (2028-33)

MSPG2
return 2033

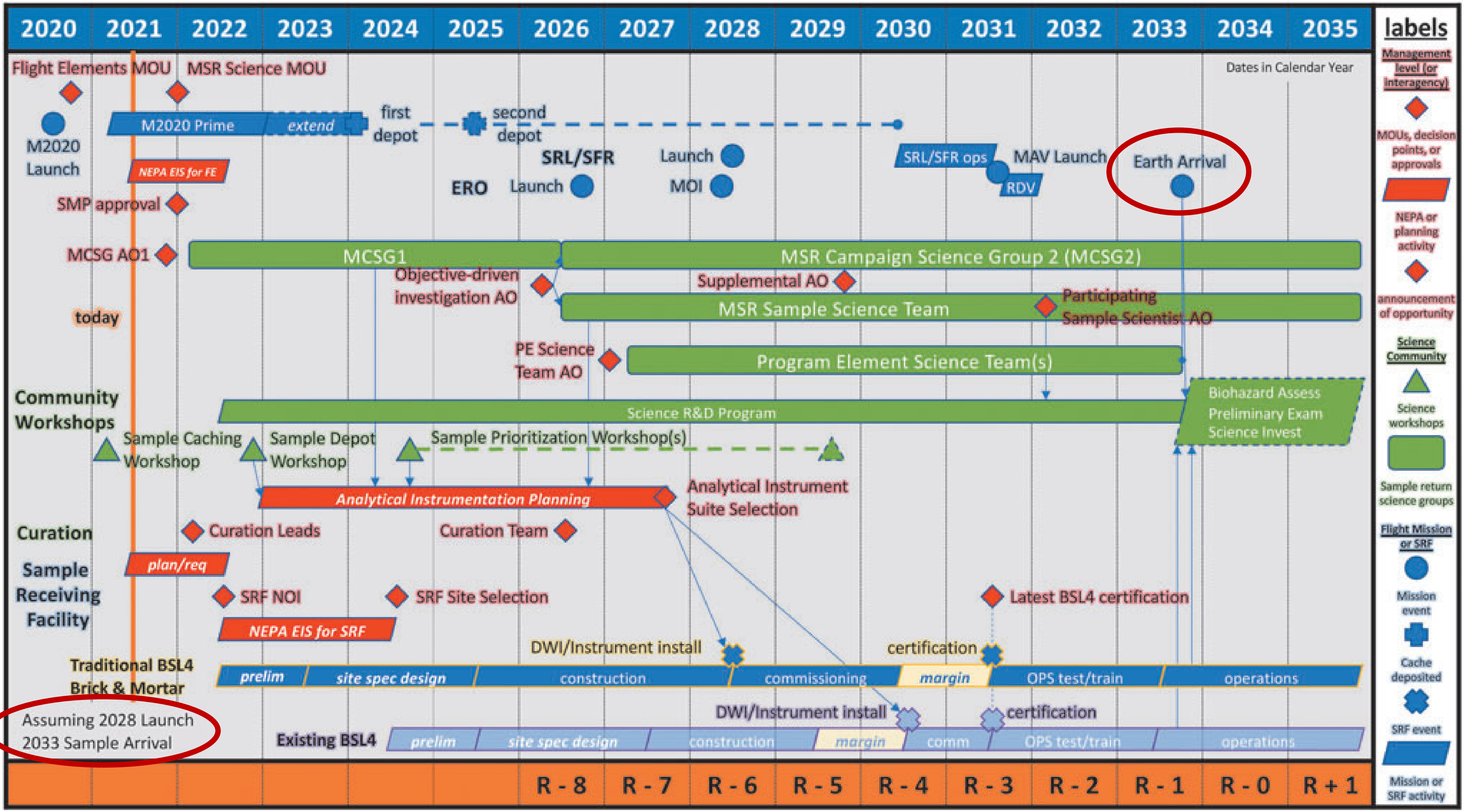


3. Next steps in the program – Timeline (2028-33)

MSPG2
return 2033

science community!

b



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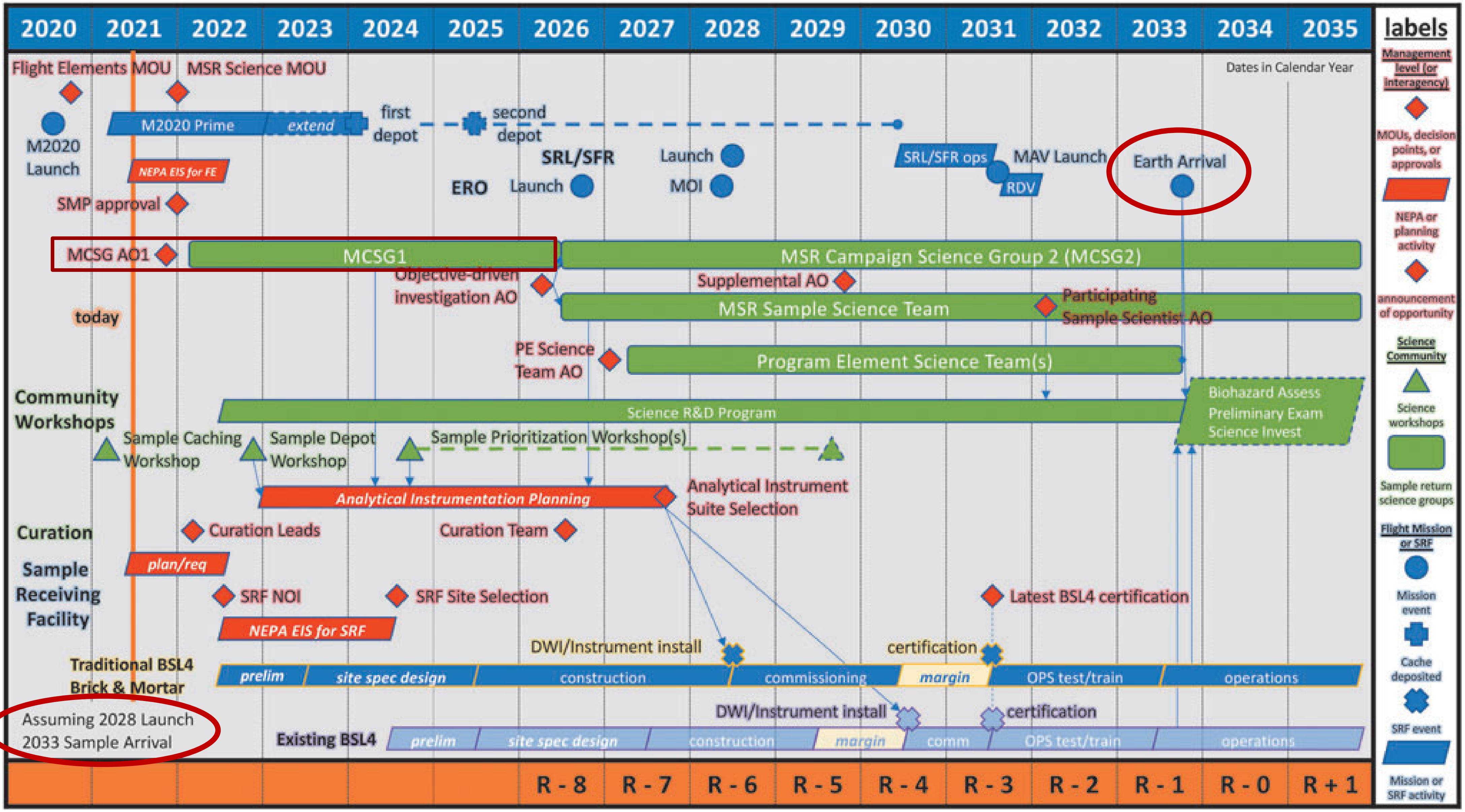
3. Next steps in the program – Timeline (2028-33)

MSPG2
return 2033

science community!

b



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MSPG2
return 2033

science community!

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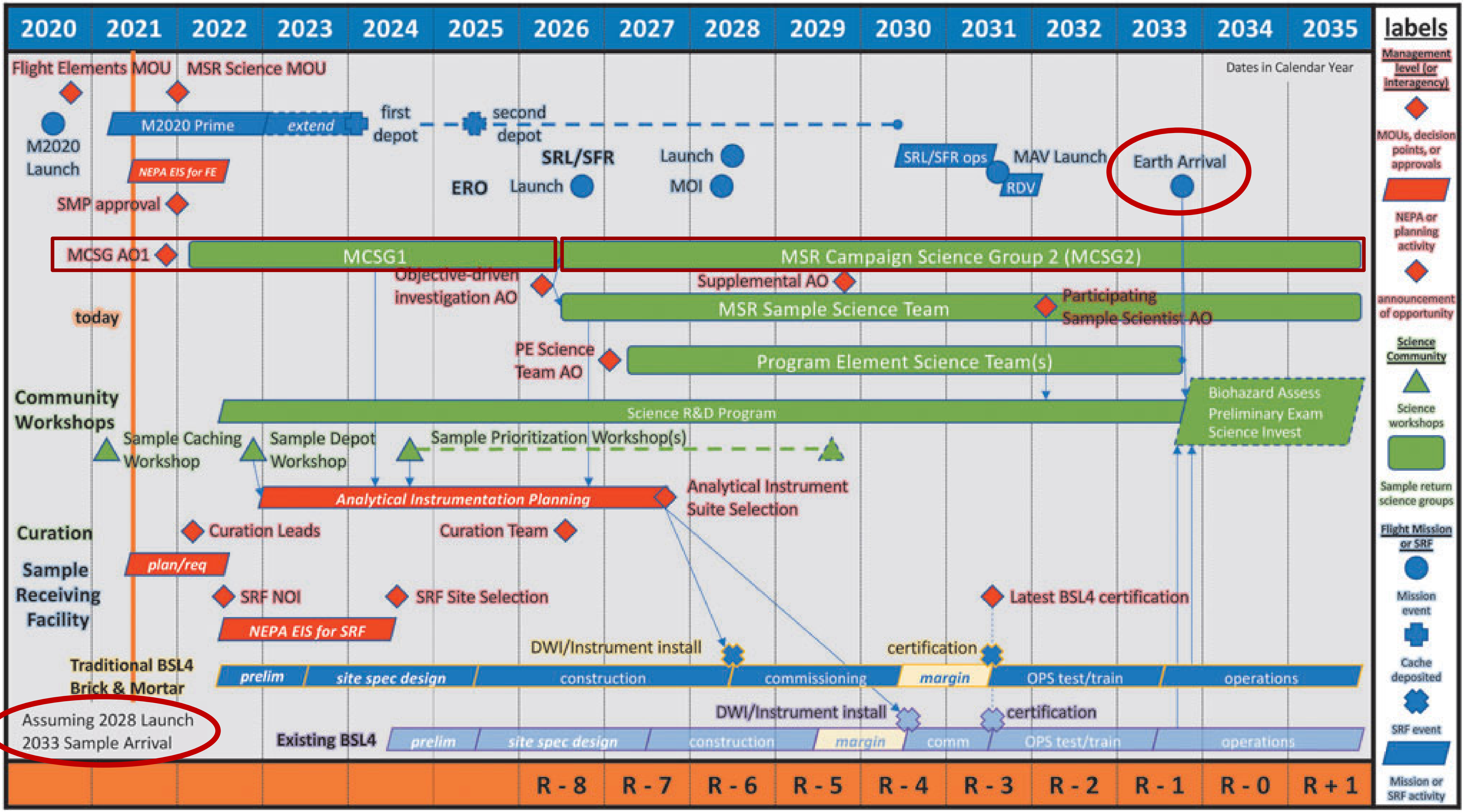

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science community!

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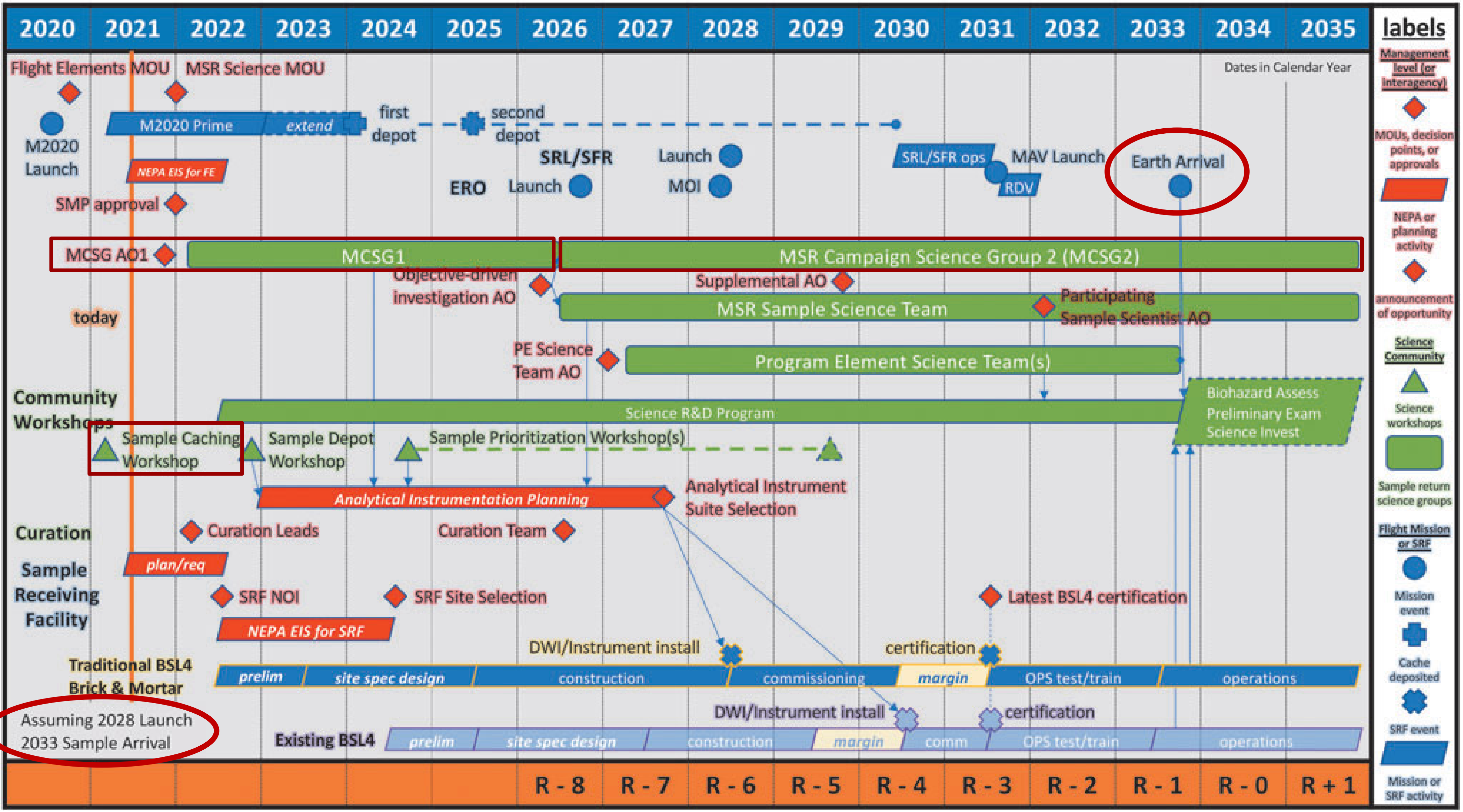

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3. Next steps in the program – Timeline (2028-33)

MSPG2
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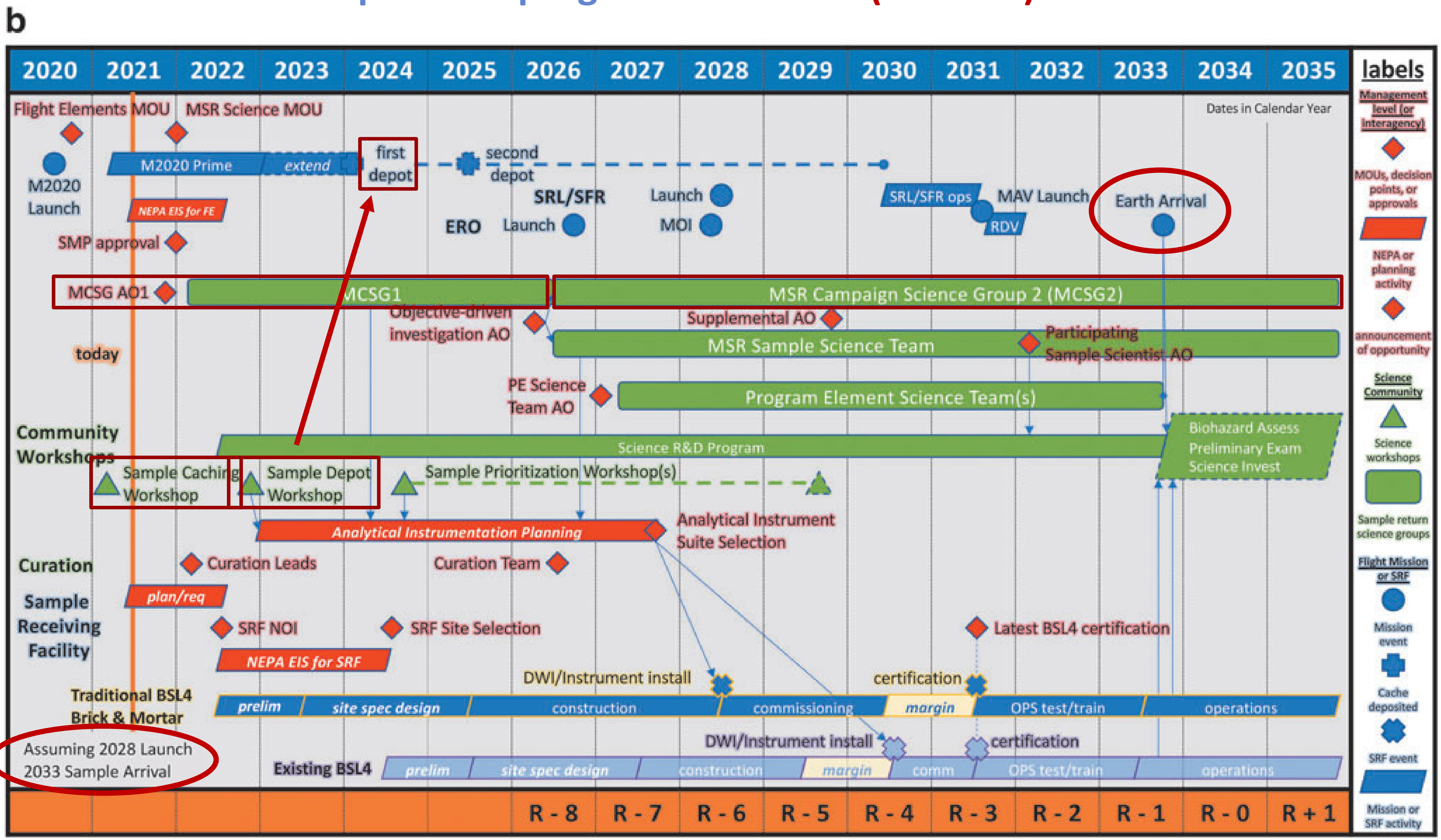
science community!



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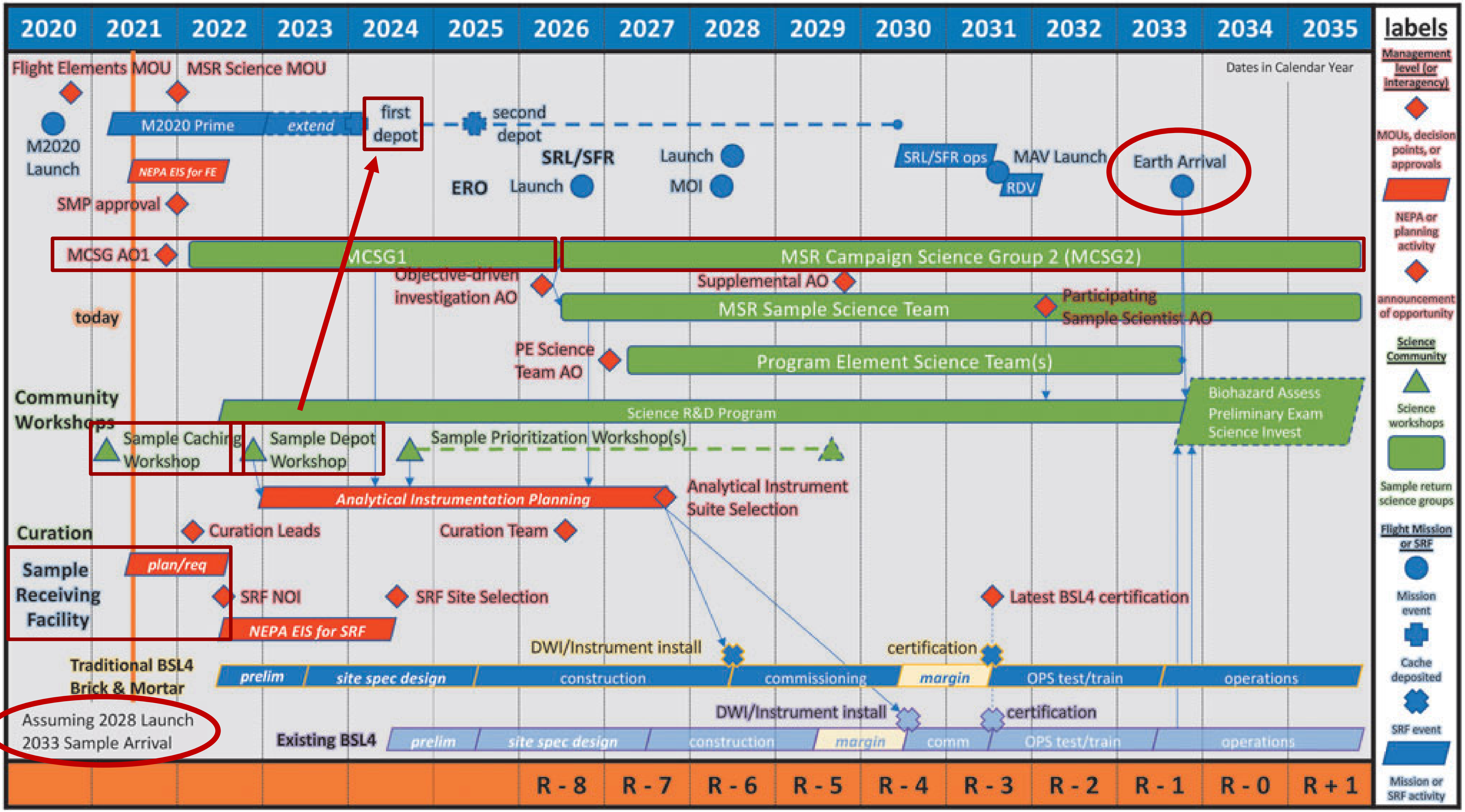
3. Next steps in the program – Timeline (2028-33)

MSPG2
return 2033

science community!

handling, extraction of atmosphere in BSL-4(?) cabinets

b



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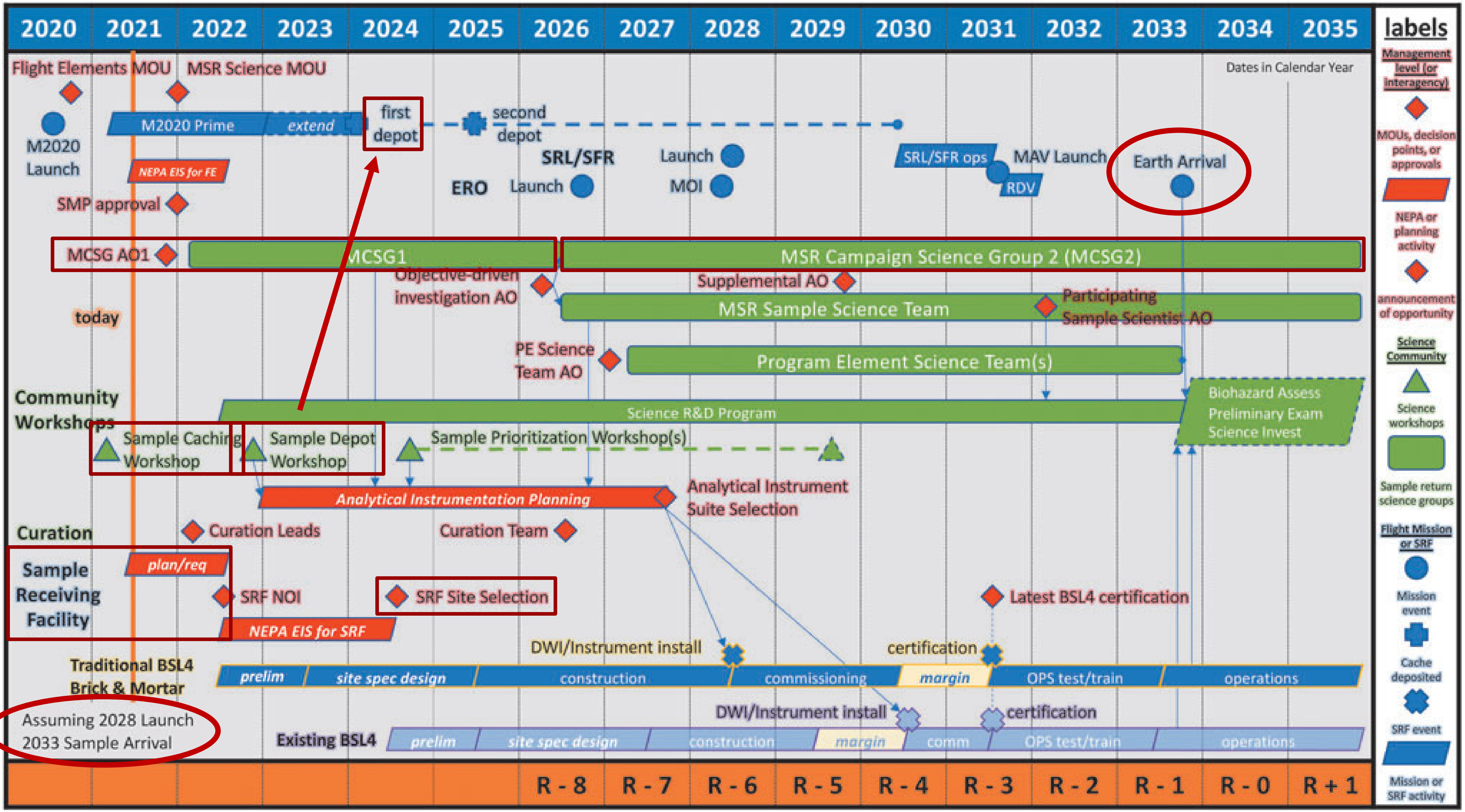
3. Next steps in the program – Timeline (2028-33)

MSPG2
return 2033

science community!

handling, extraction of atmosphere in BSL-4(?) cabinets

b



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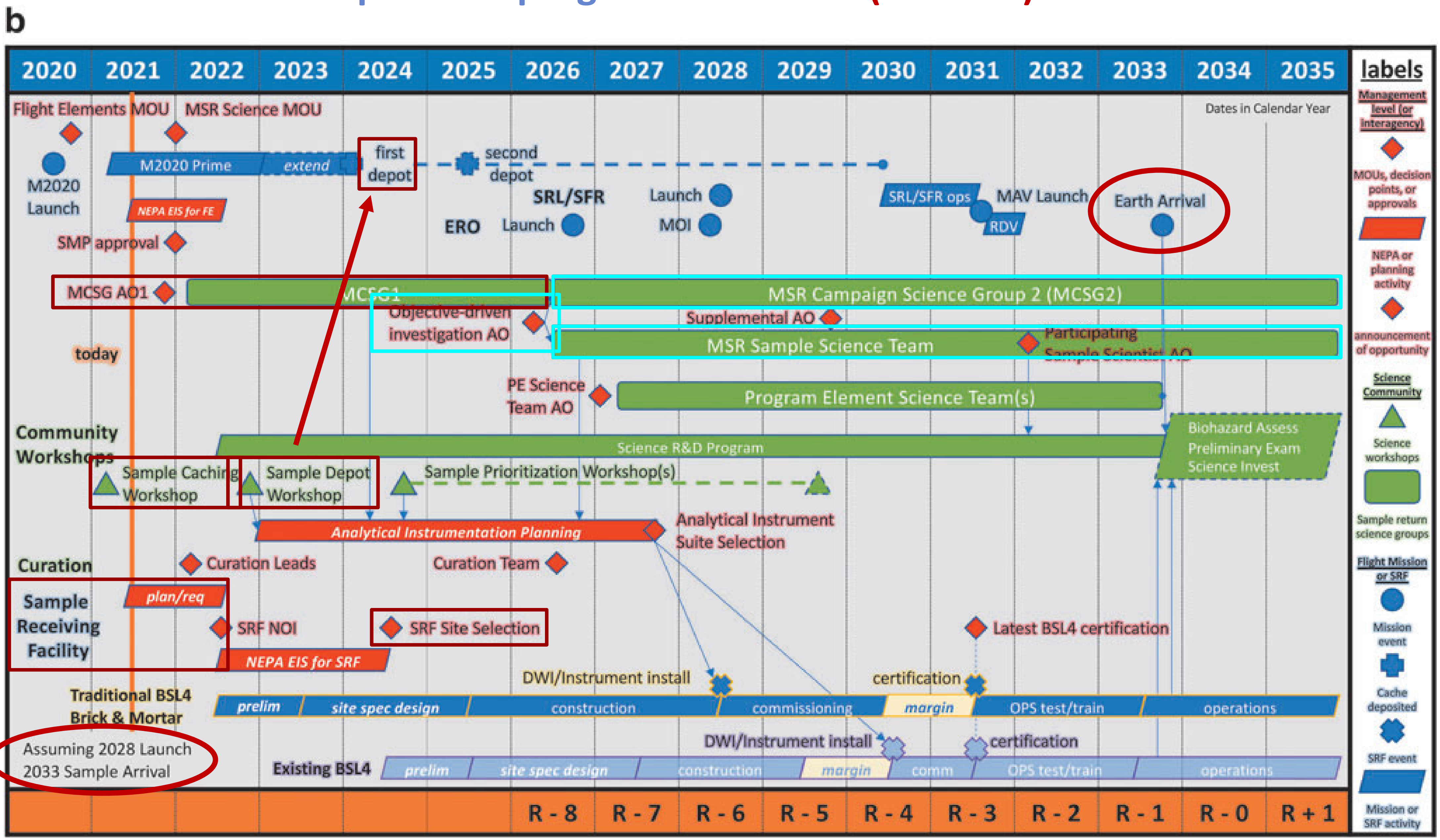

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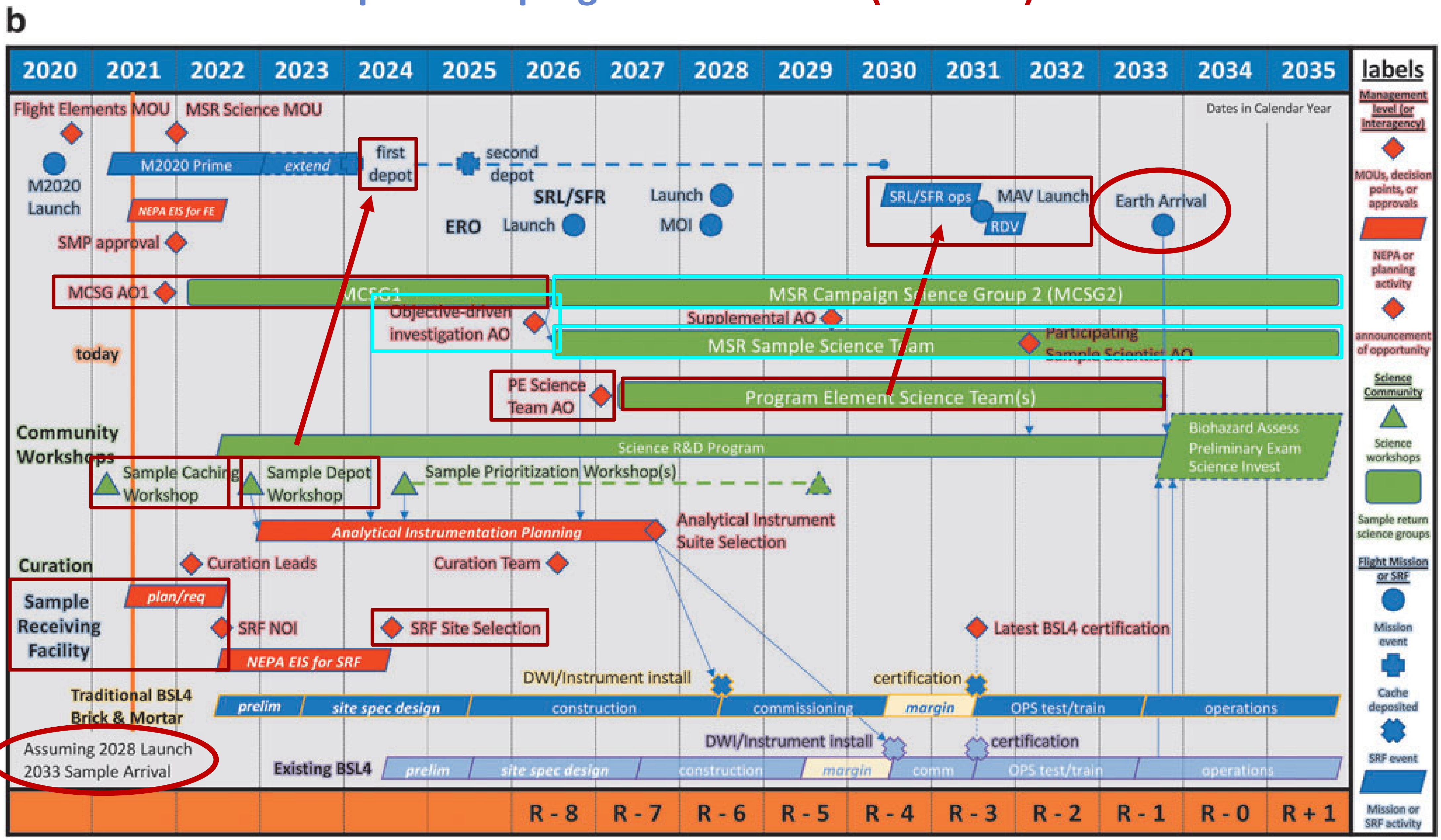
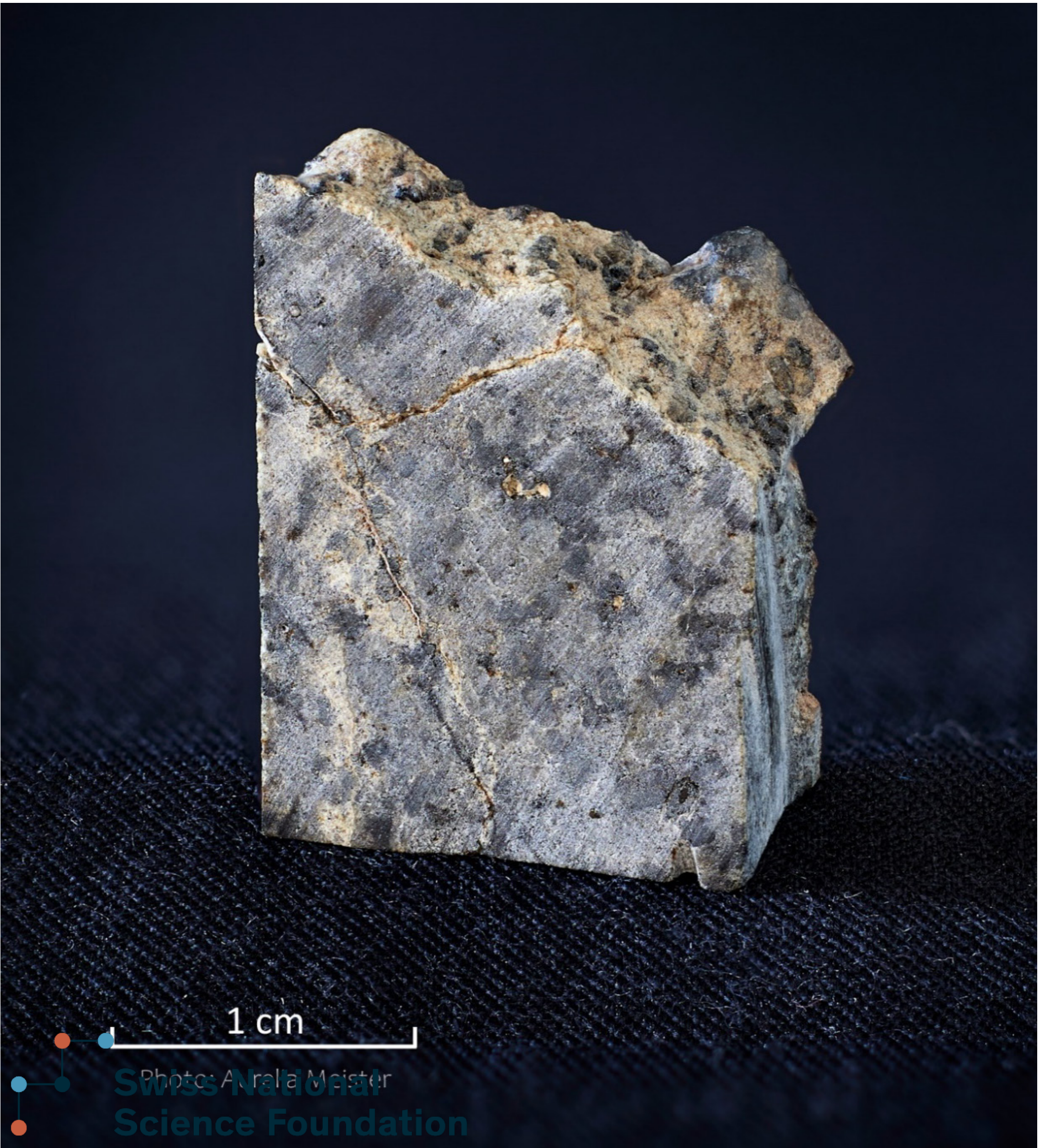


4. Martian Meteorites



NWA n.n., 143 g
ETH IGP collection (purchased from JNMC)
Photo: Aurelia Meister

DaG 476, 5 g
ETH IGP collection

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5. Conclusions

- **MSR will happen / is happening**
- First sample set successfully taken, placed –on the martian ground– into 1st depot
- Perseverance perseveres
- lots of opportunity for **science community participation** (2022-2035):
  - Workshops
  - Working groups, e.g. MSR Campaign Science Group (MSCG-2, rotating)
  - Sample facility requirements, analytical instrument suite

- **2026 at the very latest: Objective-driven examination AO (particularly time- & sterilization sensitive)**
  - **consortium studies preferred**
  - **PIs part of MSR Sample Science Team**
- Also: get prepared for later **regular "safe" samples' investigations**

Swiss National Science Foundation

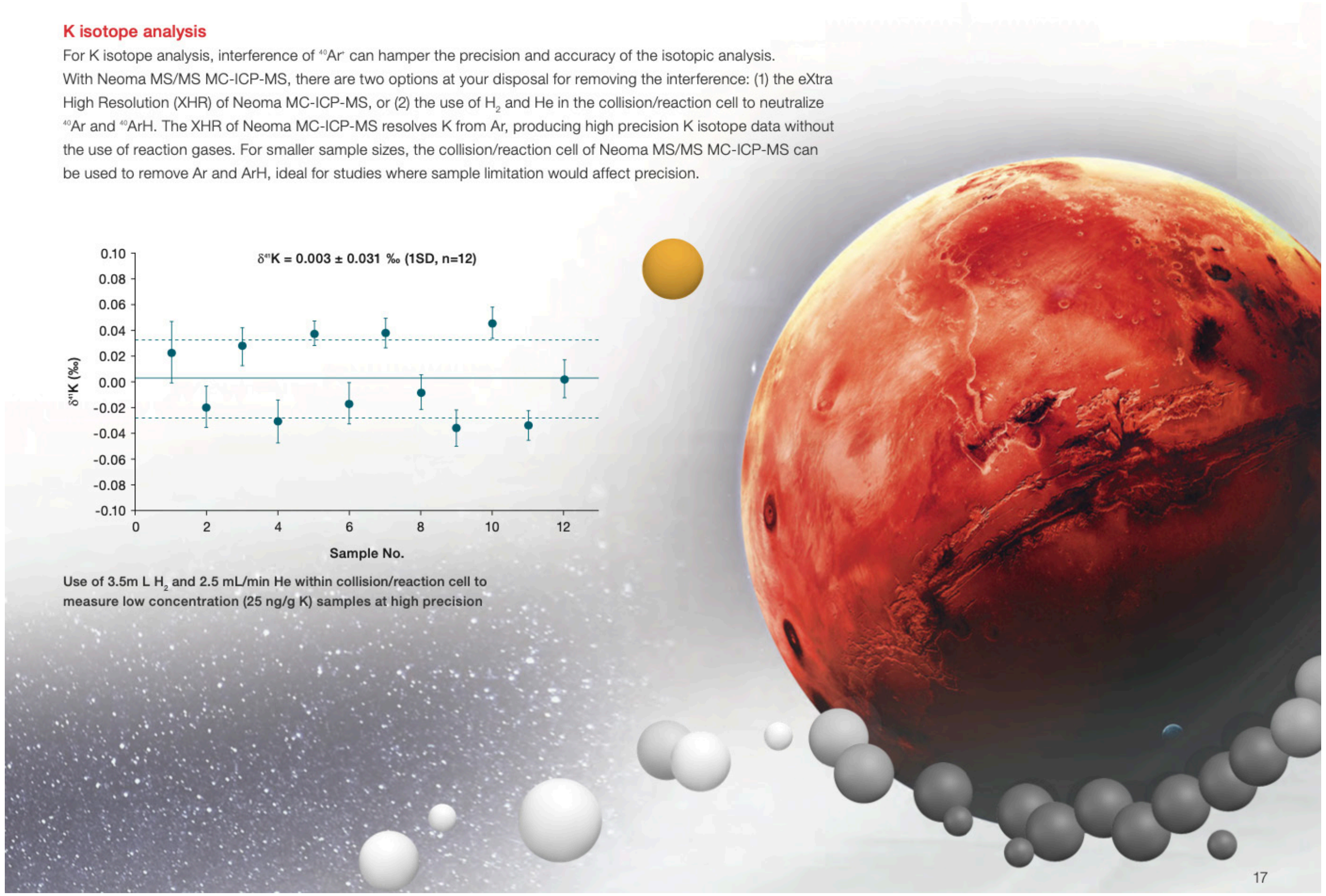
Thank you

Getting ready for Mars Sample Return

Objective

- prepare Switzerland for Mars Sample Return, and other potential returned samples (e.g. JAXA's MMX mission or future comet sample return).
  → past example OSIRIS-Rex, Hayabusa II

- Requires
  - **cutting-edge** labs/**instrumentation**
  - continued research output



K isotope analysis

For K isotope analysis, interference of $^{40}Ar^{+}$ can hamper the precision and accuracy of the isotopic analysis. With Neoma MS/MS MC-ICP-MS, there are two options at your disposal for removing the interference: (1) the eXtra High Resolution (XHR) of Neoma MC-ICP-MS, or (2) the use of H_2 and He in the collision/reaction cell to neutralize ^{40}Ar and ^{40}ArH. The XHR of Neoma MC-ICP-MS resolves K from Ar, producing high precision K isotope data without the use of reaction gases. For smaller sample sizes, the collision/reaction cell of Neoma MS/MS MC-ICP-MS can be used to remove Ar and ArH, ideal for studies where sample limitation would affect precision.

Use of 3.5m L H_2 and 2.5 mL/min He within collision/reaction cell to measure low concentration (25 ng/g K) samples at high precision

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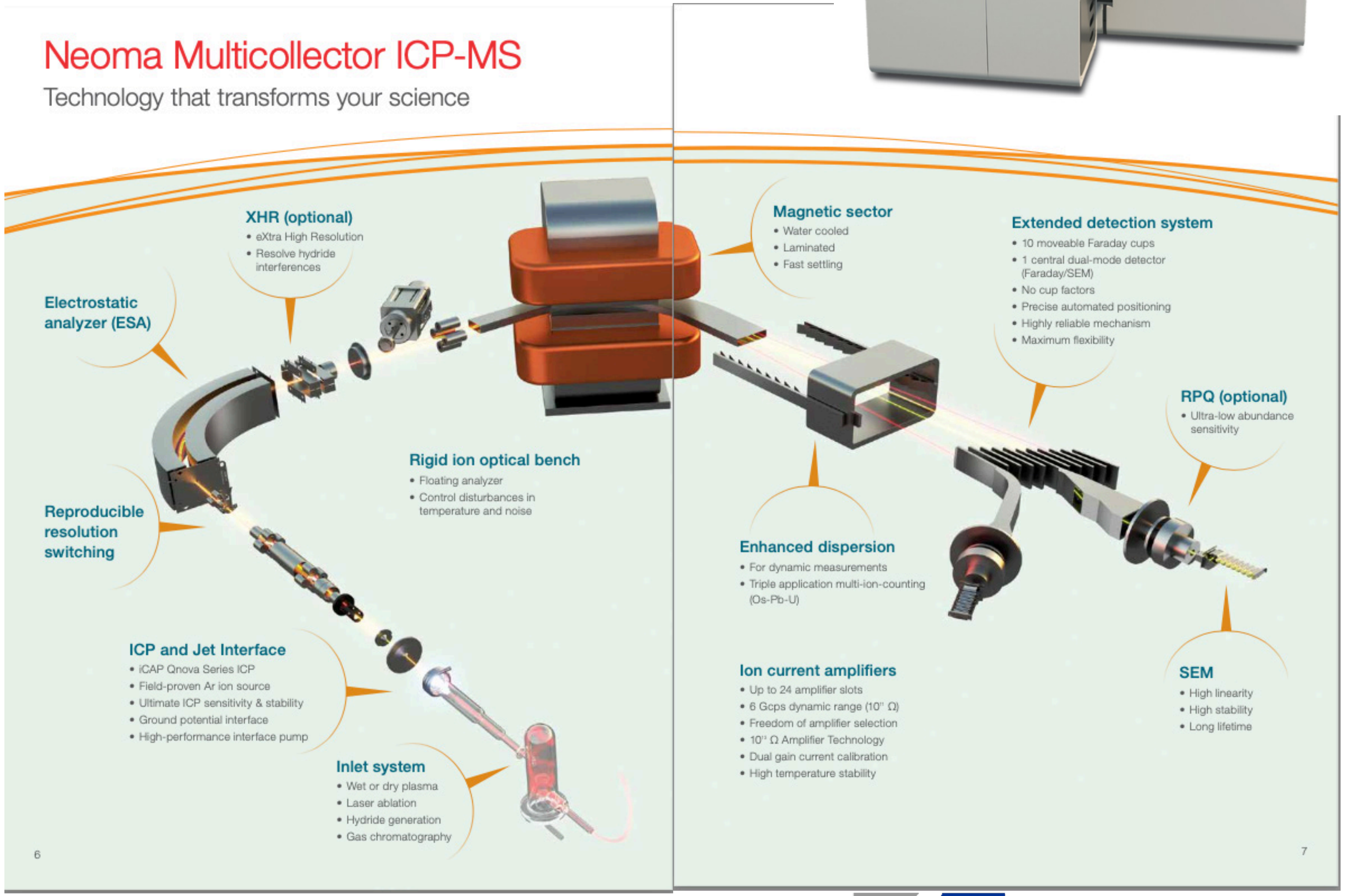
The next generation of MC-ICP-MS

Analyses of extraterrestrial materials e.g., meteorites

High precision Isotope ratios:
Precision in part per million (ppm) range
e.g. **PhD Kasia Liszewska – Fe isotope – Domain A**

Requires chemical separation of element prior to analysis



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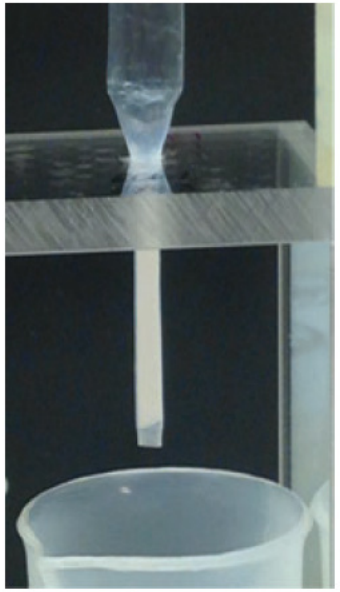
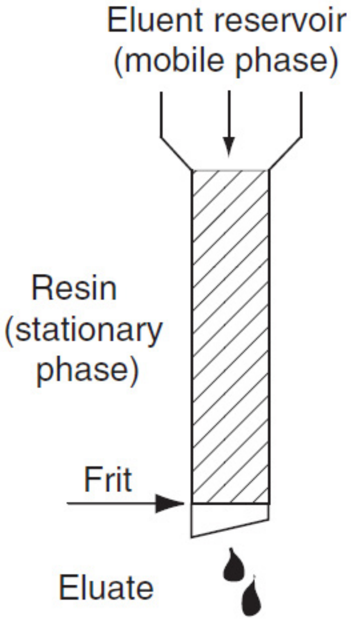
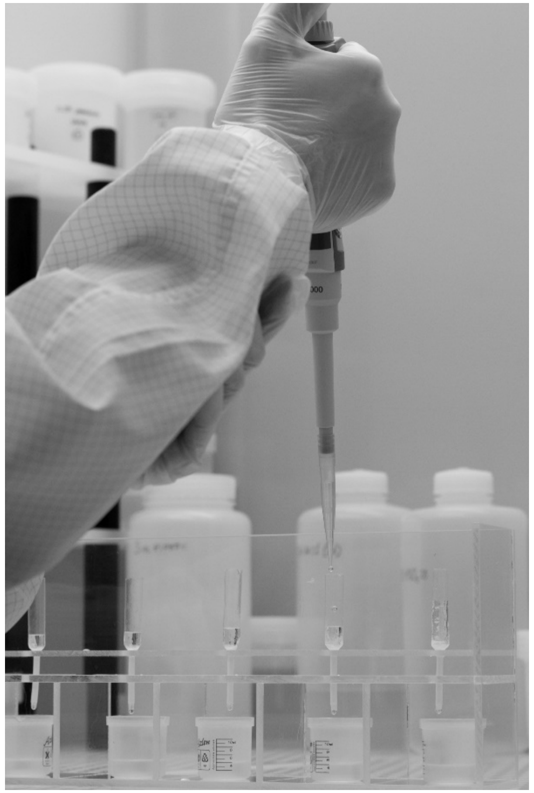
Element separation – Ion exchange chemistry



Schönbächler 2017

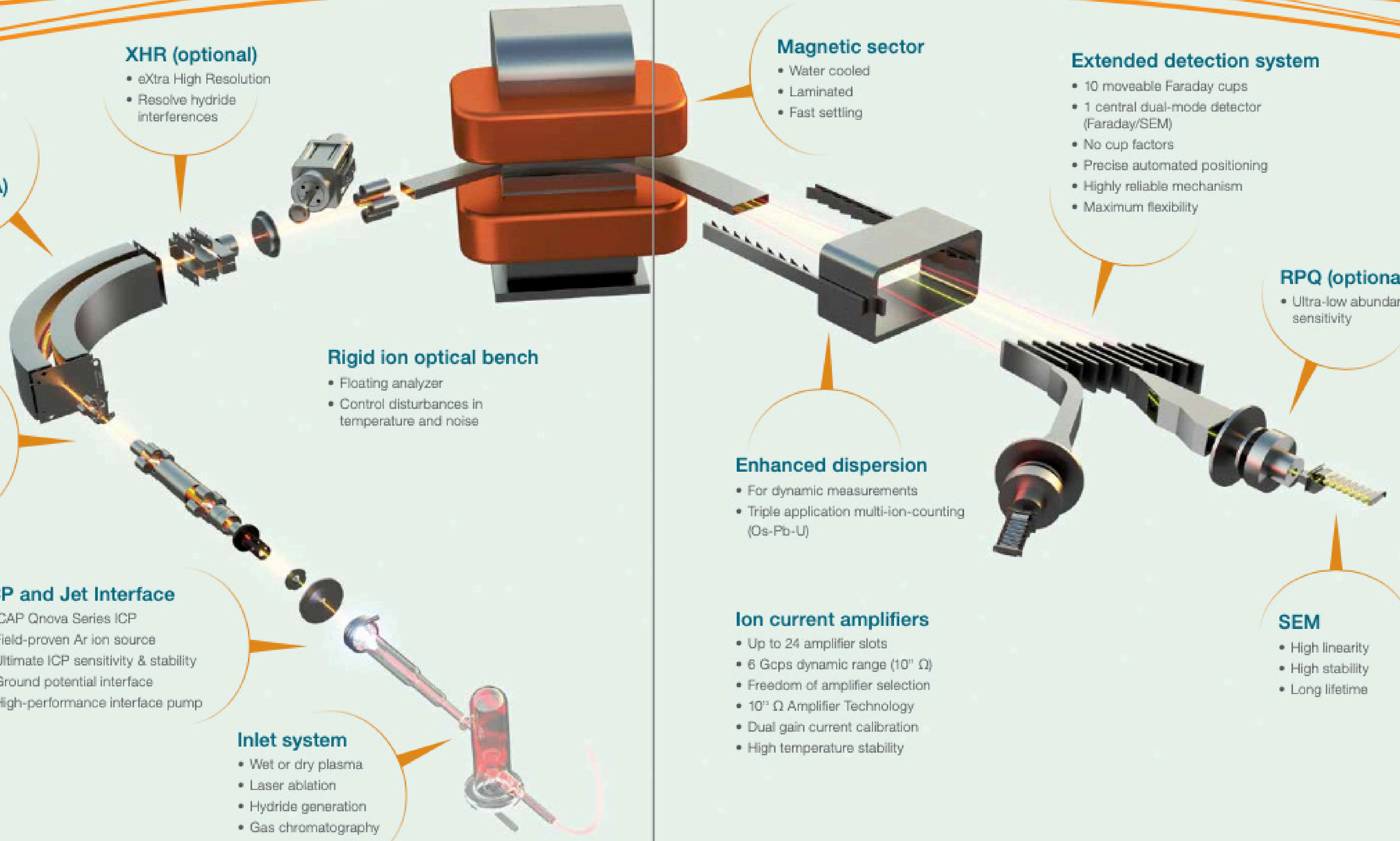




- Carried out in **clean room laboratory**
- 10 ETH workstations supplied with ultra-clean Class 10 (ISO 4) air **dedicated to cosmochemistry**

Neoma Multicollector ICP-MS

Technology that transforms your science



Electrostatic analyzer (ESA)

XHR (optional)

- eXtra High Resolution
- Resolve hydride interferences

Reproducible resolution switching

Rigid ion optical bench

- Floating analyzer
- Control disturbances in temperature and noise

ICP and Jet Interface

- iCAP Qnova Series ICP
- Field-proven Ar ion source
- Ultimate ICP sensitivity & stability
- Ground potential interface
- High-performance interface pump

Inlet system

- Wet or dry plasma
- Laser ablation
- Hydride generation
- Gas chromatography

Magnetic sector

- Water cooled
- Laminated
- Fast settling

Extended detection system

- 10 moveable Faraday cups
- 1 central dual-mode detector (Faraday/SEM)
- No cup factors
- Precise automated positioning
- Highly reliable mechanism
- Maximum flexibility

RPQ (optional)

- Ultra-low abundance sensitivity

Enhanced dispersion

- For dynamic measurements
- Triple application multi-ion-counting (Os-Pb-U)

Ion current amplifiers

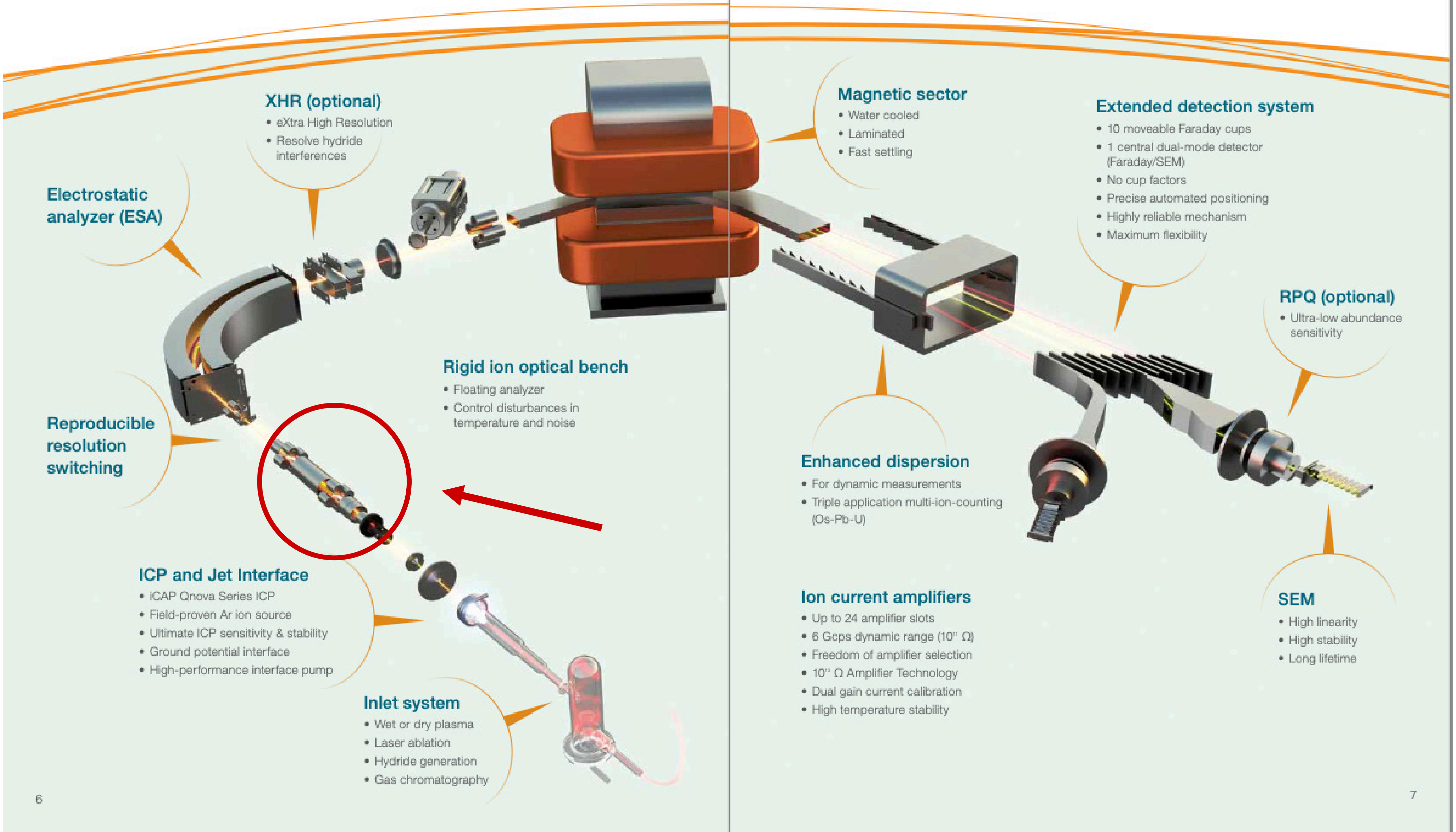
- Up to 24 amplifier slots
- 6 Gcps dynamic range (10^{11} Ω)
- Freedom of amplifier selection
- 10^{13} Ω Amplifier Technology
- Dual gain current calibration
- High temperature stability

SEM

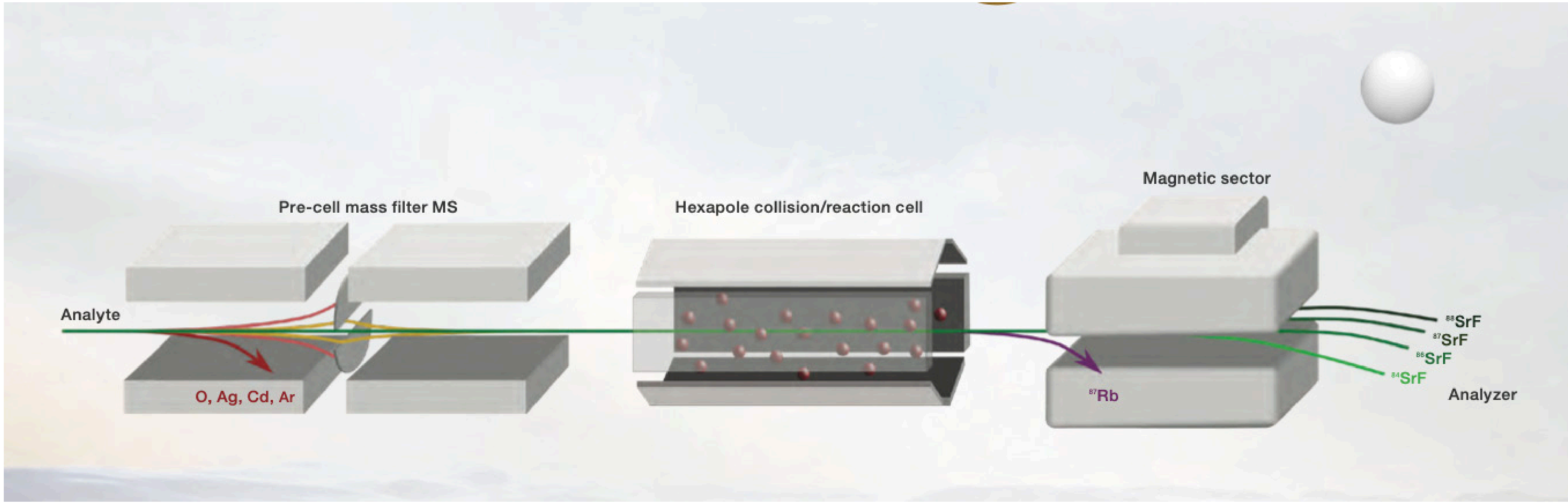
- High linearity
- High stability
- Long lifetime

Neoma Multicollector ICP-MS

Technology that transforms your science



Neoma – mass filter & collision cell



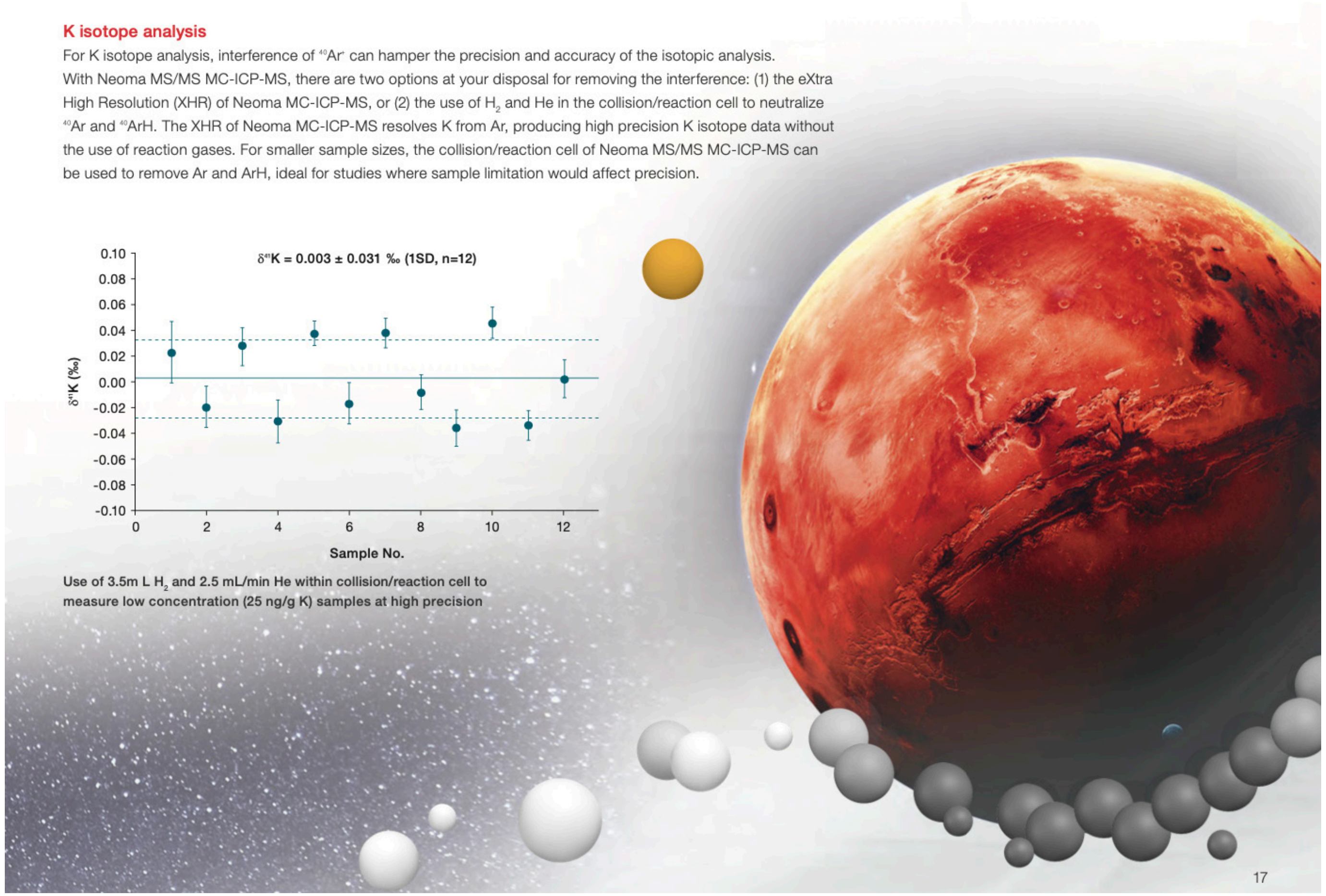
From Brochure Thermo Fisher

Getting ready for Mars Sample Return

Objectives

- Swiss wide access within PlanetS / SIPS
- Located at Earth Science, ETH Zurich

- Open for projects on extraterrestrial samples



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