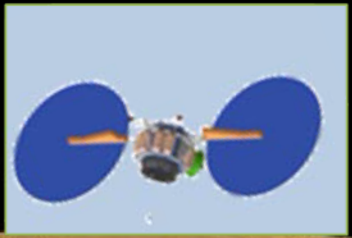
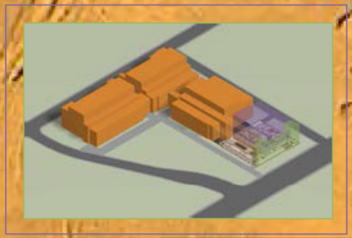




MSR Current Architecture Concept

Robert Shotwell

Chief Engineer Mars Program

NASA Jet Propulsion Laboratory

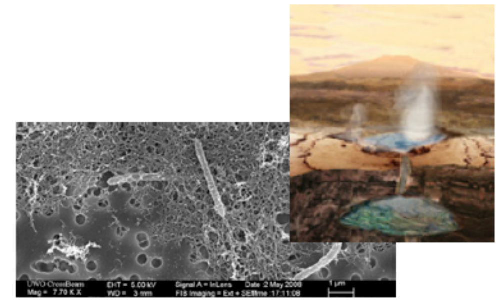
28 July, 2015

Mars Exploration Program (MEP)

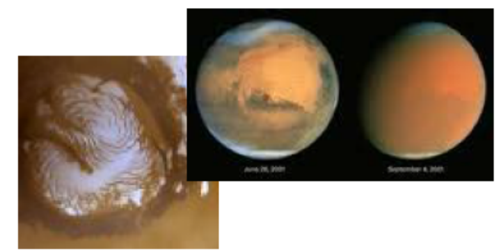
- The Mars Exploration Program is a science-driven, strategically interconnected series of missions and related functions:
  - Scientific questions answered on earlier missions serve to refine the investigations and payloads of later missions
  - Capabilities developed and demonstrated on earlier missions serve to reduce risk and enhance contributions of later missions
  - Orbital missions do “double duty” by providing relay and critical data observations which *multiply* the effectiveness and return of what landed missions would be capable of without them
  - Effectiveness of each mission enhanced by shared program-wide support: R&A, Formulation & Engineering Offices, Technology Planning and investments

Mars Science Strategy

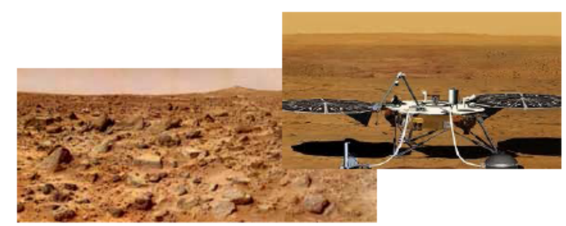
- **Goal I: Determine If Life Ever Arose On Mars**
  - Objective A: Characterize past habitability and search for evidence of ancient life
  - Objective B: Characterize present habitability and search for evidence of extant life
  - Objective C: Determine how the long-term evolution of Mars affected the physical and chemical environment critical to habitability and the possible emergence of life



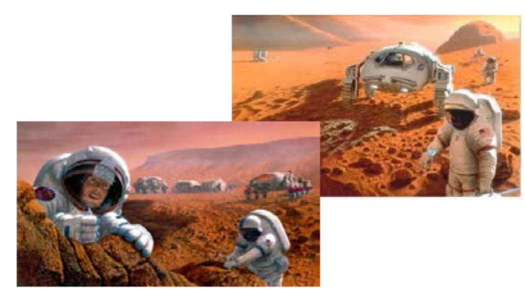
- **Goal II: Understanding The Processes And History Of Climate On Mars**
  - Objective A.: Characterize Mars' Atmosphere, Present Climate, and Climate Processes Under Current Orbital Configuration
  - Objective B.: Characterize Mars' Recent Climate and Climate Processes Under Different Orbital Configurations
  - Objective C.: Characterize Mars' Ancient Climate and Climate Processes



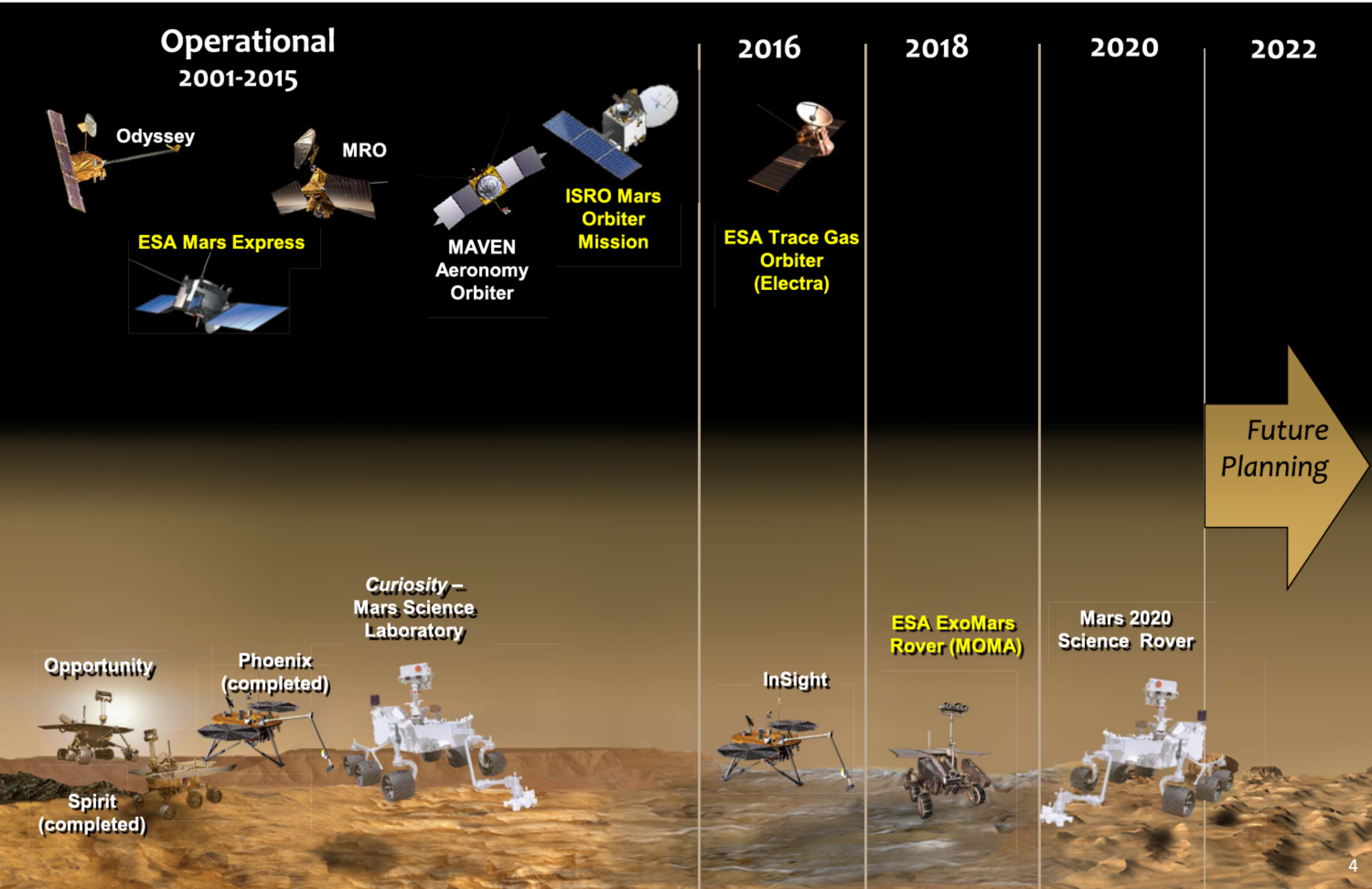
- **Goal III: Determine The Evolution Of The Surface And Interior Of Mars**
  - Objective A.: Determine the nature and evolution of the geologic processes that have created and modified the Martian crust
  - Objective B.: Characterize the structure, composition, dynamics, and evolution of Mars' interior
  - Objective C.: Understand the origin, evolution, composition and structure of Phobos and Deimos.



- **Goal IV: Prepare For Human Exploration**
  - Objective A: Obtain knowledge of Mars sufficient to design and implement a human mission with acceptable cost, risk and performance



Mars Exploration Mission Timeline



Motivation: Sample Return is Key to the Future of Mars Science

"The highest priority missions for Mars in the coming decade are the elements of the Mars Sample Return Campaign – [beginning with] the Mars Astrobiology Explorer-Cacher (MAX-C)"

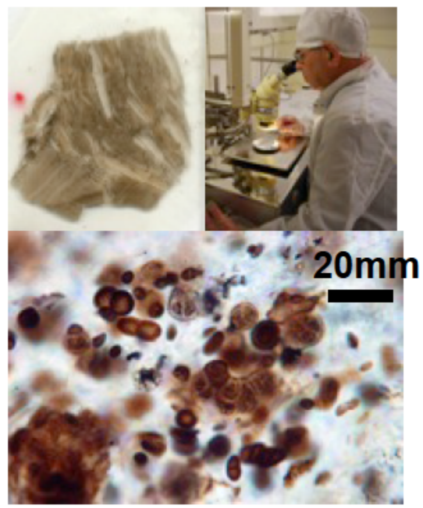
Committee on the Planetary Science Decadal Survey; NRC, March 2011, p.164

The Mars 2020 Mission is *"consistent with the Decadal Survey's MAX-C concept: to seek out and identify materials from the former habitable environments, to collect them, and to cache them on Mars for return to Earth by later spacecraft missions."*

Report of the Mars 2020 Science Definition Team; Mustard, et al., July 2013, p.14

Reasons for returning samples for analysis on Earth…

Could use advanced instrumentation not amenable for flight to Mars.



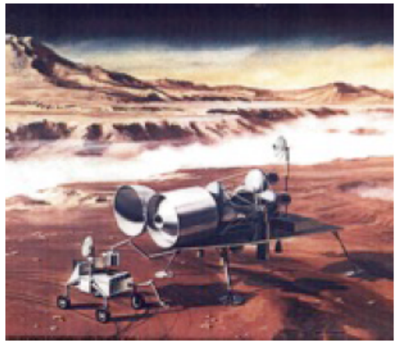
Could employ techniques requiring complex sample preparation.

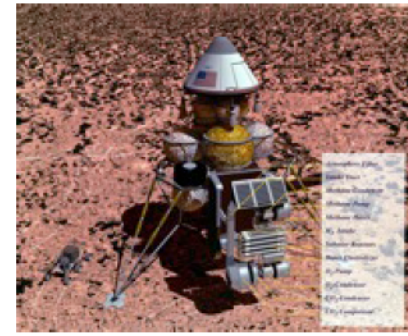
Could use a virtually unlimited array of different instruments, including future instruments not yet even designed.

- **Acknowledged as the only credible method to perform definitive detection of a biosignature.**
- **Gain the ability to run sequential analyses and replicate analyses in different labs.**

Adapted from ND-SAG (2008); iMARS (2008); NRC Decadal Survey (2011), M-2020 SDT (2013)

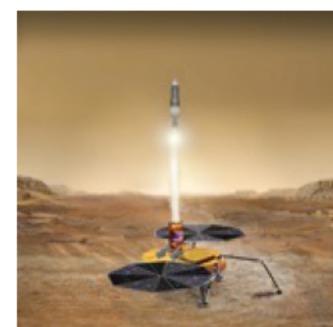
History of Mars Sample Return



- First era of concepts considered and studied in the 1970's and 1980's, with a wide variety of approaches and goals
- Second era of concepts gained momentum late '90's after claims of bio-signatures discovered in meteorite ALH84001 -> Focus on **Astrobiology** emerges
  – Strong international interest: Initially CNES (1999-2003), then multilateral iMEWG (2007-2009), and eventually bilateral NASA-ESA (2009-2011)
- Multi-project "Campaign" Approach adopted during 2010 Planetary Science Decadal Survey development
- Remains the basis for current planning approach described in following slides

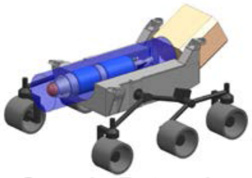


Notional Elements, Functions, and Sample States

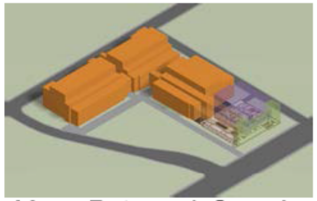
Elements

Mars Sample Caching Rover Concept



Mars Sample Return Lander Concept

Mars Sample Return Orbiter Concept



Mars Returned Sample Handling (MRSH) Facility

Functions

Launch from Earth/Land on Mars → Select Samples → Acquire/Cache Samples

→ Retrieve/Package Samples on Mars → Launch Samples to Mars Orbit *

→ Capture and Isolate Sample Container → Return to Earth → Land on Earth *

→ Retrieve/Quarantine and Preserve Samples on Earth → Assess Hazards → Sample Science

* Launching orders of MSR orbiter and lander can be reversed

Stable Sample States

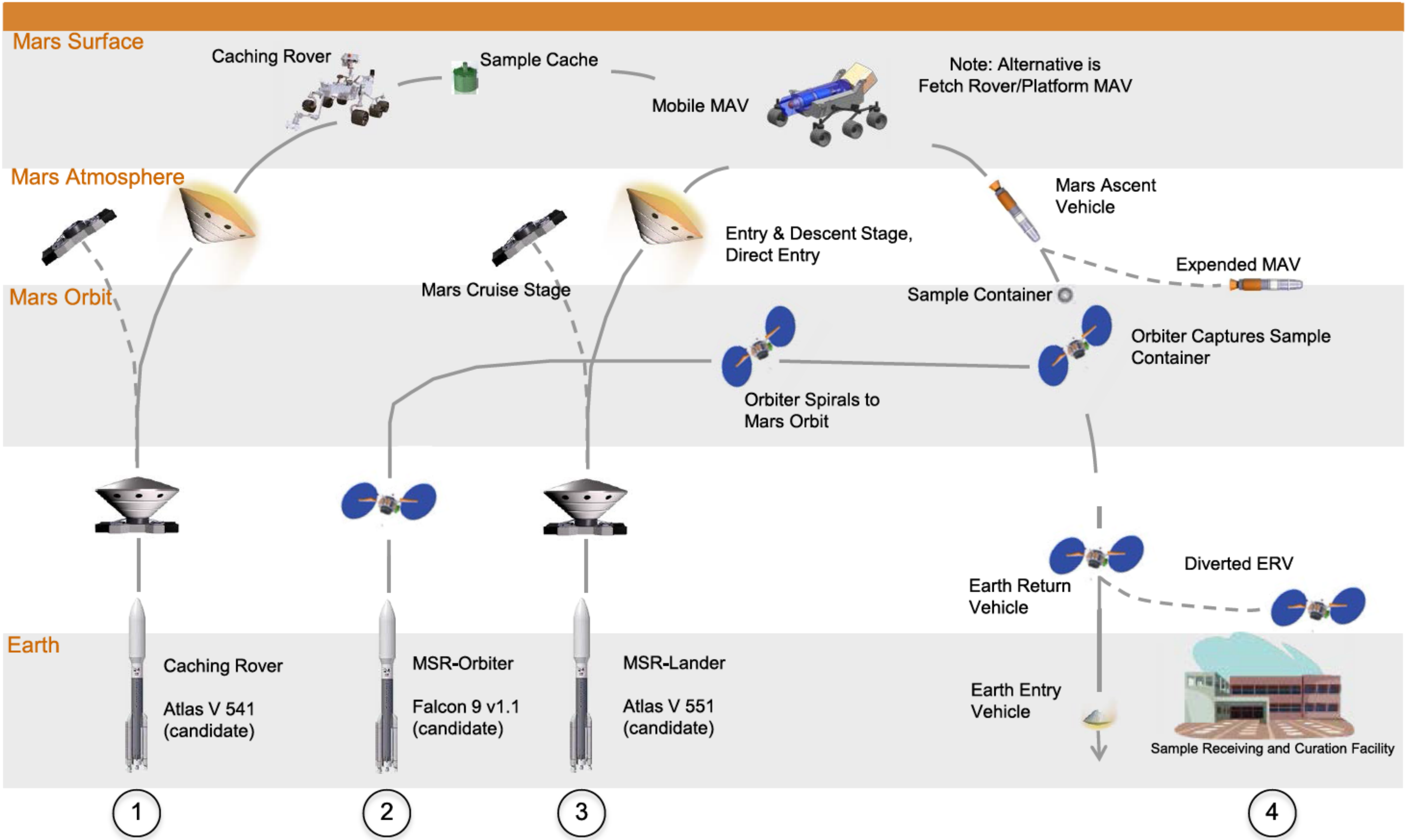
Sample Canister On Mars Surface

Orbiting Sample (OS) in Mars Orbit

Orbiting Sample (OS) On Earth

Sample Science

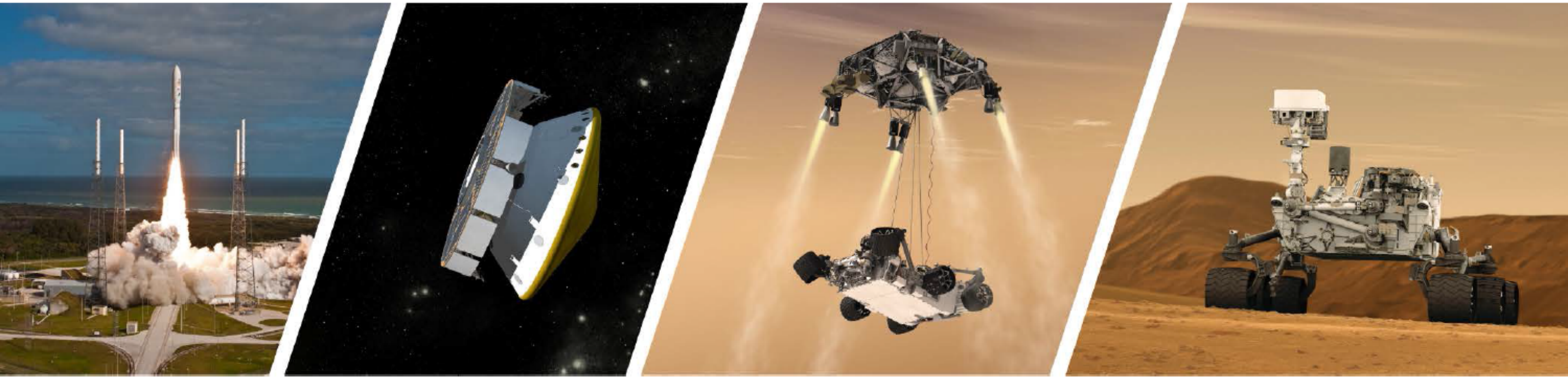
Current Architecture Concept



Note: MSR-Lander and MSR-Orbiter can be launched in either order

Pre-Decisional: For planning and discussion purposes only.

Mars 2020 Mission Concept



LAUNCH

- MSL class/capability launch vehicle
- Period: Jul/Aug 2020

CRUISE/APPROACH

- 7.5 month cruise
- Arrive Feb 2021

ENTRY, DESCENT & LANDING

- MSL EDL system: guided entry and powered descent/Sky Crane
- 25x20km landing ellipse
- Access to landing sites ±30° latitude, ≤0.5 km elevation
- ~1000 kg rover

SURFACE MISSION

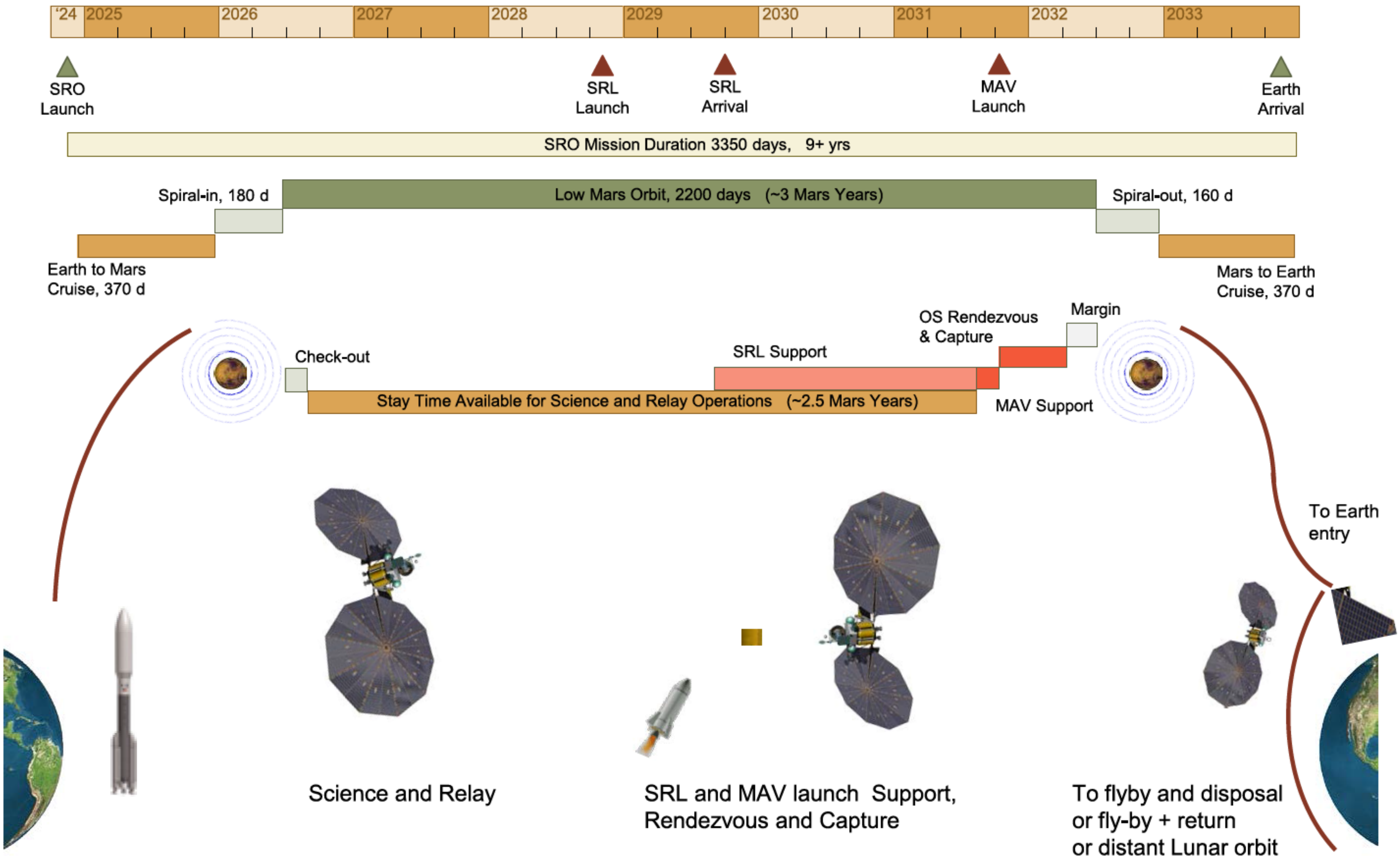
- Prime mission of 1.5 Mars year
- 20 km traverse distance capability
- Seeking signs of past life
- Returnable cache of samples
- Prepare for human exploration of Mars

M2020 includes sample acquisition and caching system

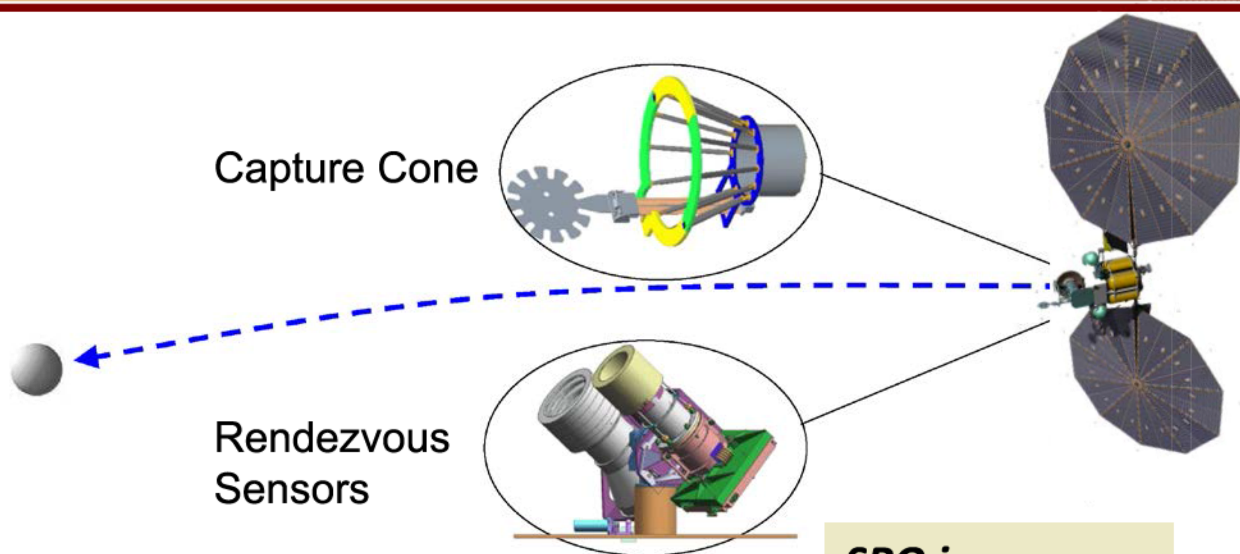
http://mars.jpl.nasa.gov/mars2020/

SRO Mission Concept

Notional Timeline and Launch Dates



Notional SRO Payload Elements

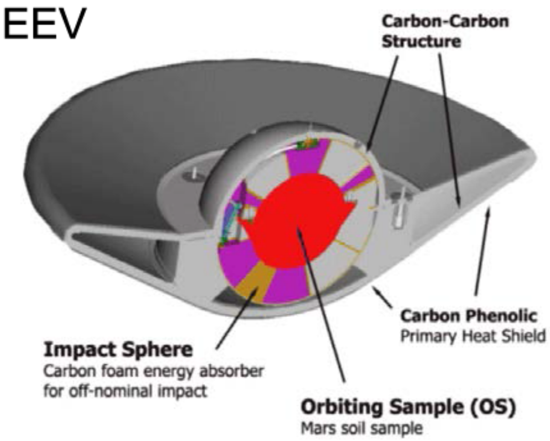


OS Capture and Handling Components

UHF Antenna

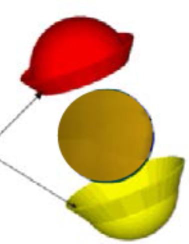
SRO is responsible for "Breaking the Chain" with Mars (PP)

EEV

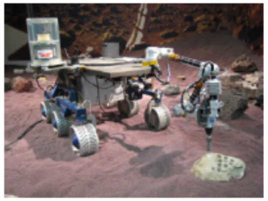


Not shown:
TBD Break-the-chain Components
Complimentary science payload

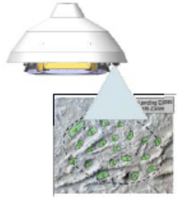
OS Containment Vessel



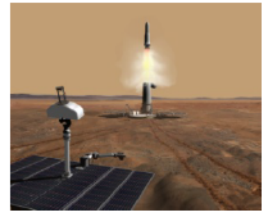
Key Technologies for MSR



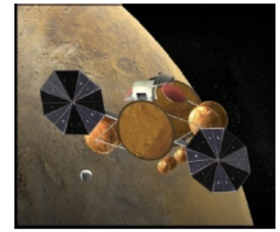
Sample Acquisition & Caching



Terrain Relative Navigation/ Hazard Detection & Avoidance



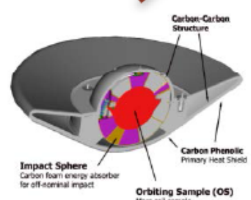
Mars Ascent Vehicle



OS Rendezvous & Capture

Caching Rover → **MSR Lander** → **MSR Orbiter** → **MRSH Sample Receiving Facility**

Enhanced Mobility



Earth Entry Vehicle

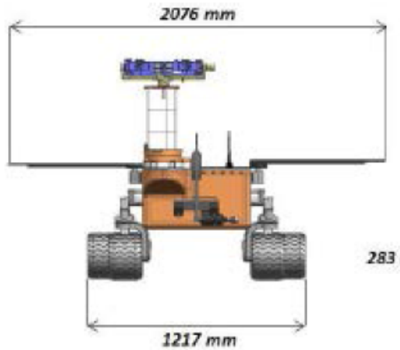
Sample Science Instruments

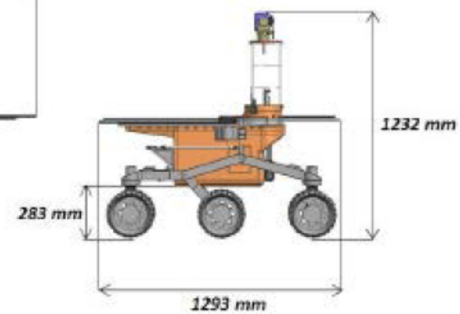
Planetary Protection to Minimize Round-trip Contaminants

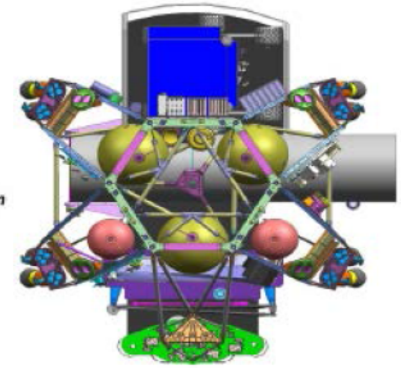
Assured Containment for Safe Earth Entry and Landing

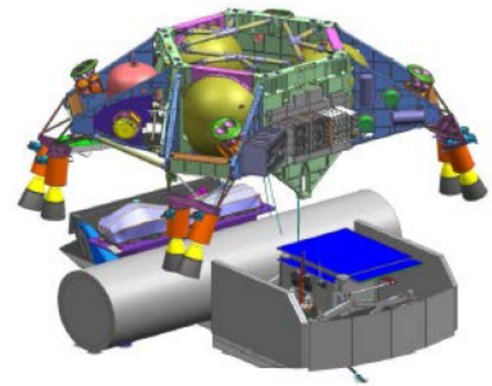
SRL Platform Studies (to date)

MAST

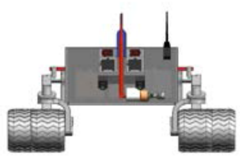


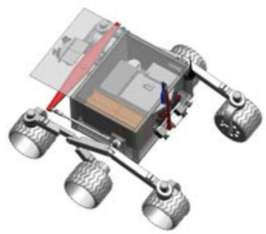


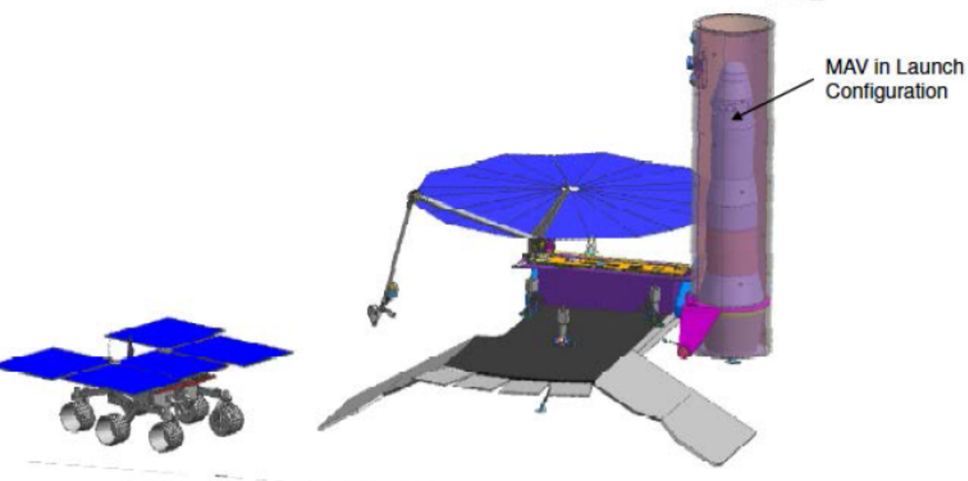




NO MAST







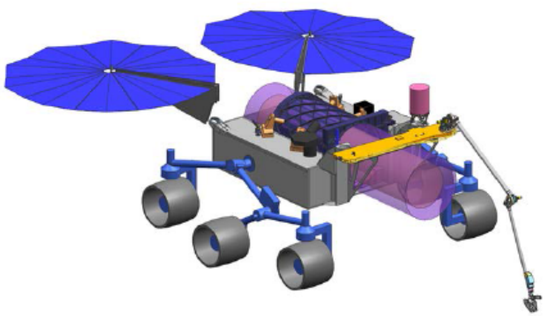
Lander before Mars Ascent

Findings:

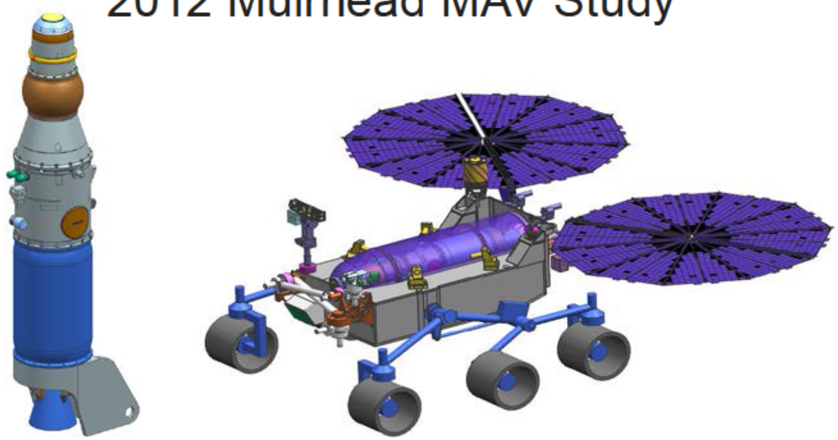
- Mass OK, Volume is challenging
  - (rover/MAV/platform): 984 kg
  - DS/MAV Volume Interferences for a 300 kg MAV
- Accessibility Issues:
  - Potential traverse limitations
  - Accessing the cache on Mars 2020

Mobile MAV Architectures

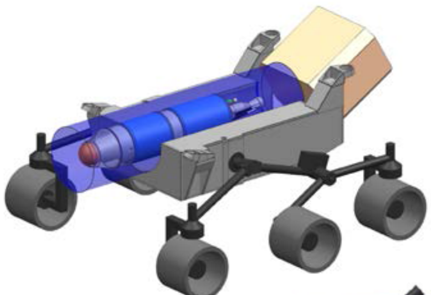
2012 Solar-powered MAV Study (Team X)

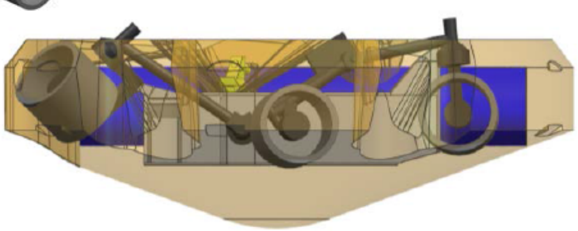


2012 Muirhead MAV Study



2014 RTG Mobile MAV configuration study





Mobile MAV has been studied more recently:

2012 Study: Mass OK, Volume is challenging

- Mass (rover/MAV/platform): 1107 kg
- DS/MAV Volume Interferences from 300 kg MAV assumed for this study

2012 Muirhead MAV Study:

Mass OK, Volume is OK

- Developed a minimum mass MAV concept
- Performed a first order Mobile MAV configuration

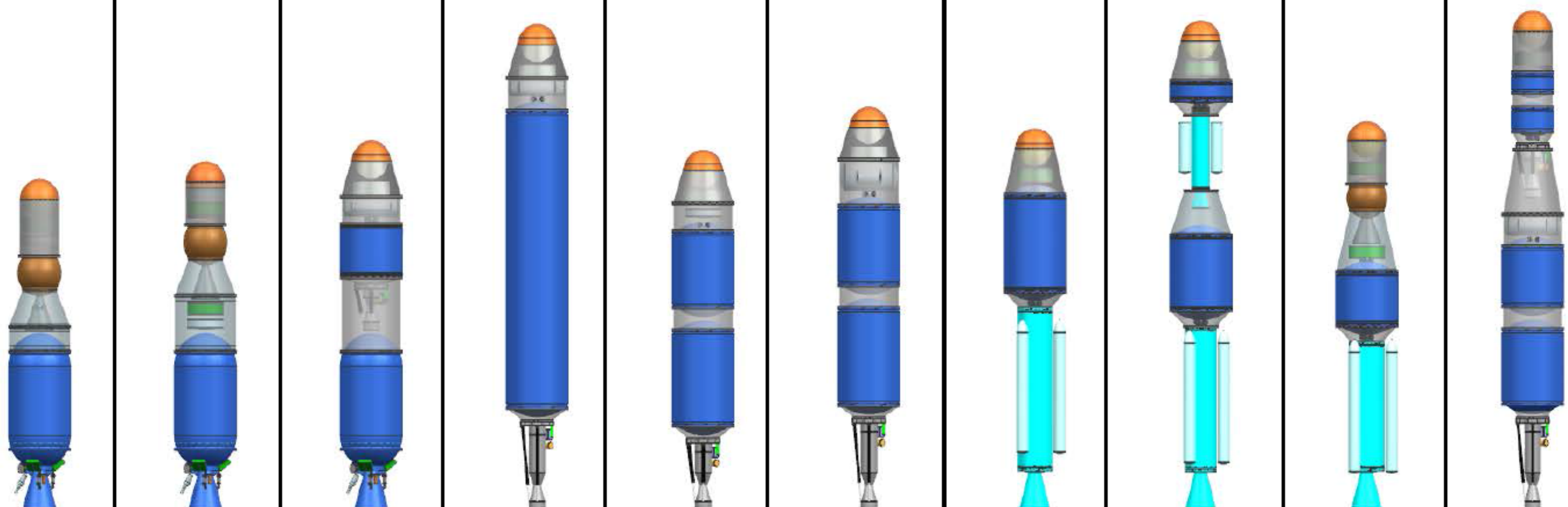
Findings:

- All concepts sensitive to MAV volume and mass
- RTG Mobile MAV looks promising but is the least mature

Comparison of Systems

Jet Propulsion Laboratory
California Institute of Technology

6.65kg Payload, 20cm Reference OS

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
	Solid-Solid G-G	Solid-Solid G-U	Solid-Liquid G-G	SSTO Monoprop	SSTO Pump BiProp	SSTO Reg. BiProp	SSTO Hybrid	Hyb-Hyb G-G	Hyb-Solid G-G	BiProp-BiProp G-G
										
Max OS	OS can grow up to ~ 30 cm diameter without fairing (stay under max case diameter)									
GLOM	176	158	237	276	182	187	166	173	157	190
Length	1.88 m	1.98 m	2.09 m	2.76 m	2.04m	2.29 m	2.16 m	2.78 m	2.21 m	2.84 m
AFT	-40 C	-40 C	+17 C	+8 C	-37 C	-37 C	-66 C	-66 C	-40 C	-37 C

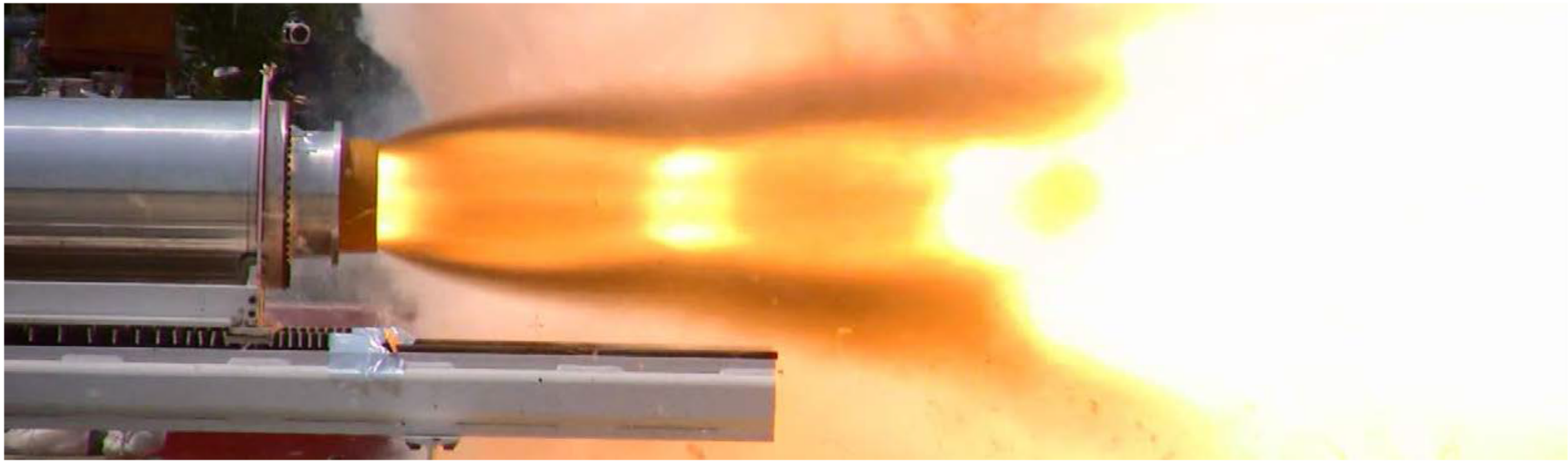
Comparison of Systems

6.65kg Payload, 20cm Reference OS

	Case 1 Solid-Solid G-G	Case 2 Solid-Solid G-U	Ruled Out		Case 5 SSTO Pump BiProp	Case 6 SSTO Reg. BiProp	Case 7 SSTO Hybrid	Ruled Out		
										
Score	0.60	0.54	0.32	0.52	0.79	0.76	0.76	0.621	0.52	0.57
GLOM	176	158	237	276	182	187	166	173	157	190
Length	1.88 m	1.98 m	2.09 m	2.76 m	2.04m	2.29 m	2.16 m	2.78 m	2.21 m	2.84 m
AFT	-40 C	-40 C	+17 C	+8 C	-37 C	-37 C	-66 C	-66 C	-40 C	-37 C

Current Hybrid Efforts

- Earth performance
  - Over 700 tests with paraffin-based fuels.
  - Demonstrated reliable ignition and stable combustion over the entire range of mass fluxes tested (5-80 g/cm^2 sec) and with a variety of oxidizers.
  - Largest paraffin motor to date has an OD of 22 in [0.56 m] and a thrust of about 35,000 lbf (our application is about a 10 in motor)
  - Throttling ratios of 3:1 have been demonstrated
- Propellants can be stored at -60C to -100C



Temperatures on Mars

- How the hottest spots on Mars compare with the coldest spots on Earth:

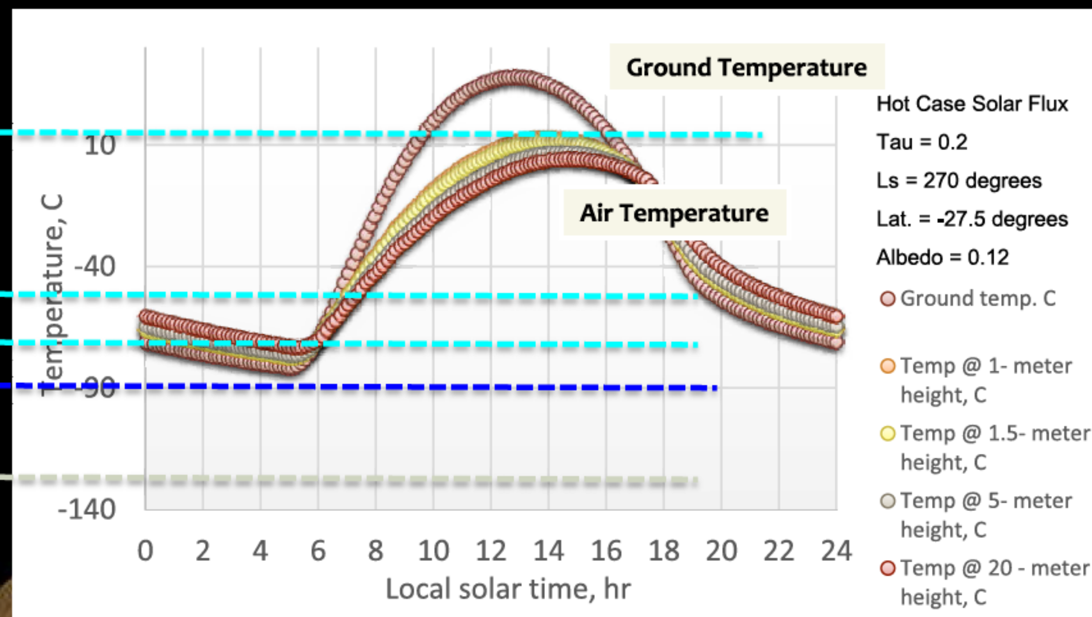
Oymyakon, Siberia
(coldest permanently inhabited place on earth)

July Average: +17 C (62 F)

January Average: -45 C
Coldest Recorded: -71.2 C

Vostok, Antarctica: -89.2 C
(Earth record holder)

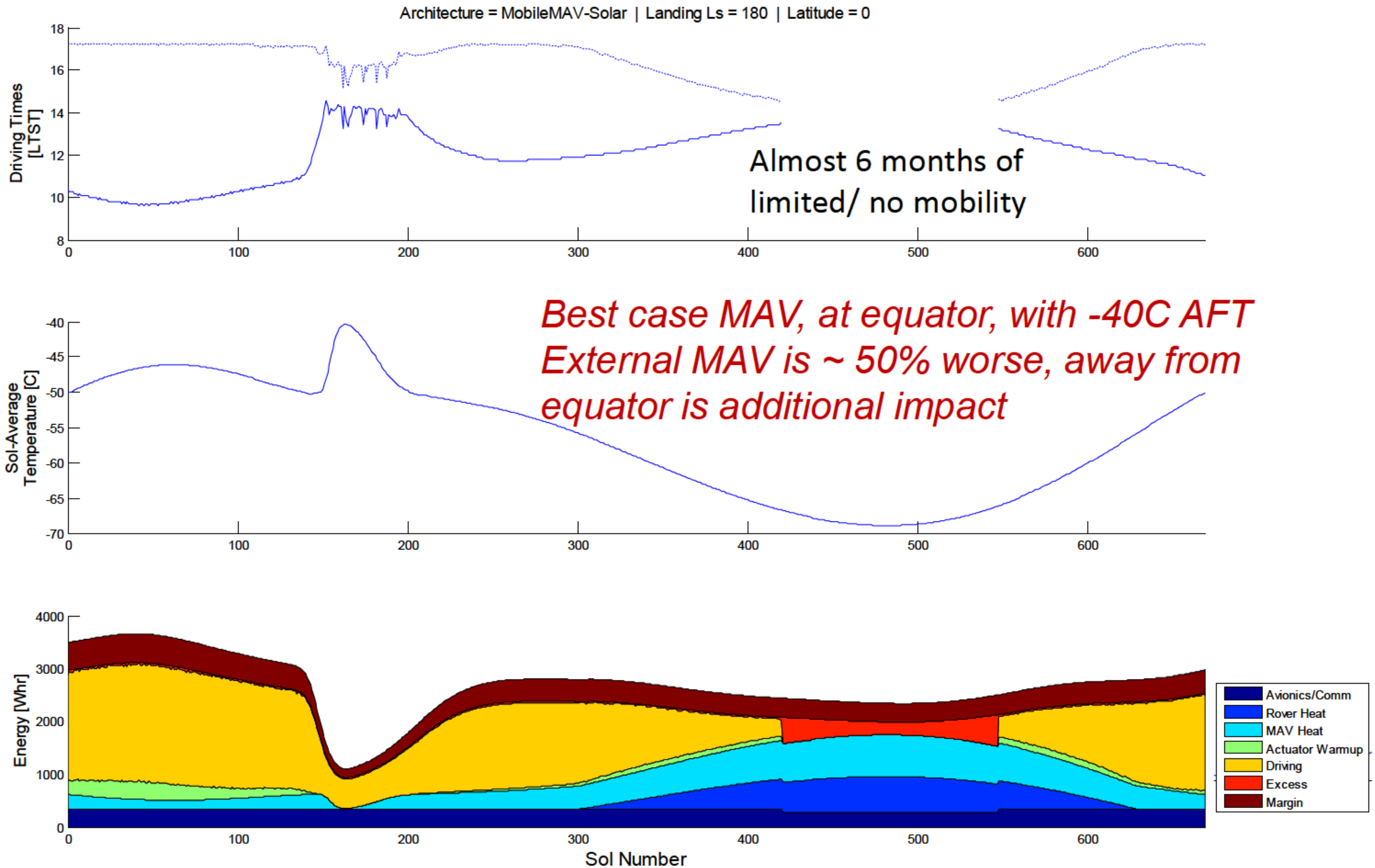
Carbon Dioxide Frost Point : -126 C
(at Mars pressure) – Atmosphere begins to freeze out. Common in winter at mid- to high-latitudes, even at mid-day. Each winter as much as 1/3 of the atmosphere "freezes out"



Data shown for hottest day at hottest spot on Mars analyzed for Curiosity design & analysis case

Southern Polar Ice Cap (largely CO_2 – Dry Ice)

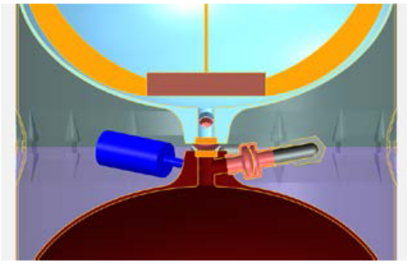
Example Profile - MobileMAV-Solar (Future Tech, Latitude = 0, Landing Ls=180°)

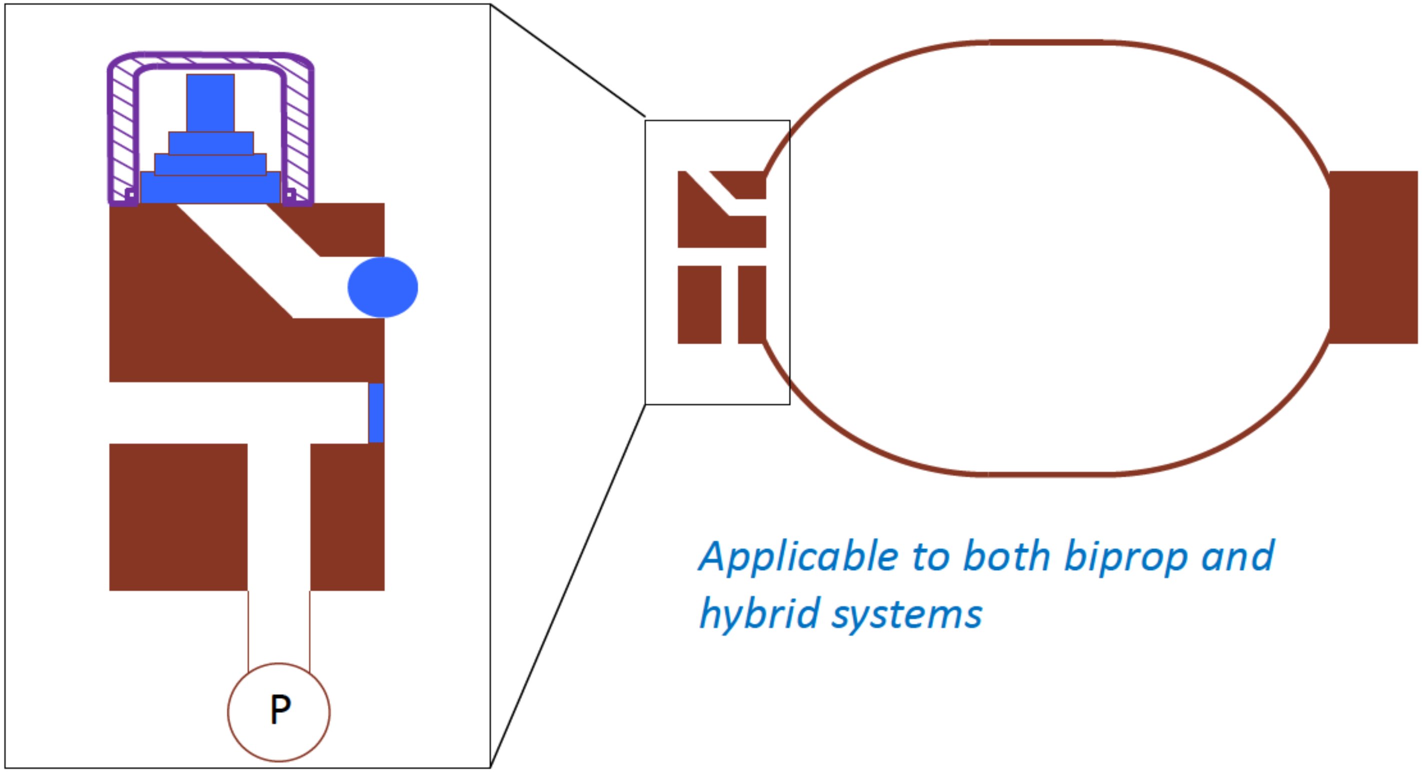


Best case MAV, at equator, with -40C AFT External MAV is ~ 50% worse, away from equator is additional impact

Frozen propellant

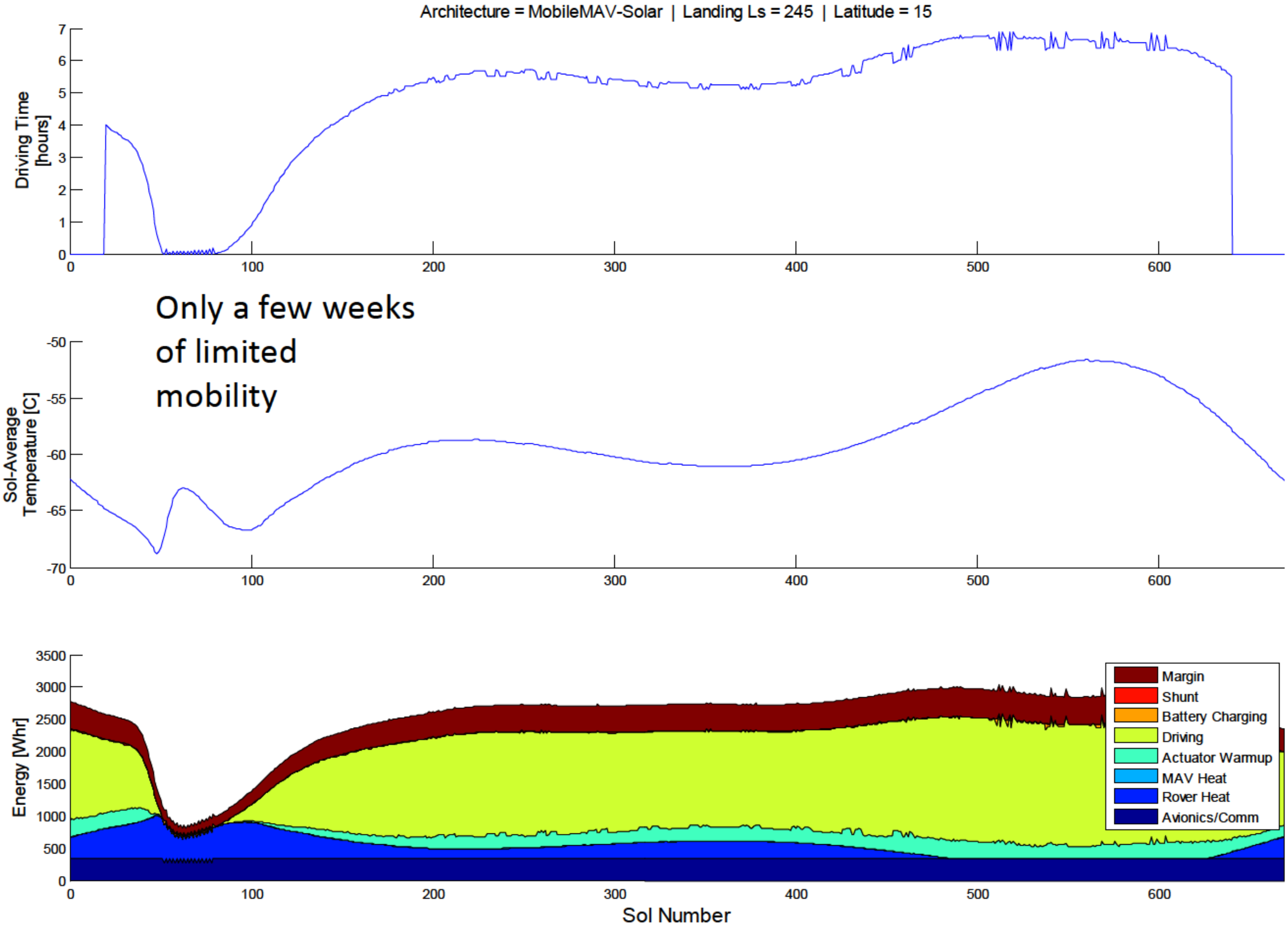
- What if we LET the propellants freeze?
- Minimize freeze thaw issues by containing wetted area to only the tank internal volume.
  - JPL envisions burst disks flush with tank wall at inlet and outlet tanks
  - Fill & drain valve with valve set flush with tank interior





Applicable to both biprop and hybrid systems

Frozen MAV


Architecture = MobileMAV-Solar | Landing Ls = 245 | Latitude = 15
Driving Time [hours]
Only a few weeks of limited mobility
Sol-Average Temperature [C]
Energy [Whr]
Sol Number
Margin
Shunt
Battery Charging
Driving
Actuator Warmup
MAV Heat
Rover Heat
Avionics/Comm

Trade Space

Hybrids

Has ability to trade length and diameter somewhat

Keep above 20C?
(During Ops, use NTO or MON3)

Keep above -5C?
(During Ops, use NTO)

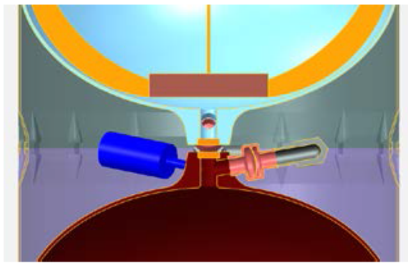
Keep above -10C?
(During Ops, use MON3)

Keep above -50C?
During Ops, (use MON25)

Passive aero-stability features

RCS Sizing

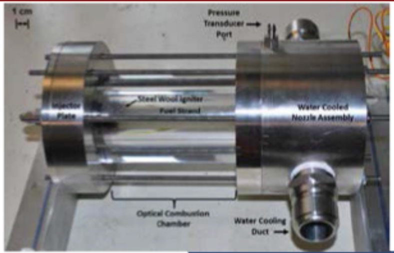
TVC approach
(no current identified solution to nozzle overheating)



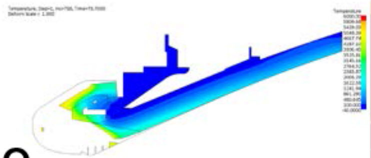
Letting Propellant Freeze during surface ops is trade for lander energy demands

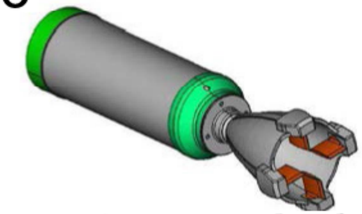
Key Remaining Challenges for Hybrid MAV

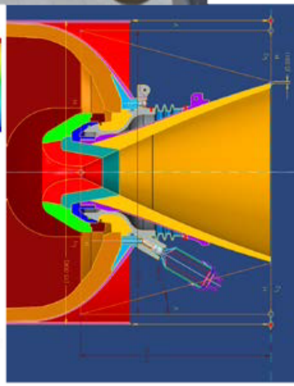
- Unknown Performance with NTO or MON3
  - Testing planned with Purdue this summer



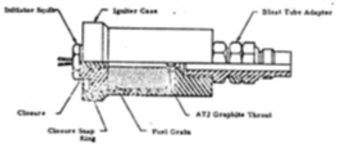
- Nozzle / TVC Design Approach
  - ~ 2 years design work applied to equivalent solid propellant system (ATK and MSFC) – no solution to date



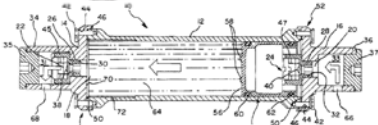




- Multiple Restarts (igniters)
  - Several options under investigation
    - Hypergols would be nice!



Solid Igniters



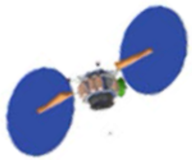
Hypergolic Liquid Injector

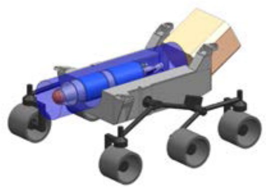
- Packaging
  - Aspect ratio of chamber
  - Oxidizer and pressurant storage form factors
    - Also investigating pumped systems

Backup

Vision for 2020s and Beyond

Now through 2020	Decade of 2020's	Beyond





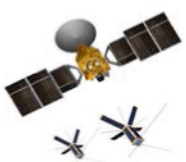
Mars 2020

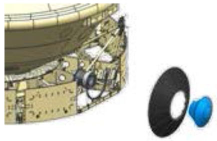
MSR Orbiter
(MSR, Comm, Complementary Science)

Sample Retrieval
(Landing, Retrieval Rover, Ascent Vehicle)

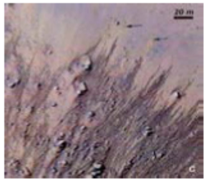
Robotic Precursor Missions

Human-Robotic Missions





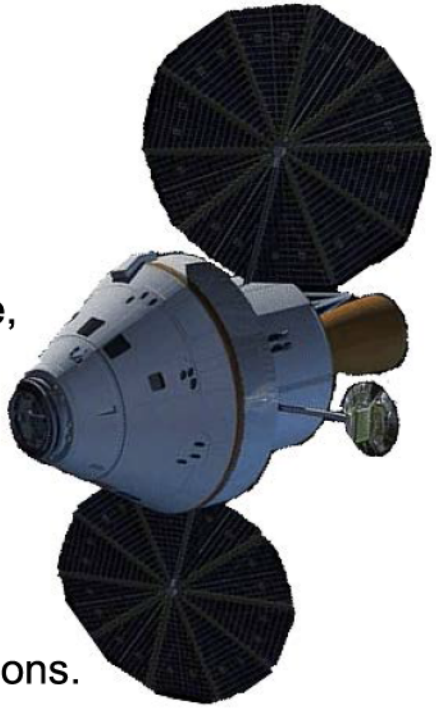
Secondary Vehicles
(CubeSat, Aerocapture)



Other Scientific Priorities

Opportunity: Mars Sample Recovery & Return During Early Crewed Operations Beyond Earth Orbit

- CONCEPT: SEP enabled robotic vehicle delivers samples to Beyond Earth Orbit (BEO) for a crew based retrieval
  - Beyond Earth Capability planned after 2021
- Sample canister could be captured, inspected, encased and retrieved tele-robotically
  - Robot brings sample back and rendezvous with a crewed vehicle
  - Cleaned sample canister would be then enclosed in a stowage case, and stowed in Orion for Earth return.
- This approach deals with key planetary protection concerns
  - Crew inspection, cleaning, and encapsulation of sample enclosures prior to Earth return
  - Removes the need to robotically “break the chain” of contact with samples at Mars, thus reducing complexity and cost of robotic missions.
- Crew entry system eliminates need for robotic Earth entry system
- Provides an early opportunity for collaboration and demonstration of capability also applicable in Mars orbit



Outline

- Background & Context for MSR
- MSR Functional Definition
- MSR Current Architecture Concept
- Potential MSR Elements: SCR, SRO, SRL, MRSH
- Key Open Trades and Technology Needs
- Potential Role for Human-Assisted Sample Return

Essential Functions* of Mars Sample Return

Acquire Samples on Mars

- Launch from Earth/Land on Mars
- Select Samples
- Acquire/Cache Samples

Get Samples off Mars

- Retrieve/Package Samples on Mars
- Launch Samples from Mars

Return Samples

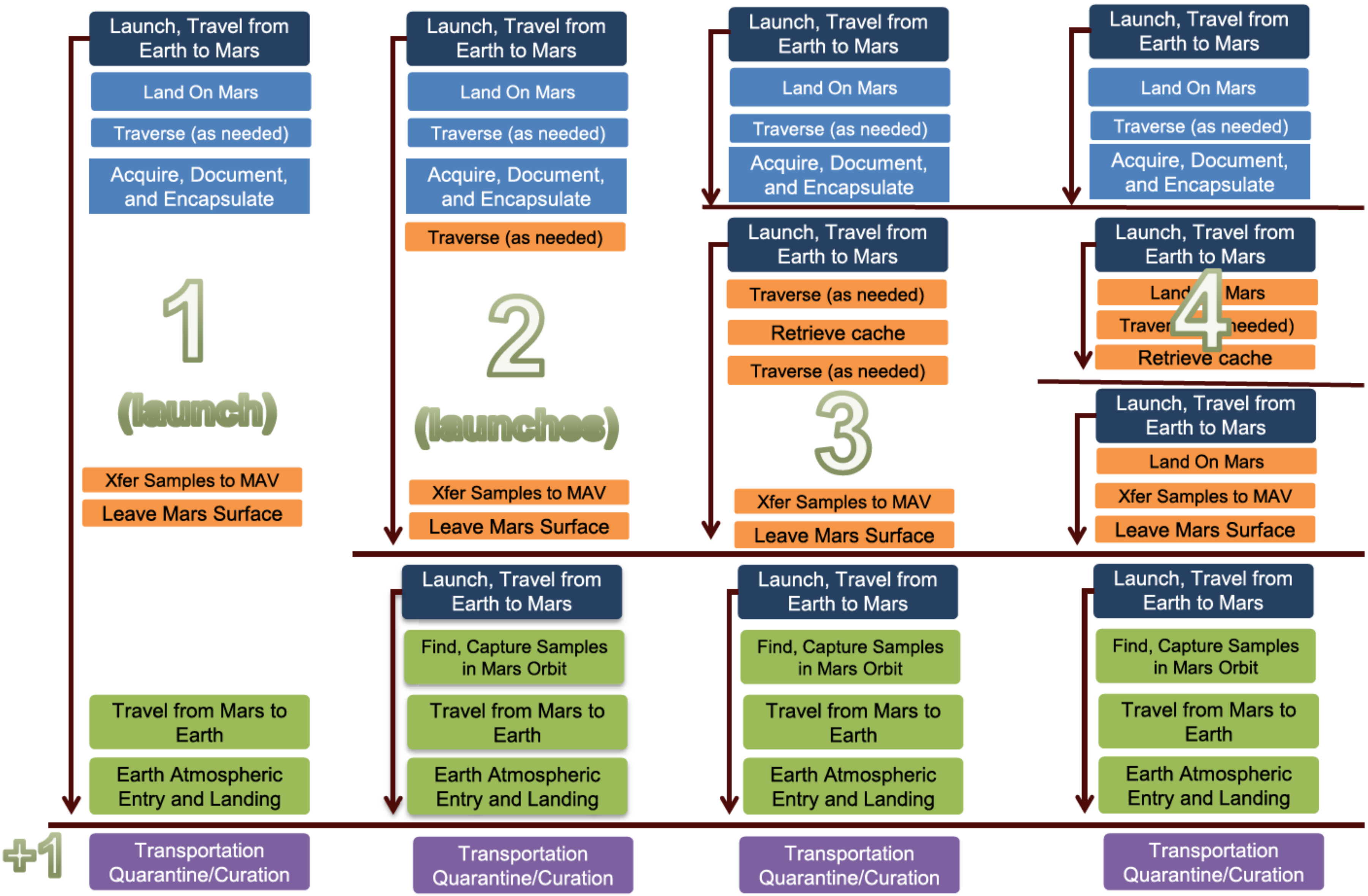
- Capture and Isolate Sample Container
- Return to Earth
- Land on Earth

Earth Ops w/ Samples

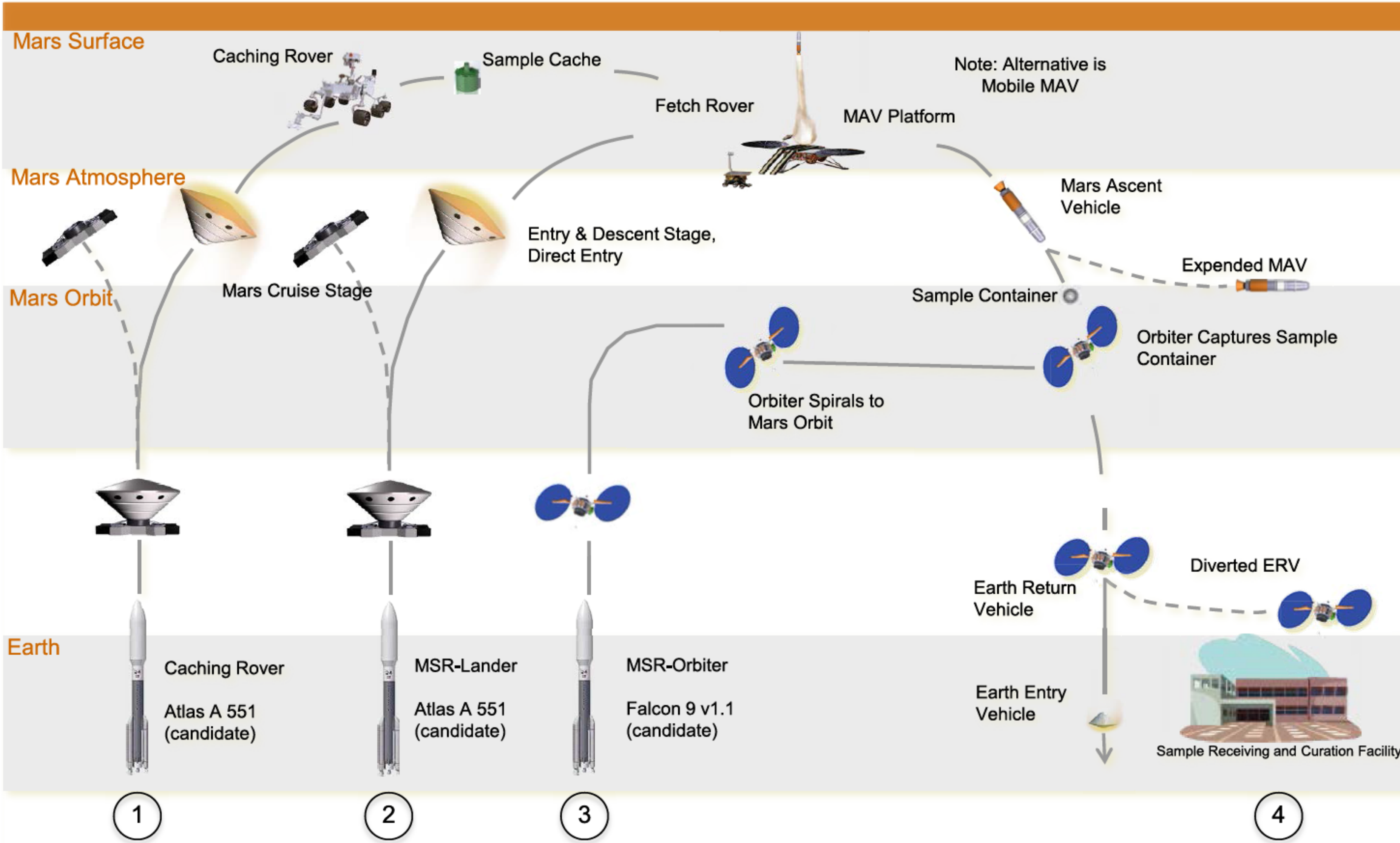
- Retrieve, Quarantine, and Store Samples on Earth
- Assess Hazards/Sample Science
- Preserve for Future Investigations

*Functions: Necessary steps; invariant to architecture implementation

Creating Architecture Options from the Functions



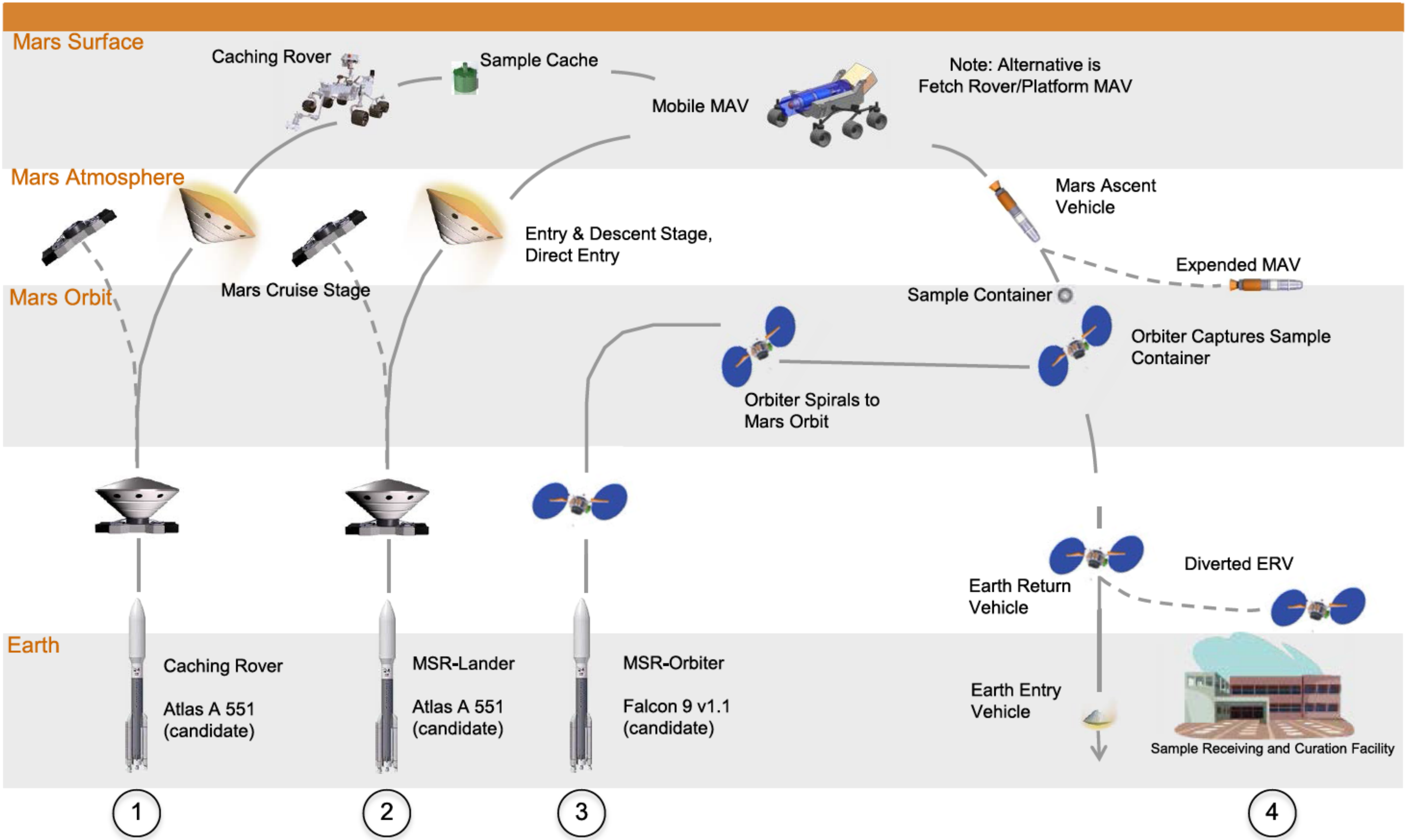
Current Architecture Concept



Note: MSR-Lander and MSR-Orbiter can be launched in either order

Pre-Decisional: For planning and discussion purposes only.

Current Architecture Concept



Note: MSR-Lander and MSR-Orbiter can be launched in either order

Stable Sample States

At the end of each MSR mission, the sample would be left in a state that is long-term stable

- Sample cache on Mars surface (or on body of SCR) should be stable for decades

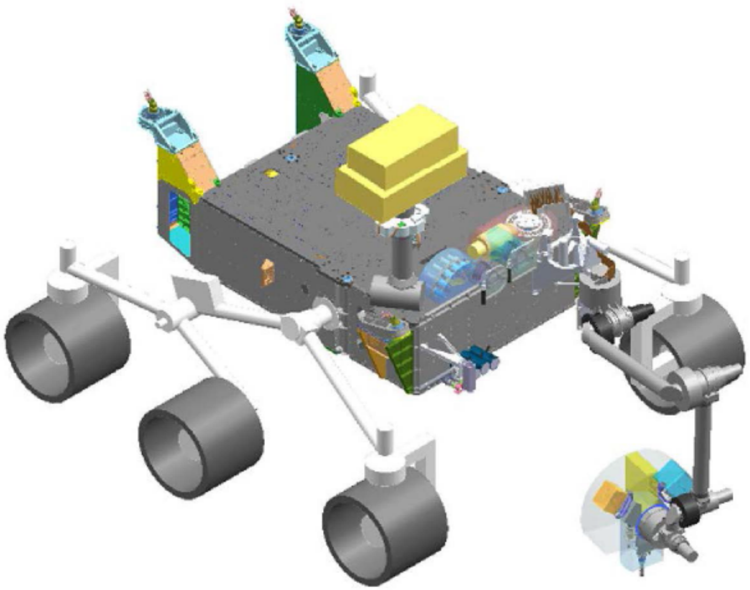
- OS in Mars orbit should have lifetime of decades

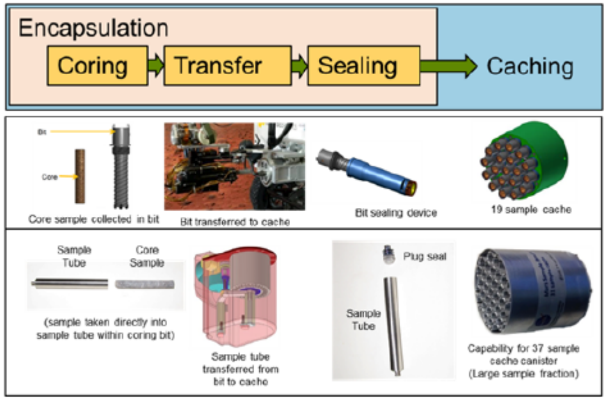
- EEV on Earth's surface would have shorter stability period (days) for sample science integrity, but containment should be stable for many years

Enables <u>temporal independence</u> between SCR, SRL, and SRO missions

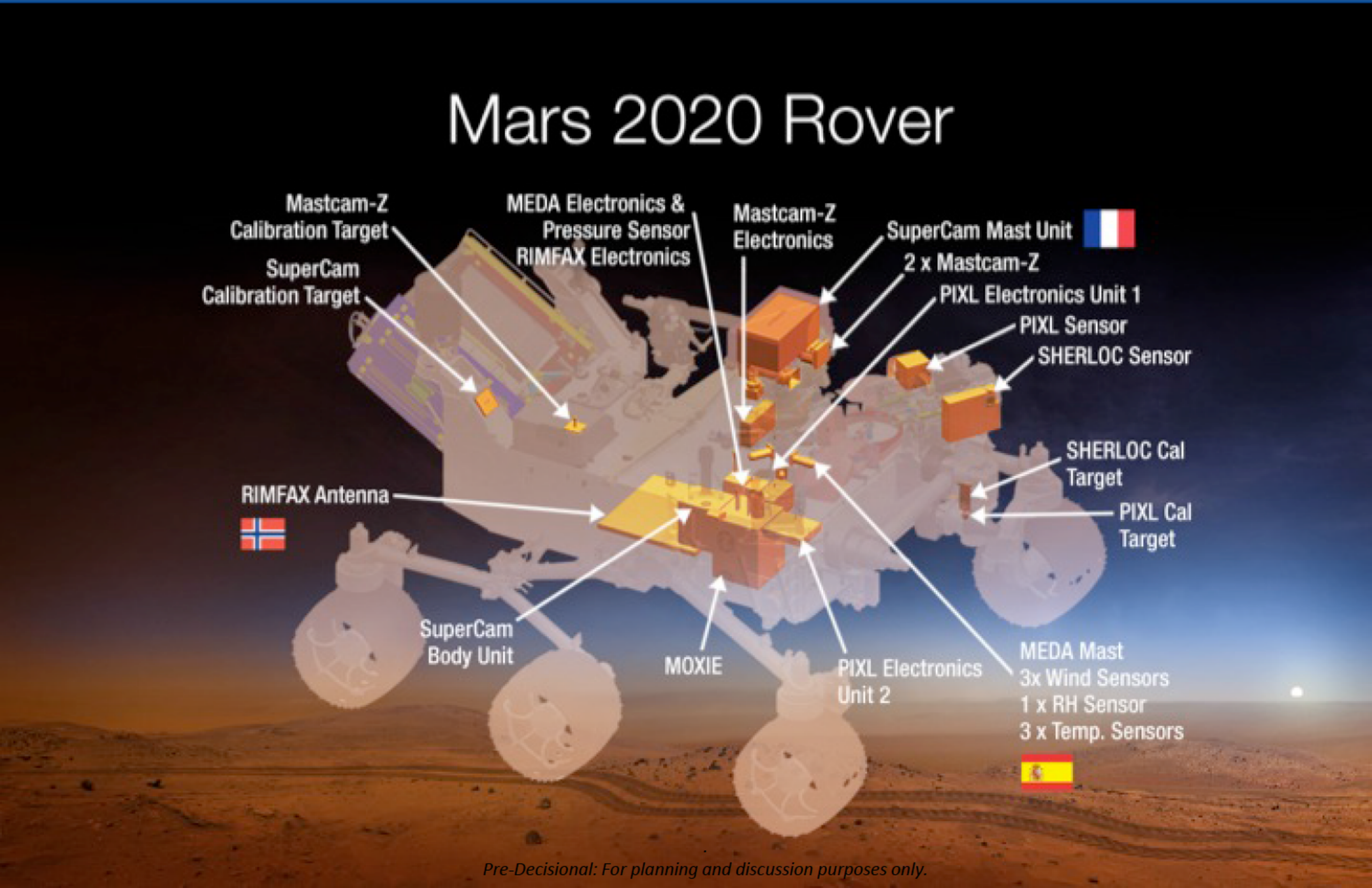
Sampling System

- New development with potential for some MSL inheritance
- Would support arm-mounted in-situ instruments selected per AO
- Provide abrading / brushing for contact and remote sensing payloads
- Enable core acquisition and caching



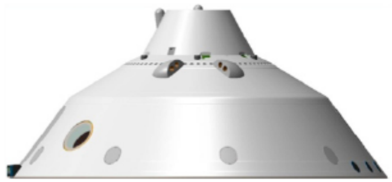


Mars 2020 Selected Payload Suite

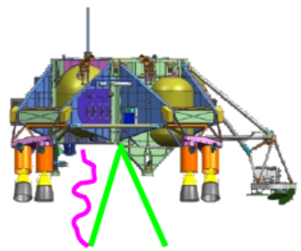


Mars 2020 Baseline Architecture

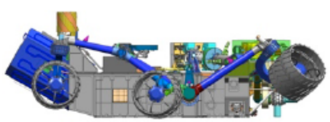
Cruise Stage



Backshell with parachute



Descent Stage/Skycrane



Rover

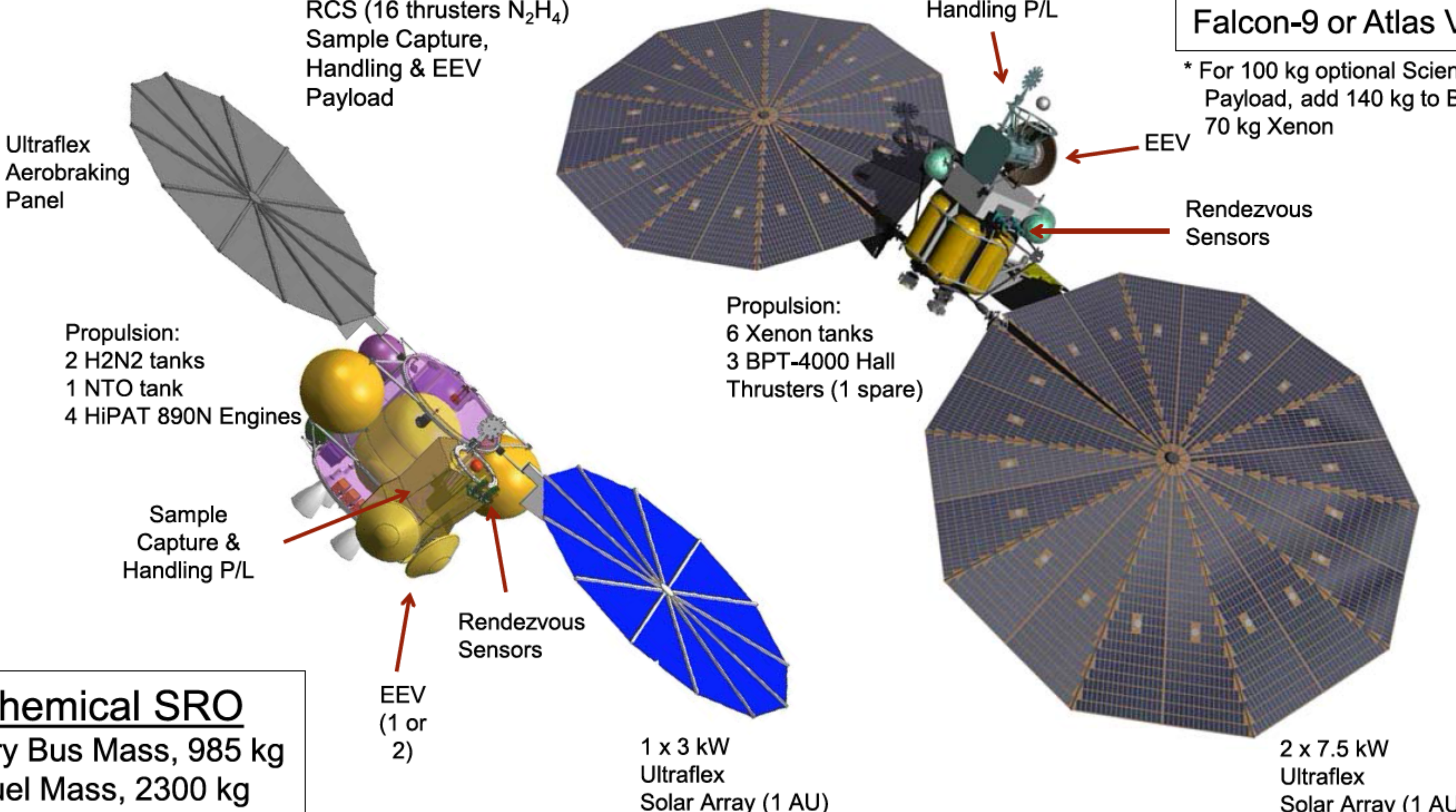
Heat Shield

SRO Chemical vs. SEP comparison

SEP SRO*
Dry Bus Mass, 930 kg
Xenon Mass, 1160 kg
Falcon-9 or Atlas V-401

* For 100 kg optional Science Payload, add 140 kg to Bus and 70 kg Xenon

Common Elements:
Telecom
C&DH
RCS (16 thrusters N_2H_4)
Sample Capture, Handling & EEV Payload



Chemical SRO
Dry Bus Mass, 985 kg
Fuel Mass, 2300 kg
Atlas V-551

Break-the-Chain

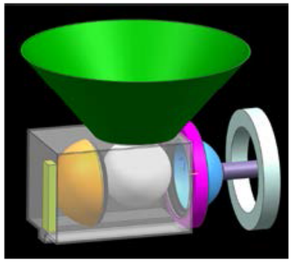
Jet Propulsion Laboratory
California Institute of Technology

Lander-Orbiter BTC trade is still open

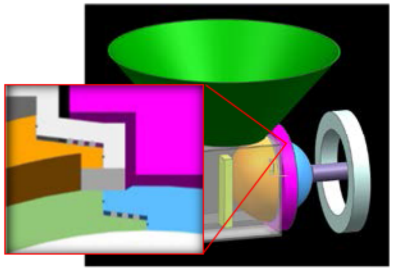
- SRL mass penalty is large
- Orbiter PP complexity is significant

Several BTC technologies are under study

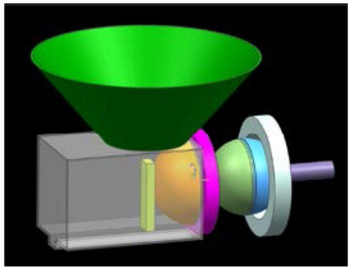
- Brazing, Welding, soft seals, combinations



OS Encapsulated



BTC Sealed



Clean System Moved to EEV

EEV Sealed

Example BTC Process Steps

Mars Returned Sample Handling (MRSH) – Current Architectural Concept

Sample Receiving Facility (SRF)

- Quarantine & isolate from terrestrial contamination
- Perform biohazard testing

One Example

Sample Assessment in SRF

- ***Preliminary sample examination***
- ***Extant life determination***
- ***Toxicity determination***
- ***Some other science as appropriate***

Landing of sample in Earth Entry Vehicle (location TBD)

Ground Recovery Operations (GRO)

SRF Location TBD

Samples transferred only if release criteria are met

SCF Location TBD

NASA Centers
National Labs
Universities

Distributed Science

- ***Extinct life detection***
- ***Geological interpretation***
- ***Materials characterization***
- ***Ground-truth for Mars missions***

Sample Curation Facility (SCF)

- Protect and preserve
- Distribute and control

Pre-Decisional: For planning and discussion purposes only.

Ground Recovery Operations (1 of 2)

Earth Delivery of Samples

- Options
  - Earth Entry Vehicle (EEV) with hard impact (no parachute) – **current concept.**
  - Stardust-style entry capsule with parachute.
  - Genesis-style entry capsule with parafoil, midair capture.
  - ESA-built entry vehicle.
  - Human mission return (Orion or Dragon) in a quarantine vault.
- EEV hard landing assumed as bounding case, with respect to all Mars 2020-related issues.

Functions

- Provide tracking and monitoring of the incoming EEV.
- Secure the landing site.
- Load EEV into a secure, environmentally-controlled ground-transportation quarantine vault.
- Transport EEV to the SRF.
- Remediate site (TBD), securely move TBD material to the SRF, if needed.

Ground Recovery Operations (2 of 2)

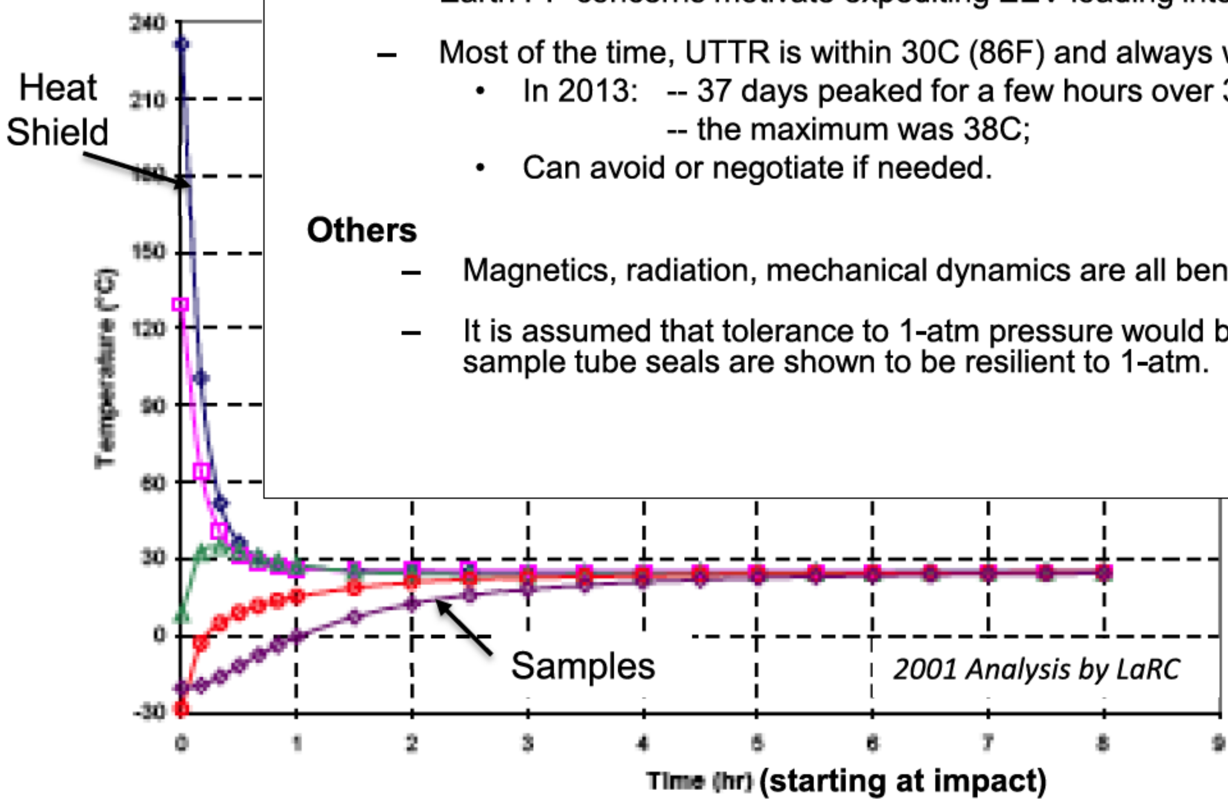
Post-landing Environments Consideration (balanced with Mars 2020)

Temperature

- The draft science temperature requirement is below 30C when unsealed, and below the greater of 30C or 10C above the maximum Mars surface site temperature when sealed. Some sites considered can reach 40C. Thermal sensitivity decreases after sealing.
- EEV could be cold-soaked before entry and entry heat is dissipated without reaching samples.
- EEV (and samples) would equilibrate to site ambient within a few hours.
- Earth PP concerns motivate expediting EEV loading into an environmentally-controlled vault.
- Most of the time, UTTR is within 30C (86F) and always within the potential 50C (122F) limit.
  - In 2013: -- 37 days peaked for a few hours over 30C; 8 days had a mean over 30C;
    -- the maximum was 38C;
  - Can avoid or negotiate if needed.

Others

- Magnetics, radiation, mechanical dynamics are all benign compared to earlier exposures.
- It is assumed that tolerance to 1-atm pressure would be controlled at the OS level, unless M2020 sample tube seals are shown to be resilient to 1-atm.



Sample Receiving Facility Concept

- SRF would provide for:
  - Receiving the ground-transportation vault,
  - Disassembly/evaluation of layers down to sample tubes
  - Sample preparation,
  - Initial science evaluation, and
  - PP protocol testing for life detection/bio-hazards.

- SRF may also provide for:
  - Extended science until samples are certified for release.
  - Long-term curation.

- SRF provides BSL-4 level quarantine, as well as protection from Earth-based contamination to samples.

- Minimum requirement is a single special-purpose BSL-4 facility in the US.

- Potential for multiple facilities (NASA, ESA, etc).
  - Assume transport of samples after triage in a US facility (or later after initial science evaluation).
  - Transport in environmentally-controlled containment vault would be needed.

- SRF studies have considered both glove-box and robotic-assisted manipulation implementations. A combination of both is most likely.