National Aeronautics and
Space Administration

NASA Mars Exploration Program

INDUSTRY DAY

18-19 OCT 2022

Welcome

Richard M. Davis	Co-host
Chad Edwards	Co-host

Oct 18: Public Plenary Session

7:30 am		*SIGN IN*	
8:00 am	(20)	Welcome	Rick Davis/Chad Edwards
8:20 am	(20)	Mars Exploration Program (MEP) Overview	Eric Ianson
8:40 am	(20)	Mars Challenges Relative to Earth-Orbit/Cis-Lunar Destinations	Chad Edwards
9:00 am	(15)	Mars Opportunities: Four Potential Commercial Services of Interest	Rick Davis
9:15	(30)	1 Spacecraft Delivery Services	Marguerite Syvertson
9:45	(30)	2 Mars Relay Telecommunications & PNT Services	Roy Gladden
10:15	*(15)*	*BREAK*	
10:30	(30)	3 Payload Hosting Services	Nathan Barba
11:00	(30)	4 Mars Imaging & Global Meteorological Services	Larry Matthies
11:30	*(1:30)*	*LUNCH BREAK*	
1:00 pm	(15)	Industry Role in Discovery: Mars Science Strategy	Michael Mischna
1:15 pm	(30)	Lessons Learned: Commercial Crew and Cargo	Marc Timm/Lee Pagel
1:45 pm	(30)	Lessons Learned: Commercial Lunar Payload Services (CLPS)	Ryan Stephan
2:15 pm	(30)	Plenary Q&A	Rick Davis/Chad Edwards +Attendees
2:45 pm		End of Plenary	
3:00 – 5:00		*SCHEDULED ~30-minute bilateral discussions: MEP and interested companies*	

Oct 18 - 19: Private One-on-One Meetings

OCT 18 – AFTERNOON OPPORTUNITIES

3:00 pm – 5:00 pm	30-min Bilateral MEP – Commercial Organization Interactions	Pre-scheduled per Notices of Interest

OCT 19 – FULL-DAY OPPORTUNITIES, DEPENDING ON DEMAND

7:00 am – 12:00 pm	30-min Bilateral MEP – Commercial Organization Interactions	Pre-scheduled per Notices of Interest
12:00 pm	*Lunch*	
1:00 pm – 5:00 pm	30-min Bilateral MEP – Commercial Organization Interactions	Pre-scheduled per Notices of Interest

Goals for MEP Industry Day

3 **Share with industry future potential MEP strategies**, including considerations of commercial partnerships for lower cost, higher cadenced Mars missions and US competitiveness in deep space

2 **Gain a better understanding of industry** developments, capabilities, and interests in potential public-private partnership models

1 **Incorporate industry feedback into MEP strategic planning**

LIFTOFF **Potential to Launch a New Paradigm for Highly Partnered, Low-cost Mars Missions**

This Mars Industry Day is for information and planning purposes only.

Neither this announcement nor this Industry Day constitutes a Request for Proposal (RFP) or implies any commitment by NASA as an outcome of these interactions.

POTENTIAL TO CHANGE THE PARADIGM FOR MARS EXPLORATION

HIGH-LEVEL CONCEPT: 4 PRIORITY SERVICES

1 **SPACECRAFT DELIVERY**
(LARGE & SMALL)

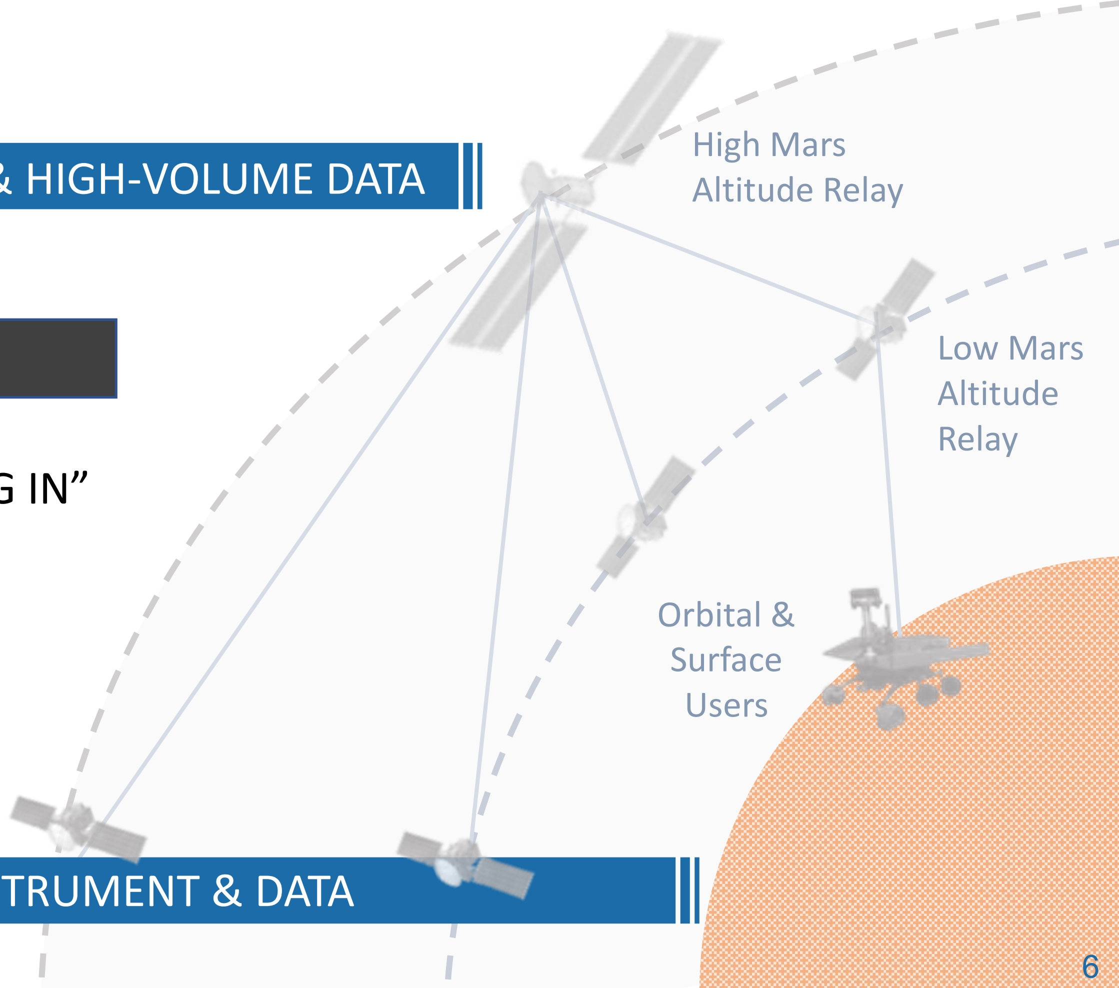
NASA PROVIDES

INDUSTRY DELIVERS NASA S/C TO MARTIAN SYSTEM

2 **RELAY & PNT**
POINTING, NAVIGATION & TIMING

NASA RECEIVES

INDUSTRY PROVIDES S/C & HIGH-VOLUME DATA

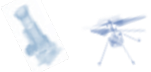


SOLVING THE FIRST TWO IS CRITICAL

3 **PAYLOAD HOSTING**

INDUSTRY PROVIDES

NASA + OTHERS "PLUG IN" INSTRUMENTS



Key priorities among Instruments

4 **IMAGING & WEATHER**

NASA RECEIVES

INDUSTRY PROVIDES INSTRUMENT & DATA

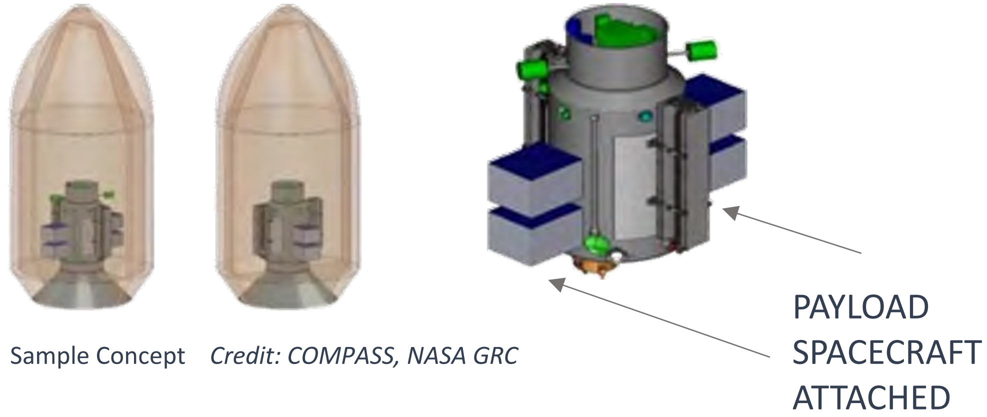
POTENTIAL TO CHANGE THE PARADIGM FOR MARS EXPLORATION

1 Spacecraft Delivery Services

Low Recurring Costs & Economies of Scale Can Open the Door to Mars Exploration

Opens up the market beyond MEP-provided payloads:

- Other Space Agencies (including emerging spacefaring nations)
- Universities (e.g., cubesat programs)
- Other Customers (e.g., industry, space societies, citizen science etc.)



Sample Concept *Credit: COMPASS, NASA GRC*

DECREASES

- **Cost of Getting Mass to Mars**
  - Economies of Scale: Ideally, multiple small payloads/ heavier single payload
- **Reduces Programmatic Risk**
  - Reduced Cost/Financial Overhead = Greater Risk Tolerance (e.g., attempt more experimental, lower TRL missions)
  - "Every 26 Months" Launch Barriers: If miss window, another ride coming soon

INCREASES

- **Frequency of Trips to Mars for Multiple Missions**
- **Access to Exploration** for Universities, Industry, and Smaller International Partners
- **Delivery of systems and networks for coordinated measurements** – and the ability to augment and/or replenish them over time
- **Flexibility**

2 Communications Relay

Return on Investment for a Mission Can Be Measured by Data Return

FOUR USER CLASSES


Large Orbiters


Large Landers/ Rovers

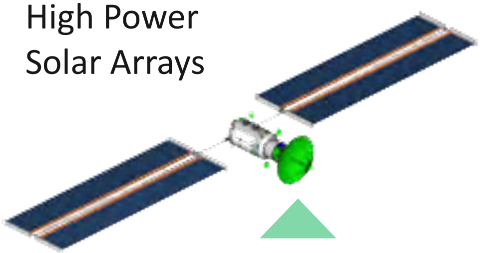

Small Satellites


Small Aerial/ Landed Payloads

- More Data from More Locations and More Spacecraft
- Expectations for Data Volume: 50-100 times that of today (or more!)
  (raw SAR; faster planet-scale high-res imaging; video)

Demand is present and will grow as data throughput expands . . . .

OPTIONS, SEPARATE & TOGETHER



HIGH-ALTITUDE RELAY

Provides relay support to orbiters for the first time

Enables orders of magnitude more throughput (with directional antenna and long comm times)

Increased contact times relax operational constraints on timing of sessions

LOW-ALTITUDE RELAY

Provides frequent daily data transfers with low power requirements for resource-constrained surface users with omnidirectional links (i.e., no capability for directional prox links)

(currently ~2 10-min opportunities per day)

POTENTIAL TO CHANGE THE PARADIGM FOR MARS EXPLORATION

3 Payload Hosting Services

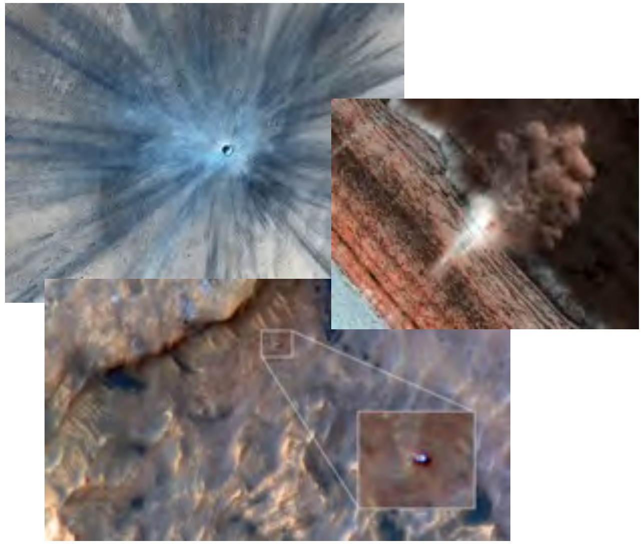
Increased scientific discovery and increased opportunities for universities and other research institutions in the United States and internationally.

ANALOGY: Racks on the International Space Station are standardized (volume, connectors), but what's in the rack can vary widely.

- Leveraging economies of scale for standardized host spacecraft and interfaces could significantly advance the safe, reliable, and low-cost delivery and operation of hosted science instrument payloads from Earth surface to Mars orbit and landed destinations
- Leveraging industry capability without imposing additional (and costly) NASA processes when industry has the equivalent for quality assurance and mission success
    - CLPS model for the moon – how about for Mars?
- Regular cadence of affordable and achievable missions with agile and flexible payloads – "plug n play"

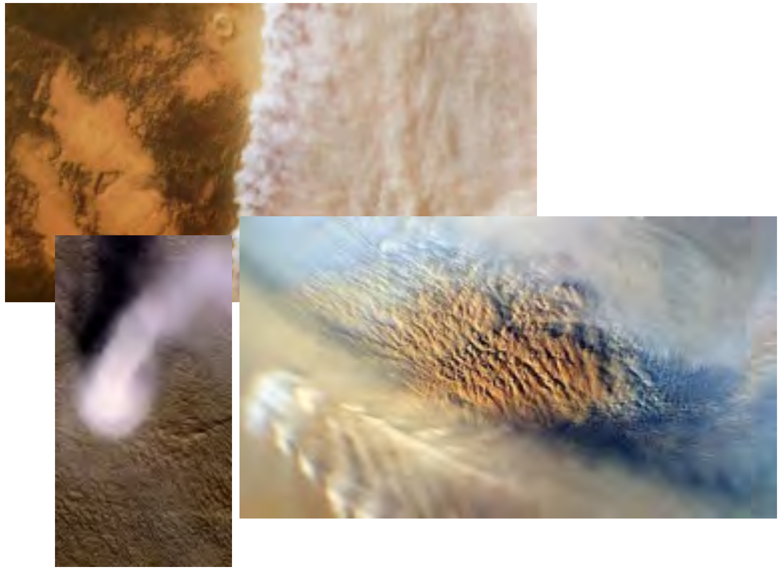
POTENTIAL TO CHANGE THE PARADIGM FOR MARS EXPLORATION

4 High-Resolution Imaging & Global Meteorological Services



- While delivering some of the most dynamic scientific findings over the last decade and a half, MRO/HiRISE has only imaged <4% of the planet at high resolution in ~15 years

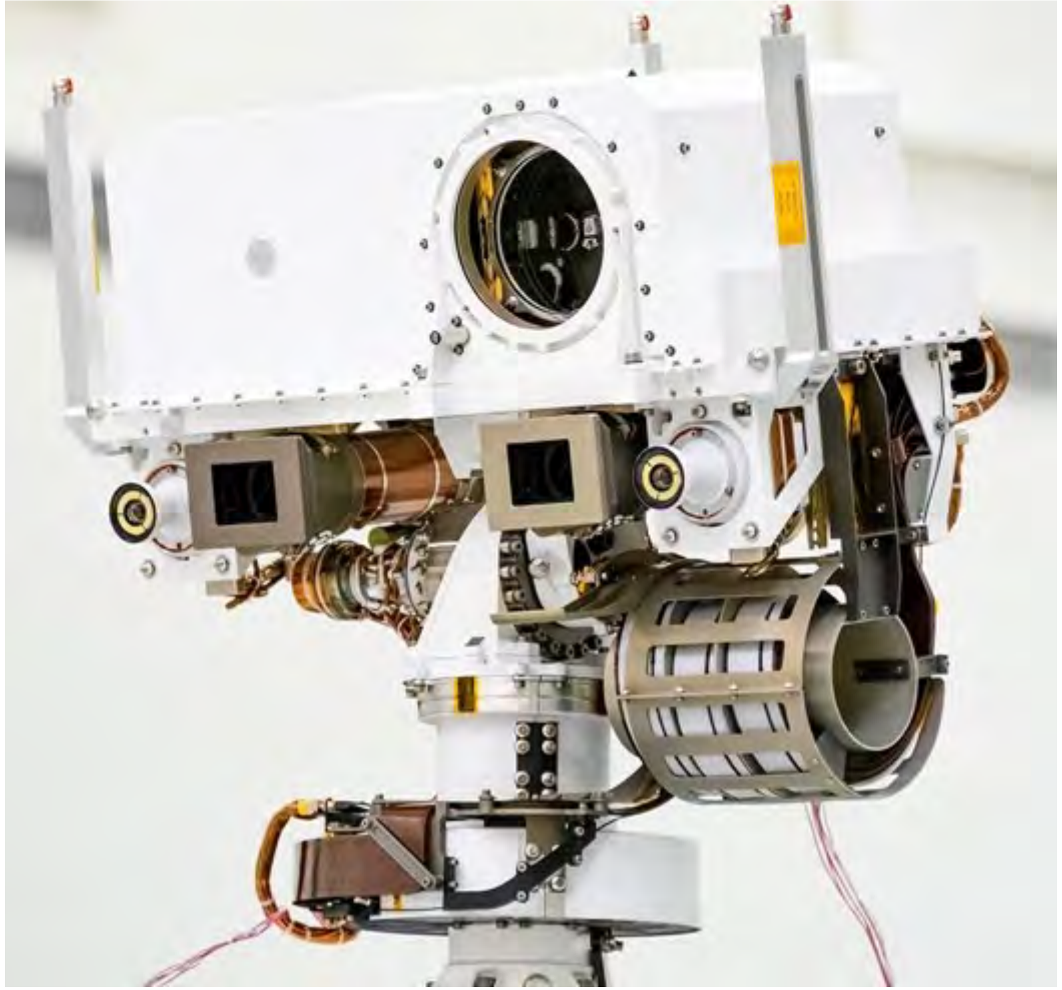
- Additional future high-resolution imaging would enable greater coverage of Mars, more evidence of Mars' changing surface, and a greater abundance of detailed landing site studies for both
- Need for high-resolution imaging will only be increased with human exploration



- Meteorological packages would extend MEP's continuous weather monitoring at Mars
- Goal is to enable weather <u>prediction</u>
- <u>Build toward a modern weather network</u> (both in orbit at different altitudes and on the surface)

With the opportunities also come recognized challenges in establishing a viable "Mars Market."

NASA/MEP is interested in
gaining early industry perspective
so we can understand the realities and
begin building potential pathways
that meet mutual interests.



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Mars Exploration Program Overview

Eric Ianson

MEP Director, NASA HQ

MARS EXPLORATION PROGRAM

MEP Overview

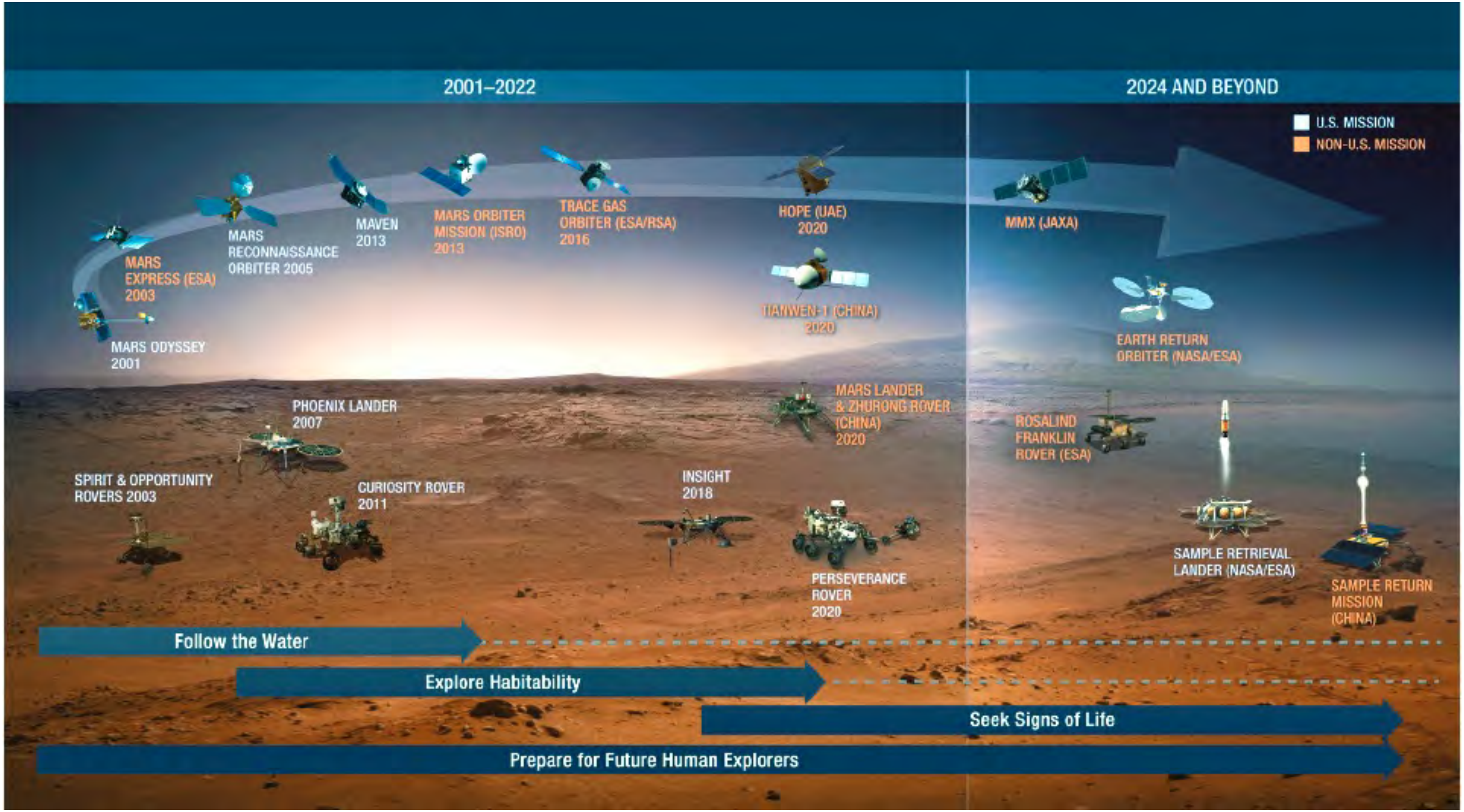
NASA MARS EXPLORATION PROGRAM

- **50+ years studying Mars and its moons**
- **25 years of a continuous presence there with our orbiters, landers, rovers – and now helicopter!**
    - Since MEP's inception (1994), Mars missions have produced mounting evidence that Mars once had habitable environments; NASA is on the cusp of returning samples from the surface
- **MEP now planning for the next 25 years:** anticipation of understanding if Mars is habitable today – not just by microbes, but future human explorers too – along with other high-priority science

MEP STRATEGIC INTENT: LOWER COST, HIGHER RETURN MARS MISSIONS

- MEP is taking a holistic view of the future program: science, technology, infrastructure, international/commercial partnering, etc.
- **Leverage commercial capabilities (e.g., economies of scale) and develop new business models to meet Program goals**

Current MEP Missions: Present and Planned



Missions contribute to four progressive organizing science themes for programmatic coherence.

PAVING THE WAY TOWARD A SUSTAINABLE HUMAN-ROBOTIC FUTURE ON MARS

Program of Record:
MEP Contributions to MSR
Highest Priority for Next Decade

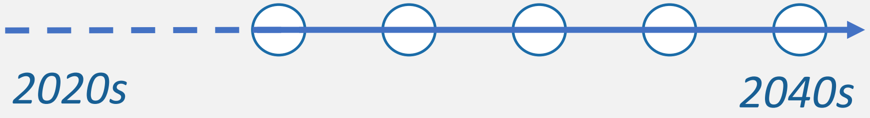
+ ONGOING MISSIONS

+

Concept:
Exploring Program Possibilities

MEP

GOAL: Increase Cadence of Mars Missions - Achieved By Lowering Costs



- **If costs come down, can substantially expand <u>compelling science</u> and data for <u>human mission planning</u>**
- **More competitively selected science community & industry opportunities**

Challenging but Achievable ‘Hills to Climb’

- **Budget constraints** while:
  - Executing Mars Sample Return is the highest science priority in the next decade
  - Commitment to Artemis achievements is a central near-term strategy in the nation’s Moon to Mars ambitions
- **Mars Relay Network orbiters are aging**, and not expected to last past ~2030, having already lived far past their original estimated lifetimes
- **Steeper requirements for next steps in Mars exploration**:
  - More sophisticated instruments and spacecraft
  - Replenishable networks of orbital and landed assets for systems science
  - Closing strategic knowledge gaps to support planning for a sustained human-robotic presence on Mars

Challenges are balanced with the growing capacity of both commercial and international organizations and the potential for new partnership models that provide mutual benefits.

Programmatic Purpose

Today, we are pleased to have representation from 70 companies, and we look forward to hearing your interests and needs.

PURPOSE **Lower cost Mars missions & US economic competitiveness in deep space**

MEP is *committed* to working with industry to leverage commercial capabilities on behalf of the nation:

- Talking with industry very early in the process feeds into MEP strategic planning for the next two decades (currently underway)
- Allows MEP to be aware of, and responsive to, what is needed for mutual success

PROSPECT

Pending assessment of this MEP Industry Day, *possible* next steps might include:

- A more comprehensive RFI for one or more service areas
- One or more funded industry studies
- Implementation of other ideas that may emerge here

RETURN ON INVESTMENT

MEP is investigating the possibility of low-cost (sub-Discovery) Mars missions, ideally at every launch opportunity, to provide stable competitive opportunities for the community

CURRENT STATE NEXT STEPS VISION

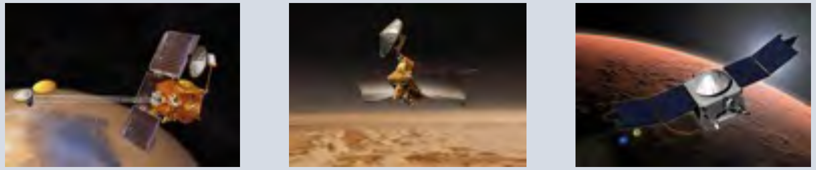
BACKUPS

MARS EXPLORATION PROGRAM

MEP Science & Technology Feed Forwards

Science: Results drive future science focus

ORBITERS



- Telecommunications Relay
- Event Coverage
- Site Reconnaissance
- Global Context/Ground Truth
- Weather (Dust Storm) Monitoring

SMALLCRAFT

LANDERS & ROVERS

Technology: Capabilities feed forward

- MEP **missions build upon one another**
  - Each new mission addresses fundamental Mars questions that evolve in response to discoveries from preceding missions
  - Each new mission leverages and extends prior capabilities
- Mission cadence **enables engineering feed-forward**

Next 2 Decades in Planning

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Mars Challenges Relative to Earth Orbit and Lunar Destinations

Chad Edwards Advanced Studies Manager, Mars Exploration Program Office
Jet Propulsion Laboratory, California Institute of Technology

MARS CHALLENGES

Introduction

- The past decade has seen extraordinary growth in commercial capabilities for low-cost spacecraft
  - CubeSats
  - SmallSats
  - Miniaturized instruments and avionics
  - New launch vehicles and rideshare opportunities
- The result has been a transformation in the economics of Earth-orbiting space missions
  - . . . and more recently we see the beginnings of new commercial opportunities for low-cost lunar missions
- We seek to capitalize on these advances and understand how they can be applied to Mars; however, we also need to be mindful of unique challenges of Mars relative to Earth-orbit and lunar mission applications

Some Tied to Large Distance of Mars	Some Tied to Unique Martian Environment
• Telecommunications & Navigation	• Atmosphere
• Transportation & Propulsion	• Dust
• Power	• Thermal

MARS CHALLENGES

Telecommunications

- Telecom challenge scales as the *square* of distance
  - A transmit-receive system that can support 1 ***Megabit***-per-second on a Moon-Earth link would only support 1 ***bit***-per-second from Mars!
  - Drives the need for **larger apertures** and **higher transmit power**

DESTINATION	DISTANCE	NORMALIZED R^2
Geostationary Orbit	~40,000 km	1
Moon	~400,000 km	100
Mars	Up to ~400,000,000 km	100,000,000

- Large Earth-Mars distance also results in long Round-Trip Light Time (up to ~45 min at max range)
  - Drives need for high levels of autonomy on Mars spacecraft

Telecommunications

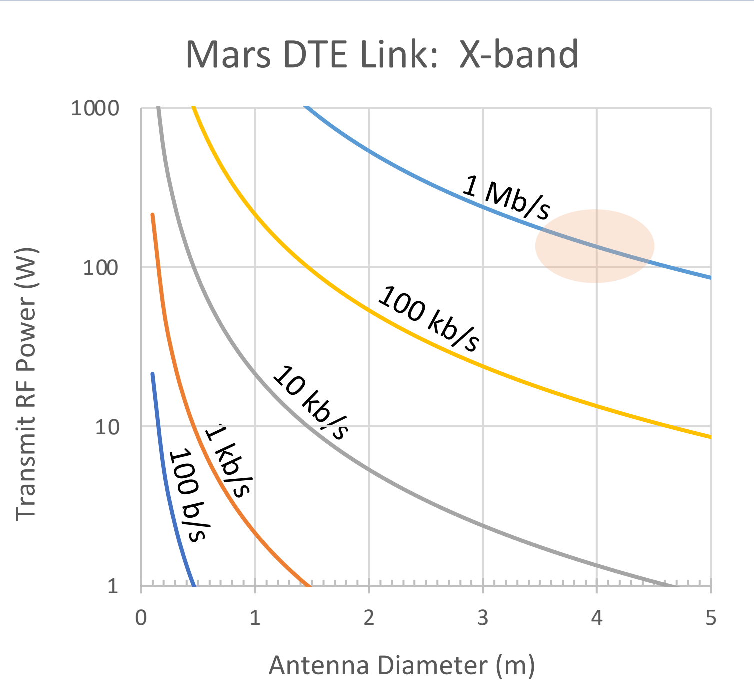
Mars DTE Link @ 2.5 AU to 34m DSN antenna vs. Small Sat to Relay Orbiter

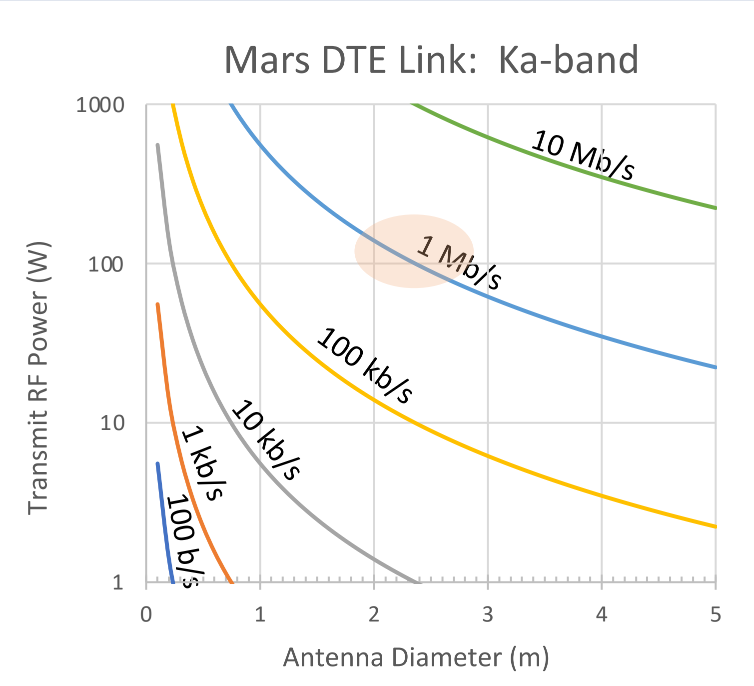
Required to achieve 1 Mb/s downlink (Ka, X-band):

>100W RF transmit power, >2-4 m high gain antenna

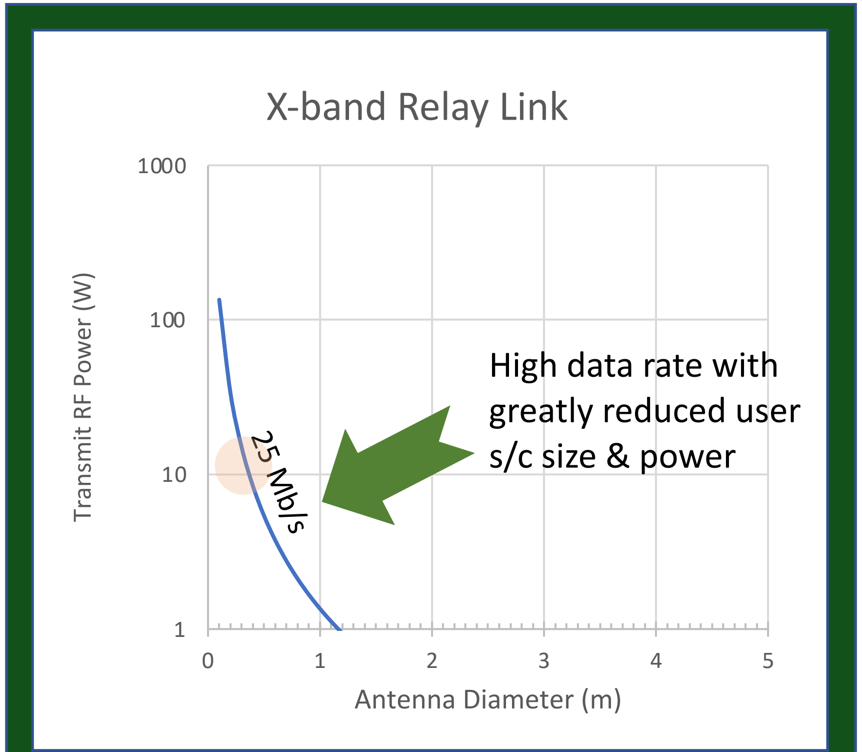
Able to achieve 25 Mb/s downlink:

15W RF transmit power, 30 cm antenna





Assumptions:
- *2.5 AU*
- *34m DSN antenna*



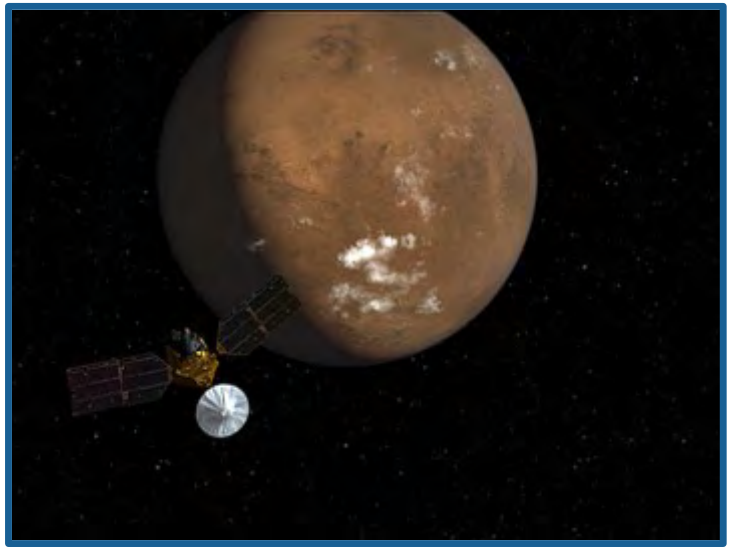
High data rate with greatly reduced user s/c size & power

Assumptions:
- *1m Relay Orbiter receive antenna*
- *8000 km relay slant range*

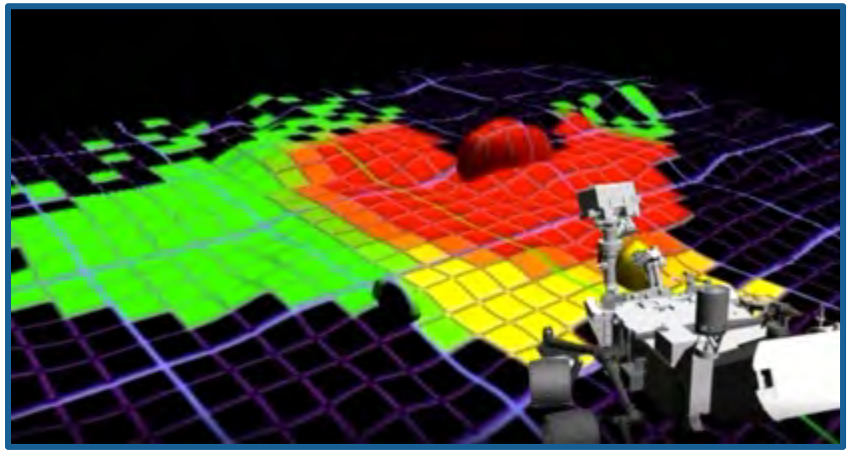
MARS CHALLENGES

Navigation

- No GPS at Mars (yet!)
  - However, desire exists for *in situ* radio-based navigation capabilities in preparation for human exploration
- Approach and on-orbit navigation is currently based on DSN radio metrics (range, Doppler, ΔDOR)
  - Onboard optical navigation was also demonstrated on the Mars Reconnaissance Orbiter mission during Mars approach in 2006
- Surface navigation to date is typically vision-based (relative to local terrain, and registered as needed against high-res orbital maps)
  - Terrain-relative navigation during EDL
  - Rover surface navigation



MRO on Approach to Mars



Vision-based Rover Surface Navigation

MARS CHALLENGES

Transportation & Propulsion

- Earth Escape and Mars Orbit Insertion require large ΔV capability
    - Drives need for high-performance propulsion system, with large impact on spacecraft dry and wet mass

ΔV costs (km/s) for Transfer from LEO

	Low-Earth Orbit (LEO)	Geosynch Transfer Orbit (GTO)	Lunar Transfer Orbit (LTO)	Sun-Earth L2	Mars Transfer	Aerobrake/ Spiral Start	Low Mars Orbit (LMO)
Chemical Propulsion	-	2.5	3.2	3.3	4.0	5.0	6.5
Solar Electric Propulsion	-	3.8	6.4	7.5	11.3	13.2	16.1

- Aerobraking/aerocapture can reduce ΔV costs of reaching final Mars orbit

MARS CHALLENGES

Other Considerations

POWER

- At 1.5 AU, solar insolation at Mars is ~45% relative to Earth
    - Drives need for increased solar array area and low-power avionics
    - Dust on lander solar arrays can lead to significant decreased power
- Radioisotope Power Systems ≠ Low-Cost!

MAGNETIC FIELD

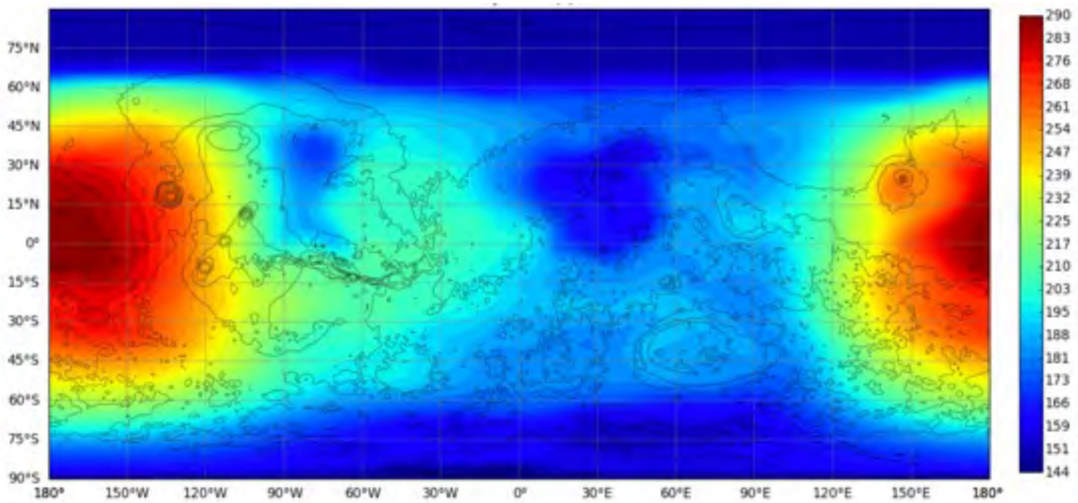
- Extremely weak Mars magnetic field precludes use of magnetic torque rods for spacecraft attitude control

ATMOSPHERE

- Thick enough to drive significant aerothermal heating during EDL (>2000 C)
- Thin enough (~1% Earth pressure) to provide only limited atmospheric drag for EDL and pose a challenge to powered flight

WEATHER

- Surface temperatures average -60 C, and can range from +20 C (equator, midday) to -140 C (poles) with large diurnal and seasonal variation
- Seasonal dust storms (NH fall/winter); τ > 10 has been observed



MARS CHALLENGES

Conclusion

Mars poses key challenges – many tied to the large Earth-Mars distance - that must be addressed when attempting to leverage Earth-orbiting and lunar SmallSat technologies

- Telecommunications & Navigation
- Transportation & Propulsion
- Power
- Environment

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Mars Opportunities:

Four Potential Commercial Services of Interest

Richard M. Davis Assistant Director for Science and Exploration
NASA Science Mission Directorate/Planetary Science Division

EXCITING ADVANCES IN COMMERCIAL CAPABILITIES & POTENTIAL GOVERNMENT-INDUSTRY PARTNERSHIPS

Advantageous Timing Potential Capabilities to Leverage New Business Models

INDUSTRY EXAMPLE:

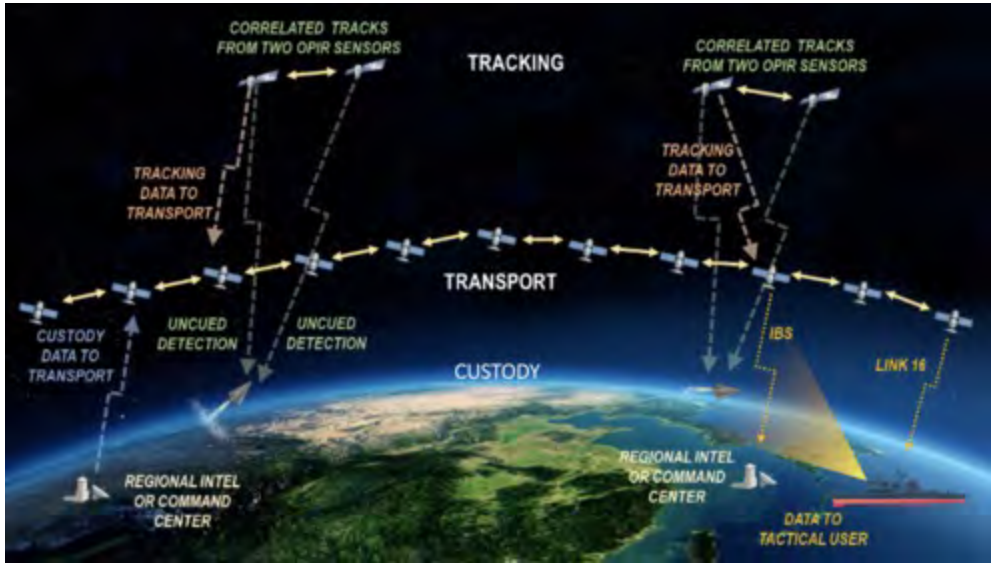
Mass-manufactured satellite fleets and supply chains

Constellation, as seen from the International Space Station. Credit: NASA

- Multiple companies have or are planning thousands of satellites to study Earth
- Lunar Commercial Services Beginning

GOVERNMENT EXAMPLE:

Space Development Agency (SDA) creating a market for *interoperable, low-cost (<$14M@) satellites from industry:*



US DoD Space Development Agency (SDA)

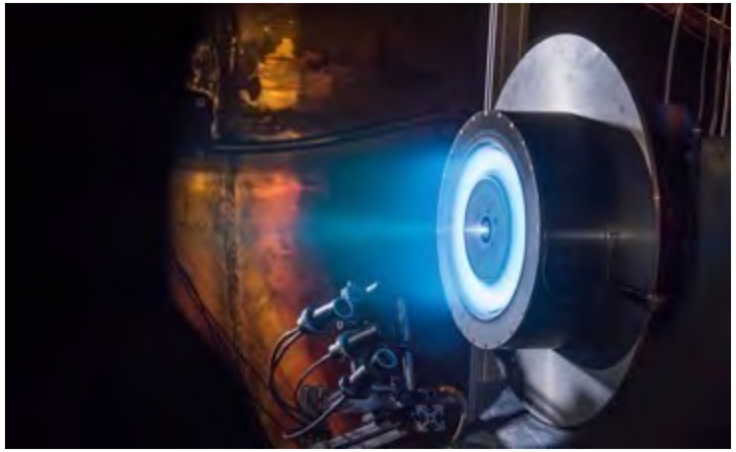
- Rate of ~1 Satellite/Week
- Several Launches/Year
- Frequent Procurements

MARS OPPORTUNITIES

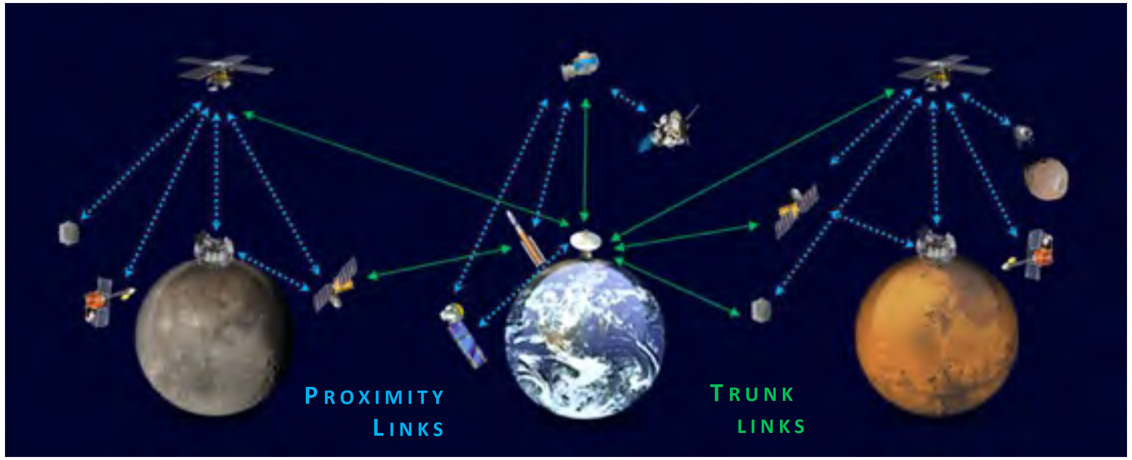
Overview of Needs

NASA is interested in commercial solutions for these service needs, including approaches that might address multiple capabilities.

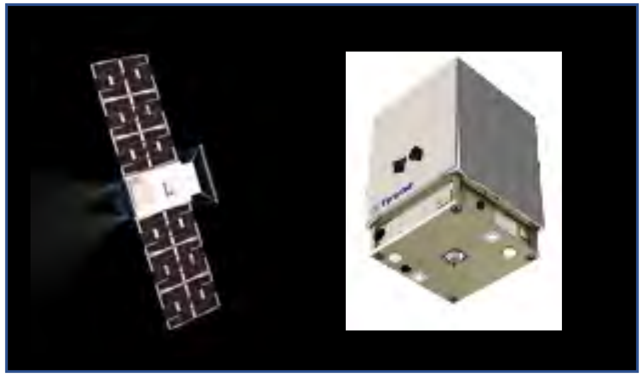
TRANSPORTATION INFRASTRUCTURE



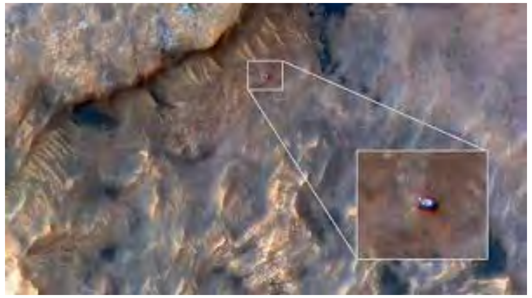
COMMUNICATIONS INFRASTRUCTURE



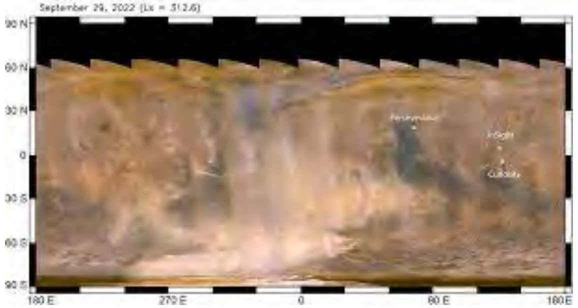
PAYLOAD SERVICES



HIGH-RES IMAGING



GLOBAL METEOROLOGY



Fundamental Assumptions

If we build an economic way out to Mars . . .

and a communications network to enable extremely large data volumes

for a growing fleet of large and small orbital and landed assets . . .

we build toward US leadership in deep space

access to discovery for more of the world

and a sustainable human-robotic presence on Mars.

✓ **PUBLIC-PRIVATE PARTNERSHIPS**

- Joint investment period when the capabilities are developed
- Private companies own, operate, manage assets

✓ **NEED FOR COMPETITION**

✓ **LUNAR PROGRAM SYNERGIES**

- Way of building business models and extending the marketplace in deep space

1

Spacecraft Delivery Services

Marguerite Syvertson	Program Area Manager Mars Exploration Program Office
Ryan Woolley	Mission Design Engineer

Jet Propulsion Laboratory, California Institute of Technology

SPACECRAFT DELIVERY SERVICES

Overview

GOAL: High-mass, low-cost delivery capability that is interoperable and replenishable – that is, get loads of stuff to Mars as cheaply and as often as possible

- Given this need is the same for all deep-space locations (what changes is how much propellant and how long), the co-investment serves multiple opportunities at the moon, Mars, and beyond

- Relatively mature market for launch to LEO capabilities
- No mature capability for braking into the Martian system
- Establish routine standardized interfaces (ports, power, etc.) for spacecraft to Mars

DESIRED CAPABILITIES

Safe, reliable, and cost-effective delivery services for spacecraft from Earth to various Mars destinations

Immediate Need

Relay capabilities, along with science priorities enabled by hosted payloads, imaging, weather

DEMONSTRATION

Next Steps

Rides for NASA & other customers at each launch opportunity

REGULAR BUS SERVICE

Ultimate Outcome

Resupply/replens & sample returns for both robotic & human exploration

ROUND-TRIP FERRIES

CURRENT STATE

INIITIAL STEPS

VISION

Introduction

DEFINITION: SPACECRAFT DELIVERY SERVICES

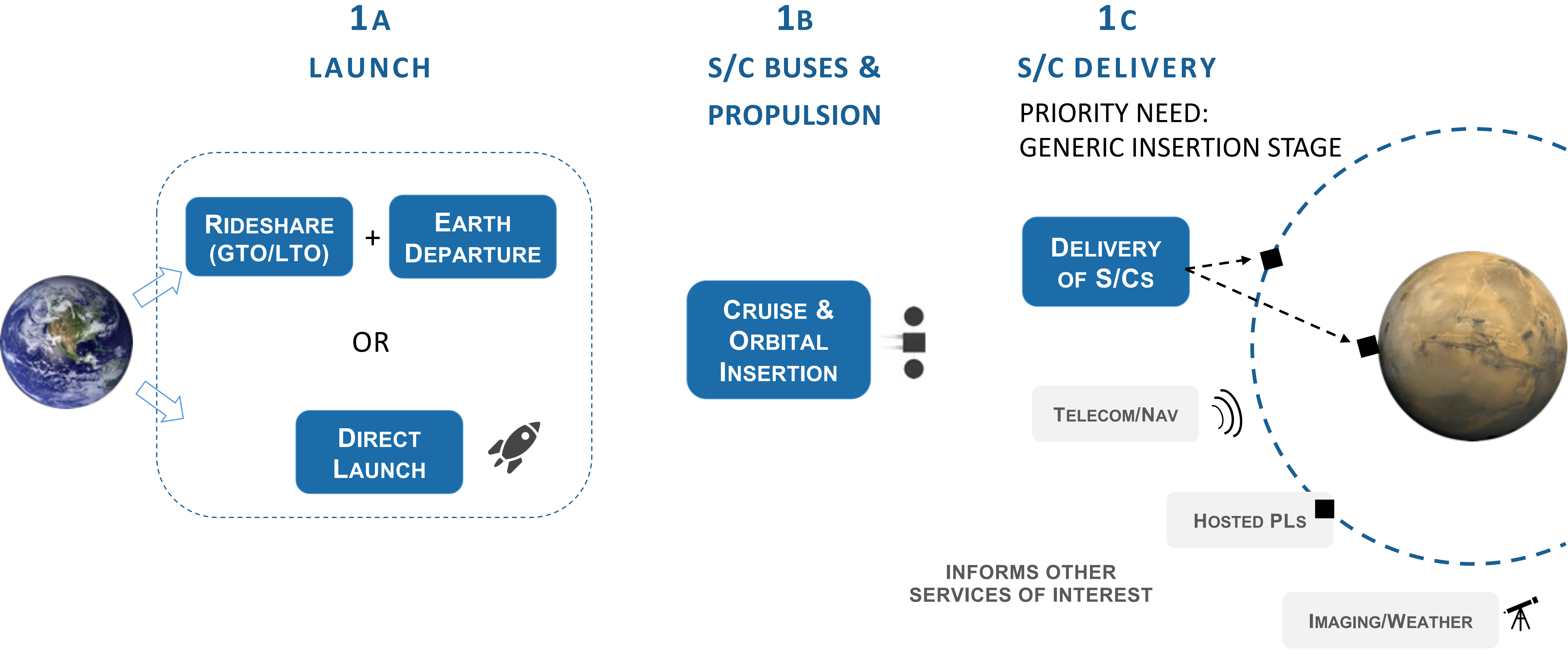
- A scenario in which one or more NASA (or other) customer-provided spacecraft are delivered to specified Mars orbits or entry trajectories by a commercial carrier vehicle, launched, owned, and operated by the provider, with support from NASA as needed
- Nominally, spacecraft would be provided physical accommodations with maintenance power and health telemetry from launch until delivery and separation at the specified conditions at Mars
- After delivery of the spacecraft, the delivering vehicle would remain in possession of the service provider, potentially available to provide other services

INFORMATION SOUGHT

- Potential technical steps, partnership approach, cost implications, and strategy to achieve this goal
- Solutions that effectively meet the needs of multiple services are of particular interest to MEP

SPACECRAFT DELIVERY SERVICES

Introduction



1A
LAUNCH

1B
S/C BUSES & PROPULSION

1C
S/C DELIVERY

PRIORITY NEED:
GENERIC INSERTION STAGE

INFORMS OTHER
SERVICES OF INTEREST

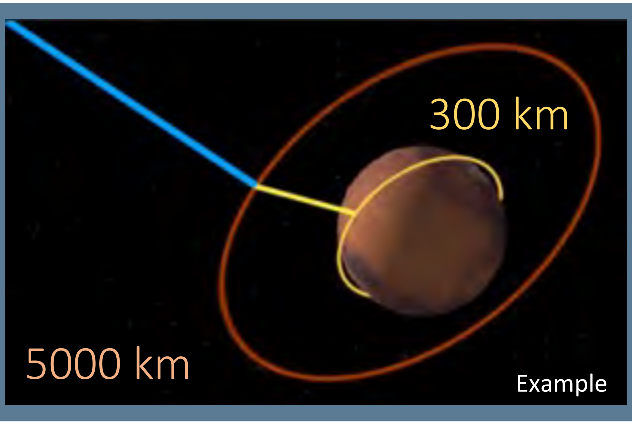
Trade Space for Spacecraft Delivery

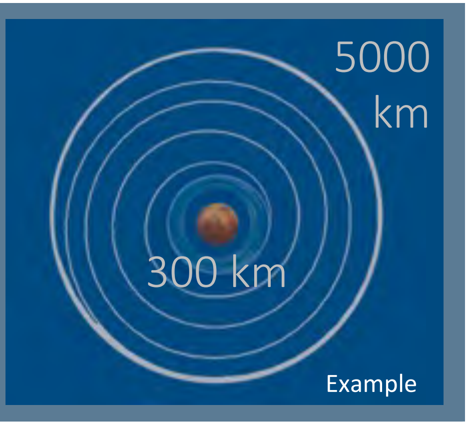
Spacecraft Delivery is Bounded by 2 Options: Chemical Propulsion & Solar Electric Propulsion (SEP)

(on a continuum of solutions characterized by delivered mass and ∆V capability)

CHEMICAL

- With high mass delivery capability, could deliver multiple comm relay birds (and/or science missions) to low Mars orbit





SEP/CHEM TUG

- Interesting Solution: Power can be used to adjust orbit for different drop offs (and, in time, potentially do round trips), depending on the needs of the mission(s)
- Once it arrives, Tug has significant power for additional tasks – e.g., ease into high-altitude, then provide comm relay and potentially other payload hosting (e.g., weather) – thus cost-effectively becoming its own additional mission
- Allows more flexible launch opportunities

Concepts

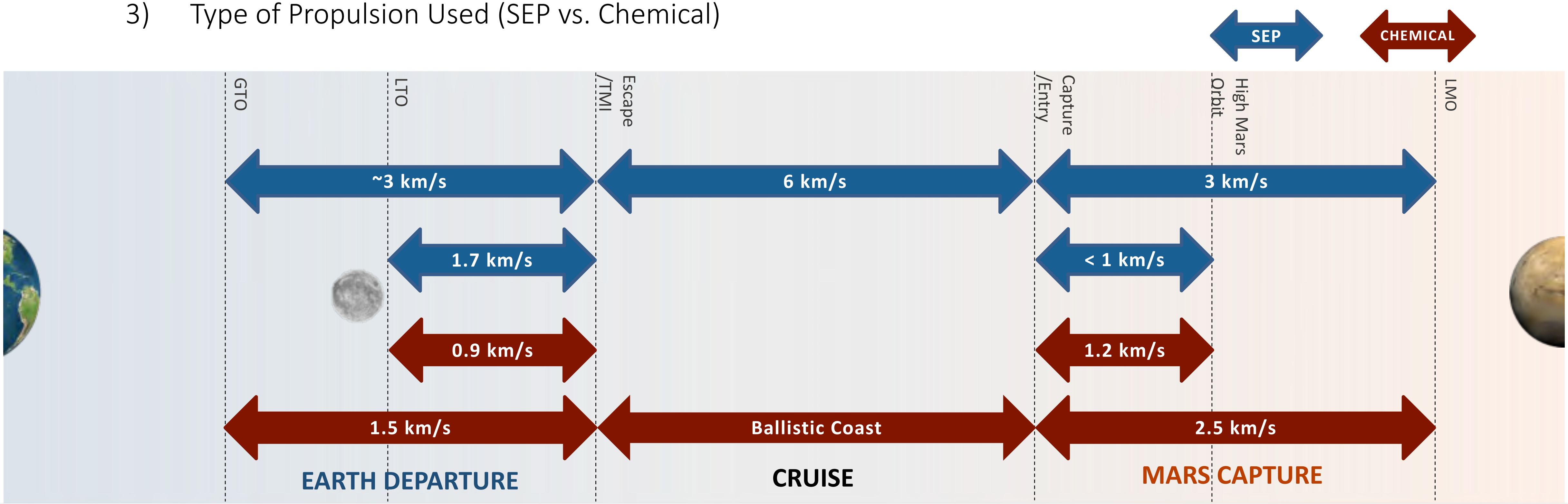
The missions envisioned that could be flown by such a delivery service include a wide range of both orbiters and/or landers, large and small.

- **Mission concepts** include single orbiters, small constellations, multiple cubesats, small landers, etc.
  - **Orbital missions** could be deployed into various orbits such as:
    - Sun-synchronous orbit (SSO)
    - Various inclinations of low-Mars orbit (LMO)
    - Elliptical inclined orbits
    - Phobos, Deimos, and Areostationary orbits (17,031 km)
  - **Landed missions** could be released upon approach hours to days before arrival or after orbital insertion descending from orbit
- **Spacecraft and mission cost are highly driven by total mission ΔV**
  - A low-cost delivery service to Mars could remove this cost driver and enable missions – and considerably smaller, cheaper, and simpler spacecraft - to be flown on a regular basis

Propulsion Needs

TOTAL PROPULSIVE ΔV REQUIRED TO DELIVER SPACECRAFT TO MARS

- Varies widely depending primarily on:
  1) Starting Point of the Mission
  2) Final Destination(s)
  3) Type of Propulsion Used (SEP vs. Chemical)



[4] R. Woolley, N. Barba, and L. Giersch, "Rideshare Strategies for Small Mars Missions," IEEE Aerospace Conference, Big Sky, MT, Mar. 2021.

[5] R. Woolley and N. Barba, "Delta-Vs and Design Reference Mission Scenarios for Mars Missions," 36th Annual Small Satellite Conference, SSC22-P1-03, Logan, UT, Aug. 2022.

SPACECRAFT DELIVERY SERVICES

Notional Desired Capabilities

Delivery services should provide the capability to accommodate 1 or more small spacecraft(s), and provide basic power, telemetry, and separation mechanisms

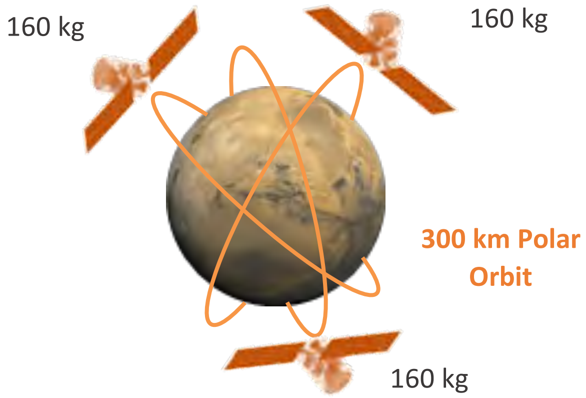
CAPABILITY	NOTIONAL DESIRED VALUE	NOTES
Minimum Total Carried Mass	200 – 500 kg	Total Mass: In any combination Carried Mass: Could be scaled based on total ΔV required
Number of Ports	1 – 4 (example) (> 2 preferred)	1 port could be subdivided for multiple smaller s/c
Port Diameter and Capacity (ea.)	15” or 24” 450 kg	Lightband or equivalent separation mechanism
Power and Volume per Port	15 W [106 x 117 x 96] cm	Power during cruise
Radiation Tolerance	30 krad	Based on up to 3-year transfer
In-space Propulsion (ΔV)	Varies (up to many km/s)	Depends widely on mission profile and propulsion type
Delivery Destinations	Various Mars Orbits Direct Entry Targeting	Total propulsion requirements vary with destination, propulsion type, and delivery strategy
Potential Starting Locations	Rideshare from GTO/LTO Direct Launch	Delivery services could be provided through rideshare or direct launch (shared or dedicated)

SPACECRAFT DELIVERY SERVICES

Reference Cases

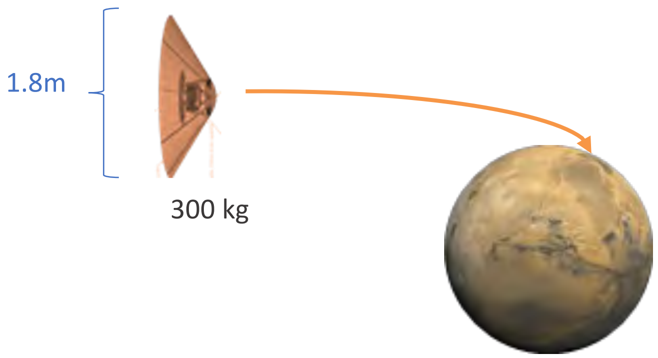
Hypothetic Reference Missions:
For Evaluation against Potential Commercial Service Solutions …

Case 1: 3 Polar Orbiters



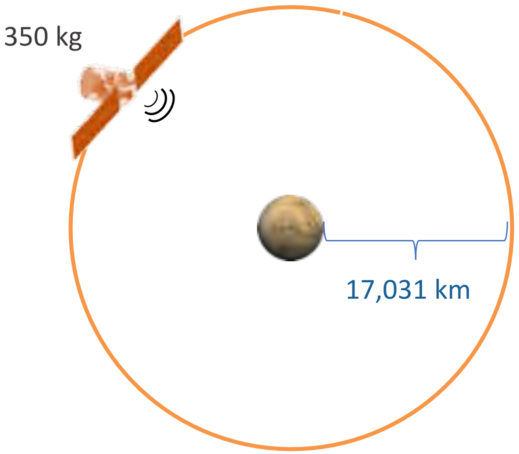
~500 KG
TOTAL MASS

Case 2: Ballistic Entry Lander



DIRECT ENTRY
SEPARATION AT E-24 HRS

Case 3: Areostationary Orbiter



AREOSTATIONARY
EQUATORIAL ORBIT

Bonus: Host spacecraft serves as communication relay @ 5000 km orbit after delivery.

SPACECRAFT DELIVERY SERVICES

Types of Requested Information on Delivery Services

TECHNICAL

1. **Ideas for Architectural Approach** – **Safe, reliable, and low-cost delivery**
2. **Estimates for Performance** – **Mass ranges and ΔV's**
3. **Mission Designs** – **Potential approaches, propulsion architecture, etc.**
4. **Current & Future Technology Capabilities** – **Heritage, maturity, gaps, plans**
5. **Delivery of Multiples** – **Multiple spacecraft and/or combination with other services**

YOUR PERSPECTIVE ON BUSINESS MODELS

Public-Private Partnership Models | Potential Non-MEP Customer Base | Strategies for Risk Management etc.

BACKUPS

SPACECRAFT DELIVERY SERVICES

Notional Spacecraft Delivery Services Reference Cases

Hypothetic Reference Missions:
For Conversations about Potential Commercial Service Solutions …

Case 1: *3 Polar Orbiters*	*Case 2:* *Ballistic Entry Lander*	*Case 3:* Areostationary Orbiter
• 3 spacecraft *High-mass Case*: 500 kg NTE (~165 kg each) *Low-mass Case*: 200 kg NTE (~ 65 kg each)	• 300 kg NTE spacecraft lander wet mass • 1.8 m cylinder x 1 m	• 350 kg NTE spacecraft wet mass
• Delivery to 300 km x 300 km x 93° SSO orbit at Mars	• Separation prior to MOI (E-24 hours) *Landing Latitude Range*: 30 S – 30 N *V-infinity Range*: 0.2 – 4.2 km/s	• Delivery to 17,031 km x 0° orbit • Continue to 5,000 km circular orbit for telecom relay service
Discuss potential for post-delivery service (e.g. telecom, imaging, etc.)		

2

Mars Relay Telecommunications & PNT Services

Roy Gladden

Manager, Mars Relay Network
Mars Exploration Program Office

Zaid Towfic • Marc Sanchez Net • Steve Lichten
Jet Propulsion Laboratory, California Institute of Technology

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

Overview

GOAL: Establish a next-generation Mars Relay Network with greatly enhanced capabilities: orders of magnitude increase in data return, increased contract time, support for landers (and for the first time) orbiters, and energy-efficient support to resource-constrained users.

Potential to add low-mass instruments that require non-occluded views of the planet (e.g., for weather, radio) science)

Potential to leverage LunaNet and other investments

- Relay function on orbiters is secondary to their science missions in design
- Relay orbiters are aging and not likely to survive past 2030
- Limited in supporting legacy surface assets; inadequate for future data return needs

- Dedicated comm relay orbiter(s):
  - near continuous visibility with Earth
  - service for surface & (for the first time) orbital assets
- Capable of 1 Tb/day data return
- Alleviate need for future Mars missions to carry their own high-performance antennas
  - thus reduces their costs, risks, and operational complexity

DEMONSTRATION

- Dedicated Mars Relay Network with orbiters positioned to optimize telecom
  - Scalable, replenishable, interoperable
  - Lay the foundation for the future human exploration of Mars

CAPACITY-BUILDING: ROBOTIC INFRASTRUCTURE

- Dedicated, standardized, interoperable Mars Relay Network* as part of a robust architecture for an interplanetary internet able to support human & robotic needs reliably

*MRN + Mars Surface Network + Earth Network + Moon Network

CAPACITY-BUILDING: HUMAN INFRASTRUCTURE

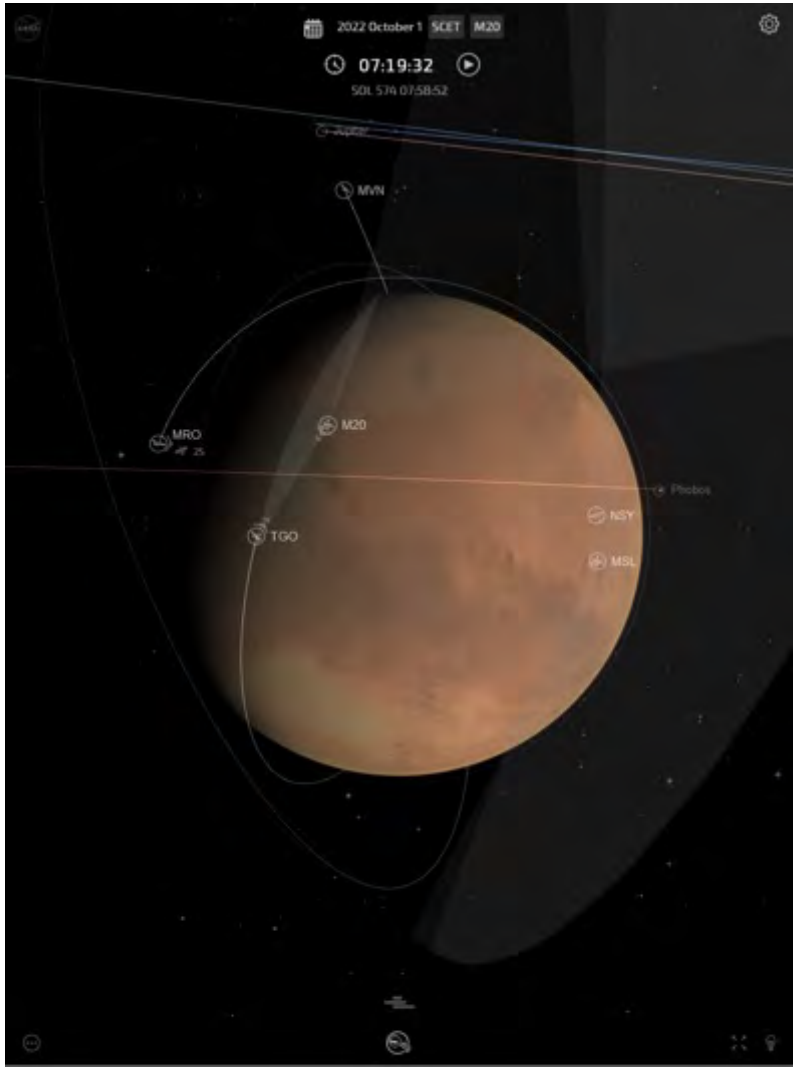
CURRENT STATE

INIITIAL STEPS

VISION

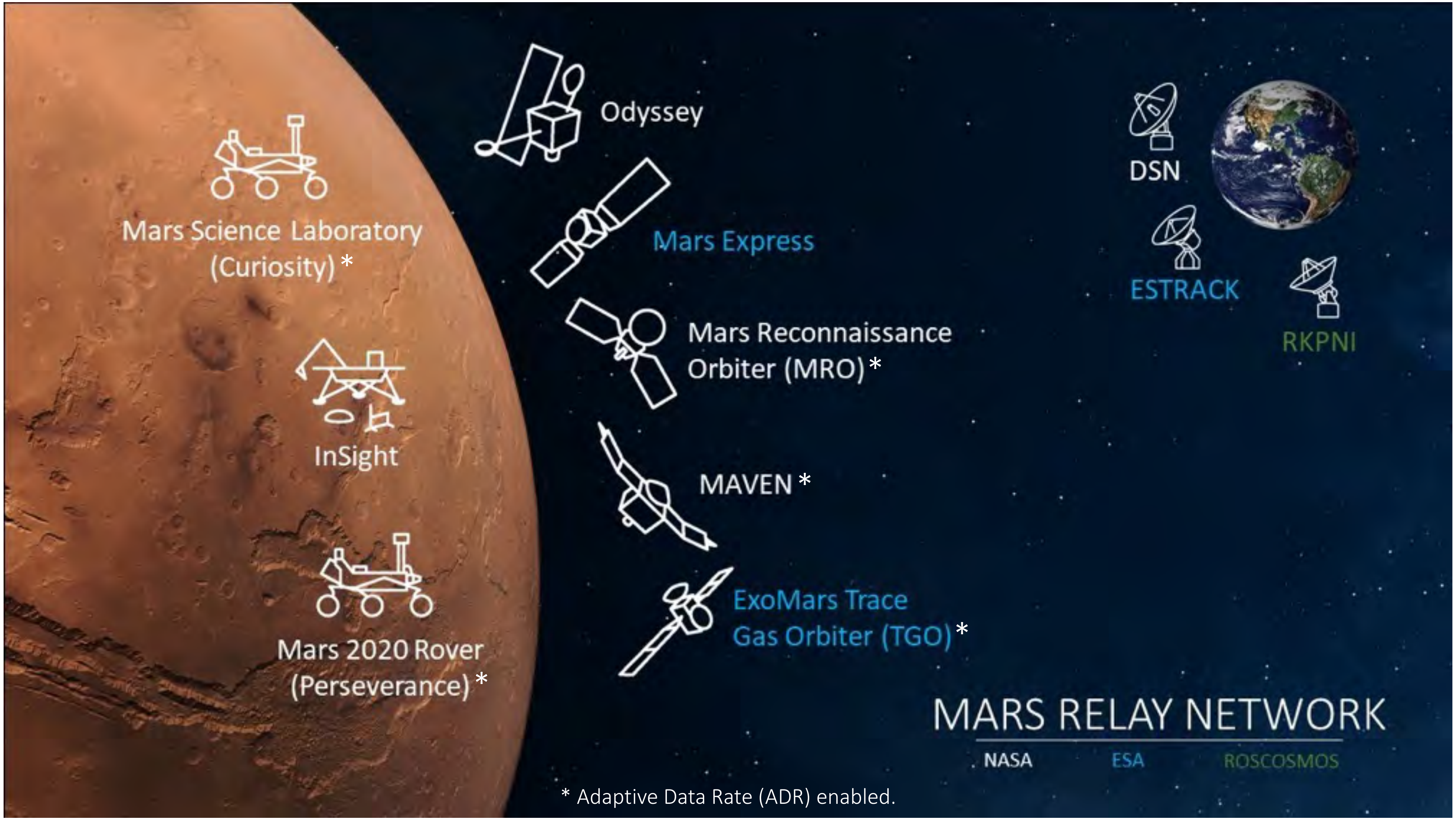
Motivation

- NASA seeks to leverage commercial space telecommunication/navigation capabilities from the terrestrial (and emerging lunar) domain and apply these to next-generation Mars Comm/Nav services.
- The long and variable distance between Earth and Mars poses a fundamental challenge for communicating with all Mars missions.
- The use of Mars orbiters to provide relay services to Mars landers enables an orders-of-magnitude increase in data return.
    - The need for direct-to-Earth telecom systems on each user spacecraft is eliminated, instead enabling high rate data transfers with relay orbiters using low-cost, low-mass, low-power, and physically smaller telecom systems.
    - Acting as “trunk lines”, the relay orbiters enable “smallsats” to do “big science”.
- Radio metric observations (e.g., range and Doppler) made on these proximity links also enable precision position, navigation, and timing services in the Mars reference frame.



https://eyes.nasa.gov/mrn

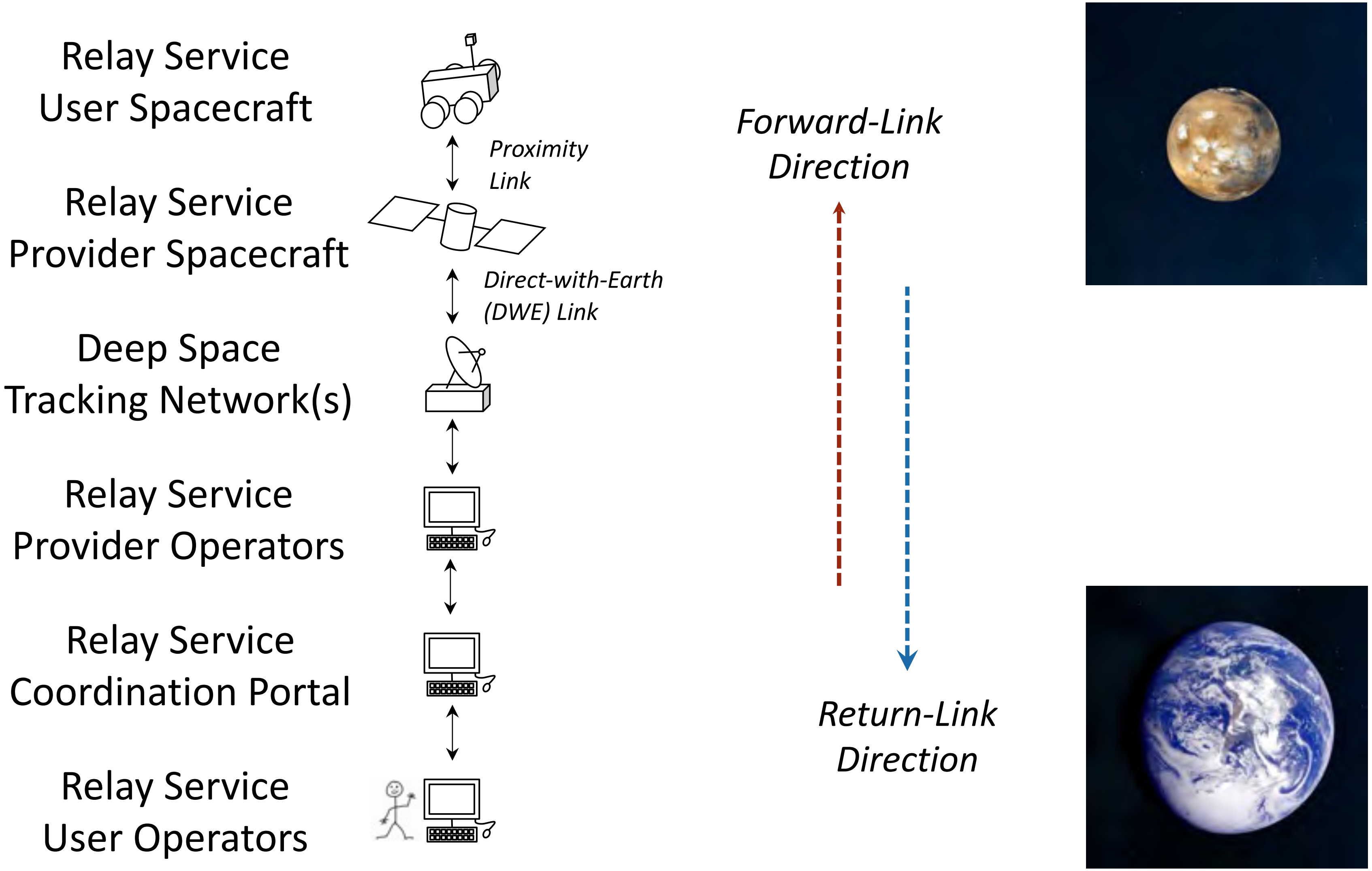
The Current Mars Relay Network



* Adaptive Data Rate (ADR) enabled.

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

Simplified Mars Relay Network Topology



Relay Service
User Spacecraft

Proximity Link

Relay Service
Provider Spacecraft

Direct-with-Earth (DWE) Link

Deep Space
Tracking Network(s)

Relay Service
Provider Operators

Relay Service
Coordination Portal

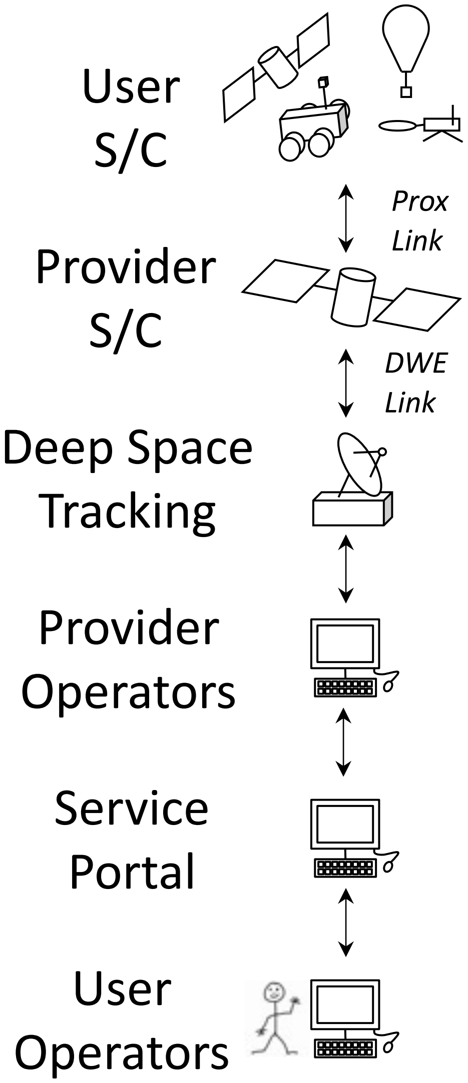
Relay Service
User Operators

Forward-Link Direction

Return-Link Direction

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

Next-Generation Proximity Services



User S/C

Prox Link

Provider S/C

DWE Link

Deep Space Tracking

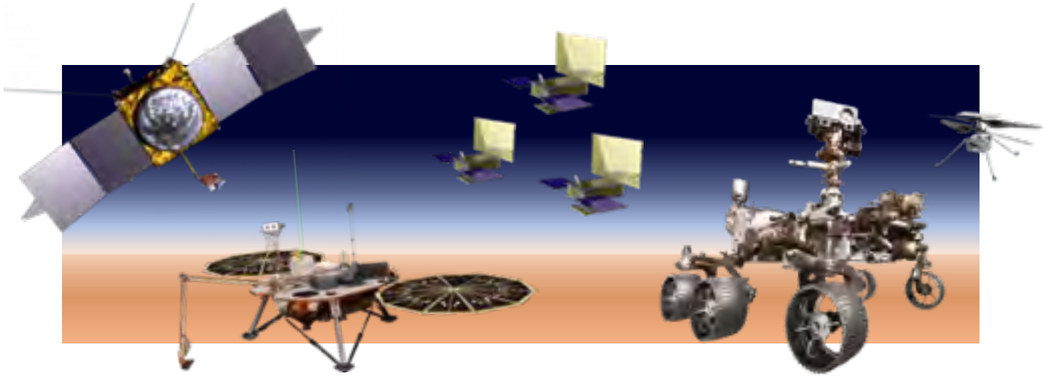
Provider Operators

Service Portal

User Operators

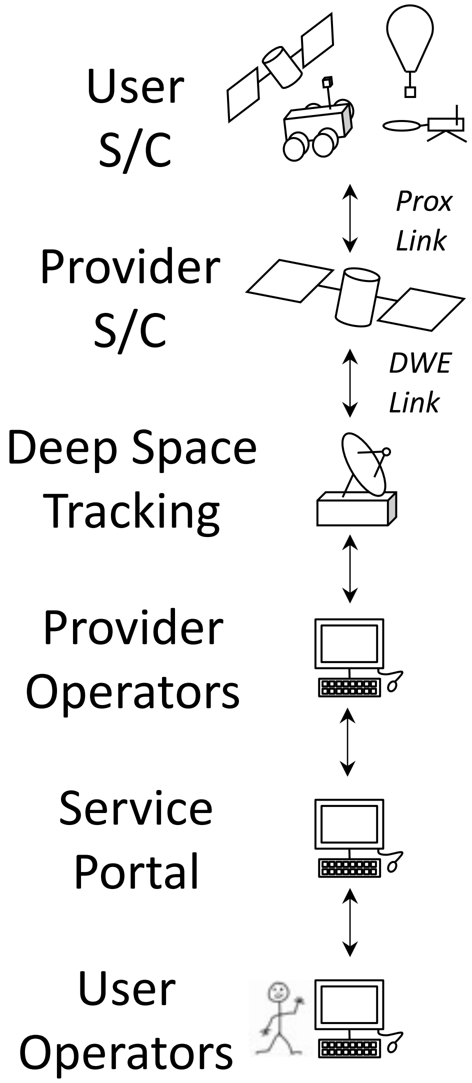
NASA is interested in securing relay services that provide:

- Solutions that support both surface and orbiter missions:
  - Low and very high data producing missions (>10 Mbps)
  - Multiple users simultaneously (>1)
- Solutions that emphasize interoperability and include interfaces that comply with CCSDS and SFCG open standards:
  - Next-generation protocols, such as CCSDS's Unified Space Data Link Protocol (USLP) standard[5]
  - Delay Tolerant Networking (DTN, see future slide)[6, 7]
- Solutions that include independently securing appropriate spectrum allocations



A variety of new missions and mission classes are expected to be achievable when an appropriate communications architecture is in place.

Legacy Proximity Services



NASA is interested in acquiring relay services to support current (i.e. UHF) and future surface missions that are considered low data rate missions:

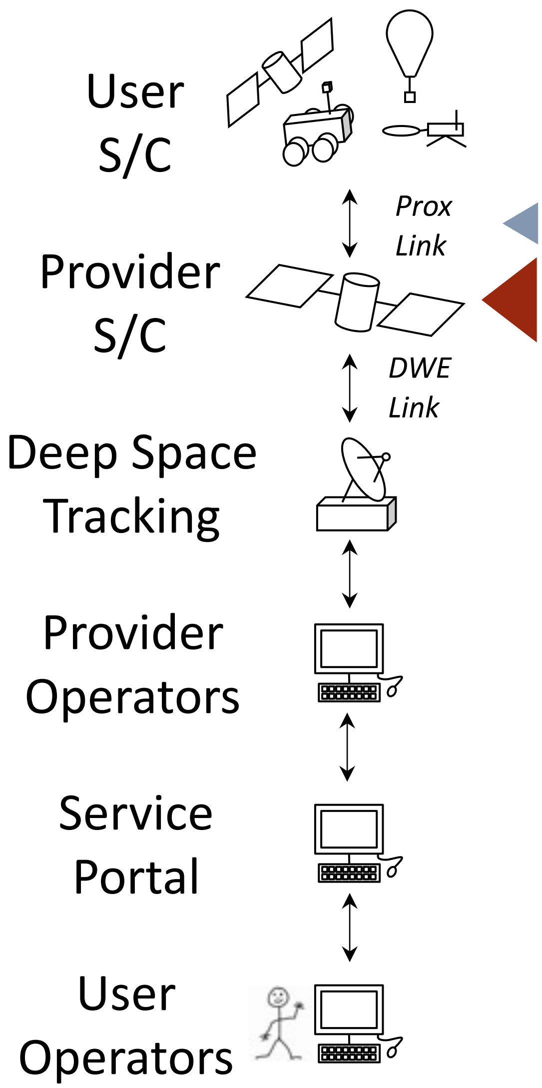
- NASA's current rovers and expected future small missions are likely to need relay services provided via UHF

The Perseverance rover carries an omnidirectional UHF antenna and communicates using CCSDS's Proximity-1 standard[1-4] *for both reliable and unreliable data transfers.*

It uses coded data rates no higher than 2 Mbps in the return-link direction and (typically) 32 kbps in the forward-link direction.

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

Geometric Considerations



User S/C

Prox Link

Provider S/C

DWE Link

Deep Space Tracking

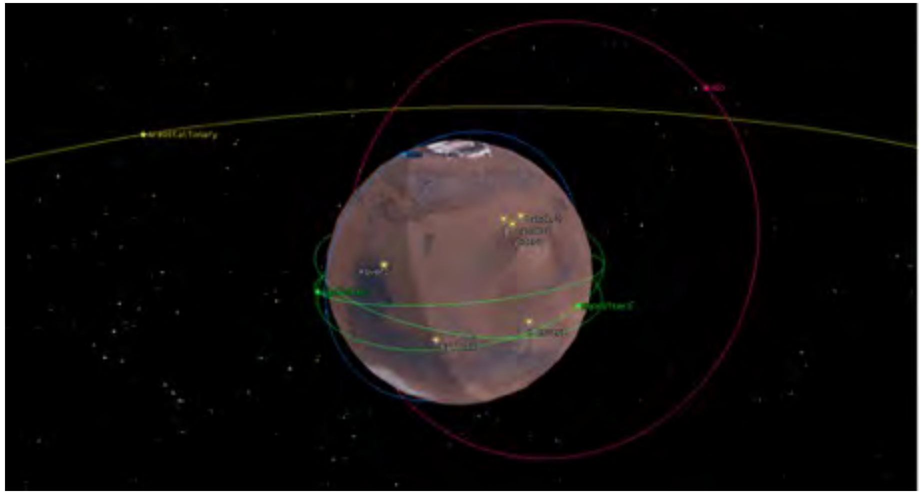
Provider Operators

Service Portal

User Operators

NASA is interested in providing relay services to users at a variety of surface locations and orbits:

- These could include low- and high-altitude circular orbiters, orbiters in highly elliptical orbits, clusters of landers at the same surface location, etc.
- These services could be provided by orbiters in a variety of different orbit types, at various altitudes, and in different constellation types:
  - Solutions that provide continuous access to the relay network are of interest, though are not required.
  - New relay service provider orbiters are expected to be the first elements of a large, confederated network in anticipation of eventual human missions to Mars.



Relay Network Design Considerations

Prior NASA studies have explored key drivers on Mars relay network design.

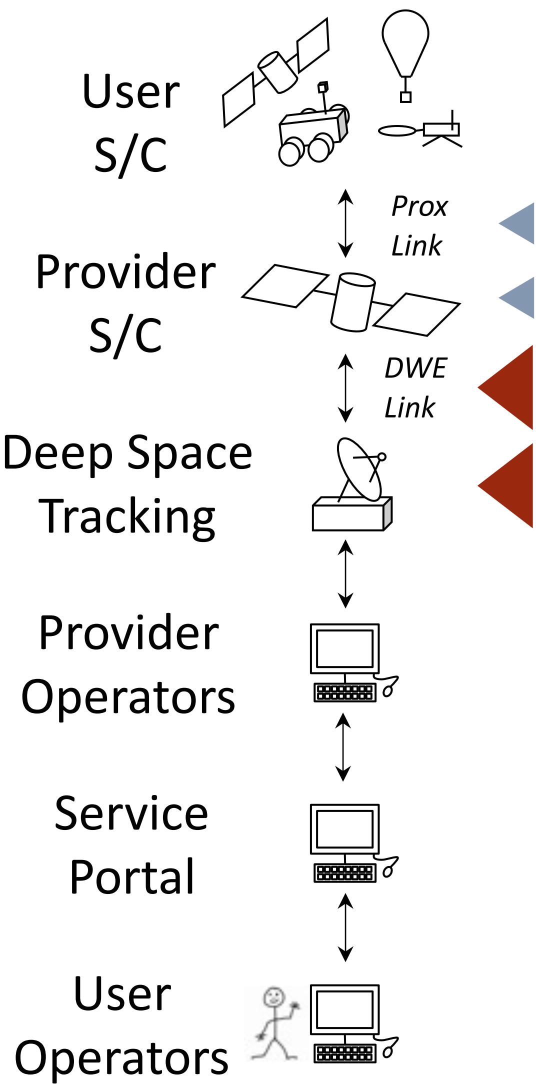
Desired Network Capability		Relay Network Design Driver
Increased service availability (increased contact time between users and relay orbiter) and support to orbiters as well as surface users	➠	***High-altitude relay orbit***
High instantaneous data rates for high-capability users (with beam steering capability)	➠	***Directional, high-frequency proximity links***
Energy-efficient data return for low-capability users (with only omnidirectional capability)	➠	***Low-altitude relay orbit to minimize 1/R^2 losses for omnidirectional links***

Optimal telecom support for a wide range of orbital and surface users *may* be best served by a *mix* of relay assets.

- High-altitude Orbiters with directional high-frequency proximity links for high-capability users
    - High-performance trunk links to Earth
- Low-altitude Orbiters with omnidirectional user proximity links for resource-constrained users
    - Shuttle data up to high-altitude orbiters for trunk link to Earth

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

Direct-with-Earth Data Rates & Deep Space Tracking


User S/C

Prox Link

Provider S/C

DWE Link

Deep Space Tracking

Provider Operators

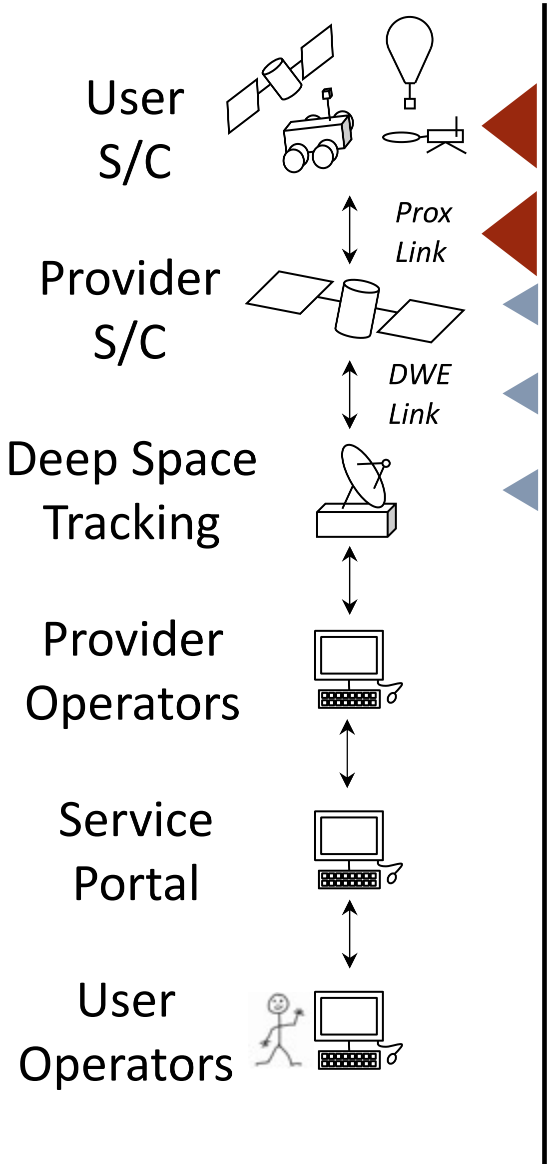
Service Portal

User Operators

- NASA is interested in achieving direct-to-Earth data rates that can:
  - Support aggregate data returns of >1 Tbit/day via reliable data transfers, even at maximum Earth-Mars range.
- NASA is interested in network architectures that may include NASA (such as the Deep Space Network, DSN) and/or non-NASA Earth ground antennas:
  - High-rate communications and tracking services are desired on a variety of wavelengths, including Ka-band and optical.[8]

The DSN stands ready to provide high-rate comm on a variety of frequencies, and is working towards a future optical comm capability.

Desired Augmentations



User S/C

Prox Link

Provider S/C

DWE Link

Deep Space Tracking

Provider Operators

Service Portal

User Operators

- NASA is interested in:
  - Implementing **Position, Navigation, and Timing (PNT) Services**, which are largely unsupported in the current Mars Relay Network.
  - Collecting **radio metric data** on the proximity link, including range and range rate information.
  - Securing **open-loop recording services** to be used for radio diagnostics, to conduct radio science, and to support critical events (i.e. Entry, Descent, and Landing[9]).
  - Acquiring **user terminals** for flight on future Mars spacecraft, expected to be compatible with available relay service providers.

Position/Navigation

Where is the user spacecraft and where is it going?

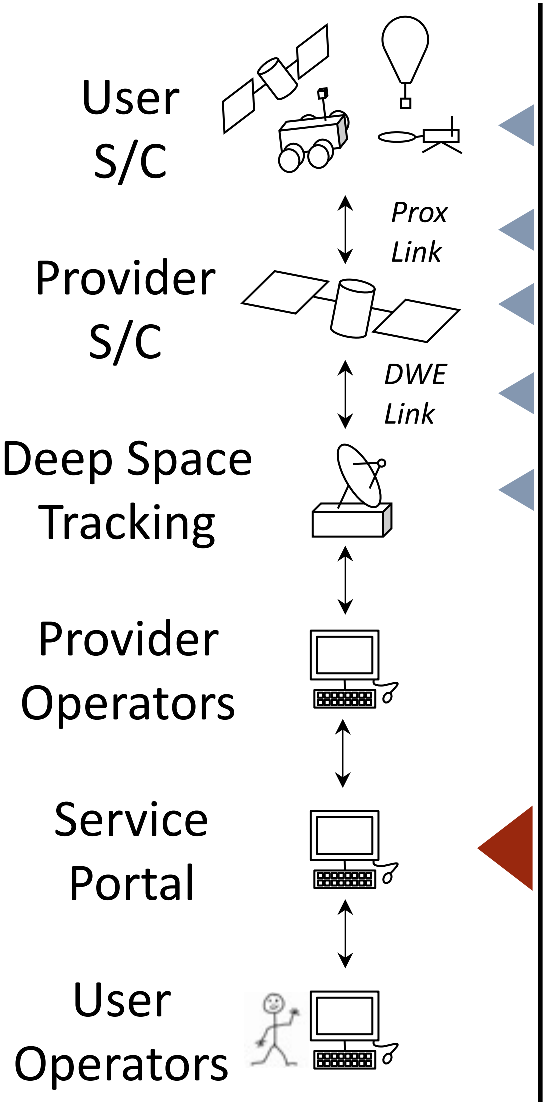
Service would be provided for both fixed and mobile users on both the surface and in orbit.

Timing

What time is it?

Service would be provided to support both time correlation and time setting activities.

Relay Service Planning, Coordination, and Accountability



User S/C

Prox Link

Provider S/C

DWE Link

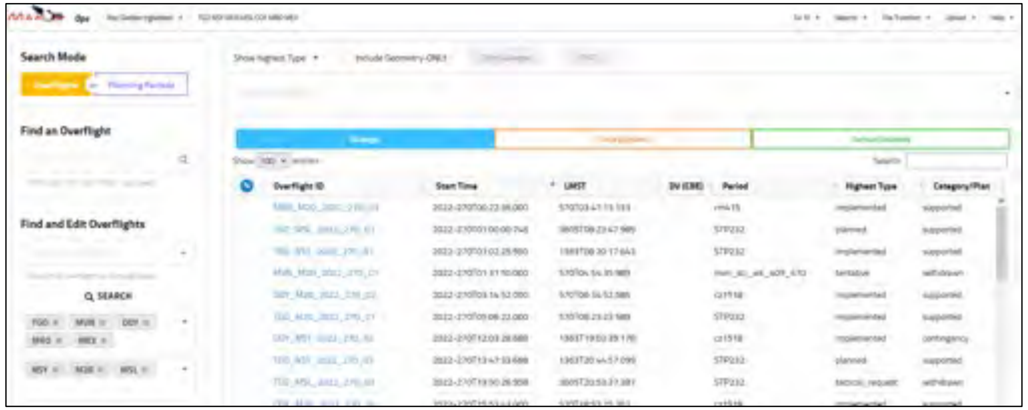
Deep Space Tracking

Provider Operators

Service Portal

User Operators

- NASA is interested in intended ground planning philosophies:
  - Until a node-rich and fully-autonomous network is instantiated, it is anticipated that we must continue to do ground planning of relay services.
  - Operators of the user spacecraft are expected to remain keenly interested in the timeliness of data delivery in both directions, thus predictability of the data delivery service is expected to remain a high priority.

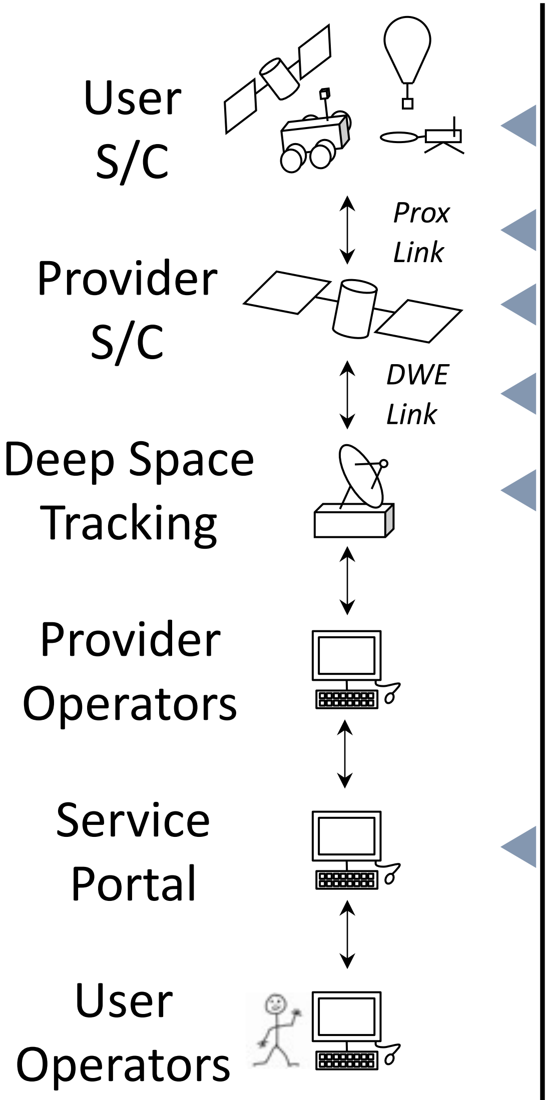


The Mars Relay Operations Service (MaROS)[10] has been implemented by NASA to aid relay network planning and coordination, and to facilitate data distribution of relay data and associated meta-data:

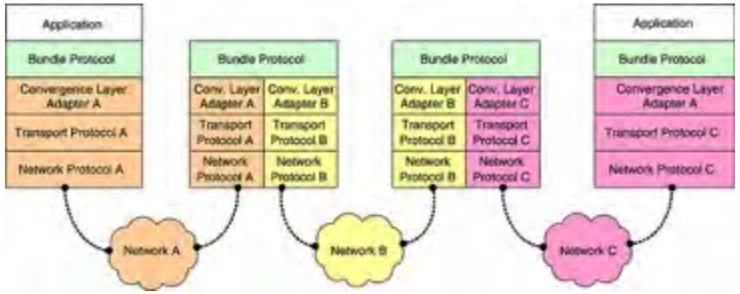
- Planning of relay services (requests and commitments)
- Performance monitoring of relay provider capabilities
- Estimation of forward- and return-link latencies
- Detection of request conflicts between various users
- Standardized system inputs and outputs
- Intermediary for forward- and return-link data
- Support for autonomous planning systems

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

Delay-Tolerant Networking Considerations



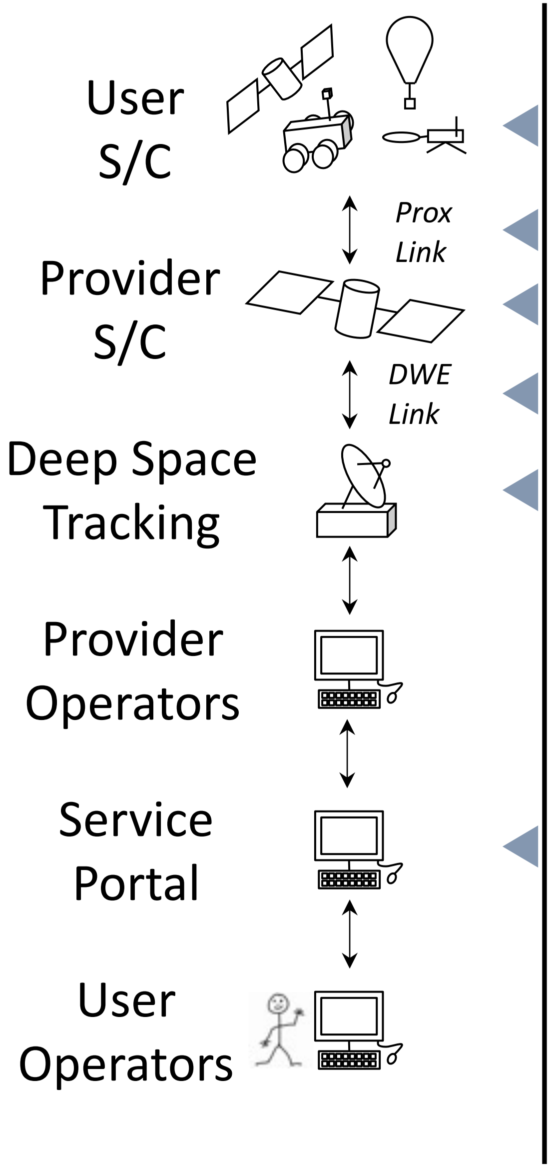
- Delay-Tolerant Networking (DTN) solutions may include the following features:
  - “Always on” and “demand access” features that support unscheduled relay sessions.
  - “Addressable” data transfers, where data can be addressed for an end recipient in any direction.
  - “Custody” data transfers, where the relay provider accepts responsibility for the ultimate delivery of the data to the end recipient.
  - Regular refreshing of the “contact graph” that specifies near-term communication opportunities with every “next node” in all directions, required for full-up, autonomous DTN functionality.



- Present-day DTN capabilities typically rely upon the use of the Bundle Protocol (BP)[11] for autonomous data routing and the Licklider Transmission Protocol (LTP)[12] for reliable data transfers, as elements of an interoperable architecture:
  - BP includes the abilities to prioritize data for “rapid” delivery and to encrypt data.
- The need to provide encrypted data transfers is not yet required by federal law for deep space applications, but this is expected to change.[13]

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

New Partnerships to Continue the Exploration of Mars



User S/C

Prox Link

Provider S/C

DWE Link

Deep Space Tracking

Provider Operators

Service Portal

User Operators

- NASA seeks commercially-provided, end-to-end solutions to both replenish and upgrade the existing Mars Relay Network in support of Mars exploration efforts to:
  - Increase the throughput by orders of magnitude.
  - Instantiate highly-robust solutions that are interoperable and replenishable.
  - Provide relay service to existing and future user spacecraft on the surface.
  - Provide relay service to smaller, dependent orbiters (for the first time!).
  - Be in place to support critical mission events, such as providing communications capabilities during Mars entry, descent, and landing events.
  - Become the foundation for a permanent relay network at Mars in anticipation of human explorers.

BACKUPS

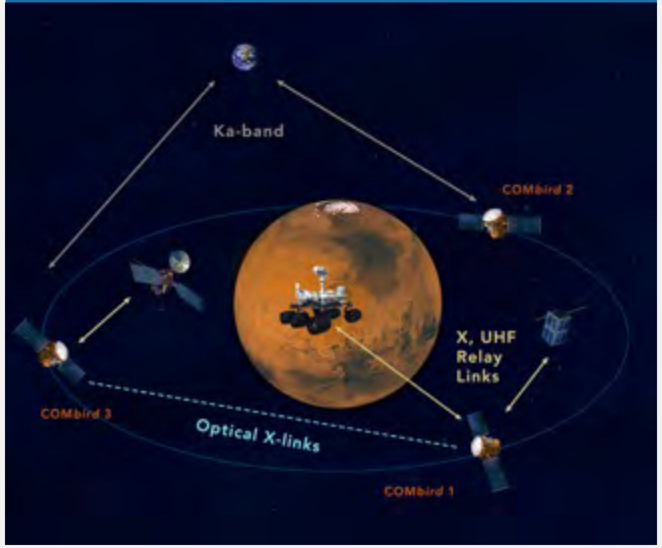
COMMUNICATIONS RELAY & PNT SERVICES

Conceptual Models: Next-Gen Mars Relay Network

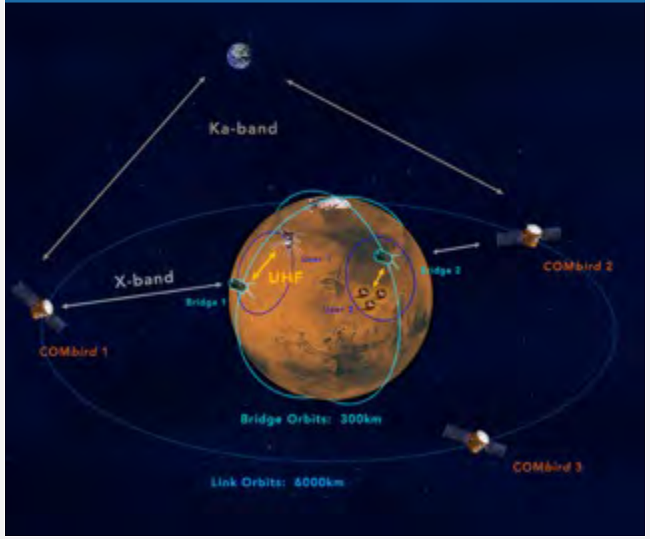
A *mix* of relay assets may best serve a wide range of orbital/surface users.

NASA MEP has a number of sharable internal studies of various configurations and assumptions, but wanted initially to keep the idea space open.

EXAMPLE OF HIGH-ALTITUDE CAPABILITIES



EXAMPLE OF LOW-ALTITUDE CAPABILITIES



High-altitude Orbiters with directional high-frequency proximity links for high-capability users

- High-performance trunk links to Earth
- Increased service availability (increased contact time between users and relay orbiter)

Low-altitude Orbiters with omnidirectional user proximity links

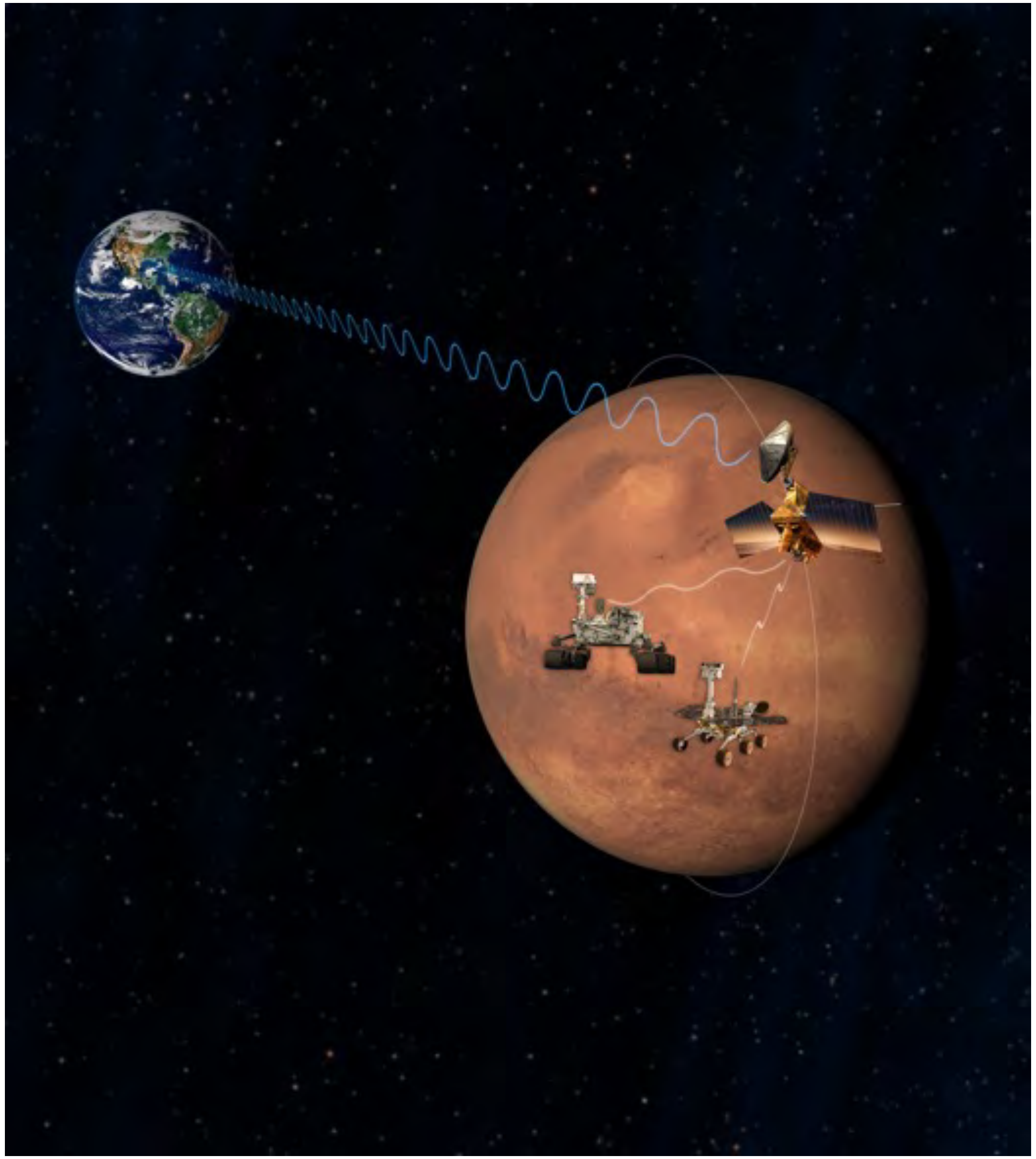
- Shuttle data up to high-altitude orbiters for trunk link to Earth
- Energy-efficient data return for low-capability users with only omnidirectional capability

Edwards, Charles D., Roy Gladden, and Charles Lee. "Next-Generation Relay Capabilities for Future Robotic and Human Mars Exploration." (2021).
https://trs.jpl.nasa.gov/bitstream/handle/2014/54217/CL%2320-6496.pdf?sequence=1

Example Desired Outcomes: Breakthrough increases in Mars telecommunication capability such as:

• Aggregate Mars Bandwidth to Earth	1000 Tb/yr	(Current:	40 Tb/yr)
• Relay Support to Large Surface Assets	200 Gb/sol @ X-band	(Current:	1 Gb/sol @UHF)
• Relay Availability for Surface Assets	Continuous (±40 deg LAT)	(Current:	20 min/sol via MRO relay)
• Relay Service to Low-altitude Mars Orbiters	Continuous (High-rate X-band Relay)	(Current:	Not Available)
• Pointing, Navigation, and Timing	Radio metrics, open-loop recording, user terminals	(Current:	Largely Unsupported)

Reference Documents



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State of Current Mars Relay Network Orbiters

MISSION	AGENCY	LAUNCH YEAR	ORBIT	UHF RELAY PAYLOAD	MAX RETURN-LINK DATA RATE	MISSION STATUS
ODY 	NASA	2001	385 km x 450 km 93 deg incl	CE-505 redundant units, quadrifilar helix antenna, 12 W transmit power	256 kb/s	Fuel usage is ~1 kg/yr, with <4 kg remaining. “All-stellar mode” in use to preserve IMU lifetime. No remaining redundancy in reaction wheel assembly.
MEX 	ESA	2003	298 km x 10,100 km 86 deg incl	Melacom single unit, patch antennas, 8.5 W transmit power	128 kb/s	Some onboard memory issues persist. Fuel load extremely low and uncertain. Available for emergency relay services for NASA’s landed assets.
MRO 	NASA	2005	255 km x 320 km 93 deg incl	Electra redundant units, quadrifilar helix antenna, 5 W transmit power	2048 kb/s adaptive data rate enabled	Fuel usage ~10 kg/yr, with ~150 kg remaining. “All-stellar mode” in use to preserve IMU lifetime. X-band TWTA is effectively single-string due to waveguide transfer switch (WTS) anomaly. Relay services expected to remain viable into the 2030s.
MAVEN 	NASA	2013	~200 x 4500 km 75 deg incl	Electra single unit, quadrifilar helix antenna, 5 W transmit power	2048 kb/s adaptive data rate enabled	Fuel usage ~5 kg/yr, with ~70 kg remaining. Fuel usage planned to allow science and relay operations through 2031. “All-stellar mode” in development and plan to transition to it in the next few months to preserve IMU lifetime.
TGO 	ESA	2016	400 km x 400 km 74 deg incl	Electra redundant units, quadrifilar helix antenna, 5 W transmit power	2048 kb/s adaptive data rate enabled	Relay services expected to remain viable well beyond 2030. Presently returning >50% of relay data from NASA’s landed assets.

MARS RELAY TELECOMMUNICATIONS & PNT SERVICES

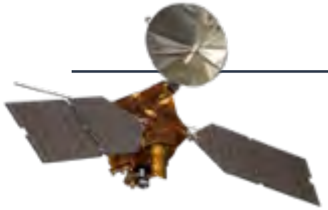
Spectrum Allocations for Proximity-Link Use at Mars

	UHF (MHz)	S-Band (MHz)	X-Band (MHz)	Ku-Band (GHz)	K-Band (GHz)
RELAY-TO-SURFACE (FORWARD)	435-450	2025-2110	7190-7235	14.5-15.35	
SURFACE-TO-RELAY (RETURN)	309-405	2200-2300	8450-8550	16.6-17.1	
RELAY-TO-ORBITER (FORWARD)	435-450	2025-2110	7190-7235		22.55-23.55
ORBITER-TO-RELAY (RETURN)	390-405	2200-2300	8450-8550		25.5-27
RELAY-TO-RELAY		2025-2120 2200-2300	7190-7235 8450-8550		22.55-23.55 25.5-27

Source: “Frequency Assignment Guidelines for Communications in the Mars Region,”
Space Frequency Coordination Group (SFCG), Recommendation SFCG 22-1R4, 10 December 2021
(https://www.sfcgonline.org/Recommendations/REC%20SFCG%2022-1R4%20(Freqs%20for%20Mars%20Region).pdf).

Potential Relay Users

While NASA/MEP does not have an explicit manifest of future Mars missions, four canonical mission classes as shown below might communicate with commercial relays over the next decades.

MISSION CLASS	EXAMPLE	TRANSMIT POWER	ANTENNA APERTURE	CIRCUIT LOSS	POINTING LOSS	POLARIZATION LOSS	NOISE FIGURE	EQUIVALENT EIRP AT X-BAND (including losses)
 LARGE ORBITERS	High-data-volume science orbiter such as the Mars Reconnaissance Orbiter	100 W	30 cm Parabolic	-2 dB	-0.2 dB	-0.5 dB	5 dB	73 dBm
SMALLSAT/CUBESAT ORBITERS 	Deep space CubeSats such as the MarCO spacecraft or ASTERIA	4 W	10 cm Parabolic					50 dBm
 LARGE LANDERS/ROVERS	Large surface assets such as the Curiosity and Perseverance rovers	15 W	30cm Parabolic					65 dBm
SMALL LANDERS/ AEROBOTS 	Small surface assets such as the Ingenuity Mars Helicopter or Mars InSight	4 W	0 dBi Omni-Directional		0 dB			3 dBm

15-MINUTE BREAK

3

Payload Hosting Services

Nathan Barba

Systems Engineer
Jet Propulsion Laboratory/California Institute of Technology

PAYLOAD HOSTING SERVICES

Overview

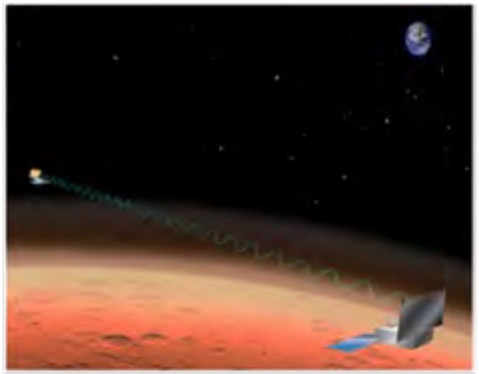
Goal: Low-cost delivery and operation of NASA payloads and demonstrations at Mars, both orbiter and landed, with reliable return of data. End-to-end service including integration, launch, operations, and disposal of host spacecraft(s).

- PHS could be further enabled by MEP transportation and telecommunications services
- Allows payload providers to focus on their instrument development and allow industry to address host spacecraft
- Desire low-cost replicable buses with standardized "plug n play" interfaces for power, data, and mechanical

PUBLIC/PRIVATE DEMONSTRATION

Market for PHS: NASA is not the only player – emerging group of countries (including emerging spacefaring nations), universities, even space societies and also companies with their own Mars ambitions.

Mini Mars Climate Sounder



Orbiter to Orbiter Radio Occultation

Triaxial Sonic Anemometer

DELIVERY & OPERATION OF ORBITAL & LANDED PAYLOADS

DELIVERY & OPERATION OF PAYLOAD NETWORKS, MOBILE PLATFORMS

CURRENT STATE

INIITIAL STEPS

VISION

PAYLOAD HOSTING SERVICES

Definitions

DEFINITION: PAYLOAD HOSTING SERVICES (PHS)

- A scenario in which an outside provider develops, owns, and operates a spacecraft platform in Mars orbit whereon NASA/MEP-provided scientific instruments may be hosted and operated.
- Servicer would be responsible for selection of launch opportunities, determine overall mission architecture, and provide the end-to-end service including operations associated with the Launch Vehicle, Launch Site, Spacecraft, Lander, Mission Design and Analysis, Ground Systems, and Payload Support.

DESIRED CAPABILITIES

Safe, reliable, and cost-effective delivery and operation services for science payloads from Earth to various Mars destinations. Example services desired are end-to-end payload delivery service, payload integration, mission operations, launch from Earth, landing on surface of Mars.

INFORMATION SOUGHT

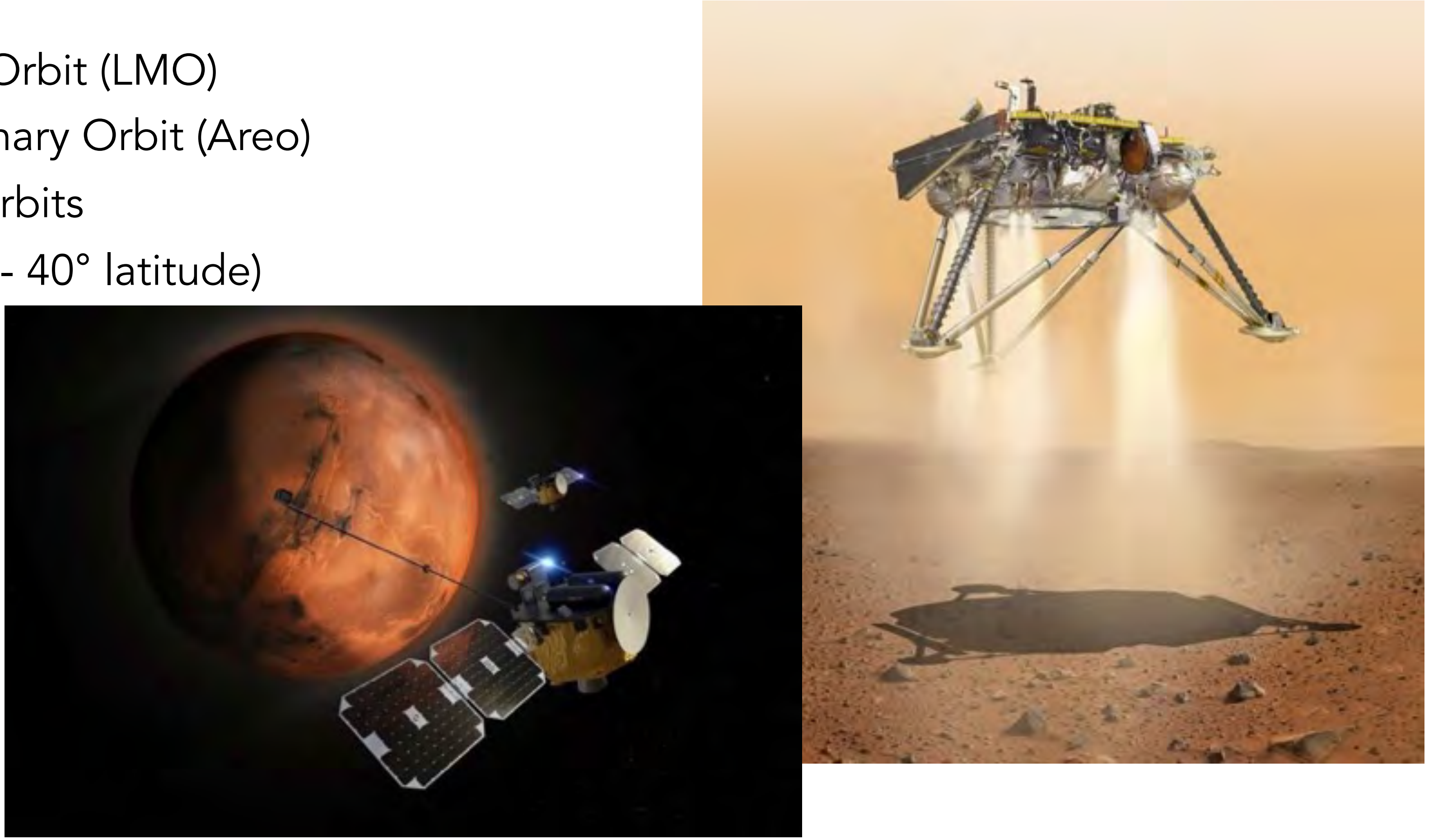
- Potential architecture for delivery, partnership approach, cost implications, and strategy to achieve this goal, potential barriers.
- Solutions that effectively meet the needs of multiple services are of particular interest to MEP

Destinations & Scenarios

Destinations of Interest: Mars Orbits and Martian Surface Destinations

Orbits and Landing Regions of Interest:

- Low Mars Orbit (LMO)
- Areostationary Orbit (Areo)
- Elliptical Orbits
- Surface (+/- 40° latitude)



PHS Notional Payloads

Payload Hosted Services – Example Cases

Example cases are for individual payloads, but payloads may be combined in a single mission.

ARCHITECTURE	ORBITER	ORBITER	ORBITER	LANDED	LANDED
NTE Mass	<5 kg	<20 kg	<40kg	< 5kg	<20 kg
Destination	Mars SSO	Mars SSO	Mars SSO	Surface; +/- 40° latitude	Surface; +/- 40° latitude
Operational Lifetime	2 – 5 years	2 – 5 years	2 – 5 years	90 – 687 sols	90 – 687 sols
Volume Envelope	20 x 20 x 20 cm	40 x 40 x 40	70 x 70 x 70	20 x 20 x 20 cm	40 x 40 x 40
NTE Power	10W Max	30W Max	100W Max	5 W Max	30W Max
NTE Energy	120 Wh	240 Wh	1000 Wh	120 Wh	240 Wh
NTE Data	200 Mb/Sol	500 Mb/Sol	2000 Mb/Sol	40 Mb/Sol	200 Mb/Sol
Pointing Scenario	Nadir or Limb Pointed	Limb Pointed	Off-Nadir Cross-track	Mounted on 1 m Mast/Boom	Deck Mounted with RA

PAYLOAD HOSTING SERVICES

Summary

- A successful Mars-focused, CLPS-like program might serve as a programmatic vehicle to allow—at reduced cost but perhaps increased risk—development of technologies for future exploration as well as delivery of science payloads.

- Opportunity to leverage lessons learned, experience, and technology from CLPS and apply to Mars.

- PHS could be further enhanced with delivery and telecommunications infrastructure services.

- Commercial companies to participate first-hand in Mars exploration and science missions.

- Options for public-private partnership to leverage NASA technical heritage and expertise.

MEP Industry Day 2022

4

Mars Imaging & Global Meteorological Services

Larry Matthies

MEP Technology Coordinator
Jet Propulsion Laboratory, California Institute of Technology

MARS IMAGING & GLOBAL METEOROLOGICAL SERVICES

Overview

GOAL: Global, high-frequency repeat coverage of Mars with high-resolution, stereo-capable imaging & Daily global meterological data for monitoring and predicting weather

Instruments on Mars Reconnaissance Orbiter (MRO)

HiRISE, 65 kg

MARCI, 0.5 kg

MCS, 9 kg

	CURRENT STATE	NEXT STEPS	VISION
High-resolution Imaging [2]	• ~30 cm/pixel; roll spacecraft to image off the ground track and to obtain stereo (High Resolution Imaging Science Experiment - HiRISE)	• At least HiRISE resolution; combination with comm relay enables planetary coverage faster • Multiples also enable more frequent repeat imaging	• Up to 10cm/pixel resolution (as affordable) for both human and robotic exploration[12] • Regular addition/replenishment with improved capabilities
Meteorology [4, 5, 10, 11]	• Daily global imaging (Mars Color Imager - MARCI) • Frequent measurement of vertical profiles of atmospheric temperature, water vapor, dust, and condensate (Mars Climate Sounder - MCS)	• Space weather and diurnal atmospheric weather monitoring • Continued or improved vertical profiling of atmospheric temperature, pressure, and constituents • Addition of wind mapping	• Sensors for measuring the drivers of weather (for prediction, especially of extreme events such as dust storms) • Add surface meteorological stations for concurrent measurements with meteorological orbiters at different altitudes
		REPLACE & UPGRADE	**UPGRADE & NETWORK**

Introduction (1 of 2)

DEFINITION: MARS IMAGING & GLOBAL METEOROLOGICAL SERVICES

- A self-contained capability for which the provider develops and operates all aspects of two distinct classes of service:

  1. High-resolution, targetable image strips with a Ground Sample Distance (GSD) of ≈30 centimeters or better, as well as stereo-imaging capabilities
  2. Daily global weather meteorological services, including:
     - Global imaging with a GSD of ≈ 1 km;
     - Atmospheric sounding; and/or,
     - Other meteorological instrument packages for measuring atmospheric temperature, atmospheric density, dust, water vapor, water ice, and wind profiles

Introduction (2 of 2)

- **Meteorological instruments are much smaller than high-resolution cameras and don’t require precise pointing control**

  ⇒ Services could be provided on a single orbiter or separate orbiters

- **Comm baseline: flight elements providing the services return data directly to Earth**
  - How much benefit accrues if a separate on-orbit telecommunication relay service[1] returns the data?
  - NASA Deep Space Network (DSN) is the baseline to receive data. Non-NASA alternative is of interest, but need to understand cost trades.

- **Needs for imaging, meteorology, and DTE services exceed the lifetime of a single orbiter or instrument**

  ⇒ Interested in replenishment strategies, particularly leveraging progressive technology developments and/or economies of scale over time.

Feedback is welcome about subsets or variants of this full capability.

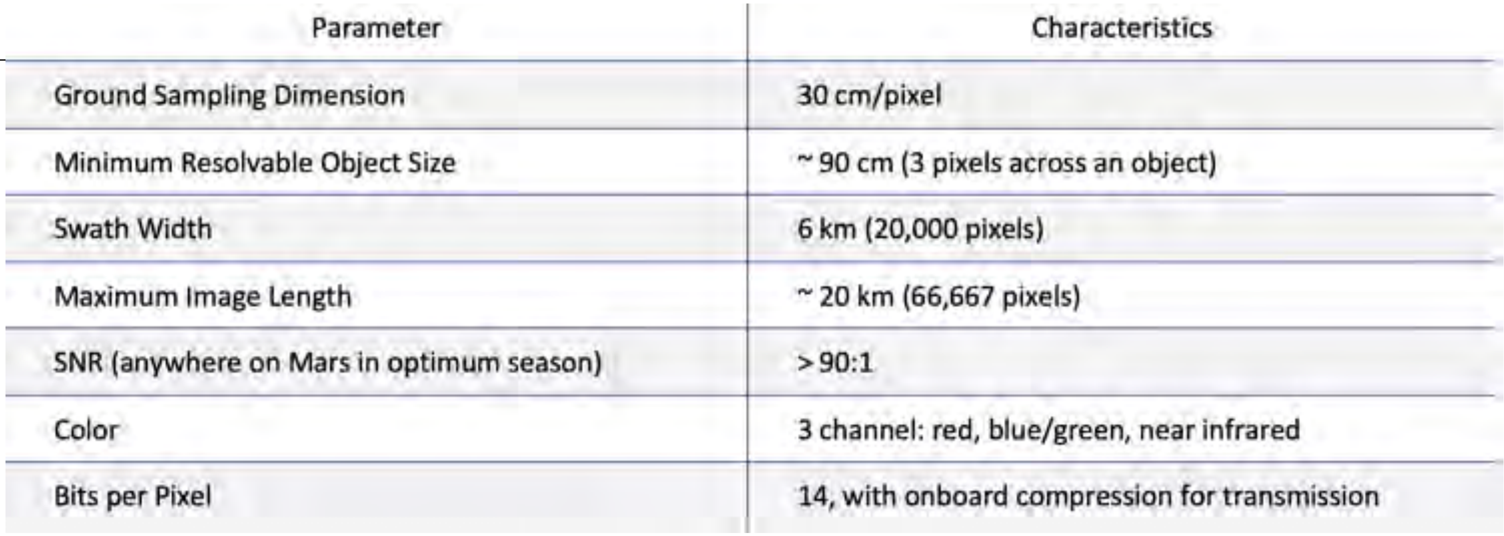
Desired Capabilities: High-resolution Imaging (1 of 3)

NASA INTERESTS

DESIRED	High Signal-to-Noise (SNR) Ratio Near-diffraction-limited Imaging Performance Red, Blue/Green, Near Infrared Spectral Bands GSD at Least Comparable to that of HiRISE
ADDED VALUE	Smaller GSD, if affordable

Imager Specifications

- Representative specifications[2] drawn from HiRISE capabilities
- Other specifications are possible, given different starting points, cost structures, or technological changes since HiRISE



Parameter	Characteristics
Ground Sampling Dimension	30 cm/pixel
Minimum Resolvable Object Size	~ 90 cm (3 pixels across an object)
Swath Width	6 km (20,000 pixels)
Maximum Image Length	~ 20 km (66,667 pixels)
SNR (anywhere on Mars in optimum season)	> 90:1
Color	3 channel: red, blue/green, near infrared
Bits per Pixel	14, with onboard compression for transmission

Desired Capabilities: High-resolution Imaging (2 of 3)

Orbit

BASELINE Near-polar, sun-synchronous, 252 x 317 km orbit that provides about 13 orbits/day similar to MRO

Pointing

DESIRED Spacecraft pointing control to achieve the required level of image quality is discussed in the literature. [2, 3, 9]

- High-resolution orbital cameras are typically pushbroom imagers with a swath width of a few kilometers.
- To maximize flexibility and to minimize the delay before a specific patch of terrain can be imaged, the ability to aim the camera is required. MRO achieves this targeting by rolling the entire spacecraft around the velocity vector to enable imaging to either side of the orbit ground track.
- DEMs are generated from stereo pairs of orbital images. With HiRISE, DEMs are also produced by rolling the MRO spacecraft so that the camera views terrain to either side of the ground track; the orbiter acquires stereo image pairs in this fashion through appropriate rolls on different orbital passes that provide overlapping coverage of the same swath of terrain.
- Some lower resolution cameras on other Mars orbiters use two imaging heads to acquire images that look forward and backward along the ground track, and thus generate stereo pairs in a single orbital pass.

MARS IMAGING & GLOBAL METEOROLOGICAL SERVICES

Desired Capabilities: High-resolution Imaging (3 of 3)

Downlink Capability and Associated Data Storage

DESIRED	Daily average downlink capability of at least ~ 30 Gb
DESIRED	Onboard lossless compression capability
ADDED VALUE	Faster and greater planetary coverage

- Prior to MRO operations, estimated total compressed image volume acquired in the 26-month primary was 17,500 Gb[2] -- a daily average of ~ 22 Gb.
- This data volume is about one-third of the capability of the MRO X-band downlink system, which delivered ~ 250 terabits in the first 10 years of operation[8], or an average of ~ 68 Gb/day.
- Onboard lossless compression has achieved an average rate of about 2.5:1[3]; availability of lossless and lossy compression might be useful.
- MRO meteorological data (next slide) has been about 6.2 Gb/day with 1.7:1 lossless compression.

MRO has vastly exceeded its mission requirements, yet has only imaged less than 5% of the planet at HiRISE resolution over a little more than a decade. The ability to return high-resolution data with greater planetary and repeat coverage is highly desired, either with a single solution, a replenishment model, or potentially in combination with communications capabilities covered earlier.

Desired Capabilities: Global Meteorology

Currently, weather monitoring relies on a combination of MARCI and MCS instruments on MRO.

DESIRED MARCI-like instrument. MARCI has the following characteristics:

Spectral Bands	Pushbroom imager that acquires limb-to-limb swaths with 5 visible and 2 ultraviolet channels to address a combination of science objectives that include dust storm monitoring. A daily global map is produced from 12 to 13 swaths over the sunlit side of Mars. Not all bands are needed for weather monitoring.
Resolution at Nadir	~ 1 km/pixel with 11 bits/pixel
SNR	~ 100:1 in the visible bands; onboard binning may be used to improve SNR

DESIRED MCS-like instrument: a thermal infrared radiometer that complements MARCI, e.g. by observing how high in the atmosphere dust has risen during a dust storm

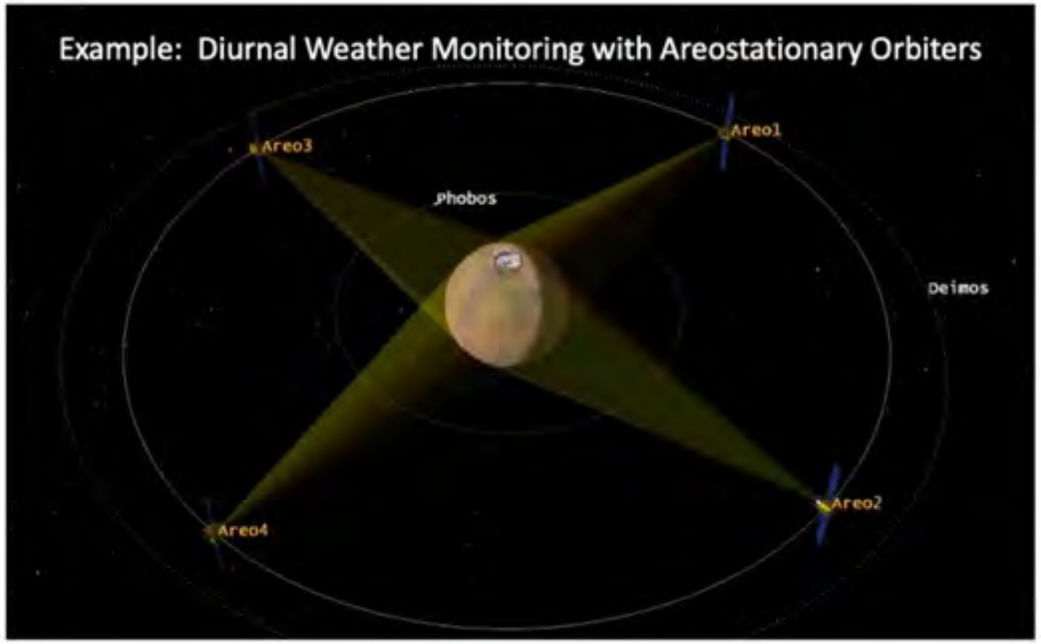
Spectral Bands	9, to acquire vertical profiles of atmospheric temperature, water vapor, dust, and condensates [9]

ADDED VALUE While the immediate need is to continue a weather monitoring capability similar to the existing one, a next-generation capability could address gaps in the current state of knowledge.

- This might use additional instruments, non-sun-synchronous orbits, and/or observations that are more frequent or obtained at different times of the Martian day.

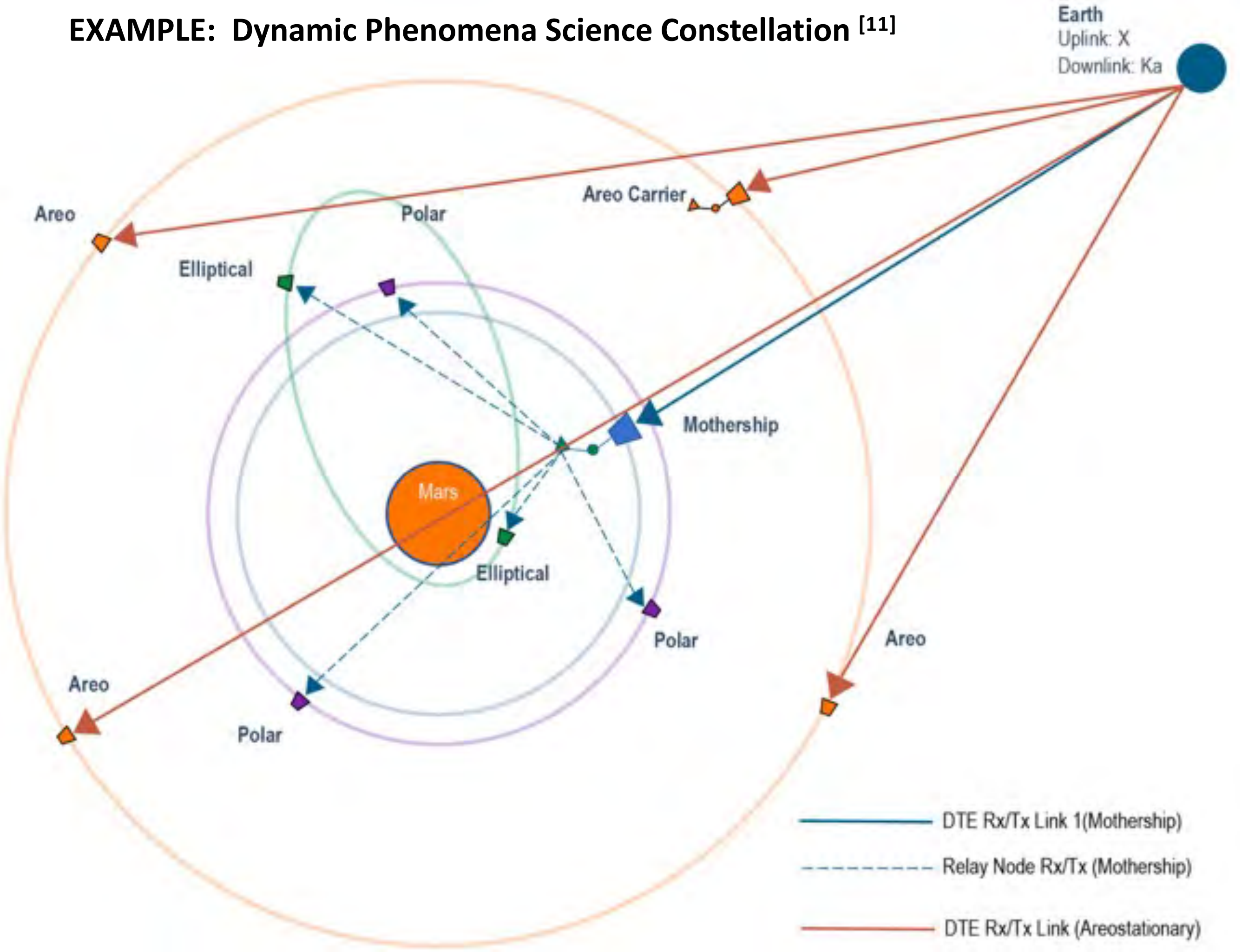
Desired Capabilities: Global Meteorology (Long-term Vision)

Illustrations drawn from recent white papers and mission studies [10, 11, 12]



Example: Diurnal Weather Monitoring with Areostationary Orbiters

EXAMPLE: Dynamic Phenomena Science Constellation [11]



References

[1] Gladden, R. E., et al., “A dedicated relay network to enable the future of Mars exploration”, *IEEE Aerospace Conference*, 2021.

[2] McEwen, A. S., et al., “Mars Reconnaissance Orbiter’s High Resolution Imaging Science Experiment (HiRISE)”, *Journal of Geophysical Research*, vol. 112, 2007.

[3] McEwen, A. S., et al., “The High Resolution Imaging Science Experiment (HiRISE) during MRO’s Primary Science Phase (PSP)”, *Icarus*, vol. 205, 2010.

[4] Bell, J. F., et al., “Mars Reconnaissance Orbiter Mars Color Imager (MARCI): instrument description, calibration, and performance”, *Journal of Geophysical Research*, vol. 114, 2009.

[5] McCleese, D. J., et al., “Mars Climate Sounder: an investigation of thermal and water vapor structure, dust and condensate distributions in the atmosphere, and energy balance of the polar regions,” *Journal of Geophysical Research*, vol. 112, 2007.

[6] Golombek, M., et al., “Detection and characterization of rocks and rock size-frequency distributions at the final four Mars Science Laboratory landing sites,” *MARS: the International Journal of Mars Science and Exploration*, vol. 7, 2012

[7] Sibille, L., et. al. (2021). Mars Reconnaissance: Civil Engineering Advances for Human Exploration. Planetary/Astrobiology Decadal Survey Whitepapers, 53(4). http://doi.org/10.3847/25c2cfeb.b96282f6

[8] Johnston, M. D. and Zurek, R. W., “The Mars Reconnaissance Orbiter mission: 10 years of exploration from Mars orbit”, *IEEE Aerospace Conference*, 2016.

[9] Lee, S. W. and Skulsky, E. D., “Mars Reconnaissance Orbiter design approach for high-resolution surface imaging”, *AAS GNC Conference*, 2003.

[10] Montabone, L., et al., “Observing Mars from areostationary orbit: benefits and applications”, white paper submitted to the Planetary Science and Astrobiology Decadal Survey 2023-2032 (PSADS).

[11] Lillis, R., et al., “MOSAIC: Mars Orbiters for Surface-Atmosphere-Ionosphere Connects”, mission concept study for the PSADS

[12] I-MIM Measurement Definition Team. International Mars Ice Mapper Mission: Reconnaissance/Science Measurement Definition Team Final Report, 2022.

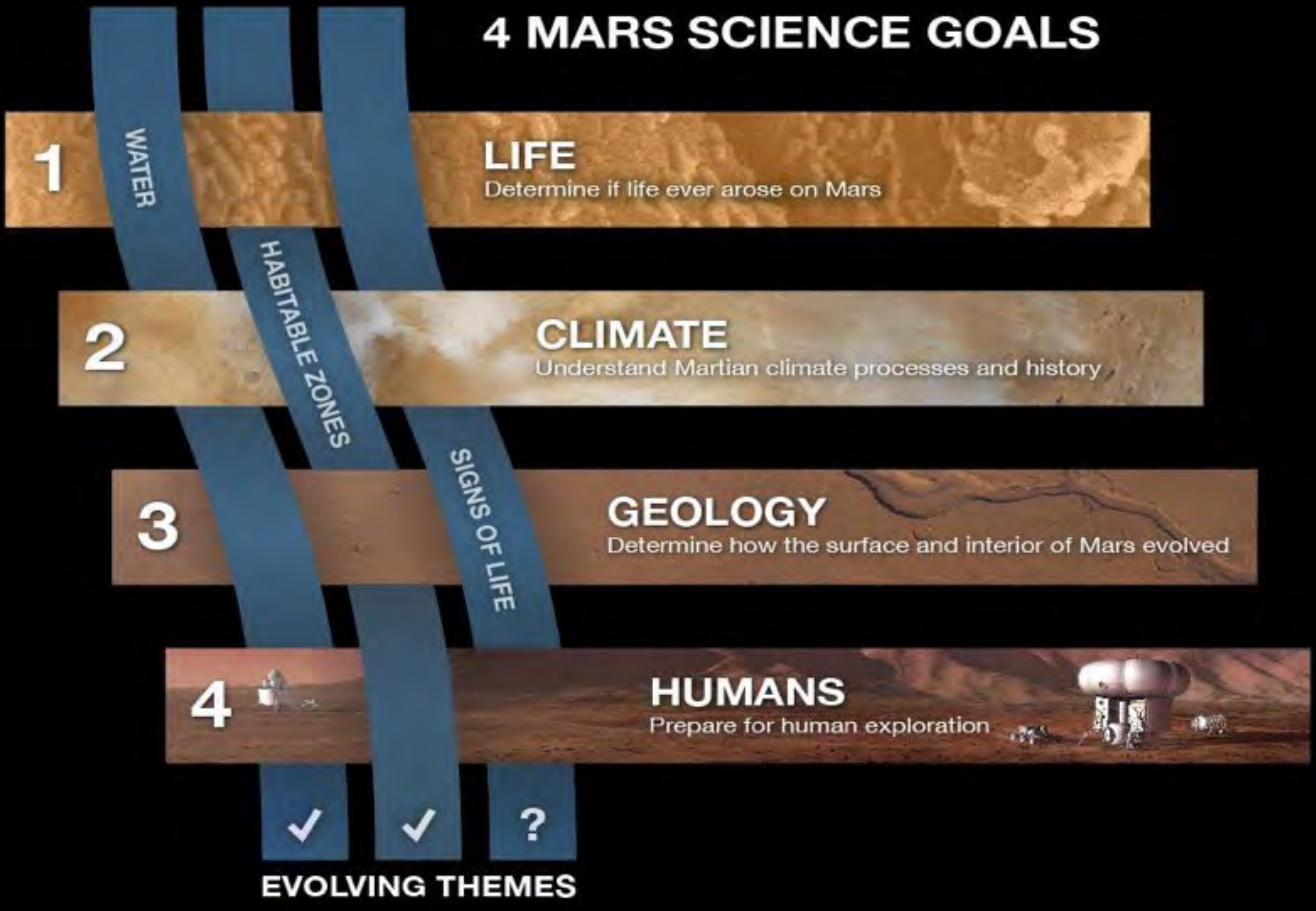
1.5-HOUR LUNCH BREAK

MEP Industry Day 2022

Industry Role in Discovery:
MEP Science Strategy

Michael Mischna
Program Scientist, Mars Exploration Program Office
Jet Propulsion Laboratory, California Institute of Technology

Science Goals and Evolving Organizing Themes



4 MARS SCIENCE GOALS

1 **LIFE**
Determine if life ever arose on Mars

2 **CLIMATE**
Understand Martian climate processes and history

3 **GEOLOGY**
Determine how the surface and interior of Mars evolved

4 **HUMANS**
Prepare for human exploration

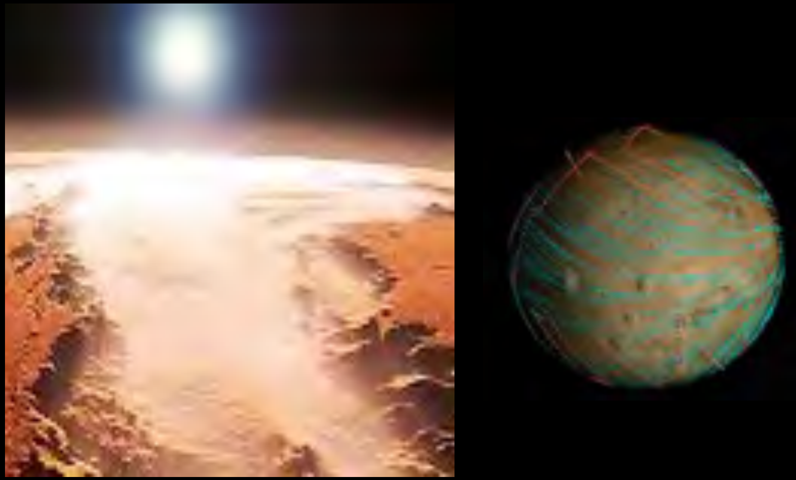
EVOLVING THEMES

Industry Role in Advancing Science

THREE MAJOR THEMATIC AREAS

Search for Life

Evolving Mars



Preparation for Human Exploration

MEP SCIENCE STRATEGY

Search for Life

1 Follow the Water: Mars once had water active on its surface and in the subsurface

A **diverse composition** and **preserved geologic record** reveal many ancient water-related environments, some of which persisted for long periods.

Water-cemented minerals

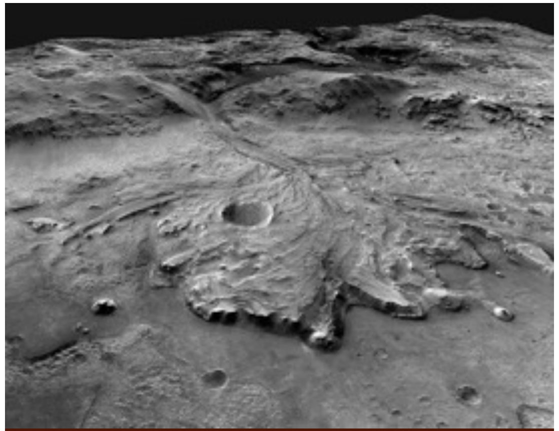
Near-Surface Ice

Channels and River Valleys

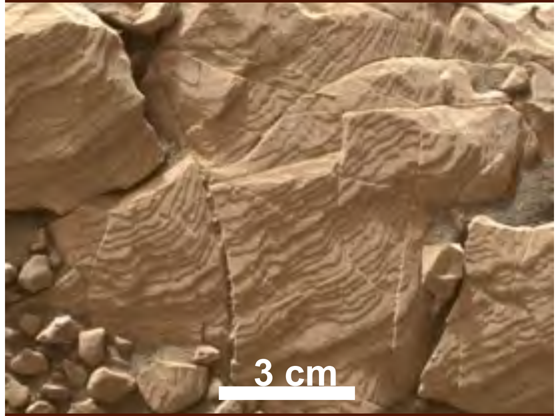
2 Mars was a habitable planet . . . but was it inhabited? Is it still inhabited?

- Evidence for relatively benign conditions, plus elements essential for life, and evidence of standing water in the ancient Mars environment
- Returned samples will tell us much more
- National Academy of Sciences *Decadal Survey for Planetary Science & Astrobiology*

  Encourages a mission to seek extant life and assess modern-day habitability as the Mars Program's next priority



“The Delta”
(Jezero Crater)

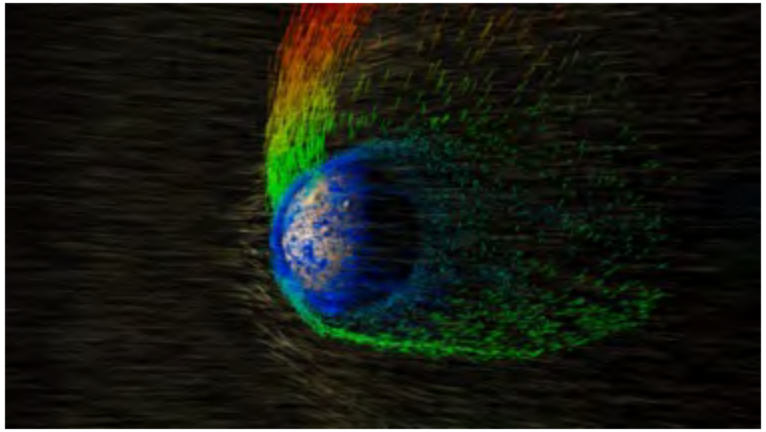


Laminations
(Gale Crater)

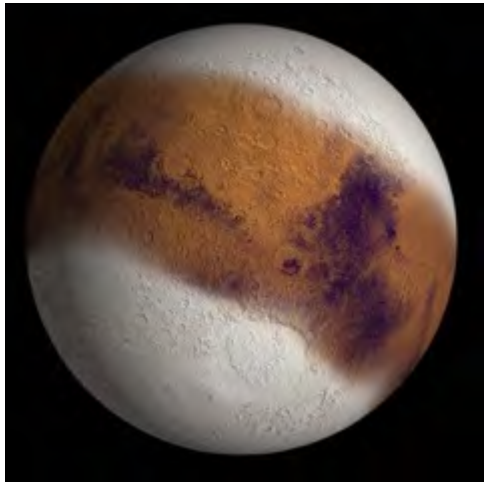
MEP SCIENCE STRATEGY

Evolving Mars

3 Mars changed over time, with the loss of an early, massive atmosphere and with ice ages up to more recent geologic times



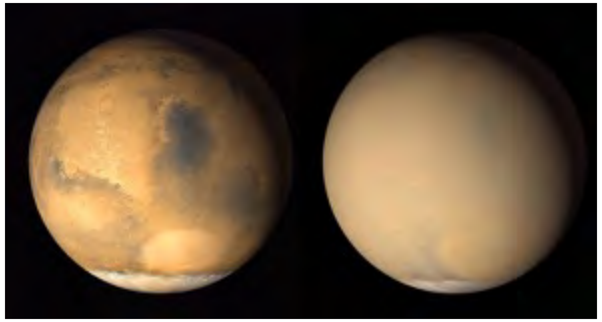
The solar wind has been stripping away Mars' atmosphere for 4 billion years. Mars today is very different from Mars long ago.



Oscillations in Mars' orbit lead to ice ages and dramatic climatic shifts.

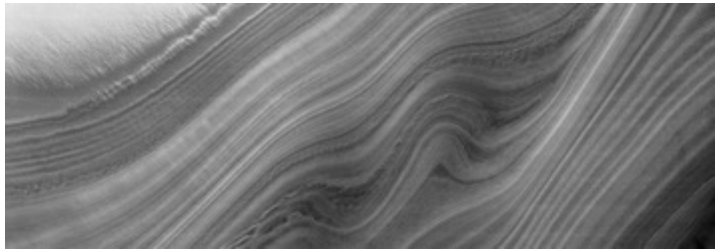
4 Modern Mars: A dynamic planet with dust storms and surface changes

DUST STORMS



Semi-regular annual pattern of regional dust storms punctuated by global storms every few Mars years

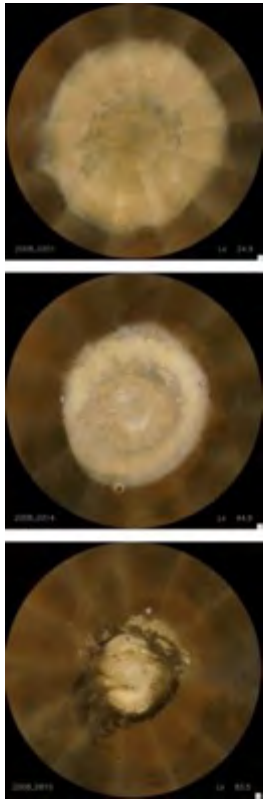
SOLAR HEATING OF N. POLE



Near-surface ice today: Remnants of past ice ages and a potential resource for the future

RSL: RECURRING SLOPE LINEAE

Seasonal flow features appear and disappear



SEASONAL SNOW

25% of Mars' atmosphere condenses over the poles in wintertime

MEP SCIENCE STRATEGY

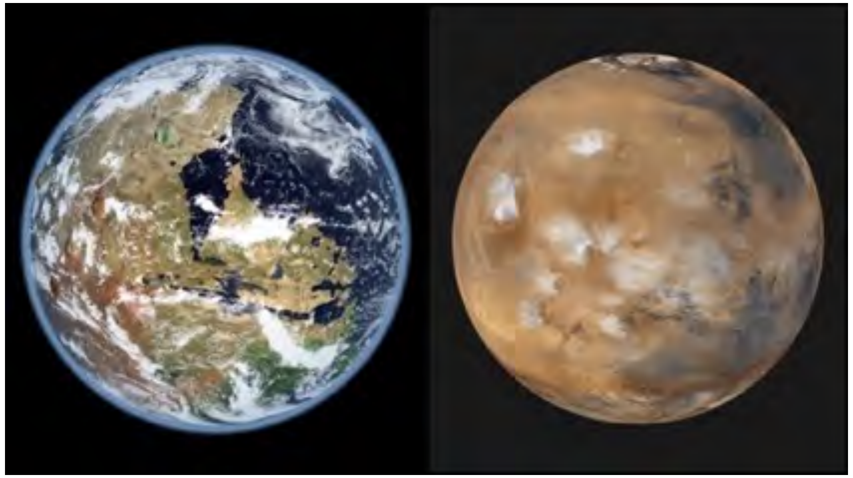
Scientific Preparation for Humans

5 Understanding the Martian environment to prepare for human exploration:

- **Mars is diverse. Where is the best place for humans to land?**
  - Scientific value, available resources, safe landing environment.
  - We have only imaged ~4% of Mars at the highest resolution to ensure landing safety and science value.
  - Both orbital and landed science is necessary
- **The martian environment is hostile.**
  - Safe human exploration requires regular acquisition of environmental data, both global and local
- **A substantial amount of precursor science is essential for the success of the human program, and of humankind's next, great voyage.**
  - Linkage between NASA SMD (MEP) and ESDMD (Human Exploration).
  - Knowledge gaps must be resolved before humans arrive
  - The program is driven by scientific curiosity

MEP Science Discovery

6 Of all the planets, Mars offers the most opportunities for exploration:



- **Mars is accessible** in ways that other planets are not in terms of distance and the most Earth-like environment
- **Mars could answer age-old questions** of whether life has evolved elsewhere in the Solar System
- **Mars has undergone tremendous climate change** through its long history
- **Ancient Martian crust is the only place in the Solar System that retains a record** of what the Solar System was like 4 billion years ago.
- **Mars offers in situ resources** (e.g., ground ice and hydrated minerals) that could sustain long-term human exploration of its surface

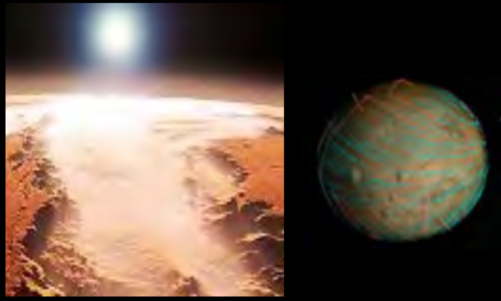
MEP SCIENCE STRATEGY

Science Perspective: Industry Role in Advancing Science

THREE MAJOR THEMATIC AREAS

Search for Life

Evolving Mars



Prep for Human Exploration

Enabled by Government-Industry Partnerships Given the Potential for More Frequent Missions with More Competitive Opportunities for the Mars Science Community

Spacecraft Delivery

High Frequency Missions & Constellations

- Global data sets acquired faster and more frequently
- Continuity in long-term data sets to support these three thematic areas
- Reduced schedule risk – if not ready, can hop on board the next ride
- Regular launch cadence

Telecommunications Relay

A Higher Data Volume, Faster

- Drives discovery-driven demand as investigation results feed forward

Lower Cost/Complexity

- No need for missions to carry own high-capability comm system – either lowers cost or more science payload mass available
- Potential for small missions to provide rich data

Payload Services

Regular, Competitive Science Opportunities

- Greater community participation (higher ed, emerging space agencies, private sector, etc.)
- More diverse science with small, focused (and networked) missions, both orbital and landed
- “CLPS for Mars”

Imaging

More Mars Coverage, More Often

- Global high-res stereo mapping of Mars at increased spatial, spectral, and temporal resolution
- Robotic & human landing site selection
- Long-term monitoring of a changing Mars

Global Weather

Next-Gen Earthlike Observations

- Networked, complementary measurements by both orbital and landed assets
- Unique views of the Martian atmosphere
- Operational support for human exploration

MEP Industry Day 2022

Commercial Crew & Cargo Framework Overview

Marc Timm Program Executive, NASA Commercial Systems Division
Lee Pagel Program Specialist, NASA Commercial Crew Program
NASA/HQ/SOMD/CSD

Commercial Philosophy Overview

NASA's Top-level Goals:

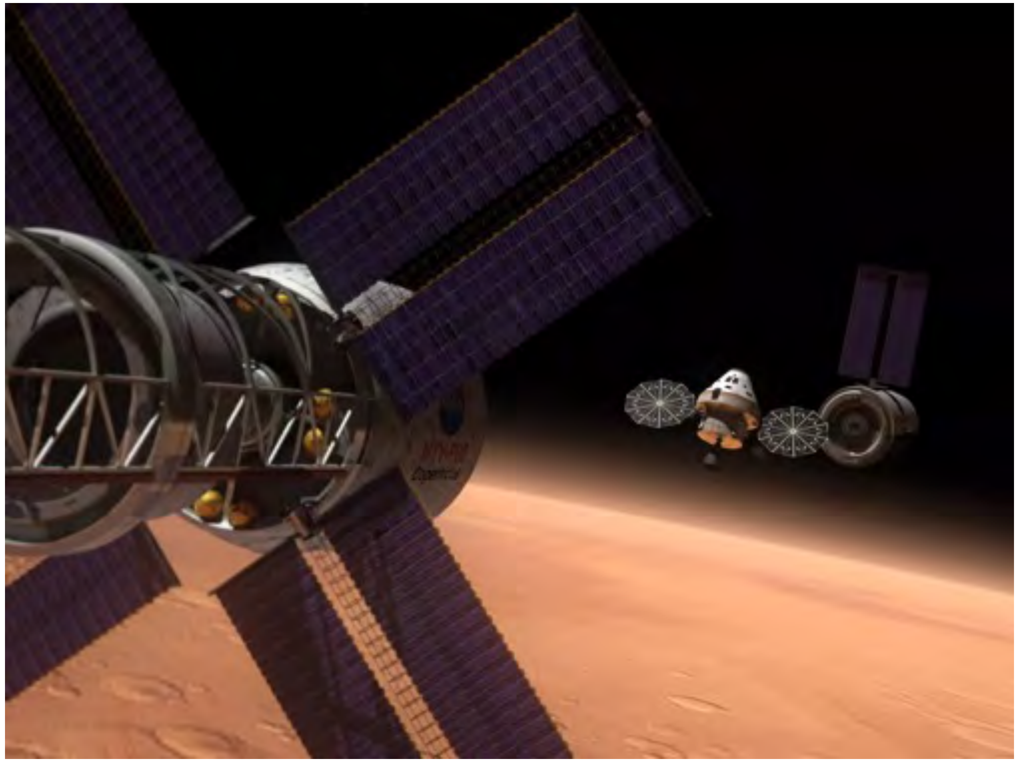
Enable Robust US Commercial Space Service Industry

- NASA does not own or operate the transportation capability
- Rather, NASA is one of many customers, purchasing commercially available space services
- Commercially licensed missions (FAA, FCC, NOAA)

COMMERCIAL CREW & CARGO

New Development & Services Framework

NASA adapted the Funded Space Act Agreement
to allow industry to develop and field crew and cargo services.



Artist Concept Depicting the Eventual Human-Robotic Exploration of Mars
Credit: NASA

Phase 1: Capability Development & Demonstration

- NASA “Other Transactional Authority” – funded Space Act Agreements (SAA)

Phase 2: Capability Certification & Services

- FAR-based contracts for Certification and Transportation Services acquisition
- Certification was necessary due to Human Spaceflight interfaces
- Consider your risk acceptance level - perhaps certification is unnecessary for certain services

COMMERCIAL CREW & CARGO

Human Spaceflight Programs

Commercial Cargo Program (COTS)

ISS Cargo Transportation

Commercial Crew Program (CCP)

ISS Crew Transportation

Communications Services Program (CSP)

Space Communications

Commercial LEO Destinations Program (CLDP):

Low Earth Orbit Space Stations
(follow on to the existing ISS program)

Reframe the Question

We need to avoid assuming that the way we do things is the one right way.

- Reframing problems is not a luxury. On the contrary, all companies need to continually reframe their businesses in order to survive as the market and technology change.

- The simple process of asking "why" questions provides an incredibly useful tool for expanding the landscape of solutions for a problem.

> “**If I asked you to build a bridge for me, you could go off and build a bridge.** Or you could come back to me with another question: ‘Why do you need a bridge?’ I would likely tell you that I need a bridge to get to the other side of a river. Aha! This response opens up the frame of possible solutions. **There are clearly many ways to get across a river besides using a bridge.** You could dig a tunnel, take a ferry, paddle a canoe, use a zip line, or fly a hot-air balloon, to name a few.
>
> - *Professor Michael Barry*

COMMERCIAL CREW & CARGO

Reframing in the Commercial Space Context

NASA typically asks for industry to "build this thing."

The reframed version of the question:

What activities is your company planning to do in space to make money . . .

. . . and how can those activities support what NASA would like to do in space?

Reframing

Do we have any reframing examples for spaceflight?

SUCCESSFUL REFRAMERS

amazon

NETFLIX

UNSUCCESSFUL REFRAMERS

Kodak

BLOCKBUSTER®

BACKUPS

And other potentially useful stuff

COMMERCIAL CREW & CARGO FRAMEWORK

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Cargo Programs

Commercial Orbital Transportation Services (COTS): Funded SAA

Cargo Transportation Services Development and Demonstration

SpaceX • ~~RocketPlane Kistler~~ • Orbital Services (Northrup Grumman)

Initial Kickoff	**5 OCT**	**2005**
Selection Announced	**18 AUG**	**2006**
First Demonstration Flight	**8 DEC**	**2010**

Commercial Resupply of Station (CRS): FAR part 15

International Space Station Cargo Transportation and Disposal Services

SpaceX • Northrup Grumman

First Service Flight	**8 OCT**	**2012**

Commercial Crew Programs & Evolution

CCDev (1, 2)/CCiCap: Funded SAA

Crew Transportation, Development, & Demonstration

Awarded	**2010**
CCDev 1	**5 partners**
CCDev 2	**4 partners**
CCiCap	**3 partners**

Extended timeframe due to limited available funding

CCtCap: FAR Part 15

Integrated Crew Transportation, Certification, & Services Acquisition

Awarded	**16 Sep 2014**
Two Partners:	**SpaceX • Northrup Grumman**
Initial Orbital Demonstration Mission:	**2 Mar 2019**

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Lessons Learned

Phase 1	Use of Funded Space Act Agreement allows maximum design flexibility during development and demonstration phase
Phase 2	Define service & certification requirements high enough to allow for design trades as designs mature • Understand how NASA will verify certification requirements closure
Development & Demonstration Phase	Publish service and certification requirements
Design & Development Phase	NASA functions as an investor during with payment only upon successful completion of pre-negotiated programmatic, testing and financial milestones
Design, Certification & Service Requirements	Make it very hard to change
Use of Organizational Barriers on Gov Program	Helps to institute social changes that are necessary for a successful partnership
Highly Interactive Partnership	Benefits all Parties
Milestone-based Payment Schedule	Aligned all work toward successful closure of agreement milestones
Paradigm	Resulted in program completion at or near budget, and definitely late - but not as late as typical NASA programs

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Backup – Commercial Crew Partners

CCDev 1

- Blue Origin
- Boeing
- Paragon Space Development Corporation
- Sierra Nevada Corporation
- United Launch Alliance

CCDev 2

- Blue Origin
- Sierra Nevada Corporation
- SpaceX
- Boeing

CCiCap

- Sierra Nevada Corporation
- SpaceX
- Boeing

CCiCap

- The Boeing Company
- SpaceX

First Commercial Crew *Credit: NASA*

MEP Industry Day 2022

Lessons Learned: Commercial Lunar Payload Services

Ryan Stephan Deputy Project Manager, Commercial Lunar Payload Services
Johnson Space Center

Commercial Lunar Payload Services (CLPS)

Overview (1 of 2)

- CLPS is an innovative, service-based, competitive acquisition approach that enables rapid, affordable, and frequent access to the Lunar surface via a growing market of American commercial providers.
  - The CLPS contract was awarded to 14 domestic teams who are all eligible to bid for Task Orders
  - Service task orders are firm fixed price (FFP) for the full scope of delivery: from payload hand-over to delivery (and often operation) on the lunar surface
- NASA wants to be one of many customers for CLPS services
- CLPS deliveries are CLPS Provider missions (not NASA missions)
  - Approved/licensed by the FAA and other agencies
  - CLPS Providers responsible for the safe integration, delivery, deployment and/or operation of payloads

COMMERCIAL LUNAR PAYLOAD SERVICES (CLPS)

Overview (2 of 2)

TO2 2023

ASTROBOTIC
PEREGRINE

TO2 2023

INTUITIVE MACHINES
NOVA-C

TO PRIME-1 2023

INTUITIVE MACHINES
NOVA-C

TO CP-11 2024

INTUITIVE MACHINES
NOVA-C

TO20A 2024

ASTROBOTIC
GRIFFIN

TO19D 2024

FIREFLY AEROSPACE
BLUE GHOST

TO CP-12 2025

DRAPER
LABS

COMMERCIAL LUNAR PAYLOAD SERVICES (CLPS)

Lessons Learned

- **NASA is a critical player in establishing early commercial capability**
- **The vendor pool is both capable and robust, but future market projections are very incomplete**
- **Roles and responsibilities in areas such as Mission Assurance and cross payload responsibilities are still maturing**

- **To create the right partnership between NASA and commercial entities requires both sides to adapt and make adjustments**
  - NASA has a very hard time sticking to a set of requirements
  - NASA has to approach mission concepts in a different way when using commercial services
  - Commercial companies need to consider NASA’s science/mission objectives in their mission planning
- **The opportunity to fly to the Moon multiple times per year will have a significant impact on both Lunar science and human exploration**

Plenary Q & A

MARS EXPLORATION PROGRAM/INDUSTRY

Preparation for Bilateral Discussions

Discussions in these meetings will be considered proprietary, but may be used to inform future NASA next steps.

BILATERAL DISCUSSIONS REMAINDER OF TODAY & TOMORROW (*remote participants may be scheduled on a later date*)

30-min sessions between interested US commercial service providers and MEP representatives

Each commercial entity provides an initial 10-min presentation addressing:

AREAS OF MUTUAL INTEREST	YOUR COMPANY'S RELEVANT CAPABILITIES AND PLANS	THOUGHTS ON VIABLE BUSINESS MODELS
• Which service area(s) would your firm have interest in providing? • How would providing such services align with your own strategic goals?	• What demonstrated capabilities prepare your firm to provide one or more of the described Mars commercial services? • Do you have near-term plans that will further advance your relevant capabilities?	• How can NASA and the commercial sector best work together to create win-win opportunities? • For service area(s) of interest, do you see a need for a Public-Private Partnership phase to demonstrate needed capability? • Or is industry ready to move directly to a service procurement paradigm?

Remaining Time: Available for Open Discussion and Q&A