Evolvable Mars Campaign Development

NSF Large Facility Workshop

Smithsonian's S. Dillon Ripley Center– May 24-26, 2016

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Agenda

- Introduction
- How Do We Plan to Explore Mars
- Mars Environment
- Mission Planning Basics
- NASA's Evolvable Mars Campaign

Evolvable Mars Campaign Development

INTRODUCTION

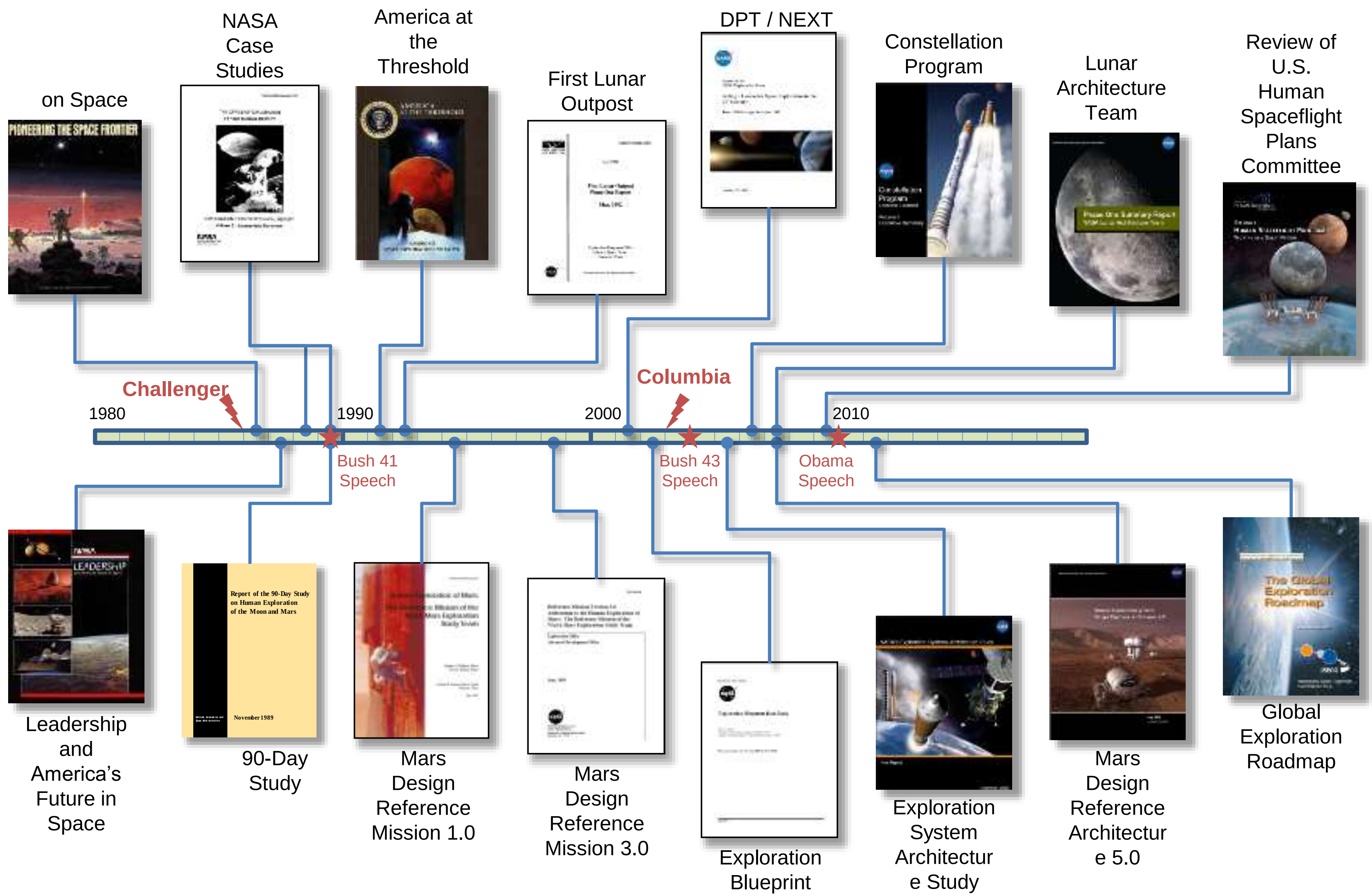
Why Do We Want To Explore Mars?

- **Long-standing curiosity, particularly since it appears that humans could one day visit there**
- **Current scientific goals (developed by MEPAG, a NASA chartered group):**
  – Determine if life ever arose on Mars
    - Characterize past habitability and search for evidence of ancient life
    - Characterize present habitability and search for evidence of extant life
    - Determine how the long-term evolution of Mars affected the physical and chemical environment critical to habitability and the possible emergence of life

  – Understand the processes and history of climate on Mars
    - Characterize Mars' atmosphere, present climate, and climate processes under current orbital configuration
    - Characterize Mars' recent climate and climate processes under different orbital configurations
    - Characterize Mars' ancient climate and climate processes

  – Determine the evolution of the surface and interior of Mars
    - Determine the nature and evolution of the geologic processes that have created and modified the Martian crust
    - Characterize the structure, composition, dynamics, and evolution of Mars' interior
    - Understand the origin, evolution, composition and structure of Phobos and Deimos.
- **Prepare for human exploration**
  – Obtain knowledge of Mars sufficient to design and implement a human mission with acceptable cost, risk and performance

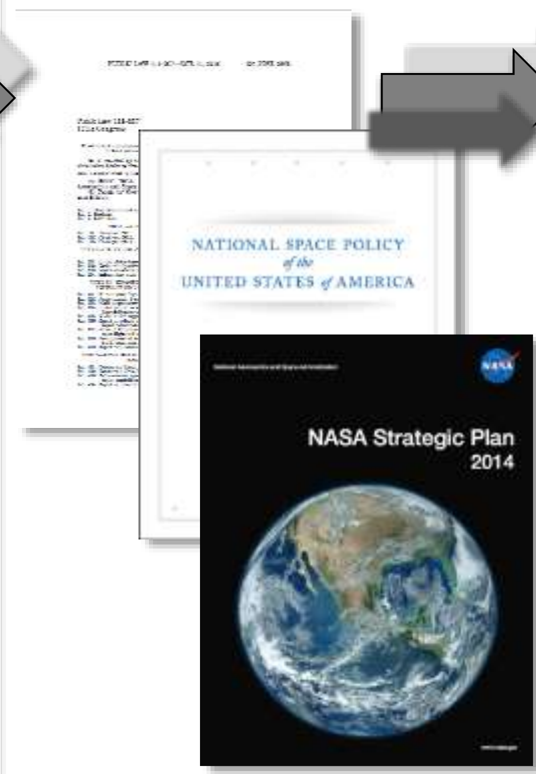
A Brief History of Human Exploration Beyond LEO



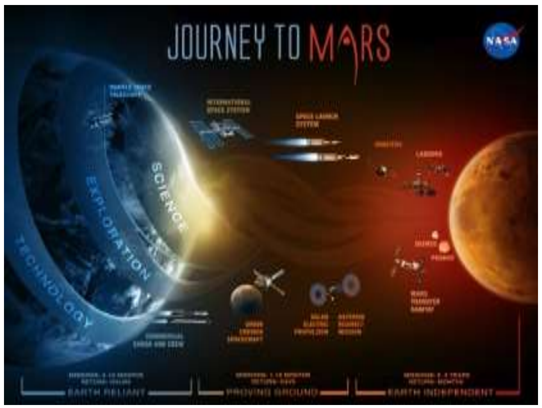
Evolvable Mars Campaign – Study Activity

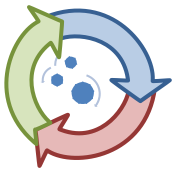
Body of Previous Architectures, Design Reference Missions, Emerging Studies and New Discoveries	2010 Authorization Act, National Space Policy, NASA Strategic Plan	Evolvable Mars Campaign

- Internal NASA and other Government
- International Partners
- Commercial and Industrial
- Academic
- Technology developments
- Science discoveries



- Establish capacity for people to live and work in space indefinitely
- Expand human presence into the solar system and to the surface of Mars





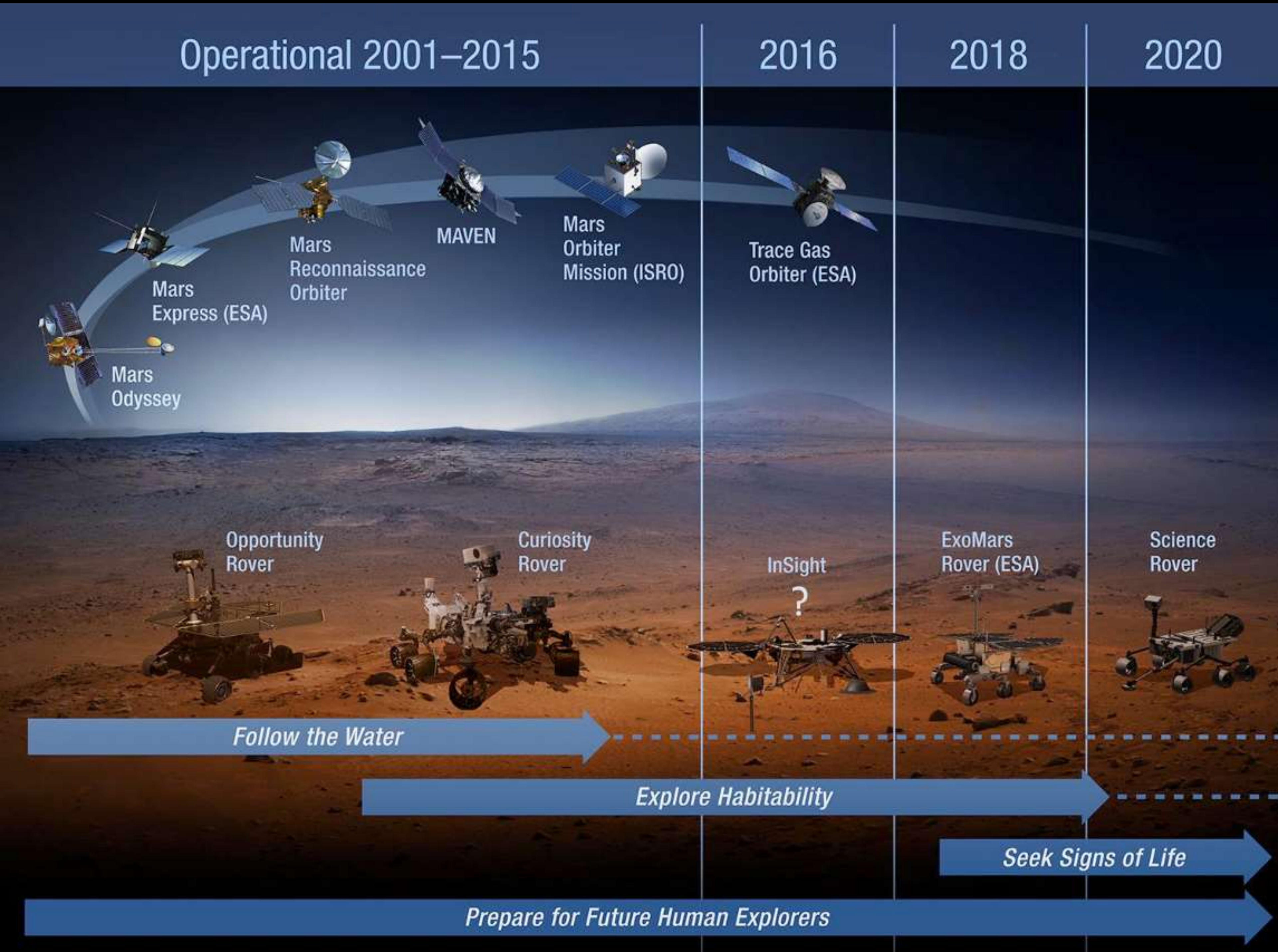
- An ongoing series of architectural trade analyses, guided by Strategic Principles, to define the capabilities and elements needed for a sustainable human presence on Mars
- Builds off of previous studies and ongoing assessments
- Provides clear linkage of current investments (SLS, Orion, etc.) to future capability needs

High Level Ground Rules and Assumptions for the EMC

- **First crew mission to Mars vicinity in 2030s - mission lays the foundation for later crew Mars surface missions**
  - Accommodate Mars Mission opportunities throughout the 2030s
  - All missions/crews return to the same location on the surface
- **Crew of 4 for Mars missions**
- **ARM / ARV SEP derived vehicle used for missions to Mars vicinity**
  - ACRM mission occurs in 2025
- **Use Lunar DRO as aggregation point for missions to Mars vicinity and Mars surface**
  - Use of Proving Ground foundational capabilities for Mars vehicle build-up and checkout
  - Use Lunar DRO for potential refurbishment and resupply location
- **Use test and validation missions as pre-deployment missions**
  - Emphasis on reducing the number of unique system developments
  - Maintain cadence of at least one crewed mission per year
  - Utilize SLS Block 1B co-manifested cargo capability to the greatest extent possible
  - 1 SLS crew flight per year in the Proving Ground
  - SLS Block 2B for Mars era missions
- **Utilize ISS to greatest extent possible for capability development**

Evolvable Mars Campaign Development

HOW DO WE PLAN TO EXPLORE MARS



Operational 2001–2015
2016
2018
2020
Mars Odyssey
Mars Express (ESA)
Mars Reconnaissance Orbiter
MAVEN
Mars Orbiter Mission (ISRO)
Trace Gas Orbiter (ESA)
Opportunity Rover
Curiosity Rover
InSight
?
ExoMars Rover (ESA)
Science Rover
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

How to Capitalize on the Unique Attributes of Human Explorers

- **Human explorers bring unique abilities to exploration:**
  - Cognition
    - Rapidly recognize and respond to unexpected findings; sophisticated, rapid pattern recognition (structural/morphological biosignatures).
  - Dexterity
    - Humans are capable of lifting rocks, hammering outcrops, selecting samples, etc..
  - Adaptability
    - Humans are able to react in real time to new and unexpected situations, problems, hazards and risks.
  - Efficiency
    - Sample and equipment manipulation and problem solving.

What “Unknowns” need to be addressed?

Known unknowns (to achieve Earth independence) – examples include:

- Human physiology in the Mars environment
  - Gravity
  - Radiation
  - Dust (e.g., perchlorates)
- Plant/animal physiology in the Mars environment
  - Gravity
  - Radiation
  - Light
- Source of usable water
  - If in the form of H2O then where is it and how can it be collected
  - If in the form of hydrated minerals then where is it, how is the raw material collected, and what is the “best” process (given local environmental conditions and available infrastructure) to extract the water
- Martian civil engineering “best practices”
  - Surface preparation/stabilization
- Martian chemical engineering “best practices”
- TBD others

Unknown unknowns

- By definition unknown, but not unanticipated
- Surface infrastructure should be implemented in such a way that it is adaptable and has built-in margin to accommodate different (than originally planned) activities without requiring a complete redesign and redeployment

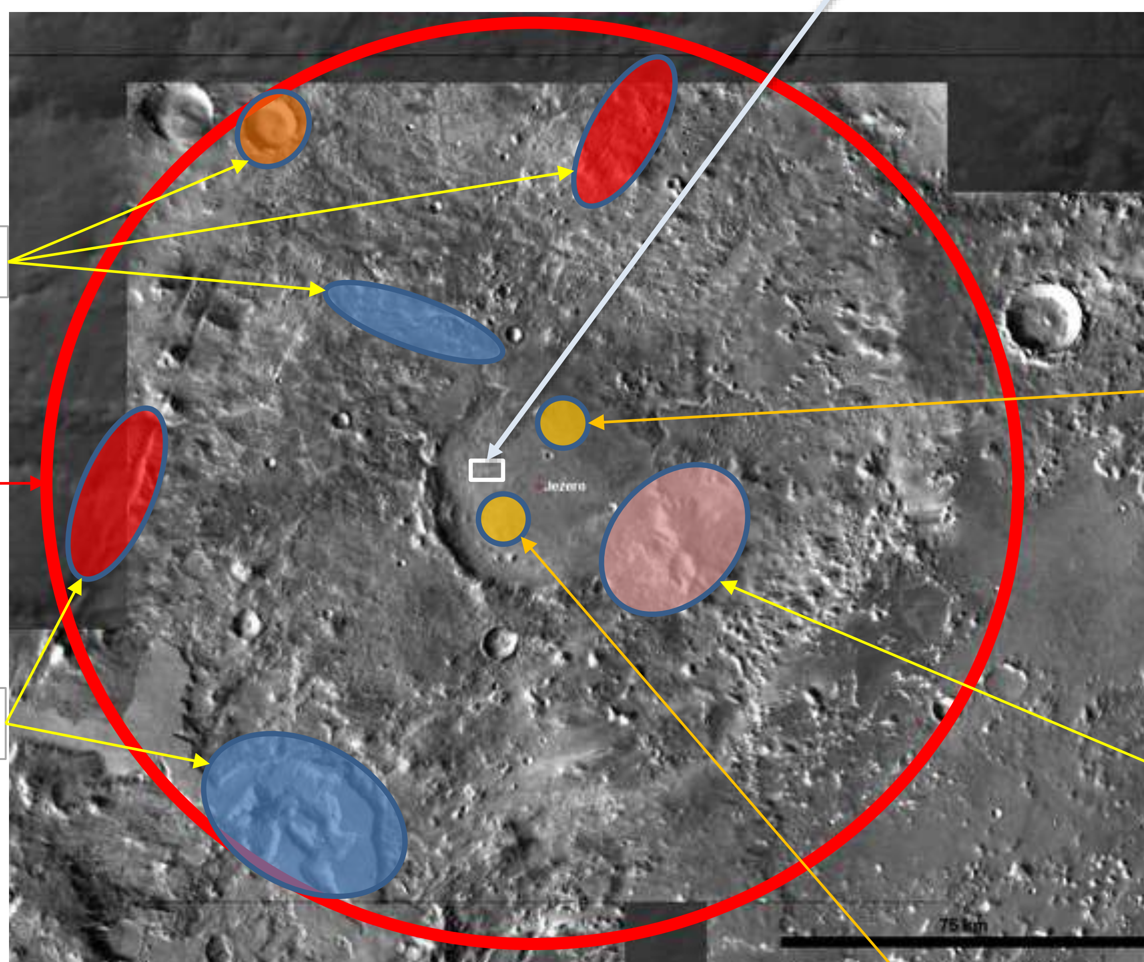
Exploration Zones, Regions of Interest, and Limits

- **Exploration Zone**
  - A collection of Regions of Interest (ROIs) that are located within approximately 100 kilometers of a centralized landing site
- **Region of Interest**
  - Areas that are relevant for scientific investigation and/or development/maturation of capabilities and resources necessary for a sustainable human presence
- **Latitude and Elevation limits**
  - Landing and ascent technology options place boundaries on surface locations leading to a preference for mid- to low- latitudes and mid- to low- elevations
  - Accessing water ice for science and ISRU purposes is attractive, leading to a preference for higher latitudes
  - Preliminary latitude boundaries set at +/- 50 degrees
  - Preliminary elevation boundary set at no higher than +2 km (MOLA reference)

Small Pressurized Rover

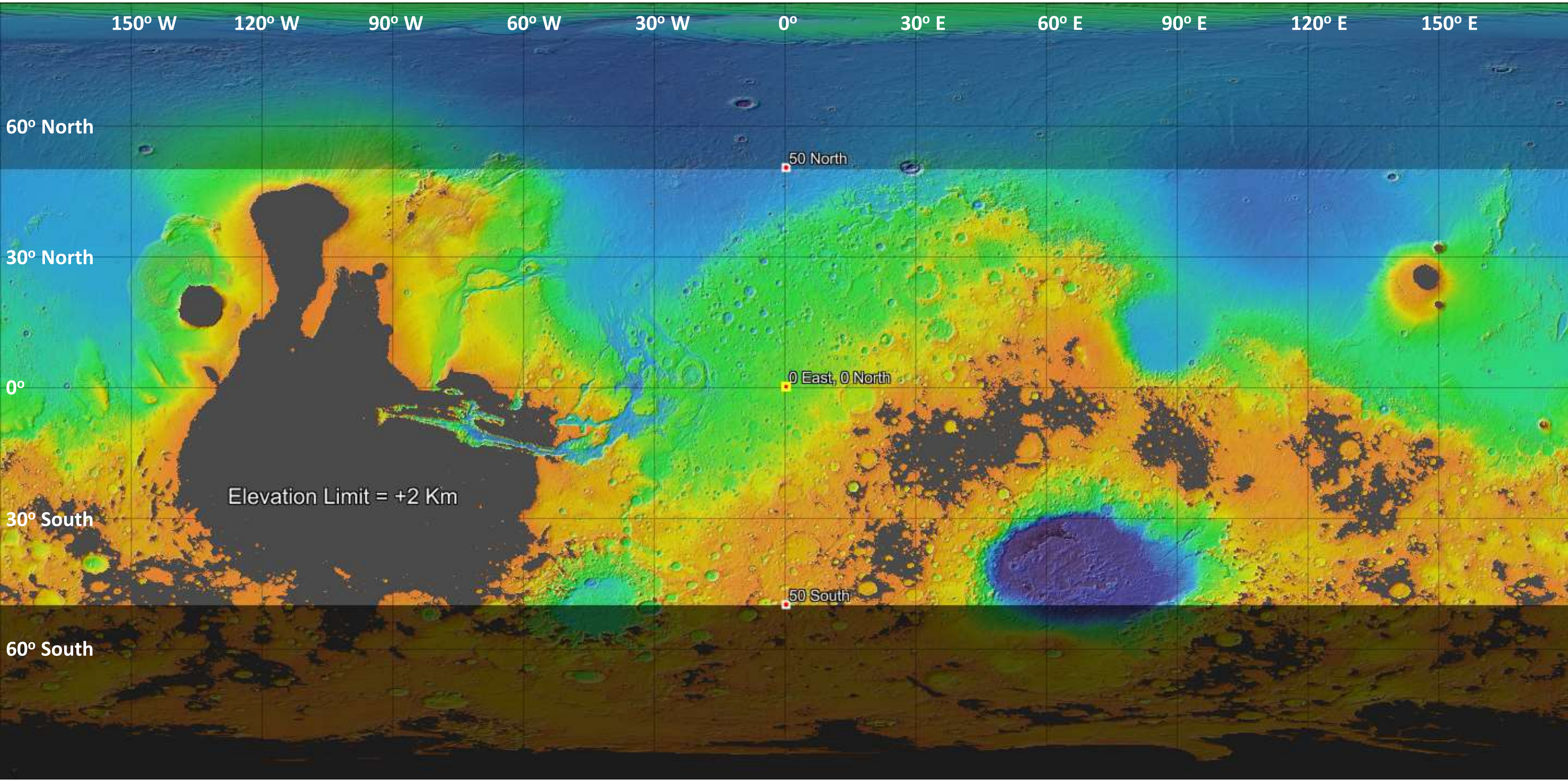
- Two crew
  - capable of carrying four crew in a contingency
- Two week duration without resupply
- ~400 km “odometer” range
  - 200 km out, 200 km back
  - Factor of 2 for actual distance over straight line distance
  - ***Results in ~100 km straight line range from starting point***

Example Mars Exploration Zone Containing Several Regions of Interest (ROI's)

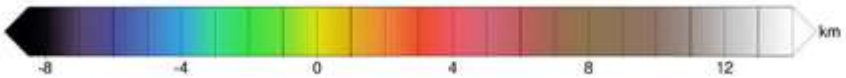


Preliminary Mars Surface Location Constraints for EZs

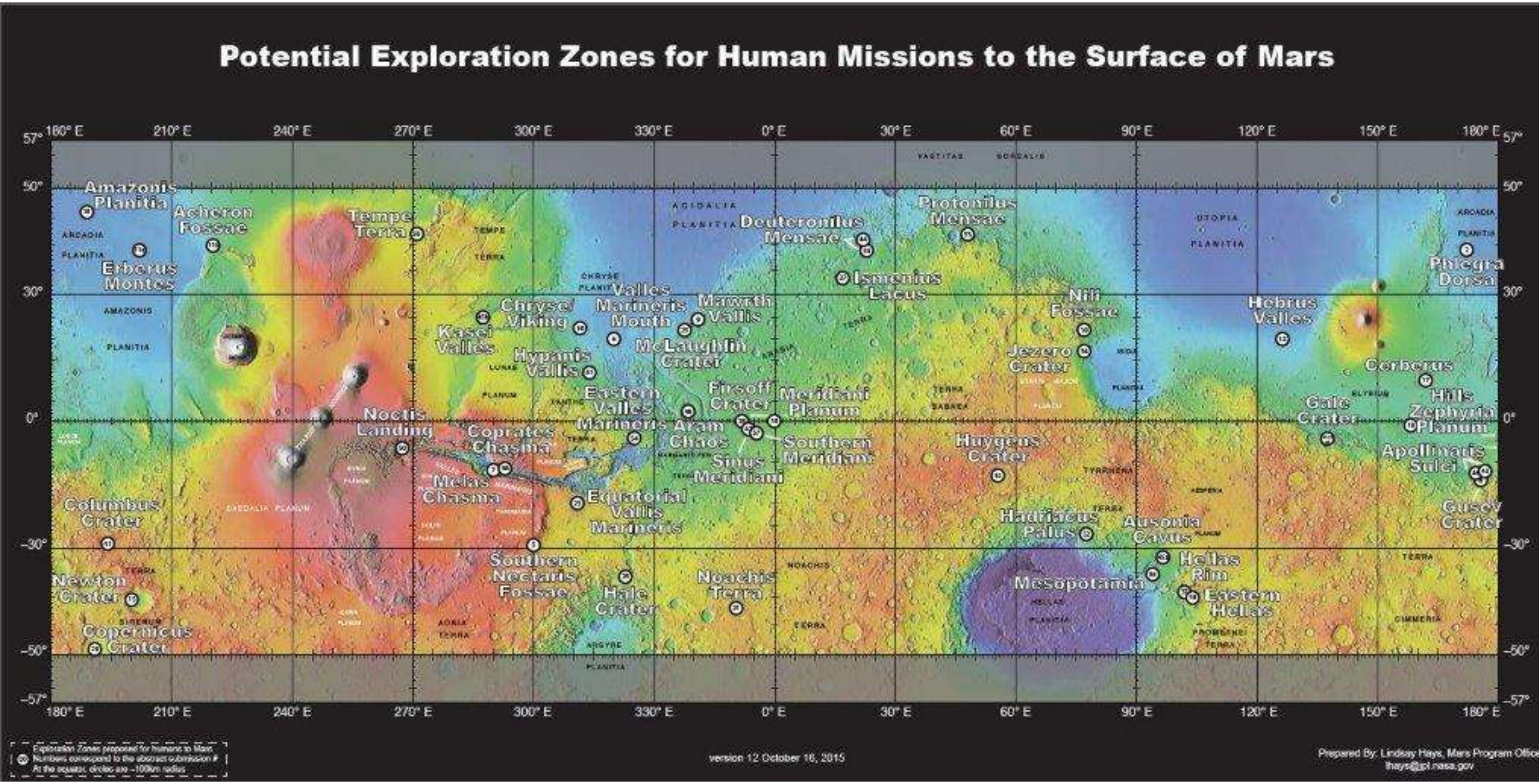
Elevation Limit = +2 km   Latitude Limits = +/- 50°



MOLA Color Legend

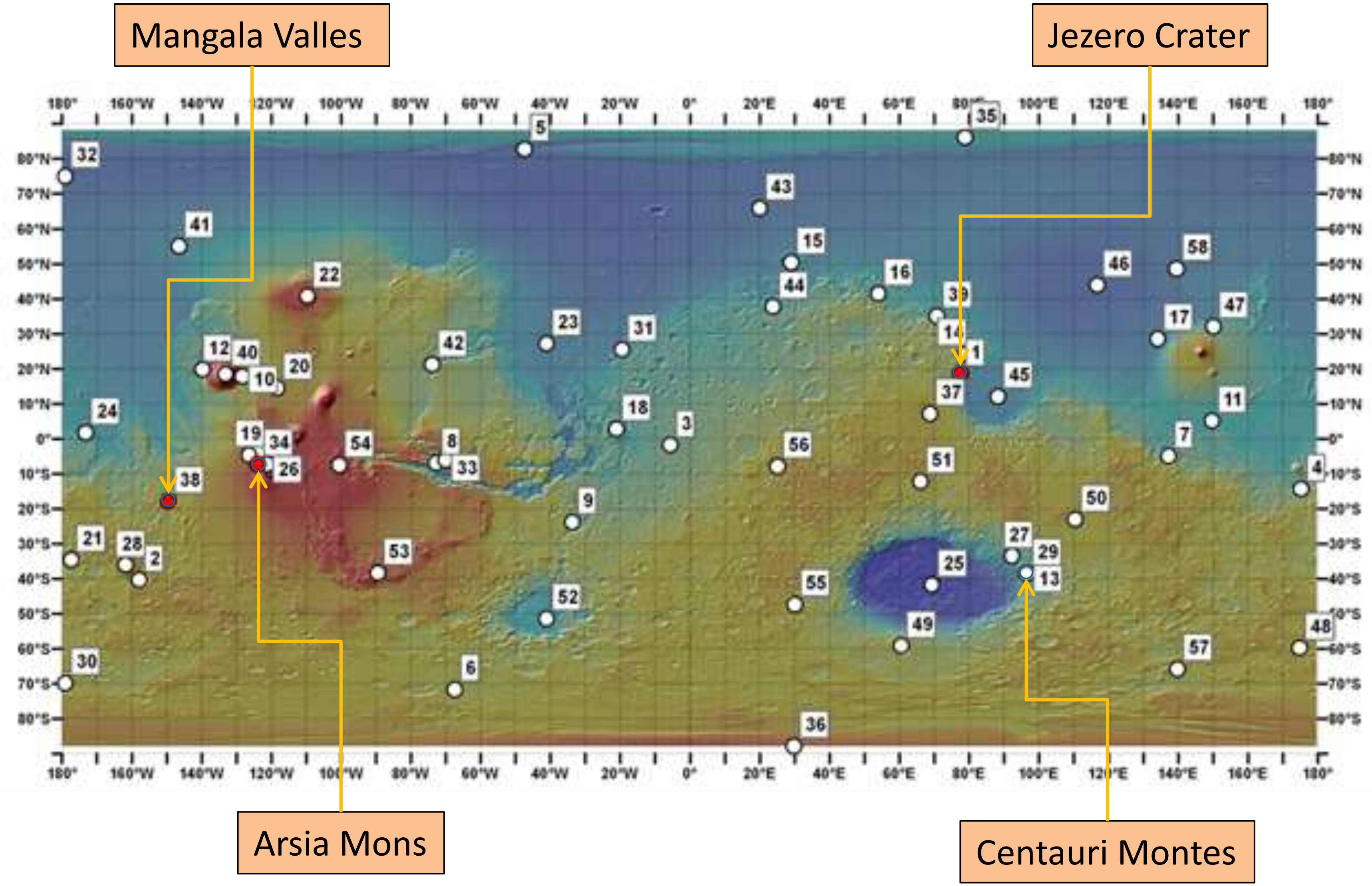


Exploration Zones Proposed at First EZ Workshop



This map is posted at http://www.nasa.gov/sites/default/files/atoms/files/exploration-zone-map-v10.pdf

HEM-SAG (Human Exploration of Mars – Science Analysis Group) candidate Mars landing sites



Bridging the Gap: A Mars Surface Field Station

- **Once the primary Emplacement objective – enabling crews to remain on the surface of Mars for 12 – 18 months – is achieved, this infrastructure and experience base will be used as the foundation for building capabilities needed for the Mars Surface Proving Ground phase**
- **These capabilities should give priority to investigating the known unknowns with flexibility to investigate unknown unknowns as they emerge.**
- **One well-established concept that is used to handle "unknowns" is the *field station* or *experiment station***
  - Field Stations bring the basic tools of research—from electricity to communication to community—to the places where research needs to be done
    - They provide access to the environment.
    - They provide logistical support for a wide range of activities including individual research projects; networking of research on larger scales; science, technology, engineering, and mathematics (STEM) training; and public outreach.
    - Through time they become environmental and operational models in which the steady accumulation of knowledge becomes a platform for future research.
  - *Field Stations* create a bridge between natural environments and [Earth-based] research laboratories. *Research laboratories* offer considerable power to conduct analyses in a predictable environment and to infer cause and effect from manipulative experiments, but they may miss factors that turn out to be critical in a natural environment. Field studies can encompass the full range of relevant interactions and scales, but they are not as tightly controlled. By offering access to both laboratories and field environments, Field Stations combine the best of both worlds.

Note: Adapted from Billick, I., et.al. 2013. Field Stations and Marine Laboratories of the Future: A Strategic Vision. National Association of Marine Laboratories and Organization of Biological Field Stations.

Mars Surface Field Station Capabilities “Scorecard”

- **EMC Assumptions**
  - Operational in the 2030s and beyond
  - Crew of four
  - Multiple visits to the same site
- **Research Support**
  - Physical sciences
  - Biological sciences
  - Atmospheric sciences
  - Human physiology
  - ISRU and civil engineering applied technology
- **Exploration Zone**
  - 100 km radius activity zone
  - +/- 50 deg. latitude
  - Less than 2 km elevation

Evolvable Mars Campaign Development

MARS ENVIRONMENT

Sizing Things Up

Earth

Diameter = 12800 km
Rotation period = 23.9 hrs
Axis Tilt = 23.5 deg

Mars

Diameter = 6800 km
Rotation period = 24.6 hrs
Axis Tilt = 25.2 deg

Moon

Diameter = 3500 km
Rotation period = synchronous

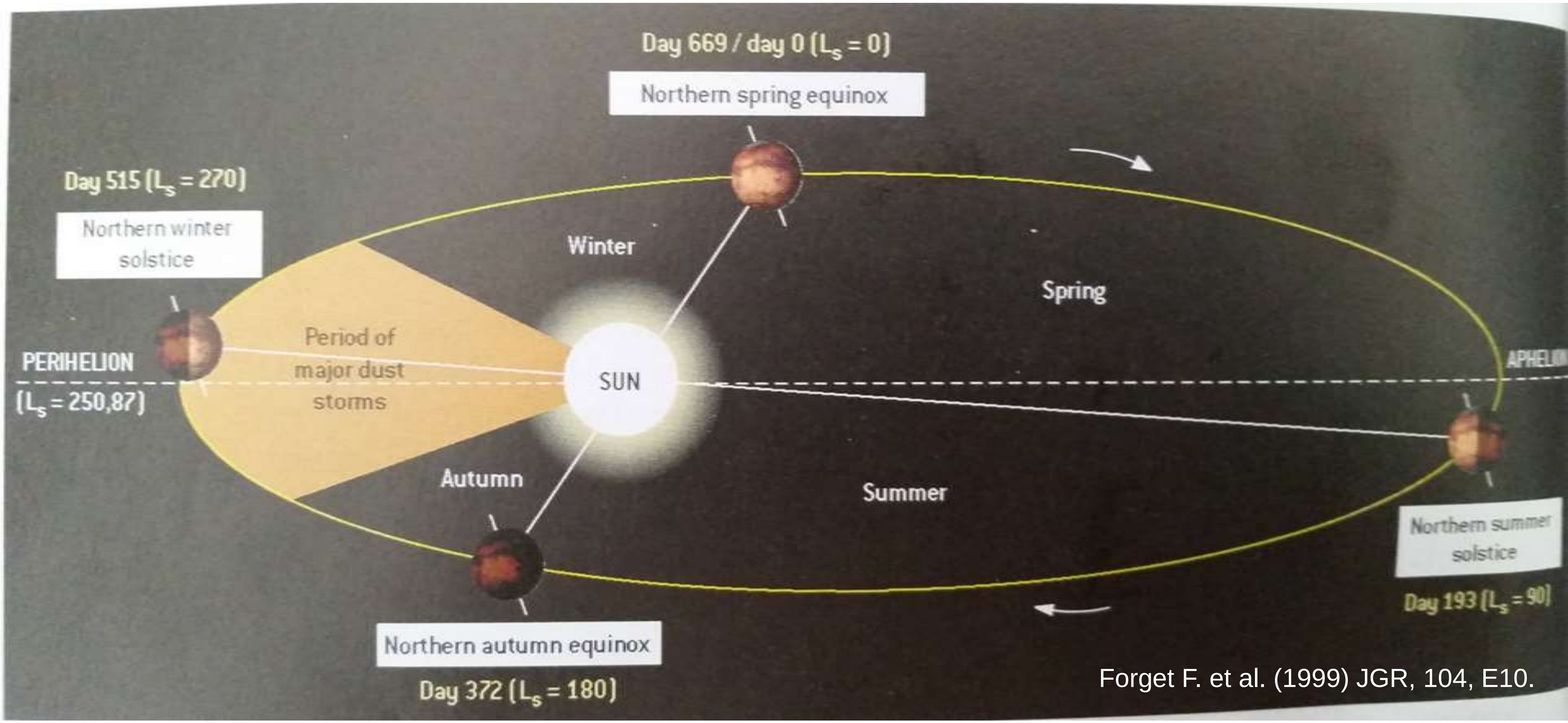
Phobos and Deimos

Diameter = ~25 km and ~15 km
Rotation period = synchronous

Some Atmosphere Charateristics

- **Pressure**
  - Averages 7.5 millibars. (1000 millibars at sea level on Earth) It can vary by 50% depending on the location on Mars and time of year.
- **Temperature**
  - Average temperature on Mars: −55 ° C (218 K; −67 ° F)
  - Nights are much colder than days
  - High: > 20 ° C (293 K; 68 ° F) (noontime at the equator)
  - Low: < −153 ° C (120 K; −243 ° F) (during the polar night)
  - Midlatitudes: - 20 ° C with a nighttime minimum of - 60 ° C
- **Humidity**
  - 100% during the night, when it is very cold, and varies during the day.
- **Wind**
  - Maximums measured by the Viking Landers was 30 m/s (60 mph), average of 10 m/s (20 mph). However, the wind is not strong.

Seasons on Mars



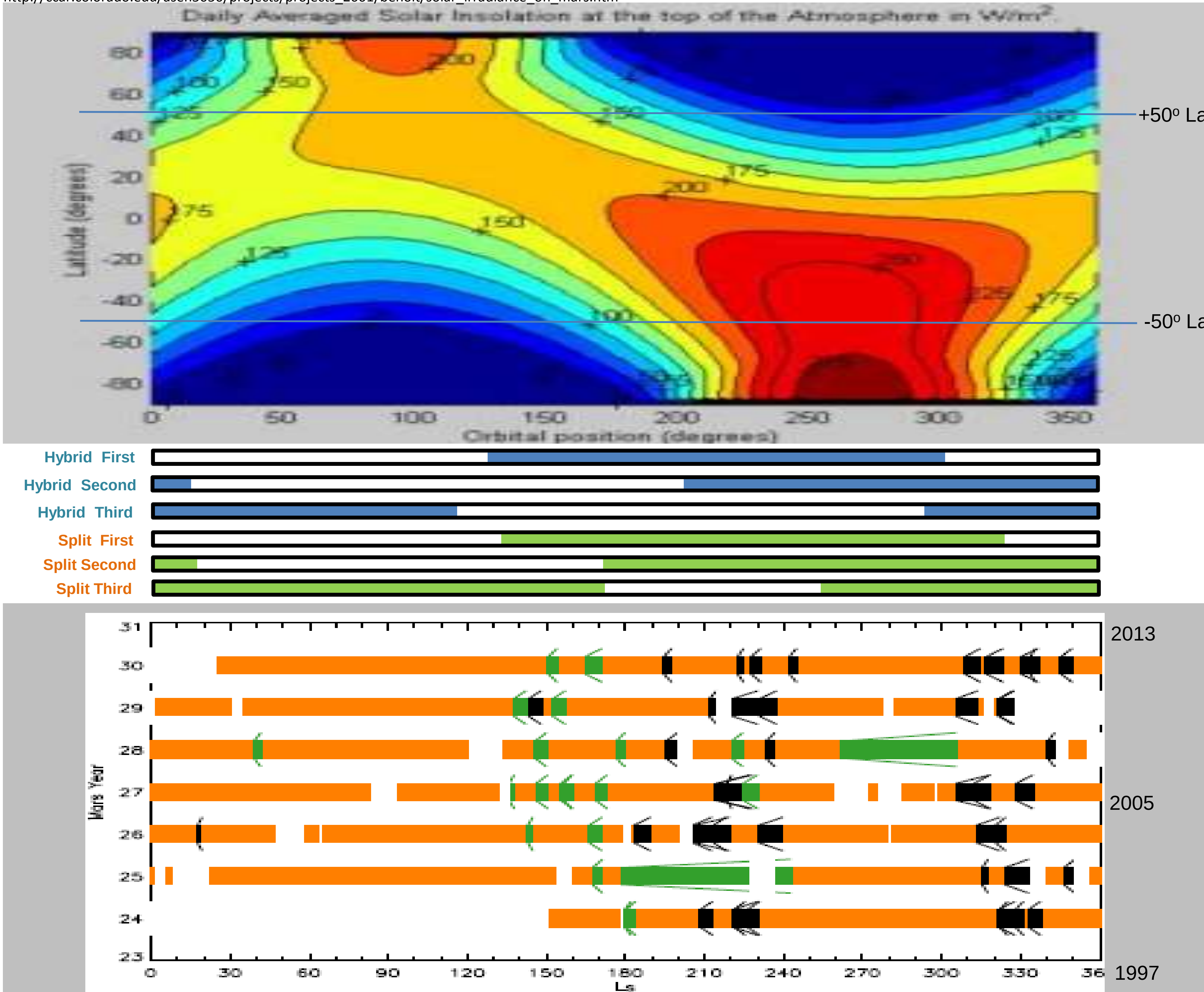
Forget F. et al. (1999) JGR, 104, E10.

The surface receives 40% more sunlight during perihelion than during aphelion.

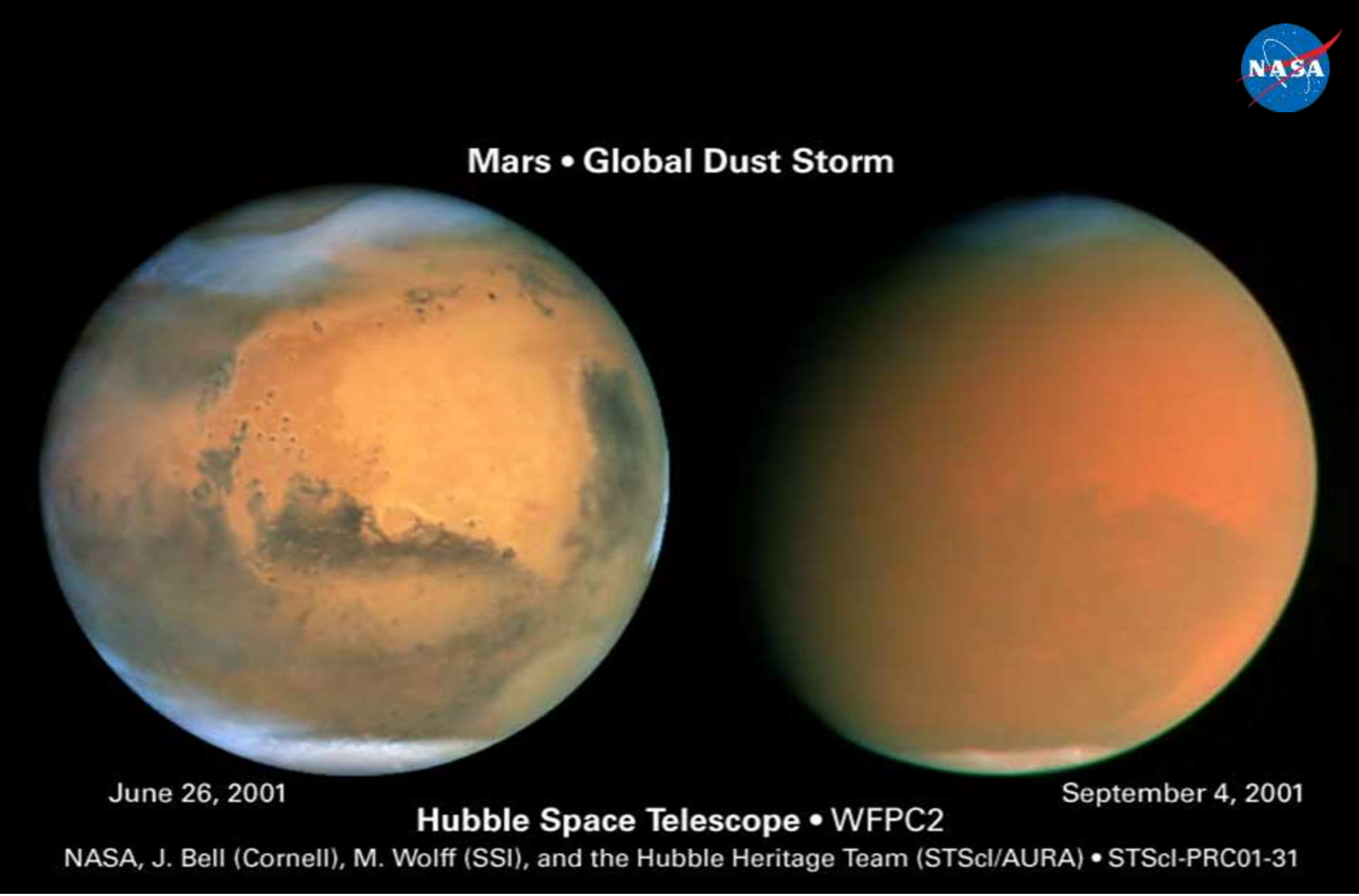
Perihelion: Dust storms

Aphelion: Cloud belts

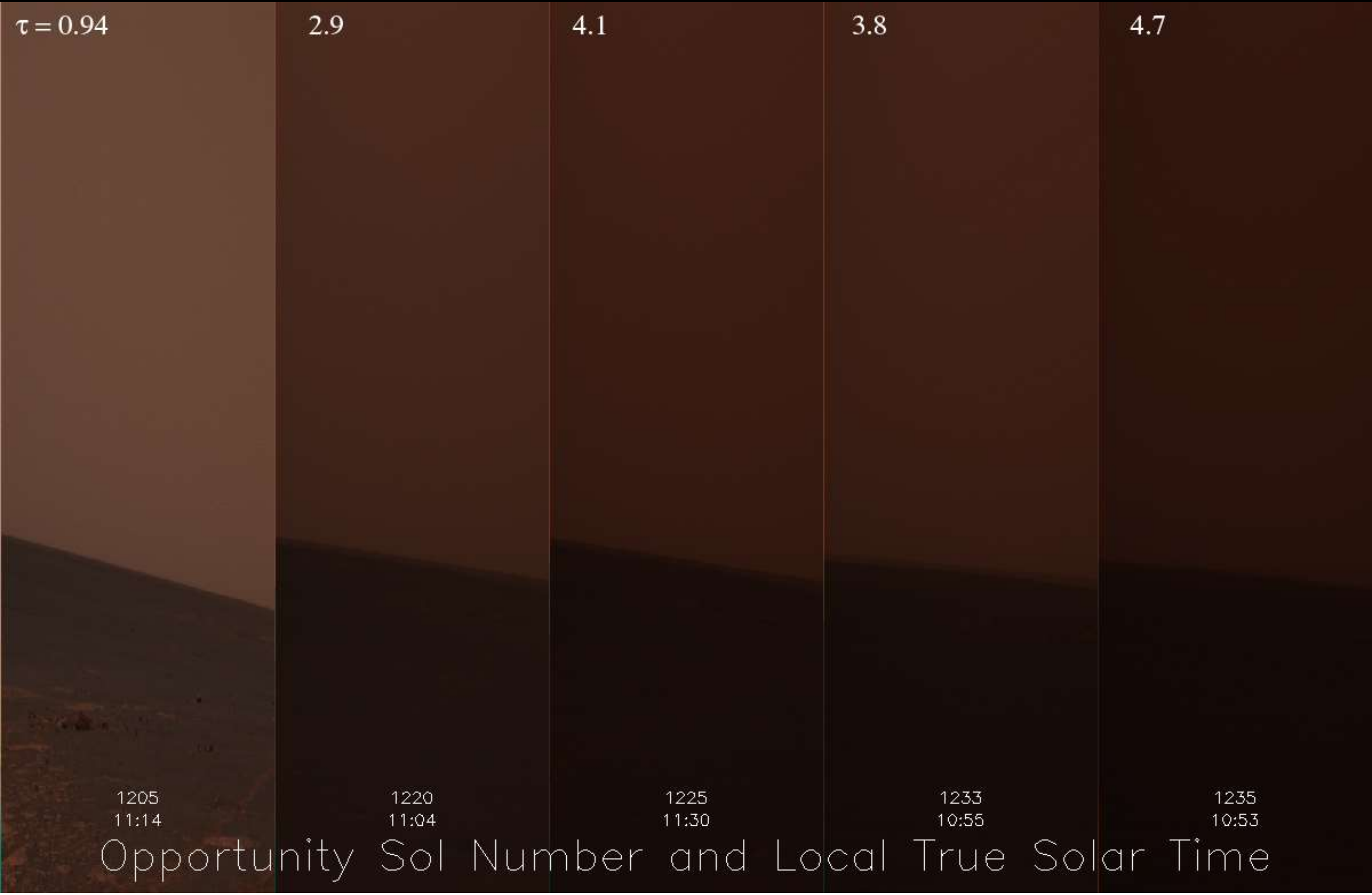
> http://ccar.colorado.edu/asen5050/projects/projects_2001/benoit/solar_irradiance_on_mars.htm



The origin, evolution, and trajectory of large dust storms on Mars during Mars years 24-30 (1999-2011), Huigun Wang[a], Mark I. Richardson[b] ([a]*Smithsonian Astrophysical Observatory*; [b]*Ashima Research*)

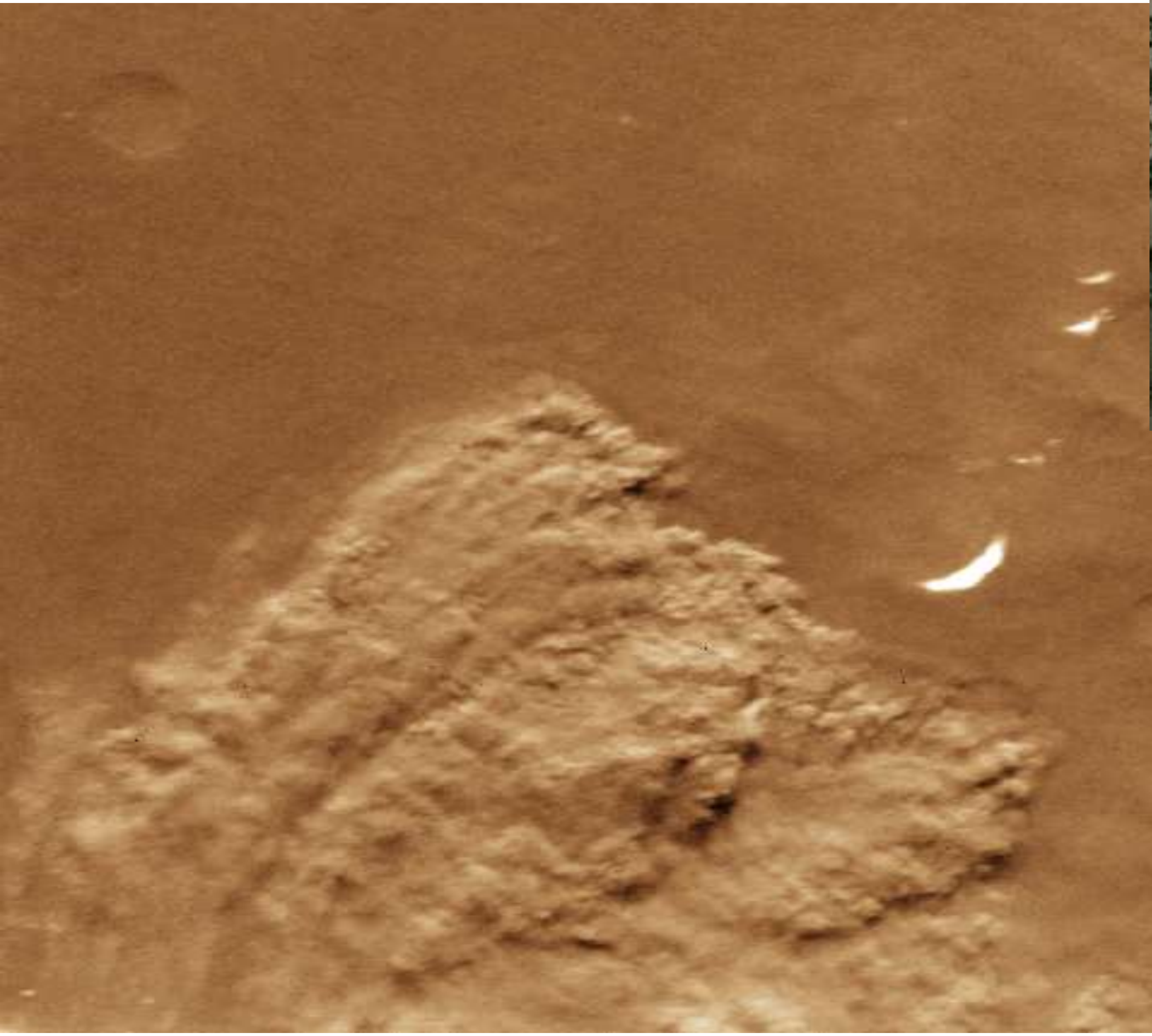

Mars • Global Dust Storm
June 26, 2001
September 4, 2001
Hubble Space Telescope • WFPC2
NASA, J. Bell (Cornell), M. Wolff (SSI), and the Hubble Heritage Team (STScI/AURA) • STScI-PRC01-31

Global Dust Storm – as seen from the surface



Regional Dust Storm – as seen from orbit

U.S. Marine Corps photo



NASA photo

Dust Devils – as seen from the surface

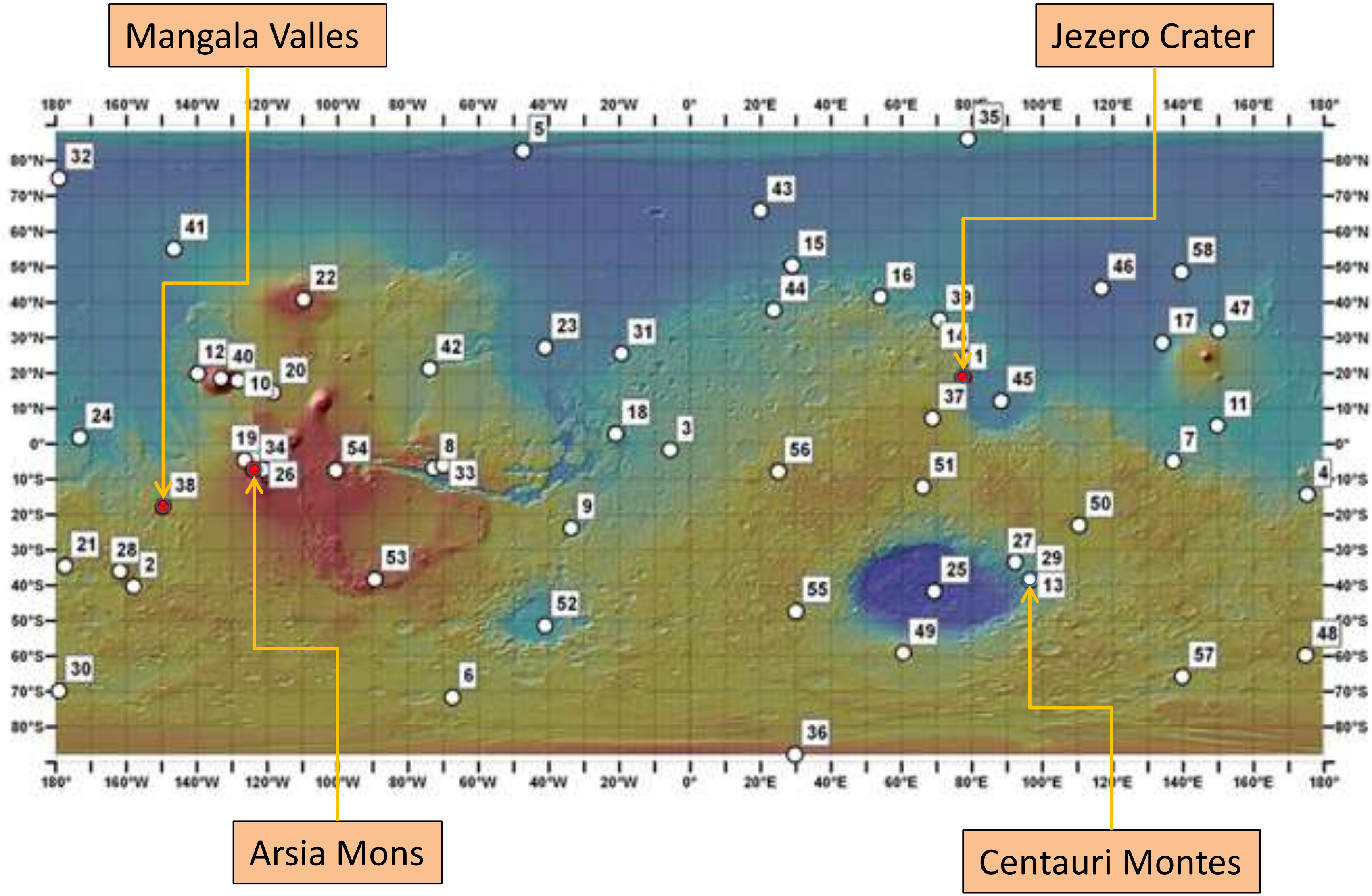
Dust Devils – as seen from orbit

"Feels Like" Wind Speed

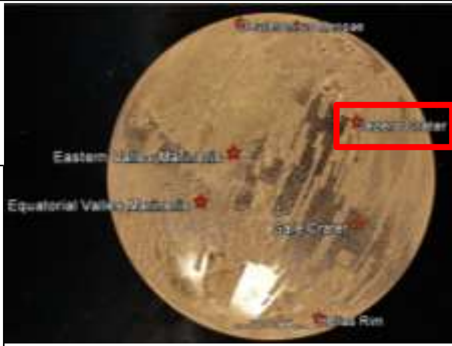
Wind speed on Mars			"Feels like" wind speed on Earth (at STP)	
mph	m/s	dynamic pressure	m/s	mph
10	4.5	0.2367	0.6	1.4
50	22.4	5.9169	3.0	6.8
67	30.0*	10.6587	4.1	9.1
100	44.7	23.6677	6.1	13.5
150	67.1	53.2523	9.1	20.3

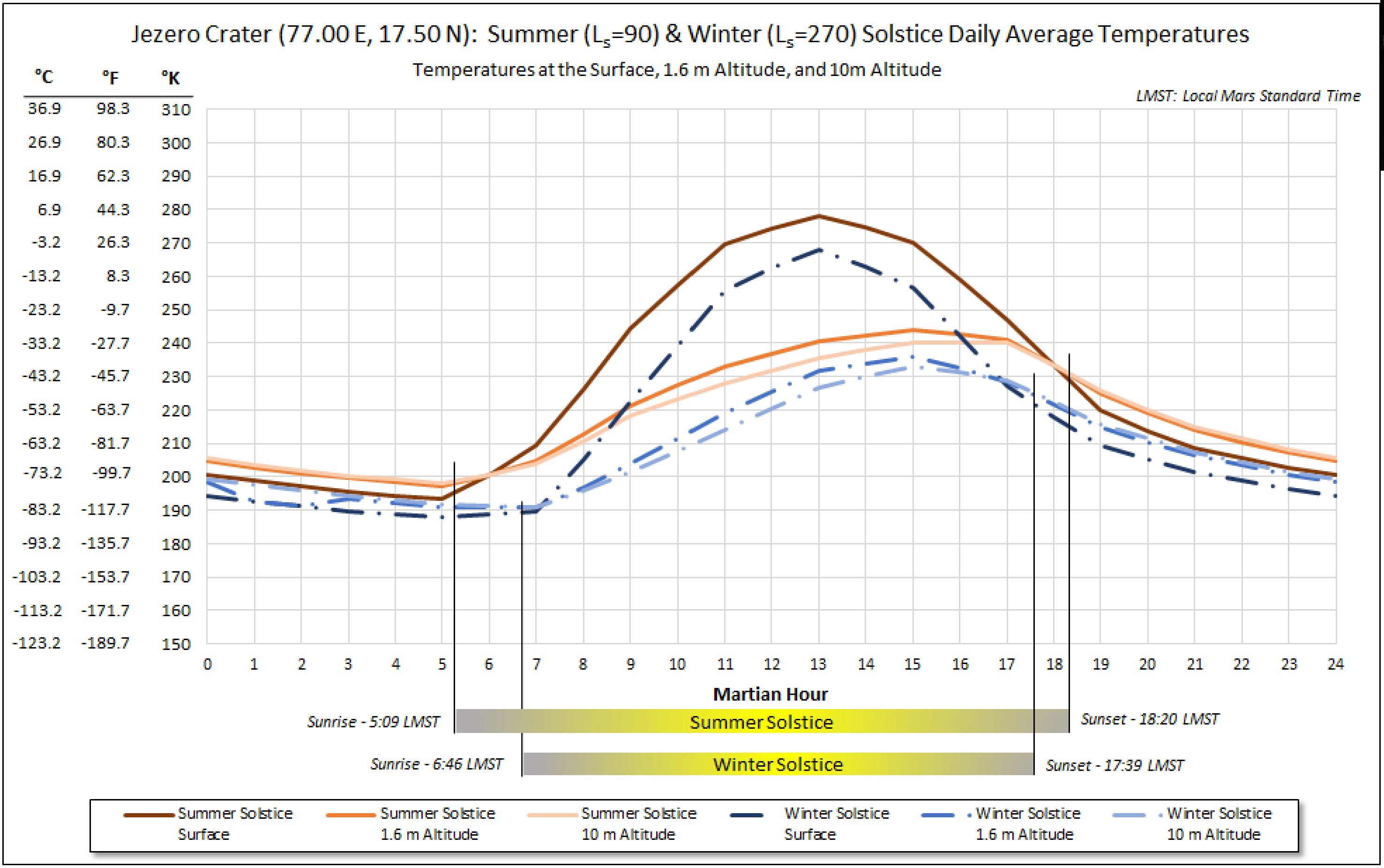
* Highest measured wind speed on the surface of Mars: Viking 2 Lander site – Utopia Planitia

HEM-SAG candidate Mars landing sites



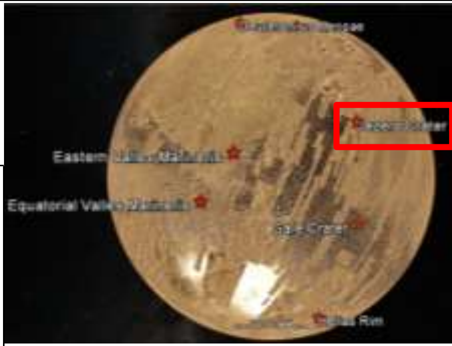
Jezero Crater

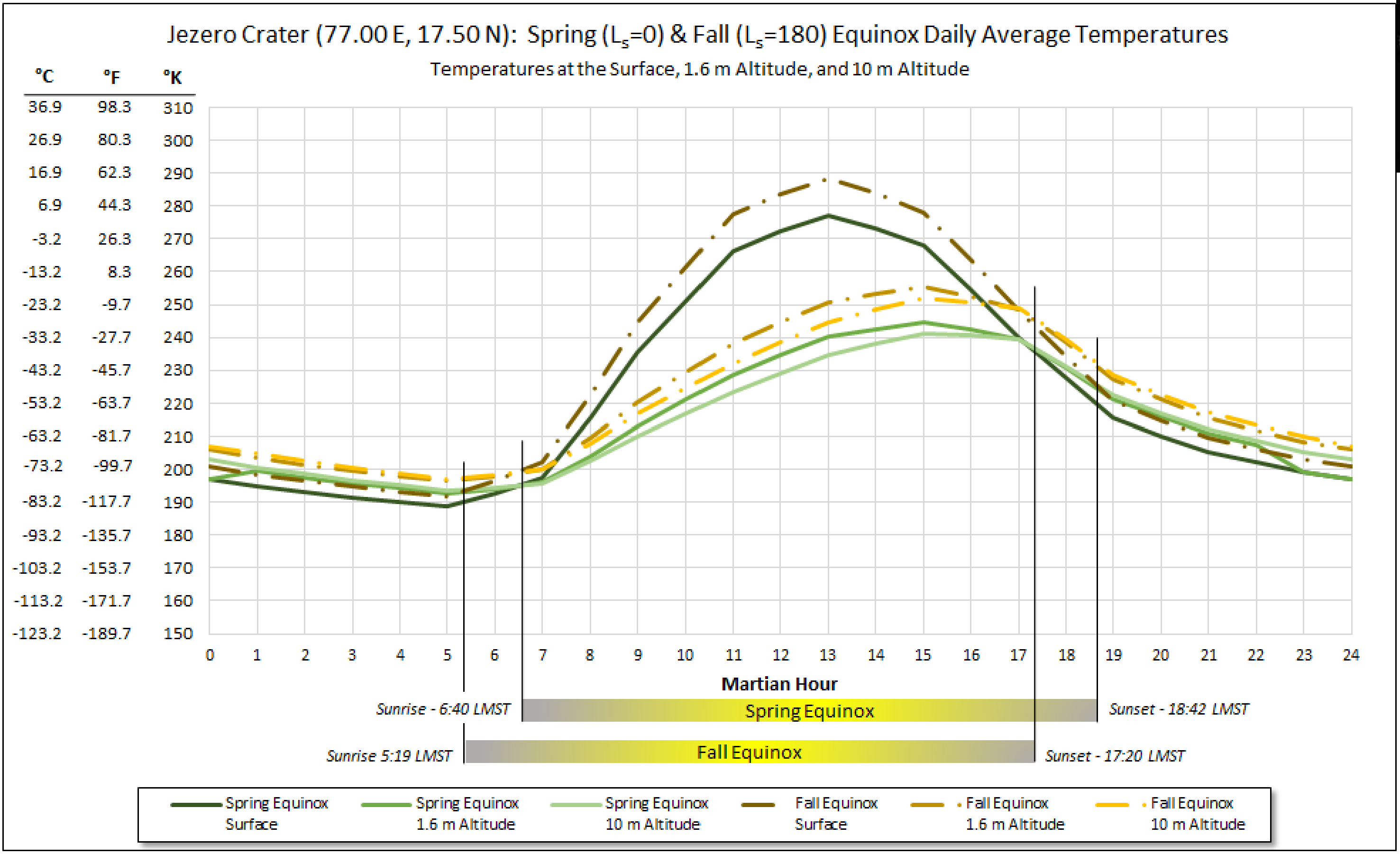




Temperatures per the Martian Climate Database, Millour et al. 2015 and Forget et al. 1999.
http://www-mars.lmd.jussieu.fr/mars/mars.html

Jezero Crater





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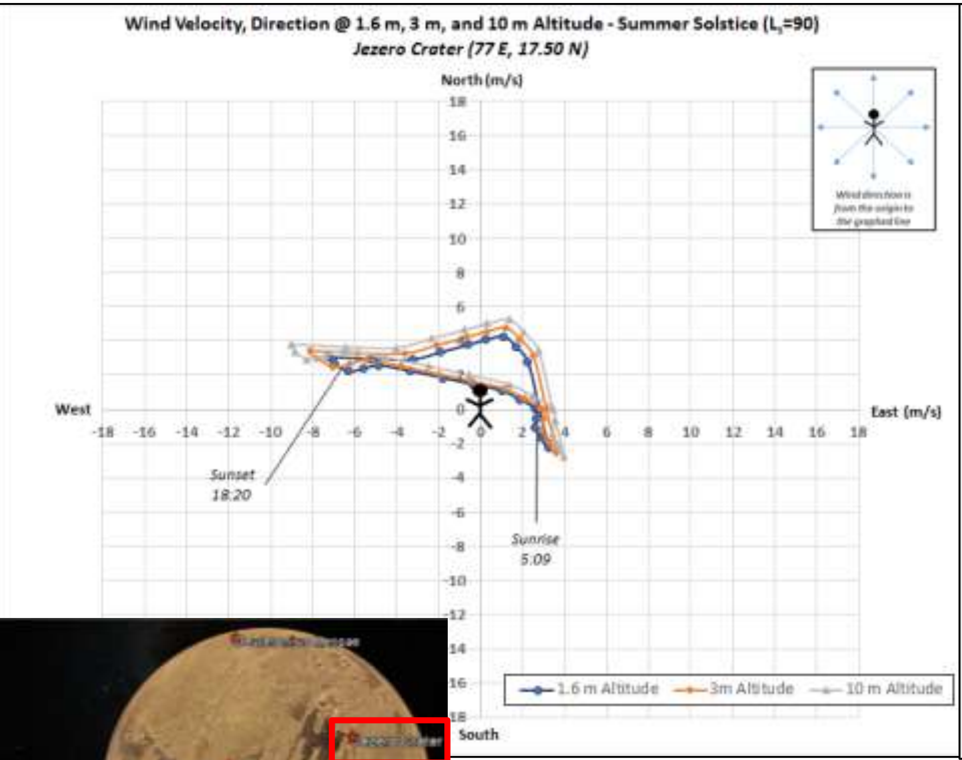
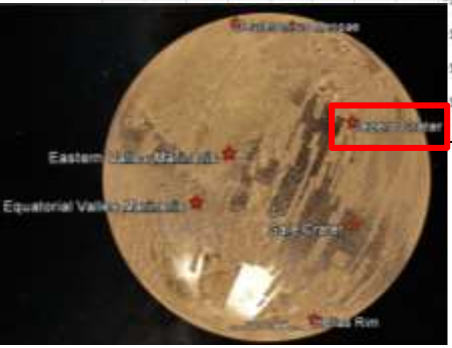
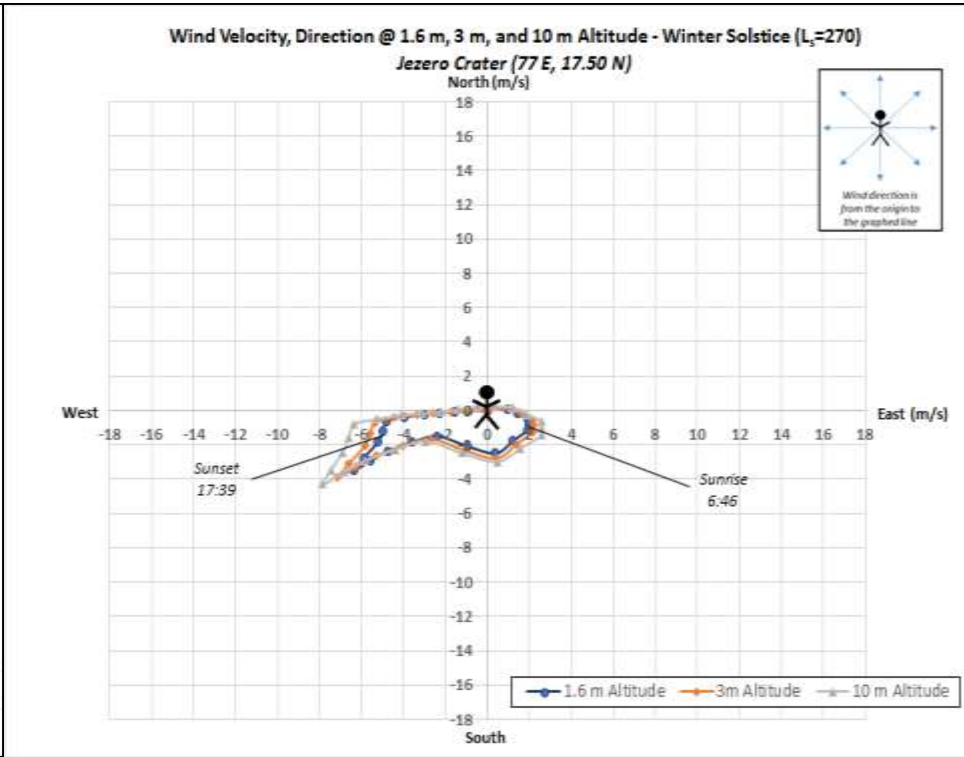
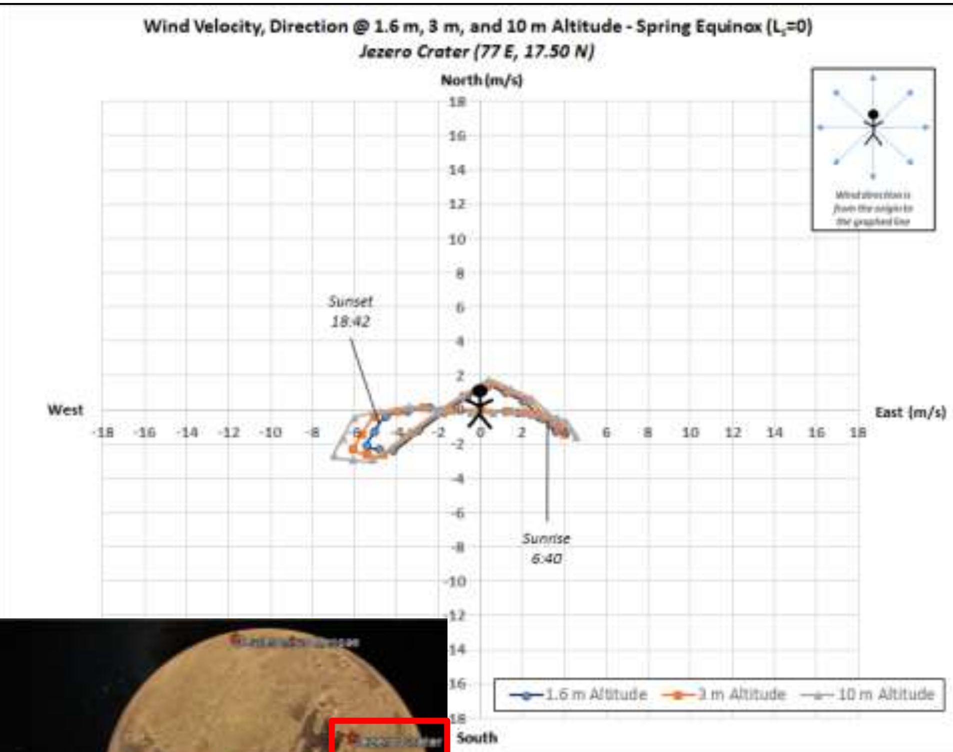


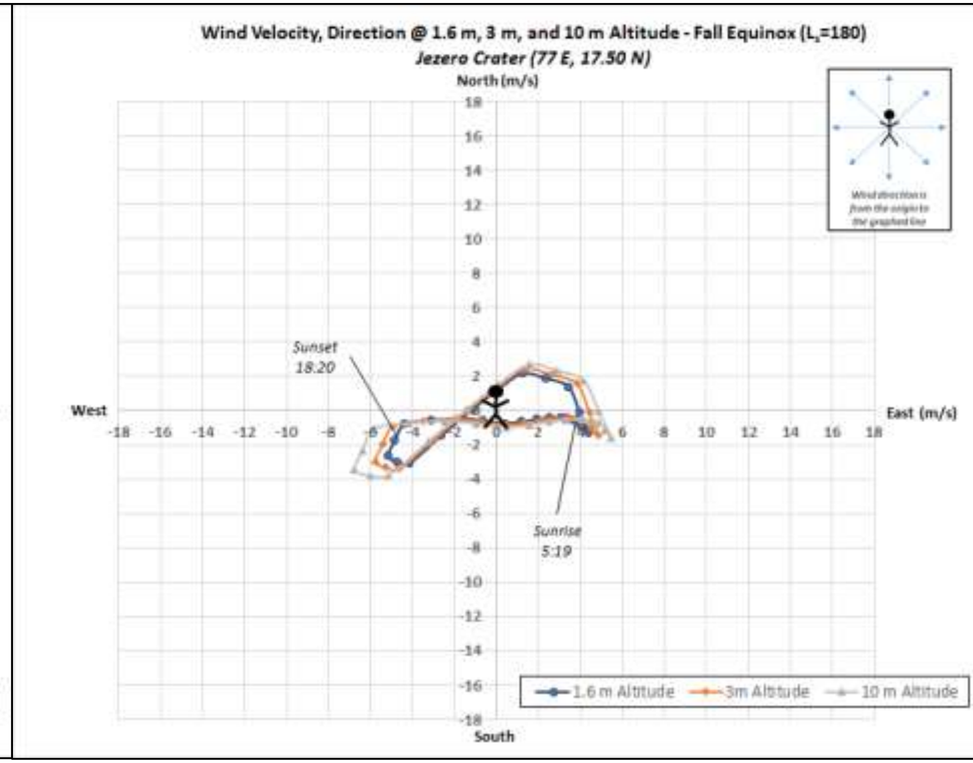


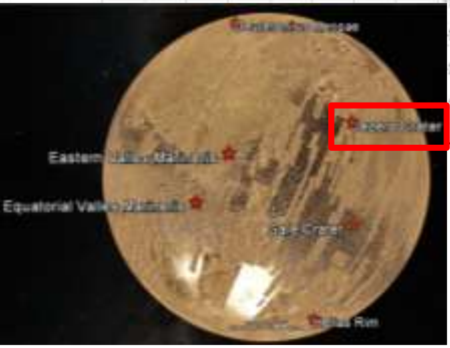


Wind velocity, direction per the Martian Climate Database, Millour et al. 2015 and Forget et al. 1999. http://www-mars.lmd.jussieu.fr/mars/mars.html

Jezero Crater







Wind velocity, direction per the Martian Climate Database, Millour et al. 2015 and Forget et al. 1999. http://www-mars.lmd.jussieu.fr/mars/mars.html

Mars Surface Field Station Capabilities “Scorecard”

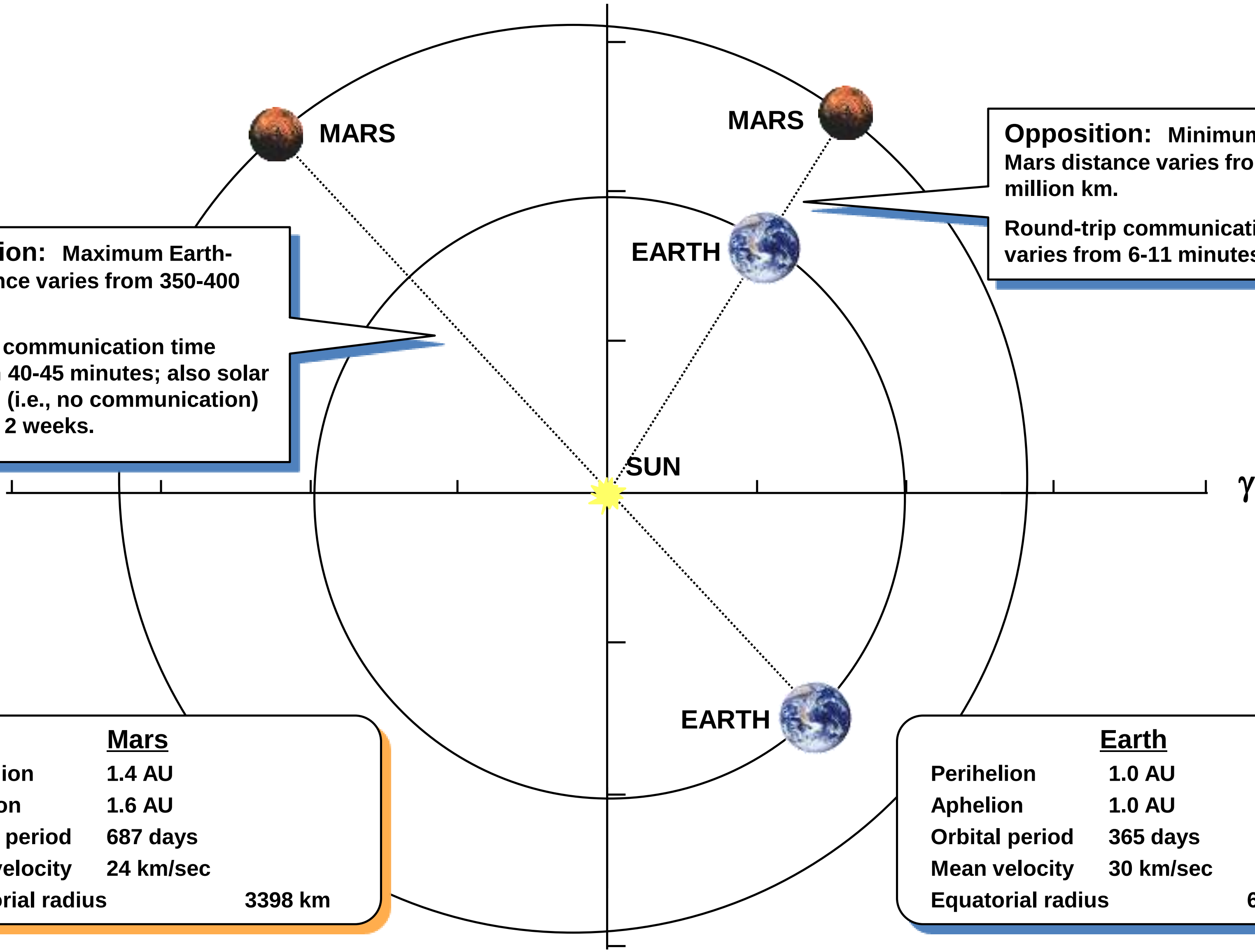
- **EMC Assumptions**
  - Operational in the 2030s and beyond
  - Crew of four
  - Multiple visits to the same site
- **Research Support**
  - Physical sciences
  - Biological sciences
  - Atmospheric sciences
  - Human physiology
  - ISRU and civil engineering applied technology
- **Exploration Zone**
  - 100 km radius activity zone
  - +/- 50 deg. latitude
  - Less than 2 km elevation
- **Mars Environment**
  - Seasonal changes
  - Periodic dust storms

- **Mars Environment (cont.)**
  - Daylight (at 50 deg lat):
    - ~15 hrs (summer solstice)
    - ~9 hrs (winter solstice)
  - Temperature range (extremes):
    - Highs > ~20 deg C
    - Lows < ~ -110 deg C
  - Winds: typically < 20 m/s with low dynamic pressure

Evolvable Mars Campaign Development

MISSION PLANNING BASICS

Earth-Mars Orbital Characteristics



Conjunction: Maximum Earth-Mars distance varies from 350-400 million km.

Round-trip communication time varies from 40-45 minutes; also solar occultation (i.e., no communication) for approx. 2 weeks.

Opposition: Minimum Earth-Mars distance varies from 60-100 million km.

Round-trip communication time varies from 6-11 minutes

Mars

Perihelion	1.4 AU
Aphelion	1.6 AU
Orbital period	687 days
Mean velocity	24 km/sec
Equatorial radius	3398 km

Earth

Perihelion	1.0 AU
Aphelion	1.0 AU
Orbital period	365 days
Mean velocity	30 km/sec
Equatorial radius	6378 km

Mars Mission Modes

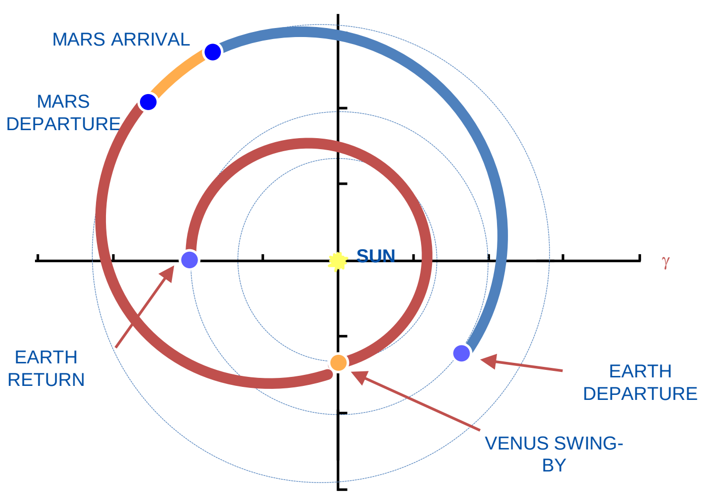
- **Round-trip human missions to Mars are double rendezvous problems**
  - Relative phasing of Earth-Mars (outbound leg) must be considered along with the relative phasing Mars-Earth (return leg)
- **This leads to two distinct mission classes**

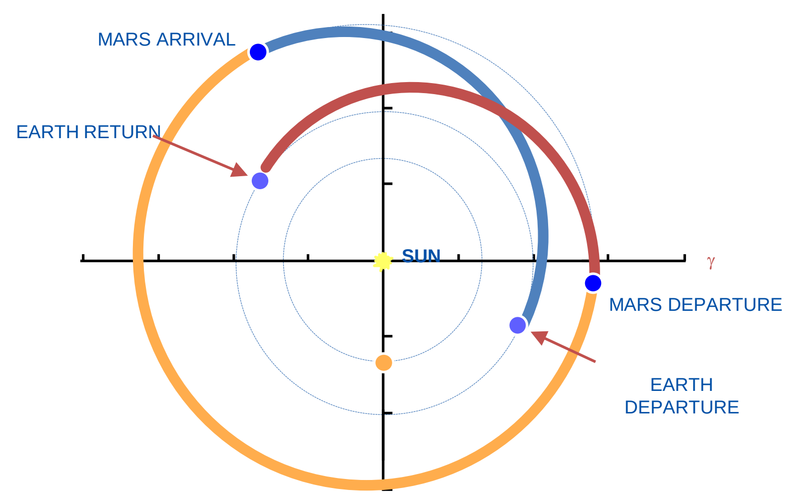
Short-Stay (Opposition Class)

- Variations of missions with short Mars surface stays and may include Venus swing-by
- Often referred to as Opposition Class missions

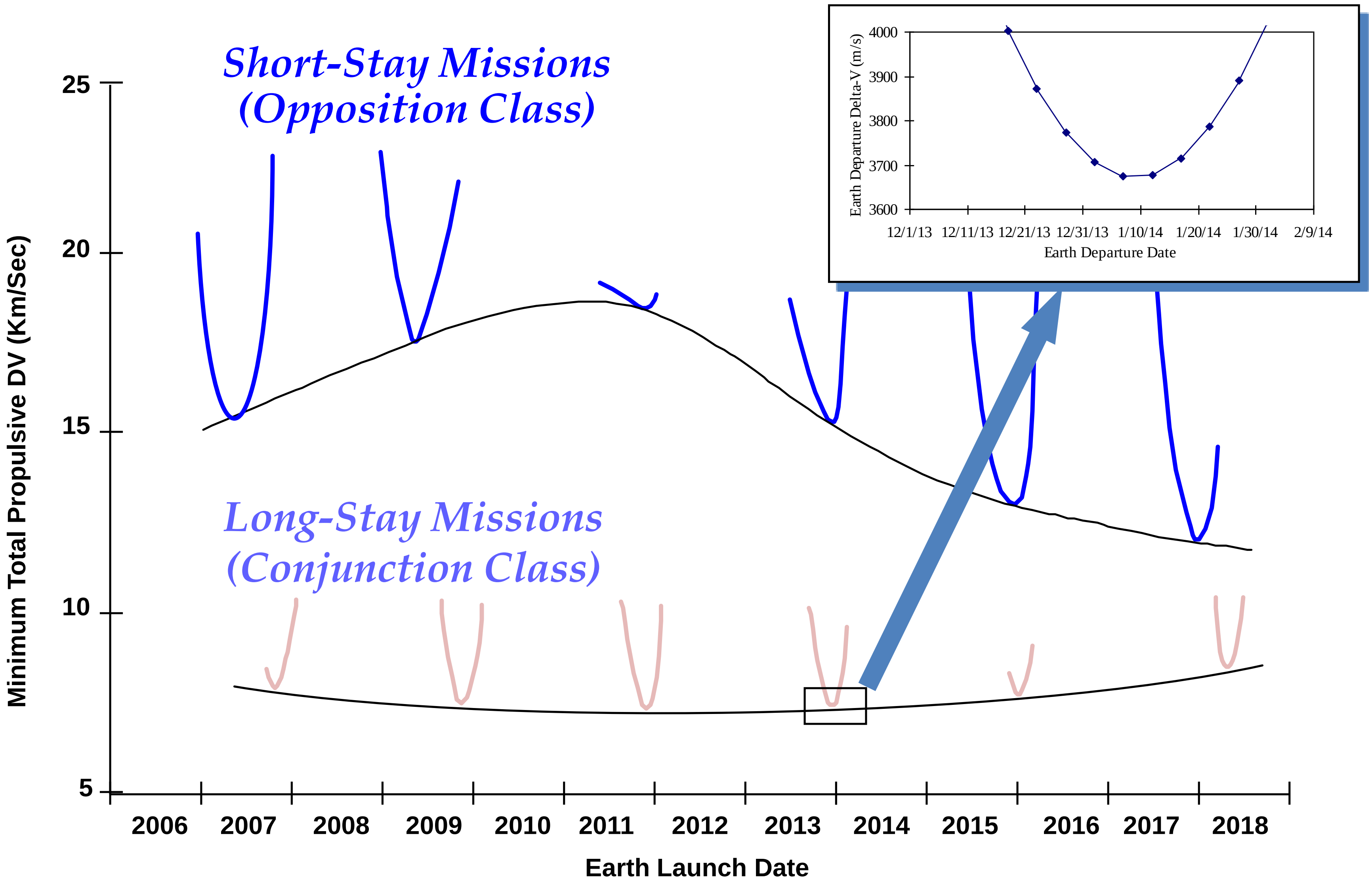
Long-Stay (Conjunction Class)

- Variations about the minimum energy mission
- Often referred to as Conjunction Class missions



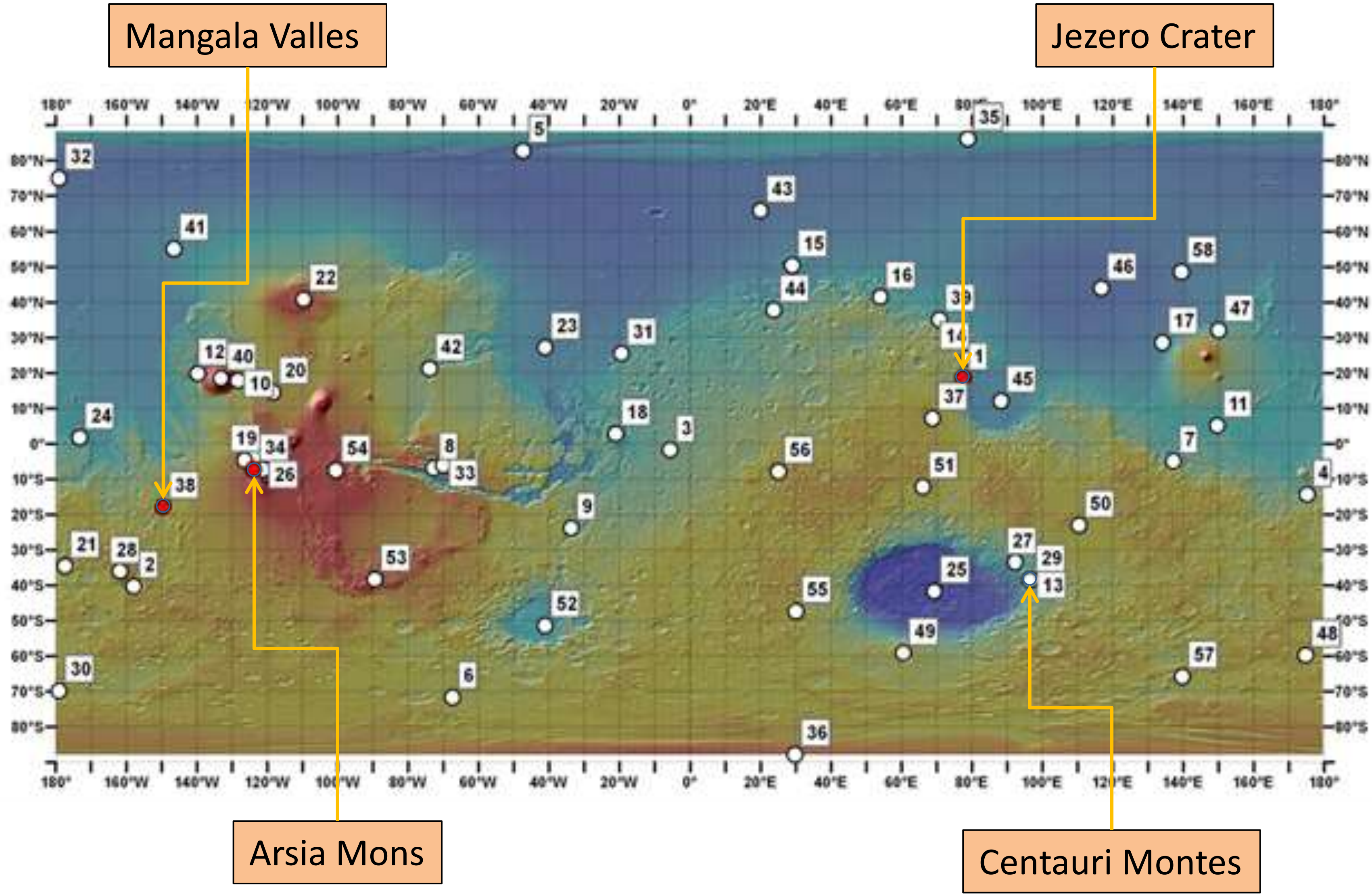


Delta-V Variations

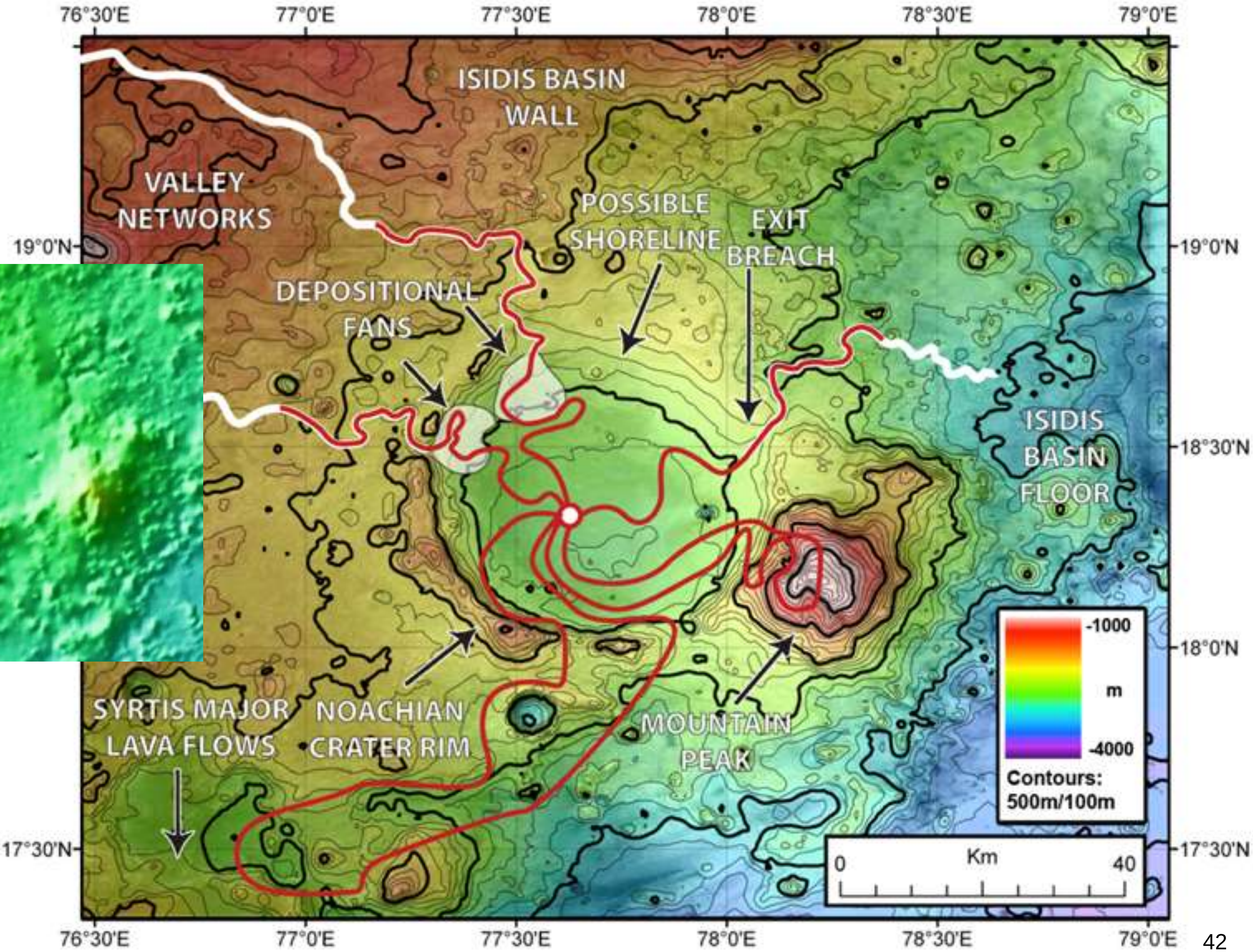


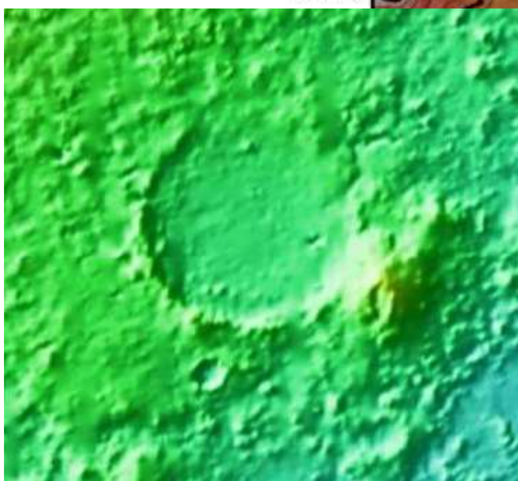
BGD-LS-98-005

HEM-SAG candidate Mars landing sites

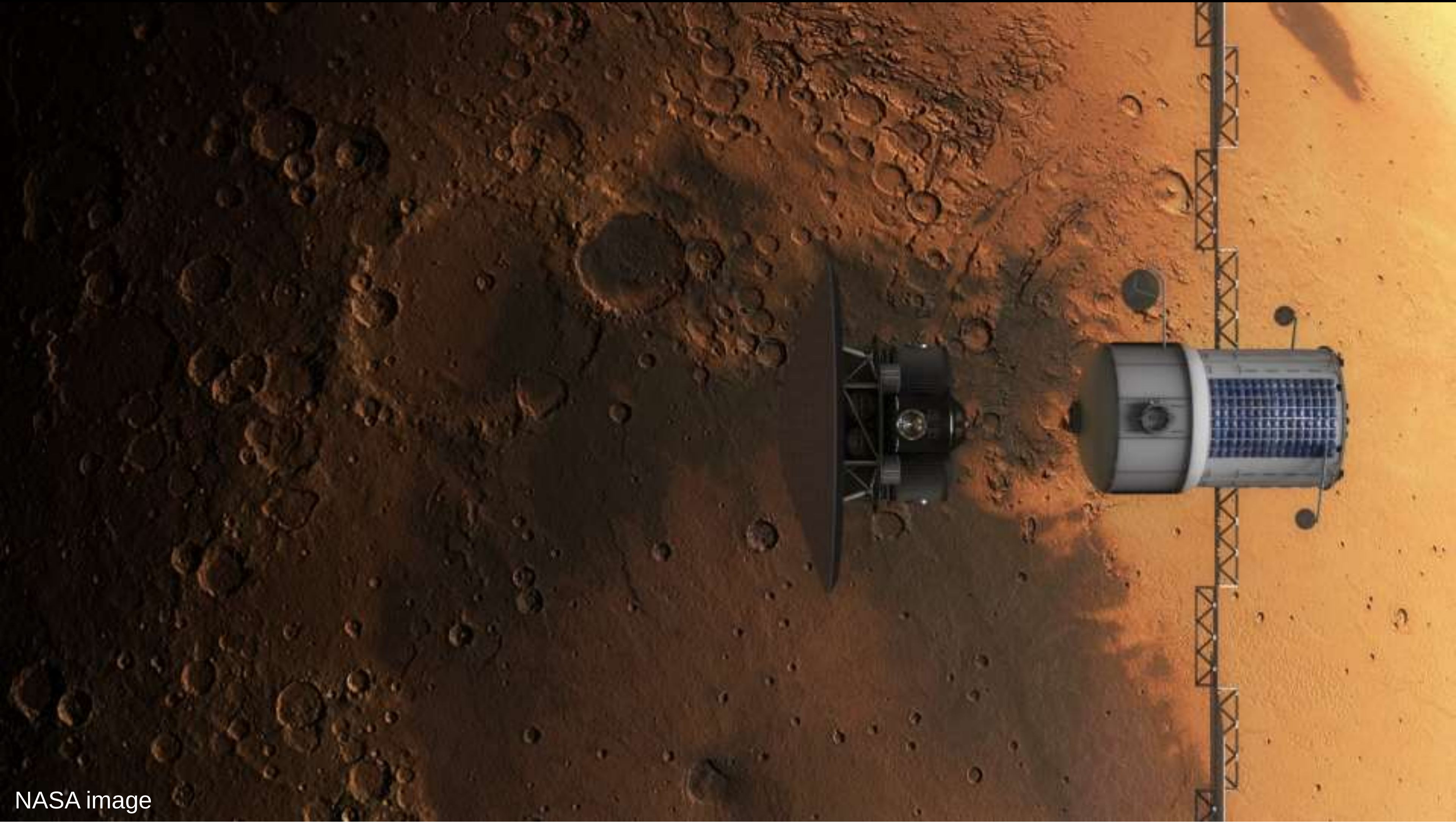


HEM-SAG Exploration Map for Jezero Crater





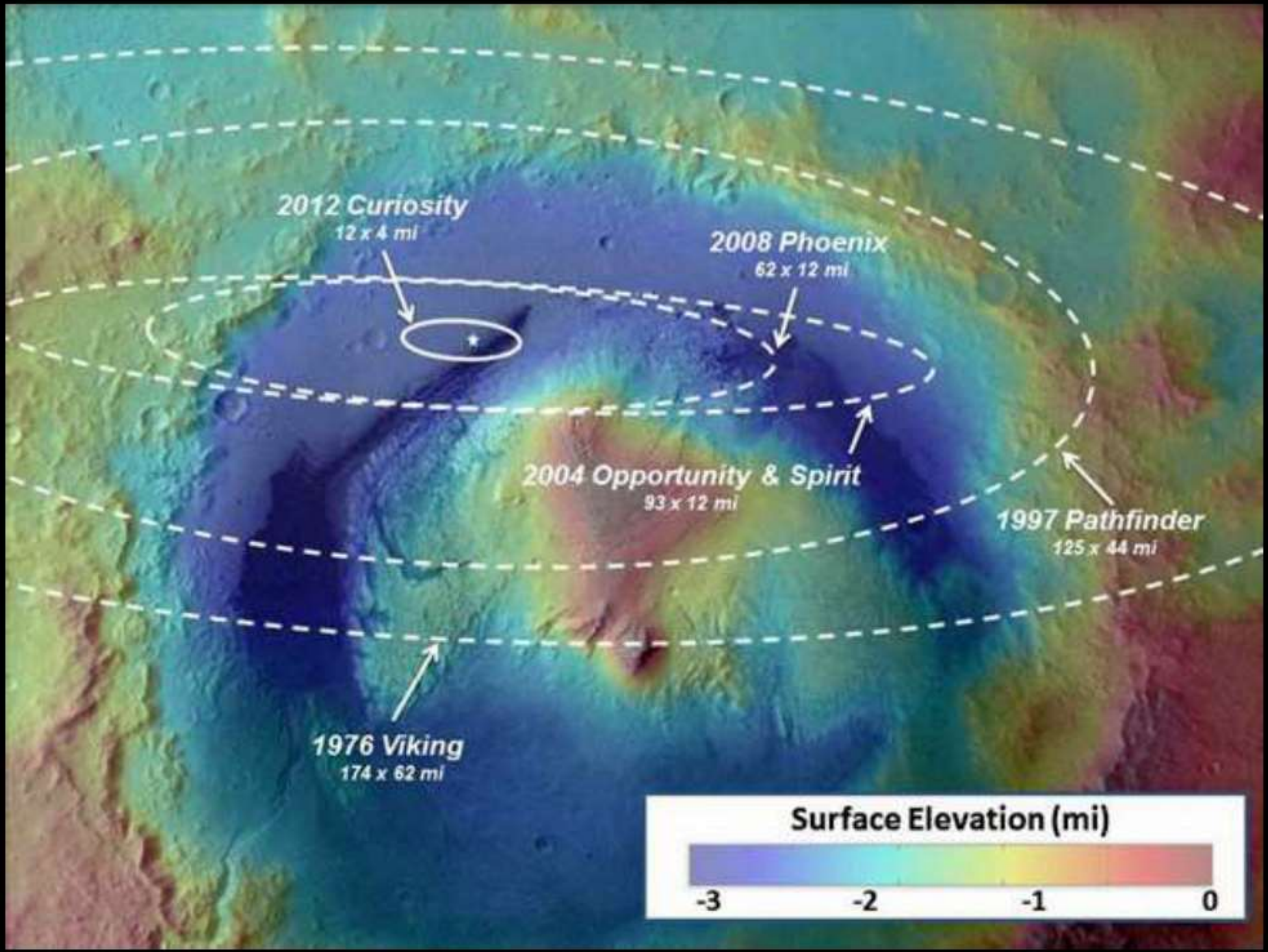
Mars Lander with Crew Departing From Orbit



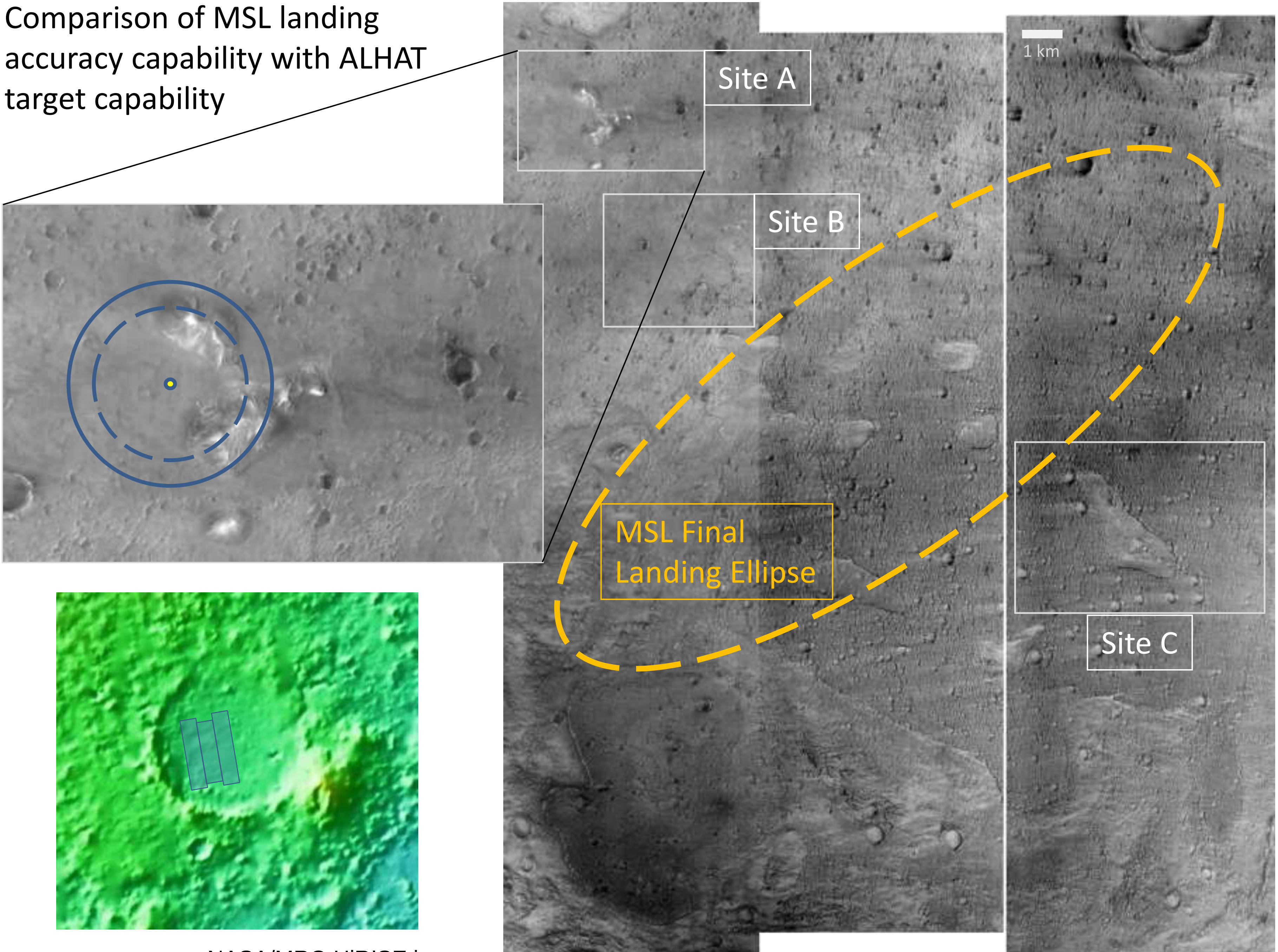
Challenges of Landing on Mars

Landing Supplies for a Human Mission Requires Greater Landing Accuracy

Because multiple landings will be required to deliver all the equipment and supplies needed, Human missions may require accuracy within 100 meters



Comparison of MSL landing accuracy capability with ALHAT target capability



NASA/MRO HiRISE images

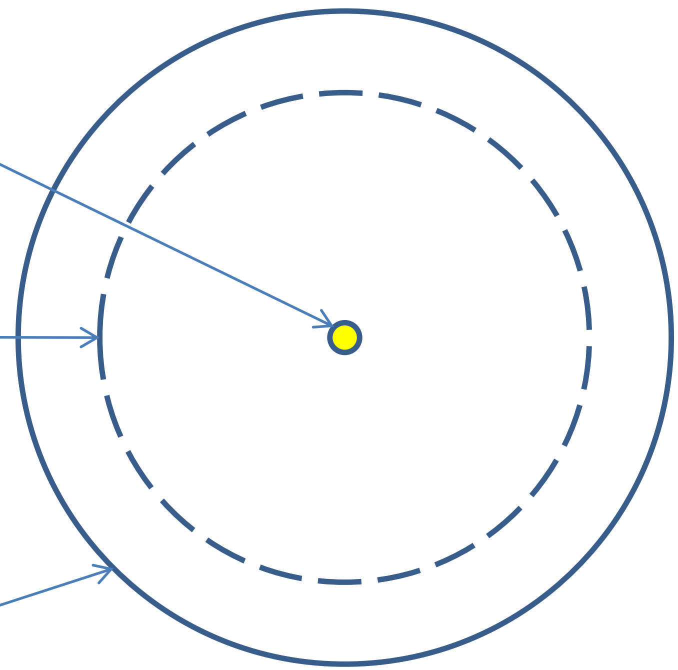
Landing Site Symbology

On the following pages this symbology will be used to indicate landing site factors discussed on the previous pages

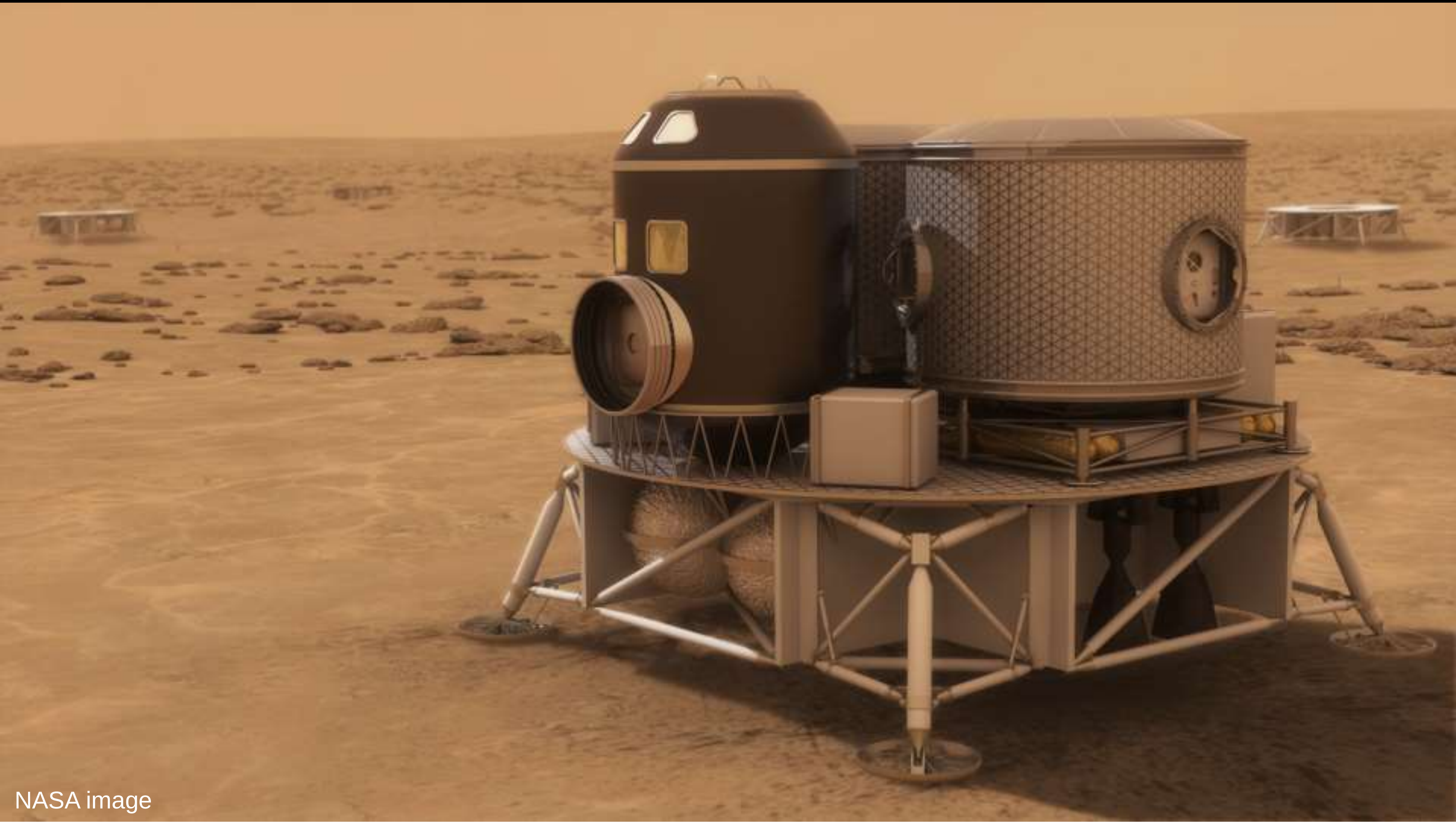
100 meter diameter circle inside of which the ALHAT system is targeting for delivery of a lander

700 meter diameter circle that analysis indicates will be the maximum range of debris lofted by a large terminal descent thruster

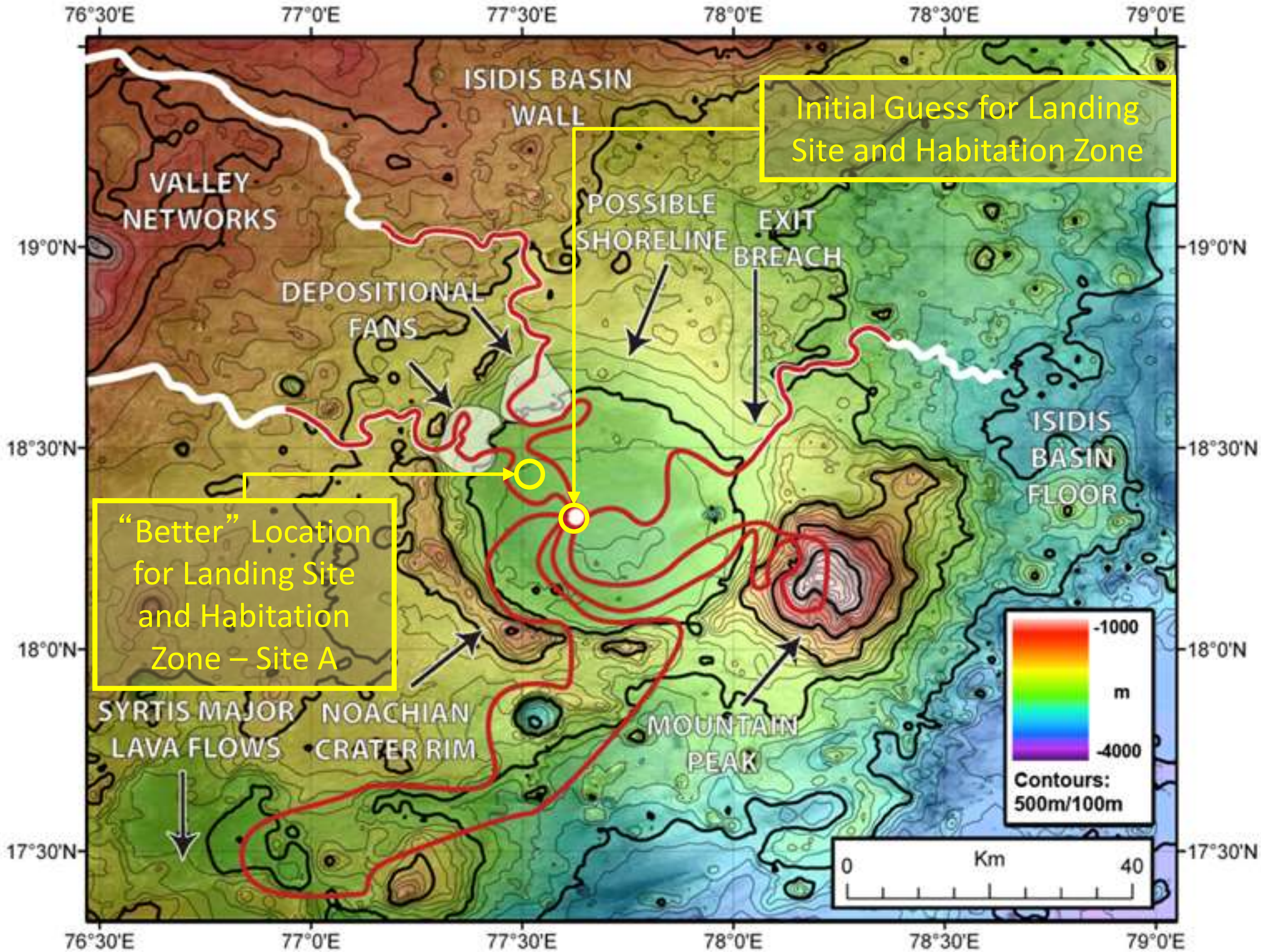
1000 meter diameter circle outside of which an element of surface infrastructure should be safe from terminal descent thruster debris



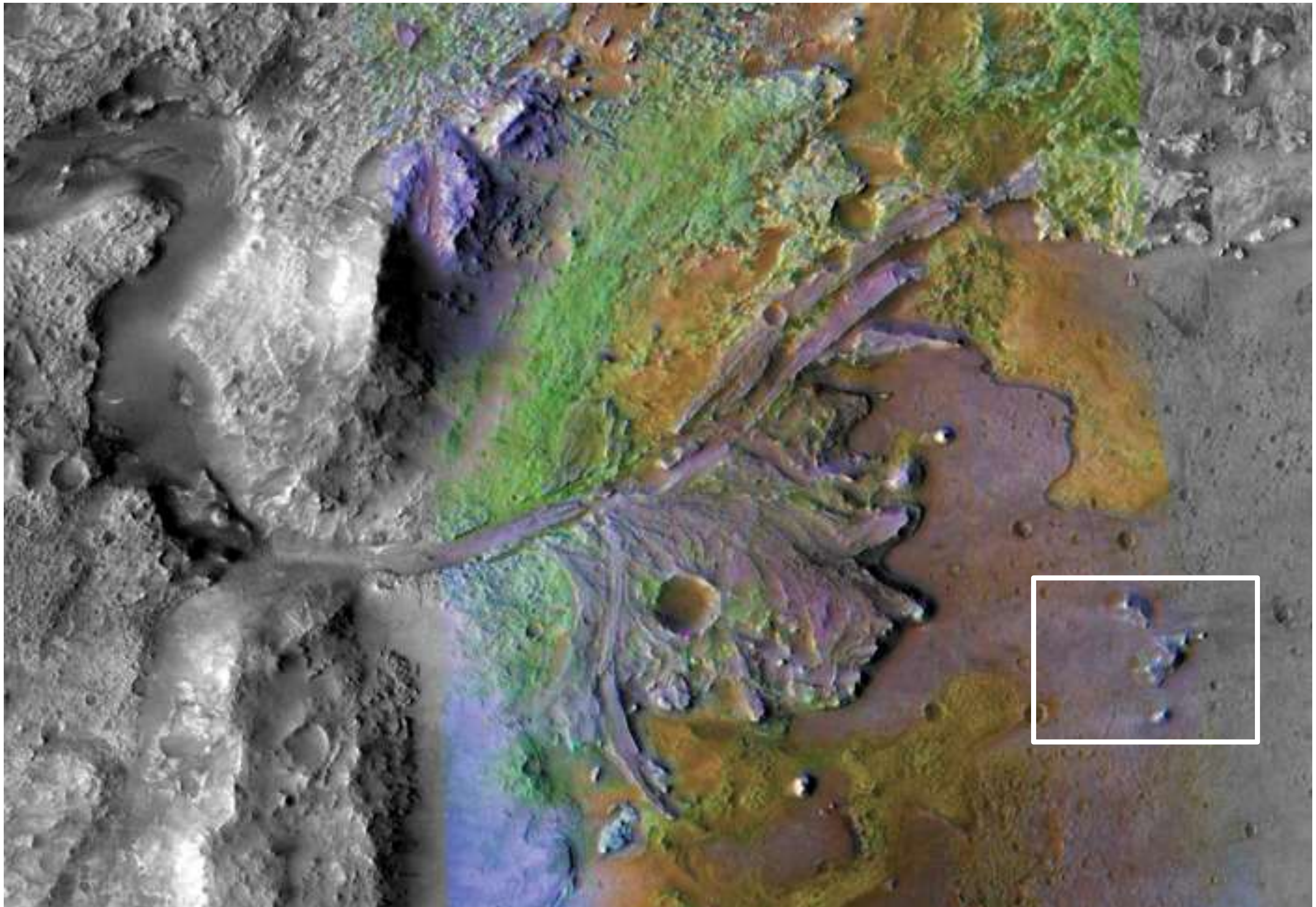
Common Lander with representative payload


NASA image

HEM-SAG Exploration Map for Jezero Crater



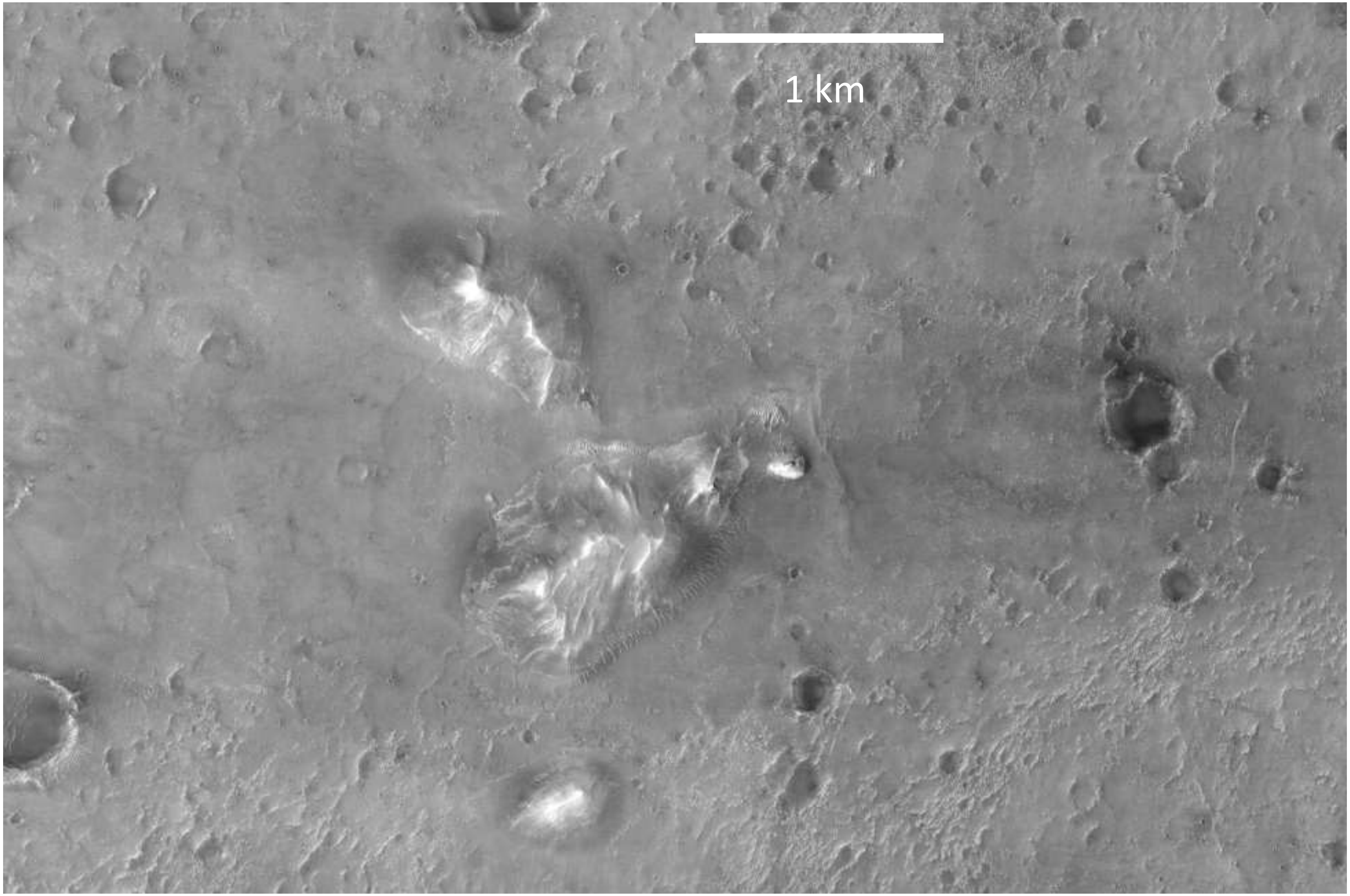
Landing Site 'A' Within Jezero Crater



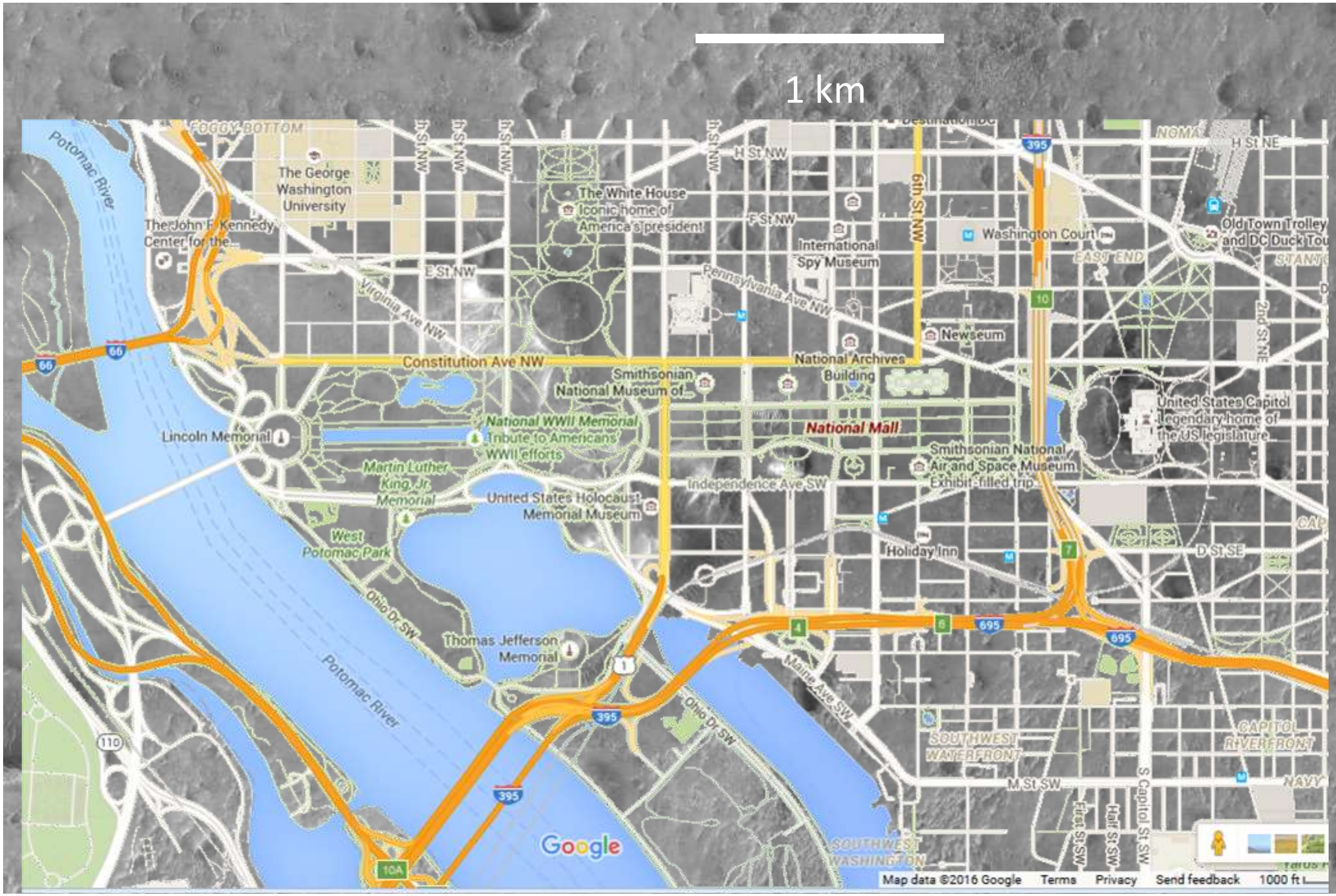
Jezero contains Fe-Mg smectite clay indicative of multiple episodes of fluvial/aqueous activity on ancient Mars, elevating the potential for preservation of organic material.
(Green = phyllosilicates, orange = olivine, purple = neutral/weak bands.)

Image credit: NASA/JPL/JHUAPL/MSSS/Brown University (Ehlmann et al. 2008)

Site A



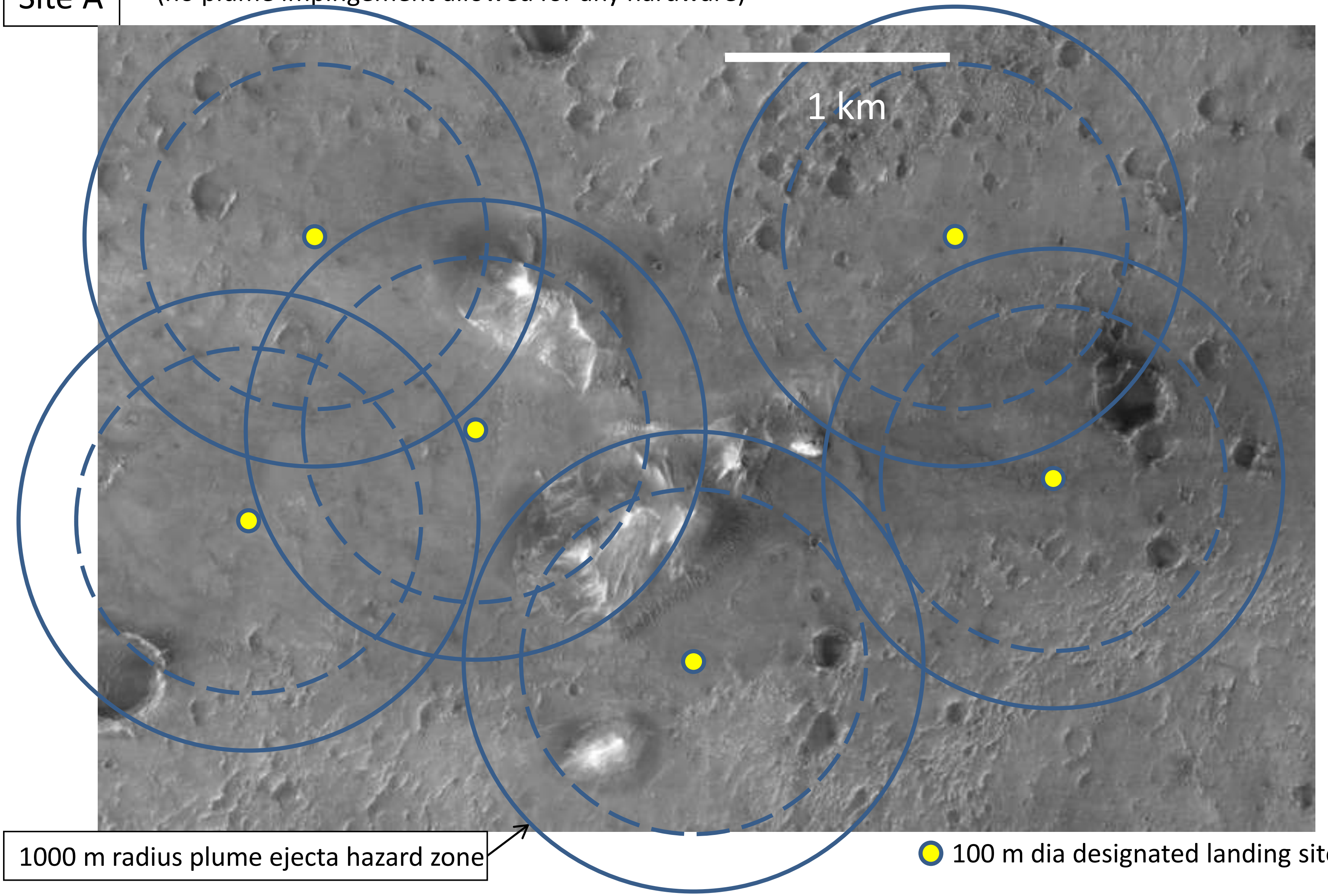
Site A


1 km
Potomac River
The George Washington University
The John F. Kennedy Center for the...
The White House
Iconic home of America's president
International Spy Museum
Washington Court
Old Town Trolley and DC Duck Tou
Constitution Ave NW
National Archives Building
Smithsonian National Museum of...
Lincoln Memorial
National WWII Memorial
Tribute to Americans WWII efforts
National Mall
United States Capitol
Legendary home of the US legislature
Smithsonian National Air and Space Museum
Exhibit-filled trip...
Martin Luther King, Jr. Memorial
United States Holocaust Memorial Museum
West Potomac Park
Holiday Inn
Thomas Jefferson Memorial
SOUTHWEST WATERFRONT
Google
Map data ©2016 Google
1000 ft

Non-Interfering Landing Zones at Site A

Site A

(no plume impingement allowed for any hardware)

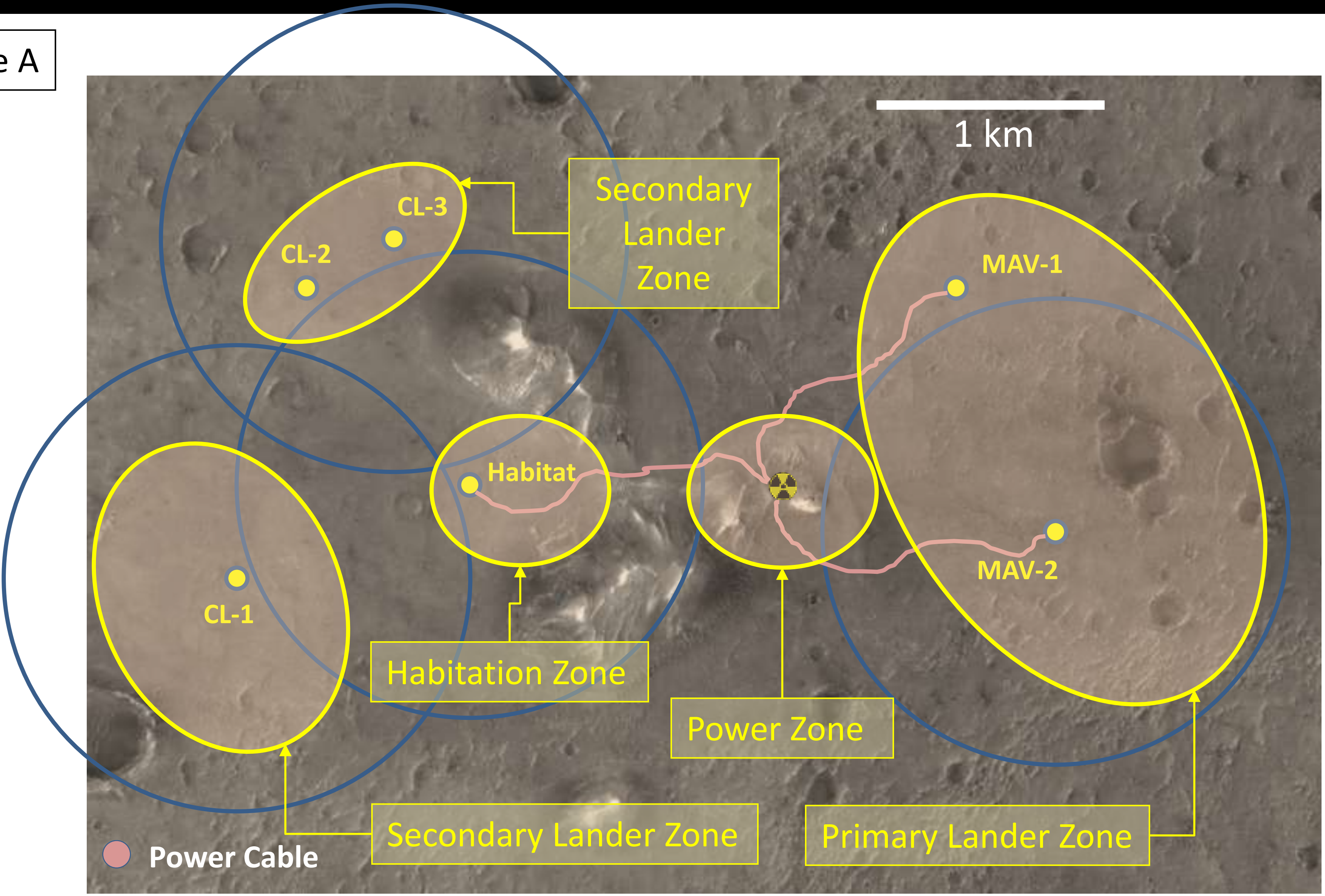


1000 m radius plume ejecta hazard zone

100 m dia designated landing site

Example of Field Station Layout with Specific Utilization Zones Identified

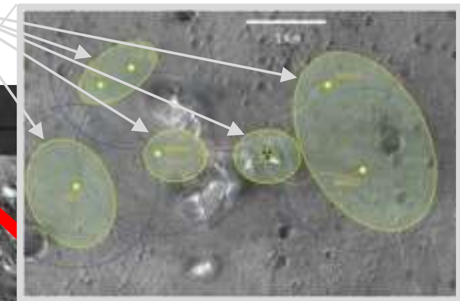
Site A

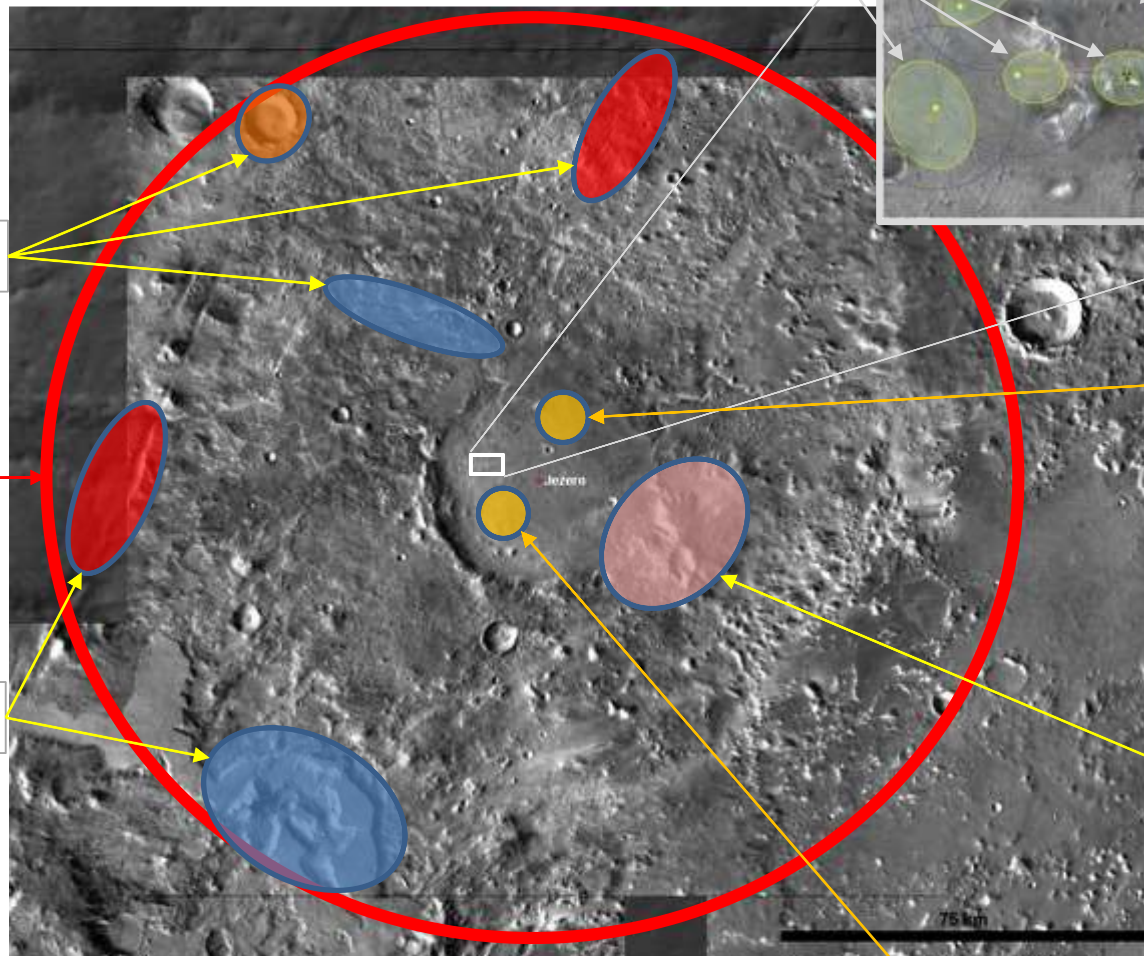


(plume impingement *allowed* for any "dead" hardware)

Example Mars Surface Field Station and Surrounding Regions of Interest (ROI's)

Engineering Considerations
Site Buildup Considerations and Constraints





Science ROI's

Exploration Zone

Science ROI's

ISRU ROI's

Science ROI's

ISRU ROI's

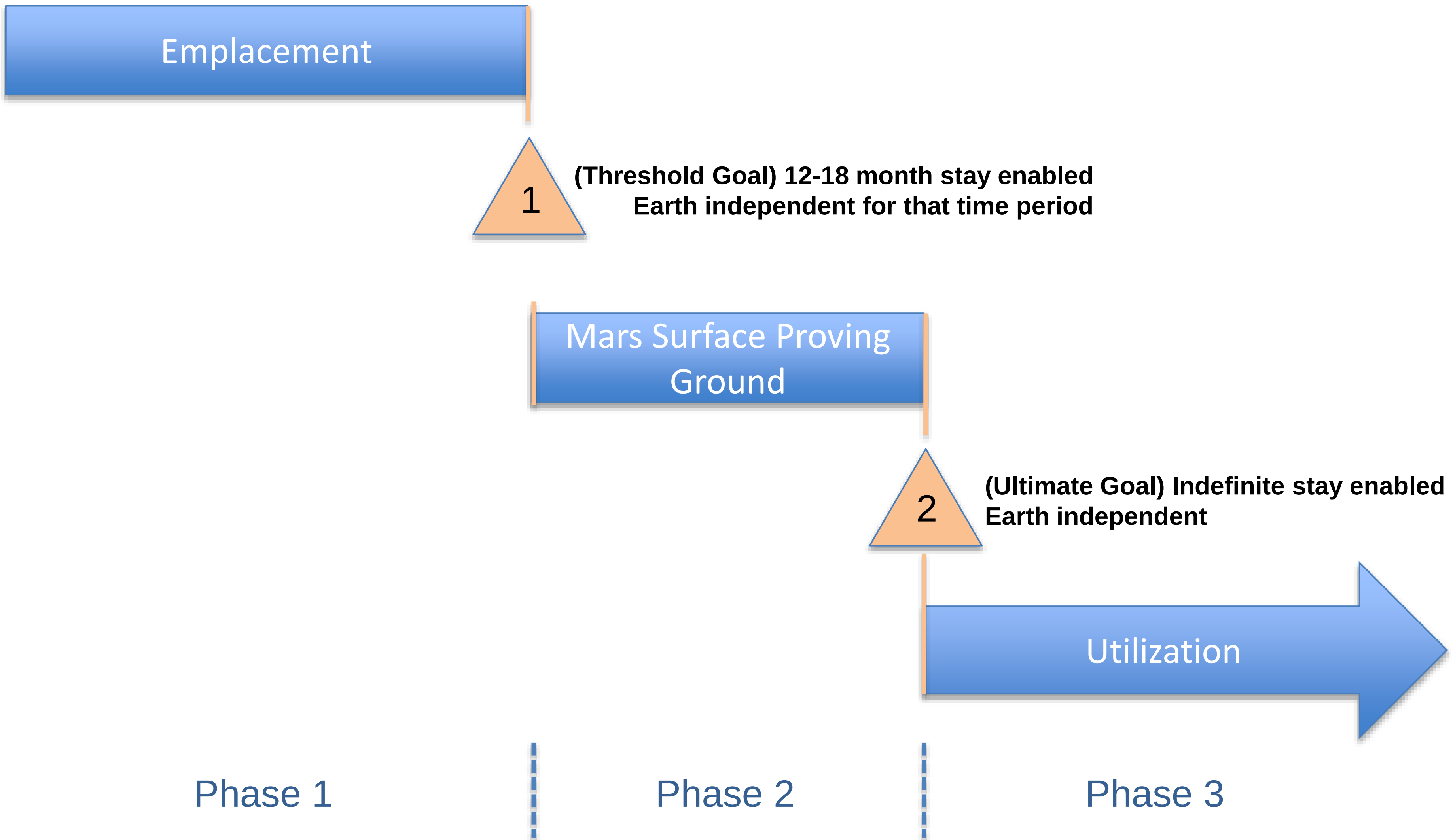
Mars Surface Field Station Capabilities "Scorecard"

- **EMC Assumptions**
  - Operational in the 2030s and beyond
  - Crew of four
  - Multiple visits to the same site
- **Research Support**
  - Physical sciences
  - Biological sciences
  - Atmospheric sciences
  - Human physiology
  - ISRU and civil engineering applied technology
- **Exploration Zone**
  - 100 km radius activity zone
  - +/- 50 deg. latitude
  - Less than 2 km elevation
- **Mars Environment**
  - Seasonal changes
  - Periodic dust storms
- **Mars Environment (cont.)**
  - Daylight (at 50 deg lat):
    - ~15 hrs (summer solstice)
    - ~9 hrs (winter solstice)
  - Temperature range (extremes):
    - Highs > ~20 deg C
    - Lows < ~ -110 deg C
  - Winds: typically < 20 m/s with low dynamic pressure
- **Crew/Mission Planning**
  - Occupied up to ~500 days followed by TBD days of dormancy
  - Approximately 25 sq km area for Field Station infrastructure

Evolvable Mars Campaign Development

THE EVOLVABLE MARS CAMPAIGN

Mars Surface Field Station Evolutionary Phases



Capabilities Needed to Achieve Primary Objectives and Defining Characteristics

- **Utilization**
  - Indefinite stay time on the surface will be enabled by:
    - Reliable source of power
    - Reliable source of breathable air and potable water
    - Ability to produce food, consistent with a basic but balanced diet and sufficient to support a crew of four (TBR)
    - Protection from / mitigation of (harmful) environmental effects
    - Ability to maintain and repair emplaced infrastructure using local resources and supplies (i.e., existing infrastructure can be maintained but not necessarily expanded)
- **Emplacement**
  - Interplanetary transportation system for crew and cargo
  - EDL at a scale sufficient to support human mission payload needs and landing accuracy
  - Basic habitation
  - Support infrastructure (i.e., power, communications, etc.)
- **Mars Surface Proving Ground**
  - Capabilities and knowledge / experience sufficient to ***bridge the gap*** between Emplacement and Utilization
    - This includes addressing the known unknowns and any unknown unknowns revealed to be an impediment to achieving Utilization objectives

Field Station Analog – McMurdo Station Antarctica

Emplacement

British National Antarctic Expedition 1902
R.F. Scott's "winter quarters hut." Used for both local scientific research and as a logistical base for traverses inland.

Photo by Tas50 - Own work, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=5736171

Permanent occupation - 1955
Naval Air Facility McMurdo part of "Operation Deep Freeze" to support the International Geophysical Year. A collection of semi-permanent structures (e.g., tents, Jamesway huts)

Mars Surface Proving Ground

Photo courtesy of USAP

McMurdo Station Today
Antarctica's largest community and a functional, modern-day science station, including a harbour, three airfields (two seasonal), a heliport, and more than 100 permanent buildings

Utilization

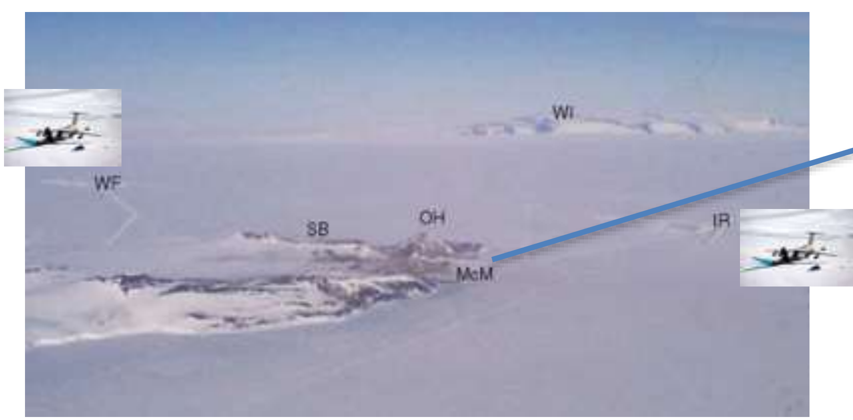
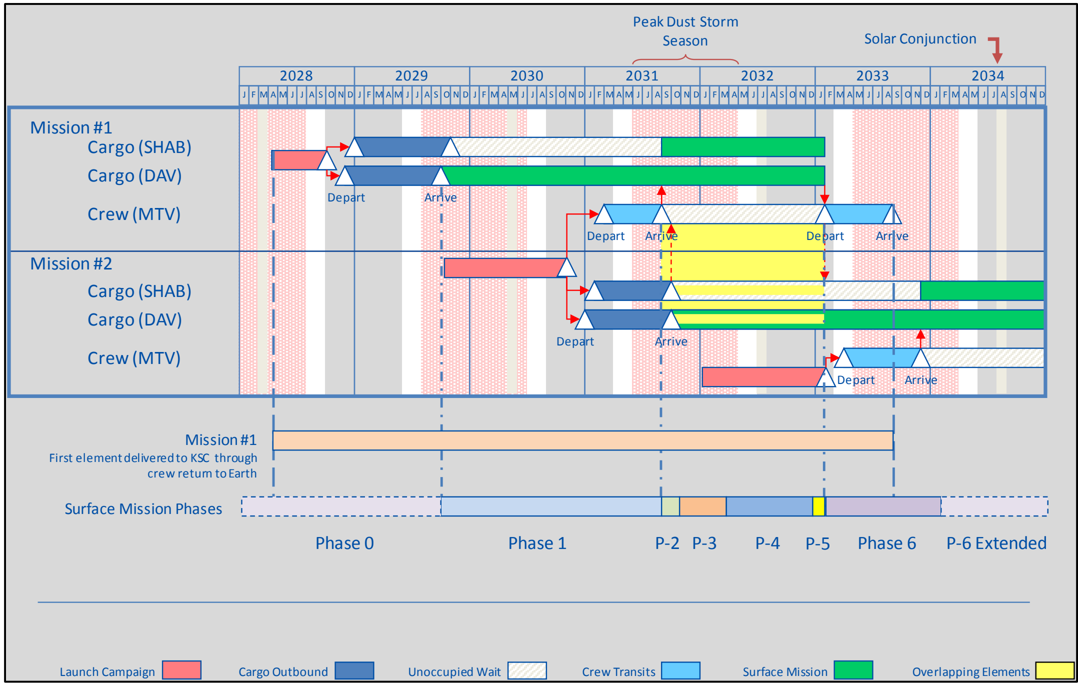


Photo by USAP/Andrew Klein

Representative Mission Phases

- **Phase 0 – Prior to Cargo Landing**
  - Observations and investigations of the landing site by previously deployed orbital and surface assets
  - Characterize habitability, including potential special regions
- **Phase 1 – Post Cargo Landing (~2.25 Years)**
  - Cargo Landing
  - FSPS and ISRU deployment
  - Exploration by robotic assets, micro-climate monitoring
  - Final crewed landing site selection
- **Phase 2 – Crew Landing & Acclimation (~30 Sols)**
  - Crew Landing and acclimation to Mars gravity environment
  - Additional deployment of assets and local science investigations as time and capabilities permit
- **Phase 3 – Local Exploration (~30 Sols)**
  - EVAs within local area (~10 km) to set up central stations and complete initial science objectives
  - Deployment of Deep drill system
- **Phase 4 – Regional Exploration (~410 Sols)**
  - Up to 19 separate 15-sol traverses with 2 SPRs
  - Mobility extends up to ~200 km from landing site
  - Sample analysis and follow-on local investigations continue
- **Phase 5 – Preparation for Ascent (~30 Sols)**
  - Final curation of samples and preparation of MAV
  - Crewed Launch with contingency window
- **Phase 6 – Post Crew Departure**
  - Robotic assets continue exploration



The figure above illustrates the relative sequence of each phase with trajectory data for a Mars surface mission set to occur in the early 2030 time frame.

Each mission will:

- Prepare a surface mission plan based on the objectives set for the EZ
- Customize the mission plan based on discoveries made and lessons learned by previous crews
- Develop a science payload (1000 kg allocated) based on the customized mission plan

Surface System Elements Needed for the Emplacement Phase

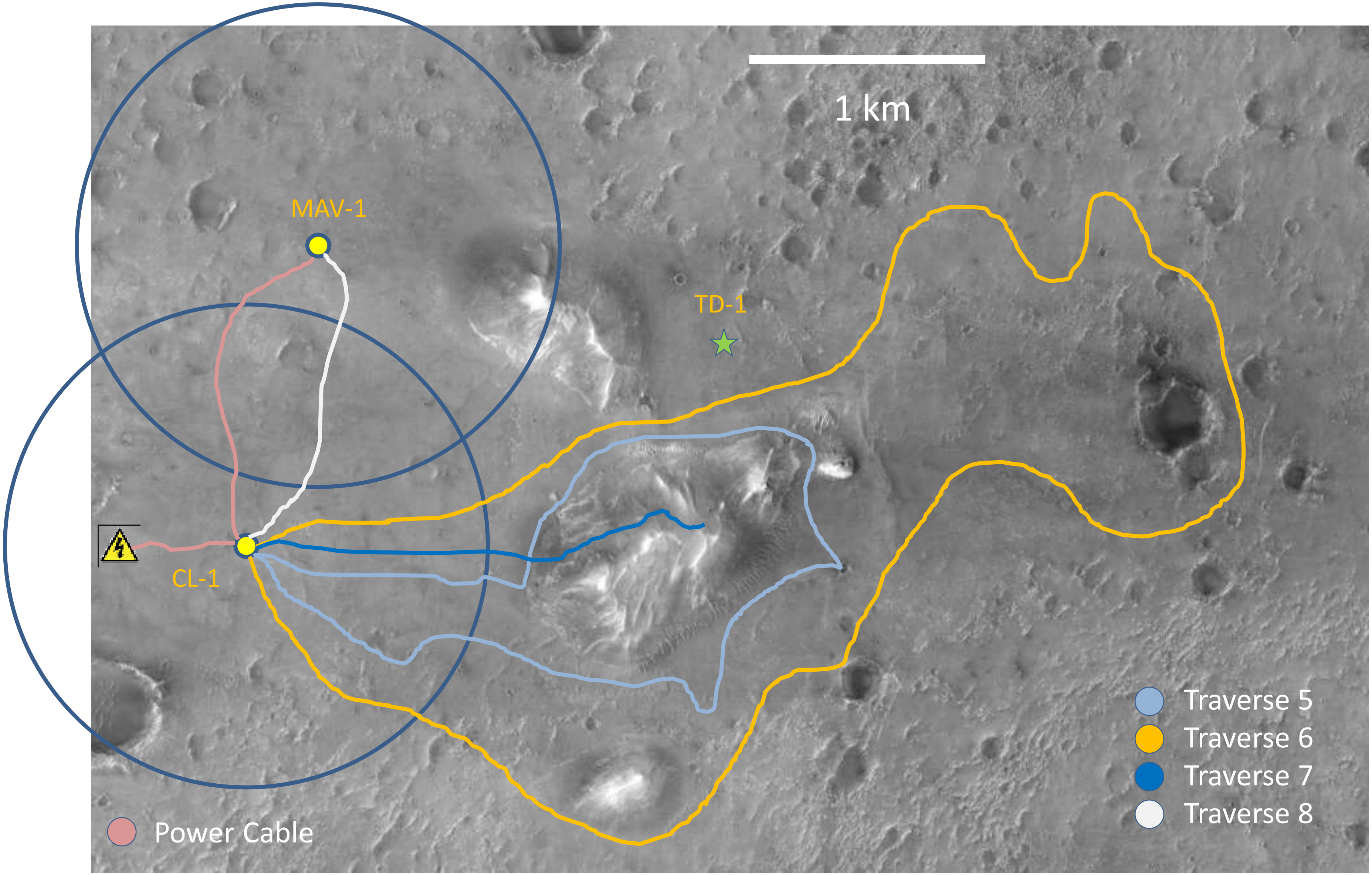
- **Mars Ascent Vehicle (MAV)**
- **Crew Descent Module**
- **Atmospheric ISRU**
- **Power (4 x 10 kW units)**
- **Robotic Rovers**
  - Special regions
  - Crew support
- **Cargo Off-loading**
- **Habitation**
- **Tunnel**
- **Science payloads**
- **Logistics modules**
- **Logistics**
  - Crew consumables
  - Fixed system spares
  - Mobile system spares
  - EVA spares
- **Mobility platform to reposition payloads**
- **Small unpressurized rover (crew)**
- **Small pressurized rover (crew)**

Surface Habitat Concept


NASA image

Site A

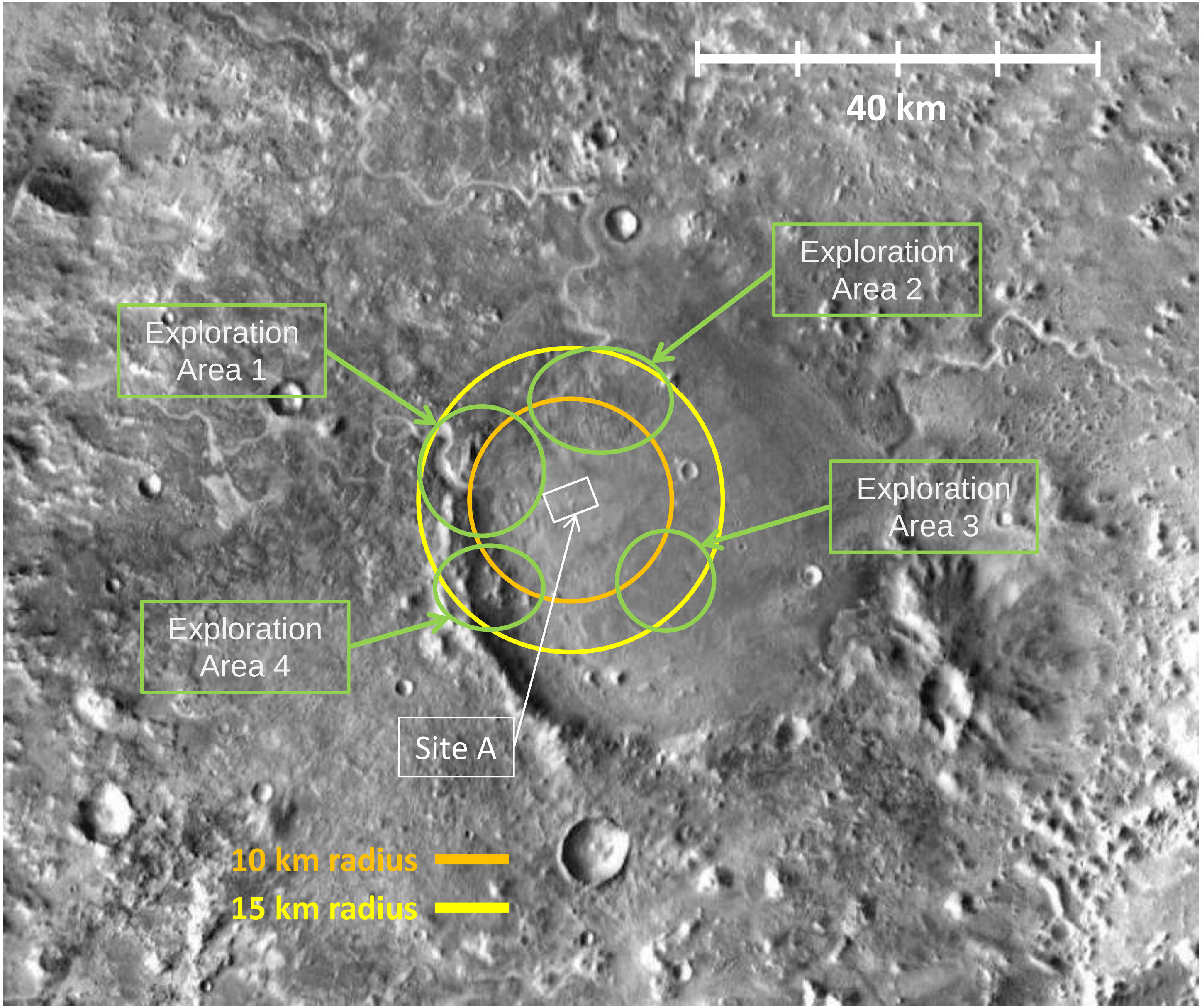
Mission 4: Short (Surface) Stay Mission (Part 2)

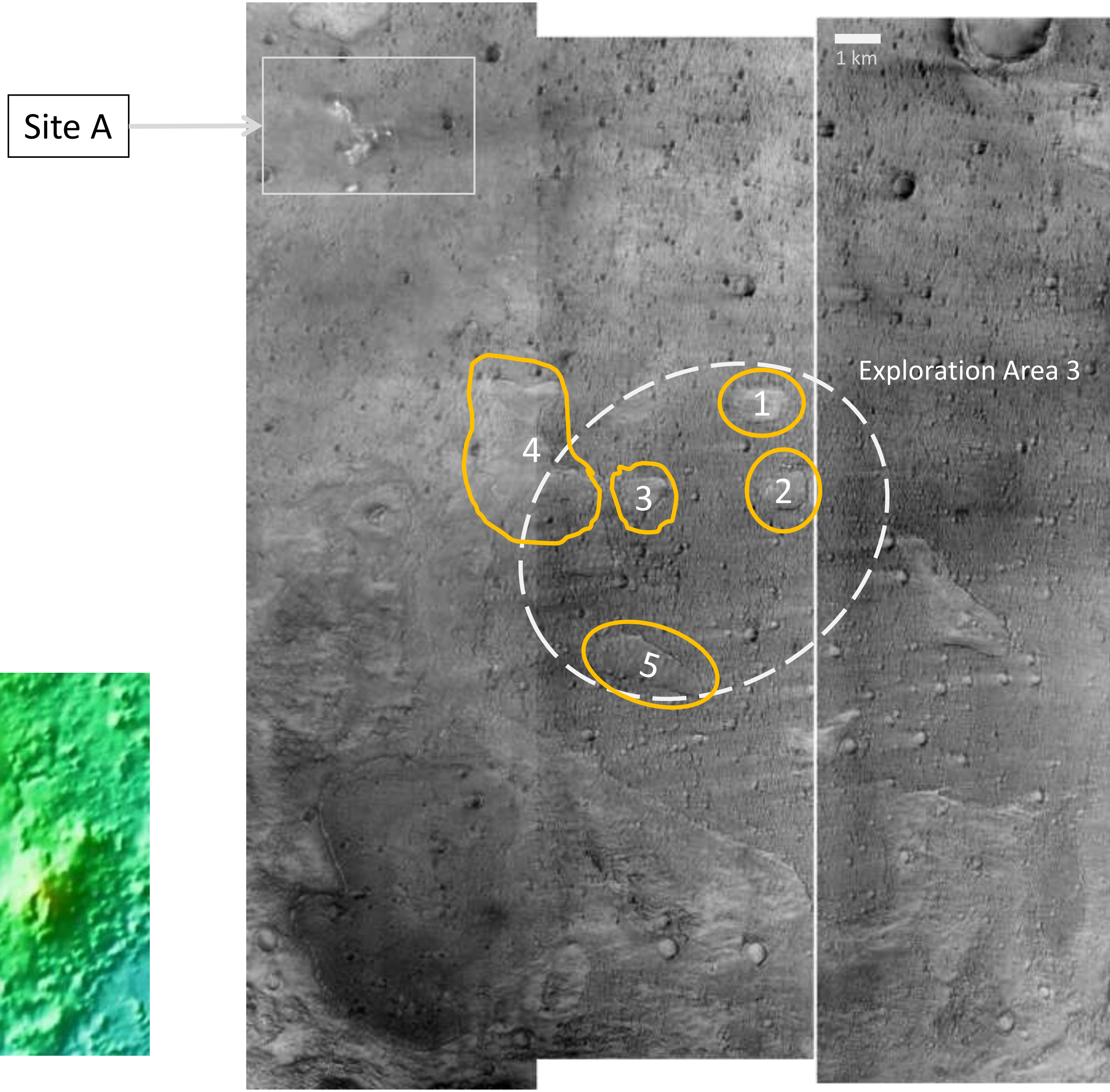


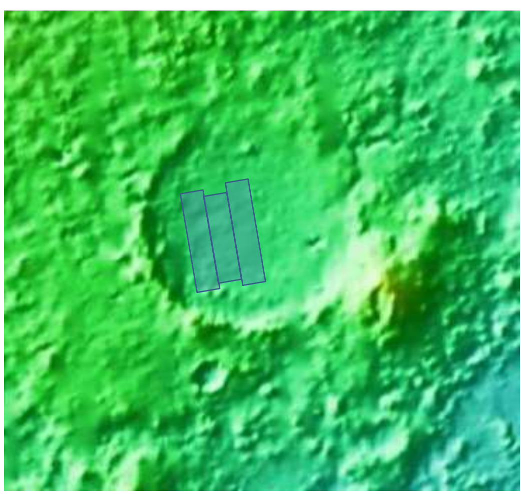
(plume impingement *allowed* for any “dead” hardware)

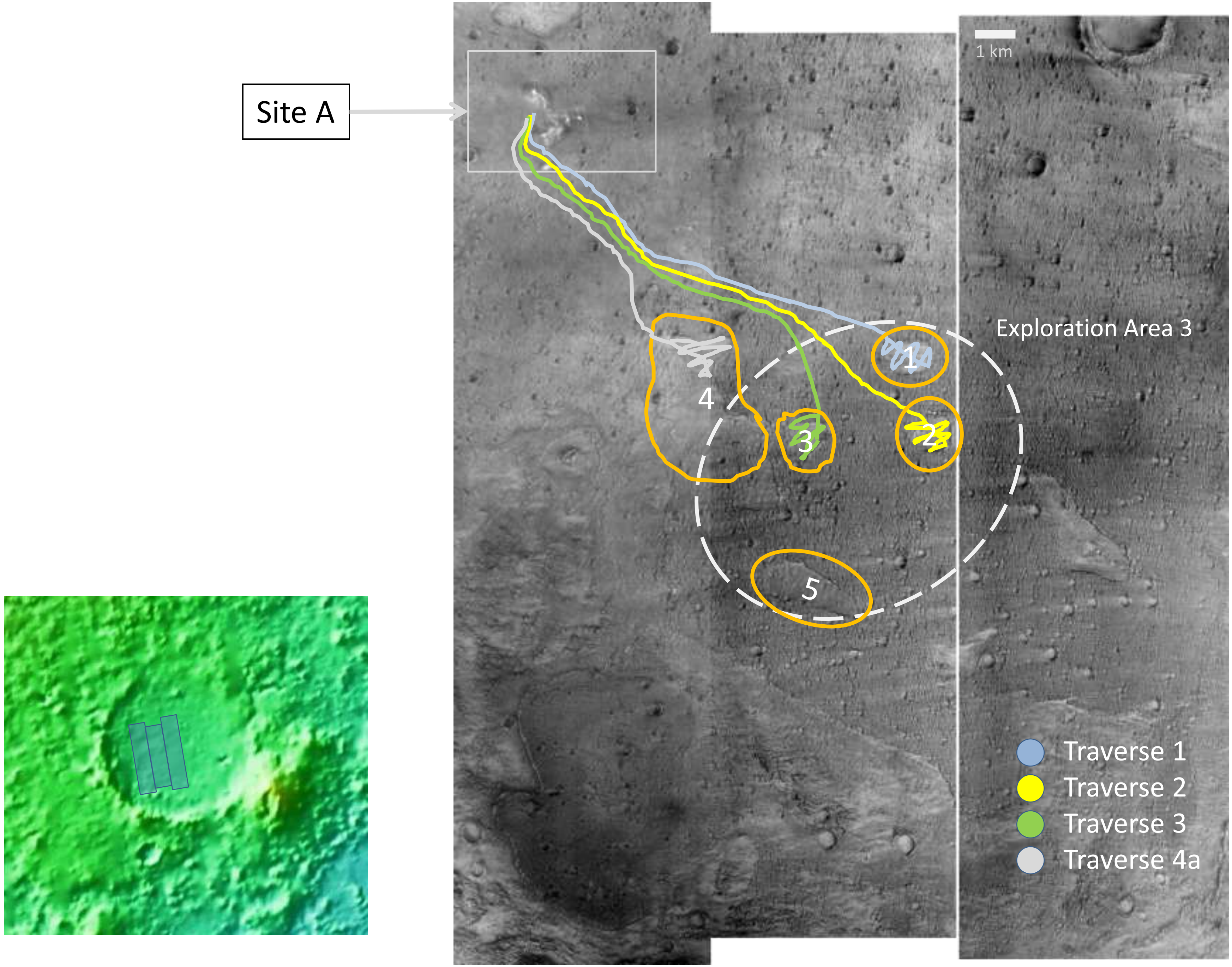
Site A

Mission 6: Full-scale Surface Habitat with Intermediate Stay Crew



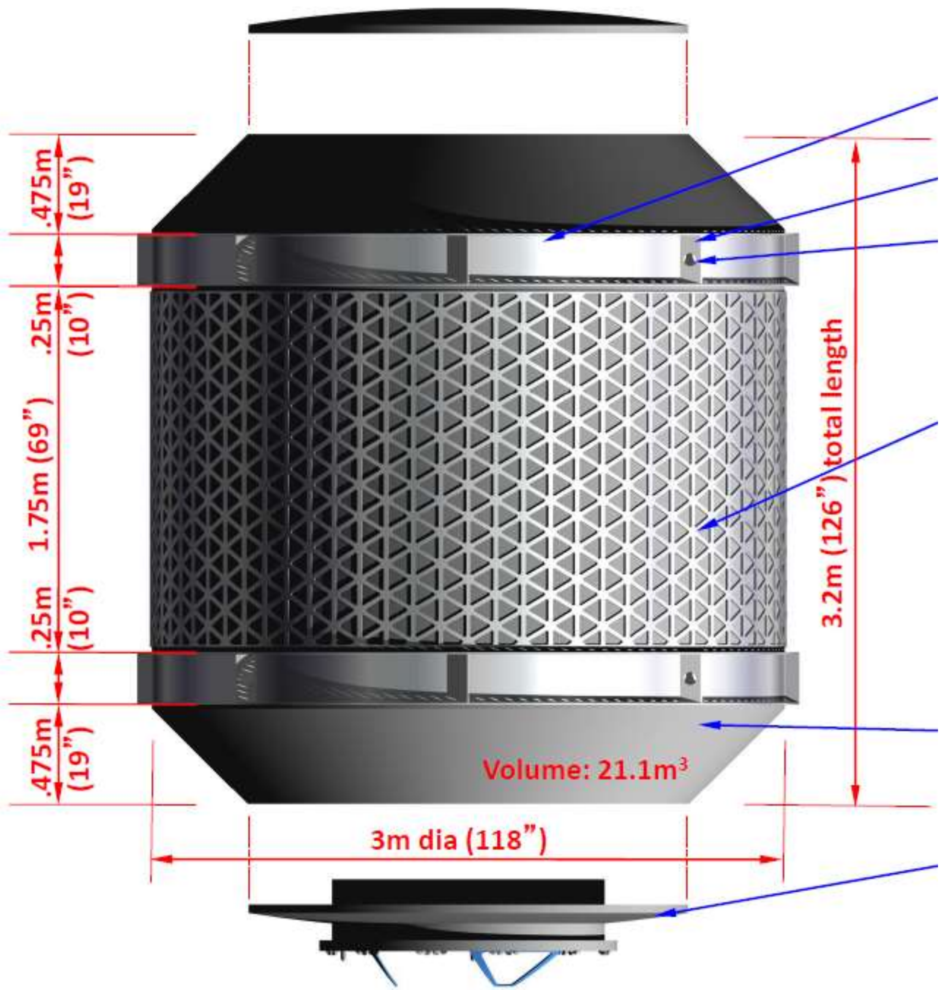

Site A
1 km
Exploration Area 3
1
2
3
4
5



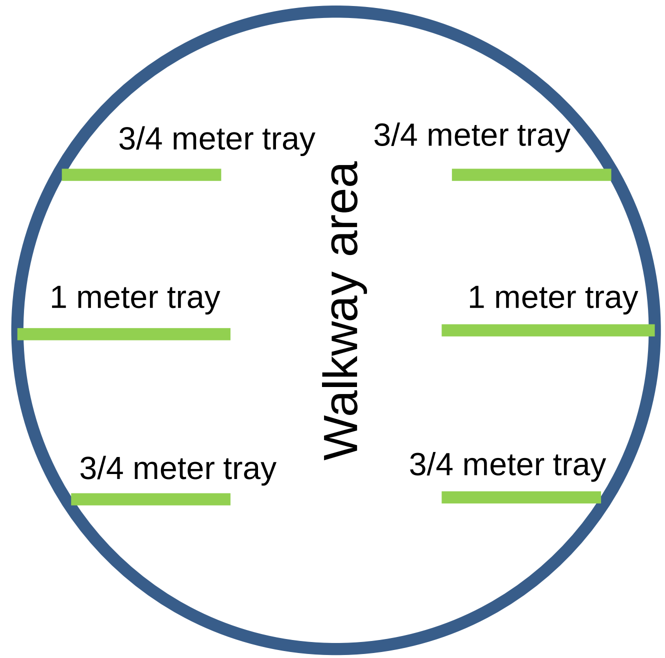


Site A
1 km
Exploration Area 3
1
2
3
4
5
Traverse 1
Traverse 2
Traverse 3
Traverse 4a

Converting Logistics Modules for Food Growth



Could we realistically squeeze any more tray area in a cylinder like this?



Total tray area = 1.75 x 2 x 2.5 = 8.75 m2 per module

For 320 m2 -> ~37 modules for 8 crew 80% food
For 160 m2 -> ~18 modules for 4 crew 80% food
For 100 m2 -> ~11 modules for 4 crew 50% food

Conceptual Plant Growth Chamber

Mars Surface Field Station Capabilities "Scorecard"

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  - Operational in the 2030s and beyond
  - Crew of four
  - Multiple visits to the same site
- **Research Support**
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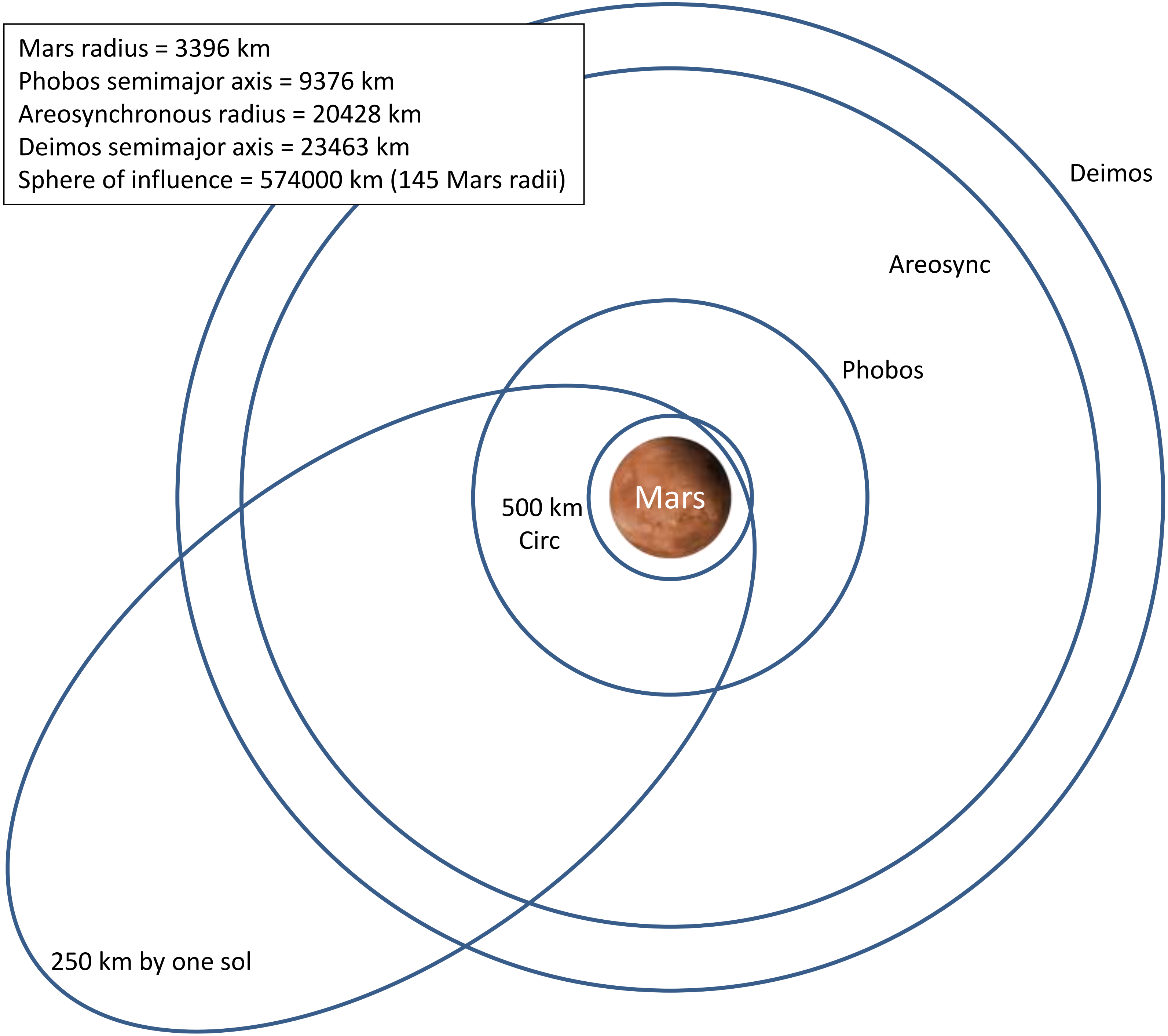
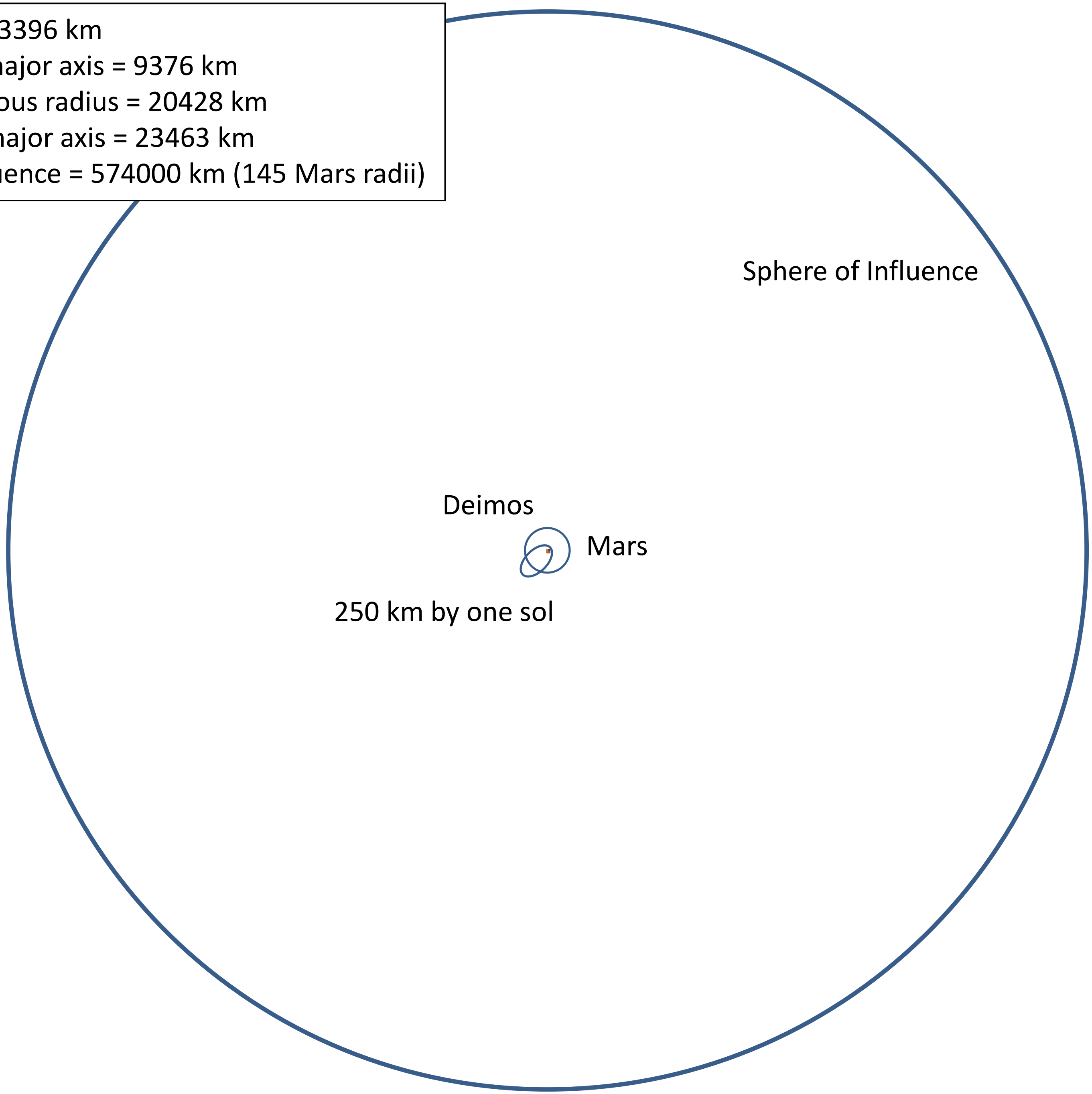
  - Temperature range (extremes):
    - Highs > ~20 deg C
    - Lows < ~ -110 deg C
  - Winds: typically < 20 m/s with low dynamic pressure
- **Crew/Mission Planning**
  - Occupied up to ~500 days followed by TBD days of dormancy
  - Approximately 25 sq km area for Field Station infrastructure
- **Field Station Capabilities**
  - Habitation (4 people x 500 days)
  - "Dedicated" research support volume
  - Communication (locally out to 100 km and high volume with Earth)
  - Power (current estimate 40 kW)
  - Surface transportation (EVA and SPR)
  - Maintenance/repair for all of the above

Evolvable Mars Campaign Development

BACKUP

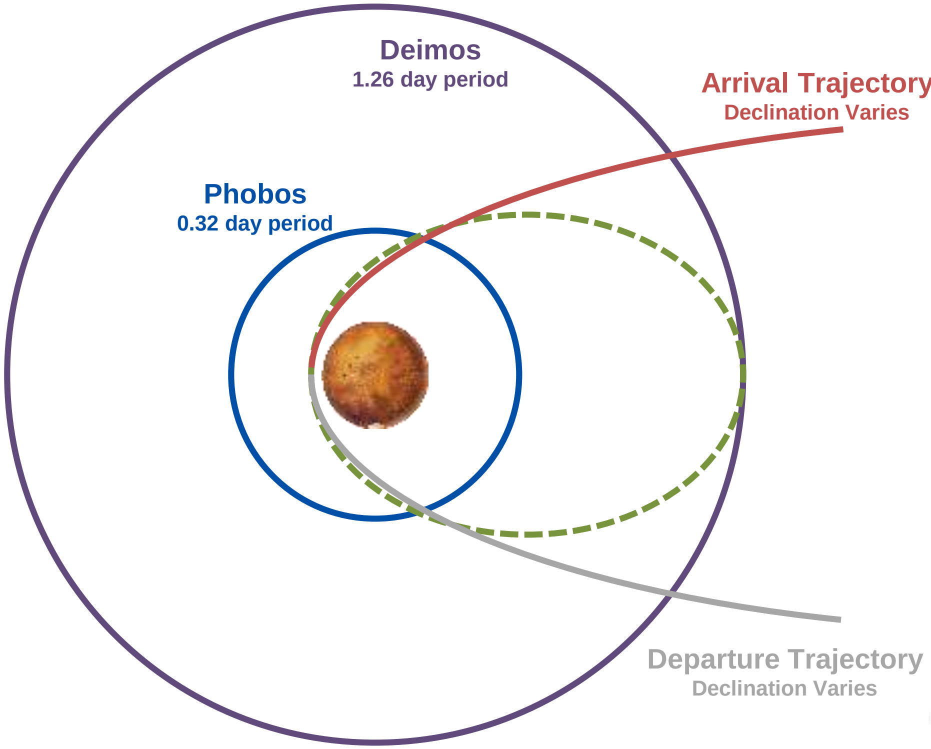

Mars radius = 3396 km
Phobos semimajor axis = 9376 km
Areosynchronous radius = 20428 km
Deimos semimajor axis = 23463 km
Sphere of influence = 574000 km (145 Mars radii)
Deimos
Areosync
Phobos
Mars
500 km
Circ
250 km by one sol

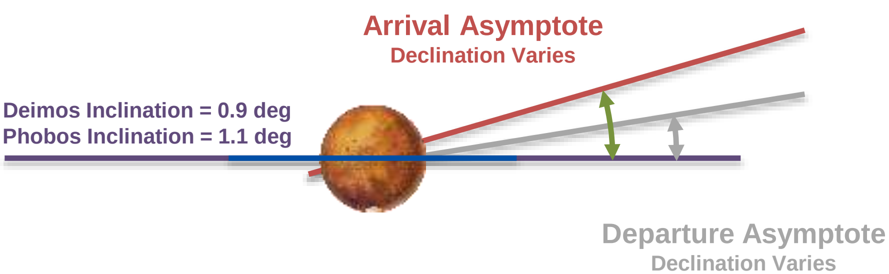
Mars radius = 3396 km
Phobos semimajor axis = 9376 km
Areosynchronous radius = 20428 km
Deimos semimajor axis = 23463 km
Sphere of influence = 574000 km (145 Mars radii)

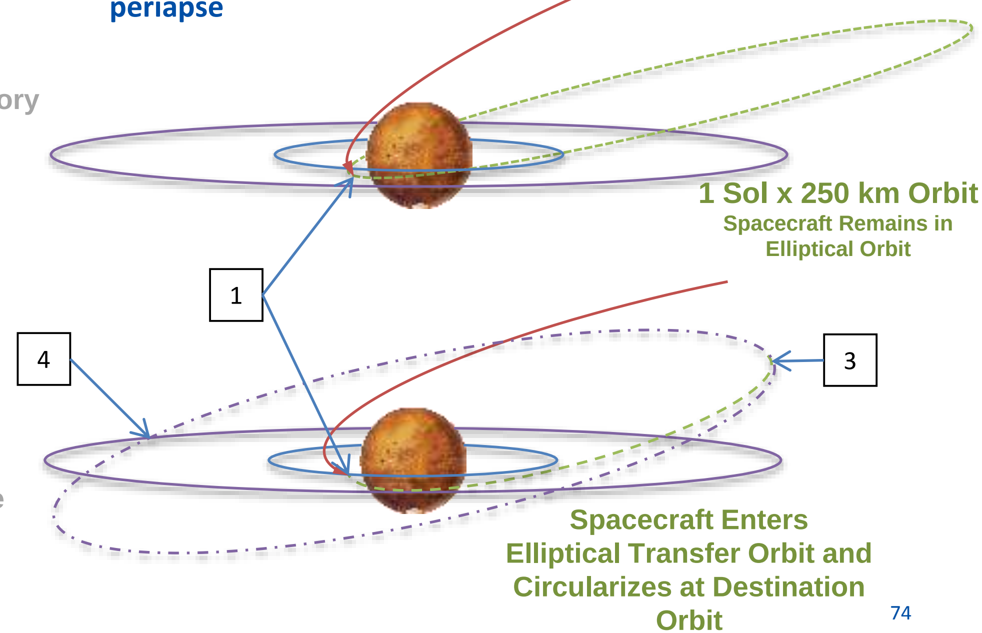


Assumed Mars In-Space Orbit Strategy (for this example)

1. Capture into an elliptical orbit at Mars with a periapse at 250 km altitude
2. If the 250 km by one sol destination orbit is used, then no further maneuvers until time for departure (step 7 below)
3. If a circular destination orbit is used, then perform a circularization maneuver making the transfer orbit the same size as the destination orbit
4. Perform a plane change maneuver (to enter Mars' equatorial plane) at the first equator crossing
5. For departure (and return to Earth) reverse the sequence of propulsive maneuvers. First perform a plane change maneuver to place the transfer orbit in the same plane as dictated by the departure trajectory
6. Perform a maneuver to enter an elliptical transfer orbit with a periapse of 250 km altitude
7. Perform a final escape maneuver at the 250 km altitude periapse

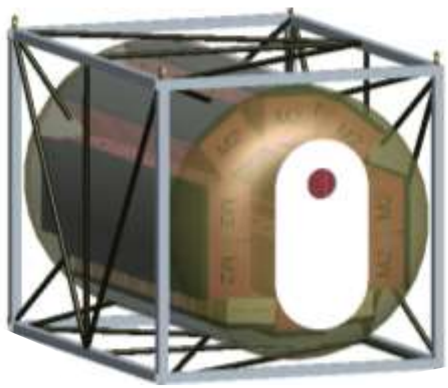






10t Mars Surface Logistics Module

06-30-2015



Design Constraints/Parameters

- Destination Mars Surface
- Module Length 5.5 m
- Module Diameter 4.5 m
- Pressurized Vol. 69 m3
- Maximum Number of CTBEs 472
- Maximum Loaded Mass 5,770 kg

Category	Mass (kg)
Structure	1,725
Protection	0
Propulsion	0
Power	220
Control	0
Avionics	55
Thermal	170
ECLSS	260
Crew Systems	15
Growth	290
Dry Mass Total	**2,735**
External Frame	110
Project Manager's Reserve	285
TOTAL	**3,130**

Description: The 10t Mars Surface Logistics Module provides pressurized delivery of logistics payloads to Mars surface. The logistics module is packaged within the lander shroud during transit to Mars. There is no specific allocation for MMOD protection. The module supports and secures pressurized cargo throughout all launch, transit, and Mars descent loads. The internal structure includes frames to secure multi-row packing of CTBEs. The module will maintain conditioning of payload for extended durations on lander (~3-4 years) prior to crew arrival on surface and transfer to habitat. The ECLSS contains atmospheric monitoring, air recharge, and passive and active thermal control systems. The module provides structural capabilities (external frame) to enable securing of log module to lander and transfer of carrier off of raised (>3m) lander deck to habitat. The module can survive transfer window from lander to habitat without external power source. The module may remain mated to habitat for extended duration without posing safety hazard to crew.

Mars Surface Exploration Vehicle

April 2014

Design Constraints/Parameters

Pressurized Vol.	12.0 m^3
Habitable Vol.	10.8 m3
Max Crew Capacity	4
Max Crew-Day Capacity*	14 crew-days
*Core vehicle capacity	
Est. power, uncrewed	1.5 kW
Est. power, crewed	2 kW
Solar power generation	3 kW
Total Batter Energy Storage	100 kW-h
Depth of Discharge	80%
ECLSS System	Open-loop
Max Speed	20 km/hr
Range	100s of km
Max. Length	6 m
Max. Width	4.1 m
Max Height	3.7 m

	Mass (kg)	
Category	**Cabin**	**Chassis**
Structure	1456	334
Protection	40	0
Propulsion (Wheeled)	0	237
Power	535	104
Control	30	39
Avionics	145	14
Environ./Active Therm	415	17
Other	120	0
Growth	823	224
DRY MASS SUBTOTAL	3564	969
Non-cargo	10	0
Cargo	579	0
INERT MASS SUBTOTAL	4153	969
Non-propellant	440	0
Propellant	0	0
TOTAL WET MASS	4593	969

The MSEV is configured as a destination servicing/exploration system for short term mission durations with the capability to support EVAs from the two suitports. The system consists of a core cabin and a destination-appropriate mobility chassis, plus a grappling/docking system. Augmentation modules e.g. a Portable Utility Pallet (PUP) can extend operational durations and ranges.

Example: Mission Manifests

Long Emplacement - Full Infrastructure Not in Place Until 2nd Crew

Lander: *18-ton* *Habitat:* *Monolithic* *Stay Time:* *500 sols* *Cargo:* *10-ton Logistics Carriers*