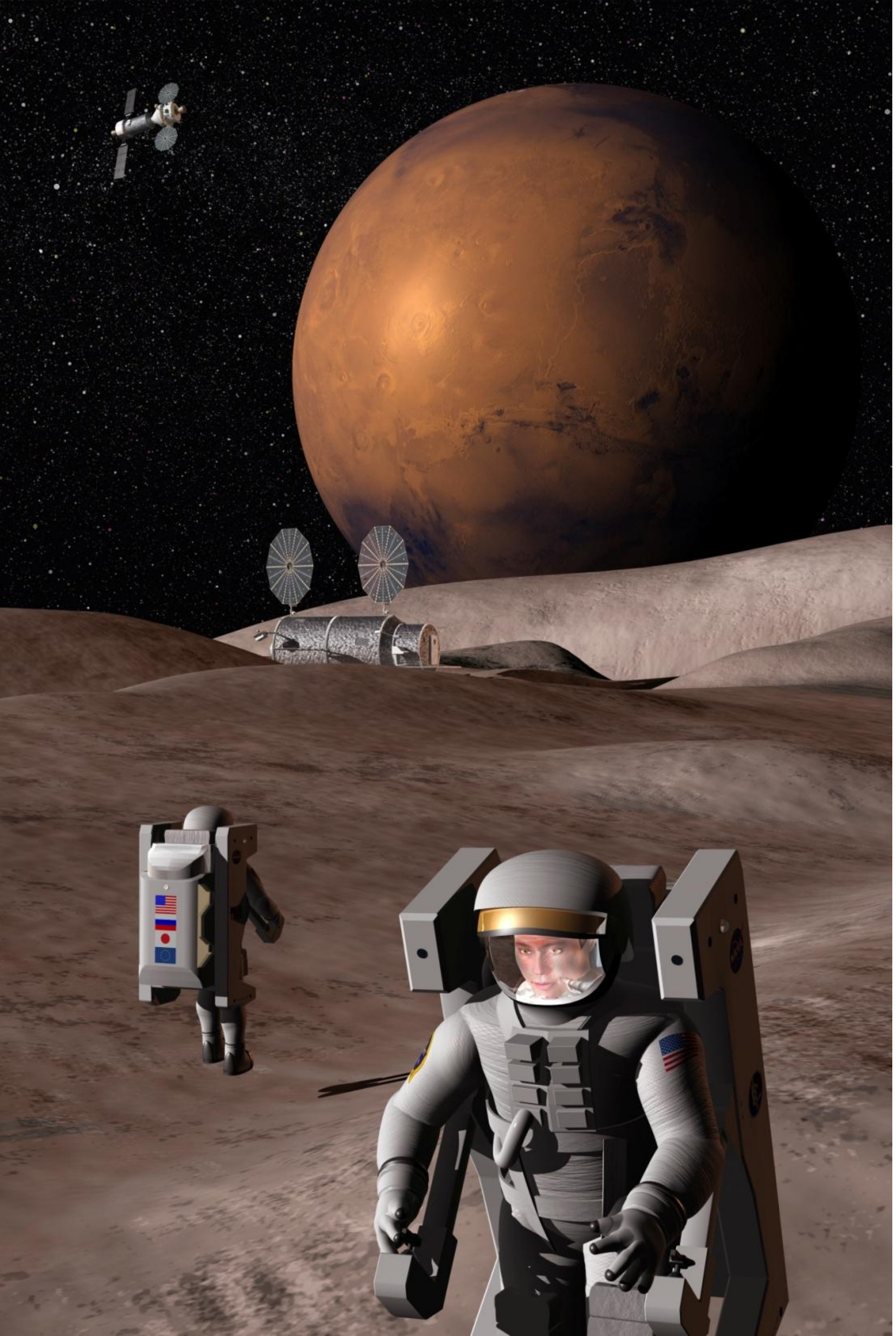


Deimos and Phobos as Destinations for Human Exploration

Josh Hopkins

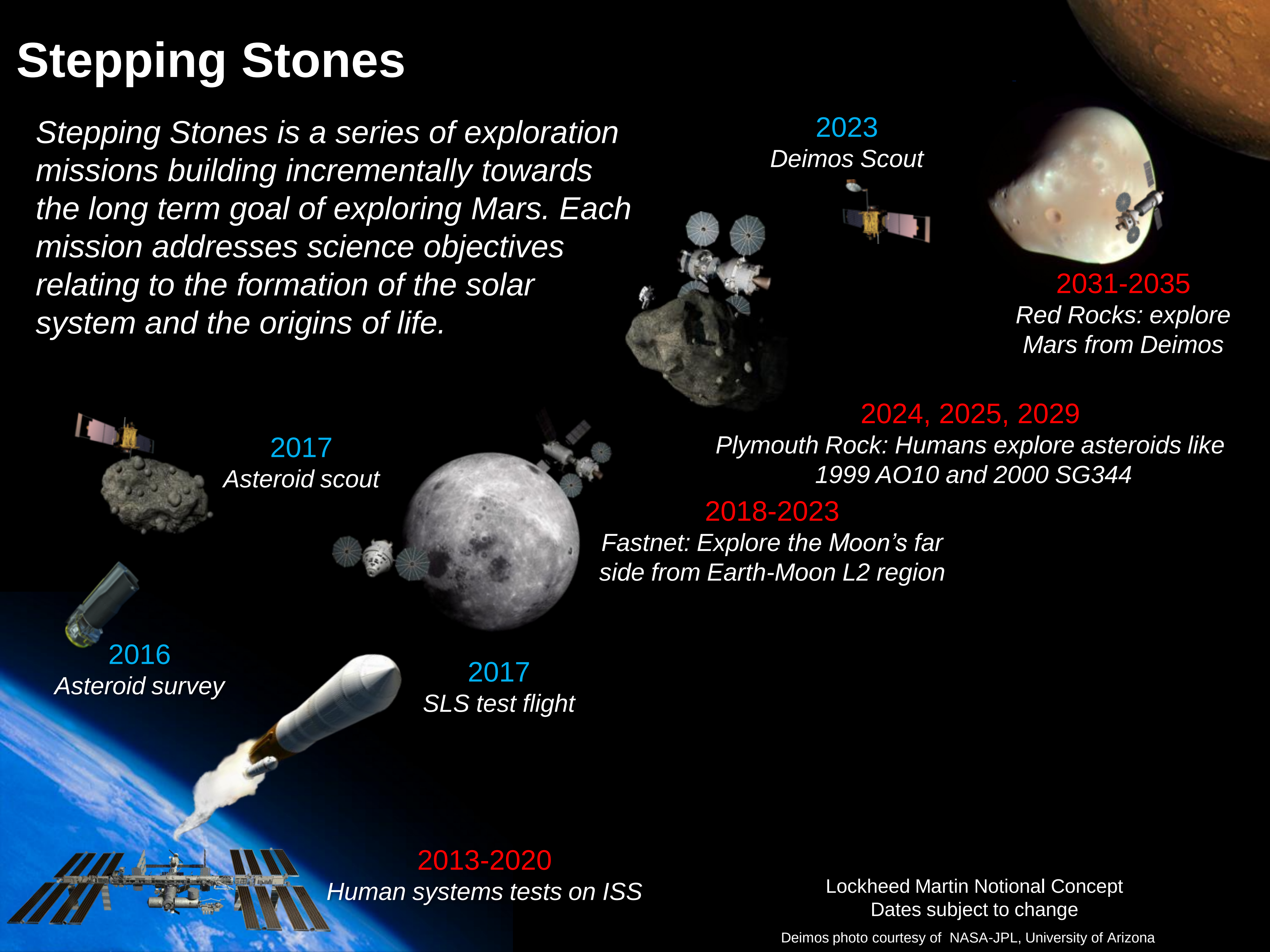
Space Exploration Architect

Lockheed Martin

Caltech Space Challenge
March 2013

Topics

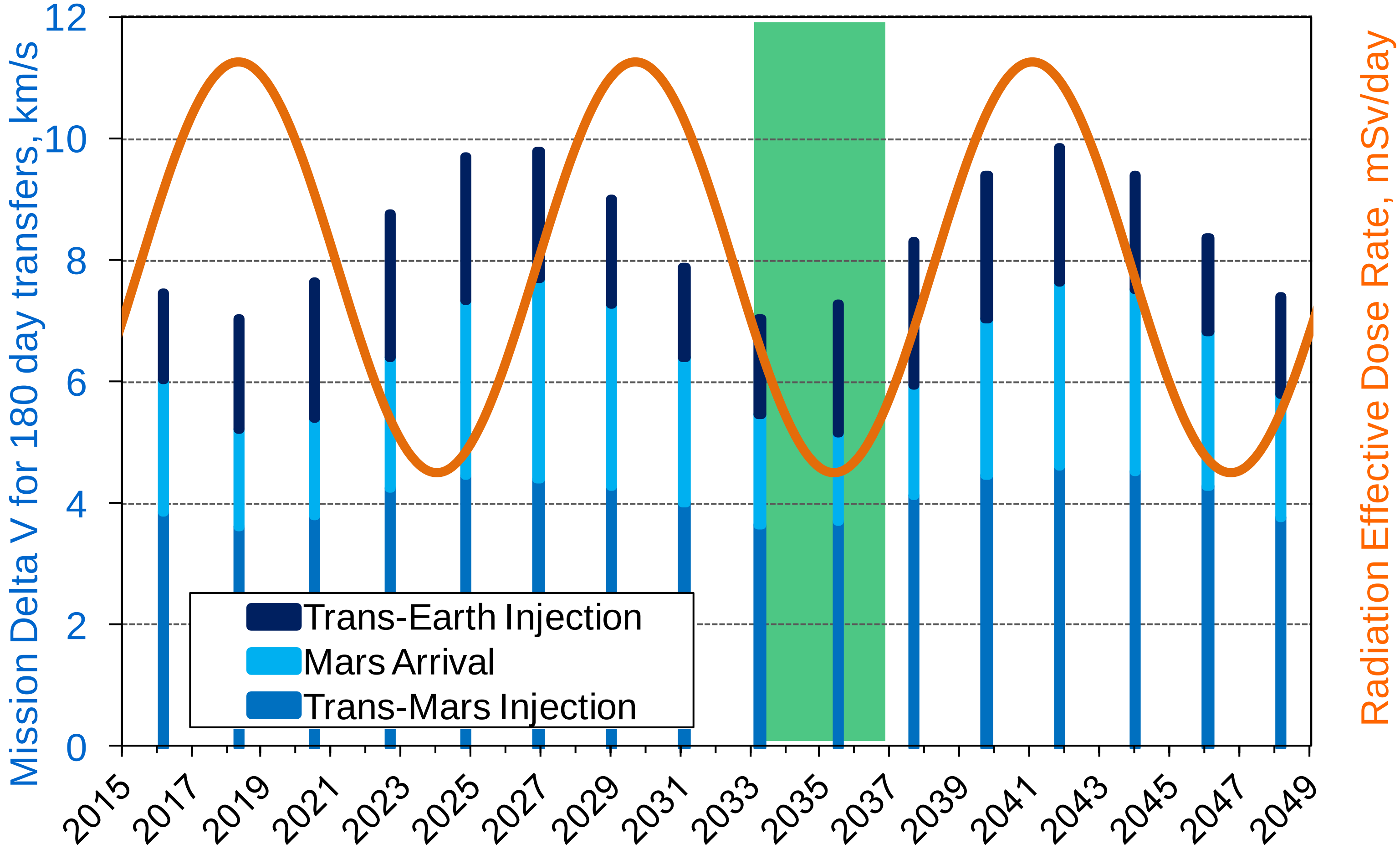
- Related Lockheed Martin mission studies
- Orbital mechanics vs solar cycles
- Relevant characteristics of Phobos and Deimos
- Locations to land
- Considerations for designing your mission
- Suggested trades


Stepping Stones
Stepping Stones is a series of exploration missions building incrementally towards the long term goal of exploring Mars. Each mission addresses science objectives relating to the formation of the solar system and the origins of life.
2023
Deimos Scout
2031-2035
Red Rocks: explore Mars from Deimos
2024, 2025, 2029
Plymouth Rock: Humans explore asteroids like 1999 AO10 and 2000 SG344
2017
Asteroid scout
2018-2023
Fastnet: Explore the Moon’s far side from Earth-Moon L2 region
2016
Asteroid survey
2017
SLS test flight
2013-2020
Human systems tests on ISS
Lockheed Martin Notional Concept
Dates subject to change
Deimos photo courtesy of NASA-JPL, University of Arizona

Summary

- A human mission to one of the two moons of Mars would be an easier precursor to a mission to land on Mars itself.
- Astronauts would explore the moon in person and teleoperate rovers on the surface of Mars with minimal lag time, with the goal of returning samples to Earth.
- “Red Rocks” mission to land on a Martian moon would follow “Plymouth Rock” missions to a Near Earth Asteroid.
- Comparison of Deimos and Phobos revealed Deimos is the preferred destination for this mission.
- We identified specific areas on Deimos and Phobos as optimal landing sites for an early mission focused on teleoperation.

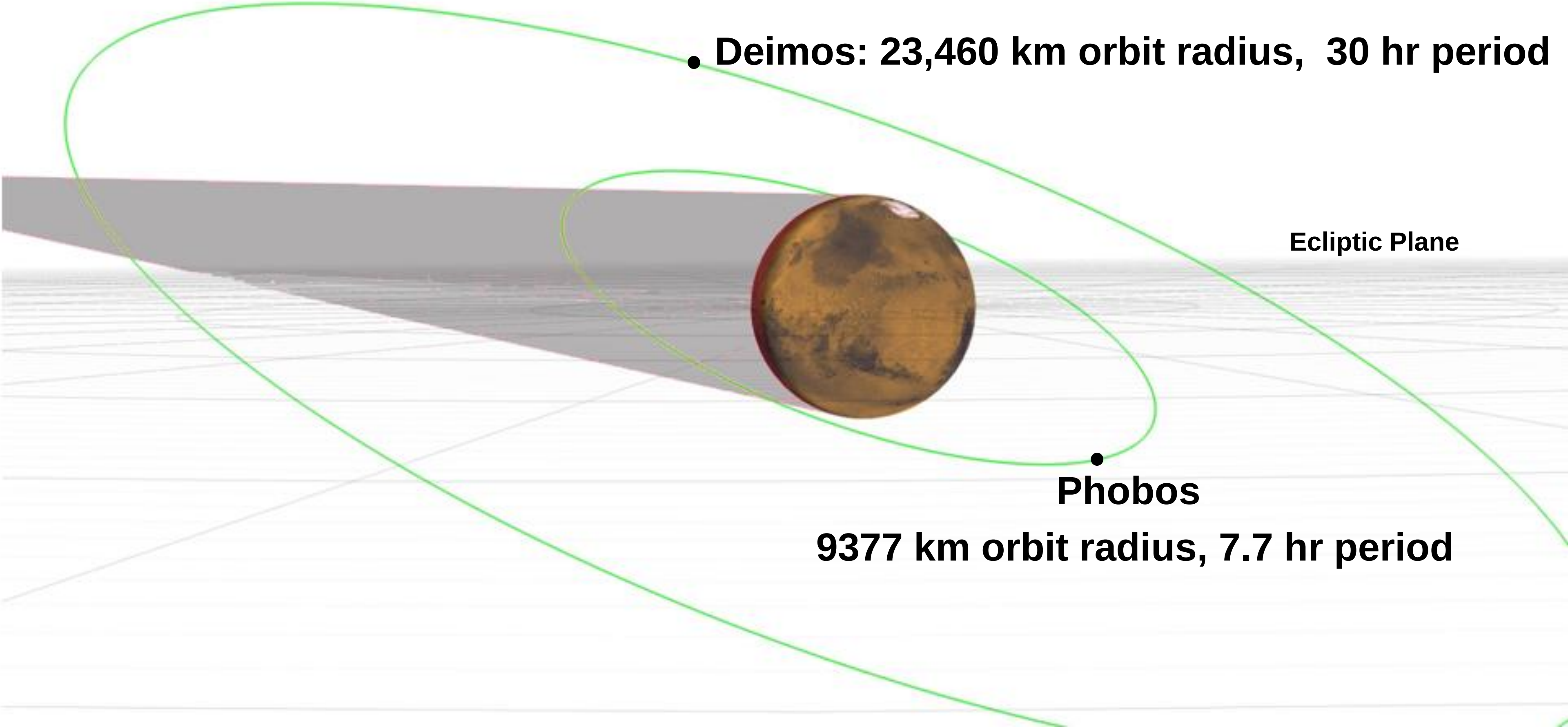
2033 or 2035 is the Best Time to Go to Mars



- **Optimum phases of 15 year orbital mechanics cycle and 11 year solar cycle (which protects from cosmic rays) probably coincide in 2033-2035**

Deimos and Phobos Orbits

- Both moons orbit in Mars's equatorial plane, and are tide locked
- Because Deimos is further than Phobos from Mars, it is easier to get to, is sunlit more often, and has better communications access

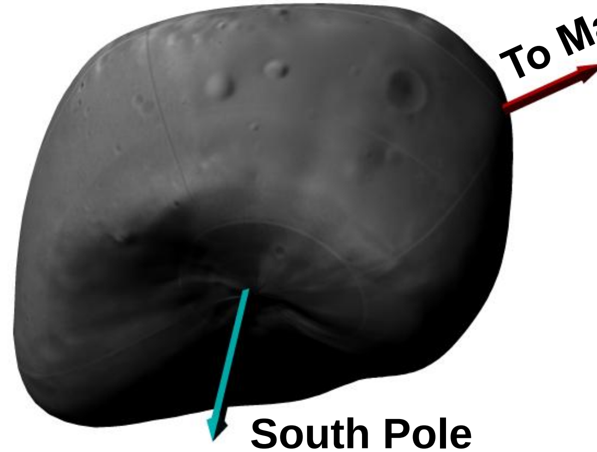


Deimos versus Phobos

	Deimos	Phobos
Mars arrival (2033) plus Earth return (2035) ΔV	**~2.9 km/s**	~3.3 km/s
Two-way speed of light lag to nadir point on Mars	0.134 s	0.040 s
Max visible Mars latitude (with 5º elevation mask)	**77.6º**	64.8º
Fraction of Mars surface visible	**97.5%**	90.5%
Duration of comm line-of-sight to asset on Mars equator	**59.6 hrs**	4.2 hours
Gap between comm passes to equatorial asset on Mars	71.8 hours	**6.9 hrs**
% time a typical Mars surface site is in view	**45%**	38%
Max eclipse duration	84 min	**54 min**
Typical nighttime duration	15.1 hr	**3.8 hr**
Max eclipse % of orbit period	**4.6%**	12.0%
Max continuous lighting duration in Northern hemisphere	**~300 days**	~140 days
Average eclipse season duration	**~83 days**	~228 days
Max continuous lighting duration in Southern hemisphere	**~225 days**	~95 days

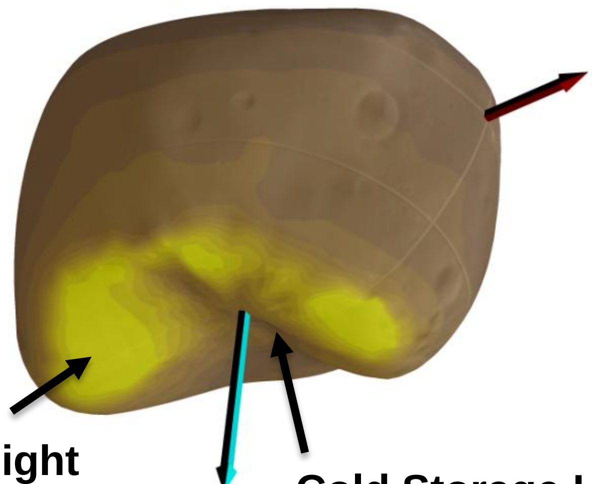
Southern Hemisphere of Deimos

Viking Orbiter Image F355B51-B59
(Credit: NASA/JPL/Emily Lakdawalla)



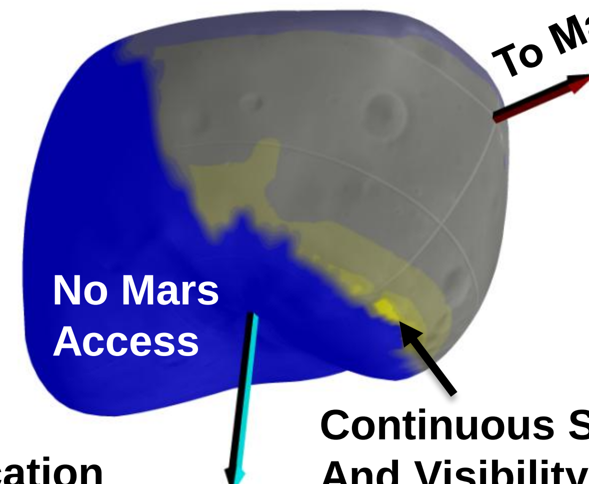
To Mars

South Pole



Continuous Summer Sunlight

Cold Storage Location



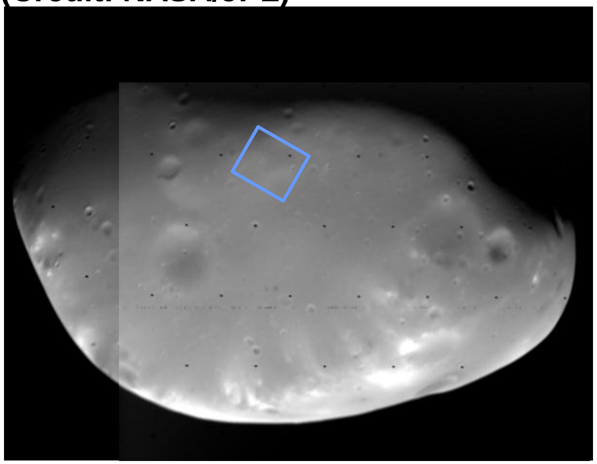
To Mars

Continuous Sumer Sunlight And Visibility to Mars (51° South, 7° East)

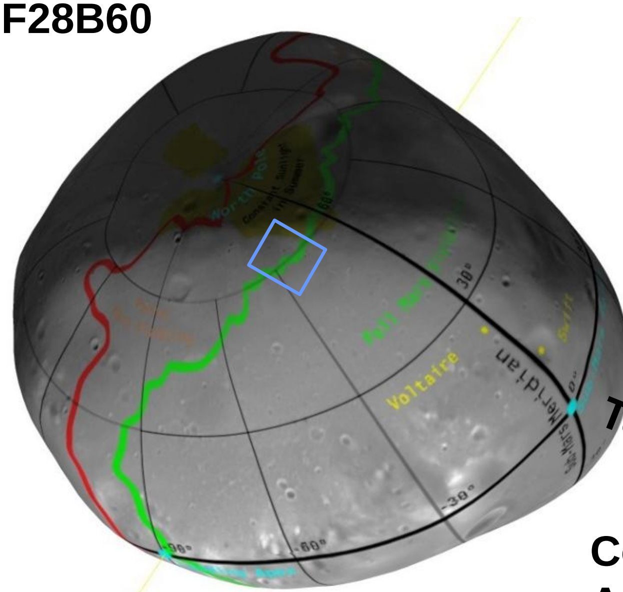
Deimos photomap courtesy of Phil Stooke, University of Western Ontario

Northern Hemisphere of Deimos

Viking Orbiter Image F28B61 and F28B60
(Credit: NASA/JPL)

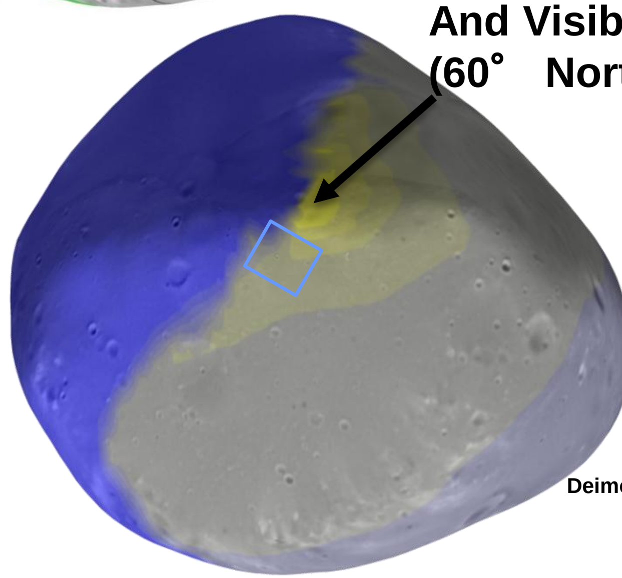


Viking Orbiter Image 423B61
(Credit: NASA/JPL)



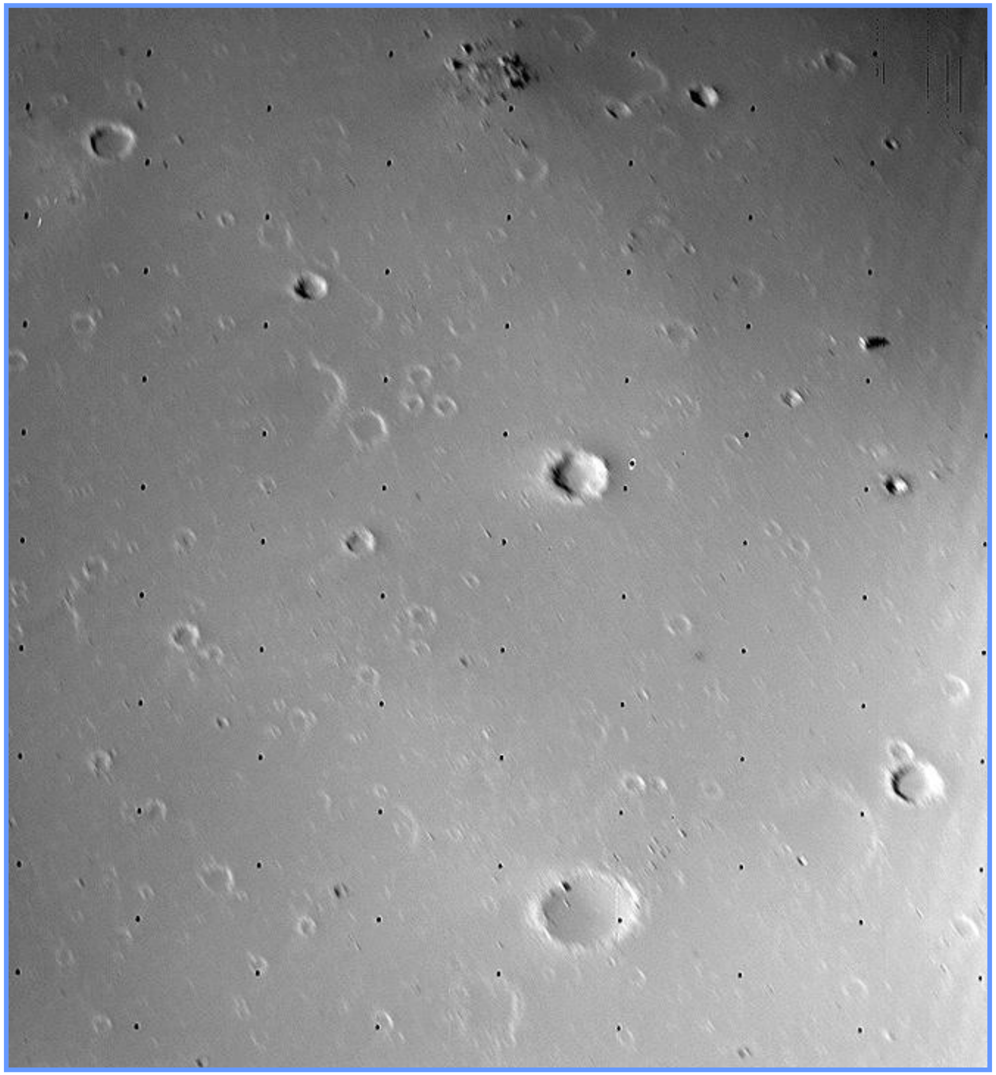
To Mars

Continuous Sumer Sunlight And Visibility to Mars (60° North, 0° East)



Deimos photomap courtesy of Phil Stooke, University of Western Ontario

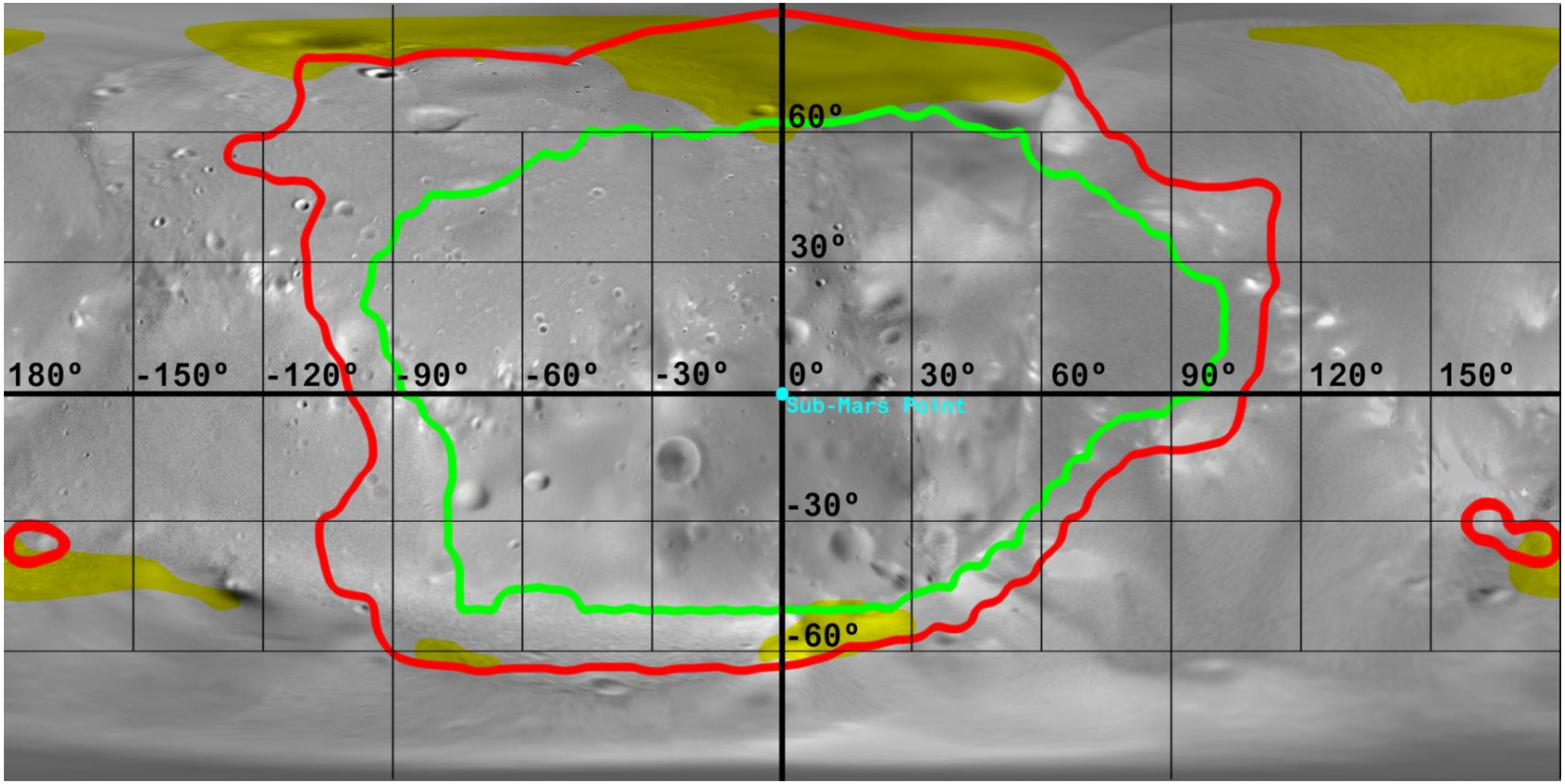
Surface of Deimos



Viking Orbiter Image 423B61
(Credit: NASA/JPL)

- Appears to be covered in regolith, smoothing out most craters
- Includes some large blocks of rock
- There should be Mars rocks here as well

Deimos Lighting and Mars Visibility

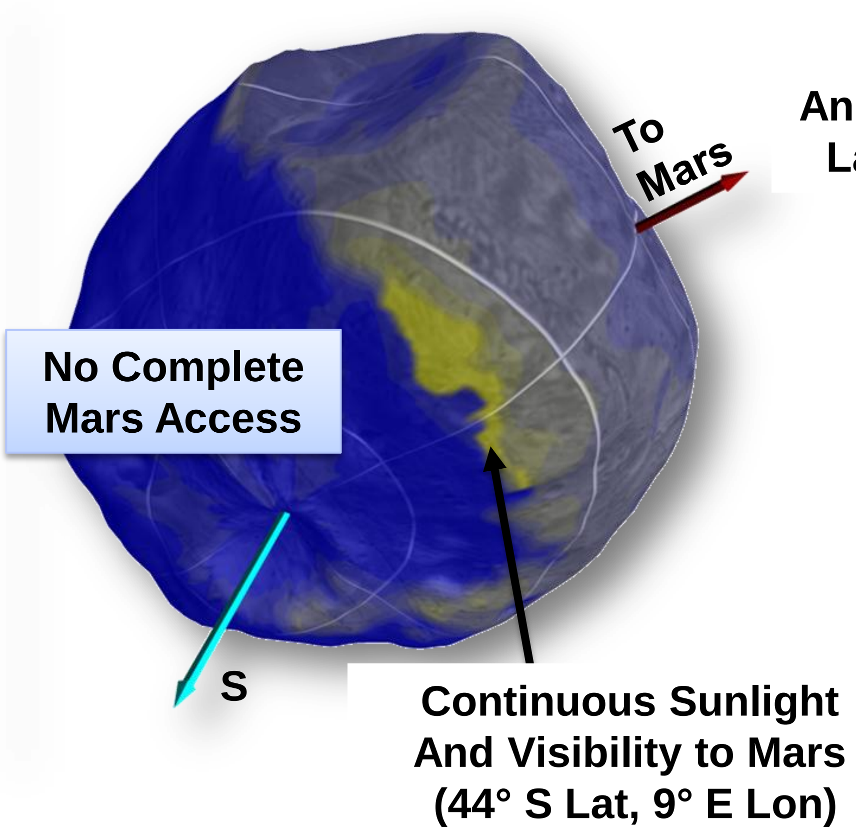


- Yellow regions have continuous sunlight during respective summer
- Inside green boundary all of Mars is visible
- Between green and red boundary part of Mars is visible

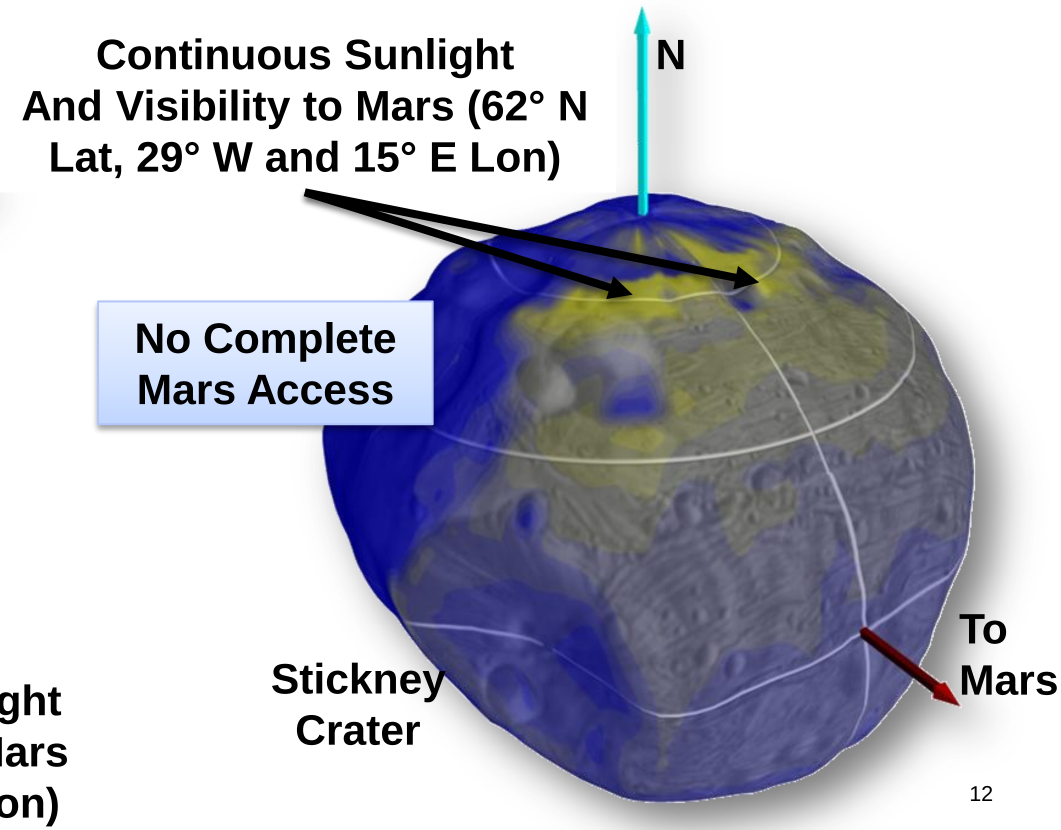
Potential Landing Sites on Phobos

- **Phobos also has regions with steady sunlight and full Mars visibility (but the regions are very small and periods of constant sunlight are much shorter).**

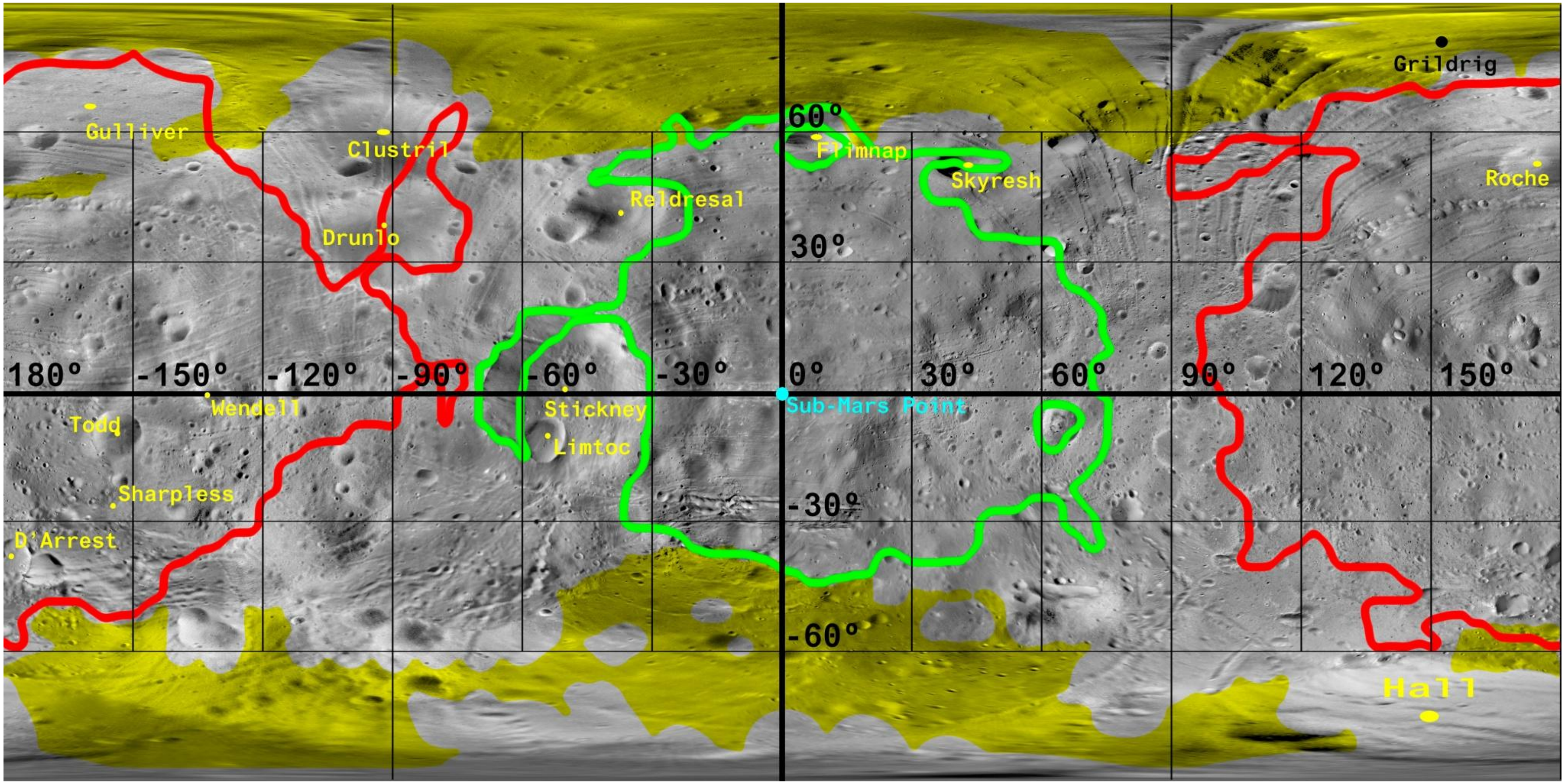
Southern Hemisphere Summer



Northern Hemisphere Summer



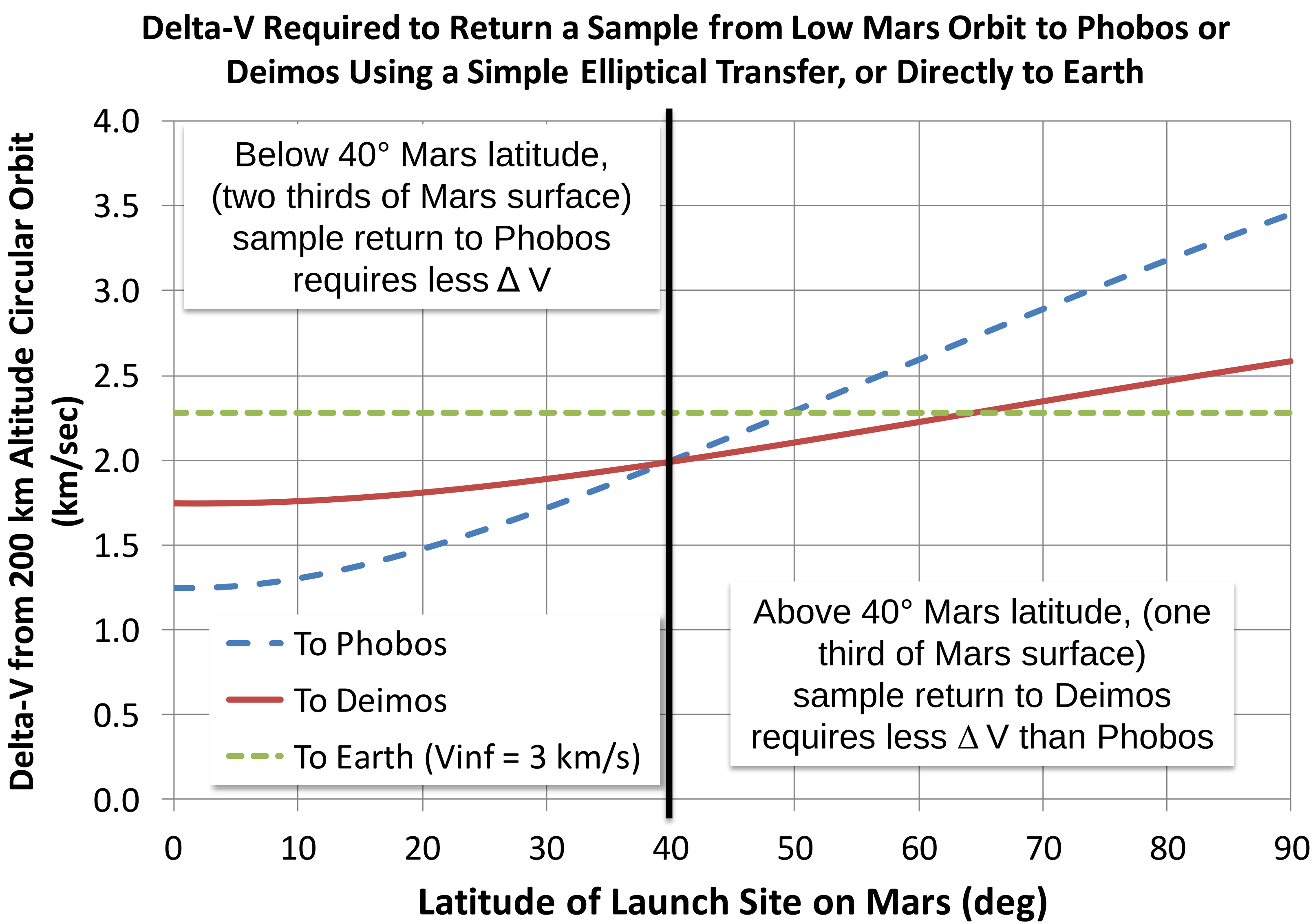
Phobos Lighting and Mars Visibility



- Yellow regions have continuous sunlight during respective summer
- Inside green boundary all of Mars is visible
- Between green and red boundary part of Mars is visible

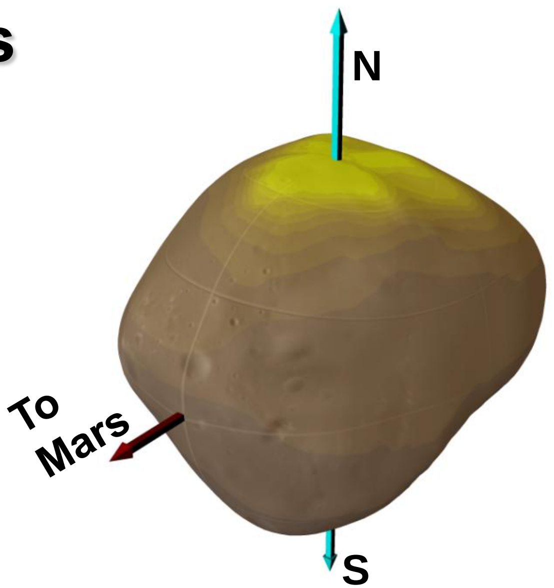
Phobos photomap courtesy of Phil Stooke, University of Western Ontario

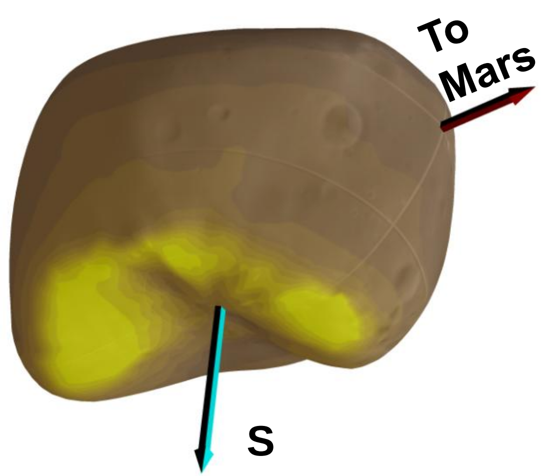
Mars Sample Return Delta-V



Advantages of Deimos

- Round trip ΔV from Earth to Deimos is about 400 m/s lower than to Phobos
- Longer communications access to assets on Martian surface
- Communications access to higher Martian latitudes
- Superior line-of-sight to Earth from Deimos due to fewer Martian occultations
- Twice as much time with constant sunlight and only a third of the eclipse season duration as Phobos

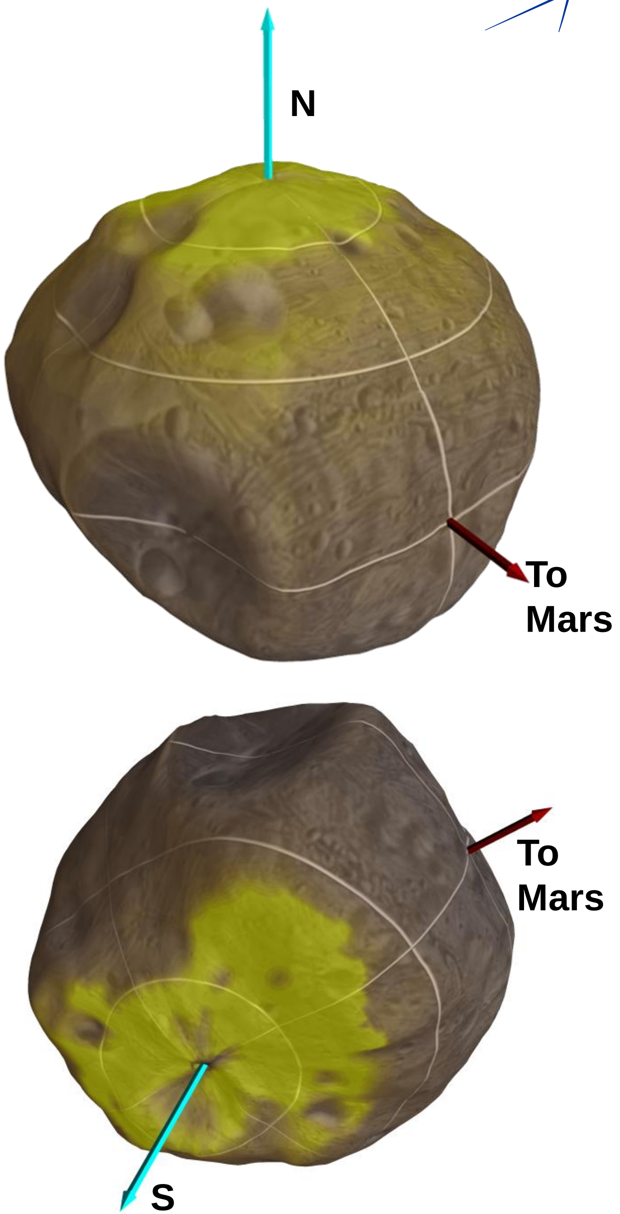




Deimos photomap courtesy of Phil Stooke, University of Western Ontario

Advantages of Phobos

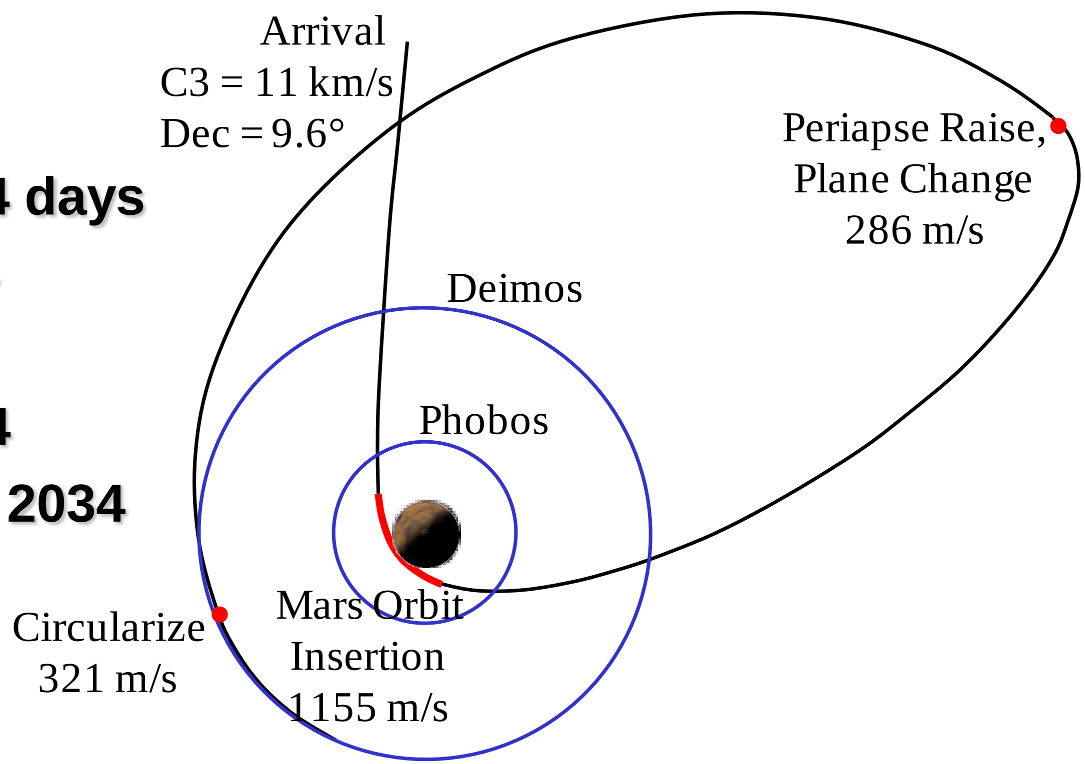
- **The gap between comm passes to Martian surface assets is much shorter.**
- **Phobos is closer to the Martian surface, resulting in higher data rates or smaller antenna & power.**
- **The maximum possible eclipse duration is 30 min shorter on Phobos.**
- **Phobos appears to be more geologically interesting than Deimos.**
- **Sample return to Phobos is easier from low latitude Mars sites.**



Phobos photomap courtesy of Phil Stooke, University of Western Ontario

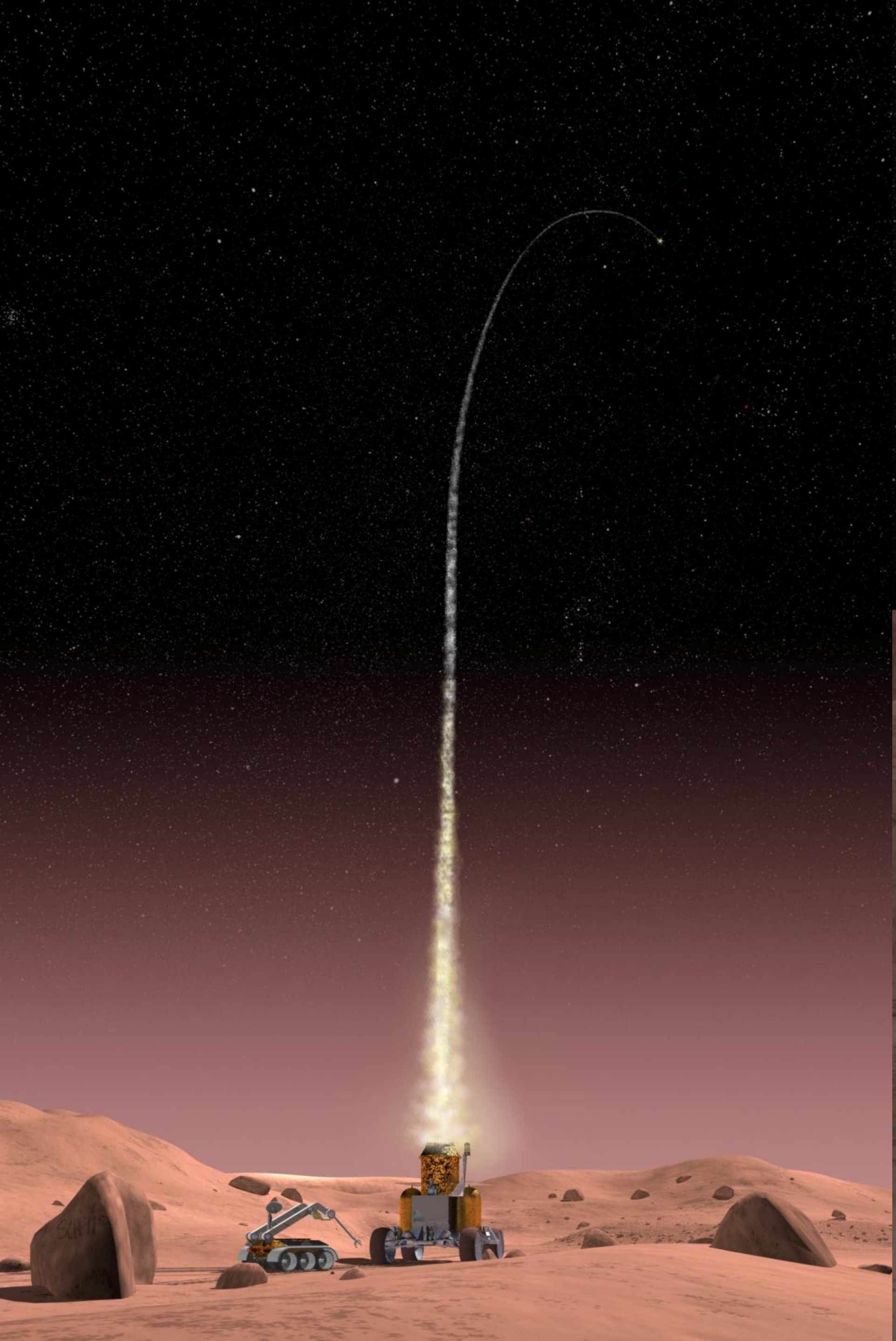
Example Mission

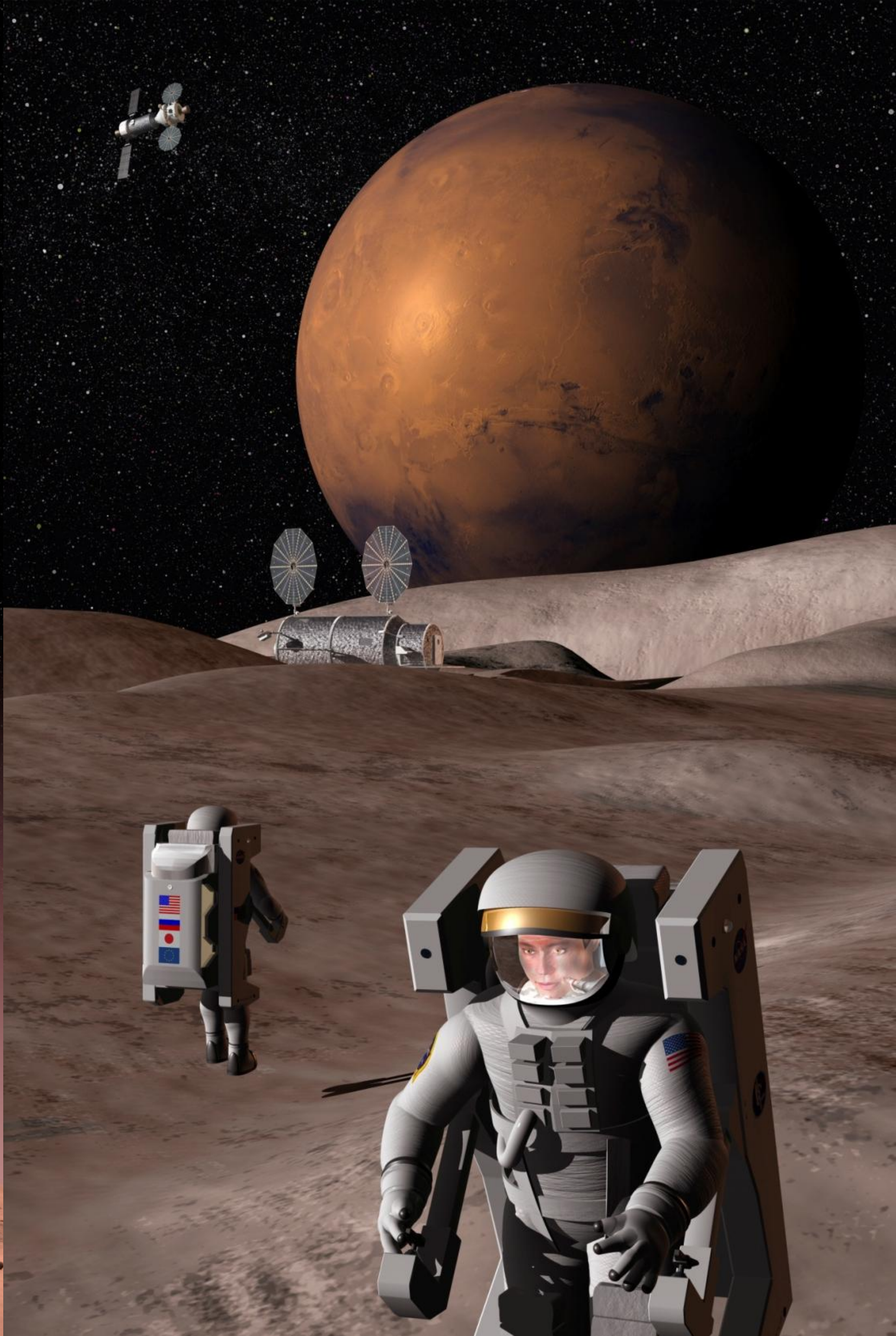
- **Depart Earth April 17 2033**
  - **$C3 = 9.2\ km^2/s^2$**
  - **Transfer 201 days**
- **Arrive Mars Nov 4 2033**
- **Arrive Deimos Nov 8 2033**
  - **Stay at Southern Site 114 days**
- **Depart for orbit Mar 2 2034**
  - **Eclipse Season begins**
  - **Vernal Equinox 4/11/2034**
- **Land at North Site April 20 2034**
  - **Stay 373 days**
- **Depart Mars 5/7/2035**
  - **Transfer 199 days**



Conclusion of our study

- For a solar-powered mission with a focus on tele-robotic operation of Mars surface assets, Deimos is a better choice of location than Phobos, due to its superior coverage of sites on the Martian surface and extended durations of constant sunlight.
- A human mission to Deimos could visit the identified Northern and Southern sites during their respective summer seasons
- Human missions to Deimos are possible with relatively few new technologies





Considerations for Your Study

- What is the purpose of your mission? Some possibilities:
  - Demonstrate technologies for future human Mars landing missions
  - Determine whether Phobos or Deimos have resources useful for future landing missions and demonstrate the ability to harvest them
  - Teleoperate science vehicles on the Martian surface, possibly to return samples to Earth
  - Understand Phobos and/or Deimos and their origins
- How does your mission fit with earlier and later flights?
  - Is this flight an immediate precursor to a Mars landing, Or a stretch from an earlier asteroid mission?
  - What aspects of your mission will require prior test flights?

Suggested Key Trades

- Conjunction class vs Opposition class mission
  - Conjunction class missions are longer duration (900-1000 days), have long stays, and lower ΔV
  - Opposition class missions are shorter in duration (~500-800 days) but have high ΔV and short stays at Mars (~30 days)
- All-up (everything in one stack) vs pre-deployed (some elements go to Mars orbit on an earlier window)
  - Related trade of whether to have a single habitat for transit + landed ops, or two separate specialized habs.
- Crew Size

Life Support Issues

- Minimum consumables requirements are something like:
  - Water: 2 kg/person/day drinking + 0.2 kg/person/day for minimal washing. Probably more on long trips for better hygiene
  - Oxygen: 0.8 kg/person/day for metabolic consumption (assumes exercise) + leaks + repressurization
  - Nitrogen: mostly driven by leak rates, repressurization (e.g. for airlocks)
  - Food: 1.8 kg/person/day (includes meal-level packaging) at ~380 kg/m^3 density
  - Be sure to account for both mass and <u>volume</u>
- Recycling water is feasible and probably necessary due to mass. Food is much harder.