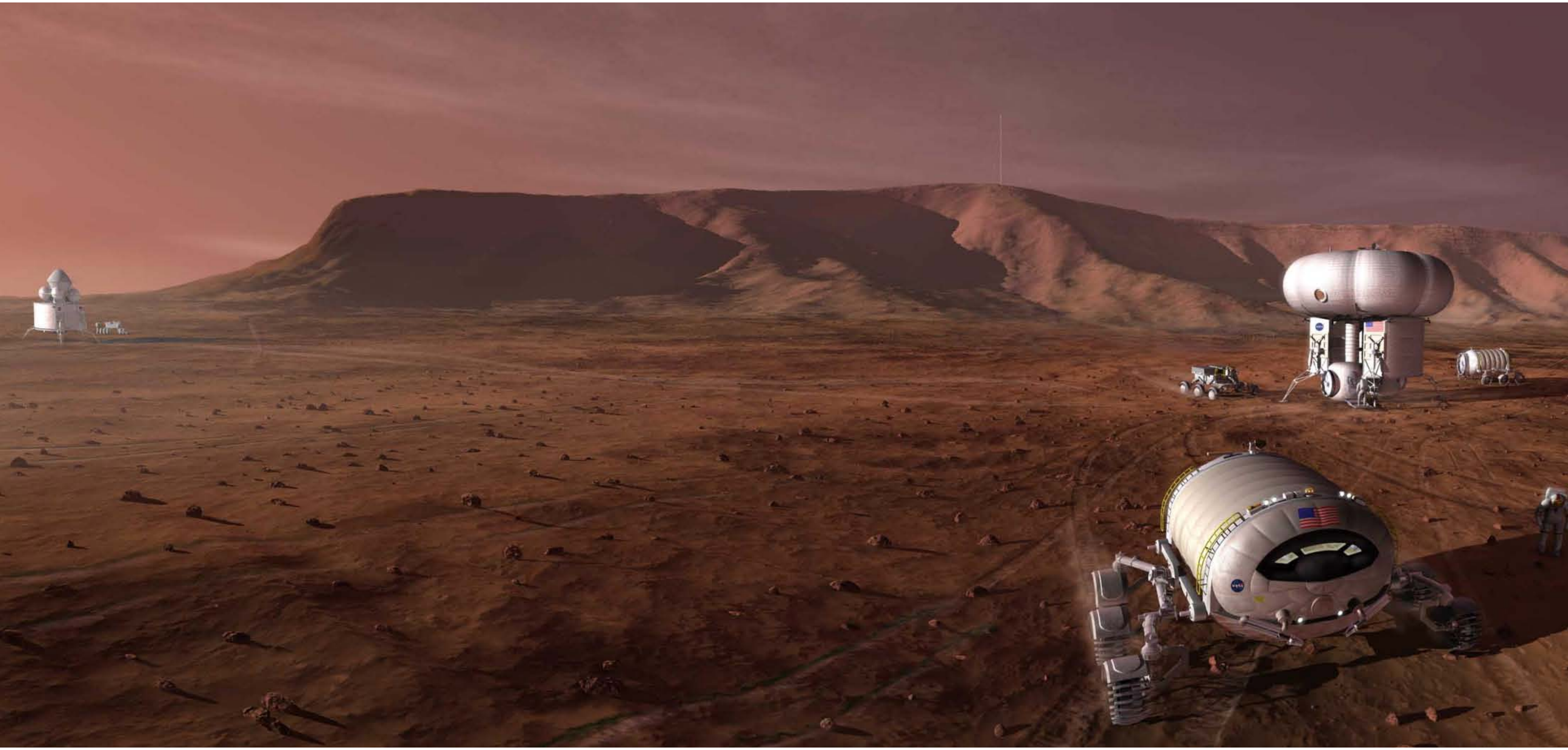
Footprints on Mars
Presentation to Boeing REACH

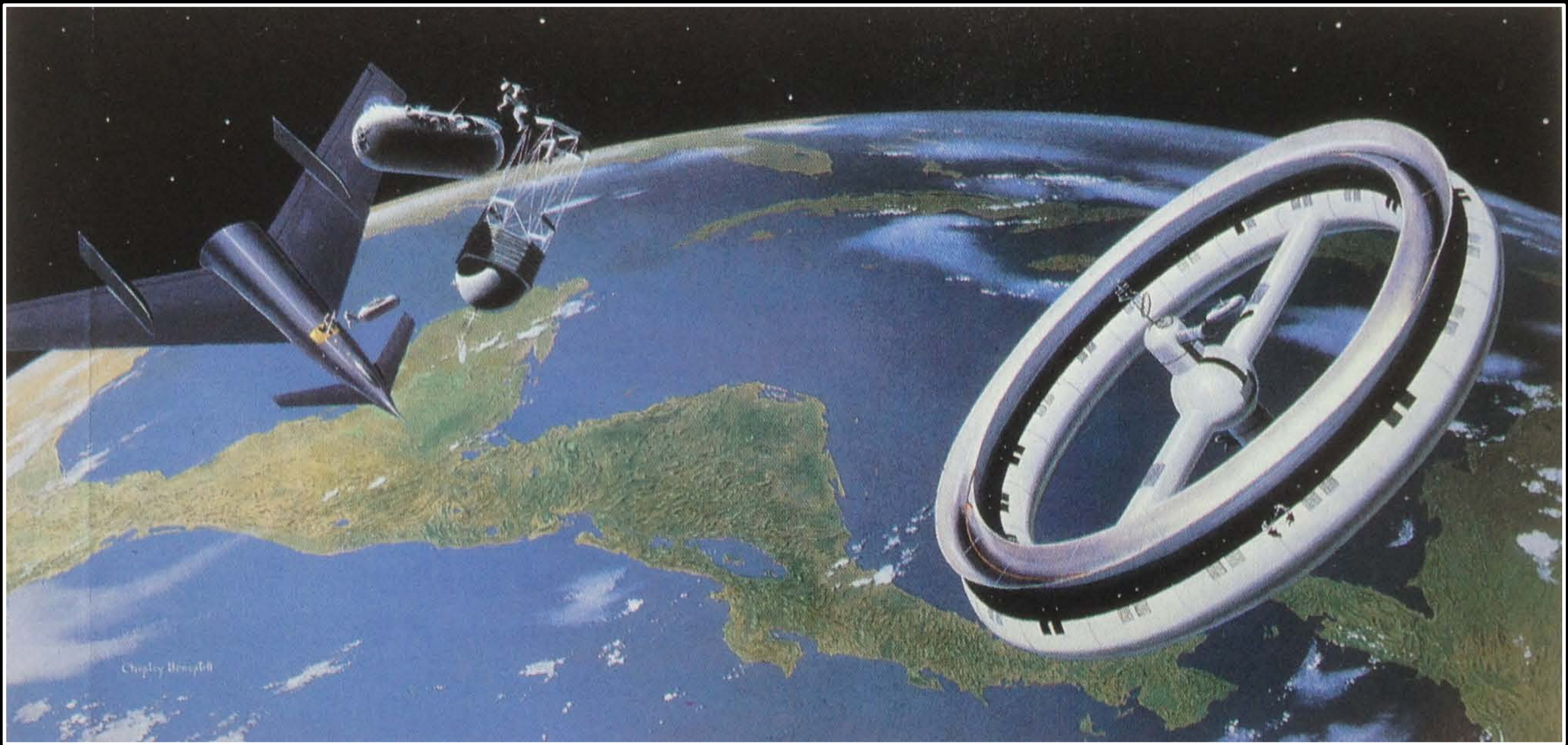
National Aeronautics
and Space Administration



Bret G. Drake
NASA Lyndon B. Johnson Space Center

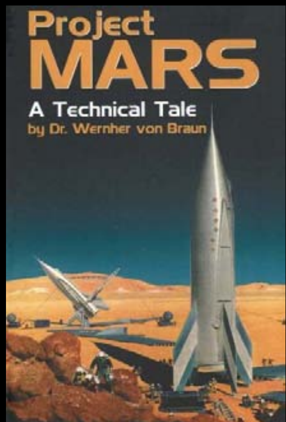
12 June, 2013

Mid-20th Century Fascination with Space



Wernher von Braun and Chesley Bonestell prediction of the future in 1951
Illustration by Robert McCall

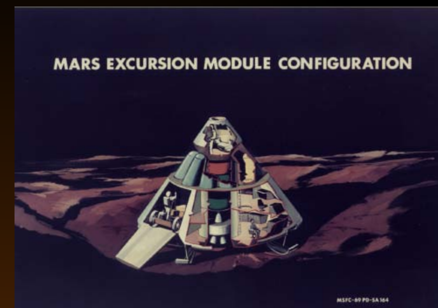
Dr. Wernher von Braun's Manned Mars Landing Presentation to the Space Task Group - 1969



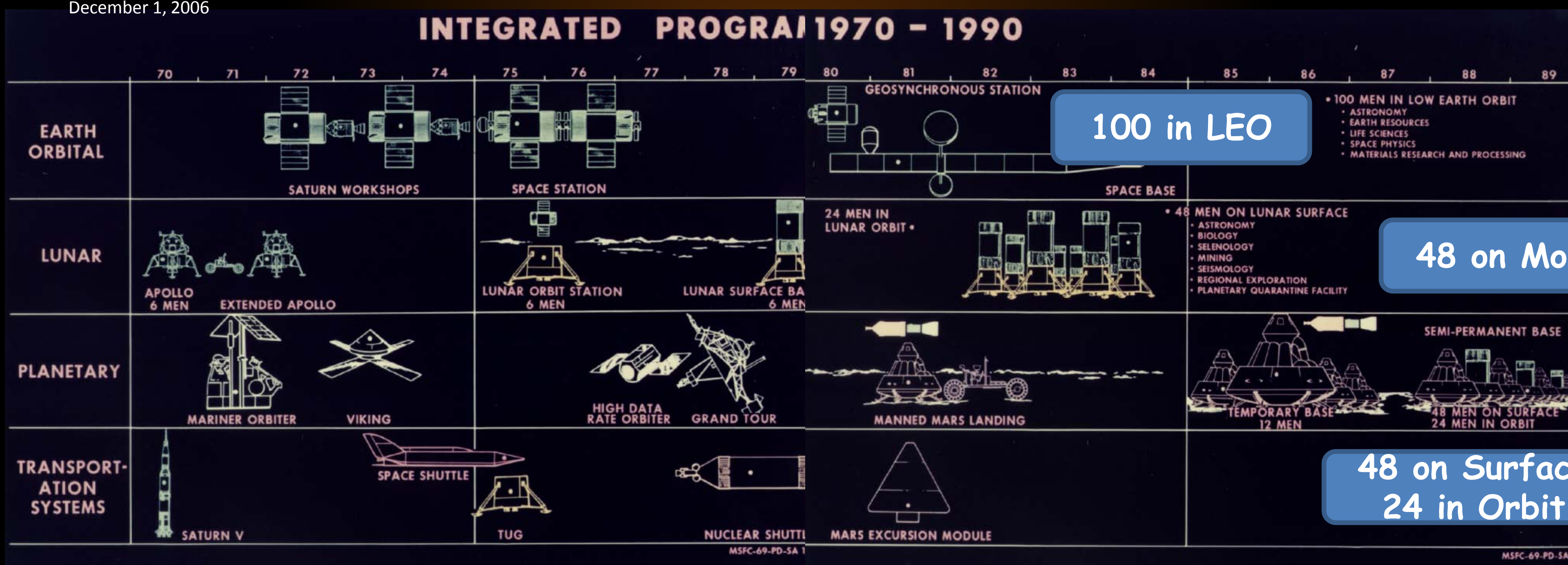
Collectors Guide Publishing
December 1, 2006

Nuclear Thermal Propulsion

640 Total Days
60 Days on Mars



Venus Swing-by
Propulsive Earth Return



100 in LEO

48 on Moon

48 on Surface
24 in Orbit

So What Happened?

Space, Especially Mars, is Hard

and, unfortunately,

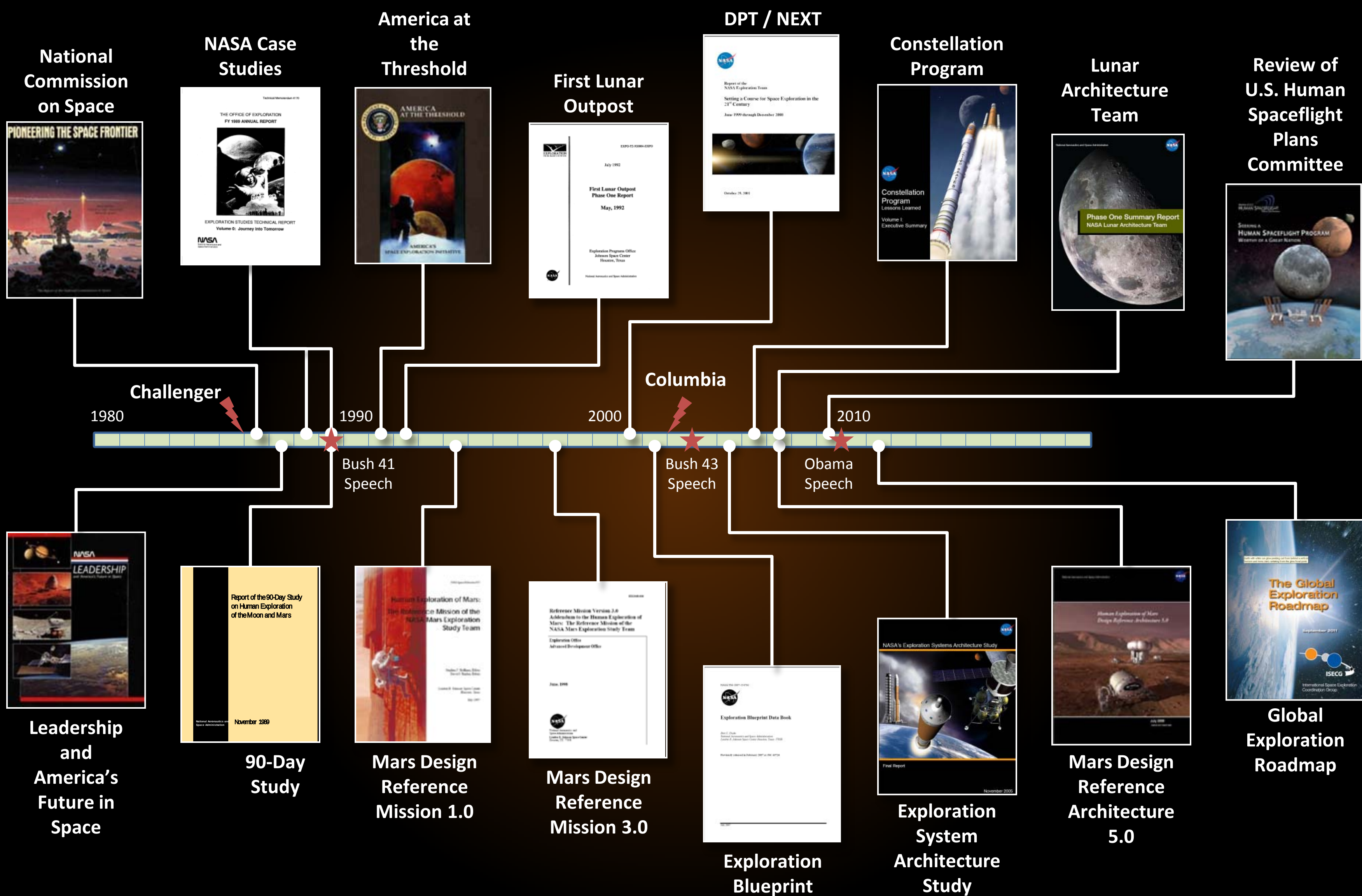
The Laws of Physics Can't be Rewritten

Human Exploration of Mars

Key Challenges

A Brief History of Human Exploration Beyond LEO

A trail of studies … to Mars



Why Do We Want To Explore Mars?

- **Long-standing curiosity, particularly since it appears that humans could one day visit there**
- **A NASA chartered group, Mars Exploration Program Analysis Group, has organized a set of four primary goals:**
  - Determine if life ever arose on Mars
  - Understand the processes and history of climate on Mars
  - Determine the evolution of the surface and interior of Mars
  - Prepare for human exploration
- **Two additional goals considered as well:**
  - Preparing for sustained human presence
  - Ancillary science such as heliophysics, space weather, astrophysics

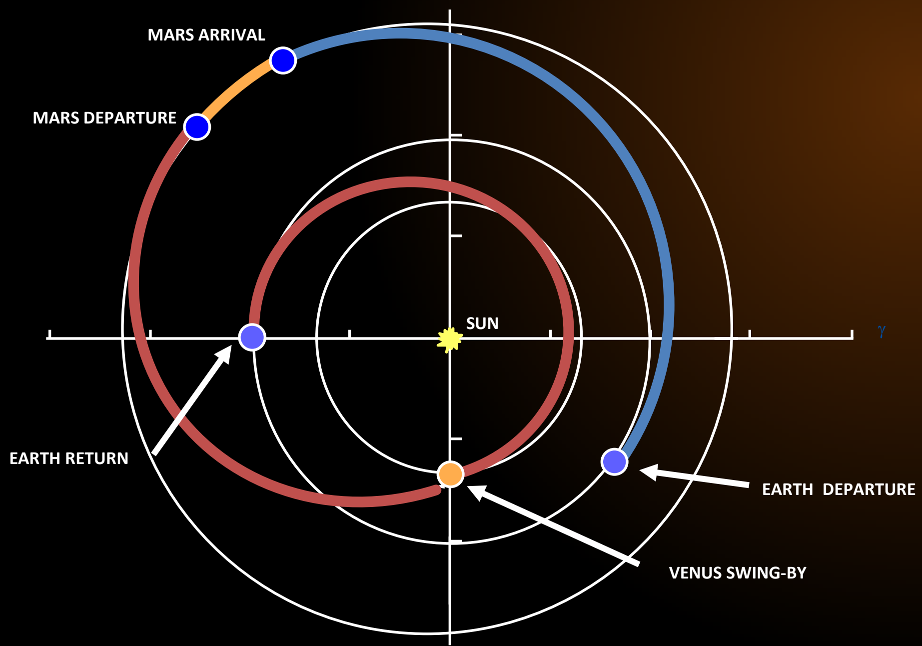
Goals and Objectives Summary Implications

- **The first three human missions to Mars should be to three different geographic sites**
- **Maximize mobility to extend the reach of human exploration beyond the landing site**
- **Maximize the amount of time that the astronauts spend exploring the planet**
- **Provide subsurface access**
- **Return a minimum of 250 kg of samples to Earth**

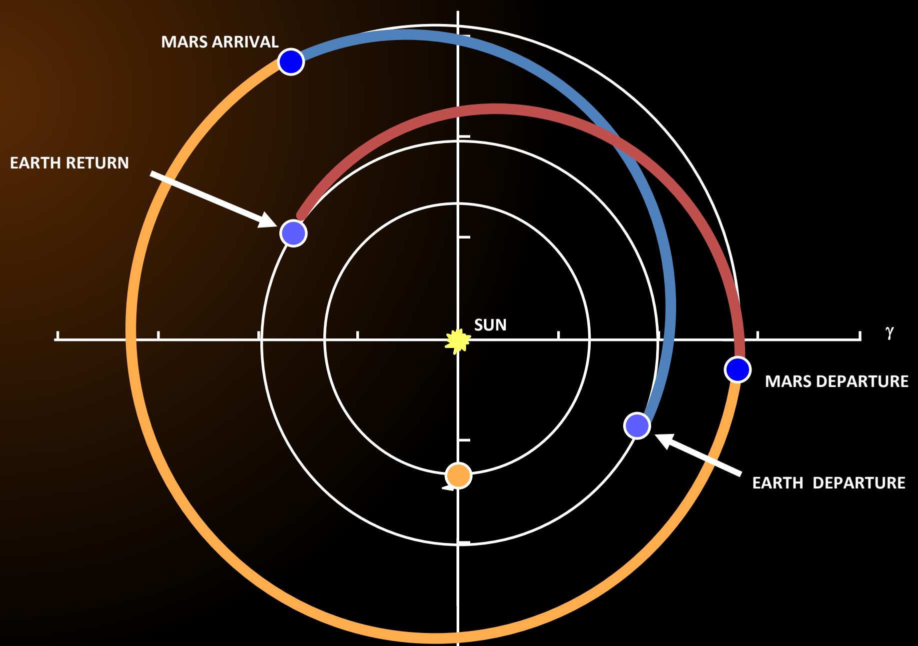
Mars Trajectory Classes

- **A trip to Mars with a return back to Earth is a double rendezvous problem**
  - Mars round-trip missions are flown in heliocentric space
  - Relative planetary alignment is a key driver in the mission duration and propulsion required

Example "Short-Stay" Opposition Class Mission

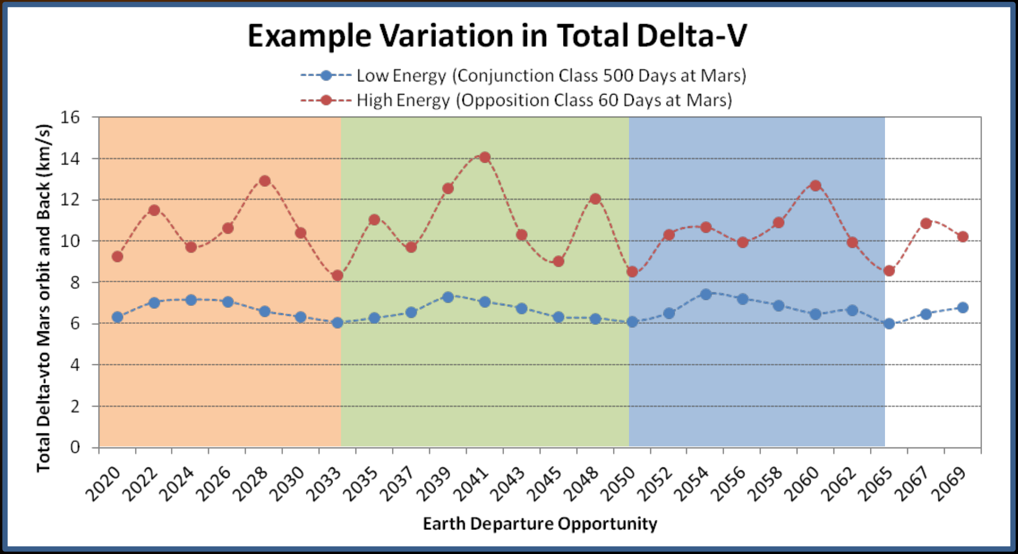


Example "Long-Stay" Conjunction Class Mission



Synodic Period – Variation in Delta-V

- **The difference in orbits of the Earth and Mars influence the mission delta-v and timing**
  - — Earth departure opportunities occur approximately ever 26 months
  - — The Earth departure "window" lasts a few weeks and is highly dependent on the propulsion system choice
  - — The round-trip mission delta-v varies over a 15-year cycle (the Synodic Cycle)
  - — Although "good" opportunities occur in 2018, 2033, and 2047, the ability to conduct missions in any opportunity across the Synodic Cycle will reduce programmatic risk



Advanced In-Space Transportation

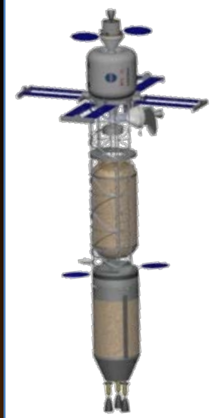
Options, options, options….

High Thrust: Chemical Propulsion

Advantages:
- More "state of the art"
- Multiple destinations

Challenges:
- High Mass / Lots of Launches
- Long-term storage of cryogenic propellants, particularly H_2
- Configuration and integration challenges
- Long-stay missions only

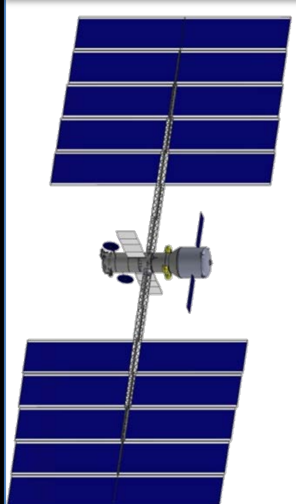
High Thrust: Nuclear Thermal Propulsion (NTP)



Advantages:
- Good combination of high thrust and high efficiency (Isp)
- Low architectural mass
- Both long and short stay missions
- Has been demonstrated (NERVA)

Challenges:
- Long-term storage of cryogenic H_2
- Large launch volume (due to H_2)
- Nuclear regulatory compliance/testing

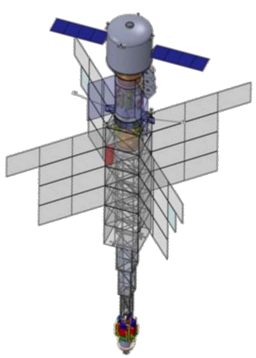
Low Thrust: Solar Electric Propulsion (SEP)



Advantages:
- Low architectural mass
- Multiple destinations

Challenges:
- Limited to long-stay missions
- Configuration and integration challenges (large solar arrays)
- Long operating times (spirals)

Low Thrust: Nuclear Electric Propulsion (NEP)

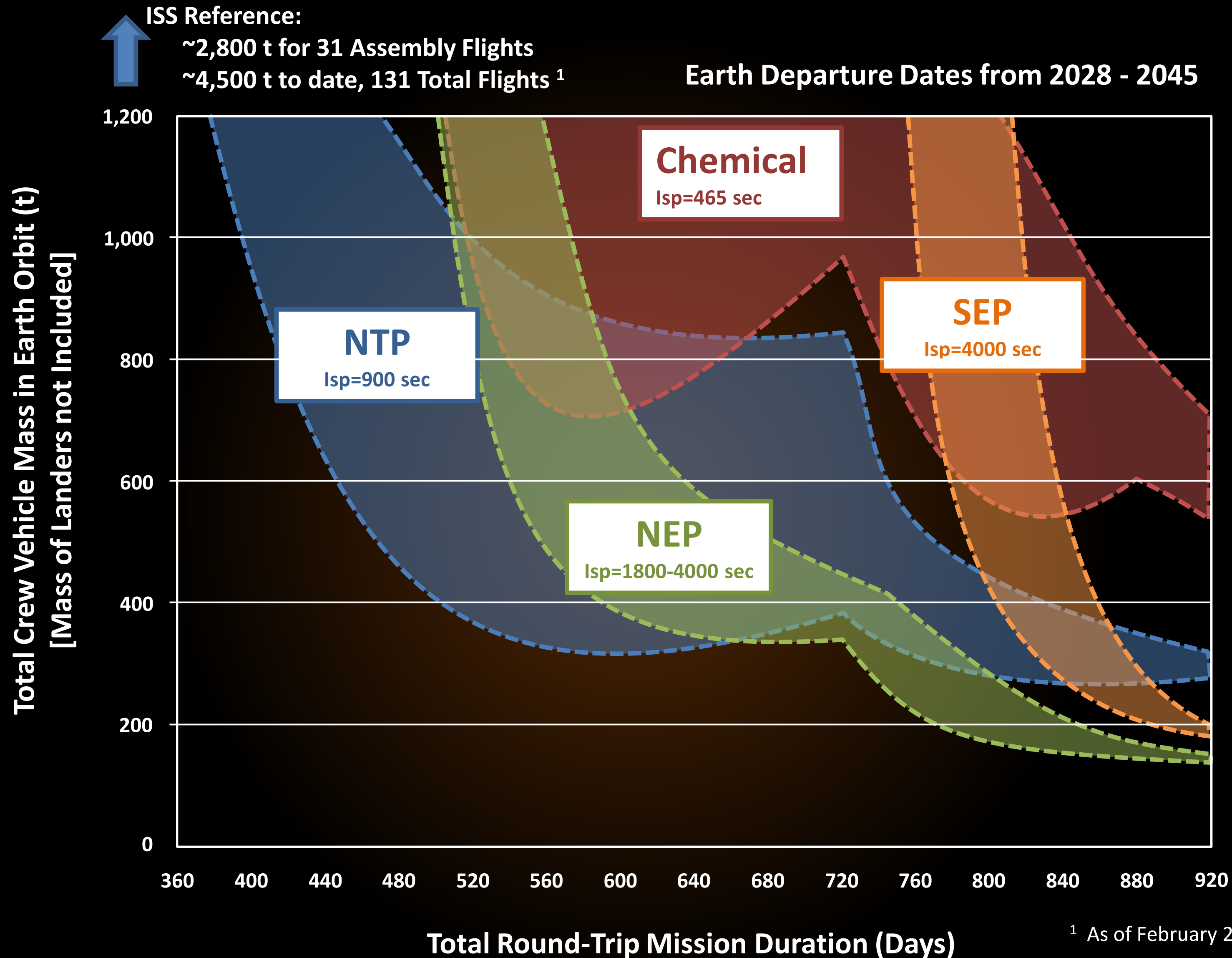


Advantages:
- Low architectural mass
- Both long-stay and short-stay (if power is high) missions

Challenges:
- No experience base for space based high power, high efficiency, nuclear reactors
- Configuration and integration challenges (large radiators)
- Nuclear regulatory compliance/testing
- Long operating times (spirals)

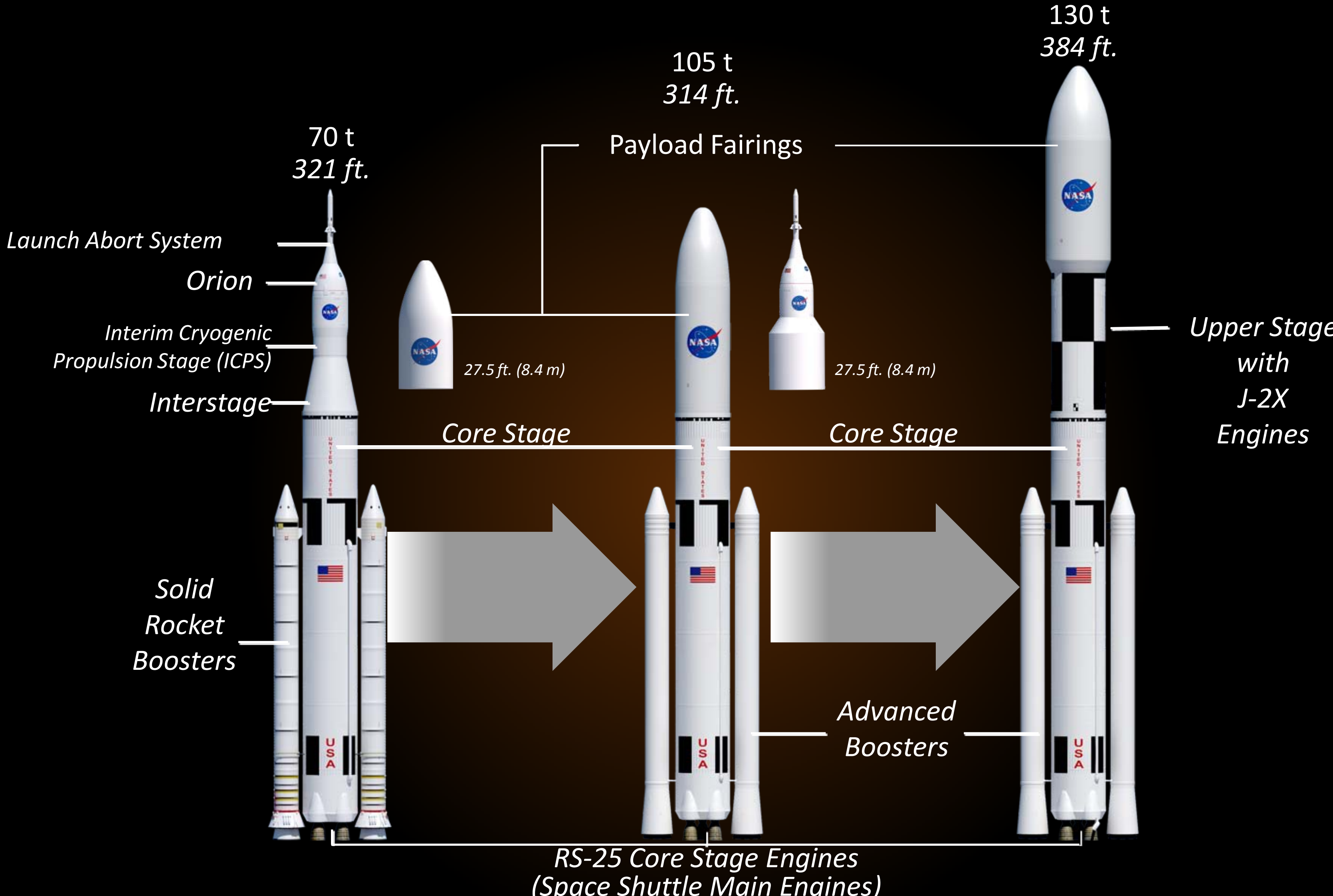
Propulsion Technology Comparisons

Crew Vehicle Mass as a Function of Trip Time – Short Stay Opposition Missions



[1] As of February 2013

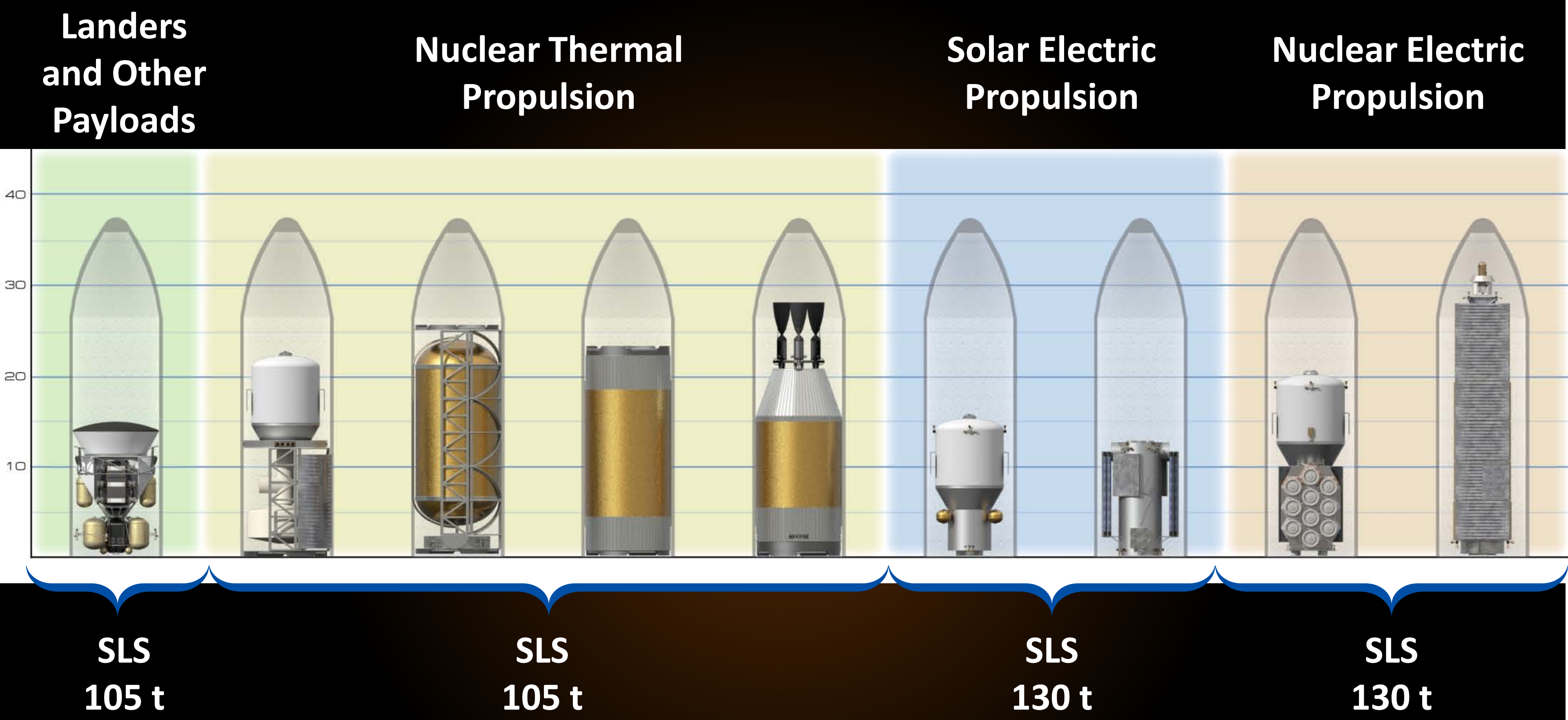
SLS Architecture Block Upgrade Approach



Starting with Available Assets and Evolving the Design

Example Launch Packaging

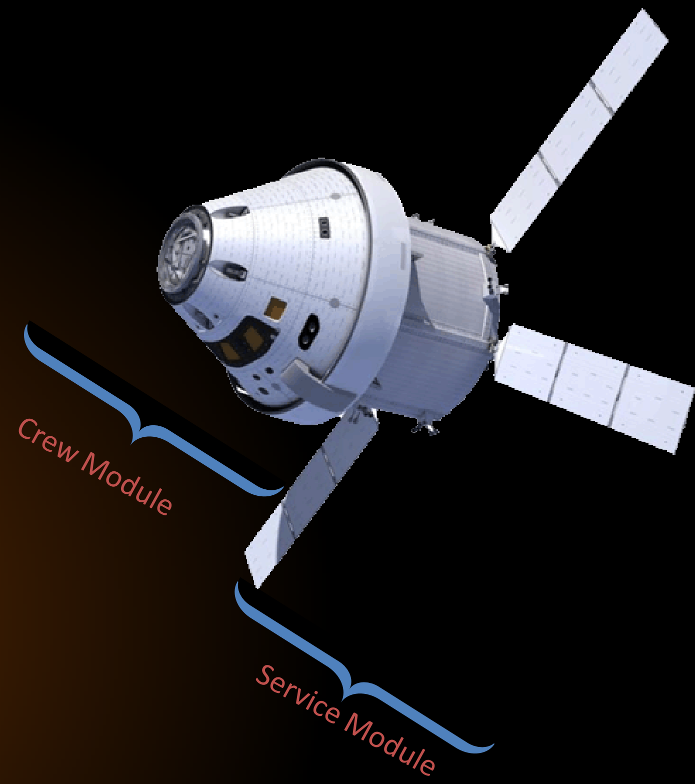
Diameter and Volume are also Key



Orion Crew Transfer / Earth Return Vehicle

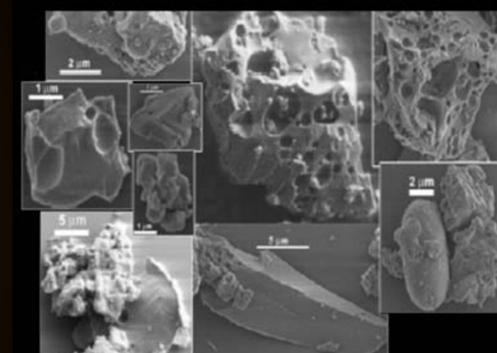
- **Crew Delivery to Earth Departure Point**
  - Provide safe delivery of 4-6 crew to Earth departure point for rendezvous with the Mars Transfer Vehicle
    - Delivery and return of checkout crew prior to the mission
    - Delivery of the mission crew

- **End of Mission Crew Return (Mars Block)**
  - Provide safe return of 4-6 crew from the Mars-Earth transfer trajectory to Earth at the end of the mission
    - 12 km/s entry speed (13+ km/s for short-stay mission)
    - 900 day dormant operations
    - 3 day active operations
    - Much smaller service module (~300 m/s delta-v) for re-targeting and Earth entry corridor set-up



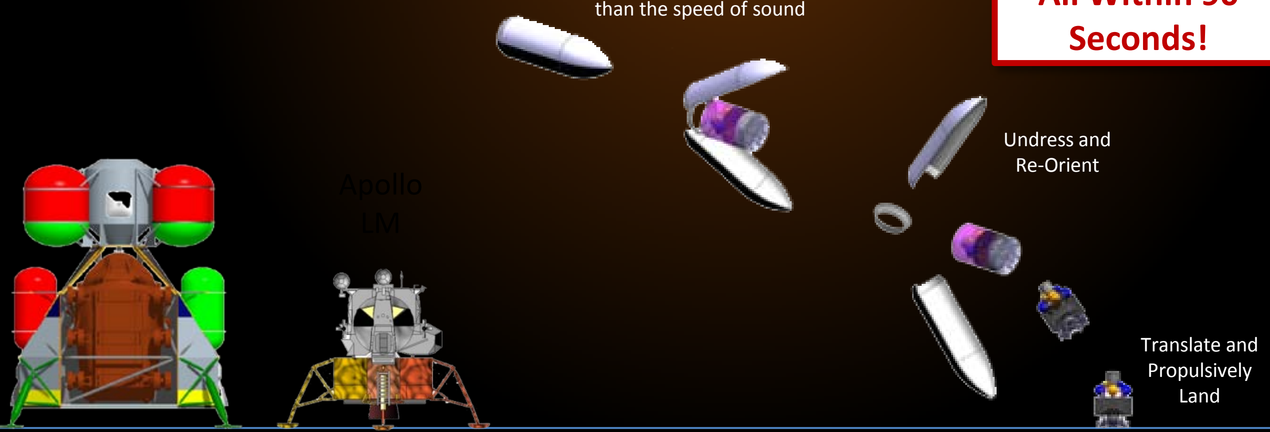
Challenges of Supporting Humans in Deep Space

- **Human missions to Mars are demanding from a human health and performance perspective**
  - Long-Duration: 600 days minimum, 900 days most probable
  - Deep-Space: Micro-gravity and harsh environment
  - Remote: No logistics train, no fast return aborts
- **Categories of Key Human Support Challenges**
  - Ocular Syndrome: Intercranial pressure
  - Toxicity: Dust and other hazards
  - Autonomous Emergency : Response to system emergencies (e.g. life support system failure)
  - Radiation: Solar Proton (solutions exist), Galactic Cosmic Radiation (currently no standards for exploration)
  - Behavioral Health and Performance: Remote isolated missions with no real-time communications.
  - Autonomous Medical Care: Response to medical issues
  - Nutrition: Food with adequate nutrition for long missions
  - Hypogravity: Adjusting to the gravity of Mars
  - Musculoskeletal: Muscle atrophy and bone decalcification
  - Sensorimotor: Sensory changes/dysfunctions



Challenges of Landing on Mars

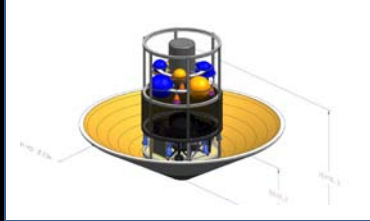
- **The Atmosphere of Mars**
  - The Good: Mars has an atmosphere that can help slow the entry vehicle down
  - The Bad: The atmosphere is thick enough that it requires a heat shield, but not thick enough to provide substantial drag (density 1% of Earth’s)
  - Atmospheric dust may prohibit ability or timing of landing at designated landing sites
- **The Current Mars Science Laboratory Landing Strategy is Limited**
  - ~ 1 mt payload to the surface (target 40 mt)
- **Key for Human Missions Challenge: <u>Supersonic Transition</u>**



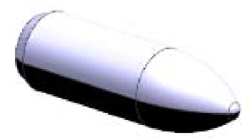
All Within 90 Seconds!

Technology Options

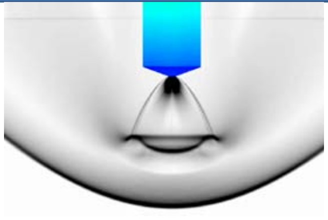
Hypersonic Inflatable Aerodynamic Decelerator (HIAD)



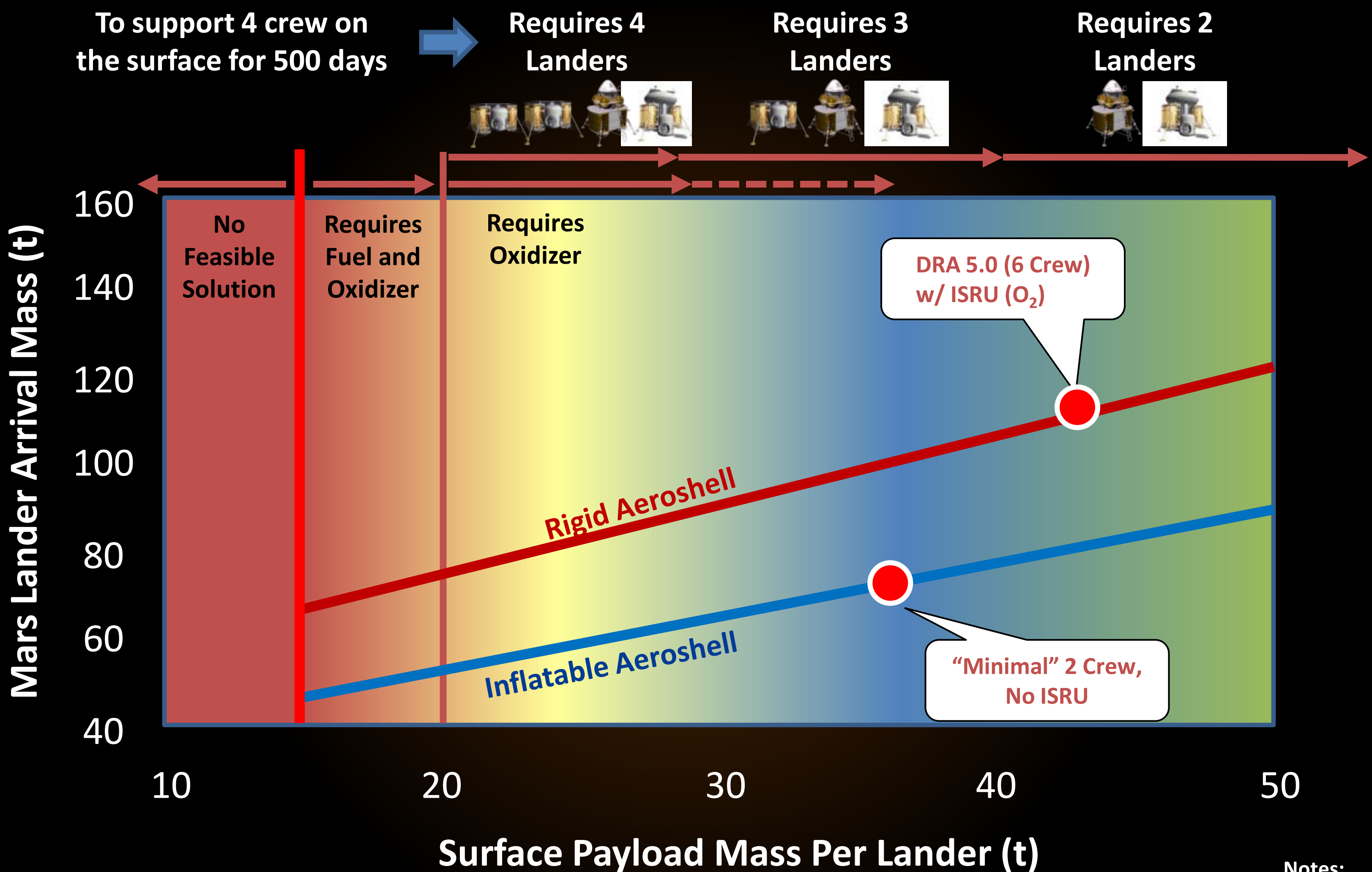
Rigid Aeroshells (mid L/D)



Supersonic Retro-propulsion



Mars Wet Lander Mass at Mars Arrival



Notes:
- Volumetric impacts not included.
- Surface payload for 4 crew case
- High Mars orbit cases

Living off of the Land: In-Situ Resources

- **Atmosphere**
  - **Atmospheric resources found globally with slight change in pressure/concentration**
  - Primary product: oxygen (O_2) bound in carbon dioxide (CO_2)
  - Oxygen can be used for propulsion, life support, and extra vehicular activity (EVA) applications
  - Production of O_2 only from CO_2 makes over 75% of ascent propellant mass
  - Production of O_2 and CH_4 (or other hydrocarbon fuel) possible with hydrogen (H_2) brought from Earth
- **Soil Processing for Water**
  - **Water resources found globally with large variations in concentration, form, and depth.**
  - Water can be used for life support, EVA, and radiation shielding
  - Water can be processed into O_2 and H_2 or with CO_2 to make fuels for propulsion and power
  - Production of O_2 and methane (CH_4) from CO_2 and H_2O allows for 100% of ascent propellant mass
- **Leverage**
  - Producing oxygen from the atmosphere provides significant leverage in terms of mass (32%) and volume (lander packaging)

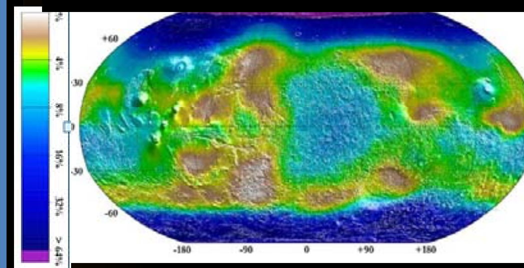
Resources

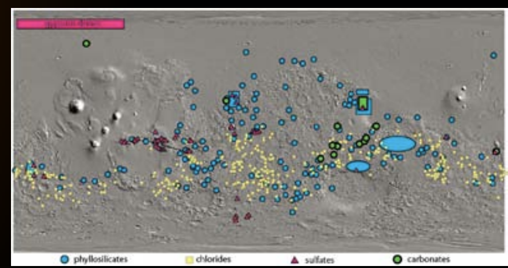
Global

Carbon Dioxide (CO_2)	95.5%
Nitrogen (N_2)	2.7%
Argon (Ar)	1.6%
Oxygen (O_2)	0.15%
Water (H_2O)	<0.03%

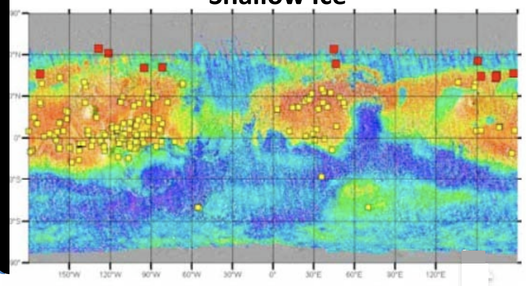
Landing Site Dependent

Water in Top 1 meter

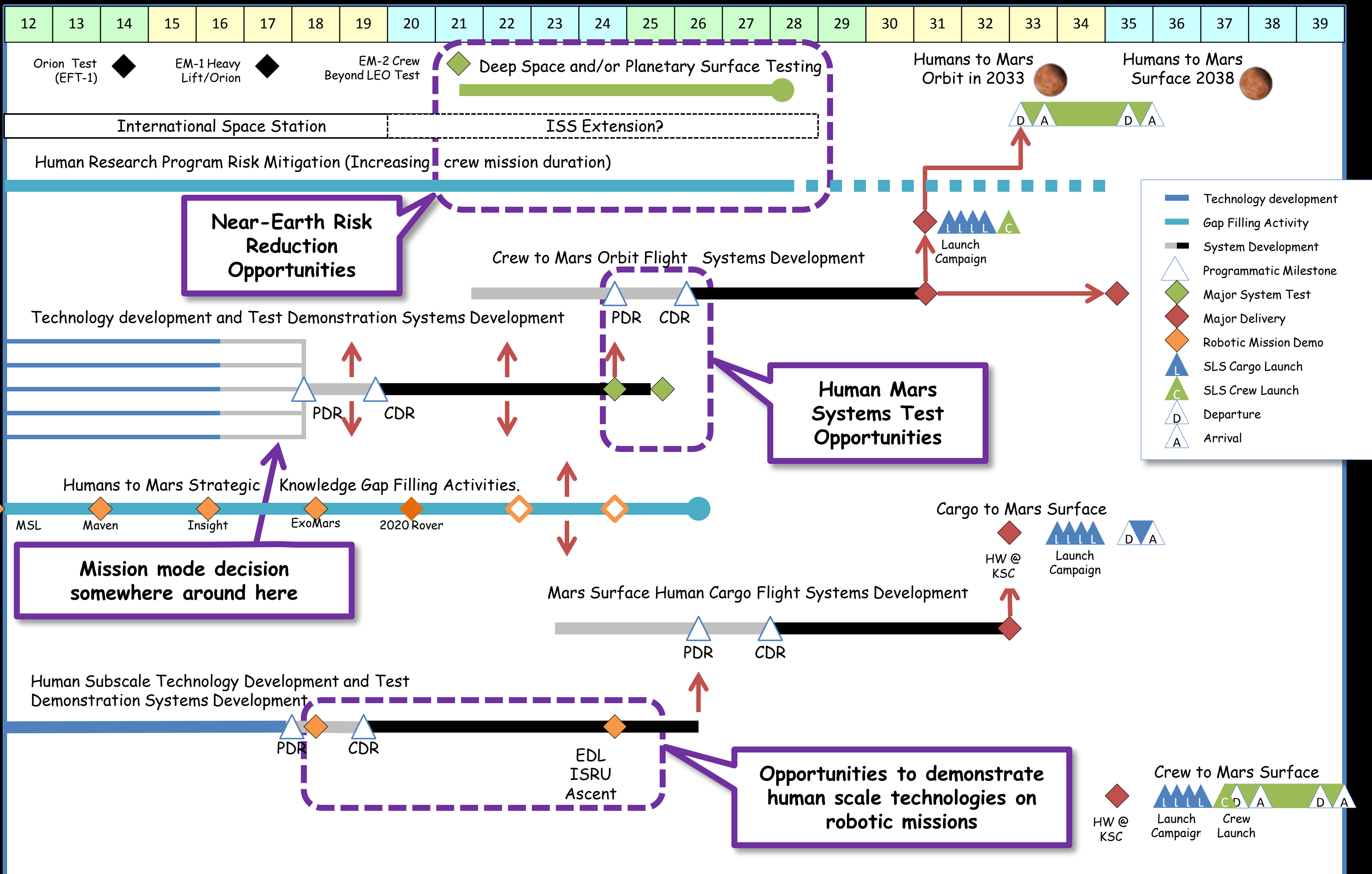




Shallow Ice



If Humans to Mars Orbit by 2033 and to the Surface Two Opportunities Later, then…



Human Exploration of Mars Capability Needs

Launch

- Multiple launches
- Short spacing
- Large mass: 130 t
- Large Volume 10 x 30 m

Space Transportation

- Advanced propulsion to reduce mass
- Fast Transits for Crew (180 days)
- Limited / lack of quick aborts

Entry Descent and Landing

- Large mass (40 t) / Large volume
- Abort to surface
- Precision landing

Crew Surface Health and Support

- Crew acclimation post landing
- Human Support (radiation, hypo-gravity, dust, behavior)
- Planetary protection

Operations

- Automated, rendezvous and docking
- Pre-deploy cargo
- No logistics
- Reliability, maintenance and repair
- Autonomous operations post landing
- Infrastructure emplacement (power)
- High continuous power (40 kWe)
- ISRU oxygen production - atmosphere
- Multiple EVAs, long-range roves, routine exploration

Historical Examples of Human Exploration