Human Health & Performance Aspects
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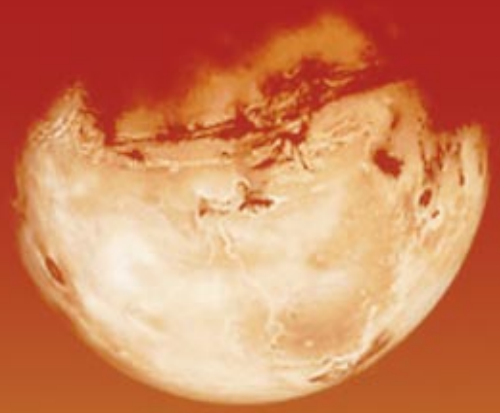
as interpreted and expanded upon by

John B. Charles, Ph.D.

for Human Space Life Sciences Programs Office
(HSLSPO)

Johnson Space Center

Houston, Texas USA

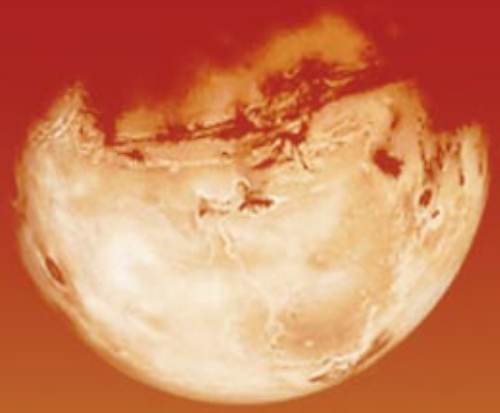


Introduction

Why Do We Go To Space?

Drivers For Space Flights

- Destiny: Space Exploration
- Discovery
  - Looking Outward: Space Sciences
  - Looking Inward: Space Life Sciences
- Profit: Commercial Space
- Threat: Space Security
  - From Beyond
  - From Ourselves
- Survival:
  - Save the Earth: Earth/space Sustainability
  - Save the Species: Space Settlements
- Consciousness: Search for Life (and Extraterrestrial Intelligence)



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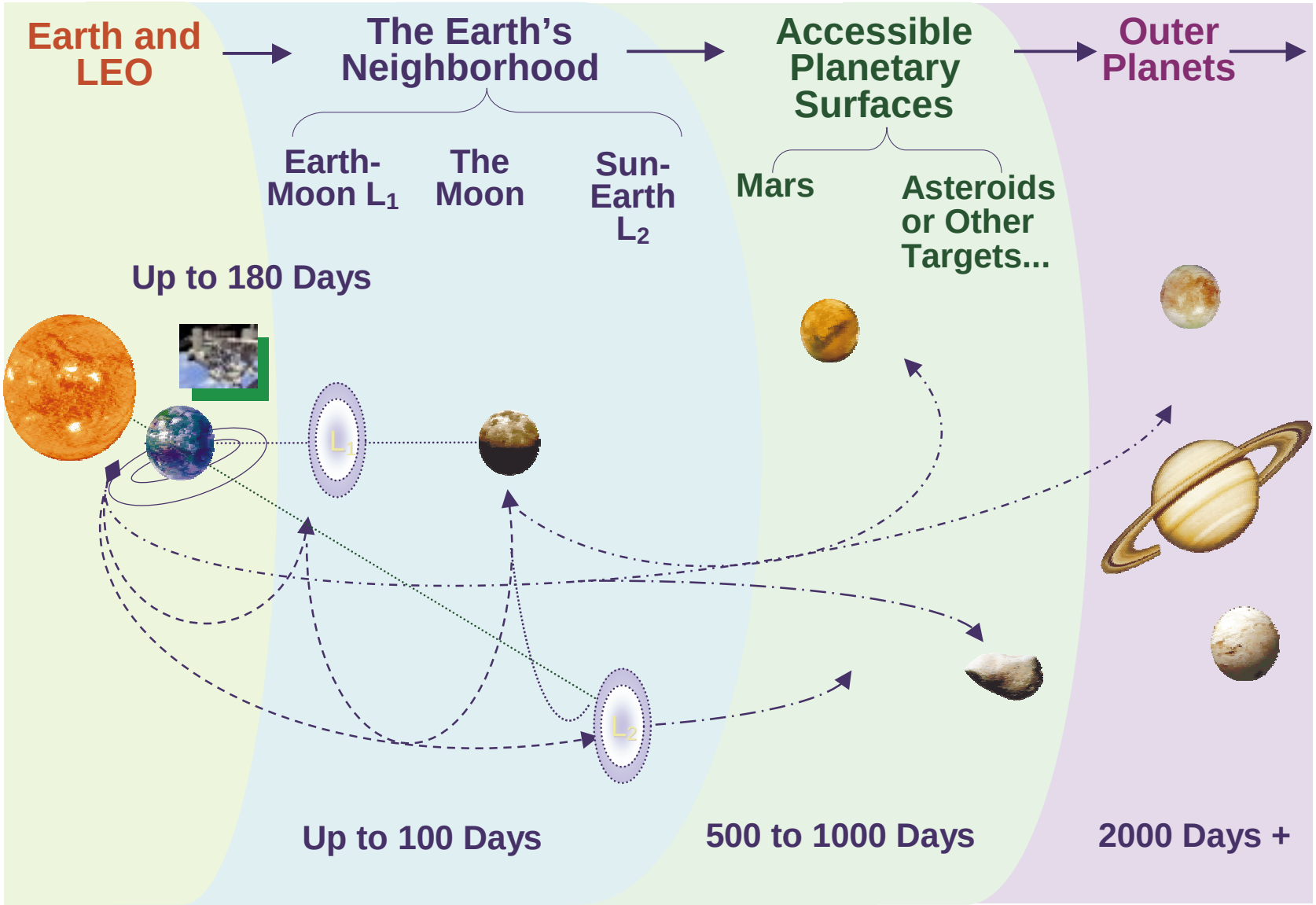
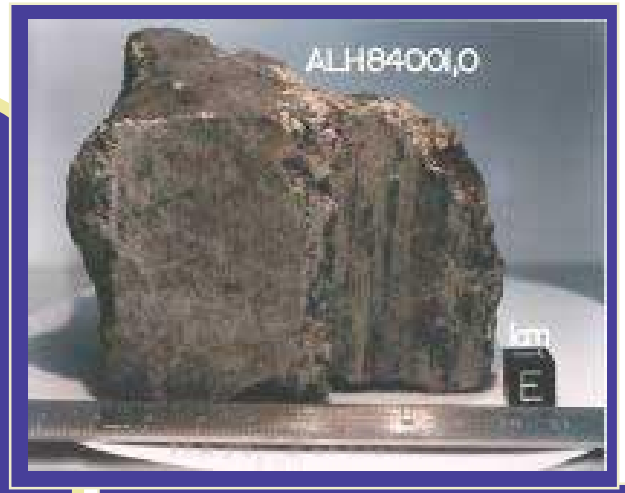
HEDS Strategic Plan

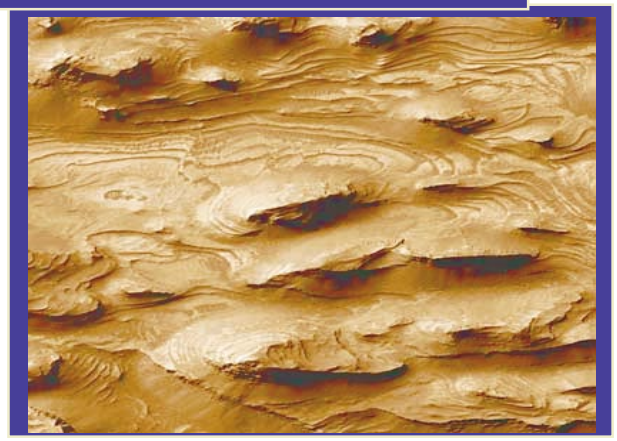
The Places We Could Go



Early Mars Expeditions



- 1996: Discovery of possible microfossil in Mars meteorite recovered in Antarctica energized Mars exploration
- Now focused on search for evidence of life (past and present)
- Variety of benefits from comparative planetology



Early Mars Expeditions

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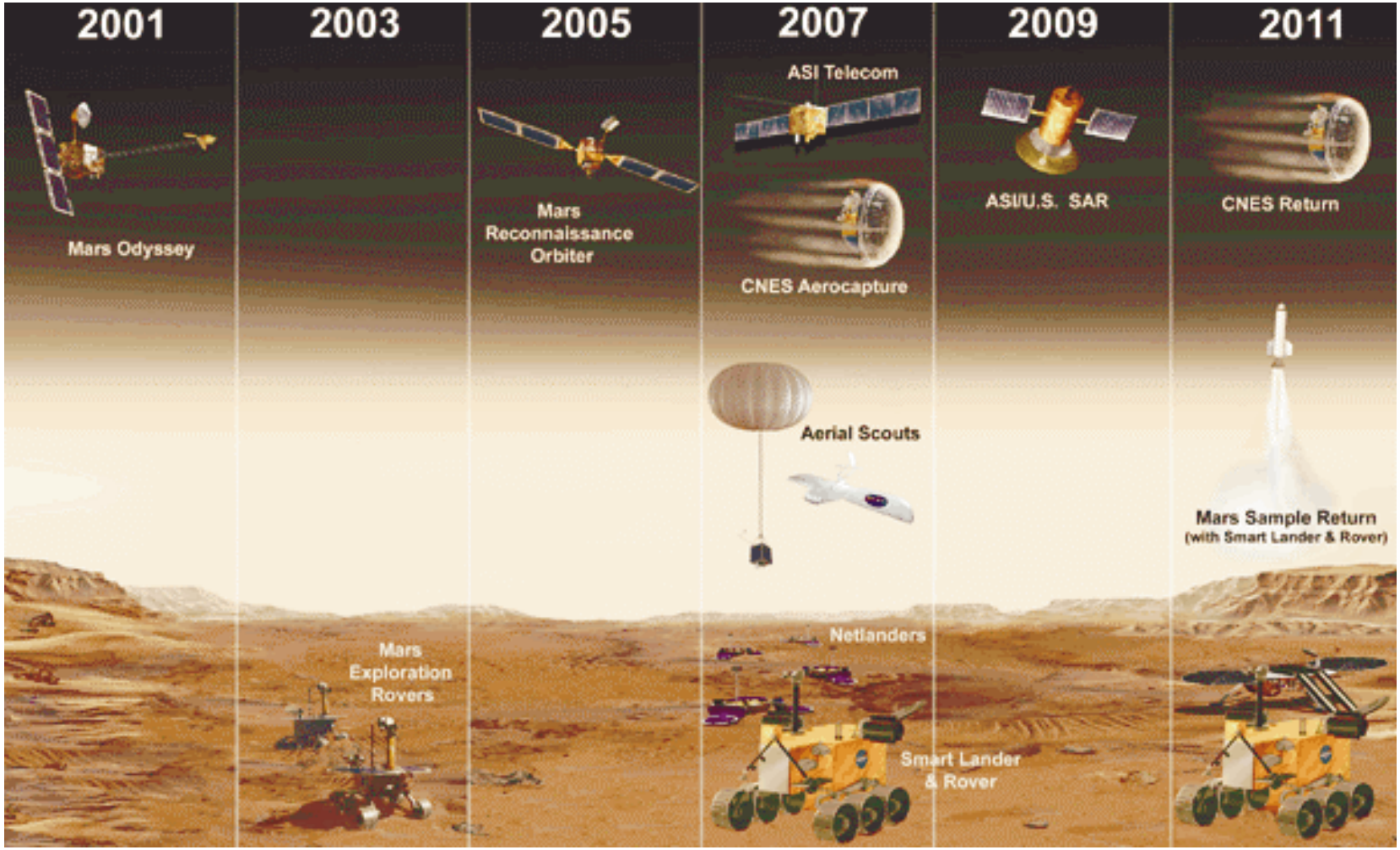


Comparing Earth to Mars

• **Gravity (m/s^2):**	9.81	3.73 (0.38🌎)
• **$Press_{atm}$ (mbar):**	1,000	6 (0.006🌎)
• **Atm. Gases:**	**N2 78%** **O2 21%** **Ar <1%**	**CO2 95%** **N2 3%** **Ar 1.6%**
• **Temp (mean) (C):**	14	-55
• **Solar day (hr.):**	24	24:38 (1.026🌎)
• **Year (days):**	365.26	687 (1.88🌎) 669.6 **Mars days**

But first…

Ad Mars per ISS!

How Will We Go Further Into Space?

International Space Station

ISS is an international cooperative research platform

To provide...

…a state-of-the-art research facility on which to study gravity's effects on physical, chemical, and biological systems

…a commercial platform for space research and development

...a testbed for advanced technology for human space exploration

Use space environment…

…to advance scientific knowledge

…to live, explore, and work productively in space

…to use the attributes of space to improve products and processes on Earth

What Are the ISS Research Areas?

Linking research communities in space and on Earth

Major Research Areas

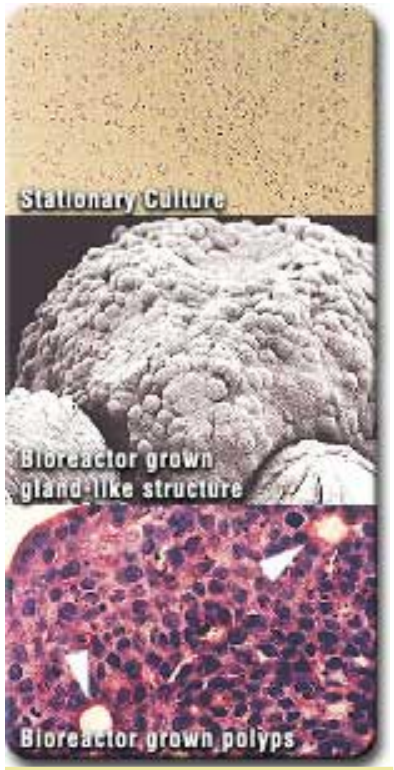
- Biomedical Research and Countermeasures
- Advanced Human Support Technology
- Earth Observation
- Space Science
- Fundamental Biology
- Physical Science
  - Materials Science
  - Biotechnology
  - Low Temperature Physics
  - Fluid Physics
  - Combustion

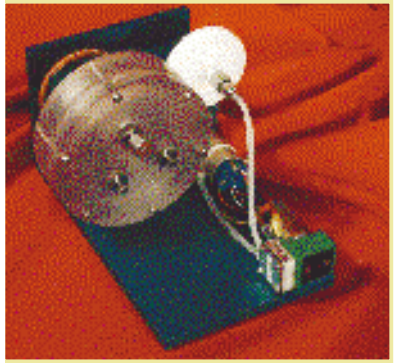
Biomedical Research and Countermeasures Program

- http://spaceflight.nasa.gov/station/science/life/biomedical.html
- BR&C Program Objectives
  - Predictions of astronaut health and safety risks
  - Diagnostics of health status
  - Management of medical and behavioral problems
  - Establishment of human physiologic norms for spaceflight
  - Protection of the astronaut from the physical and physiologic effects of space flight
  - Rehabilitation of crewmembers after space flight
- The BR&C Program includes five research elements:
  - Radiation Health
  - Behavior and Performance
  - Physiology
  - Environmental Health
  - Operational and Clinical Research

Physiology

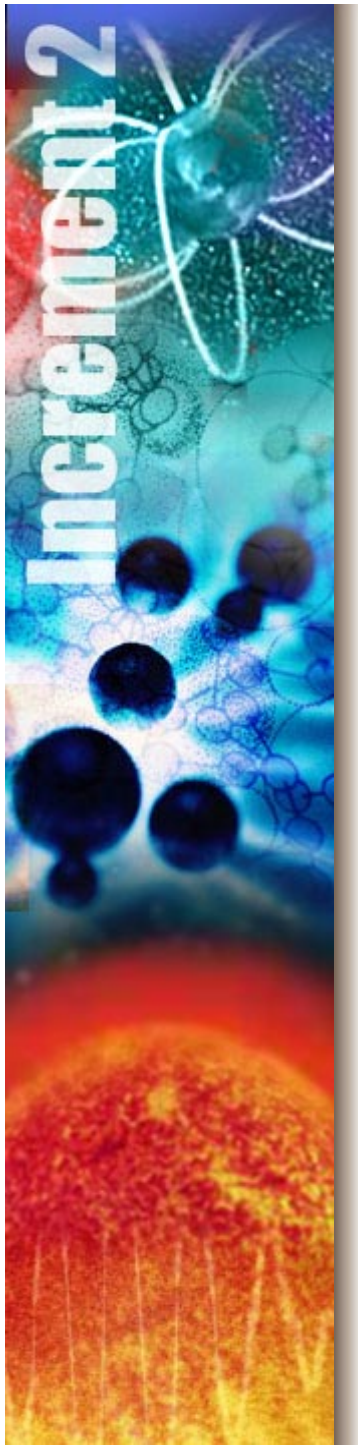
- http://spaceflight.nasa.gov/station/science/life/physio.html
- Virtually every system in the body — from bones and muscles to the immune system — is tied to and affected by the force of gravity
- The unique value of orbital research in physiology and biotechnology has led to a vigorous program of cooperation between NASA and the National Institutes of Health that includes 18 cooperative agreements and a series of flight experiments.





Biotechnology

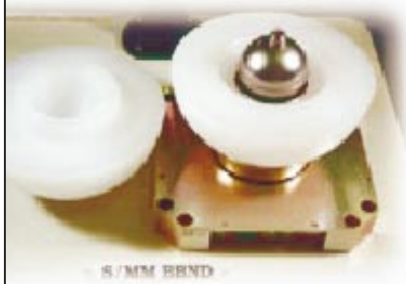
- http://spaceflight.nasa.gov/station/science/life/cancer.html
- 3-D tissue growth in the rotating bioreactor
- growth and study of cellular structures including tissues and macromolecular crystals
- determine the structure of macromolecular crystals to design bioactive molecules with the potential to treat diseases such as AIDS, diabetes and cancer



Radiation Research

- Continuous monitoring of the radiation environment with dedicated equipment
  - The Phantom Torso (TORSO): monitors radiation absorption at brain, heart, stomach, thyroid, colon (2 month study)
  - Dosimetric mapping (DOSMAP): document nature and distribution of radiation inside ISS and around crew-members' bodies - German investigator, periodic data download (4 month study)
  - Bonner Ball Neutron Detector (BBND): monitors neutron radiation that may affect blood-forming bone marrow
    - NASDA provided hardware
    - Increments 2 and 3 (ongoing 8 months)
- Medical research and care
  - Data base of personal annual and lifetime exposure limits for crew members with regular medical examinations (ongoing)

Phantom Torso

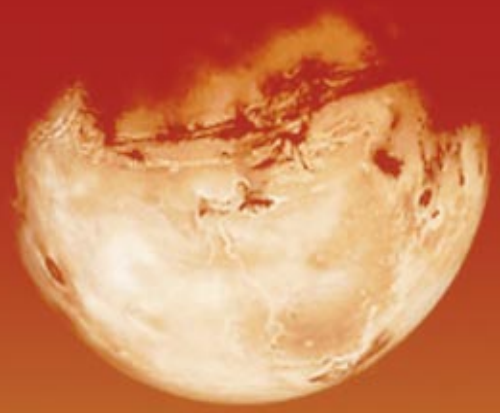


Bonner Ball

ISS Biology Research Facilities @ Assembly Complete

- Human Research Facility (HRF) containing multiple pieces of equipment to support medical monitoring equipment* (2/01 and 2/02)
- Life sciences glove box (9/04)
- Biology habitats
  - Cells (9/04 and 2/05)
  - Insects (9/04)
  - Rodents (rats, eventually mice - 10/05)
  - Plants (07)
  - Fish (fresh water and marine-07)
  - Egg Incubator (07)
- Centrifuge for biology habitats (5/06)

*Elements of the Crew Health Care System may be used in research activities as required and available



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isclaimer

At this time, NASA does not have the authority to undertake a piloted Mars mission. No claim to the contrary can be inferred from this presentation.

This presentation is based upon the Mars Design Reference Mission (NASA Special Publication 6107, July 1997)and summarizes the work of NASA scientists, engineers, and planners who defined it. This work forms a basis for comparing different approaches and criteria involving new or improved technologies, in order to select from among them at the appropriate time.

Bibliography

Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team **(Stephen J. Hoffman and David I. Kaplan, eds.) NASA Special Publication 6107, July, 1997.**

The author has augmented the information in the primary source with insights from many formal briefings, informal conversations, and personal musings, some of which are based on the following works:

Oberg, James E. ***Mission to Mars : Plans and Concepts for the First Manned Landing.*** **Harrisburg, PA: Stackpole Books, 1982.**

Collins, Michael. ***Mission to Mars: An Astronaut's Vision of Our Future in Space.*** **New York: Grove Weidenfeld, 1990.**

Zubrin, Robert. ***The Case for Mars: The Plan to Settle the Red Planet and Why We Must.*** **New York: The Free Press, 1996.**

Early Mars Expeditions

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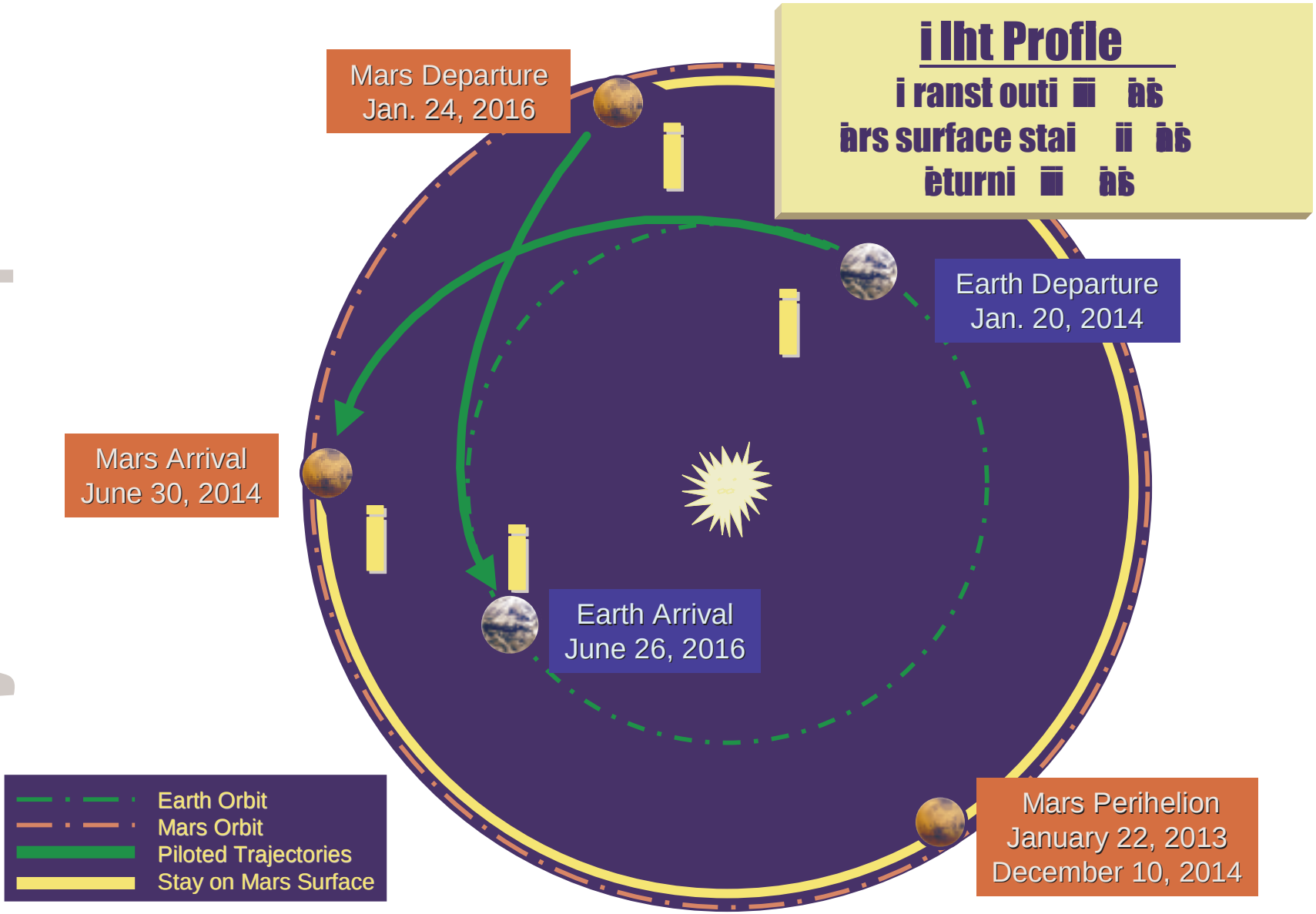
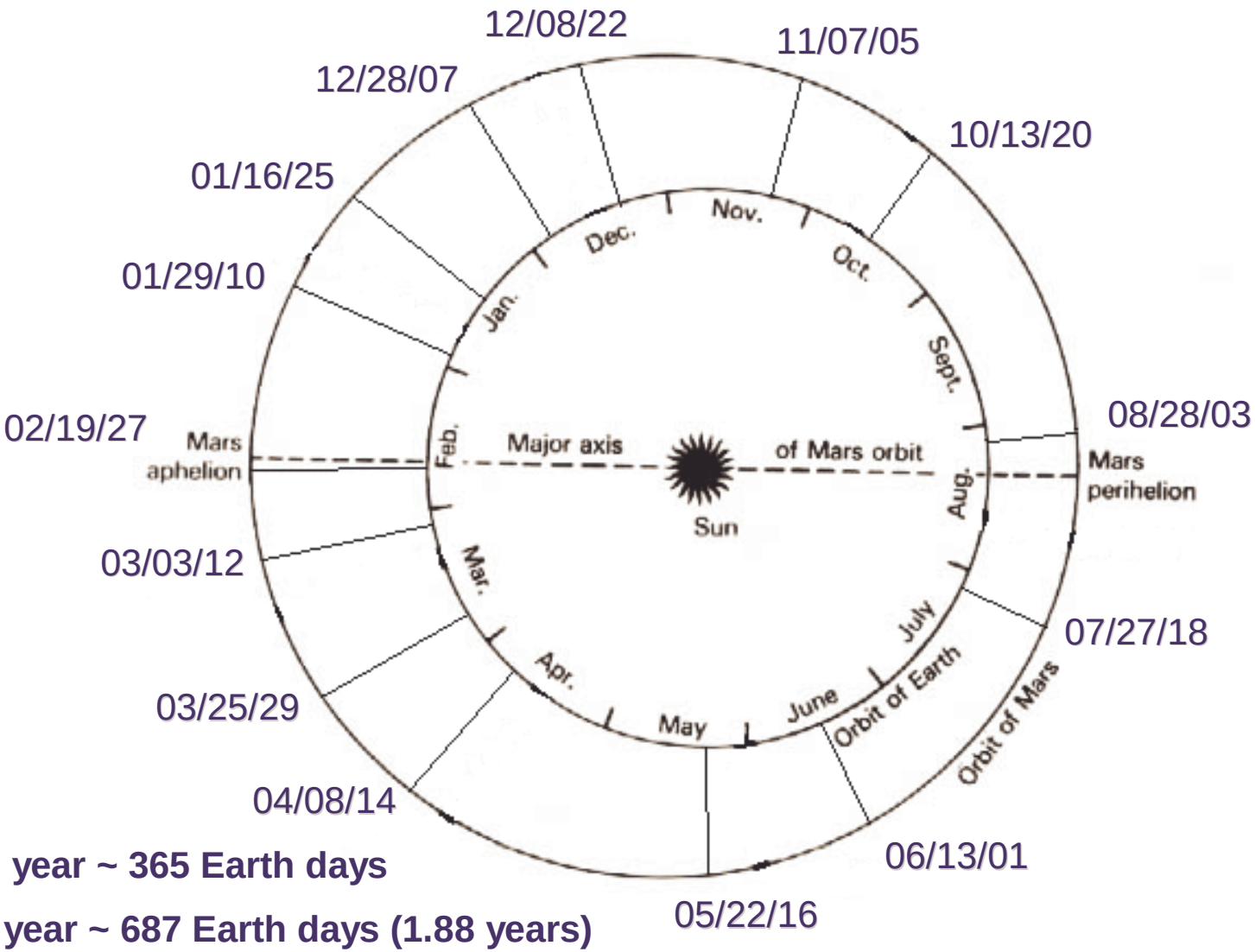


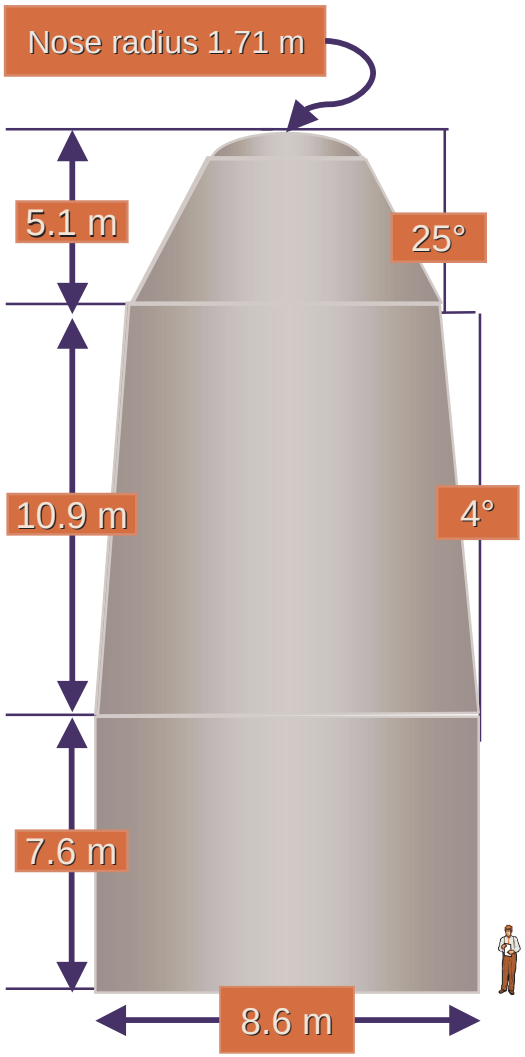
Earth-Mars Oppositions 2001-2029



Earth year ~ 365 Earth days

Mars year ~ 687 Earth days (1.88 years)

Vehicle Concepts
based on the Triconic Aeroshell

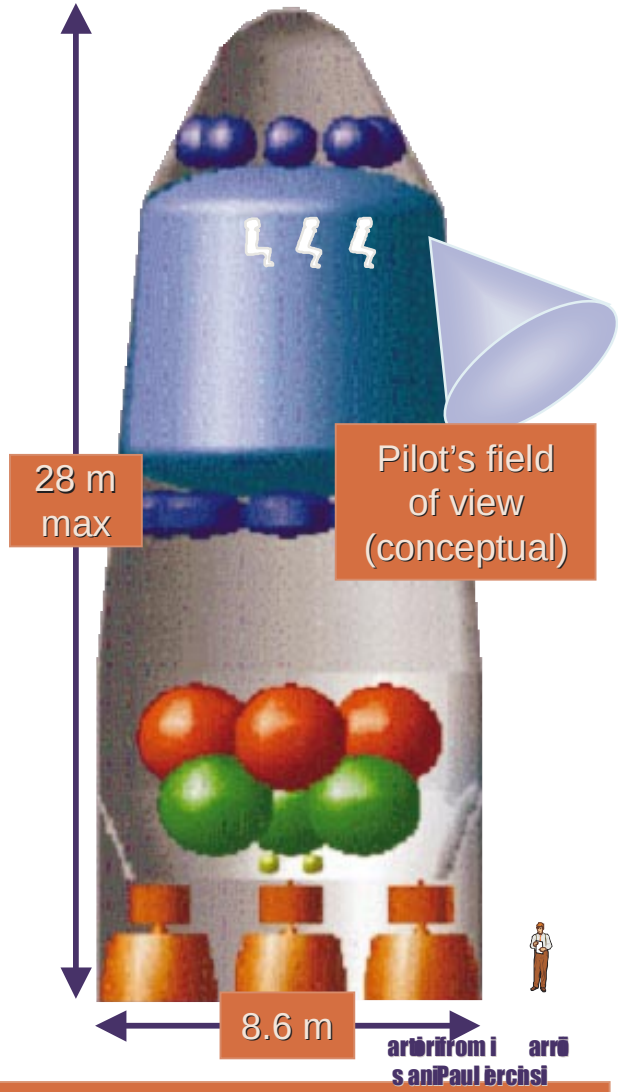


Vehicle Components & Functions

Piloted transit habitat vehicle
- outbound transit habitat
- Mars crew landing vehicle
- Mars surface habitat

Cargo vehicle
- arrives at Mars before crew
- delivers Mars ascent vehicle and ISRU plant to Mars surface

Trans-Earth vehicle
- Earth return vehicle
- arrives at Mars before crew
- waits in orbit around Mars to transport crew home



Triconic Aeroshell
- sized to "Magnum" booster
- defines the size & shape of the Mars vehicles

Crew Seating
- $+g_x$ for aerobraking (seatbacks 23° forward of vertical)
- $+g_z$ for landing (seatbacks vertical)

ISRU: *in situ* resource utilization

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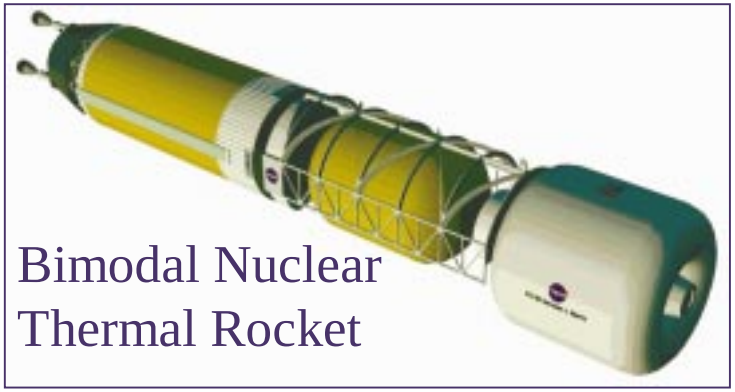
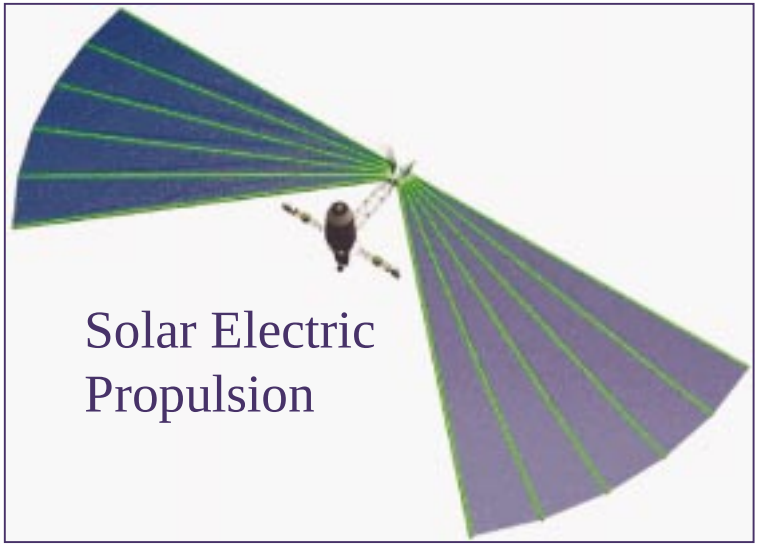
- Round trip: ~30 mo.
  - Outbound transit: 4-6 mo.
  - At Mars (mostly on surface): 18 mo.
  - Inbound transit: 4-6 mo.
  - Ballistic trajectory
    - crew depart from ~LEO: propulsive
    - Mars orbit insertion & landing: propulsive and/or aerobrake
    - Mars ascent, departure: propulsive
    - Earth entry, descent, landing: propulsive and/or aerobrake
- Baseline: Nuclear Thermal Rocket (NTR)
  - ^{235}U, LH_2
- Variant: Solar Electric Propulsion (SEP)
  - Spiral out to highly eccentric Earth orbit (HEO) (~9 mo.) uncrewed
  - Crew inserted for chemical propulsion departure
  - Similar to NTR thereafter





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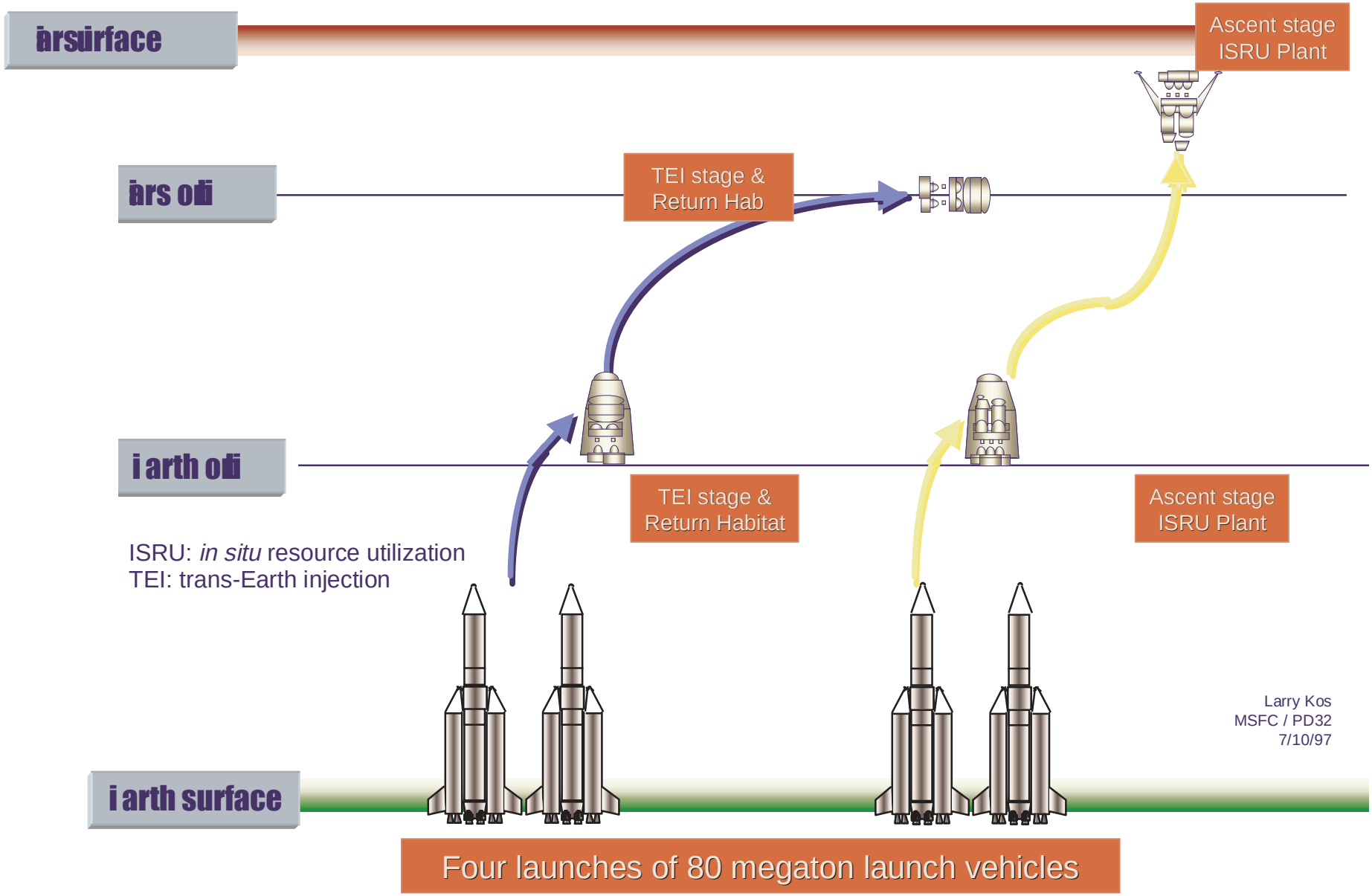

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MSFC / PD32
7/10/97

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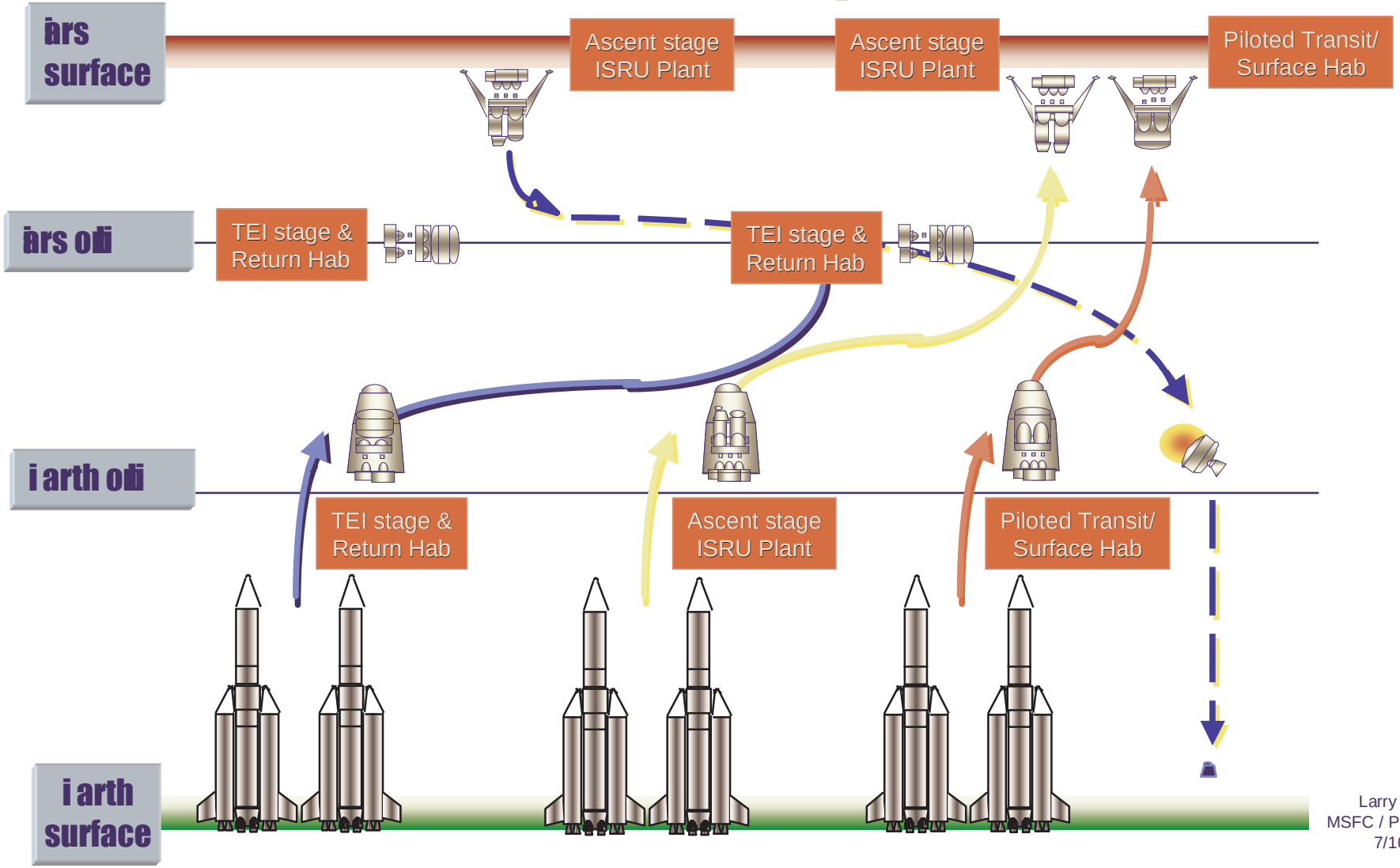

Larry Kos
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Two launches of 80 megaton launch vehicles
(Six launches including backup vehicles)

ISRU: *in situ* resource utilization
TEI: trans-Earth injection

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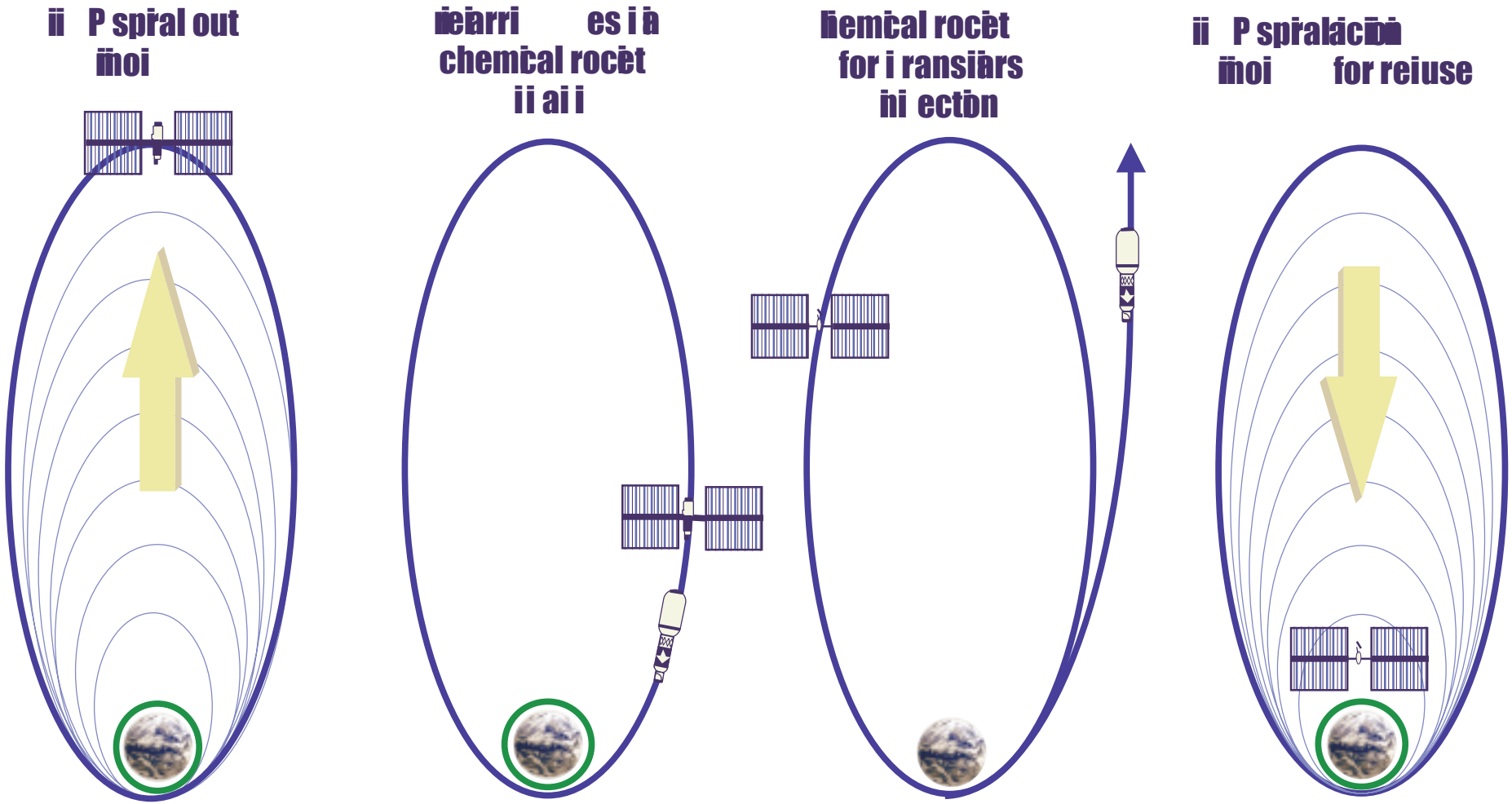

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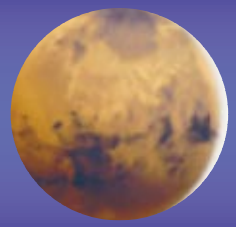
- Trans-Mars Injection (Earth-departure maneuver)
  - Impulsive propulsion (nuclear-thermal, chemical) may prohibit abort within hours or days of TMI
  - Low-thrust propulsion (solar-electric, plasma) ***if available after TMI*** may permit abort, but only with long return time lasting weeks or months
- Missed Mars orbit insertion or direct entry
  - Mars flyby may result in multi-year return to Earth that is similar in duration to nominal mission

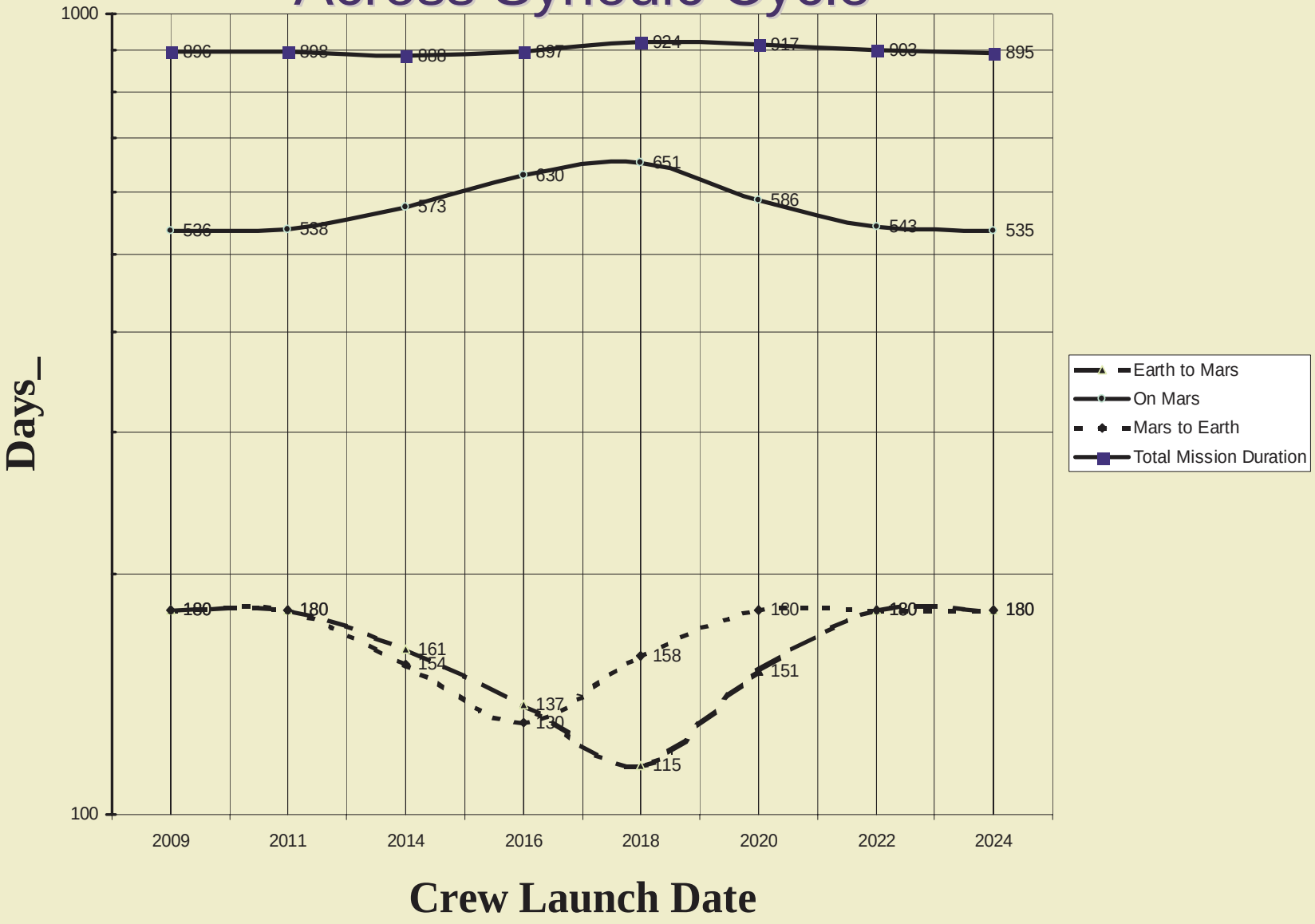


iAirt to ìarsi optbns

- Life support and other resources already deployed
- Mars environment provides the most safety after Earth (offers radiation shield and partial gravity)

Early Mars Expeditions

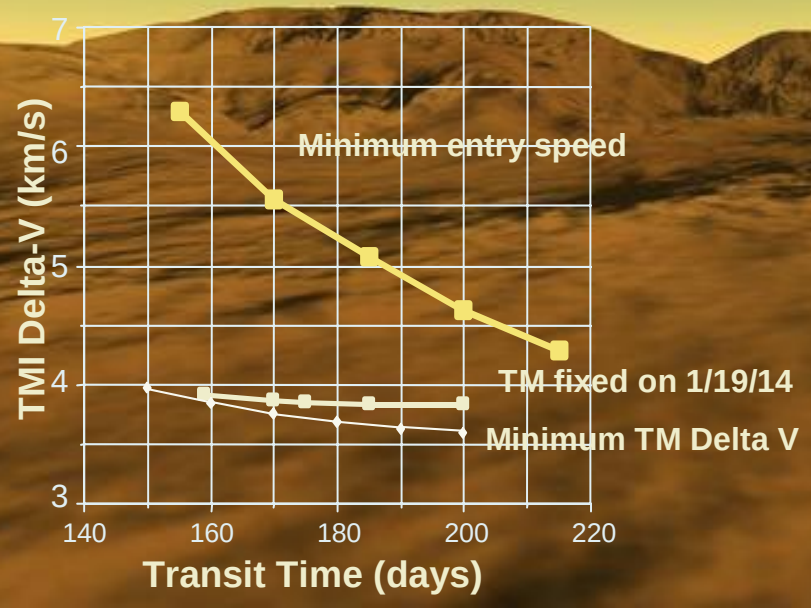
Durations of Transits and Lay-Overs Across Synodic Cycle

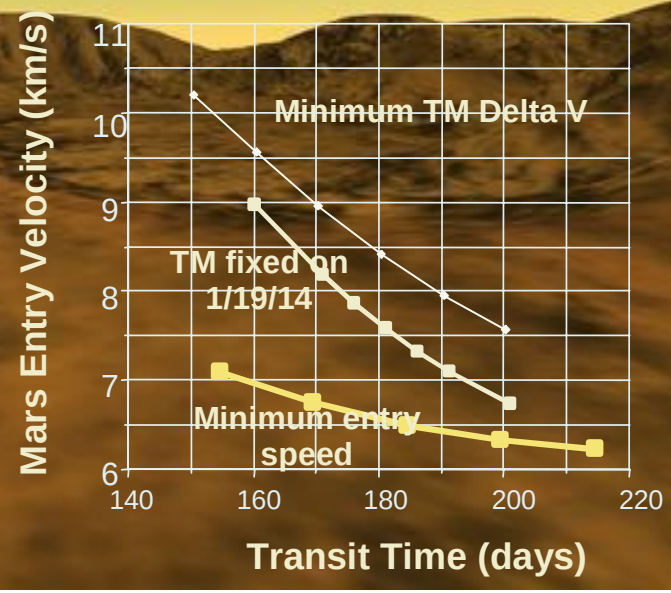


Key Parameters Affecting Aeroassist (DRM V3.0)

Earth-Mars 2014 Opportunity Crewed Launch

- Choice of launch date and trip time have significant impact on TMI ΔV and V_e at Mars
- Non-optimum TMI ΔV trajectories can reduce Mars entry velocity 0.7-1.2 km/s with 2-6% increase in TMI ΔV



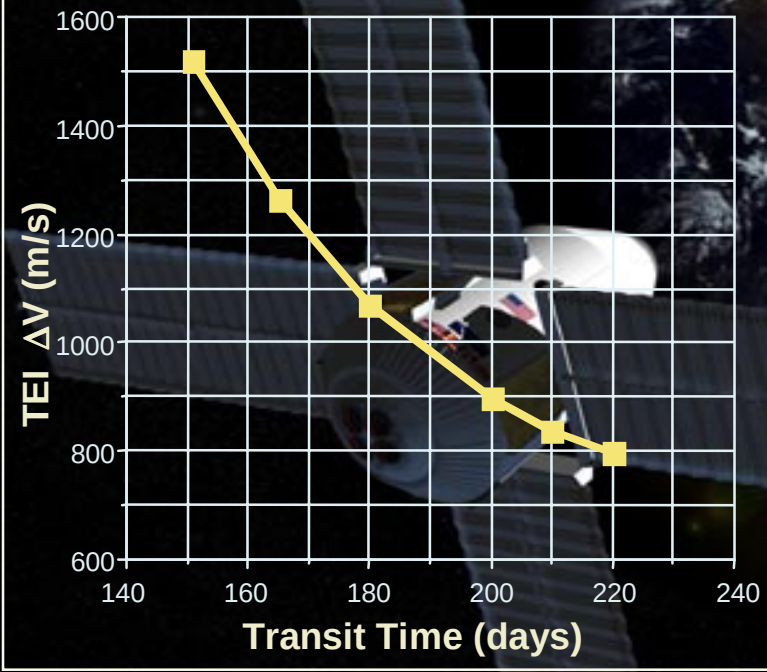


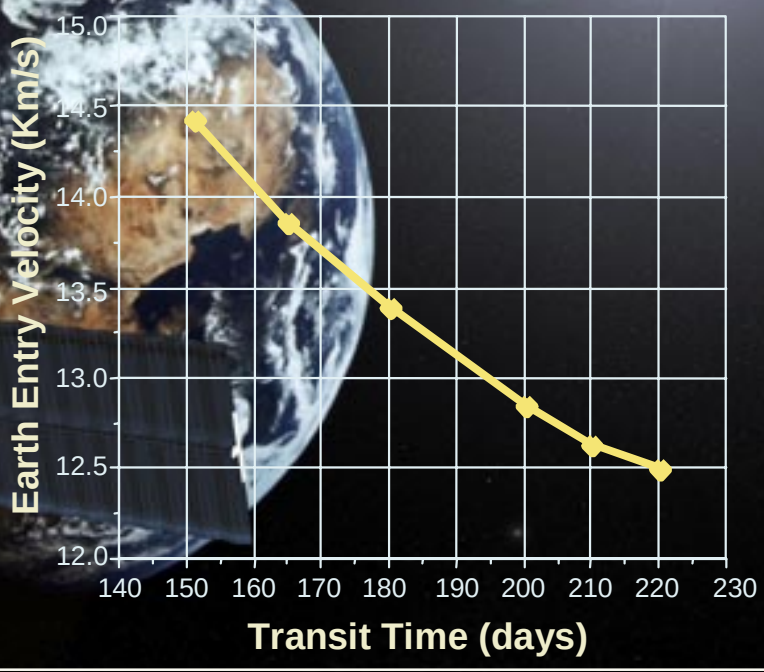
POC: E. Lyne (U-Tenn), M. Munk (JSC)

Data from Jim Arnold, Dec. 16, 1997

Key Parameters Affecting Aeroassist (DRM V3.0)

Mars-Earth 2016 Opportunity, minimum trans-Earth injection conditions





- ➔ Choice of launch date and trip time have significant impact on TEI ΔV and Ve @ Mars
- ➔ Increasing trip time reduces both TEI ΔV and Earth entry velocity
- ➔ DRM conditions -> 13.0 - 13.5 Km/s entry velocity
- ➔ Further analysis needed to look at synodic period effects on Earth entry velocity

Data from Jim Arnold, Dec. 16, 1997

Mars Mission & Propulsion Options constant acceleration

- Plasma rocket: variable specific impulse magnetoplasma rocket, VASIMIR
- Continuous acceleration ~0.01 g
  - Not biologically protective g-level
  - Benefit: short trip time, reduced exposure to weightlessness, radiation, other risks
- Round-trip: ~8 month
  - 1 month spiral out to HEO
  - 3 month outbound
  - 1 month at Mars
  - 3 month Return
- Supercritical H2 propellant also serves as radiation shield

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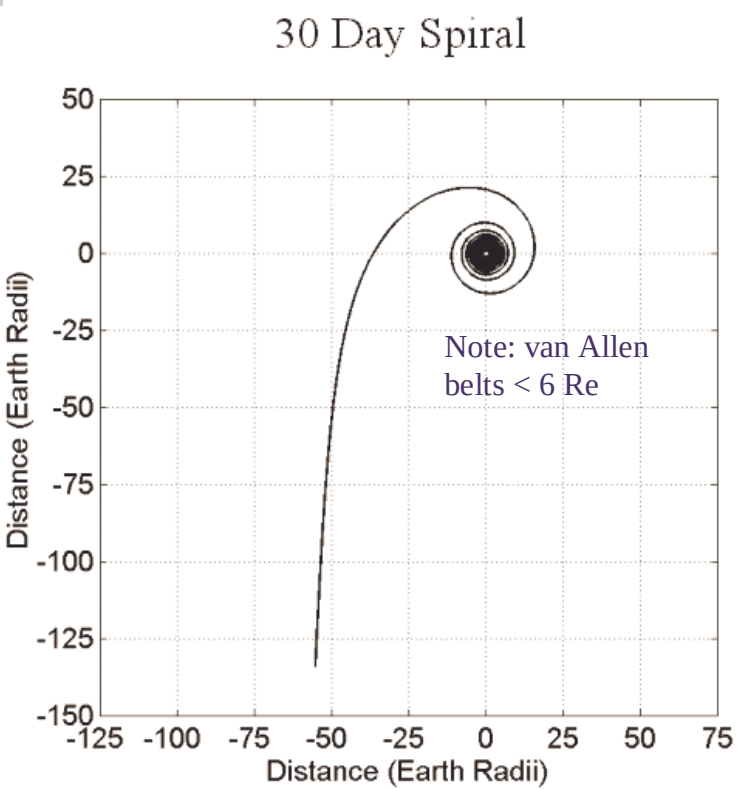
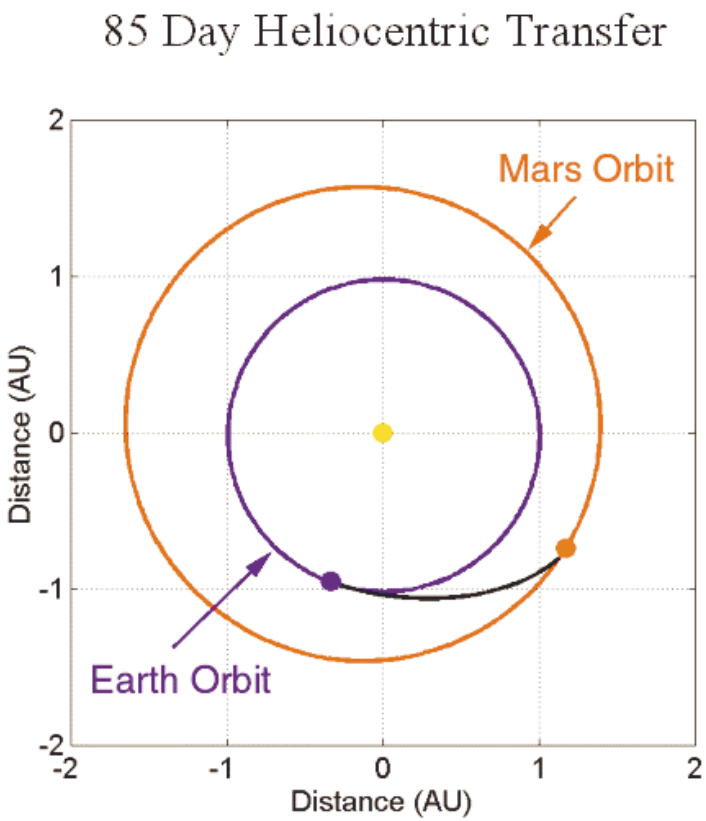
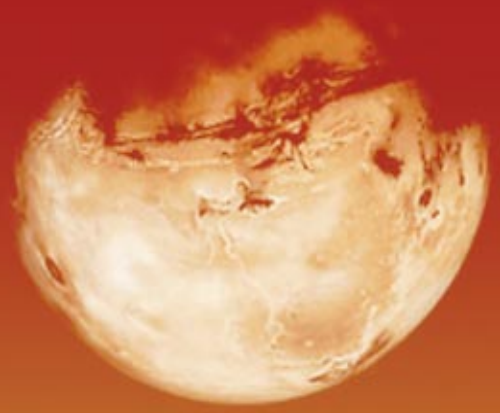




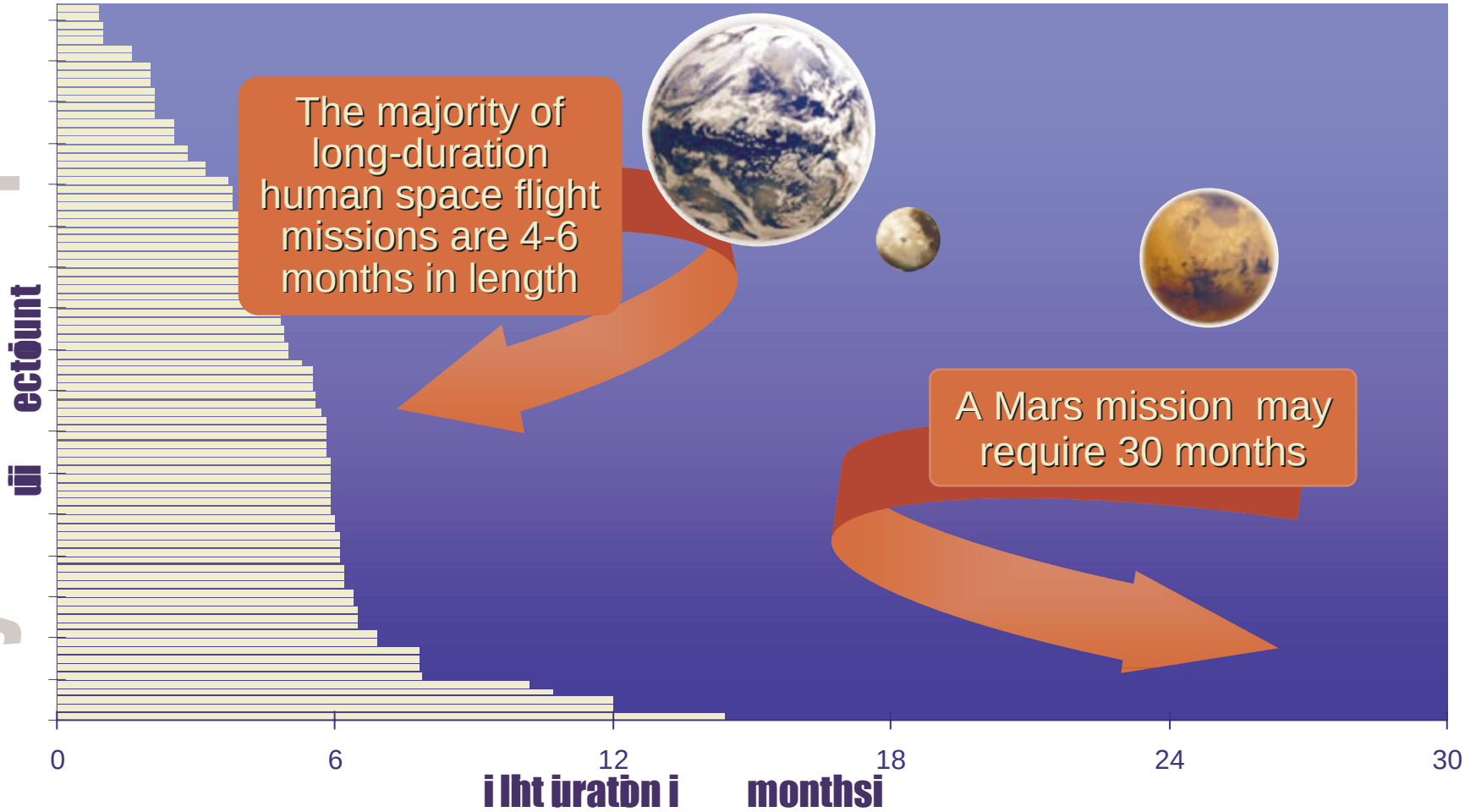


Ethical Issues

Early Mars Expeditions

Humanpiace i lht i i perènce

(Includes flights longer than 30 days as of January 1998)



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Astronautics
Critical Path Roadmap (CPR)

CPR: blueprint for focused evolving research and technology for "risk reduction" to prevent or reduce the risks to humans in space environment

- Mars Design Reference Mission (1997) - "most challenging" scenario
- Identified: 55 risks, 343 critical questions in 12 risk areas

- Habitation systems
  - Advanced life support
  - Environmental health monitoring
  - Food and nutrition
- Medical care systems
  - Clinical capabilities
  - Multi-system (cross-risk) alterations
- Adaptation and countermeasure systems
  - Bone loss
  - Cardiovascular alterations
  - Human behavior and performance
  - Immunology, infection and hematology
  - Muscle alterations
  - Neurovestibular adaptation
  - Radiation effects

Medical Requirements

Human Health & Performance during Interplanetary Space Flight

- **Basic Elements**
  - Nutrition (adequate, appropriate, appealing)
  - Rest (avoid chronic fatigue)
  - Exercise (fitness, recreation, motivation)
  - Human Performance (psychosocial, workload, human-robotic interface, & circadian factors)
- **Habitability** including extra-vehicular activity, advanced life support, & environmental health
- **Countermeasures & preventive measures** for deleterious physiological effects
- **Diagnosis** of new or pre-existing conditions
- **Treatment** subsequent to diagnosis
- **Research** directed towards fulfilling all of the above

Elements & Interfaces

Early Mars Expeditions

Space Medicine
- in-flight debilitation, long-term failure to recover, clinical capabilities, and skill retention

Advanced Life Support
- atmosphere, water, thermal control, logistics, waste disposal

Environmental Health
- atmosphere, water, contaminants

Planetary Extra-Vehicular Activity
- dust, suit design, serviceability

Radiation Effects
- carcinogenesis, CNS damage, fertility, sterility, heredity

Human Performance
- psychosocial, workload, sleep

Human Health & Performance

Early Mars Expeditions

Bi lements &ateibres

Bone Loss
- fractures, renal stones, osteoporosis, drug reactions

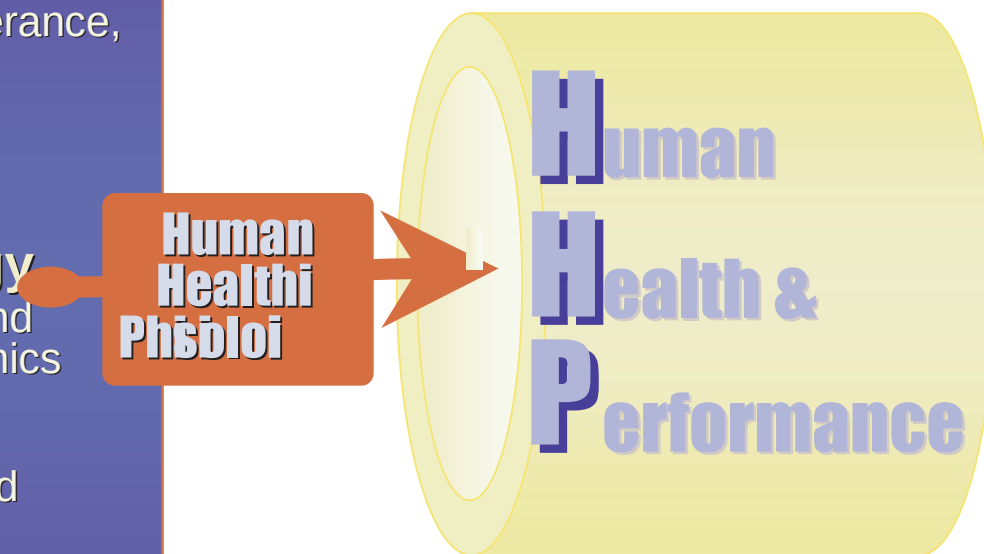
Cardiovascular Alterations
- dysrhythmias, orthostatic intolerance, exercise capacity

Food and Nutrition
- malnutrition, food spoilage

Immunology & Hematology
- infection, carcinogenesis, wound healing, allergens, hemodynamics

Muscle Alteration
- mass, strength, endurance, and atrophy

Neurovestibular Adaptations
- monitoring and perception errors, postural instability, gaze deficits, fatigue, loss of motivation and concentration



Early Mars Expeditions

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- air purifier
- water purifier
- particulate analyzer
- microbial analyzer
- waste manager/recycling
- food storage
- food processor
- clothing manager (e.g., washing machine)
- lighting levels
  - intensity (threshold level)
  - periodicity (circadian rhythmicity)

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Performance

Physical Challenges

Radiation

	Earth launch	Transit	Mars landing	Mars surface	Mars launch	Transit	Earth landing
Source	van Allen belts (trapped radiation)	GCR (quiet sun); SPE (active sun); nuclear power reactor		GCR (quiet sun); SPE (active sun); nuclear power reactor		GCR (quiet sun); SPE (active sun); nuclear power reactor	
Exposure	SEP option: 3 passengers or more	4-6 months		18 months; shielded by Mars' bulk & atmosphere		4-6 months	
Cumulative Exposure	hours-days		4-6 months		22-24 months		26-30 months

GCR: galactic cosmic radiation
SPE: solar particle events
SEP: solar electric propulsion

Issues: Radiation

Issue: Radiation Environment

- Attenuation of GCR and SPE by atmosphere and bulk of planet
- Possible risk from neutron backscatter from surface
- TBD shielding for EMU and habitat

CPR: Radiation effects (possible synergy with hypogravity and other environmental factors)

- Early or Acute Effects from Radiation Exposure (esp. damage to Central Nervous System)
- Carcinogenesis Caused by Radiation

Physical Challenges

	i arth i aunch	i ranst	ars i anni	ars urface	ars i aunch	i ranst	i arth i anni
i i oai	up to 3 g	0 g	3-5 g	1/3 g	TBD g	0 g	3-5 g
ites	boost phase (8min); TMI (min)	4-6 months	aerobraking (min); parachute braking (30s); powered descent(30s)	18 months	boost phase (min); TEI (min)	4-6 months	aerobraking (min); parachute braking (min)
imulati e hipoi i	0		4-6 months		22-24 months		26-30 months
transtion	1 g to 0 g		0 g to 1/3 g		1/3 g to 0 g		0 g to 1g

TMI: trans-Mars injection
TEI: trans-Earth injection

Early Mars Expeditions

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ioneiai arthiars communicatons time is i iini i

Health care functons

- Nutrition
- Exercise
- Psychological support
  - planned activities
    - entry/landing simulations
    - housekeeping
    - refresher training
    - cruise science (rover operations/site preparation, microgravity, astronomy, and biomedicine)
  - communications
    - reliable contact with mission control, family, & friends
- Health Care
  - autonomous care
  - telemedicine

Hatat facltes

Exercise & conditioning for Mars surface activities

Recreation & privacy

Maintenance & housekeeping (including workshop)

artwork from Constance Adams and Kris Kennedy for the JSC TransHab Team

Impacts of Prolonged Weightlessness

Physical tolerance of stresses during aerobraking, landing, and launch phases, and strenuous surface activities

Bone loss

- no documented end-point or adapted state
- countermeasures in work on ground but not yet flight tested

Cardiovascular alterations

- pharmacological treatments for autonomic insufficiency

Muscle atrophy

- resistive exercise under evaluation

Neurovestibular adaptations

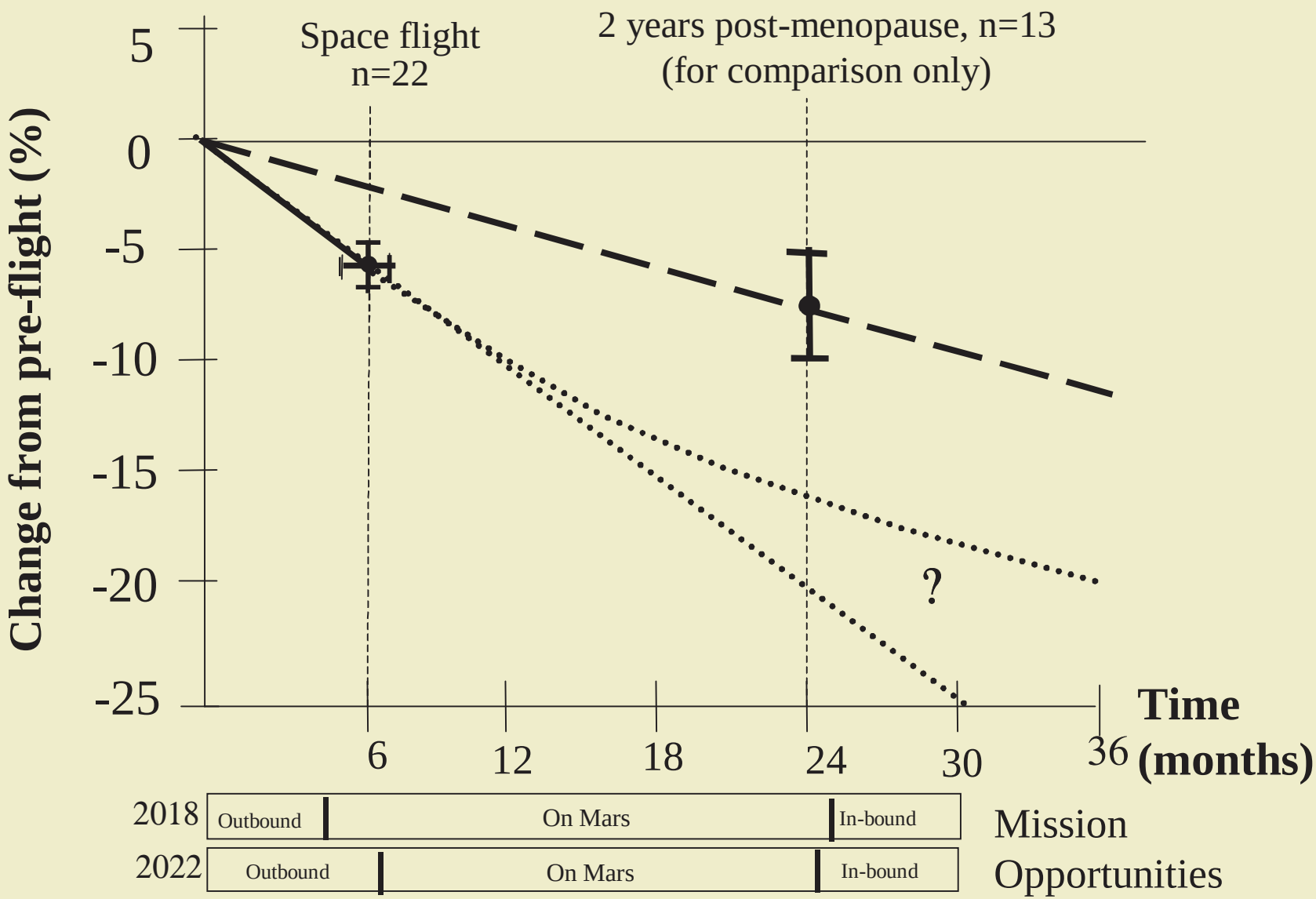
- vehicle modifications, including centrifuge
- may require auto-land capability

Physiological Risks

Physical tolerance of stresses during aerobraking, landing, and launch phases, and strenuous surface activities

- CPR: Musculo-skeletal atrophy
  - Inability to perform tasks due to loss of skeletal muscle mass, strength, and/or endurance
  - Injury of muscle, bone, and connective tissue
  - Fracture and impaired fracture healing
  - Renal stone formation
- CPR: Cardiovascular alterations
  - Manifestation of serious cardiac dysrhythmias and latent disease
  - Impaired cardiovascular response to orthostatic stress and to exercise stress
- CPR: Neurovestibular alterations (possible synergy with radiation)
  - Disorientation
  - Impaired coordination
  - Impaired cognition

Bone Interim Weightlessness

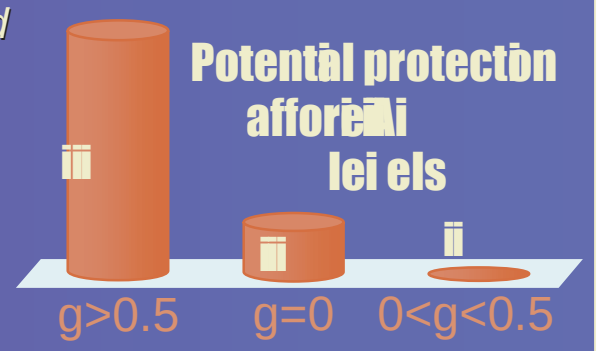


Artificial Rai tonsiderations

an artificial rai tipreseri e phisiolocal function
urnilonni iuration missionsi

Actions neeeito accomplish ars mission transit

- **Vigorously investigate** AG to reach a consensus about AG for Mars mission
- **Explore current approach**: AG may be used to pre-adapt crew to Mars gravity (outbound) and re-adapt to Earth gravity (inbound):
  - provides extended physiological protection from 1 g
  - eases transition throughout 1/3 g exposure
  - requires AG capability of 1 g outbound and *inbound*
- **Define parameters** for optimal g level
  - initiate benchmark studies based on best guess
  - evaluate protective effects (if any) of 1/3 g
  - continue studies on optimal angular rate:
    - few problems if $\omega < 1$ rpm
    - some problems if $1 > \omega > 6$ rpm
    - more problems if $6 > \omega > 10$ rpm
    - no data if $\omega > 10$ rpm

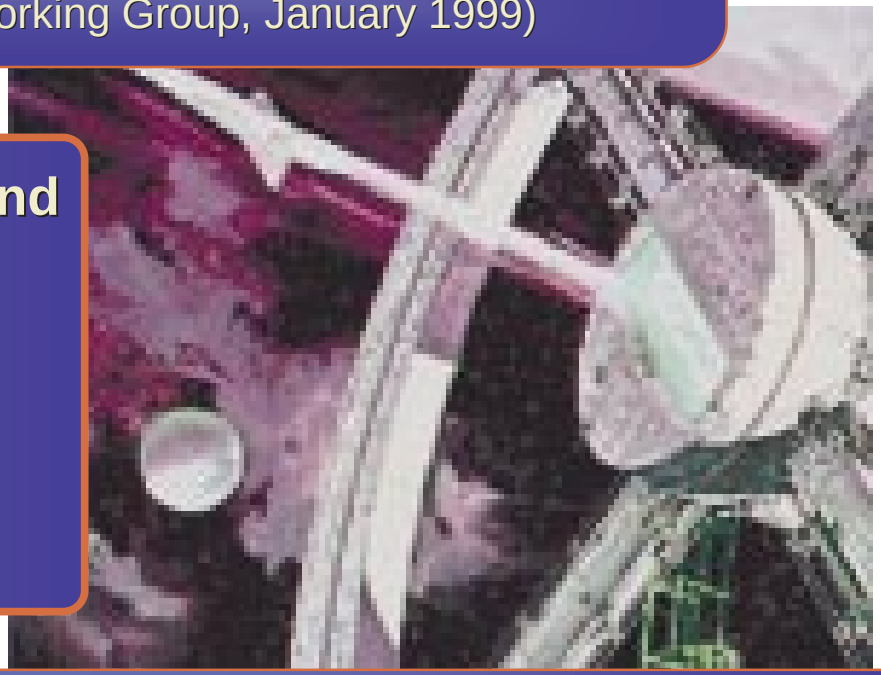


Note: no consensus currently exists on AG levels needed for exploration missions

Artificial Gravity

What steps are required to certify Artificial Gravity as a countermeasure to eliminate weightlessness?

(per Artificial Gravity Working Group, January 1999)



- **Establish a comprehensive ground research program**
- **Implement a flight research program**
  - International Space Station
  - Space Shuttle

- **Focus on the following research priorities**
  - Determine optimal characteristics for intermittent AG
  - Identify g threshold values needed to maintain HHP (including 1/3 g exposure for 18 months)
  - Determine optimal AG characteristics (e.g., radius and angular velocity)

Early Mars Expeditions

Artificial Concepts

Continuous Ionic Thrust Ion ω

1969: NERVA powered duplicate vehicles docked for rotation

1999: Bimodal NTR design allows rotation

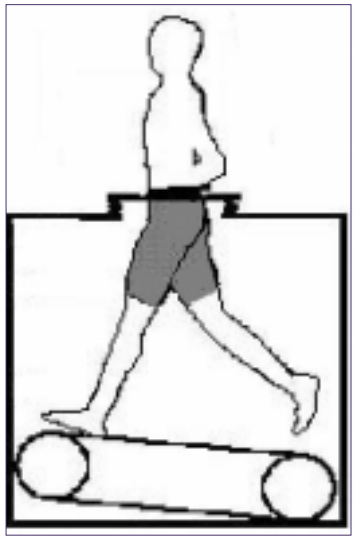
- 0.38 g outbound
- 0.8 g inbound

Early Mars Expeditions

Concepts

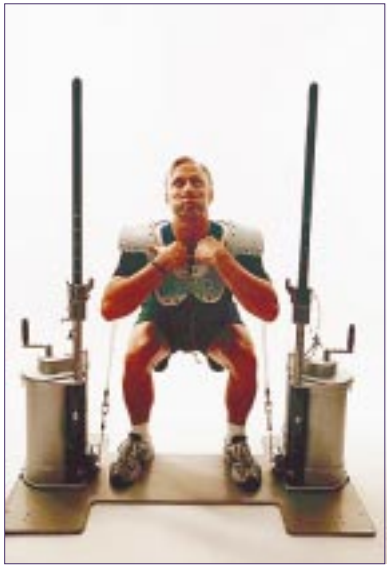
Mai tiAumentationi
urhi i ercise n i ranst anin arsurface

Space Cycle™
(Kreitenberg, UC-Irvine)



Exercise in LBNP
(Hargens, NASA ARC)

Human-powered centrifuge
(Greenleaf, NASA ARC)



ISS Resistive Exercise Device
(Schneider, NASA JSC)

Self-Generated LBNP
(Hargens, NASA ARC)

Early Mars Expeditions

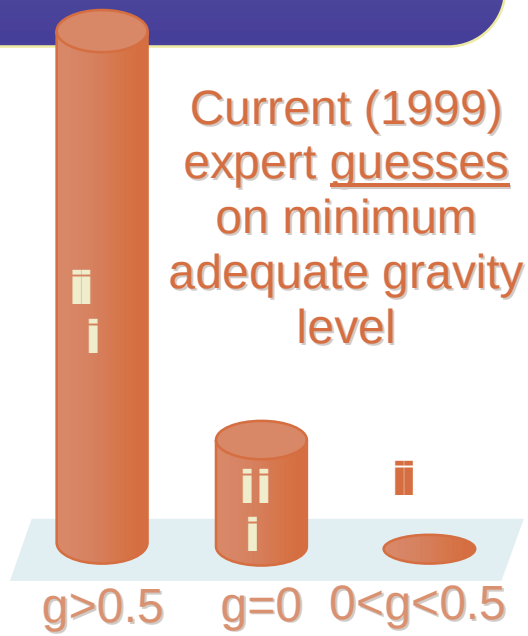
Issues Hypothesis

Issue: Efficacy of 0.38 g in countering deconditioning = ???
Therefore, Mars surface gravity assumed to be:

- Too ***LOW*** to be beneficial (for preserving bone integrity, etc.)
- Too ***HIGH*** to be ignored (for avoiding g-transition & vestibular symptoms)

Periodic health monitoring will also serve as applied research:

- probably longest period away from Earth to date
- probably longest exposure to hypogravity (0<g<1) to date



Peak Physical Challenges

Strategy for Surface Operations

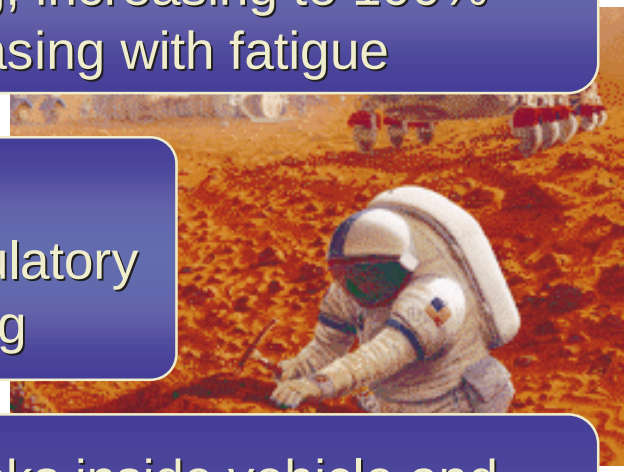
Early Mars Expeditions

Background

Anecdotal evidence suggests ~50% of Russian *Mir* crewmembers are ambulatory *with assistance* immediately after landing, increasing to 100% within hours, then decreasing with fatigue

Assume

Only 3 out of 6 Mars crewmembers are ambulatory immediately after landing



Strategy

Start with passive tasks inside vehicle and progress to strenuous tasks on surface

- **First 1-3 days** activities limited to reconfiguration of lander/habitat and surface reconnaissance
- **Then**, conduct first Mars walk(s) in vicinity of lander (umbilical instead of backpack?)
- **Next,** use unpressurized rover for early, shorter excursions
- **After a week or more**, extended excursions are possible

Strategy for Mars Surface Operations

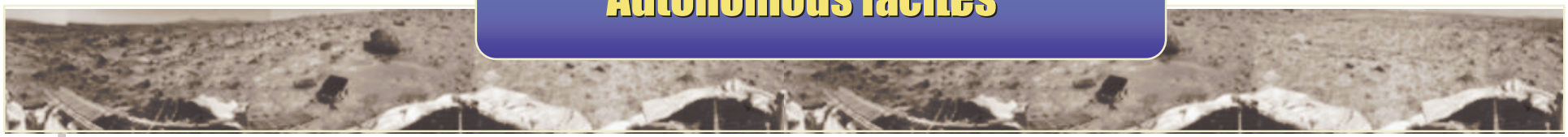
Anecdotal evidence: ~50% of Russian *Mir* crewmembers are ambulatory *with assistance* immediately after landing, increasing to 100% within hours, then decreasing due to fatigue for several days

Conservative assumption: only 3 out of 6 crewmembers will be ambulatory immediately after landing

Strategy: start with passive tasks inside vehicle (day 1-3) and progress to strenuous tasks on surface (second week)

Mars surface capabilities requirements

Autonomous facilities



Medical health care

- Radiation Protection
- Medical Surgical care
- Nutrition - Food Supply
- Psychological support
  - meaningful work
    - surface science
      - **planetary**
      - **biomedical**
    - simulations of Mars launch, trans-Earth injection, and contingencies
    - progressive debriefs, sample processing, etc.
    - housekeeping
  - communications capability

Habitat

- Maintenance/housekeeping
  - workshop with HRET capabilities
- Exercise supplemental to Mars surface activities
- Recreation
- Privacy

HRET: human-robotic exploration team

Early Mars Expeditions

Health care

- Radiation Protection
- Medical Surgical care
- Nutrition - Food Supply
- Psychological support
  - meaningful work
    - surface science
      - **planetary**
      - **biomedical**
    - simulations of Mars launch, trans-Earth injection, and contingencies
    - progressive debriefs, sample processing, etc.
    - housekeeping
  - communications capability

Habitat

- Maintenance/housekeeping
  - workshop with HRET capabilities
- Exercise supplemental to Mars surface activities
- Recreation
- Privacy

Issues in Environmental

- Issue: Dust
  - Operational: fouling of habitat or pressure garment fittings and mechanisms could pose risk to health and safety
  - Medical: possible risk if inhaled
    - Physical irritant
    - Reactive and oxidizing
    - Pulmonary inflammation

      effects likely additive

- Issue: Biohazards
  - Dependent on extant biological activity
    - Possible health threat to crew (maybe not)
    - Planetary protection issues (Mars as well as Earth)

- CPR: Immune/Infection/Hematology
  - Allergies and Hypersensitivity Reactions
  - Immunodeficiency and susceptibility to infections
  - Altered Wound Healing

Early Mars Expeditions

Issues: Human Behavior and Performance

Issues:

- Small group size
- Multi-cultural composition
- Extended duration
- Remote location
- High autonomy
- High risk (both expensive and life-threatening)
- High visibility (e.g., high pressure to succeed)

CPR: Behavior and Performance

- Sleep and circadian rhythm problems
- Poor psychosocial adaptation
- Neurobehavioral dysfunction
- Human-robotic interface

Issues: Human Behavior and Performance

Issue: Circadian Rhythm

- Sol = 24.62 hr
  - Human intrinsic rhythm = 24.1 ± 0.15 hr
    - synchronization not assured – may require (chronic) intervention?
- Synchronization successful (best case): Unknown efficacy in maintaining circadian health
  - Daylight EVA ops: safety, efficiency
  - Shorten perceived stay (by 2.5% !)
  - Complicate Earth-based support (ref. Viking, Pathfinder/Sojourner; MER 2003 planning)
- Failure to synchronize (worst case):
  - Crew awake during Mars night every 41 days (40 sols)
    - Well-rested "night-time" ops vs. fatigued daylight ops
    - -200 deg F temperature
      - EMU issues
    - Limited visibility (no IR capability): increased risk of accident, trauma
  - Radiation minimized: reduced SPE influence at night (?)

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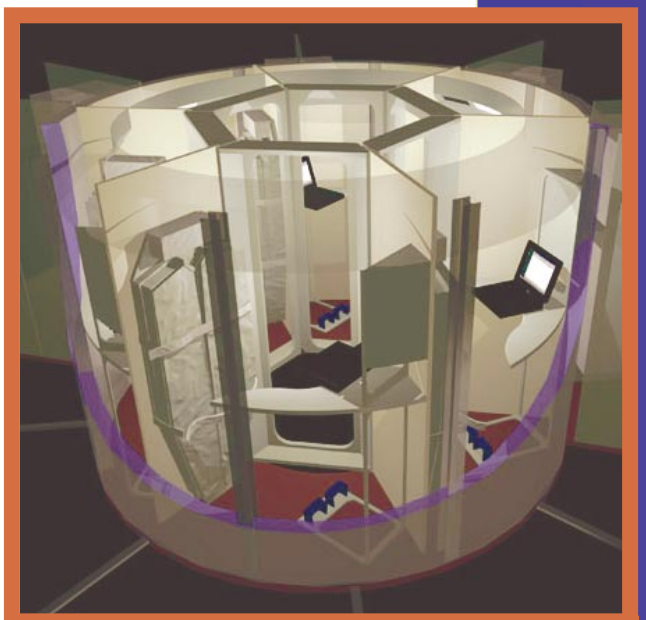

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Autonomous i acltes

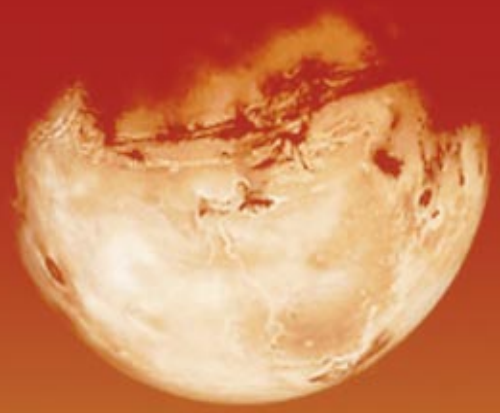
(one way Earth-Mars communications time is 3-22 min.)

Crew health care

- Nutrition
- Psychological support
  - meaningful work
    - simulations of Earth aerobraking, contingencies
    - debriefs, reporting, & consultation with primary investigator
    - housekeeping
    - cruise science
      - Mars sample analysis?
      - microgravity, astronomy, other?
  - communications capability

Habitat

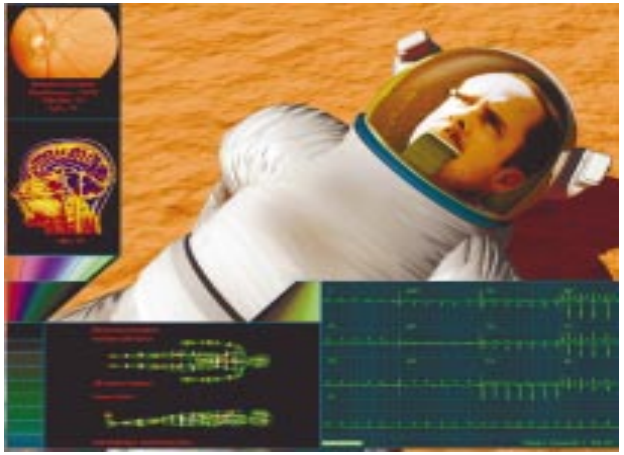
- Maintenance/housekeeping
  - workshop
- Exercise - supplemental to Mars surface activities
- Recreation
- Privacy



Acute ethical issues

Early Mars Expeditions

Medical Problems



CPR: Medical care systems for prevention, diagnosis or treatment

- Difficulty of rehabilitation following landing
- Trauma and acute medical problems
- Illness and ambulatory health problems
- Altered pharmacodynamics and adverse drug reaction

- Expected illnesses and problems
  - Orthopedic and musculoskeletal problems (esp. in hypogravity)
  - Infectious, hematological, and immune-related diseases
  - Dermatological, ophthalmologic, and ENT problems
- Acute medical emergencies
  - Wounds, lacerations, and burns
  - Toxic exposure and acute anaphylaxis
  - Acute radiation illness
  - Development and treatment of decompression sickness
  - Dental, ophthalmologic, and psychiatric
- Chronic diseases
  - Radiation-induced problems
  - Responses to dust exposure
  - Presentation or acute manifestation of nascent illness

pace ècne issues

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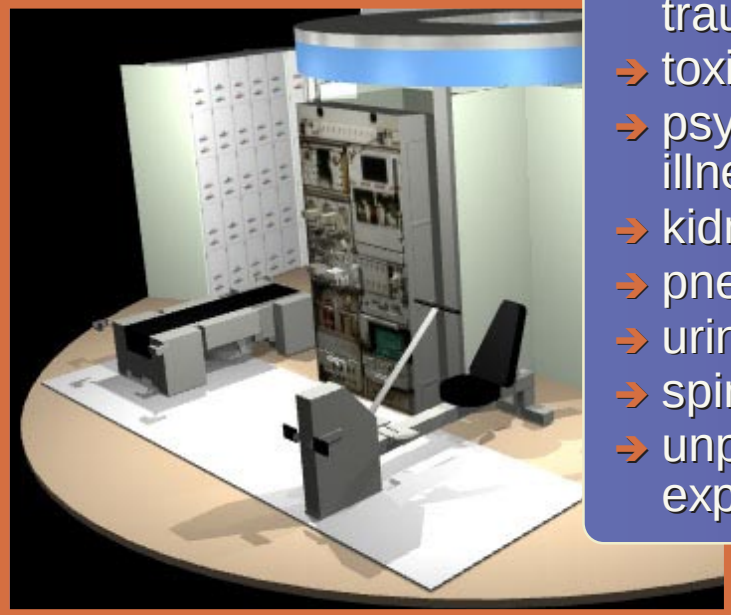
- skin rash, irritation
- foreign body
- eye irritation, corneal abrasion
- headache, backache, congestion
- gastrointestinal disturbance
- cut, scrape, bruise
- musculoskeletal strain, sprain
- fatigue, sleep disturbance
- space motion sickness
- post-landing orthostatic intolerance
- post-landing neurovestibular symptoms



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- infectious disease
- cardiac dysrhythmia, trauma, burn
- toxic exposure
- psychological stress, illness
- kidney stones
- pneumonitis
- urinary tract infection
- spinal disc disease
- unplanned radiation exposure

Data from R. Billica, Jan. 8, 1998

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Projected Rates of Illness or Injury

Past i i perence

ii ii
personi ear

Based on U.S. and Russian space flight data, U.S. astronaut longitudinal data, and submarine, Antarctic winter-over, and military aviation experience:

- Incidence of *significant* illness or injury is **0.06 per person-year**
  - as defined by U.S. standards
  - requiring emergency room (ER) visit or hospital admission
- Subset requiring intensive care (ICU) support is **0.02 person per year**

ars i

ii ii
personi mission

For DRM of 6 crewmembers on a 2½ year mission, expect:

- **0.9 persons per mission,** or ~one person per mission, to require ER capability
- **0.3 persons per mission,** or ~once per three missions, to require ICU capability
  - ~80% require intensive care only 4-5 days
  - ~20% do not.

Note: Decreased productivity, increased risk while crew reduced by 1-2 (including care-giver)

Data from R. Billica, January 1998, and D. Hamilton, June 1998

Early Mars Expeditions

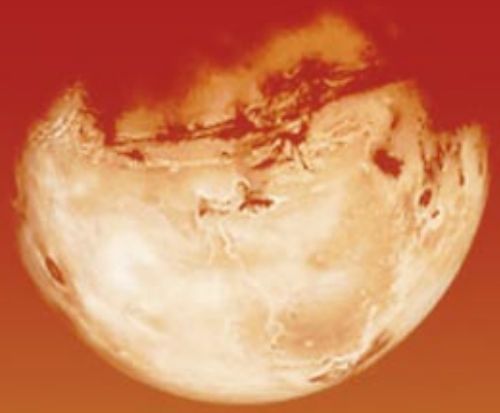
Autonomous Medical Care

Medical Health Care Impacts

- non-invasive diagnostic capabilities for medical/surgical care
- **"smart" systems**
- **non-invasive imaging systems**
- definitive surgical therapy including robotic surgical assist devices and surgical simulators
- blood replacement therapy
- laboratory support

Medical Elements

- preventive health care
- diagnostic/therapeutic capabilities from ground-based consultants



Conclusions

Early Mars Expeditions

Steps to Mars – Robotic Probes & Ground-Based Research

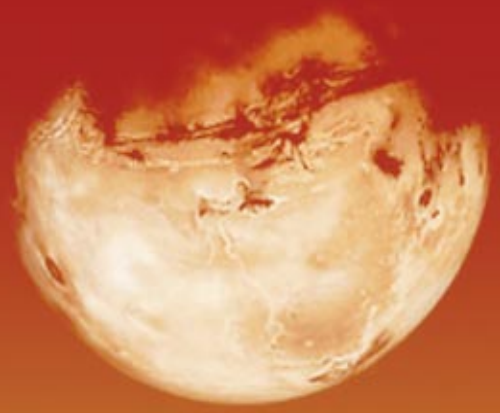
- NASA recently focused human space flight on ISS (plenty to do)
  - Study human responses to long-duration space flight in ISS
  - Improve life support capabilities
  - Prepare for next step outward (destination: Moon, Mars, Earth-Moon L2)
- Continued robotic exploration of Mars
  - Preliminary study of planet without risking humans
    - Select appropriate goals for human exploration
  - Document space radiation environment (e.g. MARIE on Mars Odyssey)
- Ground-based research
  - Quantify biological responses to non-low space radiation
  - Develop appropriate shielding
    - Recent Orion shows inadequacy of aluminum shielding compared to hydrogen compounds (polyethylene) [illegible]
      (good thing we haven't sent people yet)

To access/download this presentation:

http://ace.arc.nasa.gov/cgi-bin/postdoc/get?url_id=50512&ext=pdf

Romance to Reality: moon & Mars mission plans, 1950-2000

http://members.aol.com/dsfportree/explore.htm



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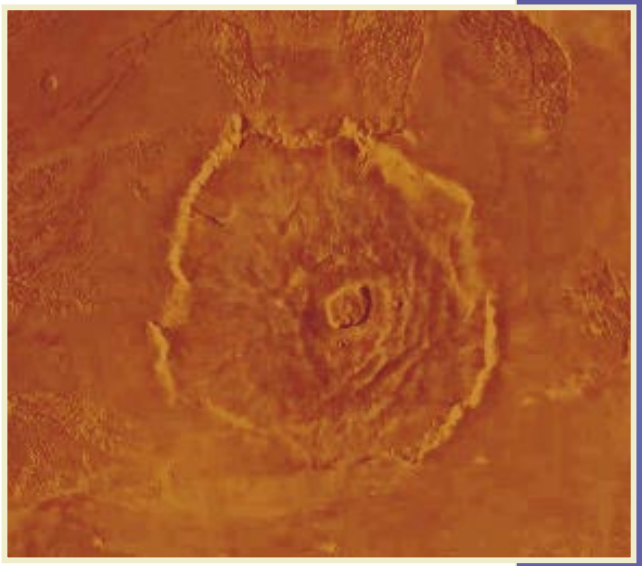
charts

Conclusions



- **Mars Design Reference Mission** requires novel technologies that allow human adaptation to:
  - **interplanetary space travel**
  - **planetary habitation**

  The medical and physiological challenges associated with interplanetary space travel will depend upon
  - **mission duration**
  - **propulsion system**

- The integration of human and robotic activities will be a critical determinant of the success of planetary exploration

Early Mars Expeditions

Conclusions

- The human element is the most complex element of the mission design
- Mars missions will pose significant physiological and psychological challenges to crew members
- Human engineering, human robotic/machine interface, and life support issues are critical
- The Critical Roadmap Research Path is required for issues that <u>may</u> be show-stoppers (bone, radiation)
- The ISS platform must be used to address exploration issues before any “Go/No Go” decision
- A significant amount of ground-based and specialized flight research will be required - the Critical Path Roadmap project will direct our research toward exploration objectives

Early Mars Expeditions

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Introduction……3

Background……5

Mission Architecture……10

Biomedical Issues…….. ……23

Acute Medical Issues……50

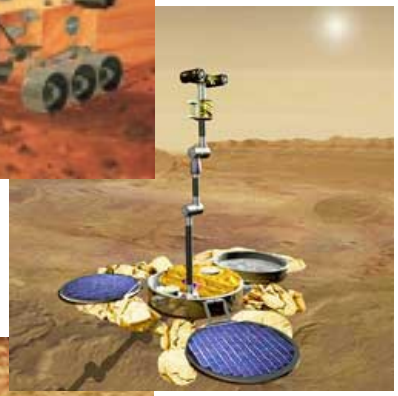
Conclusions…… ……55

Backup……58

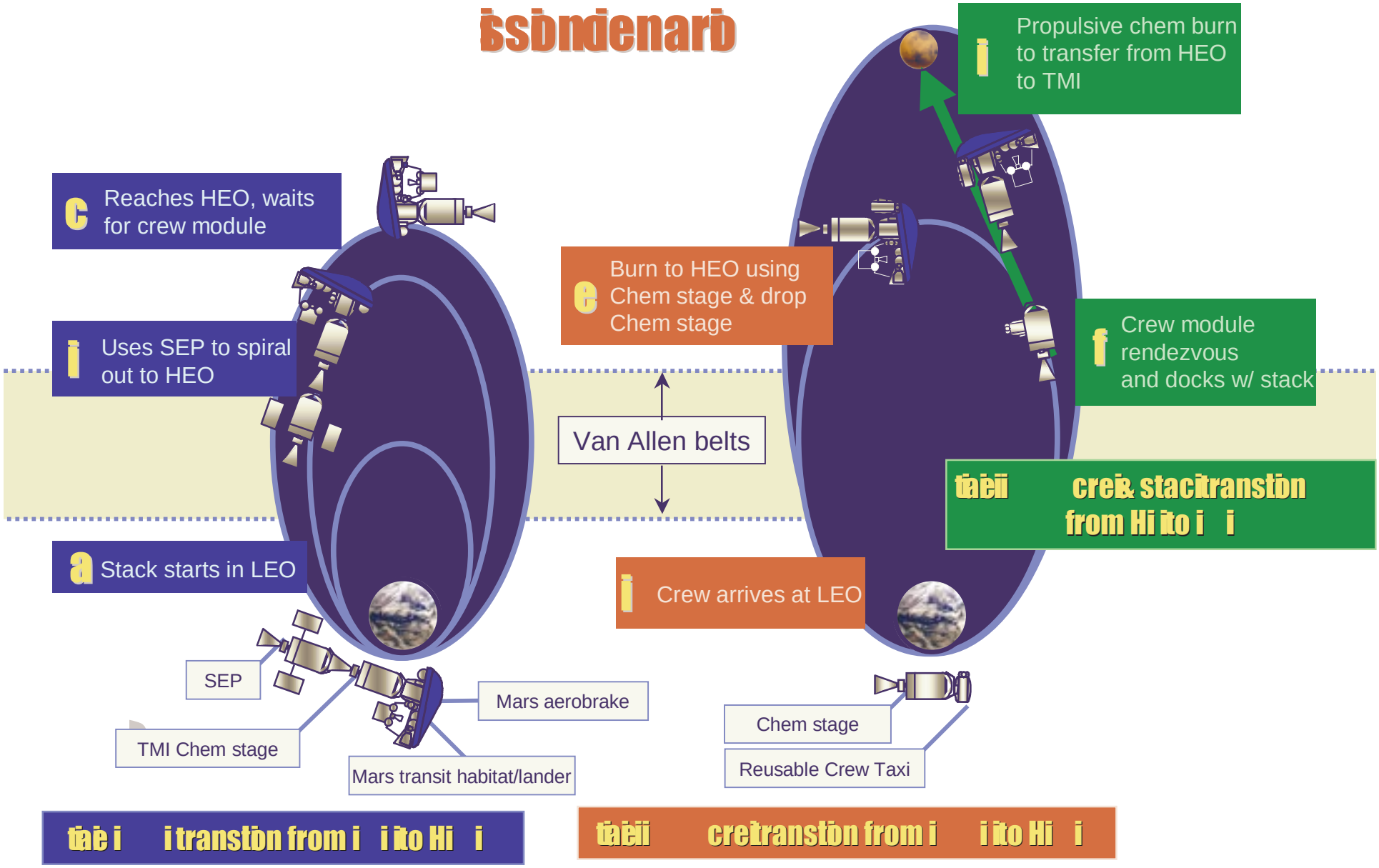
Mars Exploration in the Early 21st Century

Early Mars Expeditions

- **1997**: Mars Global Surveyor orbiter
  - (still operational)
- **2001**: Mars Odyssey Orbiter
  - (high res. mapping & imaging)
- **2003**: Mars Exploration Rovers (2)
  - Mars Express Orbiter & Beagle-2 lander (ESA)
- **2005**: Mars Reconnaissance Orbiter
  - (20-30 cm res.)
- **2007**: precision lander with large mobile science laboratory; first Mars Scout missions; French lander; Italian comsat
- **2009**: possible US/Italian orbiter with ground-penetrating radar to search for water
- **2011, 2014** &/or **2016**: science orbiters, rovers & landers; possible return of 2 kg. sample.



Solar Electronic Propulsion Mission Scenario



LEO: low Earth orbit
HEO: high Earth orbit

SEP: solar electronic propulsion
TMI: trans-Mars injection

from SEP Team package, Nov. 1997

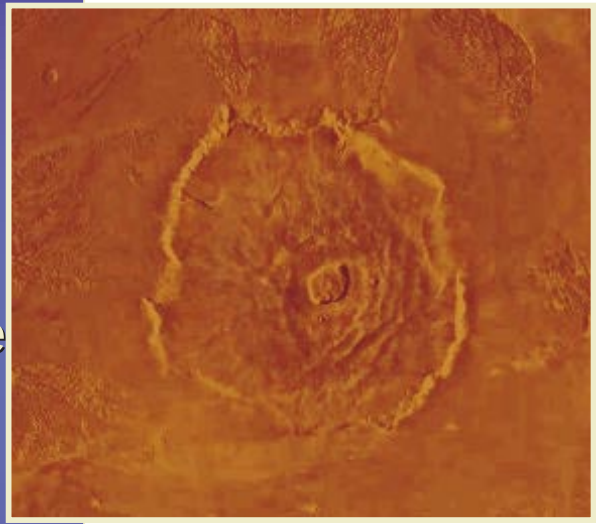
Early Mars Expeditions

acrouni

- **Humanpiace i fediences Proiams ffice** identifies critical areas of research and development that will assure human health and performance capability for exploring and developing space.

- The **ars esin eference ission** is a benchmark for determining both the content and direction of mid- and long-term research activities.

- Near-term focus continues to be on tasks and techniques that expand human performance during Space Shuttle and International Space Station missions.



Human Space Sciences Programs

JSC is the center for human operations in space and oversees these human research functions:

- Space Medicine
- Biomedical Research and Countermeasures
- Advanced Human Support Technologies
  - Advanced Life Support
  - Advanced Human Engineering
  - Advanced Environmental Monitoring and Control
  - Elements of Advanced Extravehicular Activity (EVA)

Human Space Sciences Program Office in HSR
coordinates these critical support functions for JSC

hārsi
from the life scènces perspecti e

Early Mars Expeditions

The Mars DRM is a “strawman” chosen to represent exploration-class missions because it requires a rigorous life sciences critical path.

Long Duration Experience

Episodes of Hypergravity

G Transitions

2
1g → 0g
0g → 1g

4
1g → 0g
0g → 1/3g
1/3g → 0g
0g → 1g

Physical Demands

Current: infrequent orbital EVAs with regular daily exercise

Mars: frequent Mars surface EVAs, possibly daily

Toxin Exposure

Current: spacecraft & terrestrial toxins only

Mars: spacecraft, terrestrial, & extraterrestrial toxins

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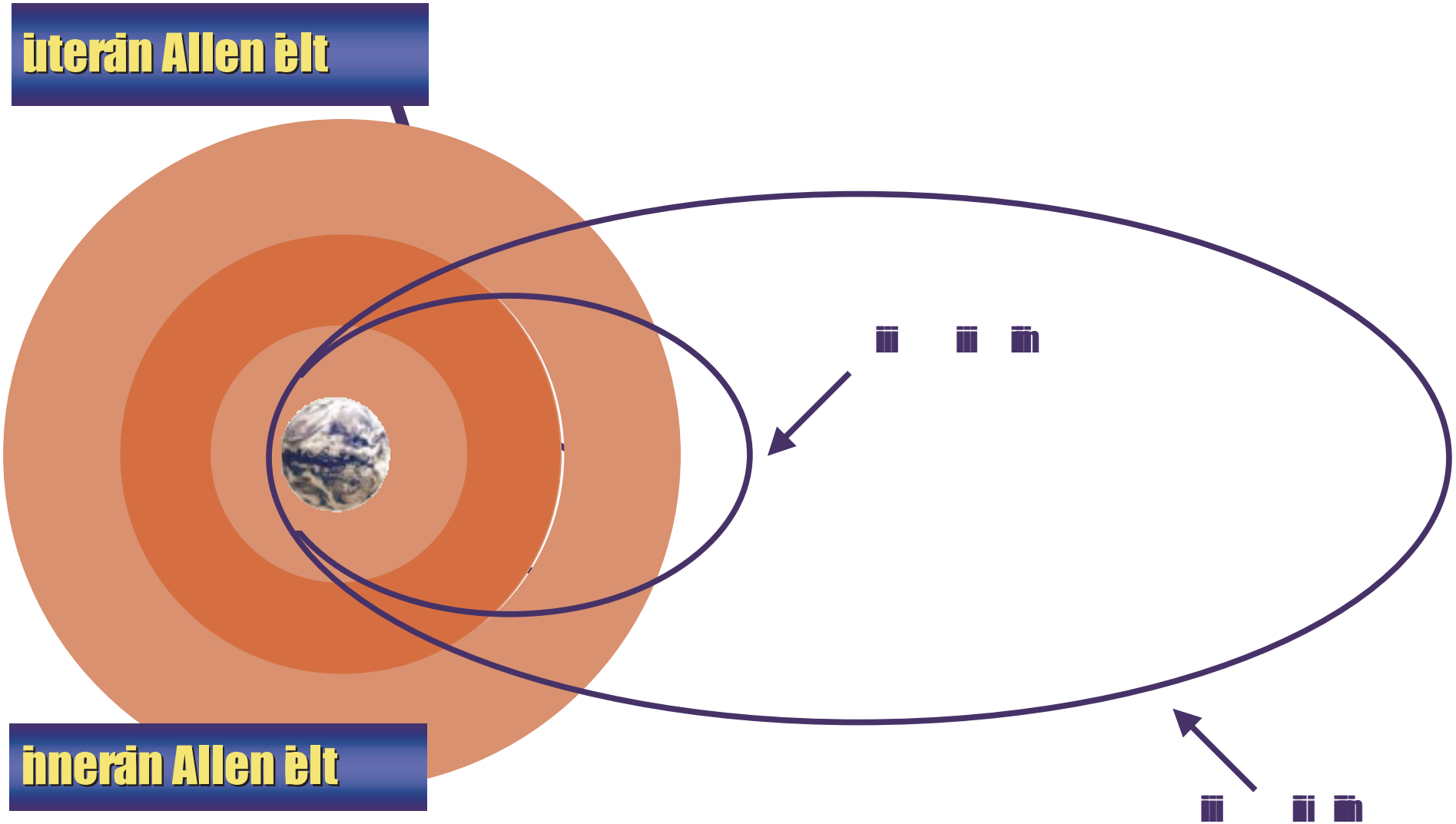
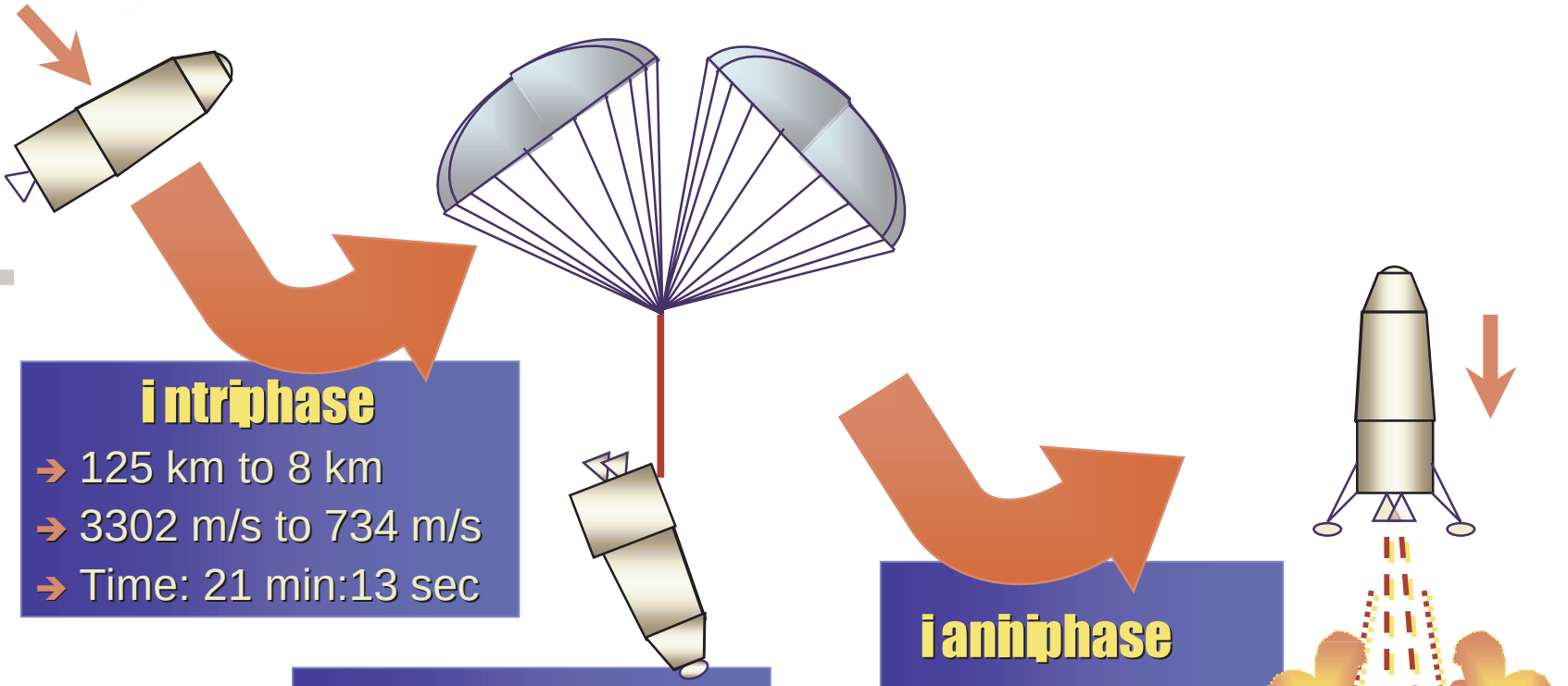


Possible Mars landing sequence



Intriphase

- 125 km to 8 km
- 3302 m/s to 734 m/s
- Time: 21 min:13 sec

Parachute phase

(saves 10 T of fuel)

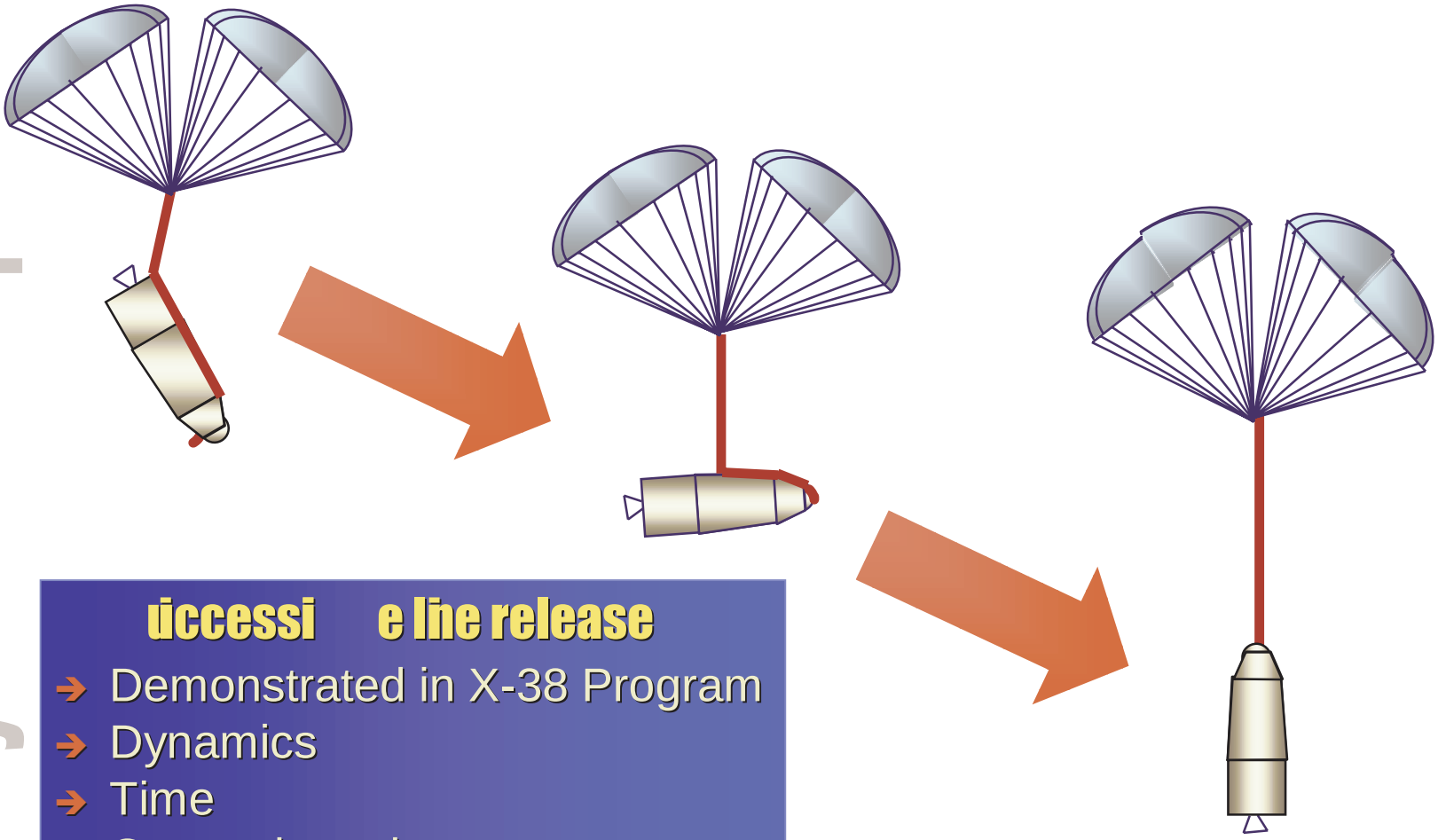
- 8 km to 5 km
- 734 m/s to 200 m/s
- Time: 36 sec

Lanniphase

- 5 km to TD
- 200 m/s to 0 m/s
- Time: 48 sec

Original figure by Michelle Munk, Mars Landing Transition Team, Nov., 1997

Possible Parachute Deployment Sequence



Successive line release

- Demonstrated in X-38 Program
- Dynamics
- Time
- Crew orientation

Original figure by Michelle Munk, Mars Landing Transition Team, Nov., 1997

Early Mars Expeditions

Early Mars Expeditions

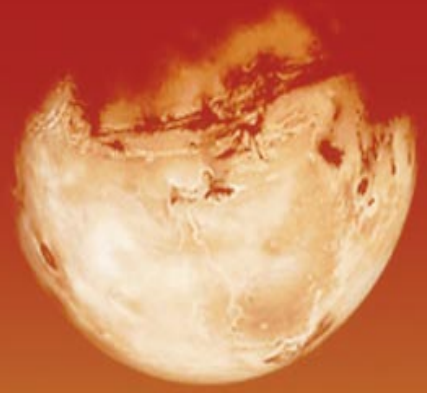
Strategy for Mars Surface Operations

Anecdotal evidence: ~50% of Russian *Mir* crewmembers are ambulatory *with assistance* immediately after landing, increasing to 100% within hours, then decreasing due to fatigue for several days

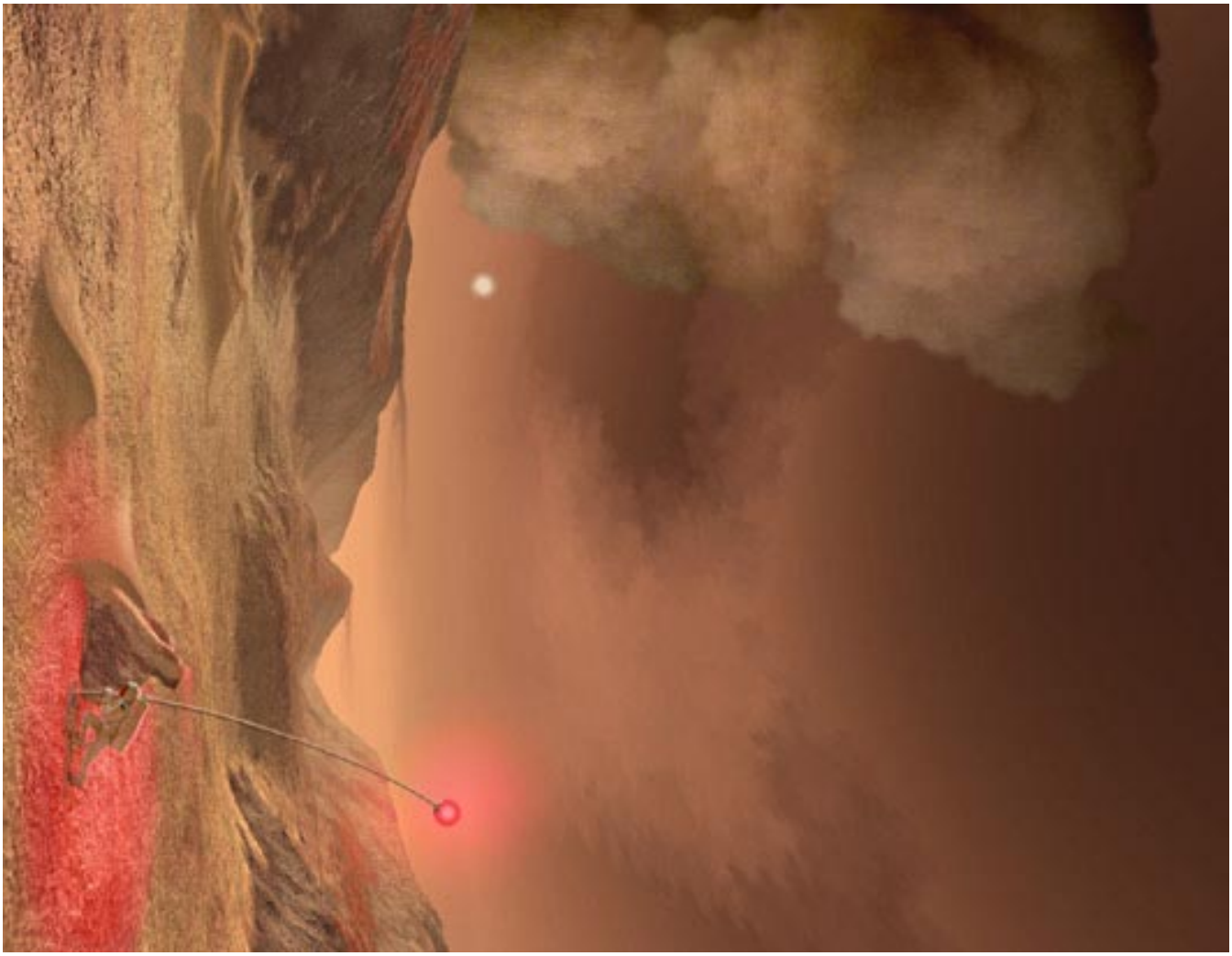
Conservative assumption: only 3 out of 6 crewmembers will be ambulatory immediately after landing

Strategy: start with passive tasks inside vehicle (day 1-3) and progress to strenuous tasks on surface (second week)

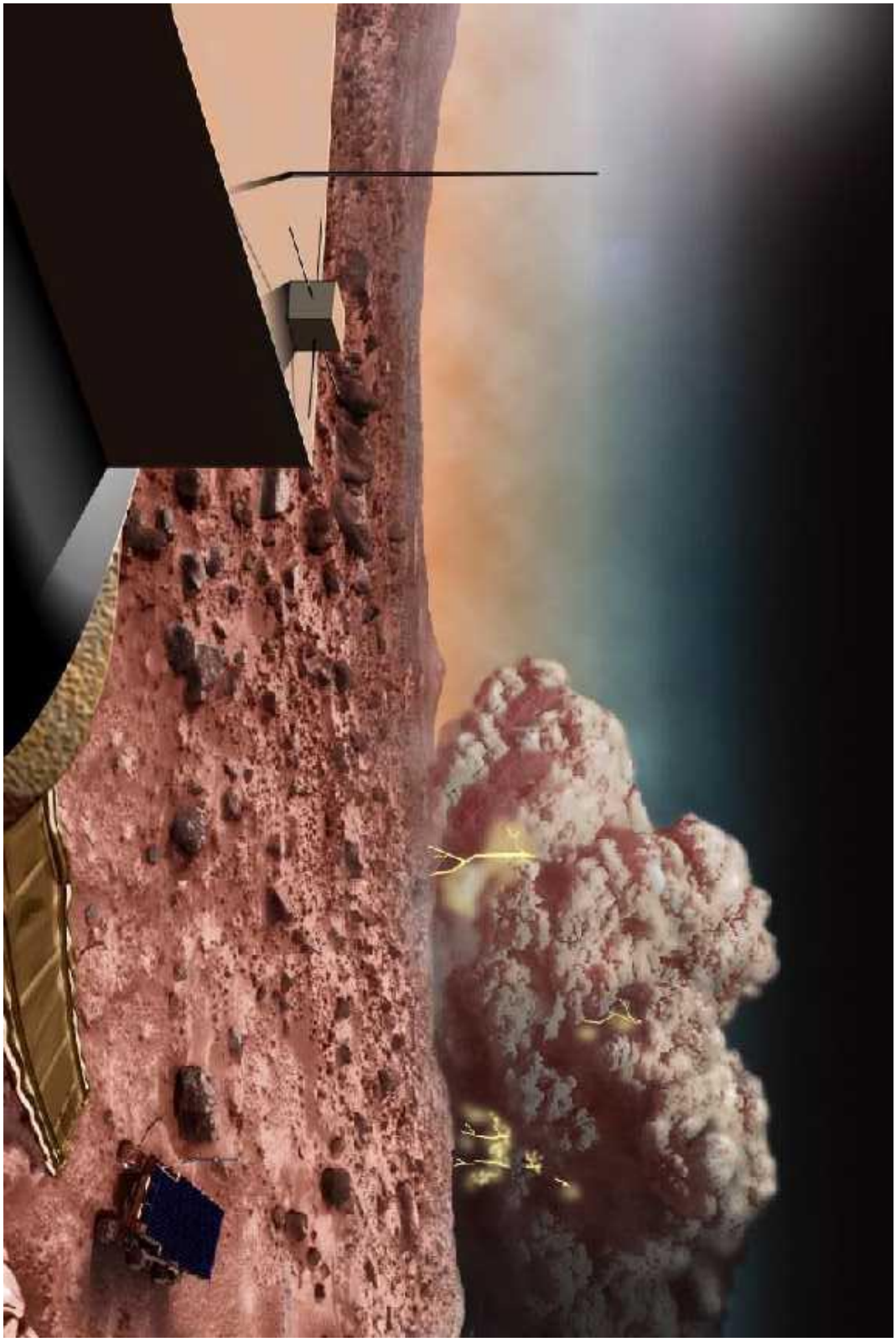
Early Mars Expeditions



Early Mars Expeditions



Early Mars Expeditions



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- alileo came to understand all nuances of opernicanism efore reecting it on religious grounds

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- NASA inestigated nuances of interplanetary epeditions efore they ere deferred on udgetary grounds

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