Human Exploration of Earth's Neighborhood and Mars

Jerry Condon / JSC/EG5 / 281-483-8173 / gerald.l.condon1@jsc.nasa.gov

Mission Scenario

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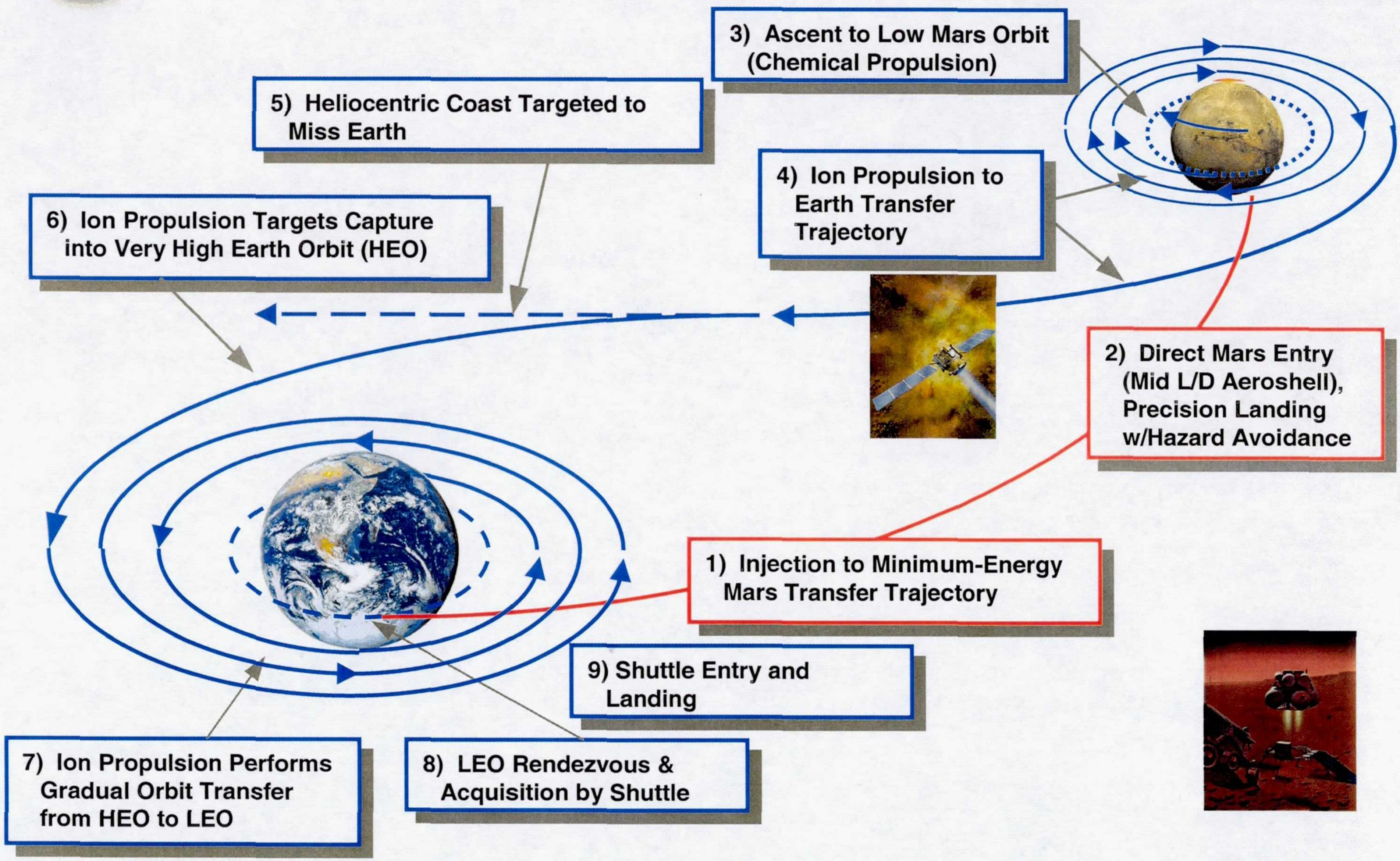

Direct Entry Landing Locations

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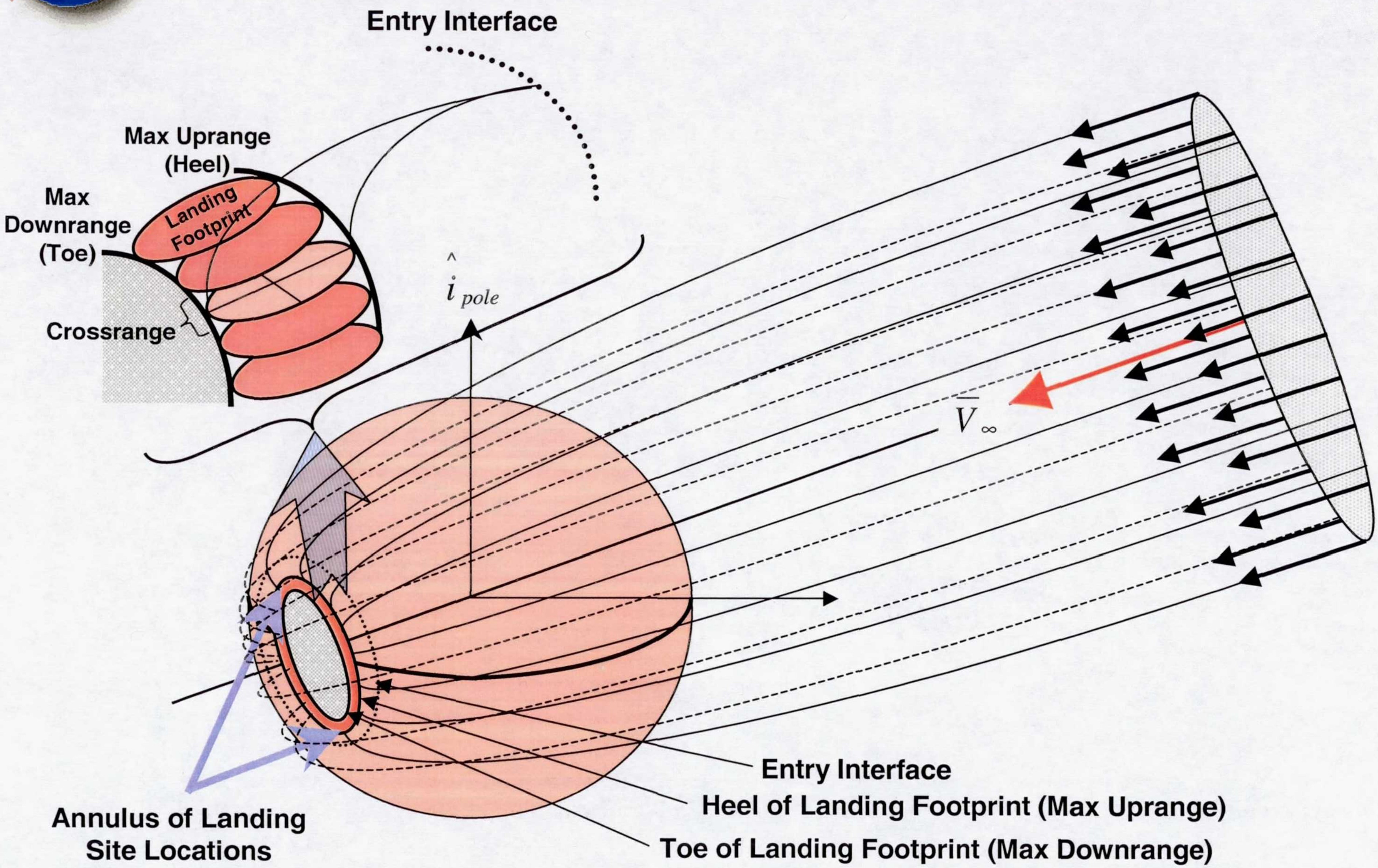

2005 Opportunity - Type I

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2005 Opportunity

Type I

Earth Departure Date
8/10/05

Earth Departure Energy
$C3 = 15.9\ km^2/s^2$

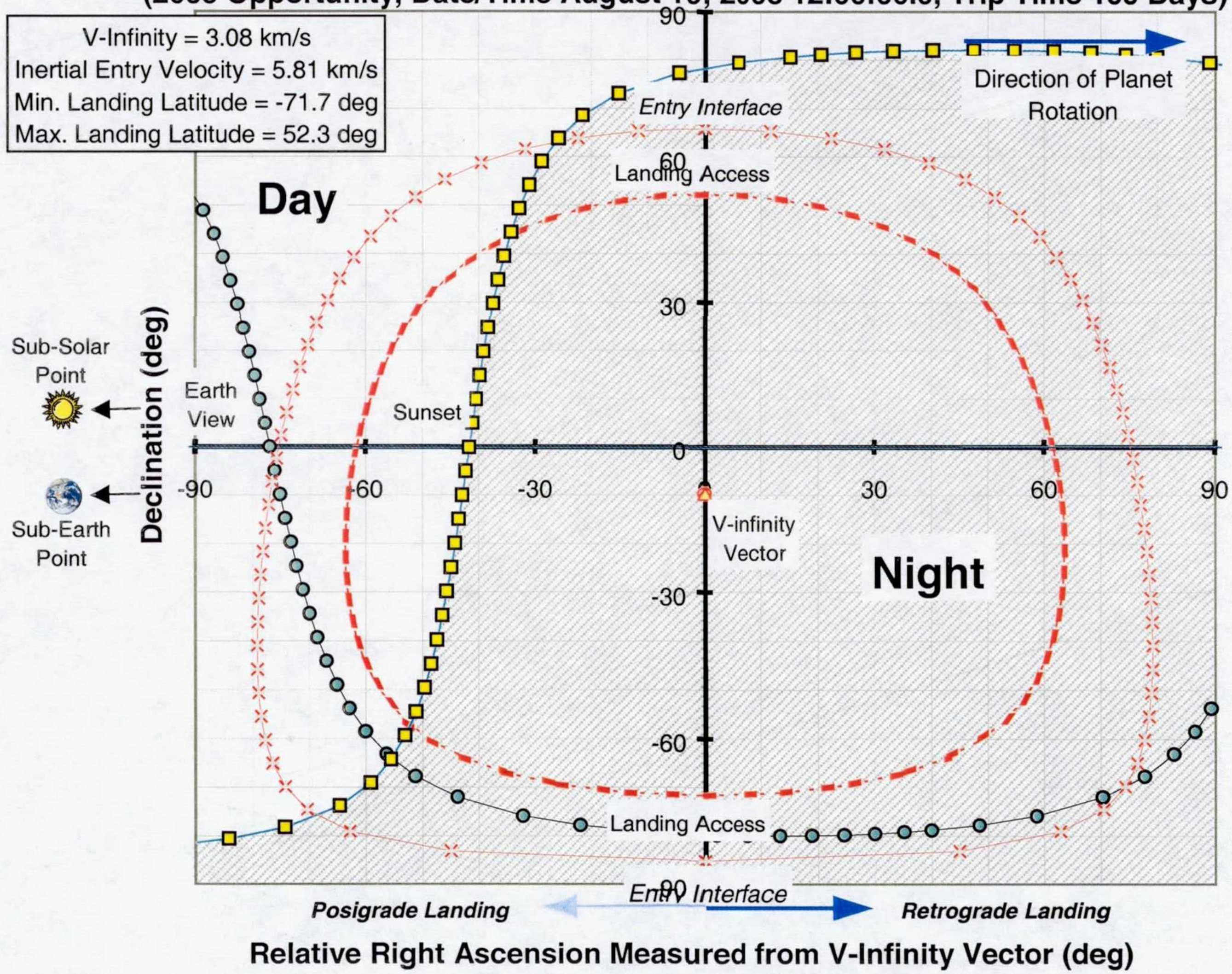
Mars Arrival Date
2/25/06

Trip Time
199 days

Mars Inertial Entry Speed
5.81 km/s

Landing Site Latitude Access
-71.7° -> 52.3°

Landing Lighting and Latitude for Direct Entry JSC Mars Sample Return
(2005 Opportunity, Date/Time August 10, 2005 12:00:00.0, Trip Time 199 Days)



Earth-Mars Superior Conjunction

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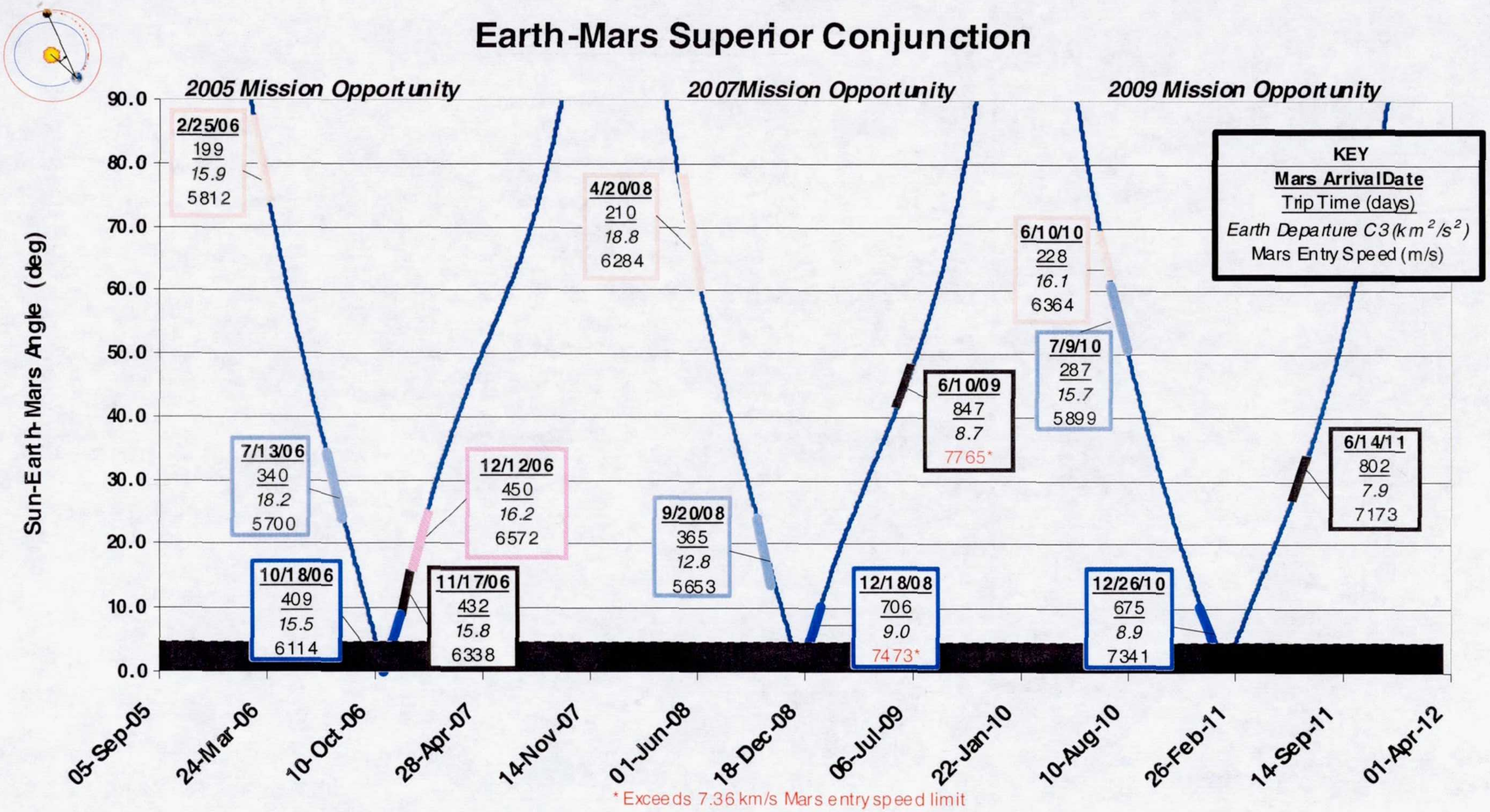

Lander Latitude Accessibility

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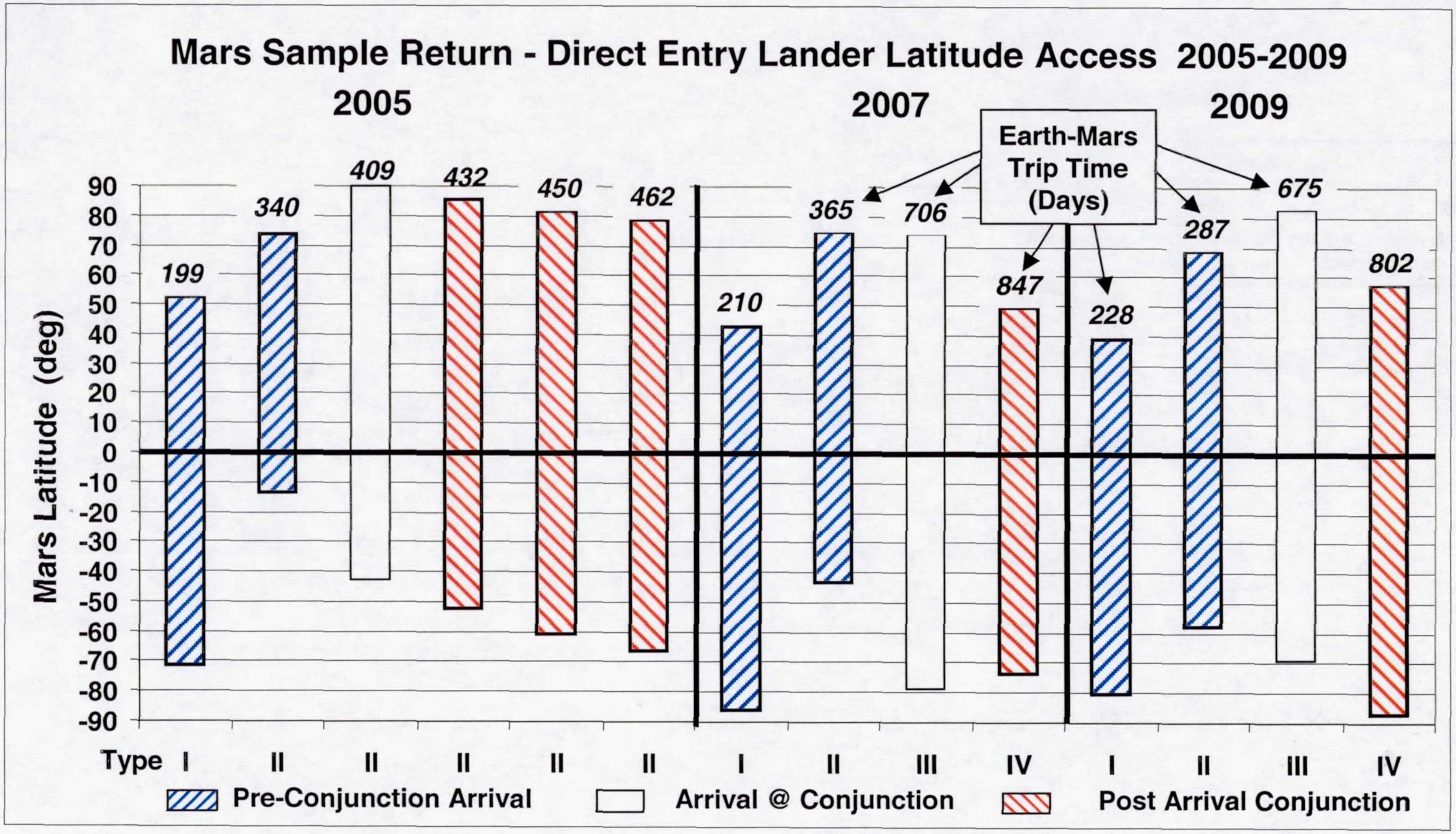

Low Thrust – Earth Return Phase

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- Two-body assumption with mass-matching at transition points, no shadowing
- Initial Conditions*
  - Mass = 350 kg
  - Power to thruster = 2.567 kW
  - Efficiency = 55.3%
  - Isp = 3127 sec.

*Based on advanced NSTAR engine similar to that used with Deep Space 1

SEP Earth Return Sequence

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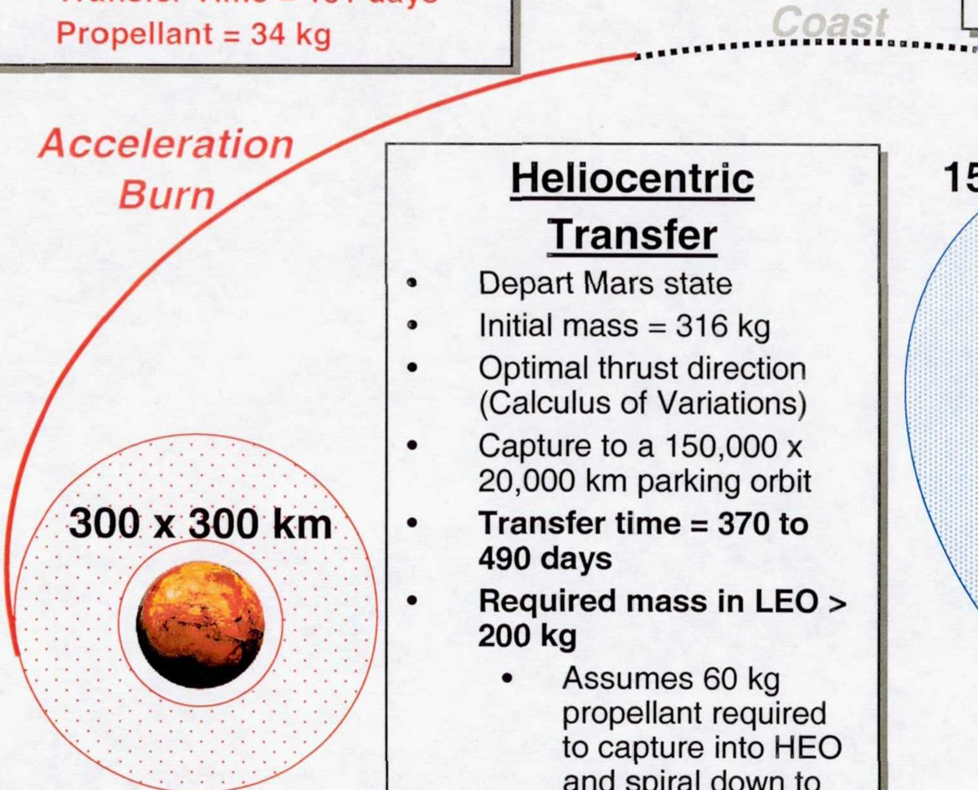
Mars Spiral Out

- Depart 300 km circular parking orbit
- Initial mass = 350 kg
- Thrust along velocity vector
- Spiral to zero energy condition
- No shadow
- **Transfer Time = 131 days**
- **Propellant = 34 kg**

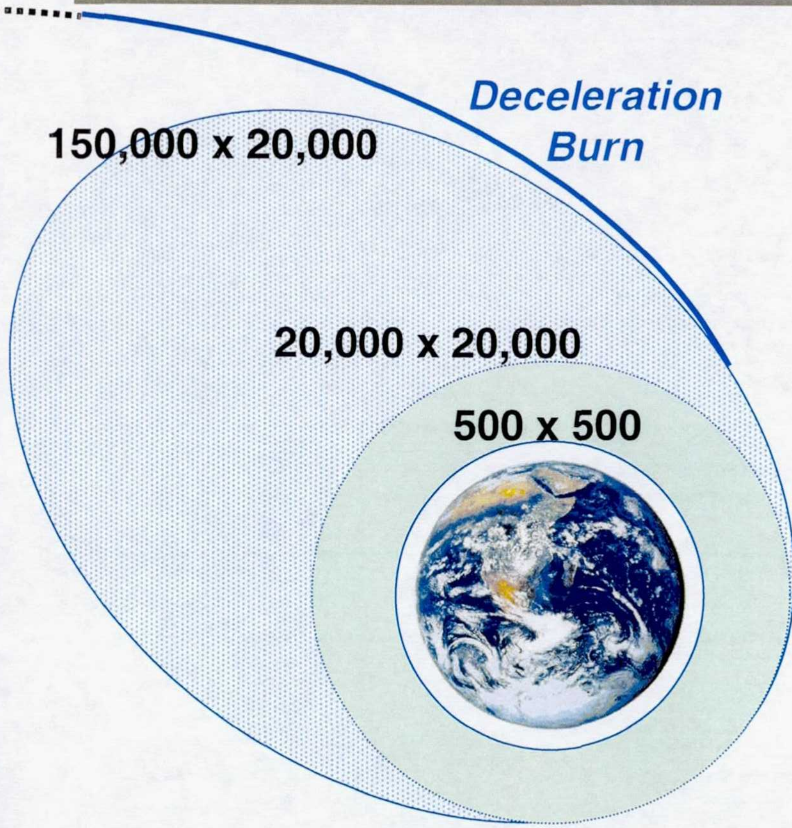
Earth 'Spiral' Down

- Depart 150,000 x 20,000 parking orbit
- Apogee Reduction to 20,000 km
  - Thrust perpendicular to line of apsides near perigee
- Spiral down to 500 km circular orbit
  - Thrust opposite velocity vector
- Preliminary 60 kg estimate for spiral down propellant (later optimized to 38 kg)



Heliocentric Transfer

- Depart Mars state
- Initial mass = 316 kg
- Optimal thrust direction (Calculus of Variations)
- Capture to a 150,000 x 20,000 km parking orbit
- **Transfer time = 370 to 490 days**
- **Required mass in LEO > 200 kg**
  - Assumes 60 kg propellant required to capture into HEO and spiral down to LEO



Missions – 2005, 2007, 2009

Ballistic Outbound Trajectories and Mars Low Thrust Return Departure Window

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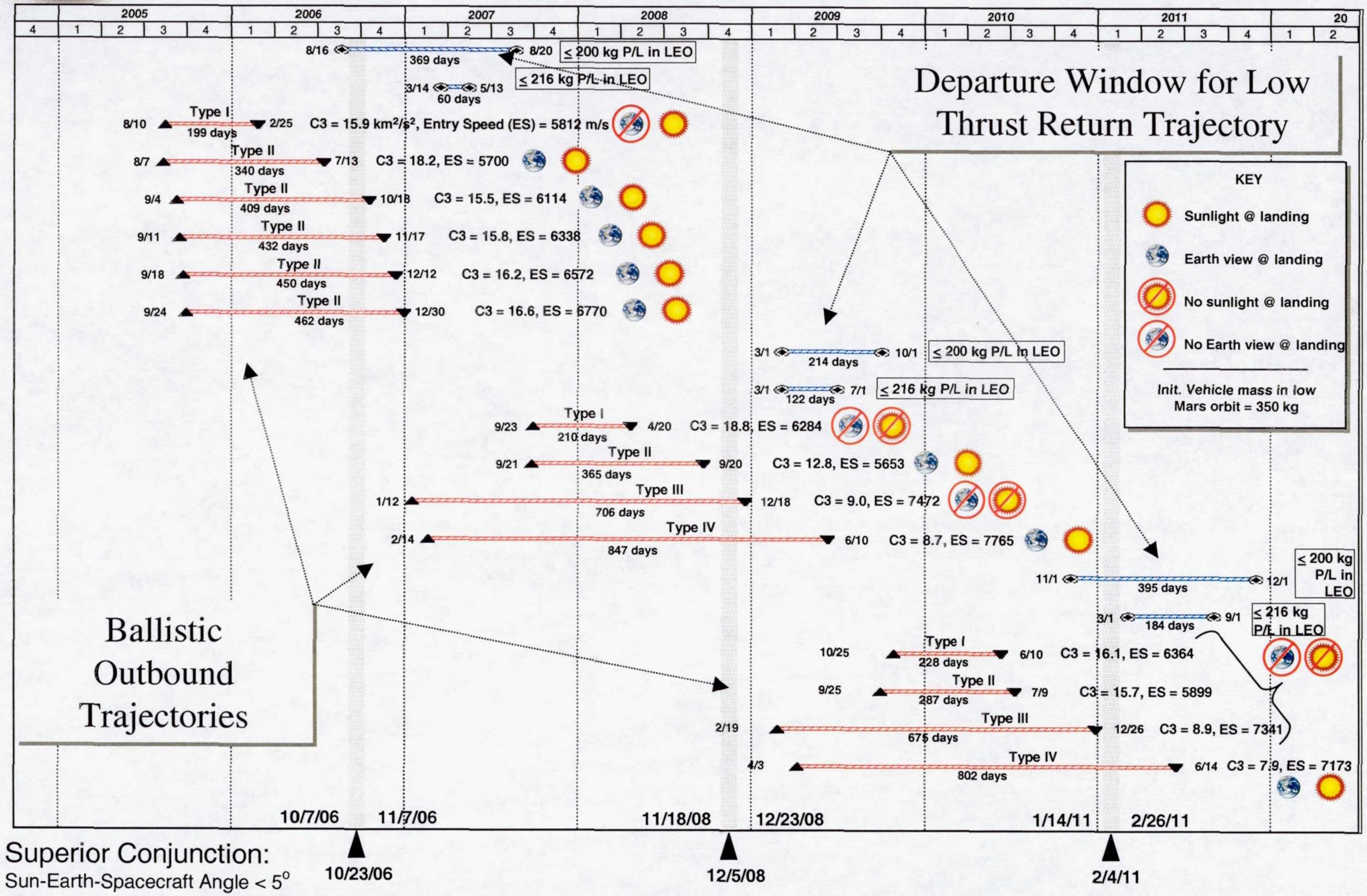
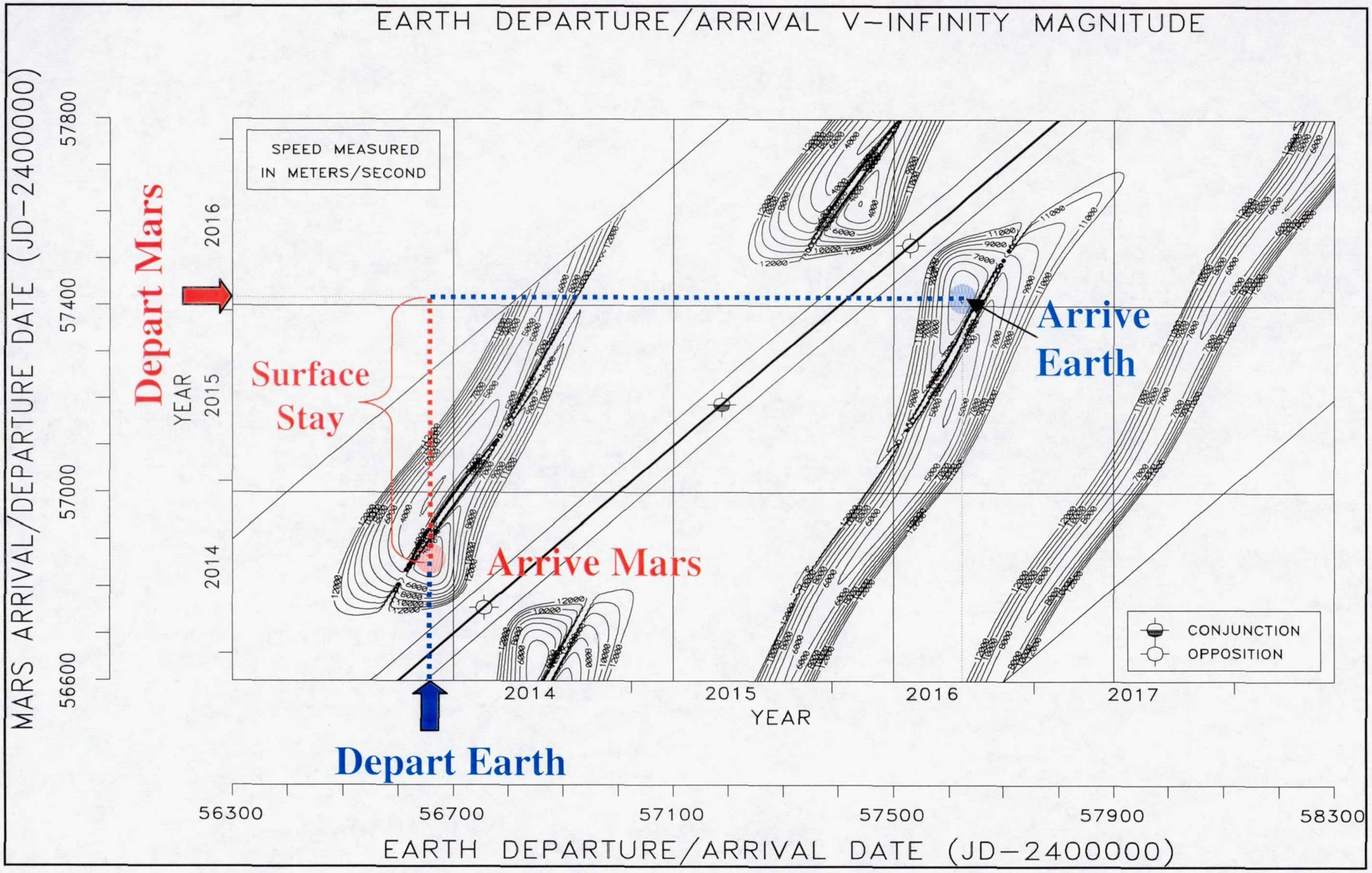


Mission Map



EARTH DEPARTURE/ARRIVAL V-INFINITY MAGNITUDE
SPEED MEASURED IN METERS/SECOND
MARS ARRIVAL/DEPARTURE DATE (JD-2400000)
EARTH DEPARTURE/ARRIVAL DATE (JD-2400000)
YEAR
Depart Mars
Surface Stay
Arrive Mars
Depart Earth
Arrive Earth
CONJUNCTION
OPPOSITION
56300
56700
57100
57500
57900
58300
56600
57000
57400
57800
2014
2015
2016
2017

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EARTH TO MOON TRANSFERS

DIRECT VS VIA LIBRATION POINTS (L1, L2)

Gerald L. Condon
Sam Wilson
Johnson Space Center / Aeroscience and Flight Mechanics Division

October 9, 2002

Libration Point Missions

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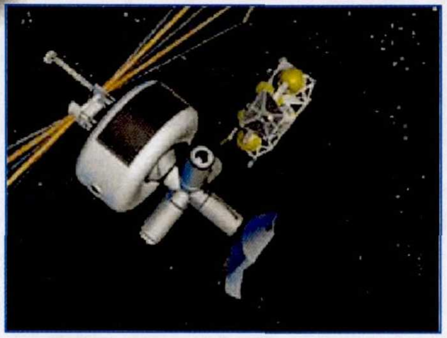
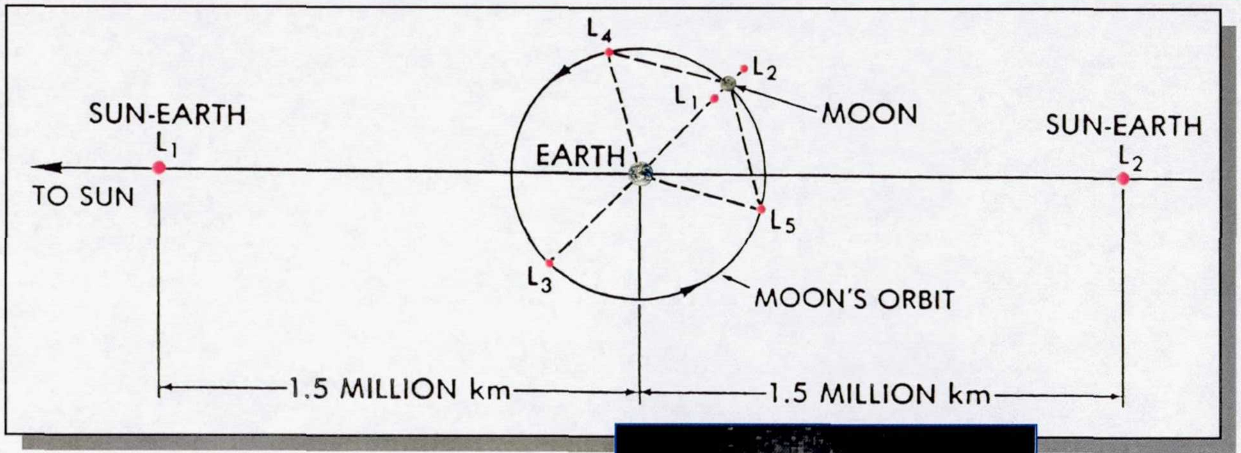
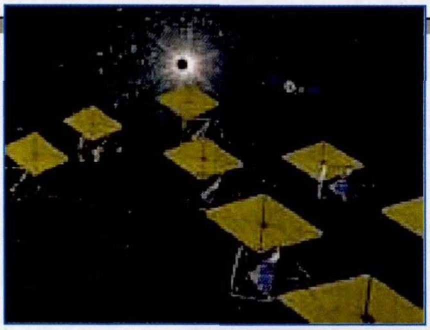


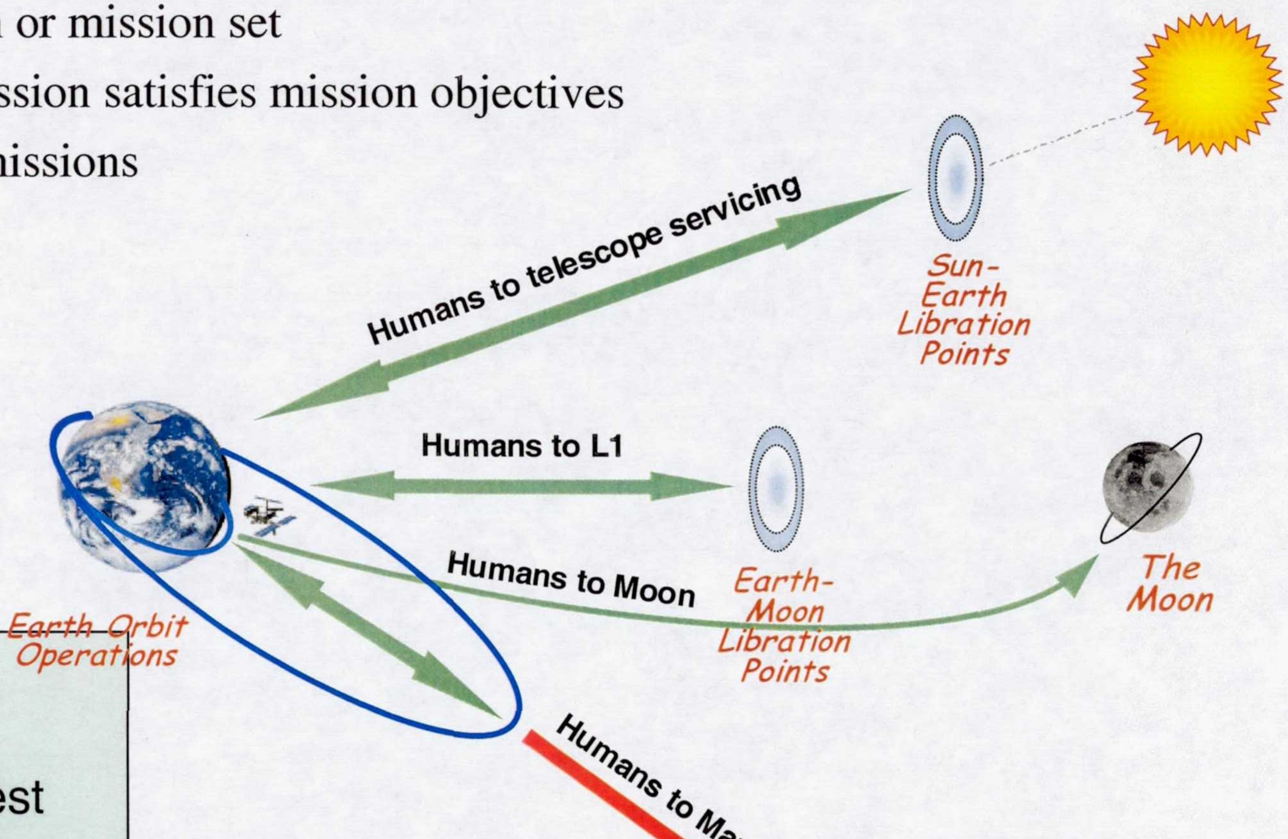


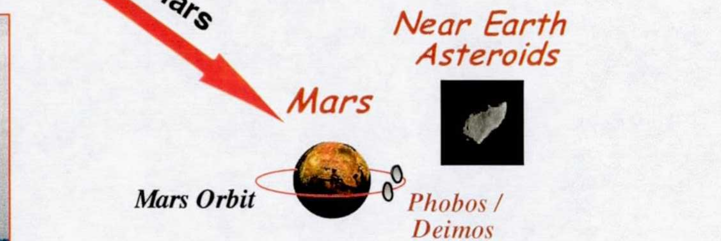
- Earth-Moon L1
  - Gateway station
    - Sorties to the Moon
    - Satellite deploy, servicing
      - Next Generation Space Telescope
      - Terrestrial Planet Finder
    - Staging area for interplanetary and asteroid missions
- Earth-Moon L2
  - Robotic relay satellites
    - Communications relay
    - Navigation aid
- Sun-Earth L2
  - Human missions to extend human presence in space



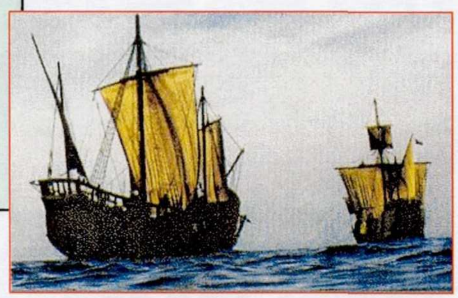
Expeditionary vs. Evolutionary

- Single mission or mission set
- Completed mission satisfies mission objectives
- Close-ended missions



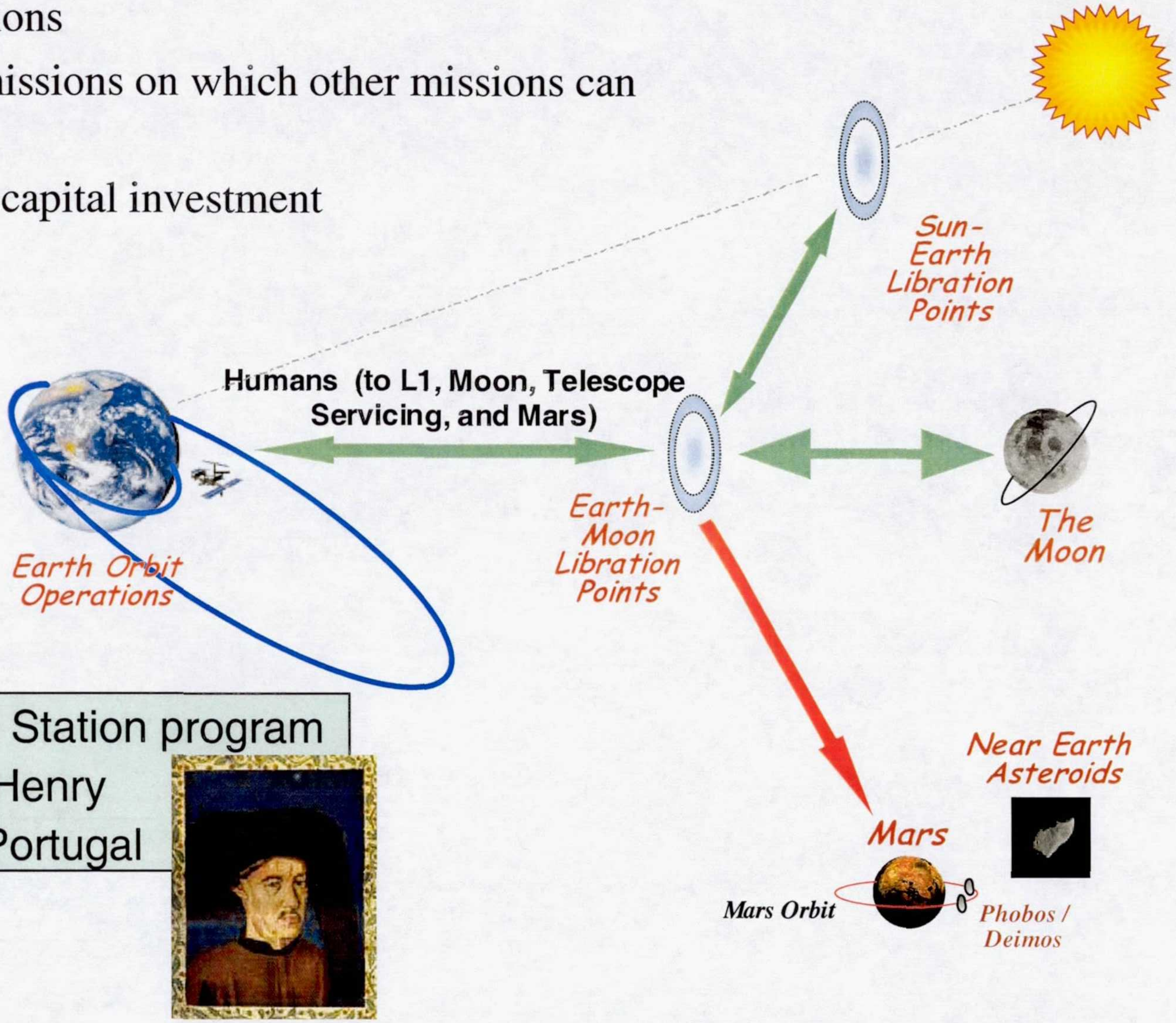


Apollo
Skylab
Apollo-Soyuz Test Project
Columbus' voyage of discovery to the new world



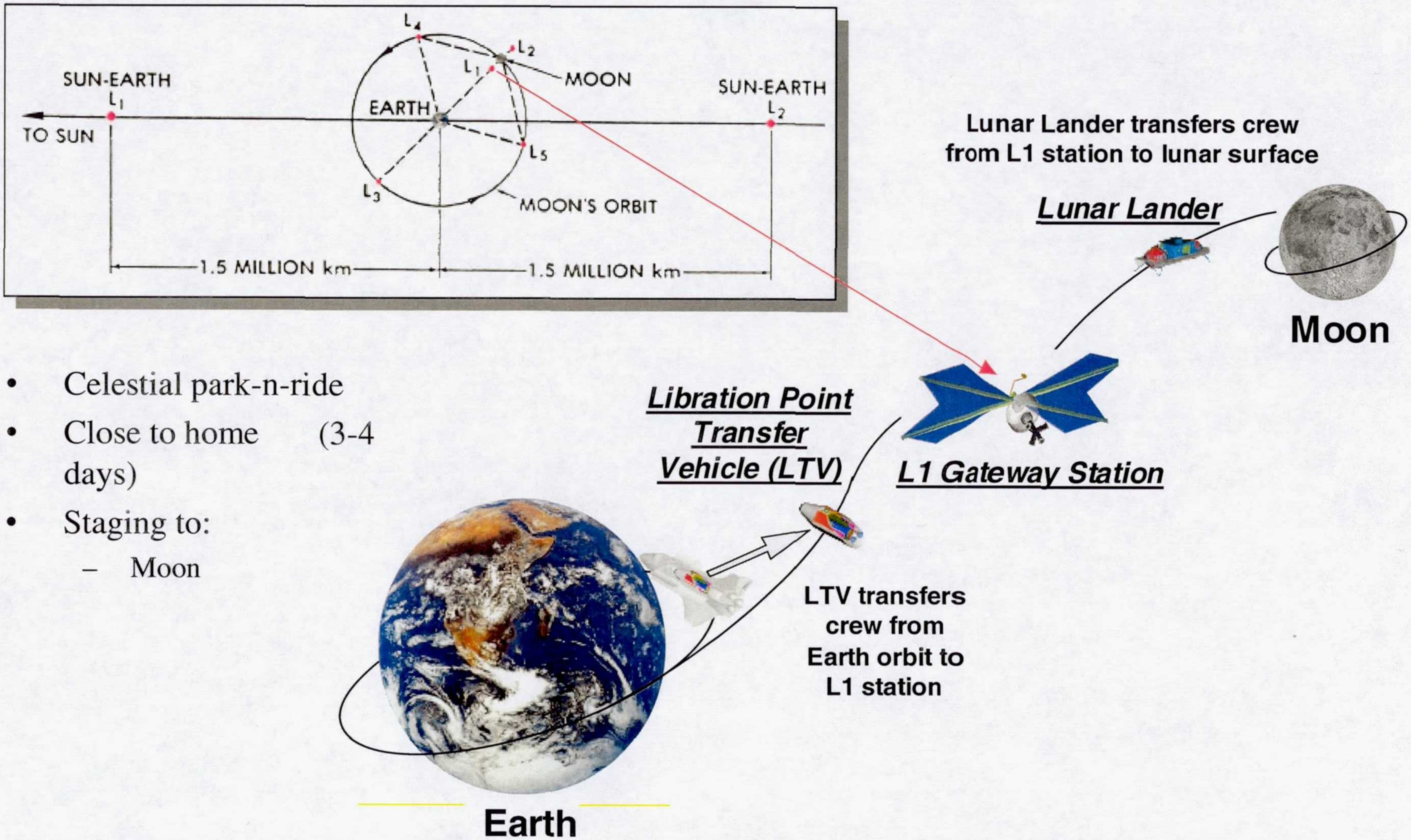
Expeditionary vs. Evolutionary

- Ongoing missions
- Open-ended missions on which other missions can build
- Greater initial capital investment



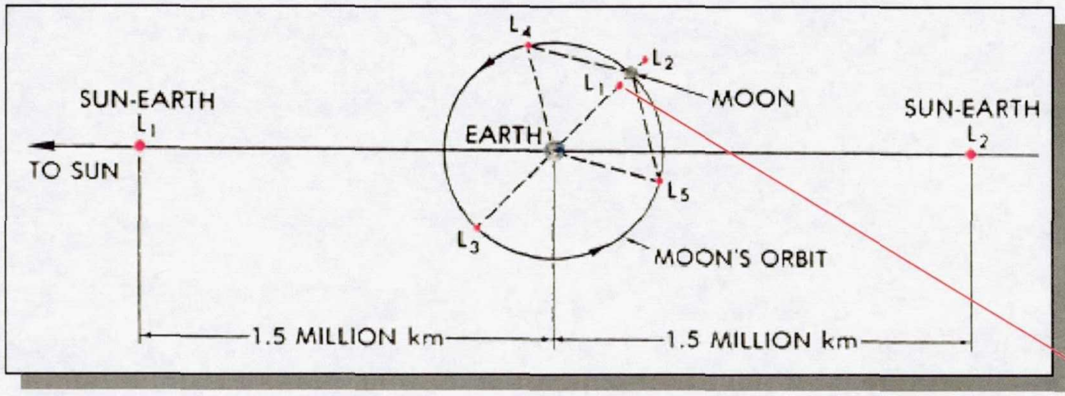
International Space Station program
Voyages of Prince Henry the Navigator of Portugal

Earth-Moon L1 – Gateway for Lunar Surface Operations

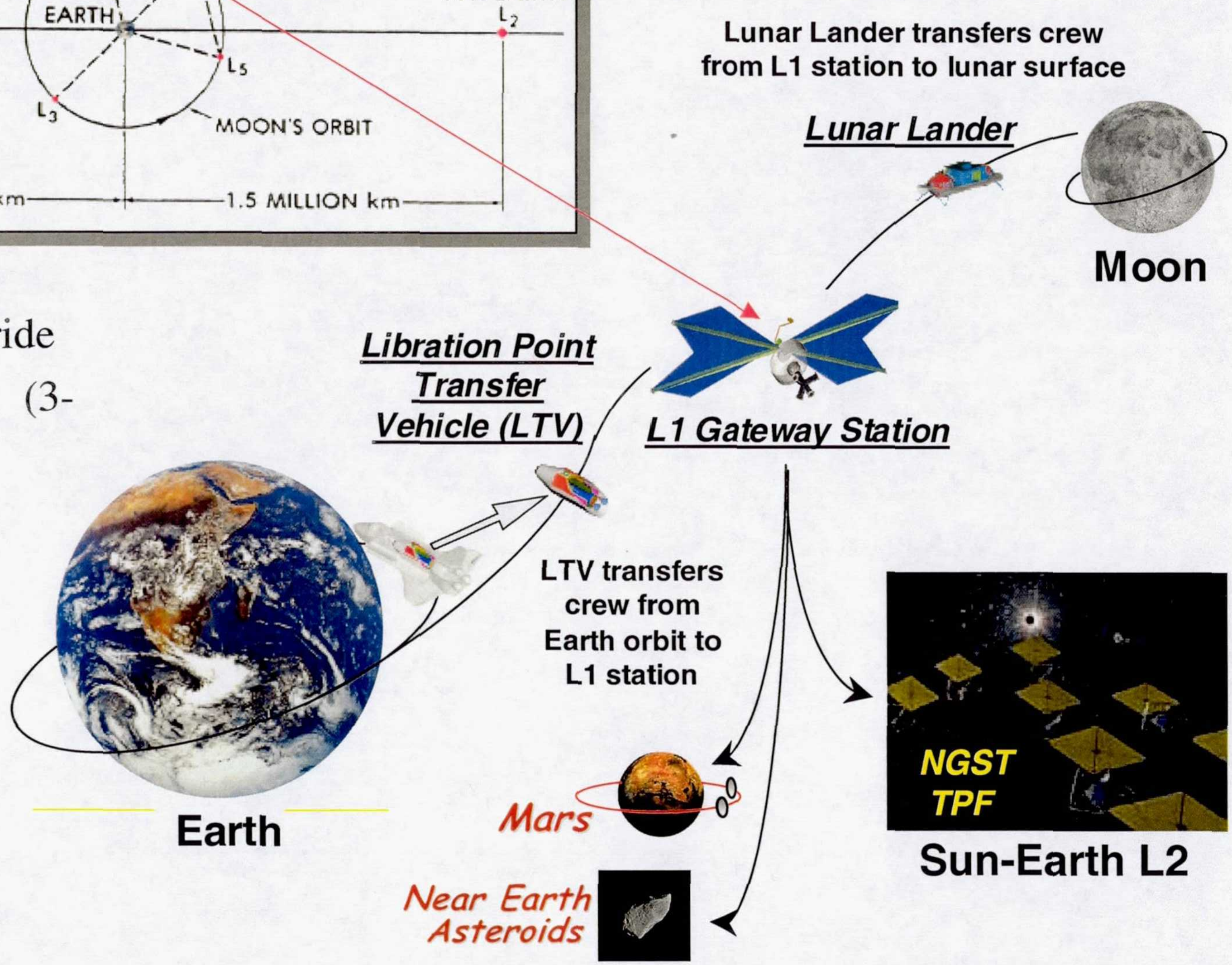


- Celestial park-n-ride
- Close to home (3-4 days)
- Staging to:
  - Moon

Earth-Moon L1 – Gateway for Lunar Surface Operations

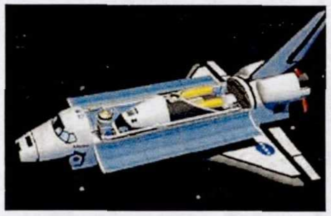


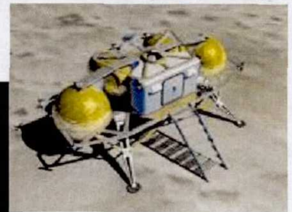
- Celestial park-n-ride
- Close to home (3-4 days)
- Staging to:
  - Moon
  - Sun-Earth L2
  - Mars
  - Asteroids
  - …

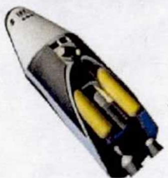


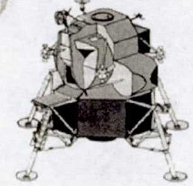
Lunar Mission: Libration Point vs. LOR

Mission Scenario Advantages









Earth-Moon L1

- No lunar departure injection window
- Global lunar access
- Reusability
- Protection from failed station-keeping
- Specialized vehicle design

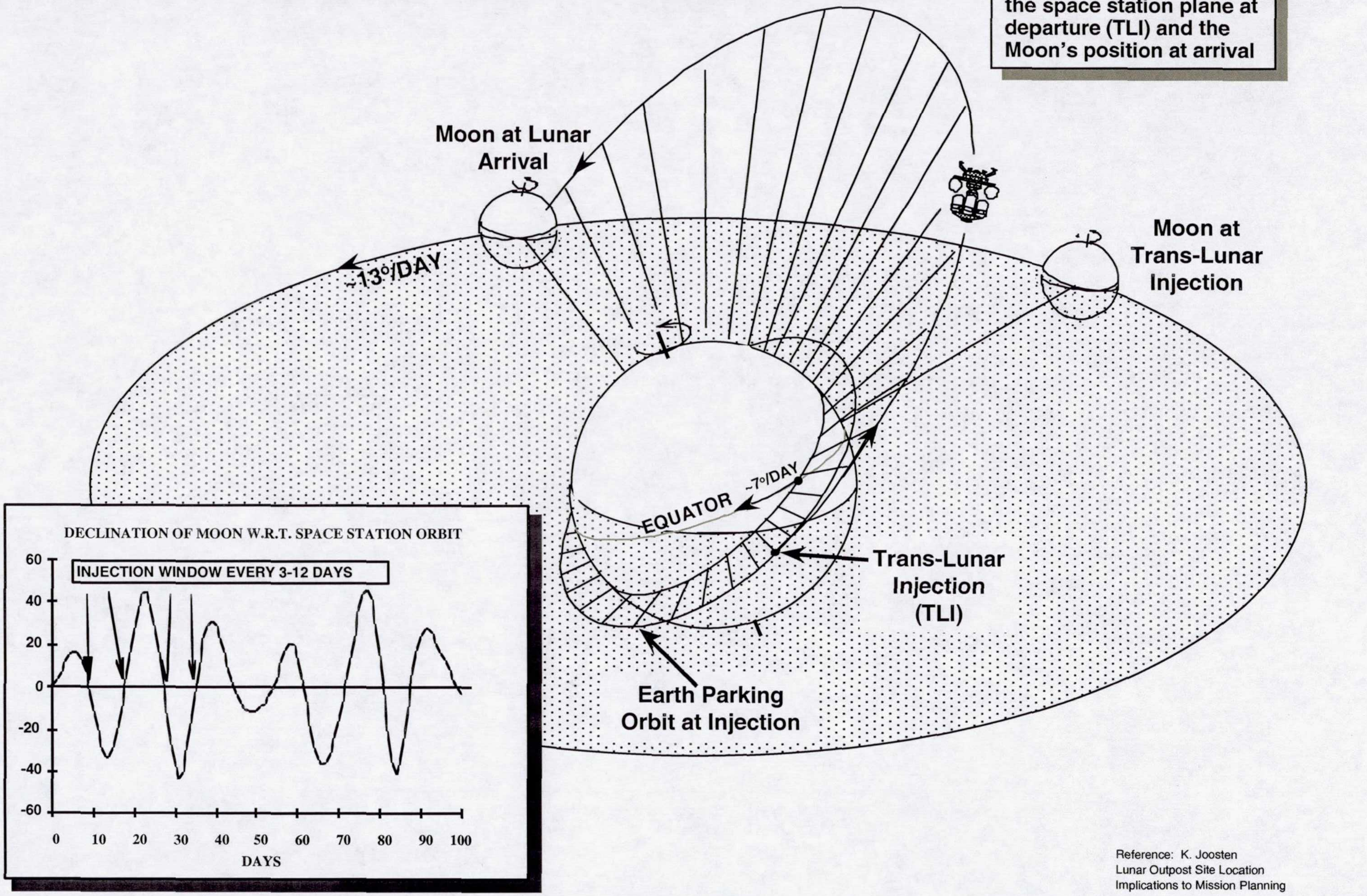
Lunar Orbit Rendezvous (LOR)

- Shorter mission duration
- Lower overall ΔV cost
- Fewer critical maneuvers required

Lunar Transfer/Orbit Diagrams

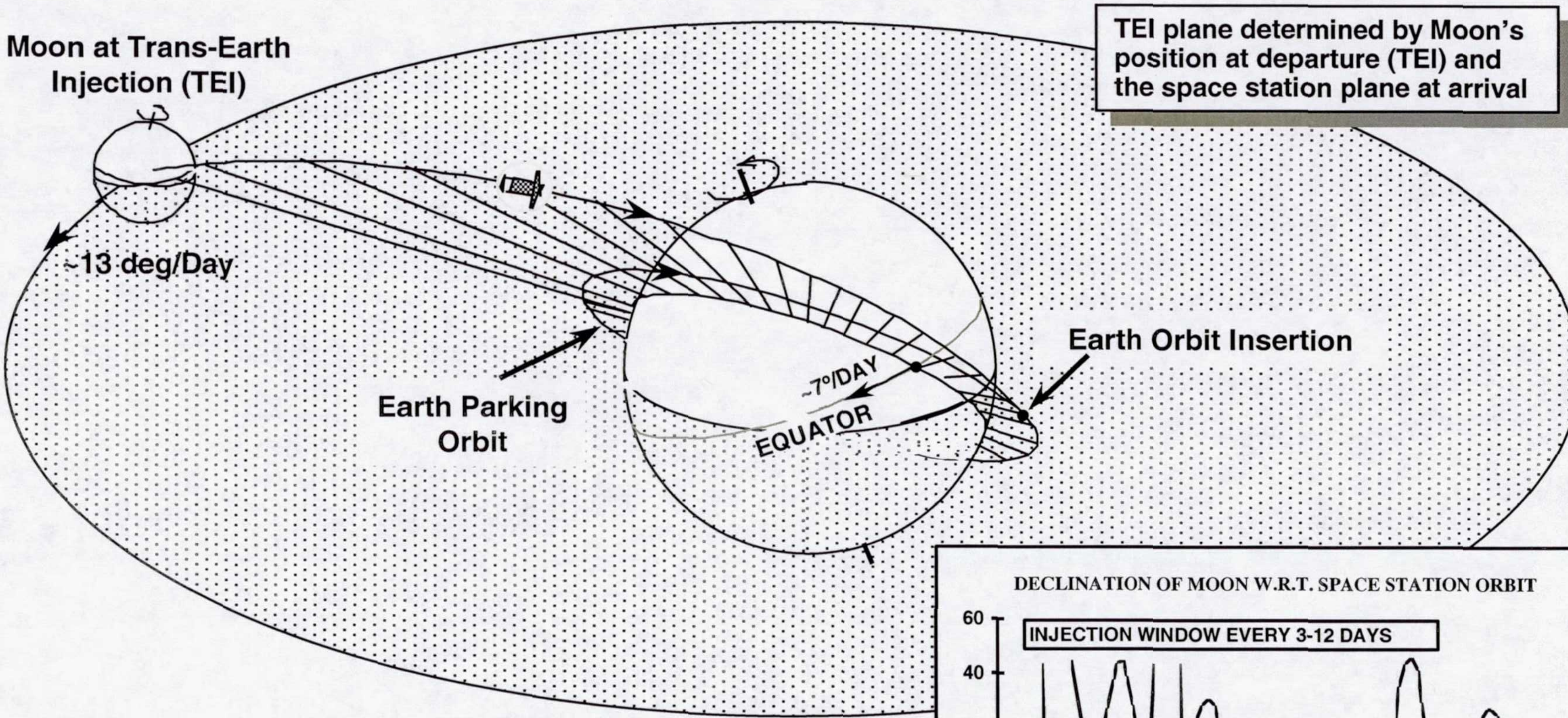
Trans-Lunar Trajectory from ISS Parking Orbit

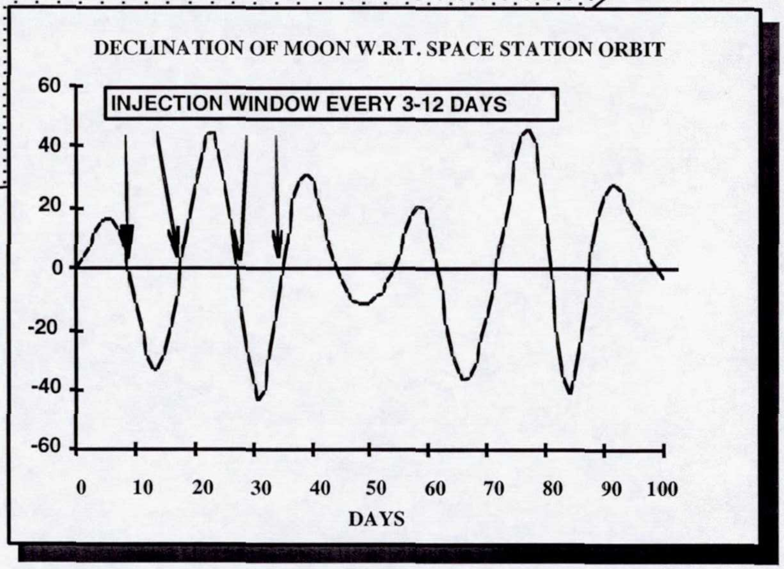
TLI plane determined by the space station plane at departure (TLI) and the Moon's position at arrival



Reference: K. Joosten
Lunar Outpost Site Location
Implications to Mission Planning

Trans-Earth Trajectories





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Lunar Outpost Site Location
Implications to Mission Planning

Parking Orbit Considerations

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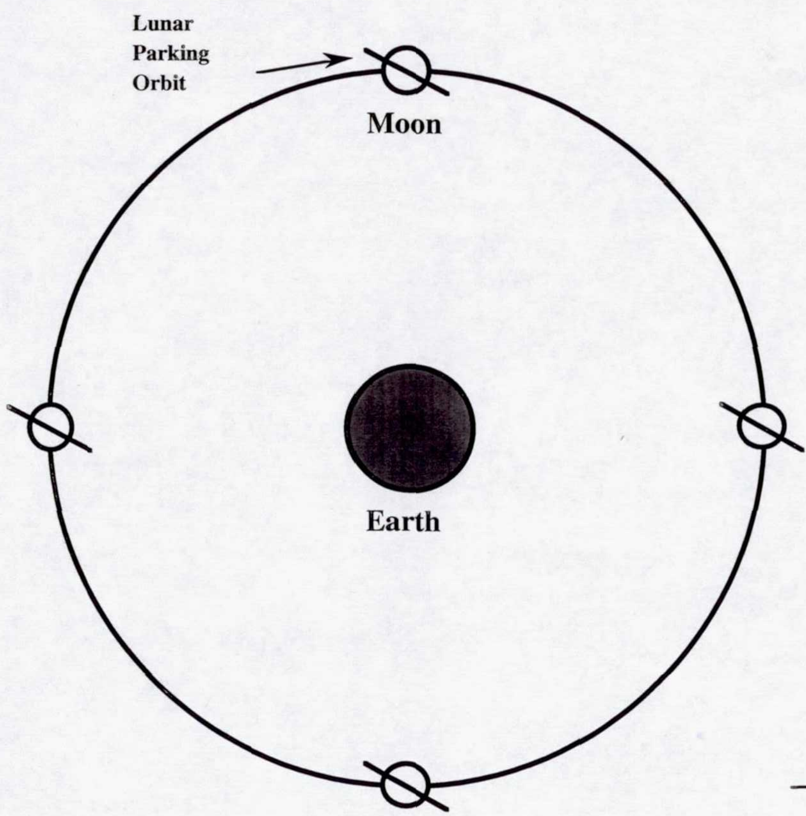
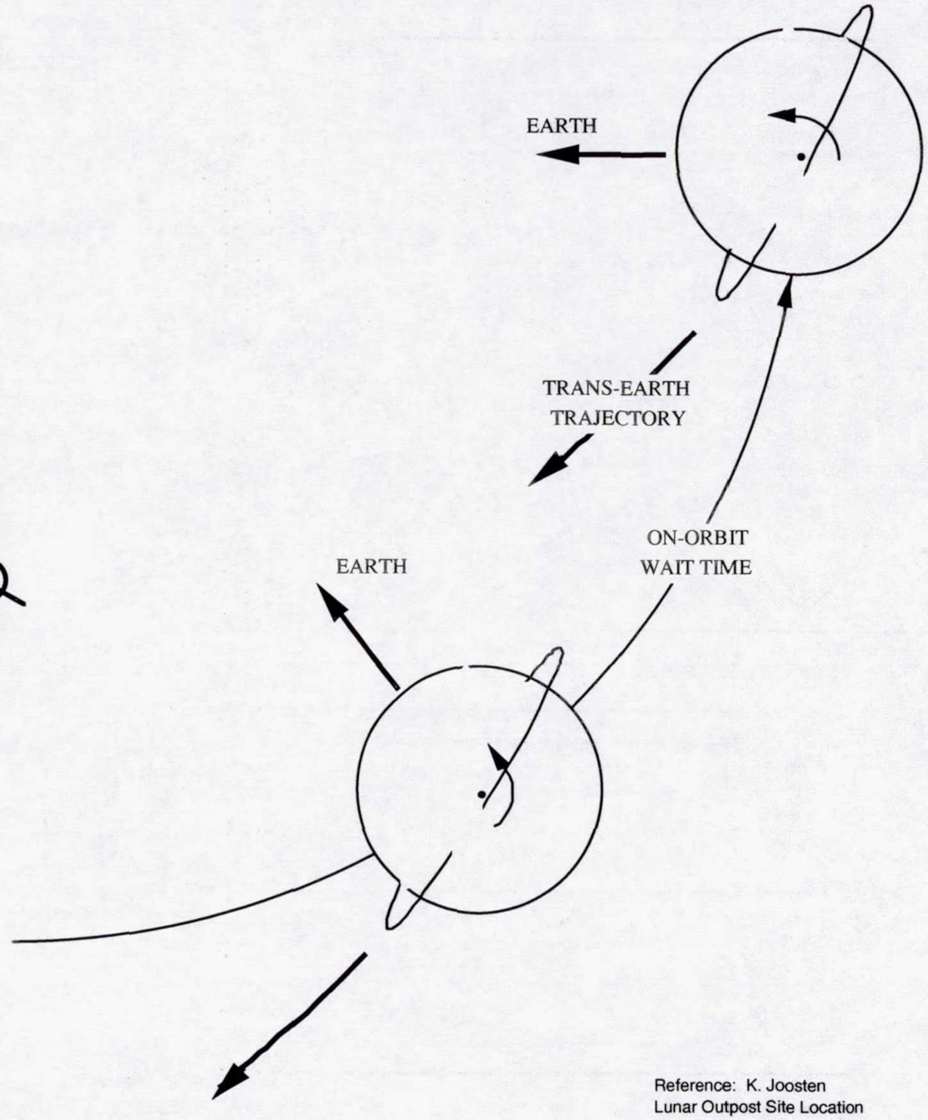
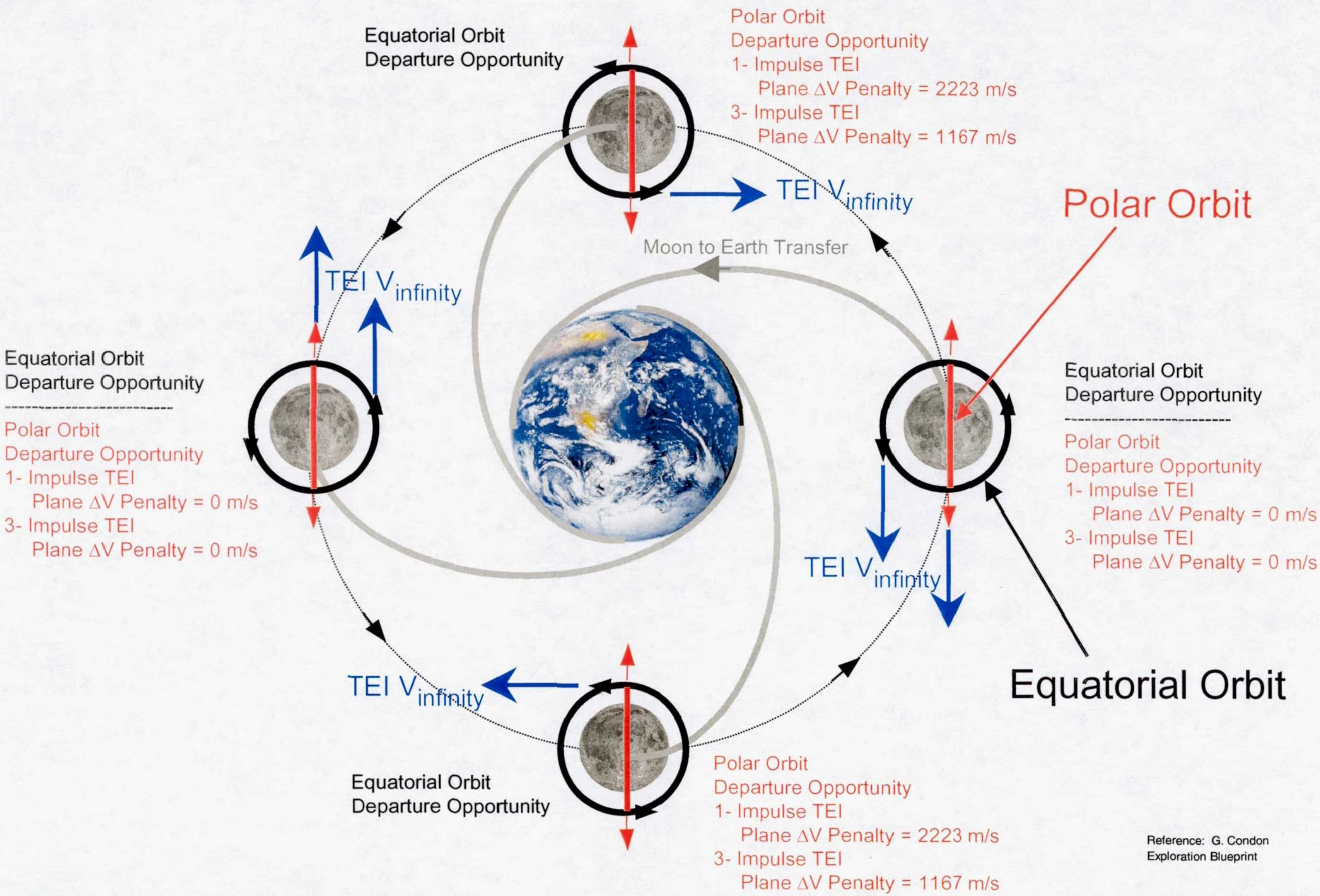




Reference: L. Wagner

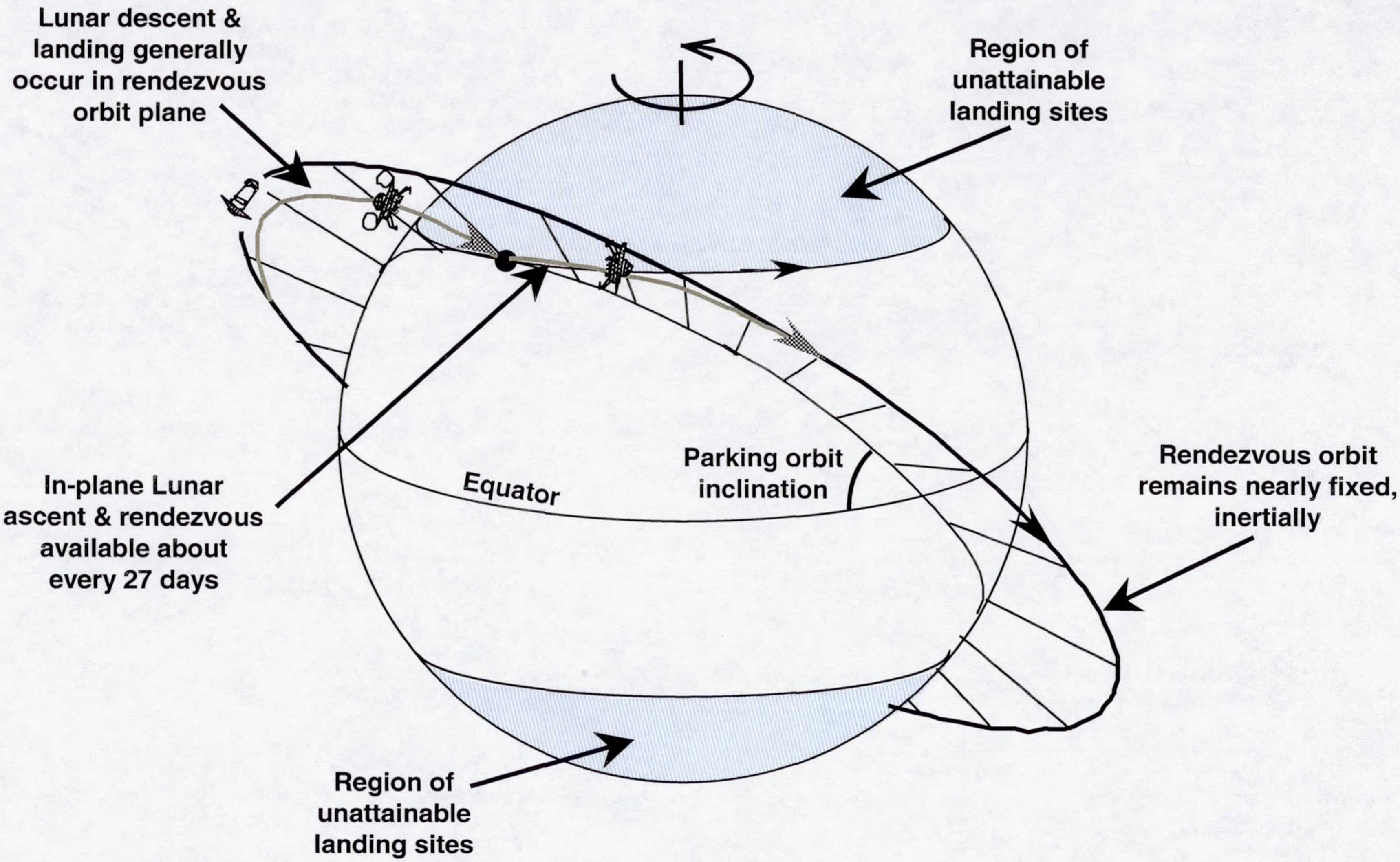
Reference: K. Joosten
Lunar Outpost Site Location
Implications to Mission Planning

Effect of Lunar Parking Orbit Inclination on Lunar Transfer Opportunities -> Moon to Earth Transfer



Reference: G. Condon
Exploration Blueprint

Landing Latitude Restrictions



Source: K. Joosten
Lunar Outpost Site Location
Implications to Mission Planning

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Comparison of Opposition Class (Short-Stay) and Conjunction Class (Long-Stay) Missions for the Human Exploration of Mars

Exploration Office

NASA/JSC

March 1998

Mars Mission Planning

- Earth-Mars Mission Planning
  - Trips to Mars and back are, in effect, a double rendezvous problem
  - First rendezvous outbound must be developed considering influence of the rendezvous inbound
  - Practical considerations dictate favorable (and different) planetary alignments relative to the sun for both transfers

- Synodic Period
  - is the period of time necessary for the phase angle between Earth and Mars to repeat itself
  - Repetition rate for identical Earth-Mars phasing, and therefore launch opportunities for similar mission classes, is ~26 months
  - The eccentricity of Mars' orbit causes significant variations in Earth-Mars relative distance and velocity from one opportunity to the next
  - The entire range of Earth-Mars geometry is encompassed by seven launch opportunities, or about 15 years
  - Before definitive claims of mission characteristics or propulsion system capabilities are made, analysis across the 15-year cycle should be performed

Earth-Mars Orbital Characteristics

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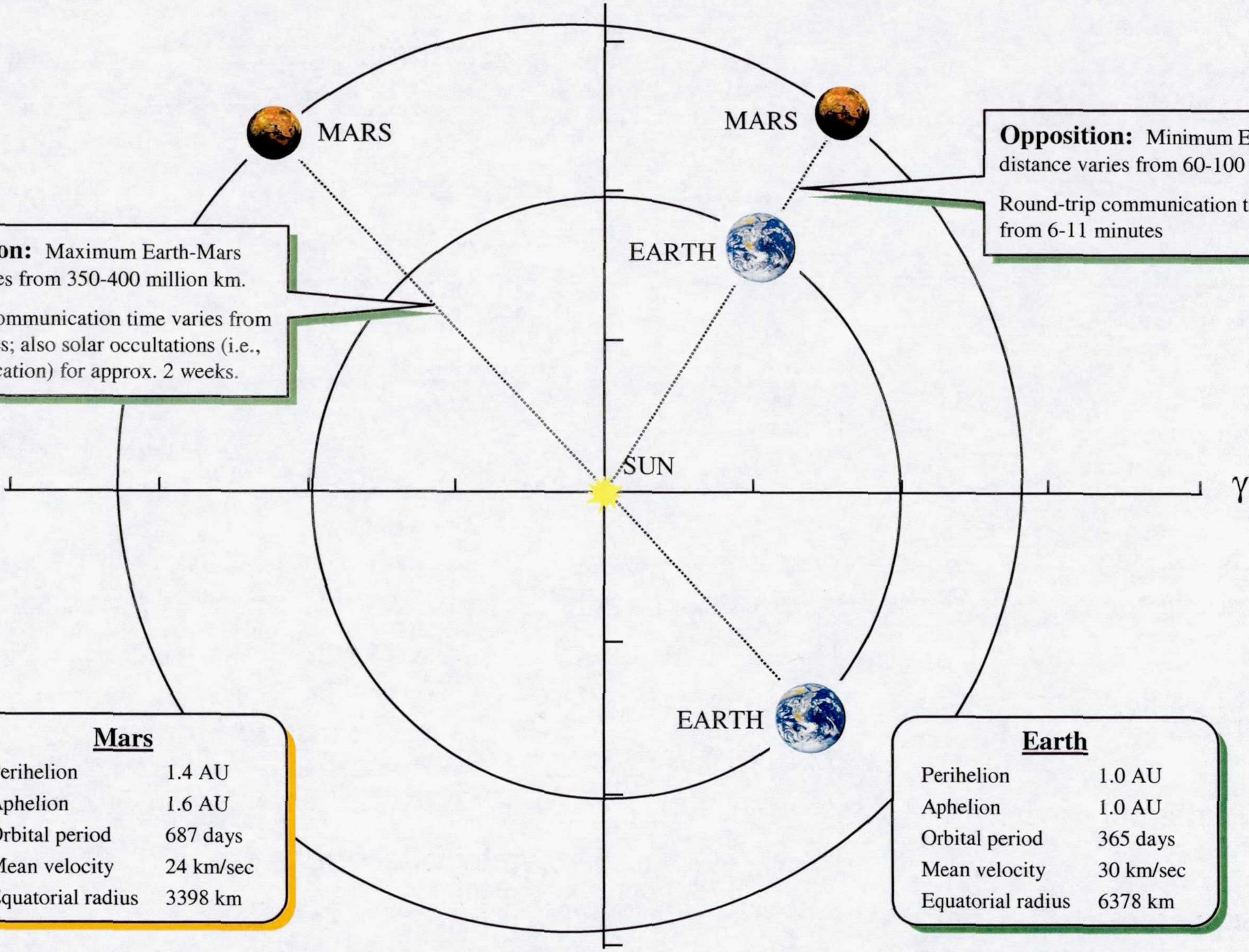

Conjunction: Maximum Earth-Mars distance varies from 350-400 million km.

Round-trip communication time varies from 40-45 minutes; also solar occultations (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

Delta-V Variations

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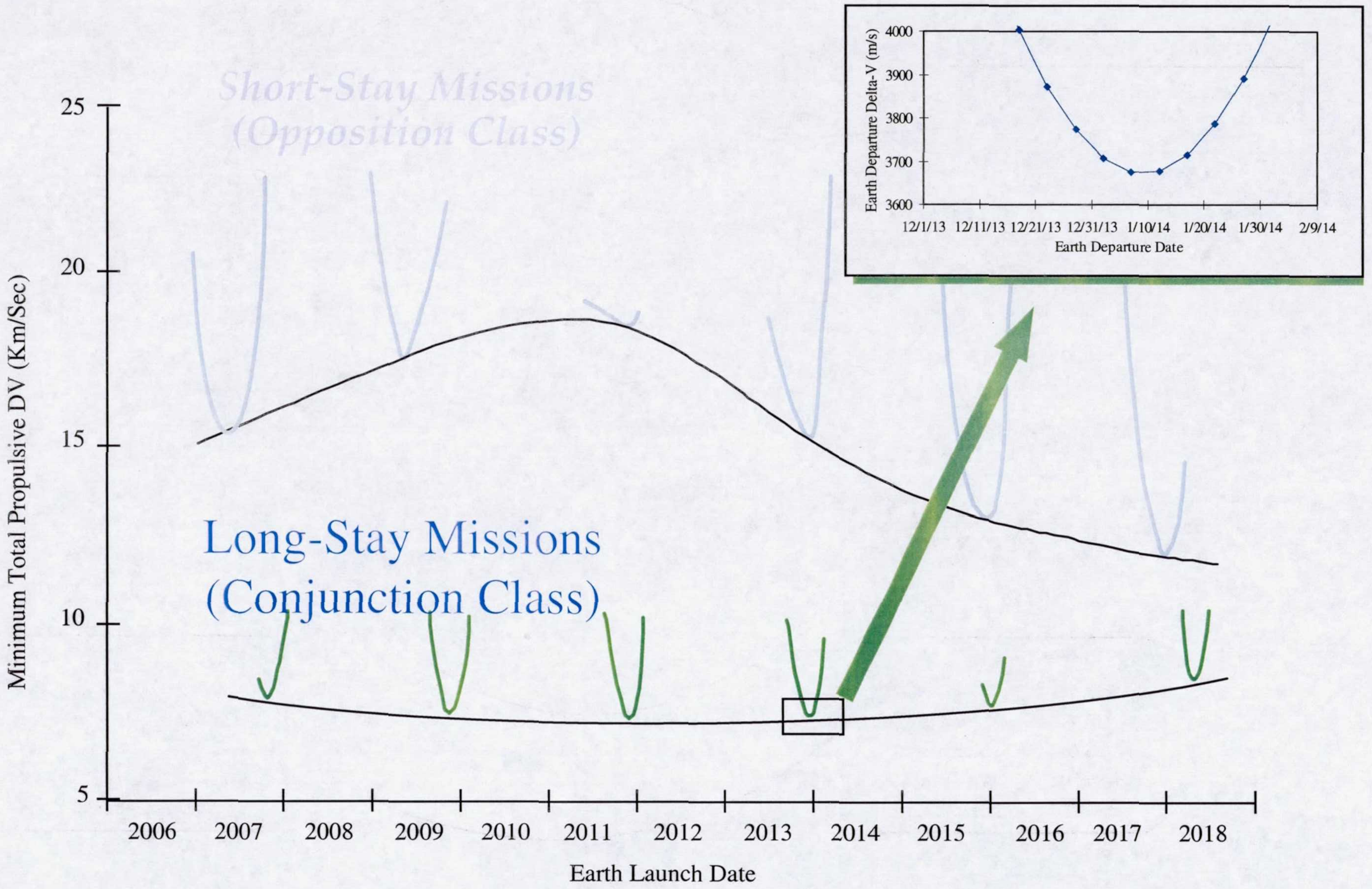

Mars Mission Duration Comparison

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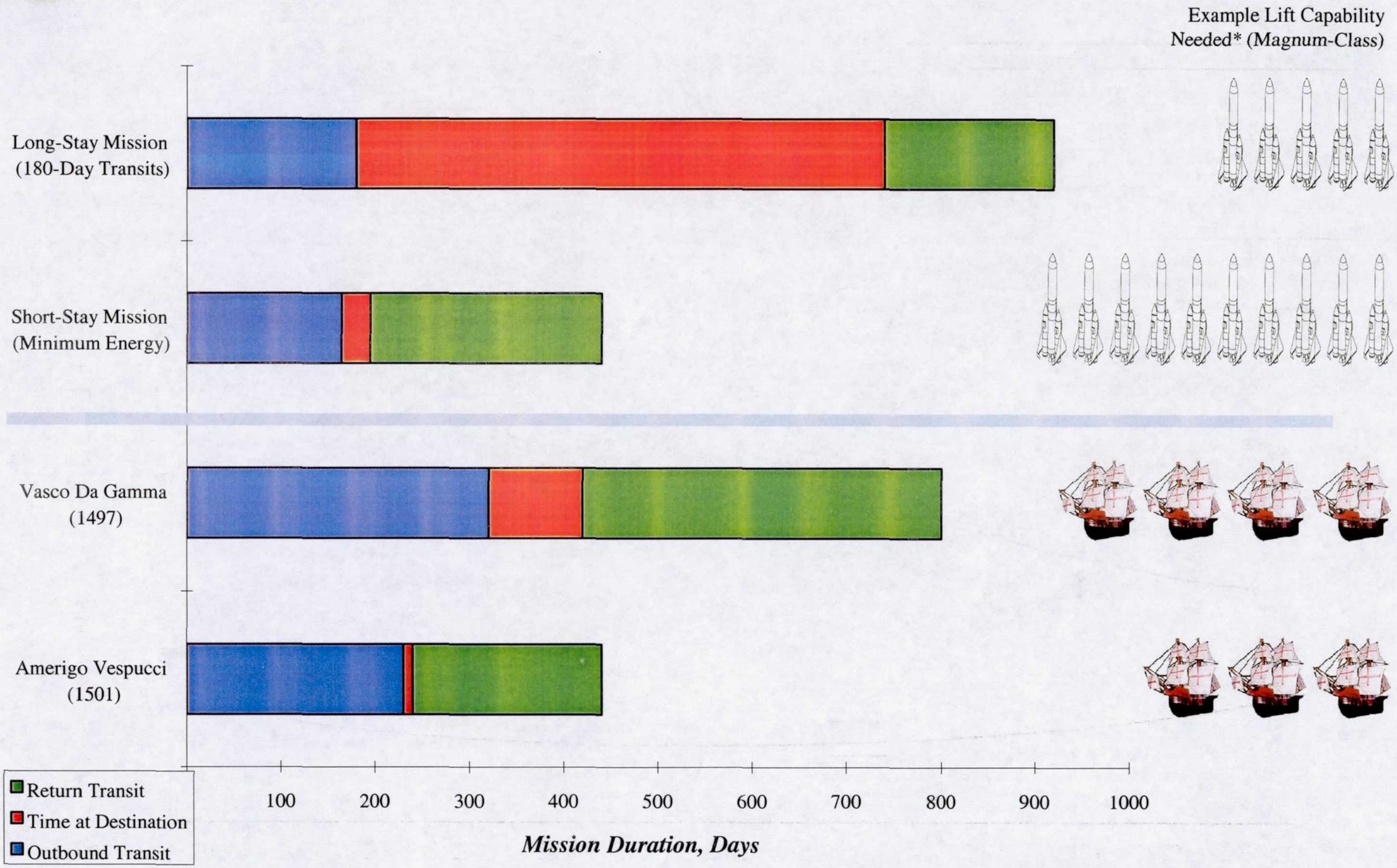

* Assuming NTP=925 sec Propulsion

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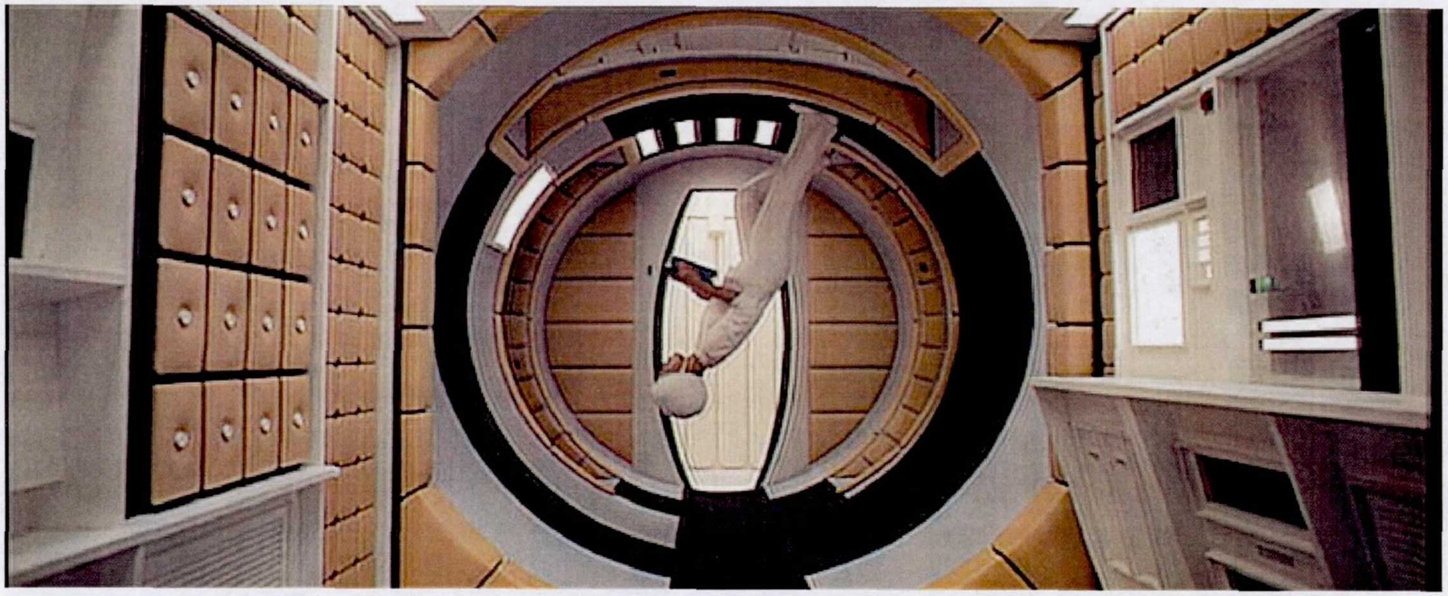
Artificial Gravity for Human Exploration Missions



NEXT Status Report

July 16, 2002

B. KENT JOOSTEN
Exploration Analysis and Integration Office
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
2101 NASA Road 1, Houston, TX 77058-3696
Mail Code: EX13 Voice: (281) 483-4645 FAX: (281) 244-7478
kent.joosten@jsc.nasa.gov

Current Configuration

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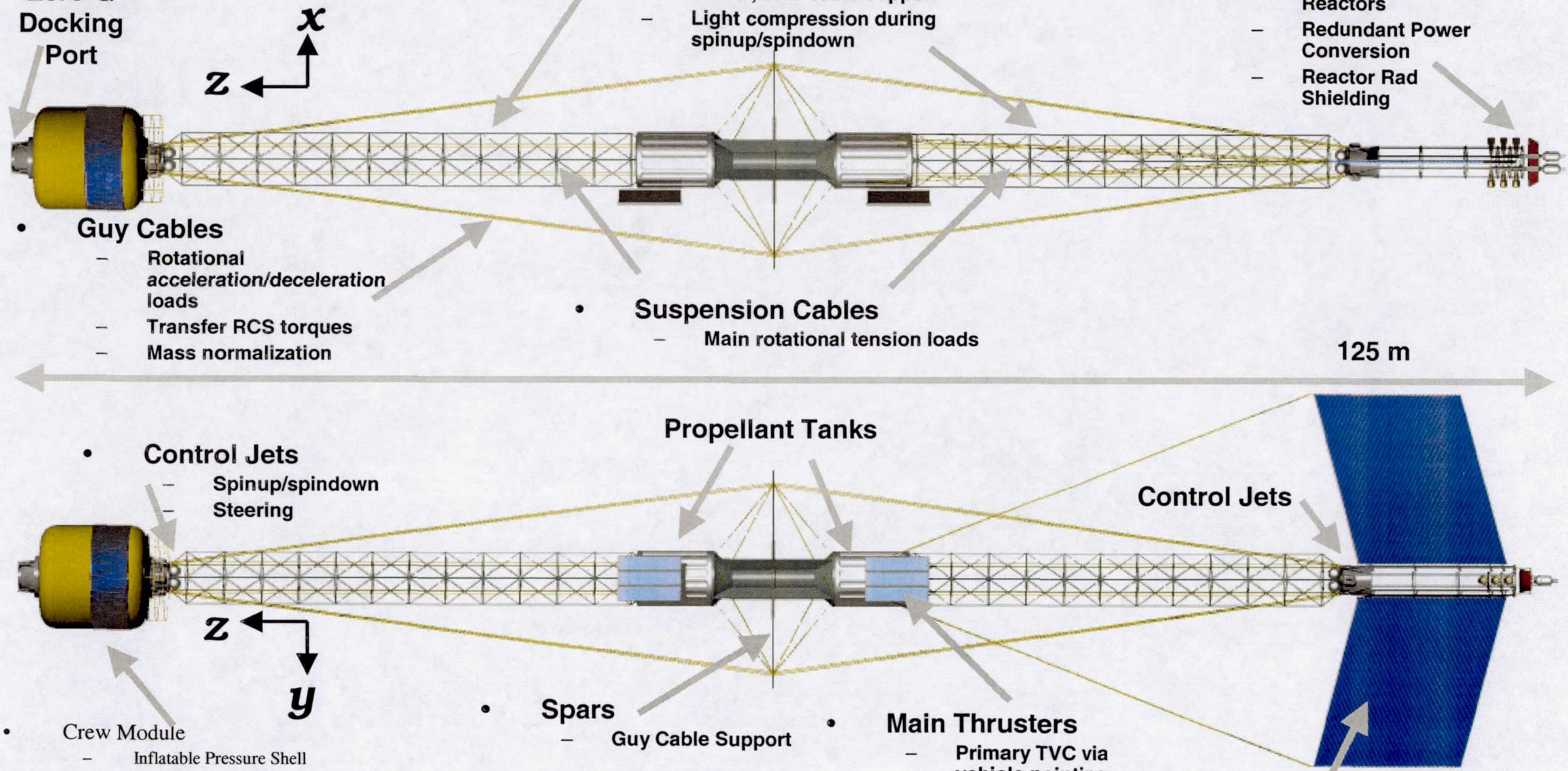
- **Masts**
  - Deployable
  - *Element zero-g positional control*
  - Power, data cable support
  - Light compression during spinup/spindown
- **Main Power**
  - Redundant Reactors
  - Redundant Power Conversion
  - Reactor Rad Shielding

Zero-G Docking Port



- **Guy Cables**
  - Rotational acceleration/deceleration loads
  - Transfer RCS torques
  - Mass normalization
- **Suspension Cables**
  - Main rotational tension loads
- **Control Jets**
  - Spinup/spindown
  - Steering

Propellant Tanks

Control Jets

- Crew Module
  - Inflatable Pressure Shell
  - Radiation Shielding
  - Micrometeoroid Protection
  - Life Support
  - EVA Support
  - Body-Mounted Radiator
- **Spars**
  - Guy Cable Support
- **Main Thrusters**
  - Primary TVC via vehicle pointing
- **Main Power Radiators**
  - Flexible, Deployable

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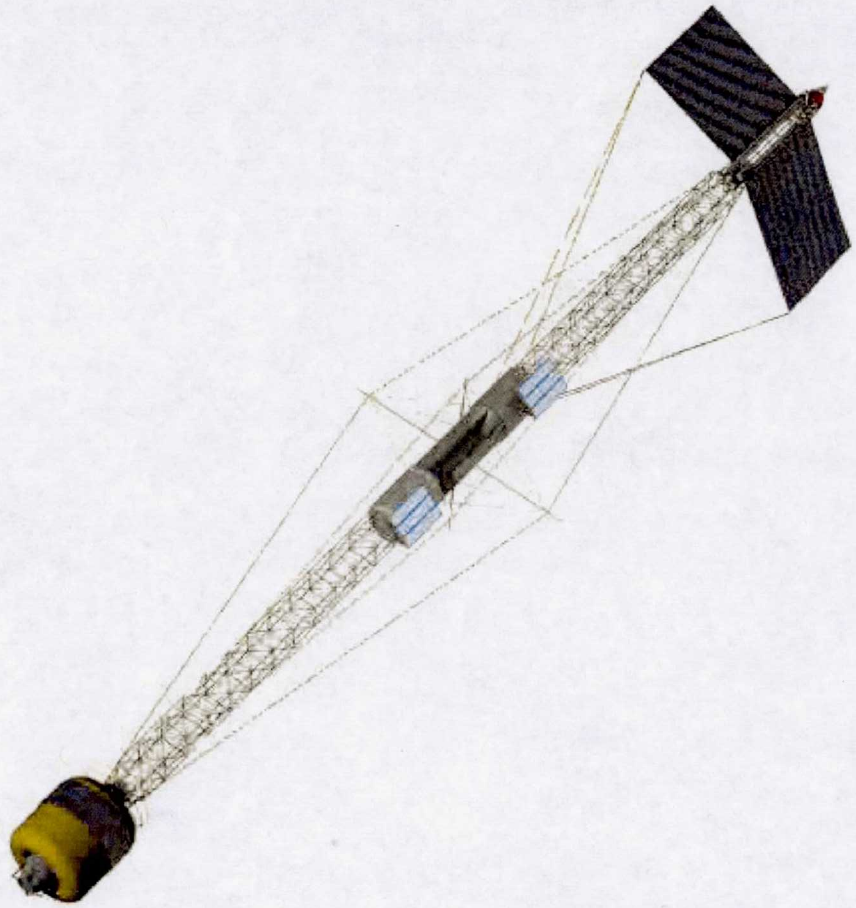

NEP Thruster Location Trades

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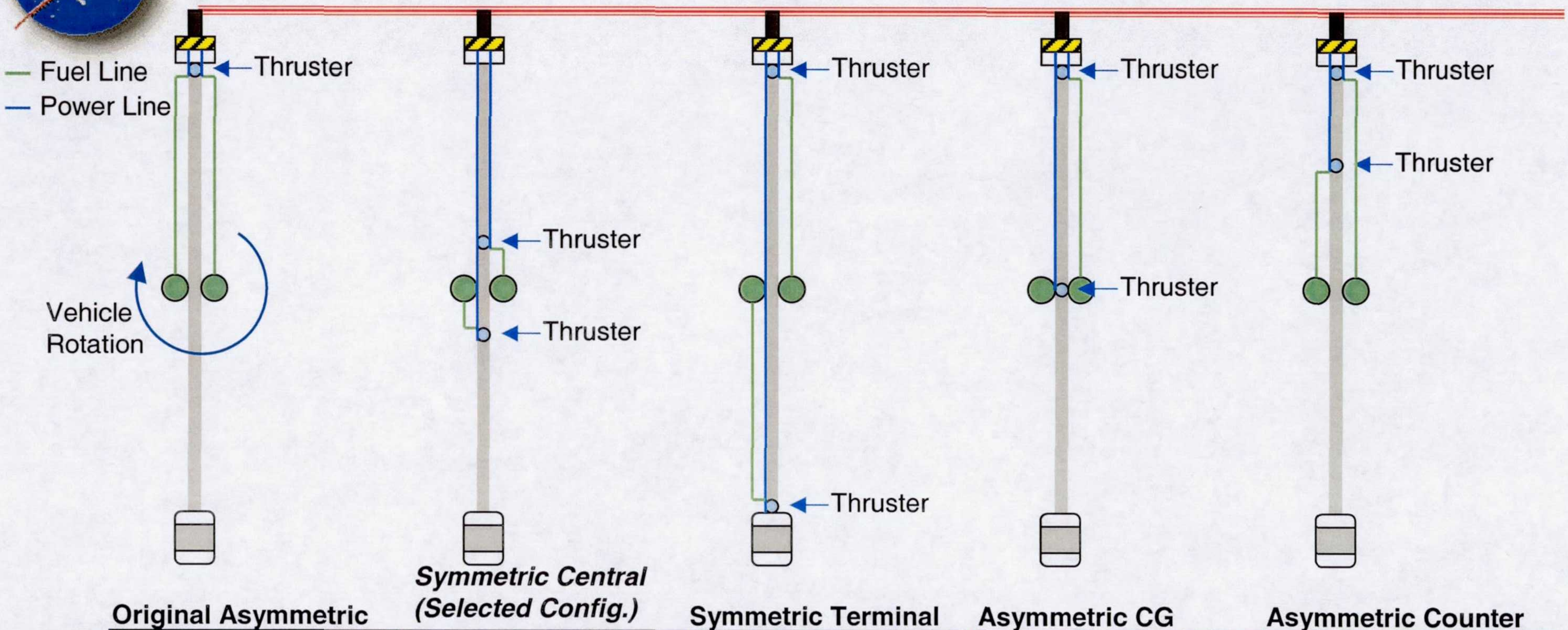

	Original Asymmetric	***Symmetric Central (Selected Config.)***	Symmetric Terminal	Asymmetric CG	Asymmetric Counter
Power Level*	-- High Power Variation	+ Counter-cycling (near constant power)	+ Counter-cycling (near constant power)	+ Counter-cycling (near constant power)	+ Counter-cycling (near constant power)
Power Lines	+ Short power lines	-- Long power lines	-- Long power lines (no worse than prevoius)	-- Long power lines	+ Short power lines
Prop Lines	-- Long prop lines	+ Short prop lines	-- Long prop lines	-- Long prop lines	-- Long prop lines
Turn Rates	+ Higher turn rates	-- Lower turn rates	+ Best turn rates	+ Higher turn rates	-- Lower turn rates

*For constant mass flow rate approach

Minor Axis Rotation

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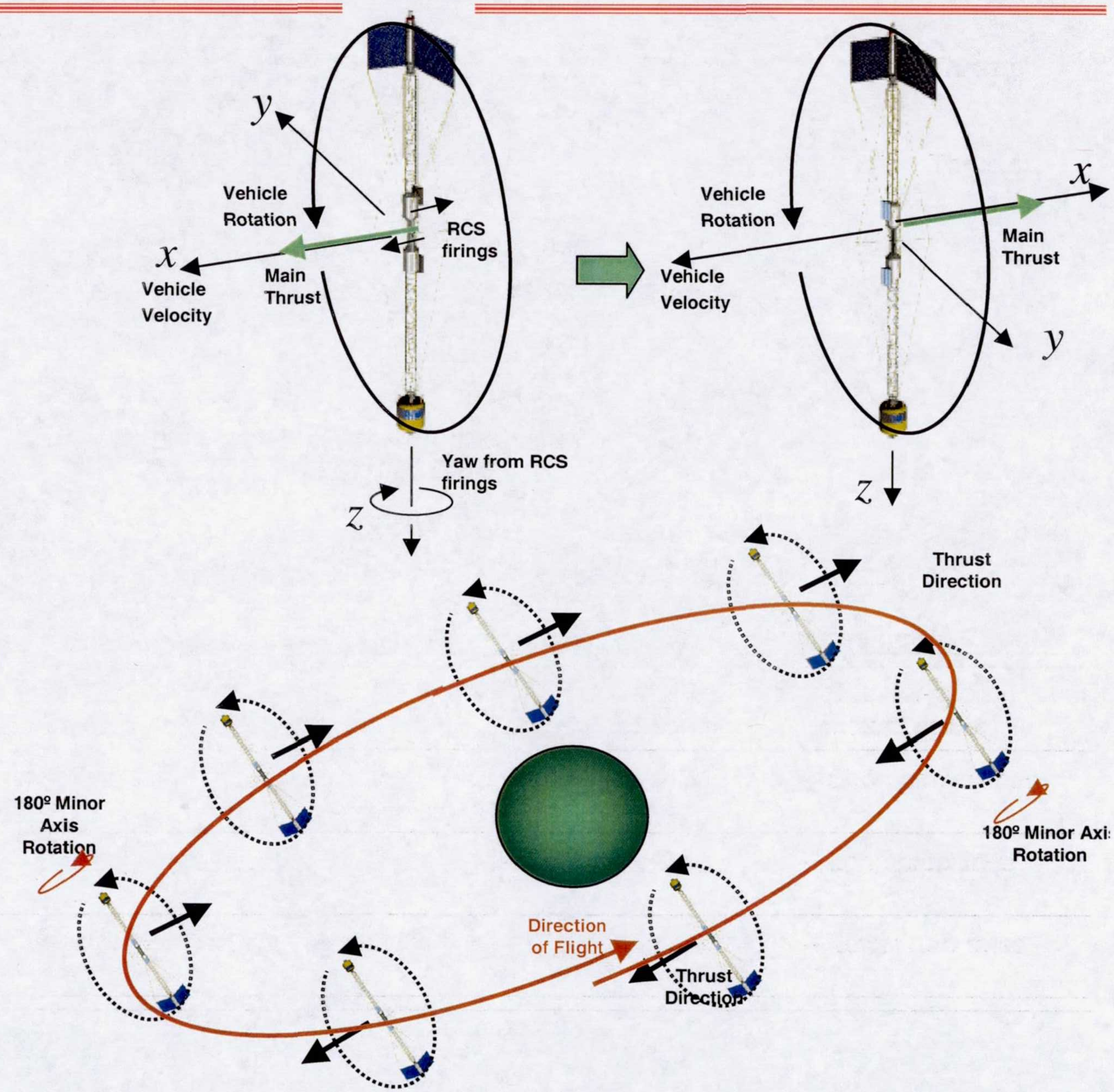
- Technique for rotating thrust vector 180°
- Rotation about vehicle z-axis
- Applications:
  - Midcourse turnaround
  - Planetary spirals (if required)
    - ~36% loss of propulsive efficiency vs. tangential thrusting
- Other possible implementation: second set of thrusters (-x thrust direction)
  - Thruster mass/expense vs. propellant required for rotation



Example Load Paths (cont)

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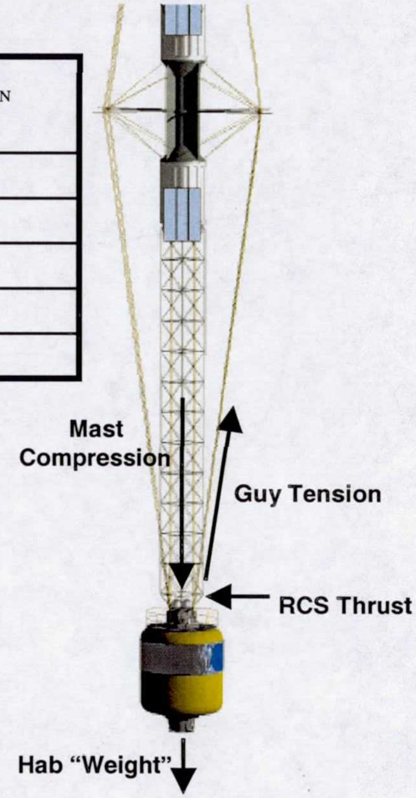
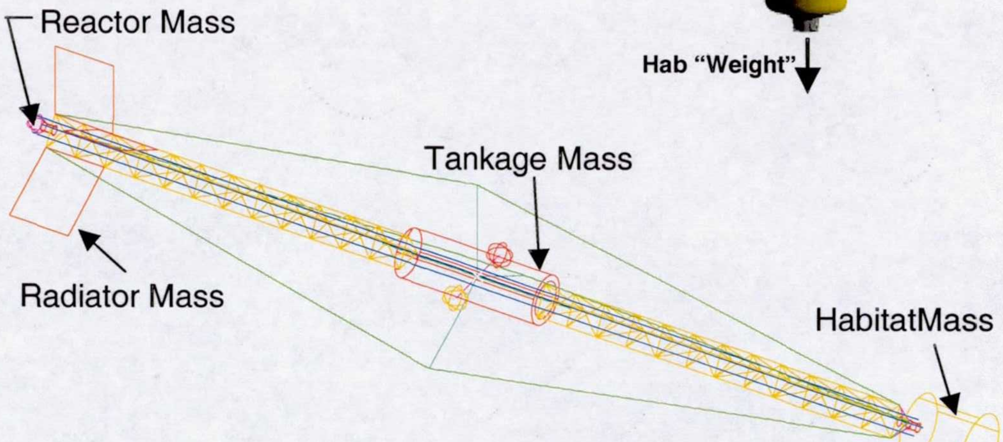
- Mast loads for spinup, spindown
  - Mast will be under compression only during period when Hab Module/Power Module "weight" is less than compression load
    - Only mast loads identified to date
  - After that, no load (suspension cables support loads)
  - For spinup/down times less greater than 24 hours, compression loads will not exceed 100N (22 lbs)
  - Maximum mast loads may result from <u>zero-g</u> operations (hard to quantify at this time)
    - Docking forces
    - Plume impingements
- LaRC Analysis
  - Providing finite element modeling and analysis for load conditions
    - 1-g
    - Spinu/spindown
    - Maneuvers during transit
  - From loads analysis, determine low lightweight a structure (such as inflatabe/rigidizable structures) could be used for mast
  - Status
    - Modeling nearly complete
    - Analysis to begin shortly

Thrust Level, N	Spinup Time, hrs.	ArcJet Power, kWe	Guy Tension, N	Max. Mast Compression, N
5	100	65	24	23
10	50	131	47	46
15	33	196	71	70
20	25	262	95	93
25	20	327	119	116

ArcJet Computations Assume:
Efficiency 30%
Isp 800 sec





Finite Element Model