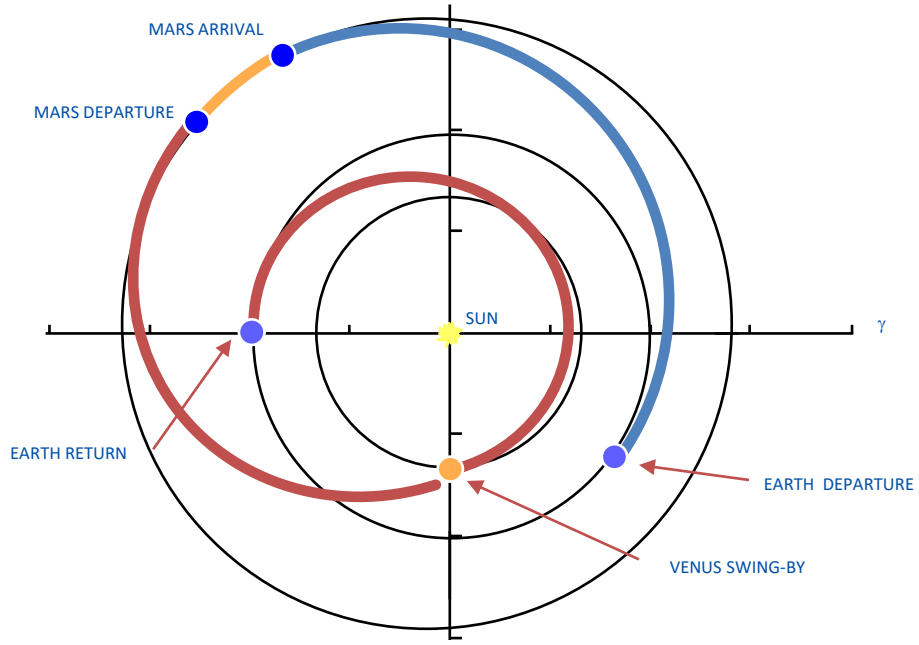
Mars Ballistic Trajectory Classes

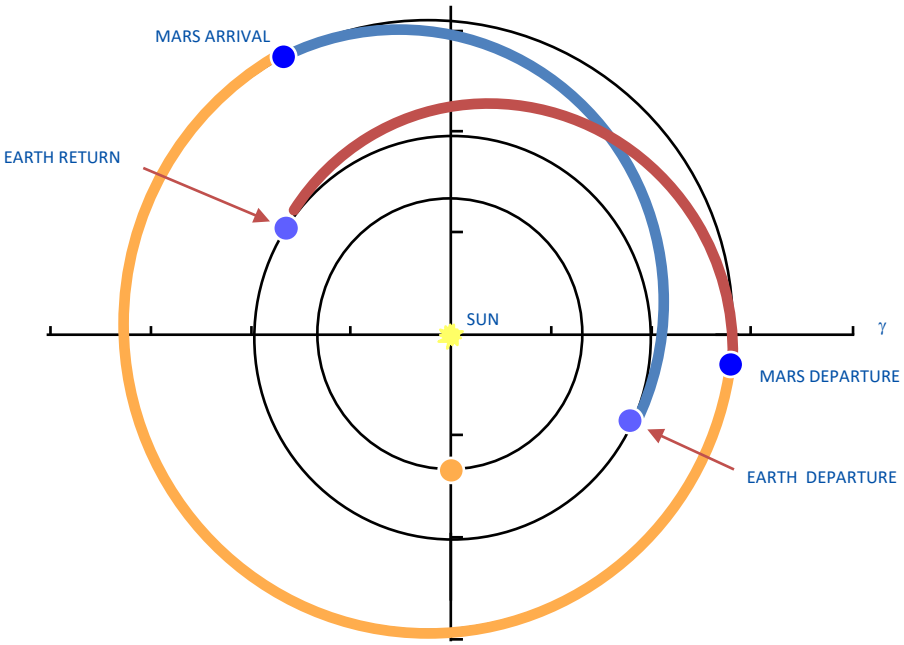
Short-Stay Missions

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



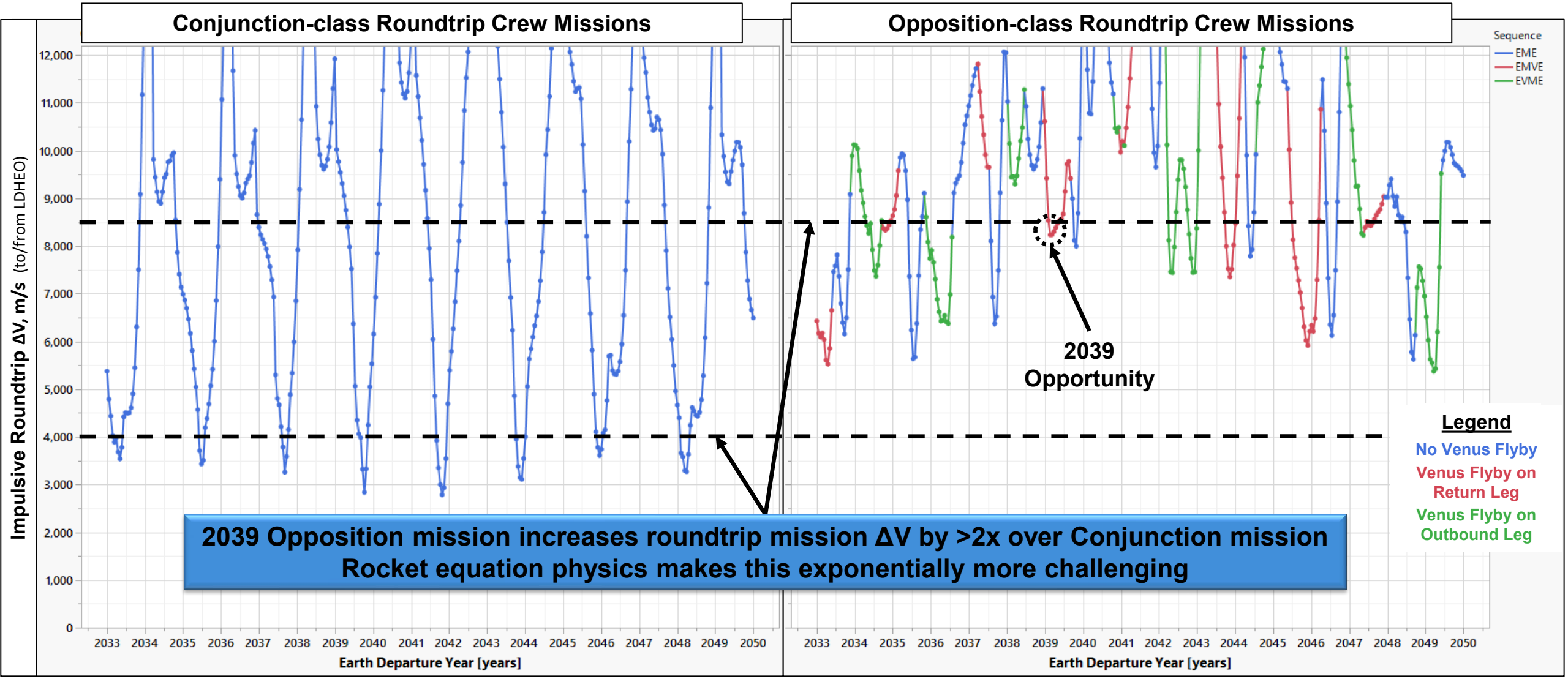
Long-Stay Missions

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



Drake, Bret G., et al, "Alternative Strategies for Exploring Mars and the Moons of Mars," 2012

Roundtrip Mars Mission Energy Requirements
Full Synodic Cycle, 2033-2050



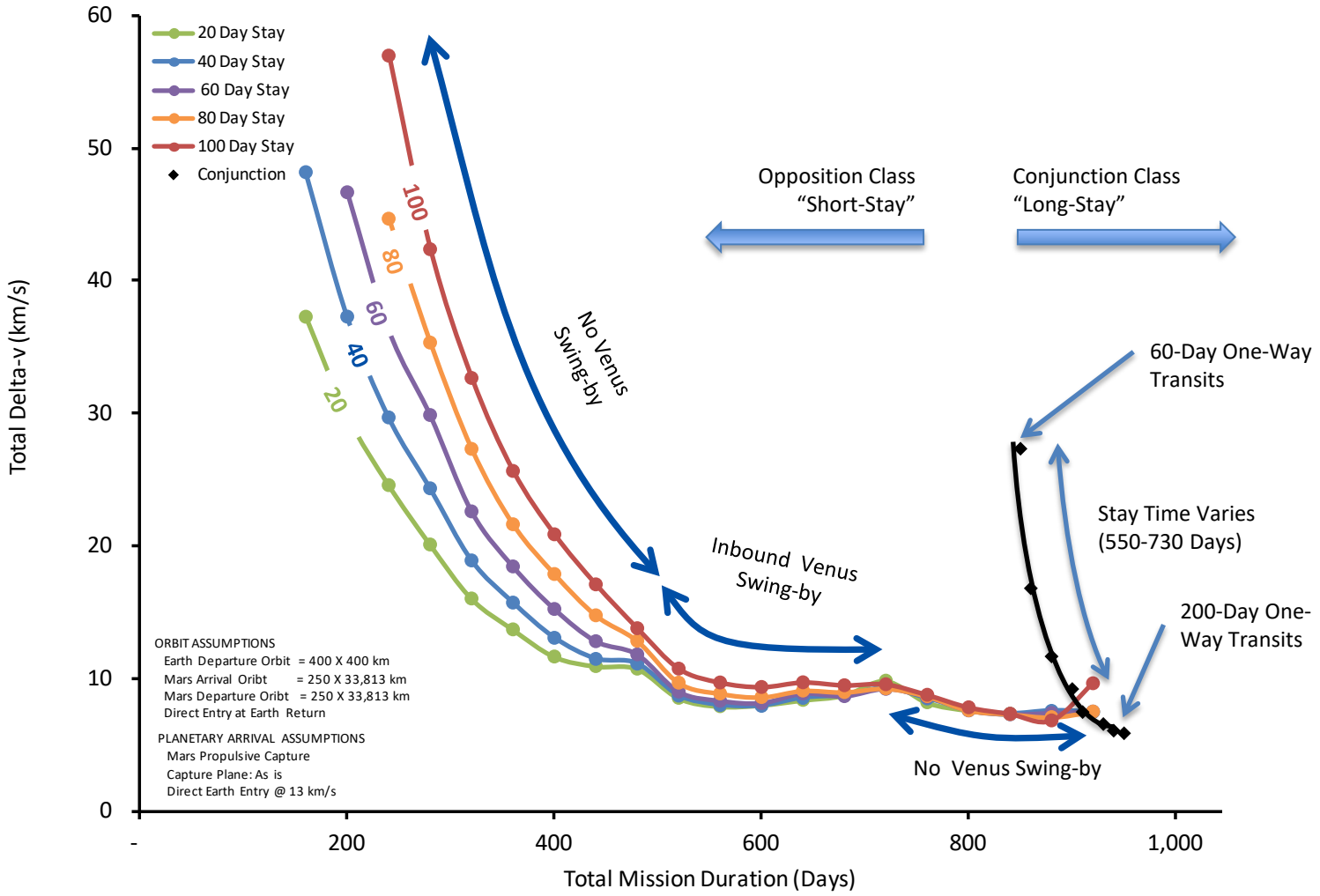
Conjunction-class data presented only includes <1000 d roundtrip times

Opposition-class data presented only includes <760 d roundtrip times

Delta-v versus Mission Duration

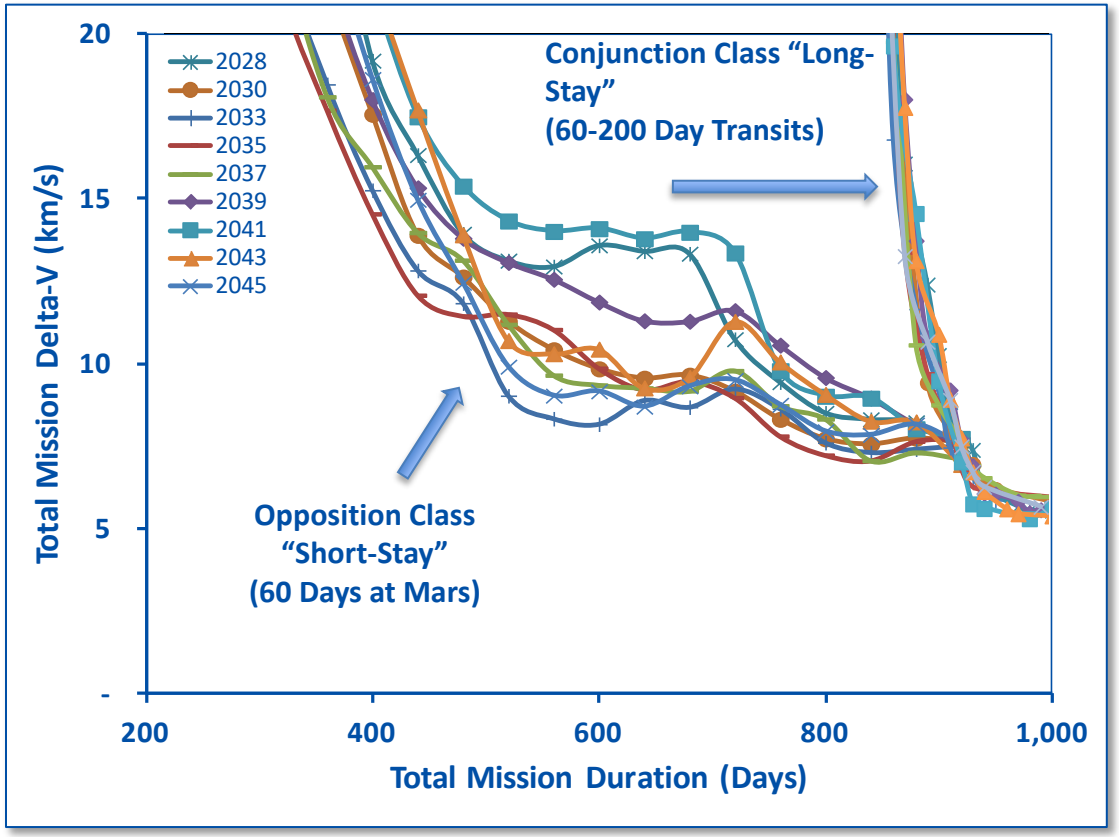
Example "Good" Opportunity (2033)

- **Opposition Mission Characteristics**
  - Short stays at Mars
  - Large variation between mission opportunities
  - Delta-v increases as mission duration decreases
  - Delta-v increases as stay time increases
  - Venus swing-by helps reduce delta-v when available
  - Missions require close perihelion passage
  - Unless constrained, result in high entry speeds at both Mars and Earth
  - ~95% of mission spent in free-space
- **Conjunction Mission Characteristics**
  - Longer overall mission duration with ~45% of mission spent in free space
  - Fast transit to/from Mars with long stay at Mars
  - Smaller variation in delta-v across opportunities
  - Natural lower arrival/entry speeds at Mars and Earth



Drake, Bret G., et al, "Alternative Strategies for Exploring Mars and the Moons of Mars," 2012

Round-trip Crew Mission Delta-v Sensitivity



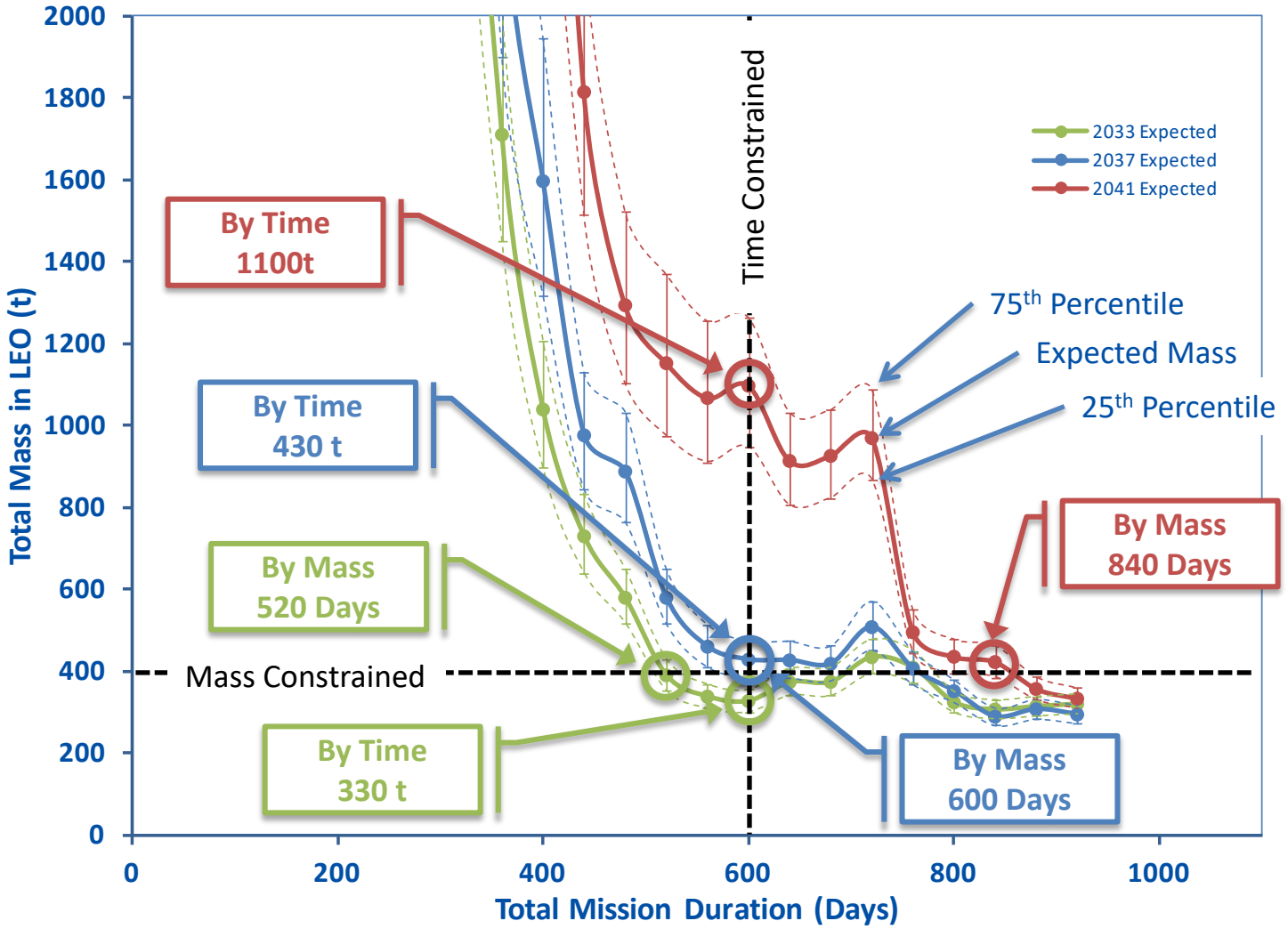
Mission Characteristics
- LEO: 400 km x 400 km
- HMO: 250 km x 33,813 km
- Direct Earth Entry: 13 km/s

- Trajectories vary across the synodic cycle
- Mission opportunities (Earth departure date) occur approximately every 26 months
- Due to the difference in orbits of both the Earth and Mars, the required trajectories vary for each Earth departure date
- Short-stay (opposition) missions demonstrate significantly variation
- Less sensitivity occurs for long-stay (conjunction) missions

Drake, Bret G., et al, "Alternative Strategies for Exploring Mars and the Moons of Mars," 2012

What Drives the Mission? Mass or Time?

First order parametric trend analysis



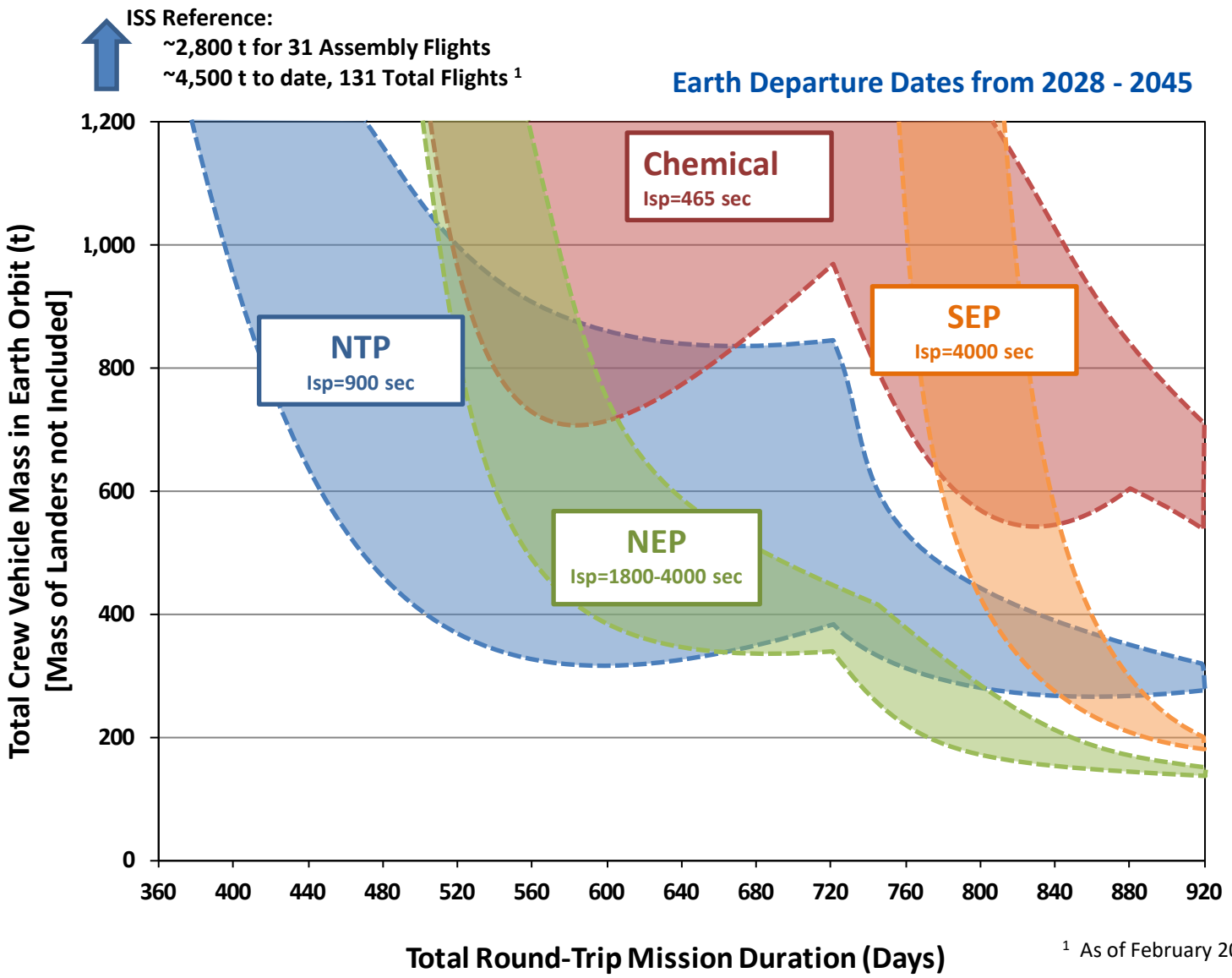
Drake, Bret G., "Presentation to National Academies Committee on Space Nuclear Propulsion," June 29, 2020

Context Notes

- Parametric estimates only
- NTP Crew Vehicle
- 900 s Isp
- All expendable
- Direct Earth entry
- Optimized vehicle design/staging
- Unconstrained launch payload/rate
- Drop tanks @ 25% mass fraction
- Near-zero boiloff
- 60-days at Mars

Propulsion Technology Comparisons

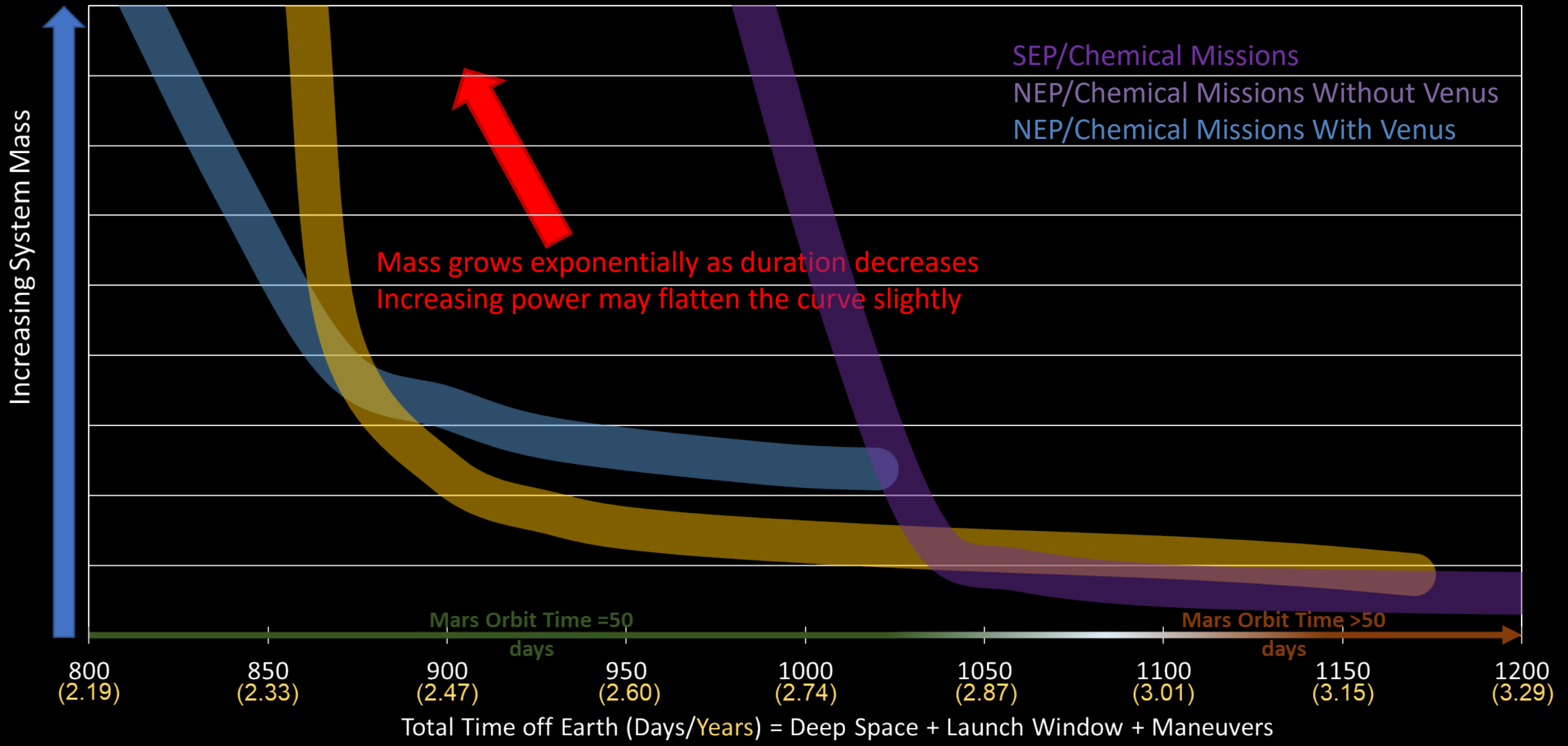
Crew Vehicle Mass as a Function of Trip Time – Short Stay Opposition Missions



1 As of February 2013

Drake, Bret G., "Footprints on Mars", 12 June, 2013

Reference Mission Sensitivity to Duration



"HUMANITY'S PATH TO MARS, The Trade Space for Unique Developments and Leveraging Opportunities in LEO and at the Moon," IEEE Aerospace Conference Panel 14.06, March 9, 2021

Mission Trajectory Choice: Opposition versus Conjunction

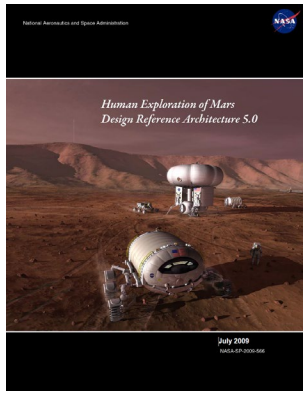
The choice depends much more on considerations other than delta-v and time

- **Mission Objectives:**
  - What is to be accomplished while at Mars?
  - Long-term campaign objectives
- **Trajectory Considerations:**
  - Frequency and consistency of missions
  - Mars arrival / departure orbit
  - Environmental considerations
  - Contingency modes
  - Earth return strategy and constraints
- **Orbit Operations:**
  - End-to-end operational concept
  - Rendezvous with pre-deployed assets
  - Plane changes
- **Crew Health Considerations:**
  - Time in free space
  - Time on Mars
  - Acceleration transitions
  - Environmental exposure
- **Mission Sensitivity**
  - Vehicle size and sensitivity
  - Sensitivity to schedule slips
  - Launch campaign
- **Programmatics and Risk**
  - Schedule (development and operational)
  - Risk (crew and mission)
  - Cost

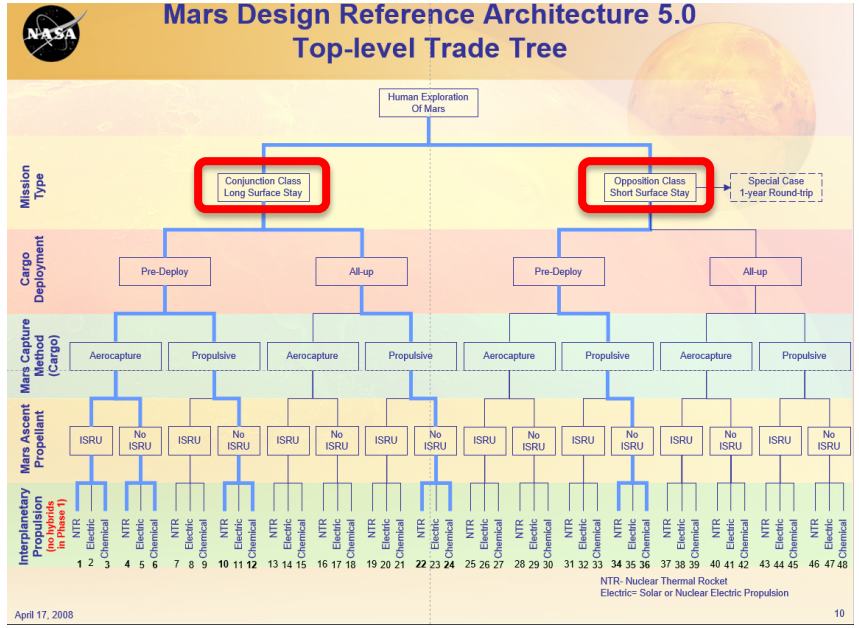
The choice of Mars trajectory is more complex than just choosing the lowest total change in velocity (delta-v)

Mission Trajectory Choice

A continuing debate – but the laws of physics haven't changed



"Human Exploration of Mars, Design Reference Mission 5.0," NASA-SP-2009-566, July 2009, 47-51.



Mission Type Figures of Merit

Cases 10 & 12 | Cases 34 & 36

Long Surface Stay (Conjunction Class)	Figure of Merit	Short Surface Stay * (Opposition Class)
Similar	Total mass in Low-Earth Orbit (mt)	Similar *
45% Smaller	LEO Complexity / Size of Crew Vehicle	Larger
~3100 crew-sols	Expected Useful Crew Sols on Surface (mission return)	~80-500 crew-sols
Best	Exploration Goal Satisfaction (range, depth, frequency)	Lower
3 / 6 kg/kg	Architecture Sensitivity (gear ratios: NTR/Chem)	4 / 13 kg/kg
No Clear disdvantage	Probability of Loss of Crew	Somewhat Less
Somewhat Less	Probability of Loss of Mission	No Clear Advantage
950	Total Mission Duration	**650 days**
500 sols	Mission Flexibility (contingency replanning)	Few sols
Less	Crew Exposure to Radiation	More
200 / 500 / **200**	Crew Exposure to Zero-G (days out / surface / back)	180 / 30 / 360
Available	Backup Lander and Surface Habitat	None
Somewhat More	Cost Through First Mission	Slight Advantage
Somewhat More	Cost Through Third Mission	Slight Advantage

Recommendation: Conjunction Class (Long Surface Stay) Mission Type

* Excluding very hard opportunities

April 17, 2008 11