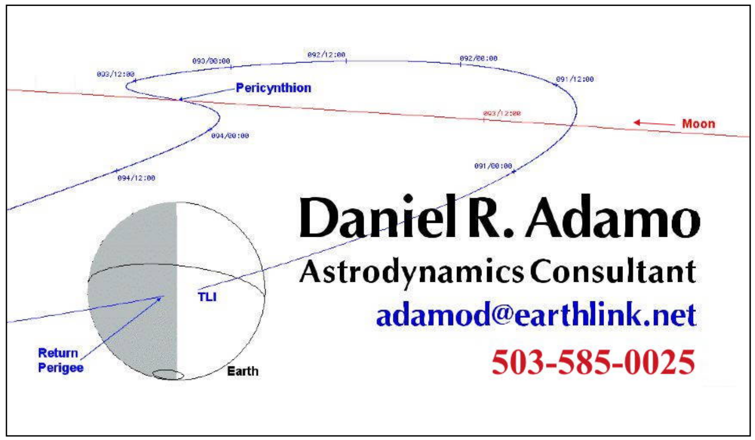
Aquarius, A Reusable Water-Based Interplanetary Human Spaceflight Transport



Space Enterprise Institute

AIAA-Los Angeles-Las Vegas Section

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Aquarius, A Reusable Water-Based iHSF Transport

Objectives

- Review major challenges to interplanetary human spaceflight (iHSF)
- Suggest strategies to address these challenges, rendering iHSF routine & sustainable
  - What knowledge gaps enable these strategies and how do they modify milestones on your favorite iHSF "technology roadmap"?
  - Water is <u>the</u> critical multi-use consumable enabling routine iHSF
  - Selenocentric distant retrograde orbits (SDROs) are the closest stable orbits to Earth from which multiple iHSF departures may be made without undue propulsive penalties
- Apply strategies to the hypothetical iHSF transport *Aquarius*, illustrating viability
  - Fly real transits between Earth and Mars orbit to demonstrate closed performance
  - Pick performance-challenged mission opportunities (do <u>not</u> fully optimize associated mission designs) to avoid one-off and unsustainable capabilities

Technical details supporting this presentation are published in a paper[1] co-authored by Space Enterprise Institute/James S. Logan, M.D.

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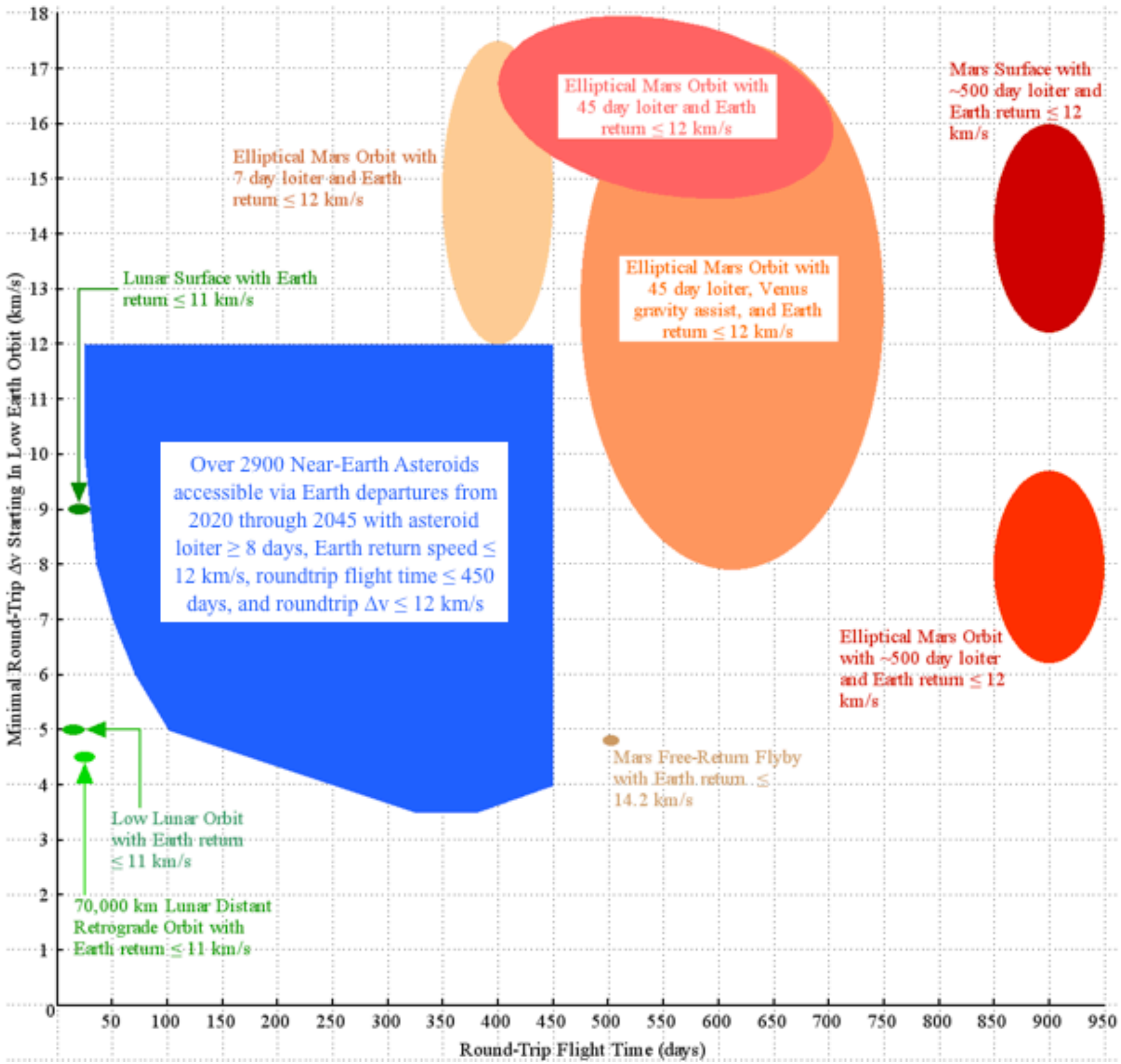
[1] The paper is published in *Acta Astronautica* Vol. 128 (2016) pp. 160-179. Reference http://www.sciencedirect.com/science/article/pii/S0094576516300868 (accessed 19 September 2020).

Near-Term iHSF Destinations Challenge Current Technology



Shaded areas are approximate for illustrative purposes

Moon missions assume minimal loiter time at the destination

Asteroid and Mars destinations may be highly inaccessible at times

Reference https://www.lpi.usra.edu/sbag/science/NHATS_Accessible_NEAs_Summary.png (accessed 19 September 2020)

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iHSF Challenge	*Aquarius* Mitigating Strategy
Excessive transit time	Reduce via trajectory design within propulsion capabilities and assume pre-emplaced Earth return consumables at destination via robotic transport or ISRU
Crew confinement	House crew of 3 in Hab module with 203 m^3 volume
Crew radiation exposure	Shield Hab with 14.5 g/cm^2 structure, plus > 37.0 g/cm^2 water, to provide > 5% of Earth's atmosphere at sea level (RP5) & assume RP100 in destination sub-surface habitat
Crew micro-gravity exposure	Provide crew with a 3-m short-arm centrifuge in docking/airlock/centrifuge module (DAC)
Closed-loop life support	Run open-loop, venting/dumping overboard
Excessive crew acceleration during Earth return	Abandon direct crew atmospheric entry in favor of lower speed return from *Aquarius* "garage" in SDRO
Propulsive efficiency	Heat water > 3000° C, disassociating it into H and O atoms to achieve I_{SP} = 900 s, and nominally deplete Hab shielding water below RP5 only during destination arrival

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Aquarius **Component**	**Mass At Departure (kg)**
Crew of 3 and miscellaneous gear in Hab & DAC	9820
Short-arm centrifuge	1700
DAC structure	26,461
HAB structure	36,457
Crew open-loop consumables, including water (m_{LS})	24,953[2]
Nuclear thermal propulsion (NTP) systems	41,700
Nominally usable NTP water propellant (m_P)	146,343
Attitude control propellant (m_{RCS})	13,903
Nominally unusable water dedicated to Hab shielding (m_S)	23,042[3]
Water tank structure holding m_P and m_S (m_T)	32,440
Total of all components (m_{TOT})	356,819[4]

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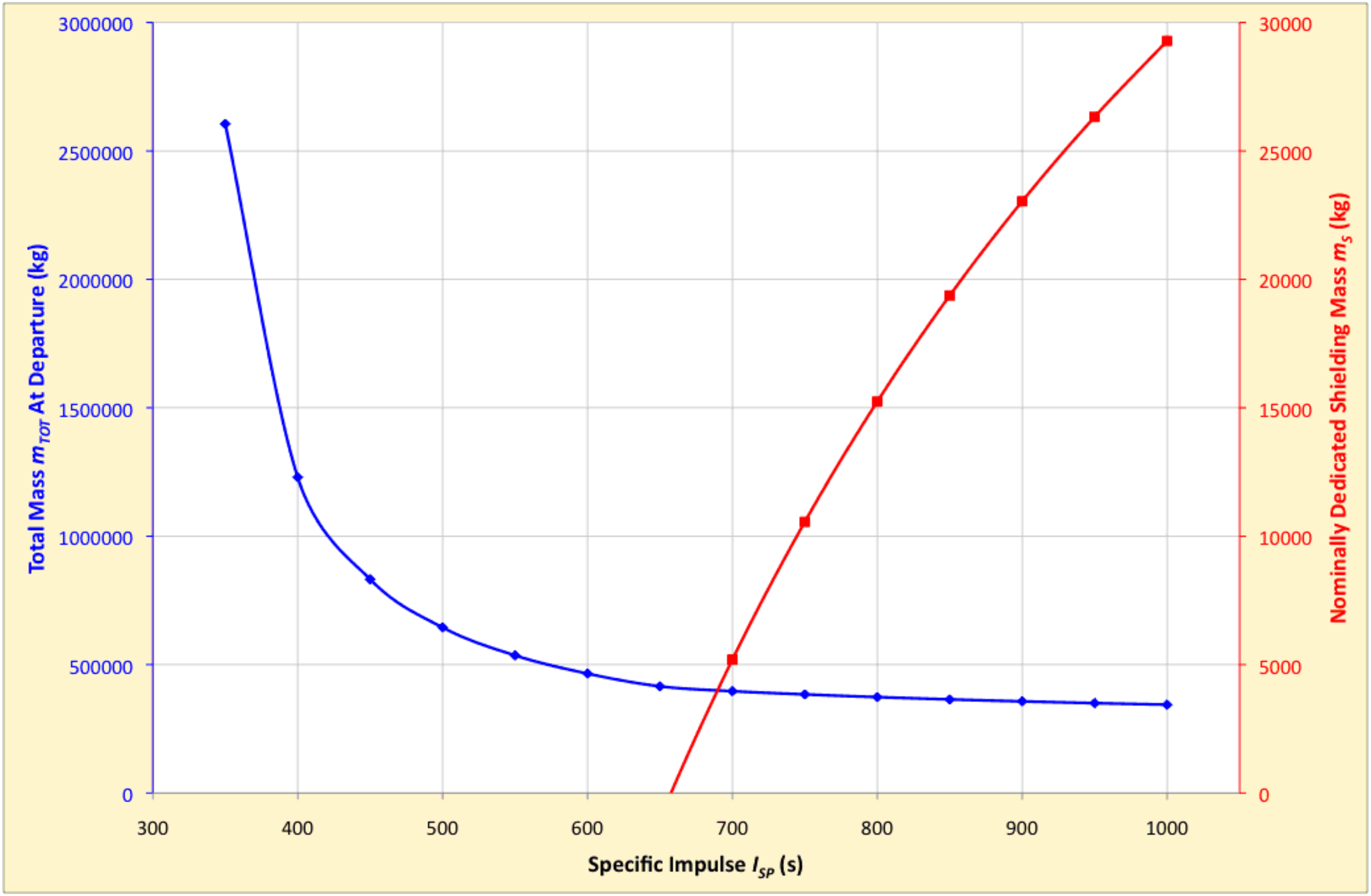
[2] This component budgets 29.26 kg per capita per day to include water for hydration/hygiene, oxygen, dehydrated food, atmospheric losses, and systems maintenance.

[3] Water mass required to provide a jacket of RP5 shielding for the Hab, a cylinder 2.3 m in radius and 12.2 m in length, is 87,053 kg (m_J). Nominally, some of this mass is consumed as propellant by NTP systems (but only during destination arrival).

[4] International Space Station (ISS) mass as of 11 January 2017 is 422,200 kg.

Scale m_P, m_{RCS}, m_S, and m_T According To NTP I_{SP}



Transit 1: Post Assembly Departure From Elliptical Earth Parking Orbit (EEPO); Arrival At Deimos (m_P values are post-burn)

Event	Date	T (days)	Δv (km/s)	m_{LS} (kg)	m_P (kg)	m_{TOT} (kg)	$m_P + m_S$ - m_J (kg)
Perigee Lowering	08 Sep 2022	0	0.242	24,953	136,692	347,168	+72,680
TMI	09 Sep 2022	1	1.116	24,855	95,468	305,846	+31,456
MOI	30 Mar 2023	204	1.586	4837	48,456	238,816	-15,555
Deimos Rendz.	31 Mar 2023	204	0.751	4837	28,976	219,336	-35,036

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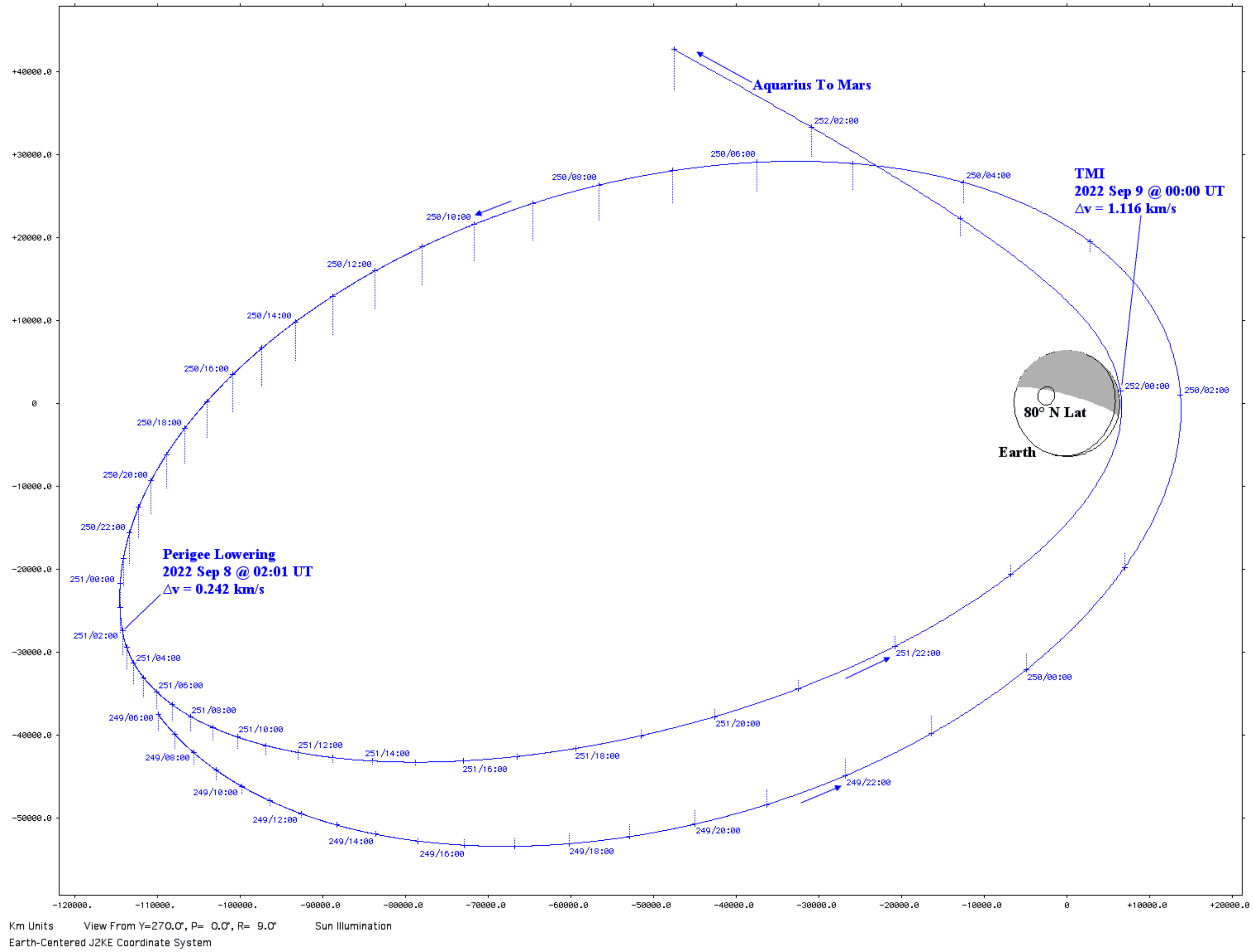
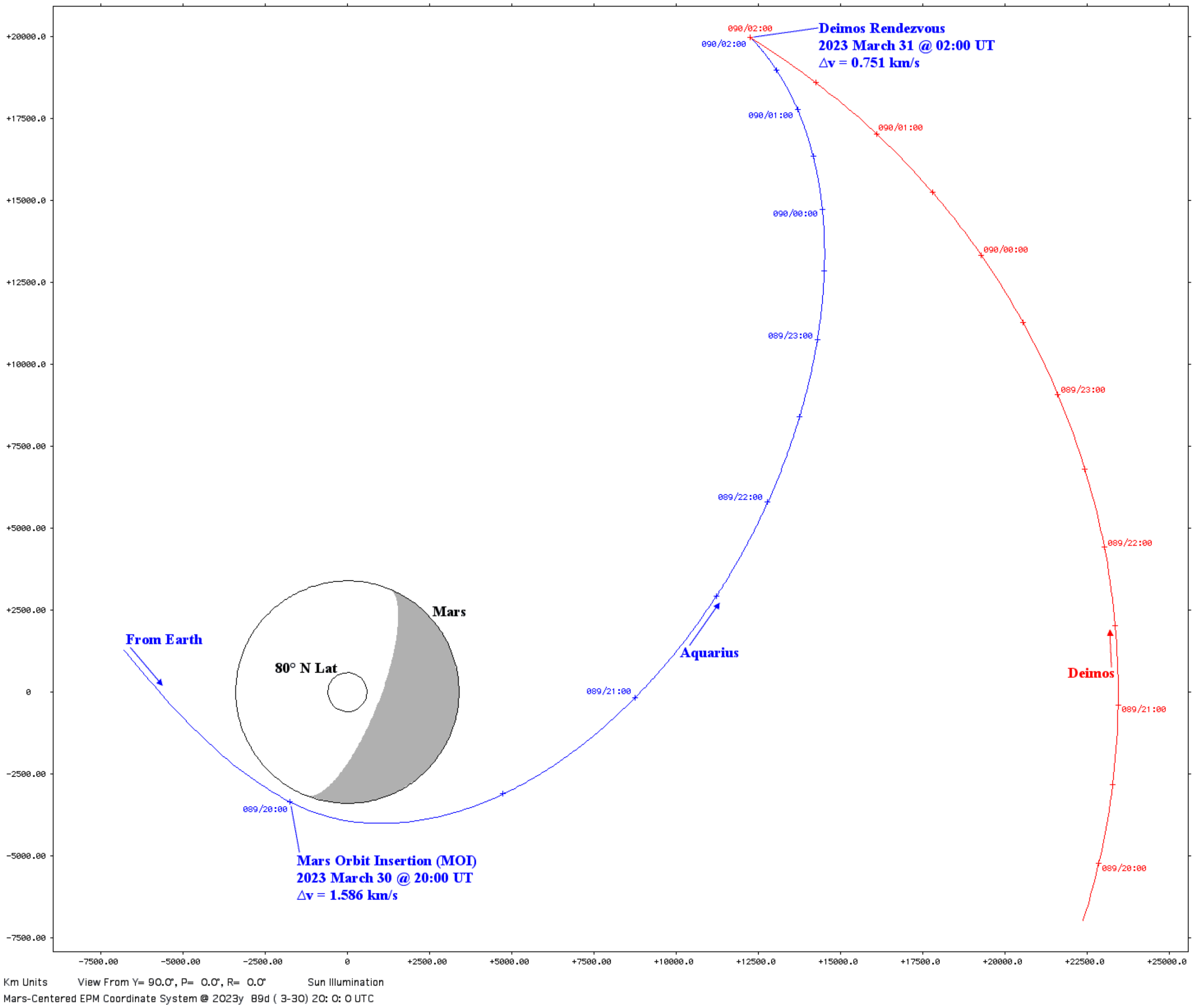
Transit 1 Departure From EEPO



Transit 1 Arrival At Deimos



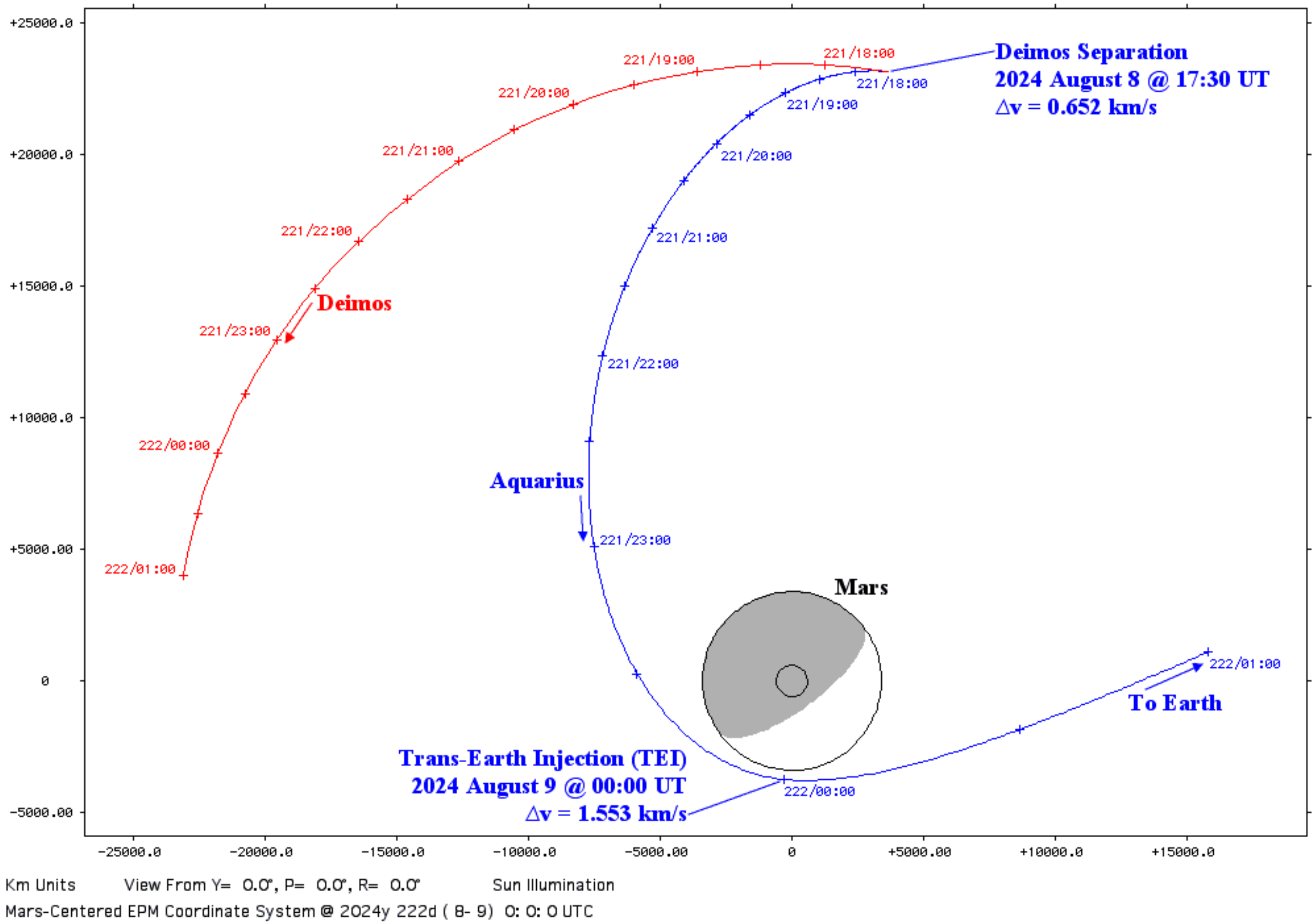
Transit 2: Departure From Deimos; Arrival At Selenocentric Distant Retrograde Orbit (SDRO) Garage (m_P values are post-burn)

Event	Date	T (days)	Δv (km/s)	m_{LS} (kg)	m_P (kg)	m_{TOT} (kg)	$m_P + m_S - m_J$ (kg)
Deimos Sep.	08 Aug 2024	0	0.652	24,953	120,934	331,410	+56,922
TEI[5]	09 Aug 2024	0	1.553	24,953	67,462	277,938	+3450[6]
TLI	03 Apr 2025	237	0.935	1583	41,873	228,978	-22,138
LOI	05 Apr 2025	240	0.378	1287	32,286	219,095	-31,726
SDRO Rendz.	06 Apr 2025	240	0.309	1287	24,748	211,558	-39,264

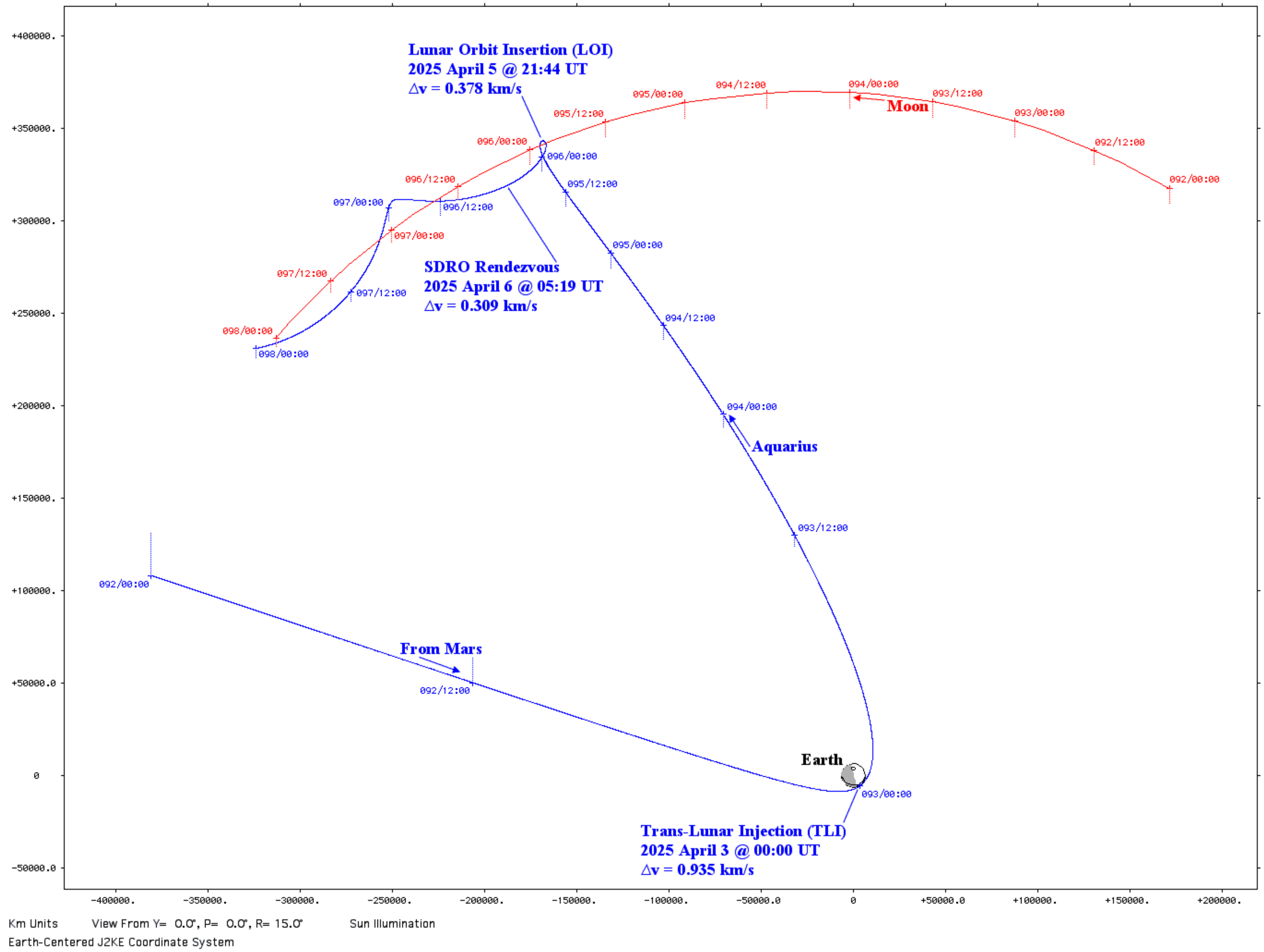
[5] This TEI consumes more m_P than any other Transit 1/2/3 event, 120,934 - 67,462 = 53,472 kg. At 37.8 kg/s m_P flow rate, TEI burn duration is 23.6 min.

[6] This is the slimmest Hab radiation shielding margin with respect to RP5 and m_J, +3450 / 87,053 = +4%, among all Transit 1/2/3 departures

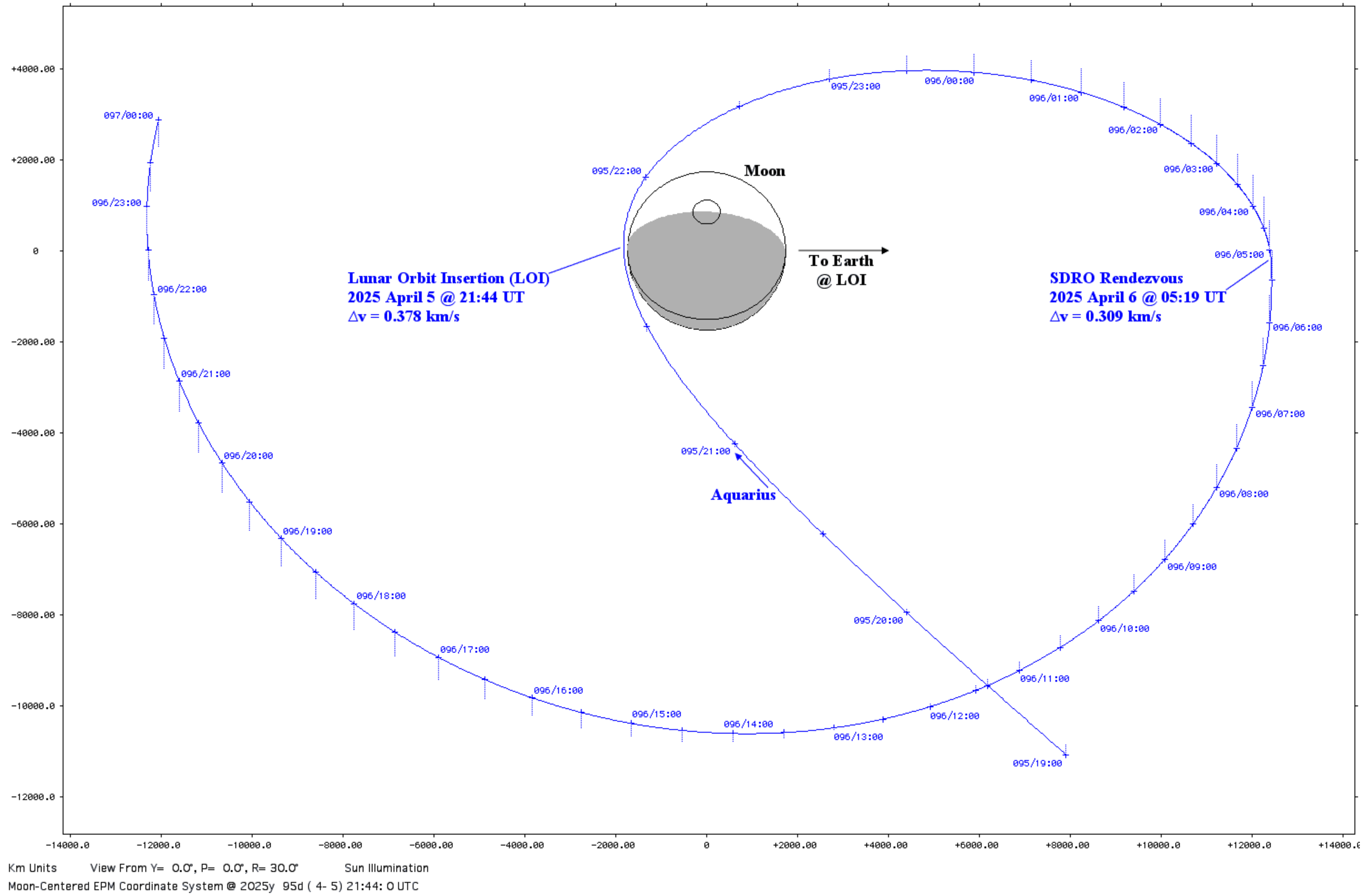
Transit 2 Departure From Deimos



Transit 2 Arrival At Earth And Transfer To SDRO Garage



Transit 2 Arrival At SDRO Garage



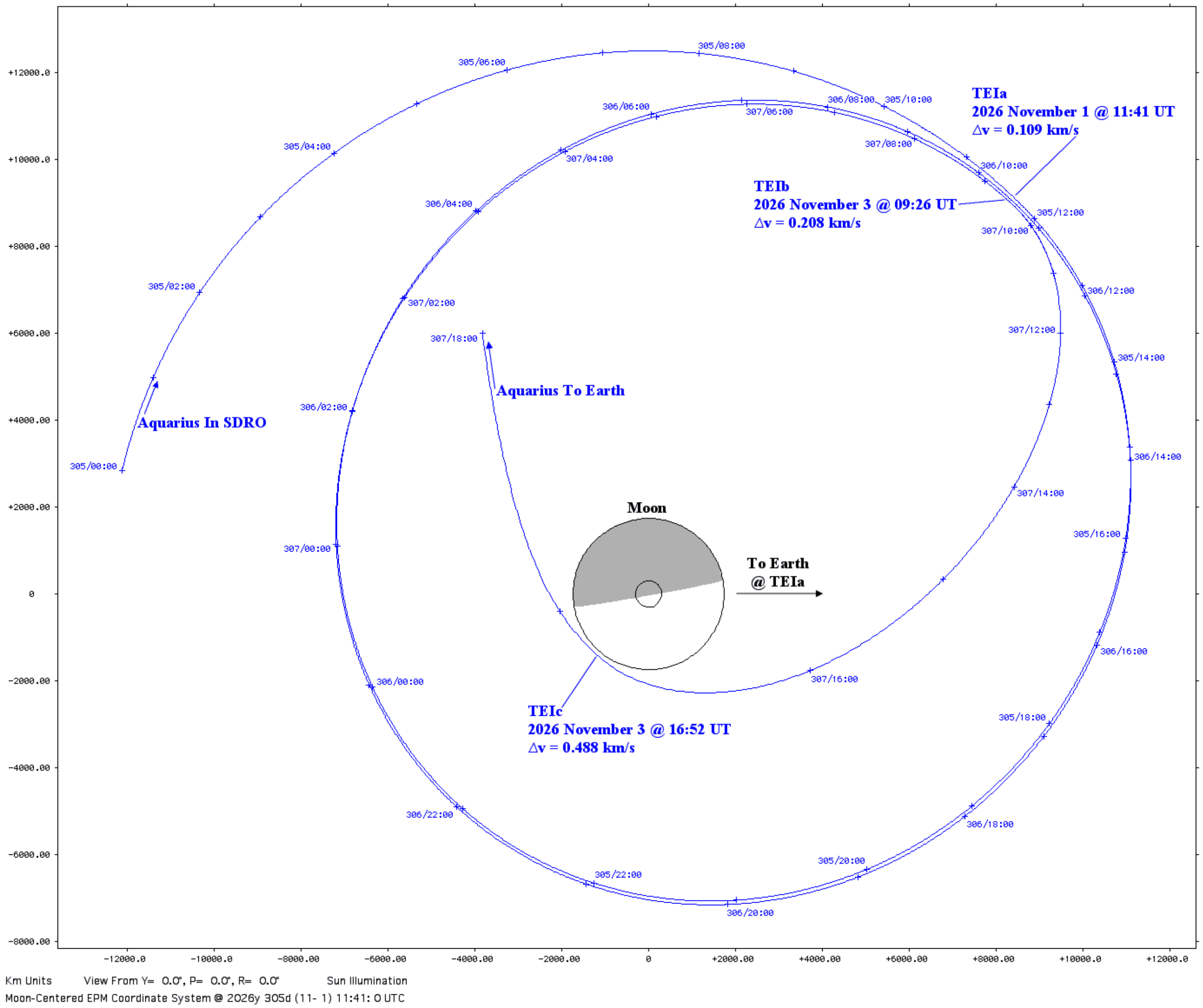
Transit 3: Departure From SDRO Garage; Arrival At Deimos (m_P values are post-burn)

Event	Date	T (days)	Δv (km/s)	m_{LS} (kg)	m_P (kg)	m_{TOT} (kg)	$m_P + m_S - m_J$ (kg)
TEIa	01 Nov 2026	0	0.109	24,953	141,963	352,439	+77,952
TEIb	03 Nov 2026	2	0.208	24,756	133,759	344,038	+69,748
TEIc	03 Nov 2026	3	0.488	24,657	115,258	325,439	+51,247
TMI	06 Nov 2026	6	0.891	24,362	84,037	293,922	+20,026
MOI	29 Jun 2027	241	1.940	1188	30,612	217,323	-33,400
Deimos Rendz.	29 Jun 2027	241	0.801	1188[7]	11,757[8]	198,468	-52,254

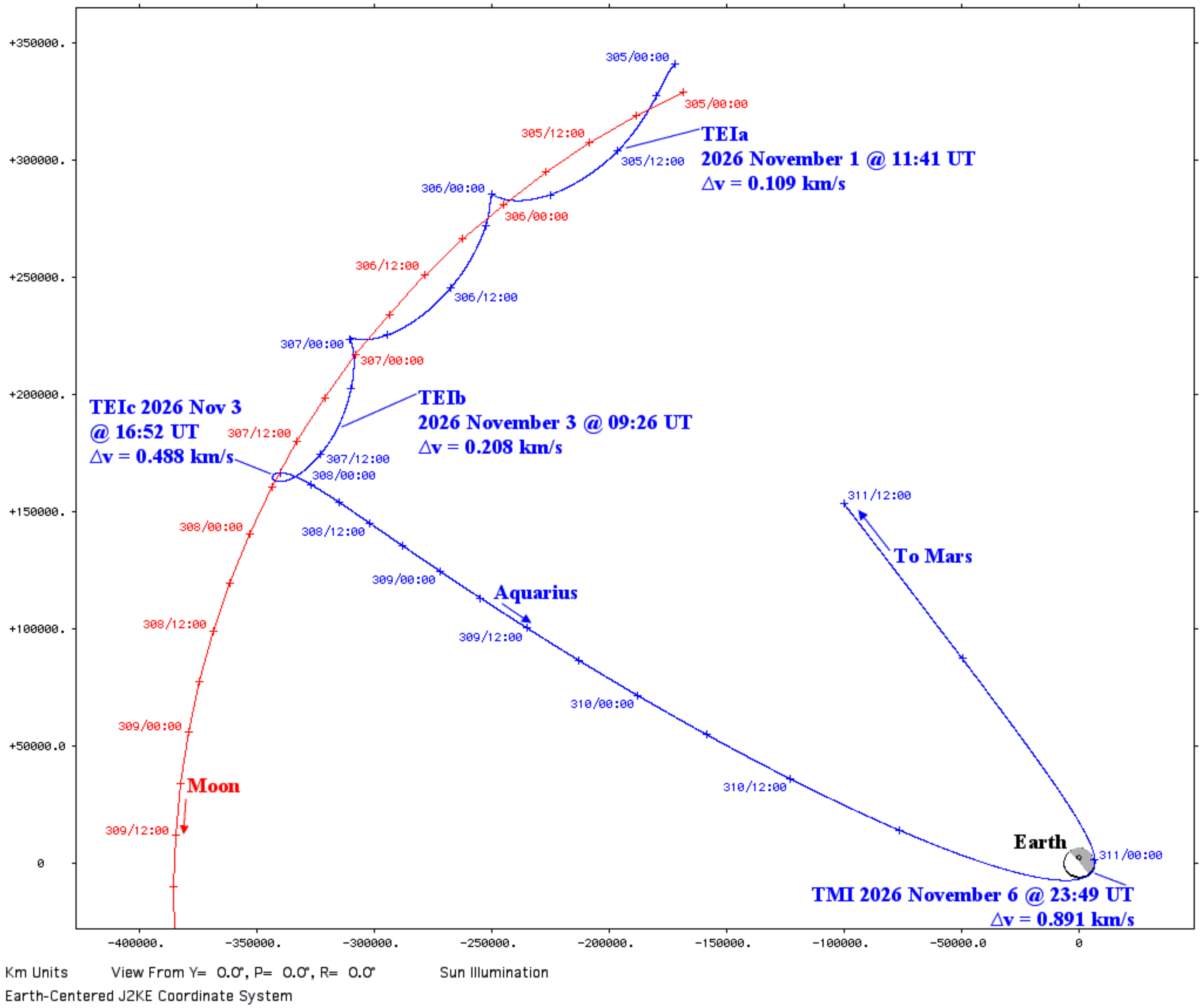
[7] This is the slimmest m_{LS} margin among all three transits and would deplete only if daily crew consumption increased an average of 5% throughout Transit 3.

[8] This is the slimmest m_P margin (8% of capacity by mass) among all three transits and equates to a surplus *Aquarius* Δv capability of 0.539 km/s at arrival. A 31° inclination with respect to the martian equator (the orbit plane of Deimos is inclined to the martian equator by 1.8°) during Mars terminal approach results in MOI Δv larger than any other Transit 1/2/3 event.

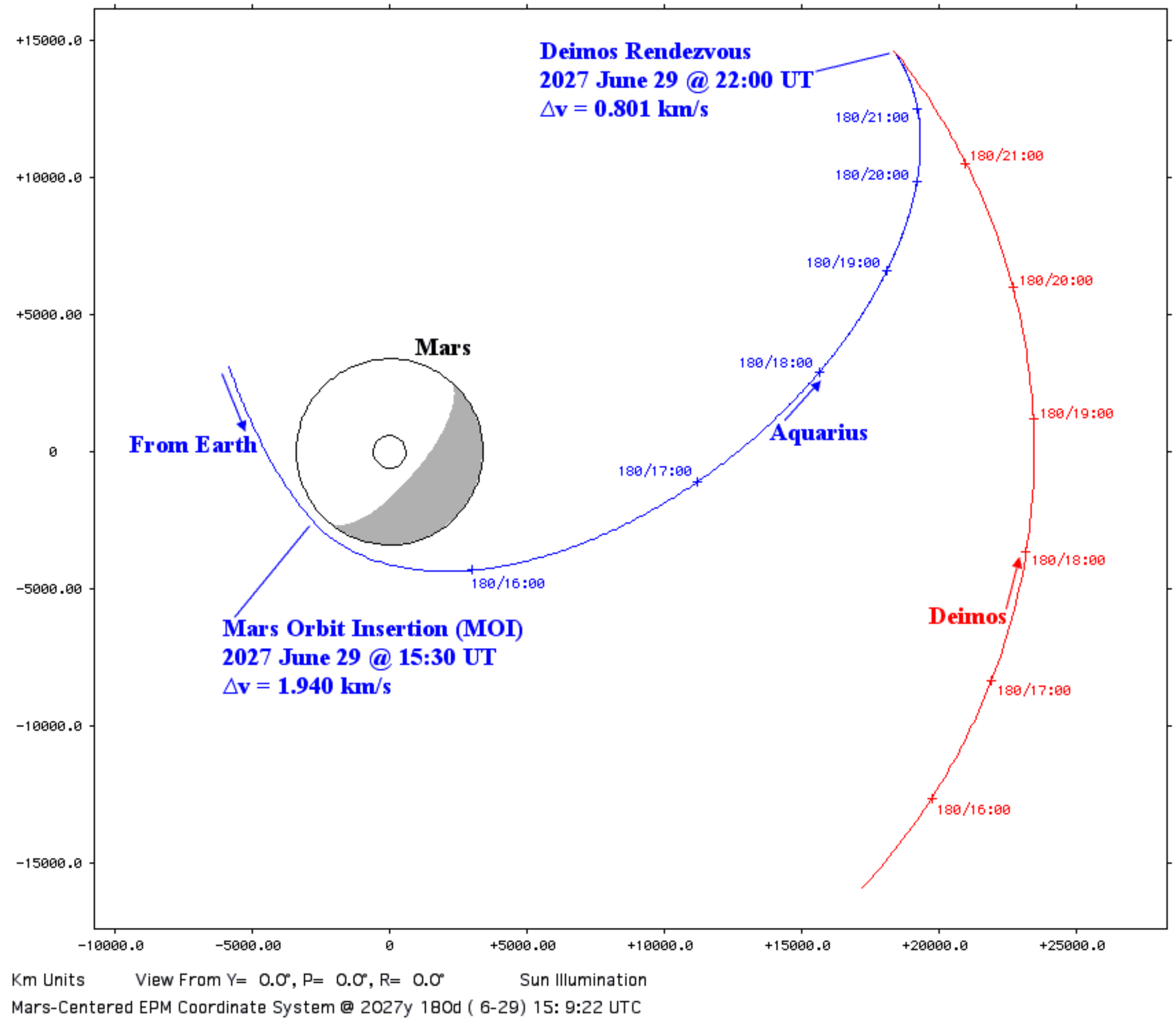
Transit 3 Departure From SDRO Garage



Transit 3 Transfer From SDRO Garage And Departure From Earth



Transit 3 Arrival At Deimos



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Parting Thoughts

- Standard iHSF architecture disclaimers apply: *Aquarius* is based on speculation, there are undoubtedly other routes to routine iHSF capability, and your mileage may vary
- Shielding the Hab to RP5 is an educated guess, but iHSF radiation exposure standards are in a state of flux with the risk to humans only partially understood (ISS has ≤ RP2)
- Shielding mass available for propulsion during arrival is the mark of a reusable iHSF transport
- If airliners could not refuel at their destinations, trans-Atlantic air travel would be about as routine as iHSF is now: caching supplies near an interplanetary destination is essential
- *Aquarius* requires a means of heating ~40 kg/s of water to > 3000° C for propulsion
  - Water is easy to store/transport, also serves as crew radiation shielding, and is abundant throughout the solar system
  - Is there a better water heating method than nuclear fission?
  - If we can operate fission power plants on Earth, even near fault lines where potential for mishaps is high, it should be easy to justify their routine use in iHSF
- "The Devil is in the details, but so is salvation." -Admiral Hyman G. Rickover, father of the nuclear navy