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Mission Analysis for a Potential Mars Sample Return Campaign in the 2020s

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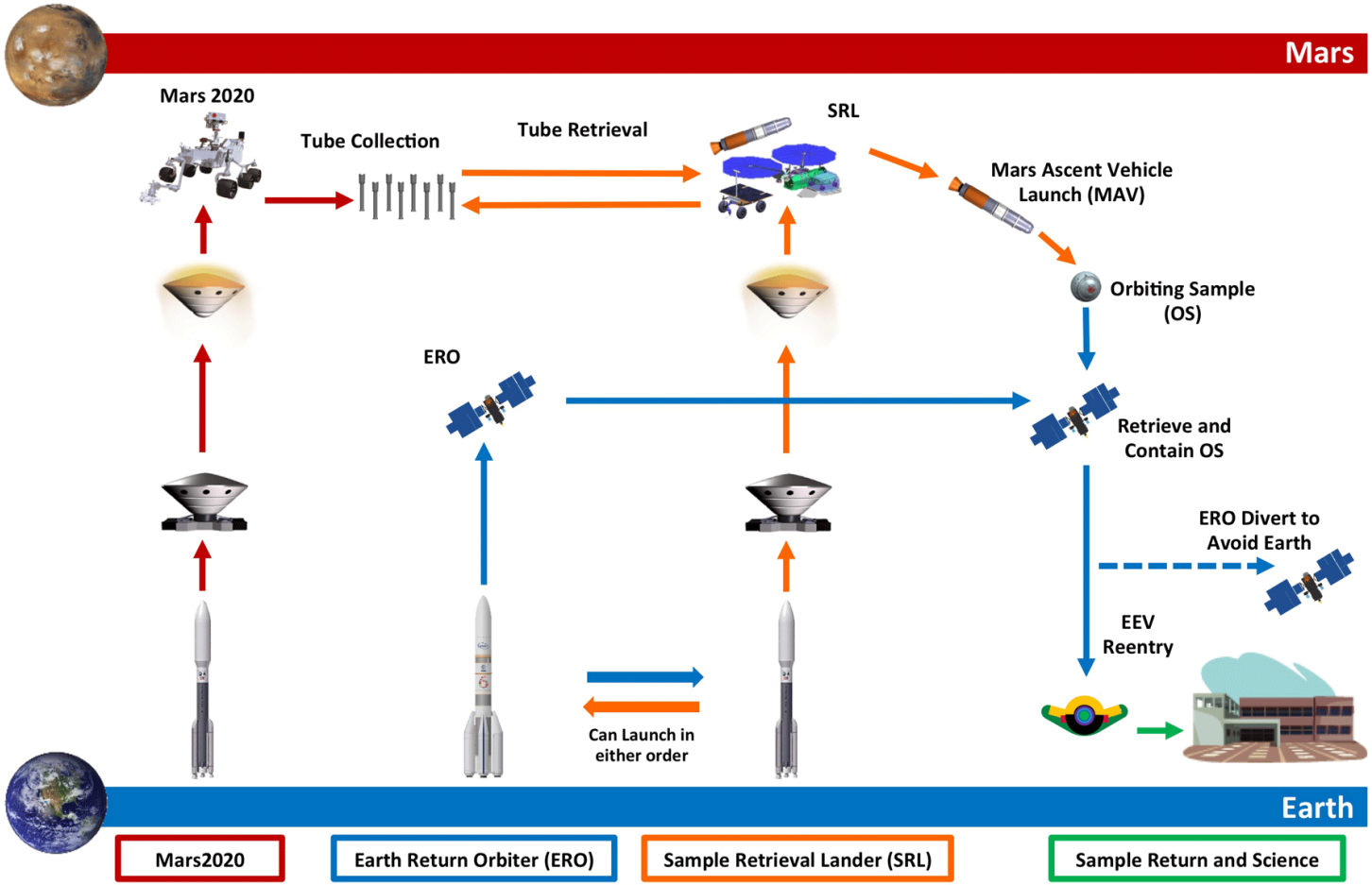
Pre-Decisional Information – For Planning and Discussion Purposes Only

Introduction

- NASA and ESA are studying options for an international Mars Sample Return campaign with potential launch options in the 2020's



Background Material

- This talk assumes you were here for the previous companion talks in this session and/or read their papers. This work is important input to this talk and there is not enough time to thoroughly review it.
  - **Lock, et al**, "Potential Campaign Architectures and Mission Design Challenges for Near-Term International Mars Sample Return Mission Concepts" discusses the motivation, previous work, and current study efforts surrounding Mars Sample Return. This includes an architectural description of the current missions under study, their major roles, foreseen implementation, and future trades being considered
  - **Woolley, et al**, "Low-Thrust Trajectory Bacon Plots for Mars Mission Design," describes low-thrust analogs to pork chop plots for Mars missions including the MSR campaign architecture studies. These bacon plots underlie the end-to-end mission analysis for all of the architectures in the current MSR studies.
  - **Laipert, et al**, "Hybrid Chemical-Electric Trajectories for a Mars Sample Return Orbiter," defines methods for developing trajectories for Mars sample return orbiters using both solar electric propulsion and high impulse chemical propulsion systems.
  - **Nicholas, et al**, "Simultaneous Optimization of Spacecraft and Trajectory Design for Interplanetary Missions Utilizing Solar Electric Propulsion," in which a tool ("MORT") is described for simultaneously optimizing the spacecraft design along-side the trajectory given mission constraints and objectives. MORT is essential for primary parameter exploration, first order spacecraft sizing and mission timeline assessment for MSR mission architecture development.

Launch and Return Opportunities

- Earth→Mars options: launch in 2026 or 2028
- Mars→Earth options: arrive in 2029, 2031, 2033

Covered in this talk

	2026 SRL		2028 SRL	
Return Date	2026 ERO	2028 ERO	2026 ERO	2028 ERO
2029	**26/26/29**	**Impossible**	**Impossible**	**Impossible**
2031	**26/26/31**	**26/28/31** (between 26/26/31 and 28/28/31)	**28/26/31** (between 26/26/31 and 28/28/31)	**28/28/31** (mostly similar to 26/26/29)
2033	(minimal benefit vs 26/26/31)	(minimal benefit vs 28/28/33)	(minimal benefit vs 28/28/33)	**28/28/33** (mostly similar to 26/26/31)

SRL Traj Options for 26/26/29

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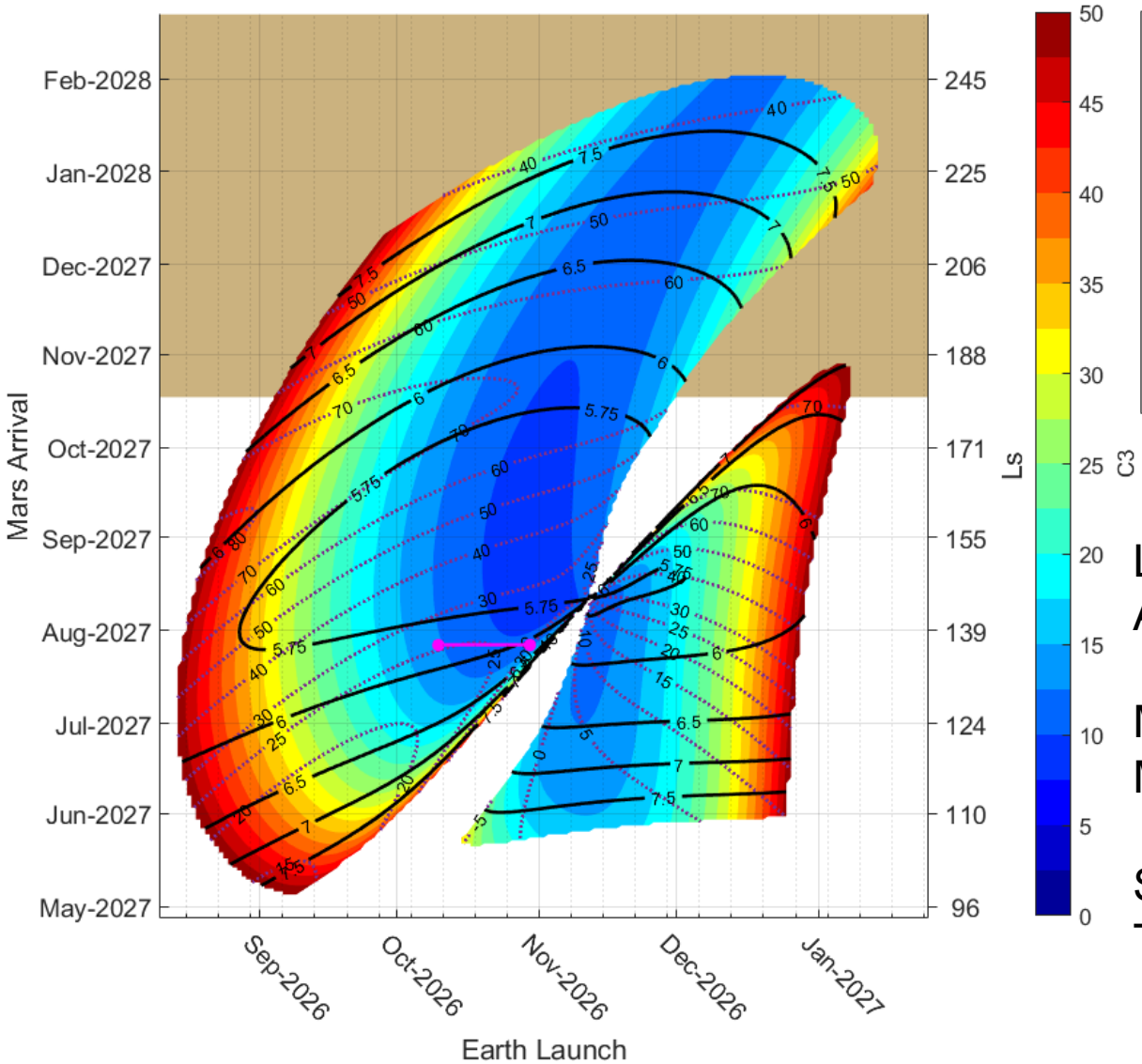
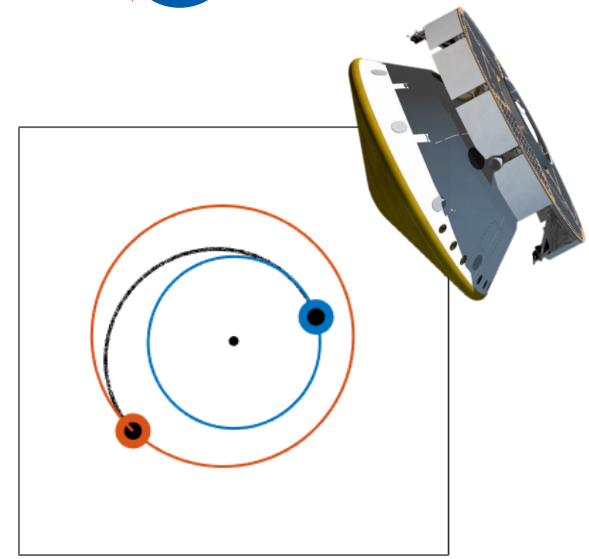


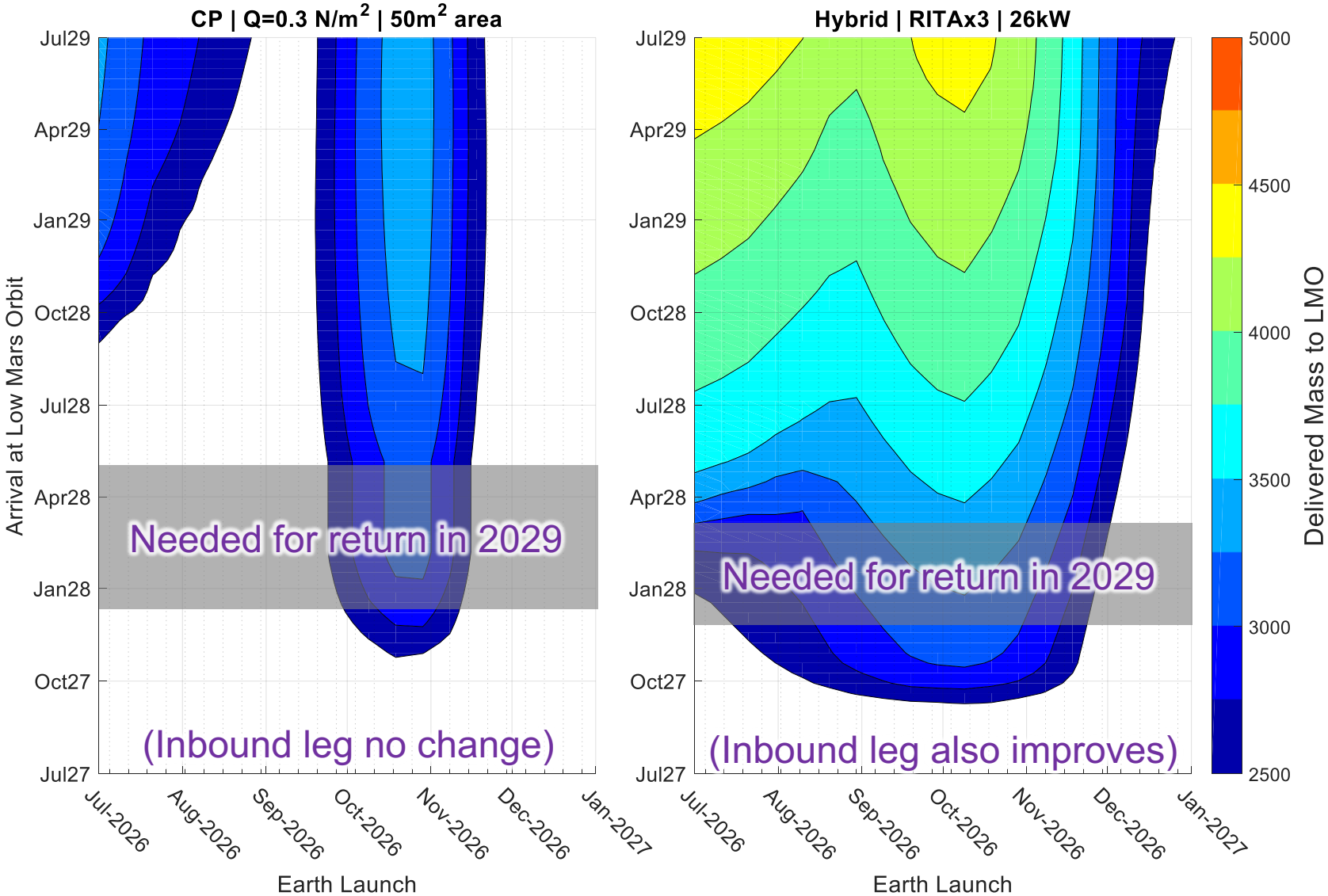


Launch: Oct 10 – 30 2026
Arrive: July 27 2027 (Ls=137)

Max C3: 12.6 km^2/s^2
Max Entry: 6.1 km/s (inertial)

Solar Elevation Angle: >25°
Time to Sunset: >1.5 hours

ERO Traj Options for 26/26/29



ERO Propulsion Architectures

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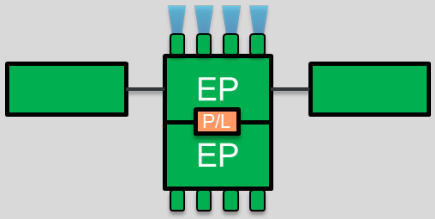
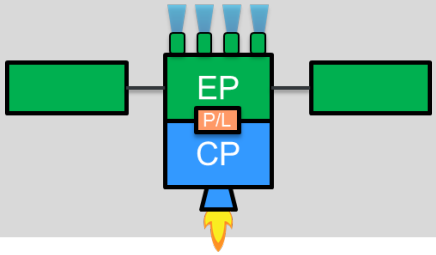
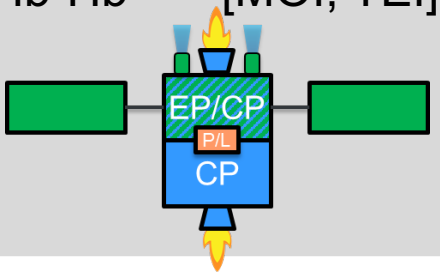
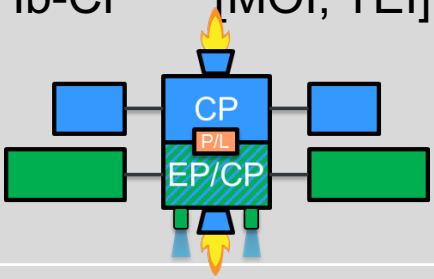
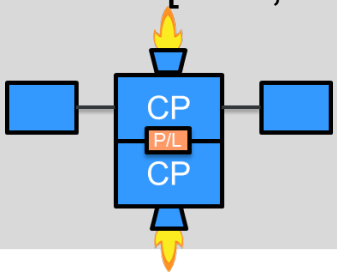
Inbound (Mars → Earth)

Outbound (Earth → Mars)

	EP	Hybrid	CP
EP	EP-EP [none] 	*Degenerate case of Hb-Hb*	*Degenerate case of Hb-CP*
Hb	Hb-EP [MOI] 	Hb-Hb [MOI, TEI] 	Hb-CP [MOI, TEI] 
CP	*Degenerate case of Hb-EP*	*Degenerate case of Hb-Hb*	CP-CP [MOI, TEI] 

Tool Fusion

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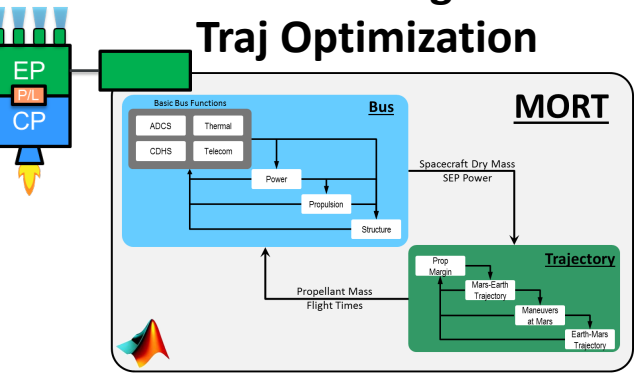
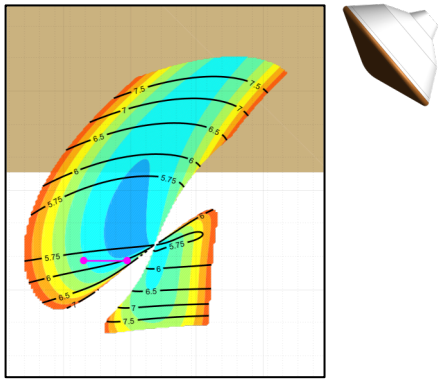
Orbiter Sizing and Traj Optimization



Other Parameters

- Timeline Constraints
- Phase Duration Models
- Trade Study Parameters

SRL Trajectory Options

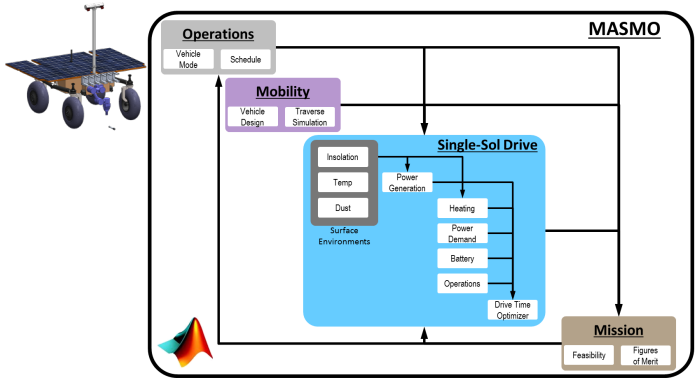


Probabilistic Campaign Timeline Model

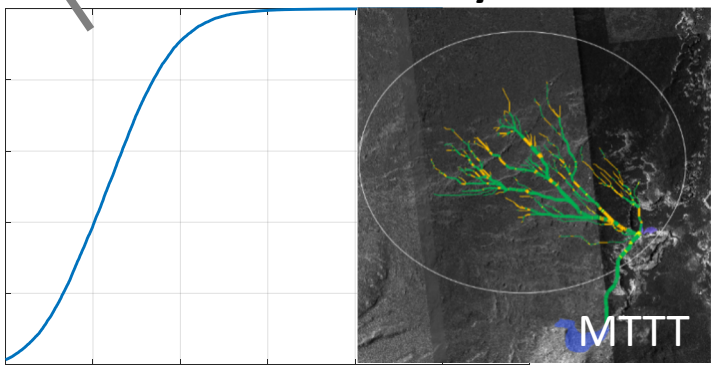
- Full campaign timeline
- Timeline success prob
- ERO Trajectory Dates
- etc

(>100 million permutations explored)

Rover Sizing and Performance



Surface Trafficability and Drive Statistics



26/26/29 Results

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	EP-EP			Hb-EP			Hb-Hb			Hb-CP			CP-CP
	T6	RIT	PPS	T6	RIT	PPS	T6	RIT	PPS	T6	RIT	PPS	
300 kg Payload													
11.2 km/s	N/A	348	N/A	865	1176	54	691	1233	N/A	N/A	N/A	N/A	N/A
11.5 km/s	217	654	N/A	1195	1765	541	1365	2093	376	N/A	N/A	N/A	N/A
12.0 km/s	352	834	251	1512	2062	868	1924	2791	717	636	1011	N/A	975
13.0 km/s	487	1181	466	2015	2646	1322	2870	3879	1162	1243	1833	339	1327
14.0 km/s	632	1413	713	2176	3038	1705	3520	4662	1390	1518	2202	396	1537
400 kg Payload													
11.2 km/s	N/A	172	N/A	620	882	N/A	284	589	N/A	N/A	N/A	N/A	N/A
11.5 km/s	82	408	N/A	914	1356	182	640	1264	N/A	N/A	N/A	N/A	N/A
12.0 km/s	171	494	96	1225	1651	364	1012	1748	187	N/A	403	N/A	573
13.0 km/s	284	764	248	1631	2188	668	1643	2653	380	495	883	N/A	773
14.0 km/s	336	984	330	1792	2568	818	2189	3332	494	610	1046	N/A	775
500 kg Payload													
11.2 km/s	N/A	N/A	N/A	382	589	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11.5 km/s	N/A	218	N/A	653	977	N/A	257	612	N/A	N/A	N/A	N/A	N/A
12.0 km/s	N/A	313	N/A	876	1284	N/A	427	992	N/A	N/A	N/A	N/A	N/A
13.0 km/s	154	467	112	1201	1739	N/A	852	1637	N/A	N/A	N/A	N/A	N/A
14.0 km/s	203	653	143	1422	2092	286	1209	2147	N/A	N/A	271	N/A	N/A
600 kg Payload													
11.2 km/s	N/A	N/A	N/A	N/A	312	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11.5 km/s	N/A	N/A	N/A	393	616	N/A	N/A	251	N/A	N/A	N/A	N/A	N/A
12.0 km/s	N/A	159	N/A	557	893	N/A	N/A	459	N/A	N/A	N/A	N/A	N/A
13.0 km/s	N/A	288	N/A	810	1268	N/A	379	897	N/A	N/A	N/A	N/A	N/A
14.0 km/s	110	403	N/A	1043	1578	N/A	596	1219	N/A	N/A	N/A	N/A	N/A

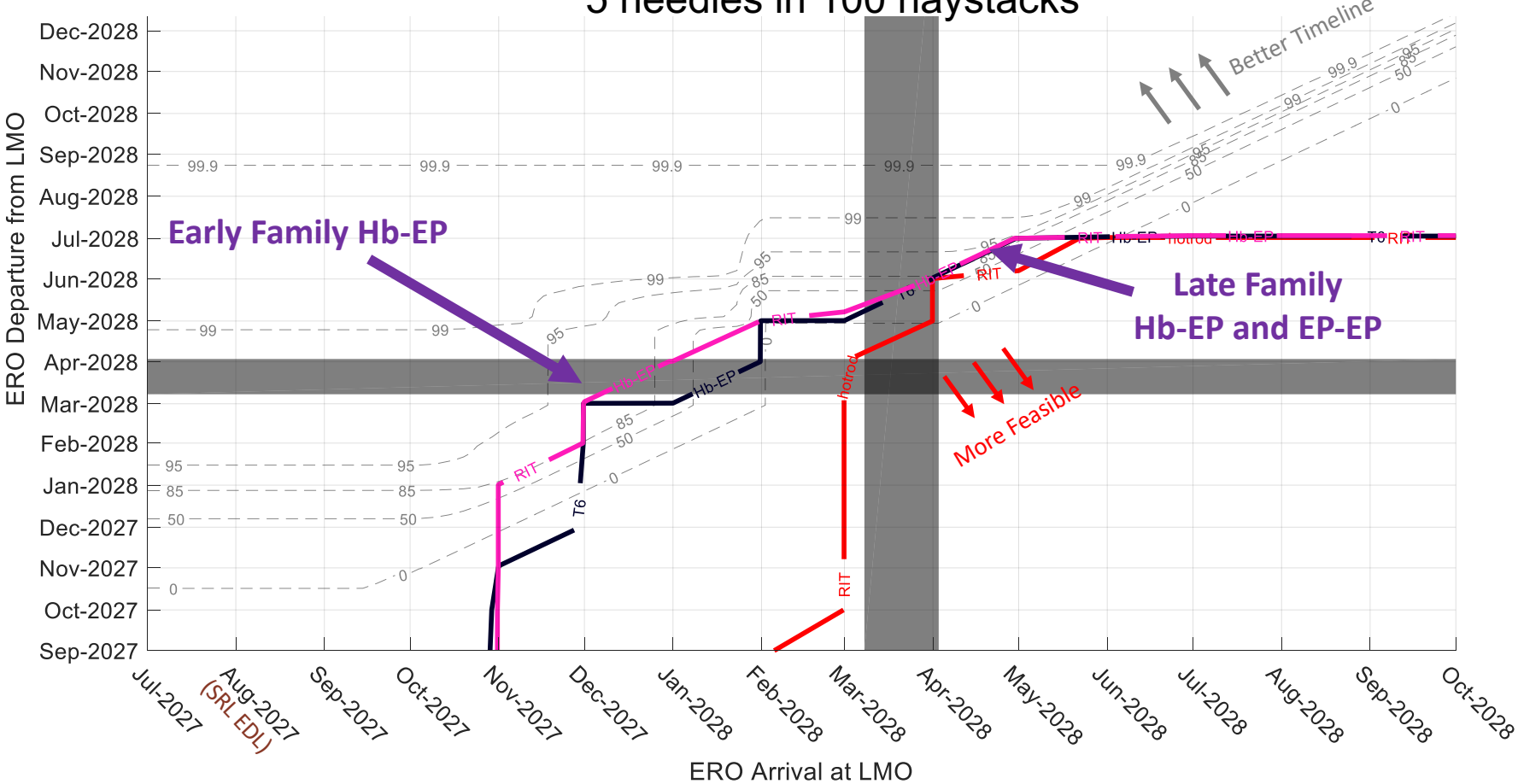
Key Conclusions

- There are valid architectural options for every propulsion architecture and engine type, but some are more robust than others.
- Among the hybrid options, Hb-EP is clearly the dominant architecture
- CP-CP does not have any valid options for the heavier payloads
- The PPS thruster is inferior to the other thruster options
- RIT and T6 options are generally similar
- The 14 km/s entry speed (difficult for EEV) is not strongly beneficial

26/26/29 Results

	Propulsion			Launch Configuration				Return Stage		Trajectory Info							
Case	Type	Active Thrusters	Power [kW]	Wet Mass	Dry Mass	Xenon Mass	Chem Mass	Dry Mass	Xenon Mass	Earth Launch	Launch C3	Mars Arrival V∞	Spiral Start Apoapsis	LMO Arrive	LMO Depart	Earth Arrival	Min Hel Dist [AU]
1	EP-EP	RITx7	77	6196	3633	2475	0	2551	812	Jun-2026	4.1	≈ 0	(SOI)	Mar-2028	Jun-2028	Nov-2029	0.82
2	Hb-EP	T6x3	30	5865	2720	622	2467	1432	281	Oct-2026	6.4	2.0 km/s	1,350 km	Nov-2027	Mar-2028	Sep-2029	0.92
3	Hb-EP	T6x4	47	6092	3087	848	2092	1792	307	Oct-2026	5.0	1.5 km/s	2,200 km	Jan-2028	Mar-2028	Aug-2029	0.98
4	Hb-EP	RITx3	33	5886	2761	683	2384	1511	287	Oct-2026	6.3	1.9 km/s	1,235 km	Nov-2027	Mar-2028	Sep-2029	0.87
5	Hb-EP	RITx4	58	5776	3110	1464	1130	1962	639	Oct-2026	7.1	1.4 km/s	13,000 km	Mar-2028	Jun-2028	Nov-2029	0.83

"5 needles in 100 haystacks"



26/26/29 Traj and Timeline (Case 4)

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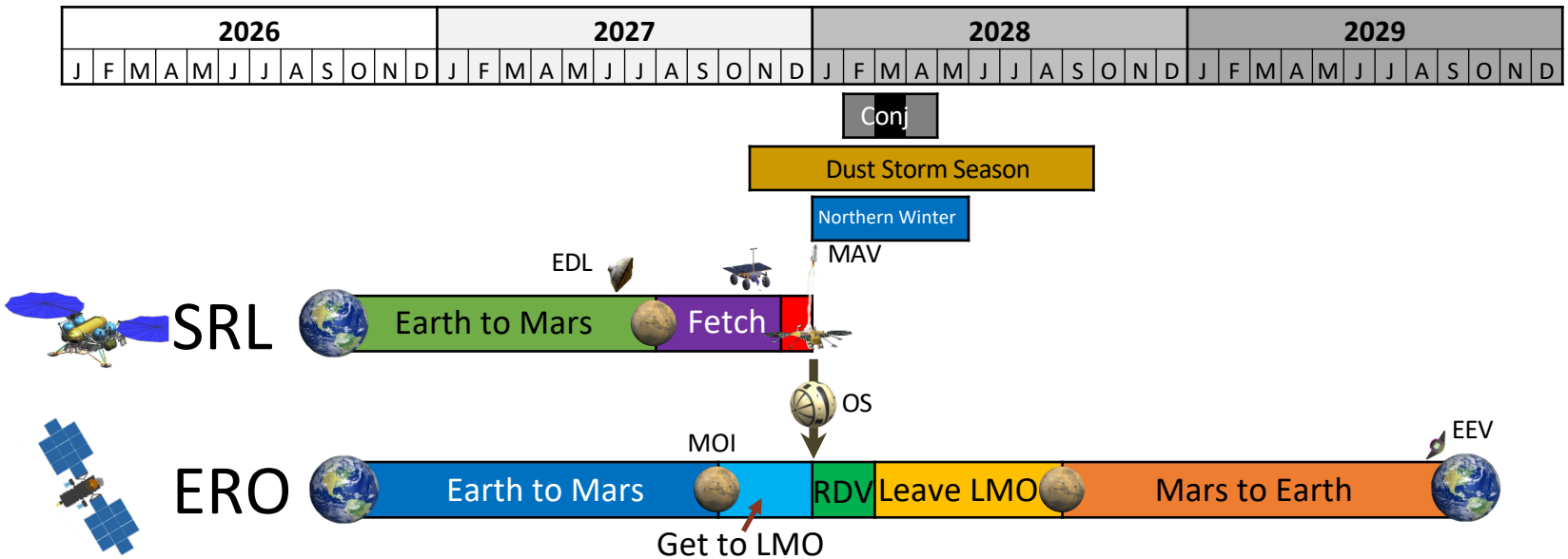
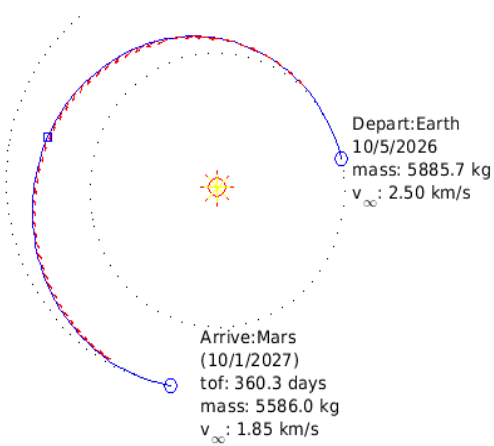
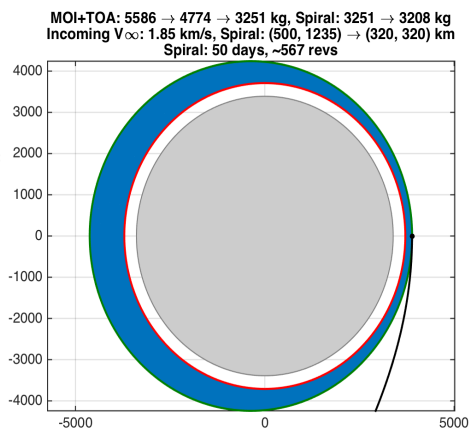
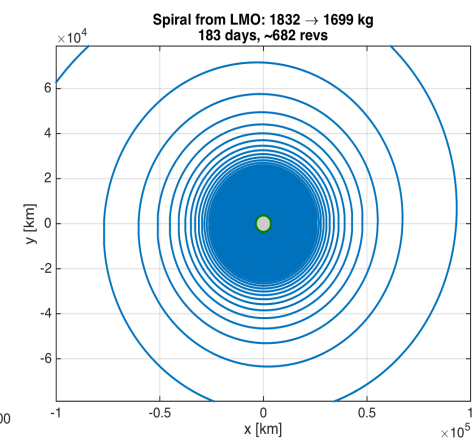




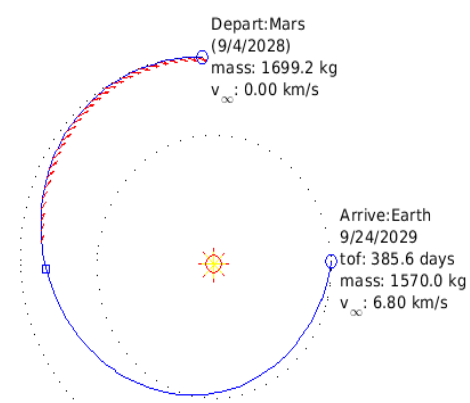
Earth-Mars Heliocentric



Capture Spiral



Escape Spiral



Mars-Earth Heliocentric

SRL Traj Options for 26/26/31

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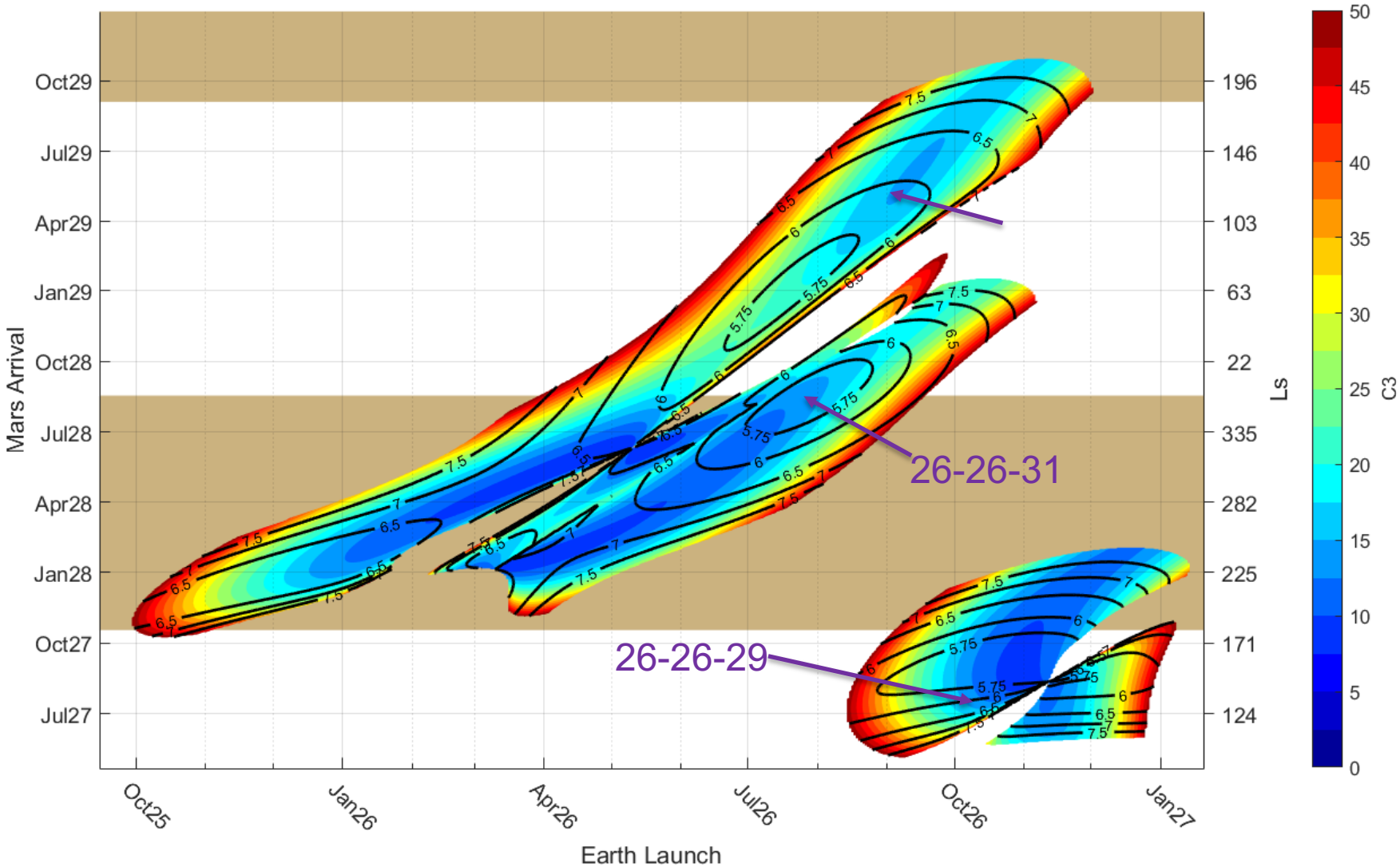
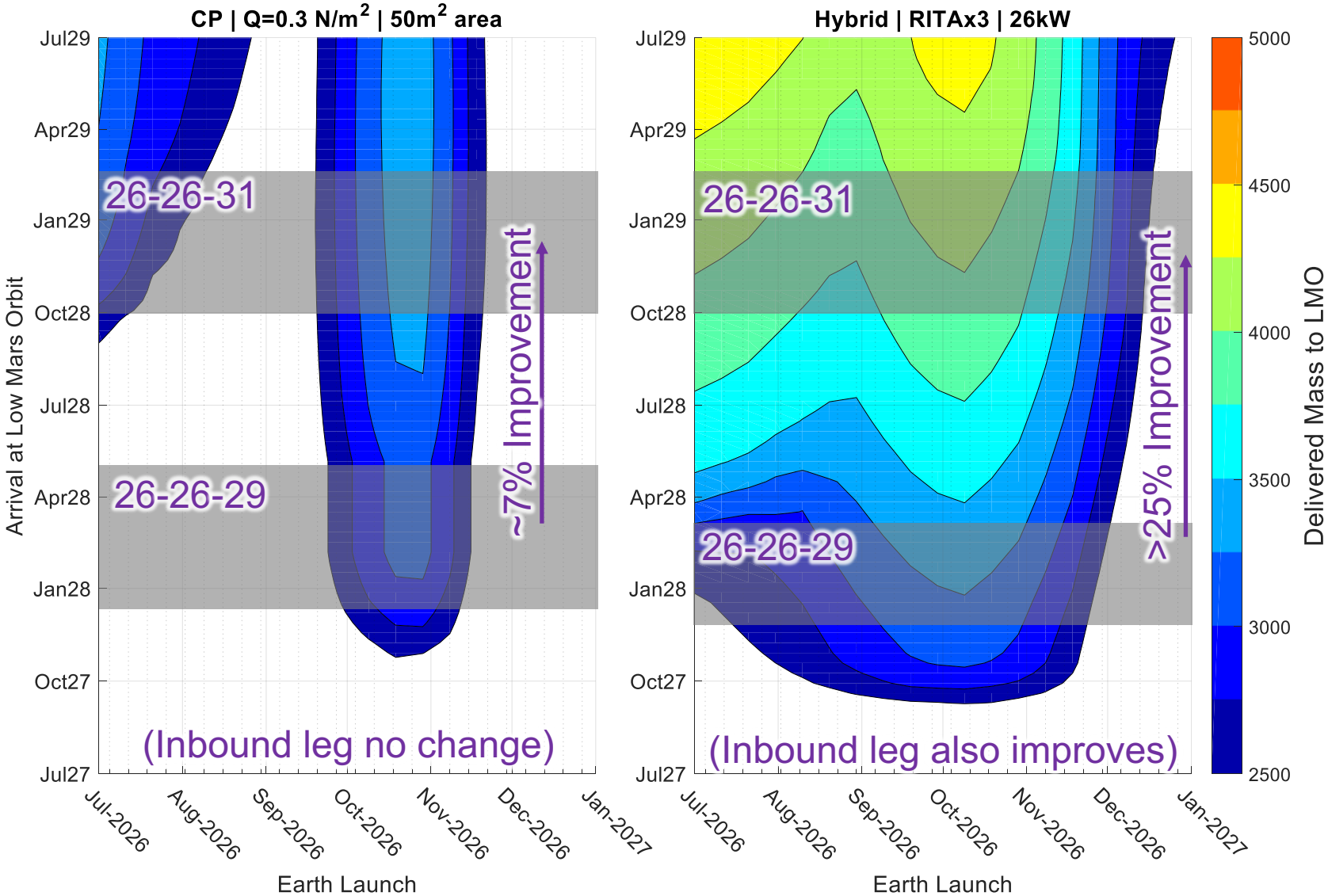
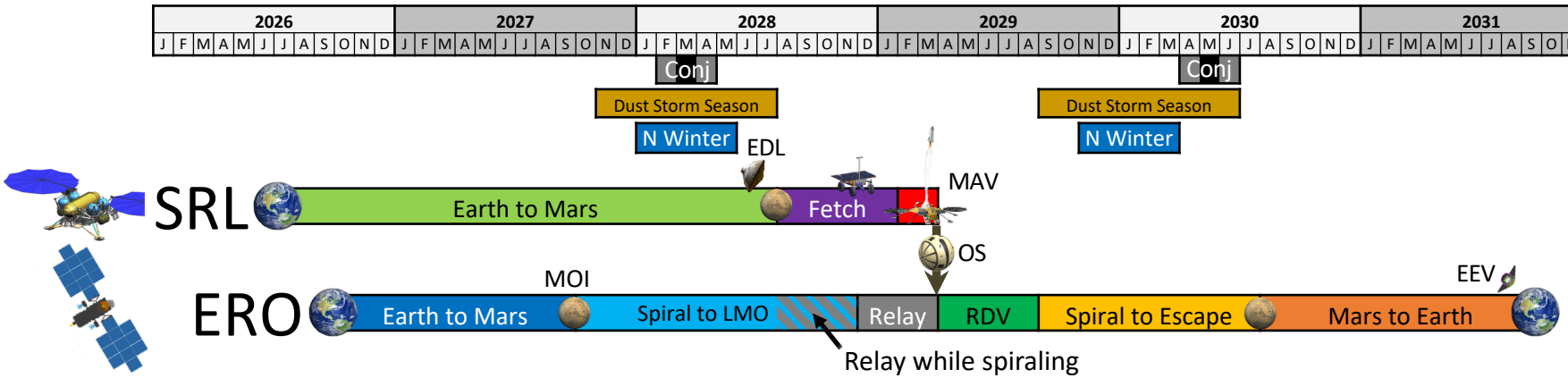


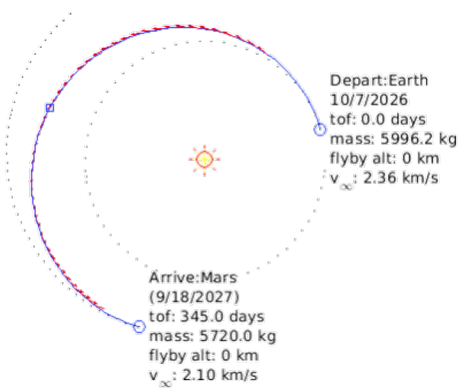
ERO Traj Options for 26/26/31



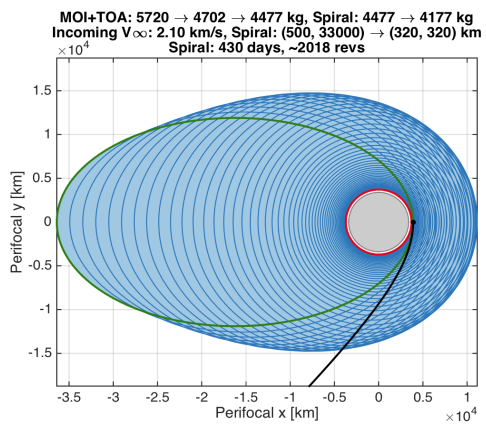
26/26/31 Traj and Timeline (Case 14)

[derived via the same analysis]

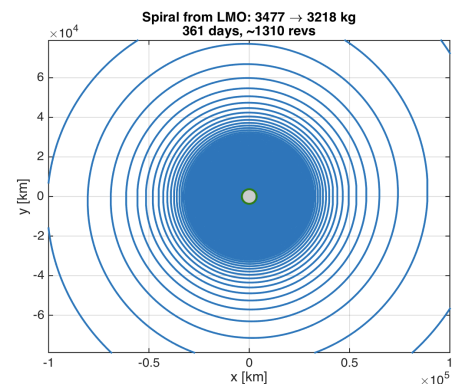




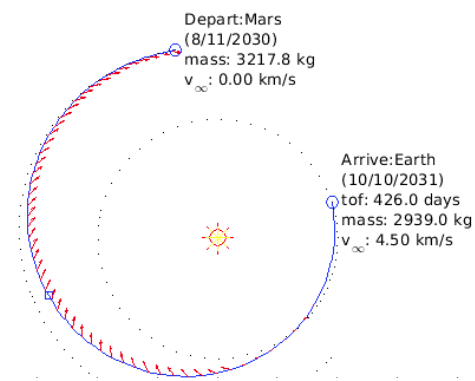
Earth-Mars Heliocentric



Capture Spiral

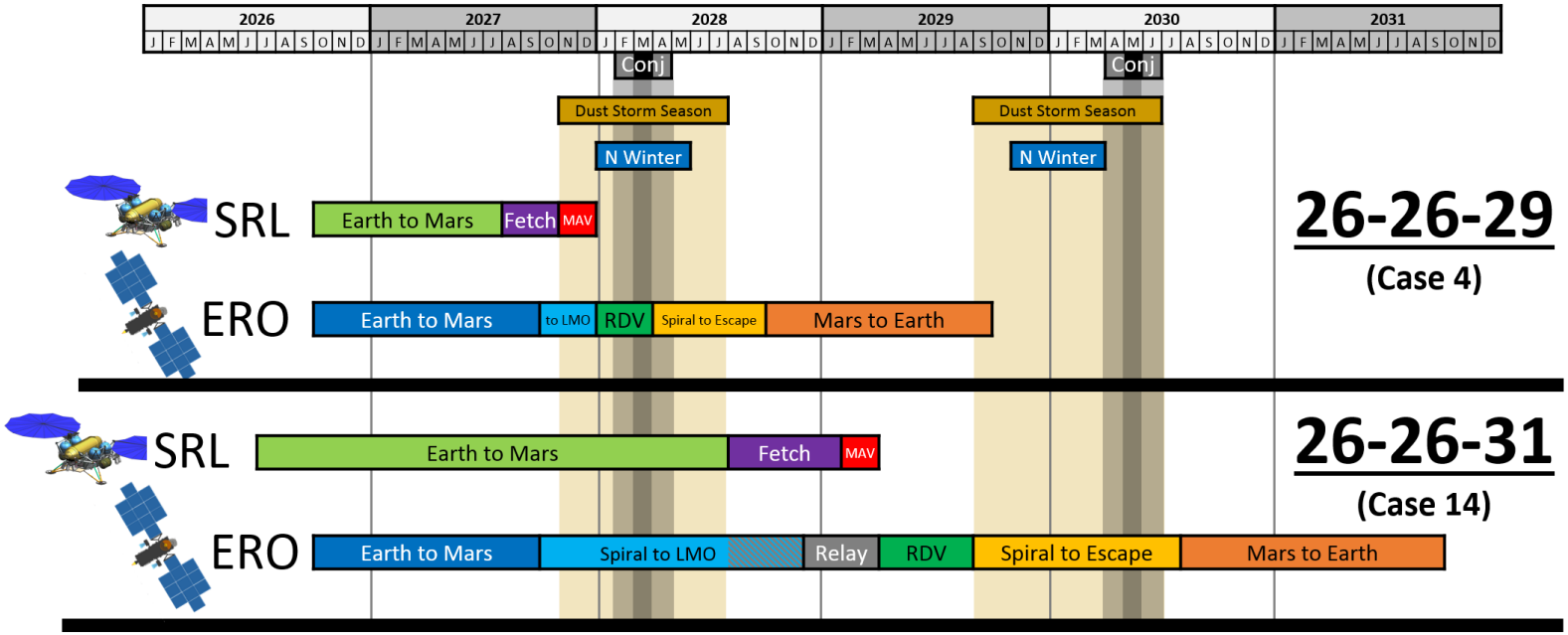


Escape Spiral



Mars-Earth Heliocentric

26/26/29 vs 26/26/31 Comparison



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4	Hb-EP	RITx3	33	5886	2761	683	2384	1511	287	Oct-2026	6.3	1.9 km/s	1,235 km	Nov-2027	Mar-2028	Sep-2029	0.87
14	Hb-EP	RITx3	33	5995	3243	1262	1269	2691	1262	Oct-2026	5.6	2.1 km/s	33,000 km	Dec-2028	Aug-2029	Oct-2031	0.97

As compared to the 26/26/29 option, the **26/26/31** option:

- Supports significantly more ERO return mass
- Enables the ERO to fully cover the relay needs of SRL
- Provides many more months for rendezvous activities
- Experiences an energetically more favorable surface season
- Avoids the historically observed dust storm season
- Encounters more conjunctions, but in less inconvenient places

Conclusions

- Campaign transportation architectures for MSR in the 2020's were exhaustively examined using a variety of trajectory and spacecraft modeling tools developed at JPL and in collaboration with ESA.
- From the millions of runs, a number of feasible architectures were identified, none of which likely would have been found using "traditional" methods of iterative point designs or isolated optimizations
- The Hb-EP architecture using gridded ion engines appears to be the optimal ERO propulsion architecture for MSR options in the 2020s
- The 26/26/31 mission option offers a number of technical benefits as compared to the faster return option available in 26/26/29
- Unfortunately, this talk could not cover everything, the full method and details are in the paper!