Human Cargo Resupply Logistics at Mars Using 150kW SEP Tug Cyclers

Ryan Woolley

John Baker

Damon Landau

Jet Propulsion Laboratory

California Institute of Technology

Kevin Post

Boeing

2017 IEEE Aerospace Conference

March 5-9, Big Sky, MT

Problem statement

Common goal: Humans on Mars by 2040

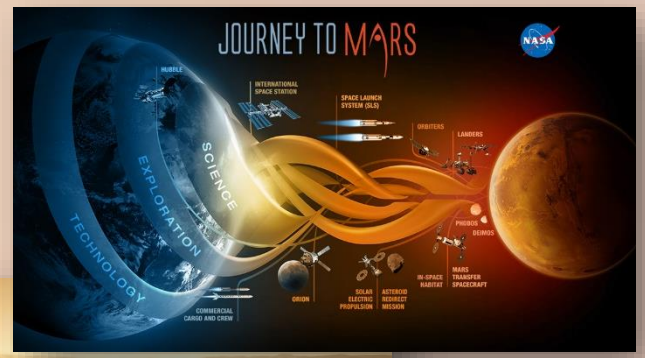
Common need: Logistics and Transportation

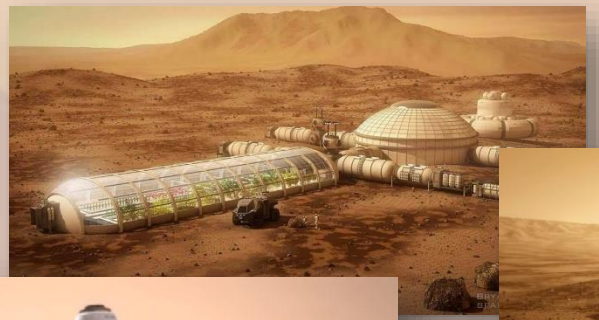
Problem: How do we get all of the "stuff" to and from Mars to support a sustained presence?

Fact: It takes lots of energy/fuel to get to Mars

Fact: Solar Electric Propulsion is fuel efficient

Potential solution: Use SEP tugs to deliver cargo and logistics

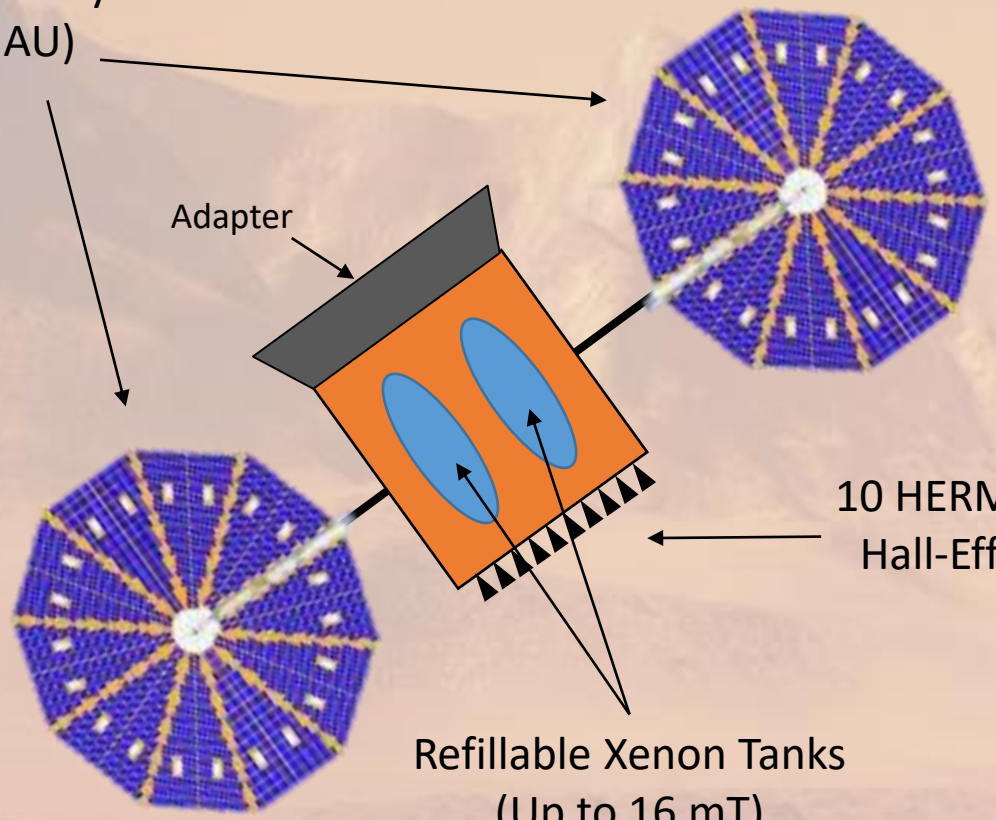




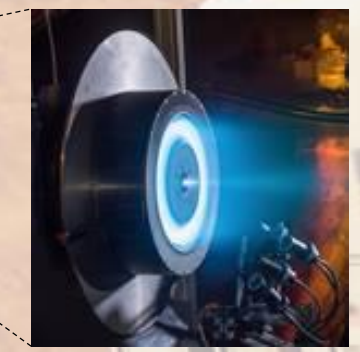
Notional SEP Tug Assumptions

Dry Mass: 8 mT

150 kW Arrays
(@ 1 AU)



10 HERMeS (ARRM*)
Hall-Effect Engines



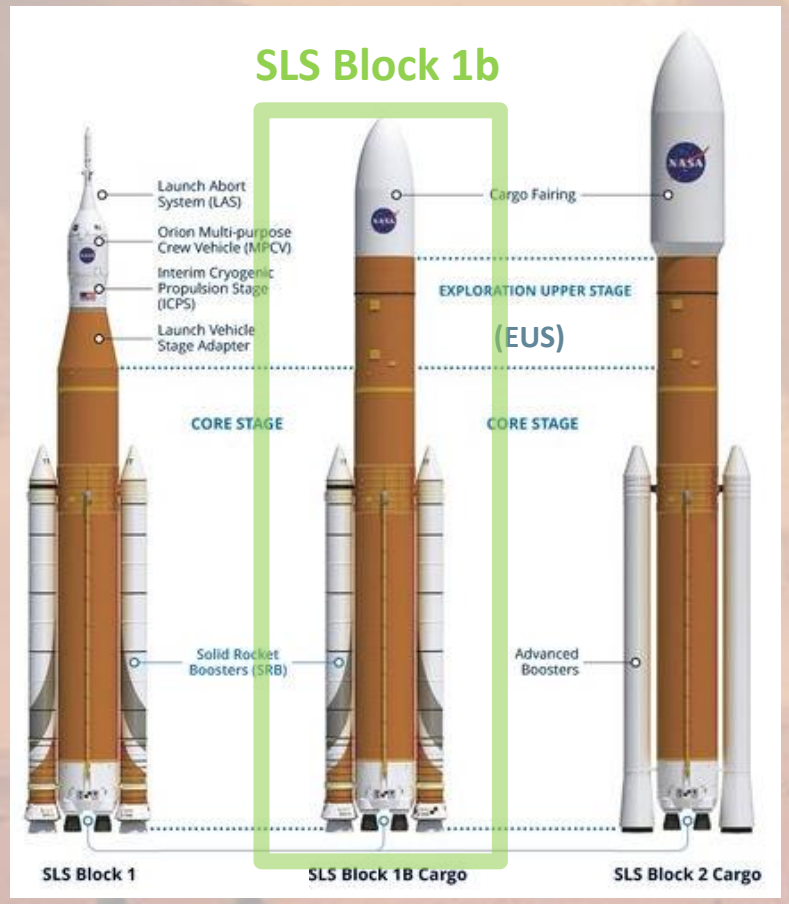
Refillable Xenon Tanks
(Up to 16 mT)

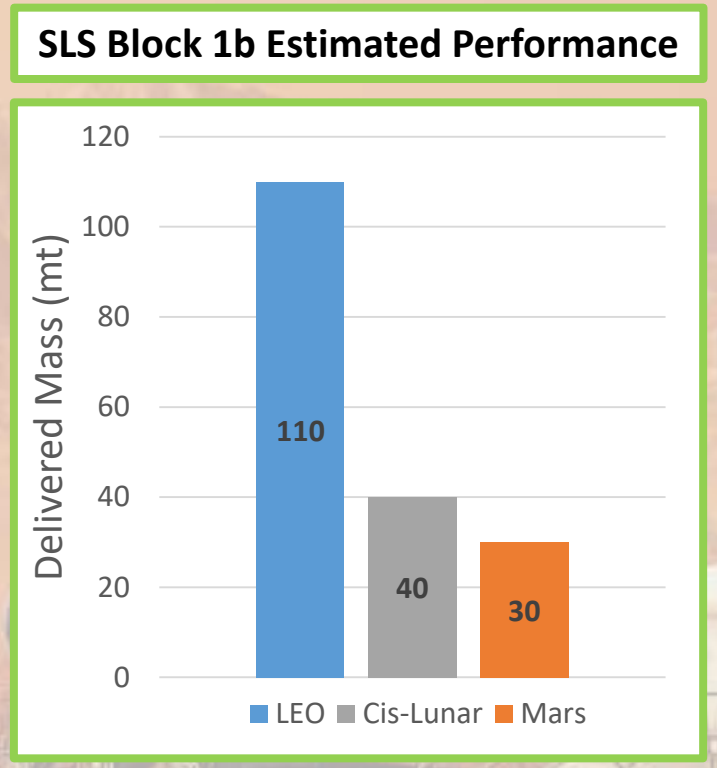
Parameter	Value	Units
Dry Mass	8	mt
Power (1 AU)	150	kW
Thruster	HERMeS	(x10)
Specific Impulse (Isp)	2660	seconds
Thrust	585 (each)	mN
Max Xenon	16	mt

*Asteroid Redirect Robotic Mission

Launch Vehicle Assumptions

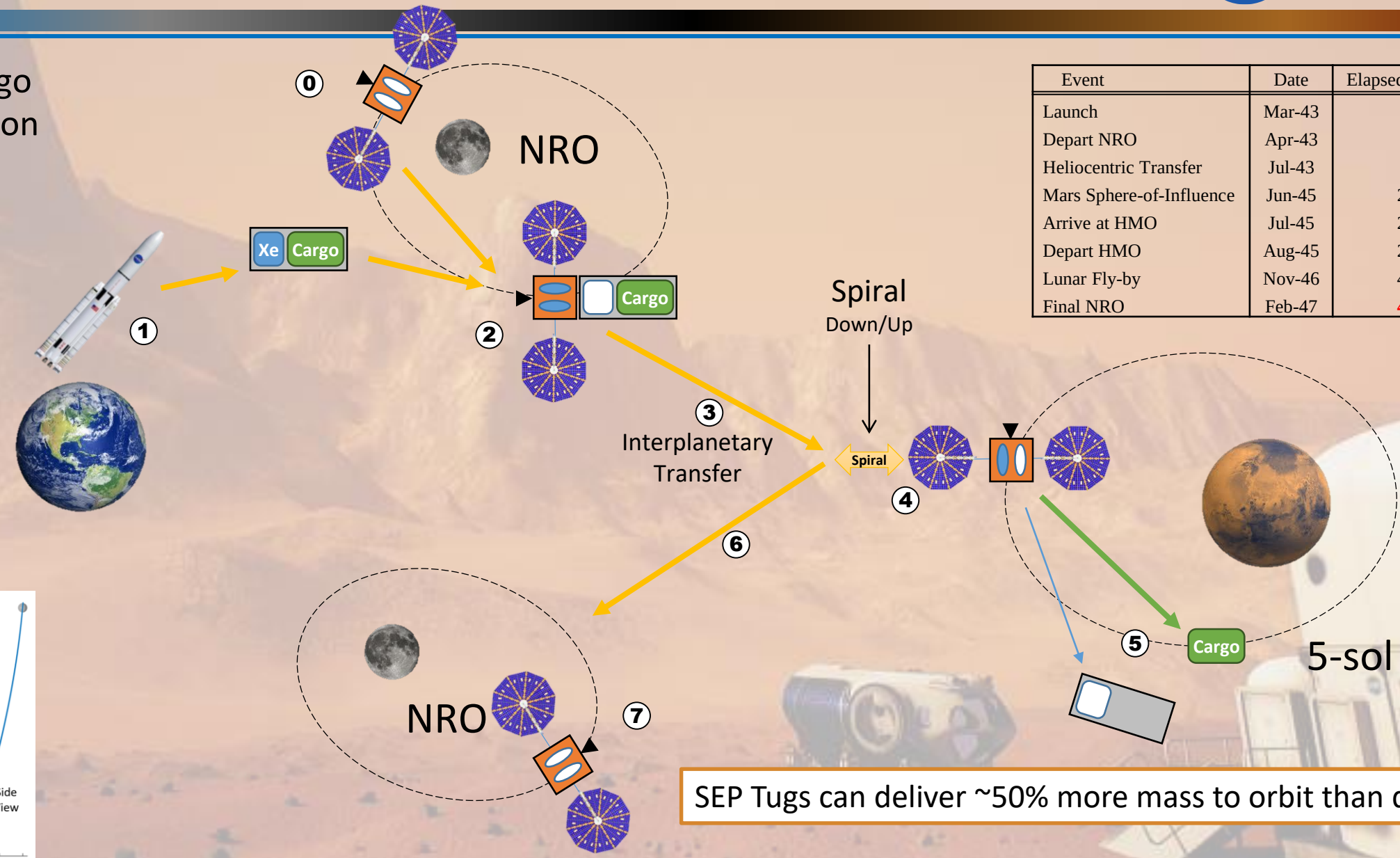
- A key building block of any Humans-to-Mars architecture is the assumed capability of a future heavy-lift launch vehicle - discretizes the whole architecture
- SLS Evolution: Block 1 (70 mT to LEO), **Block 1b (110 mT),** Block 2 (130 mT)



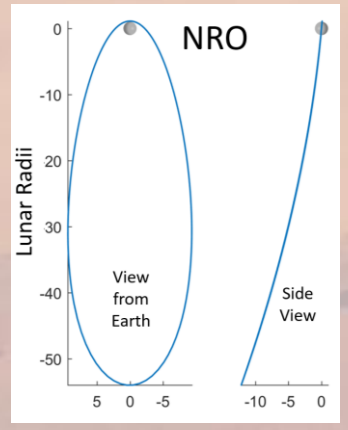


Orbital Resupply Concept

Cargo - Cargo
Xe - Xenon



Event	Date	Elapsed Months
Launch	Mar-43	0
Depart NRO	Apr-43	1
Heliocentric Transfer	Jul-43	4
Mars Sphere-of-Influence	Jun-45	27
Arrive at HMO	Jul-45	28
Depart HMO	Aug-45	29
Lunar Fly-by	Nov-46	44
Final NRO	Feb-47	47

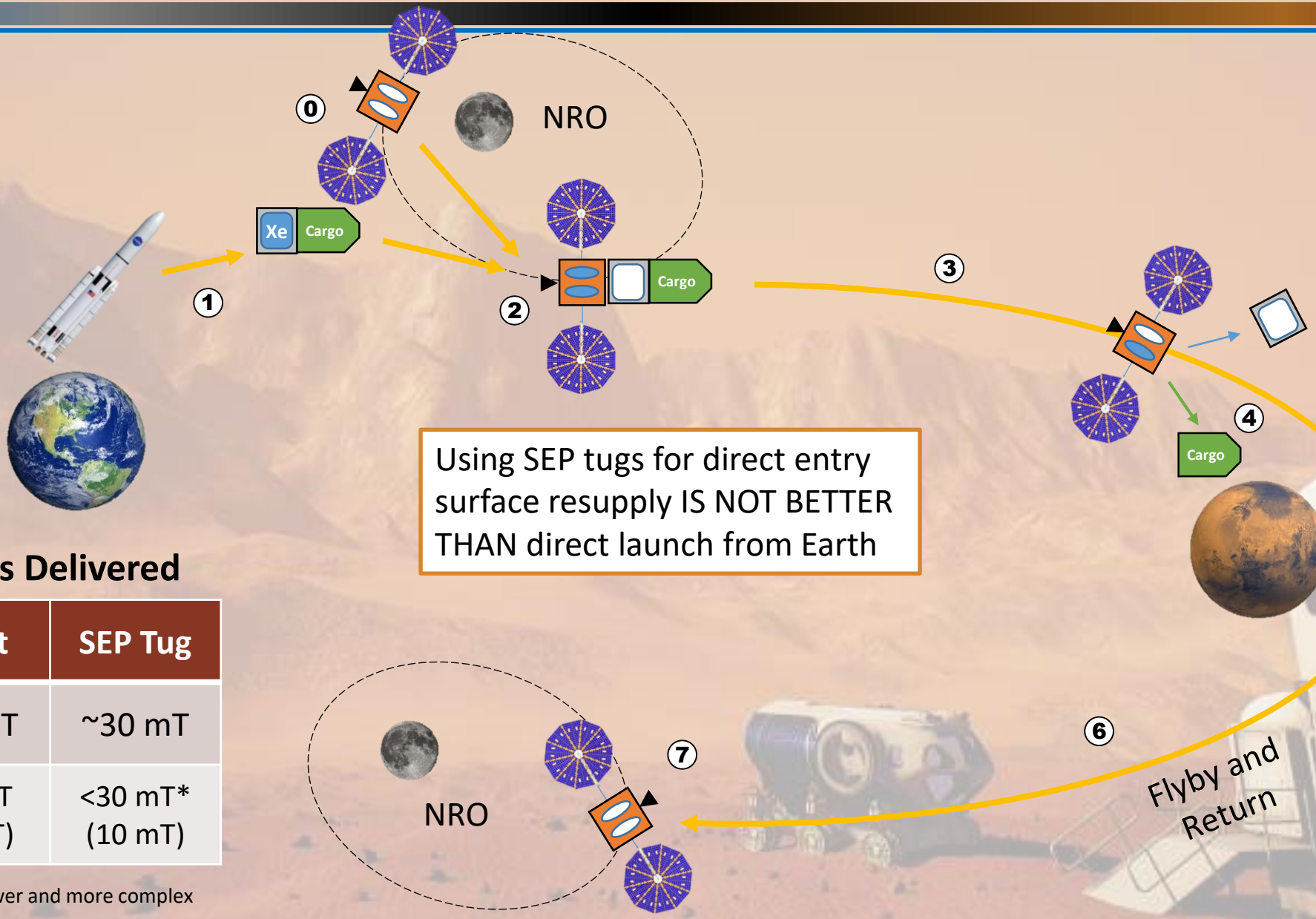


SEP Tugs can deliver ~50% more mass to orbit than direct

Pre-decisional. For planning and discussion purposes only.

Surface Resupply Concept

Cargo - Cargo
Xe - Xenon



Using SEP tugs for direct entry surface resupply IS NOT BETTER THAN direct launch from Earth

Maximum Mass Delivered

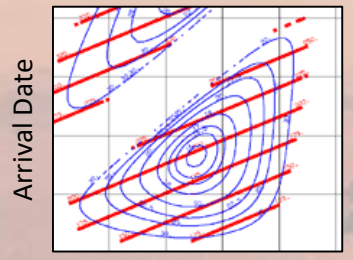
	Direct	SEP Tug
Orbit	~20 mT	~30 mT
Entry (Surface)	~30 mT (10 mT)	<30 mT* (10 mT)

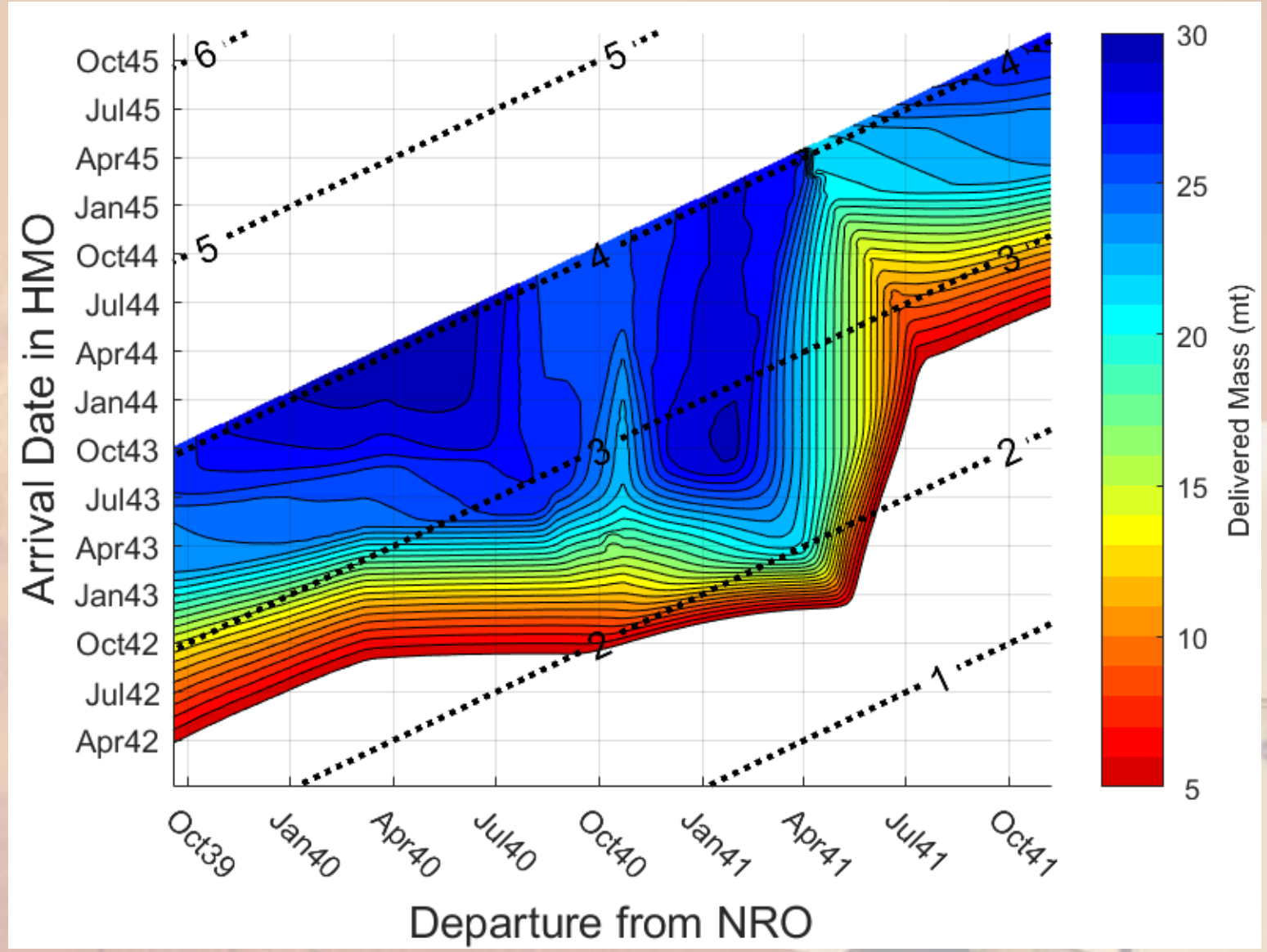
*Similar mass, but much slower and more complex

Low-Thrust Trajectory Maps – “Bacon” Plots

- Need a “roadmap” of SEP trajectories analogous to ballistic porkchop plots
- Shows **maximum delivered mass** for launch/arrival space
  - Architecture assumptions built in
  - Simulations in MALTO
- Thousands of trajectories were generated over **2038-2054**
- Created for both:
  - Earth→Mars
  - Mars→Earth

Ballistic “Porkchop” Plot



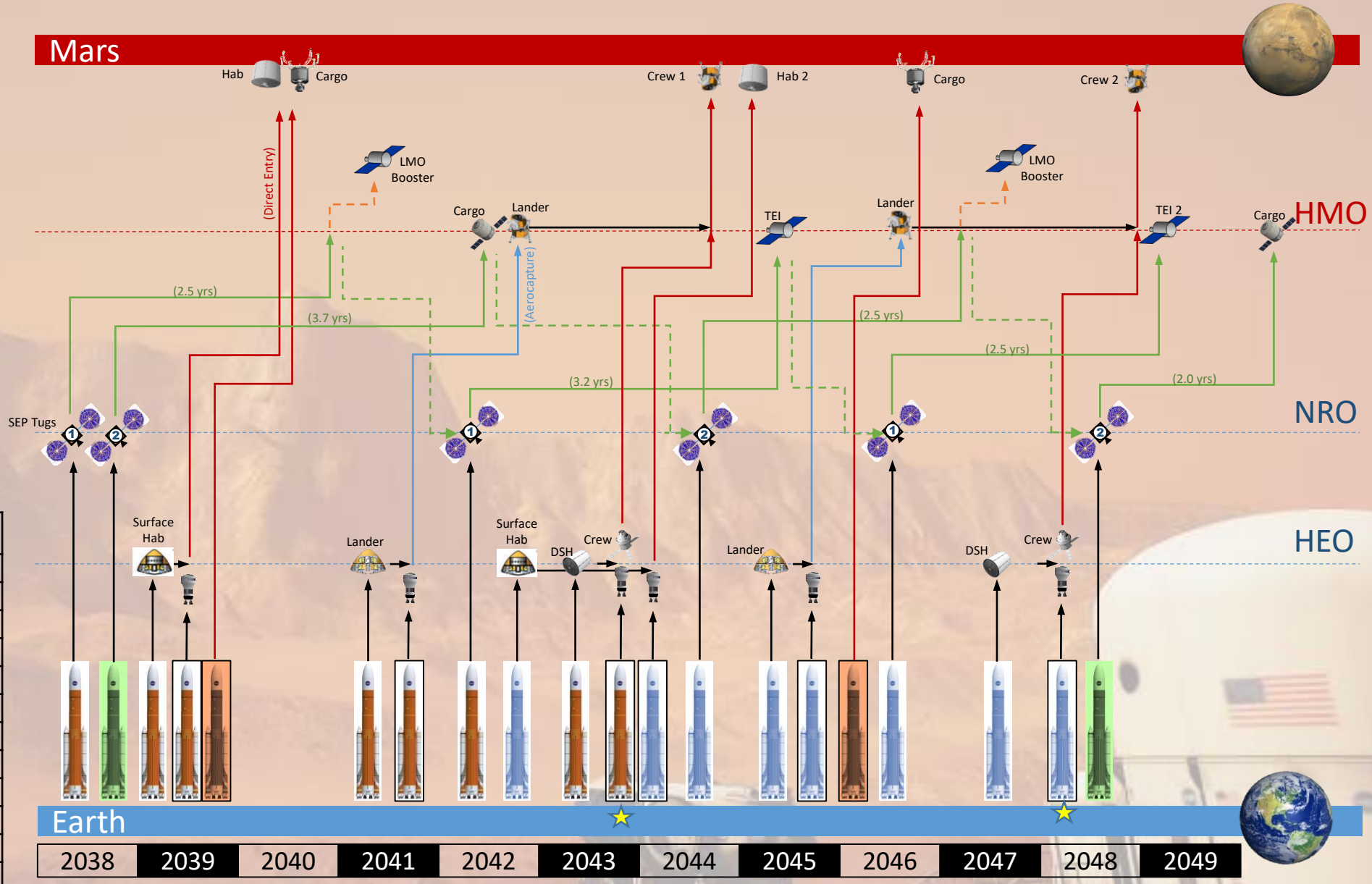


Pre-decisional. For planning and discussion purposes only.

Example launch sequence for a sustained human outpost

Mission element mass assumptions:

Mission Element	Mass Allocation	Includes Prop?
Crew		
Orion (Command + Service)	20 mt	yes
Deep-Space Habitat (DSH)	30 mt	no
Surface Habitat (HAB)	35 mt	no
Propulsive		
TEI Stage	26 mt	yes
MOI Stage	28 mt	yes
LMO-to-HMO Booster Stage	26 mt	yes
Crew Lander/MAV	50 mt	yes
Exploration Upper Stage (EUS)	14 mt	no
SEP Tug	8 mt	no
Resupply		
Orbital Resupply Module	15-30 mt	no
Surface Resupply Module	20-30 mt	yes



Key

- Launch associated w/ 1st expedition
- Launch associated w/ 2nd expedition
- Ballistic Trajectory Required
- Orbital Cargo Launch
- Surface Cargo Launch
- Aerobraking
- Low-Thrust Transfer
- Ballistic Transfer
- Ballistic w/ Aerocapture
- EUS
- Crewed Launch

Conclusions

- Sustained human presence on Mars will require a significant amount of cargo
- Solar Electric Propulsion (SEP) can be very efficient for cargo delivery
- A precursory study of the benefits of reusable SEP tugs showed that
  - Mass delivered to Mars orbit can by increased by ~50%
  - SEP tugs do not appear to be beneficial to direct entry surface cargo
- Other key findings:
  - SEP tugs are feasible using technology currently in development (eg. ARRM)
  - SEP may take longer, but it is much more flexible
  - This flexibility allows for more robust launch sequencing
- Future Work:
  - More sophisticated tools for architecture **design** and **optimization**
  - Seek better understanding of **benefits vs. disadvantages** of SEP usage