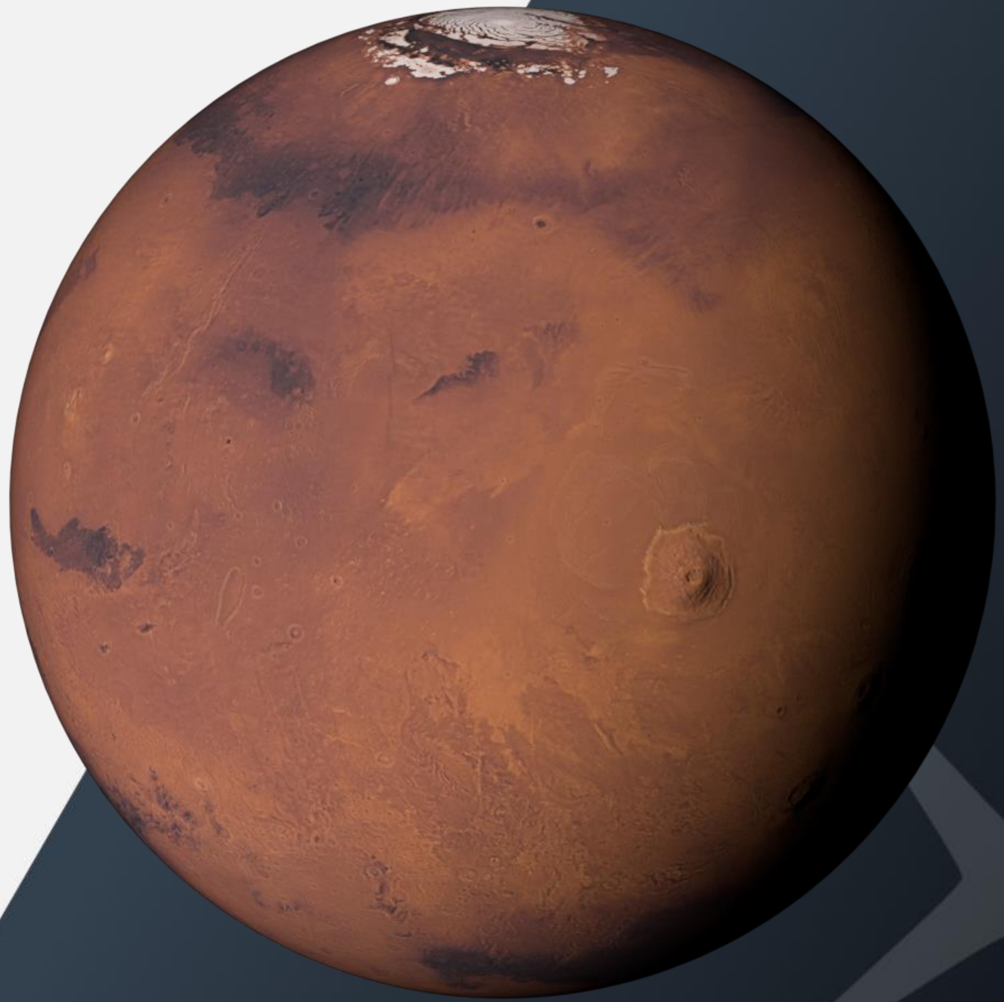
Interplanetary Rideshare Cost/Benefit Analysis:

A Mars Mission Approach



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Small Satellites Beyond Earth

- Interplanetary Small Satellites interest is growing
- Driven by the Scientific Community / Governments
- Motivated by experiences in Low Earth Orbit
  - Cost, Speed, Constellations, etc.
- Small numbers right now, but growing
- Launch is a **big challenge**
  - Similar to what happened in LEO

- Is it possible to use LEO experience to help?

Low Earth Orbit Experience

Spacecraft/Mission development phases:

1 FEASIBILITY

- AMSAT
- Universities
- CubeSats

2 UTILITY

- SSTL
- NASA Exobiology
- SkyBox
- Planet
- Spire

3 WIDE ADOPTION

- NASA
- ESA
- JAXA
- Startups
- DoD
- [...]
- Global

Interplanetary Missions Forecast

Following a similar path:

1 FEASIBILITY
- NASA MarCO
- SLS – Artemis 1
- ESA M-Argo

2 UTILITY
- Simplex 4 missions
- ESA Hera mission

3 WIDE ADOPTION ?

Low Earth Orbit Experience

Launch access phases:

Piggyback

Schedule and Orbit Constrains from primary

i.e. ELaNa, Sherpa, Ariane ASAP, ABC

Small Launch Vehicles

Schedule and Orbit Flexibility

i.e. Rocket Lab, Virgin Galactic

Dedicated Rideshare

- ✓ Lower Cost
- ✓ No primary

i.e. PSLV, SpaceX, Vega

Space Tugs

- ✓ Increased Orbit flexibility
- ✓ Simpler spacecraft

i.e. MOMENTUS, D-Orbit, UARX Space

CAL POLY

UARX

Interplanetary

Launch access phases:

Piggyback

Similar Schedule & Orbit Challenges

i.e. MarCO, Artemis 1, EscaPADE/Psyche

NASA

Lunar Lander Rideshare

Rocket Lab

Lunar launch

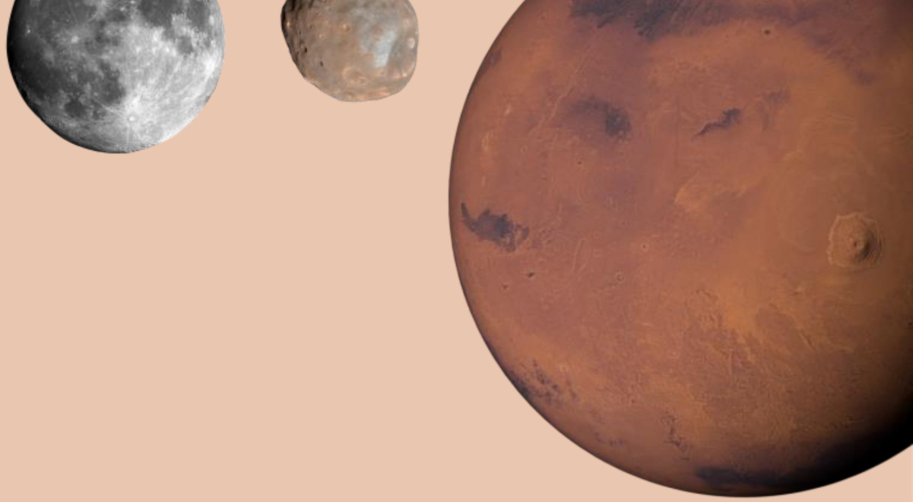
Rideshare & Space Tugs

?

CAL POLY

UARX

Interplanetary Missions Favor Tugs



- Orbits Constrain Schedule
  - Encourages Rideshare
- Long and Complex Cruise Phases
  - Requires Critical Non-Mission Knowhow and Infrastructure
- Large Propulsion Requirements
  - Complex / Costly Spacecraft

Tugs can reduce Spacecraft and Mission Complexity

Sample Mars Mission to compare Tug and Individual Travel

Mission Scenario

Parameter	Value
Initial Orbit	Mars Transfer Orbit
Destination Orbit	500km Low Mars Orbit
Propulsion Type	Chemical propulsion (Isp = 250s)
Payload Mass	10 x 100kg small satellites
Required Delta-V	2.1 km/s
Propellant-Mass Fraction	58%

Sample Mars Mission to compare Tug and Individual Travel (cont.)

Mass Comparison

Component	Space Tug	Individual
Space tug (dry)	445 kg	-
Payloads mass	10 x 100 kg	10 x 100 kg
Extra Prop. system	-	10 x 32 kg
Fuel mass (Isp=250s)	1995 kg	1820 kg
Total launch mass	**3440 kg**	**3140 kg**
Propellant-Mass Fraction	58%	58%

Sample Mars Mission to compare Tug and Individual Travel (cont.)

Operational Cost Comparison

Concept	Space Tug	Individual
Planning	$180,000	$81,000
Execution	$50,000	$30,000
DSN Fees	$2,500,000	$2,500,000
Total operational cost	**$2,730,000**	**$2,611,000**
x10 spacecraft	-	$26,110,000
Space Tug savings	**$23,380,000**	-

Conclusions

- Interplanetary Small Satellites market tracking events in LEO
- Need to prepare for wide adoption phase
- Tugs are a key enabling technology
- Initial mission opportunity is critical to activate system
- Must define accommodations on Tug (standardization?)
- Need international effort
  - Lower numbers
  - Interplanetary missions driven by Governments