Mars Small Spacecraft Concept Studies

Nathan Barba, Tom Komarek, Ryan Woolley, Lou Giersch,
Vlada Stamenković, Mike Gallagher, and Charles D. Edwards

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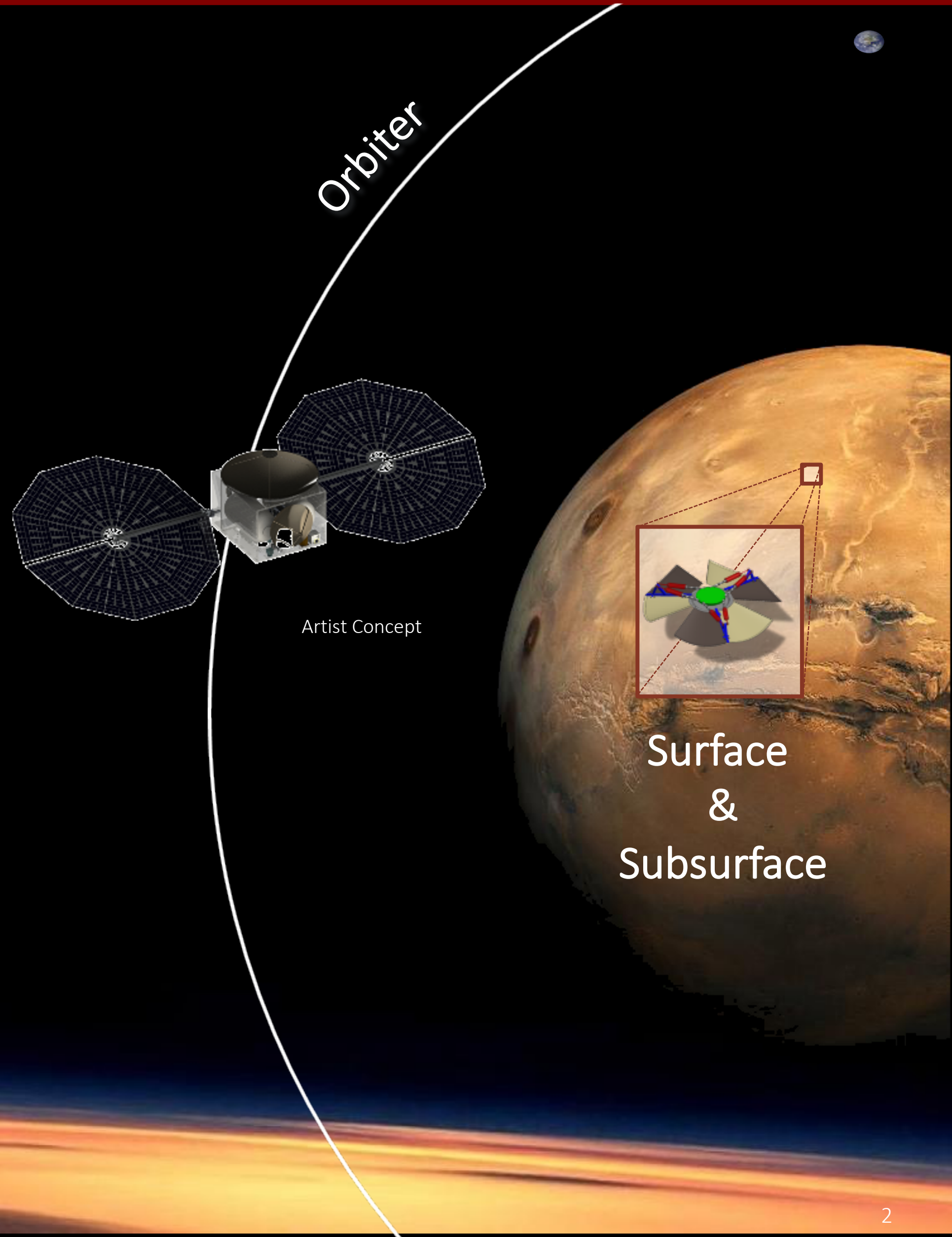
Motivation

- Potential Mars Sample Return campaign focused on returning samples collected by M2020.
- Desire for parallel science investigations during MSR.
- Need for smaller, affordable missions to perform important science investigations.
- Possibility of missions with constellations and networks to conduct multi-point science observation and ground-truthing.



Key Questions and Primary Goals

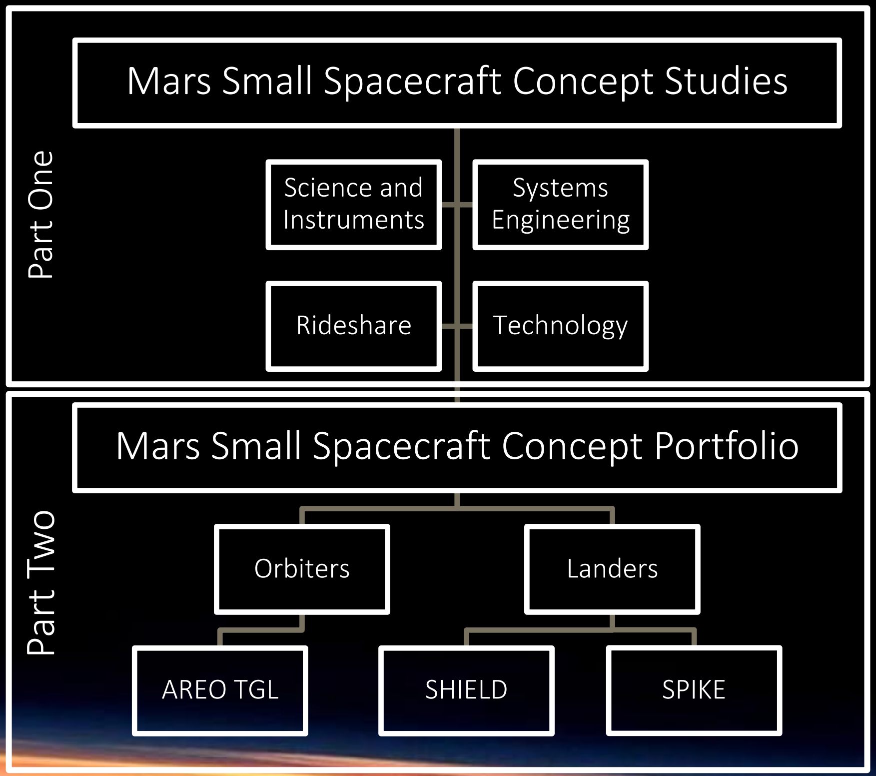
Key Questions

- Can small spacecraft missions deliver **compelling science**?
- Are the small spacecraft mission concepts **technically feasible**?
- Can these small spacecraft missions studied fit into an **affordable cost** envelope?

Goals for all mission concepts studied:

- The mission should be science driven, with goals traceable to the Decadal Survey, MEPAG goals, HEO SKGs, etc.
- S/C mass target: 250 kg +/- 100 kg (ESPA Class)
- Transport to Mars
- Mission cost target: < $200M , includes cost for launch, rideshare, or piggyback config.
- Provide concept examples for both Orbiters and Landers

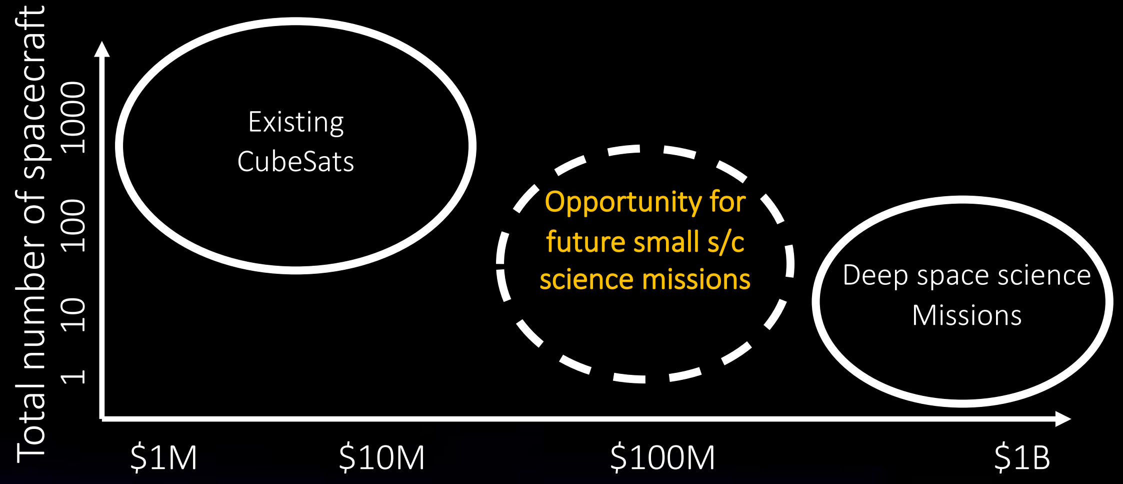
Mars Small Spacecraft Study Approach



Small Spacecraft Mass and Volume Target

S/C Mass and Volume Target Motivation (250 kg +/- 100 kg, ESPA Class)

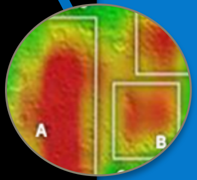
- Spacecraft should have the capability to transit on its own propulsion from Earth orbit to Mars.
- Possible order of magnitude cost savings for launch services.
- Spacecraft science payload capacity target is < 10 kg of science payload for orbiters and < 5kg of landed science payload.
- Strong development in commercial small spacecraft sector.
- JPL currently developing enhancing technology for small spacecraft telecommunications and propulsion.



Compelling Science from Orbit

- Timely & recent decadal class science questions well suited for Mars small spacecraft in Mars orbit.

Trace Gas Localization



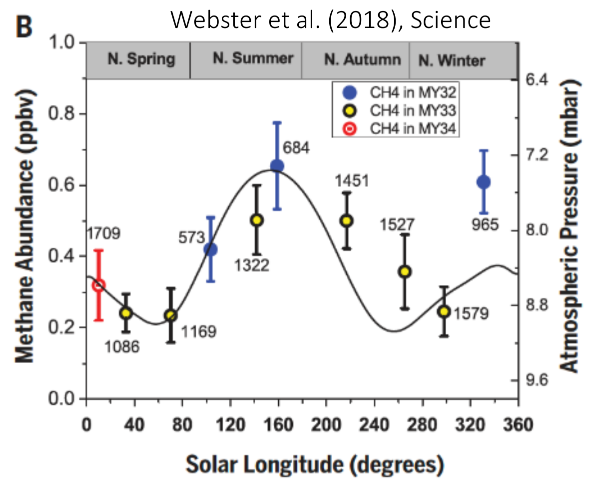
- Questions: where is methane coming from, where is it destroyed? Is the source abiotic or biotic (extinct vs extant).
- Areostationary configuration can answer this question.

Delivery of Organics by Meteoroids

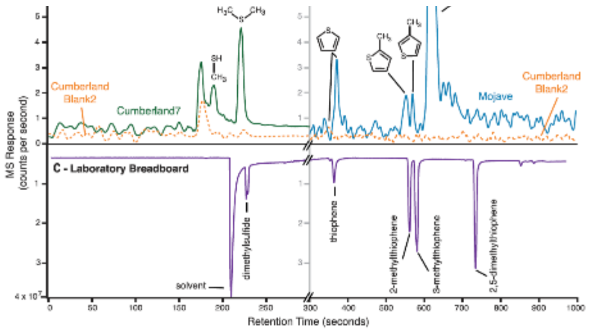
- Questions: How much material, especially organics, is delivered to the surface (Exogenic Influx)
- CCD whole-disk monitoring device with selected filters staring from areostationary orbit can address this question.

Evidence of seasonally variable CH_4 and carbonates

Webster et al. (2018), Science



Eigenbrode et al. (2018), Science
Organic Matter … at Gale Crater



Compelling Science for Surface/Subsurface

- Timely & recent decadal class science questions well suited for Mars small spacecraft for Mars surface/subsurface.

Groundwater

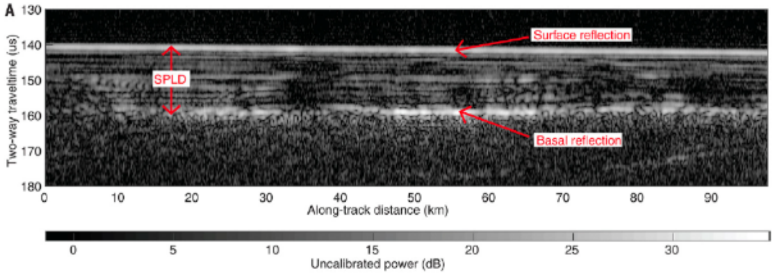
- Questions: Is there liquid water in the subsurface, what is its chemistry?
- Mini EM sounders (using induction) and B-field sensors can address this question.

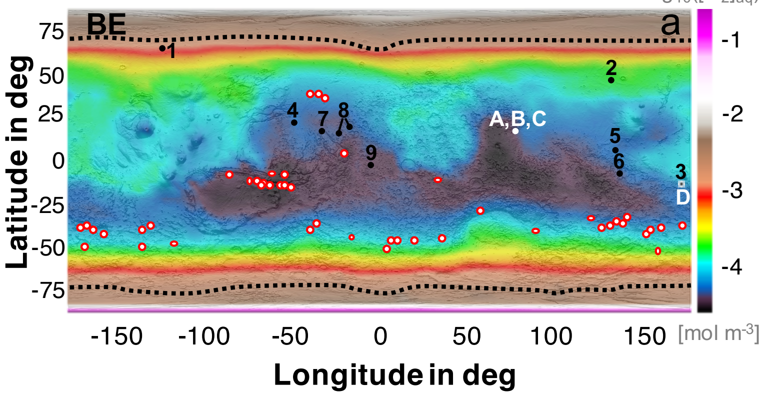
4-D Networks & Scouts

- Questions: What is the spatial and temporal variability in key properties across the surface and subsurface (with surface assets or penetrators)?
- Sniffers, EM field, weather, subsurface-atmosphere exchange (global coverage of fundamental fast-changing processes)

Evidence of groundwater, near-surface brines and aerobic environments

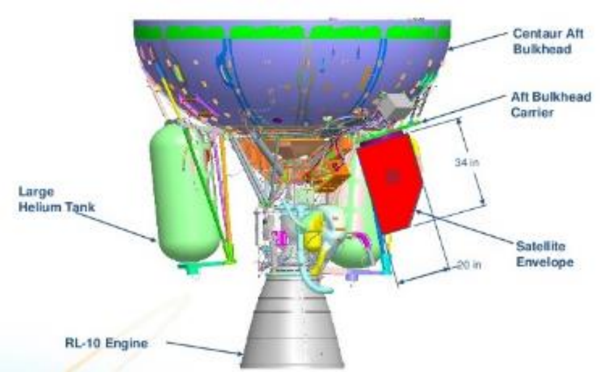
Orosei et al. (2018), Science





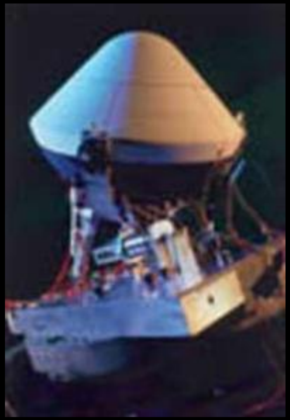
Stamenković et al. (2018), Nature Geo

Three Key Methods to Get Small Spacecraft to Mars



Source: ULA, Aft Bulkhead Carrier Auxiliary Payload User's Guide

Small spacecraft mounded on Aft Bulkhead Carrier (ABC)



Source: NASA/JPL/Caltech

Deep Space 2 piggyback released prior to arrival on Mars Polar Lander Mission in 1999.

Many small LVs are in development for Earth/Moon use. Firefly + solid motor would be capable to reach Mars. Others may follow.

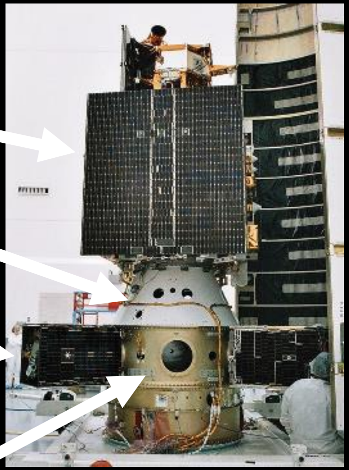
Source: Firefly Alpha Users Guide

Primary Payload

Primary Payload Adapter

Secondary Payload

ESPA Ring Adapter

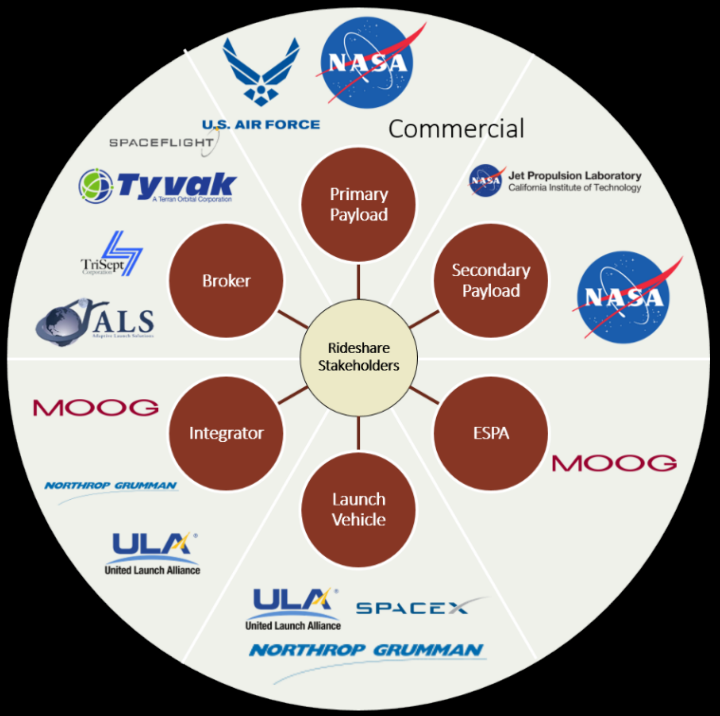


Science Test Payload STP-1 (USAF 2007) Payload Stack
Source: Aerospace.org

	① Piggyback on Mars Bound Mission		② Small Launch Vehicle + Solid	③ Rideshare as Secondary P/L on ESPA
	release after launch	release prior to arrival		
Estimated dry mass to Mars	< 80 kg	mission specific	< 200 kg	< 250 kg
Launch Opportunity Frequency	Once every 2 years	Once every 2 years	As needed	~10 launches to GTO per year

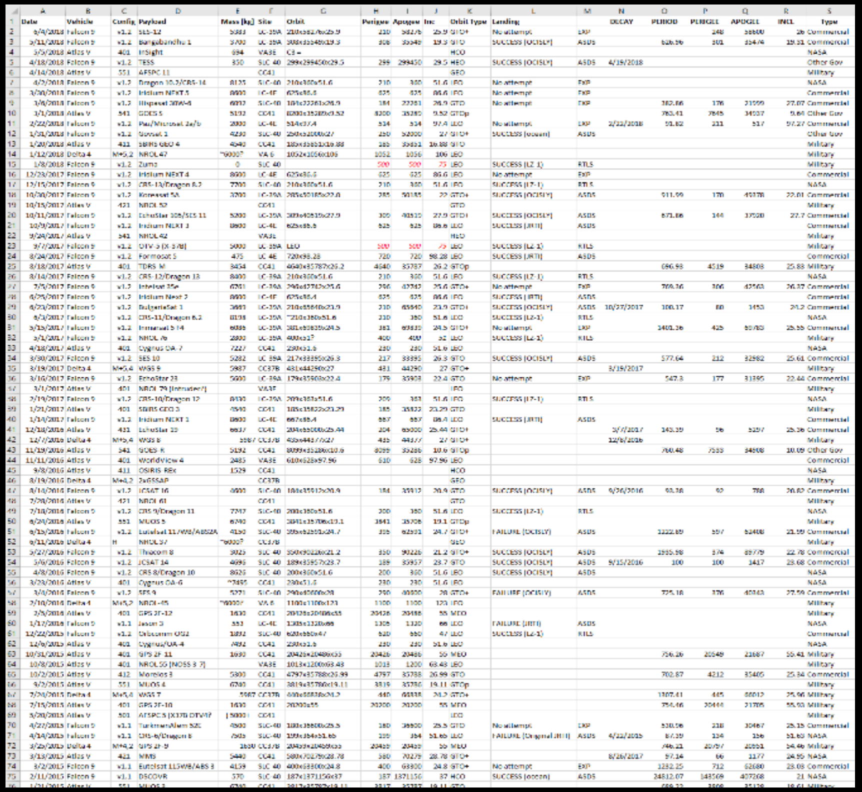
Access to Mars via Rideshare

Rideshare Stakeholders

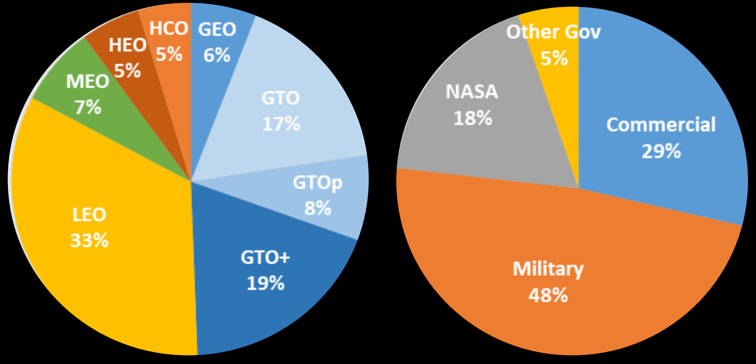


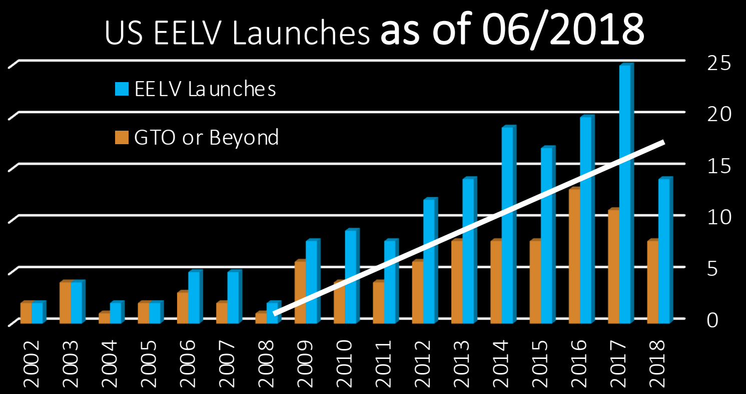
Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

Compiled internal database of US EELV launches: Atlas V, Delta 4, Falcon 9



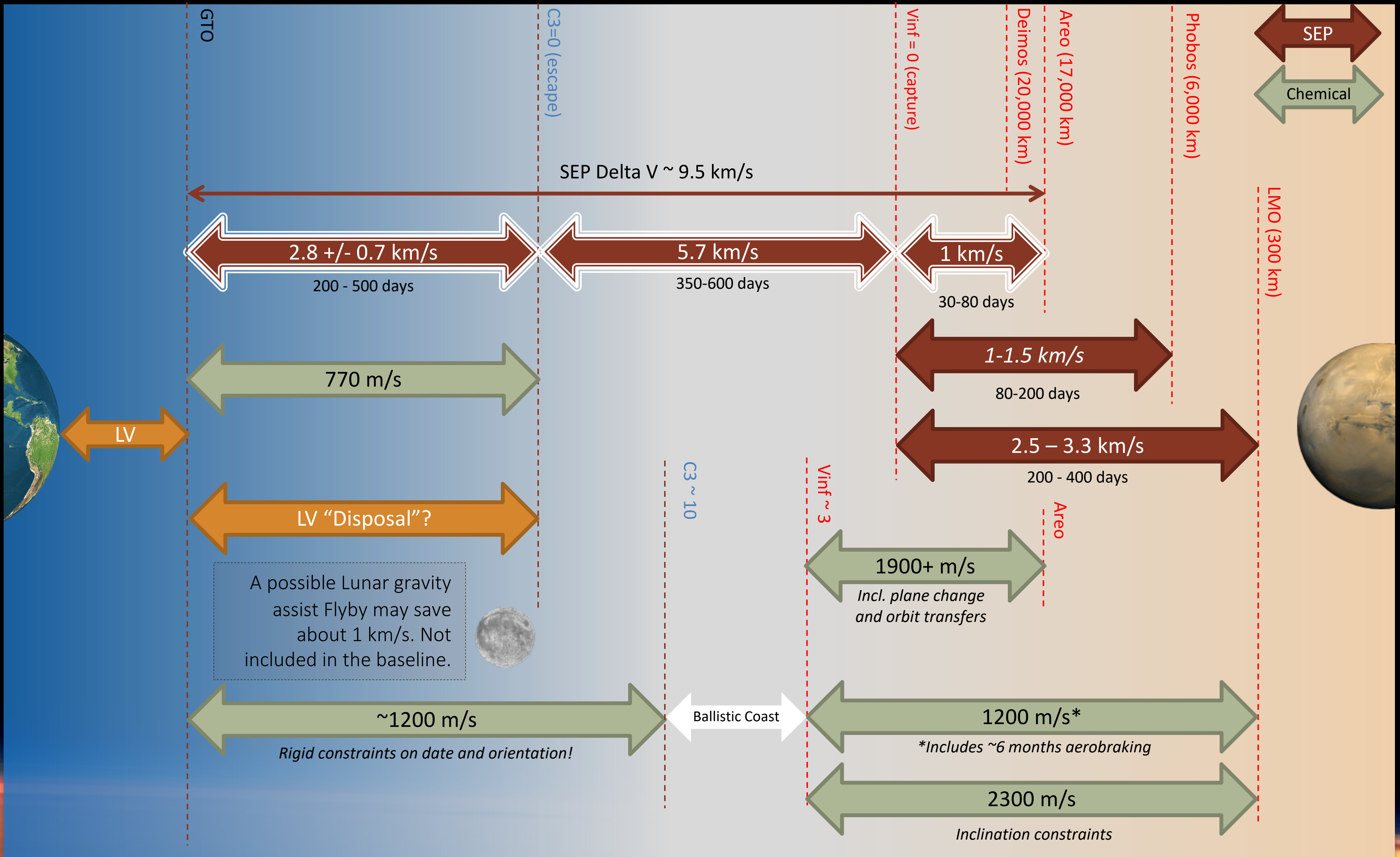
Statistics since 2002: 168 total launches of Atlas V, Delta 4, and Falcon 9 . ~50% go to GEO





We can reliably count on an affordable GTO launch opportunity as a secondary payload brokered by one of the brokers and/or integrators.

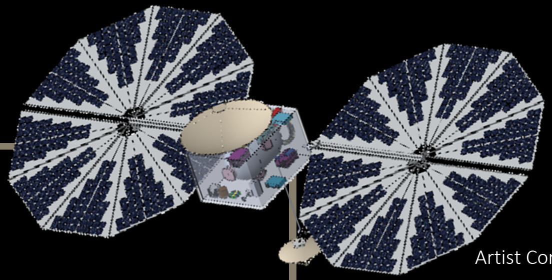
Path to Mars Orbit Via Rideshare



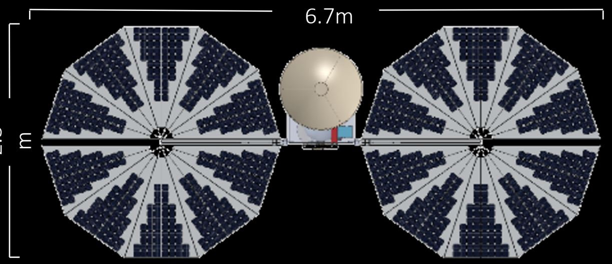
Pre-decisional. For planning and discussion only.

SEP delivers ~60% more mass to High Mars Orbit

AREO TGL: Areostationary Concept Case Study



Artist Concept



Features

Mass: 220kg to 350kg per spacecraft

Target: Mars – Areostationary Orbit (17,000 km)

Configuration: Single spacecraft, future constellation.

Launch: Secondary Payload on ESPA Grande

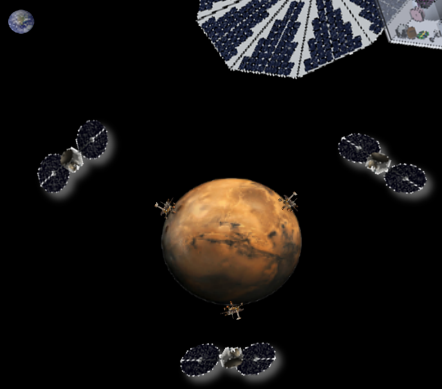
Cruise: Solar electric propulsion

Enabling Technology: None required

Risk Class: D

Cost : $100 M to $200 M per spacecraft

Lifetime: ~3 Earth years on orbit then replenished.



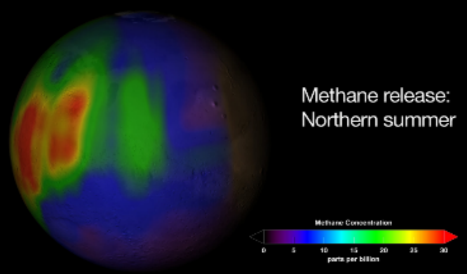
Artist Concept

Science and Instruments

- Localization and diurnal concentrations of methane, other trace gases, and water.
- Spatial Heterodyne Spectrometer (JPL)
- TBD - Camera

Telecom

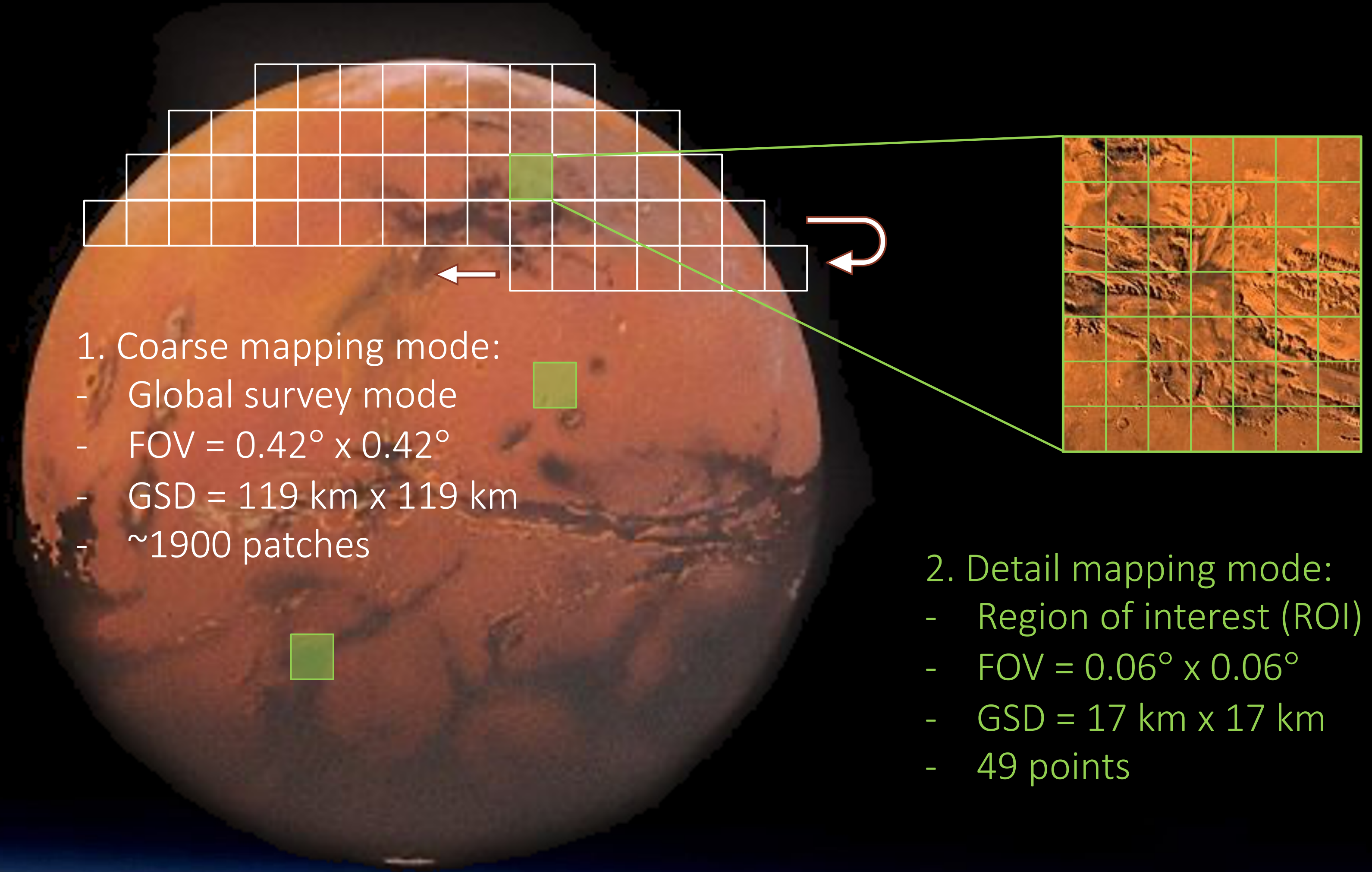
- X-Band proximity link to surface, MSL-like rates.
- Ka-Band, Direct to Earth, MAVEN-class data rates.



Source: NASA

Delta-V	• Spiral out: 1.6 km/s • Cruise: 5.7 km/s • Spiral in: 0.9 km/s
Telecom	• DTE: Ka-band dedicated, X-band backup and DFE • Optional crosslink • Body fixed antenna, and solid state power amplifier.
Propulsion	• 2x MaSMi Hall Thrusters
ACS	• 0.2 degree pointing capability
Power	• 2.1kW(BOL) lightweight SA • Secondary batteries – 250Wh capacity
C&DH	• Dual-Core LEON3FT (SPHINX), 100MHz, 8GB NAND Interfaces: RS422, SPI, I2C, Spacewire, GPIO, UART
Mechanical	• ~1m x ~1m x ~1m • Compatible with ESPA/ESPA Grande
Payload	• Spatial Heterodyne Spectrometer • Multispectral Wide Field

Conceptual Operational Scenario for AREO TGL



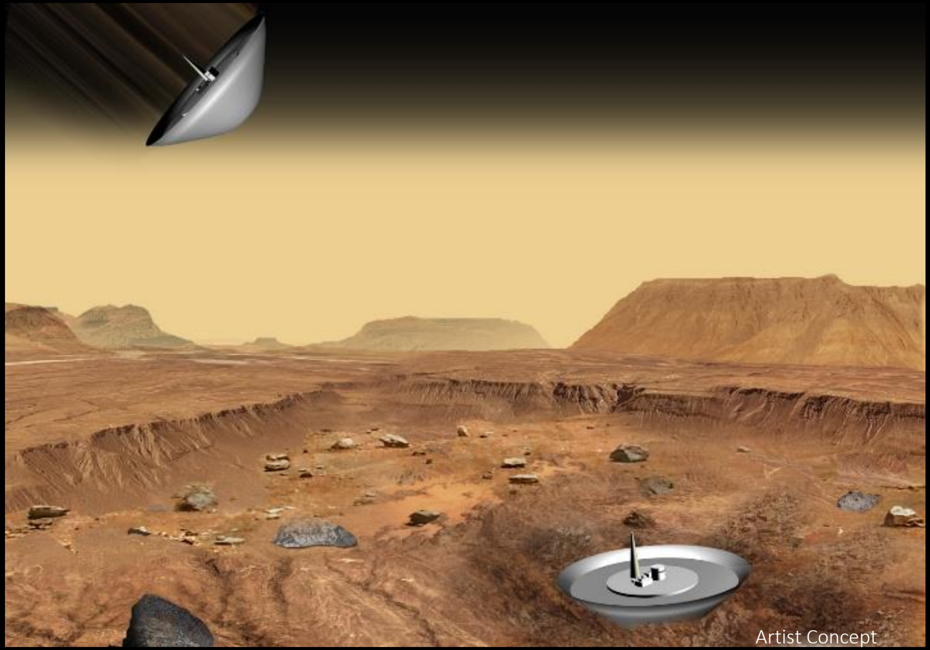
1. Coarse mapping mode:
- Global survey mode
- FOV = 0.42° x 0.42°
- GSD = 119 km x 119 km
- ~1900 patches

2. Detail mapping mode:
- Region of interest (ROI) identified
- FOV = 0.06° x 0.06°
- GSD = 17 km x 17 km
- 49 points

SHIELD: Surface/Subsurface Concept Case Study

SHIELD – Small High Impact Energy Landing Device

- SHIELD enables the transportation of small scientific payload(s) affordably to the surface
- Mass target of <50kg
- Entry Veolcity target: 60 m/s,
- Expected impact on payload < 1000g.
- Total science payload up to 5 kg.
- Science payload can vary, investigating options for mobility.
- Science goals of high priority for Decadal science, MEPAG, and HEO SKG's.



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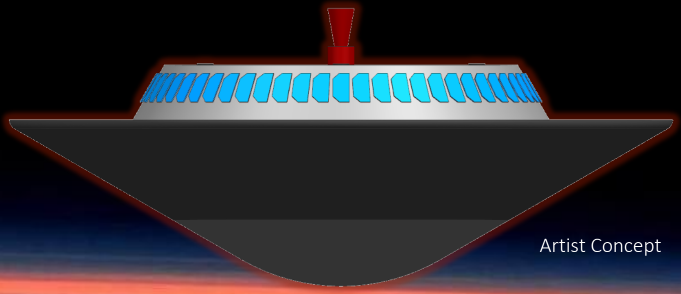
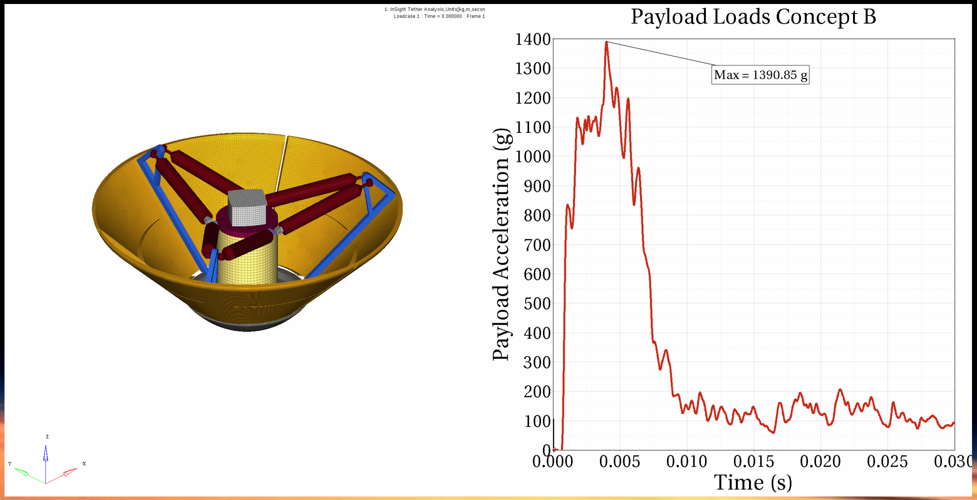


Artist Concept



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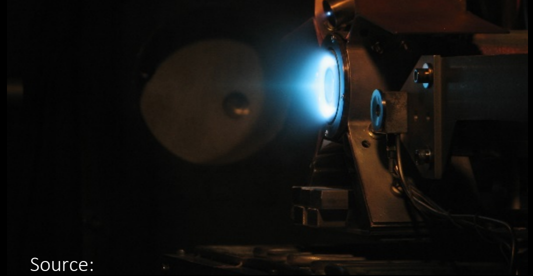
Identified Enhancing Technologies for Interplanetary Small Spacecraft

- Deep Space Telecommunications
  - Deep space low-power low mass transponder (JPL)
  - Low mass, low power Ka-Band Klystron amplifier (SBIR)
  - Deployable antennas (JPL)
- Solar Electric Propulsion Thrusters
  - High through-put low-mass hall thrusters (JPL)
- Incubator for future Mars small spacecraft technology
  - TH_2OR Water Sounding Instrument
  - SHIELD Surface Lander

Klystron Beam Tester

Source: Miniature Klystron for Cubesats, 2018

Magnetically Shielded Miniature Thruster



Source: http://wirzresearchgroup.com/research/plasma-space-propulsion/demonstration-and-characterization-of-a-low-power-magnetically, NASA/JPL

Transmission H_2O Reconassaince Instrument

Conclusions

Scientifically Compelling

Mars small spacecraft can accomplish decadal class science whilst being complementary to Flagship missions.

Low Cost

Mars small spacecraft can get to Mars for the cost of < $250 M which includes phases A to D and the launch vehicle.

Technically Feasible

Mars small spacecraft can transit to Mars from Earth GTO and fit within the EELV Secondary Payload Adapter (ESPA) mass and volume constraints.

Small affordable spacecraft missions from Earth GTO to Mars are possible and deliver Decadal-class science complementary to Flagship missions.