Omaha Trail to Lake Matthew

Lake Matthew Team / Celestia

Omaha Trail to Lake Matthew

- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- Tramway
- Omaha Trail Benefits
- MATT + Omaha Trail

Lake Matthew Team / Celestia

Omaha Trail to Lake Matthew

Rationale for the Omaha Trail

MATT: The Mars Terraformer Transfer

Omaha Crater: Cargo & Propellant

Deimos ISRU, Deimos Dock

Deimos Rail Launcher (DRL)

Mars Lift (ML)

Tramway

Omaha Trail Benefits

MATT + Omaha Trail

Lake Matthew Team / Celestia

Omaha Trail to Lake Matthew

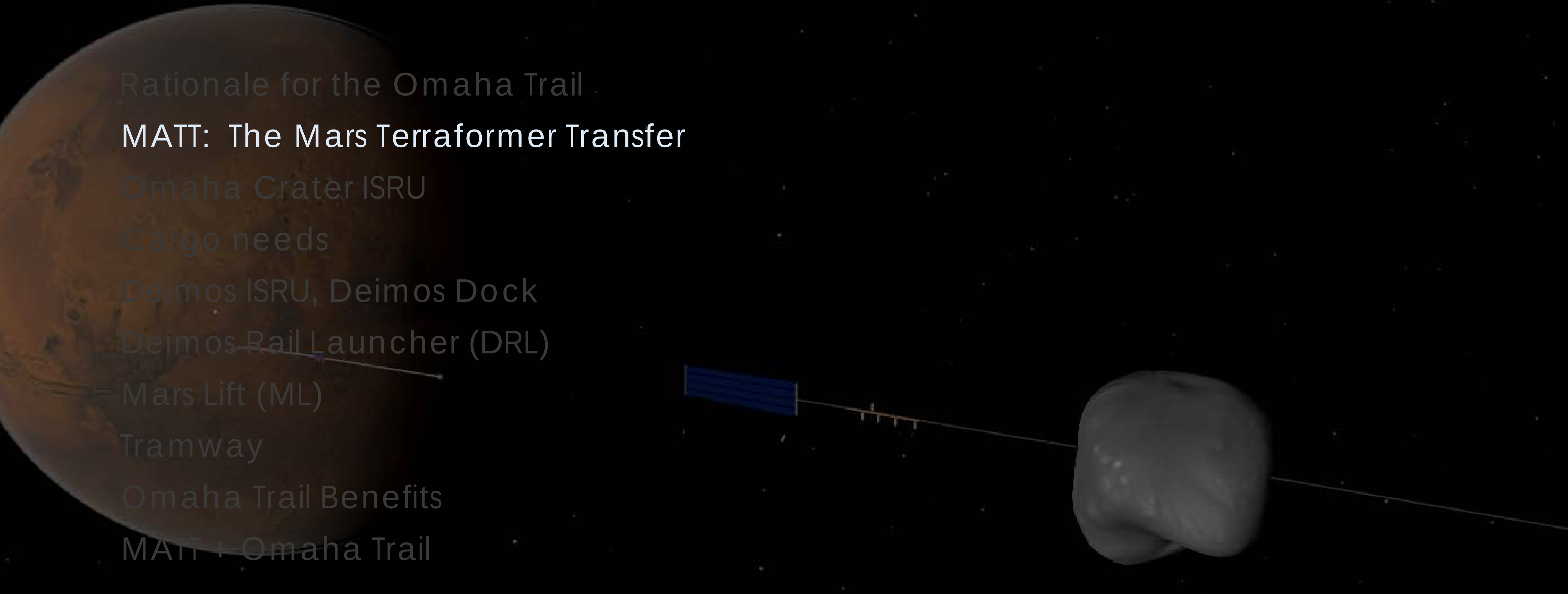
Objective for the Omaha Trail:

- High-efficiency transport infrastructure to Lake Matthew facilities at Omaha Crater

Rationale for the Omaha Trail:

- It would reduce the number of required Earth launches
- It would lower cargo transport cost
- An integrated system orchestrates and justifies R&D for each infrastructure component
- It would enable faster crew return with less cosmic radiation exposure

Omaha Trail to Lake Matthew



- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater ISRU
- Cargo needs
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- Tramway
- Omaha Trail Benefits
- MATT + Omaha Trail

Lake Matthew Team / Celestia

Terraformation

Benefits of Terraformation

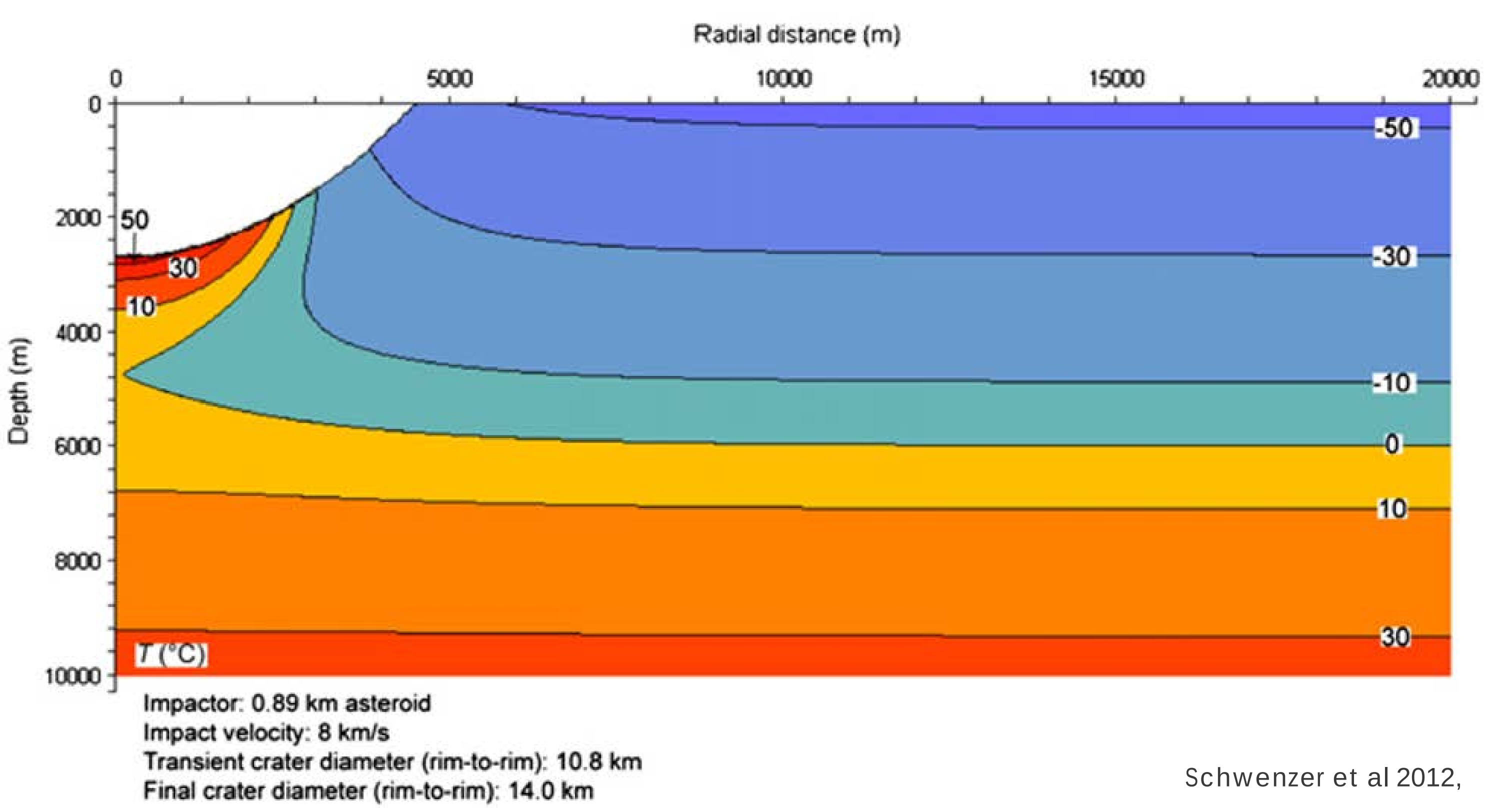
- Cuts mass, energy and labor needed
- Cuts R&D cost
- Enables scaled ISRU for self-sufficiency
- Follow-on benefit: Sole-source contracts for Mars facilities, provisions and rare metals

Practical Terraformation

- Impactor example:

  - Bedrock to +50 °C
  - Meltwater
  - Air pressure > 1 kPa
  - Lake formation possible

- This is the common, natural way to terraform a site on Mars



Schwenzer et al 2012,

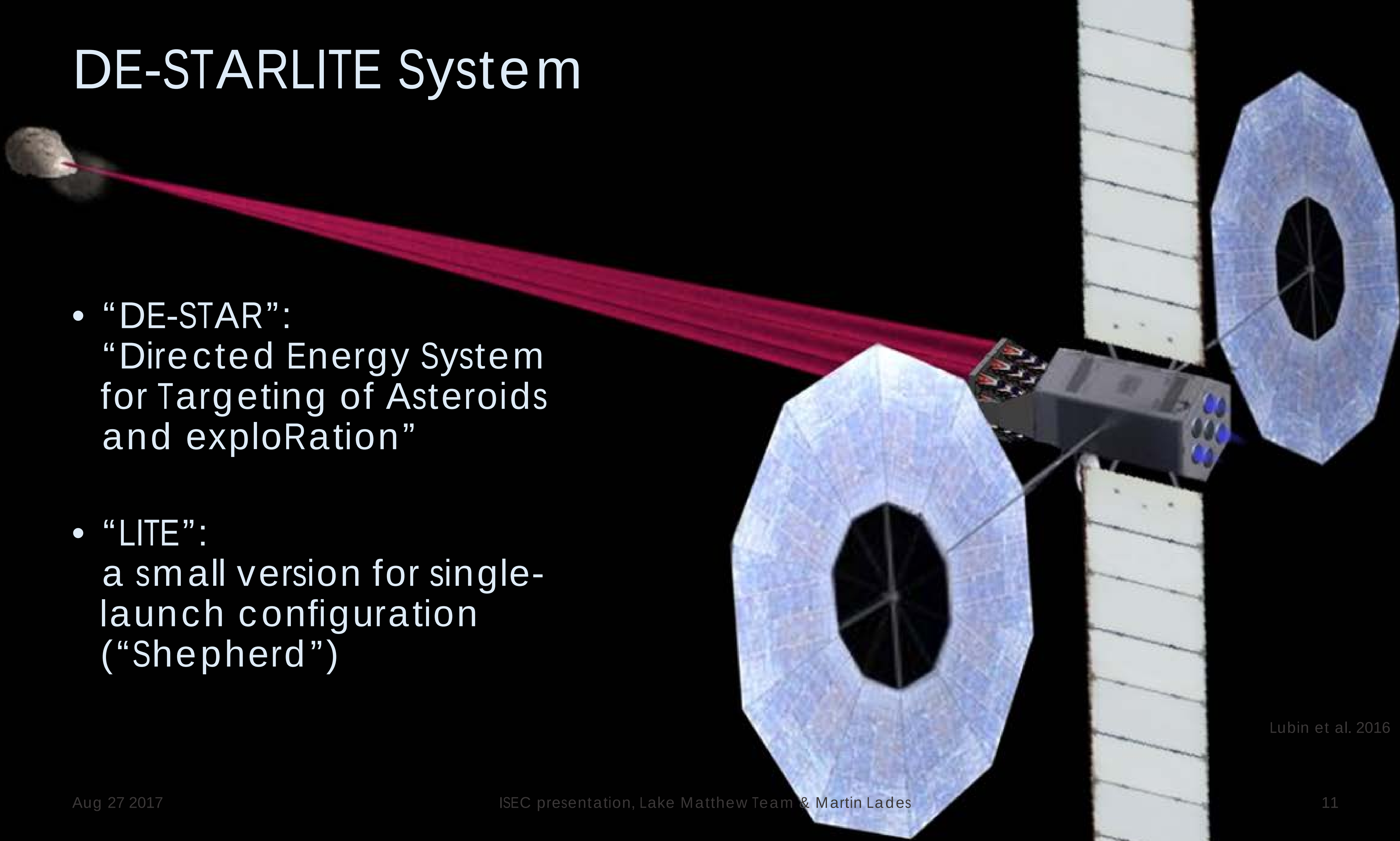
Practical Terraformation

MATT

- Mars Terraformer Transfer

LakeMatthew.com

DE-STARLITE System



- “DE-STAR”:
  “Directed Energy System for Targeting of Asteroids and exploRation”

- “LITE”:
  a small version for single-launch configuration (“Shepherd”)

Lubin et al. 2016

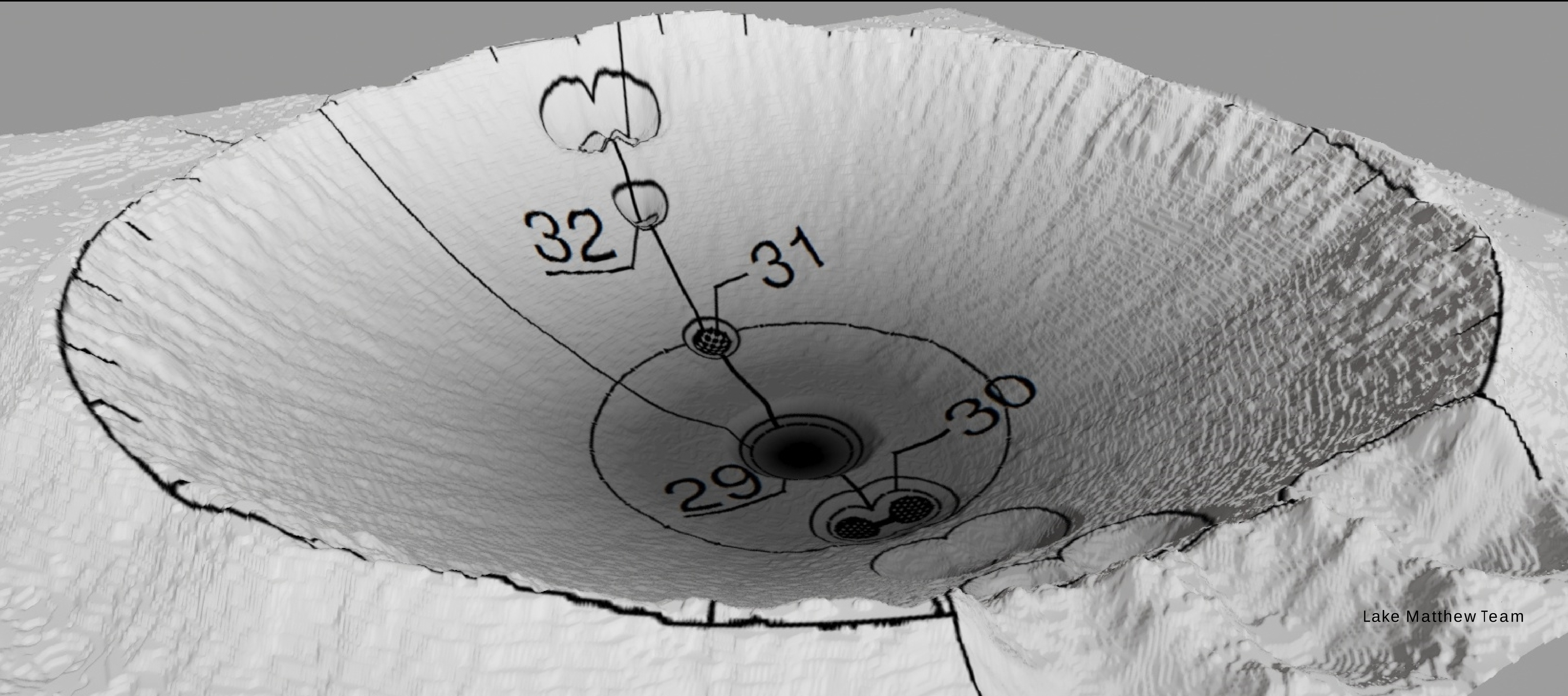
Flight Plan (NDA)

- Shepherd: COTS, single-launch payload
- Tracking and trajectory changes: <100 m at Mars
- The impact occurs in 2036
- Impact: 9 km crater, structured depressions, 9 km^2 heat lens, > 1 kPa, new lowest point on Mars
- Result: Lake Matthew

Omaha Crater – Designated Impact Site

- Ice abundant locally in near-surface
- Freshwater stable to 11 °C, for persistent Lake Matthew and other reservoirs

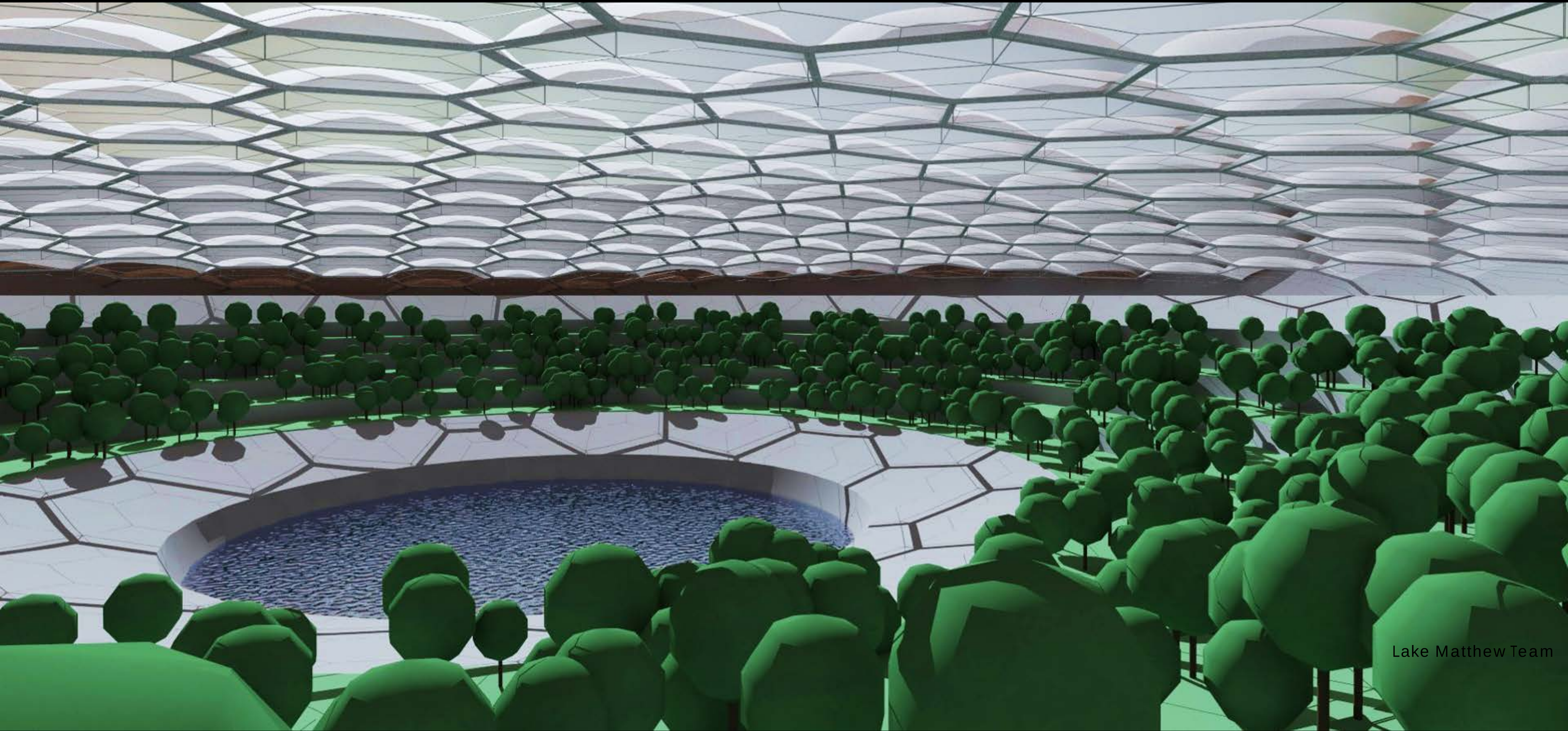
Omaha Crater



Lake Matthew Team

Jonathan S Blair/National Geographic/Getty Images

Habitat and Greenhouse Domes



Lake Matthew Team

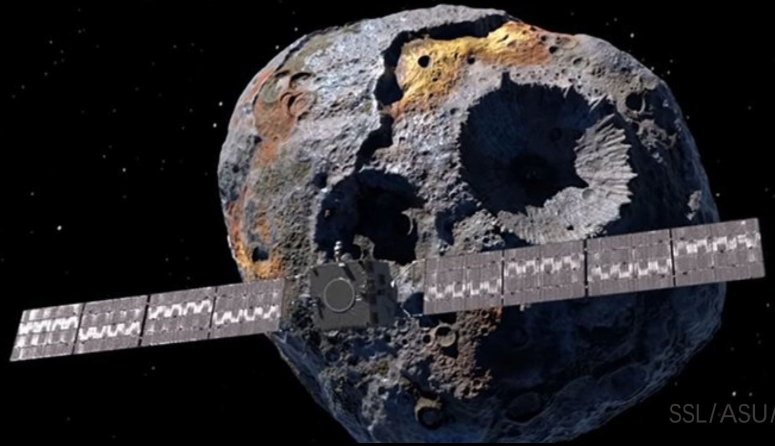
Mining

- Principal rare metals in Type IVA meteorite, at scale of 16 Psyche:

Element	Concentration (ppm) by mass	Value at current pricing ($)
Platinum	6.2	$ 2,093,000,000,000,000,000
Palladium	4.0	$ 1,268,000,000,000,000,000
Rhodium	2.8	$ 1,038,000,000,000,000,000
Gold	1.6	$ 698,000,000,000,000,000

Davis 2005, D'Orazio & Folco 2003, Hoashi et al. 1993, Shen et al., 1996

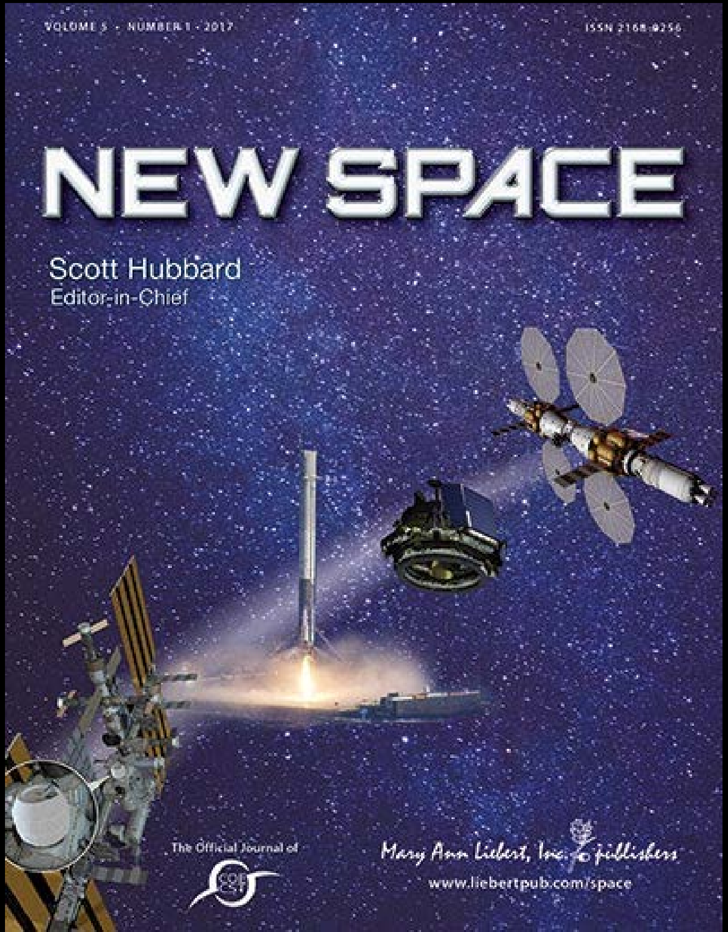

NASA/JPL-Caltech/MSSS


SSL/ASU/P. Rubin/NASA/JPL-Caltech

Mining

Article in press:

"A Station at the End of Musk's Railroad"



Element	Concentration (ppm) by mass	Value at current pricing ($)
Platinum	6.2	$ 2,093,000,000,000,000,000
Palladium	4.0	$ 1,268,000,000,000,000,000
Rhodium	2.8	$ 1,038,000,000,000,000,000
Gold	1.6	$ 698,000,000,000,000,000

MATT In Context

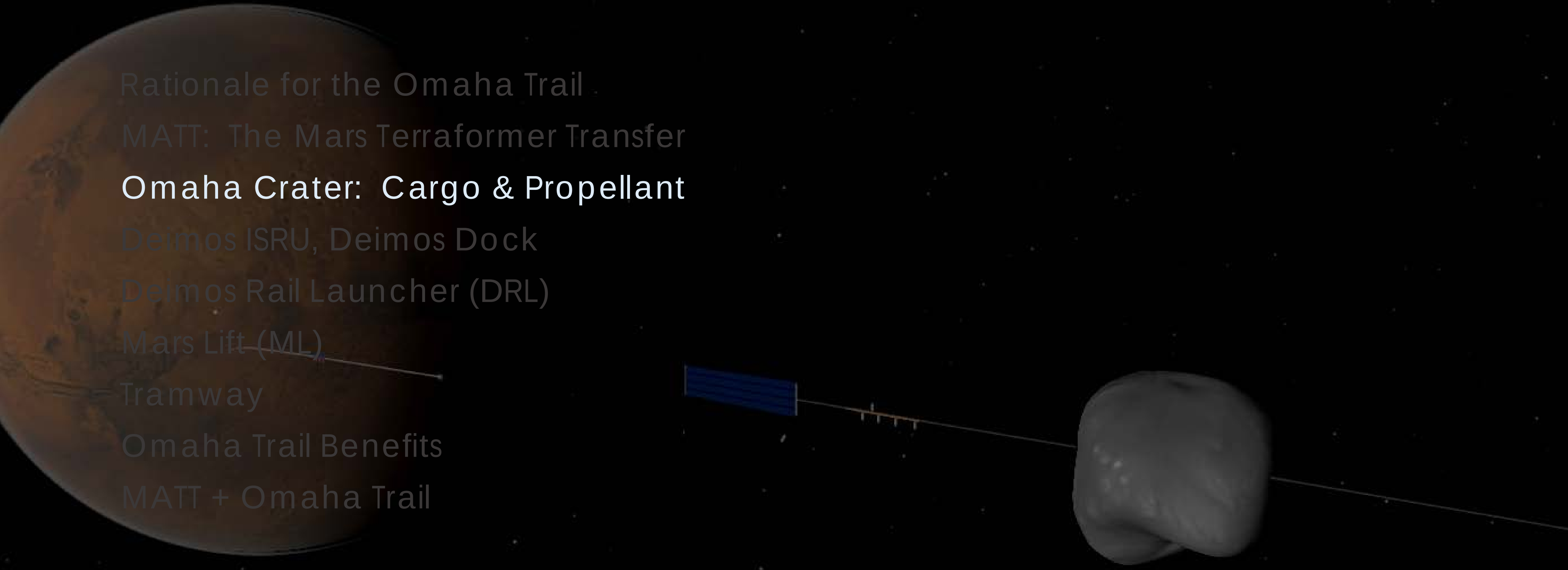
From Omaha Crater to the Omaha Trail:

- At Omaha Crater, Mars’ paucity of natural resources and severity of environment no longer constrain settlement growth, from 2036
- Transport efficiency becomes the constraint
- Hence the Omaha Trail


Ludovic
Celle

Omaha Trail to Lake Matthew

- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- Tramway
- Omaha Trail Benefits
- MATT + Omaha Trail



Lake Matthew Team / Celestia

Omaha Crater ISRU

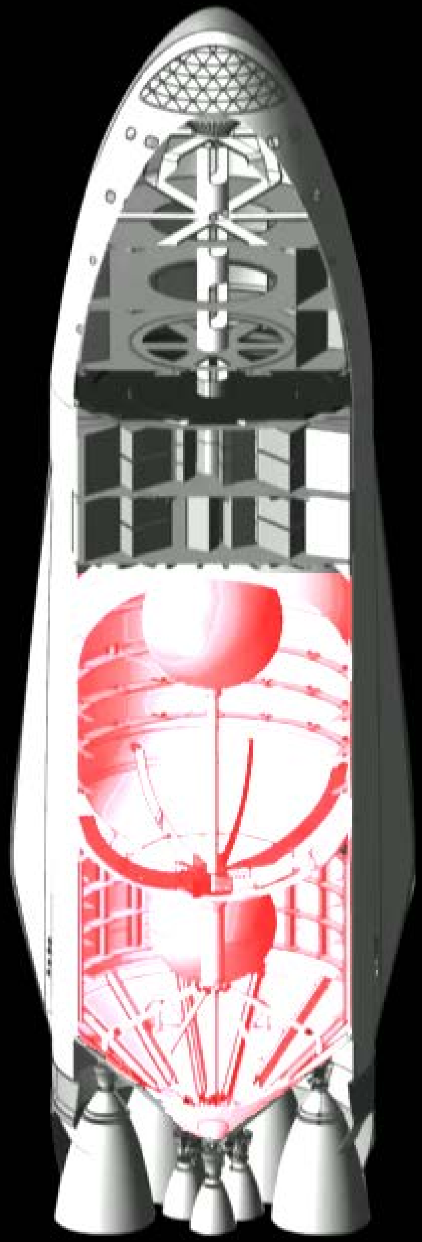
- Self-sufficiency in:
  - Breathing and propellant gases
  - Treated water and brine
  - Bulk fertilizer, hydroponic sand
  - Staple foods
  - Most construction materials

- Hence ~90% cut in cargo

Omaha Crater Cargo

- Cargo required for:
  - Construction titanium powder, ETFE foil
  - Complex tools and parts
  - Industrial gases, reactants, catalysts
  - Medical supplies
  - Novelty foods

- Most mass of cargo ships devoted to:
  - Propellant
    - 1950 tons propellant
    - 450 tons cargo
    - 150 tons dry mass



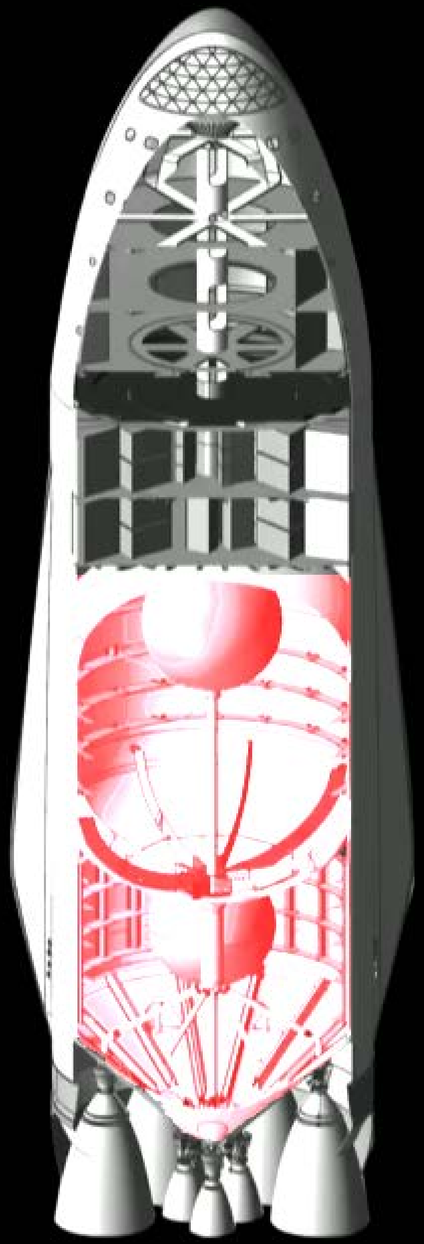
SpaceX

Omaha Crater Propellant

- Total propellant per cargo flight: 87,000 tons

- Cargo with Mars surface propellant: 300 tons
- Cargo with LMO propellant: 450 tons

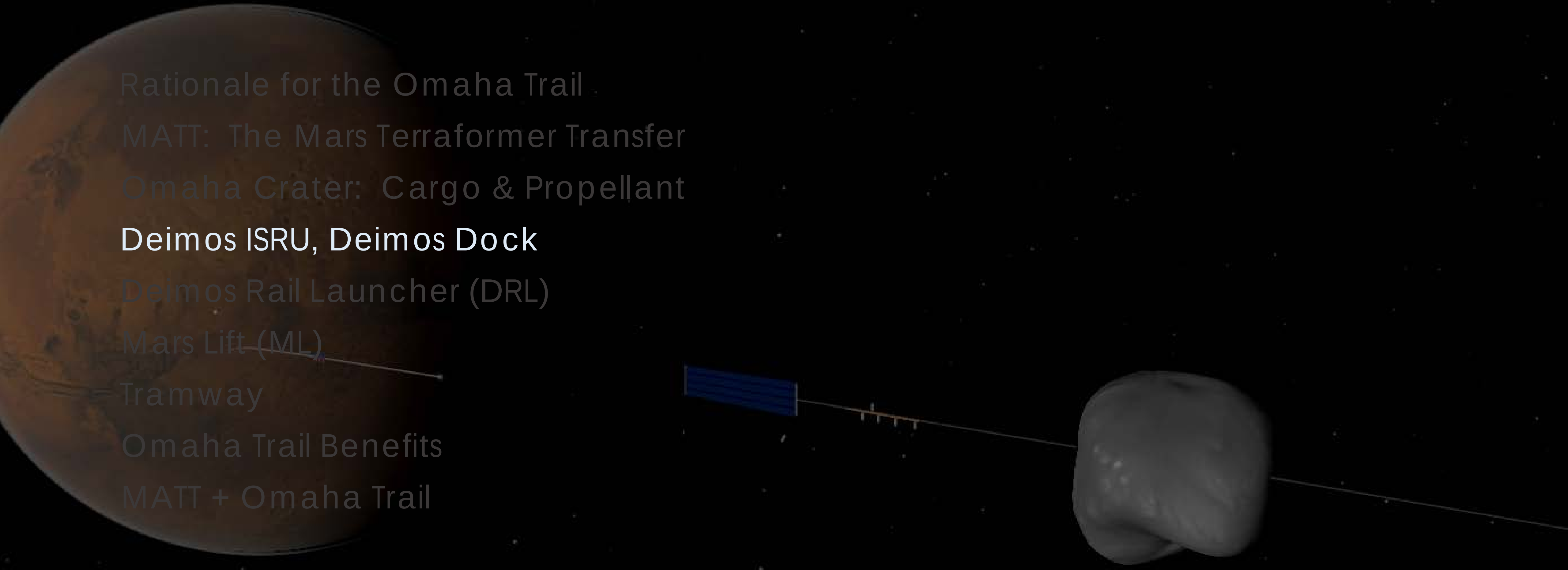
- Incentive to tank up in Mars orbit
- Incentive to perform ISRU in Mars orbit



SpaceX

Omaha Trail to Lake Matthew

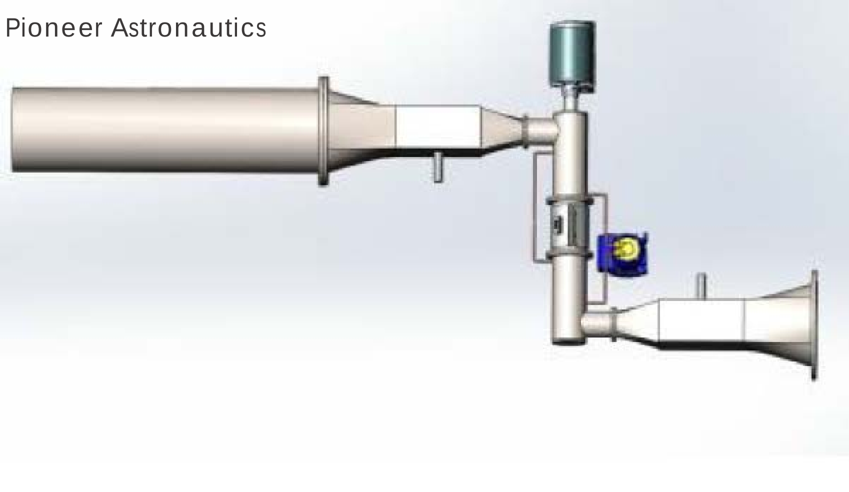
- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- Tramway
- Omaha Trail Benefits
- MATT + Omaha Trail



Lake Matthew Team / Celestia

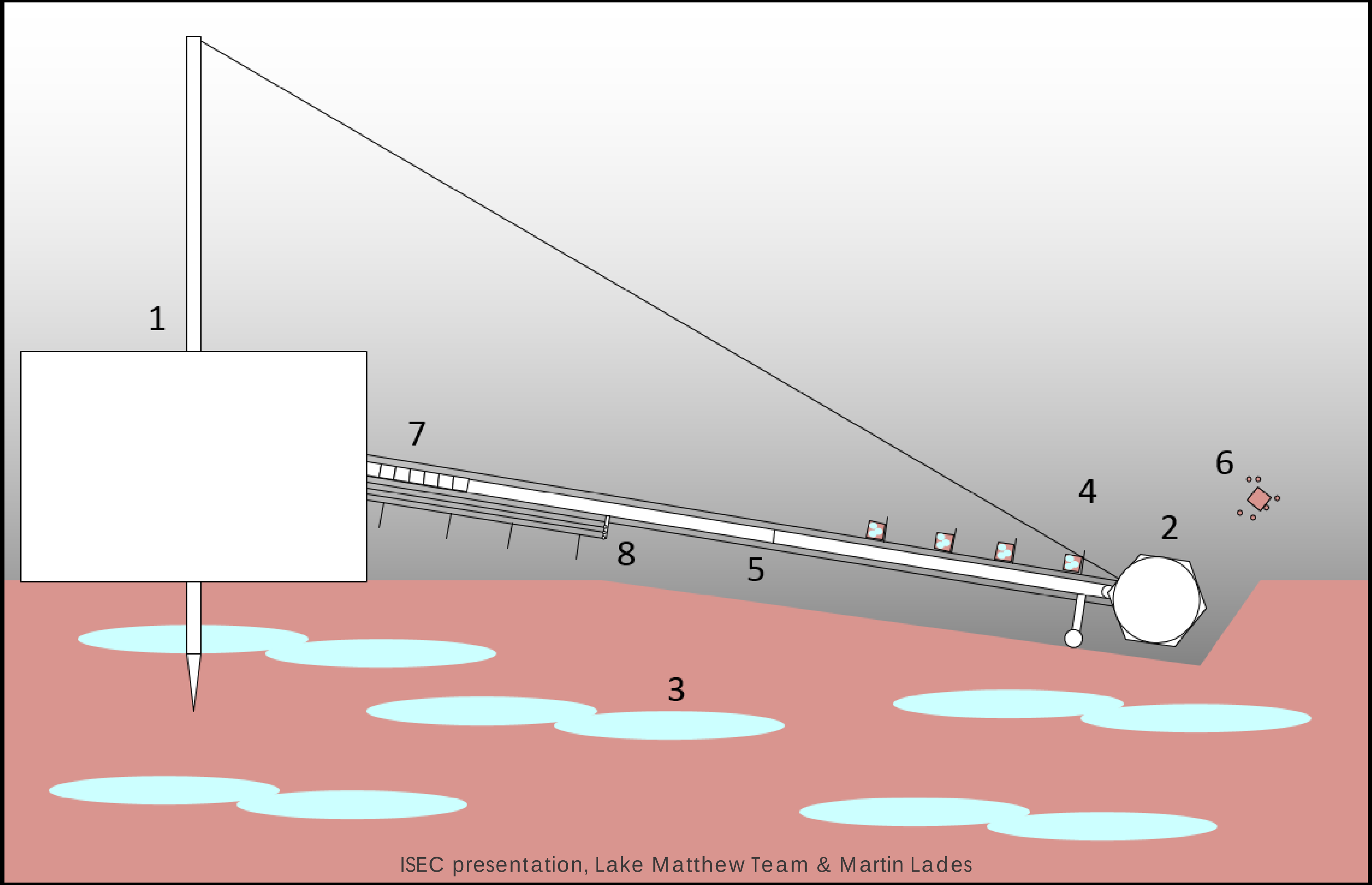
Deimos ISRU

- Deimos density: 1.5 g/cm^3 (Murchie et al. 2013)
- ~50 wt% volatiles, within 20-60 m of polar surface (Fanale and Salvail 1990)
- Products: oxygen, methane, treated water
- Methods: CAVoR, alternate coal gasification reactions (Nichols 1993)



Carbonaceous Asteroid Volatile Recovery (CAVoR) system, Phase I

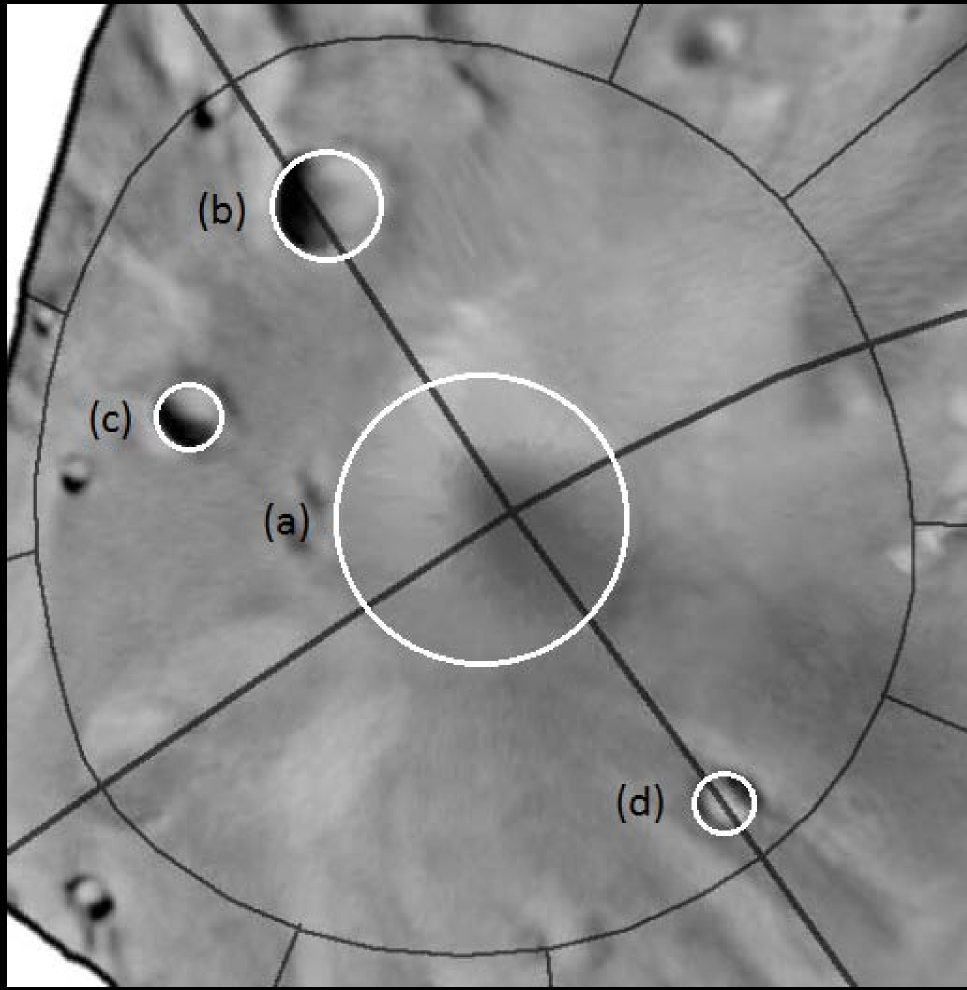
Deimos ISRU



Lake Matthew Team

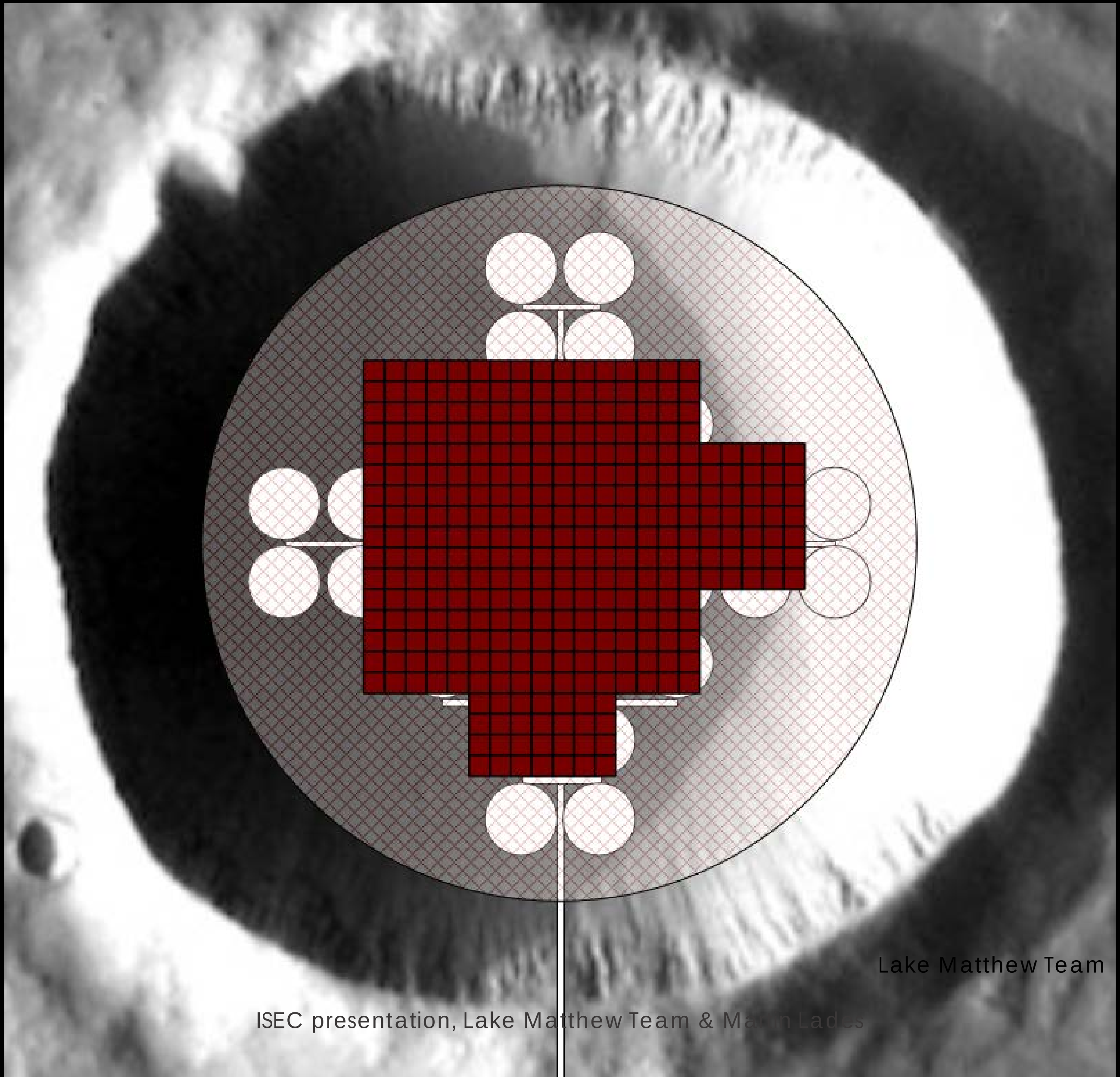
Deimos ISRU

- (a) hypothetical South Pole volatile mining site, 1 km diameter crater / depression
- (b) and (c) summer-shaded craters, best for cryogenic storage
- (d) sunlit crater, best for water storage

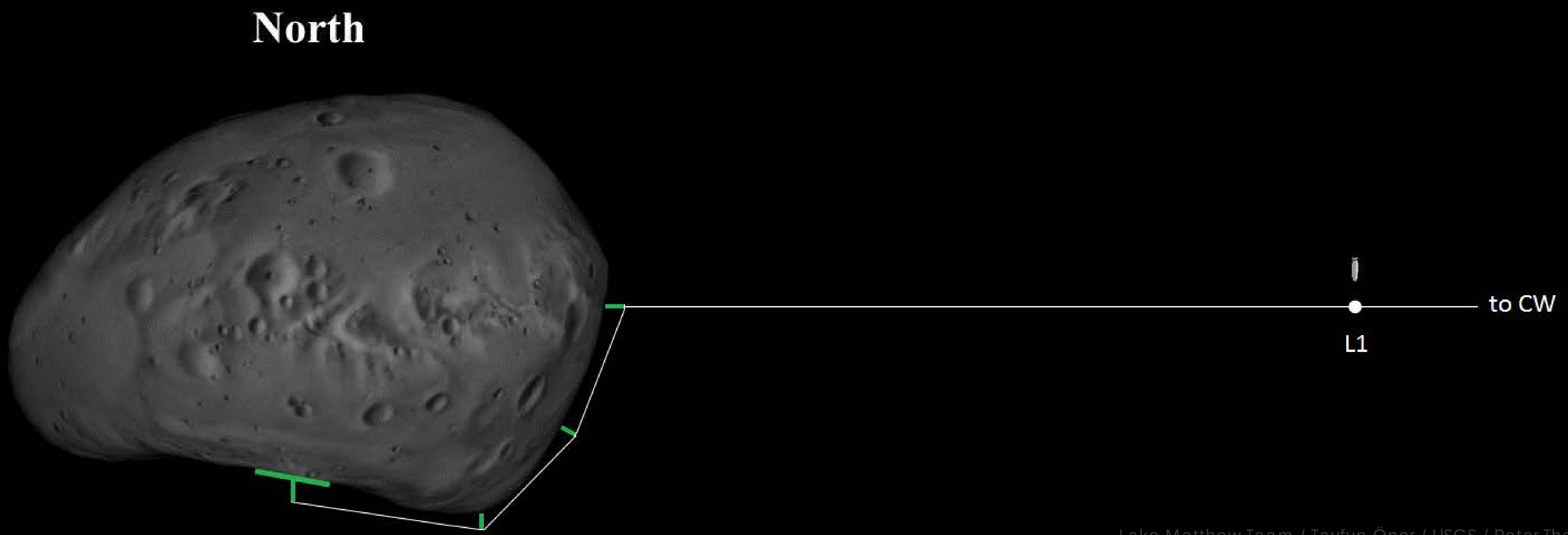


Chuck Clark

Deimos ISRU

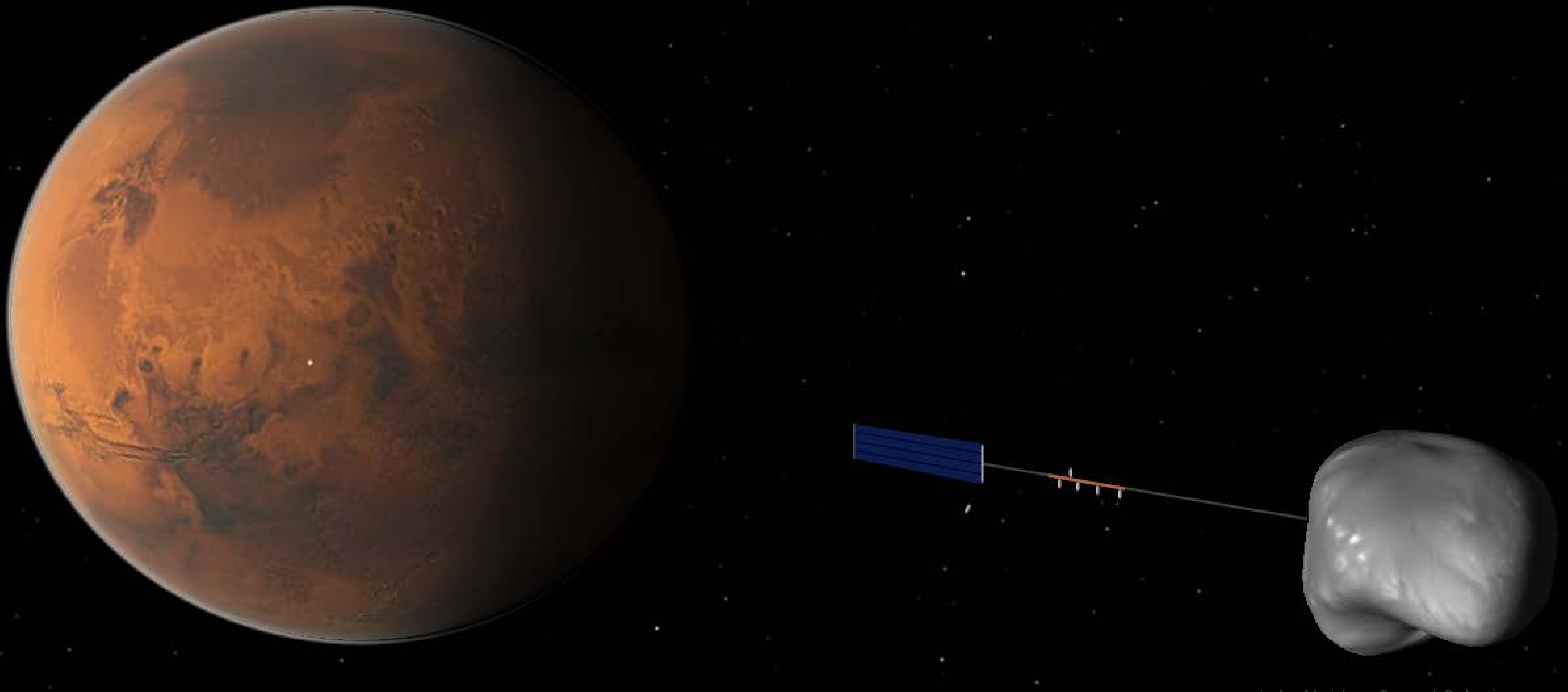


Deimos Dock



Lake Matthew Team / Tayfun Öner / USGS / Peter Thomas

Deimos Dock



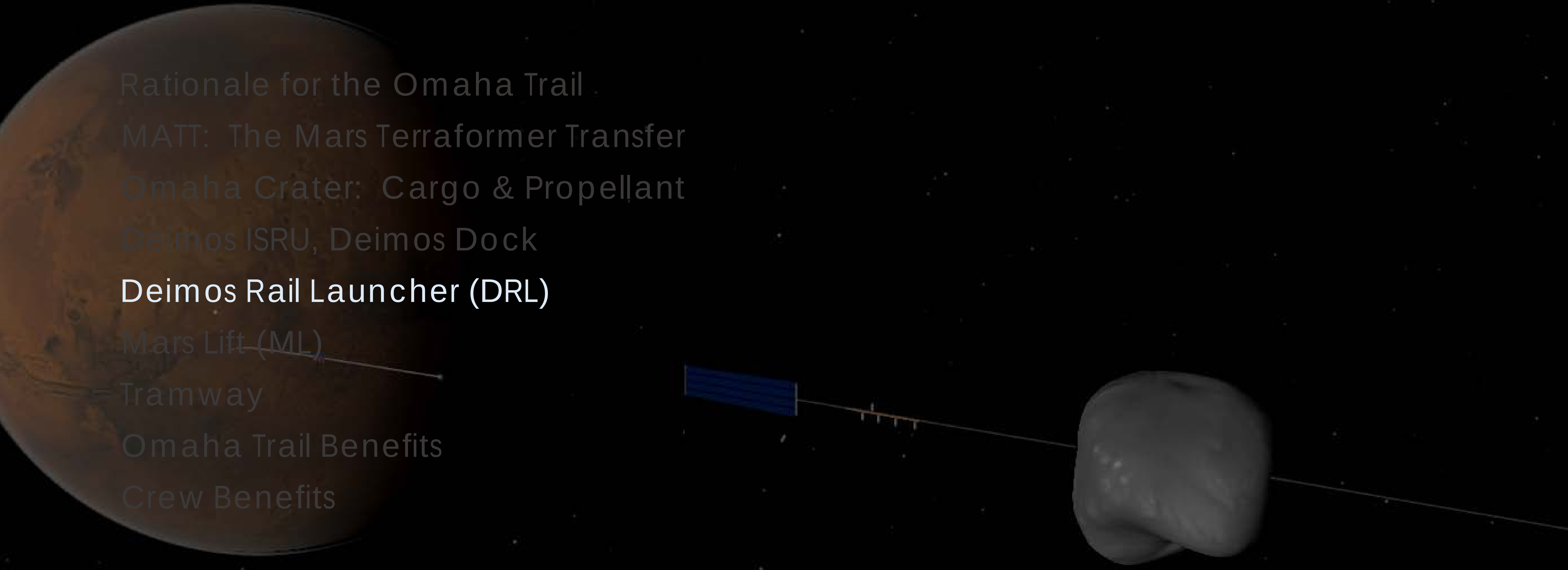
Lake Matthew Team / Celestia

Deimos Dock

- Value:
  - Propellant is produced at 4x Mars surface rate, due to 4x cumulative PV
  - Maximized delta-v, with Deimos-Mars round-trip fueling at Deimos Dock
  - 100% of Omaha Crater power is freed for use on Mars
  - Deimos hot mining waste is efficiently converted to shields and counterweights
  - Deimos is a proving ground for tech used elsewhere on the Omaha Trail
  - Deimos provides a vacuum platform, recoil mass, and ISRU products useful for a Deimos Rail Launcher (DRL)

Omaha Trail

- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- Tramway
- Omaha Trail Benefits
- Crew Benefits



Lake Matthew Team / Celestia

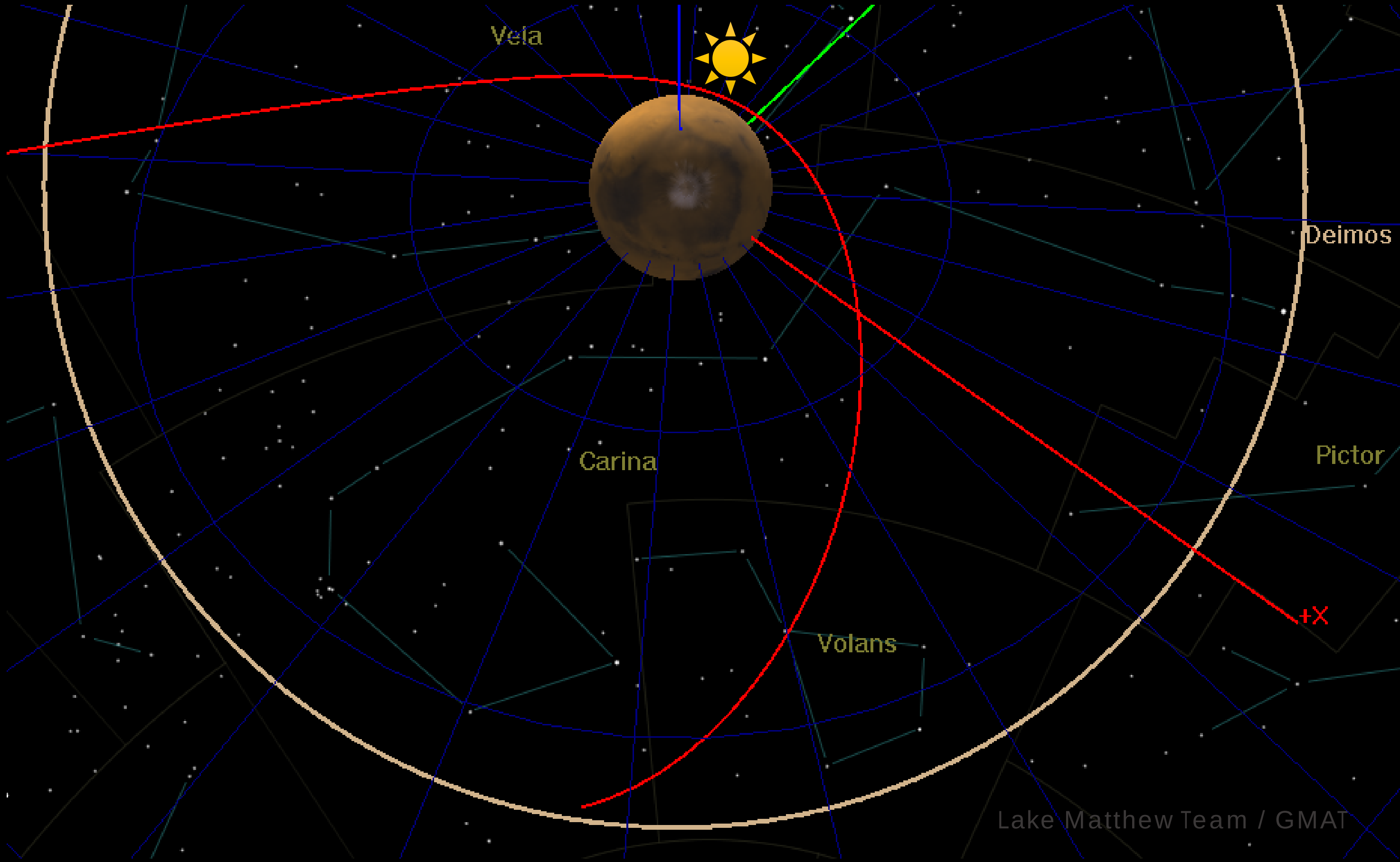
Deimos Rail Launcher (DRL)

- Assisted launch of spacecraft from Deimos, in the spirit of a catapult launcher on an aircraft carrier

U.S. Navy

Deimos Rail Launcher (DRL)

- Value:
  - 1 km/s propellant-free delta-v
  - DRL is the most efficient conversion of Deimos PV into delta-v
  - Launch to Mars EDL or to Earth return insertion, with decision point at Mars periapsis (☀)



Deimos Rail Launcher (DRL)

- Helical coil electromagnetic launcher: DRL considerations:
  - Highest efficiency of a rail launcher: >80% with LOX superconducting coils
  - Runs off HVDC power at high voltage for low losses
  - Bidirectional armature for acceleration and deceleration
  - Potentially adaptable to lightweight tether frame tensioned with counterweight and power line repulsion

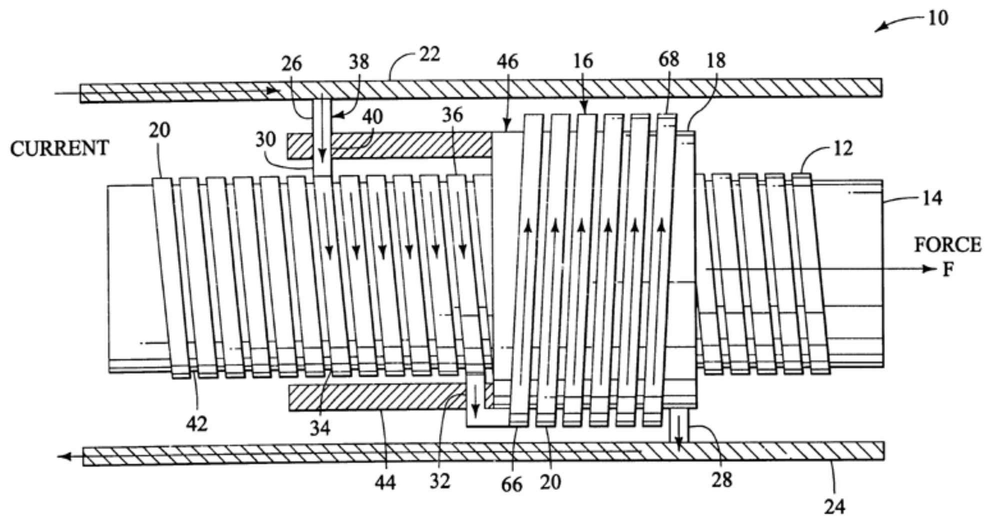
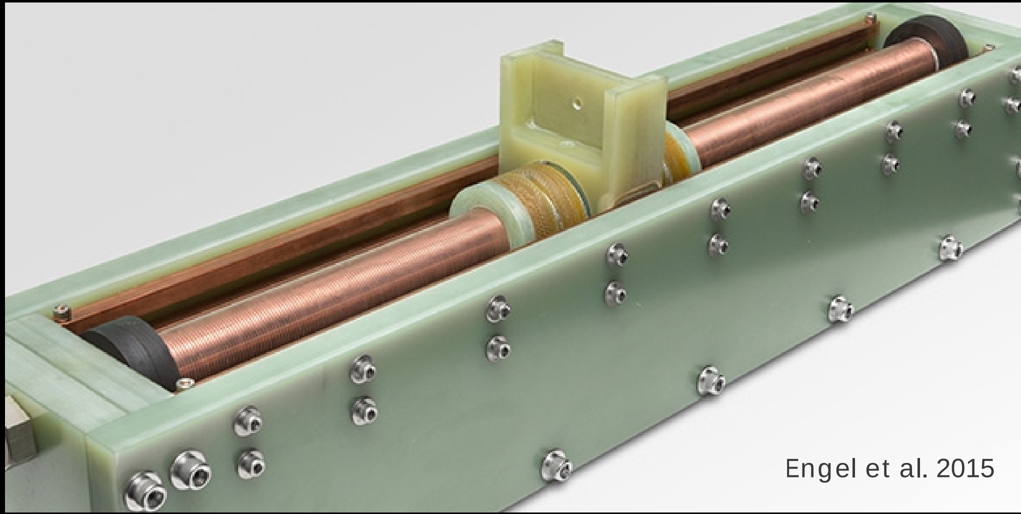


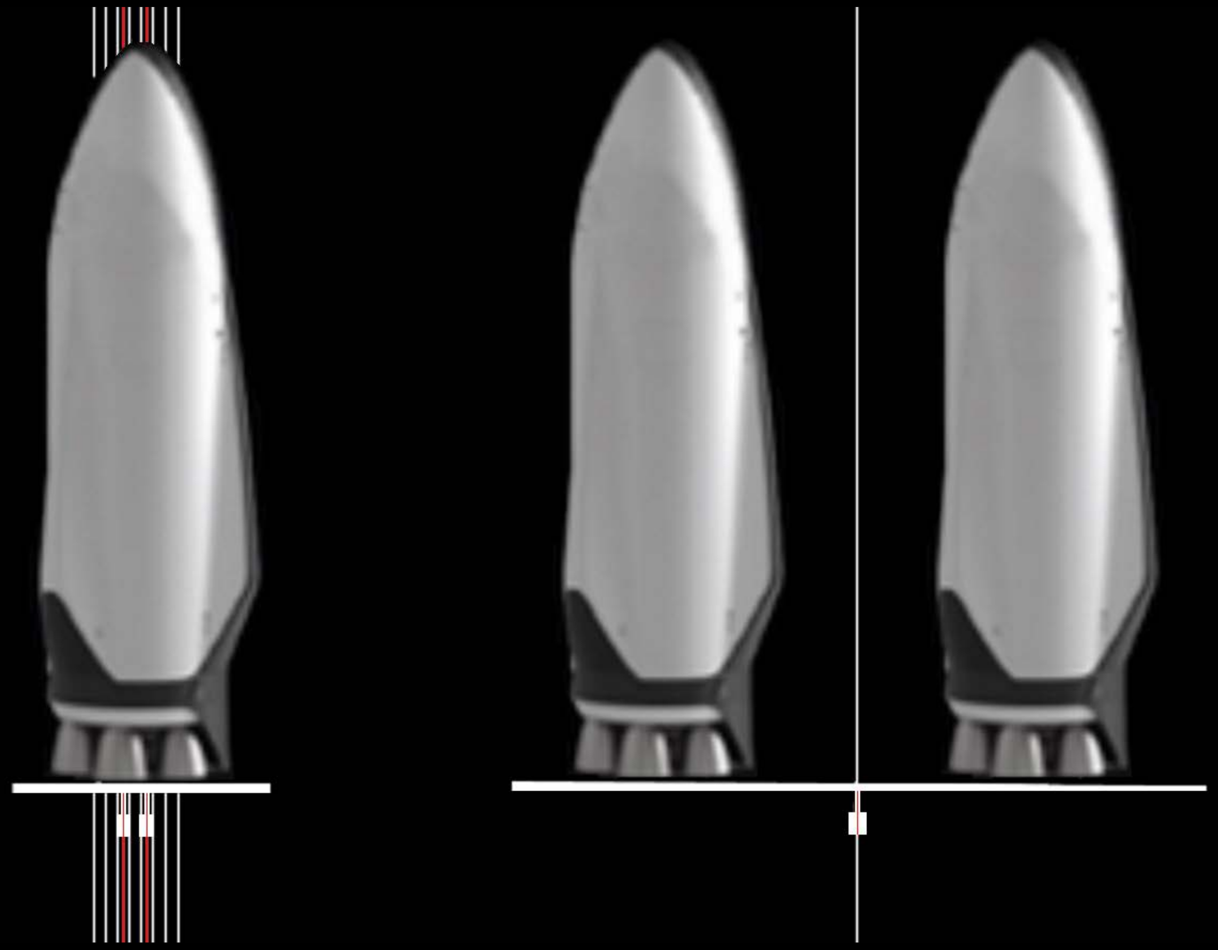
FIG. 1
PRIOR ART

Engel 2004


Engel et al. 2015

Deimos Rail Launcher (DRL)

- Possibility of platform without wheels, mounted e.g. with repulsive Lorentz tubes
- Superconducting operation: armature with LOX dewar, and stator with LOX fill
- Gentle acceleration: e.g., 0.5 m/s^2 over 1000 km rollout
- Conservation of angular momentum clears Deimos

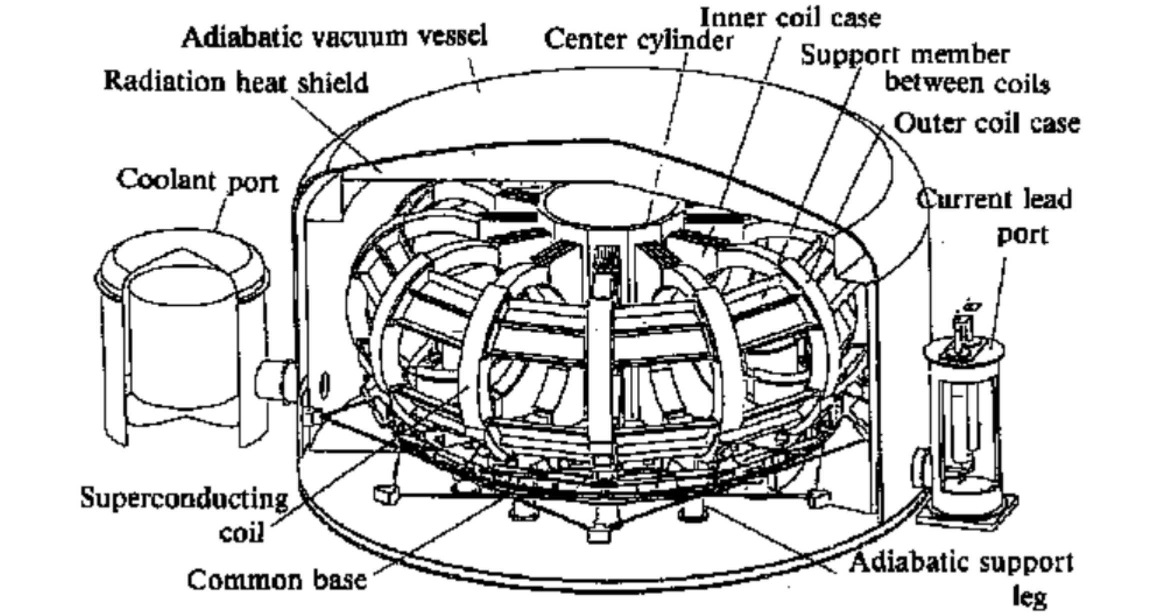


Lake Matthew Team

Deimos Rail Launcher (DRL)

- Power:
  - 300 MW HVDC supplies ~600 gigajoules of energy during launch.
  - With 80% DRL efficiency, need an extra 2.8 terajoules
  - Superconducting magnetic energy storage (SMES) can supply
  - SMES can be low-mass on Deimos: vacuum operation at cryogenic LOX plant

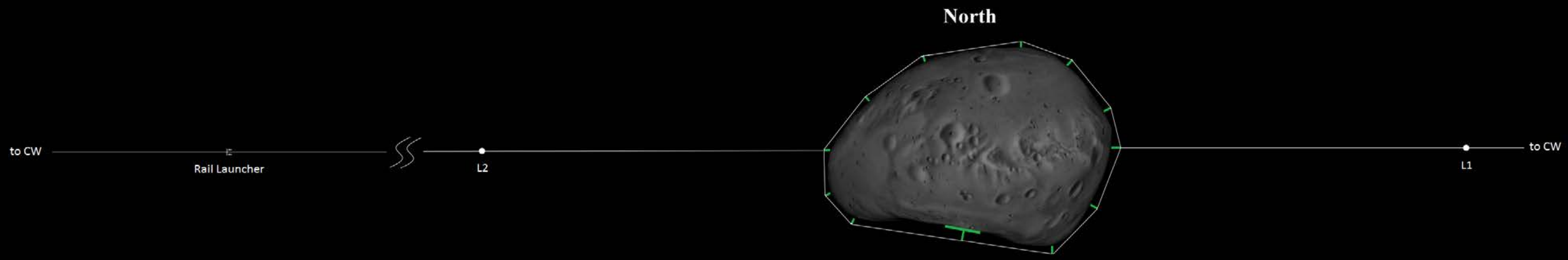

Toshiba / Chubu Electric



Toshiba / Chubu Electric

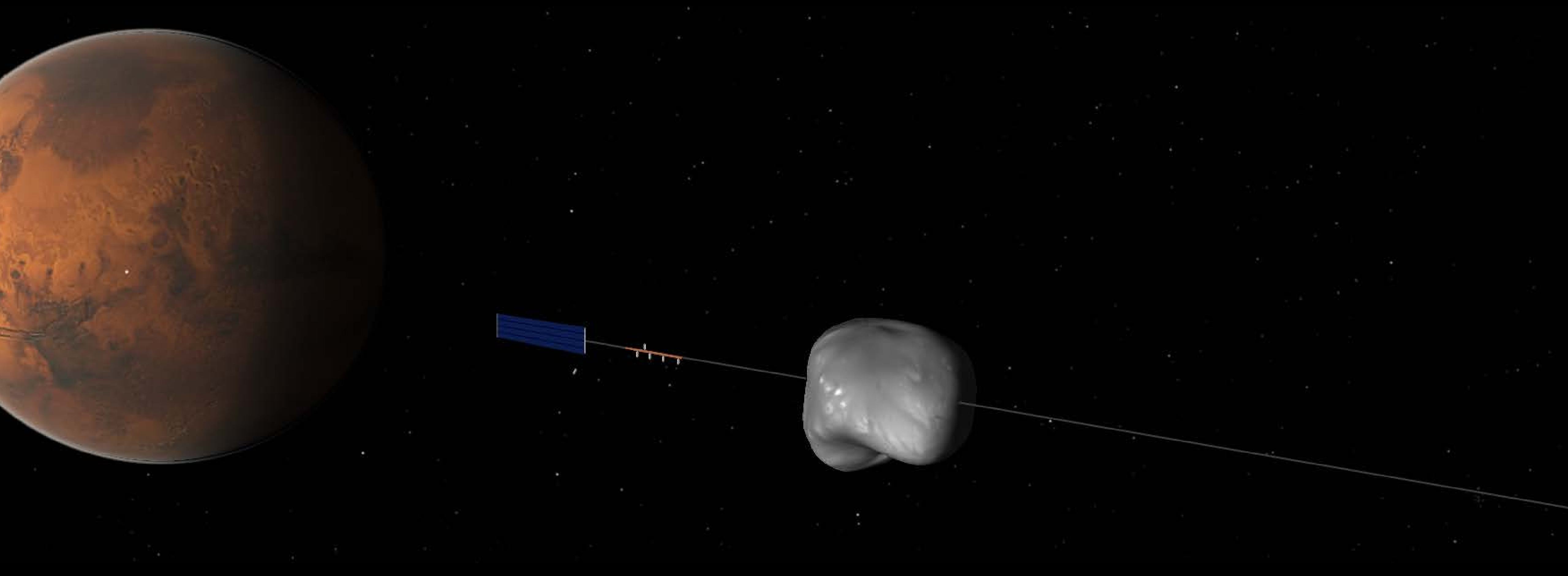
Fig. 2.5. Conceptual design of the ISTEC superconducting coil for the 100 kWh small-scale SMES.

Deimos Rail Launcher (DRL)



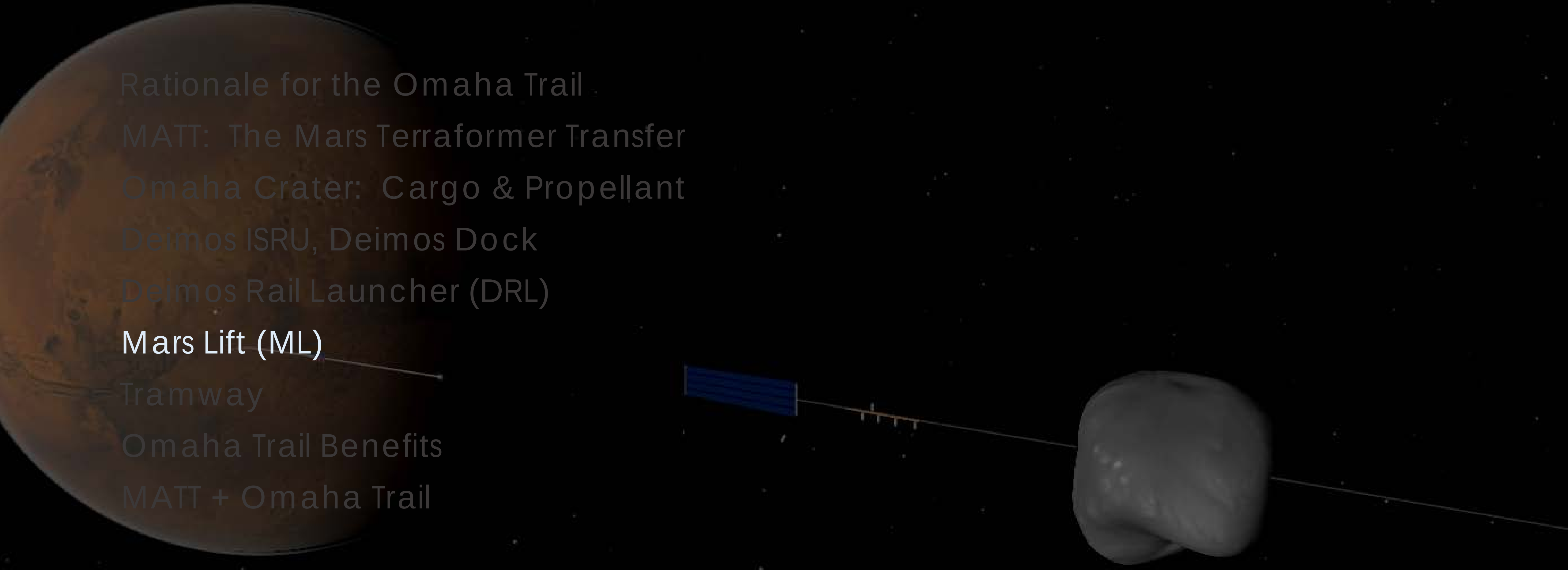
Lake Matthew Team / Tayfun Öner / USGS / Peter Thomas

Deimos Rail Launcher (DRL)



Lake Matthew Team / Celestia

Omaha Trail to Lake Matthew



Lake Matthew Team / Celestia

- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- **Mars Lift (ML)**
- Tramway
- Omaha Trail Benefits
- MATT + Omaha Trail

Mars Lift
for Omaha Trail to Lake Matthew

M. Lades, part of combined presentation with MATT/Lake Matthew Team

Mars Lift

- **Value:**
  - **Space Elevators follow the Railway Paradigm:**
    - Invest in infrastructure, reap benefits from it.
  - **Case for a Mars Space Elevator**
    - Save a drastic percentage of propellant compared to landing rockets on the planet and taking off again for faster buildup of Mars infrastructure.
    - Lighter demands than Earth due to the Mars-Moons System promising a lighter feasibility condition.
  - **Mars Lift**
    - Reduced requirements for an architecture as close as possible to implementation.
    - Branding distinction from Earth Space Elevator.

Boundary Conditions for Mars Lift

Plus

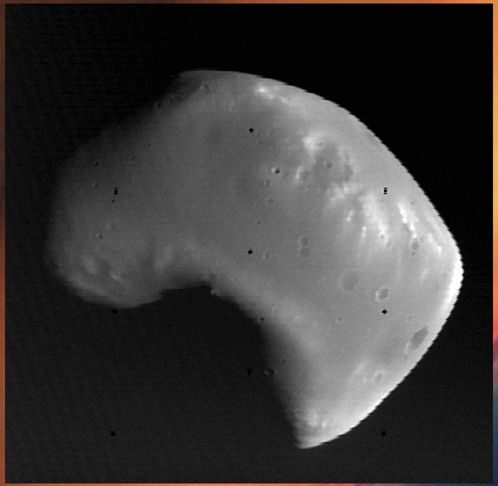
1. Lower gravity of Mars (~ 1/3 Earth) and similar rotation speed (ω) => **better for elevators than Earth**
2. Moons, with elevators

Minus

1. Moons, to avoid
2. Dust storms up to 80 km altitude ⇔ Not even the highest peaks avoid them, (Clancy, 2008)
3. Static electricity in the Martian atmosphere ⇔ ~2 orders of magnitude higher conductivity than Earth. More frequent discharges (lightning) (Simoes et al. 2008)
4. Remote environment ⇔ Everything has to be brought in at first. In situ resource utilization (ISRU) is imperative for the whole Mars Lift concept.

and the Elevator Feasibility Condition

Moons

	Phobos	Deimos
		

- Mars radius: 3396 km
- km from Mars center (above surface)

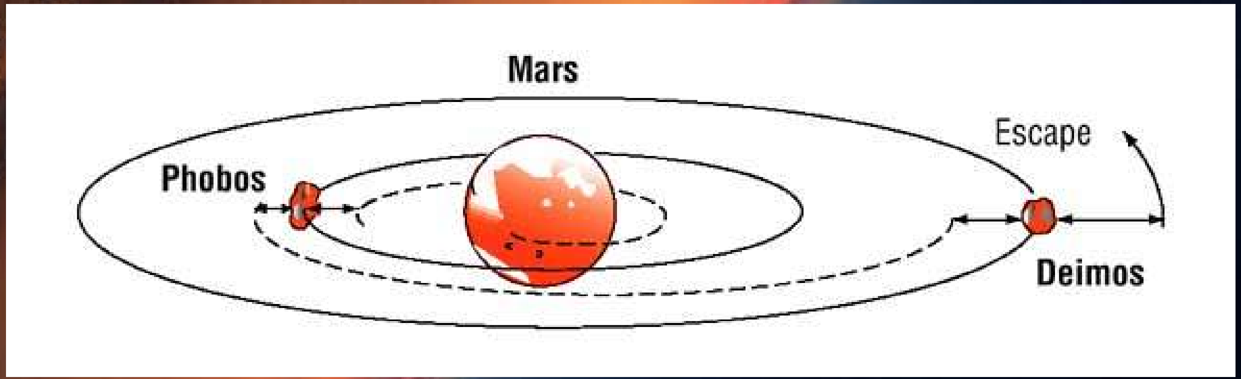
	Phobos	Deimos
km from Mars center (above surface)	9380 (5840)	23436 (~20100)
Orbit period:	27600 s	109000 s
(Mars days)	0.319	1.262
Projected speed over ground:	1920 km/h	162 km/h (retrograde)
Mass:	$1.072\ 10^{16}$ kg	$1.5\ 10^{15}$ kg
Radius:	11.1 km	6.2 km

- Areostationary Orbit, km from Mars center (above surface):
  20427 (17031)

Options for Mars Lift

1. Use the Moons

- Phobos Tethers
  - Drop Tether of ~5740 km to avoid Mars atmosphere
  - Phobos Elevators L1, L2
- Deimos Tethers
  - Deimos Elevators, L1, L2



(Penzo, P. , July 1984)

2. Avoid the Moons

Off-Equator Mars Lift to avoid the moons

1. Use mountains (Olympus Mons, etc.) to avoid dust
2. Do not use mountains

Conclusions: Elevators for Mars Lift

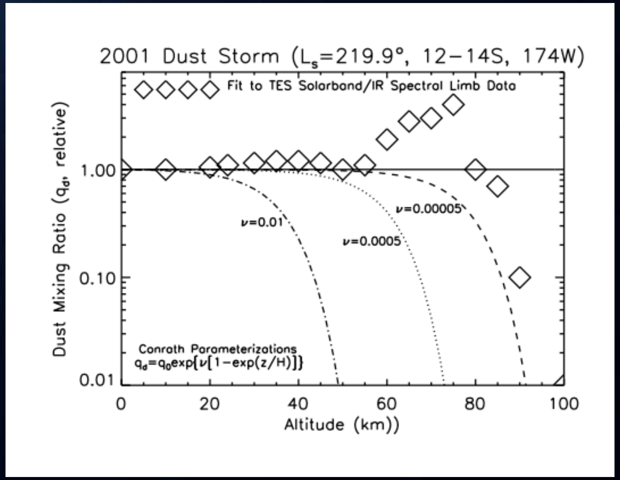
- **Phobos Drop Tether**
  - + Avoids dust storms and electrostatic charge of the Mars atmosphere
  - + Is the shortest possible tether of only ~6000 km
  - 100 km vertical remain to be bridged
  - Terminal velocity in Mars atmosphere is ~1000 km/h
  - Even taking the lateral 1920 km/h of Phobos out with some other constructs, the vertical fall is hard to brake
  - Braking a 100 km fall
    - Mars atmosphere: ~600 Pa, 0.6% of Earth. There will be no hypersonic aerodynamic Mars cargo planes!
    - Adding a parachute to every container or similar seems impractical
    - Rockets burn propellant, which we are trying to avoid. ~3 mt per 10 mt cargo container, prohibitive
    - Infrastructure to brake the containers from the ground would be huge and therefore appears also prohibitive

  ⇒ **Mars atmosphere is just dense enough to be annoying but not useful**

  ⇒ **Drop tether economics appears undesirable**

- **Ground Tether**, **has to be**
  - robust against dust or requires a cleaning mechanism
  - protected against electric discharge
  - clear of the moons, therefore needs to be deployed off the equator
  - almost ~20000 km long (or longer, clearing Deimos)

⇒ **Conclusion: Ground Tether further Investigated**



Mars Lift, Feasibility Condition

Version 2.0/Mars of the feasibility condition (work in progress):

1. The usual leaky integrator equation for the constructed/decaying tether that needs to be regularly serviced to remain in operation.
2. Moves from sums to factors where possible, stronger optimization criterion.
3. Includes a Geometry Condition: Irrespective of tether strength, a minimal tether size/surface area needs to be provided for climbers/rappellers to operate.
4. No Capstaning (wrapping around the wheels) for vehicles on Space Elevators
5. For Mars Lift, the direction is down and no climber motors or (almost no) power sources are necessary. Service/material comes from Deimos.

Candidate Anchor Site 1, Elevator Peak

- Elevator Peak
  - ~ 6200 m Elevation
  - 18 S, 59.5 W

Candidate Anchor Site 2, Pinnacle Station

- Morava Valles
  - ~ -2000 m
  - 12.65 S, 23.6 W

Mars Lift, Tether Strength and Taper

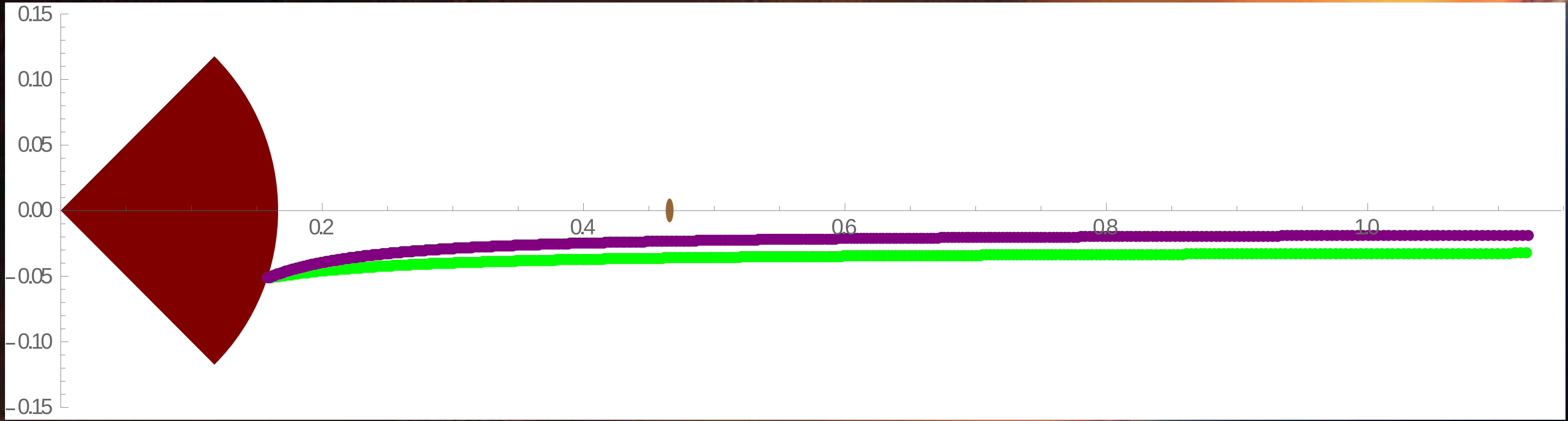
- Specific Strength in MYuri is the relevant variable for Space Elevators
  - MYuri is a derived unit equal to N/tex (with tex = g/km) and GPa/(g/cm^3) or 10^6 Nm/kg = 10^6 m^2/s^2
  - We assume a specific mass of CNTs of ρ=1.5 g/cm^3 (values 1.3 – 2 are common)
  - Investigated are typically two tether strengths σ0 of:
    - 10 GPa => 6.6 MYuri
    - 20 GPa => 13.3 MYuri
  - Potential composed of gravitational pull, dependent on the distance from the center of gravity, and centrifugal force, dependent on distance from the rotation axis $V = -V0\left(\frac{r_s}{r} + \frac{1}{2}\frac{r_\perp^2}{r_s^2}\right)$ with $V0_{Mars} \approx 2.097$ km^2/s^2
  - and the relationship between tether cross section on the ground and the maximum at the aerostatic orbit is: $\frac{T}{T0} = \frac{A}{A0} = e^{\frac{\rho}{\sigma 0}\Delta V}$
- Taper factors
  - 10 GPa tether: 4.15 (just tether, no loads)
  - 20 GPa tether: 2.03 (just tether, no loads)

with A0 = 50 mm^2 **(10x safety factor for 20 GPa) =>**
bracket for Tether Mass: ~1700 mt

Mars Lift, Curvature, Elevator Peak

$$\frac{d^2 \vec{r}}{d \tilde{s}^2} = -\alpha \left(\vec{g} \left(\vec{r} \right) \right)_{\perp}$$

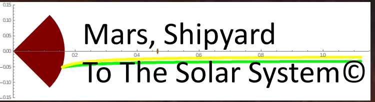
- The curvature follows the tether shape equation
- Curvatures for 10 GPa and 20 GPa tethers anchored at18° latitude for Elevator Peak:



- Clearance of moving Phobos orbit requires at least 185 km from the equator at Phobos orbit (brown ellipse) (1.12° latitude, Jacobson/Lainey, 2014)
- Presented are first approximative results. Shape will slighly change. Units of plot are in fraction of areosynchronous Orbit Radius (compare Gassend, 2004)
- Tether angles off the vertical ~28° (20 GPa) and ~40.7° (10 GPa)
- Payload goes with the Cos of tether angle!

Mars Lift, Curvature, Pinnacle Station

- Lower latitude of 12.65° vs. 18° => less curvature of the elevator => tether angles: ~20° (20 GP) and ~28.5° (10 Gpa)
- Still clears Phobos orbit comfortably by a factor of ~1.8 of the orbit change in this first calculation.
- If dust is tolerable, the lower latitude site offers integration advantages for the Omaha Trail.



Mars Lift, Counterweight

ISEC

- The safest option appears to terminate Mars Lift inside the Deimos orbit, e.g., at ~23000 km radius, put the top Ares station at ~400-500 km inside Deimos orbit.
- Bracketing the counterweight mass preliminarily for this situation:
  - The gradient of the combined potential of gravity and centrifugal force leads to

$$\vec{\nabla} V\,(60000\ \mathrm{mt},\ 23000\ \mathrm{km}) \approx 2 \times 10^{6}\ \mathrm{N}$$

  - A 20 Gpa tether has at areostationary Orbit approximately that strength and that counterweight condition should not be exceeded.
- The Geometry Condition leads to a relatively strong elevator, variations of the counterweight mass scenario are still investigated.
- Putting the counterweight mass further out, e.g., past Deimos, will help to reduce the counterweight mass if necessary.
- Keep Ares Station close to Deimos for efficient transfers.

Mars, Shipyard
To The Solar System©

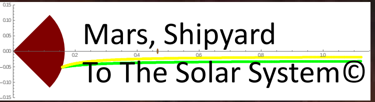
Mars Lift, Deployment and Anchor Forces

- Expected is a ground force of up to 10^6 N for a functional elevator and to pull it into place for deployment.
- A large tractor (e.g., group of tanks) will have to pull the elevator to position or it will have to be deployed in its lightest form (TBD) and to be built up.
- How can an off equator configuration be kept stable while the elevator is built up, including building the counterweight?
- It is an advantage that the counterweight mass can be iteratively increased by transporting material from Deimos.

- **It is easier to build from above.**

Mars Lift, Summary

- A simplified feasibility condition using rappellers and only going down, no motor or large power source required.
- The energy gained going down could possibly be used to build up (e.g., fuse new material to) or protect (e.g., clean/sweep) the Mars Lift elevator.
- To Do:
  - Look for further minimization of Elevator requirements
  - Investigate ideas for elevator protection and growth
  - Investigate deployment scenarios
- Thanks to the all supporters!



References

Disclaimer: All presented results are first approximations and may undergo corrections without notice.

- LakeMatthew.com
- Most astrodynamics data via Wolfram system (Mathematica, etc.)
- nasa.gov
- Background artwork: Kees Veenenbos, www.space4case.com and data: MOLA Science Team (NASA)
- MarsTrek site, JPL
- Google Earth, Mars Maps
- Tethers for Mars Space Operations. The Case for Mars II. 62 Science and Technology Series. pp. 445–465, Penzo, July 1984.
- Non-Equatorial Uniform-Stress Space Elevators, Gassend, 2004, including presentation on Off-equator space elevators and C code.
- Lunar Frontier Transportat System, Pearson et al., 2007
- Lunar Tether Transport, Levin, in Lunar Space Elevators for Cislunar Space Development, Pearson, 2005
- High Altitude Dust Global Distribution, Vertical Mixing, and Particle Sizes During the 2001 Planet-Encircling Dust Storm, Clancy, 2008
- The Schumann resonance: A tool for exploring the atmospheric environment and the subsurface of the planets and their satellites, Simoes et al, 2008
- Martian satellite orbits and ephemerides, Jacobson/Lainey, 2014

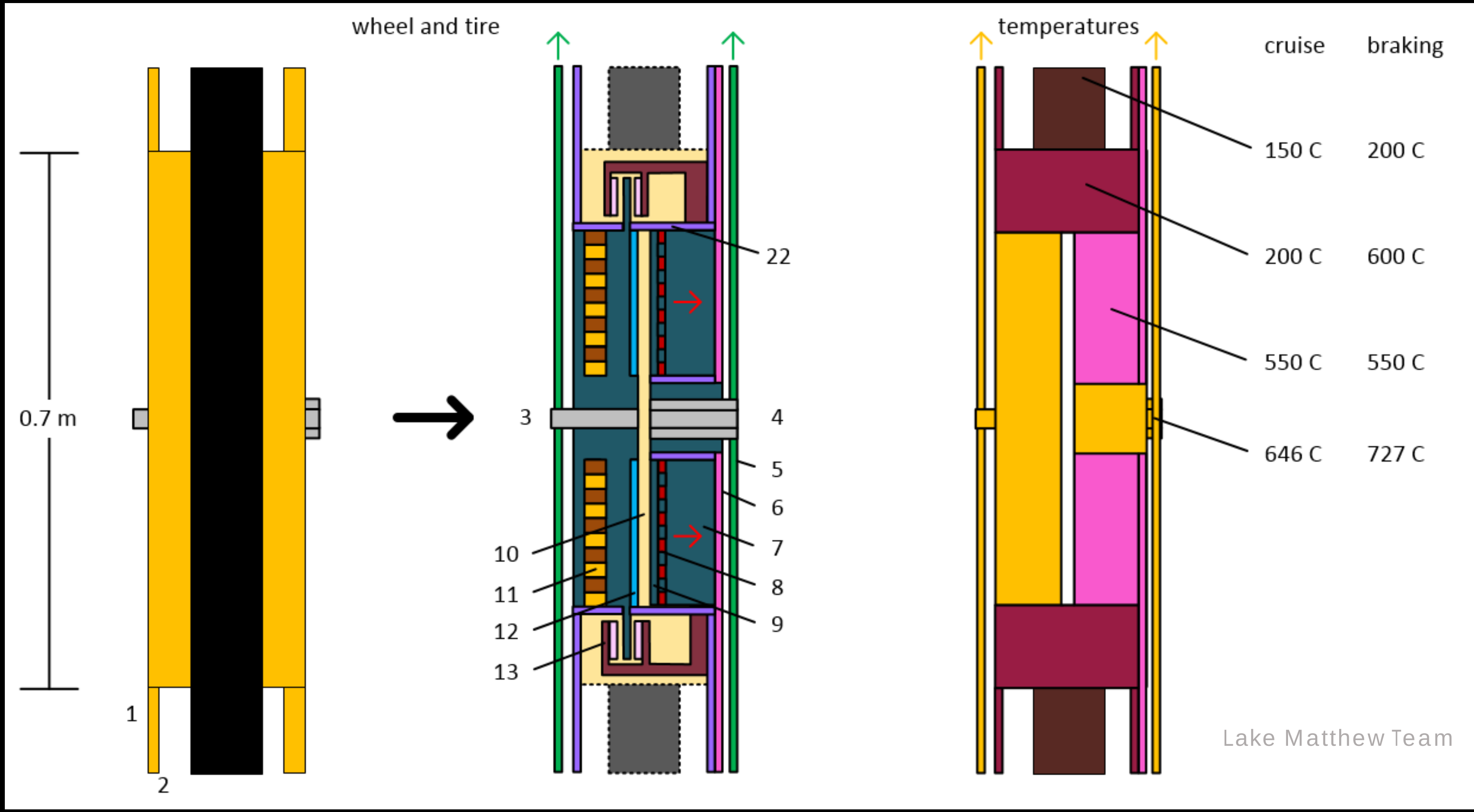
Mars, Shipyard
To The Solar System©

Mars Lift (ML)

Lake Matthew Team / Celestia

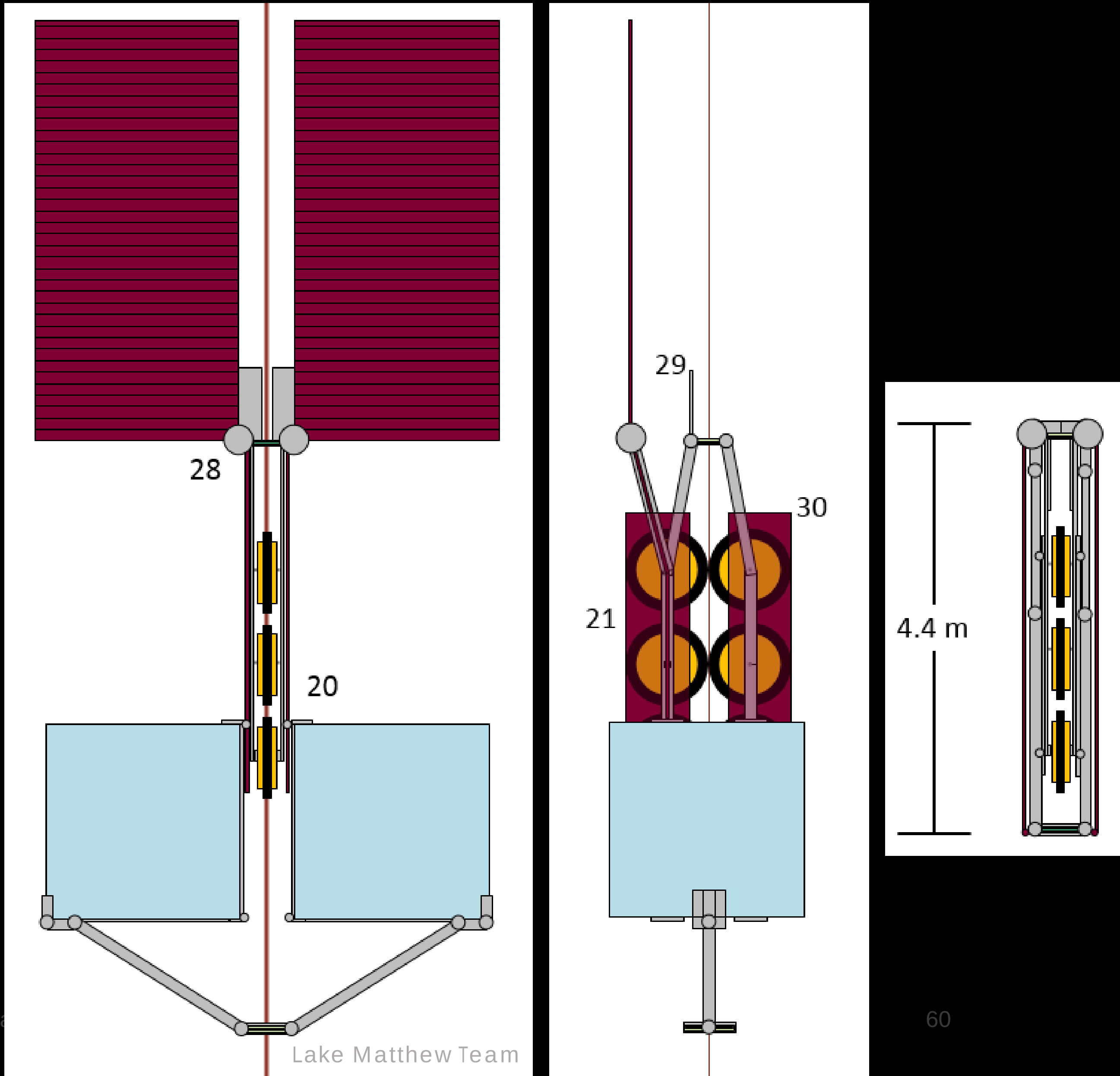
Mars Lift (ML)

- Rappeller heat management:
  - Brakes must counter gravitational acceleration
  - Friction brakes would quickly overheat
  - Eddy current brakes can work, but radiators are required



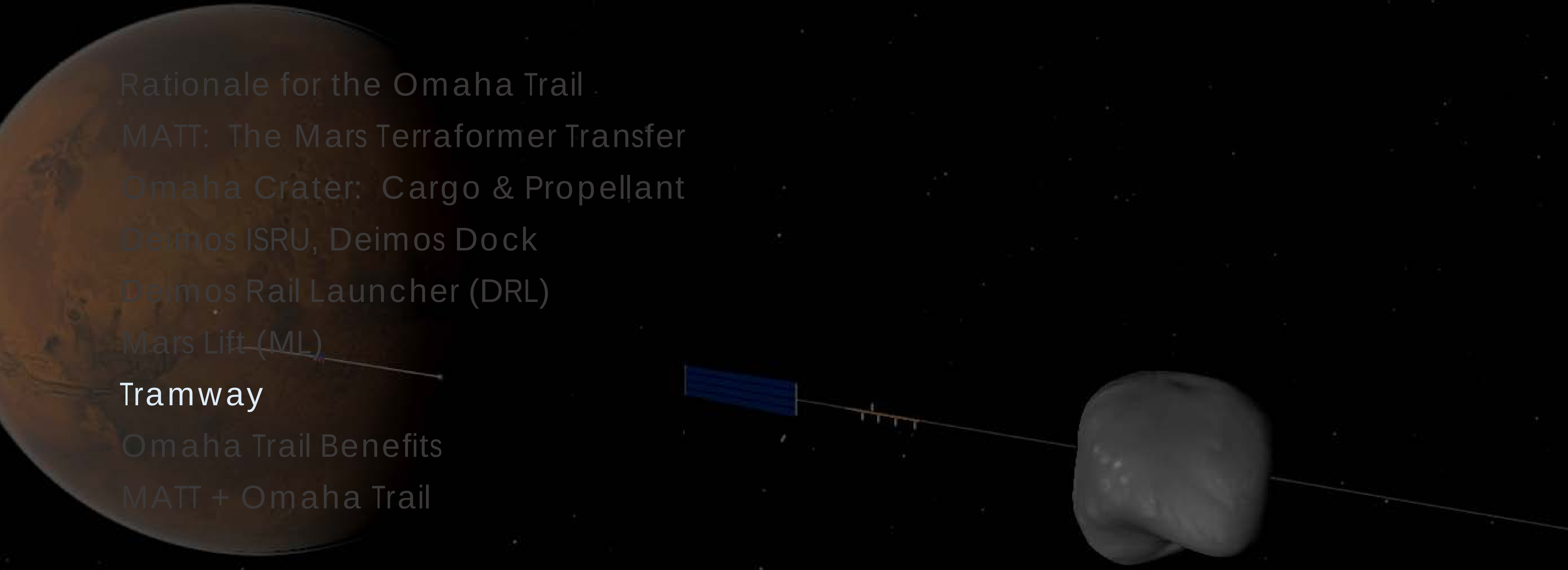
Mars Lift (ML)

- Rappeller design considerations:
  - Unpowered descent for cargo delivery
  - Should be a mass-produced vehicle, easily repaired at Omaha Crater
  - Lightweight, with compact storage
  - Notional 10-ton payload (5 tons x 2)



Omaha Trail to Lake Matthew

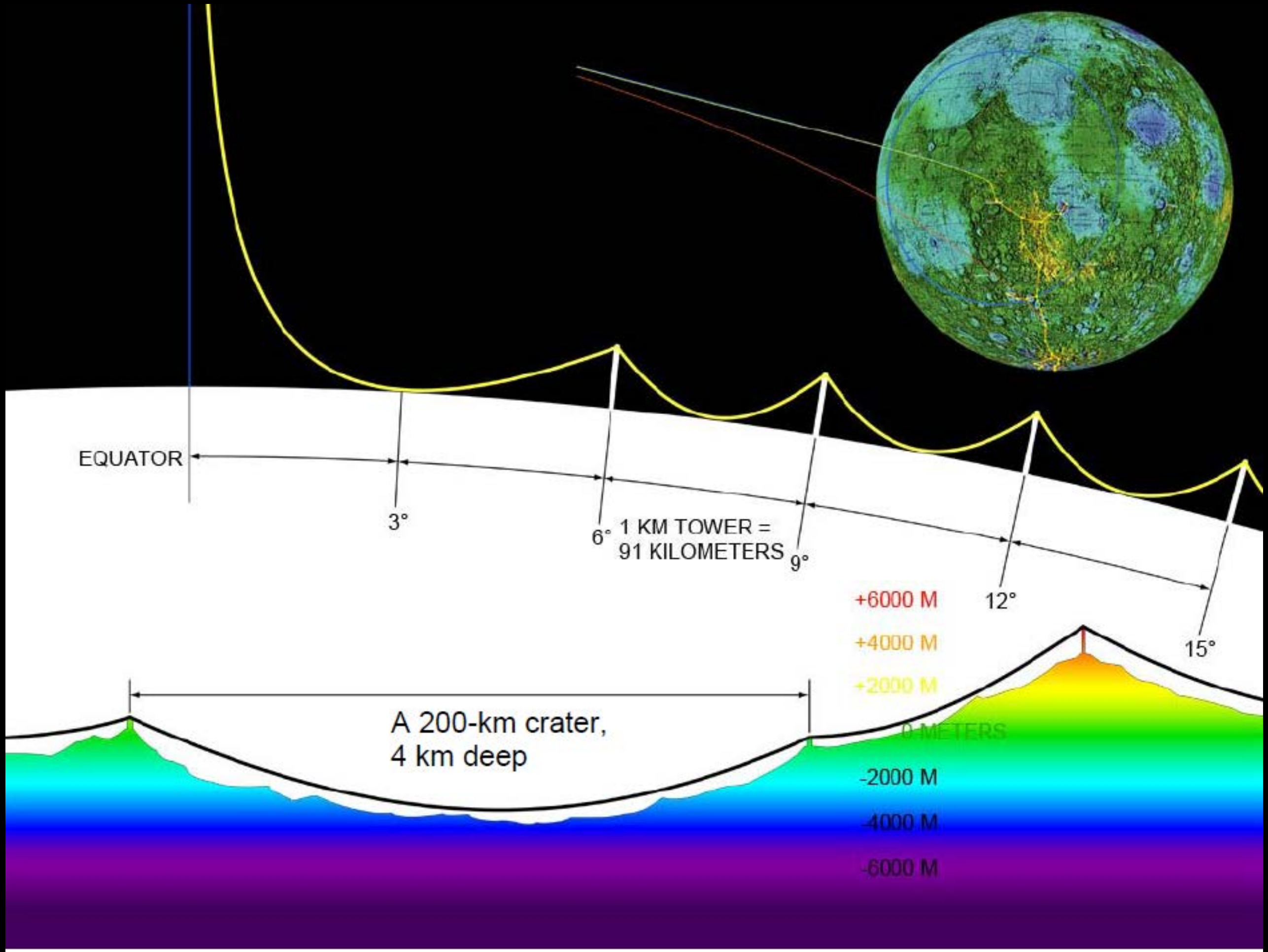
- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- **Tramway**
- Omaha Trail Benefits
- MATT + Omaha Trail



Lake Matthew Team / Celestia

Tramway

- Conceptual design in the spirit of lunar tramway (Pearson et al. 2005)

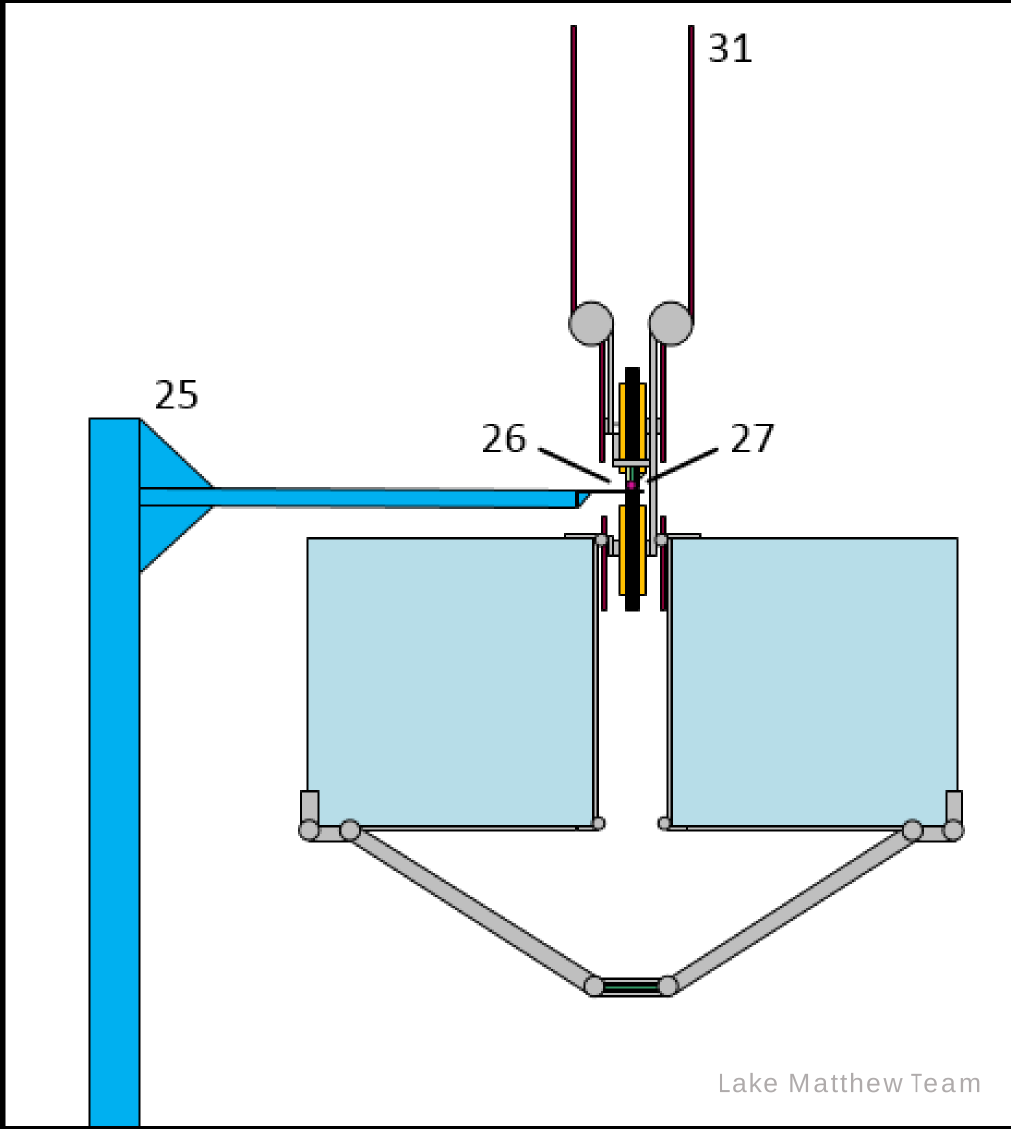


Pearson et al. 2005

Figure 9. Lunar Space Elevator and Tramway

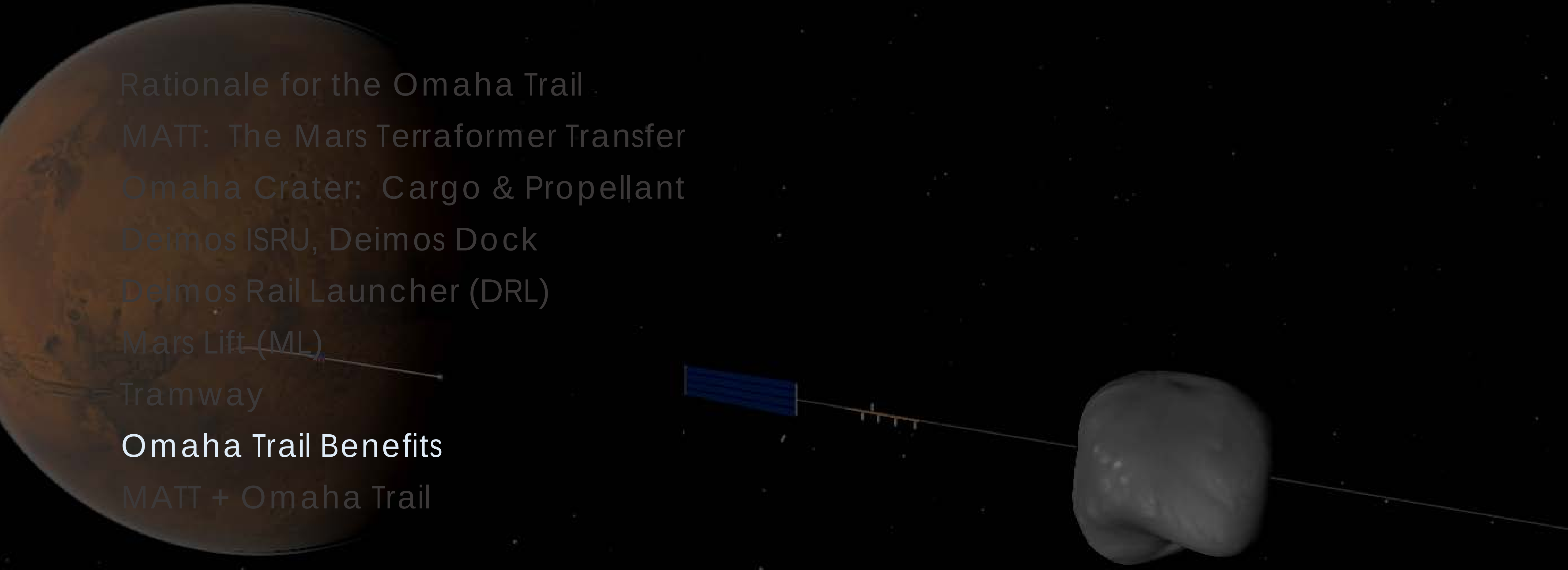
Tramway

- ISRU alloy pylons
- CNT cables with Omaha Crater HVDC power
- Notionally 10x60 mm^2 cable cross-section with 70 kN tensioning
- 30+ km pylon separation, peak-spanning, 400+ m pylon height
- The rappeller should be designed to convert into HVDC tramway “trammer”



Omaha Trail to Lake Matthew

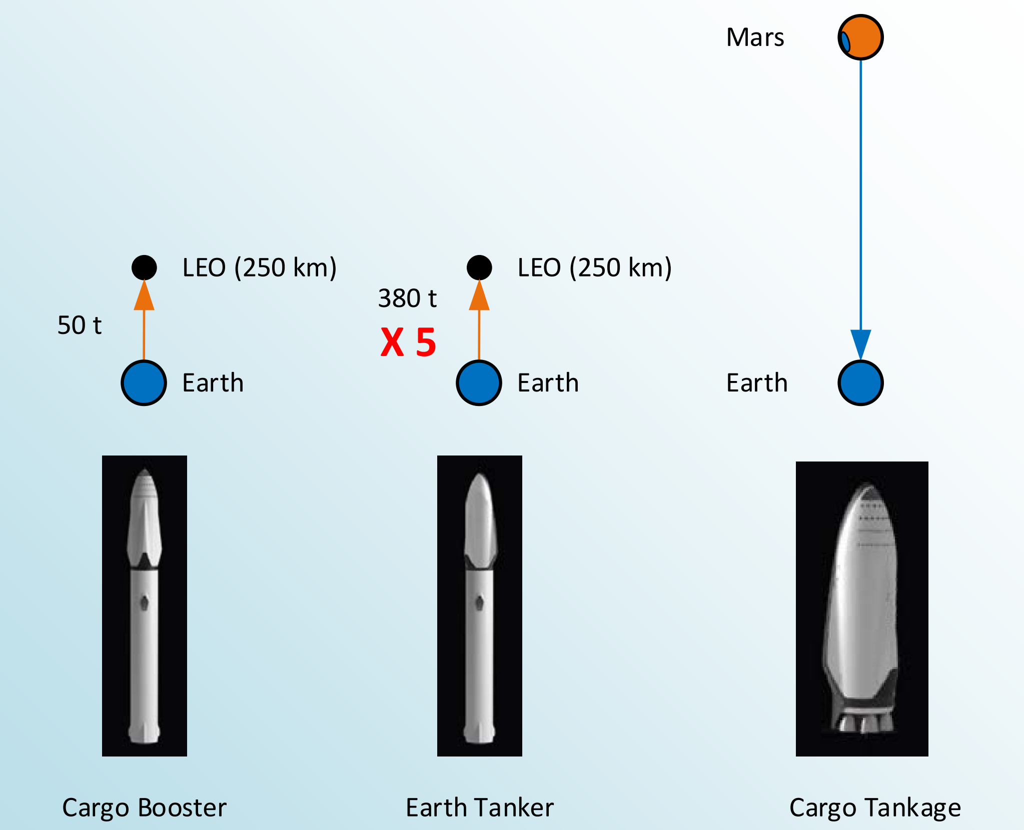
- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- Tramway
- **Omaha Trail Benefits**
- MATT + Omaha Trail



Lake Matthew Team / Celestia

Omaha Trail (With Tankers) Cuts Propellant ~86%

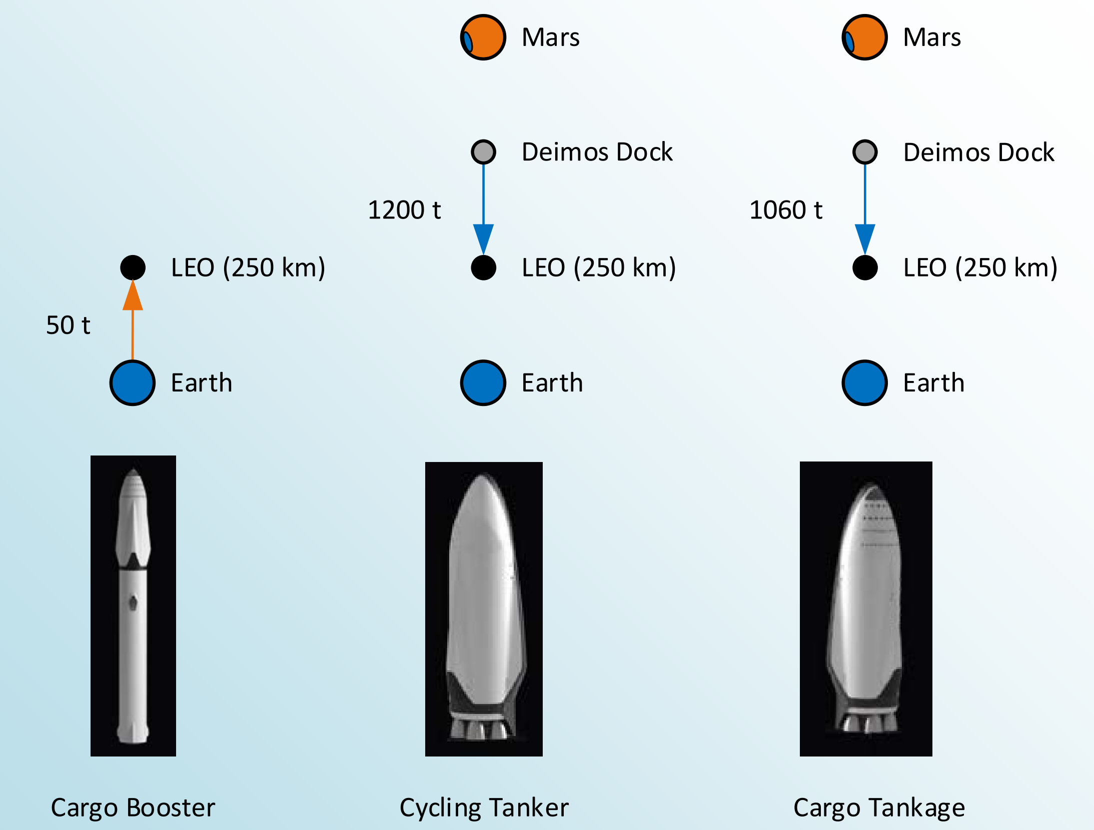
Propellant delivery – SpaceX baseline



87,380 tons propellant needed

per 450 tons cargo

Propellant delivery – Omaha Trail with Tankers



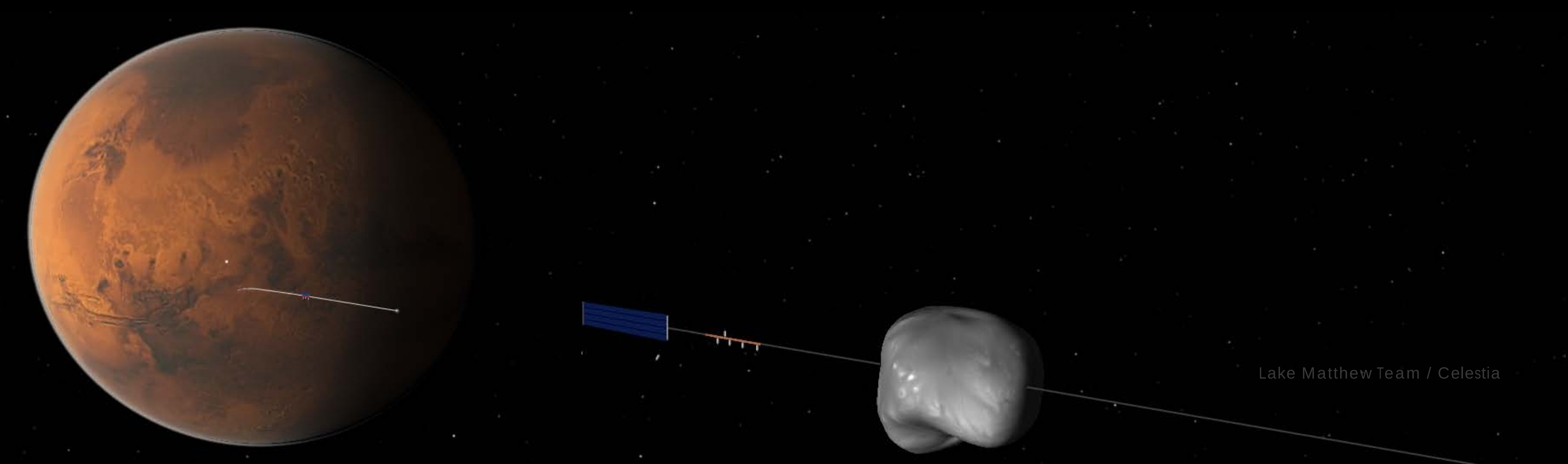
12,480 tons propellant needed

per 450 tons cargo

(**86% cut**)

Omaha Trail Benefits

- Cuts Earth cargo/tanker launches by 83%
- Cuts propellant requirement ~86%
- 100% of Omaha Crater power would be freed for use on Mars

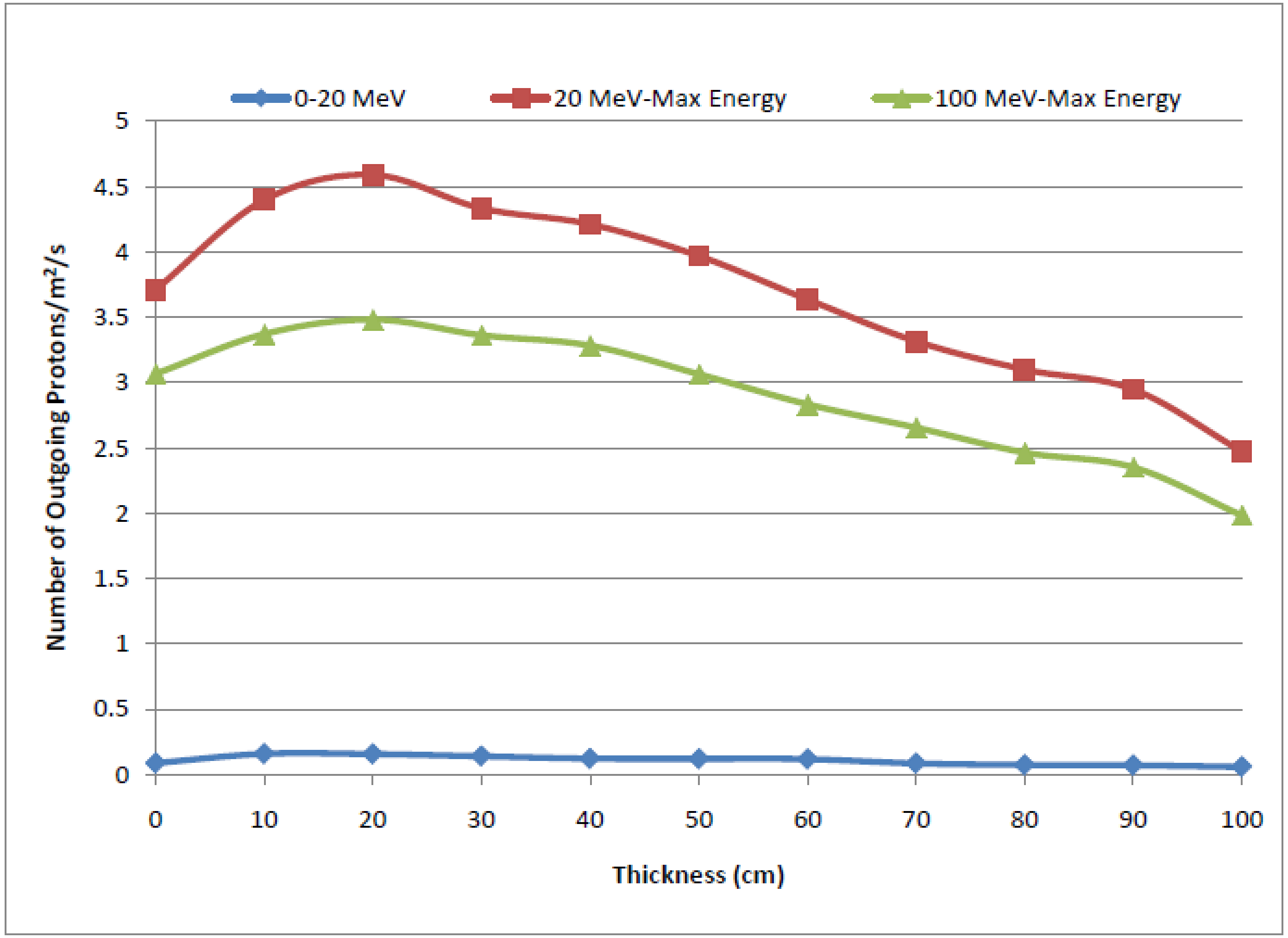


Crew Benefits

- Crewed Earth-return on the Omaha Trail:
  - Faster crew return: All propellant for Earth insertion, cutting transit time by more than half, thereby cutting cosmic radiation exposure by more than half
  - 300+ tons of water shielding: Deimos water adds 1 m+ depth of shielding to block all cosmic rays < 20 MeV, and at higher MeV block 2/3 of neutrons, 1/3 of muons and 1/3 of protons

Crew Benefits

- Crewed Earth-return on the Omaha Trail:



Aguayo et al. 2011

Figure 27: Cosmic Proton Flux through Water

Crew Benefits

- Crewed Earth-return on the Omaha Trail:
  - Faster crewed ITS return: Omaha Trail reserves all propellant for Earth insertion burn, cutting transit time by more than half, and cutting cosmic radiation exposure by more than half
  - 300+ tons of water radiation shielding: Deimos ISRU water can give an extra 1 m depth of shielding to block all cosmic rays < 20 MeV, and at higher MeV block 2/3 of neutrons, 1/3 of protons, and 1/3 of muons
  - Fast return with extra water shielding cuts radiation exposure >80%, preventing career-limiting exposure

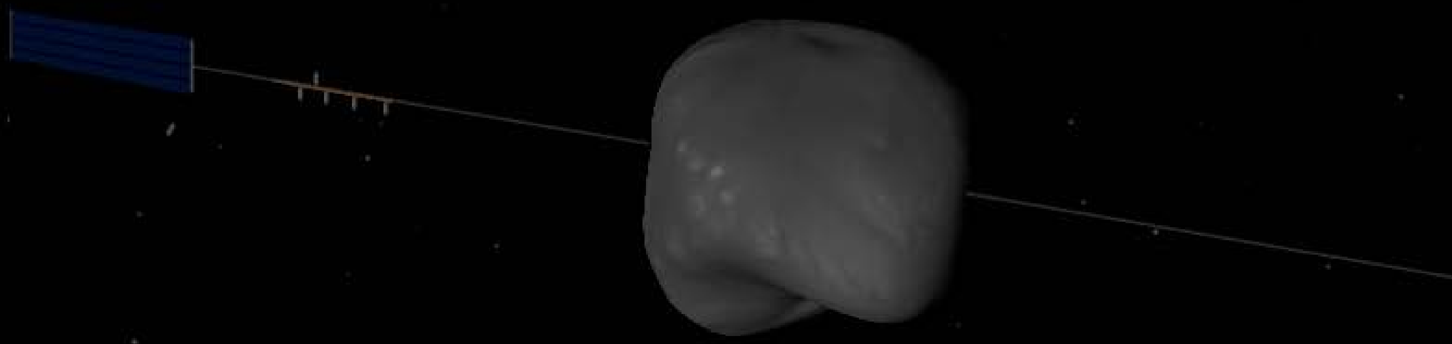
Omaha Trail to Lake Matthew

Rationale for the Omaha Trail:

- It would reduce Earth launches (83%)
- It would lower transport cost (opportunity for Omaha Trail Consortium)
- It orchestrates and justifies R&D for each infrastructure component (Deimos ISRU -> Deimos Dock -> DRL -> ML -> tramway)
- Fast crew return with less radiation exposure
  (cuts transit time in half, and cuts cosmic radiation exposure >80% to prevent career-limiting exposure)

Omaha Trail to Lake Matthew

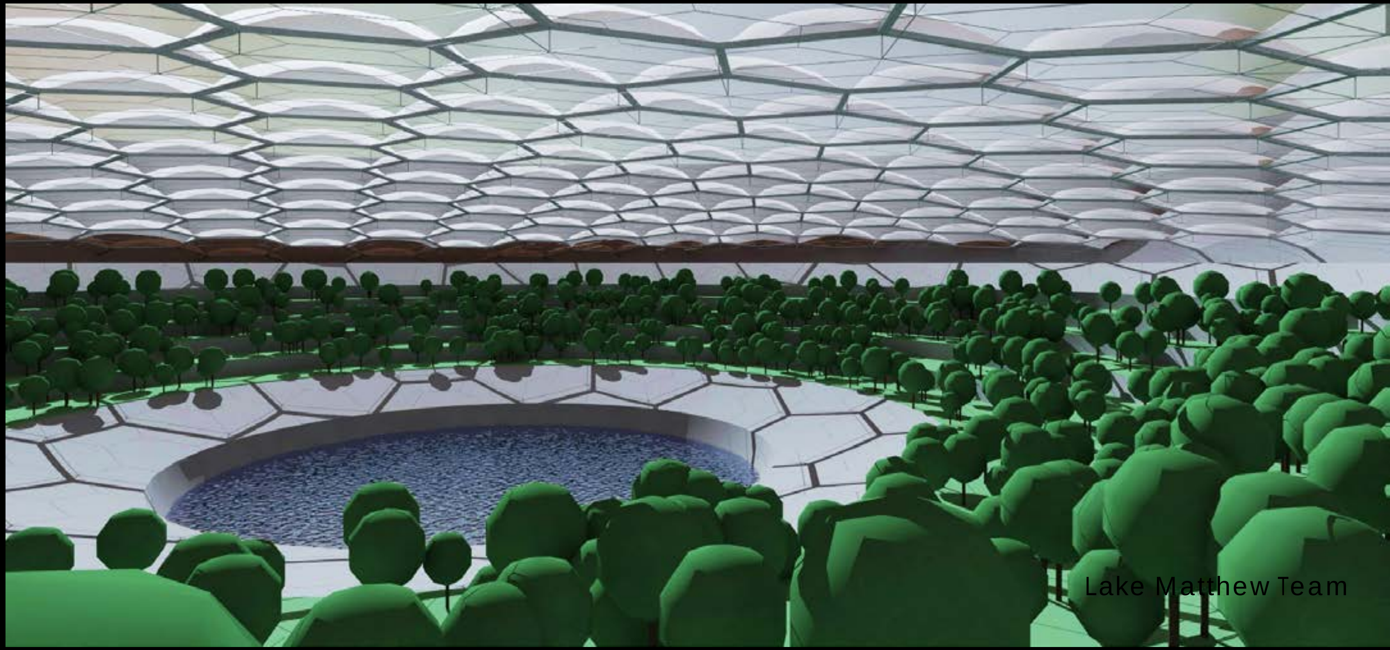
- Rationale for the Omaha Trail
- MATT: The Mars Terraformer Transfer
- Omaha Crater: Cargo & Propellant
- Deimos ISRU, Deimos Dock
- Deimos Rail Launcher (DRL)
- Mars Lift (ML)
- Tramway
- Omaha Trail Benefits
- **MATT + Omaha Trail**



Lake Matthew Team / Celestia

MATT Cuts Earth Cargo Launches ~ 90%

- Habs 2 orders of magnitude larger than reference, with same cargo mass
- ISRU self-sufficiency in many massive products
- Cuts cargo mass, and cuts Earth launches of cargo/tankers, ~90%



MATT + Omaha Trail

Rationale for combining:

- MATT terraforming cuts Earth cargo launches by ~90%, for affordable, robust facilities
- MATT and Omaha Trail together cut required Earth cargo launches by >95%, and enable:
    - Multiple martian settlements
    - Rapid planet-wide exploration
    - Extensive commercial development
    - Faster, safer crew transport home

Omaha Trail to Lake Matthew

Thank you!

Lake Matthew Team / Celestia

Links

Lake Matthew – LakeMatthew.com

New Space Journal – liebertpub.com/overview/new-space/610

References

Disclaimer: All presented Omaha Trail results are first approximations and may undergo corrections without notice.

Aguayo, E., Kouzes, R. T., Ankney, A. S., Orrell, J. L., Berguson, T. J., & Troy, M. D. (2011). Cosmic ray interactions in shielding materials. *Pacific Northwest National Laboratory Report No. PNNL-20693*.

Davis, A. M. (Ed.). (2005). *Meteorites, Comets, and Planets: Treatise on Geochemistry* (Vol. 1). Elsevier.

D'Orazio, M., & Folco, L. (2003). Chemical Analysis of Iron Meteorites by Inductively Coupled Plasma-Mass Spectrometry. Geostandards and Geoanalytical Research, 27(3), 215-225.

Engel, T. G., Timpson, E. J., & Veracka, M. J. (2015). Demonstration of a reversible helical electromagnetic launcher and its use as an electronically programmable mechanical shock tester. *IEEE Transactions on Plasma Science*, *43*(5), 1266-1270.

Engel, T. (2004). *U.S. Patent No. 6,696,775*. Washington, DC: U.S. Patent and Trademark Office.

Fanale, F. P., & Salvail, J. R. (1990). Evolution of the water regime of Phobos. *Icarus*, *88*(2), 380-395.

Gay, S. E. (2010). *Contactless magnetic brake for automotive applications* (Doctoral dissertation, Texas A & M University).

Hoashi, M., Brooks, R. R., & Reeves, R. D. (1993). Palladium, platinum and ruthenium in iron meteorites and their taxonomic significance. Chemical geology, 106(3-4), 207-218.

Hughes, G. B., Lubin, P., Bible, J., Bublitz, J., Arriola, J., Motta, C., ... & Wu, J. (2013). DE-STAR: phased-array laser technology for planetary defense and other scientific purposes.

Lubin, P., Hughes, G. B., Eskenazi, M., Kosmo, K., Johansson, I. E., Griswold, J., ... & Riley, J. (2016). Directed energy missions for planetary defense. *Advances in Space Research*, *58*(6), 1093-1116.

Murchie, S. L., Fraeman, A. A., Arvidson, R. E., Rivkin, A. S., & Morris, R. V. (2013). Internal characteristics of Phobos and Deimos from spectral properties and density: relationship to landforms and comparison with asteroids.

Nichols, C. R. (1993). Volatile products from carbonaceous asteroids. *Resources of near-earth space*, 543-568.

Pearson, J., Levin, E., Oldson, J., & Wykes, H. (2005). Lunar space elevators for cislunar space development. *NASA Institute for Advanced Concepts Study Technical Report*, *7*.

Schwenzer SP, Abramov O, Allen CC, Clifford SM, Cockell CS, Filiberto J, Kring DA, Lasue J, McGovern PJ, Newsom HE, Treiman AH. “Puncturing Mars: How impact craters interact with the Martian cryosphere.” Earth and Planetary Science Letters. 2012 Jun 15;335:9-17.

Shen, J. J., Papanastassiou, D. A., & Wasserburg, G. J. (1996). Precise Re-Os determinations and systematics of iron meteorites. Geochimica et Cosmochimica Acta, 60(15), 2887-2900.

Image Credits

Blair, Jonathan S. / National Geographic / Getty Images: Eden Project greenhouse, Cornwall, England

Celestia Software: Simulated imagery of Mars system

Celle, Ludovic: Mars illustration

Clark, Chuck: natural boundary mapping of Deimos

HiRISE / MRO / LPL (U. Arizona) / NASA: Deimos imagery

NASA / JPL-Caltech / Malin Space Science Systems: Mars imagery

Öner, Tayfun / USGS / Thomas, Peter: Deimos mappings and orthographic renderings

Pearson et al. 2005: Lunar Space Elevator and Tramway

Pioneer Astronautics: CAVoR visualization

SpaceX: ITS visualizations

SSL / ASU /P. Rubin / NASA / JPL-Caltech: 16 Psyche artist's concept

Toshiba / Chubu Electric: SMES unit

U.S. Navy: F-14 on catapult

Wood, Roy: Surprise Lake inside Aniakchak Caldera

Veenenbos, Kees: Olympos Mons rendering: www.space4case.com, and Data: MOLA Science Team (NASA)