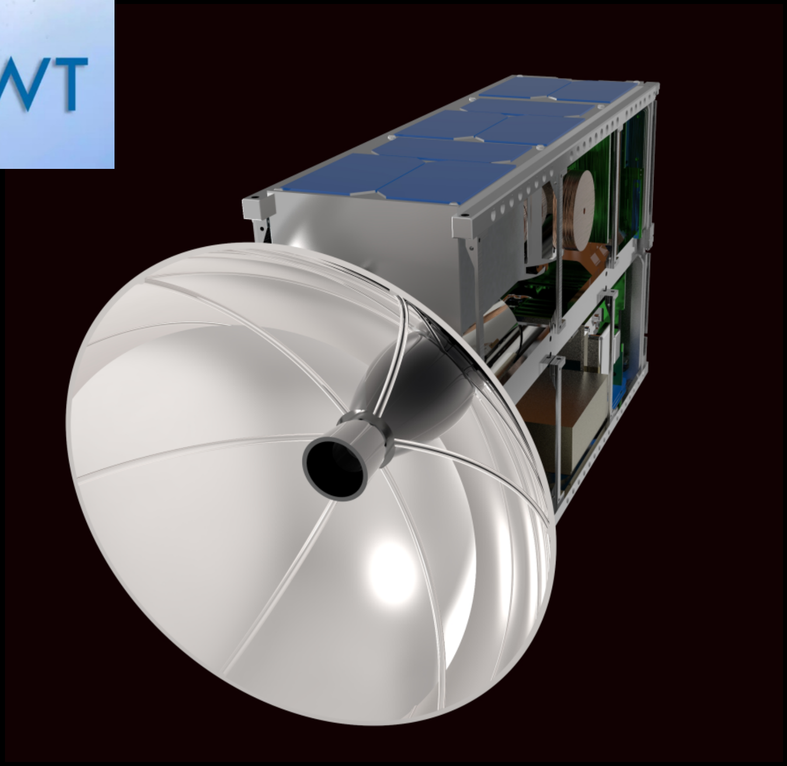

ISRU of Water for Interplanetary Steam Propulsion using Carbon Nanoparticles

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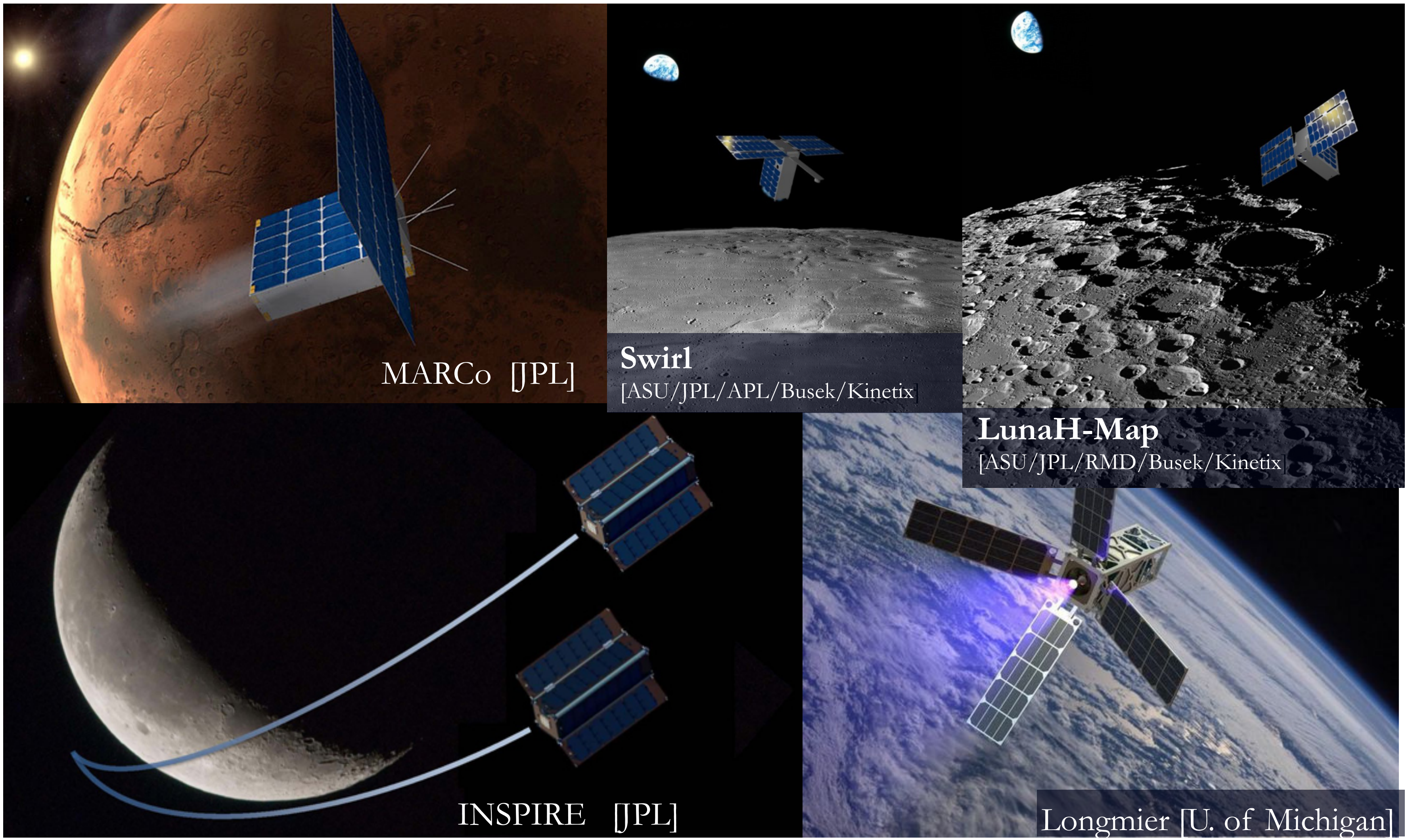
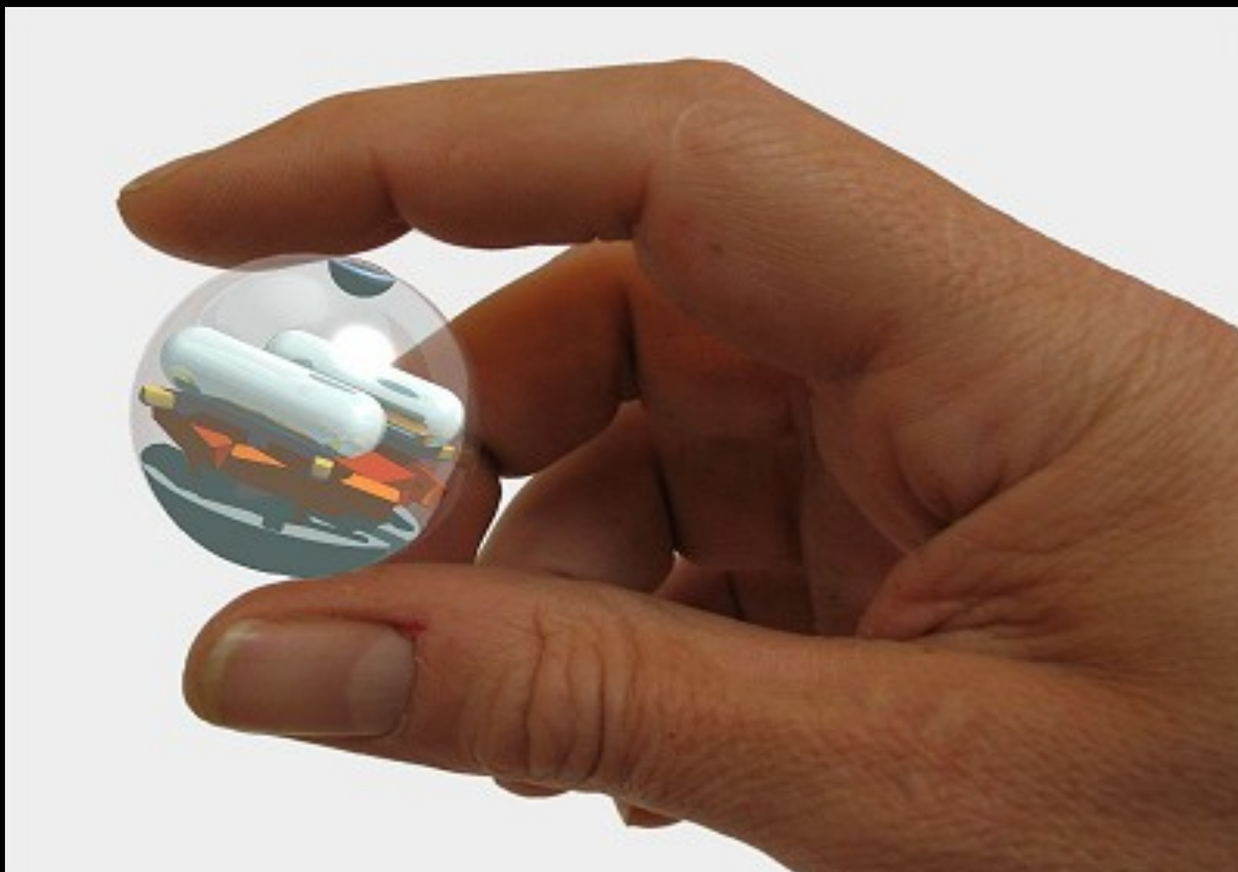
SpaceTREx

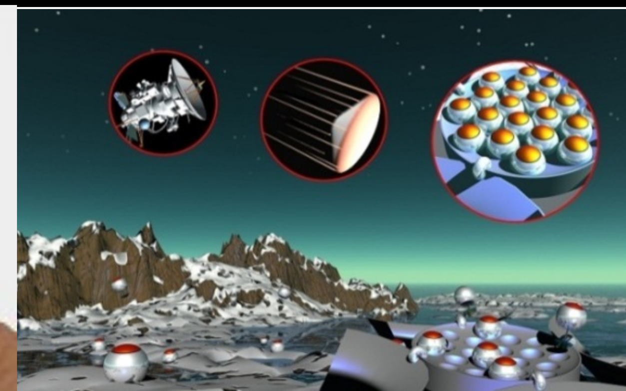
Space and Terrestrial Robotic Exploration Laboratory

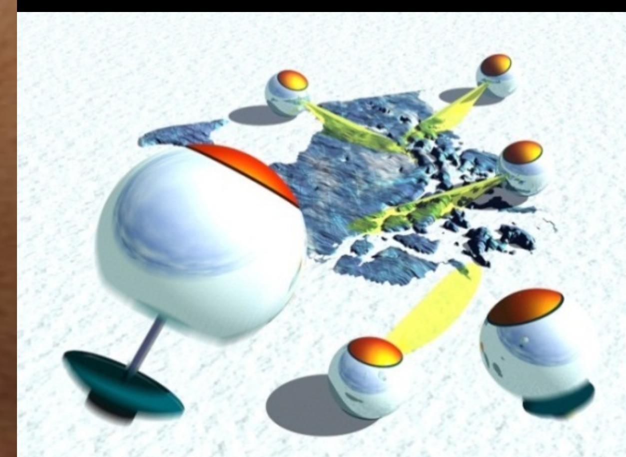
Motivation – Interplanetary Exploration



Planetary Surface Exploration/Prospecting







[Dubowsky et al., 2006; Thangavelautham et al., 2008]

Need for a Sustainable Propulsion System

- High or good-enough delta V
- Long storage life, minimal thermal footprint
- High thrust – particularly for capture burns.
- Low-storage risk, safety
- Propellants that are compatible with ISRU methods
- Ease of refueling

Water Steam vs. Water Electrolysis

- We are pursuing both approaches.
- Focus here will be water steam and we will compare against water electrolysis

Water Steam Propulsion

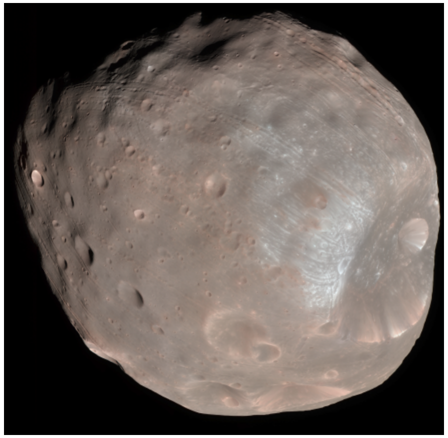
- Properties of steam well understood
  - Minimal storage risk
- Isp up to 200 s
  - Generated from super heated steam, +1500 C
- Use of carbon nanoparticles to heat the water using solar thermal concentrator.
  - Free power sources, up to 99 % of sunlight can be converted to heat.

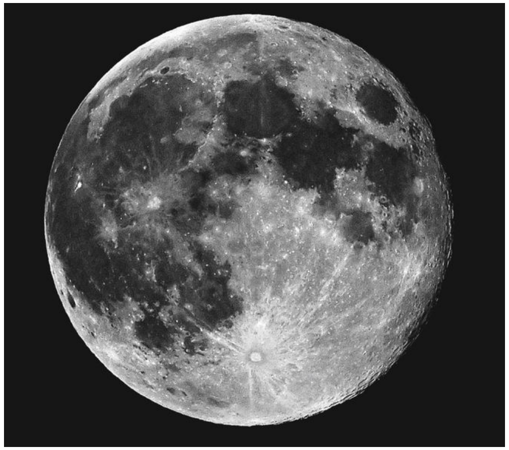
Steam Propulsion

- Achieve high temperatures with low-fidelity concentrator
- Compact, solid-state heating platform
- Comparably high thrust force compared to electrical propulsion methods.

Steam Propulsion

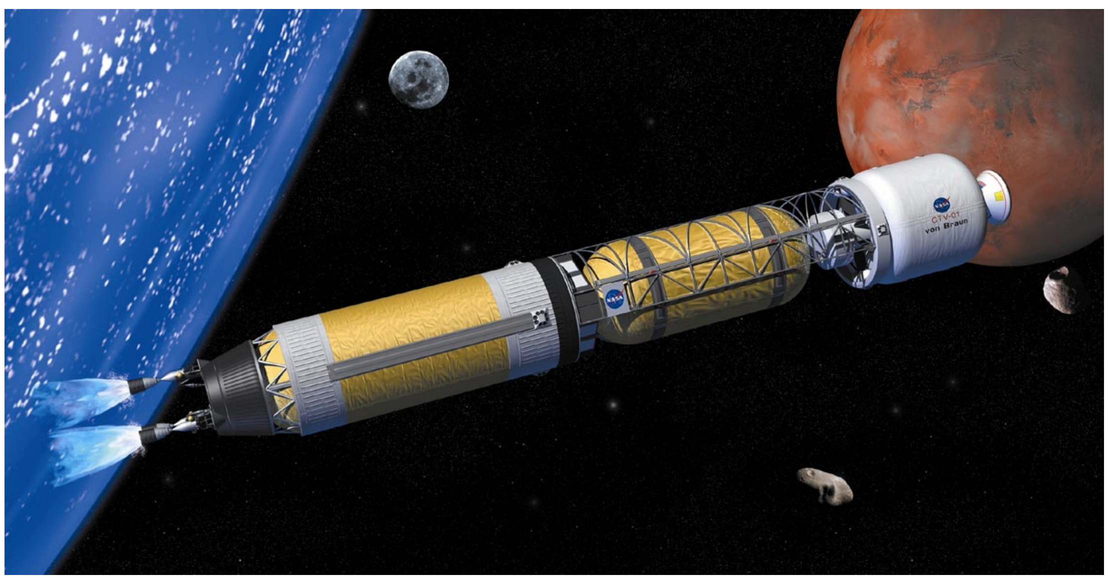
- Comparable in Isp to mono-props
- Compatible with ISRU methods to extract water from Deimos/Phobos, asteroids, Moon.
- Probably not a solution for Mars



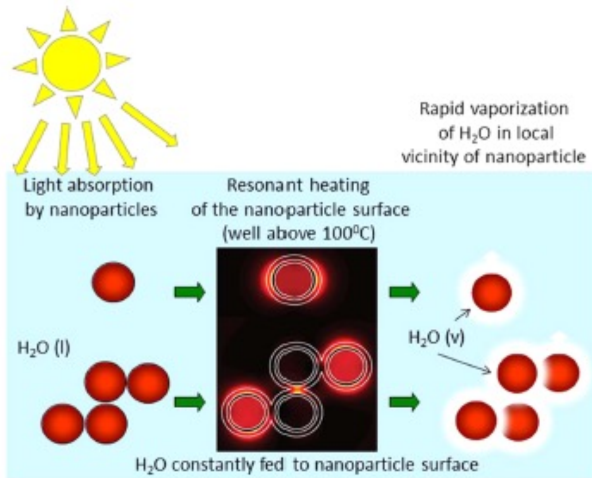


Steam Propulsion

- Steam propulsion is not a new concept.
- Old concepts required fission reactors, were meant to be large tug-boats of cis-lunar space.



Steam Generation Using Carbon Nanoparticles



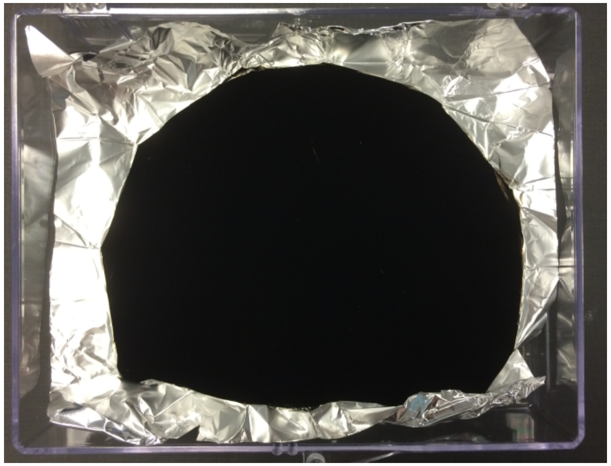
Source: "Solar Vapor Generation Enabled by Nanoparticles Halas, et al. 2013

- Concentrated light absorbed due to sub-wavelength geometry.
- Particles resonate, collect and transfer energy as heat.

Steam Generation Using Carbon Nanoparticles

- **Carbon Black N115, 82-86 % absorptivity**
- **Vanta Black, 99.5 % absorptivity**

Carbon Black N115

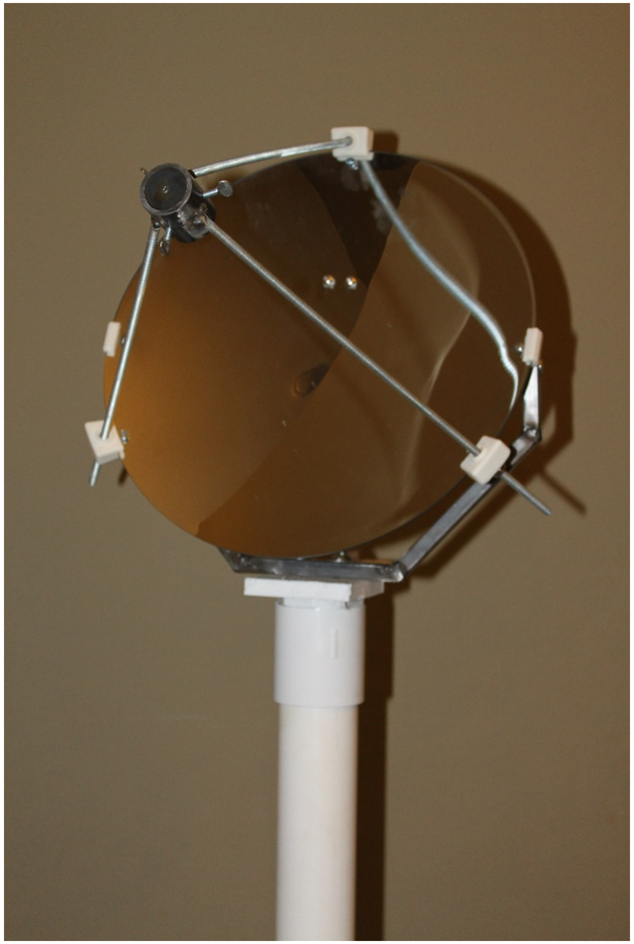


Vanta Black

Steam Generation Using Carbon Nanoparticles

- These nanoparticles may naturally occur on asteroids.
- Heating occurs an molecular scale. Very precise and local.
- Some of this maybe a challenge for in space-propulsion.

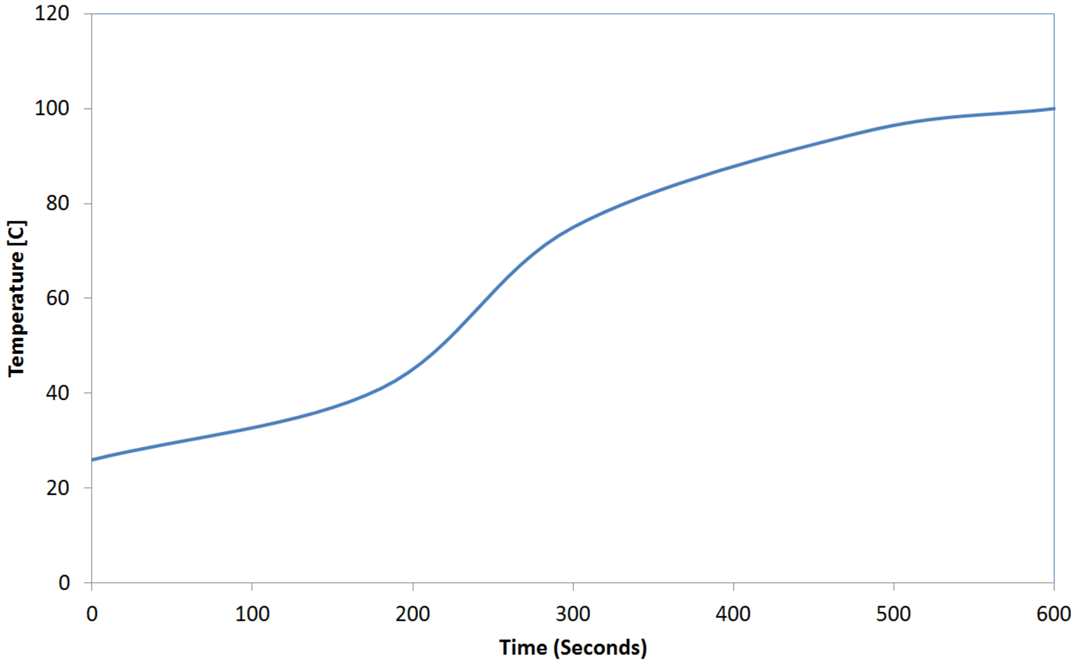
Laboratory Experiments



Initial Tests

Concentrator Test Results

- Time for wood to catch fire: ~5-7 seconds
- Time for 15 ml of distilled water to boil: 10 minutes got upto 100°C
- Steam was evident ~5.5min



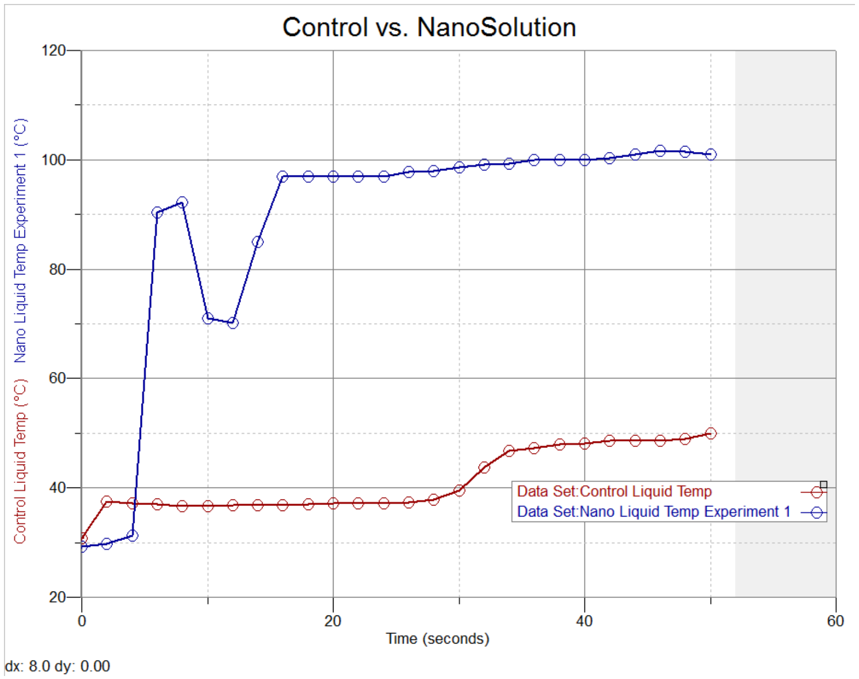
Early Results with Carbon Nanoparticles

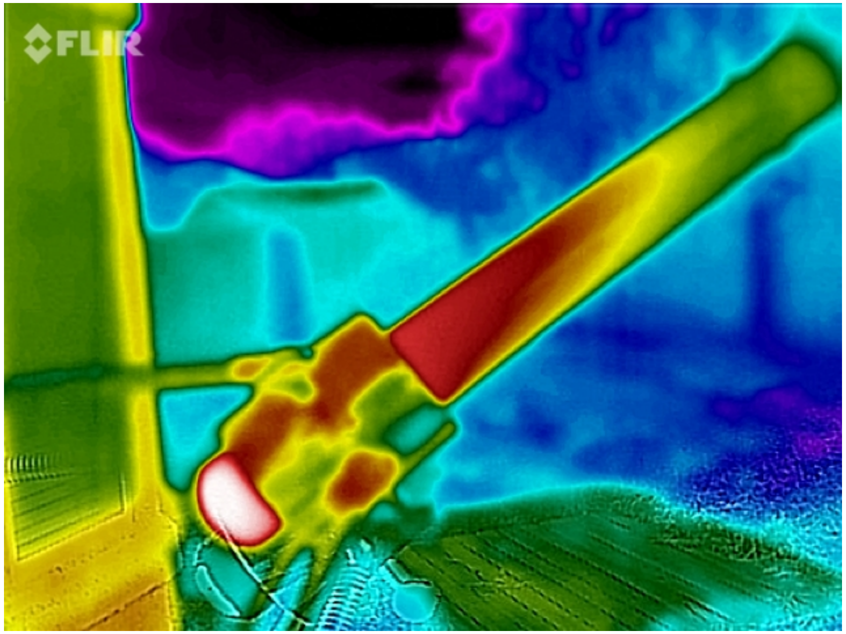
- **Solar to heat conversion efficiency: 82 %**

Condition	Time to Boil	Deviation
Distill Water	600 sec	10 %
Distill Water + Nanoparticles	40 sec	15 %

- **Up to 15x shorter time to boil.**

Early Results with Carbon Nanoparticles



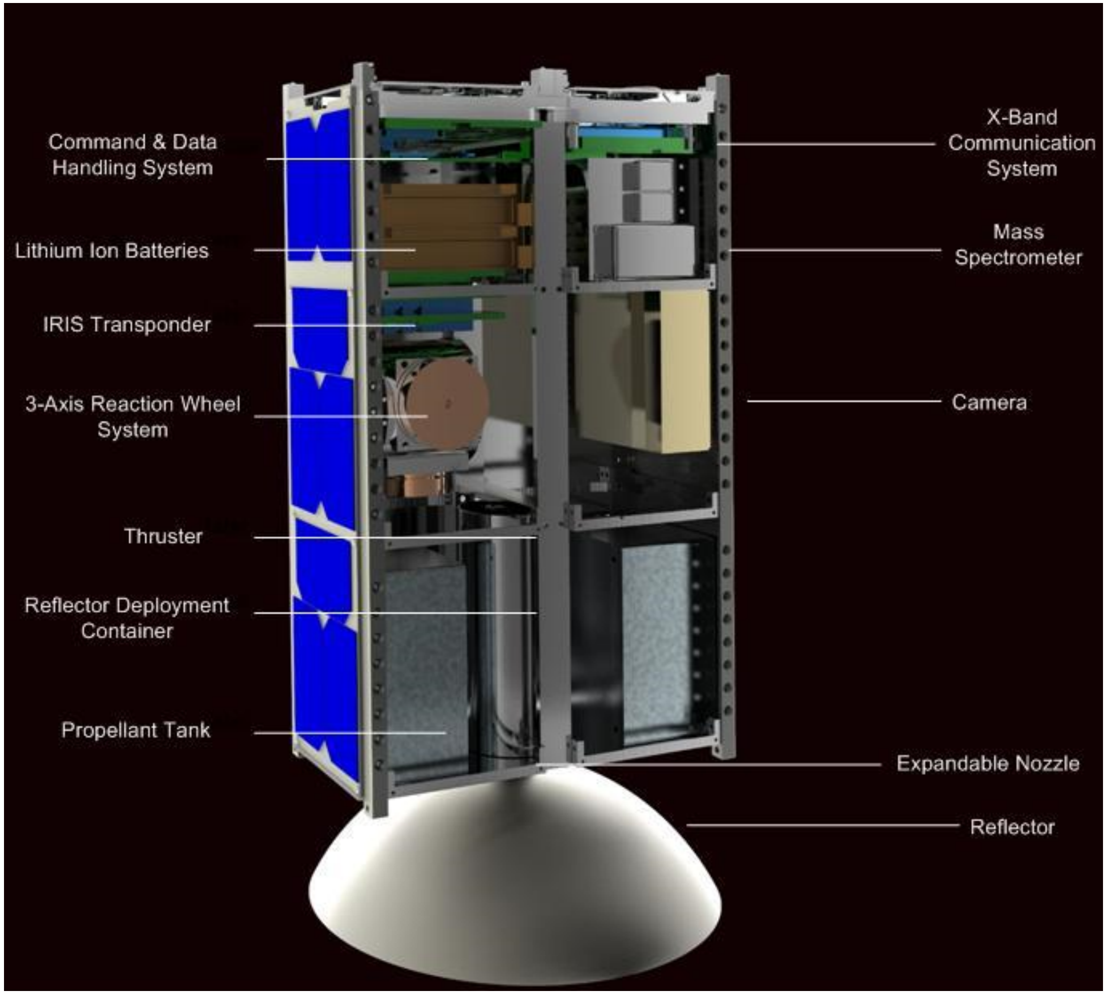


Solar Thermal Steam Propulsion Concept

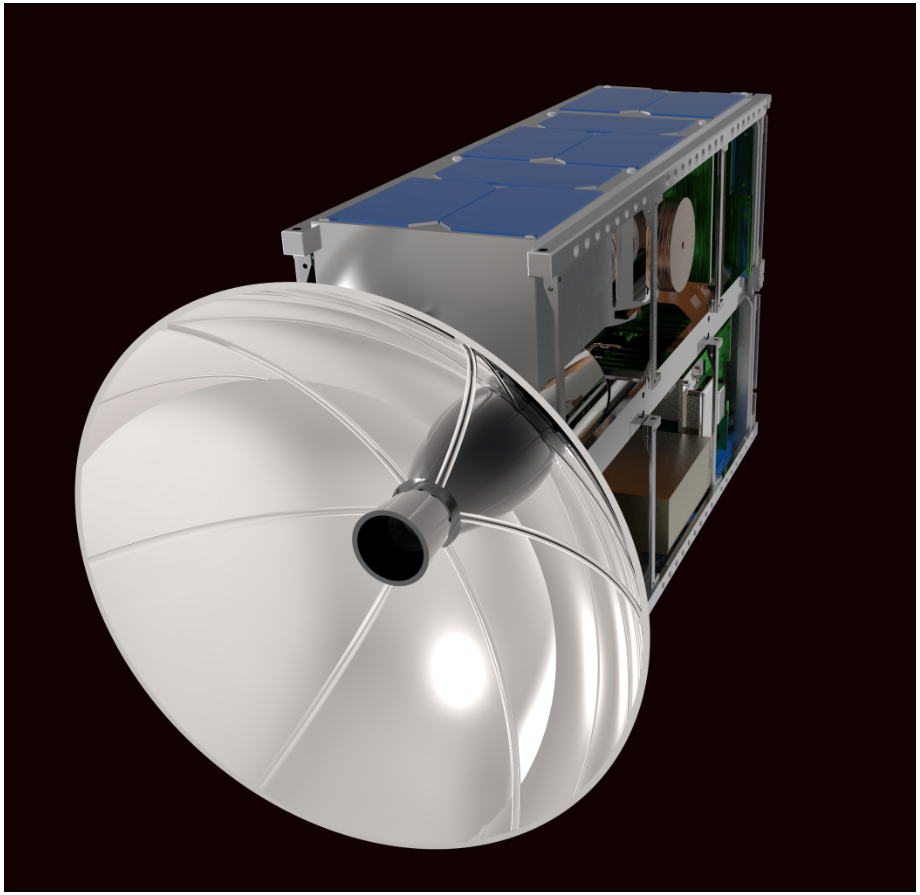
Components	Mass (kg)	Volume (L)
Propellant	7	7
Propulsion Dry Mass	3	1
Comms & ACDS	2	1
Structure	1	0.5
Power	1	0.5

- **Aggressive, optimized design.**
- **Delta V = 1400 m/s vs. 2500 m/s for Photovoltaic Electrolysis.**

Solar Thermal Spacecraft Concept

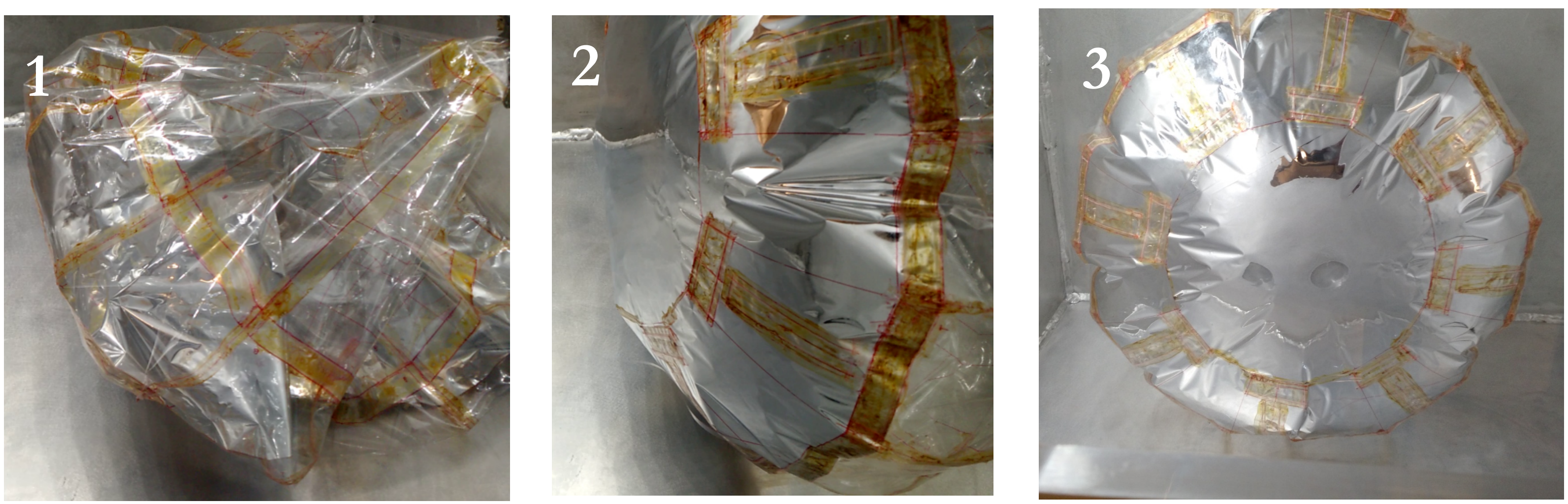


Solar Thermal Spacecraft Concept



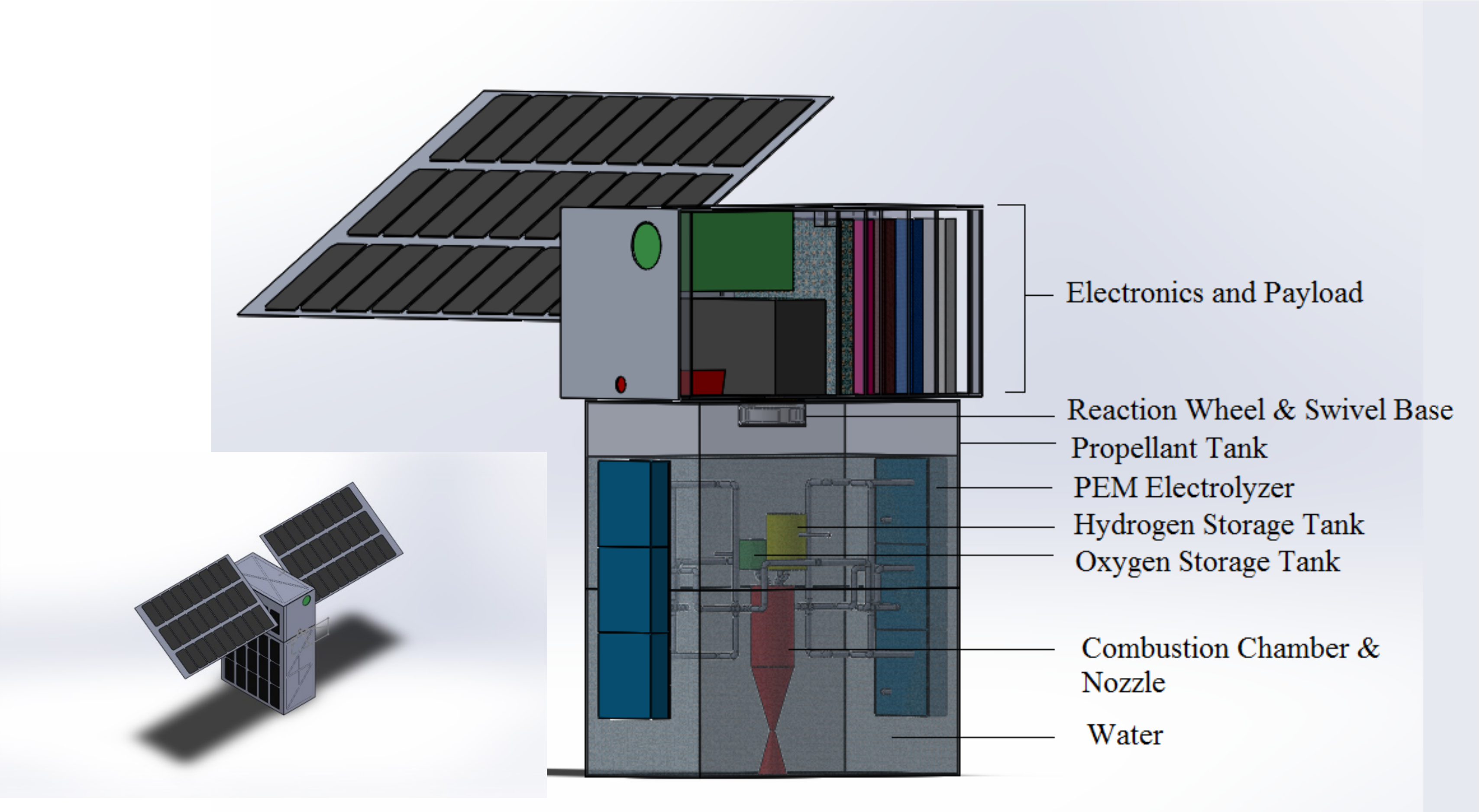
Inflatables

- Few grams of solid powder inflates parabolic antenna, UV resin cures inflatable into shape.
- Further enhancements can pave the way for a solar thermal concentrator



[Babuscia, Chandra, Thangavelautham 2016]

PV Electrolysis Spacecraft Concept



System Performance

- For short pulses

  I_{sp} = 360s

- For a 6U CubeSat
  - Total Mass – 14 kg
  - Dry Mass – 4.5 kg
  - ΔV = 4000 m/s

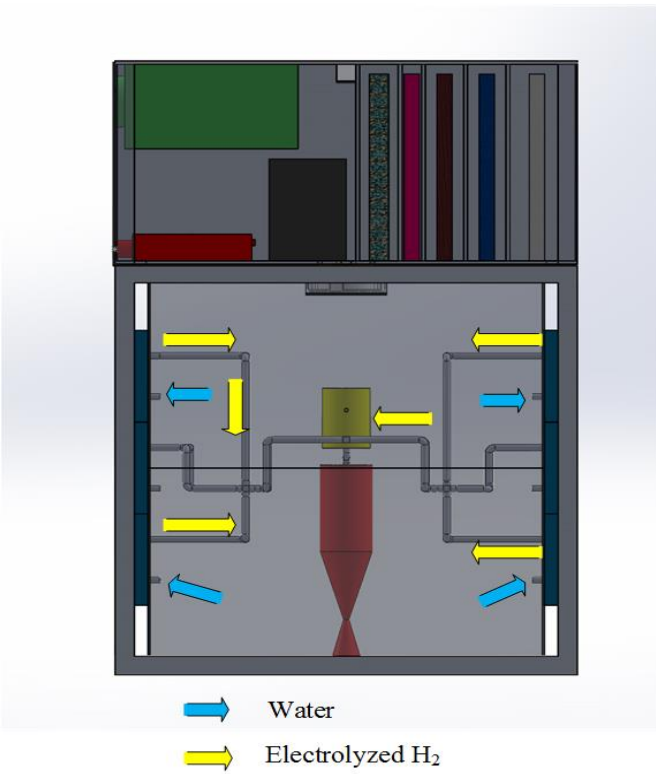
To	Required ΔV
Low Lunar Orbit	4040 m/s
EML – 1	3770 m/s
EML - 2	3430 m/s

Sutton, George P., and Oscar Biblarz. "Thrust Chambers." Rocket Propulsion Elements. 8th ed. Wiley. 301-305. Print.

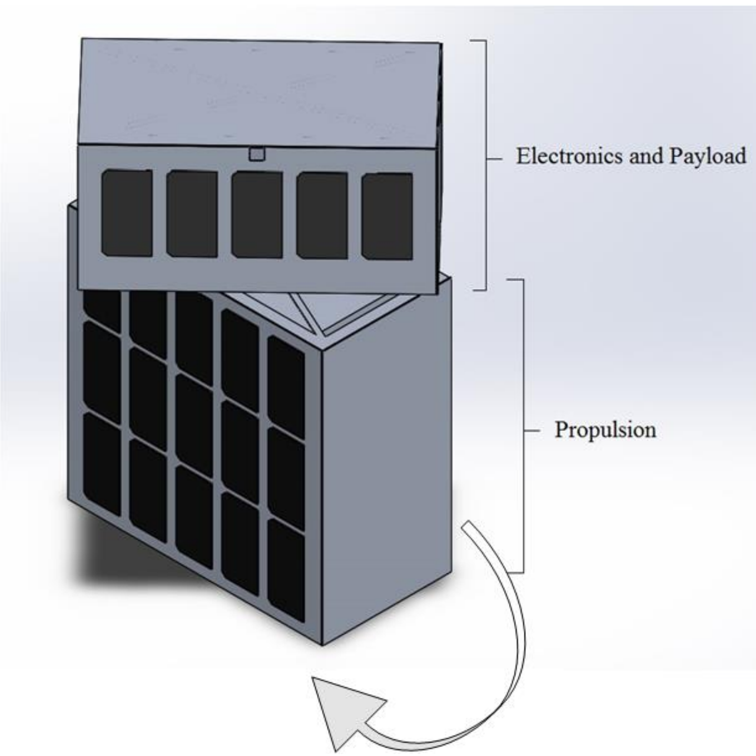
PV Electrolysis Spacecraft Concept

- Concept developed based on currently available state of the art CubeSat components
- PEM Electrolyzer with 85-90 % conversion efficiency
- Dual-body design, lower stage is centrifuge to separate water from the propellants.

System Operation

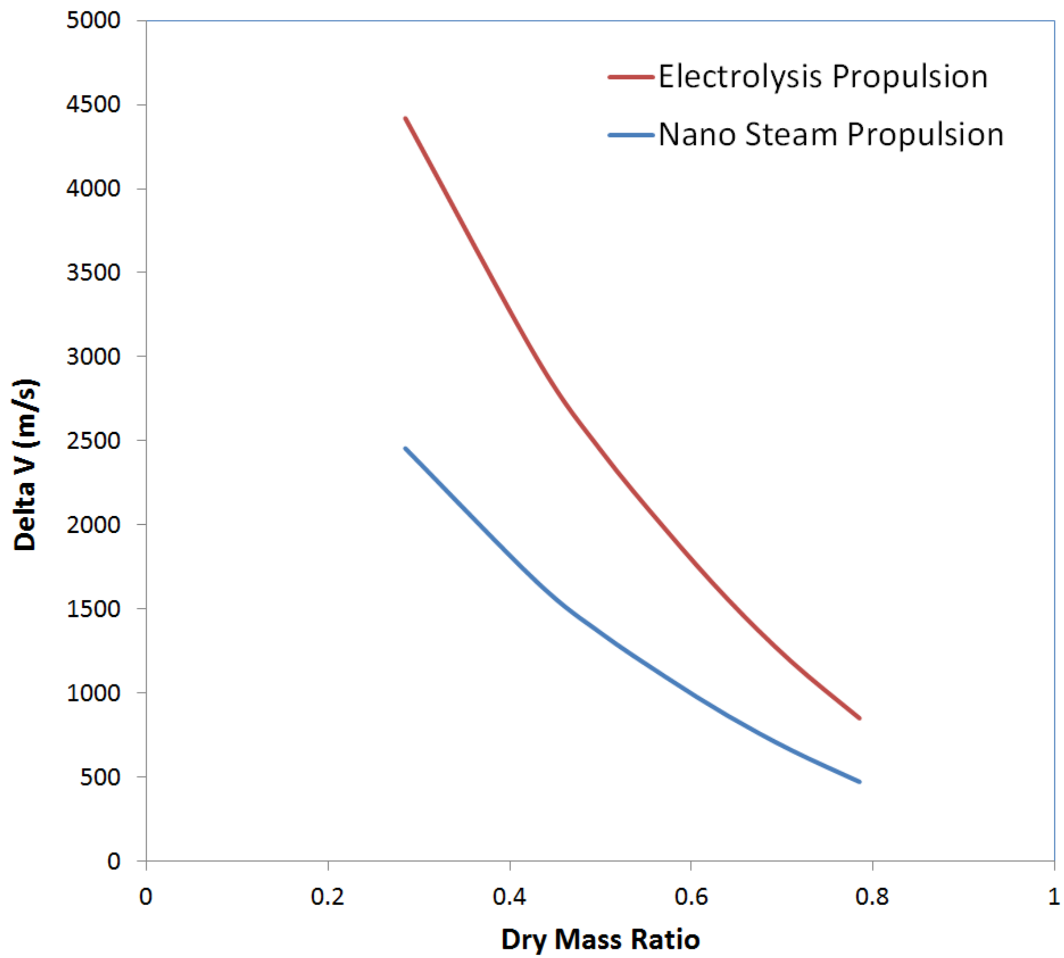


Side View of PVEPS



Lower segment rotates to separate water from reactants

General Case & Electrolysis Comparison



Discussion

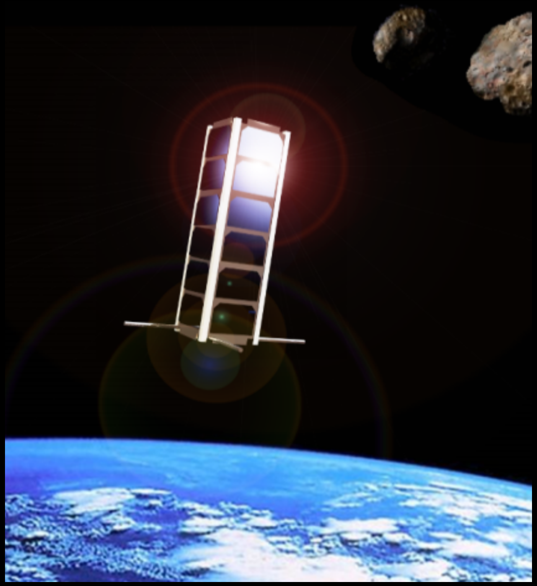
- Overall, solar-thermal steam propulsion system is simpler, but at the cost of reduced performance
- Well aligned with a water-based cis-lunar economy concept.
- Water can be with impurities, particularly sulfur, carbon monoxide
- Easier adoption, until advancements make electrolysis options more practical.

SpaceTREx Capabilities

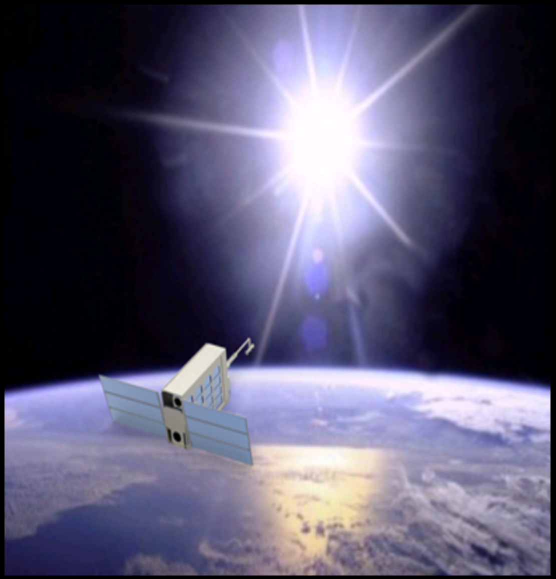
Design, Build, Test, Fly…

SpaceTREx Team

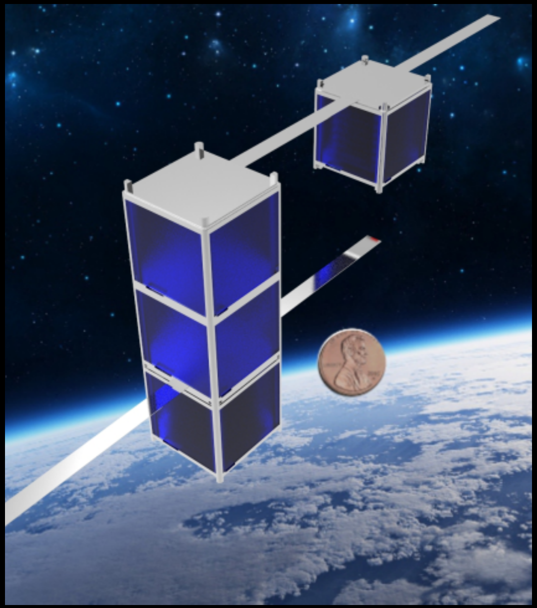
Current Space Missions



AOSAT I



SWIMSat



SunCube FemtoSats


SpaceTREx
Adventure Awaits