APIS: Asteroid Provided In-situ Supplies

Trans Astronautica Corporation

ICS Associates Inc.

Joel C. Sercel, PhD and Team

February 16, 2016

Acknowledgements

- Our NIAC Team
  - NASA HQ, U of H, U of CF, J.R. French, JSC (S. Love)
- Our ESI Team
  - MoUS&T, CSM, NASA,U of H
- Our SBIR Team
  - JSC, CSM, White Sands Range, CASIS
- Our ESO Study Team
  - J.R. French, UofH, NASA Ames
- The ARM FAST
- Our Private Sponsors
  - Motiv Space Systems, Art Dula, Decos Holdings

Areas of Work

- Asteroid Accessibility, Discoverability and Composition
    - U of H, U of CF, ICS Associates Inc.
- Subscale Demonstrations and Tests of Optical Mining
    - CSM, ICS Associates Inc.
- Analytical Modeling of Optical Mining
    - ICS Associates Inc.
- Mission-System Analysis and Economics
    - ICS, TransAstra, J.R. French, Others…
- Experiments With Bulk Heating and Materials Properties
    - MoUS&T, CSM
- Full Scale Demonstration at White Sands
    - TransAstra
- Omnivore Thruster Development and Solar Thermal Simulator
    - TransAstra

Why I'm Here:
The NASA Challenge Today

"The mismatch between NASA's aspirations for human spaceflight and its budget for human spaceflight is the most serious problem facing the Agency."

NASA Advisory Council Findings: August 2014

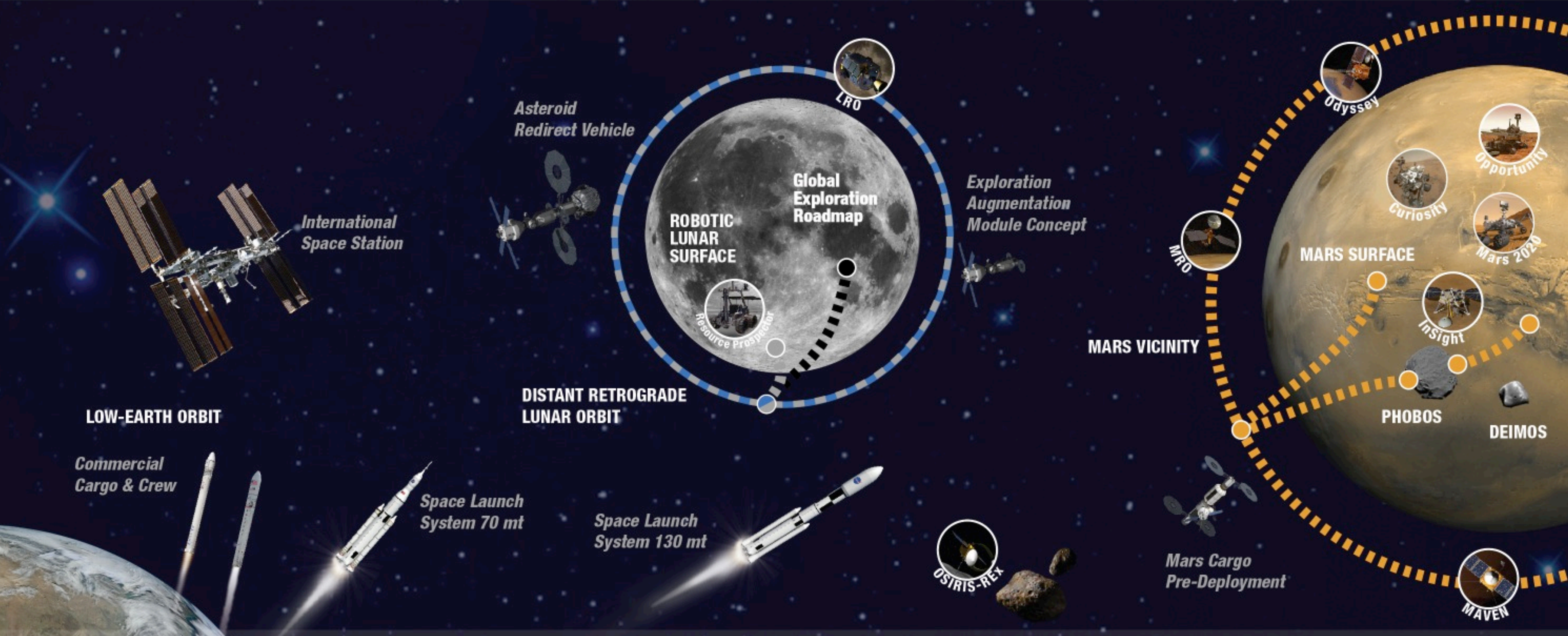
I'm an Entrepreneur and I'm Here to Help

:-)

EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

EARTH RELIANT | **PROVING GROUND** | **EARTH INDEPENDENT**

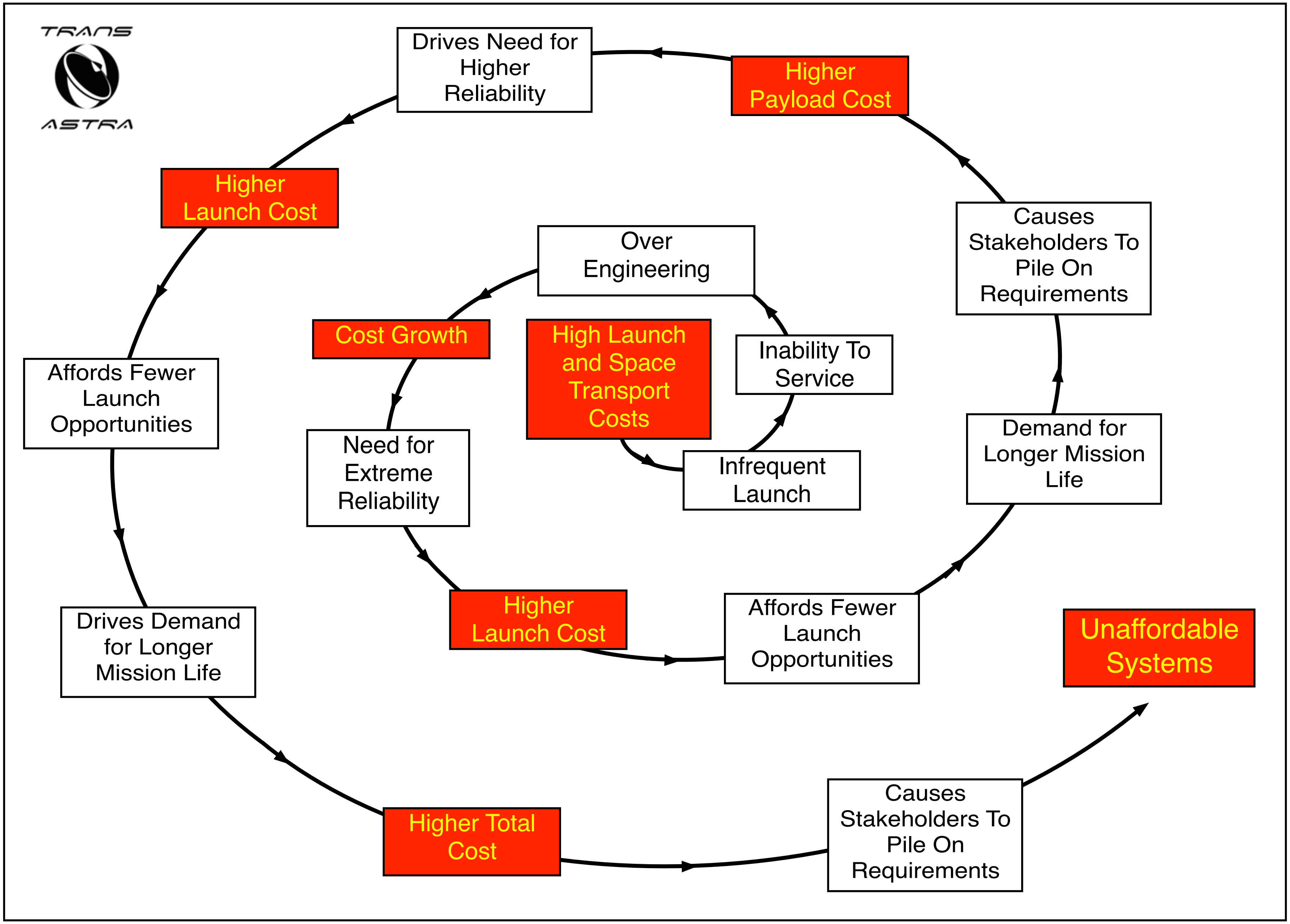


THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades
- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses


Drives Need for Higher Reliability
Higher Payload Cost
Causes Stakeholders To Pile On Requirements
Demand for Longer Mission Life
Affords Fewer Launch Opportunities
Higher Launch Cost
Need for Extreme Reliability
Cost Growth
Over Engineering
Inability To Service
Infrequent Launch
High Launch and Space Transport Costs
Higher Launch Cost
Affords Fewer Launch Opportunities
Drives Demand for Longer Mission Life
Higher Total Cost
Causes Stakeholders To Pile On Requirements
Unaffordable Systems

But Things Are Changing

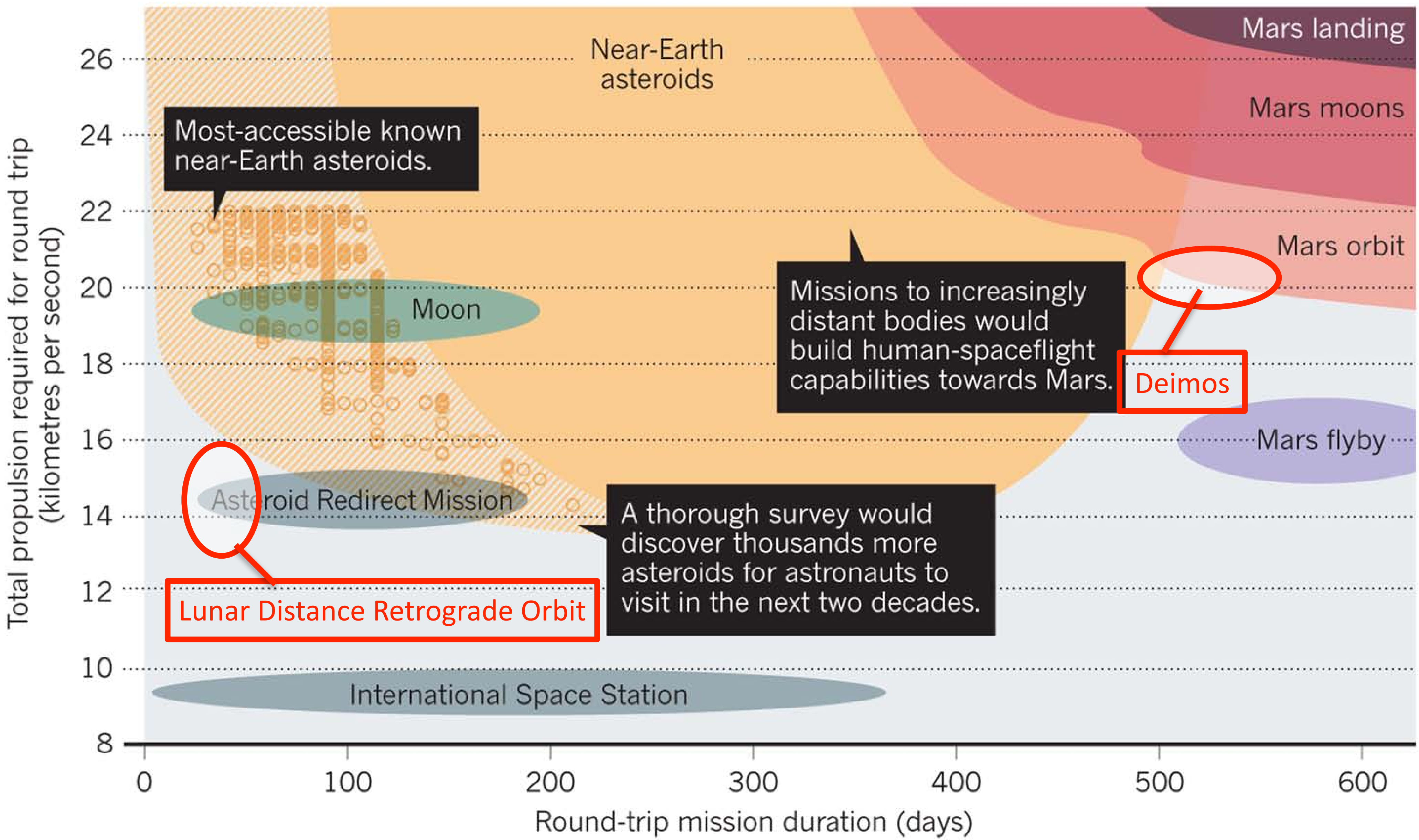
		NASA Model Based Prediction			SpaceX Actual Performance			
		NASA Approach				Firm Fixed Price Acquisition		
Elements	Weight (lbs)	DDT&E (FY2010 $M)	Flight Unit (FY2010 $M)	Total (FY2010 $M)	Weight (lbs)	DDT&E (FY2010 $M)	2 Test Flt Units (FY2010 $M)	Total (FY2010 $M)
Stage One (Including Engines)	39,080	$1,535	$206	$1,741	39,080	$188.7	$109.3	$298.0
Stage Two (Including Engine)	6,520	$608	$44	$651	6,506	$89.0	$23.6	$112.6
Fee (12.5%)		$268	$30	$298		$0.0	$0.0	$0.0
Program Support (10%)		$241	$21	$263		$0.0	$0.0	$0.0
Contingency (30% Vehicle, 10% Engine))		$674	$68	$741		$0.0	$0.0	$0.0
Vehicle Level Integration (8%)		$258	$24	$282		$22.2	$10.6	$32.8
Total	**45,600**	**$3,584**	**$393**	**$3,977**	**45,586**	**$299.9**	**$143.6**	**$443.4**

>10X Cost Reduction

NASA's Numbers, Not Ours

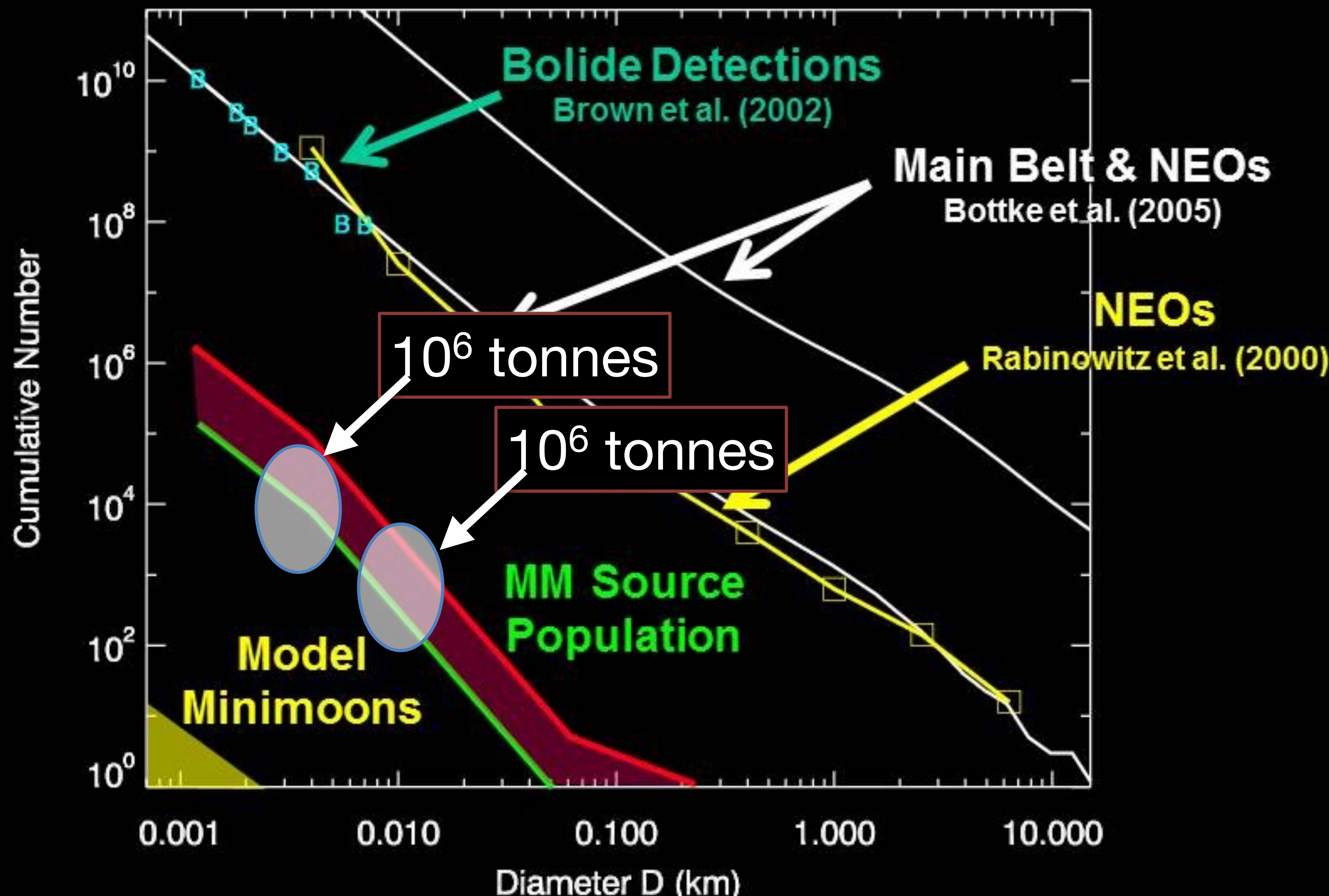
[redacted]

Where to Go For Resources?



At least one roughly 10-metre-wide asteroid passes as close as the Moon each week (artist's impression).

Asteroid Source Populations



Our NIAC Study Provides New Insights Here

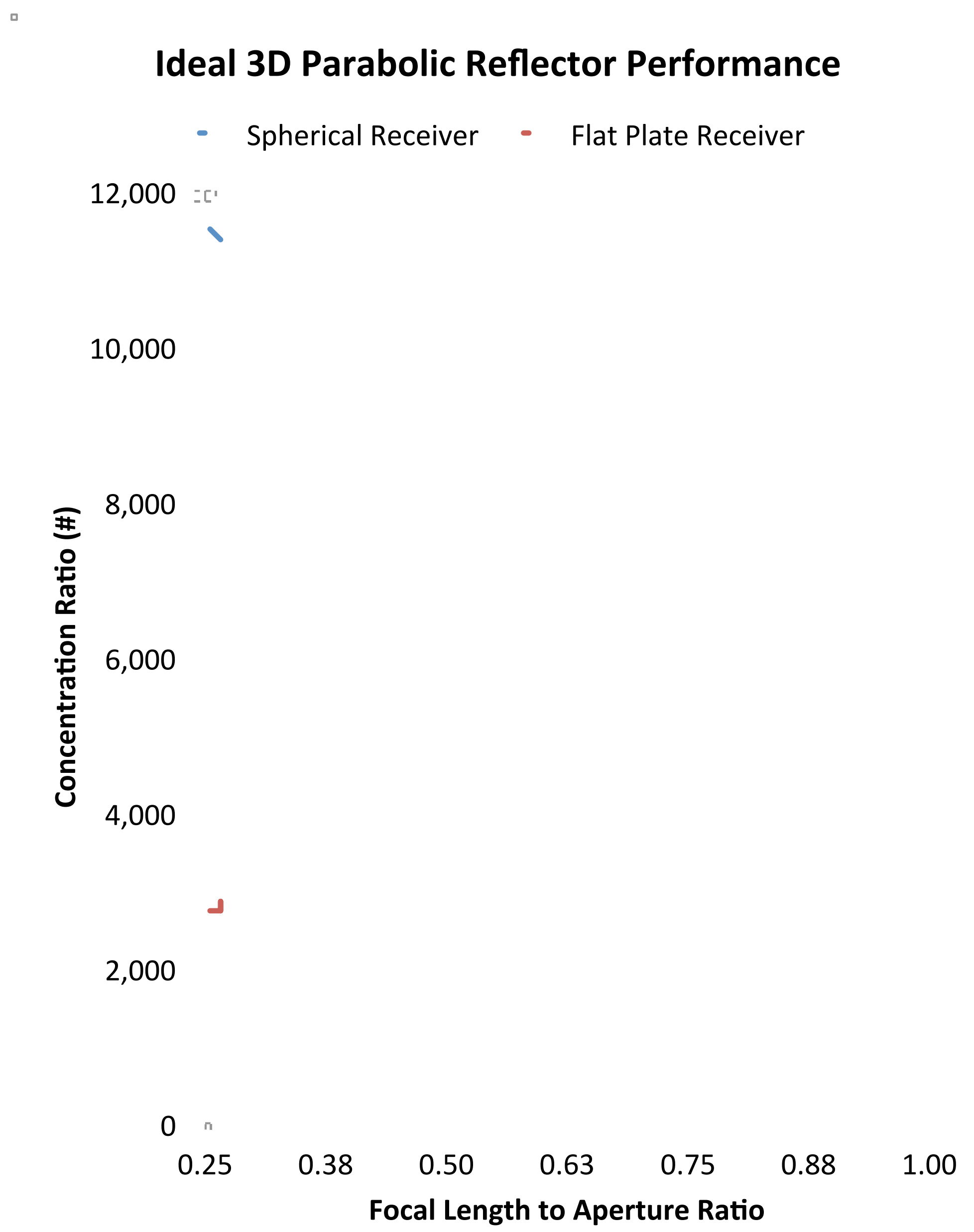
Volatile Materials in Asteroids

- 10 to 50% of known large asteroids are likely hydrated CI-CM-like

- CI-CM chondrites are typically 10-20% water by weight in the form of hydrated minerals

- CI-CM materials are friable and may be in rubble piles with regolith or in blocks on asteroids.

Parabolic Reflector Performance



2m Diameter Solar Furnace Demonstration on A Stainless Steel Bolt

The Solar Furnace at White Sands

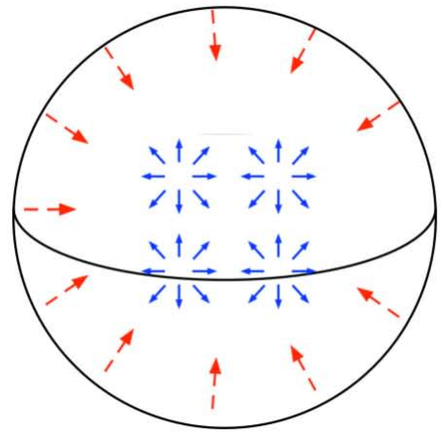
What Happens When Highly Concentrated Sunlight Hits An Asteroid-Like Rock?

The limiting case in which volatile release stays in place and can not diffuse through rock (assuming an ideal gas):

$$P_g = \frac{\rho f_g R_g T}{M f_V} = \sigma_{g\max}$$

- P_g = Gas pressure in rock, 4.68x10^{08} Pa
- f_g = Volatile mass fraction of rock, (0.2)
- R_g = Ideal Gas Constant, J/(molK)
- M = Molecular weight of gas, kg/mol (0.018 for Water)
- f_v = Void Fraction of Rock (typically 0.2)
- $\sigma_{g\max}$ = Resulting Tensile Stress, Pa

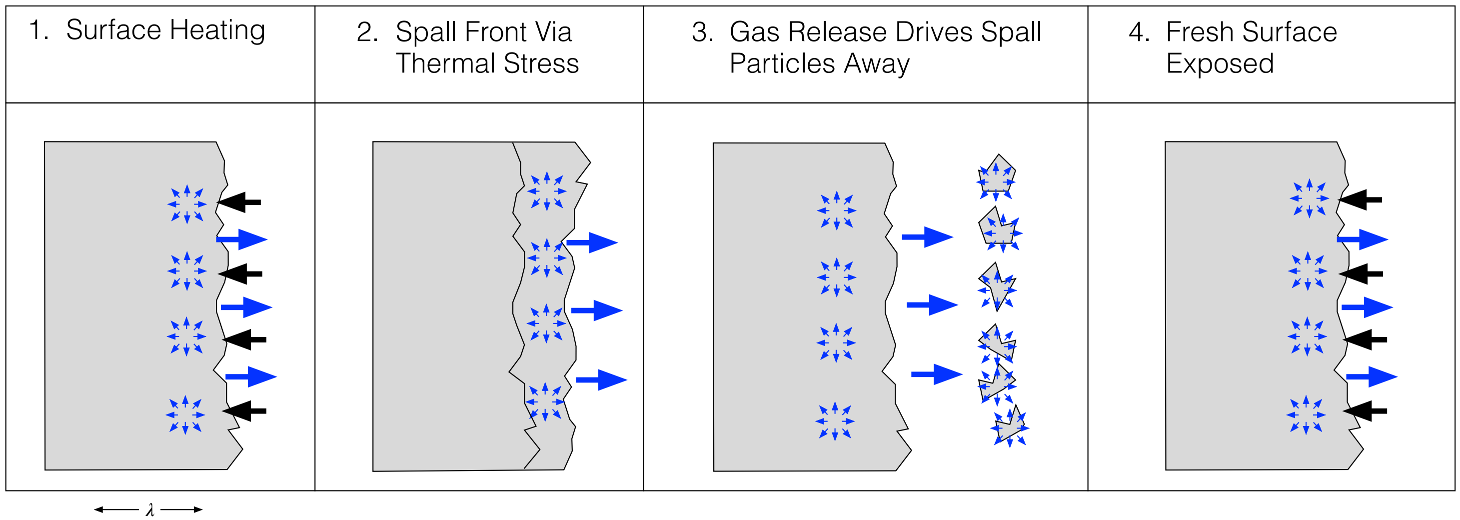
Gas Pressure Outward



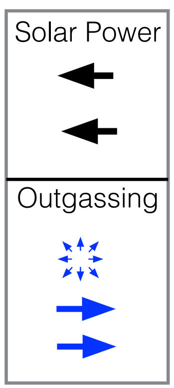
Heat Flux Inward Resulting In Gas Release

10 To 100 Times The Tensile Stress Of Typical Carbonaceous Chondrite Meteorites

The Patent Pending Optical Mining Process Does Not Require Costly or Massive Electric Power or Robotics

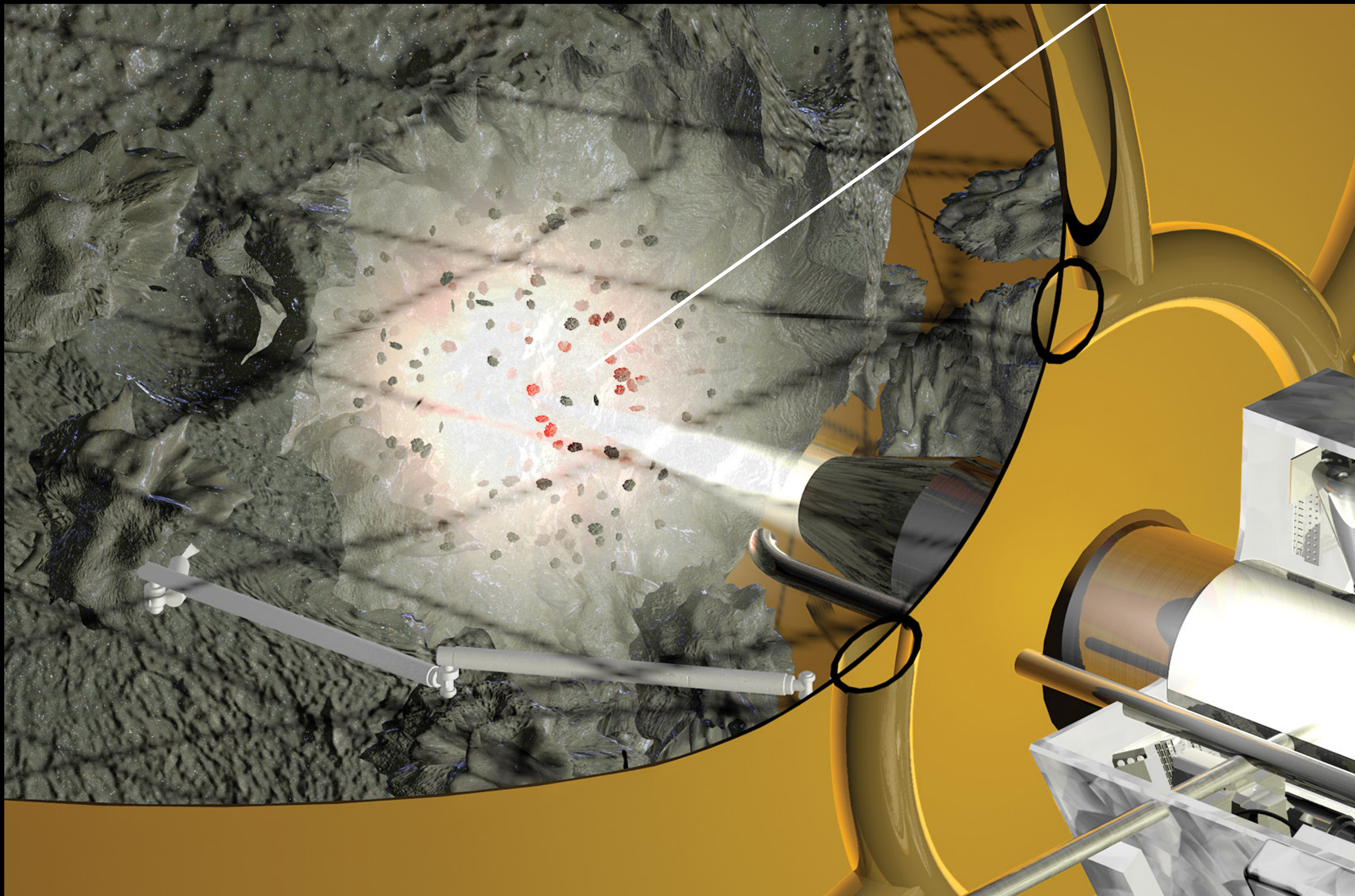


Progress continues at ≈1m/hr at surface blackbody peak temperature ≈1000K:



1. Cold surface temperature rises to near the blackbody temperature associated with the intensity of the applied radiation over a period of a few seconds establishing a mm scale hot layer.
2. A spall surface is created primarily by compressive thermal stress aided by thermal shear and gas pressure gradient.
3. mm scale spall particles fully outgas in seconds as surface outgassing drives them from the asteroid.
4. Process repeats in a cyclic fashion exposing new surface to applied radiation.

Our Physics-Math Model Shows How It Works



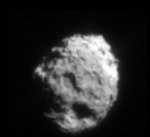
Can We Do That in Space?

Let’s *Think*… Like We *Live* In Space

Cold-Dark

Debris

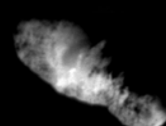
1.4 kW/m^2

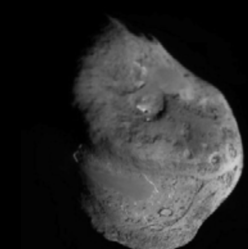


Vacuum

150,000,000

Zero Gee





Radiation

A 40ft Diameter Reflector in Space in 1992

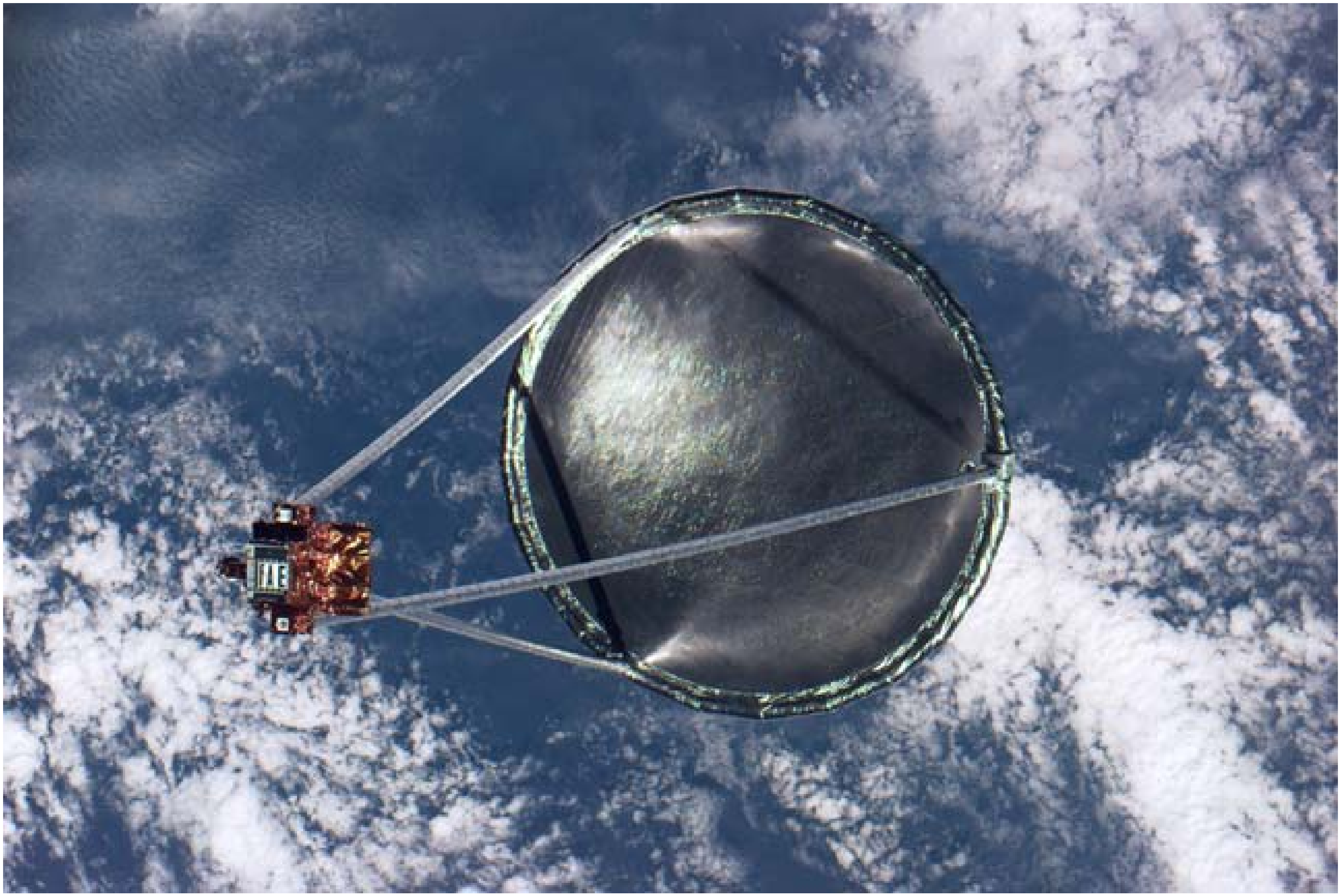
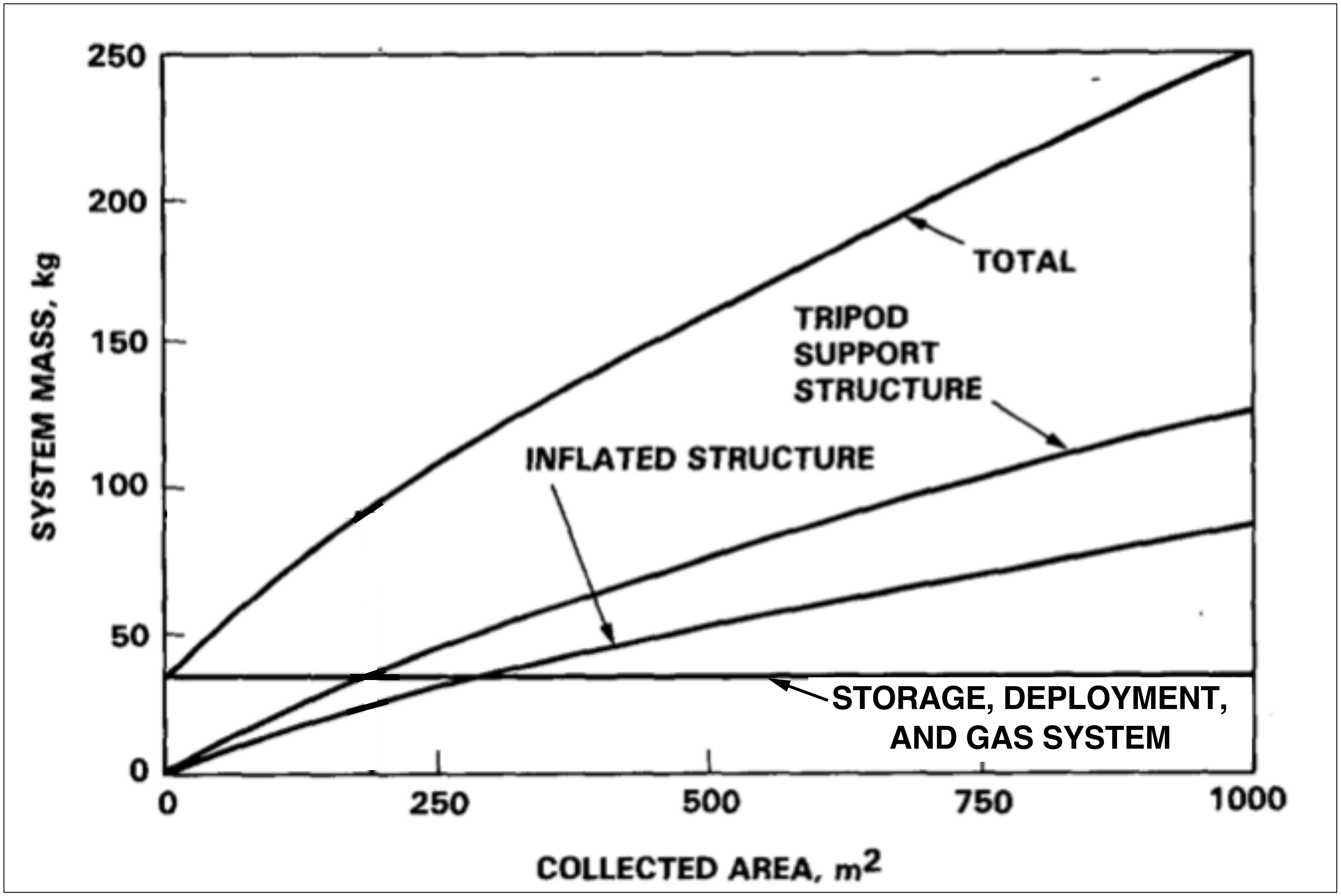
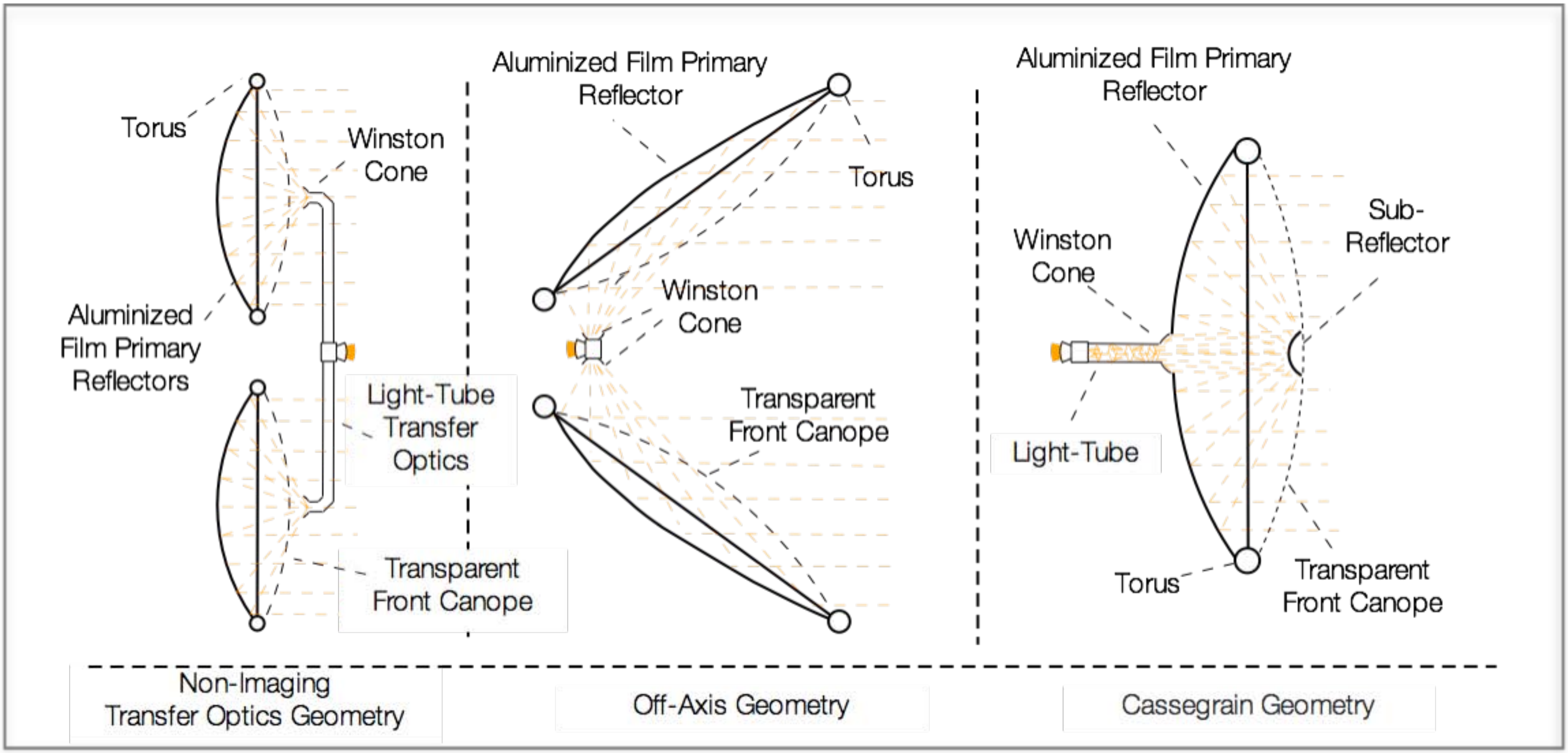


Photo of Precision 14m Diameter Inflatable Reflector In Space Shuttle Flight Demonstration

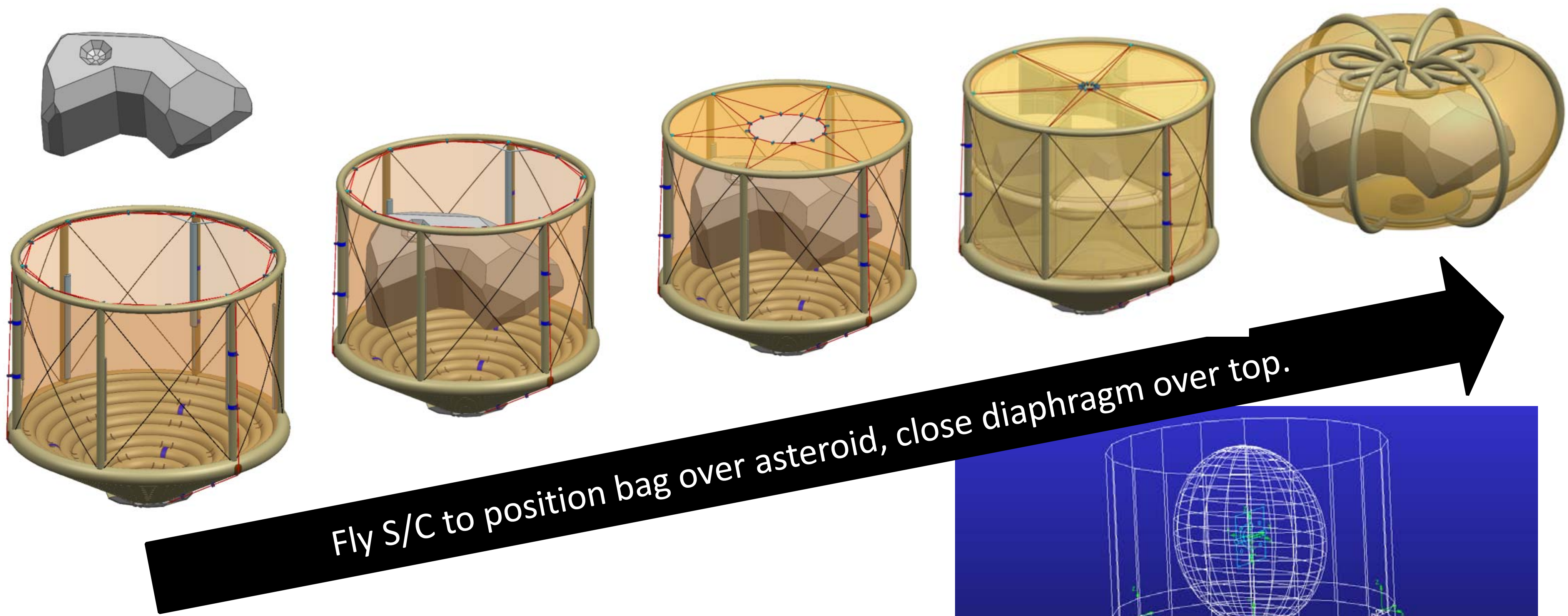
Inflatable Reflector Scaling



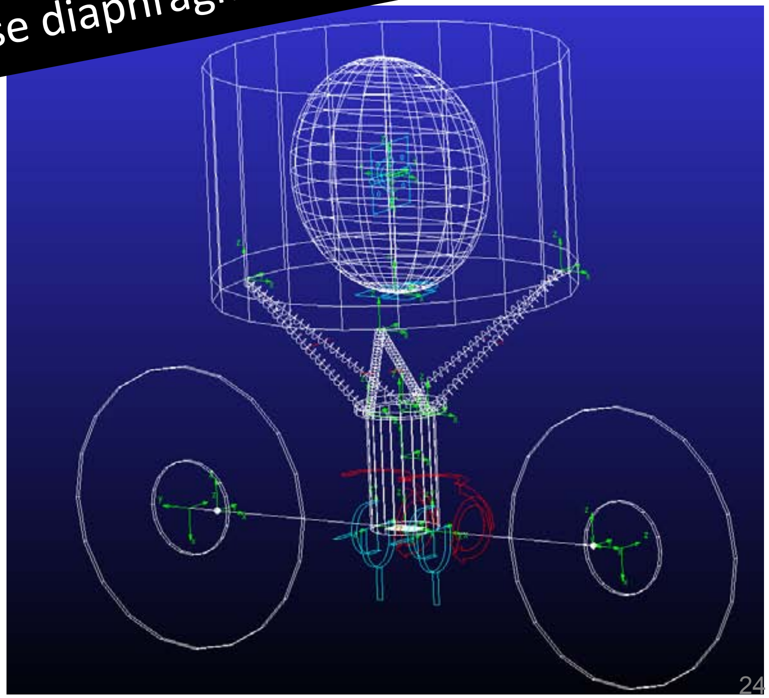
Some Possible Inflatable Reflector Configurations



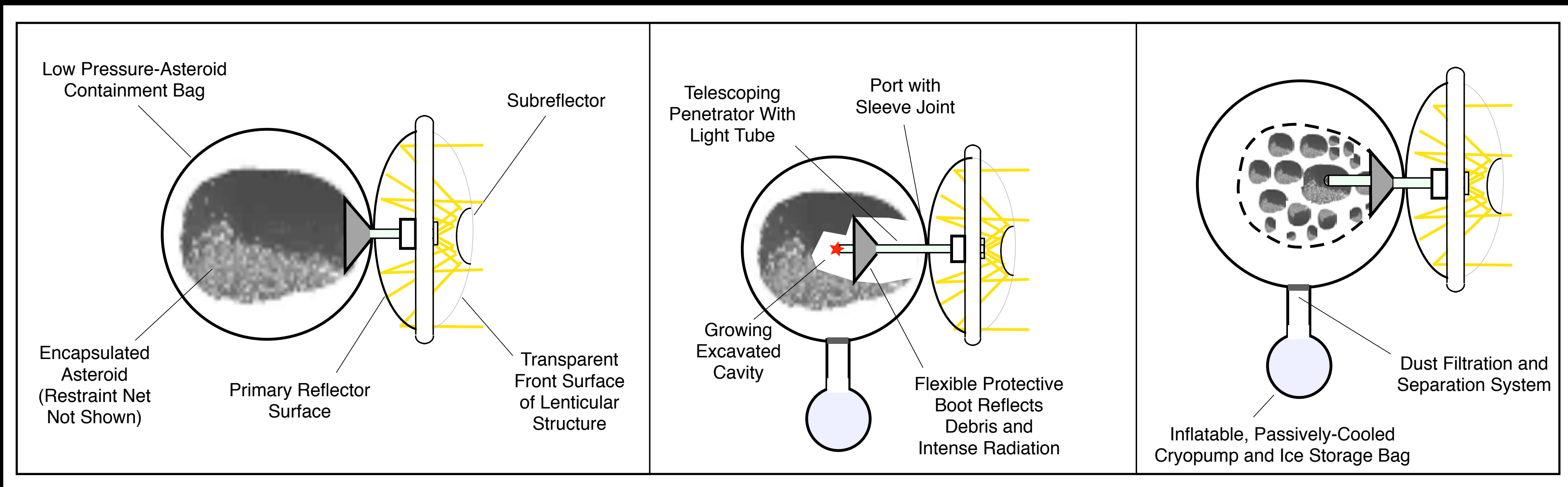
Capture Sequence: Currently TRL-4



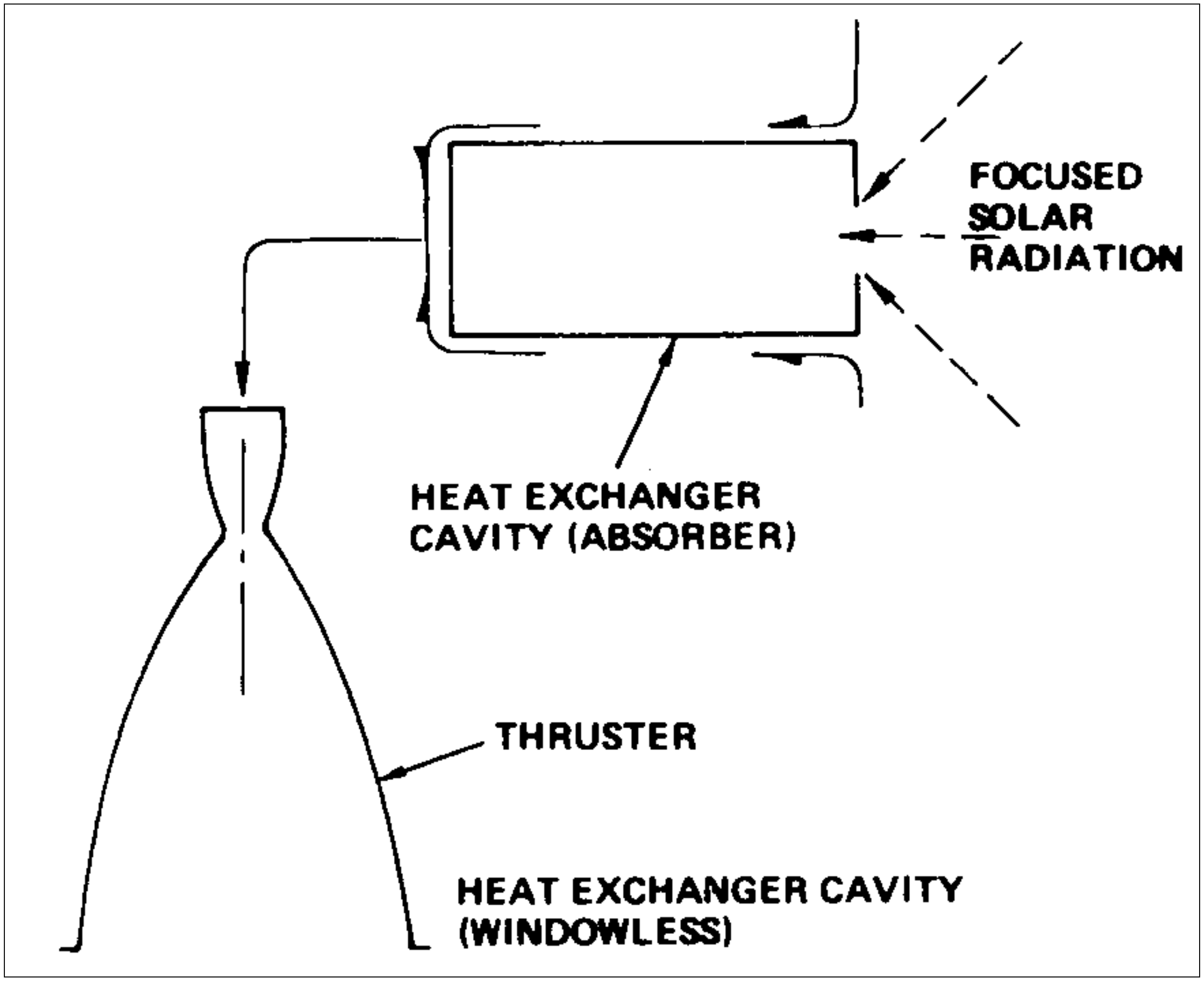
- S/C approaches and matches spin.
- When asteroid is centered in the bag, close top diaphragm.
- Mechanism provides elasticity to control loads to solar arrays .



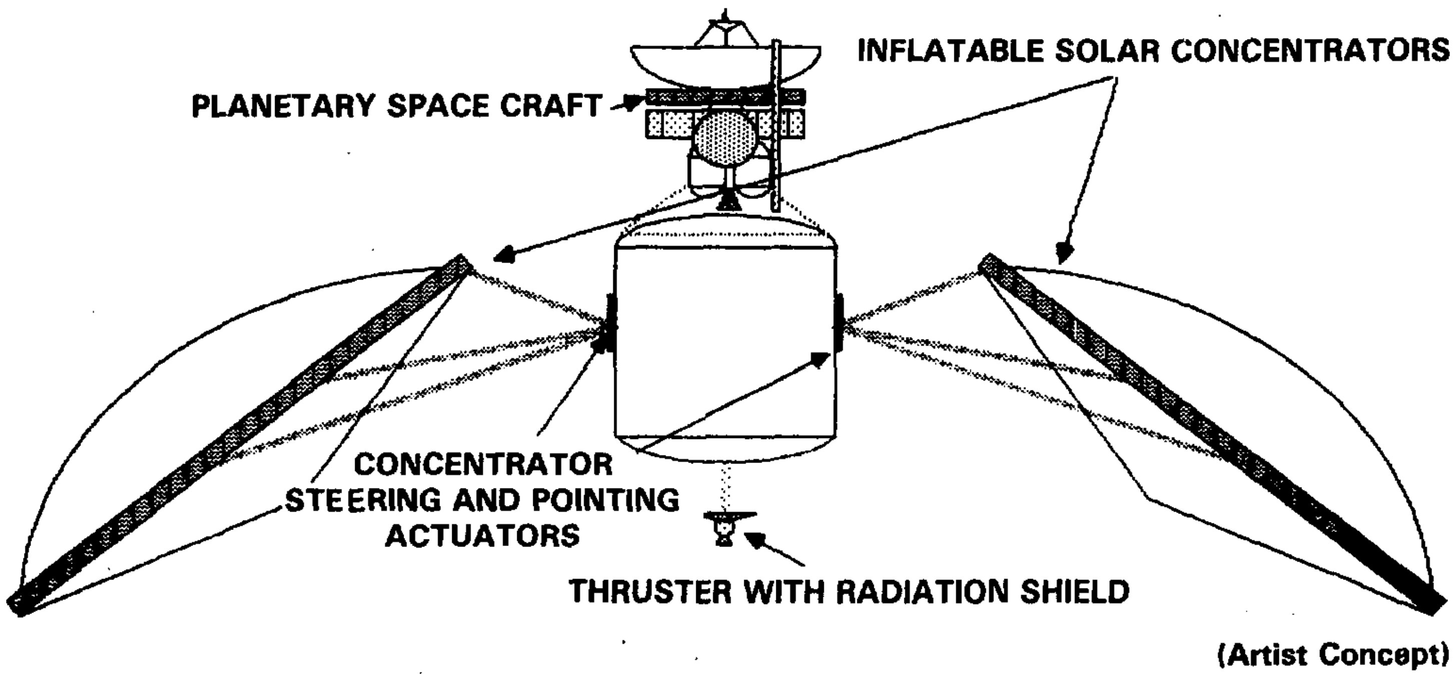
ISRU Concept

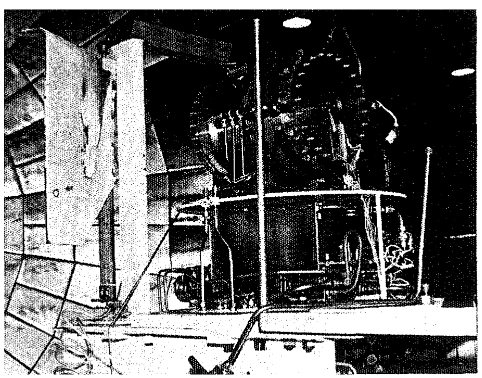


Solar Thermal Propulsion

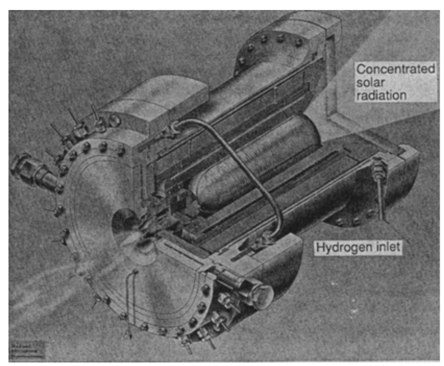


Solar Thermal Rocket (STR) Propulsion



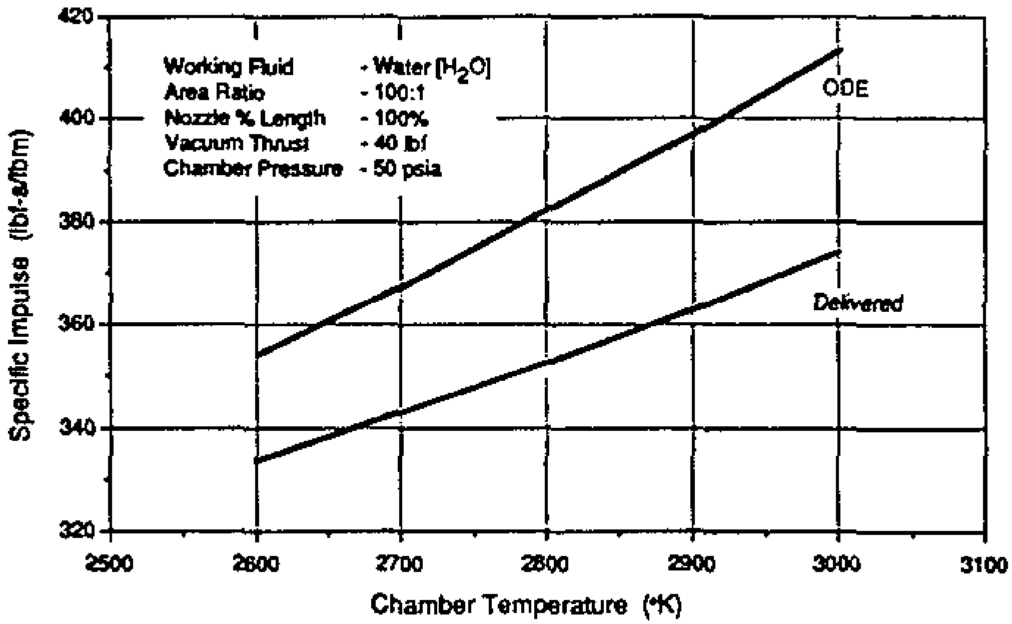


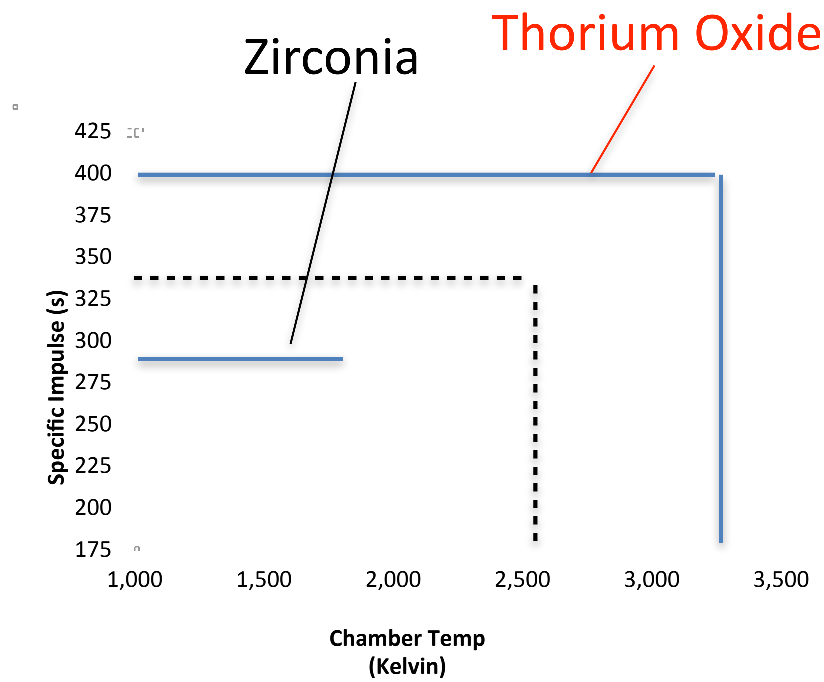
Rocketdyne STR Thruster on Air Force Test Stand in 1992



- Currently at TRL 3-4 Based On Decades of Ground Development
- Key Features:
  - 100X higher Thrust Than SEP
  - Omnivorous for propellant type (H2O, CO2, etc…)
  - Isp>300s for H20 Propellant
  - Relatively simple and robust in concept

Water-Based Solar Thermal Rocket Specific Impulse Performance



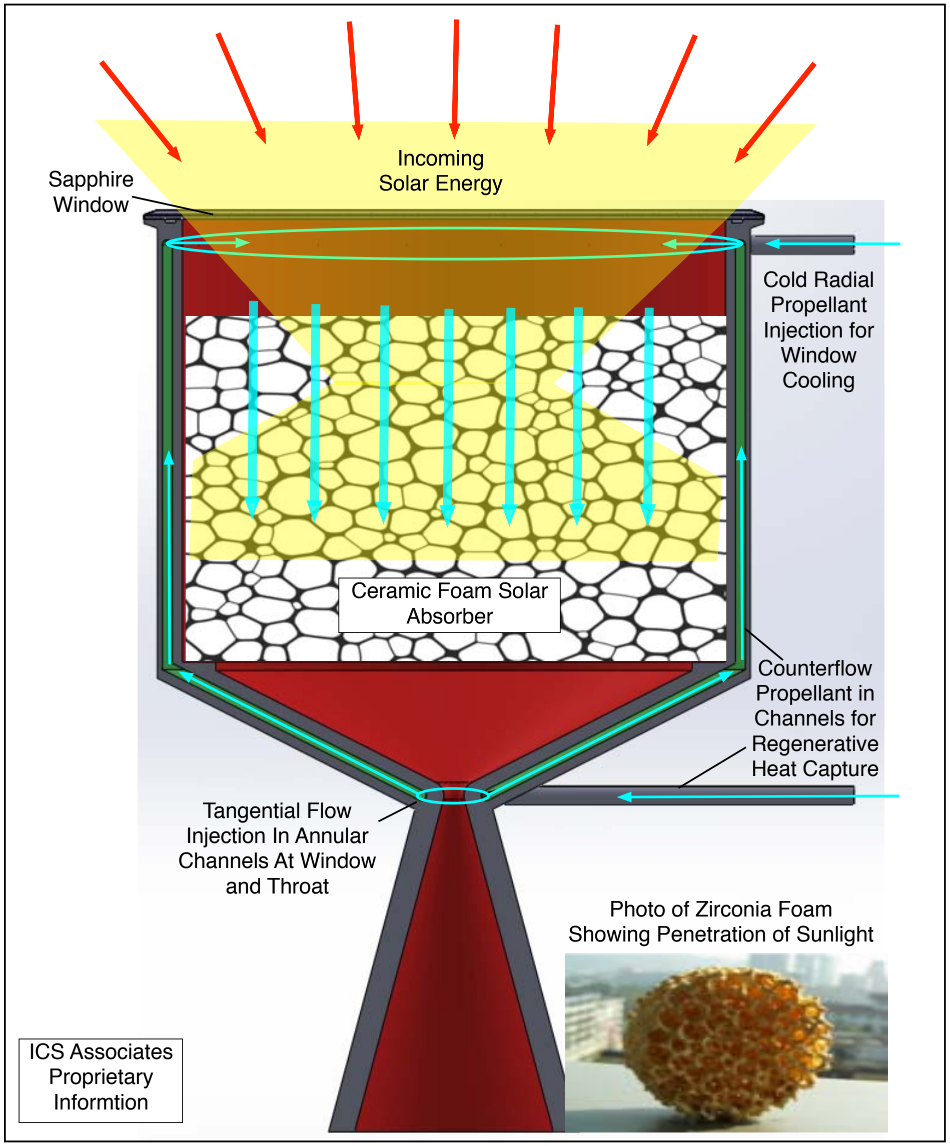


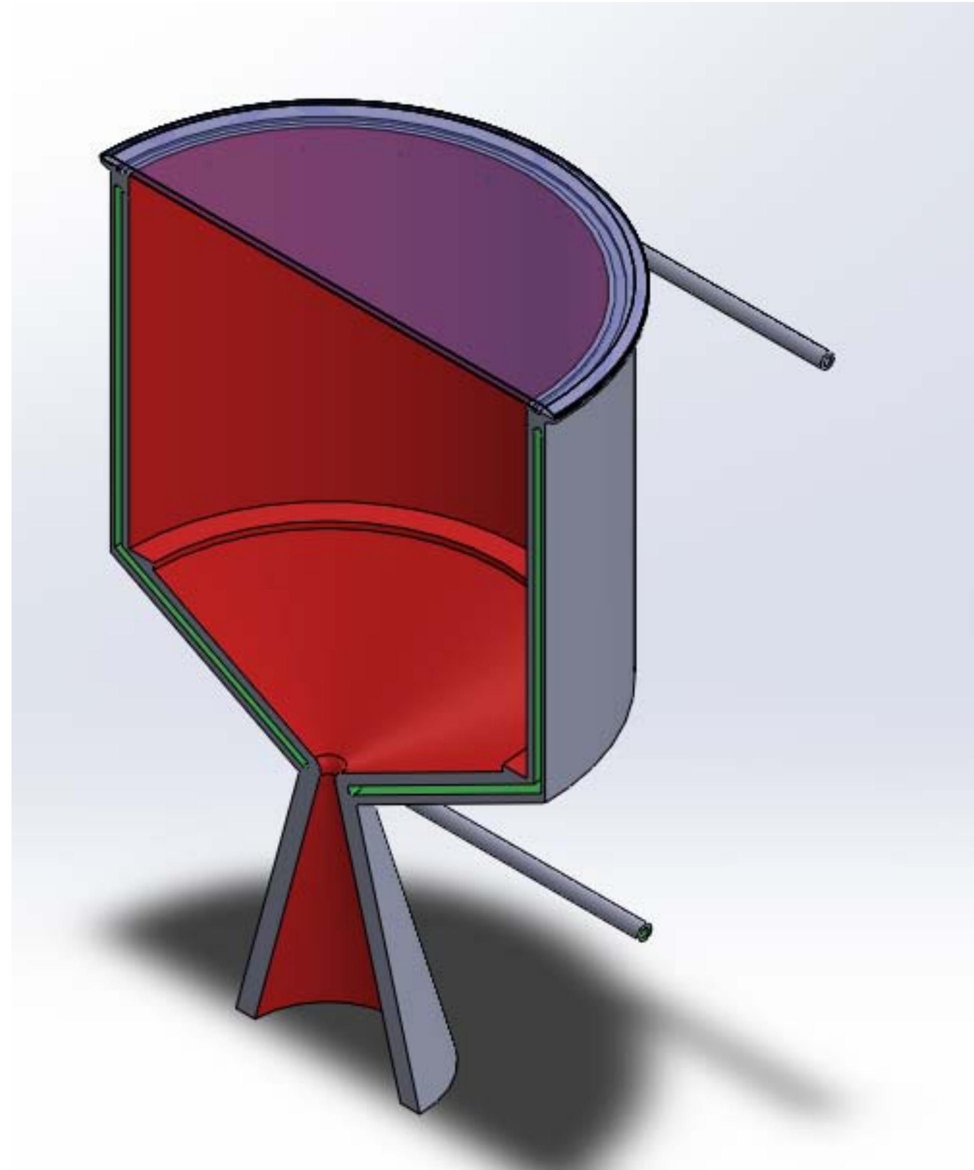
As reported in Figure 11 of AIAA-92-1719, "Solar Thermal Propulsion Status and Future", JAMES SHOJI, PATRICK FRYE, and JAMES MCCLANAHAN from the Space Programs and Technologies Conference. March 1992

Scaled from personal communication with James French, August 2013 based on ODK code run with performance derated to account for real losses.

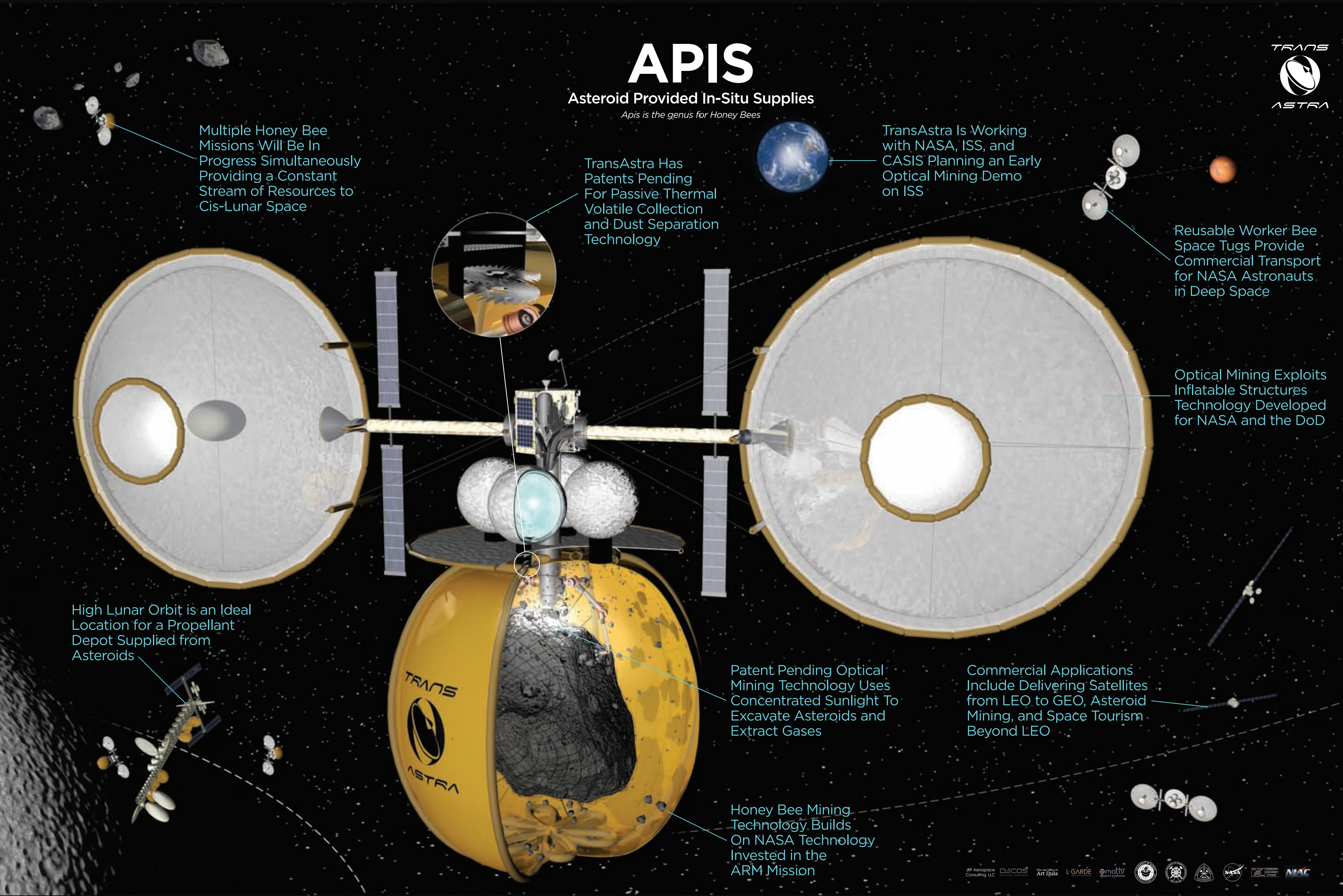
The two results are effectively in agreement, so we will use them. They are significantly derated from ideal calculations based on experience with real rocket engines.

The Omnivore Thruster

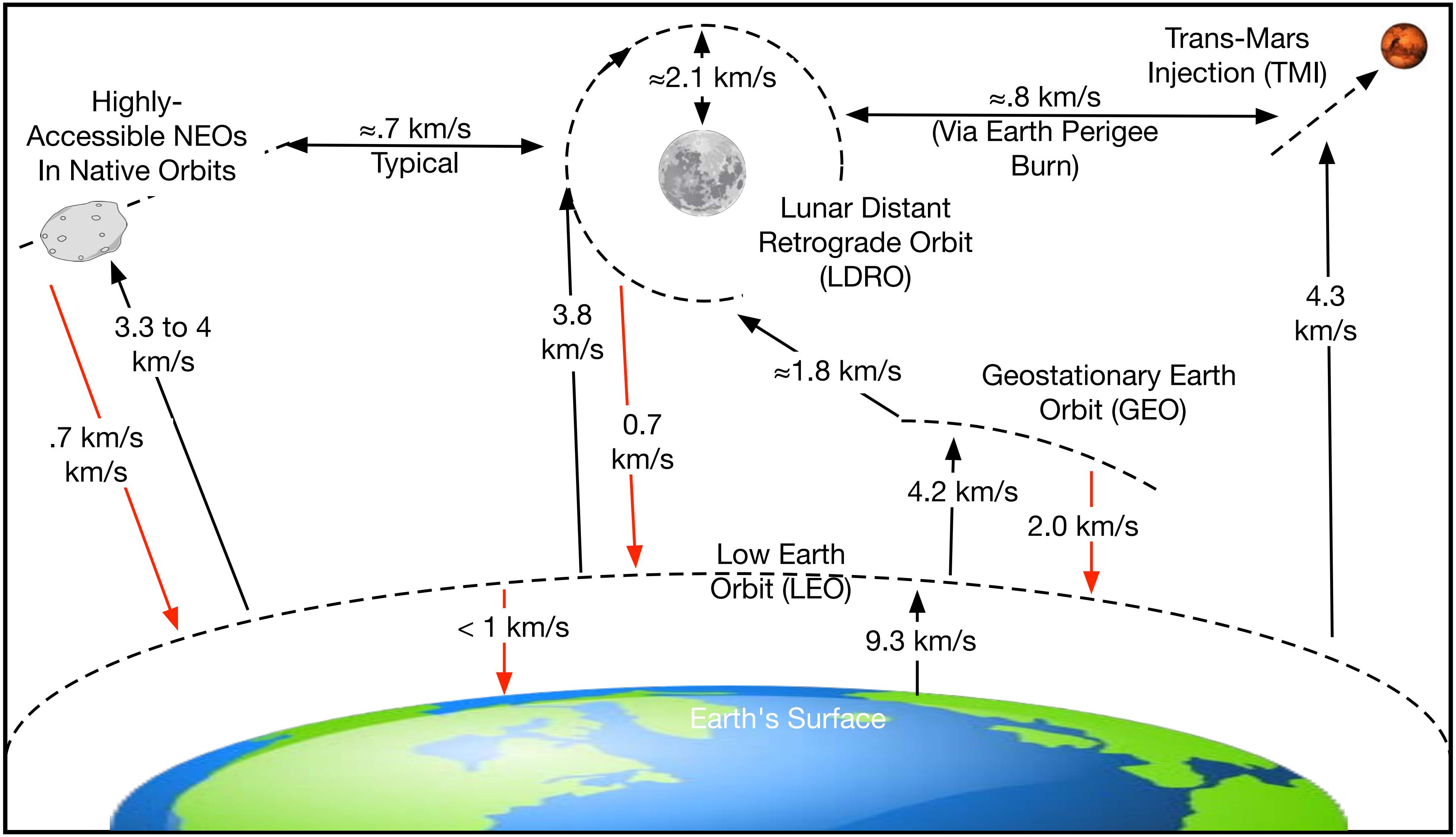




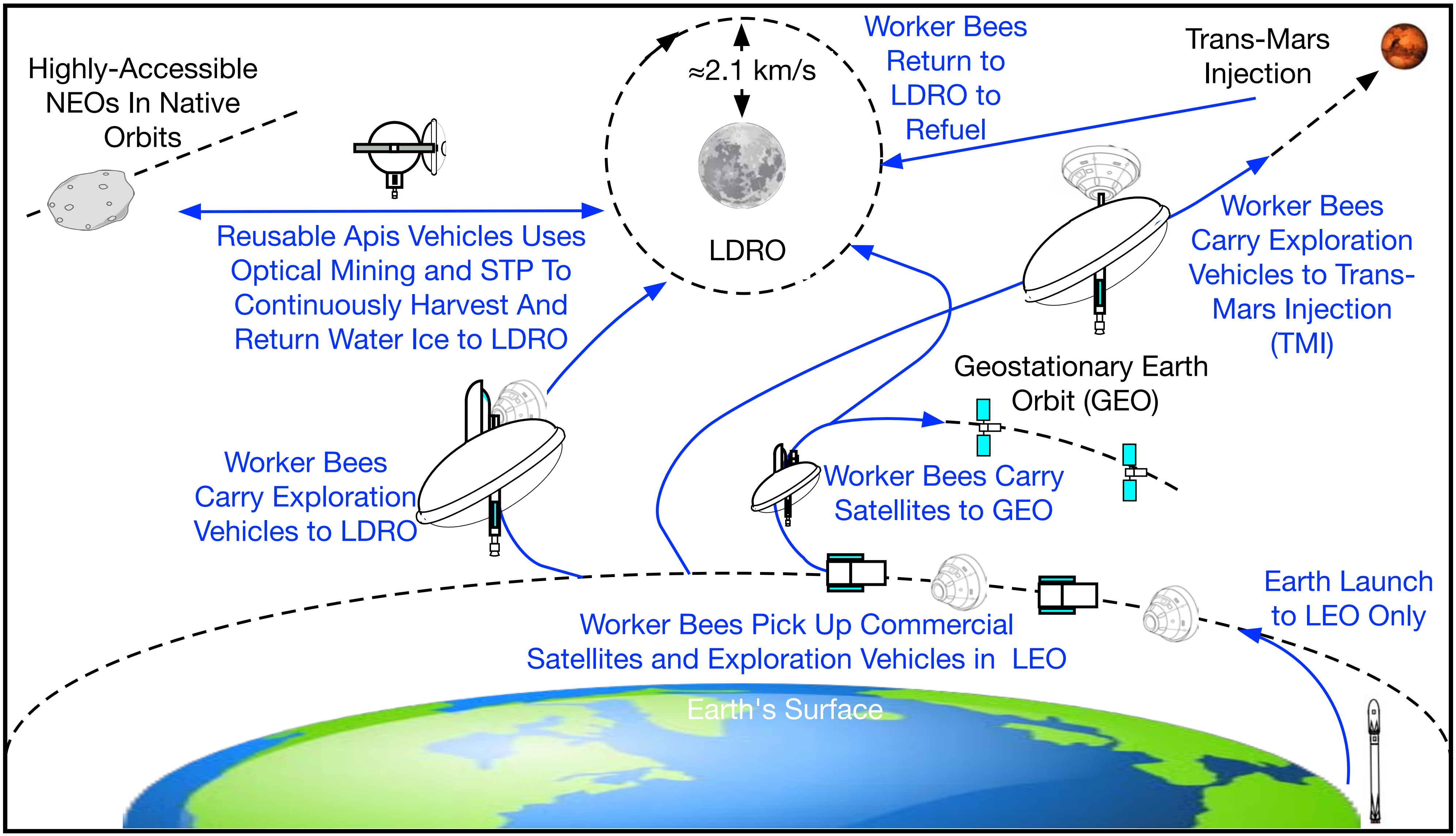
Zirconia Provides Isp=170s, Thorium Oxide Provides Isp=350s


APIS
Asteroid Provided In-Situ Supplies
Apis is the genus for Honey Bees
TRANS ASTRA
Multiple Honey Bee Missions Will Be In Progress Simultaneously Providing a Constant Stream of Resources to Cis-Lunar Space
TransAstra Has Patents Pending For Passive Thermal Volatile Collection and Dust Separation Technology
TransAstra Is Working with NASA, ISS, and CASIS Planning an Early Optical Mining Demo on ISS
Reusable Worker Bee Space Tugs Provide Commercial Transport for NASA Astronauts in Deep Space
Optical Mining Exploits Inflatable Structures Technology Developed for NASA and the DoD
High Lunar Orbit is an Ideal Location for a Propellant Depot Supplied from Asteroids
TRANS ASTRA
Patent Pending Optical Mining Technology Uses Concentrated Sunlight To Excavate Asteroids and Extract Gases
Commercial Applications Include Delivering Satellites from LEO to GEO, Asteroid Mining, and Space Tourism Beyond LEO
Honey Bee Mining Technology Builds On NASA Technology Invested in the ARM Mission
NASA
NIAC

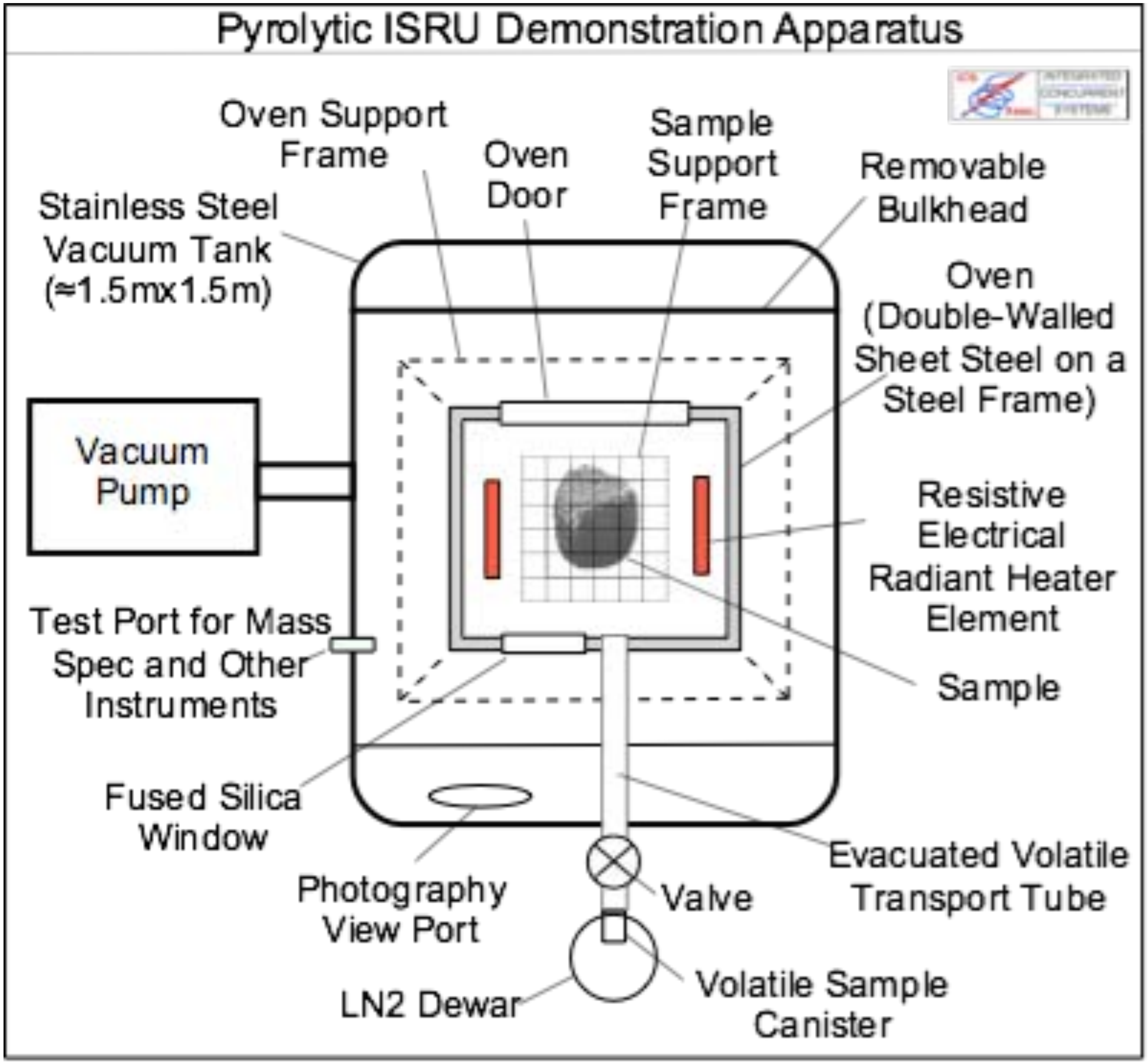
A Map of Cis-Lunar Space



Worker Bee Transportation Network

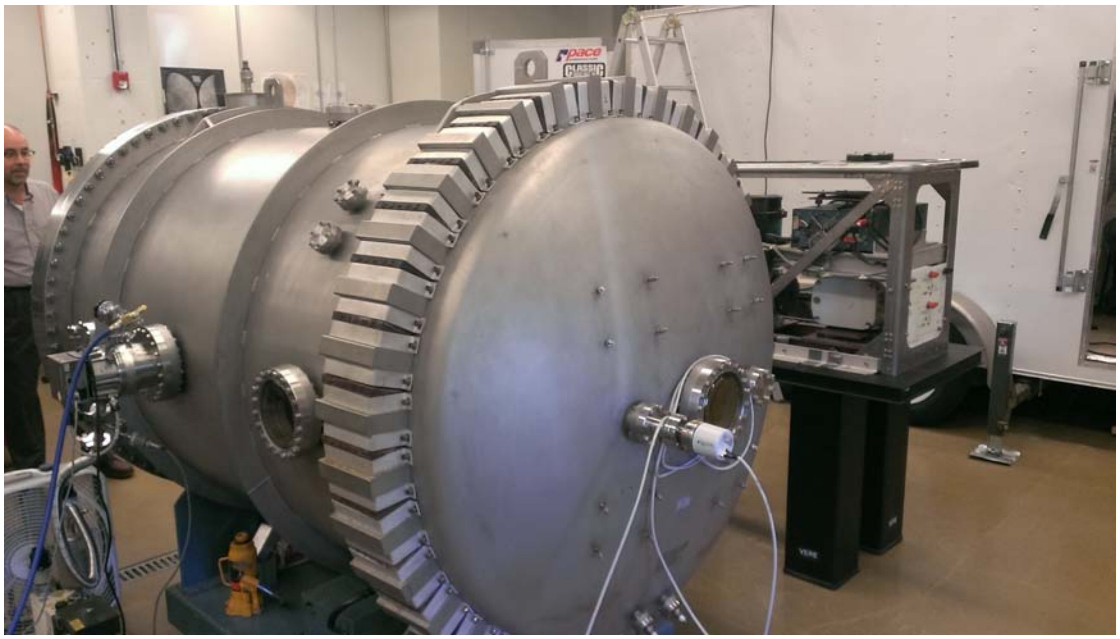


Coordinated With ESI



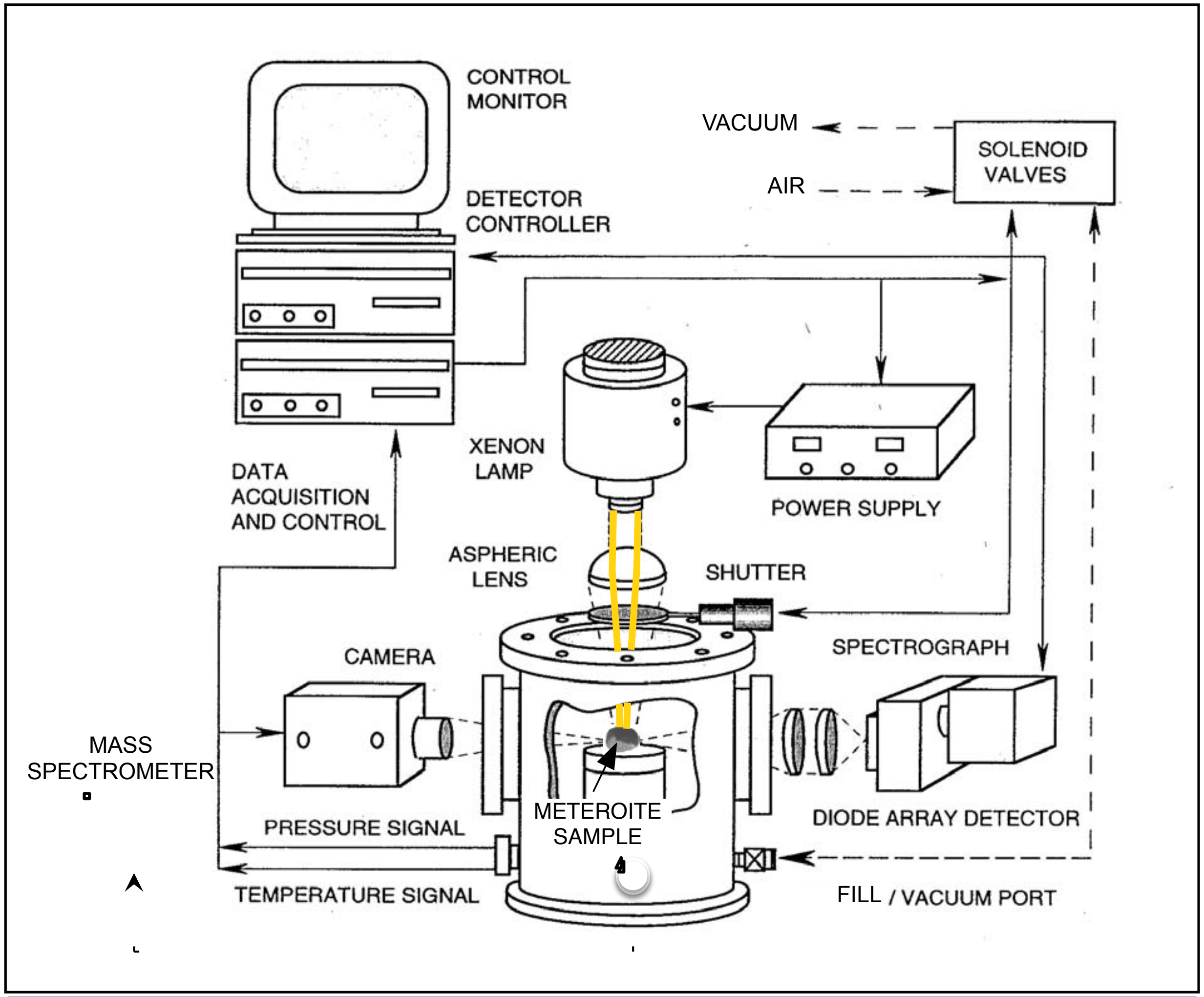
Architect: Sercel, PI: Gertsch (MoS&T), Lab: Dreyer (CSM)

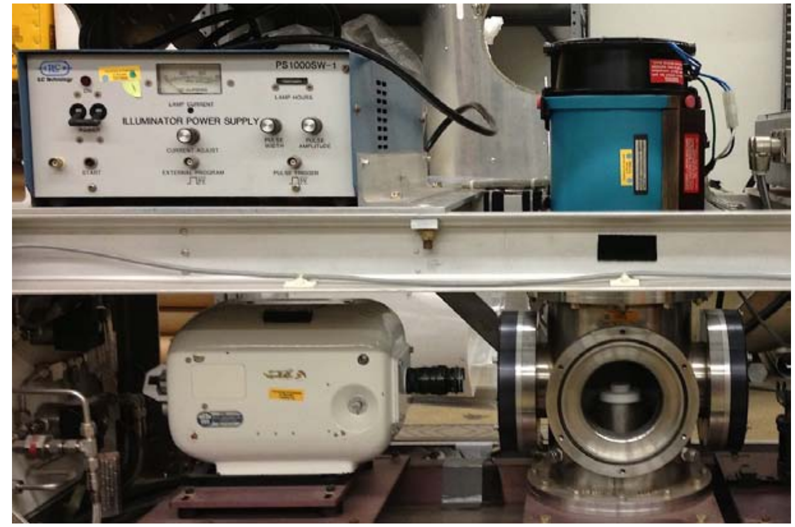
Our Solar Thermal Oven Simulator

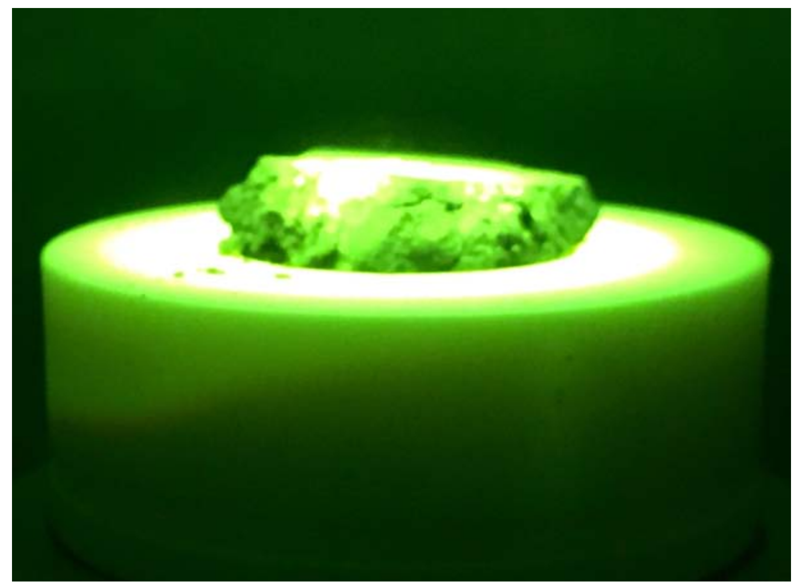


Year 1 Oven Development and Initial Tests Complete
Year 2 Research Program Now Gearing Up

SBIR Sub-Scale Optical Mining Demonstrations

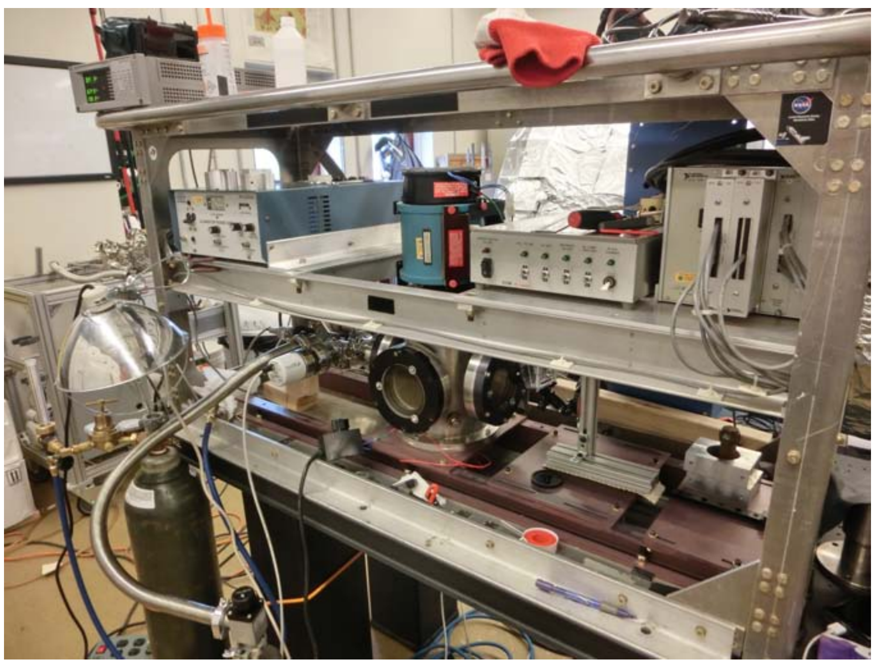


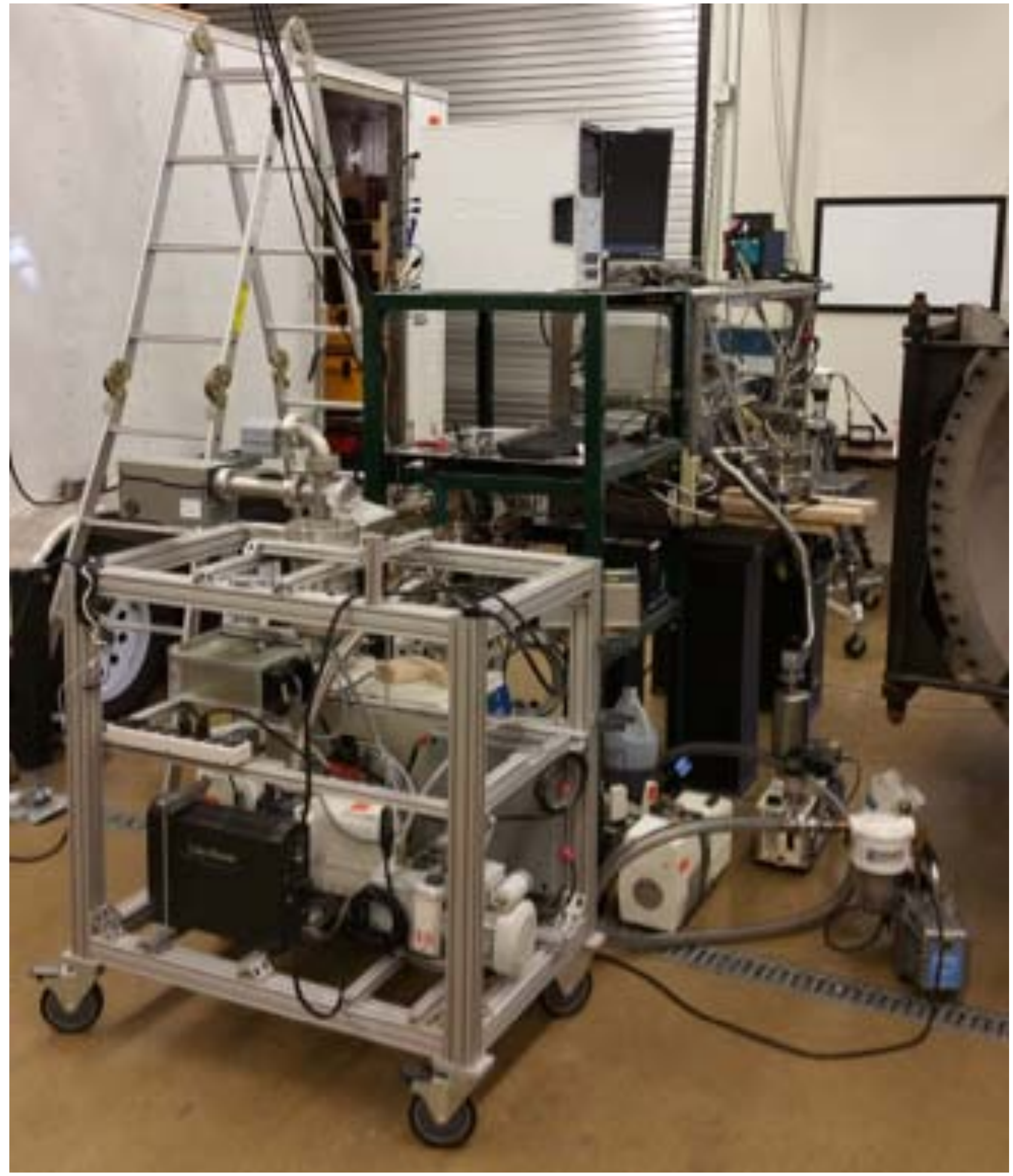




Architect and PI: Sercel, Lab: Dreyer (CSM)

CSM Lab



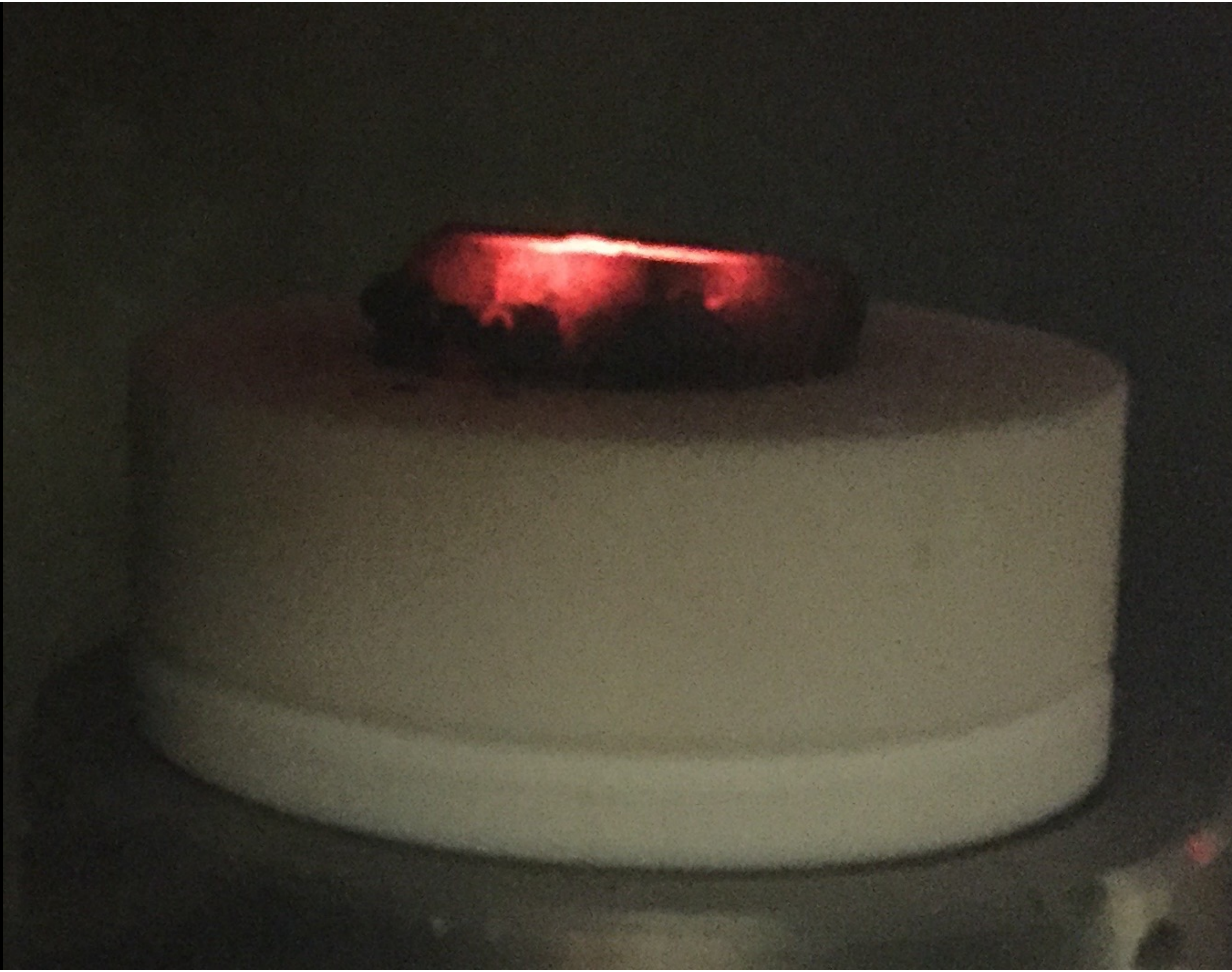


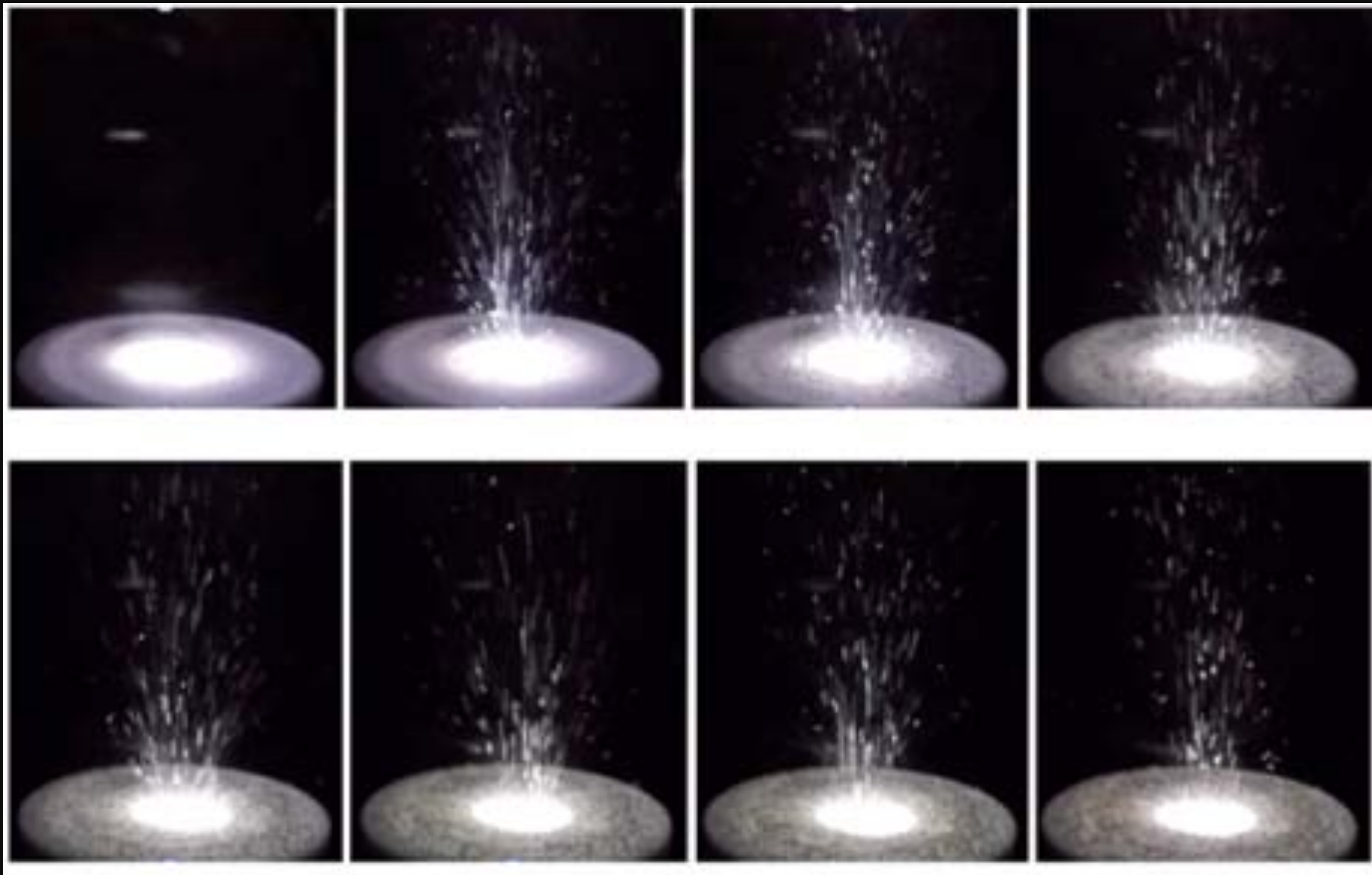
Experimental Methods

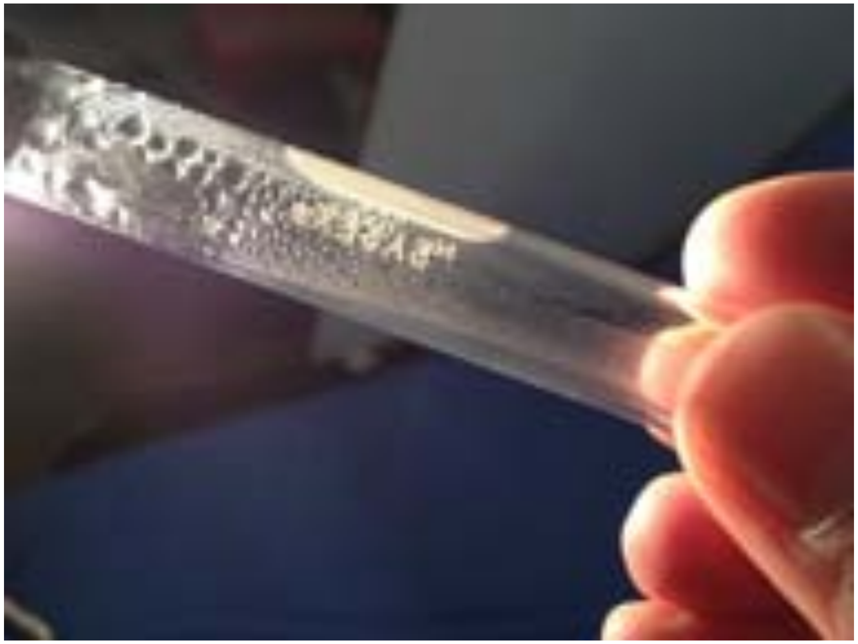
- Xenon Arc Lamp, nominally 150 W
- Focus variable from ~10 to 1000 W/cm^2
- Video: 1280 x 720, 240 fps
- Mass Spectrometer
  - Before and After, 1-200 amu
  - 8 mass values every 3 seconds during run
- Chamber pressure recorded at 20Hz
- Sample Measurements
  - Before and After mass
  - Before and After photographs

37 Subscale Optical Mining Tests Have Been Completed

Test #	Sample Type	Form	Result	Test #	Type	Form	Result
1	Serpentine	Block	preparatory	20	Tray	None	Control
2	Serpentine	Block	preparatory	21	Lizardite	Thin slice	Floatation
3	Serpentine	Block	preparatory	22	UCF Simulant 2	Thin slice	Off gassing
4	Lizardite	Block	Particle spalling	23	UCF Simulant 2	Block	Preparation test
5	Lizardite	Block	Explosive fracturing	24	UCF Simulant 2	Block	Preparation test
6	Lizardite	Thin slice	Floatation	25	Lizardite	Block	Floatation
7	Murchison	Thin slice	Floatation	26	Lizardite	Block	Preparation test
8	Serpentine	Thin slice	Control	27	UCF Simulant 2	Powder	Cancelled
9	Anorthosite	Thin slice	Control	28	Lizardite	Block	Floatation
10	Harzburgite	Thin slice	Control	29	Lizardite	Block	Irradiance Testing
11	Serpentine	Thin slice	Control	30	Lizardite	Block	Irradiance Testing
12	Serpentine	Thin slice	Control	31	Lizardite	Block	Particle spalling, Floatation
13	Murchison	Thin slice	Floatation	32	UCF Simulant 2	Block	Spalling
14	UCF Simulant 1	Thin pieces	Melting	33	UCF Simulant 2	Block	Spalling
15	UCF Simulant 1	Block	Off gassing	34	UCF Simulant 2	Block	Cryotrapping
16	Jbilet	Block	Off gassing	35	UCF Simulant 2	Block	Cryotrapping
17	Lizardite	Thin slice	Floatation	36	Murchison	Block	Cryotrapping, Particle spalling
19	Ceramic Base	none	Control	37	Lizardite	Asteroid Regolith	Spalling/Floatation plume

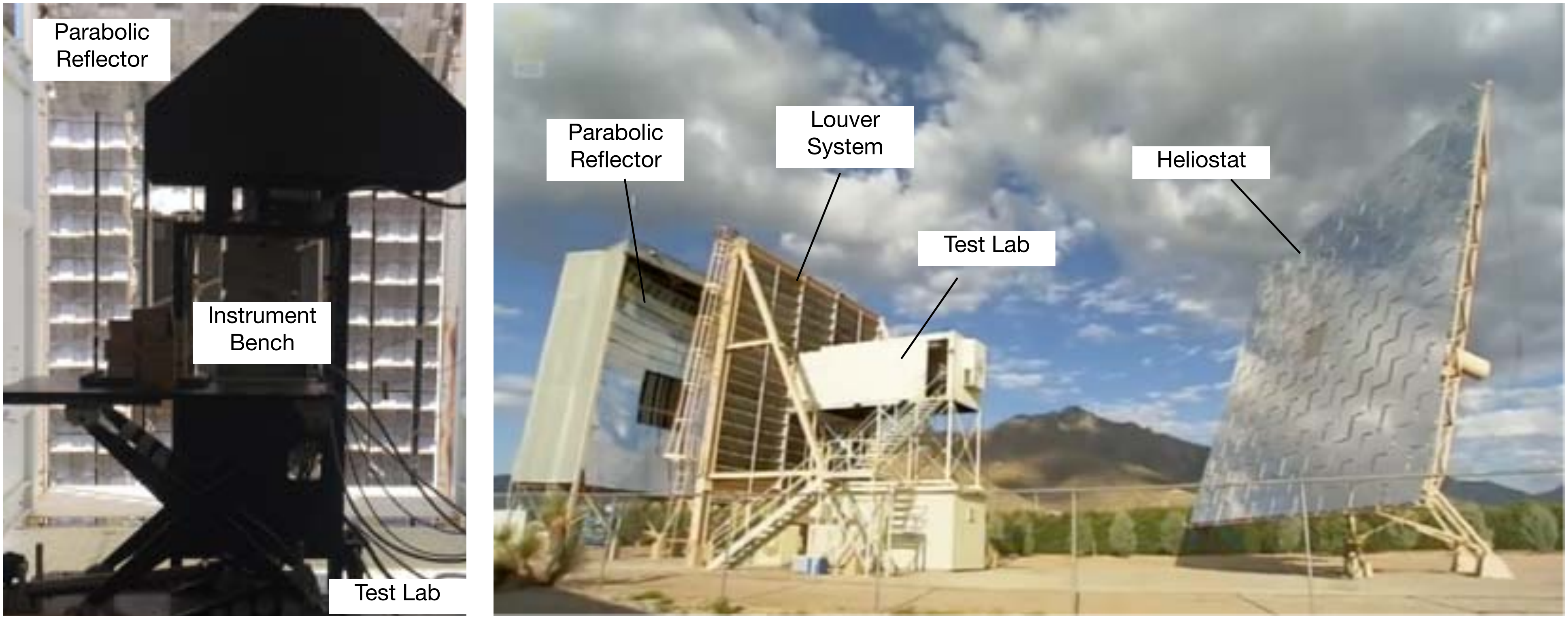




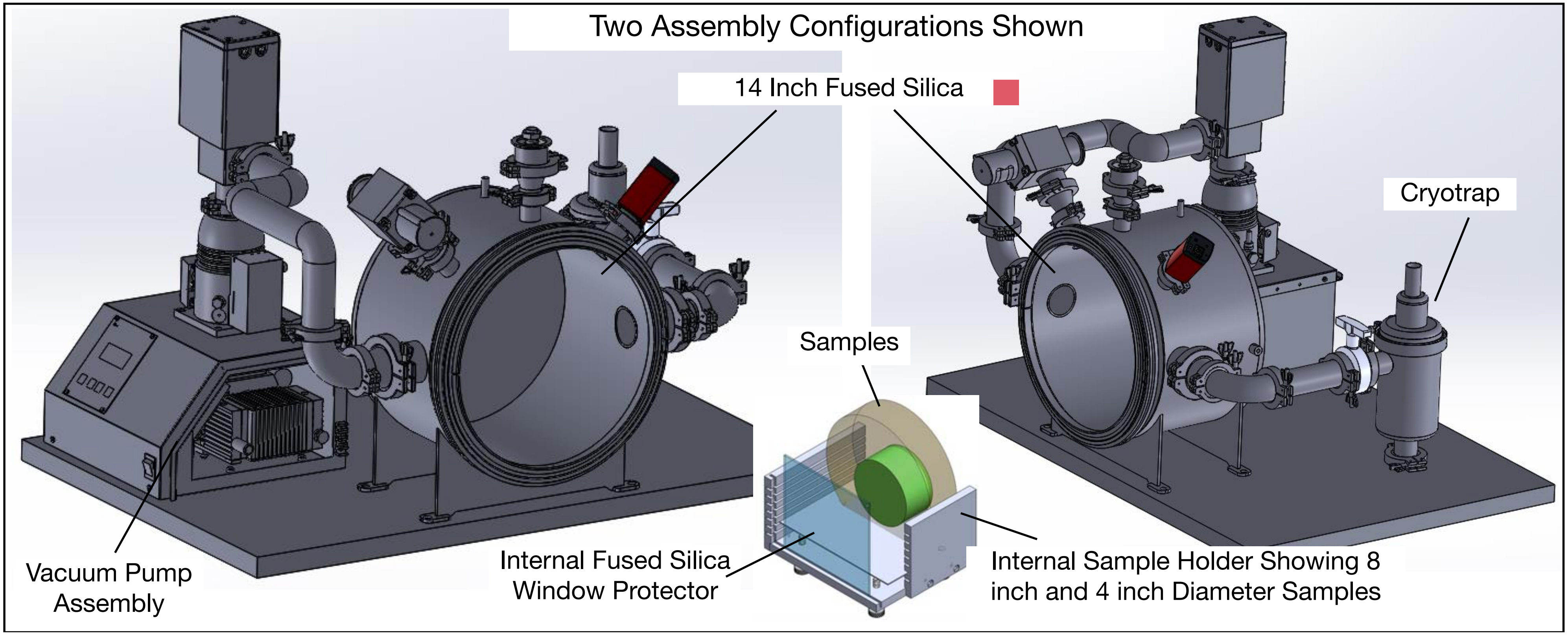



PYREX

2015 Full Scale Demonstration



Aspects funded by SBIR, NIAC and Private Sponsors


Two Assembly Configurations Shown
14 Inch Fused Silica
Cryotrap
Samples
Vacuum Pump Assembly
Internal Fused Silica Window Protector
Internal Sample Holder Showing 8 inch and 4 inch Diameter Samples


HiCUBE

Full Scale Optical Mining Demonstrated at White Sands

The PI Holding A High Fidelity Simulant After It Was Spalled In Vacuum. Spall products can be seen in the vacuum chamber falling into the collection

Cryotrapped volatiles can be seen after the removal of the cryotrap from the vacuum system after a test run using low fidelity gypsum based simulant.

Successful Optical Mining Demonstration on University of Central Florida Asteroid Simulant

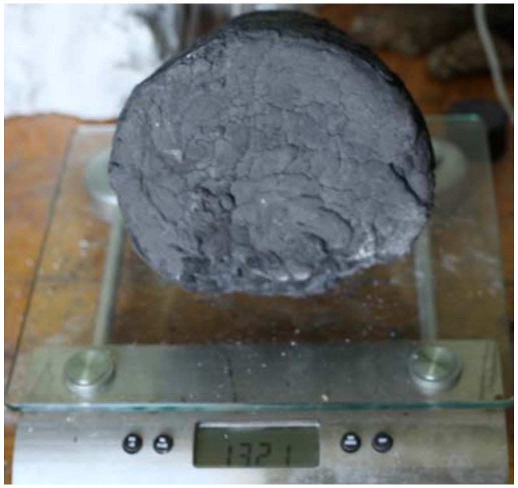


Image Before Test:
1.32Kg

Image After Test
1.19Kg with Spall

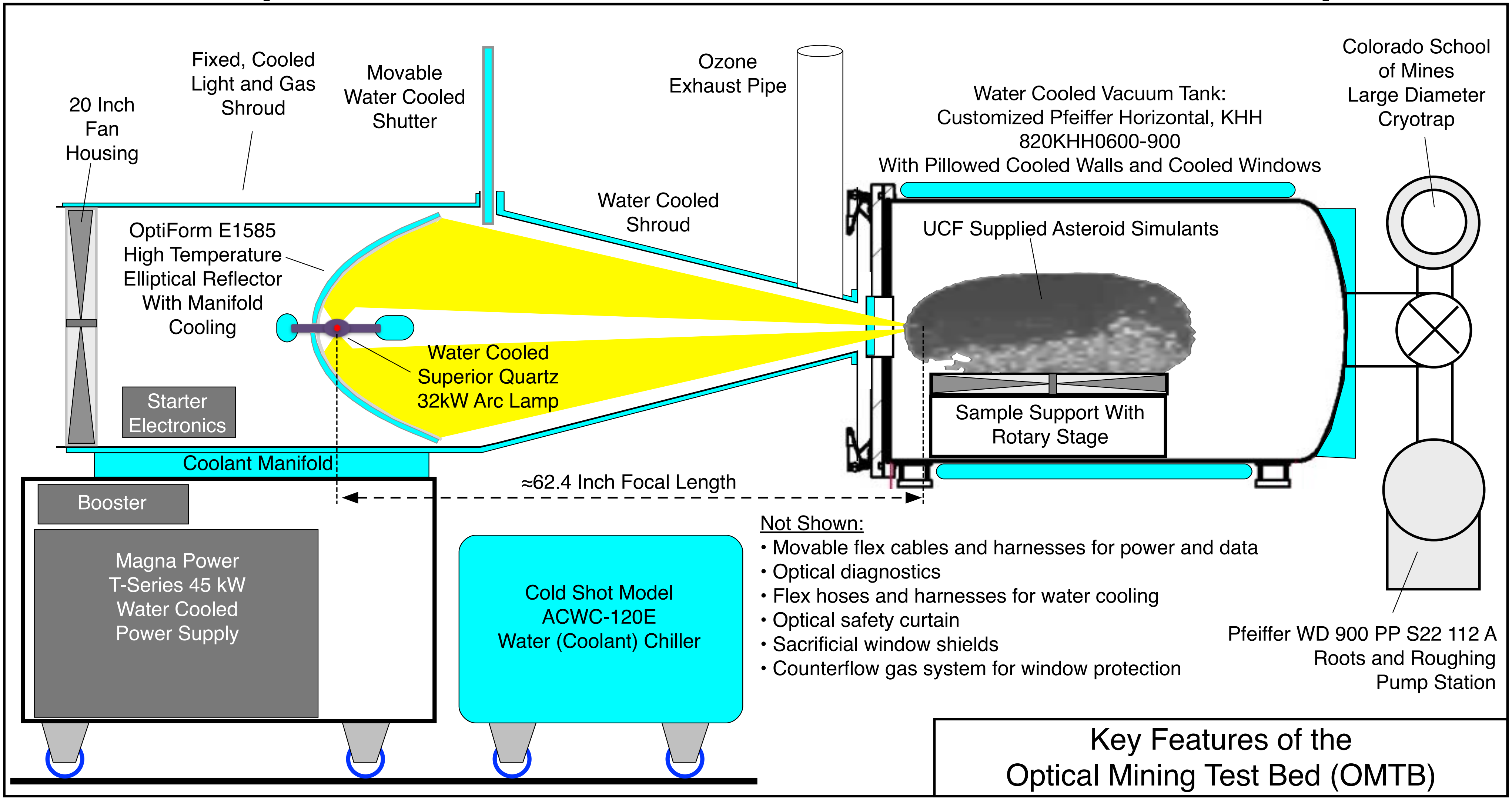
After Removal From
Vacuum Chamber

Image After Test: 1.0Kg

Spall Product 0.22kg

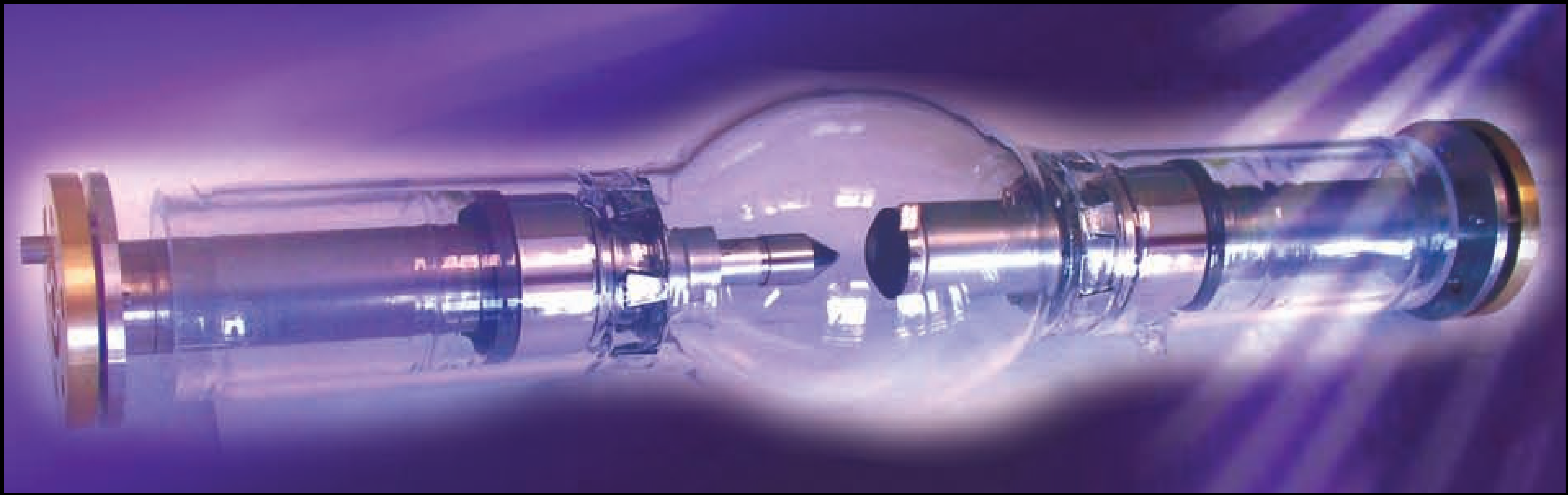
130 Grams Of Volatile Mass Lost Out Of 220 Grams Of Spall Production (Or 350 Grams Of Source Material). Suggests 37% Volatile Yield By Weight

Solar Thermal ISRU and Propulsion TestBed Concept

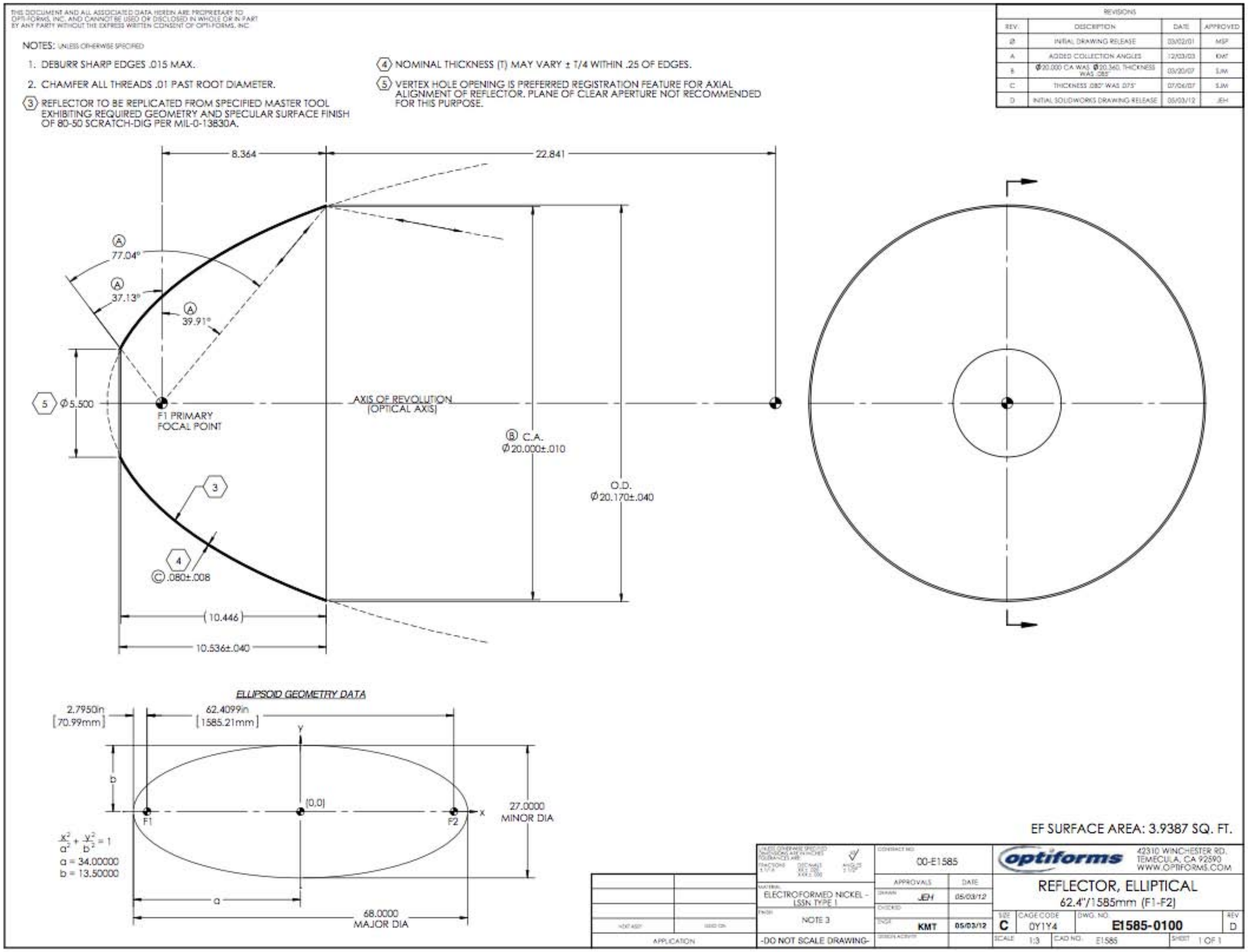


The World's Largest Lightbulb

The Superior Quartz Sx32000D High Pressure Short Arc Xenon Arc Lamp

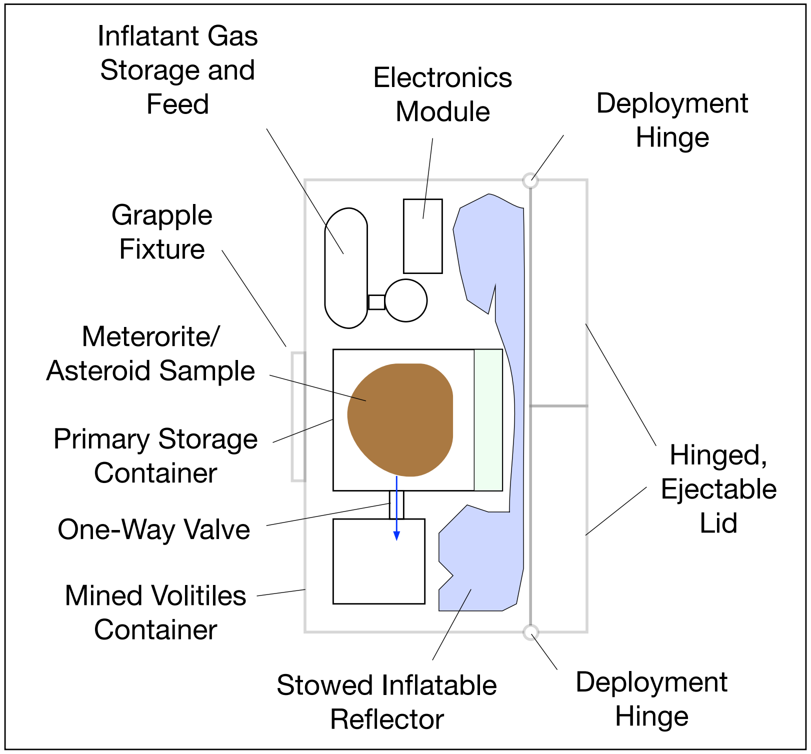


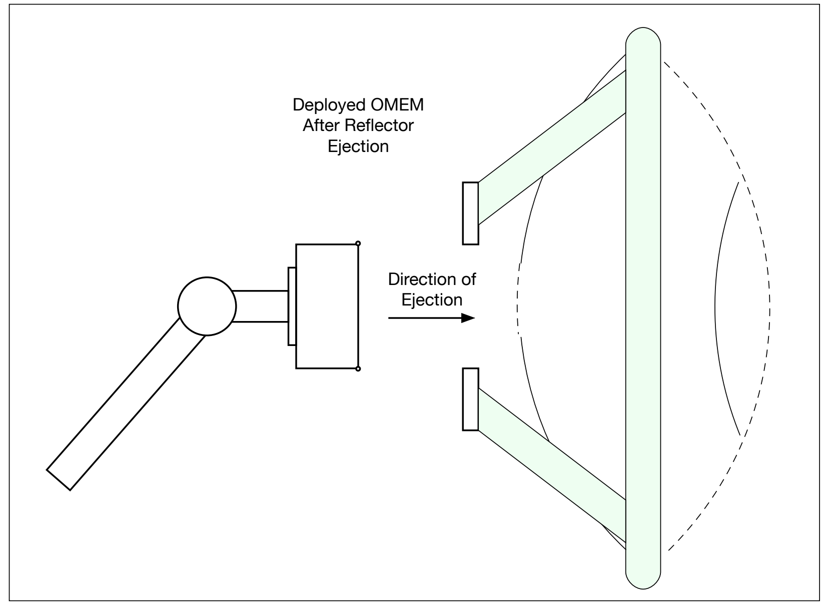
Elliptical Reflector

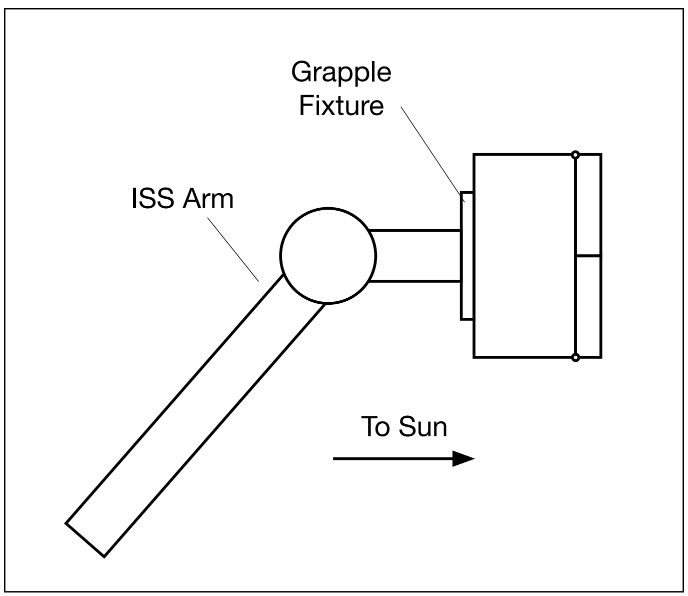


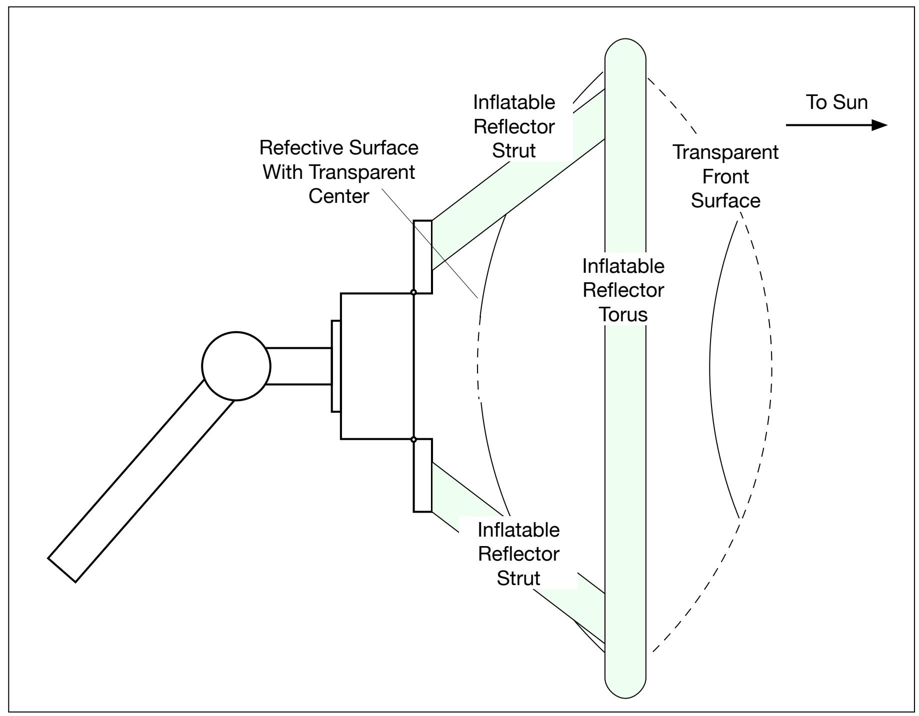
Several other reflectors available

ISS Flight Demonstration #1



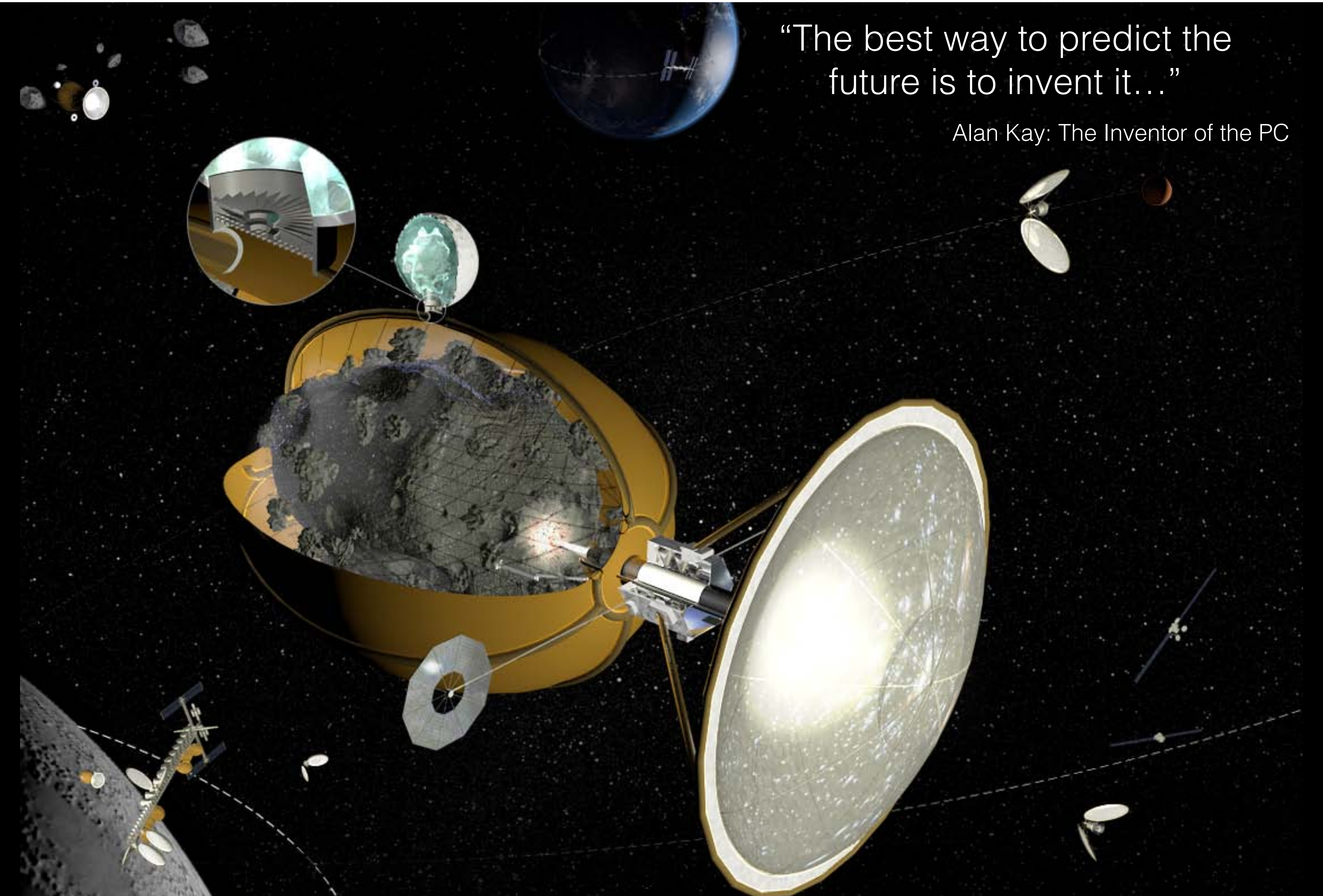






“The best way to predict the future is to invent it…”

Alan Kay: The Inventor of the PC



“The future is not laid out on a track. It is something that we can decide, and to the extent that we do not violate any known laws of the universe, we can probably make it work the way that we want to.”