



**Enabling Technologies for Asteroid Exploration**

Grant Bonin | Chief Engineer | SRR 2016



# About Deep Space Industries

- Established in 2012 as an asteroid mining company
  - Vision: to enable the human development of space by harvesting space resources
  - Locally sourced for local use
- Headquarters at NASA Ames Research Park
  - 12 full-time staff, 12 contractors
  - Planning 6-10 hires over summer



# The Silicon Valley of Space Resources

First Look

## Luxembourg woos would-be asteroid miners with \$223-million program

The Grand Duchy of Luxembourg allocated 200 million euros for asteroid mining operations that could eventually provide a stream of resources from space.

By Ben Thompson, Staff | JUNE 6, 2016

Save for later



Mark A. Garlick/Harvard-Smithsonian Center for Astrophysics/AP | [View Caption](#)

## SPACENEWS

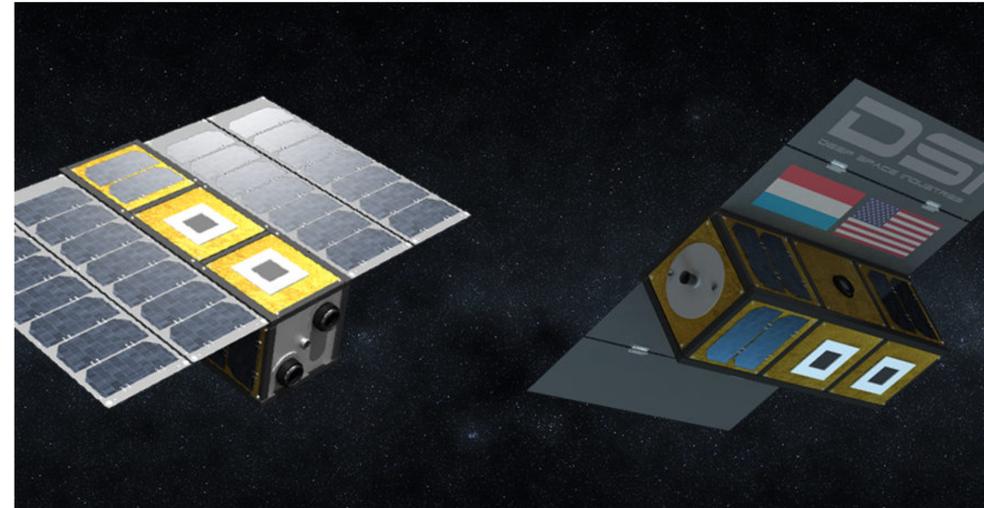
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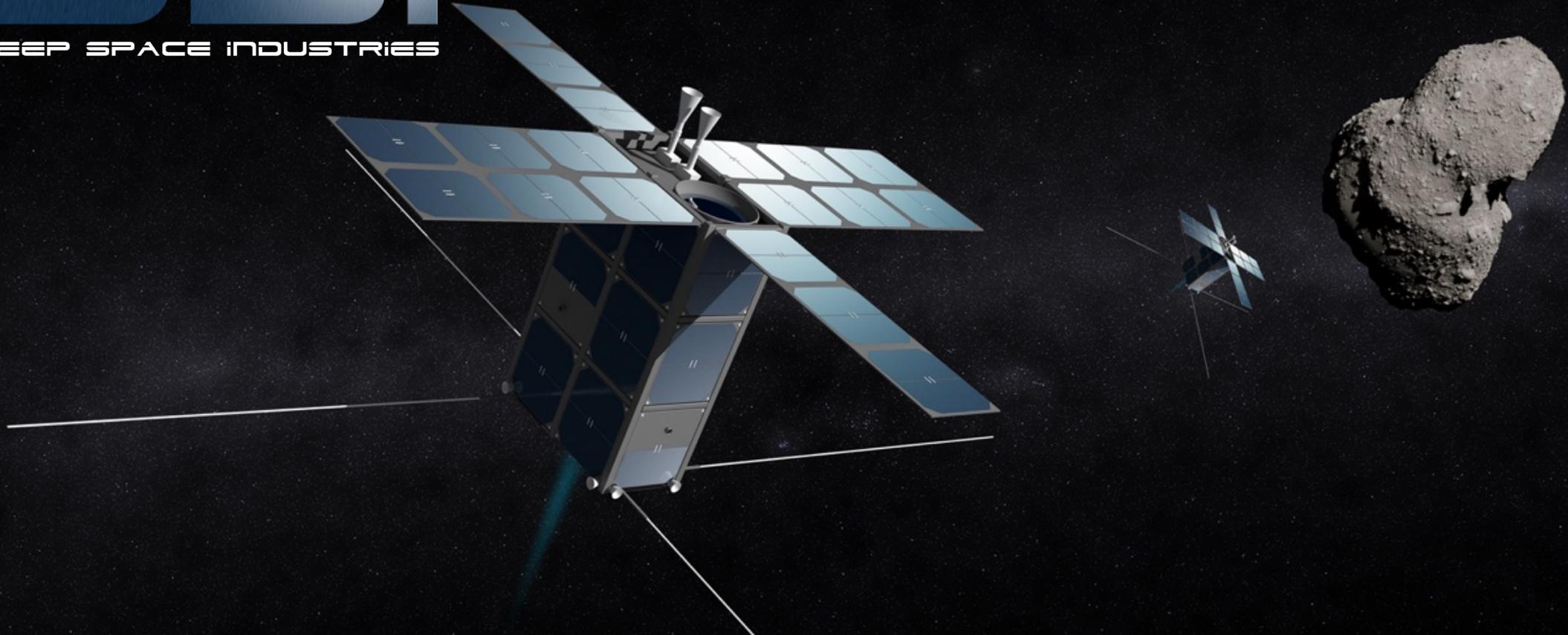
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## Luxembourg invests to become the 'Silicon Valley of space resource mining'

by Peter B. de Selding — June 3, 2016



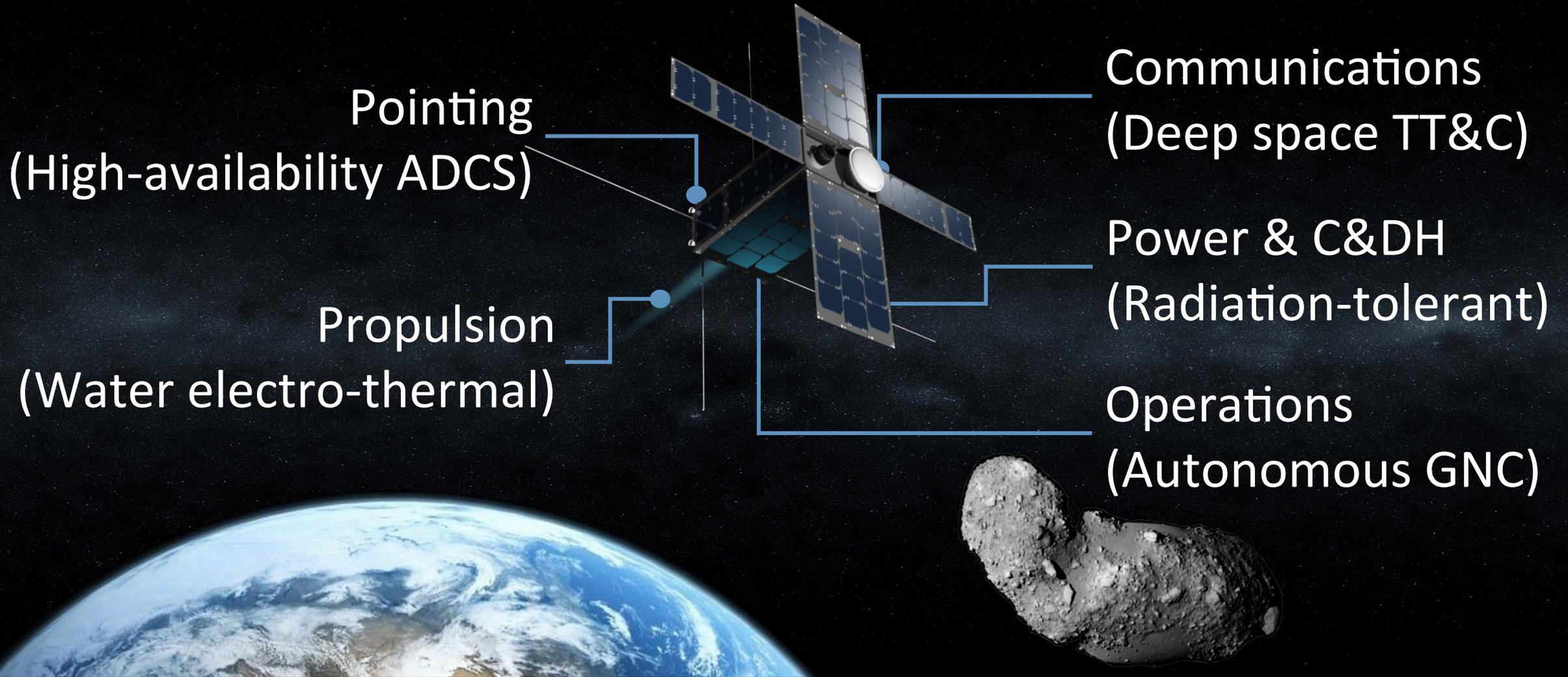
The Luxembourg government's backing for space mining ventures includes an initial \$225 million in seed money for R&D and co-financing. One early investment will be in Deep Space Industries' Prospector-X nano-satellite to test space-mining technologies. Credit: Deep Space Industries

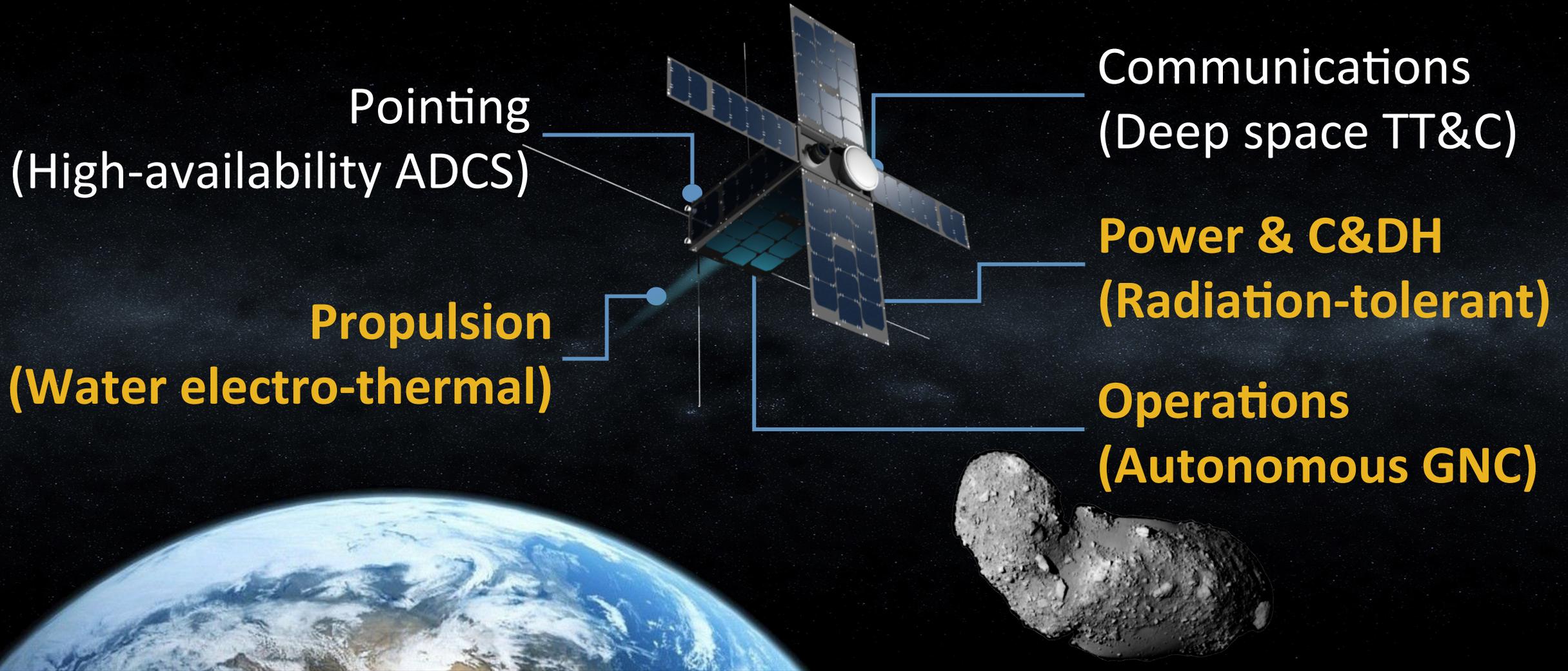


# Cornerstone Technologies

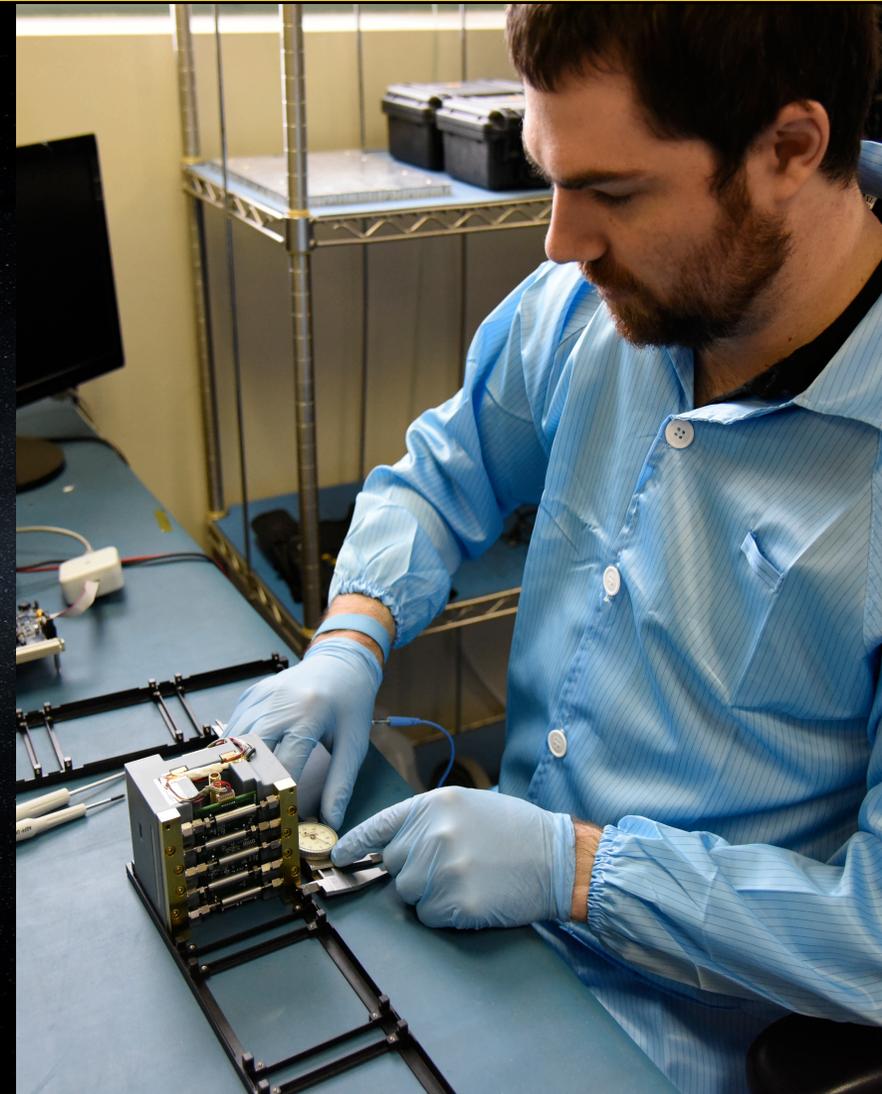
Key enablers for low-cost asteroid missions

# Mission-enablers: "C3PO"



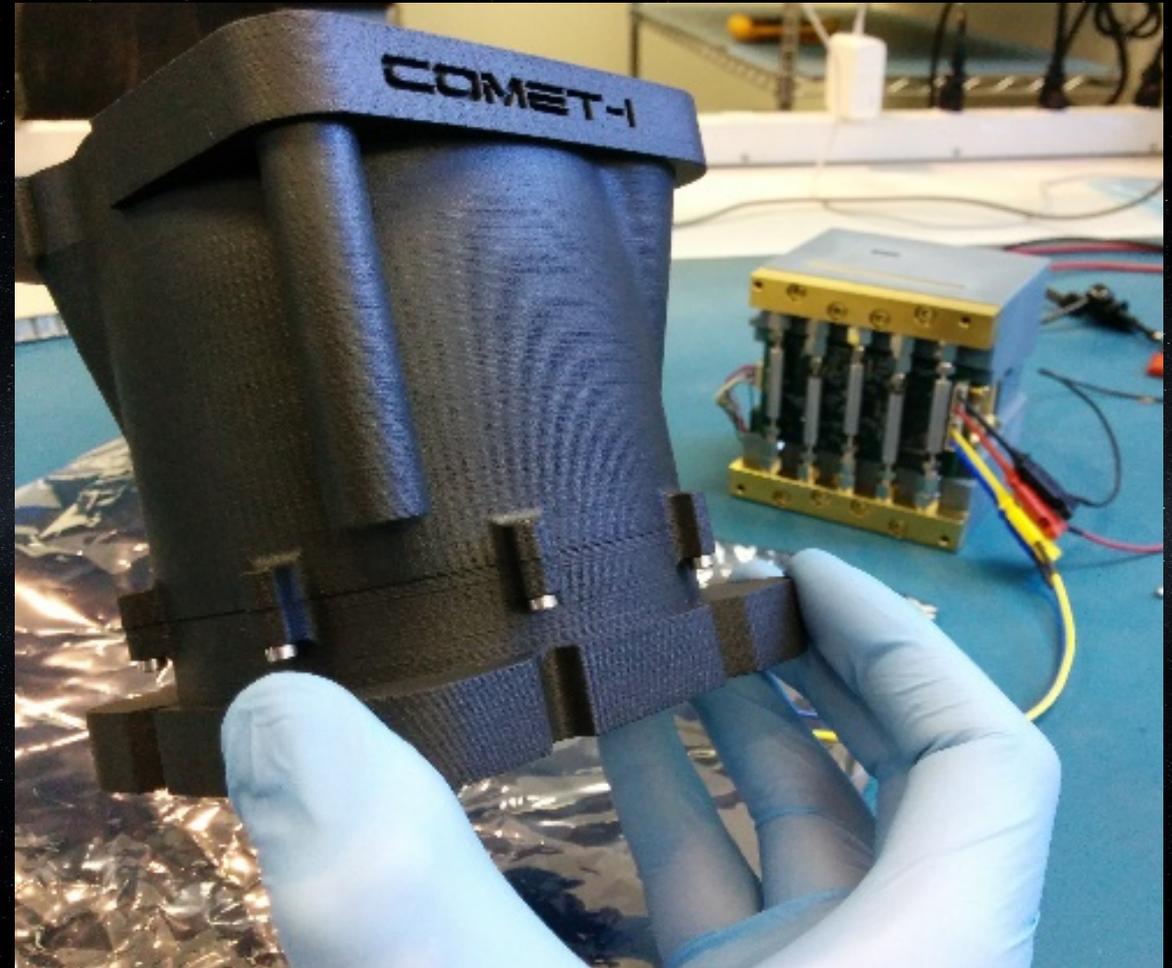


# Example: DSI Water Propulsion

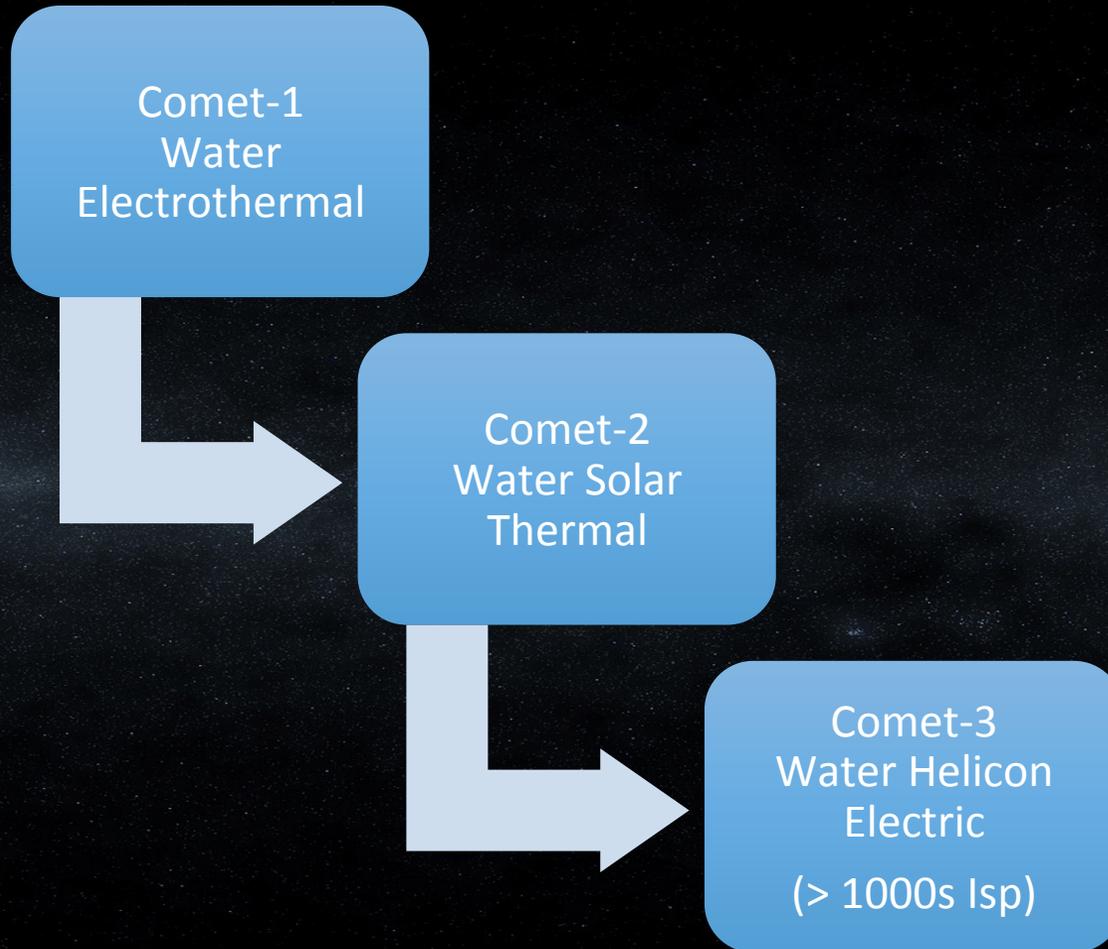


# The Comet-1 Water Thruster

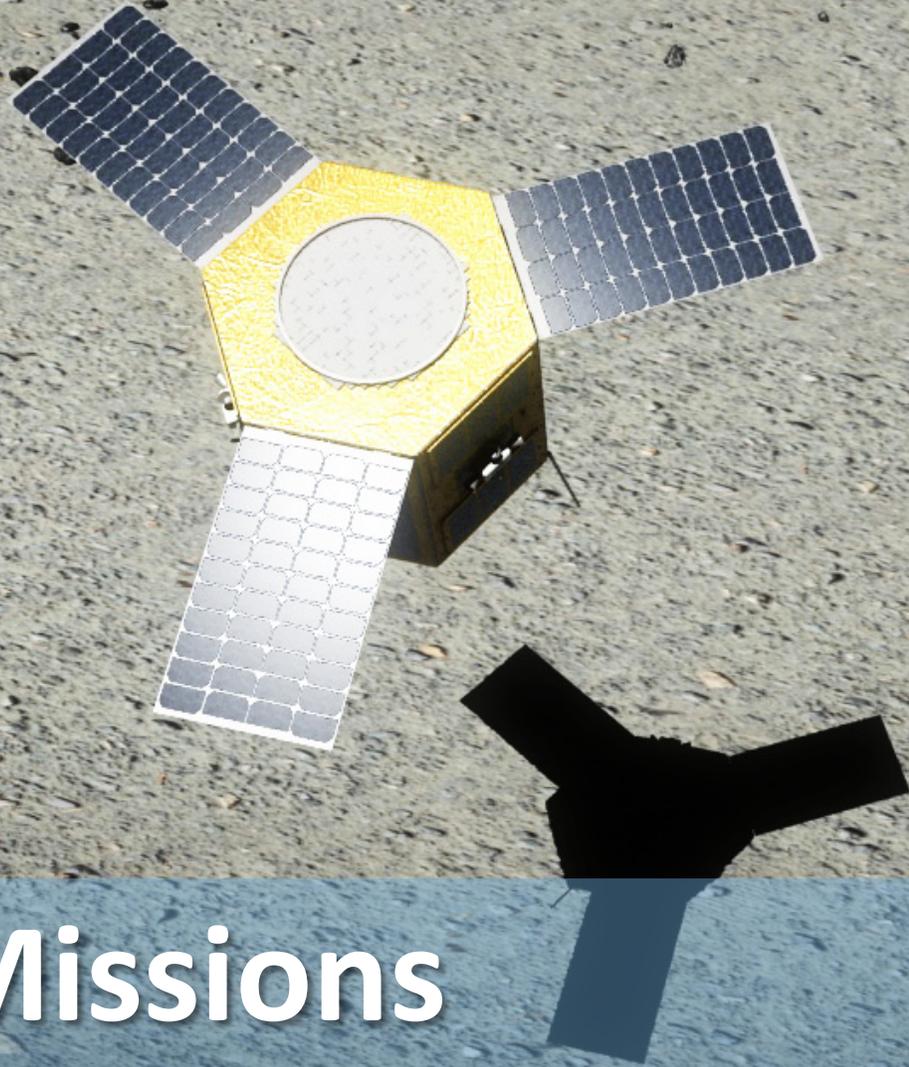
System Parameter	Value
CubeSat Volume	1U (expandable)
Specific Impulse	170 – 195 s
Propellant Mass	300 g (expandable to 750g)
System Dry Mass	350 g
Mass Flow (minimum)	1.7 mg/s
Propellant Temperature	900°C
Minimum Impulse Bit	1 mNs
Impulse Resolution	250 μNs
Bus Voltage	8 V to 34 V
Power Consumption	10 - 100W
Current status	TRL5 (TRL6 by SmallSat)
Number of flight-manifested units	5 (all in 2017)



# Comet Propulsion Roadmap



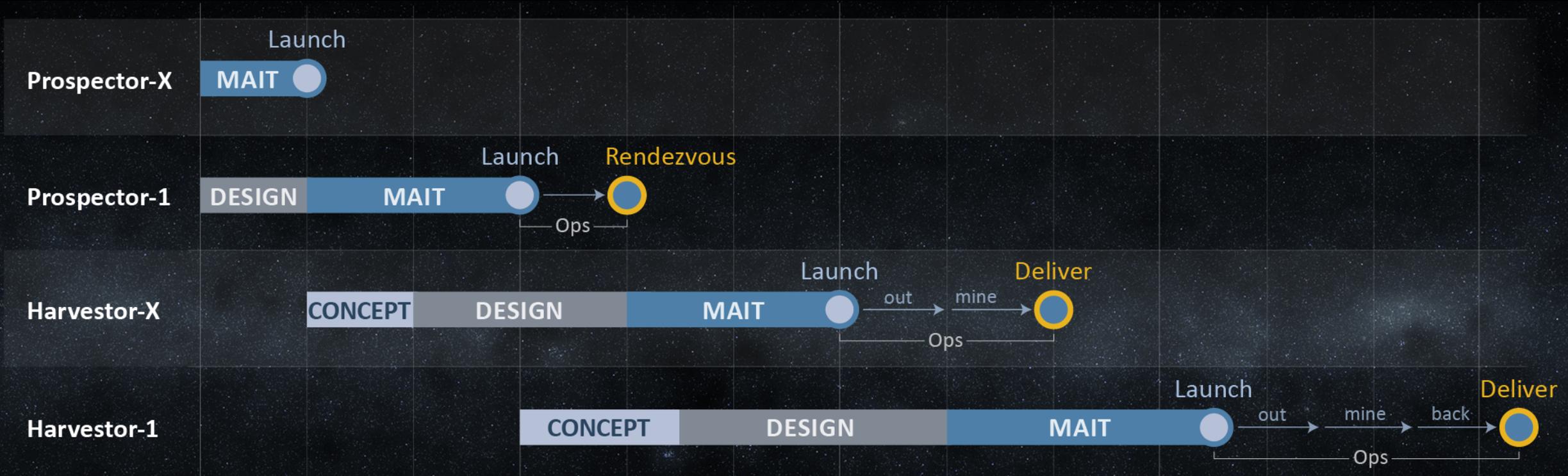
Water is the  
unifying theme of  
all DSI efforts



# DSI Asteroid Missions

From small explorers to industrial mining missions

# Mission Roadmap



MAIT – Manufacturing, Assembly, Integration, Test



# Prospector-X

- Built and operated by DSI Europe
- Launched to low-Earth Orbit as secondary payload (Q4 2017)
- Images the LV upper stage to test proximity optical navigation
- Images the moon to test longer-range optical navigation
- Uses DSI *Comet* water thruster for orbit raising
- Validates the robustness of core interplanetary avionics stack
- Tests key asteroid mission TT&C and science payload (TBA)

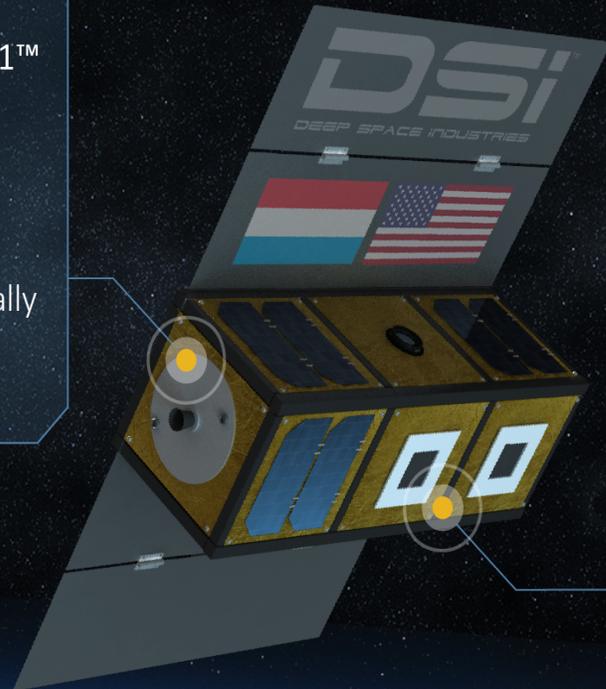
# INTRODUCING: PROSPECTOR-X™



The inaugural mission of the Luxembourg and Deep Space Industries partnership, Prospector-X™ is a 3U spacecraft that will operate in low Earth orbit, testing critical innovations engineered for future missions in deep space.

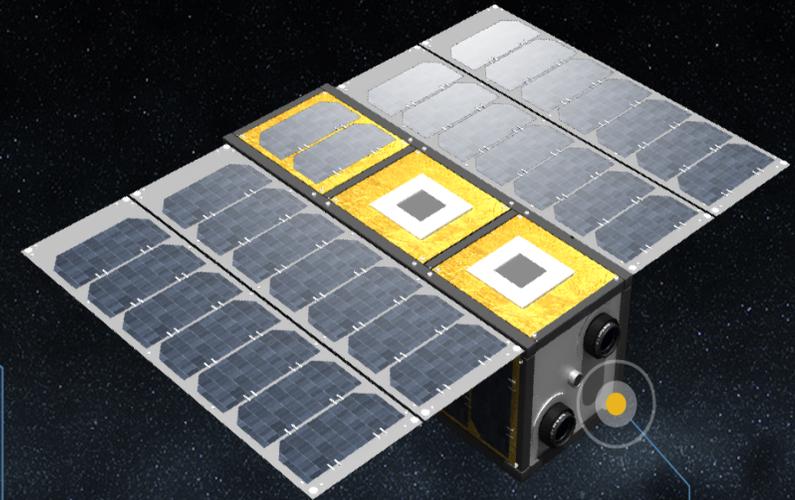
## PROPULSION

The Deep Space Comet-1™ electrothermal thruster uses the most abundant resource in the solar system – water – as propellant. It is intrinsically inert, launch safe, and cost-effective.



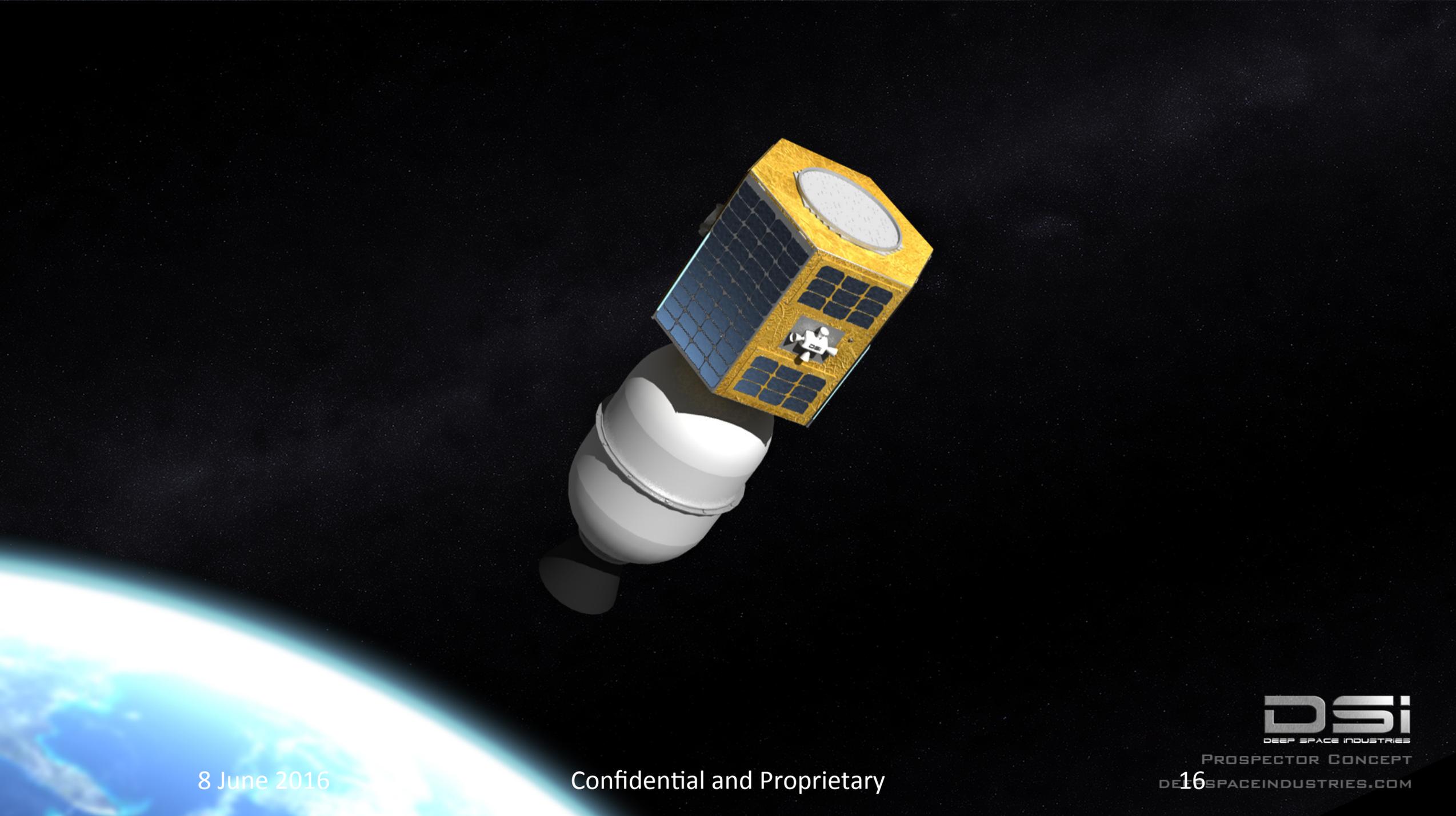
## DEEP SPACE AVIONICS

Modular, scalable, and intrinsically radiation-tolerant avionics combine the best of commercial technologies with rigorous screening and innovative design approaches to enable cost-effective, yet radiation-robust subsystems for deep space.



## OPTICAL NAVIGATION

A two-camera optical navigation system enables proximity operations at asteroids or at close range to other targets. This vision system is developed jointly between Deep Space and the University of Luxembourg's SnT.



8 June 2016

Confidential and Proprietary

# Prospector-1

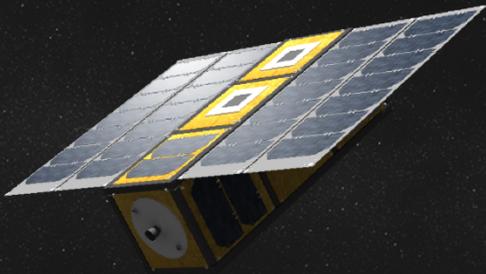
- DSI's first micro-spacecraft asteroid mission
- Launched to low-Earth Orbit as secondary payload
- Injected to asteroid using chemical propulsion stage
- Uses DSI *Comet* water thrusters for cruise, rendezvous and proxops
- Uses X-band TT&C for absolute navigation, PX optical systems for relative navigation
- Uses VIS/MWIR cameras and neutron spectrometer to take images and map water
- Will attempt to land, and use surface instruments to assess mechanical regolith properties

# Prospector Size Comparison

## NANOSATELLITE

1 – 10 kg

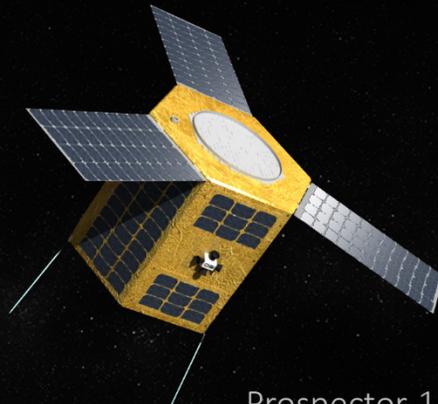
Prospector-X



Compare size to Toaster

## MICROSATELLITE

10 – 100 kg



Prospector-1

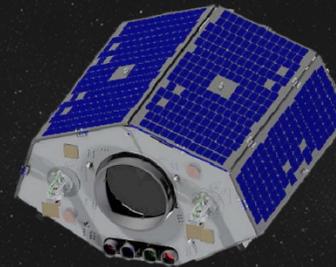


Compare size to Beachball

## SMALL SATELLITE

100 – 500 kg

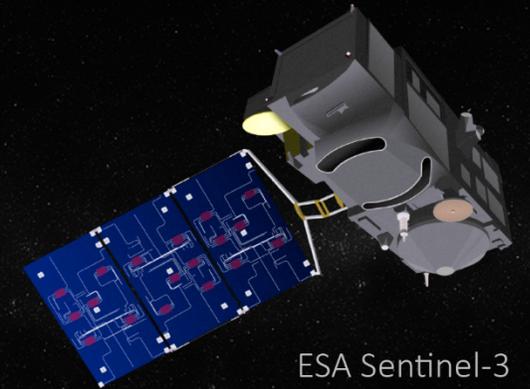
NigeriaSat-2



Compare size to Beer Fridge

## STANDARD SATELLITE

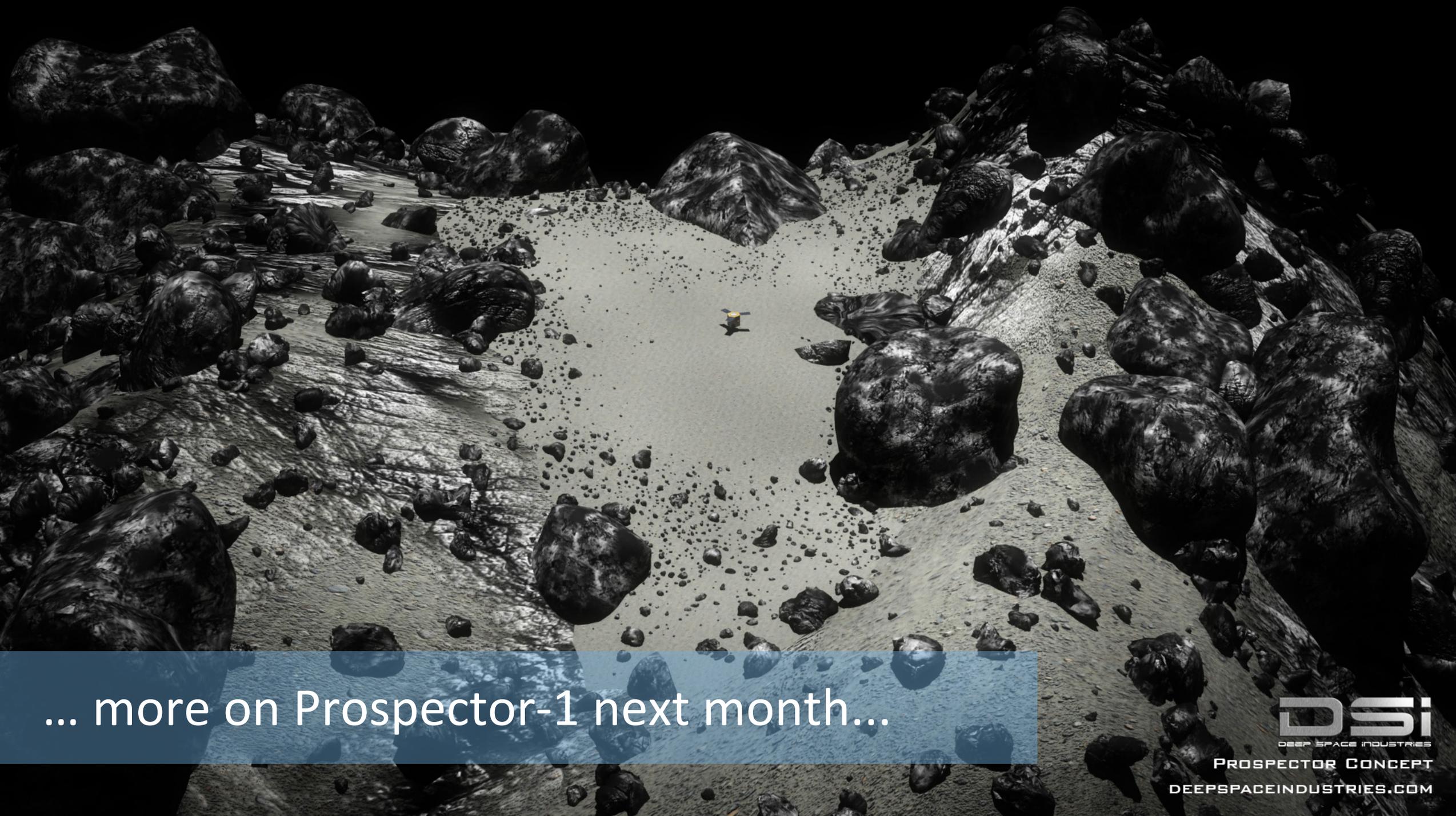
>500 kg



ESA Sentinel-3



Compare size to Cadillac Escalade



... more on Prospector-1 next month...

**DSI**  
DEEP SPACE INDUSTRIES

PROSPECTOR CONCEPT  
DEEPSPACEINDUSTRIES.COM

# NASA Contract for Asteroid Simulants

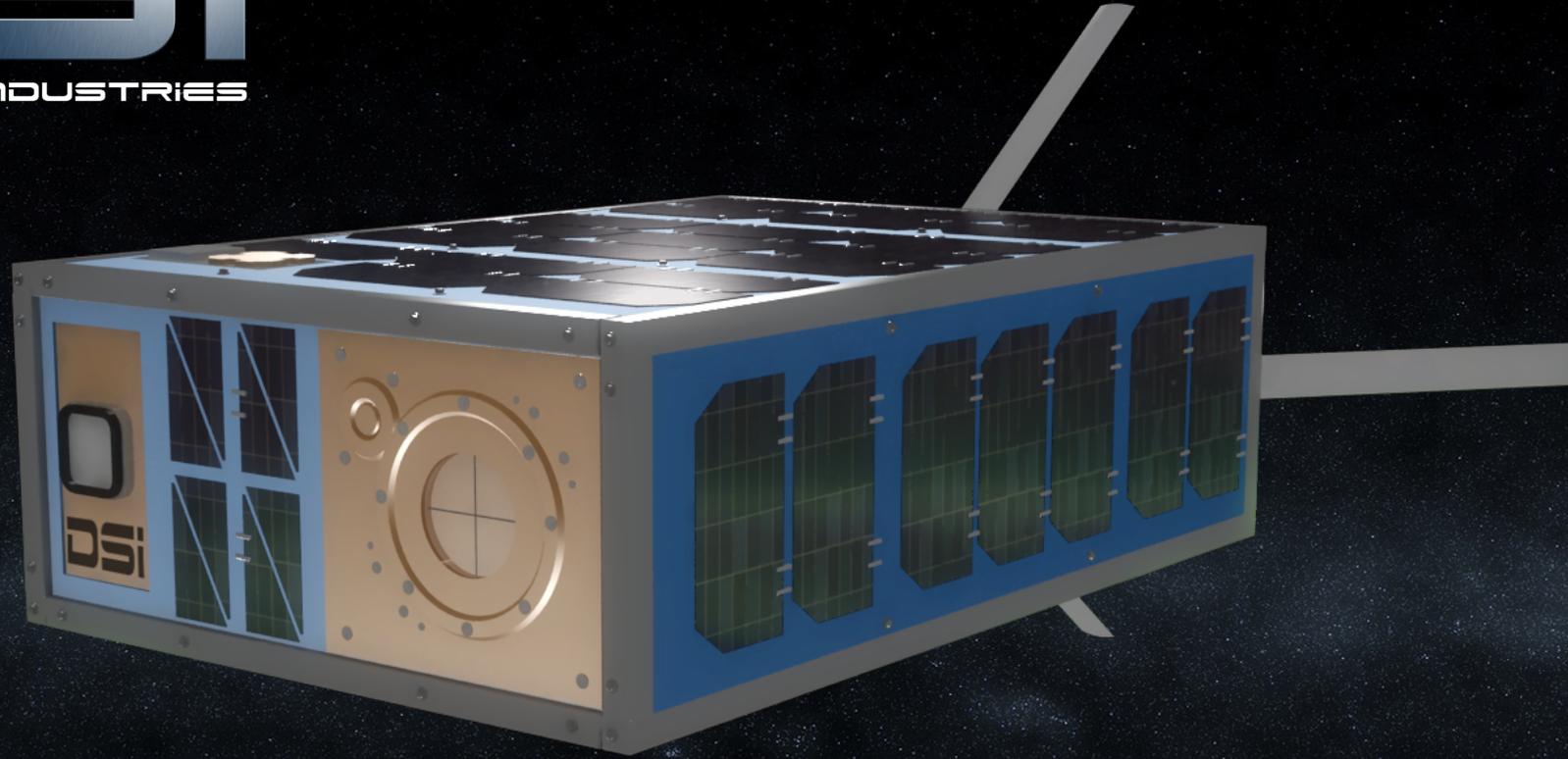


Tagish Lake  
Prototype  
Simulant



CI (Orgueil)  
Prototype  
Simulant

**Producing five tons for NASA over next two years via SBIR  
...plus kgs to multiple tons for other research customers**

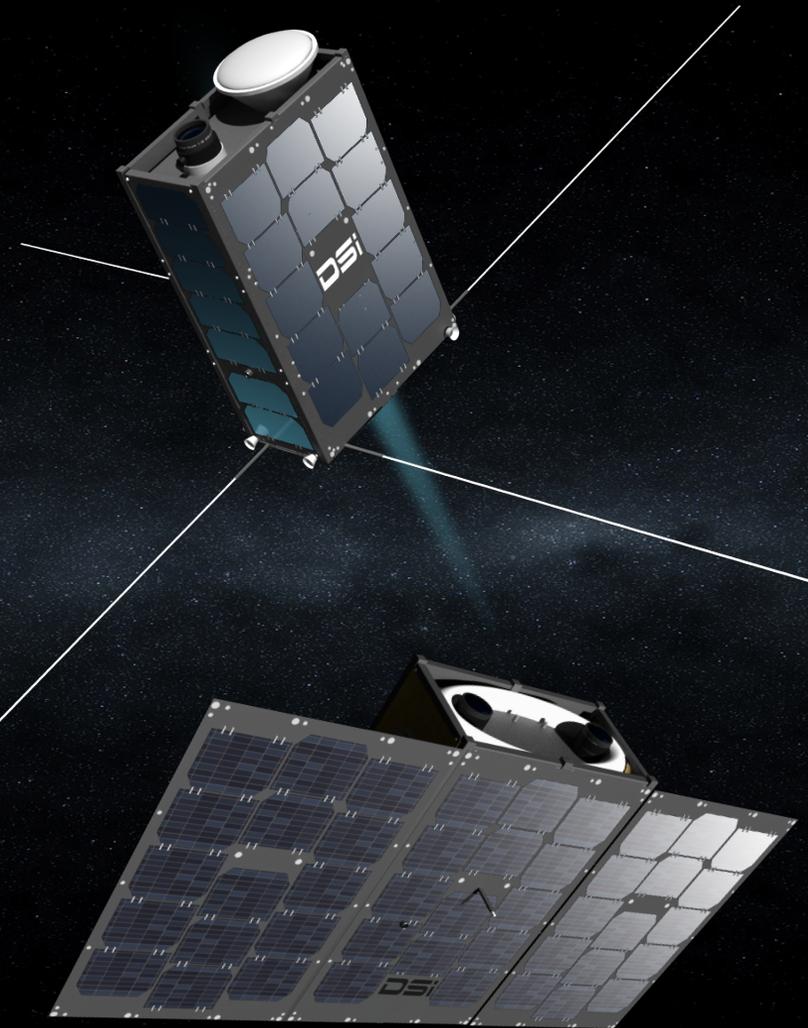


# DSI Commercial Missions

Furthering our missions by enabling customer missions

# DSI Commercial Missions

- DSI asteroid prospecting technologies enable commercial missions
  - Every key technology for smallsat asteroid missions enhances LEO satellites and applications
- DSI is a mission prime contractor
  - Choose parts of project that align with technology roadmap
  - Partner with leading satellite platform providers
  - DSI model is *entirely* about partnerships
- DSI is *not* a services or applications company
  - Chasing applications (remote sensing, communications) would consume company and change our identity



# HawkEye 360

SmallSat Symposium and 15 others follow



**SatelliteFinance** @SatFinance · May 25

Backed by #AlliedMinds, HawkEye 360 contracts **Deep Space Industries** to build smallsats for US\$30m constellation [ow.ly/VkAJ300yWjv](https://ow.ly/VkAJ300yWjv)



**Dr. Phil Metzger** @DrPhiltill · May 31

Interesting! Asteroid miners @GoDeepSpace won a contract to build a constellation of spacecraft for Earth orbit.

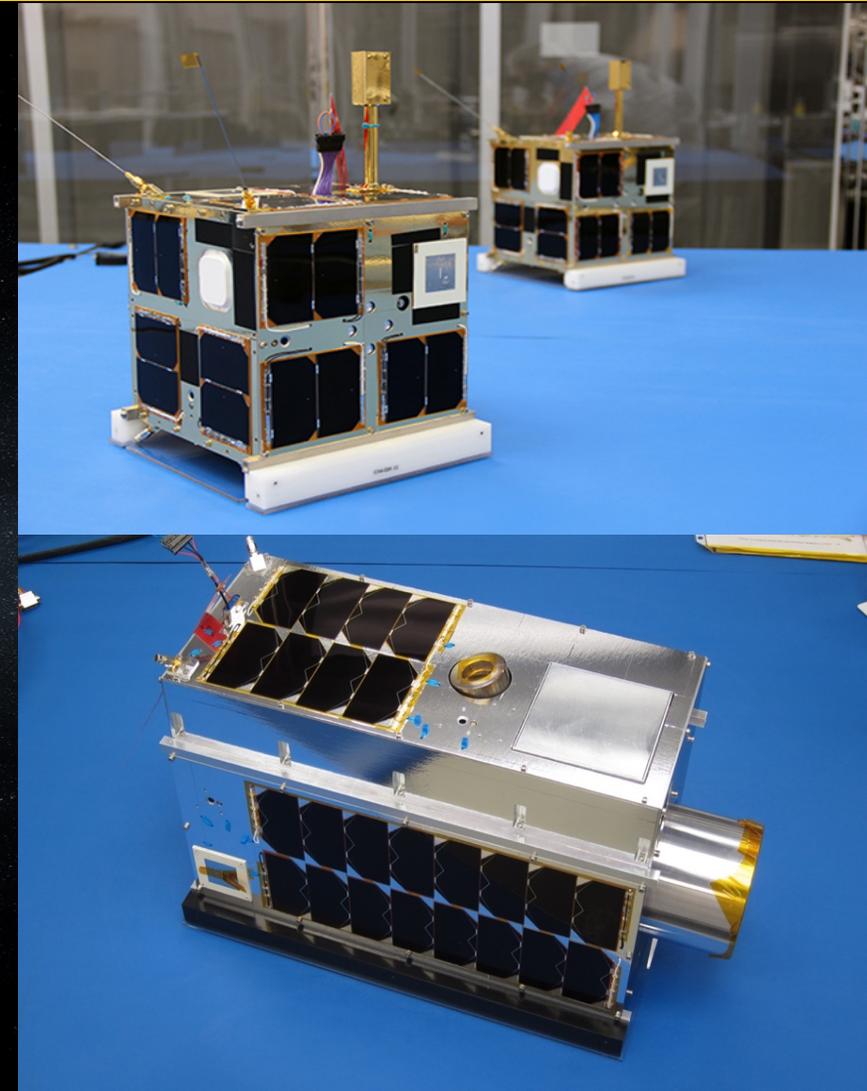


HawkEye<sup>360</sup>  
An Allied Minds Company

**Deep Space Industries and SFL selected to provide...**

The Pathfinder space-based global wireless signal monitoring system will be developed by Deep Space Industries and UTIAS Space Flight Laboratory

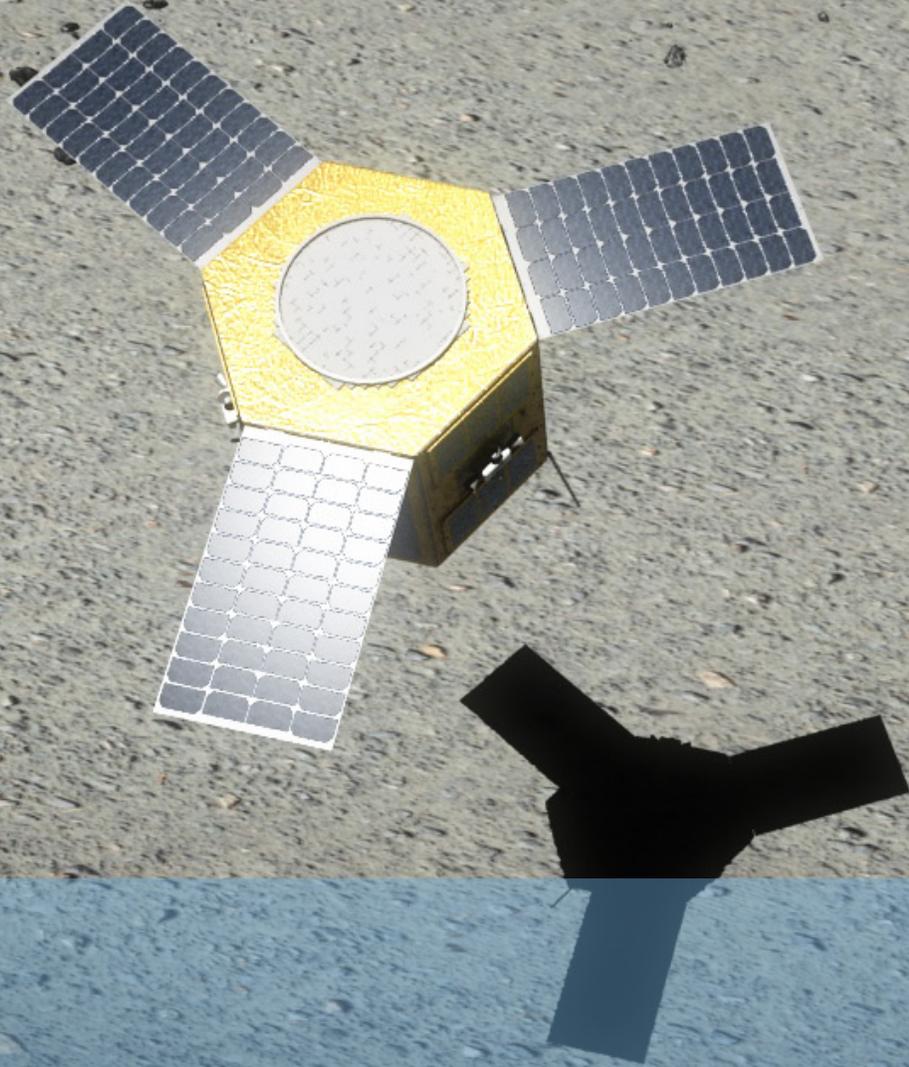
[deepspaceindustries.com](https://deepspaceindustries.com)





# Selling bottled water in space...

- DSI is building its *Comet* line of thrusters for nano- and microsatellite missions
- DSI is flying spacecraft propelled by water for itself and its customers
- DSI intends to launch *Prospector-1* by end of the decade, propelled by water thrusters, with the objective of proving water abundance at a target asteroid
- DSI is working to develop next-generation solar thermal and water electric thrusters for larger spacecraft
- DSI is actively studying storable high-performance bipropellants derived from water
- **The Goal:**
- **DSI is creating an ecosystem of spacecraft products today that can be supplied by space resources tomorrow**



... Questions?

[grant.bonin@deepspaceindustries.com](mailto:grant.bonin@deepspaceindustries.com)

# Prospector-1 Mission Concept

- Prospector and injection stage launched to LEO
  - Flown as secondary, launch-vehicle agnostic
- Spacecraft commissioned in LEO months prior to injection
  - Target selected well in advance
  - No time-critical operations
- Chemical injection and sunlit cruise
  - Mid-course corrections using DSI water thrusters
  - X-band TT&C
- Rendezvous and proximity operations
  - 30 day minimum ProxOps with worst-case loitering delta-V
  - VIS/MWIR multi-spectral imagery campaign
  - Neutron spectroscopy for water mapping
- EOM descent and landing
  - Identification of candidate landing site
  - Incrementally closer ProxOps, landing attempt in-pass
  - On-board gravimeter, instrumented legs for testing regolith mechanical properties

