Hummingbird Space Exploration (HSX) Team

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HSX

NEW SPACE: BIG PICTURE

Smallsats

- Missions: Tech demo, science and communications.
- Low function wrt. large sat.[1]

***Solar cell:* 75%**
***Attitude ctrl:* 40%**
***Nav:* 16%**
***Orbit ctrl:* 9%**
***Data-rate:* <9600bps**

***Growing:* 550/yr by 2020**

Nanolaunchers

- NO MORE rideshare.
- 5-500*kg* LEO demand. [2]

ARCA — *100kg LEO*
ROCKET LAB — *150kg SSO*
GALACTIC (Virgin) — *200kg SSO*
Orbital ATK — *468kg LEO*
CHINA AEROSPACE SCIENCE & INDUSTRY SHENZHEN (GROUP) CO., LTD (CASIC) — *500kg SSO*

Space Debris

***Currently:*[3]**

500,000 > *Marble-size*
20,000 > *Softball-size*

- Avg cubesat lifespan: 8*month*.
- Avg orbital lifespan: <5*yr*. [1]
- “Dead-sat” and spent stages on orbit.
- Kessler Syndrome.

[1] Bouwmesster J. and Guo J. “Survey of Worldwide Pico- and Nanosatellite Missions, Distributions and Subsystem Technology.” *Acta Astronautica* (2010).
[2] Niederstrasser C. and Frick W. “Small Launch Vehicles – a 2016 State of the Industry Survey.” *IAC-16-B4.5.10* (2016).
[3] “Space Debris and Human Spacecraft.” *NASA* <https://www.nasa.gov/mission_pages/station/news/orbital_debris.html> (2013)

HSX

7 MARKET NEEDS

1. Higher mission capabilities via larger volume.
2. Timely launch.
3. Low tech barrier.
4. Maneuverability.
5. Sample return mission.
6. Launch abort.
7. Neutral or negative space-debris footprint.

Legacy: *BioDOME CAPSULE*

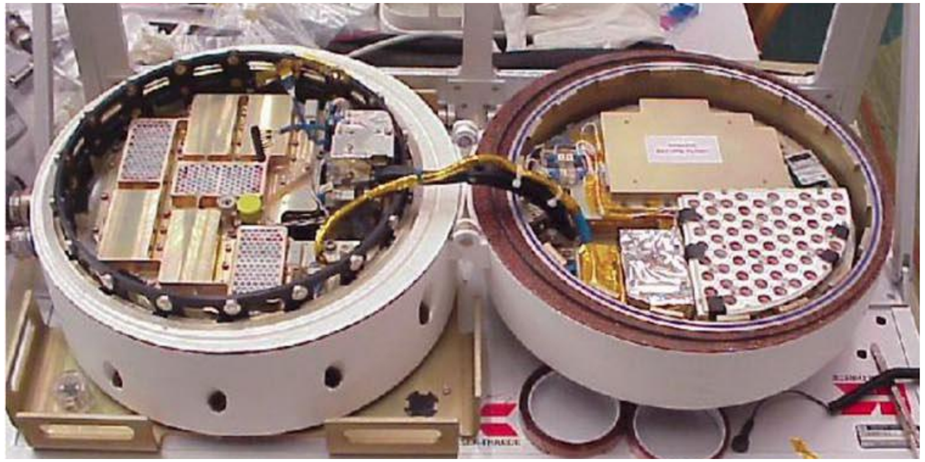
Mission 1 *Free-Flyer*

- Microgravity experiments.
- Space exposure experiments.
- On-orbit maneuverability.
- UTTR landing.

Mission 2 *ISS*

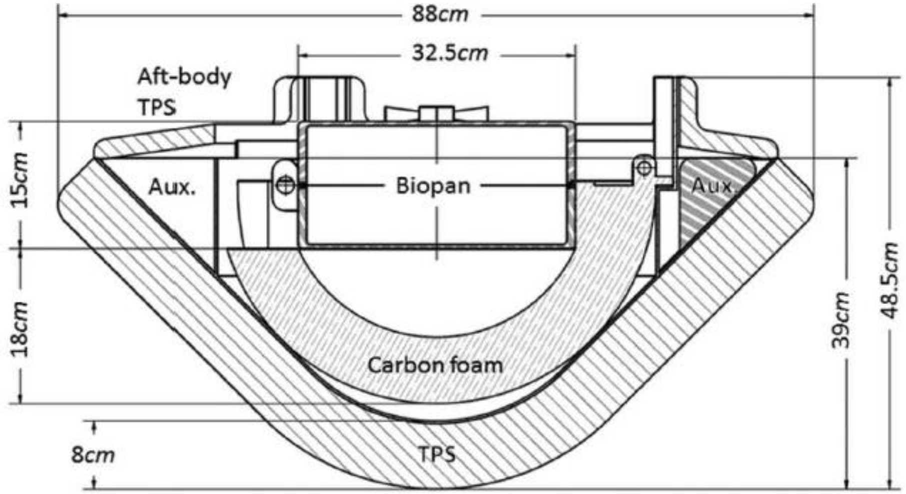
- Docking
- Detachable Biopan unit.
- Robotic arm retrieval.
- UTTR landing.

➢ Carrier spacecraft for ESA Biopan



[1]

88*cm* dia. 15*kg* payload.



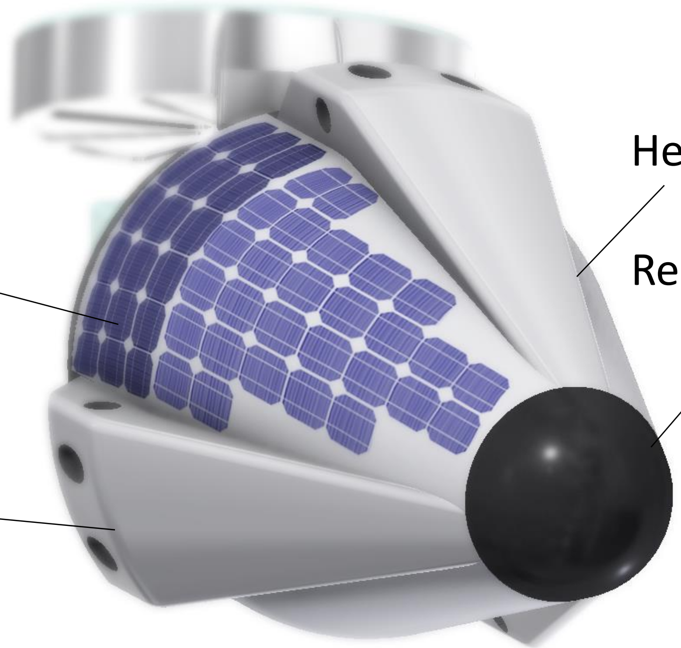
➢ **Status:** Sizing and optimization completed. Published in *Journals of Spacecraft and Rockets* (2016) [2]

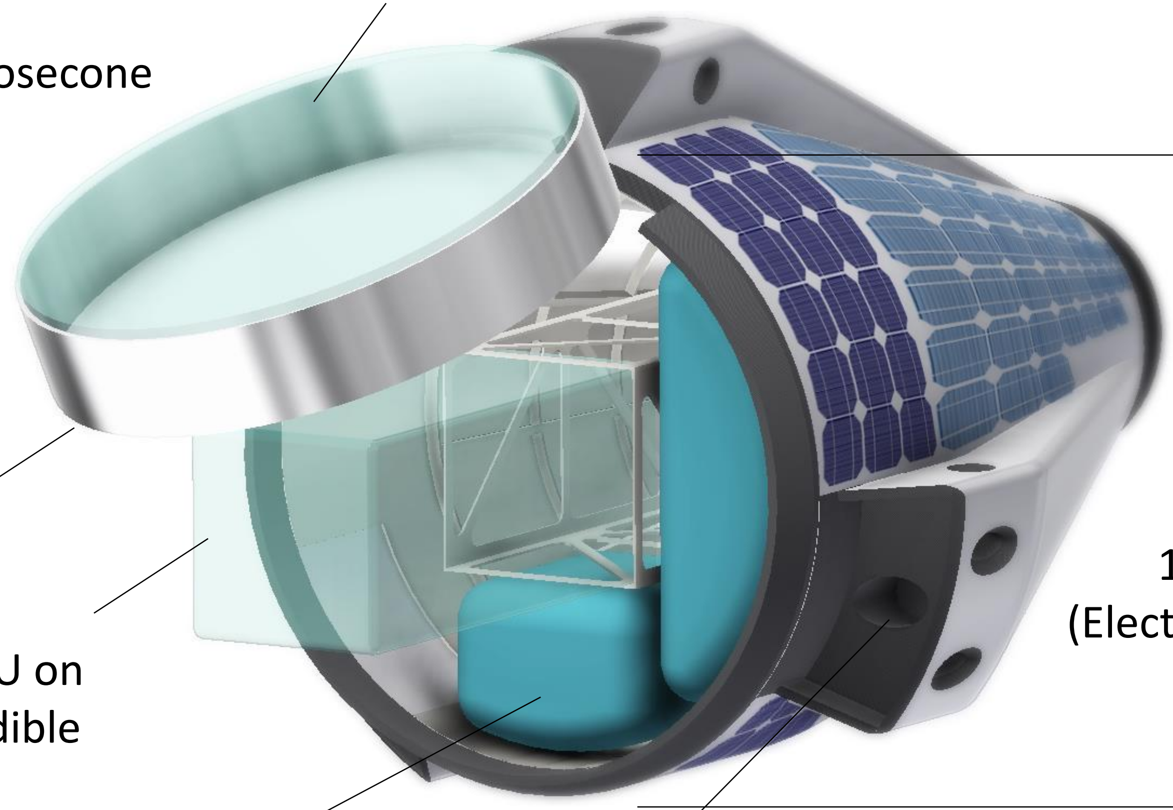
[1] "Chapter 6: FOTON Retrievable Capsules," European Users Guide to LowGravity Platforms, European Space Agency, Rept. UIC-ESA-UM-0001, Erasmus User Centre and Communication Office, Noordwijk, The Netherlands, 2005.
[2] Rossman G., LeVine M. J., Lawlor S., Sloss T., Mishra P., Tan Z. P. and Braun R. D. *Conceptual Design of a Small Earth Reentry Vehicle for Biological Sample Return*", *Journals of Spacecraft and Rockets* (2016).

BioDOME 2.0:

Hummingbird Capsule

Small Agile Robust



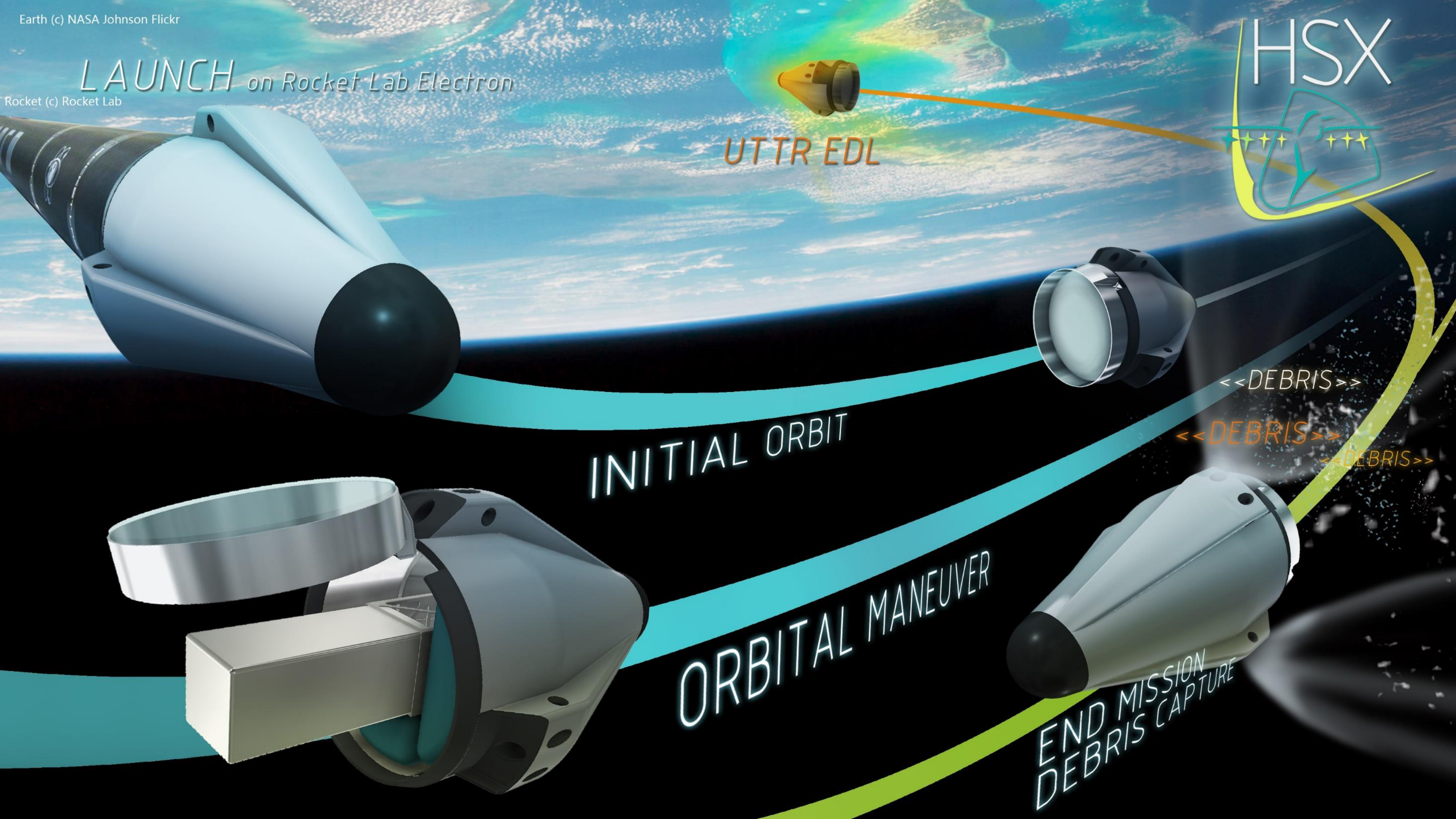


Target Specs

225kg Total Mass

36kg Payload to LEO

12 x 3U Volume



Earth (c) NASA Johnson Flickr
LAUNCH on Rocket Lab Electron
Rocket (c) Rocket Lab
UTTR EDL
HSX
INITIAL ORBIT
<<DEBRIS>>
<<DEBRIS>>
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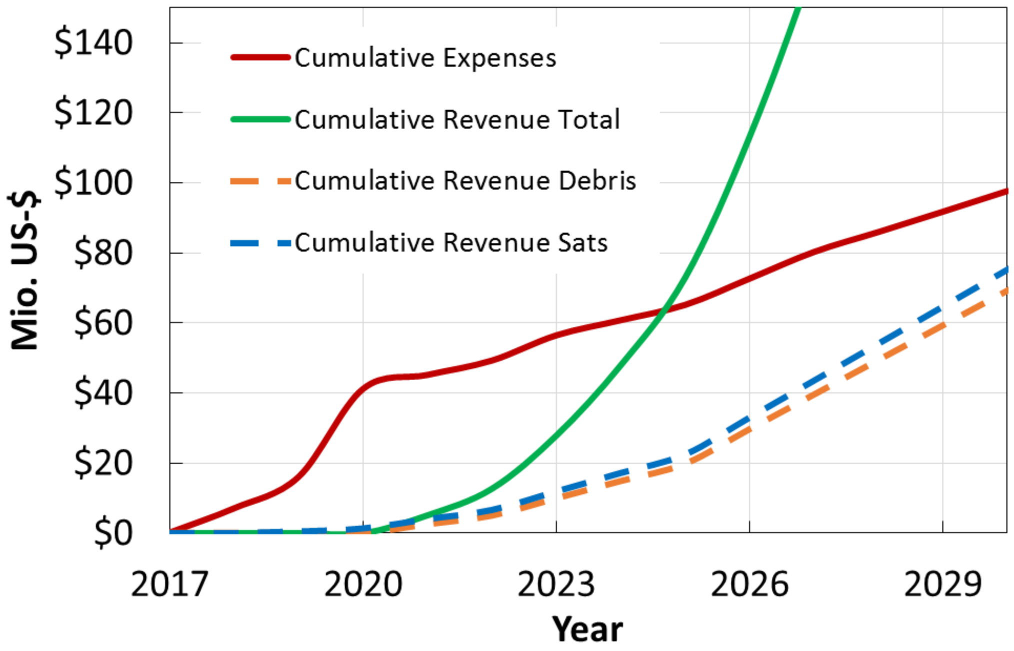
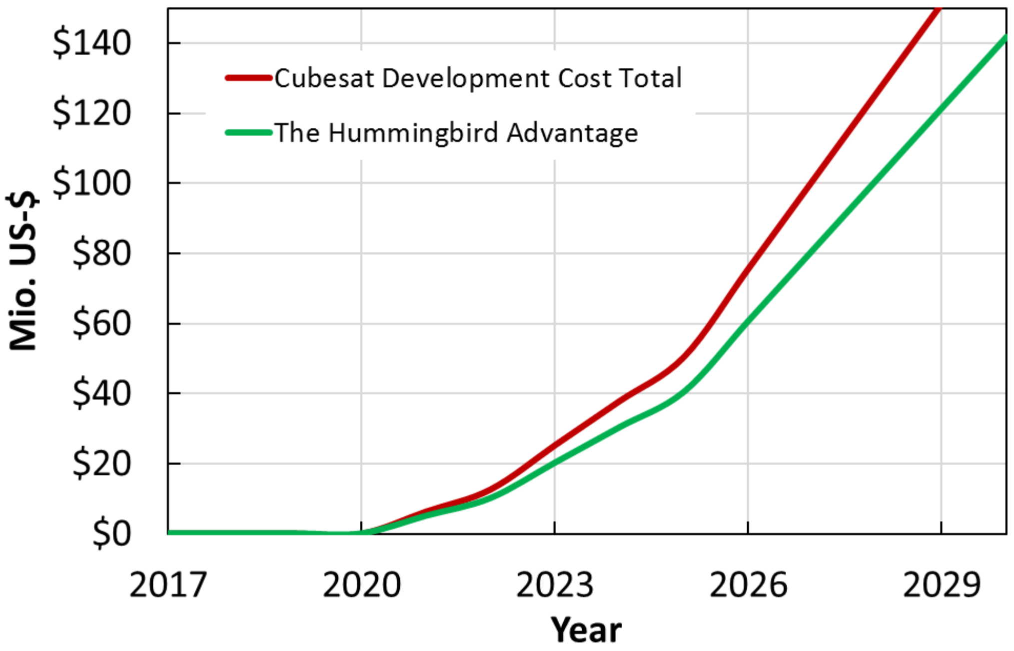
ORBITAL MANEUVER
END MISSION
DEBRIS CAPTURE

Cost Estimates





- Total Cost to 1st Flight Model: $15.6M
- Avg cost per capsule (w/ reuse): $440,000
- Breakeven Year: 2025
- Longterm savings for cubesat developers: $74,000 / satellite

→ Analysis covers only cubesat industry and debris recovery

Status

Concepting

Goal

Traction Validation

+1 year plan:

1. Minimal viable product.
2. Business plan refinement.
3. Mission profiles development.
4. Sizing and optimization.
5. Team development.
6. Initial design review.

+2 year plan:

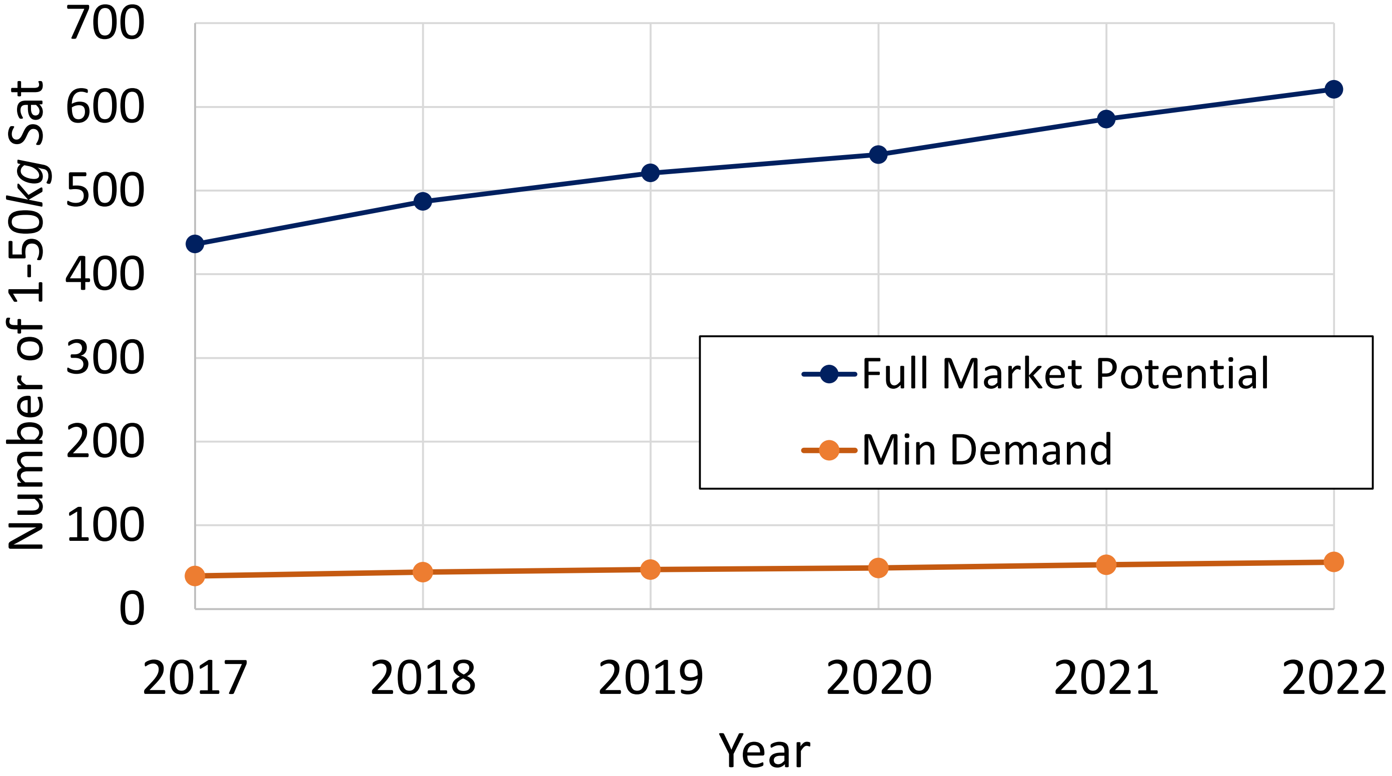
1. Components design.
2. Components test.
3. Ground-test Vehicle 1.

We're here for:

- **Academia → industry exposure.**
- **Industrial feedback.**
- **Advisors & collaborators.**
- **Reach-out to clients.**

HSX

Market Potential



- Linear growth in cubesat market [1]
- Min demand: >9% of cubesats demand maneuvering capability [2]
- Other markets under assessment: reentry capability, exposure-experiment, in-space manufacturing, space-tug debris-removal etc.

[1] Buchen E. and DePasquale D. "2014 Nano / Microsatellite Market Assessment." *SpaceWorks* (2014).

[2] Bouwmesster J. and Guo J. "Survey of Worldwide Pico- and Nanosatellite Missions, Distributions and Subsystem Technology." *Acta Astronautica* (2010).

Development Timeline

Potential Investment

- Business plan competition (BPC) support.
- Startup accelerators
- NASA SBR funding.

Formation as a "Tech Consultation Company"

Transition to "Real Product Company"

Software Phase

Hardware Phase

CONCEPTING

COMMITTING

Preliminary market/product R&D

VALIDATING

- Min viable product
- Freeze cost/market projection

PROTOTYPE

Sizing&Optimization

PDR

Component design and dev

1st test article

May 2017 **Jul 2017** **Dec 2017** **May 2018** **Dec 2018** **May 2019**

Values

- BPC credentials, exposure/ feedback
- Exit Strategy

- Built up detailed market analysis and insights.
- Potential for publication.

- Academic papers publication.
- Patent-filing for Hummingbird.

Bifurcation: Join with established new space company?

HSX Cost/Year

$166k (2017)

$6.97m (2018)

$8.46m (2019)

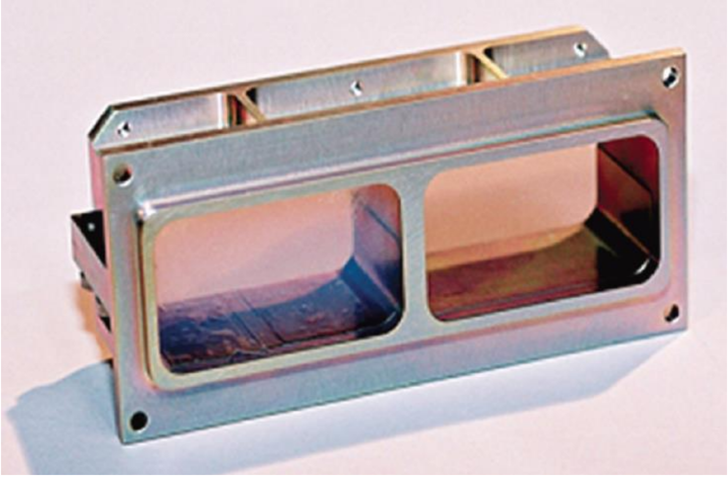
$24.1m (2020)

HSX

Tech Details

Aerogel Debris Capture

Experimentally proven capture capability: [1-2] <0.1mm 3-10km/s particle capture



Alternative materials: [3] Polyimide foam, foil stack

Hummingbird Strategy:

Velocity-matched intercept → larger particle capture. Higher-density materials possible.

Alternative Methods: [4,5] Robotic arm, Gossamer device, Flexible capture

[1] Woignier T., Duffours L., Colombel P. and Durin C. "Aerogels Materials as Space Debris Collectors." Advances in Materials Science and Engineering (2013).
[2] Horz F., Cintala M. J., Zolensky M. E., Bernhard R. B., Davidson W. E., Haynes G., See T. H., Tsou P. and Brownlee D. E. "Capture of Hypervelocity Particles with Low-Density Aerogel." NASA TM-98-201792 (1998).
[3] Hanada T. and Ariyoshi Y. "Passive Orbital Debris Removal using Special Density Materials." Kyushu University, IHI Corporation and JAXA Propriety.
[4] Nock, K. T. et al., "Gossamer Orbit Lowering Device (GOLD) for Safe and Efficient De-orbit", AIAA/AAS Astrodynamics Specialist Conference (2010), developed by Global Aerospace Corporation
[5] Benvenuto, R. and Lavagna, M. R., "Flexivle Capture Devices for Medium to Large Debris Active Removal: Simulations results to Drive Experiments", ESA Robotics (2013)

Tech Details

Propulsion

Hybrid System

1 *Chemical*

- **MMH+NTO** or AF-M315E [1]
- Launch abort and on-orbit maneuverability
- 15 kg of propellant

2 *Electrical*

- Hall effect thruster
- On-orbit maneuverability
- 18 kg of propellant

Total: $\Delta V = 1.75\ km/s$

Automatically analyze given mission trajectory, identify nearby[2,3] reachable debris and autonomously perform capture/return.

[1] Spores et al. "GPIM AF-M315E Propulsion System." 49th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit (2013).
[2] Cerf, M., "Multiple Space Debris Collecting Mission Debris Selection and Trajectory", EADS Astrium Space Transportaion (
[3] Barbee, B. W. et al., "Design of Spacecraft Missions to Remove Multiple Orbital Debris Objects", AAS Guidance and Control Conference (2012)