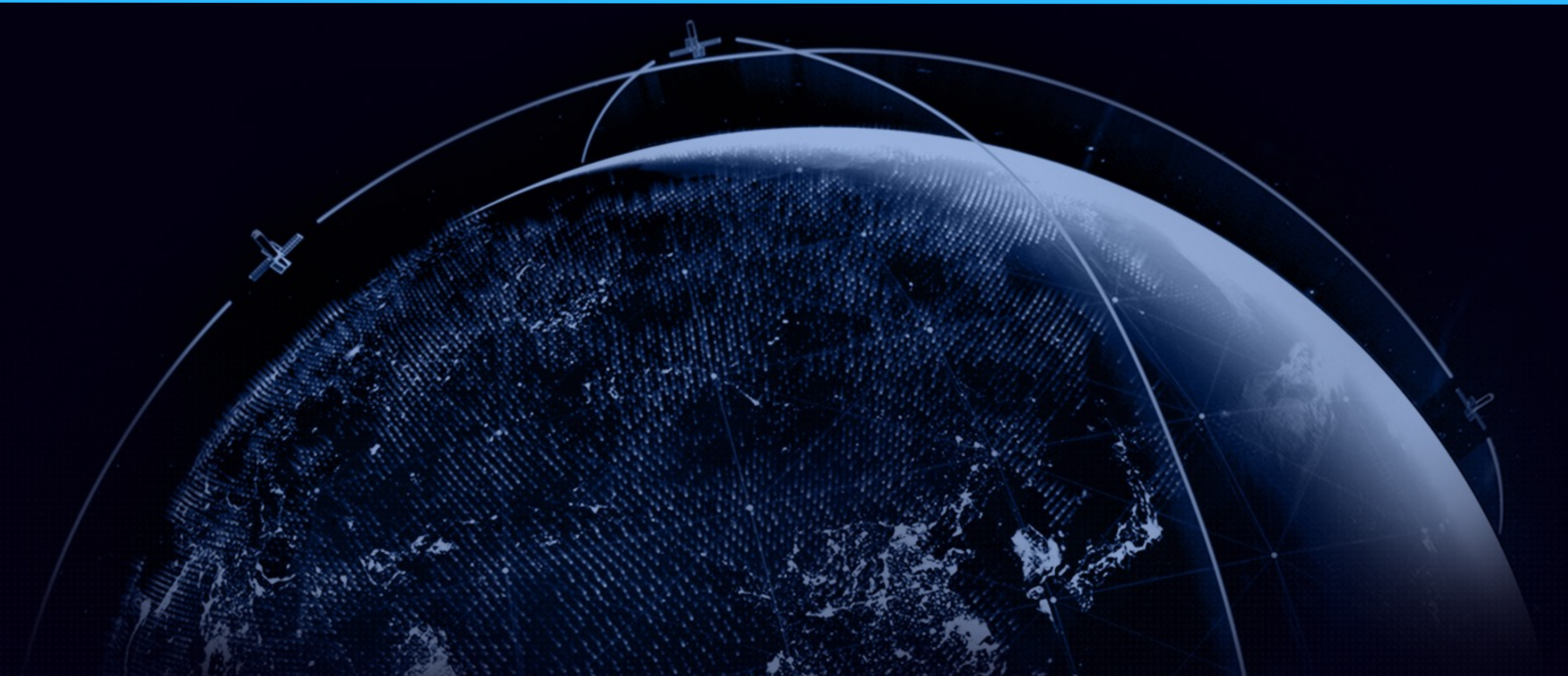
Dragon*Con 2021

SMALL SATELLITE REVOLUTION

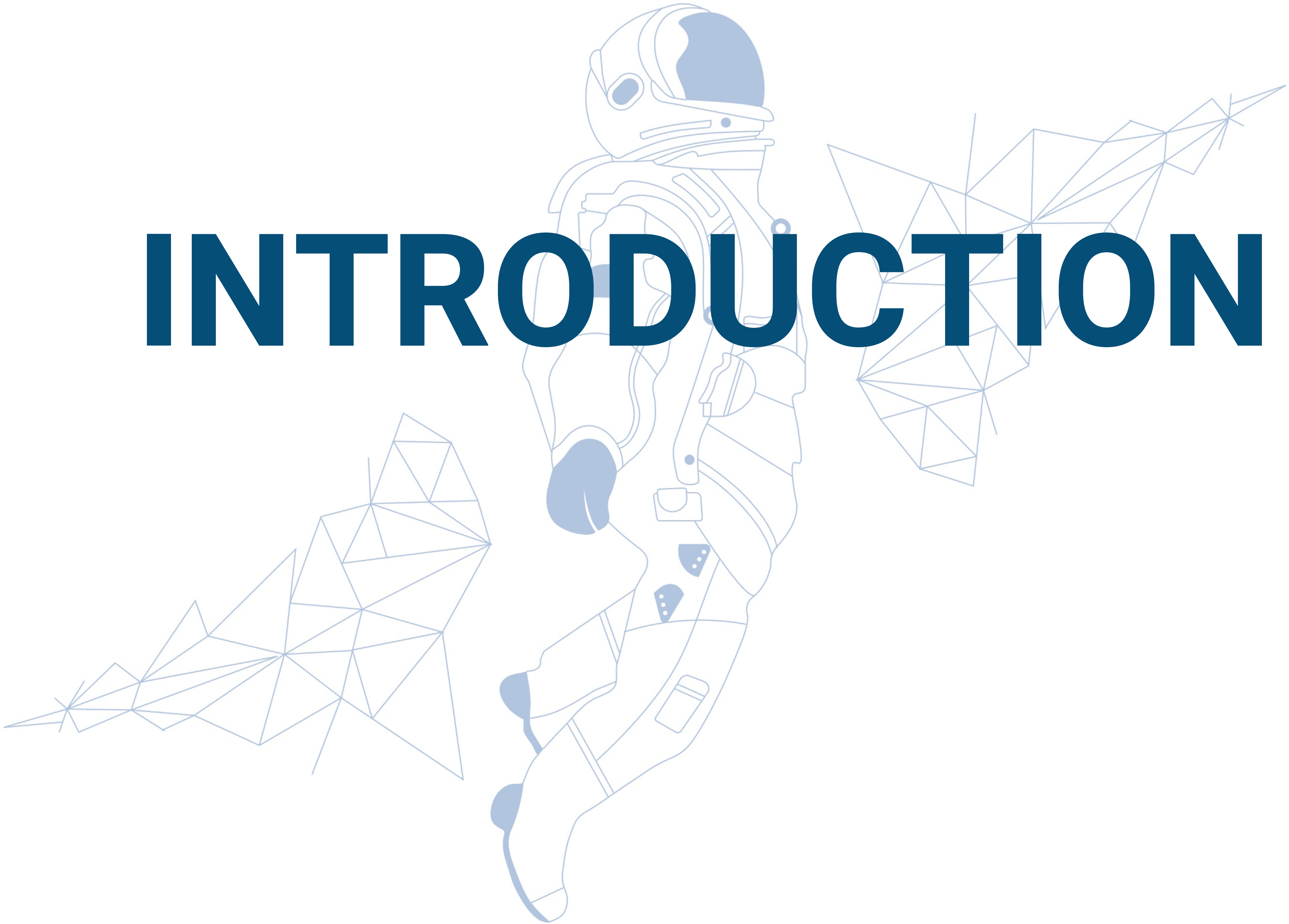
From University Missions to Constellations



John E. Bradford, Ph.D.

SpaceWorks®

INTRODUCTION

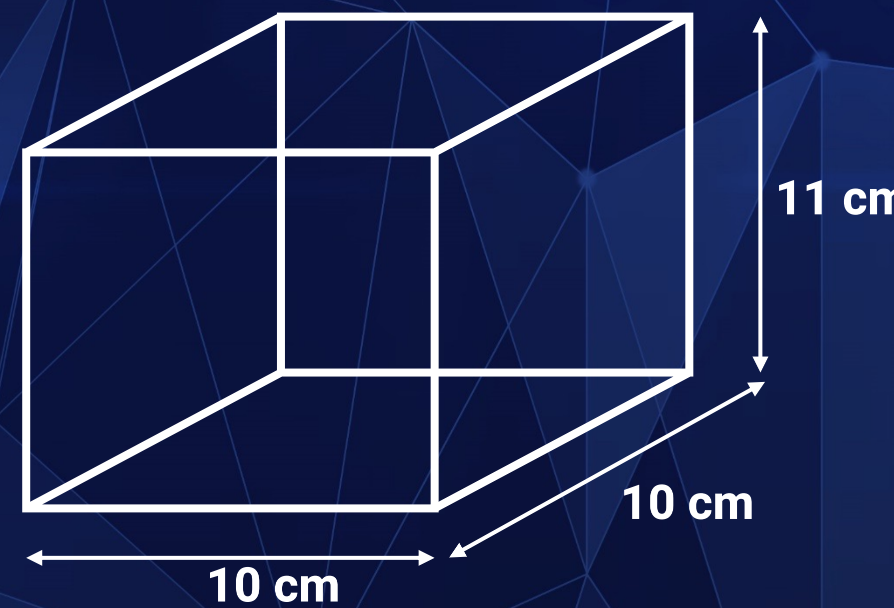


IN THE BEGINNING…

- After Sputnik, satellites quickly matured and became large and heavy in order to provide the needed capabilities
- Typical development costs of $100M-$Bs made them primarily the purview of the military and very large telecom operators
  - Designed to function for 10-20 years in space with no ability to service/repair
- For both the military and telecom, GEO has also been a very desirable orbit
  - GEO is hard to reach for any launch system, often requiring an additional rocket stage
- Because satellites were so expensive and took so long to build, could not afford to have a launch failure
- So, historical launch vehicles (Atlas, Delta, Titan, etc.) were designed to be very reliable – this drove up their costs as well
- So we ended up with very expensive industry that created barriers to entry…

THE CUBESAT

- Simple form factor satellite design proposed in 1999 by Bob Twiggs (Stanford)
- First flight of CubeSat occurred in 2003



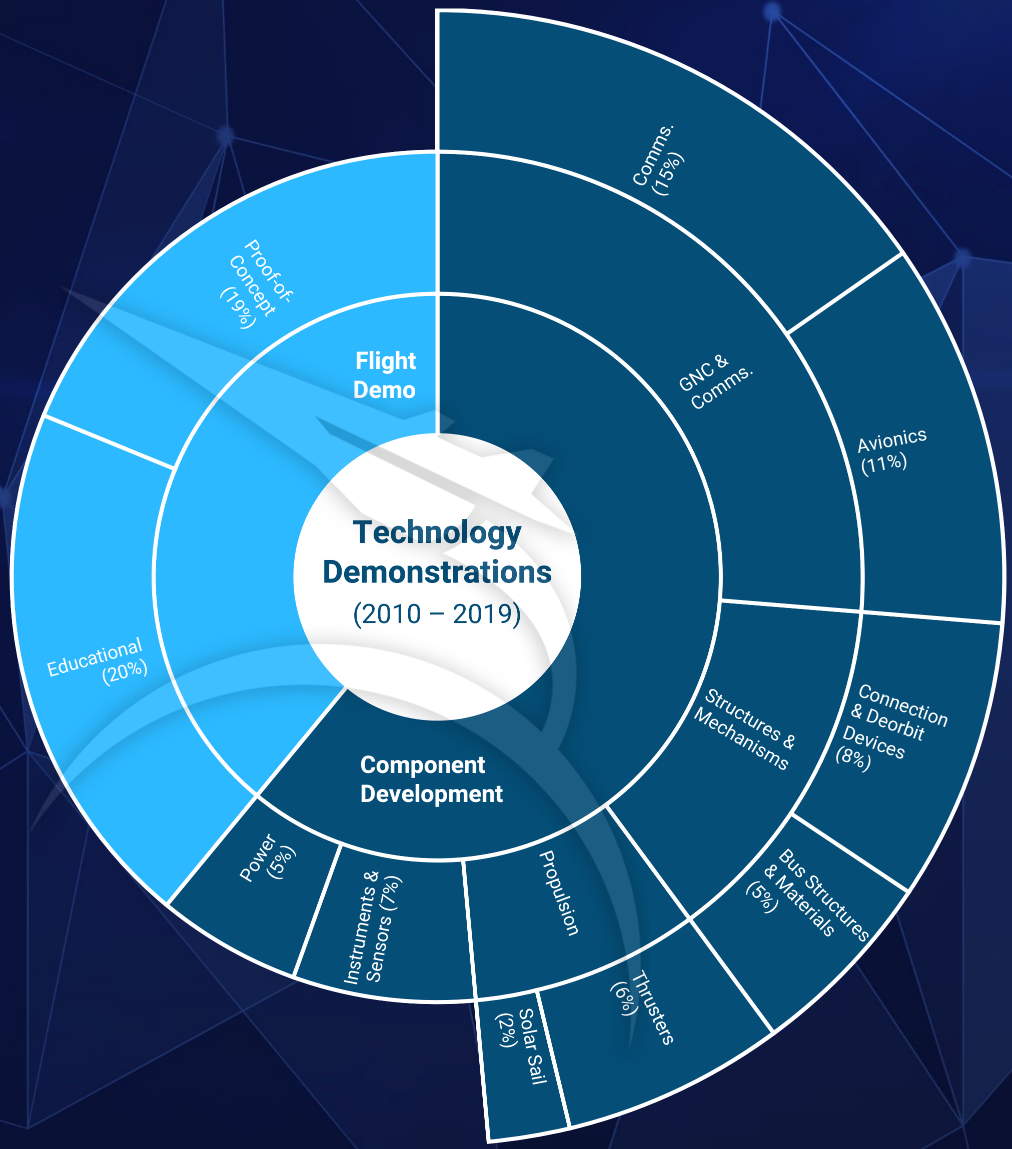
"1U"
Mass < 1.33 kg

SMALL SATELLITE DEFINITIONS

AS TECHNOLOGY DEMONSTRATIONS

- Early Cubesat/smallsat missions were simple technology demonstrators and research enablers primarily used to support satellite component development

- <u>Examples</u>
  - GNC & Communications
  - Structures & Mechanisms
  - Propulsion
  - Sensors
  - Power



ENABLERS

- Standardization created a commodity market for basic satellite components and allowed economies of scale
  - A simple satellite that could operate in space can now be built for <$25,000
- Significant reductions in launch cost
  - Increased support/opportunities for secondary payloads on primary launch vehicles and emergence of dedicated launch systems
  - e.g. NASA CSLI – CubeSat Launch Initiative
- Government-support as educational programs
  - e.g. NASA ELaNa – Educational Launch of Nanosatellites
- Growing interest in space
  - Push by more universities to offer programs and be engaged in industry, providing actual flight hardware and flight demonstrations (students wanting to do more)

INDUSTRY DEVELOPERS AND OPERATORS

0 - 50 kg

- planet.
- ASTROCAST
- Capella Space
- AERIAL MARITIME
- SATELLOGIC
- HawkEye 360
- spire
- SpaceQuest
- ASTRO DIGITAL

50 – 250 kg

- OneWeb
- planet.
- EARTH i
- ICEYE
- AXELSPACE

250 - 1,000 kg

- SPACEX
- iridium
- urthecast
- SPACEBELT
- Globalstar

1,000 - 2,000 kg

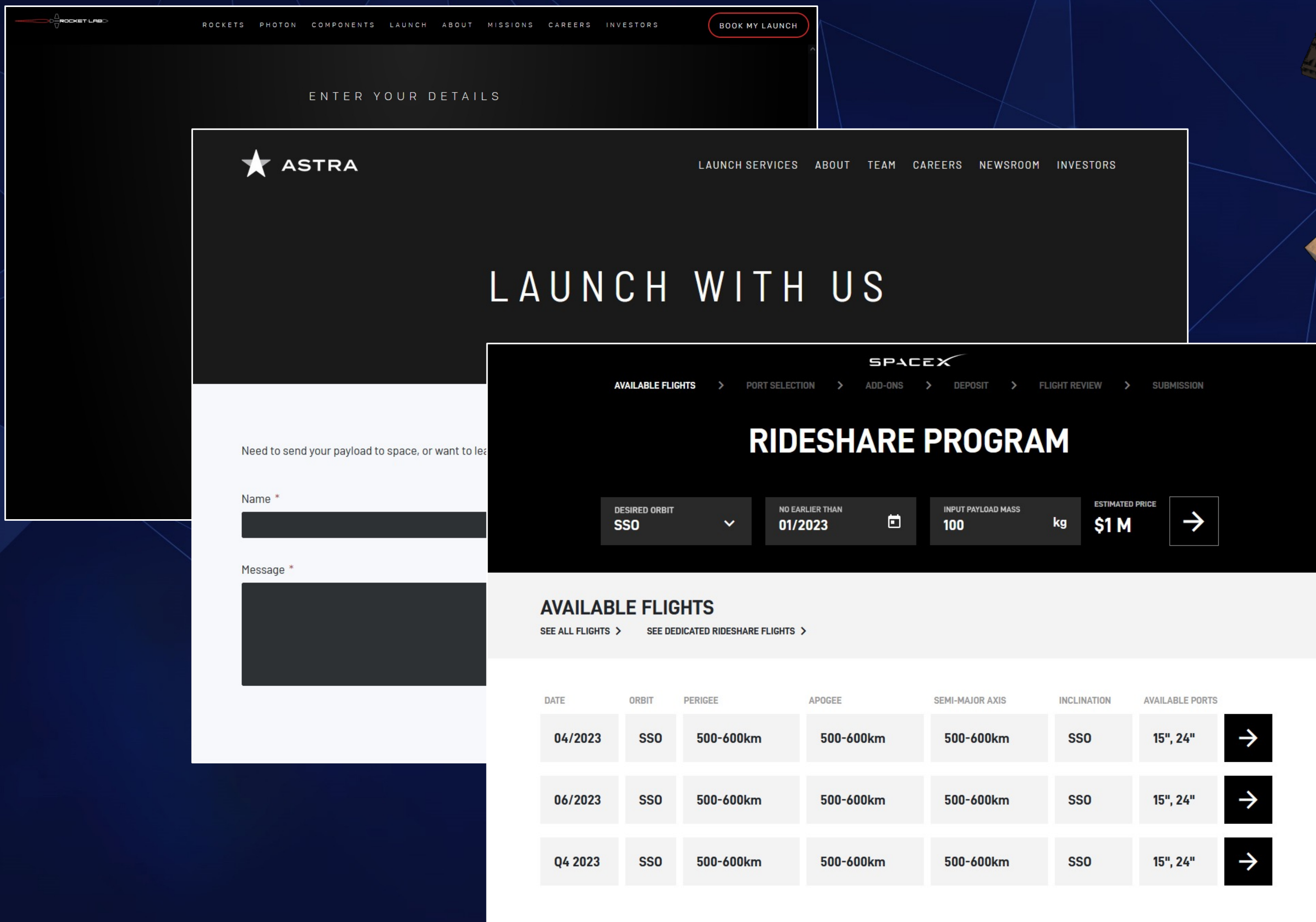
- AMOS by Spacecom
- SES
- urthecast
- ABS

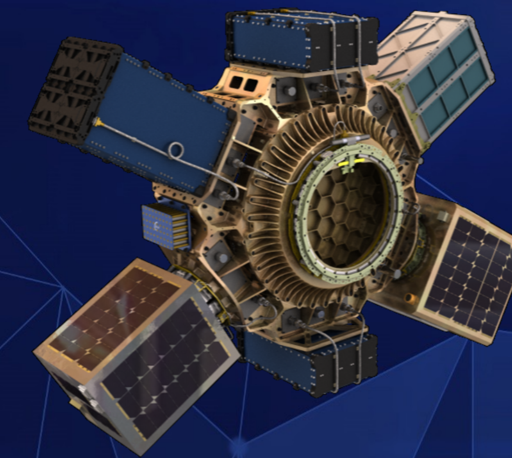
2,000 kg+

- INTELSAT
- ARABSAT
- ECHOSTAR
- SES
- ViaSat
- hispasat
- TURKSAT
- inmarsat
- DigitalGlobe

BY MASS CLASS

HOW DO I GET TO ORBIT ?





CURRENT STATE OF THINGS

- We have - collectively as the World - launched about ___?____ satellites (ever)

CURRENT STATE OF THINGS

- **We have - collectively as the World - launched about 11,000 satellites (ever)**

- **As of 2020, there were about 6,500+ satellites in orbit**
  - 3,370 operative and 3,170 inactive
  - Remainder have re-entered the atmosphere for demise or been destroyed

***Data from Bryce Space**

CURRENT STATE OF THINGS

- We have - collectively as the World - launched about 11,000 satellites (ever)
- As of 2020, there were about 6,500+ satellites in orbit
  - 3,370 operative and 3,170 inactive
  - Remainder have re-entered the atmosphere for demise or been destroyed
- From 2020 to 2021, the active number has increased by 28%
- In 2011, there were ~40 satellites launched that weighed < 600 kg
- In 2020, there were ~1200 satellites launched that weighed < 600 kg

*Data from Bryce Space

WHAT ARE THEY ALL DOING ???

Number of satellites	Main purpose
1832 satellites	Communications purpose
906 satellites	Earth Observation
350 satellites	Technology development and demonstration
150 satellites	Navigation and positioning
104 satellites	Space science and observation
20 satellites	Earth science
10 satellites	Other purposes

SMALL-SAT TRENDS

Small Sat Applications

Earth Observation / Remote Sensing

Optical/SAR Imagery
AIS/ADS-B
GPS-RO Occultation

Communications

Data/Voice
Internet-of-Things
Amateur Radio

Scientific

Ionospheric Observation
Materials Testing
Microgravity Research

Technology

Component Qualification
Hardware Testing
Risk Reduction

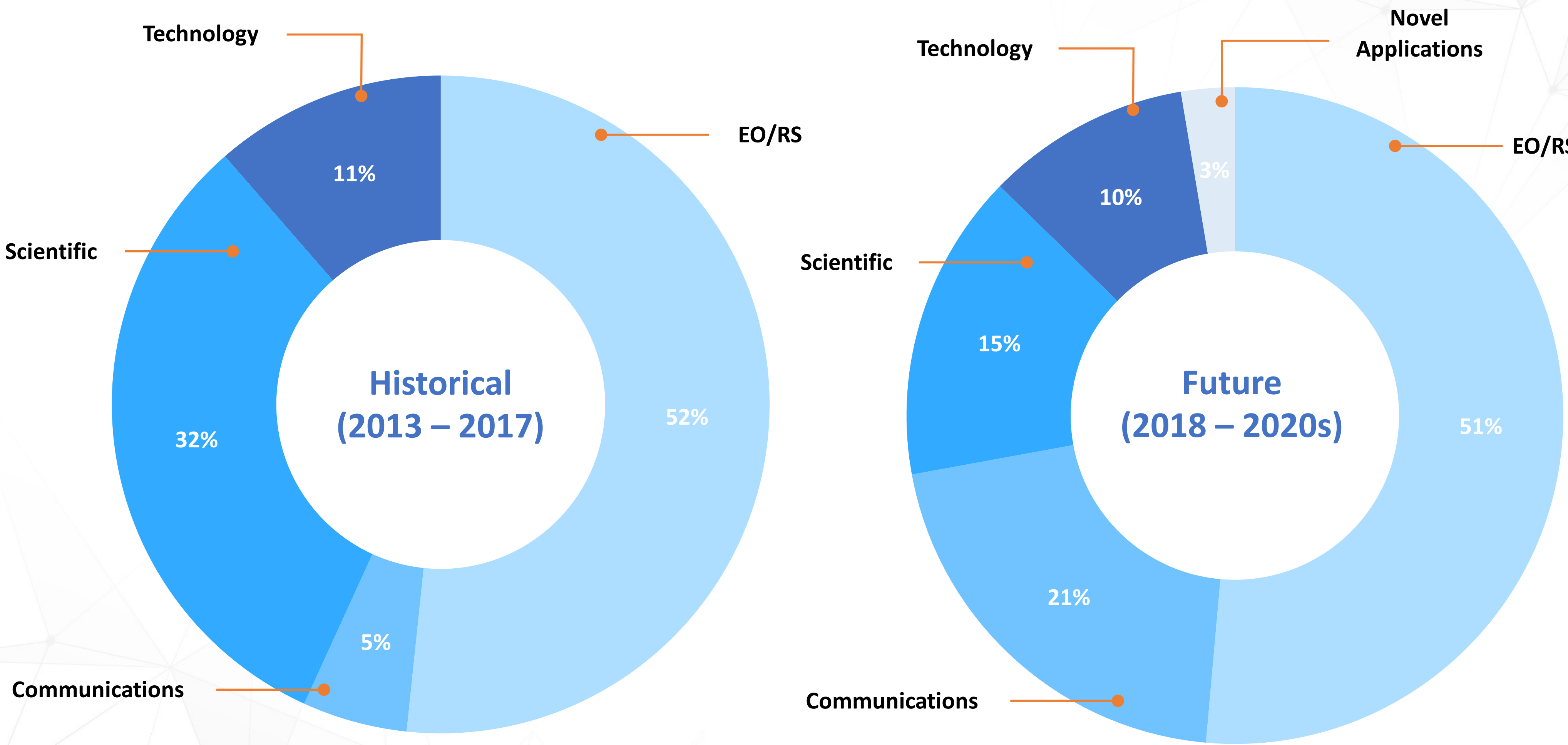
Navigation

GPS
Galileo
GLONASS

Novel Applications

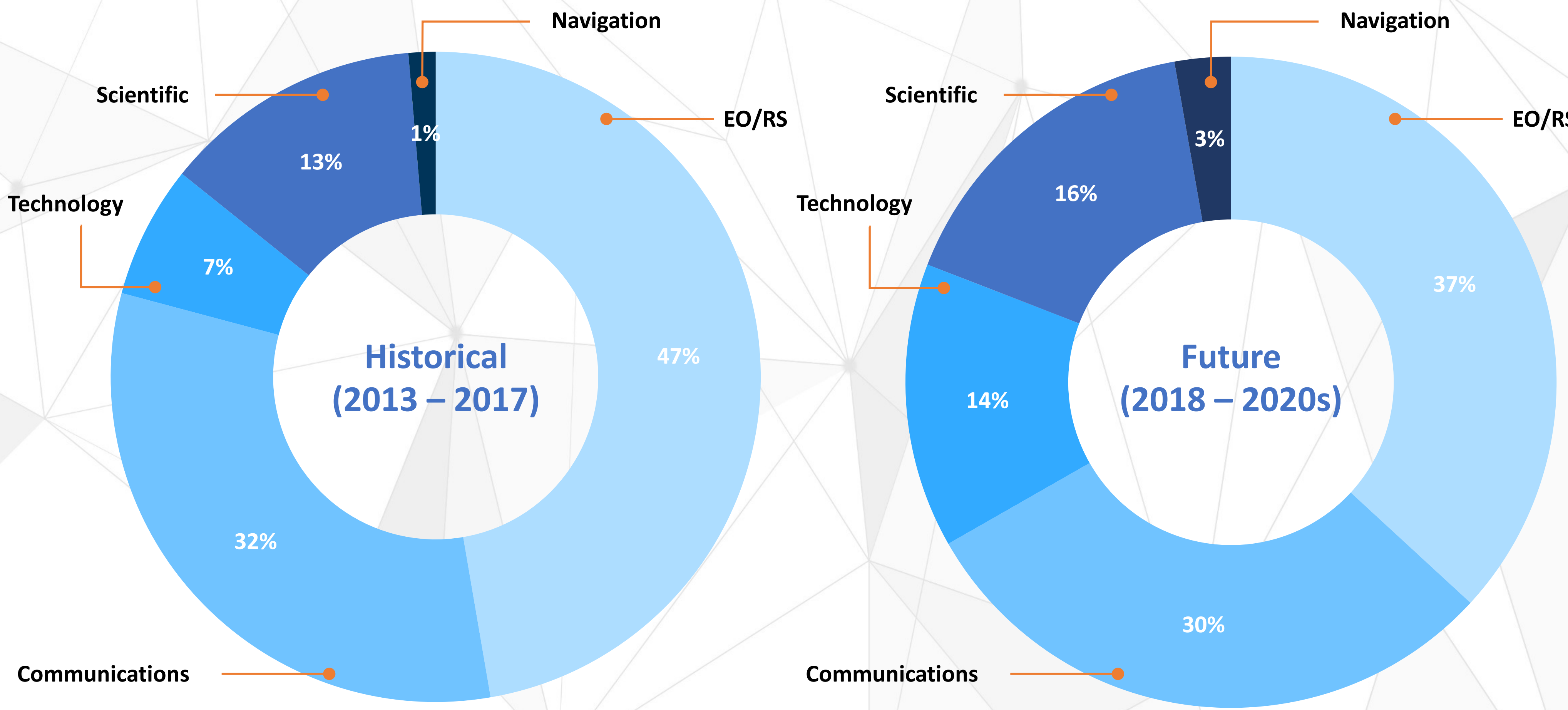
Space Burial
Virtual Reality
Blockchain
Data Arks

Satellite Applications (1–100 kg)

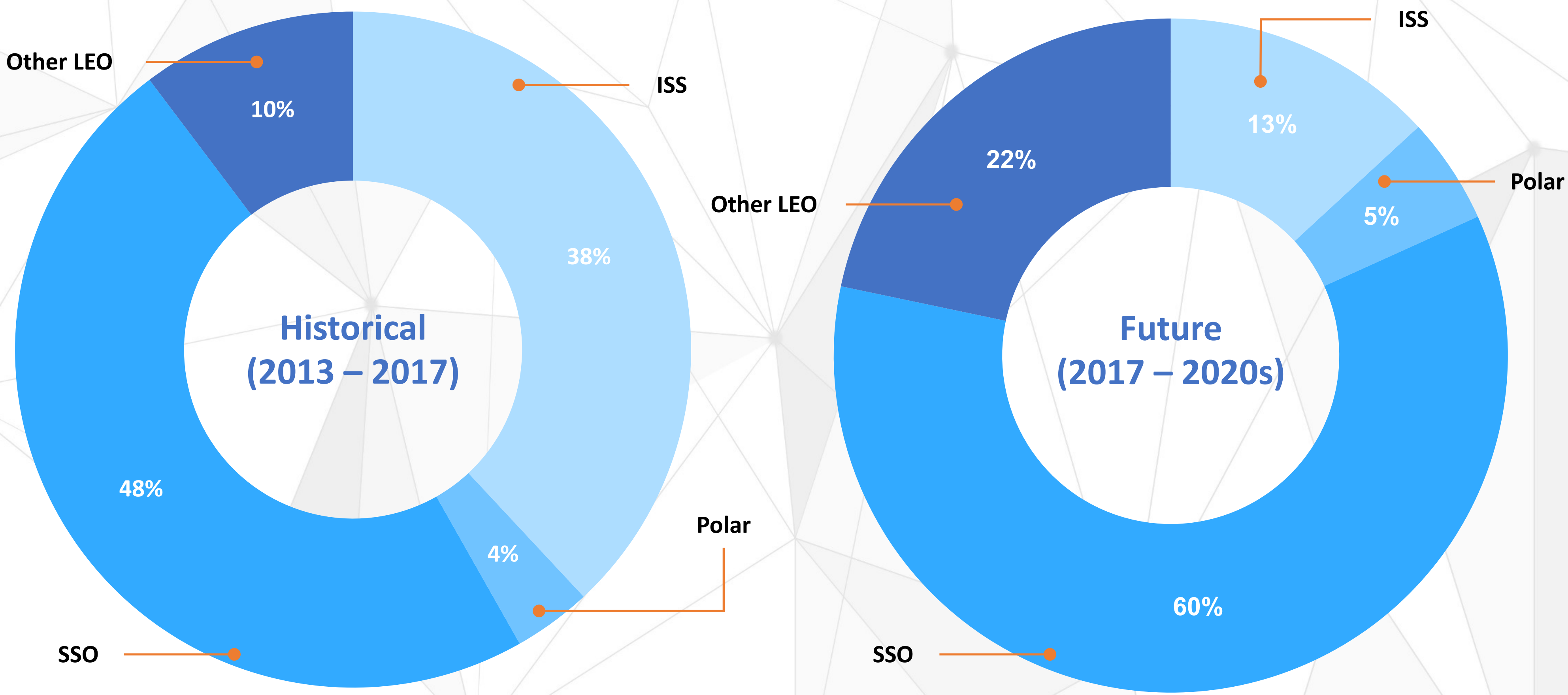


Earth Observation and Remote Sensing continue to dominate the market, driven primarily by growth of large commercial constellations.

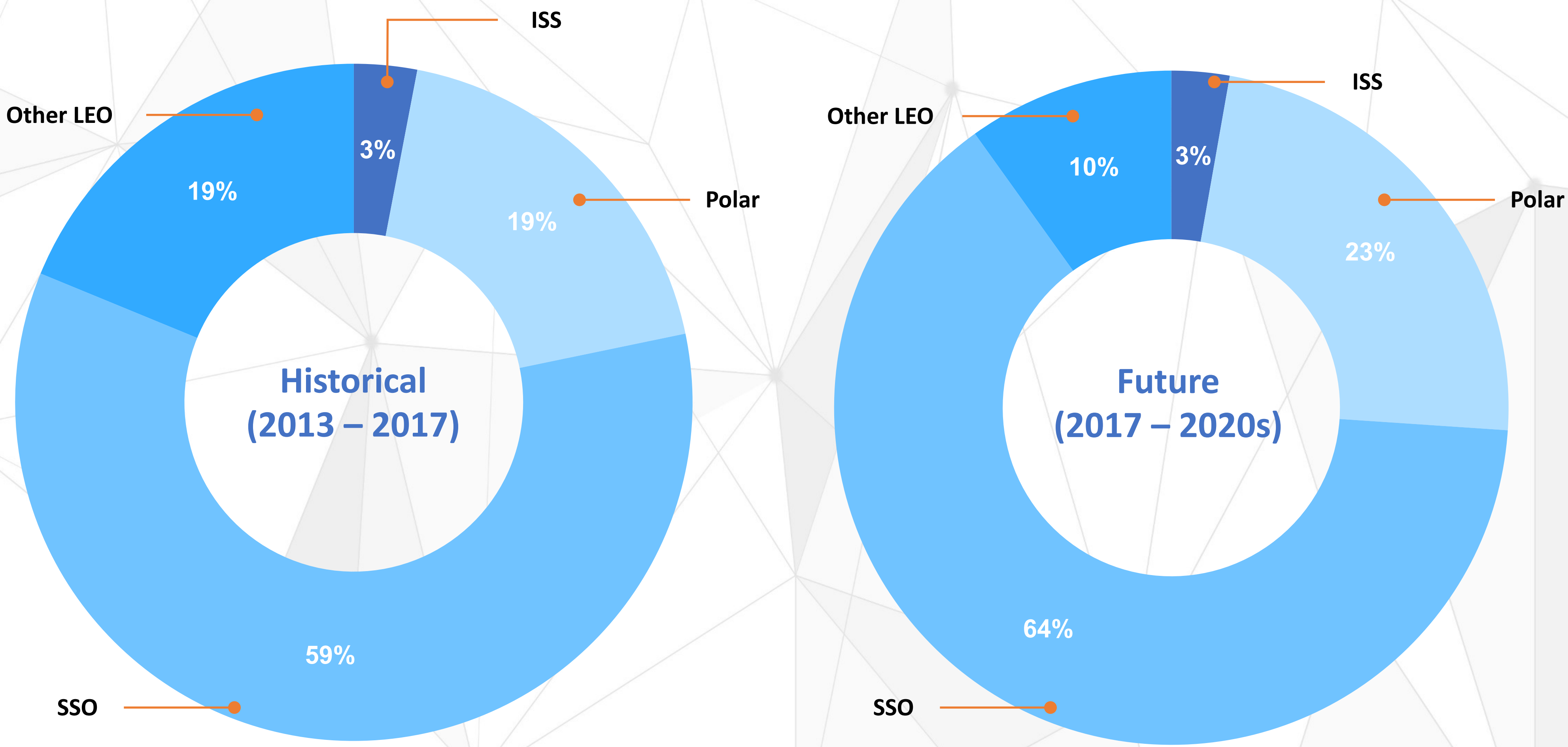
Satellite Applications (101–500 kg)



Satellite Orbital Destinations (1–100 kg)

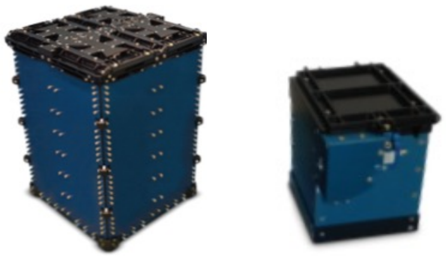


Satellite Orbital Destinations (101–100 kg)



TECHNOLOGY

SMALL SATELLITE DISPENSERS



(image credit: ISIS)

Manufacturer

ISIS

Variations

ISIPOD (1U / 2U / 3U)
QuadPack (6U / 12U / 16U)

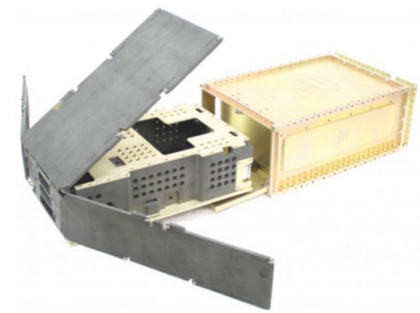
(image credit: Tyvak)

Manufacturer

Tyvak

Variations

Rail-POD (3U)
NLAS Mk. II (6U)



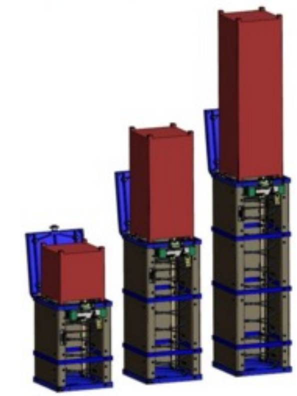
(image credit: PSC)

Manufacturer

Planetary Systems Corp.

Variations

Canisterized Satellite Dispenser (3U / 6U / 12U)



(image credit: Astrofein)

Manufacturer

Astro-und Feinwerktechnik Adlershof

Variations

SPL (1U)
DPL (2U)
TPL (3U)

SMALL-SAT PROPULSION

ThrustMe
Cold Gas Thruster

THRUSTME

I2T5
COLD IODINE THRUSTER

Imagine having a cold gas thruster without a pressurized propellant tank – such a system is now available!
ThrustMe's I2T5 is a non-pressurized cold gas propulsion system operating with solid iodine propellant. The I2T5 stand-alone system includes the propellant storage, flow control, power processing unit (PPU), as well as thermal management and intelligent operation all embedded into a 0.5U form factor. Its standardized architecture allows for very short lead times and batch production to better serve constellation needs.

PRODUCT INFORMATION

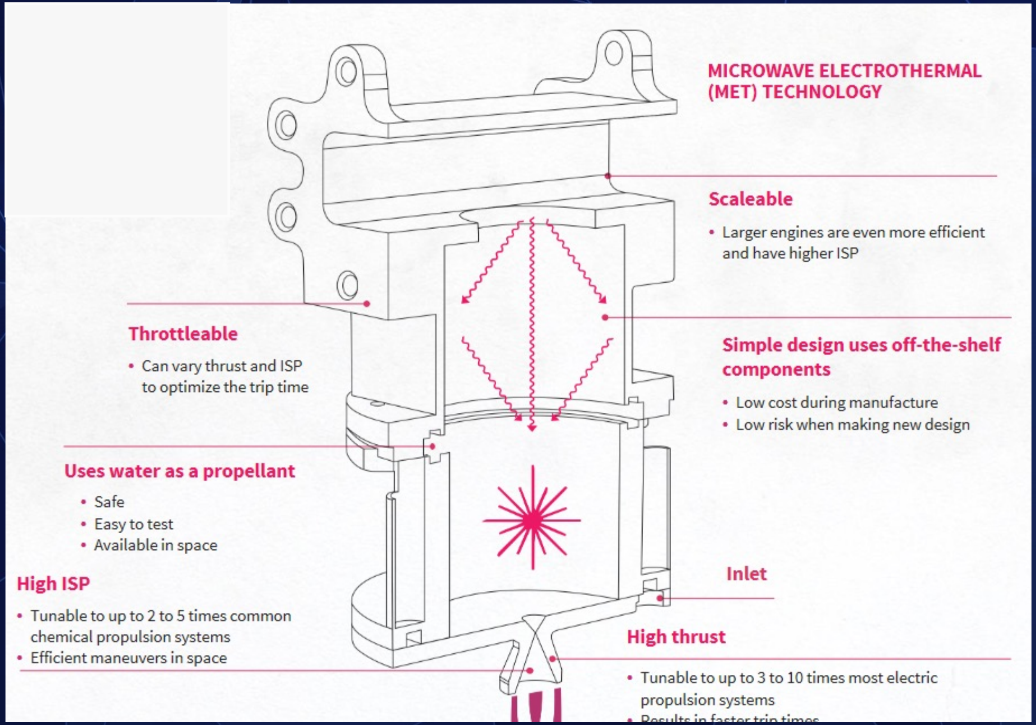
I2T5

ADVANTAGES
- ✓ Safe
- ✓ Convenient
- ✓ Economical

PERFORMANCE & SPECIFICATIONS

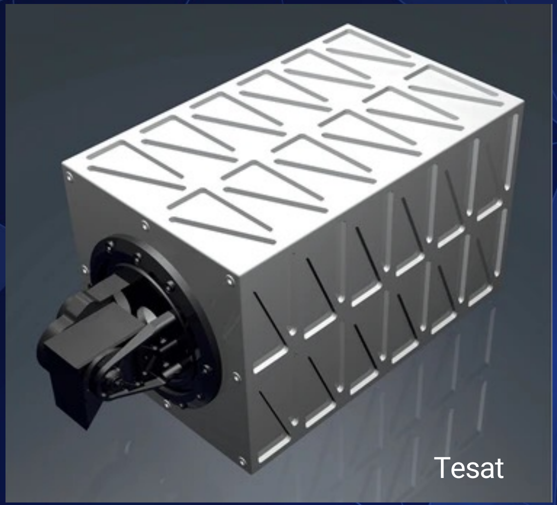
Thrust	0.2 mN
Total impulse	75 Ns
Form factor	0.5 U
Total wet mass	0.9 kg
Total power	5 - 10 W
Start-up time	10 min

Momentus, Inc.
H2O Microwave Electrothermal (MET)

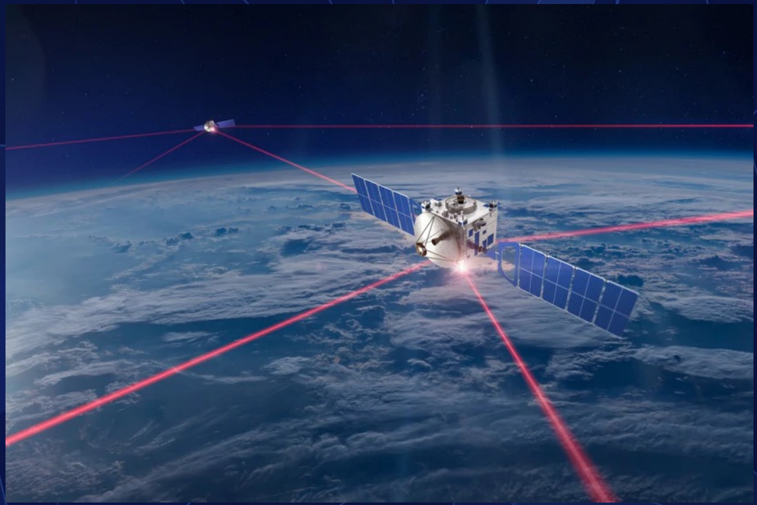


SMALL-SAT COMMUNICATIONS

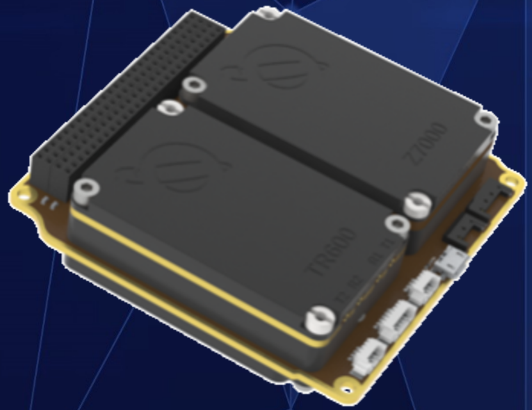
Space-to-Ground Laser Communications



Satellite-to-Satellite Interlink



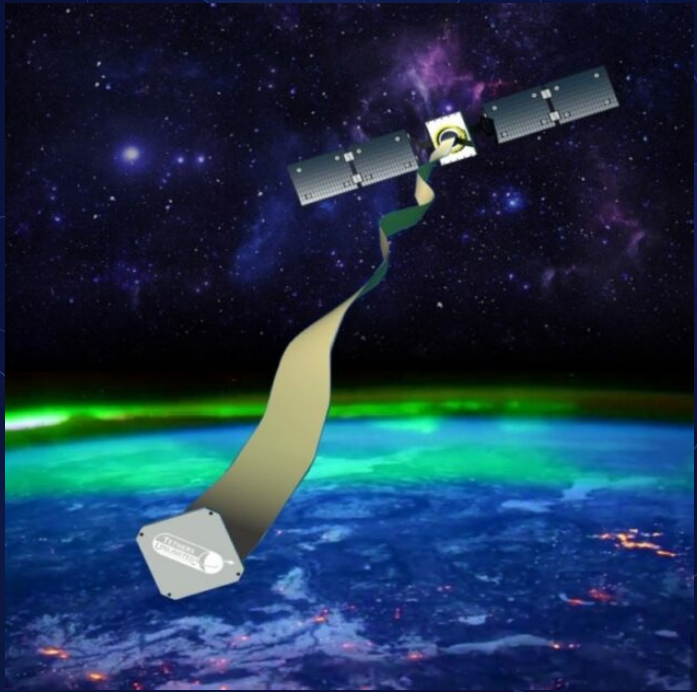
Software Defined Radios (SDRs)



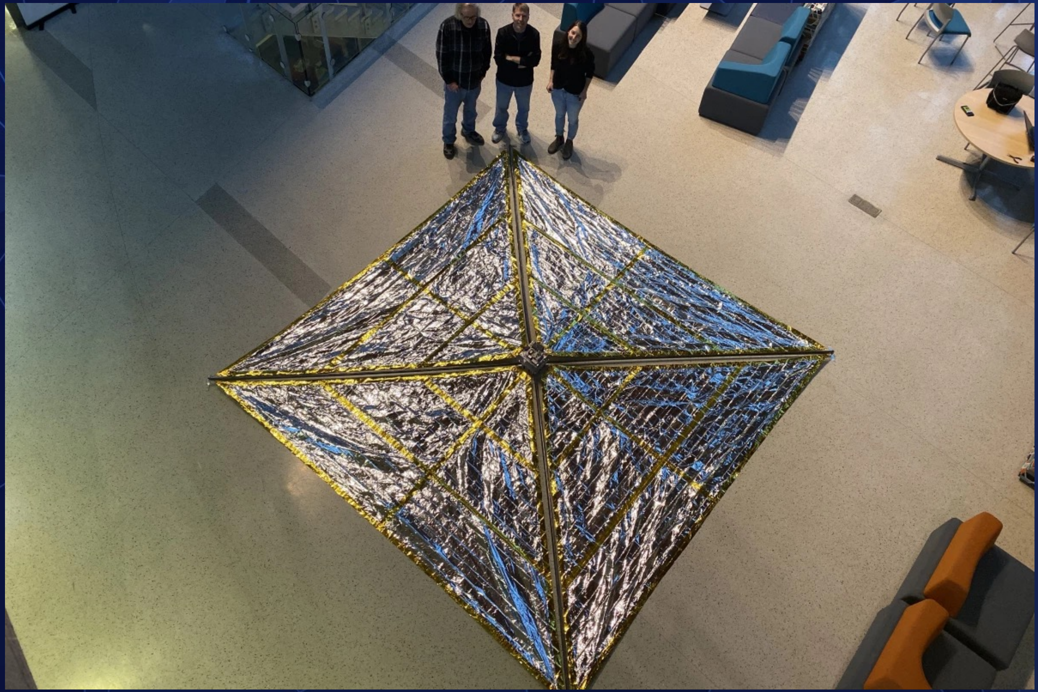
GOMSpace

SMALL-SAT DEORBIT SYSTEMS

Tethers Unlimited
Deorbit Terminator Tape



Drag Sails
Spinnaker3, Purdue



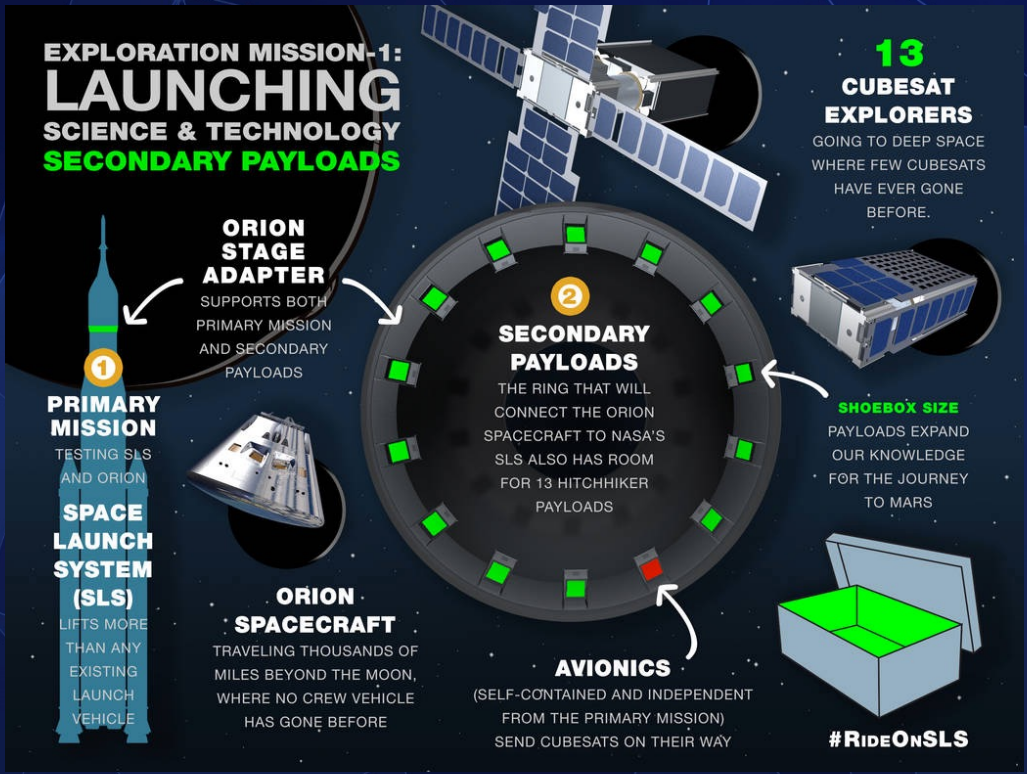
FUTURE MISSIONS & CHALLENGES

MEGA CONSTELLATIONS

Name/System	S/C Mass (kg)	Current On-Orbit	Constellation Size	Purpose
SpaceX Starlink	260 kg	1,600	12,000 (30,000*)	Broadband Internet
Amazon Kuiper	n/a	0	3,236	Broadband Internet
OneWeb	150 kg	72	648	Broadband Internet
Planet (Labs)	4-5 kg	175	-	Earth Imaging
LightSpeed	700 kg	0	298	Broadband Internet
O3b	700 kg	20	27	Broadband Internet
Guo Wang	n/a	0	12,992	Broadband Internet

INTERPLANETARY MISSIONS

- **13 6U Cubesats to fly on Artemis-1 mission**
  - BioSentinel
  - Cubesat to Study Solar Particles (CuSP)
  - LunaH-Map
  - Lunar Flashlight
  - Lunar IceCube
  - NEA Scout
  - SkyFire
  - +3 from NASA's Cube Quest Challenge
  - +3 for international partners



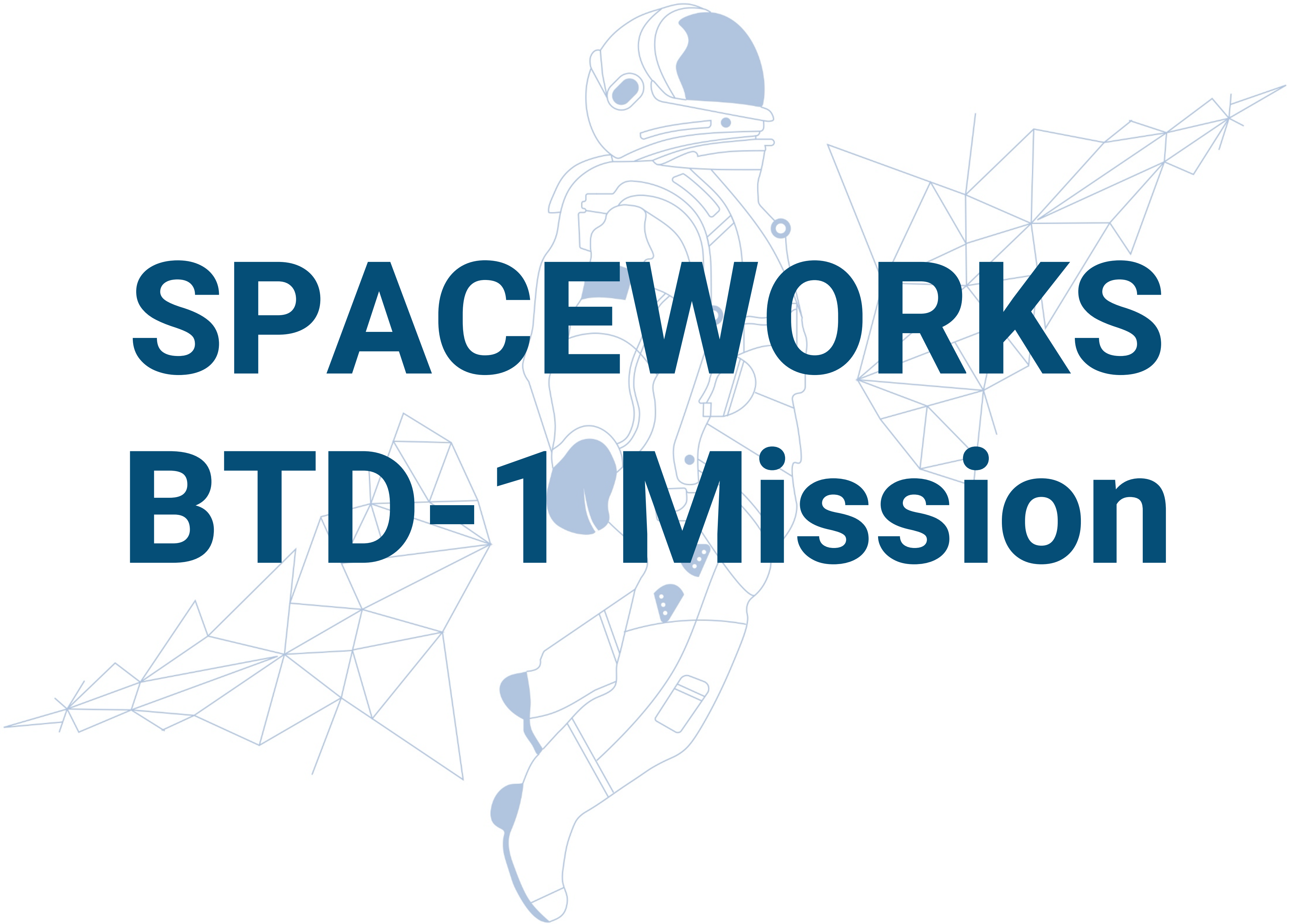
ORBITAL DEBRIS CLEANUP

- ESA is conducting ClearSpace-1 mission for space debris removal

- In 2025, a 4-armed robot will capture a 100-kg piece of orbiting debris located ~500-km altitude
    - Debris is Vega rocket's secondary payload adapter (Vespa)

- If successful, will be the first removal of previously generated debris from orbit

- Program cost is ~$130M



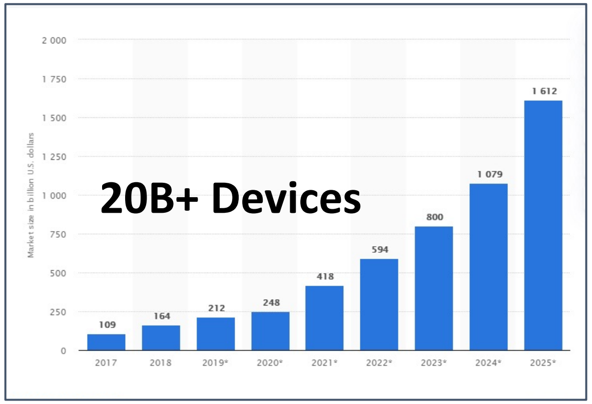
SPACEWORKS BTD-1 Mission

MOTIVATION

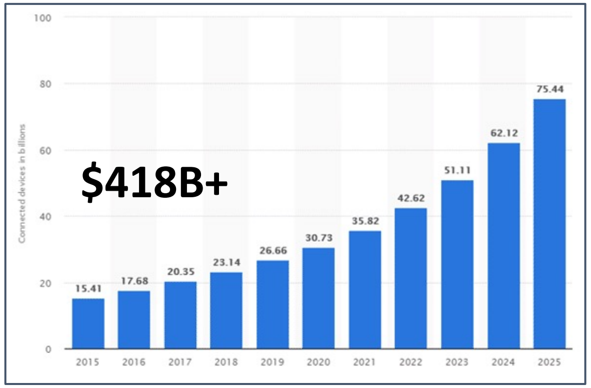
SpaceWorks Internal Studies in 2014-2015 Identified Emerging IoT/M2M as a Significant Opportunity for Infusion of Space-based Capabilities

- **The global Internet-of-Things (IoT) is a rapidly growing marketplace with billions of emerging devices**
- **Despite high accessibility to existing terrestrial/cellular networks, only fraction of the Earth's surface is supported for connectivity**
- **Existing satellite network services are expensive (e.g. Iridium)**
- **Launch provider costs have lowered significantly and cubesat technology has rapidly matured**

Market Forecasts



Credit: Statista 2019



Credit: Statista 2019

Current IoT and M2M Devices & Applications

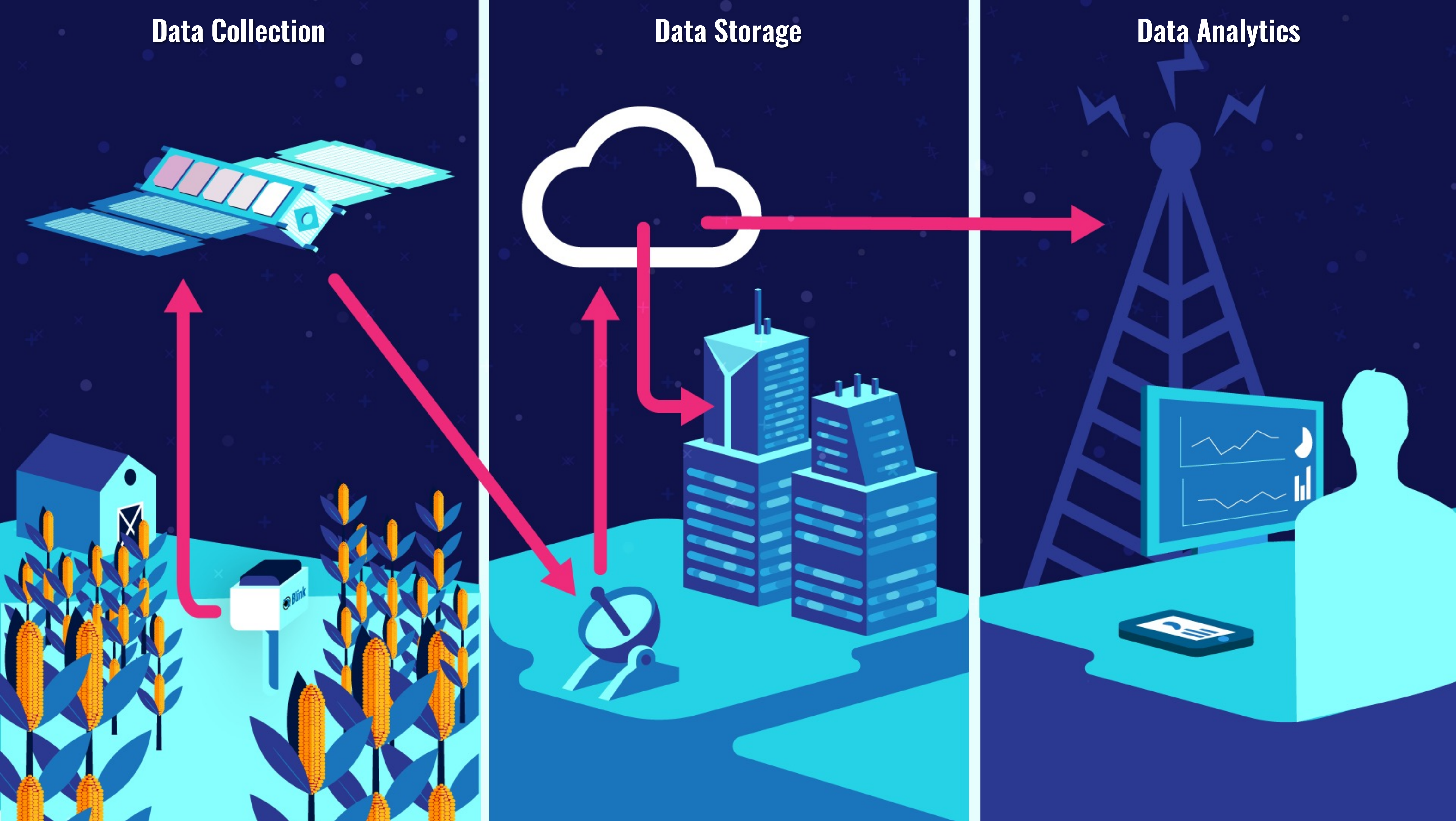
Commercial/Consumer

Industrial

Using active signal collection (we're ears, not eyes), our small satellite network provides an affordable global network for satellite-IoT

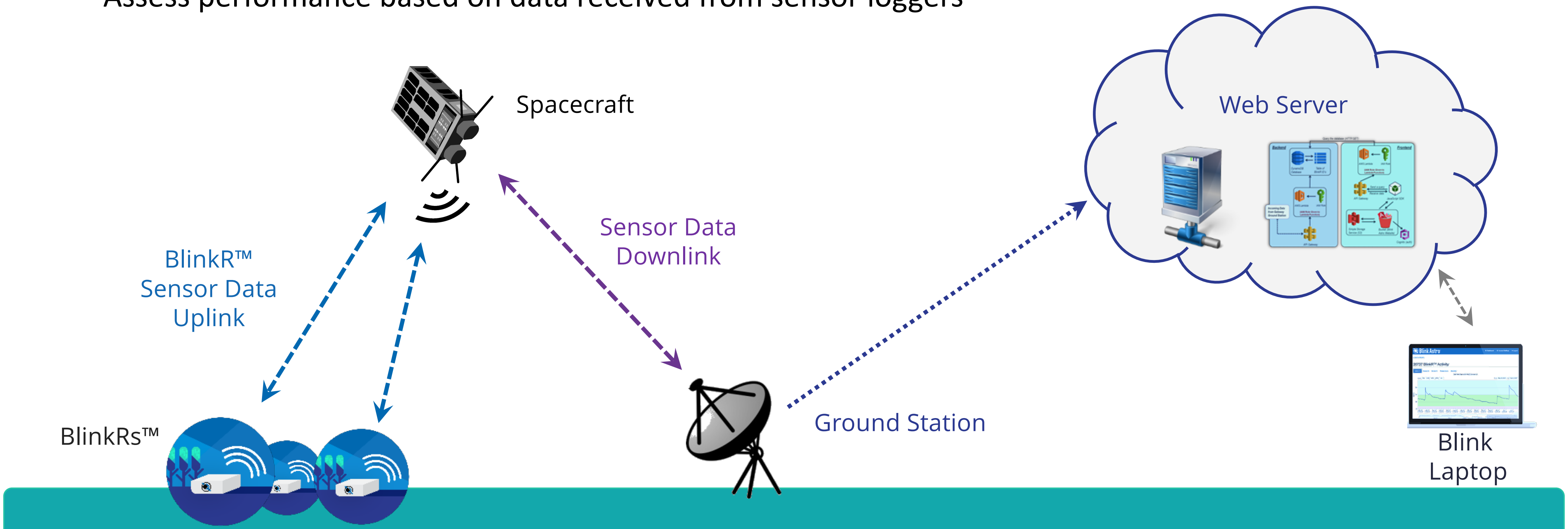
- Globally Deployed BlinkR™ Transmitters
- Cubesat-based LEO Network (BlinkSats™)
- Single-Provider Integrated IoT Network


Constellation of BlinkSats™ receives data directly from sensors, providing global coverage from Low Earth Orbit.
No relay hubs are needed.
Small BlinkR™ transmitters/ground terminals actively send secure data to satellites.
Blink's network accommodates sensors from many industries
Patent No. US 10,368,251 B1


Data Collection
Data Storage
Data Analytics
Blink

BTD-1 | End-to-End Demonstration Overview

- **Objective: Complete a full end-to-end network link demonstration for short-burst data services, consisting of:**
  - Custom-developed receiver payload on board host spacecraft
  - Custom-developed sensor loggers / ground transmitters
  - Partner provided satellite downlink communications to ground station
  - Assess performance based on data received from sensor loggers

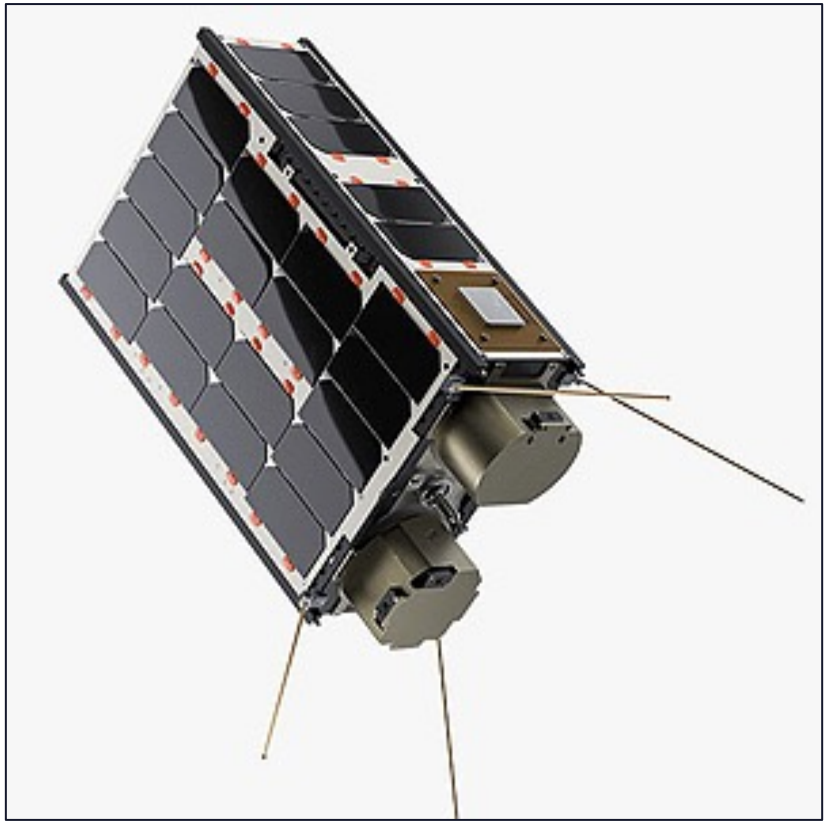


BTD-1 | Hosted Payload Opportunity

- **NanoAvionics Multipurpose Platform Spacecraft Bus**
  - Nanosatellite bus manufacturer based in Lithuania
- **6U Cubesatellite Form Factor (aka M6P)**

- Empty Bus Mass: 4,570 g
- Max Payload Mass: 7,500 g
- Payload Volume: up to 4U
- Regulated Voltage Rails: 3.3 V, 5V; (3V-18V configurable)
  - Maximum Power
    - 3.3V Rail 20 Watts
    - 5V Rail 20 Watts
    - 3V-18V Rail 20 Watts
- Max. Channel Output Current: 3A
- CAN/UART Data Interfaces

NanoAvionics M6P Spacecraft



BTD-1 | Launch Vehicle Opportunity

- **ISRO Polar Satellite Launch Vehicle (PSLV) C-45**
- **Launched from the Satish Dhawan Space Centre in Sriharikota (Andhra pradesh, India) on April 1, 2019**
- **Multiple manifest with primary payload + 29 spacecraft**

- **PSLV-QL Form Factor**
  - First PSLV 4 strap-on booster configuration
- **Propellants**
  - Stage 1: Composite Solid
  - Stage 2: Earth Storable Liquid
  - Stage 3: Composite Solid
  - Stage 4: Earth Storable Liquid

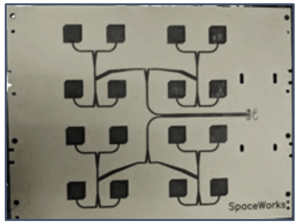
- **First mission by ISRO which launched satellites in three different orbits in Sun Synchronous Orbit (SSO)**
  - EMISAT – 780 km altitude
  - Numerous Satellites (including “M6P”) – 504 km altitude
  - Orbital Platform Experiment mission on Launch Vehicle – 485 km altitude

• BTD-1 | Mission and Hardware Development Timeline

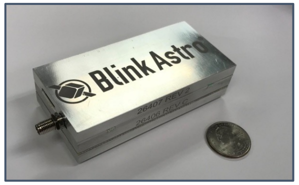
Date	Milestone
April 2018	Contract Signature for NanoAvionics M6P Hosted Payload
August 2018	Completed and Shipped BTD-1 Payload for Tech Demo
December 2018	Start of production for BlinkR ground transmitters
April 2019	BTD-1 launches on M6P spacecraft (PSLV-C45)
May-August 2019	Successful data transmission from multiple ground BlinkRs to BTD-1 Payload

- Blink developed a custom communication system for an orbital flight test
- Flight hardware was shipped 125 days after contract signature
- BTD-1 demonstrated key network technologies:
  - Low noise, high performance receiver
  - Tunable from 1 GHz to 6 GHZ
  - Multiple access technologies
  - Doppler compensation
  - Flexible data rate, modulation, and encoding

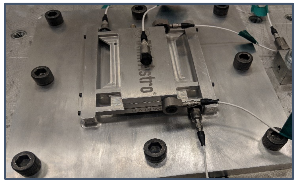
Antenna Assembly



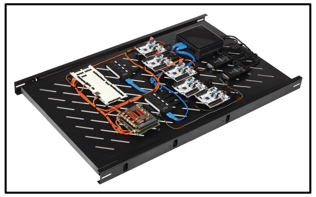
Radio Main Assembly



Vibration Testing

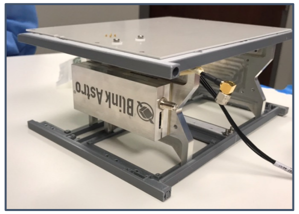


Flat Sat Testing



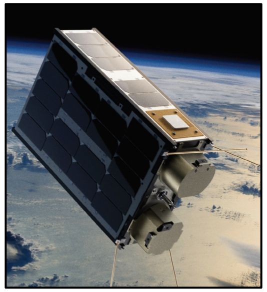
Launch

Integration Fit Check

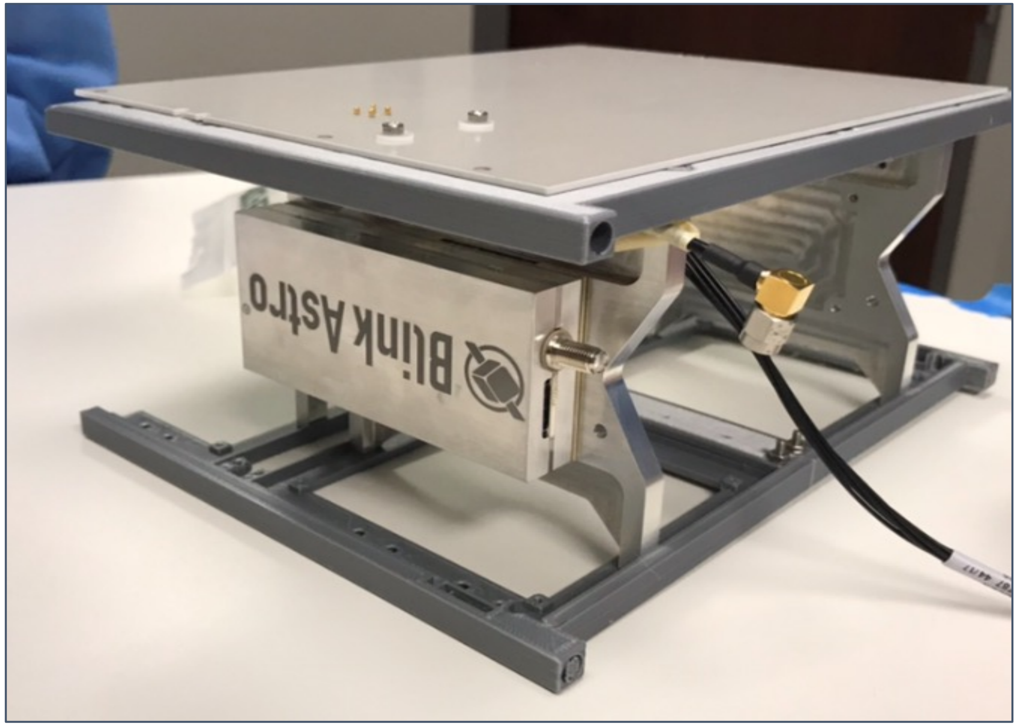


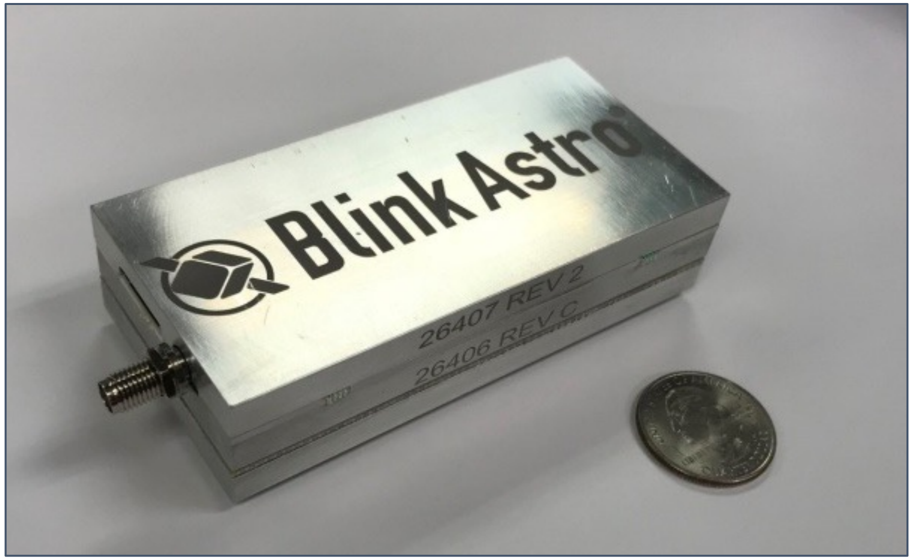
Field Testing

In-Orbit Testing

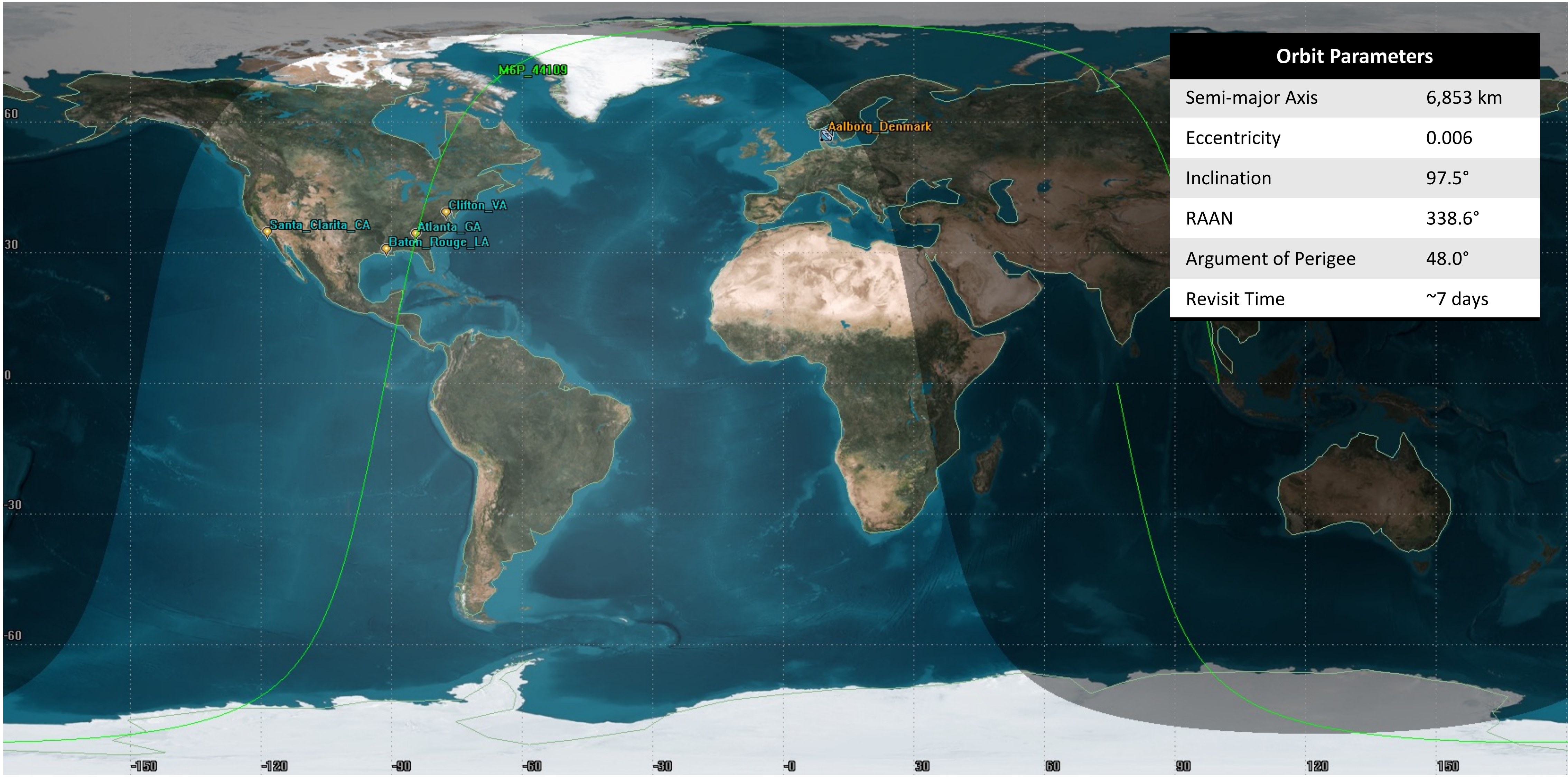


BTD-1 | Radio Hosted Payload





• BTD-1 | Mission Ground Track



Orbit Parameters	
Semi-major Axis	6,853 km
Eccentricity	0.006
Inclination	97.5°
RAAN	338.6°
Argument of Perigee	48.0°
Revisit Time	~7 days

• BTD-1 | BlinkR™ Mission Ground Transmitter Prototype

BlinkR™ Product: BTD-1 Tech Demo

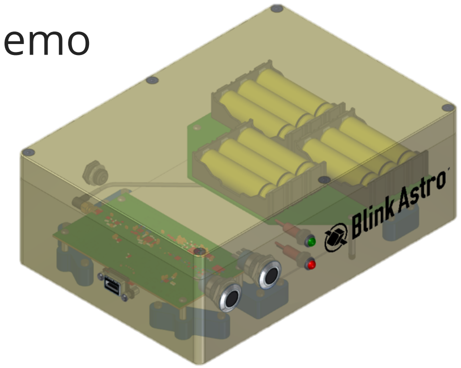
Purpose:

- Characterize performance of BTD-1 custom satellite radio demo

Features & Sensors:

- Custom radio and antenna design
- Air temperature, pressure, quality
- GPS & battery health
- Customizable data sampling interval
- Customizable transmission interval
- 50,000+ TX messages per battery pack

Current TRL: 7



• BTD-1 | Key Mission Accomplishments

Verified Key Technical Aspects of Our Space-Based IoT/M2M Solution
and
Showed Team's Ability to Rapidly Develop Novel, Low-Cost Space Hardware

- **Designed and qualified a radio payload optimized for IoT Application**
- **Designed and tested prototype ground transmitter for technology demonstrator**
- **Commissioned radio payload for IoT signal reception while in orbit**
- **Successfully transmitted and received messages from ground transmitters by the hosted radio payload**
- **Characterized link performance capability during demonstration**

- **Successfully demonstrated signal reception by hosted radio payload at multiple sites across the United States as well as multiple access of multiple ground transmitters in a single location**

SpaceWorks®

Engineering Today, Enabling Tomorrow

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