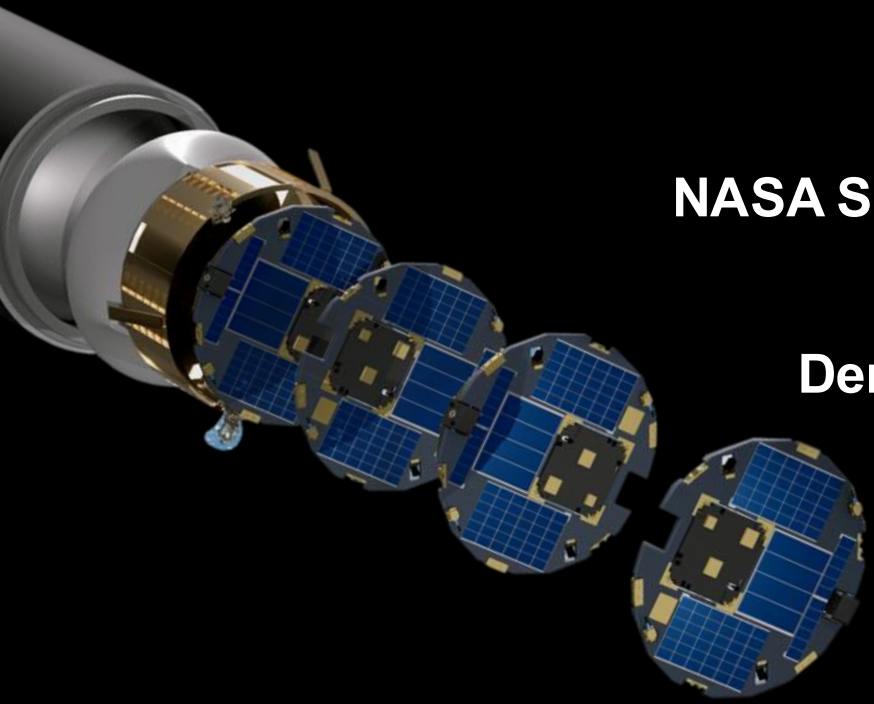
National Aeronautics and
Space Administration



NASA Small Spacecraft & Distributed Systems

Recent and Upcoming Technology Demonstrations and Development Efforts

Bruce D. Yost
NASA Ames Research Center

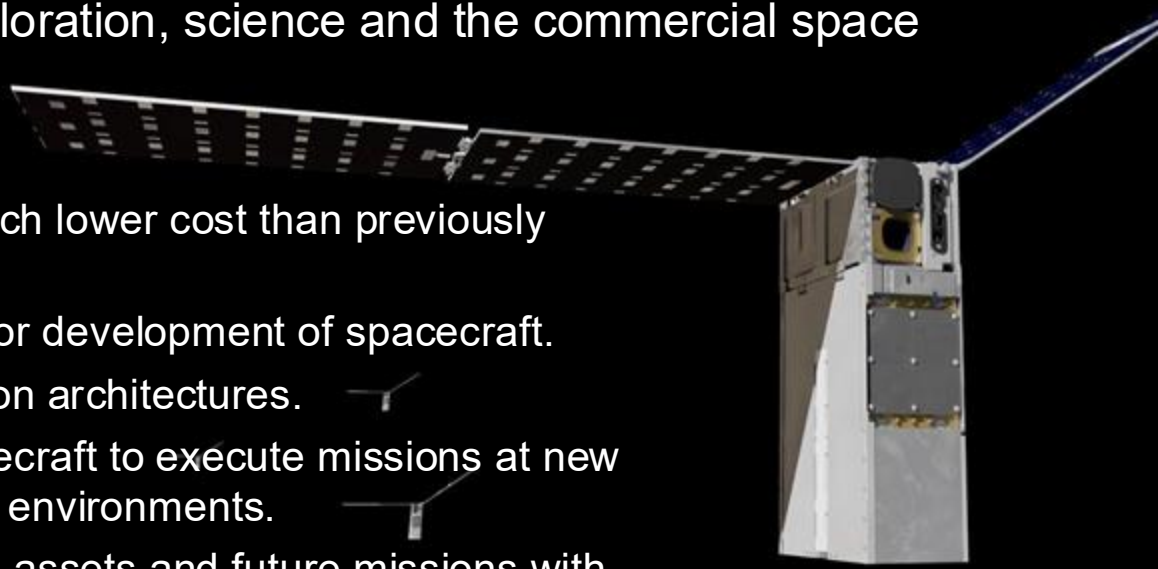
www.nasa.gov

2025 Robotics and Autonomy Workshop
University of California, Berkeley ♦ September 23, 2025

Small Spacecraft & Distributed Systems Objectives

The Small Spacecraft & Distributed Systems expands U.S. capability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science and the commercial space sector.

- Enable execution of missions at much lower cost than previously possible.
- Substantially reduce time required for development of spacecraft.
- Enable and demonstrate new mission architectures.
- Expand the capability of small spacecraft to execute missions at new destinations and in challenging new environments.
- Enable the augmentation of existing assets and future missions with supporting small spacecraft.

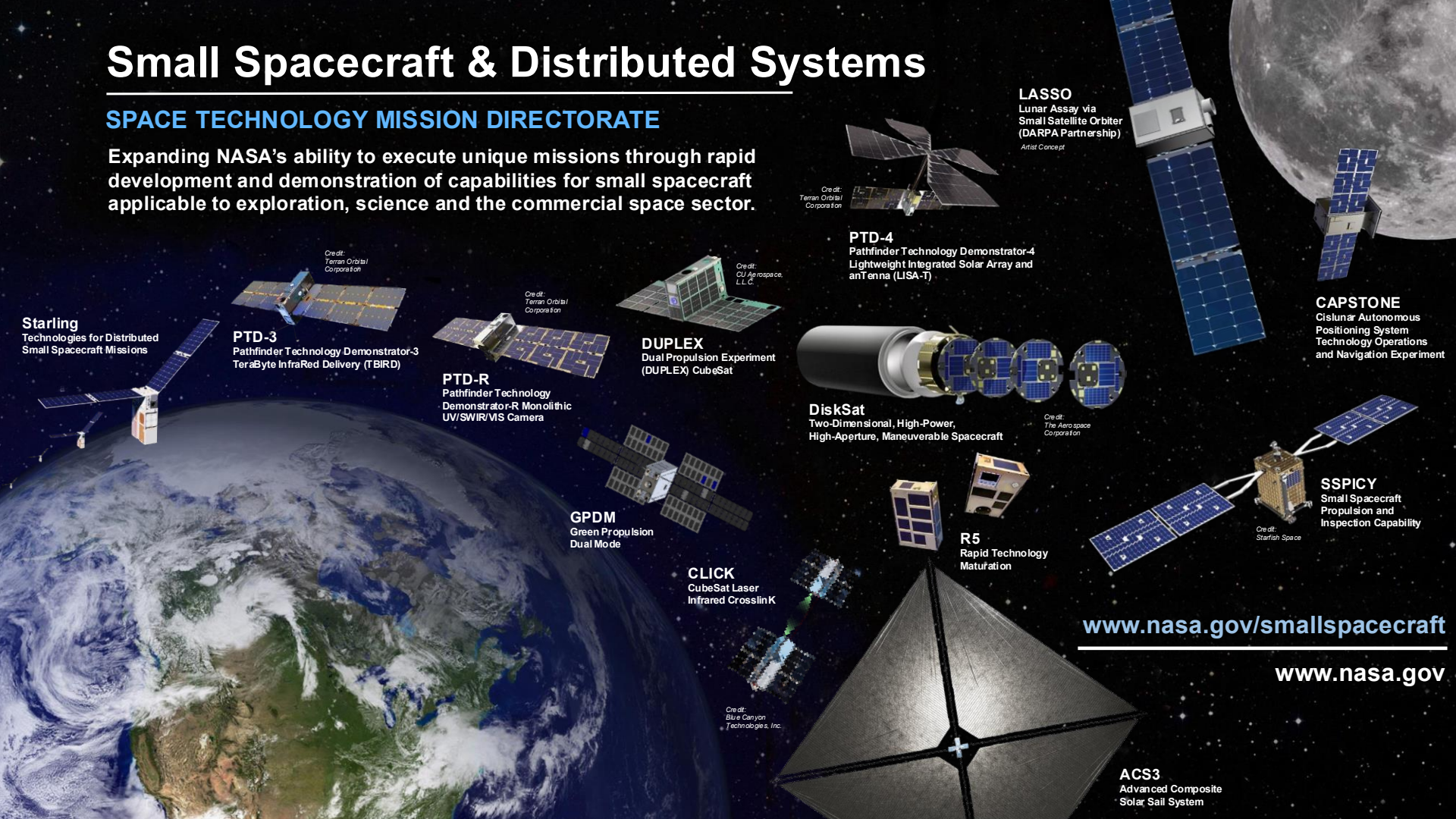


Starling Spacecraft
Image Credit: NASA

Small Spacecraft & Distributed Systems

SPACE TECHNOLOGY MISSION DIRECTORATE

Expanding NASA's ability to execute unique missions through rapid development and demonstration of capabilities for small spacecraft applicable to exploration, science and the commercial space sector.



Starling
Technologies for Distributed Small Spacecraft Missions

Credit: Terran Orbital Corporation

PTD-3
Pathfinder Technology Demonstrator-3 TeraByte InfraRed Delivery (TBIRD)

Credit: Terran Orbital Corporation

PTD-R
Pathfinder Technology Demonstrator-R Monolithic UV/SWIR/VIS Camera

Credit: CU Aerospace, LLC.

DUPLEX
Dual Propulsion Experiment (DUPLEX) CubeSat

GPDM
Green Propulsion Dual Mode

CLICK
CubeSat Laser Infrared CrosslinK

Credit: Blue Canyon Technologies, Inc.

Credit: Terran Orbital Corporation

PTD-4
Pathfinder Technology Demonstrator-4 Lightweight Integrated Solar Array and anTenna (LISA-T)

LASSO
Lunar Assay via Small Satellite Orbiter (DARPA Partnership)
Artist Concept

CAPSTONE
Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment

DiskSat
Two-Dimensional, High-Power, High-Aperture, Maneuverable Spacecraft

Credit: The Aerospace Corporation

R5
Rapid Technology Maturation

SSPICY
Small Spacecraft Propulsion and Inspection Capability

Credit: Starfish Space

ACS3
Advanced Composite Solar Sail System

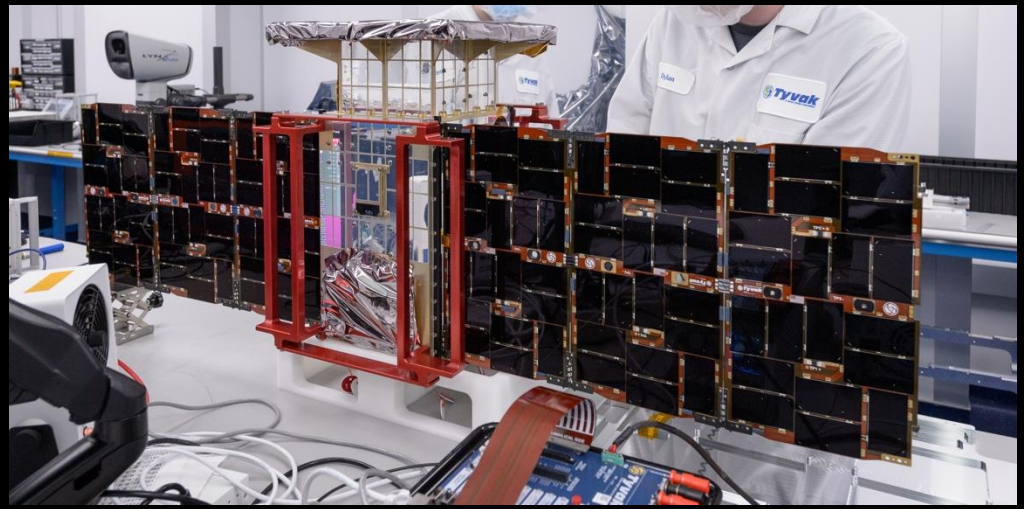
www.nasa.gov/smallspacecraft

www.nasa.gov

2024-2027 Launch Schedule

Technology Demonstrations	Launch Timeframe
PY4: *Four CubeSat Swarm of PYCubed-Based Spacecraft*	Launched March 4, 2024
ACS3: *Advanced Composite Solar Sail System*	Launched April 23, 2024
R5 (S2 and S4): *Rapid Technology Maturation*	Launched July 3, 2024
PTD-4: *Pathfinder Technology Demonstrator-4: Payload: LISA-T High-Power Deployable Solar Array Antenna*	Launched Aug 16, 2024
PTD-R: *Monolithic UV/SWIR/VIS Camera*	Launched Aug 16, 2024
DUPLEX: *Dual Propulsion Experiment*	Launched Sept 14, 2025
R5 (S7): *Rapid Technology Maturation*	Nov 15, 2025
R5 (S3 and S5): *Rapid Technology Maturation*	NET Nov 2025
DiskSat: *2D, High-Power, High-Aperture Maneuverable Spacecraft*	Dec 8, 2025
GPDM*: Green Propulsion Dual Mode*	NET Jan 2026
SSPICY: Small Spacecraft Propulsion and Inspection Capability	NET Oct 2026
CLICK B/C: *CubeSat Laser Infrared CrossLinK*	NET Nov 2026

On-Orbit U-Class Technology Demonstration Mission



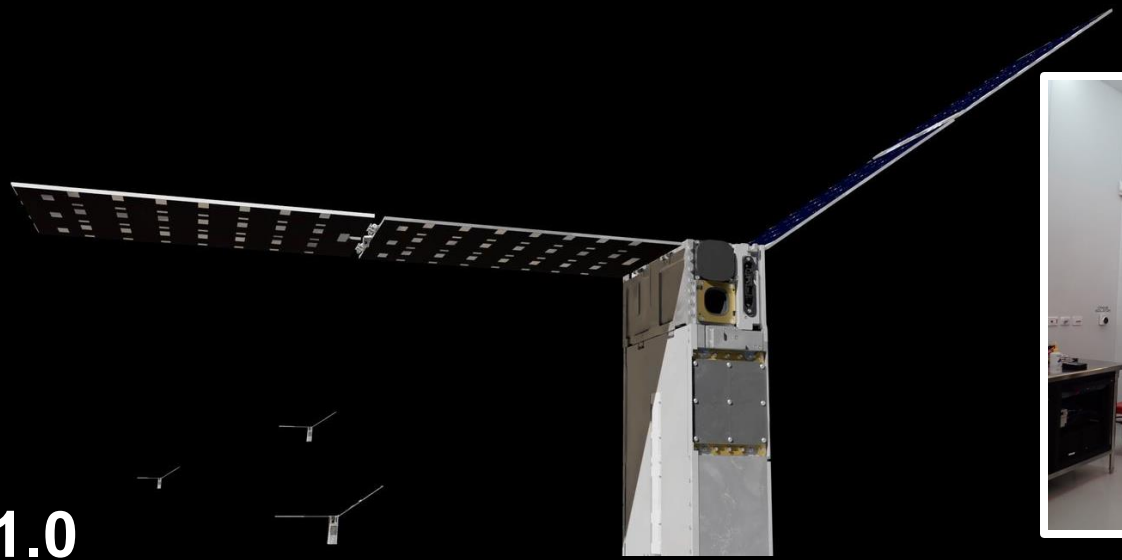
CAPSTONE

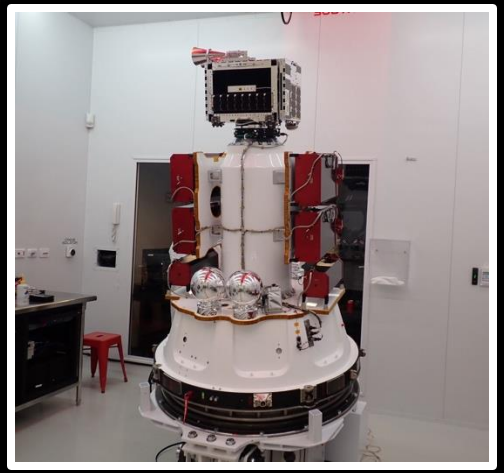
Launched: June 28, 2022 Status: Ongoing

Primary mission demonstrated ability to enter and maintain a near rectilinear halo orbit around the Moon as well as demonstrate one & two way ranging and autonomous spacecraft navigation. Extended mission demonstrating and testing technologies for autonomy and standards-based, interoperable communications and networking in the cislunar environment.

Image Credits: NASA

On-Orbit U-Class Technology Demonstration Mission

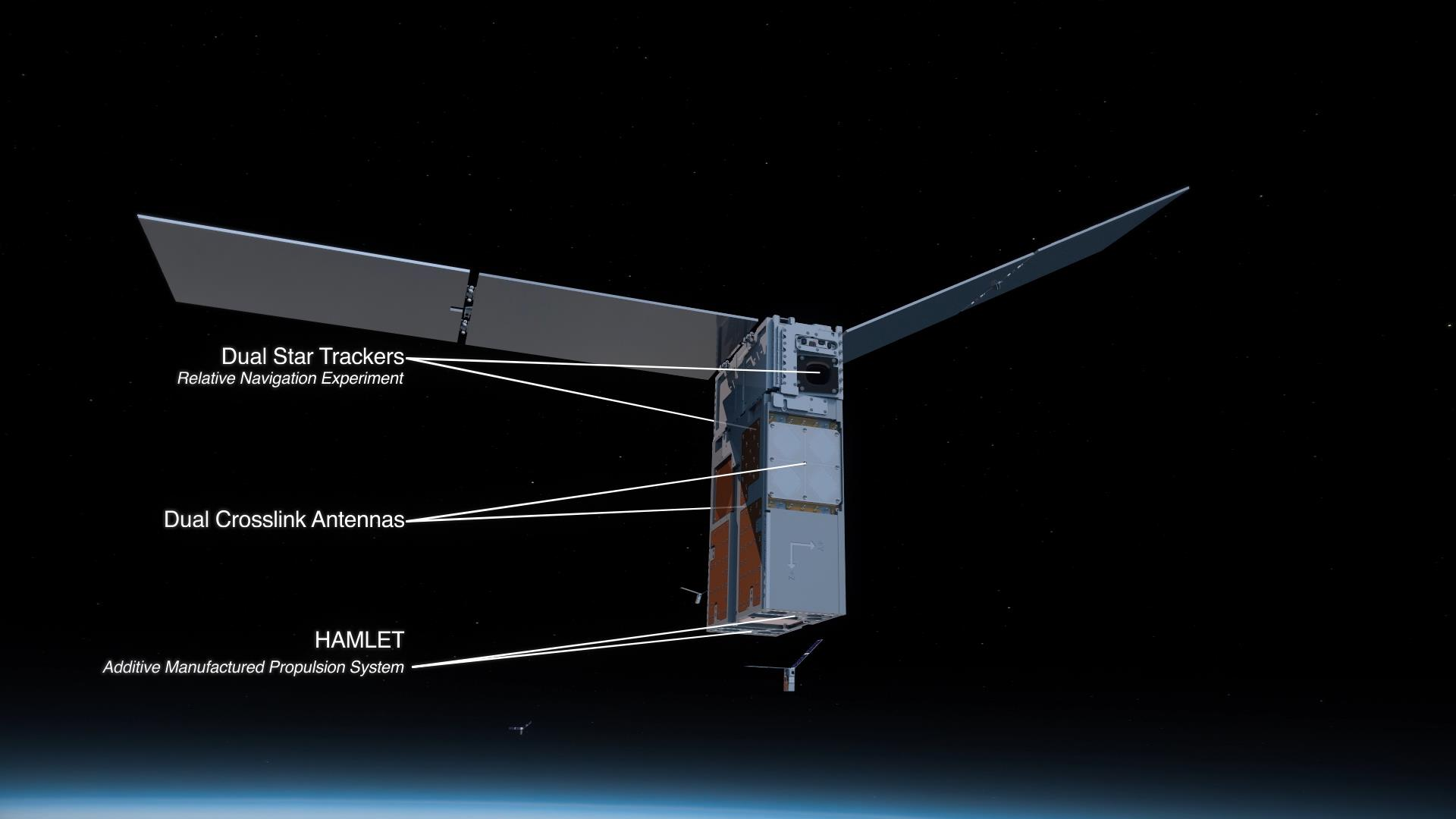




Starling 1.0

Starling's four 6U CubeSats launched on July 17, 2023 from Rocket Lab Launch Complex 1 in Mahia, New Zealand. Starling is testing swarm maneuver planning and execution, communications networking, relative navigation, and autonomous coordination between spacecraft.

Image Credits: NASA. *Inset Image Credits: Rocket Lab*


Dual Star Trackers
Relative Navigation Experiment
Dual Crosslink Antennas
HAMLET
Additive Manufactured Propulsion System

Starling 1.0 (Completed) – Results and Technology ‘Firsts’

MANET
Communicate

- Cross-link networking between nodes
- First use of an Ad-Hoc network between multiple spacecraft.
- First demonstration of autonomous multi-hop data routing through multiple spacecraft.
- Implements B.A.T.M.A.N-adv protocol

StarFOX
Navigate

- Relative navigation without GPS.
- First demonstrations of autonomous angles-only navigation for a satellite swarm including:
  - First demonstration of multi-target and multi-observer relative navigation.
  - First autonomous initialization of navigation for unknown targets.
  - First simultaneous absolute and relative orbit determination.

ROMEO
Control

- Goal autonomous swarm reconfiguration and cluster maintenance.
- Demonstrated autonomous generation and execution of onboard of station-keeping maneuver plan for single spacecraft.

Distributed Spacecraft Autonomy
Operate

- First fully distributed autonomous operation of multiple spacecraft.
- First use of space-to-space communications to autonomously share state information between multiple spacecraft.
- First demonstration of fully distributed reactive operations onboard multiple spacecraft.
- First use of fully distributed automated planning onboard multiple spacecraft.
- First use of a general-purpose automated reasoning system onboard a spacecraft.

Starling 1.5 Goals and Objectives

Goals

- Demonstrate a model of space traffic management (STM) between two cooperative swarms/constellations with onboard conjunction assessment (CA) and collision avoidance (COLA) capabilities.
- Develop autonomous maneuvering methods and tools that could be operationalized for NASA flight missions

Project Objectives

- Demonstrate onboard conjunction assessment (CA) for Starling's planned maneuvers
- Demonstrate continuous CA checking of passive and active/maneuvering objects
- Demonstrate a ground-based space situational awareness (SSA) / space traffic management (STM) hub that facilitates on-orbit autonomous CA/COLA
- Demonstrate collision avoidance (COLA) maneuver of Starling spacecraft in response to an onboard CA detection

Starling 1.5 launched as Starling 1.0. Starling 1.5 operations are completed.

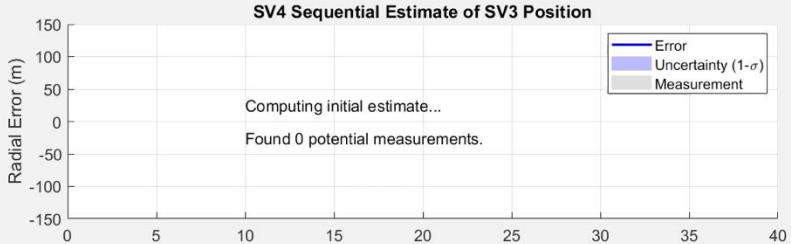
9

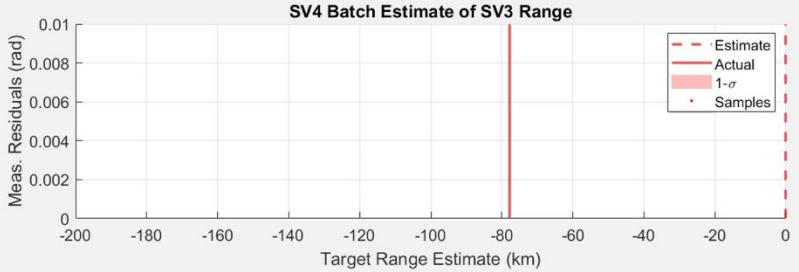
RENDEZVOUS SPACE

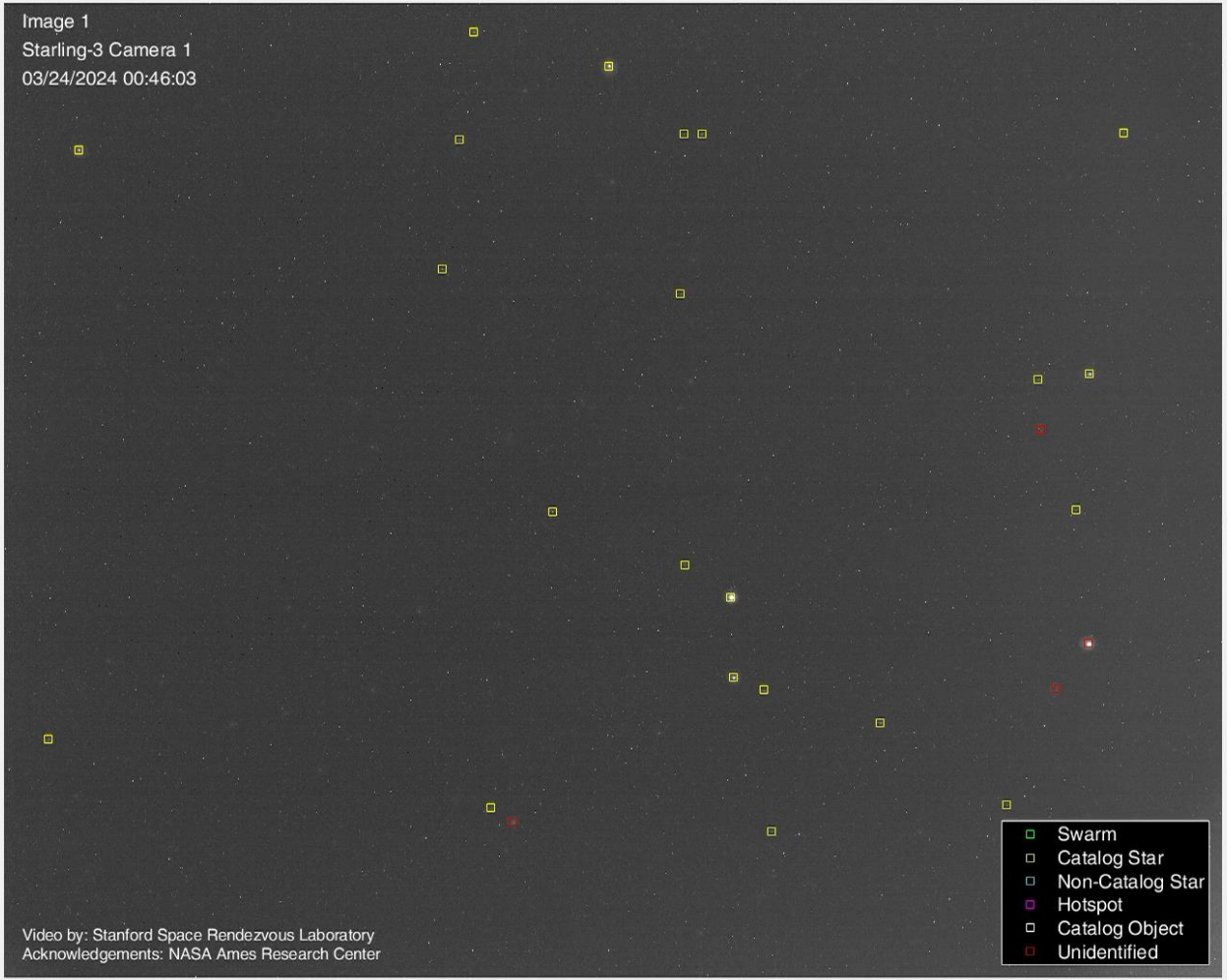
NASA | STARLING | BLUE CANYON TECHNOLOGIES

Video Credit:
Stanford University

SV4 Tracker 2 View







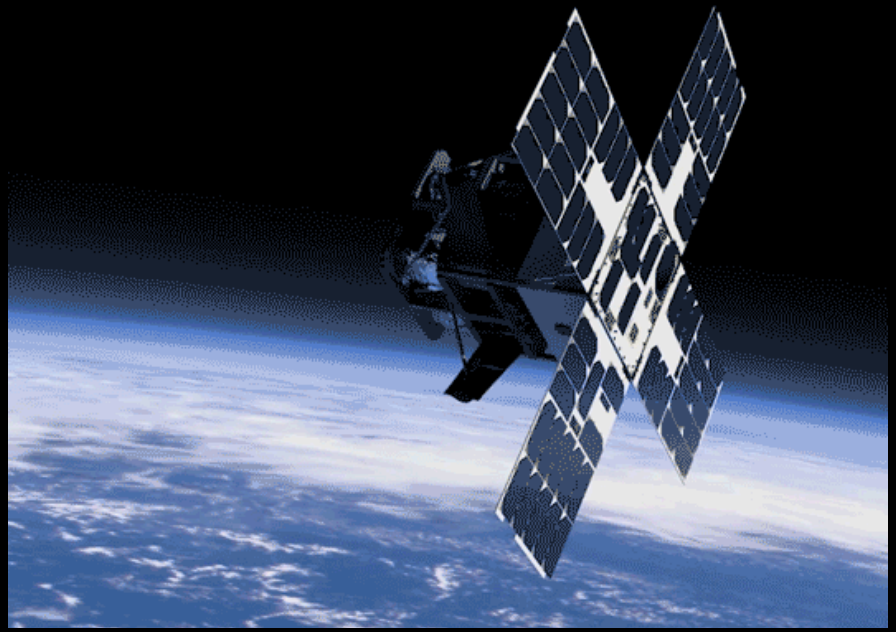
STARLING: StarFOX EXPERIMENT

Video Credit:

Stanford Space Rendezvous Laboratory

On-Orbit U-Class Technology Demonstration Mission

Advanced Composite Solar Sail System



Advanced Composite Solar Sail System (ACS3)
Launched: April 23, 2024

Confirmed full deployment of the composite boom
solar sail in low-Earth orbit. The unfurled solar sail measures approximately 84 m^2.

Image Credits: NASA

On-Orbit U-Class Technology Demonstration Missions

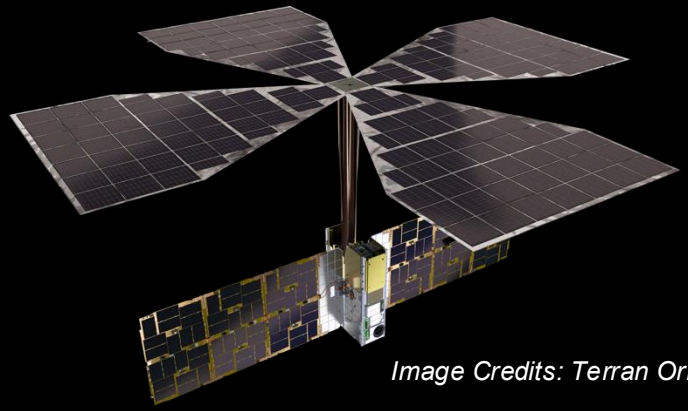


Image Credits: Terran Orbital

Pathfinder Technology Demonstrator (PTD-4)
Launched: August 16, 2024

Demonstrate Lightweight Integrated Solar Array and anTenna (LISA-T) – A high-power deployable solar array antenna.

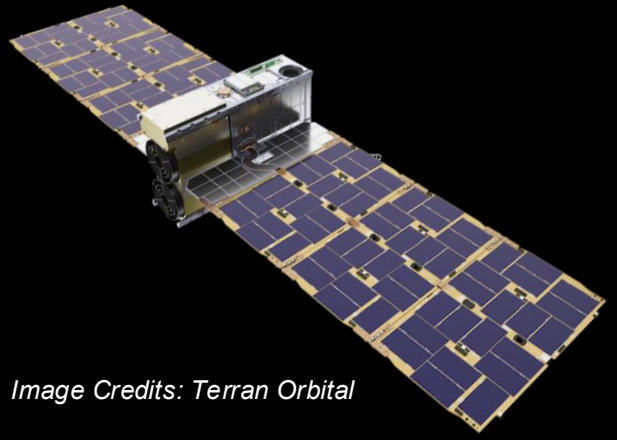


Image Credits: Terran Orbital

Pathfinder Technology Demonstrator (PTD-R)
Launched: August 16, 2024

Demonstrate a new type of UV and SWIR telescope that may be used in a wide range of applications.

On-Orbit U-Class Technology Demonstration Missions

Realizing Rapid, Reduced-cost high-Risk Research (R5)

Realizing Rapid, Reduced-cost high-Risk Research (R5)
Launch Timeframes:
S2 & S4 – Launched July 3, 2024
S7 – November 15, 2025
S3 & S5 – NET November 2025

Overview:
Build and operate rapid, low-cost, highly-capable spacecraft platforms to demonstrate payloads of interest and technology relevant to human spaceflight.

R5-S2 & R5-S4:
Primary objective (Power-on, autonomously commence operations, and successfully transmit telemetry) and many secondary objectives (e.g., spacecraft commanding, propulsion system demonstration) met.

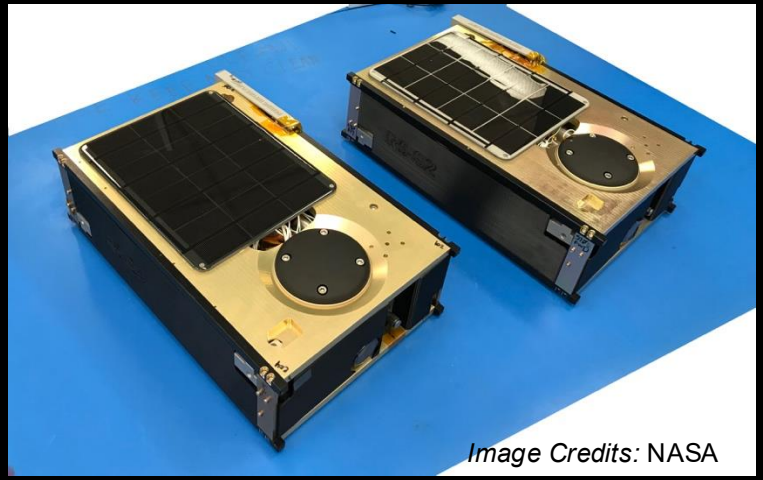
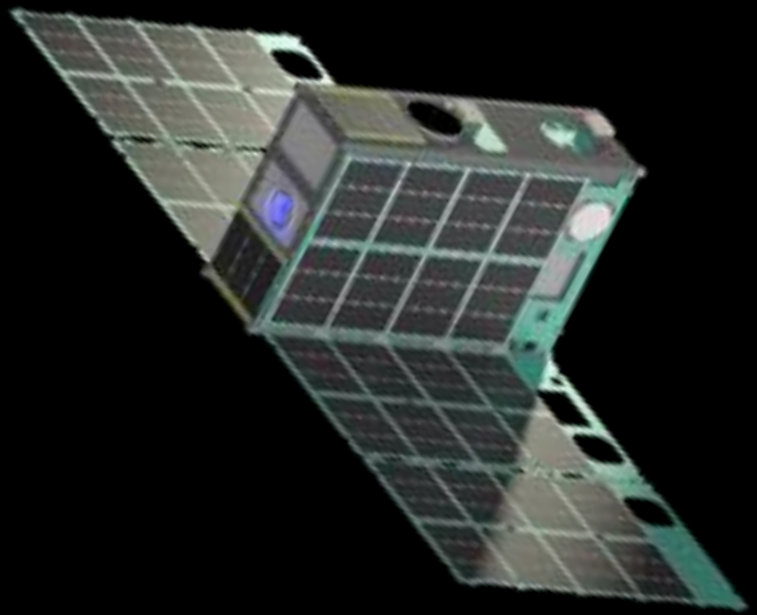


Image Credits: NASA

R5-S7, S3 & S5:
Refinement and improvement of lean processes and technologies demonstrated by R5-S2 & S4 to include improved GNC performance, power generation, and downlink capability.

On-Orbit U-Class - 2019 Tipping Point Project

Dual Propulsion Experiment



A 6U Dual Propulsion Experiment (DUPLEX) CubeSat. Both propulsion systems, the Fiber-fed Pulsed Plasma Thruster and Monofilament Vaporization Propulsion, were developed with NASA SBIR funding.

Launched: September 14, 2025

Image Credits: CU Aerospace, LLC.

Upcoming U-Class Technology Demonstration Mission

Green Propulsion Dual Mode (GPDM)

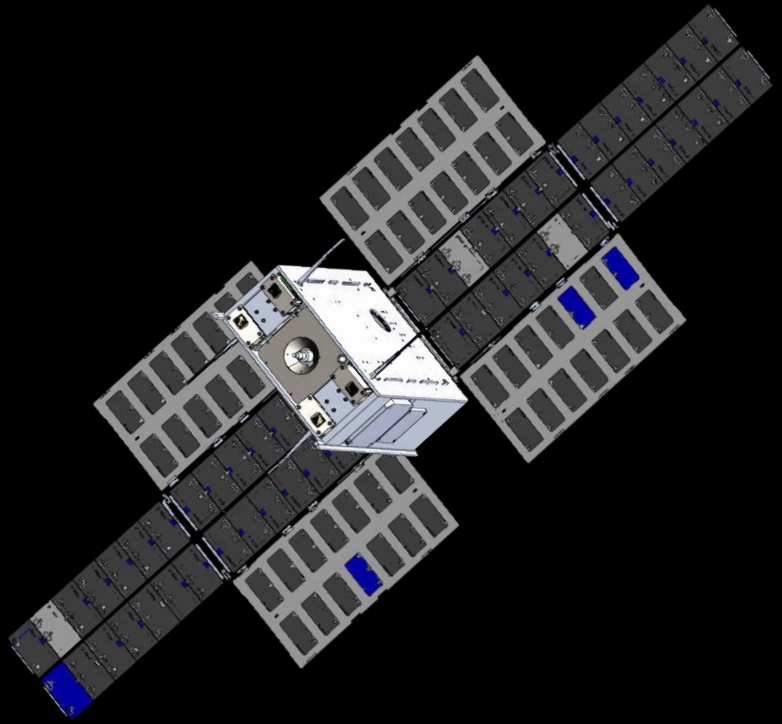


Image Credits: NASA

Green Propulsion Dual Mode (GPDM)

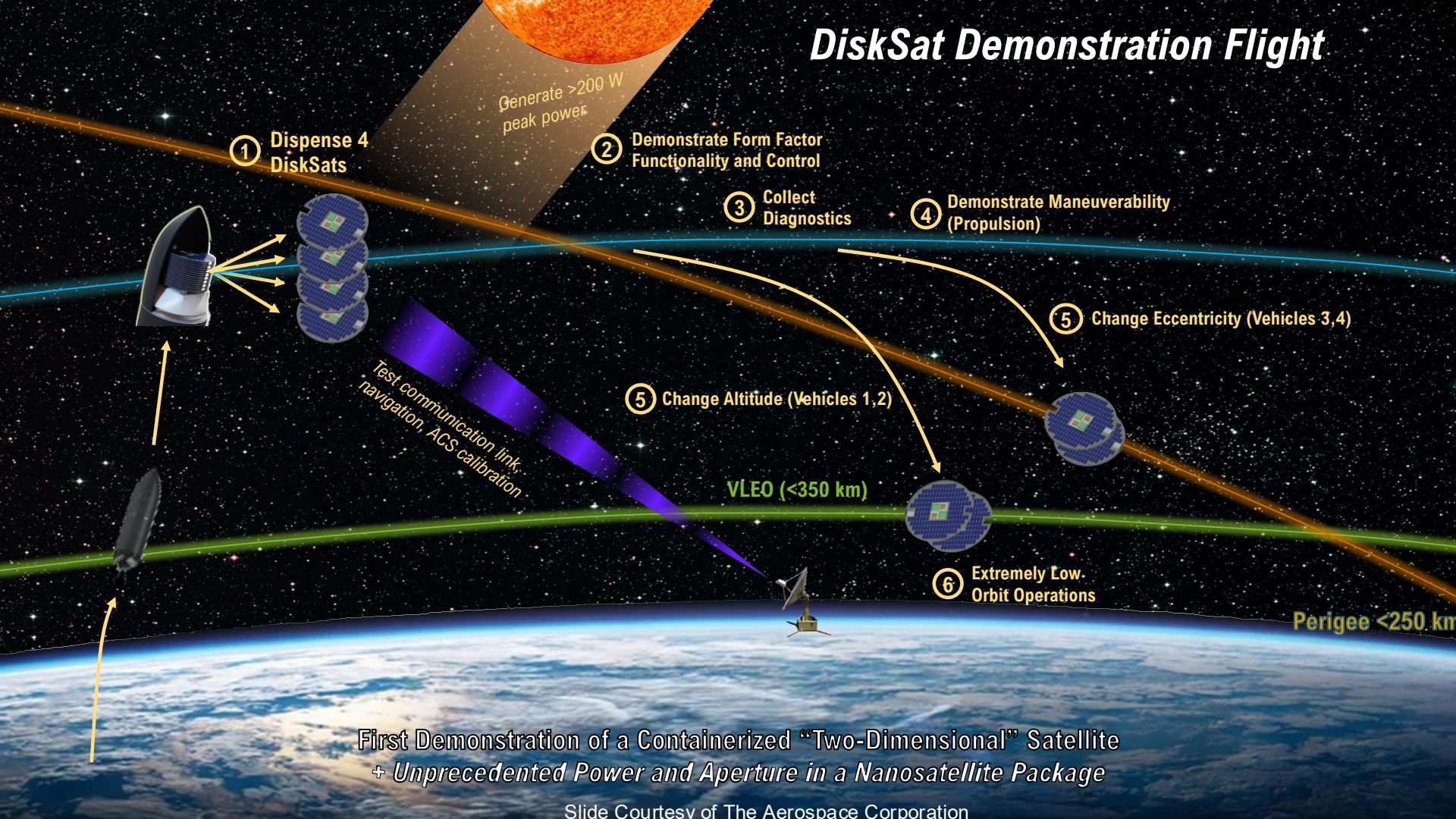
Launch Timeframe: NET January 2026

Demonstrate chemical and electrospray characteristics (higher thrust and higher efficiency) for in-space propulsion using ASCENT/green propellant on a 6U-sized CubeSat.

Upcoming SmallSat Technology Demonstration Mission - DiskSat

Image Credits: The Aerospace Corporation

DiskSats are high-power and high-aperture alternatives to CubeSats. They are launched in tight stacks but are deployed individually to ensure no recontact between satellites. This first DiskSat demonstration is slated to launch December 8, 2025.


DiskSat Demonstration Flight
Generate >200 W peak power
1 Dispense 4 DiskSats
2 Demonstrate Form Factor Functionality and Control
3 Collect Diagnostics
4 Demonstrate Maneuverability (Propulsion)
5 Change Eccentricity (Vehicles 3,4)
5 Change Altitude (Vehicles 1,2)
Test communication link, navigation, ACS calibration
VLEO (<350 km)
6 Extremely Low Orbit Operations
Perigee <250 km
First Demonstration of a Containerized "Two-Dimensional" Satellite
+ Unprecedented Power and Aperture in a Nanosatellite Package
Slide Courtesy of The Aerospace Corporation

Upcoming U-Class Technology Demonstration Mission

CubeSat Laser Infrared CrosslinK (CLICK B/C)

Image Credits: Blue Canyon Technologies, Inc

CubeSat Laser Infrared CrosslinK (CLICK B/C)
Launch Timeframe: NET November 2026

Demonstrate optical crosslink and precision ranging between two 3U CubeSats at a data rate of 20 Mbps and range up to 580 km

Upcoming SmallSat Technology Demonstration Mission

Small Spacecraft Propulsion and Inspection Capability (SSPICY)

Small Spacecraft Propulsion and Inspection Capability (SSPICY)
Launch Timeframe: NET October 2026

Demonstrate electric propulsion and other advanced capabilities to perform rendezvous, proximity operations, inspection, and characterization of up to 4 resident space objects in LEO of US origin for the purpose of future remediation.

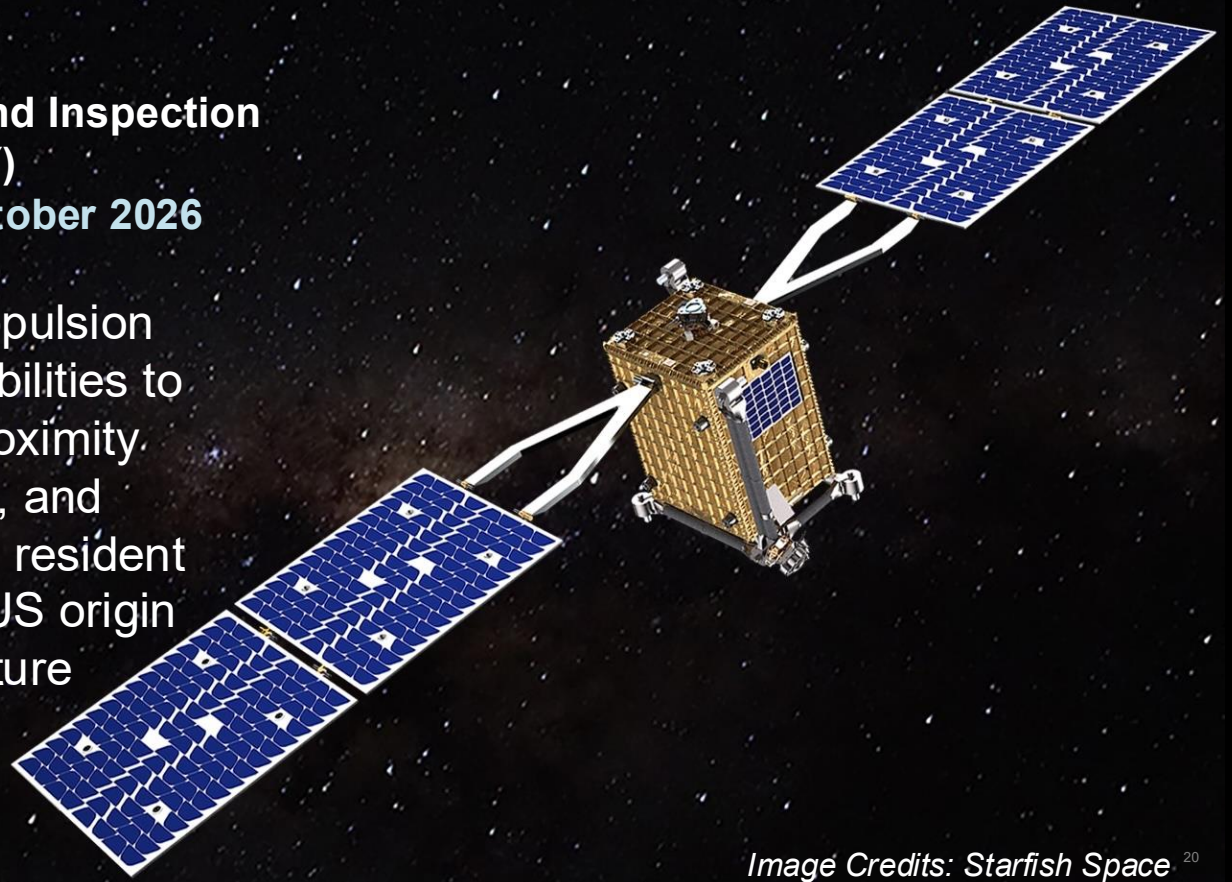


Image Credits: Starfish Space

Announcement of Collaboration Opportunity Projects – 2018

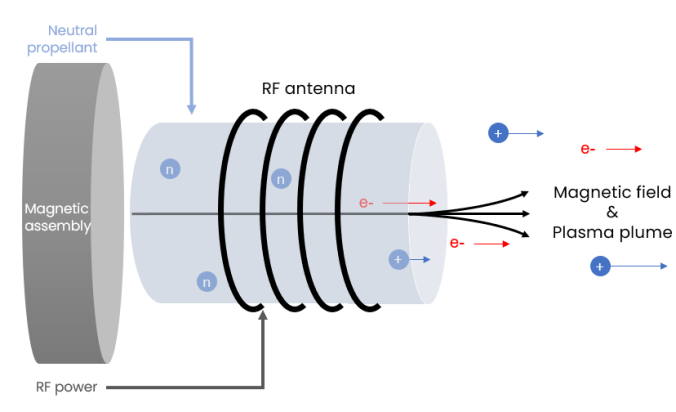
Diagram of the concept of operations for the Cislunar Autonomous Position System (CAPS). CAPS is an innovative spacecraft-to-spacecraft navigation solution demonstrated on the CAPSTONE mission currently in orbit around the Moon. CAPS is anticipated to allow future spacecraft the ability to determine their location relative to the Moon without relying exclusively on tracking from Earth.
Image Credits: Advanced Space, LLC

A public-private partnership with NASA's Goddard Space Flight Center

The Vulcan Wireless CubeSat radio, NSR-SDR-S/S. This CubeSat radio is a fully integrated, full-duplex, software-defined radio transponder. The radio transponder is being tested for compatibility with NASA's Space Network.
Image Credits: Vulcan Wireless, Inc.

A public-private partnership with NASA's Goddard Space Flight Center

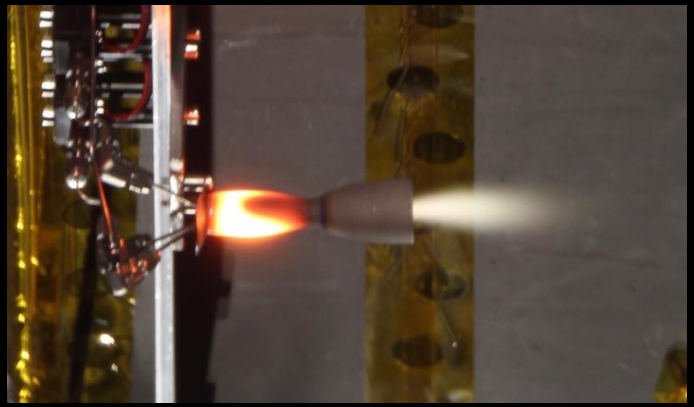
Announcement of Collaboration Opportunity Projects - 2020



The Phase Four RF plasma thruster operates by using RF to heat propellant into ionized plasma that is then ejected away from a spacecraft by a permanent magnet, creating thrust.

Image Credits: Phase Four

A public-private partnership with NASA's Glenn Research Center



A prototype bipropellant thruster is shown in ambient pressure testing. The key technology being tested is the propellant pump - an enabling technology for launch safety approval (no stored gas) and system performance (lightweight tanks). Testing includes a propulsion system composed of monopropellant and bipropellant systems.

Image Credits: Stellar Exploration, Inc.

A public-private partnership with NASA's Ames Research Center

University SmallSat Technology Partnership Successes to Date

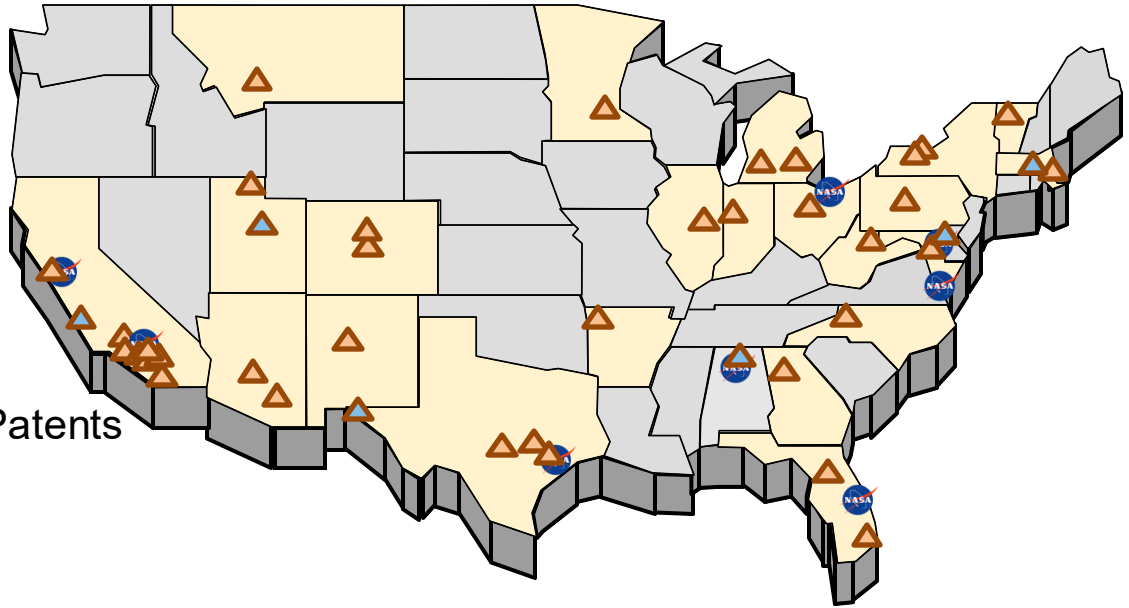
Investments:
- Over $30,000,000 awarded
- 54 partnerships in 6 cohort years
- 36 universities in 22 states (+6 supporting collaborators in 6 states)
- 8 of 10 NASA centers partnered

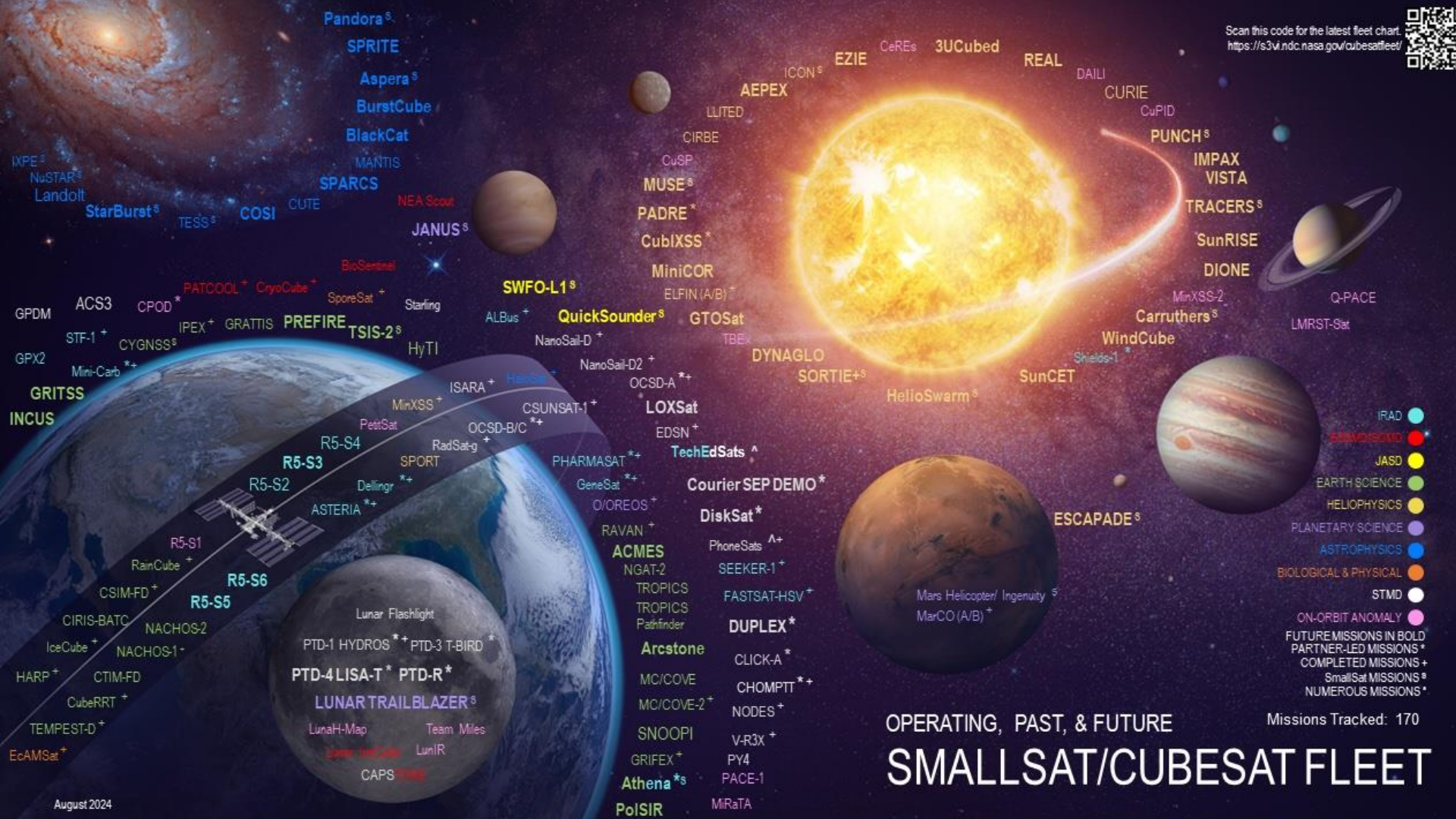
Results:
- 24 flight demonstrations performed/planned
- 1 Intersatellite Network Planning/ Routing tool software open-sourced
- Numerous New Technology Reports/Patents
- 30+ conference presentations
- 50+ papers published
- 100+ students involved
- Many technology readiness levels (TRL) raised

36 Universities in 22 States

8 NASA Centers (including JPL FFRDC)

6 Supporting University Collaborators in 6 States




Scan this code for the latest fleet chart.
https://s3vi.ndc.nasa.gov/cubesatfleet/
Pandora §
SPRITE
Aspera §
BurstCube
BlackCat
MANTIS
SPARCS
IXPE §
NuSTAR §
Landolt
StarBurst §
TESS §
COSI
CUTE
NEA Scout
JANUS §
BioSentinel
PATCOOL +
CryoCube +
SporeSat +
Starling
GPDM
ACS3
CPOD *
IPEX +
GRATTIS
PREFIRE
TSIS-2 §
STF-1 +
CYGNSS §
HyTI
GPX2
Mini-Carb *+
GRITSS
INCUS
ISARA +
MinXSS +
PettSat
CSUNSAT-1 +
OCSD-B/C *+
R5-S4
R5-S3
RadSat-g +
SPORT
R5-S2
Dellingr *+
ASTERIA *+
R5-S1
RainCube +
R5-S6
R5-S5
CSIM-FD +
CIRIS-BATC
NACHOS-2
IceCube +
NACHOS-1 -
HARP +
CTIM-FD
CubeRRT +
TEMPEST-D +
EcAMSat +
Lunar Flashlight
PTD-1 HYDROS *+
PTD-3 T-BIRD *
PTD-4 LISA-T *
PTD-R *
LUNAR TRAILBLAZER §
LunaH-Map
Team Miles
LunIR
CAPS
August 2024
SWFO-L1 §
ALBus +
QuickSounder §
NanoSail-D +
NanoSail-D2 +
OCSD-A *+
LOXSat
EDSN +
TechEdSats ^
PHARMASAT *+
GeneSat *+
O/OREOS +
RAVAN +
ACMES
NGAT-2
TROPICS
TROPICS Pathfinder
Arcstone
MC/COVE
MC/COVE-2 +
SNOOPI
GRIFEX +
Athena *§
PolSIR
Courier SEP DEMO *
DiskSat *
PhoneSats ^+
SEEKER-1 +
FASTSAT-HSV +
DUPLEX *
CLICK-A *
CHOMPTT *+
NODES +
V-R3X +
PY4
PACE-1
MiRaTA
ICON §
EZIE
CeREs
3UCubed
REAL
DAILI
AEPEX
LLITED
CIRBE
CuSP
MUSE §
PADRE *
CubIXSS *
MiniCOR
ELFIN (A/B) +
GTOSat
TBEx
DYNAGLO
SORTIE+§
HelioSwarm §
CURIE
CuPID
PUNCH §
IMPAX
VISTA
TRACERS §
SunRISE
DIONE
MinXSS-2
Carruthers §
WindCube
Shields-1 *
SunCET
Q-PACE
LMRST-Sat
ESCAPADE §
Mars Helicopter/ Ingenuity §
MarCO (A/B) +
IRAD
EARTH SCIENCE
HELIOPHYSICS
PLANETARY SCIENCE
ASTROPHYSICS
BIOLOGICAL & PHYSICAL
STMD
ON-ORBIT ANOMALY
FUTURE MISSIONS IN BOLD
PARTNER-LED MISSIONS *
COMPLETED MISSIONS +
SmallSat MISSIONS §
NUMEROUS MISSIONS ^
OPERATING, PAST, & FUTURE
SMALLSAT/CUBESAT FLEET
Missions Tracked: 170


NASA