Starling Swarm Mission

Technology Objectives, Status, and Future Applications

SpaceOps 2024 Workshop



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NASA Ames – Spacecraft Swarms

NASA Ames Research Center has been working on enabling the vision of spacecraft "swarms" for over a decade.

- Spacecraft Swarms:
  - Groups of spacecraft **cooperating with each other** to achieve a goal
  - Acts as a **single unit** versus needing to command and control each spacecraft separately
  - Include **autonomy** so that they can change behavior based on engineering or science measurements
  - Numerous advantages over monolithic spacecraft missions including multi-point and opportunistic science, and mission robustness.

Starling is a mission to test and demonstrate key technologies that are essential to this vision.

Starling Project Summary

- Research and Technology Project
- Starling is flying 4 x 6U spacecraft in LEO
- Launched via Rocket Lab Electron (July 18, 2023)
- The Starling primary mission will test multiple swarm technologies
  - Reconfiguration and Orbit Maintenance Experiments Onboard (ROMEO)
  - Mobile Adhoc Network (MANET)
  - Starling Formation-Flying Optical Experiment (StarFOX)
  - Distributed Spacecraft Autonomy (DSA)
- Mission extension to Starling 1.5 via software upload to demonstrate autonomous collision avoidance with SpaceX Starlink constellation
- Funding
  - NASA Space Technology Mission Directorate (STMD)
    - Small Spacecraft Technology (SST) Program
    - Game Changing Development (GCD) Program



Partners	Roles
NASA Ames Research Center	Project Management Systems Engineering Payload Avionics & Software Propulsion System Spacecraft I&T Mission & Experiment Operations
Blue Canyon Technologies	Spacecraft Bus Spacecraft Bus Operations
Rocket Lab	Launch
Stanford University	Relative Navigation Experiment
York Space Systems (formerly Emergent Space Technologies)	Cluster Management Software
CesiumAstro Inc.	Crosslink Radios
L3Harris Technologies Inc.	Flight Dynamics Ground Software

Swarm Technologies in Starling

Network communication protocols:

(MANET – Crosslink/Networking)

- Uses the BATMAN infrastructure-less adhoc network for mobile devices to demonstrate a reliable self-configuration network in space applicable to 100s of spacecraft. Crosslink radios provided by Cesium Astro.

Navigation algorithms:

(StarFOX –Absolute and Relative Navigation)

- Enables onboard vision-based trajectory estimation of agents in swarm. Uses standard star trackers and the Absolute and Relative Trajectory Measurement System (ARTMS) autonomous angles-only swarm navigation architecture developed by Stanford's Space Rendezvous Lab.

Cluster flight control algorithms:

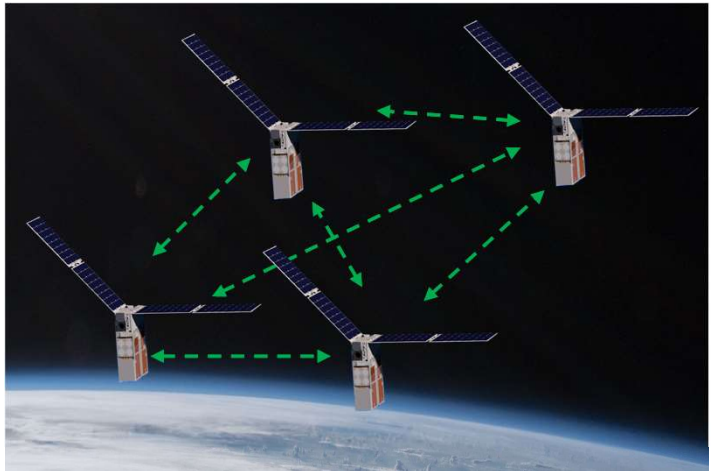
(ROMEO – Autonomous maneuver planning and execution)

- Demonstrates onboard autonomous maneuver planning and execution to maintain relative vehicle positions. Utilizes Cluster Flight Application (CFA) software from Emergent Space Technologies.

Autonomous reactive operations software:

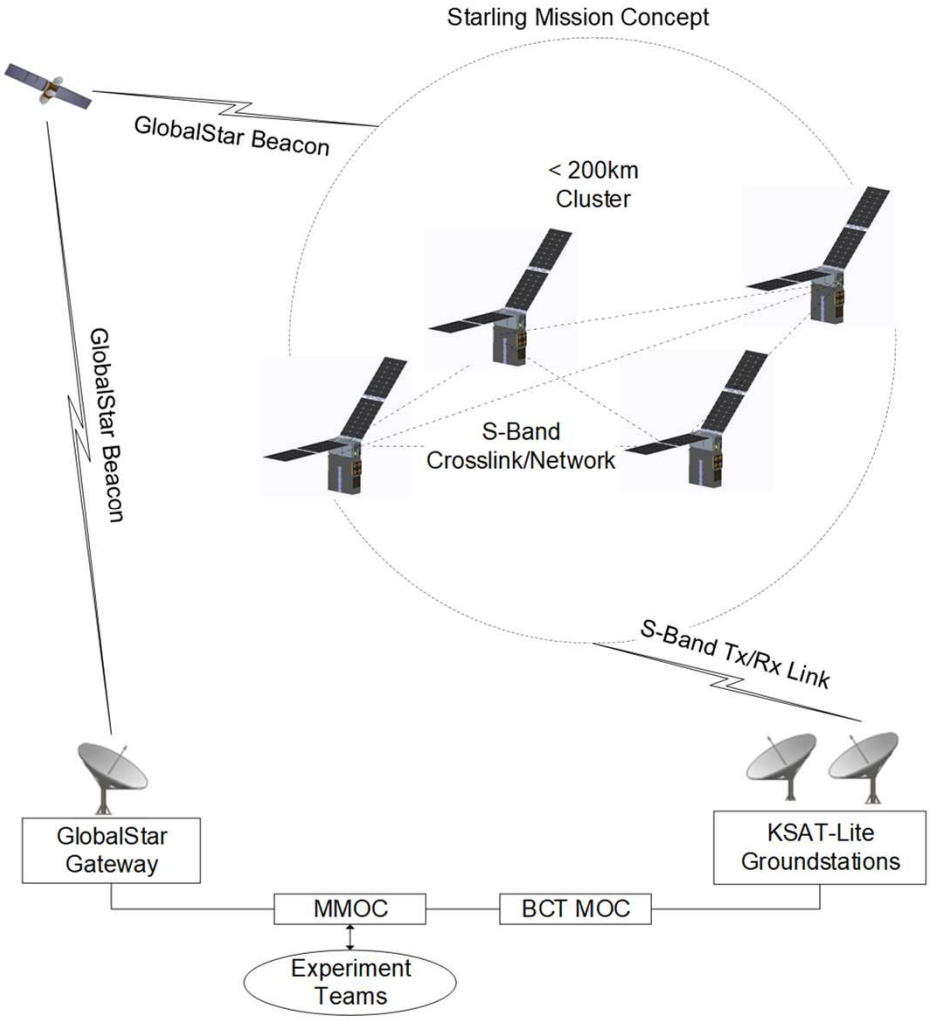
(DSA – Distributed Spacecraft Autonomy)

- Demonstrates autonomous reconfiguration of observation tactics in response to external sensor data. Objective is to maximize the scientific productivity of a spacecraft swarm by quickly reacting to changing conditions.



The intent is to test each technology to understand what works, what are the limitations, and what is still needed in terms of swarm technology development.

Mission Overview



- Four spacecraft
  - Blue Canyon 6U Cubesat Bus
  - Payload includes separate processor for experiments and Cesium Crosslink Radios
  - Cold Gas Propulsion
- KSAT-Lite Ground Stations (Svalbard, Awarua) and GlobalStar Beacon
- Distributed Operations at Blue Canyon and NASA Ames
- Launched on Rocket Lab Electron, Mahia NZ
- ~ Sun Sync, 575 km Circular Orbit

Swarm Formations

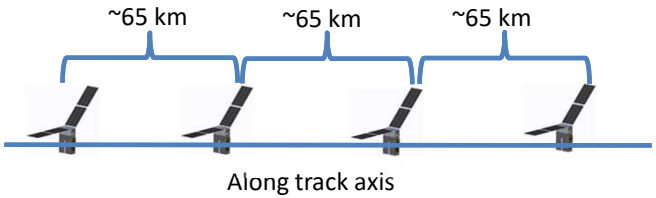
First phase of mission:

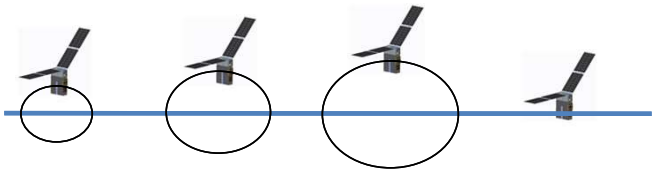
Deploy all four S/C into in-train formation

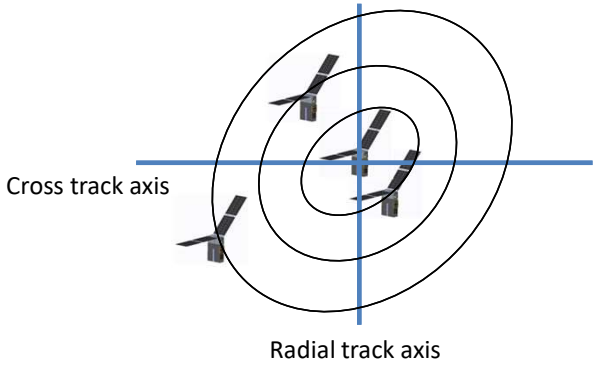
- Spacecraft deployed such that along-orbit drift is minimized
- A series of maneuvers arrest the drift rate between spacecraft to establish along-track separation

Second phase of mission:

- After commissioning and experiment time in the in-train formation, move into Passive Safety Ellipses (PSEs), whereby the spacecraft will maneuver into stable relative orbits with varying cross-track and radial amplitudes
- This phase is for the benefit of StarFOX, to introduce some additional motion in the FOV of the star trackers







Starling Project Status

Progress

Phase	Name
A	Concept & Tech Dev
B	Preliminary Design
C	Final Design
D	Integration & Test
E	Launch & Operations

Phase E: Operations

- Bus Commissioning ✓
- Propulsion System Commissioning ✓
- Payload Commissioning ✓
- Begin Swarm Experiments ✓
- Complete Primary Mission ✓



Image Credit: Rocket Lab

Starling completed its primary mission on 5/20/2024 meeting most of its objectives. The project is now embarking on its extended mission to demonstrate Space Traffic Management/Coordination in partnership with the SpaceX Starlink constellation.

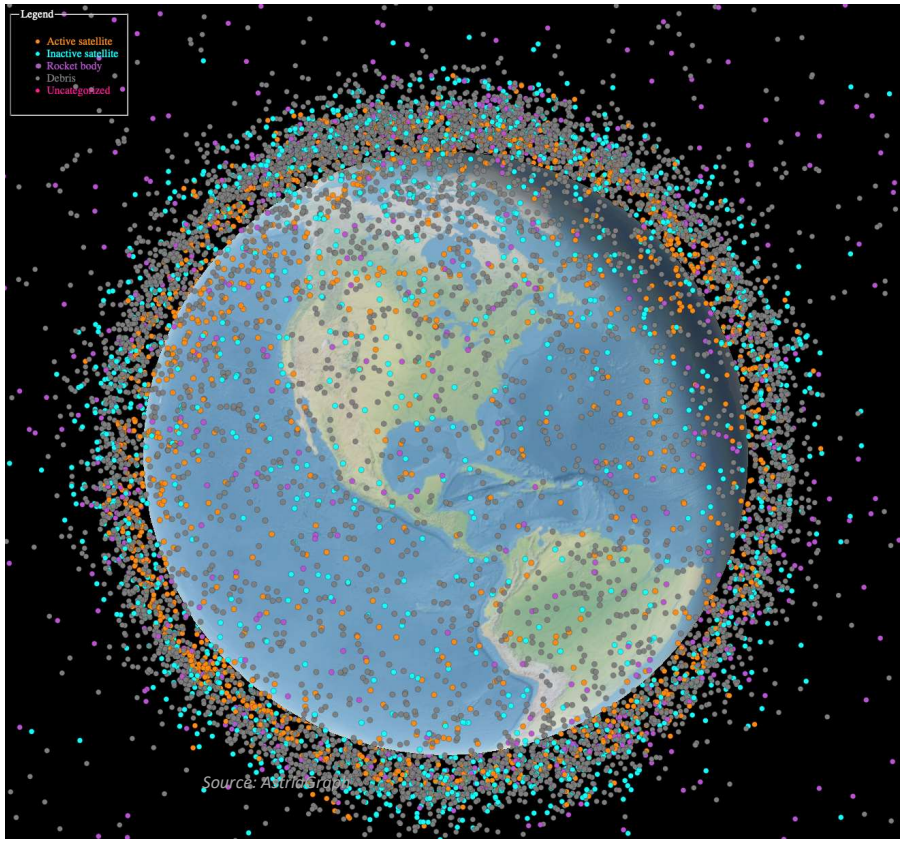
Primary Mission Results

Objective	Met Min Success Criteria	Met Full Success Criteria	Result
Operate 4 spacecraft in swarm for 4 or more months in LEO		X	Operated all four spacecraft for 10 months, forming and maintaining the swarm formations, producing daily orbit determination products, while conducting swarm experiments utilizing the crosslink radios.
Adhoc Network Testing with Crosslink Radios (MANET)		X	Network established and demonstrated point to point messages, routing of messages, and file transfer using multiple modulation schemes and data rates.
Navigation Experiments (StarFOX)		X	Demonstrated absolute and relative orbit determination using Star Tracker cameras only, tracking multiple members and sharing observations between spacecraft to improve accuracy.
Distributed Spacecraft Autonomy (DSA)	X		Demonstrated autonomous collaboration and consensus between 3 swarm members on science observation plan. First demonstration of a fully distributed onboard reasoning system able to react quickly to changes in science observations.
Managing the swarm configuration (ROMEO)	X		Established and maintained swarm separation distances 50-100 km through manually commanded maneuvers. Demonstrated onboard maneuver planning, but unable to execute due to issues with planned propellant usage and timing. Continuing to investigate during mission extension.

Starling 1.5 Extended Mission

Goal: Demonstrate enhanced space traffic management between different owner/operators of Low Earth Orbit (LEO) spacecraft

- Partner with SpaceX's Starlink constellation to demonstrate coordinated conjunction assessment and collision avoidance

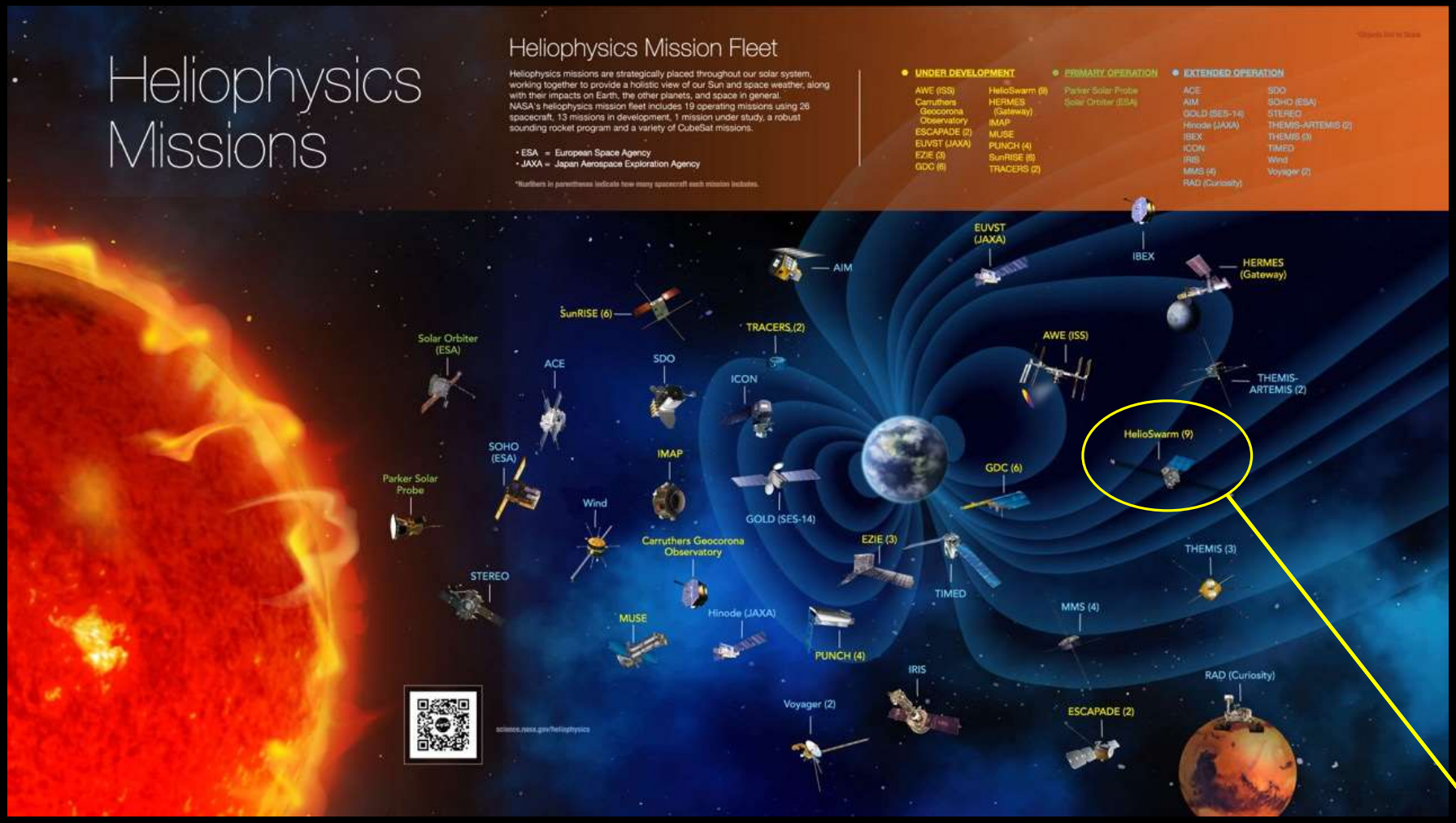


Current State-of-the-Art

- 18th Space Defense Squadron predicts conjunctions and issues warnings to owner/operators when a conjunction event passes a threshold
- Coordination via phone/email to arrive at a course of action
- Does not scale with the number of satellites being put into LEO including those with autonomous maneuvering

Objectives:

- Starling will demonstrate onboard CA:
  - Continuous checking of passive/active maneuvering objects
  - Planned Maneuvers
- 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



Helioswarm – Launch 2029

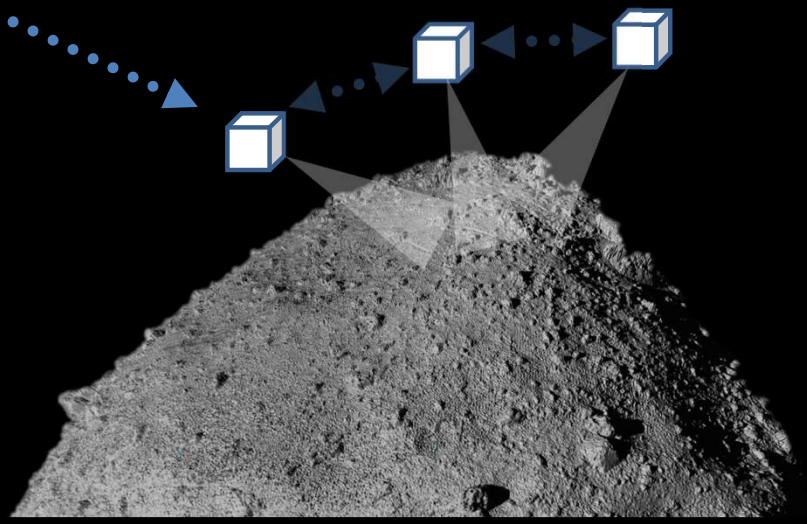
https://eos.unh.edu/helioswarm

Future Swarm Missions



Communication with Earth

Swarm-Explorers
Formation Flying and Inter-Communicating Remote Sensors



- Spacecraft swarms have the potential to revolutionize space science and exploration
  - Multi-point science data collection
  - Autonomous reactive operations and opportunistic science
  - Mission Robustness with multiple smaller spacecraft and networked communications