National Aeronautics and Space Administration

Starling1
Mission Technologies Overview

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Starling1

- Mission to fly 3 to 4 cubesats in LEO to test swarm* related technologies in space.
- Partnership between Air Force Research Lab (AFRL), NASA Ames Research Center
  - Shiver - AFRL mission to investigate formation flying and autonomous station keeping
  - Spacecraft vendor: Adcole Maryland Aerospace (AMA)
- Sponsor: NASA Space Technology Mission Directorate
  - Small Spacecraft Technology Program (SSTP)
  - Game Changing Technology (GCD)
- Currently in Phase A – scheduled to launch in early 2021

Characteristics of a spacecraft swarm

- Multiple distributed spacecraft
- Reconfigurable formations / functionality
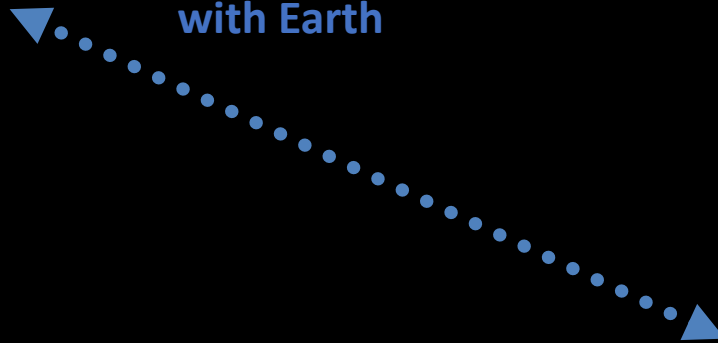- Act in unison to achieve objectives with minimal commanding / oversight

* Technologies also applicable to general category of distributed assets

Communication with Earth
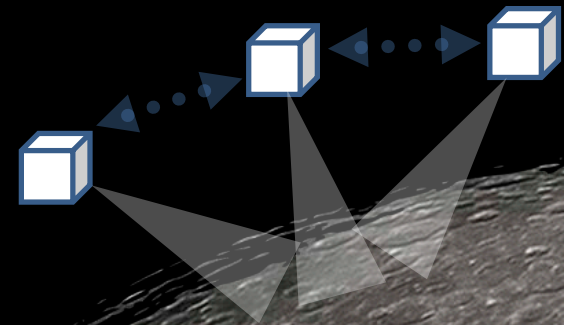
Starling-Explorers
Formation Flying and Inter-Communicating Remote Sensors

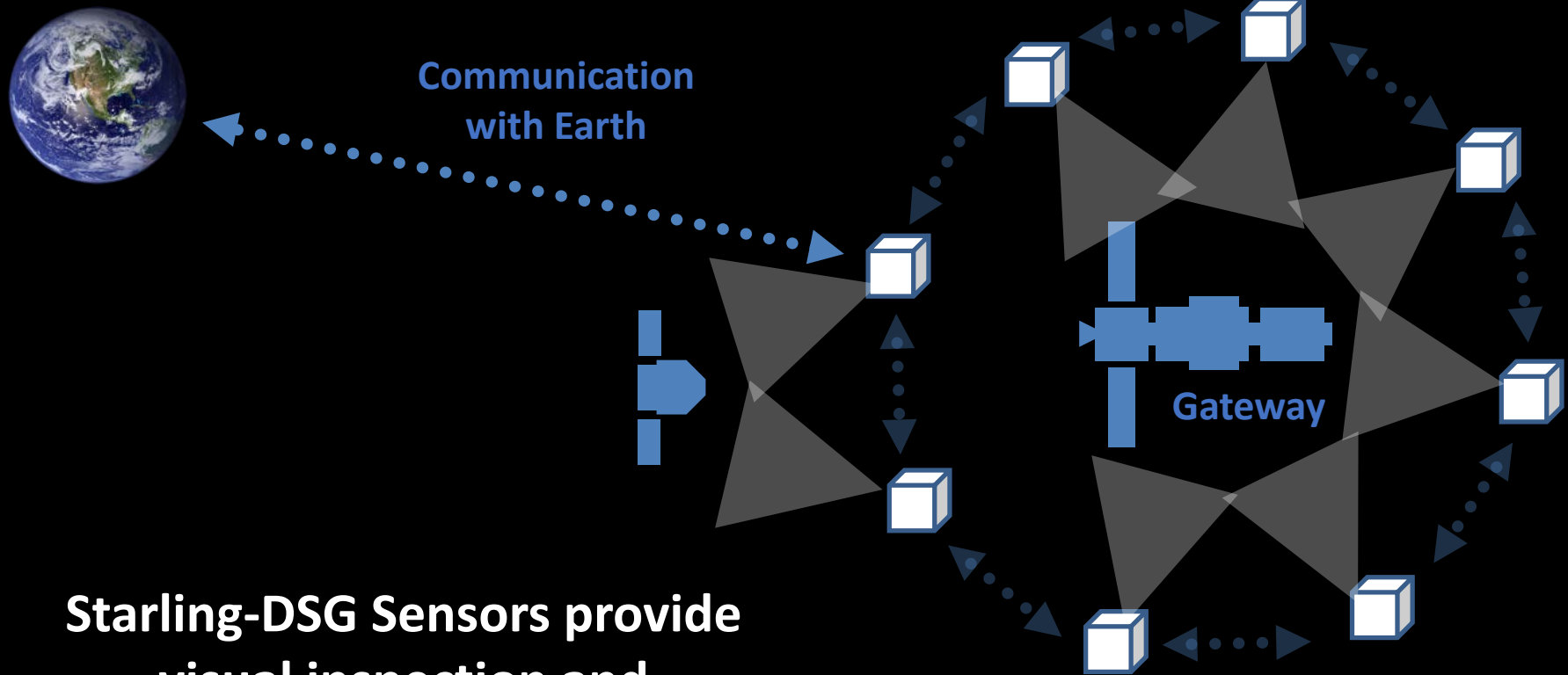**Starling-Explorers provide coordinated flight and communication with sensors such as ground penetrating radar or magnetometers**

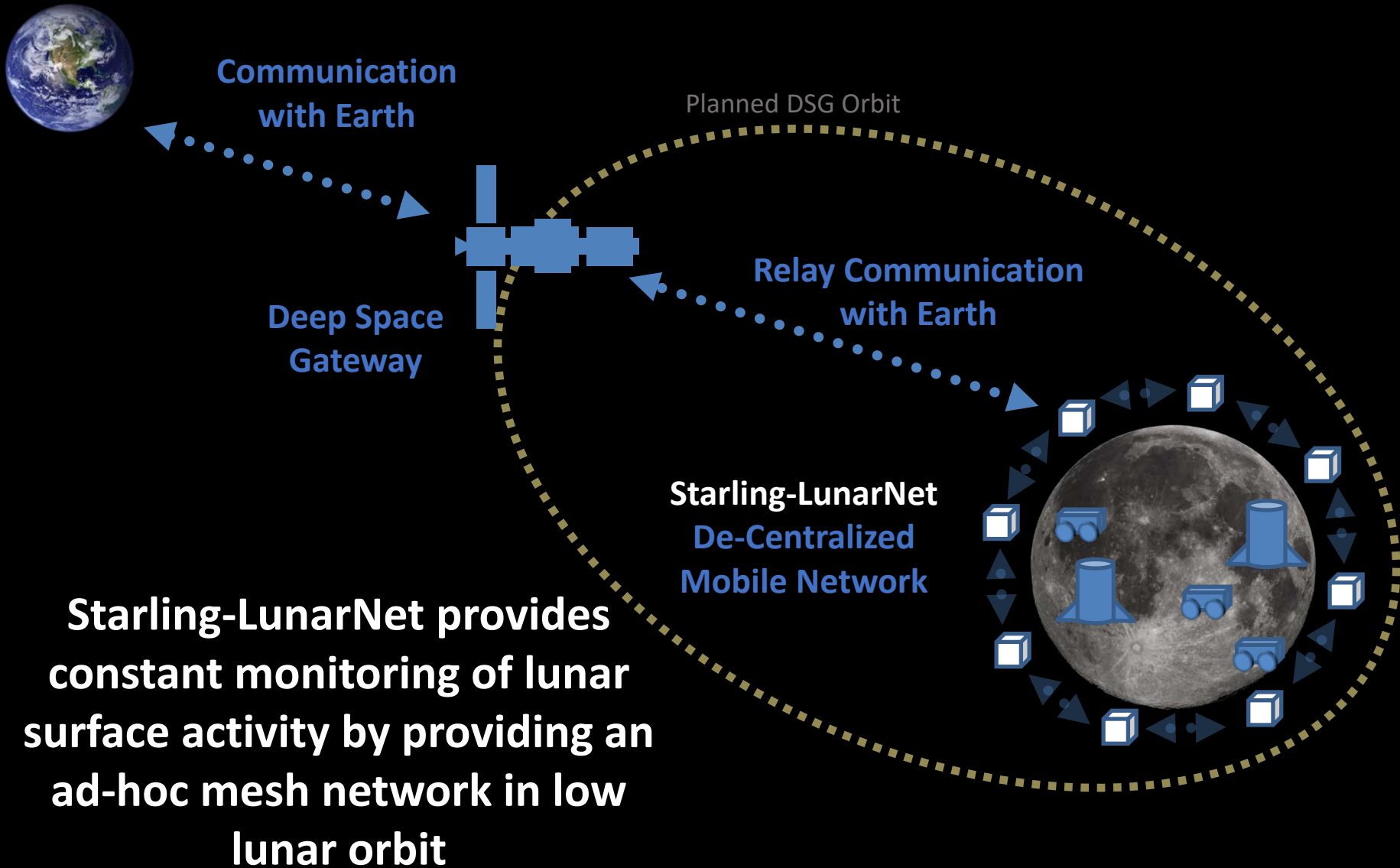10/31/2018

Communication with Earth

Gateway

Starling-DSG Sensors provide visual inspection and monitoring for Deep Space Gateway operations

Starling-DSG Sensors Mobile Network with Autonomous Navigation

Communication with Earth

Planned DSG Orbit

Deep Space Gateway

Relay Communication with Earth

Starling-LunarNet
De-Centralized Mobile Network

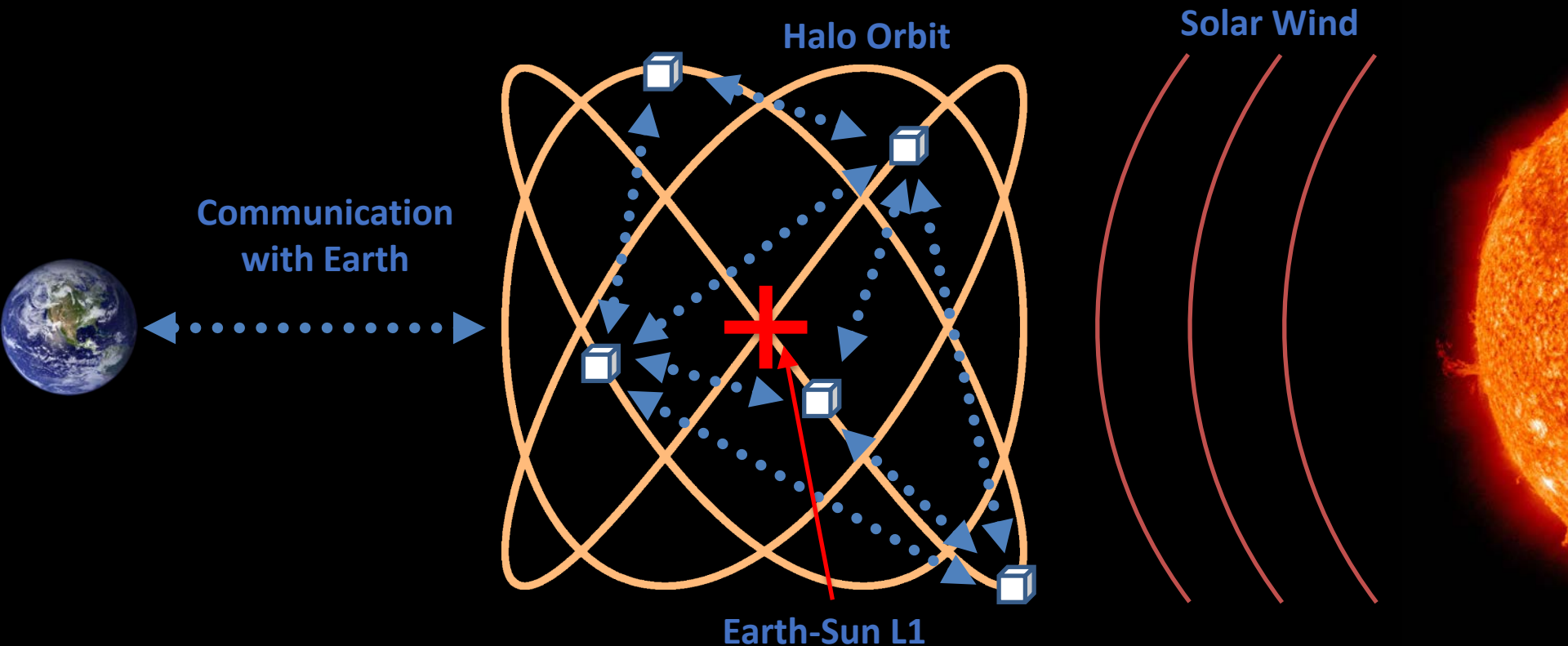**Starling-LunarNet provides constant monitoring of lunar surface activity by providing an ad-hoc mesh network in low lunar orbit**

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Starling-SolarWind in L1 halo orbit autonomously performs radio tomography and in-situ measurements to monitor and characterize solar wind

Renea Conn, Tracie, and Jay Bookbinder. "A Small Spacecraft Swarm Deployment and Stationkeeping Strategy for Sun-Earth L1 Halo Orbits." *American Astronomical Society Meeting Abstracts*. Vol. 231. 2018.

The core technologies enabling swarms are a mixture of mature in-space, mature on-the-ground, and new to-be-developed:

Knowledge – How do we know the relative positions and movements of the spacecraft in the swarm?

Communications – How do we get information to, from, and among the spacecraft in the swarm?

Control – How do we maintain the configuration of spacecraft in the swarm?

Operations – How do we command the swarm configuration and return data from it?

Access – How do we get the swarm into space and deploy it?

We know how to do all of these with constellations of larger spacecraft using traditional operations, but not how to do it cost-effectively for large swarms of small spacecraft.
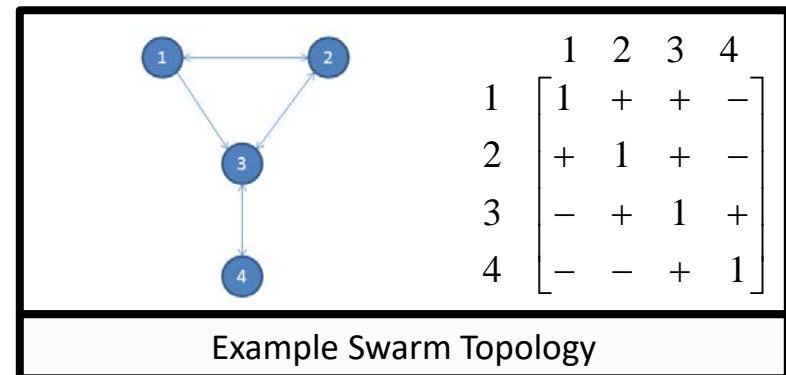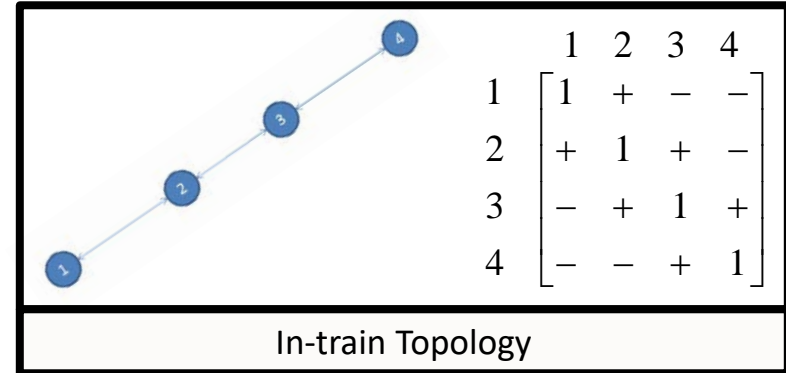
Starling1 is a cubesat mission that will nominally deploy four spacecraft in order to demonstrate the following swarm related Technologies

- Communication protocols:
  - Are scalable to 100s of spacecraft
  - Resistant to multiple lost nodes
  - Can autonomously map the network topology
- Relative navigation:
  - Uses simple suite of sensors
  - Uses standard spacecraft components (e.g., star trackers), thus no additional size nor weight is added.
  - Does not rely on earth-centric resources (e.g., GPS)
  - Can work with non-cooperative targets
- Autonomy software:
  - Automatically reconfigure in response to sensor feedback

- B.A.T.M.A.N.
  - "Better Approach to Mobile Ad hoc Networking"
  - Mobile Ad-hoc Networks (MANET) protocol
  - Self-configuring
  - Built for dynamic topologies
  - Decentralized network control
- CCSDS File Delivery Protocol
- Challenges
  - MANET protocols have no flight heritage
    - No test or simulation data for expected orbital dynamics and cyclical motions
    - Unclear impact of SBUs or thermal noise will impact performance
  - Differences in spacecraft hardware (radios, processors)
    - Spaceflight radios do not use the IP stack that MANET's are typically built around
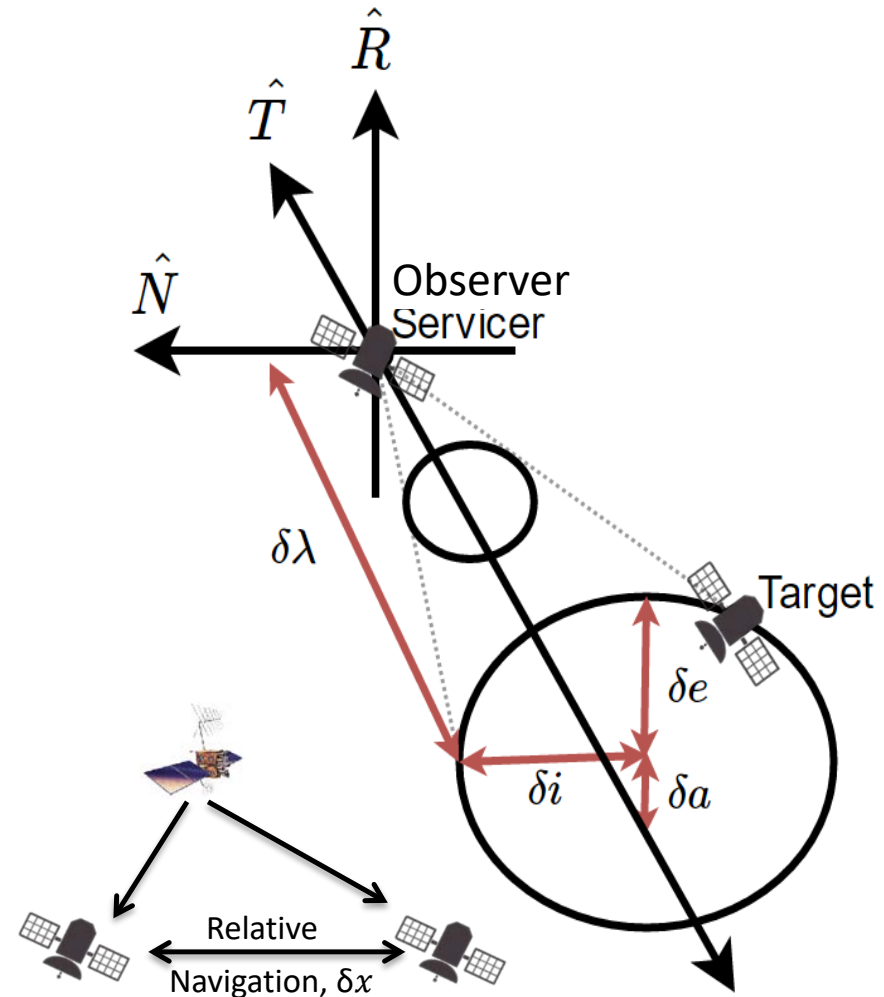 - Imperfect antenna coverage with nulls

$$\begin{array}{c} & \begin{matrix} 1 & 2 & 3 & 4 \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \end{matrix} & \begin{bmatrix} 1 & + & - & - \\ + & 1 & + & - \\ - & + & 1 & + \\ - & - & + & 1 \end{bmatrix} \end{array}$$

In-train Topology

$$\begin{array}{c} & \begin{matrix} 1 & 2 & 3 & 4 \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \end{matrix} & \begin{bmatrix} 1 & + & + & - \\ + & 1 & + & - \\ - & + & 1 & + \\ - & - & + & 1 \end{bmatrix} \end{array}$$

Example Swarm Topology

- Ad Hoc Network experiments:
  - Broadcast Test
  - Point to Point Test
  - Routing Test
  - File transfer characterization using CFDP
  - RF Stress Tests (bandwidth, distance)
  - File synchronization

- Stretch Experiment Goals
  - Ground comm query one S/C through another
  - Ground command to entire swarm through a single S/C

- Starling Formation-flying Optical eXperiment (StarFOX) – Stanford University partnership
  - Passive sensors
  - No cooperation required
  - COTS hardware
  - Minimal hardware
  - Wide FOV

- Verification by GPS (~1-10 m)

- Challenges
  - New methods for finding and tracking multiple targets need to be developed
 - Algorithm requires sharing of maneuver information between spacecraft

Exp.	Formation Geometry	Observer Count	Target Count	Maneuver Inclusion	Other Input
A*	In-train	Single	Single	-	-
B*	In-train	Single	Multi.	-	-
C	In-train	Multi.	Single	-	Inter-Satellite Link
D*	In-train	Multi.	Multi.	-	Inter-Satellite Link
E	In-train to Projected Circular Orbit	Single	Single	Maneuver for acquiring PCO separation	Maneuver Plan
F**	Projected Circular Orbit	Single	Single	-	-
G**	Projected Circular Orbit	Single	Multi.	-	-
H	Projected Circular Orbit	Multi.	Single	-	Inter-Satellite Link
I**	Projected Circular Orbit	Multi.	Multi.	-	Inter-Satellite Link
J	Projected Circular Orbit	Single	Single	Maneuver for acquiring PCO separation	Maneuver Plan

(*) or (**) can be conducted simultaneously, as illustrated below
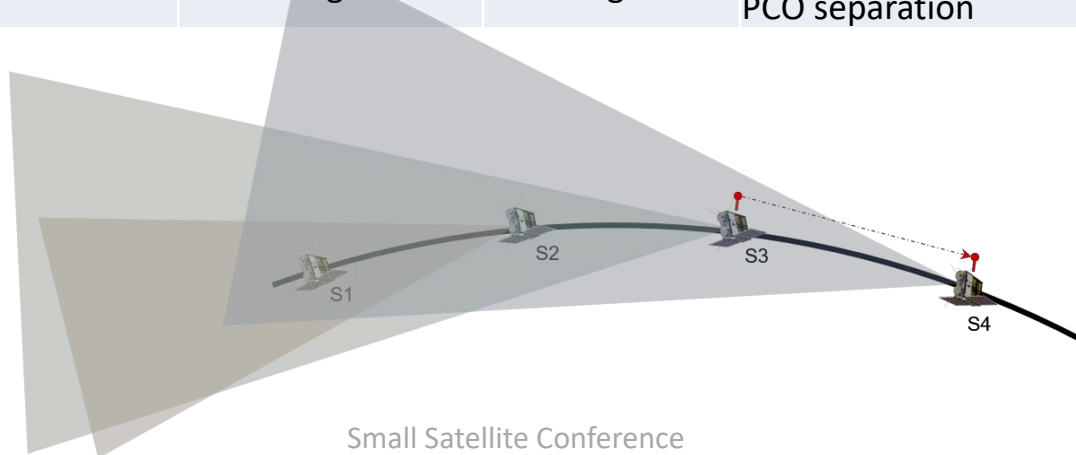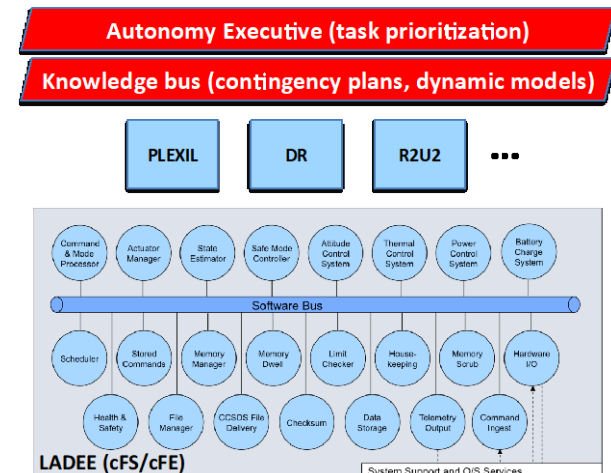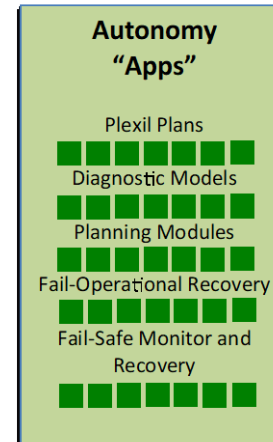
Distributed Spacecraft Autonomy

Opportunity

- **Autonomy is the least mature technology** required for multi-spacecraft missions
- Autonomy can significantly increase the effectiveness of multi-spacecraft missions by **operating them as a collective** rather than individually
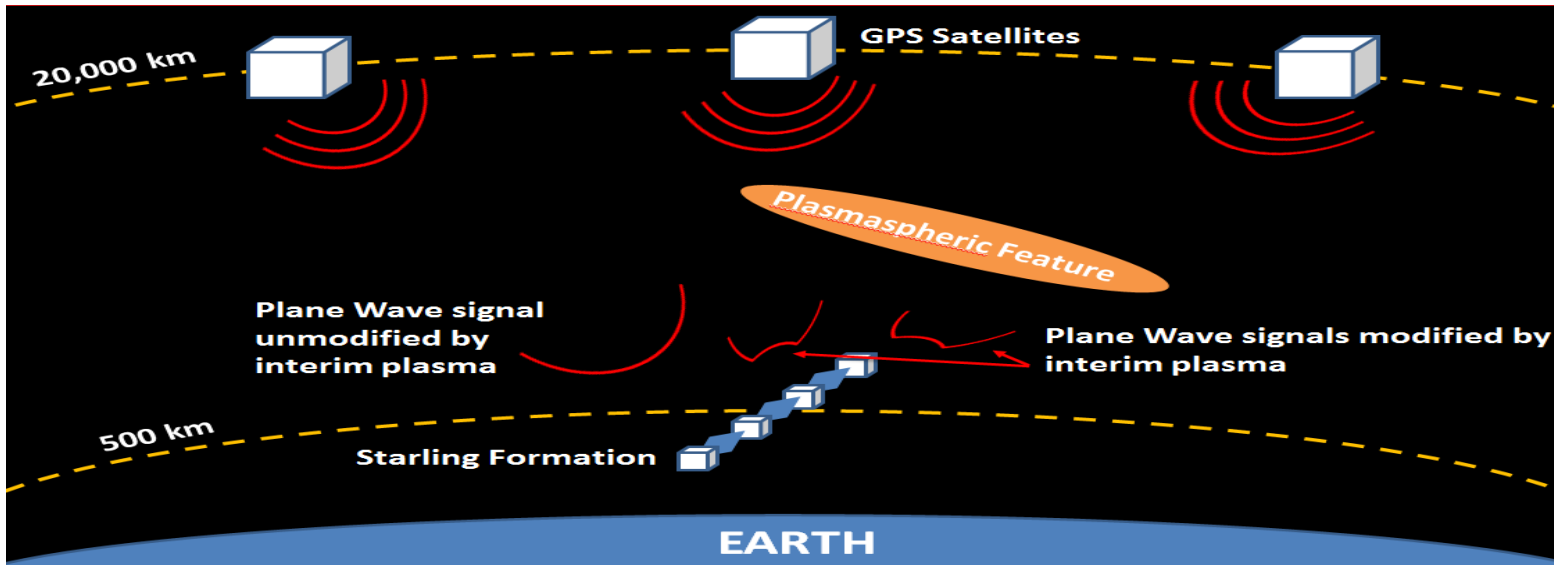
Goals

- Demonstrate flight-relevant autonomy technology in a scalable multi-spacecraft mission
- Develop and extensible autonomy architecture for collective operation of a swarm including high-level commanding, dynamic reconfiguration, and handling uncertainty across a distributed system.
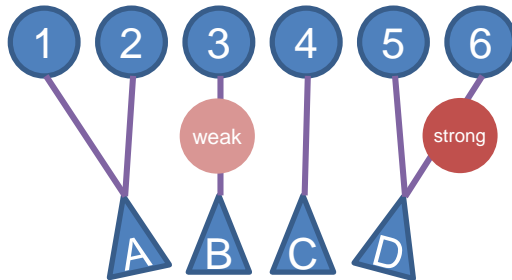- Establish scalability as a core design option for space missions

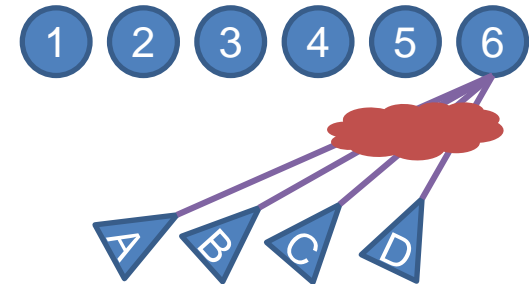**Autonomously reconfigure the spacecraft attitude and channel selection/sampling to improve signal strength and resolution of feature image**

- Experiment approach still in progress

- Starling1 is a new multi-spacecraft mission to investigate swarm technologies:
  - Adhoc Network Communications
  - Relative Navigation
  - Autonomous Reconfiguration
- Combined with the Shiver formation experiments, expect that spacecraft swarm technologies will be at high TRL in next few years.

BACKUP

NEED

- A capability to coordinate an entire spacecraft swarm with minimal resources

GOALS

- Enable **Operational Success** by providing a platform that supports swarm technology development
- Conduct **Orbital Tests** to develop technology that enables large scale, destination agnostic swarms

OBJECTIVES

- Per the Starling One Phase A Decision Memorandum, L1 requirements and Objectives are synonymous and are defined in two types:
  - **Operational Success** = Needed to develop a platform that supports scalable swarm development
  - **Orbital Test** = Tech development that enables scalable swarms
- (See Level 1 Requirements for details)

Type	Name	Requirement	Rationale
Operational Success Objectives	OBJ-001 Peer-to-Peer Comms	Starling1 shall conduct in-space peer-to-peer communications.	Peer-to-peer RF communication is already flight proven and is required in order to develop additional scalable swarm technology.
	OBJ-002 Absolute Position Knowledge	Starling1 shall collect absolute position knowledge for each spacecraft.	Absolute position knowledge is needed to verify position data for relative navigation (RelNav) testing and for measuring range performance of peer-to-peer communication.
	OBJ-003 Mission Duration	Starling1 shall fly at least three spacecraft in LEO for three months.	Three spacecraft are needed to prove in-space, multi hop communication. Three months allows time for commissioning and technology demonstration but should not drive component reliability and cost.
	OBJ-004 Swarm Spatial Maintenance	Starling1 shall conduct swarm position maintenance.	The ability to vary peer-to-peer range will help with assessing performance of tests and will prolong the duration of in-range operations.

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Type	Name	Requirement	Rationale
Orbital Test Objectives	OBJ-005 Relative Position Knowledge (RPK)	Starling1 shall conduct inter-spacecraft relative position knowledge testing.	RPK is needed for determining comm performance. If relative position can be obtained without GPS or TLEs, the technology could help implement deep-space swarm missions.
	OBJ-006 Peer-to-Peer Comm Performance	Starling1 shall conduct network performance testing over an in-space communications network.	Peer-to-peer communication technology must evolve to enable scalability to large swarms (>100 spacecraft). In general, in-space testing of comm network technologies is required to raise TRL.
	OBJ-007 Autonomous Reconfiguration	Starling1 shall conduct autonomous swarm reconfiguration testing	In order for swarms to be cost effective, they will need to achieve their objectives operate with minimal operational oversight.

- ## Spacecraft will deploy 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

- ## Then move into Projected Circular Orbits (PCOs)
  - Spacecraft will maneuver into stable relative orbits with varying cross-track and radial amplitudes