Reducing Data Latency with Intersatellite Links

2021 CubeSat Developers Workshop

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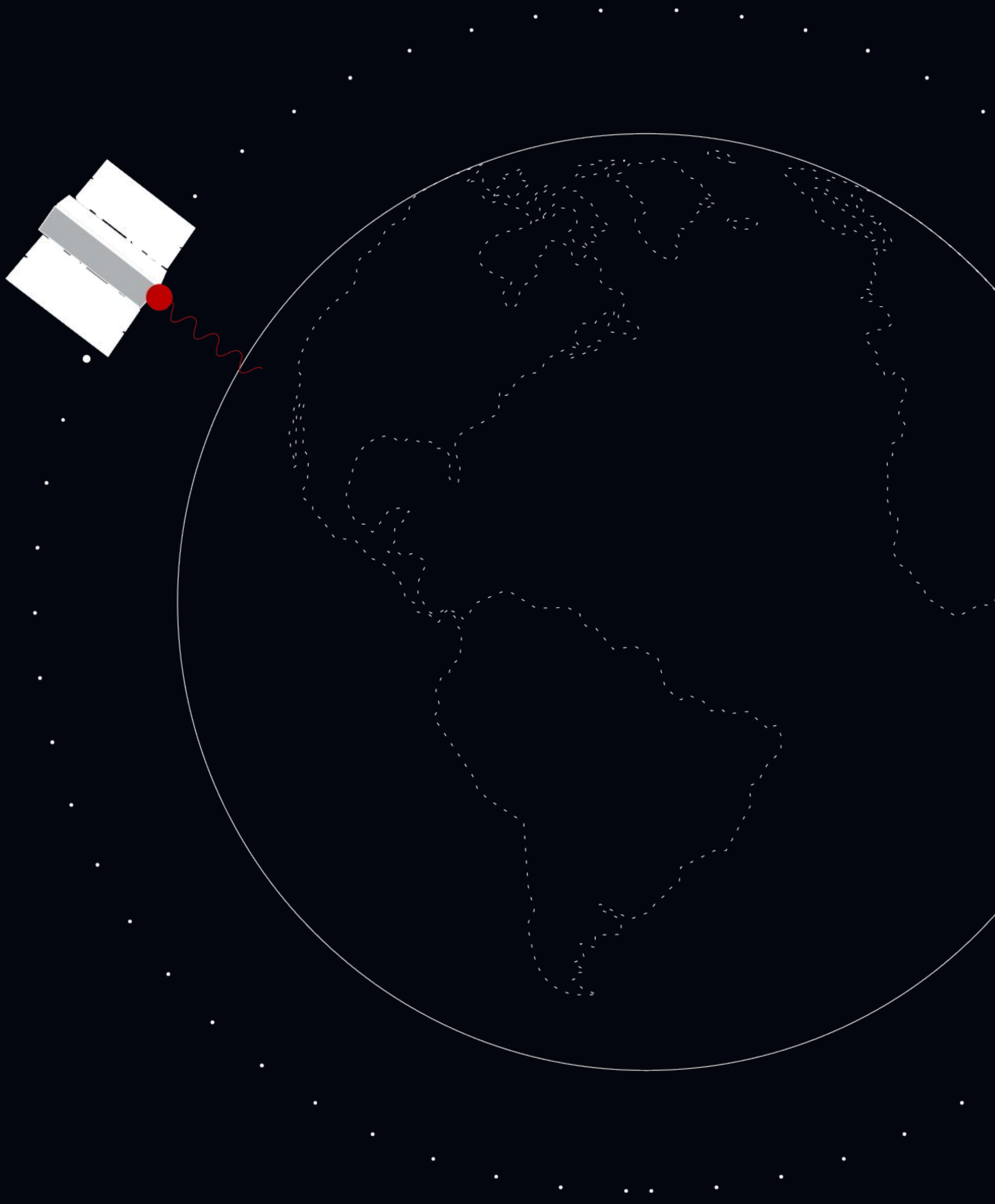
Agenda

1. The Spire Constellation
2. Intersatellite Links (ISLs)
3. RF-ISL Missions
4. Next Steps

The Spire Constellation

Overview of the Spire Constellation and Ground Station Network



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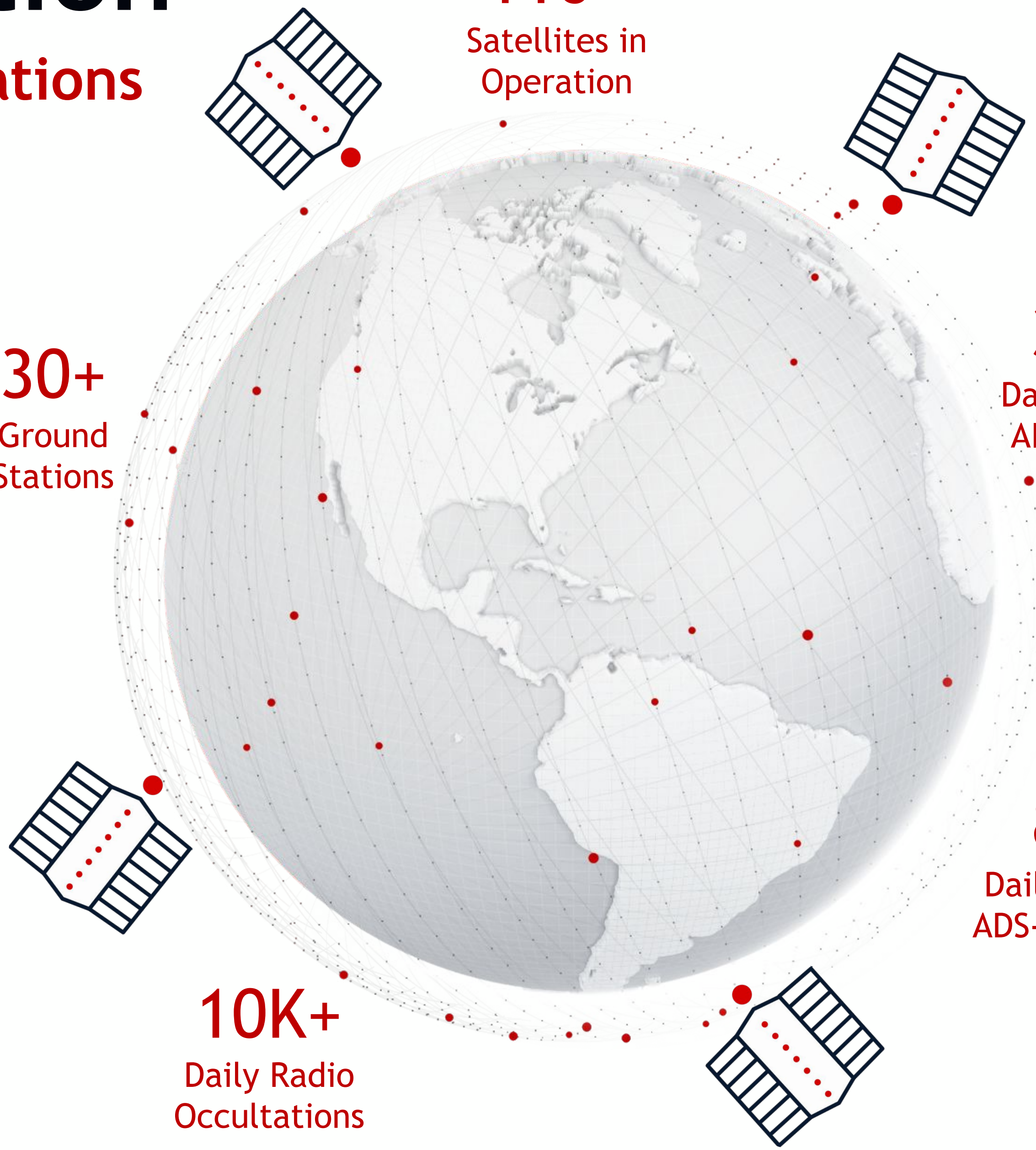
The Spire Constellation

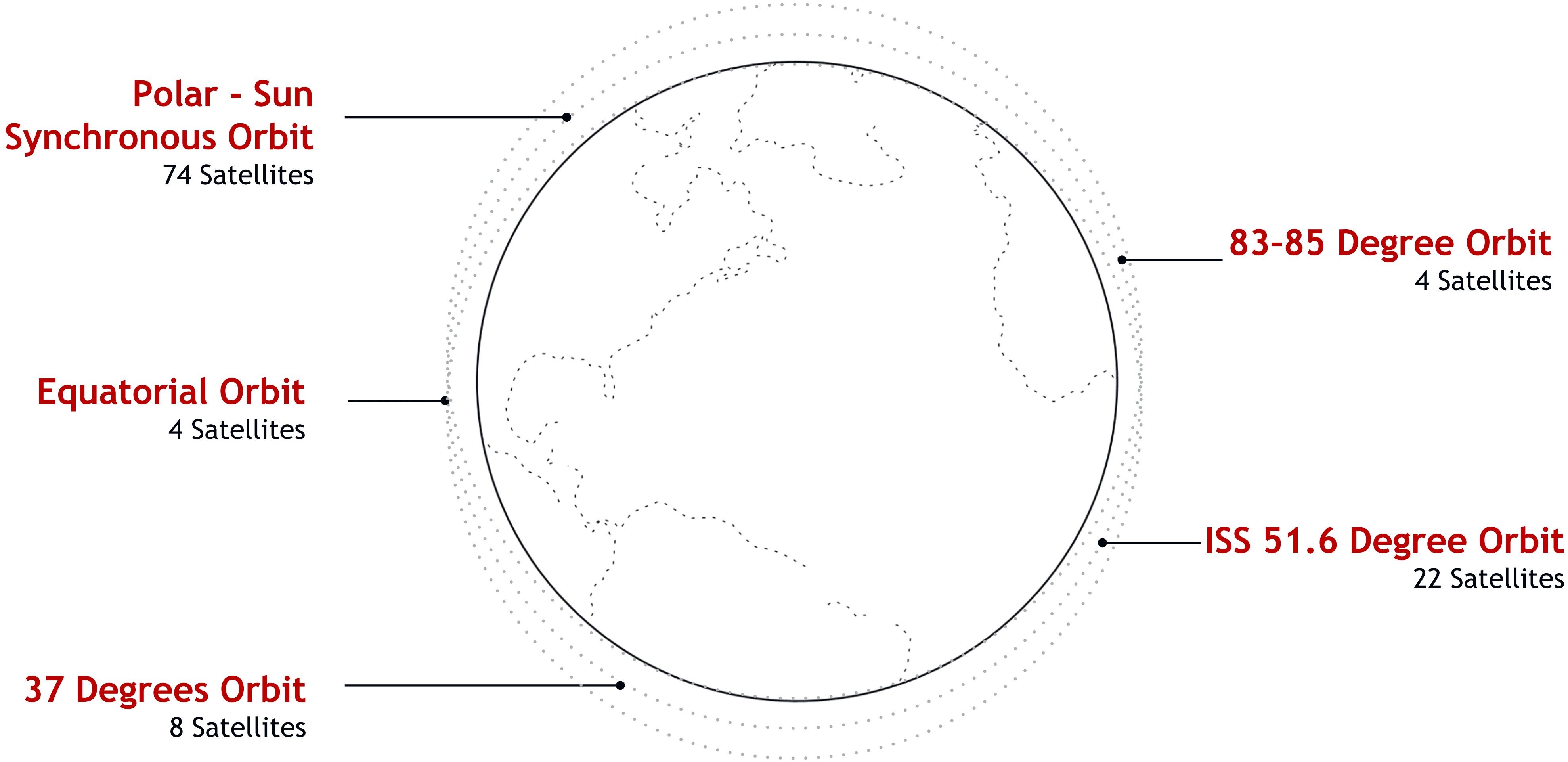
One of the largest private constellations in the world

- The LEMUR is Spire's 3U CubeSat platform used to track maritime, aviation, weather and other activity from space
- We operate one of the largest RF sensing fleets and are one the largest producers of radio occultation and space weather data
- Our data provides a global view with coverage in remote regions like oceans and poles
- We are continuously launching improved sensors and upgrading them in-orbit
- We turn ideas into live feed from space in as little as 6-12 months



The Spire Constellation

112 LEO-Based Cubesats in a diverse set of orbits enabling global coverage high daily revisit



With a Global Footprint

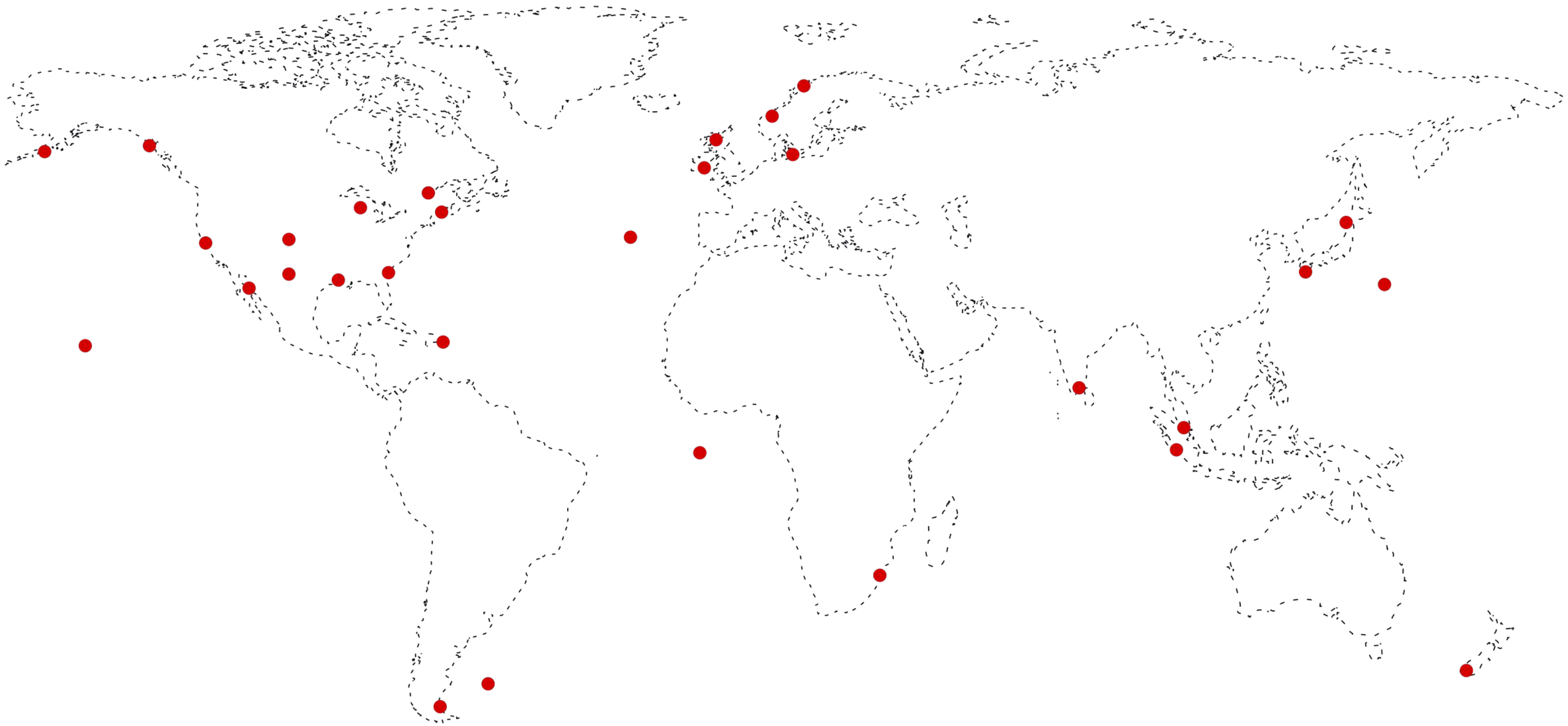
We own and operate the most geographically dispersed and largest network of ground stations, which allows us to repatriate our satellite-generated data at record speed

30+

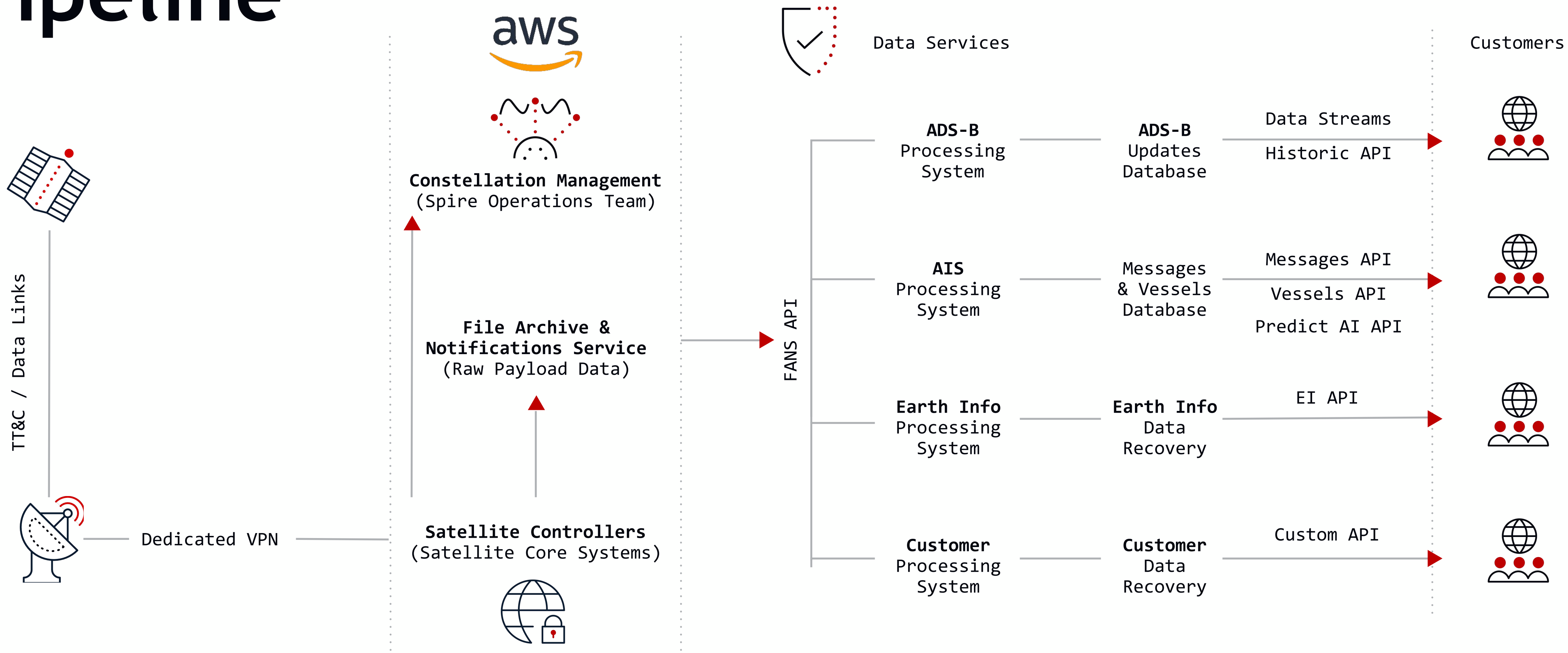
Ground stations

70+

Antenna systems



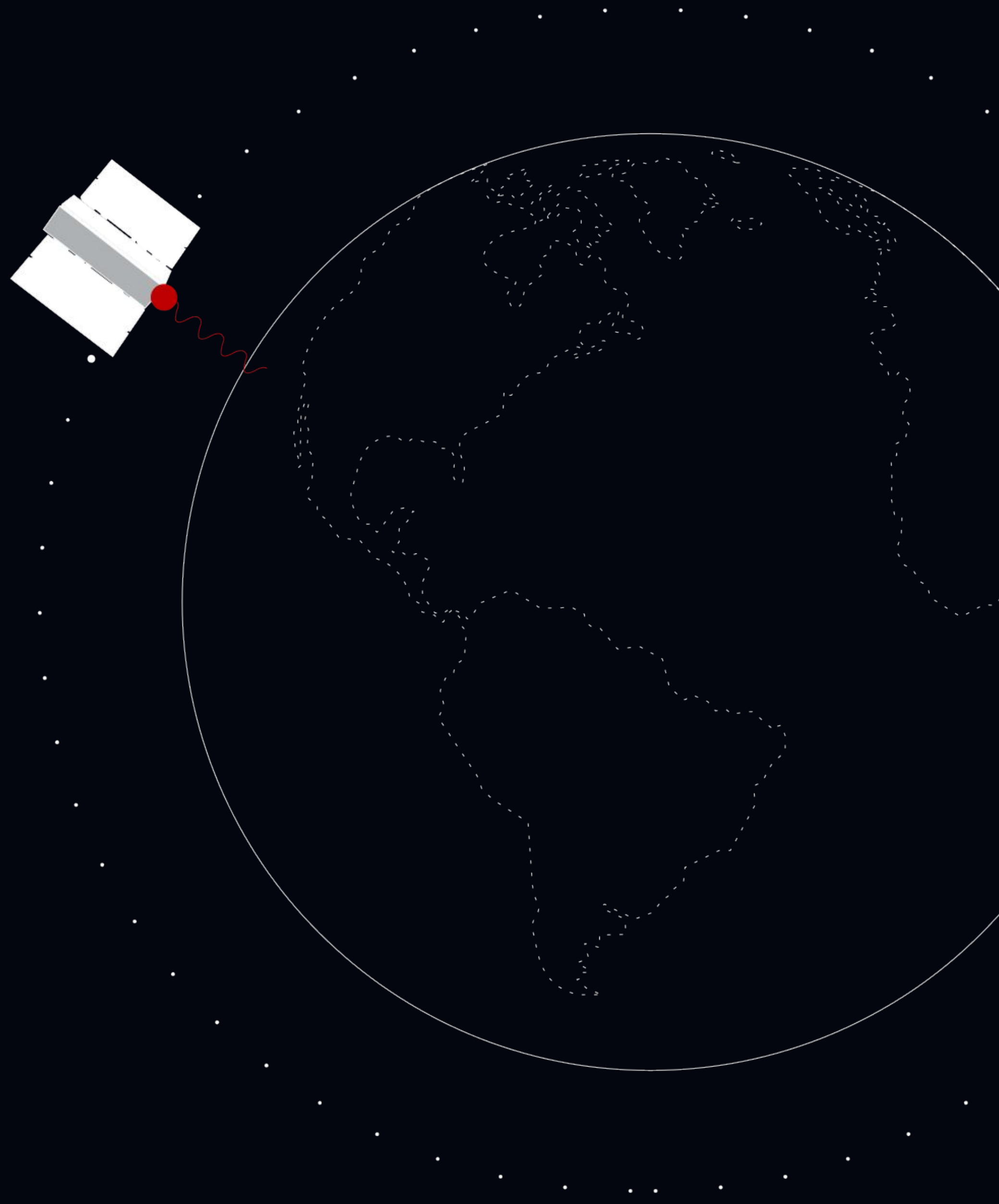
Scalable and Secure Cloud Data Services Pipeline



Fully secure and encrypted TT&C link, data links, U.S.-based cloud processing, and data distribution service; data remains encrypted from collection onboard the satellite to desktop user token

Intersatellite Links (ISLs)

Why ISLs are essential to meet global data latency requirements



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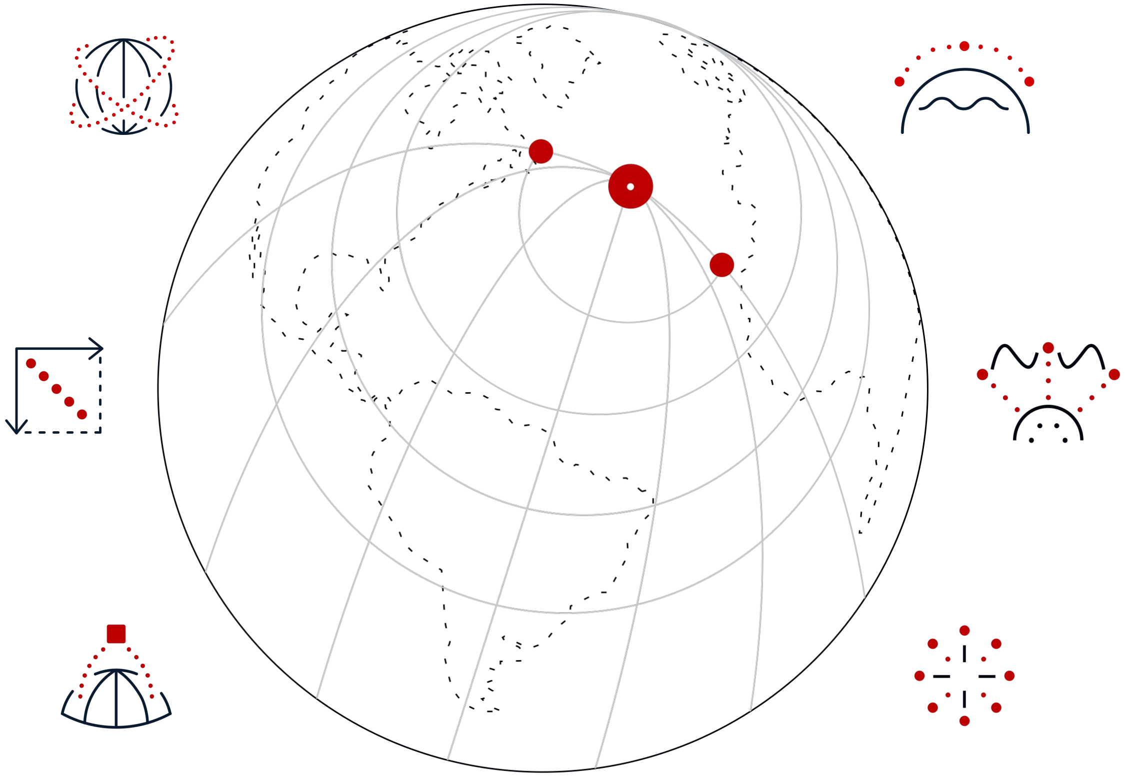
Why Intersatellite Links?

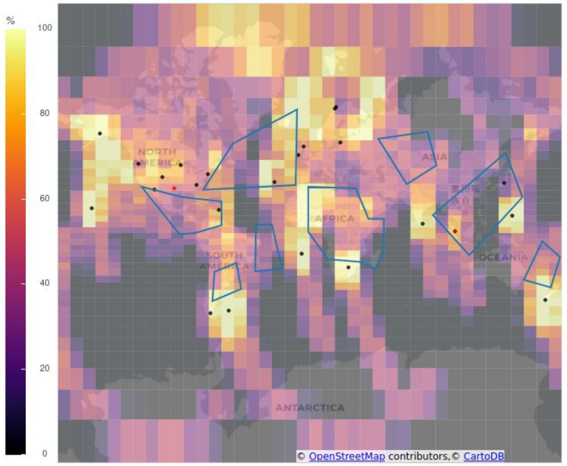


- Data latency is perhaps the single most critical metric when assessing the utility of space-based data collection
- Spire continues to increase data collection capabilities on-orbit with more satellites with improved collection capabilities
- Data collected by the Spire constellation is time sensitive and must be delivered to the end-user within a matter of minutes not hours for many applications
- Certain data sets are particularly time sensitive, such as ADS-B position messages for aircraft
- Even with 30+ ground stations and autonomous constellation management tools, so much of Spire’s data is collected over open ocean or in remote regions outside of the coverage of the ground segment
- In addition to strategically expanding the ground station network with more stations in designated areas of interest, **the utilization of intersatellite links is the most impactful way to globally reduce data latency for the most time sensitive data**

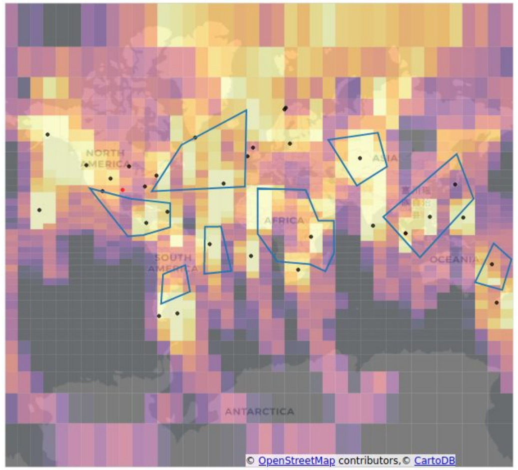
Constellation Latency Simulations

Data Latency Improvement with **Ground Stations**

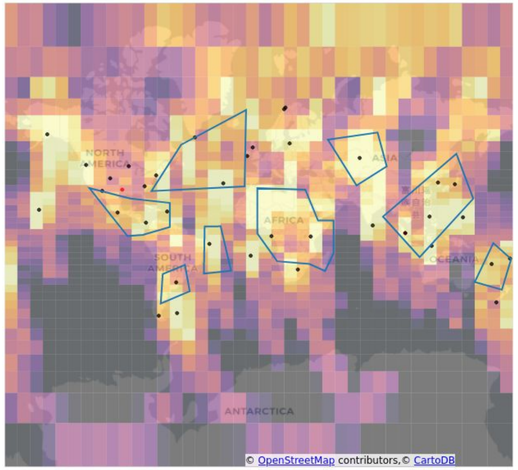
Comprehensive simulations completed to quantity impact of expanded ground station network



Current GSs



Current GSs + 7 New GSs



Current GSs + 13 New GSs

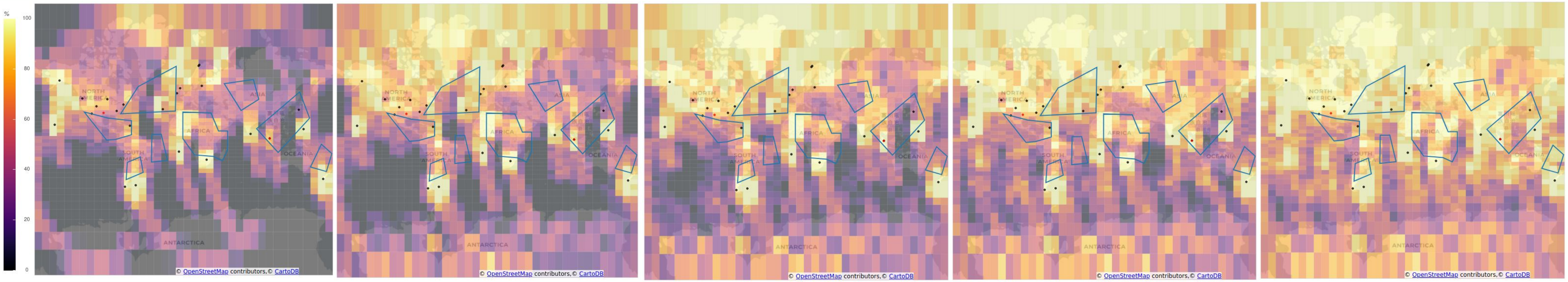
- Targeted GS expansion can dramatically improve latency for designated areas of interest
- Global low-latency requires ISL

	Approximate Relative Latency Improvement w/ Strategic Ground Station Expansion (%age)		
Region	Current GSs	Current + 7 New GSs	Current + 13 New GSs
Global	0%	24%	**32%**
Designated AOIs	0%	56%	**75%**

Constellation Latency Simulations

Data Latency Improvement with **Low Data Rate RF-ISLs**

Comprehensive simulations completed to quantity impact of low data rate RF-ISLs for various ranges (assuming ~550km orbits)



No ISL 2000km 3000km 4000km 5000km

- Uniform global improvement of latency with the addition of ISLs
- Max range of ISL has major impact to overall data latency reduction

	Approximate Relative Latency Improvement w/ Low Data Rate RF-ISL @ Various Ranges (%age)				
Region	No ISL	2000km	3000km	4000km	5000km
Global	0%	21%	41%	63%	**96%**
Designated AOIs	0%	14%	22%	38%	**66%**

RF-ISL

Overview of the Spire RF-ISL

Ongoing Missions

Note, the Spire development of ISL capabilities is supported by funding from the UK Space Agency through the ESA ARTES Pioneer Programme.

Spire RF-ISL Mission Overview

Batch 1 Mission

The first set of two S-band RF-ISL demonstration satellites with the following mission objectives and parameters

- Batch-1 RF-ISL satellites launched in Sept 2020 on a Soyuz mission to SSO
- Top Level Objectives
  - Validate theoretical S-band link budget and reduce uncertainty on link budget factors with known variance
  - Demonstrate **in-plane intersatellite communications**, including scheduling of ISL contacts, pointing of the spacecraft, closing the link
  - Determine the usability of the allocated spectrum (i.e. interference)
  - Establish realistic data rates for various link distances
  - Demonstrate compatibility with Batch 2

Batch 2 Mission

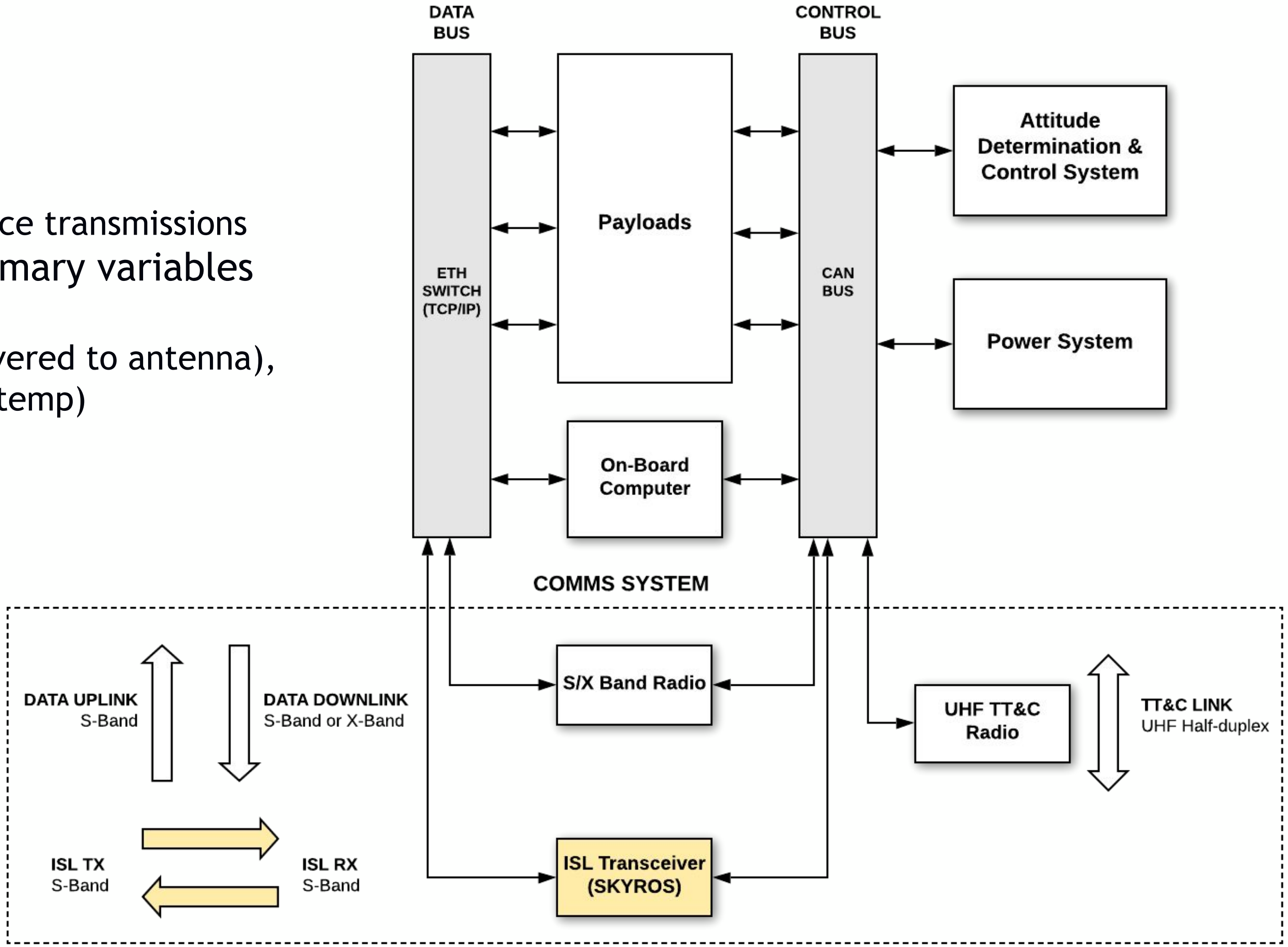
The second set of two S-band RF-ISL demonstration satellites with the following mission objectives and parameters

- Batch 2 RF-ISL satellites launched into different orbits on two launches
  - First Batch-2 RF-ISL satellite launched on NG-14 to an ISS orbit in Oct 2020
  - Second Batch-2 RF-ISL satellites launched on a SpaceX Rideshare launch to SSO in Jan 2021
- Top Level Objectives
  - Incorporate learnings from the development and qualification phase of Batch 1
  - Validate and demonstrate the updated link budget with the expected improved performance
  - Demonstrate **cross-plane intersatellite communications** under more stringent test conditions (i.e. larger changes of distance within contacts, higher slew rates, higher doppler rates, etc) using real-life payload test data
  - Demonstrate the ConOps under all enveloping test conditions, including scheduling ISL contacts, pointing the spacecraft, initiating and closing the link both **in-plane and cross-plane**

RF-ISL Batch 1

Mission Design

- **Link Design**
  - S-band frequency selected
    - 1 MHz bandwidth allocations for Space-to-Space transmissions
  - Link budget calculated with the following primary variables requiring validation
    - System Noise Temp, Transmission (signal delivered to antenna), Antenna Characteristics, and Receiver (noise temp)
- **Satellite System Architecture**
  - 3U LEMUR2 CubeSat standard bus with the following configuration changes:
    - GNSS-Radio Occultation antennas removed, replaced with ISL antennas (QTY: 2)
    - **Standalone ISL transceiver module (‘SKYROS’) developed** (consisting of a digital motherboard and a custom RF daughterboard / RF shield).
- **Orbit Selection**
  - Shared launch to SSO for in-plane ISL demo



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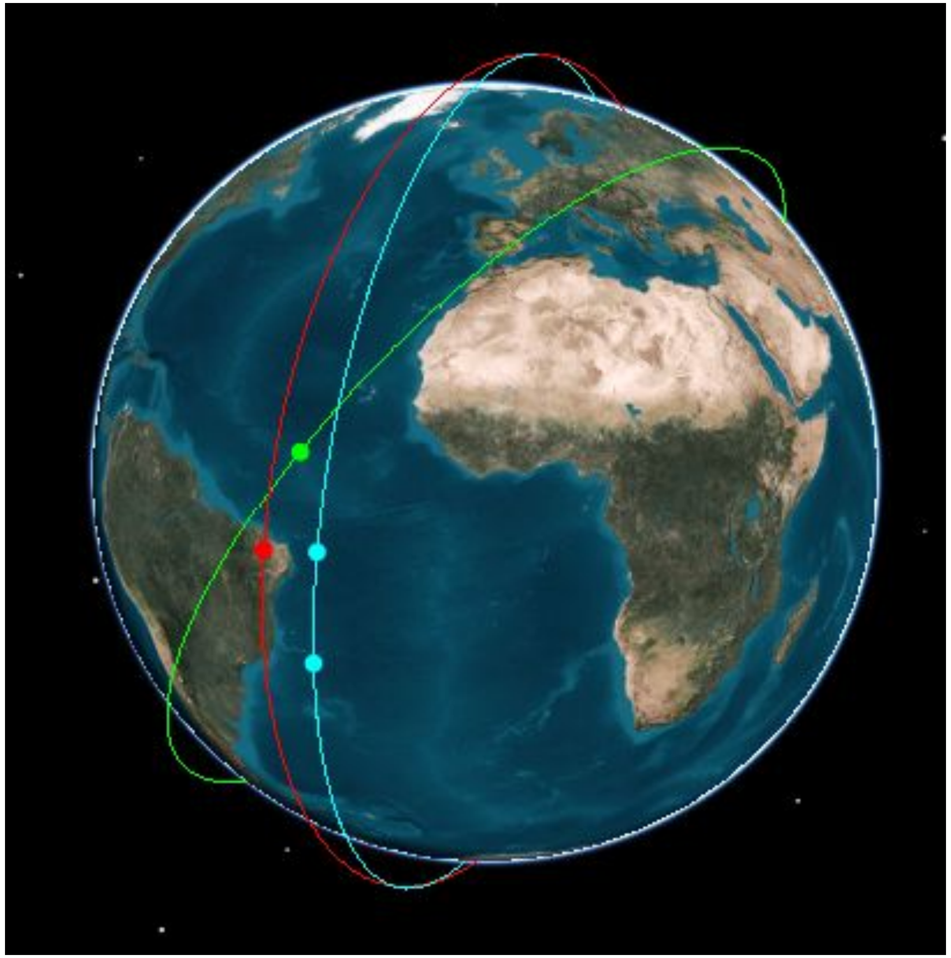
RF-ISL Batch 2

Mission Design

- **Updates from Batch 1**
  - Improved version of SKYROS S-Band RF-ISL Transceiver module
    - Improved power amplifier to increase output power to antenna while maintaining the required signal quality
    - Improved circuit matching to mitigate higher frequency gain drops and associated noise figure variations across frequency bands
    - Updates to circuit board layout to improve thermal performance
    - Minor modifications to mechanical design of SKYROS module to improve thermal performance
  - Improved antenna design
    - Improved impedance matching across substrates
    - Optimized patch dimensions
- **Satellite System Architecture**
  - Identical to Batch 1 (same heritage LEMUR2 3U CubeSat bus)
- **Orbit Selection**
  - Originally planned to launch both Batch-2 satellites on same SSO launch
  - Decided to split Batch 2 launch across ISS and SSO launch to ensure that high relative velocity contact windows would be available for evaluation (~15km/s vs. shared SSO launch with max relative velocity of ~1km/s)



Batch 2 Launch Configuration (Green and Red)

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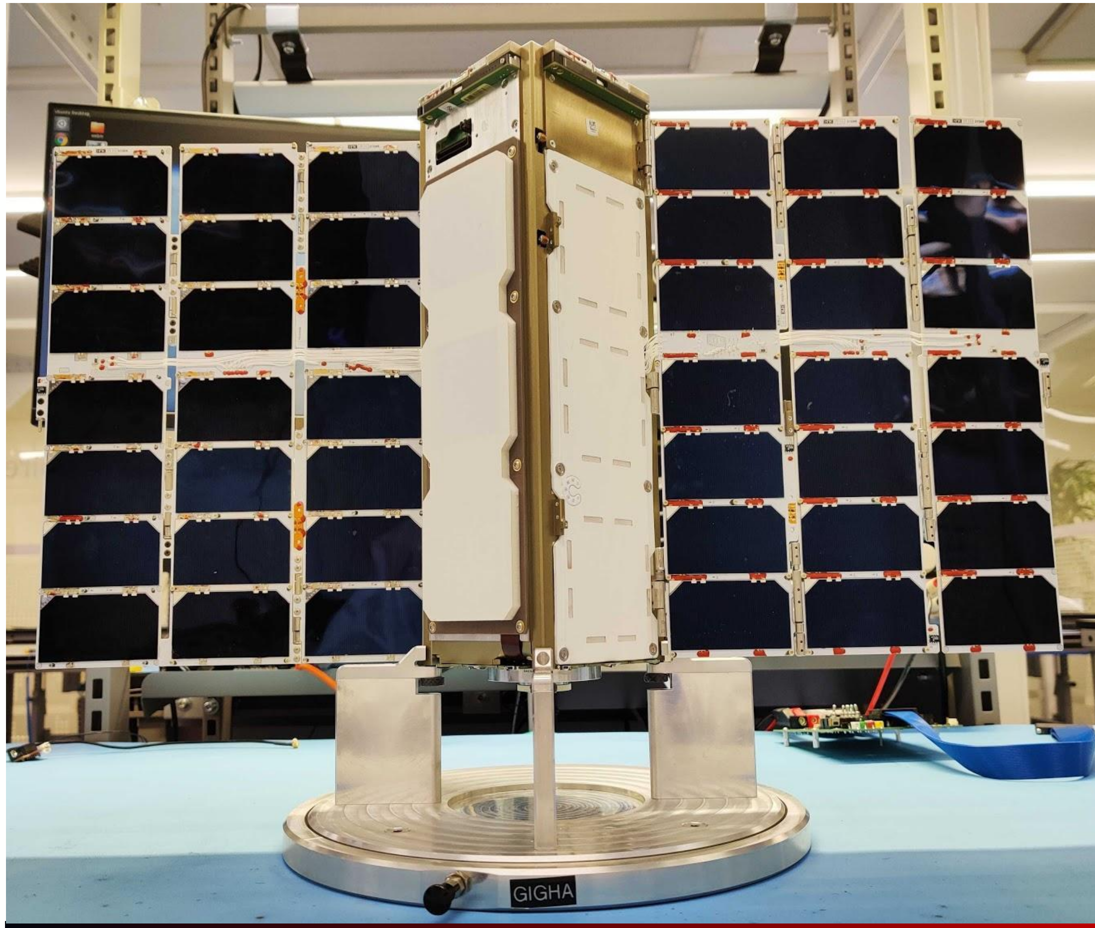
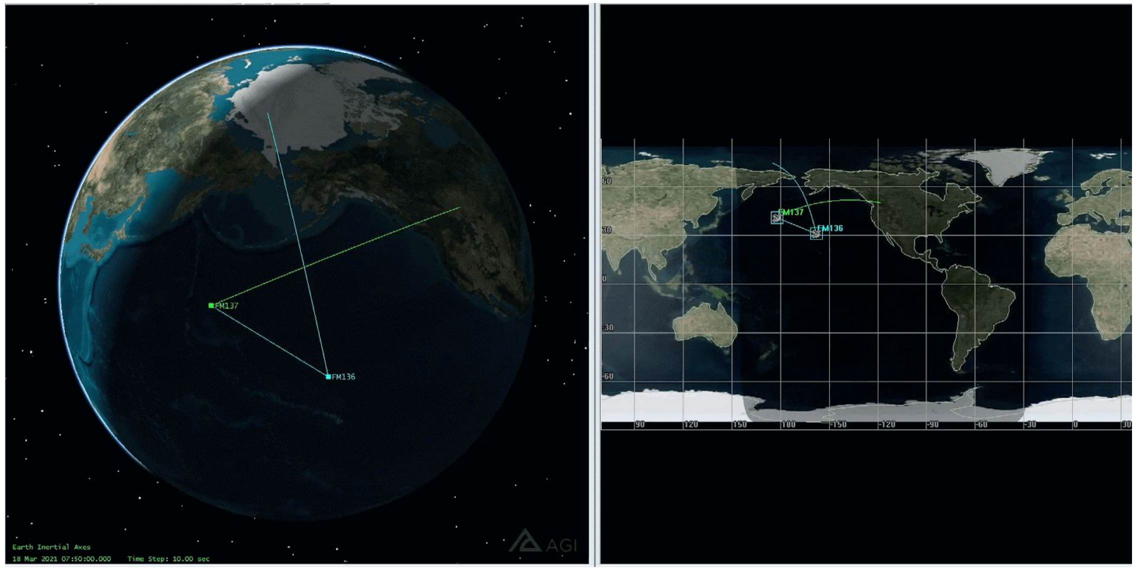
Spire RF-ISL On-Orbit Demonstration



On-Orbit Testing of the Batch 1 & 2 RF-ISL Missions to Date

- Several RF ISL trials have been conducted on-orbit since the launch of the first batch of ISL-capable satellites in Sept 2020
- After completing the first stage of hardware and RF link characterization, the focus is now on data / file transfer and demonstration of the practicality of ISL to reduce data latency
- Both in-plane and cross-plane links have been established between Batch 1 / 2 satellites
- Successful data transfer at **100k Baud has been demonstrated at distances >4300km**
- These trials have shown a **reduction in data latency of up to 5 hours** in some cases, validating the potential of ISLs

Long Distance Data Transfer Trial



	Min	Max
Distance (km)	217	4307
Relative velocity, slant range direction, (km/s)	-9.6	9.6
Relative acceleration, slant range direction (m/s^2)	5.3	449

- The goal of this trial was to continue evaluation of data transfer performance over long distances
- FM137 (Batch 2 ISS) □ FM136 (Batch 2 SSO)
- Test Duration (Mar 18, 2021)
  - 07:50:00 UTC
  - 08:02:00 UTC
- Average altitudes during mission
  - FM136: 528km
  - FM137: 405km
- 2.8MB worth of data was transferred at a TX symbol rate of 100 kBaud
- Maximum distance reached just over **4300km**

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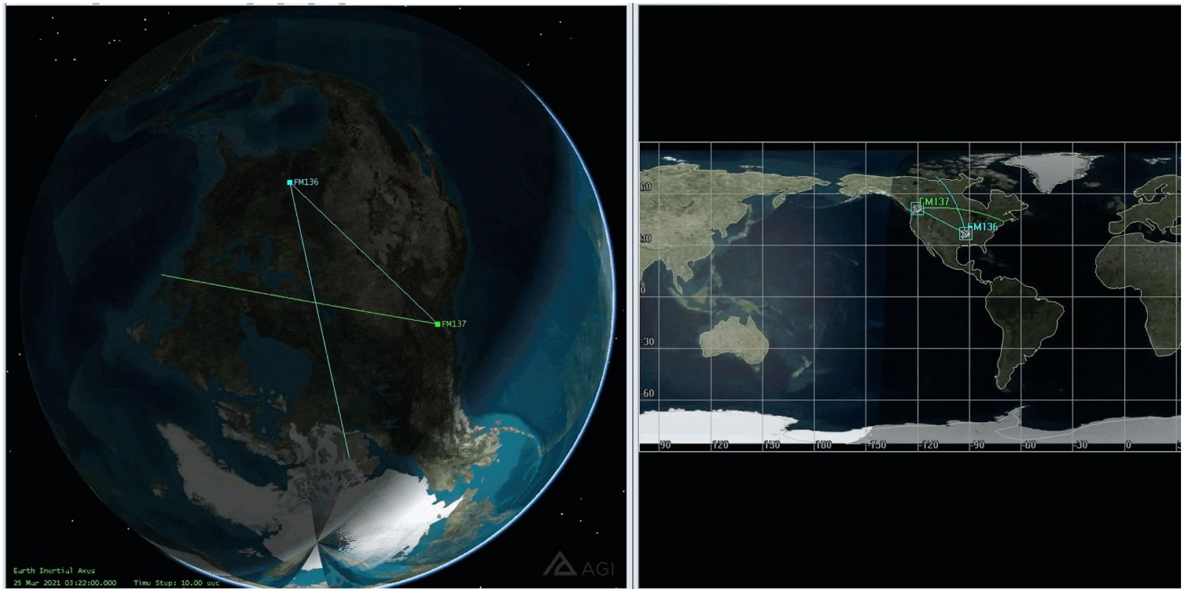
Latency Reduction Trial

- The goal of this trial was to demonstrate the ability to detect the difference in latency between the files in the TX and RX satellite
- FM137 (Batch 2 ISS) ¤ FM136 (Batch 2 SSO)
- Test Duration (Mar 25, 2021)
  - 03:22:00 UTC
  - 03:31:00 UTC
- Average altitudes during mission
  - FM136: 528km
  - FM137: 404km
- **9.51MB** worth of data was transferred at a TX symbol rate of 100 kBaud
- Latency reduction **>5 hours**
  - After the files were transferred, they were downlinked to the ground by both satellites using the standard Spire downlink mechanisms.
  - Note, this trial was not selected to maximize this metric, it just so happened that GS availability was more favorable for FM136 vs FM137



	Min	Max
Distance (km)	124	3815
Relative velocity, slant range direction, (km/s)	-12.53	12.53
Relative acceleration, slant range direction (m/s^2)	4	1301

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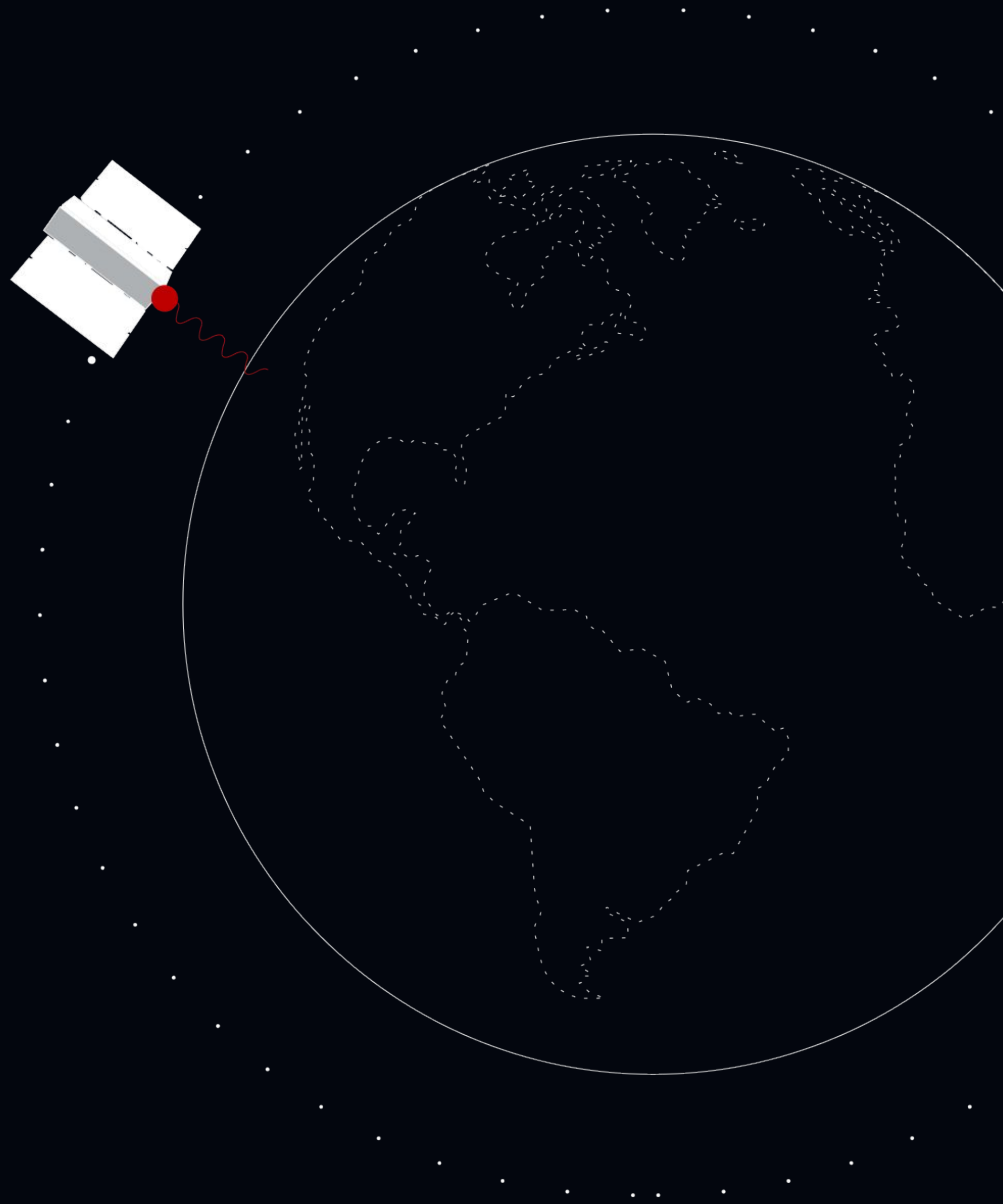
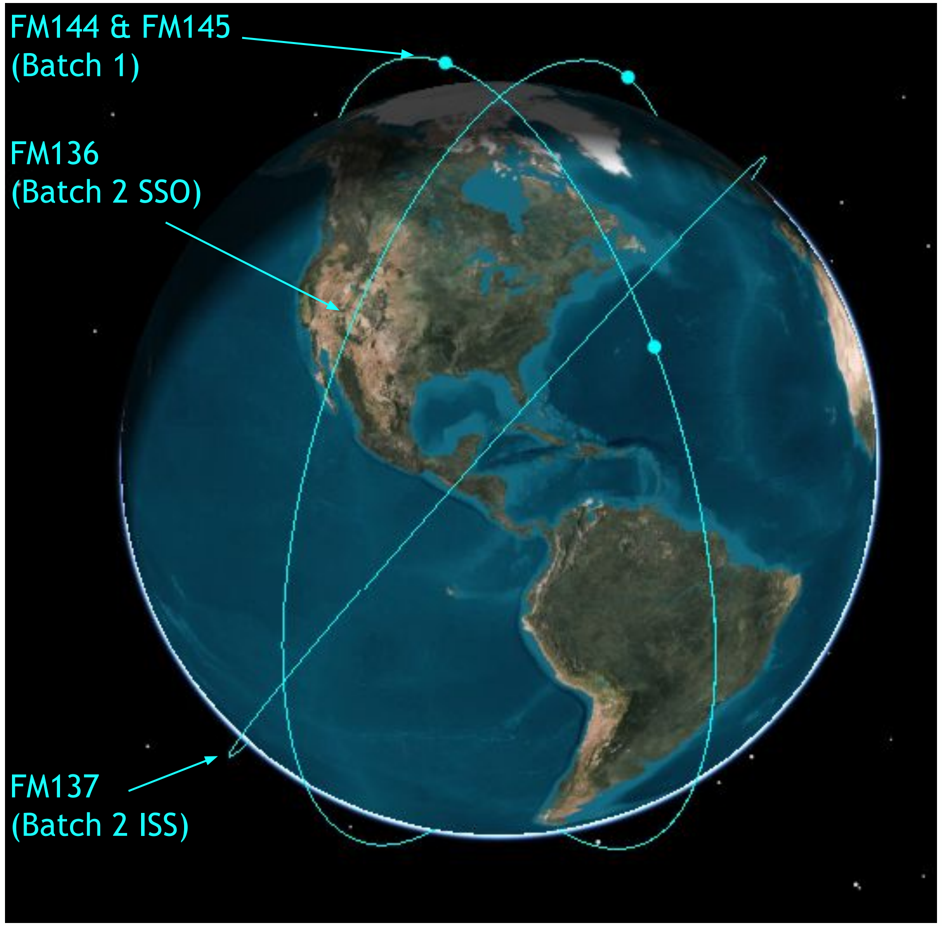
Next Steps

Continued RF-ISL On-Orbit Testing & O-ISL



Continued RF-ISL On-Orbit Testing

- Moving forward will continue to test the limits of RF-ISL capabilities with on-orbit Batch 1 & 2 satellites
  - Statistically significant number of tests for various cases
- Example: Multi-Hop Testing
  - Taking advantage of orbital configurations to perform data forwarding / relay demonstration
    - i.e. ISL1□ISL2 (forwarding)□ISL3
- Advanced link evaluation including
  - Demonstration of updated modem on satellites with continued data transfer demonstrations
  - Thorough evaluation of link FER, SNR, time to acquire lock and other relevant parameters for different link conditions
  - Determine max Tx/Rx switching time for different SNRs
  - Experiment with different symbol rates and MODCODs

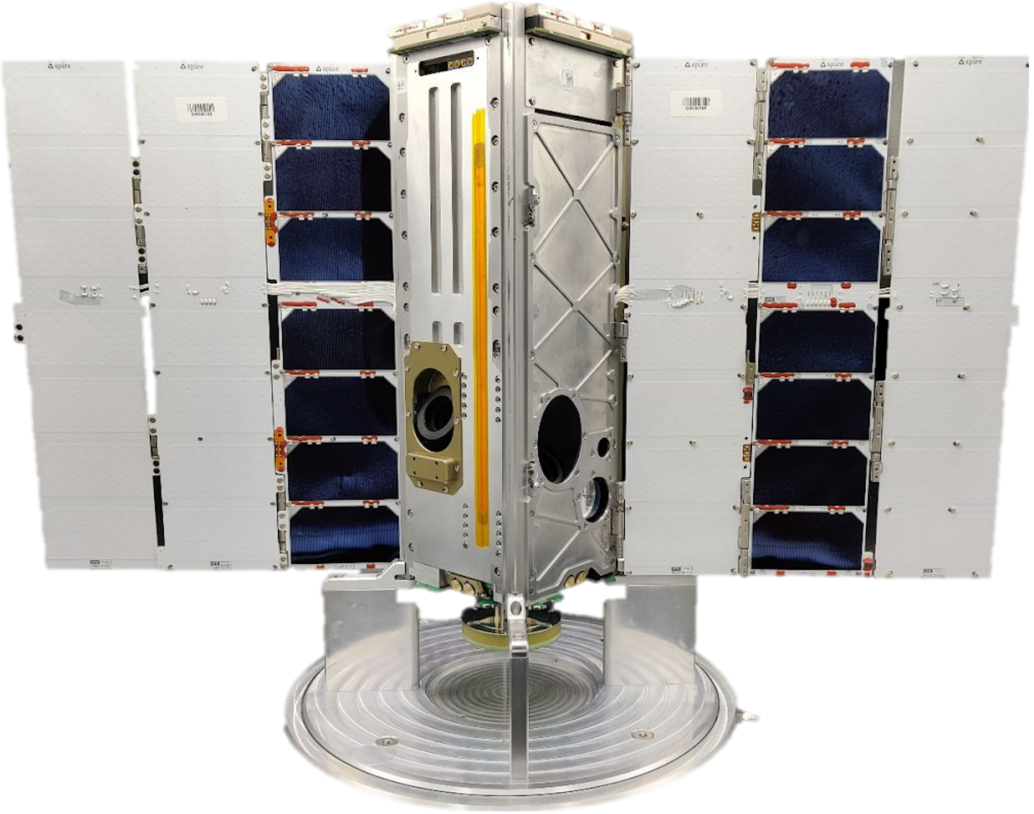


Optical ISL

- Free space optical (i.e. laser) communications to support increased intersatellite data rates
  - Higher data rates means more data can be transferred during crosslink windows, reducing latency for larger %age of data

- Spire initial tech demonstration planned for launch in 2021

- Full mission demonstration planned for 2022



Thank You!

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