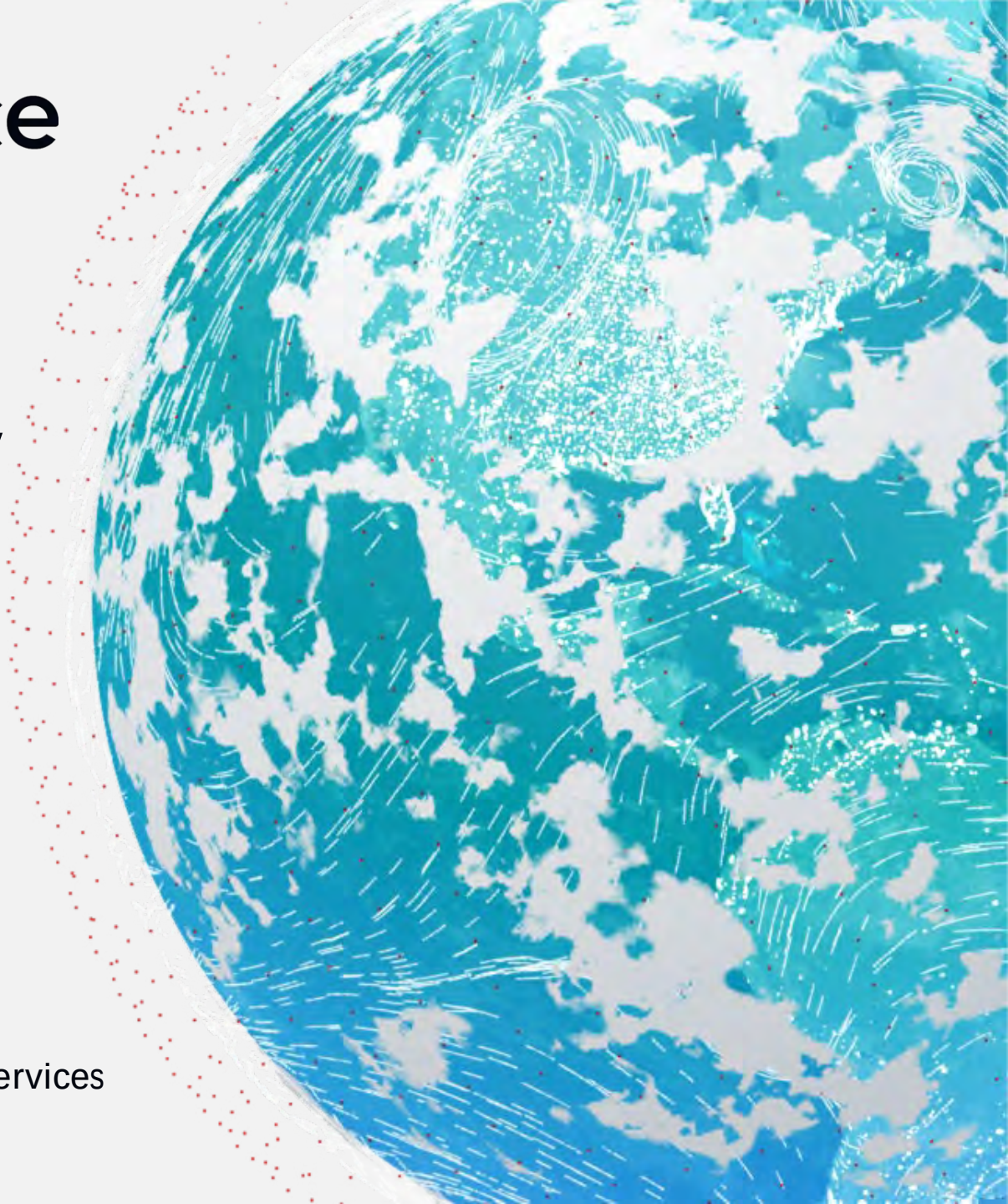
spire | earth intelligence

Spire Global UK Nanosatellite Technology Developments for Earth Intelligence Applications

From beneath the surface to the edge of space



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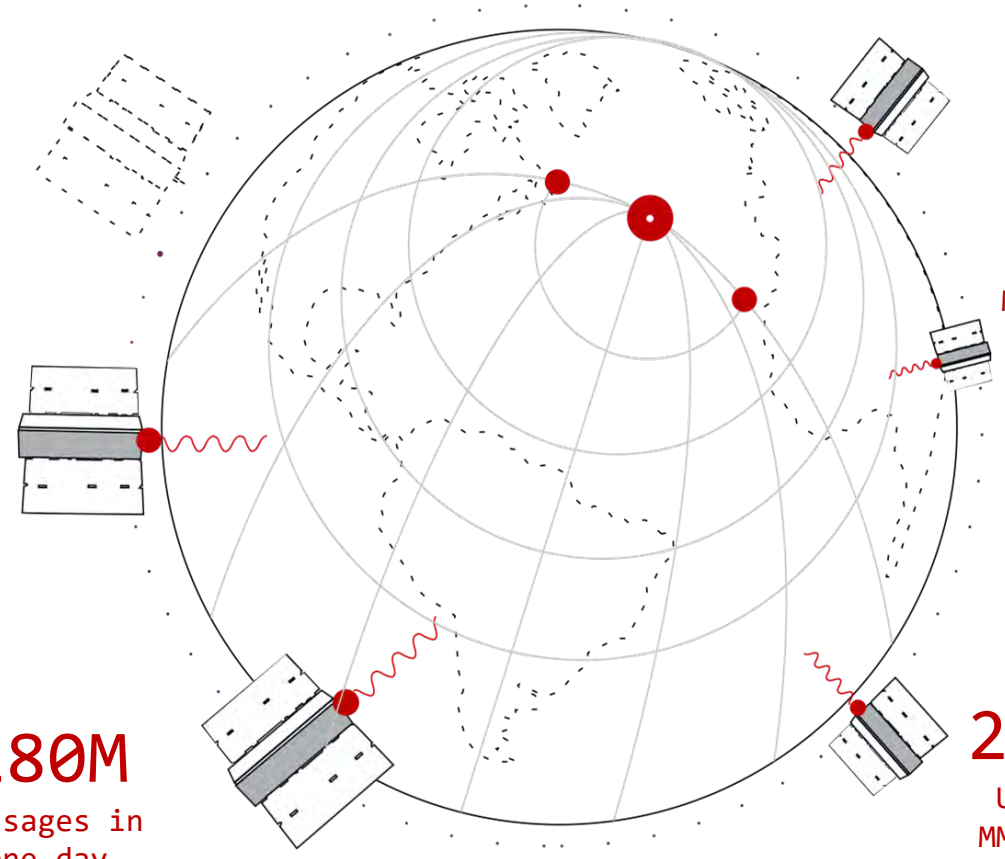
The Spire Constellation

One of the largest private constellations in the world.

- The Low Earth Multi-Use Receiver (LEMUR) is Spire's 3U CubeSat platform used to track maritime, aviation, and weather activity from space
- We operate the world's largest RF sensing fleet and are the largest producer of radio occultation and space weather data
- Our data provides a global view with coverage in remote regions like oceans and poles; all data can be refreshed within 15 minute cycles
- 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

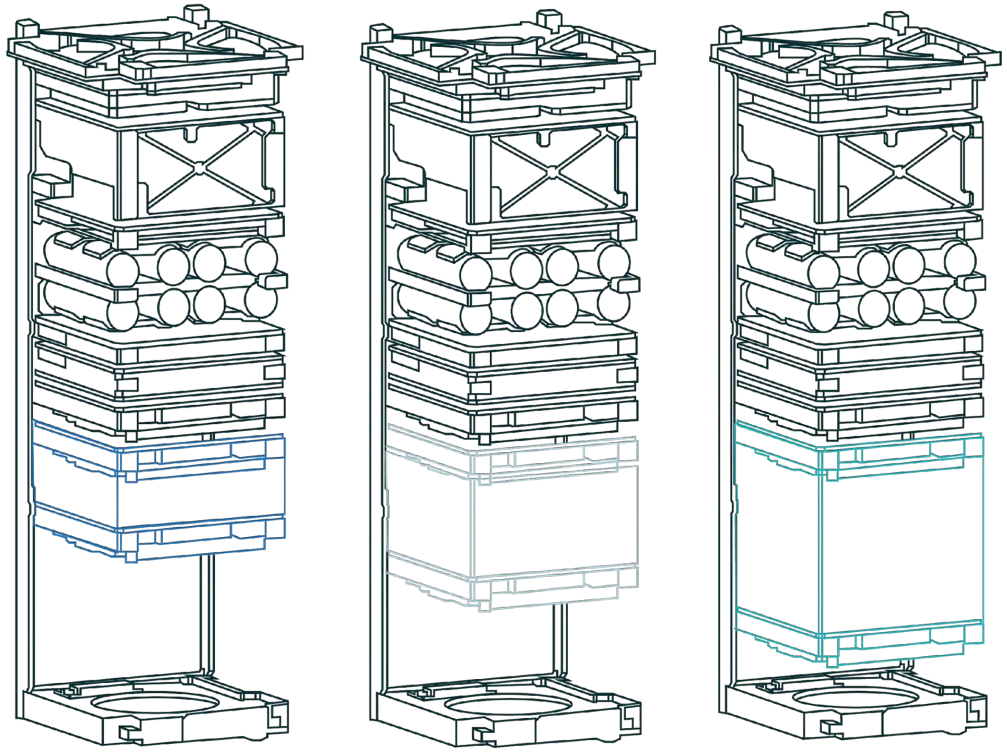
Much of this capability is developed in the UK, including all satellites.



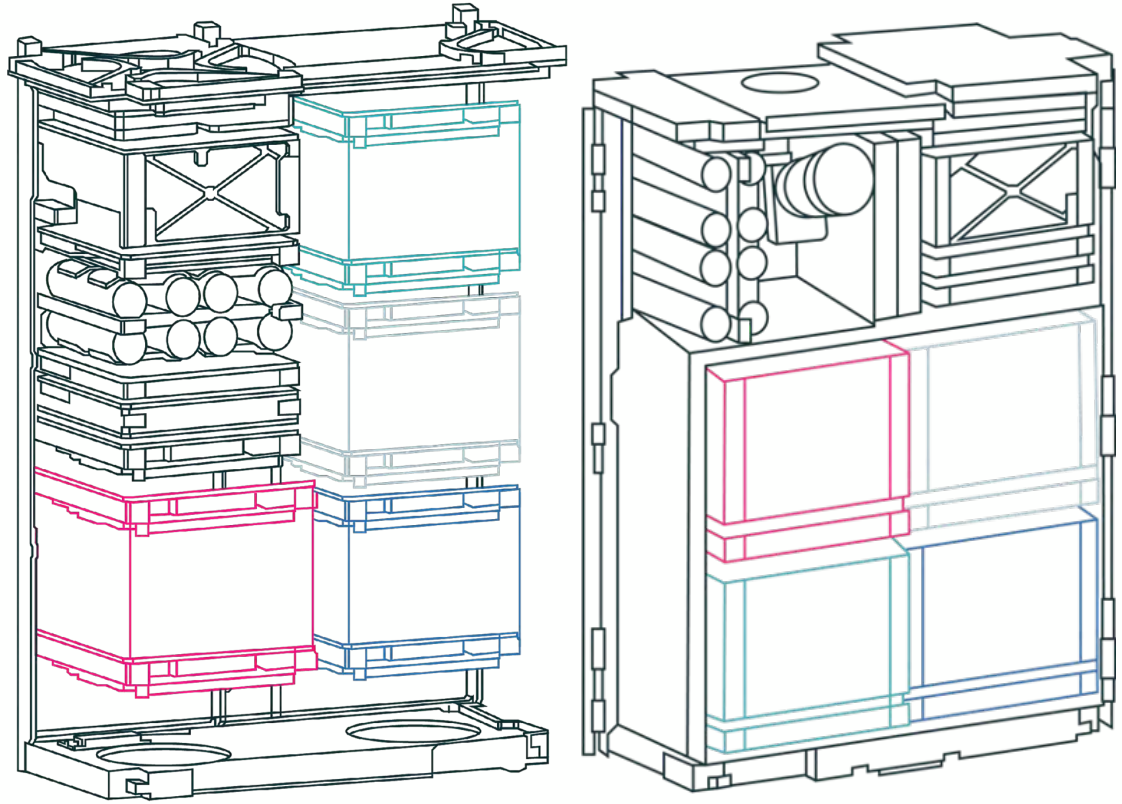
LEMUR Cubesat: key features

Parameter	6U Carrier Specs	3U Carrier Specs
Empty Carrier Mass	5.4 kg	4.2 kg
Payload Mass	Up to 4.2 kg	Up to 1.4 kg
Total Mass	9.6 kg	Up to 5.6 kg
Payload Power	5W - 12W Orbit Average, 35W Peak	
Data Interface	CAN bus (CS), Ethernet (TCP/IP), UART	
Onboard Storage	1 GB	
Pointing Accuracy	3-degree nadir	
Transmitters	UHF: 400-450 MHz, 9600 baud S-band: 2.20GHz, 1Mbit X-band: 8.2GHz, 40Mbit	UHF: 400-450 MHz, 9600 baud S-band: 2.20GHz, 1Mbit X-band: 8.2GHz, 40Mbit
Receivers	UHF: 400-450 MHz, 9600 baud S-Band: 2.032GHz, 1Mbit	UHF: 400-450 MHz, 9600 baud S-Band: 2.032GHz, 1Mbit

Platform flexibility



Hosted payload (rideshare) service for 1/3 U, 2/3 U and 1U payloads

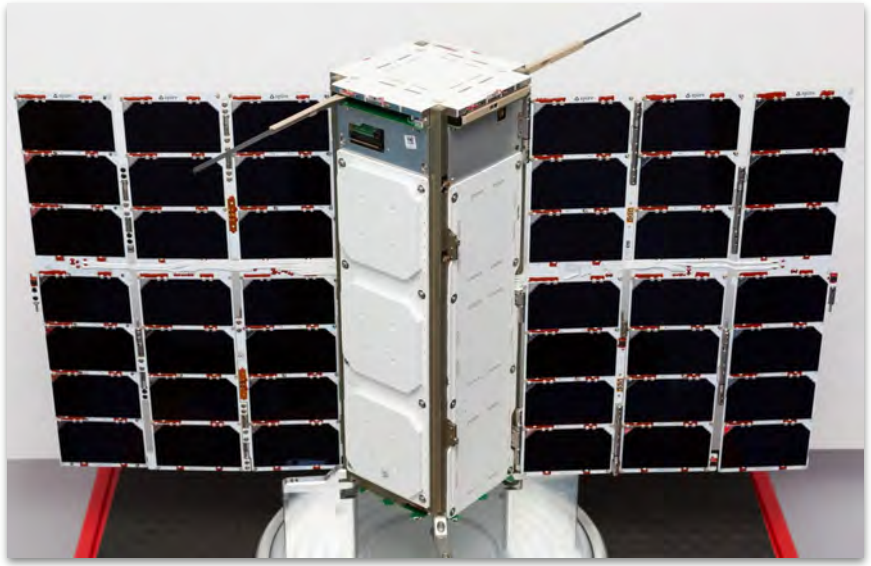


6U Bus-Up to 4U of hosted payload volume (either 1Ux3U or 2Ux2U)

Spire GNSS Earth Observation Satellites

Spire GNSS-RO satellites

- 3U form factor
- Moderate gain, dual antennas (rising/setting RO)
- Multi-GNSS signals tracked
- Rapid on-orbit innovation

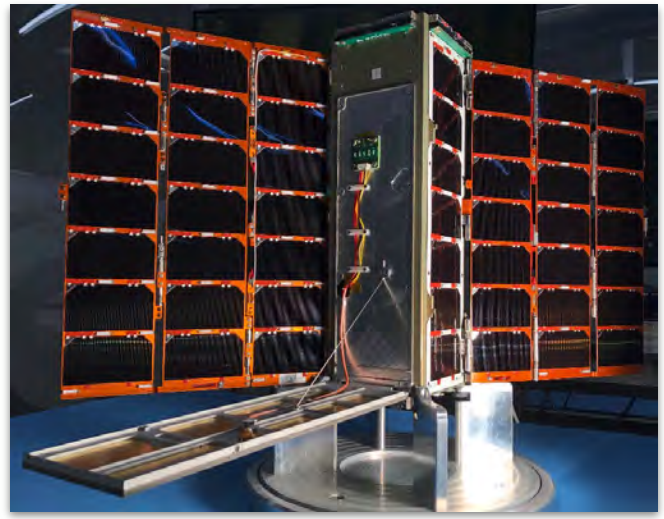


Spire GNSS-R satellites

- 3U form factor

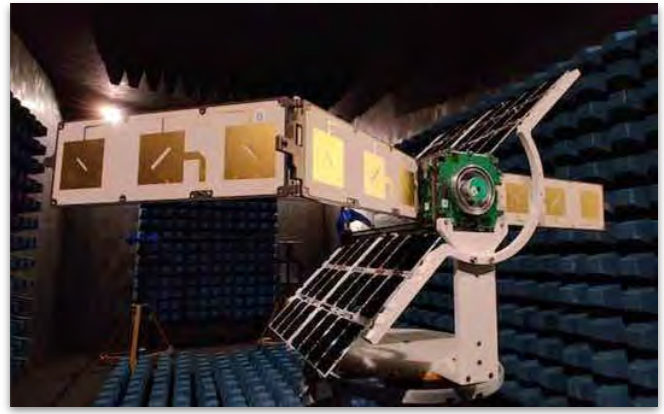
Batch 1

- Dual nadir antennas
- Multi-GNSS signals tracked
- 30 simultaneous reflections
- Launched **DEC 2019**



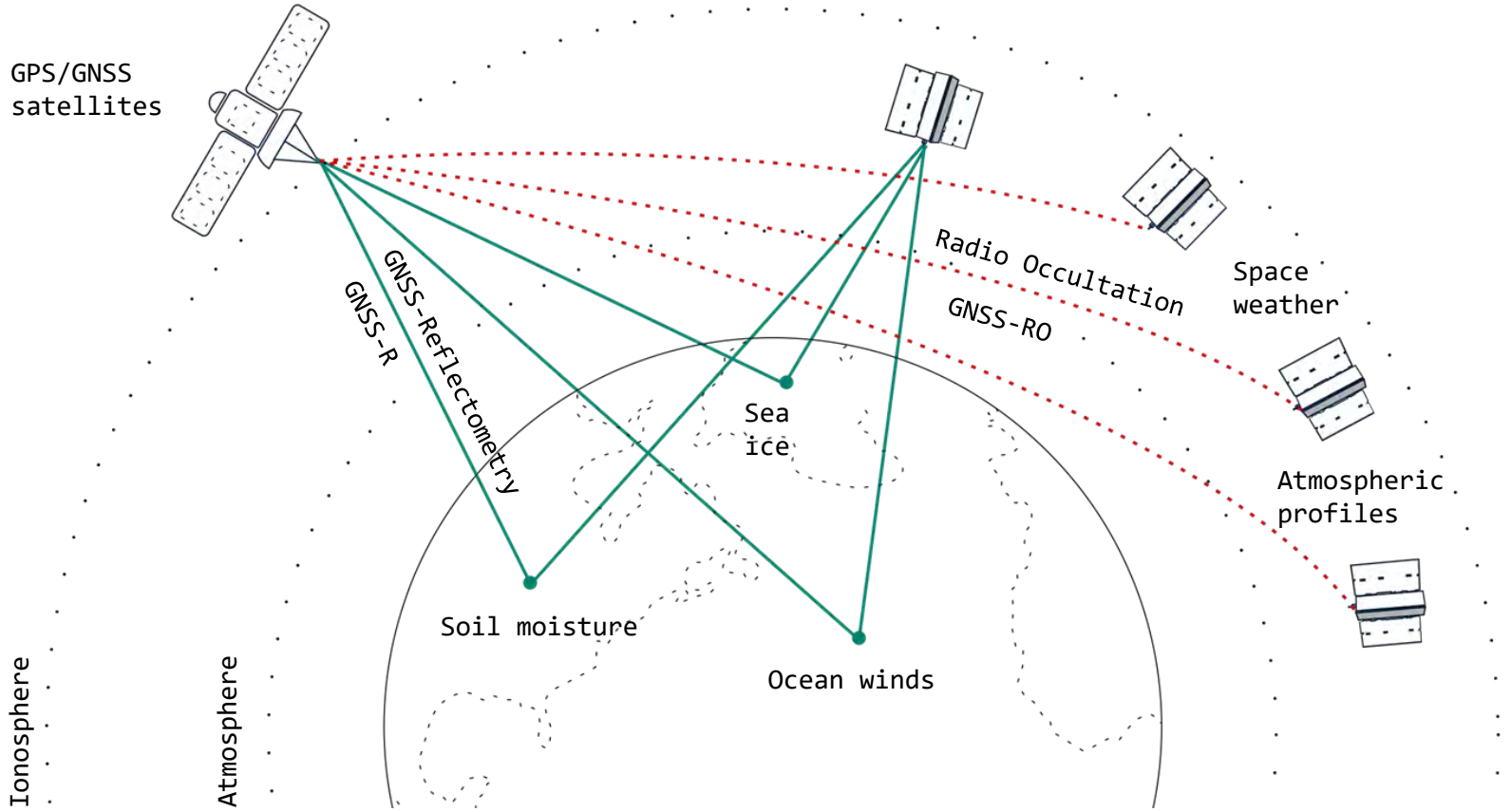
Batch 2

- Triple GNSS-R antennas
- Multi-GNSS signals tracked
- 45 simultaneous reflections
- Advanced calibration
- Launched **JAN 2021**



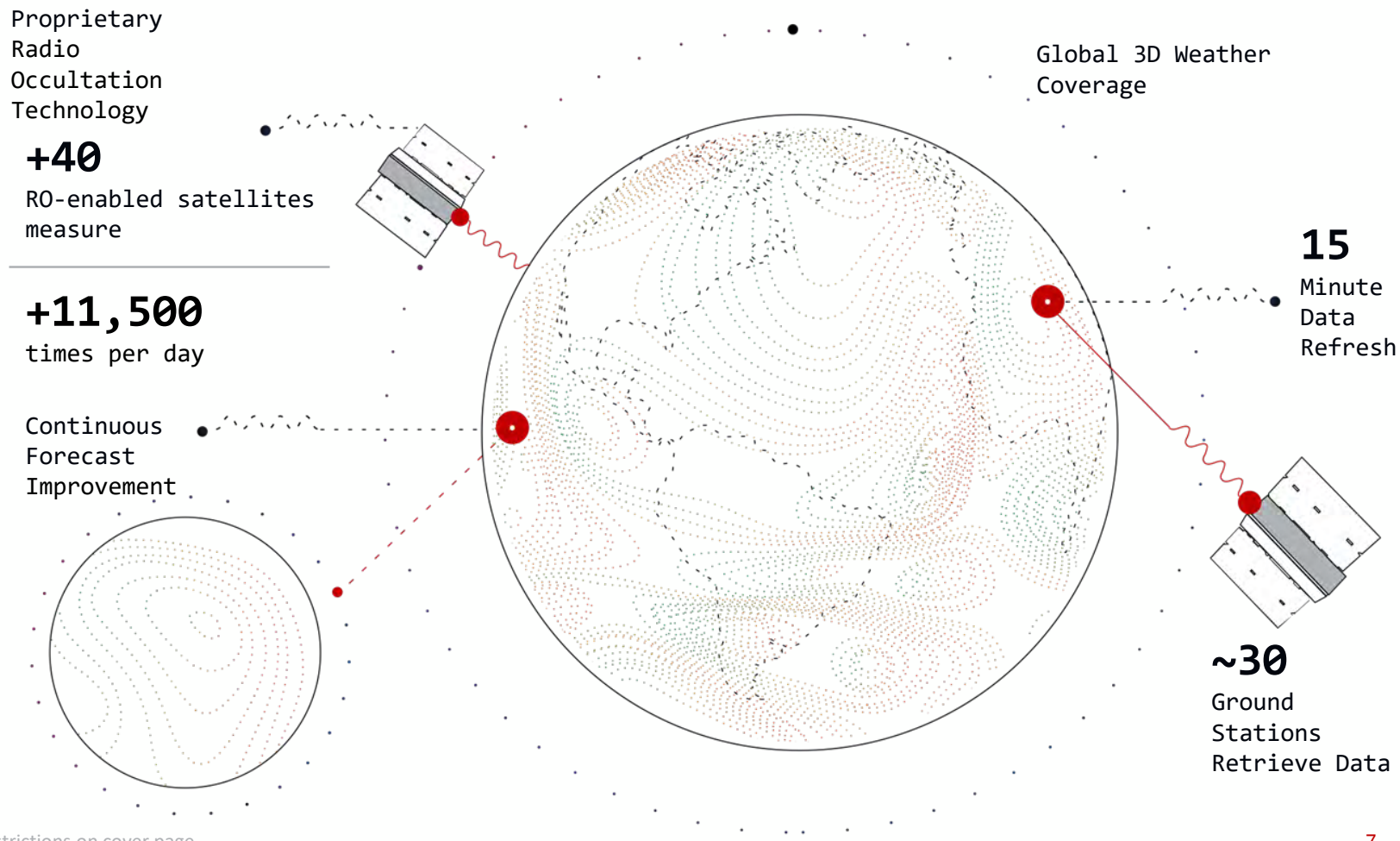
Spire Earth Intelligence

- **Atmospheric sounding (radio occultation)** for Numerical Weather Prediction (NWP)
- **GNSS-Reflectometry** for soil moisture, ocean winds, sea ice extent and age
- **Grazing angle bistatic radar altimetry** for sea ice
- **Ionospheric sounding** for space weather monitoring
- **Space domain awareness** through **Precise Orbit Determination (POD)**



GNSS Radio Occultation (RO)

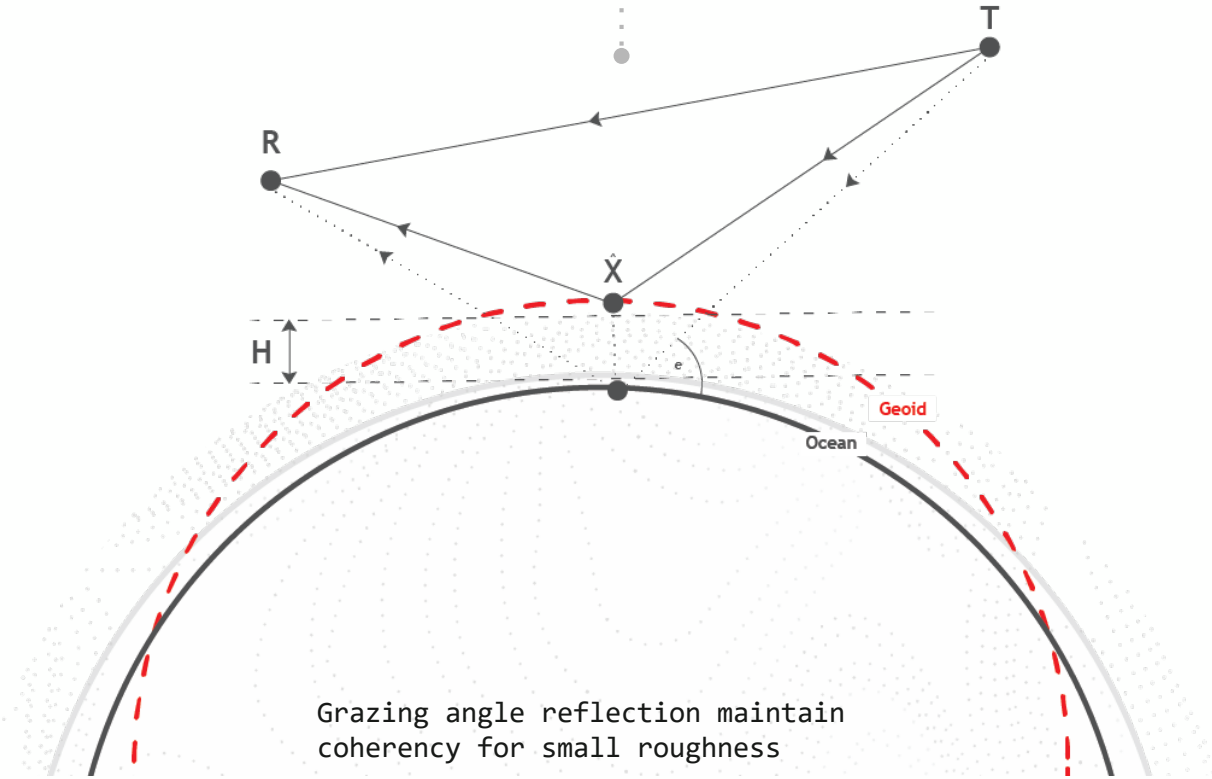
- Spire collects weather data from the atmosphere via our advanced software-defined (SDR) GNSS receiver for remote sensing & precise orbit determination
- High-quality GNSS profiles through the boundary layer; multi-GNSS constellation capabilities
- **Key Features:** High accuracy, low data latency, high data spatial resolution, high reliability, high quality



GNSS-R Grazing Angle Altimetry

A passive reflection/altimeter measurement made from radio occultation satellites, this measurement can tell the exact height of a surface and in the case of sea ice, the extent (or area) of the surface relative to open water

Phase-delay altimetry is a type of GNSS-R that uses **coherent reflections of GNSS signals at low grazing angles (5-30 deg)** to estimate sea surface and sea ice heights **(~ cm)**



Grazing angle reflection maintain coherency for small roughness

USE CASES/APPLICATIONS

- Sea ice extent relative to open water and sea ice thickness
- Classification of sea ice; first year or multi-year ice
- Sea surface height measurements

Use Cases: Climate monitoring, research, Arctic maritime domain awareness

SPIRE DIFFERENTIATORS

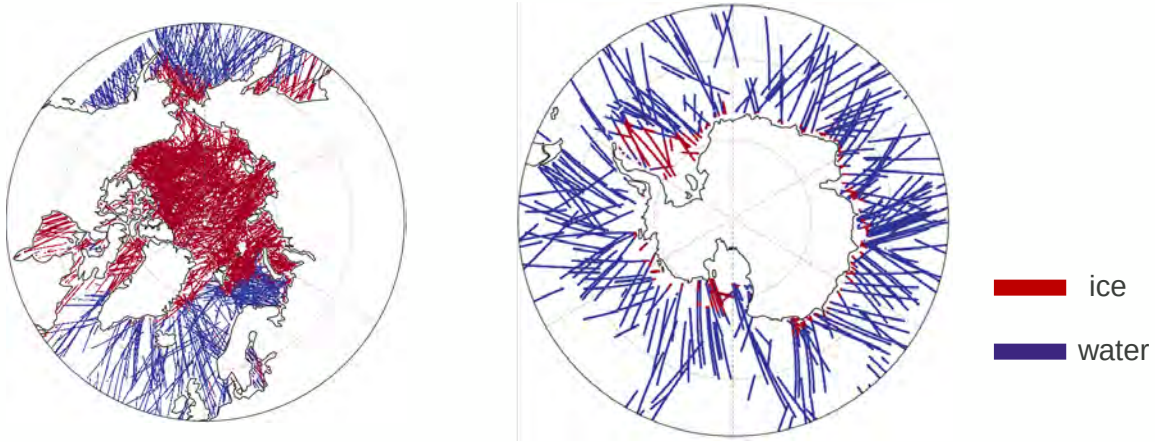
- Excellent polar coverage, particularly relevant for sea ice applications
- No need to launch new satellites into space; RO satellites currently in space can make this measurement
- Capable of meeting the required precision (~10 cm) needed for mapping mesoscale (10-200 km) ocean features and for improving ocean modeling and forecasting skill

RO Satellites as Sea Ice Sensors

With support from NOAA, Spire pioneered a new grazing angle GNSS-R technique using RO sats for precision altimetry and sea ice mapping

- Spire utilizes a novel GNSS low grazing angle reflectometry technique (GNSS-R) to produce measurements for sea ice extent, classification and altimetry
- This technique has the potential to deliver high resolution (approximately 0.5 x 8 km footprint) and fast return rate (less than 24 hours) sea ice measurements

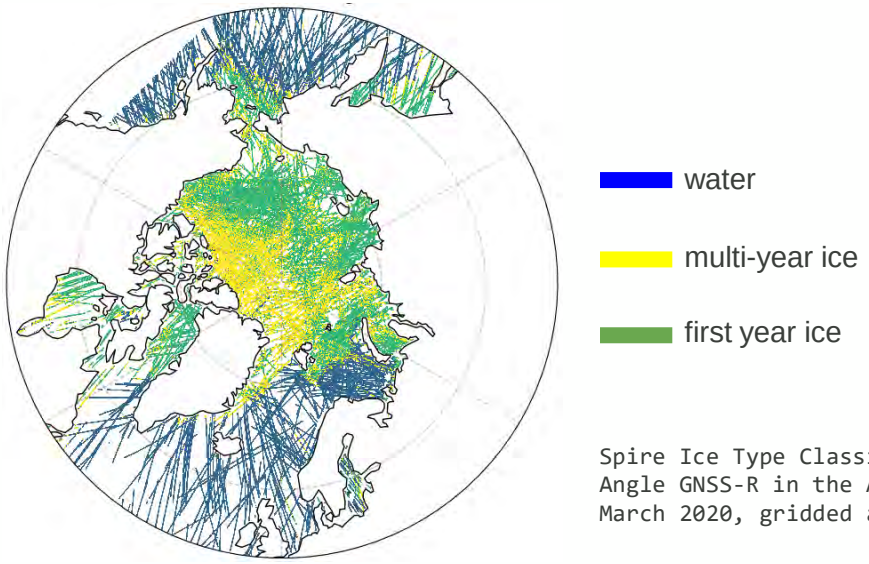
SEA ICE EXTENT



Spire Ice Detection from Grazing Angle GNSS-R using RO sats in the Arctic and Antarctic, data from March-May 2020, gridded at 5 km resolution

Spire's sea ice extent measurements have the capability to distinguish sea ice from open water to map sea ice coverage.This also allows us to delineate the marginal ice zone (MIZ), which is a transitional region between open sea and dense drift ice.

SEA ICE CLASSIFICATION



Spire Ice Type Classification from Grazing Angle GNSS-R in the Arctic, data from March 2020, gridded at 5 km resolution.

Spire's sea ice classification measurements allows for the categorization of ice type (i.e., age of the ice).

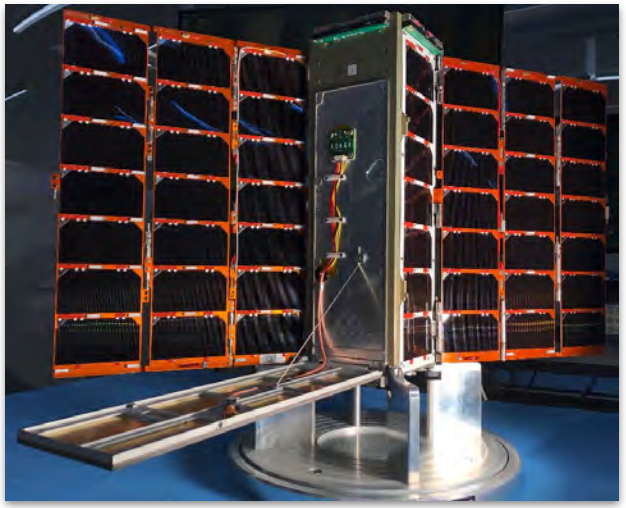
Spire GNSS-R Missions

Spire GNSS-R Satellite Constellation (four and growing)

- Two “Batch-1” satellites launched in Dec. 2019 (operational phase)
- Two “Batch-2” satellites launched in Jan. 2021 (cal/val phase)
- Prototype sats for long-term, high-res (3 km) soil moisture (SM) observations
- Level 2 along-track SM preview product under evaluation by GSFC (Kumar)
- Further GNSS-R constellation build out in 2022 (KAUST-sponsored mission)

Parameters	NASA CYGNSS	Spire GNSS-R Batch-1	Spire GNSS-R Batch-2
Simultaneous reflections observed	4	**30**	**27 (larger bandwidth)**
GNSS Constellations tracked	GPS	**GPS, QZSS, Galileo, SBAS (soon)**	**GPS, QZSS, Galileo, SBAS (soon)**
Direct antenna	L1 Single patch	**L1/L2 single patch**	**L1/L2 single patch**
Reflection antenna	2, 3x2 L1 LHCP array (off-nadir) 14 dB peak gain	**2, 3x1 L1 LHCP array (nadir), beamforming**	**3, 3x1 L1 LHCP array (nadir, 35 deg off-nadir, and beamforming**
GNSS receiver	SGR-Resi	**STRATOS v1**	**STRATOS v2 (direct sampling, onboard calibration, larger FPGA)**
Mass	25 kg	**5 kg**	**5 kg**
Orbit	35 deg	**37 deg**	**SSO: 9:30 LTDN (global)**

Spire “Batch-1 GNSS-R satellite



Spire “Batch-2” GNSS-R satellite