

# Small Satellites: The Execution and Launch of a GPS Radio Occultation Instrument in a 6U Nanosatellite

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# Tyvak: Satellite Solutions for Multiple Organizations

- Wide Variety of Customers
  - Commercial
  - Civil
  - Defense
- Facts and Figures
  - Tyvak Nanosatellite Systems founded in 2011
  - Holding company Terran Orbital Corp. founded in 2014
  - Tyvak International founded in 2015
    - Fully independent European establishment
- 3 locations, > 60 employees
  - Irvine, CA
  - San Luis Obispo, CA
  - Torino, Italy



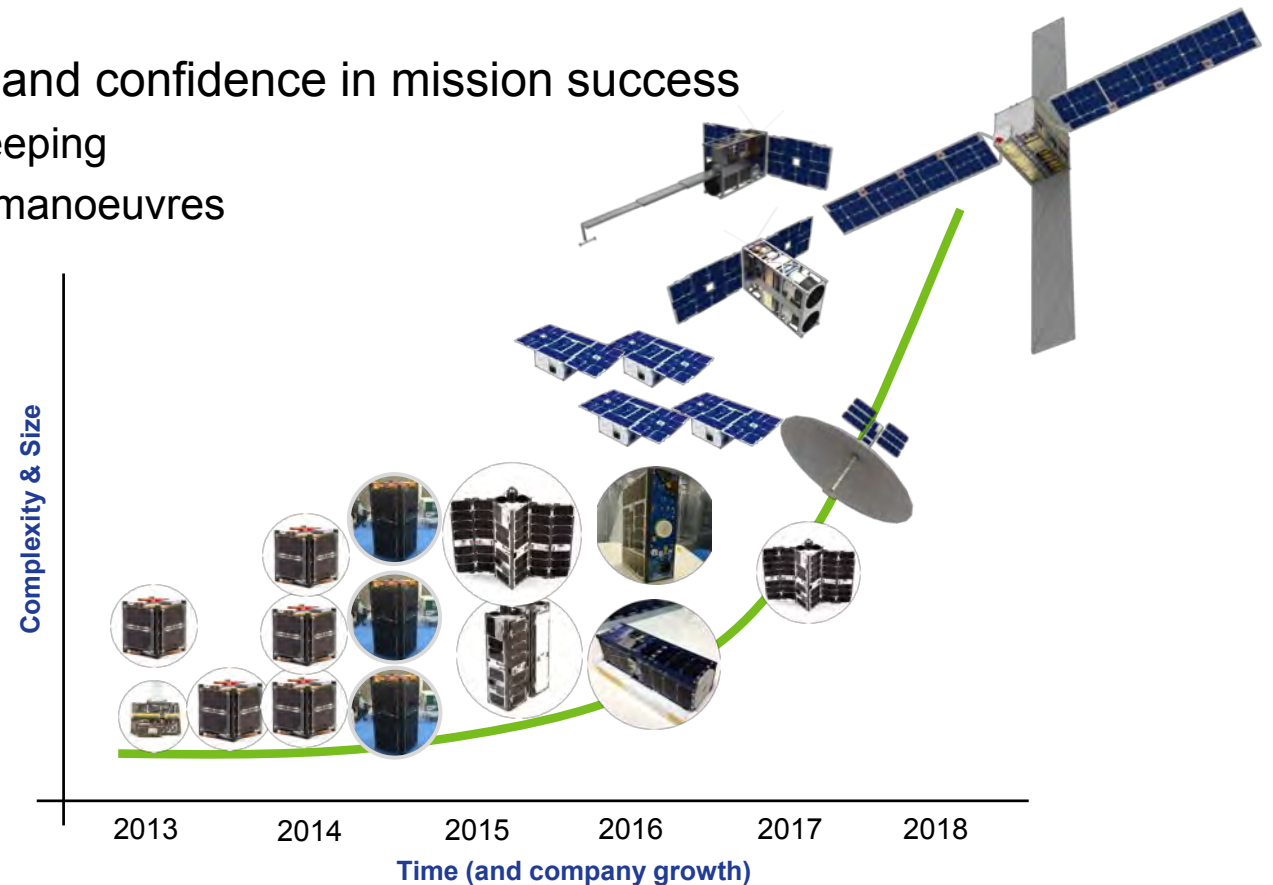
# Nanosatellite evolution

- Nanosatellites have evolved to powerful instruments for advanced operational capabilities and high mission utility

- Operational : fulfil critical official government or commercial missions
  - Substantial mission life (> 3years)
- High utility: high level of performance, reliability and confidence in mission success
  - Precise attitude control, formation flying, station keeping
  - Proximity operations, orbit boost/control, disposal manoeuvres

- Multiple Applications

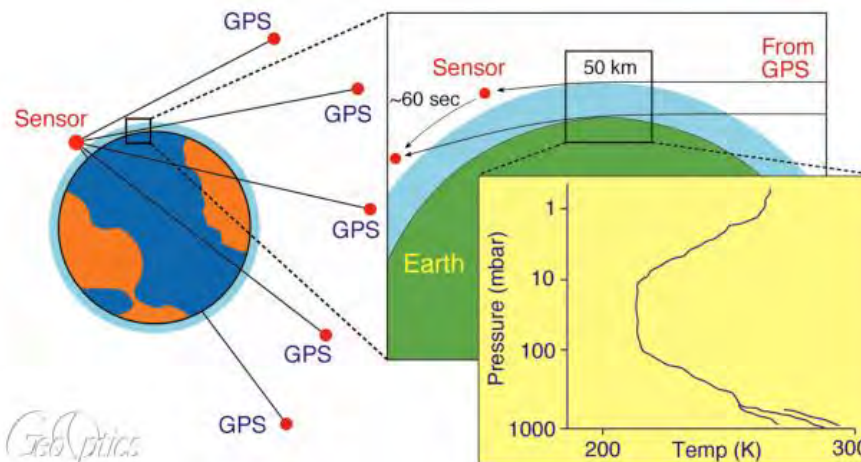
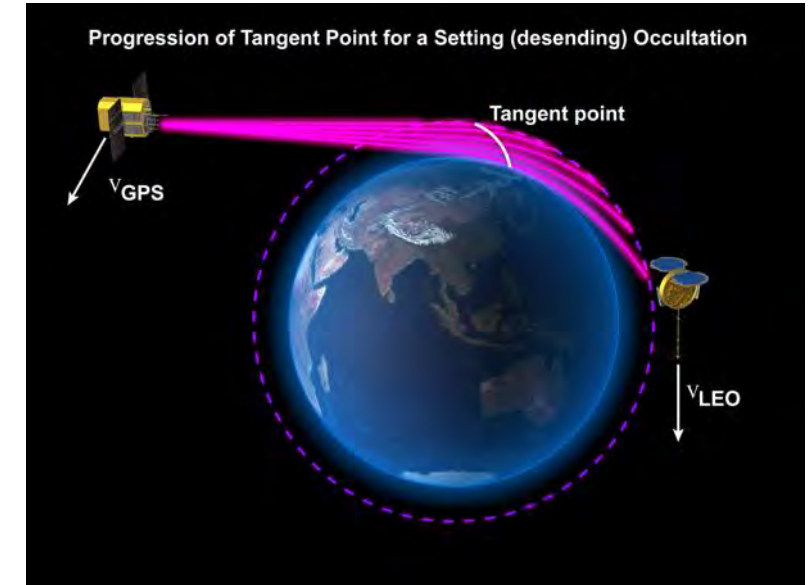
- GPS Radio Occultation
- Advanced Optics Demonstrations
- Atmospheric Science
- RF Signal processing
- Technology Demonstrations



# Background



- Tyvak is developing the GeoOptics, Inc. CICERO constellation of satellites.
  - Completed first three satellites in the constellation
  - Intended to gather vital data on the Earth's weather, climate and environment.
- Program utilizes Tyvak's Endeavour small satellite platform
  - 6U CubeSat, high-speed communications, 3-axis high performance attitude control
  - The CICERO Constellation will test and demonstrate the newly developed instrument and the integrated satellites
- Data gathered will provide:
  - Weather monitoring and forecasting information to the National Oceanic and Atmospheric Administration (NOAA)
  - Science and Weather Data to Other government and commercial customers.



In the past, larger satellites have executed these missions.  
Small satellite missions can collect more distributed data with faster revisit times around Earth.

**The GPS Radio Occultation instrument development emphasized building an instrument of equal quality to previous instruments.**

# CICERO – Radio Occultation Constellation

- Mission

- Demonstration and operational constellation of radio occultation observation satellites for a Commercial Customer
- Data Products to be delivered to Customer as part of commercial data buy for near real-time weather data

- Launch

- First 4 units to be launched May and June 2017
- 3 more spacecraft to be launched in Q4 2017

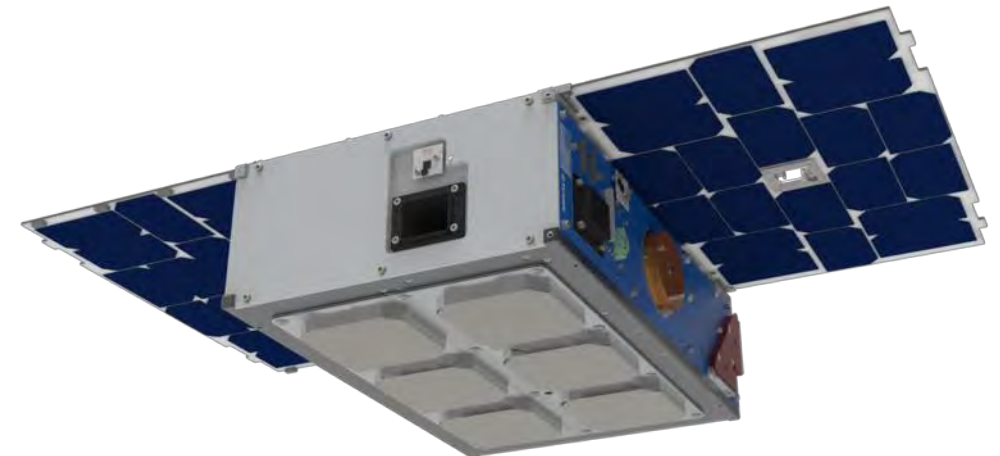
- Technologies Developed and Demonstrated

- Scientific RO instrumentation made in collaboration with JPL
- Very low EMI spacecraft, extensive RF shielding

- Program Challenges & Experiences

- Low EMI requirement
- GPS Antenna and RO Payload Development

Phased 2 x 3 patch array for GPS L1 and L2





- Data capacity

- 2Mbps X-Band transmitter can Download all RO data collected in 1 Orbit along with associated back-orbit telemetry
- Compatibility with KSAT Network for fast data delivery

- Algorithms to target RO Opportunities

- Calculated on the ground and then event scripts for vehicle slews for optimal RO opportunities are executed
- Will be automated on the vehicle using the onboard propagator in future batches

- GPS RO Instrument Improvements

- Updated software to support GLONASS
- Software upload and re-flash capabilities

Parameter	Cion
Size	6U CubeSat
Mass	~10kg
Power	21 W Orbit avg.
ADCS	Full 3 axis stabilized, 2 Star Trackers, 3 reaction wheels
Battery	120 W-hrs
Comms	X-band down (Payload) UHF up/down (S/C housekeeping)

# Cion - CICERO Instrument for GPS-RO



## • Key Challenges & Experiences

- Miniaturize the instrument from a power and mass perspective but ensure end data product quality and support essential JPL heritage software compatibility.
- The quality and effectiveness of collaboration is far superior when the collaborators are within driving distance. JPL has been on-site for system test verifications, and design reviews.

## • Cion Instrument Features:

- RF Inputs: 3 antenna inputs with 4 down converters each
- Processor: 1.2 GHz Dual Core Arm processor
- RAM: 1GB Flash: up to 256GB
- DSP: Programmable FPGA for Digital Signal Processing
- Sub-channels: 16 GPS (8 dual freq satellites)
- External Clock: High performance Osc (10MHz,  $\sim 5 \times 10^{-12}$ )
- Ext PPS output and Ext event input

## • Accommodations:

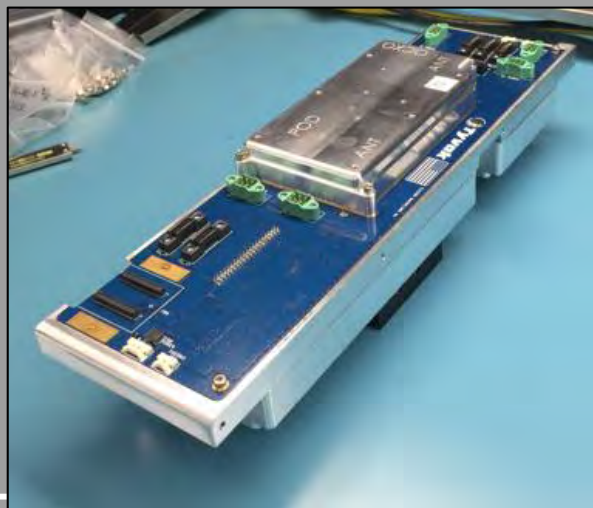
- Volume: 3U available
- 30cm X 10cm X 6cm utilized by final payload configuration
- Mass: 1.2kg
- Power:  $\sim 8$  watts at 12 VDC
- Comm Interfaces Available : Two RS 422, USB and Ethernet

# TriG!Vs!Cion!

TriG!



Cion!



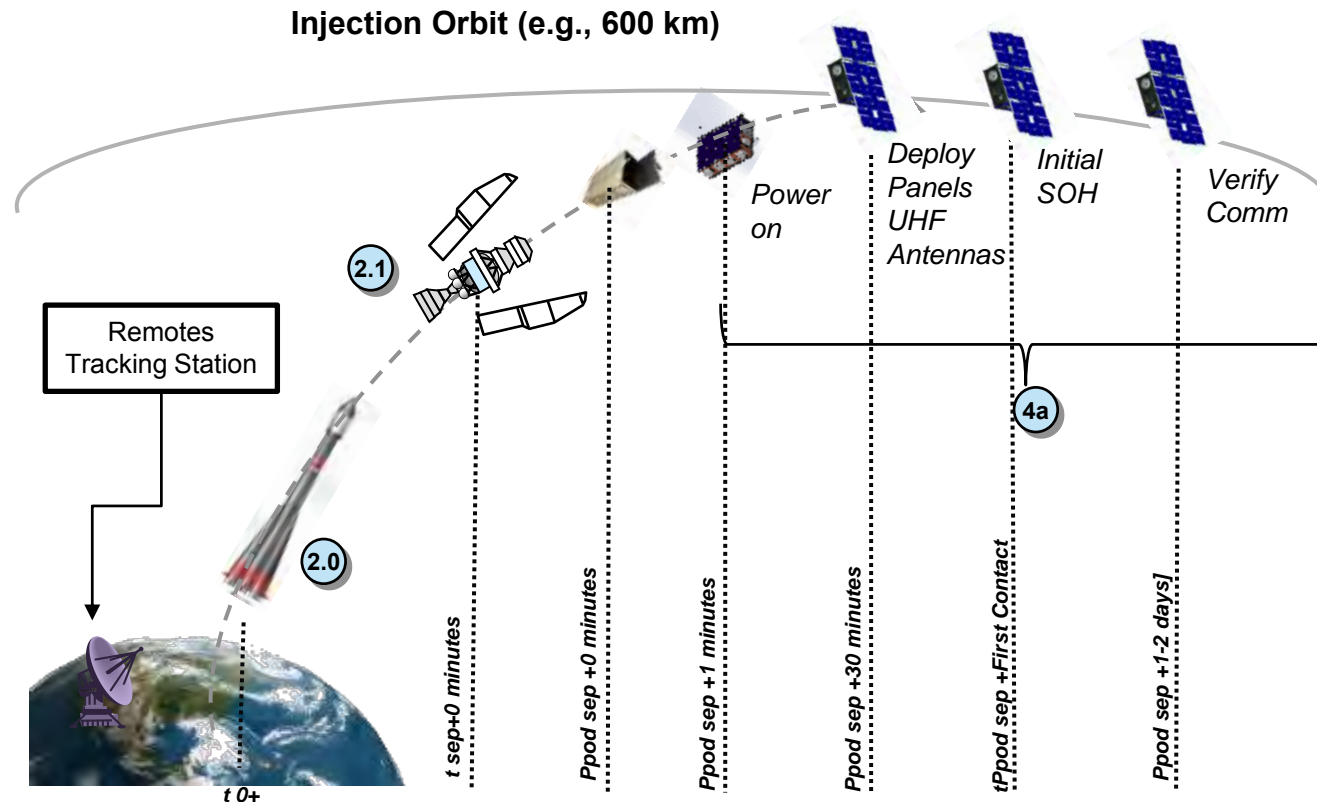
Significant reduction in Size, Weight, and Power

Parameter	TriG	Cion
Size	11 x 19 x 22 cm	30 x 10 x 6 cm
Mass	~6 kg	1.2 kg
Power	~65 Watts	8 Watts

- **Antenna incorporates combiner into the phased array**
  - Eliminated need for external RF Combiner
  - Eliminates need for complex coax harnessing and associated mass
- **EMI/EMC**
  - Bus design has a RF gasket enclosure to prevent EMI
  - Payload resides in its own separate volume within the 6U CubeSat
- **External Inputs**
  - Temperature controlled highly stable Crystal Oscillator for precise data clocking and timing
  - External GPS for Position, Orbit Determination
- **Collection Rate**
  - 1kHz, 100Hz, or 50Hz native data collection rate from all channels



# Launch and Early Operations (LEOPS)



## • Launch

- Rideshare using 6U dispenser
- Power on

## • Initialize

- Only core avionics will turn on
- Deployables released
- ADCS turn on and auto transition to sun pointing

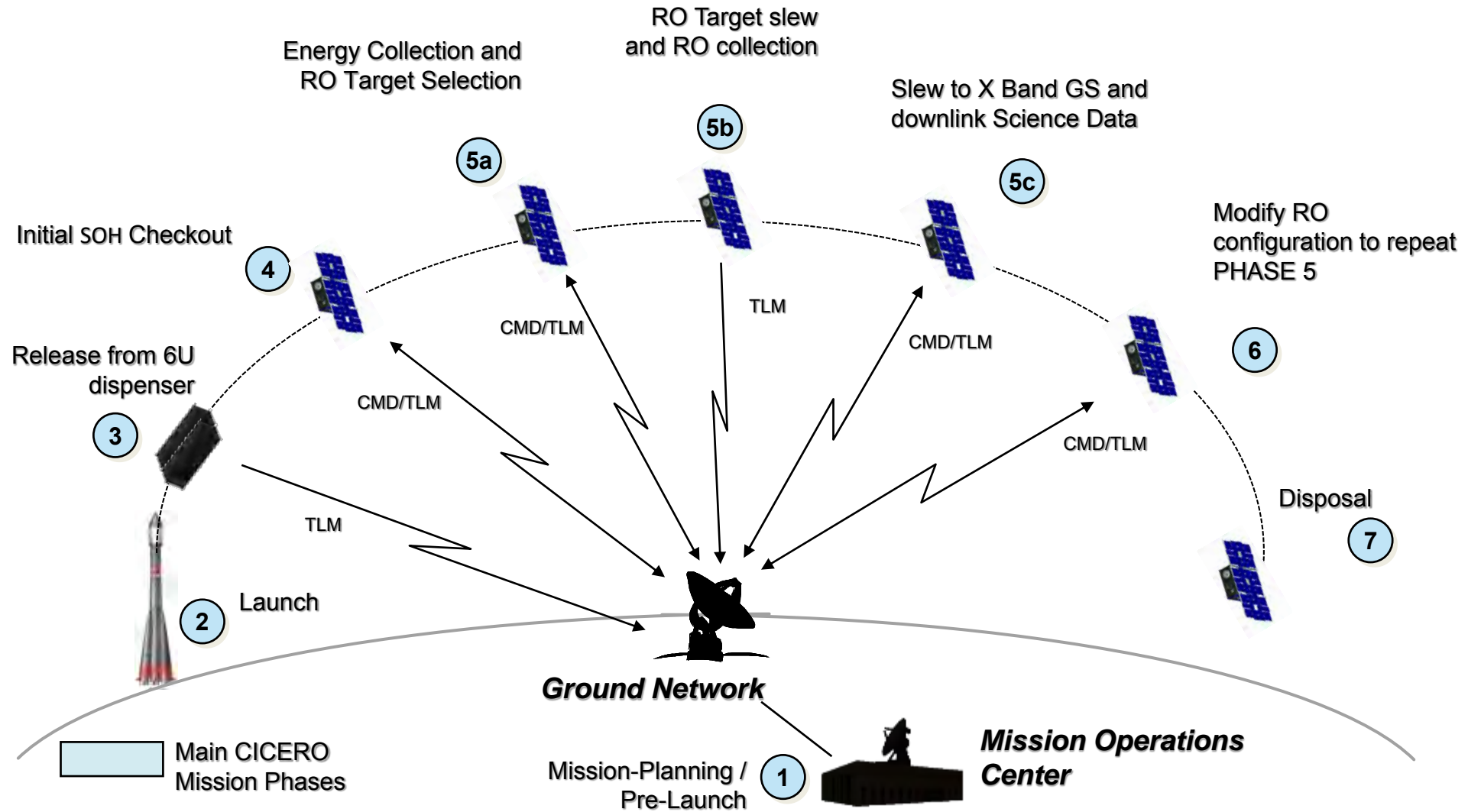
## • Initial SOH

- GPS seeded Propagator used to initiate SOH over UHF stations
- SOH on demand if GPS not available

## • Verify Comm

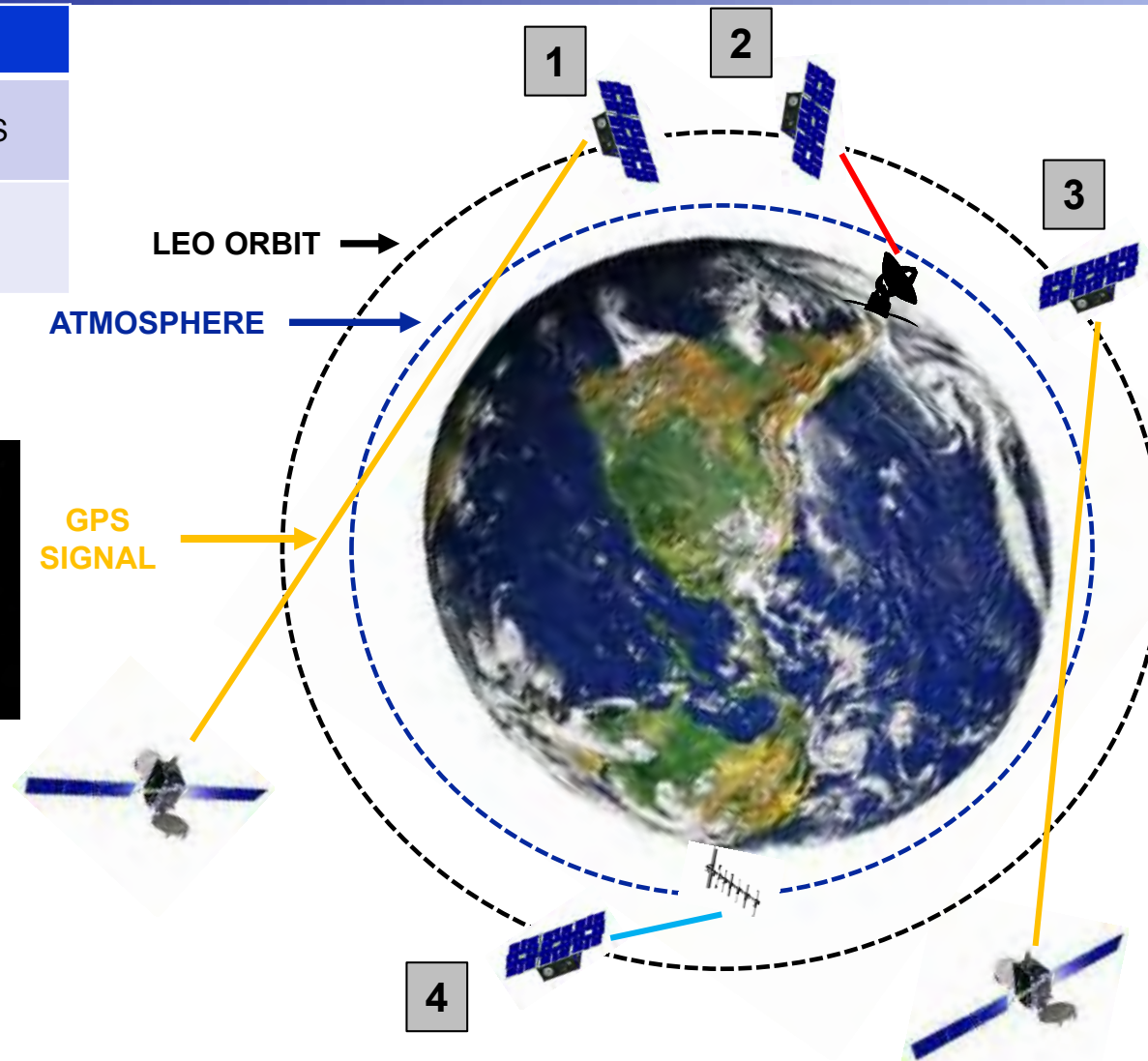
- Checkout uplink/downlink using UHF, downlink using X-Band

# Summary of CICERO Mission Phases



# Mission Operations Overview

LEGEND	
	GPS/GNSS
	CICERO



1. **Nominal RO Collection** – CICERO-OP1 collects RO while slewing for Sun-Pointing
2. **X-Band Data Downlink** – Every orbit CICERO has at least 1 pass with X-Band station for downlink
3. **Target RO Collection** – CICERO-OP1 slews to target RO collection
4. **UHF Uplink** – Uplink any specific RO targets or modify collection angle

## Collection Flexibility

Spacecraft will slew for optimal RO coverage and also to track certain events prioritized by operators

## High Degree of Automation

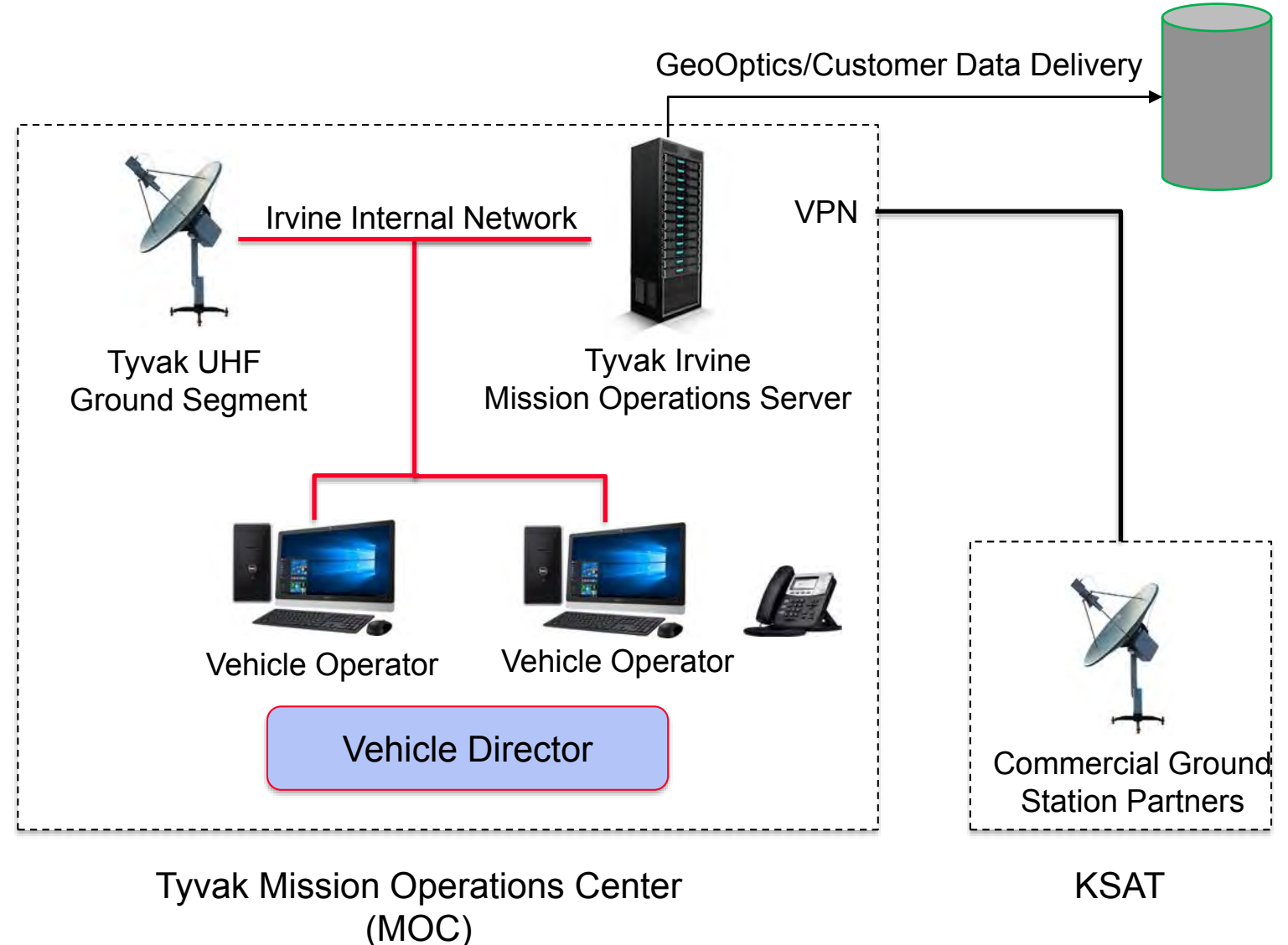
Each spacecraft has the ability to operate more than a weeks worth of automated collection and data downlink events

# Mission Operations

- **Mission Operation Center (Tyvak, Irvine)**
  - Main UHF system on-site
  - Additional UHF station is available K-SAT site in Tromsø
  - UHF only
  - All data from all sites comes directly to Tyvak once downlinked
- **Kongsberg Satellite Services (K-Sat)**
  - Additional Downlink Stations available for X-Band

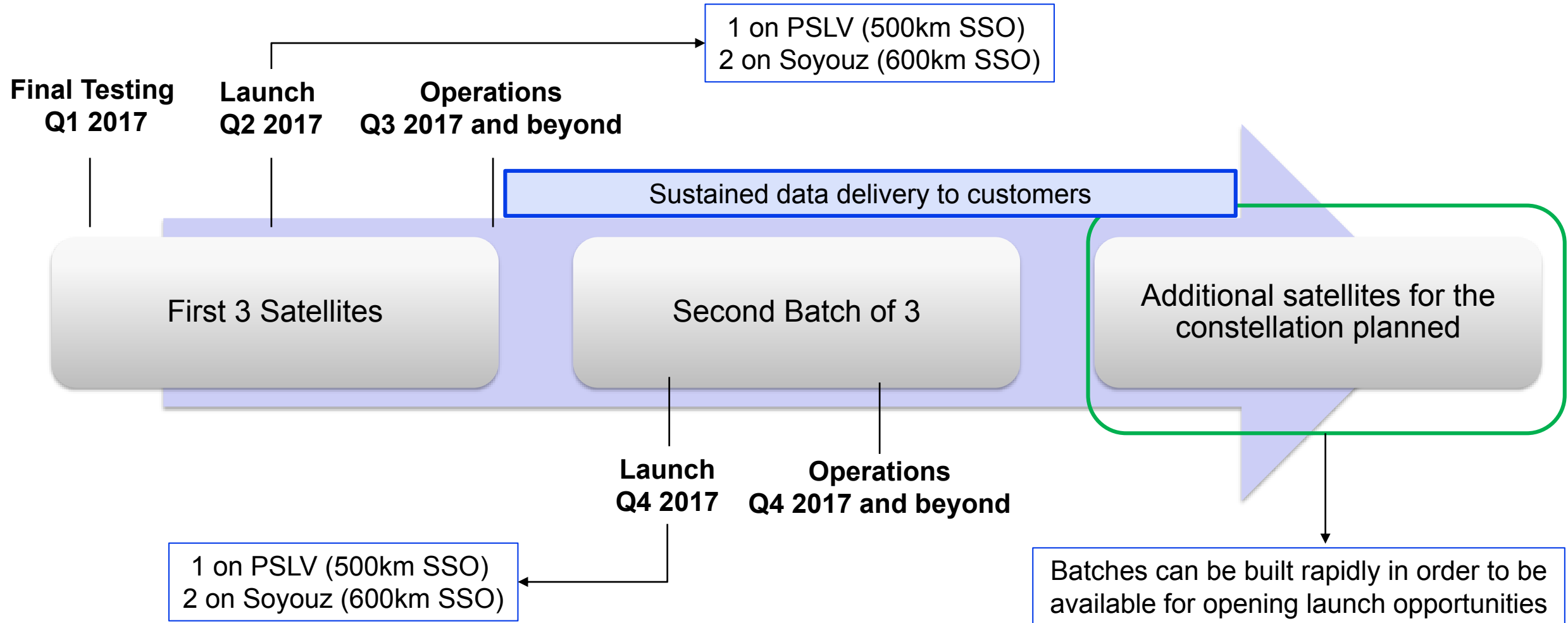


Nominal Operations are mostly autonomous for the routine RO collection and Data Downlink. Fault Flag notify operators of any off nominal cases and put the spacecraft into Safe Mode.

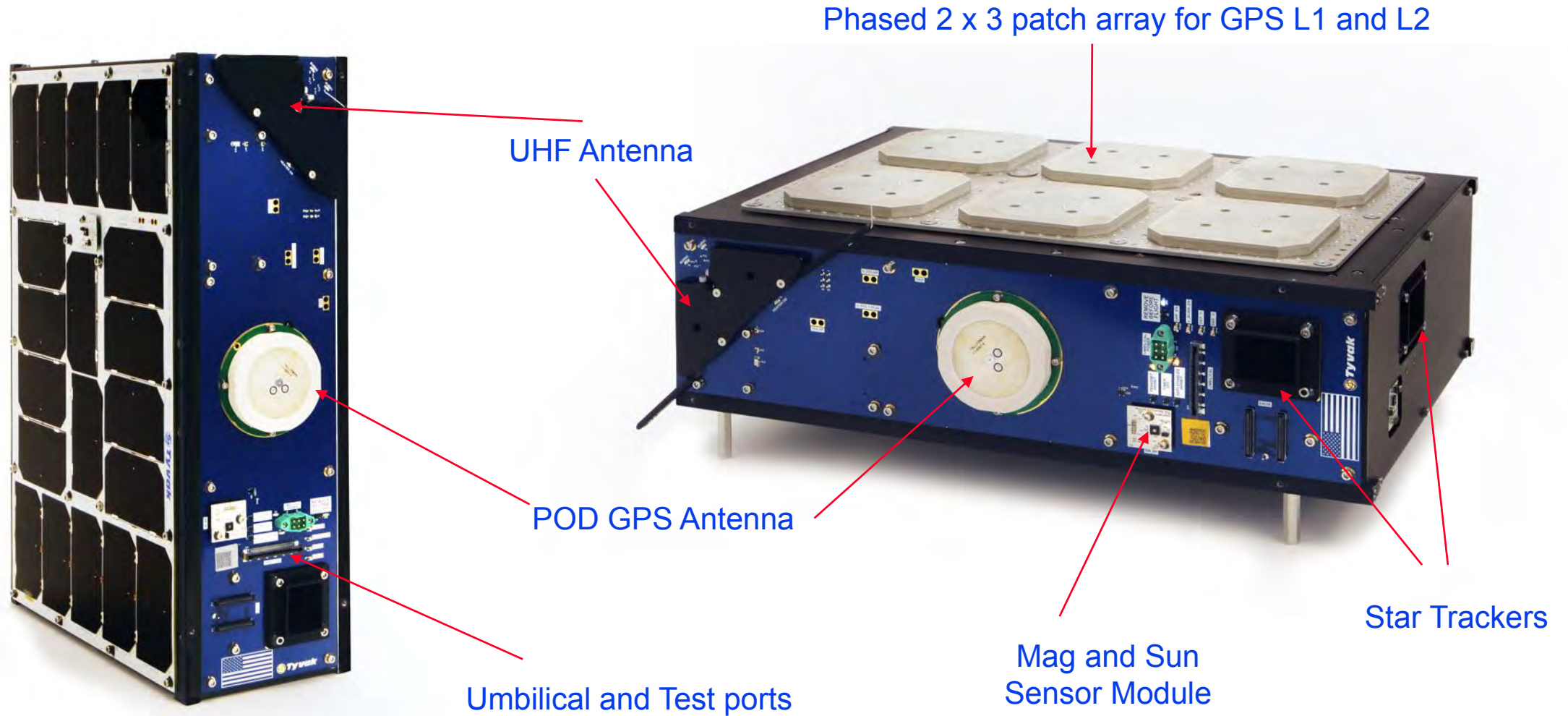




# Timeline



# Final Configuration





**Questions?**  
**Come see us at our Booth!**

## Special Thanks to our partners GeoOptics

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