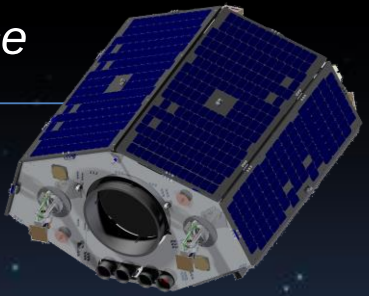
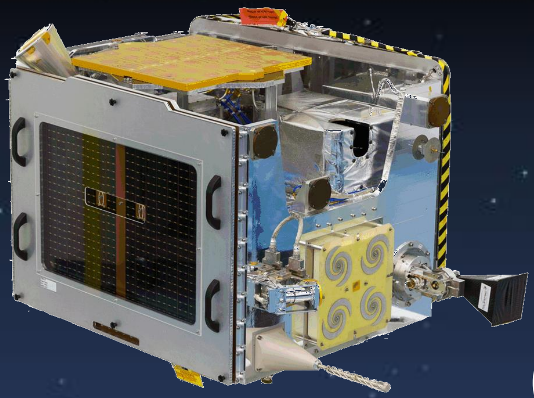
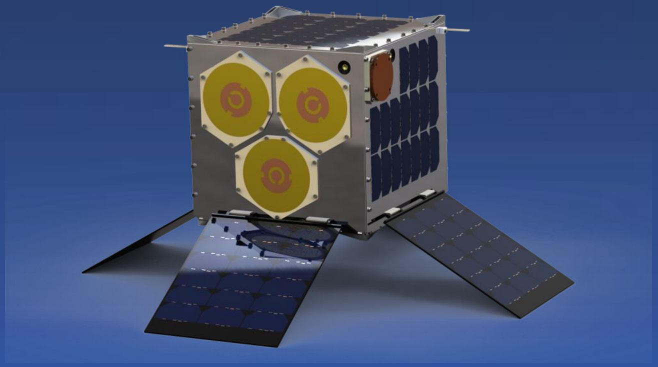
Changing the economics of space





ORORO
(Orbital Radio Occultation and Reflectometry Observers)

Martin Unwin, J. Friend *SSTL*
C. Gommenginger *NOC*
J. Rosello *ESA*



Ack: SSTL, NOC, ESA, CEOI/InnovateUK, CYGNSS, ECMWF

Measuring High Wind Speeds Over Ocean, 15-17 Nov 16 Met Office

Introduction

- GNSS Remote Sensing
  - Use of GNSS navigation signals for measuring atmosphere and Earth's surface
  - GNSS offers global source of signals
    - ~120 satellites at 20,000+km altitude broadcasting L-Band signals towards the Earth
    - **GPS**, Galileo, Glonass, Beidou, SBAS, QZSS, IRNS, …
  - GNSS Reflectometry (GNSS-R) – measure reflections off surface
  - GNSS Radio Occultation (GNSS-RO) – measure signal bending through atmosphere
- ORORO - Orbiting Radio Occultation & Reflectometry Observers
  - Concept of combined instrument in very small satellite
  - GNSS receiver and antennas

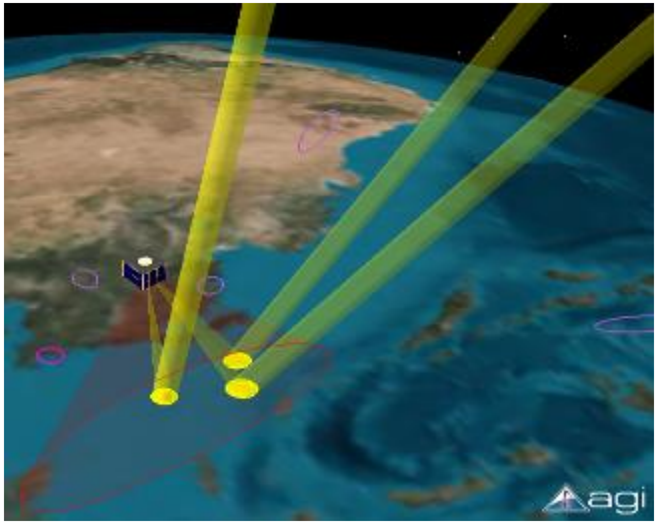
Spaceborne GNSS Reflectometry

- GNSS Reflectometry
  - Detecting GPS / GNSS signals reflected off the Earth's surfaces
  - "Multipath" signals should contain geophysical imprint
  - Bistatic radar – but no need for radar transmitter
- Using Earth-reflected GPS signals for ocean sensing first discussed in 1988
  - 1993 ESA proposed reflectometry for ocean **Altimetry** – PARIS
  - US & European studies on **Scatterometry** in late 90s – 00s
  - First reflected signal detected 1998 (JPL using SIR-C data)

First dedicated in-orbit experiment:
UK-DMC (2003) – feasibility

First on-board processing instrument: UK TDS-1 (2014)

First GNSS-R Constellation:
NASA CYGNSS (Dec 2016)

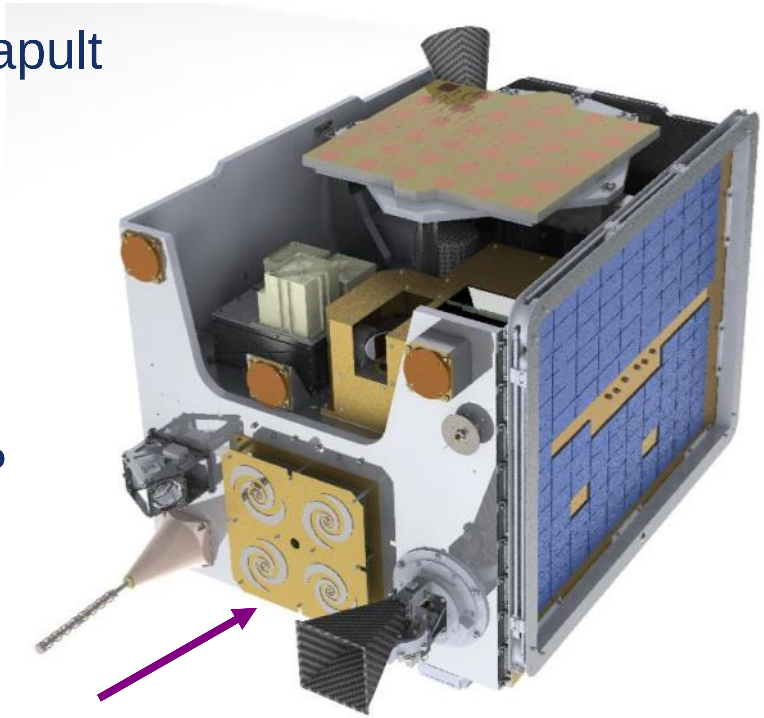


UK TDS-1 and SGR-ReSI

- TechDemoSat-1 Mission
  - 160 kg UK Satellite Demonstration
  - 8 UK payloads
  - Includes SSTL's GNSS-R payload the SGR-ReSI
  - Launched **July 2014**
  - Operated by SSTL & Sat App Catapult
- **SGR-ReSI**
  - COTS Based GNSS Receiver
  - Co-processor for Reflectometry
  - Zenith antenna: hemispherical dual patch
  - Nadir antenna – **13 dBi gain**, LHCP 30° beamwidth flared spiral
    - Also two single freq. zenith patch antennas
  - 5-10 watts, 1.5 kg

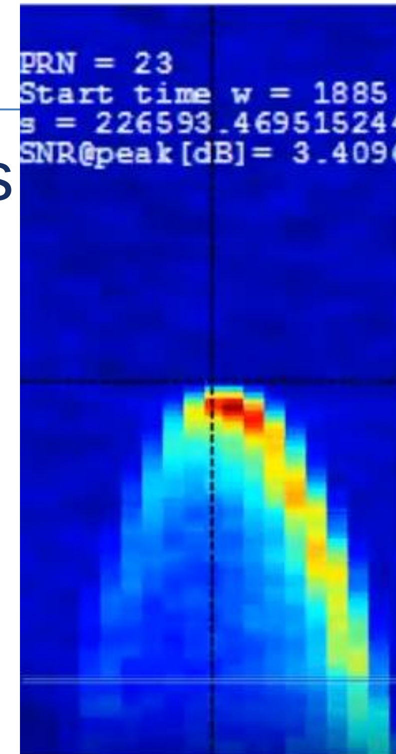
SGR-ReSI Unit

Zenith Antenna

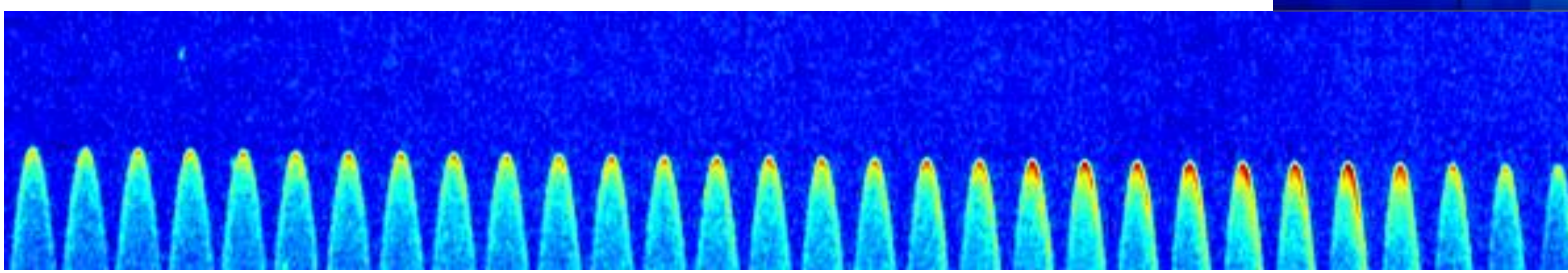


Nadir Antenna

On-board DDM collection

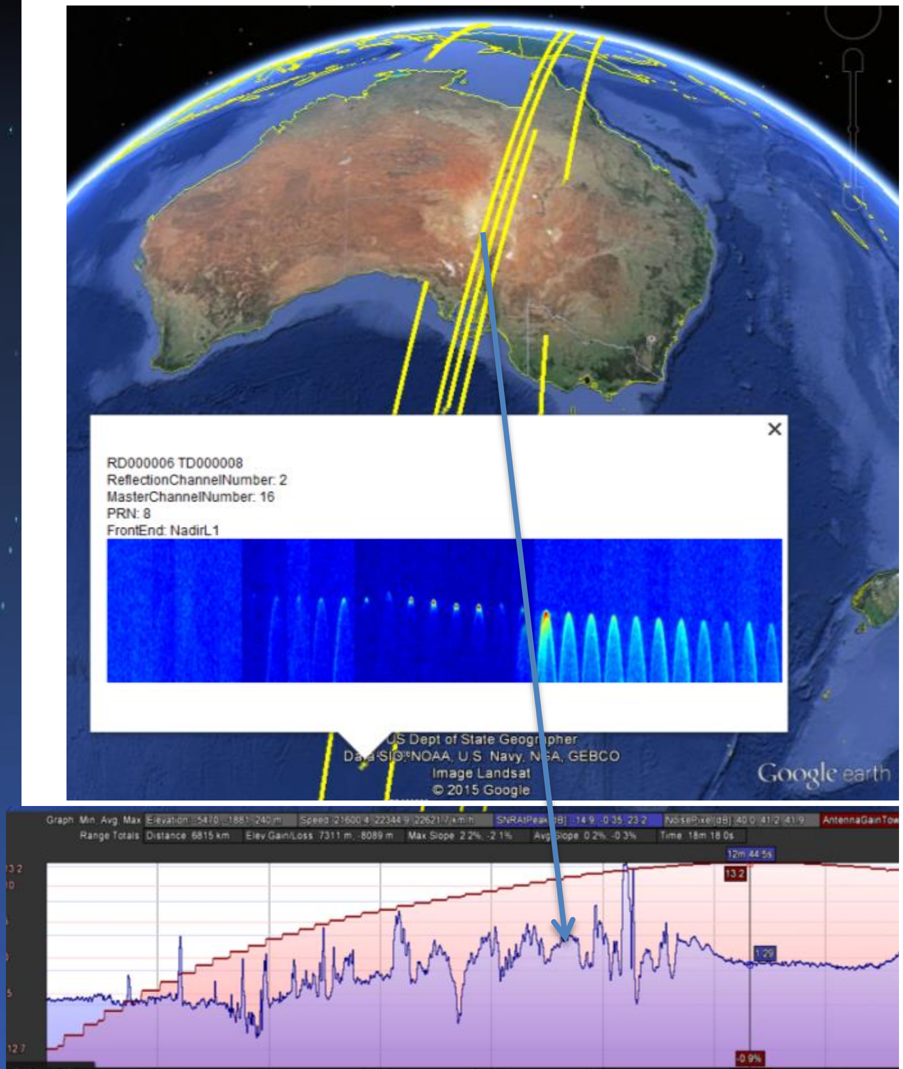


- On-board processing of data generates 4 x Delay Doppler Maps - Level 1A
  - Shows spread of reflected GNSS signal
  - Spread related to surface roughness
- Processed on ground into Level 1B
  - Reformat, add meta-data,
  - calibration information
- 1 Measurement per second per track



- Over ocean DDMs L1B processed into Level 2
  - ***Wind Speed*** and mean square slope
  - Products of operational use
- Strong reflection => low winds

Example TDS-1 Tracks in Google Earth



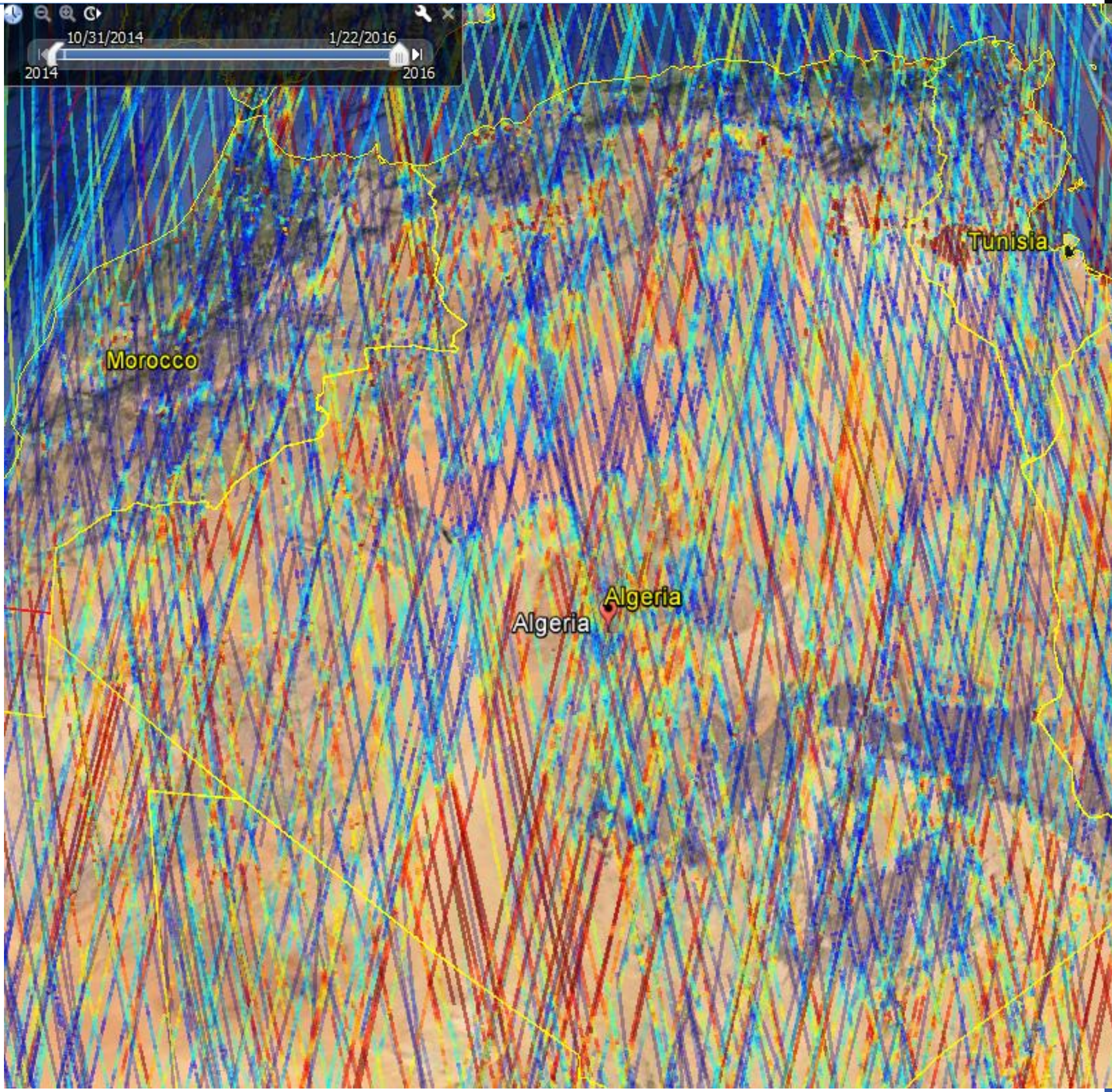
- Signals collected over land, sea and ocean
  - Level 1b
- Level 2 winds generated over ocean
  - NOC presentation
- Data accessible:
  - Sept 2014 – May 2016

  www.merrbys.org

  Continues to evolve

Land Applications: North Africa

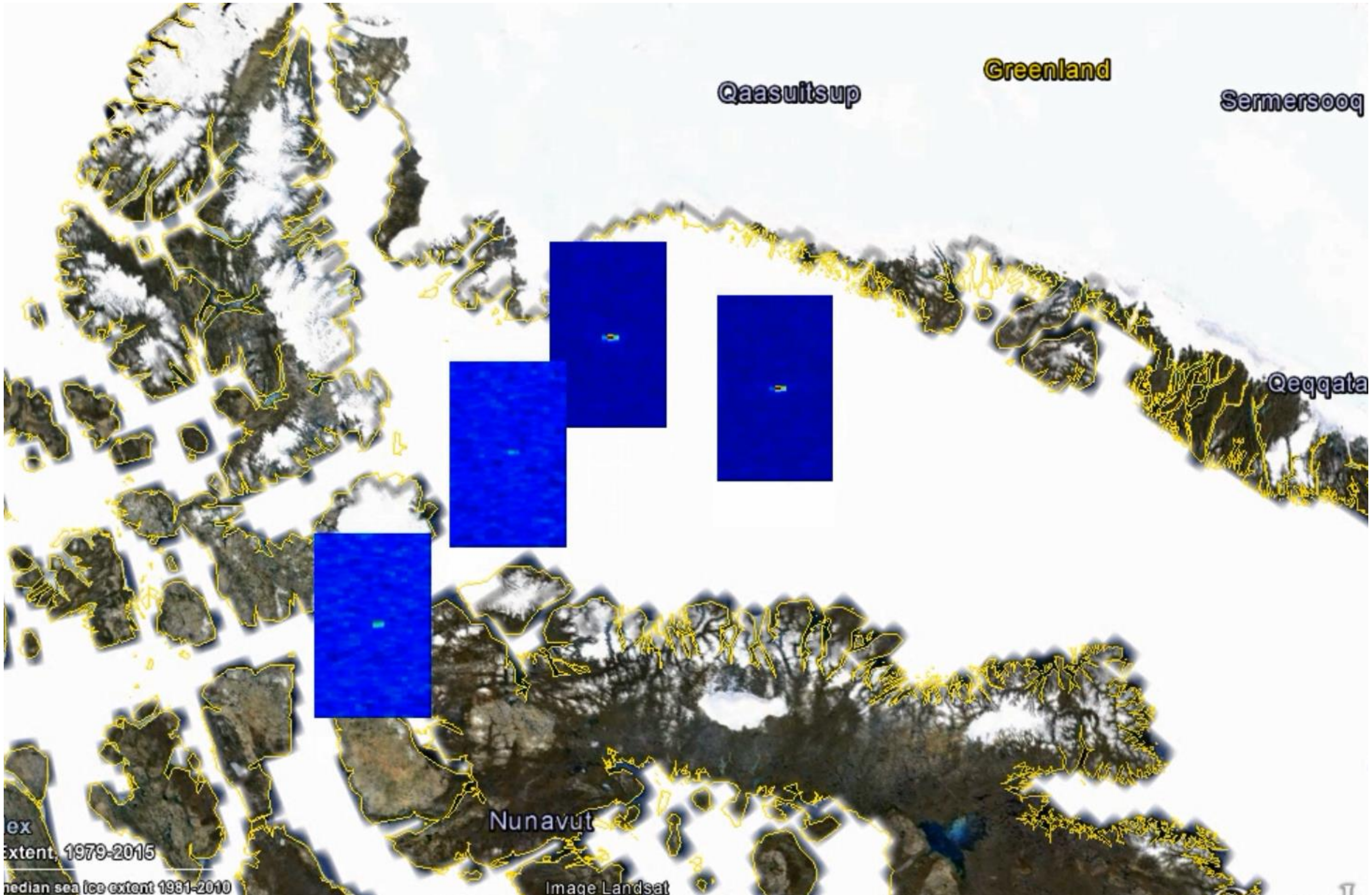
- Land Collections show geophysical patterns
  - Water, soil moisture, soil roughness, salinity, biomass,
- Strong reflections
  - Salt lakes in Tunisia and Algeria
  - Some desert areas
- Weak reflections
  - Vegetation
  - Mountain ranges
  - Other deserts
- Some temporal variations visible, but TDS data is sparse



Many applications – hydrology, flooding, climate, etc.

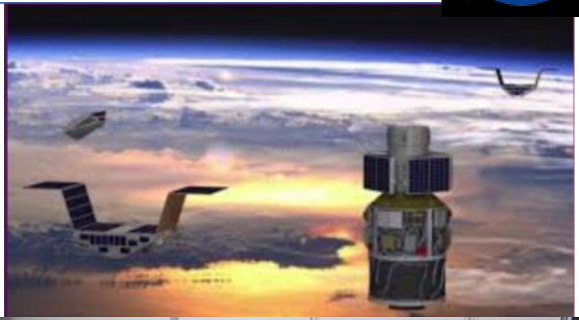
Ice Sensing

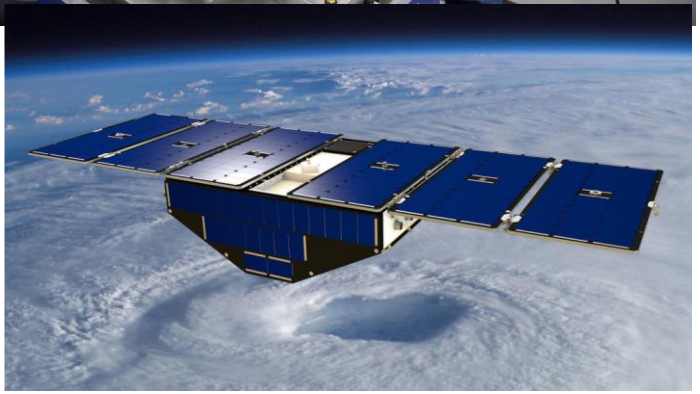
- Reflections off ice very strong
  - Can detect edges, resolution few kms
  - Also potential for altimetry over ice
- E.g. Northwest Passage – iced over in March



CYGNSS Mission

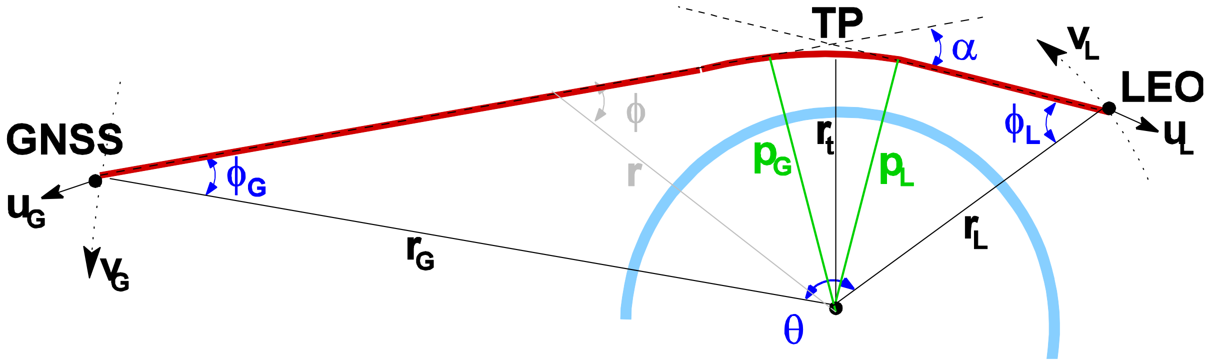
- NASA **CYGNSS** mission
  - 8 small satellites sensing hurricanes using GNSS Reflectometry
- SGR-ReSI payload
  - Designed in SSTL UK
  - Manufactured in SST-US
- GPS signals penetrate through rain
  - View inside hurricanes
  - Also valuable for sea state monitoring
- Orbits: 35º inclination to target tropics
  - Potential for follow-on polar mission
- Launch 12th Dec 2016





Combining GNSS-RO with GNSS-R

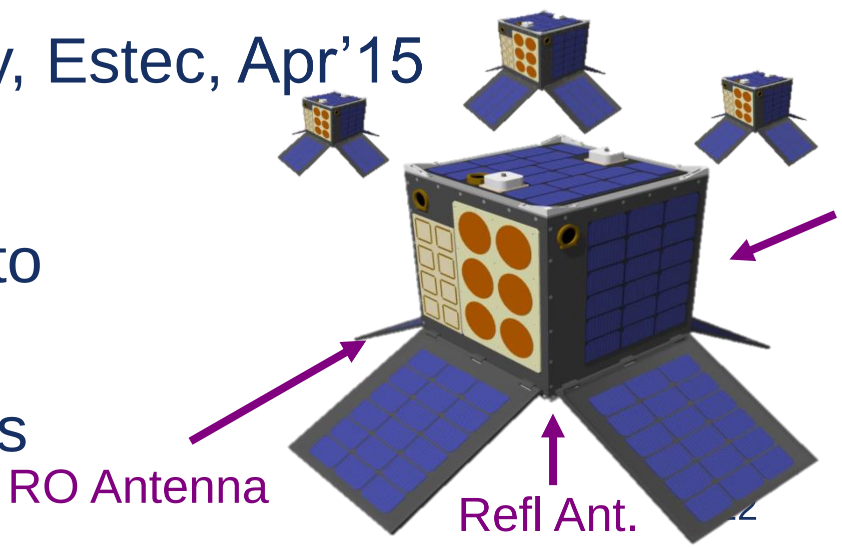
- Benefits of GNSS-RO well established:
  - METOP-A/B & SG, and COSMIC-1 / 2 (Formosat-3 /7)
  - Plus other scientific & commercial missions
  - Bending angle α recovered from GNSS signal => **Tempr & Press**



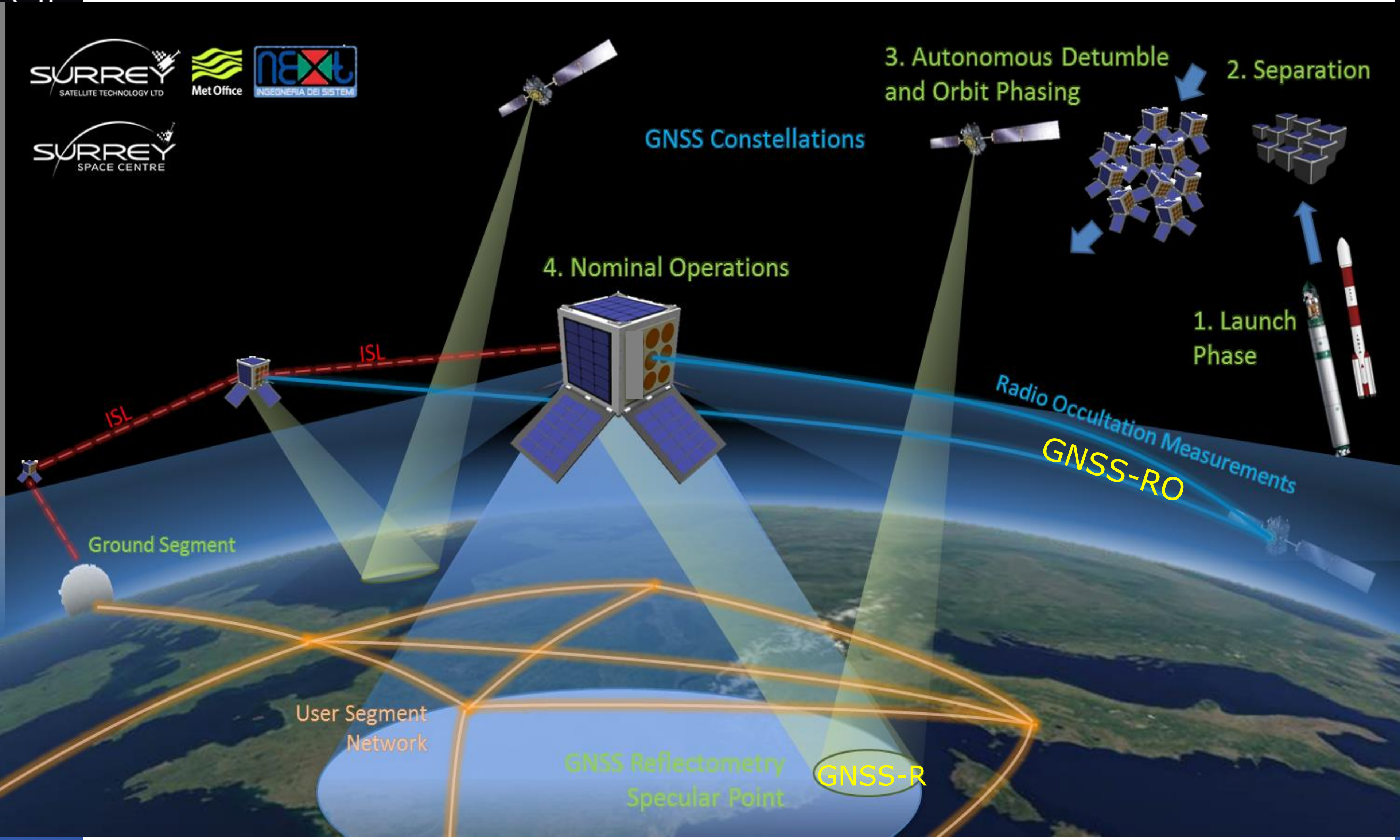
- Using same core technology as Reflectometry
  - GNSS position calculation from zenith antenna
  - Many of same “meta-data” needed (Ephemeris etc.)
  - Closed and open tracking loops techniques, similar data flow
  - GNSS antenna technology
- Both benefit from same advances
  - Adding extra constellations (Galileo, etc.)
  - Predictive open loops

SysNova ORORO

- ESA GSP 2nd SysNova challenge - **Weather**
  - ‘Remote Sensing with Multiple Cooperative Nanosats
- SSTL proposed “ORORO” constellation Dec 2014
  - Uses instrument combining GNSS-RO with GNSS-R
  - Low cost concept for **30 satellite constellation** for spatial **/** temporal cover
- Concept selected by ESA for CDF exercise
  - Concurrent Design Facility, Estec, Apr’15
- Completed CDF report
  - A number of adjustments to satellite platform,
  - Prelim. set of requirements

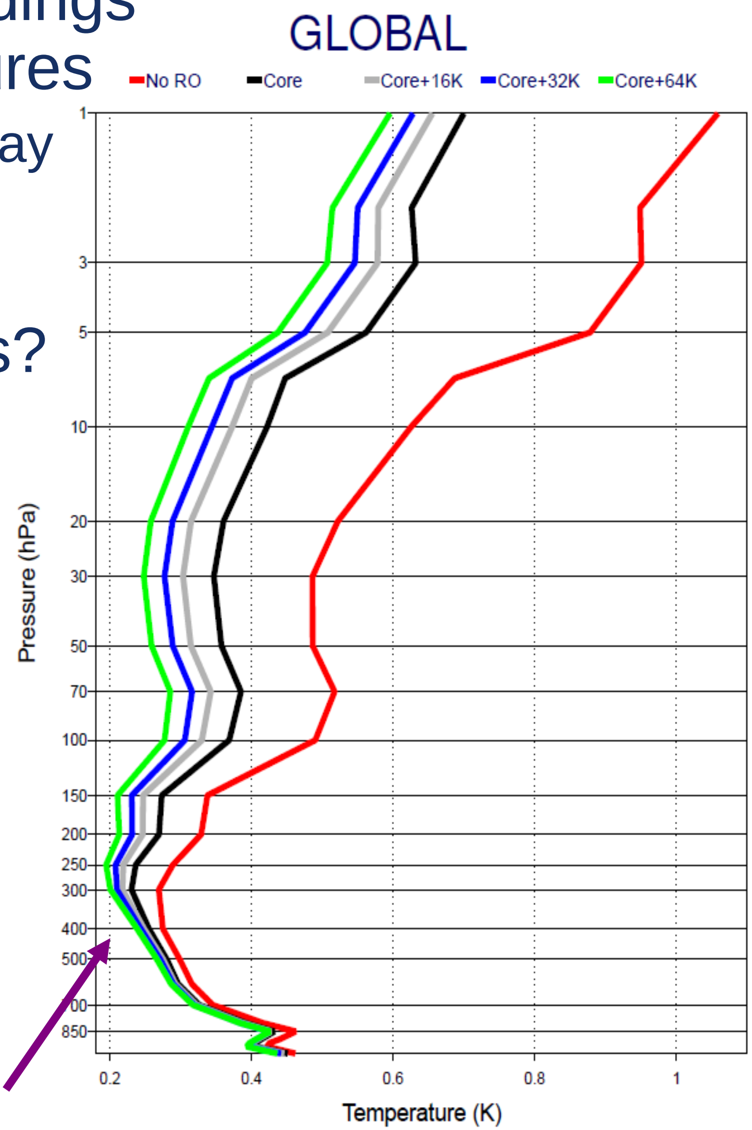


Visualisation of ORORO



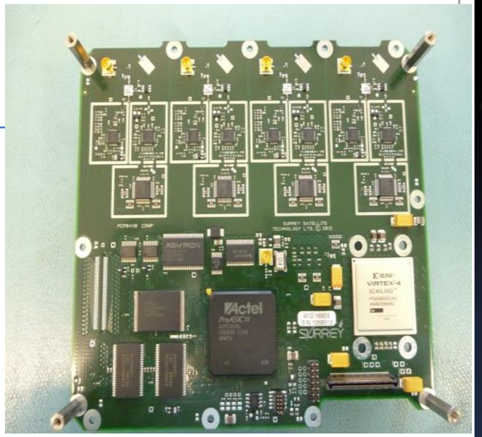
Impact of More GNSS-RO Measurements?

- Current impact of GPSRO soundings to NWP near top satellite measures
  - Approx 2,500 Radio Occultations/day
  - How many more measurements before impact falls?
- Harnish study, more occultations?
  - 16,000 => big impact on **EDA** (Ensemble Data Assim.)
  - 128,000 => less, but not saturated!
- ECMWF study with ESA 4000116920 Nov16
  - Combination of lower accuracy ORORO with accurate “core” measurements
  - Simulated 16,000, 32,000 and 64,000 ORORO occultations
  - Notable improvement if ORORO measurements added

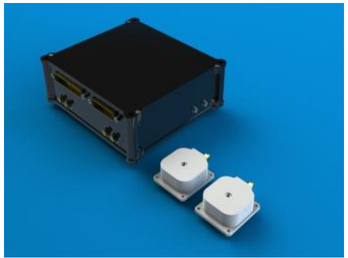


Grey, blue, green

Study Challenges

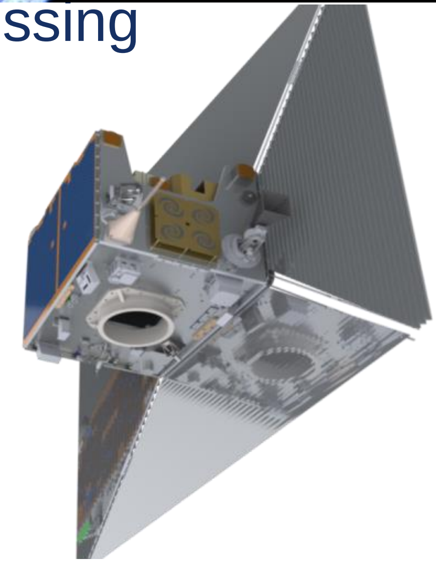


- ESA-funded study commencing late 2016
- Challenges in next-gen SGR-ReSI
  - RF design and error budget
    - Target 2 µrad bending angle (MetOp-SG 0.5 µrad)
    - Dual frequency RF solution plus LNAs and antennas
    - Oscillator – ovenized to control errors? Or lower power TCXO?
    - Antenna size / SNR trade-off
  - Multi-GNSS constellation
    - GPS and GALILEO, options for GLONASS and BEIDOU (freqs?)
    - Increase occultations: 500+ => 1000 => 2000 per satellite per day?
  - Processing architecture
    - Channel tracking schemes – open, closed loop
    - Use of co-processor / FPGA efficiently
    - Component selection to maintain low power & footprint
  - Data-flow – minimal data rate without quality compromise
- Aim to have a breadboard instrument by early 2018
- Platform challenges
  - Separate study commencing
  - Miniaturisation, power, payload antenna mounting,



TechDemoSat-1

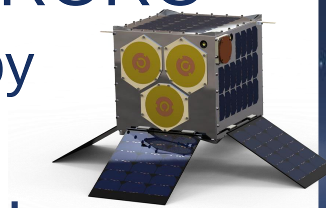
- TDS-1 still operating 2 days out of 8
  - ESA studies supporting reflectometry data gathering and scientific review
- Experimentation on-going
  - New signals L2c, Galileo E1, etc., new processing
  - Potential for ocean altimetry with TDS-1
- UK TDS-1 mission ends Summer 2017
  - Then deploy de-orbit sail, game over?



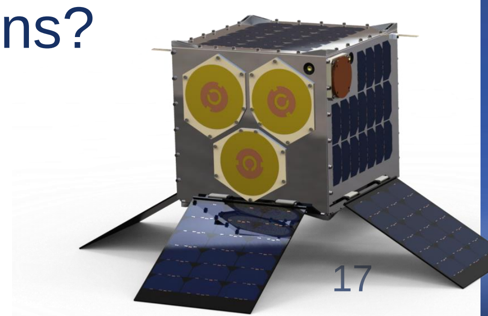
- Possible mission extension?
  - Proving 24/7 wind measurement service, short latency
  - Investigating case for funding
    - Looking for potential users for pilot service
  - Even with CYGNSS TDS-1 would remain valuable mission
    - Continuity with CYGNSS, & experimental flexibility
    - Only GNSS-R polar coverage, dual frequency, Galileo
    - Stepping stone towards ORORO

Future of GNSS Remote Sensing

- Quality vs Quantity of satellites?
  - Studies suggest best solution is combined:
  - Core of high quality measurements (few)
  - Augmented by many observatories, medium quality
- Only small satellites (10-20 kg) needed for ORORO

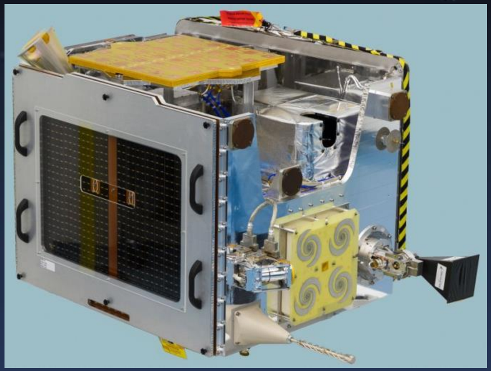


  - Cost need not be high for many sats, fast to deploy
  - Strength is in spatial and temporal coverage
- But no constellation unless funding framework
- Institutional or commercial?
  - Now precedents for commercial approach to GNSS-RO
    - NOAA funding for Spire & GeoOptics
  - But how to combine with institutional missions?
    - Or Private Public Partnership?



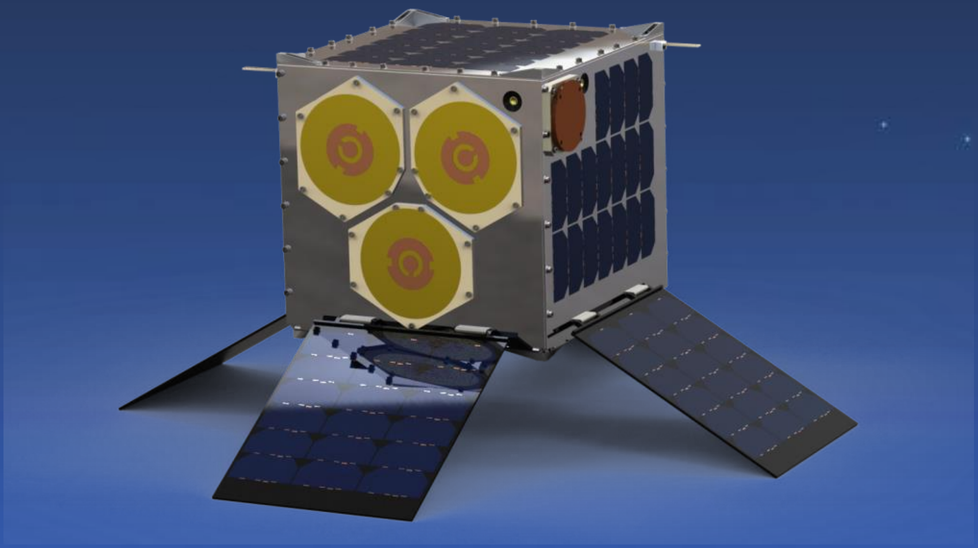
Where there's a will there's a way!

Changing the economics of space



Thank You

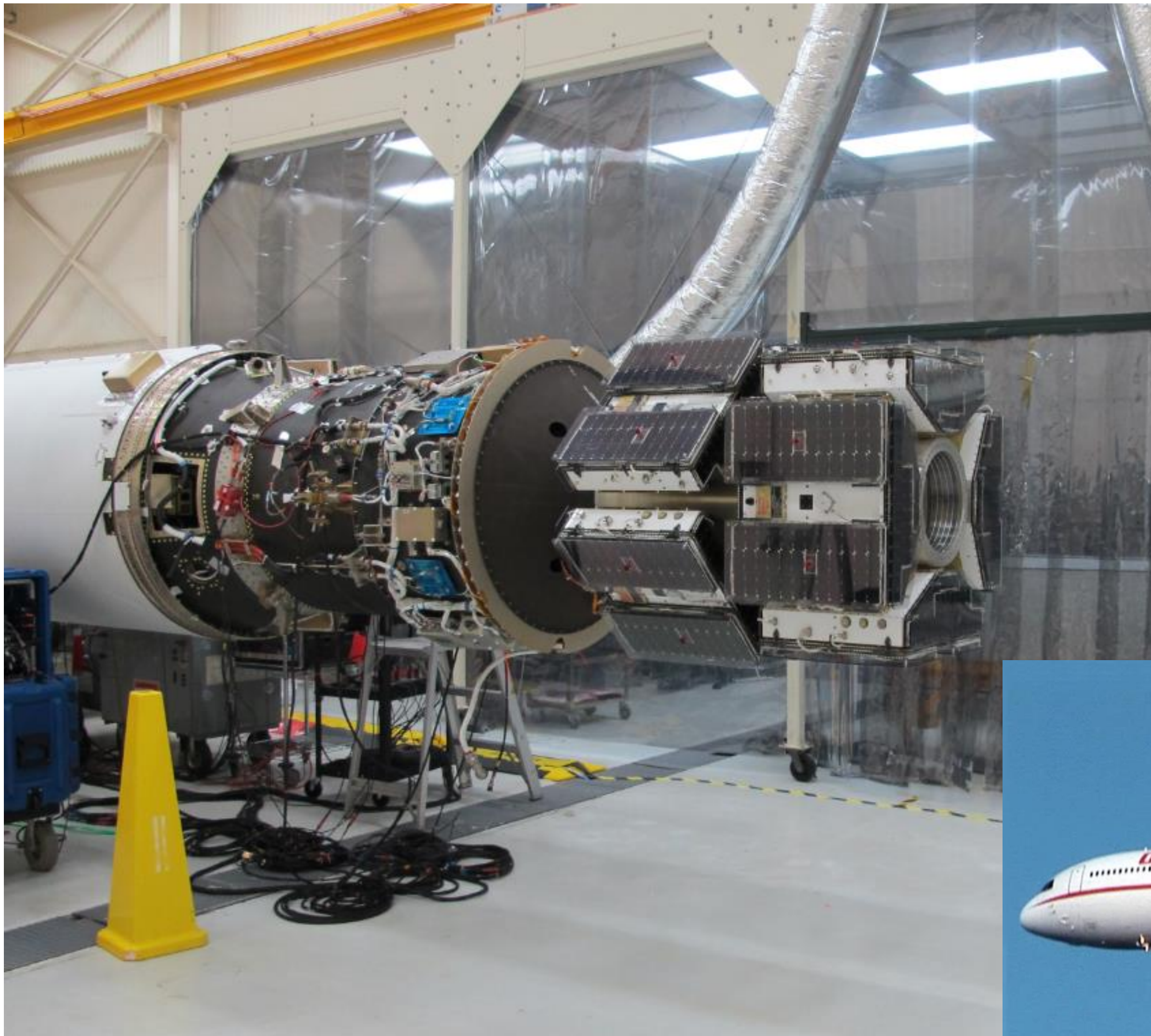
www.merrbys.co.uk



Tycho House, 20 Stephenson Road, Surrey Research Park, Guildford, Surrey, GU27YE, United Kingdom
Tel: +44(0)1483803803 | **Fax**:+44(0)1483803804 | **Email**: info@sstl.co.uk | **Web**:www.sstl.co.uk

CYGNSS Status

- 8 satellites mated with Pegasus launcher



Launch slipped from 21st Nov

(due to Hurricane Matthew)

to **12th Dec**

Cape Canaveral Florida