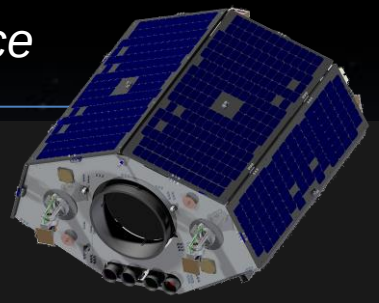
SURREY SATELLITE TECHNOLOGY LTD

Changing the economics of space



ESA Study
GNSS Reflectometry Instrument & Algorithms

NCEO/CEOI Conference, 19th Sept 2012

#01xxxxx

Overview

- GNSS for Remote Sensing
  - Concept and UK-DMC Experiment
  - Scientific needs
- SGR-ReSI Development
  - Algorithms and Testing
- TechDemoSat-1 Status
- WaveSentry
- CYGNSS
- Future

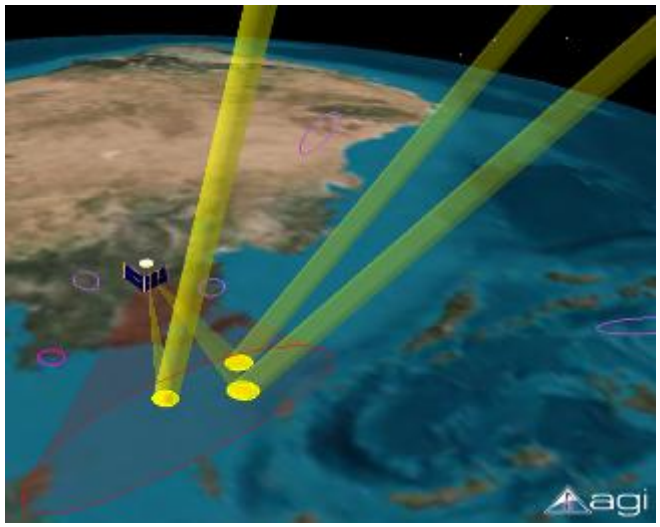
Global **N**avigation **S**atellites **S**ystems

- Current signals in space:
  - GPS
  - GLONASS
- Under construction:
  - Galileo
  - COMPASS
- Plus SBAS signals
- Galileo & GPS Modern.
  - Adds civil multi-frequency signals
- Soon 120+ GNSS transmitters in space
- GNSS already used from space for radio-occultation (ionosphere & troposphere)

GIOVE-A - Galileo precursor satellite

GNSS Reflectometry

- GNSS reflectometry
  - Detecting GNSS signals reflected off the Earth's surfaces
  - Signals should contain geophysical imprint
- Using Earth-reflected GPS signals for ocean sensing first proposed in 1988
  - 1993 ESA proposed reflectometry for ocean altimetry
  - First reflected signal detected 1998 (JPL SIR-C experiment)
  - ESA OPPSCAT Study proposed GPS Delay Doppler Maps
  - First dedicated in-orbit experiment: UK-DMC (2003)

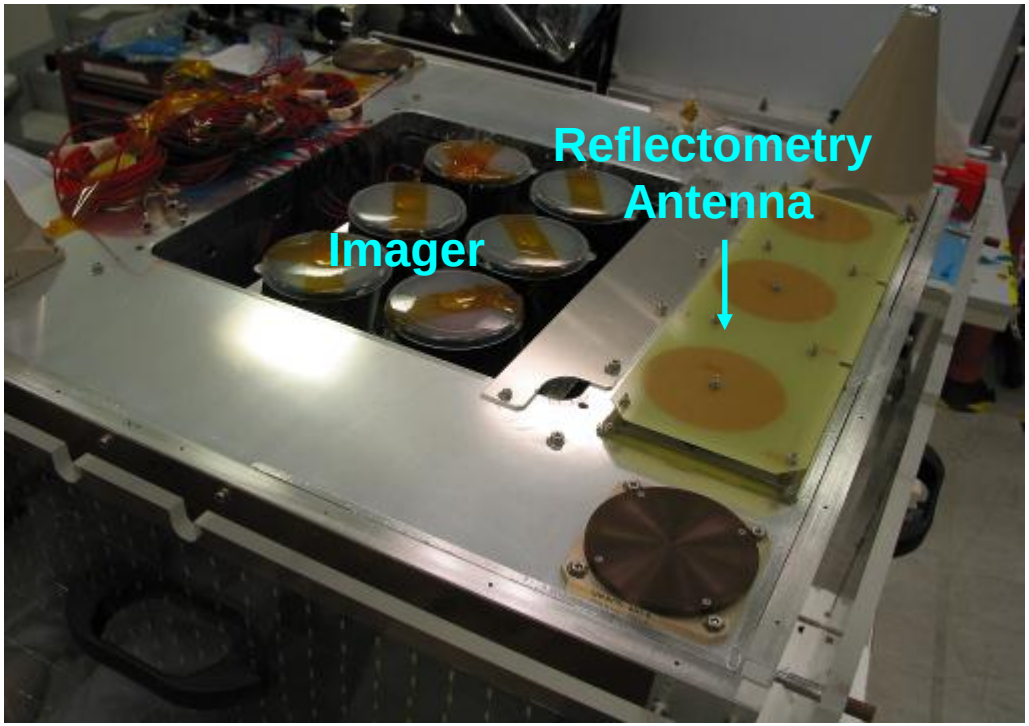


Example

UK-DMC-1 Experiment

- Pioneering GPS Reflectometry experiment in orbit
  - Carried on UK-DMC satellite, launched **Sept 2003**
  - Support from BNSC Newton fund

- Hardware:
  - GPS Receiver with 3 RF Sections
  - Data-recorder for IF sampled output
  - Medium gain 12 dBi LHCP nadir antenna

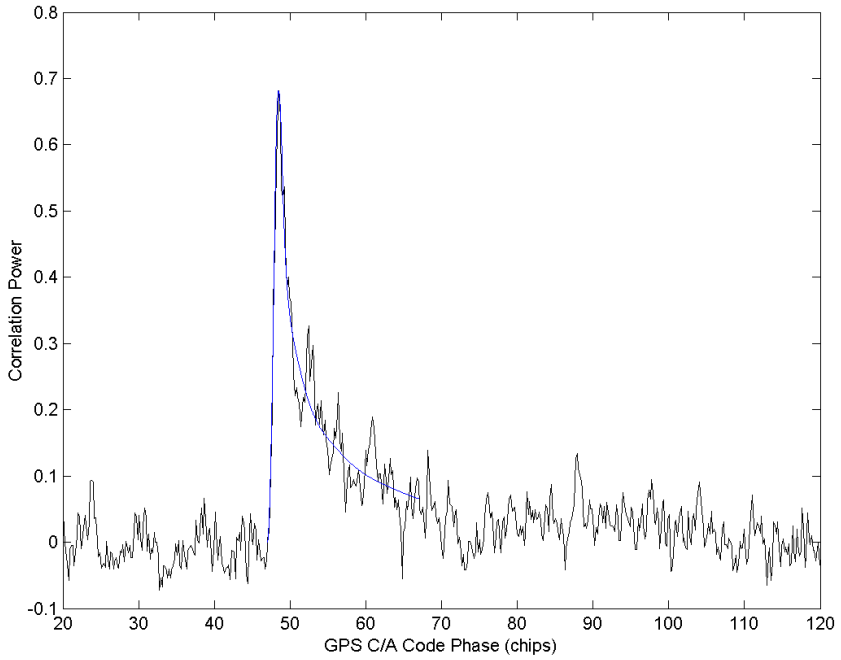


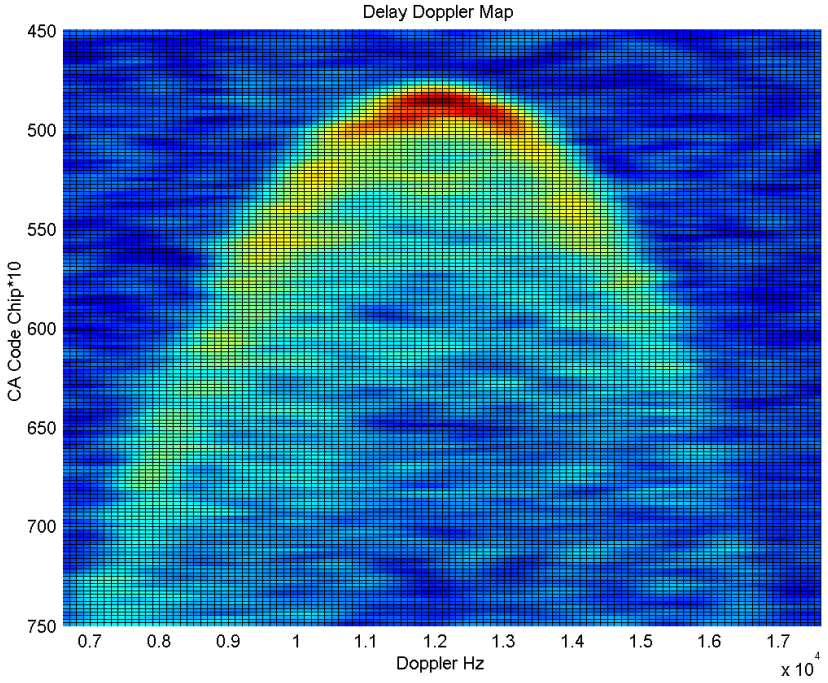
- SSDR collects 20 seconds of raw data

- First dedicated GNSS reflectometry experiment

Recovered Signals

- Processing sampled data reveals reflected signals
  - Correlate data with GPS code & carrier
  - Coherent 1 ms, then incoherent to 1 second
- Correlation shape related to ocean roughness





- ~60 collections gathered over sea, land and ice
  - Signals collected from all surface types!

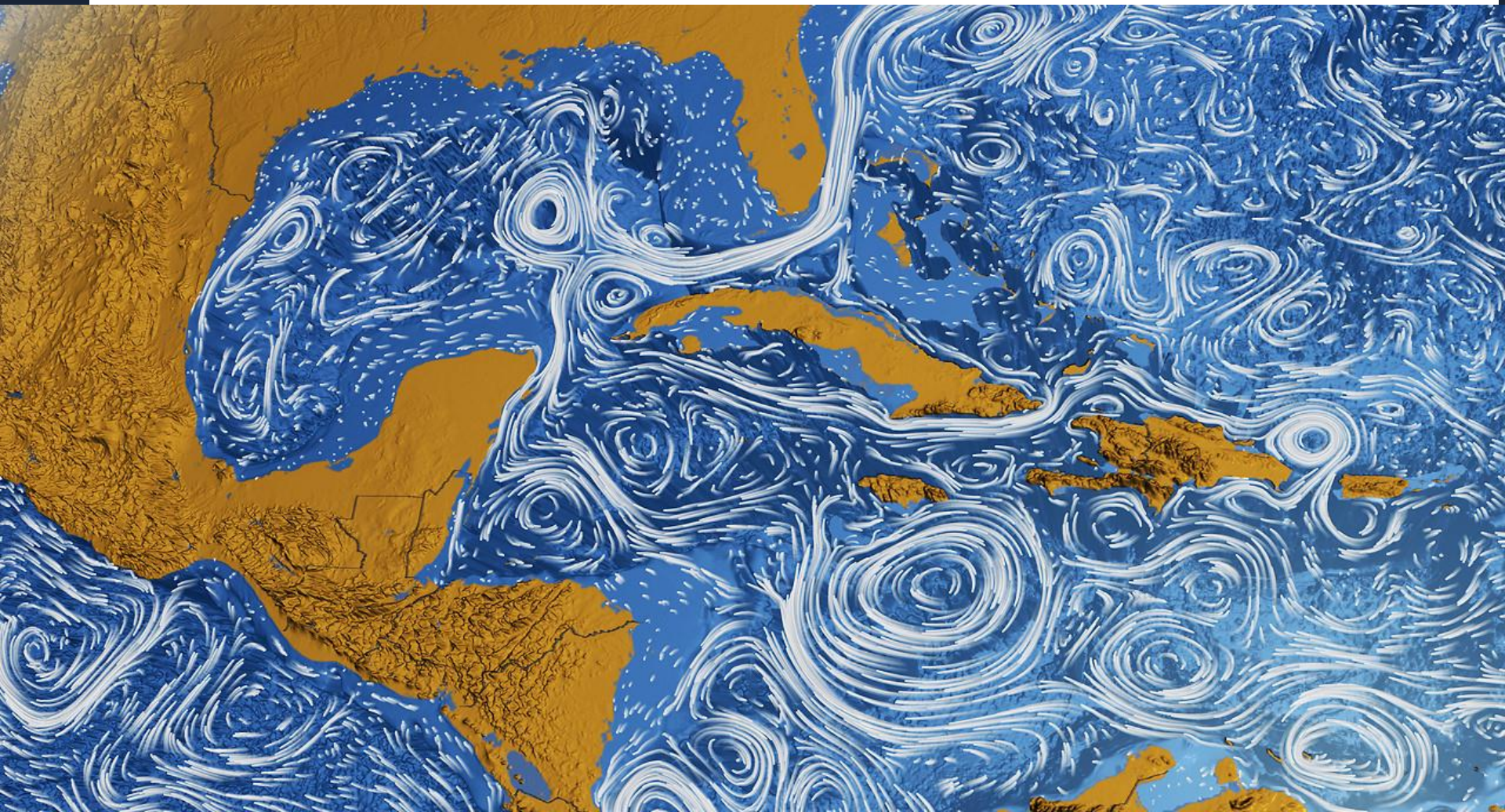
Need for SGR-ReSI

- Science & Operational case for applications
  - Notably a need for **ocean roughness determination**
  - Near-real time – Meteorology (wind retrieval), sea state services
  - Science – gas transfer => climate modelling, SMOS calibration
- Key opportunity of GNSS Reflectometry is temporal and spatial resolution
  - Low cost, low power instrument can be put on multiple satellites
  - Either dedicated constellation or satellites of opportunity
  - Needs are to have established low data rate interfaces
- Other potential applications include
  - Snow and Ice monitoring
  - Land, soil moisture, biomass
  - Radio-Occultation

Importance of Spatial / Temporal Resolution

- Ocean currents
- NASA Perpetual Ocean

http://www.youtube.com/watch?v=dKCI09RnZH0



New Instrument Development

CEOI Project: (UK Govt) 2009 / 2010

SSTL - Project lead, management, SGR-ReSI core development & test

SSC - Antenna design and test

National Oceanographic Centre - Ocean Reflectometry applications & requirements, Inversion models & outreach

Bath - Atmospheric applications & requirements

Polar Imaging Ltd - Ice sensing Applications

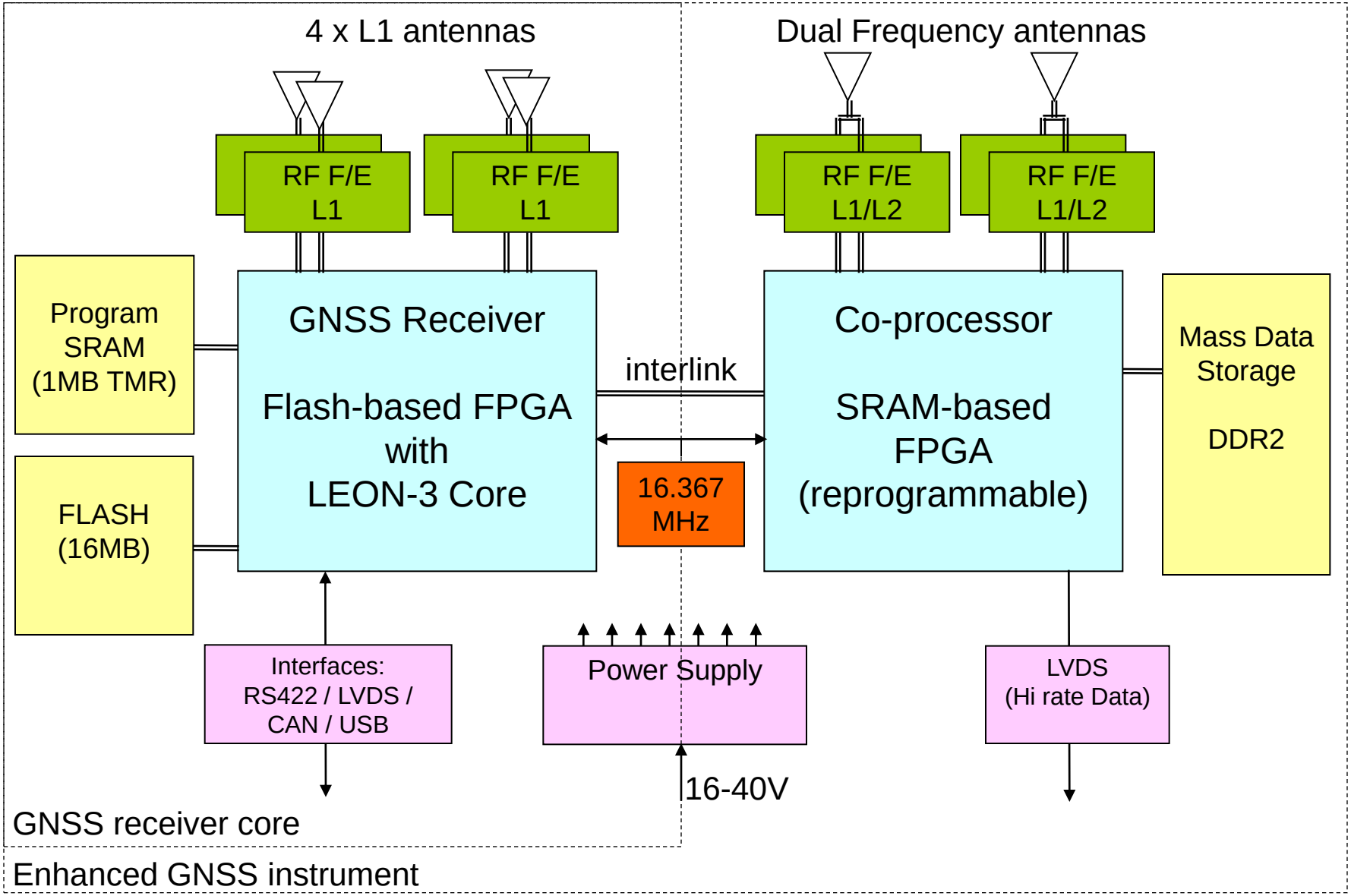
SURREY SPACE CENTRE

National Oceanography Centre, Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

UNIVERSITY OF BATH

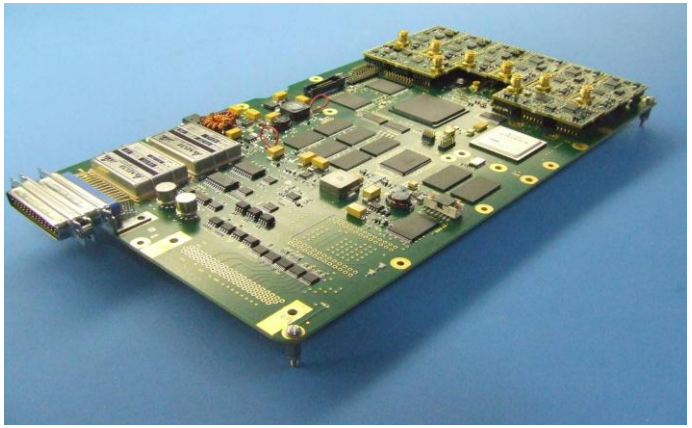
Polar Imaging

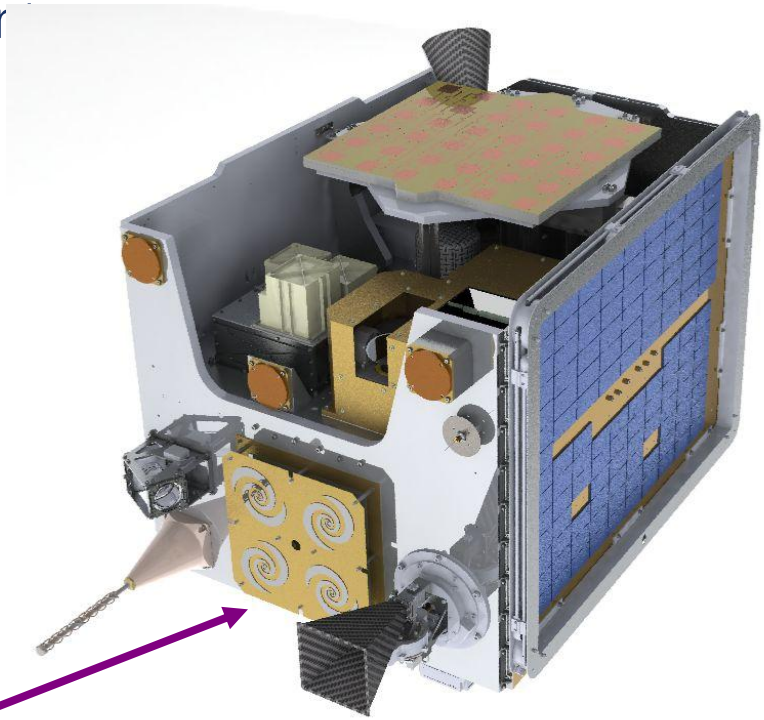
SGR-ReSI Basic Block Diagram



SGR-ReSI on TechDemoSat-1

- 160 kg UK Satellite
  - Launch ~March 2013
- First flight on TechDemoSat-1
  - Part of Sea State Payload
  - Accompanied by Altimeter
- Six front-ends
  - Two dual frequency (L1 & L2C) ar
  - Two single frequency antennas
- Primary goals for ReSI
  - Replacement for SGR-10
  - Ocean roughness sensing through reflectometry
    - Collection of data for models
    - Real-time demonstration
- Additional strategic goals





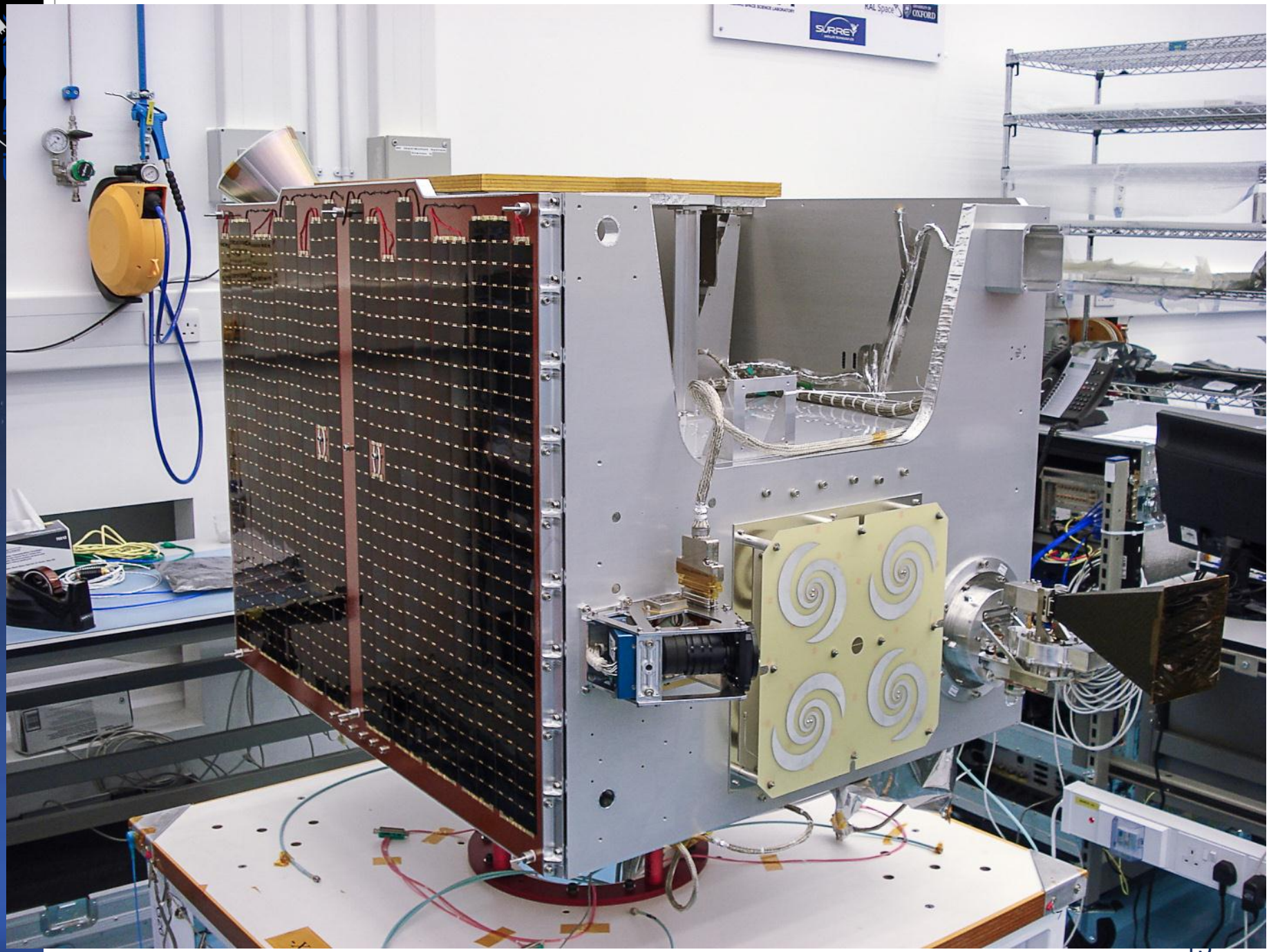
TechDemoSat-1 Payload overview

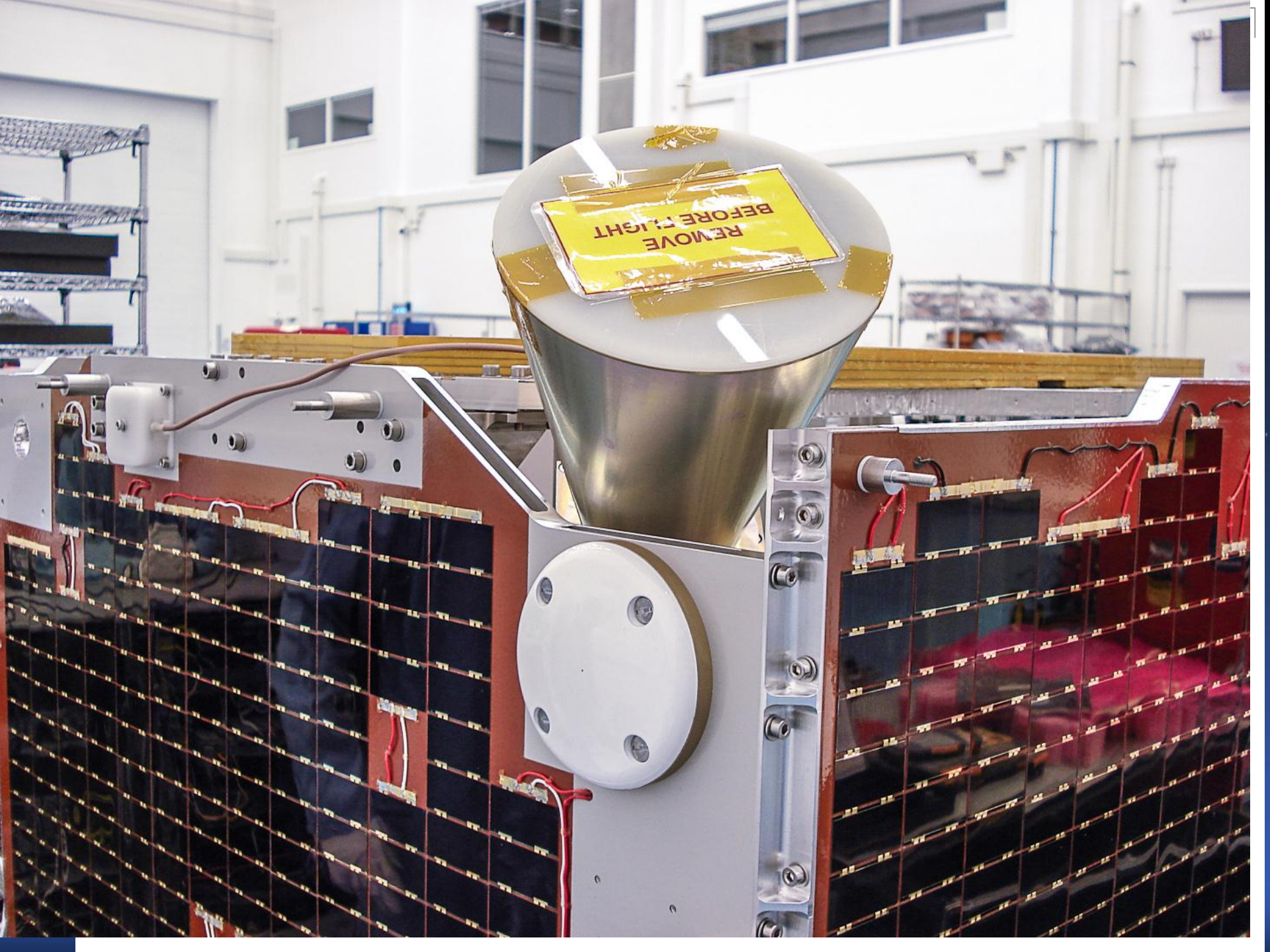
- **Maritime Suite -** Sea State Payload (SSTL)
  - SGR-RESI plus SSP Altimeter
- **Space Environment Suite**
  - Micro (μ) Radiation Environment Monitor (University of Surrey)
  - Charged Particle Spectrometer (MSSL)
  - Langton Ultimate Cosmic ray Intensity Detector (Langton Star Centre)
  - Highly Miniaturised Radiation Monitor (RAL)
- **Air and Land Monitoring Suite**
  - Compact Modular Sounder (Oxford University / RAL)
- **Platform Technology Suite**
  - De-Orbiting Sail (Cranfield University)
    - Deployable sail to increase aerodynamic drag and lower the orbit
  - CubeSAT ACS (SSL) - Miniaturised attitude, orbit sensors
  - Software experiments (SciSys / Logica)

SGR-ReSI

SGR-ReSI
Flight Model (2)

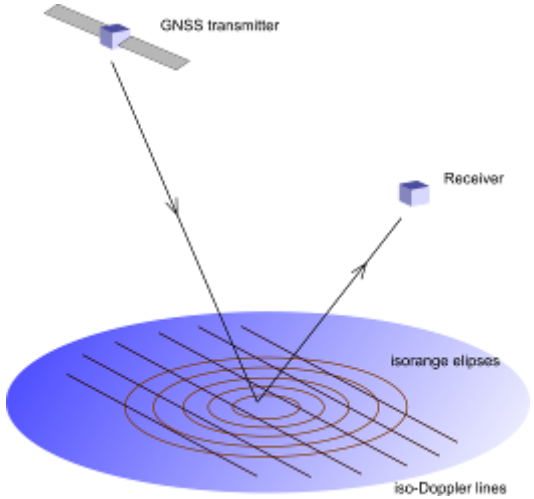
Nadir Antenna


SURREY
KAL Space
OXFORD

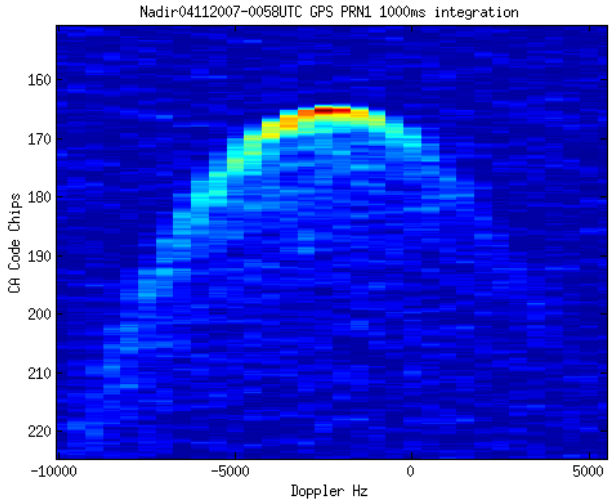

REMOVE
BEFORE FLIGHT

On-board Algorithms

- Reflectometry real-time tracking
  - Prediction and automatic allocation of channels to reflections
  - Open-loop tracking
  - (eventually) on-board Delay-Doppler Map [DDM] generation
- Subject of PhD research at SSC & SSTL by Philip Jales
  - Input from science drivers and results obtained from UK-DMC data (NOC)
  - Use Delay Doppler Map shape to determine the ocean MSS

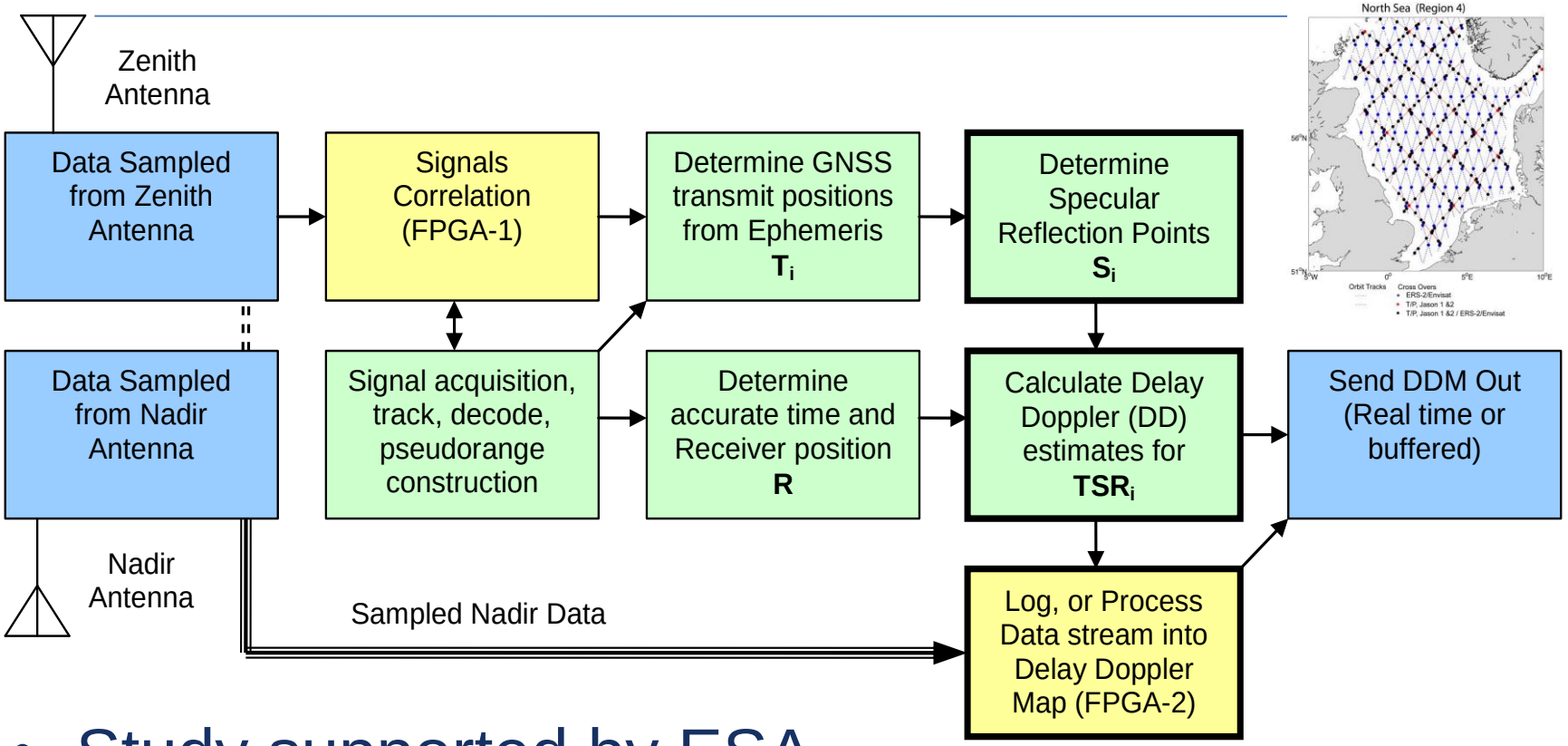


Spatial distribution of scattering

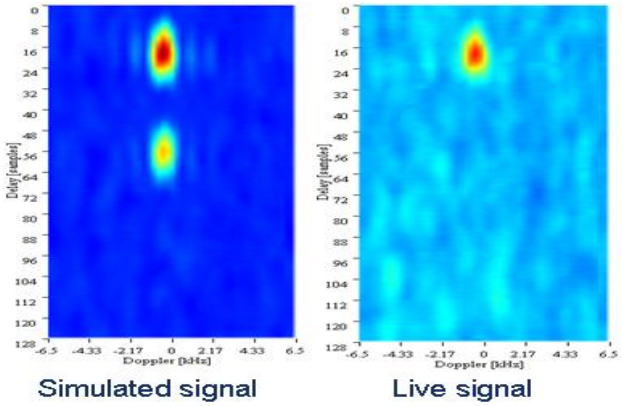


Signal distribution of scattering

Algorithm Development and Validation



- Study supported by ESA
  - Partnership with NOC, Southampton
  - End-to-end instrument demonstration

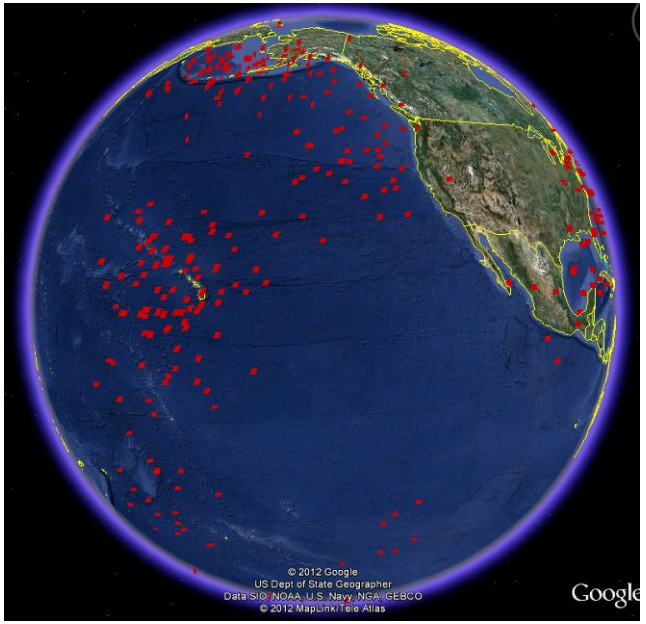


TDS-1 Cont…

- Environmental Test Campaign about to commence
- SGR-ReSI integrated on TDS-1 available & operational
  - Antennas, LNAs integrated
  - GNSS Receiver core robust & tested
  - Co-processor operational and tested
- Reflectometry algorithm development underway
  - Preliminary algorithms will be completed and tested prior to launch, further optimisations anticipated
- Operations planning – supporting both
  - A) Semi-operational Delay Doppler Map => dmss
  - B) Experimental Raw Data collections

WaveSentry Project

- Industry partnership to collate and exploit wave knowledge
  - TSB (UK Govt) sponsored,
  - Led by HR Wallingford
  - Management Marine South East
- Data Suppliers:
  - Buoys around UK
  - Ferries / Ship wave instruments
  - SSTL's GNSS-Reflectometry
  - Other satellite wave data

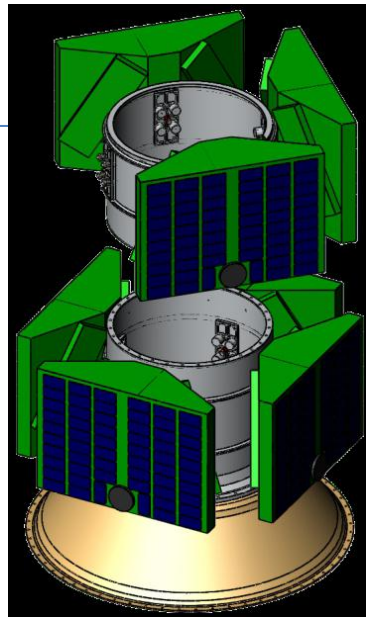


- Potential Users:
  - Off-shore wind and wave energy suppliers,
  - off-shore gas and oil, shipping management
  - Scientists
- SSTL activities – **Reprocessing UK-DMC data** using latest tools
  - Found many more signals in data away from beam centre
  - NOC converting data into dmss results and validating

Recent News: CYGNSS

- NASA selected ocean wind study proposal led from 19 submitted for Earth Venture 2 programme
  - University of Michigan - PI
  - South West Research Institute
  - SST-US
  - NASA Ames
- Will make measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes, helping better weather forecasting
- Constellation of 8 microsatellites
  - Mass of each: 18 kg
- Payload is the SGR-ReSI
  - Supplied by SST-US / SSTL
- Optimised for tropical storms
  - Orbit 500km, 35 degrees incl.

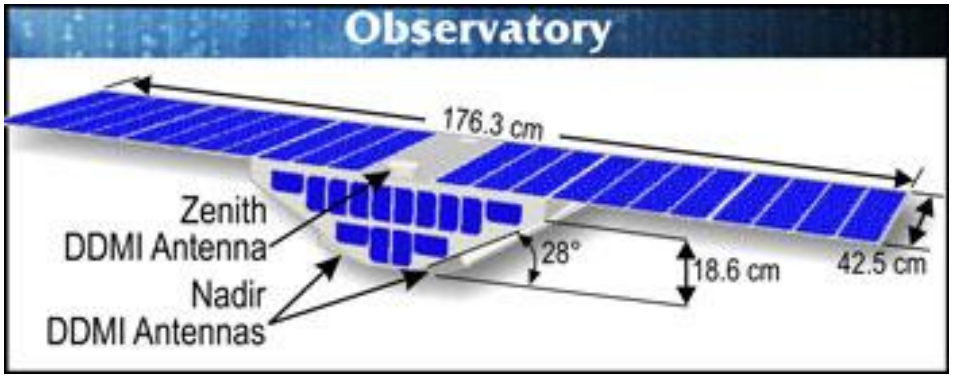
CYGNSS / ReSI



- Project website
- http://aoss-research.engin.umich.edu/missions/cygnss/
- Operational in 2017
- Contracts currently under negotiation

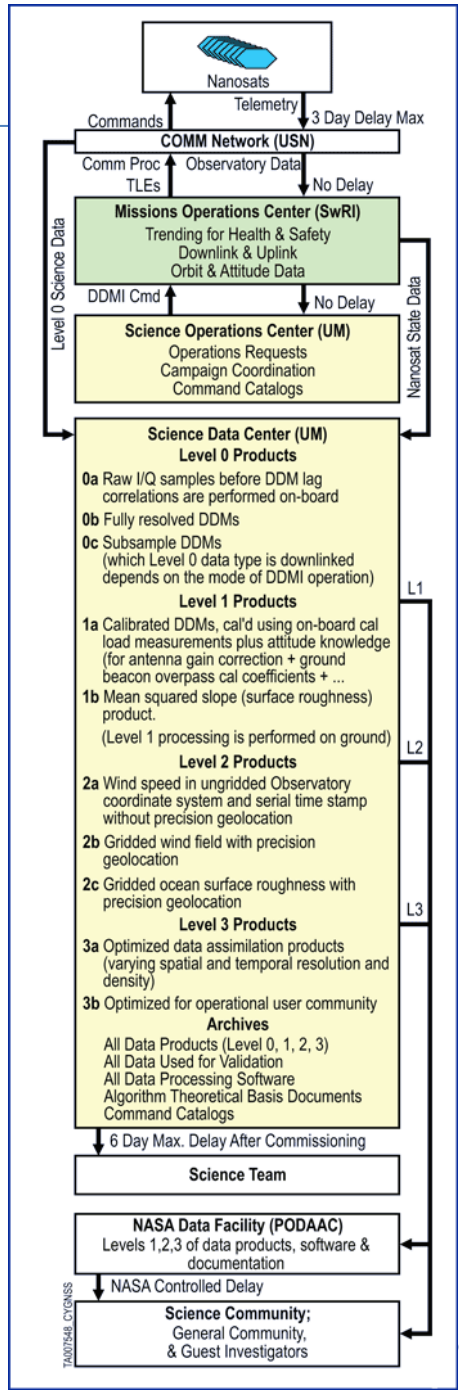
Terminology Key

CYGNSS Element	Definition
DDMI	Delay Doppler Mapping Instrument: Instrument/Payload; DMR + 2 nadir and 1 zenith antennas
DMR	Delay Mapping Receiver: GNSS receiver core; enhanced DSP
S/C	Spacecraft: Nanosatellite
DM	Deployment Module: Interface to LV; deploys constellation
FS	Flight segment: Constellation + DM
Observatory	Integrated DDMI and S/C
Constellation	All 8 observatories



CYGNSS Data Products

- L0: Delay Doppler Maps
- L1: Directional Mean Square Slopes
- L2: Ocean roughness
- Wind Speed with geolocation
- L3: Assimilated products with temporal and spatial coverage



Future

- Payload of opportunity
  - Flying on SSTL's or other missions
  - Generating low data rate streams
- Providing services for meteorology, marine users and scientists
- Enhanced SGR-ReSI
  - Additional signals – Galileo, Glonass, SBAS, etc.
  - Increased density of measurements
  - Increased on-board data reduction
    - Smarter collection, compression, inversion
  - Broader applications: ice, snow, land, atmosphere
- UK **TechDemoSat-1** offers experimental platform
- NASA **CYGNSS** offers important operational service for hurricane sensing

Summary

- **SGR-ReSI** for **GNSS Reflectometry** (GNSS-R)
- Successful instrument development from concept to feasibility to instrument to mission
  - Seedcorn funding from BNSC / CEOI was vital
    - Although << 50% funding
  - Academic partnerships also opened doors
  - Substantial industrial funding only possible due to “day job” supplying space GPS receivers
- NASA CYGNSS constellation to measure hurricanes in 2017
  - First step towards COSMIC-type wind / wave monitoring constellation using GNSS-R
- TechDemoSat-1 to be launched 2013
  - Gather data for models
  - Demonstrate other sensing
  - Puts UK in the lead

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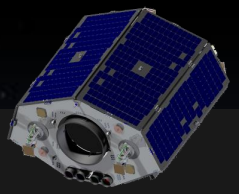

Thank You

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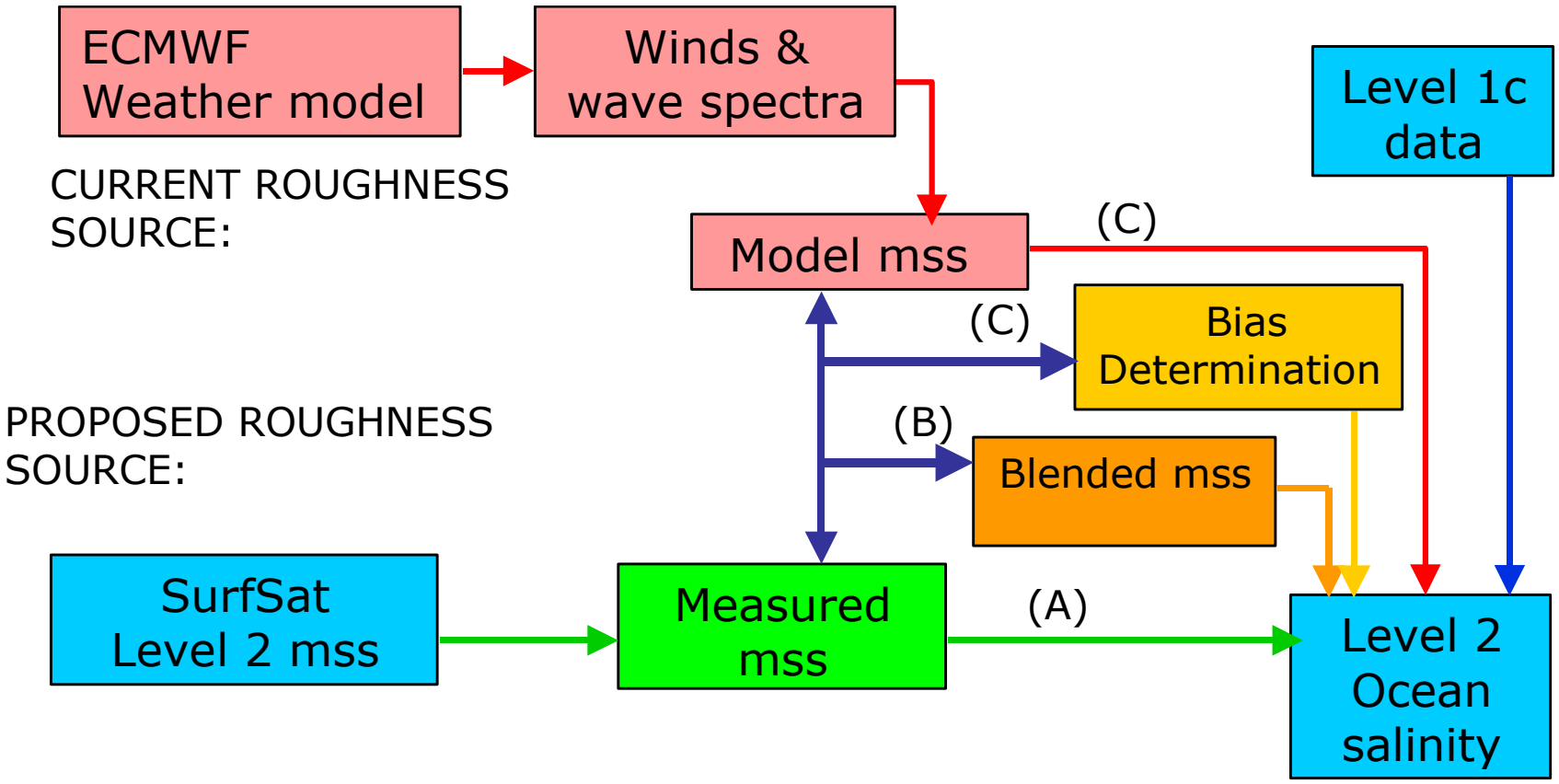
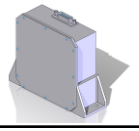
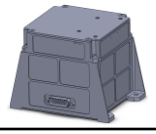
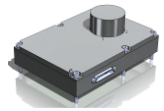
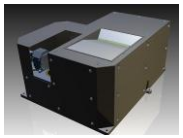
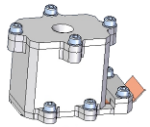
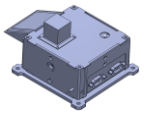
Tel: +44(0)1483803803 | **Fax**:+44(0)1483803804 | **Email**: info@sstl.co.uk | **Web**:www.sstl.co.uk

MSS CORRECTIONS FOR SMOS

- Three ways mss can be used to improve SMOS salinity
  - A) Direct sea roughness, B) Blended with ECMWF, C) Bias check



TechDemoSat-1 Payload Overview

Payload	Supplier	Description	Illustration
MuREM	University of Surrey (Surrey Space Centre)	The Micro (μ) Radiation Environment Monitor (MuREM) is a miniature radiation environment and effects monitoring payload.	
ChaPS	Mullard Space Science Laboratory (MSSL)	The Charged Particle Spectrometer (ChaPS) is designed to measure electron and ion populations in the orbit of the host spacecraft.	
LUCID	Langton Star Centre	The Langton Ultimate Cosmic ray Intensity Detector (LUCID) allows characterisation of the energy, type, intensity and directionality of high energy particles.	
CMS	University of Oxford / RAL	The Compact Modular Sounder (CMS) is a set of compatible optical, detector, cooling and electronic sub-systems which can be used to implement miniature infrared remote sensing spectrometers or radiometers.	
HMRM	Rutherford Appleton Laboratory	The Highly Miniaturised Radiation Monitor (HMRM) is a an ultra-compact, low power radiation monitor developed for re-use on future ESA missions.	
CubeSAT ACS	Satellite Services Ltd	The CubeSAT ACS payload is a complete 3-axes attitude determination and control subsystem for Cubesats.	
DOS	Cranfield University	The De-Orbit Sail (DOS) is intended to demonstrate a novel means for de-orbiting a satellite at the end of its mission lifetime through deploying a sail to increase aerodynamic drag.	
Sea State Payload	Surrey Satellite Technology Limited (SSTL)	a) Experimental Altimeter, b) SGR-ReSI - GNSS Remote Sensing Instrument – Measures ocean roughness using reflected GNSS signals