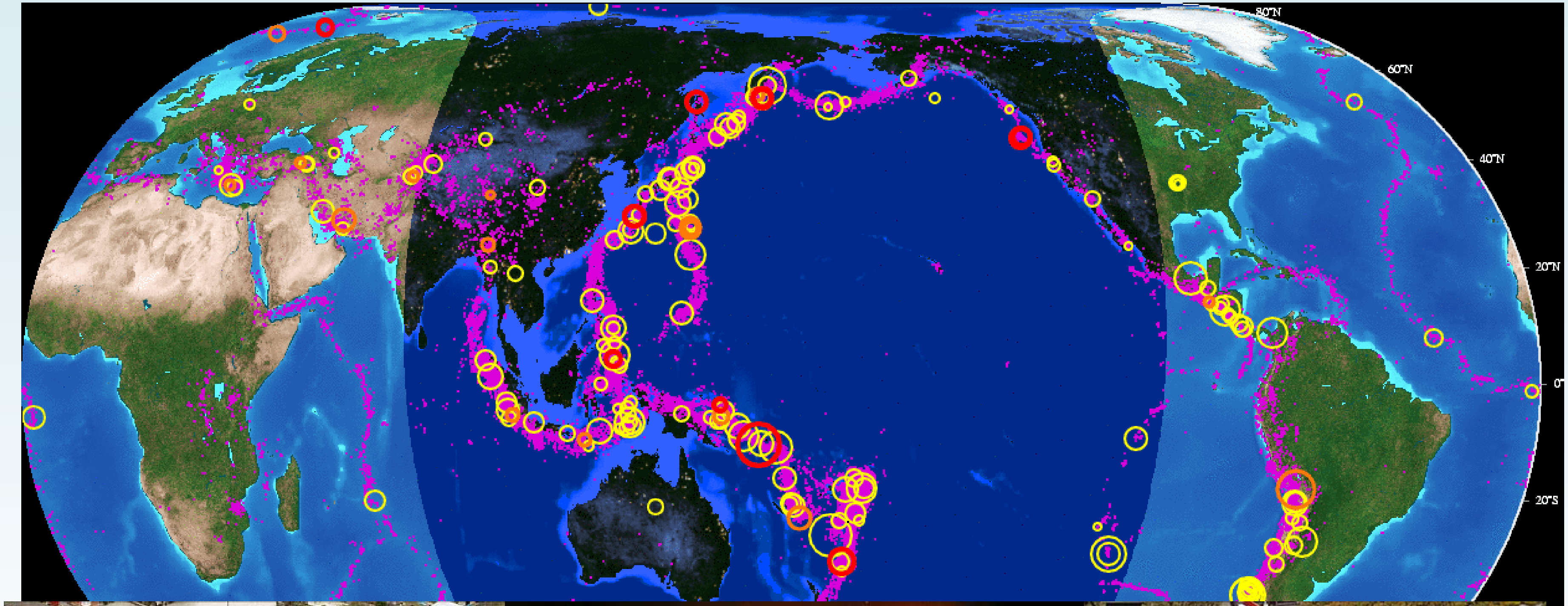
TwinSat:
A Russia-UK satellite project to study ionospheric disturbances associated with earthquake and volcanic activity

Vitaly Chmyrev[1], Alan Smith[2], Dhiren Kataria[2], Boris Nesterov[3], Christopher Owen[2], Peter Sammonds[4], Valery Sorokin[5], Filippos Vallianatos[6]

[1] Schmidt Institute of Physics of the Earth (IPE), Russian Academy of Sciences, 10, B. Gruzinskaya Str., 123995 Moscow, Russian Federation
[2] Mullard Space Science Laboratory, University College London, Holmbury St Mary, Dorking, Surrey RH5 6NT, UK
[3] JSC Design Bureau POLYOT, Omsk, Russia
[4] Institute of Risk and Disaster Reduction, University College London, Gower Street, London, UK
[5] Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Russian Academy of Sciences (IZMIRAN), 142190 Troitsk, Moscow region, Russian Federation
[6] Laboratory of Geophysics and Seismology, Technological Educational Institute of Crete, Chania, Crete, Greece

IRIS



Earthquake impact

- Haiti (2010) – 316,000 dead, 1,000,000 homeless
- 1 million death earthquake expected this century

- Kobe (1995) - $100 billion
- Sichuan (2008) - $150 billion
- Sendai (2011) - $265 billion ($100 billion in insurance losses) - Impacted global economy

LAI Evidence

- Enhancement of seismic activity produces DC electric field disturbances in Ionosphere over areas of 100s km diameter
- ULF geomagnetic field oscillations detection in the ionosphere
- Small scale plasma density irregularities with correlated ELF emissions
- VHF electromagnetic radiation is generated in the atmosphere (1-10km) over the quake zone

LAI Evidence

- Seismic-related disturbances in the troposphere create the conditions for over-horizon propagation of signals from ground stations on routes passing over earthquake area
- Anomalous effect in Shumann resonance phenomena
- Outgoing IR (8-12 microns) anomalies in the atmosphere
- Changes to total water vapour column and aerosol parameters, and ozone concentration.
- Concentration of charged soil aerosols and of Radon gas

LAI Process

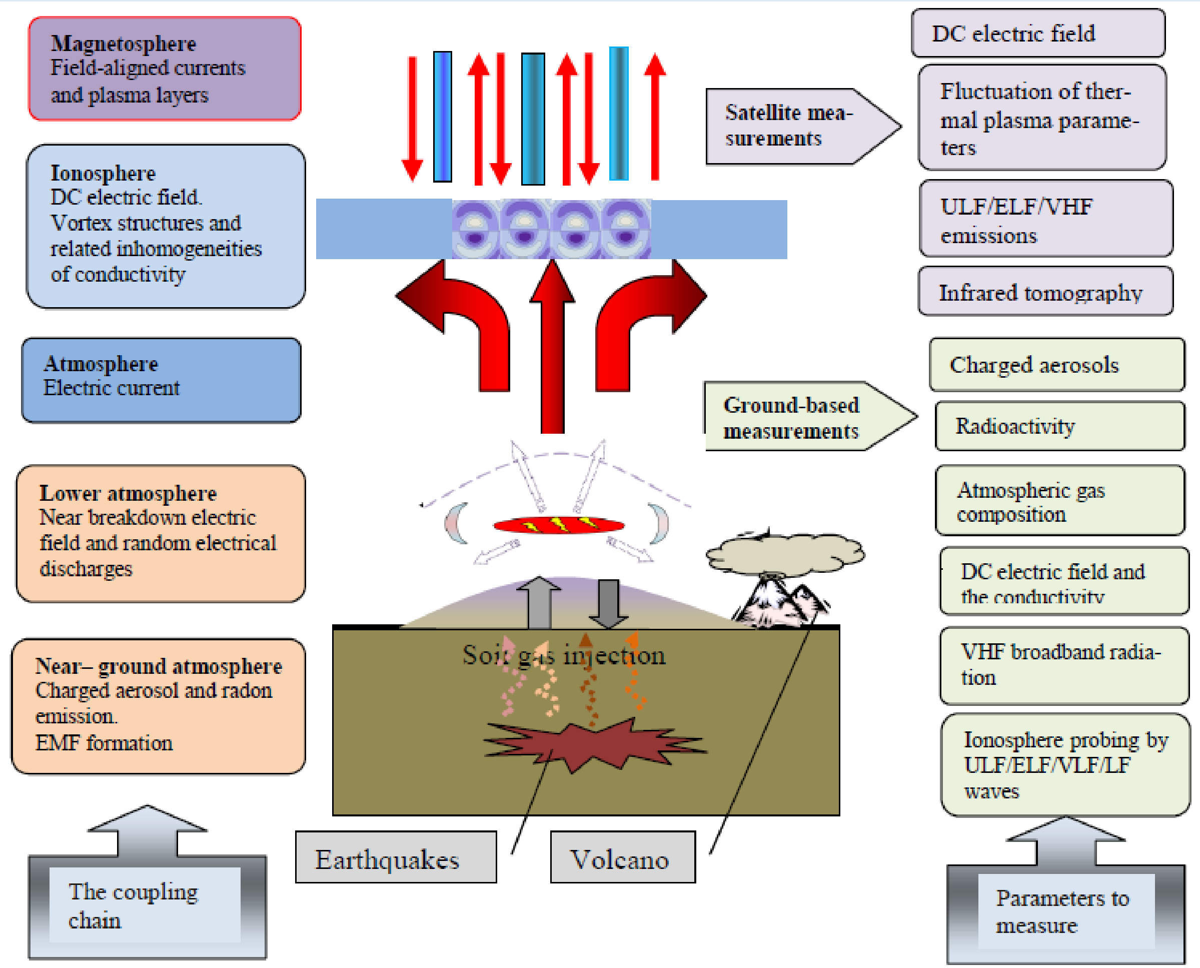
Electromotive force causes DC field in lower atmosphere and ionosphere

↑

Gravity and vertical convection cause electromotive force

↑

Growth of seismic activity leads to enhancement of charged aerosols and Radon injection

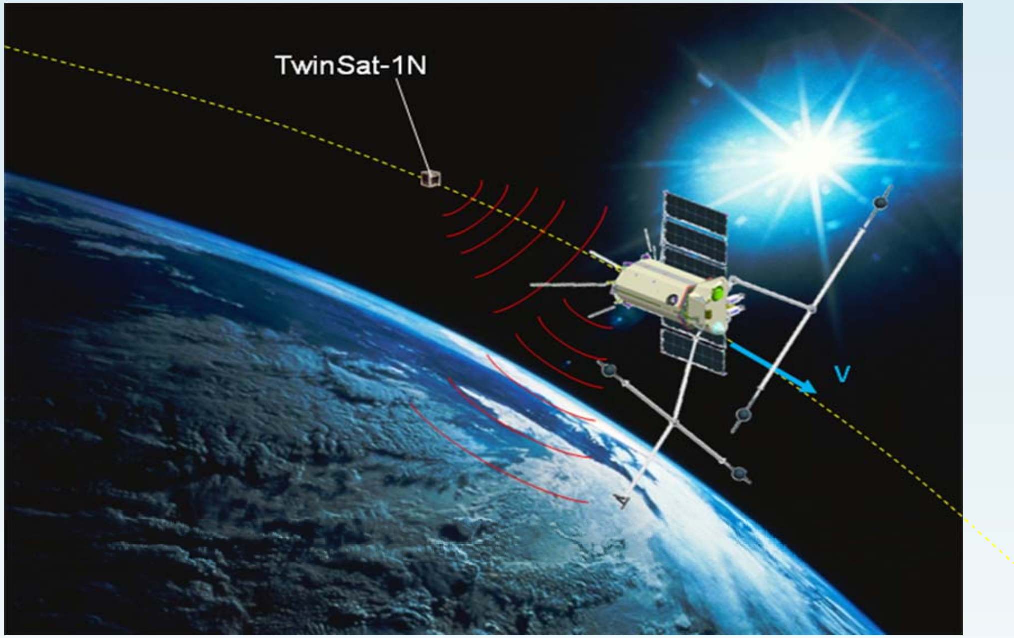

Magnetosphere
Field-aligned currents and plasma layers
Ionosphere
DC electric field.
Vortex structures and related inhomogeneities of conductivity
Atmosphere
Electric current
Lower atmosphere
Near breakdown electric field and random electrical discharges
Near– ground atmosphere
Charged aerosol and radon emission.
EMF formation
The coupling chain
Satellite measurements
DC electric field
Fluctuation of thermal plasma parameters
ULF/ELF/VHF emissions
Infrared tomography
Ground-based measurements
Charged aerosols
Radioactivity
Atmospheric gas composition
DC electric field and the conductivity
VHF broadband radiation
Ionosphere probing by ULF/ELF/VLF/LF waves
Parameters to measure
Soil gas injection
Earthquakes
Volcano

DC electric field reaching the breakdown value in lower atmosphere causes:

- Chaotic electrical discharges
- Heating and IR emission
- Broadband VHF emission
- Airglow in visible range
- Refraction and scattering of VHF => over the horizon reception

DC field in ionosphere may cause instabilities resulting in:

- Periodic or localized structures in the form of solitary dipole vortices or vortex chains
- Associated plasma density and electrical conductivity disturbances
- Magnetically aligned currents and plasma layers stretched along the geomagnetic field.
- ULF magnetic field oscillations
- Electron number density fluctuations
- ELF electromagnetic emissions
- Schumman-resonance-like anomalous line emissions



TwinSat

- As part of the UK celebration of Gagarin50 a Russian delegation visited the UK in June 2010
- As a result a proposal for a very low cost space mission involving a Russian micro satellite and a UK nano satellite has been developed

Programme Stages

Stage 1 – Research and Development

•Phase 1 – Development and Launch of TwinSat

- Demonstration of two satellite approach to improve discrimination of earthquake precursor signals from other disturbances
- Acquisition of precursor data from a wide variety of instruments, space and ground
- Analysis of TwinSat data to determine optimum prediction algorithm

Stage 2 - Implementation

•Phase 2 – Design of early warning satellite constellation and ground segment

•Phase 3 – Development and commissioning of early warning constellation

•Phase 4 – Operations of an early warning constellation

Stage 1 Objectives

- To validate current experimental findings and theoretical models addressing the short-term earthquake precursors through specialized and coordinated twin-satellite and ground based observations;
- To develop a comprehensive theoretical model describing the formation and interconnection of the precursor signals and the causal mechanism(s) (if present) between the driving seismic activity and the ionospheric signatures;
- To search for new precursory signals and estimate potential for accuracy improvement of forecasting the time and position of impending earthquakes;
- To determine the feasibility of a follow-on satellite constellation for reliable earthquake prediction taking into consideration the danger of false alarms and ambiguity;
- To evaluate possible ‘earthquake occurrence probability algorithms’ based on the above results.

Programme elements

- Space Sector (TwinSat)
  - Micro-satellite – TwinSat-1M
  - Nano-satellite – TwinSat-1N
- Ground Sector
  - Science stations in earthquake regions including Kamchatka
- Data Centre
  - Accessible, open, supported
- Modelling
  - Coordinated LAI modelling

TwinSat-1M

Characteristic	Value
Satellite dimensions (without booms)	46 diam x 53 cm
Mass (including payload)	~40-50 kg
Mass of separation system	2.8 kg
Power Average Maximum	 90 W 140 W
TwinSat-1N separation velocity Linear Angular	 3 cm/s < 6^o/s (TBD)
Attitude Control	3-axis, 8 arc min stability
Orbit	800 km, Sun-synchronous, 98.6^o inclination, 100min period
Telemetry to ground Fast channel (X-band) Slow channel (145/435 MHz)	 >50 Mbit/s 20 Kbit/s
Onboard memory	>5 Gbyte
Inter-satellite link frequency	2-3 GHz (TBD)
Active lifetime	>3 years

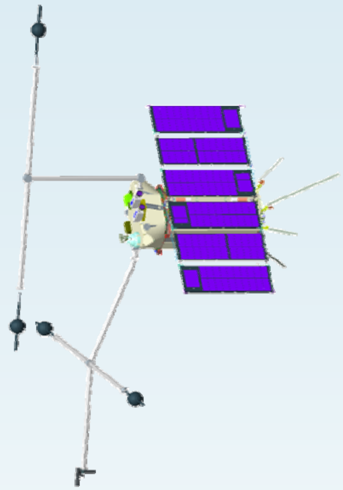


Figure 3. TwinSat-1M

TwinSat-1M Elements

- Onboard Control Complex (OCC) including the radio channel unit with antennas, central controller, user navigation device with antenna, power module, telemetry commutation, optional GLOBALSTAR modem interface modules and harness;
- Attitude Control System (ACS) including; the actuator unit with the ACS controller, driver-flywheels (6 units) module, and the electromagnetic devices, startracker, two digital sun sensors and 6 sensors for the preparatory orientation on the Sun , fluxgate magnetometer and harness;
- Power supply system (PSS) including the Gallium Arsenide solar cell array, Ni-MH battery, controller and harness;
- Temperature Control System (TCS) including electrical heater, heat insulation, radiation surfaces, temperature sensors and harness;
- Spacecraft structure including frame and booms;
- TwinSat-1N separation system.

TwinSat-1M Science Measurements (prelim)

- Vector of DC electric field, +/- 250 mV/m, resolution 0.5 mV/m;
- Spectral and wave characteristics of 6 electromagnetic field components in ULF/ELF range (0.5 – 350 Hz);
- Spectrum of electric field oscillations in ULF/ELF and VLF/LF (3-300 kHz) ranges; amplitude and phase variations of ground based VLF/LF transmitter signals;
- Spectrum of magnetic field oscillations in VHF range (26 – 48 MHz);
- Variations of thermal and super thermal (0.3 - 20 eV) plasma parameters;
- Energy distributions of electron and ion fluxes with energies 0.3 – 300 eV for two directions, time resolution 0.1s;
- Lightning activity in the sub-satellite regions (optical measurements) – needed to discriminate against lighting-related events.
- IR Imager (to be decided)

TwinSat-1N

Characteristic	Value
Dimension	10 x 10 x 22 cm
Mass	2.5 kg
Power Average Peak	 2.2W 4.0W
Attitude control	3 axis stabilized, ~1^{o} accuracy
Intersatellite Link frequency	2.4 GHz
Telemetry to TwinSat-1M Fast channel (1.7-2.7 GHz)	 64 kbps
Telemetry to Ground Slow channel (145/435 MHz)	 4.8 kbps
Active livetime	>3years

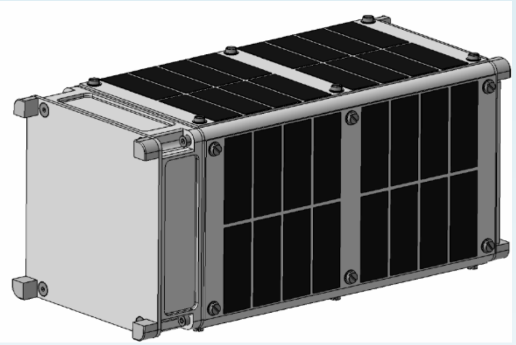
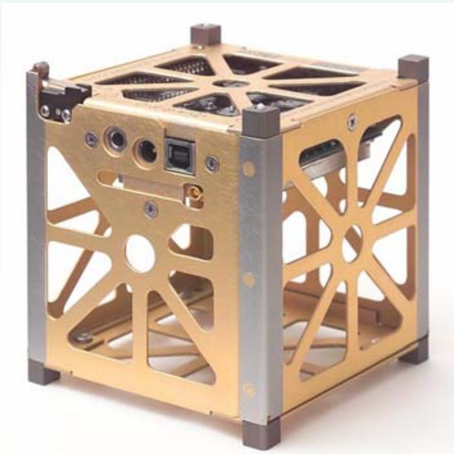
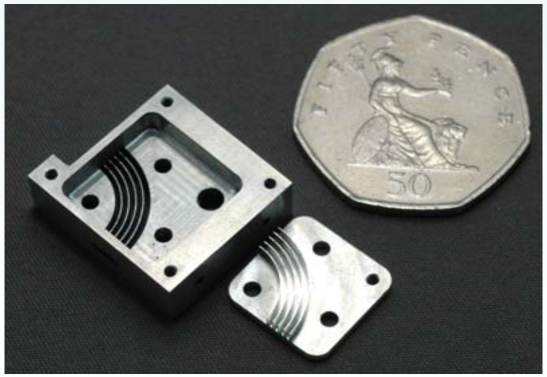


Figure 4. TwinSat-1M

TwinSat-1N Science Measurements (prelim)

- Variations of thermal and super thermal (0.3 – 20 eV) plasma parameters;
- Energy distributions of electron and ion fluxes with energies 0.3 – 300 eV for two directions, time resolution 0.1s;
- Wave form of ULF/ELF magnetic field oscillations (0.5 – 350 Hz), one or two components.

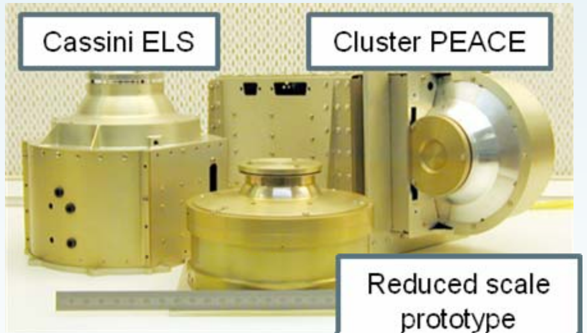




In-situ Plasma Instrumentation

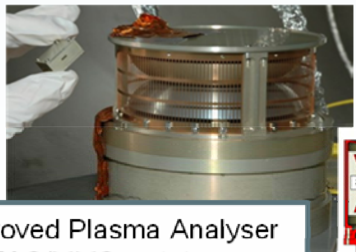
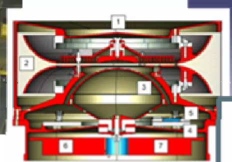
- Strong plasma instrumentation heritage
  - Magnetospheric missions: Cluster, Double Star, Polar
  - Planetary environments: Cassini, Mars and Venus Express, Mars 96 (launcher failed)
  - Cometary studies: Giotto
- Top-hat with enhanced capabilities
  - Solar Orbiter EAS
  - Baseline for EJSM, L-Depp
  - Other studies: MMS, Cross-scale
- Strong instrument development programme and state-of-the-art test and calibration facilities

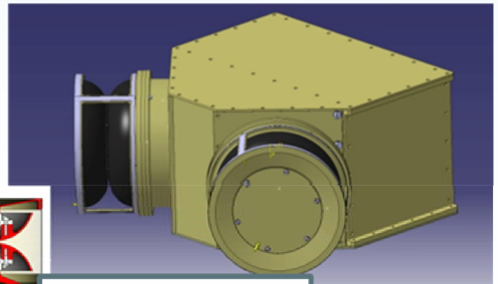

FONEMA on MARS96

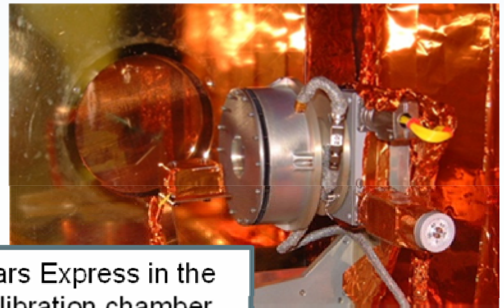

Cassini ELS

Cluster PEACE

Reduced scale prototype



Improved Plasma Analyser EAS/MMS prototype

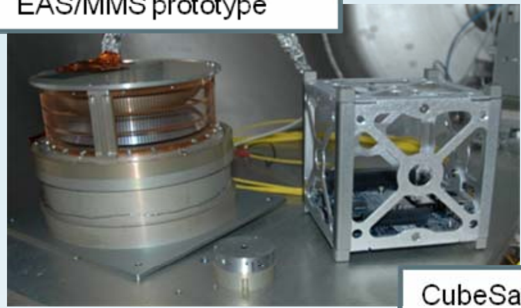

Solar Orbiter EAS CAD models


Mars Express in the calibration chamber

Instrument Miniaturisation

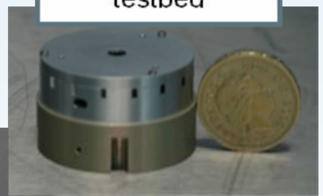
- Aggressive development programme
- Low resource analyser development using MEMS-based (Micro-Electro-Mechanical Systems) fabrication techniques
- Generic technologies suitable for creating highly integrated “matchbox” sized analyser systems: small, low resource, more capable
- Technology demonstration on UK TechDemoSat mission (2012)
- Strongly linked to CubeSat R&D programme

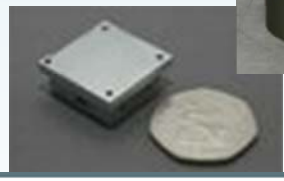
Improved Plasma Analyser EAS/MMS prototype



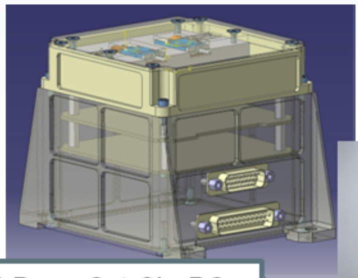
CubeSat

EJSM prototype testbed

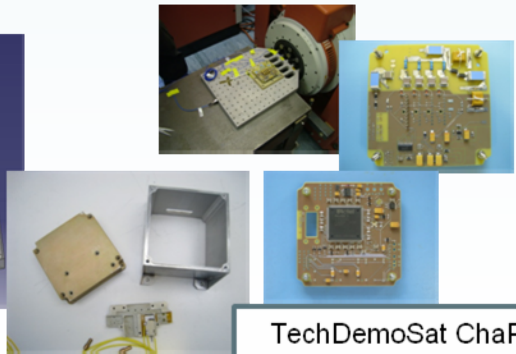




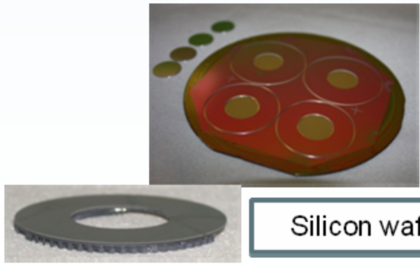
High temporal resolution proof-of-concept analyser



TechDemoSat ChaPS instrument CAD model



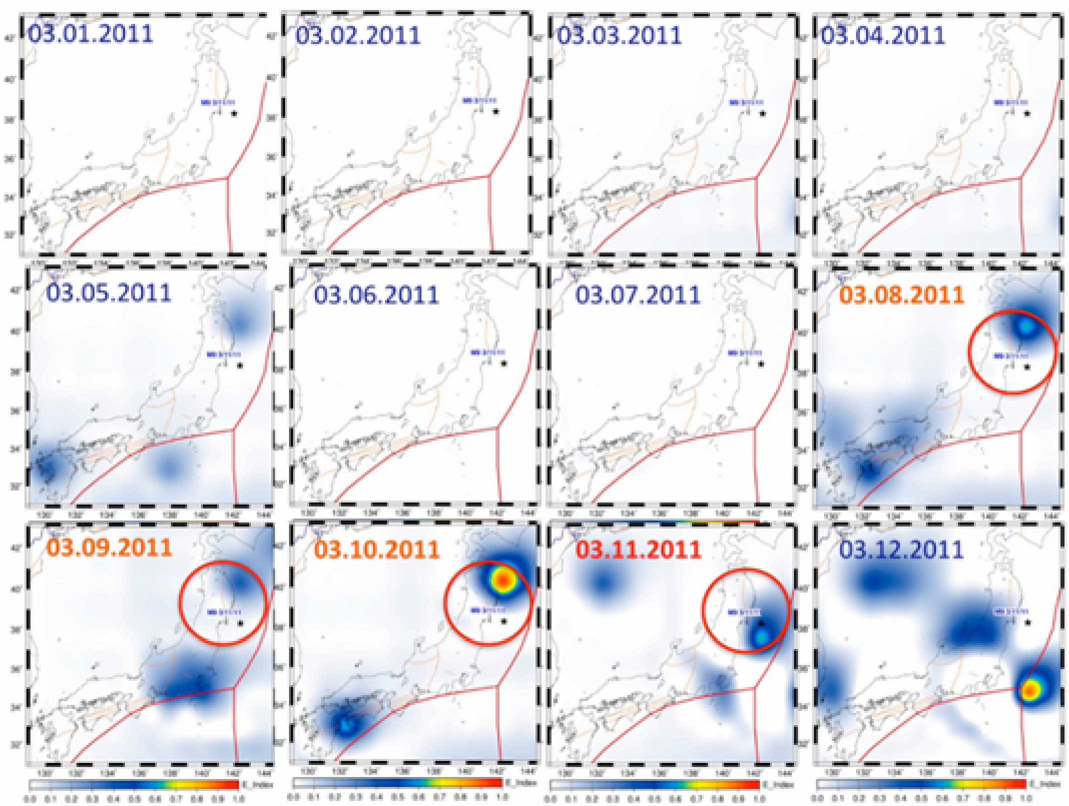
TechDemoSat ChaPS instrument components



Silicon wafer analyser

Infrared Measurements

- Outgoing long wave (8-12 μm) radiation intensity and thermal images of seismically active zones.

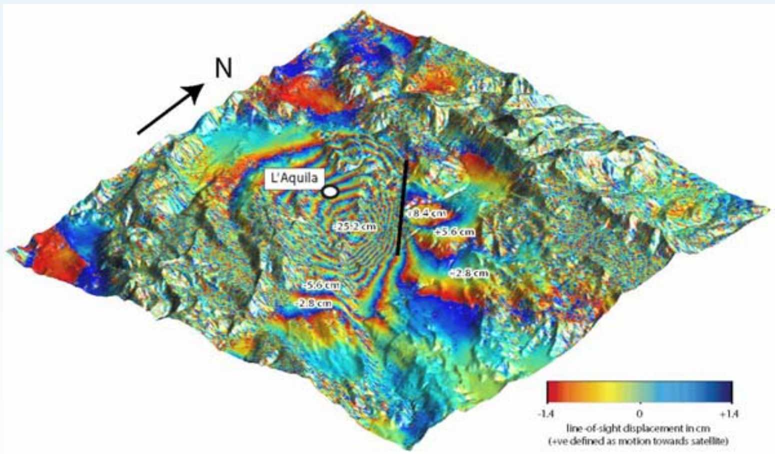


Ouzounov et al., 2011

Measurements from other Space Assets

- Space Weather monitoring to be able to take account of magnetospheric effects.

- Spatial strain maps of potential earthquake areas from InSAR data

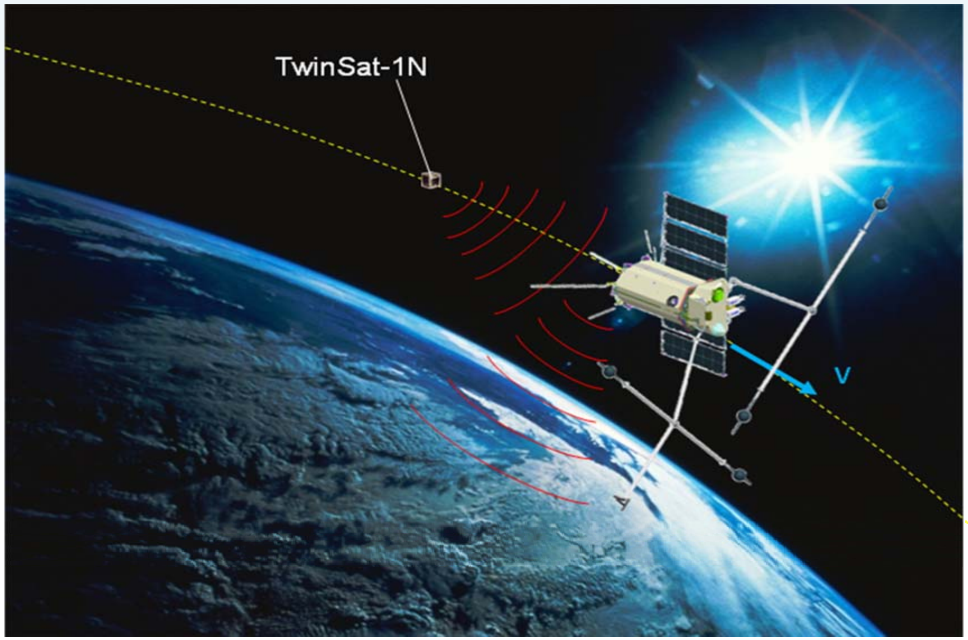


Walters

Ground Measurements

- Atmospheric gas composition;
- Radon emission and variations of radioactivity;
- Dynamics of aerosol injection;
- Atmospheric DC electric field and current variations;
- Spectral and wave characteristics of ULF/ELF/VHF electromagnetic emissions including the arrival direction finding and locating the radiation sources;
- Remote sensing of ionospheric disturbances through the registration of amplitude and phase variations of VLF/LF signals from ground-based transmitters at appropriate propagation routes;
- Seismic and magnetic field oscillations.

- We believe this to be an exciting, low-cost opportunity to study a very important phenomena which could ultimately lead to more effective earthquake and volcanic eruption prediction.



TwinSat

Thank You