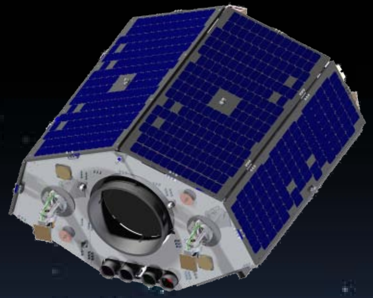
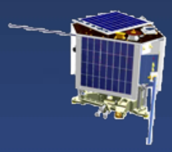
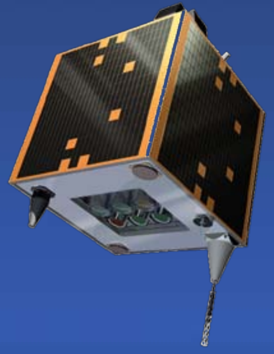
SATELLITE TECHNOLOGY LTD



Microsatellites

moving from research to constellations
meeting real operational missions





Professor Sir Martin Sweeting FRS

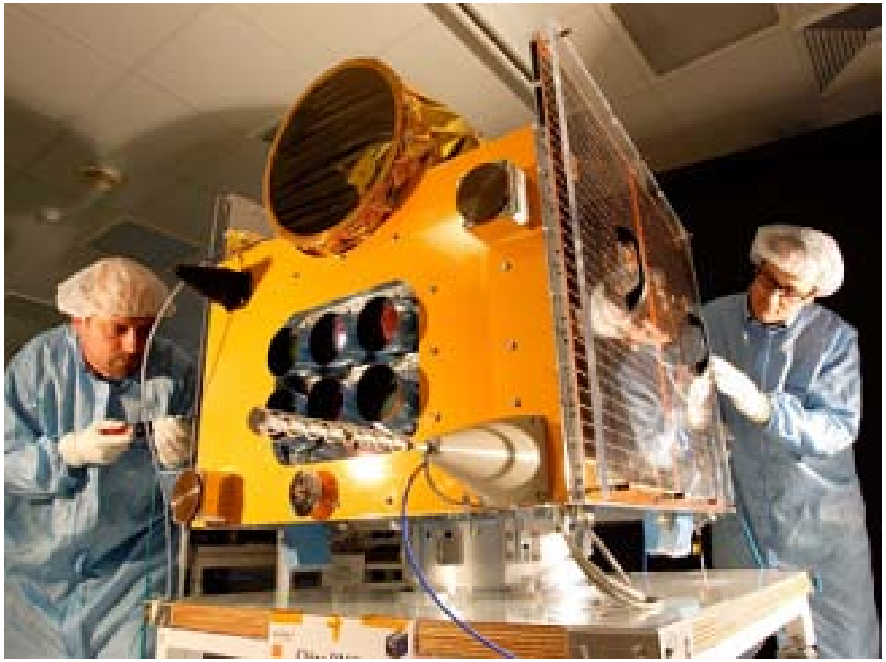
Director, Surrey Space Centre

Executive Chairman, SSTL

Nano-satellite Constellation Mission Idea Contest

Tokyo, 9-11 June, 2010

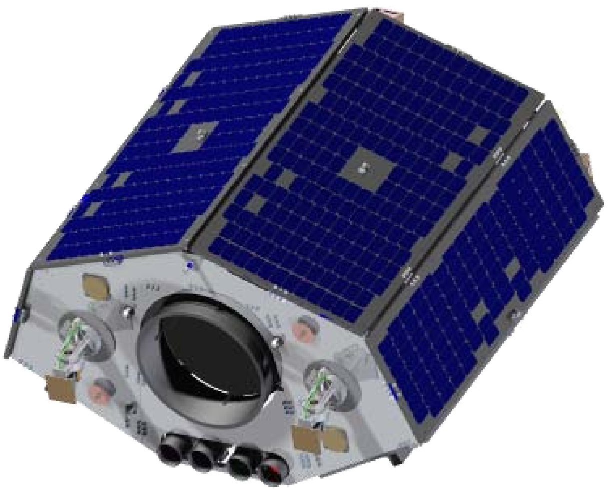
What are 'Small Satellites'?



= f (Mass + Time + Cost + Utility)

Innovative use of the latest technologies

What are 'Small Satellites'?

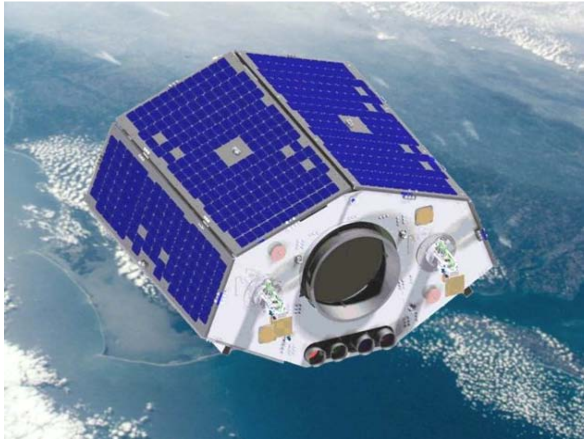


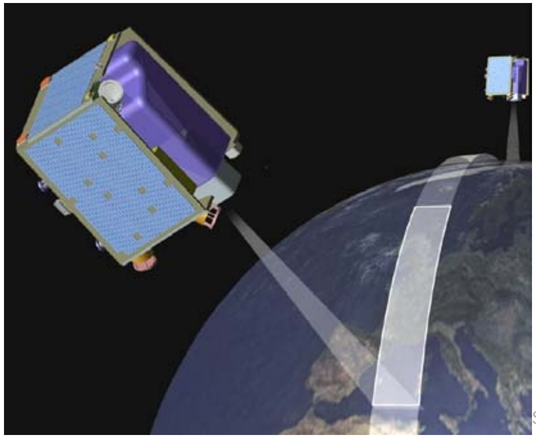
	Mass	*Cost*	*Time*
Large	1000kg+	$300M+	10yrs+
Small	>1000kg	$50M	3yrs
Mini	250kg	$35M	2yrs
Micro	100kg	$15M	1-2yrs
Nano	1-10kg	$5M	~1 yr
Pico	100gm	> $100k	>1yr

Small satellites and technology?

By exploiting enormous commercial investments, we can now build highly capable small, low-cost and reliable satellites built using the latest COTS terrestrial technologies…

Changing the Economics of Space

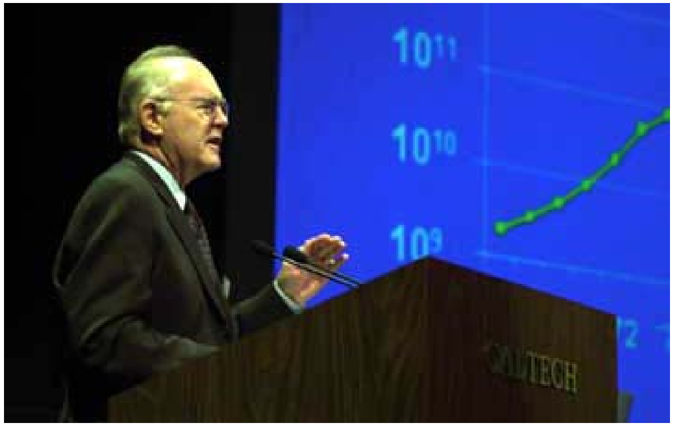


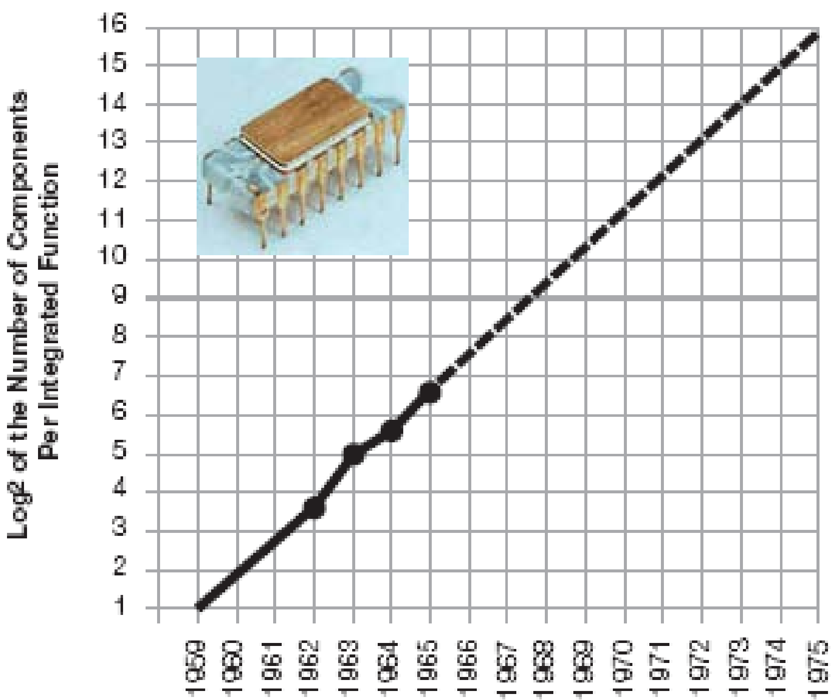


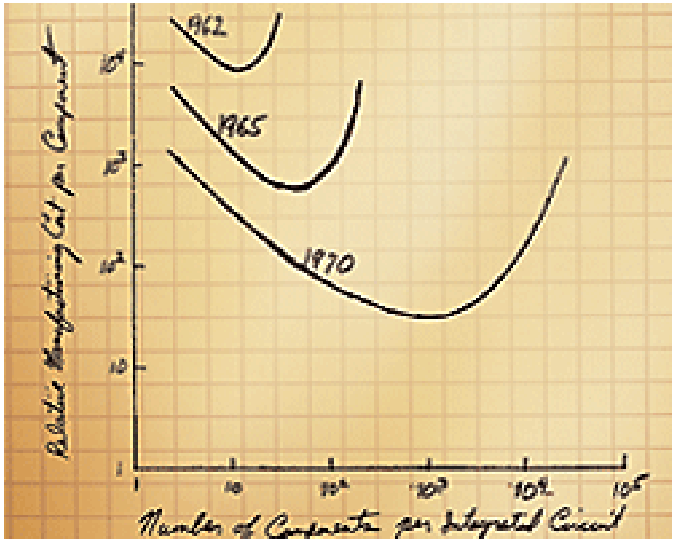
Moore's Law

Electronics, Volume 38, Number 8, April 19, 1965
"Cramming more components onto integrated circuits"

Intel co-founder Gordon Moore observed that the number of transistors on a chip was increasing exponentially: doubling every two years – or 10 times every 6.5 years

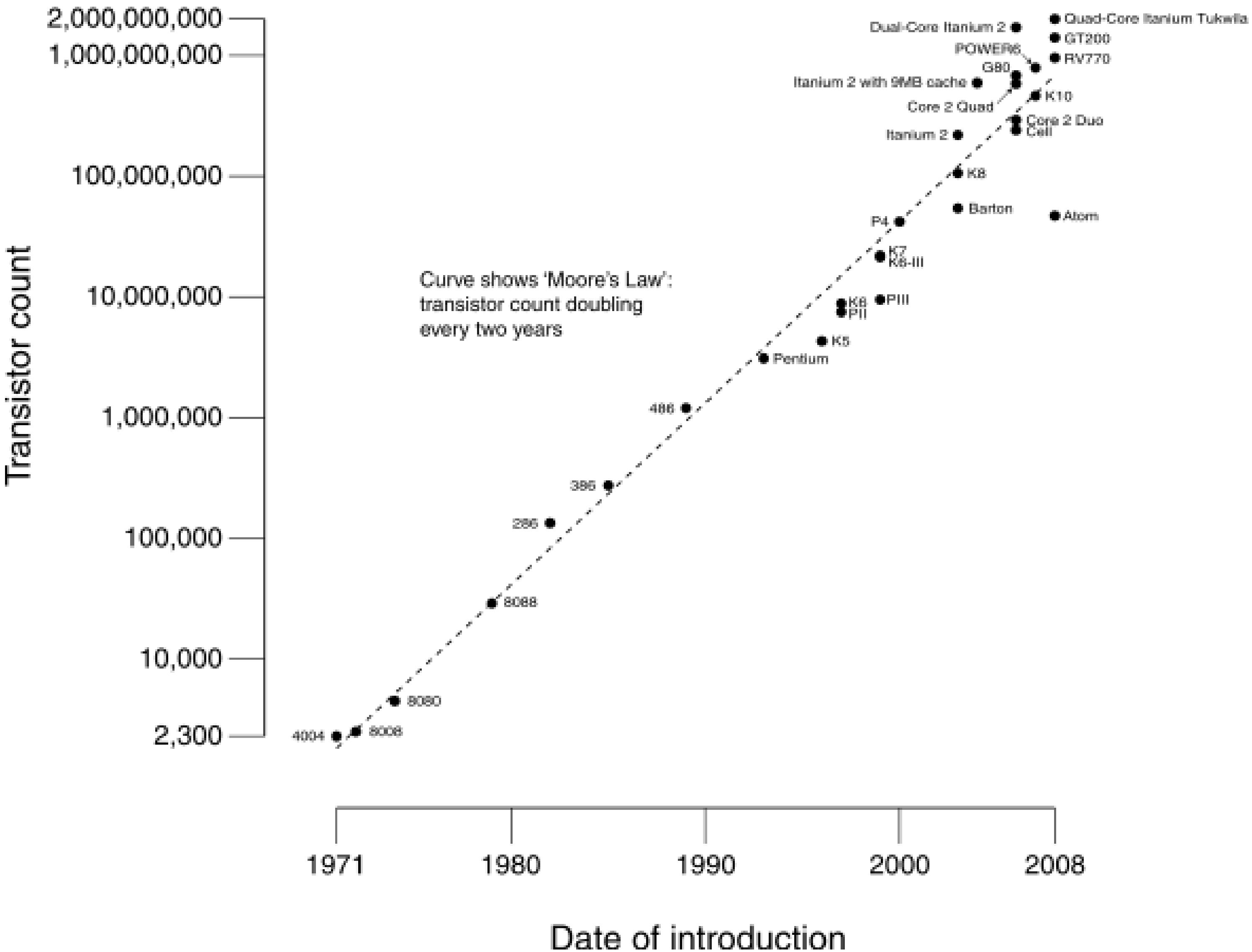






Moore's Law has held for 40 years

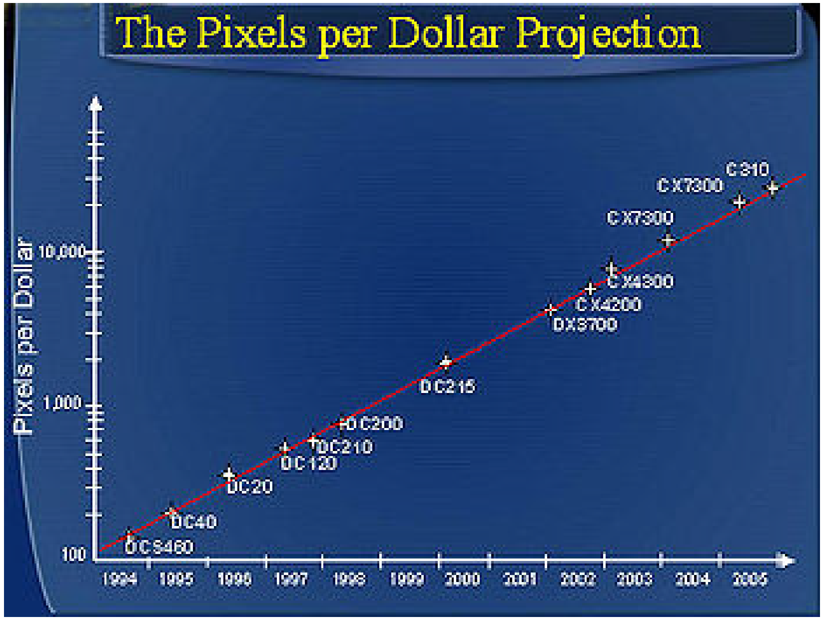
CPU transistor counts 1971-2008 & Moore's Law

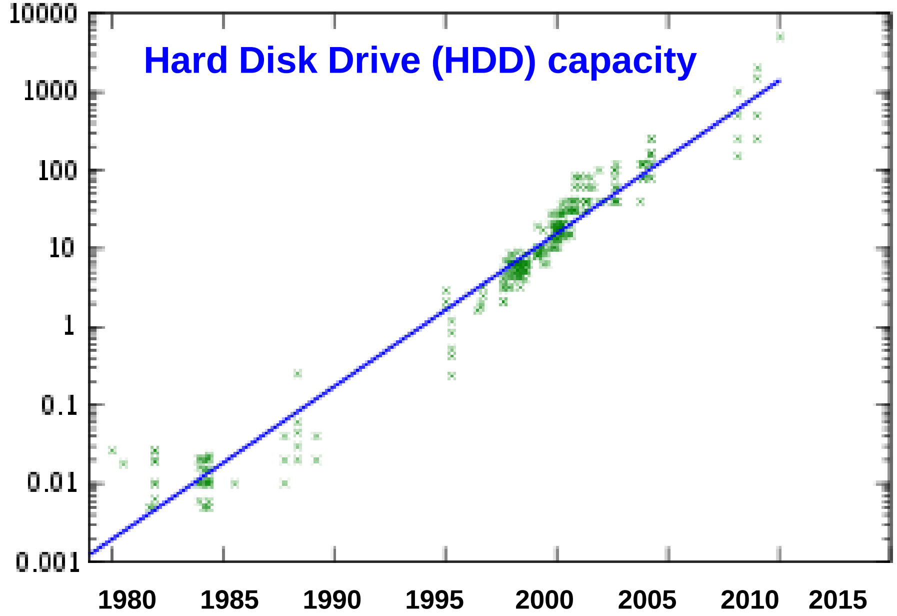


Implications

Almost every measure of the capabilities of digital electronic devices is strongly linked to Moore's law:

processing speed, memory capacity… and the number of pixels in digital cameras

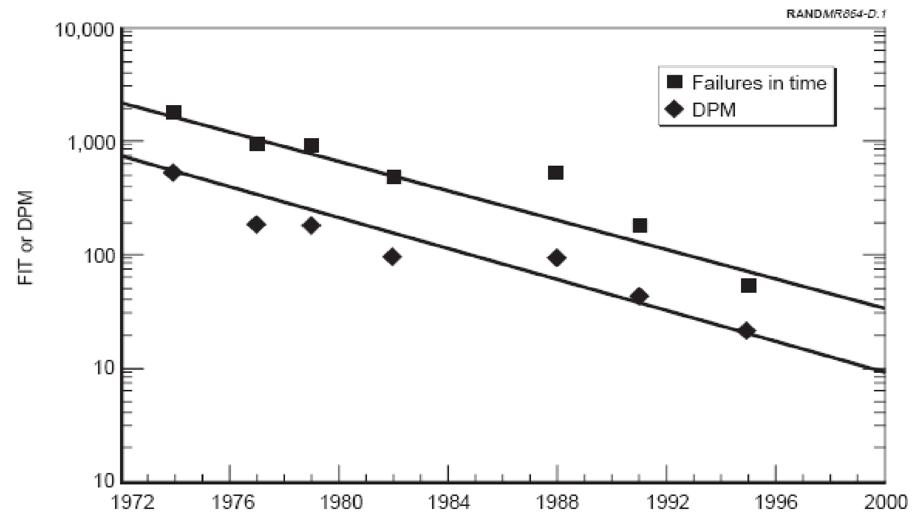




Revolution in manufacturing process

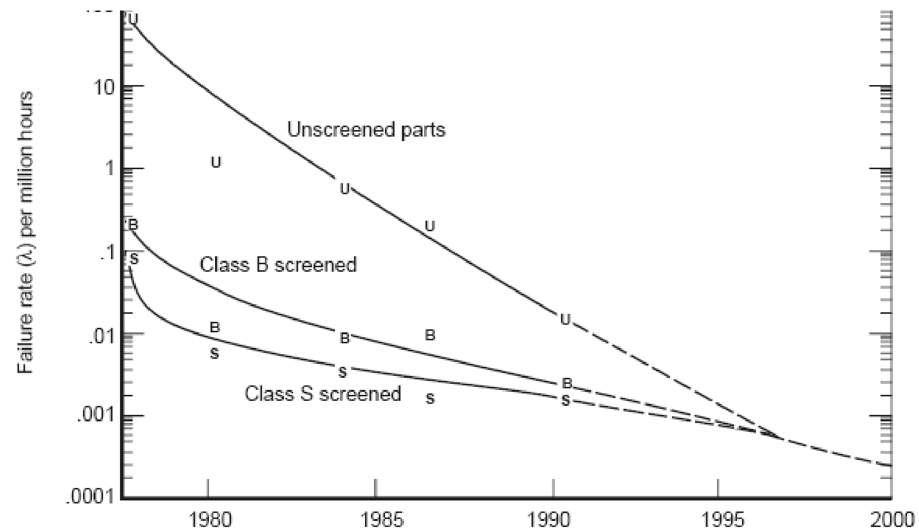
The enormous commercial market for industrial and consumer electronics has driven manufacturing processes for:

- **high volume, density**
- **low unit cost**
- **high reliability**



SOURCE: Reprinted by permission of Intel Corporation. Copyright Intel Corporation 1996.

This has resulted in dramatically reduced component failure rates



SOURCE: *Quality Magazine* (Plum, 1990, p.53).

COTS has become the new 'Hi-Rel'

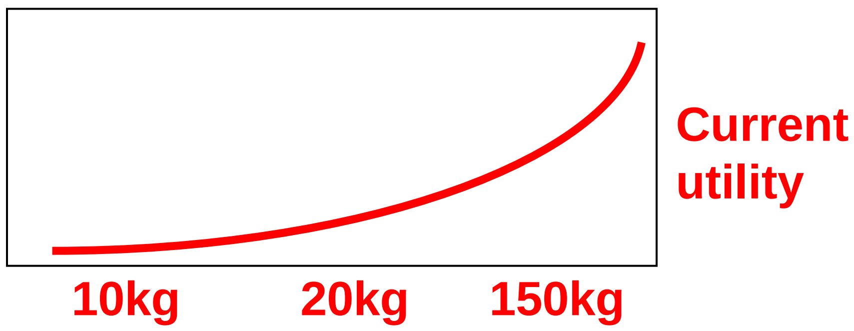
What are the questions?

Technology advances enables us to make satellite subsystems smaller and smaller…

Reduced mass beyond a certain point becomes largely irrelevant – whereas smaller <u>volumes</u> means that we run into limitations placed by the laws of physics…

- **Very limited surface area for power generation**
- **Limited RF power available for bulk data transfer**
- **Limited propellant for orbit changing dV**
- **Limited aperture for instruments restrict resolution & s/n**

This begins to restrict applications – a tiny satellite platform and a large instrument makes little sense



What has been the Surrey Experience?

How did it start?

What can mini / micro / nano-satellites do?

How did it become sustainable?

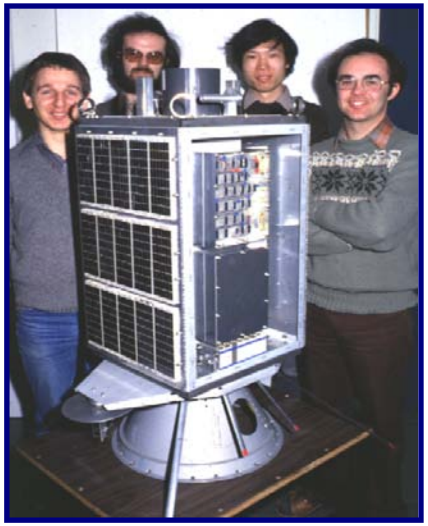
Where are the markets?

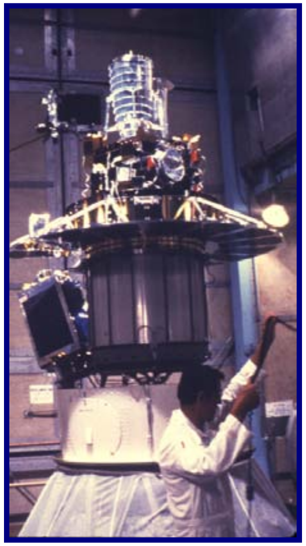
Where is it going….?

Space @ Surrey … in the beginning

A hobby that turned into research … and then into a business

1970 – 1985: 5 years tracking satellites and then built 2 microsatellites

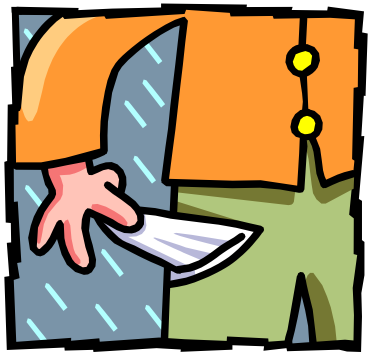




How to continue…

UoSAT-1 funded from donations from industry, AMSAT, govt, volunteers (~£250k 1981)

UoSAT-2 funded by UoS (~£0.5M in 1984) - but could not repeat this investment



Surrey needed to establish a commercial company to attract & handle external funding to build satellites

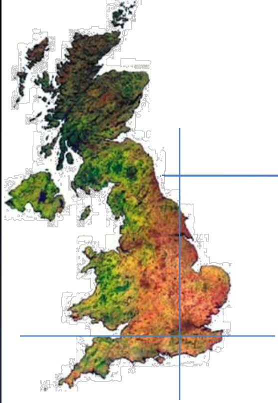
SSTL formed in 1985

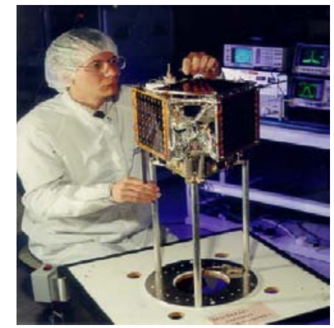
Wholly-owned by UoS

Objective: to fund academic research in small satellites at Surrey

“fast-forward” to 2010…

Space @ Surrey today….





Surrey Space Centre: **formed in 1979 at the University of Surrey, pioneering microsatellites — now 100 academic researchers specialising in space engineering.**

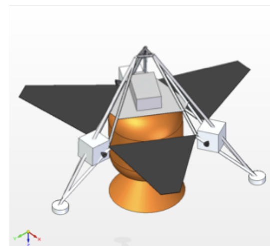
SSTL: **commercial company spun out from the University in 1985 to exploit the fruits of SSC research**

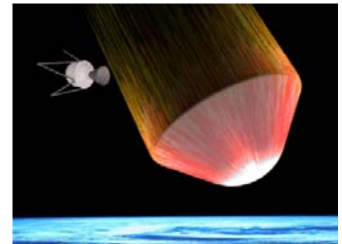
SSC+SSTL: **achieving a synergy of academic research and commercial exploitation**

Space at Surrey - research

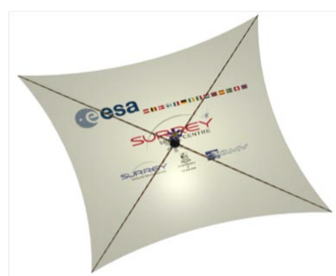
Academic space research…
Looking over the horizon…

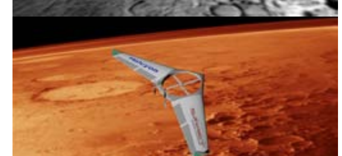
- Antennas & RF systems
- Astrodynamics
- Autonomy in Space
- Control systems
- Embedded systems
- Planetary Environments
- Propulsion
- Remote Sensing
- Satellite systems
- Signal Processing
- Space Robotics

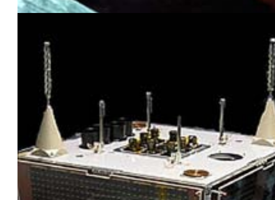


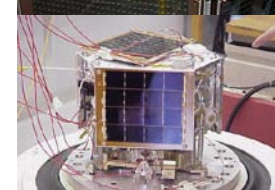


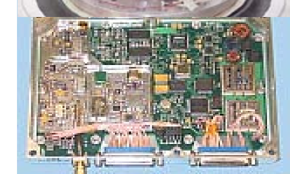
100 academic researchers
Multi-disciplinary
Systems-oriented
Harsh environments



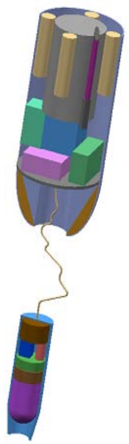




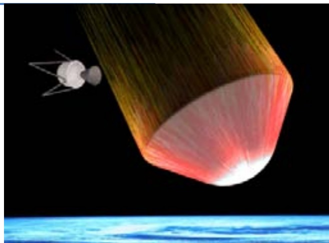


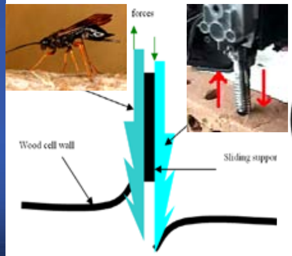


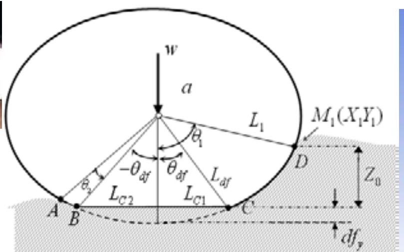
Robotic Space Exploration

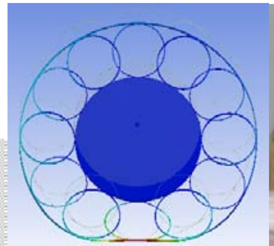


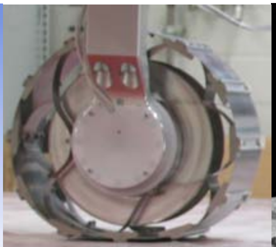
- Bio-inspired drill for planetary missions
- RDV and Docking/ Teleoperation, on-orbit servicing
- Mars Unmanned Aerial Vehicle (UAV)
- ESA and PPARC funded ExoMars rover studies
- Micro-Rovers, traction control, tracked and legged vehicles
- Entry Descent and Landing systems (EDLS)

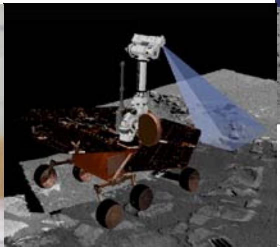


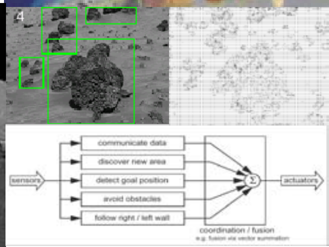




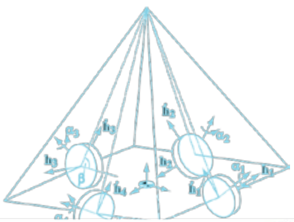


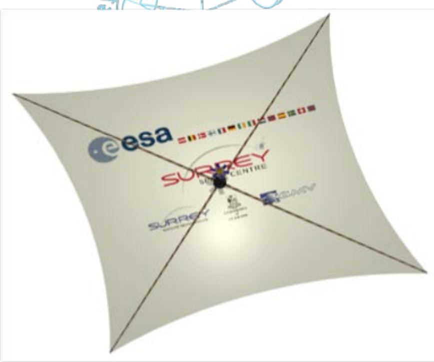




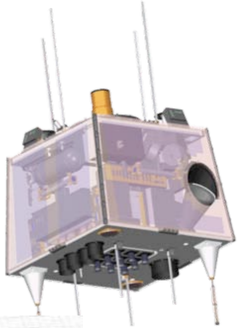


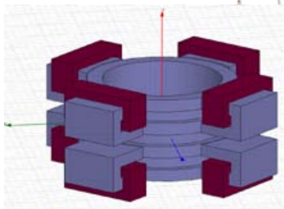
Space Vehicle Attitude Control

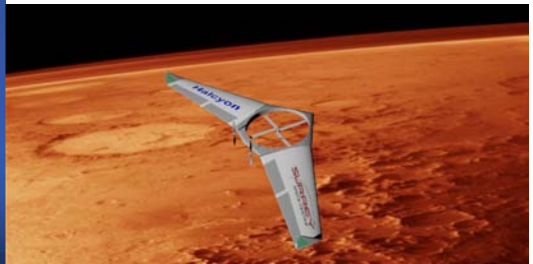


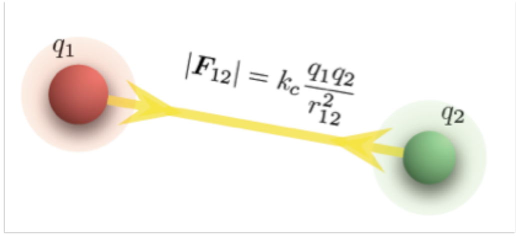


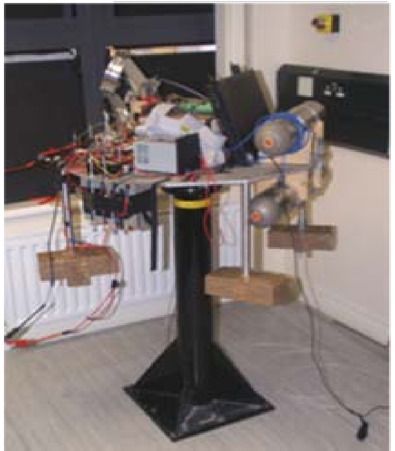
- CMGs for agility/stability
- Combined attitude control/energy storage
- Underactuated control
- EM levitation, magnetic bearings
- Optical laser ISL control
- Quad-rotor aerobot
- Solar sails/kites
- Electrostatic formation flying
- Lorentz force formation flying



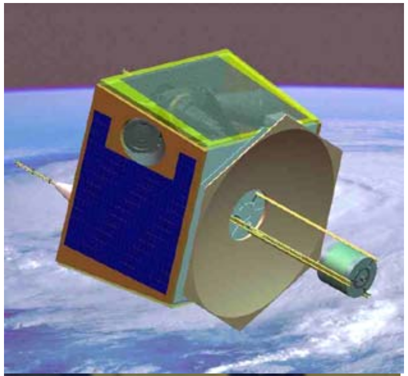


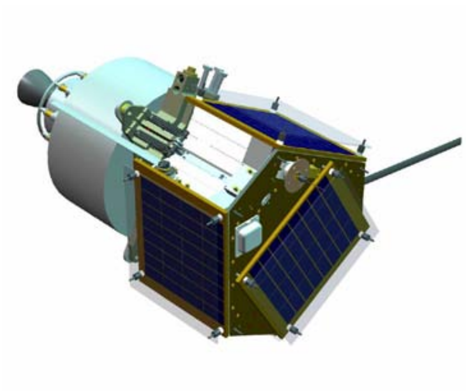






Space Vehicle Orbit control



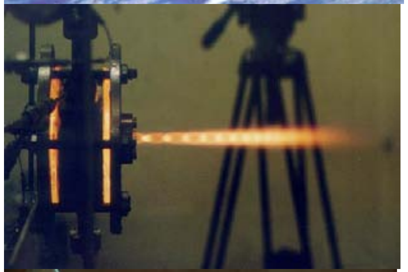


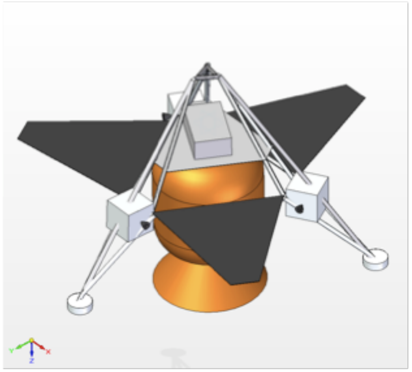
Electro-thermal Resistojets (xenon, butane, nitrous oxide)

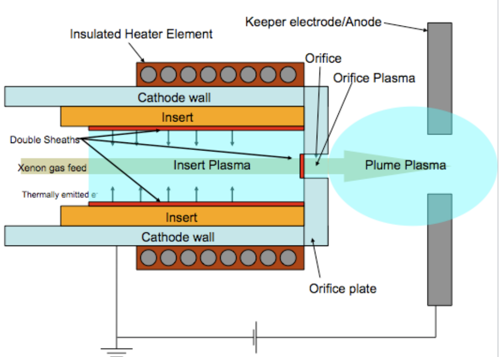
Hybrids (hydrogen peroxide)

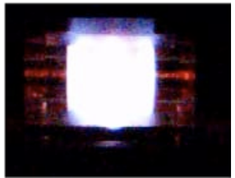
PPT Thruster

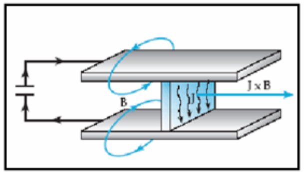
- Hollow Cathode Thruster
- Helicon Double Layer Thruster
- Field Emission Electric Thruster
- Solar Thermal Thruster
- Monopropellant Thruster





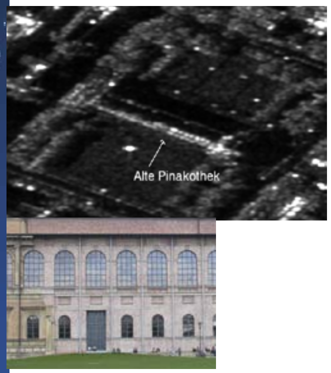






Space Remote Sensing

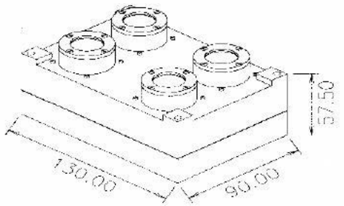
SAR feature extraction

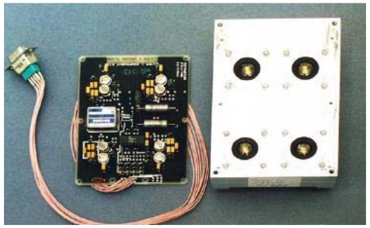


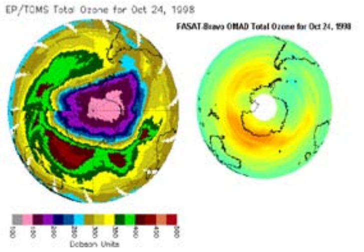
SAR material classification

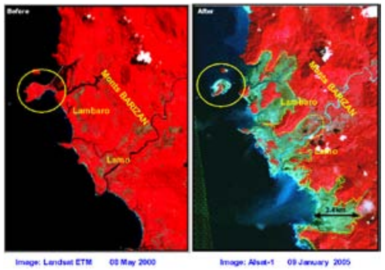
Thermal IR imaging

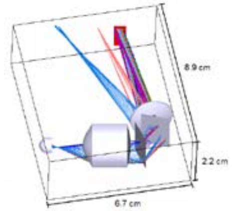
- **Hyperspectral remote sensing instrument for vegetation stress monitoring**
- **low-cost, low-mass Infra-Red optical systems**
- **low-cost Ozone monitor, and analysis of its flight results**
- **Low cost Ozone and SO_2 monitoring**
- **SAR feature extraction and materials clasification from double reflections**
- **Bi/multi-static L/X SAR**
- **Intelligent on-board image processing for change detection**
- **Optical feature detection through image sequences**
- **topside ionospheric sounding concepts**
- **GPS Reflectometry for sea-state monitoring (bi-static SAR scattering)**





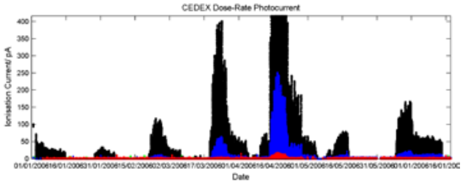


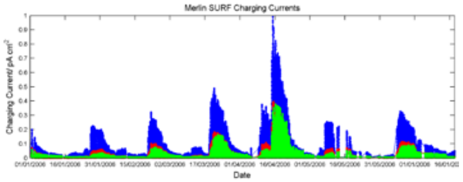


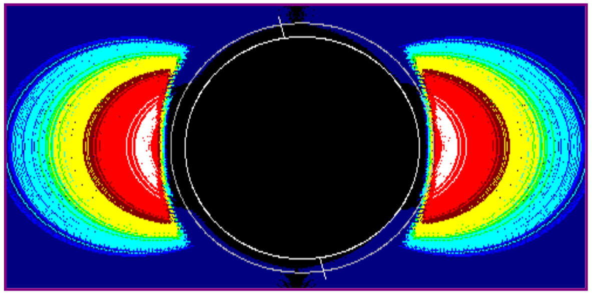


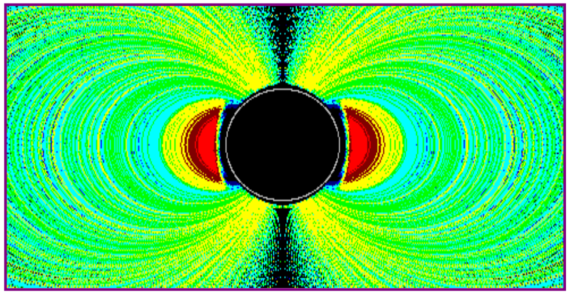
Space Weather

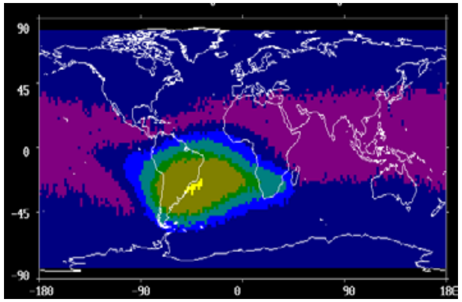
- Miniature radiation monitors, environment and effects research
- The effects of the space radiation environment on modern COTS components
- 22 instruments flown on SSTL satellites over 28 years in LEO and MEO
- Characterising the MEO for Galileo

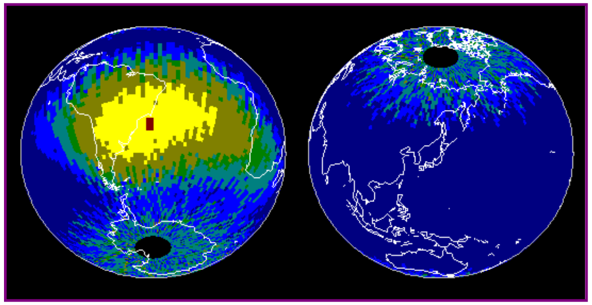


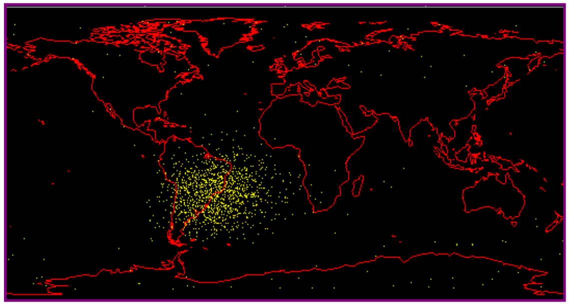




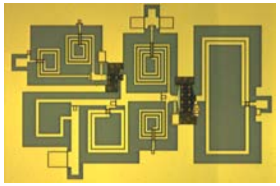




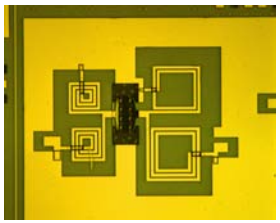




RF & OBDH & Nanosatellites



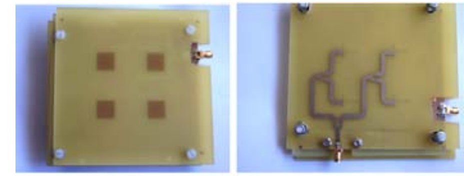
High-Efficiency MMIC Class-E GaN Power Amplifier



High-Efficiency MMIC Class-F GaN Power Amplifier

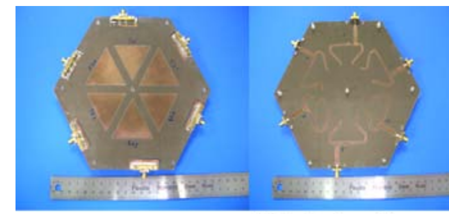
RF and Antenna Systems

- **Novel Smart Antennas**
- **Active, Integrated Antennas**
- **RF/Microwave**
- **Power Amplifiers**
- **Nano/Pico-Satellite Comms.**



(a) View from the front (b) View from the back

Broadband Dual-Polarized Planar Array

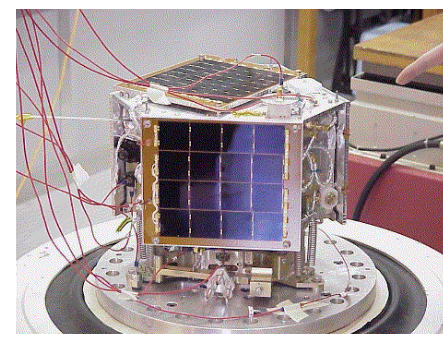


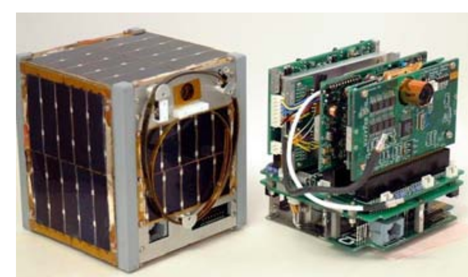
(a) Front view of the array (b) Back view of the array

Beam-Switching Smart Antenna

On-Board Data Handling Systems

- **Distributed computing for satellite clusters**
- **Reconfigurable System-on-a-Chip**
- **SPACEWIRE, Robust Architectures**
- **Optimisation of IEEE 802.11 for ISLs**
- **Wireless Sensor Networks**
- **Integrated Image Processing**





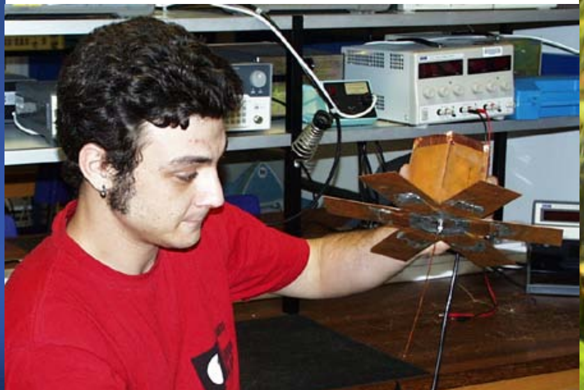
Academic space training

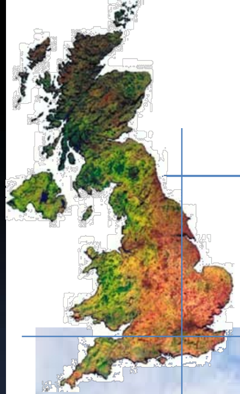
Space Degree Courses at Surrey

- Space Technology & Planetary Exploration (BEng/MEng)
- Physics with Spacecraft Technology (BSc/MPhys)
- Aerospace Engineering (BEng/MEng)

- Space Technology & Planetary Exploration (MSc)
- Satellite Communications Engineering (MSc)
- Mobile & Satellite Comms. Engineering (MSc)
- Satellite Engineering (MSc)

Short Courses for Industry, KHTT Training, Outreach





SSTL – space business

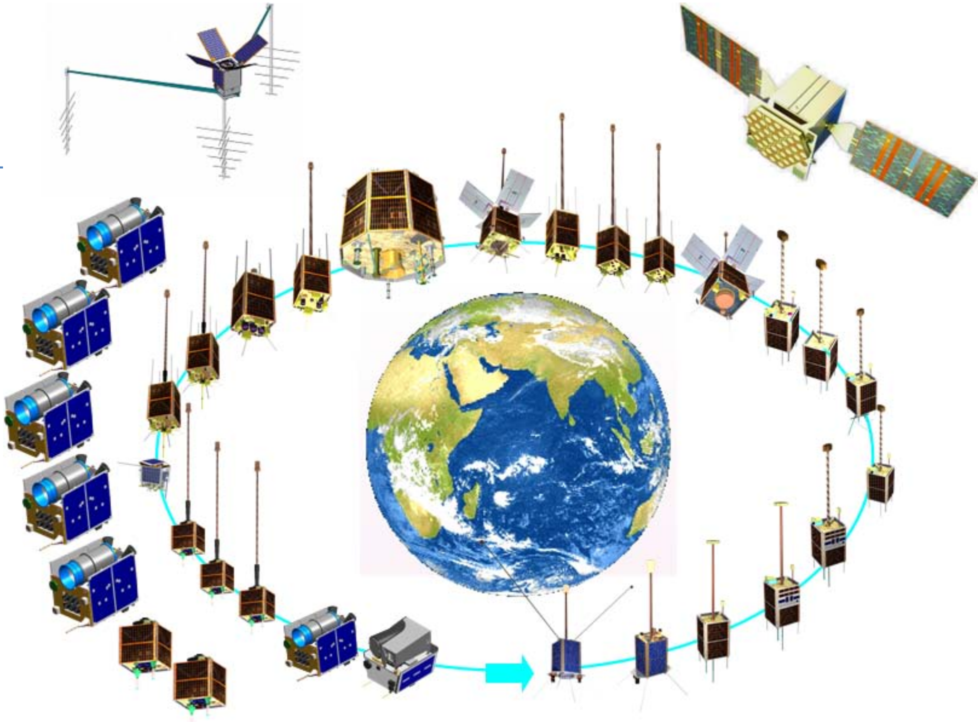
SSTL, formed in 1985, employs 320 staff in the UK & USA. Primary shareholder since 2009 is EADS Astrium with Surrey University

Application of small satellites to real needs… at affordable costs

Stimulating sustainable business opportunities

Since 1981….

- 34 Satellites launched
- >200 satellite-years on-orbit experience








BNSC BRITISH NATIONAL SPACE CENTRE · esa · deimos IMAGING · MDA · Los Alamos NATIONAL LABORATORY · EADS astrium · ThalesAlenia Space

100% mission success in last 10 years – all delivered on time & in budget

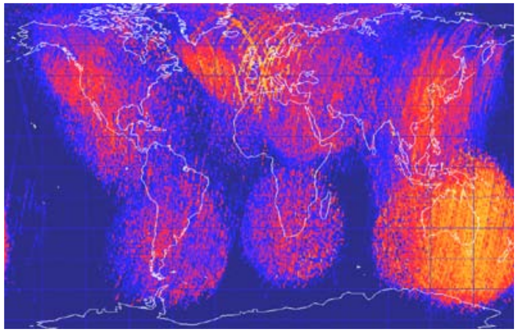
- **Question:** if they are so small and low cost, then they cannot do anything useful…?

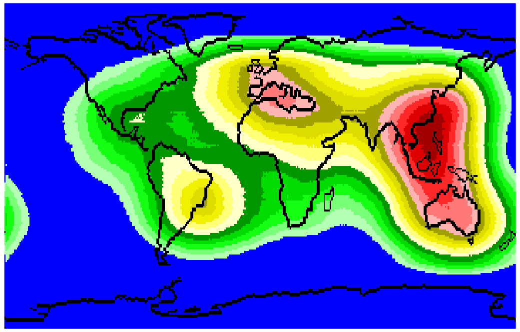
  - Communications
  - Technology Verification
  - Earth Observation
  - Space Science
  - Navigation
  - Military & Civil applications

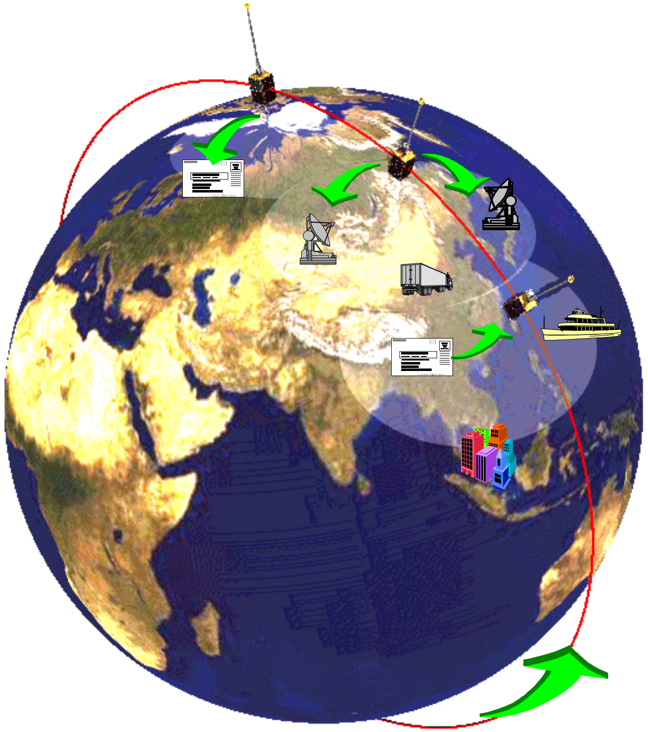
Indeed, they can do some things that are not practical with large satellites!

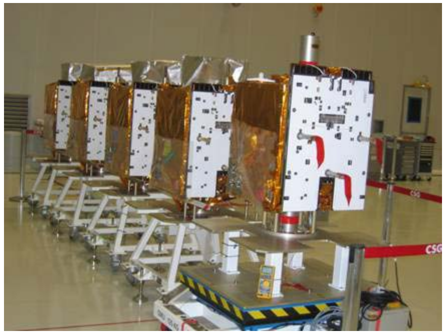
LEO Communications

- Digital S&F ‘email’ comms to remote regions
- Early ‘internet’ (1990’s)
- Advanced DSP payloads
- Signal monitoring & analysis
- Single satellite provides global reach





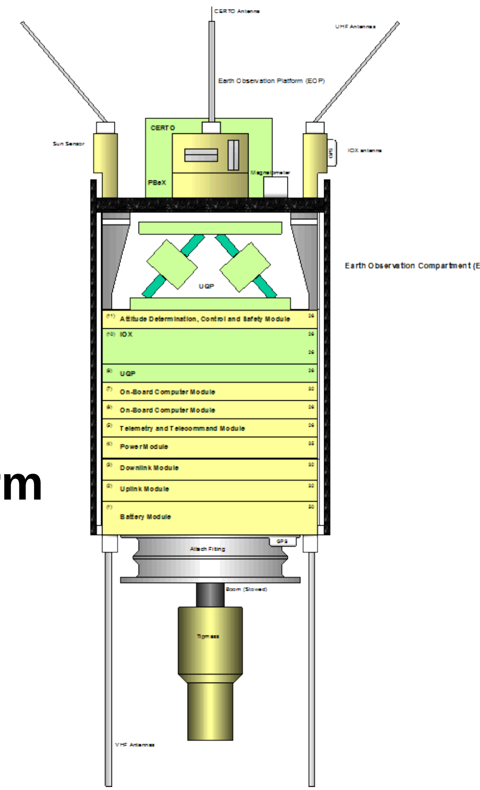




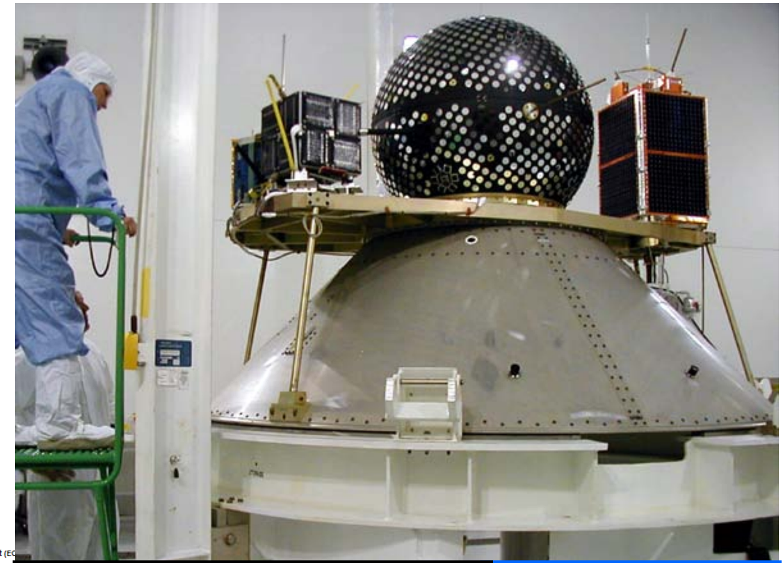
French ESSIAM system

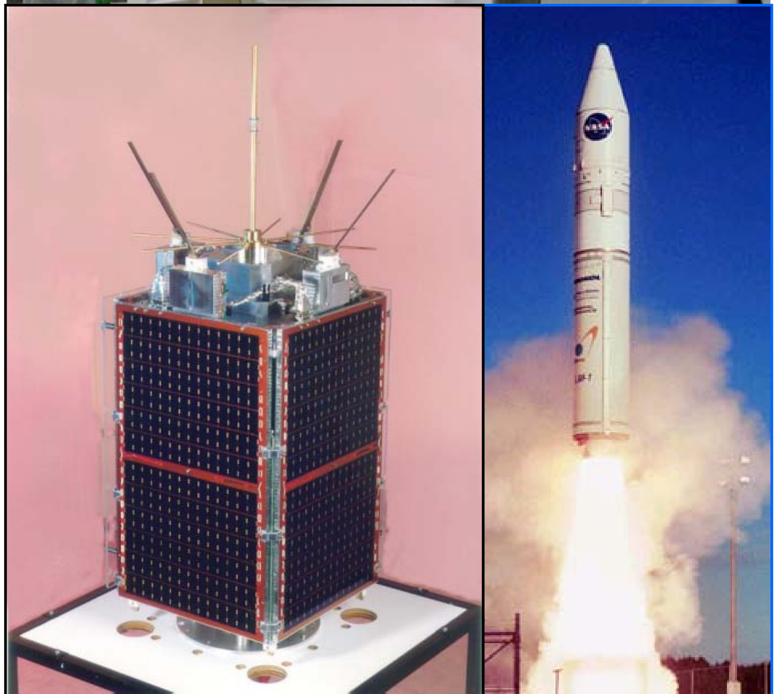
Technology Verification

USAF-STP FCT PICOSat



- Polymer batteries
- Ionospheric tomography
- Ultra-quiet platform



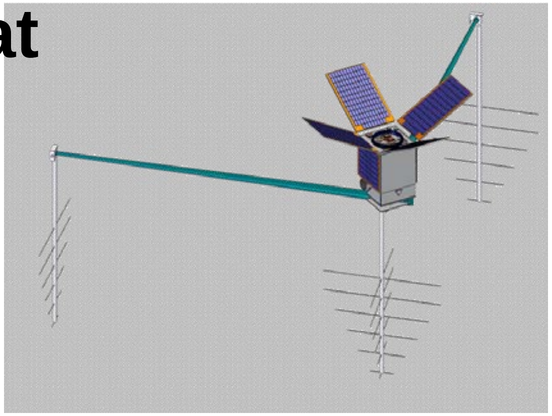


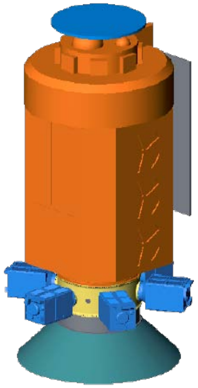
Research

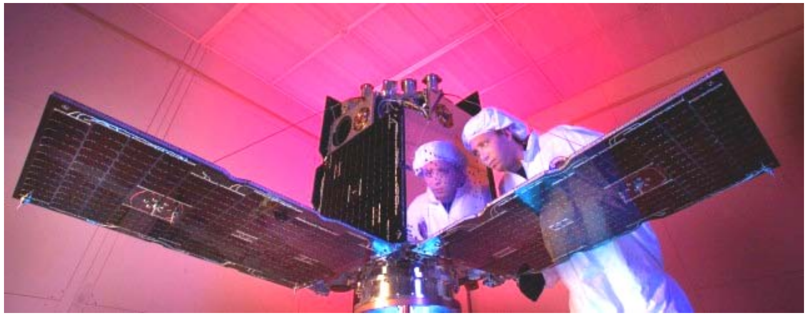
CFESat

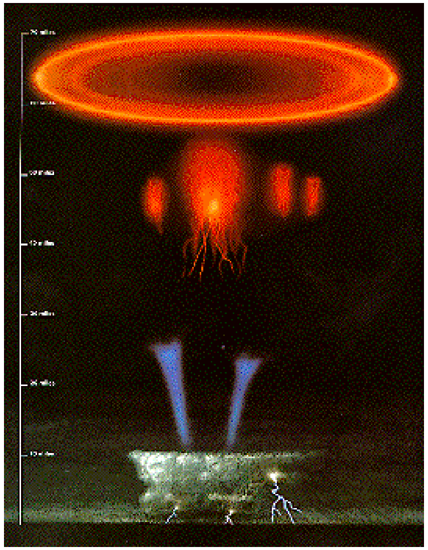
Mission detects broad-band emission from different types of lightning

Flight experiment of LANL's new FPGA-based software radio for VHF/UHF spectrum monitoring







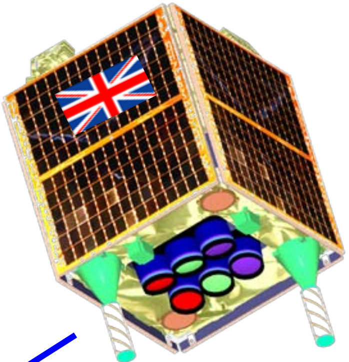


Launched on USAF ATLAS EELV

Cape Canaveral March 2007

Microsatellites & the Internet…

UoSAT-12: the first civil satellite to have an Internet address (1999)



UK-DMC: carrying a Cisco router demonstrated the power of microsatellites + internet

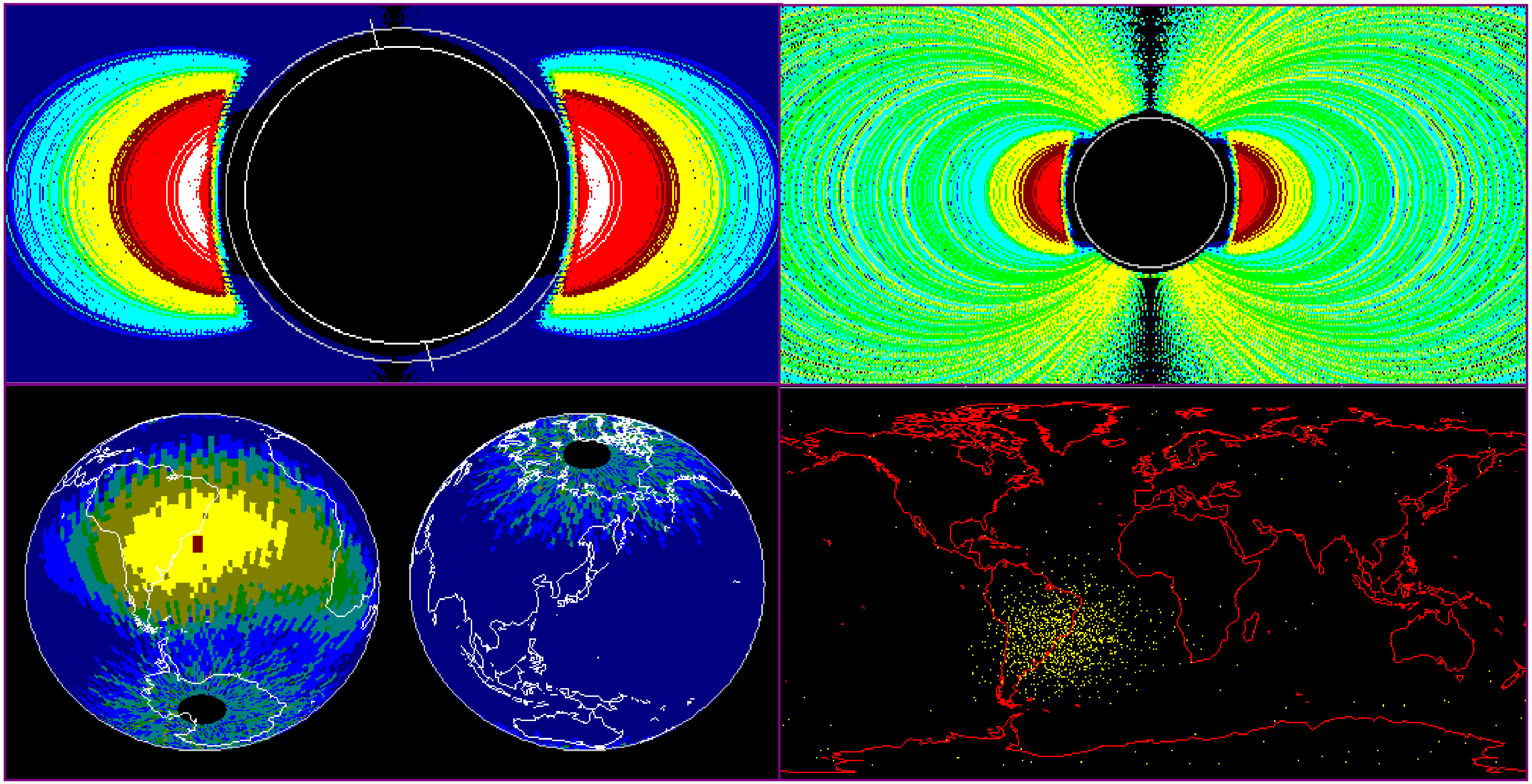
VMOC: an IP- based application for satellites, using an available IP-based infrastructure – first demonstrated using UK-DMC to USAF at VAFB in 2004

Task

secure Internet

image

Space Weather

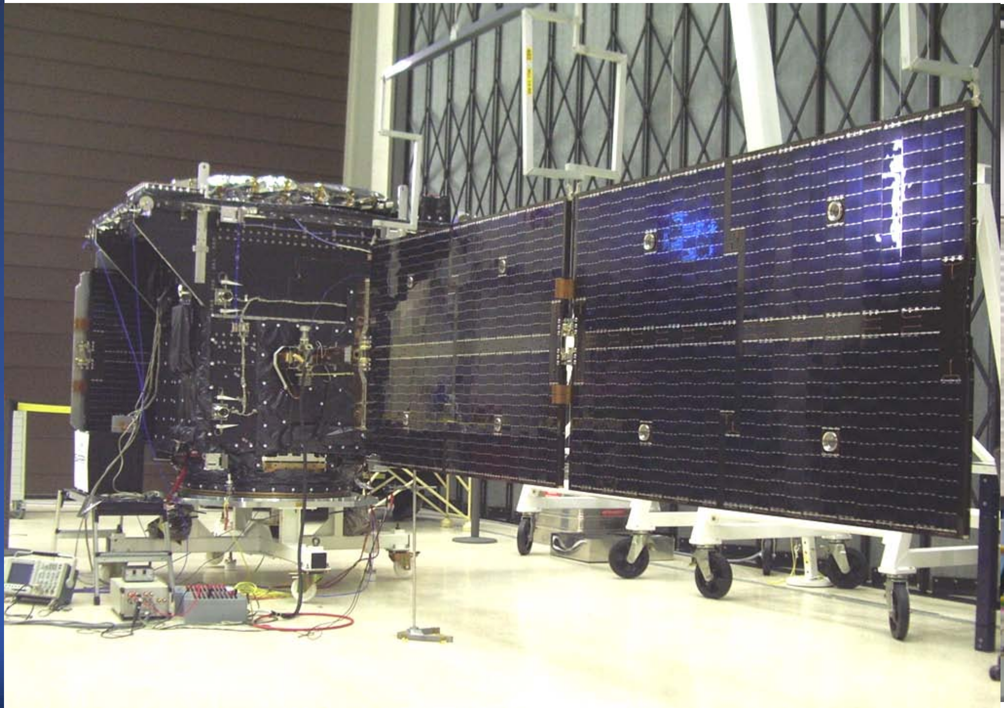


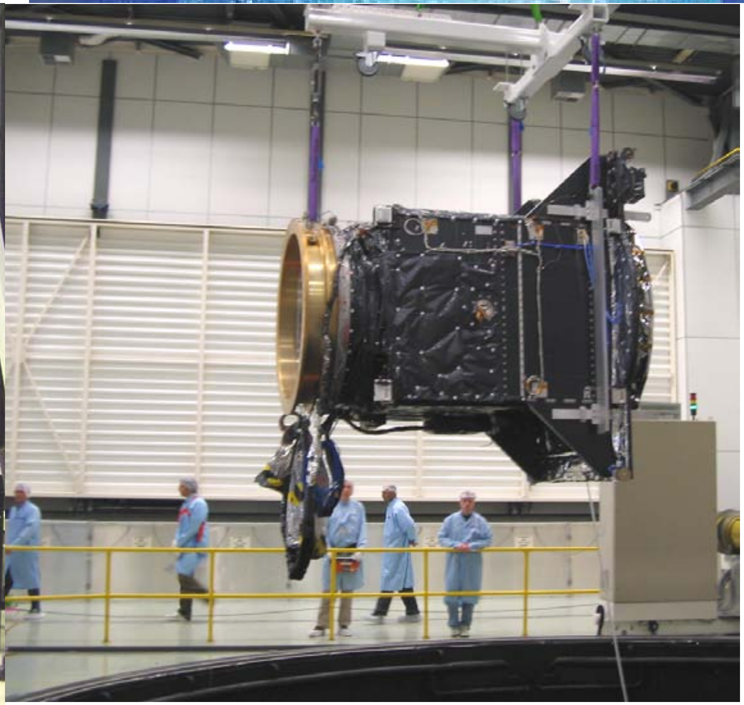
The effects of the space radiation environment on modern COTS components

GALILEO: Navigation for ESA

SSTL

- To secure Europe's Galileo navigation system
- Built by SSTL in 30 months, $30M, launched on time; 660kg
- Now in 5th year – exceeding its 2.5 years planned operational lifetime
- Awarded 14 satellites for FOC with OHB (DL)





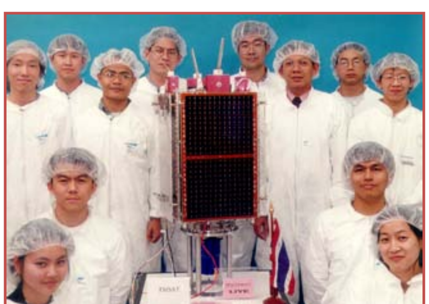
International co-operation

- Kazakhstan
- USA
- Nigeria*
- Turkey*
- Algeria*
- China
- Malaysia*
- Singapore
- Thailand
- Chile*
- Portugal
- S.Korea
- S. Africa
- Pakistan*

- Train engineers as nucleus of a space agency & industry
- Launch first national microsatellite & demonstrate its applications & utility
- Establish national space facilities & capabilities
- Create new space SMEs
- Six space agencies trained and at least 3 space SMEs

Korea

Portugal



Thailand

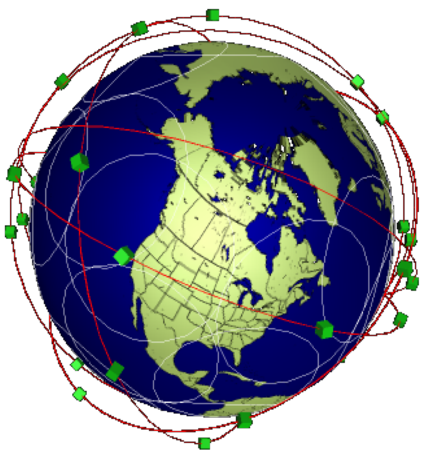
Malaysia

Algeria

Nigeria

Chile

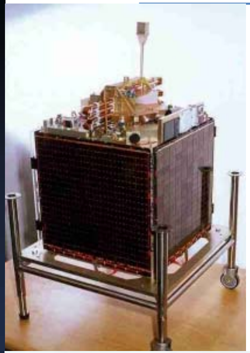
Constellations & Swarms

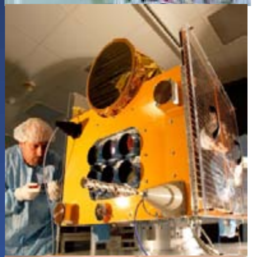


'Constellations' and 'Swarms' of small satellites enable an affordable capability to achieve:

- **Rapid revisit – increased temporal resolution**
- **Contemporaneous data gathering – data merging**
- **Particularly for Earth Observation**

The evolution of EO microsatellites






1980's experimental research

- UoSAT-1
- UoSAT-2

1990's experimental proof-of-concept

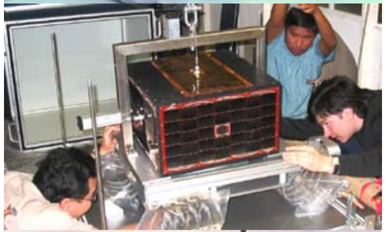
- UoSAT-5, UoSAT-12
- KiTSAT-1, KiTSAT-2, KiTSAT-3
- ThaiPhatt, FASat-B, TiungSAT-1, PoSAT-1
- Tsinghua-1, SunSAT-1

2000 demonstration

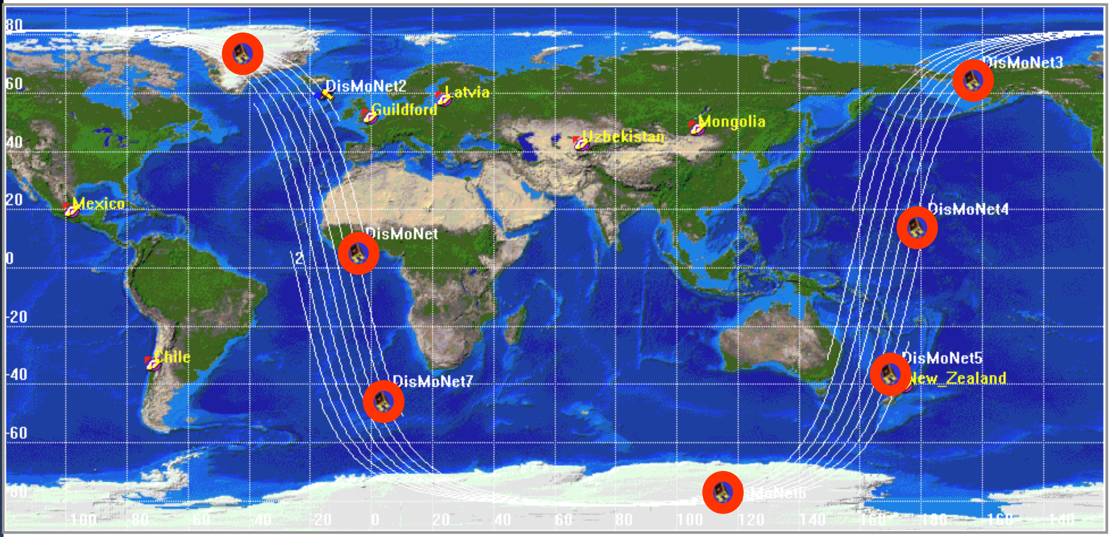
- BIRD
- PROBA
- LAPAN-TUBSAT

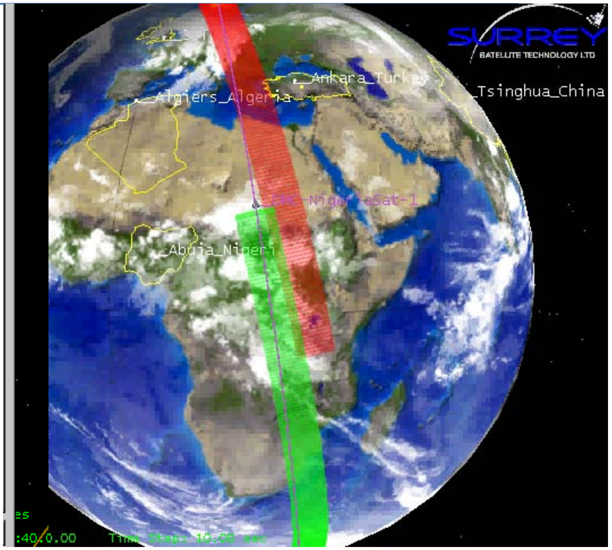
2005 operational

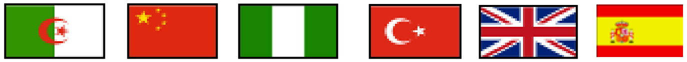
- DMC: Alsat-1, Beijing-1, BILSAT-1
  NigeriaSat-1, UK-DMC
- RapidEye (x5)

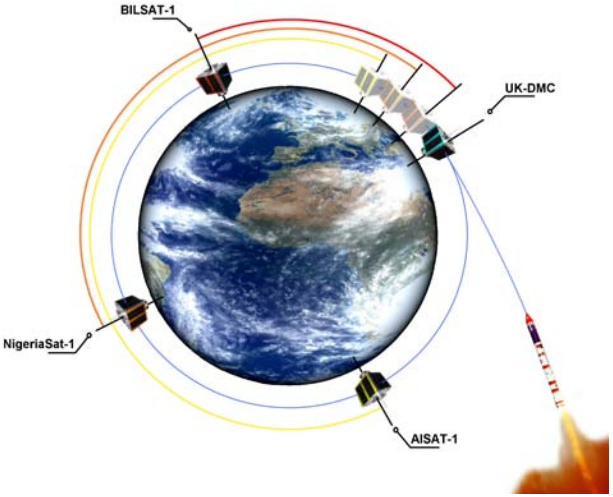



Disaster Monitoring Constellation







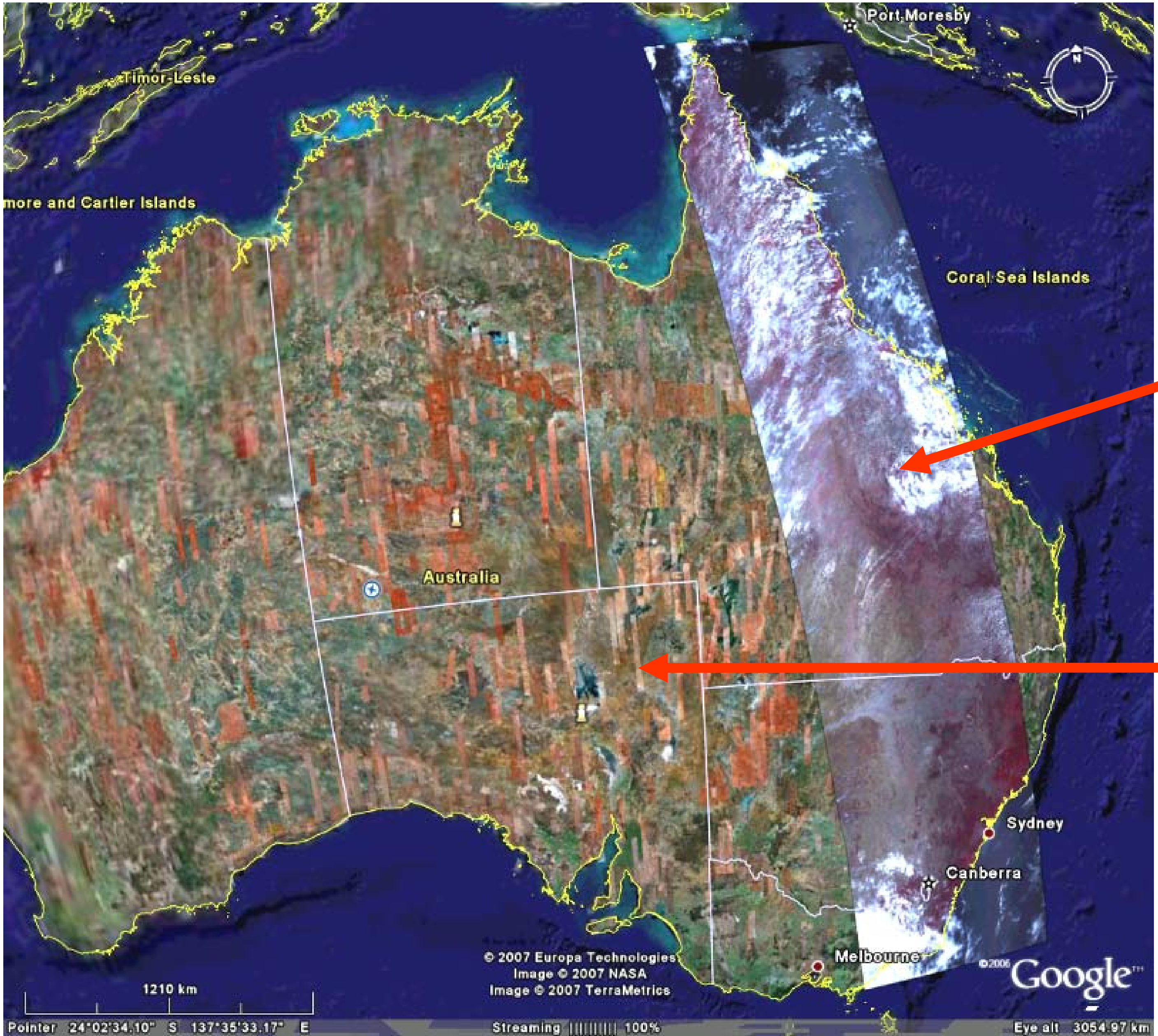


Novel International Collaboration – 6 countries

- ★ Individual satellite ownership
- ★ Collaborative operation
- ★ Data sharing and exchange
- ★ Daily imaging worldwide (600km swaths)
- ★ National, disaster and commercial use

The whole is greater than the sum of the parts – global daily imaging

DMC: Large area imaging



32m GSD
600 km imaging swath

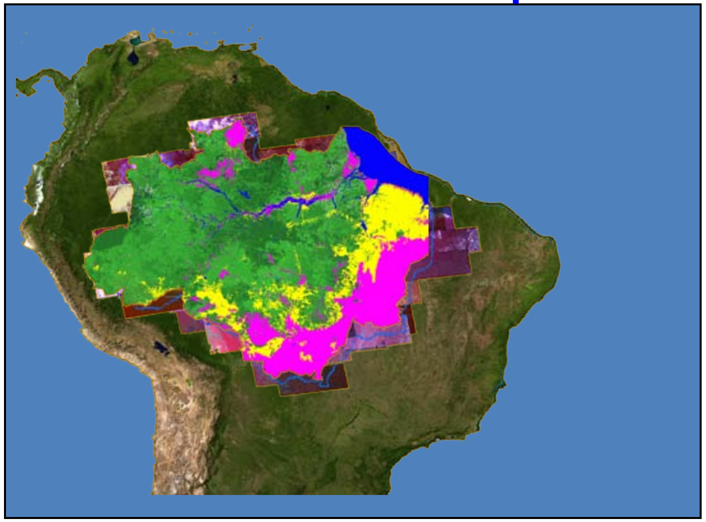
4,000 km strip

LANDSAT image tiles

One image strip taken by DMC
In comparison with multiple strips used in GOOGLE Earth

DMC – applications

Multispectral imagery at 32m GSD



Deforestation & Land Cover

Global Science, Climate change

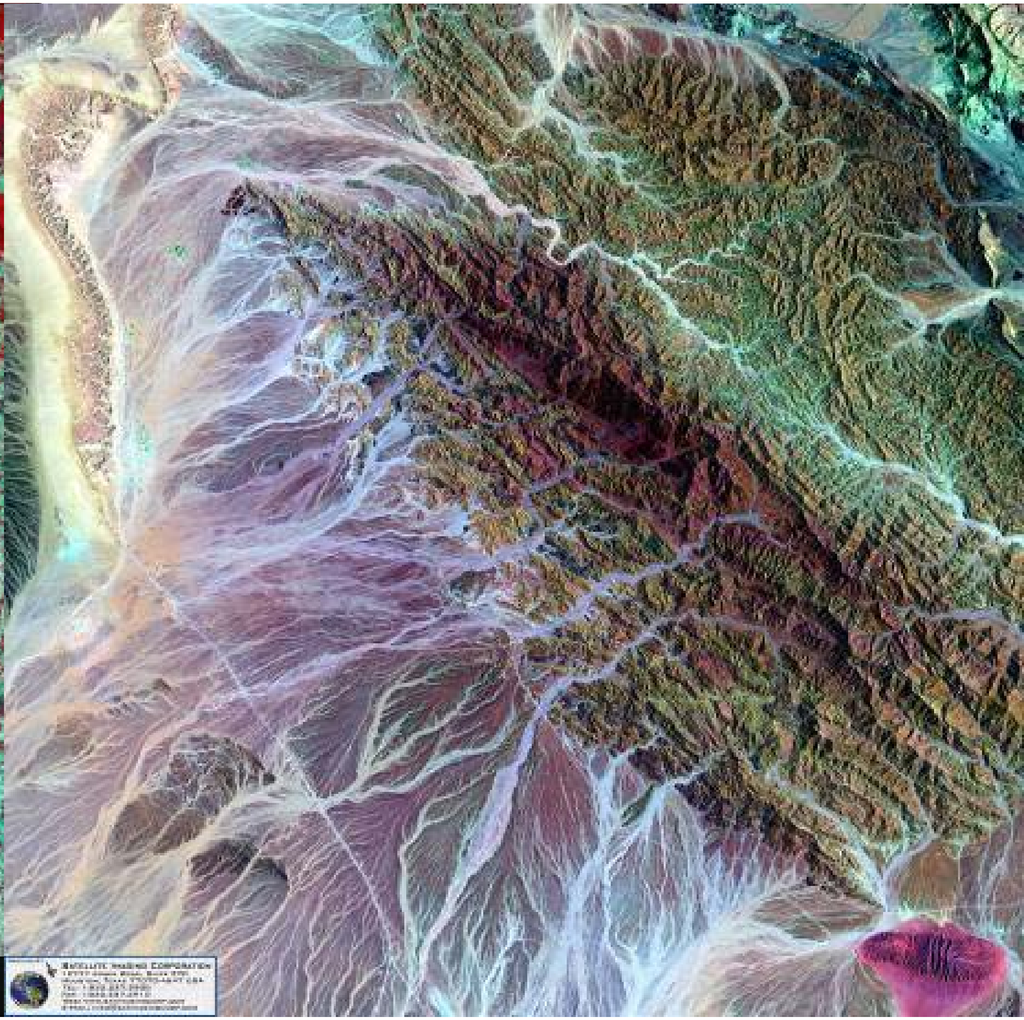
Flooding, disaster response

Fires: prediction, tracking

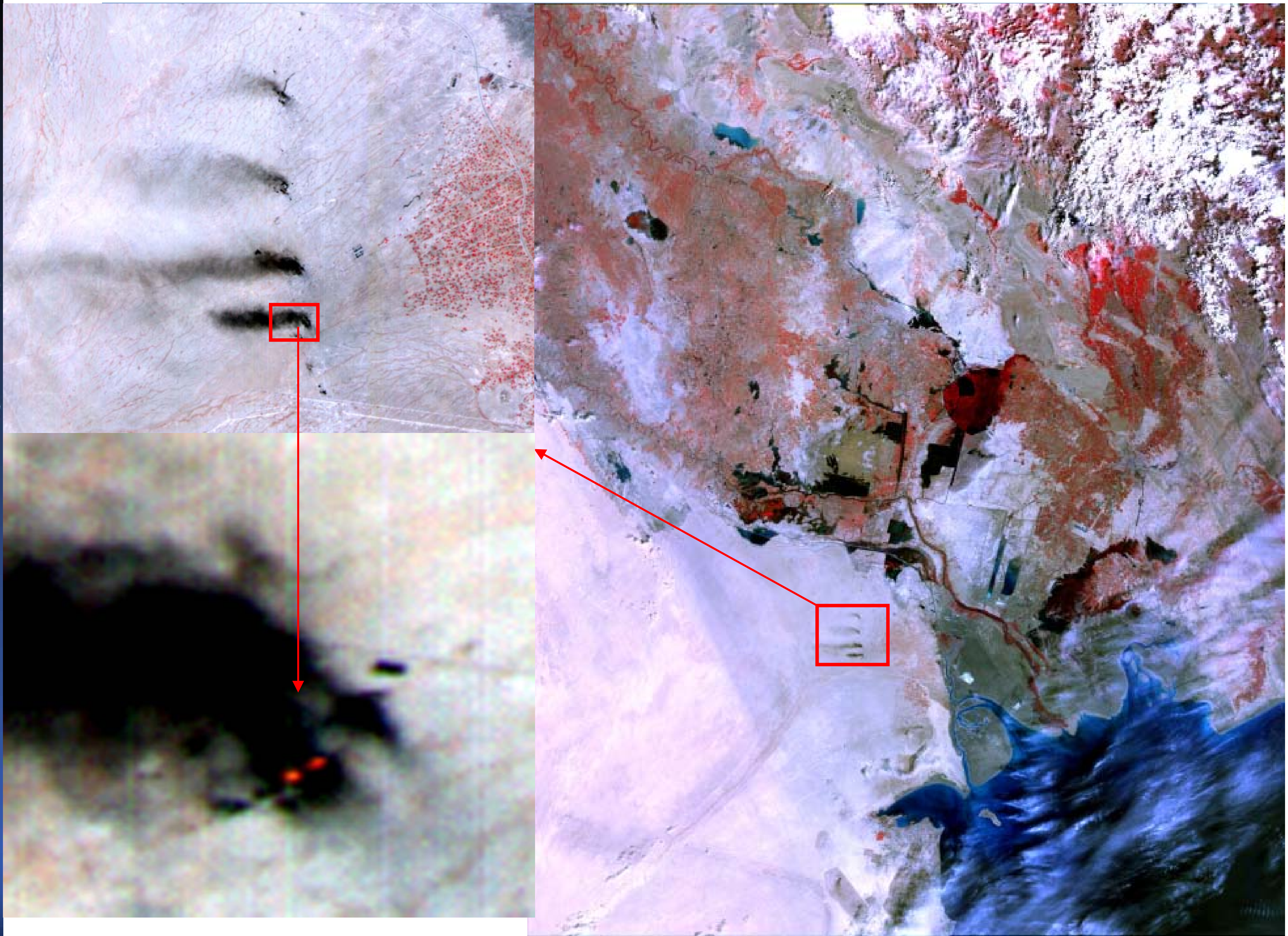
DMC – applications

De-forestation

Mineral deposits

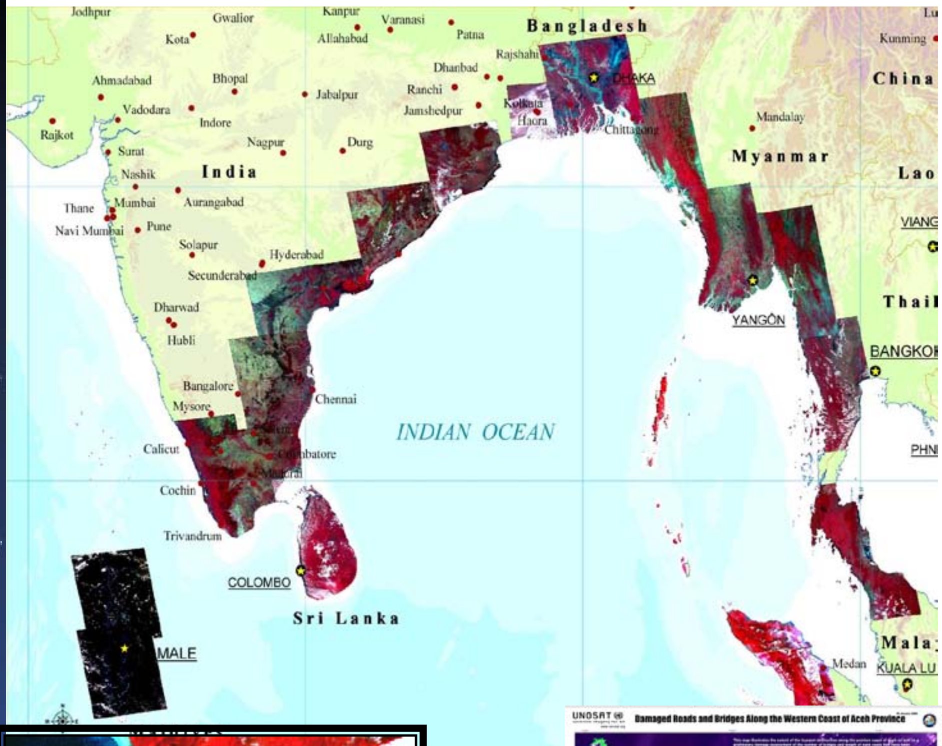


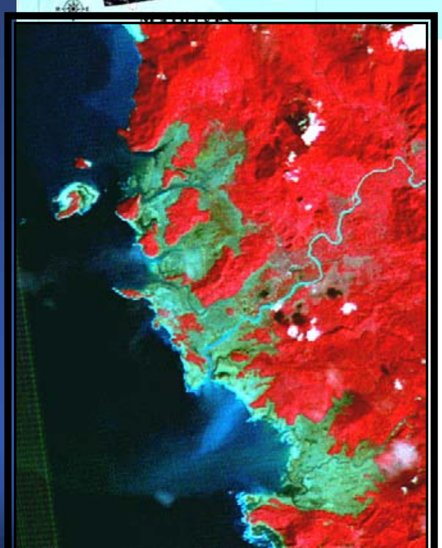
DMC: Responsive imaging



©SSTL

DMC in the International Charter

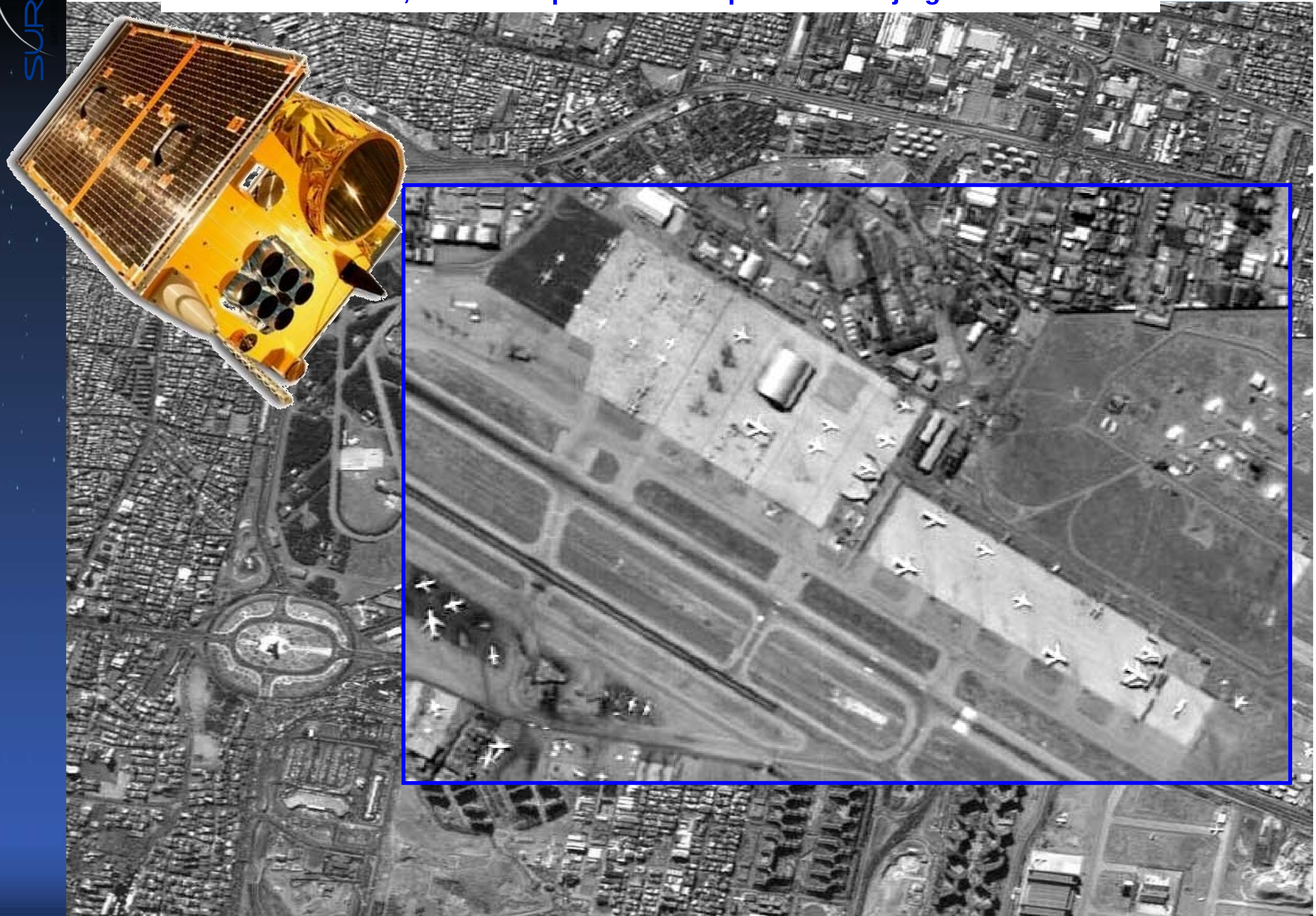




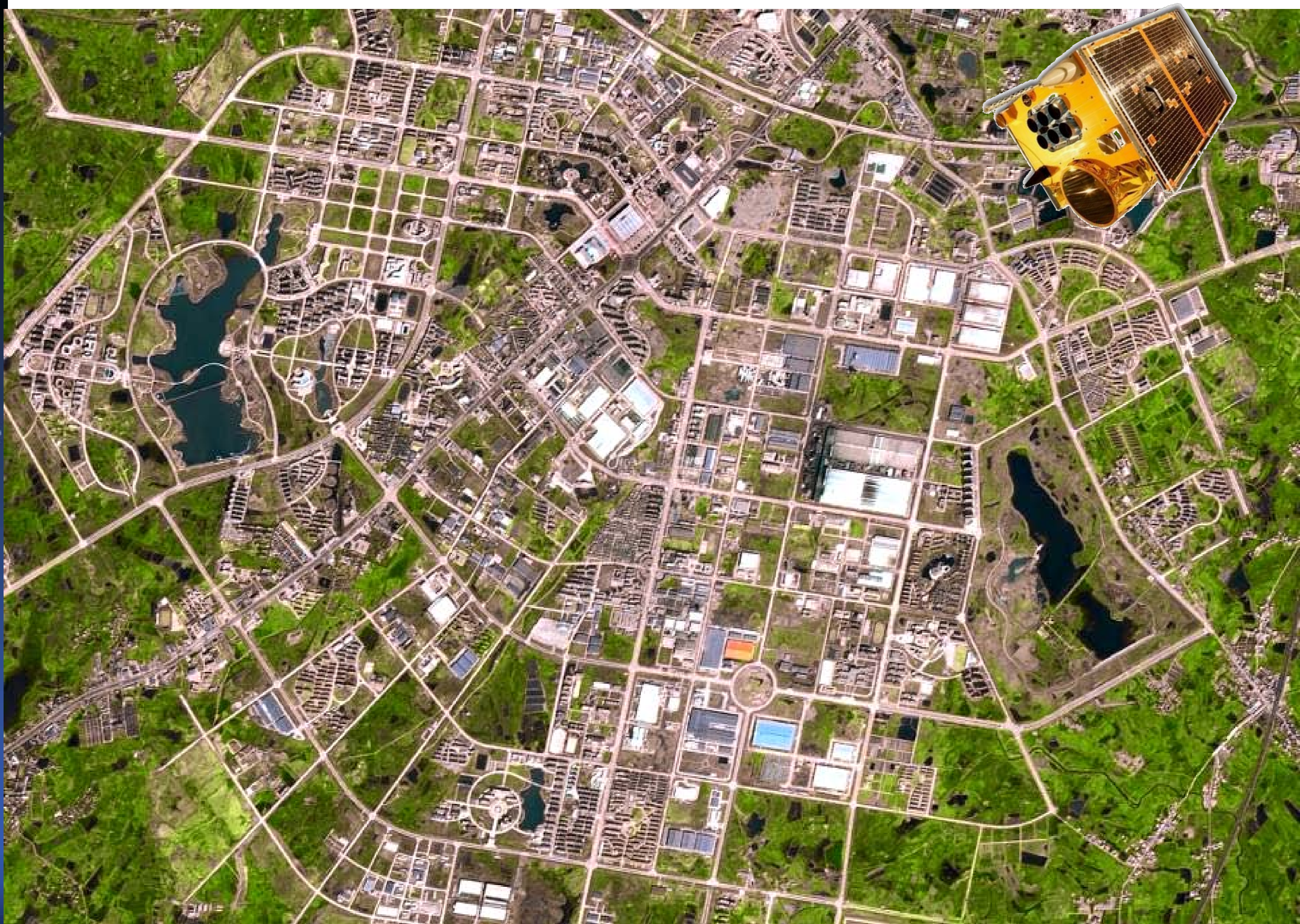
- **International charter space and major disasters**
- **2005-2008 DMC has:**
  - responded to 93 activations
  - with 332 wide-area images
- **Major campaigns in 2008:**
  - Floods in Southern Africa
  - Earthquake in China
  - Cyclone in Myanmar

High Resolution Imaging

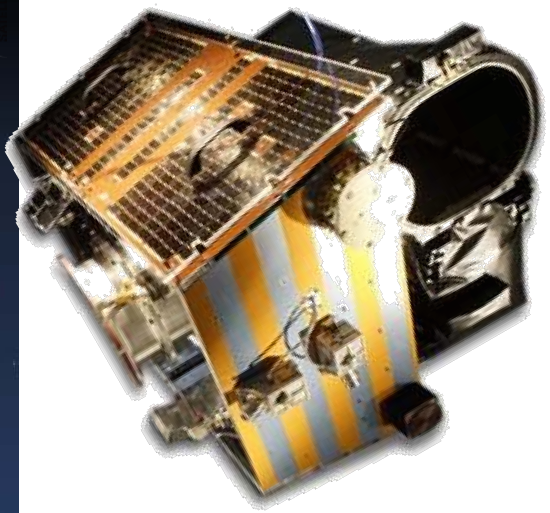
Small section of 3,000 km strip at 4-m GSD pan from Beijing-1 microsatellite



Data Fusion: simultaneous MS & PAN



High resolution UK TOPSAT



TopSat

2.8m GSD Pan

5.6m GSD 3-band

Multispectral (RGB)

Sustainability - DMC 'Road-Map'

2003 **DMC 1:** first generation with 32m GSD m/s & 600km wide swath (4m GSD pan on Beijing-1), in orbit since 2003

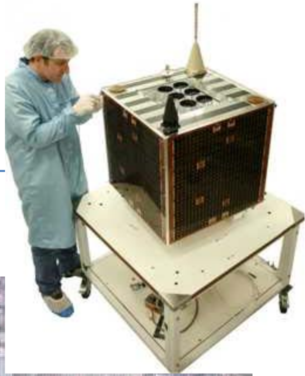
2009 **DMC 2:** current generation providing 650 km 'wide-swath' 22m GSD m/s resolution, in orbit since mid-2009; 2.5m GSD pan for launch in 2010 (NigeriaSat-2)

2011 **DMC 3:** next generation with ~1.5-metres GSD pan and 5m m/s

2012 **DMC 4:** hyperspectral imaging

2013 **DMC 5:** SAR to provide all-weather, day-&-night coverage

DMC – 2nd generation launched



29 July 2009 – successful launch of UK-DMC2 and Deimos-1

Urban development

agriculture & precision farming

Commercial exploitation

Commercial exploitation of EO satellites in DMC

Returning revenues to DMC partners (~$3M pa)

Stimulating new space business

RapidEye
geo facts
turned into knowledge

Commercial EO Constellation

Five RapidEye satellites launched August 2008

First commercial EO constellation

MDA JENA SSTL

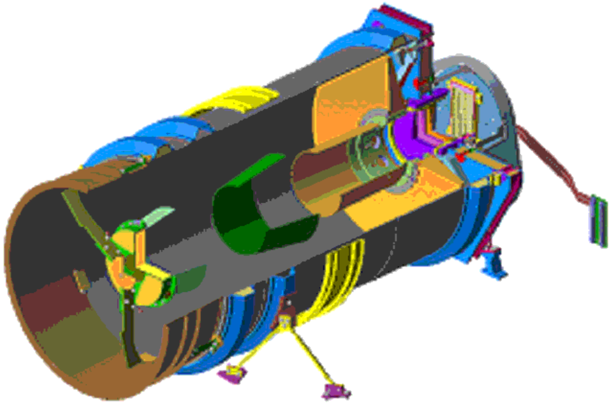
http://www.rapideye.de

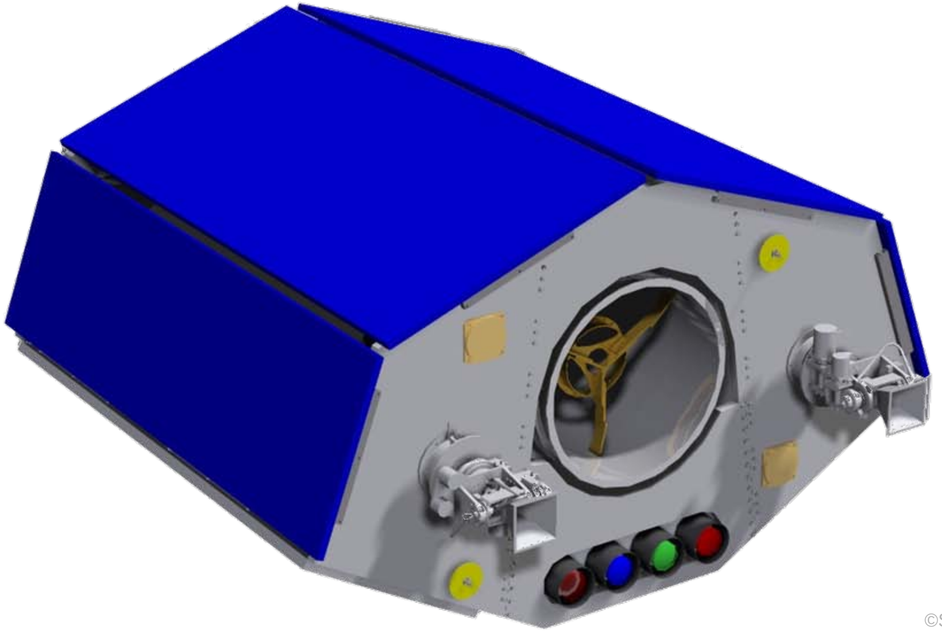
NigeriaSat-2: high resolution DMC-2

launch in 2010

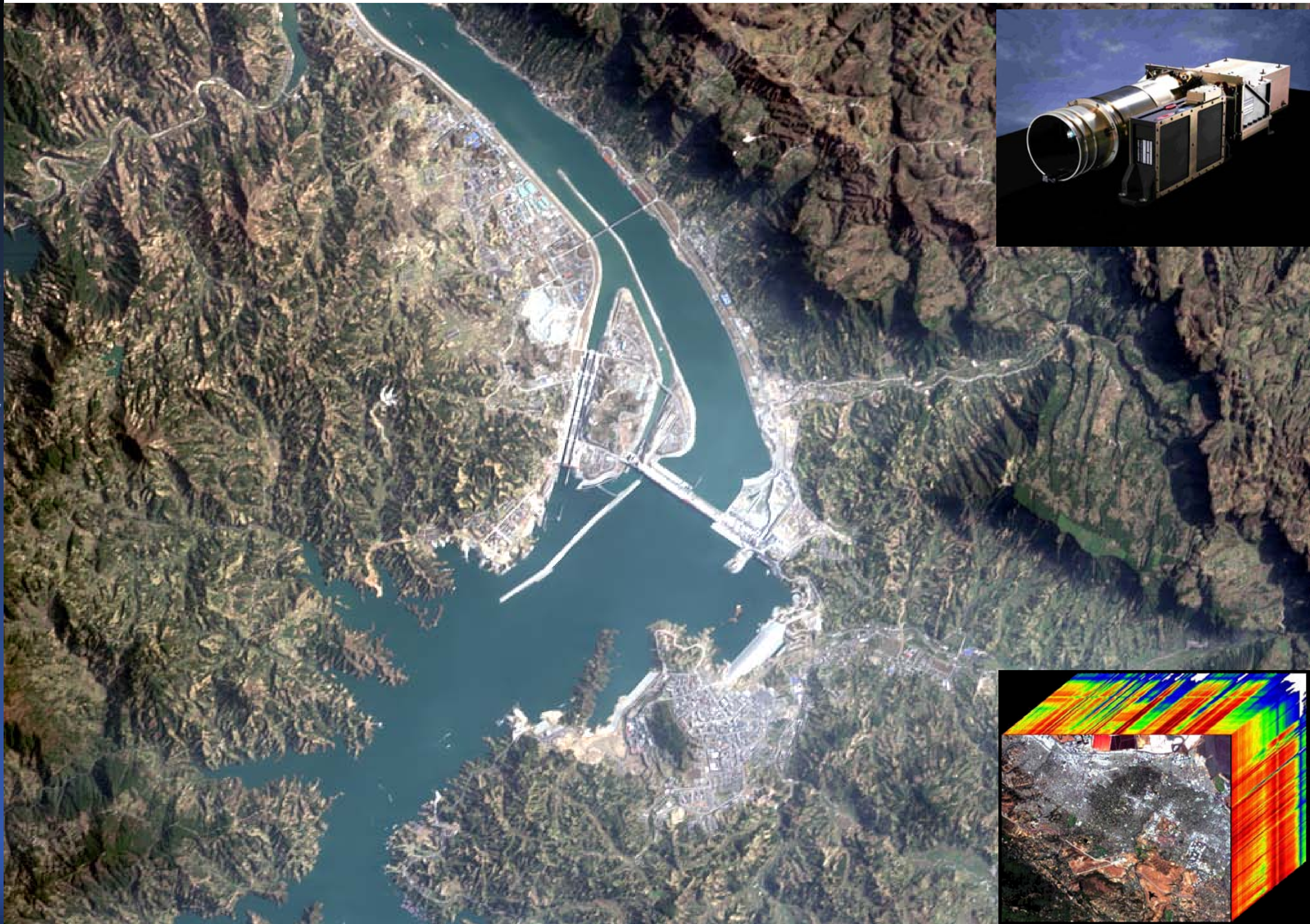
- 2.5m PAN
- 5m 4-band multispectral

- Medium-Res Imager, 32m
  4-band multispectral 320km swath
- 7 year life
- Agile imaging modes
- 2T-bit onboard storage
- 200 Mbps X-band downlink
- 150,000 sq.km per day

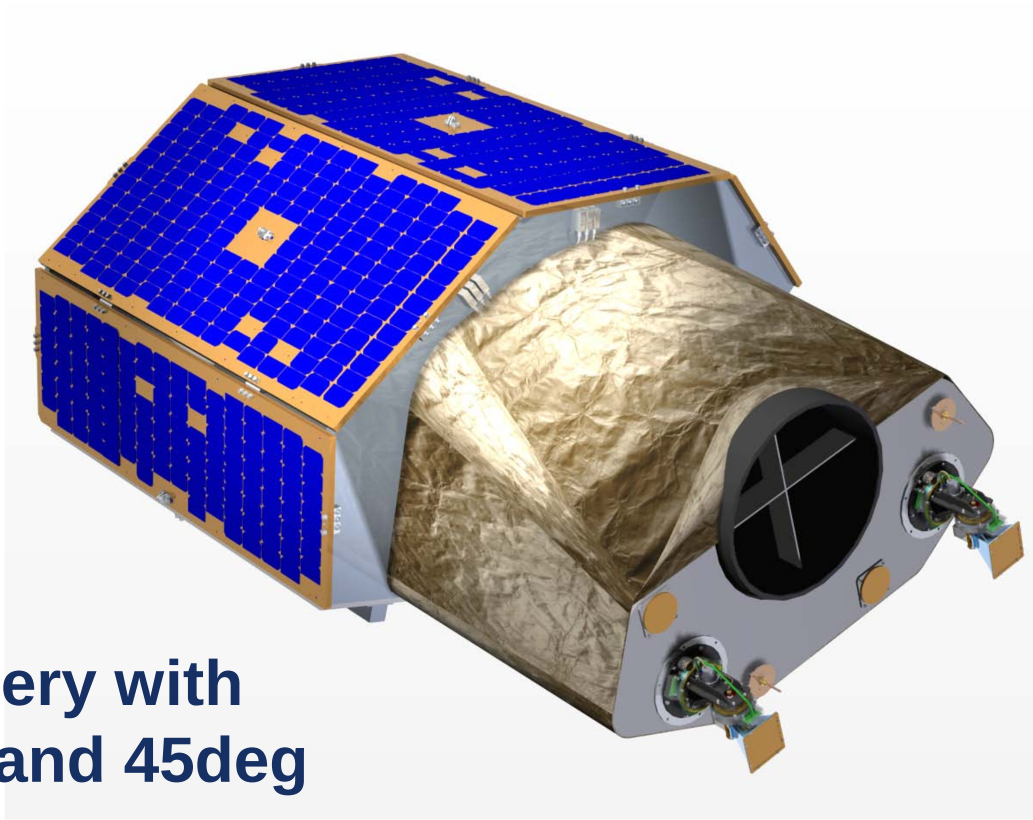




DMC 4: Hyperspectral - CHRIS Instrument



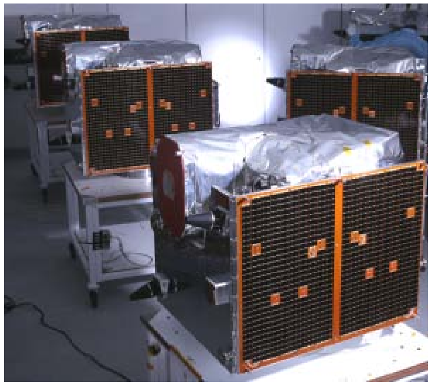
High-resolution sub-1m EO mission



0.75-m GSD pan imagery with high speed downlink and 45deg fast slew off-pointing

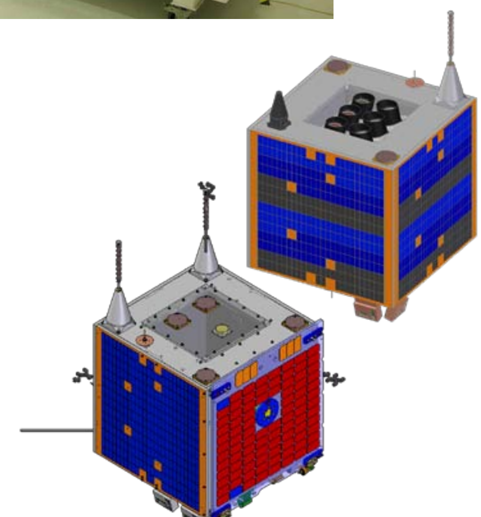
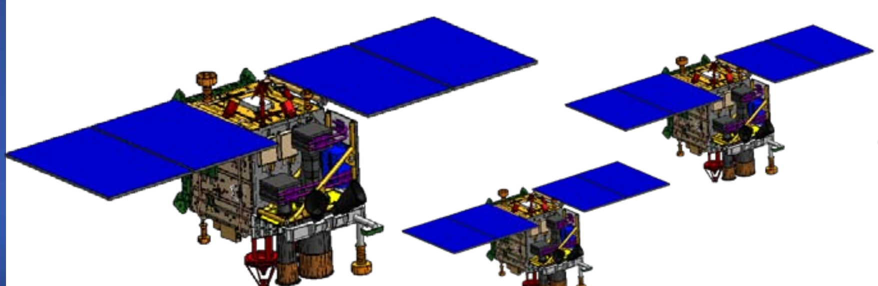
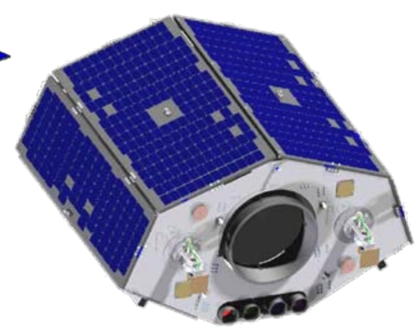
Is it sustainable?

2008-9 : “One Year, Seven Satellites”




2010: 5 further satellites to be launched:

- NigeriaSat-2 (2.5m, 5m, 32m) plus NX
- Russia Vniiem “Kanopus” (3 satellite platforms)
- Canadian surveillance of space mission (Sapphire)
- A rapid-pace 10 month mission
- EO satellite for Kazakhstan – working with ASTRIUM
- GEO & EO for Sri Lanka
- Galileo FOC – 14 navigation satellites/payloads with OHB for EC

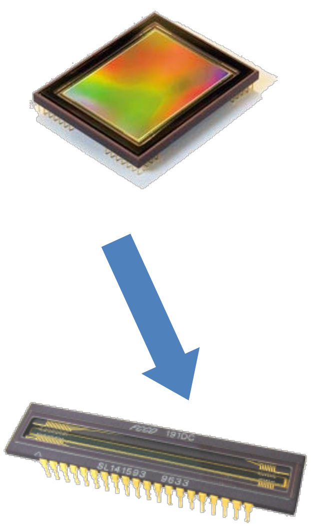

So, are we following Moore's Law?

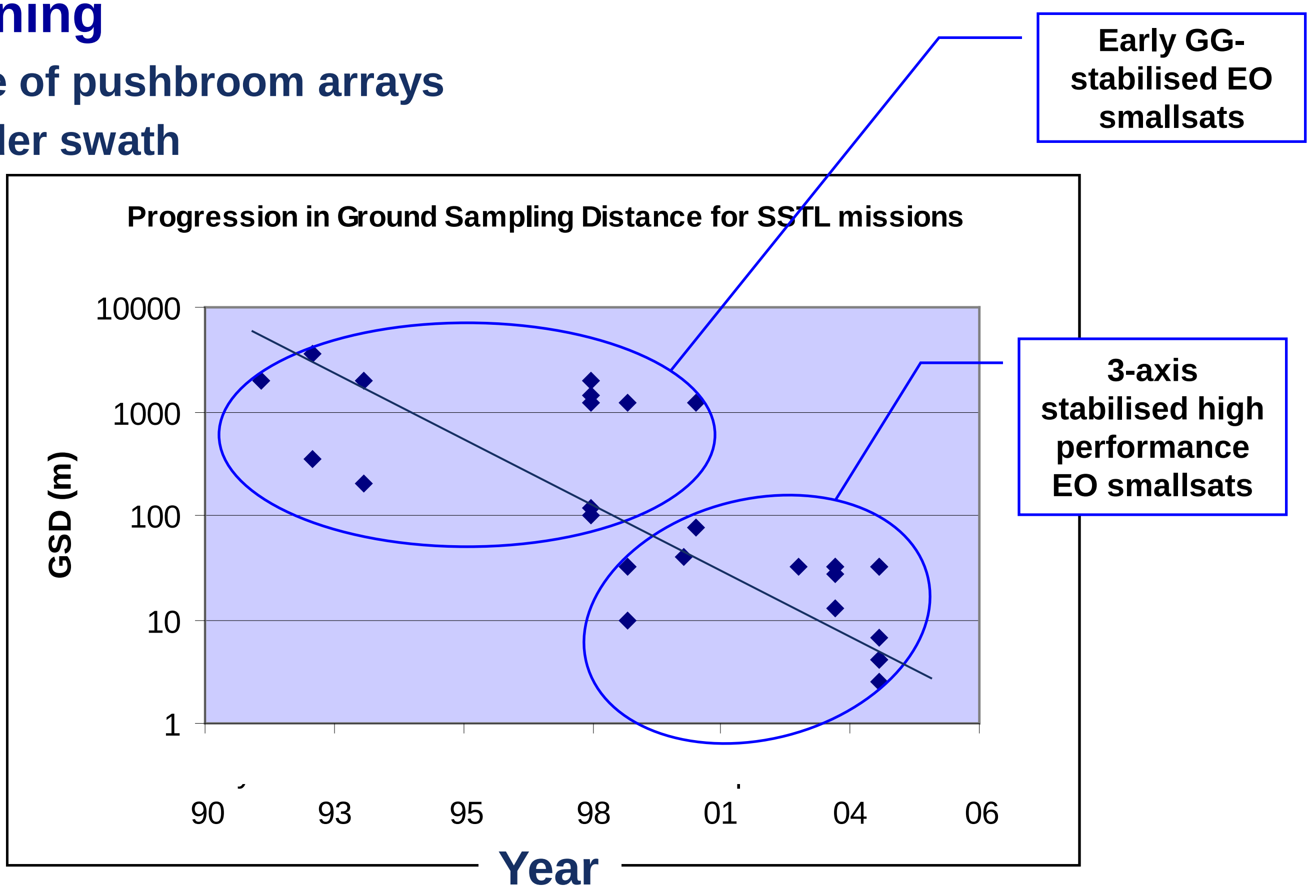
Early microsatellite EO missions

- Poor location / timing
- Poor pointing control
- Necessitated the use or 2-D arrays, limited swath

Later missions improved attitude control & used GPS positioning

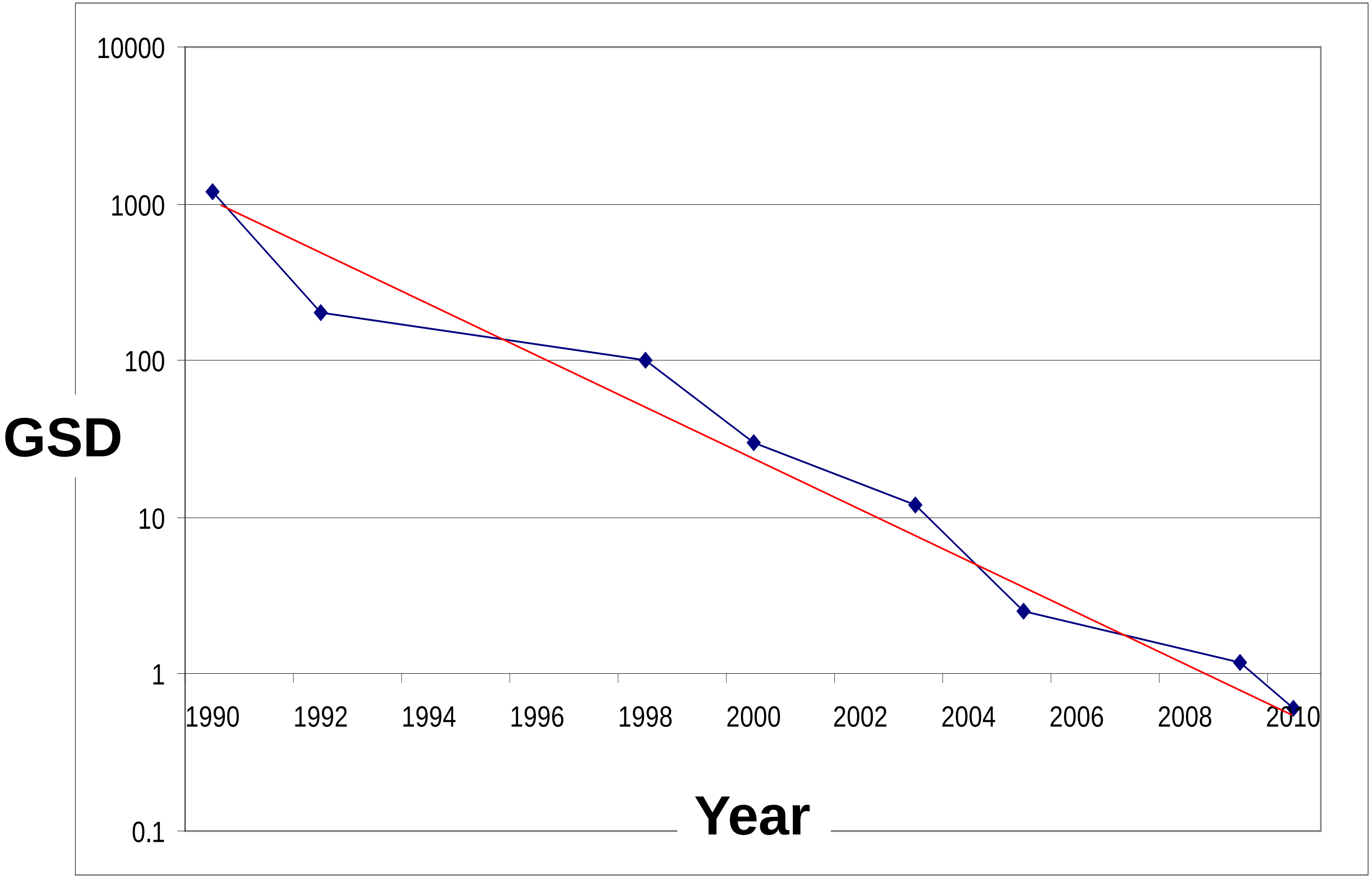
- Use of pushbroom arrays
- Wider swath





GSD trend

Follows Moore's Law (or better)



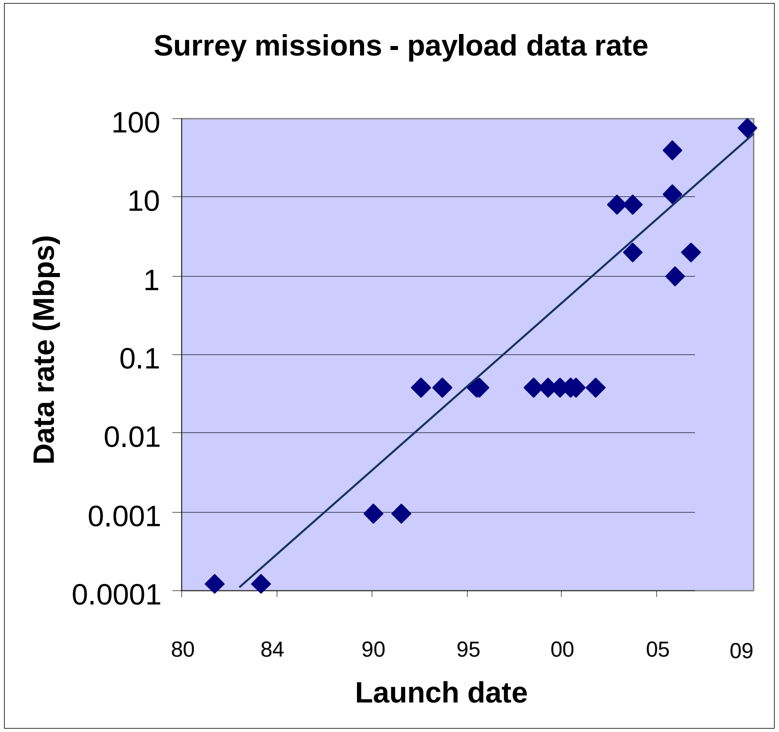
But it is not just GSD…

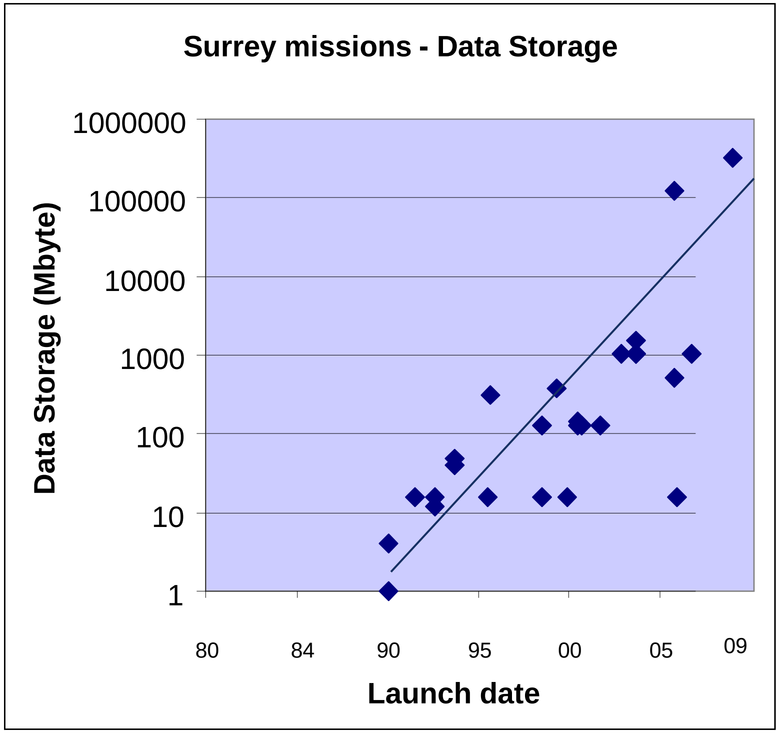
EO missions also drive data volume

Two orders of magnitude improvement per decade

- data return
- data storage

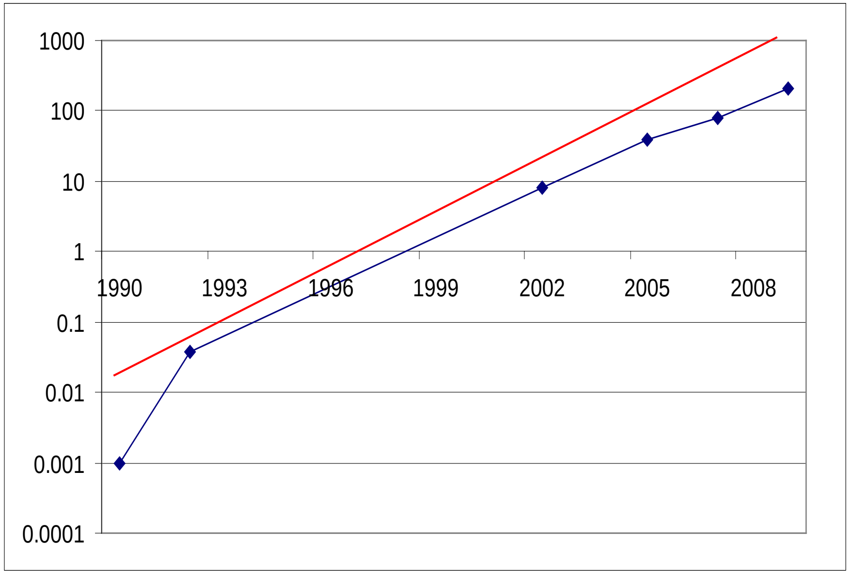
“Moore’s law of microsats”



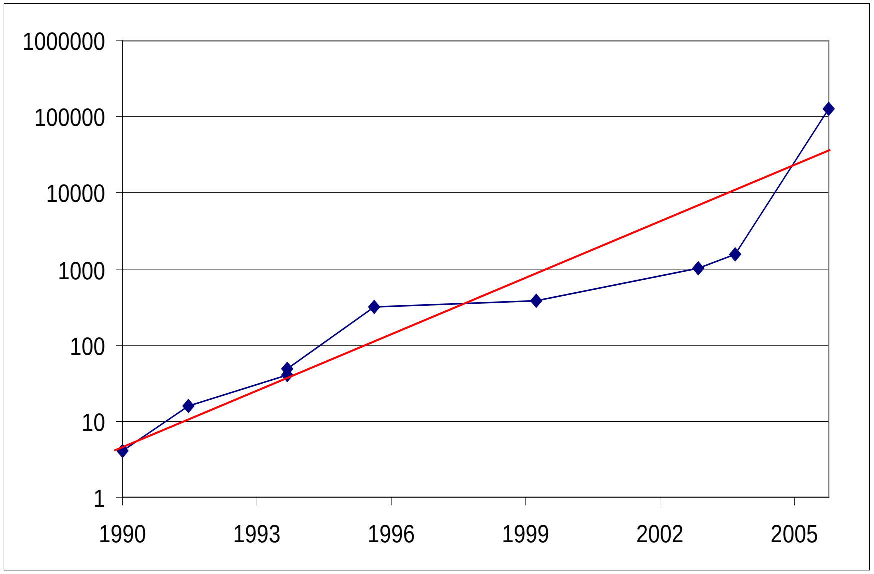


Moore's law is the key

Microsatellite mission data rates (Mbps) and data volumes (kbyte) generally tracking "Moore's Law" (or better)…

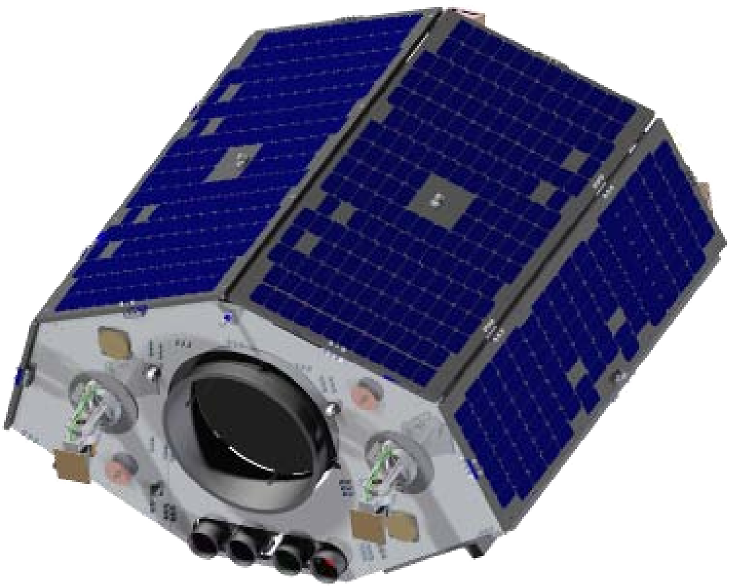


data rates (Mbps) - v- year



data volumes (kbytes) -v- year

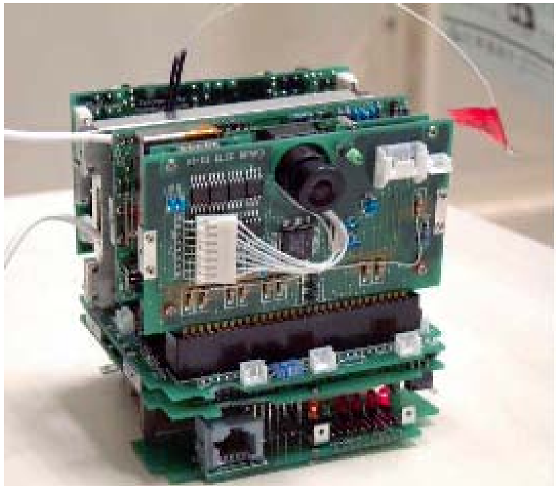
What are the implications for nanosats?

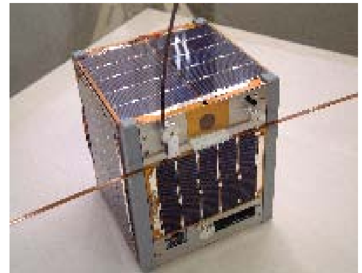


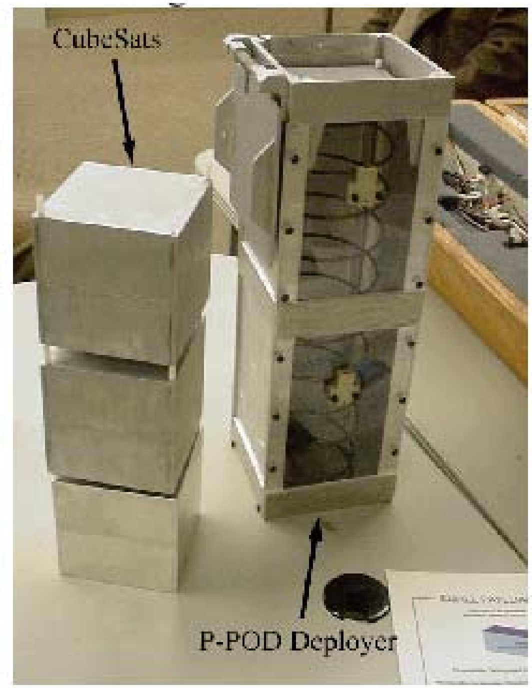
A business has been shown for micro-minisats in the range of 50-300 kg..

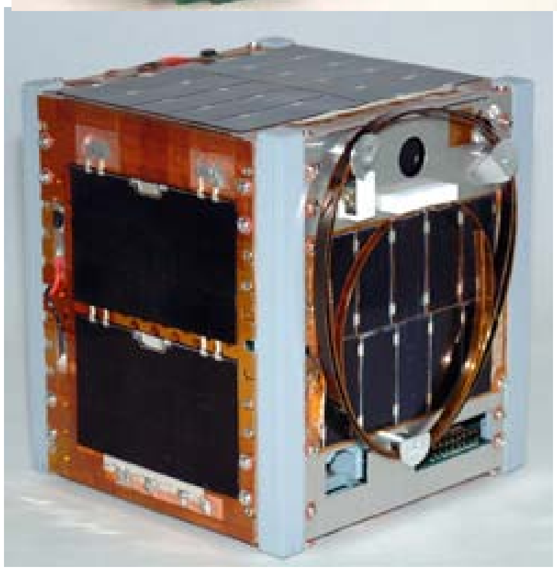
But what about <10kg nanosats?

Nanosatellites – Cubesats…



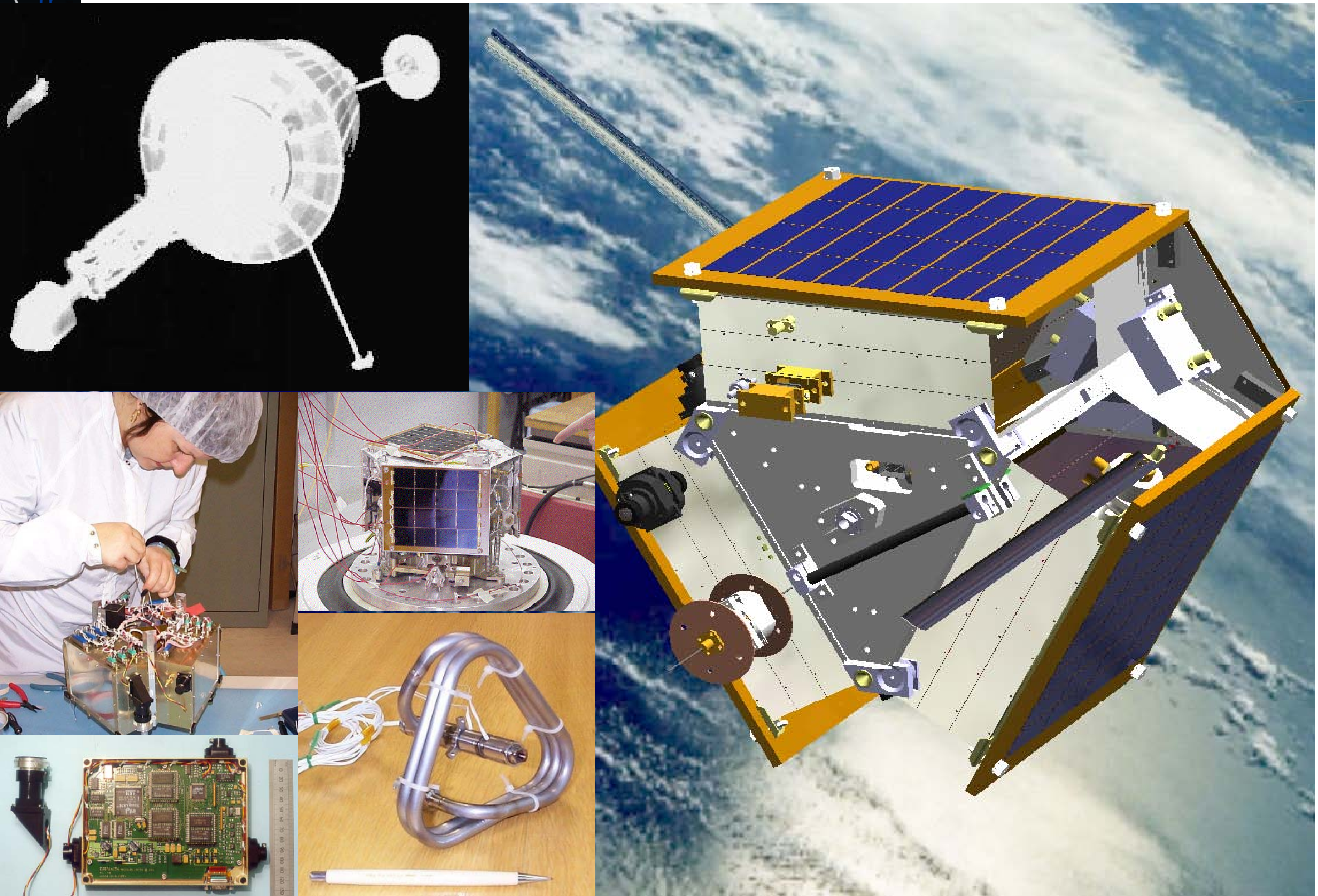




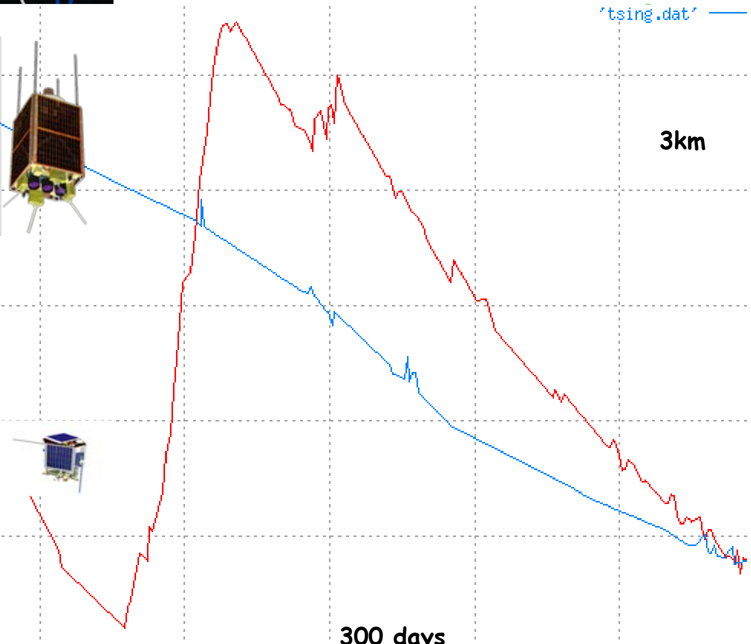


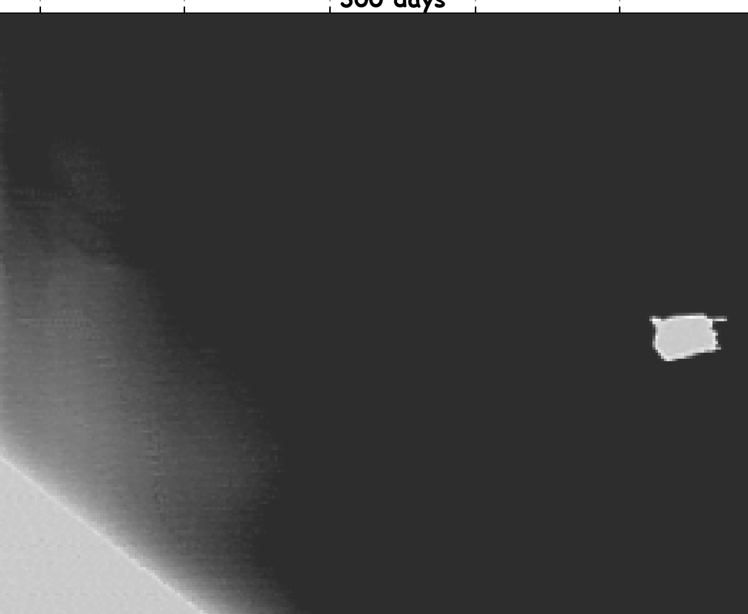
~100 universities worldwide now have nanosat projects of some sort

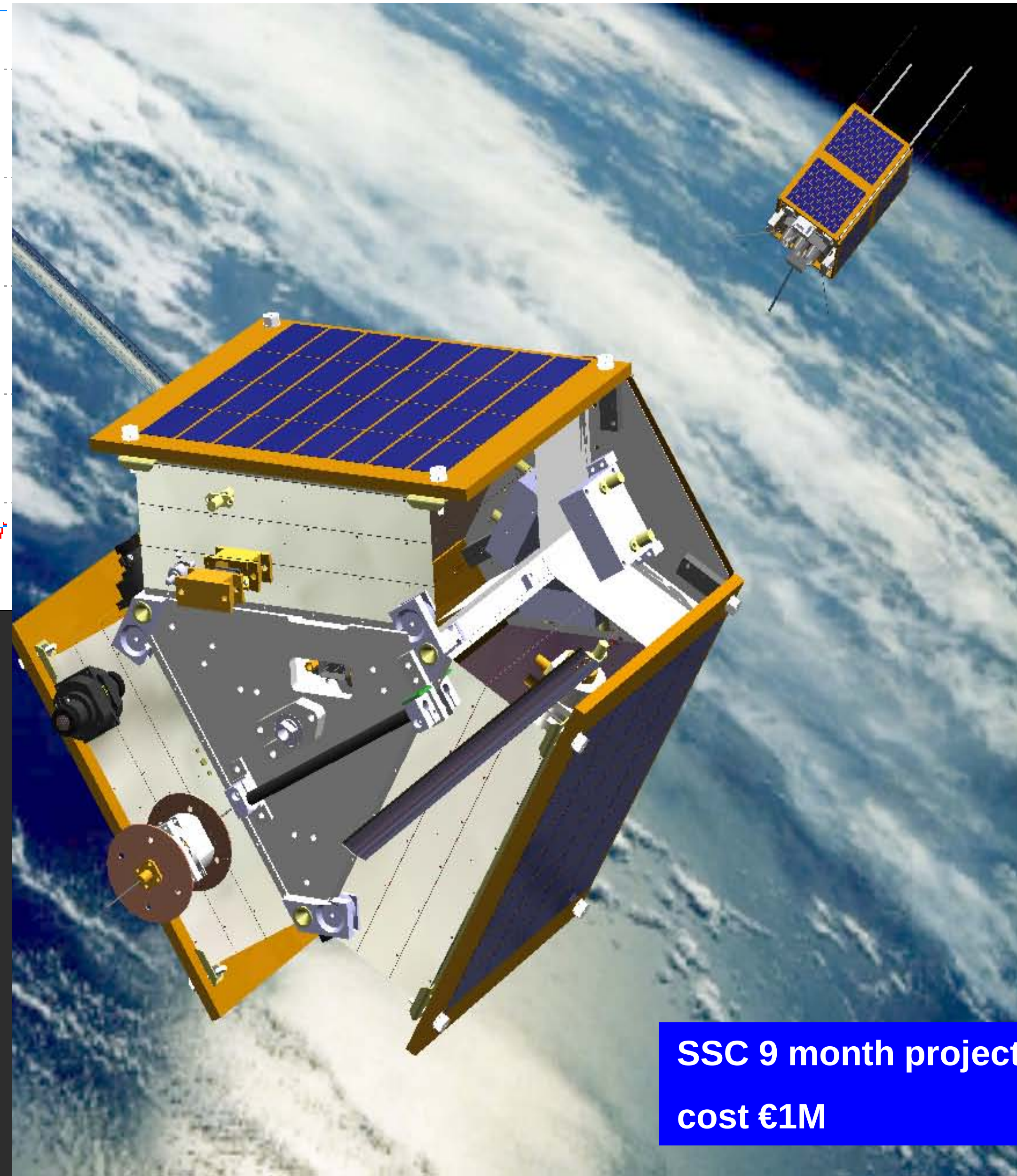
SNAP-1 nanosatellite mission 2000



SNAP-1 orbit manoeuvres







SSC 9 month project

cost €1M

What type of applications?

In-orbit inspection – awareness

Space debris removal

Passive sensing – bi-static radar, signal analysis

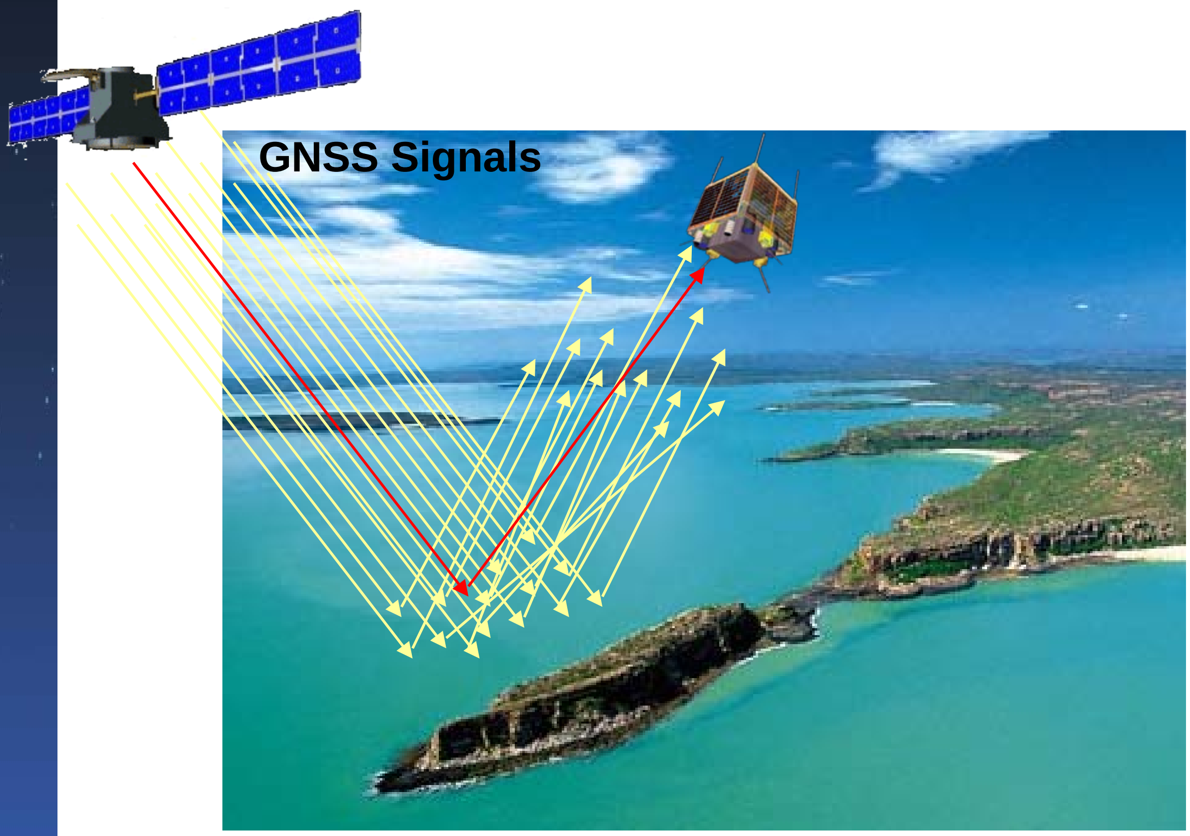
Spatial/temporal sampling of geoplasmas

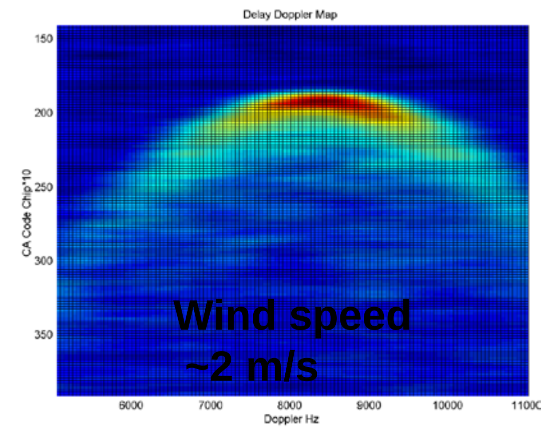
Robotic assembly in orbit of larger structures

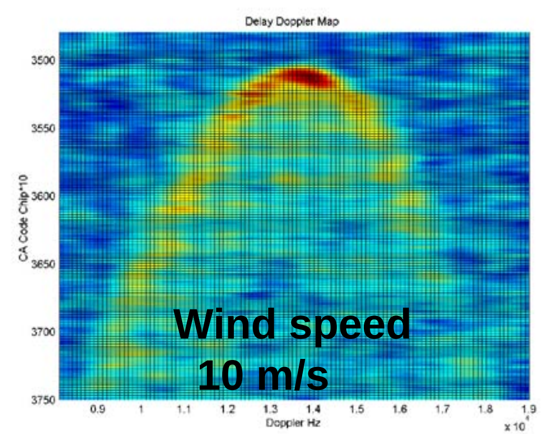
Ocean monitoring…

GPS reflectometry

To measure ocean surface roughness (sea-state)



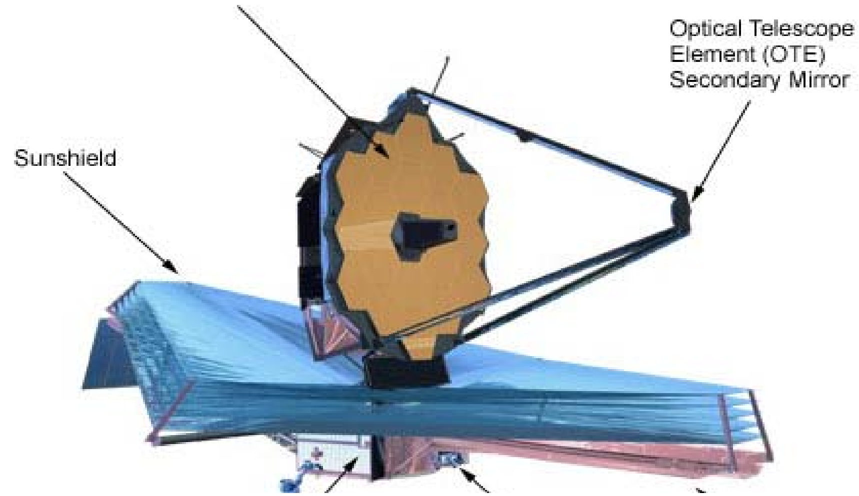




Subject of several SSC PhDs
in collaboration with SSTL

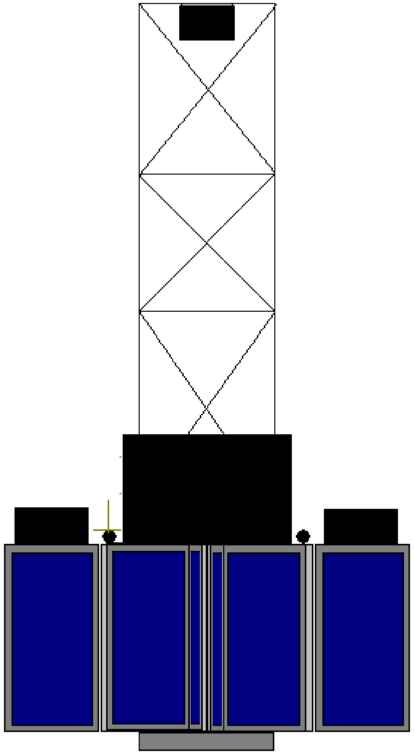
Next Generation Space Telescope

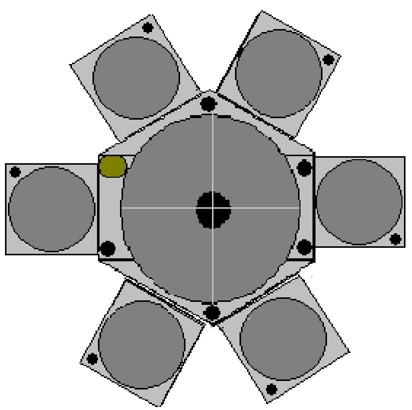
- Future space telescopes with aperture diameter of over 20 metres will require assembly in space
- High-precision formation flying has very high cost and may not be able to maintain stable alignment over long periods of time
- Autonomous assembly is a key enabler for lower cost approach to large telescopes



Stage 1: secondary mirror deployment and initial imaging

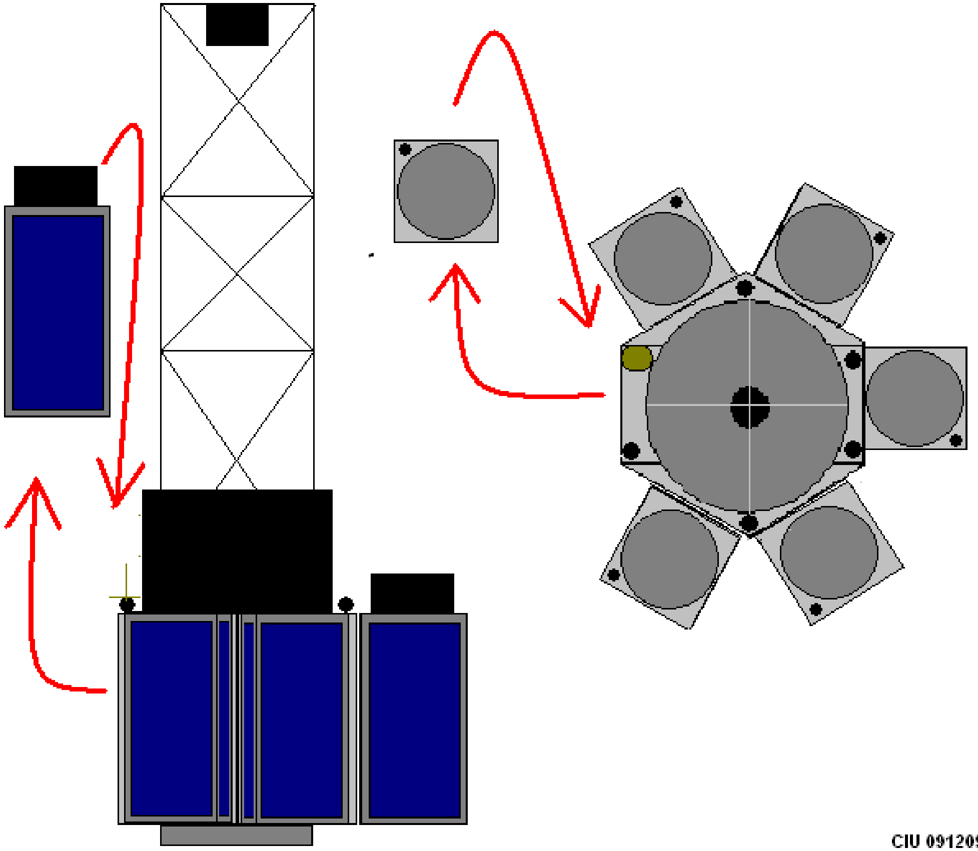
Stage 2: imaging with multiple mirrors





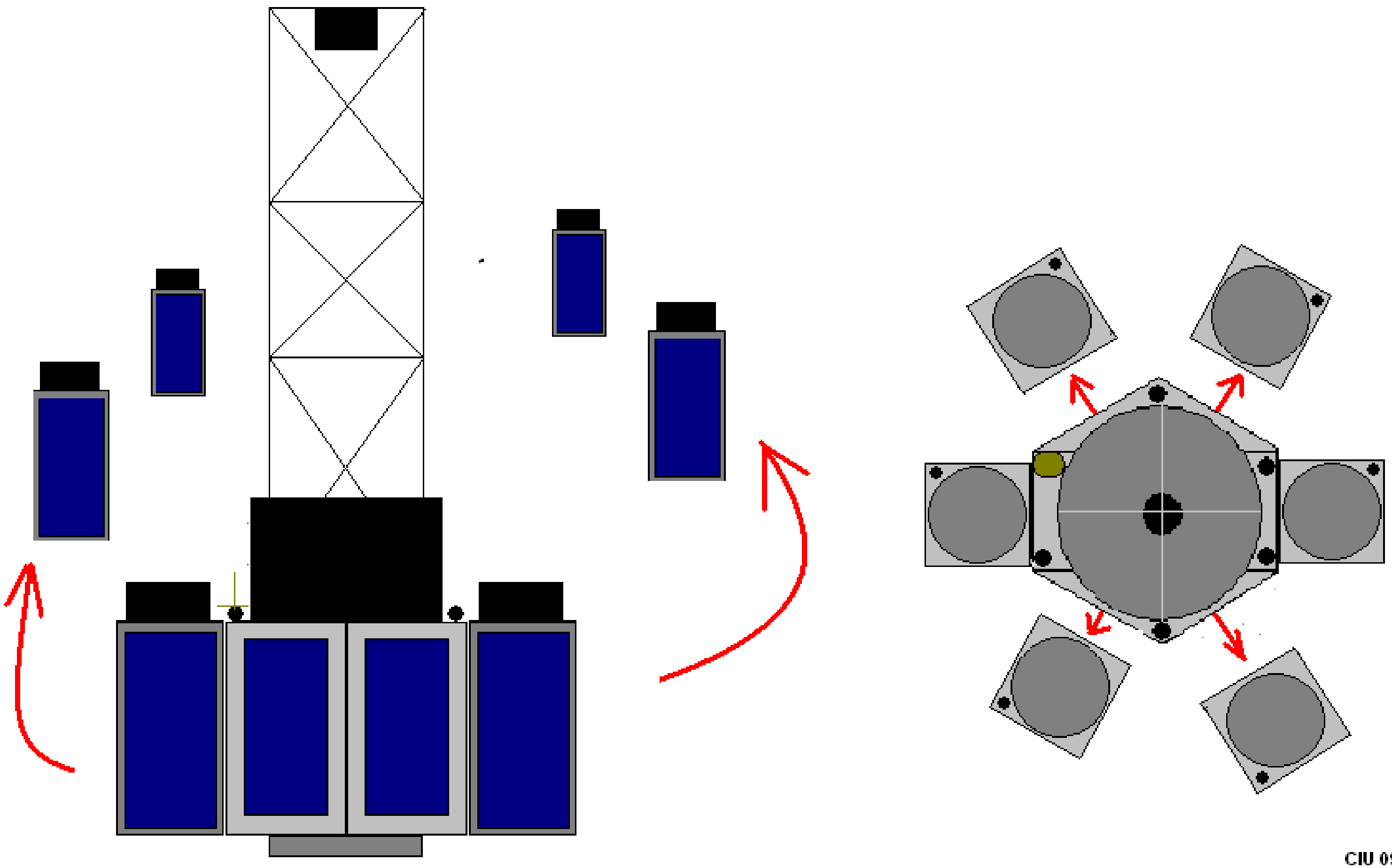
Mission Concept

Stage 3: **Separation and re-docking of one mirror. Test and verification of reassembled mirror.**



Mission Concept

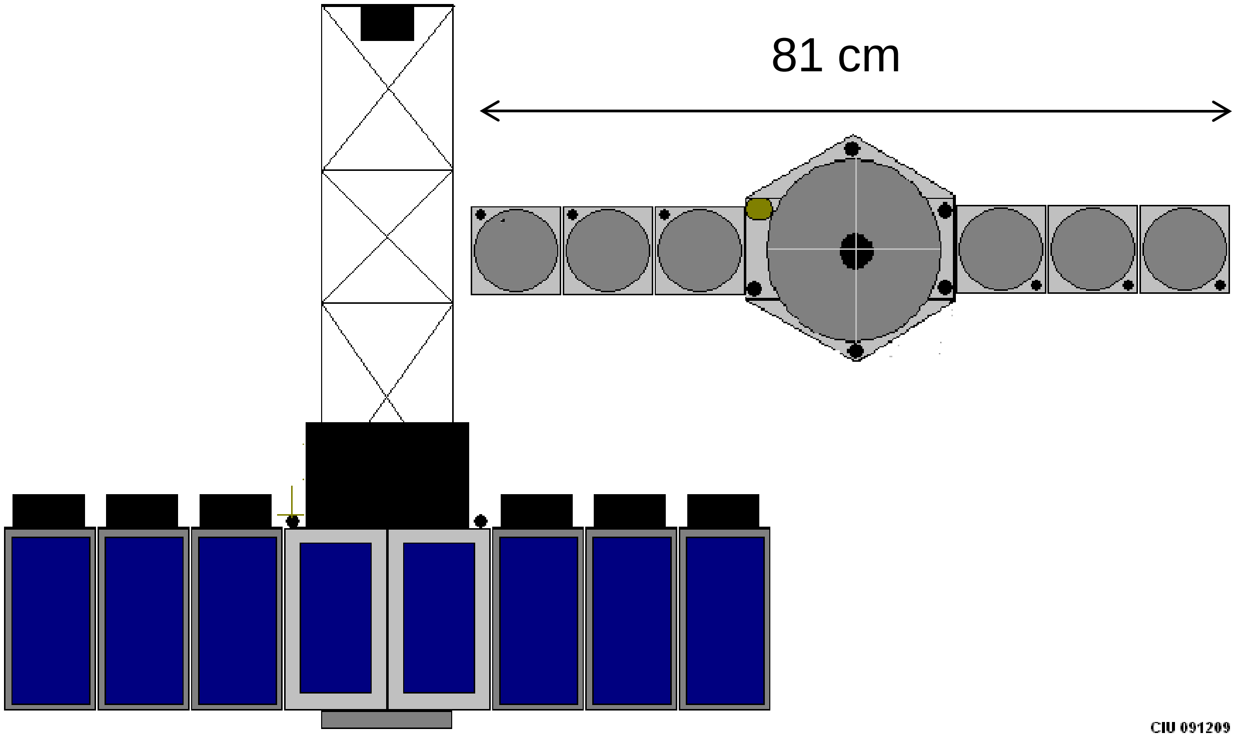
Stage 4a: **Undocking and separation of four satellites.**



CIU 091209

Mission Concept

Stage 4b: Docking in long baseline configuration – increased spatial resolution.



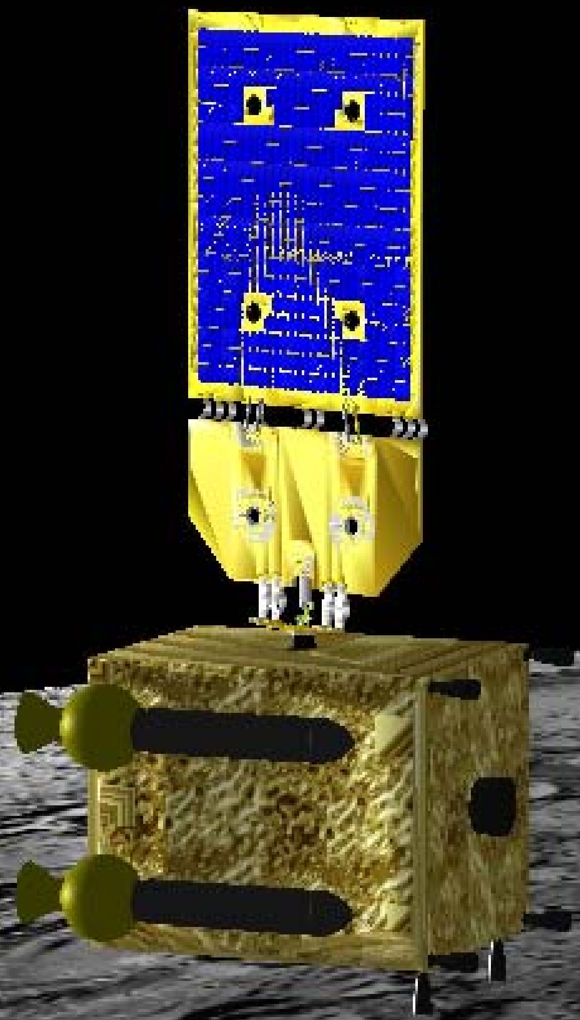
and beyond……

for small satellites……

MoonLITE: UK mission to Moon

A **polar orbiter** for communication, positioning plus orbital remote sensing

Multiple micro-penetrators
for both far-side and near-side deployment and in-situ geophysics & geochemistry

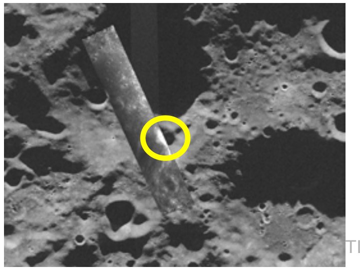


Birbeck
Imperial
MSSL
OU
QinetiQ
PSSRI
Leicester
SSC
SSTL
UCL

19 universities from 10 European countries

SSTL Responsible for:

- **Project Management on behalf of ESA**
- **System Design lead**
- **Mentoring/guidance for student teams**
- **Builds on MoonLITE and Chandrayaan-1 experience**



Conclusions?

micro / mini-satellites have successful business model – but it took almost 20 years to establish!

Capabilities primarily constrained by technology development

Nano-satellites are still in their infancy and the business model constrained by laws of physics rather than technology at present

Needs some innovative 'out-of-the-box' service-level applications/business model ideas


Arigato!
Small satellites
'Changing the Economics of Space'…