Miniaturisation of Space Systems at Surrey

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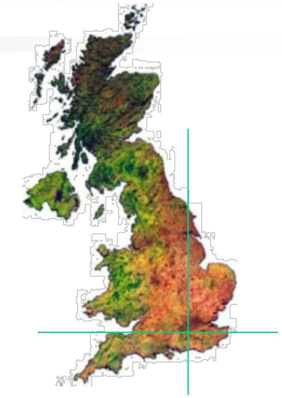
CEOI Emerging Technologies Workshop
1st May 2014

SSC and SSTL

Pushing the Boundaries of Low Cost "Small Satellite" Space System Applications and Technologies



Surrey Space Centre (SSC): formed in 1979 at the University of Surrey, pioneering microsatellites — now 90 academic researchers specialising in space engineering.

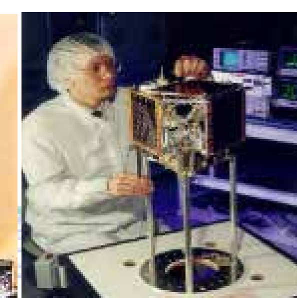
Research Portfolio: ~£2M pa : Industry (Airbus S&D, SSTL, etc.), EU, ESA, TSB, EPSRC, etc.

Surrey Satellite Technology Ltd (SSTL): formed in 1985 by the University of Surrey, is a British satellite manufacturing company with 600+ staff, acquired by EADS-Astrium in 2009 and now owned by AirBus. SSTL Group also includes: SST-US in Denver, Co; DMCii (EO services) and SSSL (launch services).

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

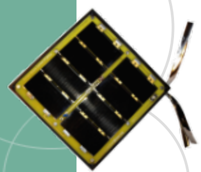






Small Satellites

- **Surrey's Small-Sat Platforms**

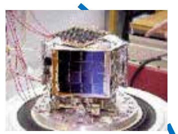


PCBSat

300 g

PalmSat

~3 kg



SNAP-1

6.5 kg

UoSAT-5

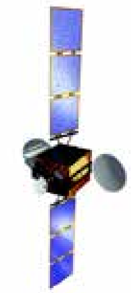
50 kg

UK-DMC

166 kg

GIOVE-A

660 kg



SSTL GEO

platform

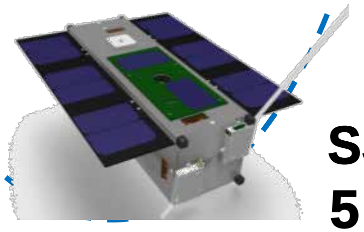
1-100 g	0.1–1 kg	1-10 kg	10-100 kg	100-500 kg	500-1000 kg	>1000 kg
$100-20000	$20-200K	$0.2-2M	$2-10M	$10-50M	$50-100M	$0.1-2B
Femto	**Pico**	**Nano**	**Micro**	**Mini**	**Medium**	**Large**

SpaceChip

10 g

CubeSats

~1-4 kg



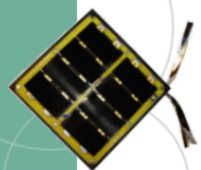
SSC Focus

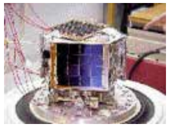
SSTL Focus

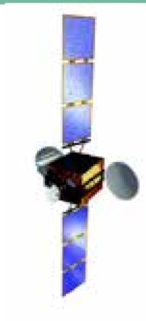
SSC is focussing on "NanoSats" in the 5-50kg class for applications, including EO.

Small Satellites

- **Surrey's Small-Sat Platforms**







PCBSat	PalmSat	SNAP-1	UoSAT-5	UK-DMC	GIOVE-A	*SSTL GEO*
300 g	~3 kg	6.5 kg	50 kg	166 kg	660 kg	platform

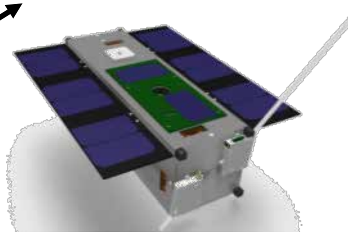
1-100 g	0.1–1 kg	1-10 kg	10-100 kg	100-500 kg	500-1000 kg	>1000 kg
$100-20000	$20-200K	$0.2-2M	$2-10M	$10-50M	$50-100M	$0.1-2B
Femto	**Pico**	**Nano**	**Micro**	**Mini**	**Medium**	**Large**

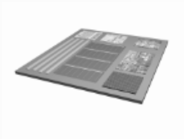
SpaceChip

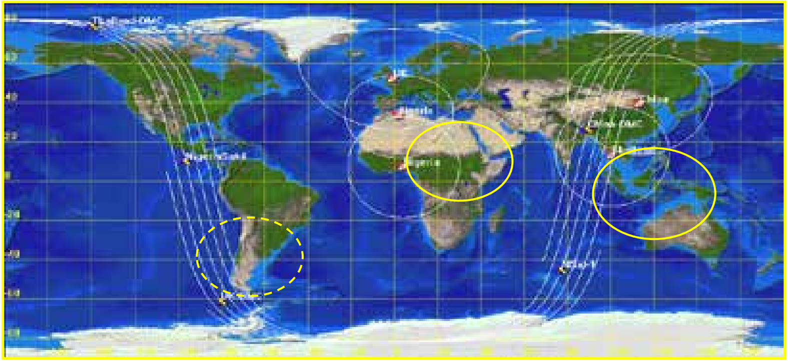
10 g

CubeSats

~1-4 kg







Disruptive Technology:- Affordable Satellite Constellations for High Temporal Resolution Observations of the Earth

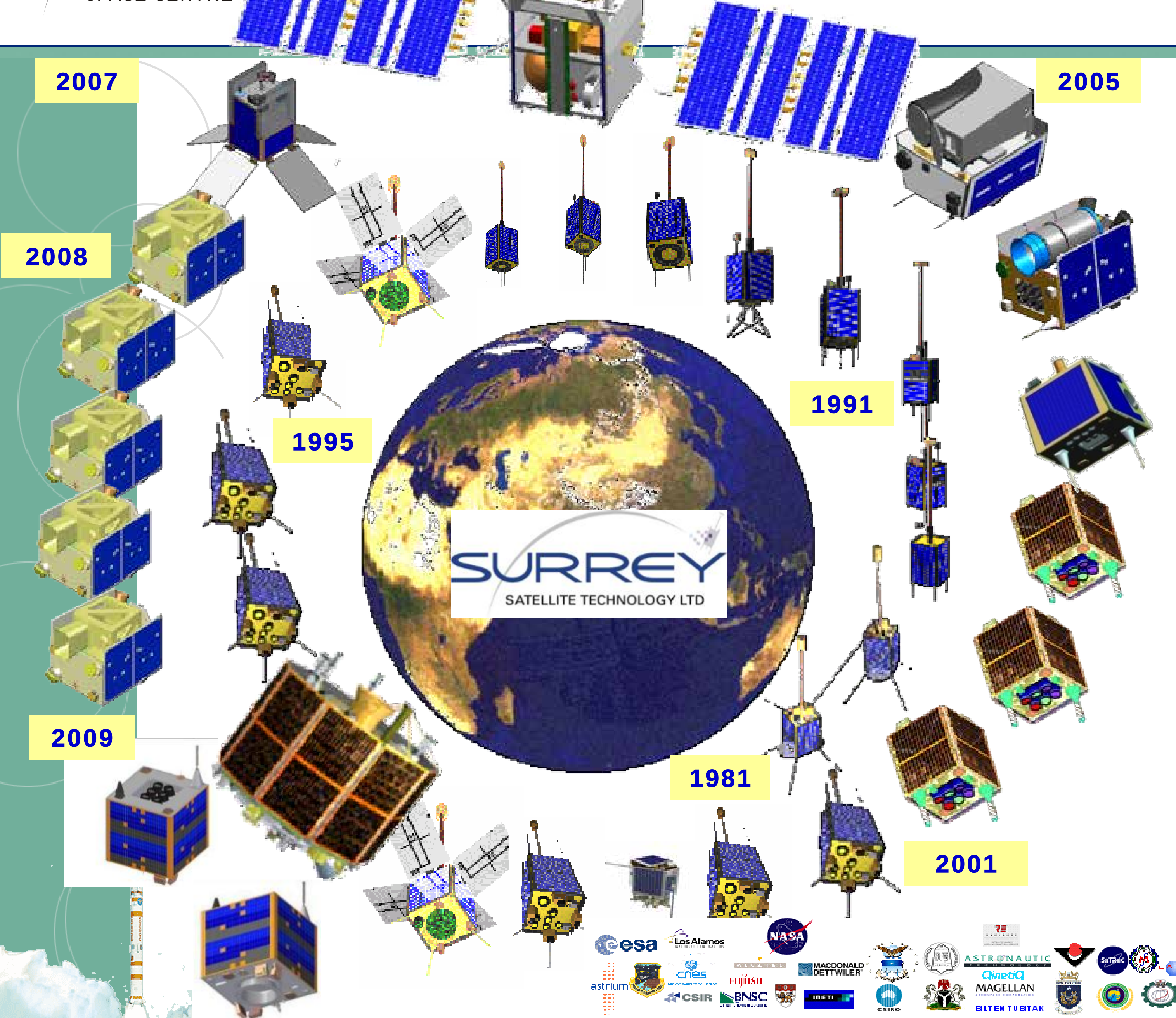
Low Cost Launches

100% launch record: 40 missions on 10 different types of launchers

Flexibility and robustness allows maximum opportunity for access to space

DELTA ARIANE TSYKLON ZENIT SS18/Dnepr COSMOS ATHENA SOYUZ ATLAS PSLV

SSTL Missions



UoSAT-1	(1981)
UoSAT-2	(1984)
UoSAT-3	(1990)
UoSAT-4+	(1990)
UoSAT-5	(1991)
KITSAT-1	(1992)
S80/T	(1992)
HealthSAT-2	(1993)
PoSAT-1	(1993)
KITSAT-2	(1993)
Cerise	(1995)
FASAT-Alfa+	(1995)
FASAT-Bravo	(1998)
Thai-Paht	(1998)
UoSAT-12	(1999)
Clementine	(1999)
SNAP-1	(2000)
Tsinghua-1	(2000)
TiungSat-1	(2000)
PicoSat	(2001)
AlSAT-1	(2002)
UK DMC	(2003)
NigeriaSat	(2003)
BILSat	(2003)
TopSat	(2005)
BEIJING-1	(2005)
Giove-A	(2005)
CFESat	(2007)
RapidEye (5)	(2008)
Deimos	(2009)
UK-DMC-2	(2009)
NigeriaSat-2	(2011)
Nx	(2011)

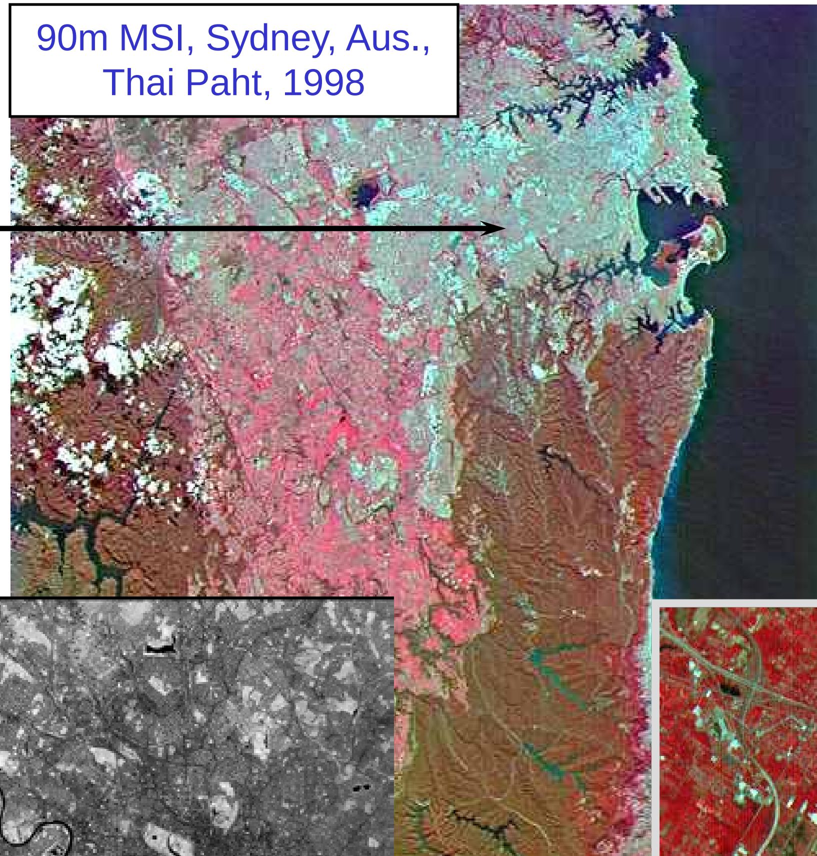
etc...

(Black = EO missions)

Staring Array Imaging

- **1980's – 90's : Panchromatic and MS Imaging**

Thai Paht 1998



90m MSI, Sydney, Aus., Thai Paht, 1998

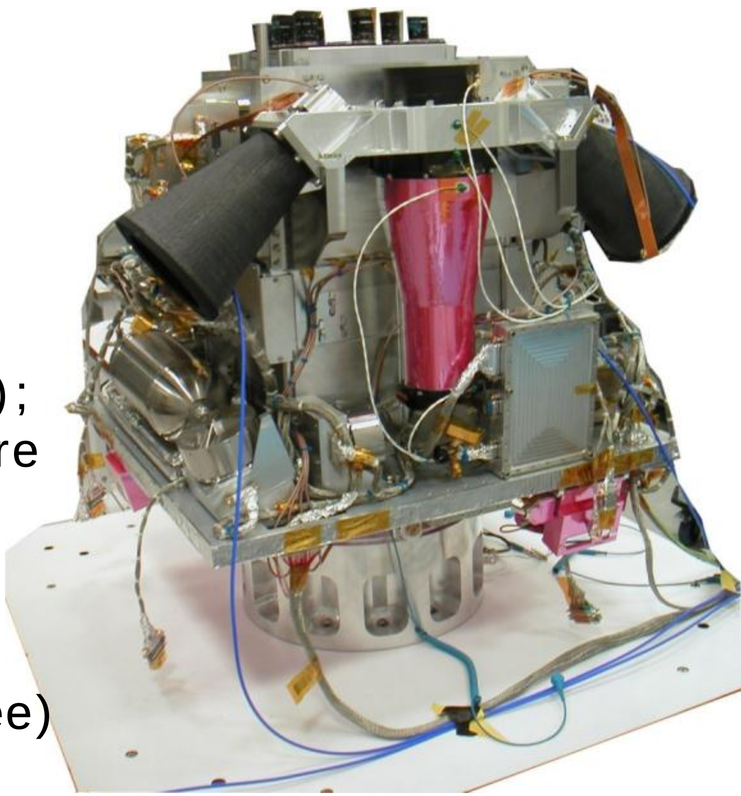
10m Pan, Los Alamitos Air Base, USA

32m MSI, Detroit, USA UoSAT-12, 1999

32m NIR, London, UK, UoSAT-12, 1999

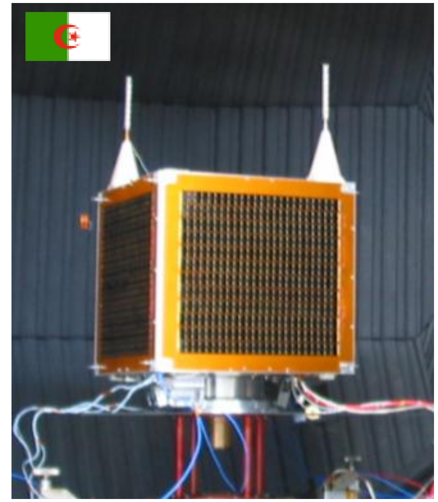
Platform Improvements

- **Mid 90's – Onwards:**
  - Introduction of gravity gradient boom with momentum wheels (control accuracy ~ a degree)
  - Move to wheel control with magnetorquers: Momentum wheel(s); coarse/fine reaction wheels; miniature CMGs.
  - Addition of Earth horizon sensors and/or star cameras (control accuracy ~ 0.1 – 0.01 degree)
  - Cold-gas thrusters.
  - More power and better OBDH
  - Typical applications hi-res EO (e.g. RapidEye, TopSat, DMC)



DMC Platforms

- AlSAT-1, UK-DMC, NigeriaSat-1
  - Customers: Algerian Space Agency, BNSC, Nigerian Government
- Enhanced microsatellites: 100 kg
- 32 m resolution, 3-band imaging (NIR, Red, Green)
  - 20,000 pixel swath
- 5-year design life
  - With orbit station keeping
- 8 Mbit/sec downlink
- 1.0 Gbyte on-board data store
- 3-axis ADCS
- AlSAT-1 Launched November 2002
  - Cosmos LV from Pletsesk
- UK-DMC and NigeriaSat-1 Launched September 2003

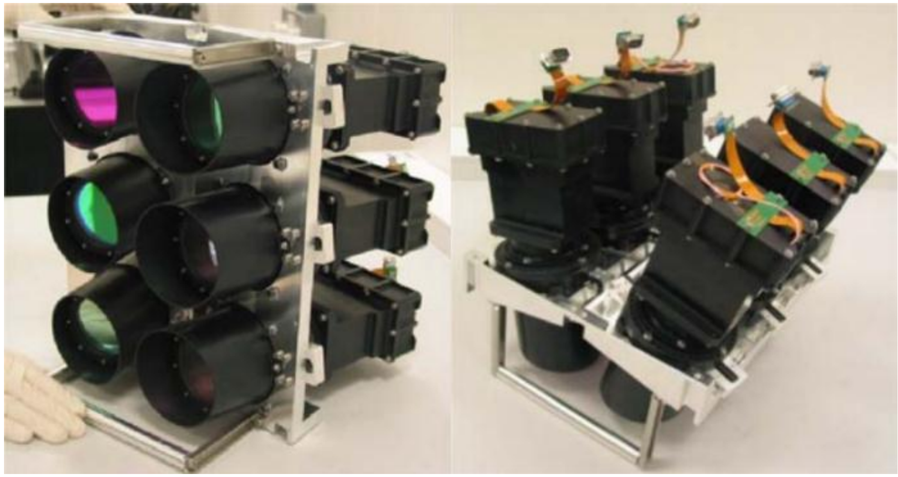


AlSAT-1

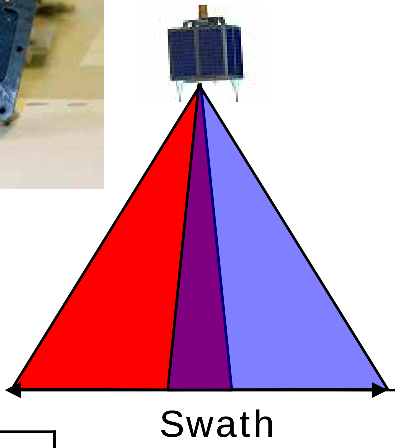
UK-DMC & NigeriaSAT-1

Push-Boom Array Imaging

- **Multi-Spectral Imaging - Push-Broom Arrays (DMC)**



SSTL – SLIM6 Push-Broom Multi-Spectral Imager



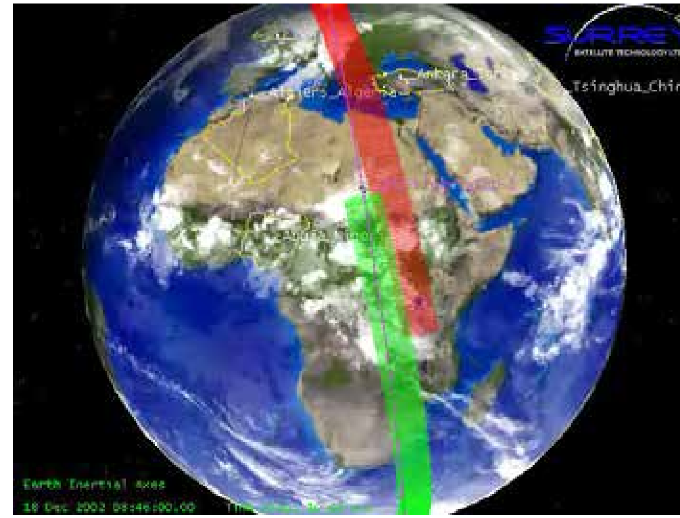
Satellite	**UK-DMC-1, Deimos-1, NX**
Satellite mass	~100 kg
Instrument	**SLIM6-2**
Instrument type	Multispectral
Instrument dimensions	314 x257 x250 mm
Instrument mass	12 kg
Peak power	28 W
Field of view	26.52 degrees
GSD	22 m
Swath	>600 km (at 686km altitude)
Detector details	6 x 14k linear CCD detector
Spectral bands	3 bands Green 520-605 nm Red 630-690 nm NIR 774-900 nm
Output data rate	133.3Mbps per bank
Data quantisation	8 or 10 bit

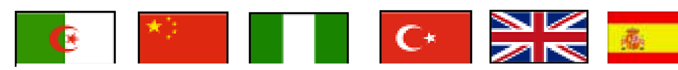
SURREY SPACE CENTRE

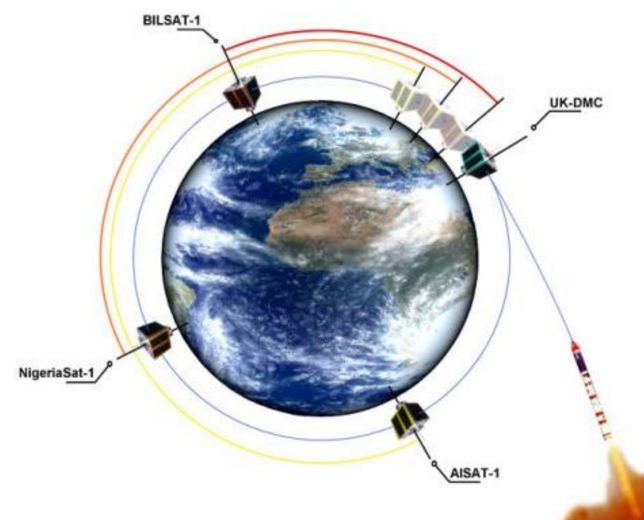
DMC Constellation

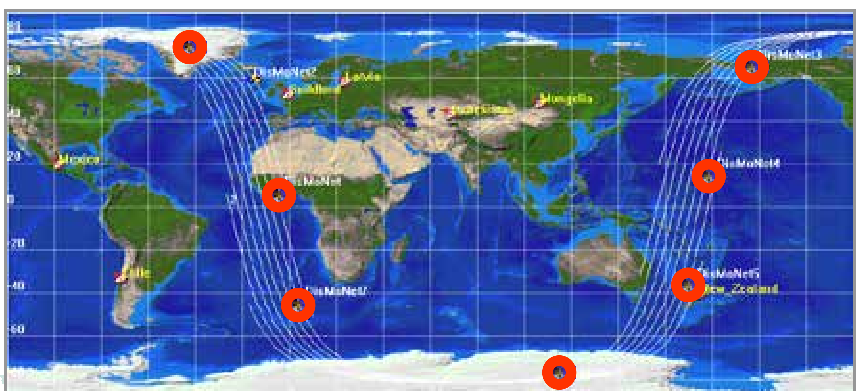
UNIVERSITY OF SURREY

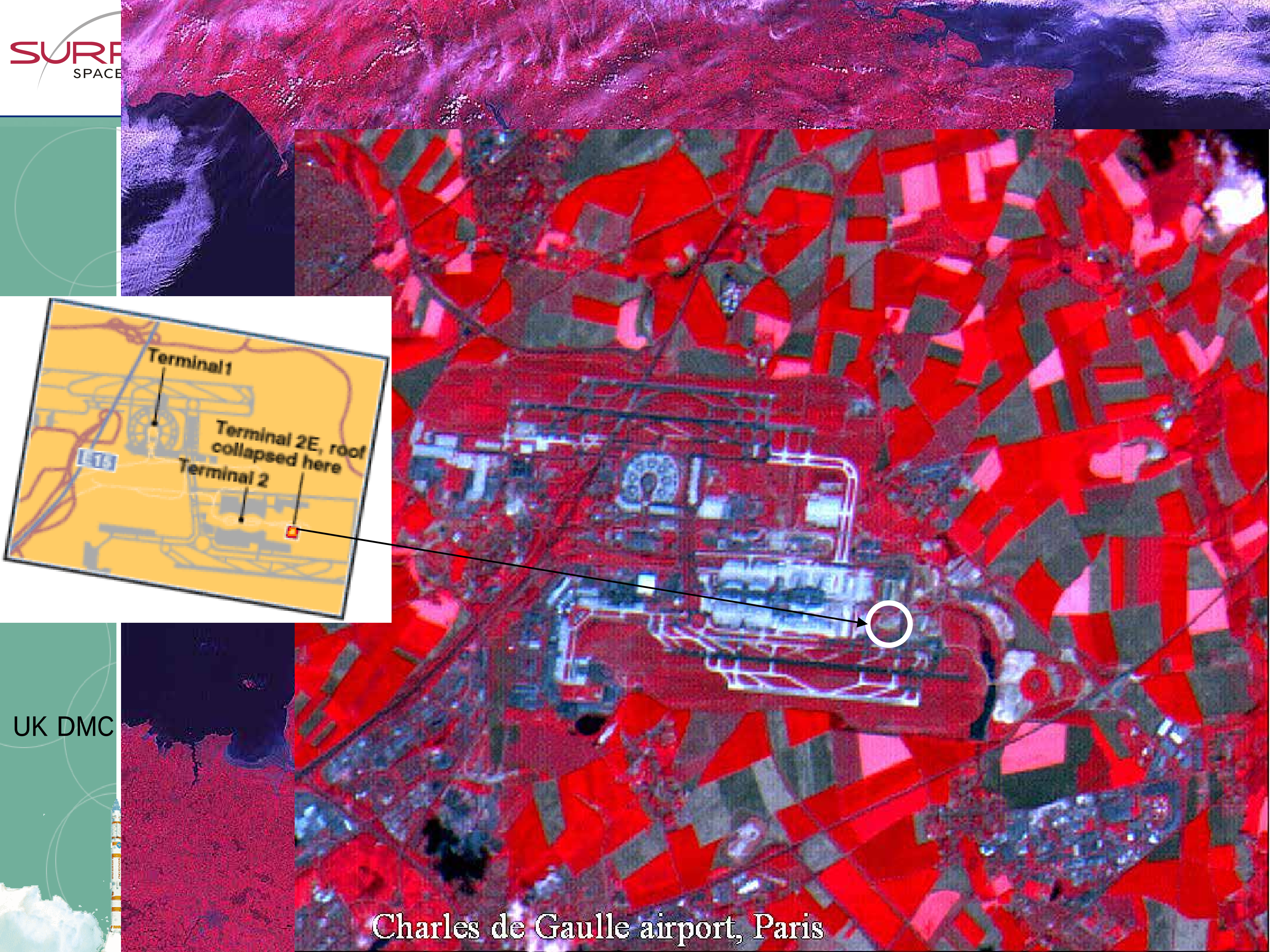
- **Disaster Monitoring Constellation**
- More satellites in the same plane à more geographical coverage at same time of day
  - In DMC scenario we have global-daily coverage with 5 satellites per plane
- Imaging of disaster areas
  - Floods, earthquakes, hurricanes etc.
  - 32m R-G-NIR imager
  - Electronic slewing from 600km swath
- Daily imaging anywhere on Earth
- Quick delivery of images
  - One Mission Control station per spacecraft









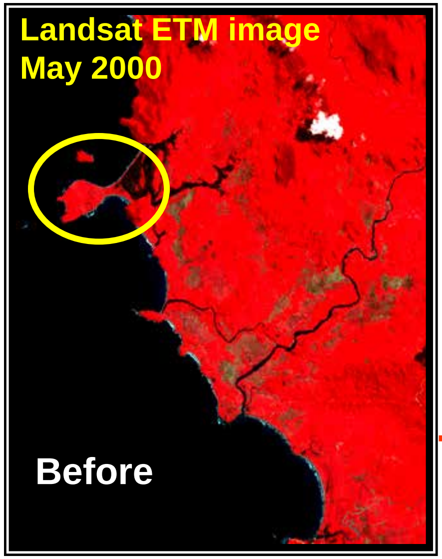


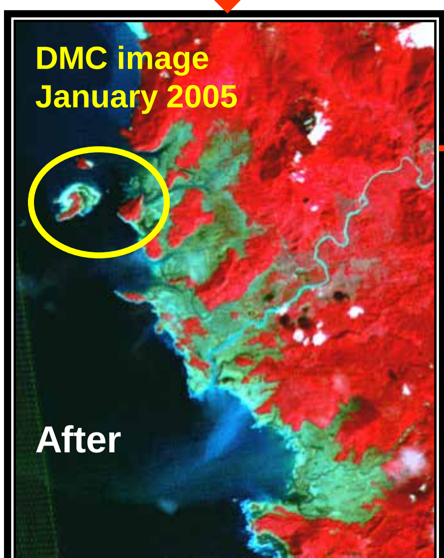
Charles de Gaulle airport, Paris

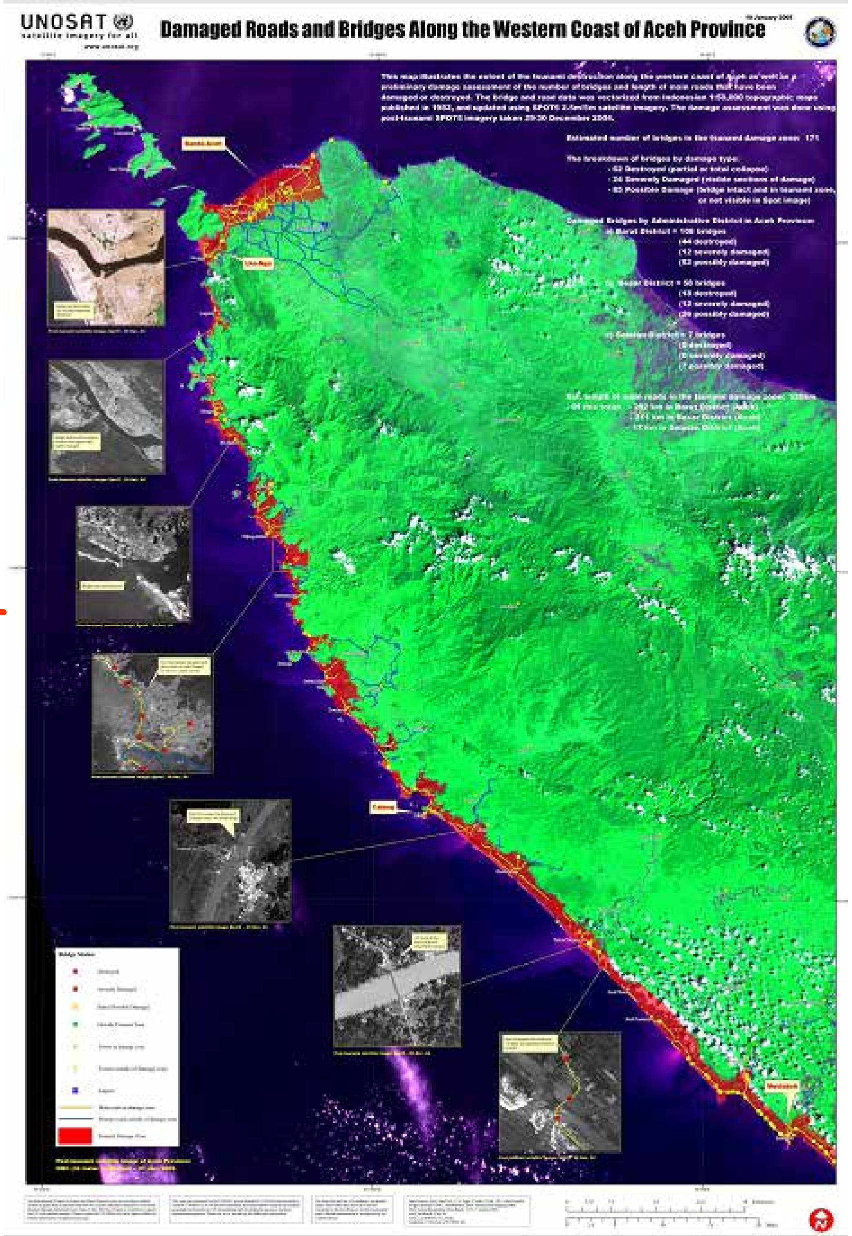
UK DMC

Asian Tsunami Disaster

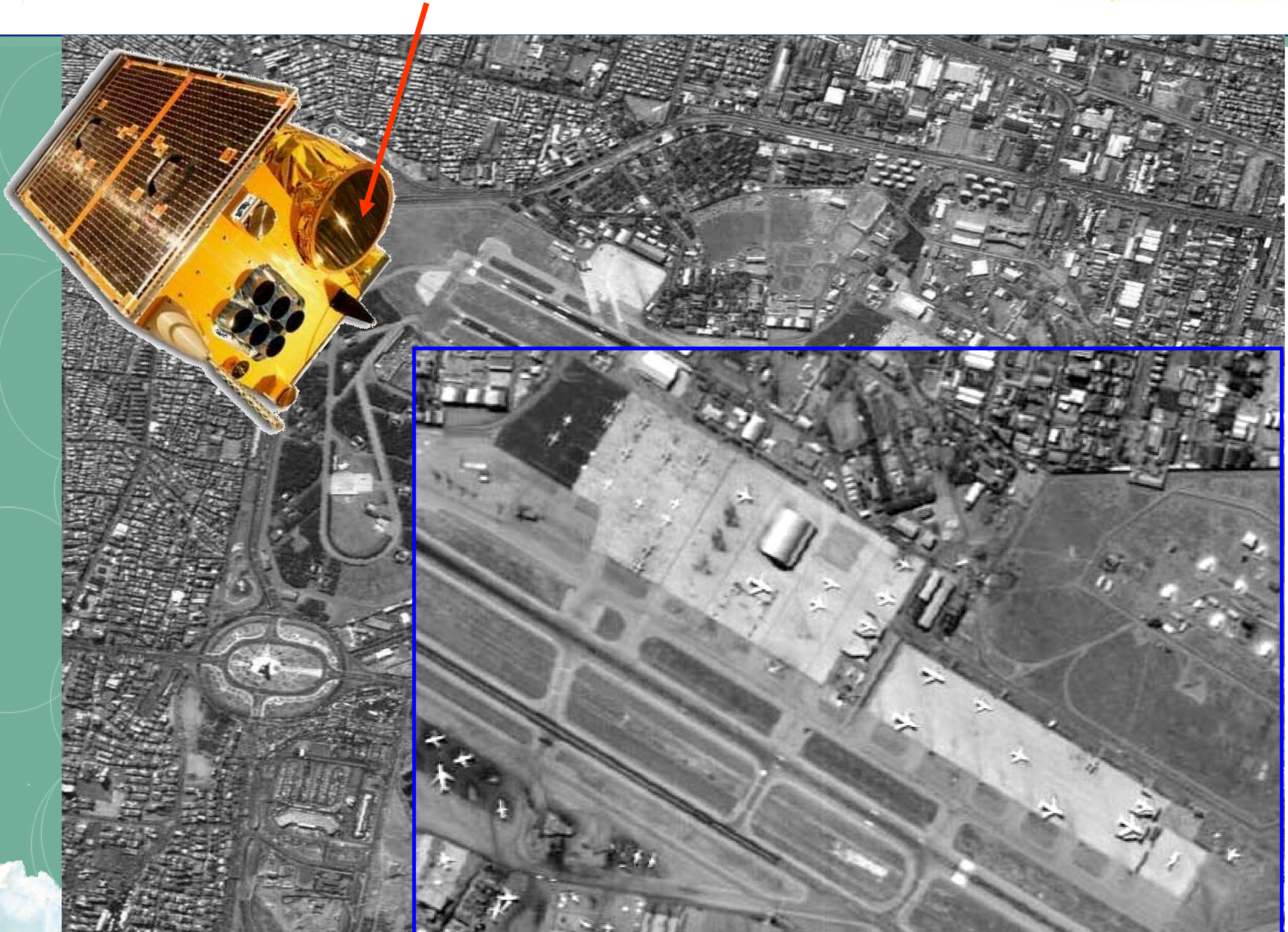
Generating maps to guide relief efforts







SSTL-150: 4m GSD PAN

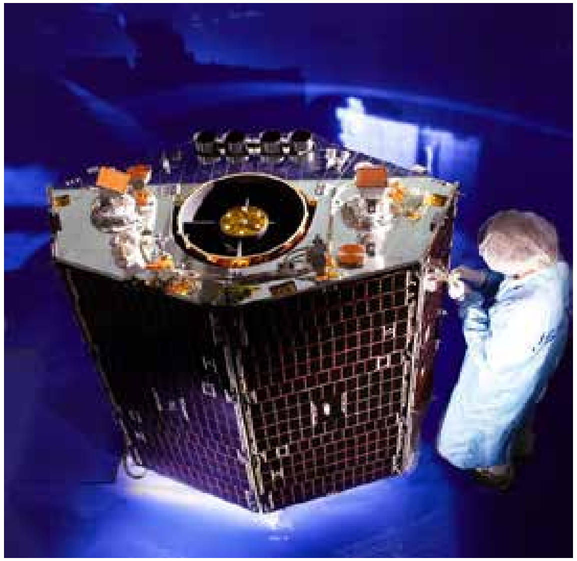


Pan & MS Data Fusion

SSTL-300: DMC-2

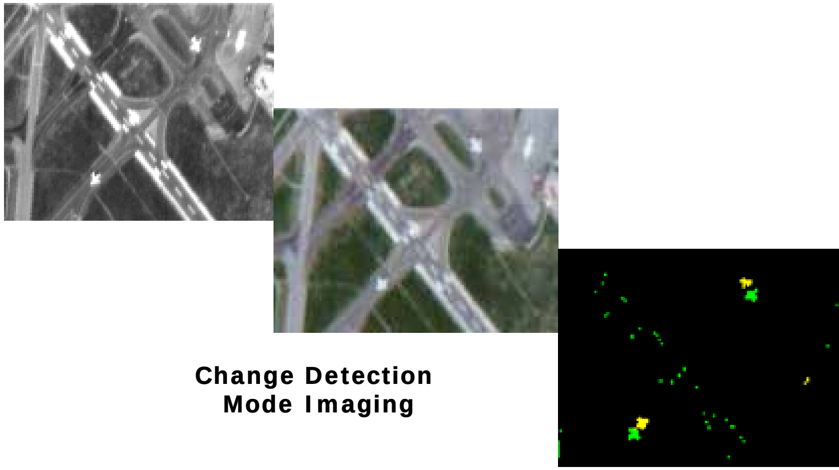
Nigeriasat-2 – Launched 2011.

- Hi-Res imager, 2.5m GSD PAN & 5.0m GSD 4-band multispectral
  - 20km swath
- Medium-Res Imager, 32m GSD 4-band MSI
  - 320km swath
- Advanced imaging (agile pointing)
- Dual X-band downlink
- 150-400 images per day
- 7 year life



Highly Agile Imaging

Extended Strip Imaging

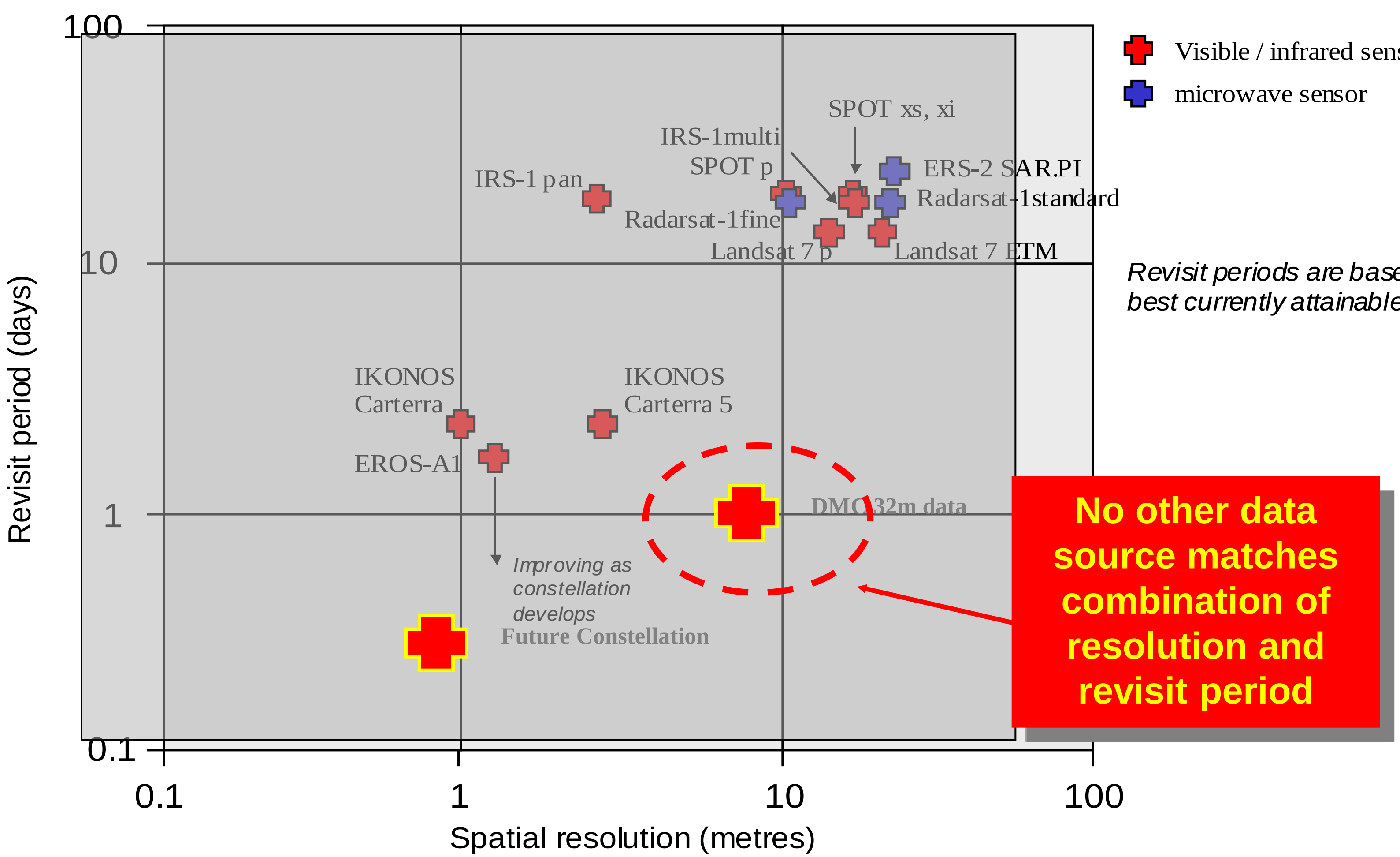


Change Detection Mode Imaging

- ## DMC-3 – Under Construction
  - Sub 1m GSD

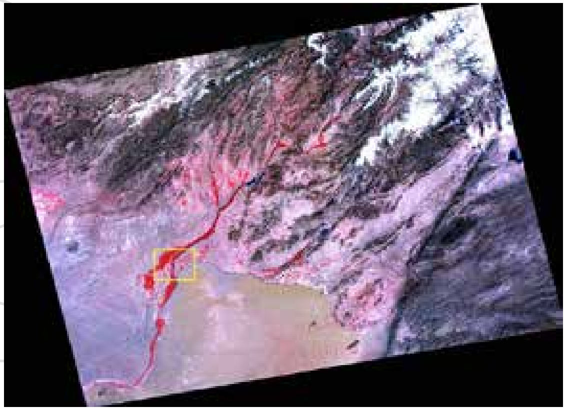
Constellations: Revisit Period

For monitoring rapidly changing phenomena

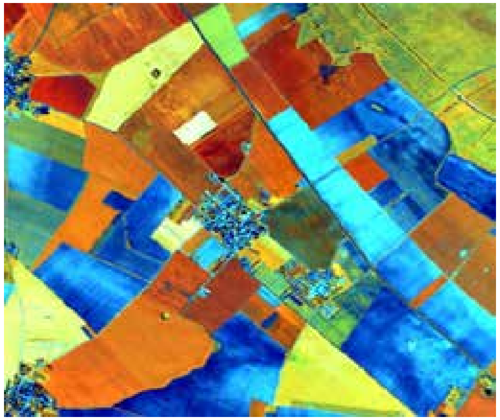


Revisit periods are based on best currently attainable

Constellations: Imaging Apps



Vegetation / Forestry / Water Quality Mapping



Precision Agriculture Water Stress, Chemicals, Run-off

Global Science – Climate Change

High temporal resolution gives unique scientific capabilities

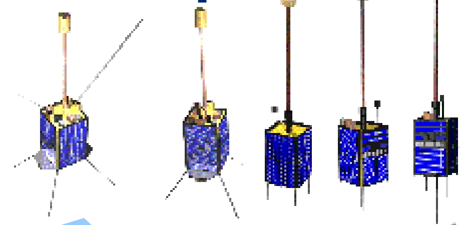
Miniaturisation

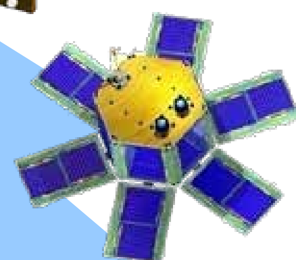
- **SSC Research Developments – 35 years**

1979-1991

UoSAT
Micro-satellites

50-65 kg





1995-2000

SNAP
Nano-satellite

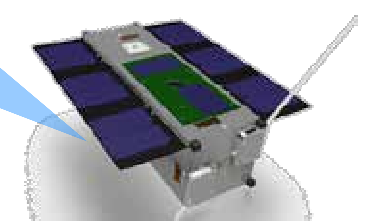
6.5 kg

- **New Instruments?**
  - Beyond Vis-NIR: TIR, UV
  - Radiometers, Spectrometers
  - GNSS Reflectometry, SAR

2001-2013

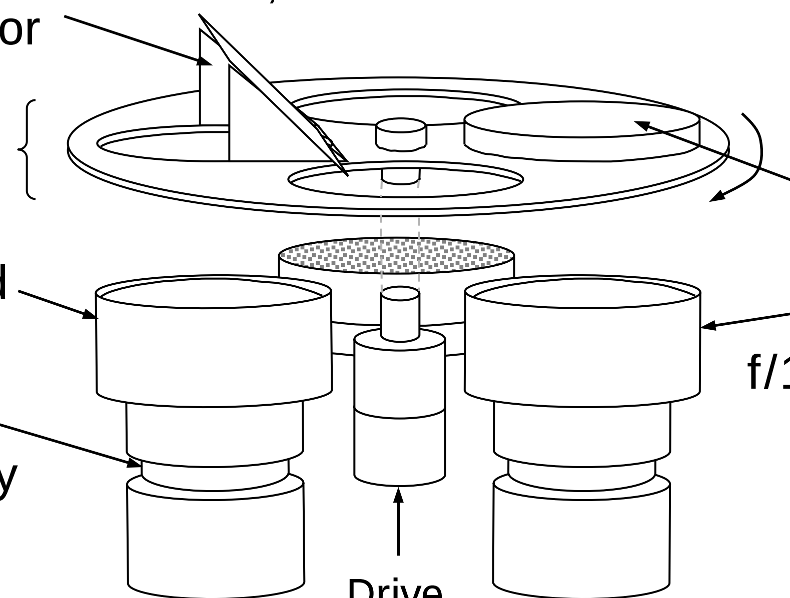
PalmSat
and CubeSats

1-4 kg



Miniaturised Instruments

- **MATI – Microbolometer Array TIR Imager**
  - In 2005 an SSC PhD developed a prototype TIR imager based on COTS microbolometer array technology.
  - The system can image day or night, and is capable of detecting hot-spots such as fires, gas/oil production flares, etc.

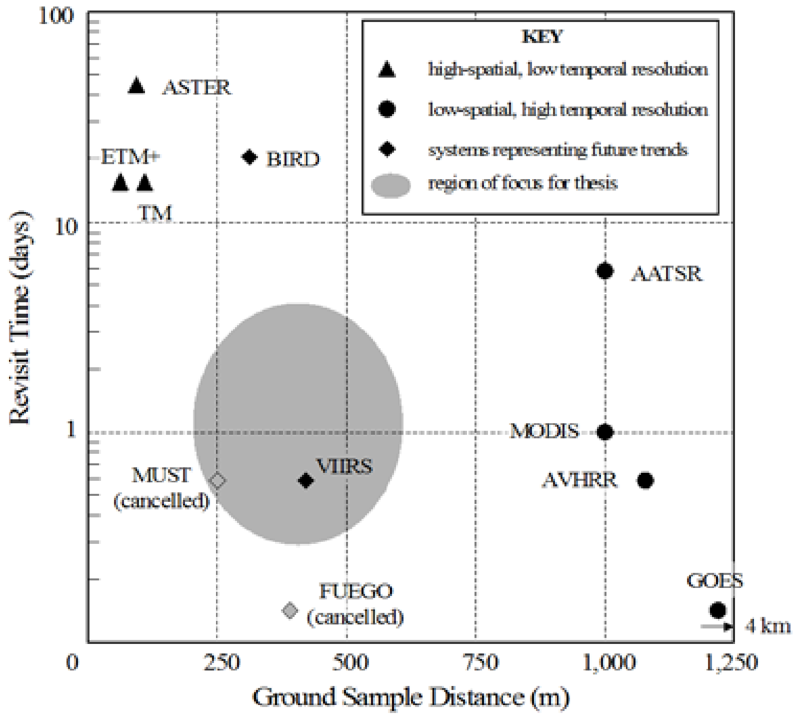


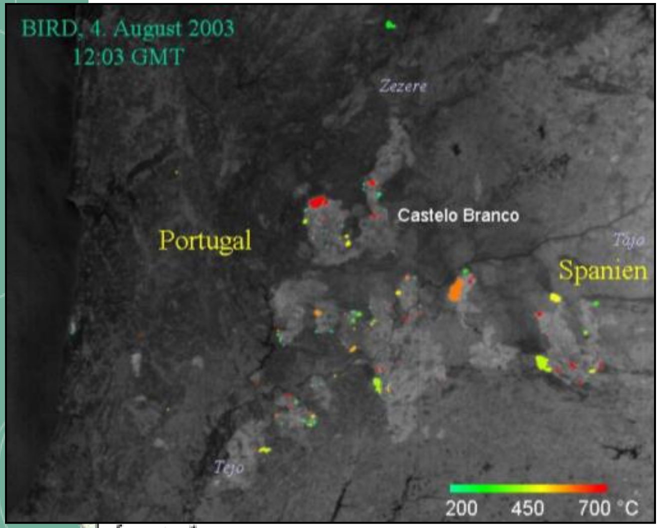
~ 150 mm x 180 mm

Mass: ~ 5kg; Power ~ 5W

Miniaturised Instruments

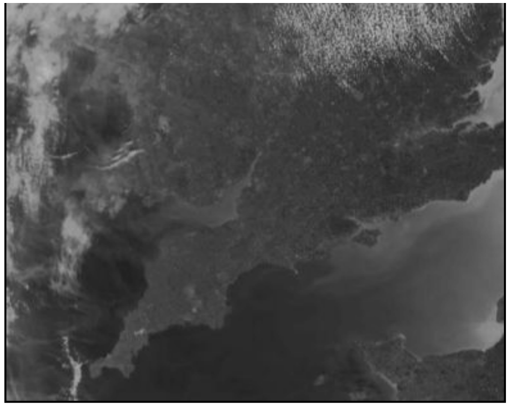
- **MATI – Microbolometer Array TIR Imager**
  - This system uses low-cost microbolometer arrays and GaAs lenses to form an image of the Earth in the Thermal Infra-Red (TIR) wavelengths, with a GSD of ~250m (using current generation sensors)
  - NETD: <0.5K @ 300 K for LWIR band; Range 265K–600K





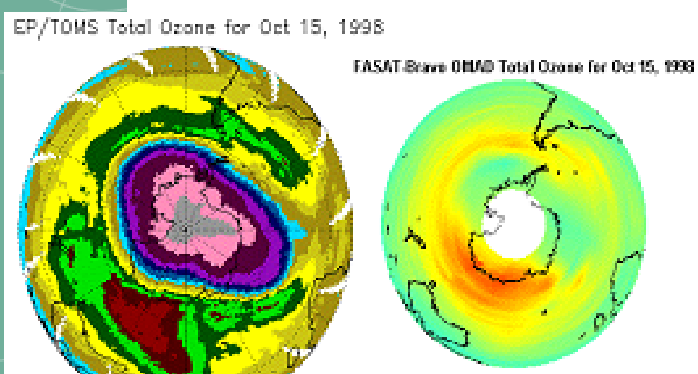
BIRD Satellite MW TIR Image of Forest Fires

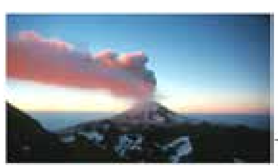
NIRST imager on Aquarius from INO



AATSR LW TIR Image

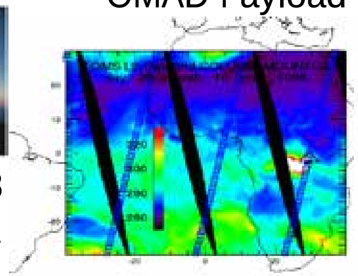
- **AQMI – Air Quality Monitoring Instrument**
  - This system uses an array of UV-VIS sensitive detectors to examine the light backscattered by the atmosphere in order to determine air quality.
  - Precise filtered colour bands are chosen to provide data on, land/cloud boundaries, Ozone, Sulphur Dioxide (volcanic eruption) and aerosol (smoke, dust) content of the atmosphere, similar to those used in the NASA TOMS and MODIS instruments.
  - A prototype instrument was flown as the 4 UV Channel OMAD Radiometer payload on FASAT-Bravo in 1998.

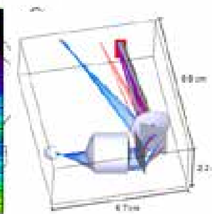


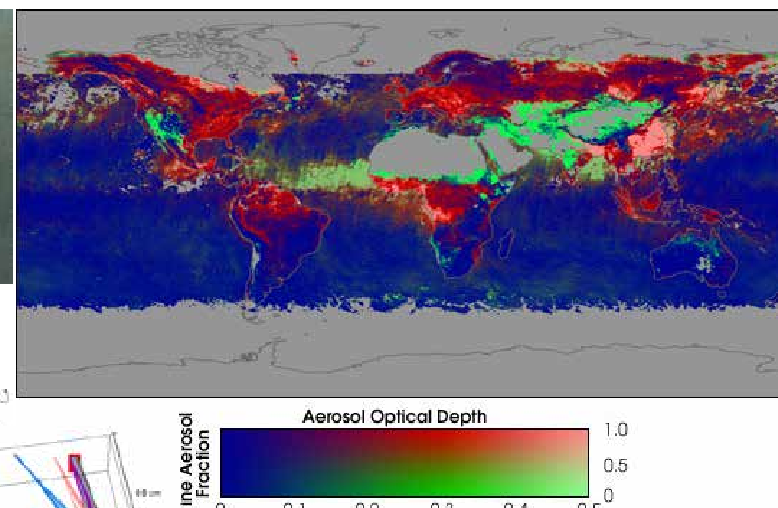


OMAD Ozone Data for 15/Oct/1998
in Comparison to NASA TOMS Data

FASAT-Bravo
OMAD Payload



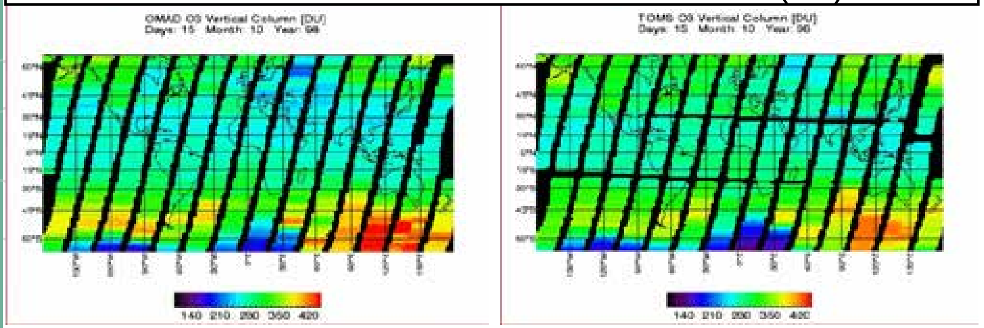




NASA MODIS Aerosol Map

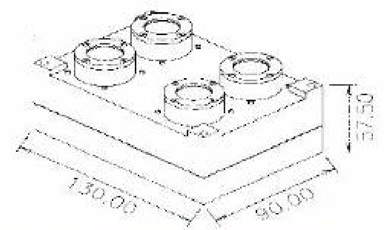
- **Solar UV Backscatter Radiometry – O_3 / Aerosols / SO_2**

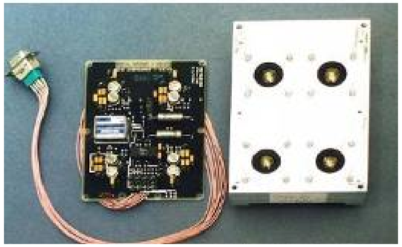
FASAT-Bravo OMAD vs. NASA TOMS Results (DU)



Channel [nm]	Gain [V/A]	Responsivity [A/W]	Total Nominal Transmission factors	Transmission at CW [%]	Spectral Bandwidth [nm]
289	1.00E+10	0.13	0.422	0.141	9.5
313	4.13E+07	0.14	0.734	0.305	9.4
334	5.40E+06	0.15	0.719	0.71	10.3
380	4.13E+07	0.18	0.147	0.48	10

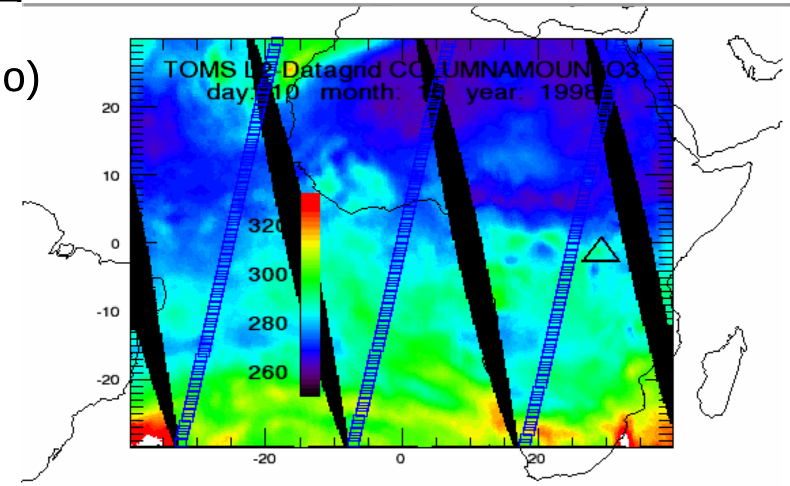
Ozone Mapping Detector (OMAD) (2kg, 0.5W)





FASAT-Bravo, 1998

Nyamuragira Eruption Oct 1998 (Rep. Dem. Congo)



Miniaturised Instruments

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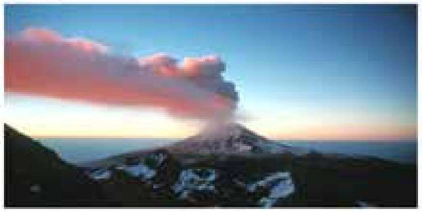
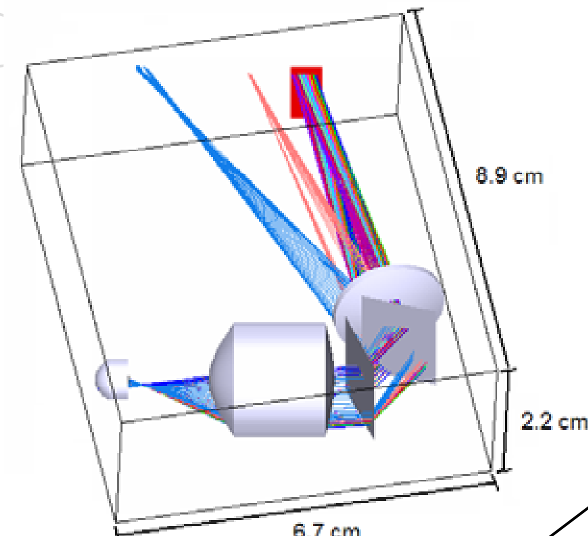
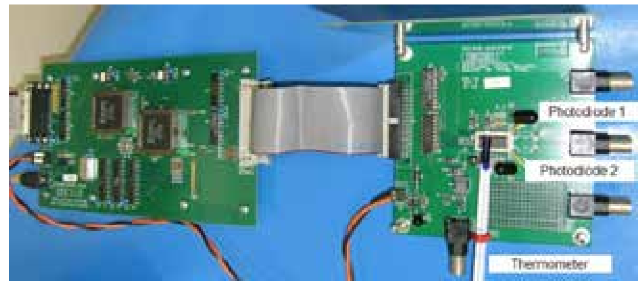
UNIVERSITY OF SURREY

- **UV Imaging Spectrometer – Volcanic Plumes**

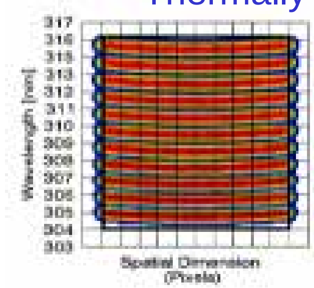




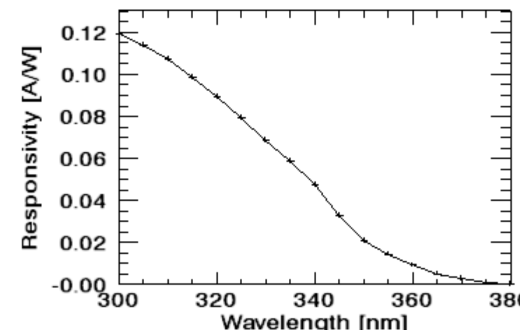


- Low Power
- Very Low-Noise Electronics
(~2 fA with Switched Integrator Amplifier +
16-bit ADC)

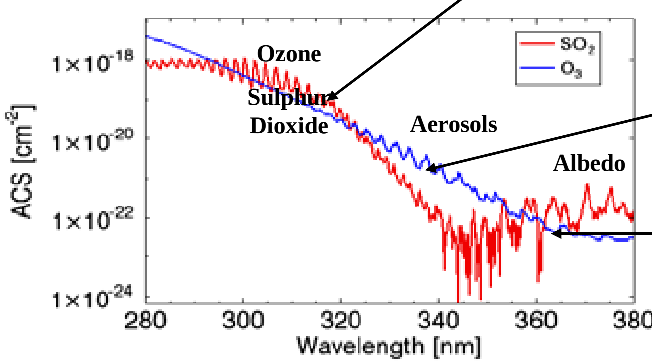
SiC Array Detector
- High response in UV
- Solar blind
- Thermally stable

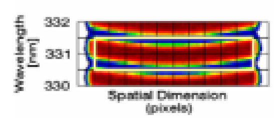


305-315 nm

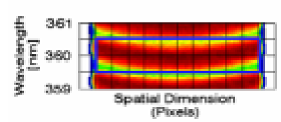


Fused Silica Transmission Gratings
- High Efficiency
- High Dispersion

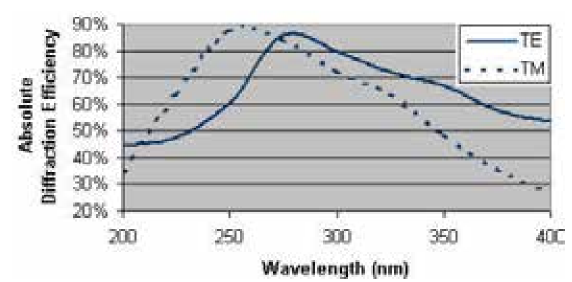




331 nm



360 nm



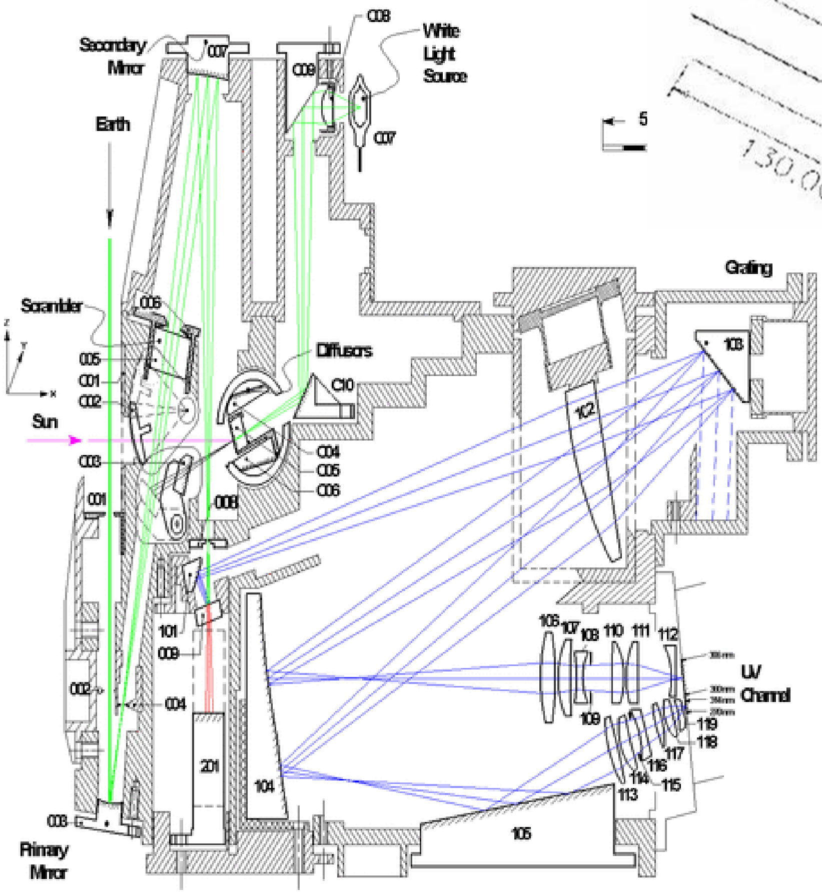
Miniaturised Instruments

SURREY SPACE CENTRE

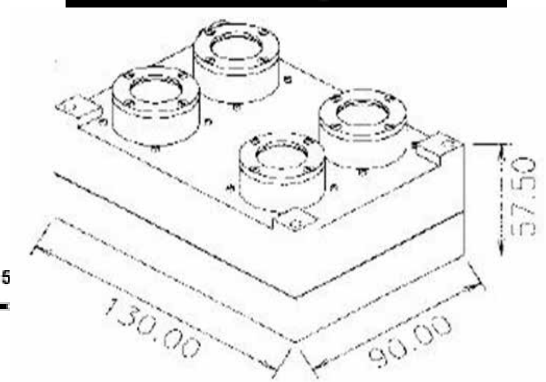
UNIVERSITY OF SURREY

- **Size Comparison**

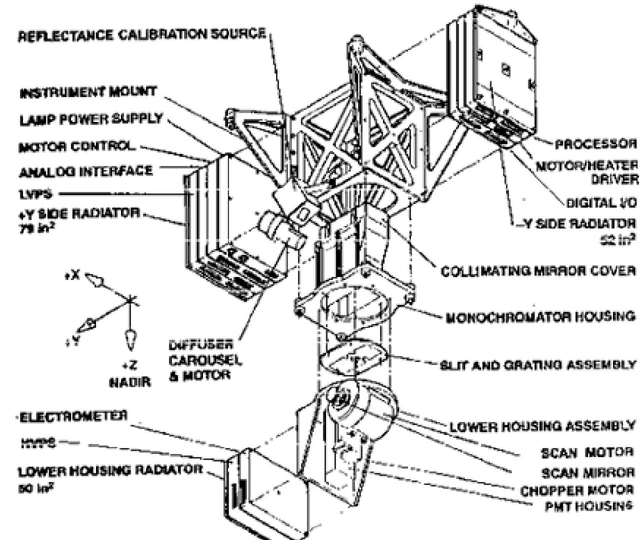
OMI (65 kg / 66 W)

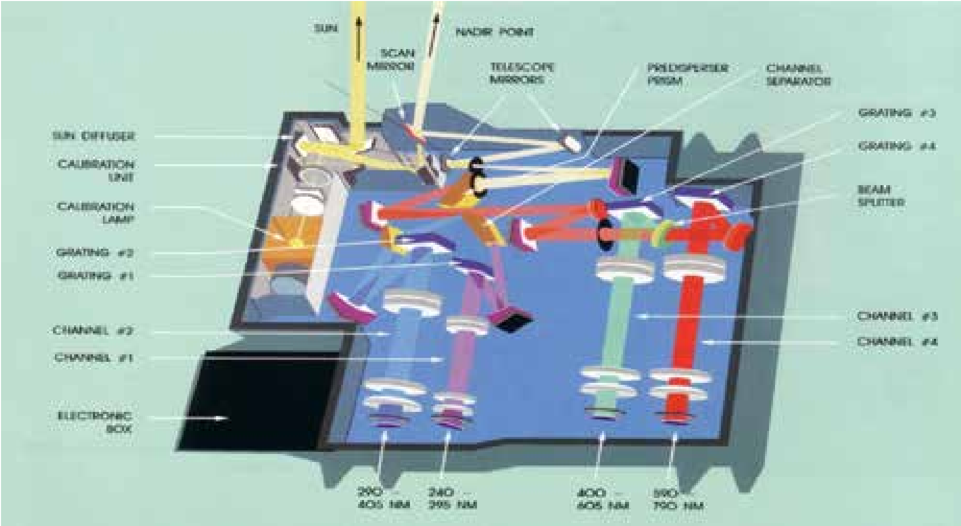


OMAD (2 kg / 0.5 W)



TOMS (34 kg / 25 W)





GOME (55 kg / 32 W)

Miniaturised Instruments

- **Measuring CO_2 from Space**
  - CO_2 measuring satellites are characterised by large size and high cost:

SCIAMACHY on ENVISAT

Source: M. Gottwald et al, 2006

Cost: £1.8B (9 instruments)

Size: 1.09 m × 0.65 m × 1.01 m

IASI Instrument on METOP-A

Source: CNES Scientific Missions Website © CNES 2013

Cost: : $946M (12 instruments)

Size: 1.2 m × 1.1 m × 1.1 m

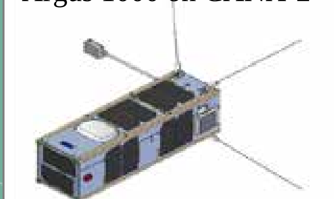
AIRS Instrument on AQUA

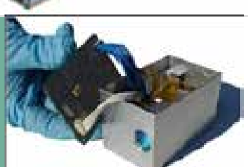
Internet source: Jet Propulsion Laboratory, 2013

Cost: $952M (6 Instruments + Launch)

Size: 1.397 m × 0.775 m × 0.762 m

Argus 1000 on CANX-2



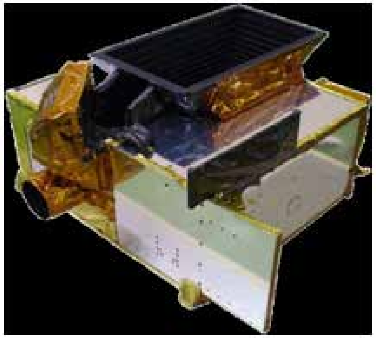


Internet source: eoPortal, 2011

Cost: $0.3M (2 instrument)

Size: 0.05 m × 0.06 m × 0.08 m

TANSO-FTS instrument on GOSAT

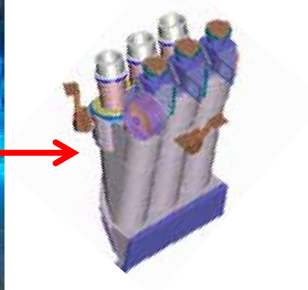


Source: M. Nakajima et al, 2009

Cost: $390M (2 instruments)

Size: 1.2 m × 1.1 m × 0.7 m

The OCO (failed)



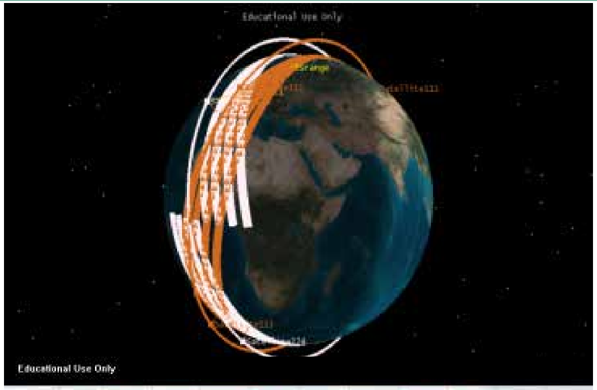
Source: D. Crisp, 2011

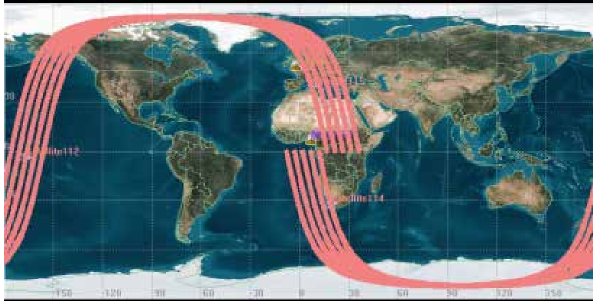
Cost: $280M (1 instrument)

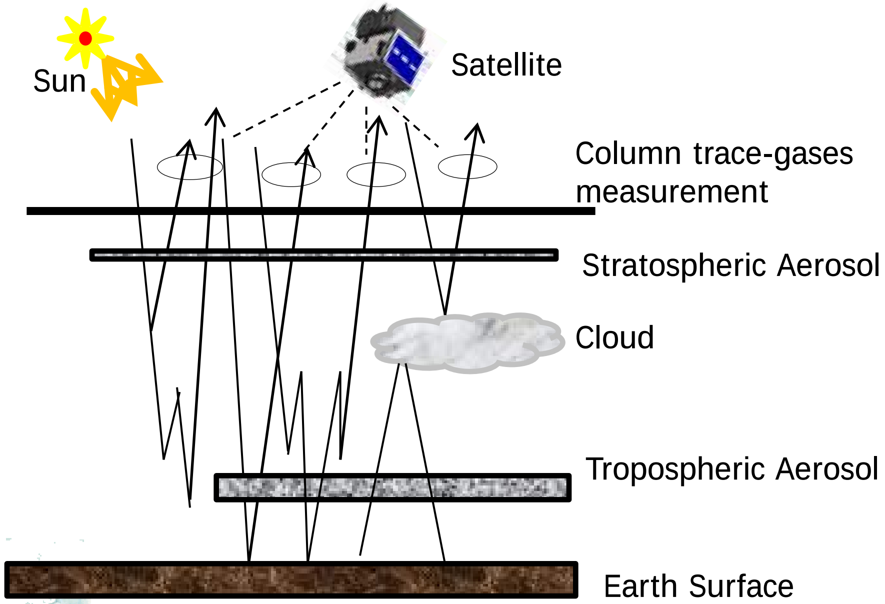
Size: 1.6 m × 0.4 m × 0.6 m

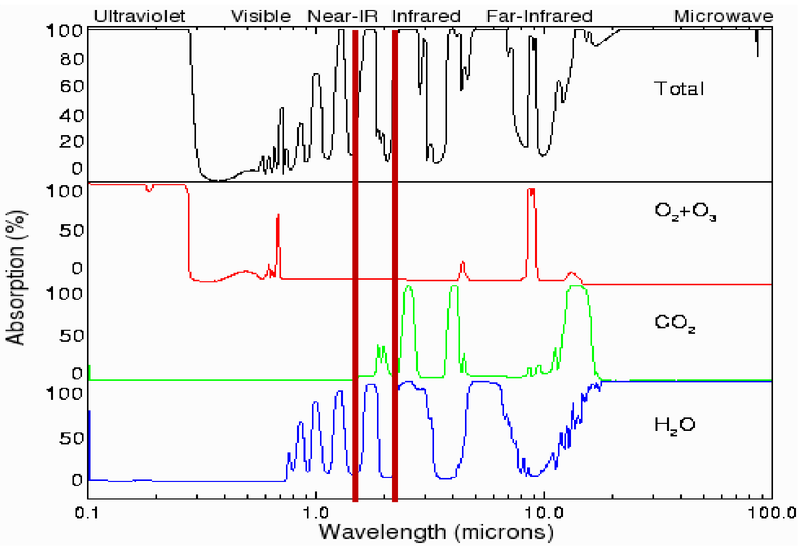
Miniaturised Instruments

- **Atmospheric CO_2 Monitoring**
  - An SSC PhD has developed a compact "solid-state" FTS spectrometer concept for atmospheric CO_2 detection and measurement using the spatial heterodyne technique.
  - Spectral resolution of better than $0.27cm^{-1}$
  - Spatial resolution of ~16km
  - Operates in the SWIR spectral range
  - Centre wavelengths of 1.6µm and 2.0µm
    - CO_2 absorption bands near 1.6µm and 2µm provide information on near-surface concentrations (≤ 2km)



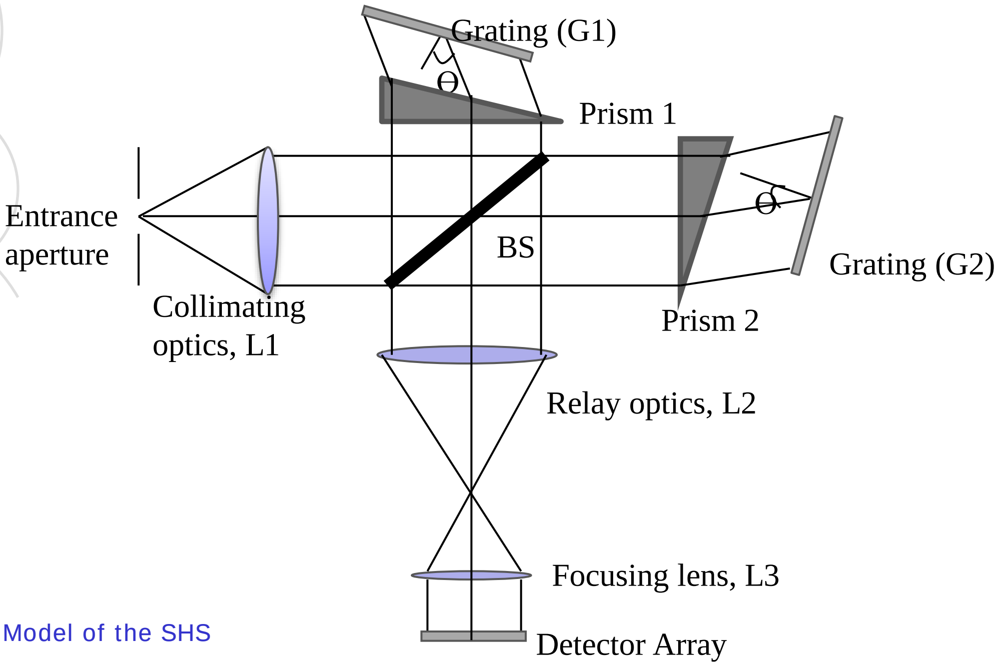




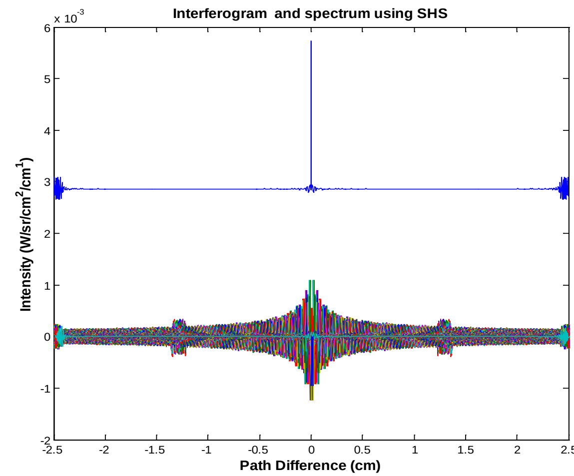


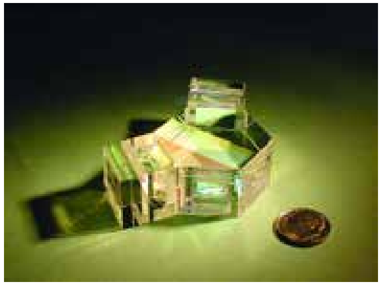
Miniaturised Instruments

- ## SSC Compact SWIR SHS Instrument

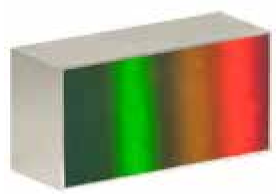


Model of the SHS

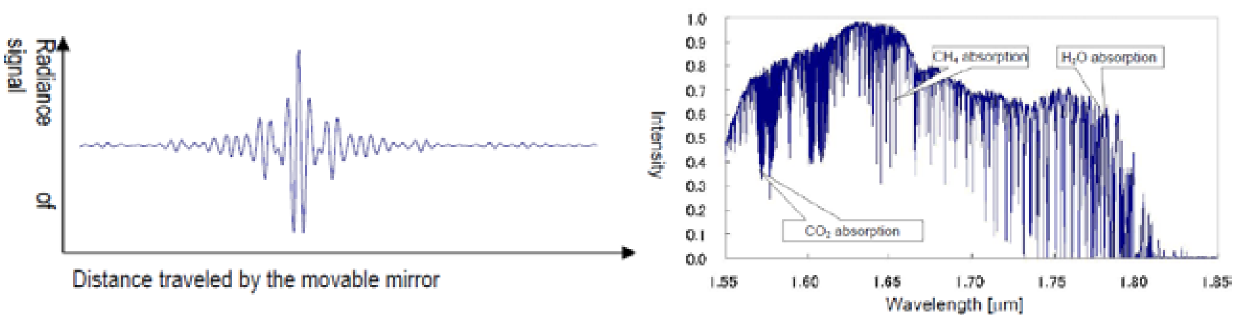




Example of a monolithic SHS

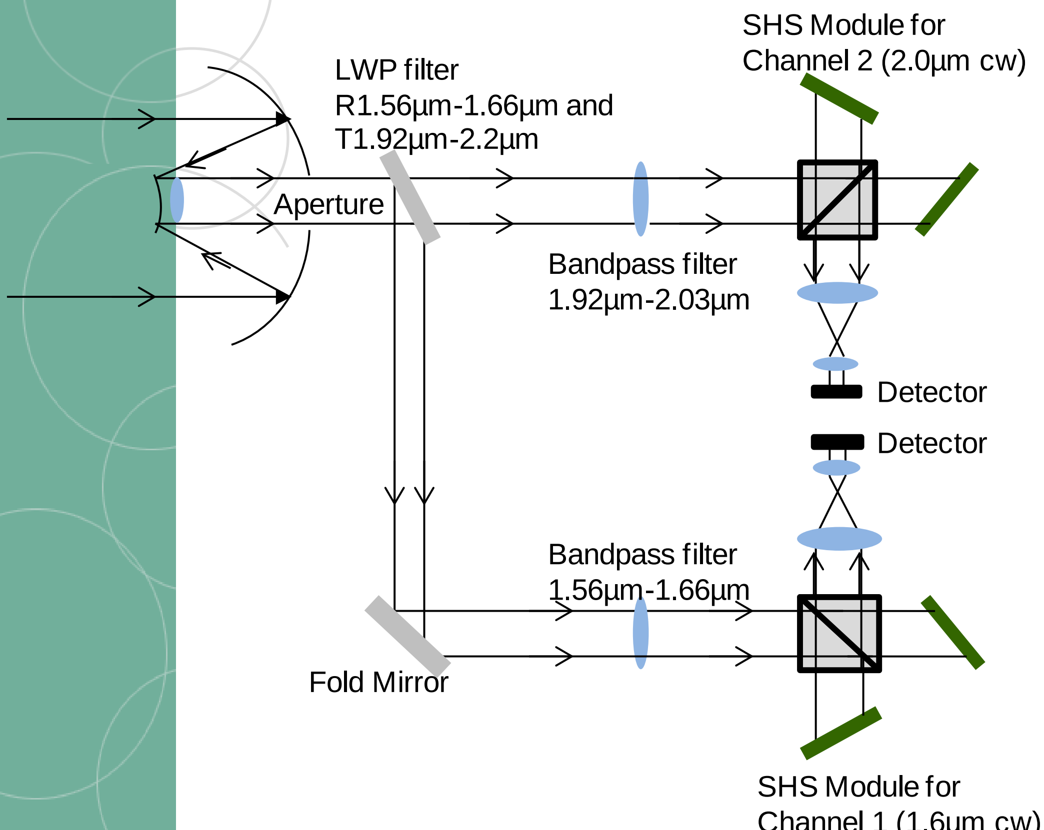


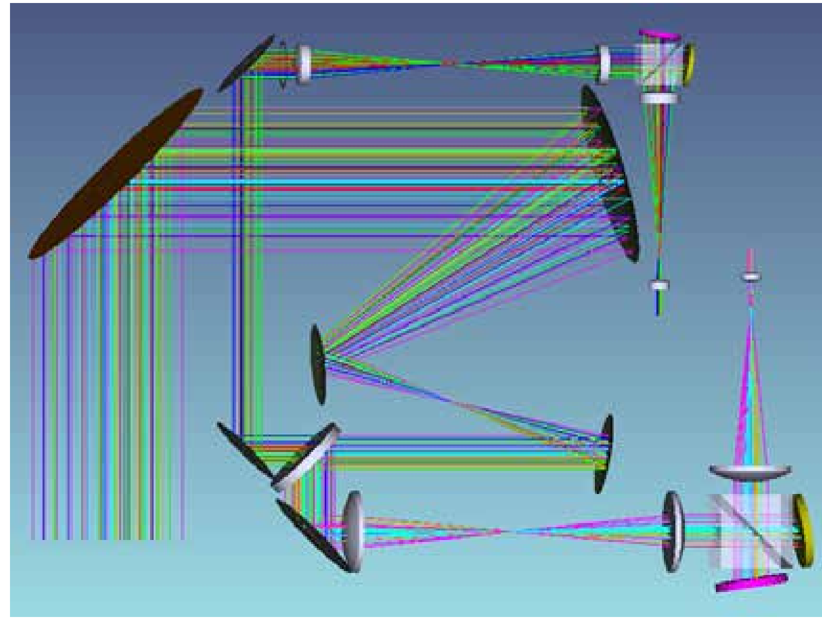
An Echelle Grating

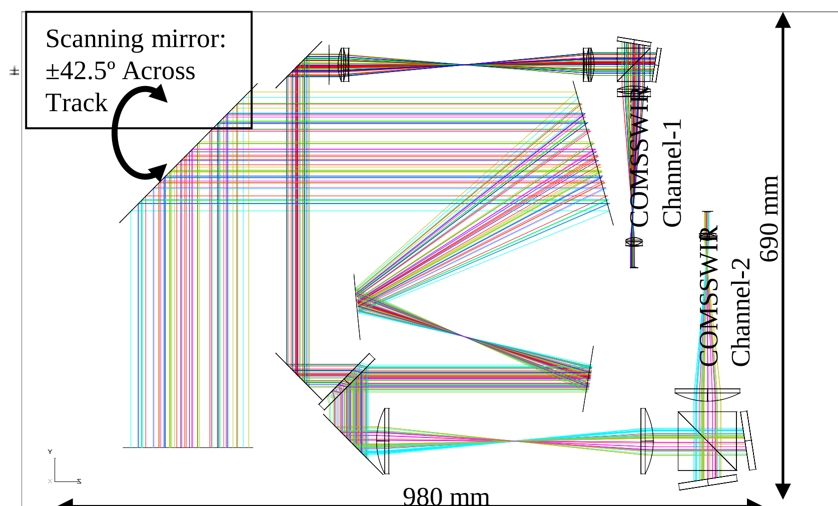


Conventional FTS Interferogram and Spectrum (Kuze et al 2009)

- **SSC Compact SWIR SHS Instrument**



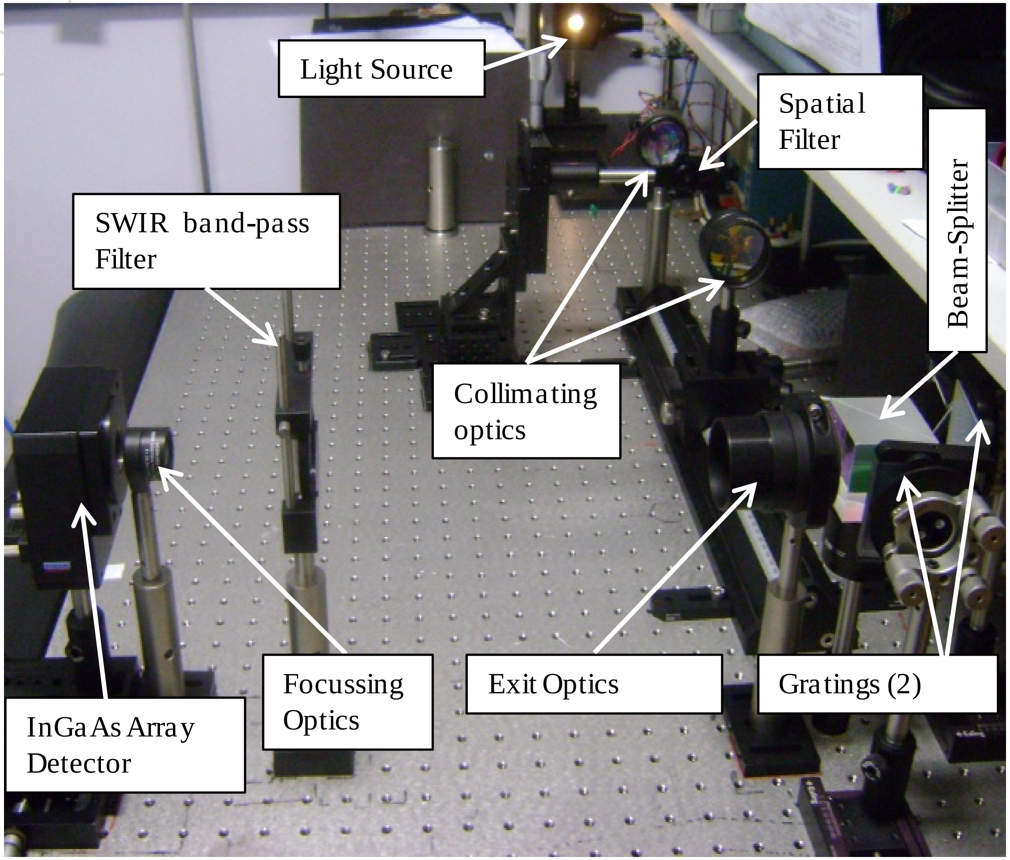




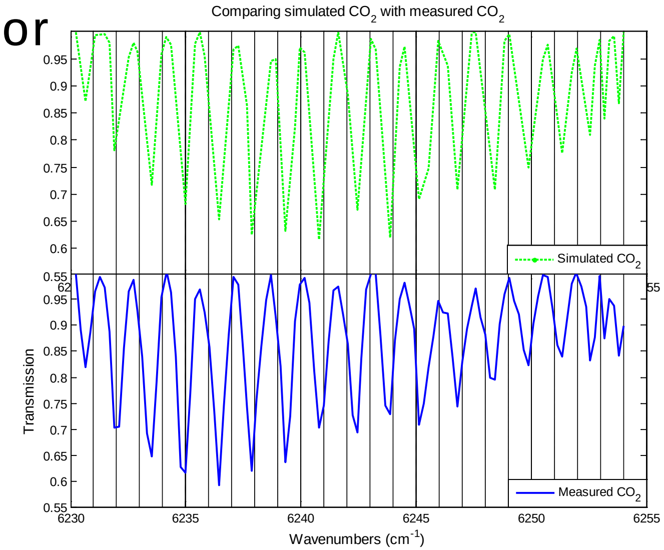
Model of the COMSHEFTS Instrument:
690 × 980 × 200 mm^3

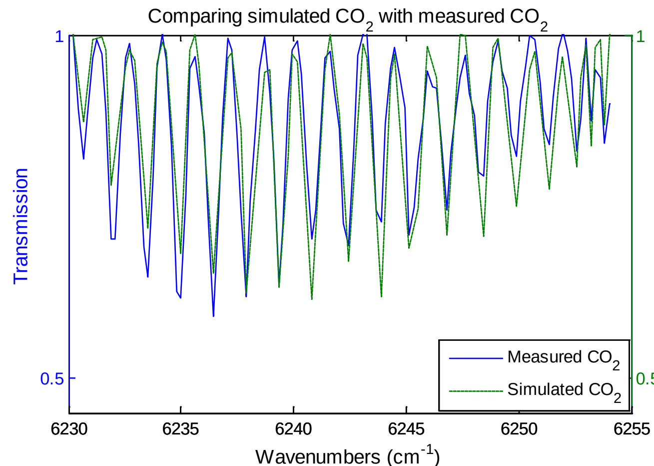
Miniaturised Instruments

- Bench-Top Demonstrator (1.6 mm Channel)
  - Input source: Quartz Halogen lamp (broadband continuum)
  - Instrument bandwidth is 6 nm (1599nm to 1605nm) – filter
  - Hamamatsu's 128 x 128 InGaAs detector



COMSSWIR Channel-1 Prototype Set-Up





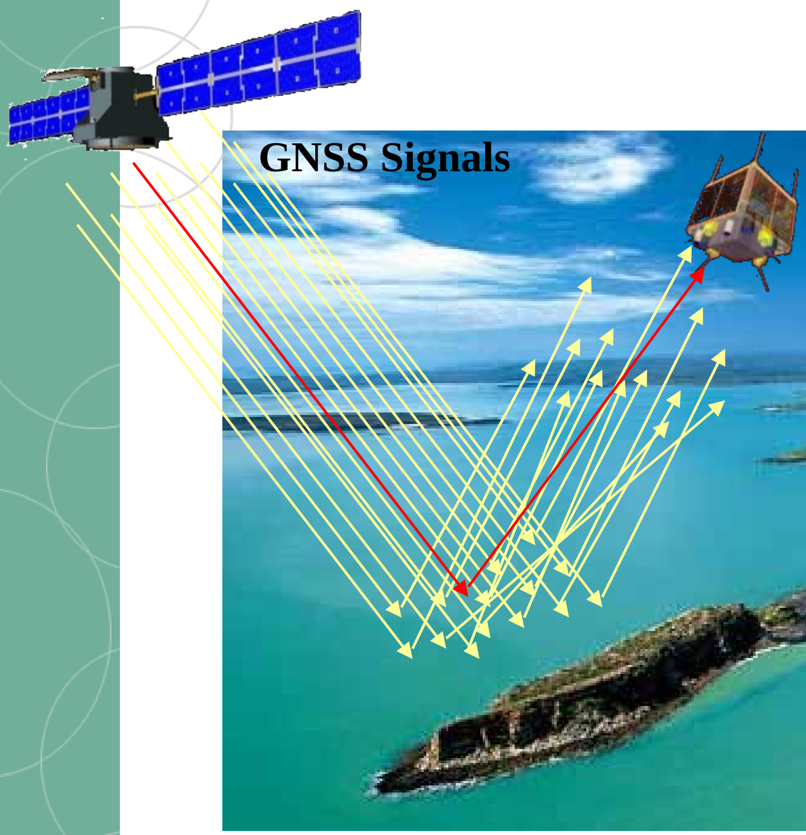
Miniaturised Instruments

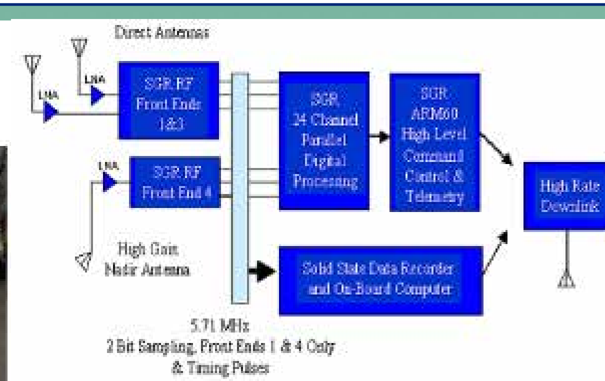
- **SSC Compact SWIR SHS Instrument**

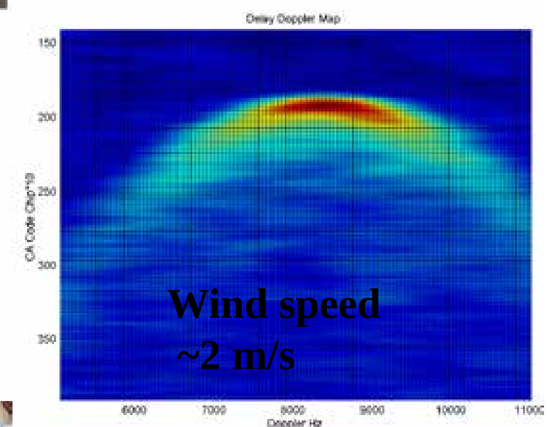
Parameter	GOSAT TANSO-FTS	OCO (Planned)	SSC Compact SHS (Target)
Size(m)	3.7x1.8x2.0	2.3x1.4x1.3	<1.0x1.0x1.0
Mass of S/C(kg)	1750	530	<100
Mass of instrument (kg)	250	150	<50
Power (W)	3800	786	<50
Spatial Resolution (km)	10.5	2.3	~16
Spectral Resolution (cm^{-1})	0.24	0.3	0.27
Altitude (km)	666	705	686
Inclination (deg)	98	80	98.14
Local time	13:00	13:00	13:00
Revisit Time	3-days	16	7-days (Array Detector)
CO2 Measurement	Total Column	Total Column	Total Column
Measurement Precision	4ppm	1ppm	1-3ppm
SNR (nadir, 5% albedo)	~120	>240	>100
Mission Life (yrs)	5	2	5

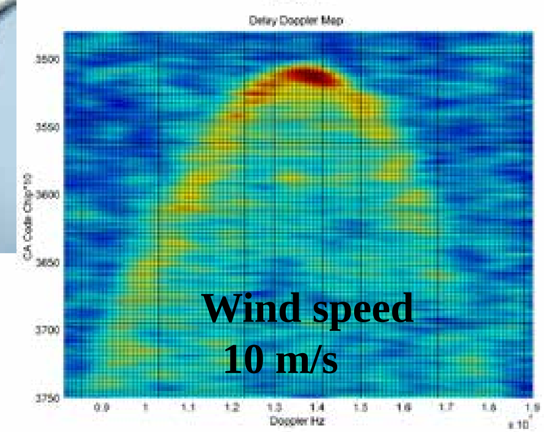
Miniaturised Instruments

- ## GNSS Reflectometry Payloads



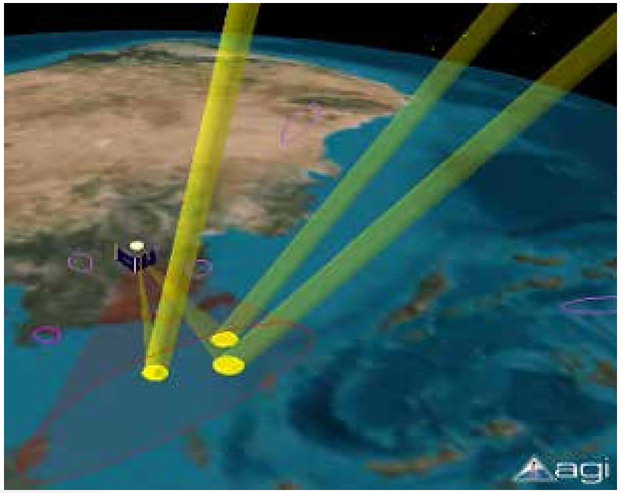




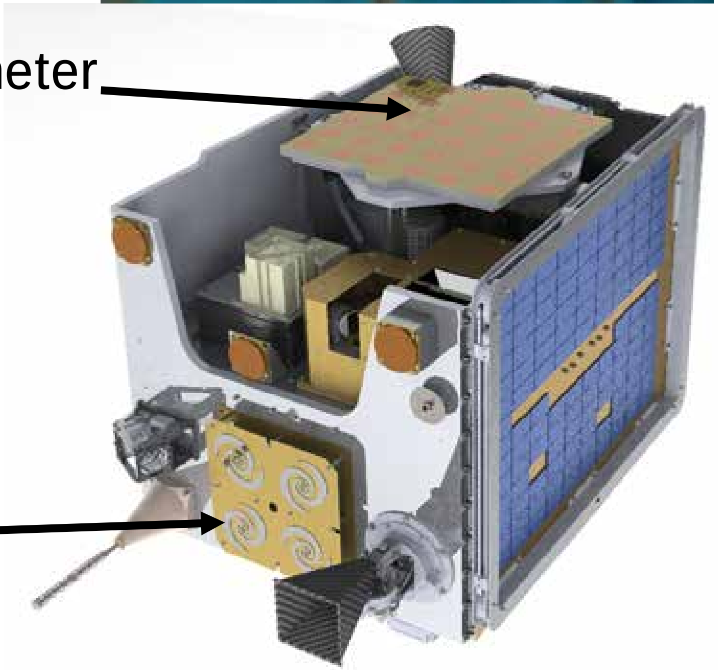


Subject of several SSC PhDs in collaboration with SSTL (EPSRC and CEOI CASE Awards)

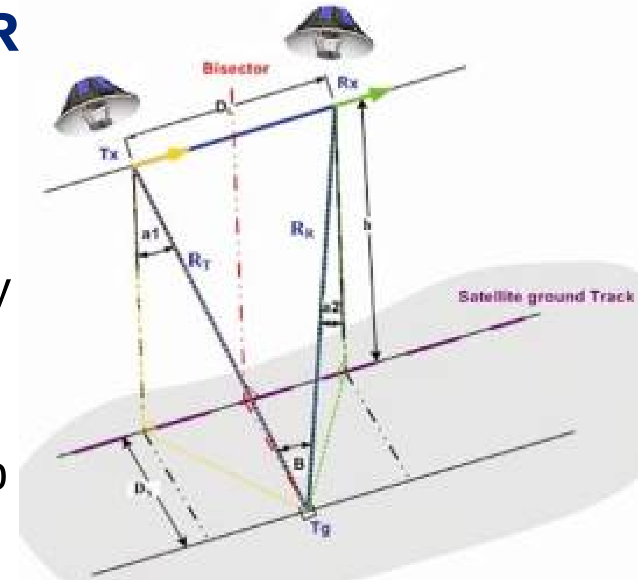
- **GNSS Reflectometry Payloads**

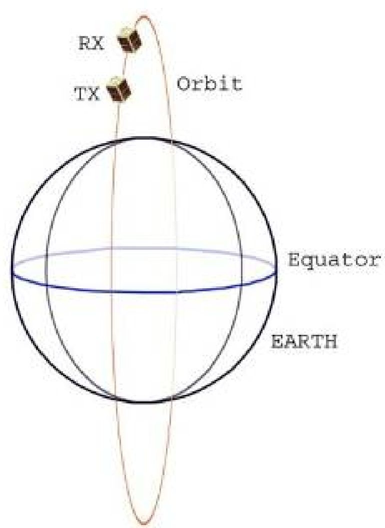


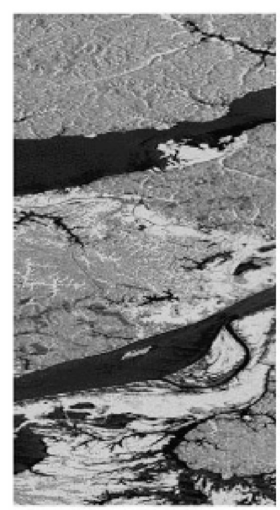
- First flight on TechDemoSat-1
  - Part of Sea State Payload
  - Accompanied by Altimeter
- Primary goals:
  - Replacement for SGR-10
  - Ocean roughness sensing through reflectometry
    - Collection of data for models
    - Real-time demonstration

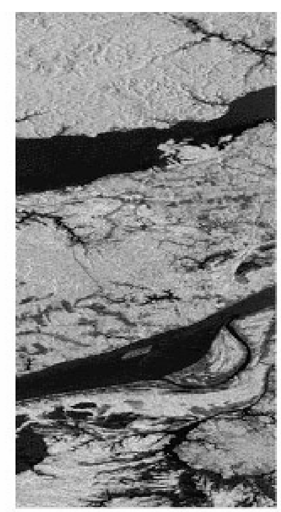


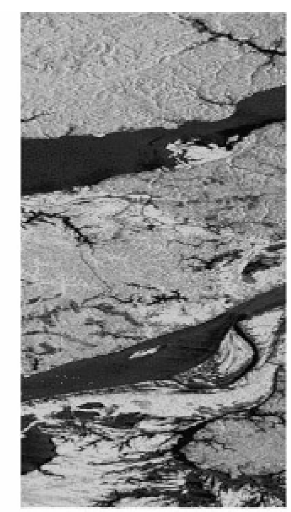
- **Bi-Static Micro-Satellite CWFM SAR**
  - SSC is also investigating the application of SAR payloads to a DMC-class 100 kg spacecraft.
  - A bi-static CW-SAR configuration was initially studied to reduce power demands (< 100W) and to provide unique image characteristics
  - We now consider mono-static extended-chirp SAR to be the way forward.
  - An L-Band or S-Band system is proposed for forestry, disaster monitoring and ocean studies.





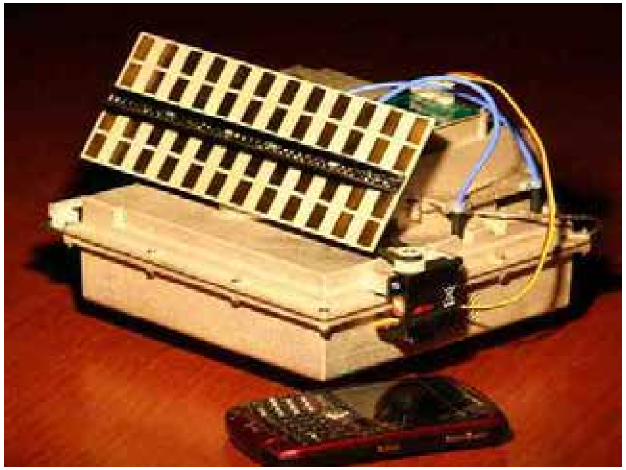

H/H polarization


H/V polarization


V/V polarization

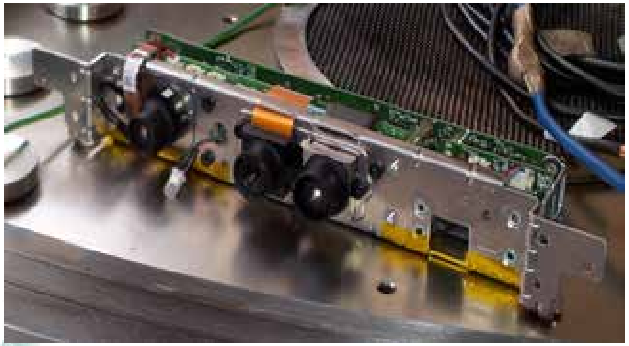
CubeSats, UAVs and Robots

- **Ever Smaller?**
  - Miniaturised instrument technology developed for small satellites has application to CubeSats, aerial platforms (UAVs) and to land mobile robots also being developed at Surrey.



“Nano-SARs”
http://www.imsar.com

HORYU-II CubeSat with SSC SCAMP Camera



Conclusions

- “MicroSats” and “NanoSats” have the potential to revolutionise the way we do space missions.
- Today, COTS technologies, including advanced, highly integrated processors, micro-sized imaging sensors and MEMS, give us new opportunities to develop advanced “SmallSat” EO missions using miniaturised instruments.
- The low cost per platform makes swarms and constellations a practical proposition.
- SSC and SSTL show how academic research and commercial industry can work together to put fundamental research to practical commercial application.