Workshop Introduction

UKSA investment in Solar Monitoring

- Increased funding was recently announced by the UKSA for improved solar monitoring

http://www.spacedaily.com/reports/UK_to_accelerate_research_into_forecasting_space_weather_999.html

- The reporting focuses on the improved warnings to satellite operators and to the CNI community that are expected to result from enhanced solar monitoring

- There are, however, additional potential benefits that could accrue if the data can be processed and disseminated to the space tracking community in a timely fashion

The potential for improved SSA

- Enhanced solar monitoring, if available in a timely fashion, could be used to **forecast** the appropriate space weather inputs to orbit models

- If the Sun is monitored at an increased number of wavelengths, the future energy input to the atmosphere can be estimated with enhanced accuracy

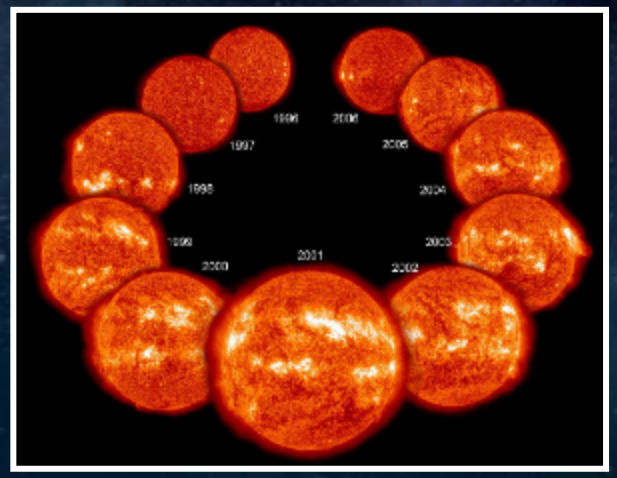
- This has the potential to:-
  - Reduce the size of the error ellipsoids around all orbital objects, (with the corollary that conjunction warning frequencies should be reduced)
  - Extend the time over which conjunction warning software algorithms can be run, enabling operators to better-optimise manoeuvres and hence save time, fuel, and money.
  - Better use of SSA assets, through more accurate, reliable custody of objects, (effort can be concentrated on those objects that are the “least well-behaved”)

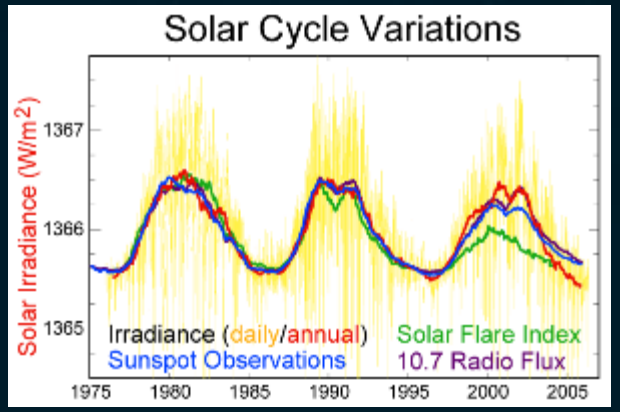
Questions to resolve

- What solar parameters should we be measuring in addition to the 10.7 cm flux?
- Where should we be monitoring from?
- How often should we be measuring them?
- How will we calibrate these measurements?
- Who will develop the “drag forecast” algorithm based on this input data?
- How will we test it?
- How will we decide if we’ve succeeded?

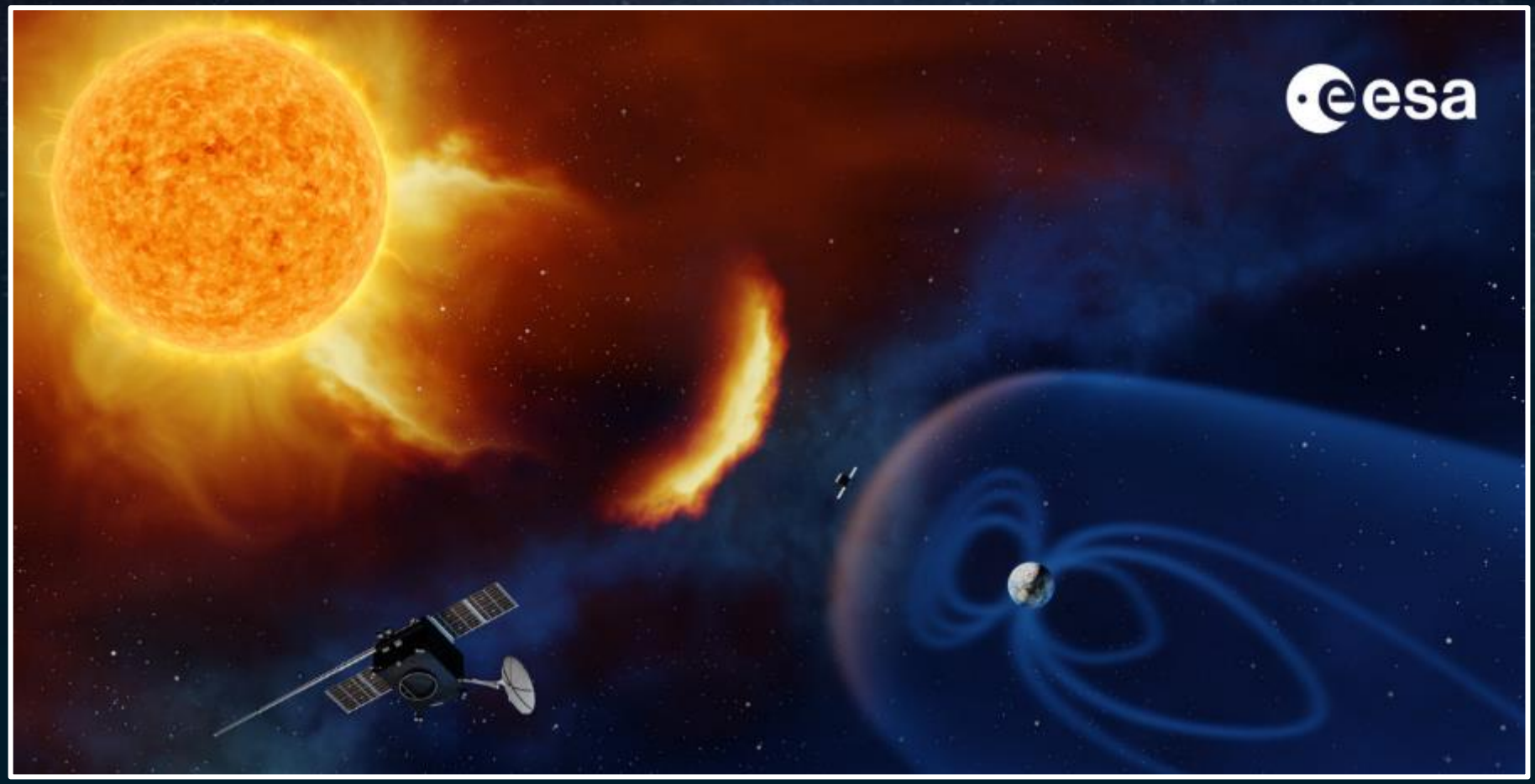
What should we be measuring?

- The solar cycle involves a change in the “hardness” of the solar spectrum, with considerably more X-ray and UV flux at the peak of the sunspot cycle compared with the minimum…and it’s variable!
- A greater proportion of the energy arriving at the Earth is thus absorbed into the atmosphere, and will affect the drag on satellite orbits
- The “orbit cleaning” effect of enhanced solar activity is an important element of future debris predictions.





Where should we be measuring from?



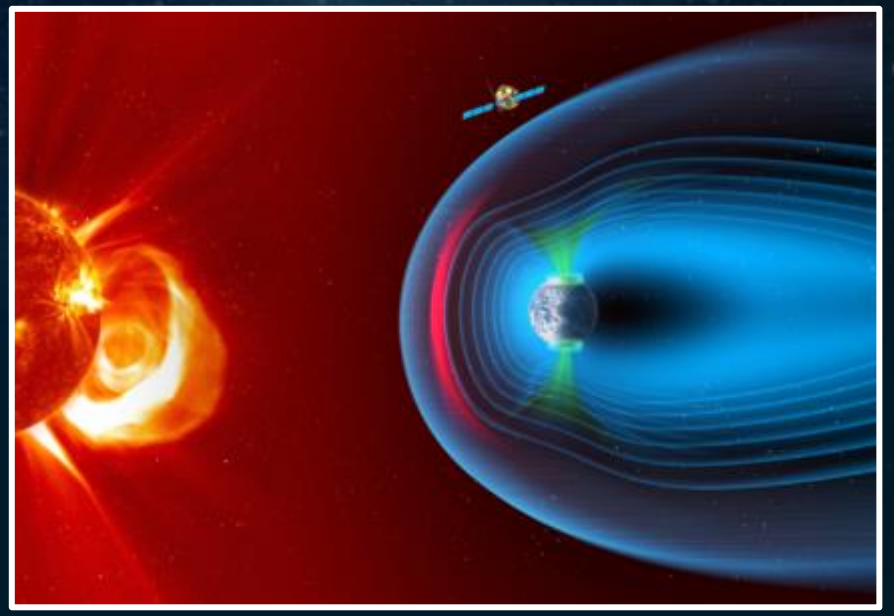
ESA’s LAGRANGE mission to L5

The SMILE mission

- Data from the Smile mission may also be relevant

- SMILE – the Solar wind Magnetosphere Ionosphere Link Explorer – aims to form an accurate picture of solar-terrestrial magnetospheric physics.

- SMILE will observe the solar wind interaction with the magnetosphere, gathering simultaneous images and video of the dayside magnetopause (where Earth's magnetosphere meets the solar wind - indicated in pink), the polar cusps (a region in each hemisphere where particles from the solar wind have direct access to Earth's ionosphere - indicated in green), and the auroral oval (the region around each geomagnetic pole where auroras most often occur).

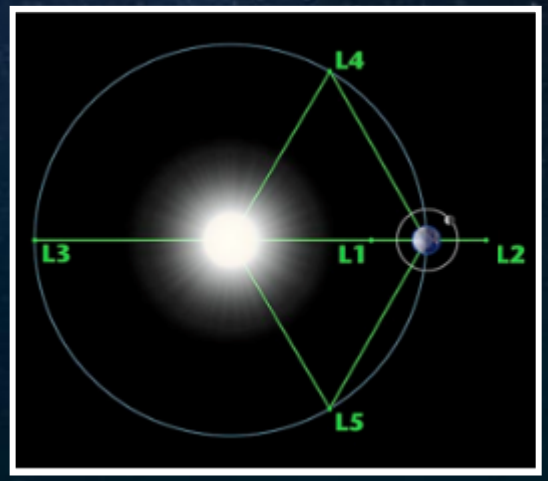


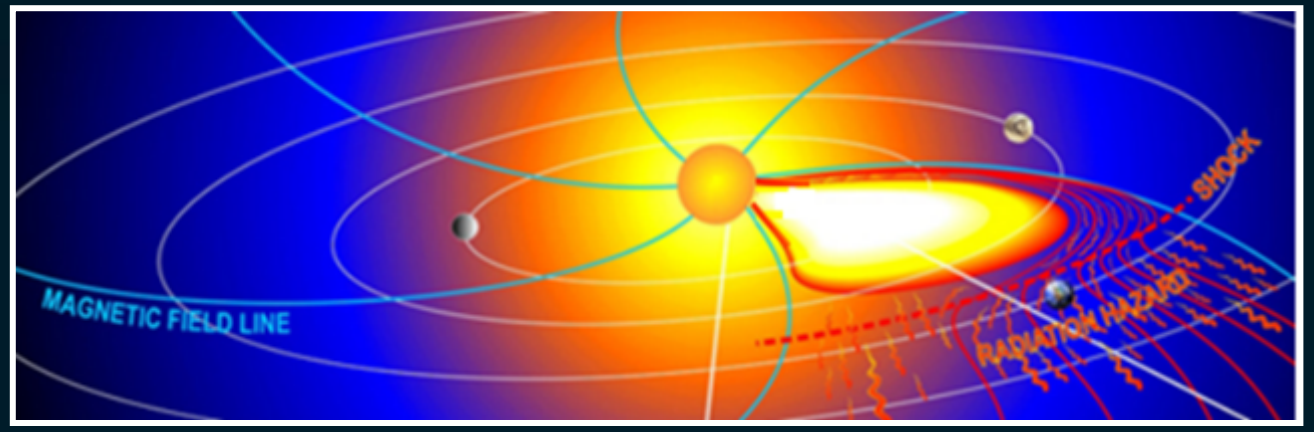
Calibration

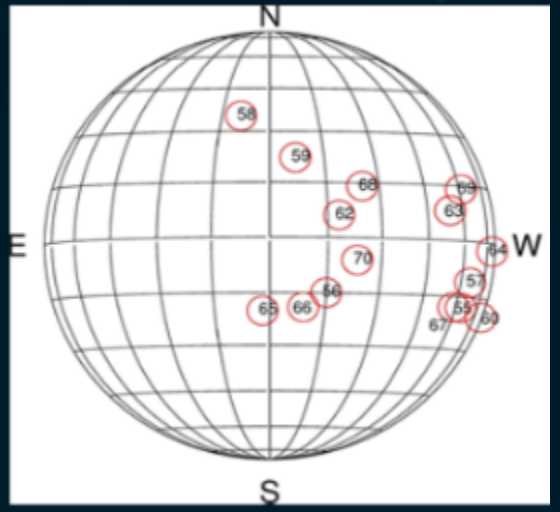
- In order to characterise the energy being emitted by the Sun, does the calibration chain lead to the TRUTHS mission in the future?
- The small satellite will carry a hyper-spectral imager measuring spectrally-resolved incoming and reflected solar radiation (320 to 2350 nm) at high spatial resolution supported by an innovative on-board calibration system
- Is this spectral range adequate?
- Would data from the CLARREO Pathfinder instrument (350–2300 nm spectral range) also assist?

The Case for L4

- A comprehensive monitoring capability requires satellites stationed at the L1, L4, and L5 Lagrange Points
- The Sun rotates anticlockwise, so an L5 mission would provide initial warning a number of days ahead of an impending solar-induced event
- An L1 mission would provide about 90 minutes' warning of the magnetic polarity of the flare and the potential coupling into the Earth's magnetosphere
- An L4 mission would provide better viewing geometry of the events that actually affect the Earth and Mars



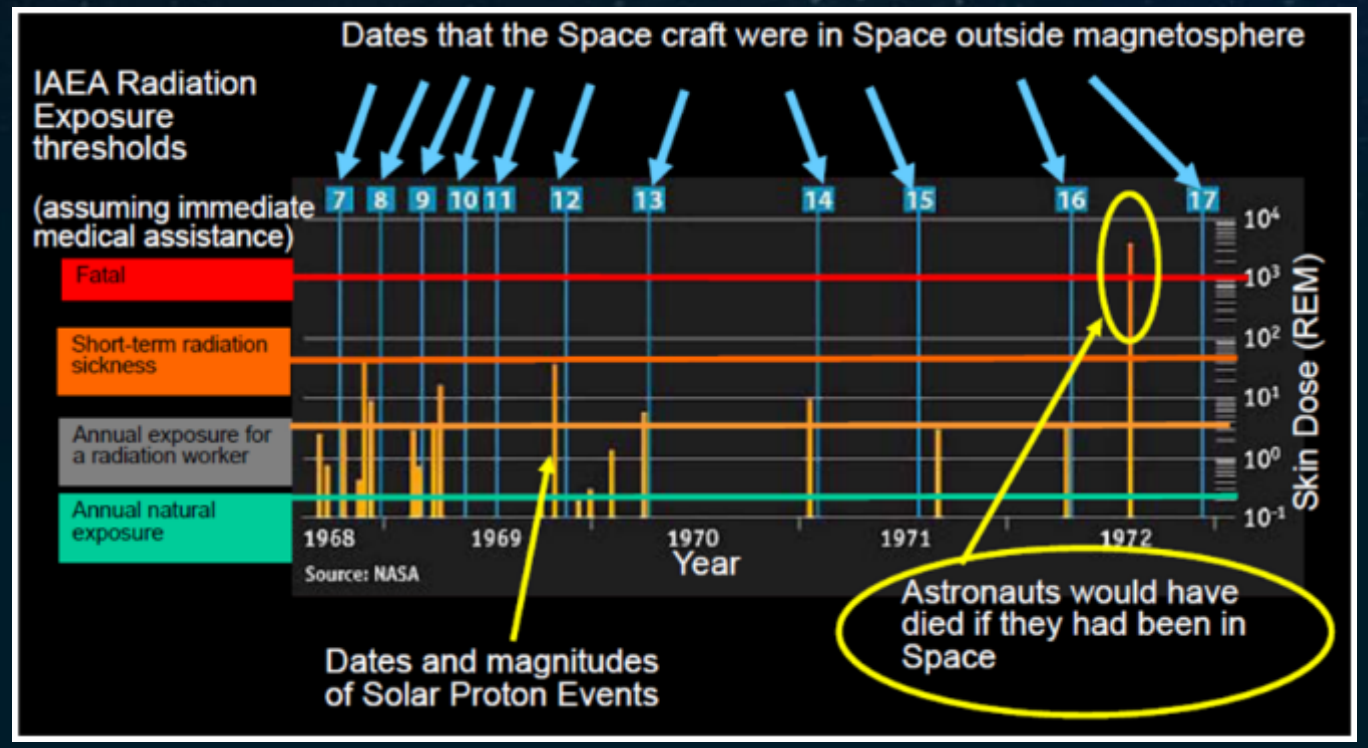


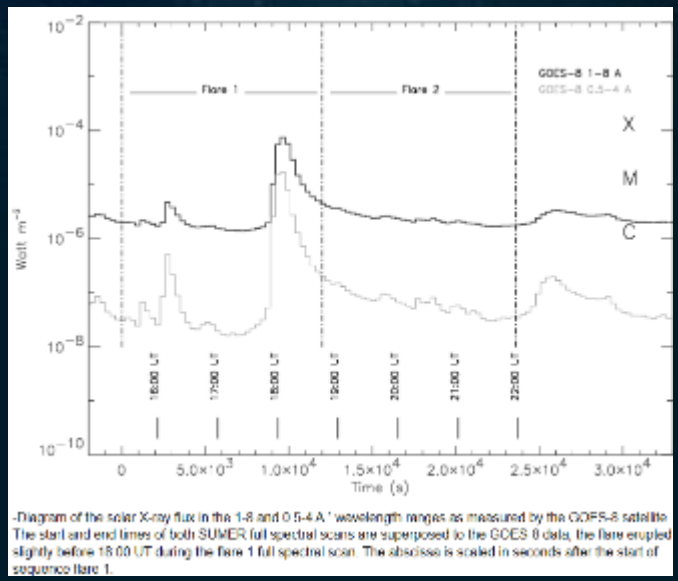


Graphic courtesy of Dr Ruth Bamford

How often should we be measuring?

- Clear evidence of X-ray transient events on timescales lasting hours
- How frequently should measurements of the solar flux be conducted?
- How often should we be seeking to update our orbit predictions?

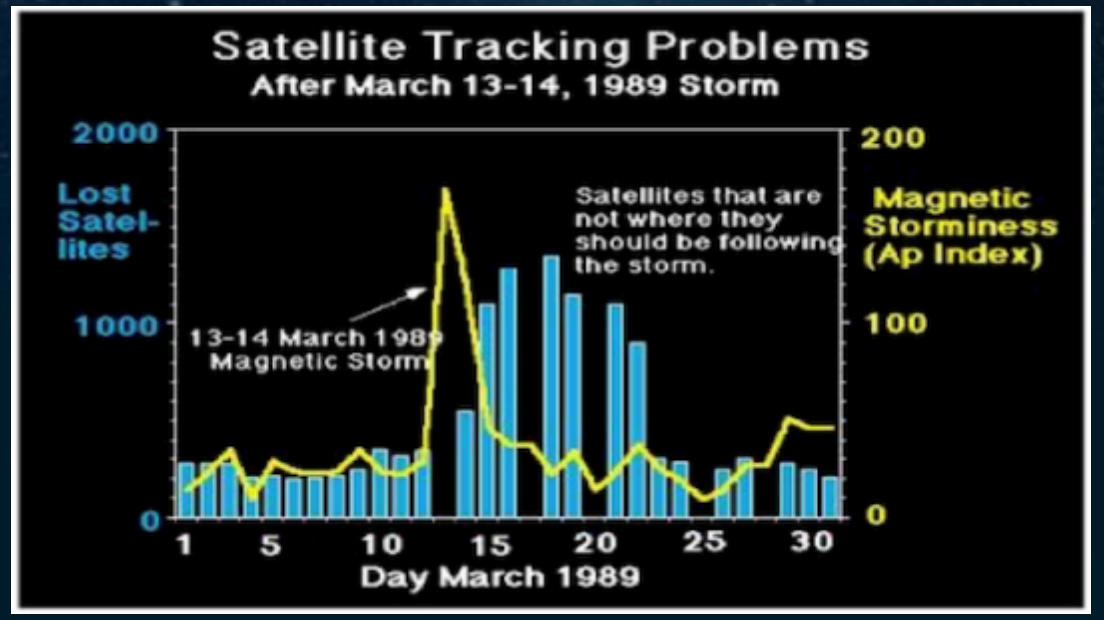




Mass Motions and Plasma Properties in the 107 K Flare Solar Corona

Algorithm Development

- Who will develop the “drag forecast” algorithm based on this input data?
- How will we test it?
- How will we decide if we’ve succeeded?
- Will we be able to demonstrate that we’ve prevented the sort of issues we experienced in 1989?



Initial Ideas for the GNOSIS Future Programme

Future Programme - Workshops

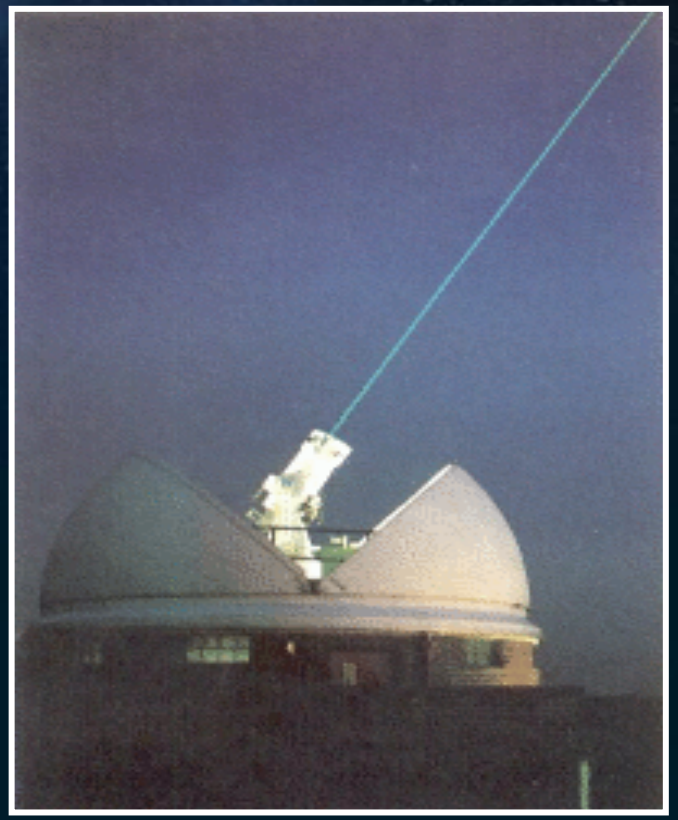
- SSA Technologies
  - Optical (passive and active)
  - Hyperspectral
  - IR
  - RF
  - ISAR
  - All of the above, but from orbit
- Catalogue Definition
  - Object Identifier
  - Orbit parameters
  - Physical properties
  - Stability (rotation, tumble)
  - RCS, Albedo, etc.
  - Spectral signatures
  - Ballistic coefficient vs time
- Products and Algorithms
  - Status report
  - Compliance with regulations
  - Space sustainability rating
  - COLA
  - Debris removal assessments
- Precision SSA and Enabled Capabilities
  - Positional Accuracy
  - Frequency of observations
  - Assessments of satellite/debris shape and composition
  - Super-trackable satellites to fully characterise the forces acting

Novel Capabilities

Enabled by Precision SSA

Precision SSA

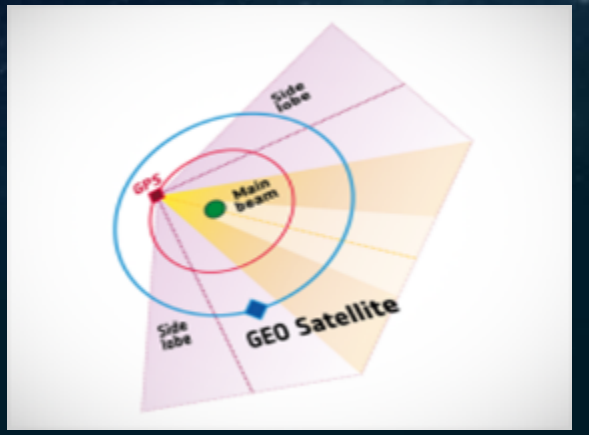
- The use of advanced sensors to provide high accuracy position and velocity information for satellites and debris in Earth orbit
- Techniques could include the use of (non-cooperative) laser ranging, advanced radar processing algorithms, and triangulation via multi-sensor observations
- Includes the concept of object characterisation via ISAR, micro-doppler measurements, spectral sensor observations, etc.
- Requires the development of new catalogue standards to allow these accurate measurements to be represented

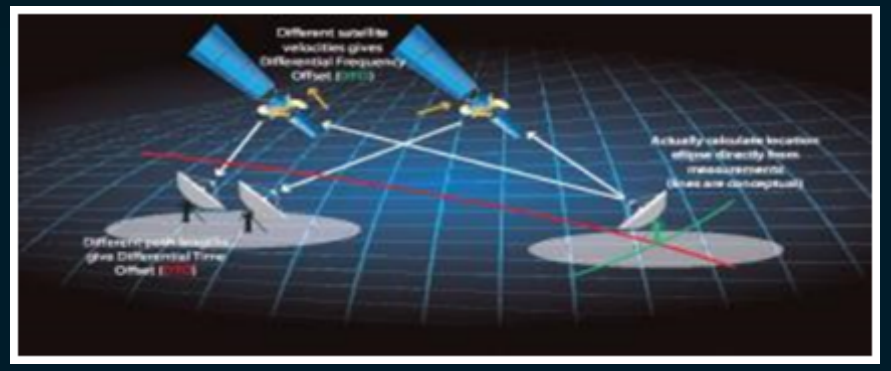


Laser rangefinders can track satellites to centimetre-level accuracy

Novel Capabilities Enabled by Precision SSA

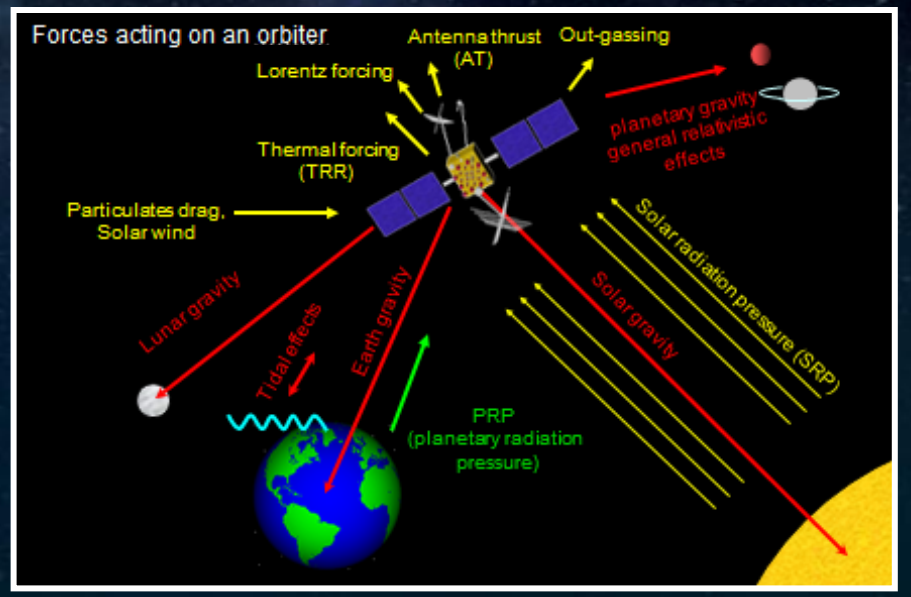
- Increased satellite duty cycle and lifetime
- Companion satellites and collaborative concepts
- Regional navigation using time-tagged signals
- Bi-Static regional surveillance and weapon targeting
- Rapid inter-satellite link applications
- GNSS monitoring
- Very high capacity, extremely resilient communications via satellite clusters
- Satellite servicing and satellite assembly
- Debris characterisation, removal and reprocessing





Super-Trackable Satellite

- A GEO satellite explicitly designed to measure the various forces acting on it might incorporate:-
  - Laser retroreflectors
  - GNSS receivers
  - RF Beacons with high duty cycle
  - Optical beacons
  - Optical inter-satellite or space-to-ground links
  - On-board star cameras
  - Solar wind measurement package
  - Solar flux monitor
  - On-board monitoring cameras
  - On board charge monitors
  - Micrometeorite impact detectors



- Its CONOPS might incorporate….
  - Accurate propellant measurements
  - Accurate solar array attitude measurements
  - Detailed propulsion system telemetry
  - Detailed power system telemetry
  - Detailed thermal telemetry

Future Programme - Sandboxes

- Sandbox 1 – Novel Optical Techniques
  - What should we build?
  - How should we process the data?
  - What products result?
  - Who wants these products?
- Sandbox 2 – Novel RF Techniques
  - What should we build?
  - How should we process the data?
  - What products result?
  - Who wants these products?
- Sandbox 3 – The case for L4
  - See the following slide
- Sandbox 4 – The case for IR
  - See slide following the following slide!

The Case for L4

- A comprehensive monitoring capability requires satellites stationed at the L1, L4, and L5 Lagrange Points
- The Sun rotates anticlockwise, so an L5 mission would provide initial warning a number of days ahead of an impending solar-induced event
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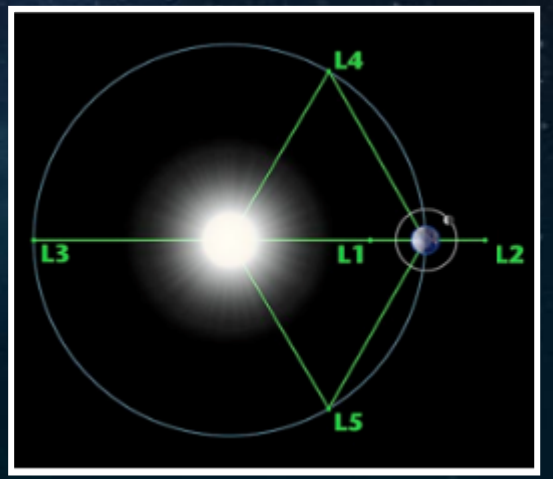
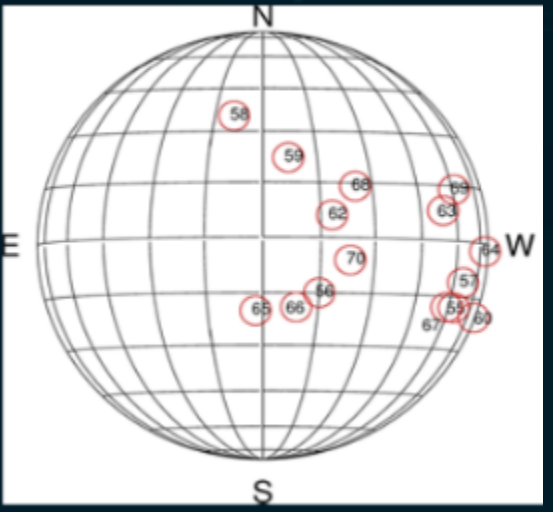
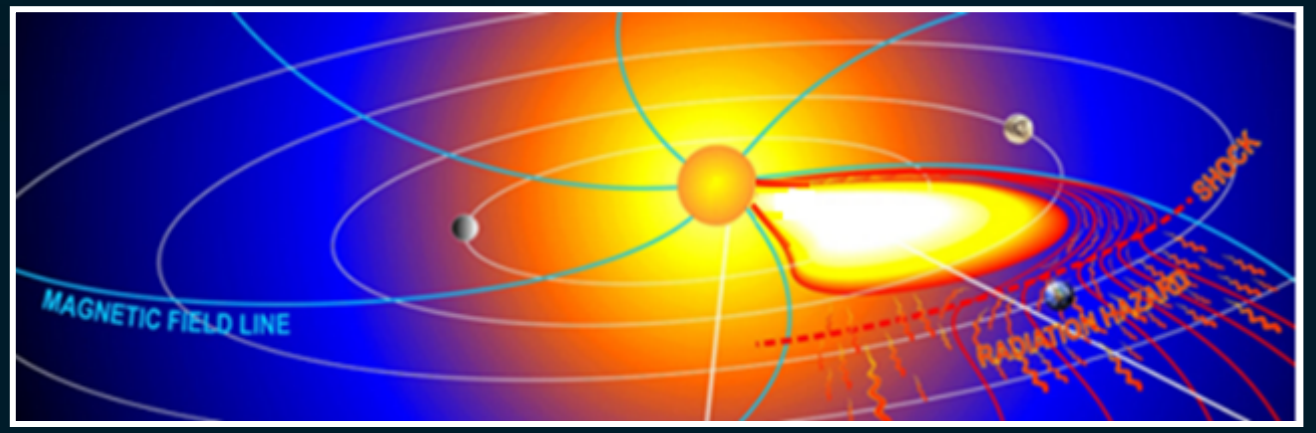


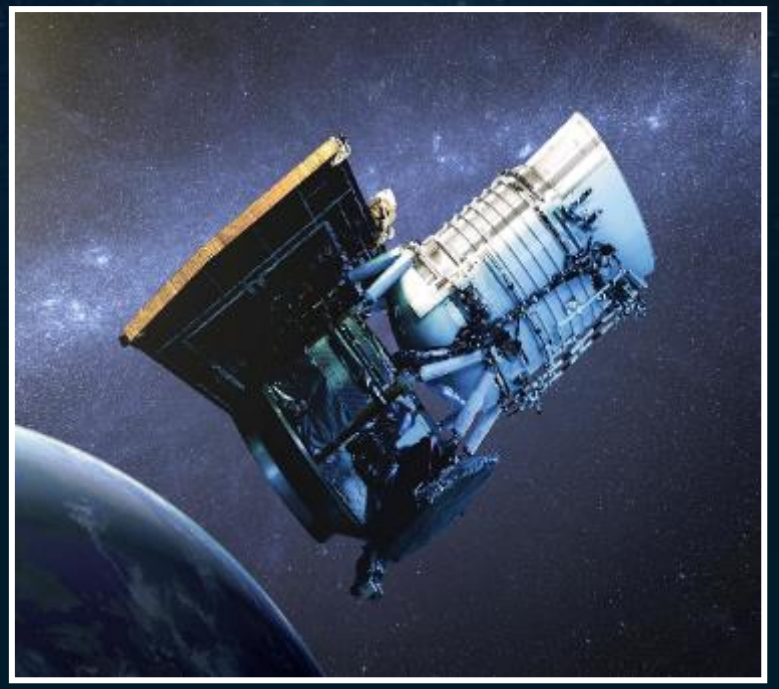


Graphic courtesy of Dr Ruth Bamford



The Case For IR

- The Wide Field Infra-red Survey Explorer satellite detected many asteroids
- Since asteroids are dark, they tend not to directly reflect much of the sunlight that falls on them
- Instead, they absorb it and then re-radiate the energy as heat
- WISE detected this infra-red energy against the cold back-ground of space
- Since the Earth's atmosphere absorbs much of the infra-red spectrum, it is more effective to put infra-red telescopes on spacecraft, rather than on the ground



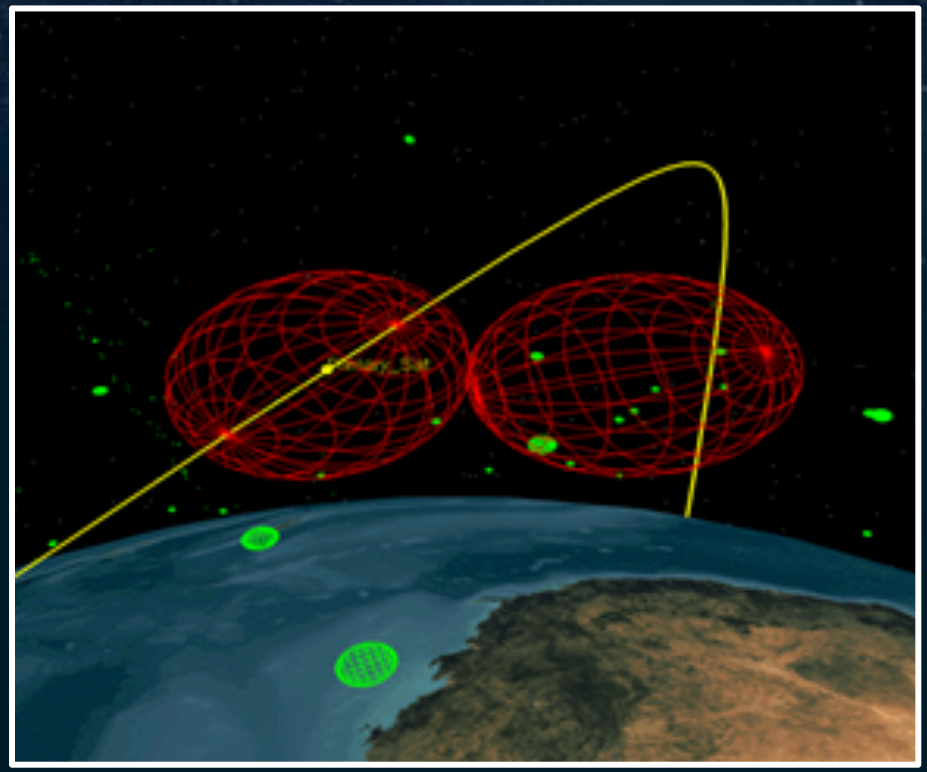
Back-Up Slides
On Potential Applications

National Navigation System

- If the UK wishes to have its own GNSS system, a precision SSA capability will be essential
- This would need to involve both laser tracking and RF monitoring capabilities

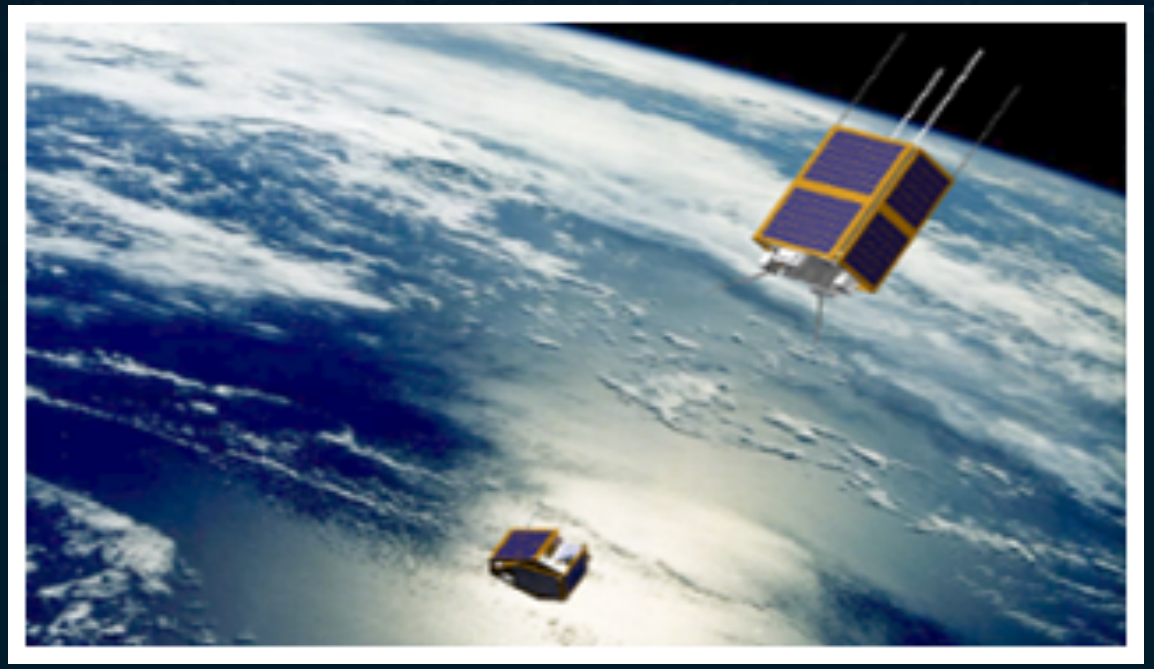
Increased Satellite Duty Cycle and Lifetime

- More accurate tracking is essential to avoid operators becoming overwhelmed by conjunction warnings as catalogue sizes increase
- Improved tracking will permit satellites to save propellant by adjusting their orbits only when conjunctions are known to be very close
- Avoids unnecessary interruptions to operations and extends the satellite lifetime

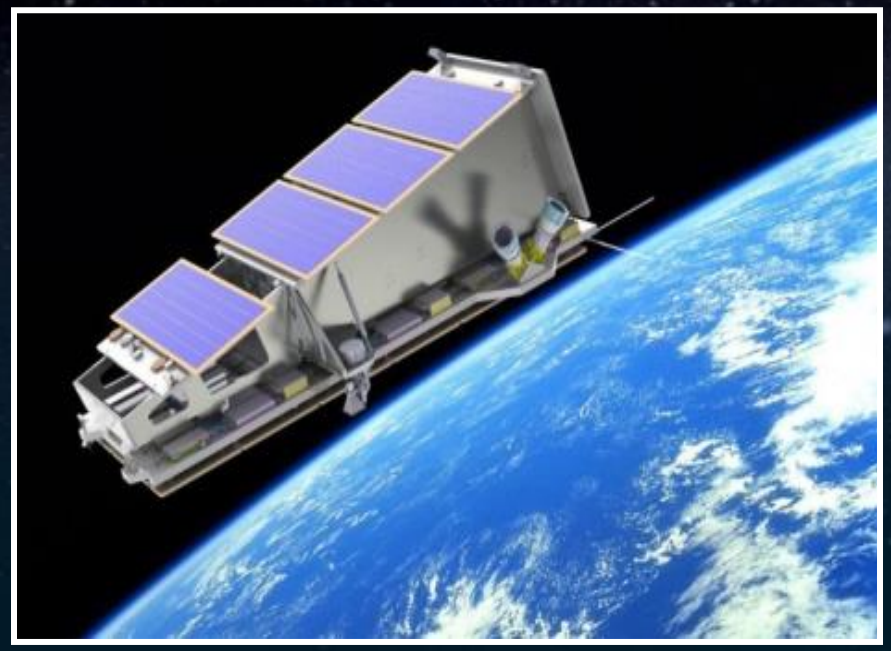


Companion Satellites

- Concept proposed by US in November–December 2014 Air & Space Power Journal
- Envisages companion satellites that monitor potentially hostile satellites in LEO
- Concept assumes monitoring of enemy satellite pointing; transponder activity; manoeuvres; etc.
- Analogous proximity operations are already happening in GEO



Urthecast

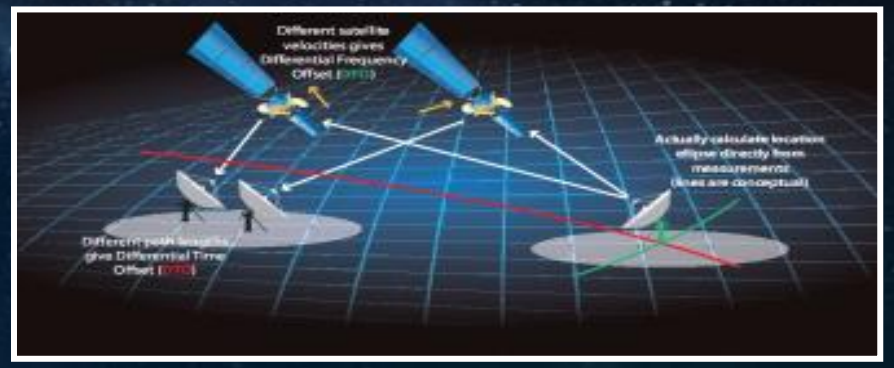


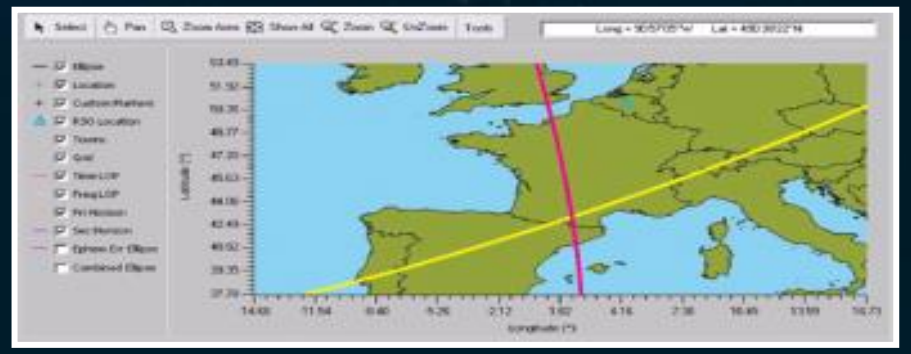
- Synergistic surveillance concept
- Four pairs of satellites
- Each pair consists of one SAR and one optical satellite

- SAR carries AIS and a cloud sensor
- Inter-satellite link allows SAR to cue optical satellite to avoid clouds
- Precision SSA facilitates this concept

Navigation Concept

- A GEO system could be used to provide a navigation function using a technique which is essentially the inverse of the Sat-Id approach which is used currently to geo-locate sources of interference.
- A signal broadcast via two (or more) GEO satellites from a well-surveyed location in the UK could be received and processed by a user terminal.
- The “time-difference-of-arrival (TDOA) and “frequency-difference-of-arrival” (FDOA) of the signal via the two satellites allows two arcs to be plotted on the surface of the Earth; their intersection is the location of the user terminal.



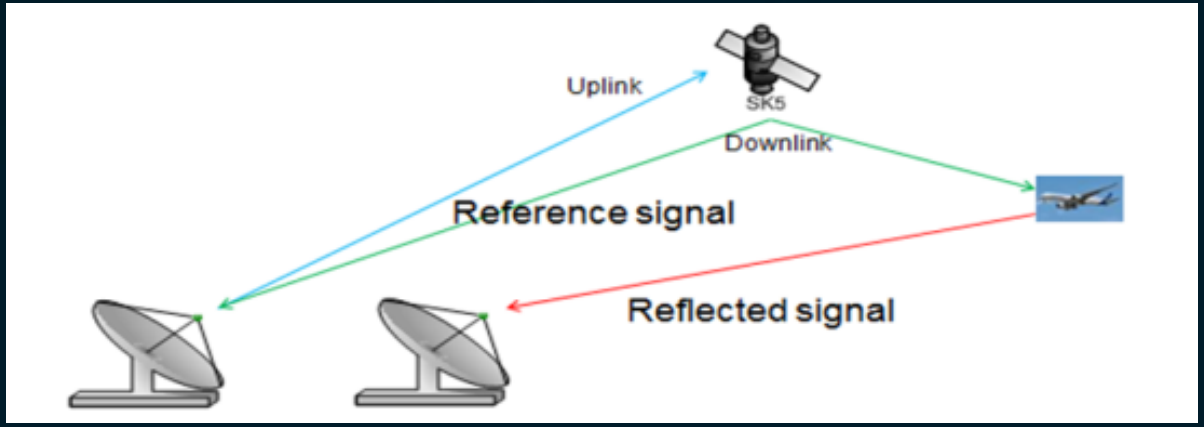


Navigation Concept

- The accuracy of the system is dependent on a number of factors, including the frequency/bandwidth used and the accuracy with which the orbits of the satellites are known.
- The use of satellites in inclined geosynchronous orbits, (e.g. Skynet 4 satellites now, and “semi-retired” Skynet 5 satellites in the Skynet 6 era), to transpond the signals could be advantageous, since the “GDOP” is improved.
- This has now been tested now using the Skynet 4 and Skynet 5 satellites
- Using more than two satellites, and making repeated measurements over a period of time further improves the accuracy, although the mutual region of visibility over which the increased accuracy would be available would be smaller
- Precision SSA enhances the navigation accuracy of such a system

Passive Bi-static Surveillance

- The (spot-beam) signals from GEO satellites could be used as the illuminator for a bi-static surveillance system to detect large vehicles and aircraft.
- The feasibility of such a system to detect moving targets has been demonstrated using a GEO satellite broadcast
- The advantage of using the GEO signals, rather than a transmitter of opportunity in theatre, is that the owner would have control over the illuminating signal , and would be able to use existing ground segment hardware



Next generation GEO communication satellites could also have a surveillance role

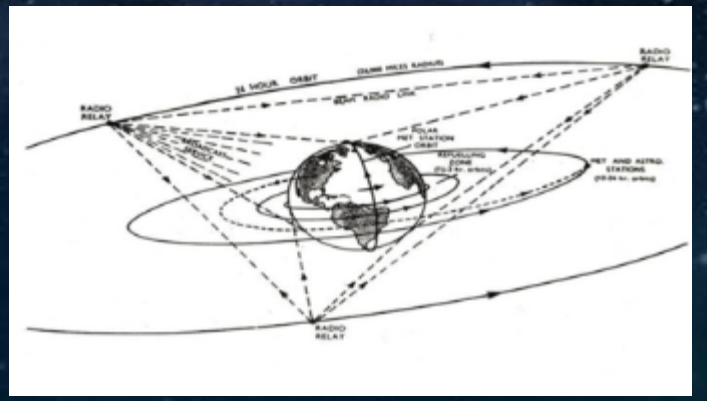
SIGINT

- Combining the output from the receive antennas on more than one satellite, it would be possible to geolocate sources of communications interference
- It would also potentially be possible to exploit comms signals in adjacent bands by transponding and processing signals intended for other satellites
- The accuracy of the system will again depend on the quality of the SSA

Not all interference is accidental!

Long-Range Inter-satellite Links

- Systems such as the European Data Relay Satellite (EDRS) will increasingly help to establish a “space wide web” of links between satellites
- This will allow commands to be sent, and data to be returned from satellites, in tactical timeframes
- Links to RPAs can be established too
- Precision SSA will shorten acquisition times and save money



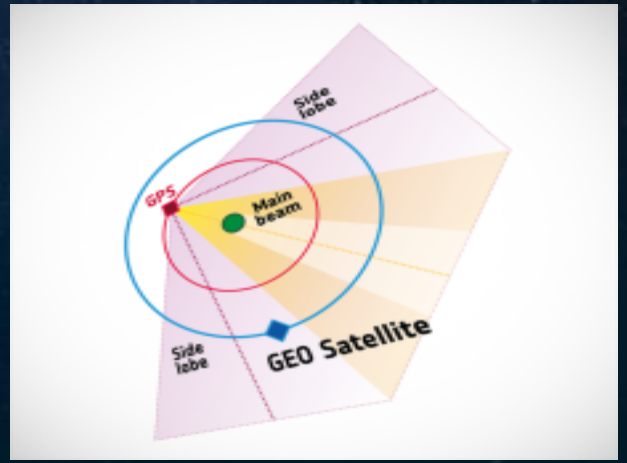
Arthur C Clarke’s 1945 Paper

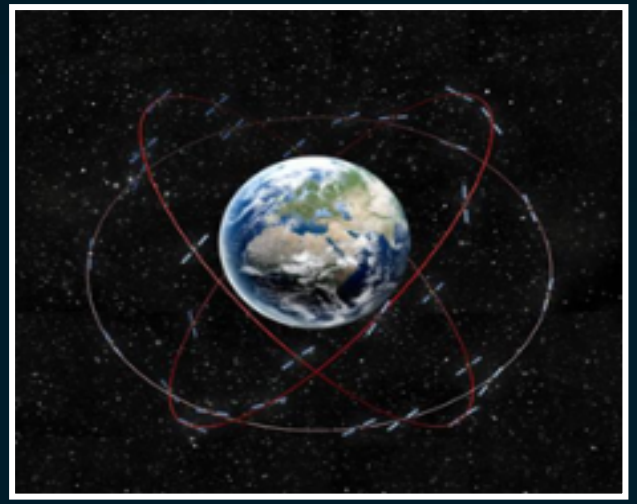
European Data Relay Satellite

GNSS monitoring from GEO

- The concept is to monitor all GNSS satellite transmissions using two or more GEO satellites

- Possible applications (detailed in the back-up slides) include:-
  - GNSS integrity monitoring
  - Meteorological measurements
  - Earthquake forecasting
  - Jammer detection and geolocation
  - High precision orbit determination
  - Orbital drag estimates
  - GNSS reflectometry
  - GNSS imaging
  - Investigation of scintillation



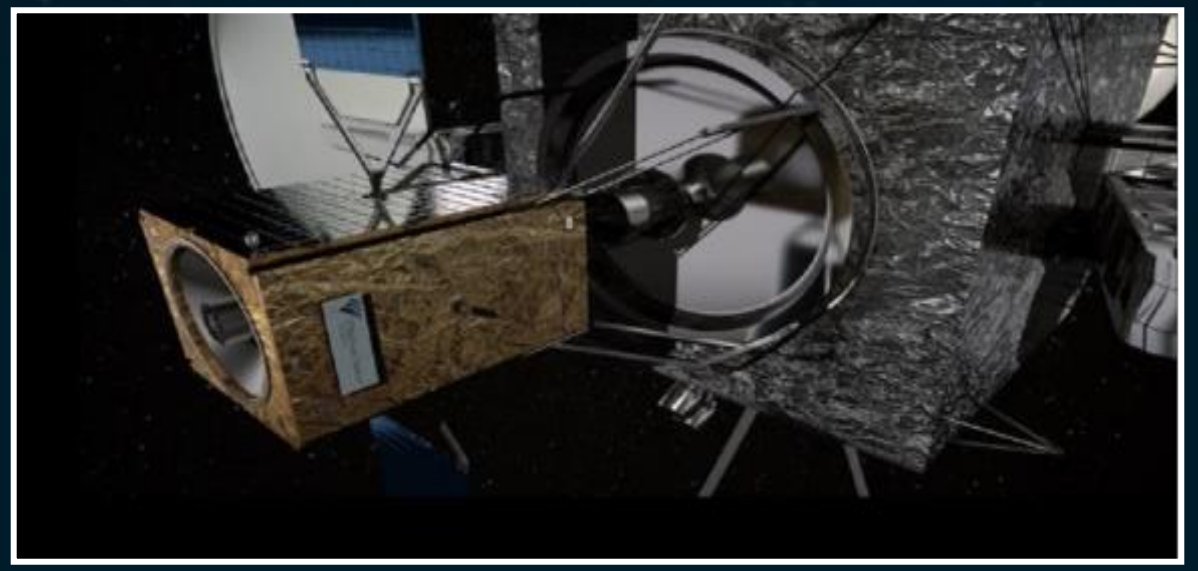


Quantum Clusters

- Clusters of smaller GEO satellites offer resilience, flexibility, increased capacity over specific theatres, and novel capabilities such as interferometric communication beams

Satellite Servicing Concepts

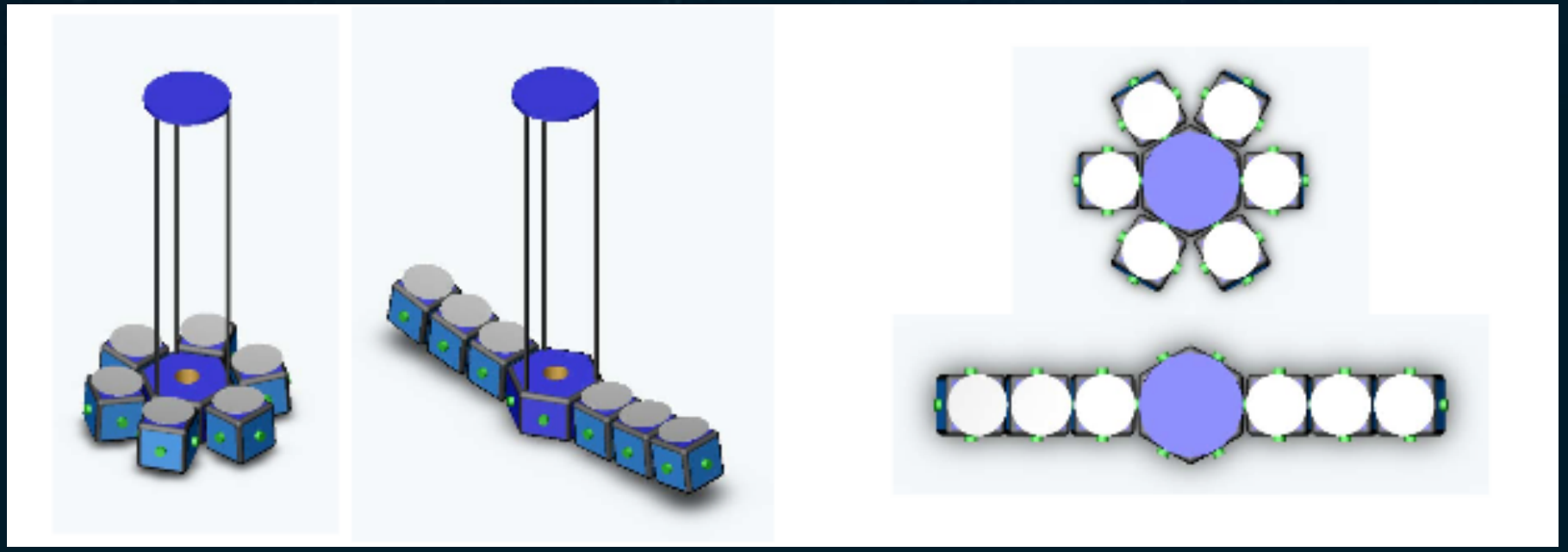
- A number of organisations are currently working on satellite servicing concepts
- Launched alongside a future GEO satellite, these could offer a variety of different mission options
- Reliance solely on on-board sensors entails risk



Satellite Assembly On-Orbit

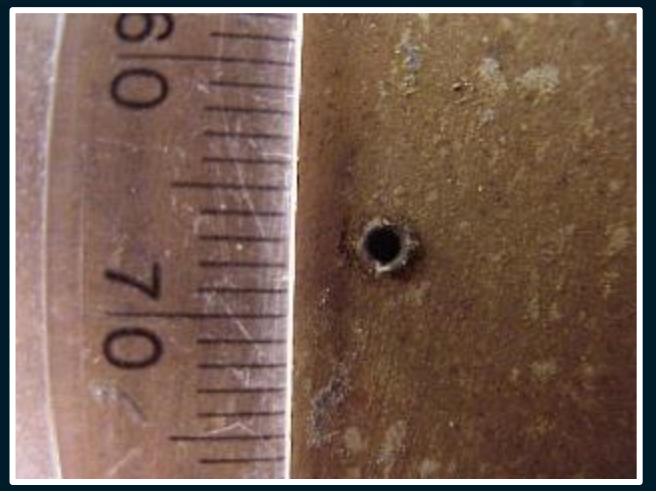
- Future surveillance concepts such as SSC's Aarest could involve reconfigurable sub-apertures to build larger mirrors in space
- Precision SSA will enable accurate rendezvous

The Strand-2 rendezvous and docking concept



Debris Population Characterisation

- The potential exists to use debris objects as “witness plates” to characterise the un-tracked small debris population
- Frequent, high accuracy tracking of objects in LEO would allow perturbations caused by impacts to be identified

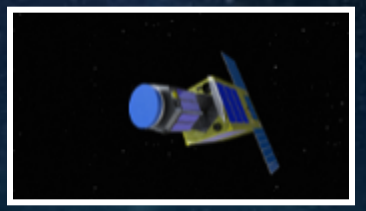


Debris Removal

- A variety of technologies, including Mass drivers; Adhesives; Harpoons; Lasers; Tethers; Nets; Grapplers; Propulsion plumes; Slingsats; Branes; De-orbit sails; and Electrostatic tractors have been suggested to remove large, long-lived debris objects
- All these concepts are technically immature and look like anti-satellite weapons in the wrong hands. It's unclear how these concepts would be financed, and the politics is hard too

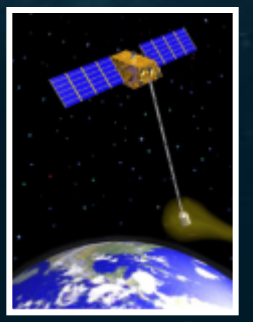
Mass driver concept

Harpoon concept

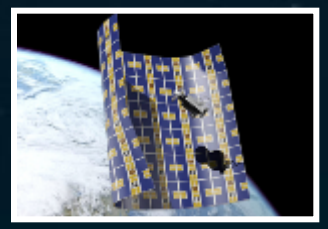


Adhesive concept

Propulsion plume concept

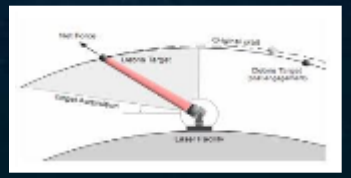


Tether concept



Brane concept

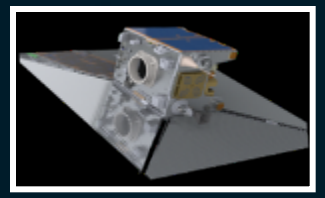
Electrostatic tractor concept



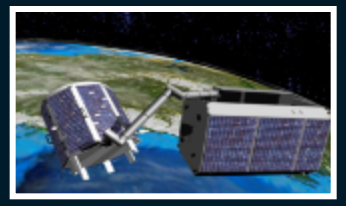
Laser concept

Slingsat concept

Net concept



De-orbit sail concept



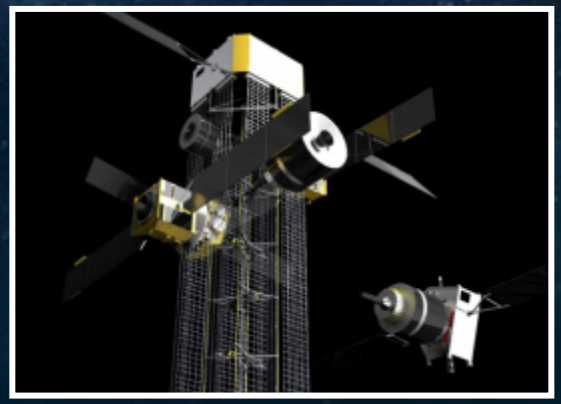
Grappler concept

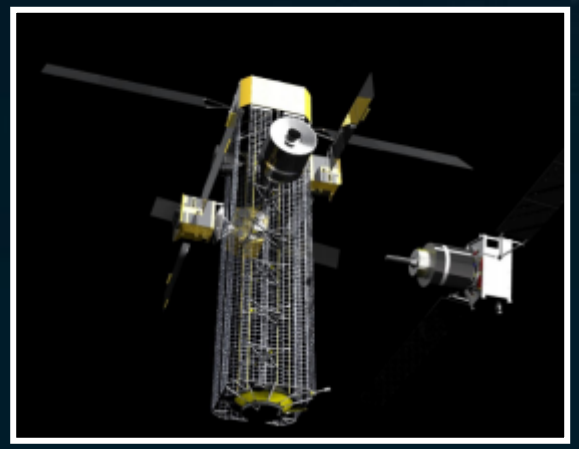
Transparent, precision SSA will be needed on target objects

Necropolis Concept

- **Technical Requirements:**
  - Trackable and manoeuvrable
  - Serviceable – the Necropolis will need fuel
  - Able to manage charging
  - Able to passivate satellites delivered to it
  - Able to process materials delivered to it

Satellite Disposal Facility in Orbit



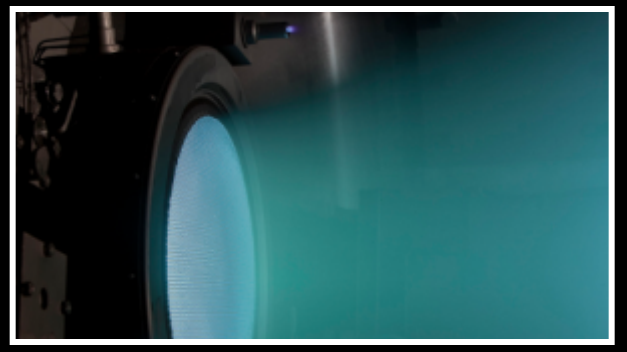


- **Benefits:**
  - Significantly less satellite de-orbit propellant
    - Lighter constellations – fewer rockets required
  - Less risky constellation disposal
  - Potential for refuelling subsequent missions using recycled materials
    - Metals and/or carbon

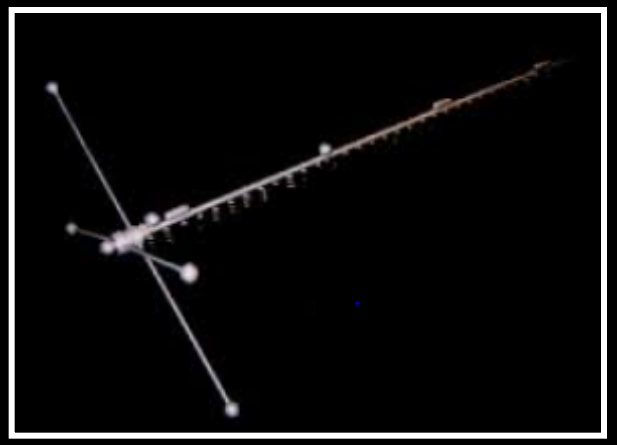
Precision SSA is again an enabler

Space Debris As Fuel

- Supposing that we could use space debris as a propellant……..
- A team in Australia is developing a thruster that works by ionising metals (and carbon) and accelerating them
- Mass-drivers have also been suggested, which can utilise almost any type of debris
- Space debris then becomes an on-orbit resource
- Precision SSA data on the location of suitable pieces of debris suddenly increases in value



Electric propulsion concept



Mass-driver concept