SSA Concepts

Dr Stuart Eves

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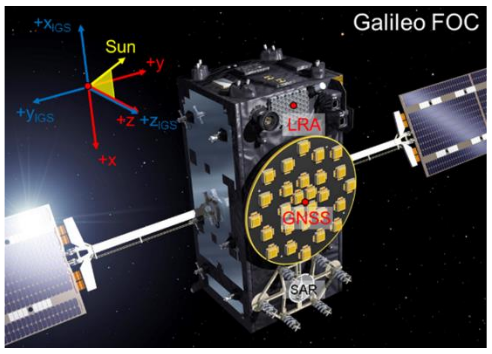
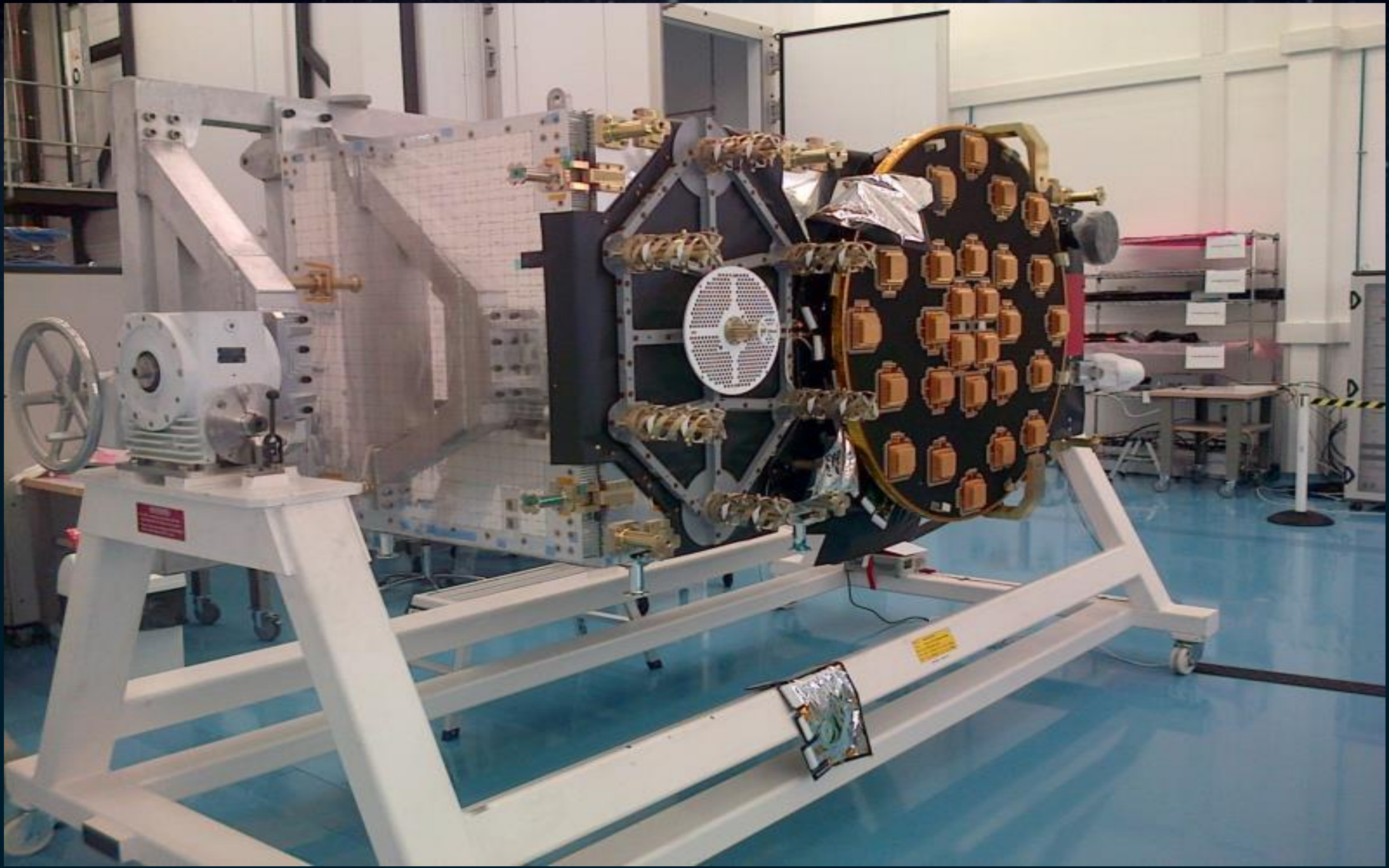
Laser Retro-reflectors

- Some satellites, (e.g. navigation and geodesy missions), are routinely equipped with laser retro-reflectors to facilitate accurate tracking
- Satellites carrying retro-reflectors can be tracked much more accurately, even when mission-ended
- Retro-reflector location needs to accommodate the likely orientation of the satellite at end of life
- Some defunct satellites are expected to tumble, whereas others may achieve a gravity-gradient stabilised configuration
- High accuracy tracking would facilitate military capabilities such as navigation and surveillance

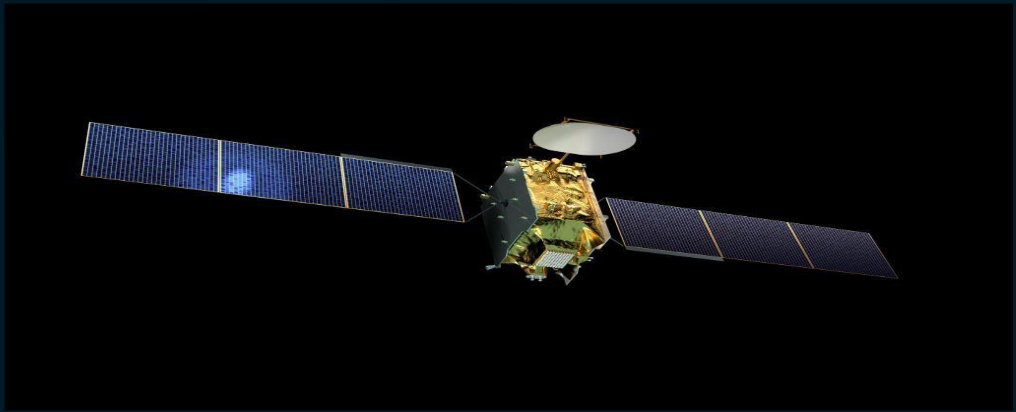


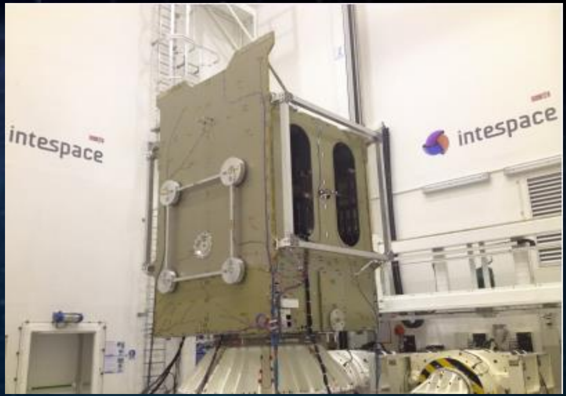
Galileo Satellite Payload



Small GEO Satellite

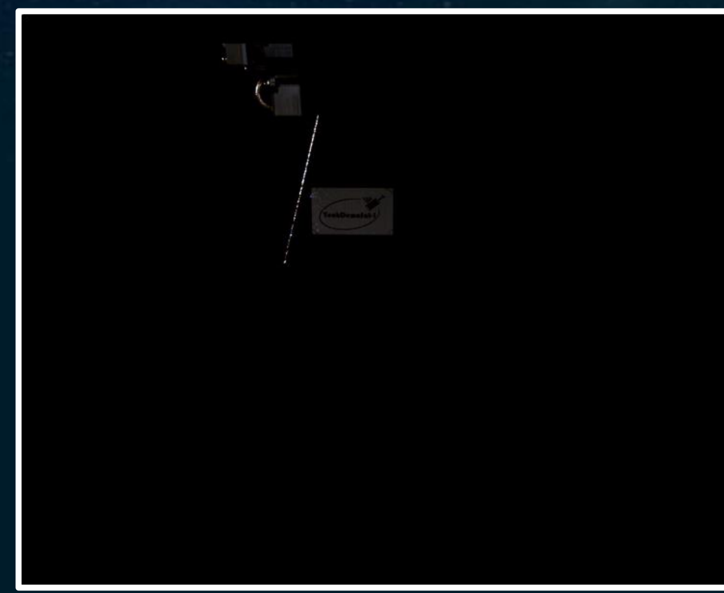
- SSTL is developing its first small GEO communications satellite
- Major Characteristics :
  - 5kW Flexible Payload (with on-board processor)
  - 3.5t Wet Mass
- Could provide a test of highly accurate tracking via laser retro-reflectors





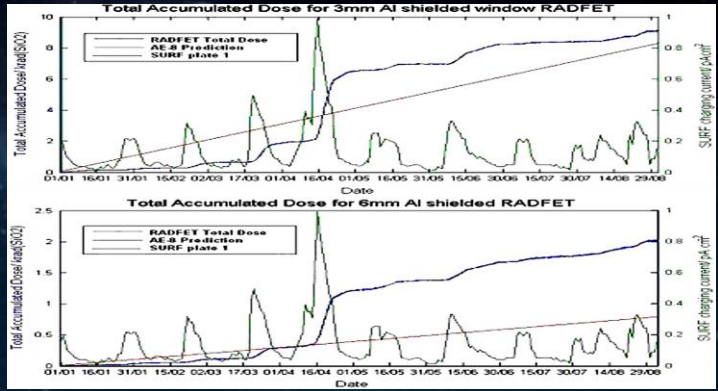
On-board Cameras

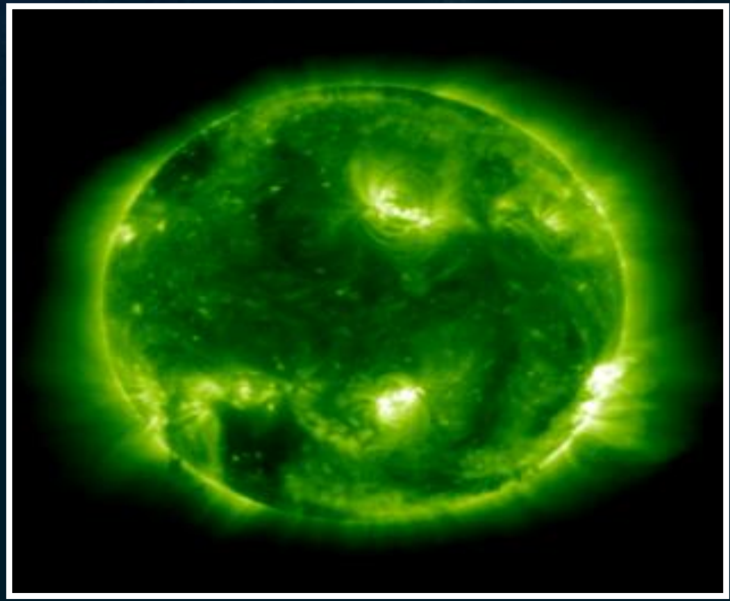
- A star camera or a dedicated video surveillance camera on a future mission could be used to provide SSA data on adjacent objects
- Both have flight heritage



Reporting of Telemetry Data

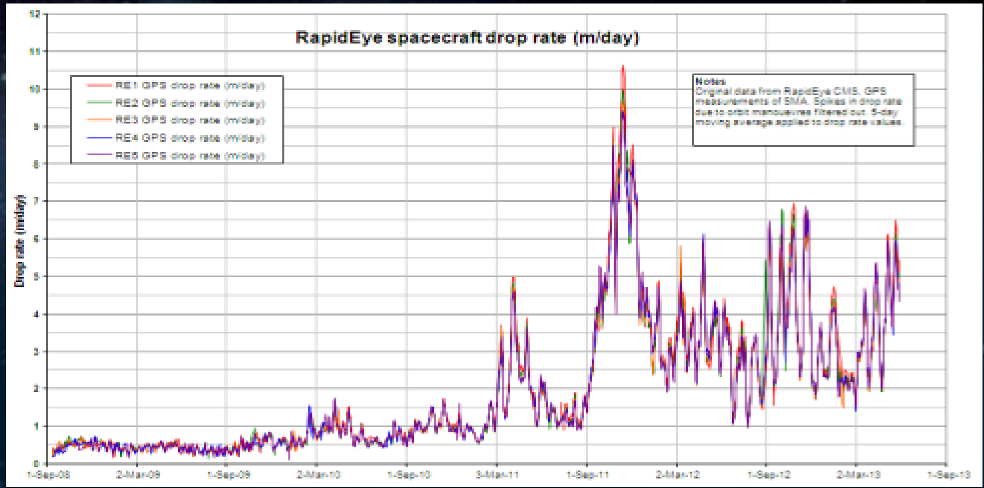
- Satellites could provide data from on-board sensors
- The example shown is accumulated radiation dose data from the Giove-A mission in MEO, showing a periodic increment roughly once per month due to enhanced levels of trapped electrons
- This is the result of an active region on the sun, (which rotates with approximately this period)
- Real-time space weather data of this sort could be fed into orbit propagation models

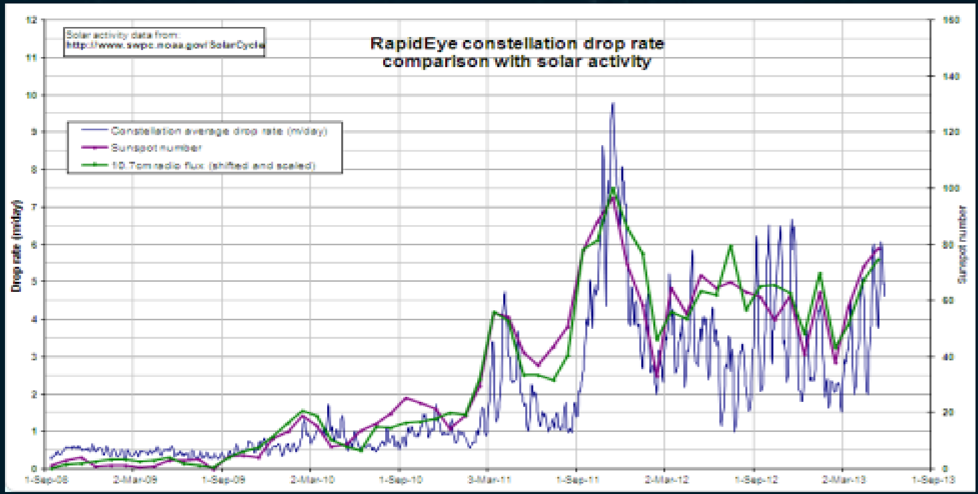




Orbital Data

- Satellite operators (usually!) know where their satellites are, and can report their positions and manoeuvres periodically
- By analogy, aircraft are required to report their positions when they are in uncontrolled airspace
- Redundant communications paths are mandated on aircraft for safety reasons
- The same could be mandated for satellites



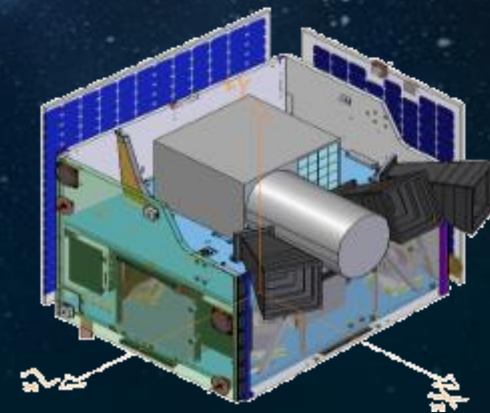


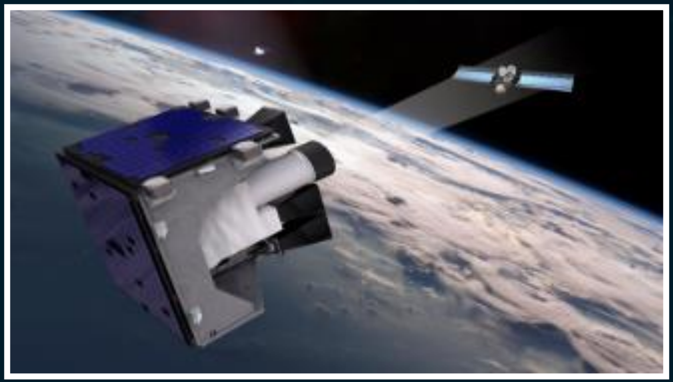
SURREY SATELLITE TECHNOLOGY LTD

Space-Based Space Situation Awareness

- Improvements to space situation awareness could include:-
  - The tracking of smaller objects, (down to cm in size)
  - More frequent and more precise tracking of GEO targets in order to maintain more accurate orbits
  - Assessments of hostile satellite configuration, operational status and current activity via LEO-LEO imaging
  - Warning of space weather events via on-board sensors
- Tracking from orbit could address all of these issues
- Launch detection from orbit is also a key capability

SAPPHIRE SURVEILLANCE of space - de l'espace

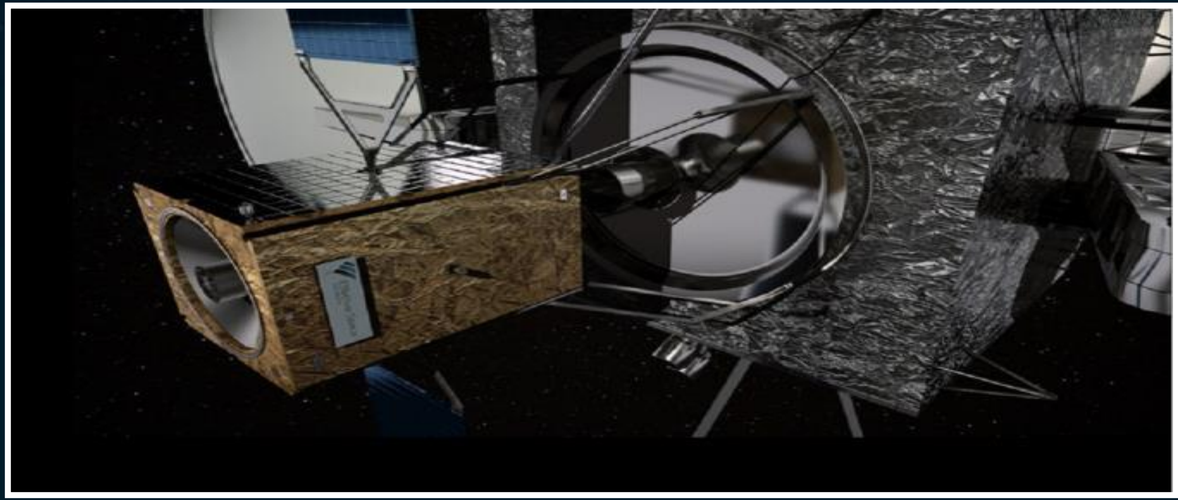




Space-Tug Concept

- SSTL is currently working on a space tug concept that is designed to attach itself to the launch separation ring on the target satellite

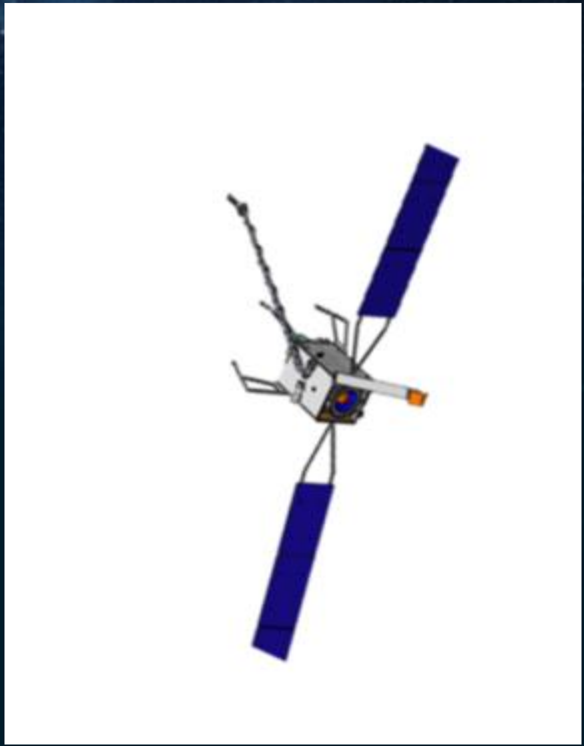
- Launched alongside a future GEO satellite, it could offer a variety of different mission options



Candidate Mission Concepts

Possible applications of a space tug launched alongside a GEO mission include:-

1. Life-extension of one or more satellites
2. Relocation of one or more satellites
3. Inclination lowering of a satellite
4. Right ascension change of a satellite
5. Monitor deployment of launch partner
6. Test proximity monitoring scheme using TT&C echoes
7. Test of SSA capabilities
8. Graveyard any “embarrassing” defunct payloads
9. Dispose of any “inconvenient” debris objects
10. Slot occupation and hardware demonstration
11. Security enhancement for existing satellites
12. Space control capabilities
13. Apogee motor failure compensation

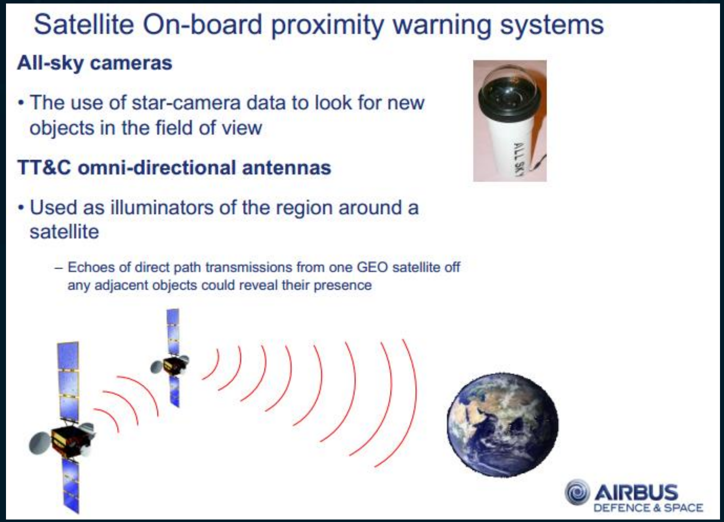


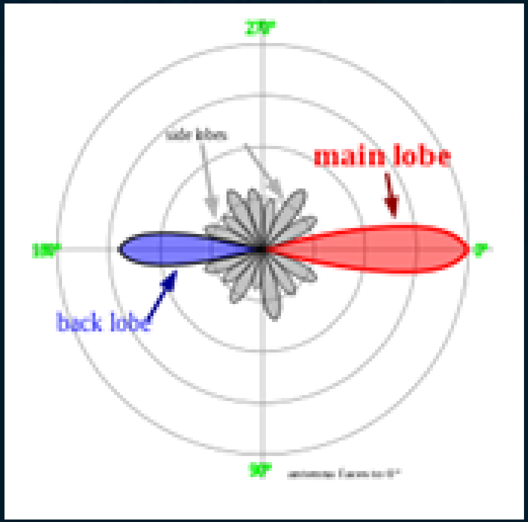
Monitor Deployment of Launch Partner

- Assuming that two satellites are launched together, the sensors on the Space Tug could be used to monitor the deployment of a GEO launch partner
- A presumption here is that the LEOP phase would be completed earlier by the Space Tug than the main GEO payload
- For safety reasons, deployment of the two satellites from the launch vehicle would ensure a reasonable initial separation, which might need to be reduced in order to perform effective detailed monitoring

Test of Proximity Monitoring Scheme

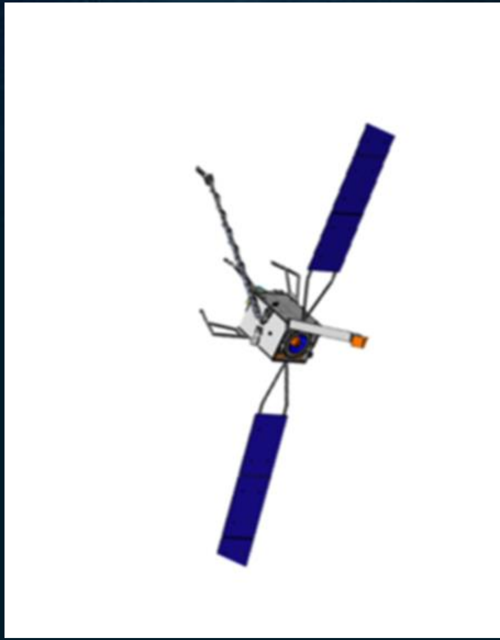
- A future mission may find that it has "company" from an operational, foreign satellite very close to it in GEO
- A space tug could provide a GSSAP-like function using its all-sky surveillance cameras
- The tug could also simulate a "stealthy adjacent payload" and allow the test of scheme to detect the presence of a foreign object near an existing asset by monitoring echoes of its own near-omnidirectional TT&C transmissions





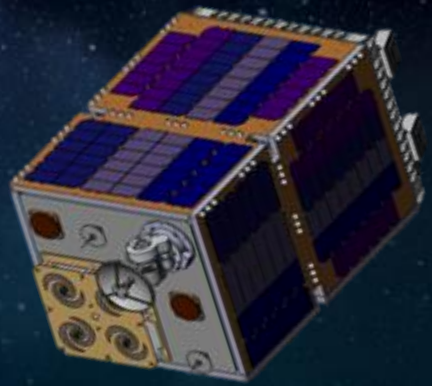
Test of SSA Capabilities

- The sensors on the Space Tug could be used to inspect an allied or foreign mission in GEO
  - Payloads could include:-
    - Cameras
      - Optical
      - IR
    - Active Sensors
      - Radar
      - Lidar
    - Passive RF Sensors
      - Software defined radio

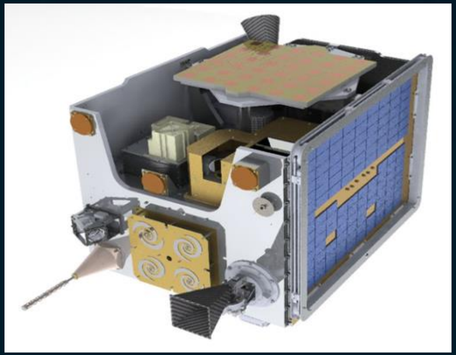


On orbit SSA Test Mission

- The possible TDS-2 or TDS-M demonstration satellite missions, if operated in conjunction with a future Carnbonite-4 mission, offer various options for a future SSA test programme



- Sensors on the TDS-M mission could include optical, IR and tunable passive RF sensors which could be tuned to Fylingdales radar frequencies for bi-static debris detection



- A variant of the Pharos wide-bandwidth RF sensor could also be tested for SSA imaging and the detection of small debris

Possible Fylingdales-related Experiments

The possible experiments that could be performed with a two-satellite configuration include:-

- Presenting a constant face (and hence a constant radar cross-section) towards the Fylingdales radar for the duration of a pass, for calibration purposes. (Different faces will have different materials – RCS from different aspects can be measured prior to launch. Orientation of steerable downlink antenna could be varied to provide "subtle" signature variation whilst in view of the radar)

- Presenting a variable radar cross section to the radar via controlled rotations around different satellite axes at known rates, for calibration purposes

- Deploy the Carbonite 4 satellite at different known separations to allow:-

  - Discrimination trials (Determining the minimum separation at which the two satellites can be detected as discrete objects)
  - Multipath trials (Determining whether, at short inter-satellite ranges, multipath effects could give rise to false targets)

  (It is suggested that these trails could be repeated at different geometries, and under different atmospheric conditions, e.g. when the propagation path is disturbed by a space weather event)

- Manoeuvre whilst in sight of the Fylingdales radar at known times, to evaluate the accuracy of the subsequent orbit derived, and any artefacts from the propulsion plume. (Calibration via highly accurate dual-band GNSS receivers on-board)

- Spoofing experiments (using the multi-core processor to analyse the received waveform and transmit back a false target signature)

- Jamming experiments (using a tuned transmitter on the satellite to generate a short-duration jamming signal which would allow the effects on the radar to be determined, without compromise to the primary mission of the Fylingdales facility)

- Bi-static debris characterisation experiment – By tuning the receiver on the satellite to the Fylingdales transmission, it may be possible to bi-statically detect very small debris, close to the satellite, that would not be detectable on the ground

- Direct reception experiment for ionospheric sounding – Direct reception of the Fylingdales signal on the satellite would potentially permit assessments of the state of the upper atmosphere

- Possible end-of-life experiment, following deployment of a de-orbit drag sail, which would change the configuration of the satellite significantly

DarkCarb

- A test satellite equipped with a thermal camera could make unique observations of other orbital objects

Sample Distance at 600 km ~ 5 m

Field Of View ~ 5 km

Spectral Band - LWIR

Temperature Sensitivity:-

<1K @ 260K

<0.5K @ 300K

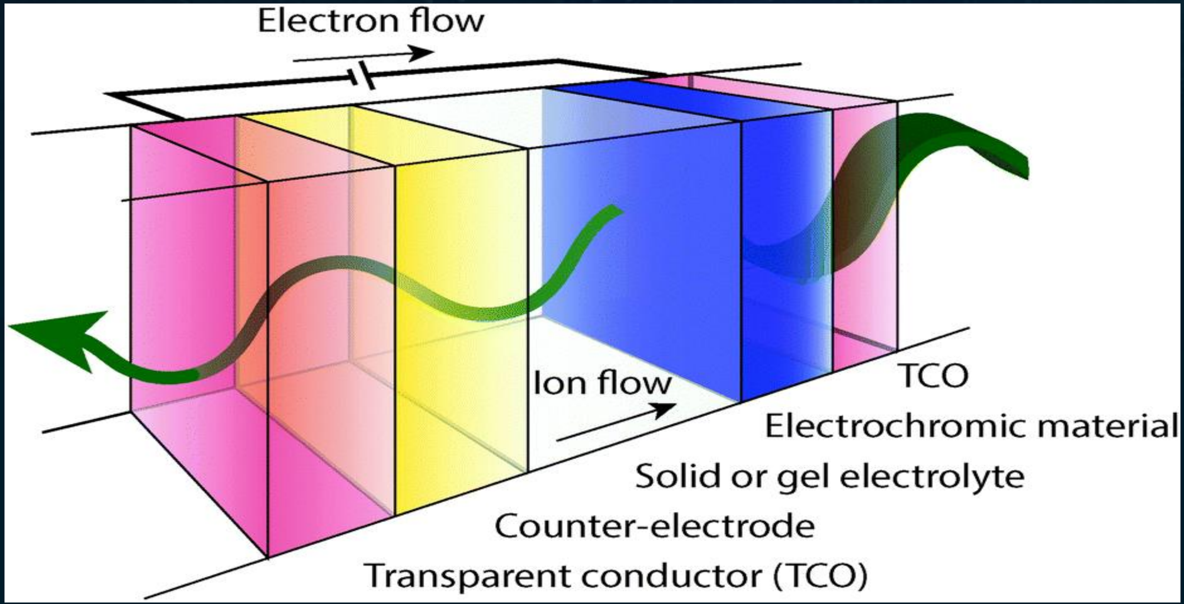
Threat Detection Packages and Angels

- Equipping the test satellite with the means to detect and report threats, (e.g. laser illumination), provides a “black box” capability

- Techniques could also be tested for guardian “angel” satellites designed to protect larger, more expensive assets can reduce the threat from active or passive in-orbit “demons” which may seek to:-
  - Intercept commanding or communications
  - Transmit jamming signals
  - Contaminate the local environment around the target satellite
  - Interpose themselves between the target satellite and the Earth
  - Detonate
  - Collide with the target satellite

Electro-Chromic Materials

- These materials offer both solid-state thermal control potential and stealth capabilities
- In an “SSA Warfare” environment, active measures to deny enemy SSA are potentially desirable



Enabled Capabilities

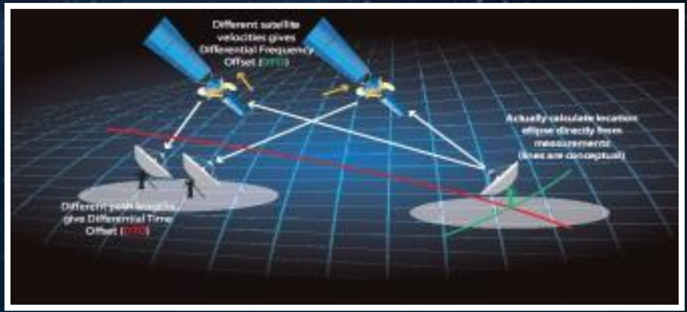
Regional Navigation Concept

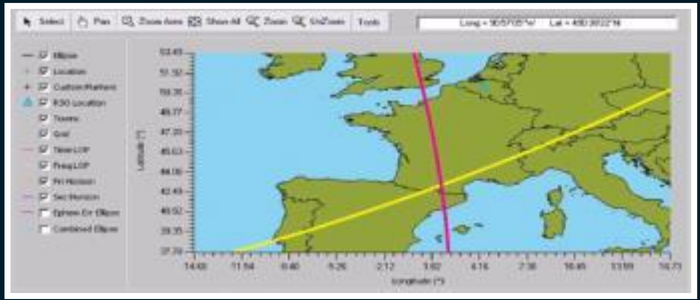
Navigation Concept

- The F-BLOS 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 geolocate sources of interference.

- A signal broadcast via two (or more) F-BLOS 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.

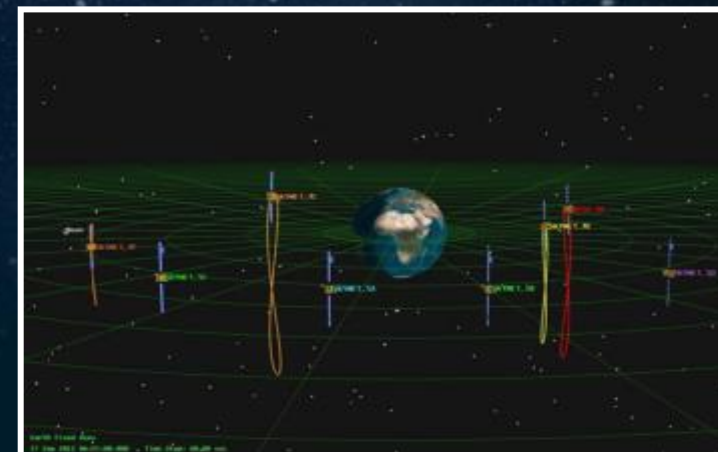
- The use of satellites in inclined geosynchronous orbits, (e.g. Skynet 4 satellites now, and “semi-retired” Skynet 5 satellites in the F-BLOS era), to transpond the signals could be advantageous, since the “GDOP” is improved. This could be tested now using the Skynet 4 and Skynet 5 satellites

- 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

Limitation of the Current Constellation

- The Skynet 4 satellites all had initial right ascension values close to 285 degrees, and so their orbits have evolved similarly
- Consequently they all cross the equatorial plane at similar times of day
- At this time, the GDOP provided by the Skynet 4 and Skynet 5 satellites would be degraded



Space Tug Mission Proposal

- It is suggested that a Space Tug could rendezvous with one of the Skynet 4 satellites and modify its right ascension by approximately 6 hours (or about 90 ˚)
- As a consequence, at least one satellite in the Skynet constellation would always be out of the equatorial plane, helping to maintain the GDOP of the system
- Initial estimates suggest that this manoeuvre would be well within the delta-v capacity of the ESS satellite, (a 180 degree right ascension change for a satellite in a 14 degree inclined geosynchronous orbit requires about 1.5 km/s)

Regional surveillance and weapon targeting

Surveillance and Weapon Targeting

- The (spot-beam) signals from the Skynet satellites could be used as the illuminator for a bi-static surveillance system analogous to Silent Sentry, (where terrestrial signals of opportunity are used as the illuminator)
- The feasibility of such a system to detect moving targets was demonstrated by DSTO in Australia using a GEO satellite broadcast
- The advantage of using the Skynet signals, rather than a transmitter of opportunity in theatre, is that the UK would have control over the illuminating signal
- Air targets could be detected, and the same system could be used to help weapon system find their way to their targets
- Precision SSA would enhance the accuracy of such a system

Inter-satellite Applications supported by Precision SSA

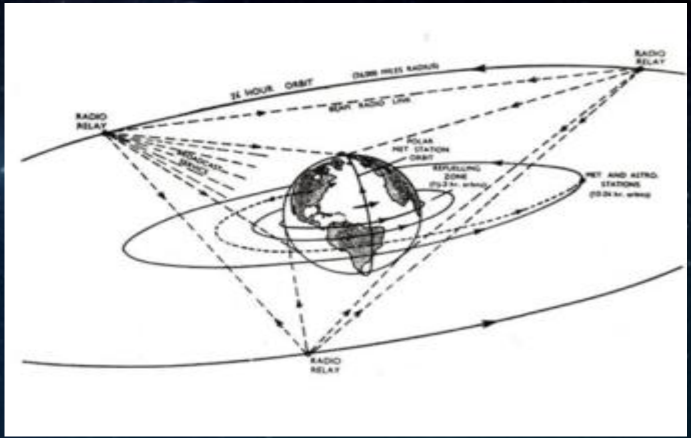
Long-Range Inter-satellite Links

- Systems such as the European Data Relay Satellite (EDRS) will help to establish a “space wide web” of links between satellites

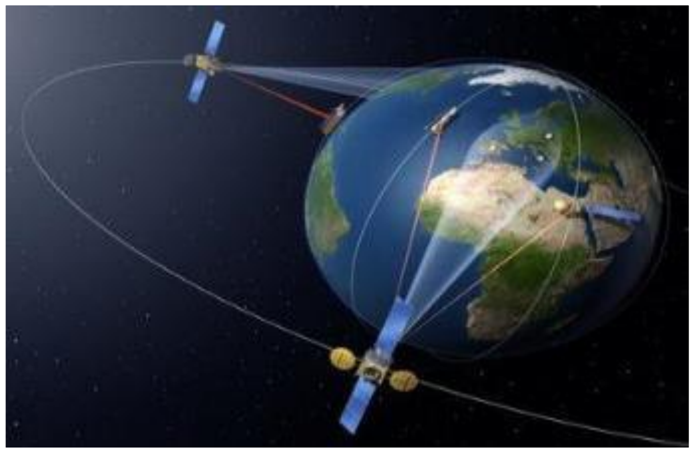
- This will allow commands to be sent, and data to be returned from satellites, in tactical timeframes

- The speed of subscriber satellites in LEO is very high

- The “point-ahead problem” is eased by precision SSA



Arthur C Clarke’s 1945 Paper



European Data Relay Satellite

Quantum Satellite Clusters

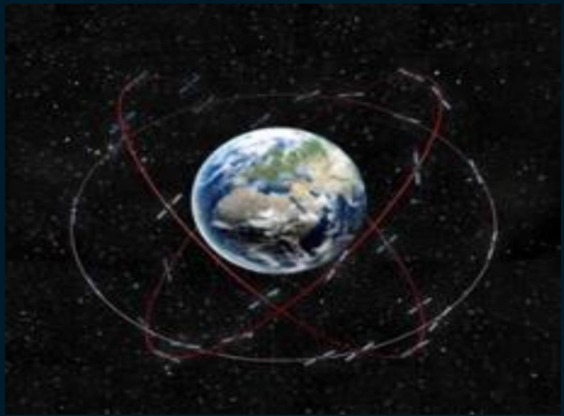
- Clusters of smaller GEO satellites offer resilience, flexibility, increased capacity over specific theatres, and novel capabilities such as high capacity, interferometric communication beams that are hard to jam
- Cluster formation flying is enabled by enhanced SSA capabilities

GNSS Monitoring From GEO

GNSS monitoring from GEO

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

- Possible applications 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

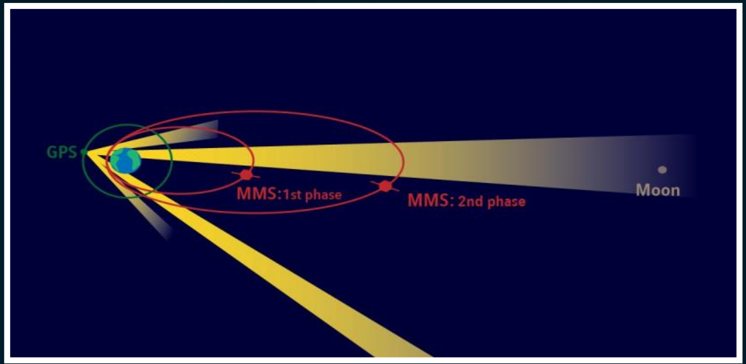


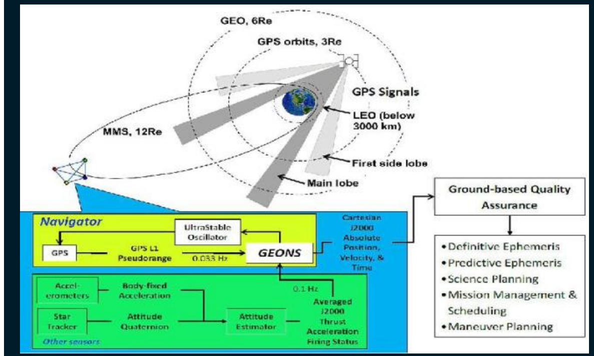
GNSS monitoring from GEO

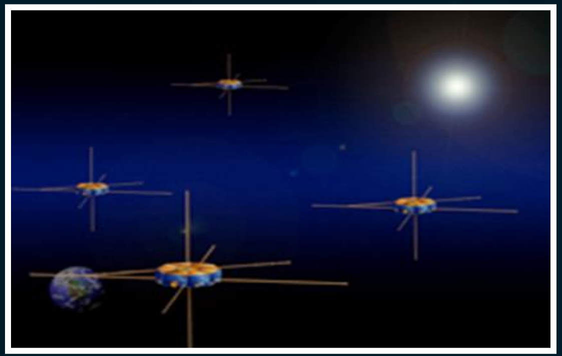
- The system concept involves two satellites, stationed more than 90 degrees apart in GEO orbit
- Both would be equipped with capable L-band receive antennas specifically designed to detect GNSS signals from the navigation satellites in MEO below them
- They could also be equipped with GEO-GEO inter-satellite links to better-enable some of the envisaged applications
- The principle of GNSS reception at GEO has been demonstrated previously in experiments such as GAGE, (for satellite orbit determination applications), using very modest receive antennas
- Initial estimates suggest that a secondary payload on a GEO satellite would enable most of these applications

Magnetospheric Multiscale Mission

- The NASA MMS mission is using GPS side-lobes to navigate out to 12 Earth radii, (GEO is only 6 Earth radii away)
- The MMS system has set the record for the highest GPS use in space.
- At the highest point of the MMS orbit, at more than 70,000 km above the surface of the Earth, MMS set a record for the highest-ever reception of signals and on-board navigation solution by an operational GPS receiver in space.
- The system can determine the position of each spacecraft with an uncertainty of better than 15 metres
- The system consistently tracks transmissions from eight to 12 GPS satellites

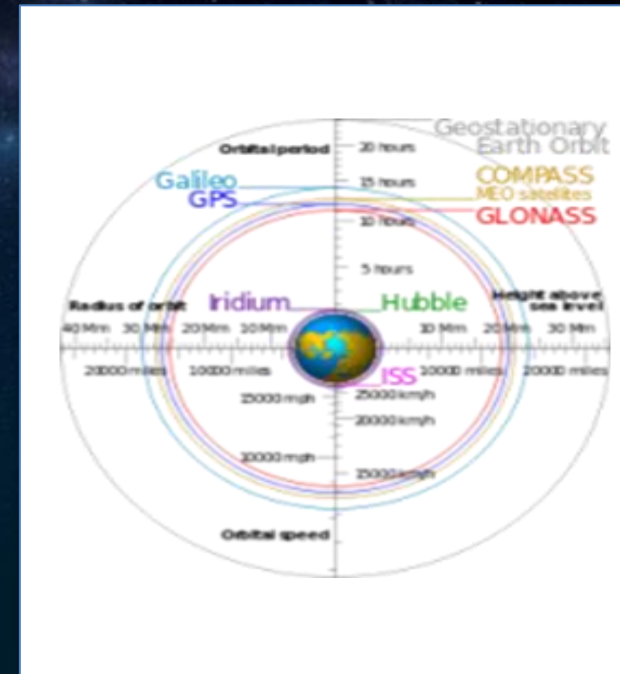






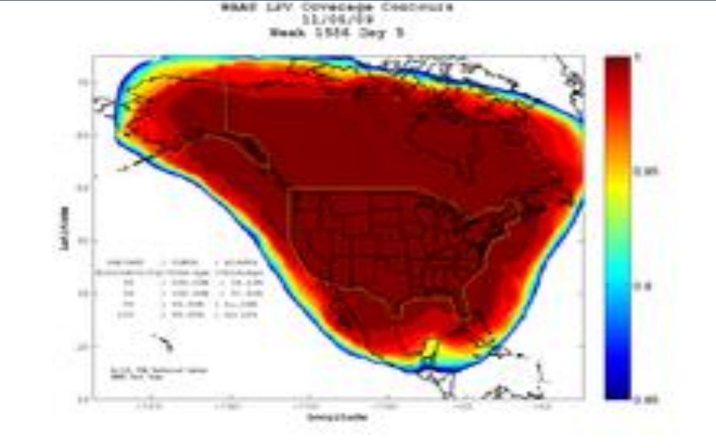
GNSS monitoring from GEO

- The satellites in the GNSS constellations would be visible for most of their orbits from single GEO satellite
- A second satellite located at a GEO slot more than 90 degrees from the first would:-
  - ensure that all satellites were in view continuously (since some would be behind the Earth periodically from the perspective of a single GEO)
  - provide a second viewpoint that would improve the collection geometry for those GNSS satellites “below” the first GEO satellite, (since they would be transmitting away from it)



GNSS Integrity Monitoring

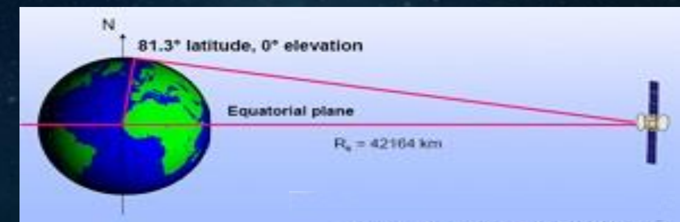
- An increasing number of safety of life applications now rely on GNSS systems.
- In some cases, (e.g. air transport and maritime applications), the GNSS users travel beyond the regions where GNSS systems such as WAAS and EGNOS are effective
- Even where these services are available, it is still important to know whether a given anomaly is due to:-
  - signal propagation effects through the Earth's atmosphere
  - some anomaly on the GNSS satellite itself
- A system of GNSS monitoring from GEO would provide this important information

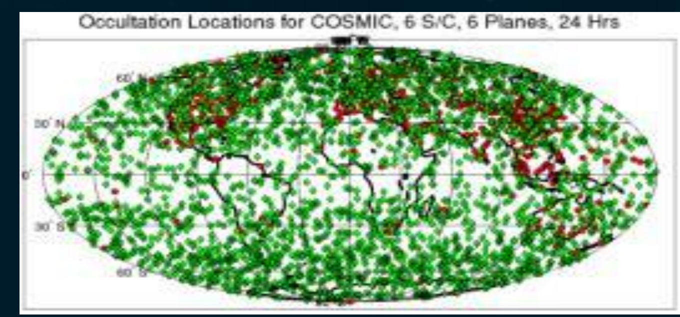


Meteorological Measurements

- Measurements of signal variations as the GNSS satellites “rise” and “set” through the Earth’s atmosphere can provide information on the temperature and water vapour profiles in the neutral atmosphere

  - A GEO satellite that is able to collect such data would periodically provide a “ring” of sampling locations corresponding to the edge of its coverage contour, (by contrast with the globally distributed data illustrated here which would be collected by a LEO constellation such as Formosat-7)
  - Although the GEO sampling would clearly not be globally distributed, as is the case with data from dedicated LEO systems, the predictable geographical sampling should allow regular time-history data to be collected for a well-defined region, enabling improvements to meteorological modelling





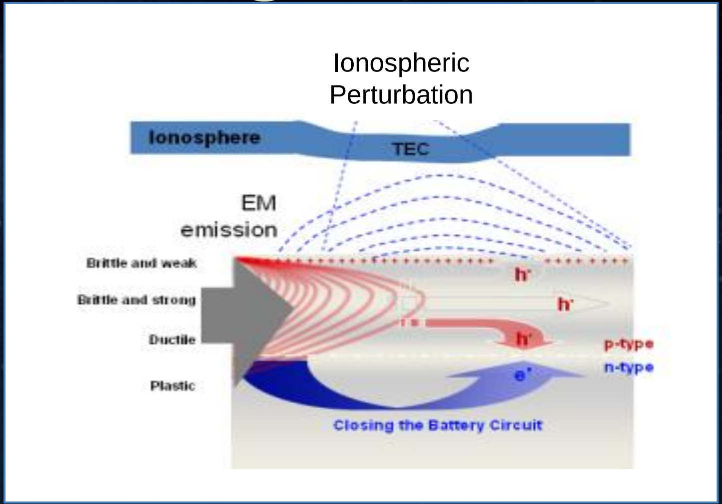
Earthquake Forecasting

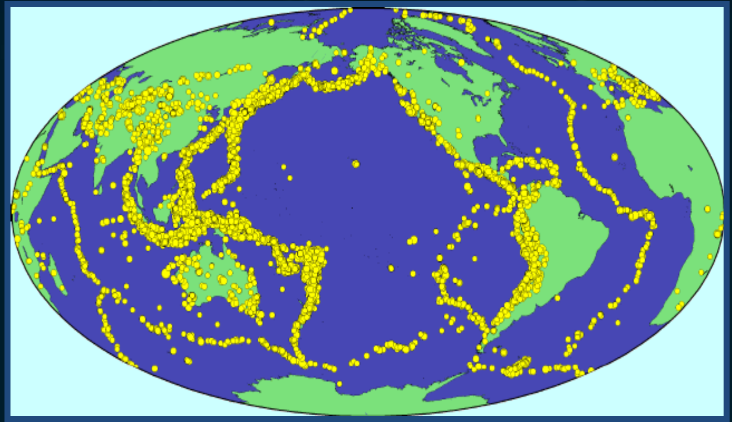
- It has been suggested that geological forces acting on rocks may lead to electromagnetic effects, including the build-up of positive charge at the Earth's surface up to a week before an earthquake event

- This positive charge has the potential to attract the free electrons in the earth's ionosphere, creating a "dip" which may be detectable as GNSS signals pass through this region, and are then collected by the GEO satellite

- This warning service would be available over a "ring" at the edge of the GEO satellite's coverage, where the GNSS satellites would appear to rise and set through the atmosphere

- A GEO satellite stationed over the Pacific ocean might thus be able to monitor much of the "Ring of Fire"





Jammer Detection and Geolocation

- GNSS jamming is of increasing concern to organisations responsible for maintaining national infrastructure
  - A GEO satellite with a sufficiently sensitive receive antenna could be used to detect and geolocate jammers
    - Jammers are used by the criminal fraternity to disguise the positions of vehicles, and these illegal transmitters have the potential to interfere with critical national infrastructure such as aircraft landing systems
  - Using either phased array beam-forming techniques, or data from both spacecraft, it would be possible to geolocate the source of interference on the surface of the Earth

High Precision Orbit Determination

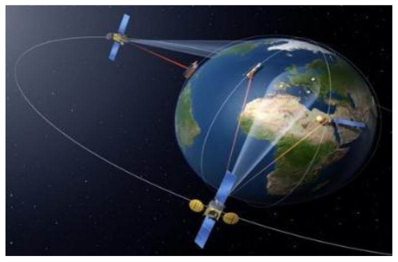
- High-precision orbit determination is another potential spin off from such a system

- GEO satellites capable of listening to a large proportion of the GNSS satellites in orbit should be able to derive a very well defined position.

- One class of adjunct payload which could benefit might be an optical inter-satellite link system operating between the two GEO monitoring satellites themselves.

- In principle, such a link could be used to exchange data on the entire GNSS fleet and thereby make it available in real time to a terrestrial monitoring station

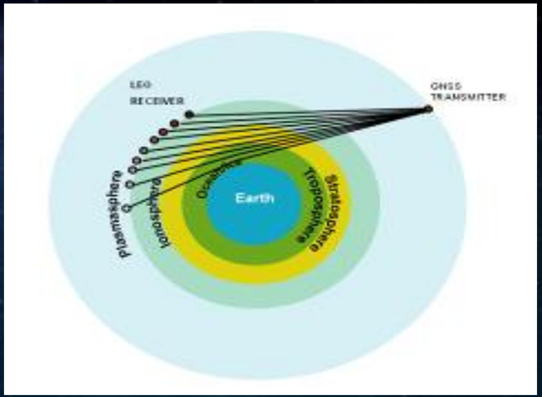
- Another application which might benefit is inter-satellite data relay, where the time taken to achieve hand-shaking between the satellites, (i.e. the period before high data rate communications can be achieved), would be shortened

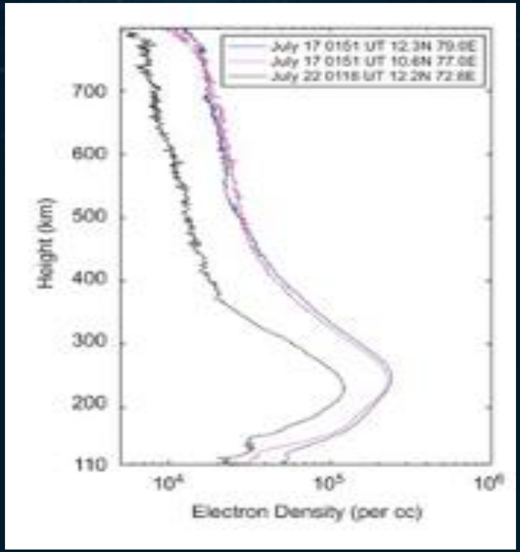


- As will be explained in the following presentation, if the monitoring satellites were used to provide an alternate navigation service themselves, then this high precision orbit determination could also be beneficial

Orbital Drag Estimates

- Monitoring of GNSS signals passing though the upper reaches of the atmosphere could provide near-real-time drag estimates which could be used to improve satellite tracking accuracy
  - Improved measurements of electron density profiles in the upper atmosphere are a key enabler for future Space Traffic Control activities
  - Estimates of potential collision risk in LEO depend on accurate evaluation of the drag experienced by the satellites and debris objects in this orbital regime
  - Observations of the signal variations as the GNSS satellites “rise” and “set” relative to a GEO satellite equipped with a GNSS receiver would allow a more timely estimate of the state of the upper atmosphere, which can be fed into orbit propagation models

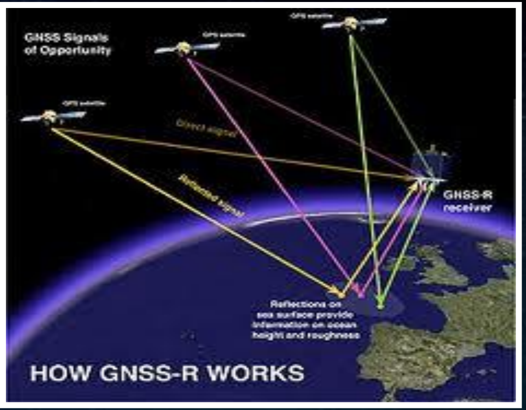




GNSS Reflectometry (and Altimetry)

- GNSS reflectometry involves the reception of GNSS signals that have been specularly reflected from the surface of the Earth.

- As the GNSS signals are reflected from the ocean surface, they experience a Doppler-shift due to the motion of the ocean surface



- Comparison of the reflected signals with the direct path signals, (in this case probably collected by the two different GEO satellites), allows an estimate of the sea-state to be made. This allows data products to be created which would be of interest to the shipping community, who are interested in routing around regions of bad weather and who are understandably anxious to avoid rogue waves.

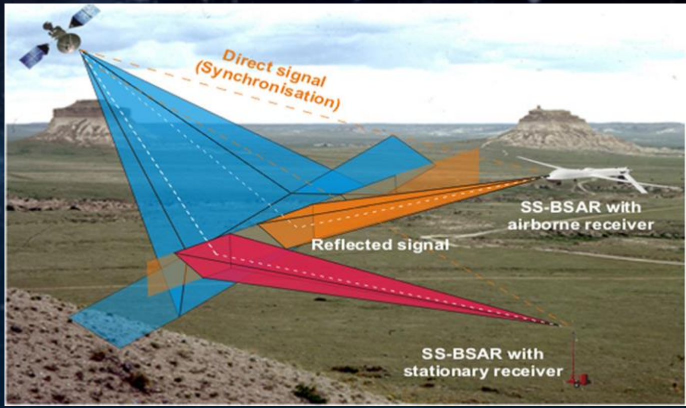
- It is also potentially possible to monitor soil moisture content using this technique. This is the primary driver for the SMOS mission, which will supply data that is of critical importance for agriculture and for the climate change debate

- And if a sufficient signal to noise ratio can be achieved, altimetry may also be possible

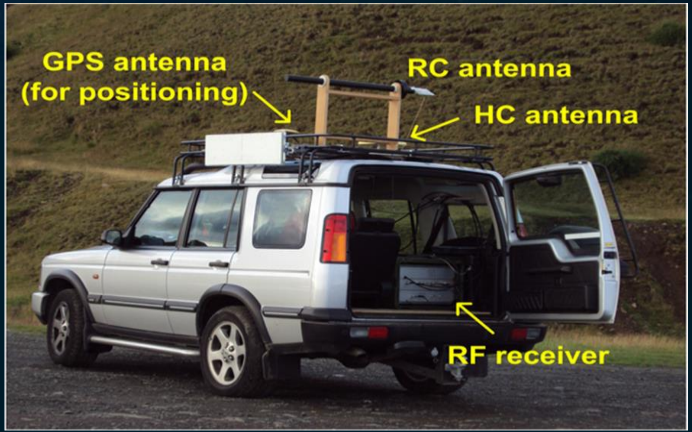
GNSS Imaging

- Although the resolution is low, it is possible to use GNSS signals for imaging

- This "bistatic radar" technique might also be possible with a sufficiently capable GEO antenna



(a) (b)



Scintillation

- One final potential use for the system might be to address an on-going scientific puzzle – that of scintillation.
- The polar regions regularly experience auroral disturbances, and these can be traced to interactions between the solar wind and the Earth's magnetosphere.
- However, scintillation also occurs over the African continent at dusk – typically at around 6 p.m. close to the Equator.
- One suggestion that has been made to explain this is that lightning activity, and in particular the upward form of lightning known as sprites, may be causing electrical disturbances in the upper atmosphere. The possible explanation for the geographical connection to Africa is that the peak intensity of lightning events is generated by convection rainfall over the African rain forest, as shown in the map.
- Although of scientific interest, it is not clear that this capability would have a direct financial value, although it may contribute to some degree to the monitoring of GNSS system integrity in the region. A monitoring satellite stationed over Australia could potentially monitor this region via occultation measurements.