Space Traffic Control: An Industry Perspective

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Rationale for Resilience and Space Traffic Control

- **Space Traffic Control is required because:-**

- **The increasing international reliance on space systems justifies additional efforts to make them more robust**

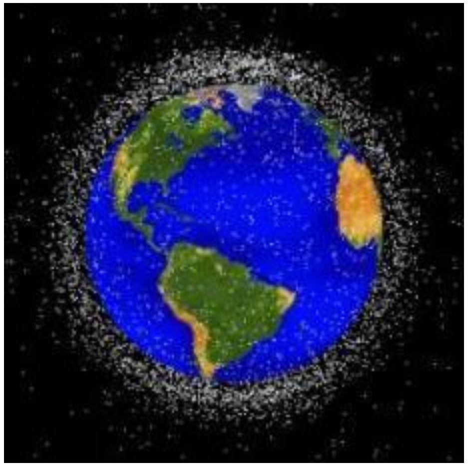
  - Space is increasingly seen a part of the critical international infrastructure, providing communications, navigation, timing, surveillance, etc.

- **Natural hazards and man-made threats to space systems are increasing**

  - Increased resilience is required simply to maintain current capability levels

  - "Space is congested, contested and competitive"

Solar Flares



Space Debris

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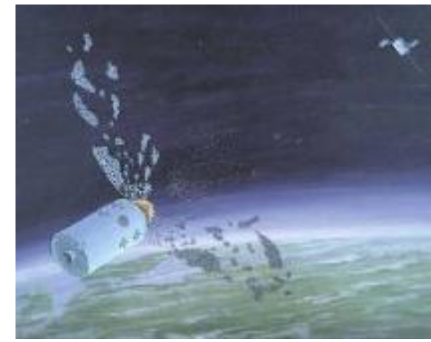
HAZARDS AND THREATS

- HAZARDS
  - Near earth objects and comets
  - Meteorite storms
  - Space weather events and cosmic rays
  - Space debris
  - Natural catastrophes on earth



- THREATS
  - Anti-Satellite (ASAT) weapons, (co-orbital or ballistic)
  - Exo-atmospheric Nuclear Burst (prompt SGEMP or total dose effects)
  - RF weapons (spoofers, jammers, or high-energy RF damage systems)
  - Cyber attacks, (signal interception, unauthorised commanding, hacking etc.)
  - Deliberately induced variations in the natural environment
  - Demons conducting disruption or surveillance operations
  - Physical attack on ground infrastructure, (ground stations, launch sites communication networks, power grid, staff, etc.)
  - Laser weapons (dazzle or damage levels)
  - Charged and neutral particle beams
  - Improved space situation awareness
  - Camouflage, concealment, and deception

An international problem needs an international solution

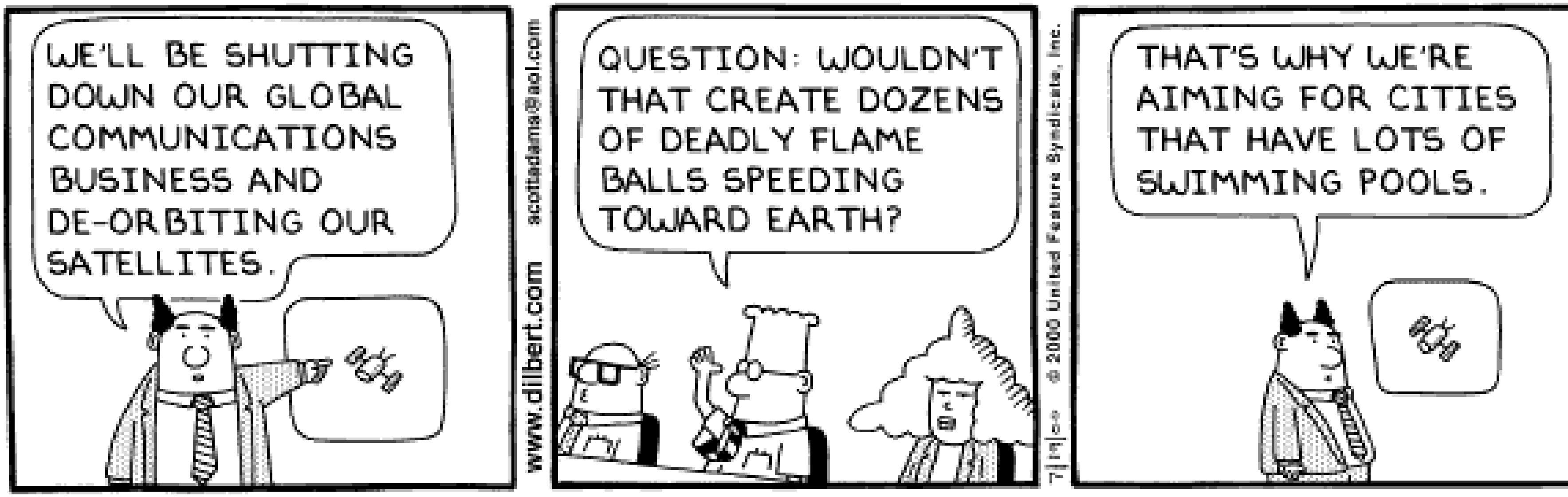
- The current catalogue is principally composed of objects for which the launching state, (and hence the ownership), is known

- The future debris population will be much larger, and much of it will be "anonymous"

    - **As we improve tracking sensitivities, it is anticipated that the population of tracked objects will rise to on the order of 200,000 objects**

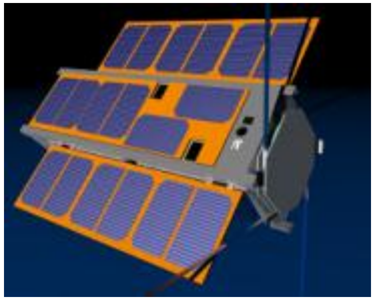
    - **In many cases it will not be possible to extrapolate an object's orbit backwards in time to establish its origin**

Even Dilbert is worried…



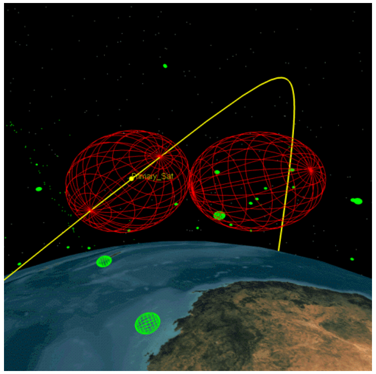
- This is not the future we want

Space Traffic Control



Desirable improvements:-

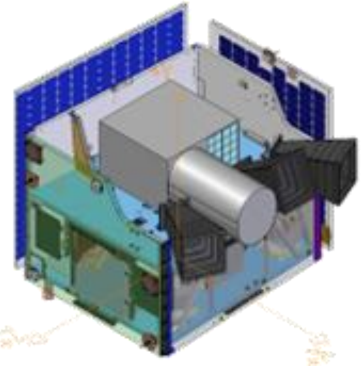
Tracking Smaller objects.
The need to track smaller (principally debris) objects, ideally down to 1 cm in size.



Smaller tracking errors.
STC requires reduced "error ellipsoids" around space objects, to the point where collision avoidance operations are cost-effective and technically feasible.

More frequent tracking.
Tracking objects more frequently, (and hence limiting the extent to which the error ellipsoids can grow with time), would be achieved most efficiently by exchanging data from multiple sensors via an international system including tracking sites around the globe.

More in-orbit tracking.
The Sapphire surveillance of space mission is expected to be the first of a series of missions which will be placed in LEO orbit specifically to detect and track other satellites in higher orbits, overcoming the traditional optical surveillance limitations of the day-night cycle and obscuration due to cloud cover.



Improved Space Weather Monitoring.
The capability to monitor space weather conditions at the Sun, in interplanetary space and at the Earth in near real-time would lead to the capability to forecast adverse space weather. A goal of STC is to provide quantitative forecasts of hazard-related environment variables with sufficient lead time (say 6 hours) to allow effective procedural mitigation.

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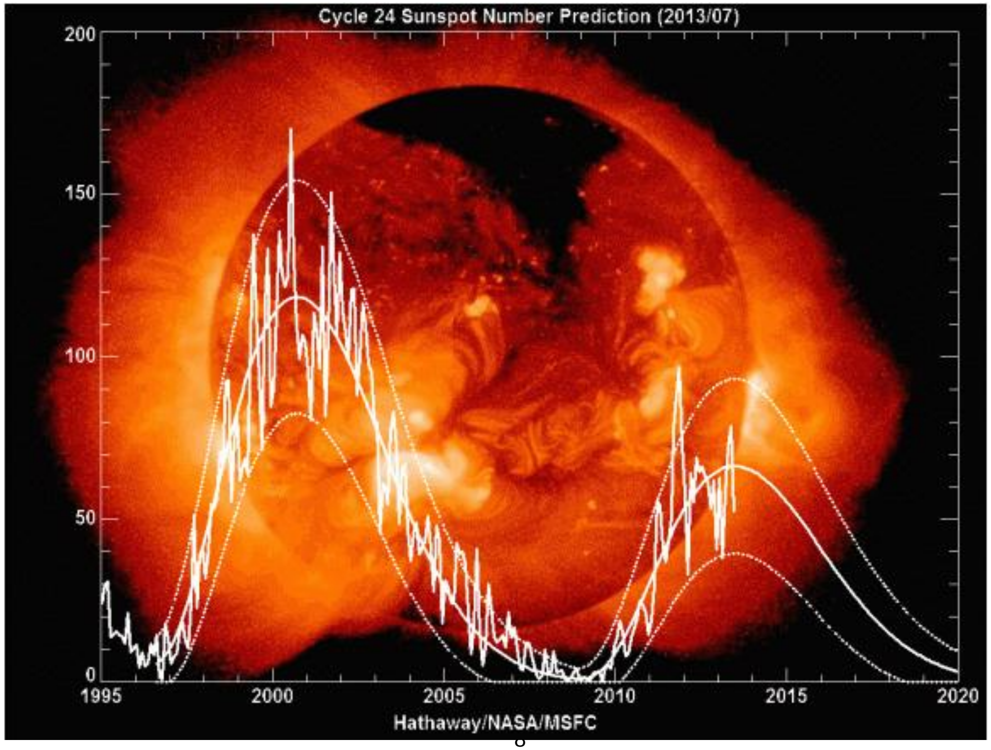
An example of the challenge…

- A laser rangefinder like the one at Herstmonceux in Kent can track satellites to centimetre-level accuracy
- But in order to fire its laser, it typically has to acquire the satellite in a targeting telescope
- The telescope is parked on the expected track of the satellite
- Tracking at the expected rate commences when the satellite enters the telescope’s field of view
- The system has an accelerating joystick to allow the telescope to catch up with the satellite, because it typically arrives “early” or “late”
- This is due to variable drag on the satellites being tracked

The system at Herstmonceux can detect the vertical motion of the site caused by the tides in the English Channel

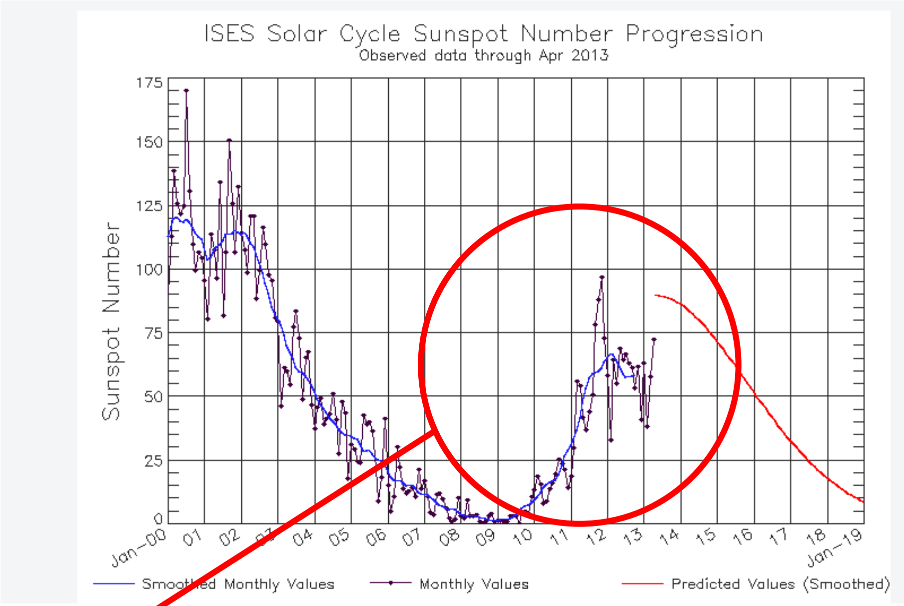
We don’t fully understand the Sun

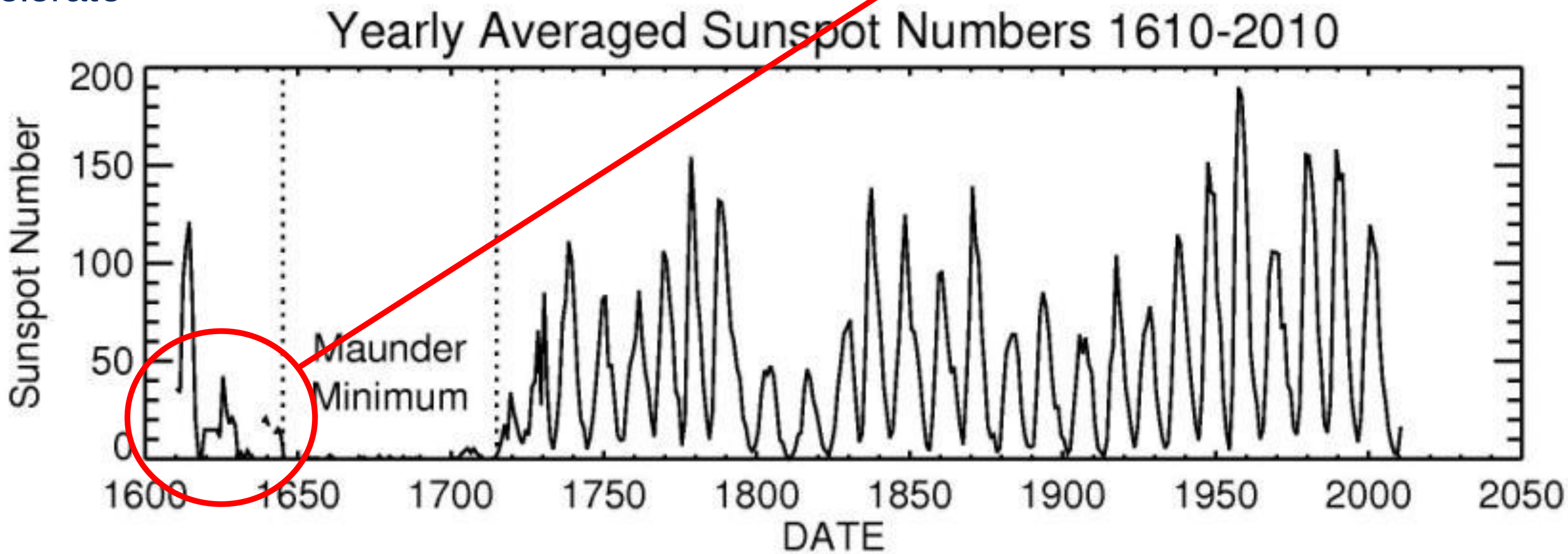
- Variations in solar activity affect the Earth’s upper atmosphere, causing perturbations to satellite orbits that change over time
- An improved understanding of the behaviour of the sun would enable better forward-prediction of satellite and debris orbits



Unreliable Solar Activity

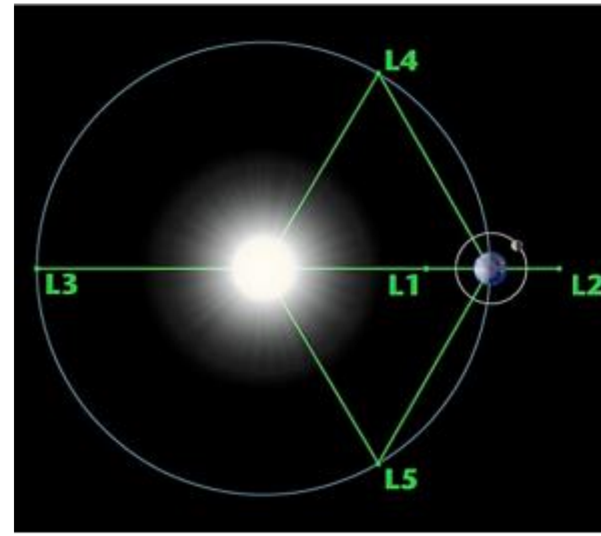
- Is there a parallel between current solar activity (top right) and the onset of the Maunder minimum (below)?
- Current predictions of debris populations assume a continuation of the 11 year solar cycle
- If the increased drag at solar maximum does not appear, the debris population growth will accelerate





Solar Monitoring Mission Concept

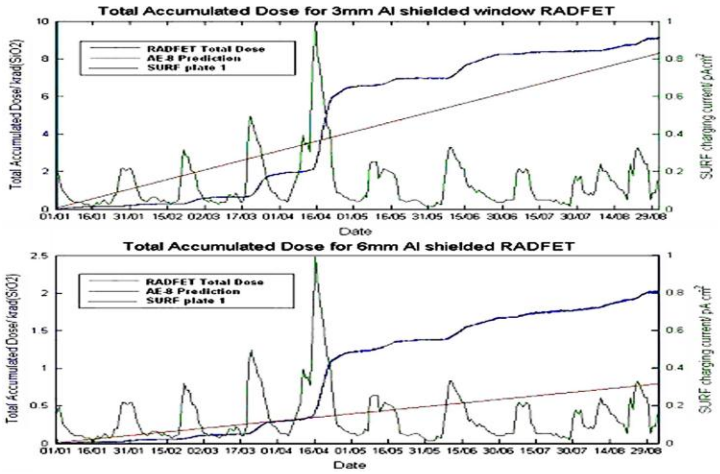
- A comprehensive monitoring capability requires satellites stationed (approximately) at both L1 and L4/L5
- The L4/L5 mission would provide initial warning of an impending solar-induced event
- The L1 mission would provide information on the magnetic polarity of the flare and hence the potential coupling into the Earth's magnetosphere
- Why two missions?
- L4/L5 imager can predict a collision but it cannot predict the interaction with the Earth's magnetic field
- L1 in-situ mission cannot give sufficiently early warning of an event. From no-alert to 'Red Alert' in 90 minutes is too short for serious action!

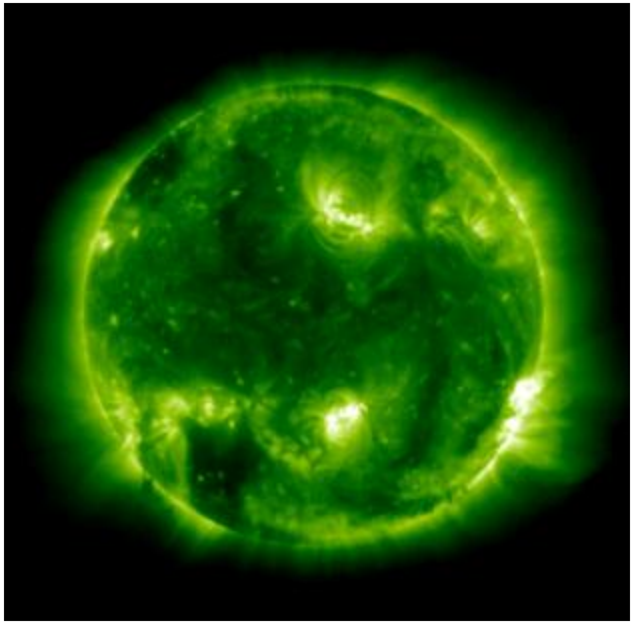


An operational system would ideally involve multiple satellites located at all three locations to provide high system availability

Reporting of Telemetry Data

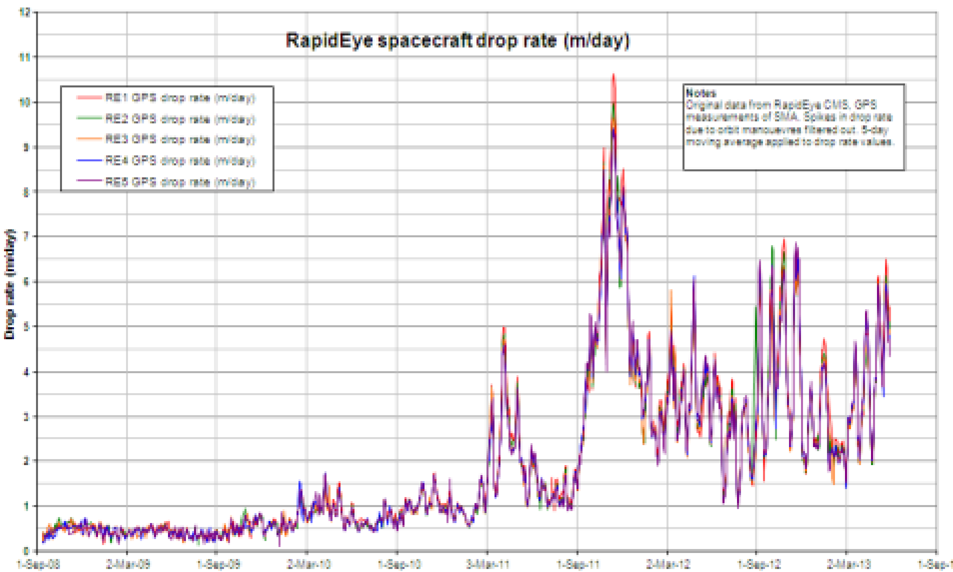
- Satellites could provide data from on-board sensors
- The example shown is accumulated radiation dose data from Giove-A, showing a periodic increment roughly once per month
- This is the result of an active region on the sun, (which rotates with this period)
- Real-time space weather data of this sort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

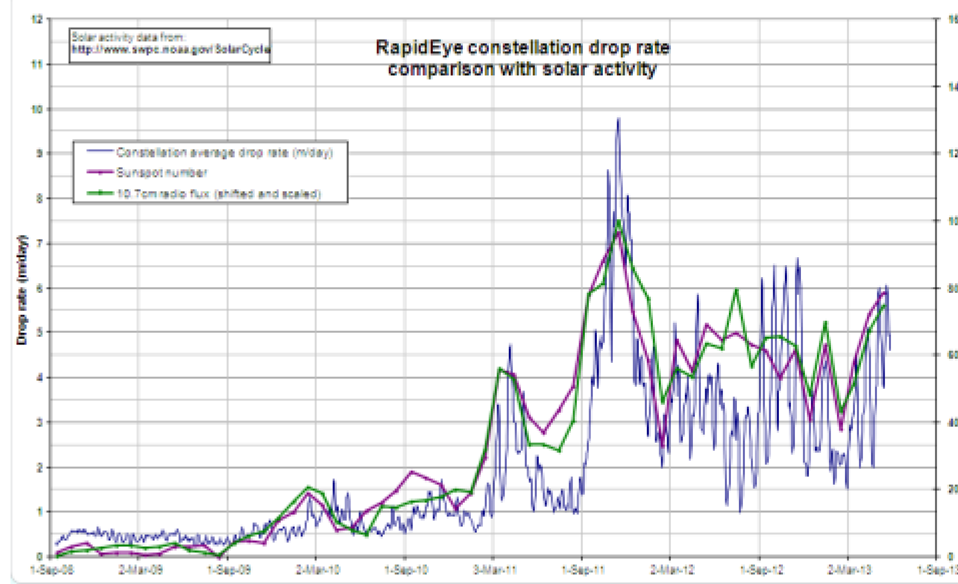




Orbital Data

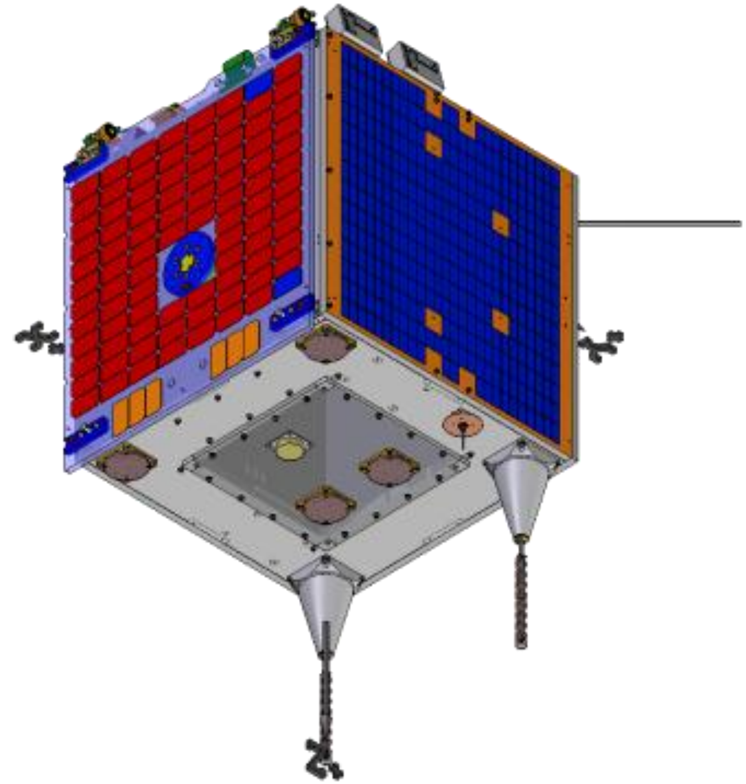
- Satellite operators (usually!) know where their satellites are, and can report their positions and manoeuvres periodically
- By analogy, aircraft are required to report their positions when they are in uncontrolled airspace
- Redundant communications paths are mandated on aircraft for safety reasons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





Tracking Beacons

- Large satellites might be required to periodically broadcast their positions to a network of receivers
- This would be somewhat analogous to the Automatic Identification System (AIS) transmitters that are mandatory for all ships over 300 tonnes
- The monitoring network might be partially based in orbit



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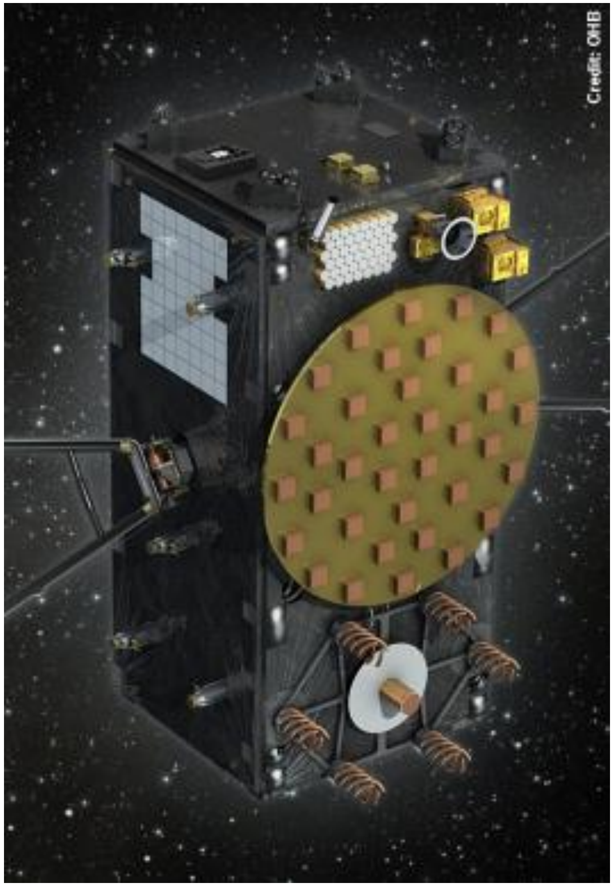
Precision Orbit Determination

- Precision orbit determination may become necessary for all active satellites
- The DORIS system (Doppler Orbitography and Radio-positioning Integrated by Satellite) is capable of providing 1 cm accuracy
- Clearly, though the satellite must be operating for this accuracy to be achieved
- The wide distribution of DORIS ground sites illustrates the need for frequent updates in order to maintain accurate ephemeris data

Laser Retro-reflectors

- Some satellites, (e.g. navigation missions), are routinely equipped with laser retro-reflectors to facilitate accurate tracking
- If all satellites were required to do so then, even when mission-ended, they could be tracked much more accurately
- The mounting of such retro-reflector arrays needs to accommodate likely orientation of satellite at end of life
- Some defunct satellites are expected to tumble, whereas others may achieve a gravity-gradient stabilised configuration



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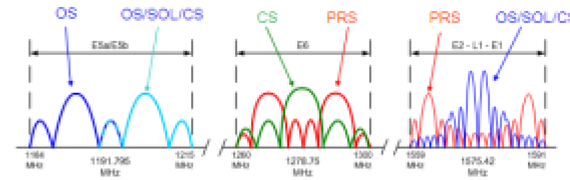
Frequency Coordination

- The international system for frequency coordination should continue to maintain standards for satellite transmissions

- In the air domain, radio frequency discipline is critical to flight safety

- This potentially becomes an increasing concern with greater numbers of manned missions

- Some vehicles will need to comply with both air traffic control and space traffic control standards, and the transition between them



Open Service (OS)	L1E1E2, E5a, E5b
Commercial Service (CS)	E6
Safety-of-Life Service (SOL)	L1E1E2, E5b
Public Regulated Service (PRS)	L1E1E2, E6
Search And Rescue Downlink	1544-1544.2 MHz

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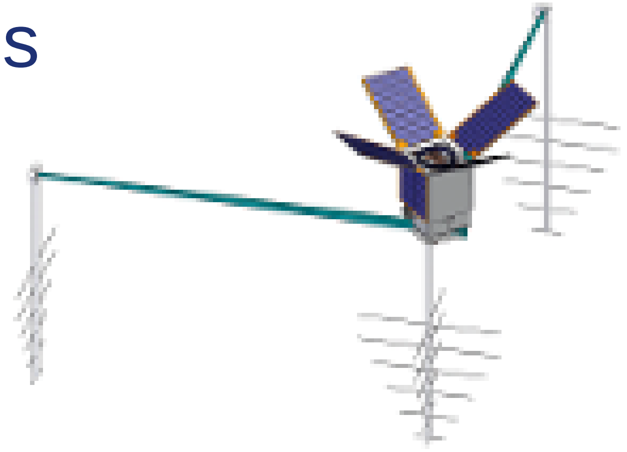
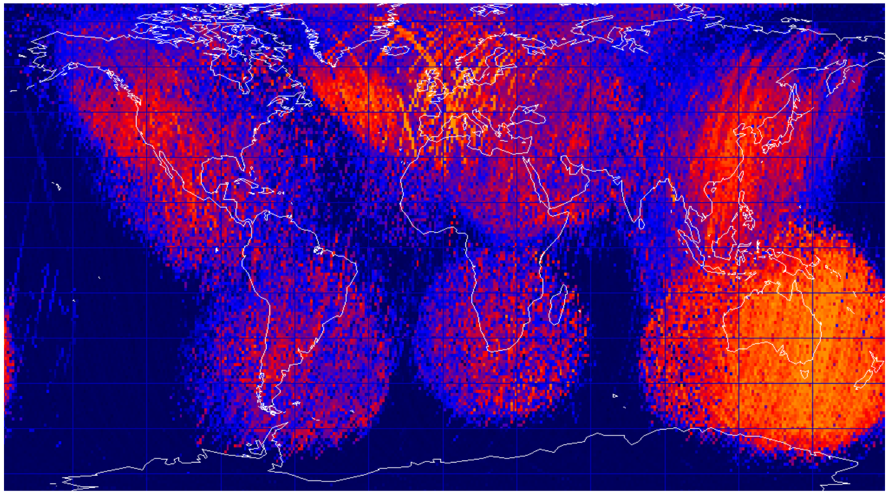
Geo-location of Interference Signals



- Interference costs money, and potentially jeopardises satellite operations
- An international system to geo-locate and report sources of interference would make life better for everyone
- Systems like RAIDRS (Rapid Attack, Identification, Detection and Reporting System) could distinguish accidental from deliberate interference



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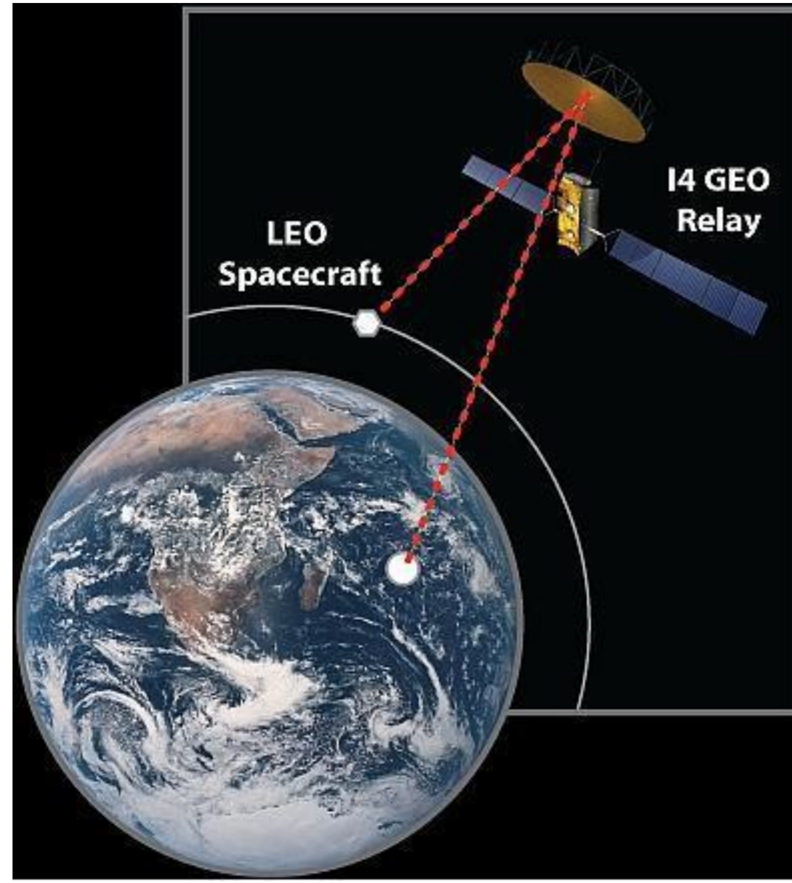
Inter-satellite Links

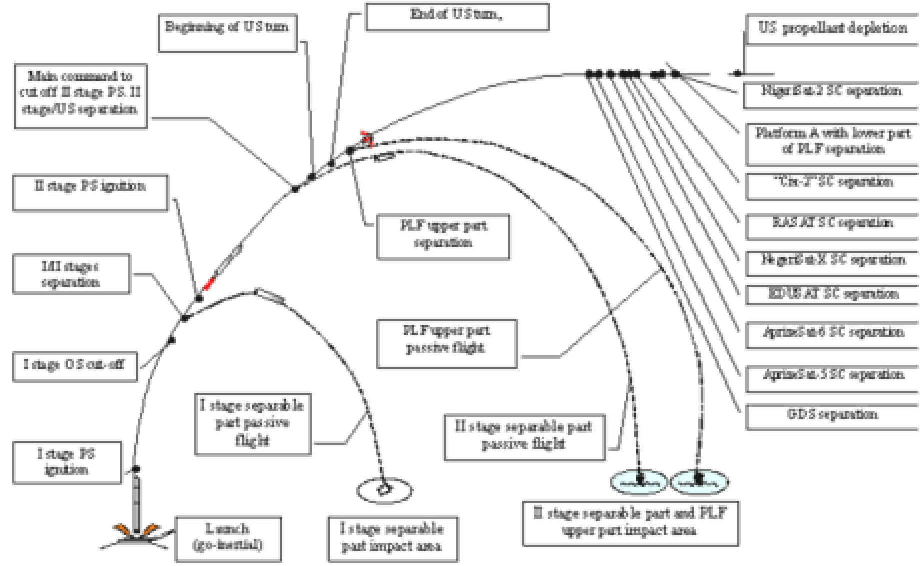
- The use of inter-satellite links provides resilience via:-
  - Additional command and control paths
  - Near-real-time reporting of data from the on-board sensors



Launch, manoeuvre, and de-orbit notification

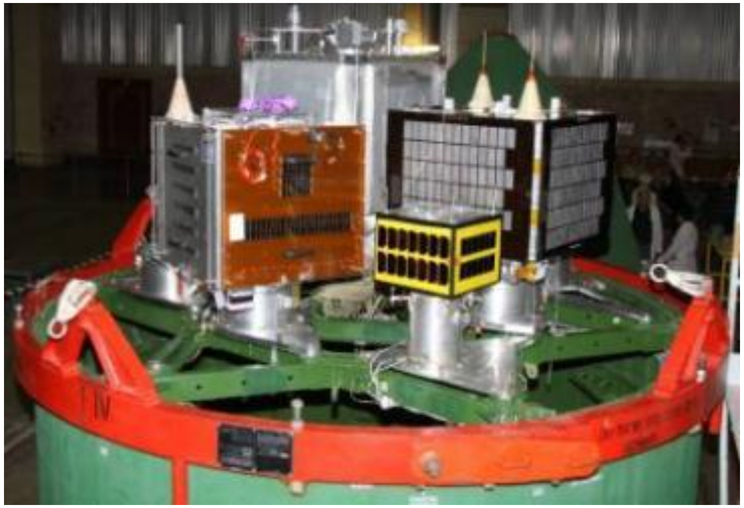
- To facilitate the inclusion of objects into the catalogue, it should remain a requirement to provide launch notification

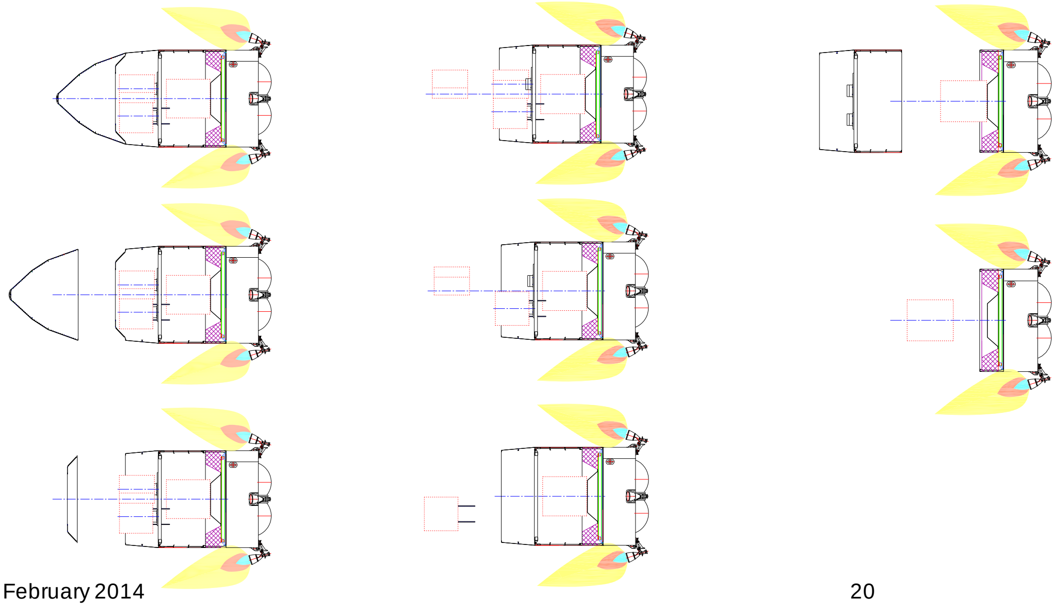
- Identity information on the various objects that are being released would also help, especially on multiple launches!



- Predicted and actual changes to orbits as a result of station-keeping, repositioning, and de-orbit manoeuvres could also be reported in appropriate time frames

Debris Mitigation Measures





It is possible to improve on a ratio of four debris objects to six operational satellites

STC Functions

- **Conjunction predictions/warnings** involving both active and inactive objects, and including the coordination of collision avoidance manoeuvres. As tracking accuracies improve, the frequency of such warnings would be expected to decrease

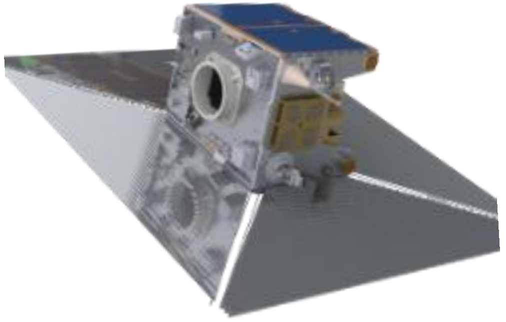
- **Notification of fragmentation events** and rapid cataloguing of the resultant fragments

- **Prediction of re-entry events** including both the time and geographic location of the events

- **Notification of station-keeping manoeuvres** (including pre-manoeuvre predictions and post-manoeuvre confirmation of the new orbit), de-orbit burns, and other actions such as the deployment of de-orbit sails that would signal the end of a satellite’s active mission

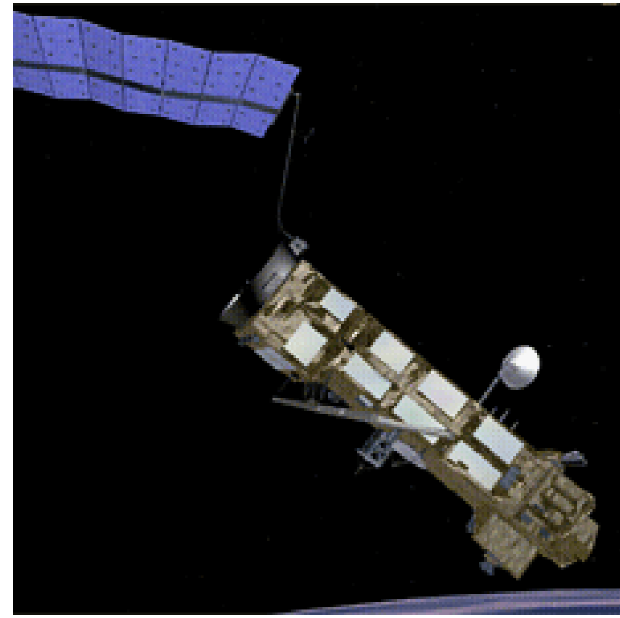
- **Forecasting and modelling of space weather** including assessments of the frequency and severity of extreme events

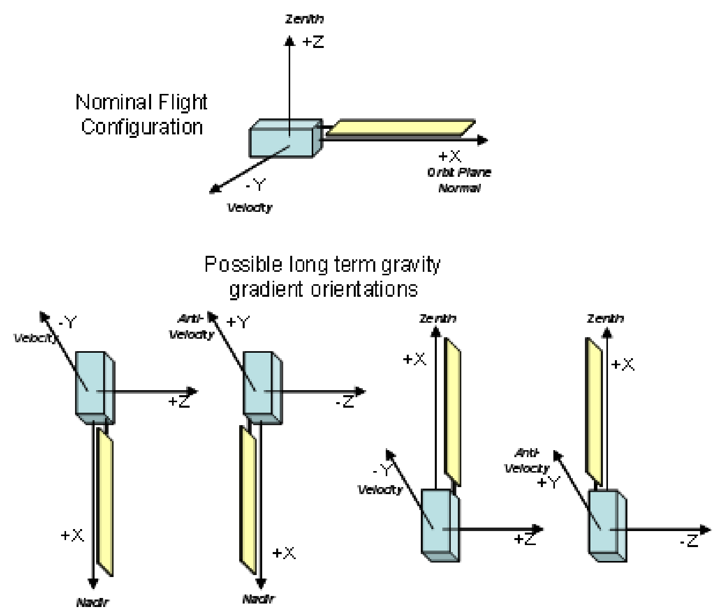
- **Debris mitigation** It is anticipated that the STC system would have a role in developing debris de-orbit capabilities, selecting which objects should be de-orbited first, and providing the tracking support necessary to enable de-orbit operations



Debris Removal Criteria

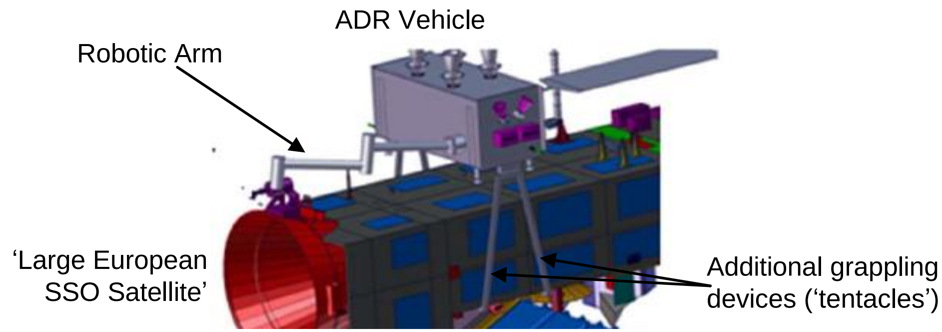
- The "value" of removing any given piece of debris will depend on a number of different parameters, including:-
  - its mass/size
  - its expected natural lifetime
  - its current orbit (and how hard it is to reach)
  - the number of other objects that it might conceivably collide with
  - its rotational motion, (if it has one)
  - who owns it





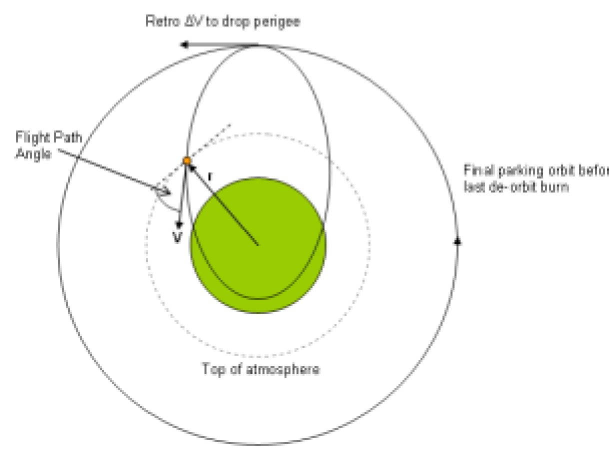
De-orbit is difficult

- Various de-orbit concepts have been proposed:
  - Nets
  - Grapplers
  - Harpoons
  - Lasers
  - Etc.



- Even when an object has been secured, the de-orbit burn leading to a controlled re-entry is challenging for large objects

- An alternate concept envisages attaching a fragmentation device to an object to ensure that it explodes as it enters the atmosphere



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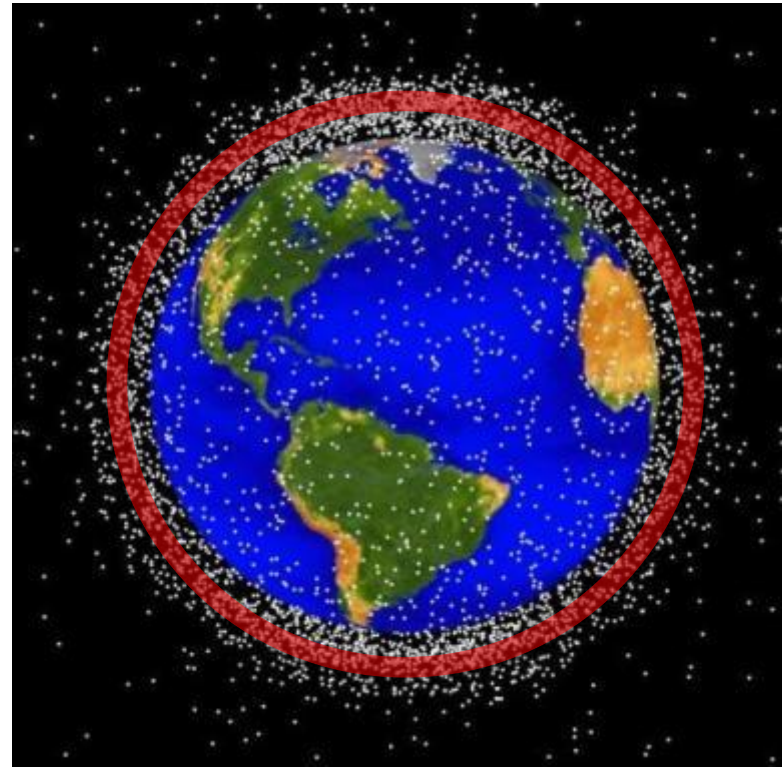
STC Functions we'd prefer to avoid……

- In the air domain, it is sometimes appropriate to designate regions as "no-fly zones"

- In space, it may become necessary to designate certain altitudes as "no-orbit zones" to avoid the Kessler scenario

- If we do end up in this scenario, the rules will need to be policed



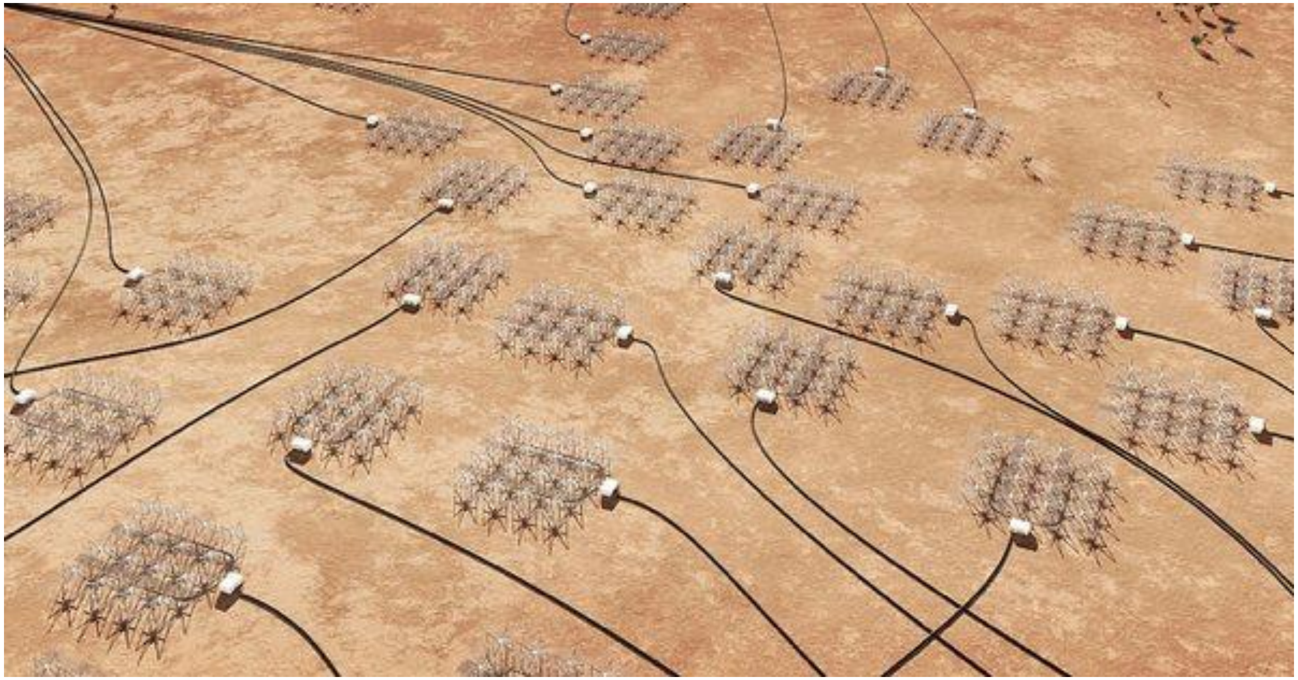
Orbit altitudes between 700km and 800km are at risk of becoming "over-populated"

The law of salvage as (potentially) applied to space

- The law of salvage
  - A concept in maritime law which states that a person who recovers another person's ship or cargo after peril or loss at sea is entitled to **a reward commensurate with the value of the property so saved**. The concept has its origins in antiquity, with the basis that a person would be putting himself and his own vessel at risk to recover another and thus should be appropriately rewarded.
- Minimizing danger to the environment
  - The maritime Salvage Convention of 1989 introduced the concept of special compensation to encourage salvors to preserve and minimize damage to the environment from fuel and oil spills
- The Space Salvage Principle
  - **If it can be shown that an inactive space object represents a reservoir of potential future debris that could further pollute the space environment, then salvors should be rewarded for de-orbiting such objects**

Novel debris detection techniques

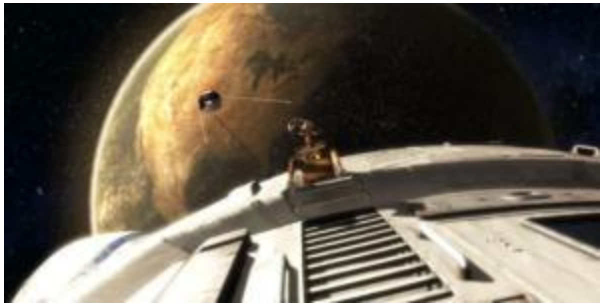
- The Murchison radio telescope array in Australia has been used to detect debris by picking up the “echoes” of terrestrial radio transmissions which have been reflected from objects in LEO



Practical Steps

- An international move to a more accurate element set format could be a start…..
  - E.g. This three-line element set format, (originally considered for adoption by the US in the 1990's), provides rates of change of the orbital elements, and hence improved tracking

- …and maybe it would be helpful to define formally where "space" actually begins?
  - Incredibly, the often cited 1967 "Outer Space Treaty" doesn't define where "outer space" actually starts
  - The "Karman line" concept is an obvious place to start



Conclusions

- An international approach to Space Traffic Control is a long-term necessity
- We must maintain the confidence of both investors in satellites and the space insurance industry
- With Space Traffic Control, the space industry stays in business!

The scene from the movie Wall-E that we need to avoid!


Space Traffic
Control Now!