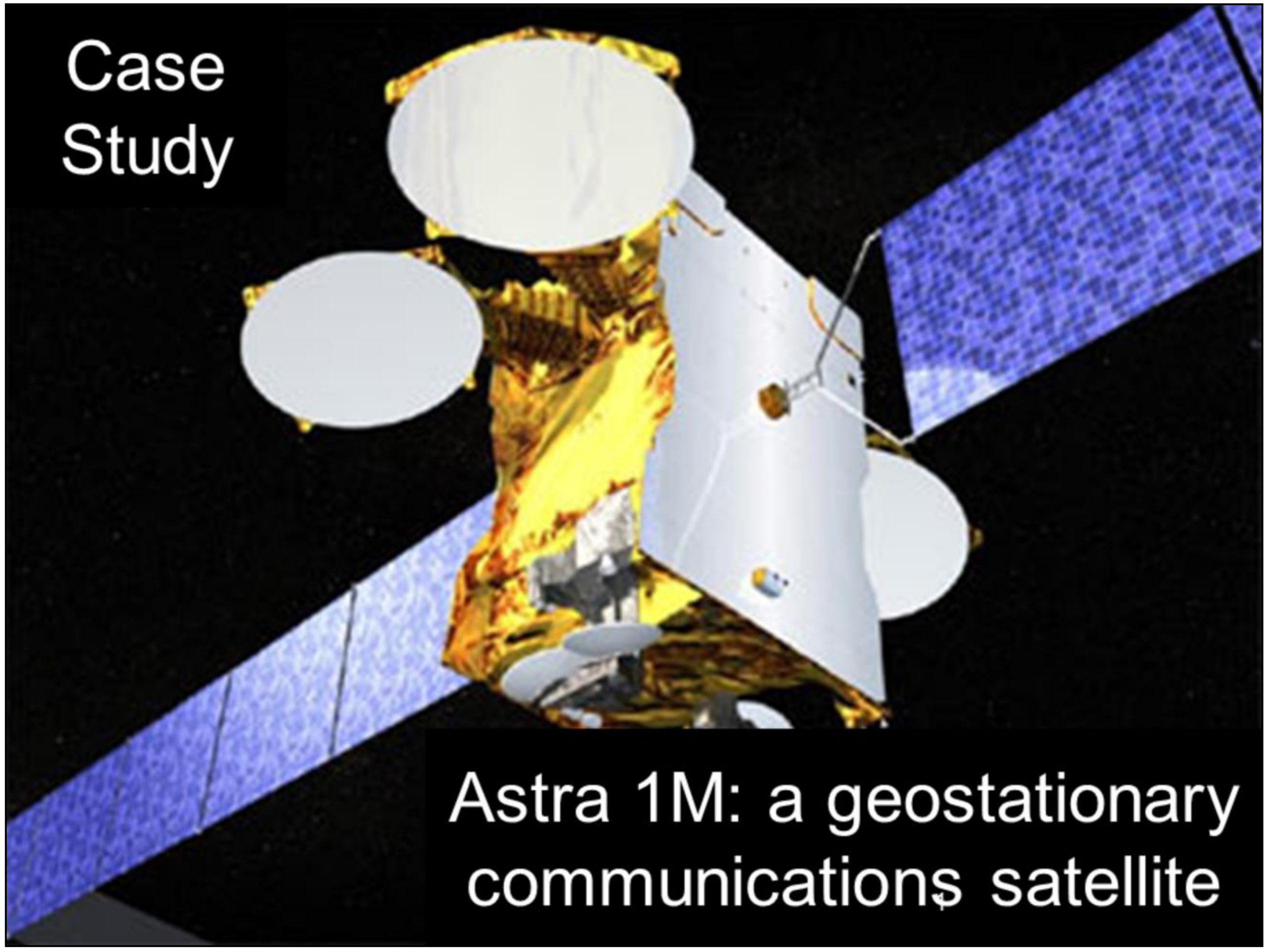


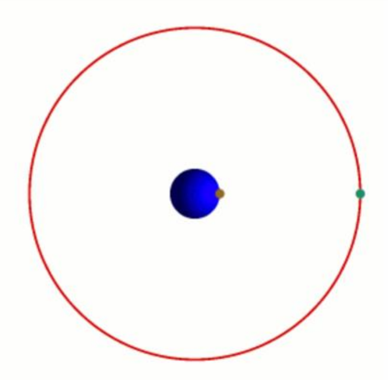
This is a case study to show you a real life example of a satellite design which will introduce you to geostationary satellites and see how the different subsystems come together.

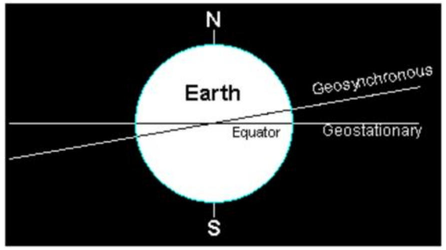
Learning outcomes

- Difference between geosynchronous and geostationary
- List advantages/disadvantages of GEO v LEO
- Describe eclipses for GEO
- Describe how to get to GEO (sequence)
- List perturbations on geostationary satellite
- Explain basics of geosat ground track
- Describe how to mitigate launch/satellite failure

What is Geostationary orbit?

- Geosynchronous is any orbit which has a period which the same as a sidereal day (23h 56min 4s).
- Geostationary lies in plane of equator with i and e=0. Altitude 35786km.

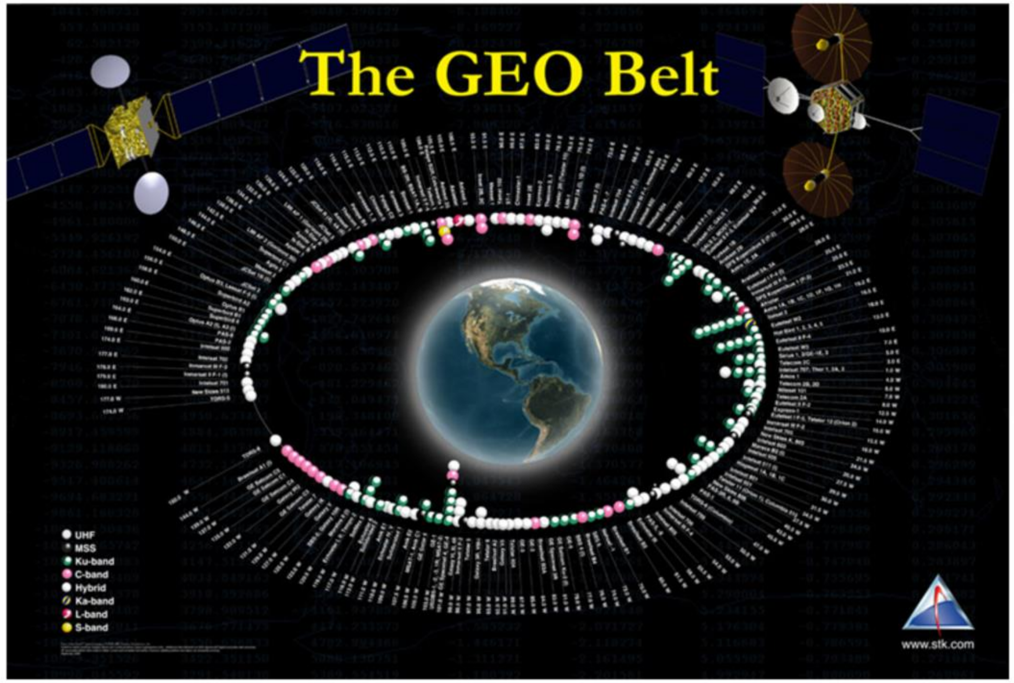




Geostationary is a special case of the geosynchronous class of orbits. It has I and e=0 whereas the geosynchronous may have an inclination or eccentricity. In reality all real orbits are geosynchronous as the ideal geostationary orbit is perturbed by the gravitation of Sun and Moon, non-sphericity of Earth and solar pressure.

Why is the period 23h 56min 4s and not 24h? We need to use sidereal (star) not (solar) day length.

What is geostationary orbit?



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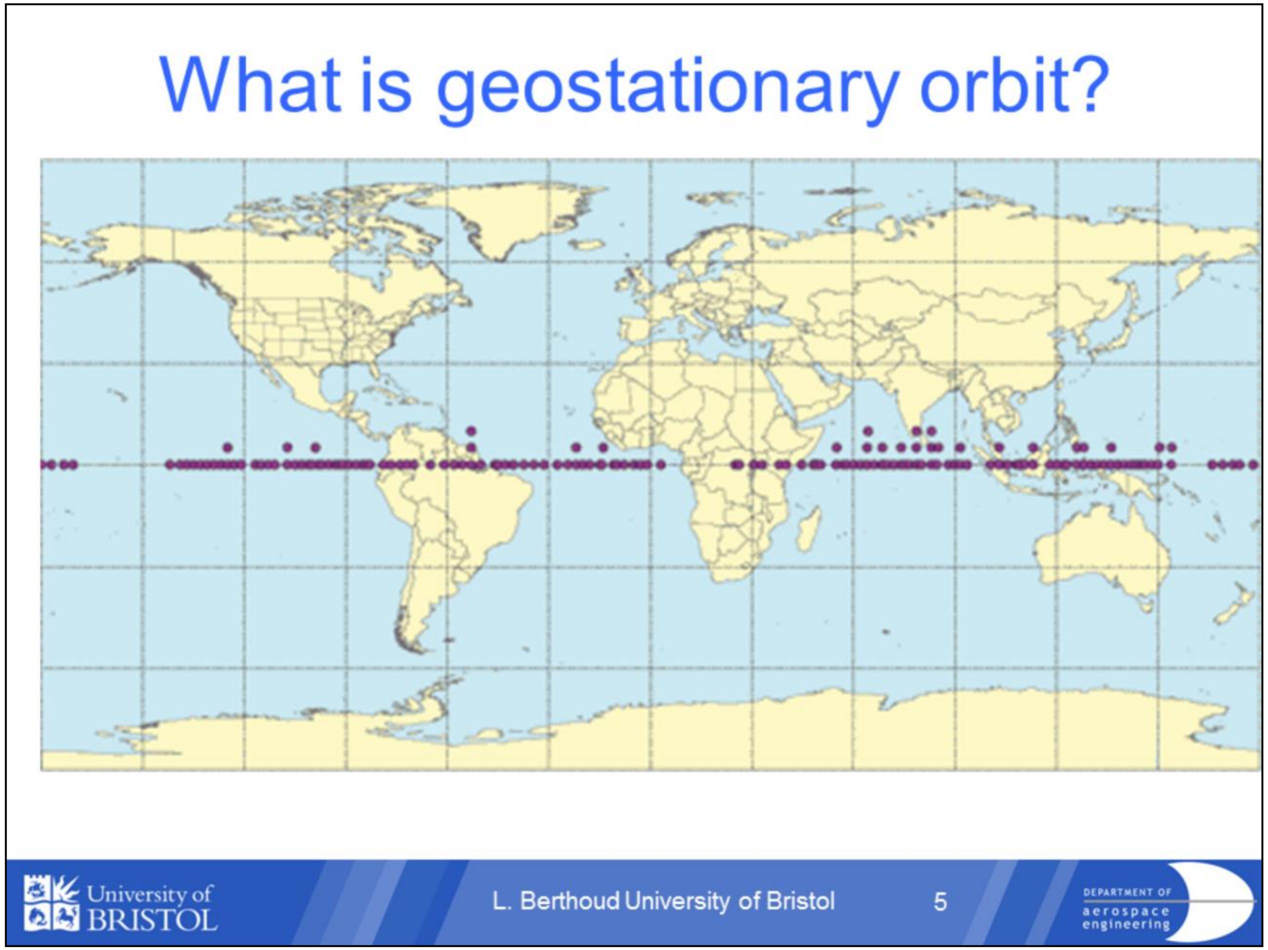
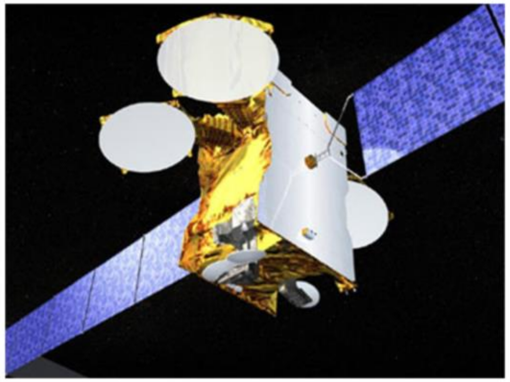
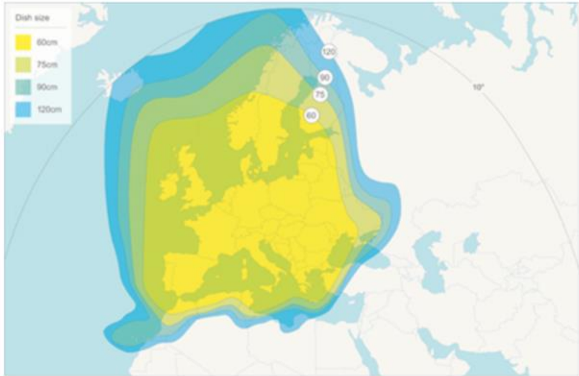
The geostationary belt is very busy! You can see here in some slots over highly populated areas there are 5-7 satellites. The slots are highly regulated, as are the frequencies. It is the International Telecommunications Union which regulates the frequencies. Some countries lease out their slots to other countries.



You can see how the inclination of geostationary orbits is zero. Those above the main line are just additional satellites, they are not actually in inclined orbits.

Case study – Astra 1M
a geostationary comsat





Footprint of Astra 1M

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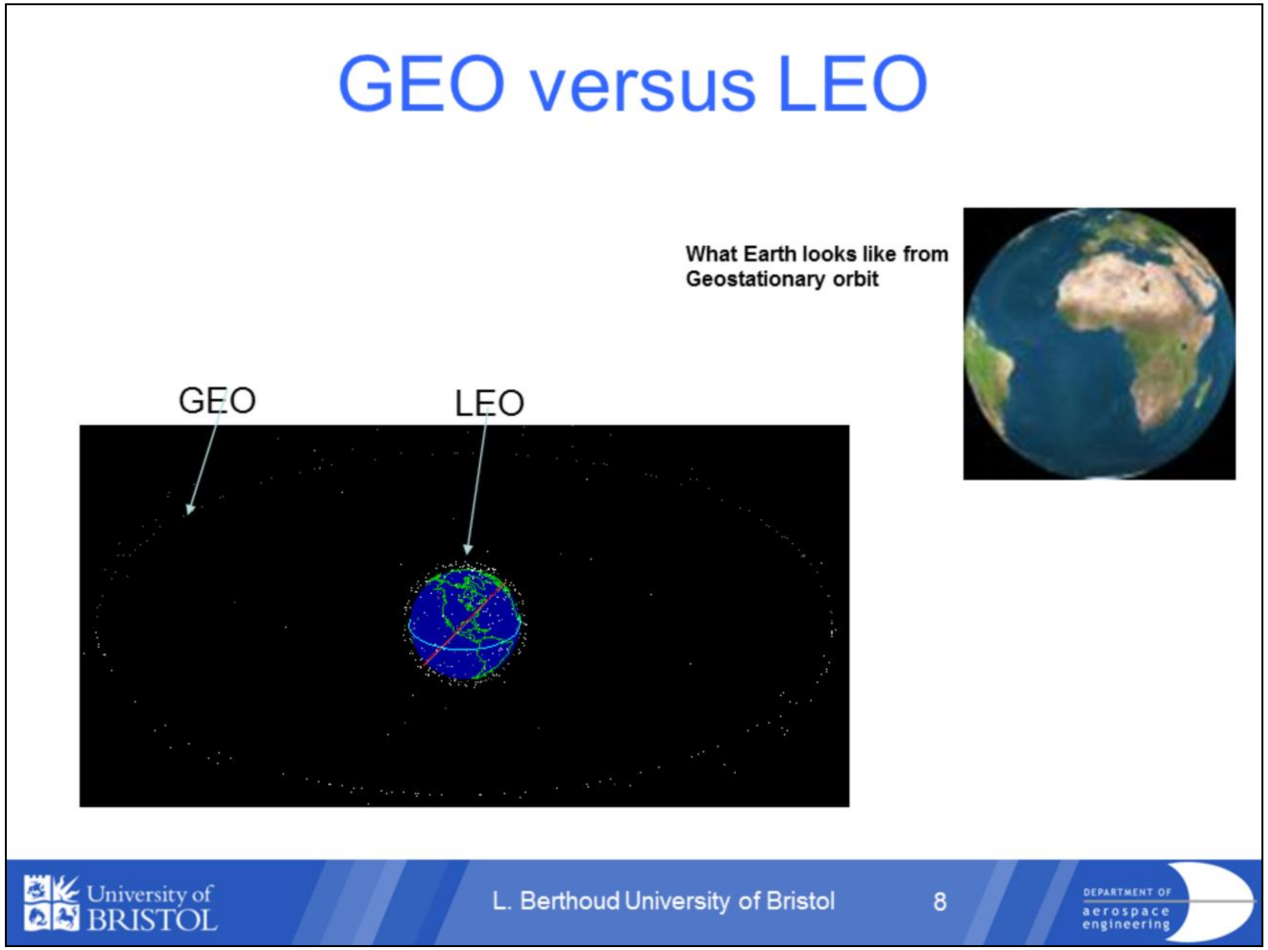
This is a specific example of a spacecraft which also allows us to think a little about geostationary orbit. Astra 1M is the name of the satellite we will look at. Astra 1M is a telecommunications satellite ie: it bounces down BSkyB TV from the Earth ground station to those locations on Earth within its footprint. The diagram on the right shows you the size of dish you need to capture a signal from Astra 1M. Ie: if you were in N. Norway you would need a 120cm dish to capture the signal.

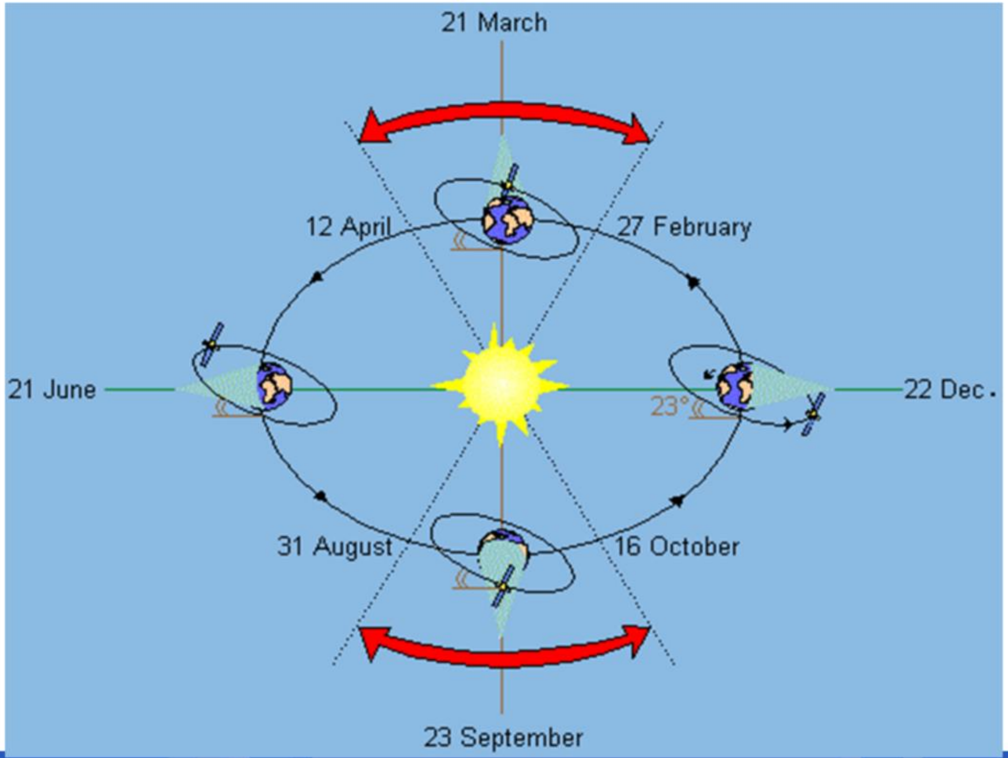
Astra 1M is located at 19.2E longitude on the equator. Which way do the dishes point in Bristol (and most UK cities)? Well, Bristol is at 2’35”W and the dishes need to look at the equator and to 19.2E or 28.2E, which means they will be looking SE.



A selection of advantages and disadvantages (not all are included):

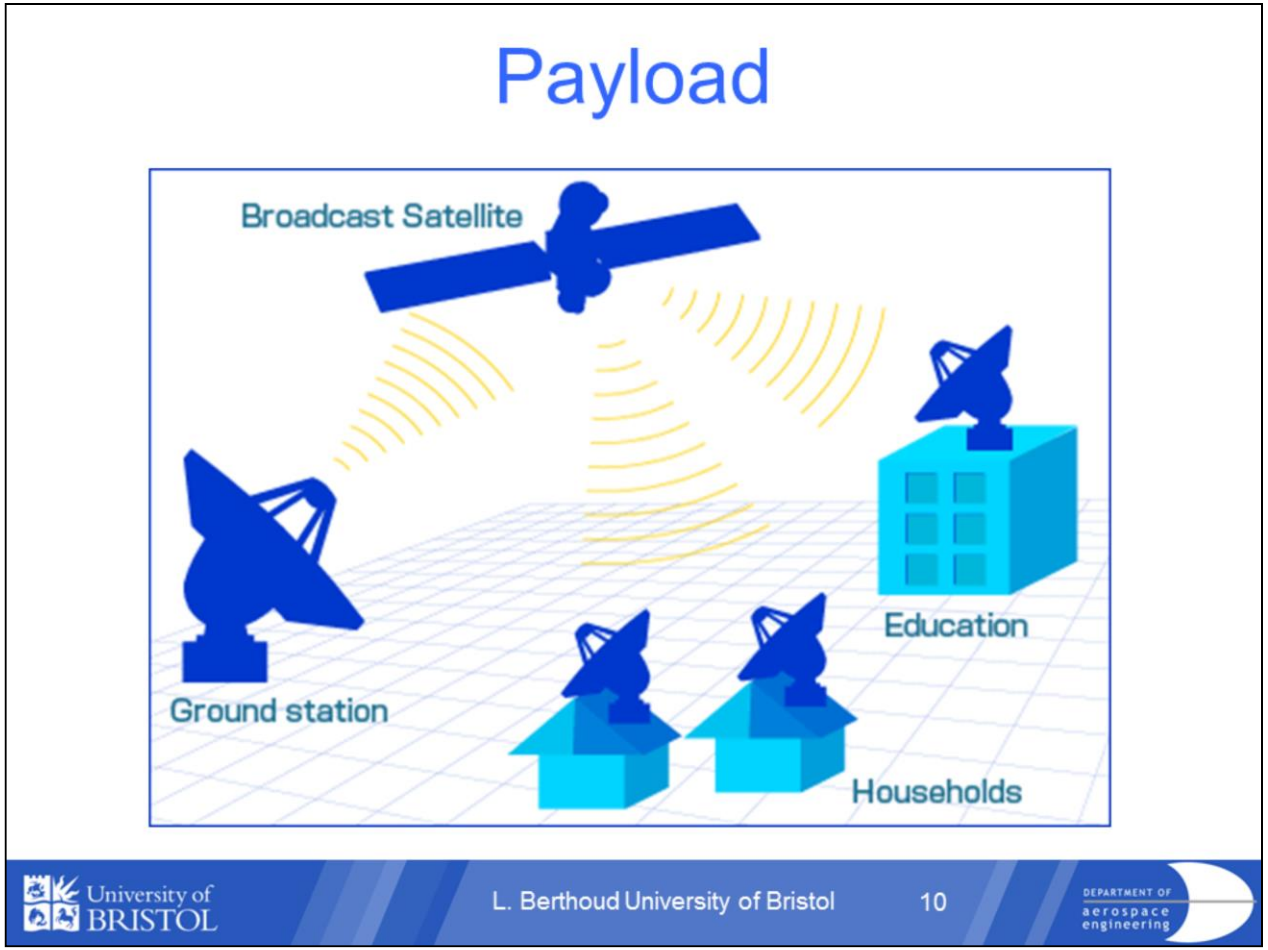
- Poor cover at the poles for GEO due to curvature of the Earth, so Russians and other countries at poles have never been that interested in Geo satellites.
- Temporal and spatial imaging continuity for GEO: if watching evolution of a weather pattern useful to have continuity
- Latency (delay time it takes for signal to go to satellite and back) is more of a problem for GEO.

Eclipses

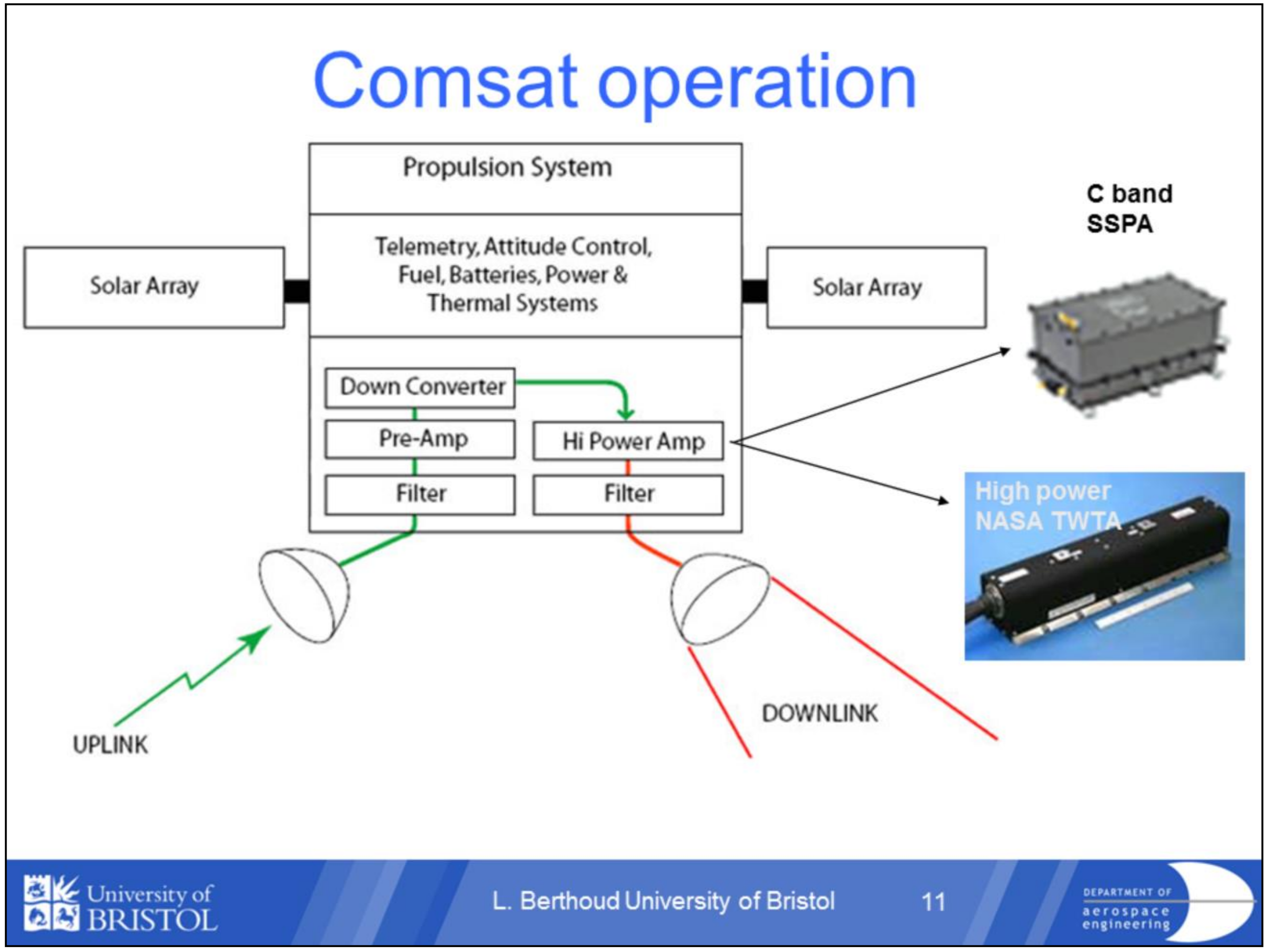


Eclipses drive the design of geostationary satellites. For geostationary orbit eclipses come in seasons: for approx. 40 days each in the spring and autumn, there are eclipses of 70mins each day.

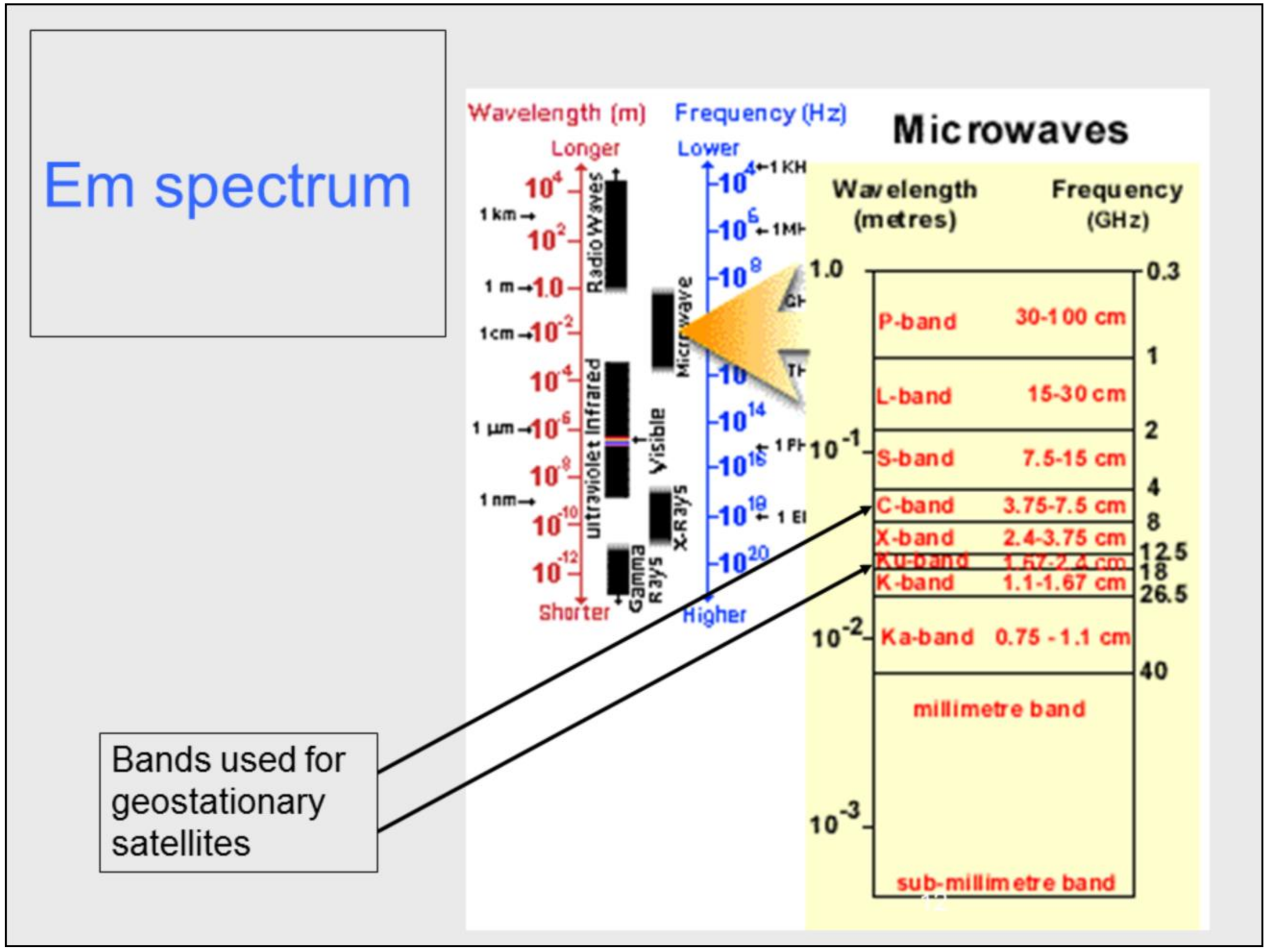
What will they affect? Payload/Equipt, thermal, Sun sensor and the power produced - so a battery is needed.



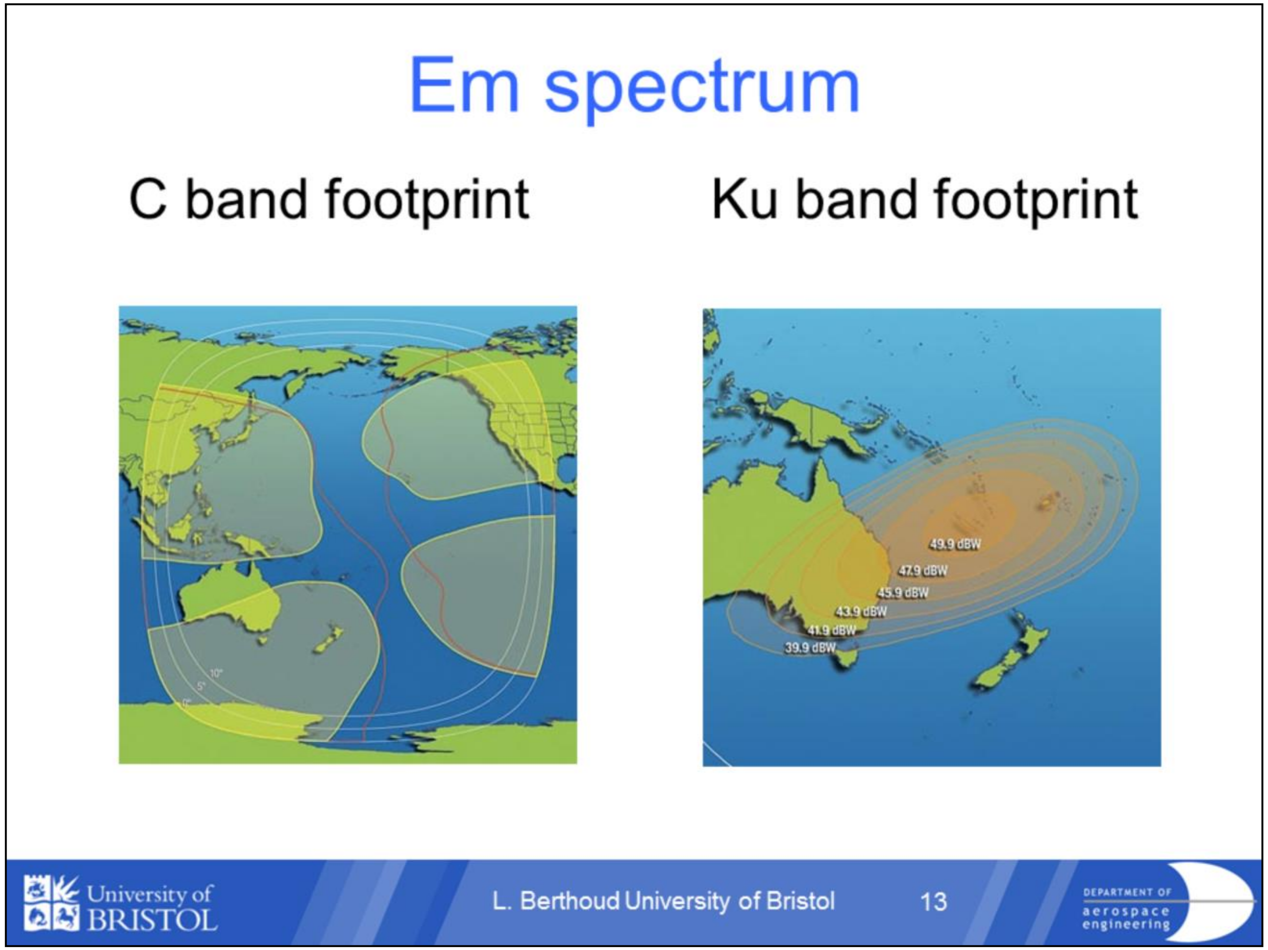
A communications satellite is effectively a relay station, it bounces the signal from a ground station on the Earth to those wishing to receive the communications ie: TV, internet, telephone etc.



The uplink is the signal from the ground station. As seen in the comms lecture, the signal is filtered, pre-amplified, downconverted (to a different frequency), amplified and then filtered again before being sent back to the receiving dish on the Earth. The high power amplifier could be a TWTA (travelling wave tube amplifier) or a SSPA (solid state power amplifier).



The sections of the EM spectrum which are used for the signals are generally C band and Ku-band. Ka band is also being explored. Power received is proportional to wavelength^2 (from comms lecture): $Pr=PtGtGr*(\lambda/4\pi R)^2$. Friis Transmission Equation says that the path loss is higher for higher frequencies.



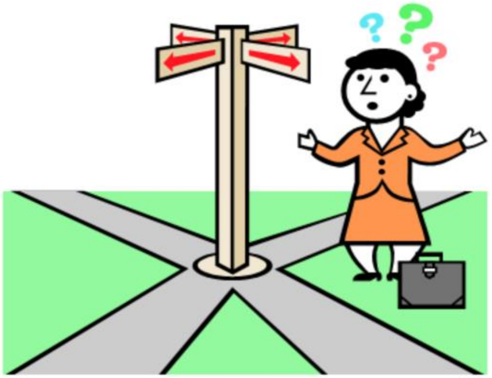
C-band was the first band to be used for satellite communication systems. However, when the band became overloaded (due to the same frequency being used by terrestrial microwave links) satellites were built for the next available frequency band, the Ku-band. Today C-Band also gets disturbed by wireless radio links and it requires larger antennas (due to larger wavelength).

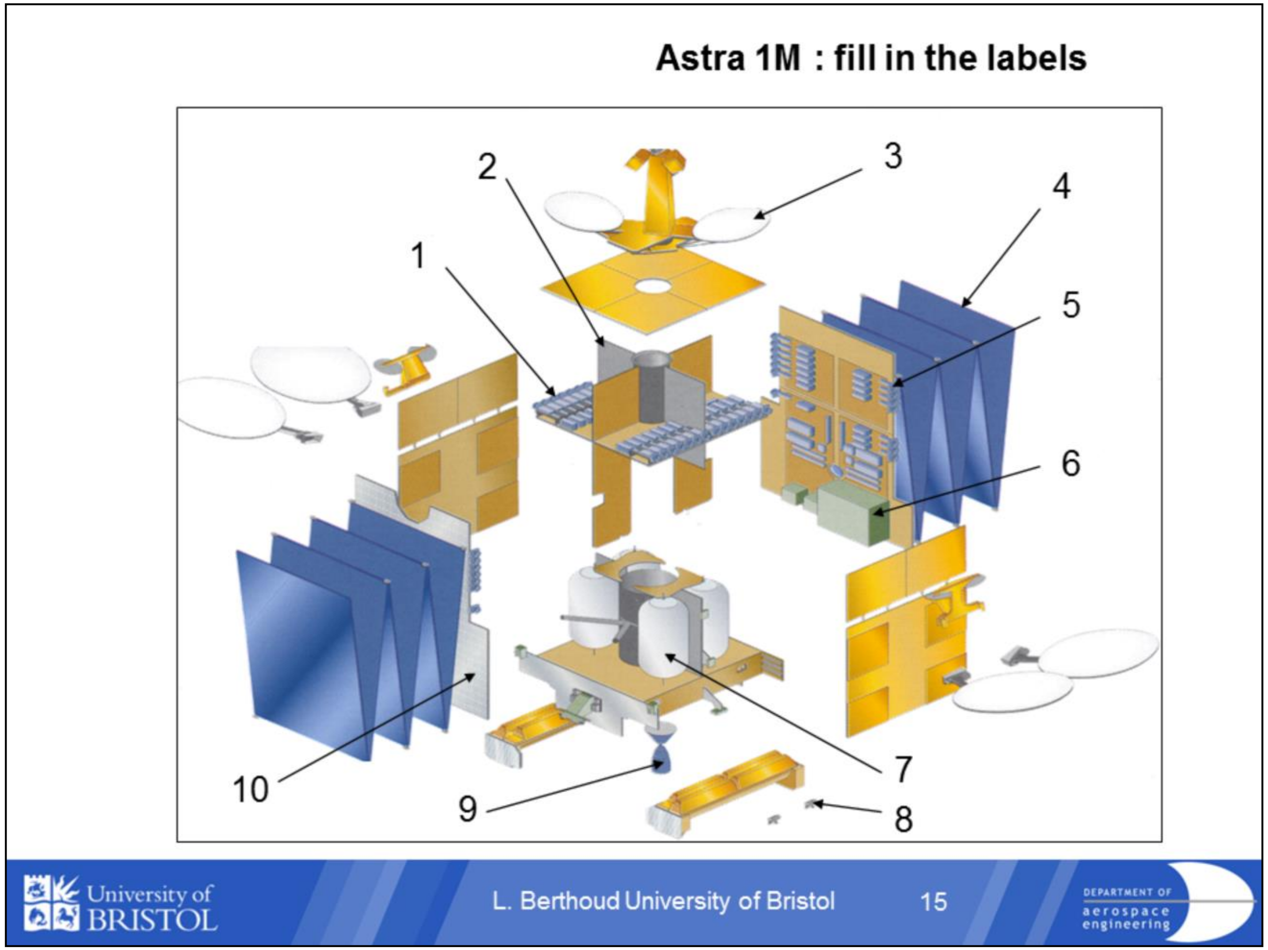
Main design trade-offs

- Power sources
- Propulsion
- Stabilisation concept
- Communications antennas
- Payload
- Autonomy

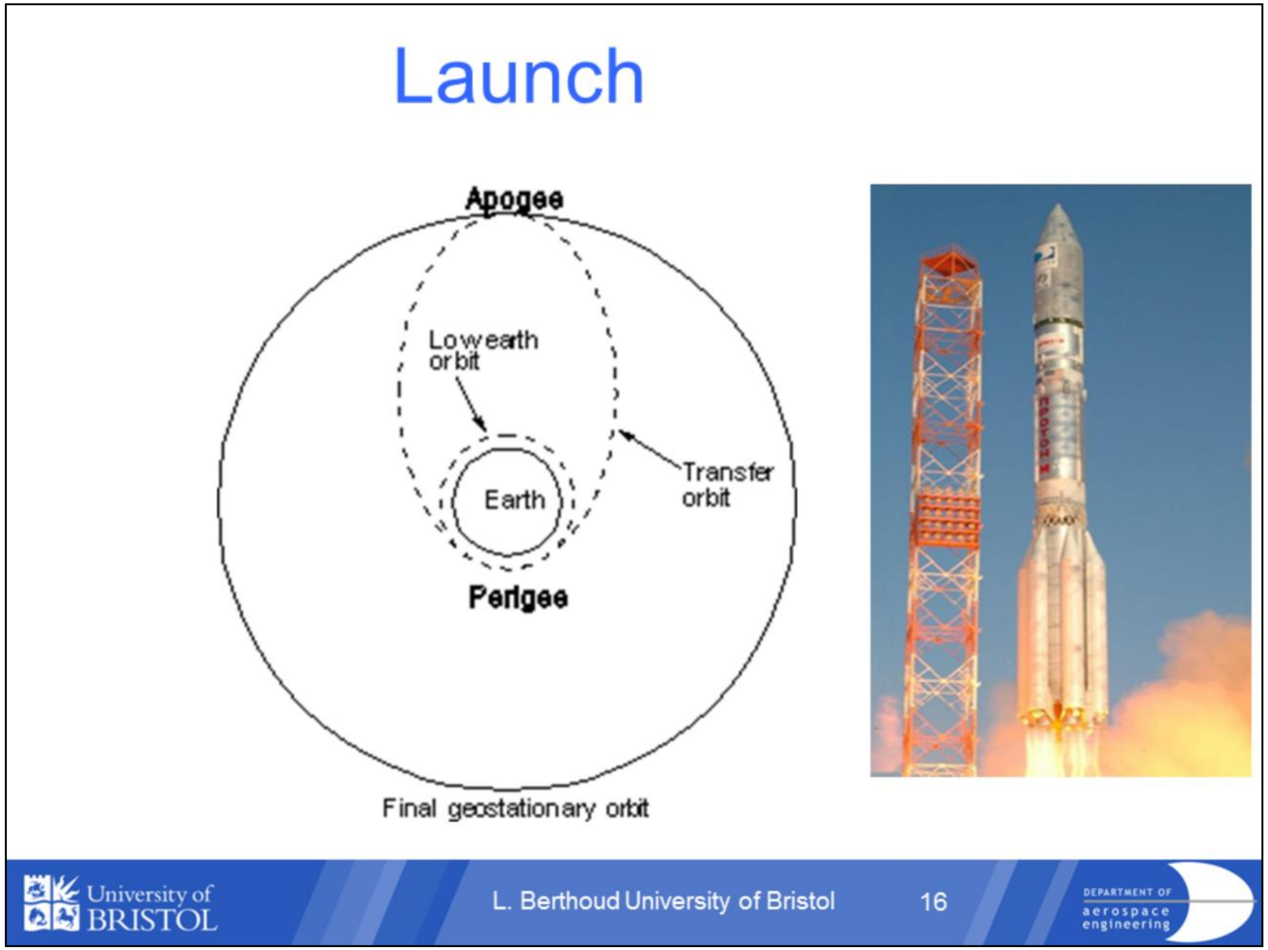
We will look at:

- Power
- Propulsion
- AOCS
- Mechanical design

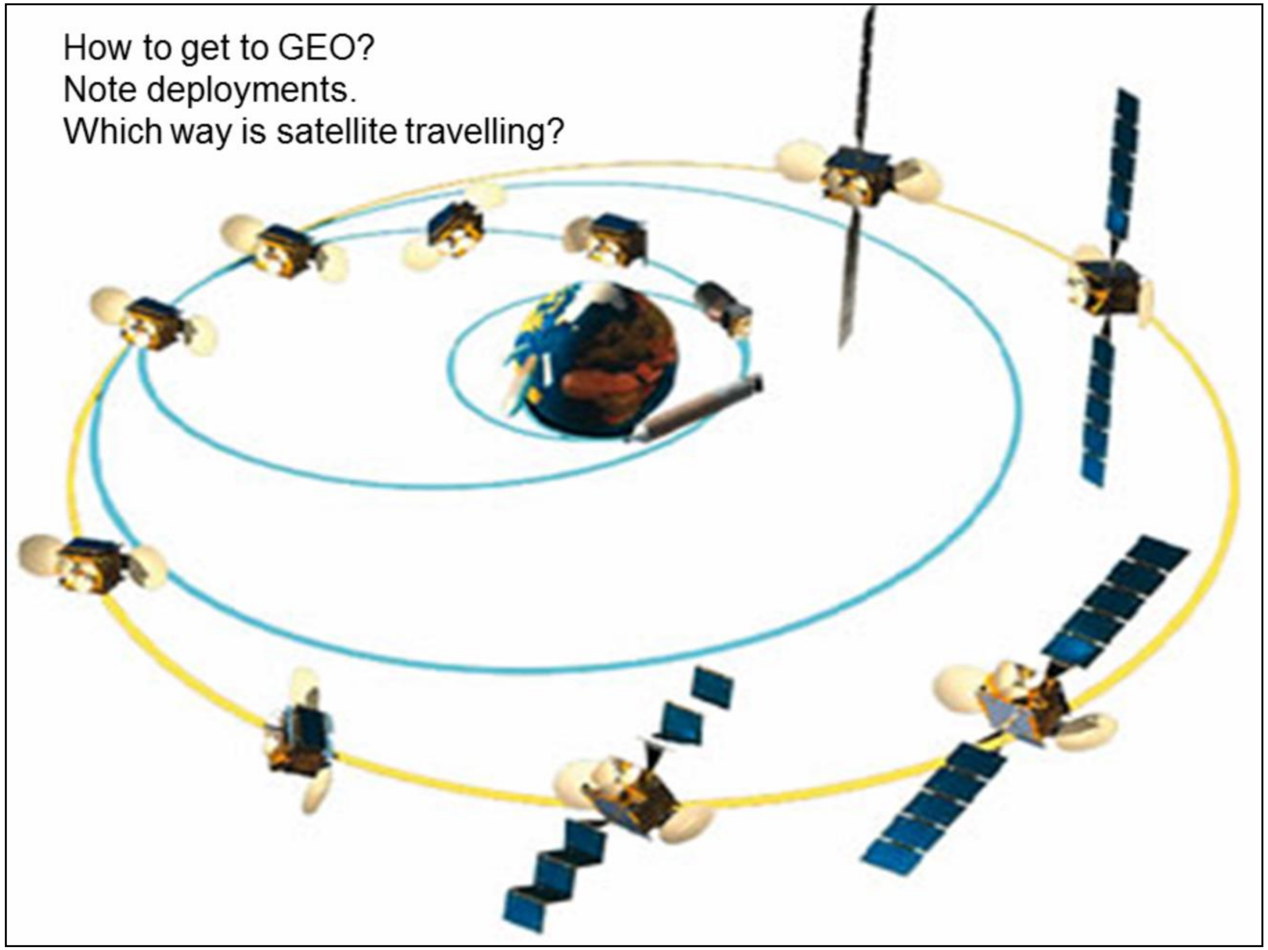




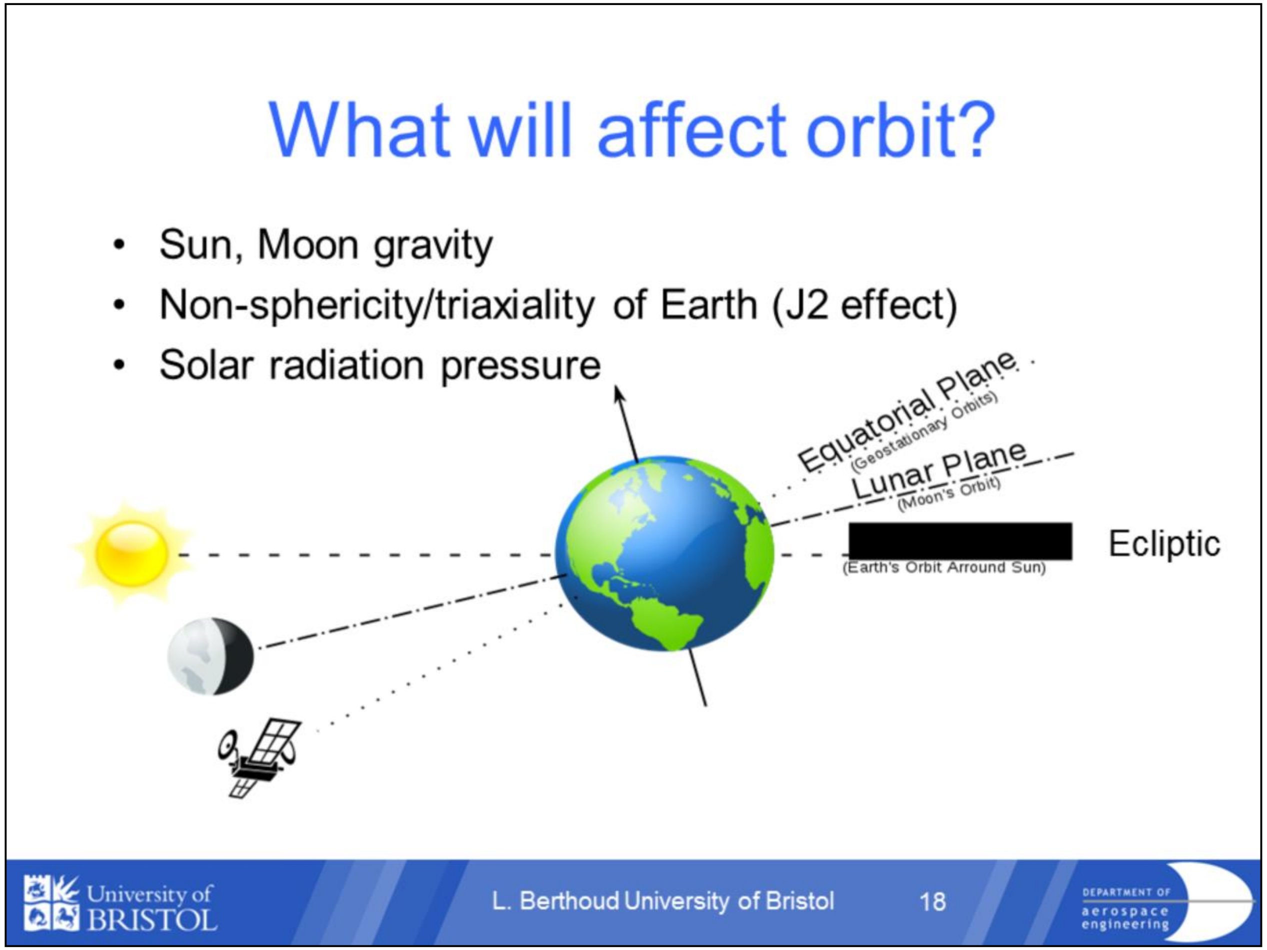
Can you fill in the labels? The difficult ones are:
1: Payload electronics 6: Battery 9: Apogee boost motor/engine
5: TWTAs 8: thrusters 10: Secondary surface mirrors
TWTA=Travelling Wave Tube Amplifier (a kind of amplifier).



As you know, getting in to GEO involves a Hohmann transfer. So first 3 stages take the spacecraft to Low Earth Orbit, then the 4th stage takes the spacecraft to GTO by raising the Perigee in several burns. Then the Apogee Boost Motor circularises the orbit and changes plane (inclination) to zero. Where do you need to launch from?

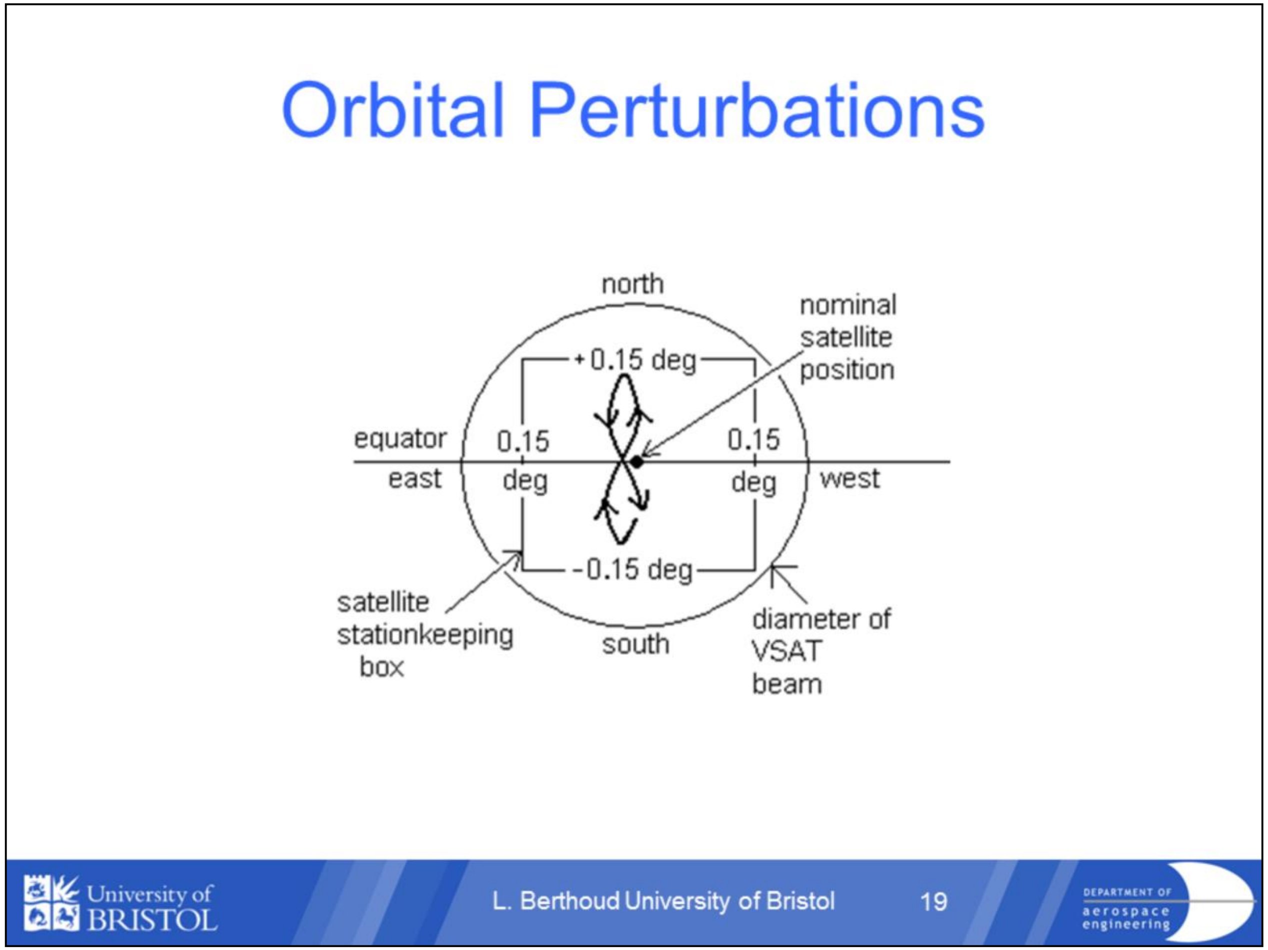


Why do we launch west to east? Extra delta V from rotation of Earth
Note the burns at perigee then deployment of antennas then burns at apogee. We only deploy solar arrays once in GEO, why?

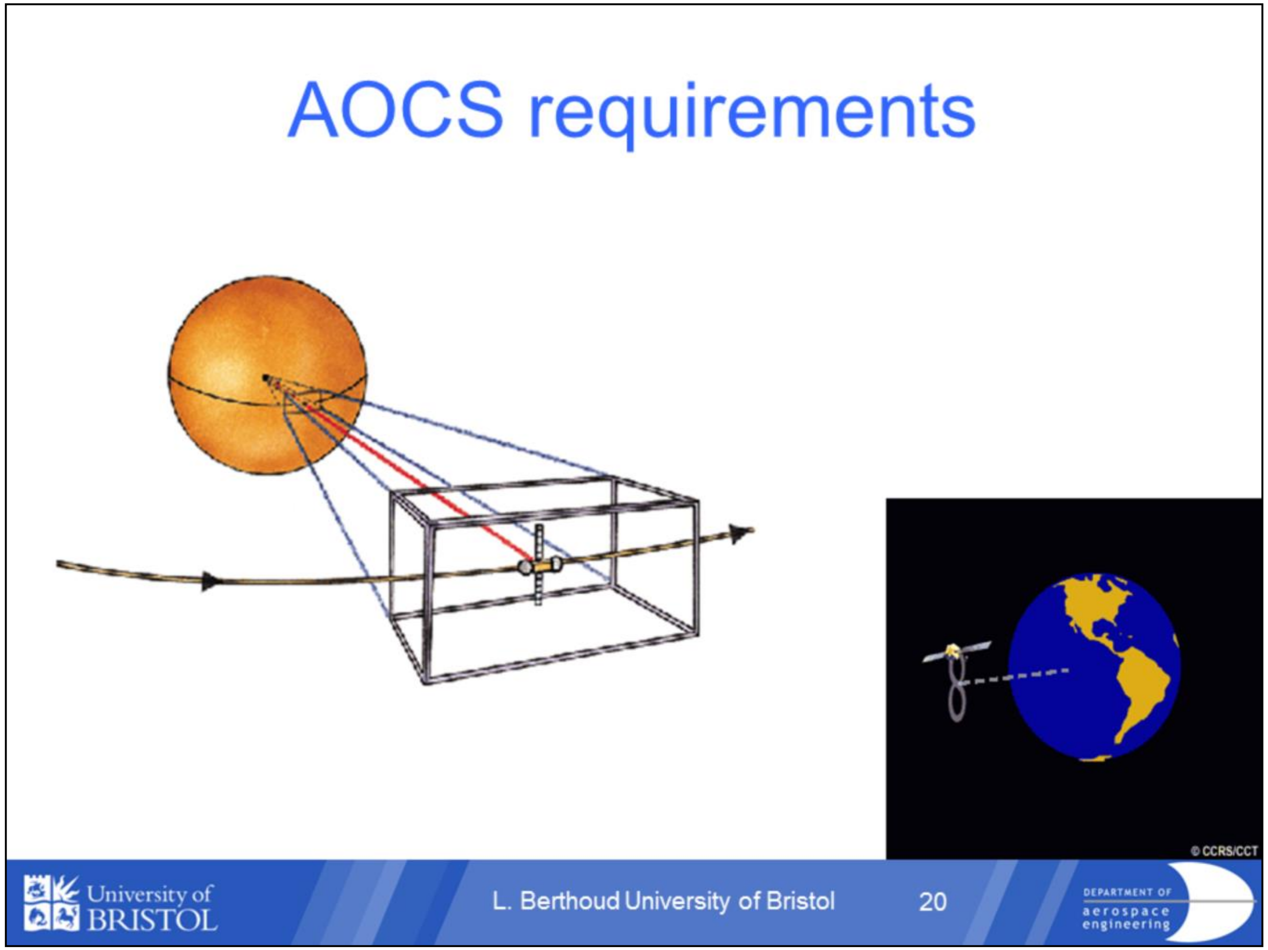


The Sun, Moon gravity will pull the spacecraft out of plane (north and south) and increases the satellite's inclination by approx 1°/yr. This is called North-South drift and accounts for up to 95% of station-keeping propellant budget (up to 50m/s per year).

East-West drift occurs due to noncircular shape of the earth's equator ('**triaxiality**'). The satellite tends to drift to one of 2 stable equilibrium points along the equator 75°E, 105°W, resulting in an east-west 'libration' (drifting back and forth) about these points. Accounts for up to 2m/s per year of propellant budget. **Radiation pressure** also affects east-west drift.

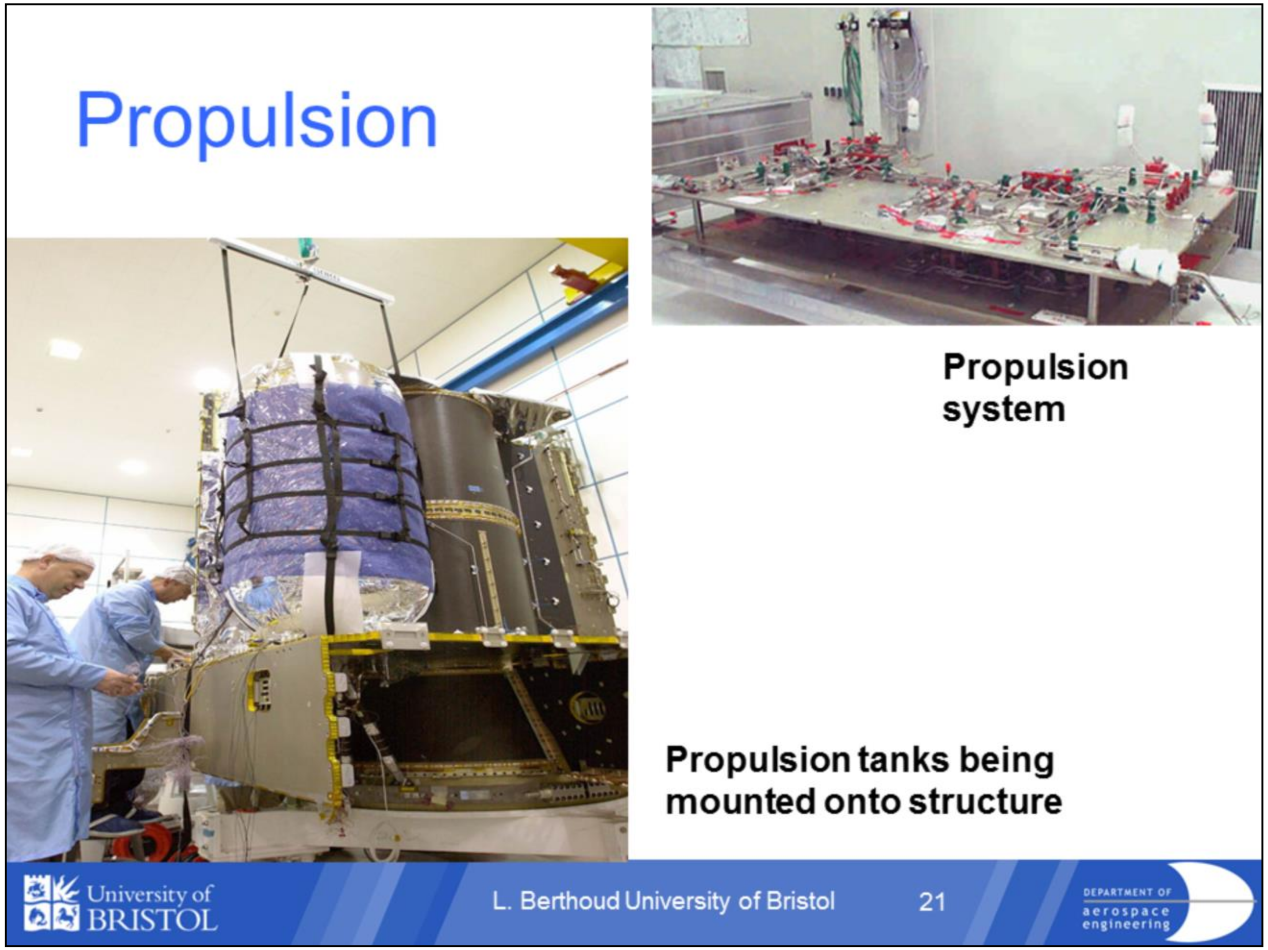


There is no such thing as a perfect geostationary orbit, due to perturbations there is always some inclination or eccentricity. The challenge for the AOCS engineers is to keep the satellite position within a defined box. For example the one above is defined as 0.15deg maximum in each direction. Plane change requires far more fuel which is why N-S drift accounts for more propellant.



Here is the stationkeeping box. AOCS design: 3 axis stabilisation and the body of the spacecraft rotates once per orbit (day) to keep the antennas pointed at the earth. The solar arrays are mounted on paddles which also rotate once per day to keep them pointed toward the sun.
4 momentum wheels, ion engine and control moment gyros
Accurate and stable pointing eg: Antenna pointing accuracy 0.15°
Earth sensor, sun sensor, RF sensor for beacon. Flap on solar panel gives twist for wheel

offloading

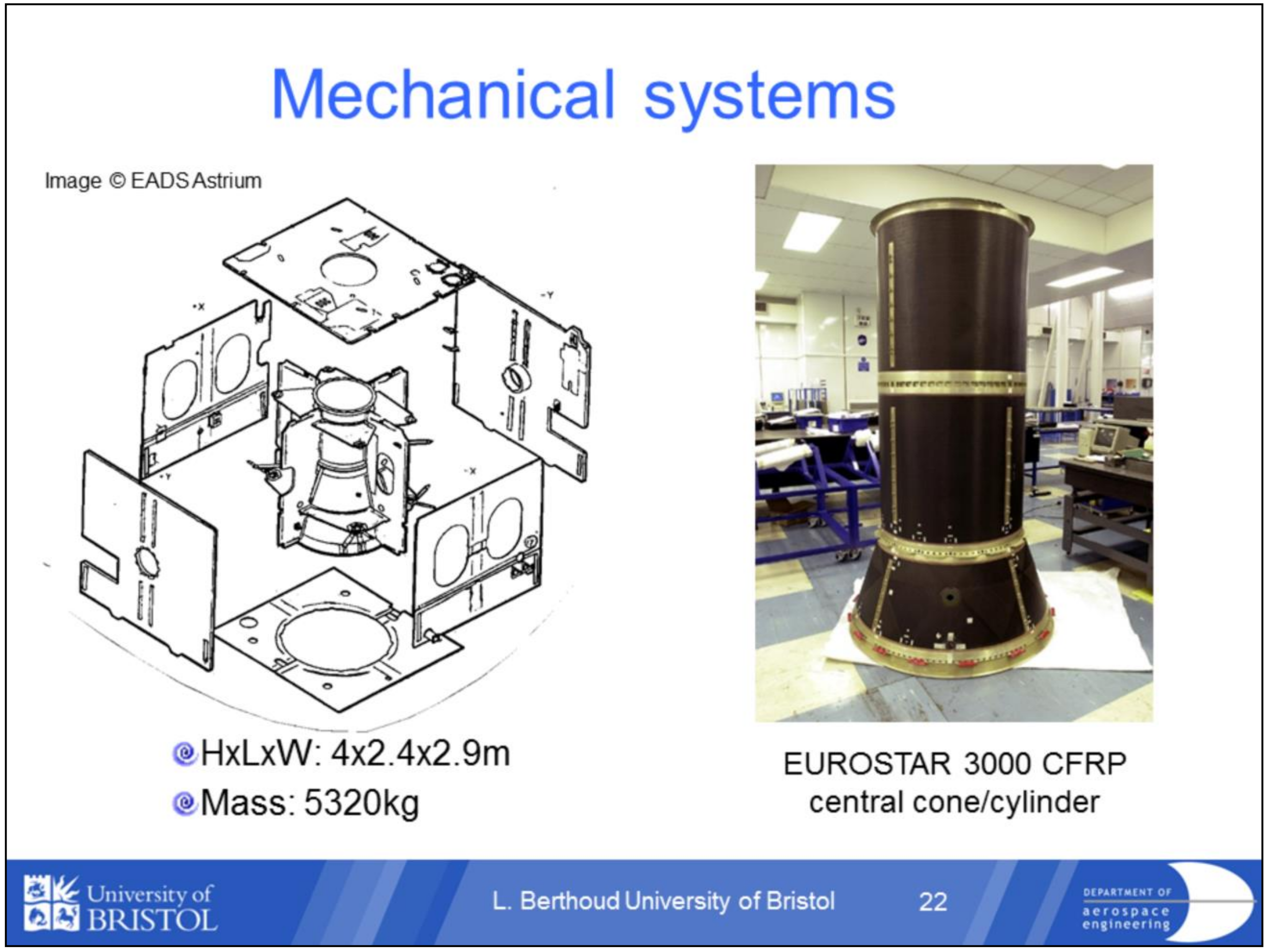


Requirements: apogee manoeuvres, orbital control and station-keeping
Design:

•1x 500N Apogee Boost Motor (ABM) used for apogee manoeuvres

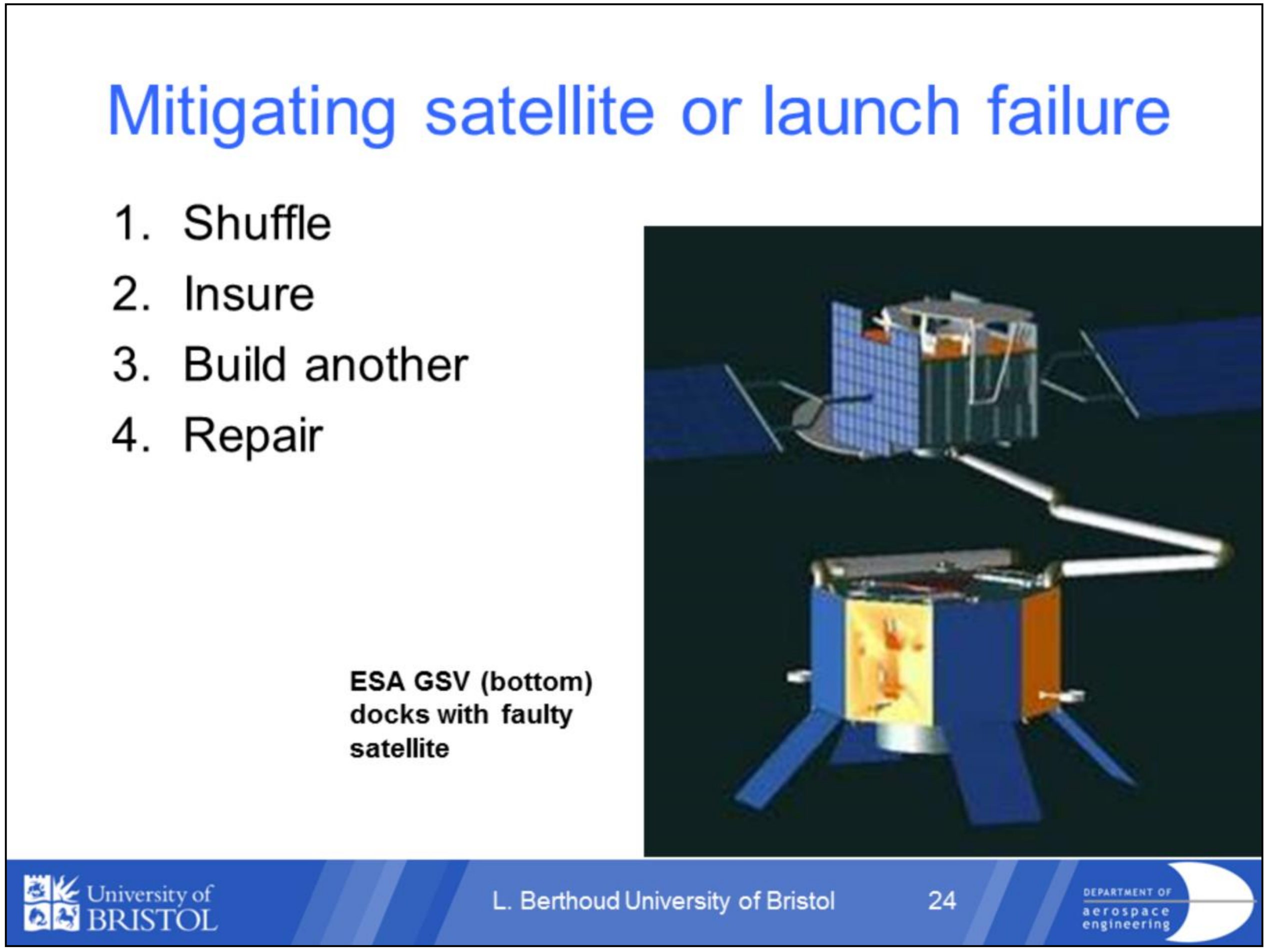
• Chemical bipropellant MMH and N_2O_4 used for ABM and thrusters

• Ion plasma engine for inclination and eccentricity control powered by batteries: 4 x SPT100 thrusters and 1x 300kg Xenon tank



The mechanical design is based around a CFRP central cone/cylinder with a box surrounding it and some shear panels for equipment. The interface to the LVA is on the bottom panel.

NiH_2 and Li Ion batteries for eclipse seasons and augmenting ion motor
2 wing x 5 panel 35m long Silicon and GaAs solar arrays producing 10kW power at end of life
Single redundant computer handles all spacecraft functions
50V bus bar electrical system



What do we do if there is a launch failure? Usually a large loan has been taken out to finance the TV operation.

You can either shuffle the existing satellites around if you have several in the same slot. Or you can build another spare one. Or you can insure which costs approx. 1/3 of the cost, or you can attempt to repair. Both ESA and NASA have worked on possibilities for repairing ie: providing fuel and battery power.

Summary

- Geostationary orbit has a period of 23hrs 56mins 4s, h=35786km, e=0 and i=0.
- A geosat stays over one point on Earth's equator for its whole orbit and are good for weather, comms and data.
- They have seasons of eclipses in Spring and Autumn for 70mins a day
- GEO is attained by doing a Hohmann transfer from LEO to GEO (the elliptical part is called Geo Transfer Orbit)
- The orbit is perturbed by Sun and Moon's gravity (causing N-S drift) and the J2 effect and solar radiation pressure (causing E-W drift).
- Commercial geosat failure is mitigated by shuffling, insuring, building spares and, in the future, repairing them.

Test Yourself! (Feedback)

1. Could you have a geostationary satellite in a polar orbit for worldwide weather monitoring?
2. Why is geostationary orbit so popular and who regulates the slots?
3. How do perturbations affect the ground track of a geostationary satellite?
4. What kind of propulsion would you use for stationkeeping of a geosat and why?
5. Why is an apogee boost motor (slide 15) needed on a geostationary satellite?
6. Why do you think that geosats have been getting larger and with longer lifetimes recently?