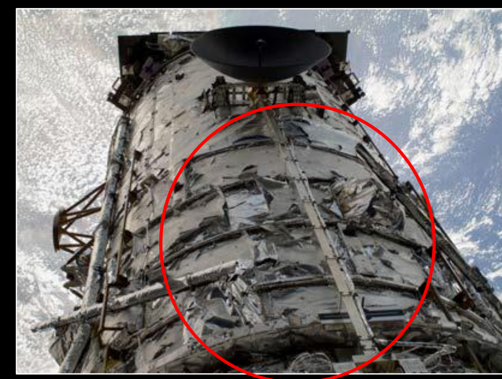
Space Environment



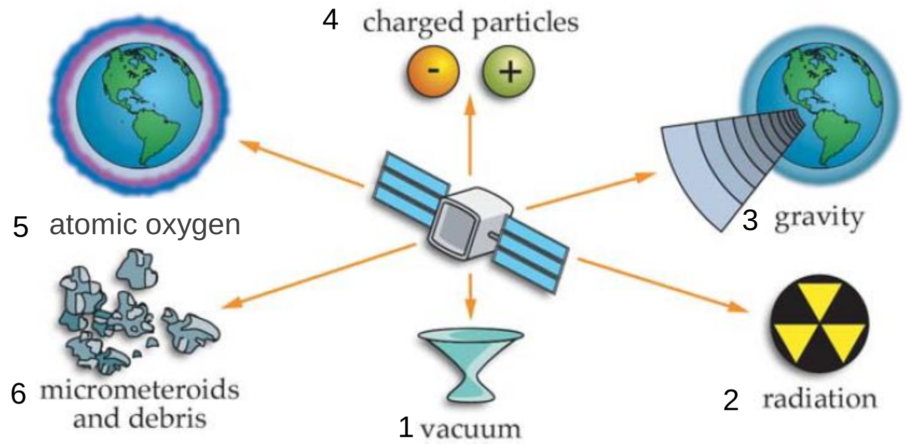
Space-exposure damage to Hubble Space Telescope multilayer insulation after 6.8 and 19yrs

5 missions serviced/repaired the Hubble Space Telescope, which is the only spacecraft designed to be serviced by astronauts. The damage to the outside of the telescope shows some of the effects of the space environment.

Learning Objectives

1. Describe 6 characteristics of the space environment
2. Describe the testing which can be done to investigate our designs for the space environment
3. Describe and evaluate the mitigation measures taken for each characteristic of the space environment

Space Envt Effects



There are six space environment effects that you should know about. Please note that we are not including thermal cycling in this as it is considered in the thermal lecture. Thermal cycling is the variation in temperature of a spacecraft which can be up to +100degC to -100degC.

1. Vacuum

Problems:

- Outgassing
- Cold welding
- No convection

Galileo spacecraft – Antenna cold welded in space

Some materials, especially composites, can trap tiny bubbles of gas while under atmospheric pressure. When this pressure is released in the vacuum of space (10^{-6} to 10^{-9} torr) , the gases begin to escape. This release is called ‘out-gassing’. These gas molecules can then deposit on other surfaces - this is not desirable esp. for optical surfaces. After launch, the vacuum in space eliminates the tiny air space between 2 metal surfaces, causing the two parts to effectively “weld” together. This is called ‘cold welding’. The lack of convection means that heat can only be transmitted via radiation and conduction.

2. Radiation (photons)

Photons – massless bundles of energy moving at light speed.

Problems:

- Surface effects (darkening)
- Solar Pressure (attitude)

Preflight Mir expt

Postflight Mir expt

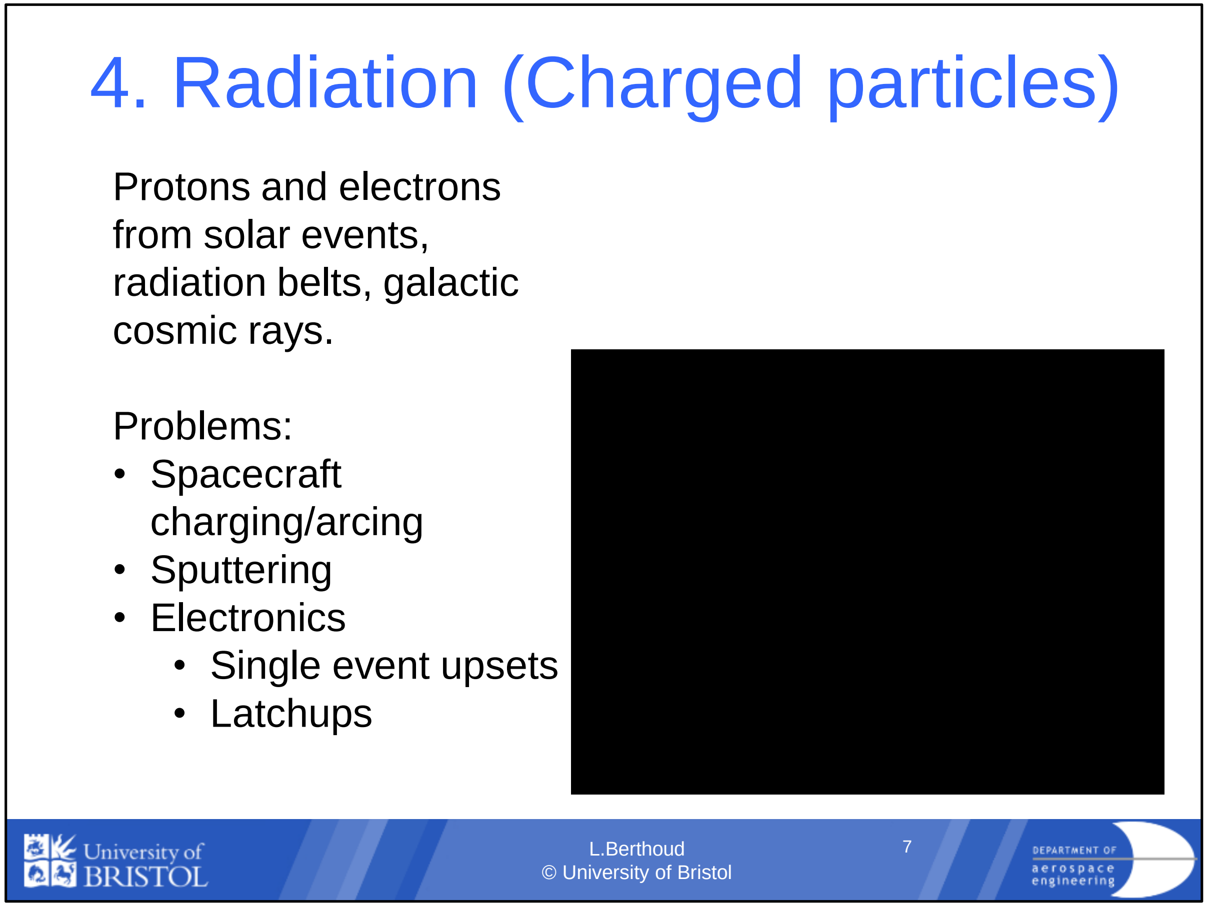
Photons are massless bundles of energy that move at the speed of light. However, prolonged exposure to ultraviolet radiation can begin to degrade spacecraft coatings. UV radiation also damages polymers by either cross-linking (hardening) or chain scission (weakening). UV under high vacuum can also create oxygen vacancies in oxides, leading to significant color changes. Over time this solar pressure can disturb the orientation of spacecraft, causing them to point in the wrong direction.

3. Microgravity

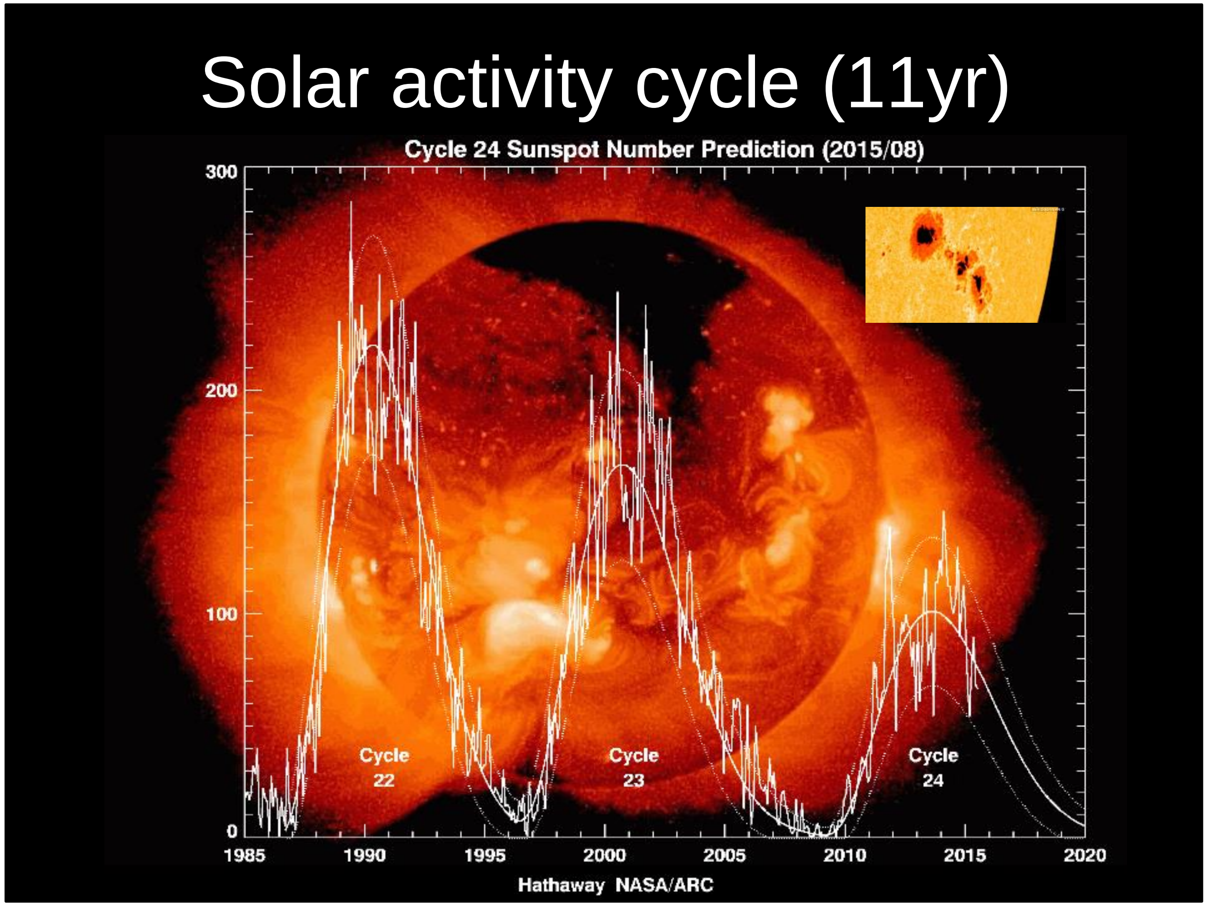
Problems:

- Deployment
- Fluid handling
- Human effects

The state of 'microgravity' comes about whenever an object is in free fall around the Earth. Video: 1:30-2:00. Astronaut Chris Hadfield shows that when wringing a wet cloth out, the fluid just flows over his hands due to surface tension. It is very hard to handle fluids in space and, for instance, propellants in tanks need special handling.



The three main sources of charged particle radiation naturally occurring in space are galactic cosmic rays, solar proton events, and the trapped radiation belts. Particulate radiation can result in cross-linking or chain scission, similar to damage by UV, resulting in polymer embrittlement. A single charged particle can penetrate a spacecraft to disrupt electronics. Each disruption is known as a single event phenomenon (SEP). It can cause single-event upsets/bit errors when a ‘1’ flips to a ‘0’ (non-permanent) and ‘latchups’ (permanent).



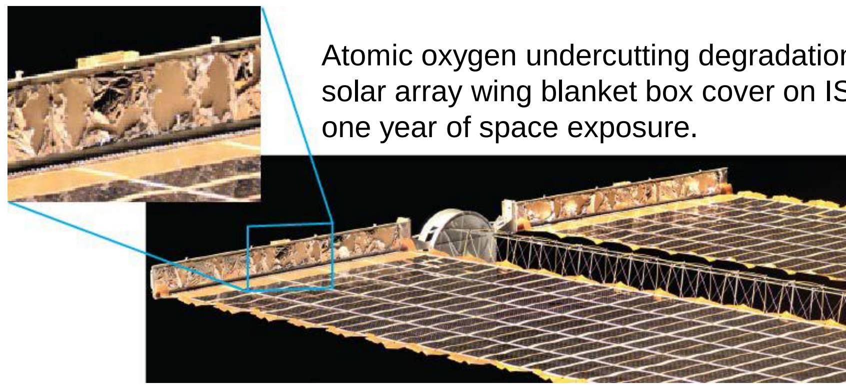
The sun goes through a natural solar cycle approximately every 11 years. The cycle is marked by the increase and decrease of sunspots which are dark regions on the sun's surface cooler than surroundings. The greatest number of sunspots in any given solar cycle is designated as the "solar maximum" and the lowest number is referred to as the "solar minimum" phase. There are more solar flares and the Earth magnetosphere is more distorted during solar maximum.

5. Atmosphere/atomic oxygen

Oxygen molecules that have been split apart by charged particles.

Problems:

- Drag – shortens orbital lifetime
- Atomic oxygen – degrades surfaces



Atomic oxygen undercutting degradation of the solar array wing blanket box cover on ISS after one year of space exposure.

In the upper parts of the atmosphere, oxygen molecules are few and far between. When radiation and charged particles cause them to split apart, they're sometimes left by themselves as atomic oxygen. Spacecraft materials exposed to atomic oxygen (atox) experience oxidation breakdown or "rusting" of their surfaces. Atox oxidizes many metals, especially silver, copper, and osmium. It reacts strongly with any material containing carbon, nitrogen, sulfur and hydrogen bonds, meaning that many polymers react and erode.

6. Micrometeoroids…

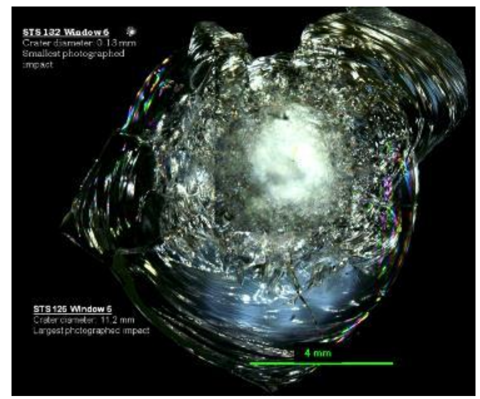
Remnants of cosmic dust, asteroids and comets.

Problems:

Hypervelocity impact damage/depressurisation

Metal

Shuttle Windows



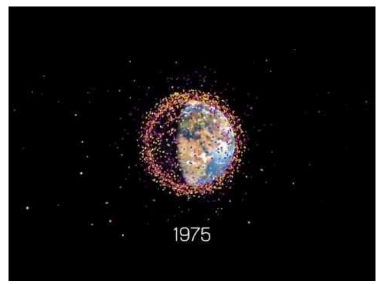
Micrometeoroids are remnants of cosmic dust, asteroids and comets. All areas of a spacecraft may be impacted by micrometeoroids traveling as fast as 60 km/s. Space debris is man-made and composed of everything from paint flakes to spent upper stages to spacecraft parts. Surfaces facing the ram direction are more likely to be hit with space debris.

6. ..and Space debris

Any man-made object in orbit which no longer serves a useful function

Problems:

- Hypervelocity impact damage
- Kessler syndrome (cascade of debris collisions)



Debris includes nonfunctional spacecraft, abandoned launch vehicle stages, mission-related debris and fragmentation debris. There are more than 20,000 pieces of debris larger than 10cm orbiting the Earth, they travel at speeds up to 8km/s. There are many smaller pieces of debris which are too small to be tracked.

Scenarios – how can we…?

1. Vacuum –deal with outgassing?
2. Radiation (photons) – use photon pressure?
3. Microgravity –handle deployment/fluids/human effects?
4. Charged particles – avoid charging, single event upsets?
5. Atomic oxygen – avoid surface erosion?
6. Meteoroids and debris – prevent, avoid and protect against debris?
7. Model the environment?
8. Measure the environment?

1. Vacuum

Solutions:

- Thermal vacuum testing
- Only low outgassing materials
- Thermal bakeout

Spacecraft in a Vacuum Chamber

Prior to flight, spacecraft undergo rigorous tests, including exposure to a hard vacuum in vacuum chambers. In this way we can test for problems with out-gassing, cold welding, or heat transfer. Thermal bakeout means that we bake the materials in an oven at high temps to remove some of the volatile compounds.

2. Radiation (photons)

Solutions:

- Modelling and testing under UV lamp + vacuum
- What is this? How does it work in space?

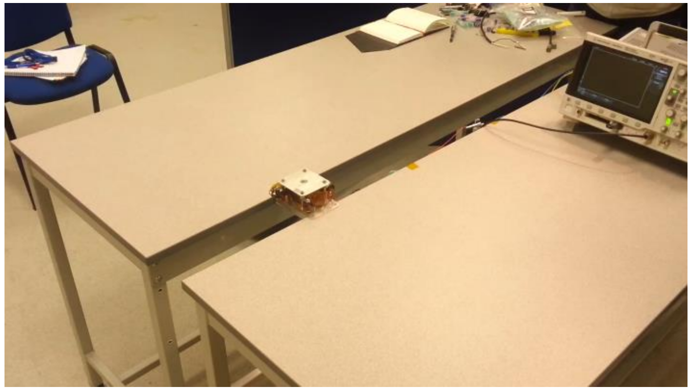
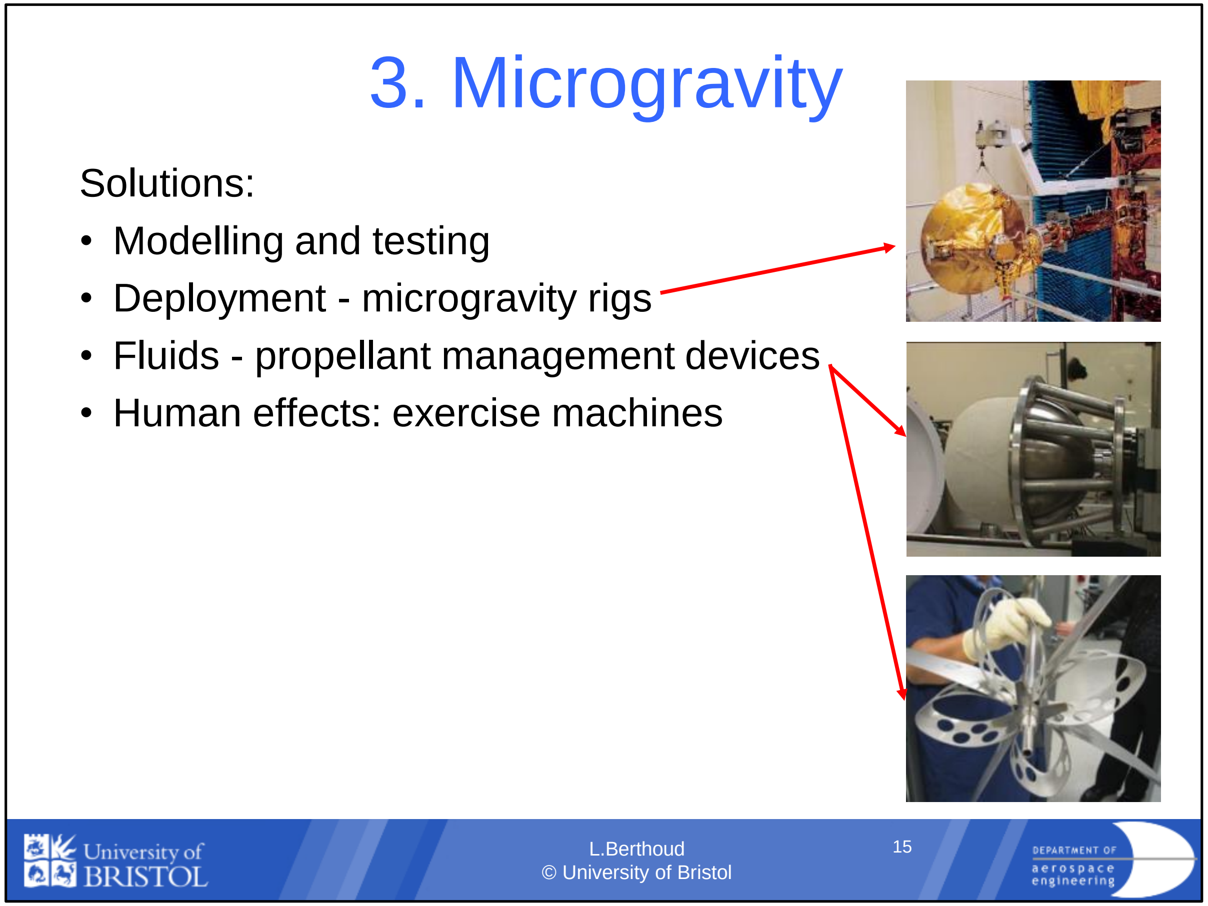


Image credit: University of Cranfield

Solar photons exert a small pressure on any surface, so if you have a highly reflective surface like a mirror you can use this pressure to move a small mass. This is called “solar sailing” and can be used to propel spacecraft. This is a prototype solar sail produced by Cranfield

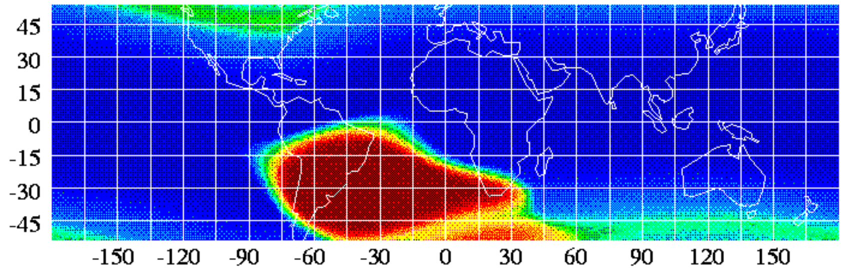


Deployment testing, such as that shown above where an antenna is being deployed, often requires microgravity rig as the structure is much lighter than would be necessary for Earth's gravity.
PMD designs utilize combinations of bladders (middle image), metal sponges, traps, troughs, vanes (bottom image), wicks, and other structures to provide more efficient liquid propellant delivery.

4. Charged particles

Solutions:

- Radiation testing
- ‘Rad-hard’ electronics
- Shielding
- Redundancy/Voting (design)
- Avoiding South Atlantic Anomaly



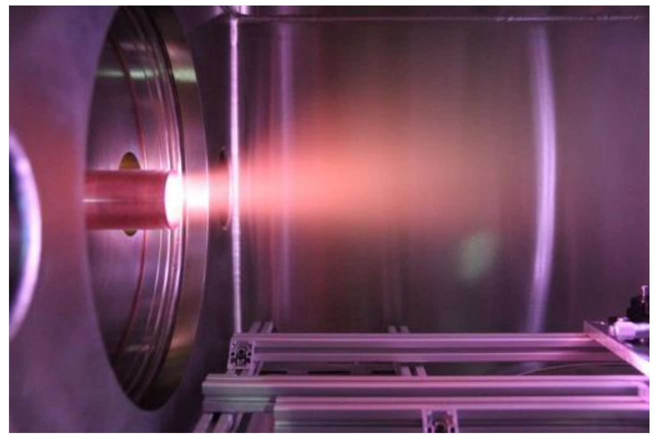
Charged particle map shows the South Atlantic Anomaly

This can be mitigated by selecting avionics that are “rad-hard” (hard against radiation) or by placing shielding around the electronics. Radiation effects may also be alleviated by using error-correction circuitry and triple-module redundancy, where two good process results “outvote” a corrupted one. The South Atlantic anomaly a region where the Earth's inner van Allen radiation belt makes its closest approach to Earth (200km).

5. Atomic Oxygen

Solutions:

- Modelling and testing
- Coatings and material selection



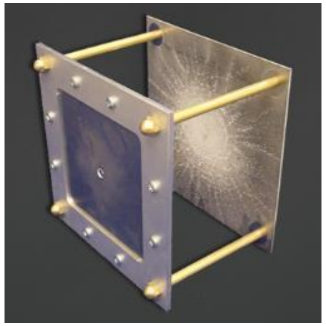
ESA's new LEOX, Low Earth atomic oxygen simulator.

ESA's new LEOX, Low Earth Orbit Facility, being fired for the first time in April 2017. This new simulator that fires a laser to generate ‘atomic oxygen’ normally encountered only in low orbits – and known to eat away at satellite surfaces. LEOX generates atomic oxygen at energy levels that are equivalent to orbital speed – 7.8 km/s – to simulate the space environment as closely as possible.

6. Meteoroids and debris

Solutions:

- Testing with hypervelocity impact
- Tracking/manoeuvering
- Whipple shields
- Active debris removal
- Regulation

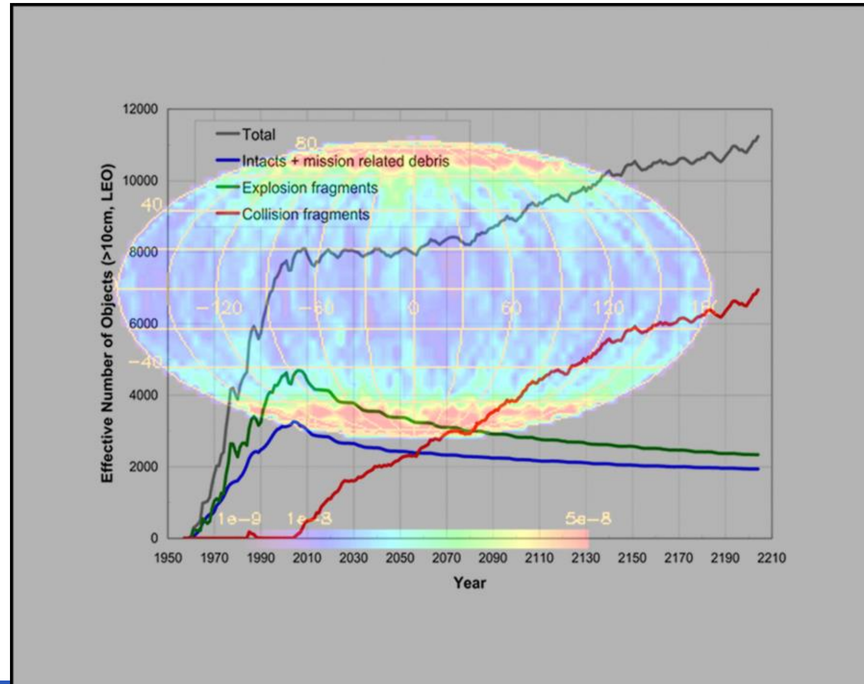


Whipple Shield

ESA e.Deorbit mission to remove debris

Meteoroids and debris are tracked by NORAD radar system in the US. A ‘Whipple shield’ places a sacrificial bumper of aluminium in front of the spacecraft to shock the projectile creating a debris cloud of smaller less lethal fragments and is used for the space station only (not worth the expense to put these on non-crewed spacecraft). Regulation to deorbit spacecraft within 25yrs of launch.

7. Model the environment



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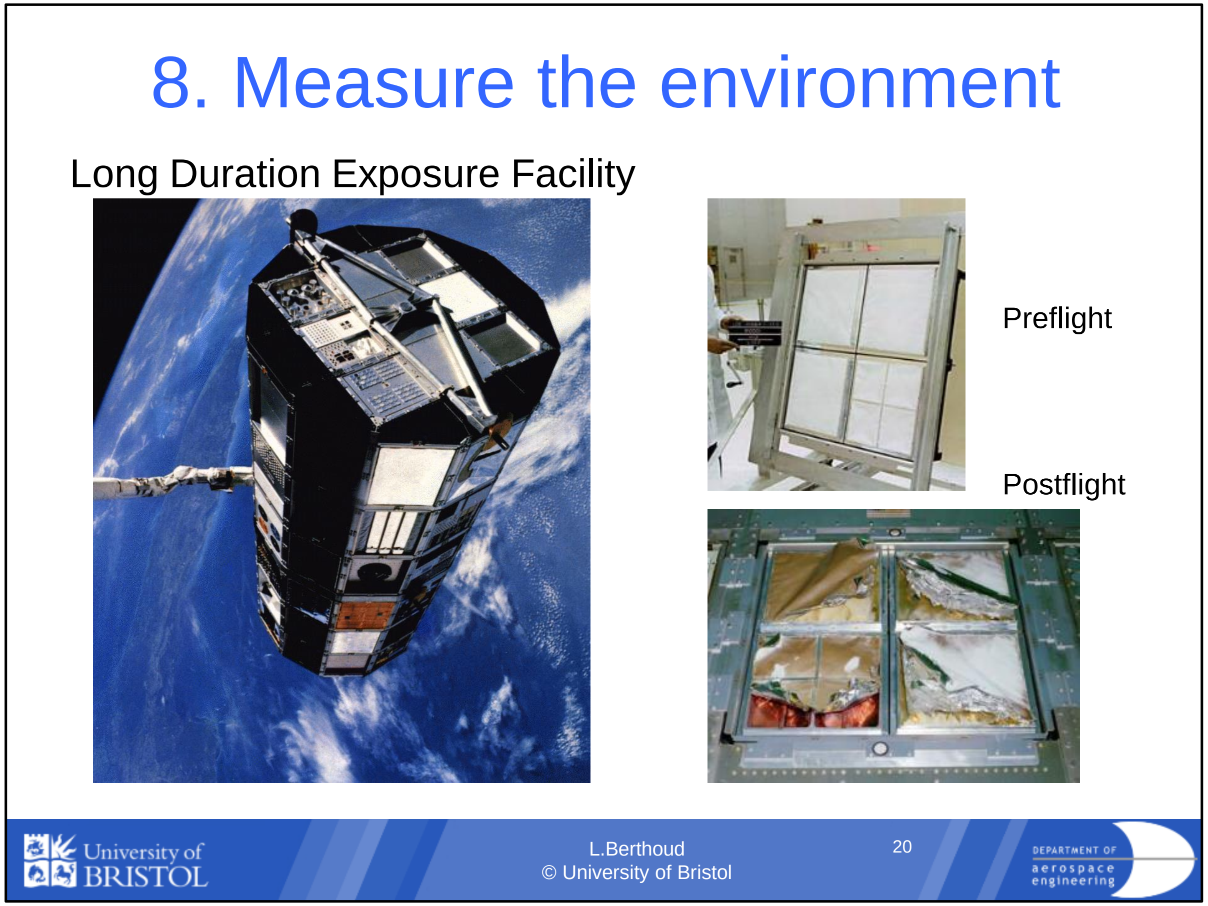
We need to develop models of all aspects of the space environment, in order to predict the future, to analyse the present and to design spacecraft. For example, LEGEND is a full-scale, three-dimensional, debris evolutionary model NASA have developed for study of the long-term debris environment.



[Left] The LDEF structure and its 57 experiments contained an estimated 12,000 to 14,000 specimens of materials. LDEF remained in space for ~5.7 years and completed 32,422 Earth orbits.
[Right] Preflight and postflight Long Duration Exposure Facility M0001 Heavy Ions in Space experiment, indicating atomic oxygen erosion and ultraviolet degradation

Summary

- **6 Space environment effects:**
- **Vacuum** causes outgassing of some materials
- **Photon radiation** can cause heating on exposed surfaces, damage to electronic components. Solar pressure can change a spacecraft's orientation
- **Microgravity**
- **Charged particles** come from: Solar wind and flares, Galactic cosmic rays (GCRs), Van Allen radiation belts
- **Atomic oxygen** causes surface degradation of some materials
- **Meteoroids and space debris** can cause serious impact damage.

Test Yourself

1. What are the six major effects of the space environment?
2. How would you mitigate against the effect of eg: atomic oxygen?
3. What kinds of testing would you suggest for investigating the effects of the space environment?
4. Describe a whipple shield. When do you think it is worth using whipple shields to protect against micrometeoroids/debris?