Debris and Future Space Activities

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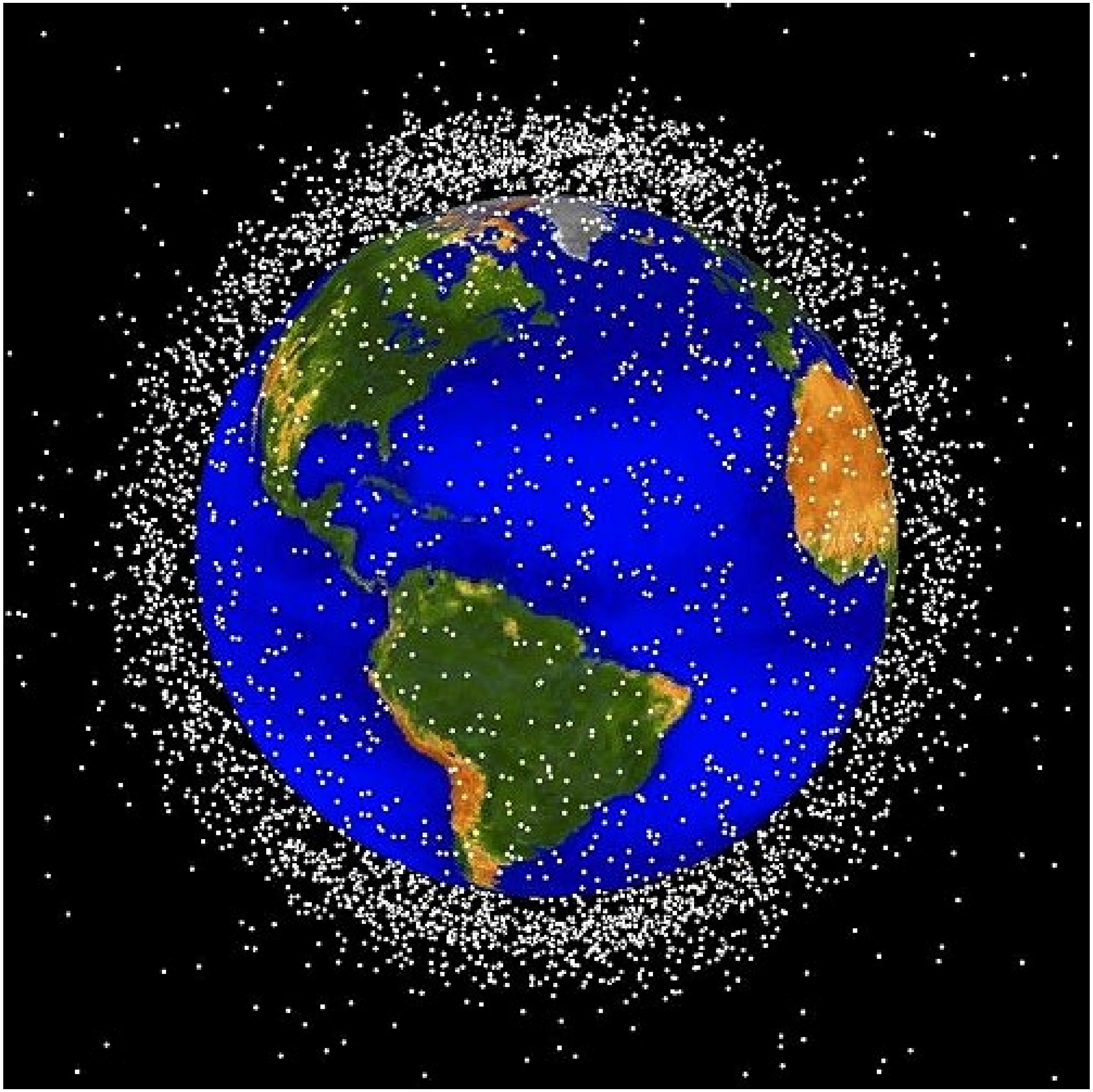
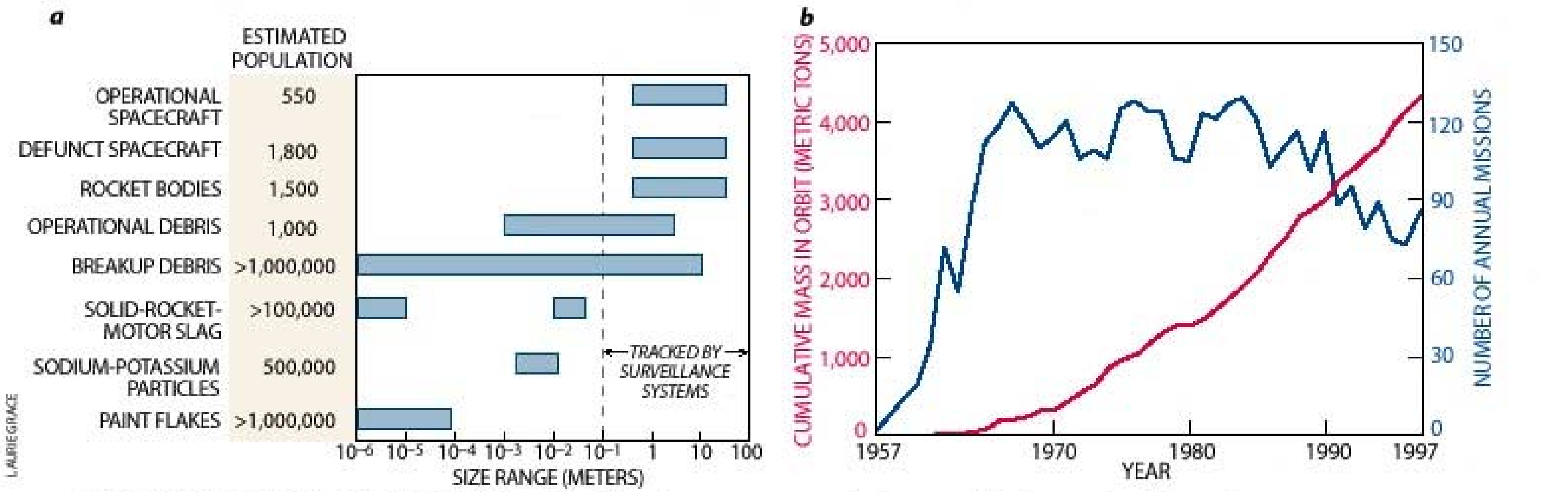
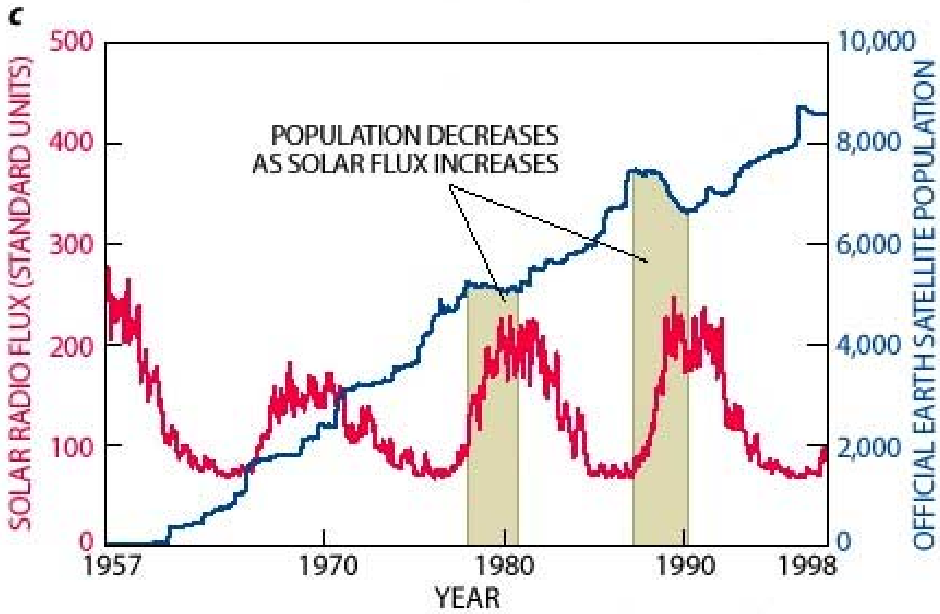
Space is our most fragile environment because it has the least ability to repair itself. Only the Earth s atmosphere can remove satellites from orbit. When the sun flares up in its eleven year cycle, it heats the upper atmosphere and makes it expand so that debris and spacecraft in low orbits are subjected to increased drag. But the higher the original orbit, the less air there is to collide with. Imagine near-Earth space as the hillsides of a deep valley, with the atmosphere as a lake which overflows occasionally and washes only the lowest hillsides clear of debris. Debris in orbit higher than about 800 km above the Earth s surface will be up there for decades, above 1000 km for centuries, and above 1500 km effectively forever. About 9000 objects larger than 10 cm in diameter are currently tracked, and there are probably more than 100,000 pieces of orbiting debris larger than a marble.

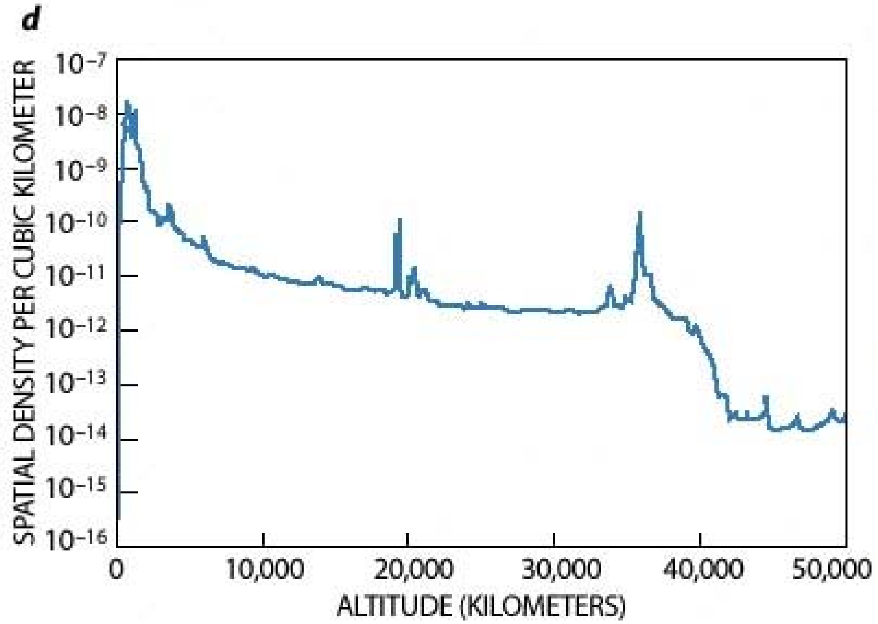


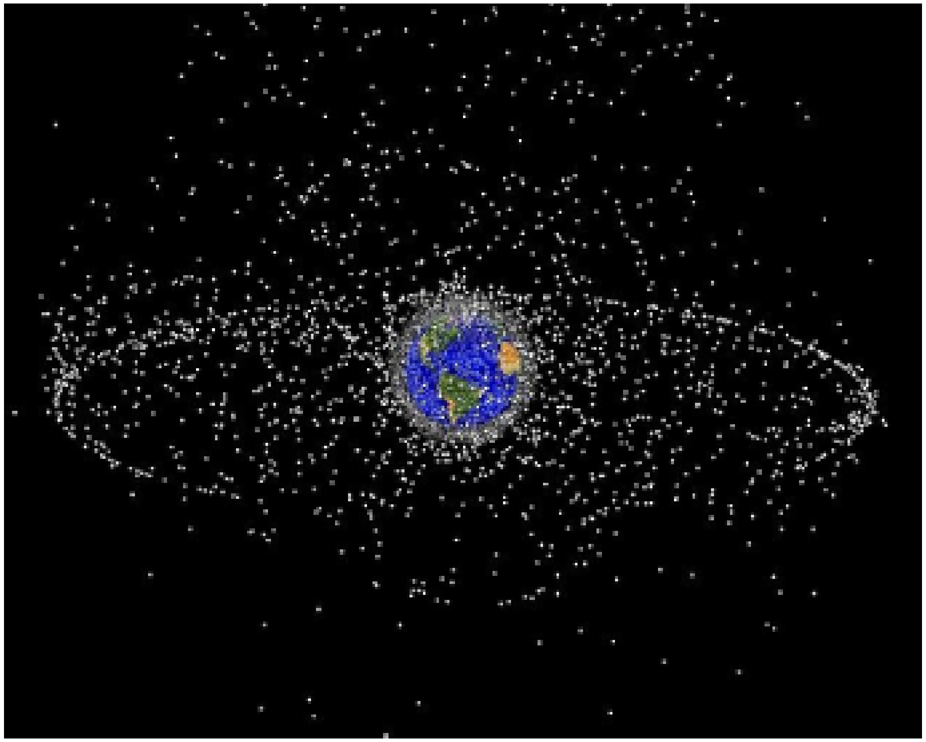


EARTH'S ARTIFICIAL SATELLITES, broadly defined as anything put into orbit either intentionally or not, come in various types and size ranges, from paint particles a thousandth of a millimeter across to the Mir space station, 30 meters long (*a*). Fewer new space missions are launched today than in the past, but the cumulative mass of satellites has continued to climb because modern spacecraft are larger (*b*). Military surveillance systems can spot only those satellites larger than 10 centimeters to one meter (depending on the orbit). Their counts have risen every year except when solar activity has been increasing (*c*). The density of these trackable objects has three closely spaced peaks at 850-, 1,000- and 1,500-kilometer altitudes, as well as smaller peaks at semisynchronous orbit (20,000 kilometers) and geosynchronous orbit (36,000 kilometers)—the most popular destinations (*d*).

Credit: Nicholas Johnson, "Monitoring and Controlling Debris in Space," Scientific American, August 1998, pp. 62-67.


c
SOLAR RADIO FLUX (STANDARD UNITS)
OFFICIAL EARTH SATELLITE POPULATION
POPULATION DECREASES
AS SOLAR FLUX INCREASES
500
400
300
200
100
0
10,000
8,000
6,000
4,000
2,000
0
1957
1970
1980
1990
1998
YEAR


d
SPATIAL DENSITY PER CUBIC KILOMETER
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
0
10,000
20,000
30,000
40,000
50,000
ALTITUDE (KILOMETERS)



A war in space could create a battlefield that will last forever, encasing our entire planet in a shell of whizzing debris that will thereafter make space near the Earth highly hazardous for peaceful as well as military purposes. But crowded near-Earth orbits are where the Bush administration wants to put parts of its proposed missile defense system such as thousands of space-based interceptor missiles and Space-Based Lasers.

The nickname Star Wars for missile defense all too accurately reflects the popular fantasy impression of how things work in space. In the Star Wars movies and in hundreds of other popular science fiction films, we see things blow up in space and the fragments quickly dissipate, leaving space clear again. But in reality, space never clears after an explosion near our planet. The fragments continue circling the Earth, their orbits crossing those of other objects. Paint chips, lost bolts, pieces of exploded rockets all have already become tiny satellites, traveling about 27,000 kilometers per hour, ten times faster than a high-powered rifle bullet. There is no bucket we could ever put up there to catch them. Anything they hit will be destroyed and only increase the debris. A marble traveling at that speed would hit with the energy of a one-ton safe dropped from a three-story building.

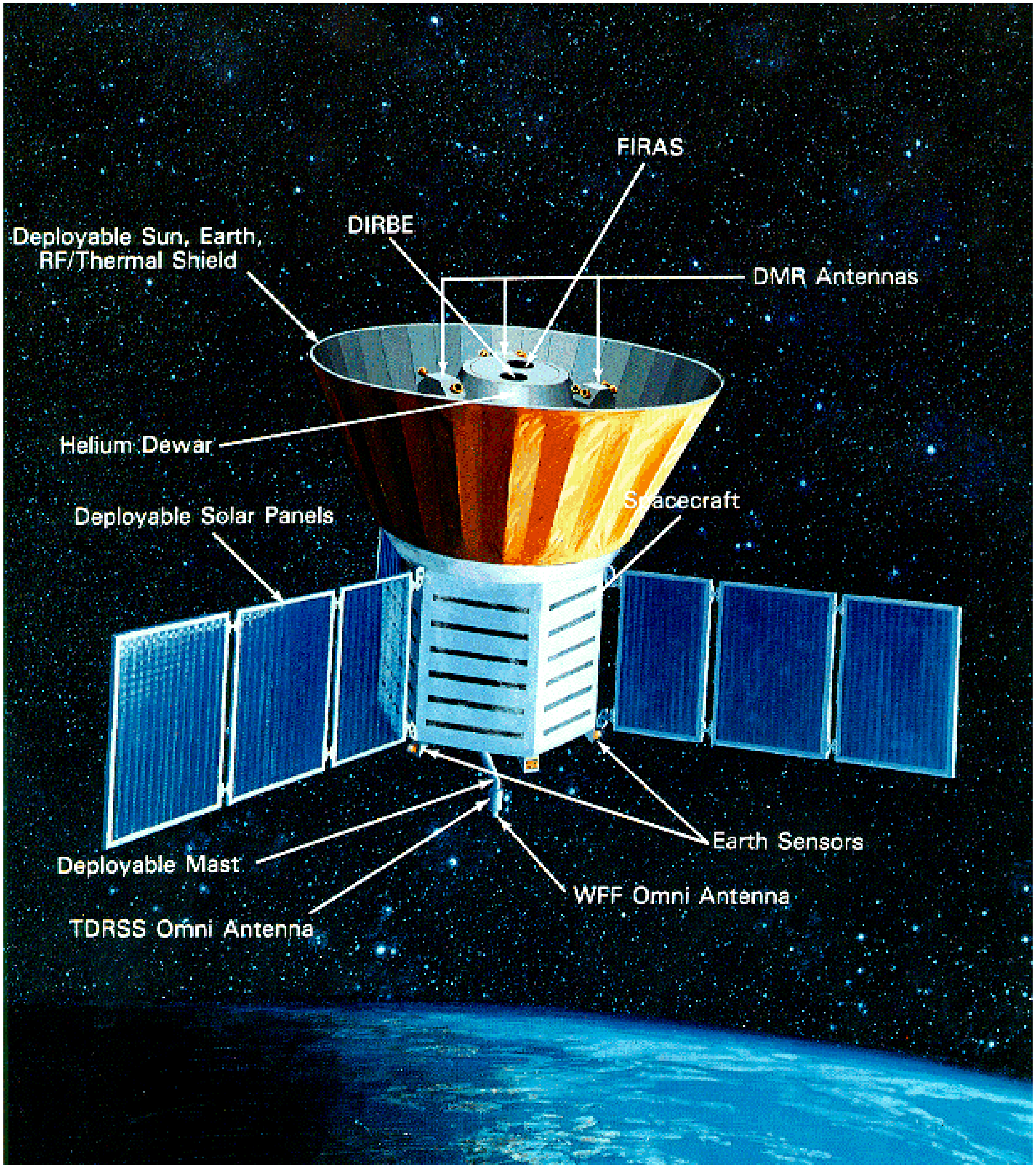
explosion from 1st STAR WARS film

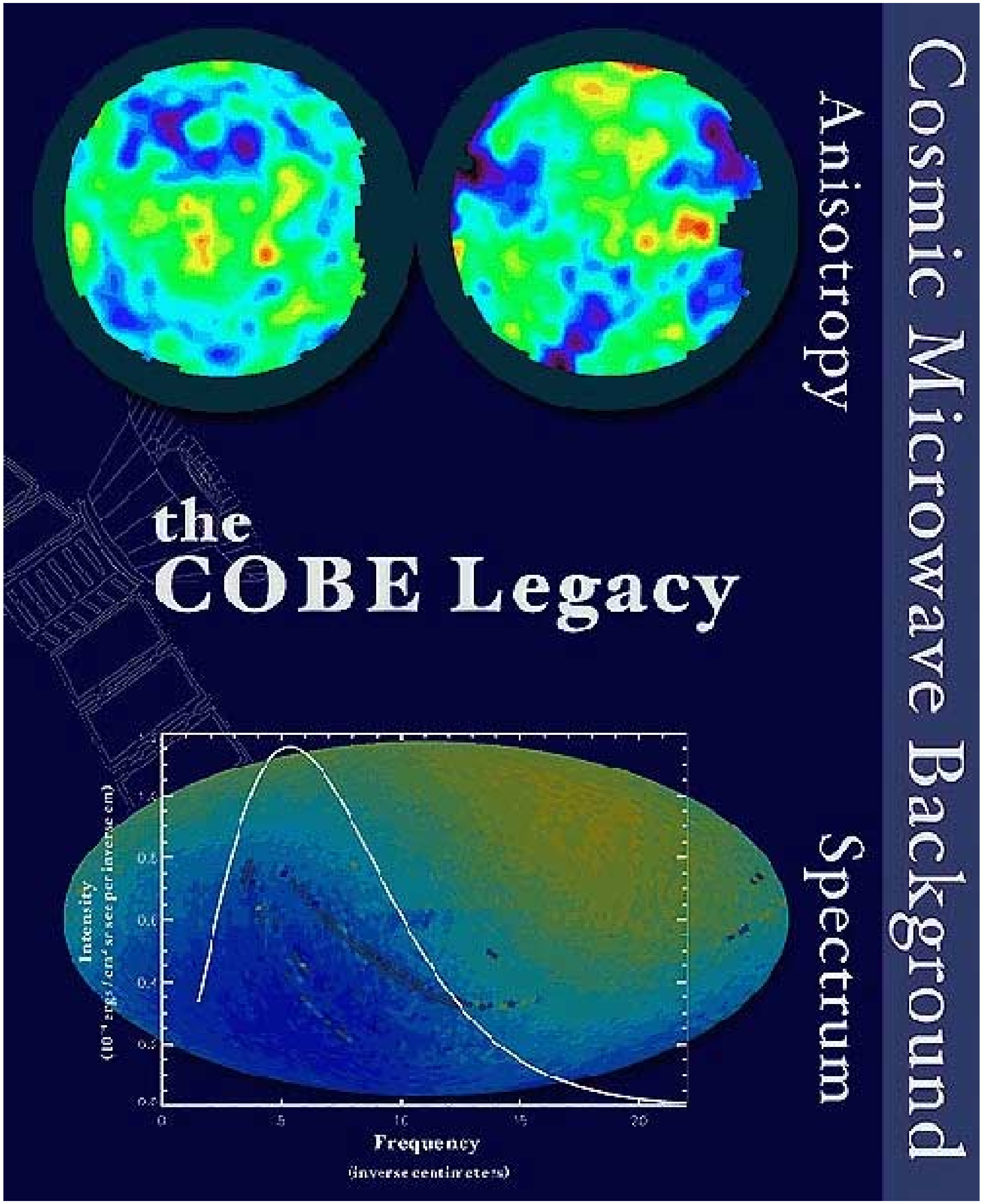
in the cockpit just afterwards

With enough orbiting debris, pieces will begin to hit other pieces, fragmenting them into pieces, which will in turn hit more pieces, setting off a chain reaction of destruction that will leave a lethal halo around the Earth. To operate a satellite within this cloud of millions of tiny missiles would become impossible: no more Hubble Space Telescopes or International Space Stations. Even the higher communications and GPS satellites would be endangered. Every person who cares about the human future in space should also realize that militarizing space jeopardizes the possibility of space exploration.

As a scientist whose research has benefited enormously from space observations, these prospects horrify me. Most of the important astronomical satellites have been placed in the Low-Earth Orbit (LEO) region (from the lowest practical orbits, about 300 km altitude, up to about 2000 km). The Cosmic Background Explorer (COBE) satellite, in a polar orbit at 900 km altitude, allowed the discovery in 1992 of the fluctuations in the first light of the universe the heat radiation that was emitted as the hot primordial plasma first cooled and became transparent about 300,000 years after the origin, long before the first stars formed. The temperature fluctuations COBE detected are relics of ancient differences in the density of the primordial universe from place to place. These initial conditions are what led over billions of years to the formation of galaxies and larger-scale structures in the universe, according to popular but before COBE unconfirmed theories such as Cold Dark Matter.

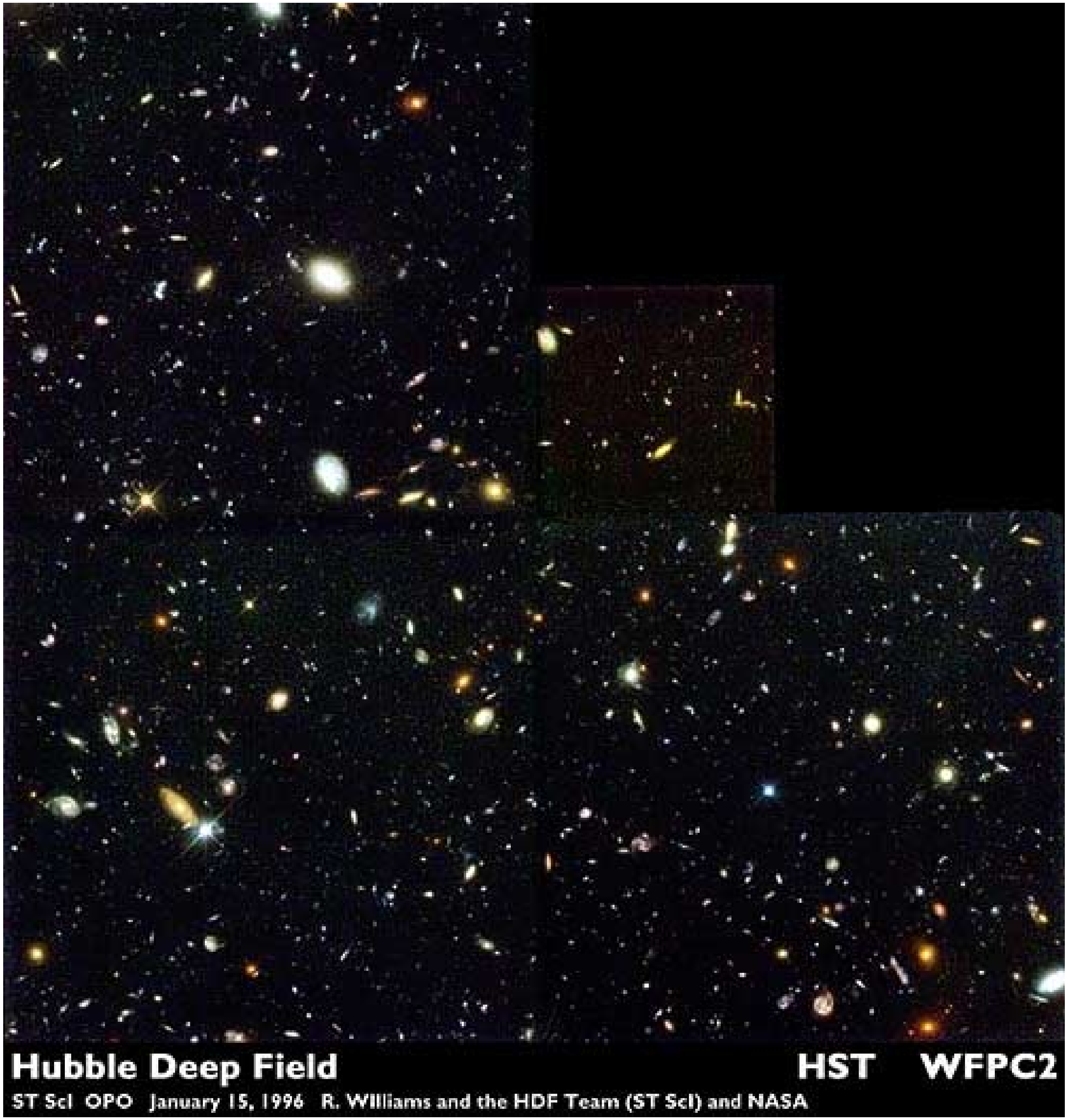
COBE

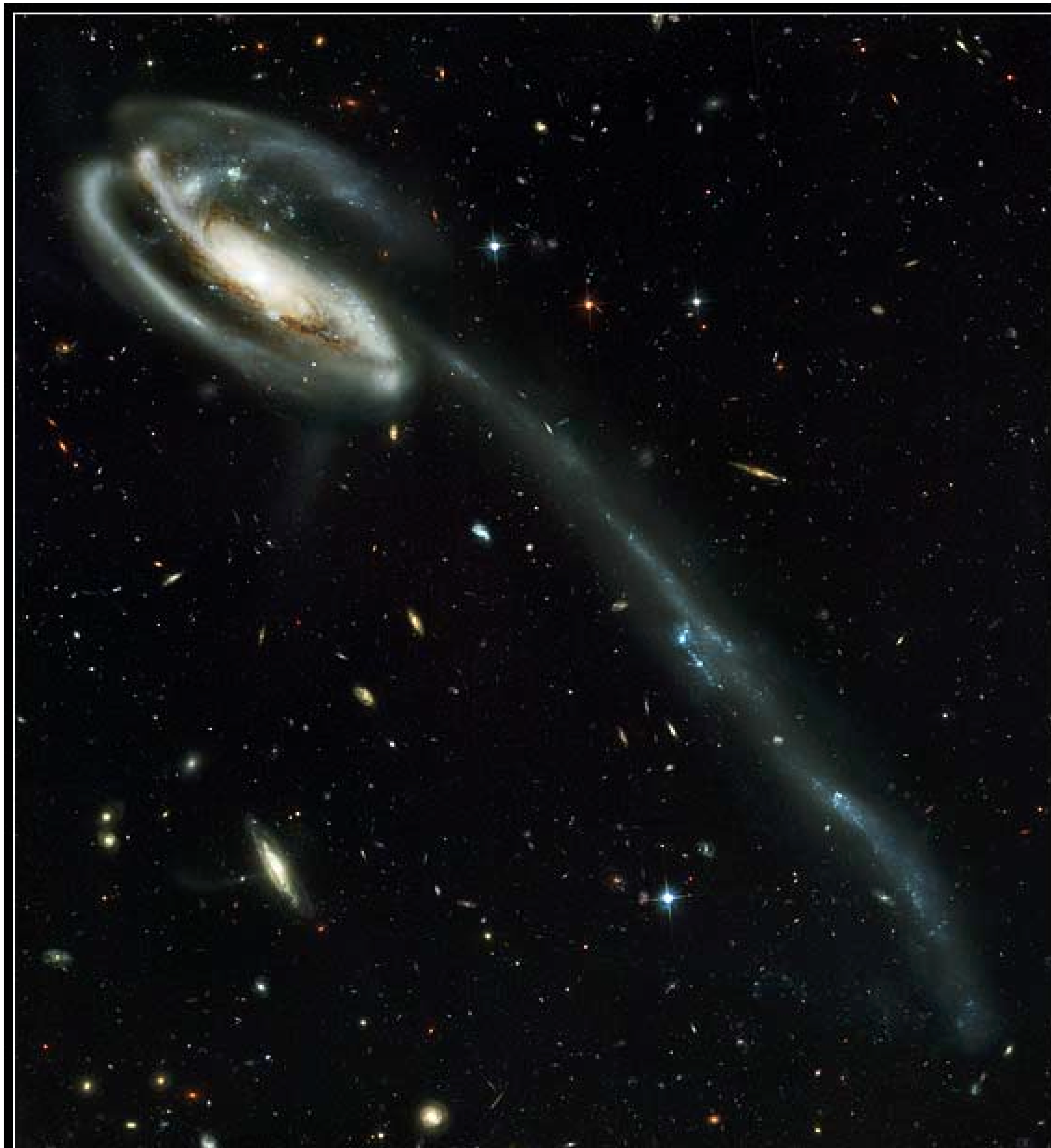

FIRAS
DIRBE
Deployable Sun, Earth, RF/Thermal Shield
DMR Antennas
Helium Dewar
Spacecraft
Deployable Solar Panels
Earth Sensors
Deployable Mast
WFF Omni Antenna
TDRSS Omni Antenna


Cosmic Microwave Background
Anisotropy
the
COBE Legacy
Spectrum
Intensity
0
5
10
15
20
Frequency
(inverse centimeters)

The Hubble Space Telescope (HST), in a 600 km orbit, has observed many Cepheid variable stars in about 20 nearby galaxies, which has finally allowed accurate measurement of the expansion rate of the universe and thus, indirectly, the time since the Big Bang. The Hubble Deep Fields the longes t time exposures with HST have given us unprecedented images of the first galaxies, which are helping us to understand the history of our own cosmic home, the Milky Way galaxy.

HST


Hubble Deep Field
HST WFPC2
ST ScI OPO January 15, 1996 R. Williams and the HDF Team (ST ScI) and NASA



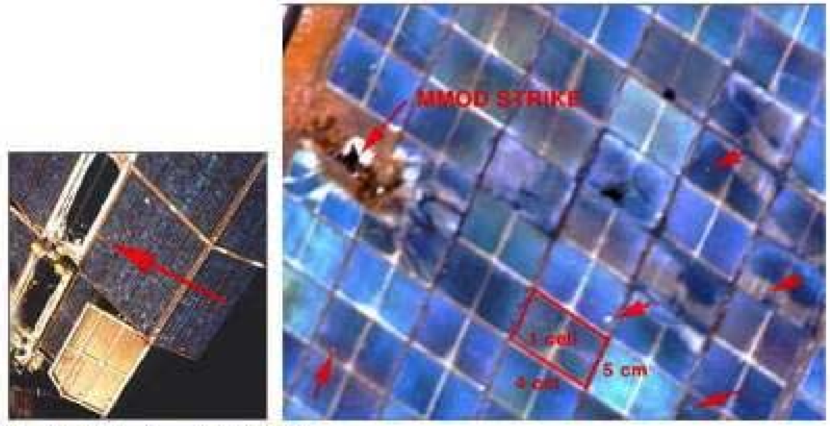
Tadpole Galaxy • UGC 10214 **HST • ACS**

NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI), G. Hartig (STScI), the ACS Science Team and ESA • STScI-PRC02-11a

The data from COBE, HST, and other new observatories should at last give astrophysicists a solid foundation on which to construct an overarching theory of the origin and evolution of the universe. But such satellites are already at increasing risk from space debris. At any moment, only about 200 kg of meteoroid mass is within 2000 km of the Earth s surface. Within this same altitude range there are roughly 3,000,000 kg of orbiting debris introduced by human activities. Most of this mass is about 3000 spent rocket stages and inactive payloads. Approximately 40,000 kg of debris is in some 4000 additional objects several cm in size or larger, most of which resulted from more than 100 satellite fragmentations. **The main threat to satellites near Earth is from the roughly 1000 kg of 5 cm or smaller debris particles, which cannot be tracked and are very numerous.**

Even BB-size fragments of debris have the destructive energy of a bowling ball moving at 100 km/hr. An average small satellite in an 800 km orbit now has about a one percent chance per year of failure due to collision with a BB-size piece of debris. And the amount of small debris is increasing. Random collisions between man-made objects in LEO are still relatively rare, but the density of such objects may already be sufficiently great at 900-1000 km and 1500-1700 km that a chain reaction or cascade of collisions can be sustained. Further growth of the debris population will increase the threat at even lower orbital altitudes. The resulting debris environment will obviously be very hostile to satellites in LEO.

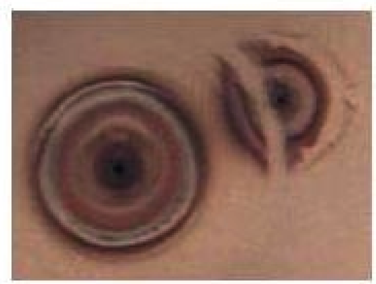
Windshield of the space shuttle damaged by a paint chip hurtling through space.



Kvant-2 Solar Panel MOD Strikes
View of the Kvant-2 solar arrays and close-up of suspected MOD strikes.

LDEF was an inexpensive satellite launched in 1982. Its sole purpose was to measure various aspects of the near-earth space environment, including atomic oxygen, radiation, orbital debris and meteoroids, among other things. Because of the Challenger tragedy, LDEF was forced to stay on orbit years longer than was originally intended, before finally being retrieved by STS-32 in 1990 and brought back to earth. The satellite has become a bottomless data source for hypervelocity impact research.

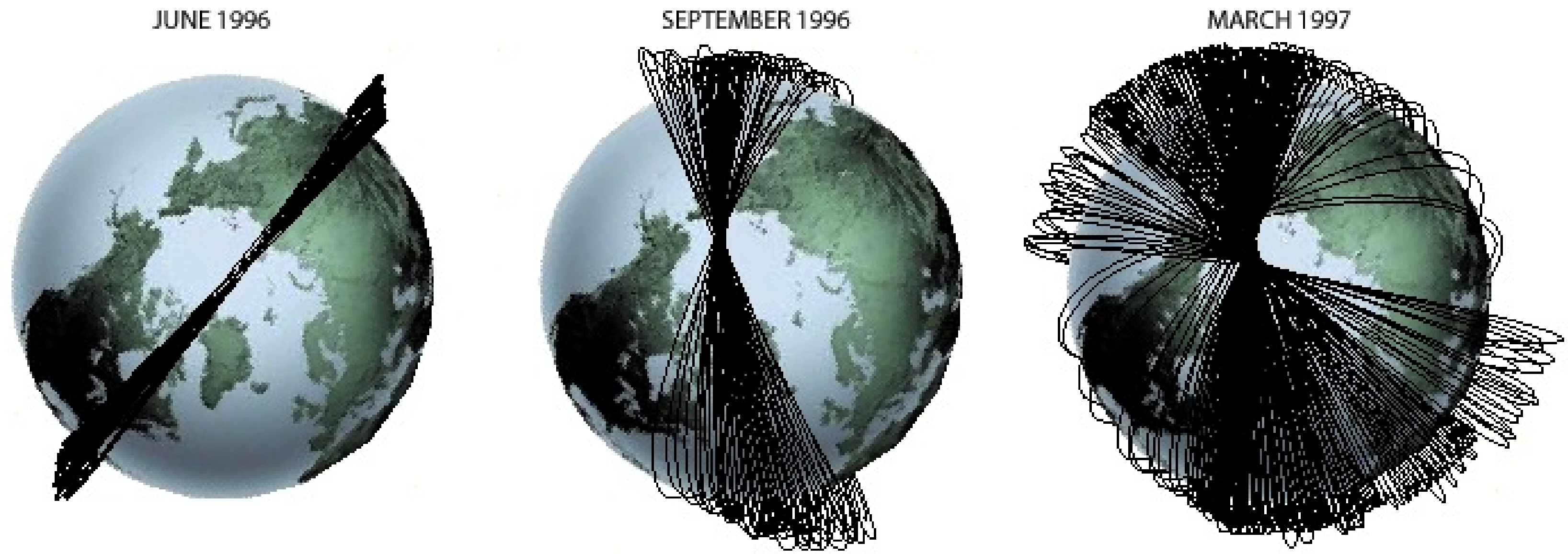
During its eight years in space, LDEF was impacted millions of times. Some of the impacts were made by very tiny particles - particles so tiny, they were only visible under an electron microscope. Others were visible to the naked eye, like the one shown in the image at right. LDEF has been a valuable source of information about the meteoroid and orbital debris environment in near-earth orbit.



Sally Ride recalled a run-in with space debris on her first shuttle flight. “About halfway through the flight there was a small pit in the window of the space shuttle and we didn`t know what it was. An awful lot of analysis was done while we were in orbit to make sure that the strength of the window would sustain reentry. It did. We were all fine. But the analysis afterward showed that our window had been hit by an orbiting fleck of paint, and the relative velocities were enough that the paint actually made a small but visible gouge in the window. Well, a fleck of paint is not the same as a small piece of metal traveling at that same speed. So, as soon as you start increasing the amount of junk in a low-Earth orbit, you have an unintended byproduct that starts putting some of your own quite valuable satellites at possible risk.”

Ride asked: “What if anti-satellite testing proceeds and we start testing rockets that clobber satellites and explode them in space? What if enough of that goes on that there`s the equivalent to a test range up in low-Earth orbit?”

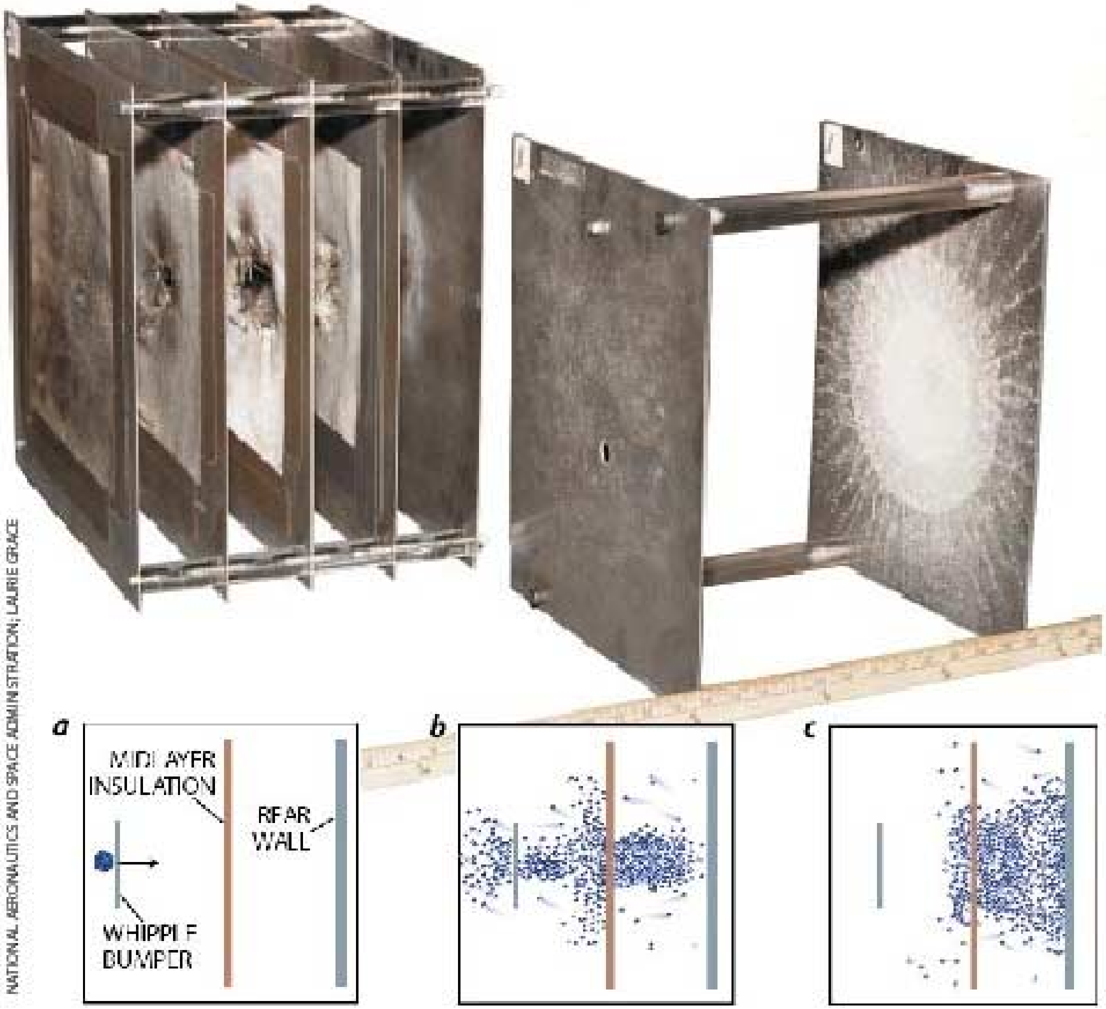
Drell Lecture, Stanford Center for International Security and Cooperation, April 10, 2002



DEBRIS ORBITS disperse soon after a satellite breakup. Three weeks after a Pegasus rocket fell apart in June 1996, the debris was still concentrated in a tight band (*left*). After three months, the slight asymmetry of Earth's gravitational field had already started to amplify differences in the initial orbits (*center*). After nine months, the debris was spread out in essentially random order (*right*). In addition, though not depicted here, the objects initially orbited in a pack and slowly fell out of sync. Debris specialists must take this process into account when assessing the risk to spacecraft such as the shuttle. Initially the shuttle may avoid the concentrated debris. Later, the risk of impact from different directions must be evaluated statistically.

NASA has designed portions of the space station with shielding to provide protection against objects smaller than 1 centimeter. It has concluded that shielding against larger objects would be too costly. Debris from about 0.5 to 20 cm in diameter is of most concern because the debris may be too large to shield against and too small to track and avoid. NASA will require DOD to detect, track, and catalog objects as small as 1 cm. However, DOD stated that achieving this capability would be technically challenging.

SPACE SURVEILLANCE, General Accounting Office Report GAO/NSAID-98-42, pp. 16-17.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION; LAURIE GRACE

SHIELDS should protect key components of the International Space Station from most objects too small to track but large enough to puncture station walls. These shields, unlike the "force fields" of science fiction, are barriers mounted on the spacecraft. As the object approaches, it first encounters a sheet of aluminum (typically two millimeters thick), known as the Whipple bumper, which causes the projectile to shatter (*a*). The fragments are slowed by one or more layers of Kevlar (*b*). Finally, the fragments bounce off the spacecraft wall (*c*).

Offensive weapons in space pose the worst threat to satellites in LEO. Fortunately, offensive weapons have not yet been introduced into space except for a few tests such as a Soviet space mine explosion, or the intentional destruction in 1985 of the still-operating Solwind satellite in a demonstration by the U.S. military. Each of these tests generated hundreds of pieces of trackable debris. Space based lasers or kinetic kill vehicles such as the proposed thousands of Brilliant Pebbles are sure to generate great quantities of space debris just during their initial deployment, and far more if they are ever used. Since each of these attack satellites will circle the earth every 90 minutes, basing weapons in space requires thousands of individual satellites in order that at least one be near its target.

SPACE
BASED
LASER
(artist's
conception)

Any kind of space warfare will put all satellites at risk. The explosion of nuclear weapons in space (prohibited by the Outer Space Treaty, but routinely considered by military planners) would indiscriminately destroy unprotected satellites by electromagnetic pulse (EMP) or nuclear radiation. Perhaps worst of all would be the deliberate injection into LEO of large numbers of particles as a cheap but effective anti-satellite measure. Any country that felt threatened by America s starting to place lasers or other weapons into space would only have to launch the equivalent of gravel to destroy the sophisticated weaponry. Many of these pieces of metallic gravel and fragments of broken weaponry would join all the other debris in orbit. It would hasten the fragmentation of the 3,000,000 kg of dead satellites and rocket bodies now in LEO, and thus tremendously increase the threat to all satellites in LEO.

- Do not introduce attack weapons into space.
- Avoid fragmentation of satellites.
  Prohibit explosions of any kind in space.
- Require all satellites to re-enter when their useful life is over.
- Ban nuclear reactors in orbit.
- Minimize light pollution from orbit.

National political leaders usually take a short-range view, hardly ever stretching past the next change of government; astronomers measure time in millions and billions of years. We must help to educate the general public to think with at least an intermediate perspective of centuries and millenia about the environmental degradation that our increasingly powerful technology is causing on and near our beautiful but fragile planet the only one like it that we know in the entire universe.