Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

Colliding Satellites: Consequences and Implications

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The collision on February 10, 2009 between the Iridium 33 satellite and the defunct Cosmos 2251 satellite at an altitude of 470 miles (770 km) significantly increases the amount of space debris in the region of space that is already the most crowded and has the greatest risk of collisions between orbiting objects. The debris cloud created by this collision is like a shotgun blast that threatens other satellites in the region.

While there have been collisions between objects in space previously, this is the first known collision of two intact satellites.

The collision took place at 11:56 AM EST on February 10 over northern Siberia, but as shown below, the debris will spread globally with time. The Iridium satellite is part of a constellation of communication satellites owned by Iridium Satellite LLC, a privately held company based in Bethesda, Maryland. The Cosmos satellite is owned by Russia. It was launched in 1993 and is no longer believed to be active or capable of maneuvering.

The two satellites were both orbiting the Earth at a speed of nearly 17,000 mph (7.5 km/s), and collided at a speed well over 22,000 mph (10 km/s). The collision will produce space debris ranging in size from large pieces to dust particles. How much debris was created is not yet known, and will depend on whether the collision was nearly head-on between the main parts of the satellites or was a more glancing blow. As the individual debris pieces from the collision are identified and tracked in the coming weeks, details of the collision should become more clear. The process of discovering debris will continue for several years.

We discuss below what the debris consequences of the collision could be.

Current Debris in Space

Space debris is any man-made object in orbit that no longer serves a useful purpose. It consists of discarded equipment and rocket stages, dead satellites, bolts and other hardware released when satellites are placed in orbit, and fragments from the breakup of satellites and rocket stages, due both to collisions and explosions. Roughly half of all the debris in space has resulted from such breakups.

There are currently about 900 active satellites in orbit, and roughly 2,300 inactive satellites. Prior to the collision, the United States and Soviet Union/Russia were each responsible for about 35% of the existing debris, and China for about 22%.[2]

Table 1 below lists estimates of the total amount of debris in orbit, by size, before this collision. "LEO" refers to low Earth orbits, with altitudes less than about 2,000 km (1,200 miles). Note that roughly half of all the debris is in LEO.

Only a fraction of this total debris is tracked from the Earth—the U.S. currently tracks about 18,000 objects, which includes the 900 active satellites. When people give debris numbers, it is important to understand whether they are talking about total debris, or just the debris that is large enough to be tracked. The U.S. Space Surveillance Network maintains a "catalog" of space objects, which consists of objects that can be tracked and whose origin is known; as of January 1, 2009, the catalog contained nearly 13,000 objects.

Size of debris particles	**> 10 cm (4 inches)**	**> 1 cm (0.4 inch)**
Debris in LEO	**14,000**	**370,000**
Debris at all altitudes	**22,000**	**750,000**

Table 1: Total estimated debris, by size, in orbit around the earth.

Because of their very high speeds in orbit, even relatively small pieces of debris can damage or destroy satellites in a collision. Since atmospheric drag at high altitudes is very small, debris at high altitudes can stay in orbit for decades or longer, so it accumulates as more is produced. As the amount grows, the risk of collisions with satellites also grows. If the amount of debris at some altitudes becomes sufficiently large, it could become difficult to use those regions for satellites.

Debris with size between 1 mm and 1 cm can damage a satellite if it hits a vulnerable area. Shielding can protect against objects of this size, but adding shielding increases the cost of satellites and of launching them, and many satellites have minimal shielding.

Debris with size greater than about 1 cm can seriously damage or destroy a satellite in a collision, and there is no effective shielding against such particles. Moreover, debris particles less than 5 to 10 cm cannot reliably be tracked from the ground so there is no warning of collisions.

Debris with size greater than 10 cm may be massive enough to create large amounts of additional debris in a collision with a satellite or another large piece of debris.

Since there is currently no effective way to remove large amounts of debris from orbit, controlling the production of debris is essential for preserving the long-term use of space.

The Most Likely, But Worst, Place for a Collision

Space debris is not spread uniformly through space, but—not surprisingly—is concentrated near the regions of space that are heavily used by satellites. The plot below (Figure 1) shows the distribution of cataloged objects in LEO before the collision. The region between 700 and 1,000 km is crowded since fragments created from breakups of satellites and rocket bodies in that region have a long lifetime due to low atmosphere drag.

The debris from the Iridium-Cosmos collision will appear near the peak that already exists just below 800 km. The spike in the plot at about 850 km altitude is due to the debris from the destruction of the Chinese Feng Yun-1C (FY-1C) satellite in January 2007.

Because of the high density of satellites and debris in this 700 to 1000-km region, this is the most likely place for a collision to occur. Adding more debris to the region increases the likelihood of additional collisions in the future.

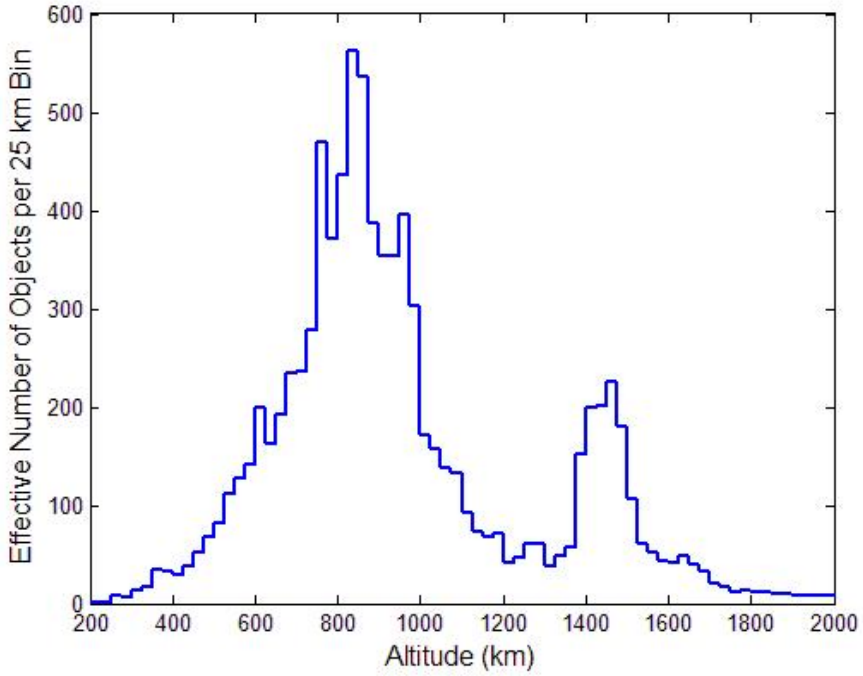
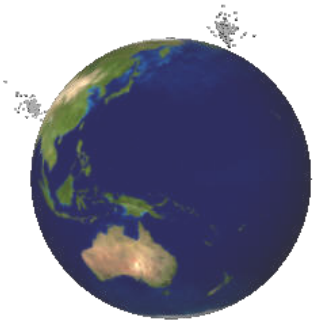


Fig. 1: Distribution with altitude of cataloged objects in LEO before the collision.

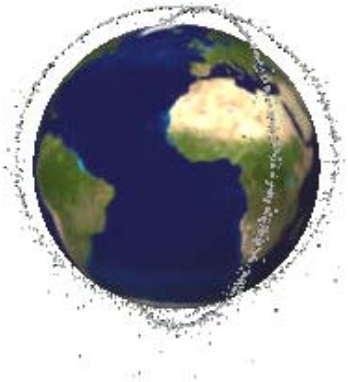
The Spread of the Debris Clouds

The debris cloud that is created when a satellite is destroyed spreads over time, as is shown in Figure 2 below. In this case two debris clouds were created, one from each of the satellites, and each cloud initially follows along the orbit of the original satellite. The two orbits in this case are roughly perpendicular to each other.

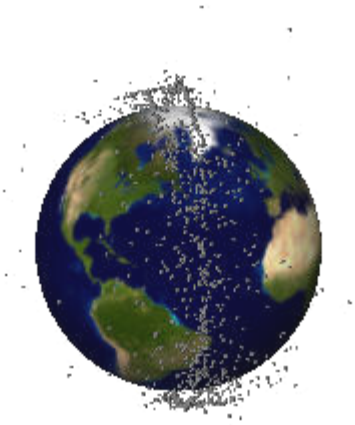
The debris in each cloud first spreads out along the orbit of the original satellite, as is seen in the figure showing the debris distribution after 10 days. But in time the debris spreads to form a shell around the earth, but is concentrated near the altitude at which the original satellites orbited (Figure 3). As a result, the debris from the collision becomes a global problem threatening all satellites that pass through that altitude.



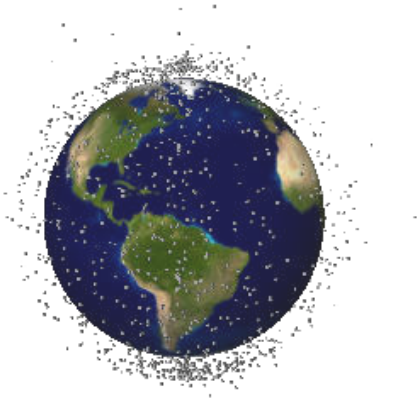
Debris clouds after 9 minutes



Debris clouds after 10 days



Debris Clouds after 6 months



Debris clouds after 3 years

Fig. 2: These figures show the spread over time of debris clouds from the collision (figure credit: Wang Ting).

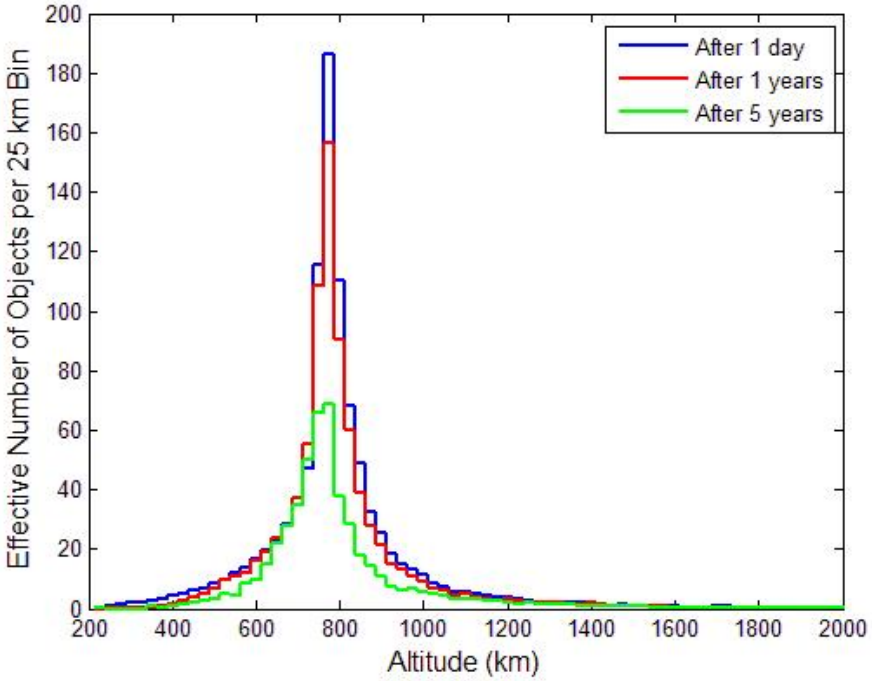


Fig. 3: This plot shows the distribution with altitude of the debris fragments over time, showing that they remain concentrated around the altitude of the original satellite. This plot assumes an initial population of 1000 fragments; the number of fragments in orbit is seen to decrease with time (figure credit: Wang Ting).

Debris Lifetime in Orbit

Over time, the residual atmospheric drag on the debris will slow it and cause it to spiral down to Earth and out of orbit. That process poses little threat to people on Earth since the vast majority of the debris particles will burn up in the dense atmosphere as they approach the Earth's surface, and most of the pieces that survive will land in the ocean.

Because there is very little atmospheric drag at the high altitude where this collision occurred, a large fraction of the debris created will stay in orbit for several decades (see Figure 4). The larger pieces, because they typically have larger mass, will tend to stay in orbit longer than smaller, lighter pieces of debris. We estimate that roughly one-quarter of the large debris will remain in orbit after 30 years.

As noted above, since there is currently no effective way to remove large amounts of debris from orbit, debris accumulates and the risk of collisions with satellites increases.

Because of its altitude, which is several hundred kilometers above the International Space Station (ISS), this debris is unlikely to pose a large, near-term risk to the ISS. On the other hand, over the next 10 to 20 years—which is the predicted ISS lifetime—a large number of debris particles will decay and pass through the ISS orbit. Figure 4 shows this includes about 80% of fragments of size 1 to 10 cm and 65% of larger fragments. This will pose a small but long-term risk to ISS.

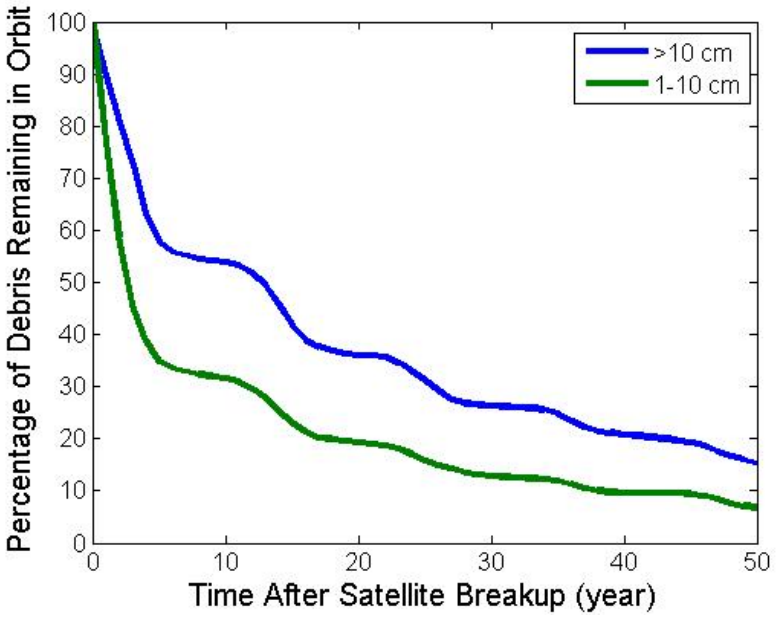


Fig. 4: Fraction of debris from the Feb. 2009 collision that is expected to remain in orbit as a function of time after the collision. The irregularity of the curves is due to effects of the 11-year solar cycle (figure credit: Wang Ting).

Previous Collisions

Table 2 below summarizes the known collisions between objects in space. As noted above, the term "cataloged debris" generally refers to debris that is large enough to be detected and tracked from the ground.

The current collision is the third known case of an active satellite being hit by a defunct satellite or other piece of debris (these are shaded in the table). Because of the large number of active satellites in space (more than 900) and the very large amount of debris, we estimate that a collision between a piece of debris larger than 1 cm (0.4 inch) with some active satellite in a near-Earth orbit would occur on average every 2 to 3 years over the next decade (prior to several debris-producing events in 2007, our estimate was a collision every 5 to 6 years). The observed collisions in 1996, 2007, and 2009 seem to roughly agree with this estimate.

Another way of describing the debris threat to satellites is that in the 800 to 1,000 km altitude band, the chance that a particular satellite will be hit by debris larger than 1 cm is now likely greater than 1% over the satellite's 5 to 10 year lifetime. While this may sound small, it is comparable to other problems that may render a satellite non-functional, such as a failure of its electronics. Debris collisions could become the largest threat to shortening the useful life of a satellite.

1991	**Inactive Cosmos 1934 satellite hit by cataloged debris from Cosmos 296 satellite**
1996	**Active French Cerise satellite hit by cataloged debris from Ariane rocket stage**
1997	**Inactive NOAA 7 satellite hit by uncataloged debris large enough to change its orbit and create additional debris**
2002	**Inactive Cosmos 539 satellite hit by uncataloged debris large enough to change its orbit and create additional debris**
2005	**U.S. rocket body hit by cataloged debris from Chinese rocket stage**
2007	**Active Meteosat 8 satellite hit by uncataloged debris large enough to change its orbit**
2007	**Inactive NASA UARS satellite believed hit by uncataloged debris large enough to create additional debris**
2009	**Active Iridium satellite hit by inactive Cosmos 2251**

Table 2: The known or suspected past collisions between objects in space.

Collision Avoidance

Currently, the U.S. Space Surveillance Network (SSN) tracks some13,000 objects and routinely updates their orbital information on the Space Track website.[3] However, the uncertainty of such data is believed to be hundreds meters in LEO. Such accuracy is not enough for effective collision avoidance. For example, on average a debris fragment would pass within 1 km of the Iridium 33 satellite every 13 days. If the satellite were maneuvered on each of these occasions, it would use the satellite's fuel and therefore reduce the useful lifetime of the satellite.

The SSN has more accurate data than is released publicly, which is used by the U.S. military, and by NASA in supporting U.S. space missions. The European Space Agency (ESA) and China use their own tracking systems to protect their critical missions.

Although the collision risk of satellites in geostationary orbit (GEO) is much lower than that of LEO satellites, almost all commercial companies have started sharing orbital data with each other for collision avoidance. However, the United States has been criticized after one of its military early warning satellites in GEO (DSP-23) failed in September 2008, because the United

States will not release tracking information about the satellite. Amateur observers are instead tracking the drifting satellite.[4]

The Debris from the Iridium-Cosmos Collision

If the two satellites hit nearly head-on, rather than a glancing blow, the energy of the collision would completely disintegrate both satellites into clouds of debris. As mentioned above, we do not yet know whether the collision was head-on.

One can estimate how much debris would result from a head-on collision between these two satellites using a model developed by NASA and revisions of that model based on recent breakup events.[5] The Iridium satellite had a mass of more than 500 kg and Cosmos satellite had a mass of nearly one ton, so that the total mass involved in the collision was roughly twice the mass of the Chinese FY-1C satellite. As a result, the number of debris particles could be considerably higher.

However, the number of particles identified in the first two weeks after the collision suggests that the number may be less than that created in the FY-1C breakup. The estimates of debris that could result from this collision are shown in Table 3 below, categorized by the size of the debris particles.

Size of debris particles	> 10 cm (4 inches)	> 1 cm (0.4 inch)	> 1 mm (.04 inch)
Number of debris particles	**1,000-2,000**	**60,000-120,000**	**3-6 million**

Table 3: Estimated debris, by size, from the collision.

The U.S. space tracking system can only reliably detect debris larger than 5 to 10 cm (2 to 4 inches), so the vast majority of the debris created in this collision will not be observed from the ground. However, as discussed above, debris larger than about 1 cm (half an inch) can significantly damage or destroy a satellite in a collision. So the total amount of dangerous debris resulting from this collision will be much greater than the amount detected from the ground.

Prior to this collision, there were roughly some 3,000 objects larger than 10 cm in the region between 700 to 900 km (450 and 500 miles) altitude, so the additional 1,000-2,000 objects created by this collision (maybe half of which will stay in this altitude band) represent a significant increase. The destruction of the FY-1C satellite created about 2,500 debris particles of this size around an altitude of 850 km (530 miles), roughly half of which may be in this altitude band.

Debris Mitigation

Since there is currently no effective way to remove large amounts of debris from orbit, controlling the production of debris is essential for limiting the risk of collisions in space. Starting in the mid-1990s, an international consortium of countries developed a set of debris mitigation guidelines that have been adopted by the United Nations.[6] For example, removing defunct satellites from heavily used parts of space can reduce the chance of this kind of collision.

The relatively slow growth of cataloged debris during the decade from the mid-1990s through 2006 suggests that these guidelines were effective. Figure 5 shows the historical growth of the catalog of objects in orbit. The red line shows the general trend line of the growth from the early 1960s though the mid-1990s. The blue line shows that the growth trend during the 1990s was significantly slower. However, the plot also shows that a single event—the breakup of the FY-1C in January 2007—created enough debris to undo the gains of the previous decade and jump the curve back up to the historical trend line. The consequences of this destruction of a relatively small satellite makes clear the potential consequences of future breakups. Debris from the current collision could cause a further significant jump in the catalog.

The current guidelines should be strengthened by making them mandatory and adding enforcement measures. Cooperation in space situation awareness should be encouraged. In particular, because of the large amount of debris that can result, significant effort should be made to prevent the breakups of satellites, whether accidental or deliberate.

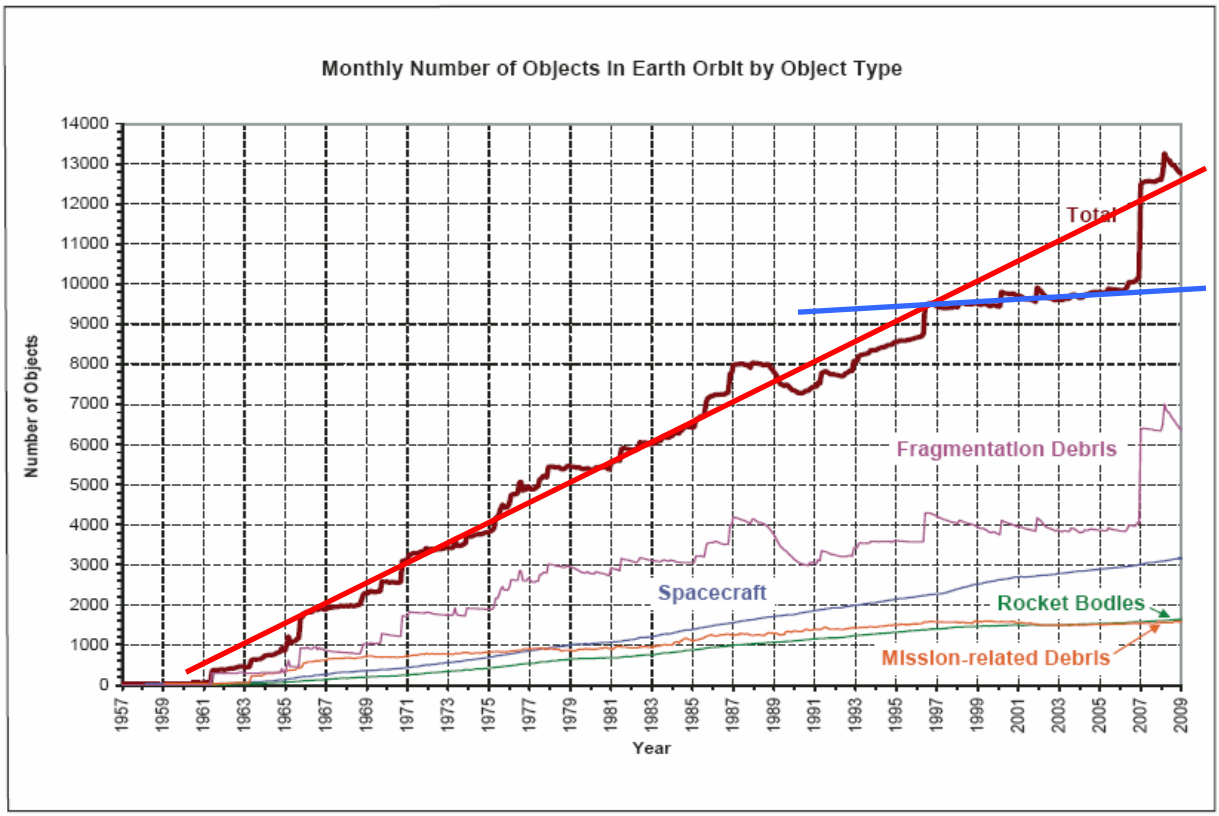


Fig. 5: The dark heavy curve shows the historical growth of cataloged objects in space. The heavy red line shows the growth trend up to the mid-1990s. The heavy blue line shows the growth trend from 1997 to 2007, and roughly follows the increase in satellites ("spacecraft") during that period. The jump in early 2007 is the debris from the FY-1C satellite. (The historical curve is from *NASA Orbital Debris Quarterly News*, Vol 13, Issue 1, January 2009, p. 11, http://orbitaldebris.jsc.nasa.gov/newsletter/newsletter.html)

Supercritical Debris

A NASA study from 2006 showed that the amount of debris is so high at altitudes near this collision that the debris density is already "supercritical," meaning that collisions between

objects in this region will create additional debris faster than atmospheric drag will removes debris from orbit.[7] As more debris is created this leads to a slow-motion chain reaction or cascade that will continue to increase the number of debris particles in this region far into the future. The 2006 NASA study showed that the number of debris particles in this region is expected on average to double every 50 to 70 years due to these collisions.

The fact that this region is already supercritical means that debris mitigation efforts, while important, are not enough. Research to identify practical and effective ways to remove debris from this region is underway, but so far no clear candidates have emerged.[8] On option being studied is robotic flights that would rendezvous with and remove massive objects from this region, such as defunct satellites and rocket bodies, since these are the objects that would create the most debris in a collision. However, such missions would be extremely expensive and are not currently practical.

The Future

In addition to the steps discussed above—debris mitigation and remediation—as space becomes more crowded and involves more countries, the international community must begin to develop and put in place measures for space traffic management, in analogy with air traffic control around busy airports. The goal would be to avoid future collisions, set up shared practices that help preserve the long-term used of space, increase transparency and communication between countries on space issues, and avoid and resolve conflicts between countries due to activities in space.

Additional resources:

David Wright, "Space Debris," *Physics Today*, October 2007
http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/technical_issues/space-debris-from.html

UCS Satellite Database: A free, online database of all active satellites
http://www.ucsusa.org/satellites

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[2] *NASA Orbital Debris Quarterly News*, Vol 13, Issue 1, January 2009, p. 11, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv13i1.pdf; the currently active satellites are listed in the UCS Satellite Database at http://www.ucsusa.org/satellites.

[3] Space Track, www.space-track.org.

[4] D. Leonard, "Wandering U.S. Spy Satellite Prompts Continuing Concerns," space.com, 25 February 2009, http://www.space.com/news/090225-wandering-spysat-danger.html

[5] The NASA breakup model is described in N.L. Johnson, P.H. Krisko, J.-C. Liou, P.D. Anz-Meador, "NASA's New Breakup Model of EVOLVE 4.0," *Adv. Space Res.*, Vo 28, No. 9, pp. 1377-1384, 2001.

[6] *NASA Orbital Debris Quarterly News*, Vol 11, Issue 2, April 2007, p. 1, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv11i2.pdf

[7] J.-C. Liu, N.L Johnson, "Risks in Space from Orbiting Debris," *Science*, Vol. 311, 20 January 2006, pp. 340-1.

[8] *NASA Orbital Debris Quarterly News*, Vol 11, Issue 4, October 2007, p. 7, http://orbitaldebris.jsc.nasa.gov/newsletter/pdfs/ODQNv11i4.pdf