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Galaxy 15, seen here in this pre-launch photo, suffered an irreparable malfunction last month that is causing it to drift through the GEO belt even as it continues to broadcast. (credit: Orbital Sciences Corporation)

Dealing with Galaxy 15: Zombiesats and on-orbit servicing

by Brian Weeden
Monday, May 24, 2010
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On April 8, 2010, news broke that the world's largest provider of fixed satellite services, Intelsat SA, had lost contact with one of its approximately 50 geosynchronous satellites. More important, the satellite's receiver and transmitter equipment was still functioning as it started to drift eastwards from its location in the geosynchronous (GEO) belt. Quickly dubbed "zombiesat" by the media, this combination of uncontrolled drifting while still having an active communications payload means that Galaxy 15 poses a serious concern to other satellite operations in the region of the GEO belt. The first satellite it will encounter, AMC 11, receives digital programming from cable-television channels, including the Food Network and MTV, and transmits it to all US cable systems for distribution.

The inability to easily and accurately determine what caused Galaxy 15's malfunction is a strong incentive to improve the ability to attribute on-orbit failures, both to try and create solutions and to reduce tensions that could arise

Over the last two months that this story has developed, many significant questions have been raised about the long-term viability of operations in the GEO region given the current operational practices of global military, civil, and commercial operators. This article examines the Galaxy 15 event in detail, explains what happened and why it poses such serious problems, and discusses some recommendations for dealing with this in the future in such a way we can continue to use space for benefits on Earth.

from a case of assumed hostile action.

Part one of this article will discuss the Galaxy 15 situation in detail, based on all the facts and reporting to date. Part two will examine the orbital mechanics of the GEO orbit and the implications for situations like Galaxy 15. Part three looks at the radiofrequency interference concerns. Part four discusses solutions to future situations of this nature and presents policy recommendations. In summary:

- This is a first-of-its-kind event, and Intelsat is setting a high standard for how a spacecraft operator should behave in a responsible manner, by communicating the problem to other space actors (including competitors) and working with them to minimize the negative impacts.
- While there is no chance of Galaxy 15 colliding with another satellite in the near-term, it is now one of the hundreds of known pieces of space debris in the most heavily-used and economically valuable zones in Earth orbit, and will pose a long term hazard to GEO satellites located over North America for decades.
- The inability to easily and accurately determine what caused Galaxy 15's malfunction is a strong incentive to improve the ability to attribute on-orbit failures, both to try and create solutions and to reduce tensions that could arise from a case of assumed hostile action.
- Development of on-orbit servicing (OOS) technologies and capabilities, along with improved global space situational awareness, are essential tools to help prevent situations like this in the future and minimizing the negative impacts such situations have on space activities and the space environment.
- The dual-use and security implications of OOS technologies means they should be developed, and more importantly used, in an open and transparent manner to promote confidence and stability in space security.

1. Just the facts, ma'am: The situation with Galaxy 15

According to news reports, on April 5, Galaxy 15 stopped responding to commands from ground operators. Galaxy 15 was providing a variety of media services to North American customers, including video transmissions, and also had a payload used by the US Federal Aviation Administration. Intelsat quickly decided to move one of its on-orbit spare satellites, Galaxy 12, from a holding location to take Galaxy 15's spot and customers. Since the satellite continued to provide service to customers, originally Intelsat deemed the anomaly not terribly serious. It would take a while for Galaxy 15 to drift far enough where its service was disrupted; by then Galaxy 12 would be in place and able to take over.

On April 20, Orbital Sciences, the company which built Galaxy 15, suggested that the communications problems with Galaxy 15 were potentially caused by a large geomagnetic storm occurring in space. In the early morning hours of April 5 the NOAA Space Weather Prediction Center in Colorado released a space weather advisory warning bulletin about the storm. Galaxy 15 had come out of the Earth's shadow and into view of the Sun as this storm was occurring, and some experts suspect this event somehow damaged the satellite's ability to receive or execute commands. However, this has not nor may never be fully verified, in large part because of the lack of ability to correlate space weather with specific malfunctions and failures.

Whatever malfunction did occur did not affect either the satellite's ability to re-broadcast signals or its ability to keep its transponders pointed at the Earth and solar panels aligned with the Sun (known as "Earth lock"). This allowed the spacecraft to continue to receive and transmit signals. What it did affect was the ability of Intelsat's ground controllers to maneuver Galaxy 15 to maintain its orbital position. Intelsat issued between 150,000 and 200,000 commands to the satellite in an attempt to get a response to either turn off its communications payload or maneuver. When these efforts failed, the company attempted to send an even stronger signal to try and force an overload of the satellite's power system and cause it to shut down. This too failed. As a result, the satellite continued to drift slowly eastward through the GEO belt. What had seemed like a small problem was about to get much bigger.

On April 30, the issue of possible interference with other satellites was publicly raised for the first time. On May 4, Intelsat announced that Galaxy 15 was too close to another satellite, AMC 11, to attempt any further interventions. Galaxy 15 drifted into AMC 11's orbital slot around May 23 and is planned to exit around June 7. During this time, it could cause interference with AMC 11's broadcasts. Over the next few months, Galaxy 15 will continue to drift through the GEO belt and past other satellites, potentially causing more interference along the way.

As a result, the satellite continued to drift slowly eastward through the GEO belt. What had seemed like a small problem was about to get much bigger.

Intelsat has announced that they will continue their attempts to regain control or turn off the satellite when the satellite is safely separated from others systems. Given the immense effort Intelsat has already attempted in this regard, it is unlikely that this will succeed. Fortunately, there is a failsafe option. At some point, the momentum wheels used to maintain the satellite's orientation will saturate and the satellite will lose Earth lock. Once that happens, the satellite will no longer able to point its solar panels at the Sun, will lose electrical power, and will shut down. Even if control cannot be re-established at that point, it will mean Galaxy 15 will no longer be able to interfere with the broadcasts of other satellites. The only question is how long it will be before this happens: Intelsat's current estimates suggest that the failsafe scenario will occur at some point this summer.

In the meantime, SES, the owner of AMC 11, has announced a plan for minimizing any interference caused by Galaxy 15 as it drifts past. The plan involves moving another satellite, SES-1, into the same orbital box as AMC 11. As Galaxy 15 passes through the area, traffic will be switched to SES-1 and then back to AMC 11 to stay as far away from Galaxy 15 as possible. SES has posted a computer animation of this process on their website. The plan also includes using a very high power antenna owned by Intelsat in Clarksburg, Maryland, to be able to better distinguish between the three satellites in the same box and transmit to the correct one with pinpoint accuracy.

2. The big racetrack in the sky: The orbital mechanics of GEO

To fully understand the technical issues involved in this event, one needs to take a close look at the space environment. The geosynchronous region is defined by the Inter-Agency Debris Coordination Committee (IADC) as:

> a segment of the spherical shell defined by the following:
> Lower altitude = geostationary altitude minus 200 km
> Upper altitude = geostationary altitude plus 200 km
> inclination of ±15 degrees from the Equator
> where geostationary altitude is defined as 35,786 km

Within this region is the *geostationary* belt, defined as a circular orbit 35,786 kilometers in altitude above the Earth with an inclination of zero (meaning it is directly over the Equator). Figure 1 illustrates this region graphically (the geosynchronous region is in blue and the geostationary belt is in green):

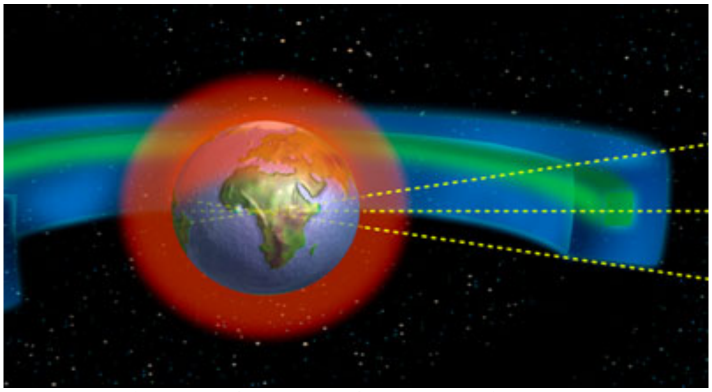
Figure 1: IADC protected zones (credit: European Space Agency)

One can imagine the geostationary belt as a giant circular racetrack and the satellites in that orbit as the cars, going around the Earth in the same general direction and altitude. Although satellites in the belt are moving around the Earth at just under 11,300 kilometers per hour (7,000 mph), they appear to an observer on the surface of the Earth to be almost stationary in the sky because GEO spacecraft make one complete orbit in the same time it takes the Earth to rotate once. If a spectator was to stand in the middle of the infield of a circular racetrack and turn in place at the same rate the cars were moving around the track, you would see the same effect—the cars would appear stationary.

Of course nothing in physics is ever this simple in reality, and indeed the situation in geostationary orbit is much more complex. It is virtually impossible to have an exactly circular orbit at exactly the right altitude, which means every object in GEO is in an orbit with some amount of inclination and eccentricity. Thus, instead of being a perfect stationary dot in the sky, satellites in GEO actually drift in a way that appears to trace a racetrack pattern on surface the Earth, with the north and south height of the racetrack corresponding to their inclination.

Satellites that can stay in a relatively fixed position relative to the Earth provide many useful services. The biggest of these is the ability to provide communications, including television broadcasts and voice services. Since the initial concept of a GEO communications satellite was theorized by Arthur C. Clarke in 1945 and the launch of the first commercial communications satellite, Telstar-1, in 1962, it has become a massive global industry. In 2008, the worldwide satellite services industry, much of which utilizes the GEO belt, brought in revenues of $67.3 billion.

Because of this massive demand to place satellites in such a narrow region, there are measures in place to regulate the GEO zone. An international legal framework managed by the International Telecommunication Union (ITU) was put in place to license and distribute satellite frequencies (in 1963) and slots (in 1973) for geostationary orbit. Each state or private entity that wishes to place a satellite in a specific position over the Equator must apply to the ITU for a license and receive permission if they would like their physical position and operating frequency to be protected from interference. The ITU specifies “slots” in GEO by a certain amount of longitude along the Equator. A slot is defined as the separation needed between satellites to prevent them from interfering with others. Over North America these slots are currently two degrees of longitude, which translates to about 1470 kilometers (915 miles) in the GEO belt.

There are almost twice as many dead and drifting objects in the GEO belt as there are operational payloads.

Within their assigned slot, a satellite operator usually maintains their satellite within a specific orbital “box”. The size of this box depends on a number of factors, including how precise the satellite’s position needs to be to serve its customers and how accurately the operator can determine and maintain its position. Typically a GEO box is around 0.1 deg of longitude or 70 kilometers (43.5 miles) in length. In certain situations, a satellite operator might be operating multiple satellites within the same slot in what is called a cluster. Clusters allows for a lot more satellites to be packed into the same area, but create significant challenges for keeping the satellites separated.

A satellite operator must periodically perform "station-keeping maneuvers" to stay within their box and slot because there are several natural forces at work in the GEO region called *perturbations* that change orbits over time. There are three significant perturbations to focus on in GEO. The first major perturbation is the gravitational pull of the Earth. The exact forward velocity of a satellite in orbit around the Earth is determined by the strength of the Earth's gravitational pull and the altitude of the satellite. The Earth is not a perfect sphere so it follows that its gravitational field, which is a function of its mass, is not the same everywhere around it. In fact, there are two "bulges" along the Equator at approximately 75° East longitude and 105° West longitude, over the Indian subcontinent and North America, respectively. As described earlier, these gravity "troughs" (officially called *libration points*) pull satellites in geostationary orbit east or west towards whichever point is closest, giving the satellite an apparent east or west drift as viewed from the ground.

The second major perturbation in the GEO orbit is the gravitational pull of the Moon and the Sun. The Moon orbits the Earth at an average altitude of 384,400 kilometers (238,800 miles) and at an inclination of between 18° and 28° with respect to the Equator. This means that the Moon is always either above or below the GEO belt and thus its gravity pulls objects in GEO north or south with respect to the Equator. The Sun, although incredibly massive, is much further away at an average of almost 143 million kilometers (93 million miles) from the Earth, so its gravitational pull has less of an impact on satellite orbits, although it is still important.

The third major perturbation is called *solar radiation pressure* and it is caused by photons being emitted by the Sun. A photon is the particle that makes up light. It has no mass but carries momentum. The photons being emitted by the Sun striking objects in orbit transfers some of this momentum, and causes a change in the object's orbit. The amount of change depends on the object's surface area in relation to its mass. A compact or heavy object will barely be affected by solar radiation pressure. However, for objects with huge solar panels, such as a communications satellite, it can significantly change their orbit over time.

The annual *Classification of Geosynchronous Objects*, published by the European Space Agency's Space Debris Office, is the best reference for what sorts of objects are located in GEO and how many there are. The February 2010 report provides the following details:

> A total of 1,238 objects known objects are in the GEO region:
>
> - 391 are under some level of control (either in longitude, inclination, or both)
> - 594 are in a drift orbit
> - 169 have been captured by one of the two libration points
> - 11 are uncontrolled with no recent orbital elements available (usually meaning they are lost)
> - 66 do not exist in the U.S. military's public satellite catalog but can be associated to a specific launch

As these numbers illustrate, there are almost twice as many dead and drifting objects in the GEO belt as there are operational payloads. And there are likely to be many more pieces of space debris that have not yet been detected: current space situational awareness (SSA) capabilities can only reliably detect objects to about the size of a basketball at GEO altitudes.

Compounding the problem of space debris are satellites that are left in the GEO belt at the end of their service life. According to the recently adopted United Nations Space Debris Mitigation

Guidelines, which are based on the more extensive IADC Guidelines, spacecraft operators are supposed to perform an end-of-life disposal maneuver to remove their satellite from the protected

 es)

Unfortunately, the guidelines don't resolve problems associated with spacecraft left in the GEO belt during the early years of the space age, and compliance with these guidelines for new spacecraft is still spotty at best. According to the February 2010 *Classification of Geosynchronous Objects* report, of the 21 GEO spacecraft that reached end-of-life in 2009, only 11 were disposed of properly. Several were moved out of the active belt but not into an orbit high enough to ensure that they do not cause problems in the near future. Three spacecraft, all Russian, appear to have been abandoned in the active belt and are now librating about the 75° East libration point. Four rocket bodies, three Russian and one American, which were used to place payloads in GEO, also orbit within the protected zone.

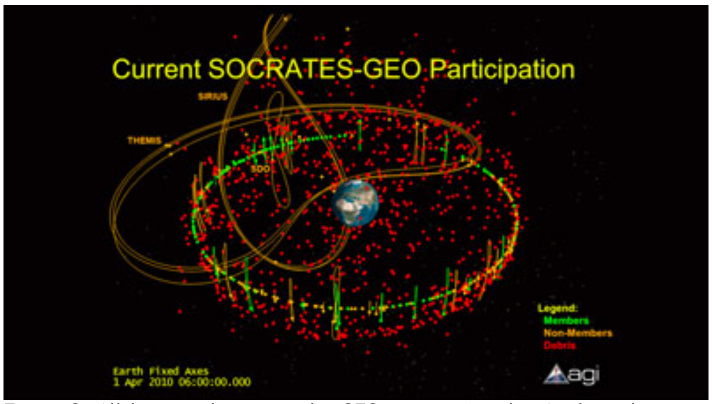

Figure 2: All known objects in the GEO region. (credit: Analytical Graphics Inc.)

Figure 2 sums up all of this information about active satellites, debris, and drifters to give a picture of what the GEO environment looks like. Active satellites are in green and orange, while space debris is in red. Far from being the simple, straightforward, organized region as it is sometimes portrayed, the GEO environment is in reality a chaotic place. Accurate stationkeeping by all satellite operators is extremely important, and the in-place failure of a satellite like Galaxy 15 makes this problem worse. While it is unlikely that Galaxy 15 will collide with another object in the near future, our current inability to remove it from the active belt means that it will remain in the region essentially forever.

While it is unlikely that Galaxy 15 will collide with another object in the near future, our current inability to remove it from the active belt means that it will remain in the region essentially forever.

Over the next several weeks, Galaxy 15 will continue to drift eastward from its original slot at 133° W towards the libration point over North America at 105° W, approximately where the Rocky Mountains are. To picture what happens next, consider a car on top of a hill with a road that goes down into a valley and then back up to another hill. If the car is pushed down the hill, it will go through the bottom and up the other side. If it has enough speed, it will go up and over the other side and escape the trough. But if it does not, then it will stop somewhere on the far hill short of the top and then roll back down, through the bottom, and then back up the first hill. Eventually, after several trips up and down, the car will settle at the bottom of the valley.

The same physics are at work with the libration points. If Galaxy 15's drift rate is high enough, it will drift through the 105° W libration point and continue across the Atlantic Ocean and perhaps be captured by the 75° E point over India. But it is much more likely that Galaxy 15 will be trapped in the gravitational valley created by the 105° W libration point and oscillate back and forth on either side of it, joining the other 43 pieces of space debris already trapped there, all of which pose a long-term navigation hazard to the GEO satellites located over North America.

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Dwayne Day · *6 weeks ago* 0

An excellent summary of the subject.

Reply Report

Intex · *6 weeks ago* +1

Very excellent. If there's a prize for this sort of essay, we have a winner.

Technology for clearing out dead stuff from GEO would seem to be a good subject for a commercial prize. Ion engines, solar sails or who knows what might compete

Reply **1 reply** · *active 104908 weeks ago* Report

Guest · *5 weeks ago* 0

Excellent response. Thank you! There are two programs underway for clearing out dud satellites and/or servicing them in LEO: one by Canada's MDA and the other by Germany's OHB. Curiously, the OHB project uses a Canadarm-like arm to grapple its target and the Canadian solution uses a kind of Svend Foyn gun to shoot a harpoon up the orbital insertion motor's throat. Either solution would work, one supposes, to get control of a satellite and make a retro burn to dump the whole lot into the Pacific. Getting such a rig up to GEO and across the kinds of distances out there to reach more than one satellite (for servicing) is a different matter, Bottom line: stop events like this one and reduce future orbital debris by de-orbiting satellites before they break up into killer-bee sized, high-speed lumps. A design contest that includes economic and legal components ought to be worth something. Maybe sone law firms might sponsor it?

Reply Report

David WELLINGS BOOTH · *6 weeks ago* 0

A very interesting article - thanks

Reply Report

Paul Remac · *6 weeks ago* 0

Many figures and features of the GEO region. Thanks

Reply Report

M. Antoniewicz II · *6 weeks ago* 0

Oh, we could be taking care of the problem right now but for ... a lack of imagination.

Check Dennis Wingo's replies in the comments section;
"Dennis Wingo, Call Your Office" - 2010May03 http://www.transterrestrial.com/?p=26484

Reply Report

Brett Buck · *6 weeks ago* 0

I note that this is ABSOLUTELY NOT a "first of it's kind event". There have been many "died in place, payload still on" failures in geosynchronous orbit. Dating back to the early 70's. For example, the second DSCS II - spinning section containing the majority of the support system failed, despun section with payload (x-band) stayed on, and for decades it blinked its beacon at 1/rev as it drifted (and still drifts) through the geosynchronous belt. But there are numerous others.

I don't think that this significantly changes the nature of he problem but in fact this is hardly an unprecedented event.

Reply [1 reply](#) · *active 104908 weeks ago* [Report](#)

Guest · *5 weeks ago* 0

...nor will it be the last,

Reply [Report](#)

[SwitzTrail](#) 80p · *5 weeks ago* +1

This is going to be over our heads for a long time and with all those satellites .2 degrees apart. We have them at 129,127,125,123,121,119,118.6., 113,111,107,105, 103, 101.
This is going to be a roller coaster.

Reply [Report](#)

Guest · *5 weeks ago* 0

How long does it take for a geosat to return to Earth?

LAGEOS will be up there for 8 million years and it is in a much lower orbit.

Reply [Report](#)

Zardar · *5 weeks ago* 0

Why does the geosat's onboard computer not have a command loss timer to force it into some sort of safe mode if it dosn't recieve a command from earth within X days?

Reply [1 reply](#) · *active 5 weeks ago* [Report](#)

Brett · *5 weeks ago* 0

I can't think of any good reason in this case. A lot of them, however, have requirements for autonomous operation and/or no effective safing system. In either case you can't bail out of the mission based on command loss. If nothing else it makes the command receiver reliability the driver for the entire system.

Reply [Report](#)

Guest · *5 weeks ago* 0

...because nobody made it a requirement; e.g., the owner, the launch agency, the insurance company, etc.

Reply [Report](#)

Post a new comment

Enter text right here!

Galaxy 15, seen here in this pre-launch photo, suffered an irreparable malfunction last month that is causing it to drift through the GEO belt even as it continues to broadcast. (credit: Orbital Sciences Corporation)

Dealing with Galaxy 15: Zombiesats and on-orbit servicing

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3. Beeps and squeaks: Electromagnetic and radiofrequency interference

The orbital mechanics of the physical environment discussed above is only part of the picture to fully understanding the scope of the Galaxy 15 challenge. There is another side to the GEO environment that is invisible to our eyes and even optical telescopes. It is the electromagnetic (EM) environment, and it is here that Galaxy 15 poses the biggest short-term challenge.

In addition to being the most physically congested region, the GEO belt is also a region in space that suffers from significant electromagnetic and more specifically radiofrequency (RF) inference. This is partly because, as discussed above, the satellites in GEO are all in relative close proximity to each other, as seen from the Earth. More importantly, though, many of the satellites in GEO broadcast on the same frequencies. To understand why this is, we need to examine the electromagnetic spectrum and talk about more physics.

The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. Figure 3 shows the EM spectrum, which stretches from very low frequency waves (radio and TV) to very high frequency waves (gamma and X-rays).

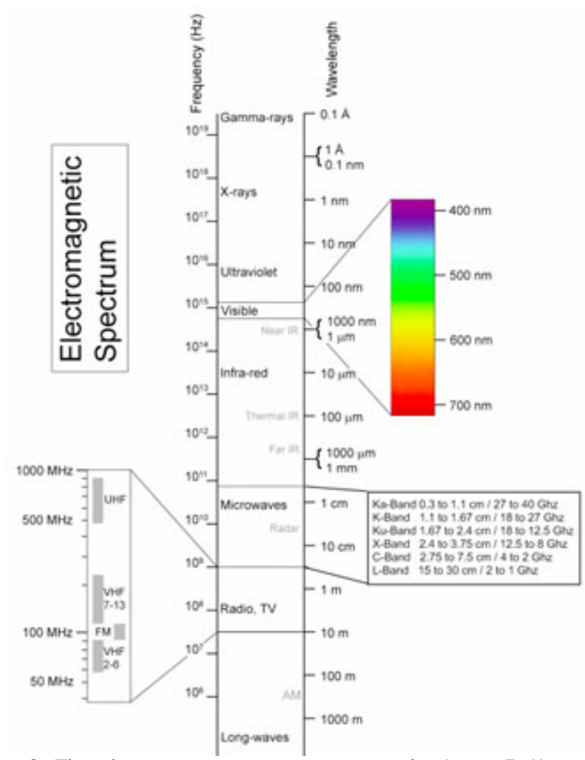

Figure 3: The electromagnetic spectrum. (credit: Louie E. Kerner, Coastal Carolina University, modified by Brian Weeden)

In theory, any of these wavelengths can be used to carry information. However, if you need to transmit from space to the ground there is a catch: the Earth's atmosphere absorbs large portions of the EM spectrum, meaning that entire ranges of the spectrum are ill-suited for this function. Figure 4 shows the wavelengths that are absorbed by the Earth's atmosphere and about how far the various types can reach. There are only two "windows" in the atmosphere that permit EM waves to travel without attenuation: the *optical window* and the *radio window*.

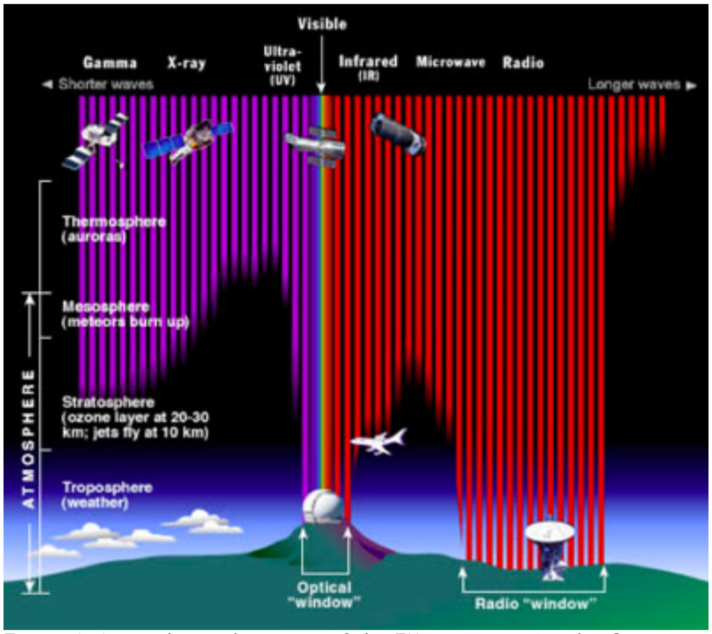

Figure 4: Atmospheric absorption of the EM spectrum. (credit: Space Science Telescope Institute)

The optical window played a massive role in plant and animal evolution on planet Earth and is the reason why our eyes have evolved to perceive the "visible" portion of the spectrum that we do. And while optical frequencies are used extensively for communications through fiber optic links, those frequencies are ill suited for satellite communications applications. Transmitted through free space, incoherent optical frequencies disperse quickly. Coherent optical signals—lasers—can carry large amounts of information but can only carry it point-to-point and not over a large area. Additionally, the technology to create and utilize lasers for communication has only recently been developed. Optical wavelengths are also blocked by physical barriers such as walls and ceilings. Radio waves, on the other hand, are very useful for space-to-ground communications. They can be generated fairly easily and reliably using just electrical power, and can be used to broadcast a signal over either a very wide or very narrow area.

Calculating the bandwidth (or information carrying) potential for a given frequency is a complicated matter, but essentially the higher the frequency used for a communications channel, the more information a signal can carry and thus the higher

Because all of its receive and transmit gear is still working, Galaxy 15 is essentially an open microphone which could accidently pickup and re-broadcast C-band signals it comes across as it drifts through the GEO

bandwidth of that channel. Figure belt.
3 also shows some of the frequency allocations, called bands, which are within the radio window. Most current communications satellites use what is called C-Band, between 2 and 4 Ghz. Recent advances in technology and engineering have allowed satellites to be built which use high frequencies such as Ku (12.5 to 18 Ghz) and most recently Ka (27 to 40 Ghz). However, given that commercial communications satellites are expensive investments, they are usually engineered to last several years or more. Thus, many of the current satellites in use, including Galaxy 15, operate in the C-Band.

A communications satellite is essentially a giant relay. Transmissions are sent to it via an uplink channel and the satellite re-broadcasts these transmissions via one or more downlink channels. The geographic area on the Earth these downlinks can cover is called the *footprint*, and they can cover the entire portion of the planet under the satellite, a technique known as *broad beaming*, or just a very small region, known as *spot beaming*. Galaxy 15's users have been shifted to other satellites, meaning that there is no longer anyone deliberately sending signals for it to re-broadcast and thus it is not actively transmitting.

However, because all of its receive and transmit gear is still working, Galaxy 15 is essentially an open microphone which could accidently pickup and re-broadcast C-band signals it comes across as it drifts through the GEO belt. This is the primary concern as it drifts past other active C-Band satellites, the first of which is the aforementioned AMC 11. As it drifts past, Galaxy 15 could pickup and re-broadcast C-band emissions intended for AMC 11, potentially causing multi-path interference.

4. Is that a tow truck coming towards me? Recommended steps to deal with future situations

Having discussed the physical and electromagnetic problems that Galaxy 15 is creating, we can now talk about what can be done to mitigate this problem or perhaps even prevent it from happening again. Unfortunately, the answer for right now is not much.

First, it cannot be understated how important space situational awareness is to this situation. SSA provides the critical information about what is happening in Earth orbit and the possible negative impacts events might have. A satellite operator such as Intelsat has excellent information about the locations of their satellites, but no accurate information about the locations of other objects in orbit, including satellites operated by others and debris. The United States military operates global networks of ground and space-based radars and optical telescopes which are used to build catalogs of objects in orbit (see "The Numbers Game", The Space Review, July 13, 2009, for more details). These catalogs are the best sources of information about space debris, but generally do not have as good information about actives satellites as those satellites' owners do.

This means that the key to establishing good SSA is data sharing between the states that operate sensor networks, and thus have the best data on locations of space debris, and the satellite operators, which have the best data on the locations their satellites. This positional data also needs to be combined with space weather forecasts, modeling, and warning. In this regard, the Iridium-Cosmos collision in February 2009 prompted the US to begin to offer SSA sharing services to nations and commercial operators through its Shared Space Situational Awareness program (formerly known as CFE). Intelsat and other members of the GEO satellite operator community have also come together to form the Space Data Association to share data among participating operators and potentially other entities. **Both of these are significant developments toward solving some of the issues associated providing SSA and data sharing and should be applauded, but much more still needs to be done.**

Intelsat is setting a new enhanced standard for how a satellite operator should respond when situations like this happen.

From all the known evidence, Intelsat should not be blamed for this incident. Unfortunately, satellites fail in the active GEO belt regularly—on average about one per year. In February 2010, another Intelsat satellite, IS-4, also failed in the active GEO belt at its operational slot of 72° E, although it was close to the end of its expected service life. On May 17, 2010, a Russian communications satellite, Express-AM1, apparently had an on-orbit failure of its attitude-control system in its operational slot at 40° E over Europe. At this time it is unknown if it can be moved to a disposal orbit.

There can be a variety of reasons for these failures. The two most likely scenarios are a severe space weather event, for which manufacturing or operational solutions that mitigate the threat are not presently available, or an equipment failure on the satellite, perhaps the result of a problem with design or manufacturing. What is unusual in the case of Galaxy 15 is that the failure did not damage its communications payload. However, this situation could have happened to any of the satellite operators—it just happened to be Intelsat this time, and it is almost certain that similar failures will occur again with another spacecraft.

Through its actions during this event, Intelsat is setting a new enhanced standard for how a satellite operator should respond when situations like this happen. Intelsat has been working feverishly not only to try and regain control or turn off the satellite, but also to notify their fellow satellite operators (and competitors) and work with them to try and find ways to mitigate the problem. **Intelsat's actions with regard to communication and cooperation in this situation should be considered the standard of care by all satellite operators for future situations of this nature.**

This is in stark contrast to what happened with another recent failure, that of DSP Flight 23 in the fall of 2008 (see "The ongoing saga of DSP Flight 23", The Space Review, January 19, 2009, for more details). DSP-23 was a US military satellite which was placed into GEO in November 2007 as part of an existing constellation which provides global missile warning.

The first reports of DSP-23's failure came not from the US government but from amateur satellite observers who had noticed that it had stopped station-keeping in its assigned slot and had also stopped broadcasting as powerfully as before. DSP-23 was originally located over Europe and drifted towards the libration point at 75° E over India, going right through a cluster of three operational satellites operated by Eutelsat and then a cluster of six satellites operated by SES Astra. Sadly, it was the same amateur observers who provided SES Astra with the first warning that DSP-23 would drift through their constellation, and it was only after it broke in the media that the US government provided assistance to SES Astra.

It is not just the United States that has acted with undue secrecy when it comes to its sensitive satellites adrift in the active GEO belt. There are numerous Russian military satellites that either failed or were intentionally left in the active GEO belt, along with many Russian rocket bodies. And while the United States has made significant strides recently in providing conjunction assessment assistance for all space actors, the Russian government still does not even provide basic catalog data on debris to the public.

Although SSA, communication, and cooperation are critical to responsibly dealing with a "zombiesat" situation, they do not solve the problem. This leads one to consider the core problems of placing objects into space, particularly in the GEO orbit: What do we do when a spacecraft "breaks"? Satellite engineers put a lot of time and effort into designing systems that are redundant on multiple levels and can withstand the harsh space environment. However, satellites are complex machines and do fail, and when they do so in orbit, their operator can't just pull over into a pit-stop to the side of the road and call for a tow to the nearest repair shop.

That may soon be changing. Recently, there has been renewed interest in the concept of on-orbit servicing (OOS), the ability to refuel, move, or even fix satellites in orbit. In 2007, a student group from the International Space University produced a detailed report on the topic, outlining which missions have the most viability from a technical and economic standpoint and what the challenges are to making OOS a reality.

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In March 2007, the Defense Advanced Research Projects Agency (DARPA) conducted an experimental mission in low Earth orbit to test some OOS technologies. Dubbed Orbital Express, it consisted of two spacecraft: the Autonomous Space Transport Robotic Operations (ASTRO) vehicle and a prototype next-generation serviceable satellite called NEXTSat. Over the course of three months, the two spacecraft conducted a series of operations, including docking and transfer of fuel and a battery change. Recently, MacDonald, Dettwiler and Associates (MDA), a major Canadian space contractor, announced that it saw increased evidence of a business case for OOS, especially in the GEO region, and that it is currently working on further developing the Orbital Express technology for GEO applications.

Development of OOS technologies could potentially allow for several beneficial capabilities. The first would be placing an on-orbit “tow truck” in the GEO belt (or in low Earth orbit) that could be used to move malfunctioning satellites such as Galaxy 15 back to their assigned slots. If everything else is working except for their ability to maneuver, the tow truck or other system could attach an auxiliary maneuvering system to the satellite to repair and allow it to resume operation.

An orbital tow truck could also be used to boost satellites out of the active GEO belt at the end of their service life. This tow truck function could also be expanded to include all the dead spacecraft, rocket bodies, and other large pieces of debris already littering GEO. Known as orbital debris removal (ODR), this process of actively removing objects is the only known way to clean out the legacy debris that exists in GEO and is a topic that has received a lot of attention lately.

Currently, one of the biggest issues with this is accurately estimating the amount of fuel remaining onboard a satellite. This is very difficult to do, with potentially serious cost implications for the operator. If they err on the side of caution and dispose of the satellite early, it could mean forgoing months or years of revenue generated by the satellite. But if they wait too long, they might not have enough fuel to move the satellite out of the way. In either case, hiring an OOS satellite to perform the disposal maneuver for them could be very beneficial.

At the 5th European Space Debris Conference in spring 2009, scientists and debris researchers concluded that simply reducing the amount of space debris we create is not going to solve the problem. There is enough existing debris that even with no new launches, debris-on-debris collisions will continue to create more debris. The researchers concluded that ODR is necessary to ensure the long term sustainability of Earth orbit, and that removing a few as five or ten of the most massive debris objects each year might be enough to stabilize the growth in debris population. These conclusions prompted DARPA and NASA to jointly sponsor the first International Conference on Orbital Debris Removal, held in December 2009.

In the end, all states need to remember that outer space is the domain of no individual state, and the actions of any one actor in space can have consequences for the orbital environment and on the operations of all other space actors.

There is a downside to developing these OOS capabilities: most of the technologies and capabilities that provide OOS could also be used to intentionally harm satellites and could be considered offensive counterspace capabilities. This is not a new concept: it dates back to almost the dawn of the Space Age with the original proposal by the American military for Project SAINT (short for SAtellite INTerceptor), a satellite consisting of a television camera and radar mounted in the nose of an Agena B upper stage. After being placed in orbit, SAINT would then maneuver close to an unfriendly target satellite, photograph and analyze it, and report back all the details to the US military. The US Air Force wanted to also give SAINT the ability to destroy or disable the target satellite, but such efforts were blocked by the Eisenhower and Kennedy administrations and the program was eventually canceled before it became reality.

Recently the US military has funded a series of technology demonstration missions and experiments to develop different technology concepts similar to those found on the original non-destructive SAINT program. On April 11, 2005, the US Air Force launched XSS-11 (USA 165), which demonstrated the capability to rendezvous and inspect satellites in low Earth orbit using onboard cameras and LIDAR (Light Detection and Ranging). And on June 21, 2006, the launch of the MiTEx satellites provided this same capability in geosynchronous orbit (see "Mysterious microsatellites in GEO: is MiTEx a possible anti-satellite capability demonstration?", The Space Review, July 31, 2006). Both XSS-11 and MiTEx were officially labeled technology demonstrators and limited to rendezvous and inspection of other pieces from their respective launches or other American satellites. However, the unofficial possibilities are obvious, and while XSS-11's position was published in the public Space Track catalog, the MiTEx satellites (cataloged under their cover names of USA 187 and USA 188) have never had their position listed publicly by the U.S. military.

NASA's Demonstration for Autonomous Rendezvous Technology (DART) satellite was launched in 2005 and was intended to maneuver close to and conduct proximity operations around the defunct US Navy MUBLCOM satellite. A navigation error that occurred when DART and MUBLCOM were about 200 meters apart resulted in the two objects bumping at a speed of around 1.5 meters per second, slow enough that neither object generated debris nor was destroyed but fast enough to change the orbit of MUBLCOM significantly.

Most recently, the United States launched the X-37B Orbital Test Vehicle 1 (OTV-1) on April 22, 2010. The X-37B is a miniature version of the space shuttle that is launched on top of a conventional space launch vehicle. It is intended to have the ability to stay on orbit for up to 270 days, with significant maneuverability within low Earth orbit and a rumored altitude ceiling of 800 kilometers. Although the OTV-1 was not equipped with a robotic arm, it could be launched with that capability in the future. Certainly, it could be equipped with sensors in its payload bay to examine other satellites.

All that said, there is no evidence that the United States has developed any of these new programs with the goal of using them for offensive counterspace purposes. All of these programs are critical milestones in developing and advancing OOS technology and the lessons learned from them could be of great benefit in situations such as another Galaxy 15 or to eventually serve as orbital debris removal vehicles. However, the continued military funding of these programs coupled with the secrecy surrounding their activities in orbit and/or orbital position serves to garner objections from military space competitors such as Russia and China and promote paranoia and fear from global peace activists. This lack of transparency may cause other states to treat these programs as if they are space weapons. This will invariably lead them to pursue policies and programs that could destabilize the space security situation, which in the long run may be detrimental to the security of US space assets and long term sustainability of Earth orbit.

Thus, it is within the interest of all space actors to continue the development of on-orbit servicing technologies that could be very beneficial to the diagnosis, recovery, or disposal of failed satellites and to remove existing space debris. **But it is crucial that this development take place in as open and transparent a manner as possible to provide the necessary confidence that it is being done consistent with the peaceful uses of outer space, as laid down in the Outer Space Treaty.**

Essential to developing OOS capabilities and using them to reduce space debris and operational problems is the need to foster enhanced and integrated global space situational awareness capabilities in as many states as possible, potentially through participation in regional or international data sharing activities. The ability of states to have multiple, independent, and potentially indigenous sources of information about activities in orbit would be a major step towards alleviating many of the concerns regarding developing of OOS capabilities, and to de-conflict OOS capabilities and dual use technologies in general, including the need to service a particular satellite or remove a specific debris object.

The satellite and space technology export controls that are currently in place in many countries will make it impossible to have full participation by all states in the technology development and operational testing of these capabilities. However, that does not mean that certain countries should be completely excluded from them. **Transparency and confidence building can still be done through briefings on planned activities, openness in regard to the orbital location of potential dual-use spacecraft, and international participation in the selection of debris objects for removal and objects to be serviced.**

Some of the core elements of these policy recommendations do appear to have support within the US government. At a recent conference hosted by the Center for Strategic and International Studies, the Vice Chairman of the Joint Chiefs of Staff, General James Cartwright, warned that the US and other countries could no longer keep the vast numbers of orbiting satellites a secret, and that in some cases secrecy is hampering the competitiveness of the American space industry. He also called for some level of international rules and management for space traffic to increase safety and stability in space. Some of this thinking may be reflected in the forthcoming changes to US national space policy, which is expected to increase emphasis on international cooperation and establishment of norms of behavior in space.

In the end, all states need to remember that outer space is the domain of no individual state, and the actions of any one actor in space can have consequences for the orbital environment and on the operations of all other space actors. There is a shared incentive to create stability and sustainability into the environment to ensure that all states can continue to have access to and use space for benefits here on Earth.

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