Intact Derelict Satellites Pose Debris Generating Risk in Concentrated Clusters

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Background

The pace of satellite launches is increasing as more countries become capable of manufacturing and operating satellites and more/larger constellations are being deployed. However, these operational satellites will be competing for space with a population of intact derelict objects (abandoned rocket bodies and non-operational payloads) in orbit. An operational spacecraft can typically maneuver itself out of harm's way, but the derelict objects, which are hundreds to thousands of kilograms in mass, cannot.

We know that collisions between massive satellites may have significant consequence if—when—they happen. Rather than dealing with the consequence of a collision between derelict objects once it occurs, the space community should be preventing catastrophic collisions from occurring in the first place.

An ongoing study is analyzing the distribution of massive (>700 kg) intact derelicts in orbit to determine which regions have the greatest debris-generating risk. It is shown that the risk associated with collisions between "dead" objects is concentrated in a few distinct groupings of derelict objects in Low Earth Orbit (LEO). Four of these clusters were initially identified in 2016 in an ongoing Massive Collision Monitoring Activity (MCMA); the following year, more derelicts were included to make the clusters more complete so that more of these high-risk objects are being monitored. [1, 2]

The current investigation aims to make the clusters even more complete with the addition of a newly identified cluster and a revamp of the previous clusters.

Quantifying Risk

Collision risk is the product of probability and consequence. Probability of collision is proportional to the spatial density of the objects, i.e. number/km^3, which characterizes how densely populated a region is.

The primary metric for consequence is average mass per derelict since the amount of mass involved in a collision determines how many debris fragments would likely be produced, both trackable and—even worse—lethal nontrackable. While it is feasible to monitor and act upon potential collisions between the trackable debris population, lethal nontrackable debris pose a greater risk due to the difficulty of taking action to predict or avoid collisions with them.

Figure 1 shows risk and its two components (spatial density and average mass) plotted across all altitudes, which identifies pockets of high debris-generation risk in LEO (less than 2,000 km in altitude). While the semi-synchronous (SEMI) region centered around 21,000 km and the geosynchronous (GEO) region around 36,000 km both have noteworthy peaks, LEO is significantly higher.

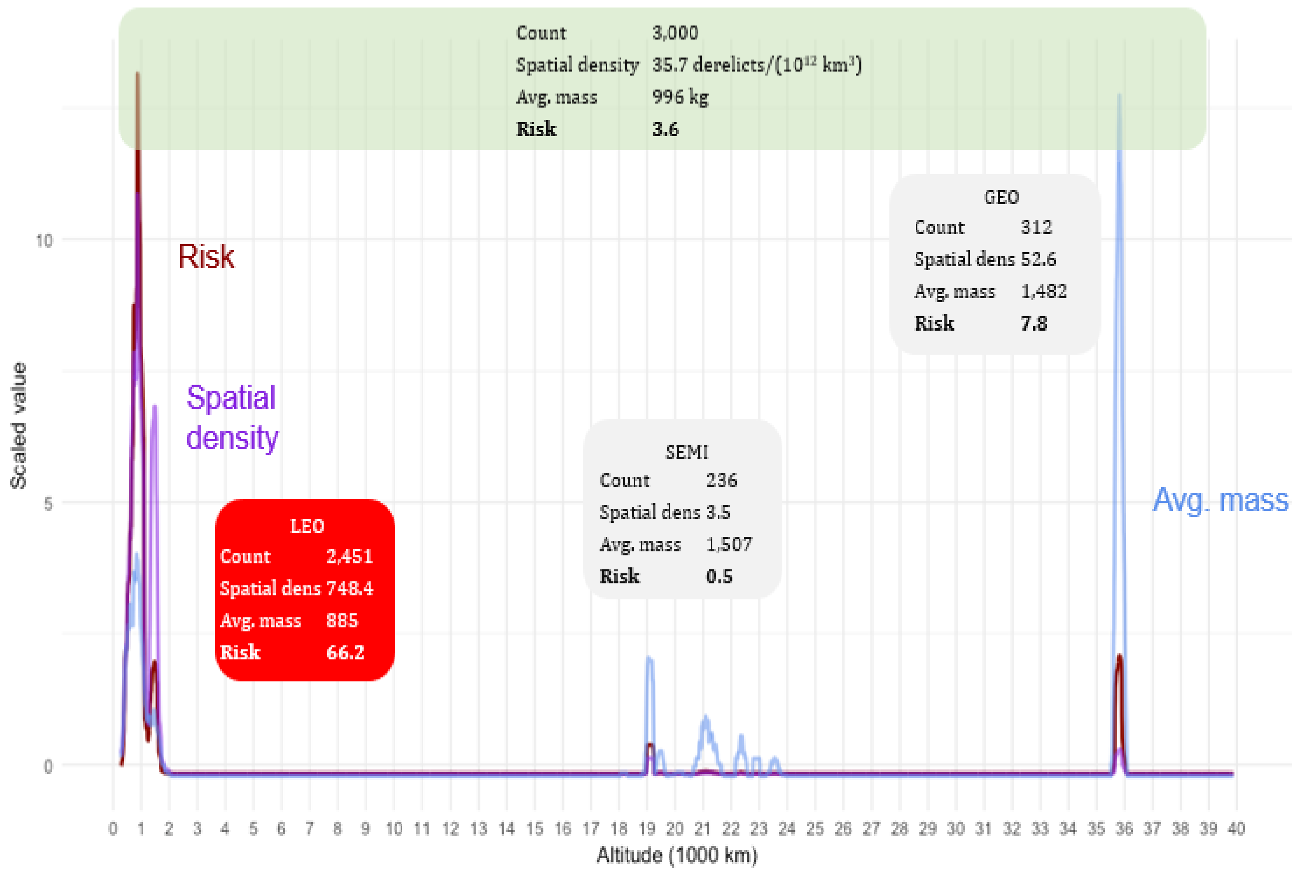

Figure 1 The spatial density, average mass, and debris-generating risk orbits intact derelicts greater than 700 kg for the three most popular Earth orbit regions (i.e., LEO, SEMI, or GEO) are depicted as a function of altitude.

While there are ~3,000 intact derelicts with mass greater than 700 kg in Earth orbit, over 80% are in LEO. So, it is not surprising that the spatial density in LEO is also higher than any other region by at least a factor of 14 (over GEO) but the average mass in LEO is smaller than in GEO. This results in the risk in LEO, on average, being nearly ten times that in GEO and over 120 times higher than SEMI.

However, the massive derelicts, and therefore the risk, are not evenly distributed throughout LEO.

Figure 2 zooms in to plot the spatial density of massive intact derelicts, average mass, and debris-generating risk in LEO as a function of altitude. Several distinctive peaks emerge, centered at 775, 850, 975, 1200, and 1500 km, that correspond to existing clusters being monitored. However, there are also some new peaks of significant importance.

It is relevant to note the original reason for monitoring a consequential subset of objects on orbit was done to reduce the computational resources needed in conjunction screening by limiting the computation to only derelicts within the same cluster instead of an all-on-all comparison. This reduces the number of computations from ~10 million (for the entire satellite catalog) to ~300 thousand (for the identified clusters). By considering only the collisions between objects > 700 kg, this analysis is able to focus on only the most consequential events.

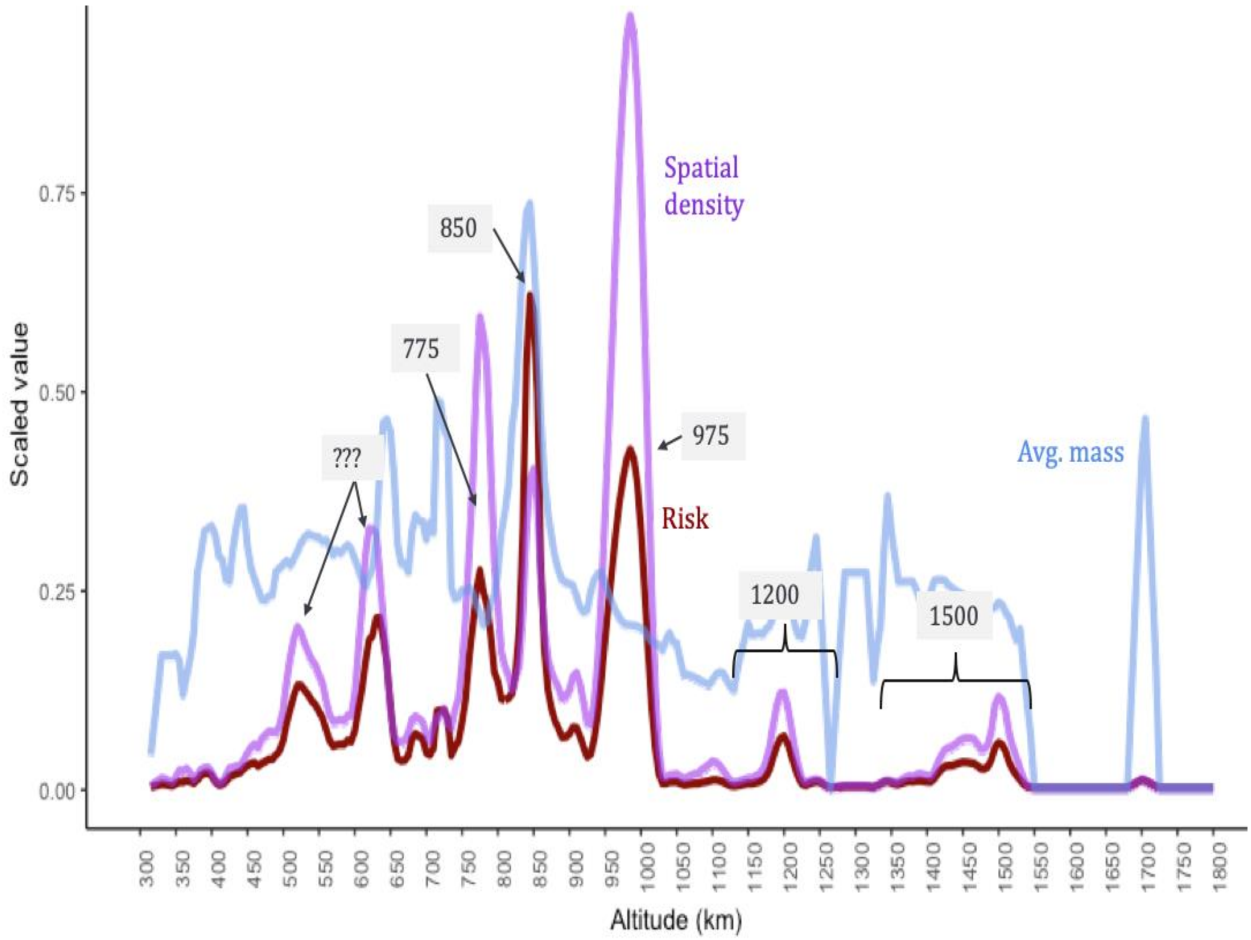

Figure 2. A closer examination of the risk contours in LEO show several clusters of intact derelicts that need to be examined more closely and also hints at modifying some of the existing clusters' altitude spans.

As Figure 2 demonstrates, the two primary peaks, C850 and C975, clearly have the great consequence (i.e., greatest average mass) and greatest probability (i.e., spatial density), respectively.

The other clusters (i.e., C775, C1200, and C1500) also have unique characteristics, however, to show their uniqueness two other factors that amplify the consequence of a potential collision must be explained: debris persistence and value of operational satellites nearby.

Generally speaking, as altitude increases, the effects of atmospheric drag decrease exponentially, meaning objects at higher altitudes will have longer orbital lifetimes (i.e., the debris from a collision will persist in orbit much longer time).

C775 has formed in a region that has more operational satellites in its vicinity so that any debris produced from a collision would pose a collision risk to more operational satellites than any other cluster.

Figure 3 overlays the distribution of operational satellites (green curve) and the logarithmic persistence or orbital lifetime (orange line) on the risk plots (red curve). In LEO, persistence of debris and the value of operational satellites put at risk from the debris generated from collisions are like two opposing forces—higher altitudes have longer persistence but generally fewer operational satellites. The concentrated overlapping of derelict risk and operational satellites at 775 km makes this cluster significant in a way that the other existing clusters are not.

The additional peaks in the spatial density of operational satellites around 500 and 600 km highlight the need to monitor the derelicts in this region.

<u>A New Cluster Emerges</u>

Most national and international debris mitigation guidelines recommend that a space object should be removed from orbit within 25 years after its mission is completed (i.e., 25-yr rule). This threshold can be met naturally simply by placing the system below 615 to 650 km. [3] If

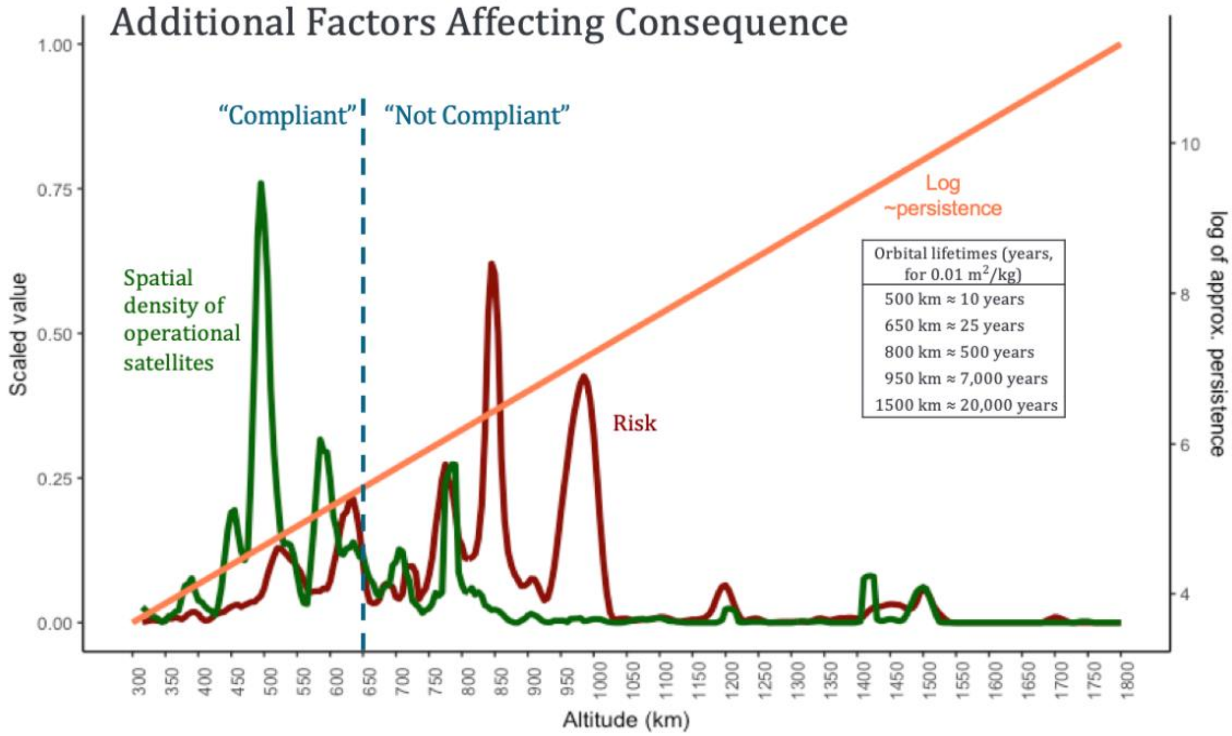

Figure 3. Persistence of debris and proximity to operational satellites are two other components of consequence that are important to consider.

satellite operators want to deploy above this altitude, applicants must demonstrate an ability to move the object to the lower orbit later. This reasoning is why MCMA initially did not consider intact derelicts below ~650 km. Before 2000, only ~3% of payloads were deployed between 500 and 750km, while from 2000 to present, ~25% of payloads have been deployed in this small sliver of LEO.

The potential unintended negative consequence of the 25-yr rule will only continue to grow as more satellites are deployed in this region and as other higher altitude objects are maneuvered to meet the 25-yr rule. Amazon's Project Kuiper is planning to deploy a constellation of 3,236 satellites to LEO, split between 590, 610, and 630 km altitude orbits. While project Kuiper may have selected the orbits carefully to provide "low-latency, high-speed broadband connectivity to unserved and underserved communities around the world" this emerging debris-generating risk at the exact altitudes where they are deploying may come as a surprise. [4]

Figure 4 shows the original "pure" clusters selected for MCMA. These clusters comprised only Russian paired rocket bodies and payloads.

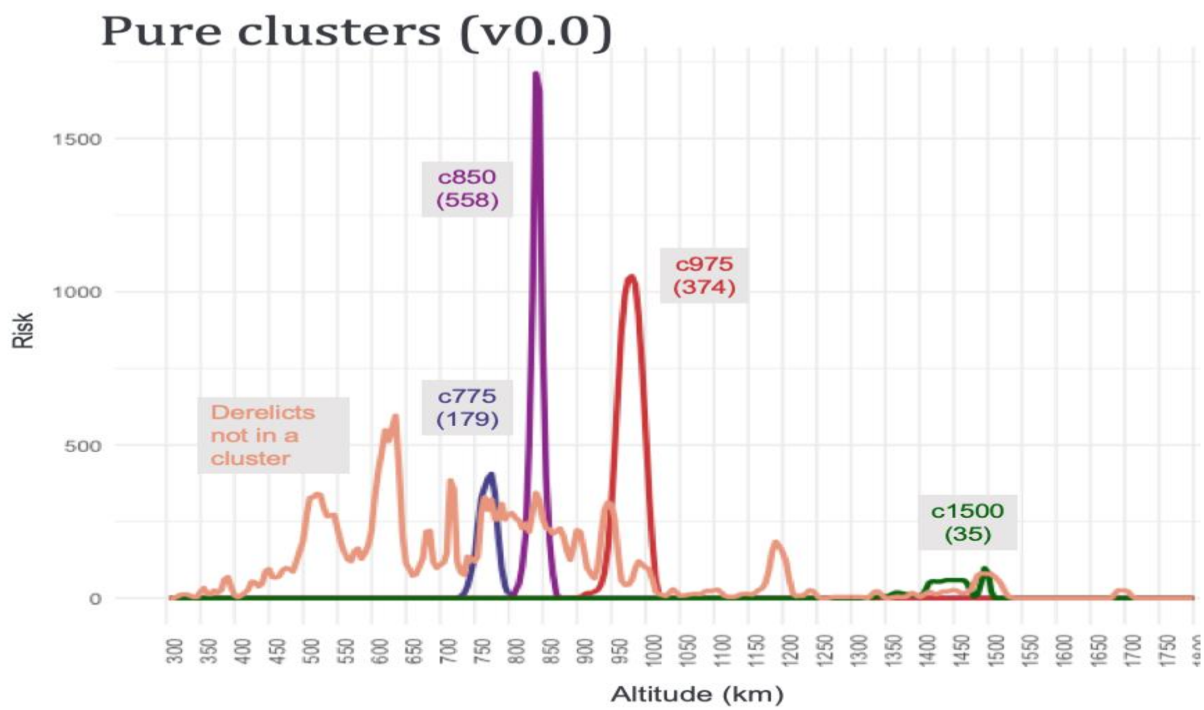

Figure 4 The debris-generating risk in the four "pure" clusters are plotted against the risk from derelicts not included the clusters.

Figure 5 plots the "complete" clusters that are currently monitored. These were formed by adding a new cluster at 1200 km and adding in all intact derelicts above 1,000 kg that resided within the altitude span of the "pure" clusters.

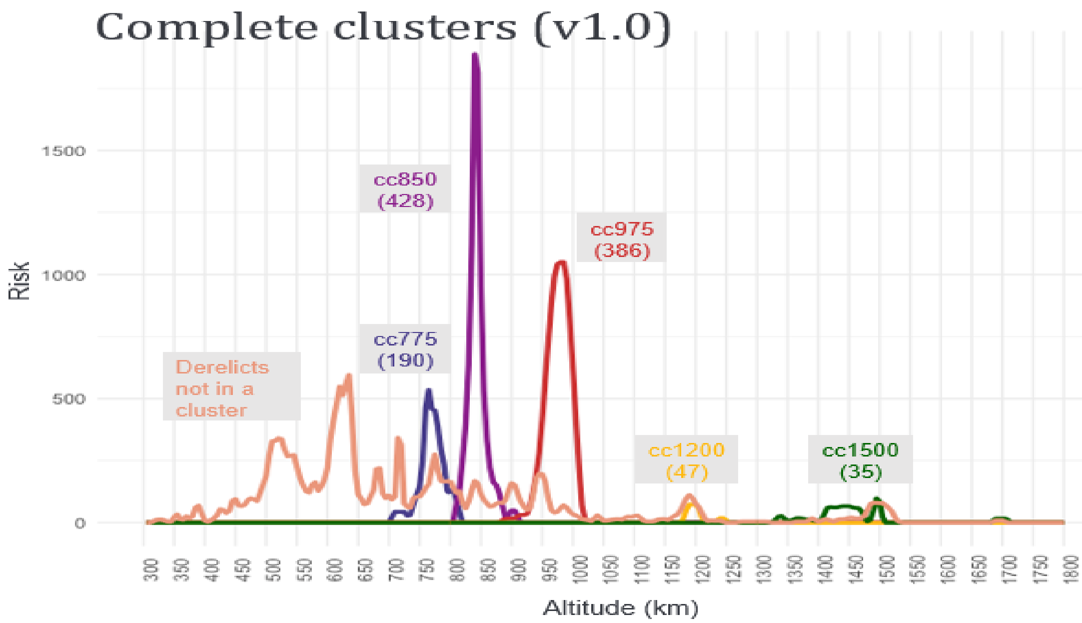

Figure 5 The plot of the debris-generating risk from the "complete" clusters shows how the number of derelicts not included in MCMA dropped moderately with the "complete" clusters.

Figure 6 shows the new proposed MCMA clusters that added a new C615 (including peaks at 550 km and 615 km), expanded the altitude span of C775 to include the risk peak around 700 km, and included all objects larger than 700 kg into each existing cluster. The derelicts not in a cluster are almost non-existent with this last configuration (i.e., MCMA v2.0).

The new cluster (C615) has a bi-modal distribution of derelicts: one peak is centered at 615 km and a smaller one is centered below it at 550 km. Since this altitude region experiences high effects of drag, objects tend to migrate downwards faster than at the higher altitude clusters, so

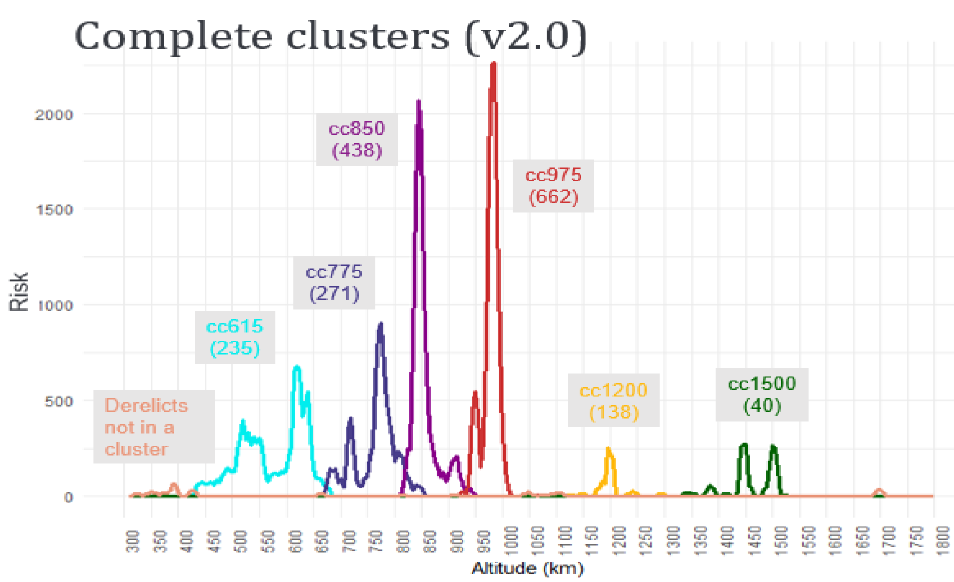

Figure 6 Debris-generating risk in MCMA v2.0 is now captured in six LEO clusters.

the cluster will be more dynamic. Therefore, bi-modal clusters are appropriate for monitoring derelicts via a compelling narrative of clusters.

Summary

Five years ago, when MCMA was first envisioned, derelicts below 700 km were not considered for inclusion in the original clusters. This analysis reiterates the significant debris-generating risk of several clusters of derelicts in LEO, in addition to including a more complete subset of the derelict population. A collision in any of these clusters will likely spread 80% of its debris within is150 km of the collision altitude, so it is important to be as complete as possible. The newly formed cluster at 550/615 is both a result of and a concern for the growing number of satellites deployed in this altitude range. As compared to the previous complete clusters, the revised clusters each contain more of the debris-generating risk from intact derelicts, thus decreasing the potential of a collision involving an object not being monitored.

[1] McKnight, D., Walbert, K., Casey, P., Behrend, S., and Speaks, S., "Preliminary Analysis of Two Years of Massive Collision Monitoring Activity," 68th Astronautical Congress, Adelaide, Australia, September 2017.

[2] McKnight, D., Speaks, S., Macdonald, J., and Ebright, K. "Assessing Potential for Cross-Contaminating Breakup Events from LEO to MEO/GEO," 69th Astronautical Congress, Bremen, Germany, October 2018.

[3] "Mitigation of Orbital Debris in the New Space Age- A Proposed Rule the Federal Communications Commission on 2/19/2019," https://www.federalregister.gov/d/2019-02230

[4] Henry, C., "Amazon planning 3,236 satellite constellation for internet connectivity," April 4, 2019, https://spacenews.com/amazon-planning-3236-satellite-constellation-for-internet-connectivity/