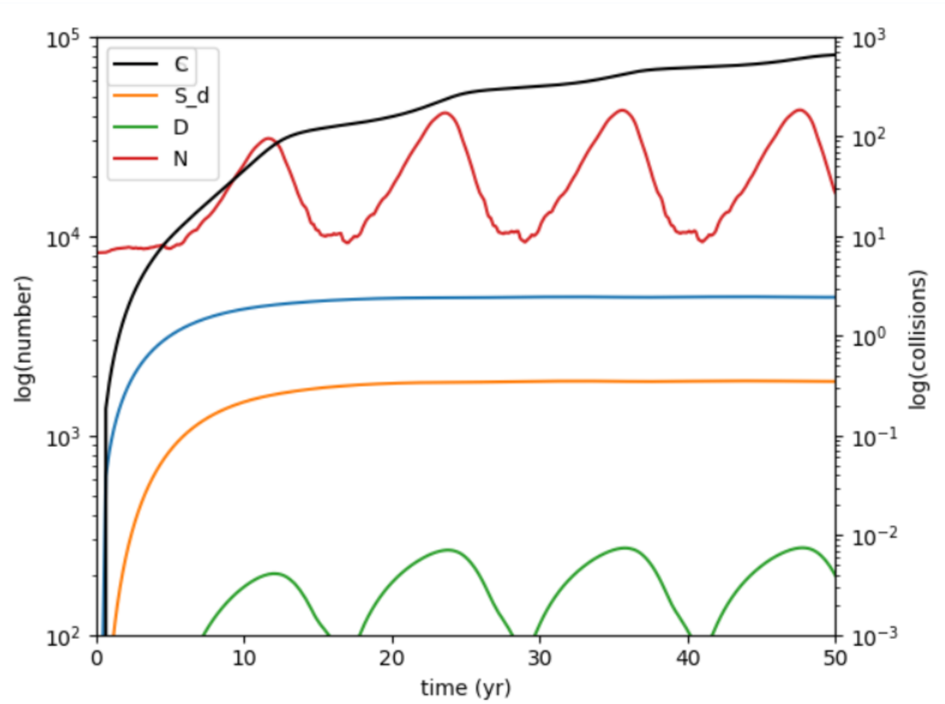
Tests/Simulations Documentation

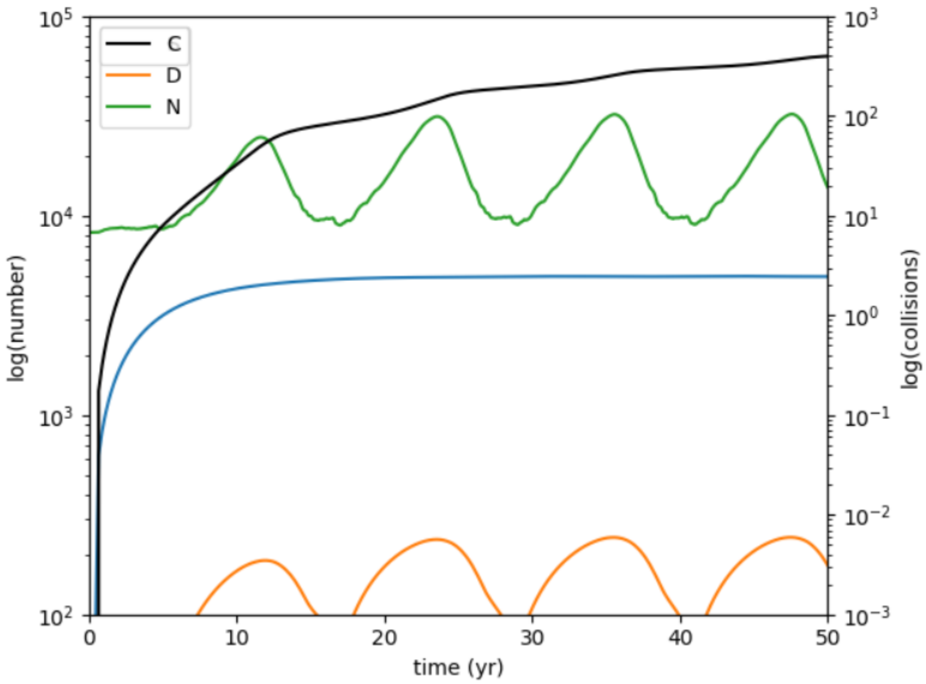
This documentation summarizes the results from all tests and simulations run using each model so far.

1 Tests

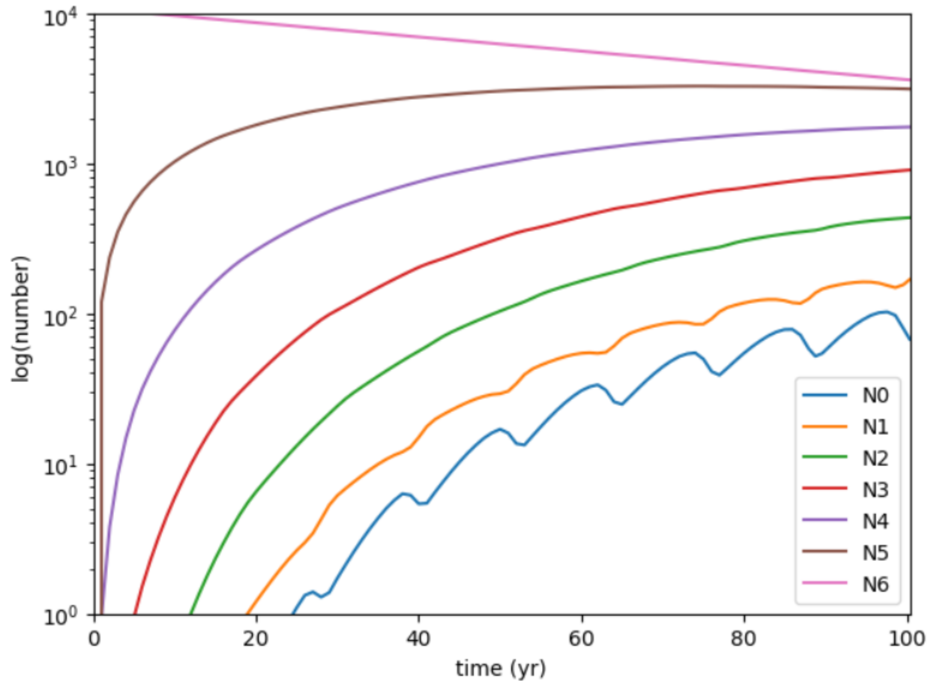
All three models had a standard set of tests run on them. The first is effectively a replication of the original Starlink model from the JASON report, with a launch rate of 1000 satellites per year and a de-orbiting lifetime of 2yr. For the full model, the resulting plot looks something like this



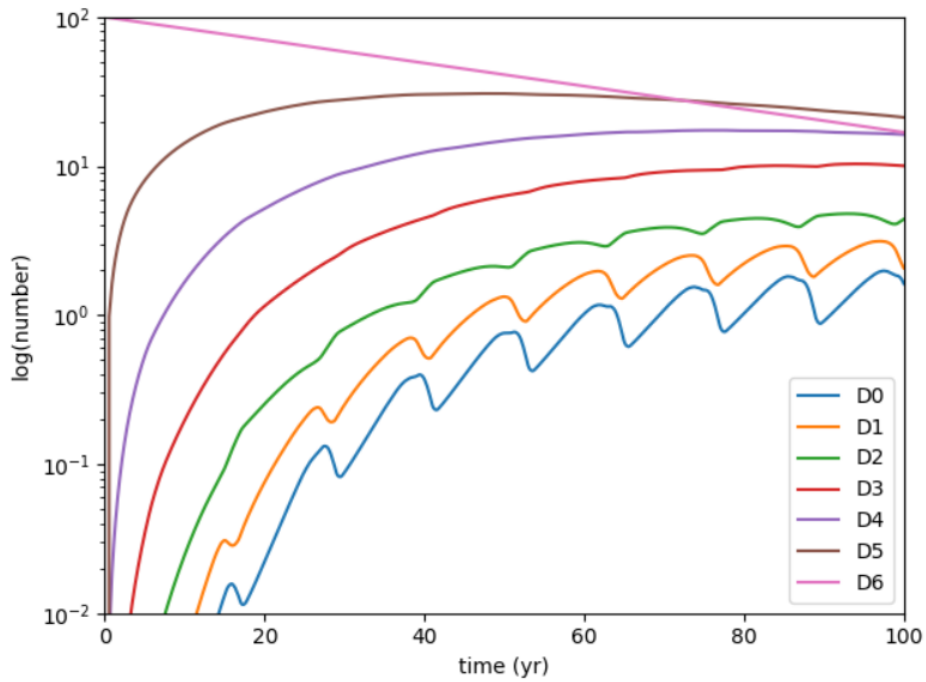
where the blue line is the total number of live satellites in the system. The number of derelicts and debris show periodic patterns of growth and decay, which follow the changes in decay lifetimes due to the solar cycle. The no-ascending model predicts identical results in this case, since there's no layers of atmosphere in the model to ascend through. For the model removing de-orbits, the results are essentially the same



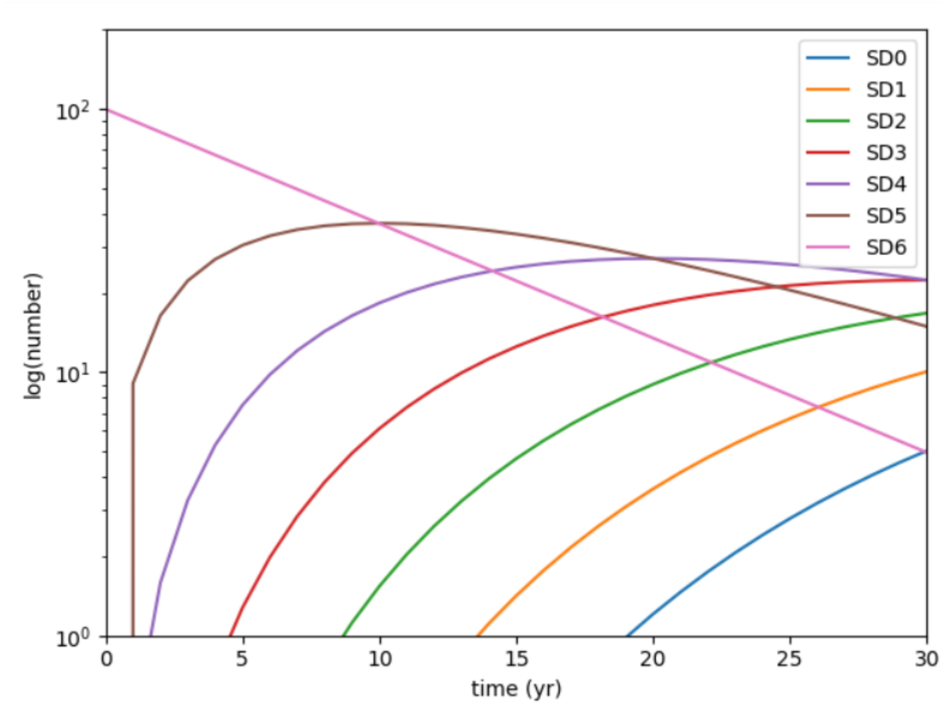
Next, a slate of tests was ran on each model to test the flow of different object types between cells, in a multi-cell system. In each of these tests, bins of width 50km with centres from 600-900km were used, and the initial value of all objects was set to zero with the exception of the object of interest in the top cell. As well, any debris flow into the top cell was turned off. Starting with the debris, we get the following result for all models, where 0 associates to the lowest cell and 6 the highest



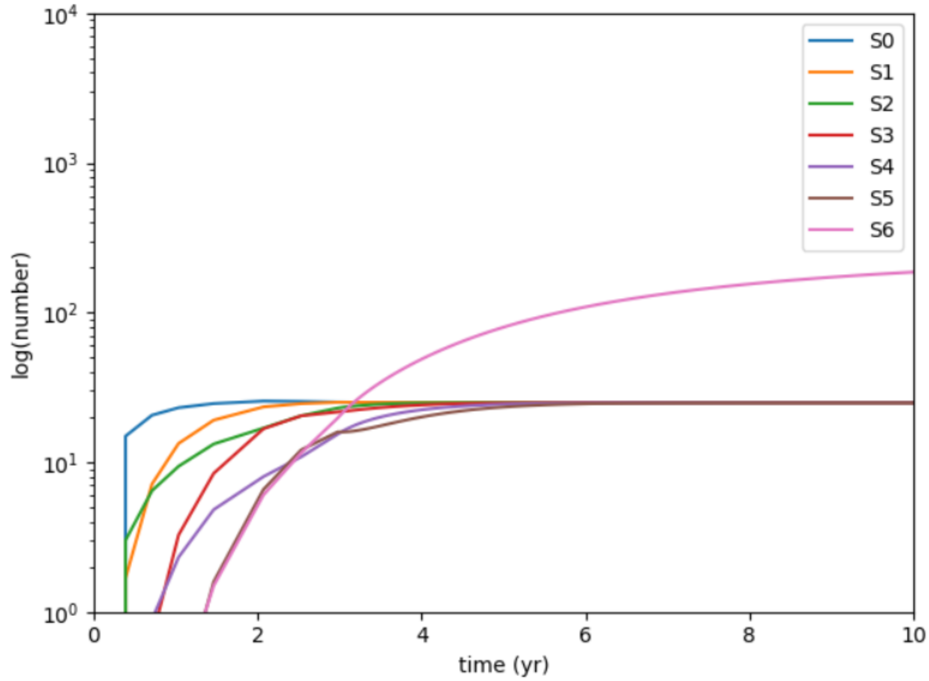
We can see the debris flow downwards as expected. The effects of the solar cycle are much more pronounced in lower cells, likely because of the smaller decay lifetime scales of those altitudes. A similar result is seen in the derelict flow test



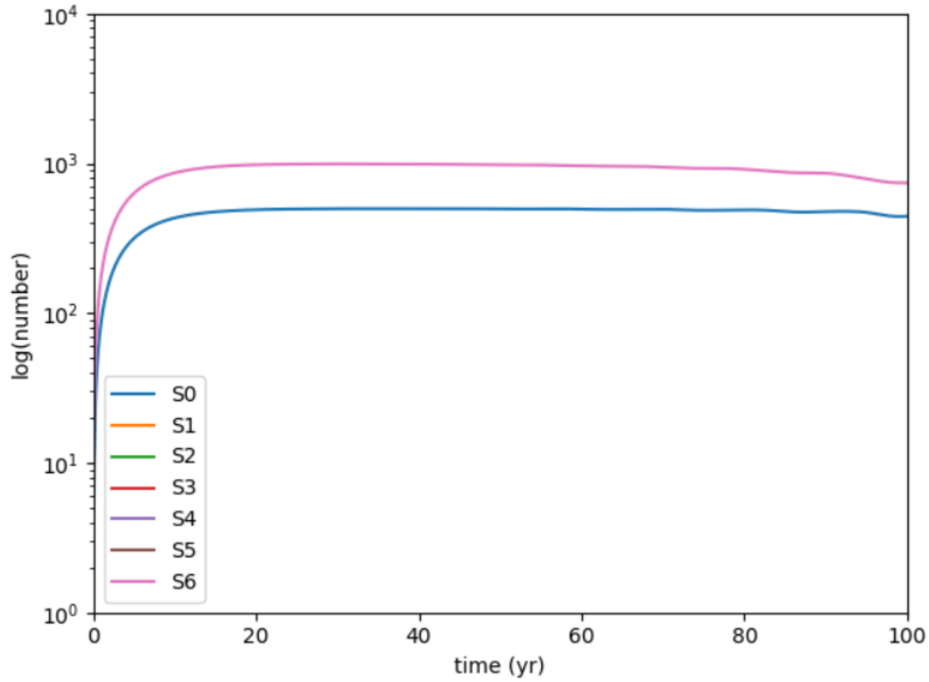
albeit with smaller decay lifetimes, as the derelict satellites have a higher area-to-mass ratio. Rocket body decays were tested as well, with the same area-to-mass ratio as the satellites, and unsurprisingly gave an identical result to the derelict satellites. In the full and no-ascending models, the de-orbiting of satellites from the top to bottom cell with a de-orbiting lifetime of 10yr, was also tested, giving the following result



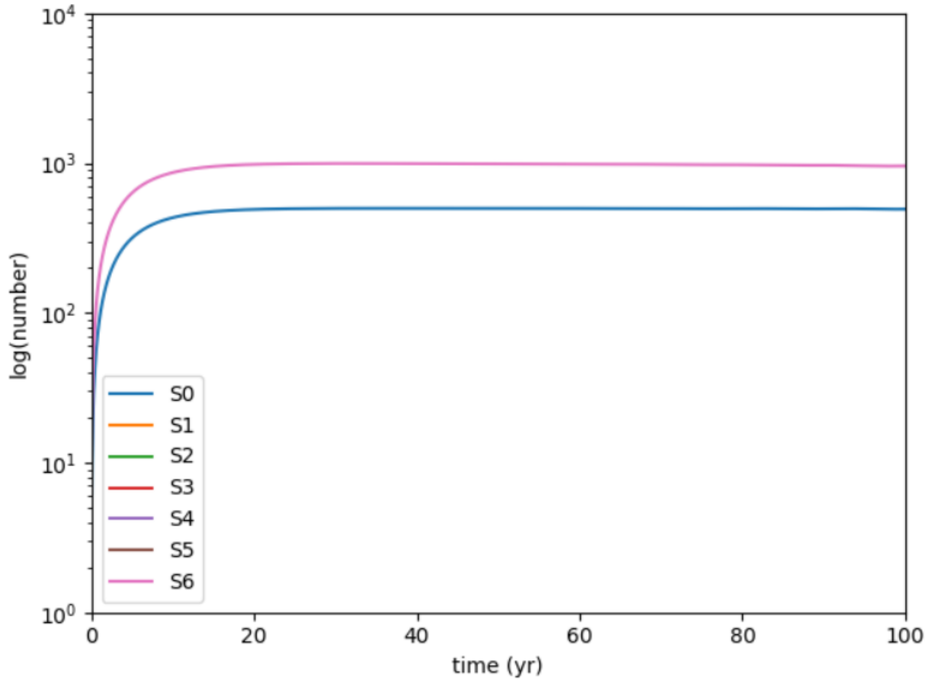
Again, very similar, just without the oscillations since the de-orbiting lifetimes were constant with time and uniform across the system. In the full model, we were also able to run a test of the satellites ascending through the cells. This was run with a launch rate of 50 per year and an ascension lifetime of 0.5yr for each cell, giving the following result



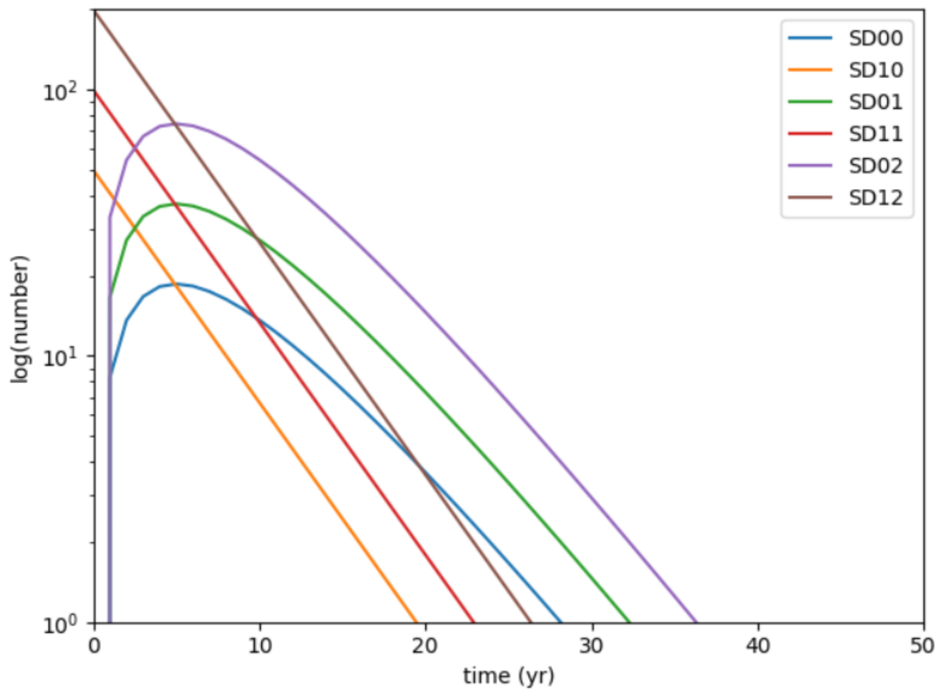
We can see the satellites moving up through the system in the first 5 years or so before things reach an equilibrium, and the top cell eventually (although later than shown in this plot) reaches an equilibrium of 250 satellites, exactly what we'd expect given that the satellite lifetime is 5yr. For the no ascending model, we instead launch all the satellites into the top and bottom shell



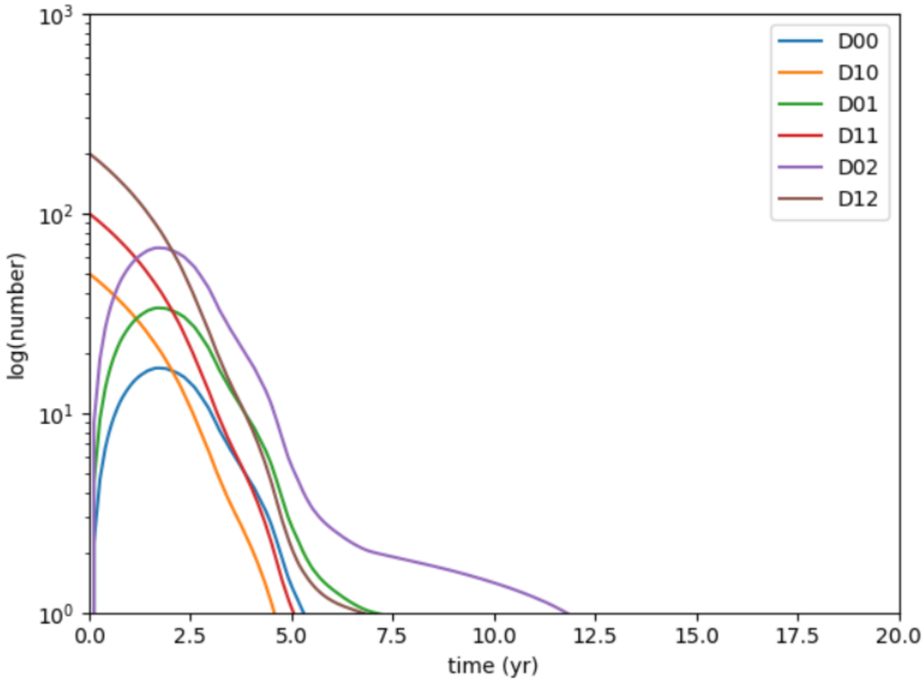
the equilibrium values are as expected, but the cause of the slight downtick near the end of the simulation is not currently known, but is likely from a buildup of derelict satellites in the shells over time, as live satellites fail to go into de-orbit properly. However, if this was the case we'd expect to see the same effect in the minimal model, and this is not what we found



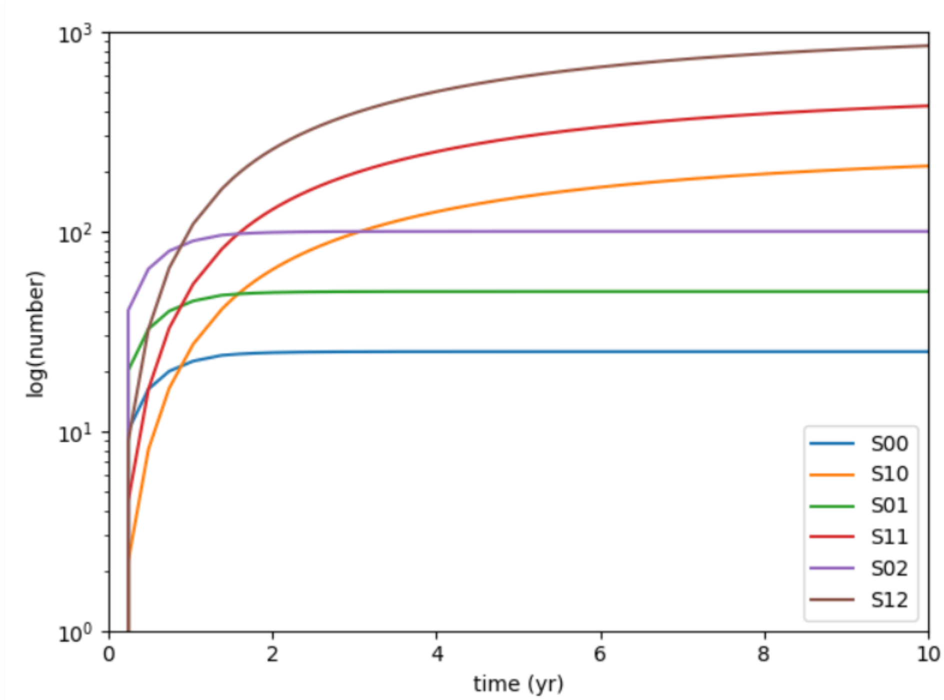
so more investigation is warranted. My guess here is that the satellites taking time to de-orbit caused just enough of a build-up to tilt the system into a less stable state. The next slate of tests were done in 2 cells near 600km, with 3 different types of satellites/rocket bodies. The first, and most basic, tested the de-orbiting of 3 different types of satellites through the bands in all the models except the minimal one.



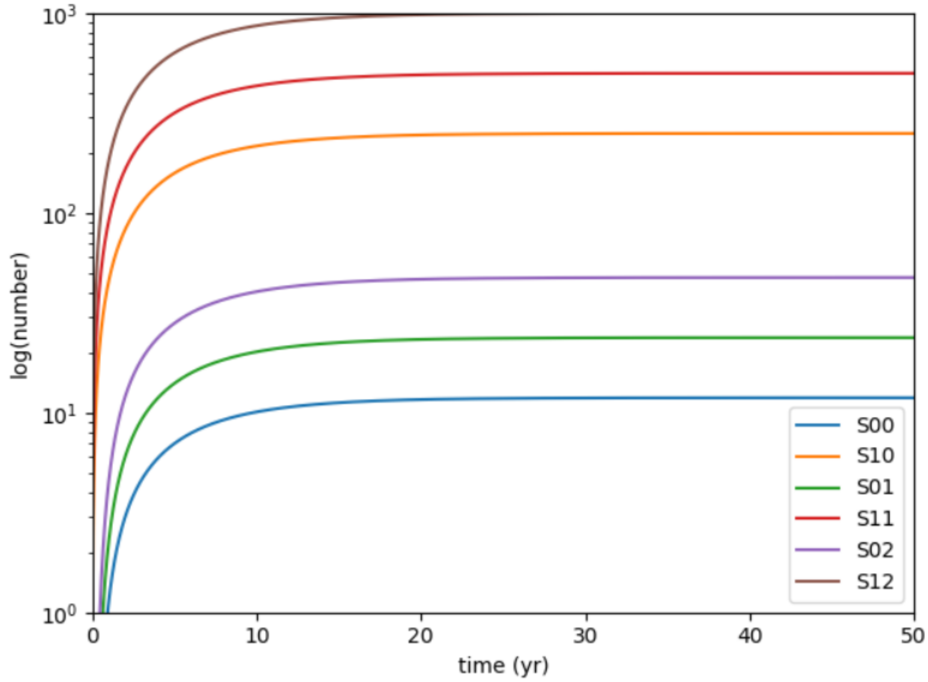
The results are exactly what you'd expect. In the legend, the first number refers to the cell and the second the satellite type. A similar test was run in all the models with derelicts instead, giving the following result



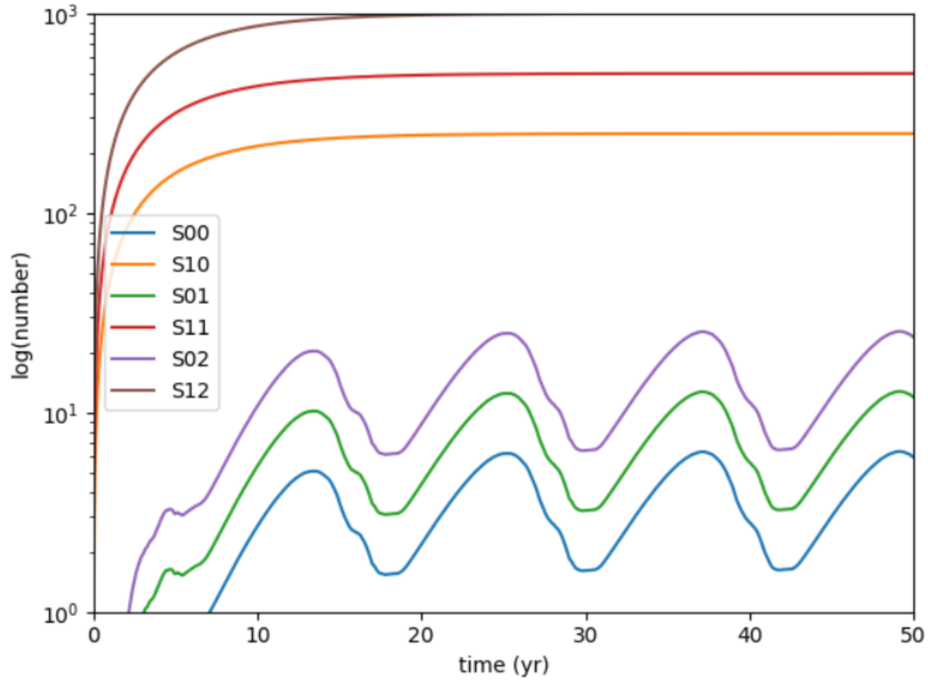
where the changing decay rates over time are due to the solar cycle. Doing the same test with rocket bodies produces the same result. We also tested launching satellites in the full model with three different launch rates



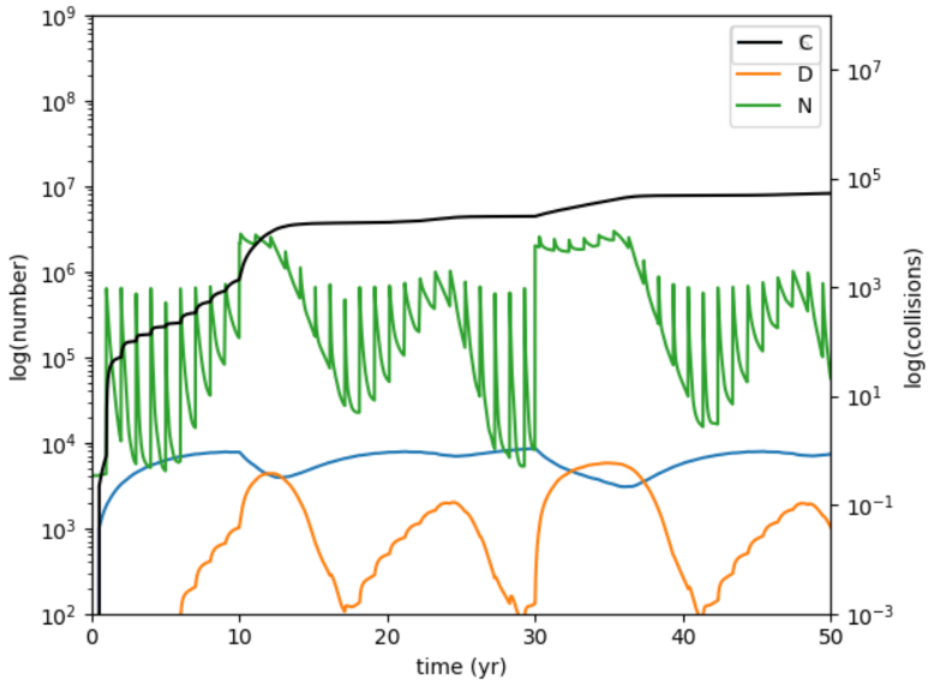
which gives the expected results. For the no ascending model, we instead launched the satellites directly into the top shell and monitored the de-orbiting satellites in the shell below



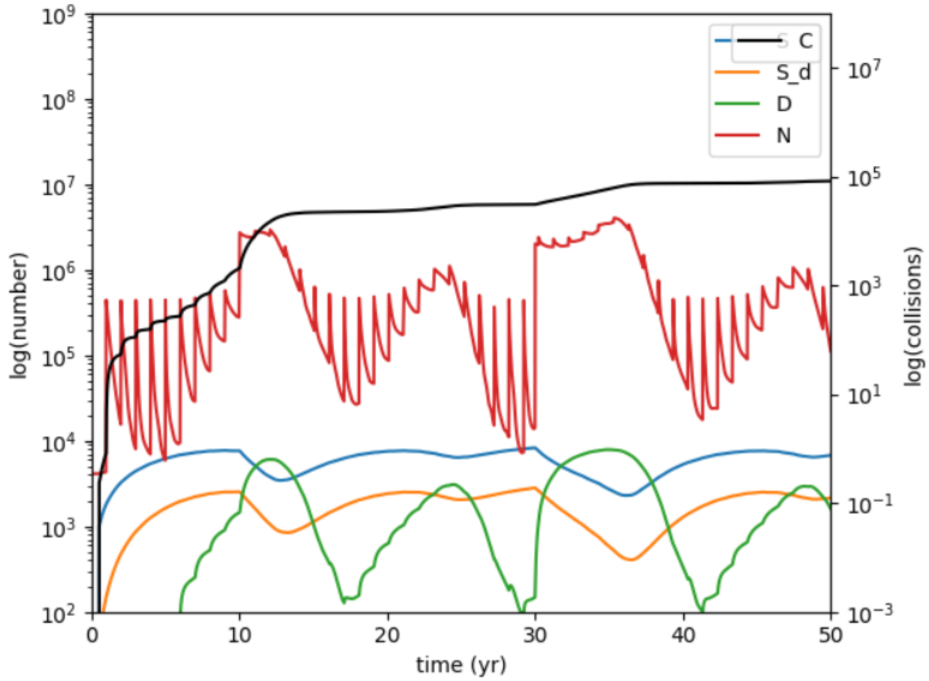
and the same for the minimal model, but monitoring the number of derelict satellites in the shell below



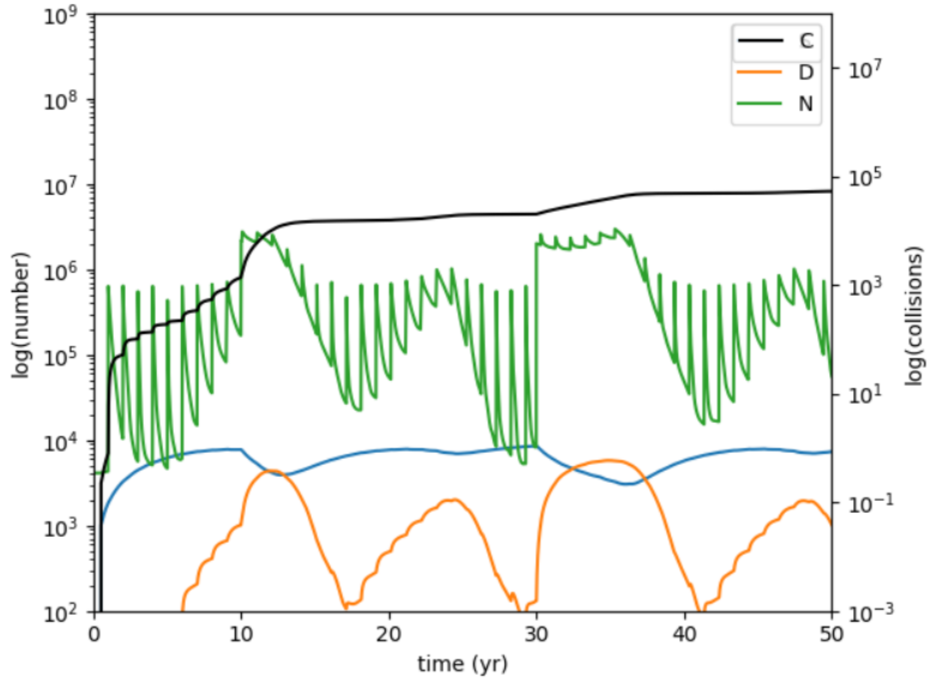
Finally, there's two larger tests that were run in all models. The first is a discrete event test, which is based on the original Starlink test. For the full model, the added events are a custom event which injects 10^6 pieces of low-area-to-mass debris at 10 and 30 years, and 10 standard rocket body explosion events per year. The result is as follows, and the discrete events can be clearly seen.



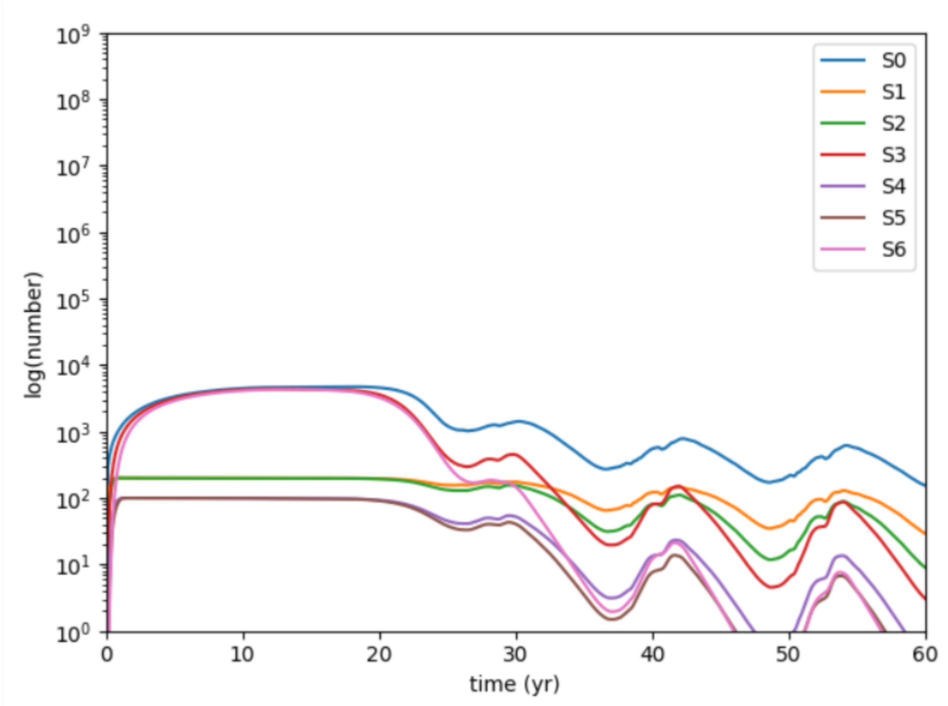
For the no-ascending model, the 10 explosion events were replaced with 10 collision events



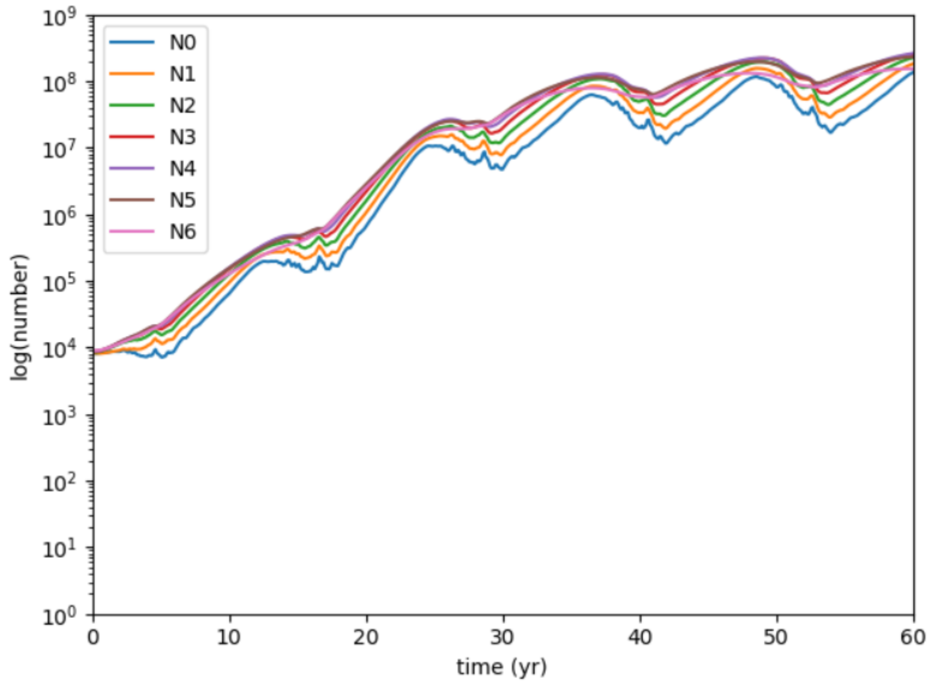
while the minimal model uses explosions like the full model



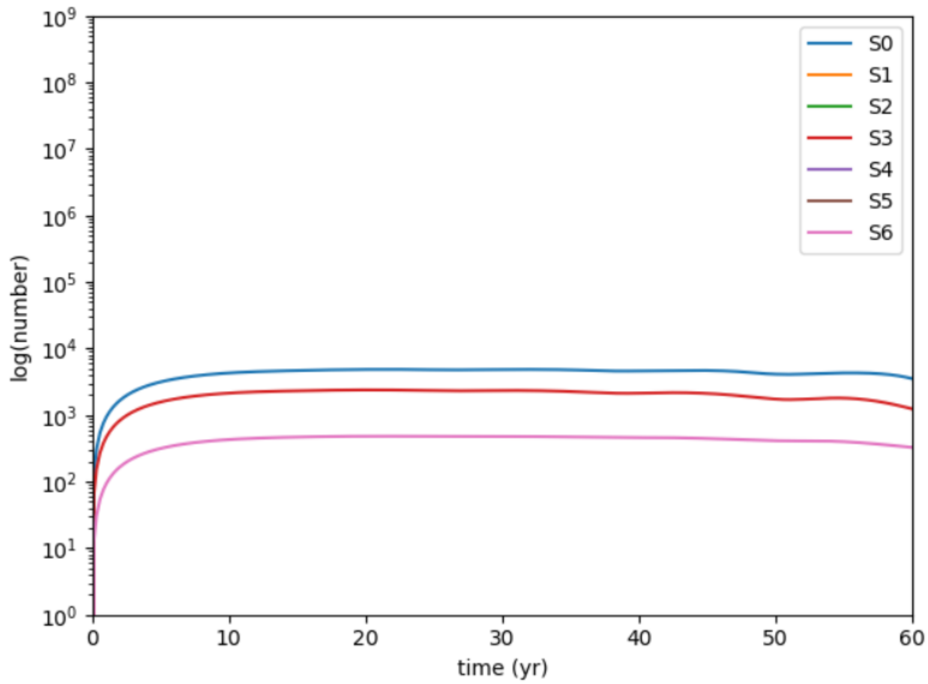
The second is a test of a Starlink style NCell system. For the full model, 3 different types of satellites are used. Each was launched at a rate of 1000 per year to 600, 750, and 900km bands respectively. The result was surprisingly stable for a bit, as seen in the plot of live satellites



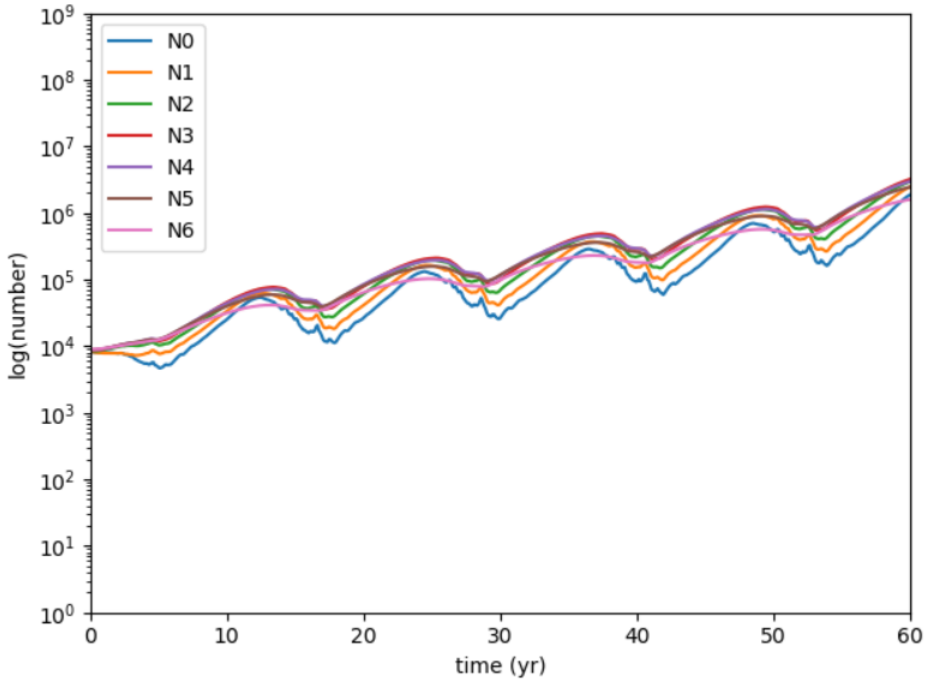
We can see the coming collapse in the plot of debris, where the amount of debris grows over time



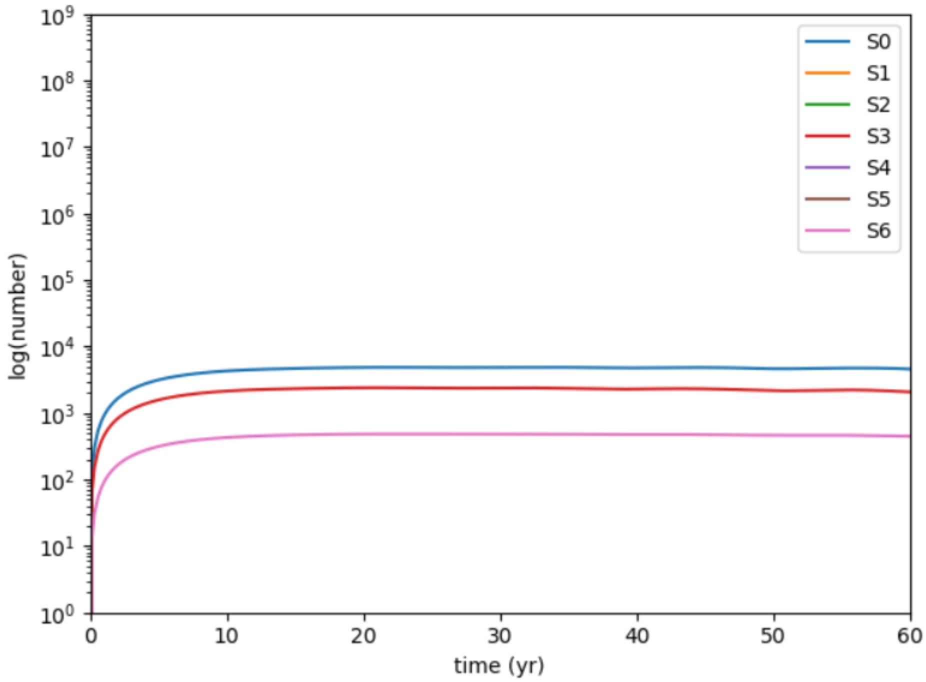
For the no-ascending model, the launch rates are adjusted. The 600km satellites still have a launch rate of 1000 per year, 750km is 500 per year, and 900km is 100 per year. The result is a more stable system, as seen in the plot of live satellites



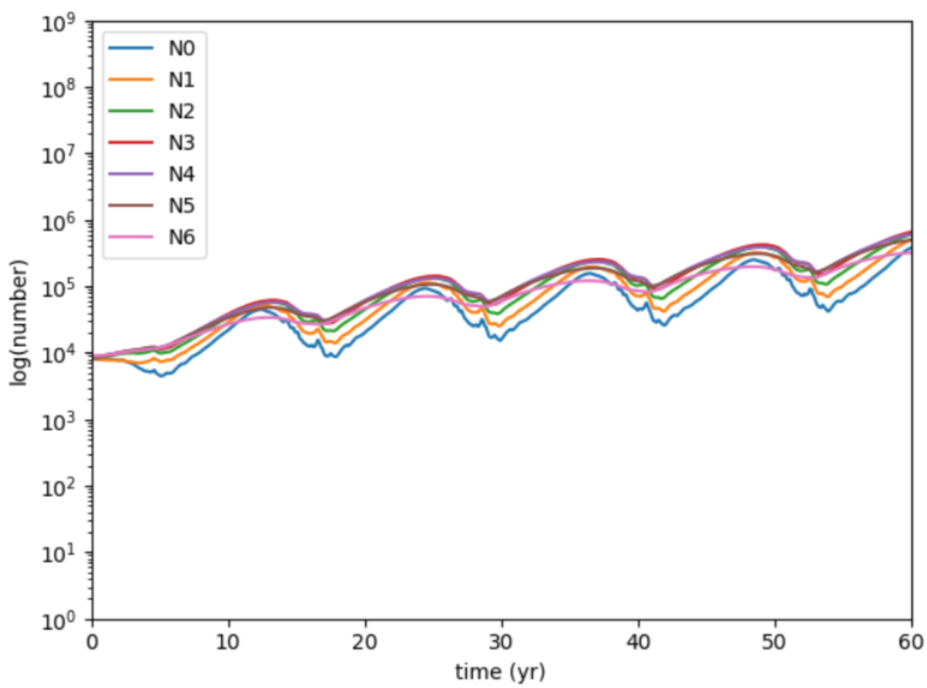
but is probably headed for a collapse as well, as seen in the debris plots



The minimal model was run under the same conditions, and produced similar results



S0
S1
S2
S3
S4
S5
S6
log(number)
time (yr)



N0
N1
N2
N3
N4
N5
N6
log(number)
time (yr)

albeit slightly more stable since de-orbiting satellites don’t stick around.