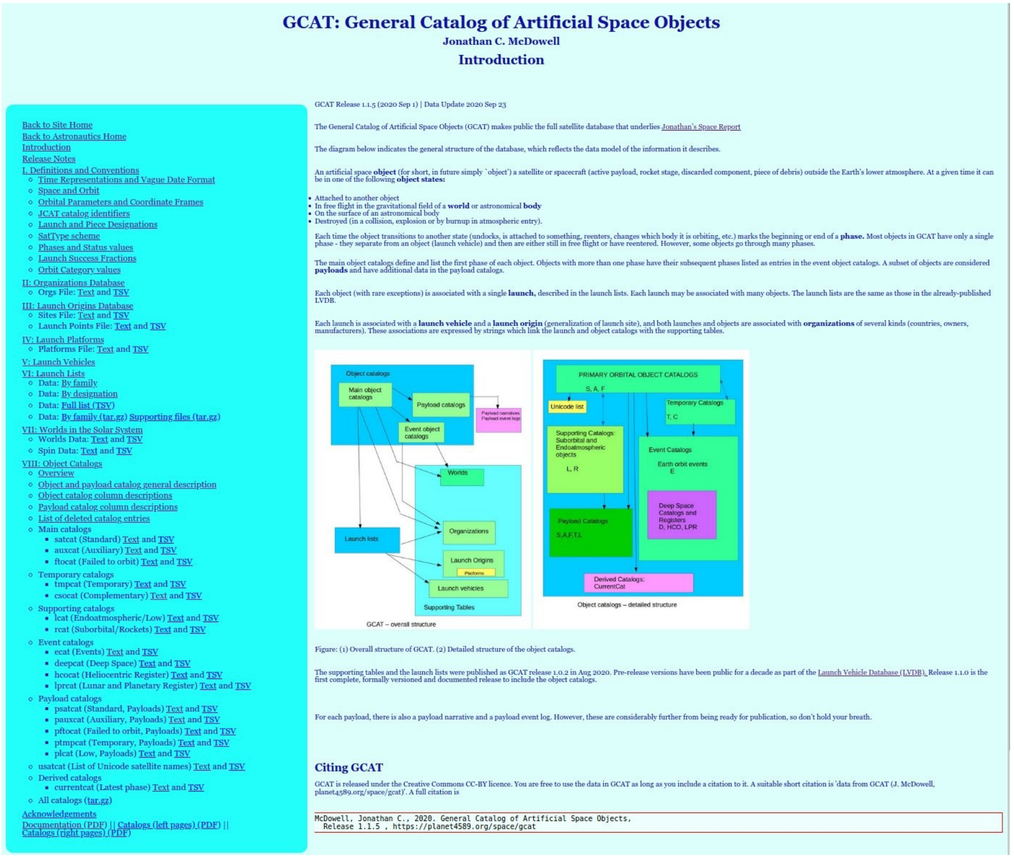
The General Catalog of Space Objects (GCAT):
An Attempt to Document the Space Age



GCAT: General Catalog of Artificial Space Objects

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GCAT Release 1.1.5 (2020 Sep 1) | Data Update 2020 Sep 23

The General Catalog of Artificial Space Objects (GCAT) makes public the full satellite database that underlies Jonathan's Space Report

The diagram below indicates the general structure of the database, which reflects the data model of the information it describes.

An artificial space **object** (for short, in future simply `object') a satellite or spacecraft (active payload, rocket stage, discarded component, piece of debris) outside the Earth's lower atmosphere. At a given time it can be in one of the following **object states:**

- Attached to another object
- In free flight in the gravitational field of a **world** or astronomical **body**
- On the surface of an astronomical body
- Destroyed (in a collision, explosion or by burnup in atmospheric entry).

Each time the object transitions to another state (undocks, is attached to something, reenters, changes which body it is orbiting, etc.) marks the beginning or end of a **phase.** Most objects in GCAT have only a single phase - they separate from an object (launch vehicle) and then are either still in free flight or have reentered. However, some objects go through many phases.

The main object catalogs define and list the first phase of each object. Objects with more than one phase have their subsequent phases listed as entries in the event object catalogs. A subset of objects are considered **payloads** and have additional data in the payload catalogs.

Each object (with rare exceptions) is associated with a single **launch,** described in the launch lists. Each launch may be associated with many objects. The launch lists are the same as those in the already-published LVDB.

Each launch is associated with a **launch vehicle** and a **launch origin** (generalization of launch site), and both launches and objects are associated with **organizations** of several kinds (countries, owners, manufacturers). These associations are expressed by strings which link the launch and object catalogs with the supporting tables.

Figure: (1) Overall structure of GCAT. (2) Detailed structure of the object catalogs.

The supporting tables and the launch lists were published as GCAT release 1.0.2 in Aug 2020. Pre-release versions have been public for a decade as part of the Launch Vehicle Database (LVDB). Release 1.1.0 is the first complete, formally versioned and documented release to include the object catalogs.

For each payload, there is also a payload narrative and a payload event log. However, these are considerably further from being ready for publication, so don't hold your breath.

Citing GCAT

GCAT is released under the Creative Commons CC-BY licence. You are free to use the data in GCAT as long as you include a citation to it. A suitable short citation is 'data from GCAT (J. McDowell, planet4589.org/space/gcat)'. A full citation is

```
McDowell, Jonathan C., 2020. General Catalog of Artificial Space Objects,
  Release 1.1.5 , https://planet4589.org/space/gcat
```

Jonathan McDowell

https://planet4589.org/space/gcat/

Why ‘General Catalog’?

In astronomy, a ‘general catalog’ of objects is a grab-all compendium from many sources which attempts to be comprehensive at the possible expense of uniformity e.g. Dreyer’s New General Catalog (NGC) of Nebulae and Galaxies

GCAT is a general catalog of known artificial objects in (or formerly in) space.

First full release August 2020
Regular data updates (about 1/month)

All data in GCAT is freely reusable under a Creative Commons – Attribution licence

What is GCAT?

GCAT is a catalog of known artificial objects in (or formerly in) space.
It differs from the US DoD SATCAT in that:

- For objects in the SATCAT, it has a lot of extra metadata (albeit frequently estimates rather than known: liberal use of the '?' flag to indicate this)
    - Owner, manufacturer
    - Size, shape, mass
    - Separation time from specified parent object
    - Events: docking, undocking, attachment to other objects
    - Launch details (time, pad, vehicle, etc)

- It includes objects that should have been in SATCAT but aren't
    - Notably debris objects/rocket stages in high orbits and deep space
    - SATCAT usually (not always) requires the object has been tracked
    - GCAT includes objects known to exist (e.g. from project documentation) even if they have never been tracked – may be useful to SSA as a search list

- It includes lots of objects that are outside the scope of SATCAT
    - Attached payloads (e.g. Spacelab on Shuttle) –
        - separate entry allows separate metadata for them
    - Objects in orbit for less than 1 rev, or objects which were marginally suborbital

- It gives additional metadata for payloads
    - Class: Military, civilian, commercial, non-profit
    - Category: Imaging, Comms, Navigation, science, etc.
    - End-of-active-life dates

GCAT SOURCES:

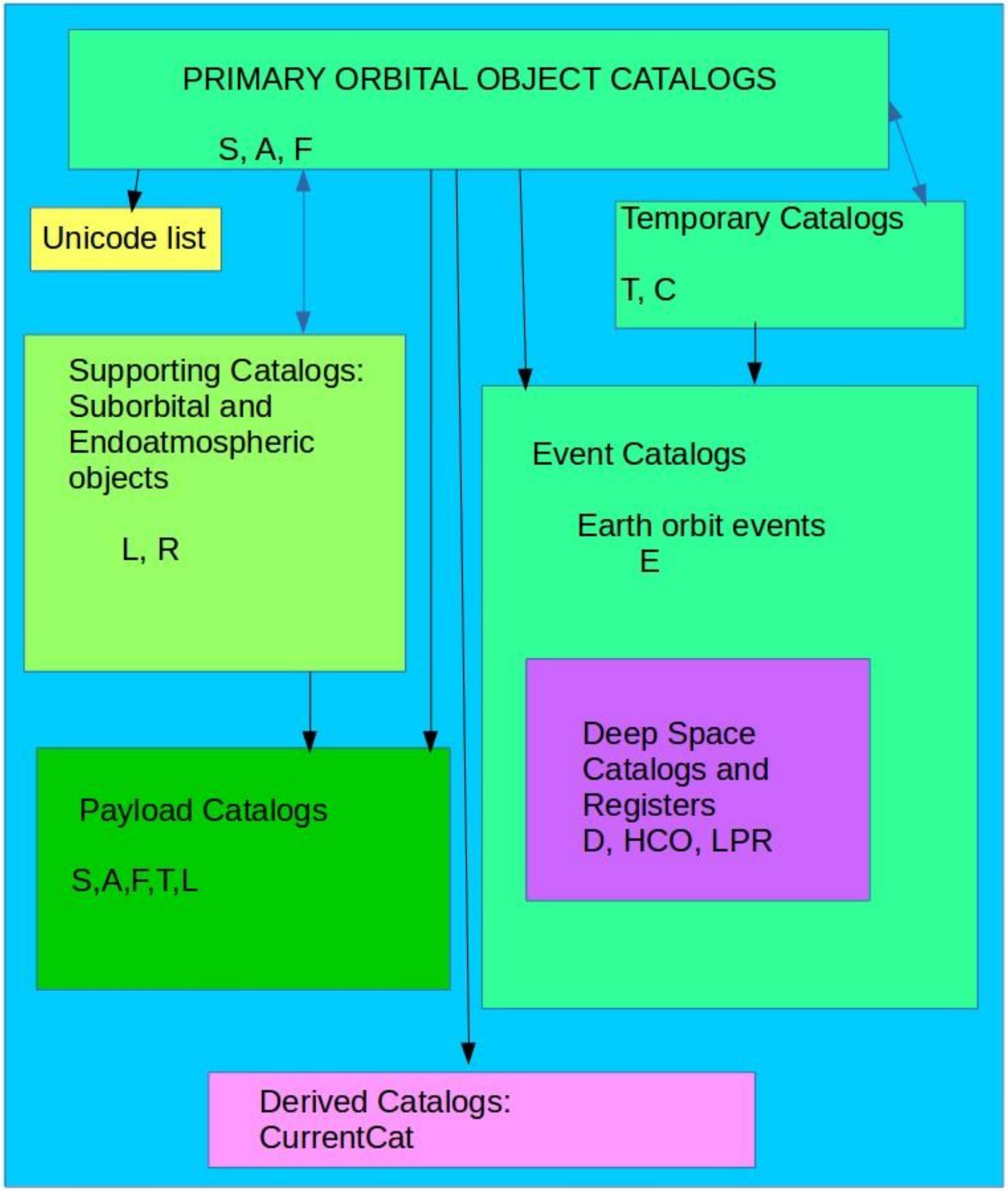
- The US DoD (18SPCS) SATCAT is a primary source
  (but not treated as infallible)

- Orbital data from hobbyists, astronomers and from other public sources included

- News stories, mission web sites, press kits, etc.

- Personal contacts with (and occasionally, harrassing phone calls to) people directly involved with the missions

- Historical sources: magazines (AvWeek, Flight, Novosti Kosmonavtiki, Missiles and Rockets, Spaceflight, JBIS, Space In Japan ...)
- Professional journals (AIAA, etc)
- Online archives (NTRS, etc.)
- In-person visits to archives (US Nat Archives, NASA centers, Vandenberg, Redstone, LAAFB, NRO, SI-NASM, ESTEC, CNES-Toulouse, UK Science Museum, Deutsches Mus., many others)
- Other enthusiasts (esp. the Novosti Kosmonavtiki team and their friends for declassified Soviet data)



Object catalogs – detailed structure

Key catalogs:

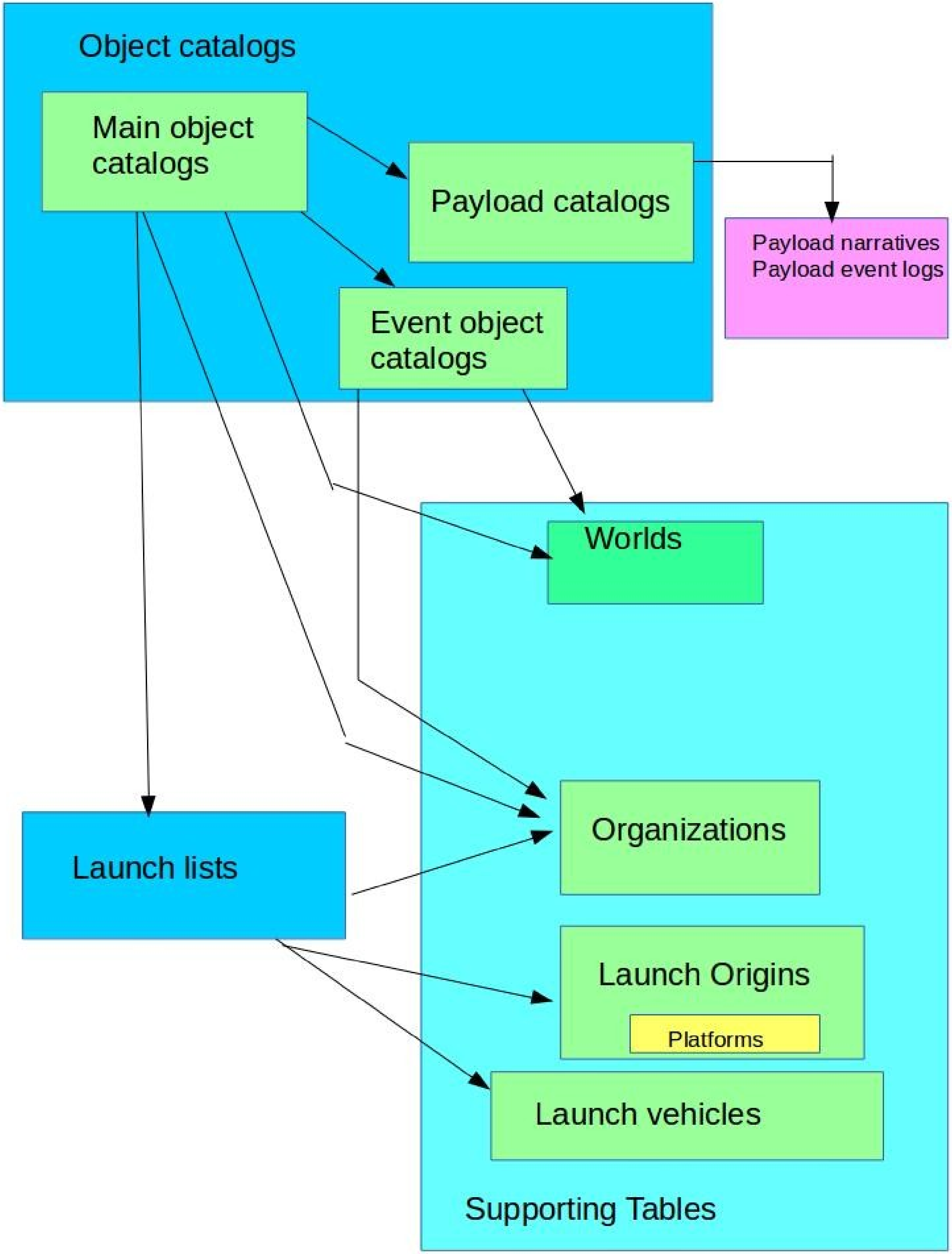
satcat - US SATCAT with added metadata

auxcat – auxiliary catalog: the objects that aren't in satcat

ftocat: - failed-to-orbit catalog

ecat: - event catalog, e.g. with multiple phases of a complex mission

deepcat - all objects beyond 150,000 km are transferred to the D catalog



GCAT – overall structure

Launch lists:
- includes suborbital launches

Launch Origins:
- generalization of launch site/pad.

FORMATS in GCAT - and more broadly (but your requirements may differ)

GCAT catalog and associated files:

Internally:
Everything is fixed format text files (mostly ASCII, some Unicode)
- Easiest to write code to without using external libraries
- Easiest for manual data entry: I am a very fast emacs user and my time is the limiting resource

Externally:
- Fixed format text with HTML <PRE> wrapper for viewing in browser (faster rendering than HTML tables)
- Tab-separated value (TSV) files that can be imported easily by Excel users (i.e. not me)

GCAT orbital data archive (not currently public)

Internally: (yes, I know many of you will hate this)
XTLE (eXtended TLE format), 1 text file per catalog object
- standard TLE is a valid sub-case
- Extended format is a 3-line format not restricted to 80 chars
- Supports 9-digit catalog numbers, JCAT IDs, hyperbolic orbits e >>1 , central bodies other than Earth
- Line 3 adds metadata for TLE source (18SPCS, Kelso, other), quality flags, other traceability
- Optional Line 0 can store the extra metadata from Space-Track's JSON format
(sat name, other stuff that should really be in the catalog)

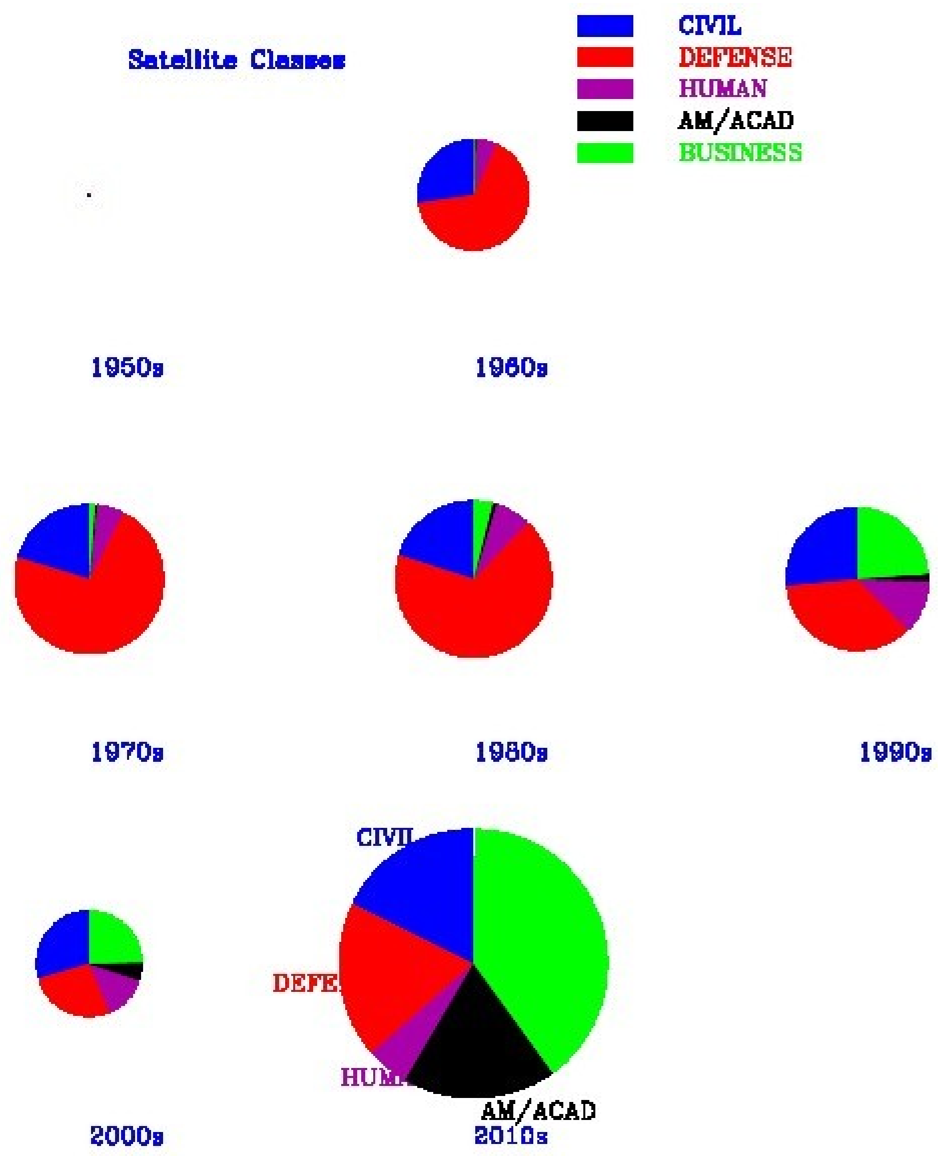
Why not XML?
- hard to parse without dependency on 3rd party libraries that might not be around in 20 years
- file size becomes huge. It still matters.

Why not JSON?
- better than XML, can parse with own code, but still noticeably slower to parse than TLE

XTLE examples

```
1 43653U 18080A   20287.00000000  .00000000 +00000-0 +00000-0 0    11
2 43653   1.6701  19.9109   0.2369927  15.1037    44.0930        0.0036859026      0
3 43653      2 HOR        OSC  EC         Sun                         Horizons.20201013
1 43653U 18080A   20288.00000000  .00000000 +00000-0 +00000-0 0    12
2 43653   1.6692  19.6573   0.2377055  15.3537    45.3572        0.0036826584      0
3 43653      2 HOR        OSC  EC         Sun                         Horizons.20201013
1 43653U 18080A   20288.00000000  .00000000 +00000-0 +00000-0 0    11
2 43653 152.7500  90.7170   4.2312428 259.3688 -8971.7502       21.3804463040      0
3 43653      2 HOR        OSC  IAU        Venus                       Horizons.20201013
1 43653U 18080A   20289.00000000  .00000000 +00000-0 +00000-0 0    12
2 43653 152.4809  90.9536   4.2647382 259.4474 -1277.1330       21.3166403137      0
3 43653      2 HOR        OSC  IAU        Venus                       Horizons.20201013
1 43653U 18080A   20289.16597222  .00000000 +00000-0 +00000-0 0    16
2 43653 152.4798  90.9540   4.2646332 259.4479    -3.4811       21.3150780504      0
3 43653      2 HOR        OSC  IAU        Venus                       Horizons.20201013
1 43653U 18080A   20290.00000000  .00000000 +00000-0 +00000-0 0    14
```

```
0 FLOCK 4V 26             2020-061BQ   P US      CSG      2020 Sep  3  -          0     516.3 x     527.0
1S000046825U 20061BQ  20305.58977741  .00000742 +00000-0 +43500-4 0    9994
2S000046825  97.4712  17.6385   0.0007805  58.4326   301.7669        15.1477889300     417
3S000046825 3 SPTR       SGP4 TEME UTC  Earth                          ntle/tle2020_305_7.txt
0 FLOCK 4V 26             2020-061BQ   P US      CSG      2020 Sep  3  -          0     516.3 x     527.0
1S000046825U 20061BQ  20305.92006922 -.00000057 +00000-0 +43101-6 0    9995
2S000046825  97.4705  17.9626   0.0007701  57.1347   303.0623        15.1477662800     469
3S000046825 3 SPTR       SGP4 TEME UTC  Earth                          ntle/tle2020_306_1.txt
0 FLOCK 4V 26             2020-061BQ   P US      CSG      2020 Sep  3  -          0     516.3 x     527.0
1S000046825U 20061BQ  20306.64670994 -.00000057 +00000-0 +43101-6 0    9991
2S000046825  97.4705  18.6763   0.0007701  54.6202   305.5749        15.1477664000     567
3S000046825 3 SPTR       SGP4 TEME UTC  Earth                          ntle/tle2020_307_1.txt
0 FLOCK 4V 26             2020-061BQ   P US      CSG      2020 Sep  3  -          0     516.3 x     527.0
1S000046825U 20061BQ  20307.83575826 -.00000065 +00000-0 +00000-0 0    9995
```

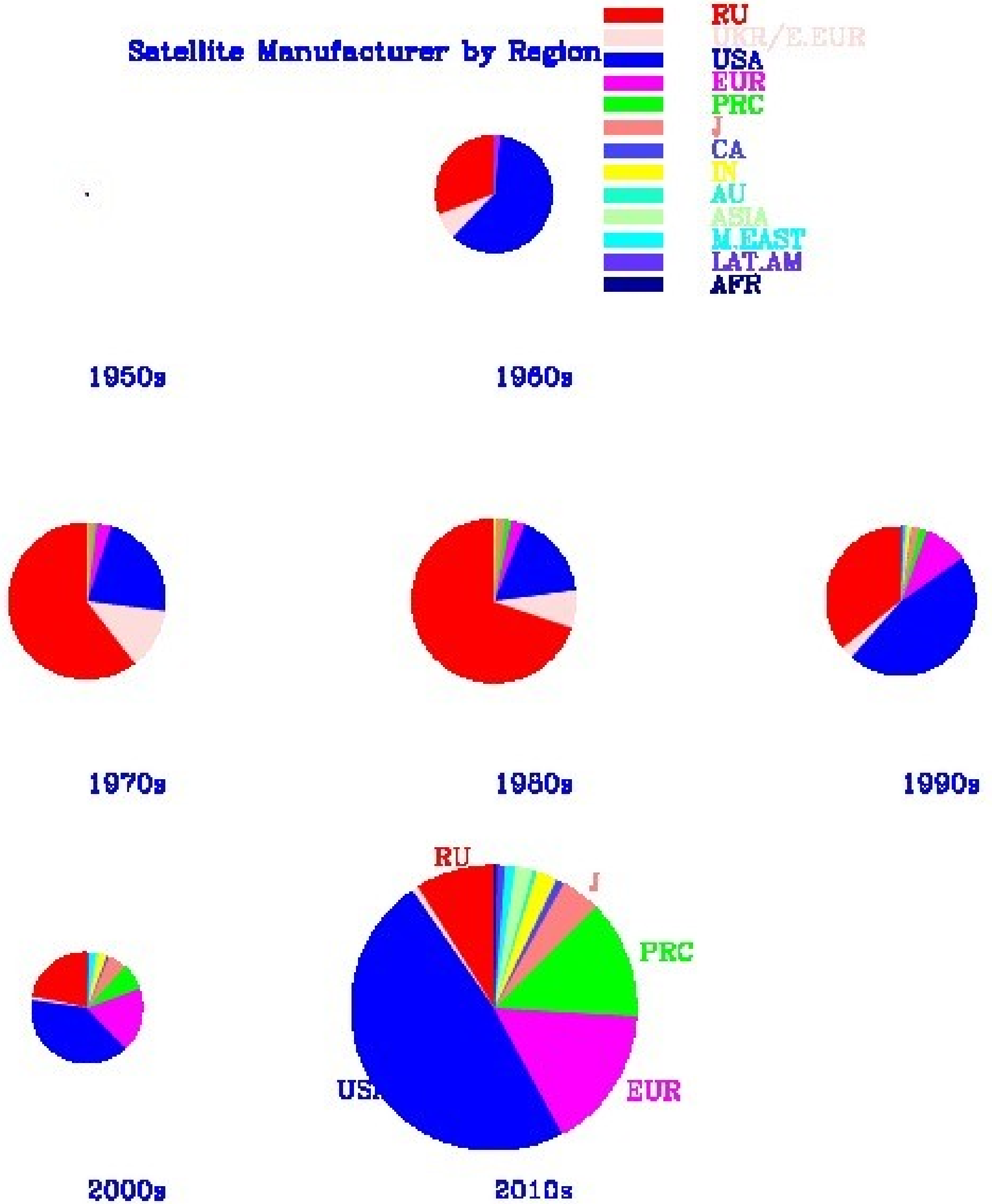


Derived understanding from GCAT:

Number of sats vs whether civil/defense/commercial

Each pie is 1 decade

Shows growth of commercial space in 1990s onwards



Derived understanding from GCAT:

number of satellites launched vs manufacturer region

Each pie is 1 decade

Shows growth of China, Europe, Japan and crash of USSR/Russia post 1990s

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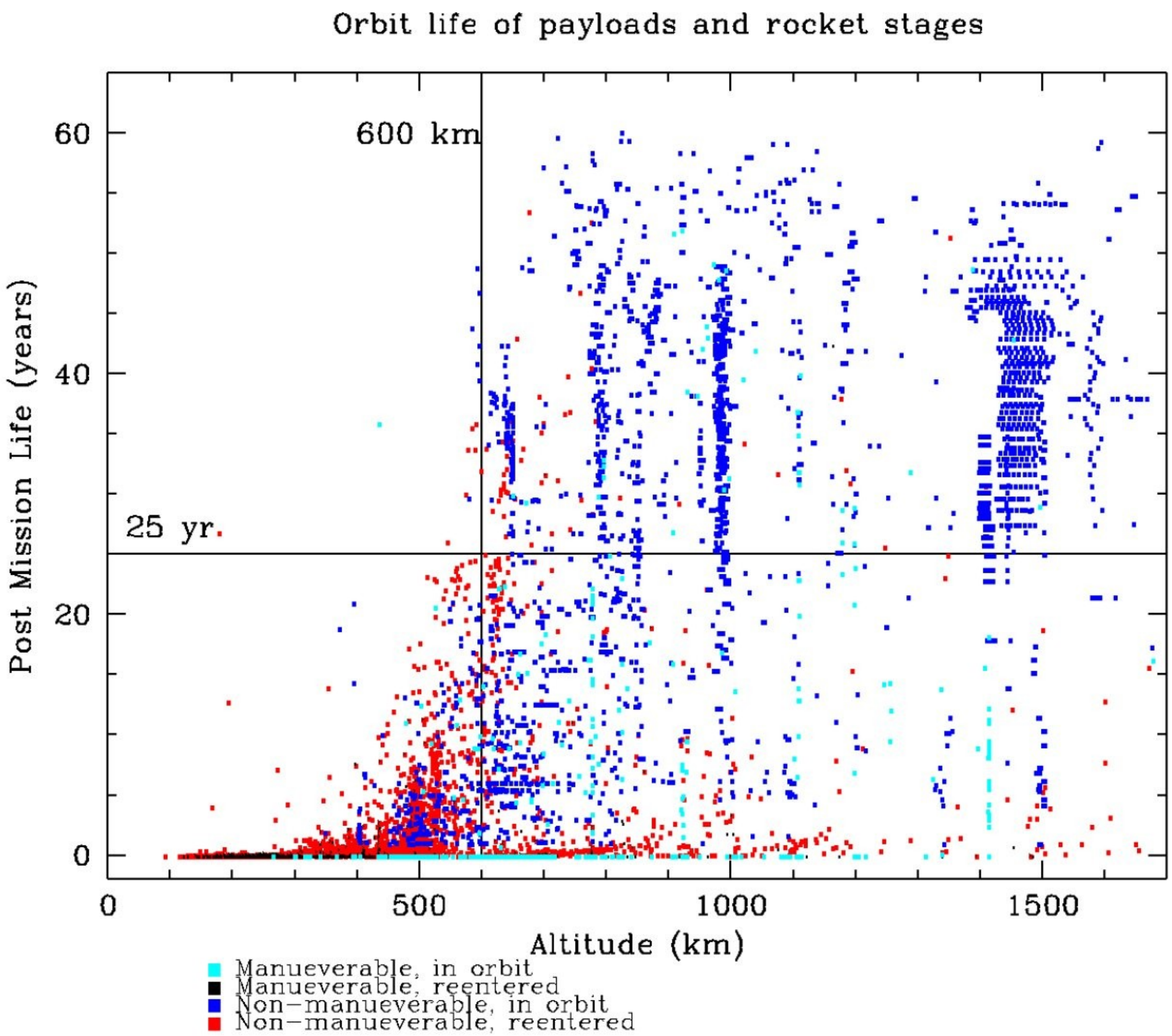
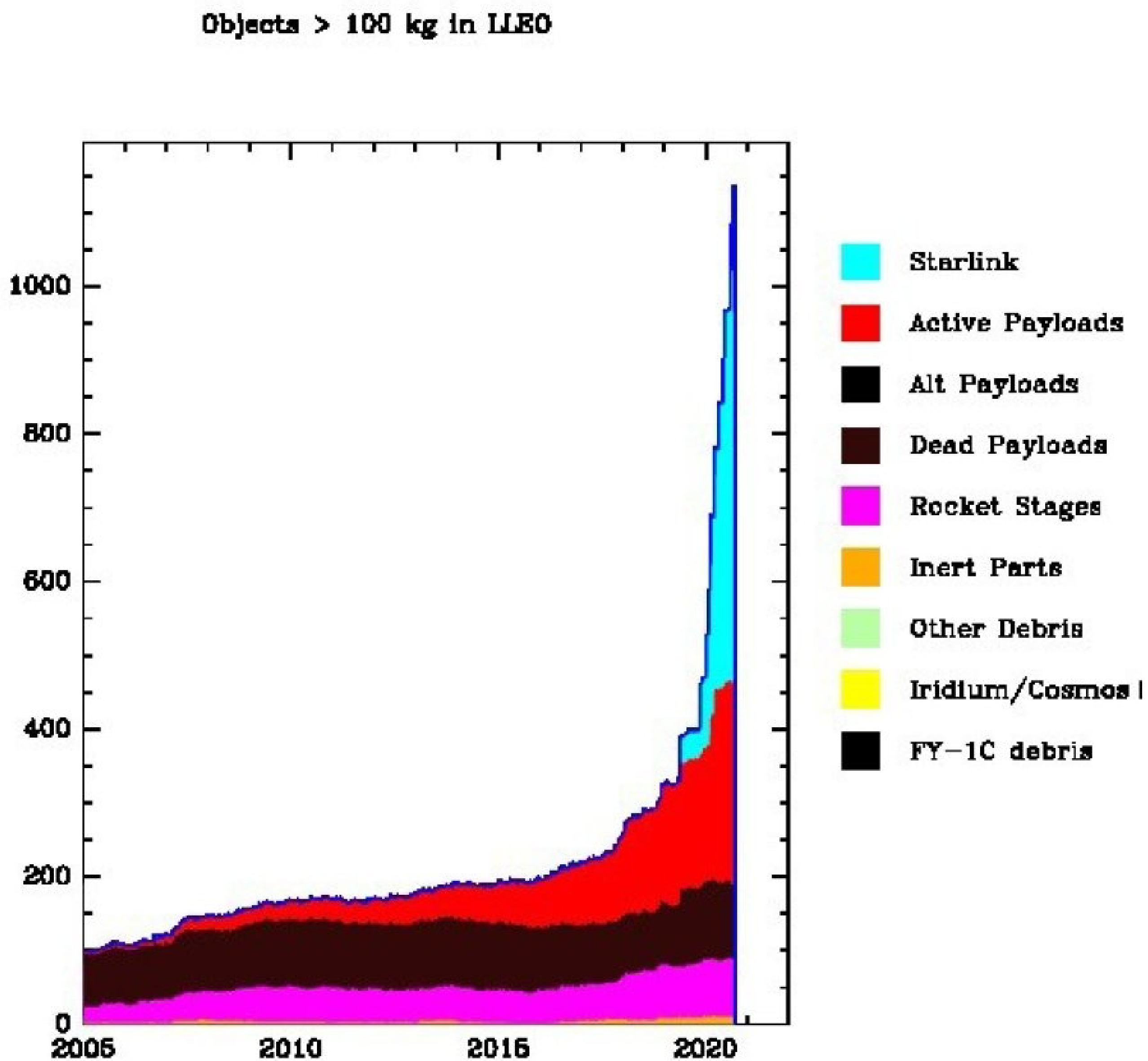


The density of the atmosphere drops off really quickly with altitude.

As a result, orbital lifetime (against natural decay) changes rapidly with height.

This is especially true in the 500-600 km region where lifetimes rise from ~years to centuries.

I pick 600 km as a working boundary between lower and upper LEO.



Musk: there are thousands of sats up already

BUT: mostly small debris or in high orbits

Not so many BIG and LOW: Starlink already dominates this subclass in mid 2020

Plot shows tracked objects below 600 km and more massive than 100 kg as of Sep 8 (Starlink in cyan)

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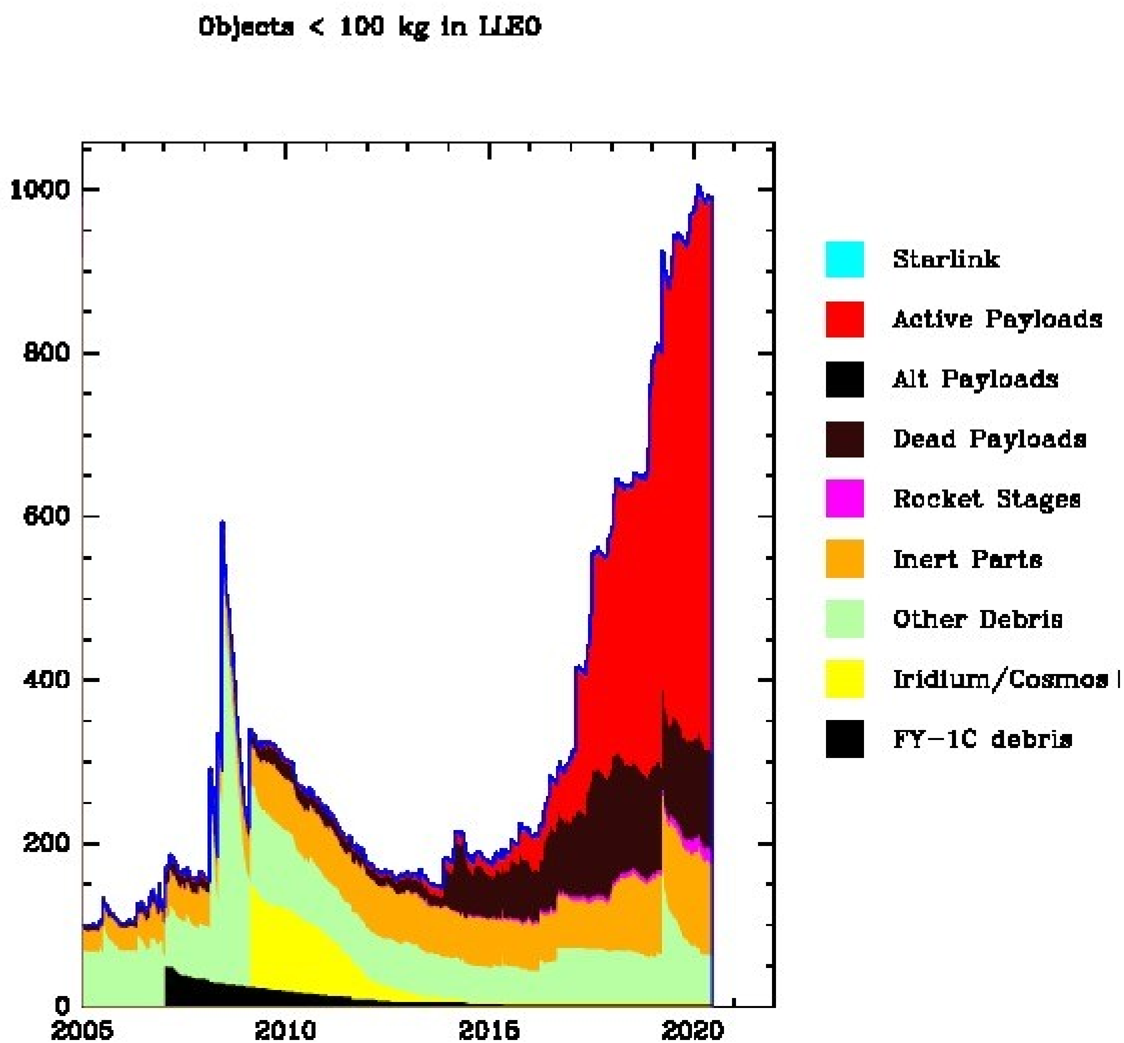

Population of SMALL, LOW objects (<100 kg, < 600 km) has also changed in past 5 years: the cubesat revolution

Tracked population was debris-dominated: now dominated by active payloads.

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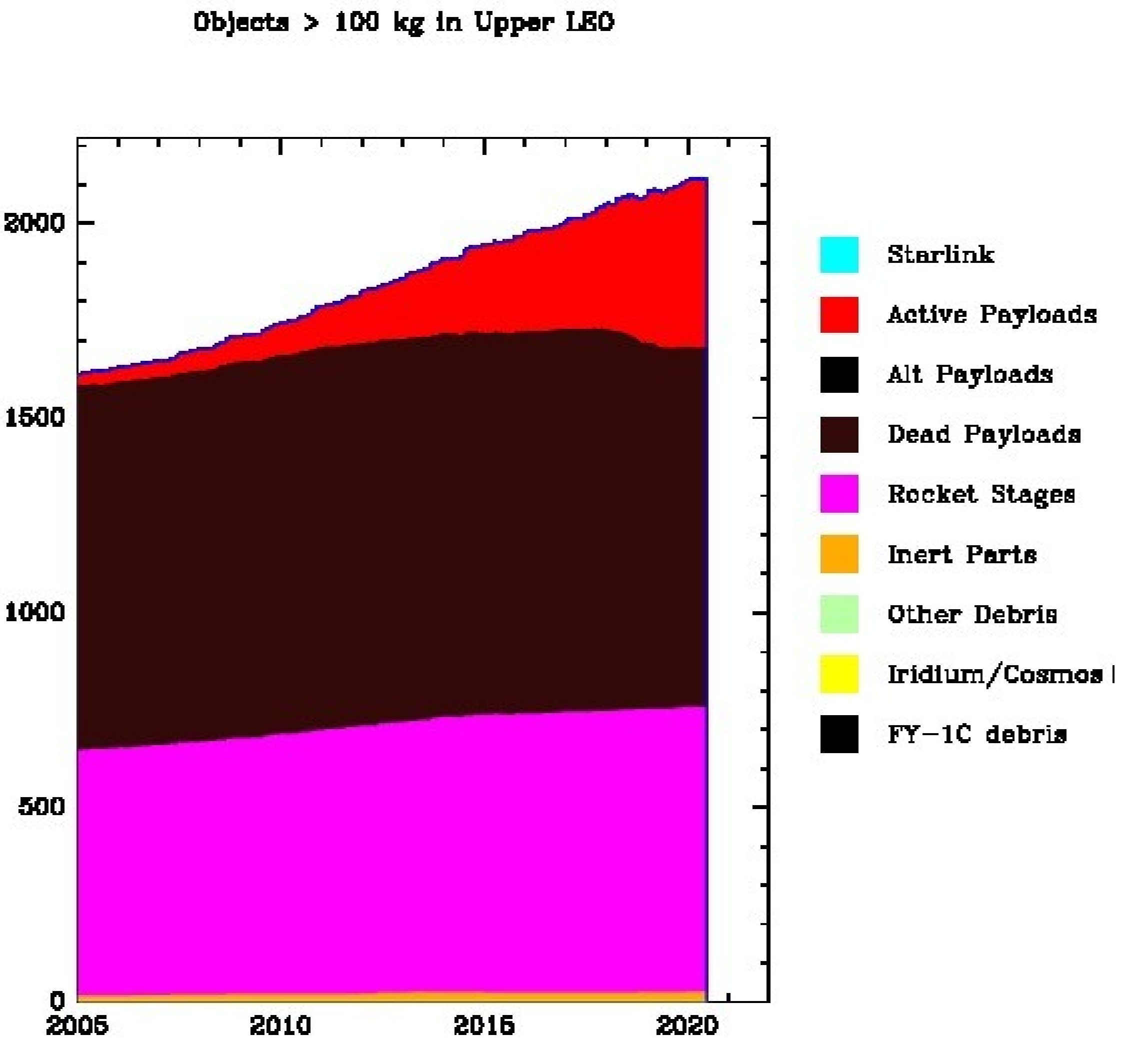

In contrast to the situation in lower (<600 km) LEO, the population is evolving only slowly in upper (>600 km) LEO. (This will change if OneWeb is deployed).

Current population of large objects: about 2000, mostly dead payloads and discarded rocket stages. **Not** currently dominated by active satellites.

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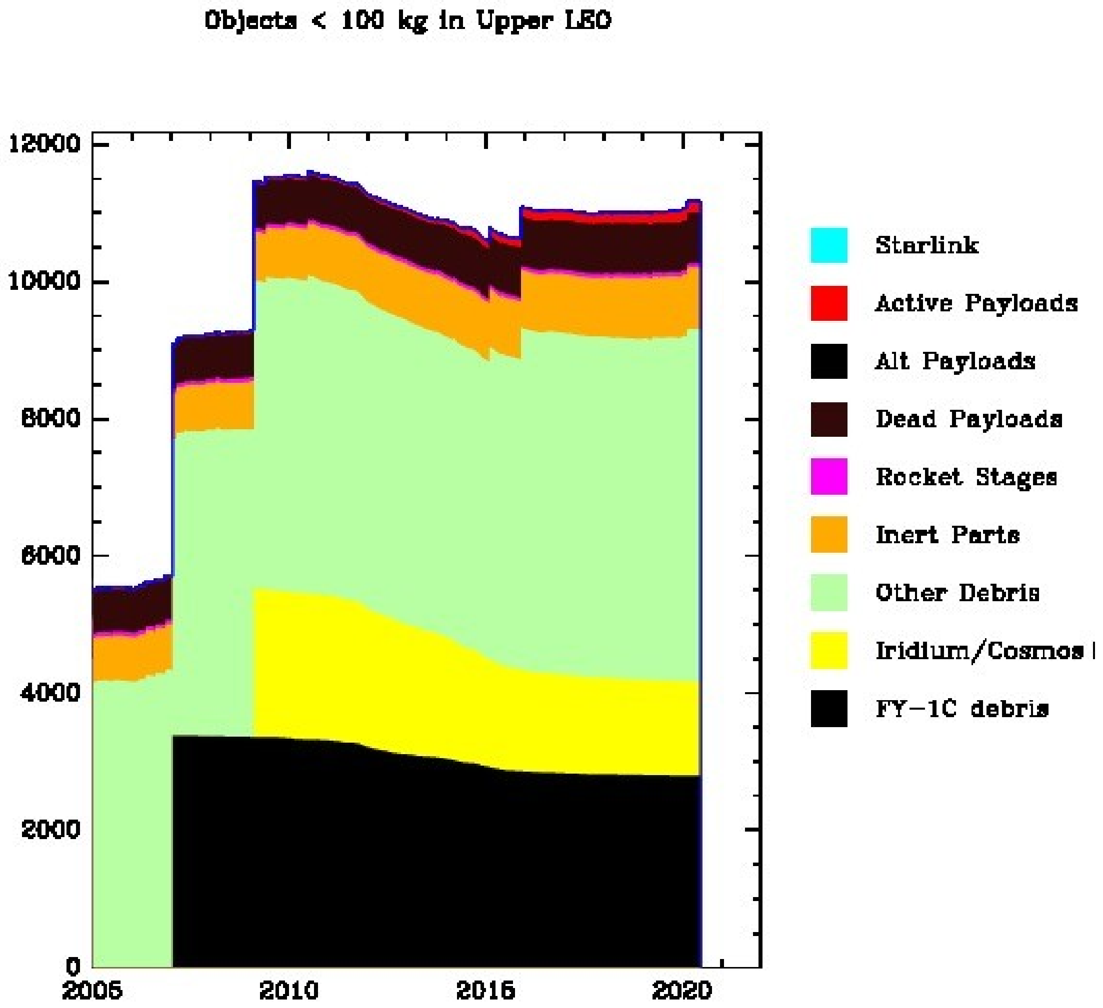


Following the large 2007 and 2009 debris events, the (tracked) small debris population in upper LEO is almost steady state over the past 10 years.

Dominated by debris from satellite collisions, ASAT tests and by rocket stage breakups caused by ignition of residual propellants (often years after launch).

Note the much higher normalization here.

Technical Challenges indicated by the Space Catalog

LEO: 1) What about the 1-10 cm population?
Related: What size of debris hit destroys vs ablates?

2) The Unmatched Cubesats: e.g. 5 tracked objects, 5 known sats launched, but we don't know which is which because either the sats are dead and externally identical, or because the owner's can't be bothered to tell the community. Currently 119 sats in this situation
Mandatory, cheap, independently powered ID boxes? AIS maybe?

3) Megaconstellations. 100 k satellites in LEO? Suggested 5 year replacement cycle => average 55 launched and 55 reentered every day.
- Current SSA workload management inadequate
- 25 year rule not good enough
- Threat to ground based astronomy

4) Secret satellites: Classified orbits just won't fly if SSA is eventually done by an international body; also dangerous in a megaconstellation traffic environment where users are manuevering constantly

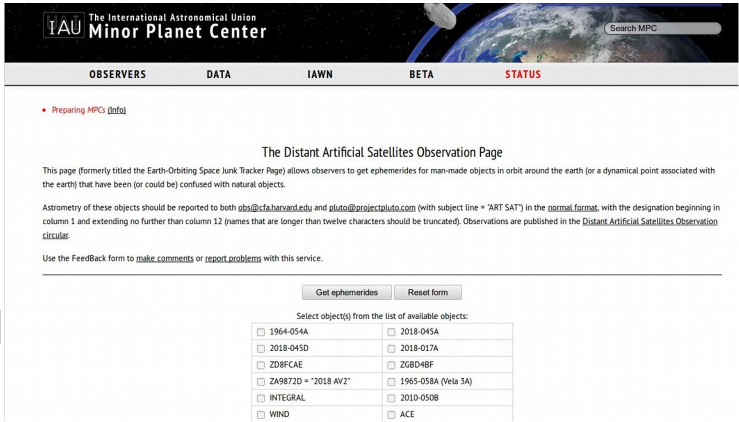
Eccentric: 5) SGP4 not adequate for late stages with very low perigee?
Orbit fits unreliable, better orbit model needed?

GTO and GEO: 6) Lots of GTO debris from rocket stage breakups.
Tracking HIGHLY incomplete for small objects in high orbits

In contrast, **beyond 150,000 km**:

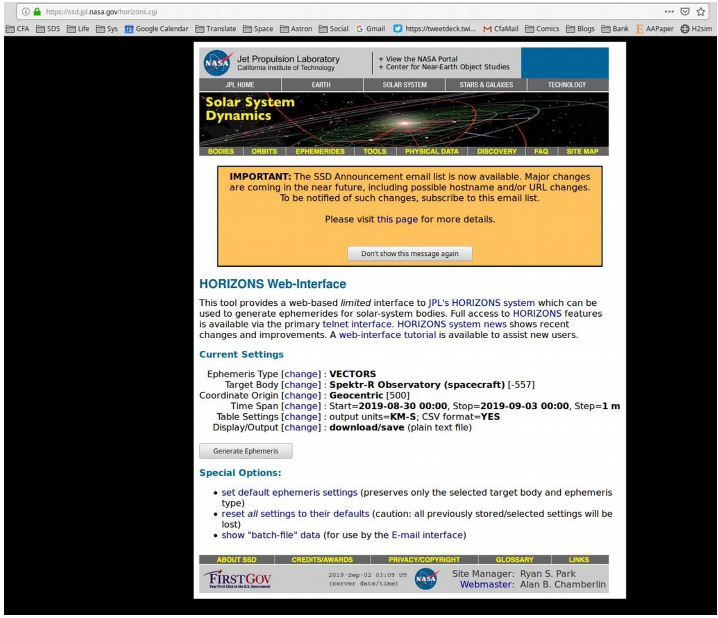
No-one is responsible for keeping track

The **US does a half-hearted job** on deep Earth orbit (DEO) objects
Enters some but not all known Earth escape objects in the satellite catalog with no orbital data.



Near-Earth Asteroid **astronomers accidentally find** DEO and some Earth escape objects. Small **unfunded** group keeping track of a subset to avoid confusion with real asteroids. (Gareth Williams, IAU MPC; Bill Gray, Project Pluto)

Active deep-space probes tracked by their operators. But **no systematic archive for this data once they are dead**.



JPL HORIZONS (Jon Giorgini) provides ephemerides and orbit data for a subset of active and dead probes: basically the ones JPL tracks or tracked (and didn't throw away the data). An immensely valuable contribution but **incomplete**.

It's all very patchy!

Why do I care?

- Historical interest. We may run into these things again in centuries to come.

- **The inner solar system in 20 years will be like LEO/GEO today** – even if asteroid mining *doesn’t* take off. More nations are sending probes to deep space. Commercial missions are already beginning. This will need governance. **Governance needs situational awareness**.

- **Astronomical confusion**. They look like asteroids when they return to Earth’s vicinity
  Example: Asteroid J002E3 turned out to be the Apollo 12 SIVB stage.
  Recaptured through SEL1 and spent a year orbiting Earth before departing again

- Earth departure states are often not accurate enough to reliably predict current location of a probe launched years ago. But if it is accidentally rediscovered, having the old orbit is enough to confirm its identity.

- **Planetary protection** concerns

- What about the **Registration Convention**? In practice, states never worried about the deep space stuff. But there is no reason this should be the case: everyone is technically in violation (Art. IV 1(d), “basic orbital parameters” does not specify Earth orbit.) .

Credit: The Expanse