Space Debris and Space Policy
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PART I: WHAT'S GOING ON IN SPACE?

PART II: HOW DO WE REGULATE ALL THIS?
October 1957: Sputnik
Most of what humanity does in space is done with robots - “artificial satellites” boxes of electronics with big solar-power-generating wings, commanded from Earth.
In 23 minutes, falls 4000 miles
BUT: moves sideways 4000 miles too!

**ORBIT:** 200 miles up
Moving sideways at 7.7 km/s (17259 mph)

**Sideways speed**

**Picks up downward speed from gravity**

Misses Earth entirely!
In 23 minutes, falls 4000 miles
BUT: moves sideways 4000 miles too!

ORBIT: 200 miles up
Moving sideways at 7.7 km/s
(17259 mph)

The speed it got from falling is now a SIDEWAYS speed!
Picks up downward speed from gravity IN NEW DIRECTION!

Fall around and around the Earth, always missing it!
SIDEWAYS speed makes you miss the Earth
 FALLING speed becomes the new sideways speed once you turn the corner...
No rocket engine needed to keep you up! [* Offer may not apply in presence of atmosphere]
A typical satellite launch ends up with at least two objects in orbit – the satellite and the last piece ("stage") of the rocket that got it there.
Remember:
the Earth is spinning -
the satellite orbit is NOT, it is fixed in space.
(well, that's only totally true if the Earth were perfectly round – never mind for now)

So each time the satellite goes round, the Earth has turned a bit

For a LEO polar orbit satellite it takes 1.5 hr to go round once, or 1/16 of a day, so the Earth has rotated 360/16 deg = about 22 degrees. Earth turns east, so satellite is now over something to the west – if it is over Florida now, it will be over New Mexico in 90 minutes or so after a quick swing over the N and S poles
GEO: Geostationary Earth Orbit

Consider a satellite whose orbit goes around the Earth's equator. Just outside the atmosphere it takes 1 ½ hours to go round the planet. Far out, at the distance of the Moon it takes a month to go round. Inbetween there is some height at which it takes exactly 23 hr 56 min.

Meanwhile, the Earth spins underneath it, also taking 23 hr 56 min to complete one full rotation.

So the satellite stays above the same point on the equator!

Kepler's Third Law lets us calculate the magic height: 35787 km above the Earth's surface (about 23000 miles).
Collisions

In LEO: Most likely collision over the poles, where SSO orbits in different planes intersect.

Example: 2009 Iridium/Strela collision

SSN 24946 Iridium 33, launched 1997 for Iridium LLC. Dry mass 556 kg

SSN 22675 Strela-2M 56, launched 1993 for Russian MoD. Dry mass 800 kg

Codename Kosmos-2251; retired 1995

Collision Feb 10 1656 UTC at

97.9E 72.5N Alt. 776 km over the Siberian Arctic

Sat 1: 7.465 km/s 12 deg E of N
Sat 2: 7.470 km/s 14 deg S of E

Relative velocity 11.64 km/s

KE of Strela in Irid frame 54 GJ
(Comparison: 1 ton truck @ 100mph = 1 MJ)
Some damage was done...

Figure from Kelso 2009
3 hours post collision (image from Kelso 2009) the debris spreads out along the orbit of each satellite

(compare meteor streams along comet orbits)

Eventually debris objects spread in RA due to differential orbital precession to make a shell

Also spread in altitude due to varying A/m ratio and hence drag coefficient

For small, light debris objects, atmospheric drag significant even at these altitudes (altitude data derived from NORAD/USSTRATCOM orbital elements via Space-Track.Org)

Current status:

Iridium debris - 629 cataloged 286 reentered

Strela debris: 1667 cataloged 566 reentered
Today, over 2000 active satellites and rising fast

Mere dozens of active sats in the ‘Space Race’ heyday
The Growth of Space Junk

Orbital Population

- Total
- Iridium/Cosmos Debris
- FY-1C debris
- Other Debris
- Inert Parts
- Rocket Stages
- Alt Payloads
- Dead Payloads
- Active Payloads

Year: 1960 to 2020
Space Junk - mass in metric tons

Orbital Tonnage

- Total
- Iridium/Cosmos Debris
- FY-1C debris
- Other Debris
- Inert Parts
- Rocket Stages
- Alt Payloads
- Dead Payloads
- Active Payloads
## A Census of Space Debris

### as of 12 Apr 2017 (including 172 objects cataloged yesterday evening!)

<table>
<thead>
<tr>
<th>Category</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total objects cataloged</td>
<td>42661</td>
</tr>
<tr>
<td>Objects still in Earth orbit</td>
<td>18296</td>
</tr>
<tr>
<td>Active payloads</td>
<td>1500?</td>
</tr>
<tr>
<td>Dead payloads</td>
<td>2796?</td>
</tr>
<tr>
<td>Rocket stages</td>
<td>1930</td>
</tr>
<tr>
<td>Adapters, jettisoned objects</td>
<td>1652</td>
</tr>
<tr>
<td>2007 Chinese ASAT debris</td>
<td>2855 )</td>
</tr>
<tr>
<td>2009 collision</td>
<td>1443 )</td>
</tr>
<tr>
<td>Other debris</td>
<td>6119 )</td>
</tr>
<tr>
<td>Residual fuel explosions</td>
<td>3826</td>
</tr>
<tr>
<td>Antisatellite weapon tests</td>
<td>3247</td>
</tr>
<tr>
<td>Accidental collision</td>
<td>1458</td>
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<tr>
<td>Battery explosion</td>
<td>1315</td>
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<tr>
<td>NaK Reactor coolant blobs</td>
<td>53</td>
</tr>
<tr>
<td>Insulation, Destruct, Other</td>
<td>518</td>
</tr>
<tr>
<td>Covers, fairings</td>
<td>300</td>
</tr>
<tr>
<td>Jettisoned motors and tanks</td>
<td>170</td>
</tr>
<tr>
<td>Multi-payload adapters</td>
<td>141</td>
</tr>
<tr>
<td>Despin devices</td>
<td>131</td>
</tr>
<tr>
<td>Deployment canisters</td>
<td>38</td>
</tr>
<tr>
<td>Insulation blankets</td>
<td>36</td>
</tr>
<tr>
<td>Nuclear reactor cores</td>
<td>14</td>
</tr>
<tr>
<td>Misc</td>
<td>28</td>
</tr>
<tr>
<td>Unknown pieces</td>
<td>794</td>
</tr>
</tbody>
</table>

Credit: Roskosmos, NASA, Arianespace, Khrunichev; El Genk 2009 (Buk)
How high are satellites?

- Green: active sats
- Red: dead sats
- Black: space junk

Van Allen Belts

LEO
GPS
GTO
GEO

Height (km)
Zooming into SSO

\[ \dot{\Omega} = \frac{3}{2} J_2 c R_e^3 \sqrt{R_G a^{-7/2}} \frac{\cos i}{1 - e^2} \]
TOTAL 66 COUNTRIES:

USA    816
China  45
Japan  40
Germany 26
S Korea  17
Russia 16
Denmark, UK 12
Australia 10
Spain  9
Singapore, France, Italy  8
Canada, Netherlands 7
India  6
Turkey, Israel 5
Belgium, Finland, Poland, Switzerland, S Africa, Brazil  4
Norway, Peru, Ecuador, Sweden, Kazakhstan, Lithuania, Czechia  3
Vietnam, Greece, UAE, Ukraine, Thailand, Malaysia,
Argentina, Egypt, Colombia, Austria, Estonia  2
Uruguay, Sri Lanka, Nepal, Jordan, Bhutan,
Bulgaria, Costa Rica, Kenya, Slovakia, Bangladesh,
Mongolia, Ghana, Philippines, Hungary, Romania,
Chile, Pakistan, Belarus, Mexico, Taiwan, Nigeria, Algeria 1
The Cubesat Explosion: STATISTICS 2019 Oct

http://planet4589.org
Space Junk Policy
So we have a traffic problem!

There’s a deeper problem: space is intrinsically global. All satellites in LEO are moving at ~ 18,000 mph.

Round the world in 90 minutes – so not over a single country for very long!

All satellites from all countries are mixed together – there are no lanes.

So it’s not good just trying to set rules on a per-country basis, you have to solve things internationally.

It’s hard to get all countries to agree, though :-( 
In 1967, the UN agreed the Outer Space Treaty

.... province of all mankind
.... not subject to national appropriation
.... all activities of non-govt orgs regulated by their govts
.... liability
.... due regard to others
... no nukes! (or other WMD).

RESOLUTION ADOPTED BY THE GENERAL ASSEMBLY

2222 (XXI). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies

The General Assembly,

Having considered the report of the Committee on the Peaceful Uses of Outer Space covering its work during 1966, and in particular the work accomplished by the Legal Subcommittee during its fifth session, held at Geneva from 12 July to 4 August and at New York from 12 September to 16 September,

Noting further the progress achieved through subsequent consultations among States Members of the United Nations,

Reaffirming the importance of international cooperation in the field of activities in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, and the importance of developing the rule of law in this new area of human endeavour,

1. Commends the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, the text of which is annexed to the present resolution;

2. Requests the Depositary Governments to open the Treaty for signature and ratification at the earliest possible date;

3. Expresses its hope for the widest possible adherence to this Treaty;
Space debris concerns started in 1980s - initially about retirement of GEO satellites … failure to agree on any formal treaty … informal agreement on best practice 1984 1993: IADC (NASA, Russia, Japan, Europe initially)
High orbit recommendations:

Push GEO sats UP by 300 km on retirement
Low orbit recommendations:

Sats should reenter within 25 years of end of mission
Outer Space Treaty says all space activities managed by governments

UN recommendations → national licensing → constraints on commercial operators
In USA, that’s FAA and FCC

Who Needs a License or Permit?

License
- U.S. Companies
  - Launching inside US
  - Launching outside US
- Foreign Companies
  - Launching inside US
  - U.S. Commercial Launch or Reentry Sites

Experimental Permit
- Reusable suborbital rockets may obtain a permit for the sole purpose of
  - Research & Development
  - Gathering data for a license
  - Crew Training

**Amateur Rocketry** activities do not need a license or permit (unmanned, $I_{sp} < 200$ Klb/sec)

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Guidance On Obtaining Licenses For Small Satellites

Full Title: Guidance On Obtaining Licenses For Small Satellites
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Tags: Satellite, Spectrum

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Federal Aviation Administration
Office of Commercial Space Transportation

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Phone: 1-800-828-9140 (Flight Service) 1-800-722-8455 (FDOT) 1-800-872-3580 (FCC)
www.faa.gov
WARNING: Your satellite is about to pass close to someone else's satellite. ONE OF YOU might want to move, But it's up to you.
FreeFlyer® simulation of two spacecraft at a possible conjunction event.
BUT WAIT, THERE’S MORE....

WELCOME TO THE ERA OF LEO MEGACONSTELLATIONS

60 SPACEX Starlink sats up so far 30,000 planned!!

How’s that going to work?
SUMMARY:

Earth orbit is filled with lots of satellites
And even more space junk

Satellites travelling at 18000 mph and going in different directions
What could possibly go wrong?

Attempts to regulate based largely on gentleperson’s agreements rather than international law

Policy and regulation moves slowly
The explosion in the use of commercial space is happening faster than the rate at which regulators can adapt.

Collisions are an ‘n squared’ problem:
10 x the population => 100 x the number of collisions.