What's Up?
The Globalization of Space
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Space Globalization:

THE OLD SPACE RACE
INTERNATIONALIZATION
COMMERCIALIZATION
DEMOCRATIZATION

Space Demographics – Who and What

Space Demographics - Where: Orbitography
When they hear 'space', many people think 'astronauts'.....
but 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.
A quick introduction to satellites

About 1000 satellites currently operating
Some in low orbit skimming just outside the atmosphere, mostly going from pole to pole

Some in 'geostationary orbit' in a ring high above the equator
In 1960s, only a few dozen sats operating at any one time

Today, over 1000 active satellites and rising
We still think of space the way it was in the 1960s

Here, the TIROS weather satellite is assembled by a US manufacturer – in this case, RCA in East Windsor, NJ
Another US company, Douglas Aircraft, builds the Thor Delta rocket.

The satellite is delivered to its owner, the US civil space agency NASA, who also buy the rocket.

Here is TIROS 2 on top of the rocket before the nose cone is added.
Here, the NASA Delta launches TIROS 2 into space from a launch site on US territory – in this case, Cape Canaveral, FL.
And the satellite operates in orbit under the ownership of NASA, using a NASA mission control center in Greenbelt, MD.
INTERNATIONALIZATION
1962 – Ariel 1, a UK owned, US built satellite with UK instrumentation

(1964's Ariel 2 carried the first – and AFAIK so far only – Cambridge satellite experiment, for radio astronomy)

Later in 1962: Canada's Alouette 1 Canadian built and owned

1965:
The first French satellite launch from the Algerian desert

France becomes the third country with orbital launch capability after the USSR and the USA
But it's not like that any more!

A typical modern (2006) satellite:

South Korea's Koreasat-5 satellite takes shape in the Thales Alenia factory in Cannes, in the south of France.
In the Ukraine, the Yuzhnoe company builds the Zenit-2S rocket
In Korolev, near Moscow, the Rocket Space Corporation “Energiya” builds the Blok DM-SL upper stage rocket
At Sea Launch home port in Long Beach, California, the satellite and Zenit rocket are loaded on the Norwegian-built floating launch platform.

The platform then sails out in the Pacific to the Equator – in international waters.
The Zenit rocket puts the Koreasat-5 in orbit where it is operated via the mission control center in S Korea with support from engineers in France.

The rocket launch is carried out by Energia Logistics (US), a US subsidiary of RSC Energiya. The launch is sold to the satellite owner by Sea Launch AG of Bern.

I count this as a US launch!
The commercialization of space
1962-1963
Telstar 1 and 2 – AT&T funded the first commercial communications satellites and paid NASA to launch them
Telstar was not followed up – the next commercial satellite system had to wait for geostationary satellites to be mature.

In 1972 the Canadian company Telesat was established as a commercial enterprise by the Canadian government. The `Anik' system was the first of a rush of first-generation commercial communications satellites built by Hughes and RCA.
1974: Western Union's Westar
1975: RCA Globcom's Satcom
1976: Comsat General's Marisat and Comstar
1976: Perumtel of Indonesia's Palapa
In the 1980s government civilian orbital launches by NASA and ESA were replaced by commercial launch services by McDonnell Douglas (now Boeing), General Dynamics (now Lockheed Martin) and Arianespace.

Apart from the Space Shuttle, NASA hasn't launched a satellite itself since 1994.
Today commercial imaging satellites are familiar thanks to Google maps!
In the 2010s, commercialization began to extend to human spaceflight. SpaceX's Dragon cargo ship arrived at the Station on 2013 Mar 3.
With the globalization of corporations, space commercialization becomes space globalization

SES (Societe Europeene des Satellites)
- Based Luxembourg, 1985 (first satellite 1988)
- Absorbed RCA Americom (New Jersey) 2001
  (Absorbed GTE Spacenet 1994)
- Absorbed GE Capital (Gibraltar) 2001
- Absorbed Nordic Satellite (Stockholm) 2005
- Absorbed New Skies (The Hague) 2006
  (spun off from INTELSAT in 1998)
- Stake in Nahuelsat (Argentina), Quetzsat (Mexico)
- Former stake in Asiasat (Hong Kong) and Star One (Brazil), etc.

As of 2014, 46 SATS OPERATING IN GEO – 10% of total Activities in many countries; satellite control centers in US and Lux. Which country do the SES satellites belong to?
The INTERNATIONAL TELECOMMUNICATIONS SATELLITE ORGANIZATION - in the 1960s, an IGO
Now 149 member countries

Operations privatized in 2001
Headquarters in Bermuda until 2009, then Luxembourg
Real headquarters in DC
Another effect of globalization and mergers: buying and selling satellites in space

1985: Satellite Business Systems sells 4 sats to MCI Corp
1992: BSkyB sells its two satellites to Telenor (Norway) and Sirius (Sweden)

– more sales here and there in 1990s, but in 2000s see whole in-orbit fleets change hands

2004 - 4 Loral Telstars become Intelsats
2006-2007 – 21 Panamsat satellites (PAS and Galaxy) sold to Intelsat
2006 - New Skies fleet sold to SES
The Democratization of Space
Dec 1961 – the first amateur satellite
Built by radio amateurs in California
Hitched a ride strapped to the side of a spy satellite rocket

OSCAR – Orbiting Satellite Carrying Amateur Radio
Guildford, 1981: University of Surrey team (under Martin Sweeting) builds amateur radio satellite UoSat-1. It becomes the basis of a series of cheap commercial satellites affordable by developing countries.
Nigeriasat-2 2011
Bilsat (Turkey) 2003
Alsat (Algeria) 2002
Uribyol S Korea 1992
Tiungsat (Malaysia) 2000
Fasat (Chile) 1998
Posat (Portugal) 1993
Nigeriasat-2 2011
Cubesats: 1 kg, 10 cm (2 lb, 4 in for the metric impaired)
Standard kit for universities to make students build sats in engineering courses
Can also make '3U' cuboids 30 x 10 cm
97 Cubesats launched 2003-Feb 2013 by 66 organizations in 20 countries
2013: CUBESAT EXPLOSION!

99 Cubesats launched Jun 2003-Feb 2013 by 63 organizations in 20 countries
120 Cubesats launched Mar 2013 – Feb 2014 by 57 organizations in 18 countries
(Cumulative: 219 Cubesats by 108 orgs in 28 countries)

Chris, Will and Robbie left NASA to found PlanetLabs in a San Fran office building – 71 satellites launched since 2013, first big Cubesat constellation
The Cubesat Explosion: STATISTICS 2016 FEB

Cubesat Launches to Feb 2016

Satellite masses 1960-2009

Satellite masses 2010-2016

Orbited TotalFail
(nono transmissions)
A: Academic/nonprofit 123 29?
B: Business/commercial 94 4
C: Civil govt. (e.g. NASA) 19 0
D: Defense/military 53 5+

OPERATED > 2 YEARS: 38 (TBR)
(CUTE-I, XI-IV 13 years and going!)

TOTAL 29 COUNTRIES:
USA 203 Japan 20 Germany 10

SCIENCE 27 (Bio 4, Astron 3) COM 37 IMG 81
TECH 141 CAL 4

http://planet4589.org
PART 2 - SATELLITE DEMOGRAPHICS
In the 2010s, most sats are either communications or imaging; technology development (including student satellites) also a big sector.
By mass however, human spaceflight dominates – comms still next
Tech/student satellites vanish, they are mostly little cubesats which don't weigh much

6-yr total 1350 t robotic, 1350 t 6 x Shuttle + ISS/PRC
Decade by decade:

Red: Imaging (spy sats) dominated in cold war

Purple: Human spaceflight tonnage huge in 1990s (100 tonnes for each Shuttle)

Green: Steady growth of communications sector
Today the space launch market has many more players.

In 2012 China had as many orbital launch attempts as the US.

12 countries plus ESA/Arianespace have launched satellites; Brazil has also tried but failed.

North and South Korea are the latest members of the club.
Decade by decade
Size of circle = total launches

Soviet launches (red) dominated in 1970s and 1980s – many satellites but each one didn't last long

US (blue) – fewer launches but the payloads were long lived

China (green) got serious about space in the 2000s

Europe (magenta) was in 3\textsuperscript{rd} place, dropped to 4\textsuperscript{th} in 2010s
Lots of countries OWN satellites – too many to show on the chart, so I grouped together E. Europe (pink), Africa (black), Latin America (dark purple), and Asia-other-than-China/India/Japan (light green)

Russia, US, W. Europe and China dominate; next Japan (orange), and India (yellow)
The 'other' countries almost vanish when considering tonnage -
Their satellites are usually tiny cubesats
Check out the steady increase in internationalization over the decades.
Lump all countries together – division between military, civilian and commercial is about even if you exclude human spaceflight (most of the tonnage, and money)

Non-profit an important sector by number of satellites, but tonnage is negligible
The defense sector (red) shrunk after the cold war.

Commercial sector became important in 1990s

Non-profit sector is a factor starting in 2010s
Part 3: Orbitography

- **Apogee:** < 50 000 km
- **HEO**
- **GEO:** ~36 000 km, fixed lat./long.
- **MEO:** 8000 – 20,000 km
- **LEO:** 500 – 2000 km
- **Perigee:** ~500 km
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.
In 1 second:
Moves sideways 5 miles
Falls 30 feet

In that 5 miles, Earth curves away from you by 30 feet!

End up the same height above the Earth -
Fall all the way around the Earth in a circle

ORBIT:
Moving sideways at 7.7 km/s (17000 mph)
1 second later:
Part of the downward speed is now sideways
Low Earth Orbit

Earth surface has $r = 6378$ km
Space Station has height 400 km, so $r = 6778$ km

This corresponds to $v = 7.67$ km/s
or $v = 17158$ mph - quite fast!!
At 400 km, orbital period is 92.5 minutes

Consider orbits around an object of mass $M$, radius $R_s$ and gravitational radius

$$R_G = \frac{GM}{c^2}$$

(where we will consider only the case $R_s \gg R_G$!). From Newton’s law of gravitation, the potential is

$$V = mc^2 \left( \frac{r}{R_G} \right)^{-1}$$

it follows trivially that circular orbits of radius $r$ will have

$$\frac{v}{c} = \sqrt{R_G/r}$$

The orbital period $T$ is then given by

$$cT = 2\pi r \sqrt{r/R_G}$$

which is Kepler’s third law.
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 1½ 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).
How high are satellites?

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

Van Allen Belts

LEO
GPS
GTO
GEO

Moon
Overall statistics (2014 data):

<table>
<thead>
<tr>
<th></th>
<th>Active</th>
<th>Dead</th>
<th>Junk</th>
</tr>
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<tbody>
<tr>
<td>LEO</td>
<td>652</td>
<td>1512</td>
<td>10327</td>
</tr>
<tr>
<td>MEO</td>
<td>86</td>
<td>262</td>
<td>758</td>
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<tr>
<td>HEO/GTO</td>
<td>25</td>
<td>151</td>
<td>1562</td>
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<tr>
<td>GEO</td>
<td>464</td>
<td>518</td>
<td>291</td>
</tr>
<tr>
<td>Deep</td>
<td>15</td>
<td>51</td>
<td>62</td>
</tr>
</tbody>
</table>

*Most satellites are either in LEO or GEO*

Special cases:

**LEO**
- SSO      282  247  5173
- others   370  1265 4625

SSO is a very specific orbit, has almost half the LEO sats – and most of the debris

**GEO**
- Stationary 452  83  14
- Graveyard   5   187 92
- Drift       7   233 167
- Other       1   22  57

Only 36 percent of dead GEO sats are in the graveyard
A Map Of Earth Orbit

Inclination (deg)

Height (km)

Active
Dead
Junk

Retrograde
Polar
Equatorial

SSO
ISS
GPS
GEO
Moon
BACKUP SLIDES
Actually we left something out of our math: the Earth is NOT ROUND! It's a little squashed at the poles (polar radius is 22 km smaller than at equator) Every time a sat goes over the poles, it gets less of a tug; over the equator it gets more. This twists the orbit – makes it rotate in space.

We consider the first term ($J_2$) in the spherical harmonic expansion of the potential. This gives first order corrections to the orbital elements (node, arg of peri.) - varying linearly in time

By picking the orbit cleverly you can make the twist do something useful.

The magenta colored orbit is what you get for a perfect sphere Earth.

It stays fixed in space so in August (in this particular case) it is facing the sun – the satellite orbits over the dawn/dusk line - but in May the orbit is edge on to the sun, orbiting noon to midnight.

The green colored orbit is SSO, turning so it's always facing the Sun.
Zooming into SSO

\[ \dot{\Omega} = \frac{3}{2} \frac{J_2 c R_e^2 \sqrt{R_G a}}{a^2} \cos i \frac{\cos i}{1 - e^2} \]
How Elliptical vs. How Polar

\[ \dot{\omega} = f_P \left( 2 - \frac{5}{2} \sin^2 i \right) \]
How Elliptical vs. How Polar

Inclination vs. Eccentricity

Molniya, Plesetsk, Baykonur, Canaveral, GTO, Kourou
Coda
The Growth of Space Junk
Space Junk - mass in metric tons

[Graph showing the accumulation of space junk over time with different categories such as Total, Active Payloads, Dead Payloads, Rocket Stages, Inert Parts, FY-1C Debris, Iridium/Cosmos Debris, and Other Debris.]

Years: 1960 to 2000
Earth orbit is now globalized
Until recently the rest of the solar system was a superpower preserve

MOON:

VENUS:

MARS:

JUPITER:
US 1973  Europe 1992 (ULS)

SATURN:
US 1979  Europe 2005 (hitching a ride with US)

COMETS:

ASTEROID:

MERCURY, URANUS, NEPTUNE: Only USA