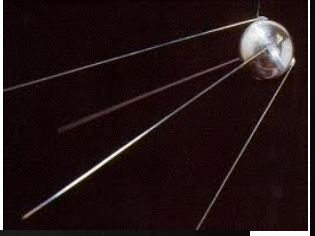
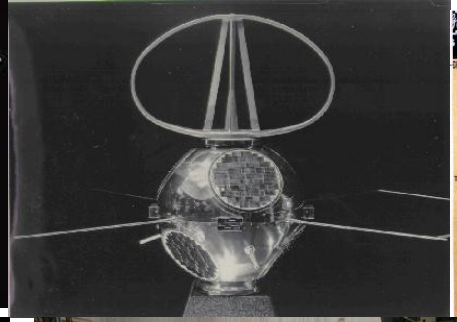
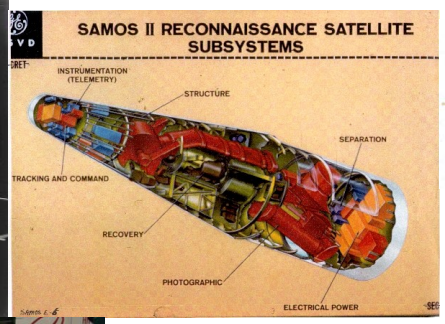
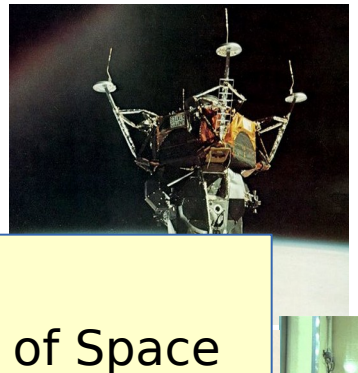
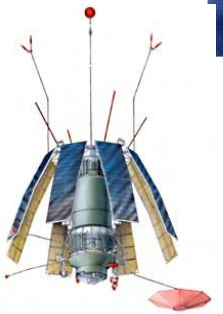
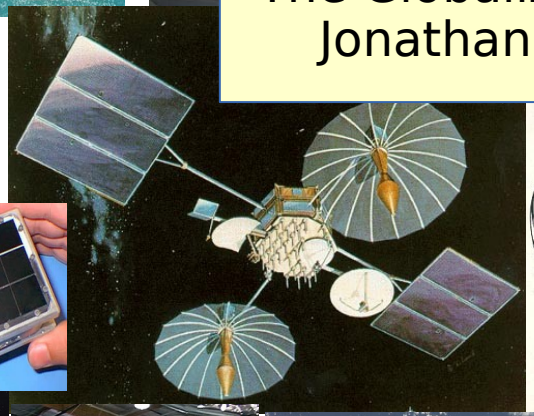
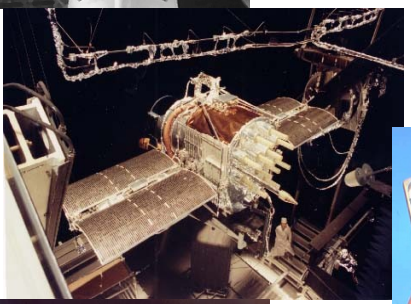
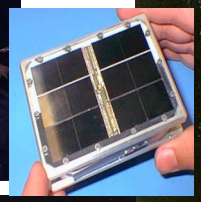
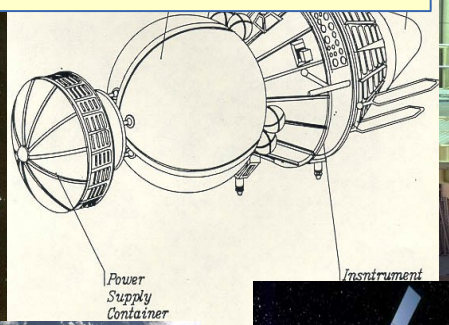




SAMOS II RECONNAISSANCE SATELLITE SUBSYSTEMS
INSTRUMENTATION (TELEMETRY)
STRUCTURE
SEPARATION
TRACKING AND COMMAND
RECOVERY
PHOTOGRAPHIC
ELECTRICAL POWER



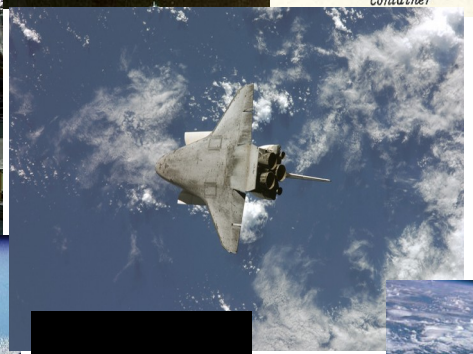
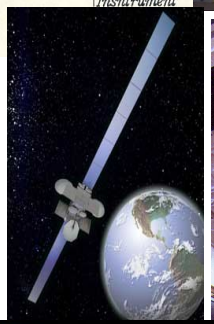
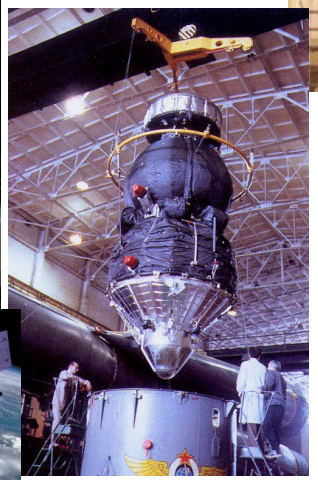


What's Up?
The Globalization of Space
Jonathan McDowell




Power
Supply
Container
Instrument









Mass
Properties
X8

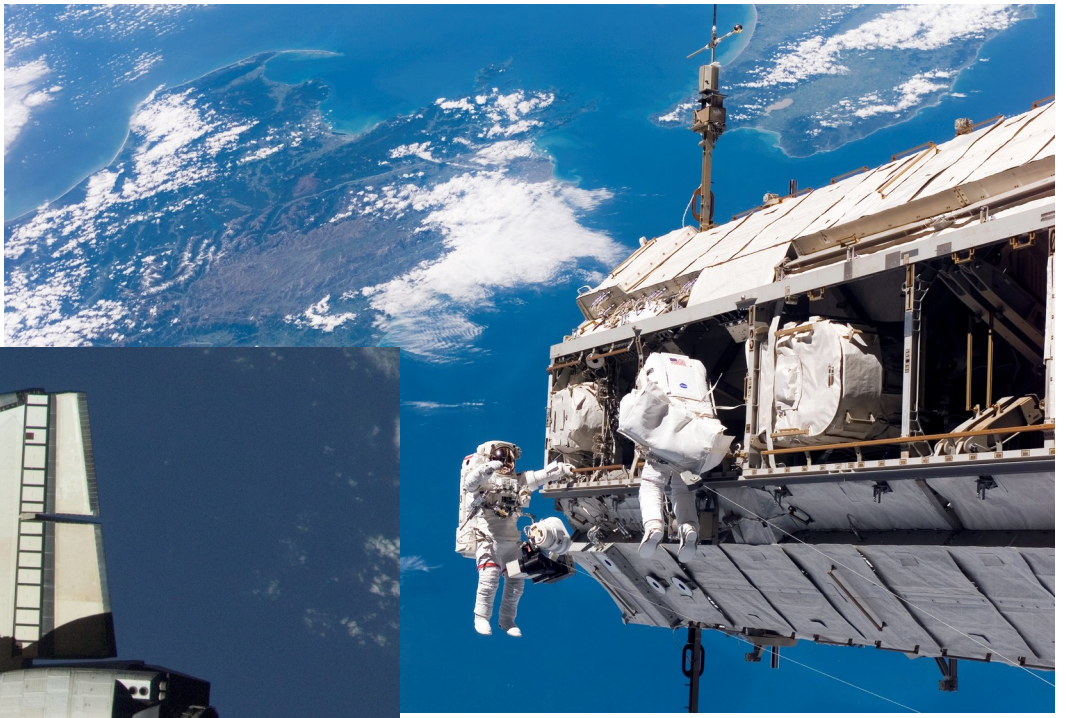
Space Globalization:

THE OLD SPACE RACE
INTERNATIONALIZATION
COMMERCIALIZATION
DEMOCRATIZATION

Space Demographics – Who and What

Space Demographics - Where: Orbitography

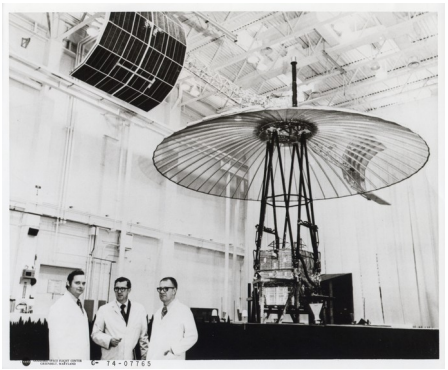
When they hear 'space', many people think 'astronauts'.....



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

Communications

Earth Imaging



Signals intelligence

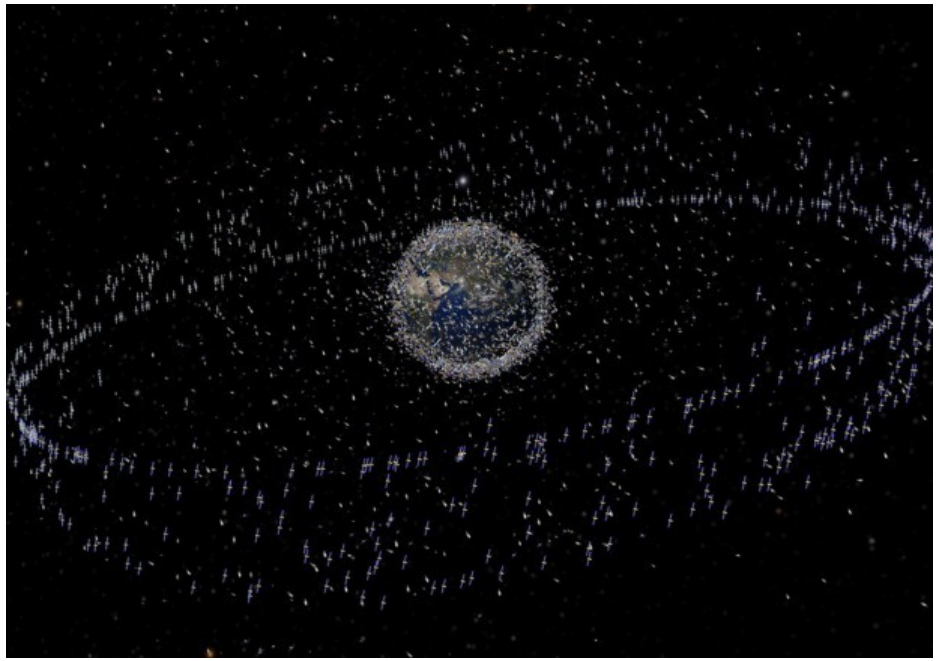
Technology
and training

Navigation (GPS)

Science
(e.g. astronomy)

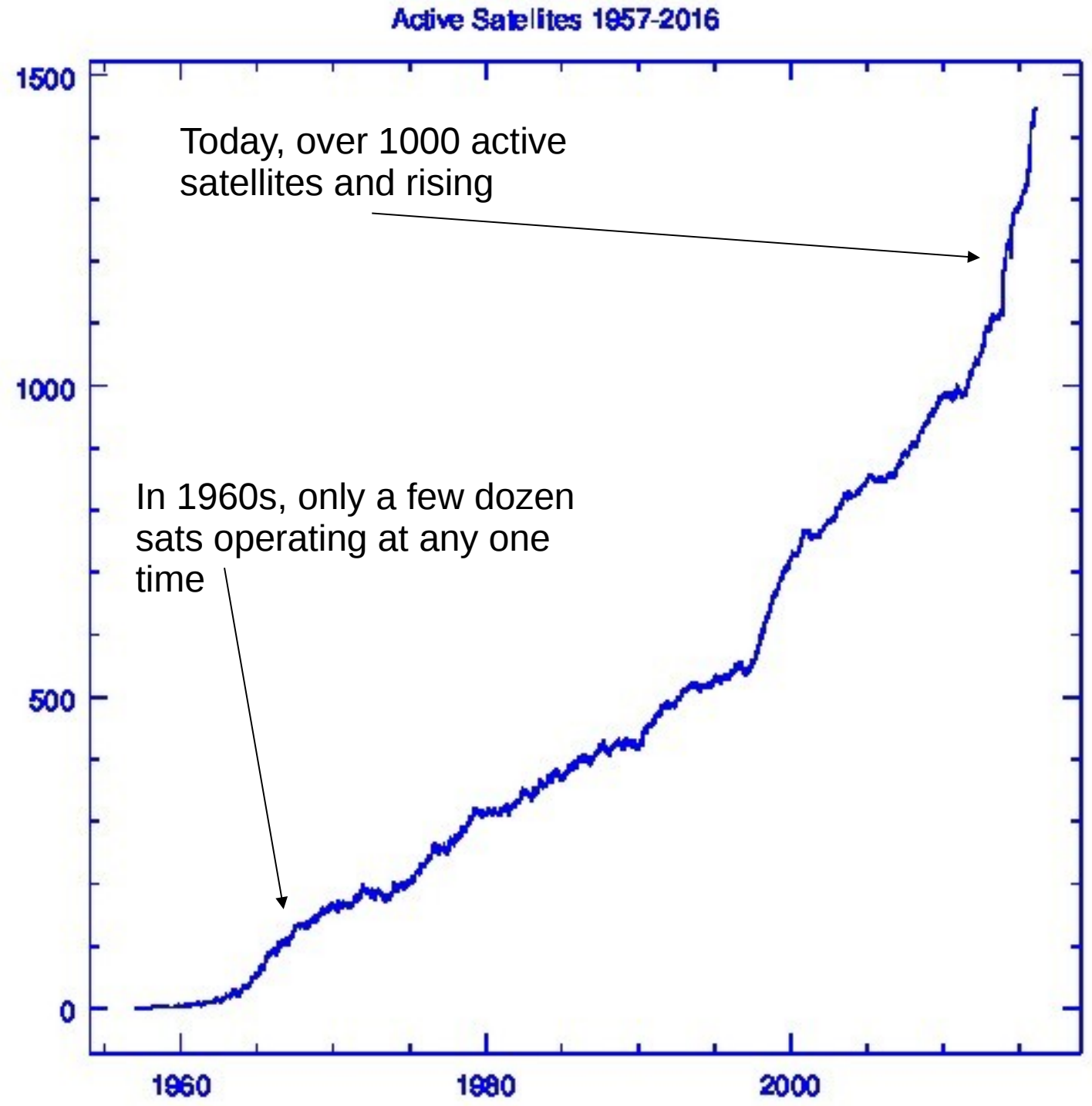
Human spaceflight

A quick introduction to satellites

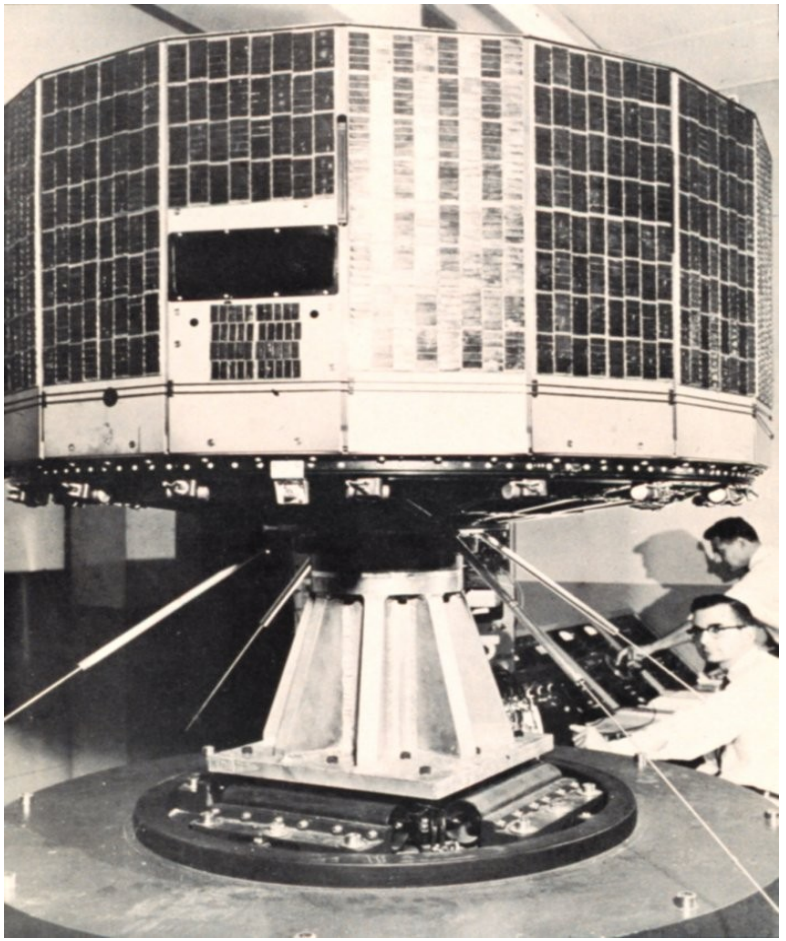


About 1000 satellites currently operating
Some in low orbit skimming just outside the atmosphere, mostly going from pole to pole

Some In 'geostationary orbit' in a ring high above the equator


Active Satellites 1957-2016
1500
1000
500
0
1960
1980
2000
Today, over 1000 active satellites and rising
In 1960s, only a few dozen sats operating at any one time

We still think of space the way it was in the 1960s

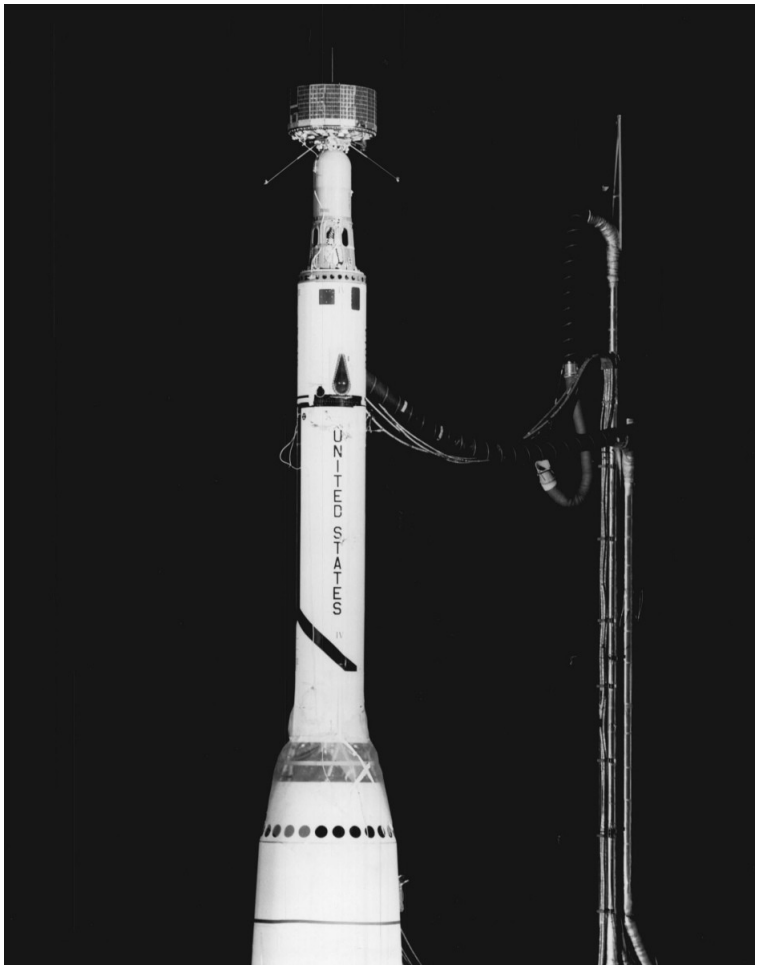


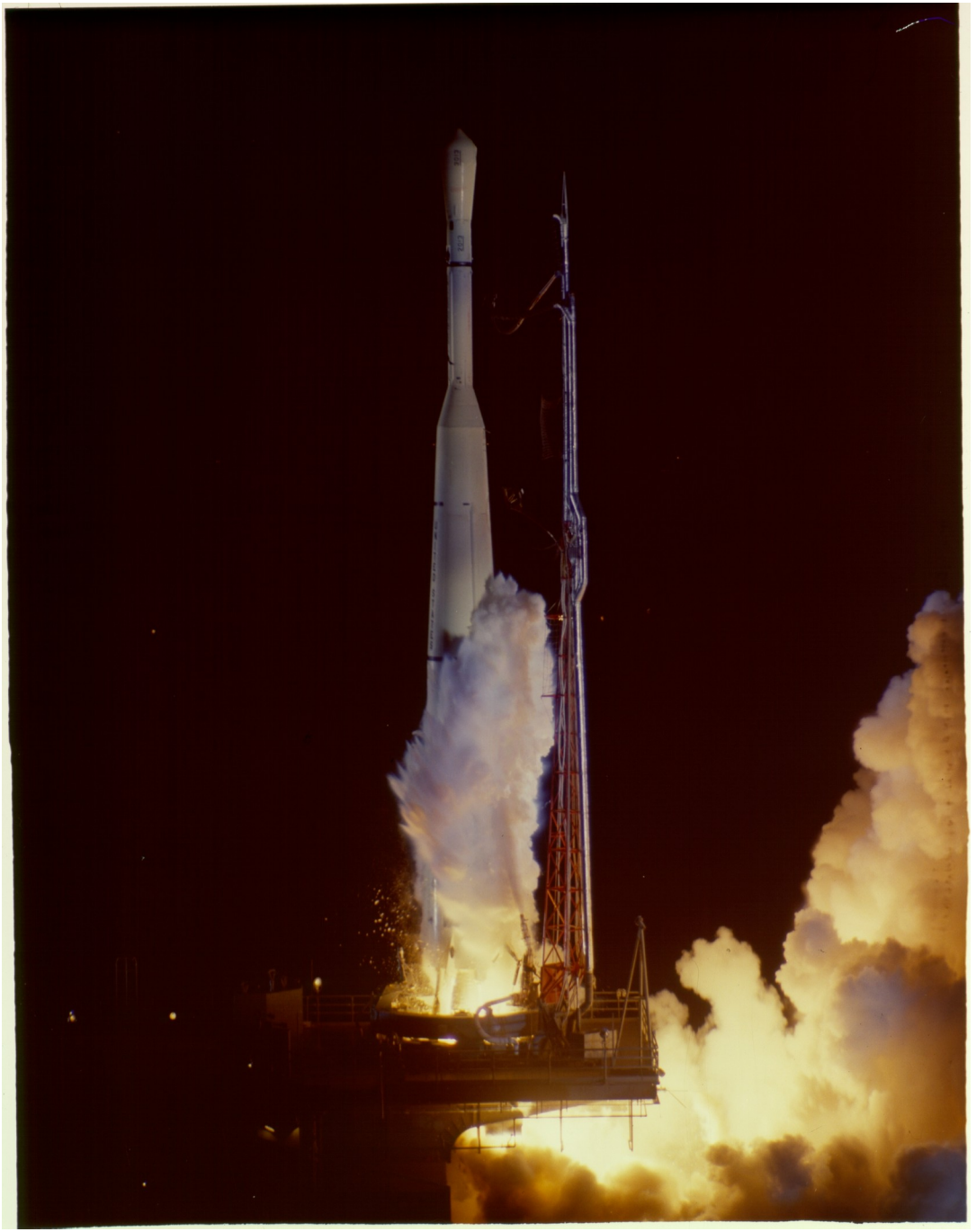
Here, the TIROS weather satellite is assembled by a US manufacturer – in this case, RCA in East Windsor, NJ

Another US company, Douglas Aircraft, builds the Thor Delta rocket.

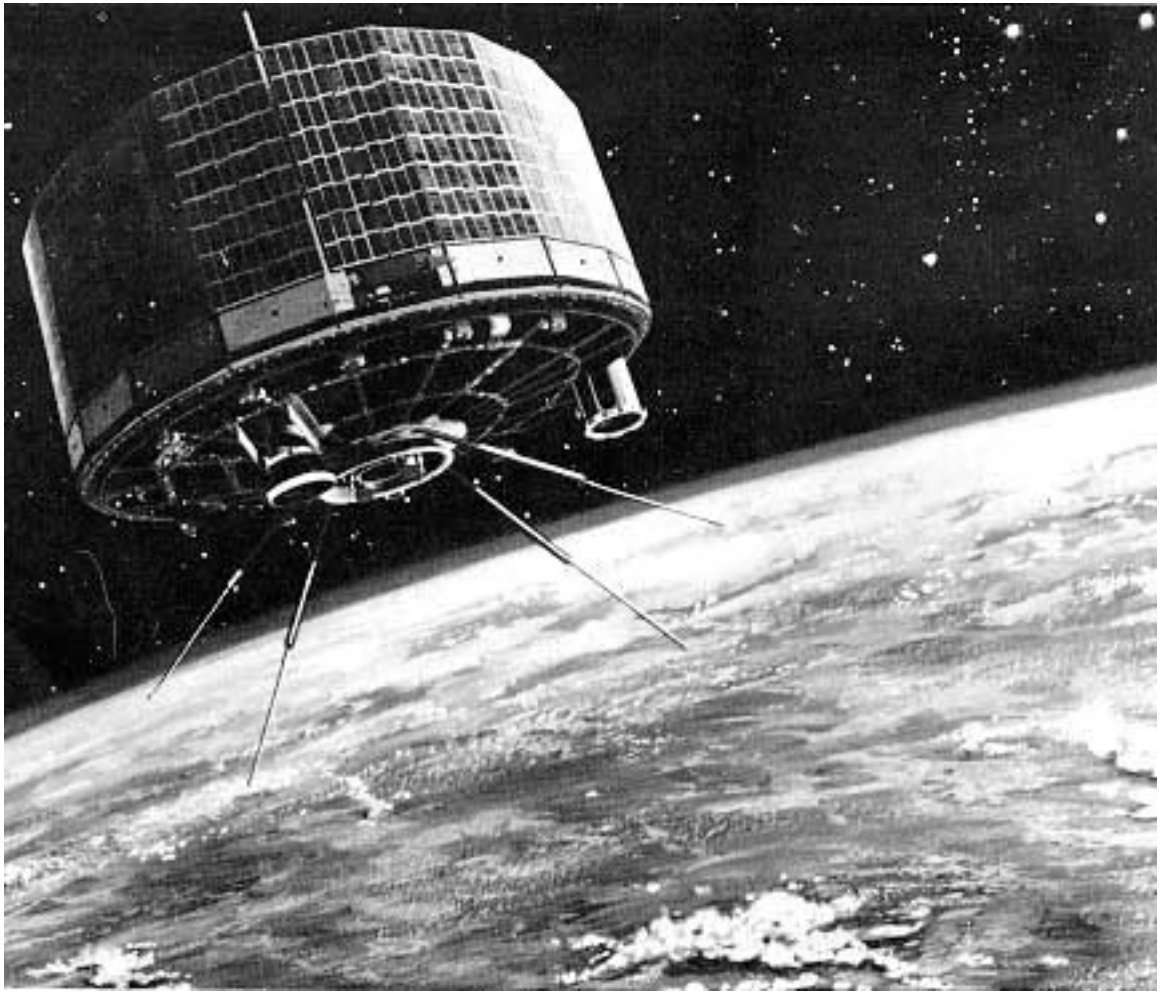
The satellite is delivered to its owner, the US civil space agency NASA, who also buy the rocket.

Here is TIROS 2 on top of the rocket before the nose cone is added



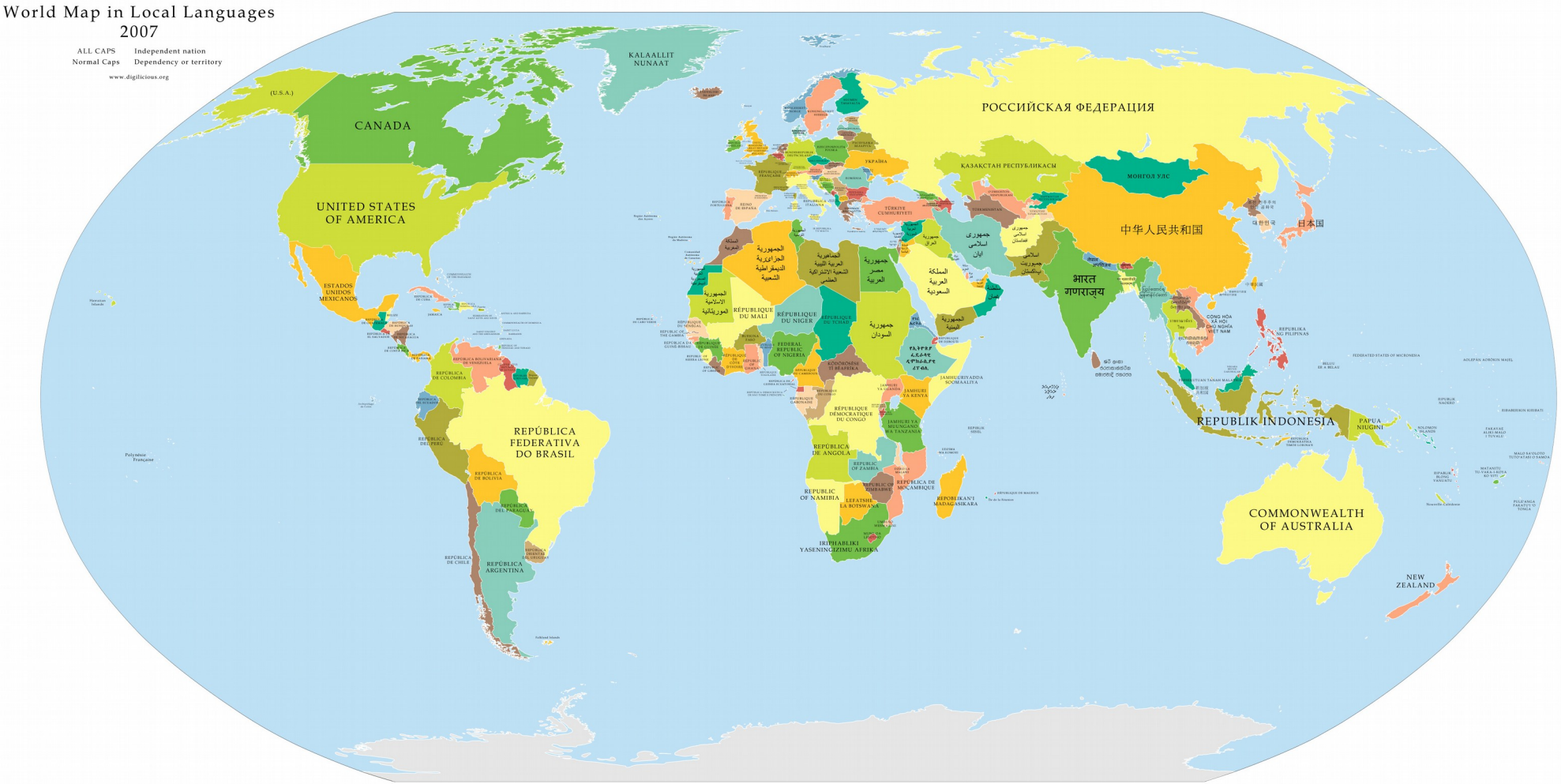


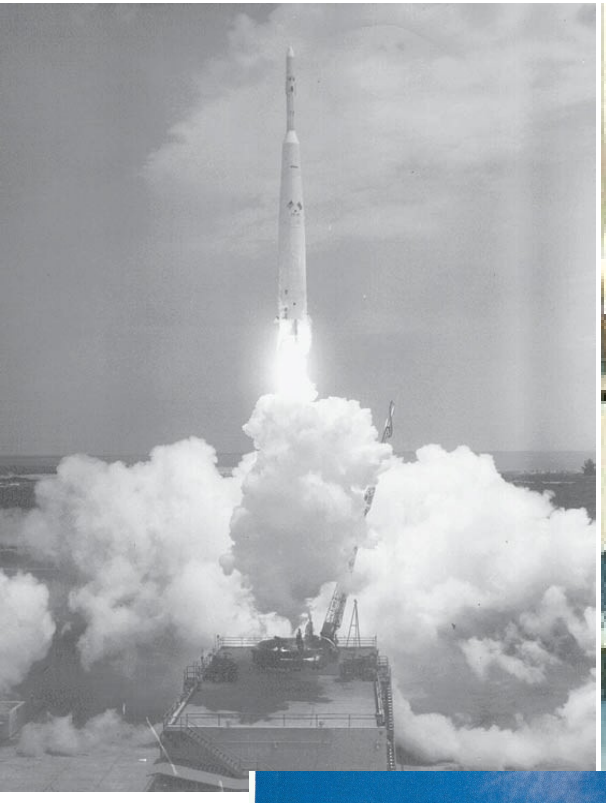
Here, the NASA Delta launches TIROS 2 into space from a launch site on US territory – in this case, Cape Canaveral, FL

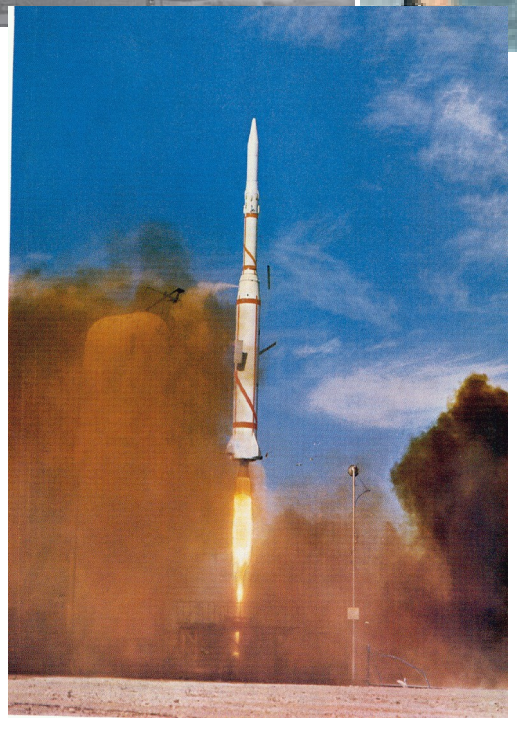


And the satellite operates in orbit under the ownership of NASA, using a NASA mission control center in Greenbelt, MD

INTERNATIONALIZATION







INTERNATIONALIZATION BEGINS..

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

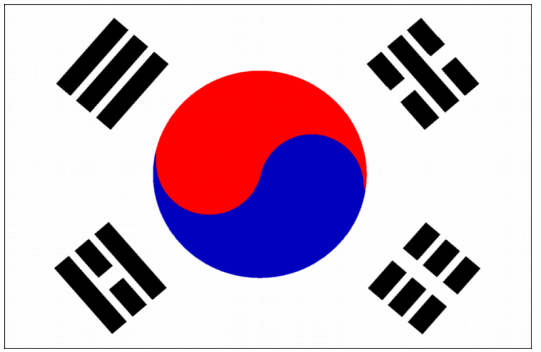
1965:
The first French satellite launch from the Algerian desert

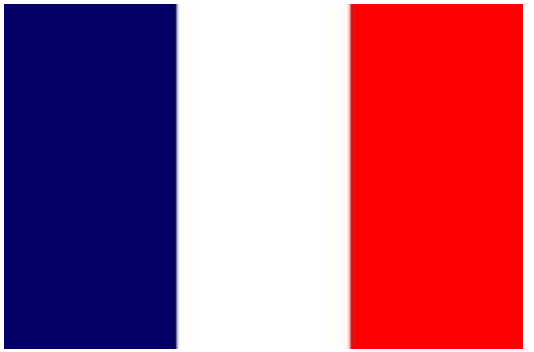
France becomes the third country with orbital launch capability after the USSR and the USA

But it's not like that any more!

A typical modern (2006) satellite:

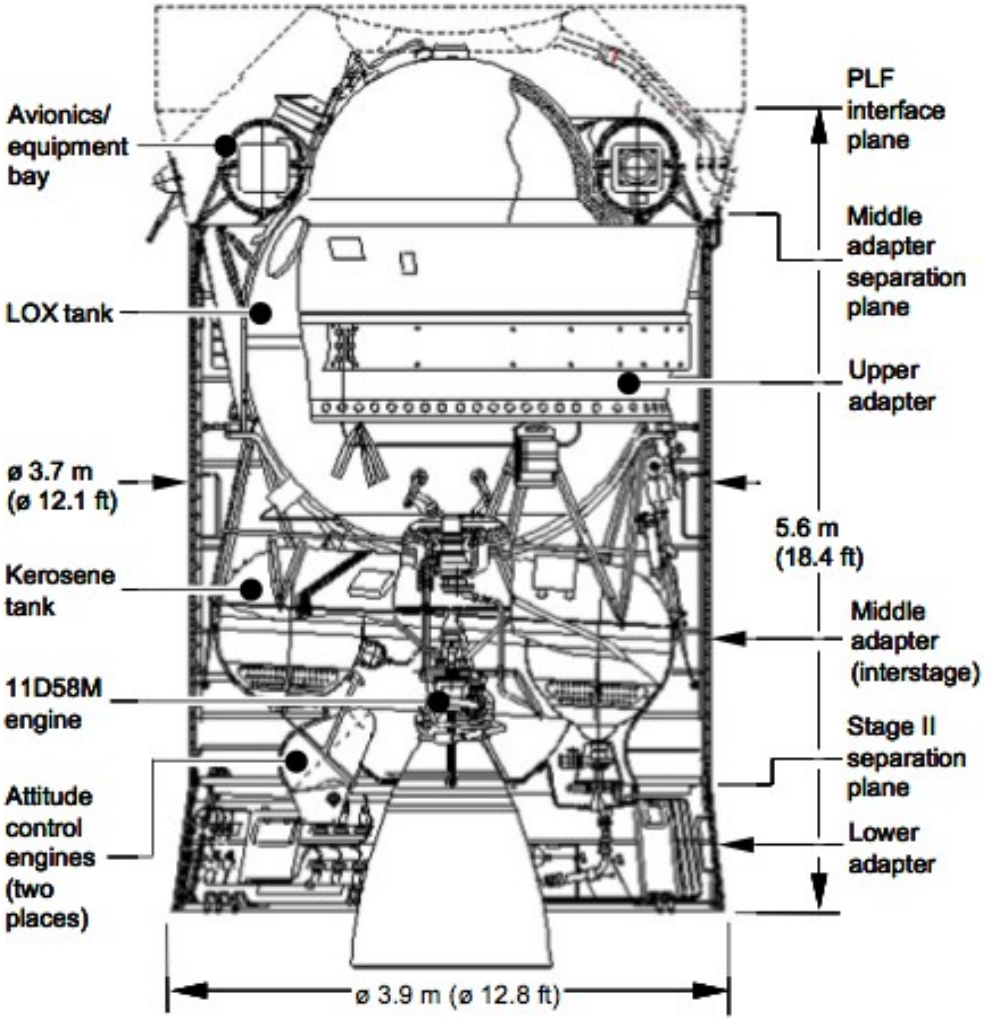
South Korea's Koreasat-5 satellite takes shape in the Thales Alenia factory in Cannes, in the south of France



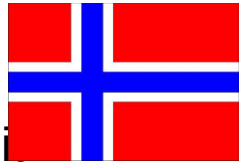


In the Ukraine, the Yuzhnoe company builds the Zenit-2S rocket

Block DM-SL (without interstage)



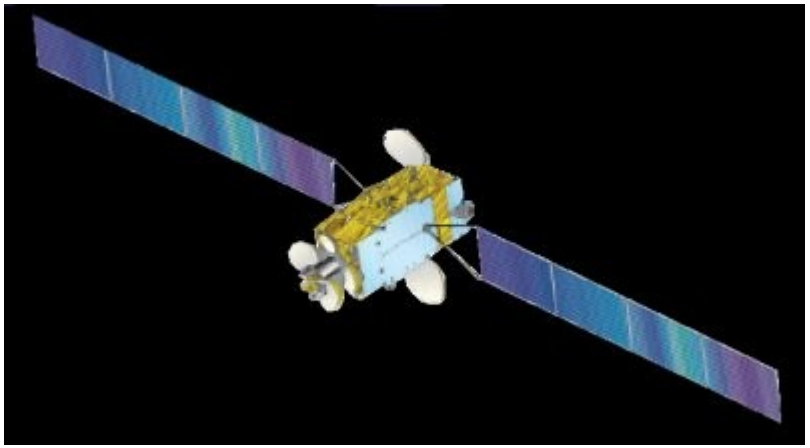
In Korolev, near Moscow, the Rocket Space Corporation “Energiya” builds the Blok DM-SL upper stage rocket

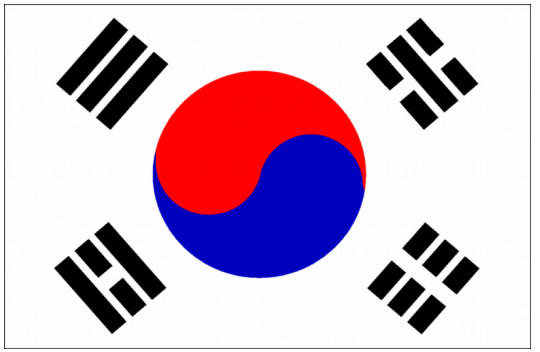


At Sea Launch home port in Long Beach, California, the satellite and Zeni rocket are loaded on the Norwegian-built floating launch platform

The platform then sails out in the Pacific to the Equator – in international waters

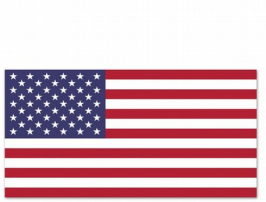
The Zenit rocket puts the Koreasat-5 in orbt
where it is operated via the mission control center in S Korea
with support from engineers in France



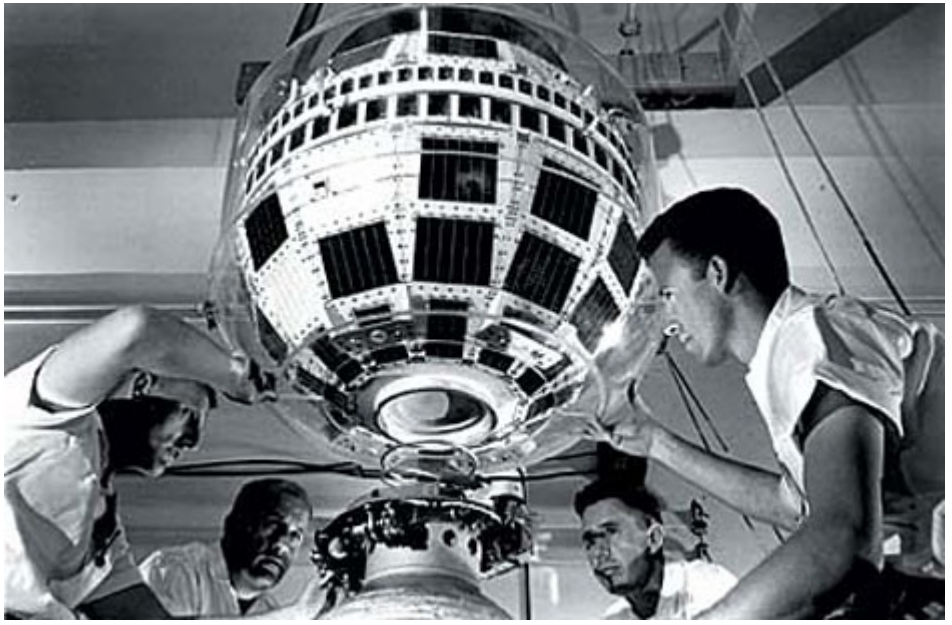


The rocket launch is carried out by Energia Logistics (US), a US subsidiary of RSC Energiya. The launch is sold to the satellite owner by Sea Launch AG of Bern

I count this as a US launch!



The commercialization of space

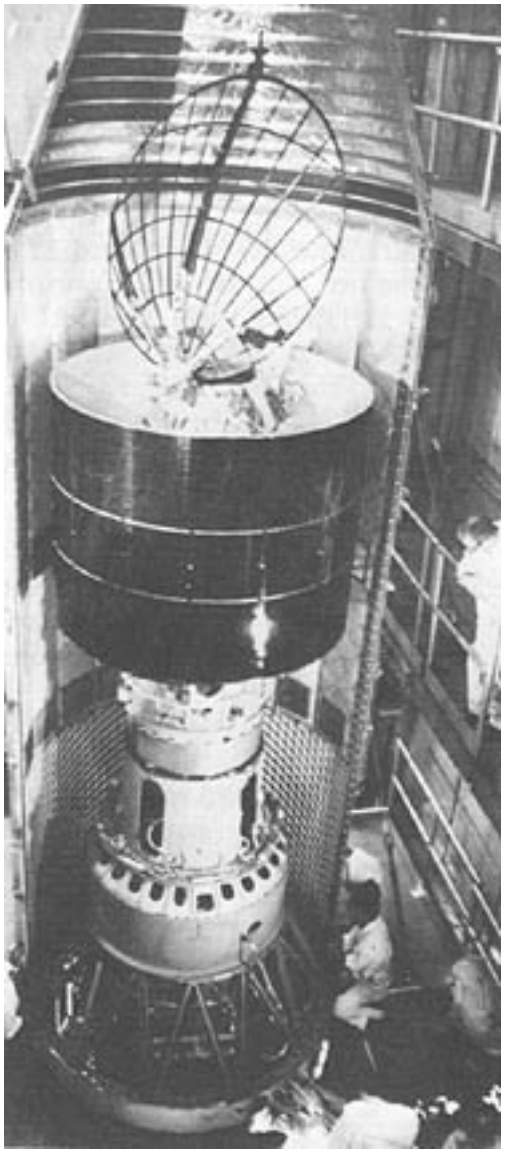


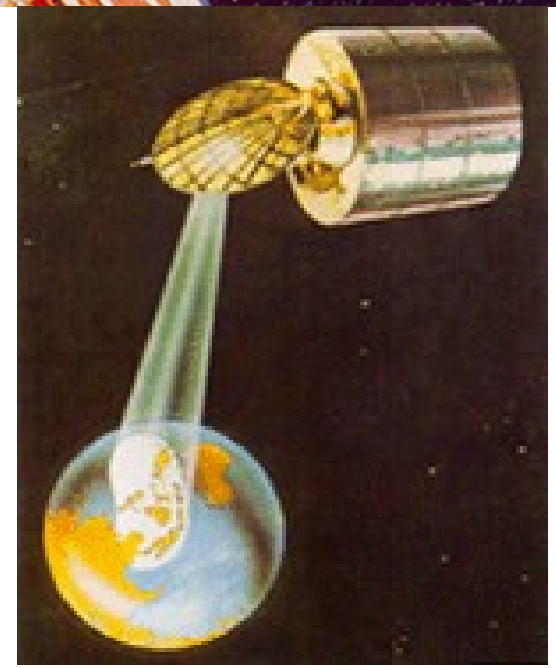
1939

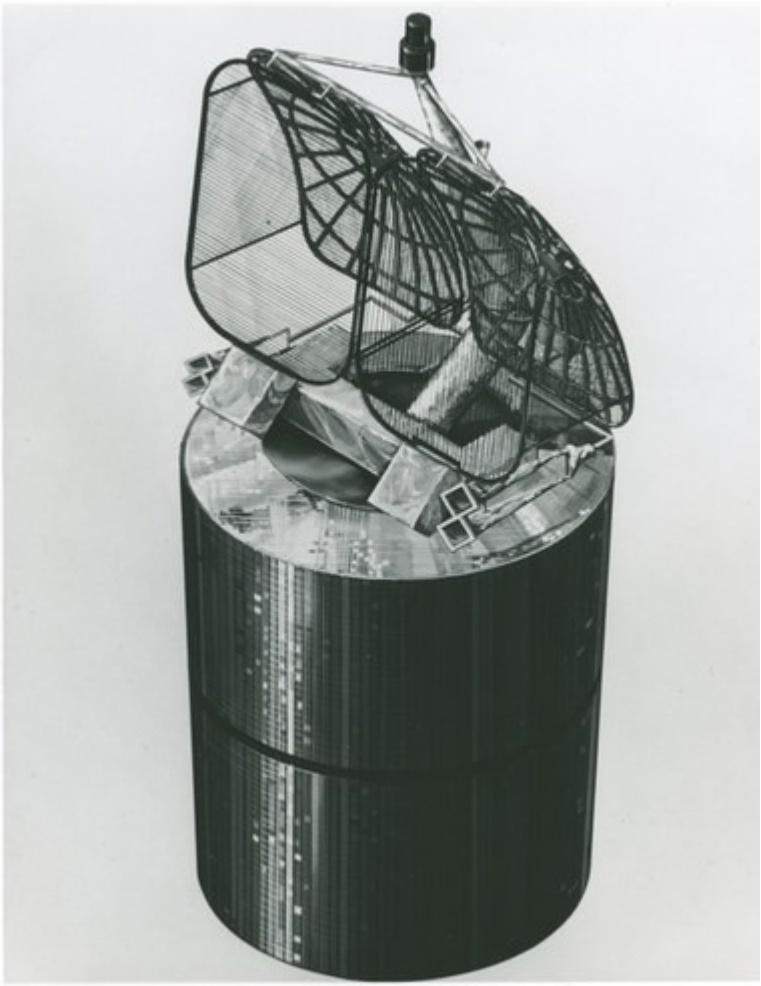
1962-1963
Telstar 1 and 2 – AT&T funded the first commercial communications satellites and paid NASA to launch them

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 satlelites built by Hughes and RCA



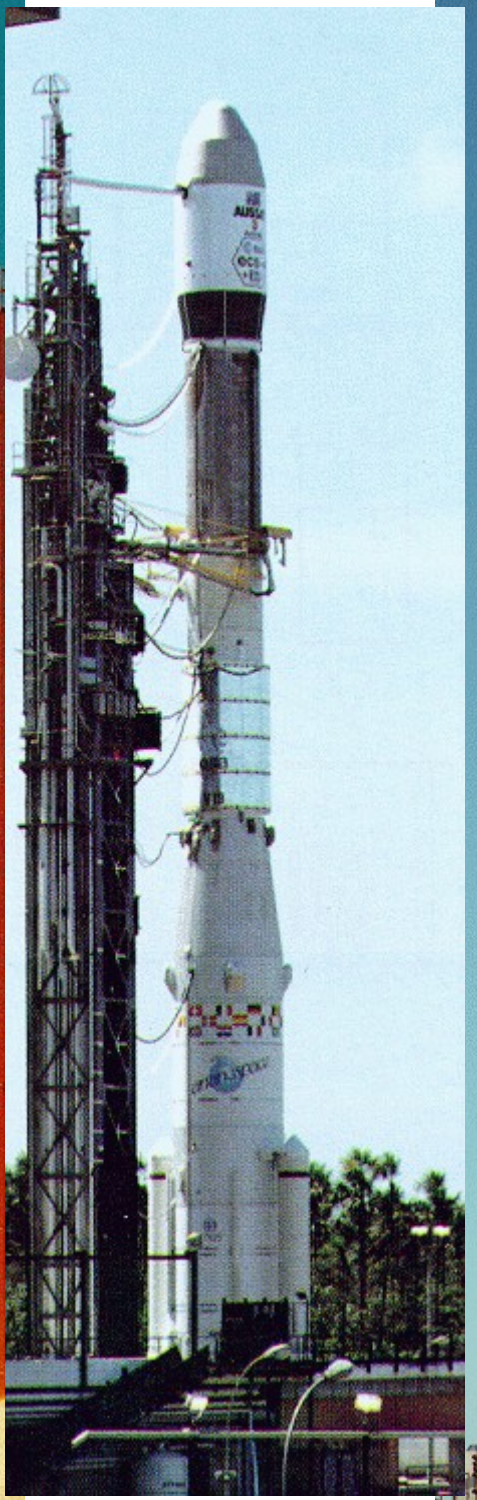




1974: Western Union's Westar
1975: RCA Globcom's Satcom
1976: Comsat General's Marisat and Comstar
1976: Perumtel of Indonesia's Palapa

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 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)
- Abosrbed 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.

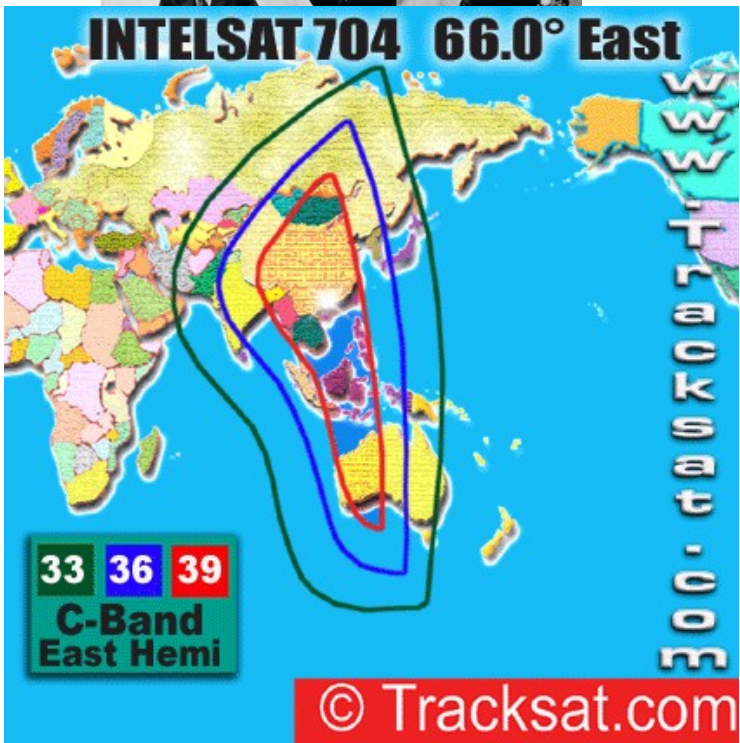
As of 2014, 46 SATS OPERATING IN GEO – 10% of total
Activities in many countries; satellite control centers in US and Lux.
Which country do the SES satellites belong to?

SES ASTRA
An SES GLOBAL Company

The INTERNATIONAL TELECOMMUNICATIONS SATELLITE ORGANIZATION
- in the 1960s, an IGO
Now 149 member countries

Intelsat

Operations privatized in 2001
Headquarters in Bermuda until 2009, then Luxembourg
Real headquarters in DC



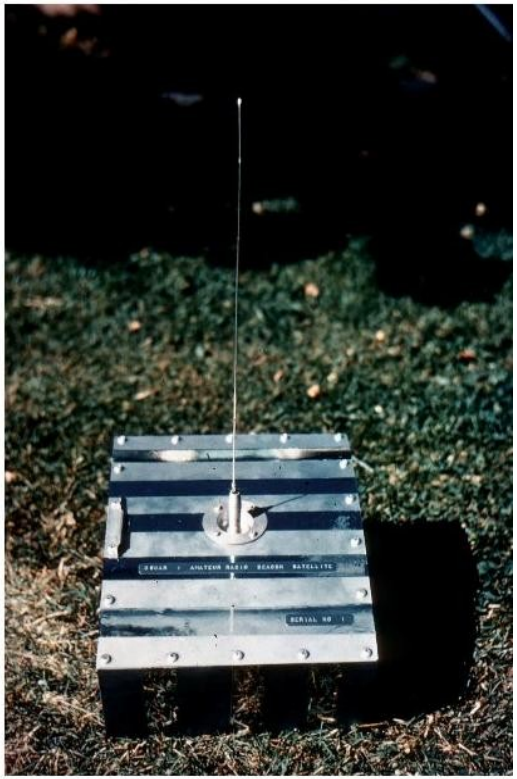
Another effect of globalization and mergers:
buying and selling satellites in space

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

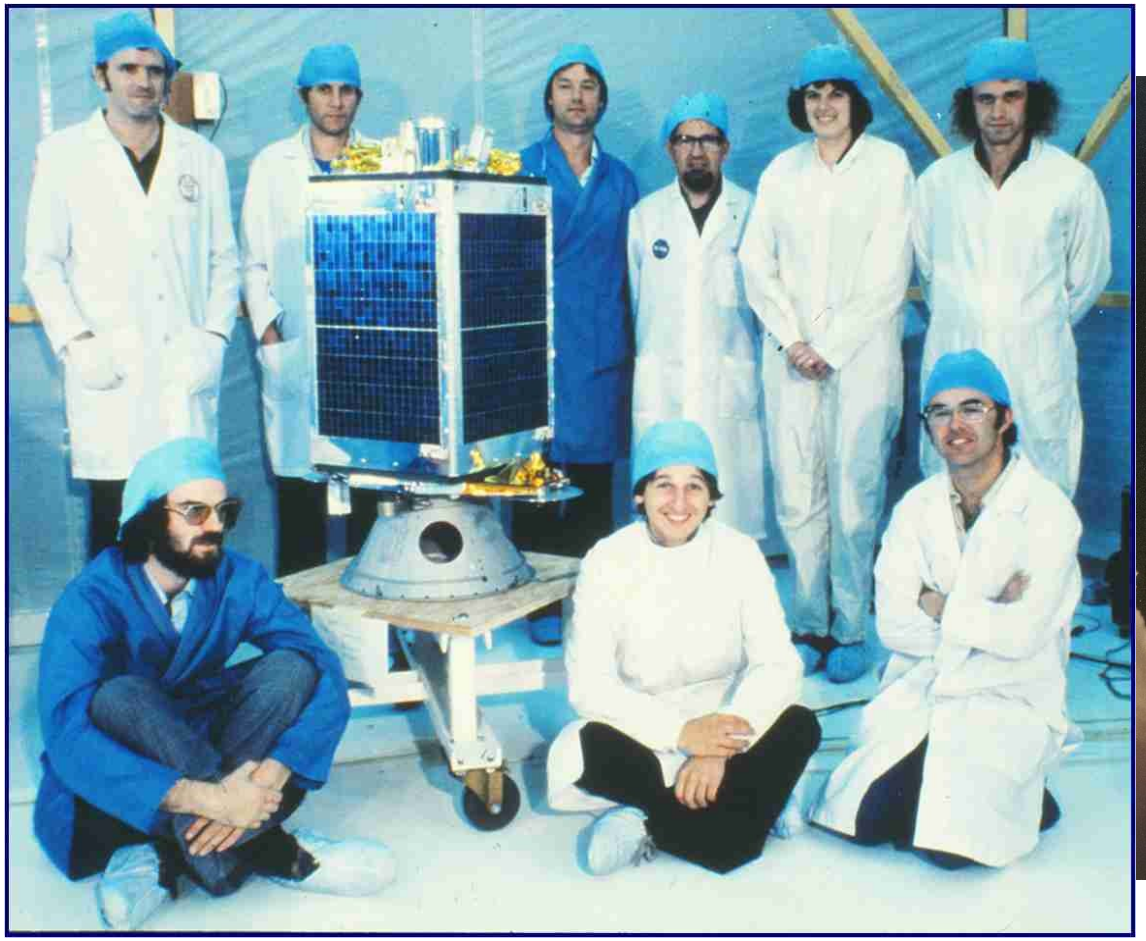
The Democratization of Space



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



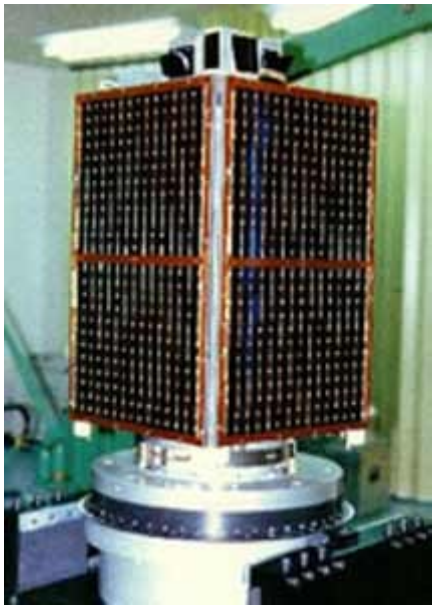
Alsat (Algeria) 2002

Tiungsat (Malaysia) 2000

Fasat (Chile) 1998

Posat
(Portugal)
1993

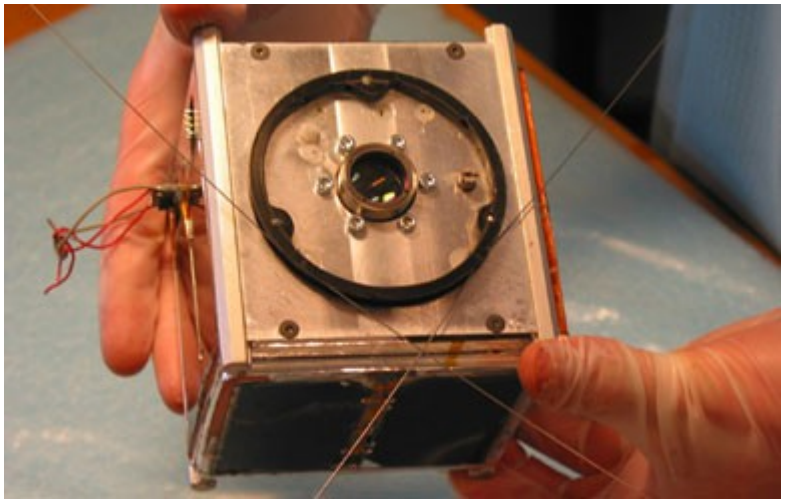
Bilsat (Turkey) 2003



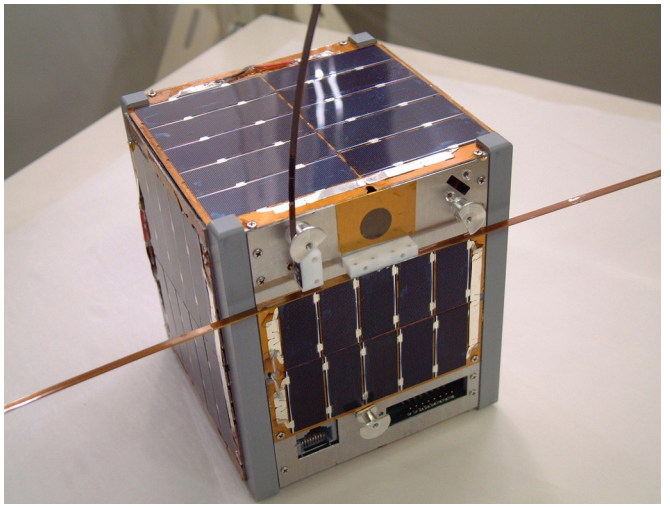
Uribyol
S Korea 1992

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



Aalborg U. 2003



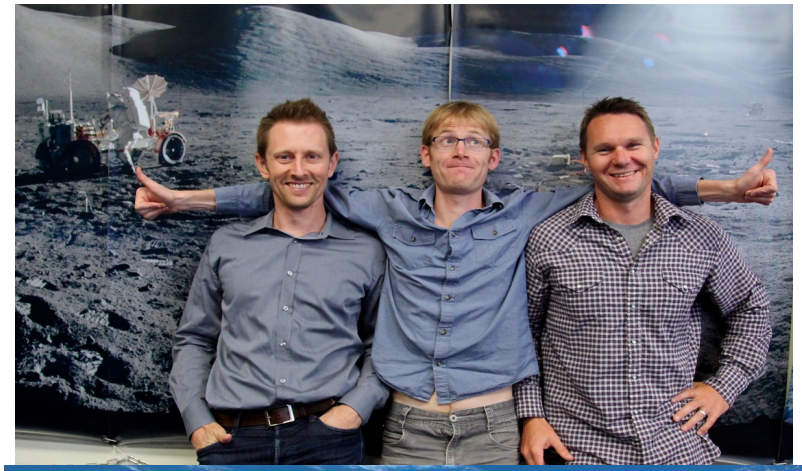
Univ. of Tokyo, 2003

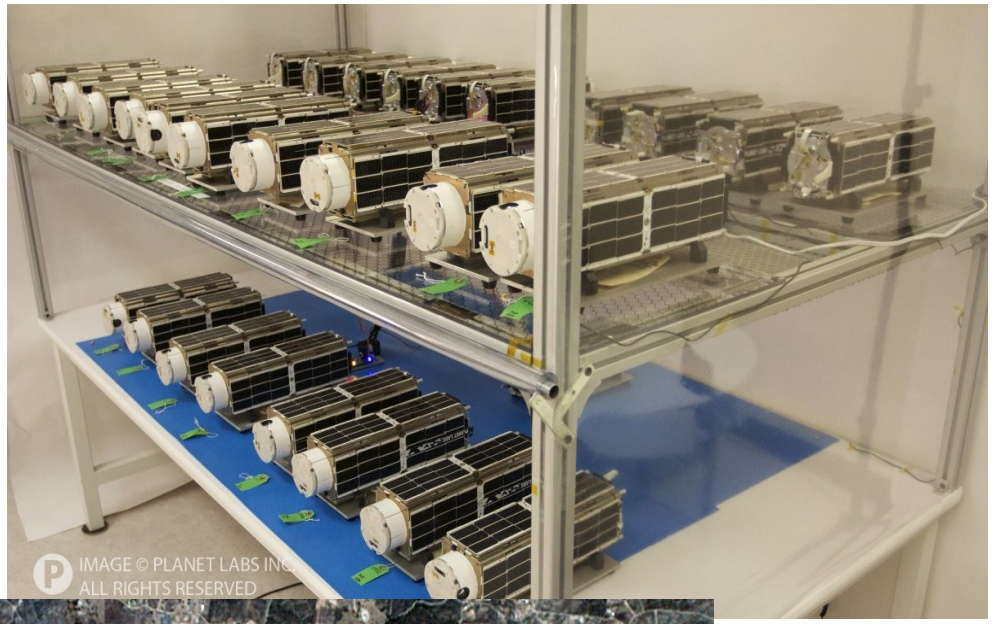
Cubesat deploy from ISS, 2012

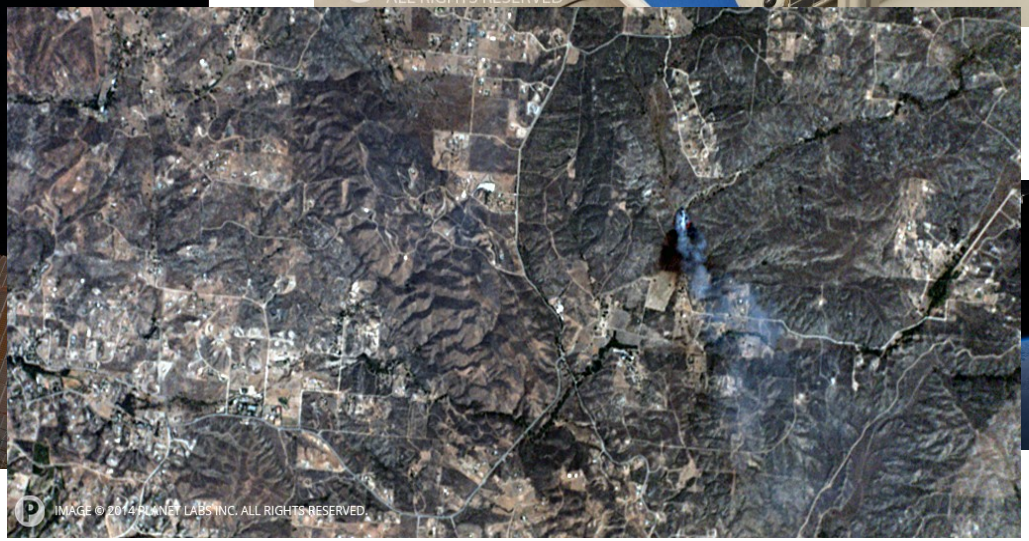
Triple-cube Quakesat, Stanford 2003

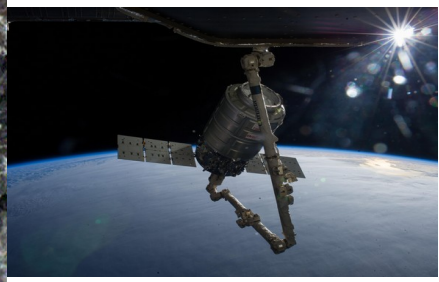
2013: CUBESAT EXPLOSION!

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)





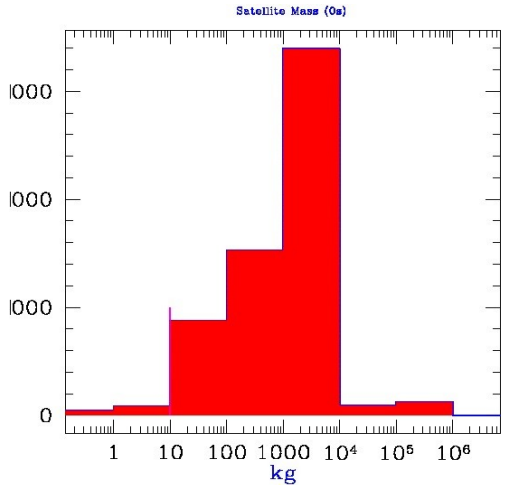




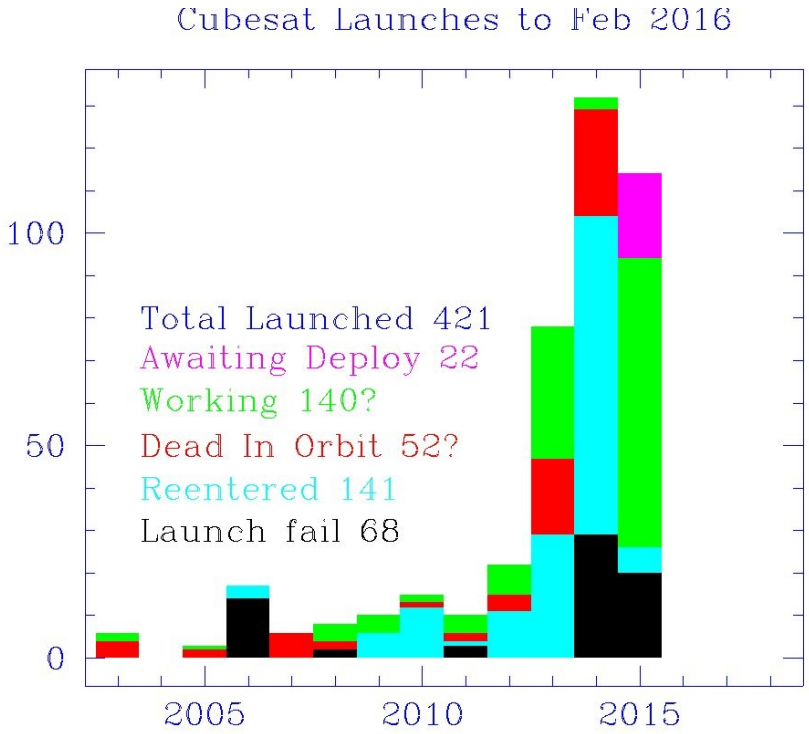
Chris, Will and Robbie left NASA to found PlanetLabs in a San Fran office building – 71 satellites launched since 2013, first big Cubesat constellation

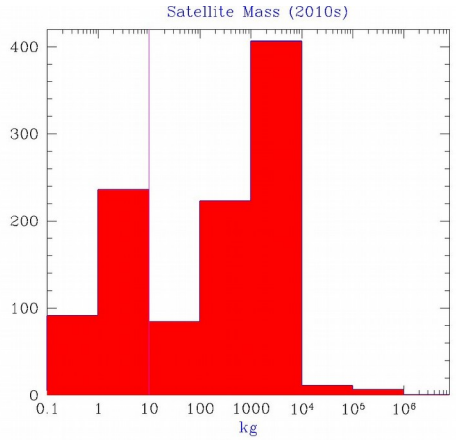
The Cubesat Explosion: STATISTICS 2016 FEB

http://planet4589.org



Satellite masses 1960-2009



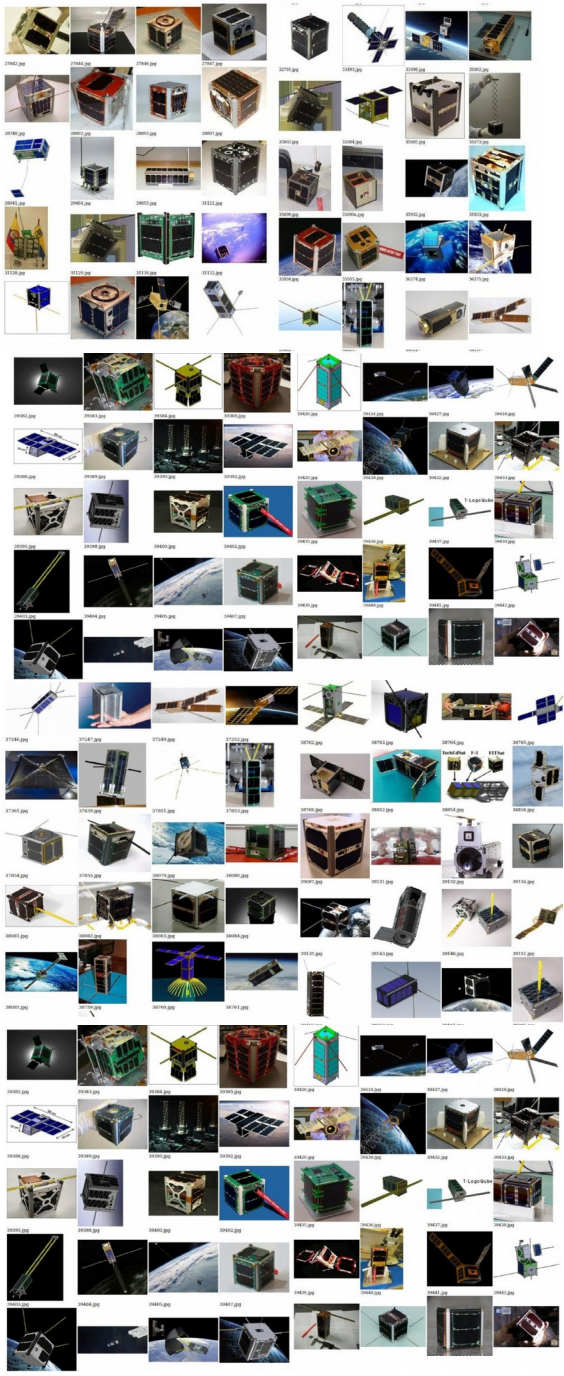


Satellite masses 2010-2016

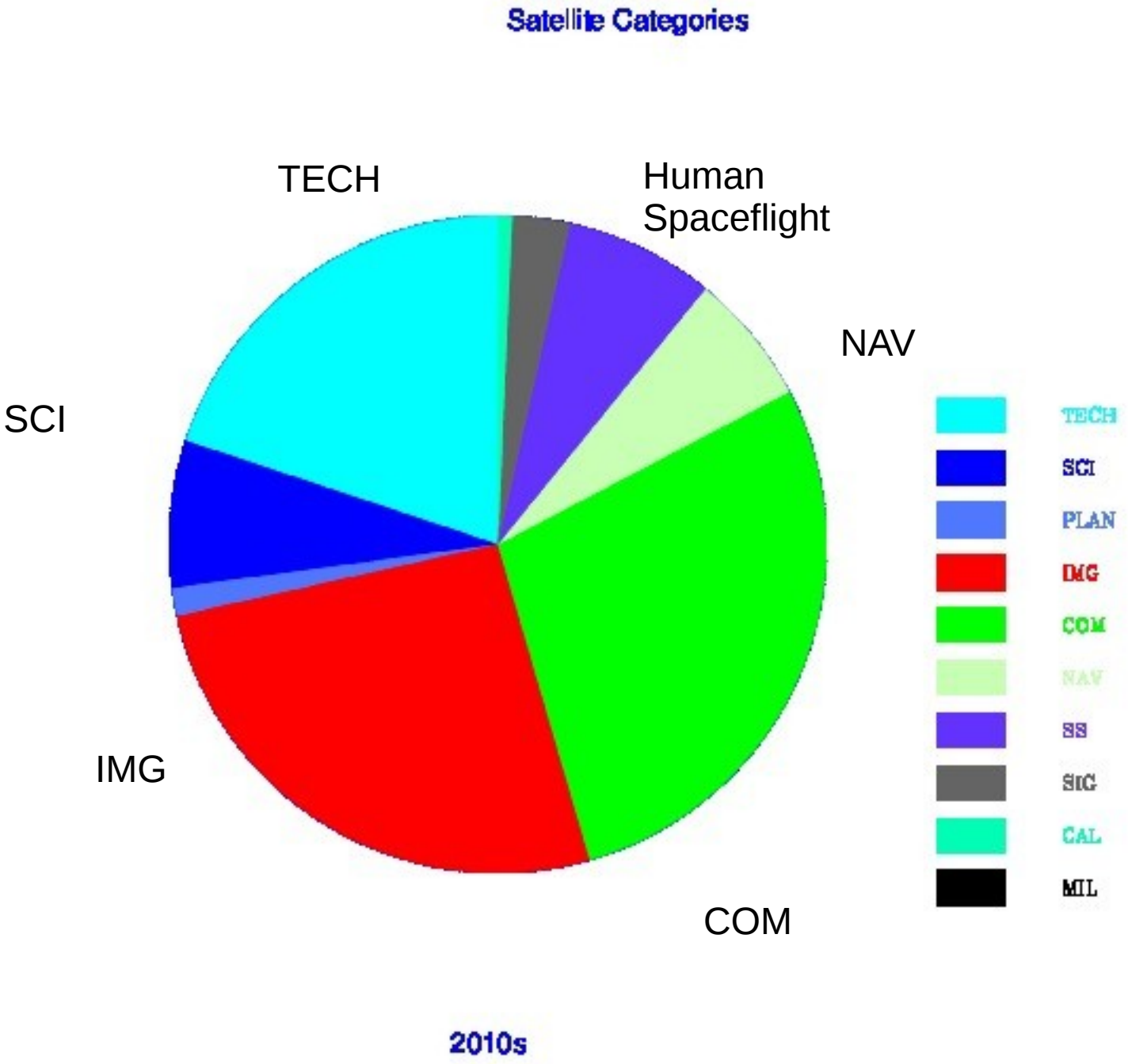
	Orbited (no transmissions)	TotalFail
A: Academic/nonprofit	123	29?
B: Business/commercial	94	4
C: Civil govt. (e.g. NASA)	19	0
D: Defense/military	53	5+

OPERATED > 2 YEARS: 38 (TBR)
(CUTE-I, XI-IV 13 years and going!)
TOTAL 29 COUNTRIES:
USA 203 Japan 20 Germany 10

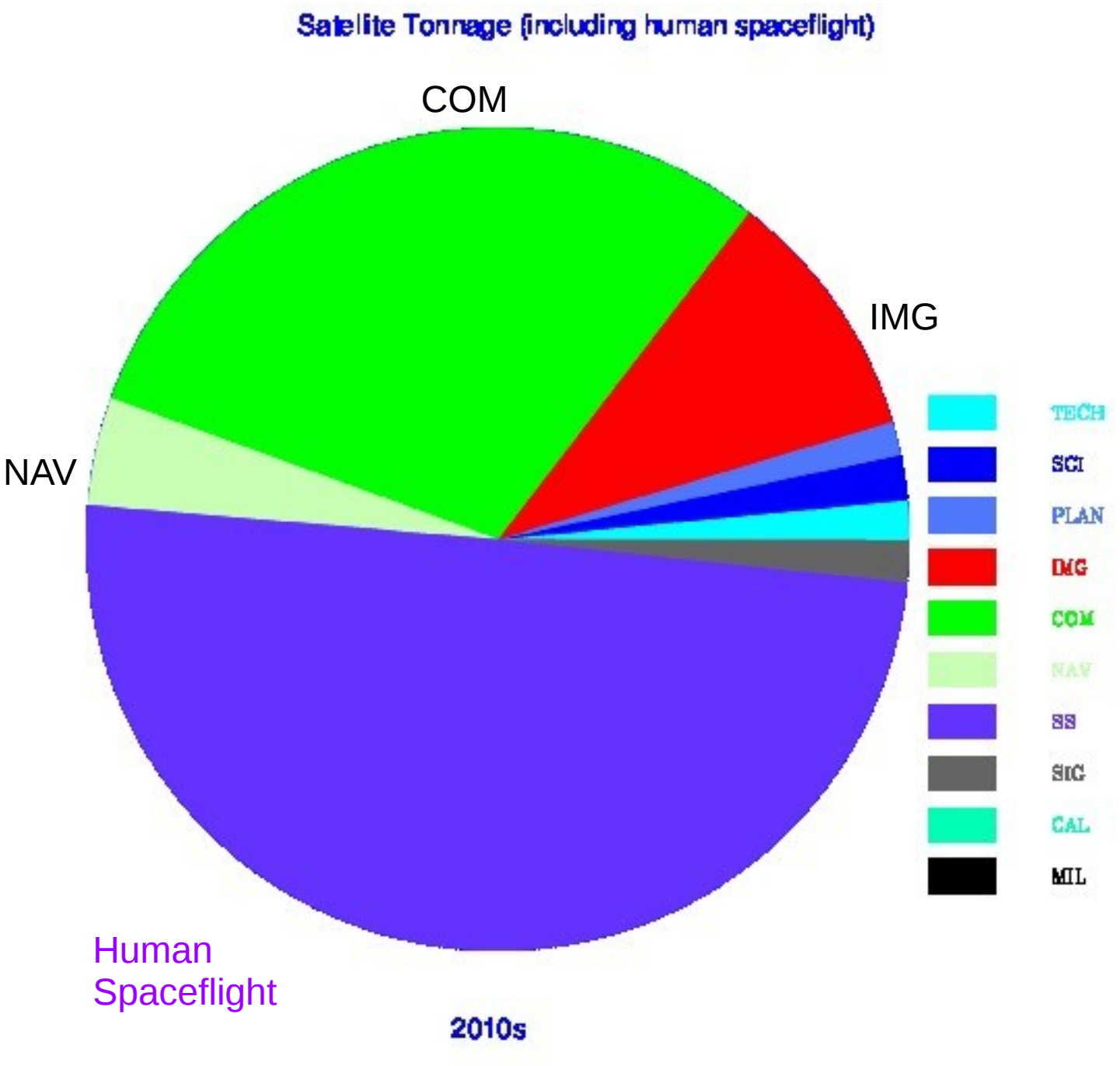
SCIENCE 27 (Bio 4, Astron 3) COM 37 IMG 81
TECH 141 CAL 4



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

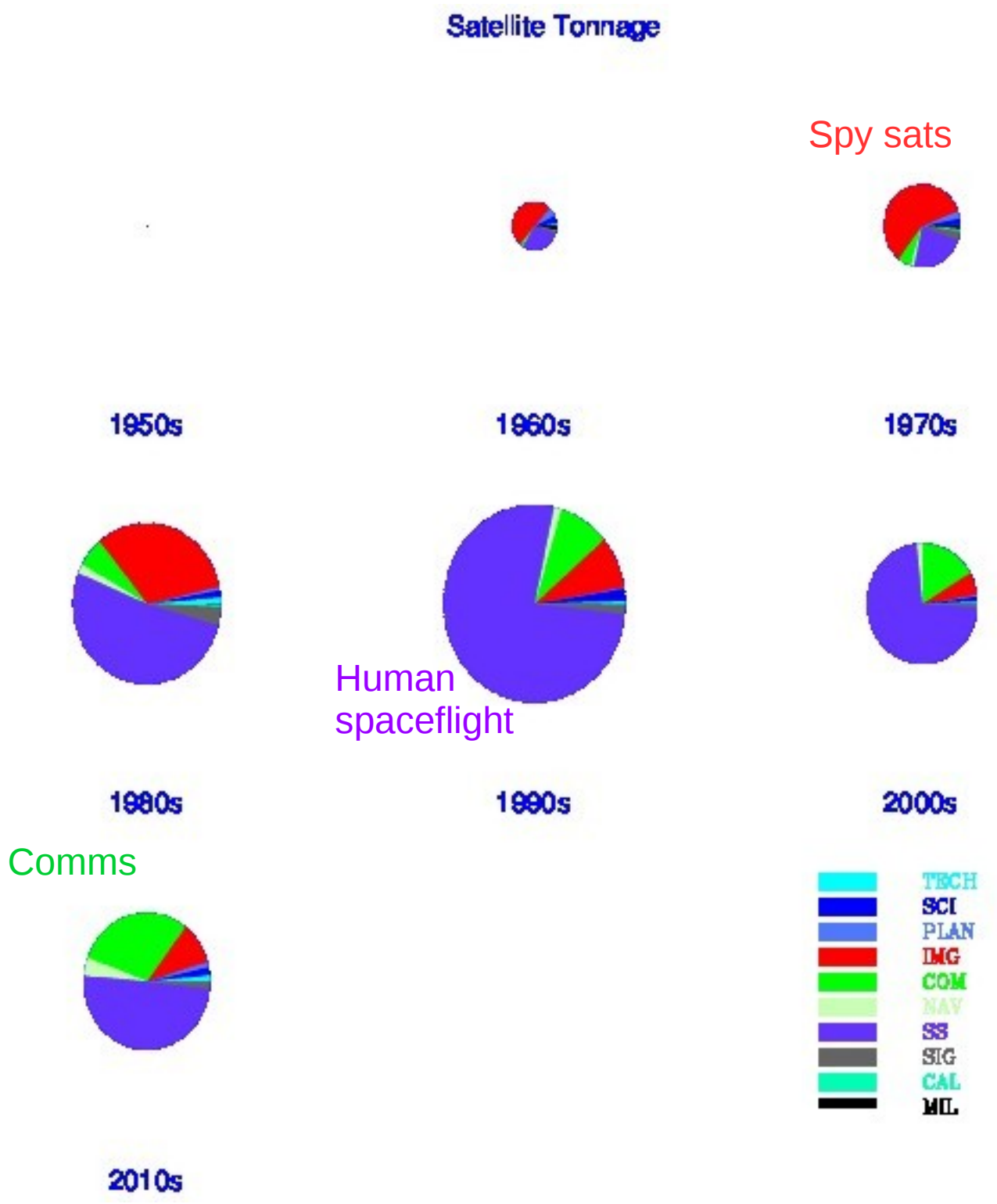
6-yr total 1350 t robotic, 1350 t 6 x Shuttle + ISS/PRC

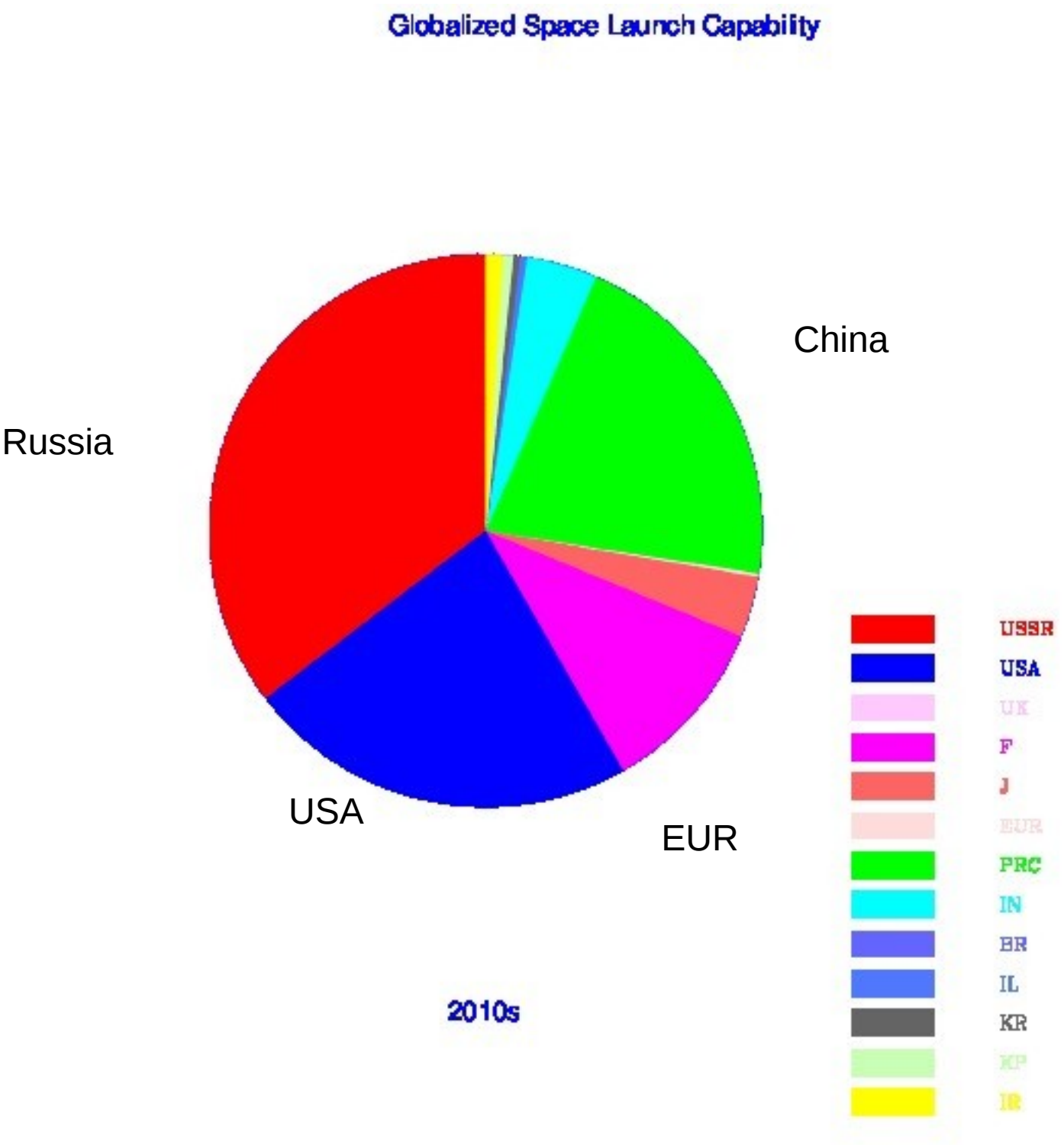
Decade by decade:

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

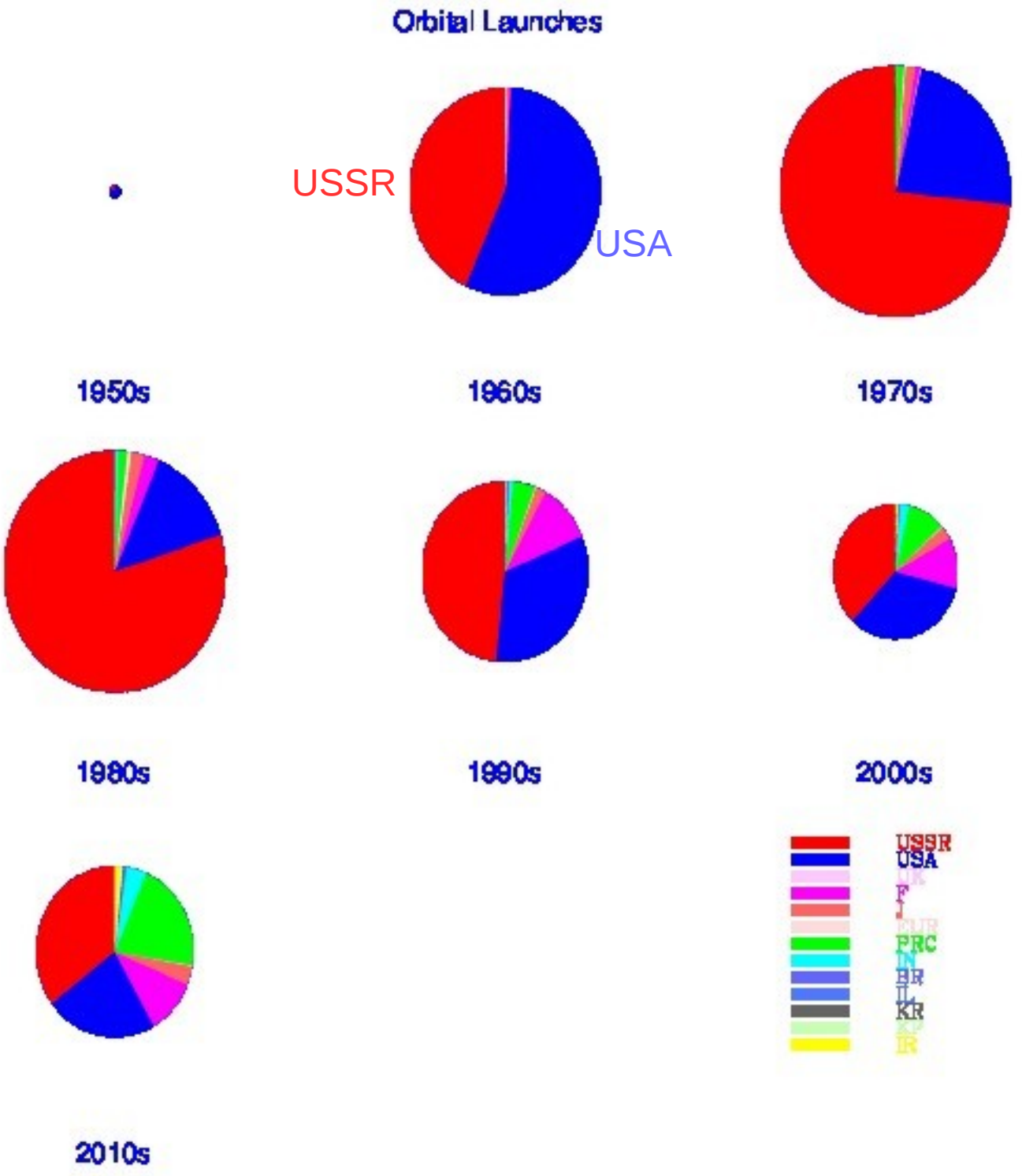
Decade by decade
Size of circle = total launches

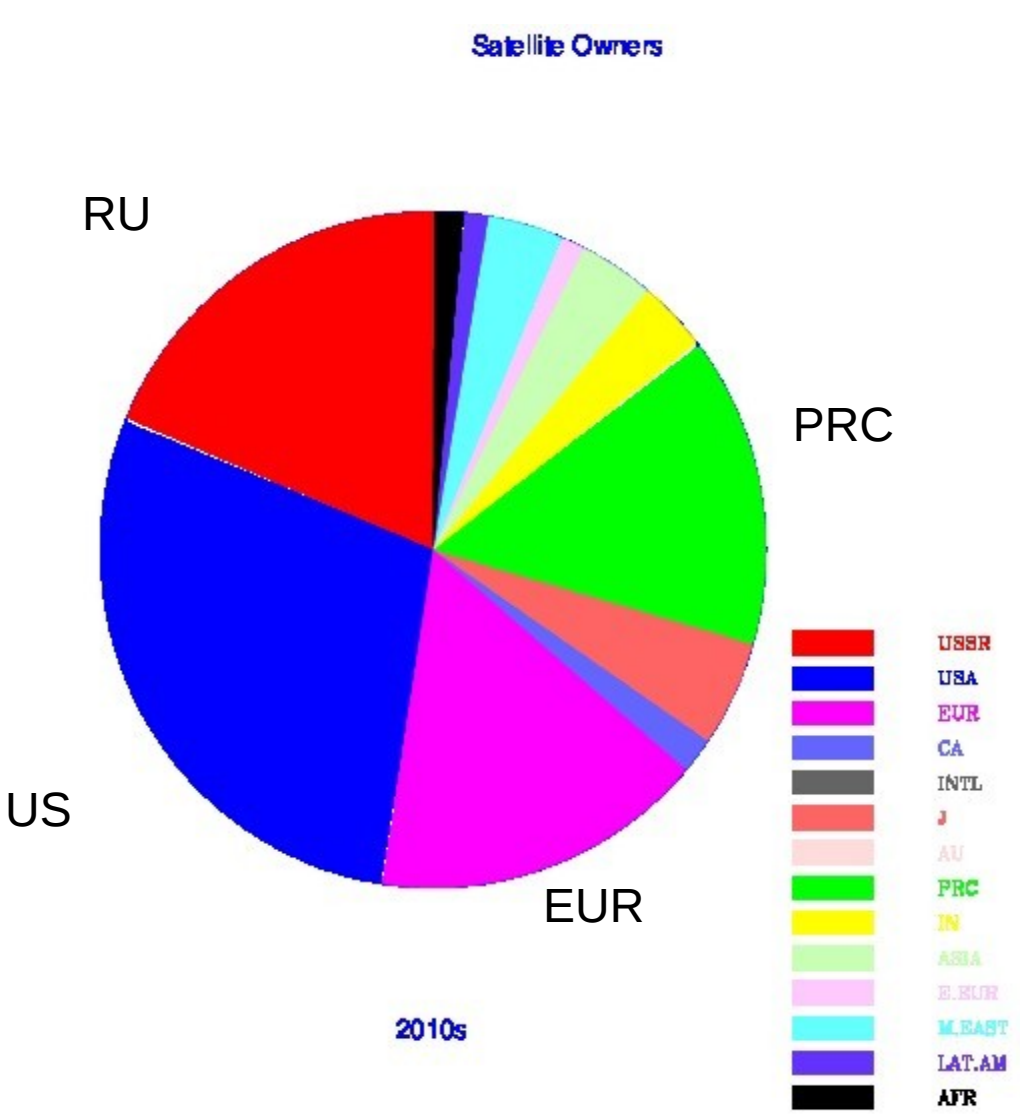
Soviet launches (red) dominated in 1970s and 1980s – many satellites but each one didn't last long

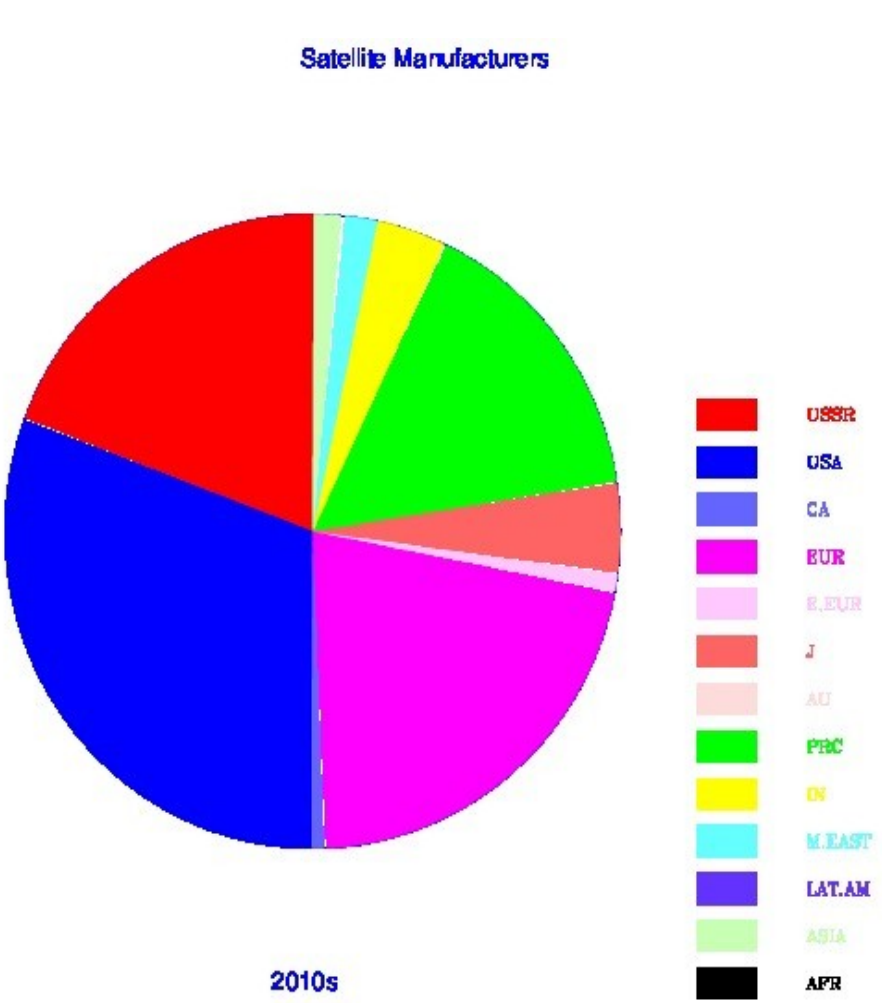
US (blue) – fewer launches but the payloads were long lived

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

Europe (magenta) was in 3rd place, dropped to 4th in 2010s

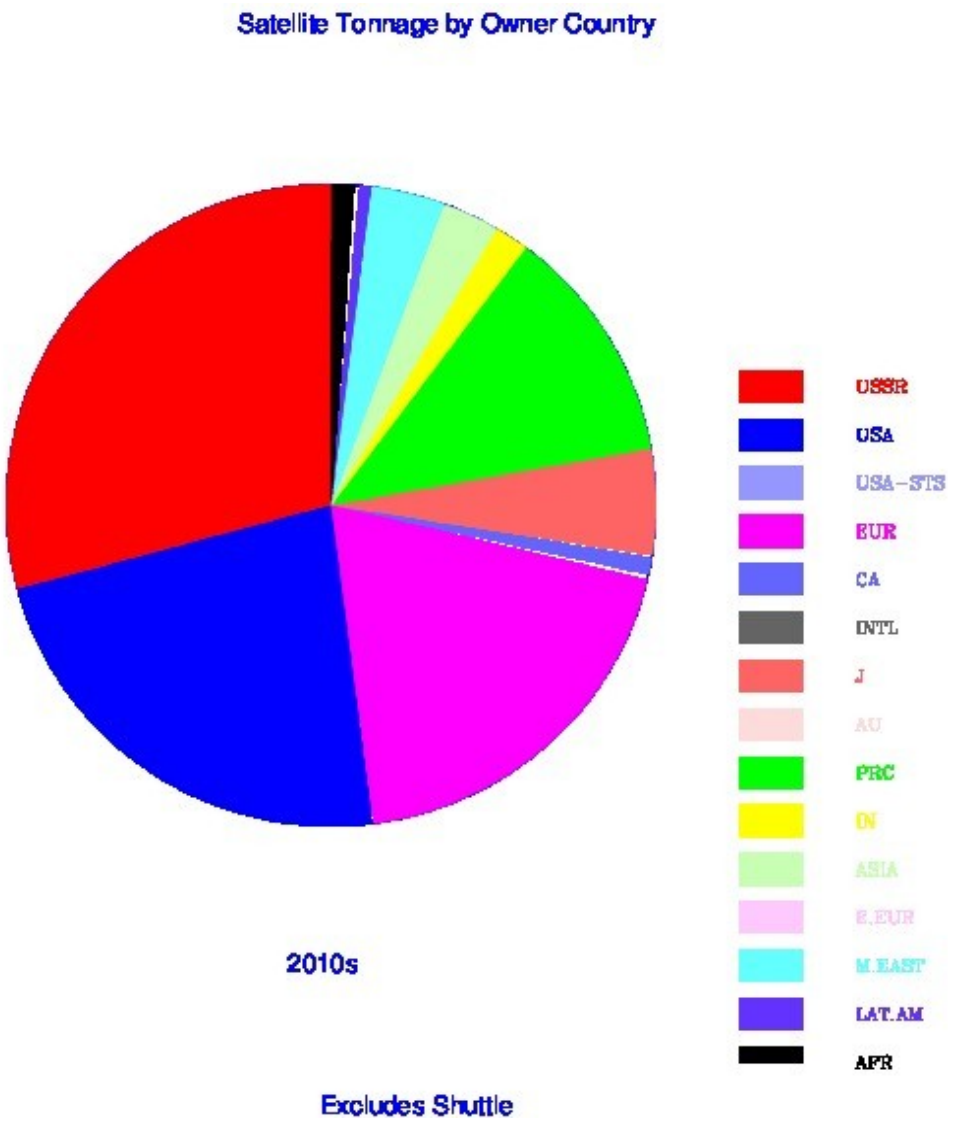


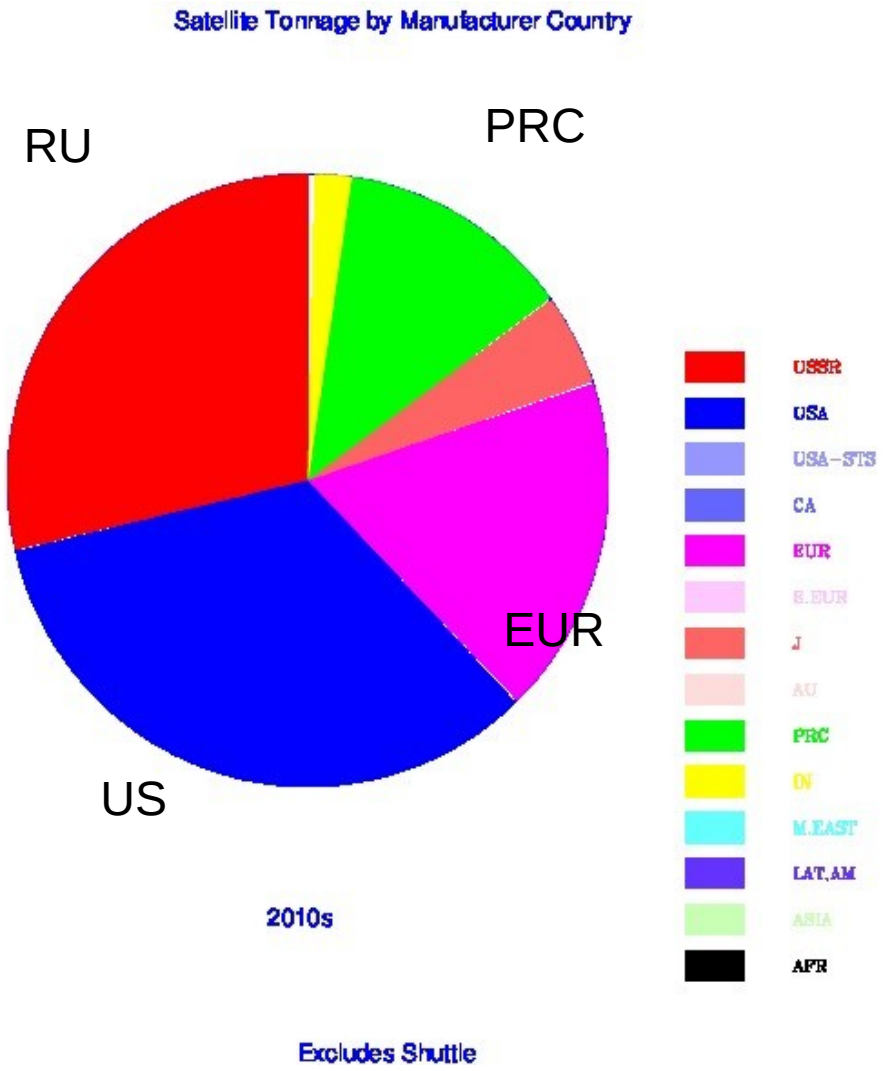




Lots of countries OWN satellites – too many to show on the chart, so
I grouped together E. Europe (pink), Africa (black), Latin America (dark purple), and Asia-other-than-China/India/Japan (light green)

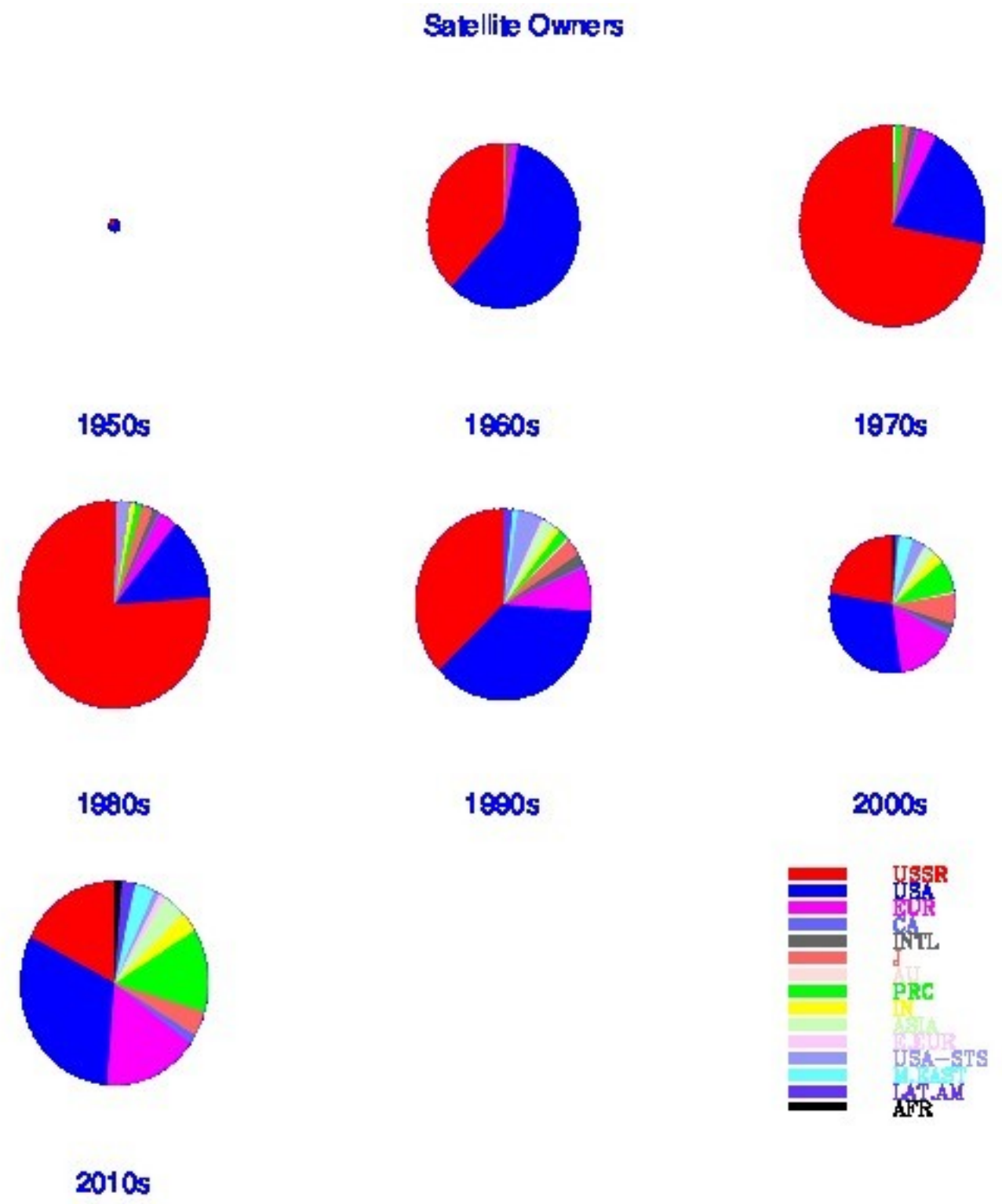
Russia, US, W. Europe and China dominate; next Japan (orange), and India (yellow)

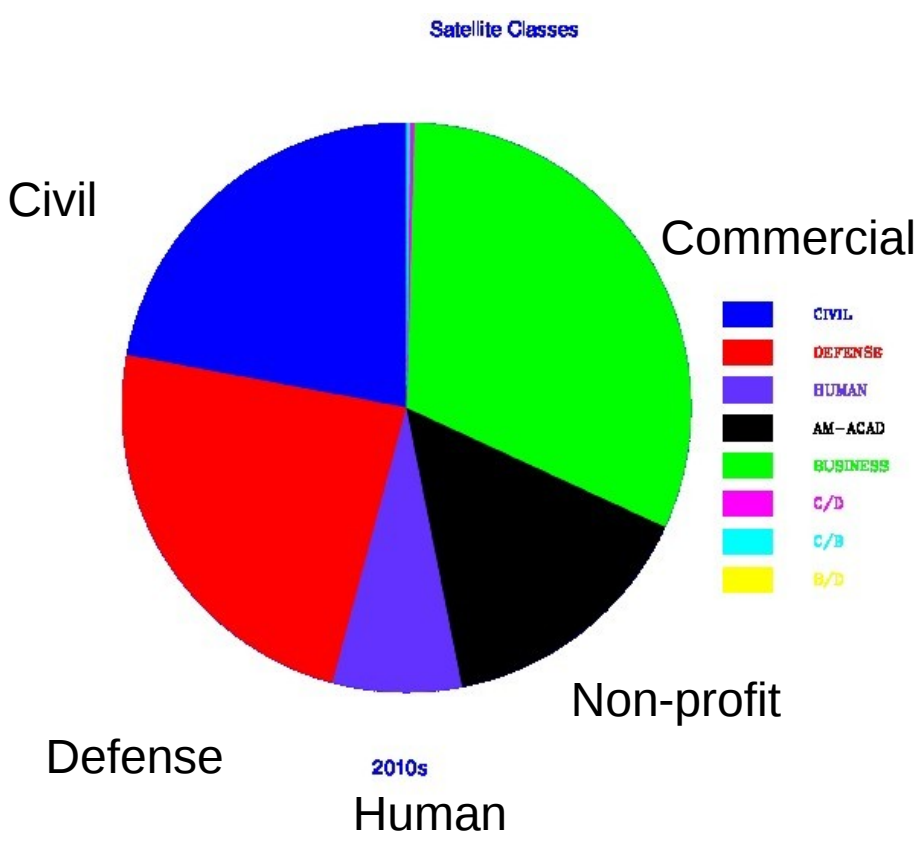


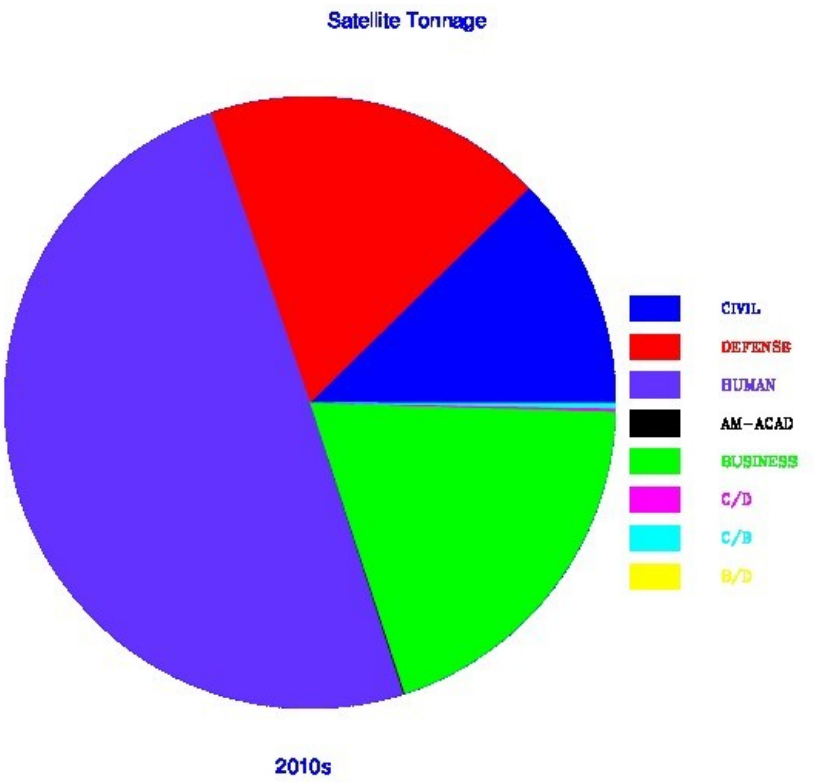


The 'other' countries almost vanish when considering tonnage -
Their satellites are usually tiny cubesats

Check out the steady increase in internationalization over the decades







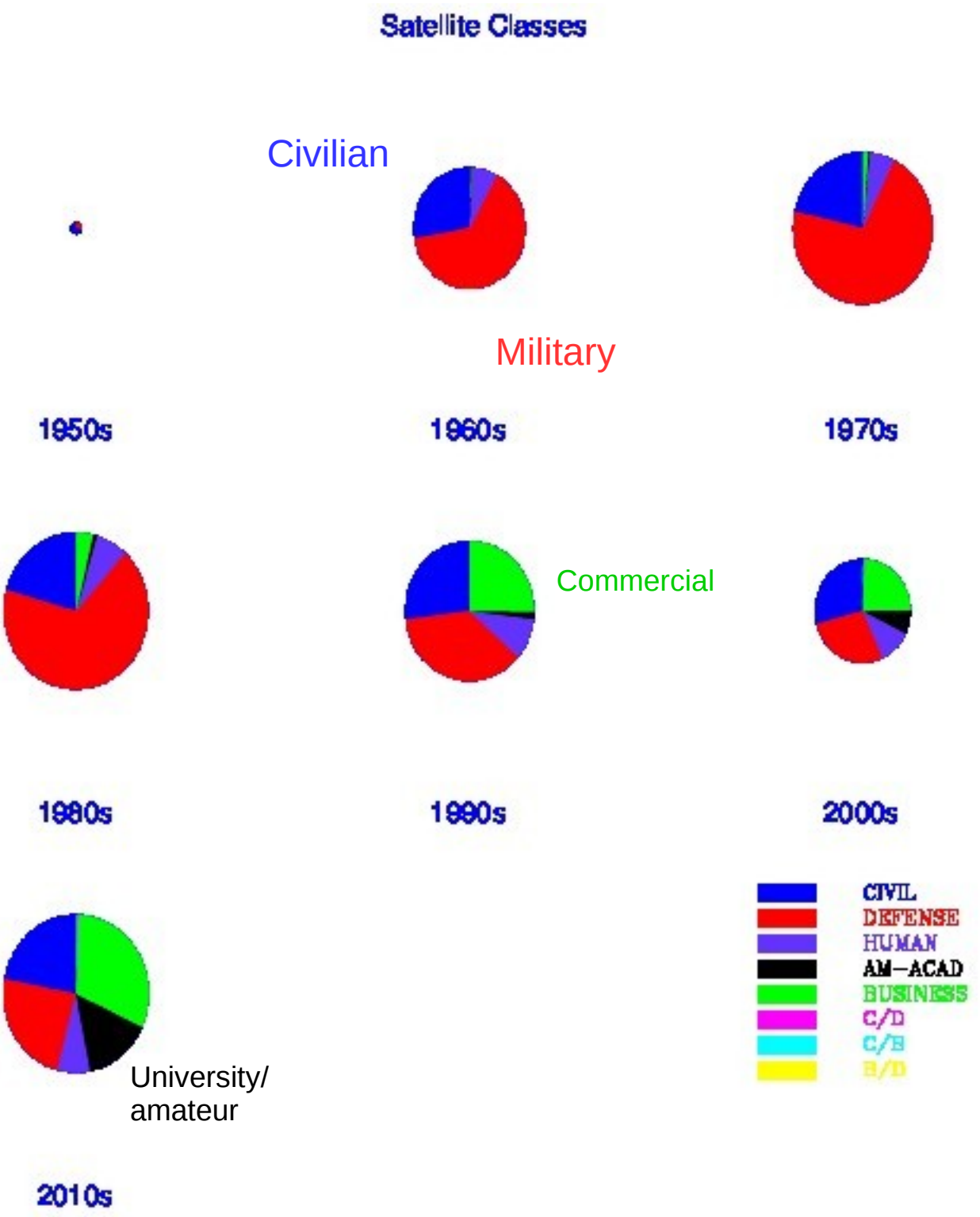
Lump all countries together – division between military, civilian and commercial is about even if you exclude human spaceflight (most of the tonnage, and money)

Non-profit an important sector by number of satellites, but tonnage is negligible

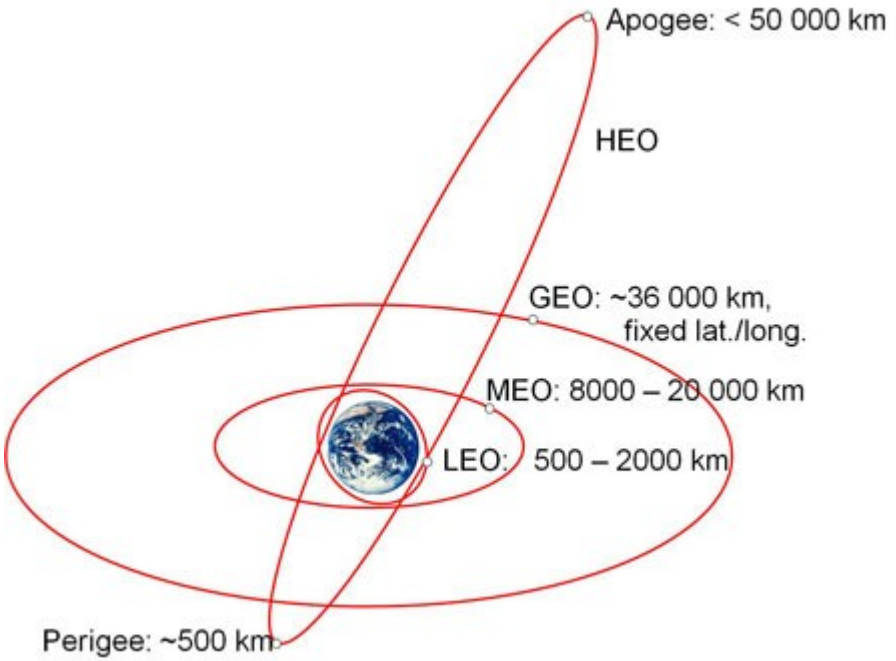
The defense sector (red) shrunk after the cold war

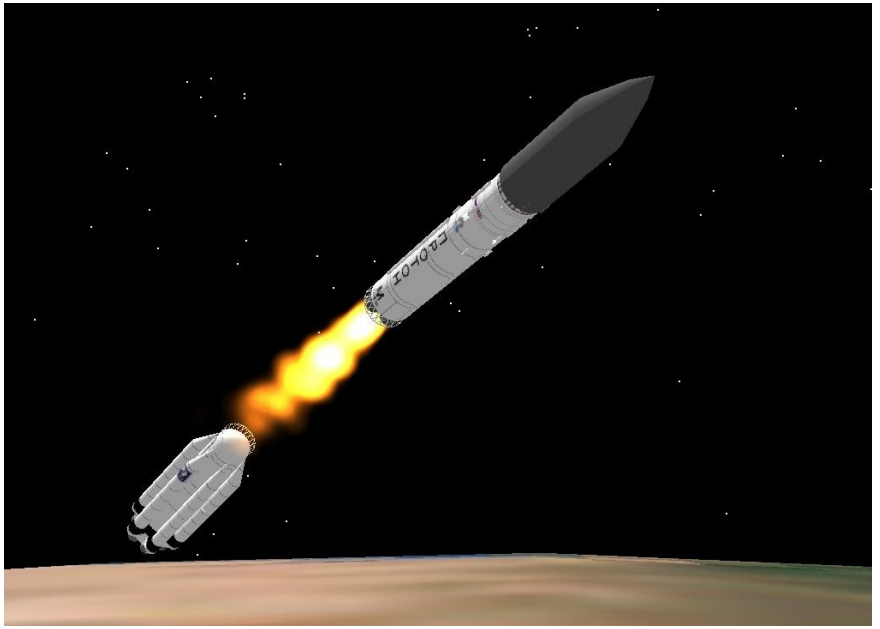
Commercial sector became important in 1990s

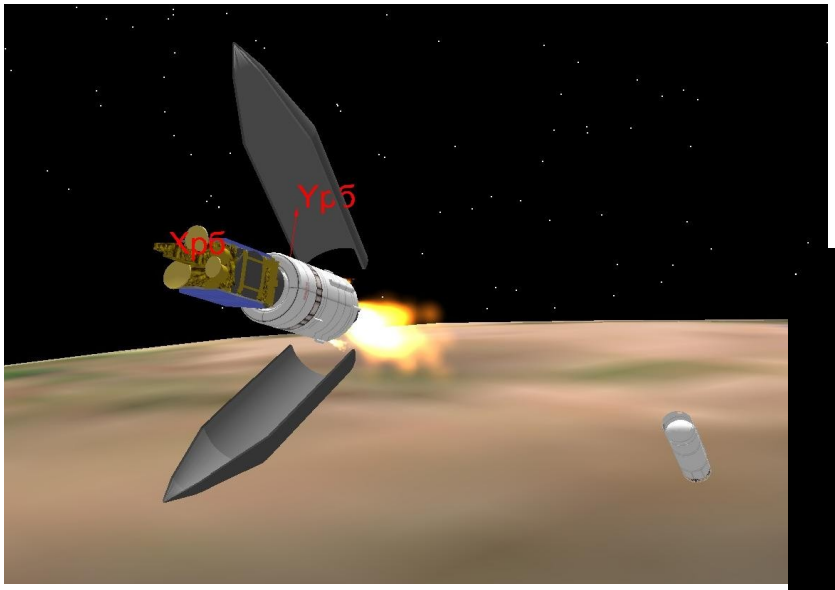
Non-profit sector is a factor starting in 2010s

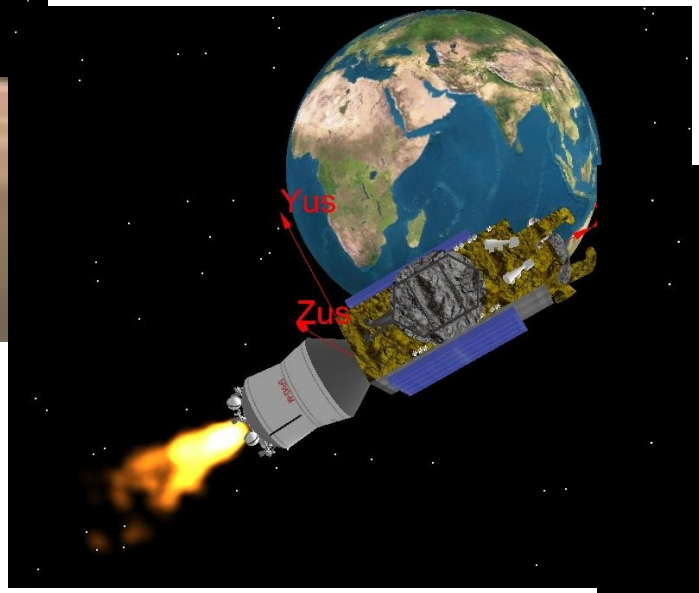


Part 3: Orbitography



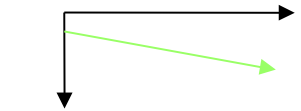




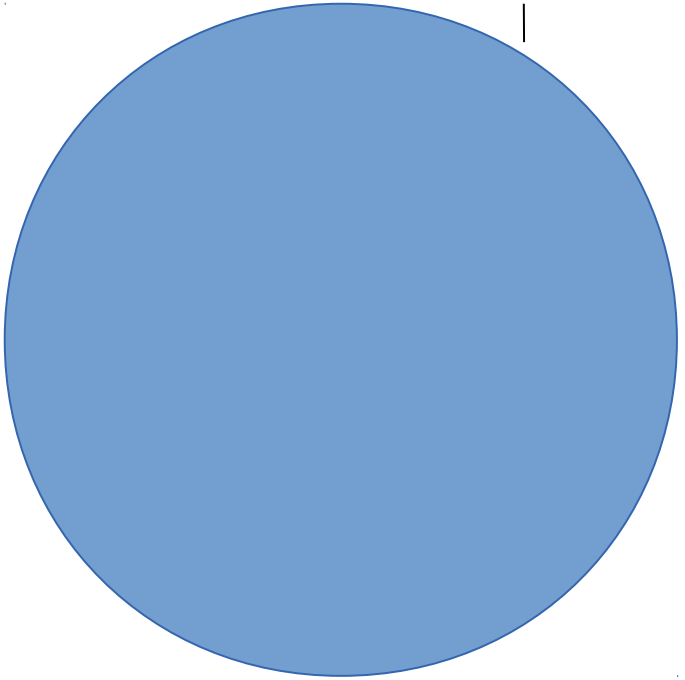


A typical satellite launch ends up with at least two objects in orbit – the satellite and the last piece (“stage”) of the rocket that got it there

In 1 second:
Moves sideways 5 miles
Falls 30 feet



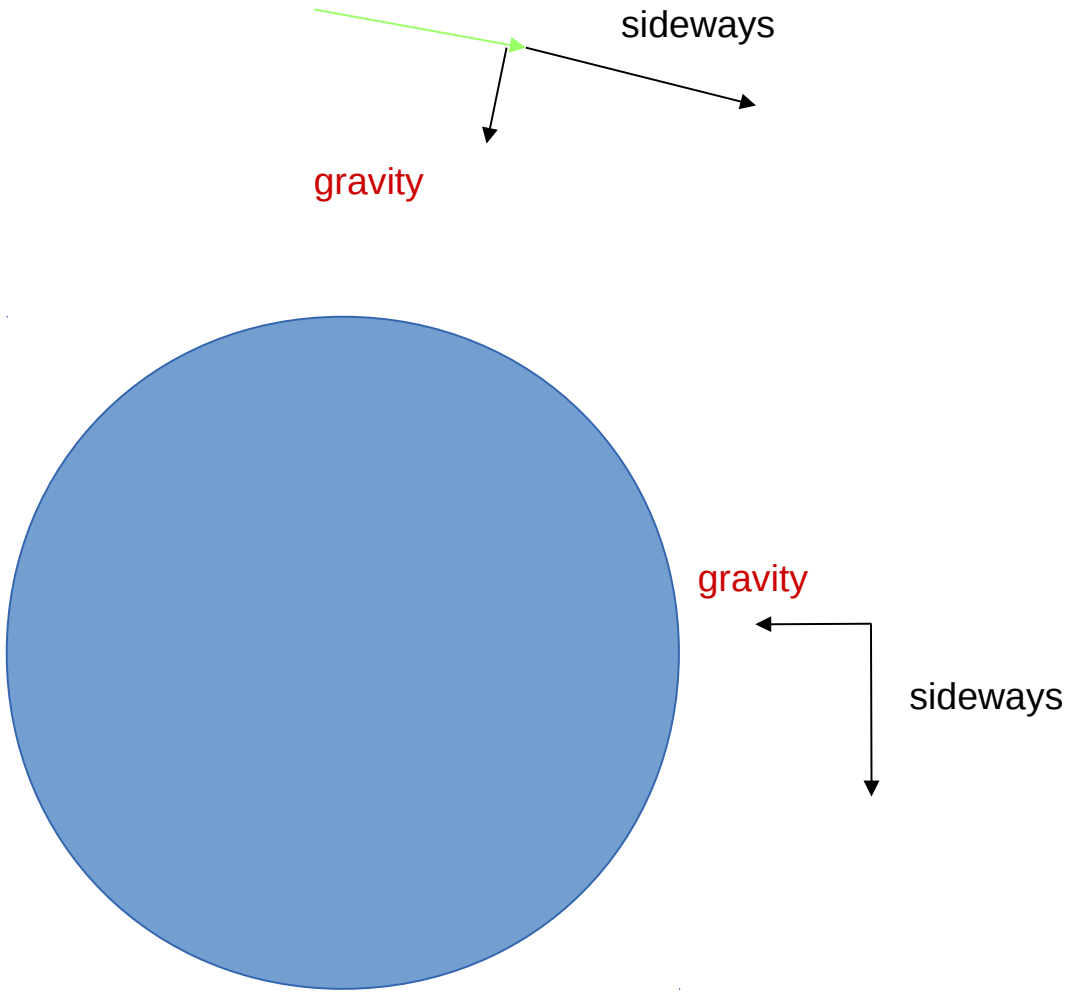
ORBIT:
Moving sideways at
7.7 km/s
(17000 mph)



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

1 second later:
Part of the downward speed is now sideways



Low Earth Orbit

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

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

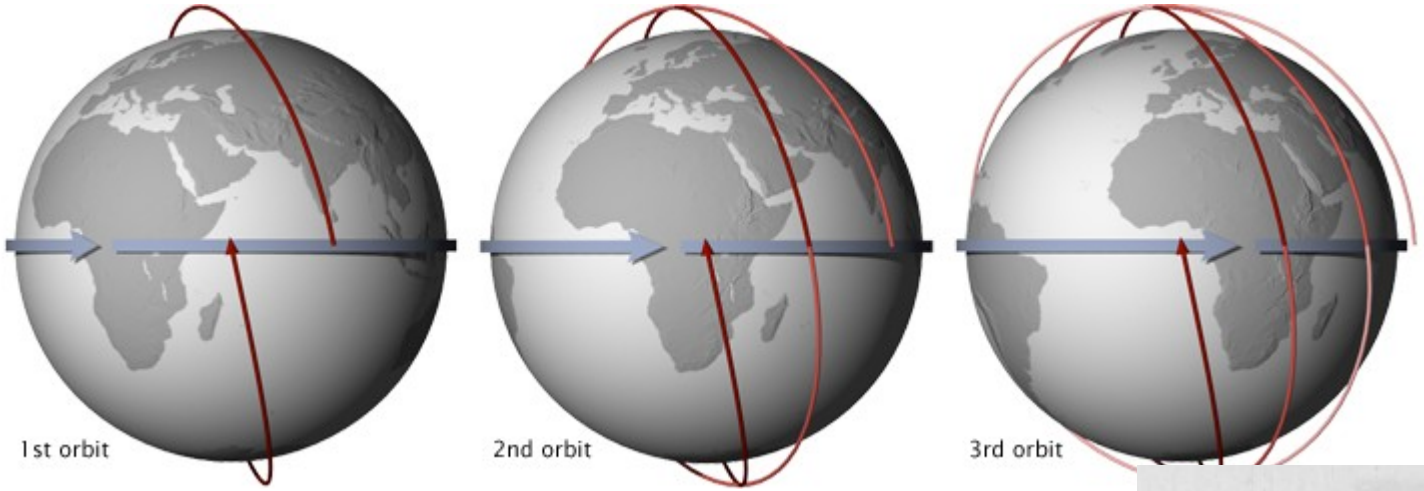
The orbital period T is then given by

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

which is Kepler's third law.

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



Remember:

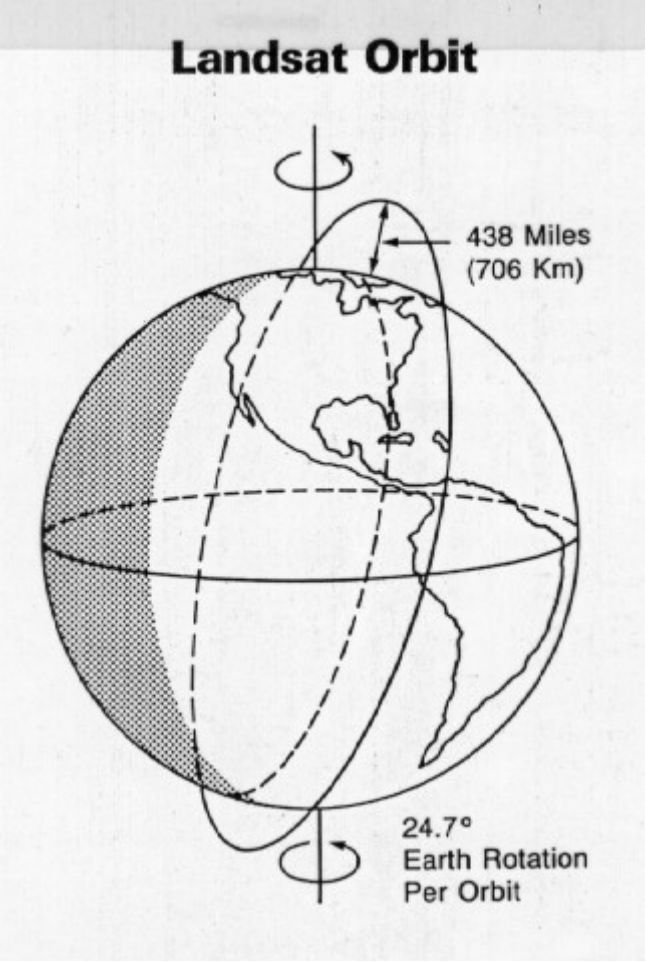
the Earth is spinning -

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



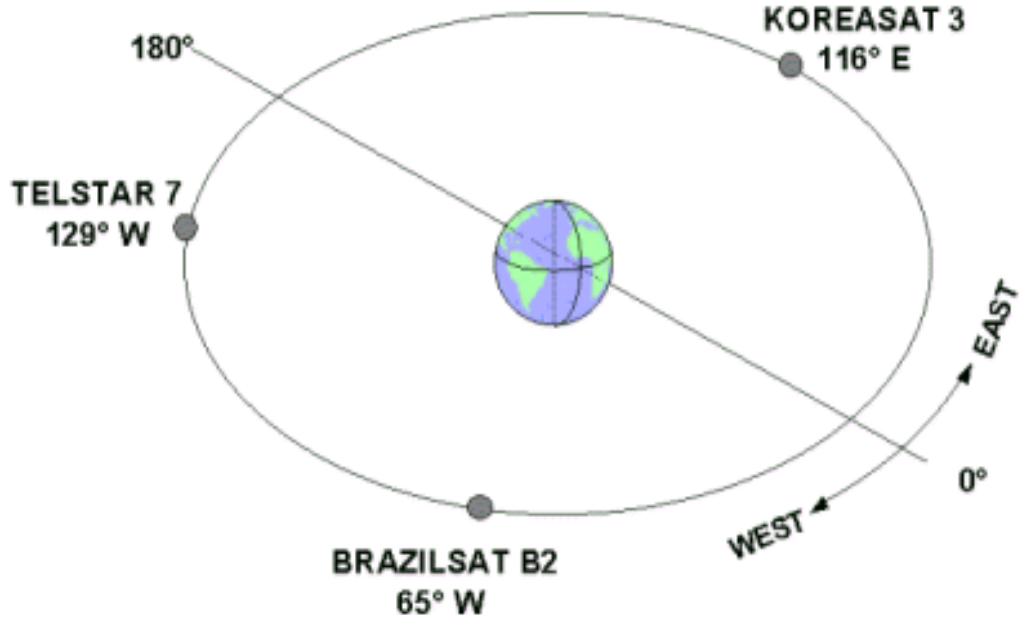
GEO: Geostationary Earth Orbit

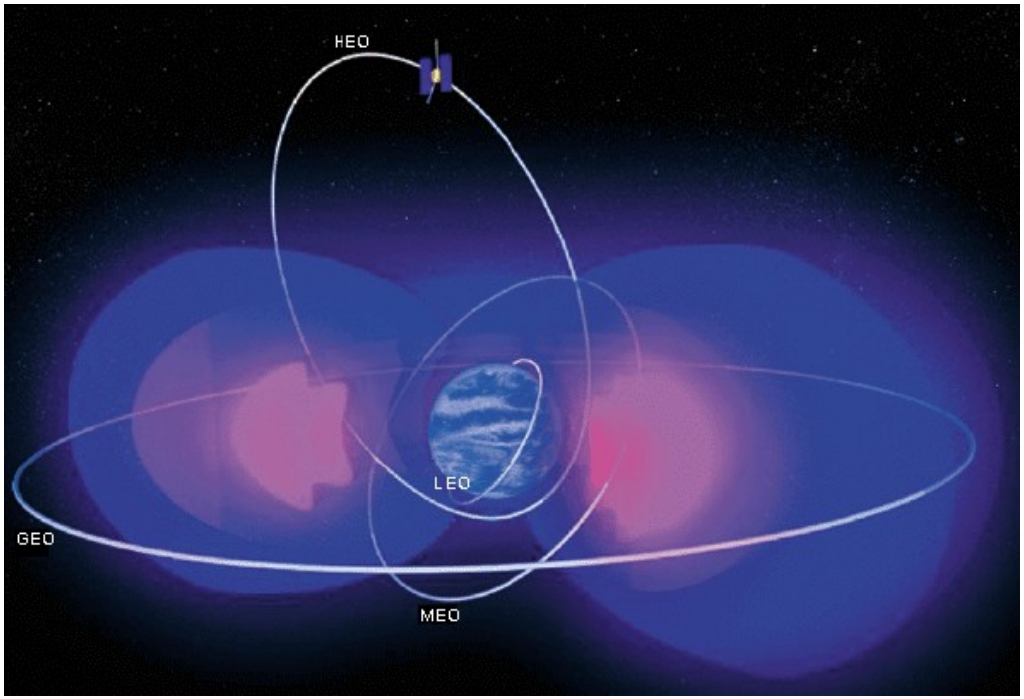
Consider a satellite whose orbit goes around the Earth's equator
Just outside the atmosphere it takes 1 ½ hours to go round the planet
Far out, at the distance of the Moon it takes a month to go round
Inbetween there is some height at which it takes exactly 23 hr 56 min

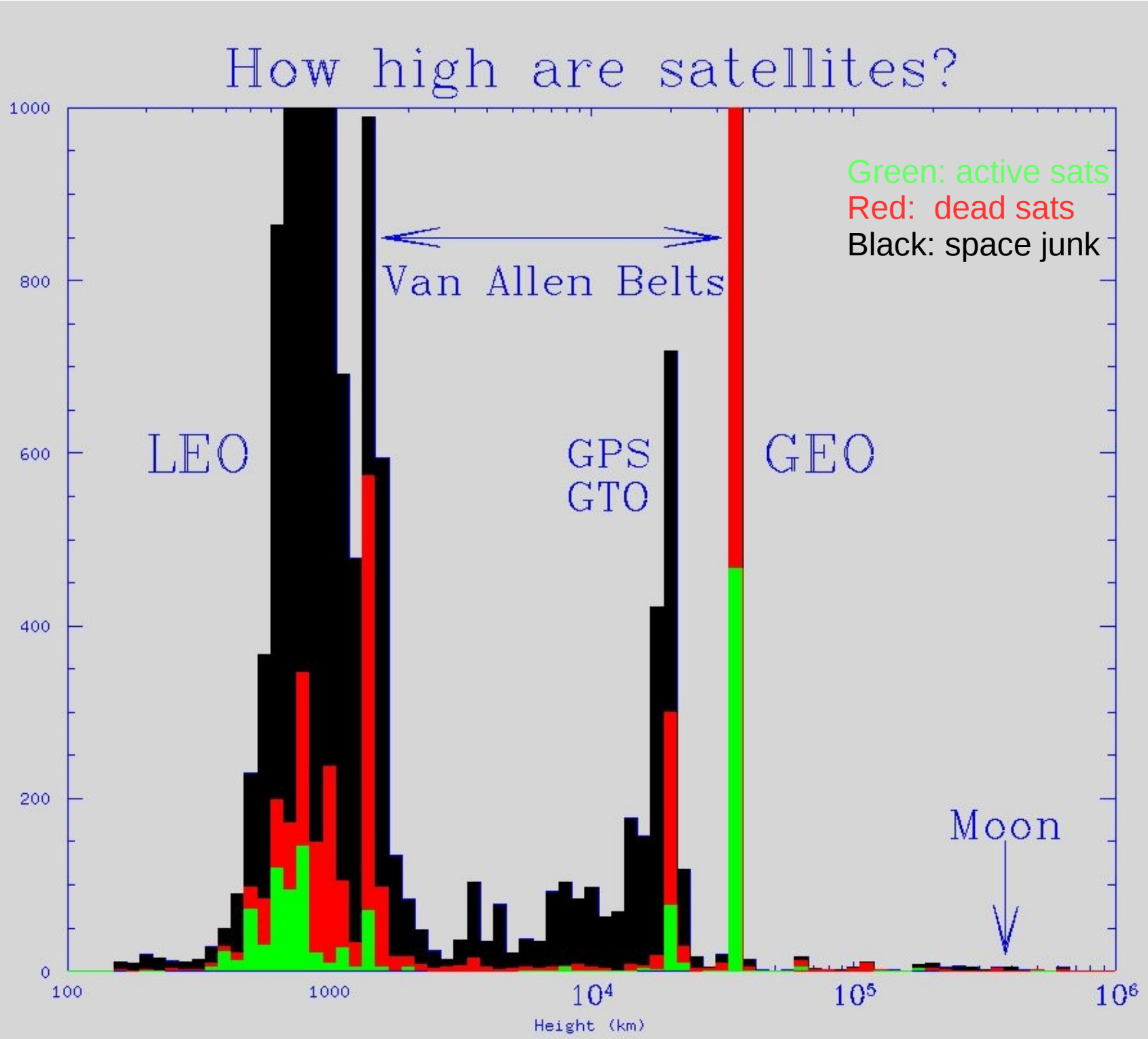
Meanwhile, the Earth spins underneath it, also taking 23 hr 56 min to complete one full rotation

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

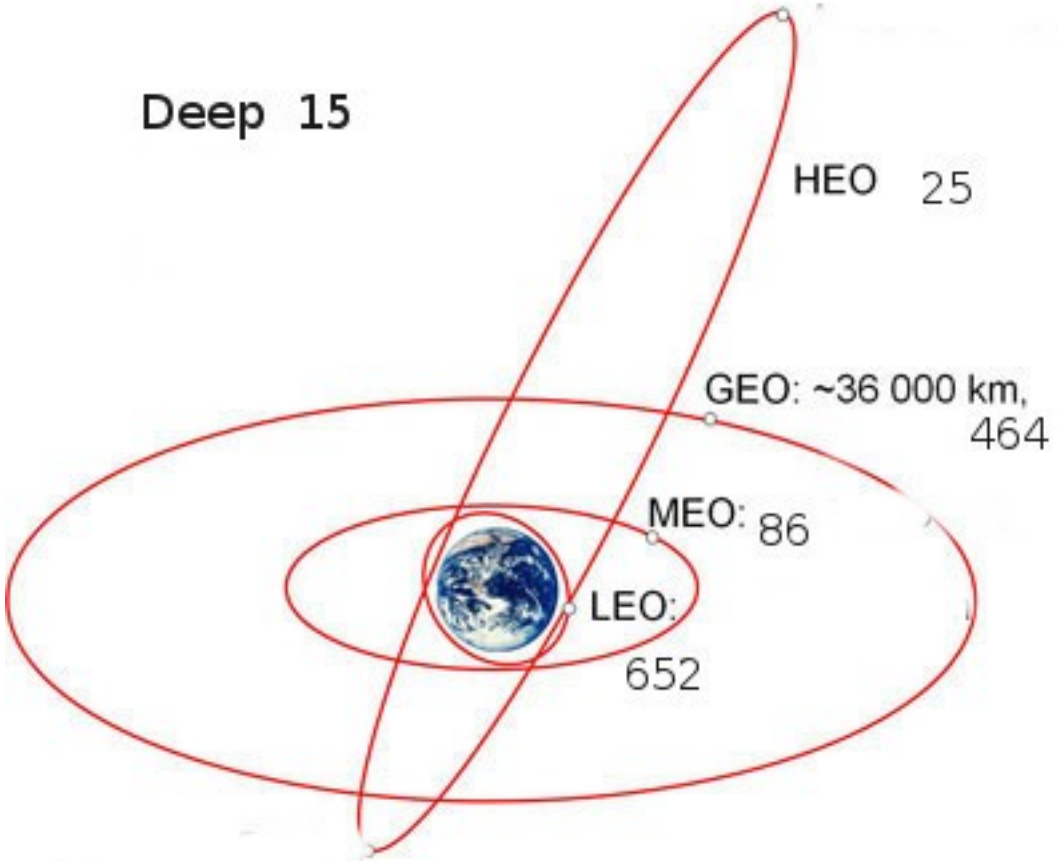
Kepler's Third Law lets us calculate the magic height: 35787 km above the Earth's surface (about 23000 miles)






How high are satellites?
Green: active sats
Red: dead sats
Black: space junk
Van Allen Belts
LEO
GPS
GTO
GEO
Moon
1000
800
600
400
200
0
100
1000
10⁴
10⁵
10⁶
Height (km)

Orbit Demographics



Overall statistics (2014 data):

	Active	Dead	Junk
LEO	652	1512	10327
MEO	86	262	758
HEO/GTO	25	151	1562
GEO	464	518	291
Deep	15	51	62

*Most satellites are either in LEO or GEO

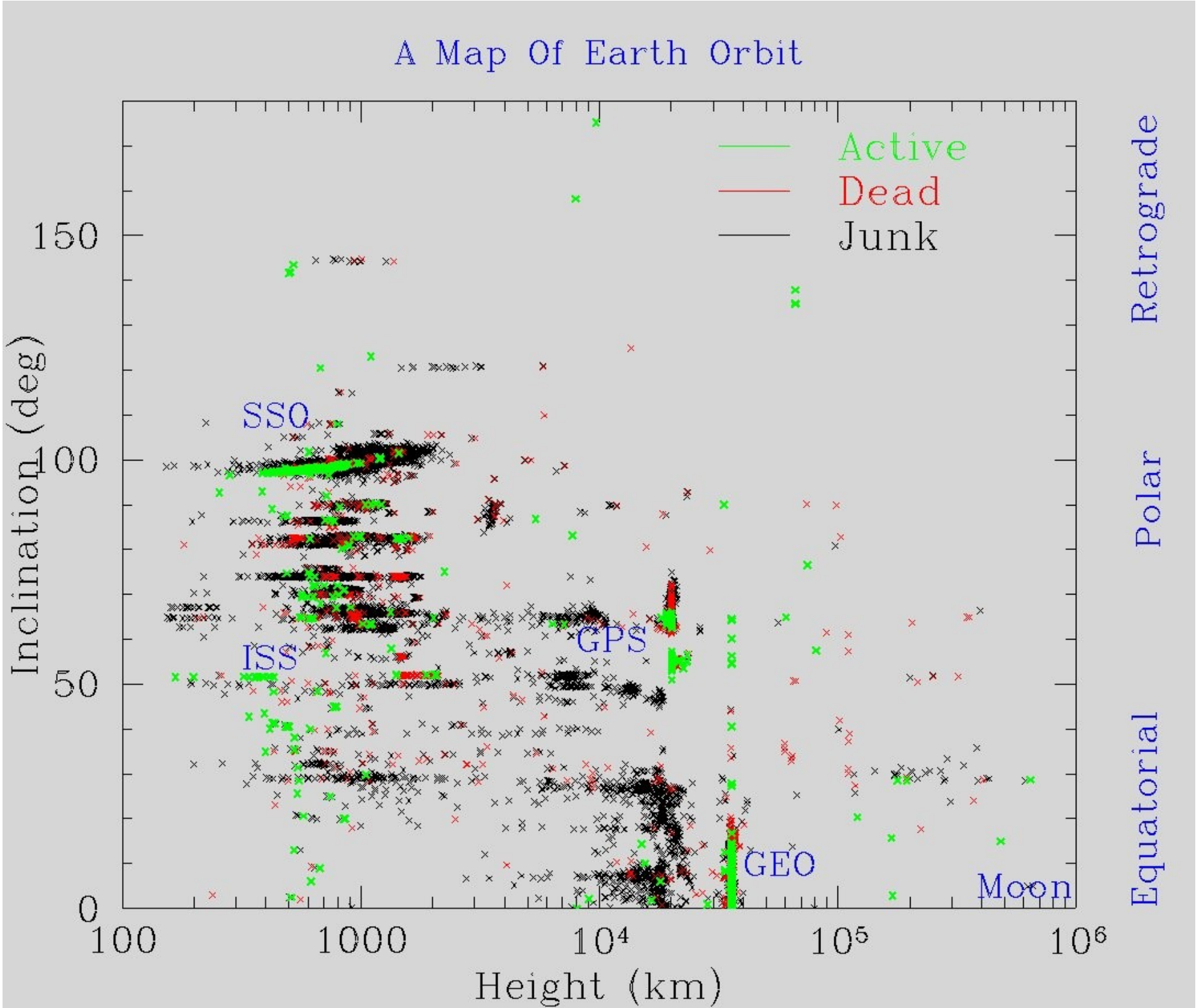
Special cases:

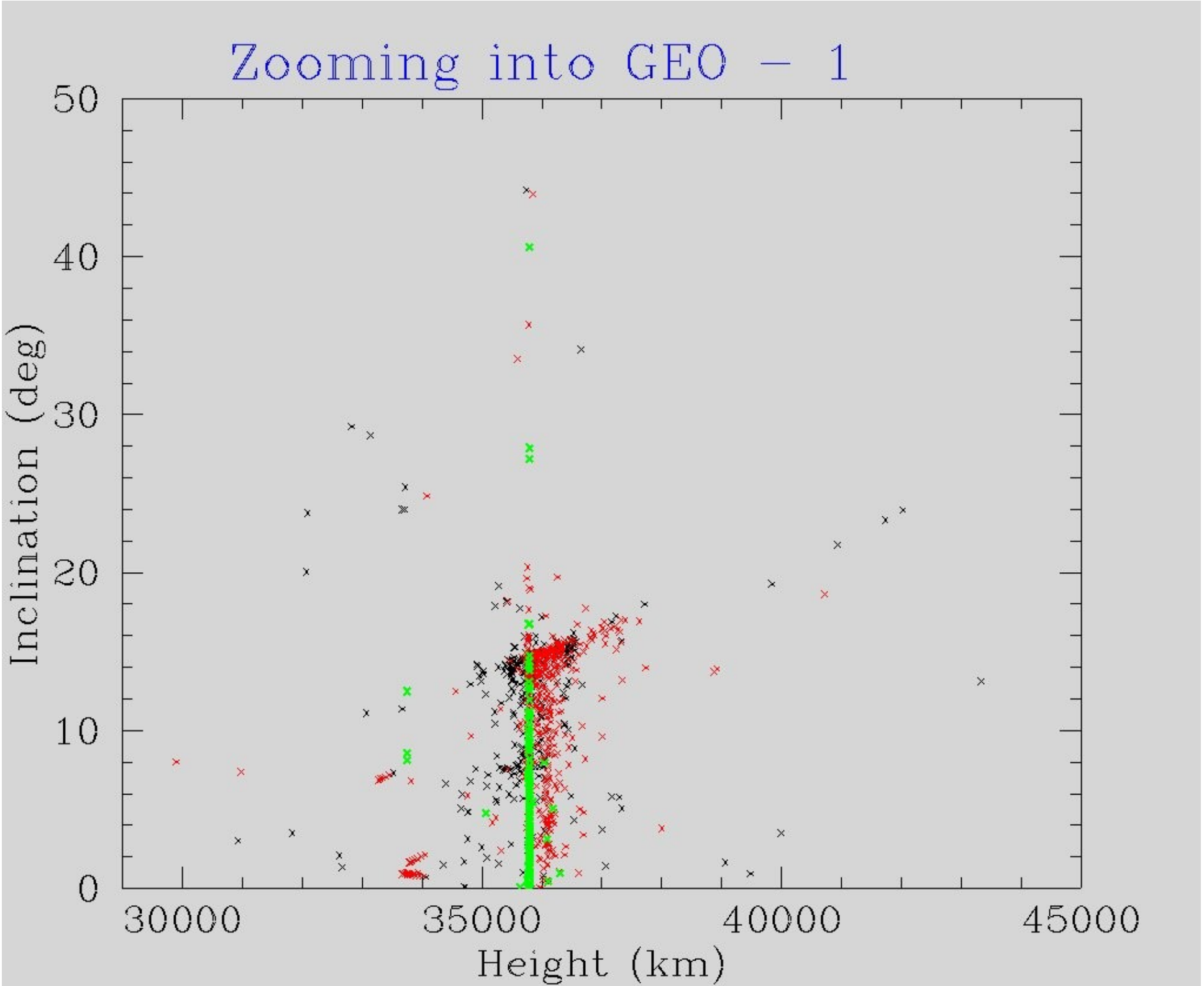
LEO			
- SSO	282	247	5173
- others	370	1265	4625

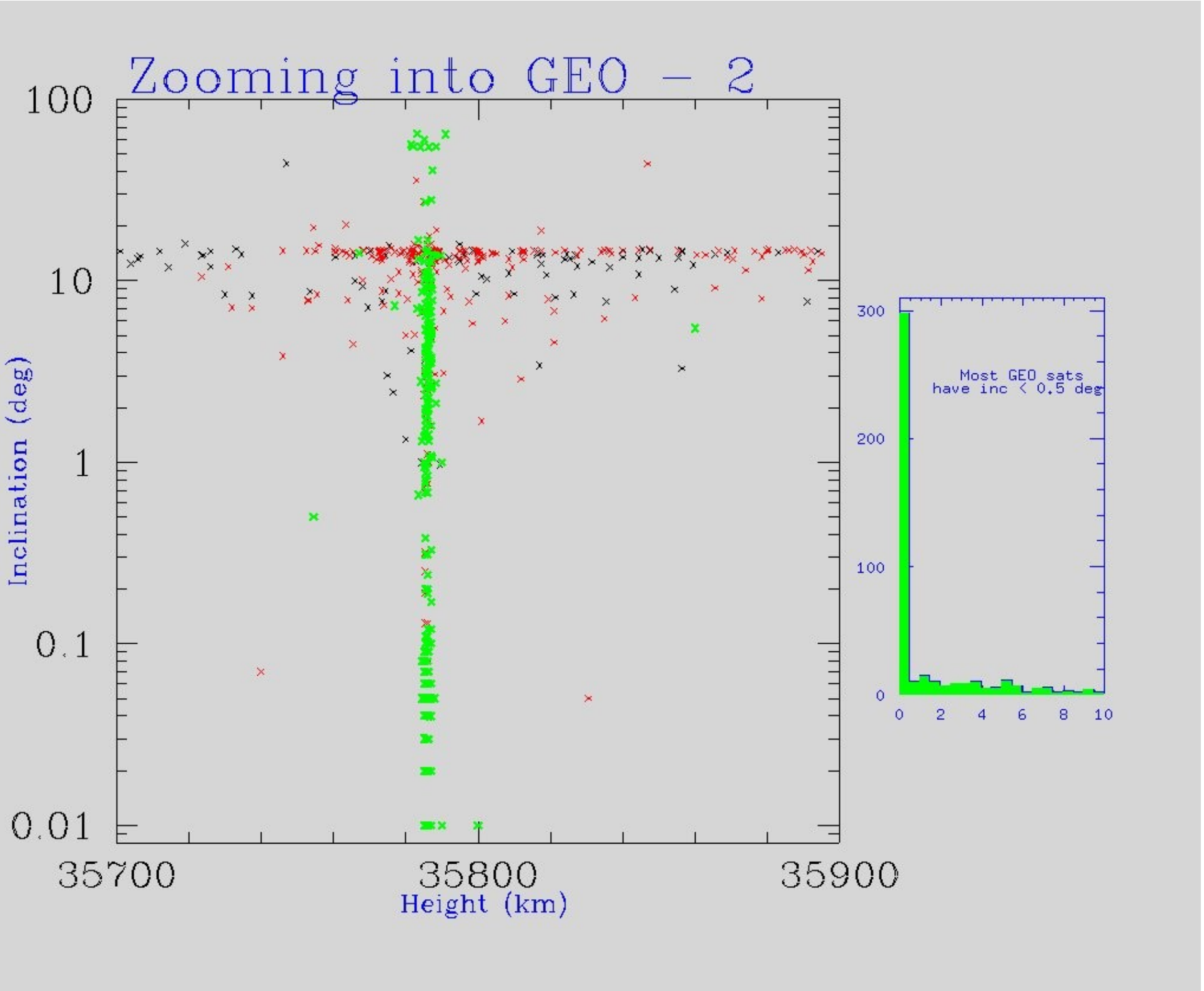
SSO is a very specific orbit, has almost half the LEO sats – and most of the debris

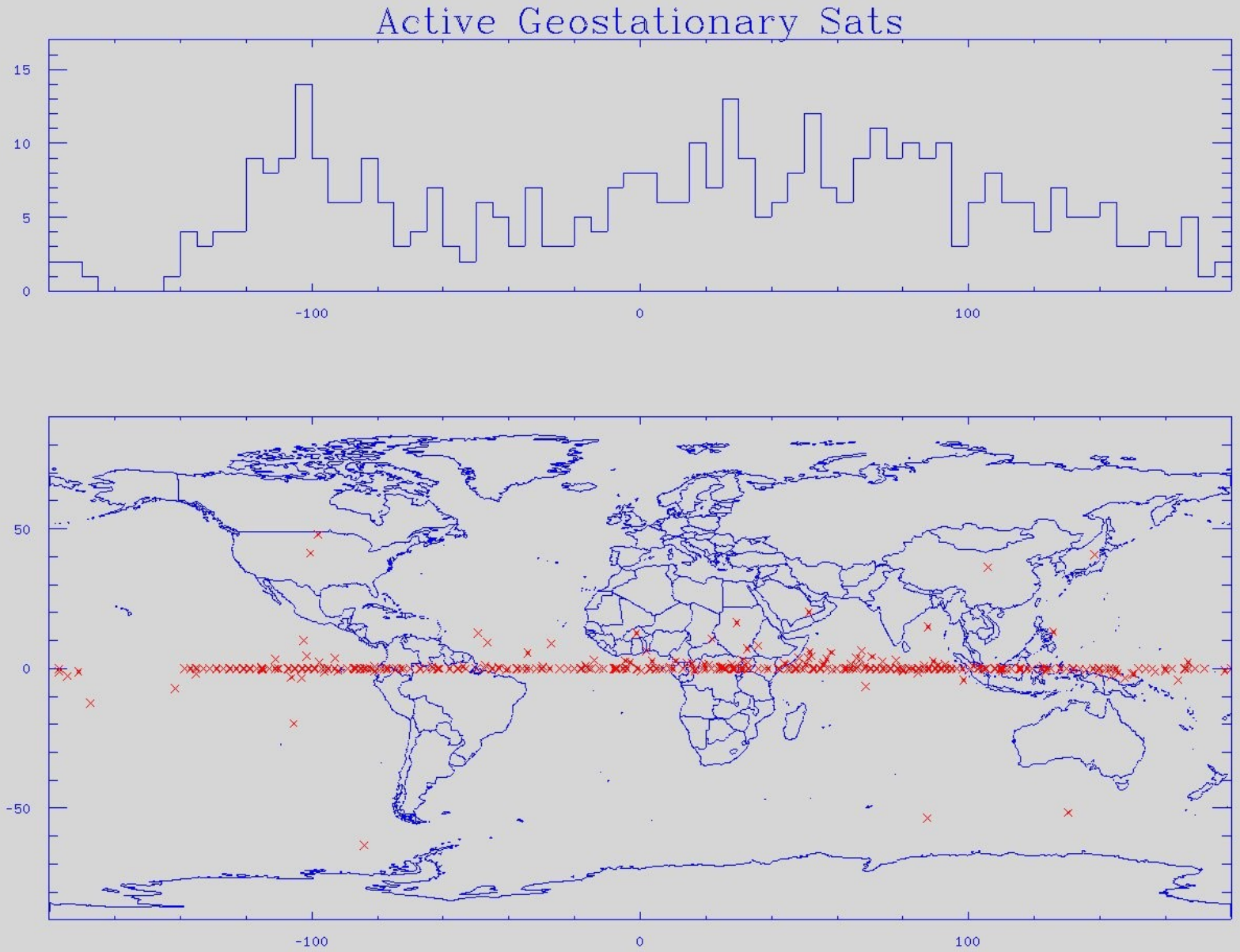
GEO			
Stationary	452	83	14
Graveyard	5	187	92
Drift	7	233	167
Other	1	22	57

Only 36 percent of dead GEO sats are in the graveyard


A Map Of Earth Orbit
Active
Dead
Junk
Retrograde
Polar
Equatorial
SSO
ISS
GPS
GEO
Moon
Inclination (deg)
0
50
100
150
100
1000
10^4
10^5
10^6
Height (km)


Zooming into GEO – 1
Inclination (deg)
Height (km)
0
10
20
30
40
50
30000
35000
40000
45000

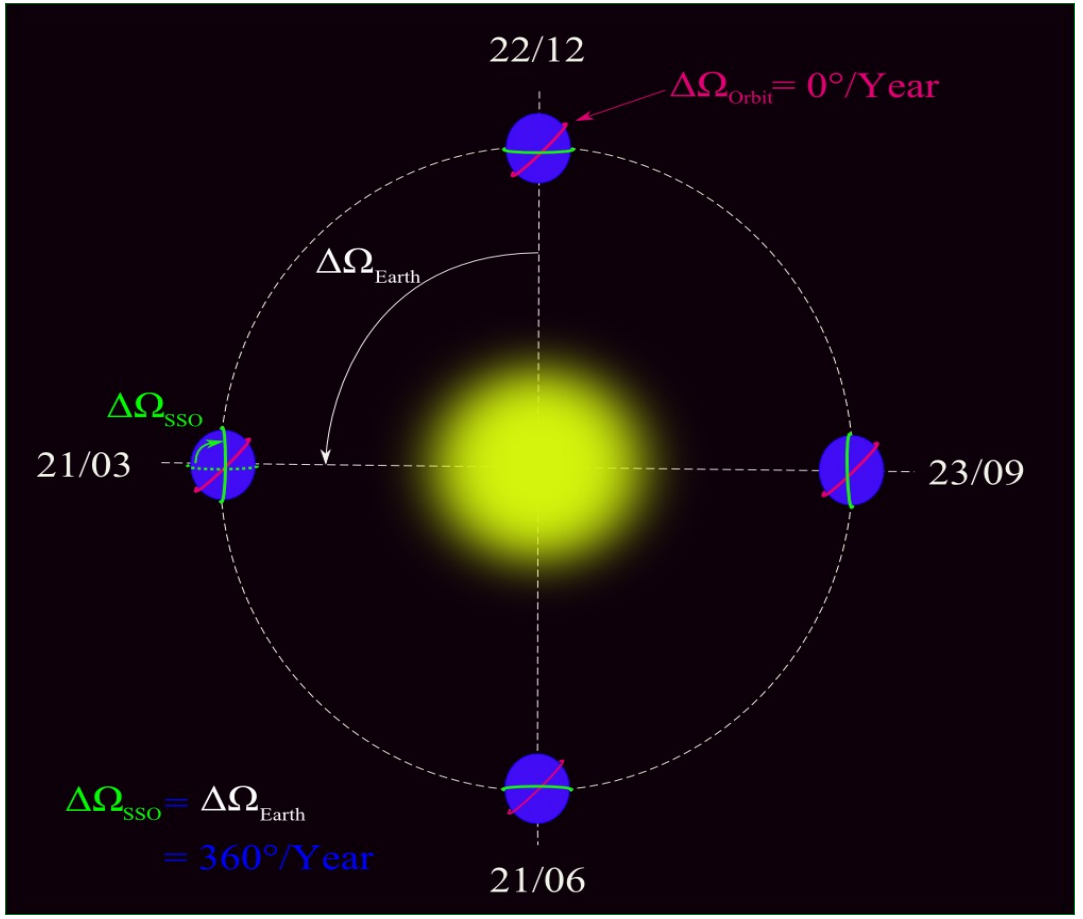

Zooming into GEO – 2
100
10
1
0.1
0.01
Inclination (deg)
35700
35800
35900
Height (km)
300
200
100
0
0
2
4
6
8
10
Most GEO sats
have inc < 0.5 deg


Active Geostationary Sats
15
10
5
0
-100
0
100
50
0
-50
-100
0
100

BACKUP SLIDES

SSO: Sun Synchronous Orbit

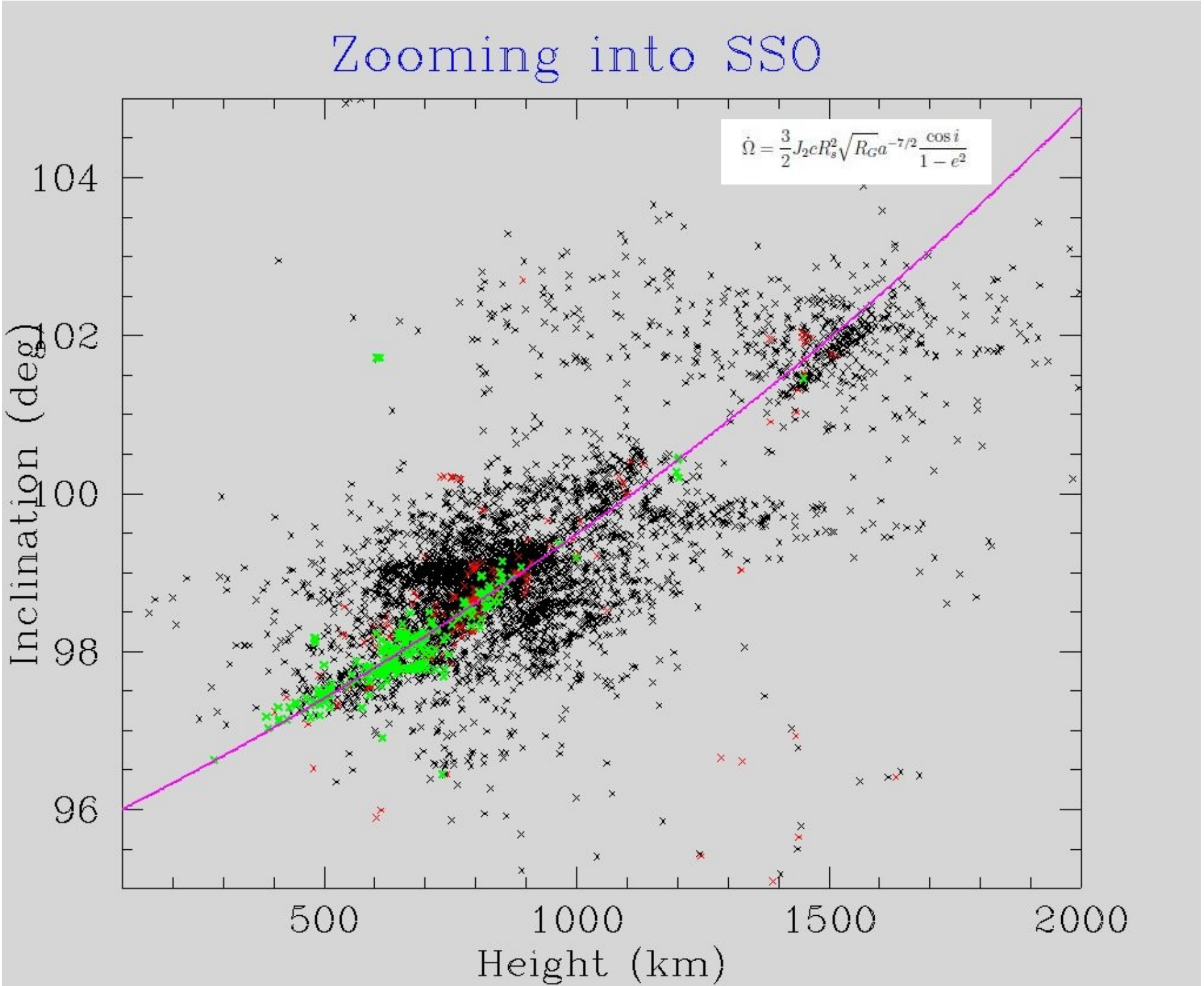
Actually we left something out of our math: the Earth is NOT ROUND!
It's a little squashed at the poles (polar radius is 22 km smaller than at equator)
Every time a sat goes over the poles, it gets less of a tug; over the equator it gets more.
This twists the orbit – makes it rotate in space.
We consider the first term (J2) 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.

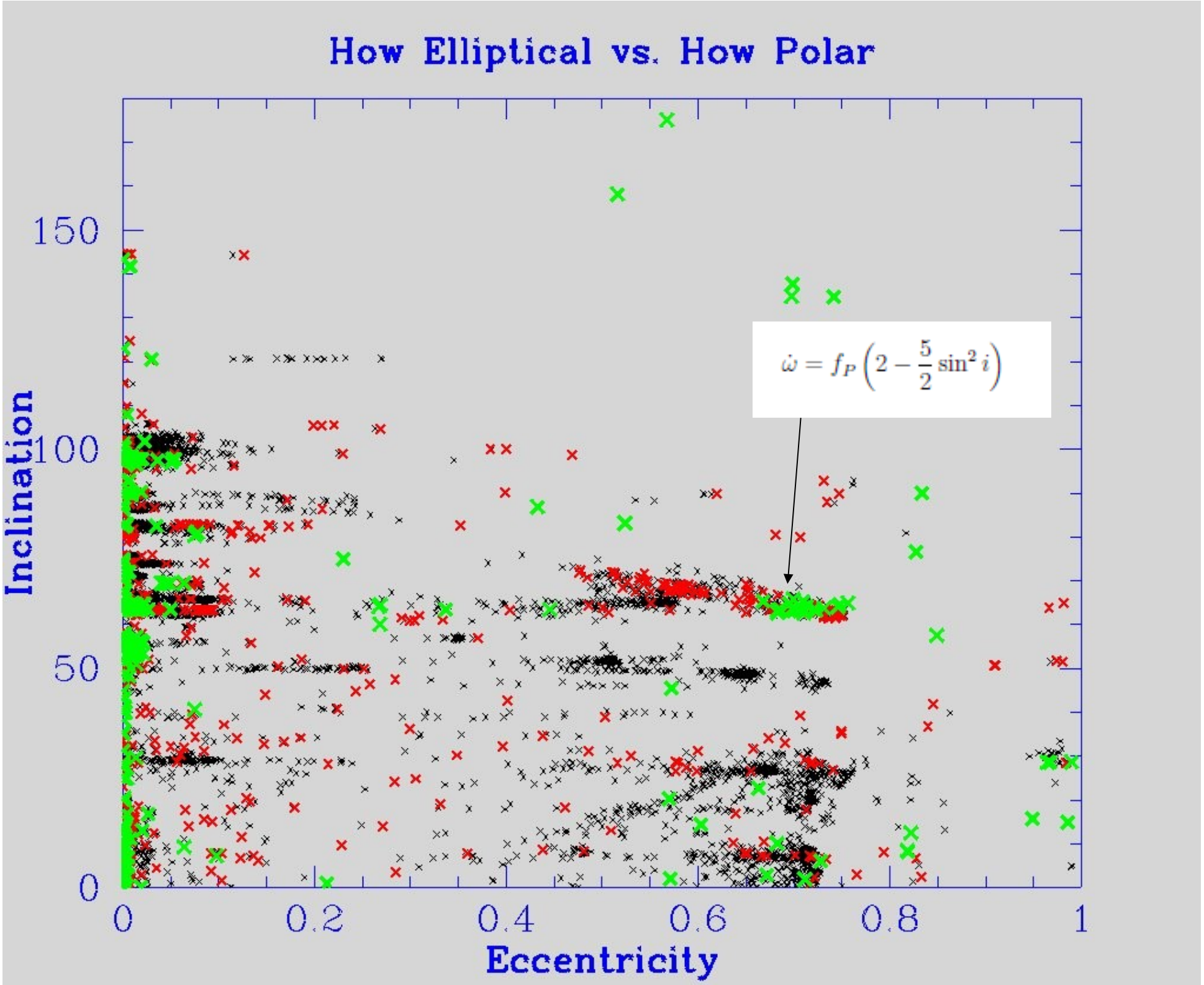


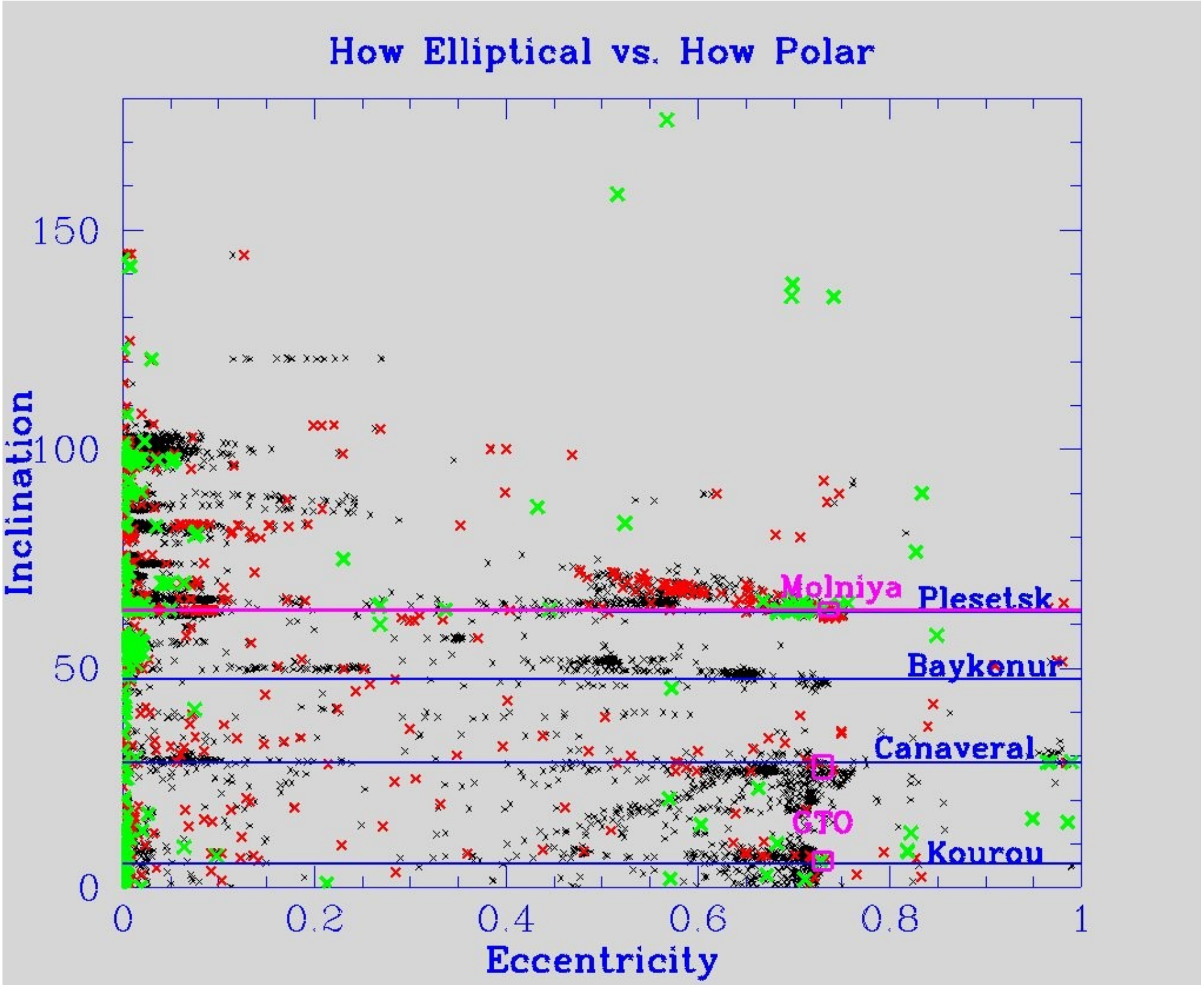
The magenta colored orbit is what you get for a perfect sphere Earth

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

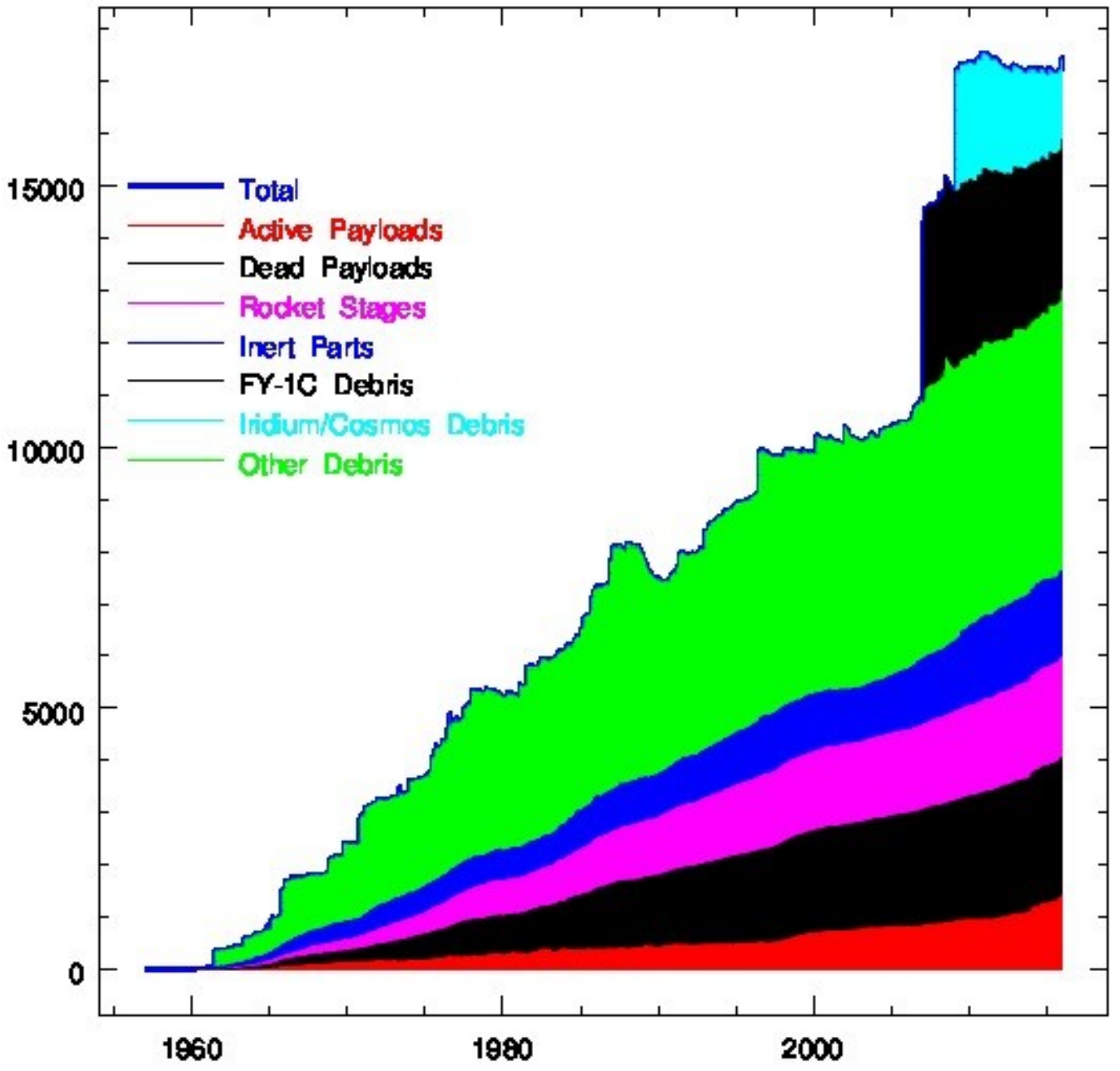

Zooming into SSO
$\dot{\Omega} = \frac{3}{2} J_2 c R_s^2 \sqrt{R_G} a^{-7/2} \frac{\cos i}{1-e^2}$
104
102
100
98
96
Inclination (deg)
500
1000
1500
2000
Height (km)


How Elliptical vs. How Polar
Inclination
150
100
50
0
0
0.2
0.4
0.6
0.8
1
Eccentricity
$\dot{\omega} = f_P \left(2 - \frac{5}{2}\sin^2 i\right)$

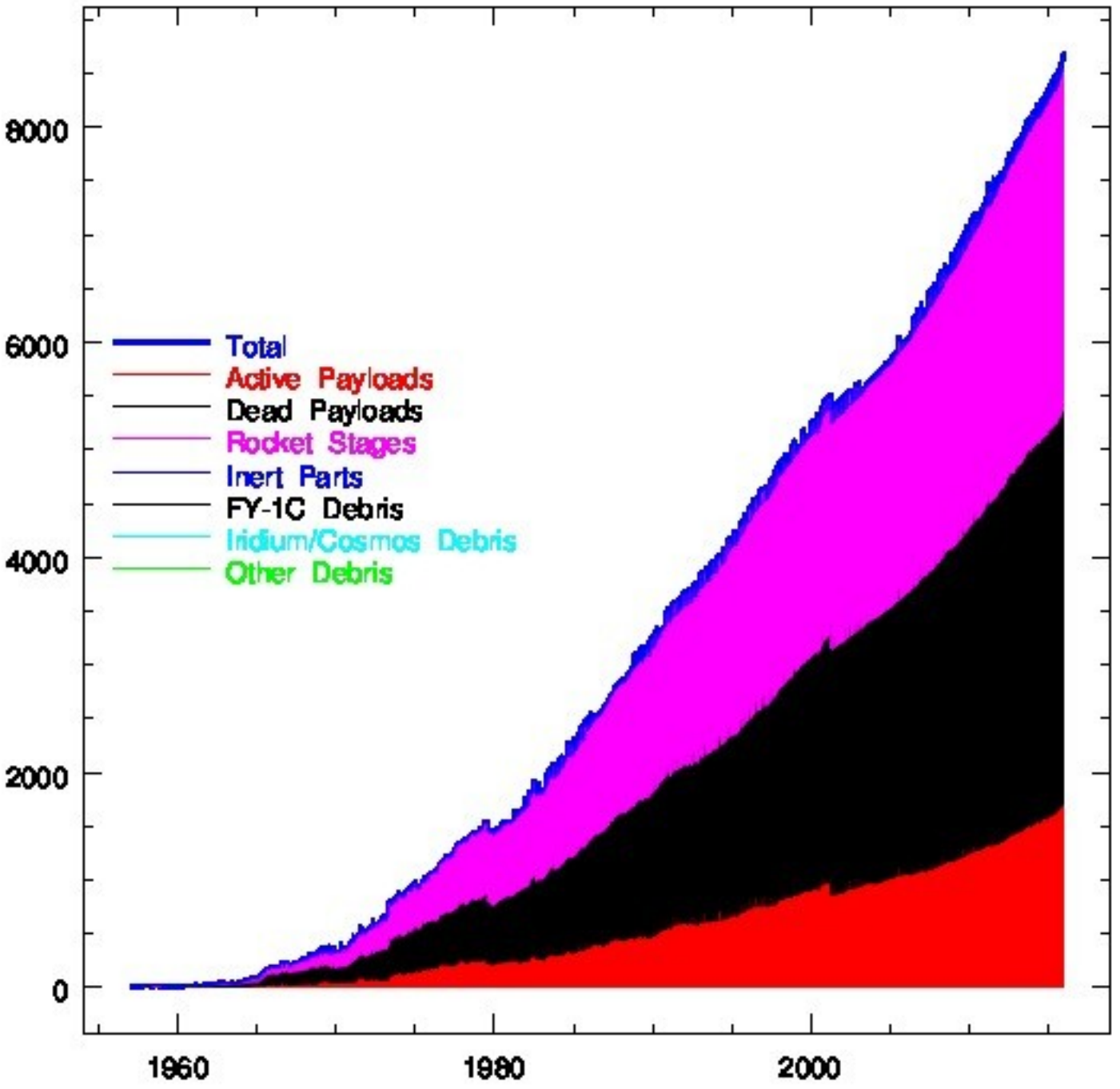

How Elliptical vs. How Polar
Inclination
150
100
50
0
0
0.2
0.4
0.6
0.8
1
Eccentricity
Molniya
Plesetsk
Baykonur
Canaveral
GTO
Kourou

Coda

The Growth of Space Junk



Space Junk - mass in metric tons



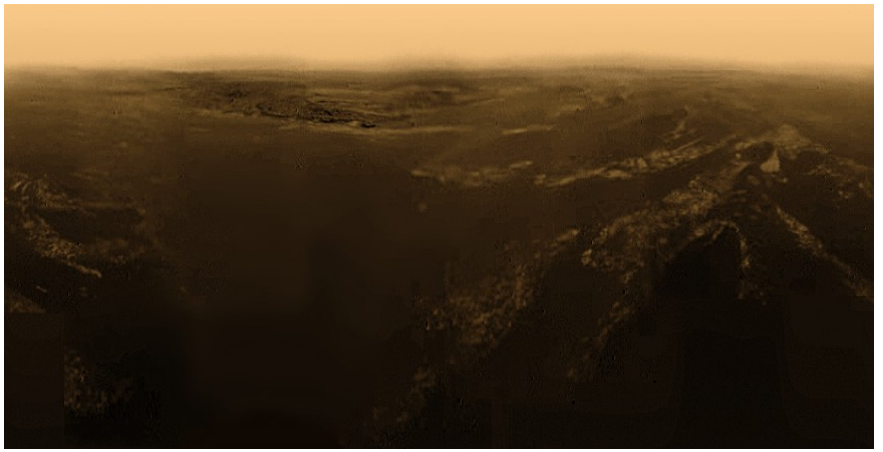
Earth orbit is now globalized
Until recently the rest of the solar system was
a superpower preserve

MOON:

USSR 1959 USA 1962 Japan 1990 Europe 2003
China 2007 India 2008

VENUS:
US 1962 USSR 1966 Europe 2006

MARS:
US 1964 USSR 1971 Japan 2003 Europe 2003



JUPITER:
US 1973 Europe 1992 (ULS)

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

COMETS:
US 1985 USSR 1986 Europe 1986 Japan 1986

ASTEROIDS:
US 1991 Japan 2005 Europe 2008 China 2012

MERCURY, URANUS, NEPTUNE: Only USA