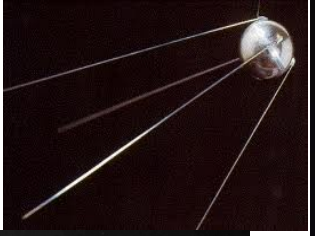
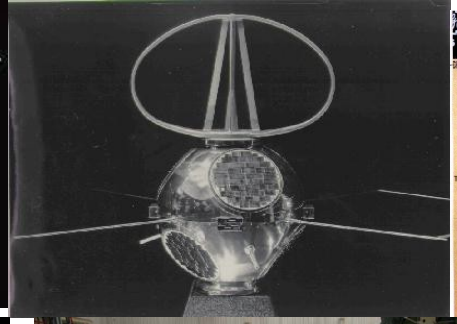
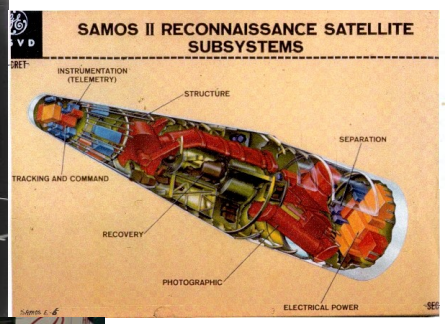


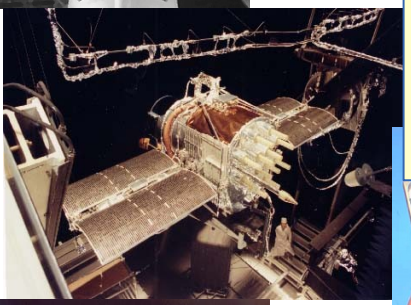



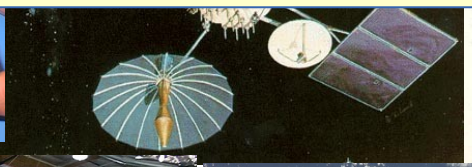
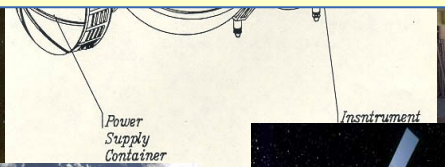








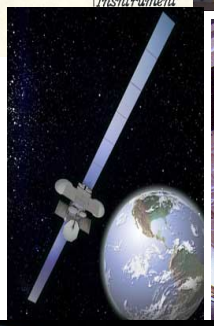














Space Debris and Space Policy

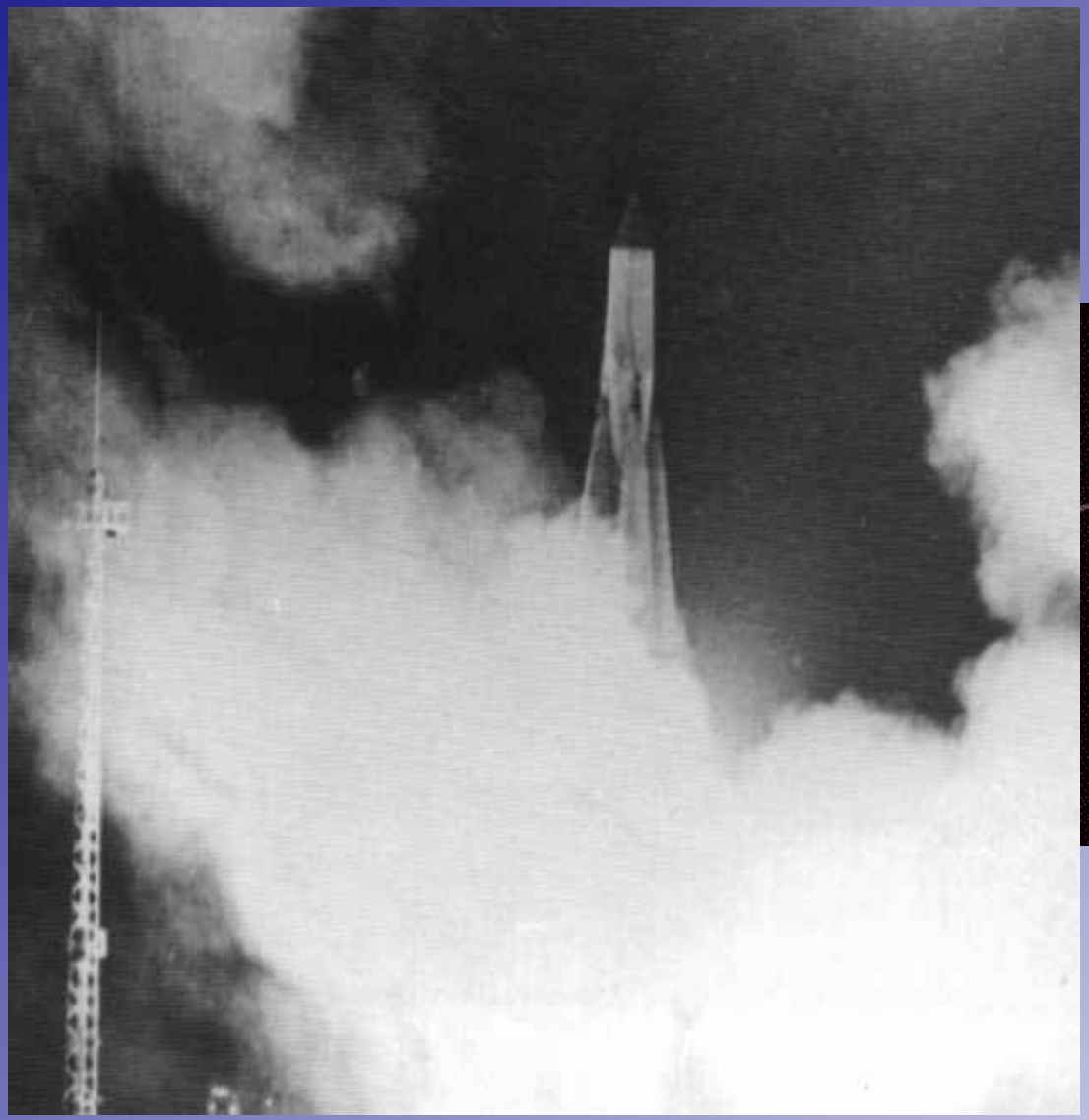
Jonathan McDowell

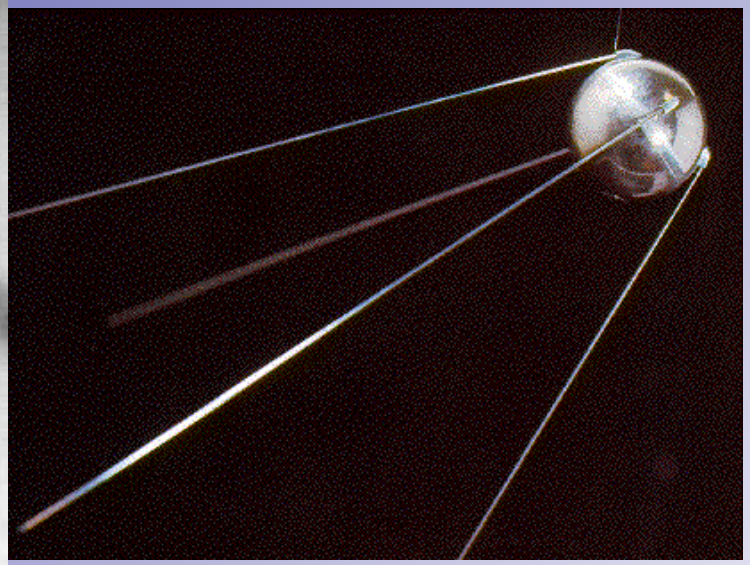
@planet4589

PART I: WHAT'S GOING ON IN SPACE?

PART II: HOW DO WE REGULATE ALL THIS?

October 1957: Sputnik

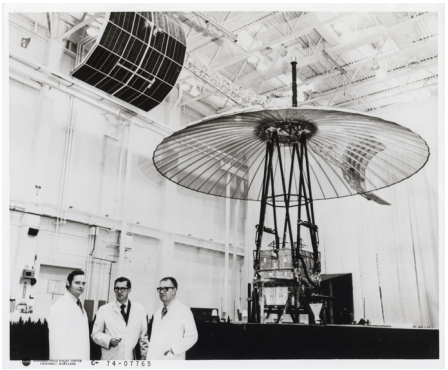




Most of what humanity does in space is done with robots -
"artificial satellites"
boxes of electronics with big solar-power-generating wings, commanded from Earth

Communications

Earth Imaging



Signals intelligence

Technology
and training

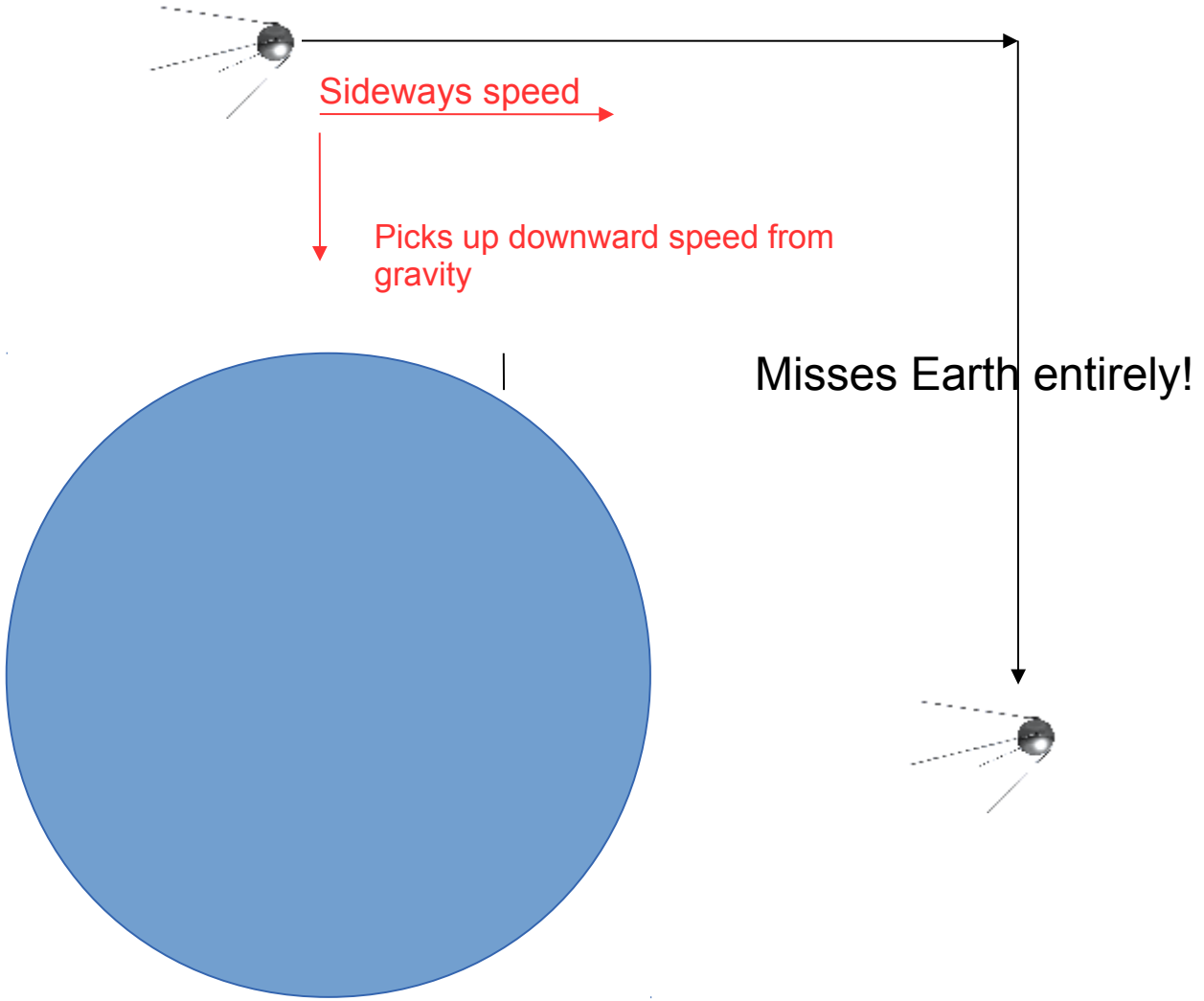
Navigation (GPS)

Science
(e.g. astronomy)

Human spaceflight

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)



In 23 minutes, falls 4000 miles
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7.7 km/s
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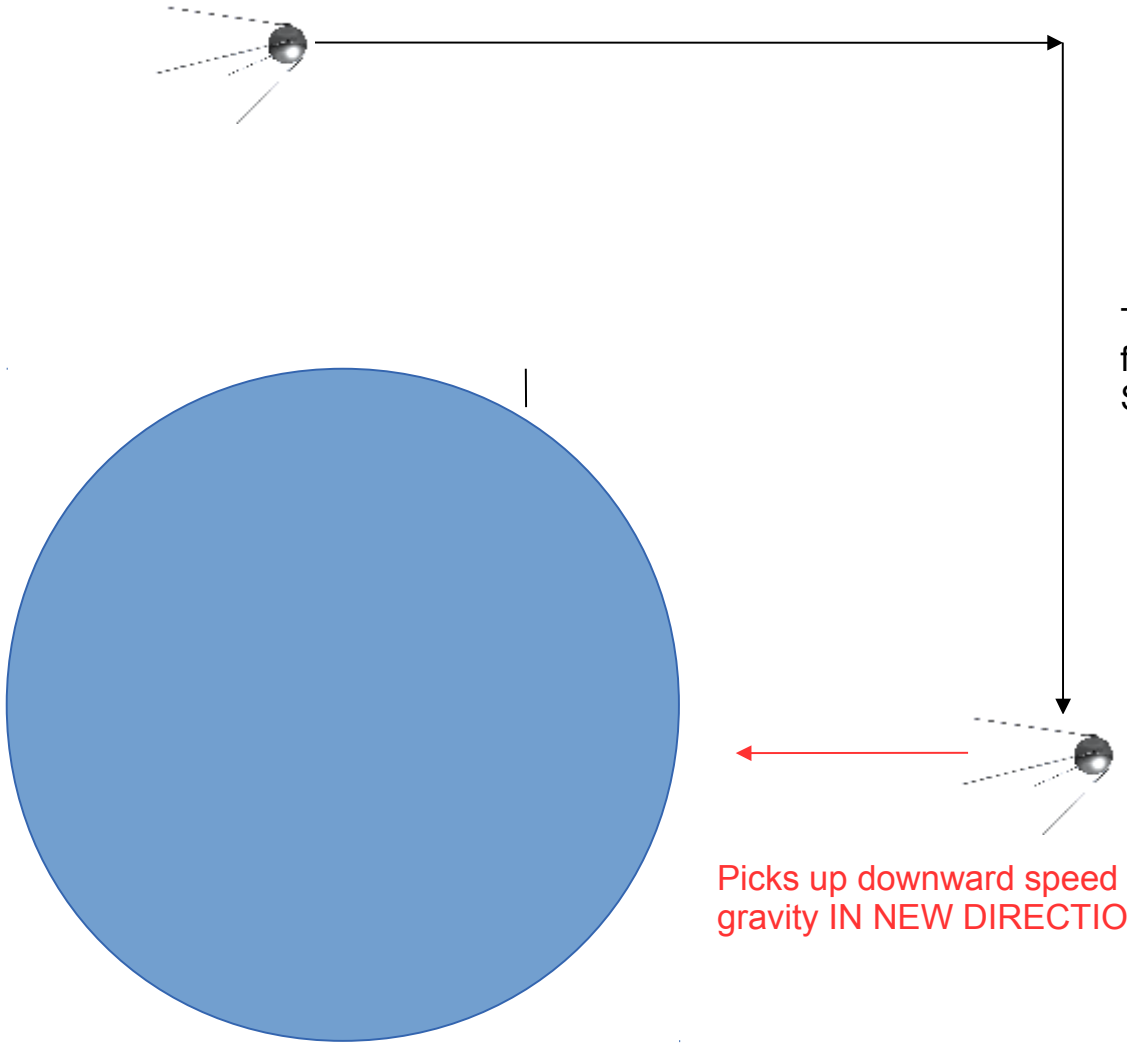
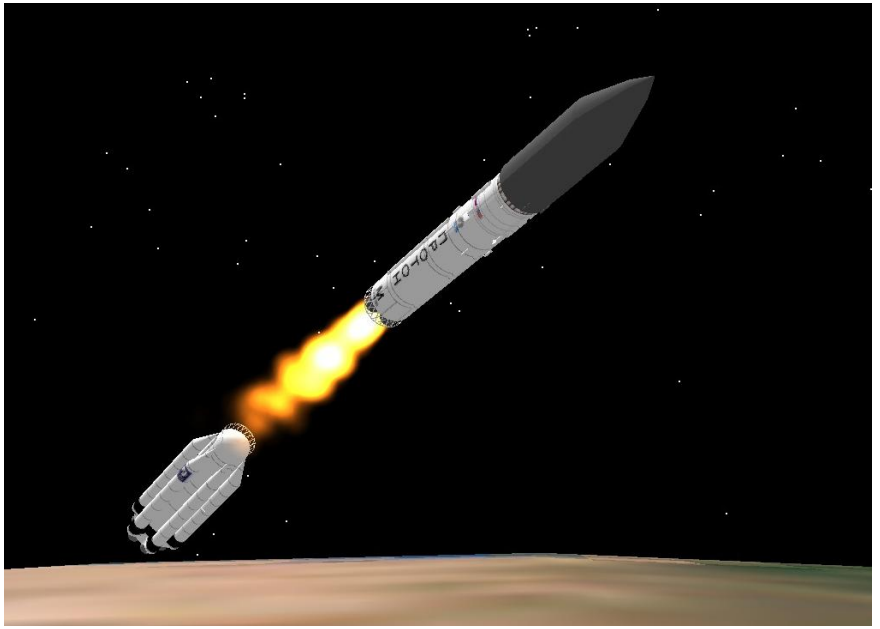
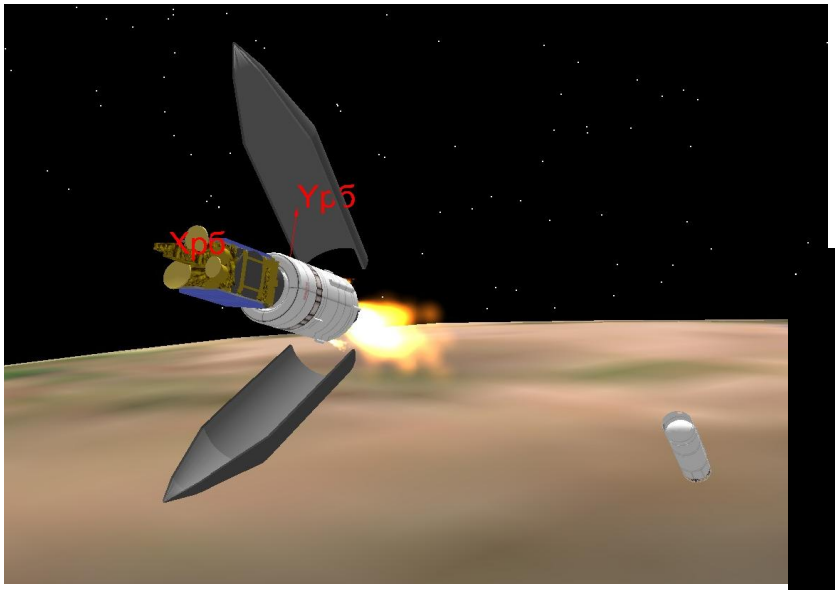


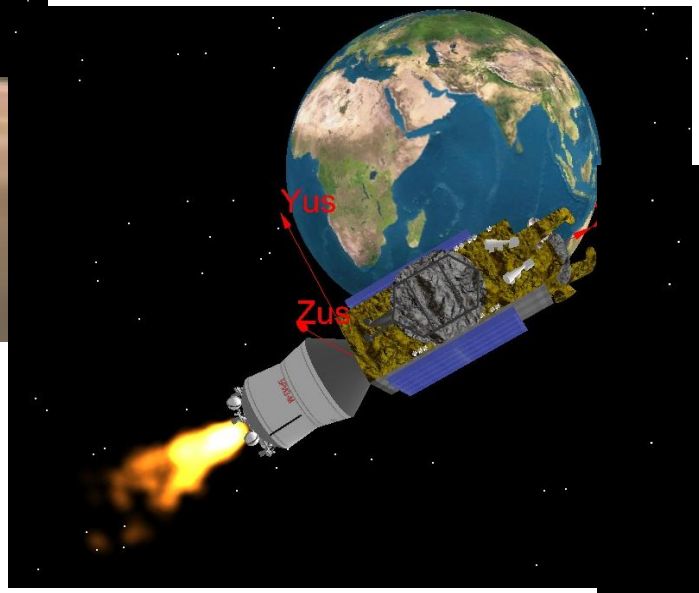
The speed it got from falling is now a SIDEWAYS speed!

Picks up downward speed from gravity IN NEW DIRECTION!

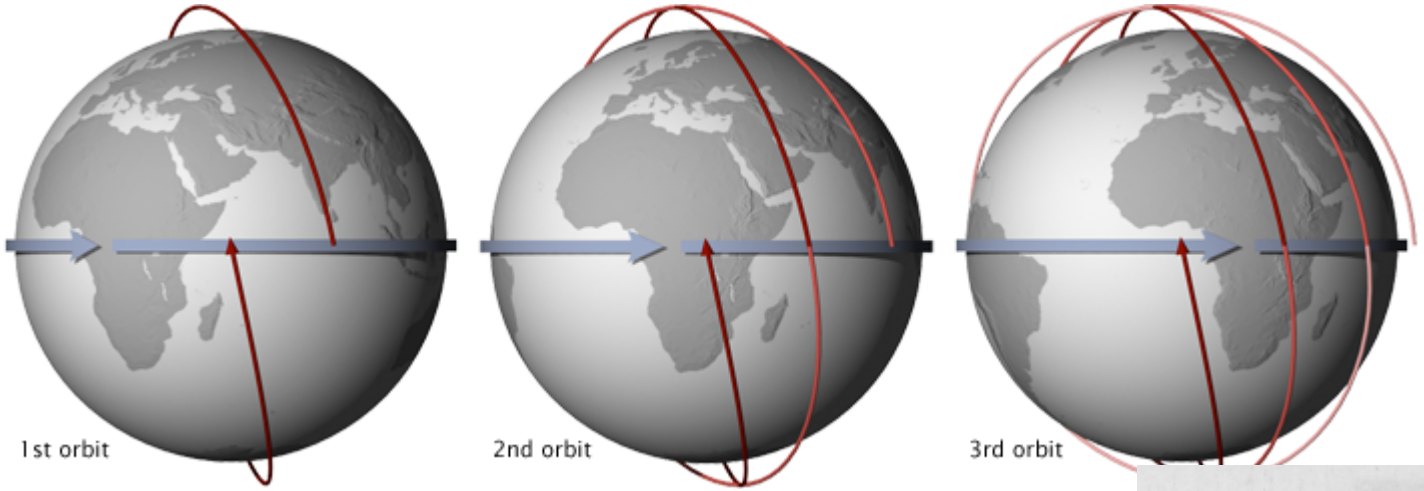
Fall around and around the Earth, always missing it!
SIDEWAYS speed makes you miss the Earth
FALLING speed becomes the new sideways speed once you turn the corner...
No rocket engine needed to keep you up! [* Offer may not apply in presence of atmosphere]







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:

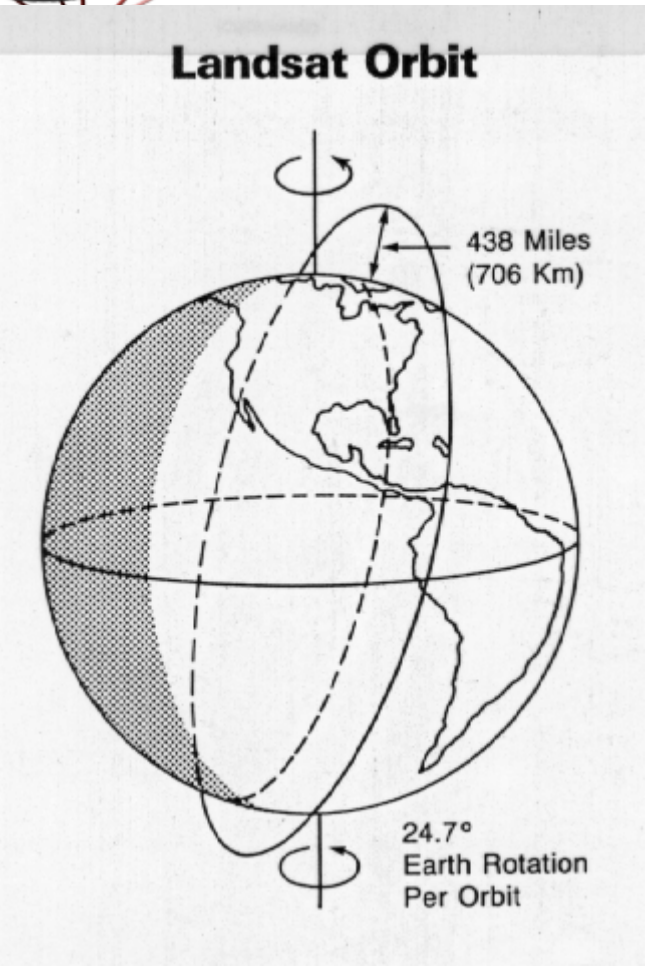
the Earth is spinning -

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



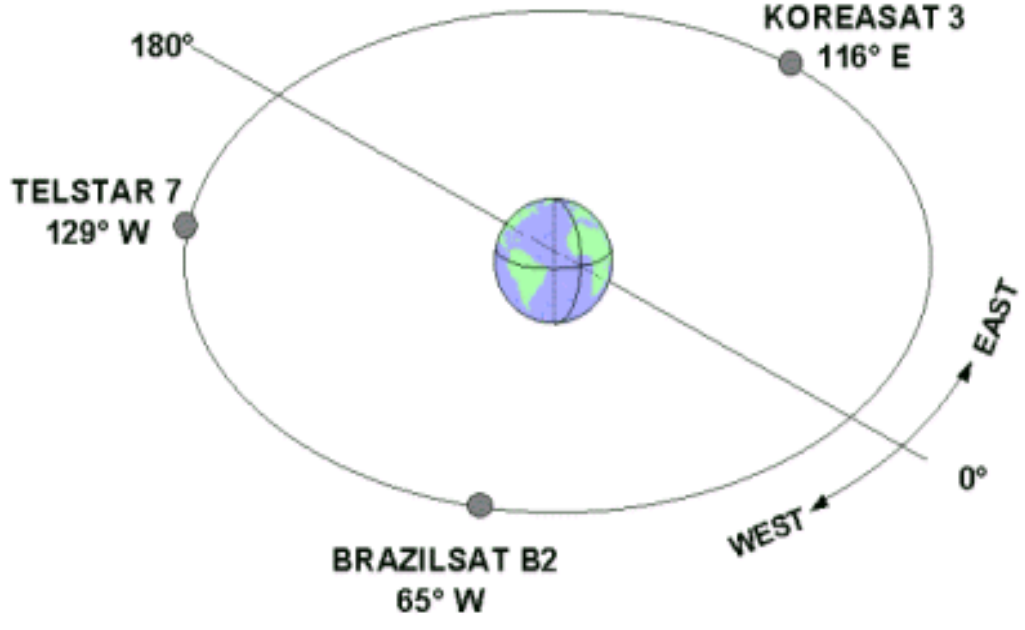
GEO: Geostationary Earth Orbit

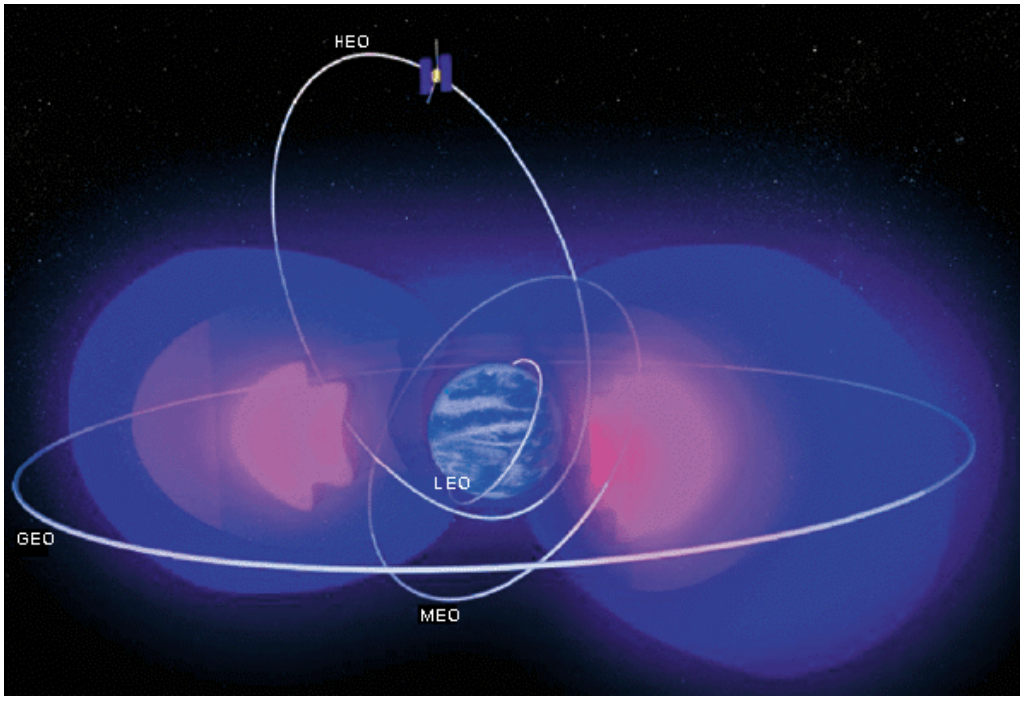
Consider a satellite whose orbit goes around the Earth's equator
Just outside the atmosphere it takes 1 ½ hours to go round the planet
Far out, at the distance of the Moon it takes a month to go round
Inbetween there is some height at which it takes exactly 23 hr 56 min

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...

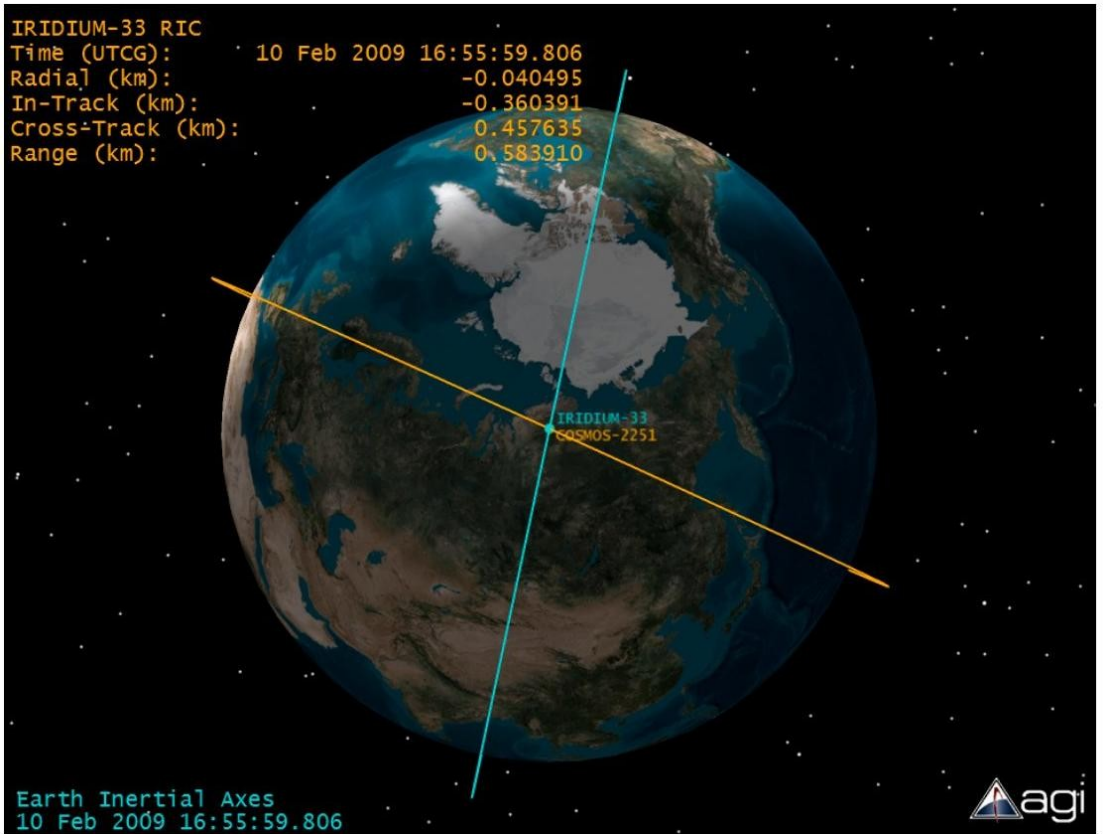
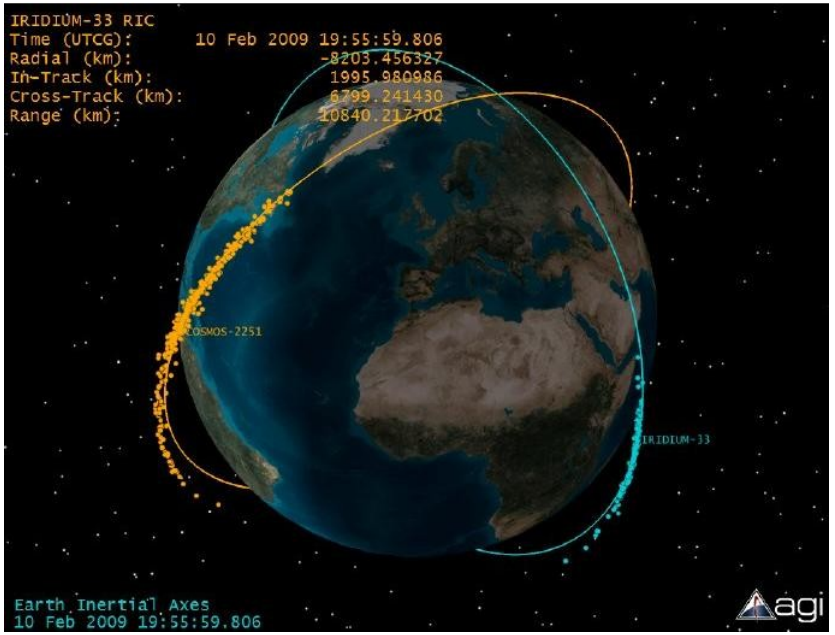
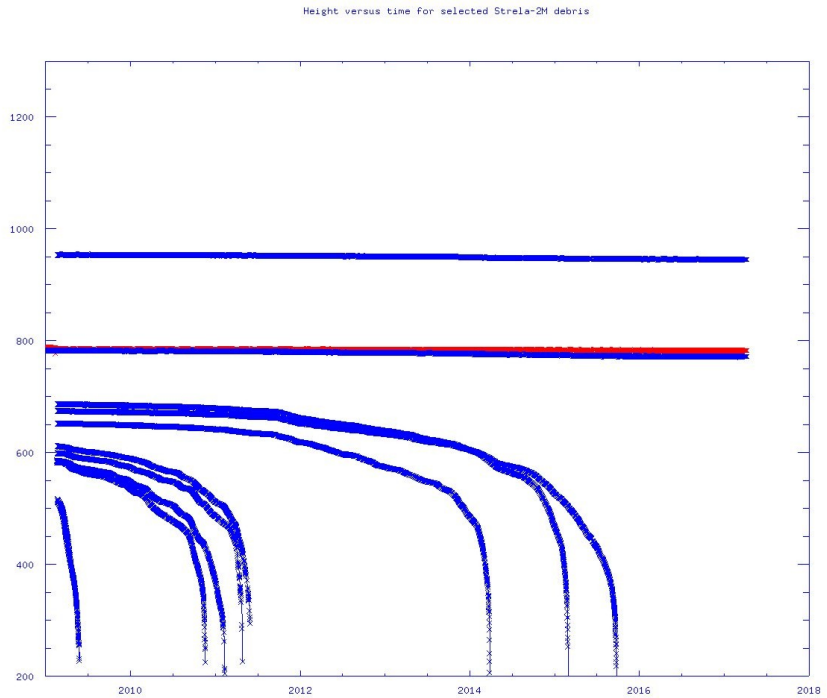


Figure from Kelso 2009





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

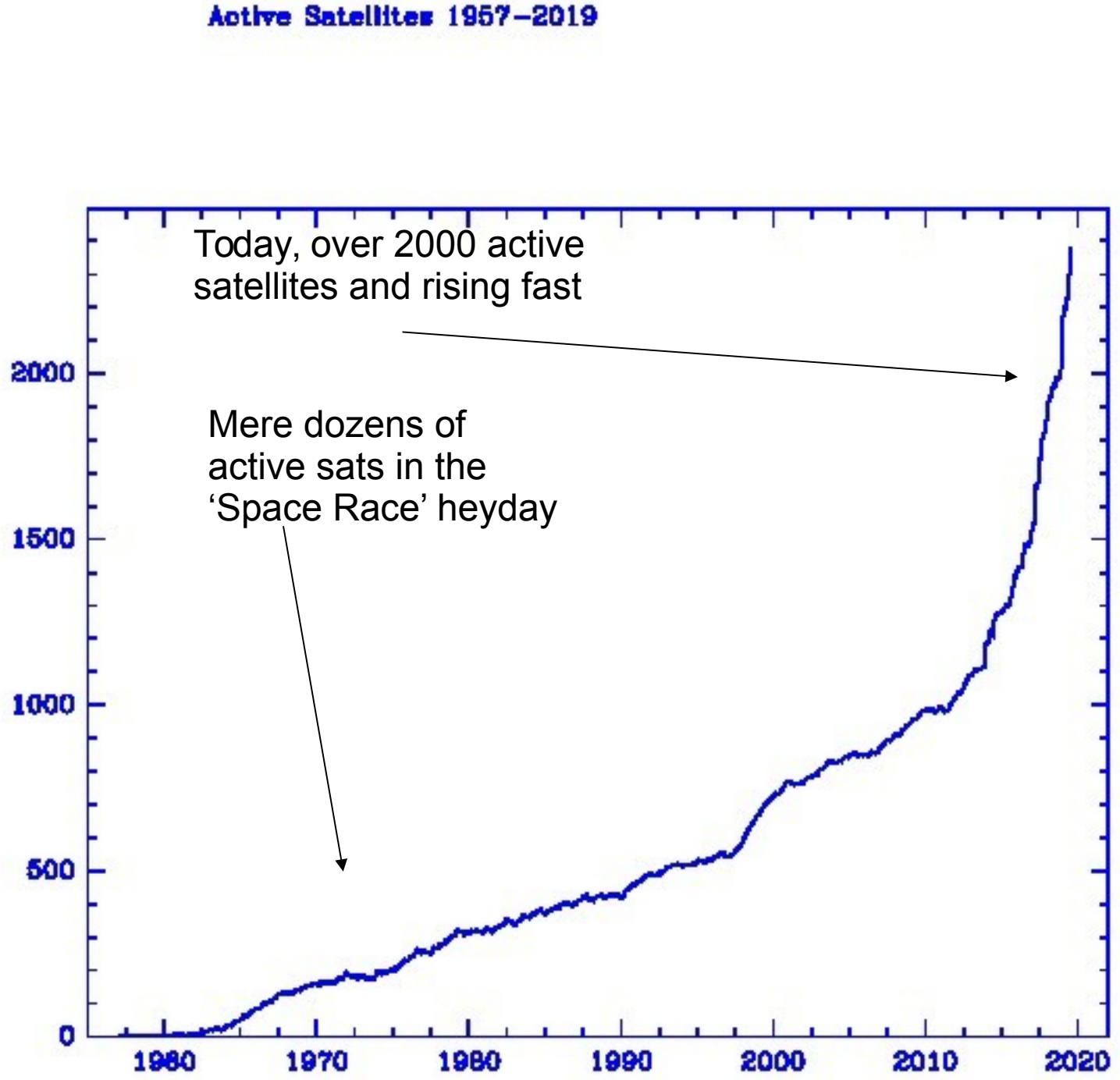
Also spread in altitude due to varying A/m ratio and hence drag coefficient

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

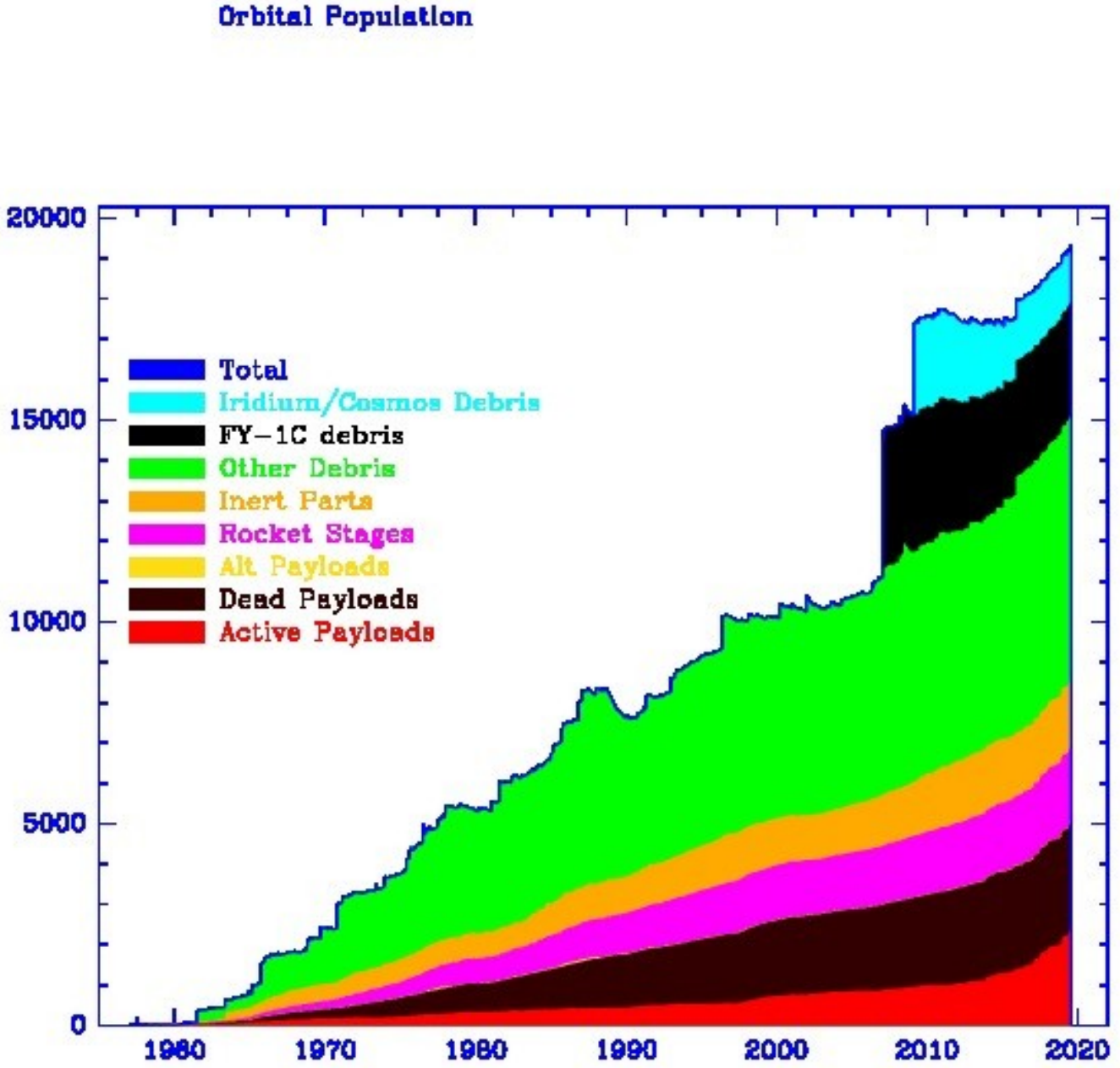
Current status:

Iridium debris - 629 cataloged 286 reentered

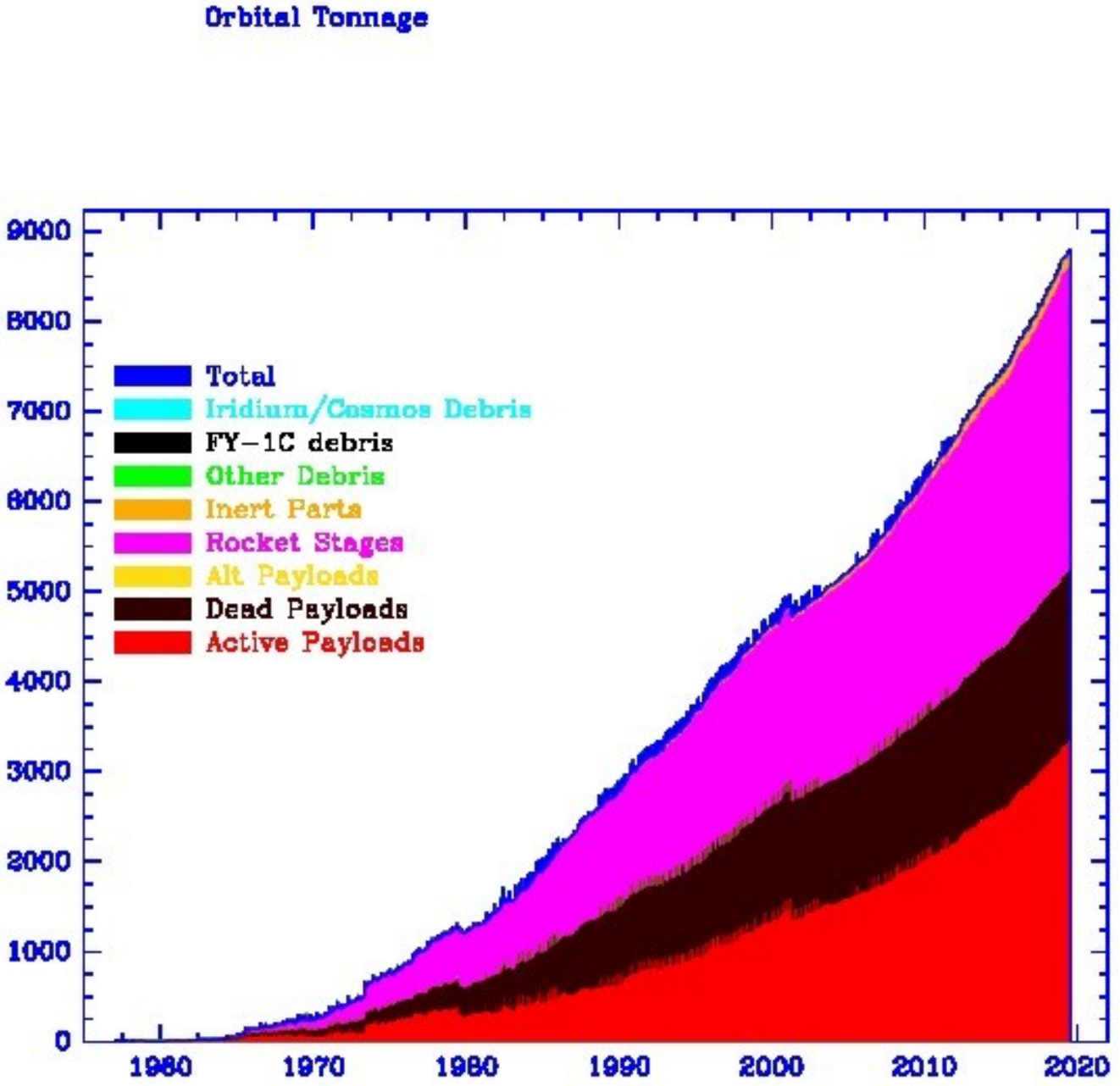
Strela debris: 1667 cataloged 566 reentered


Active Satellites 1957–2019
Today, over 2000 active satellites and rising fast
Mere dozens of active sats in the 'Space Race' heyday
2000
1500
1000
500
0
1960
1970
1980
1990
2000
2010
2020

The Growth of Space Junk



Space Junk - mass in metric tons



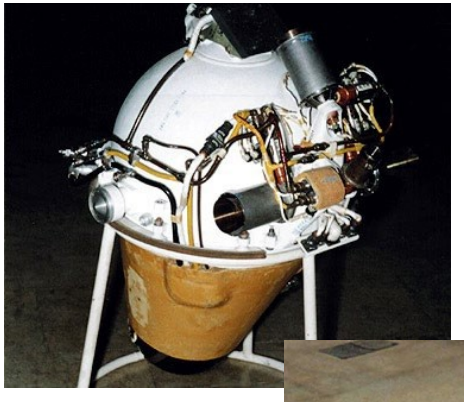
A Census of Space Debris

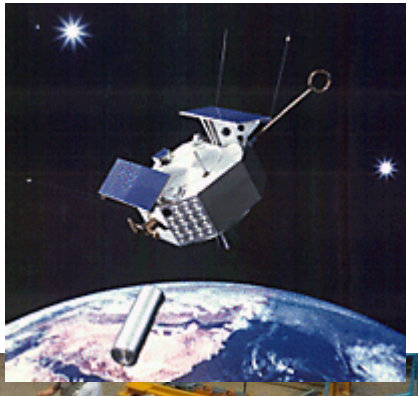
as of 12 Apr 2017 (including 172 objects cataloged y esterday evening!)

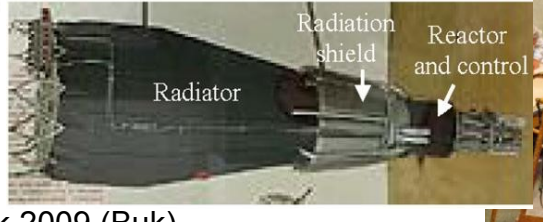
Total objects cataloged	42661	
Objects still in Earth orbit	18296	
Active payloads	1500?	
Dead payloads	2796?	
Rocket stages	1930	
Adapters, jettisoned objects	1652	
2007 Chinese ASAT debris	2855)	
2009 collision	1443)	10417
Other debris	6119)	

Covers, fairings	300
Jettisoned motors and tanks	170
Multi-payload adapters	141
Despin devices	131
Deployment canisters	38
Insulation blankets	36
Nuclear reactor cores	14
Misc	28
Unknown pieces	794

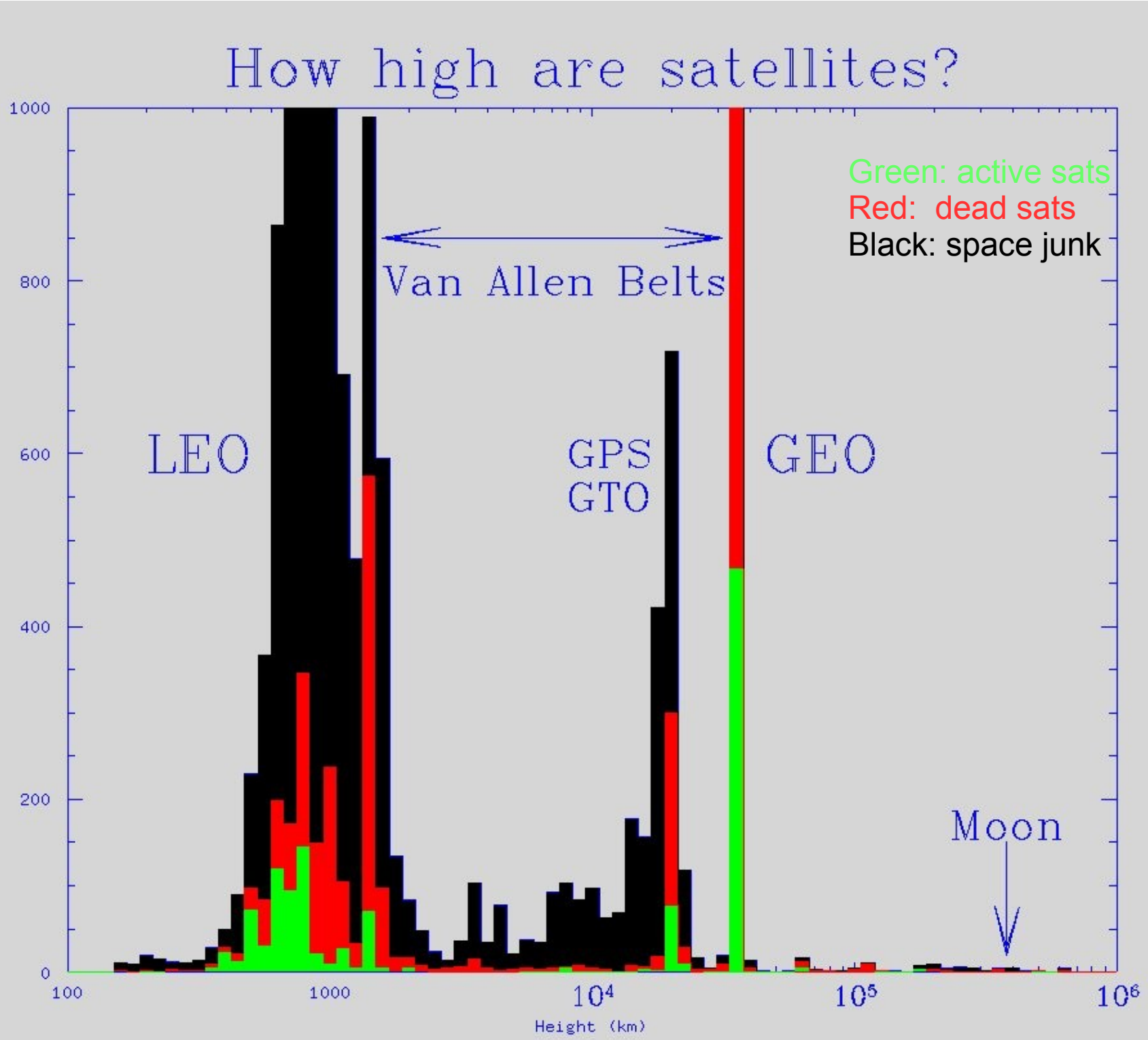
Residual fuel explosions	**3826**
Antisatellite weapon tests	**3247**
Accidental collision	**1458**
Battery explosion	**1315**
NaK Reactor coolant blobs	**53**
Insulation, Destruct, Other	**518**

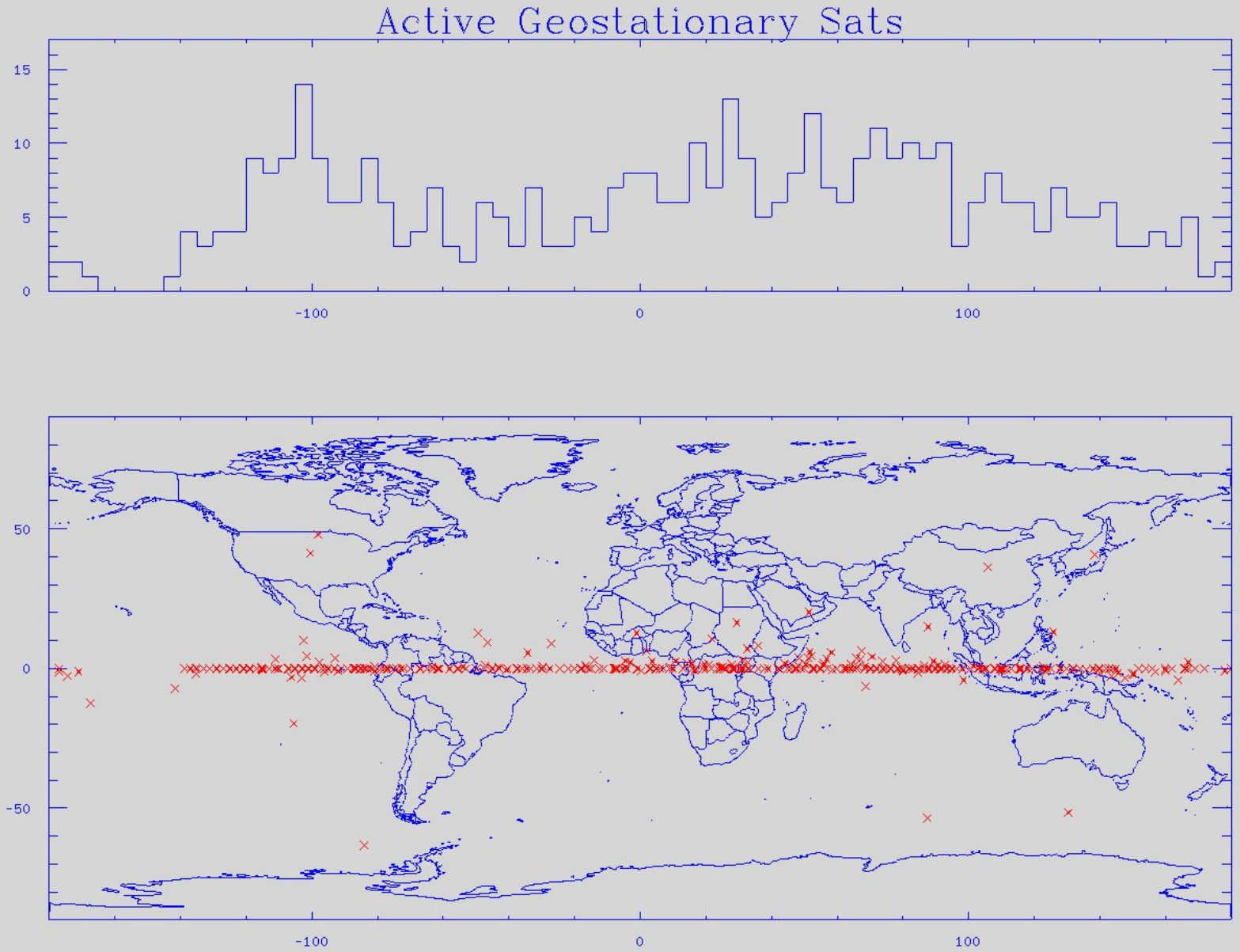


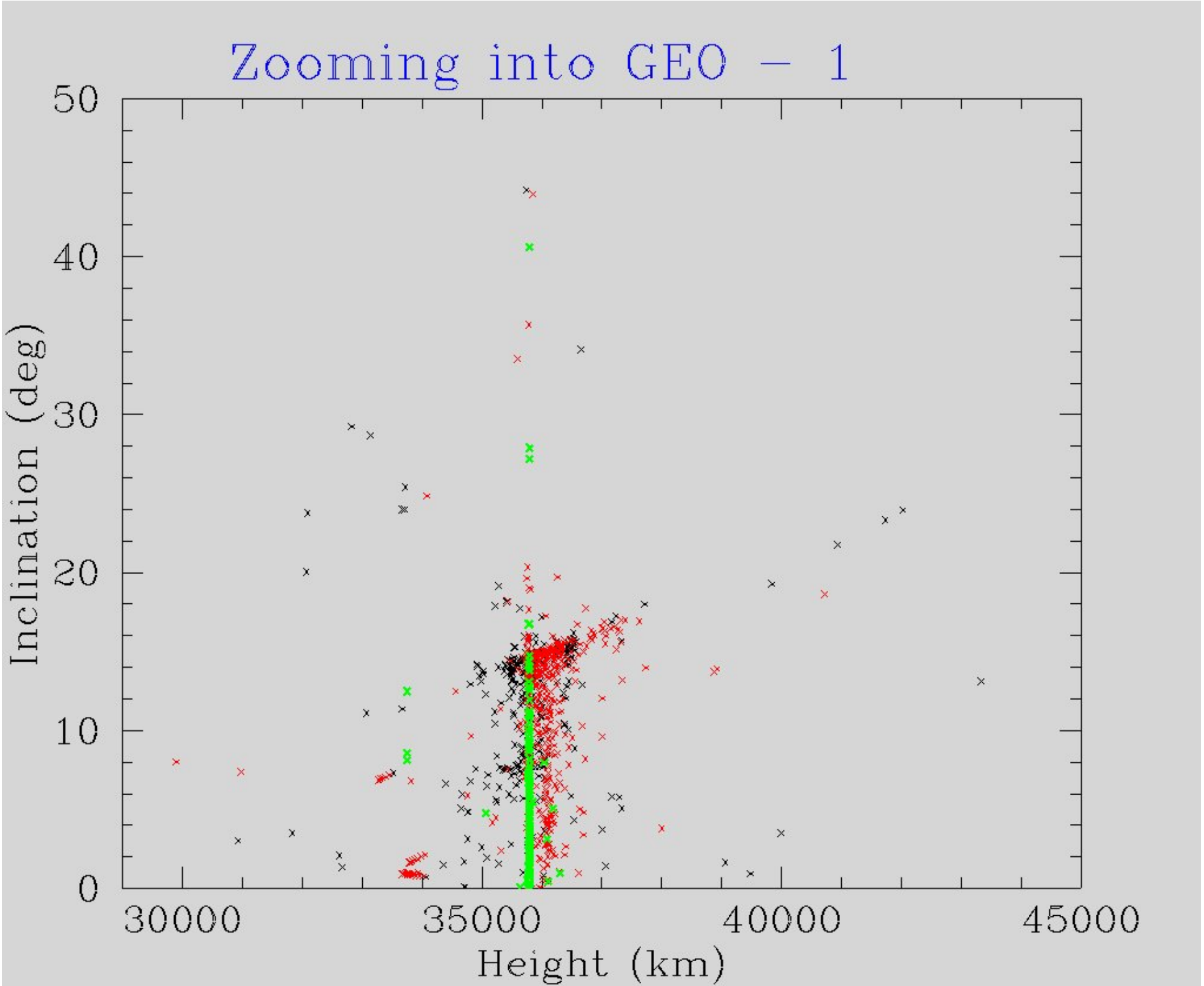




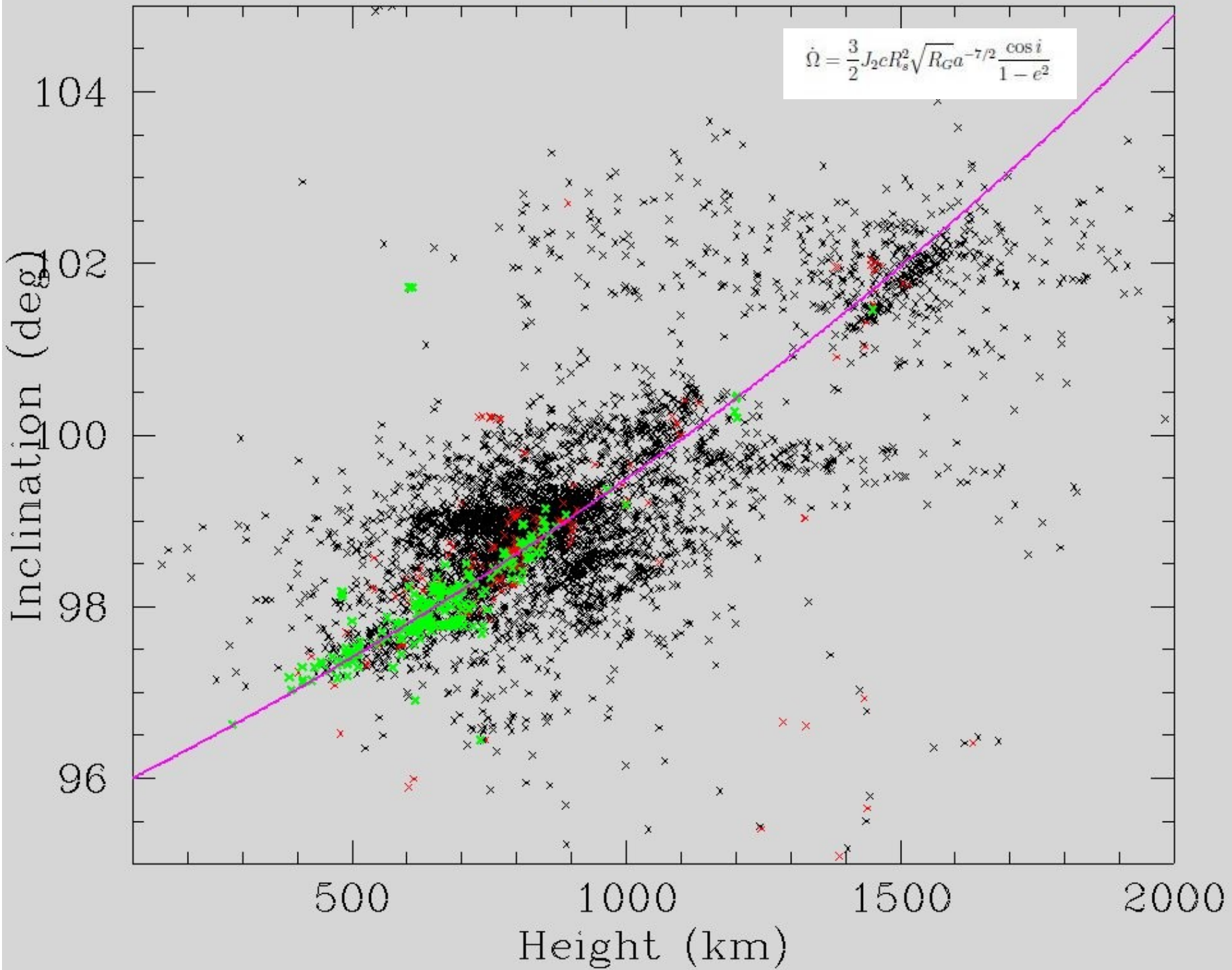
Credit: Roskosmos, NASA, Arianespace, Khrunichev; El Genk 2009 (Buk)


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

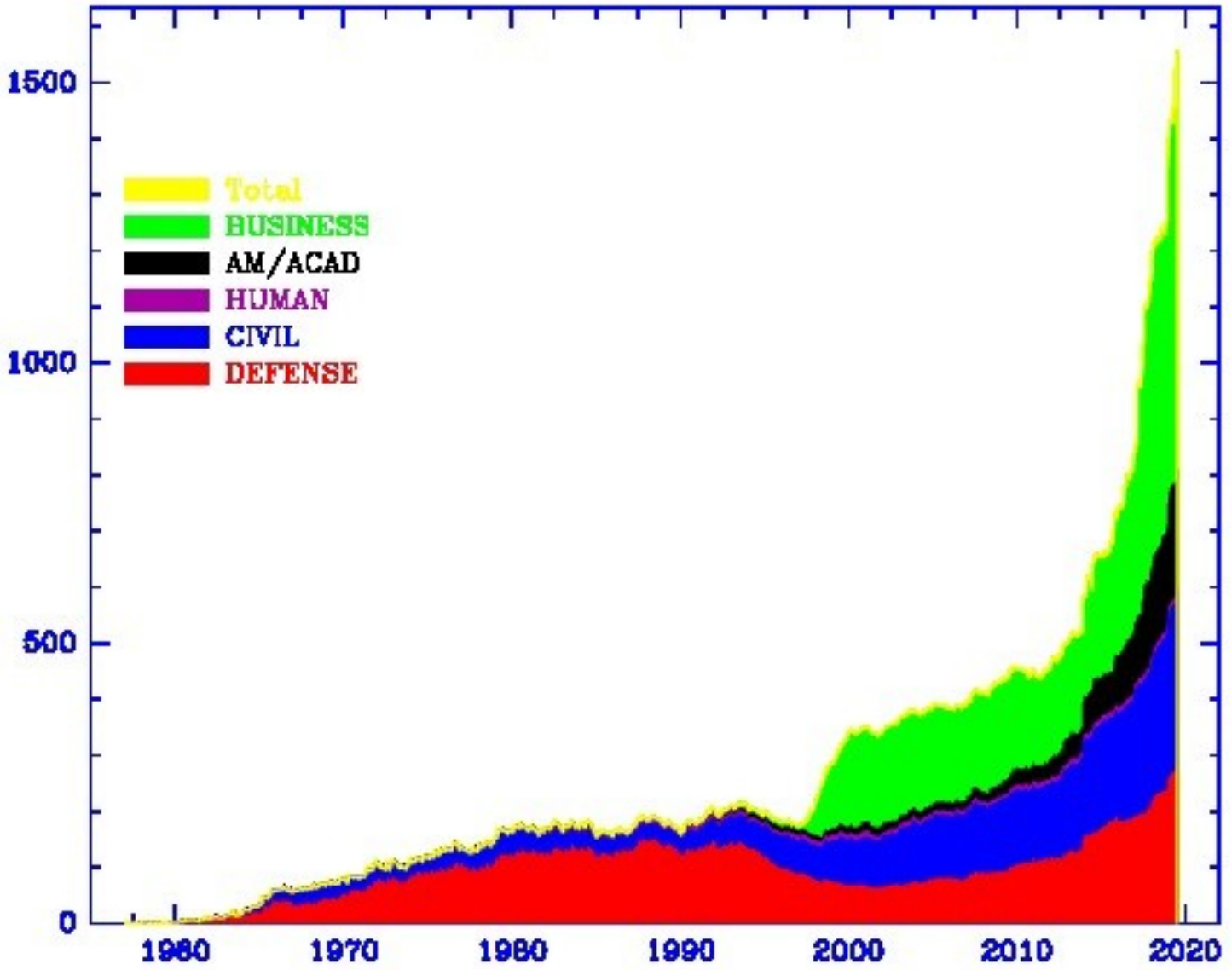

Active Geostationary Sats
15
10
5
0
-100
0
100
50
0
-50
-100
0
100

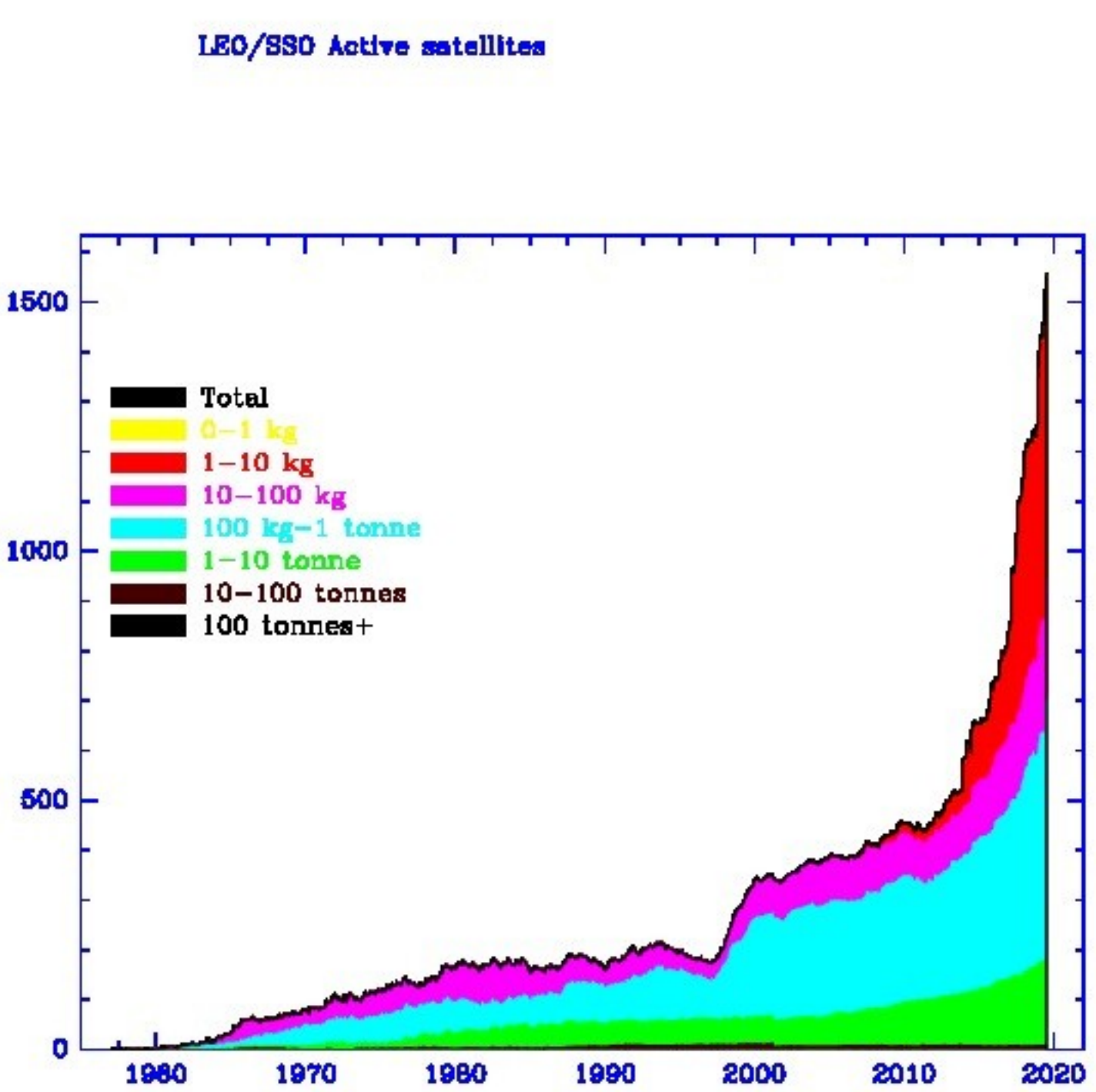

Zooming into GEO – 1
Inclination (deg)
Height (km)
0
10
20
30
40
50
30000
35000
40000
45000

Zooming into SSO



LEO Active satellites




LEO/SSO Active satellites
1500
1000
500
0
Total
0–1 kg
1–10 kg
10–100 kg
100 kg–1 tonne
1–10 tonne
10–100 tonnes
100 tonnes+
1960
1970
1980
1990
2000
2010
2020

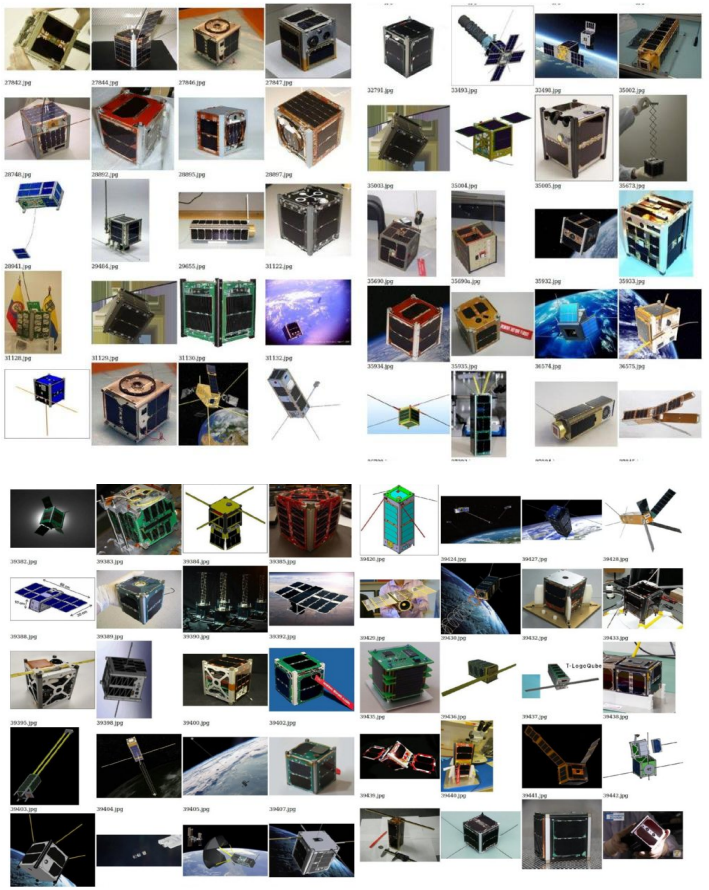
LEO+SSO

The Cubesat Explosion: STATISTICS 2019 Oct

http://planet4589.org

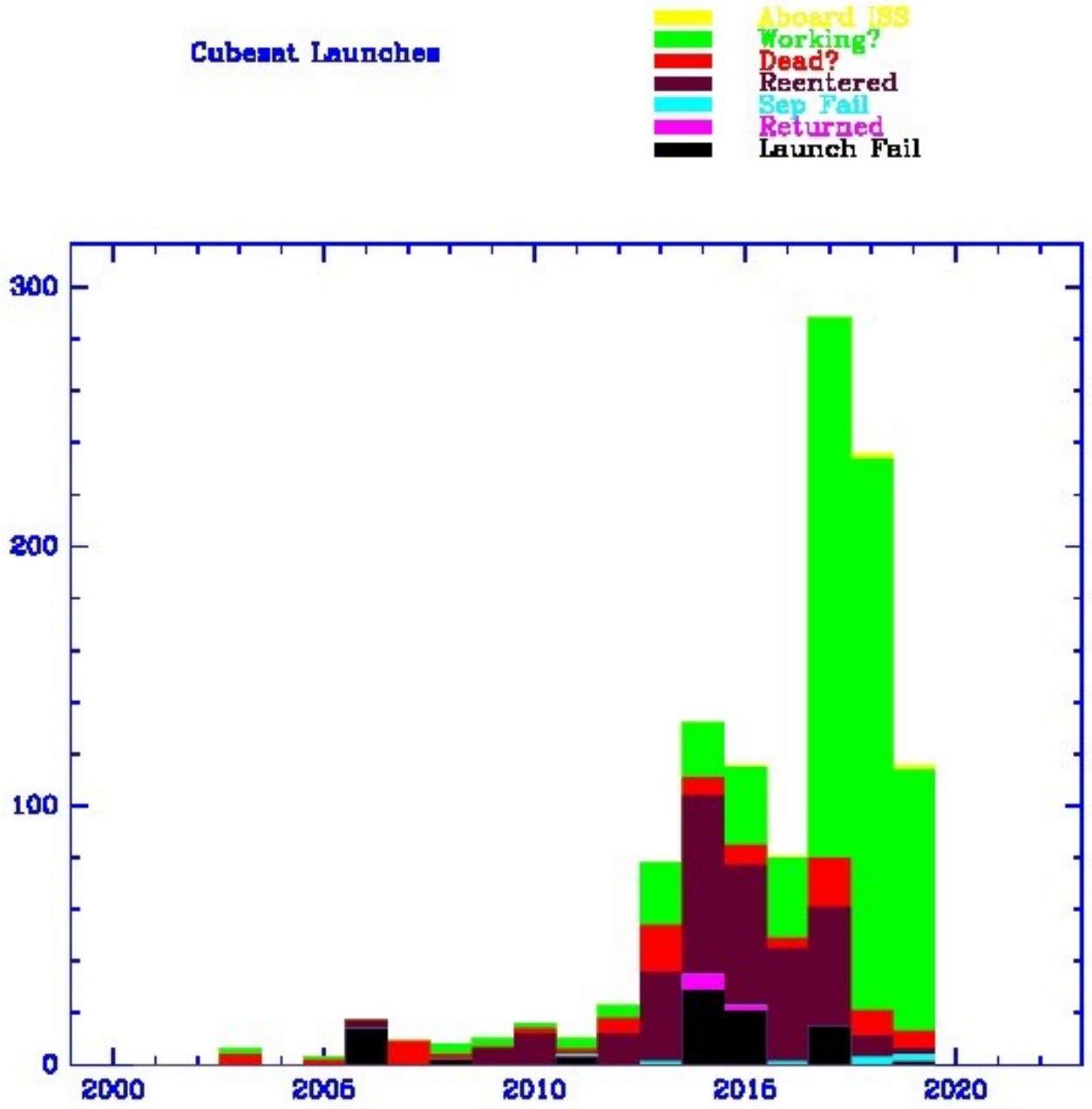
TOTAL 66 COUNTRIES:

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, Netherlads 7
India 6
Turkey, Israel 5
,Belgium,Finland,Poland,Switzerland,S Africa, Brazil 4
Norway,Peru,Ecuador,SwedenKazkahstan, Lithuania,
Czechia 3
Vietnam,Greece, UAE, Ukraine, Thailand, Malaysia,
Argentina, Egypt, Colombia, Austria, Estonia 2
Uuruguay, Sri Lanka, Nepal, Jordan, Bhutan,
Bulgaira, Costa Rica, Kenya, Slovakia, Bangladesh,
Mongolia, Ghana, Phillipines, 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

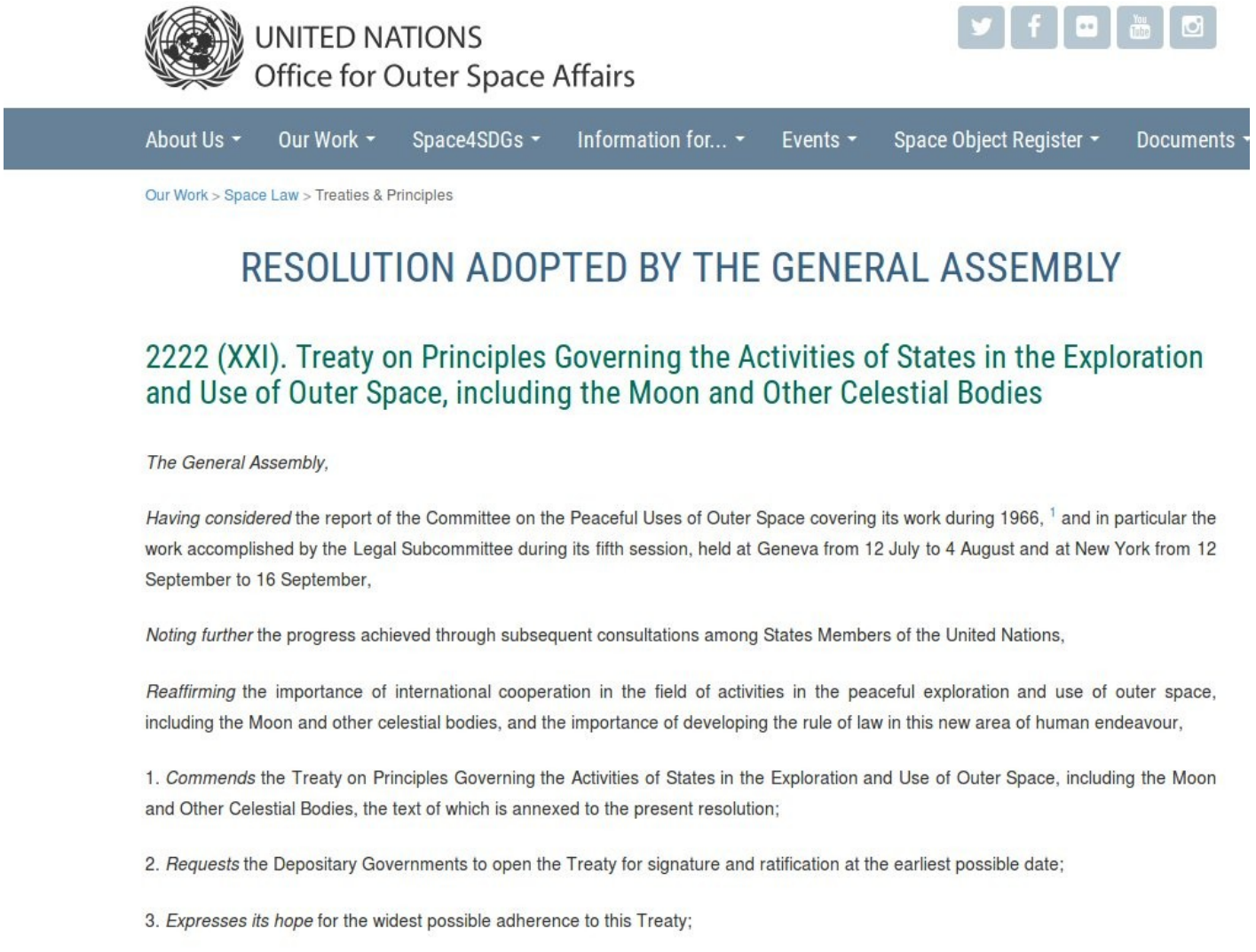
…. not subject to national appropriation

…. all activities of non-govt orgs regulated by their govts

…. liability

…. due regard to others

… no nukes! (or other WMD).



UNITED NATIONS
Office for Outer Space Affairs

About Us | Our Work | Space4SDGs | Information for... | Events | Space Object Register | Documents

Our Work > Space Law > Treaties & Principles

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, [1] 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,

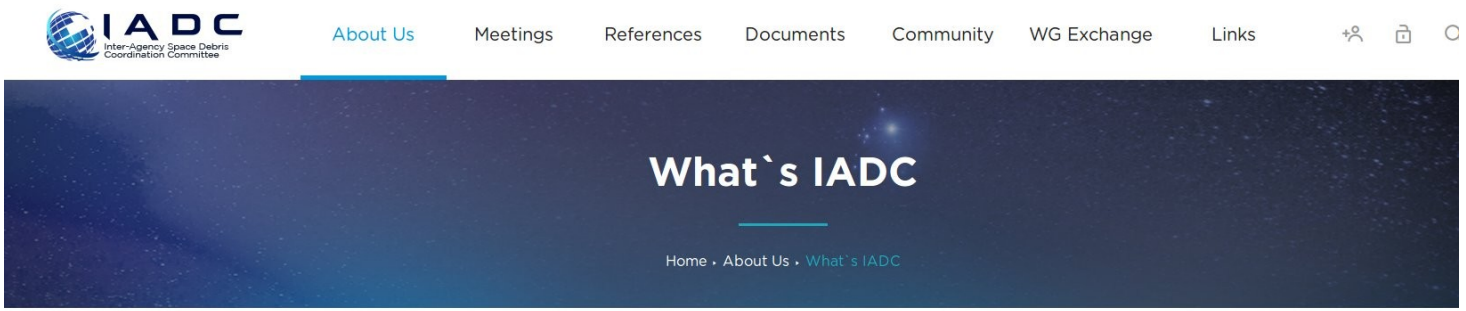
1. *Commends* the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, the text of which is annexed to the present resolution;

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;

UNITED NATIONS
Office for Outer Space Affairs

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)



Welcome to the
Inter-Agency Space Debris Coordination Committee
Website

The Inter-Agency Space Debris Coordination Committee (IADC) is an international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space.

The primary purposes of the IADC are to exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options.

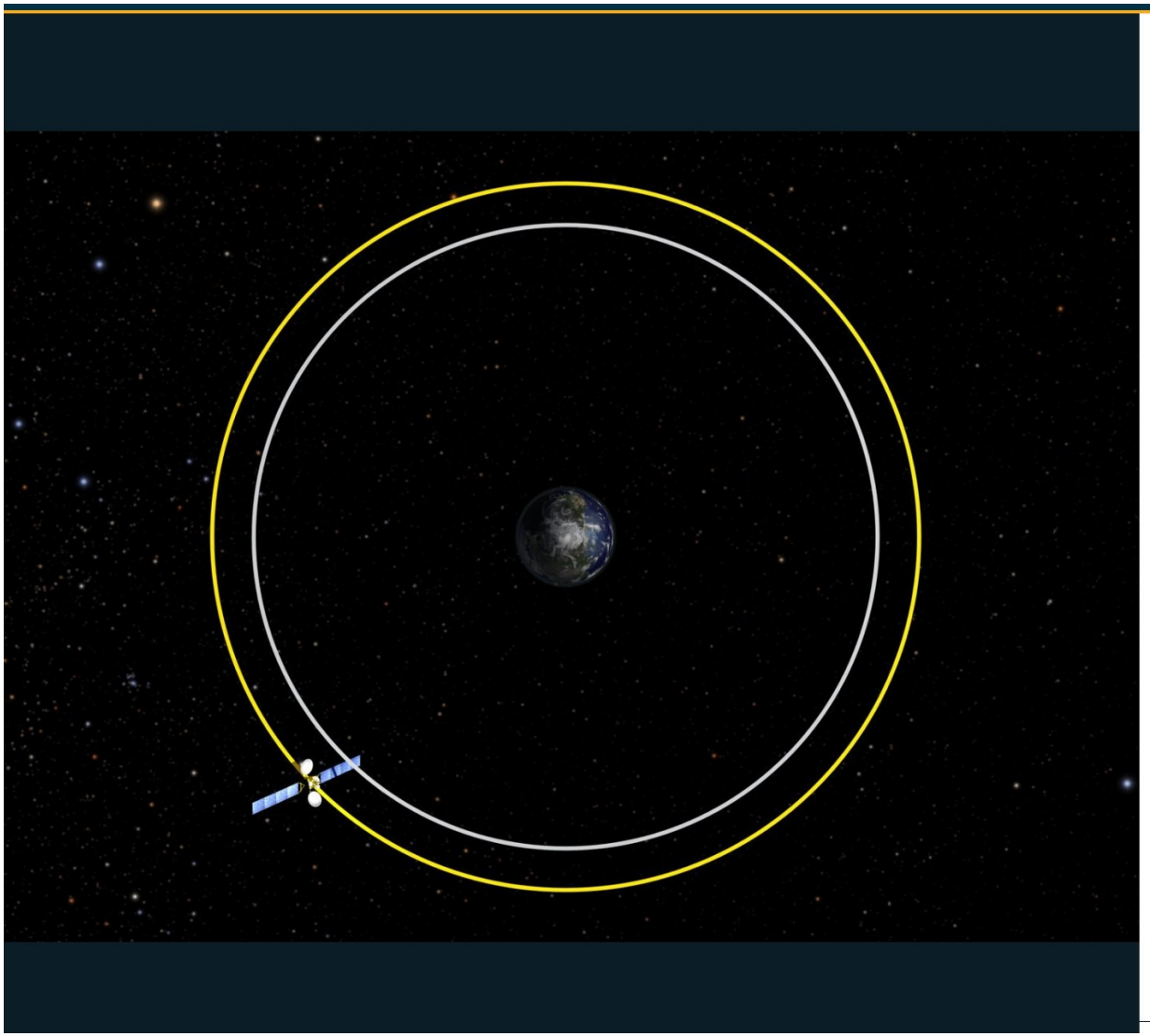
IADC

The IADC member agencies include the following

- **ASI** (Agenzia Spaziale Italiana)
- **CNES** (Centre National d'Etudes Spatiales)
- **CNSA** (China National Space Administration)
- **CSA** (Canadian Space Agency)
- **DLR** (German Aerospace Center)
- **ESA** (European Space Agency)

High orbit recommendations:

Push GEO sats UP by 300 km on retirement



ENABLING & SUPPORT

Mitigation scenarios: Graveyard orbit 300 km above GEO

10/04/2008 1427 VIEWS 7 LIKES 201640 ID

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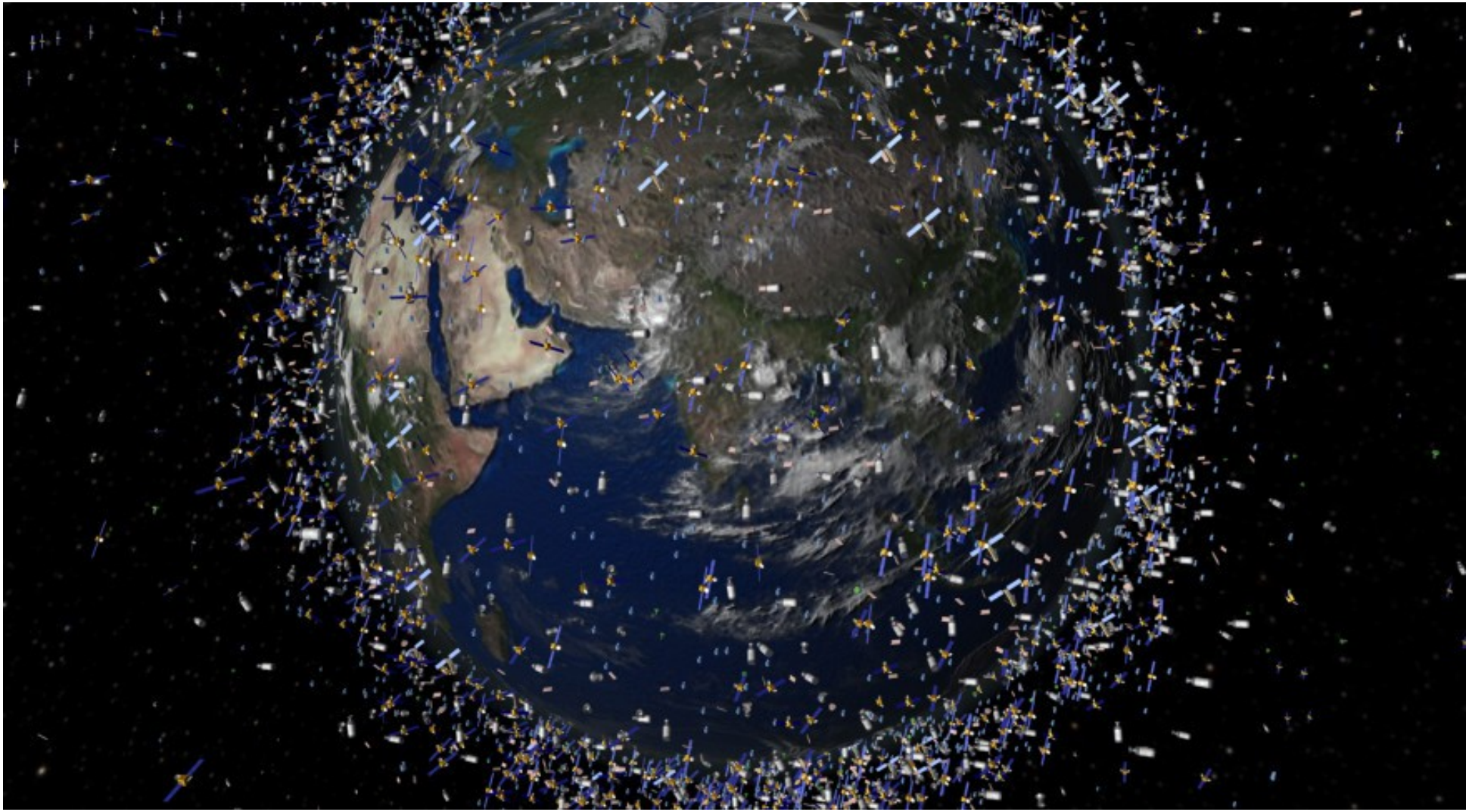
DETAILS RELATED

In order to eliminate collision risk, GEO satellites should be moved out of the geostationary ring at the end of their mission. It is recommended that their orbit should be raised by about 300 km, which is considered a safe distance to avoid future interference with active GEO spacecraft. The change in velocity that is required to raise the orbit altitude by 300 km is 11 meter/sec, and the required propellant corresponds to that necessary for three months of station keeping. This means spacecraft operators have to stop operations three months before the spacecraft runs out of fuel and give up considerable revenue in order to reorbit their spacecraft. However, today, this is the only possibility for preserving the unique resource of the geostationary ring.

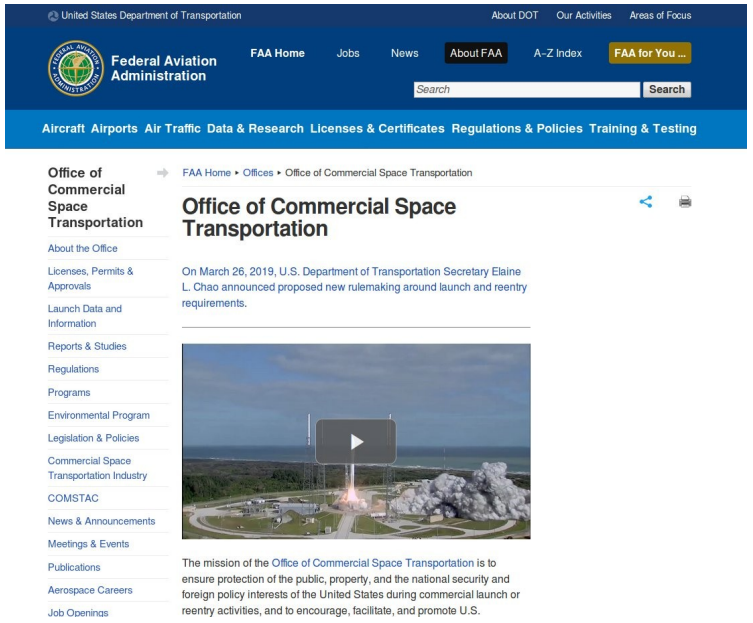
Low orbit recommendations:

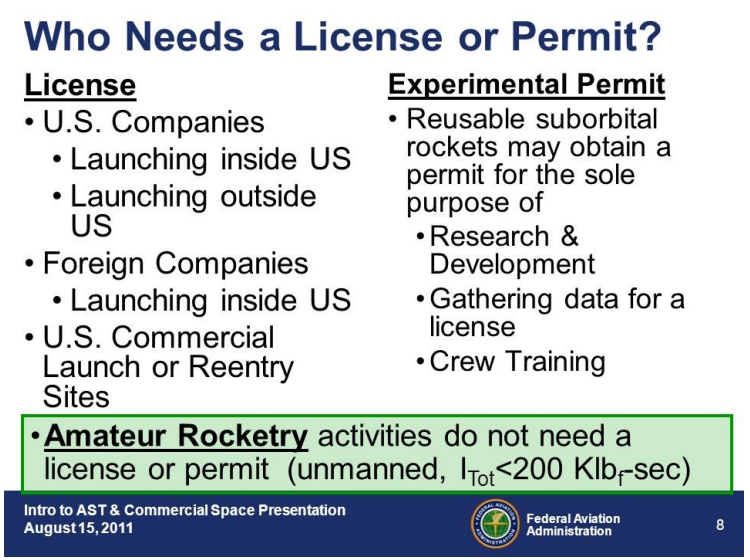
Sats should reenter within 25 years of end of mission

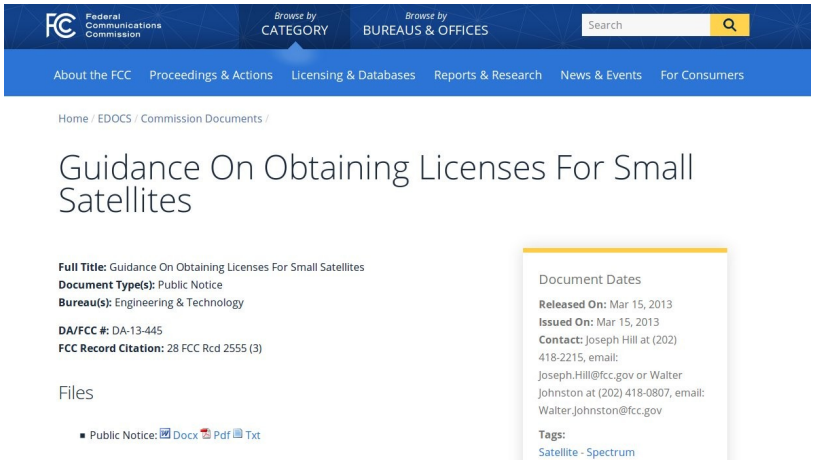


Outer Space Treaty says all space activities managed by governments

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







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.

```
UNCLAS
QQQQ
<> CONJUNCTION SUMMARY MESSAGE FOR: SATELLITE A
<> REAL
<> MESSAGE CREATION TIME: 2010 071 (12 MAR) 22:31:12.000 CENTER: JSpOC
<> MESSAGE VERSION: V2.0
<>
<> **********************************************************************
<> RELATIVE DATA:
<> TIME OF CLOSEST APPROACH (UTC): 2010 072 (13 MAR) 22:37:52.618
<> MISS DISTANCE (M):      715
<> RELATIVE SPEED (M/S): 14762
<> CLOSEST APP. REL. POSITION (M):          27.4       -70.2       711.8
<> CLOSEST APP. REL. VELOCITY (M/S):        -7.2    -14692.0     -1437.2
<>
<> **********************************************************************
<> ASSET: 12345                                  INT. DES.: 1997-030E
<> COMMON NAME: SATELLITE A
<> TIME OF LAST ACCEPTED OB: <6 HOURS FROM MESSAGE CREATION TIME
<> LUPI/DC SPAN USED (DAYS):   7.88/  5.50  RESIDUAL ACCPT:  97.8 %
<> NUM OBS AVAIL/USED: 592/ 418
<> APOGEE (KM):   779  PERIGEE (KM):   765  INCLINATION (DEG):  86.4
<> RADAR CROSS SECTION (SCALED): LARGE (>1m sq)  WEIGHTED RMS: 0.864
<> BALLISTIC COEFFICIENT (M2/KG):   0.045663
<> SOLAR RADIATION PRESSURE COEFFICIENT (M2/KG):   0.000000
<> ENERGY DISSIPATION RATE (W/KG):  4.54570E-05
<> GEOPOTENTIAL: EGM-96 36Z,36T  DRAG: JACCHIA70DCA  LUNAR/SOLAR:  ON
<> SOLAR RAD PRESS: OFF  SOLID EARTH TIDES: OFF  IN-TRACK THRUST: OFF
<> ----------------------------------------------------------------------
<> ASSET TDR POSITION (M):    2570098.594   2244663.456   6281494.300
<> ASSET TDR VELOCITY (M/S):  4418.768701   4833.542969  -3526.781960
<> ----------------------------------------------------------------------
<>
<> **********************************************************************
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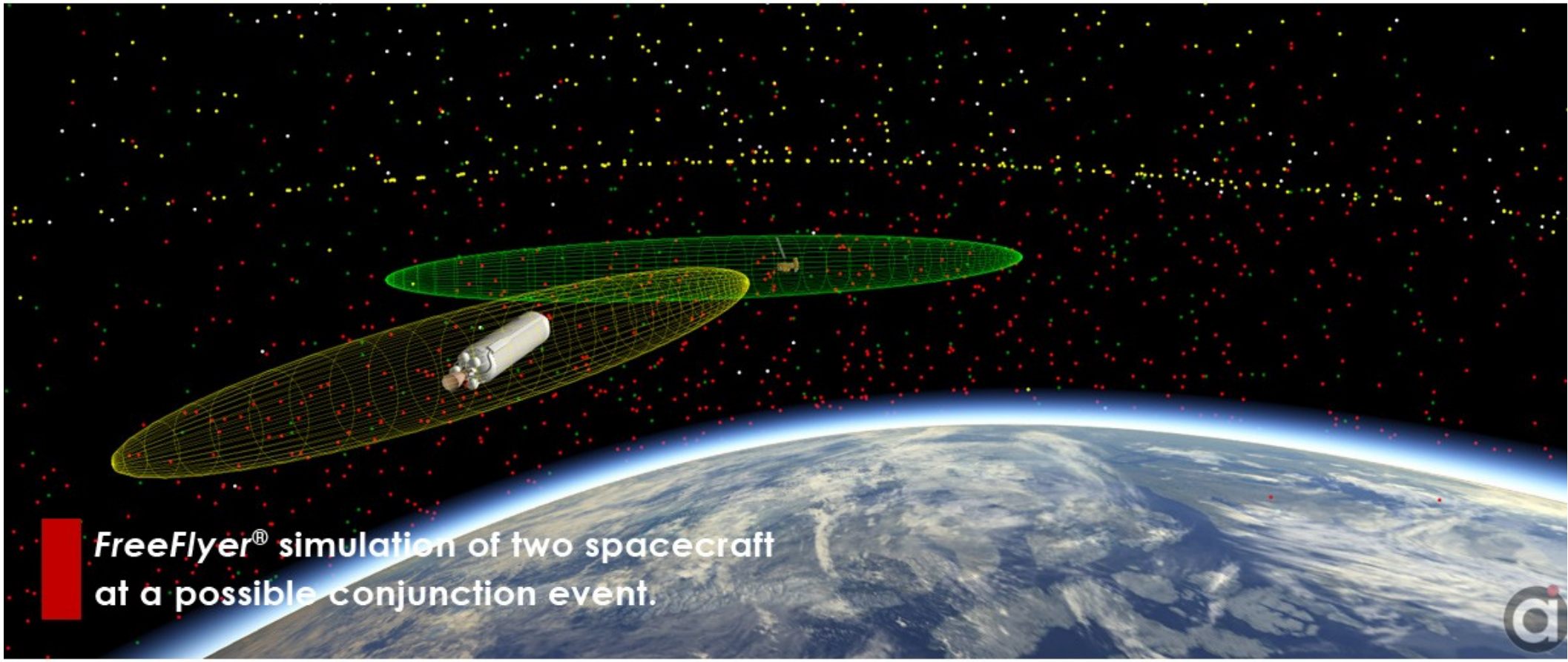
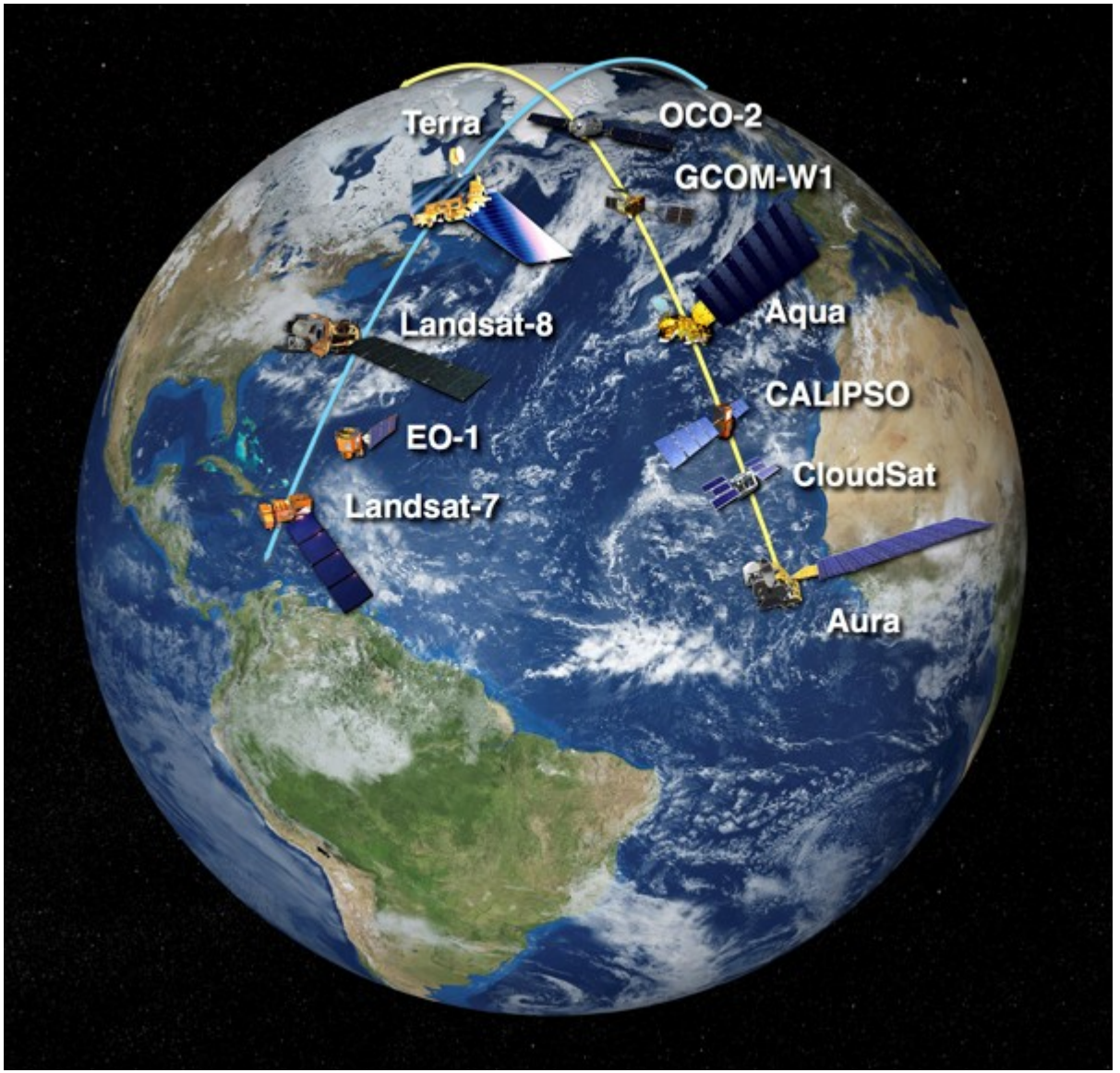
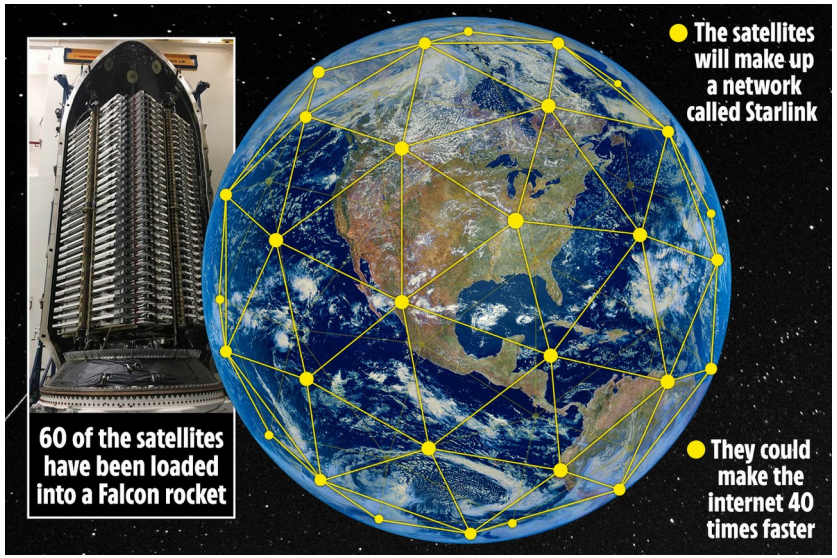


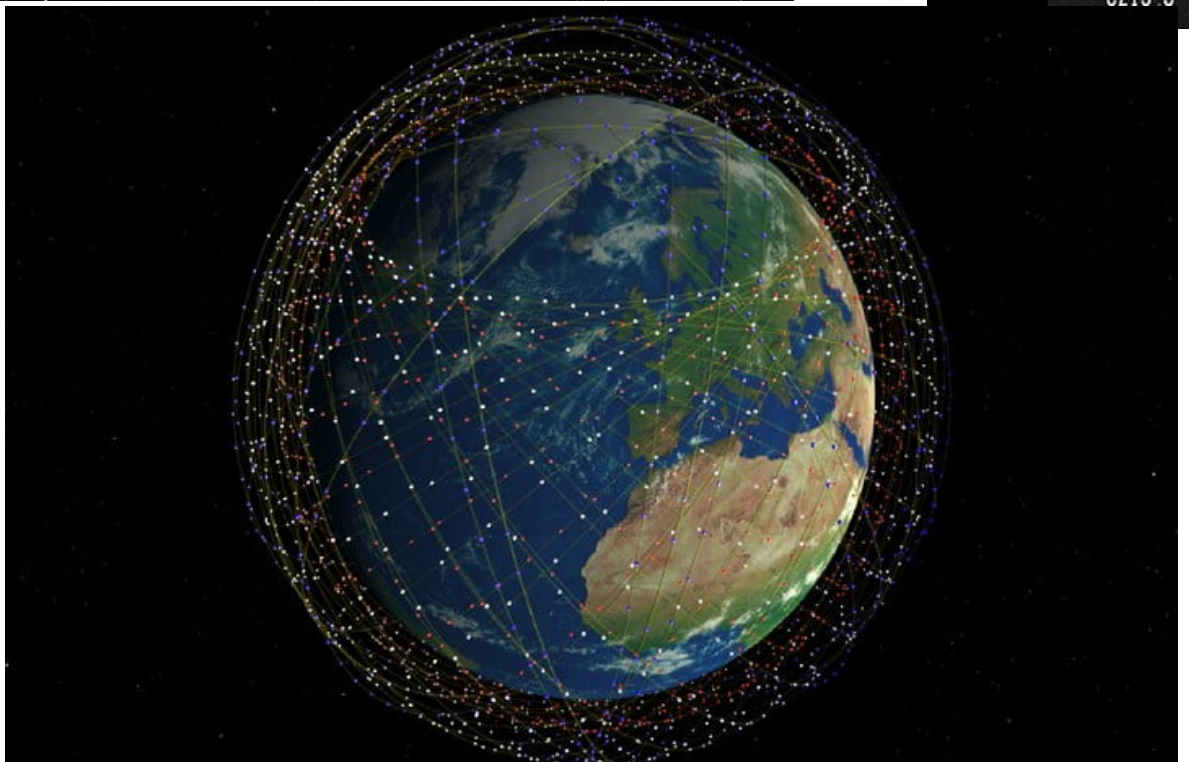
FreeFlyer® simulation of two spacecraft at a possible conjunction event.


Terra
OCO-2
GCOM-W1
Aqua
Landsat-8
CALIPSO
EO-1
CloudSat
Landsat-7
Aura

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.