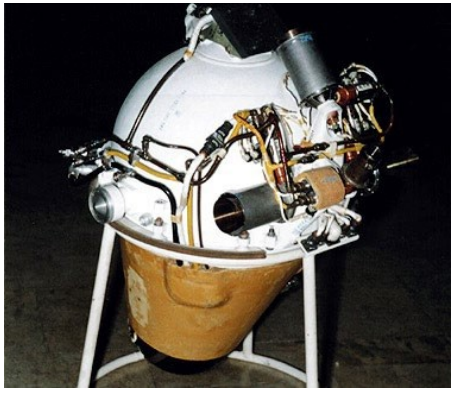
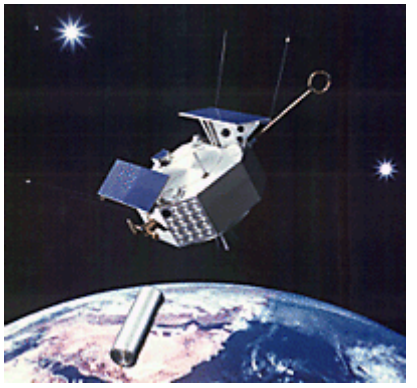
Orbital Debris

Jonathan McDowell

Fairings

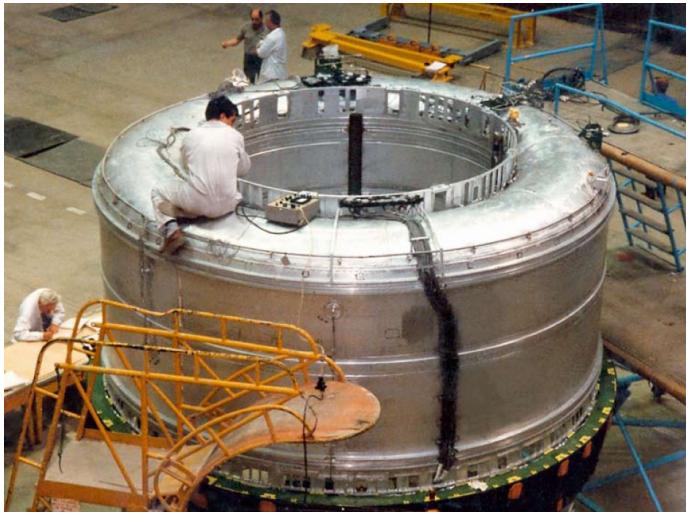
Ullage motors





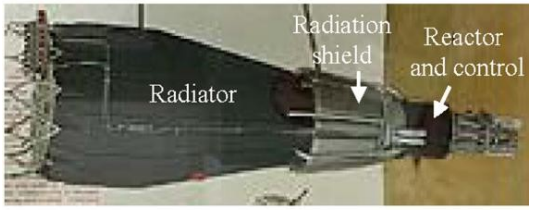
Deployment canisters

Despin devices



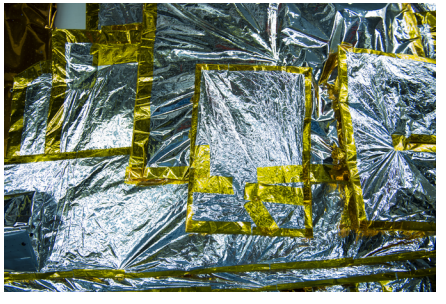
Propellant tanks

Insulation blankets

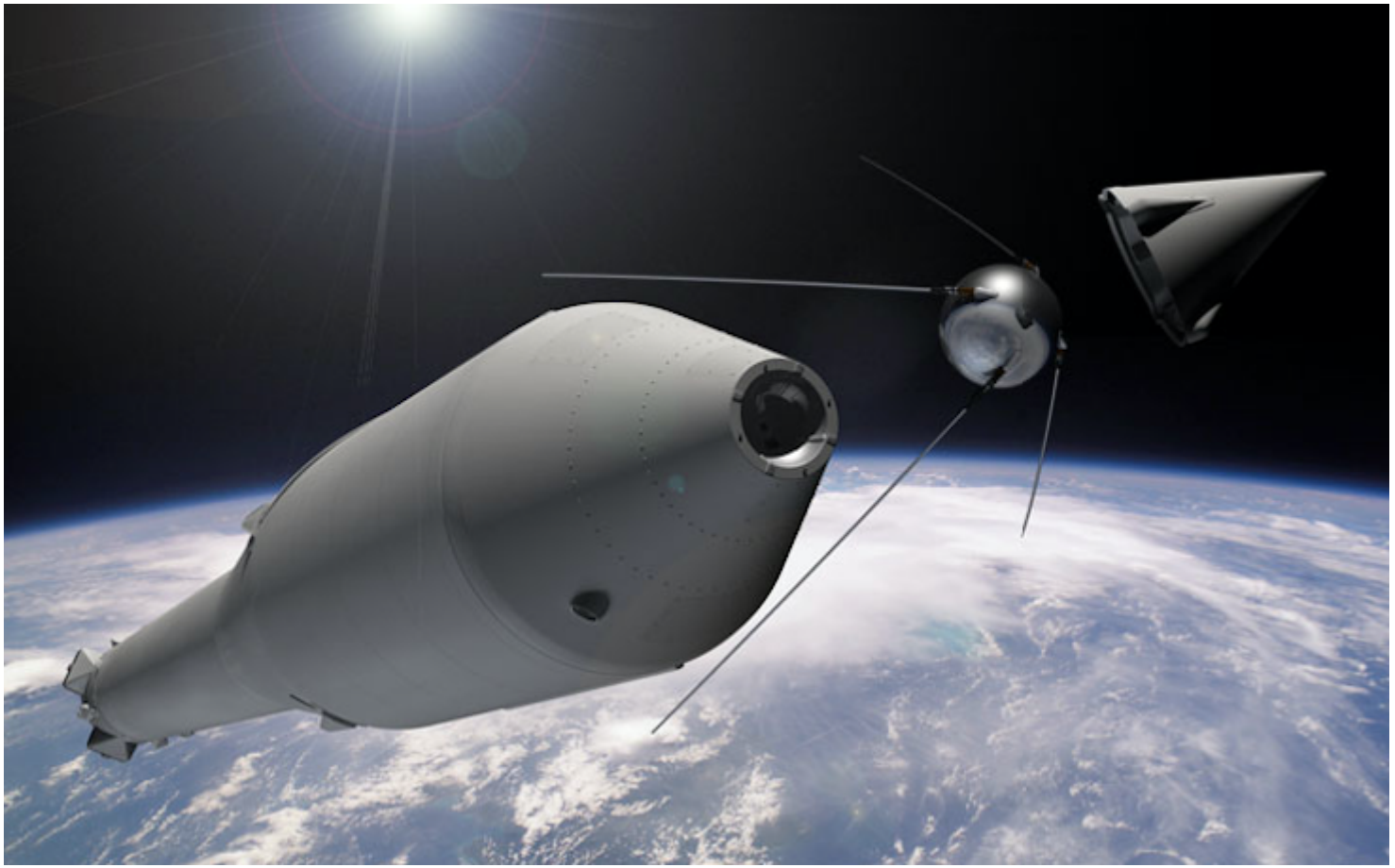


Nuclear reactors (!)

Dual-launch adapters



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



Credit: A. Zak/Pop.Mech.

October 1957: The first satellite – and the first two pieces of orbital debris (empty R-7 core stage, and nose cone)

Oldest piece of debris still in orbit: dead satellite Vanguard I, from 1958

CATALOGED OBJECTS IN EARTH ORBIT

Total cataloged objects in orbit 23000
Catalog fairly complete for objects > 10 cm in Low Earth Orbit
VERY INCOMPLETE at higher altitudes (e.g. geostationary)

LIVE SATELLITES: 4500 (+- 100)
[1600 Starlinks, 1500 other maneuverable, 1400 non-maneuverable]

TYPES OF ORBITAL DEBRIS:

1) DEAD SATELLITES 3000 cataloged objects

2) OLD ROCKET STAGES 1900

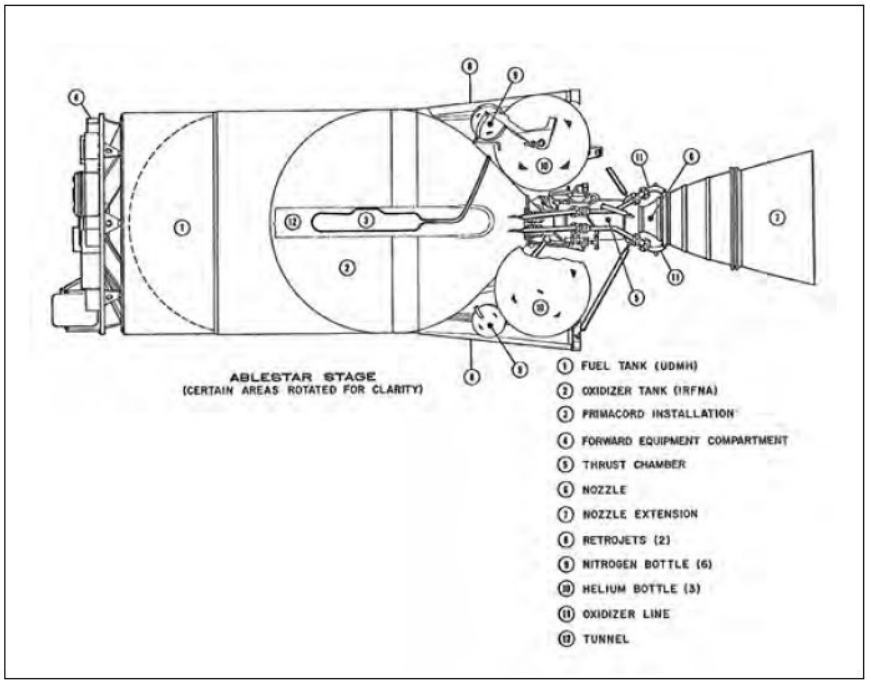
3) LITTERING 1700
(interstage adapters, optics covers, fairings)

4) DISINTEGRATION DEBRIS 11800
(exploding rockets, antisatellite tests, collisions, etc)
Uncataloged debris: 0.5 million > 1 cm, 0.1-1 billion > 1 mm?

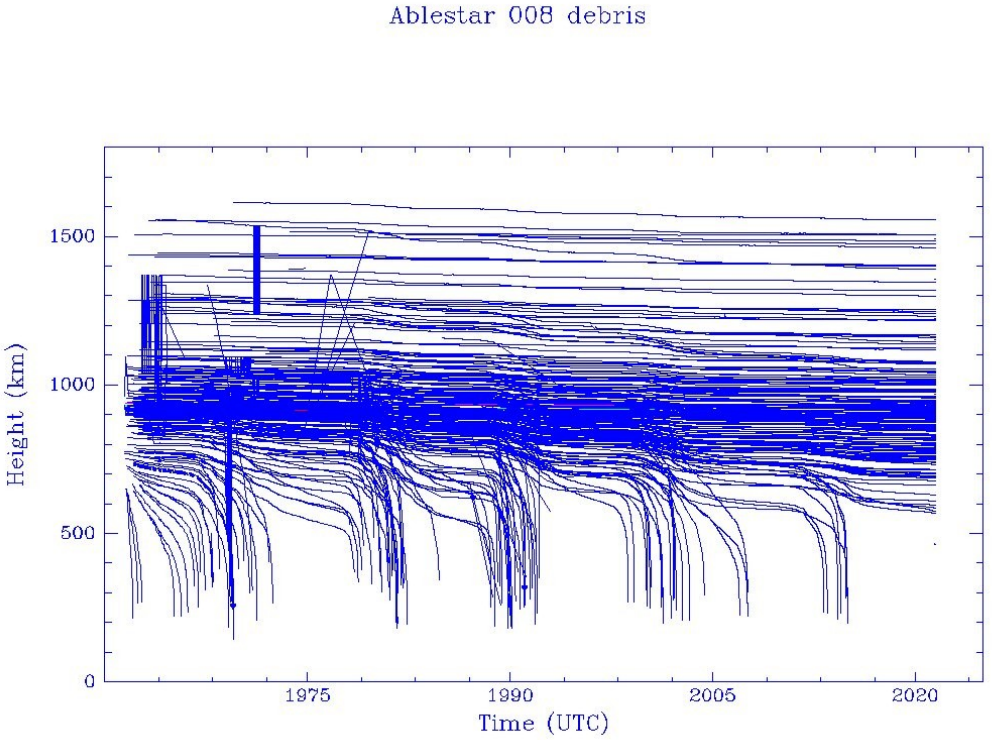
FIRST MAJOR DEBRIS EVENT: 29 JUNE 1961

EXPLOSION OF ABLESTAR 008 ROCKET STAGE INTO 300+ PIECES

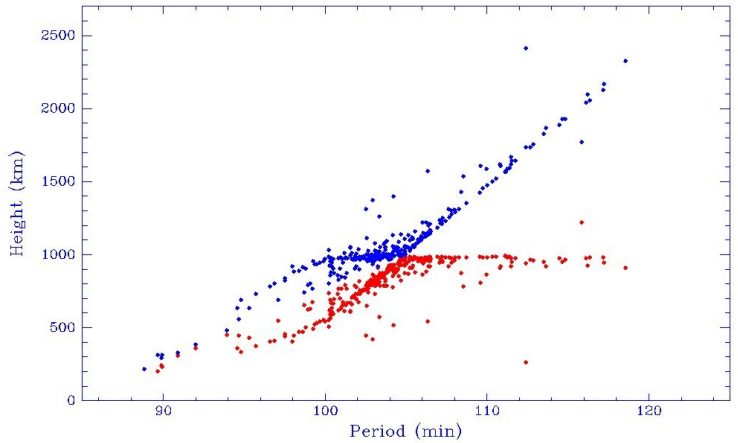
187 STILL IN ORBIT

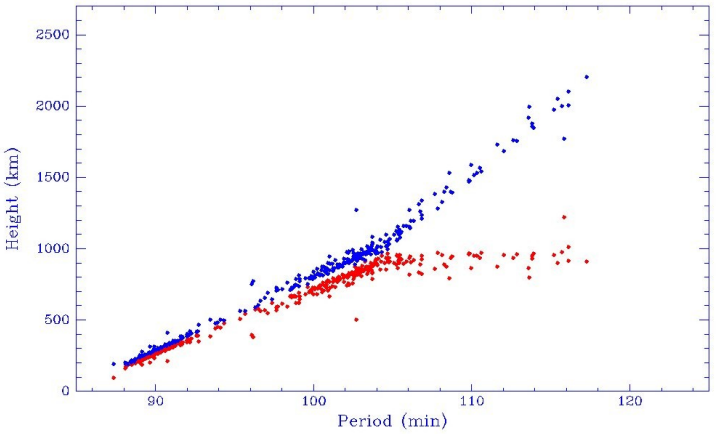


AB008 Gabbard Diagram – Jan 1964



AB008 Gabbard Diagram – Jan 2021





MILESTONES IN ORBITAL DEBRIS HISTORY

Jun 1961 - First upper stage disintegration

May 1963 - Project West Ford

Nov 1968 - First Antisatellite test (Kosmos-248/249/252)

Dec 1973 - First Delta stage breakup: leads to new designs allowing propellant depeletion

Jan 1978 - Kosmos-954 (US-A 325) nuclear reactor reentry over Canada

Jul 1979 - Skylab reentry over Australia – leads to design for controlled deorbit of large payloads

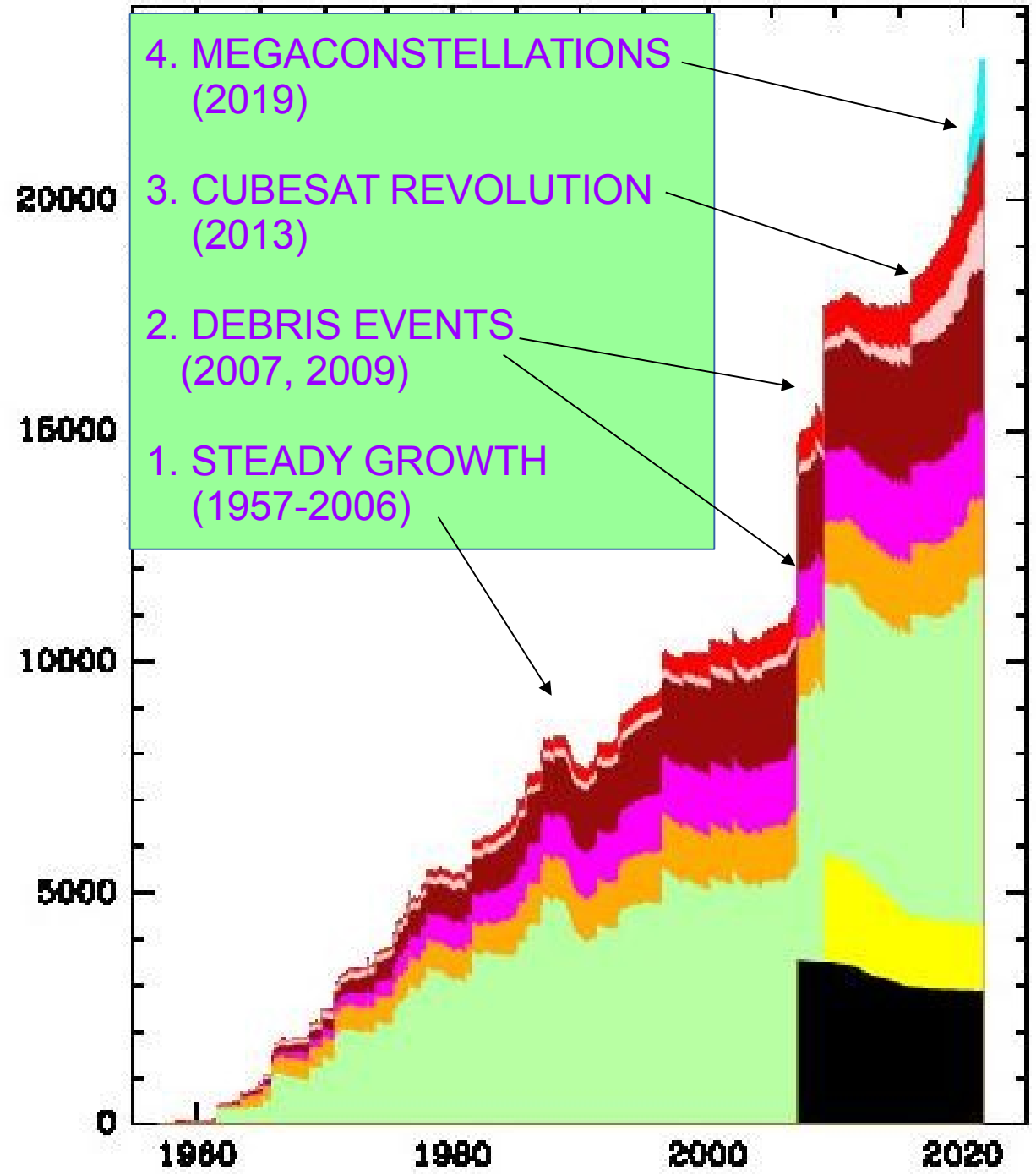
Jul 1981 - First major battery explosion (Kosmos-1275 Parus navsat)

Feb 1991 – First major SOZ breakup in high orbit

Jan 2007 - Chinese antisatellite test (largest long lived deliberate debris event)

Feb 2009 - Iridium 33/Kosmos-2251 collision

The Growth of Space Junk



STARLINK
LIVE SATS, PROP
LIVE SATS, NO PROP
DEAD SATS
ROCKET STAGES
LITTERING
DEBRIS
IRID-COS. DEBRIS
CHINESE ASAT DEB

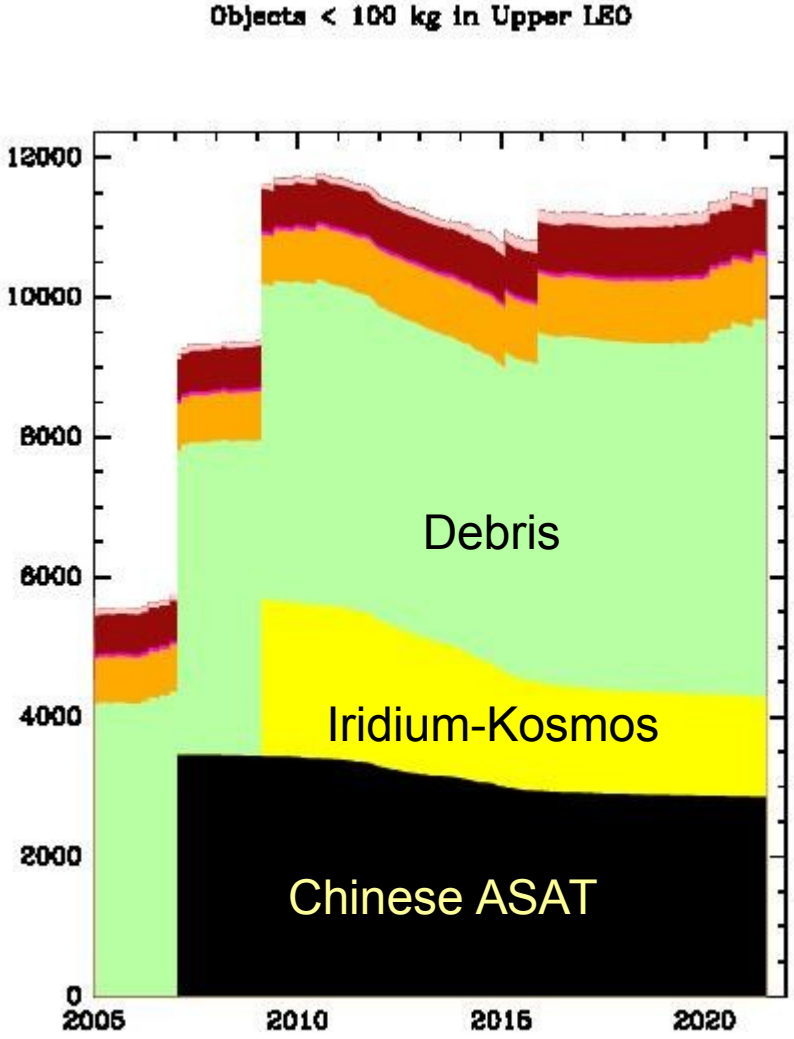
EVOLUTION OF THE CATALOGED ORBITAL POPULATION 1957-2021

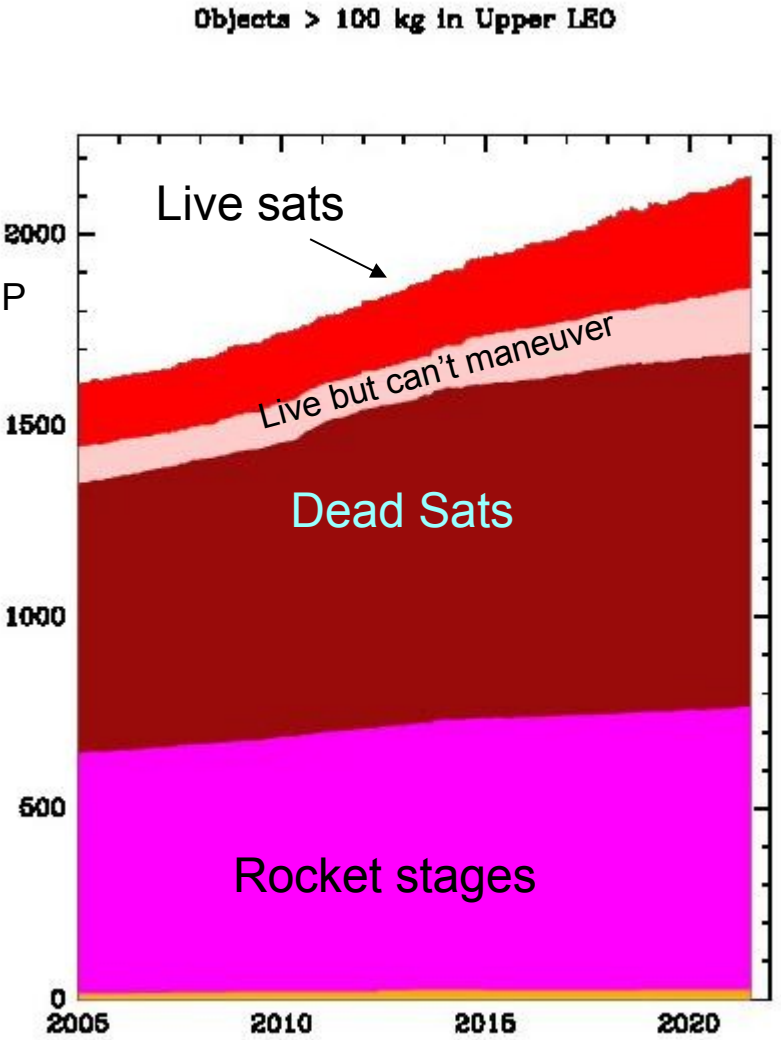
Data source: https://planet4589.org/space/gcat

TRENDS IN UPPER LEO (600 -2000 km):

DOMINATED BY DEBRIS; LIVE SATS (RED) SLOWLY INCREASING

TOTAL POPULATION STABLE SINCE 2007-2009 JUMP



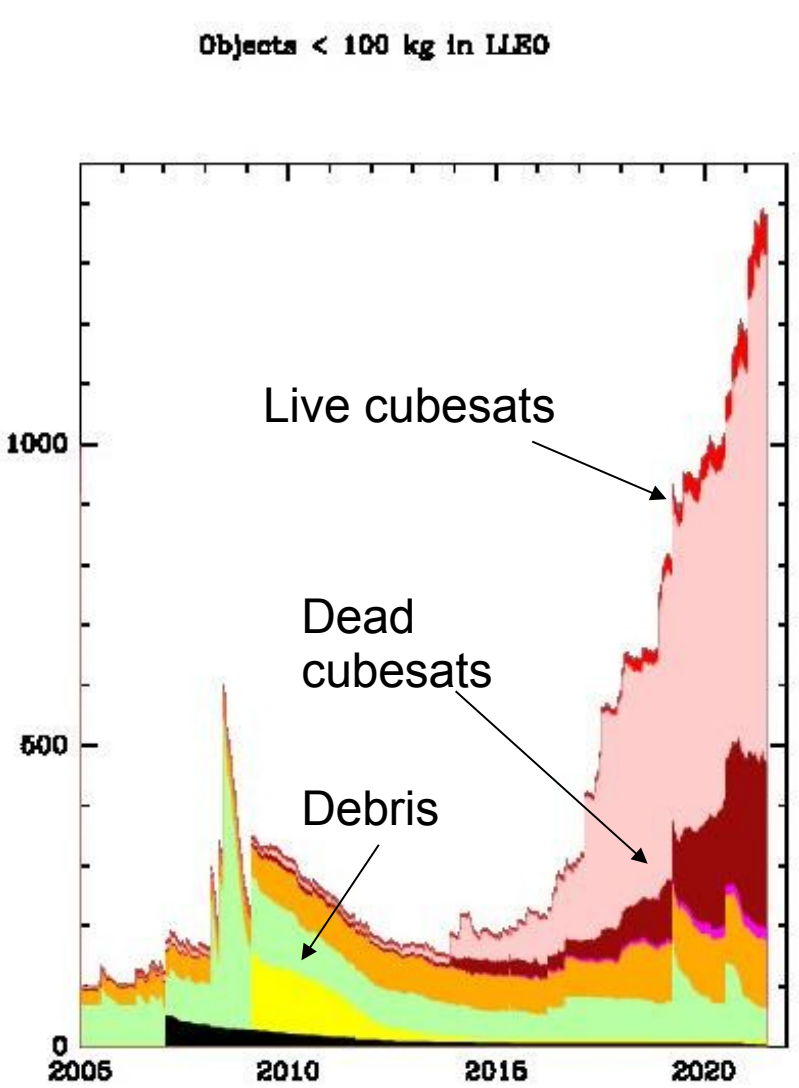


SMALL THINGS:
MOSTLY DEBRIS

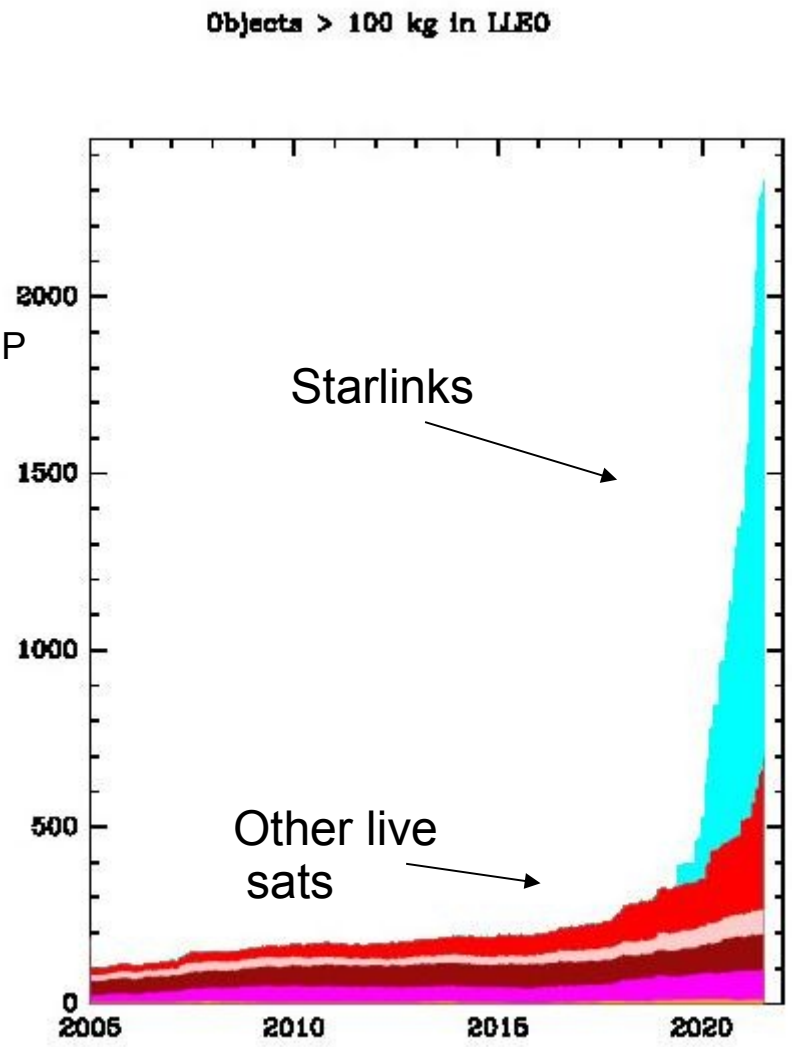
BIG THINGS:
MOSTLY DEAD SATS AND ROCKETS

TRENDS IN LOWER LEO (200-600 km):

RAPID CHANGE IN PAST 5 YEARS
NOW DOMINATED BY LIVE SATS



STARLINK
LIVE SATS/PROP
LIVE SATS/NO PROP
DEAD SATS
ROCKET STAGES
LITTER
DEBRIS
IRID-COS DEBRIS
CHINA ASAT DEB.



SMALL THINGS:
MOSTLY LIVE CUBESATS
WITH NO PROPULSION

BIG THINGS:
OVERWHELMINGLY STARLINKS

SUMMARY

ORBITAL DEBRIS ENDEMIC (BUT GROWING) SINCE SPUTNIK

MASS DOMINATED BY DEAD SATS AND ROCKETS

NUMBER DOMINATED BY DISINTEGRATION DEBRIS

UPPER LEO (>600 km): STABLE/SLOW GROWTH

LOWER LEO (<600 km): TRANSFORMATIVE CHANGE IN PAST 5 YEARS

HIGH ORBIT: WORRYING LACK OF DATA

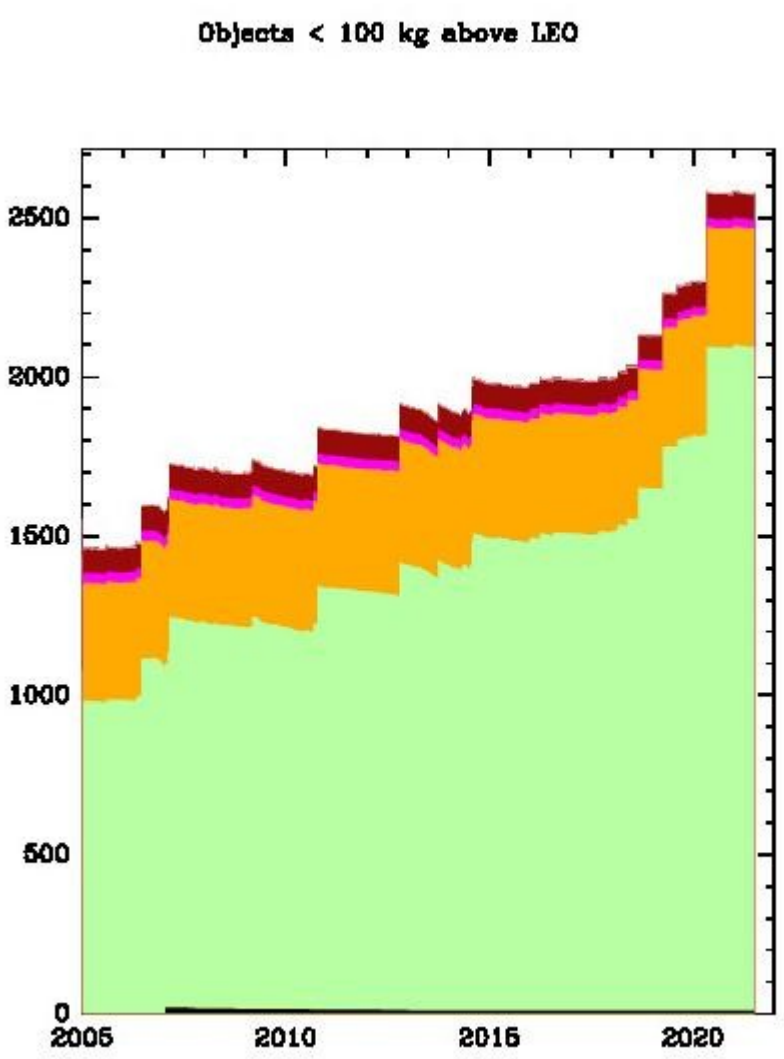
LARGE UNCONTROLLED REENTRIES – MOSTLY AVOIDED EXCEPT CZ-5B

WHAT IS THE CARRYING CAPACITY OF LEO?

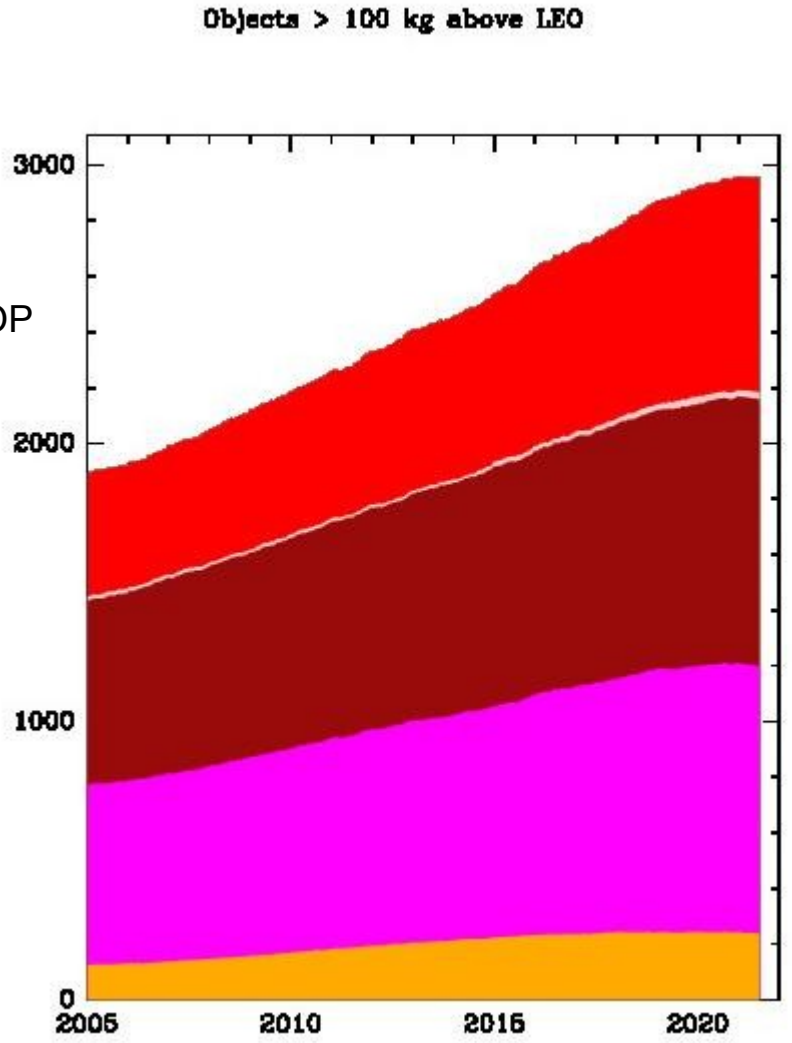
BACKUP SLIDES

OBJECTS IN HIGH ORBIT (MEO, GTO, GEO)

MODERATE GROWTH



STARLINK
LIVE SATS/PROP
LIVE SATS/NO PROP
DEAD SATS
ROCKET STAGES
LITTER
DEBRIS
IRID-COS DEBRIS
CHINA ASAT DEB.



SMALL THINGS:
STEPS FROM DEBRIS EVENTS
HIGHLY INCOMPLETE?

BIG THINGS:
ALL SATS HAVE PROPULSION
MORE DEBRIS THAN LIVE SATS

Two threats:

- in-orbit collisions: danger to space traffic

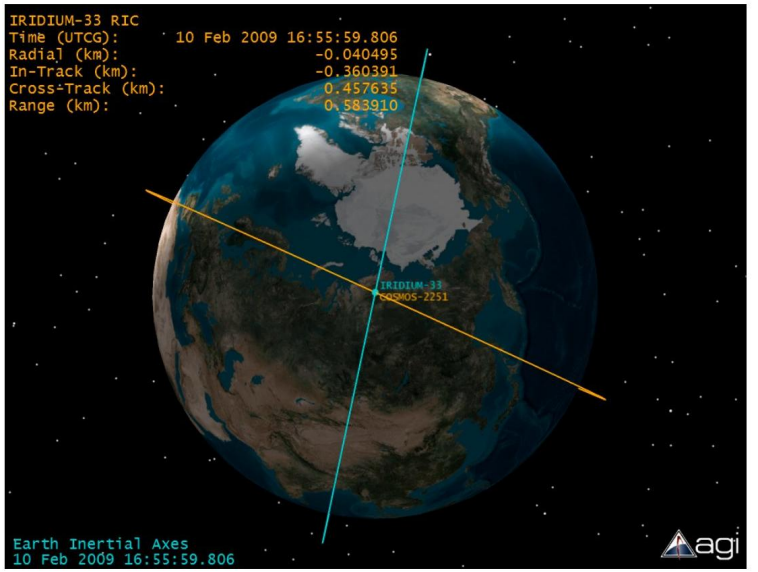
  [Threat real and increasing]

- uncontrolled reentry: danger to property and people on Earth surface

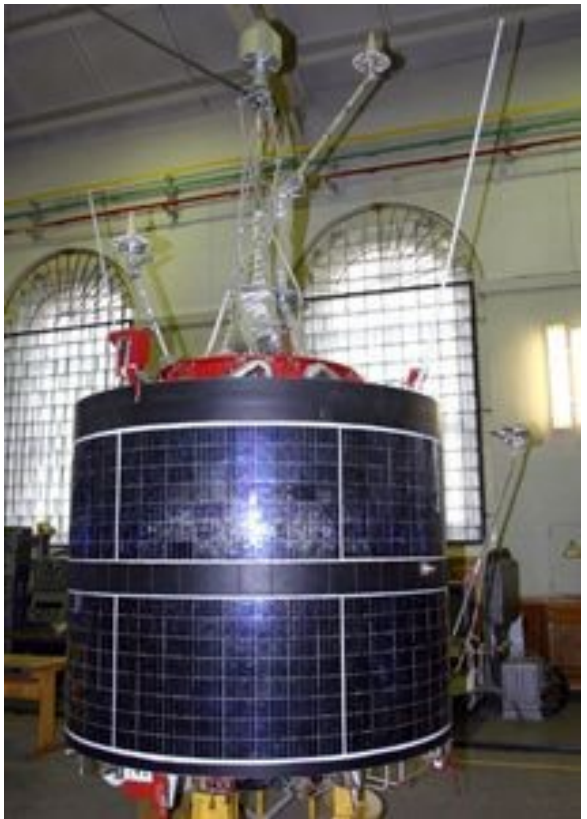
  [Threat from LARGE uncontrolled reentries only
  Since Skylab, these have mostly been avoided
  Mostly not a concern - BUT: Chang Zheng 5B]

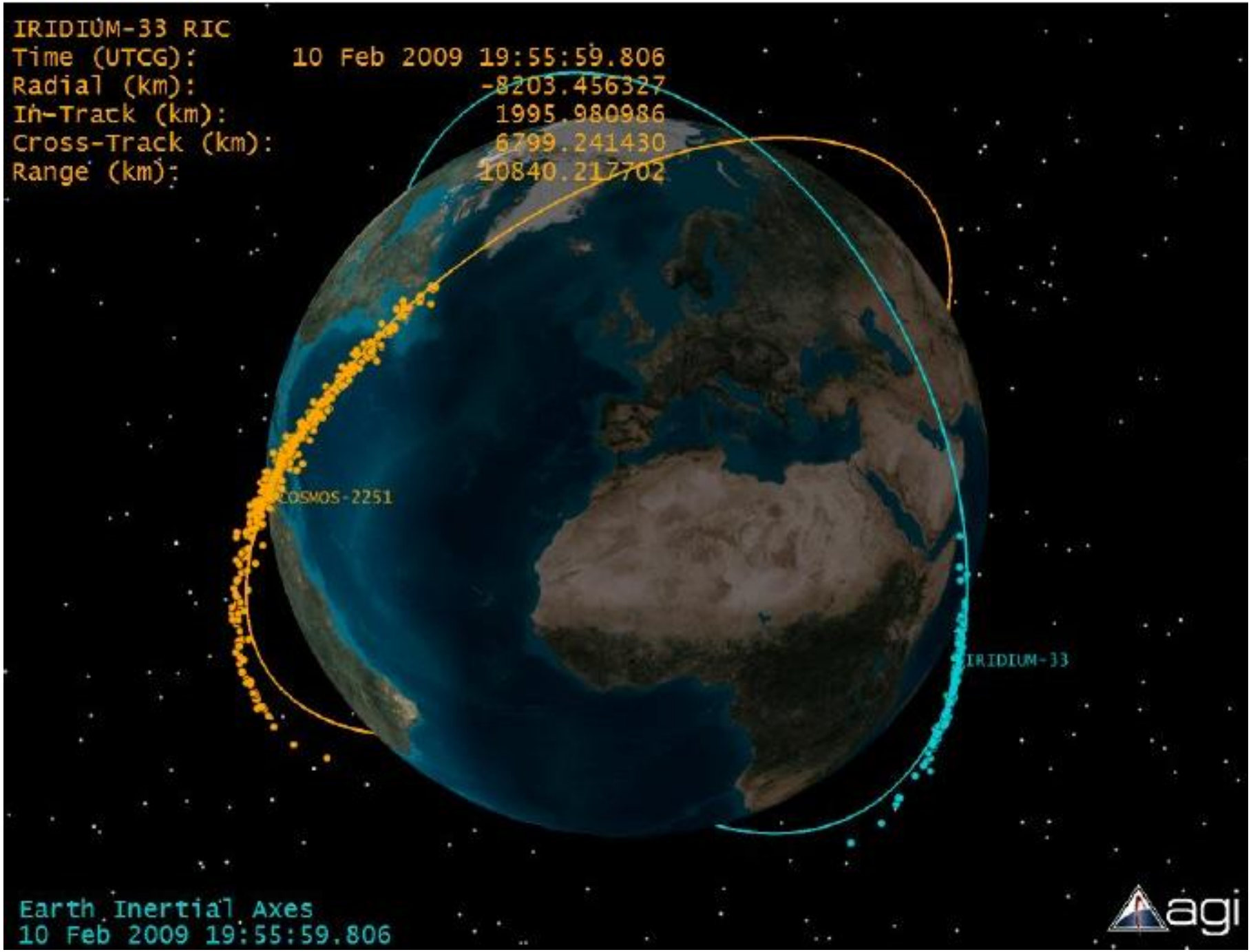
Iridium 33/Kosmos-2251 collision - 2009 Feb 10

Center of mass enegy 20 GJ
Thousands of cataloged debris

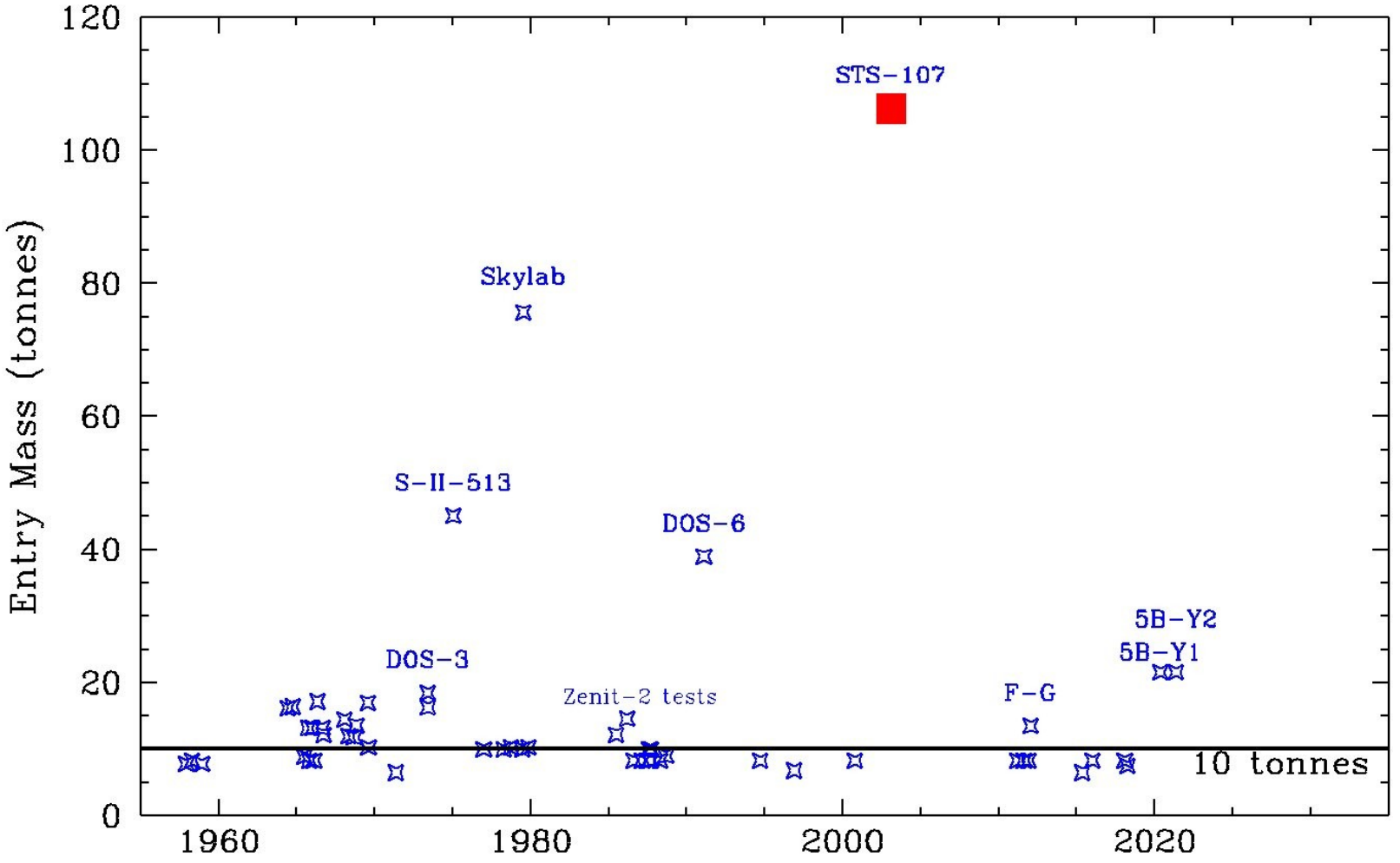


(Kelso 2009)




IRIDIUM-33 RIC
Time (UTCG): 10 Feb 2009 19:55:59.806
Radial (km): -8203.456327
In-Track (km): 1995.980986
Cross-Track (km): 6799.241430
Range (km): 10840.217702
COSMOS-2251
IRIDIUM-33
Earth Inertial Axes
10 Feb 2009 19:55:59.806
agi

(Kelso 2009)



Since mid 1980s
No deliberate uncontrolled reentries above 10 tonnes except for CZ5B

DOS-6 = Salyut-7 failed, intended controlled disposal did not occur

Fobos-Grunt Mars probe failed to leave orbit, reentered

STS-107 Columbia shown for comparison

on

try.

-	OV-102 Columbia (STS-107)	106.4	2003 Feb 1	Texas/Louisiana		
1	Skylab space station	75.7	1979 Jul 11	Australia		
2	Saturn S-II-13 (Skylab rocket)	45.1	1975 Jan 11	Atlantic Ocean (w of Madeira)	34N	19W
3	DOS 6 space station/TKS-M module (Salyut-7/Kosmos-1686)	39.0?	1991 Feb 7	Argentina	35S	64W
4	CZ-5B-Y1 core stage	21.6	2020 May 11	Cote d'Ivoire		
5	CZ-5B-Y2 core stage	21.3	2021 May 9	Indian Ocean	72E	3N
6	DOS 3 space station (Kosmos-557)	18.5	1973 May 22	Indian Ocean		
7	Saturn SA-5 rocket/Jupiter nosecone	17.2	1966 Apr 30	Brazil		
8	N-6 No. 1 satellite (Proton-4)	17.0	1969 Jul 24	Unknown		
9	Apollo BP-15/Saturn SA-7	16.4	1964 Sep 22	Indian Ocean		
10	Almaz-1 space station (Salyut-2)	16.3	1973 May 28	Pacific Ocean near Fiji		
11	Apollo BP-13/Saturn SA-6	16.2	1964 Jun 1	Pacific Ocean	14N	179E
12	Tselina-2 No. 3L/Zenit-2 11S772 rocket (Kosmos-1714)	14.6	1986 Feb 27	Pacific Ocean?		

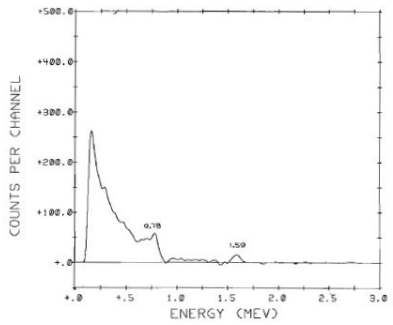


Figure 24.3 The spectrum above is the cumulative addition of individual spectra recorded over the anomaly of Figure 24.4, with local background either side subtracted. The small peak at 1.59 meV is from the fission product ^{140}La and confirmed the evidence of Figure 24.4. The single overflight by the spectrometer thus provided conclusive proof of the presence and the nature of the radioactive debris on the lake.

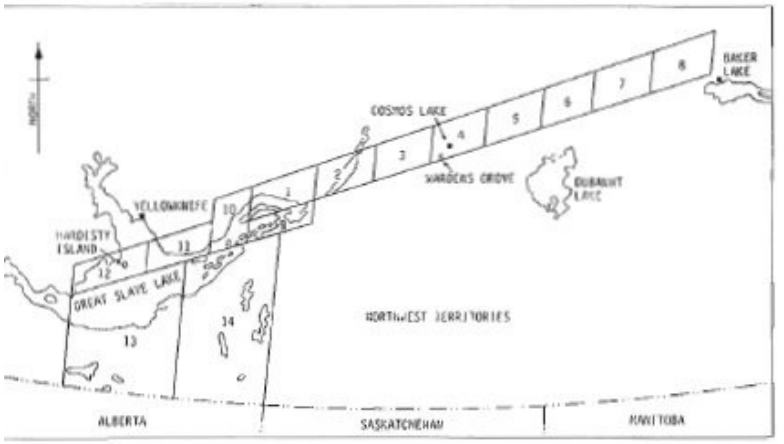
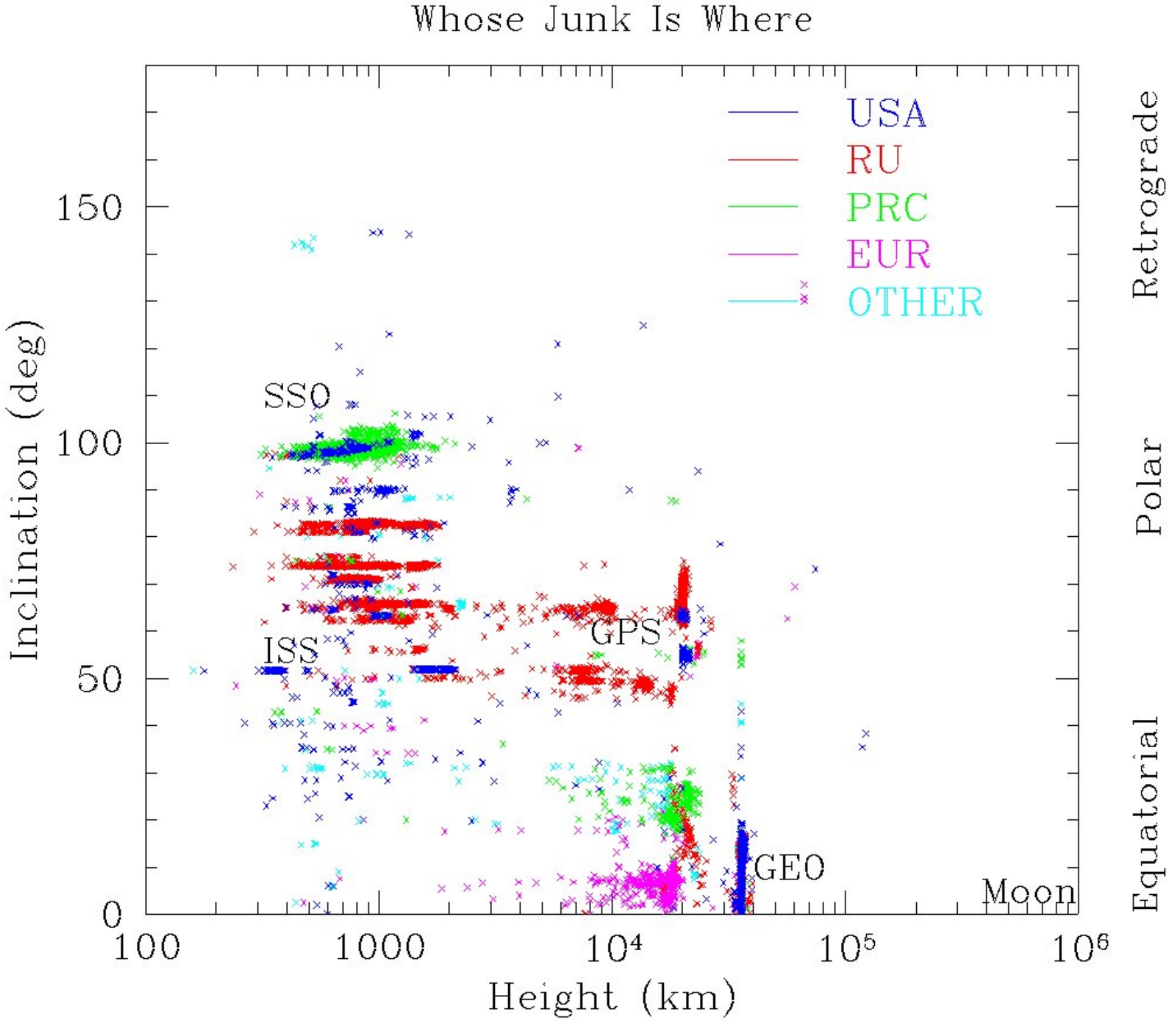
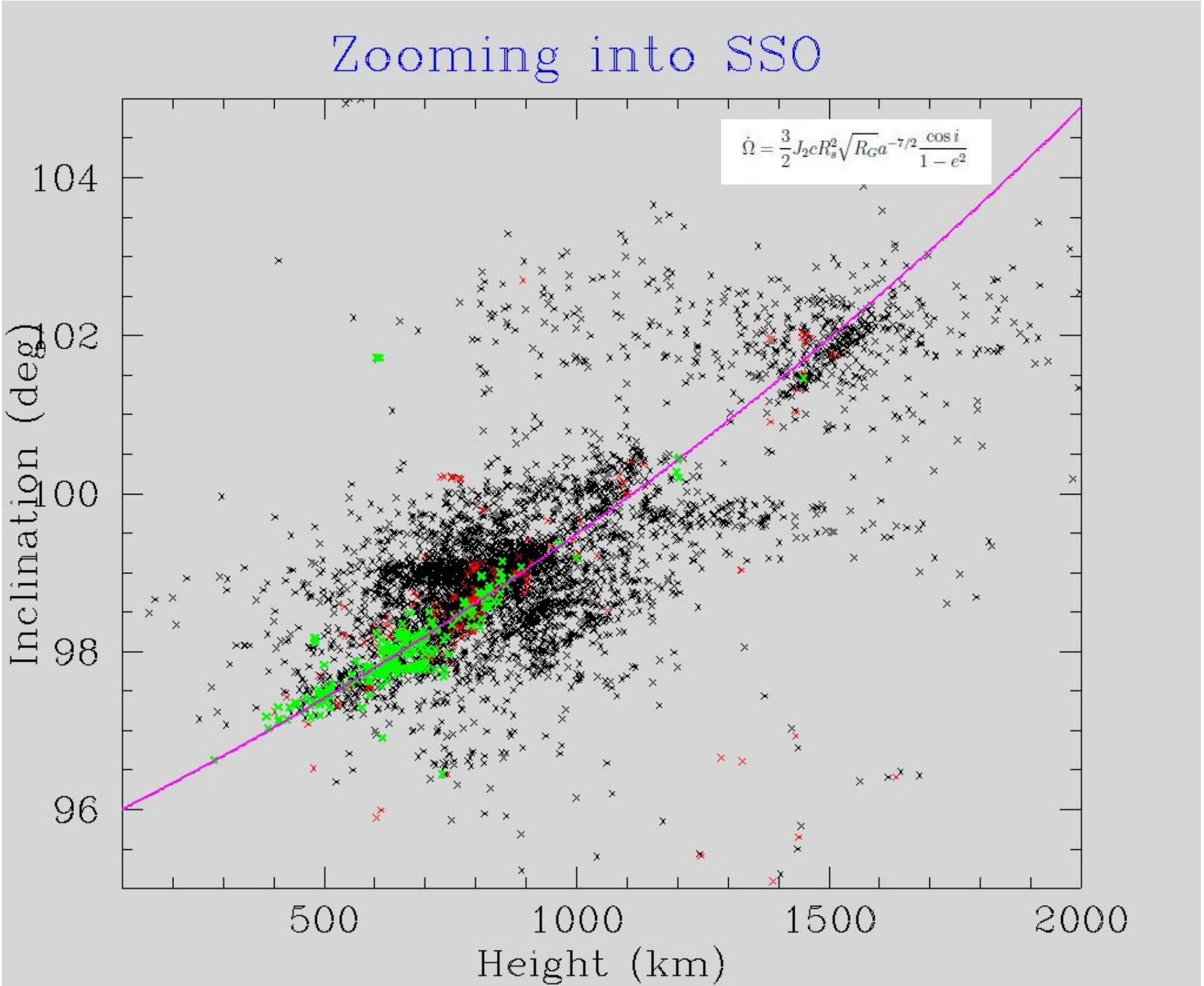
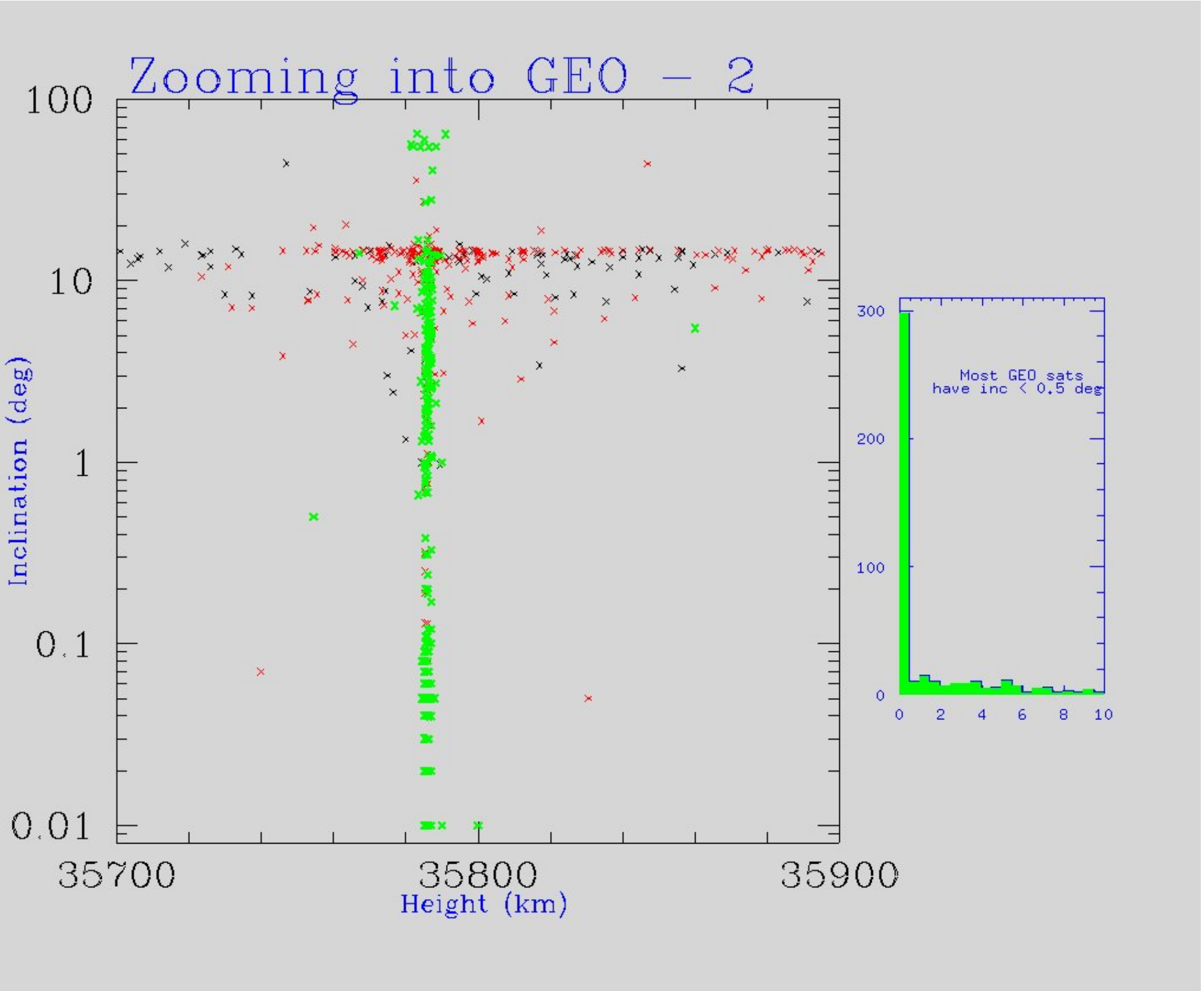


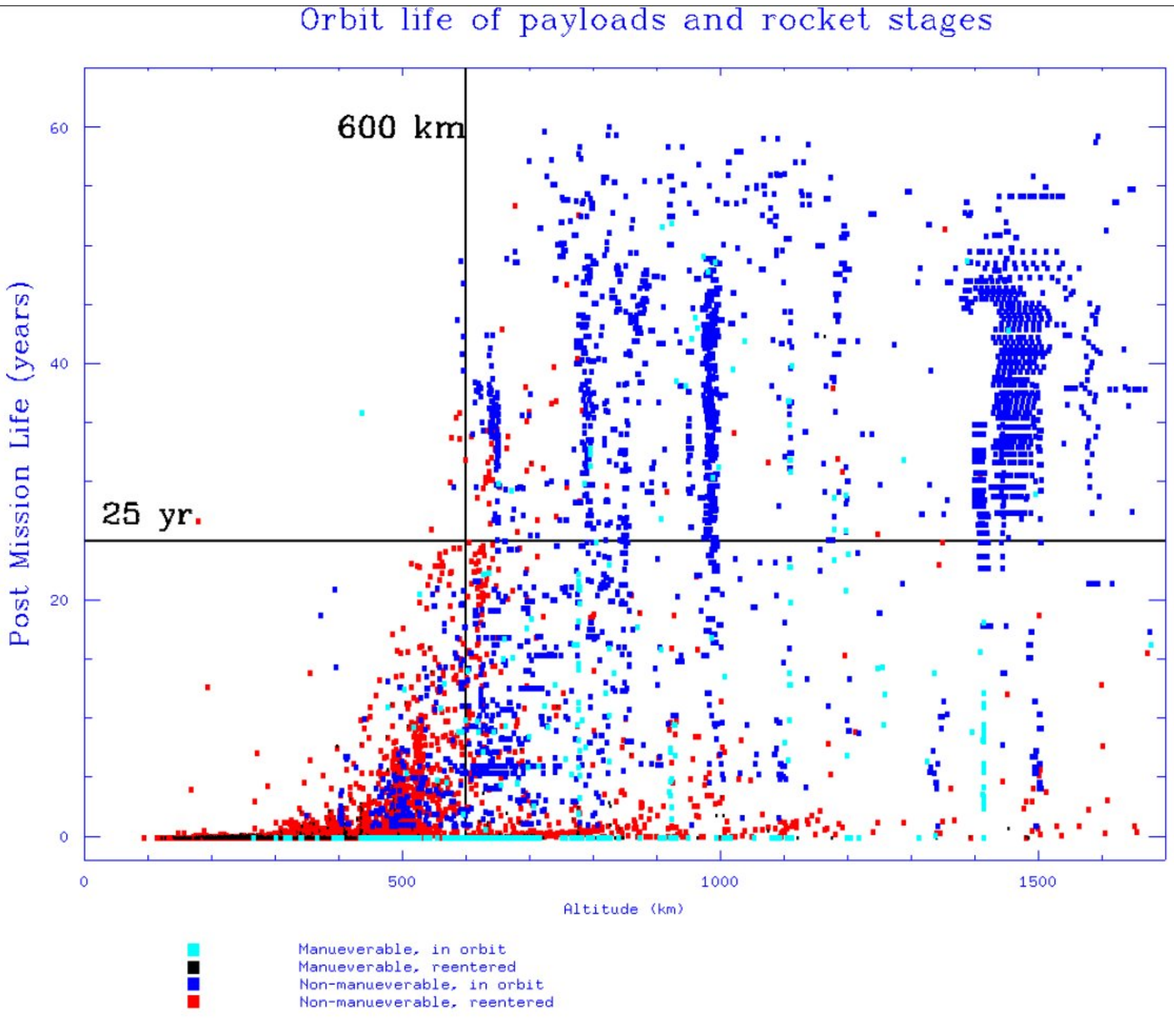
Figure 24.1 The impact trajectory of the satellite stretches from Great Slave Lake northeast toward Baker Lake. Sectors 13 and 14 were established with wind borne material in mind.

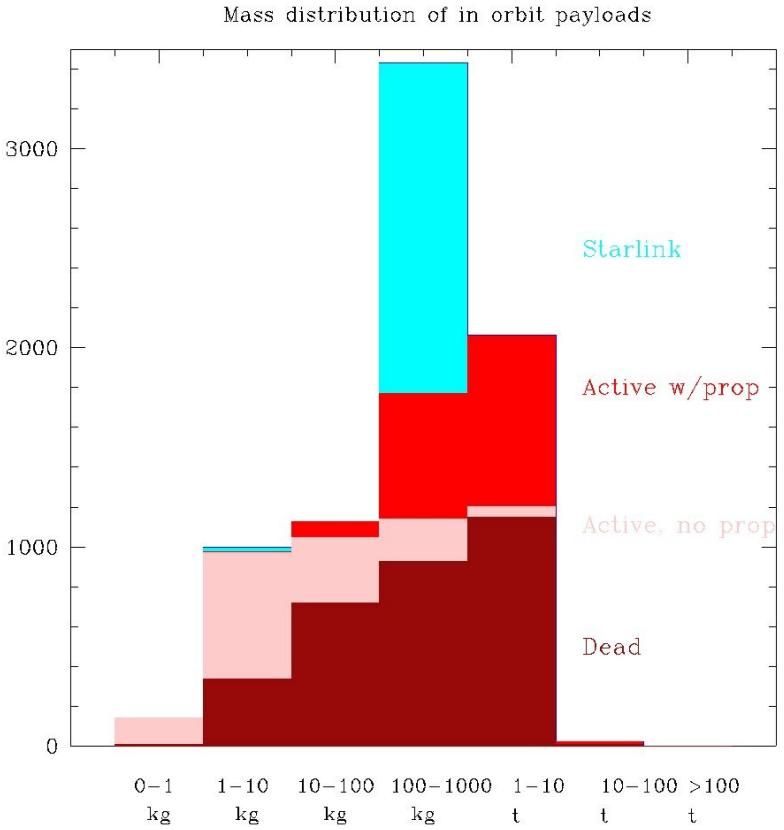
Kosmos-954:
Nuclear reactor falls on Canada, Jan 1978

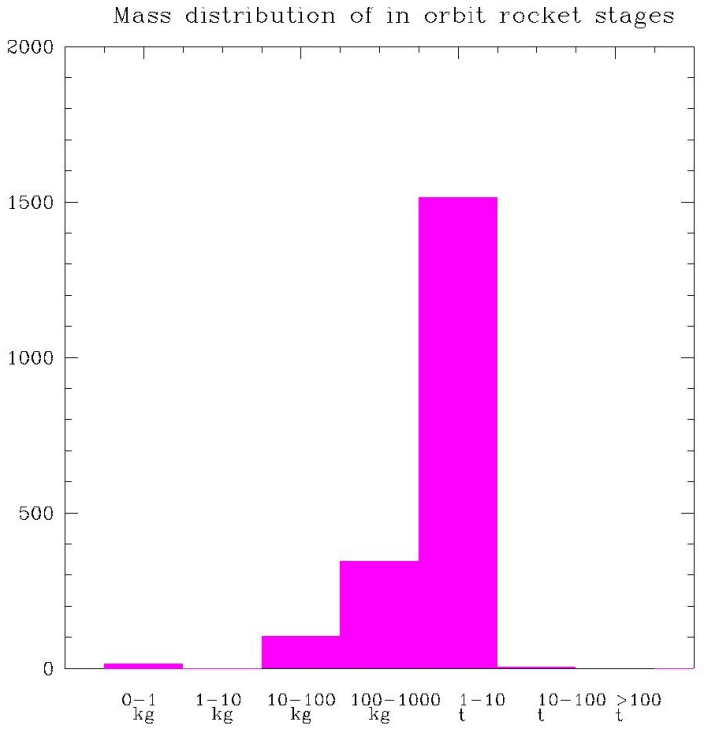

Whose Junk Is Where
USA
RU
PRC
EUR
OTHER
SSO
ISS
GPS
GEO
Moon
Retrograde
Polar
Equatorial
Inclination (deg)
0
50
100
150
100
1000
10^4
10^5
10^6
Height (km)

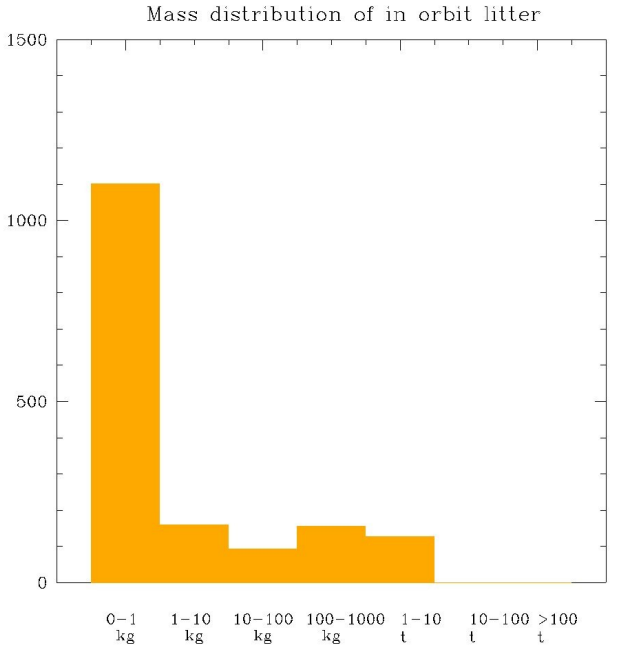

Zooming into SSO
$\dot{\Omega} = \frac{3}{2} J_2 c R_s^2 \sqrt{R_G} a^{-7/2} \frac{\cos i}{1-e^2}$
104
102
100
98
96
Inclination (deg)
500
1000
1500
2000
Height (km)


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


Orbit life of payloads and rocket stages
600 km
25 yr.
Post Mission Life (years)
60
40
20
0
0
500
1000
1500
Altitude (km)
Manueverable, in orbit
Manueverable, reentered
Non-manueverable, in orbit
Non-manueverable, reentered







Current in-orbit population:

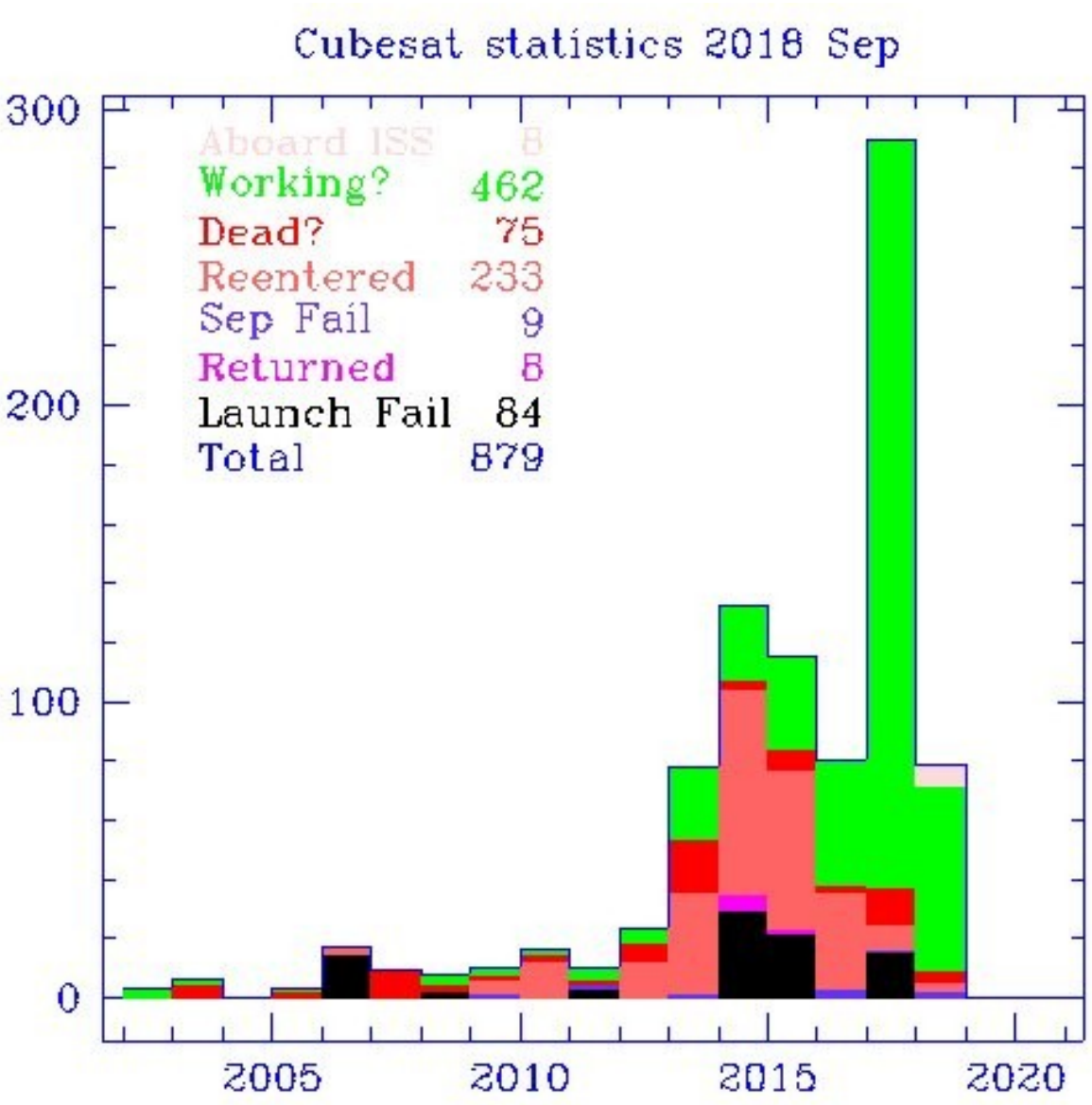
Rocket stages and maneuverable sats are big (100 kg – 10 t)

Non-maneuverable sats and litter are mostly small (less than 100 kg)

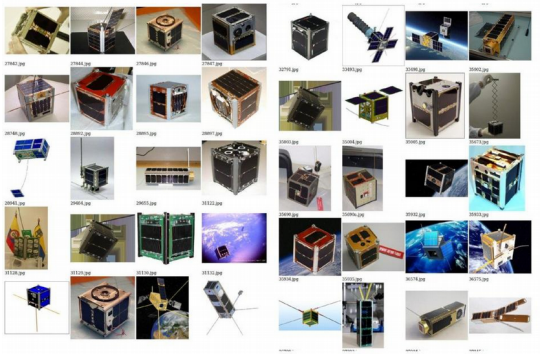
Mass of disintegration debris poorly known but mostly small

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

The Cubesat Explosion



http://planet4589.org



TOTAL 57 COUNTRIES:

USA 652
Japan 32
China 21
Germany 14
S Korea, Russia 13
Denmark 11
UK 10
Italy, Singapore 7
Canada 6
Netherlands, Spain, France,Turkey 5
Belgium,India,Australia,Israel 4
Brazil, Norway,Peru,Lithuania, S Africa 3
Switzerland,Vietnam,Ukraine,
Ecuador ,Argentina,Austria,Switzerland, Finland,
Greece, Sweden 2
Kazakhstan, Emirates, Uruguay, UAE,
Algeria, Poland, Pakistan, Colombia,
Romania, Hungary,Estonia, Bangladesh,
Bulgaria, Bhutan, Chile, Costa Rica, Czechia,
Ghana, Kenya, Mongolia, Malaysia, Nigeria,
Phillipines, Pakistan, Poland, Slovakia, Taiwan 1

Includes 33 startup commercial companies

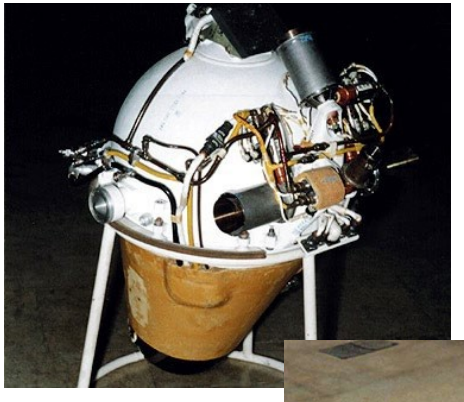
A Census of Space Debris

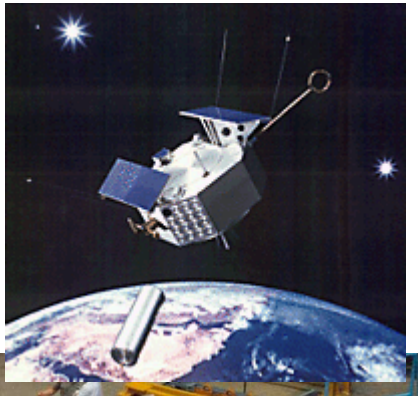
as of 12 Apr 2017

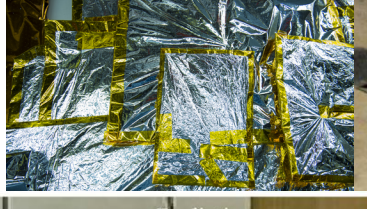
Total objects cataloged	42661	
Objects still in Earth orbit	18296	
Active payloads	1500?	
Dead payloads	2796?	
Rocket stages	1930	
Adapters, jettisoned objects	1652	
2007 Chinese ASAT debris	2855)	
2009 collision	1443)	10417
Other debris	6119)	

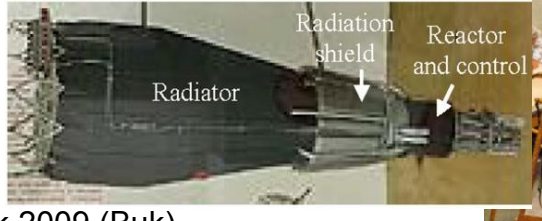
Covers, fairings	300
Jettisoned motors and tanks	170
Multi-payload adapters	141
Despin devices	131
Deployment canisters	38
Insulation blankets	36
Nuclear reactor cores	14
Misc	28
Unknown pieces	794

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)