Large Satellite Constellations – An Astronomer's Friend or Foe?

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www.quotesnative.com
Some people feel the rain. Others just get wet.
- Bob Marley
QN

- Watch for movie references!

The Plan

- Satellites 101
- Satellite Constellations 101
- The Good
- The Bad
- The Ugly
- Eye on the Future

Pop Quiz

Pop Quiz

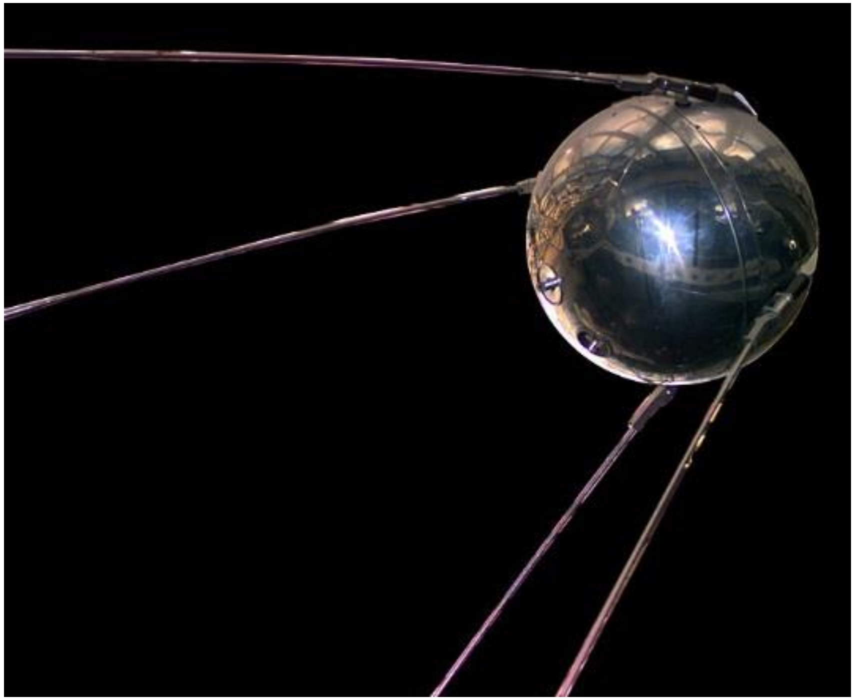
What was the first earth-orbiting satellite?

Satellite (n.)

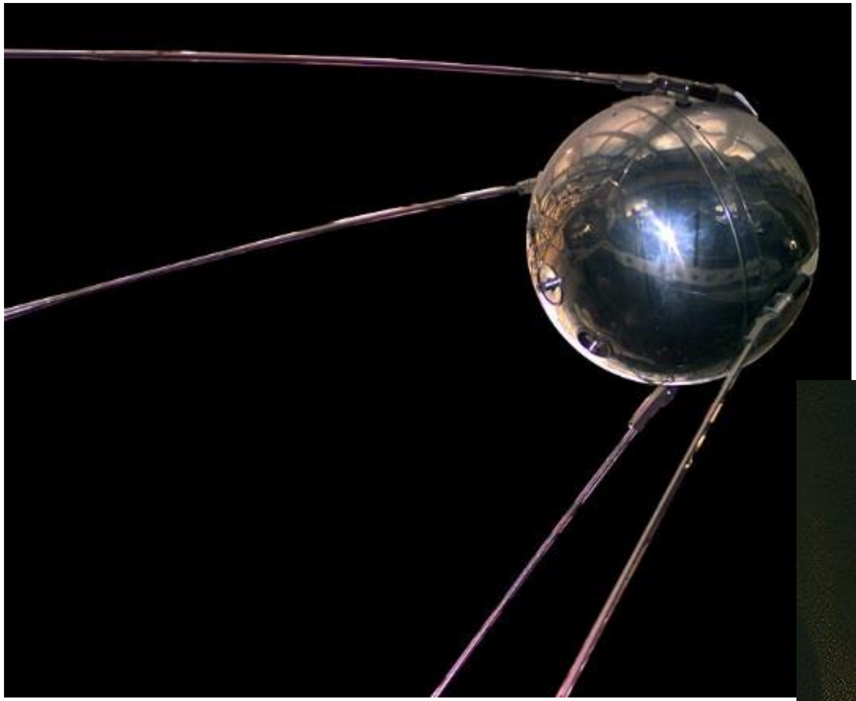
According to www.etymonline.com …

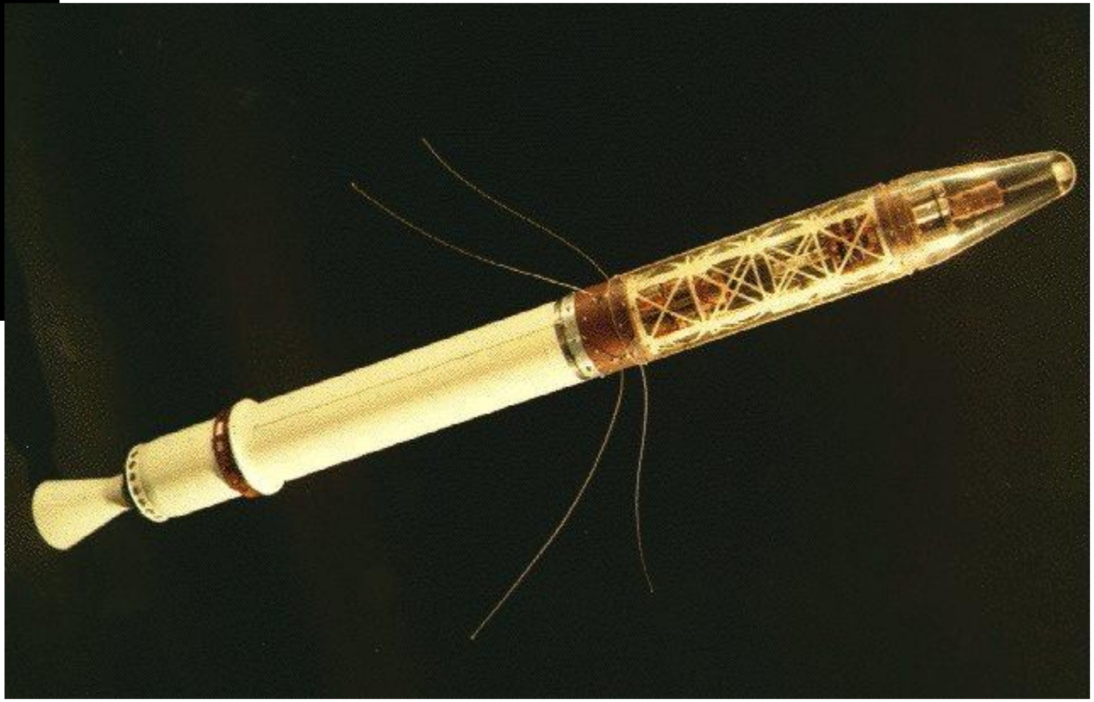
1540s, "follower or attendant of a superior person," from Middle French *satellite* (14c.), from Latin *satellitem* (nominative *satelles*) "attendant, companion, courtier, accomplice, assistant," perhaps from Etruscan *satnal*

Satellites 101



Satellites 101





First Satellite Launches by Country*

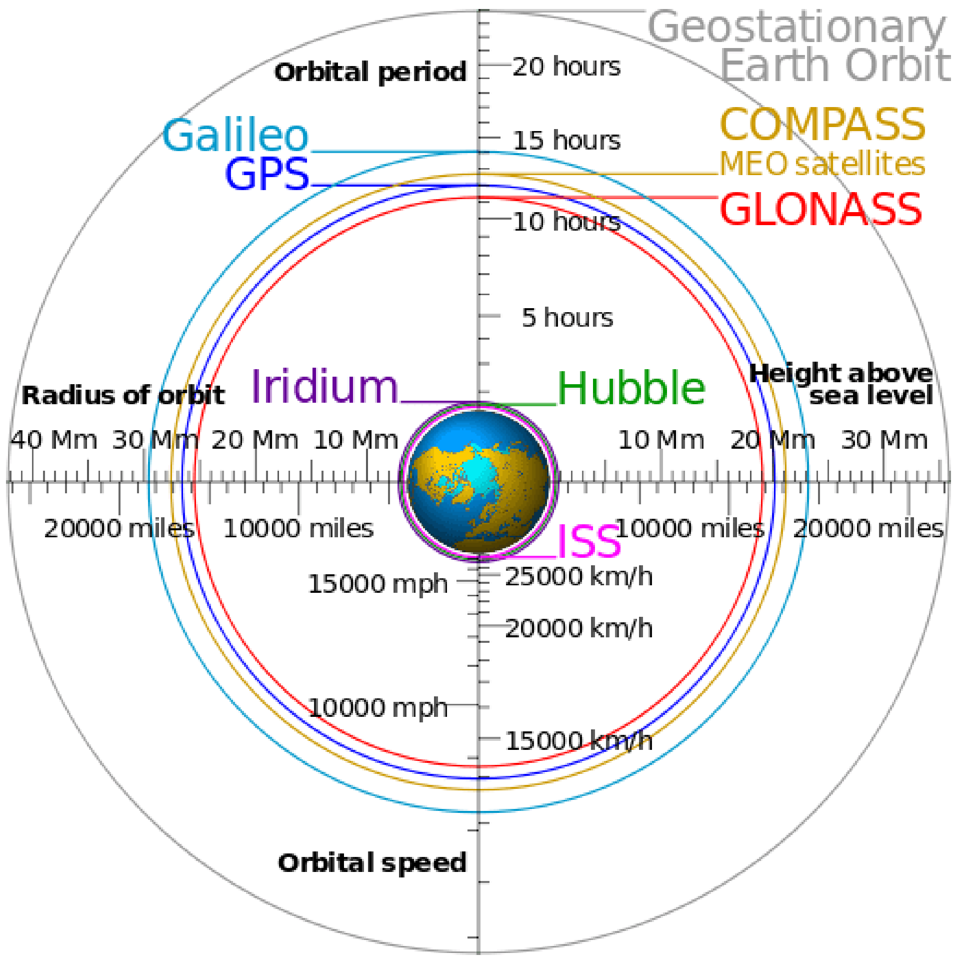
Country[a]	Sector	Satellite	Rocket	Location	Date (UTC)
Soviet Union[c]	Governmental	Sputnik 1	Sputnik-PS	Baikonur, Soviet Union (today Kazakhstan)	4 October 1957
United States[d]	Governmental	Explorer 1	Juno I	Cape Canaveral, United States	1 February 1958
France[f]	Governmental	Astérix	Diamant A	CIEES/Hammaguir, Algeria	26 November 1965
Japan	Governmental	Ohsumi	Lambda-4S	Uchinoura, Japan	11 February 1970
China	Governmental	Dong Fang Hong I	Long March 1	Jiuquan, China	24 April 1970
United Kingdom[g]	Governmental	Prospero	Black Arrow	Woomera, Australia	28 October 1971
European Space Agency[h]	Governmental	CAT-1	Ariane 1	Kourou, French Guiana	24 December 1979
India	Governmental	Rohini D1	SLV	Sriharikota, India	18 July 1980
Israel	Governmental	Ofeq 1	Shavit	Palmachim, Israel	19 September 1988
Ukraine[c][i]	Governmental	Strela-3 (x6, Russian)	Tsyklon-3	Plesetsk, Russia	28 September 1991
Russia[c]	Governmental	Kosmos 2175	Soyuz-U	Plesetsk, Russia	21 January 1992
Iran[j]	Governmental	Omid	Safir-1A	Semnan, Iran	2 February 2009
North Korea	Governmental	Kwangmyŏngsŏng-3 Unit 2	Unha-3	Sohae, North Korea	12 December 2012[k]
New Zealand	Private Industry	Dove Pioneer, Lemur-2 (x2); Humanity Star	Electron	Mahia Peninsula, New Zealand	21 January 2018[8]

*with their own rockets

Spacecraft Launched by Country

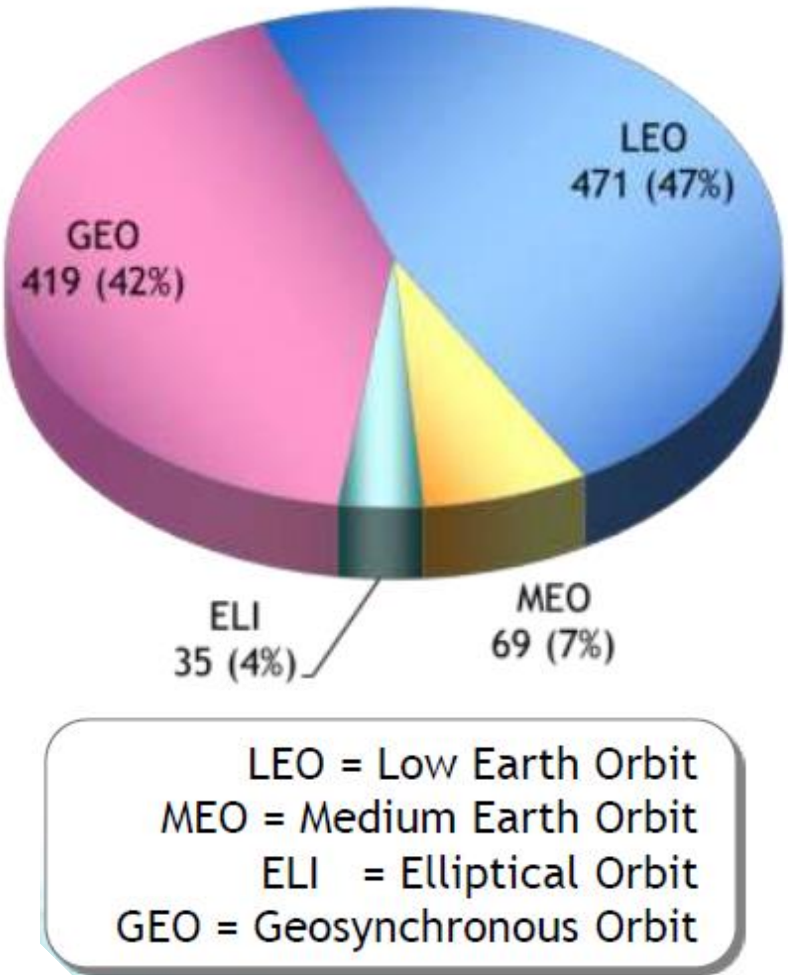
Sources: Spacecraft Encyclopedia; spaceflight101.com; CSIS China Power Project; Economist.com

Orbits of Modern Satellites



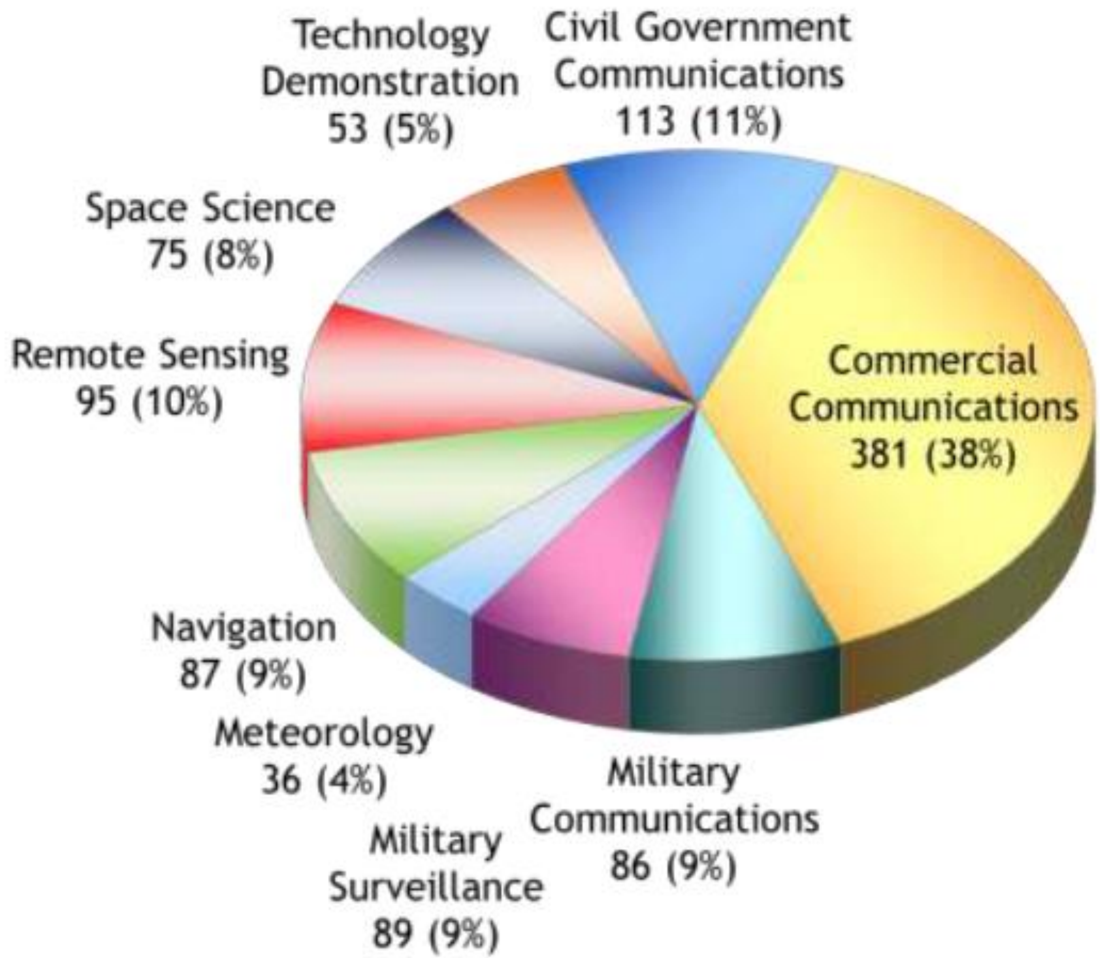
https://upload.wikimedia.org/wikipedia/commons/b/b4/Comparison_satellite_navigation_orbits.svg

Operational Satellites by Orbit (2012)



Source: https://www.sia.org/wp-content/uploads/2014/11/Website-Refresh14-Satellite-101.pdf

Operational Satellites by Function (2012)



Source: https://www.sia.org/wp-content/uploads/2014/11/Website-Refresh14-Satellite-101.pdf

This was fine until about 10 years ago …

Then along came …

New Kids on the Block

New Kids on the Block

Satellite Constellations – WHY?

- Individual satellites provide limited coverage areas – either narrow bands (if in LEO) or small circles (if in GEO)
  - A satellite system, or constellation, extends coverage area
- Demand for ever-faster broadband internet connections is maxing out today's satellites
  - Netflix, streaming video games, HDTV, etc, etc, etc

http://spacenews.com/divining-what-the-stars-hold-in-store-for-broadband-megaconstellations/

Satellite Constellations – WHY?

- Traditional $X00M satellites cost too much, take too long to build – and so by necessity have a really long life-span
  - They are obsolete before they are even launched!
  - Then, if you lose one, you are really out of luck

- Alternative – constellation satellites are much cheaper, can be built a lot quicker, and if you lose one, the loss is not as devastating

http://spacenews.com/divining-what-the-stars-hold-in-store-for-broadband-megaconstellations/

How Many Do You Need?

- For global coverage, will need several satellites at different orbits
  - GEO satellites cannot “see” polar regions (the earth rotates!)
  - Will also need some LEO and MEO satellites for full coverage

- Can be approximated using non-overlapping spherical hexagons
  - Depends on orbital altitude, many other things

Who is Already Doing What?

- Communications
  - BGAN – 3
  - COMPASS – 10, adding 25 more
  - Globalstar – 24
  - Iridium – 66
  - O3b – 16
  - ORBCOMM – 31
  - TDRSS – 9
- Other
  - Sirius / XM – 5
- Earth Observation / Disaster Management
  - A-train – 5
  - DMS – 8
  - Planet – 32
  - Pléiades – 2
  - SPOT – 7
- Navigation
  - Galileo – 30
  - GLONASS – 24
  - GPS – 70

Who Else is Planning on Doing What?

- Plans made public since 2016 …
  - OneWeb - up to 1,320 LEO satellites, 720 to MEO
  - BOEING - up to 2,956 satellites to LEO
  - SPACEX - 4,425 satellites in Phase I, another 7,518 satellites in Phase II
  - Telesat - two constellations of 117 satellites each
  - planet. - no fewer than 67 satellites in LEO
  - SAMSUNG - up to 4,600 in LEO
  - CASC - 300 satellites
  - CASIC - 156 satellites

Source: Peterson, G., et al., "Implications of Proposed Small Satellite Constellations on Space Traffic Management and Long-Term Debris Growth in Near-Earth Environment," 67th International Astronautical Congress, Guadalajara, Mexico, 2016. Paper IAC-16-A6.7.8.

The Bottom Line …

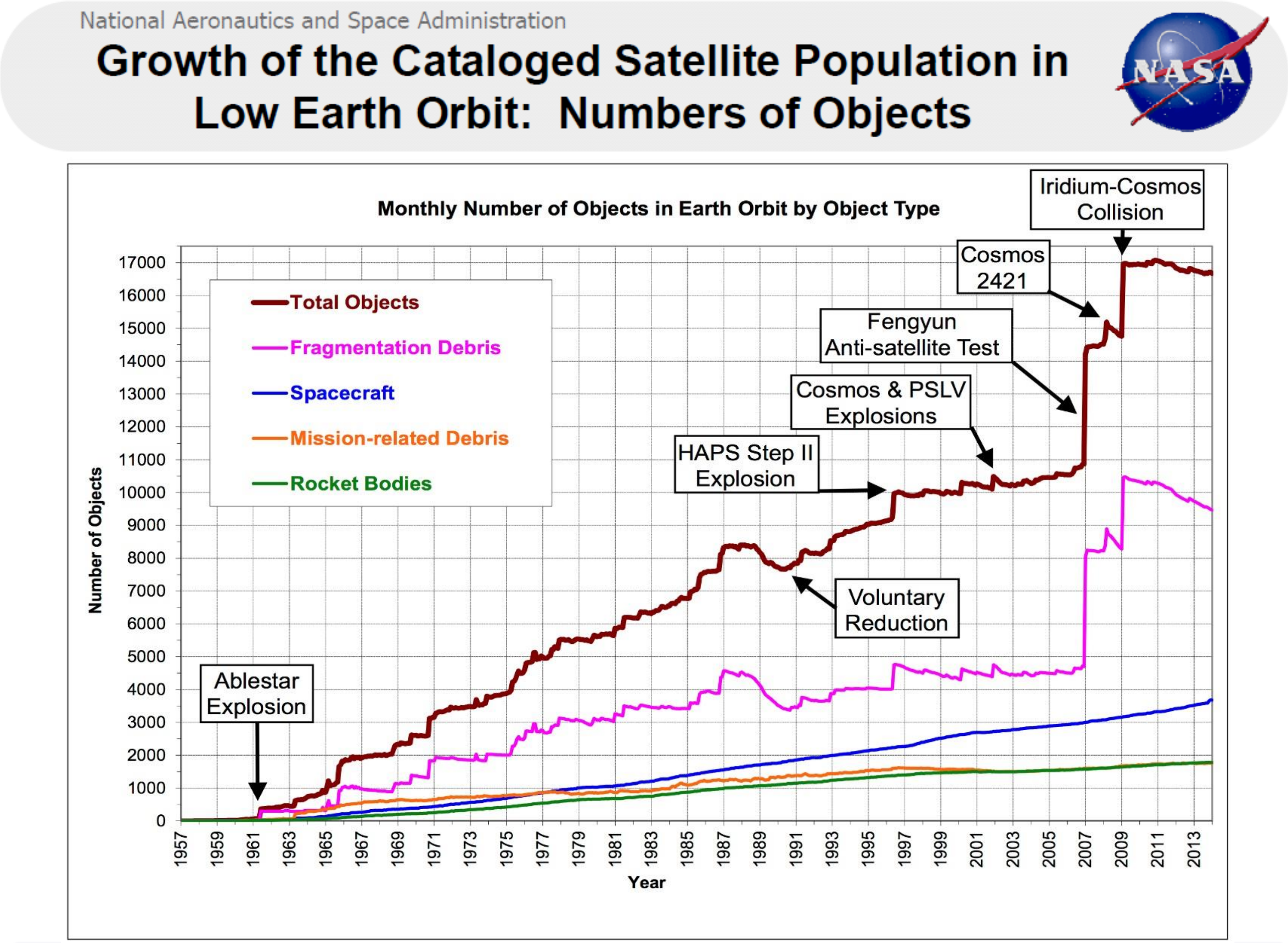
- By the mid-2020s, more than 22,000 new satellites could be in space

- So what?

- Is this good news?
  Bad news?

- Should we care?

Sizeable Stuff That's Already Up There




WHY WORRY?

The Good News Is …

- Move over WWW, here comes … SkyNet?
- More communications to places where now the internet is slow or non-existent
- Better assistance with disaster management
- Can be dedicated to astronomical studies WITHOUT atmospheric interference

Space-based internet

- Not limited by fiber capacities

- No huge expense associated with fiber-based communication infrastructure

- Can compete with AT&T, Verizon, etc.

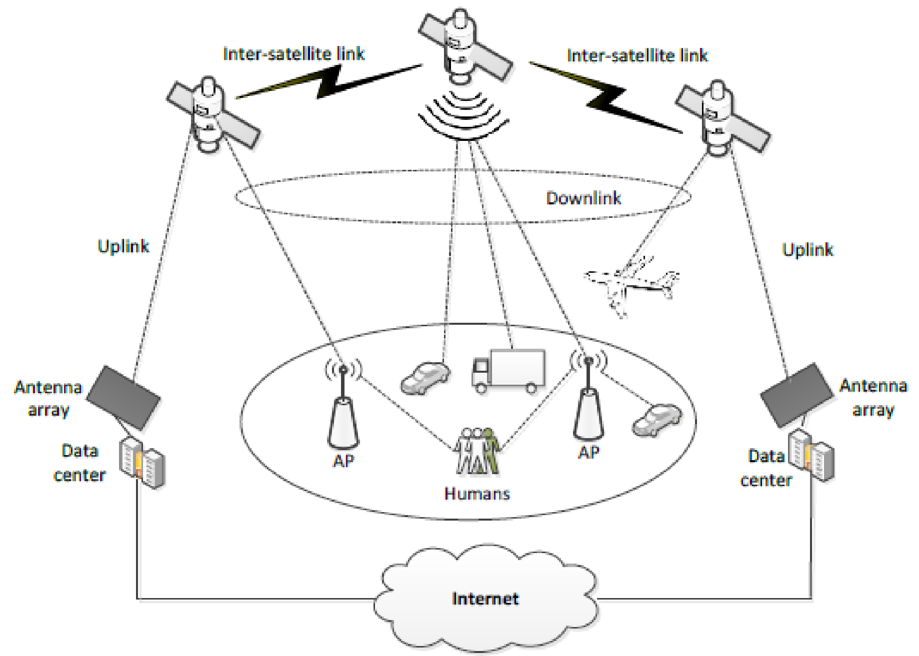


Figure 2 Space Internet system

Source: "Mobile Internet from the Heavens", [arXiv: 1508.02383](https://arxiv.org/abs/1508.02383), Cornell University, August, 2015.

A More Global Reach

- Farooq Khan, President, Samsung Research “internet services available to everyone in the world via low-cost micro-satellites."
  - "4,600 such satellites operating at data rates in excess of Tb/s in LEO orbit can provide overall capacity of one Zetabyte/month or 200GB/month" → enough for 5 billion users worldwide

Source: “Mobile Internet from the Heavens”, arXiv:1508.02383, Cornell University, August, 2015.

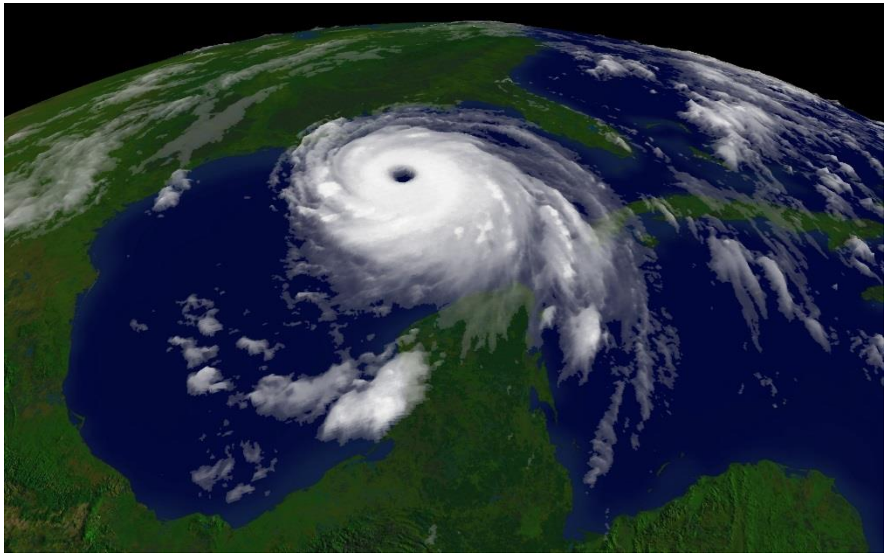
HELP!

- Different situations need data collected in different wavebands
  - Agricultural droughts - optical & near infrared data
  - Tracking a hurricane or monitoring flooded areas beneath clouds - microwave sensors
  - Landslide studies - depend on accurate high-resolution digital elevation models
    - Stereo-viewing optical sensors
    - Interferometric Synthetic Aperture Radars
    - Light Detection and Ranging instruments
  - Fires or volcanoes - thermal imagery is needed

Source: R. Navalgund, "Disaster management needs satellite constellations", https://www.scidev.net/global/disasters/opinion/, November 11, 2009.

HELP!

- Disaster managers need satellites with sensors that collect data in all regions of the electromagnetic spectrum
  - Can only be accomplished by a satellite system with a suite of sensors



Source: R. Navalgund, "Disaster management needs satellite constellations", https://www.scidev.net/global/disasters/opinion/, November 11, 2009.

Totally Devoted to You

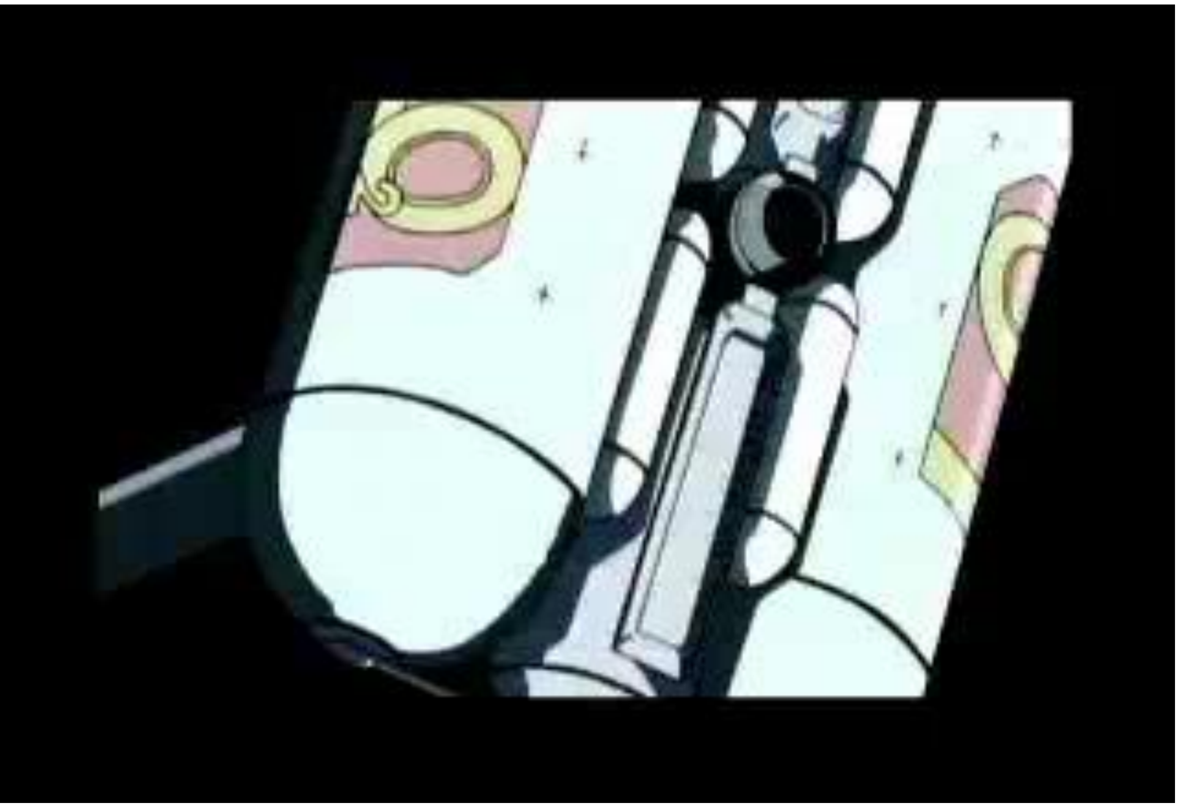
- BRITE (BRIght-star Target Explorer) / CANX-3 (Canadian Advanced Nanosatellite eXperiment-3)
  - University of Toronto, TU Graz, Universität Wien
- Objectives
  - Photometric observations brightest stars in the sky
  - Study low-level oscillations & temperature variations
- Observation precision > 10X better than GBO
- Mission's science team
  - University of British Columbia, l'Université de Montréal, University of Toronto, Universität Wien

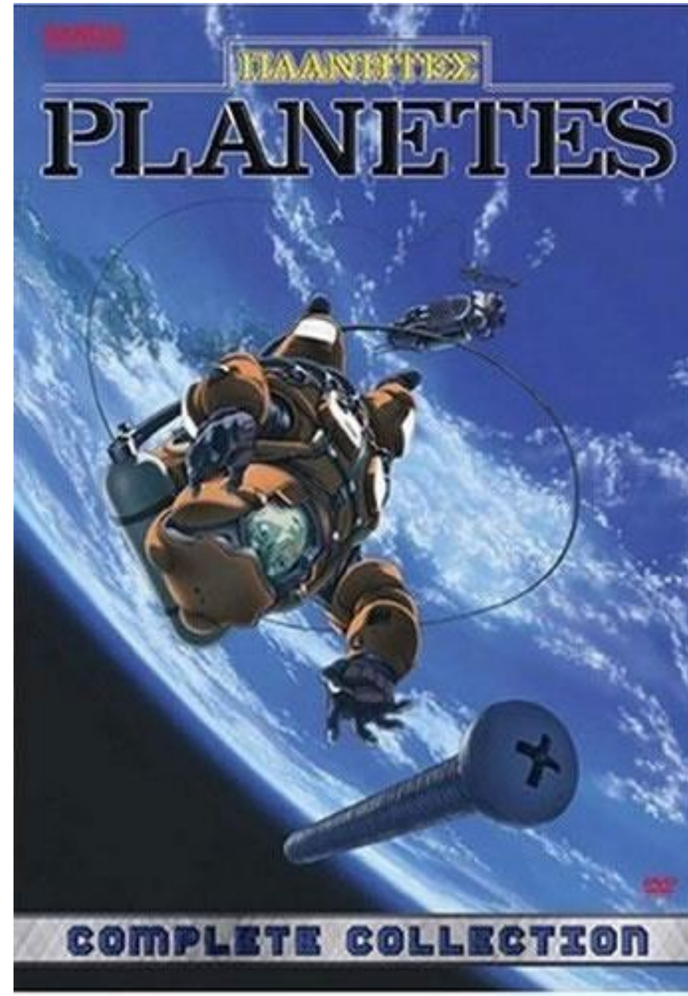
O.F. Koudelka, "The BRITE Nanosatellite Constellation," Proceedings of the 49th Session of UNCOPUOS-STSC (UN Committee on the Peaceful Uses of Outer Space-Scientific and Technical Subcommittee), Vienna, Austria, Feb. 6-17, 2012.

The Bad News Is …

- Increased possibility of on-orbit impact by a piece of space junk
- More clutter in the catalogue of space objects
- Number of close-approach warnings likely to increase by a factor of 100X
- Can cause interference to RA observations

The Kessler Syndrome





Don’t Blink!

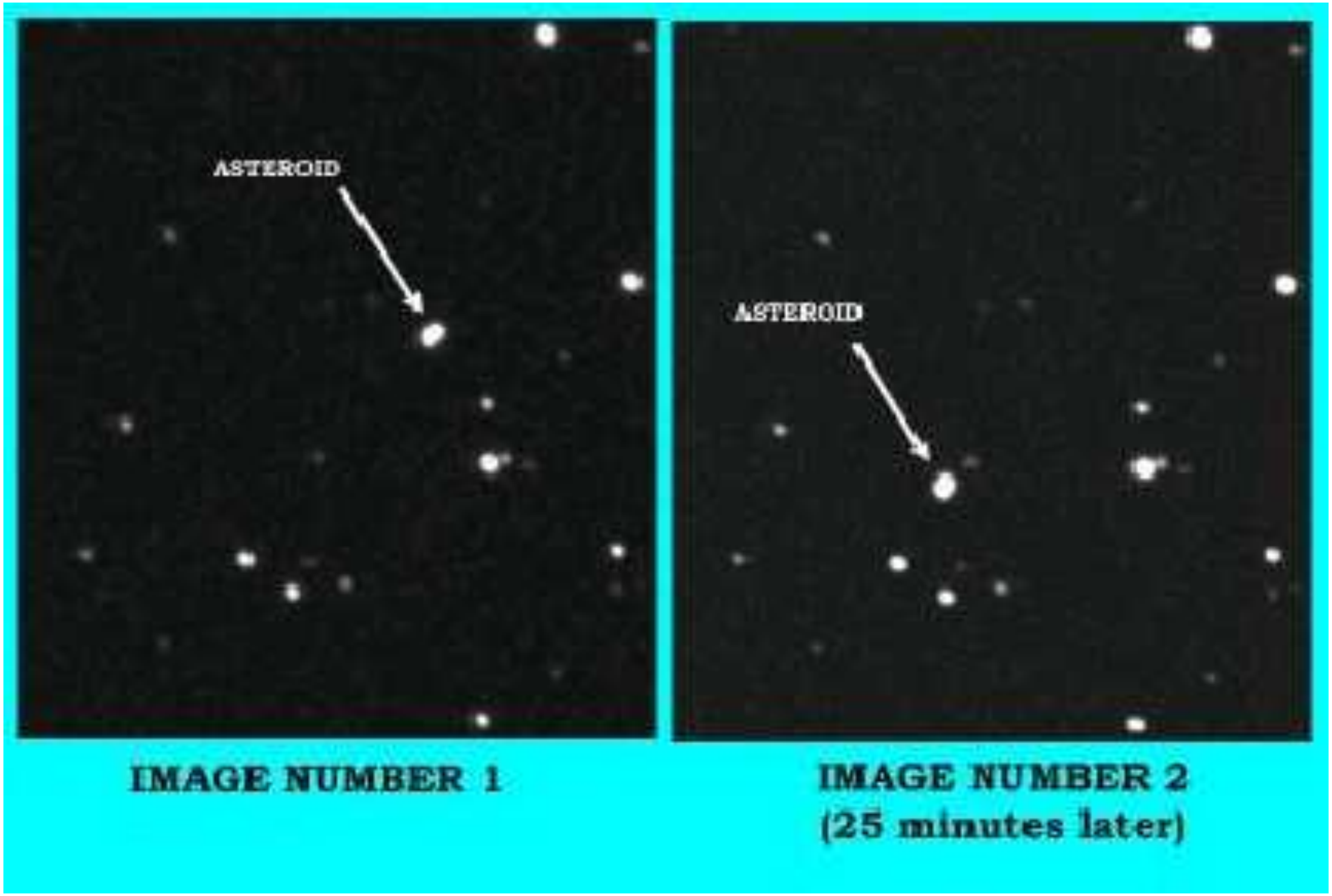

ASTEROID
ASTEROID
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IMAGE NUMBER 2
(25 minutes later)

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Close Approach Warnings

MISSOURI S&T Civil, Architectural and Environmental Engineering

Using today's thresholds, more than 25,000 warnings would be issued **each day**, all of which must be adjudicated by the operators that receive them [Peterson, G., et al., 2016]

Action	NORAD Catalog Number	Name	Days Since Epoch	Max Probability / Start (UTC)	Dilution Threshold (km) / TCA (UTC)	Min Range (km) / Stop (UTC)	Relative Velocity (km/sec)
Analysis	11962	METEOR 2-6 [?]	3.665	4.102E-02	0.011	0.026	12.993
	05430	THORAD AGENA D DEB [-]	4.437	2016 Dec 15 22:17:33.656	2016 Dec 15 22:17:34.041	2016 Dec 15 22:17:34.426	
Analysis	22487	COSMOS 2233 [?]	5.747	6.658E-03	0.012	0.051	2.564
	22422	SL-16 DEB [-]	5.791	2016 Dec 18 14:39:18.100	2016 Dec 18 14:39:20.050	2016 Dec 18 14:39:22.000	
Analysis	25272	IRIDIUM 55 [+]	2.017	4.151E-03	0.029	0.113	6.674
	25414	ORBCOMM FM18 [+]	3.059	2016 Dec 15 13:14:16.221	2016 Dec 15 13:14:16.970	2016 Dec 15 13:14:17.719	
Analysis	24883	ORBVIEW 2 (SEASTAR) [-]	1.974	3.380E-03	0.056	0.183	10.115
	30522	FENGYUN 1C DEB [-]	2.213	2016 Dec 15 04:47:28.336	2016 Dec 15 04:47:28.830	2016 Dec 15 04:47:29.324	
Analysis	41787	PATHFINDER 1 [+]	1.384	2.575E-03	0.010	0.041	4.135
	41145	NOAA 16 DEB [-]	2.311	2016 Dec 14 19:06:54.223	2016 Dec 14 19:06:55.432	2016 Dec 14 19:06:56.641	

Can You Hear Me Now?

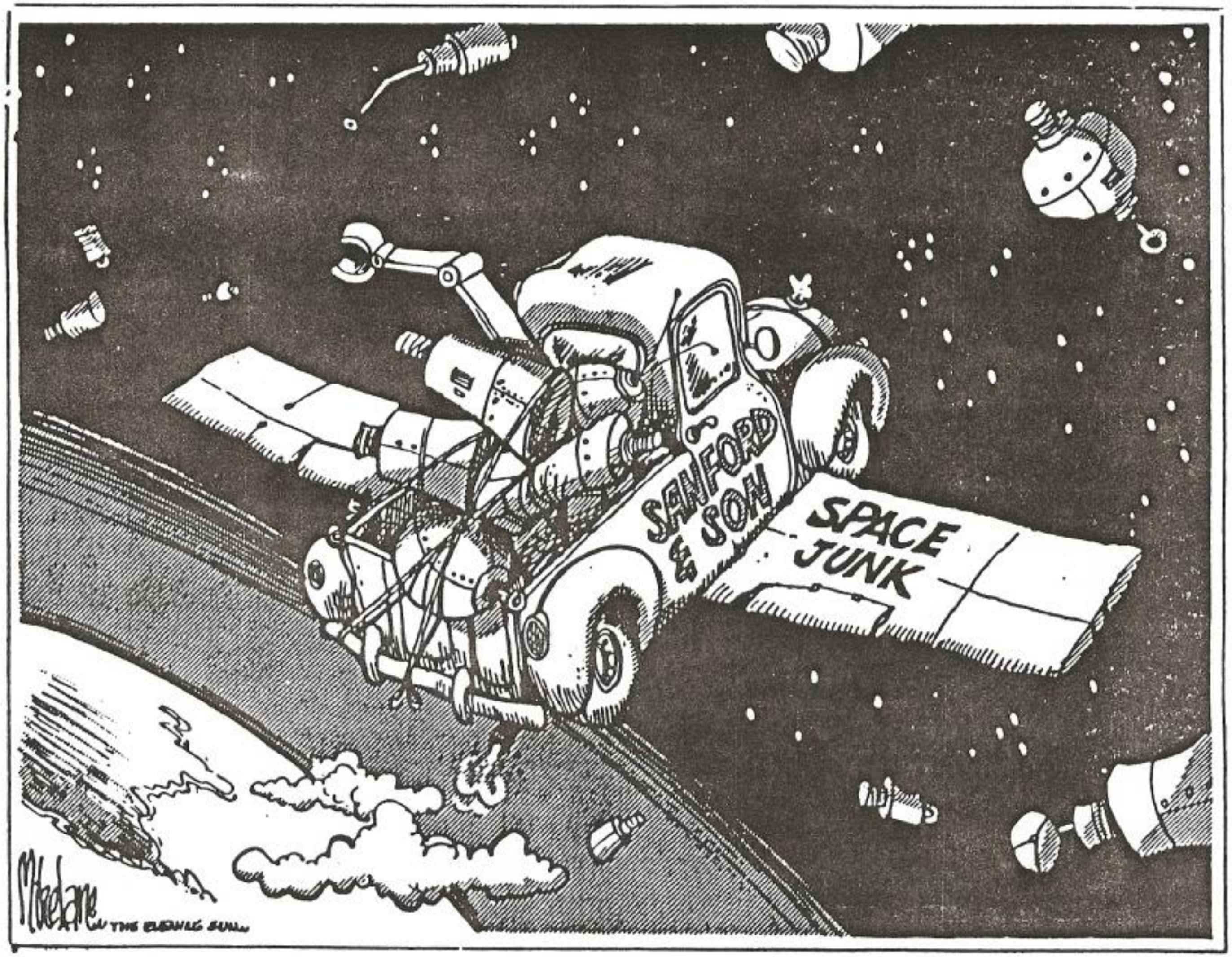
Satellite emitters known to cause interference to radio astronomy observations (NRAO, 2009)

Satellite	Uplink (GHz)	Downlink (GHz)	Type		Satellite	Uplink (GHz)	Downlink (GHz)	Type
AMSC	1.632 - 1.661 13 - 13.5	1.53 - 1.559 10.75 - 10.95	GEO-1		ICO	1.98 - 2.01	2.17 - 2.2	MEO-10+
CD Radio	7.1	2.31 - 2.36	GEO-2		Inmarsat	6.43 - 6.45 1.63 - 1.66	3.6 - 3.63 1.53 - 1.56	GEO-8
Celestri	28.6 - 29.1 29.5 - 30.0	18.8 - 19.3 19.7 - 20.2	LEO-63 GEO-9		Iridium	1.616 - 1.6265 29.1 - 29.3	1.616 - 1.6265 19.4 - 19.6	LEO-72
Comstar	5.945 - 6.405	3.72 - 4.18	GEO-1		MSAT	1.632 - 1.661 13.0 - 13.15 13.2 - 13.25	1.53 - 1.559 10.75 - 10.95	GEO-1
Constellation	1.610 - 1.6265	2.4835 - 2.5	LEO-46+		Navstar (GPS)	1.57542 and 1.2276		MEO-24
DirecTV	16 Ku-band transponders		GEO-3		Orbcomm	0.148 - 0.15	0.137 - 0.138	LEO-36
EchoStar	17.3 - 17.8	12.2 - 12.7	GEO-4		SBS	14.025 - 14.466	11.725 - 12.166	GEO-4
Globalstar	1.61 - 1.62135 5.091 - 5.250	2.4835 - 2.5 6.875 - 7.055	LEO-48		Starsys	0.148 - 0.15	0.137 - 0.138	LEO-24
Glonass	1.60256 - 1.61550		MEO-23		Teledesic	28.6 - 29.1	18.8 - 19.3	LEO-288+
GOES	2.2091	1.691, 1.6857	GEO-3		WorldSpace	7.025 - 7.075	1.452 - 1.492	GEO-3

What It All Means for Astronomy

- Use the technology for your benefit!
- Increase your space situational awareness!
- Be pro-active – be involved!
- ?????

If Only …



IADC Statement on Large Constellations of Satellites in Low Earth Orbit

- What is the IADC?
  - Established to exchange information on space debris research activities between its member space agencies.
  - Main function → review all on-going space debris activities between member organizations.
  - Also …
    - recommends new opportunities for cooperation
    - facilitates exchanging information and plans concerning orbital debris research activities
    - identifies and evaluates options for debris mitigation.

IADC Statement on Large Constellations of Satellites in Low Earth Orbit

- General U.N. guidelines RE: space debris
  - Spacecraft … should be designed not to release debris during normal operations.
  - The potential for break-ups during mission should be minimized.
  - All space systems should be designed and operated so as to prevent accidental explosions after end-of mission.
  - All on-board sources of stored energy of a spacecraft or orbital stage … should be depleted or safed when they are no longer required.
  - Each program or project should demonstrate … that there is no probable failure mode leading to accidental break-ups.
  - A spacecraft or orbital stage should be periodically monitored to detect malfunctions that could lead to a break-up or loss of control function.

IADC Statement on Large Constellations of Satellites in Low Earth Orbit

- General U.N. guidelines RE: space debris
  - Intentional destruction of a spacecraft … should be avoided.
  - Spacecraft or orbital stages that are terminating their operational phases in orbits that pass through the LEO region … should be de-orbited; retrieval is also a disposal option.
  - A spacecraft or orbital stage should be left in an orbit in which … atmospheric drag will limit the orbital lifetime after completion of operations to maximum of 25 years.
  - If a spacecraft or orbital stage is to be disposed of by re-entry, … debris that survives to reach the surface of the Earth should not pose an undue risk to people or property.
  - Spacecraft design should limit the consequences of collision with small debris which could cause a loss of control, thus preventing post-mission disposal.

Inter–Agency Space Debris Coordination Committee

IADC-15-03
September 2017

IADC Statement on Large Constellations of Satellites in Low Earth Orbit

IADC recommendations

4.2 Constellation Design

- 4.2.1 Altitude Separation
- 4.2.2 Number of spacecraft
- 4.2.3 Altitude separation

4.3 Spacecraft Design

- 4.3.1 Reliability of the Post Mission Disposal
- 4.3.2 Design to minimize consequences of break-ups
- 4.3.3 On-ground Risk

IADC Statement on Large Constellations of Satellites in Low Earth Orbit

IADC recommendations

4.3 Spacecraft Design

4.3.4 Structural Integrity

4.3.5 Trackability

4.4 Operations

4.4.1 Launcher Stages

4.4.2 Collision Avoidance

4.4.3 Disposal Strategy

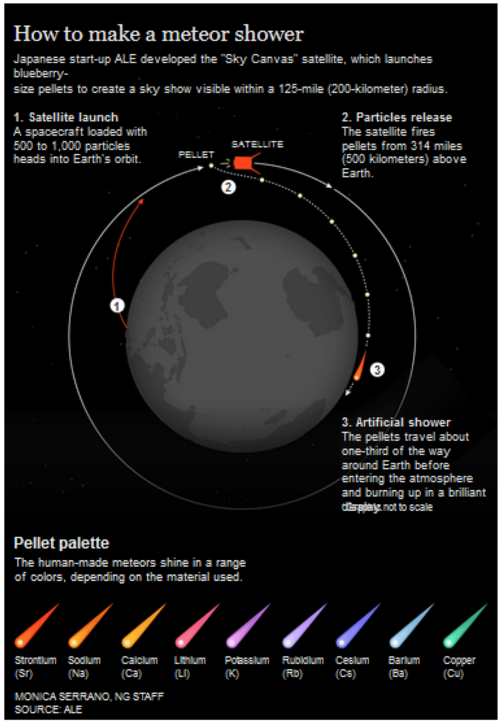
4.4.4 Launch and Early Operations

Inter–Agency Space Debris Coordination Committee

IADC-15-03
September 2017

And … If You Think Space is Cluttered Now …

Get Ready for Artificial Meteor Showers



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Movie References

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Civil, Architectural and Environmental Engineering

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- Skynet → from the Terminator movies
- HELP! → 1965 movie with the Beatles!
- "Totally Devoted to You"
  - Olivia Newton John song from "Grease"
- Don't Blink!
  - From the Dr. Who episode with the Weeping Angels
- Can You Hear Me Now?

SKYNET

GREASE

verizon wireless

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