Small Satellite and LEO Introduction

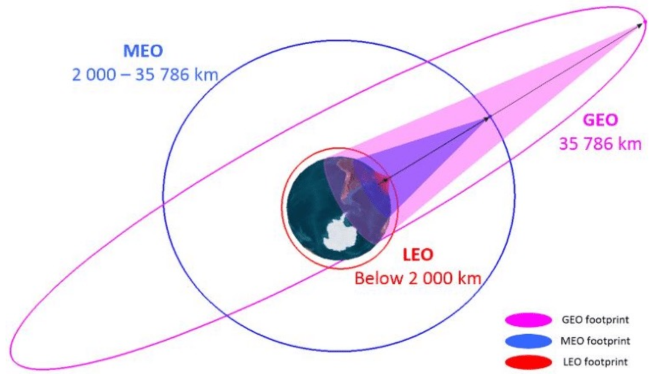
Small Satellite Workshop 2025

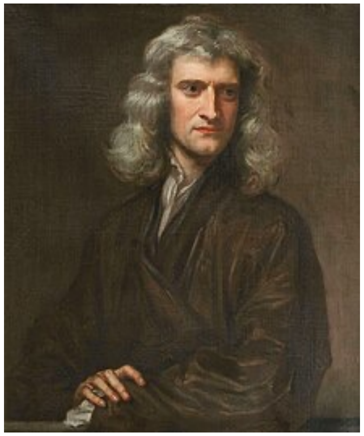
Resources and Disclaimer

- The workshop material we be heavily based on external resources of the followings
- State of the Art Small Satellite by NASA
- CubeSat 1-0-1 by NASA
- KiboCUBE Academy
- Resource page
  - https://satworkshop24.syssec.org/resources

What is Satellite?

- How can it circle around the Earth?
  - Basic Physics
  - Balance between gravity and velocity
    - The closer to earth, faster the velocity
    - Vice versa
- GEO satellites
  - Geo-stationary Earth Orbit
  - A circle per day
- LEO satellites
  - Low Earth Orbit
  - A circle per 90 ~ 120 min
    - Eclipses every 1:30 ~ 2 hours

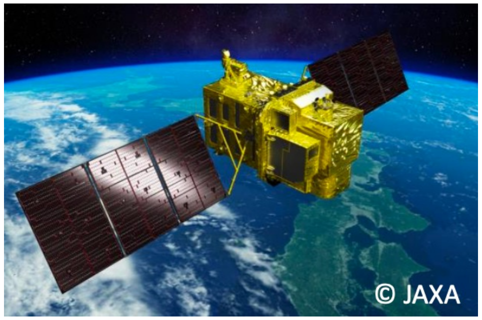




Isaac Newton,
image: Wikipedia

Johannes Kepler,
image: Wikipedia

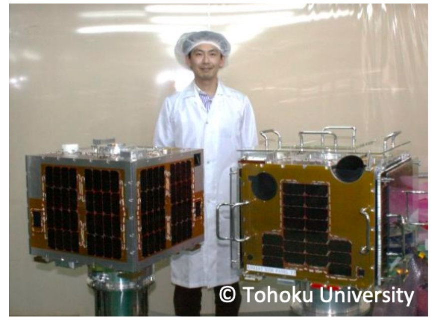
Spacecrafts



Large satellite

- Large mass
- High cost
- Long development time

- Dedicated launch
- Need high-reliability, low-risk
- High-performance, low observation frequency



Small satellite

- Small mass
- Low cost
- Short development time

- Small mass = Frequent launch opportunities
- Low cost
  - Can try challenging missions, realize large
- Constellations/networks
  - Frequent Observations
- Rapid Development
  - Can utilize brand new technologies
- Suitable platform for space education and rapid technology demonstration

Small satellites

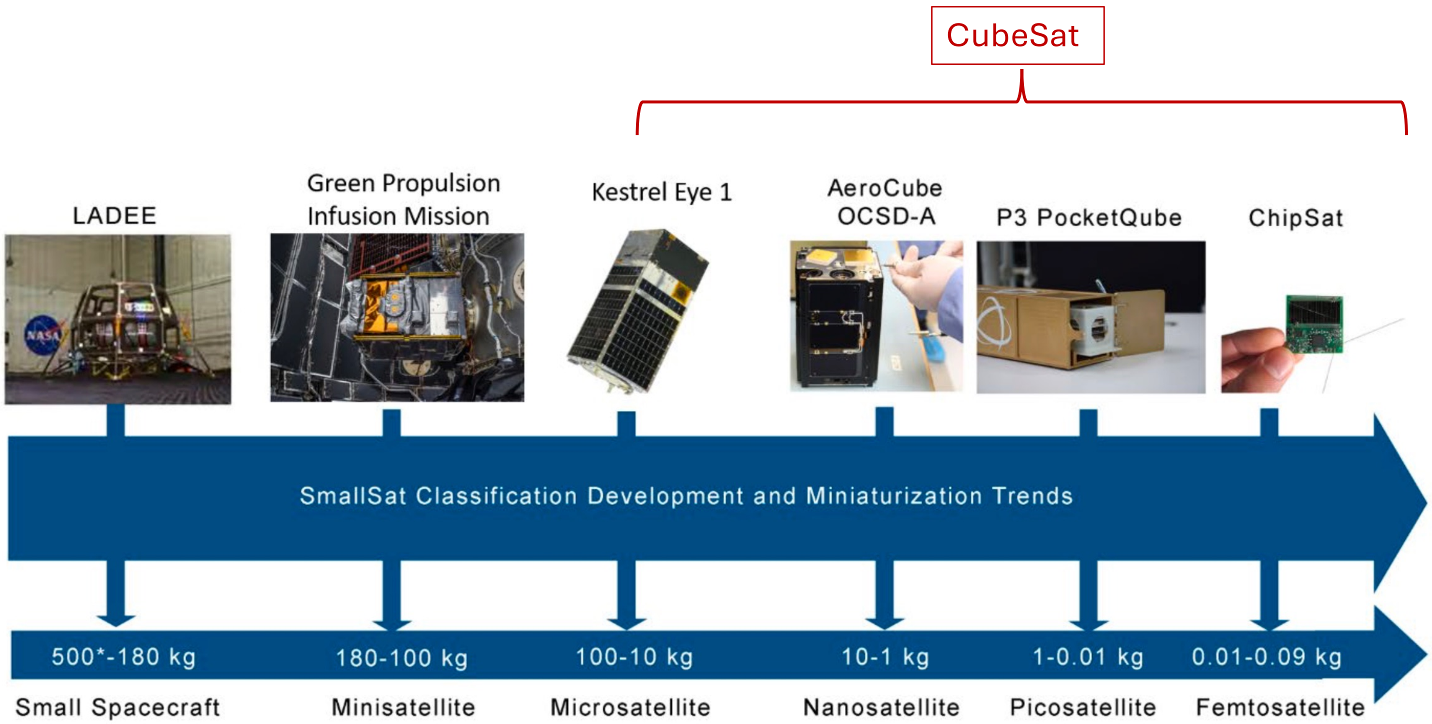


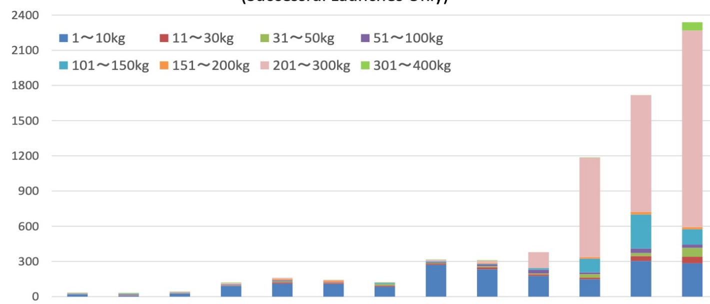
Image: State-of-the-Art small satellite technology @ NASA

Small Satellites on the Rise

- The number of small satellites smaller than 400kg, including mega-constellations, is rapidly increasing.
- Large portion of them are mega-constellation of communication satellites

<ins>Launches of Small Satellites (1~400kg)</ins>

(Successful Launches Only)



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1～10kg	19	9	26	90	112	106	85	272	234	177	149	304	284
11～30kg	2	5	4	4	10	7	10	11	16	13	13	42	56
31～50kg	1	2	3	3	8	1	11	5	10	8	30	26	76
51～100kg	1	4	2	4	9	7	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
101～150kg	4	6	2	4	2	2	10	8	6	14	116	291	131
151～200kg	2	1	2	2	10	13	1	1	5	2	12	21	17
201～300kg	4	2	4	11	10	6	1	11	21	135	848	994	1678
301～400kg	2	3	2	3	0	1	4	2	5	0	3	1	70
Total	35	32	45	121	161	143	124	316	311	380	1187	1717	2340

Small satellite Launches

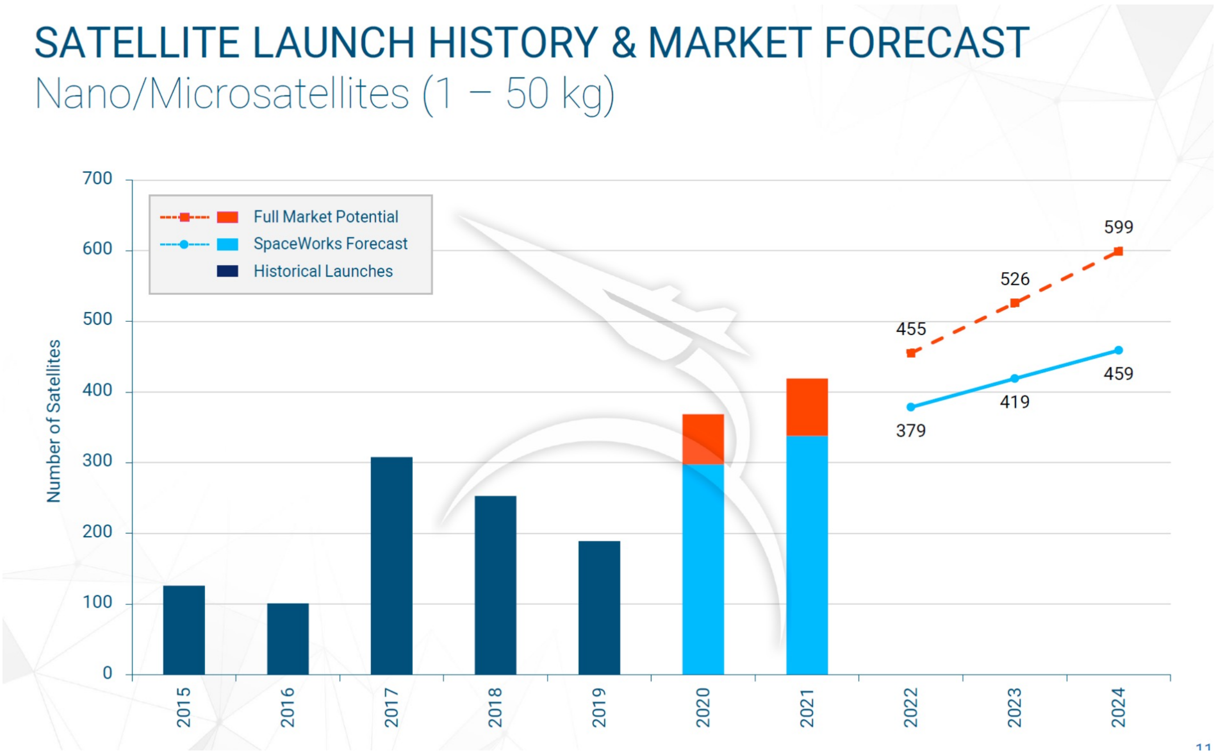
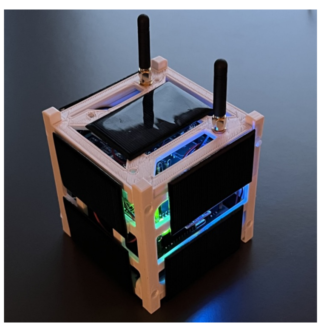
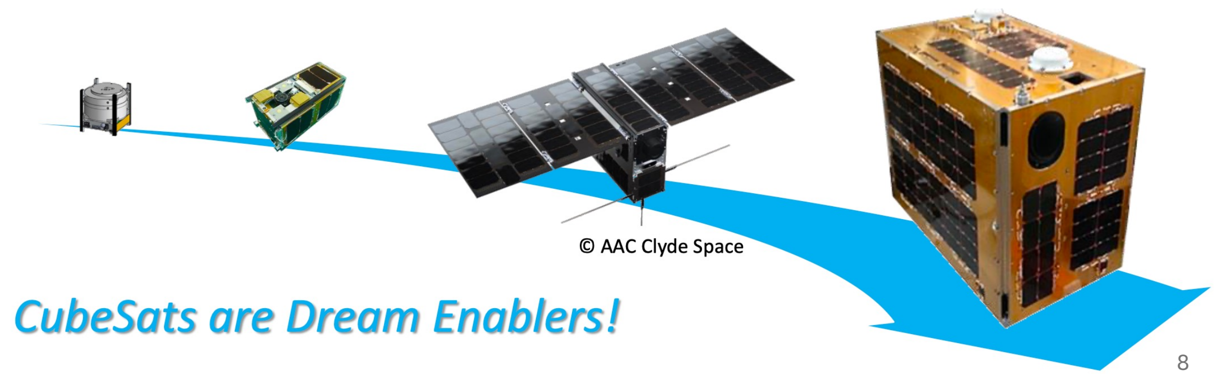


Image: SpaceWorks

Small Satellite Opportunities

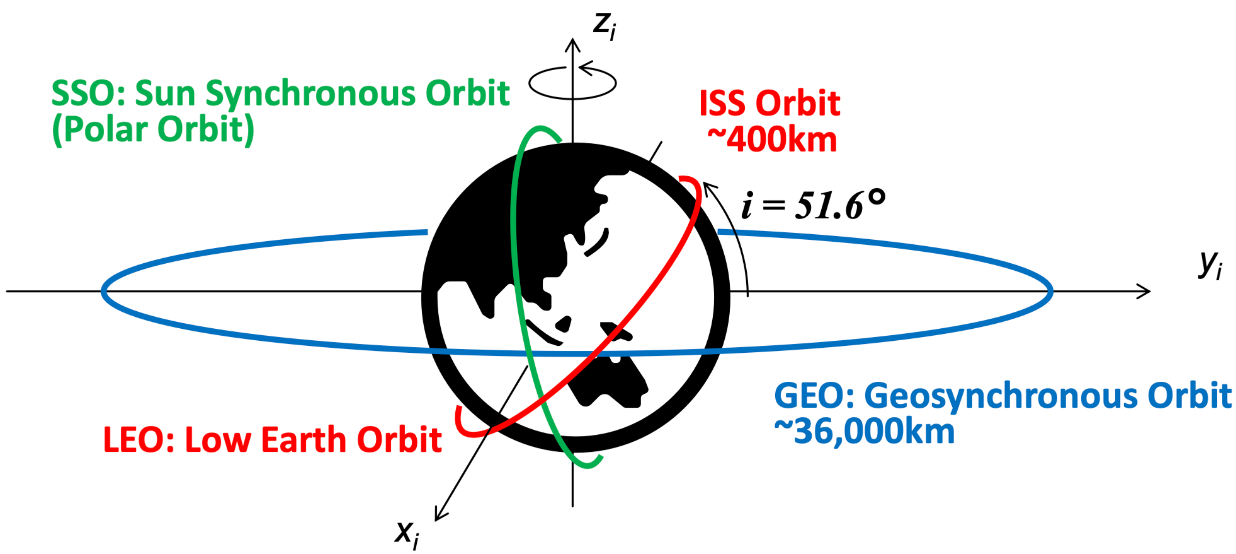
- "Start small, go big!"
- CubeSats have become a major game-changer
  - No longer for education only, but for actual space exploration
  - Achievements obtained from CubeSats can be applied to advanced missions.
- Even 1U CubeSats bring everything within your reach!





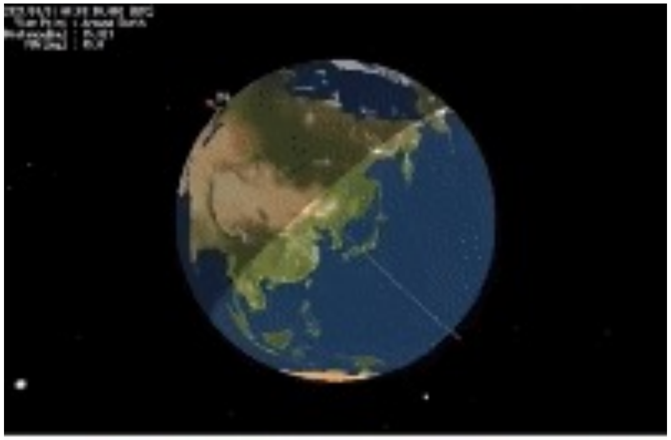
Different kinds of of Earth Orbit

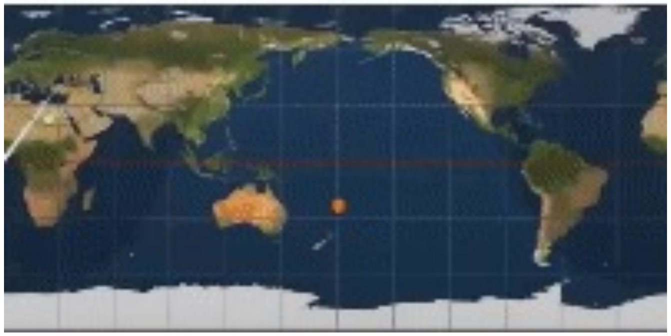
- GEO, ISS orbit, SSO, LEO



Example: ISS Orbit

- ISS Orbit:
  - Altitude: ≃ 400km*
  - Inclination: ≃ 51.6 deg
  - Orbital period: ≃ 91 min
  - Orbit altitude changes for about ±20km
- CubeSats deployed from the ISS stay in almost the same orbit as the ISS.
- Slight differences in initial relative velocity and different mechanical characteristics, such as mass and shape (and hence, ballistic coefficient), make the CubeSats separate from each other into different orbits.
- ISS orbit covers the ground surface of regions with lower latitude (between ± 51.6 deg).
- ISS rotates around the Earth about 16 times a day, while the Earth rotates about 22.5 deg during the 1 orbital period of the ISS.



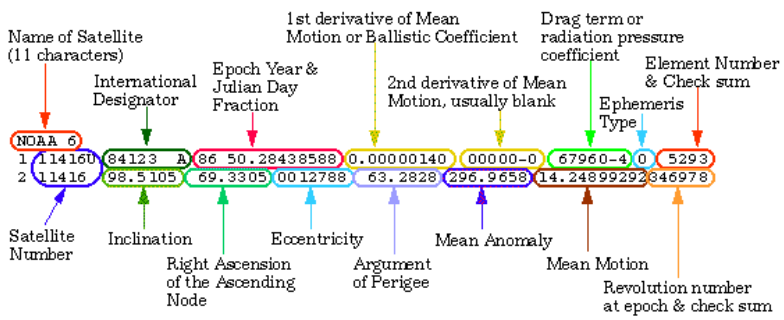


Spheresoft

TLE (Two Line Element)

- TLE: Data format encoding orbital element
  - Two-line text containing information about the movement of an object in orbit around the Earth at a given time (“epoch”)

```
ISS (ZARYA)
1 25544U 98067A   08264.51782528 -.00002182  00000-0 -11606-4 0  2927
2 25544  51.6416 247.4627 0006703 130.5360 325.0288 15.72125391563537
```



https://www.space-track.org/documentation#/tle

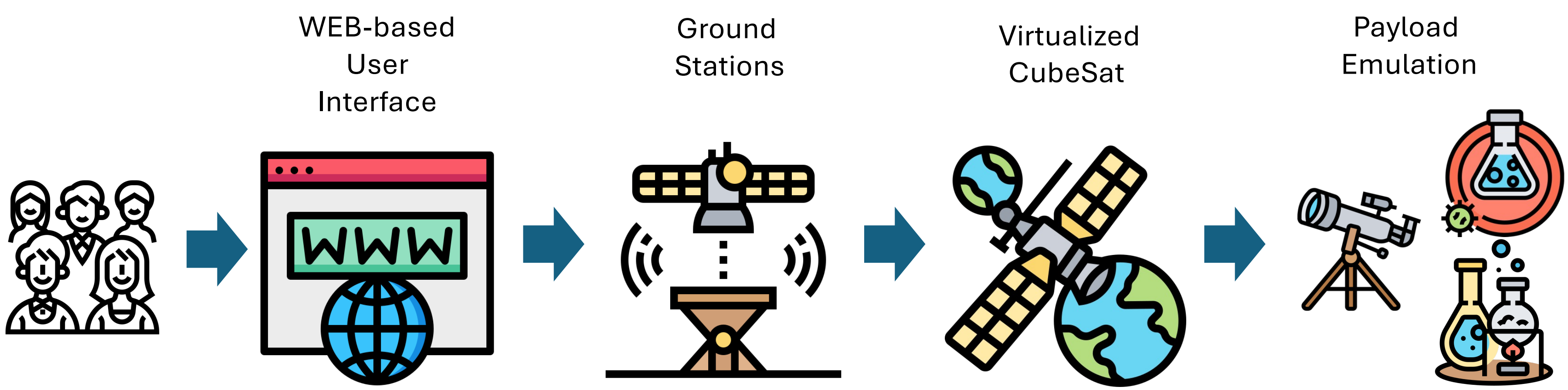
NORAD ID

- The Satellite Catalog Number (SATCAT)
- A.K.A NORAD (North American Aerospace Defense) ID is a sequential nine-digit number
  - Assigned by the USSPACECOM in the order of launch or discovery to all artificial objects in the Earth oribit
  - NORAD ID 1: Sputnik

https://www.space-track.org/

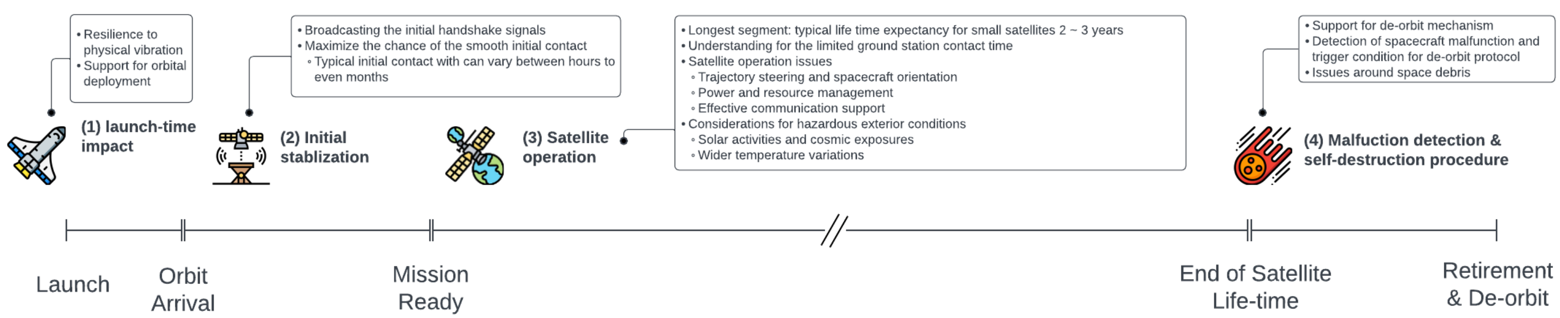
Satellite Operational Components

- Ground Station
- Command and Control
- Satellite structure
- Payload component



Operational Processes

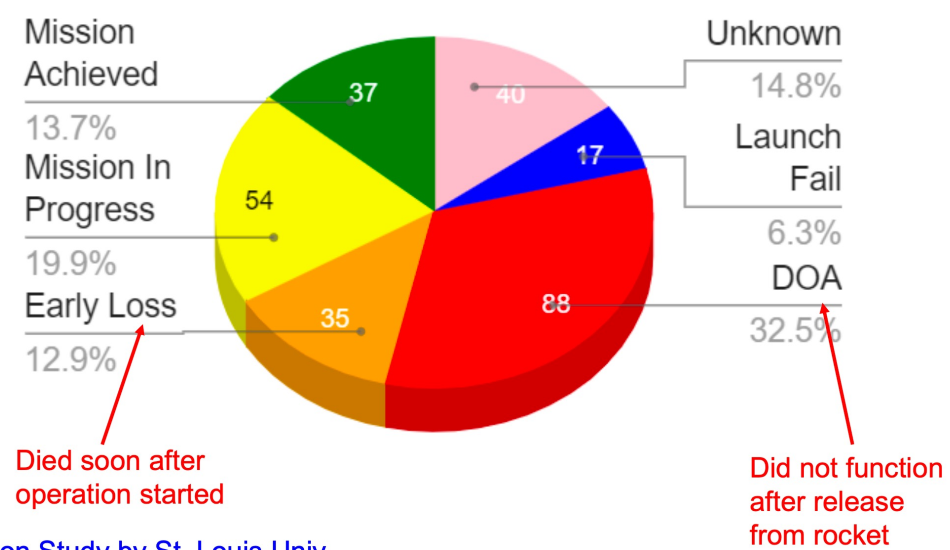
- Temporal perspective
- Depicts post-launch operations only
- Comparable or even more time are required for
  - Planning, development, and testing



CubeSat Failures

Failure rate is about 50%

CubeSat Mission Status, 2000-present (271 spacecraft)



Based on Study by St. Louis Univ.
https://sites.google.com/a/slu.edu/swartwout/cubesat-database

Frequent Causes of Failure and Countermeasures

- Radiation causes electronics failures
  - Use space-proven parts or conduct radiation tests during early development phases

- Electric power subsystem fails to provide power, or battery voltage gets very low and cannot be recovered
  - Design satellite behaviors under low battery voltage
  - Make solar power generation possible in any situation

- Communication subsystem fails to communicate with the ground station because of component failures, insufficient RF power or EMI (Electromagnetic Interference)…
  - Implement backup systems (redundant receivers, etc.)
  - Calculate the link equation correctly and add enough link margin
  - Conduct ground tests using EM or FM in a realistic situation
  - Find and consult with communication technology experts

Why Space System is Difficult?

Harsh Space Environment	
Vacuum	Vaporization, cold welding, friction, electric discharge, change of material, heat spot…
Radiation	Electronics parts malfunction and breakdown, degradation of solar cells and materials…..
Thermal	Large temperature differences/cycles, heat shock, heat spot…..
Launch	Vibration, shock, acceleration, sound vibration…..
Distance	Long range communication over 500-2000 km…..

Others: Atomic Oxygen, Plasma, Debris/Meteoroids, Ultraviolet rays

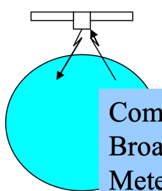
Non-Maintainable System

- A satellite cannot be touched after launch
- Sometimes a satellite must survive 10+ years without any human interactions

- Be imaginative
  - Consider all the possible events and anomalies which may happen to your satellite and prepare countermeasures
- Be rigorous
  - Conduct ground tests in various settings in the space environment, in various operation modes

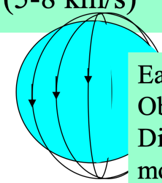
Space Features

①Providing 3 D View



Communication, Broadcasting, GPS, Meteorological, Earth Observation

②High Speed Earth Coverage (5-8 km/s)



Earth Observation, Disaster monitoring

③Above Atmosphere

- Space Telescope, Various spectral observations,
- Solar power generation

④Long time μG environment

- New material/medicine
- Life science experiment

⑤Space as Exploration Target

- Observation of Planets, Small bodies
- Particles, Fields, etc.

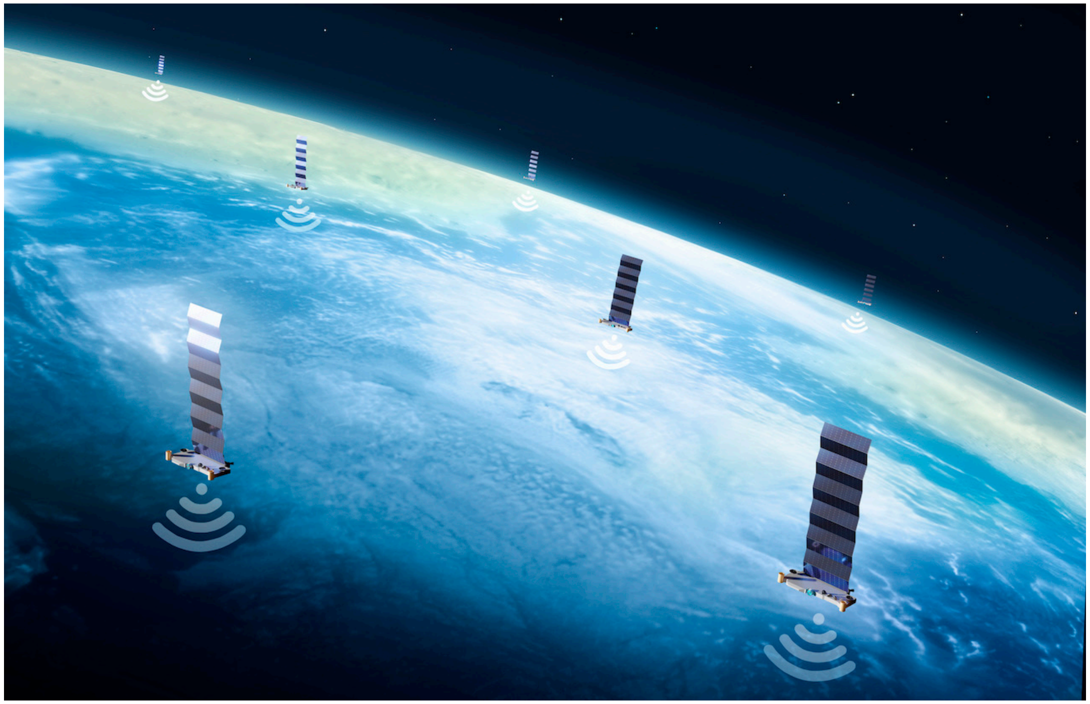
⑥"Humans in Space" (travel)

⑦⑧---- Waiting for other new ideas !

Communication/broadcasting satellite

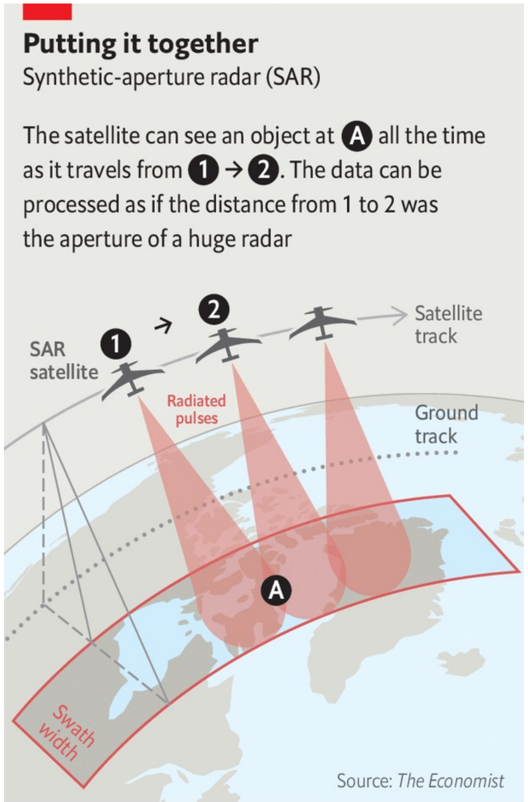
- Starlink Broadband
  - Mega constellation

1. Providing 3D view



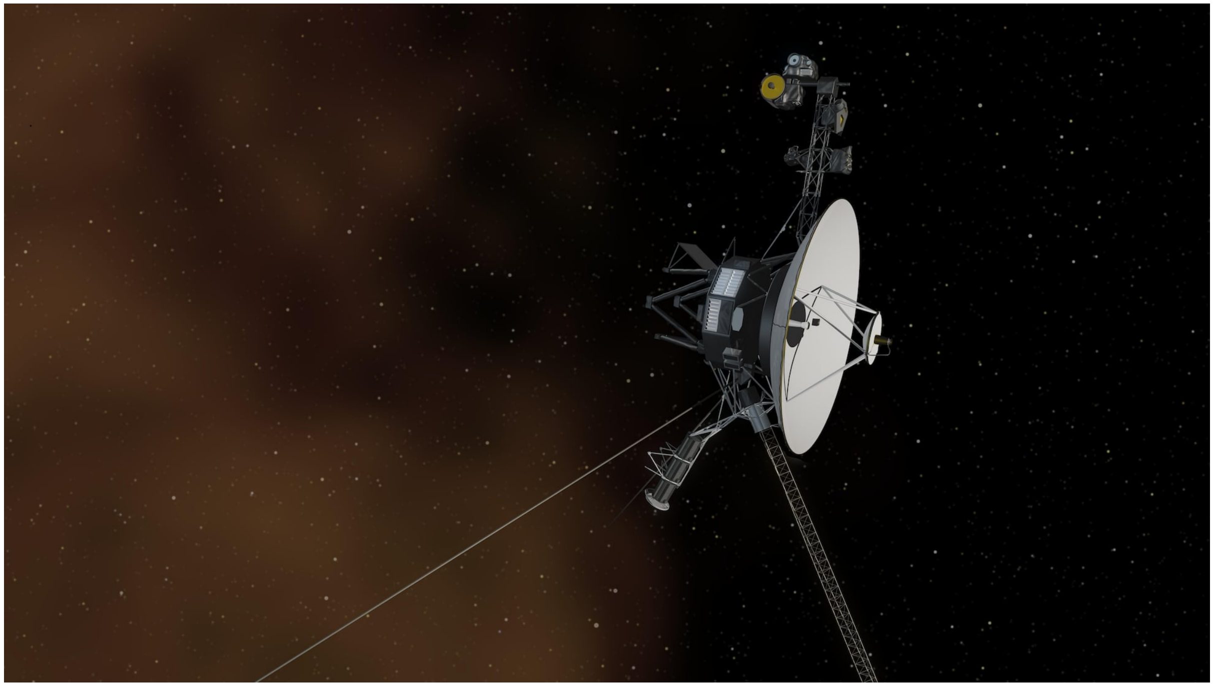
Synthetic Aperture Radar (SAR)

- A technique for producing fine-resolution images from a resolution-limited radar system
  1. Providing 3D view
  2. High speed coverage of the Earth



The Economist

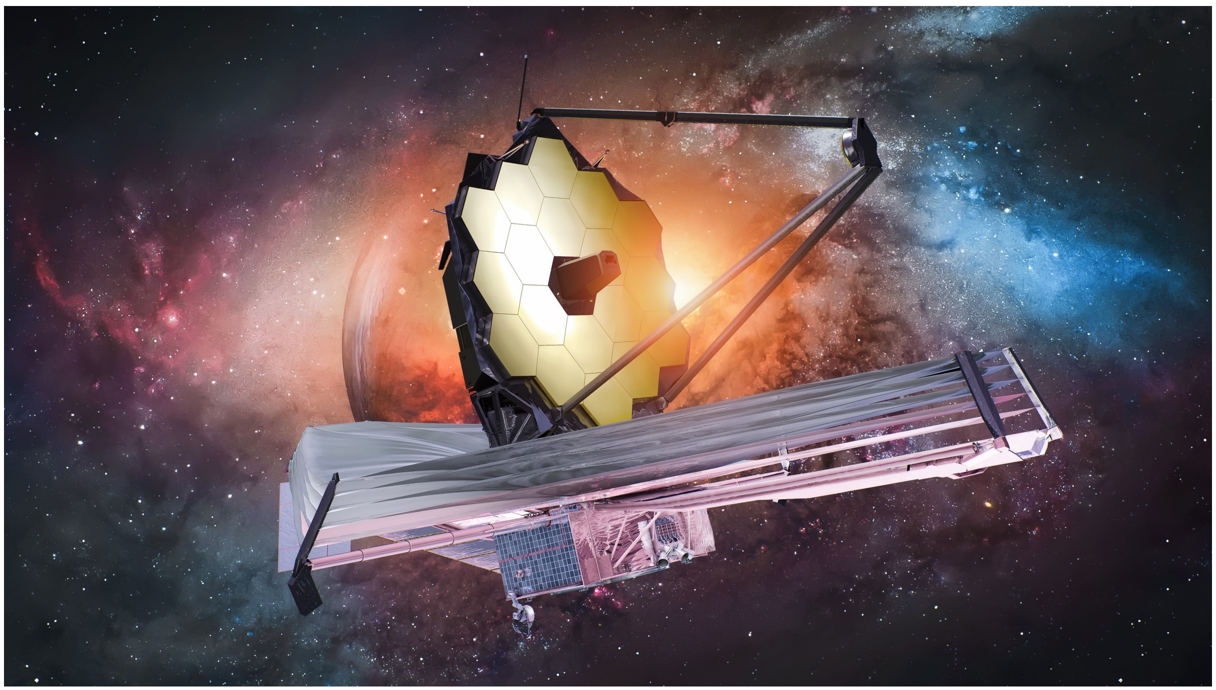
Deep Space Exploration Probe



'Voyager 2' probe in interstellar space.
NASA/JPL-CALTECH

5. Space as an exploration target

James Webb : Space Telescope



3. Staying above the atmosphere

What is Your Space Mission?

- How future will look like for you?
  - Will space be important for you?

- What applications can we think of?
  - Considering special features of the space
  - What would be interesting applications relevant to your research?
    - It is an open question to you!

Backup

Space Governance

- Who own the space?
- Still practical regulation and procedures to follow
- Many recommendations, but only a few enforceable regulations

- Open problem!