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FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA

SPACE TECHNOLOGIES

Lesson 1 – Introduction to Space Technologies

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Content of lesson 1

- Spacecraft classification based on the purpose of use
- Spacecraft classification based on mass
- Spacecraft classification based on method of use
- Deployers, separation systems and payload adapters
- Earth‘s orbits classification and their usage
- Examples of satellite constellations and orbit usage

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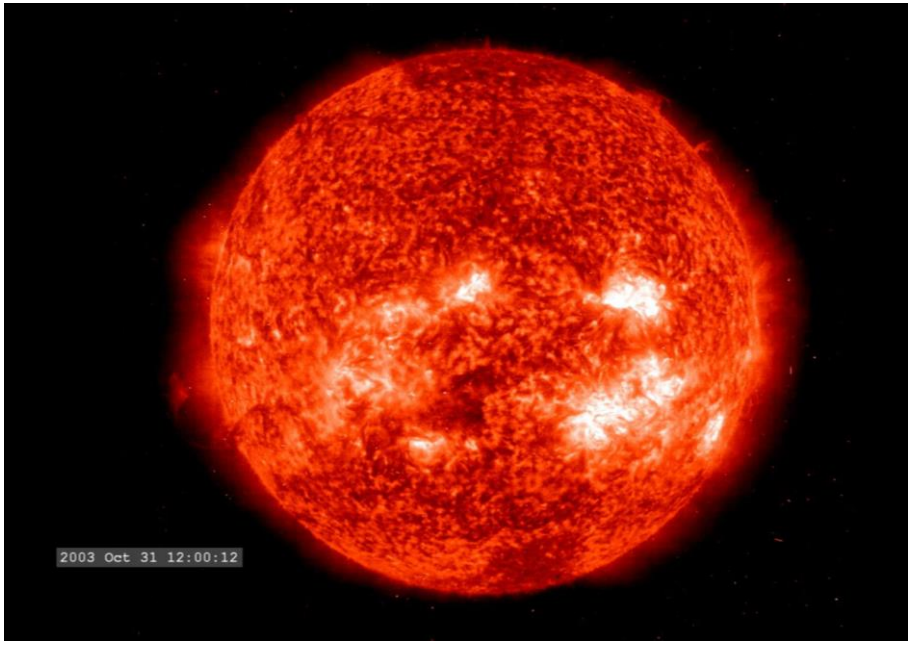
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Satellite classification based on the purpose of use

- **Space observation**

  Atmosphere and Earth magnetic field do not allow to measure many astrophysical phenomena (e.g. particles of cosmic radiation can interact with atmosphere or can be deflected by Earth magnetic field, light of galaxies is scattered and defocused by atmosphere).





Space observation / Earth observation / Interplanetary mission / Technological research / Military use / Communication and navigation / Educational / Radio-amateur

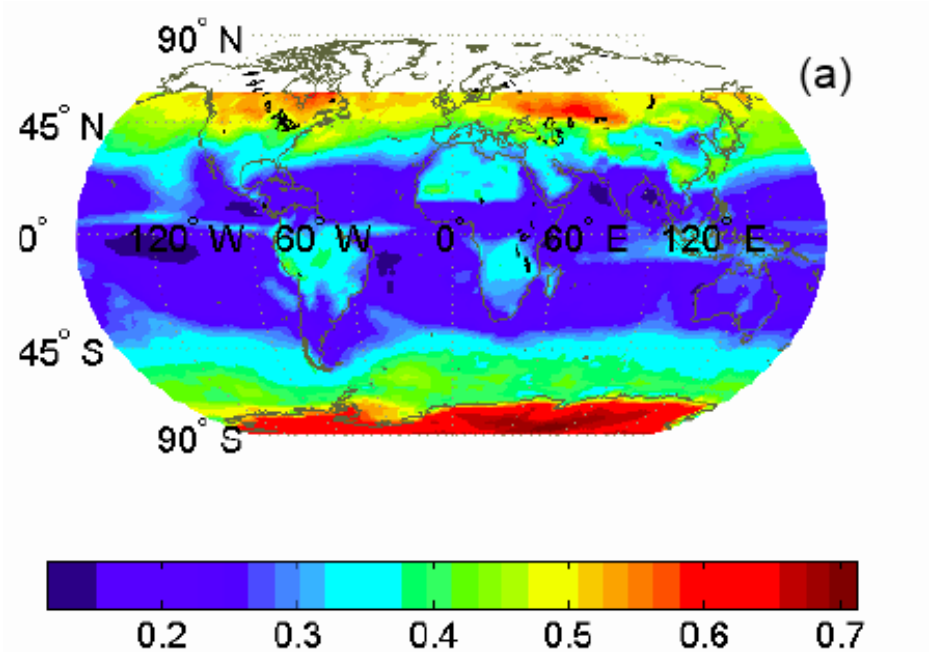
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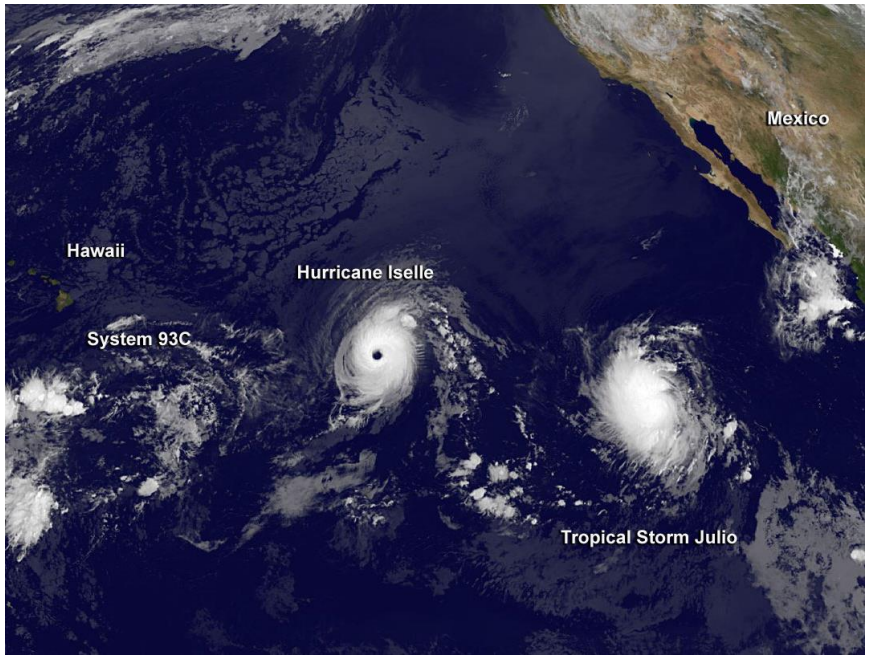
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Satellite classification based on the purpose of use

➢ Earth observation

Weather forecast, climatic change and land monitoring (ice melting, greenhouse effect, deforestation, coastal erosion, fire detection), hi-resolution Earth imagery for precise maps and disaster monitoring.





Space observation / Earth observation / Interplanetary mission / Technological research / Military use / Communication and navigation / Educational / Radio-amateur

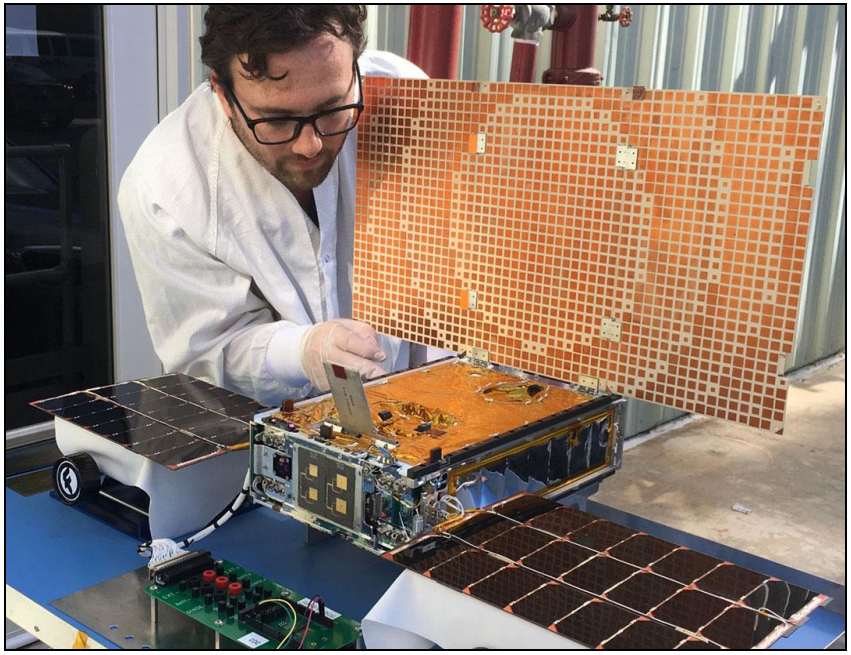
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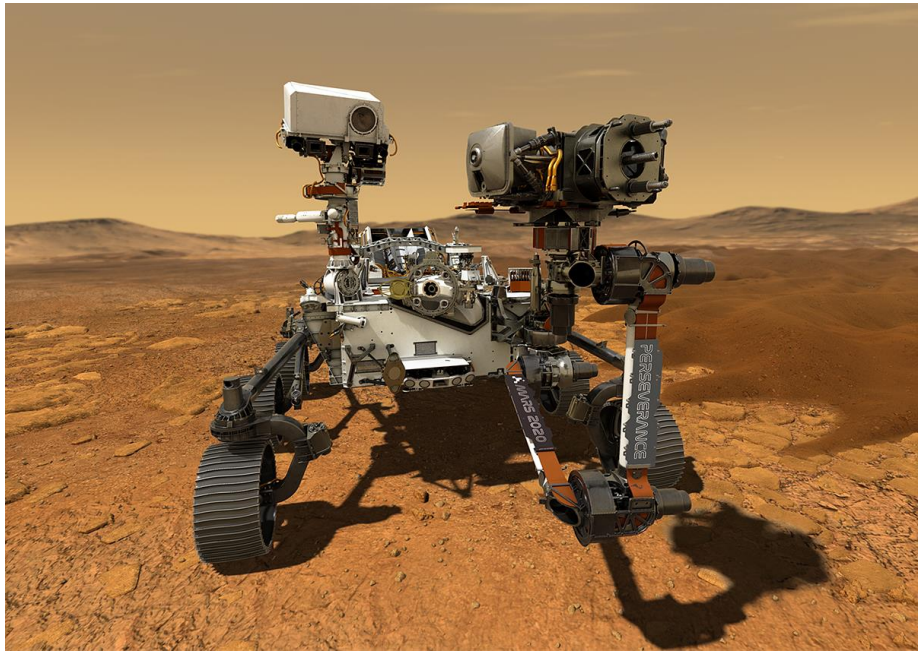
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Satellite classification based on the purpose of use

- **Interplanetary, asteroid or interstellar mission**

  Research of planets, moons, asteroids and other objects in Solar system. Testing of new technologies for planetary defense system against asteroids. Development of new technologies for future interstellar missions.





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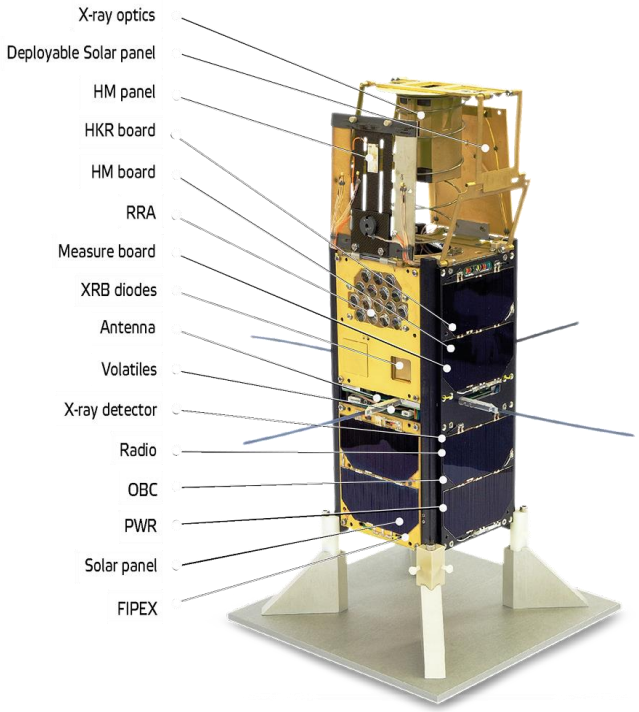
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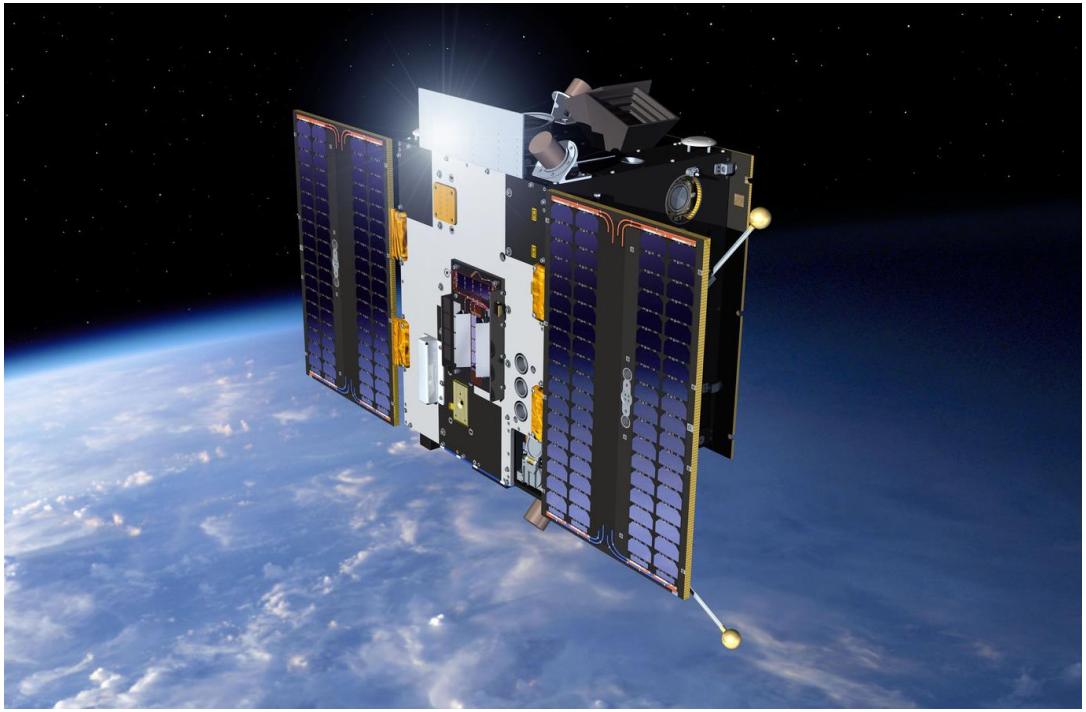
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Satellite classification based on the purpose of use

➢ Technological research

In-orbit demonstrators of new technologies before their real usage. Getting a higher technology readiness level (TRL) is necessary for better commercial success.





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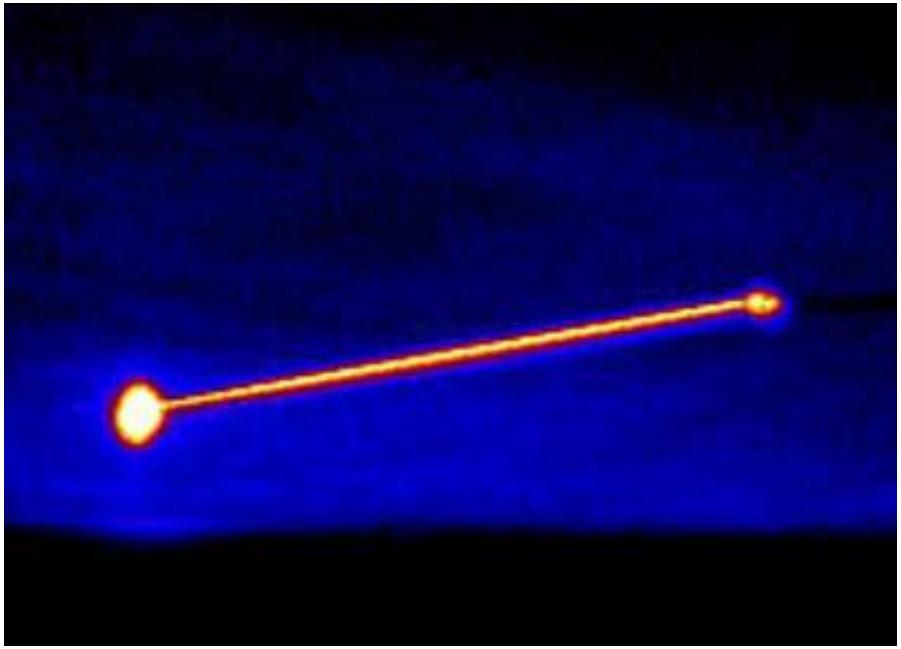
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Satellite classification based on the purpose of use

- **Military use**

  Monitoring of military and naval bases, photogrammetry (calculation of object size and distances), monitoring of thermal emission of missiles and aircrafts, secured communication, secured control of unmanned aerial vehicles, monitoring of radio communication systems.





Space observation / Earth observation / Interplanetary mission / Technological research / Military use / Communication and navigation / Educational / Radio-amateur

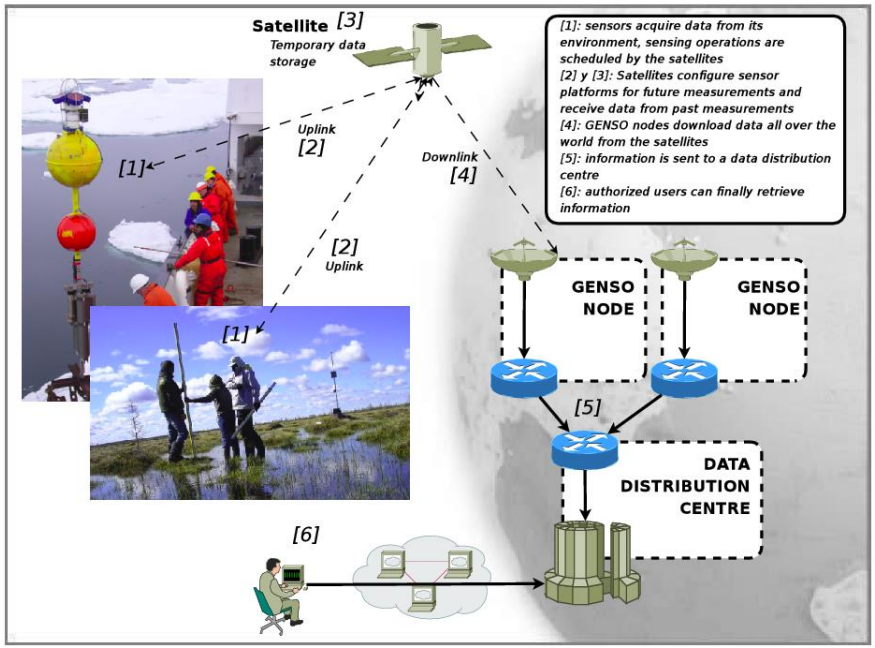
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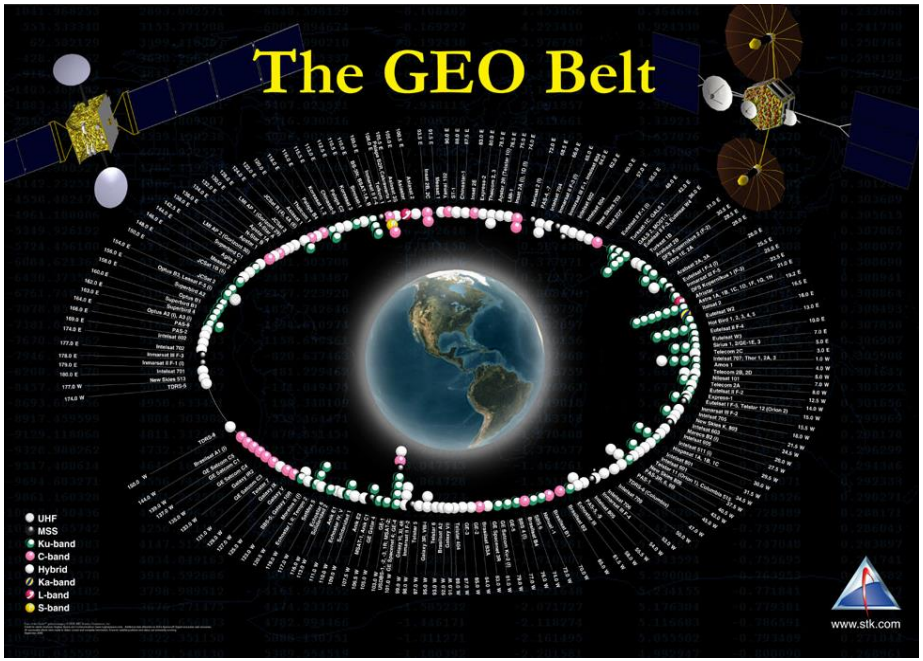
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Satellite classification based on the purpose of use

➢ Communication and navigation

TV and radio broadcasting, satellite telephone networks, data relay networks, search and rescue systems, global navigation satellite systems.





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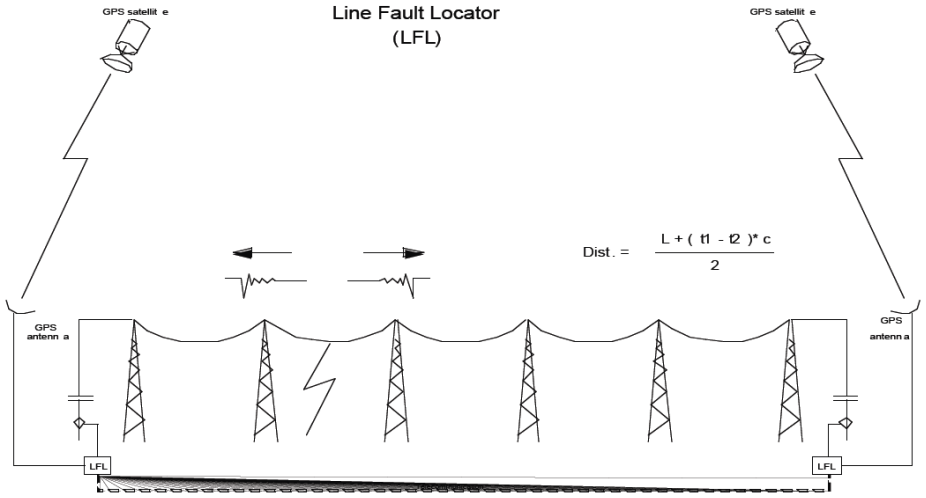
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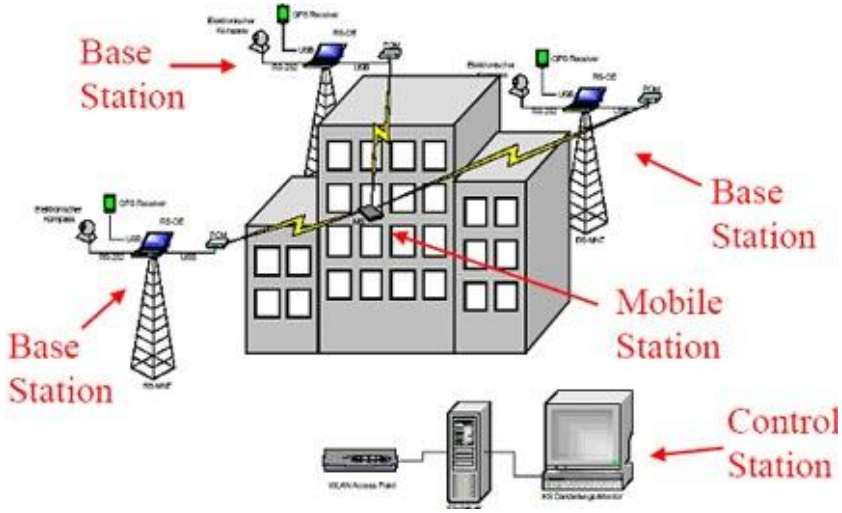
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Satellite classification based on the purpose of use

➢ Communication and navigation

Global navigation satellite systems are based on precise timing and there are also used as a time reference in many applications, such as precise synchronization of laboratory instruments around the world (high-energy particles tracking, gravitational waves detection), fault localization in large power distribution networks, time synchronization of base stations for cellular networks or terrestrial TV broadcasting tower.





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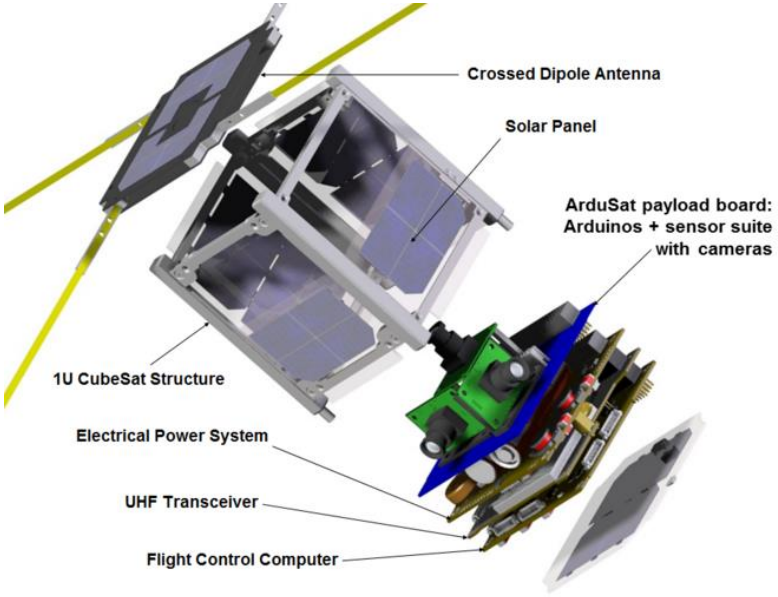
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Satellite classification based on the purpose of use

➢ Educational and amateur research

Satellites designed to educate a new generation of space enthusiasts, technicians and engineers at all levels of education (elementary school, secondary school, universities) as well as for experiments of hobbyists (many crowd-funding projects).





Space observation / Earth observation / Interplanetary mission / Technological research / Military use / Communication and navigation / Educational / Radio-amateur

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Satellite classification based on the purpose of use

- **Radio-amateur**

  Satellites designed to training skills of radio-amateurs, offering a radio transponders and signal repeaters for radio-contact beyond the line of sight or other services (e.g. slow-scan television, packet radio, morse-code beacon).





Space observation / Earth observation / Interplanetary mission / Technological research / Military use / Communication and navigation / Educational / Radio-amateur

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… so it's time for a small summary



- satellites have found application in almost all areas of human civilization (even where it is not obvious at first sight)
- more and more people and private companies can develop own satellites (not only national or international space agencies)
- more and more countries and private companies can launch rocket into space (problems with coordination and safety in near future)
- use of space is becoming more about commercial interests than about prestige and scientific research.

and now what the satellites look like…

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Satellite platform classification based on mass

- In a technical manner:
  - Large spacecraft (> 1000 kg)
  - Medium or small spacecraft (500 kg – 1000 kg)
  - Mini spacecraft (100 kg – 500 kg)
  - Micro spacecraft (10 kg – 100 kg)
  - Nano spacecraft (1 kg – 10 kg)
  - Pico spacecraft (0.1 kg – 1 kg)
  - Femto spacecraft (< 0.1 kg)

"Standard satellites" in the sense of common understanding.

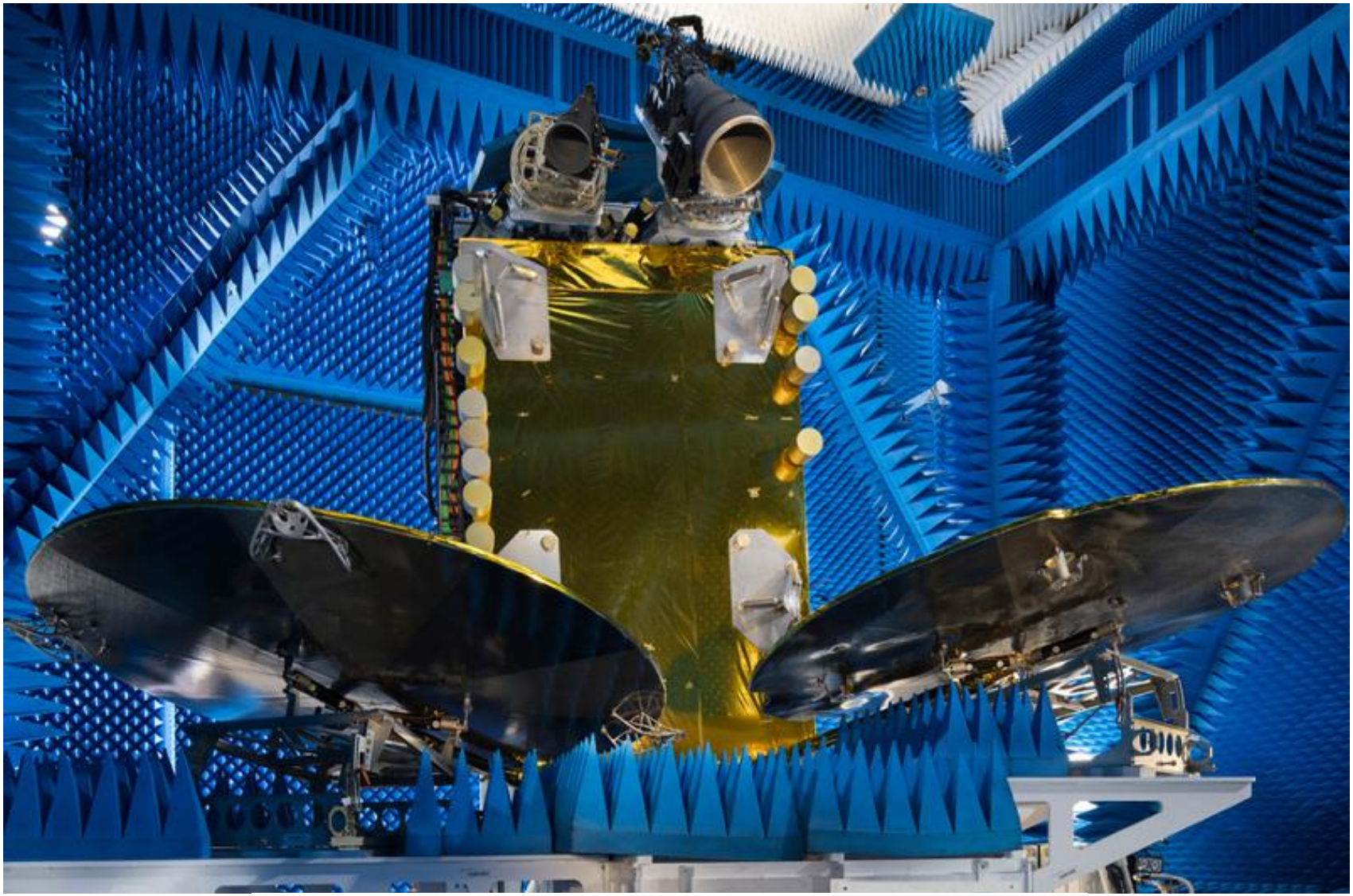
"Small satellites" in the sense of common understanding.

- As miniaturization of electronics systems and sensors continues, the phrase "small satellites" is commonly used for nano-, pico- and femto- satellites, partly also for micro- satellites.
- Each class of spacecraft has many ready-to-use platforms available of the market, with customizable payloads (systems what customers need to operate in space).
- Last decade, platforms based on CubeSat standard dominate in the class of nano- and micro-satellites with payload mass up to approx. 15 kg.

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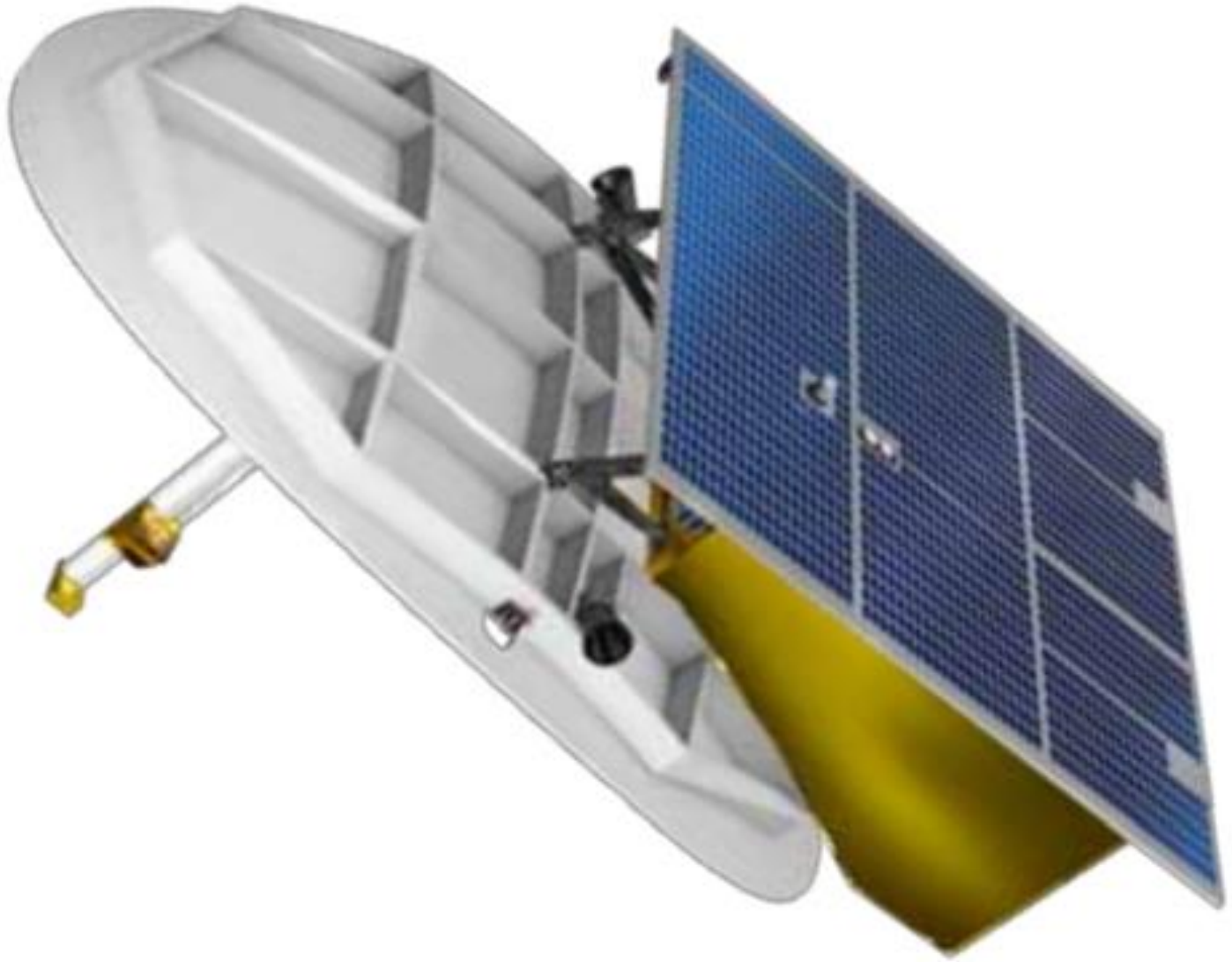
Bangabandhu-1 satellite based on Spacebus 4000 platform (payload mass up to 5700 kg).



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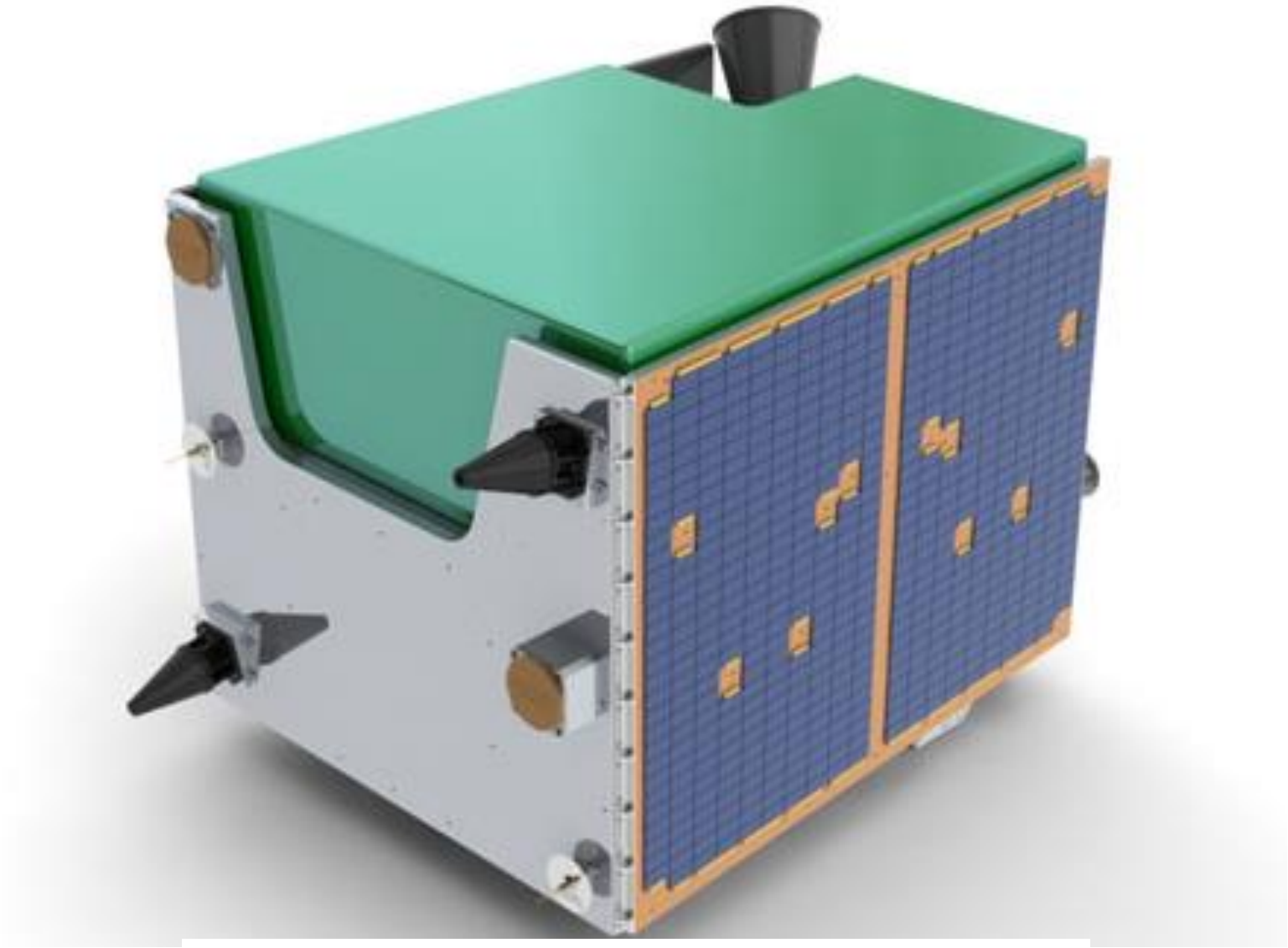
OHB SmartLeo platform (payload mass up to 400 kg).



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SSTL-150 platform (payload mass up to 50 kg).



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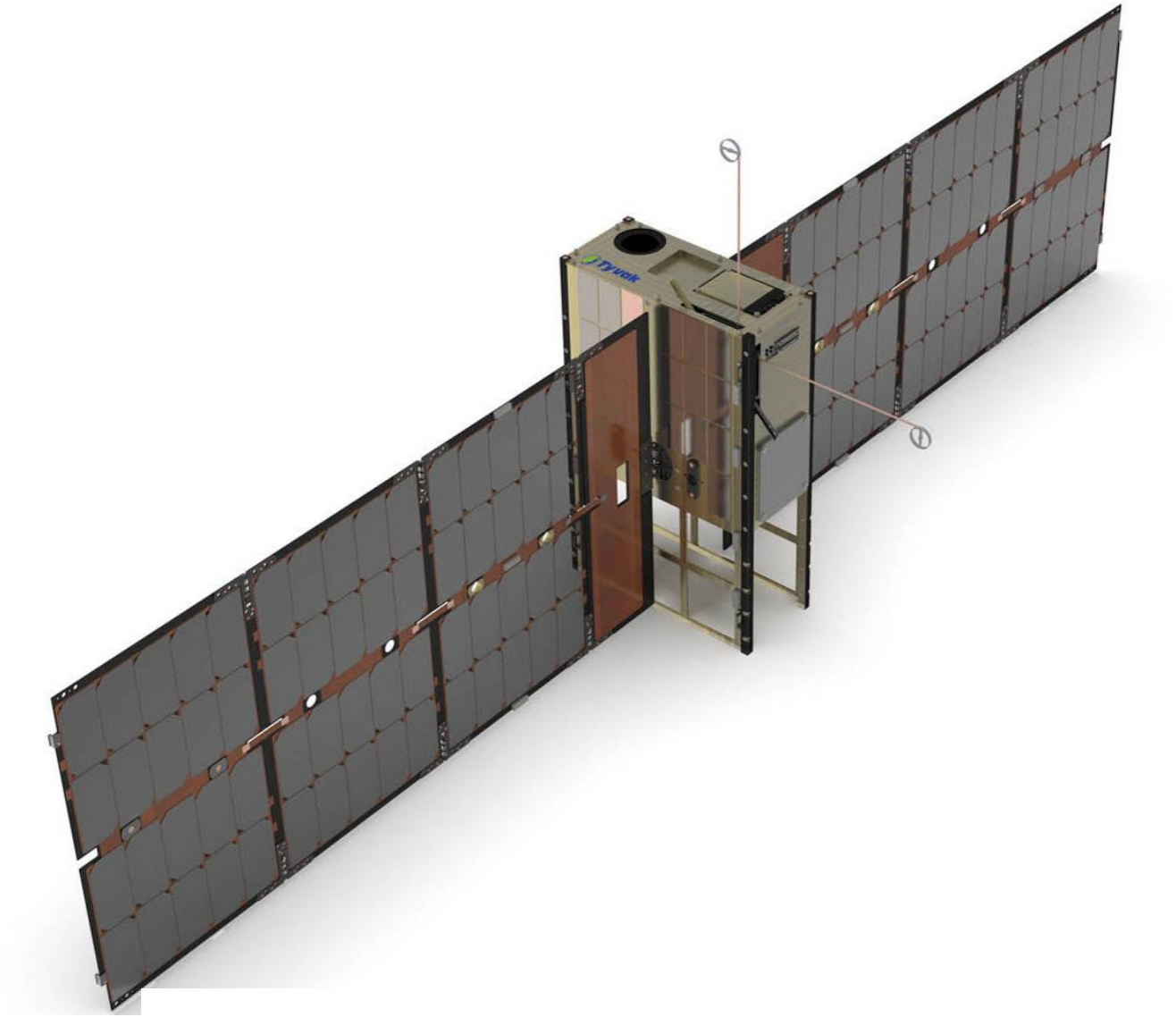
ISIS platform based on 1U CubeSat standard (payload mass up to 0.7 kg).



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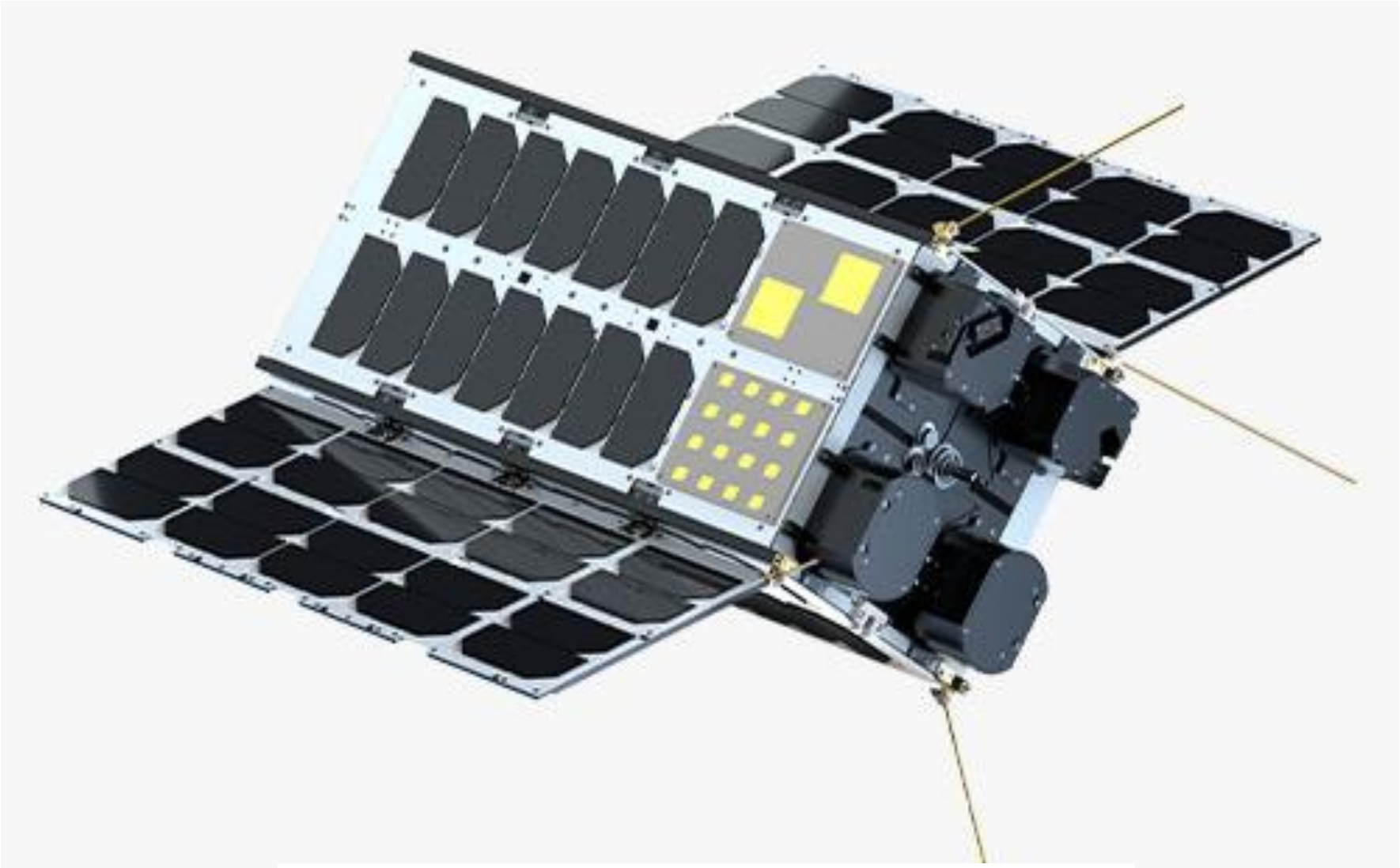
TRESTLES platform based on 6U CubeSat standard (payload mass up to 3 kg).



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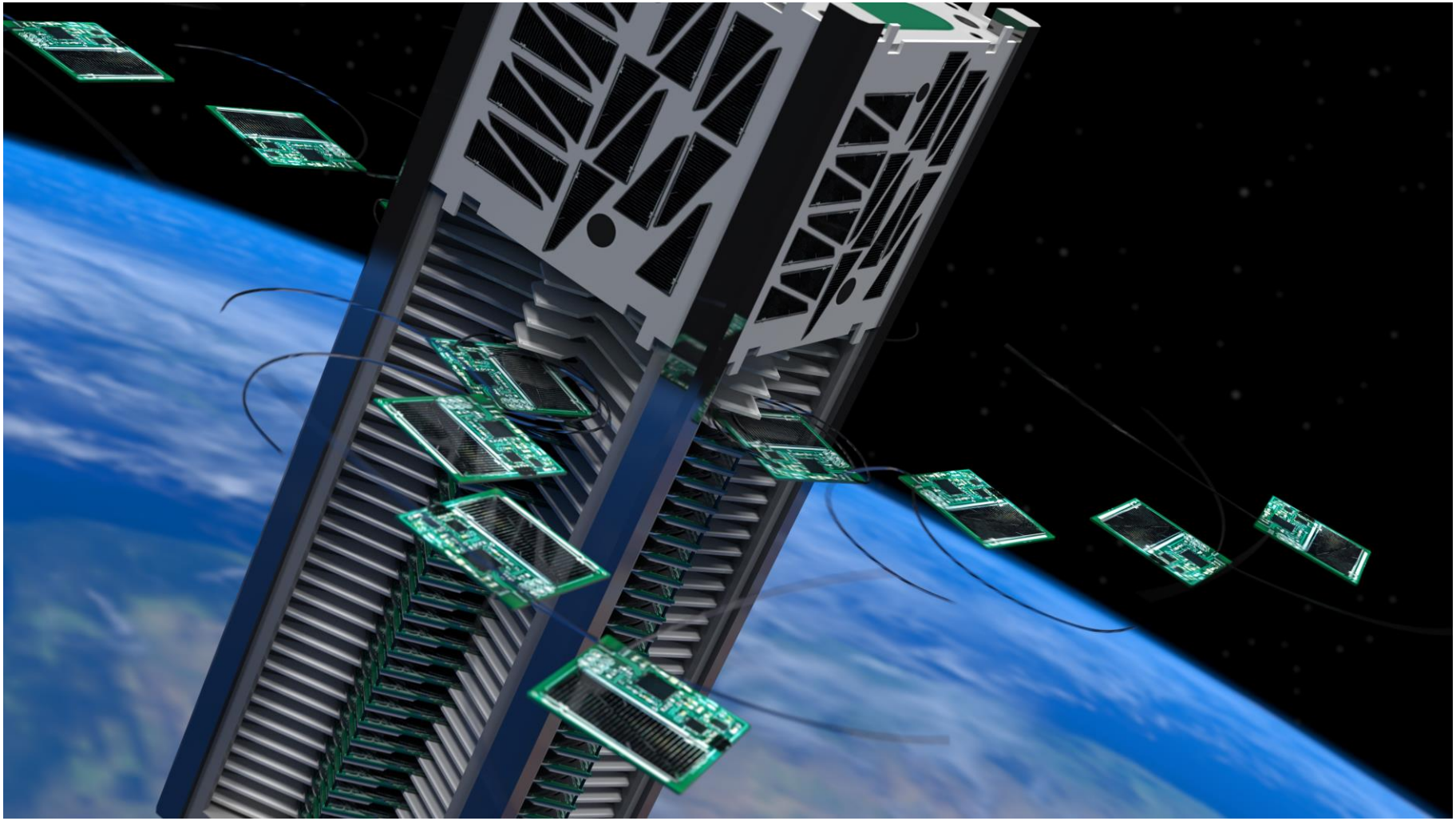
M16P-R platform based on 16U CubeSat standard (payload mass up to 15 kg).



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KickSat-2 (based on 3U CubeSat standard) used as mothership for femtosatellites.



More than 100 femtosatellites (3.5 cm x 3.5 cm) was released at low orbit 325 km in 2019.

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For a deeper overview of satellite platforms, search for the following key words and phrases: satellite bus, satellite platform, nanosatellite platform.



Platforms are characterized by several basic properties:

- Payload mass (how heavy your instruments can be taken onboard)
- Payload power (how many power can be given to your instruments)
- Launch mass (total mass you will pay to launch provider)
- Lifetime on orbit (given by radiation susceptibility)
- Attitude determination and control capability
- Orbital maneuver capability
- Communication link throughput

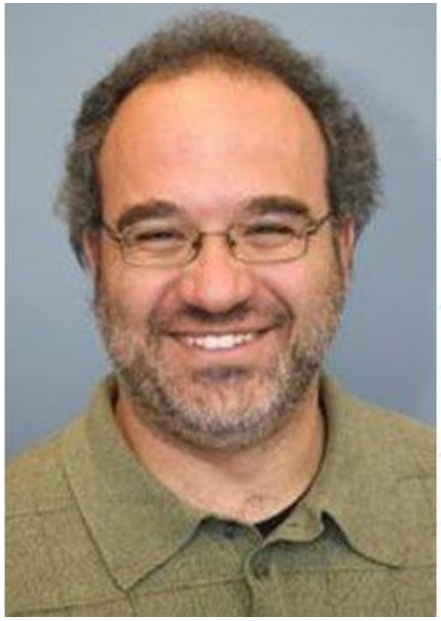
Usually, the smaller the satellite platform, the less payload mass, less power, less attitude accuracy, less lifetime, lower data throughput…. but also much less expensive.

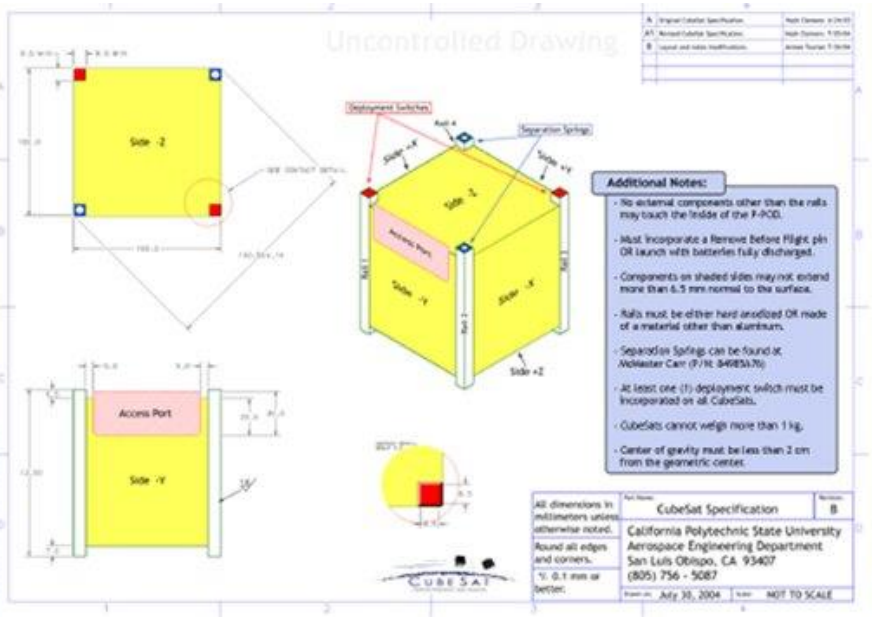
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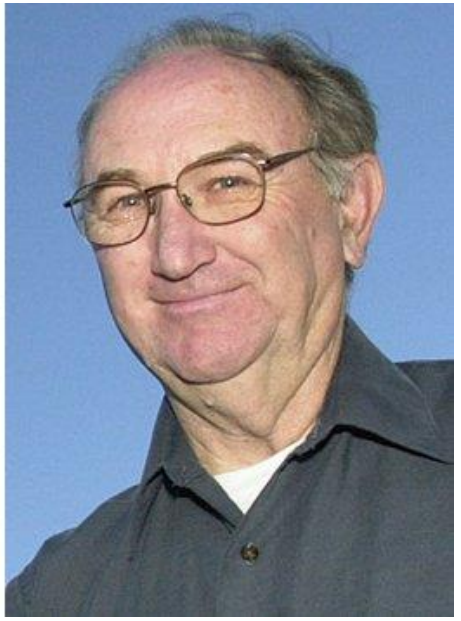
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CubeSat standard for small satellite platforms.

- in last decade dominates in the field of micro-, nano- and pico- satellites
- originated in 1999 by two professors at universities in USA for educational purposes
- now many subclasses (0.5U, 1U, 2U, 3U, 6U, 12U) and commercial products available









For a deeper overview of CubeSat platforms and launch requirements, search for the following key words and phrases: CubeSat design specification, CubeSat units, CubeSat deployer.

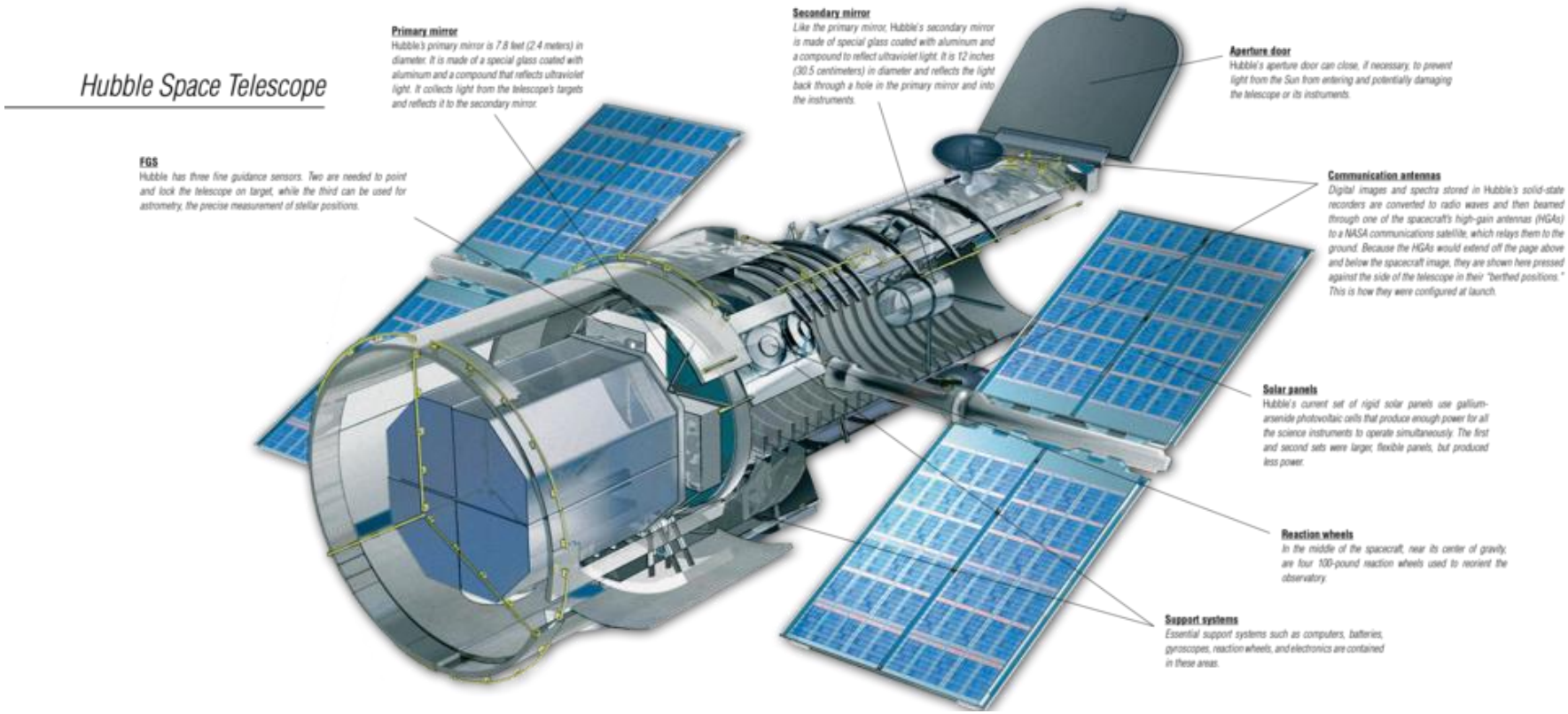


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Spacecraft classification based on method of use

- **Observatory**
  Spacecraft launched on Earth or Solar orbit to observe distant objects free of undesirable effects of the Earth´s atmosphere (typically space telescopes).



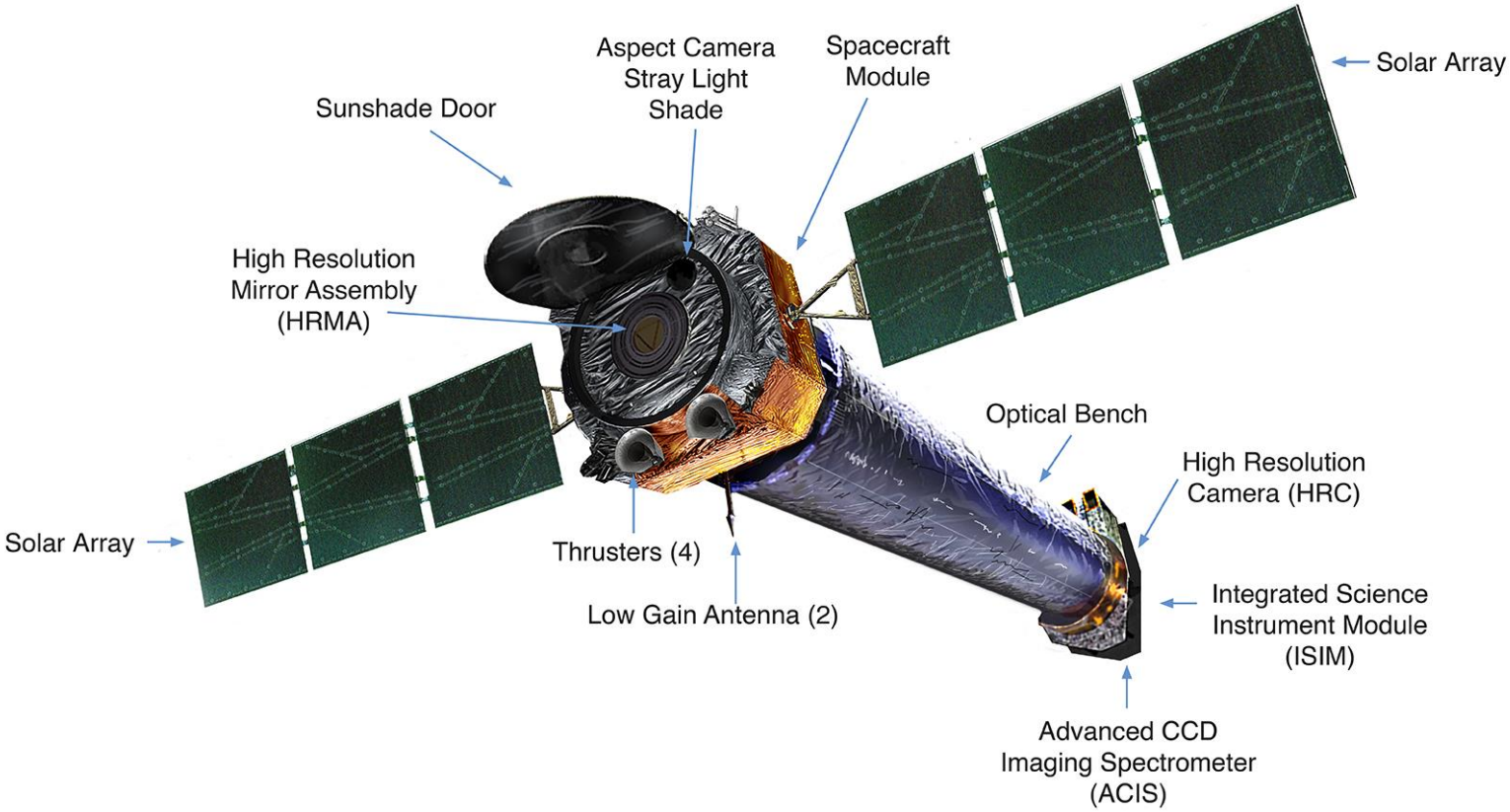
Observatory / Orbiter / Lander / Rover / Flyby / Atmospheric / Penetrator / Communication

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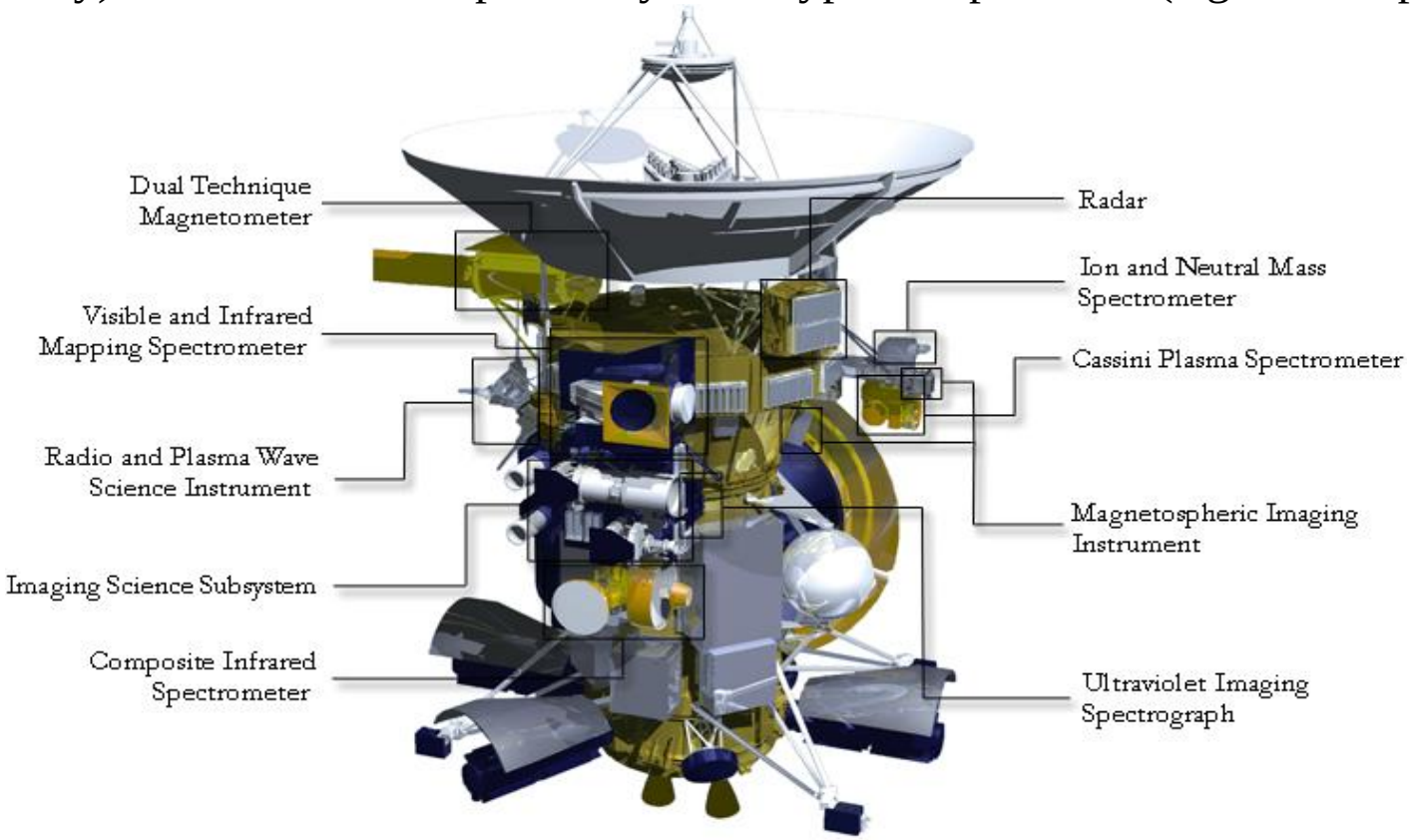
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Spacecraft classification based on method of use

- **Orbiter**

  Spacecraft launched and maneuvered into orbit of Earth or distant planet. Orbiters (especially interplanetary) can also be accompanied by other types of spacecraft (e.g. lander, penetrator).



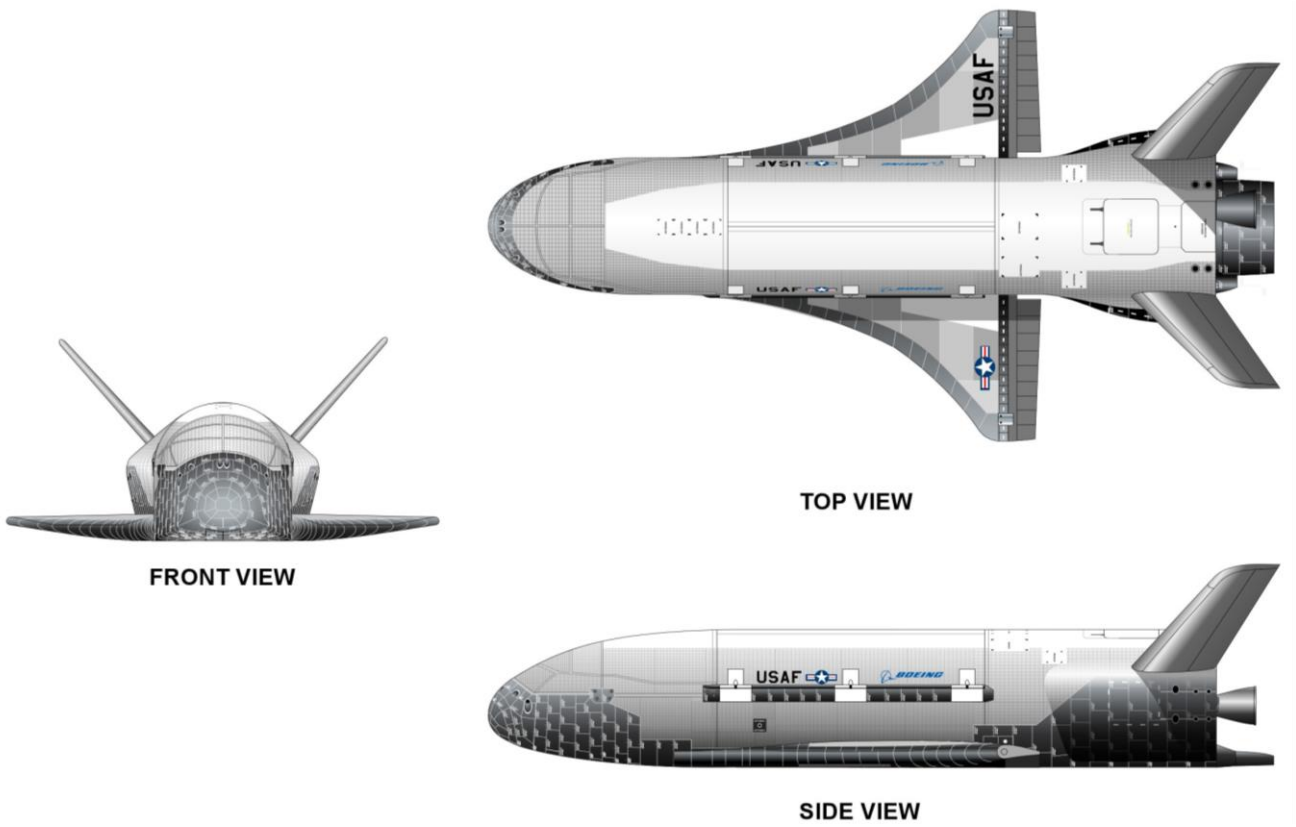
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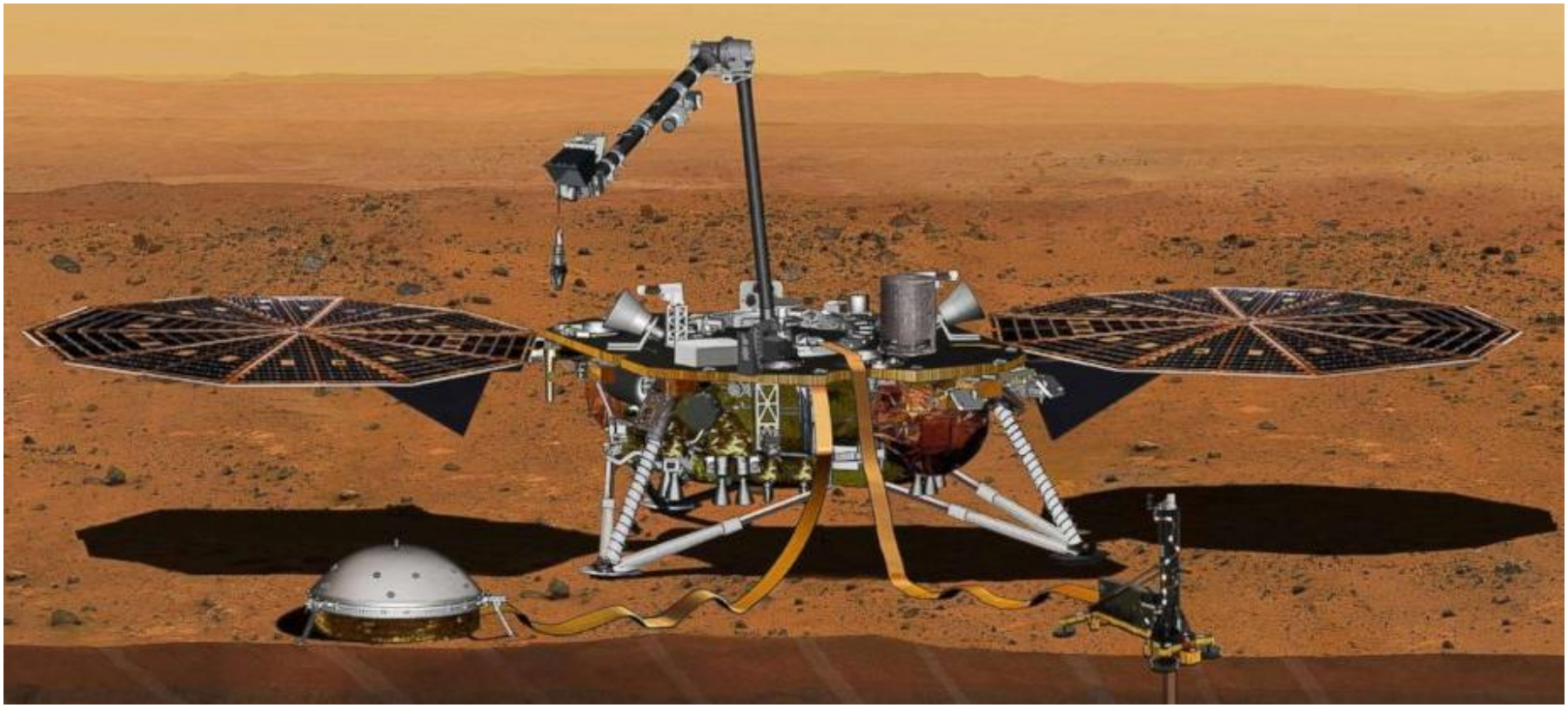
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Spacecraft classification based on method of use

- **Lander**

  Spacecraft designed to land on the surface of a planet (or moons, asteroids) and conduct experiments at fixed place. Landers often cooperate with rovers and/or orbiters.



Observatory / Orbiter / Lander / Rover / Flyby / Atmospheric / Penetrator / Communication

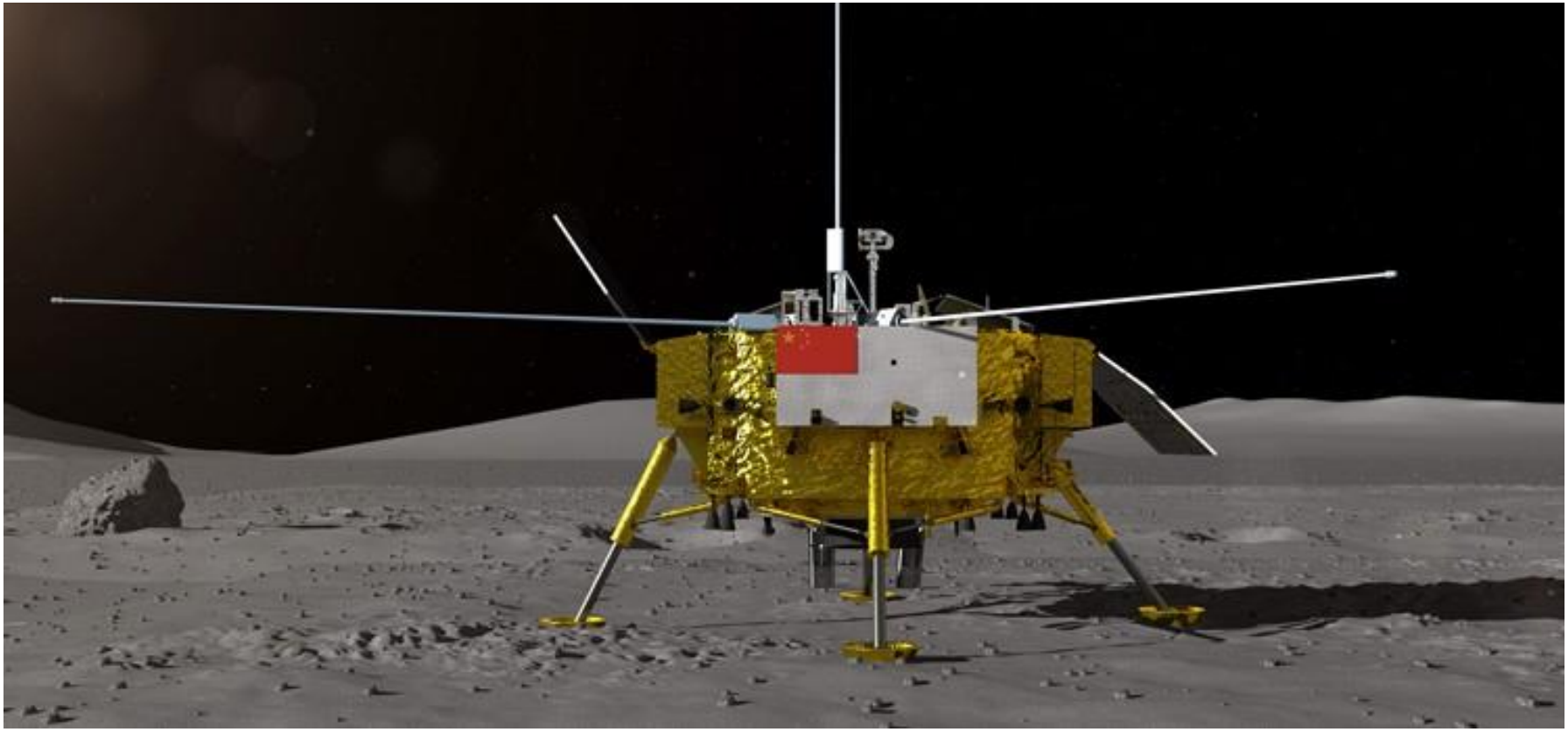
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Spacecraft classification based on method of use

- **Rover / Drone**

  Spacecraft designed to land on the planets (or moons) together with lander and conduct experiments during the journey on the surface.



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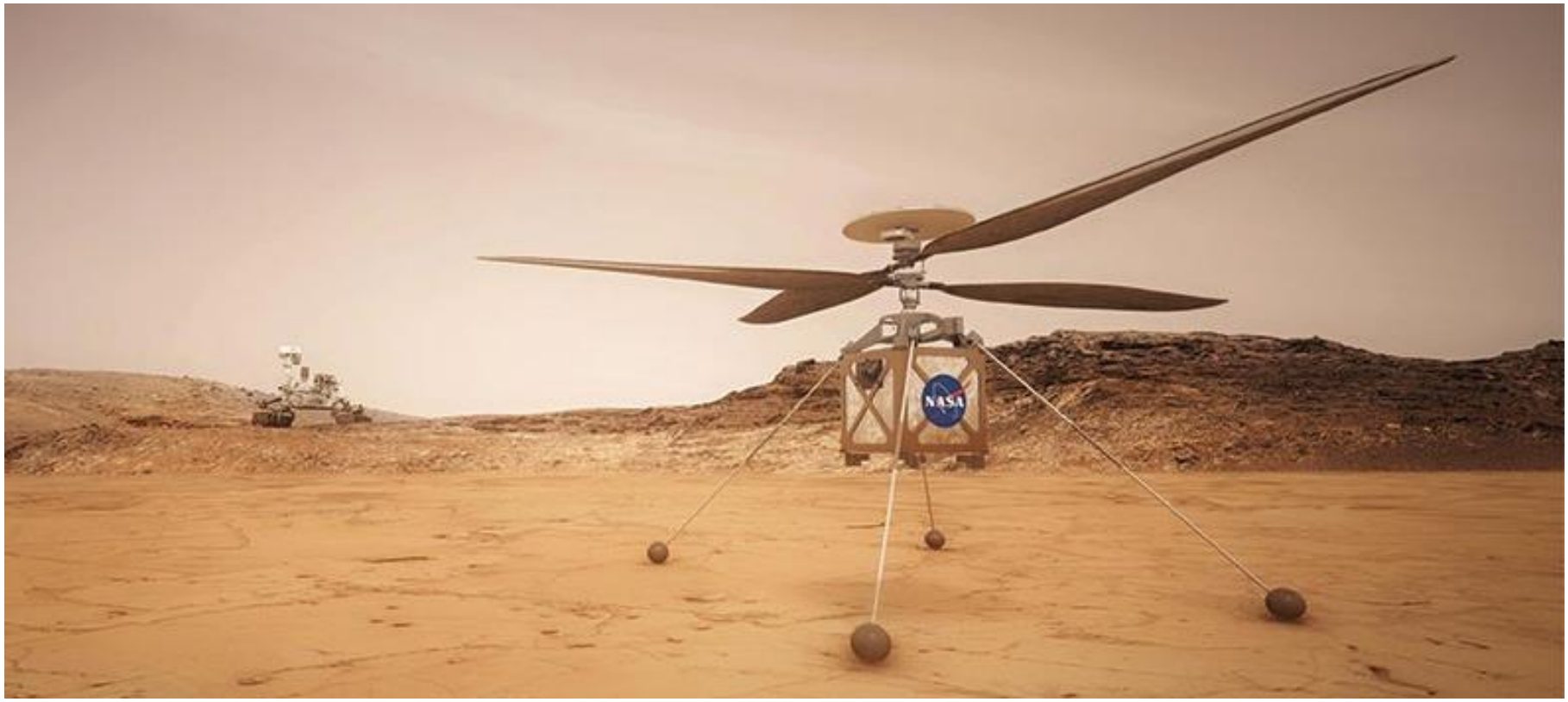
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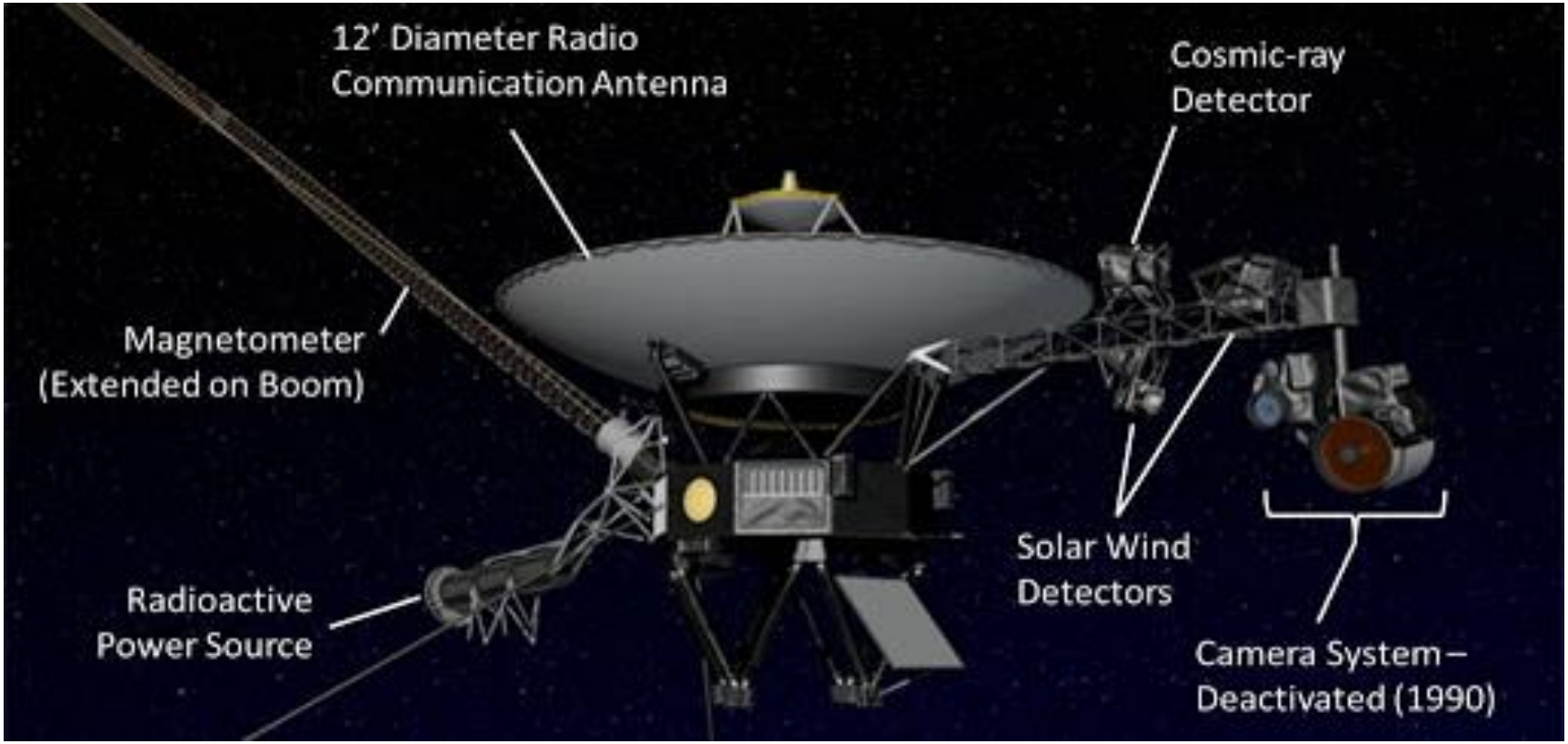
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Spacecraft classification based on method of use

- **Flyby**

  Spacecraft launched on solar orbit or escape trajectory and never captured into planetary orbit. Planets, moons or asteroids are observed during passing in close proximity.



Observatory / Orbiter / Lander / Rover / Flyby / Atmospheric / Penetrator / Communication

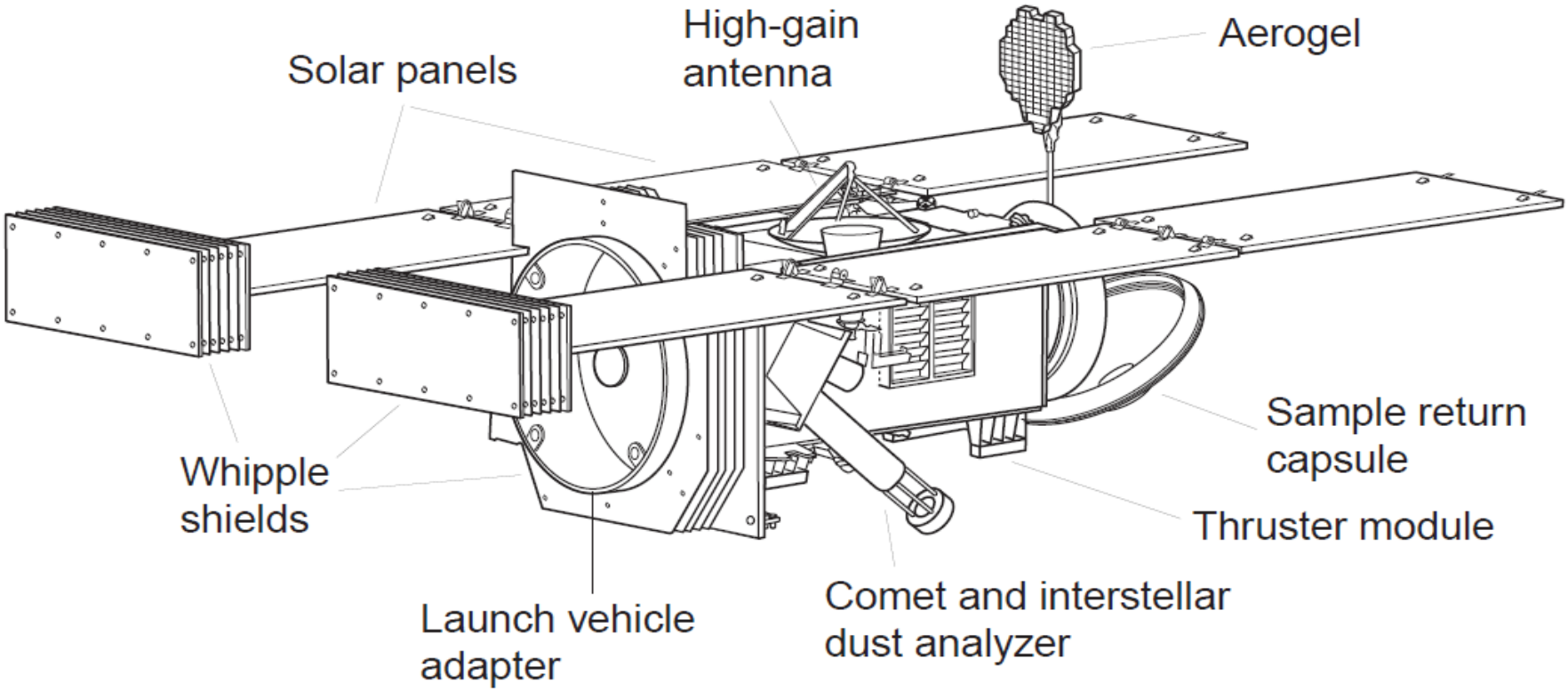
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  Spacecraft launched on solar orbit or escape trajectory and never captured into planetary orbit. Planets, moons or asteroids are observed during passing in close proximity.



Observatory / Orbiter / Lander / Rover / Flyby / Atmospheric / Penetrator / Communication

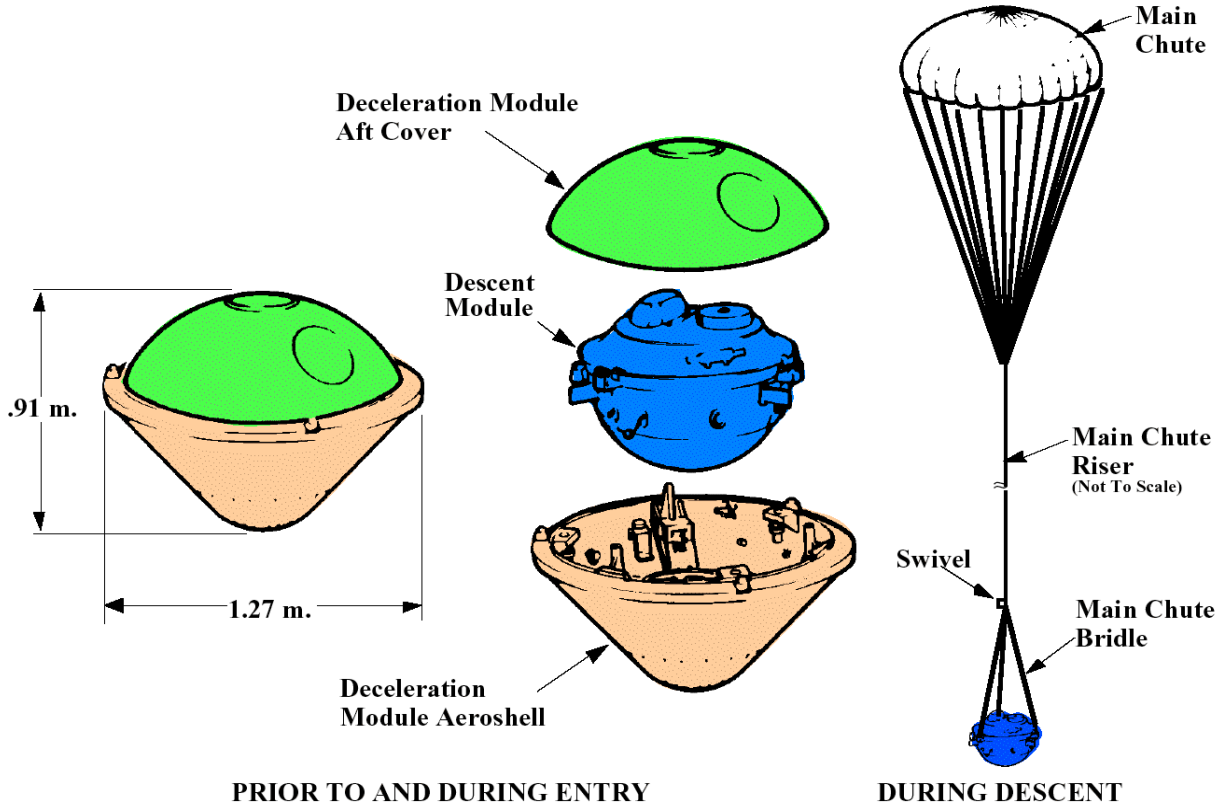
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Spacecraft classification based on method of use

- **Atmospheric**
  Spacecraft for short mission and data collecting during descending into atmosphere of the planet. Usually atmospheric probes are released from main spacecraft (flyby, orbiter).

The Galileo Probe



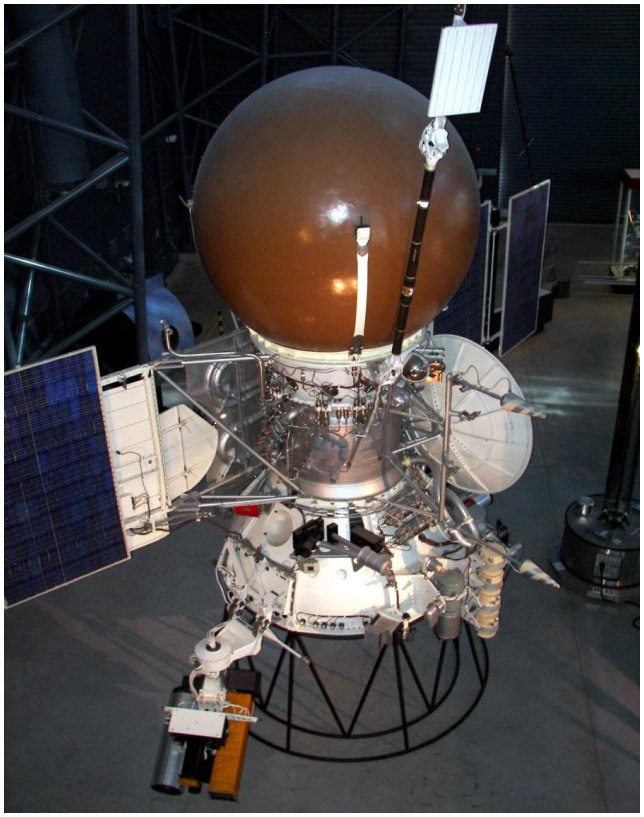
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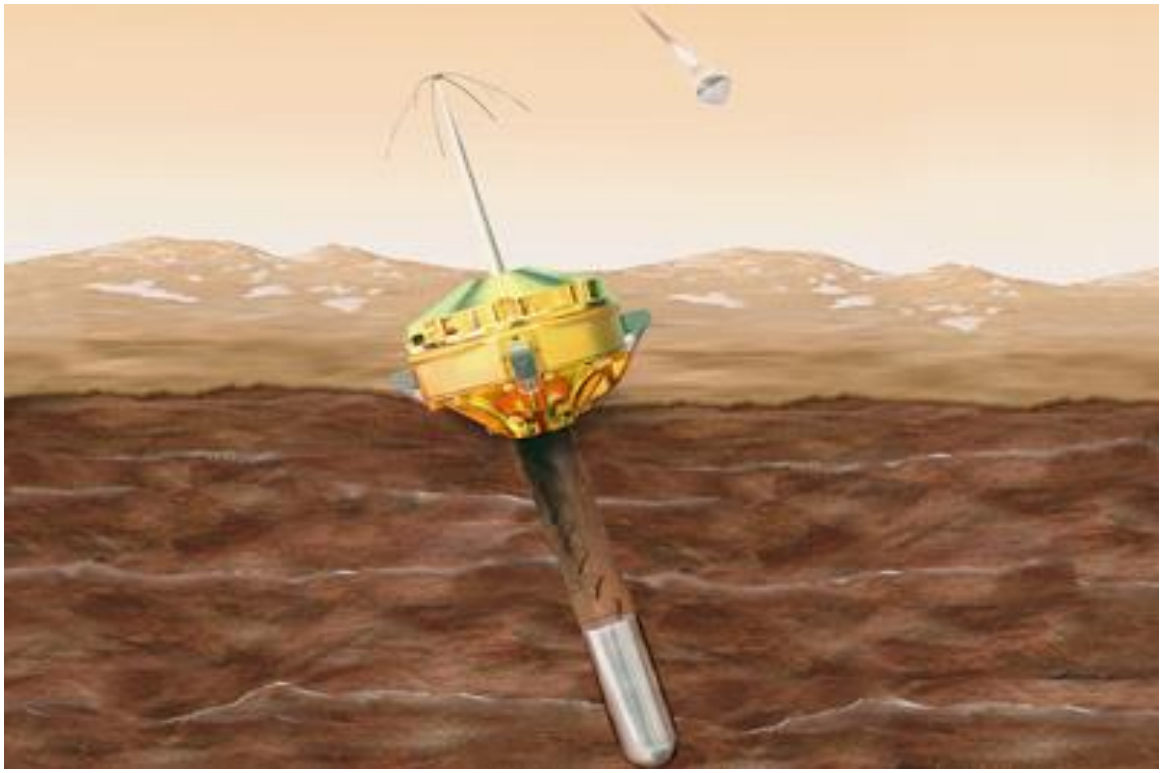
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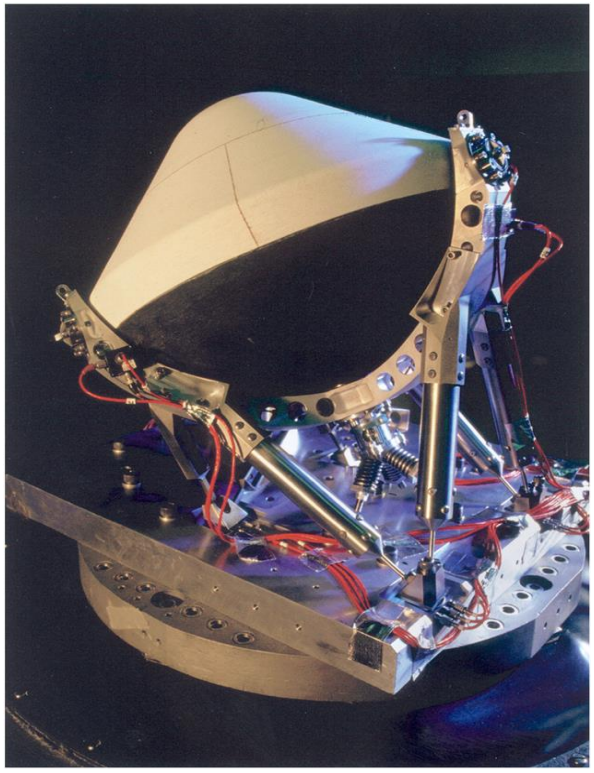
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Spacecraft classification based on method of use

- **Penetrator / Impactor**

  Penetrator spacecrafts are designed to penetrate the surface by the kinetic energy, survive the impact and collect data about properties of material. Impactors generally do not survive the impact, data collected by the main spacecraft (orbiter, flyby).





Observatory / Orbiter / Lander / Rover / Flyby / Atmospheric / Penetrator / Communication

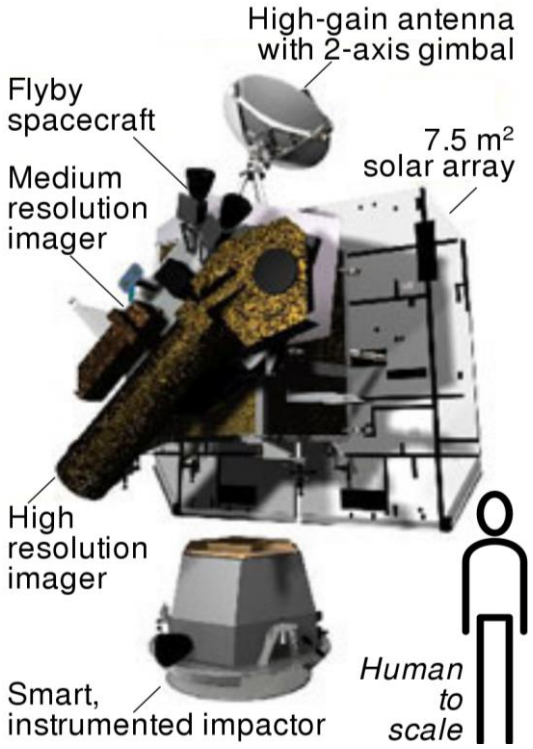
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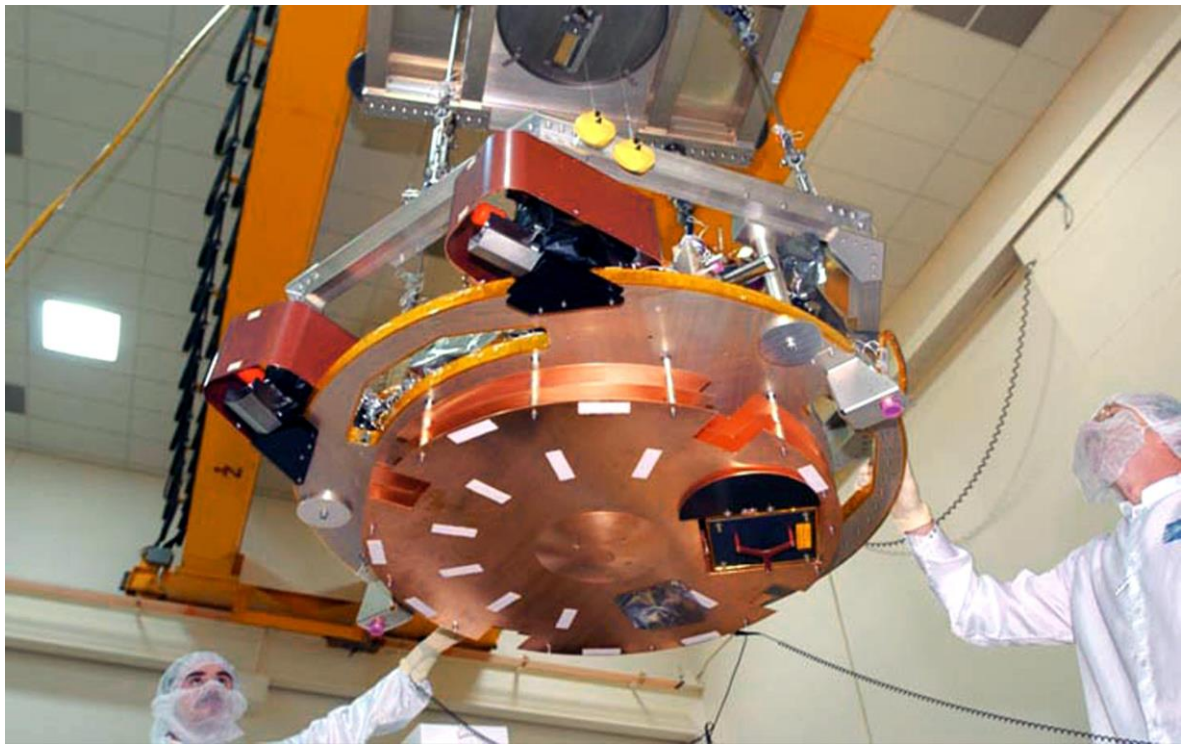
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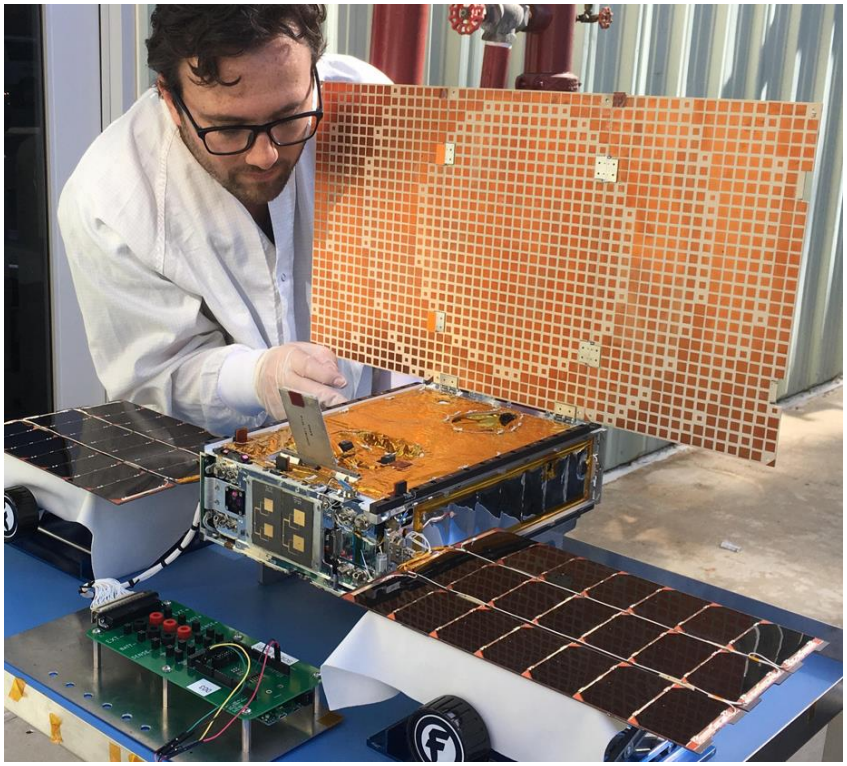
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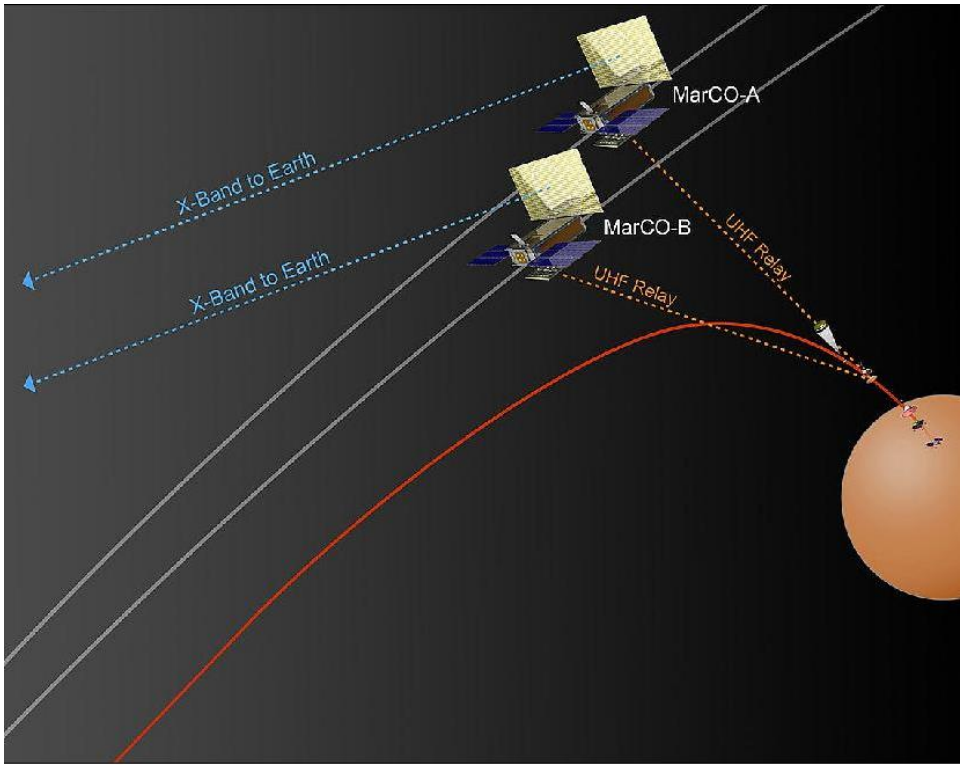
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Spacecraft classification based on method of use

- **Communication and navigation**
  Spacecrafts serving as a data relay system between ground communication facility and rovers, penetrators, landers on a distant planet.





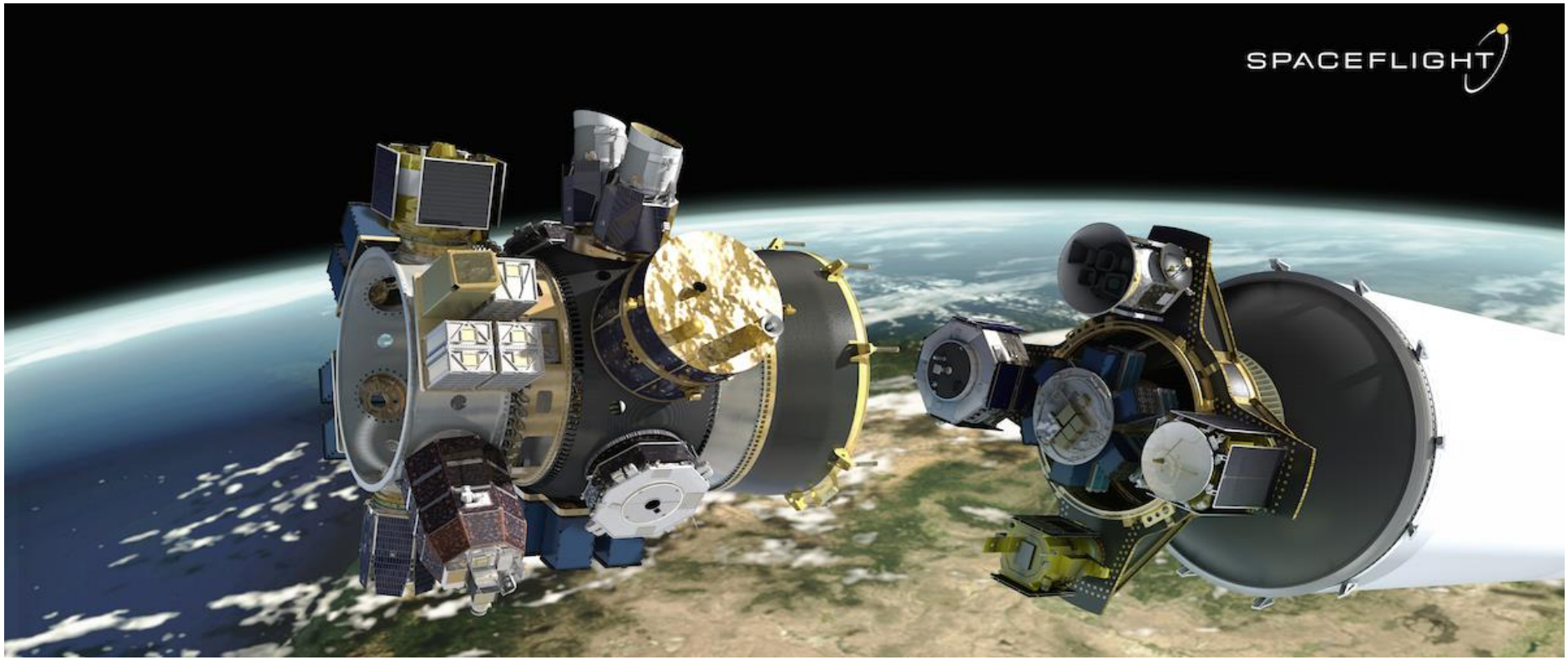
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Payload adapters, separation systems and deployers

- payload adapters are robust mechanical constructions for safety attaching of heavy satellites
- separation systems are electrically controlled parts for reliable releasing of satellites into orbit
- deployers are boxes on payload adapters, dedicated for releasing of many small satellites



Payload adapter of Spaceflight Company with satellites and deployers on Falcon 9 rocket (animation of satellite separation - https://youtu.be/ls7z7CWmoC8).

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SpaceX payload adapter for Falcon 9 rocket without and with Orbcomm satellites.

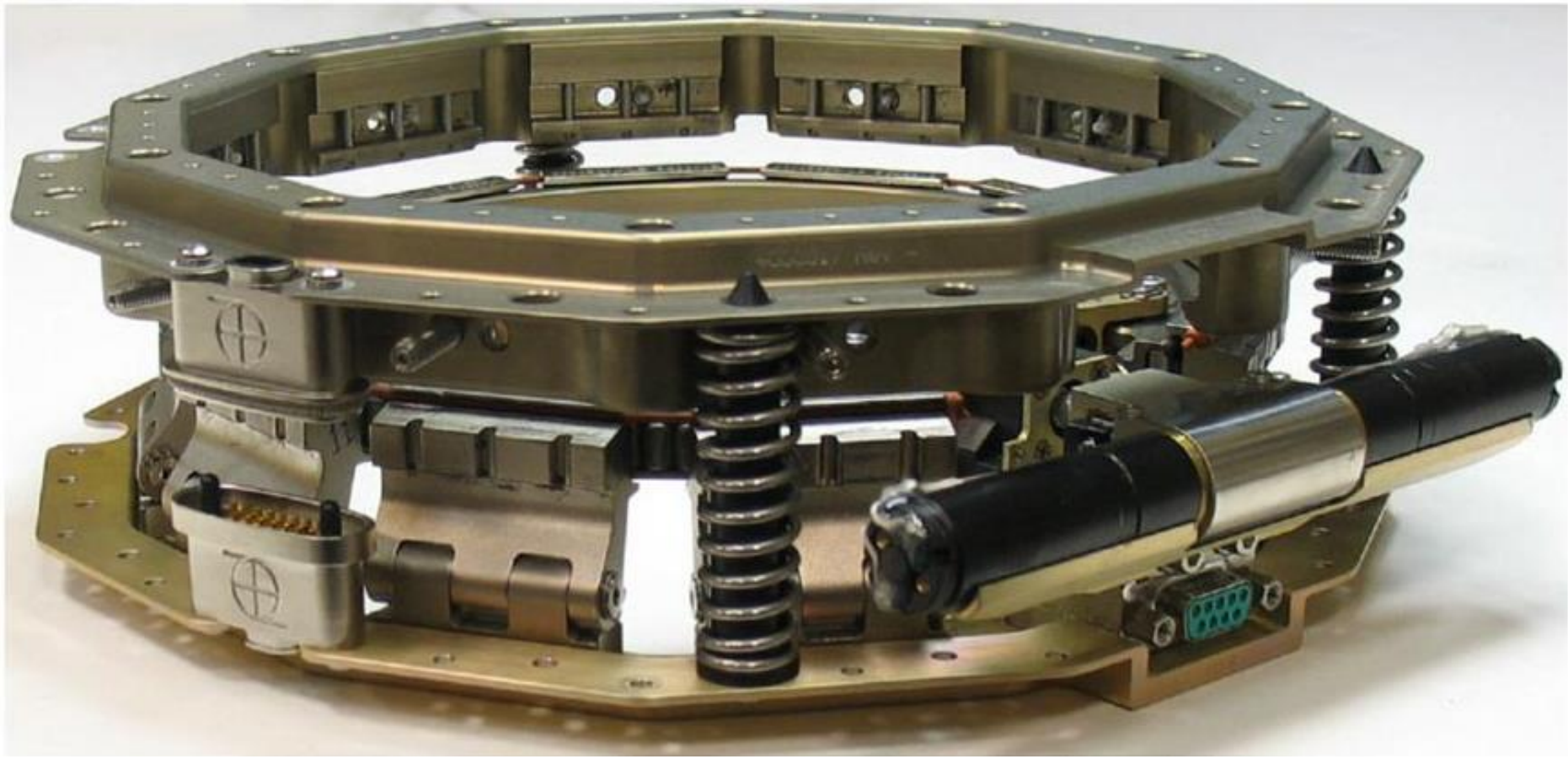




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Mark II motorized separation system (Planetary Systems Corporation).



Lower part attached to the payload adapter, upper part attached to the satellite. Several mechanical locks around the separation system are released by electric motors and large springs push the satellite into orbit.

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CarboNIX separation system for Planet SkySats on Falcon 9.

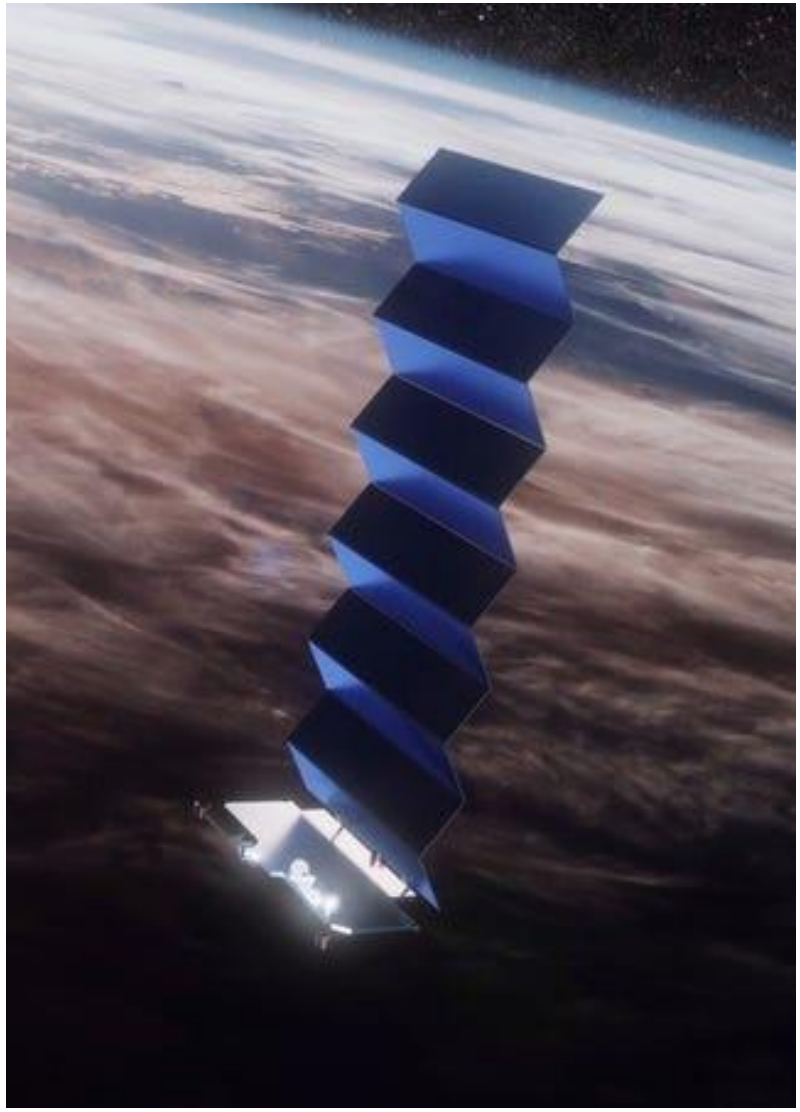


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Starlink satellites (60 pcs) in payload adapter of Falcon 9 rocket and one after releasing.





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ISIS deployer for CubeSats – configurable from twelve 1U CubeSats to one 12U CubeSat.



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… so it's time for a small summary



- there are many customizable commercial satellite platforms with mounting interface (payload adapter and separation system) to rocket used by launch providers
- smallest satellite platforms like CubeSats can be also purchased or commonly manufactured ownself in accordance to design specification guidelines
- all satellites must pass the test procedures (at least vibration test, thermal-vacuum test) prescribed for each type of rocket
- most of rocket launches is "rideshare" – one primary payload (satellite) and many small secondary payloads (other satellites) together into space

and now what orbits the satellites use…

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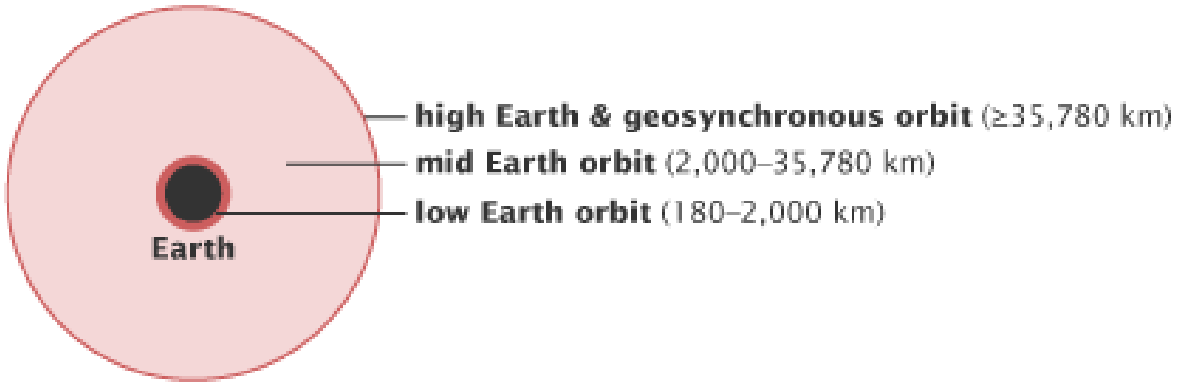
Earth‘s orbits classification and their usage

Classification by altitude of orbit:

- Low Earth orbit (LEO – altitude up to 2000 km altitude)
- Medium Earth orbit (MEO – altitude from 2000 km up to 35786 km)
- Geosynchronous / Geostationary Earth orbit (GSO/GEO - 35786 km altitude)
- High Earth orbit / Highly elliptical orbit

Classification by orbit inclination:

- Inclined orbit
- Non-inclined orbit
- Near equatorial orbit



Some other classifications exist (beyond the scope of this introduction) - by eccentricity, by synchronicity, … (see this link or search phrase „classification of orbits“).

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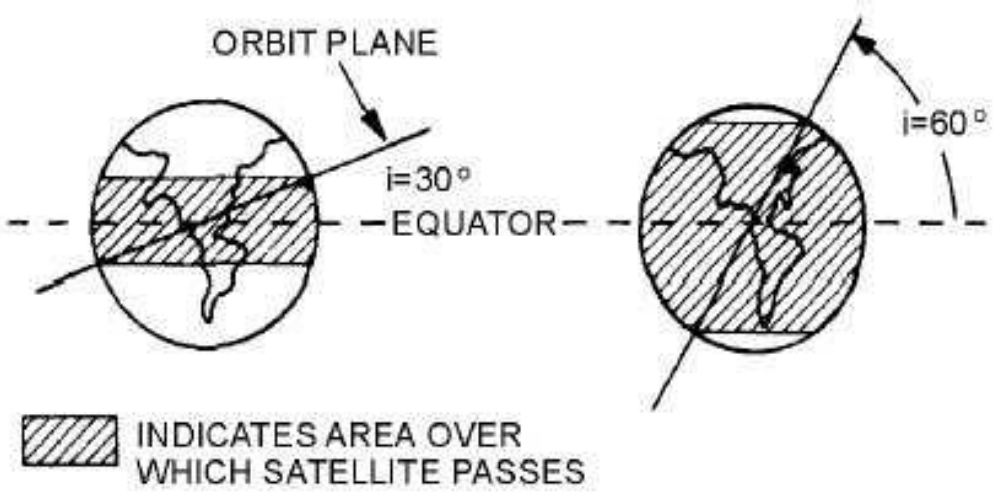
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Earth‘s orbits classification and their usage

➢ Low Earth orbit (LEO – altitude up to 2000 km)

Advantages

- **shorter communication distances**
  radio-communication can be established with lower antenna gain → lower antenna gain means smaller and less directional antennas → smaller and less directional antennas allow to use smaller and less expensive platforms with less accurate attitude control
- **lower delay of signal propagation**
  shorter communication distance → lower delay of signal propagation → more suitable for real-time voice communication (satellite telephone) or for real-time machine control
- **shorter revisit period**
  shorter orbital period → one point on the Earth can be observed several times per day by one satellite → more suitable for data gathering from remote sensors or for spy satellites
- **better image resolution**
  lower altitude above Earth surface → images with higher resolution per pixel → more suitable for satellite mapping and exploration
- **less expensive launch**
  rocket can carry much more mass to LEO than to MEO or HEO → price of launch per one kg of payloads decreases for lower orbits → more satellites with the same financial budget

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Earth‘s orbits classification and their usage

- **Low Earth orbit (LEO – altitude up to 2000 km)**

Disadvantages

- **smaller coverage of the Earth’s surface**
  needs for large satellite constellation and large ground station network when global coverage services (e.g. satellite telephone network, network for access to Internet) are required
- **higher relative speed of satellite against ground station**
  satellite is visible from the ground station only for a short time
  higher Doppler effect have to be instantaneously compensated by the frequency tuning
  antennas on the ground station must be able to track a fast movement of satellite
- **faster de-orbiting due to residual atmospheric drag**
  especially on lower orbits - satellites will reentry approx. during 2 years from 400 km altitude, ½ year from 350 km altitude, 20 days from 300 km altitude (but it depends on factors like Sun activity, shape and mass of satellite, orbit eccentricity). Higher LEO orbits can be quickly overcrowded → small de-orbiting systems are researched.



On this issue you can search phrases: space debris mitigation, de-orbiting system, satellite decay time, orbital decay, orbital lifetime.



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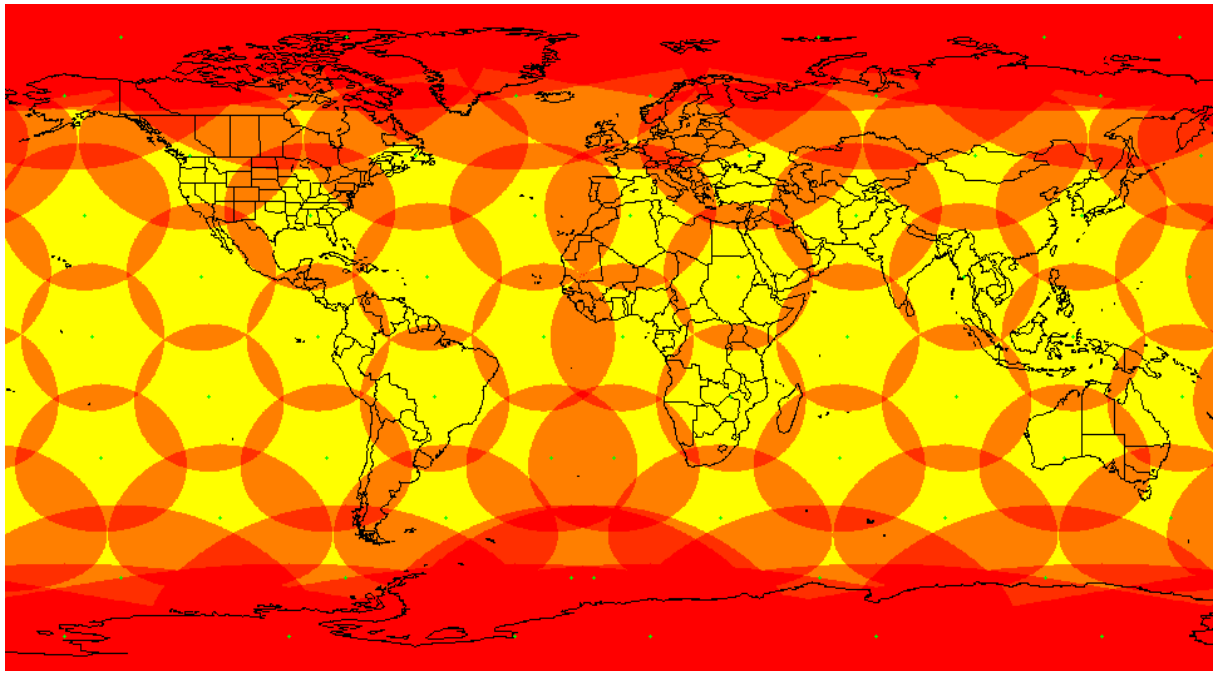
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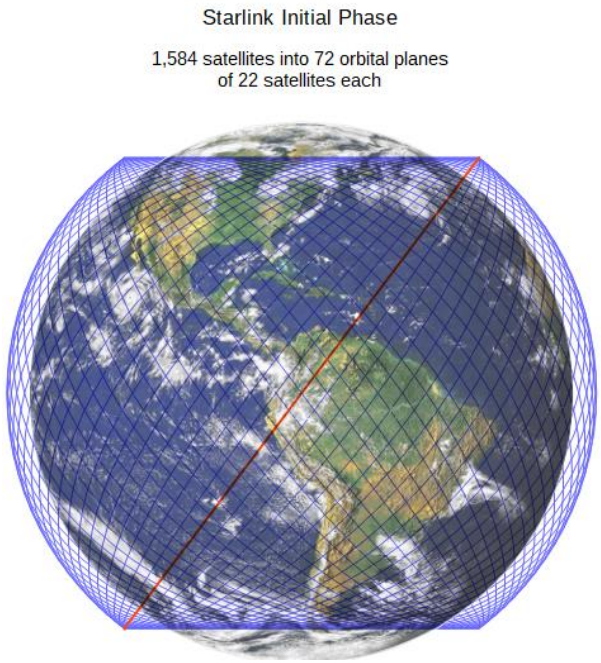
Earth‘s orbits classification and their usage

- **Low Earth orbit (LEO – altitude up to 2000 km)**

Applications

voice and low-speed data networks (e.g. Iridium, GlobalStar), future global networks for Internet access (e.g. OneWeb, Starlink, TeleSat), high resolution satellite imagery (e.g. PlanetLabs, DigitalGlobe constellations), weather satellites (e.g. NOAA-15, NOAA-18)





Current orbital planes of Iridium network in comparison to future Starlink (SpaceX) network.

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Earth‘s orbits classification and their usage

- **Medium Earth orbit (MEO – altitude from 2000 km up to 35786 km)**

Advantages

- **larger coverage of the Earth’s surface**
  needs for smaller satellite constellation and smaller ground station network than for LEO when the services with global coverage (e.g. global weather monitoring, global navigation satellite systems) are required
- **lower relative speed of satellite against ground station**
  satellite is visible from the ground station for a longer time than LEO satellites
  lower Doppler effect, more easily compensated than for LEO satellites
  antennas on the ground station can easily track a slow movement of satellites
- **less utilized orbits**
  lower probability of unwanted collisions or damage by other satellites and space debris (real situation on LEO, at least one collision and several dangerous close passings)

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Earth‘s orbits classification and their usage

- **Medium Earth orbit (MEO – altitude from 2000 km up to 35786 km)**

Disadvantages

- **longer communication distances**
  radio-communication have to be established with higher antenna gain → higher antenna gain means larger and more directional antennas → larger and more directional antennas must be placed on larger and more expensive platforms with more accurate attitude control
- **higher delay of signal propagation**
  longer communication distance → higher delay of signal propagation → less suitable for real-time voice communication (satellite telephone) or for real-time machine control
- **longer revisit period**
  longer orbital period → one point on the Earth can be observed again after longer period than in case of LEO orbits → less suitable for data gathering or for spy satellites
- **worse image resolution**
  higher altitude above Earth surface → images with lower resolution per pixel → less suitable for precise satellite mapping and exploration
- **more expensive launch**
  rocket can carry less mass to MEO than to LEO → price of launch per one kg of payloads increases for higher orbits → less satellites with the same financial budget

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Earth‘s orbits classification and their usage

- **Medium Earth orbit (MEO – altitude from 2000 km up to 35786 km)**

Applications

Global navigation satellite systems GPS (USA), Glonass (Russia), Compass (China), Galileo (European Union), special communication satellites (coast guard in Polar Regions, high speed private links)



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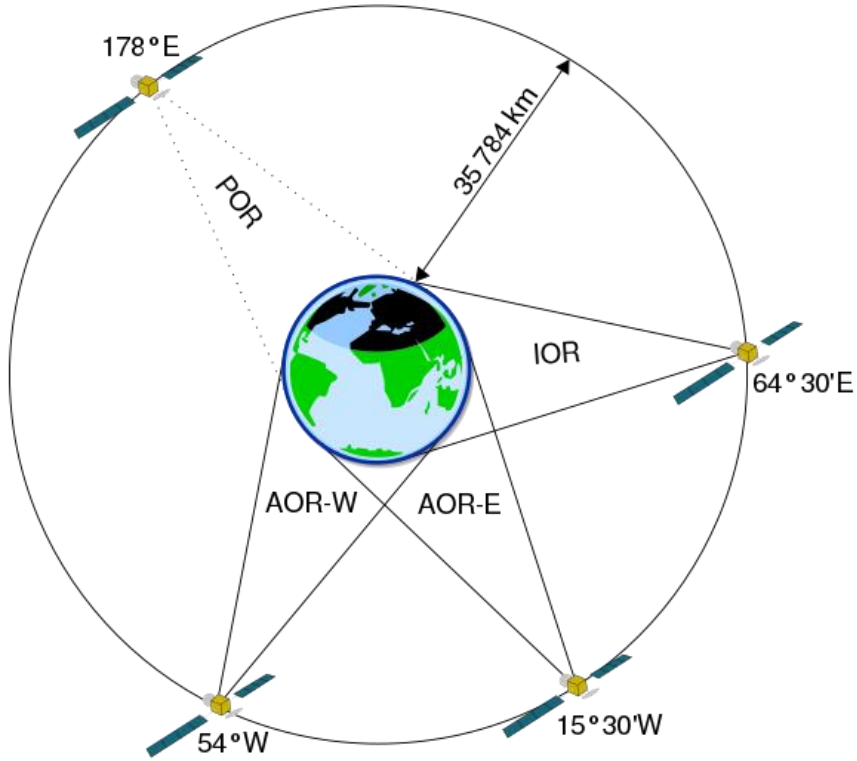
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Earth‘s orbits classification and their usage

➢ **Geostationary Earth orbit (GEO – altitude 35786 km, inclination = 0°)**

Advantages

- **very large coverage of the Earth’s surface**
  only 3 satellites (theoretically) required for almost global coverage (except polar regions), from practical reason at least 4 satellites (e.g. Inmarsat satellite phone network)
- **zero speed of satellite against ground station**
  satellites are visible from the ground station continuously at the same positions, only fixed antenna without tracking required, no Doppler effect



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Earth‘s orbits classification and their usage

- **Geostationary Earth orbit (GEO – 35786 km, inclination = 0°)**

Disadvantages

- **very long communication distances**
  radio-communication have to be established with high antenna gain → high antenna gain means large and directional antennas → large and directional antennas must be placed on large and more expensive platforms with more accurate attitude control
- **high delay of signal propagation**
  long communication distance → high delay of signal propagation → less suitable for real-time voice communication (satellite telephone) or for real-time machine control
- **bad satellite visibility in northern or southern areas**
  satellites are visible in low elevation above horizon in northern and southern areas, buildings or natural terrain can make impossible the satellite reception
- **very expensive launch**
  rocket can carry low mass to GEO than to LEO → price of launch per one kg of payloads increases for higher orbits → less satellites with the same financial budget
- **overcrowded orbit**
  old satellites have to be move away (graveyard orbit) to release positions to new satellites

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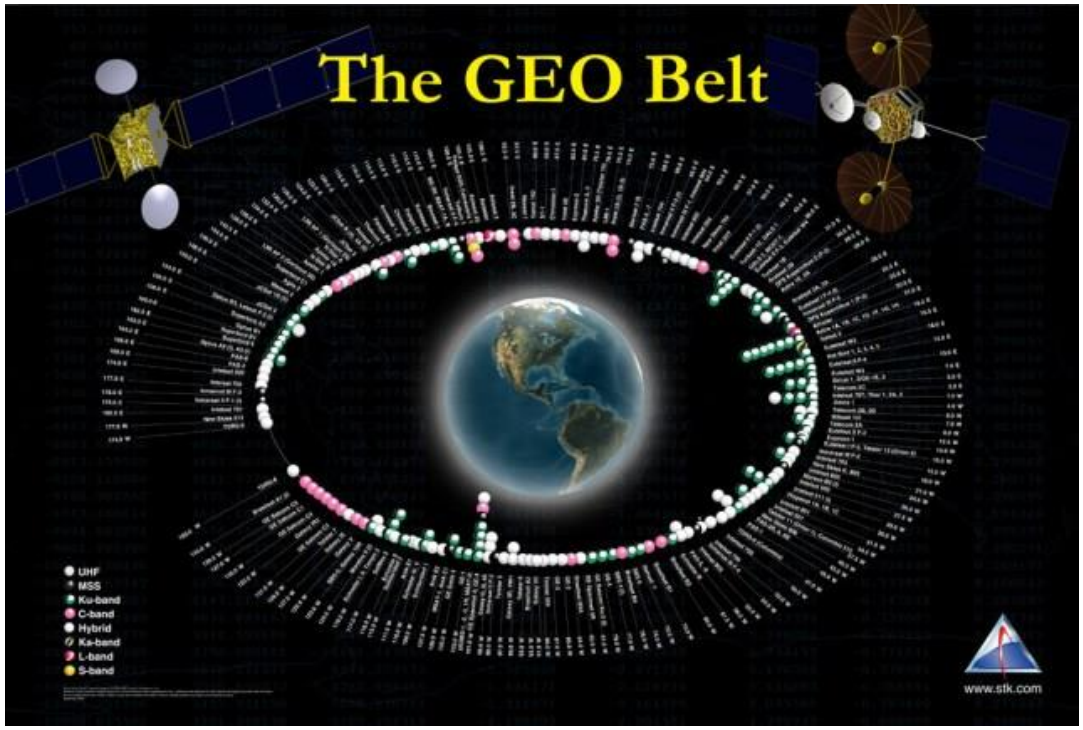
Earth‘s orbits classification and their usage

- **Geostationary Earth orbit (GEO – altitude 35786 km, inclination = 0°)**

Applications

Digital television and radio broadcasting (DVB-S/S2), data and voice call network (e.g. InmarSat), corrections and support to GNSS systems (WAAS, EGNOS, GAGAN,…), weather forecast services (MeteoSat, GOES)





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Earth‘s orbits classification and their usage

➢ **Geosynchronous Earth orbit (GSO – altitude 35786 km, inclination > 0°)**

Advantages

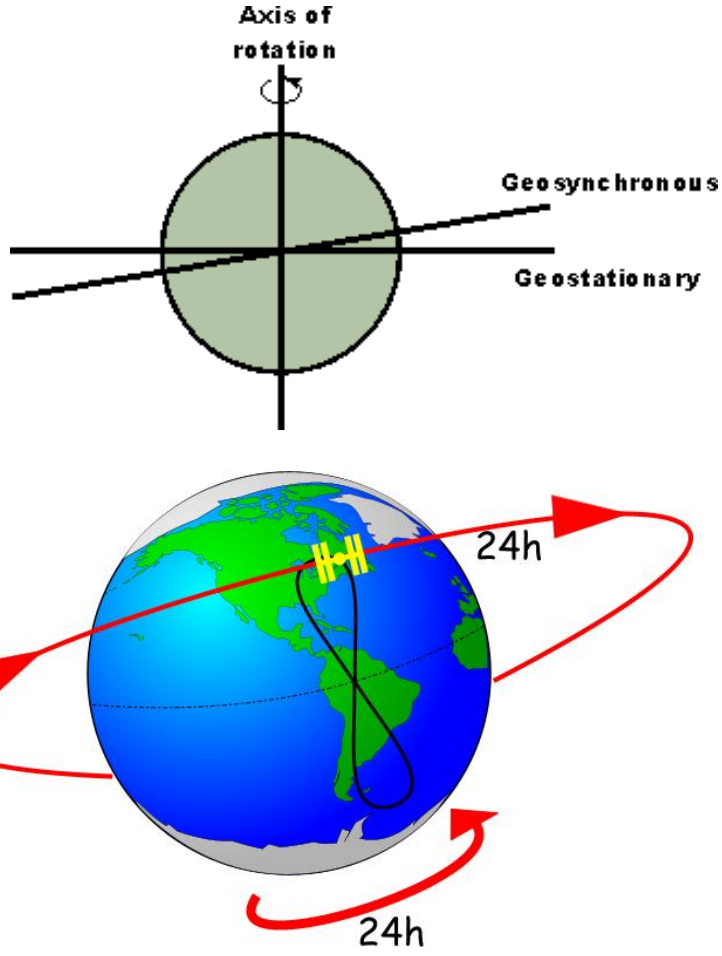
- **very large coverage of the Earth’s surface** as geostationary satellites
- **very low speed of satellite against ground station** satellites are visible from the ground station as slowly moving, negligible Doppler effect
- **better visibility in northern or southern areas** satellites slowly moves to higher elevation above horizon from the point of view from the ground station

Disadvantages

as geostationary orbit except bad visibility

Applications

Support of GNSS systems (navigational and correction signal broadcasting) for urban area, military observation and communication



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Earth‘s orbits classification and their usage

➢ **High Earth orbit / High elliptical orbit (max. altitude above 35786 km)**

Advantages

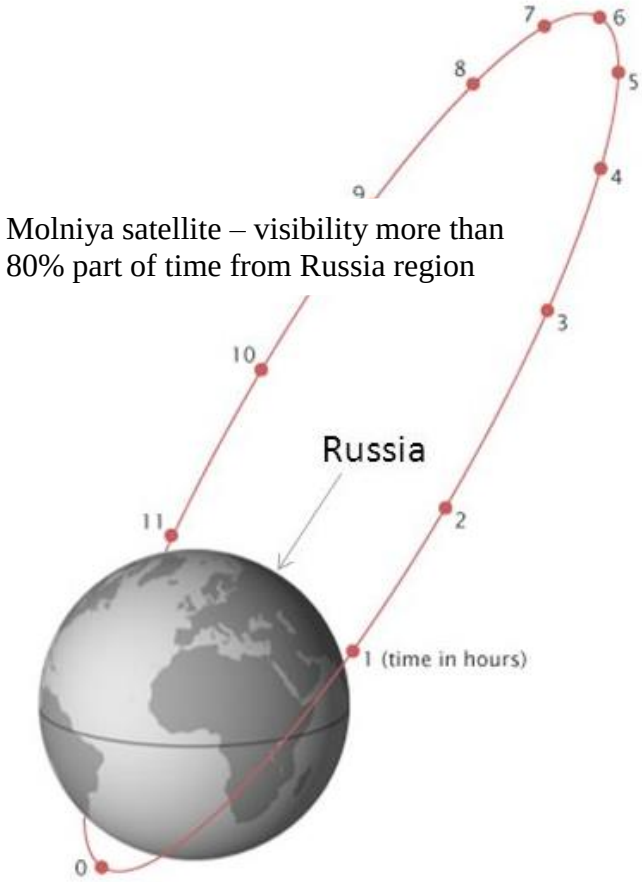
- **very large coverage of the Earth’s surface**
  as geostationary satellites
- **better visibility in urban area**
  small amount of satellites (3 or 4) on the same elliptical orbit can ensure good visibility (at least one in high elevation above horizon) for a long time in requested area

Disadvantages

as geostationary/geosynchronous orbit except bad visibility and orbit overcrowded

Applications

Support of GNSS systems (navigational and correction signal broadcasting) for urban area, military observation and communication

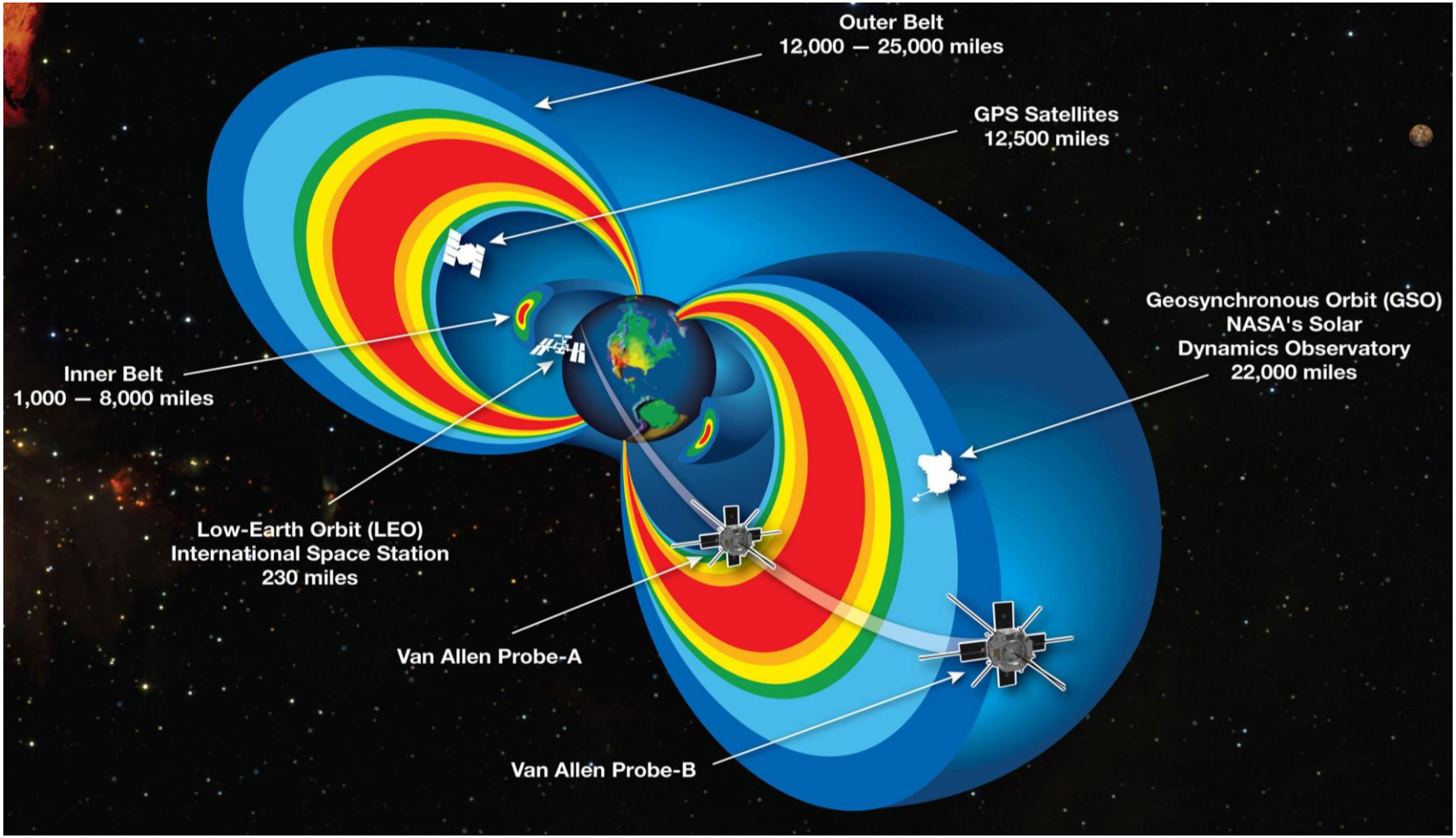


Molniya satellite – visibility more than 80% part of time from Russia region

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Earth‘s orbits classification and their usage



Some orbits are not suitable for satellites due to high radiation (Van-Allen radiation belts).

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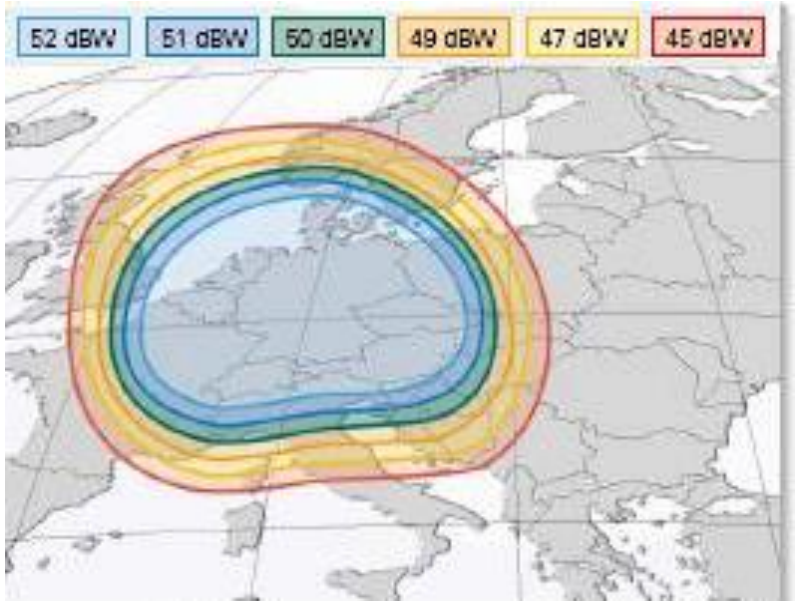
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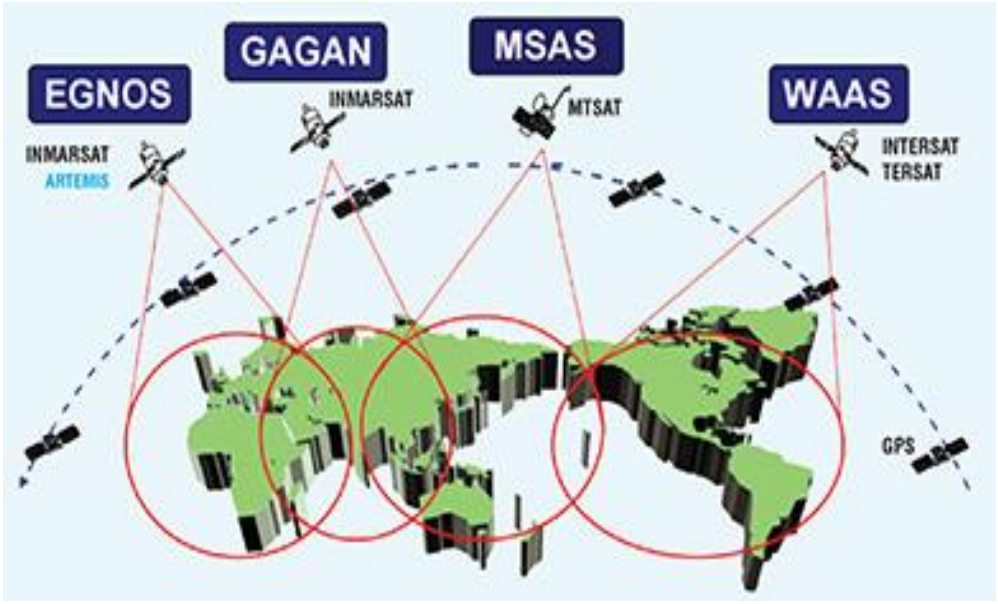
Earth‘s orbits classification and their usage

Classification by orbit inclination – angle between orbital plane and reference plane (planet's equator) is used to plan a service with effective coverage by satellite or constellation.

- **Non-inclined or near equatorial orbit**

  Usually used as geostationary or geosynchronous orbits for services above fixed regions, requiring only a low number of satellites – e.g. DVB-S television broadcasting, SBAS corrections to global satellite navigation systems, etc.





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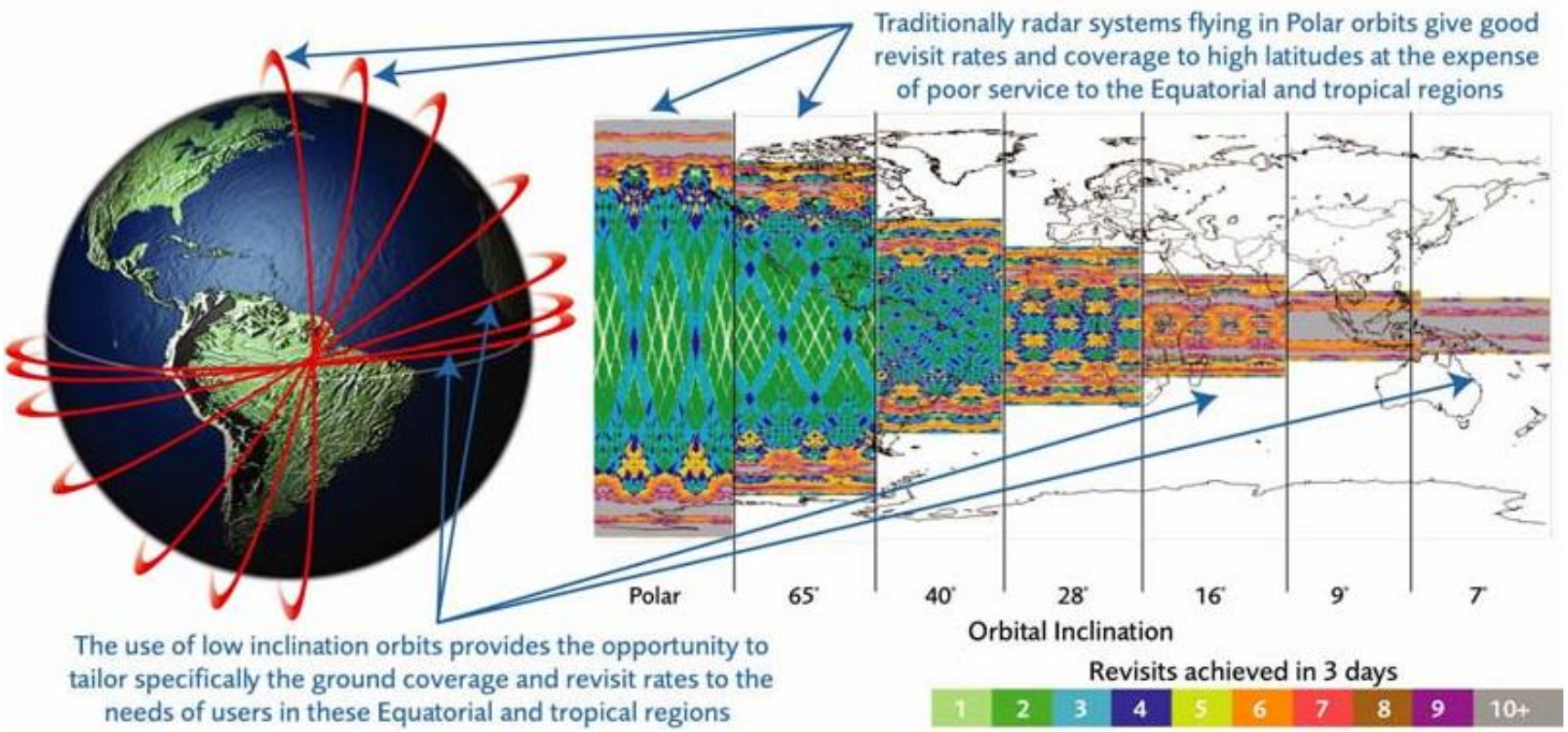
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Earth‘s orbits classification and their usage

Classification by orbit inclination – angle between orbital plane and reference plane (planet's equator) is used to plan a service with effective coverage by satellite or constellation.

- **Low-inclined orbit**

  Usually used for Earth observation in equatorial regions (e.g. illegal logging of forests).



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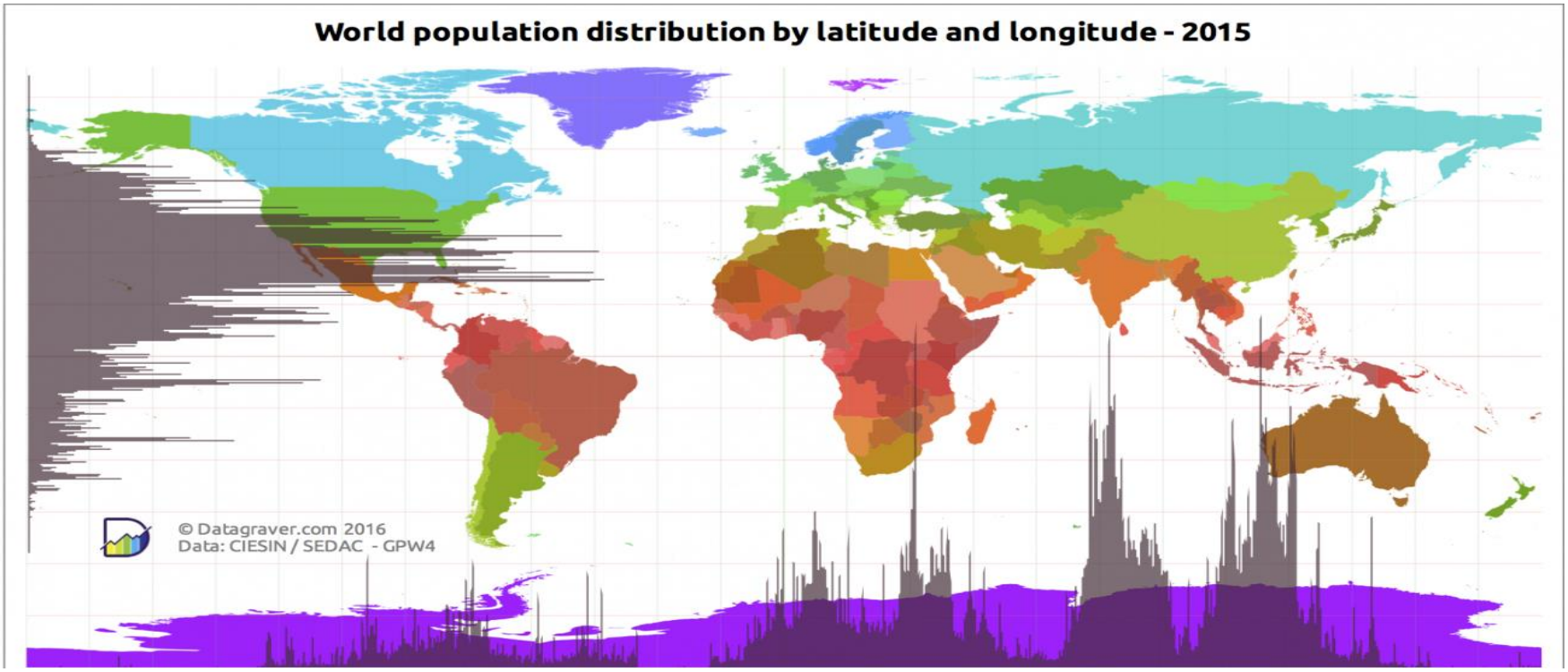
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Earth‘s orbits classification and their usage

Classification by orbit inclination – angle between orbital plane and reference plane (planet's equator) is used to plan a service with effective coverage by satellite or constellation.

- **Medium-inclined orbit**

  Usually used for data services in the most populated regions (e.g. latitude up to ±50°) and for space stations with human crew (ISS, MIR, SkyLab, Tiangong) – lower radiation dose.



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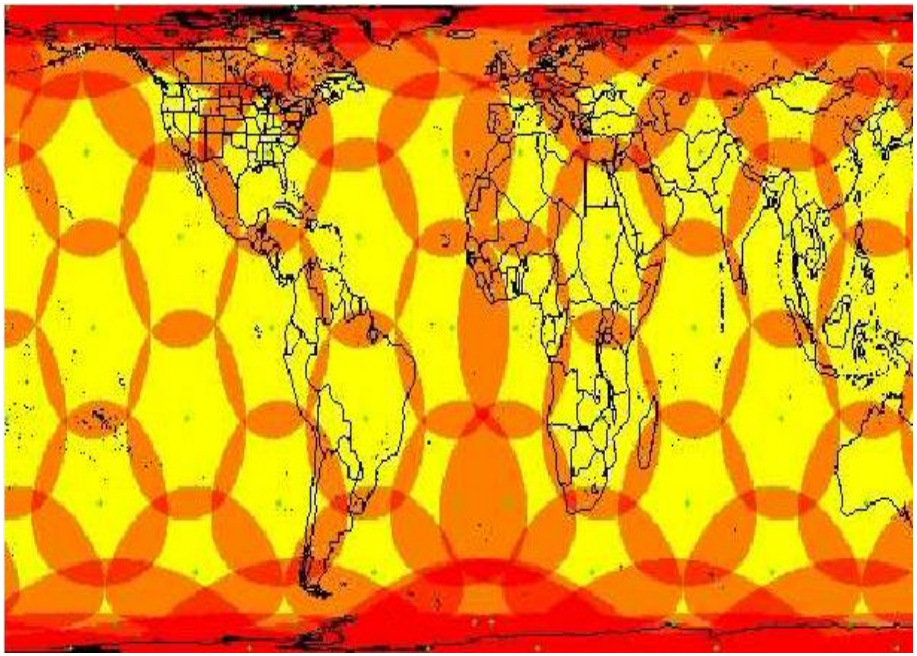
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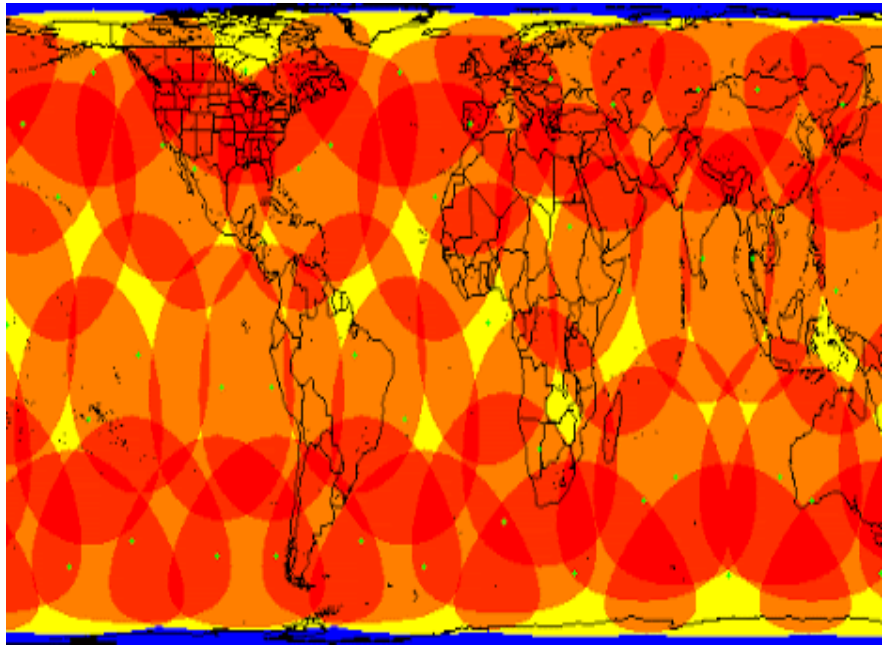
Earth‘s orbits classification and their usage

Classification by orbit inclination – angle between orbital plane and reference plane (planet's equator) is used to plan a service with effective coverage by satellite or constellation.

- **High-inclined or polar orbit**

  Usually used for Earth observation and data services with global coverage, including Polar Regions, which are unobserved from low-inclined orbits. Poor coverage in equatorial region.





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… so it's time for a small summary



- Orbital altitude influences covered area on the Earth and must be choose as compromise between several requirements (delay of signal propagation, link budget of data transmission, image resolution, revisit time, size of constellation, size of ground station network) for planned application.
- Orbital inclination allows to focus a service of satellite constellations into the area of interests (equatorial area, most populated area, global coverage) or to avoid the crossing of radiation belts for satellite lifetime preserving and astronauts safety.
- One kind of orbit generally should not fit all requirements on system, modern real systems require complex constellations with different orbits.

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Example of constellations - Global navigation satellite systems (GPS, Glonass, Galileo, BeiDou)

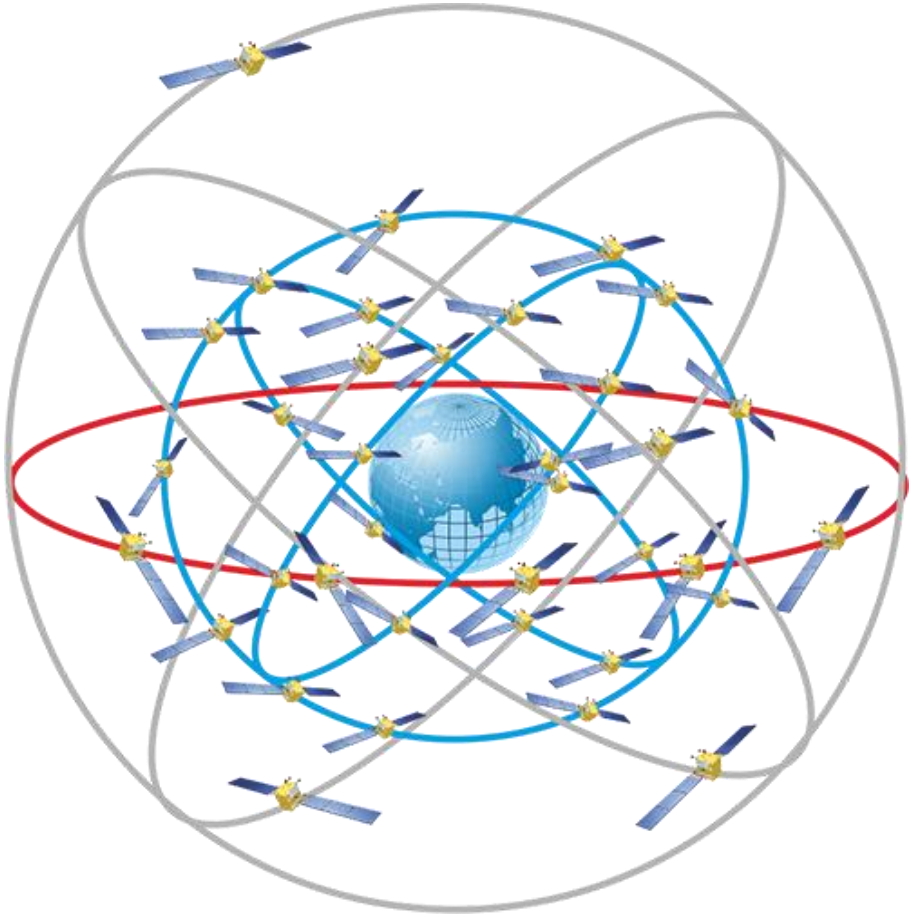
- approximately 30 satellites in each systems
- orbital altitudes between 19100 km (Glonass) and 23222 km (Galileo)
- orbital inclination between 55° (GPS) and 64.8° (Glonass)

MEO altitudes are sufficiently high to ensure visibility of at least 4 satellites at the same time (required for positioning by multilateration principle) with relatively small constellation (approx. 30 satellites).

Higher altitude is unpractical due to outer Van Allen radiation belt and due to necessity of data broadcasting (parameters of orbits, satellite health, corrections) to the handheld GNSS receivers.

Medium inclinations allow to optimize the signal coverage of the most populated regions without overservicing of Polar Regions.

China Compass system with 27 satellites on MEO orbit will be expanded by 3 geosynchronous satellites and 5 geostationary satellites for better signal integrity in preferred areas.



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Example of constellations – SpaceX Starlink satellite network for future global Internet access

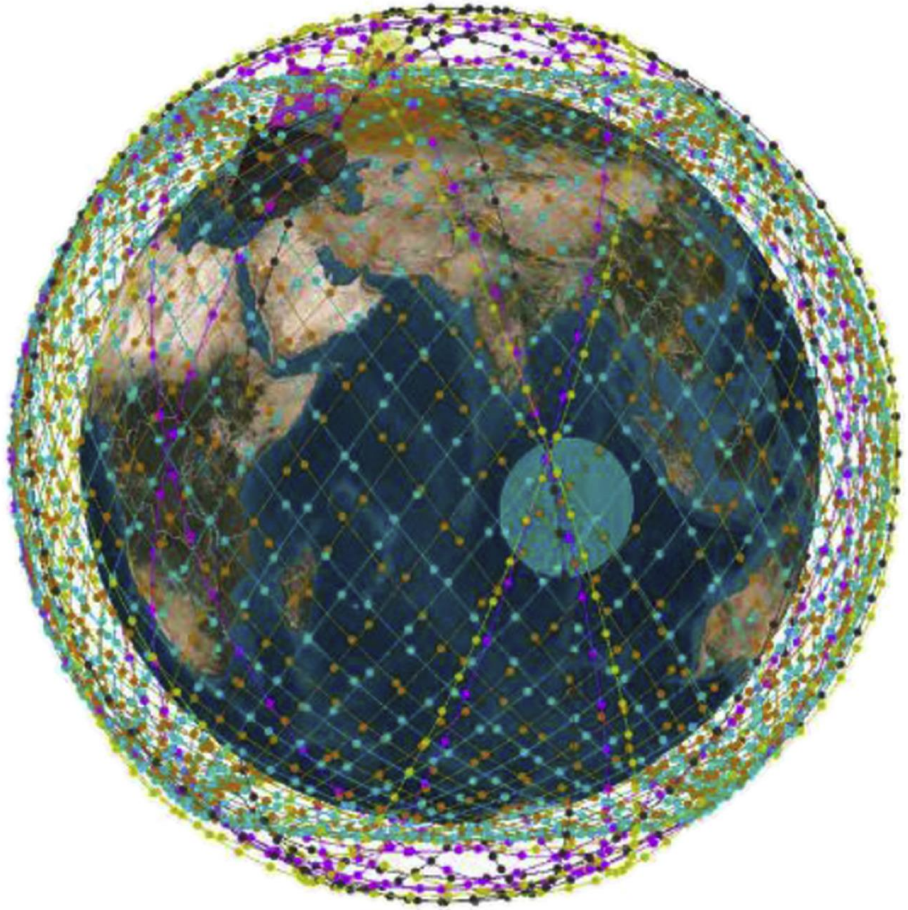
- approximately 4425 satellites in different orbits
- orbital altitudes between 335 km and 1325 km
- orbital inclination between 53° and 98°

Altitudes are low due to requirements on low latency and high speed data connection to the Internet.

Constellation is huge due to requirements on redundancy and good visibility of satellites from the Earth (at least one satellites have to be in elevation above 40°).

Different orbital inclinations allow the efficient signal coverage of the most populated regions as well as low populated Polar Regions.

Different orbital altitudes allow the efficient usage of inter-satellite links for access to the ground gateway.



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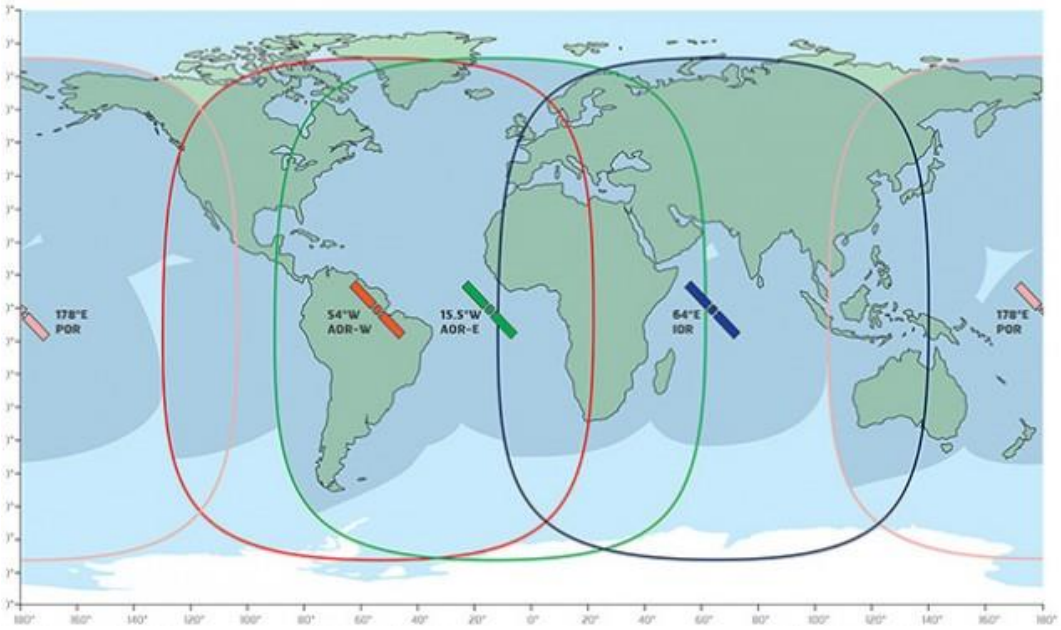
Example of constellations – Inmarsat geostationary network for telephone and data services

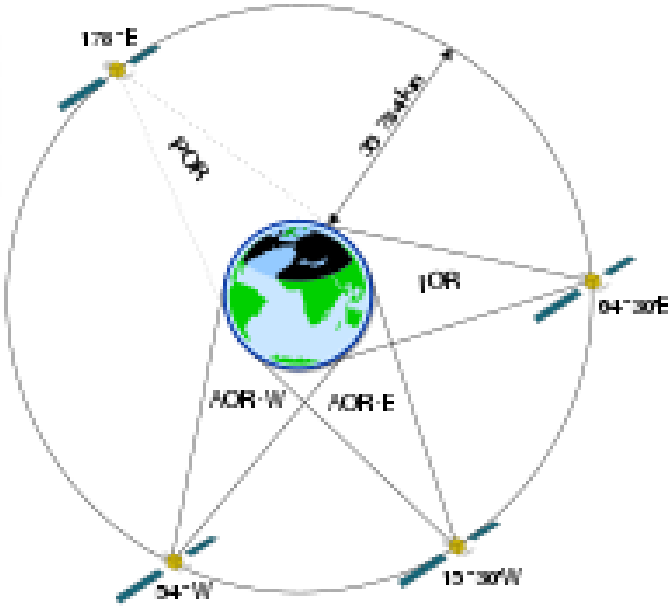
- 4 satellites in geostationary orbits

High geostationary altitude allows to cover the most of population with few of satellites, stable position of satellite allows to use a fixed mount high gain antennas (e.g. parabolic dish) for higher data rate.

Long communication distance cause a high signal delay, it suitable only for delay insensitive services (e.g. emergency phone calls from boats, payment terminals in areas uncovered by terrestrial systems).

Polar regions without coverage, in northern or southern regions the reception can be blocked by terrain or buildings (geostationary satellites are visible in low elevations).





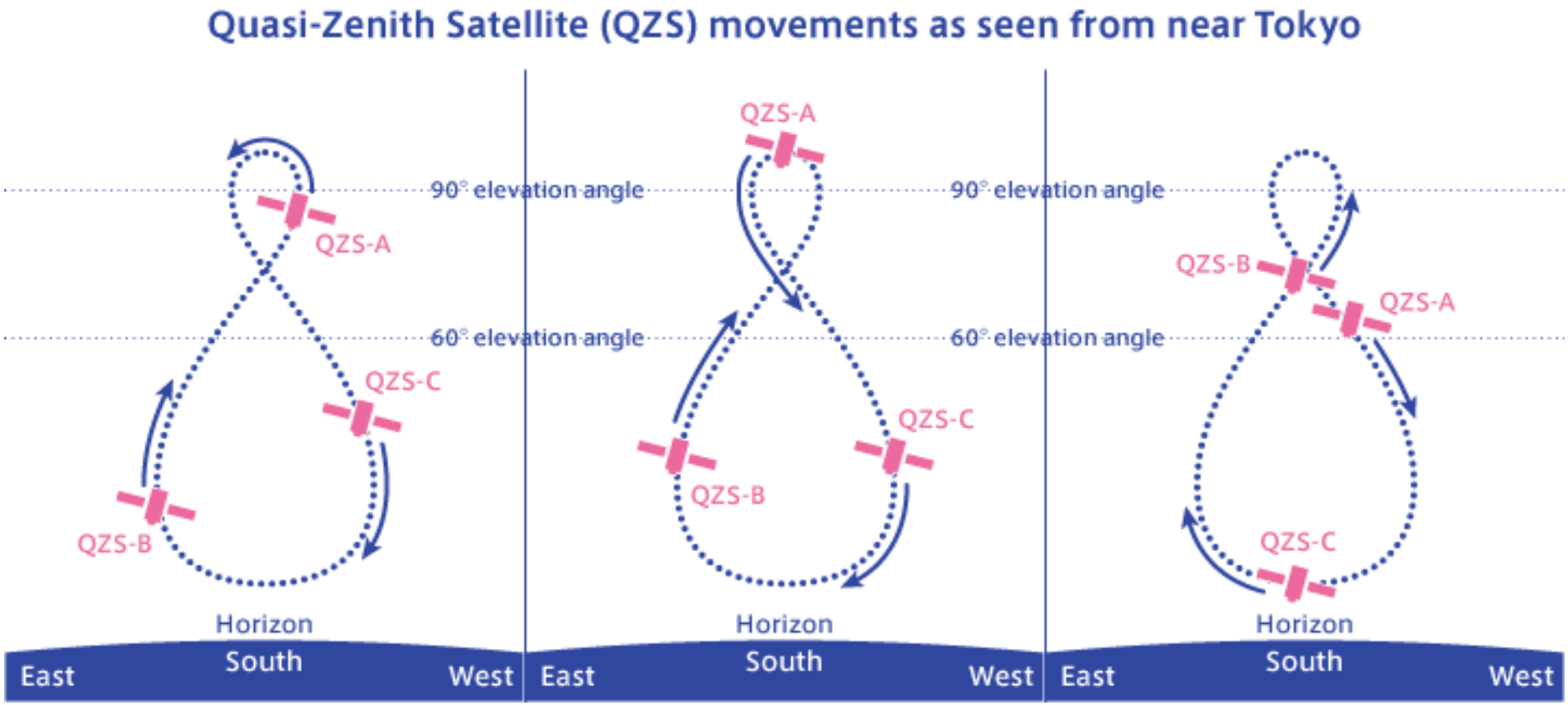
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Example of constellations – QZSS network for GPS enhancement in urban area of Japan

- 3 satellites in geosynchronous orbits with 41° inclination

Three geosynchronous orbits allow to cover urban areas of Japan by QZSS signals, because at least one of three satellites is always visible in high elevation. QZSS signals enables sub-meter position accuracy of GPS system in handheld devices.



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