

SAMARA UNIVERSITY

L3. Introduction to nanosatellite design



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INTRODUCTION

- What is CubeSat?
- CubeSat history

FLIGHT REQUIREMENTS

- Flight requirements
- Payload requirements

OPERATING ENVIRONMENT

- Pre-launch phase
- Launch phase
- Deployment phase
- Flight phase

CUBESAT DESIGN

- Structure
- Deployable Structures

CUBESAT SUB SYSTEMS

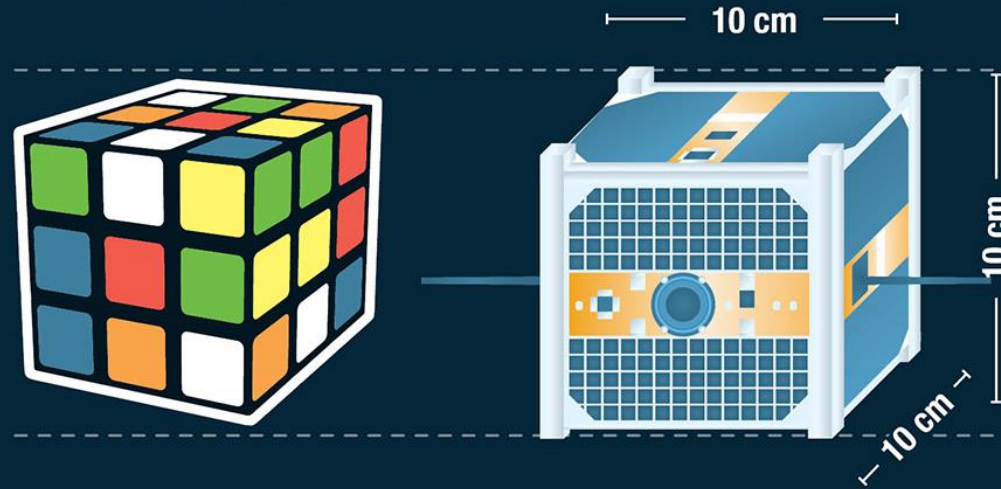
- Onboard computer
- Power system
- Attitude control system
- Communication system

What is CubeSat ?

3

A
CubeSat is a
miniature
cube-shaped
satellite

DIMENSIONS



ADVANTAGES



FAST DEVELOPMENT
(less than 2 years)



SIMPLE TECHNOLOGY



SIMPLE TO DESIGN

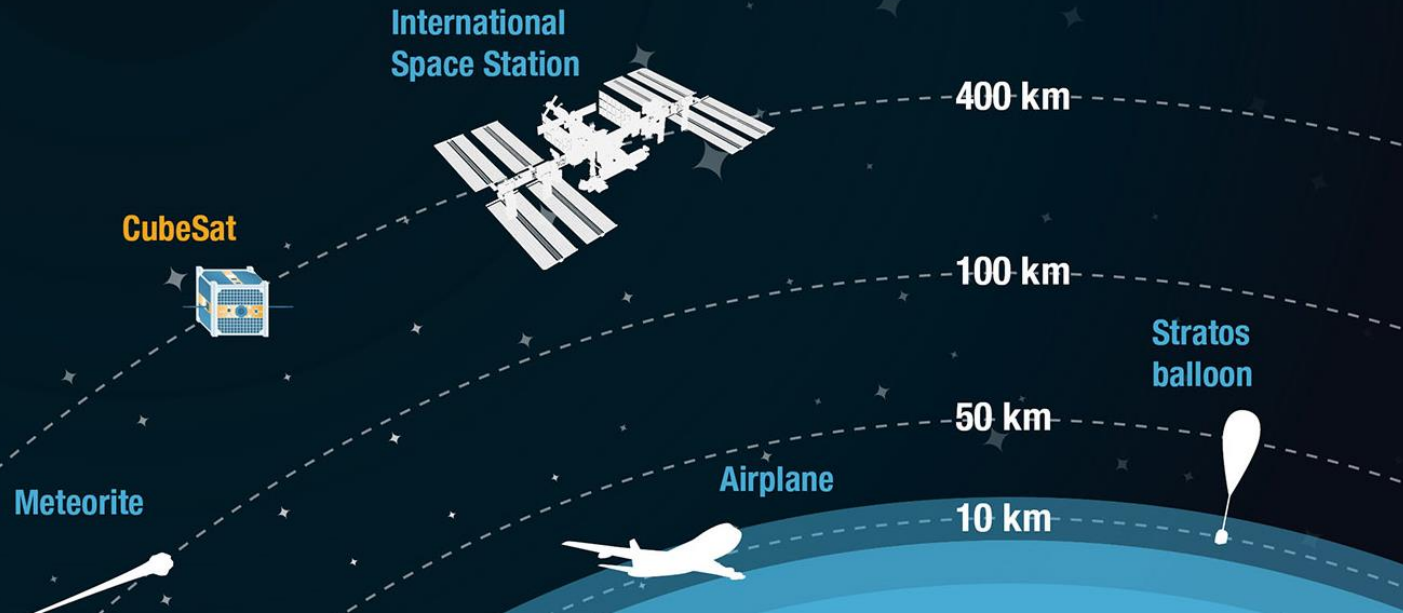


NO SPACE DEBRIS
(Burn up in the atmosphere)



LOW COST

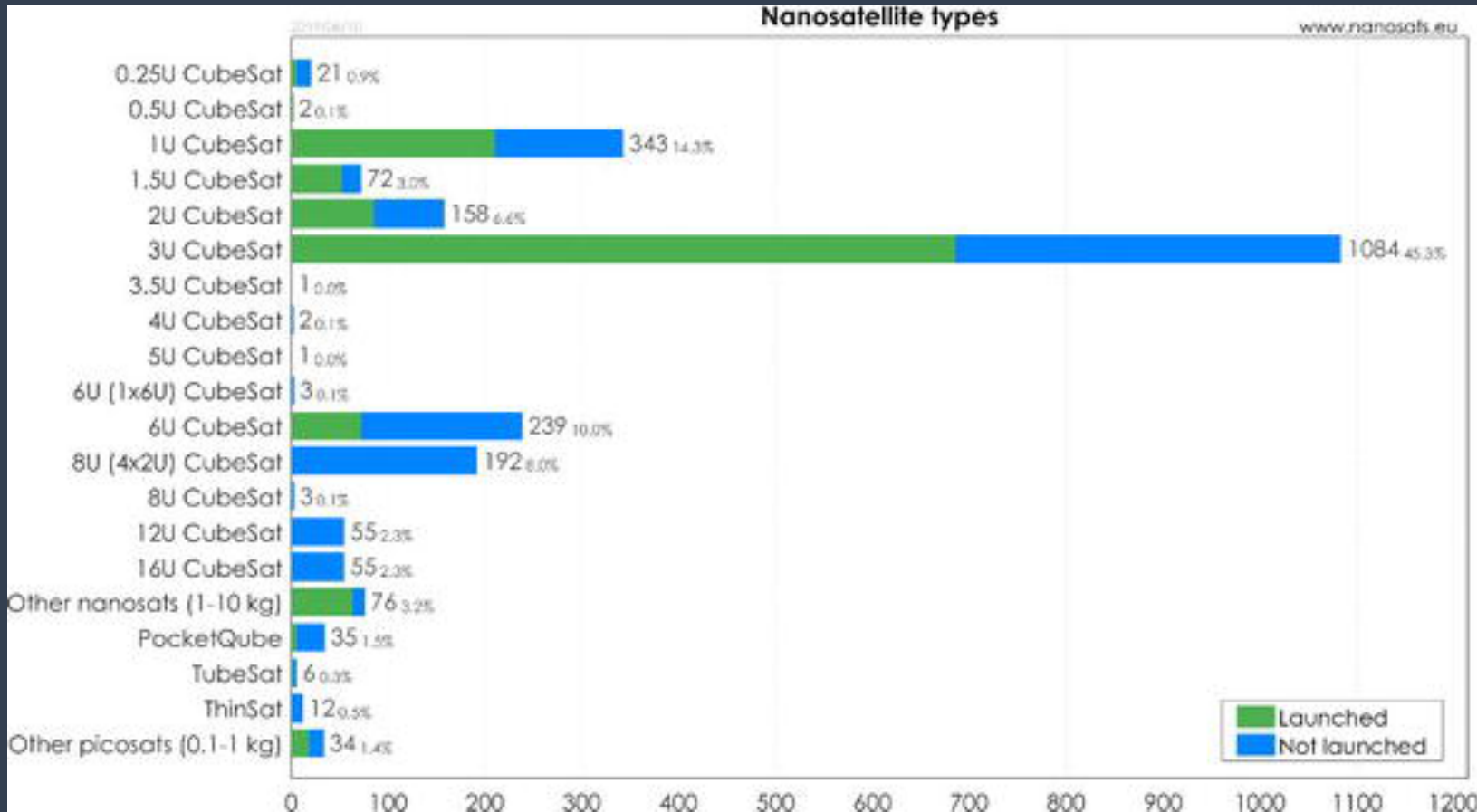
ORBIT



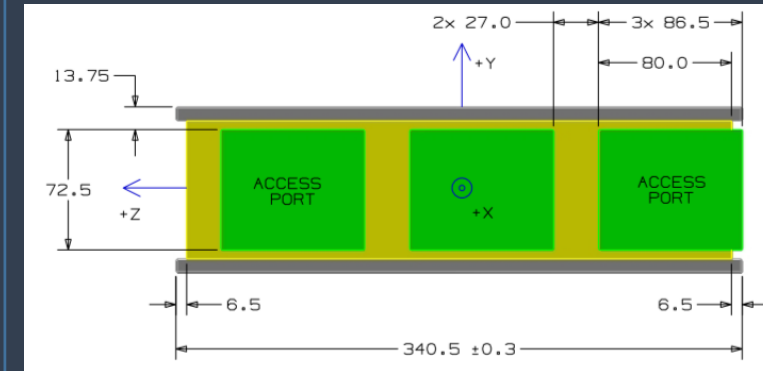
What is CubeSat ?

5

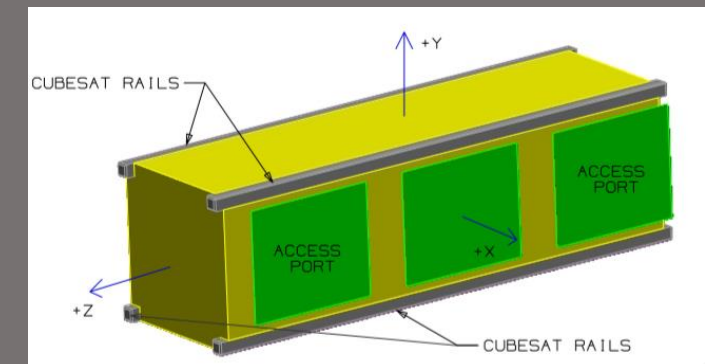
CubeSat most popular form-factor



DIMENSIONS



ACCESS PORTS



FLIGHT GOALS			User requirements Financial restrictions Political restrictions		
FLIGHT REQUIREMENTS			Performance Costs Active time Reliability		
LAUNCHER ROCKET	Volume Environment Mass distribution	CubeSat REQUIREMENTS	Orbit Power Mass Operation	GROUND SEGMENT	Ground station Data processing
SUB-SYSTEM REQUIREMENTS			Temperature control Design Power Electronics Communication Attitude control		

The **DETERMINING FACTOR FOR EVERY FLIGHT** is the **PAYLOAD**.

For normal operation, the payload module requires a number of resources provided by the service systems module.

PAYLOAD REQUIREMENTS

ATTITUDE

Payload module must be oriented in the right direction

DATA

Data coming from the payload module must be reported to ground structures

ORBIT

It is necessary to maintain the desired orbit for flight purposes

DESIGN

Payload should be mounted on a special place on satellite to meet the requirements

POWER

Payload module should have enough power supply



PRE-LAUNCH PHASE



LAUNCH PHASE



DEPLOYMENT PHASE



FLIGHT PHASE

Design, manufacture and assembly of a CubeSat, as well as its integration with the launch vehicle is a process that takes usually 1-1,5 years. Components and subsystems should be preserved stable condition for months. During these periods, careful control of the environment is important.

HARD VIBRATION ENVIRONMENT

Arises due to the **operation of the main engines** of the launch vehicle, as well as aerodynamic instability during the ascent of the vehicle in the lower layers of the earth's atmosphere

CONSTANT COMPONENT OF ACCELERATION

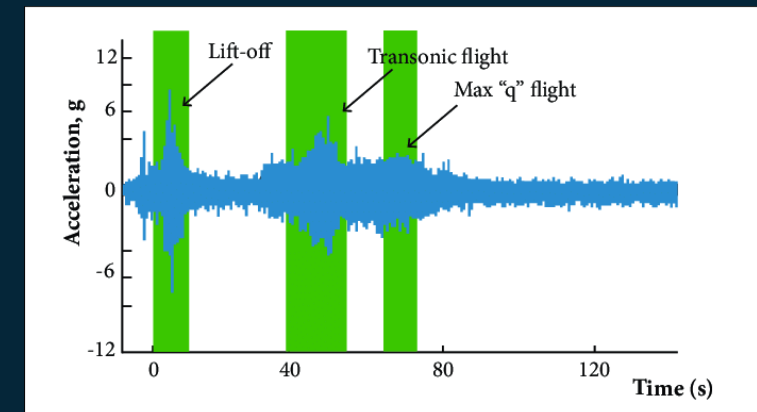
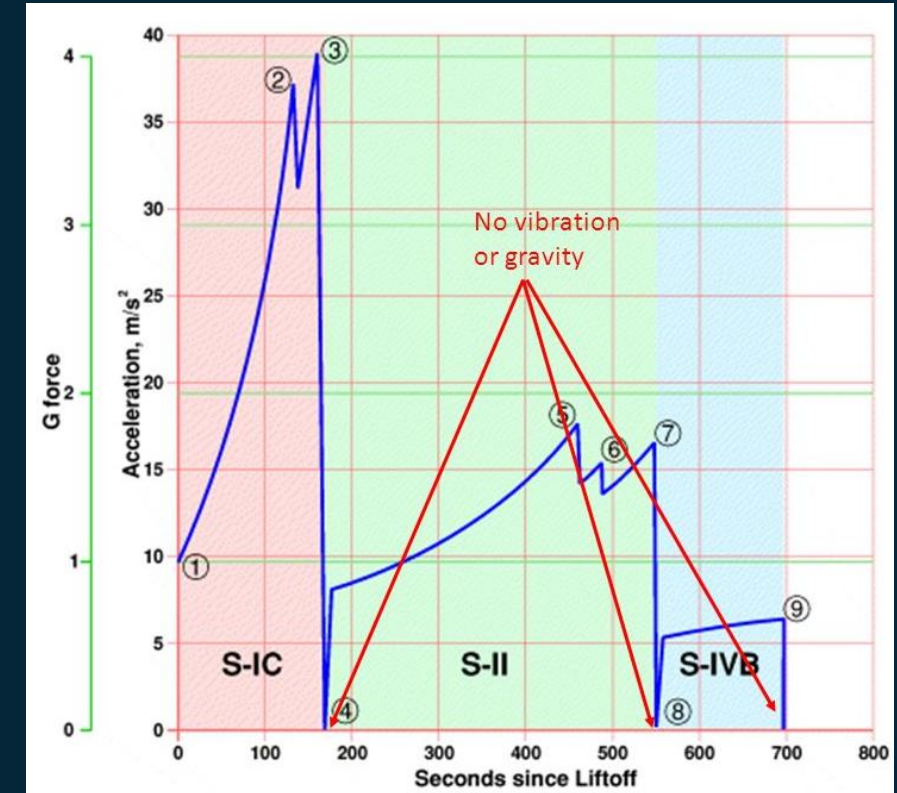
Acceleration depends on the type of launch vehicle. **Low-mass** vehicles experience **higher acceleration** values, while high-mass vehicles and manned spacecraft tend to have lower acceleration values.

MECHANICAL SHOCK

Occurs when **starting the engines** of rocket stages and separating, when **separating** the payload from the launch vehicle

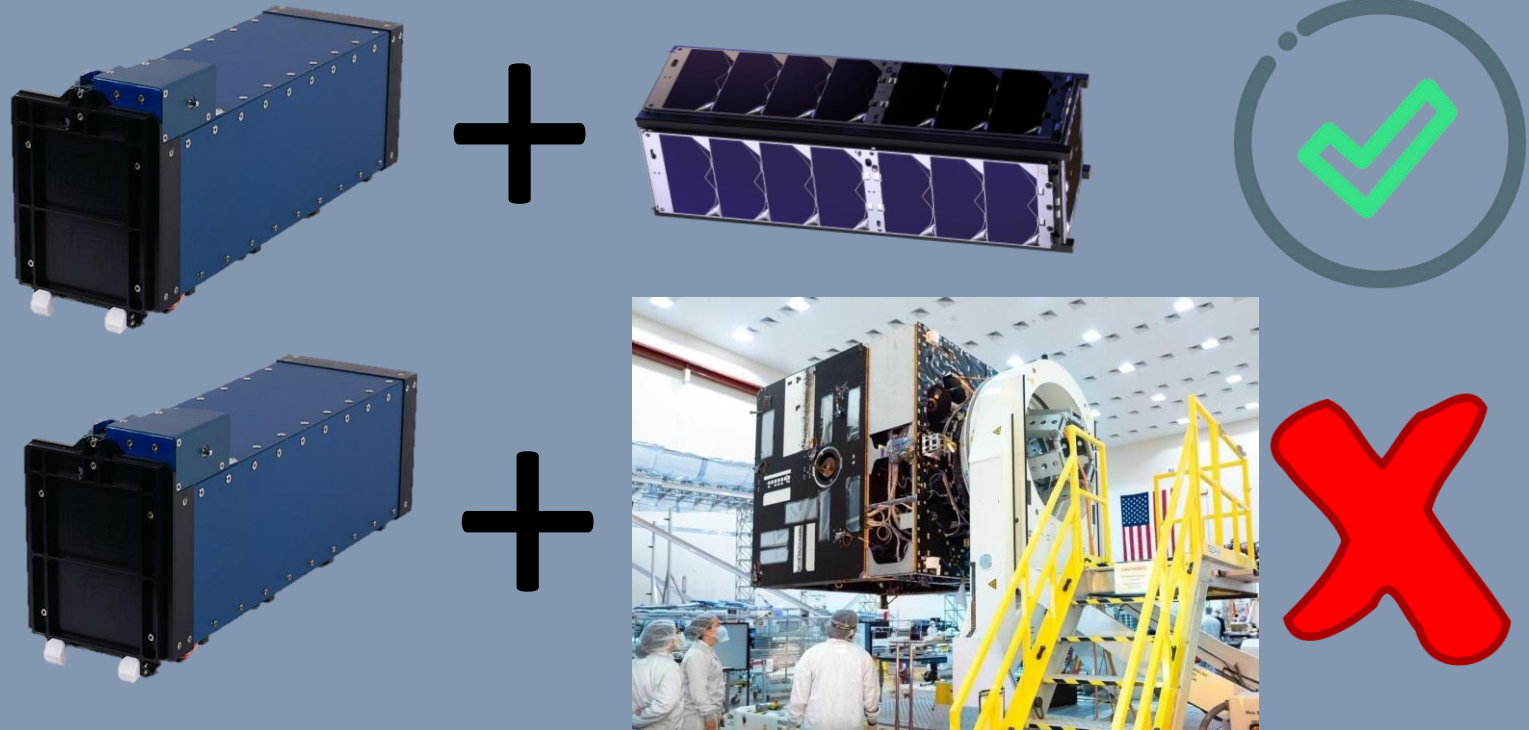
THERMAL ENVIRONMENT

During launch is determined by the temperature of the **head fairing**. It rises from friction - when moving at high speed through the atmosphere.



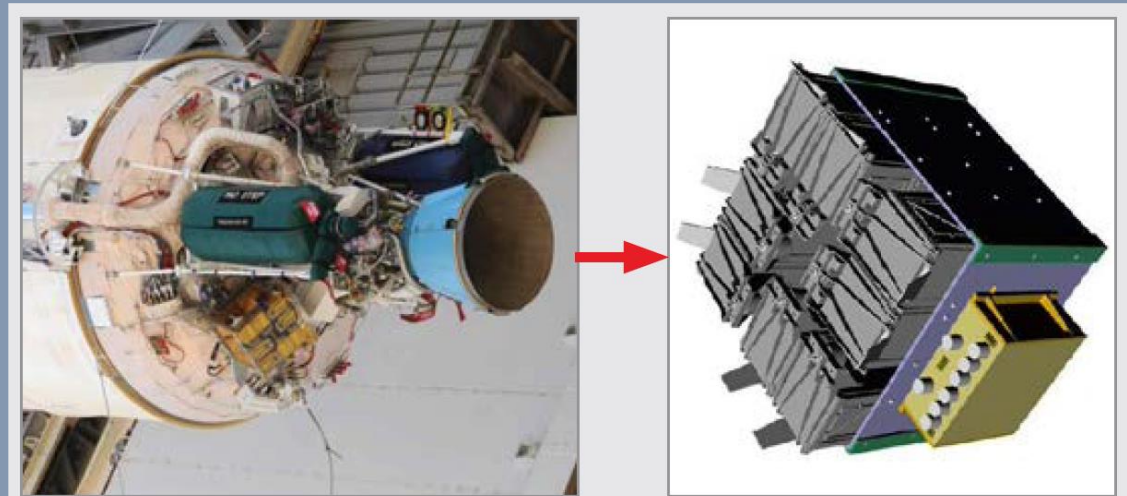
CONTAINER LAUNCH FROM ISS

- CubeSat should meet container requirements
- CubeSat should meet ISS safety requirements



CONTAINER LAUNCH FROM ROCKET

- CubeSat should meet container requirements
- CubeSat should meet rocket safety requirements



CONTAINER LAUNCH FROM PRIMARY SPACECRAFT

- CubeSat should meet container requirements
- CubeSat should meet primary spacecraft safety requirements



COSMONAUT LAUNCH

- CubeSat should have holder
- CubeSat should meet ISS safety requirements





GRAVITY



ATMOSPHERE



SUN



MAGNETIC FIELD AND RADIANCE

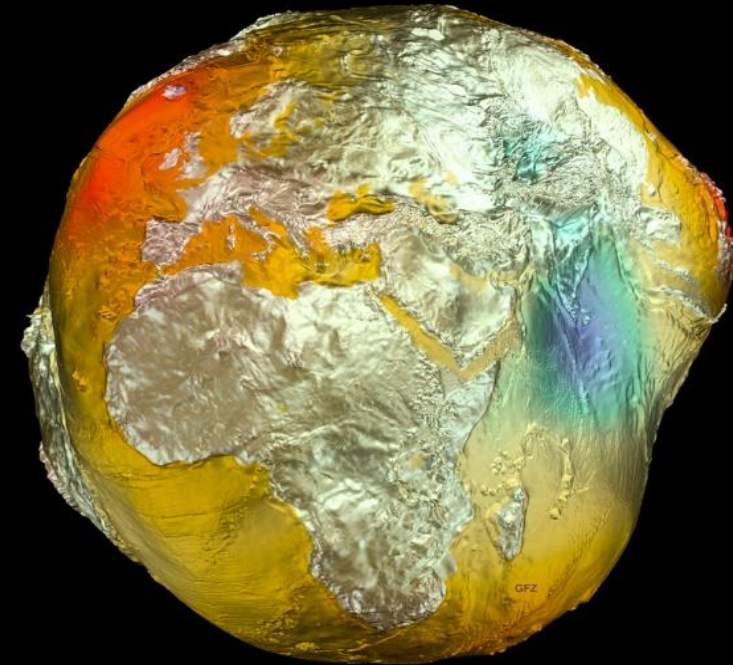
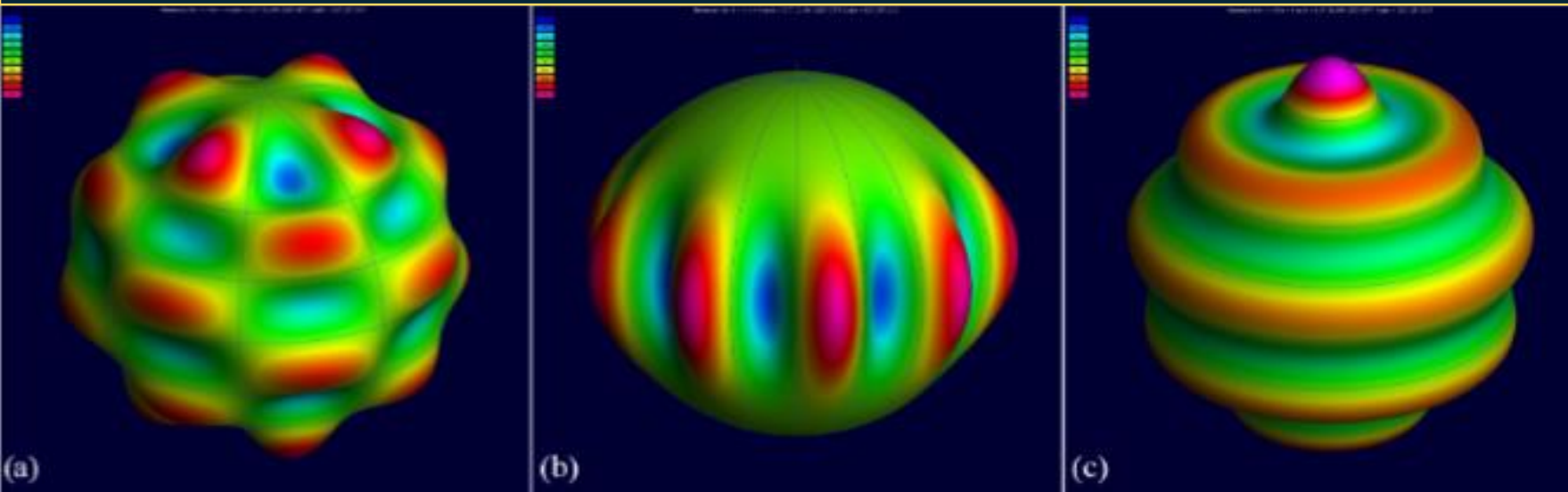


GRAVITY INFLUENCE

For a more **accurate orbit calculation** of the spacecraft, it is necessary to take into account the influence of **various disturbing forces**.

As the flight **altitude decreases**, an increasingly important role is played by the mass of the **Earth**, the **difference** between its shape and a **symmetrical sphere**, as well as **aerodynamic forces**.

EARTH GRAVITY FIELD HARMONICS



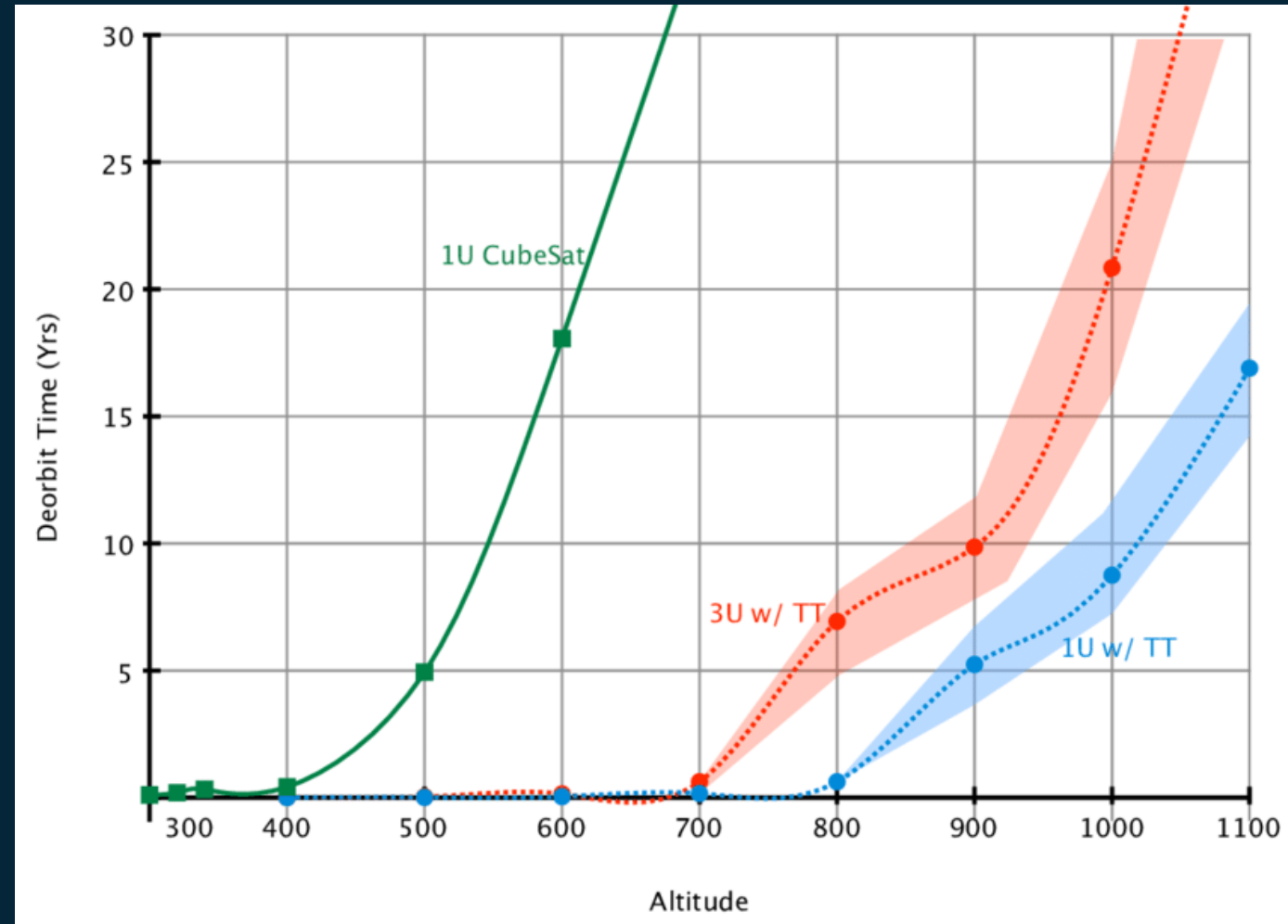
ATMOSPHERIC INFLUENCE

ATMOSPHERIC DRAG

$$\mathbf{F}_D = \frac{1}{2} \rho S C_D V_r^2 \left(\frac{-\mathbf{V}_r}{|V_r|} \right)$$

ATMOSPHERIC DENSITY
MODELS

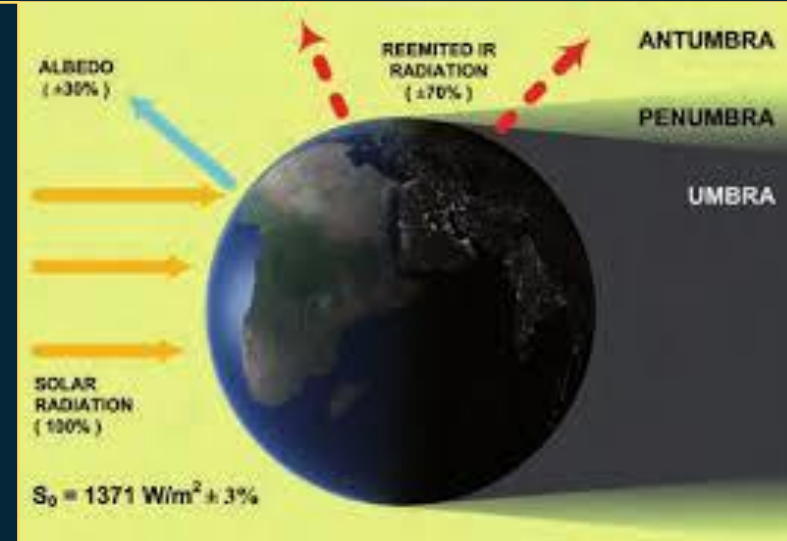
- Static (depends on altitude)
- Dynamic (depends on altitude, time, sun activity, magnetic field)



SUN INFLUENCE

HEAT

- The **dominant** role in the supply of heat belongs to **solar radiation**, the value of which in the near-Earth environment is **1400 W/m²**;
- The **secondary** source of heat is the **Earth's albedo** (reflection of solar radiation) and the **Earth's own radiation** (radiation of the Earth as a black body), the value of which is about **200 W/m²**.
- Solar **heat increases** atmospheric **density**



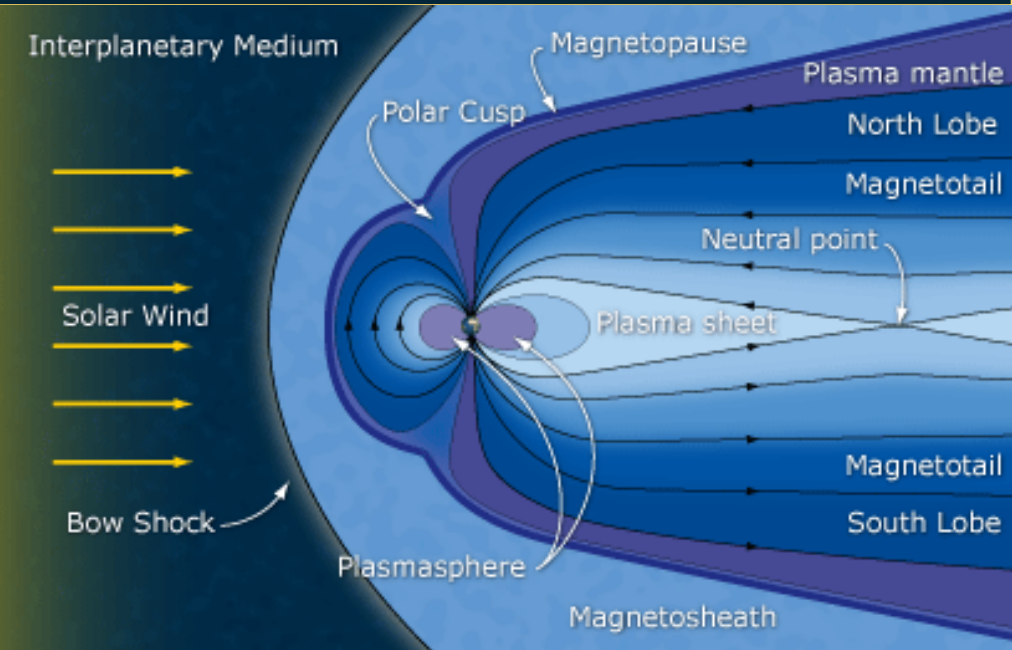
RADIATION

- **Brittleness** is a form of material destruction caused by exposure to **UV radiation**. Many **polymers** are **sensitive** to photons, which have enough energy to modify the structure of chemical bonds.;
- **UV radiation** also causes electrical changes that affect the **degree of resistance** and **optical changes** that affect the temperature characteristics and the **degree of transparency**..
- **Solar cells** are especially sensitive to UV radiation (cover glasses and the adhesive layer associated with them darken). The illumination of the cell decreases and the operating **temperature rises** - both of these factors are **extremely detrimental** to the state of the cell.

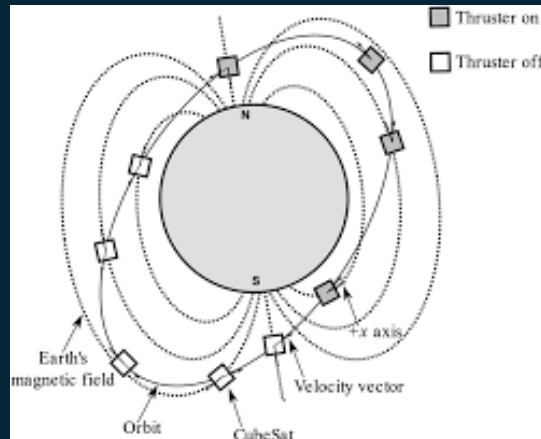
MAGNETIC FIELD

STRUCTURE

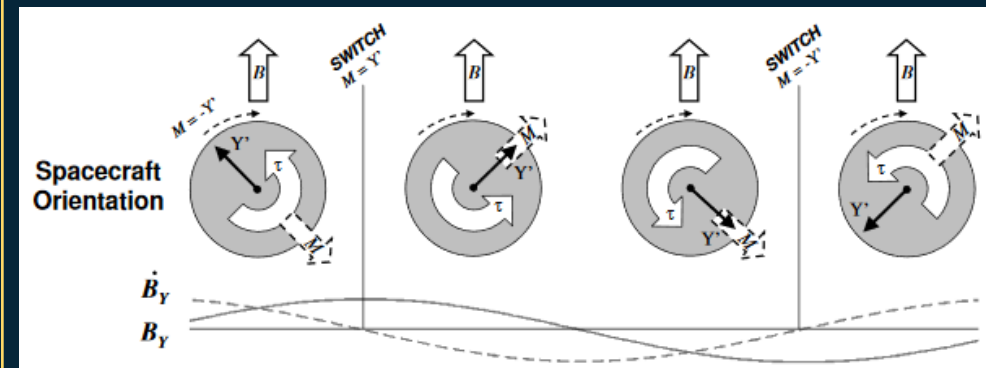
- The Earth's magnetic field has two main sources;
- On the surface, the **main role** is played by the **currents circulating inside the planet**.
- With **increasing altitude**, the role of fluxes caused by the motions of **electrons and ions** in the magnetosphere increases.
- The **solar wind plasma**, which carries its own magnetic field, **transforms** a simple **dipole field** into the **form shown in the figure** and has both open and closed magnetic field lines.



MAGNETIC FIELD FOR NAVIGATION



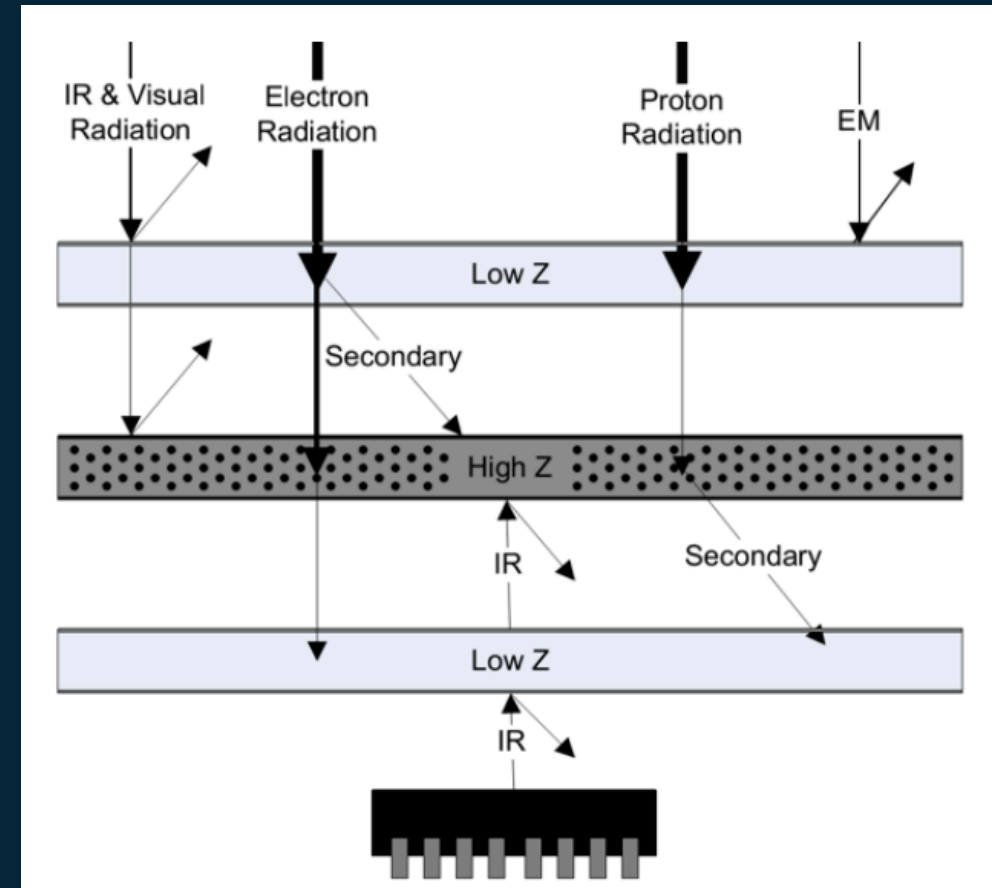
MAGNETIC FIELD FOR CONTROL



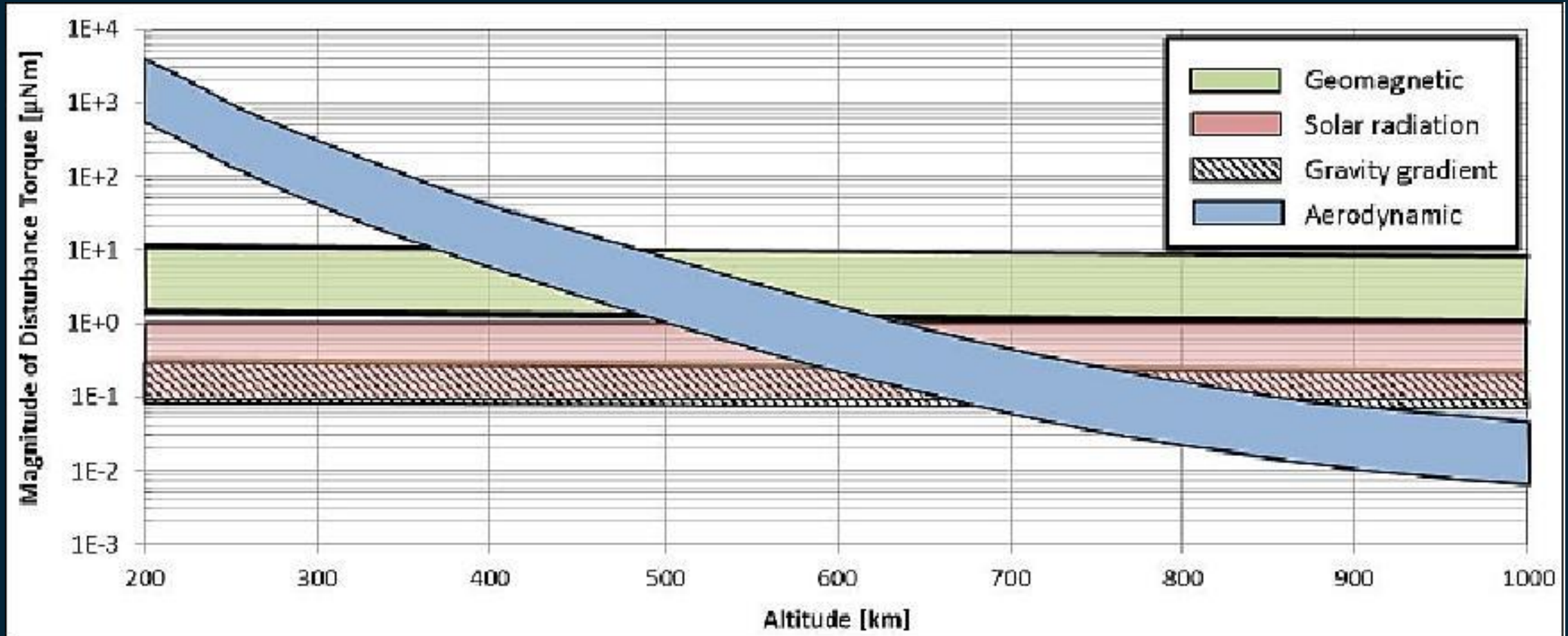
RADIATION

To make sure that **transistors**, **diodes** and other **electronic components** are able to maintain their properties in a radiation environment, it is necessary to **calculate the total radiation dose** inside the spacecraft (in units of rad).

- A more **detailed three-dimensional analysis** is carried out to determine the dose at the actual location of the **"soft" components**.
- Usually the **dose is reduced** by moving parts to **specific places**.
- If it is still high, then point **shielding is applied** (that is, placing a shielding made of **aluminum**, **tantalum**, **tungsten** over a certain part) or another version of the electronic component that is more **resistant to radiation** is chosen.

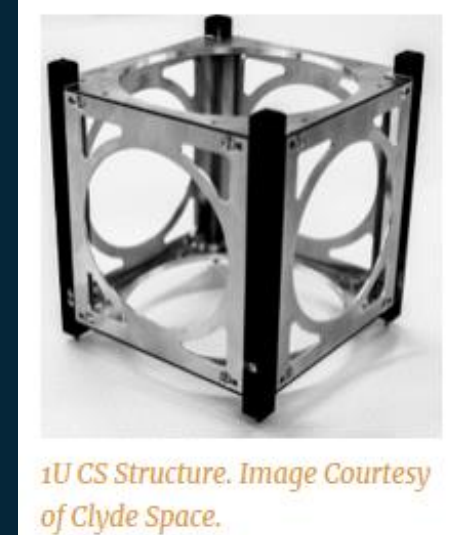


SUMMARY

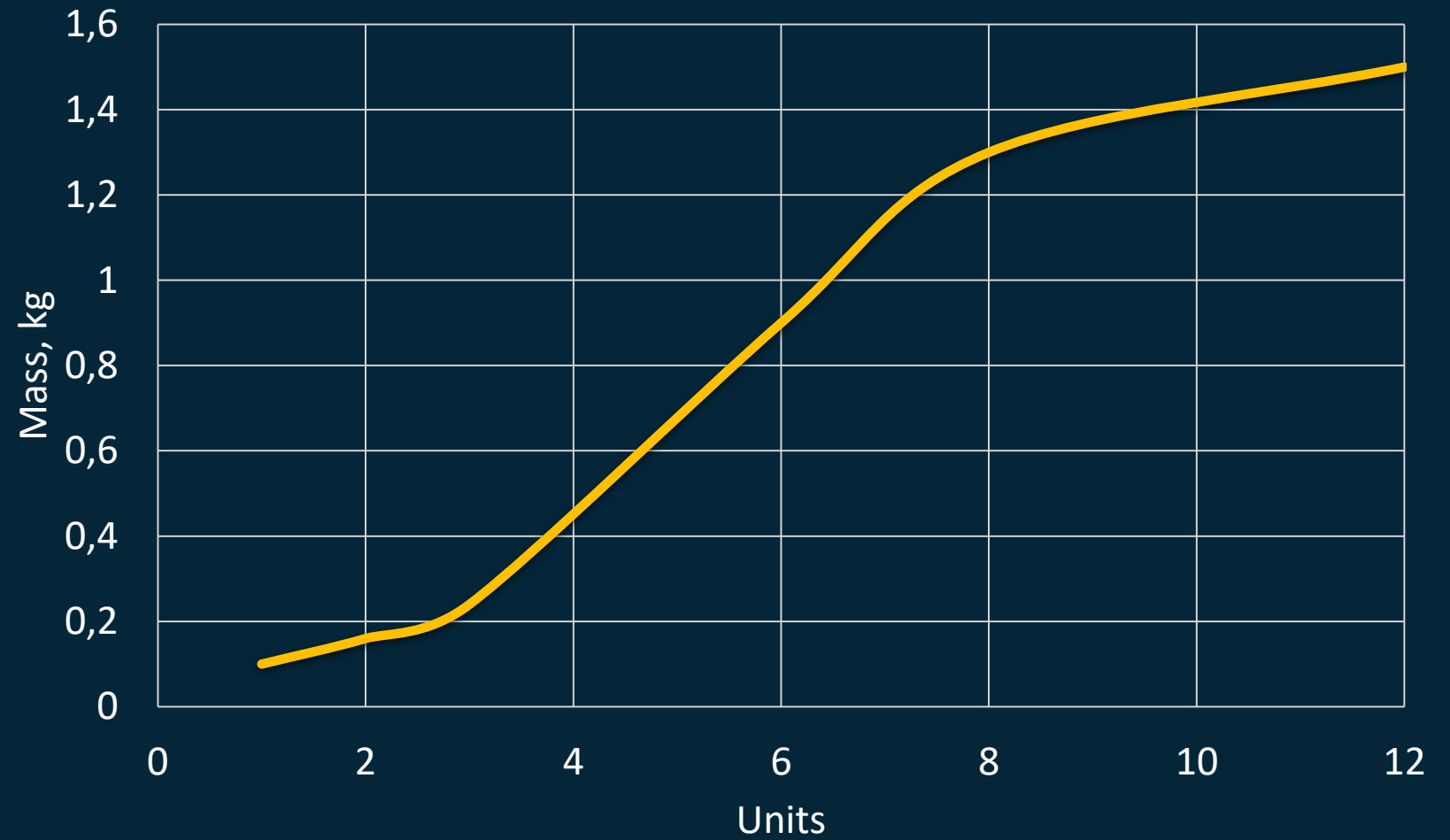


STRUCTURE




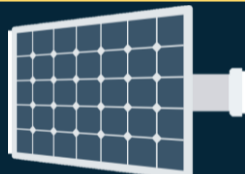
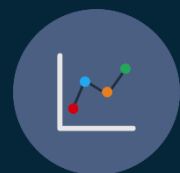
The design should work under **static** and **dynamic** load conditions during testing and **launch**, and then in a **zero-gravity** environment.



STRUCTURE



DEPLOYABLE STRUCTURES

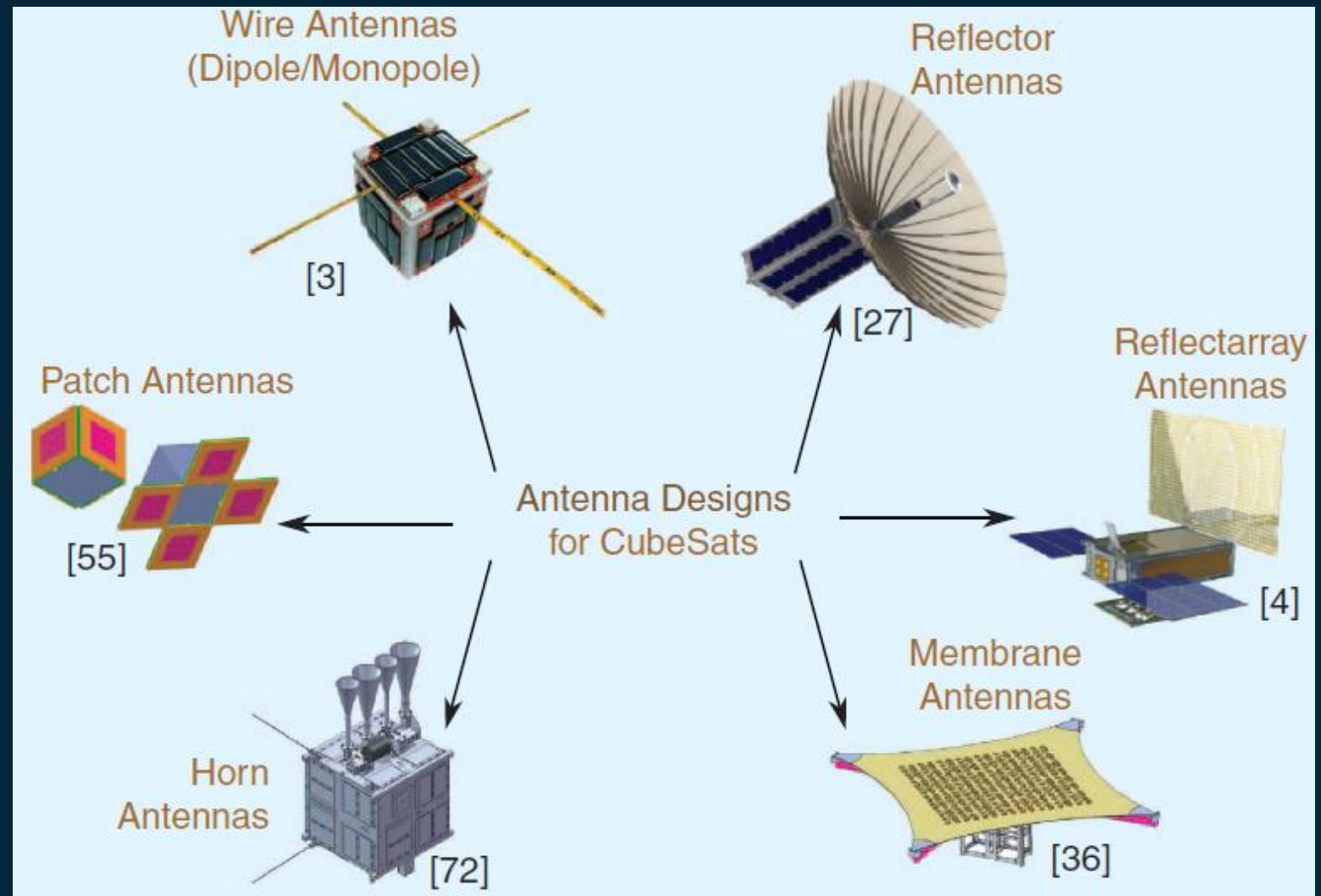
<p>Often</p>  <p>Rare</p>		ANTENNAS
		AERODYNAMIC STABILIZER
		SOLAR PANELS
		PAYLOAD
		OTHER

ANTENNAS

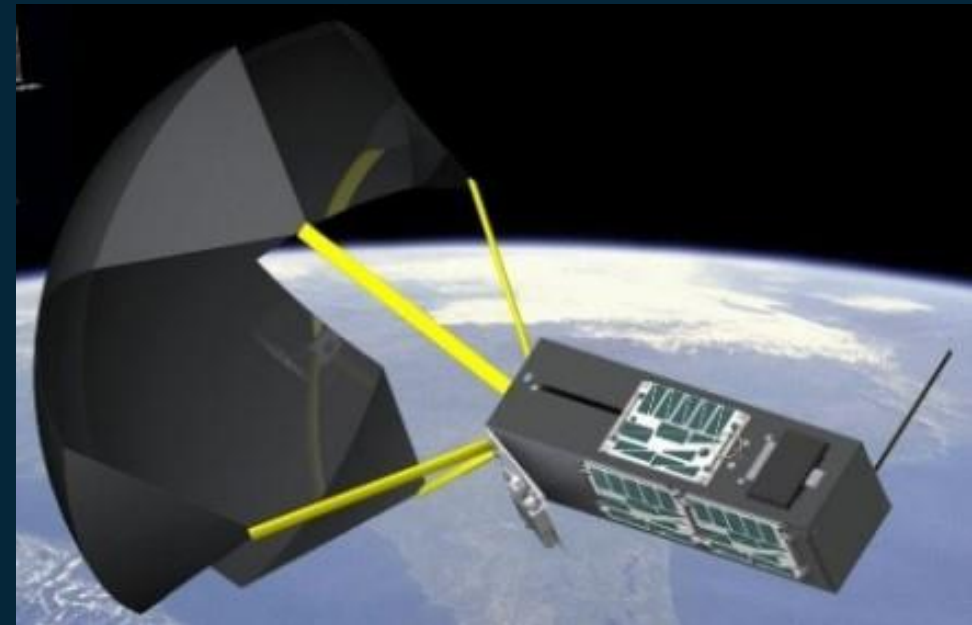
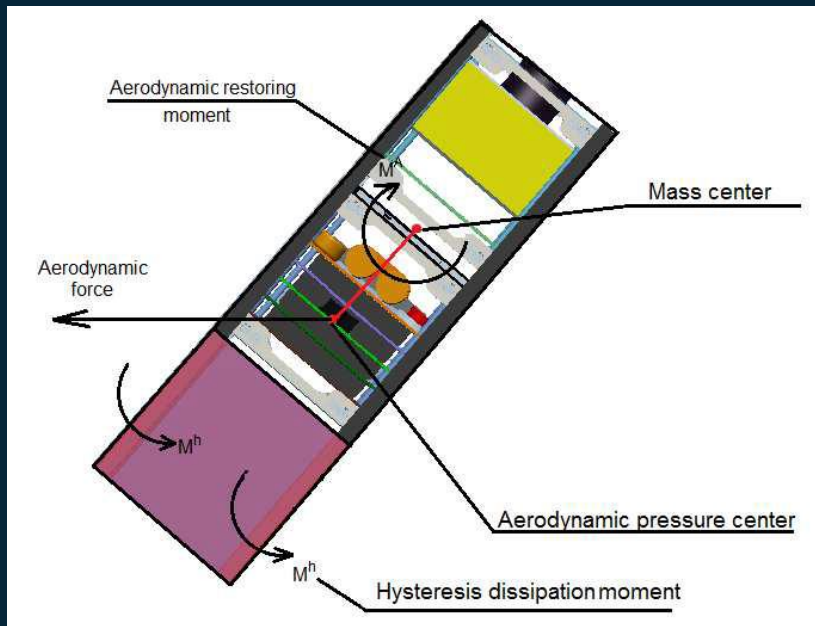
Antenna design

depends on

- Speed communication requirements
- Attitude control system
- Orbit

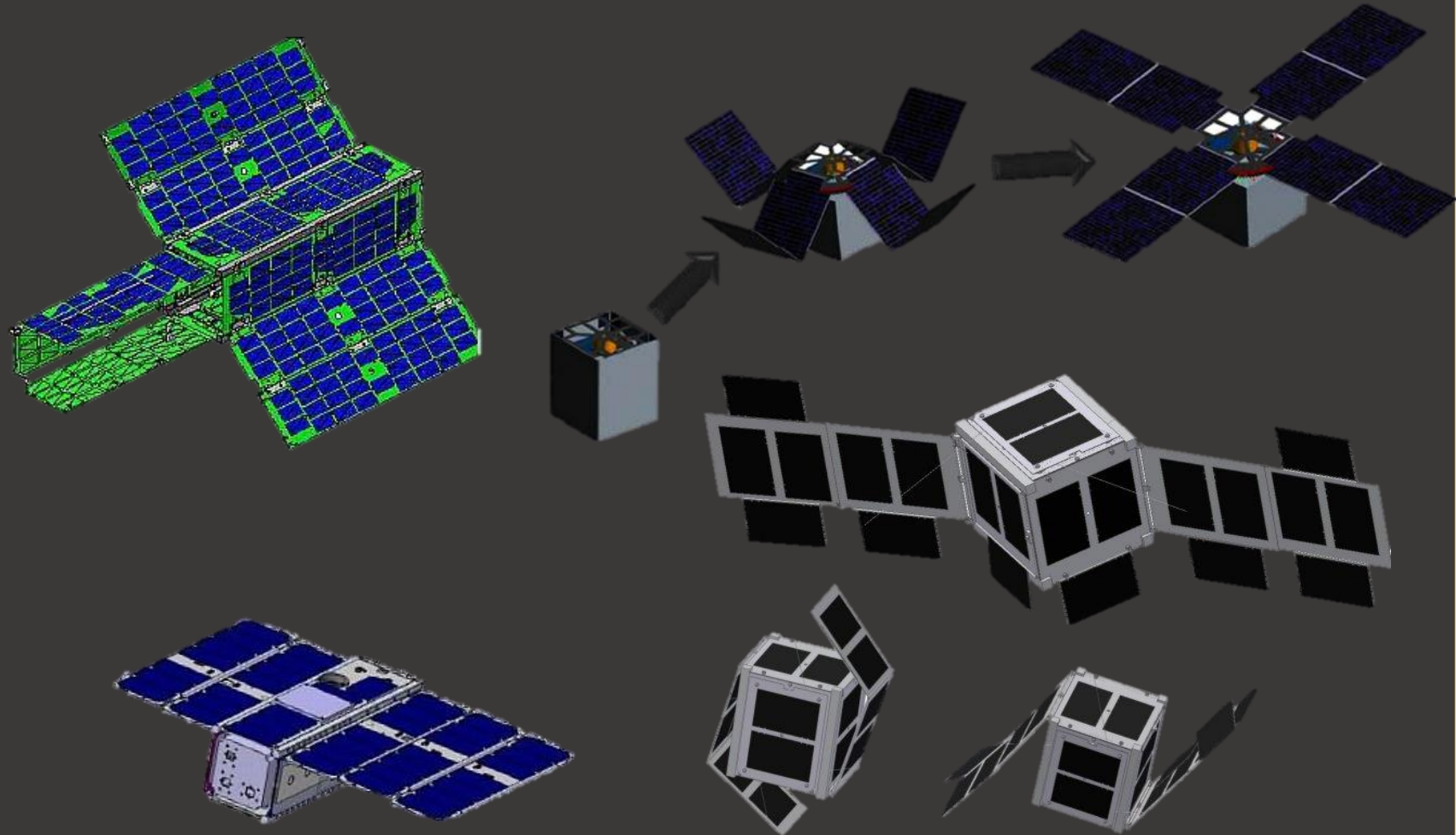


AERODYNAMIC STABILIZER



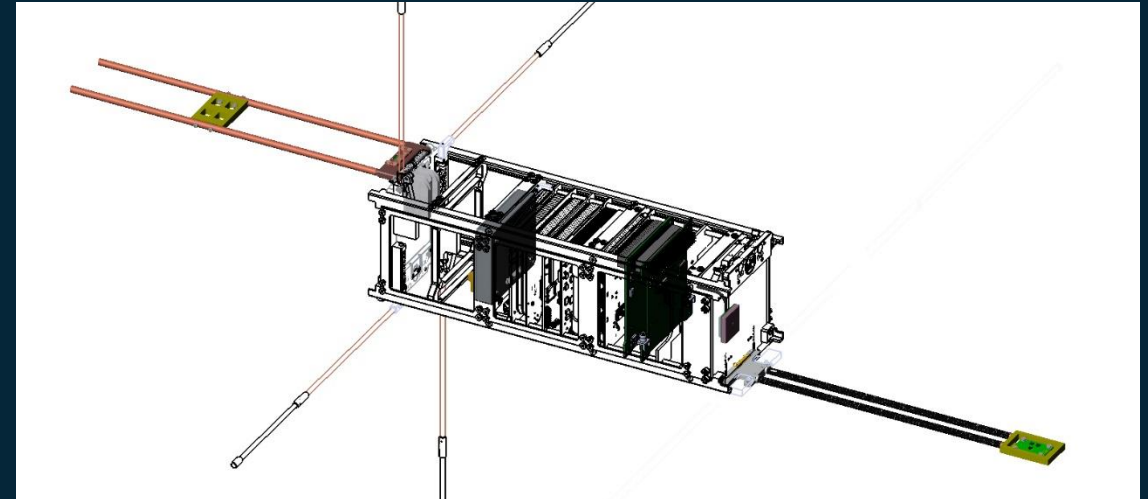
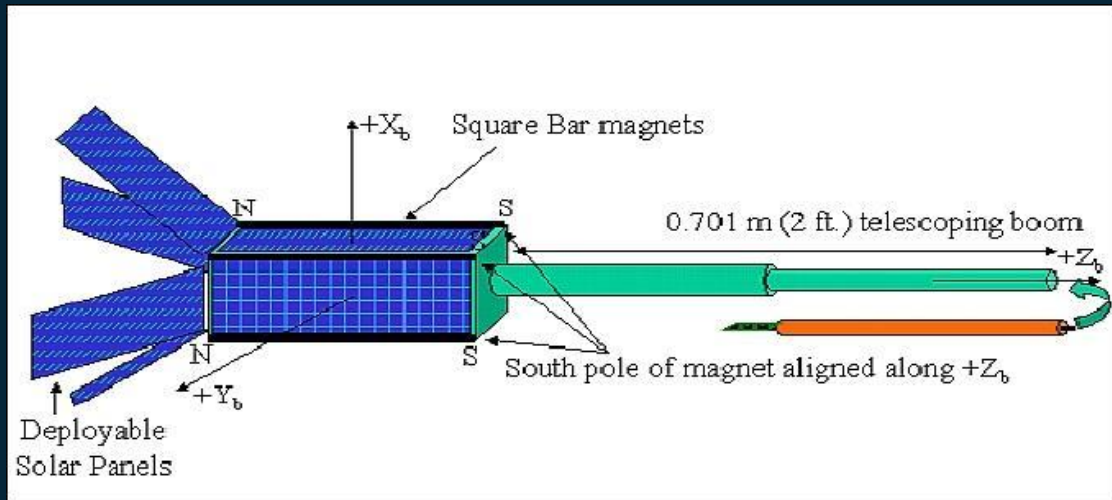
SOLAR PANELS

The **area** available of the solar panel is **strongly limited** on the CubeSat – so the solution is to **use deployable solar panels**.



PAYLOAD

To meet EMC requirements sensitive payload or sensors can be mounted on a transformable structure.





ONBOARD COMPUTER



ELECTRICAL POWER SYSTEM

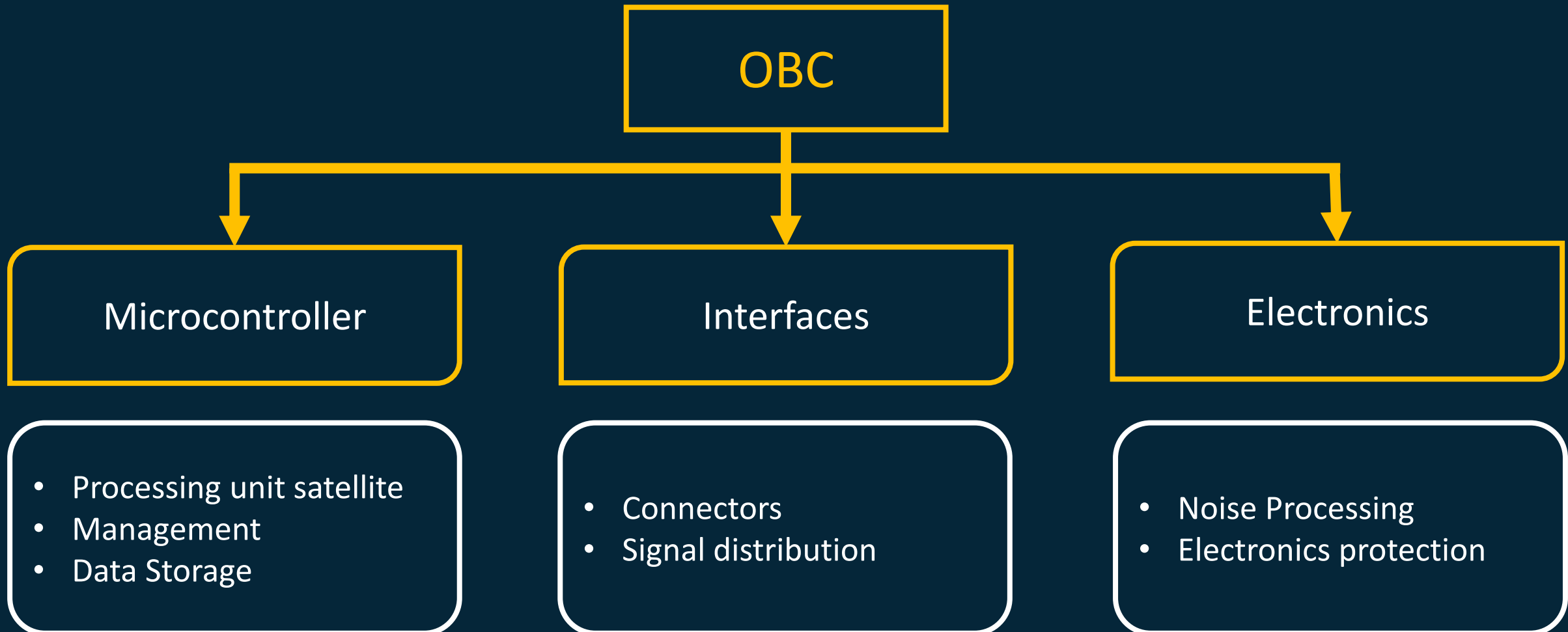


ATTITUDE CONTROL and DETERMINATION SYSTEM

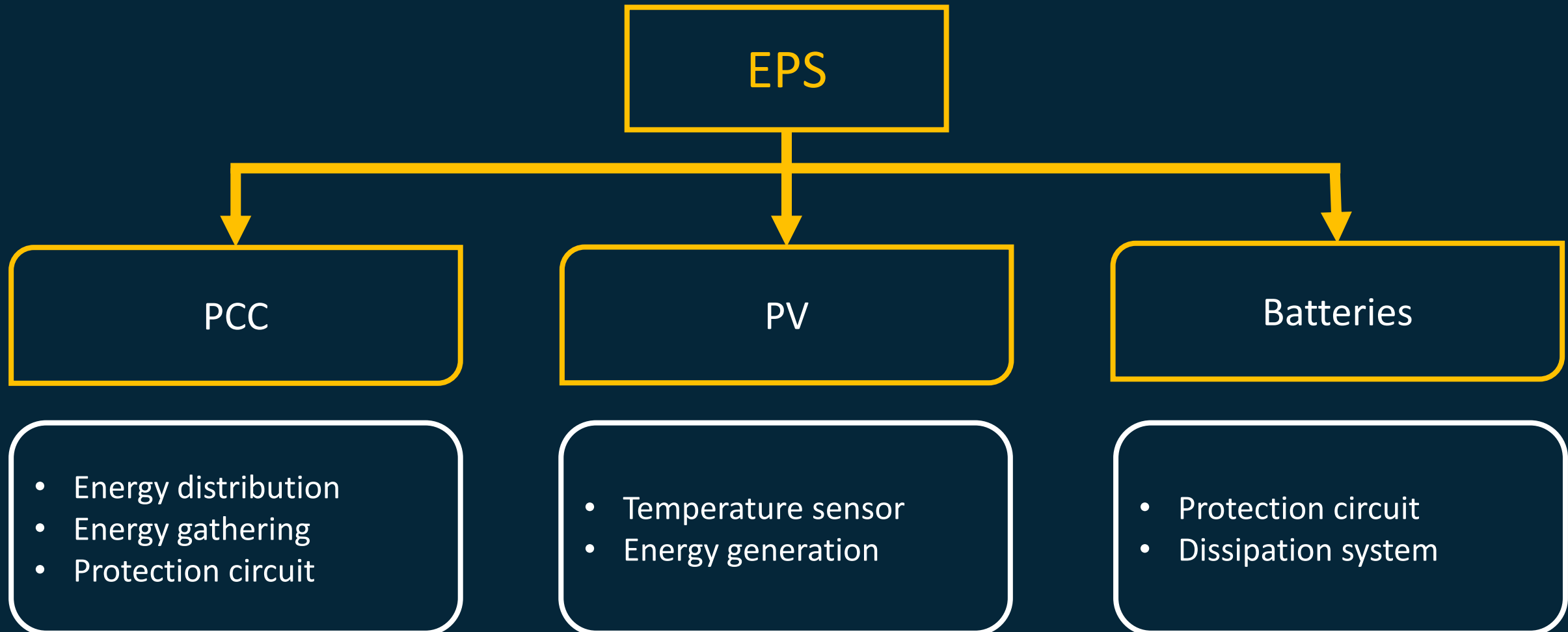


COMMUNICATION SYSTEM

ONBOARD COMPUTER

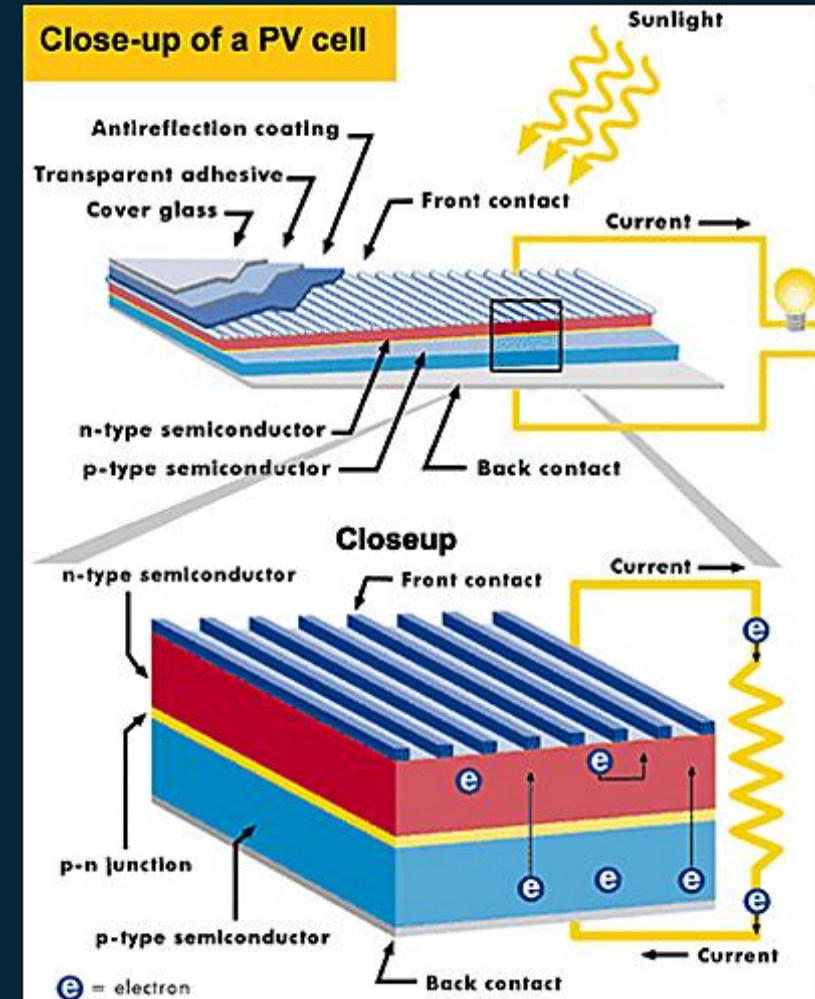
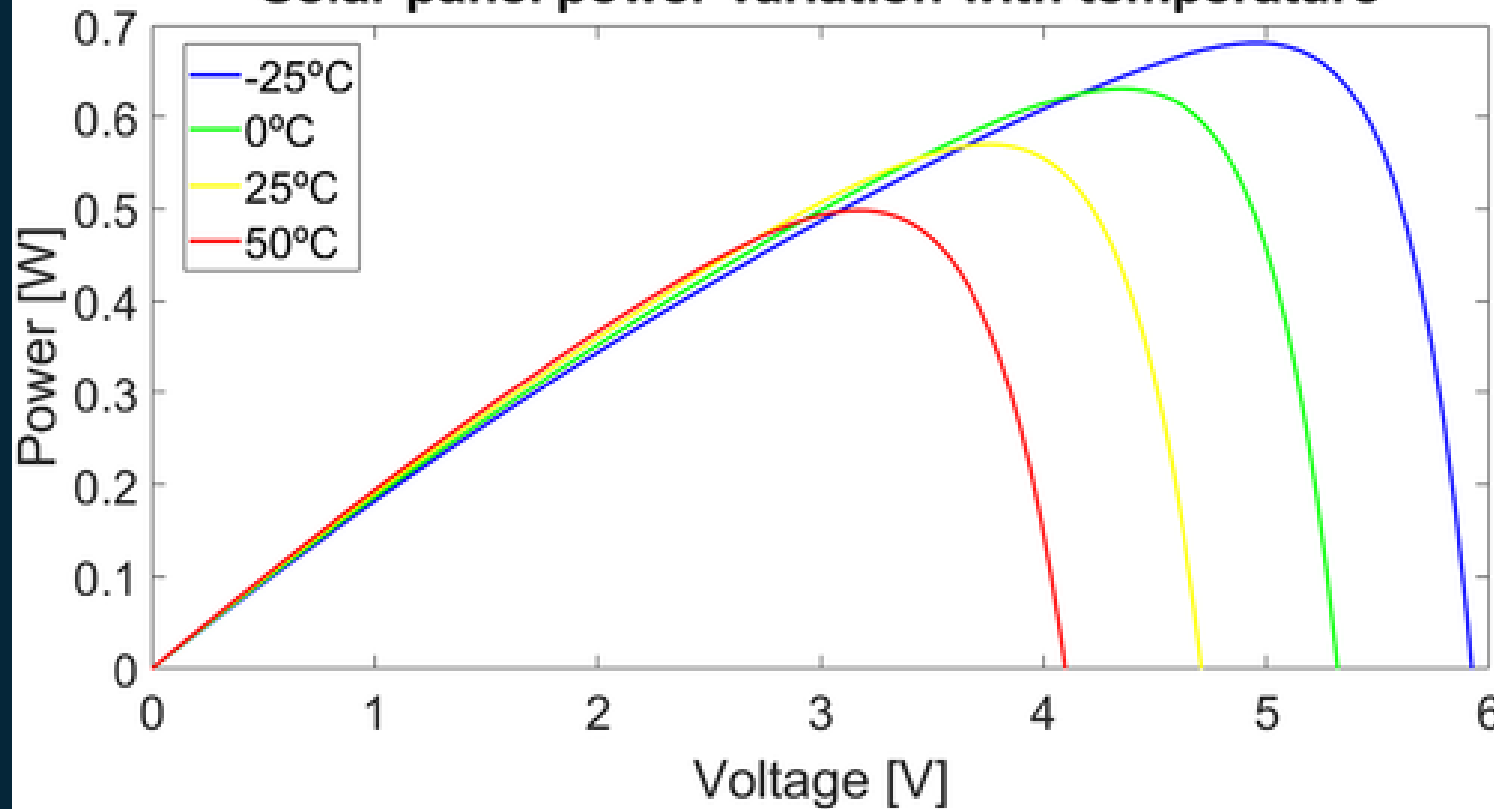


ELECTRICAL POWER SYSTEM



ELECTRICAL POWER SYSTEM

Solar panel power variation with temperature



ELECTRICAL POWER SYSTEM

- The **nominal voltage** has to be line with the buses voltage **required by the modules** supplied by the battery.
- The **energy density determines the size** of the battery compared to the needed energy
- The **maximum discharging current limits the maximum number of modules** running **at the same time**. This also limits the maximum consumption of any single module.
- The **self-discharge** will affect the **battery capacity**, so it must be taken into account when deciding the total capacity.
- The **charging time** of the battery **minus the oversize part** cannot be longer than the sunshine time, **or else it will be a lack of electricity** during the eclipse.
- The **thermal charging and discharging range** are linked to the spacial conditions, and must be **line with the thermal regulation** modules to provide optimal or minimal operating conditions
- The **maximum number of cycles depends on the length of the space mission**. As the capacity of the battery diminishes over time, one can choose to over-size the battery or to choose a type which has a higher number of maximum cycles.

Lithium Polymer

Strengths:

- Can have different tiny forms
- Low weight
- Safest batteries

Weaknesses:

- Less Energy saving than Li-Ion batteries
- More expansive
- Regulated charge



Lithium Ion

Strengths:

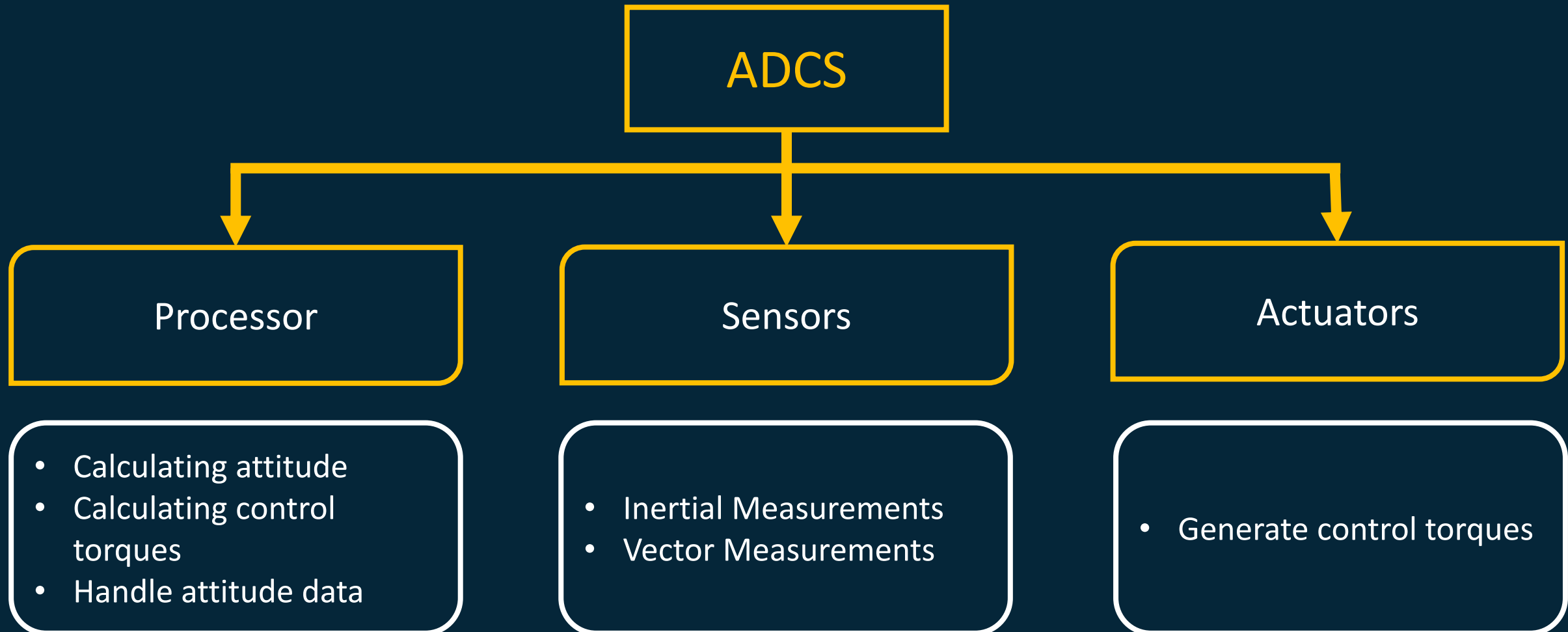
- Can have different tiny forms
- Low weight
- Highest power saving

Weaknesses:

- Shortest life cycle than Lithium Polymer batteries
- Can cause bypass



ATTITUDE DETERMINATION and CONTROL SYSTEM



ATTITUDE DETERMINATION and CONTROL SYSTEM

INERTIAL SENSORS

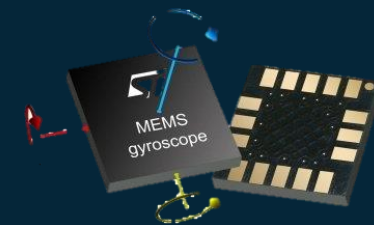
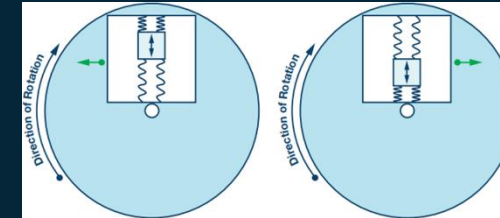
ADVANTAGES

- Extremely scalable in manufacturing, resulting in very **low unit costs** when mass produced
- MEMS sensors possess extremely **high sensitivity**
- MEMS switches and actuators can attain very **high frequencies**
- MEMS devices require very **low power consumption**

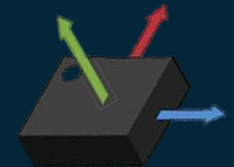
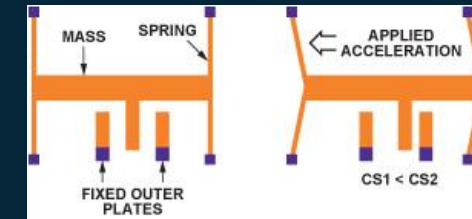
DISADVANTAGES

- Time zero drift
- Temperature drift
- Low accuracy

Gyroscope



Accelerometer



VECTOR SENSORS

ADVANTAGES

- High accuracy
- Small mass and dimensions

DISADVANTAGES

- High power consumption
- Expensive

Magnetometer

Star tracker

Sun sensor

Horizon sensor

GPS



ATTITUDE DETERMINATION and CONTROL SYSTEM

SENSOR POTENTIAL ACCURACY

STAR TRACKER

1 arcsecond

SUN SENSOR

1 arcminute

HORIZON SENSOR

6 arcminutes

MAGNETOMETER

30 arcminutes

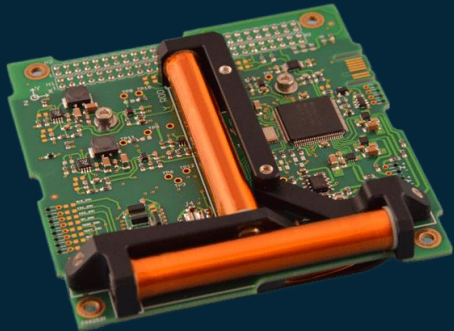
GPS

6 arcminutes

ATTITUDE DETERMINATION and CONTROL SYSTEM

ACTIVE ACTUATORS

Magnetorquers



ADVANTAGES

- Low cost
- Controlled value of torque

DISADVANTAGES

- Low accuracy
- Cause EM disturbances
- Torque depends on orbit

Reaction wheels



ADVANTAGES

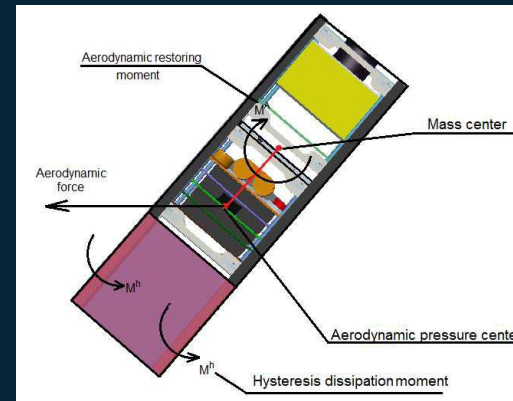
- High control torque
- Fast control operations
- Controlled value of torque

DISADVANTAGES

- Expensive
- High power consumption
- Big volume

PASSIVE ACTUATORS

Aerodynamics



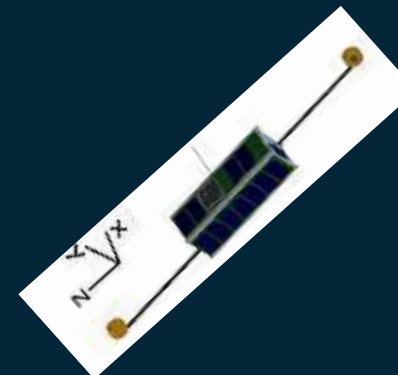
ADVANTAGES

- Low cost
- No energy consumption

DISADVANTAGES

- Low accuracy
- Depends on CubeSat design
- Depends on orbit

Gravity



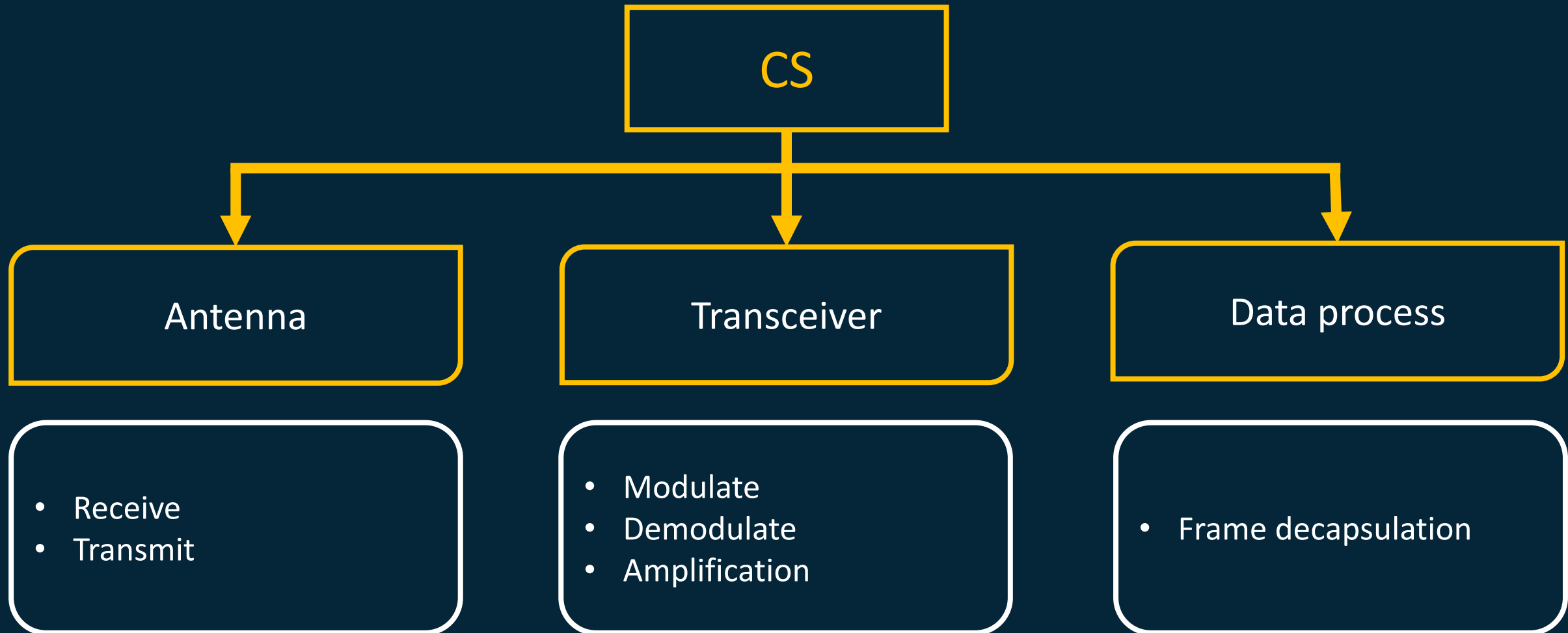
ADVANTAGES

- Low cost
- No energy consumption

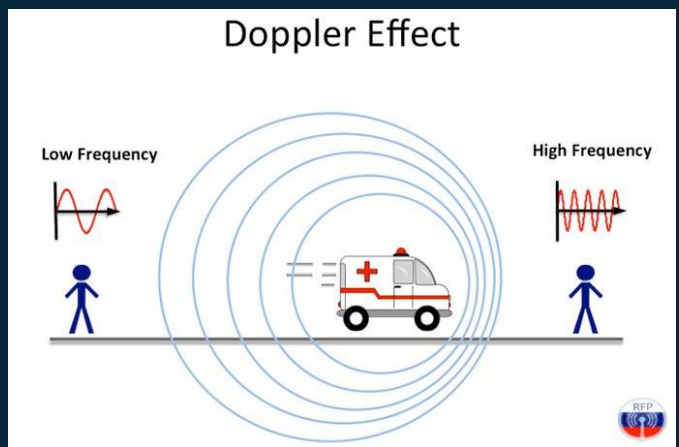
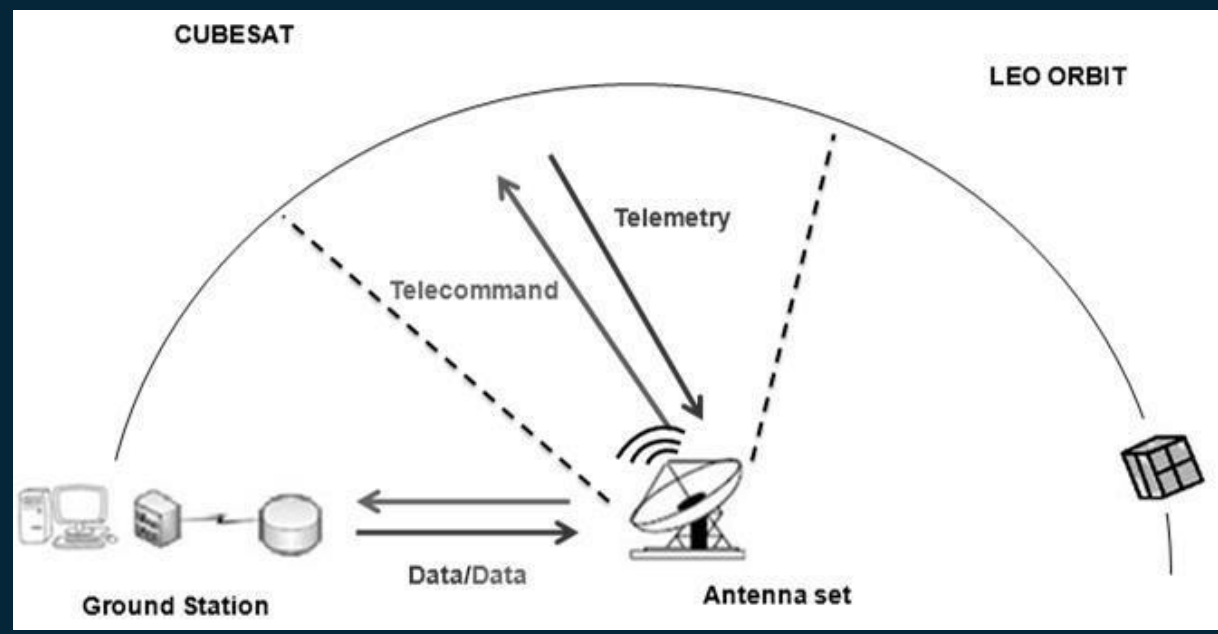
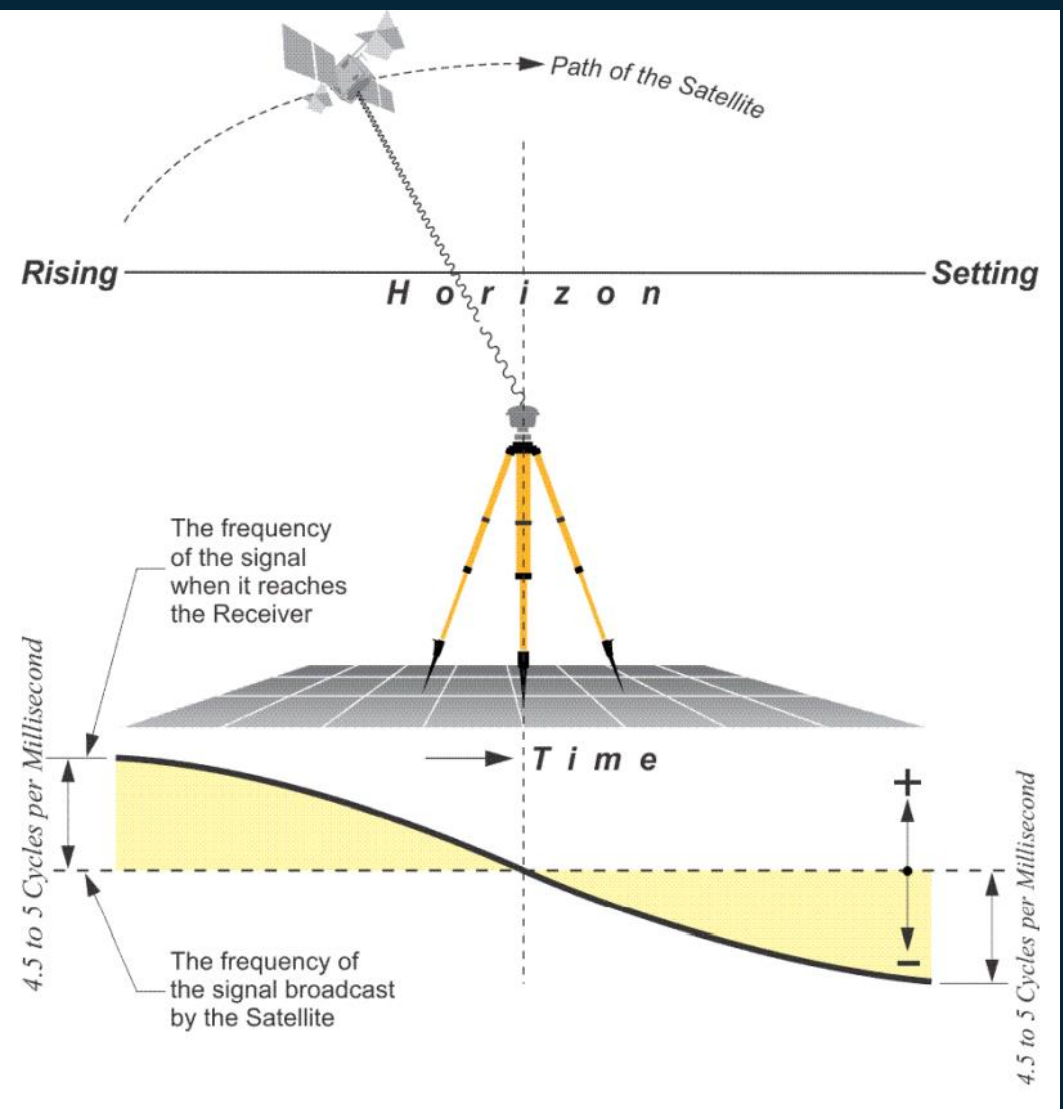
DISADVANTAGES

- Low accuracy
- Depends on CubeSat design
- Depends on orbit
- CubeSat can be stabilized upside down

COMMUNICATION SYSTEM



COMMUNICATION SYSTEM



COMMUNICATION SYSTEM

TRANSMISSION SPEED



Research program



CubeSat design complexity

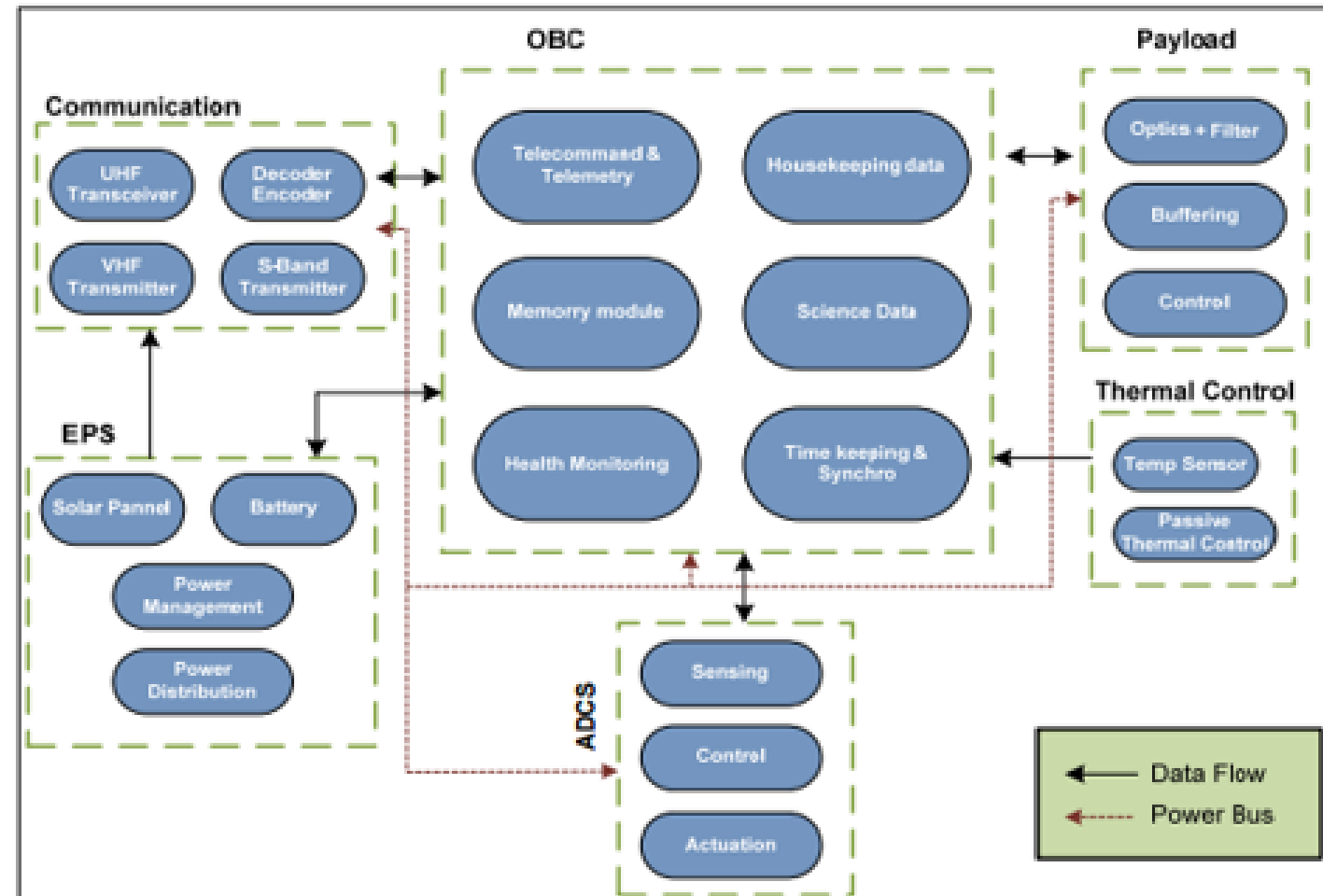


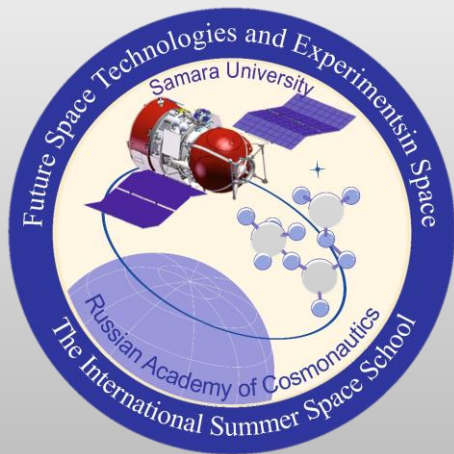
Data storage volume

Spacecraft availability for earth stations
during communication sessions.

SUMMARY

- The **main determining factor** for every flight is the **payload**.
- Mission analysis should take in account **environmental factors**
- CubeSat design should take in account **deployment type**
- The main disturbances during flight are caused by **gravity** and **atmosphere**
- CubeSat can use **active** and/or **passive** actuators
- **CubeSat is a complex system** that consists of different elements





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THANKS FOR ATTENTION

