L3. Introduction to nanosatellite design

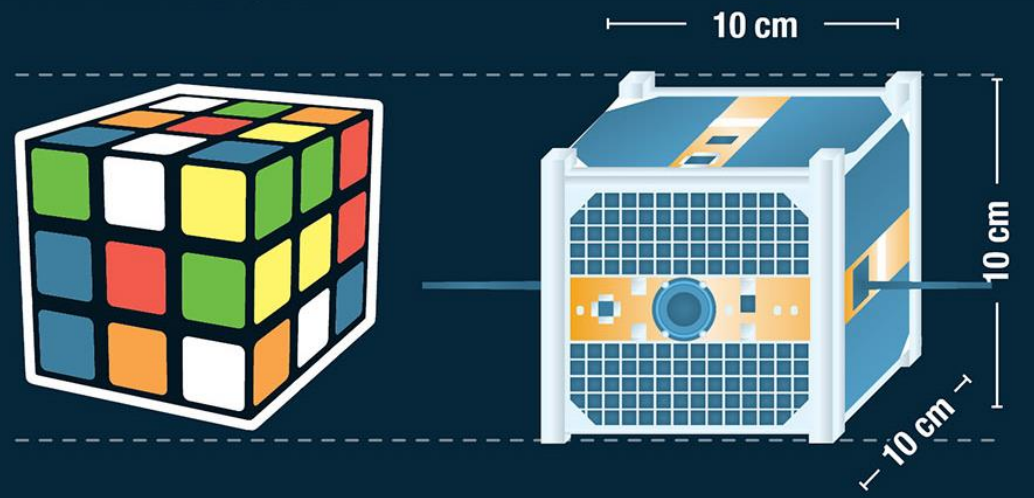
Dr. Lomaka Igor

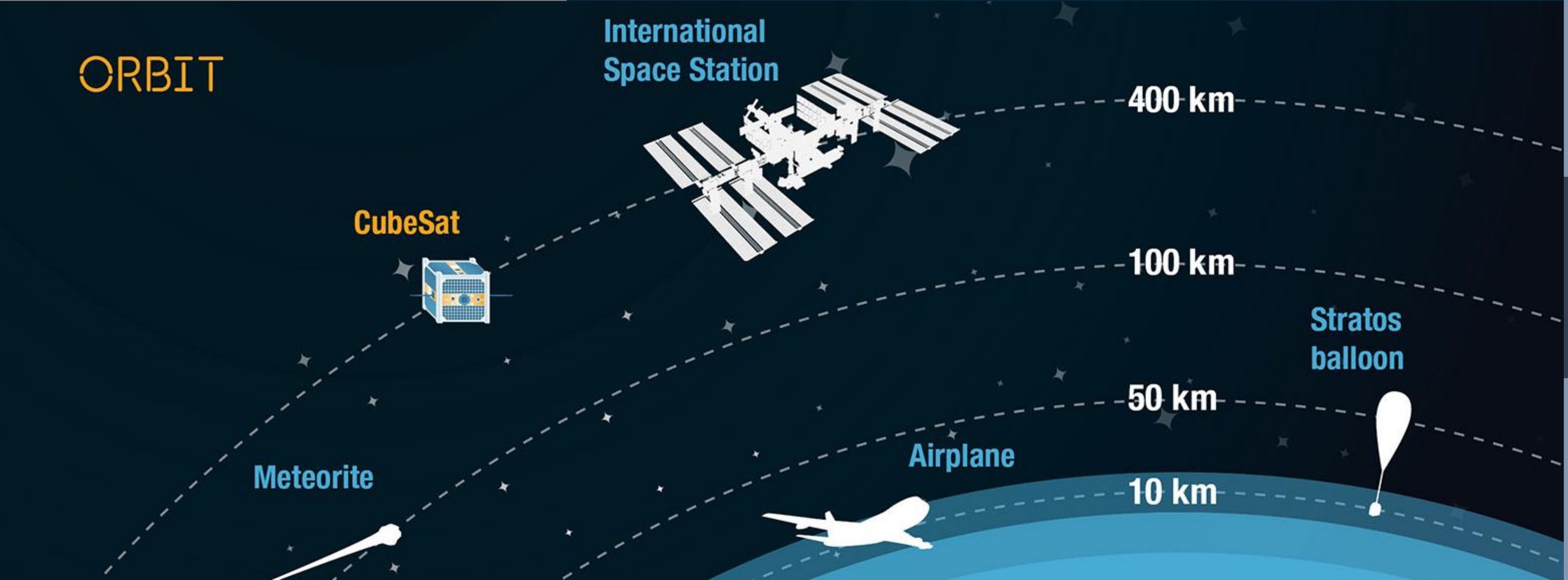
Presentation content

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

A **CubeSat** is a miniature **cube-shaped satellite**

DIMENSIONS

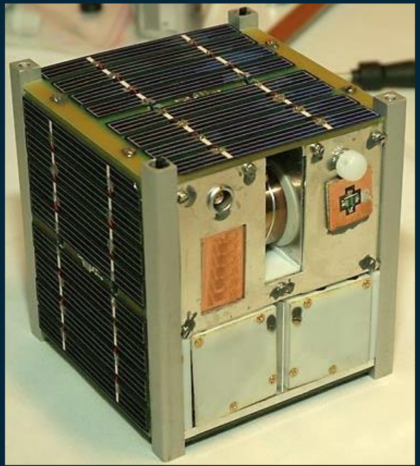


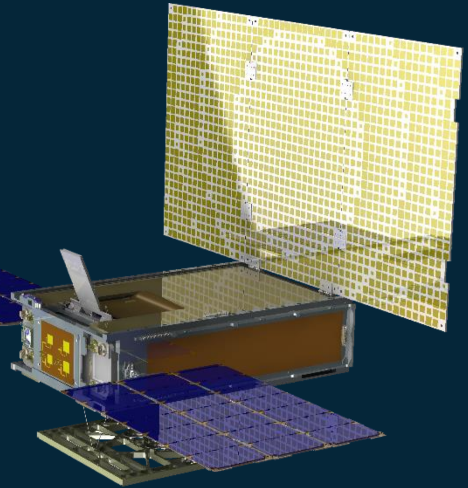


ADVANTAGES

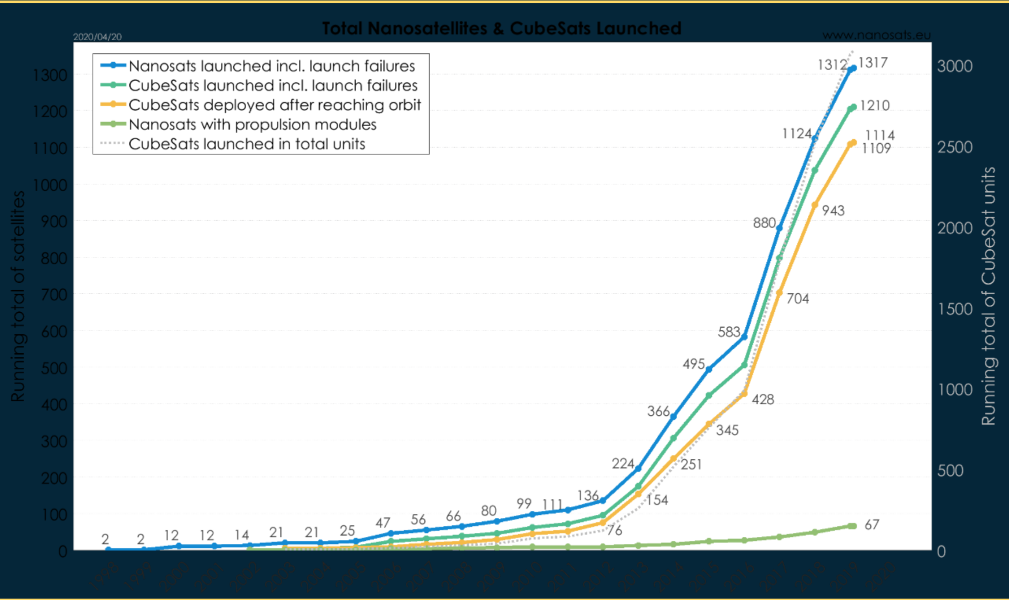
- FAST DEVELOPMENT (less than 2 years)
- SIMPLE TECHNOLOGY
- SIMPLE TO DESIGN
- NO SPACE DEBRIS (Burn up in the atmosphere)
- LOW COST

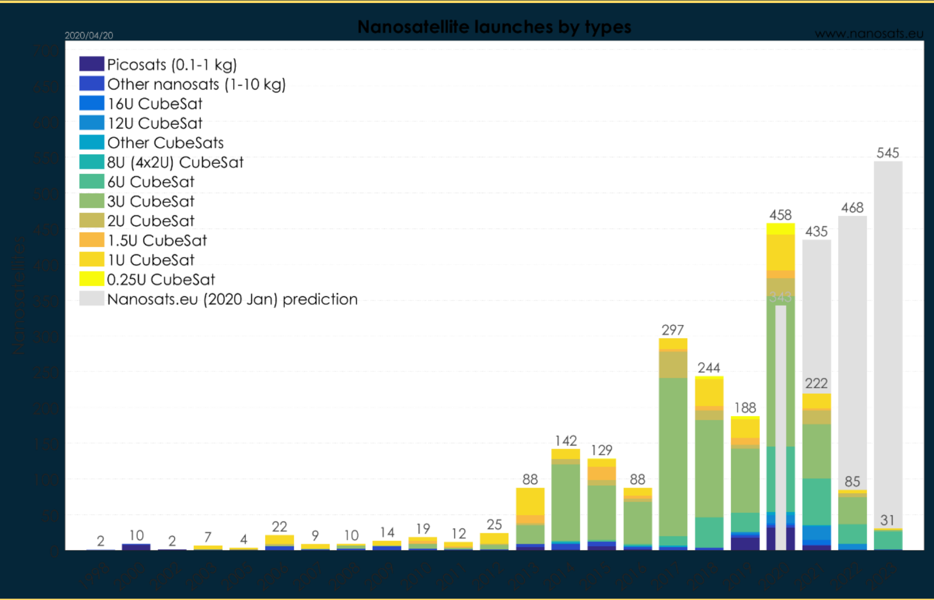
CubeSat history



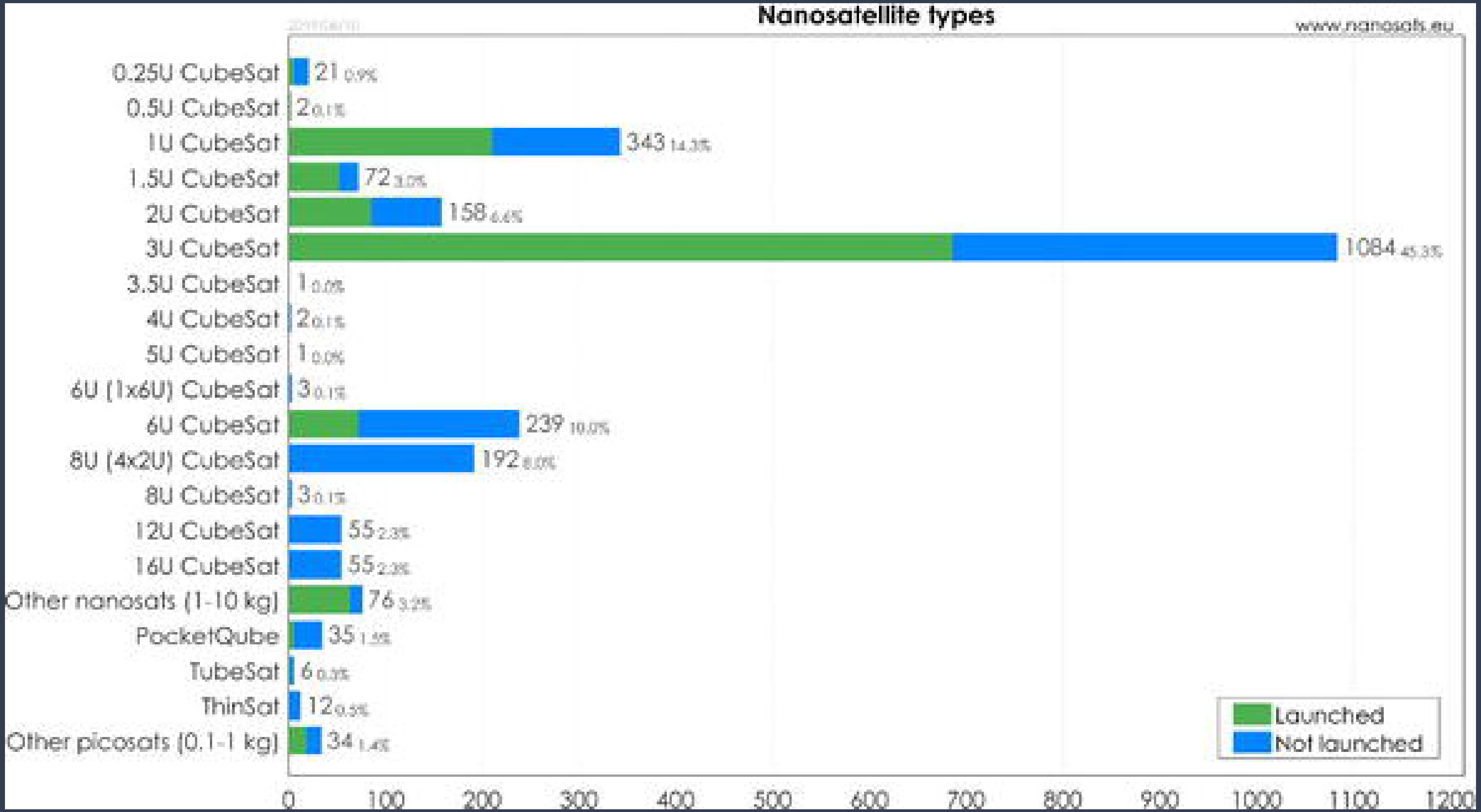


1999 NANOSATELLITE PROGRESS LINE 2025

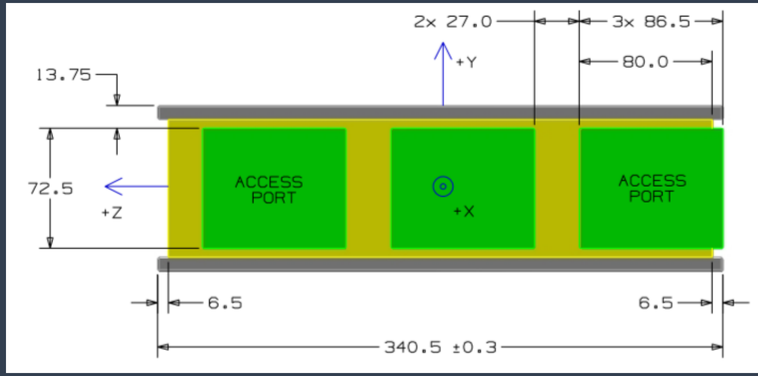




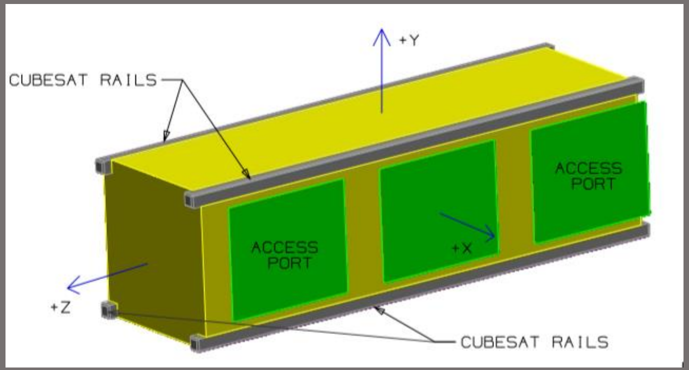
CubeSat most popular form-factor



DIMENSIONS



ACCESS PORTS



Mission requirements

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

Payload

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

Operating environment

PRE-LAUNCH PHASE

LAUNCH PHASE

DEPLOYMENT PHASE

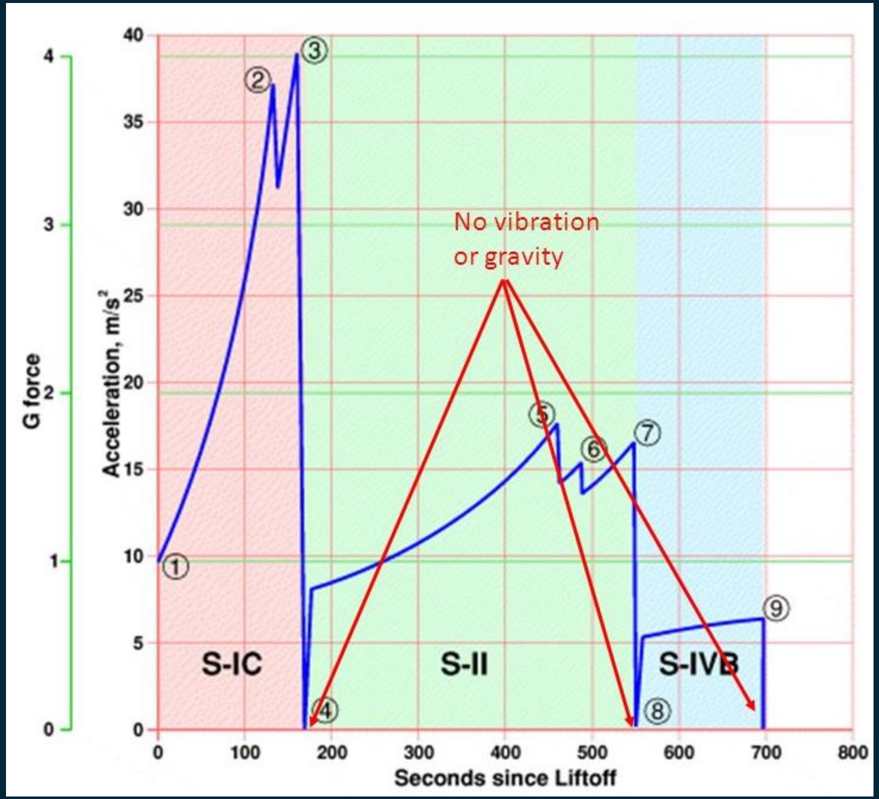
FLIGHT PHASE

Pre-launch 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

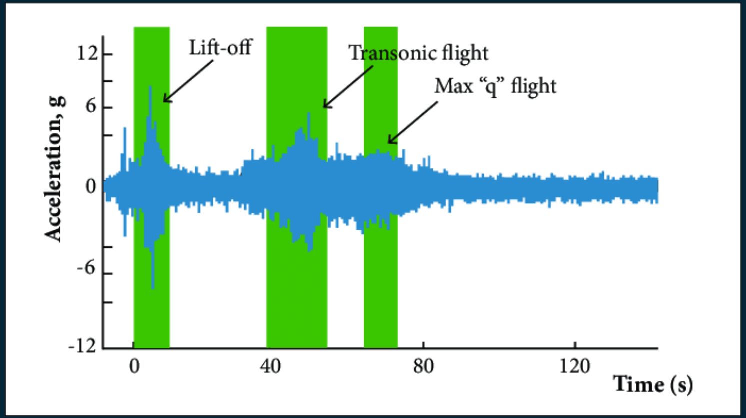


CONSTANT COMPONENT OF ACCELERATION

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



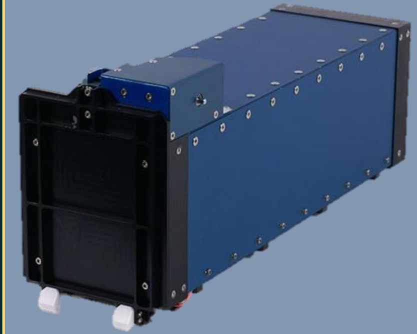
THERMAL ENVIRONMENT

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

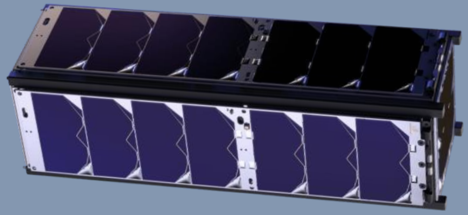
Deployment phase

CONTAINER LAUNCH FROM ISS

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



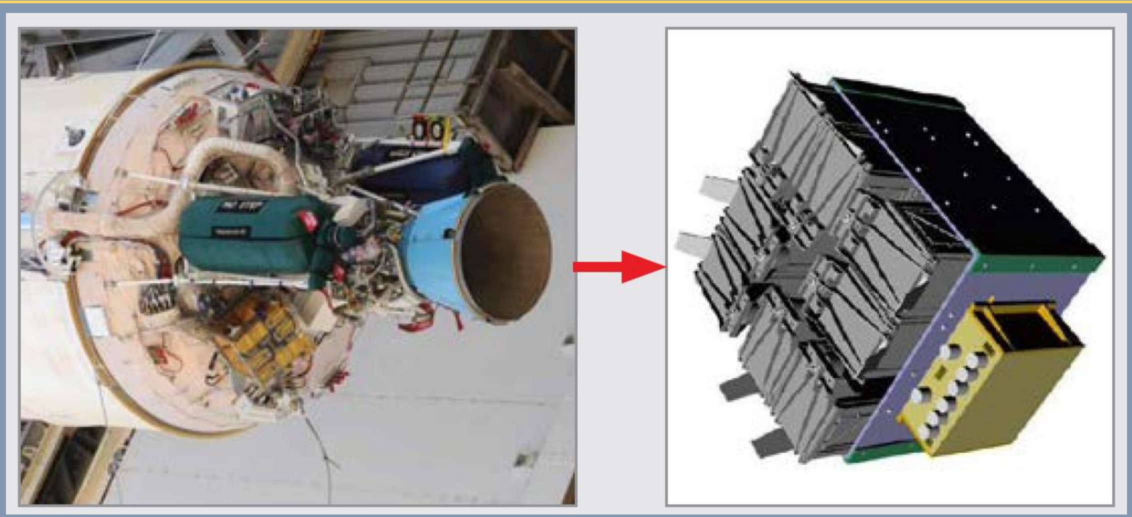
+



+

CONTAINER LAUNCH FROM ROCKET

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



Deployment phase

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	

Deployment phase

Flight phase

GRAVITY

ATMOSPHERE

SUN

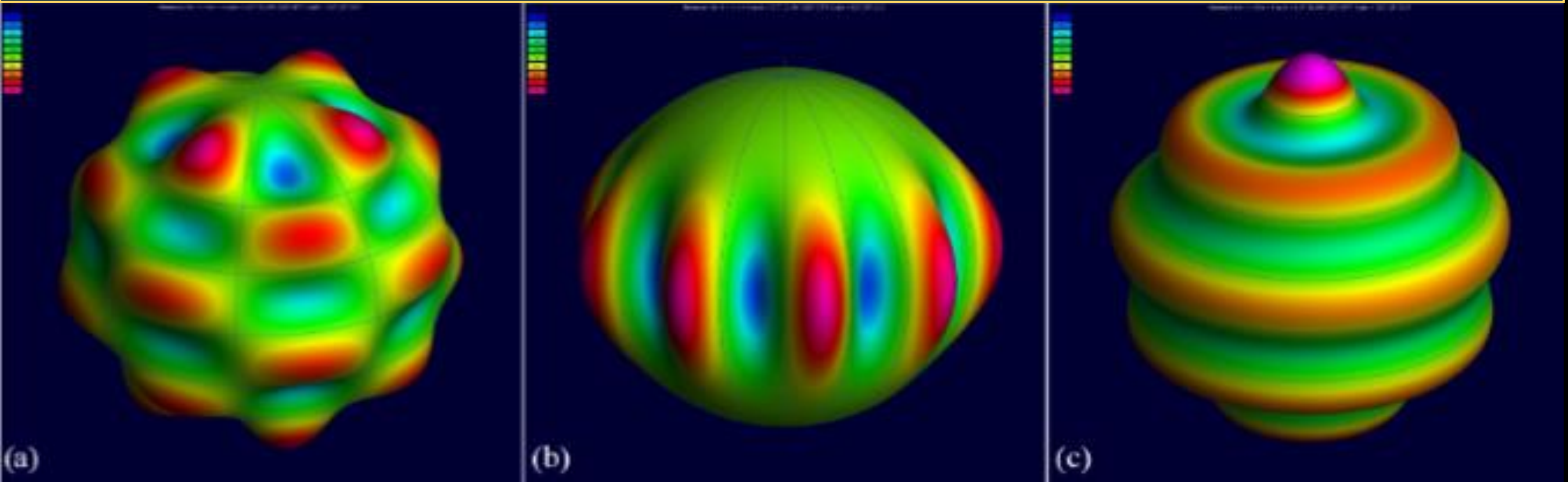
MAGNETIC FIELD AND RADIANCE

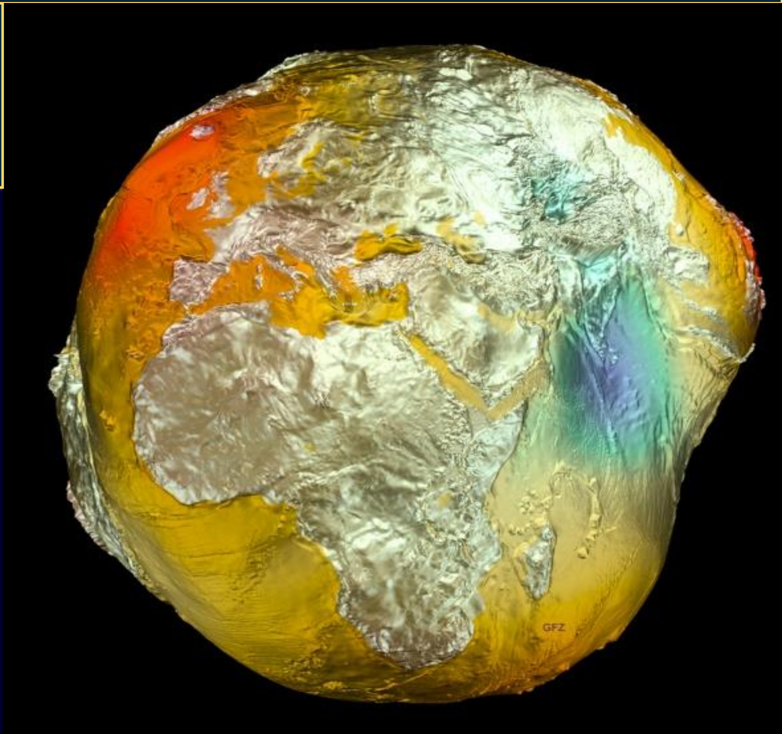
GRAVITY INFLUENCE

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





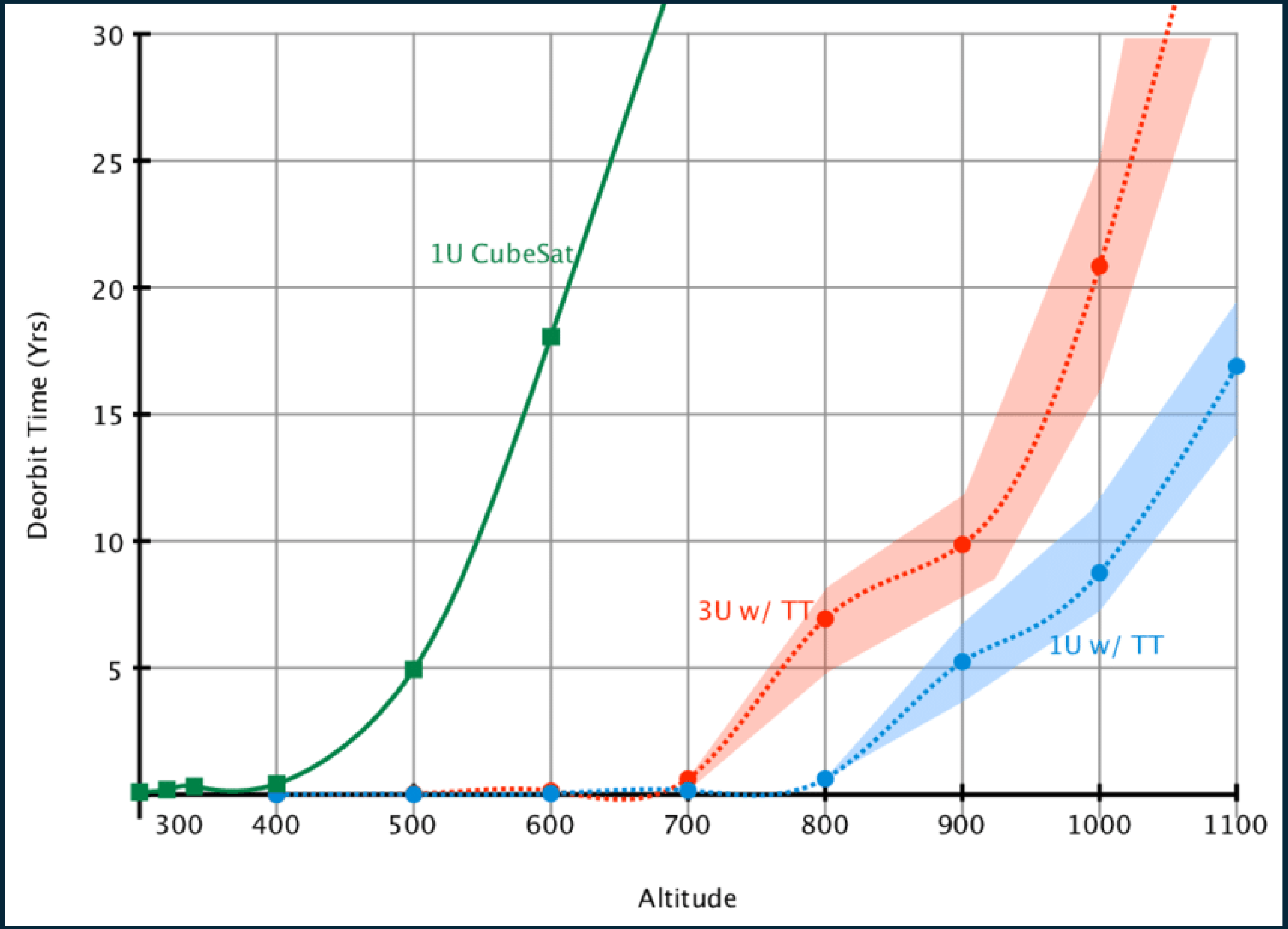
ATMOSPHERIC INFLUENCE

ATMOSPHERIC DRAG

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

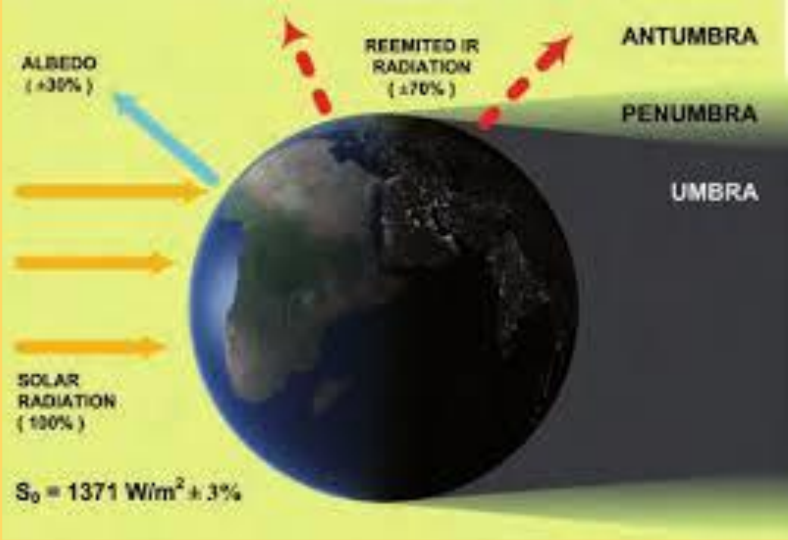
ATMOSPHERIC DENSITY MODELS

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



SUN INFLUENCE

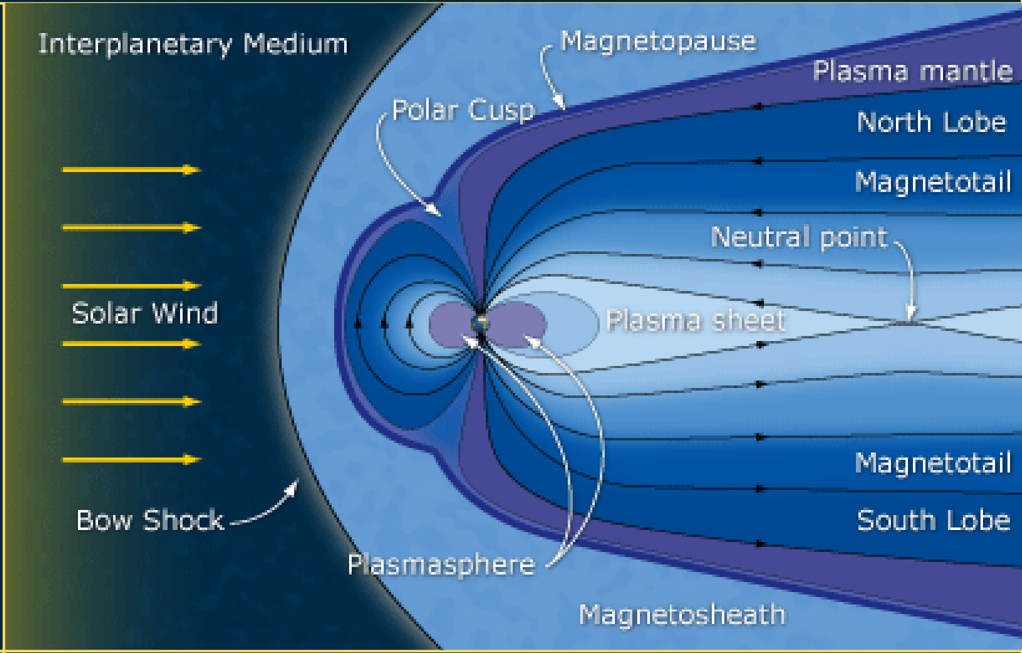
HEAT	• The dominant role in the supply of heat belongs to solar radiation, the value of which in the near-Earth environment is 1400 W/m^2; • The secondary source of heat is the Earth's albedo (reflection of solar radiation) and the Earth's own radiation (radiation of the Earth as a black body), the value of which is about 200 W/m^2. • 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.



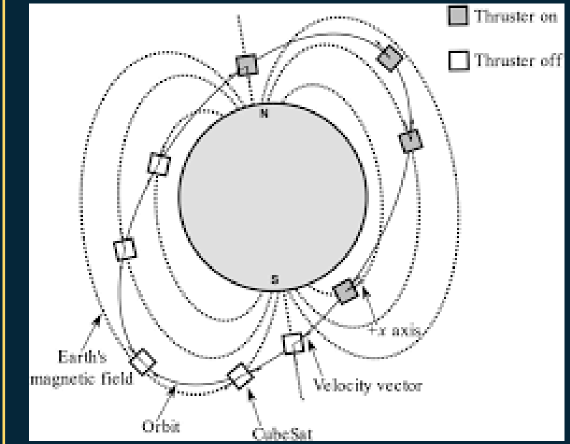
MAGNETIC FIELD

STRUCTURE

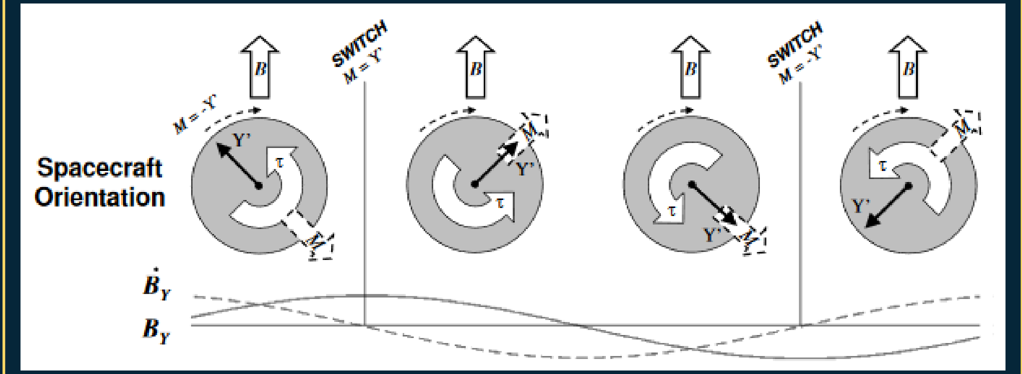
- The Earth's magnetic field has two main sources;
- On the surface, the main role is played by the currents circulating inside the planet.
- With increasing altitude, the role of fluxes caused by the motions of electrons and ions in the magnetosphere increases.
- The solar wind plasma, which carries 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



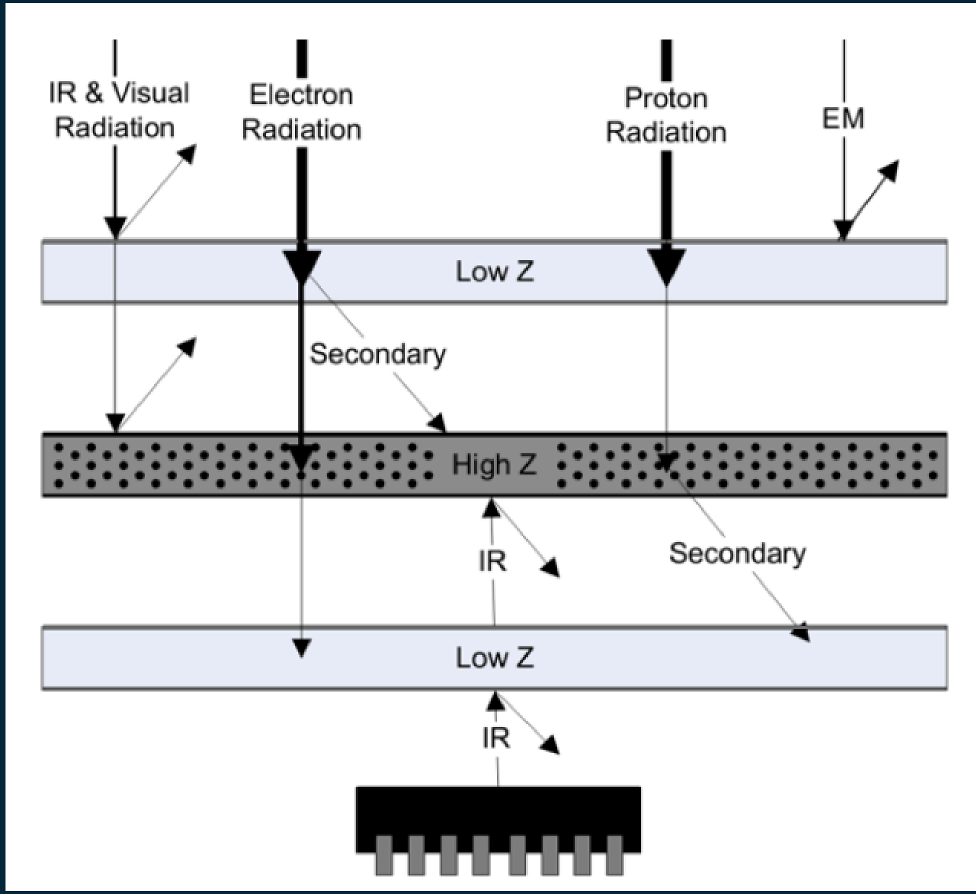
MAGNETIC FIELD FOR CONTROL



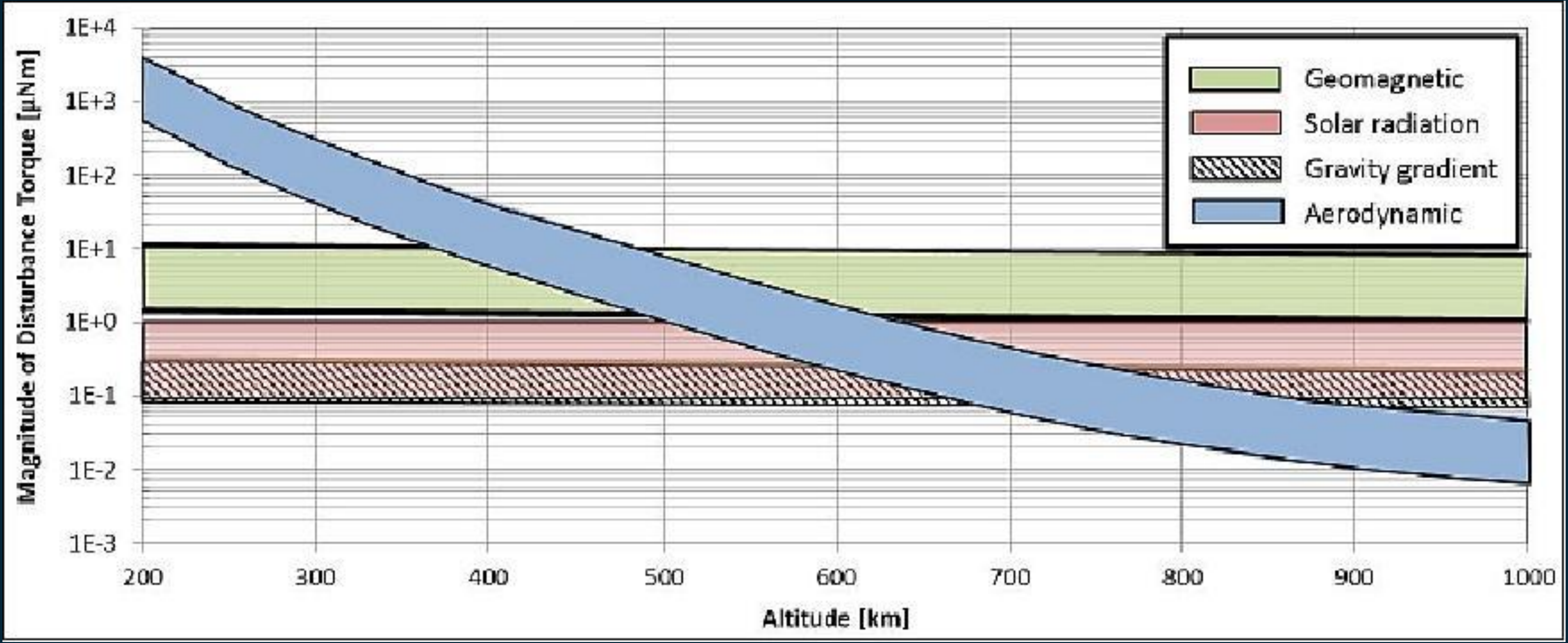
RADIATION

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

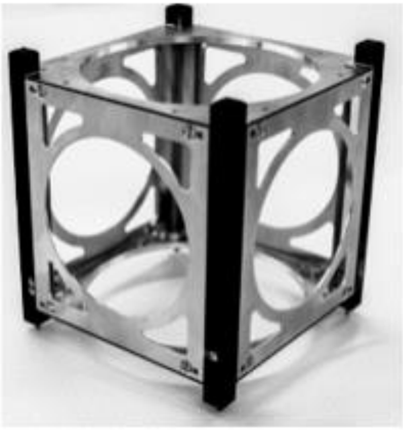

1E+4
1E+3
1E+2
1E+1
1E+0
1E-1
1E-2
1E-3
Magnitude of Disturbance Torque [µNm]
200
300
400
500
600
700
800
900
1000
Altitude [km]
Geomagnetic
Solar radiation
Gravity gradient
Aerodynamic

STRUCTURE

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

The 6U Supernova Structure Kit. Image Courtesy of Pumpkin, Inc.

NanoAvionics Small Satellite Structures. Image Courtesy of NanoAvionics (2015).



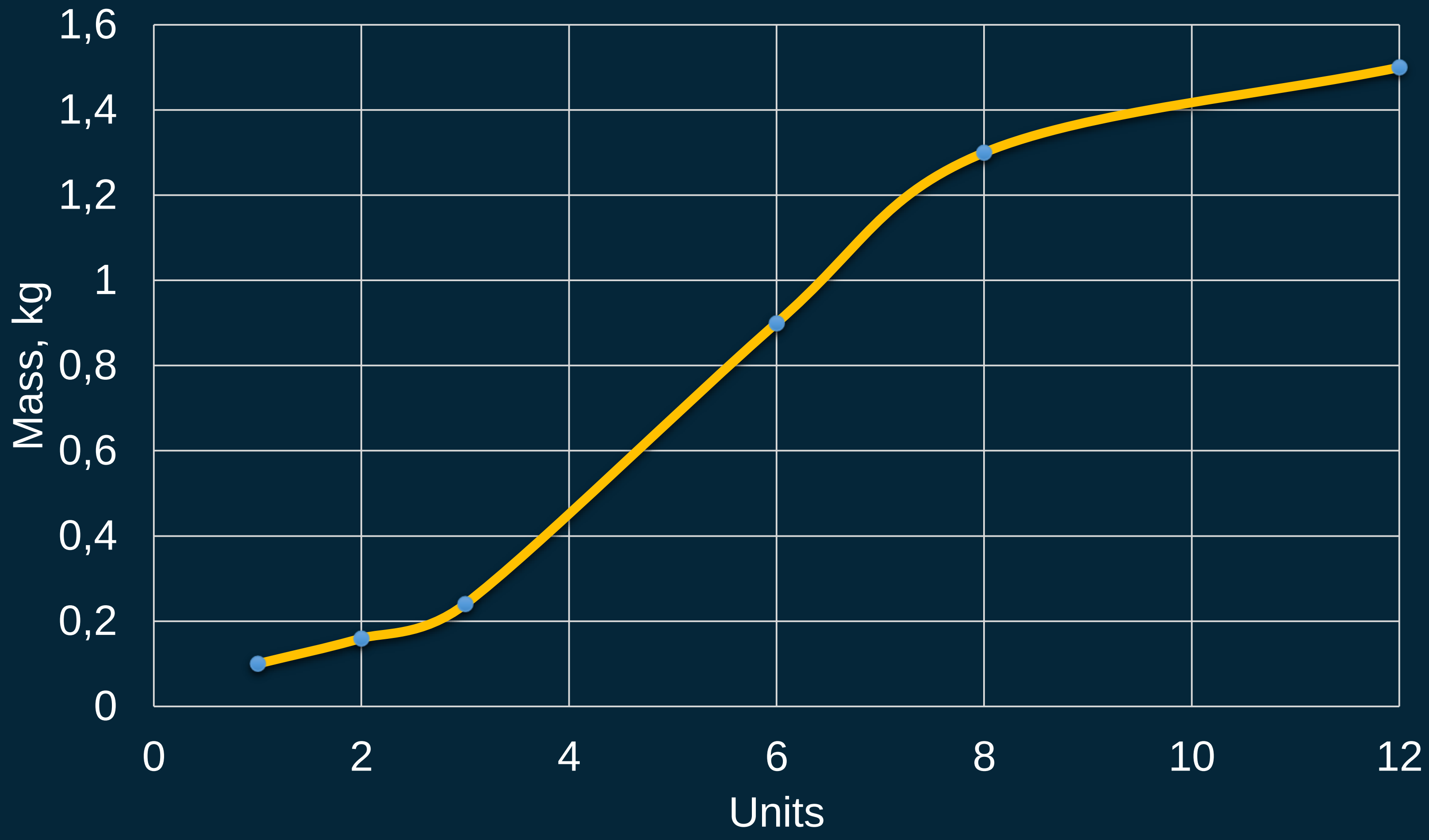
1U CS Structure. Image Courtesy of Clyde Space.

Figure 6.3: The Radius Space Modular Structures. Image Courtesy of Radius Space (2015).

1U Skeletonized CubeSat Kit. Image Courtesy of Pumpkin, Inc. (2015).

The GOMspace 6U nanosatellite structure. Image Courtesy of GOMspace ApS.

STRUCTURE

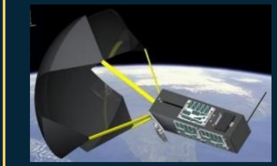


DEPLOYABLE STRUCTURES

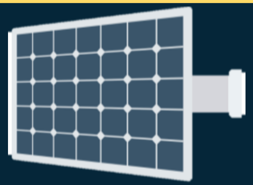
Often

Rare

ANTENNAS



AERODYNAMIC STABILIZER



SOLAR PANELS

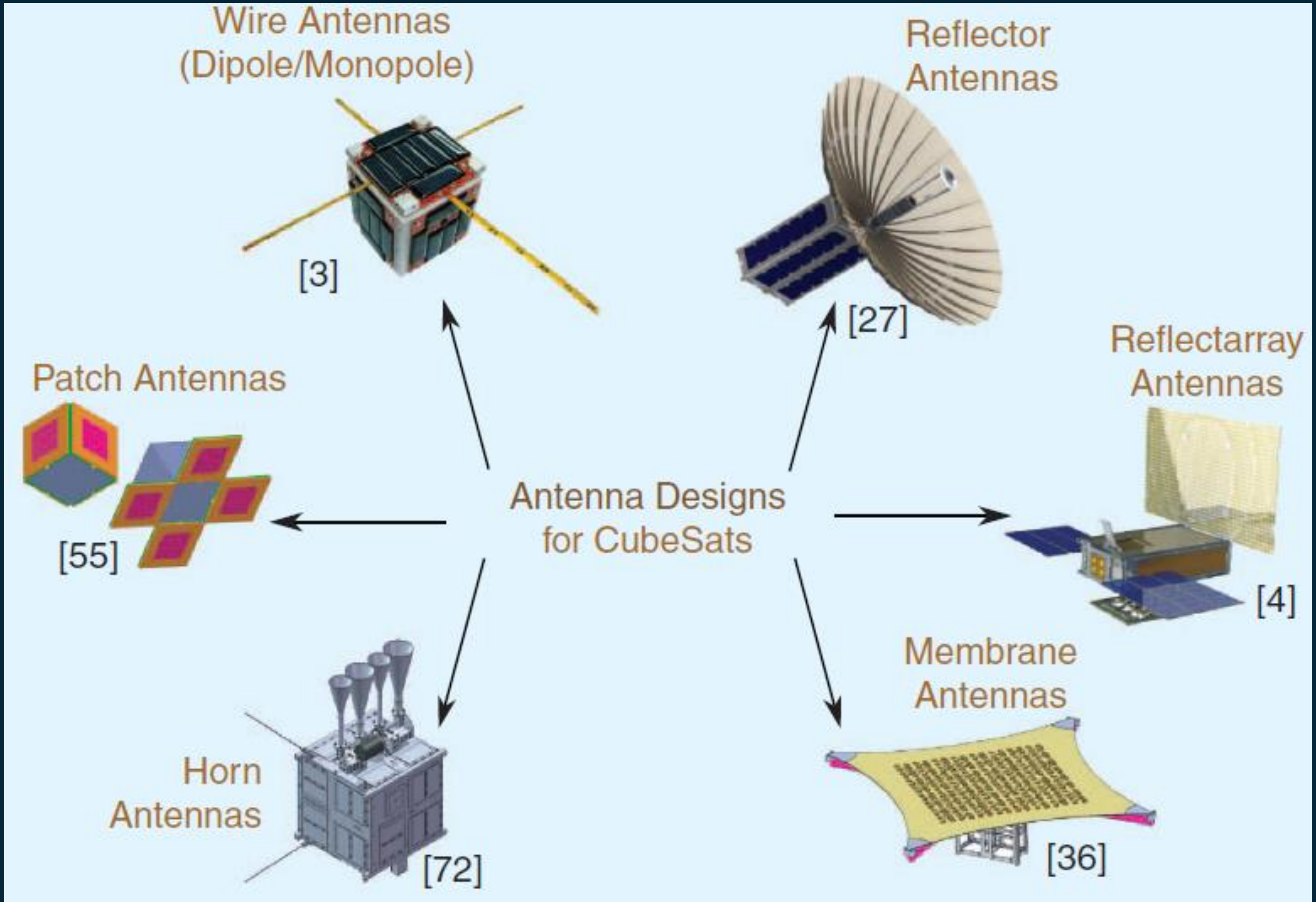
PAYLOAD

OTHER

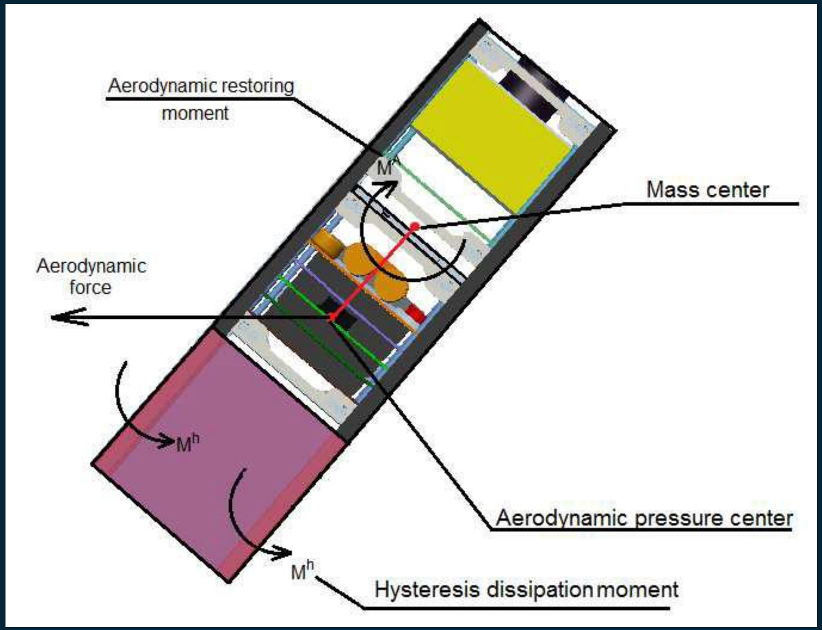
ANTENNAS

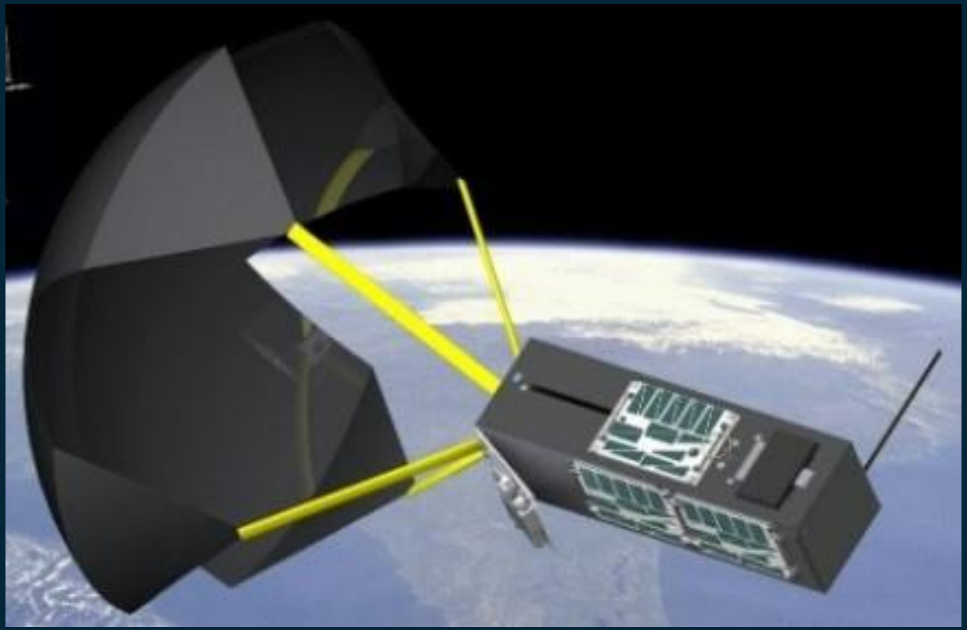
Antenna design depends on

- Speed communication requirements
- Attitude control system
- Orbit



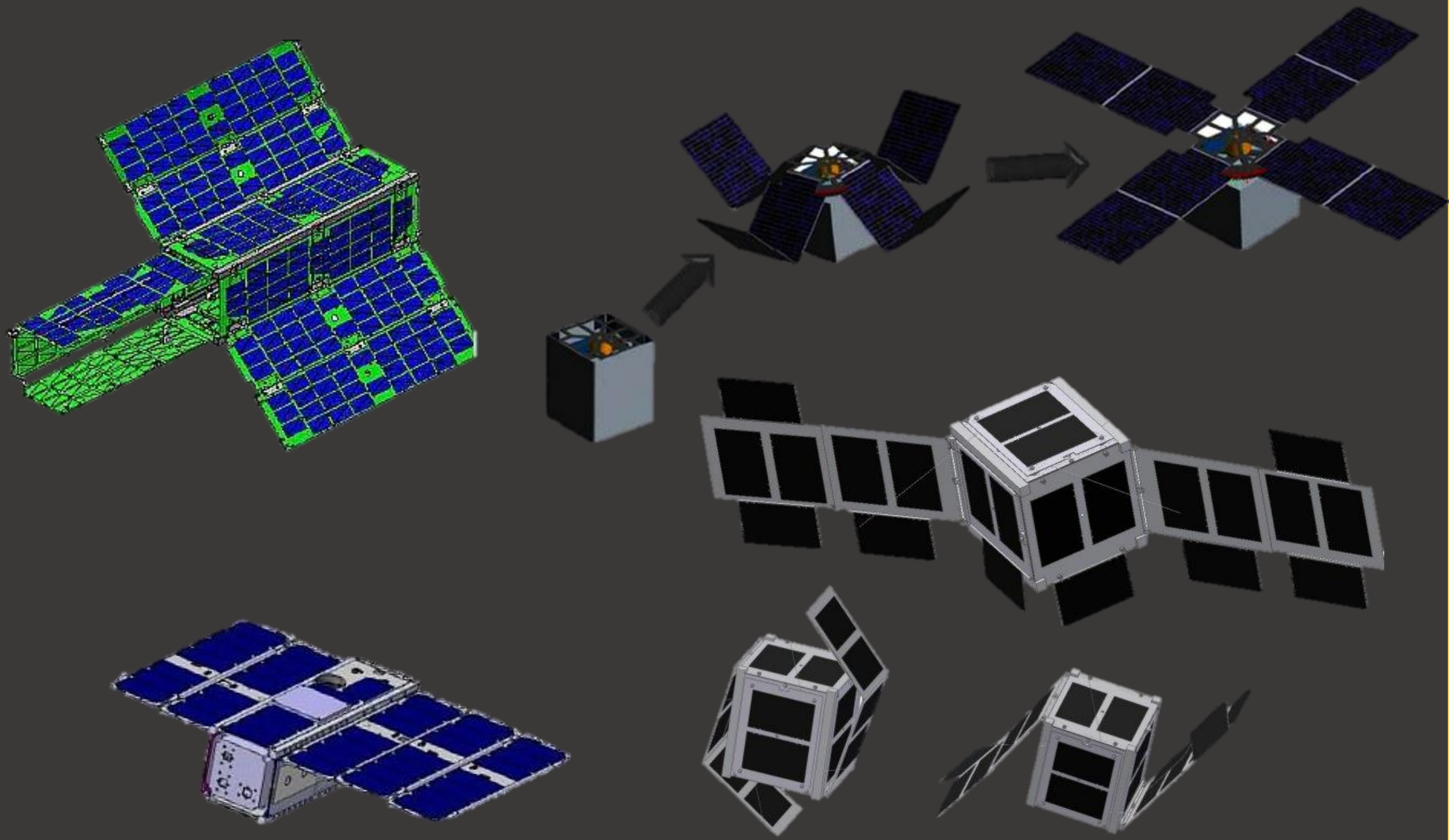
AERODYNAMIC STABILIZER





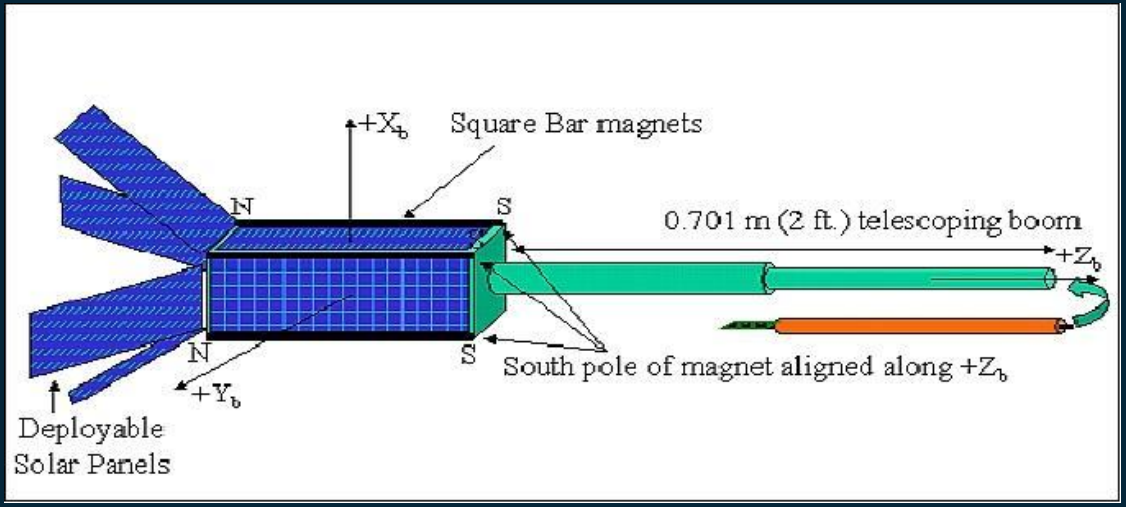
SOLAR PANELS

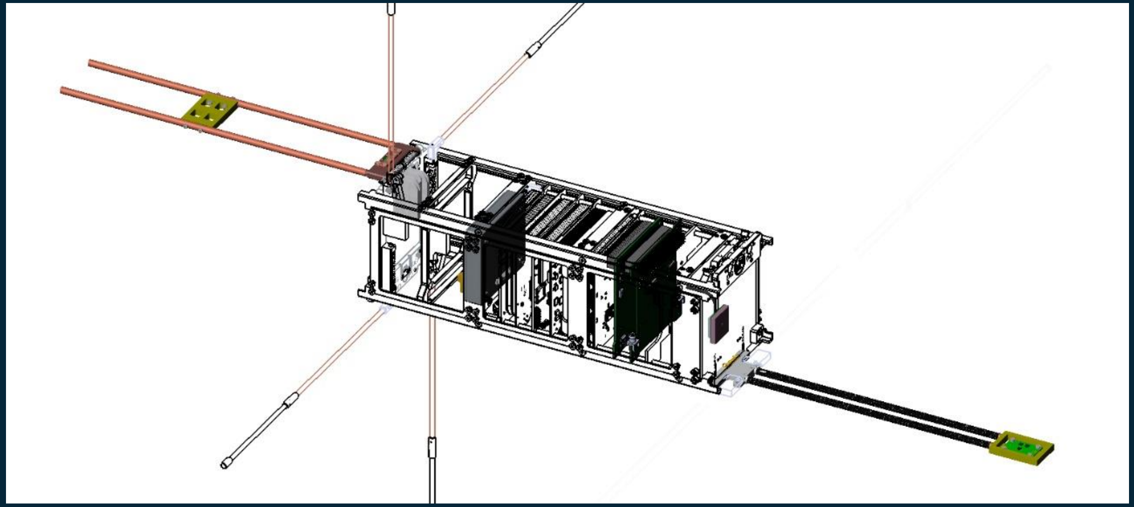
The area available of the solar panel is strongly limited on the CubeSat – so the solution is to use deployable solar panels.



PAYLOAD

To meet EMC requirements sensitive pay load or sensorы can be mounted on a transformable structure.





CubeSat SubSystems

ONBOARD COMPUTER

ELECTRICAL POWER SYSTEM

ATTITUDE CONTROL and DETERMINATION SYSTEM

COMMUNICATION SYSTEM

ONBOARD COMPUTER

OBC

Microcontroller

- Processing unit satellite
- Management
- Data Storage

Interfaces

- Connectors
- Signal distribution

Electronics

- Noise Processing
- Electronics protection

ELECTRICAL POWER SYSTEM

EPS

PCC (Power Control Circuit)

- Energy distribution
- Energy gathering
- Protection circuit

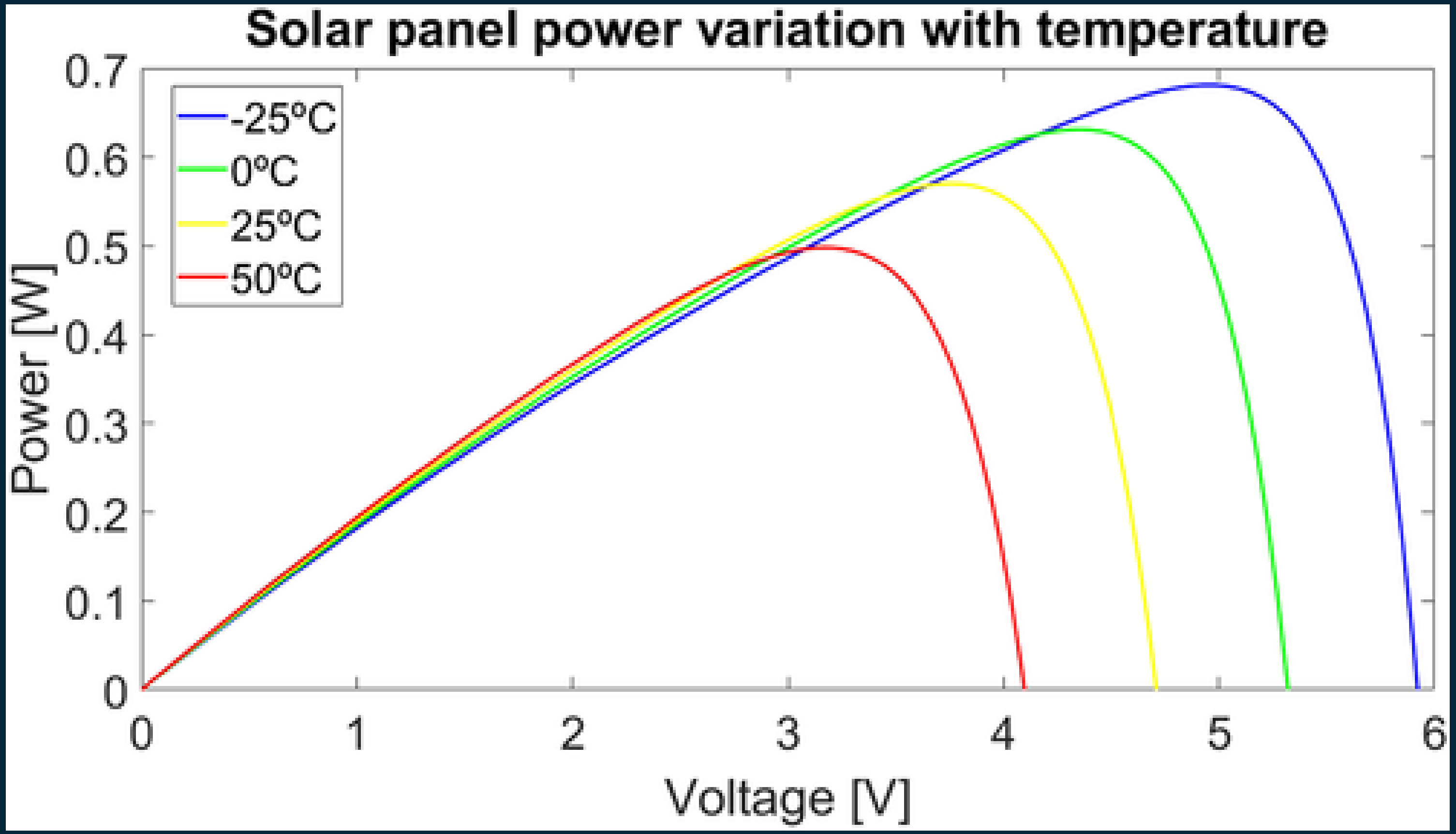
PV (photovoltaic panel)

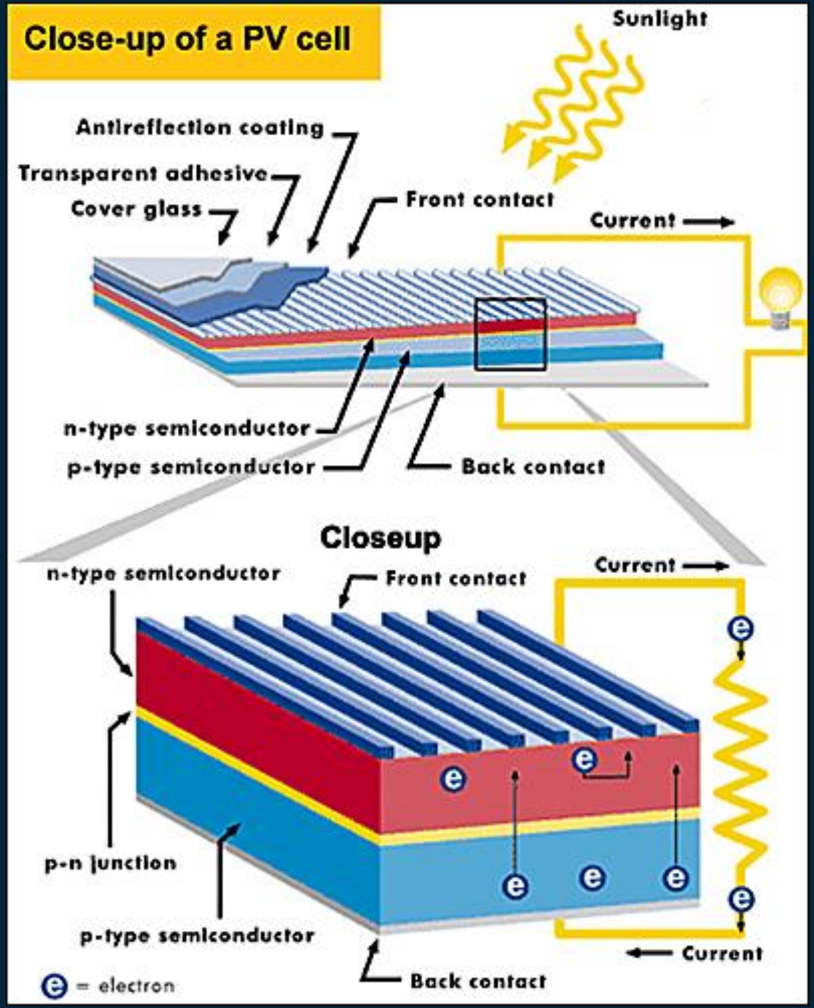
- Temperature sensor
- Energy generation

Batteries

- Protection circuit
- Dissipation system

ELECTRICAL POWER SYSTEM

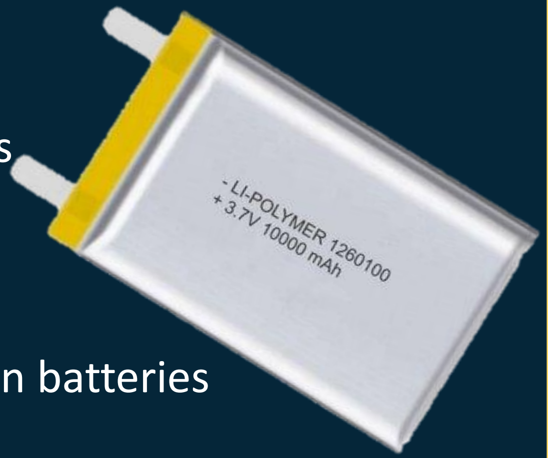




ELECTRICAL POWER SYSTEM

- 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

ADCS

Processor

- Calculating attitude
- Calculating control torques
- Handle attitude data

Sensors

- Inertial Measurements
- Vector Measurements

Actuators

- Generate control torques

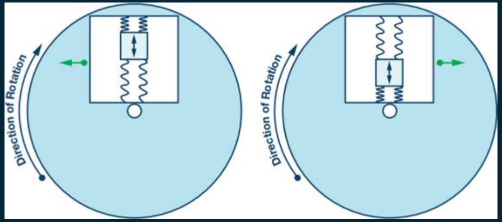
ATTITUDE DETERMINATION and CONTROL SYSTEM

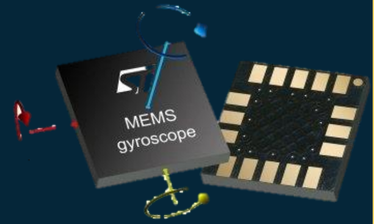
INERTIAL SENSORS

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

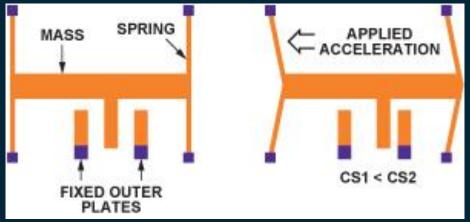
DISADVANTAGES
- Time zero drift
- Temperature drift
- Low accurancy

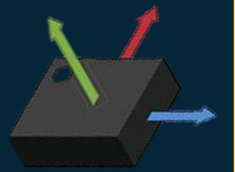
Gyroscope





Accelerometer





VECTOR SENSORS

ADVANTAGES
- High accuracy
- Small mass and dimensions

DISADVANTAGES
- High power consumption
- Expensive

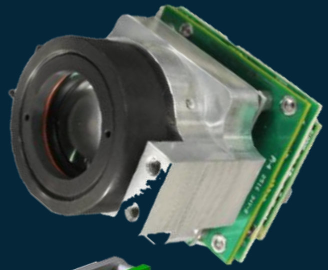
Magnetometer

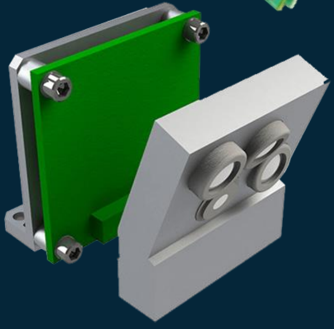
Star tracker

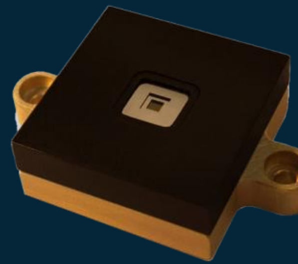
Sun sensor

Horizon sensor

GPS





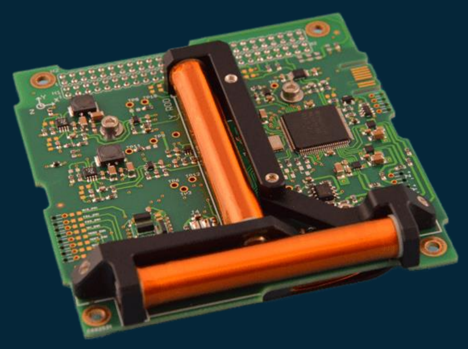


ATTITUDE DETERMINATION and CONTROL SYSTEM	
SENSOR POTENTIAL ACCURACY	
STAR TRACKER	1 arcsecond
SUN SENSOR	1 arcminute
HORIZON SENSOR	6 arcminutes
MAGNETOMETER	30 arcminutes
GPS	6 arcminutes

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

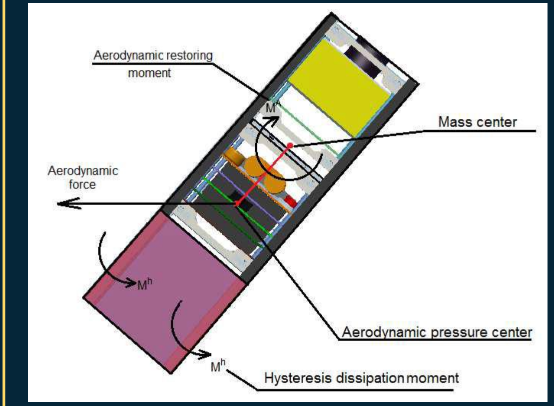
Reaction wheels

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

DISADVANTAGES
- Expensive
- High power consumption
- Big volume

PASSIVE ACTUATORS

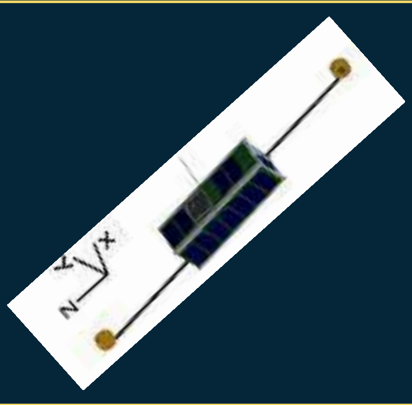
Aerodynamics



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

CS

Antenna

- Receive
- Transmit

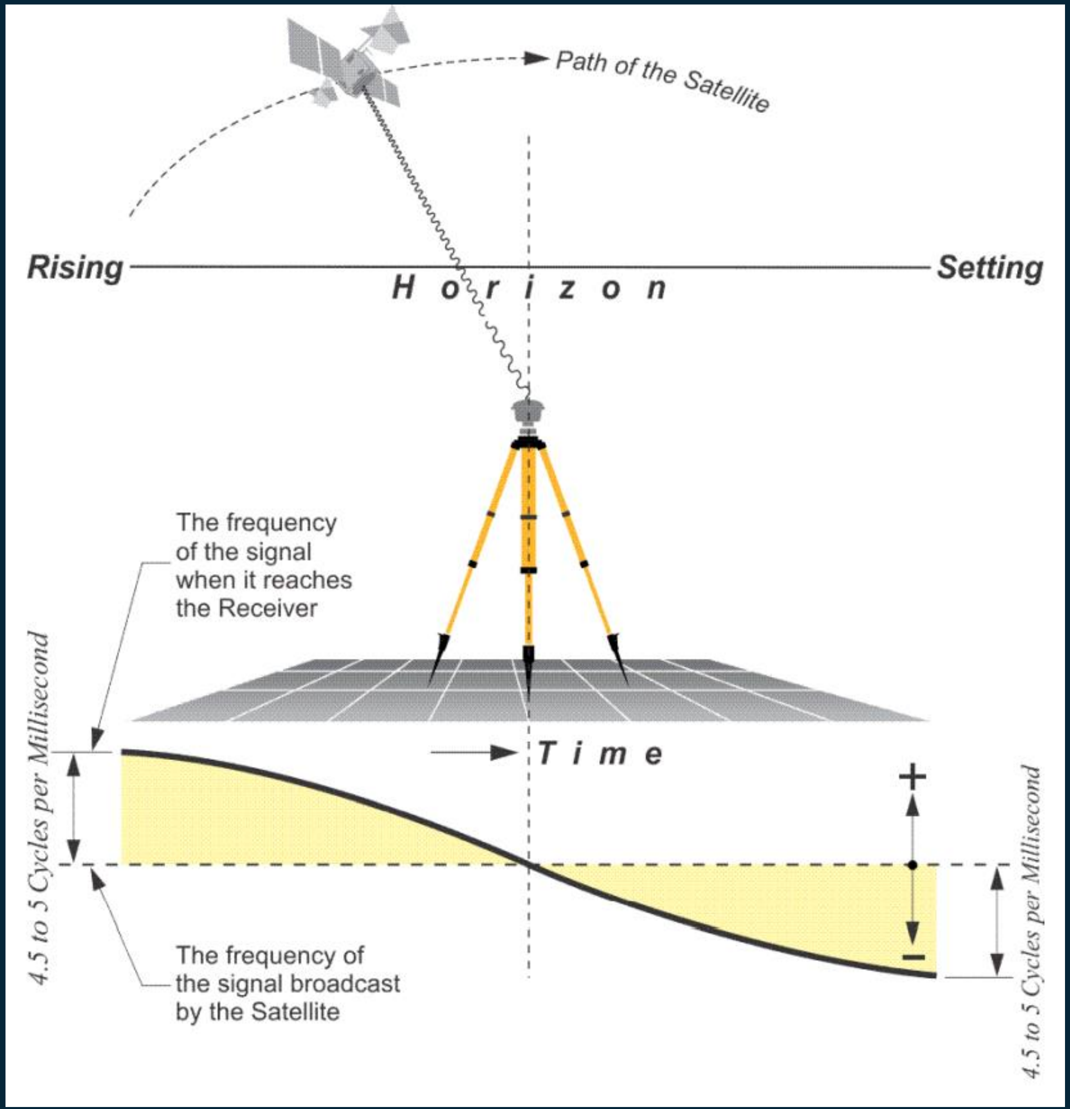
Transceiver

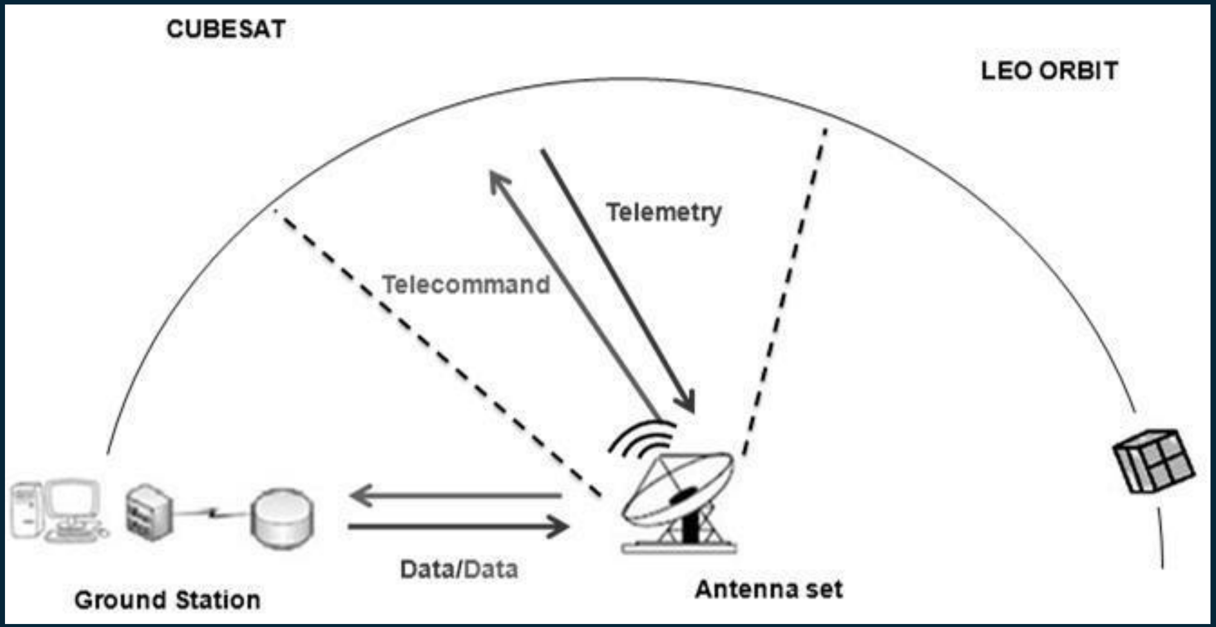
- Modulate
- Demodulate
- Amplification

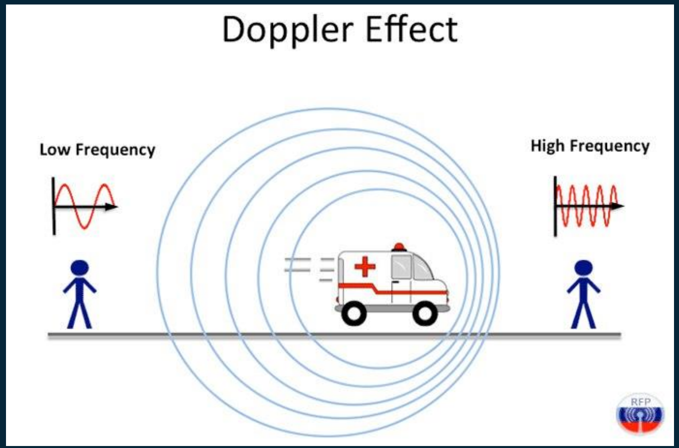
Data process

- Frame decapsulation

COMMUNICATION SYSTEM





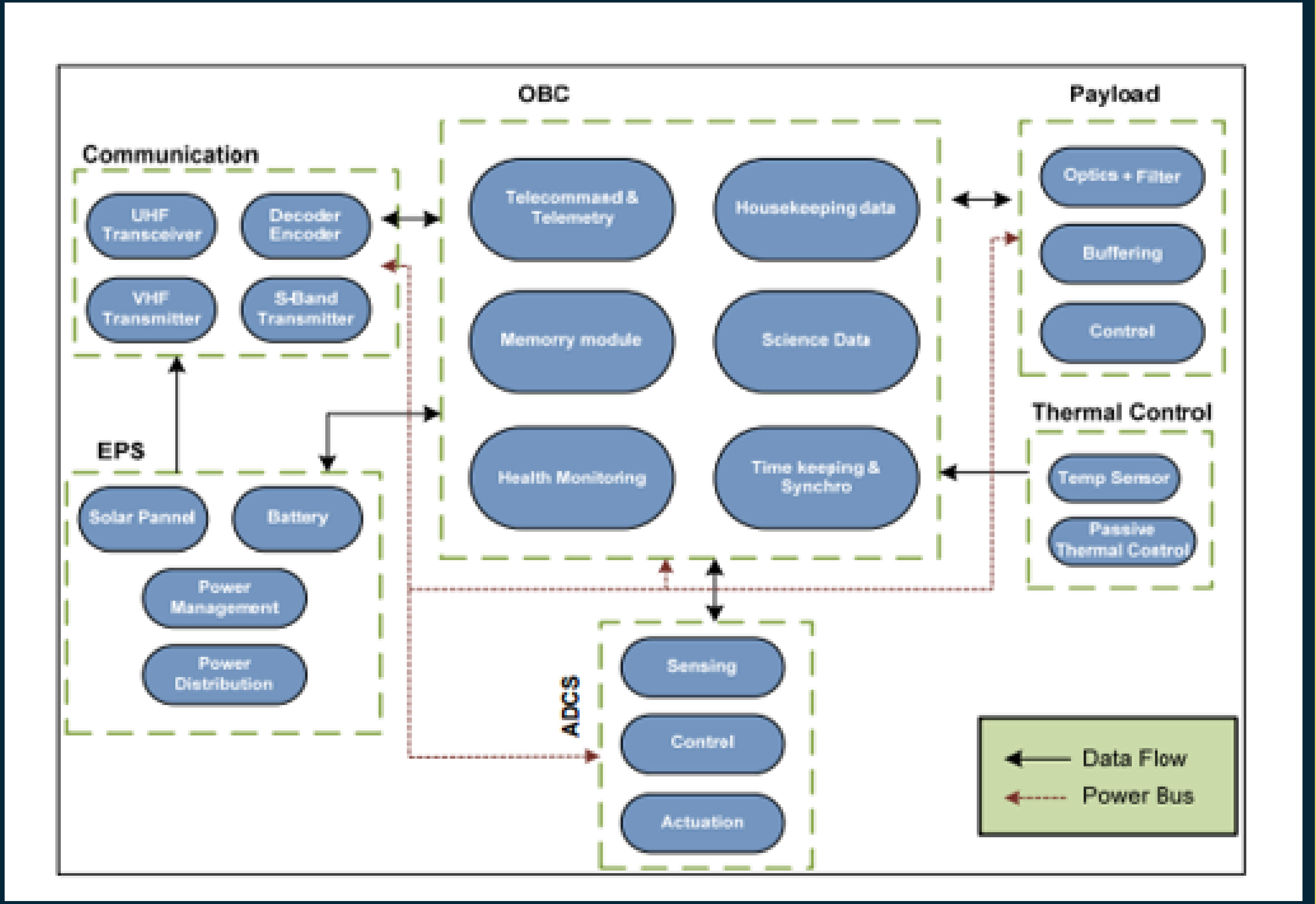


COMMUNICATION SYSTEM

TRANSMISSION SPEED	←	Factor
	←	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



THANKS FOR ATTENTION