Welcome !

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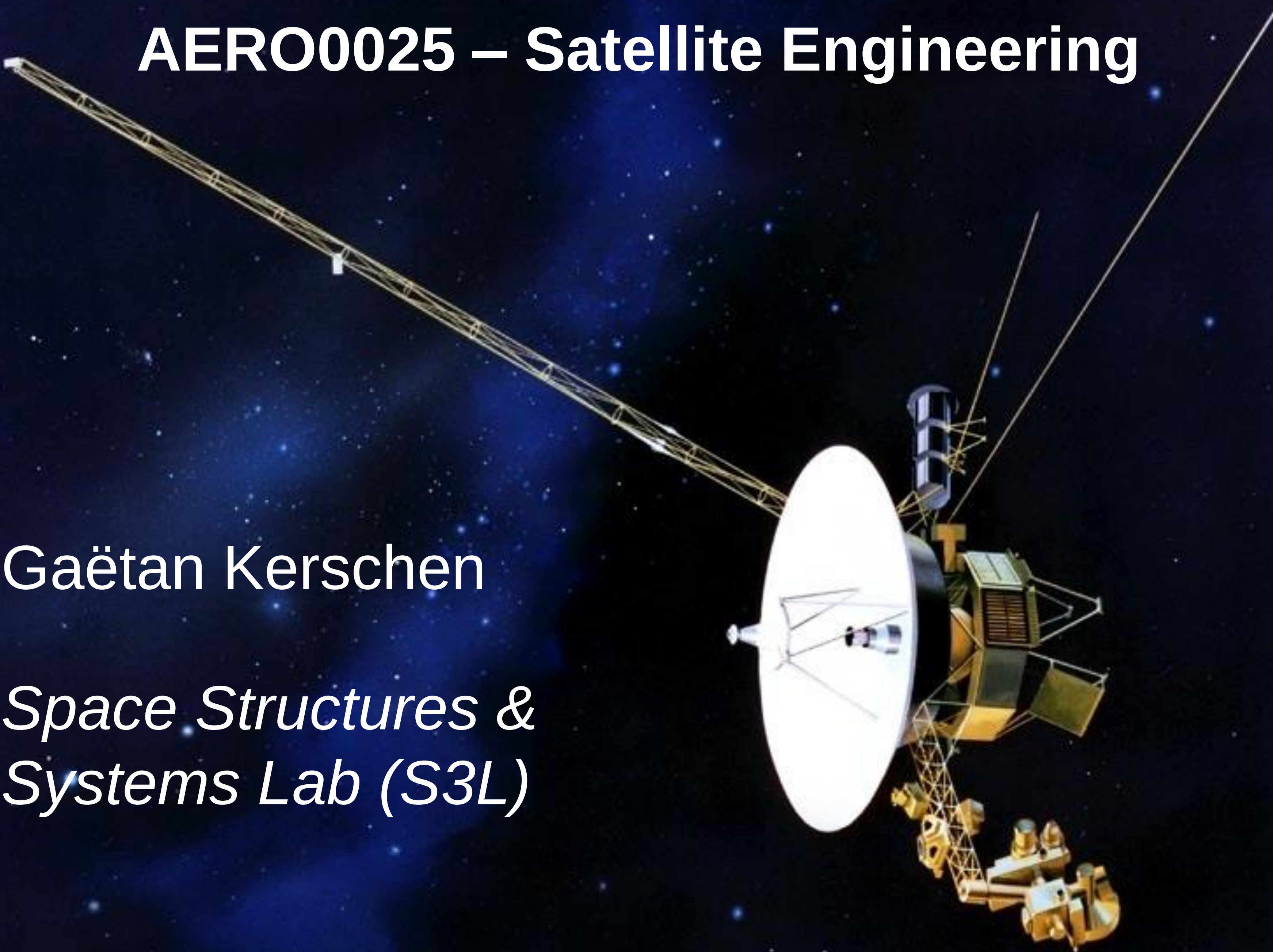
AERO0025 – Satellite Engineering



Gaëtan Kerschen

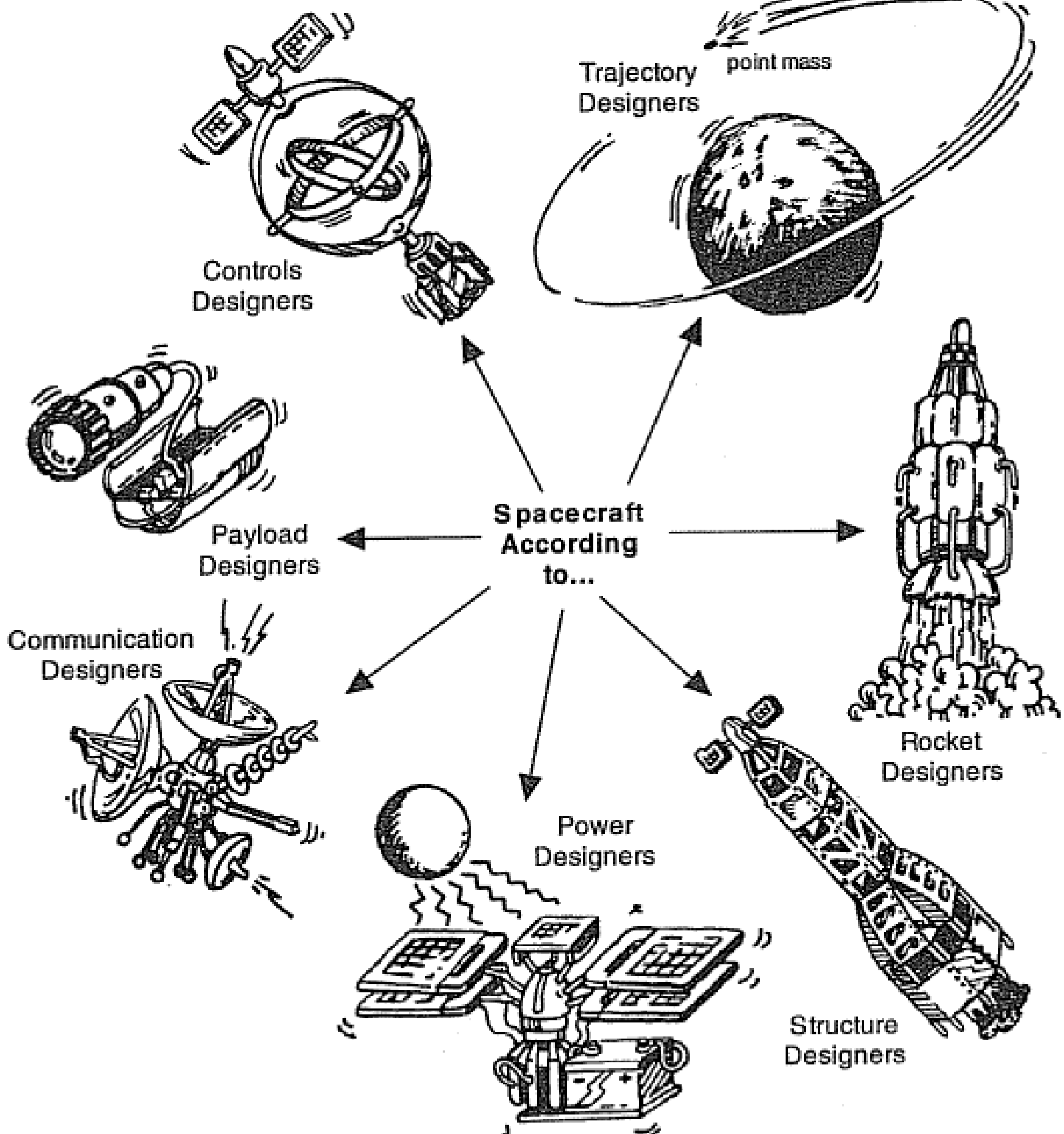
Space Structures & Systems Lab (S3L)

The University System

Natural tendency to create specialists rather than generalists

Highly specialized courses in aerospace engineering at ULg and main focus on mechanical/structural aspects

A spacecraft designed by structural engineers



point mass
Trajectory Designers
Controls Designers
Payload Designers
Spacecraft According to...
Communication Designers
Rocket Designers
Power Designers
Structure Designers

Course Objectives

A well-designed satellite is a sound compromise among the requirements of the different engineering disciplines

1. Give you an overview of the different satellite subsystems and expose you to the inherently **multidisciplinary** aspect of satellite engineering.

2. Describe you subsystems **interactions** and introduce you to **systems engineering.**

Next Year

Telecommunications

Space environment

Vibrations

Space propulsion

Composites

Bus design

Astrophysics
Earth observation
Optics

Payload design

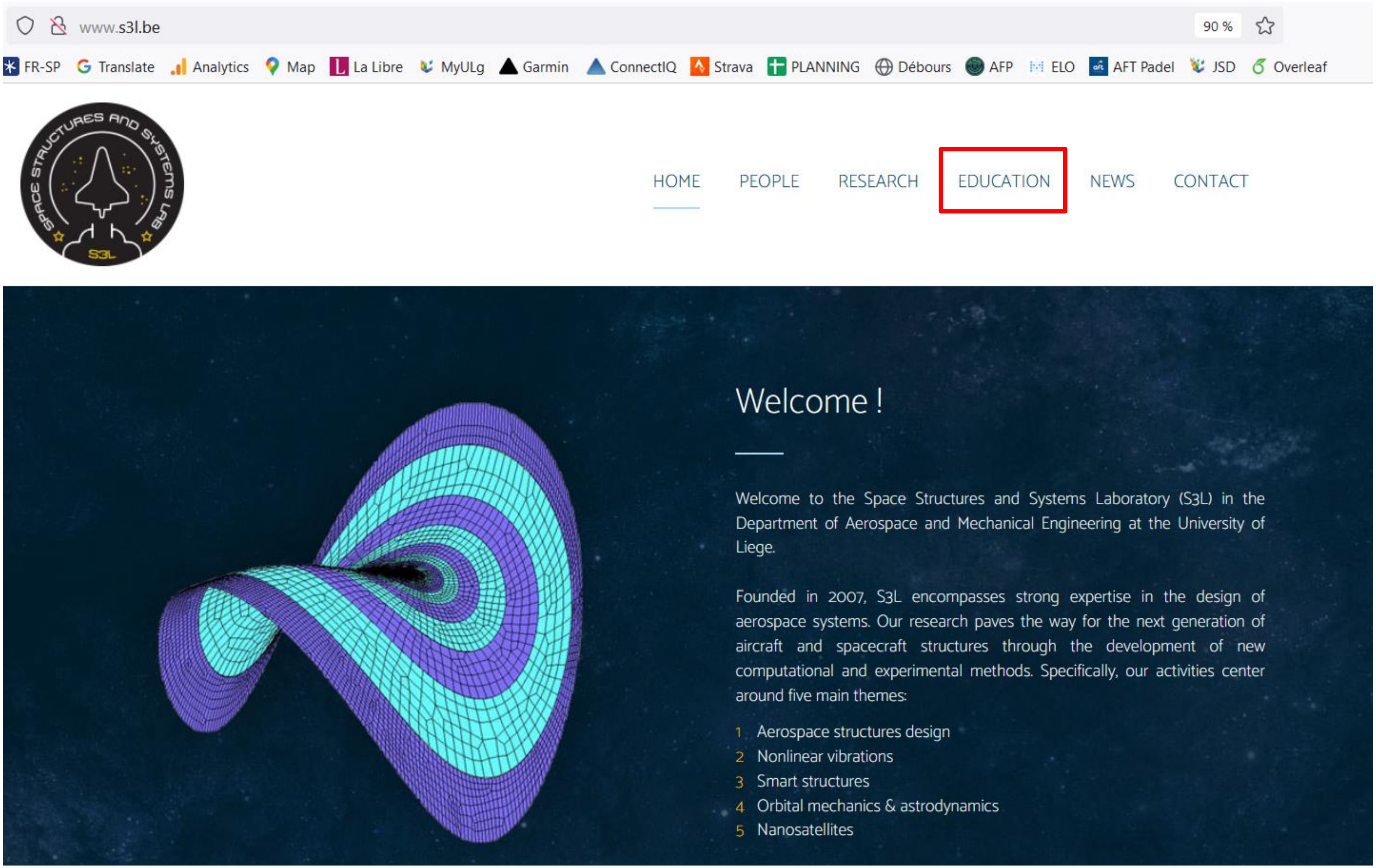
Astrodynamics
Reentry

Mission analysis

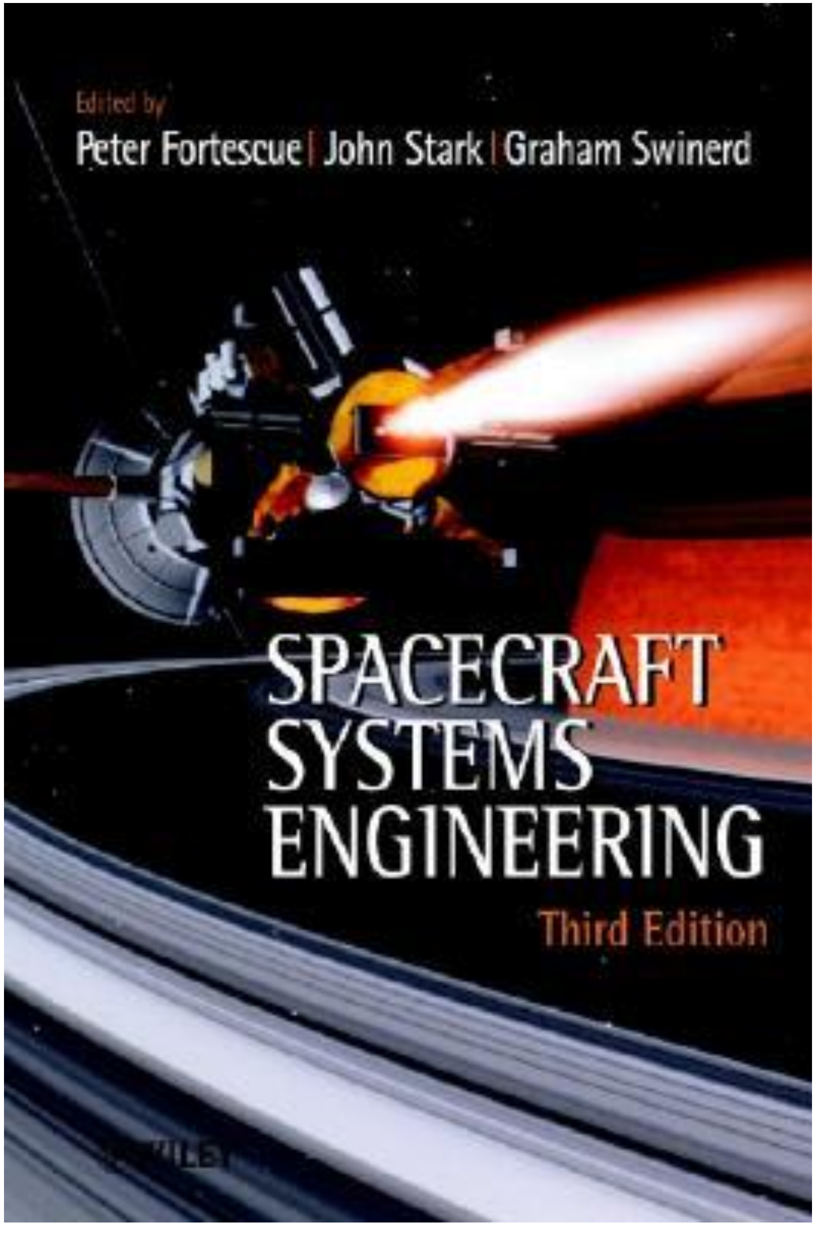
Launch vehicle design

Launch vehicle

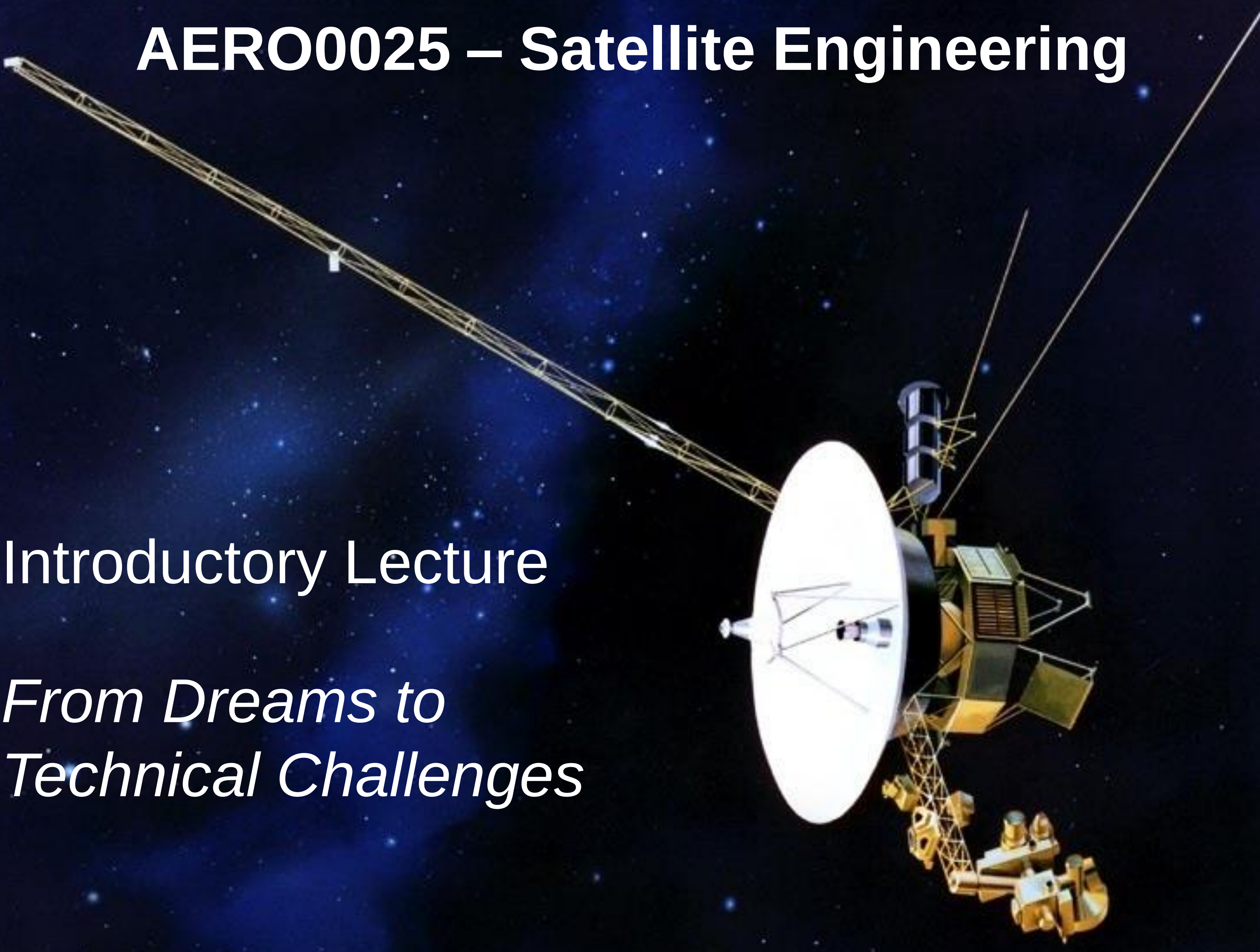
Course Details (See S3L Web Site)



Textbook


Edited by
Peter Fortescue | John Stark | Graham Swinerd
SPACECRAFT
SYSTEMS
ENGINEERING
Third Edition

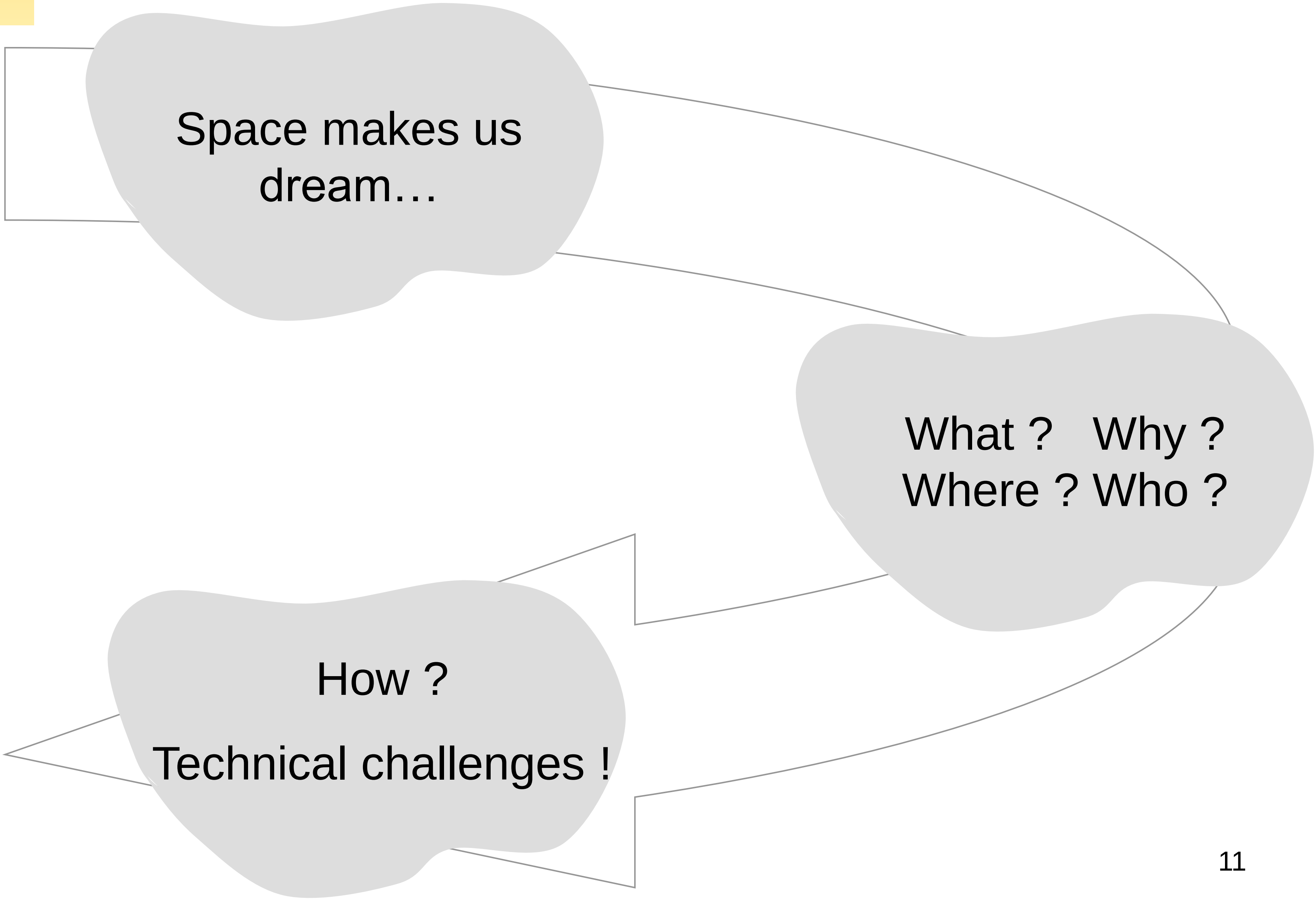
AERO0025 – Satellite Engineering

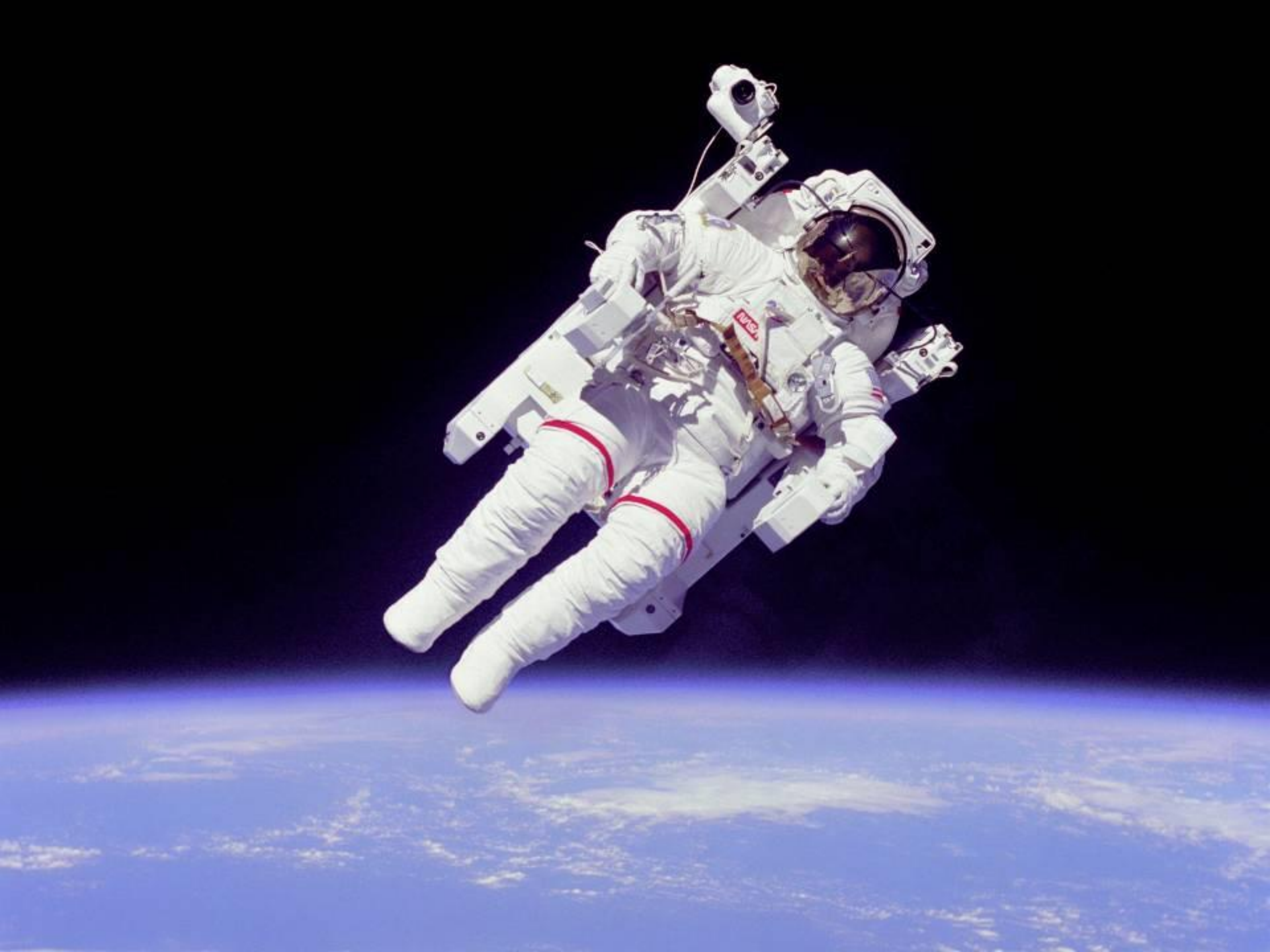


Introductory Lecture

From Dreams to Technical Challenges

From Dreams to Technical Challenges





WHAT DO
YOU SEE ?

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SPACE IMAGING

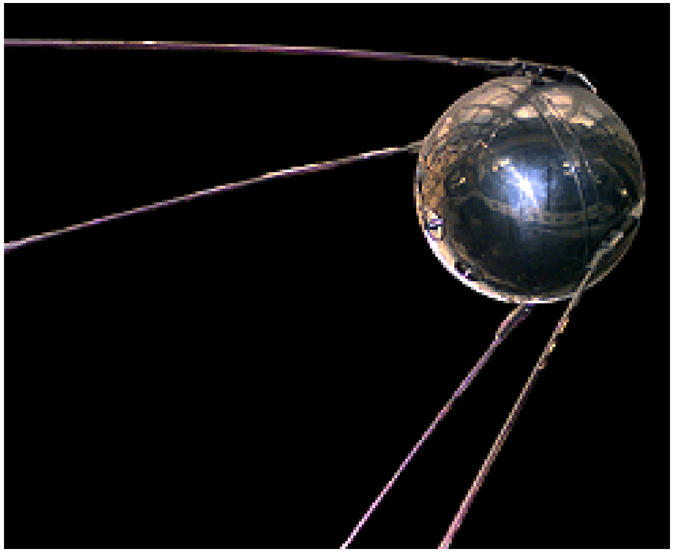
Emphasis of Some…

Technical challenges

Examples of design interaction

Failures

Satellite #1: Sputnik, 1957



Objective: Identification of high atmospheric layers density

First artificial satellite, Oct. 4, 1957

Several failures of the launch vehicle (May, June, July 1957) before the successful flight

Sputnik: Technical Data

Weight	84 kgs
Dimensions	0.6 m diameter sphere
Power	1 W radio transmitting unit
Propulsion	-----
ADCS	**-----**
Communications	**2 antennas, 2.4 m and 2.9 m (spherical radiation pattern)**
Orbit	LEO, 950 x 220 kms, i= 65°, T=96 mins
Launch vehicle	R-7 Semyorka (Soyuz basis)

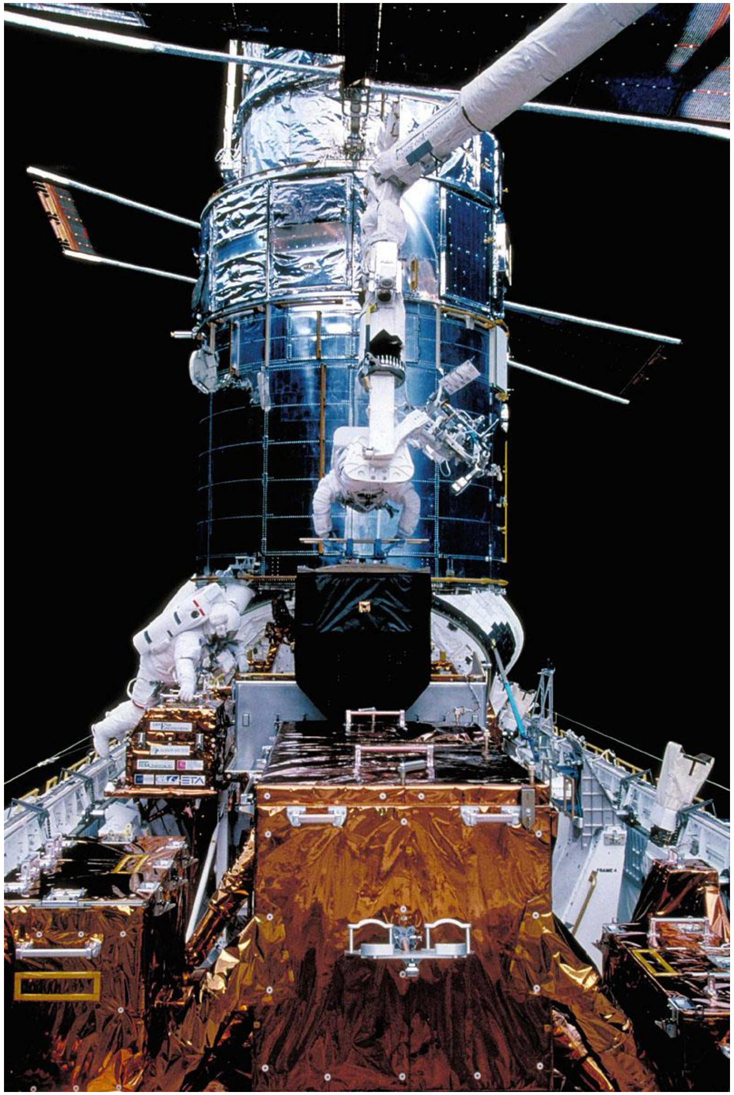
Satellite #2: ISS

Objective: Perform science experiments

ISS: Technical Data

Weight	445 tons
Dimensions	109m x 73m
Power	110 kW, solar panels
Propulsion	**Zvezda (2 x 3070 N thrusters, N2H4 and N2O4) + Progress + STS + ATV**
ADCS	Control moment gyroscopes + thrusters (130 N) + star trackers + infra Red horizon sensors + magnetometers + solar sensors + GPS
Communications	Ku-band (TV, high-speed data) and S-band (audio) antennas
Orbit	**LEO, 339 x 342 kms, i= 51°, T=91 mins**
Launch vehicle	**Soyuz and Space Shuttle**

Satellite #3: HST, 1990



Objective: Astronomy

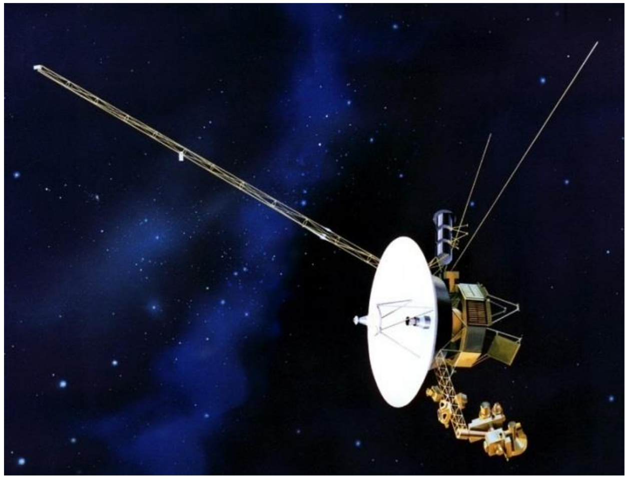
Pointing accuracy: 0.007”

Defective mirror and solar panels, recovery thanks to servicing mission

HST: Technical Data

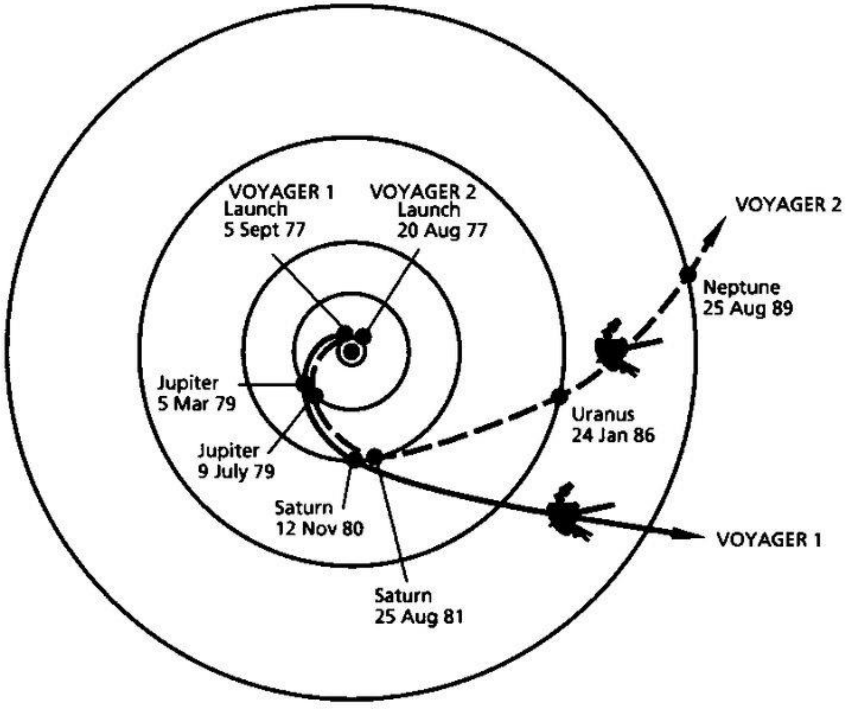
Weight	**11 tons**
Dimensions	13.2 m high, 4.2 m diameter
Power	4.5 kW, solar panels
Propulsion	-----
ADCS	**Reaction wheels, magnetometers, star trackers, gyroscopes, fine guidance sensor (lock onto guide stars), magnetic torquers**
Communications	**2 high-gain antennas (S-band)**
Orbit	LEO, 600 kms, i= 28°, T=96 mins
Launch vehicle	**Space Shuttle**

Satellite #4: Voyager, 1977



Objective: Space exploration (planets and their moons)

Unique feature: farthest man-made object from earth (100 UA)



Jupiter, Saturn, Uranus, Neptune and their moons

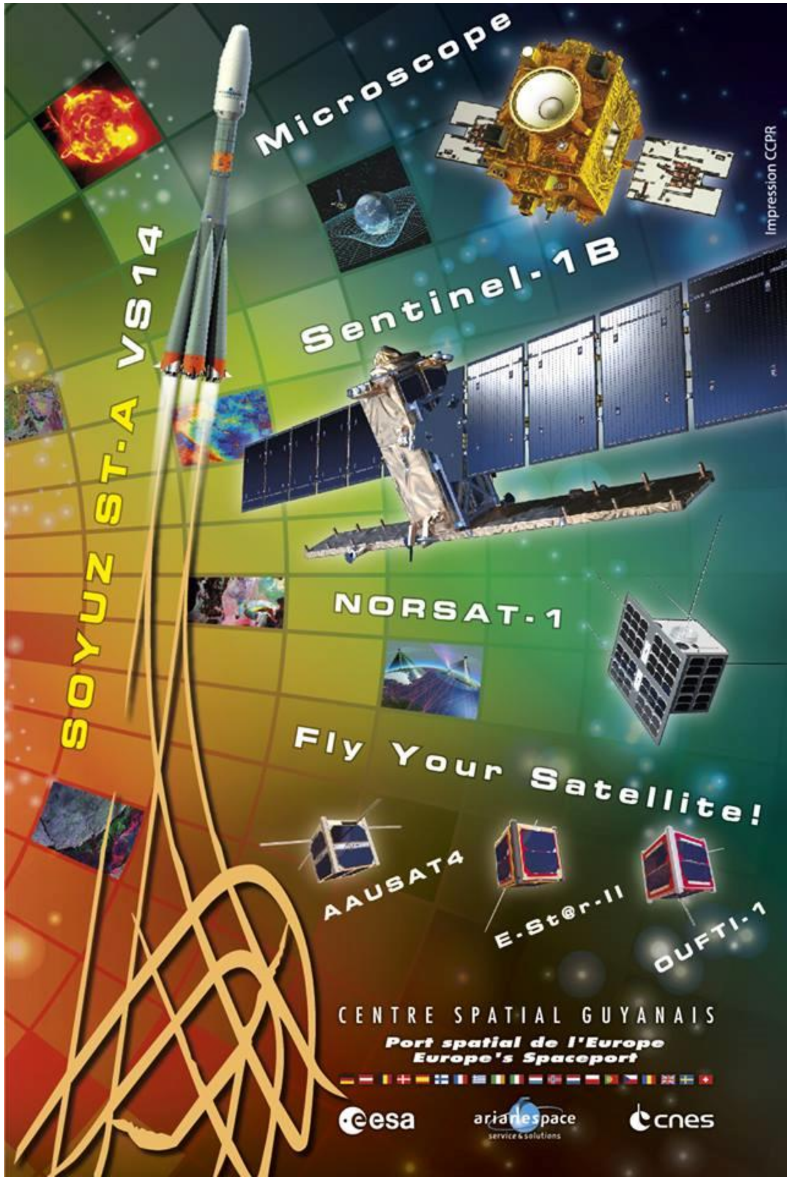
23 W radio could transmit data over a distance of 10^9 km

Alignment every 176 years + 12 years to meet Neptune

Voyager: Technical Data

Weight	720 kgs
Dimensions	0.6 m high, 1.8 m diameter (bus)
Power	**470 W, 3 RTGs**
Propulsion	Centaur (LH_2+LOX) + gravity assist + 16 N_2H_4 thrusters
ADCS	16 N_2H_4 thrusters + sun sensors + star tracker
Communications	3.7 m high-gain antenna (S band: uplink, X-band: downlink), low-gain antenna
Orbit	**Outer planets exploration**
Launch vehicle	Titan III + centaur upper stage

Satellite #5: OUFTI-1, 2016



Objectives:

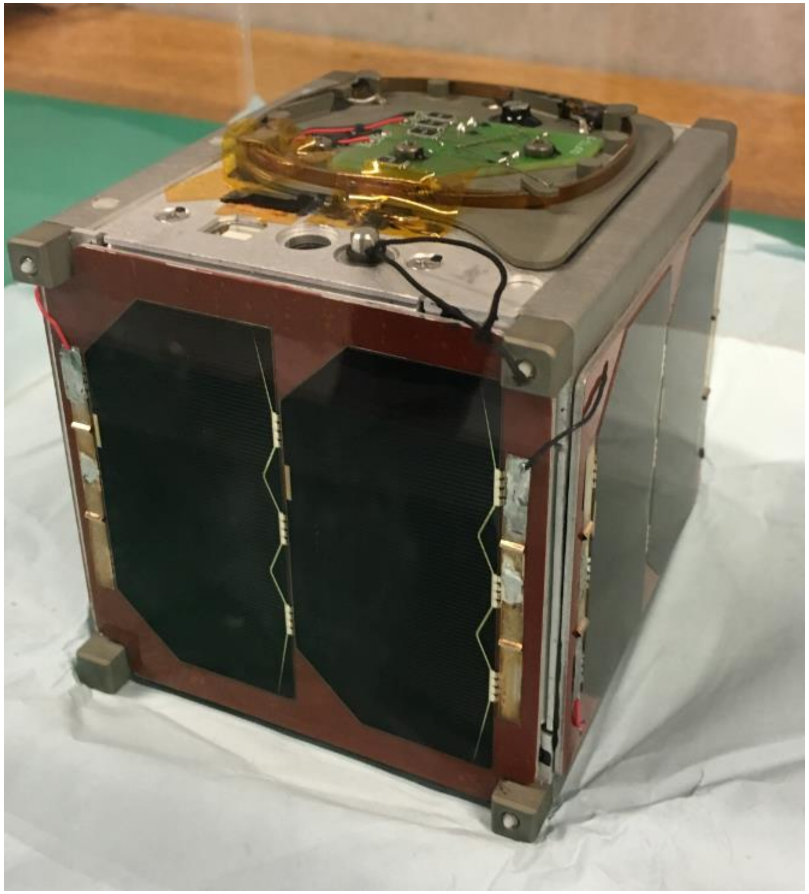
1. On-orbit validation of D-STAR
2. New solar cells

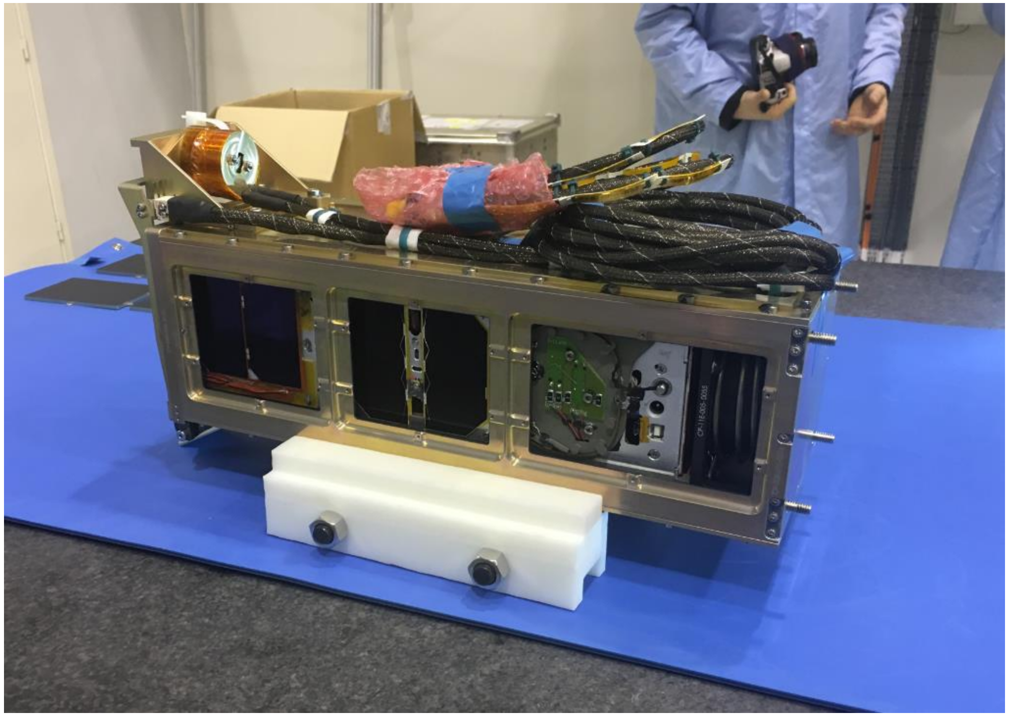
Entirely designed by students

Launched at the fourth attempt !

Unknown failure three weeks after launch.

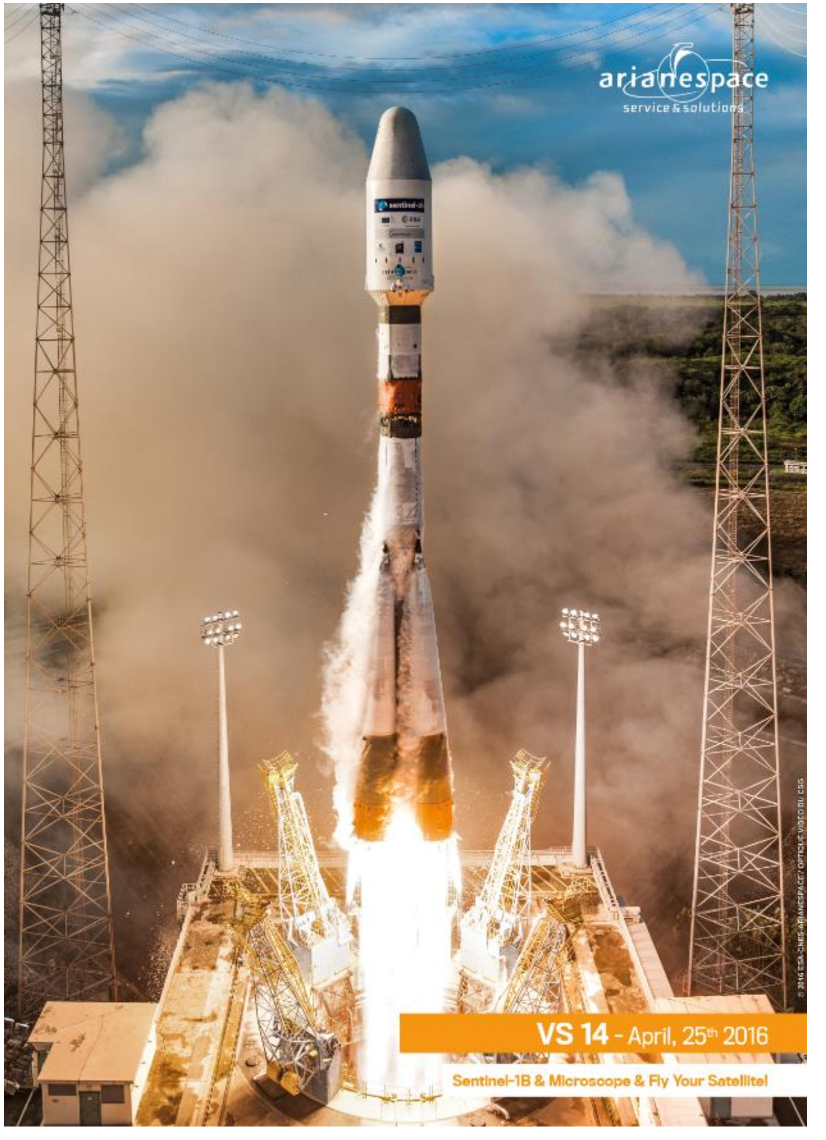
Satellite #5: Integration March, 2016





Satellite #5: Integration March, 2016

Satellite #5: Launch on April 25, 2016



OUFTI-1: Technical Data

Weight	1 kg
Dimensions	**10 cm x 10 cm x 10 cm**
Power	**1 W**
ADCS	Passive (permanent magnets and hysteretic materials)
Propulsion	None
Communications	145 MHz + 435 MHz (Ham radio bands)
Orbit	LEO, 660 x 450 kms, i= 98°
Launch vehicle	Soyuz


THEY ALL
LOOK
DIFFERENT !!!

The Launch Vehicle May Also Fail !

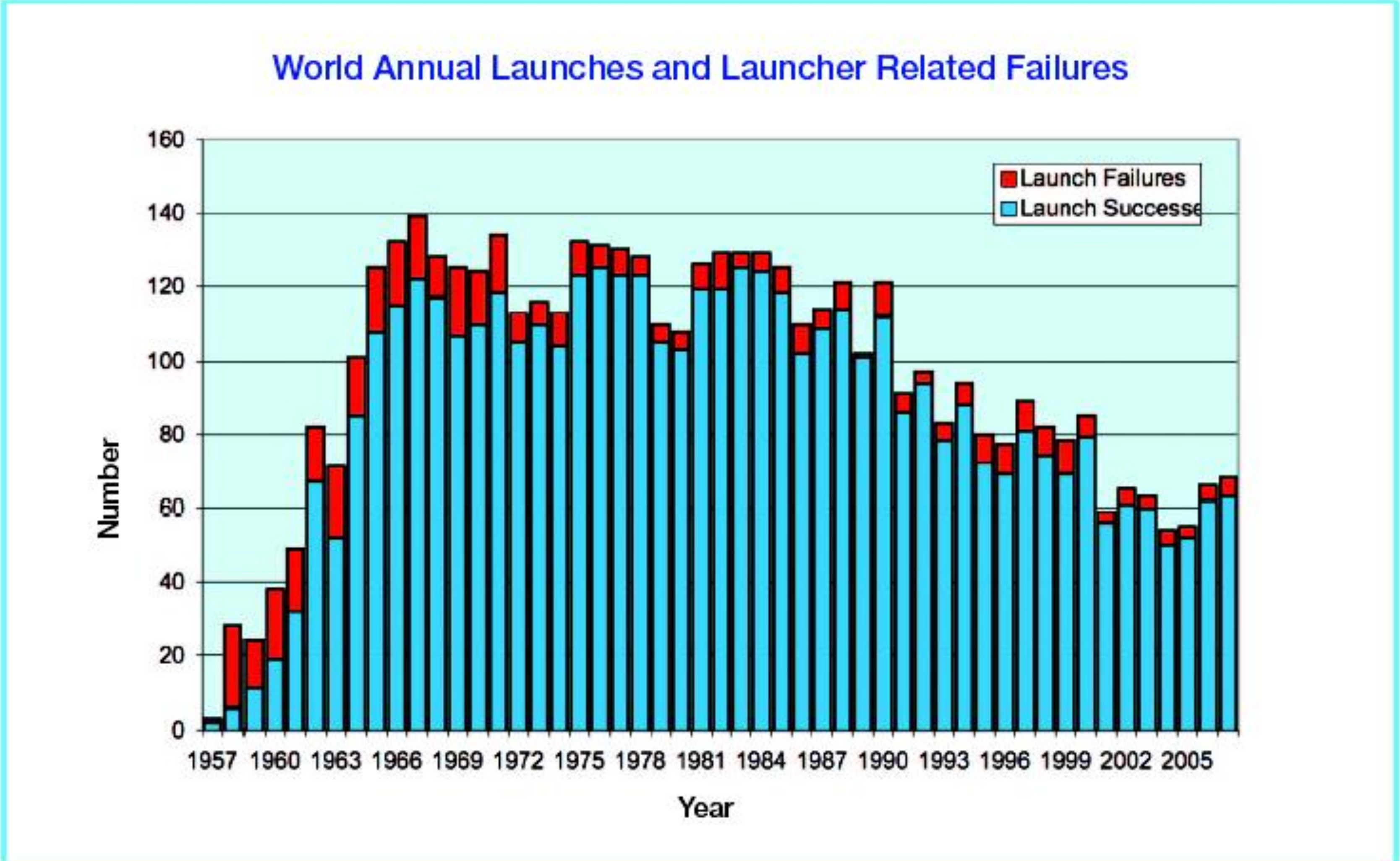
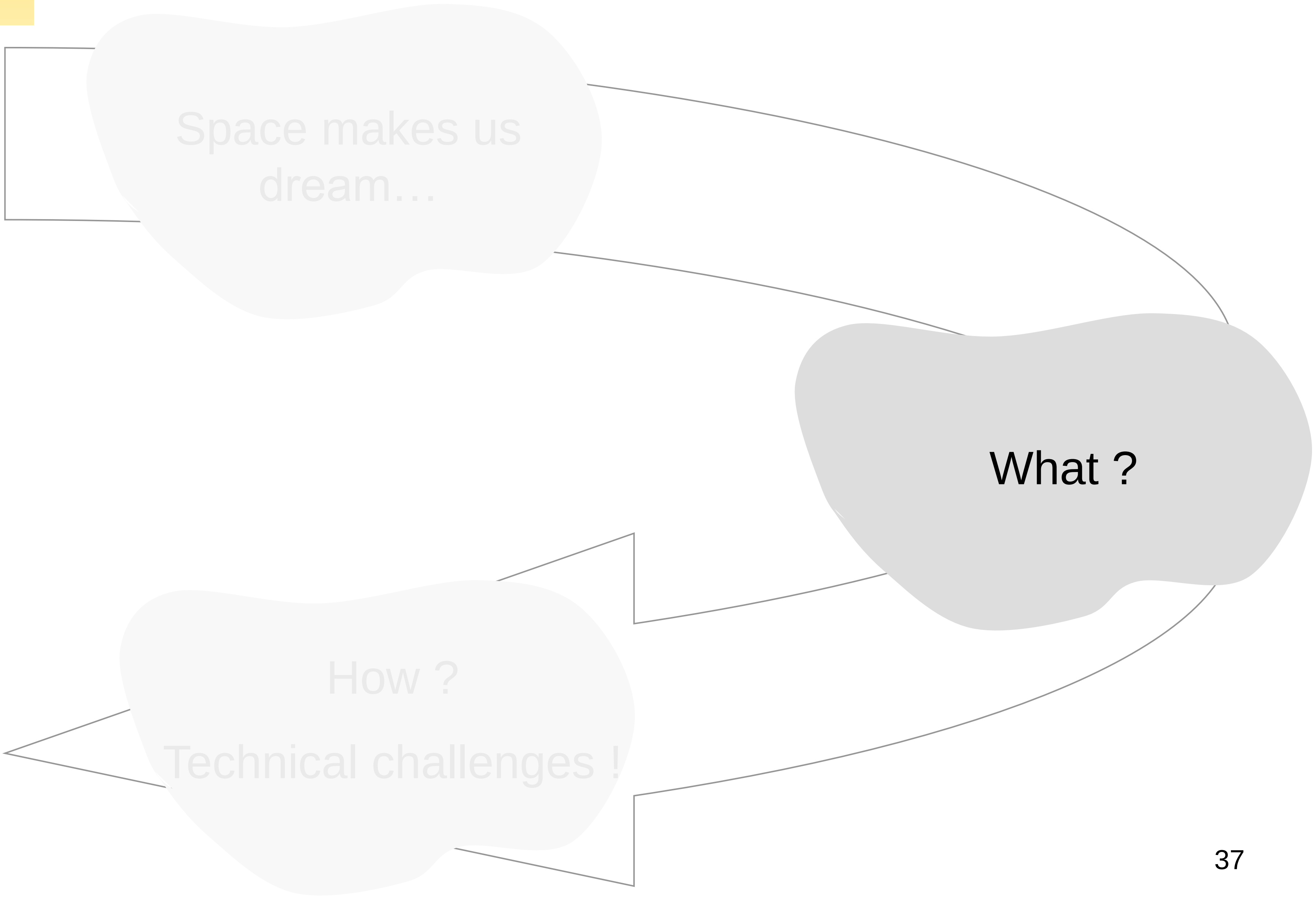
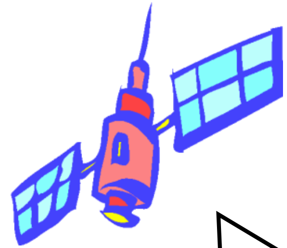


Chart 2: **Orbital launch attempts since 1957.** Source: Ascend Space Review

From Dreams to Technical Challenges

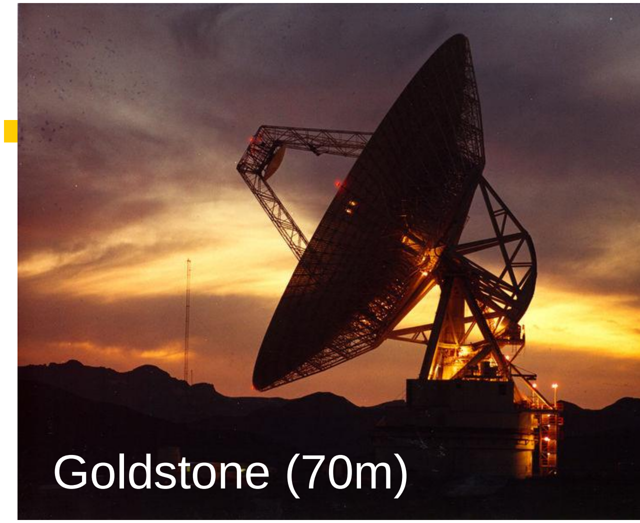


An Element Within a Larger System



Severe constraints (size, weight, launch site, orbit, vibrations)

- Telemetry for satellite data and status (TM)
- Telecommands (TC)
- Determination of satellite's position


Goldstone (70m)

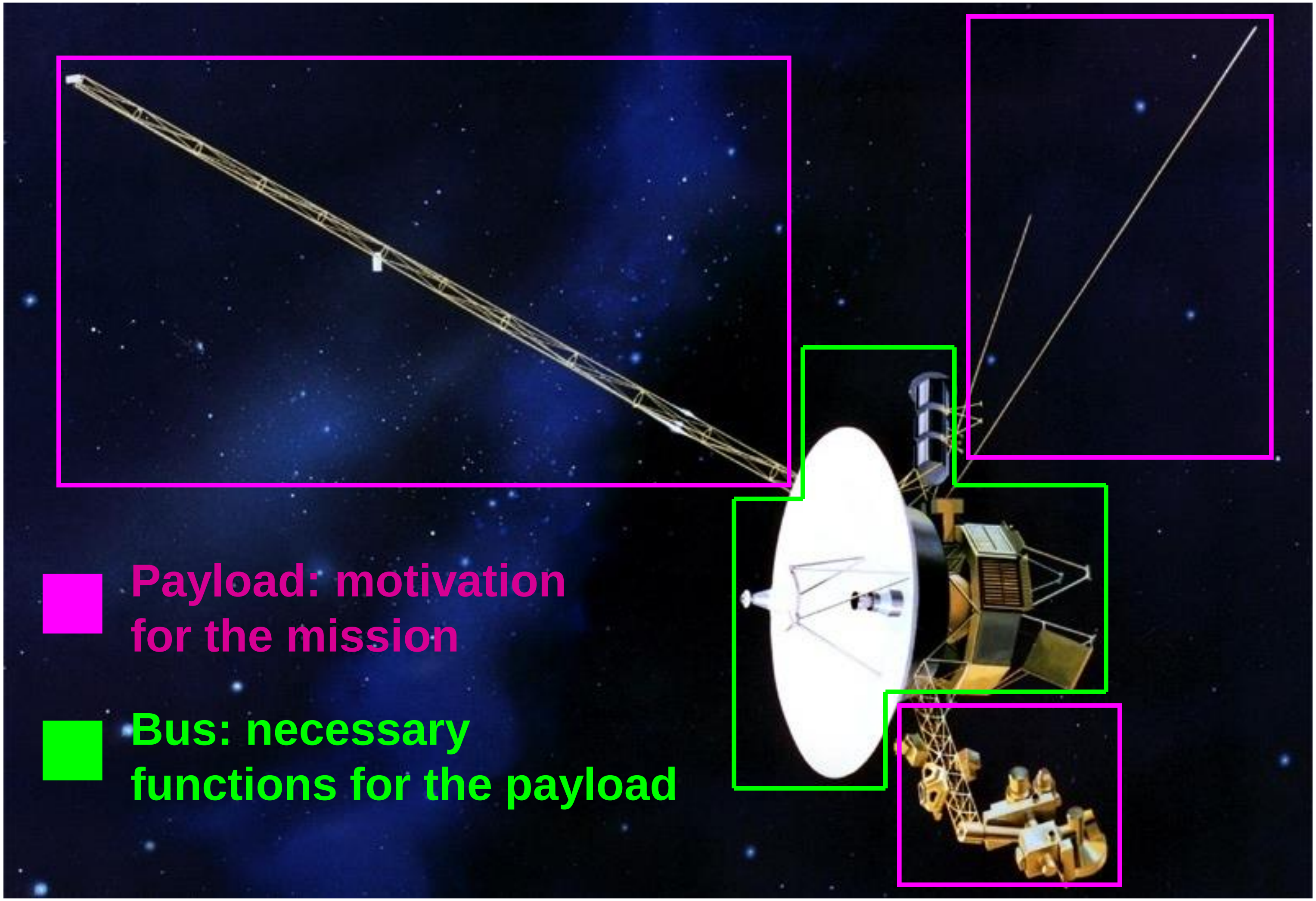
Madrid (70m)

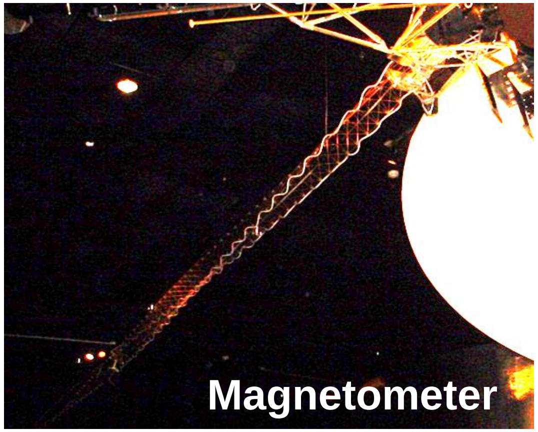

Canberra (70m)

Deep space network: 3 ground stations (120° apart around the world)

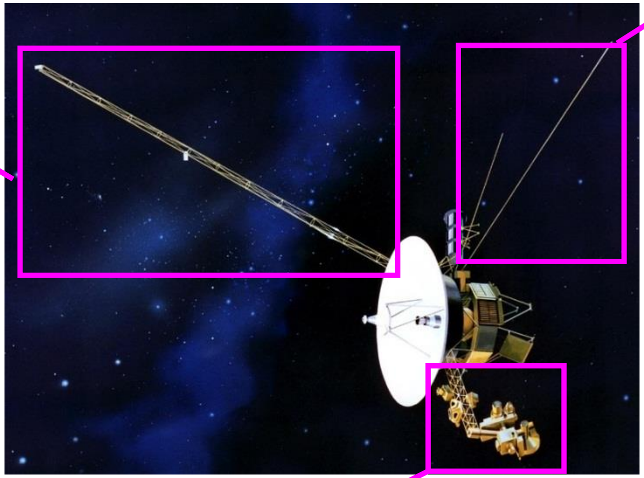

ESA Redu ground station (Belgium)

A Satellite Comprises Two Main Elements

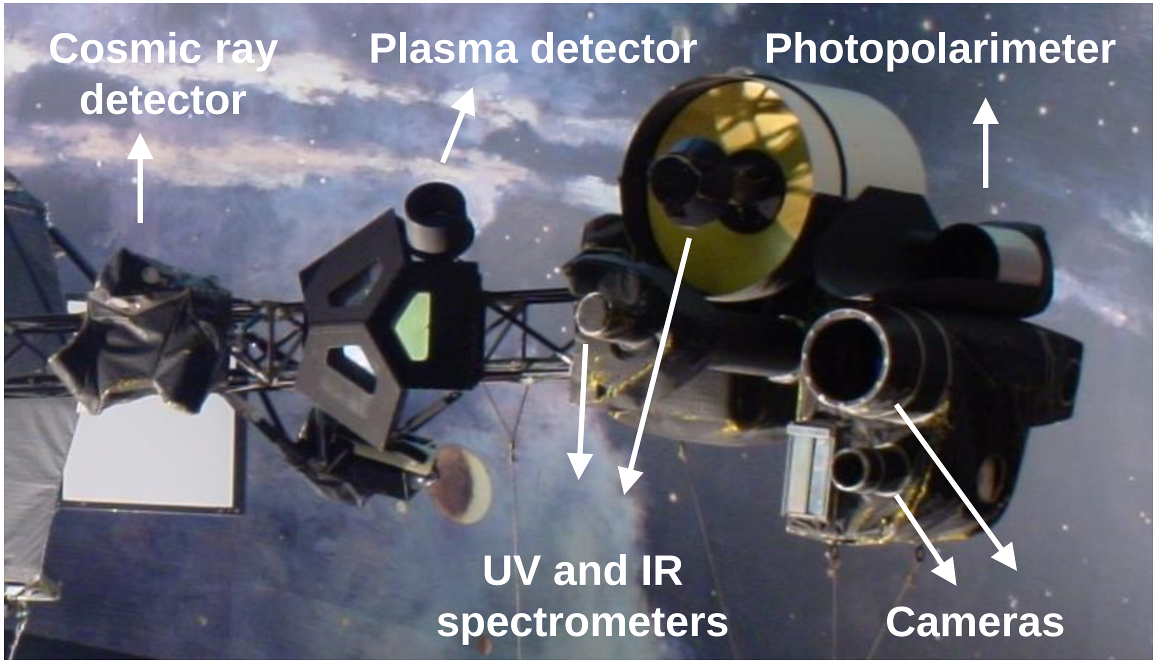




Antennas: planet radio emissions

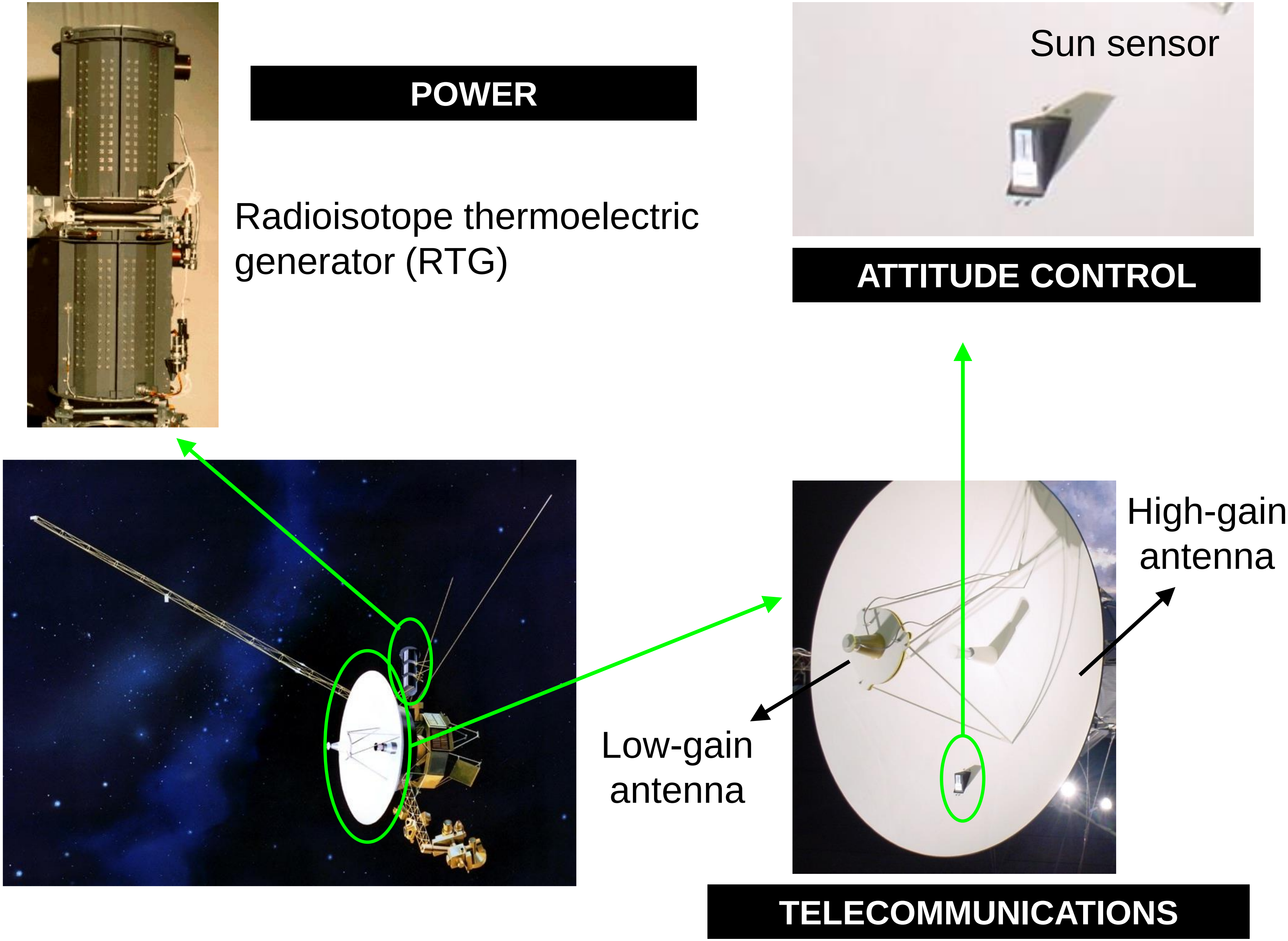


PAYLOAD



Bus: Complex Assembly of Subsystems

STRUCTURE & MECH.	Withstand launch and orbit loads + properly deploy and run mechanisms
PROPULSION	Spacecraft maneuvers and trajectory
THERMAL CONTROL	Withstand temperatures imposed by the harsh space environment
TELECOMMUNICATIONS	Communicate and exchange information with ground
ATTITUDE CONTROL	Ensure correct orientation in space
POWER	Powering the subsystems and payloads
ON-BOARD COMPUTER	The “brain” of the satellite

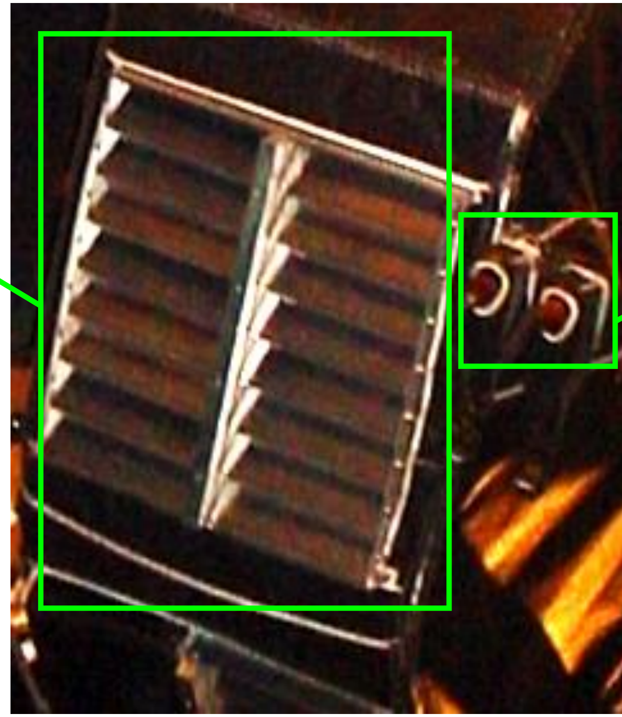

POWER
Radioisotope thermoelectric generator (RTG)
Sun sensor
ATTITUDE CONTROL
High-gain antenna
Low-gain antenna
TELECOMMUNICATIONS

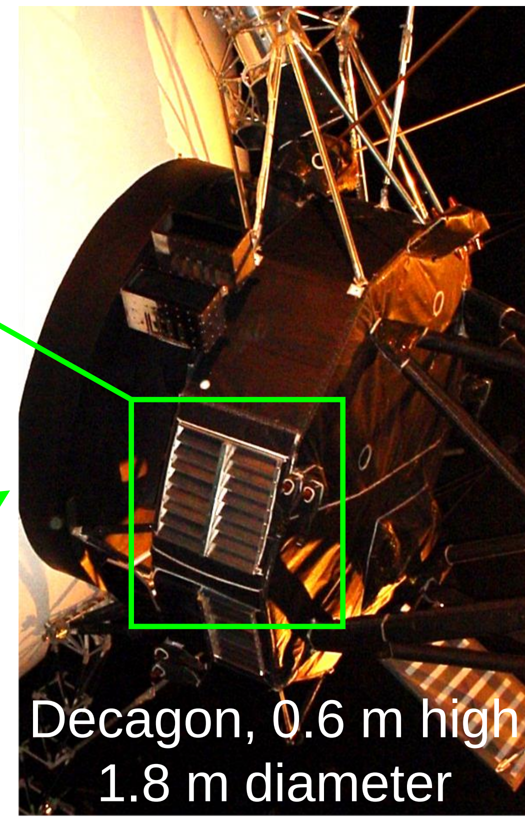
Louvers

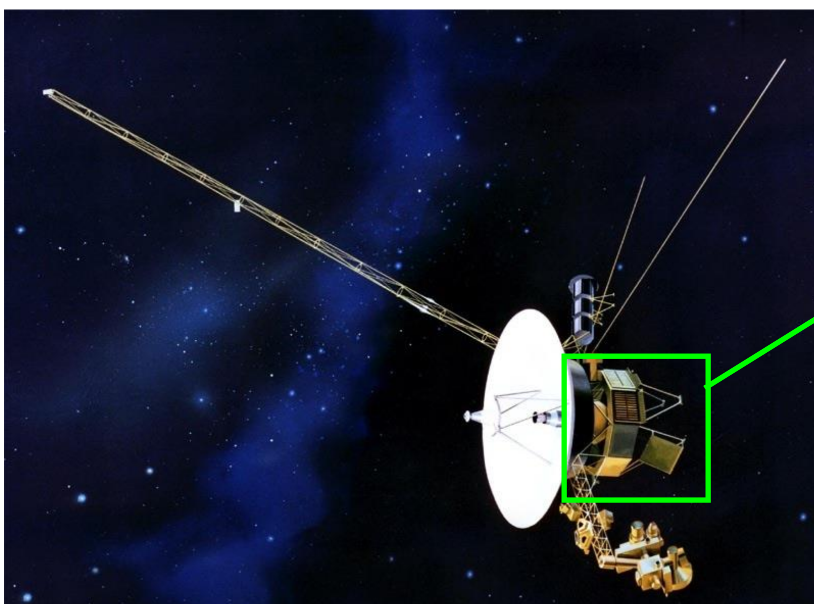
THERMAL CONTROL

N_2H_4 thrusters

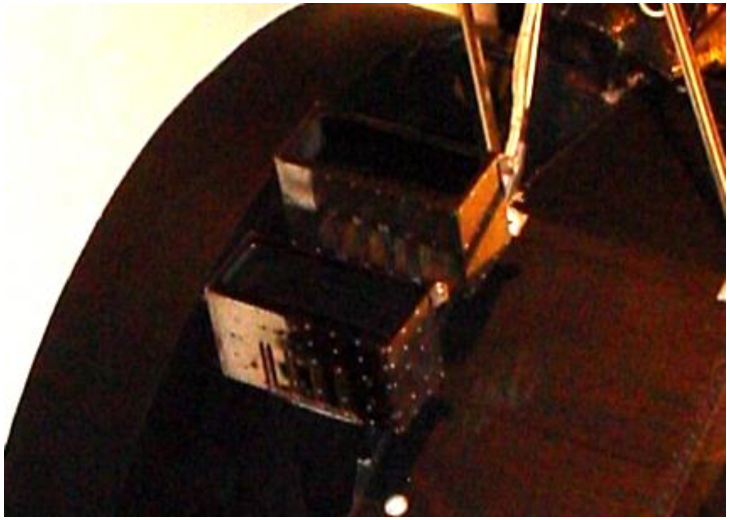
PROPULSION





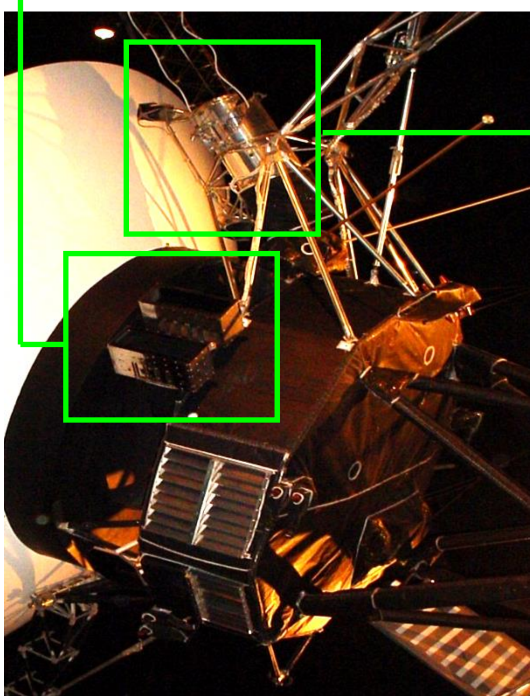


STRUCTURE

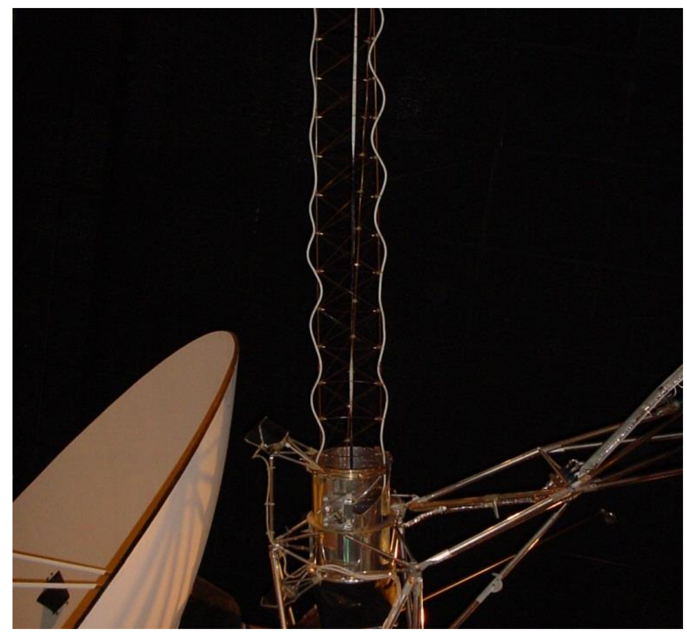


ATTITUDE CONTROL

Star tracker

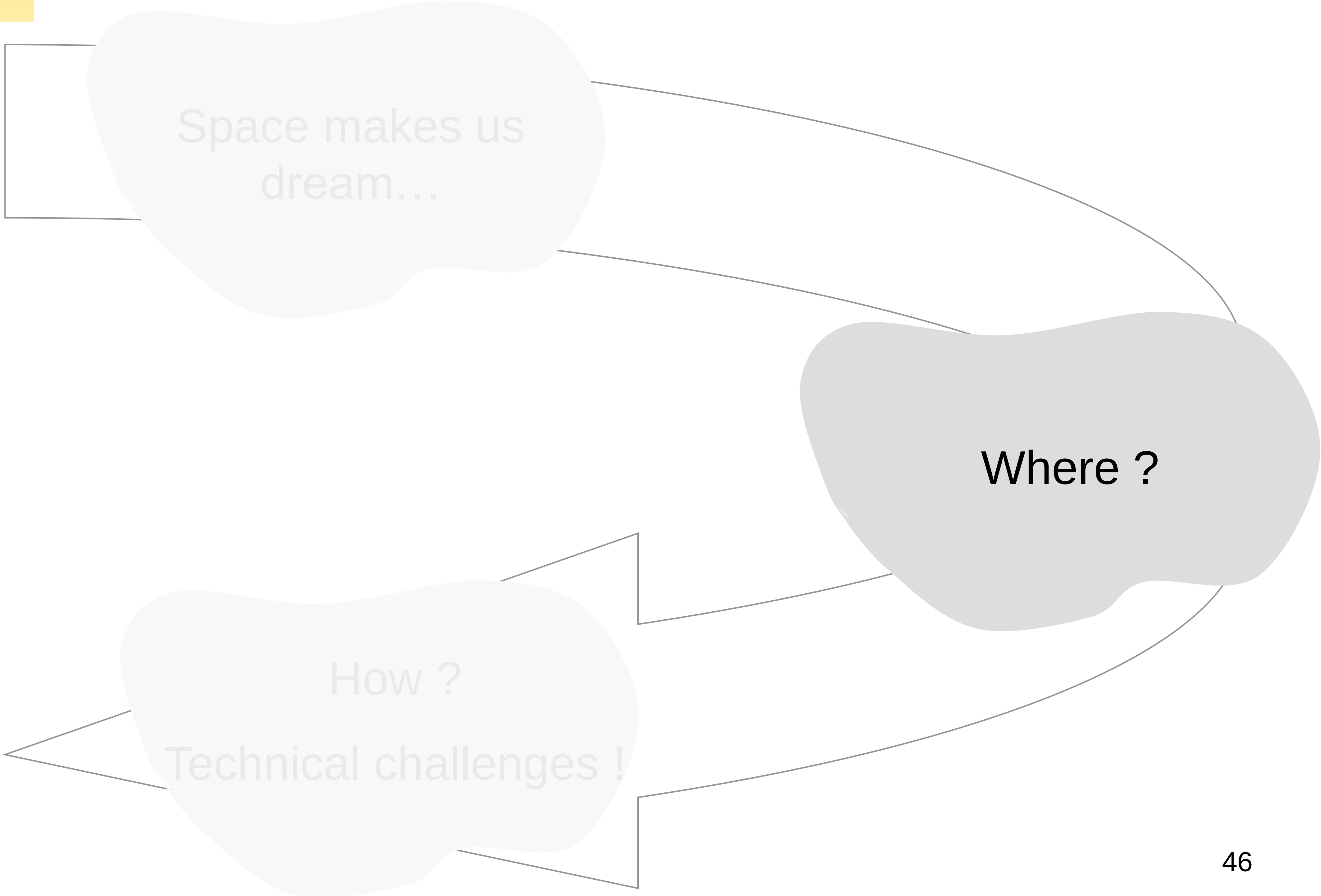


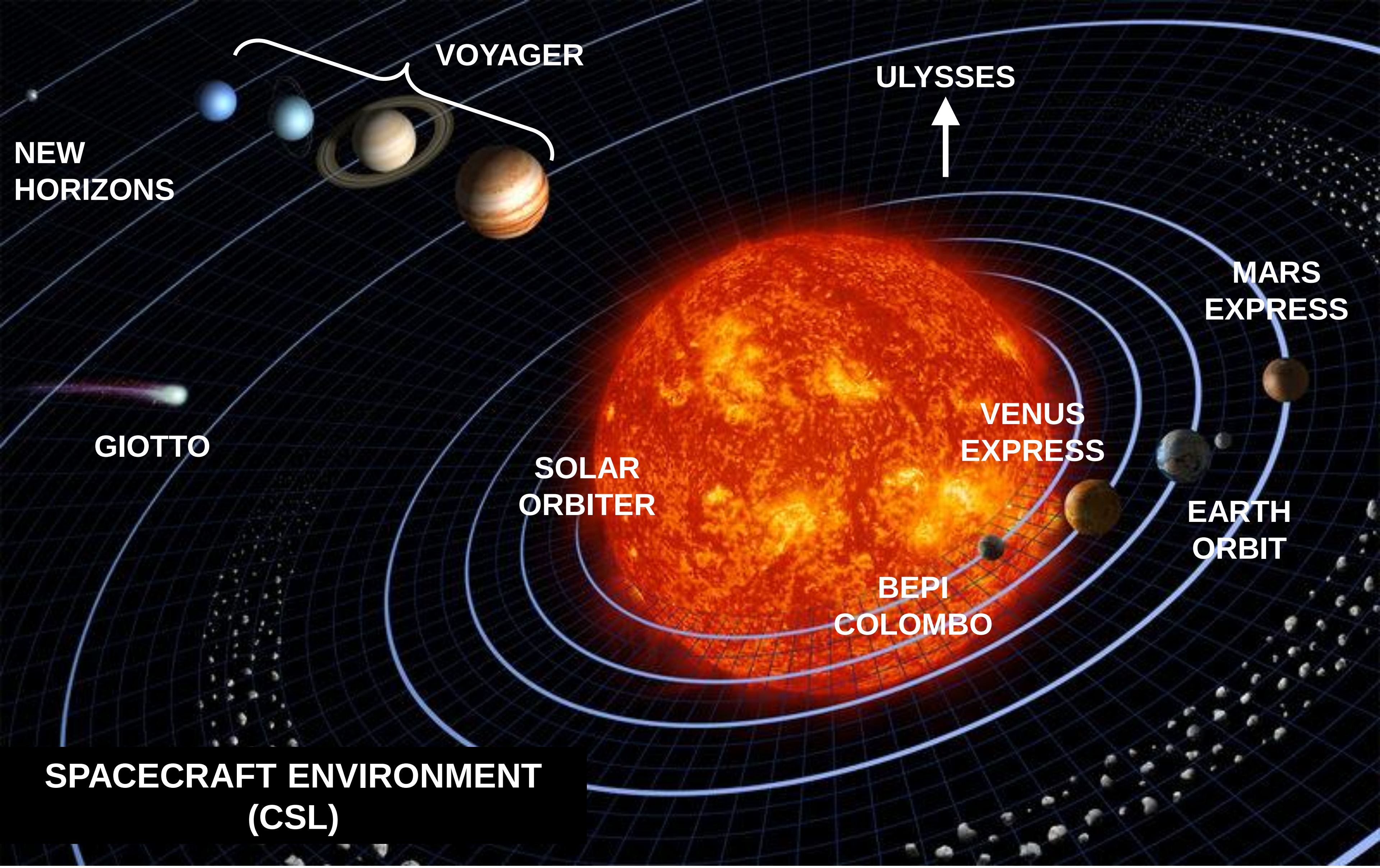
MECHANISMS



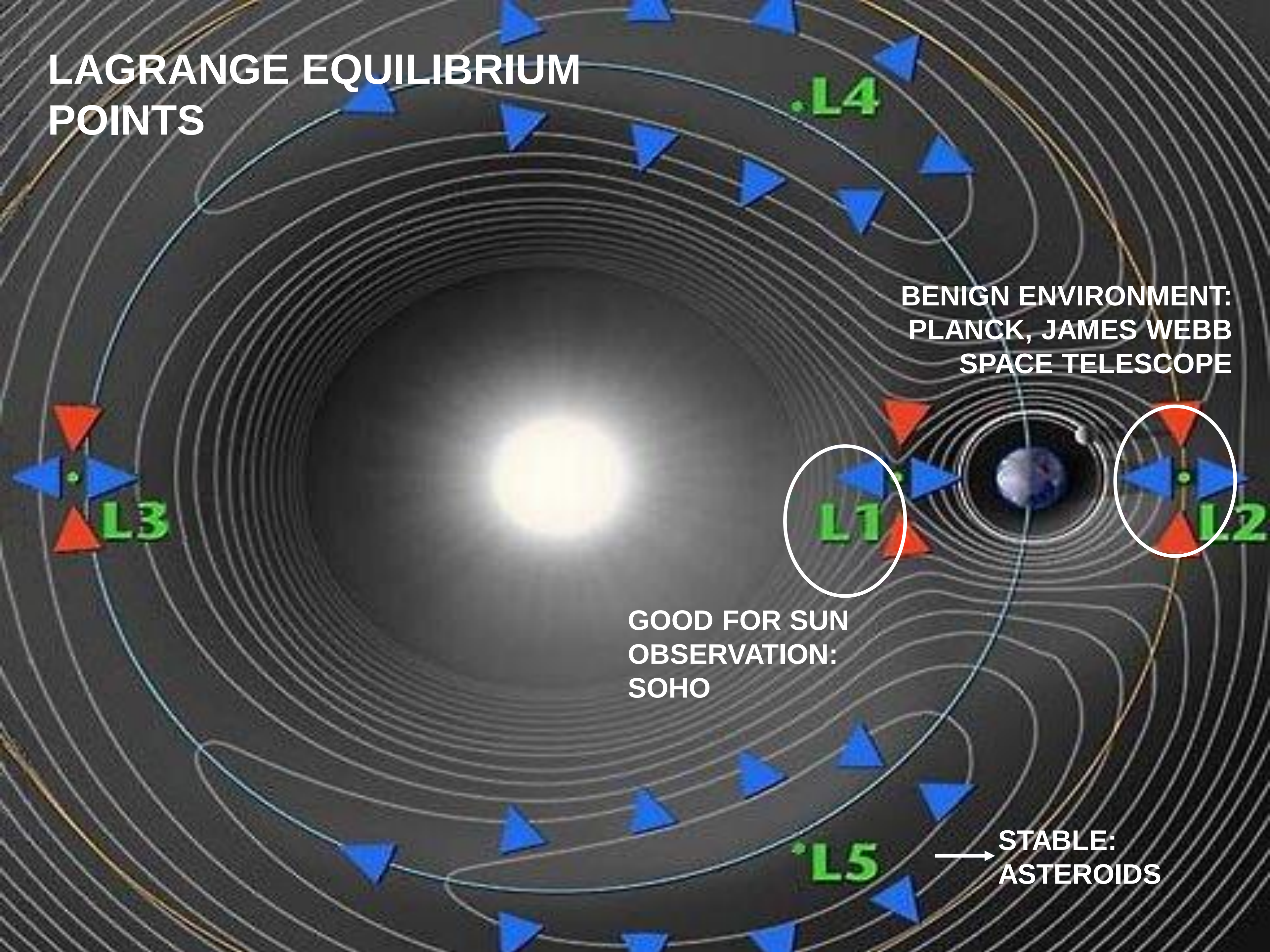
Box containing a deployable truss on which the magnetometer is mounted

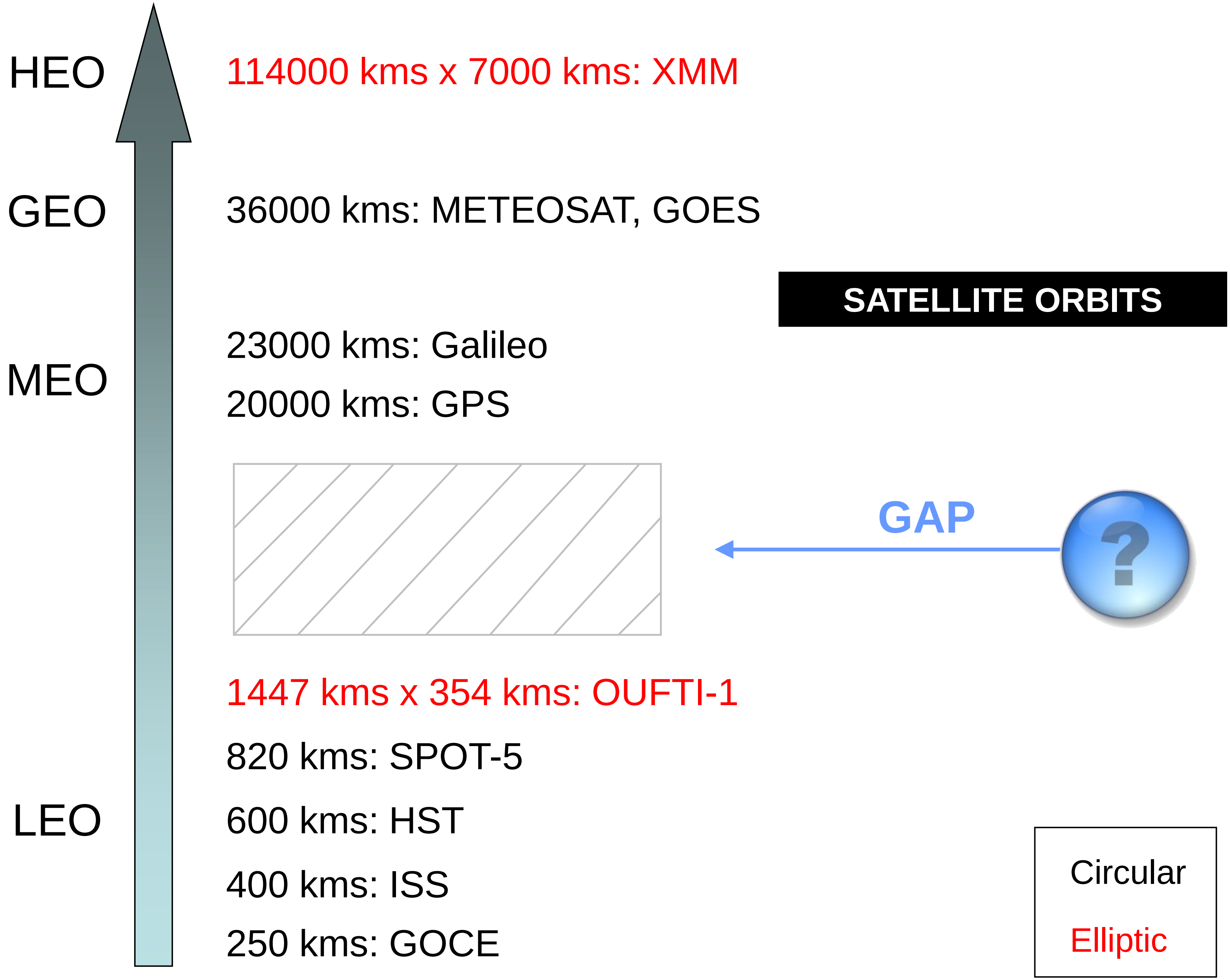
From Dreams to Technical Challenges



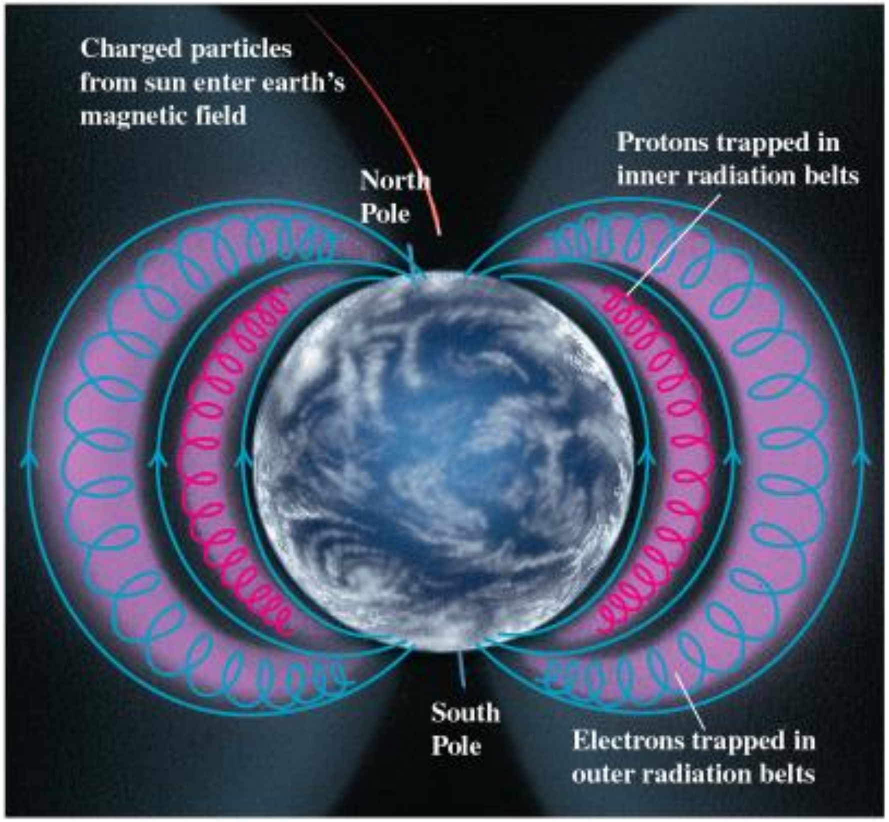


Severe constraints (magnetic field, temperatures, atmosphere, launch vehicle, ground station visibility, eclipse duration)

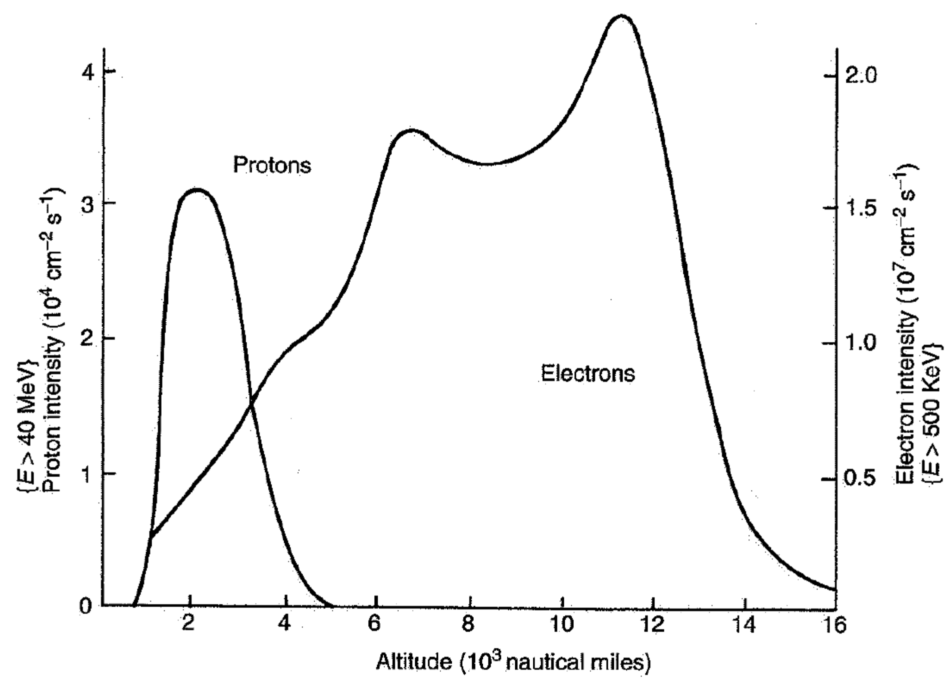

LAGRANGE EQUILIBRIUM POINTS
.L4
BENIGN ENVIRONMENT: PLANCK, JAMES WEBB SPACE TELESCOPE
L3
L1
L2
GOOD FOR SUN OBSERVATION: SOHO
L5
STABLE: ASTEROIDS


HEO
114000 kms x 7000 kms: XMM
GEO
36000 kms: METEOSAT, GOES
SATELLITE ORBITS
MEO
23000 kms: Galileo
20000 kms: GPS
GAP
?
1447 kms x 354 kms: OUFTI-1
820 kms: SPOT-5
LEO
600 kms: HST
400 kms: ISS
250 kms: GOCE
Circular
Elliptic

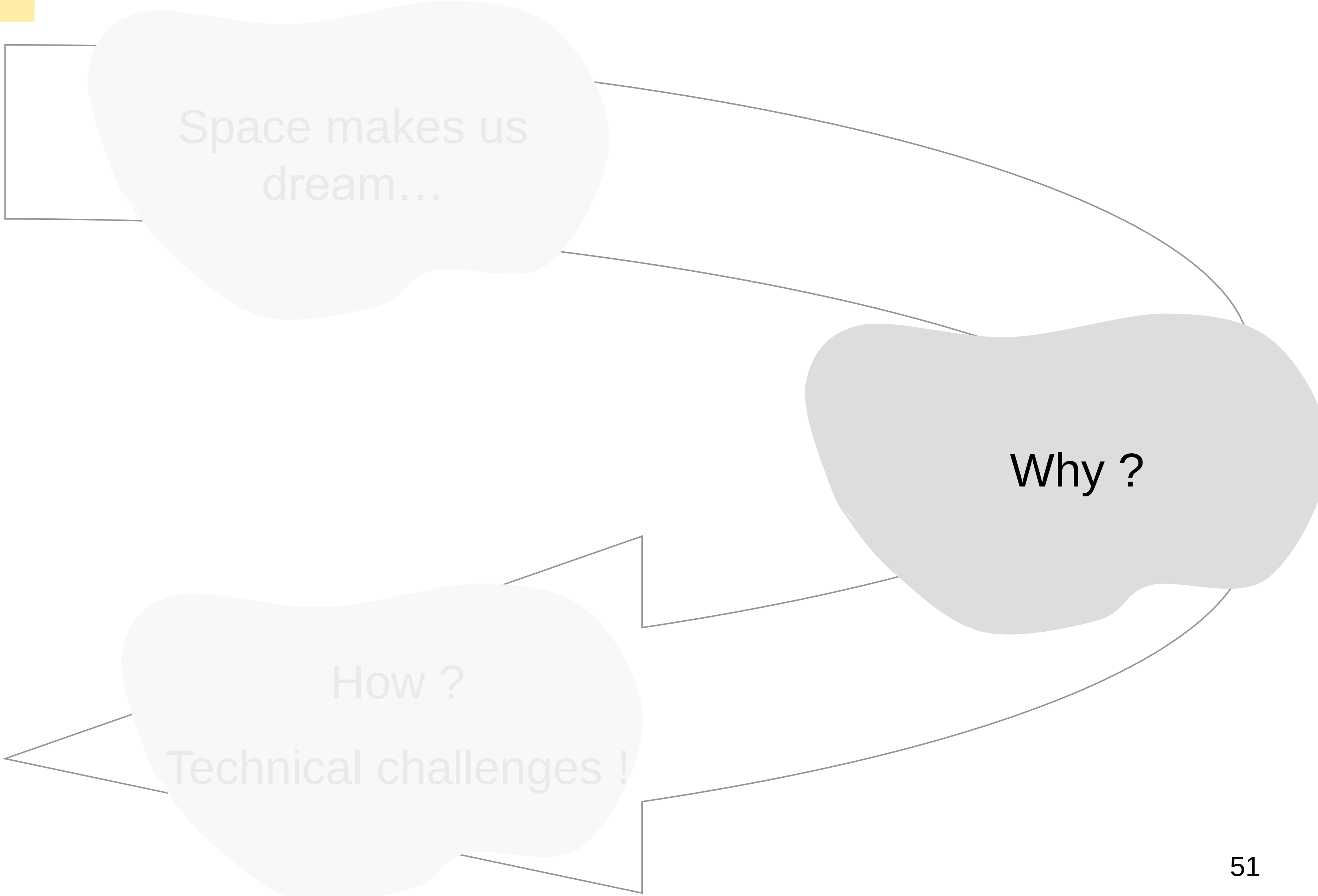
Gap ? Van Allen Belts



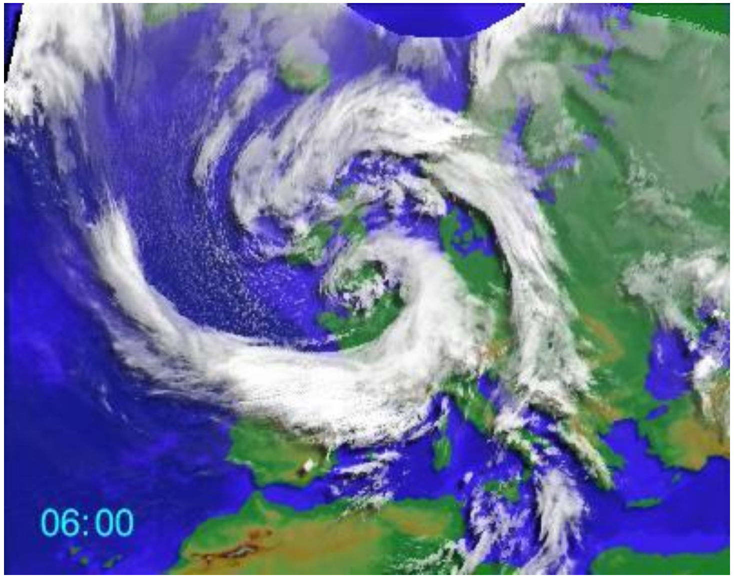
SPACECRAFT ENVIRONMENT



From Dreams to Technical Challenges

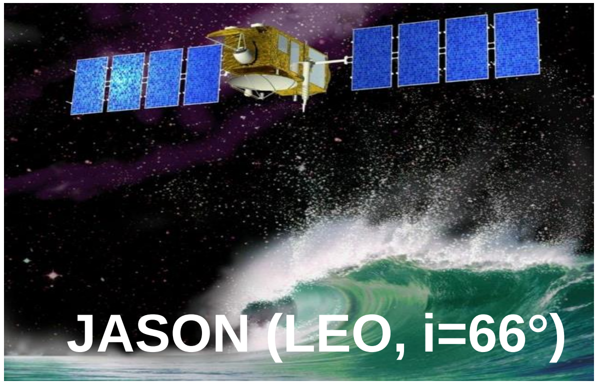


Earth Observation: Weather Satellites



Weather satellites see more than clouds: fires, pollution, sand storms

Earth Observation: Other Satellites



Measurements of the surface height of the oceans to an accuracy of 3.3 cms

In-orbit configuration: 26 m x 10m x 5m (the size of a bus)

Information about the earth (land, water, ice and atmosphere)

EARTH OBSERVATION

Military satellites (resolution: on the order of 1cm !)

http://www.space.com/news/080219-satellite-shootdown.html

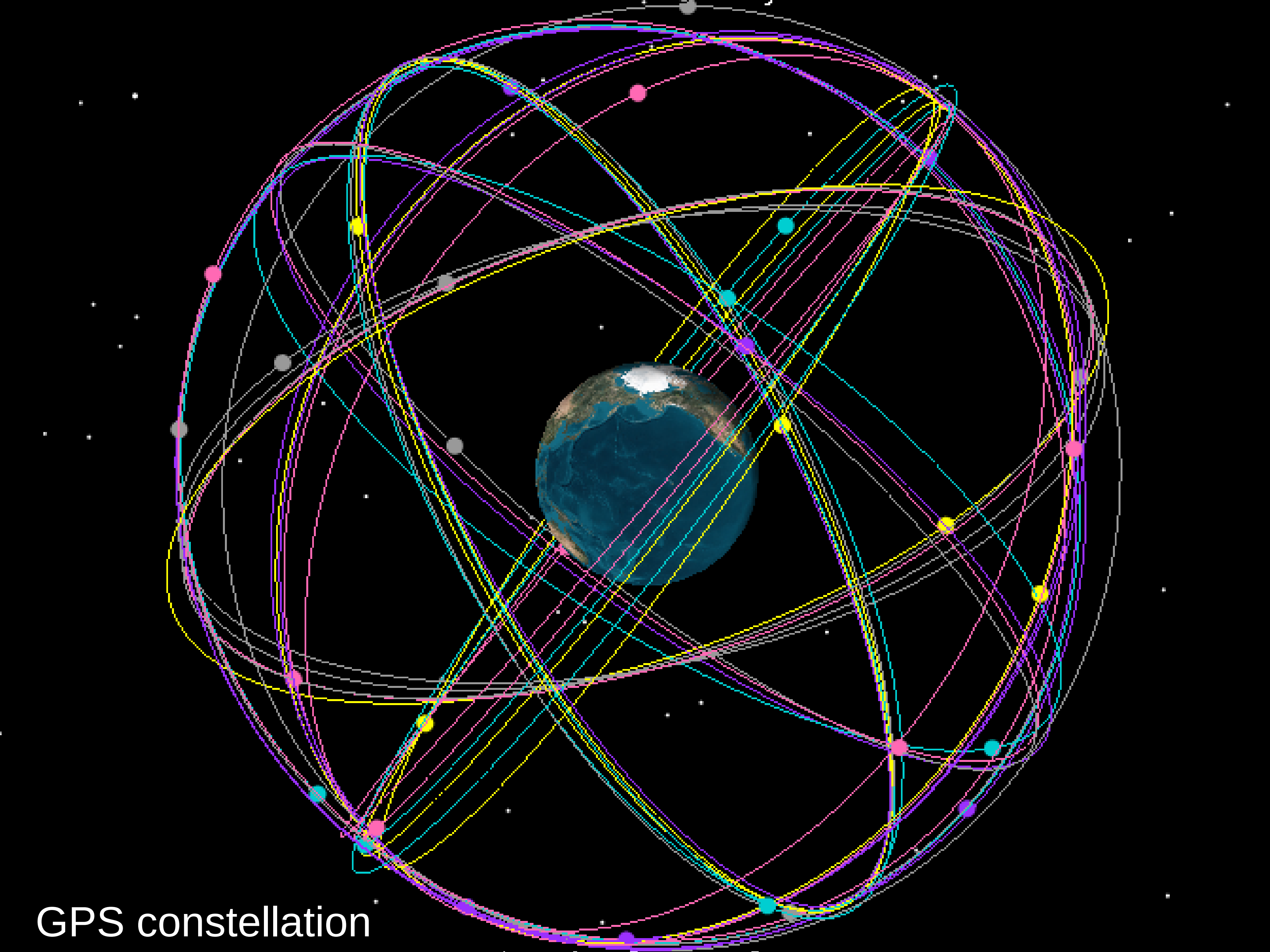
Communications and Navigation

Eutelsat: 2500 televisions and 1000 radio stations

Iridium: a constellation of 66 satellites

GPS (USA): 31 satellites in 6 orbital planes spaced equally in their ascending node locations

Galileo (Europe), Glonass (Russia)


GPS constellation

Space Observation and Exploration

Too many examples !

- Cassini-Huygens (Saturn), SOHO (Sun), Galileo (Jupiter), Voyager (different planets), HST (universe), Corot (asteroseismology), NEAR shoemaker (asteroid encounter), etc.
- Observation using different wave lengths (XMM $\Rightarrow$ X rays, IRAS $\Rightarrow$ infrared)
- A single mission has not a single instrument (e.g., more than 10 for Galileo)

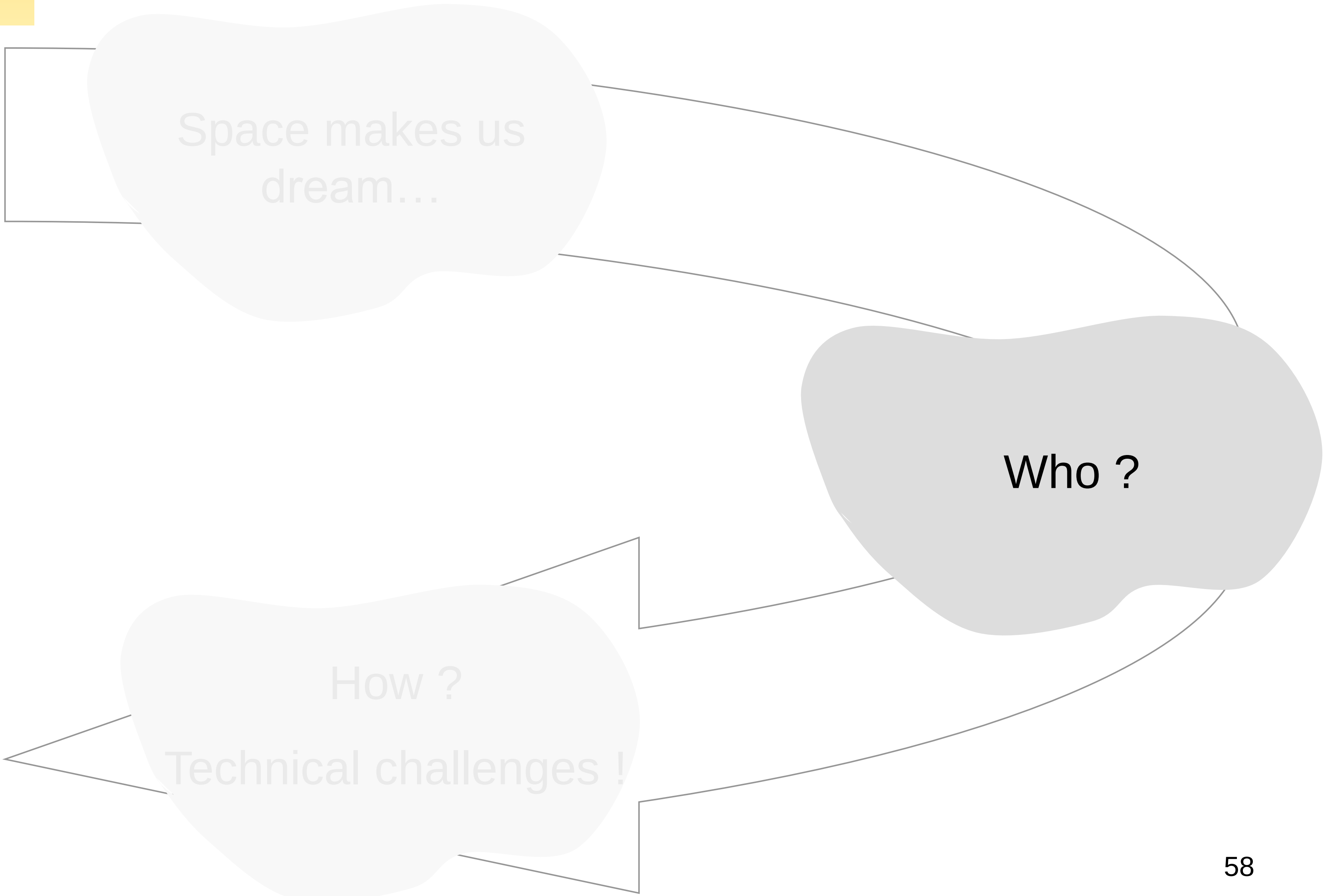
ASTROPHYSICS

Space Tourism: Inflatable Hotel !

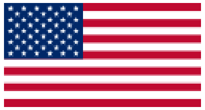
Experimental space habitat — GENESIS 1

http://www.bigelowaerospace.com/

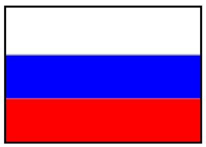
From Dreams to Technical Challenges



Key Players



NASA, JPL, Lockheed-Martin, Northrop-Grumman, Boeing



Roscosmos, Energia

ESA,
CNES, DLR, ASI,
Airbus D&S,Thales Alenia Space, Ariane Group

Two emerging countries

Belgium ? A Truly Strong Expertise !

AMOS, Cegelec, Euro Heat Pipes, Gillam, Ionic Software, Lambda-X, SABCA, SAMTECH, SONACA, Spacebel, Safran Aero Boosters, ETCA, Verhaert, Vitrociset, Walphot

Euro Space Center and ESA Redu ground station

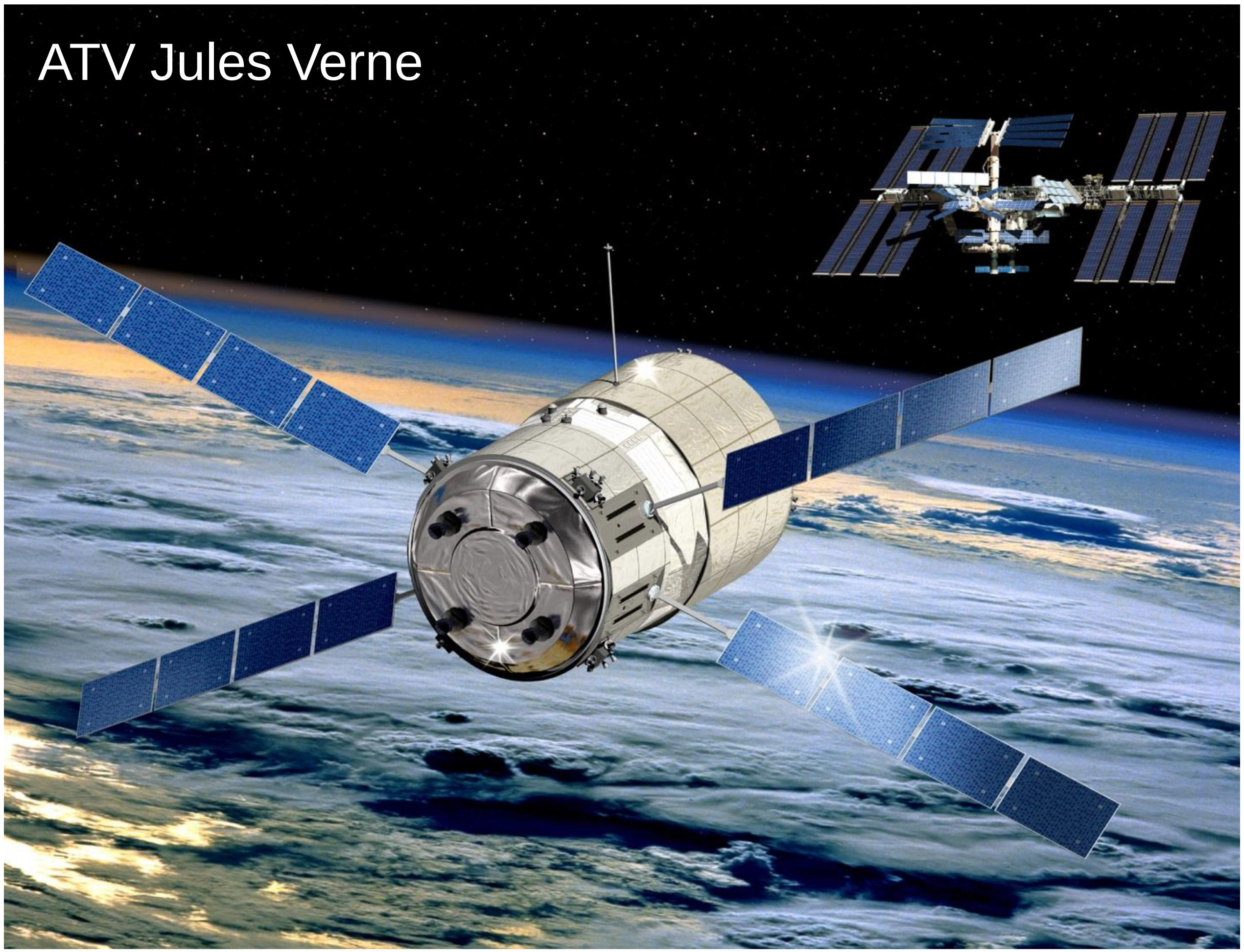
ULiege: 2 unique Masters + Liege Space Center (CSL)

UCL: radiation and hyperfrequences

ULB: microgravity research center

http://www.wallonie-espace.be/membres.html

An Example of Belgium's Know-How



EHP: heat pipes

ETCA: power conditioning units

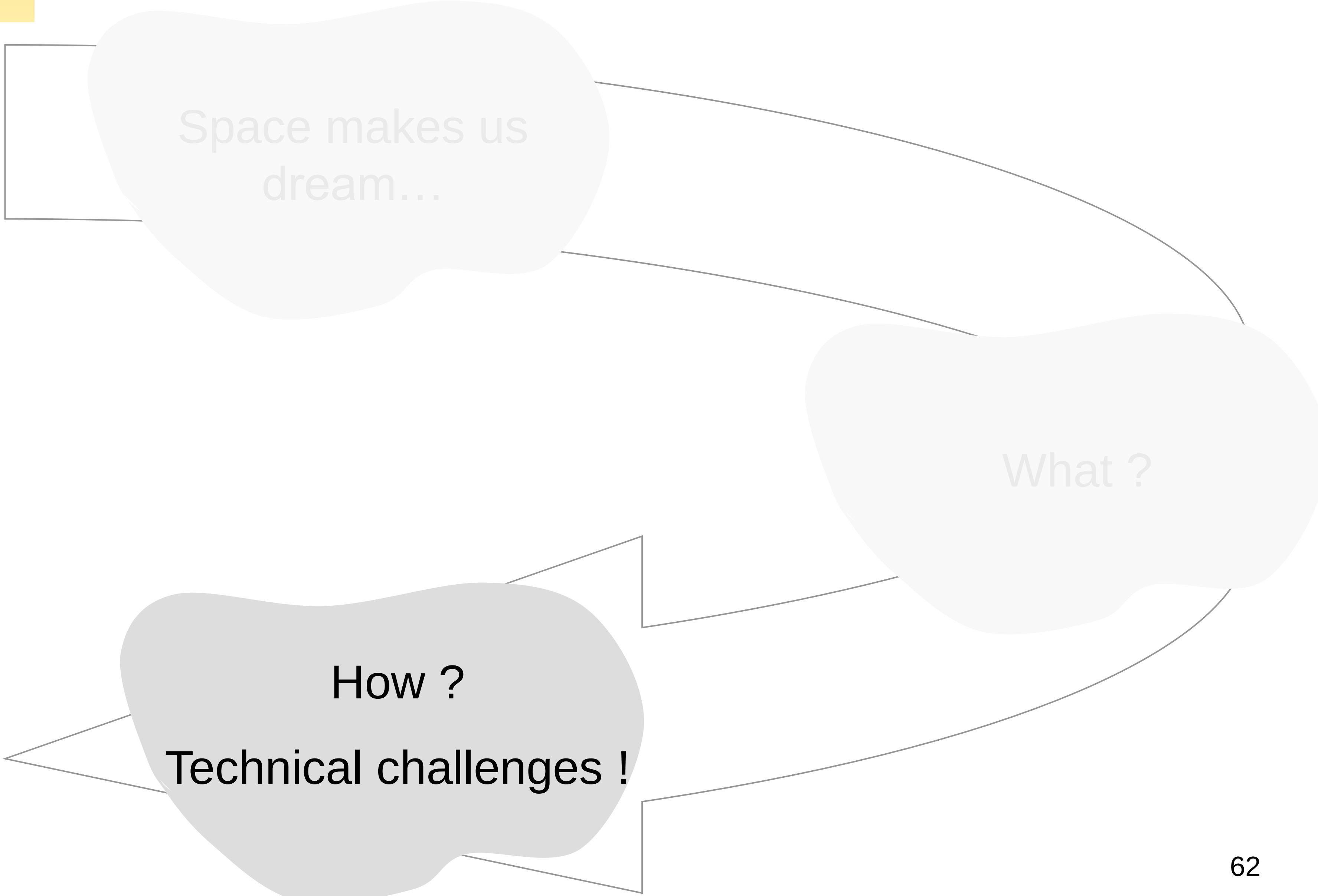
Spacebel: software

Rhea: software

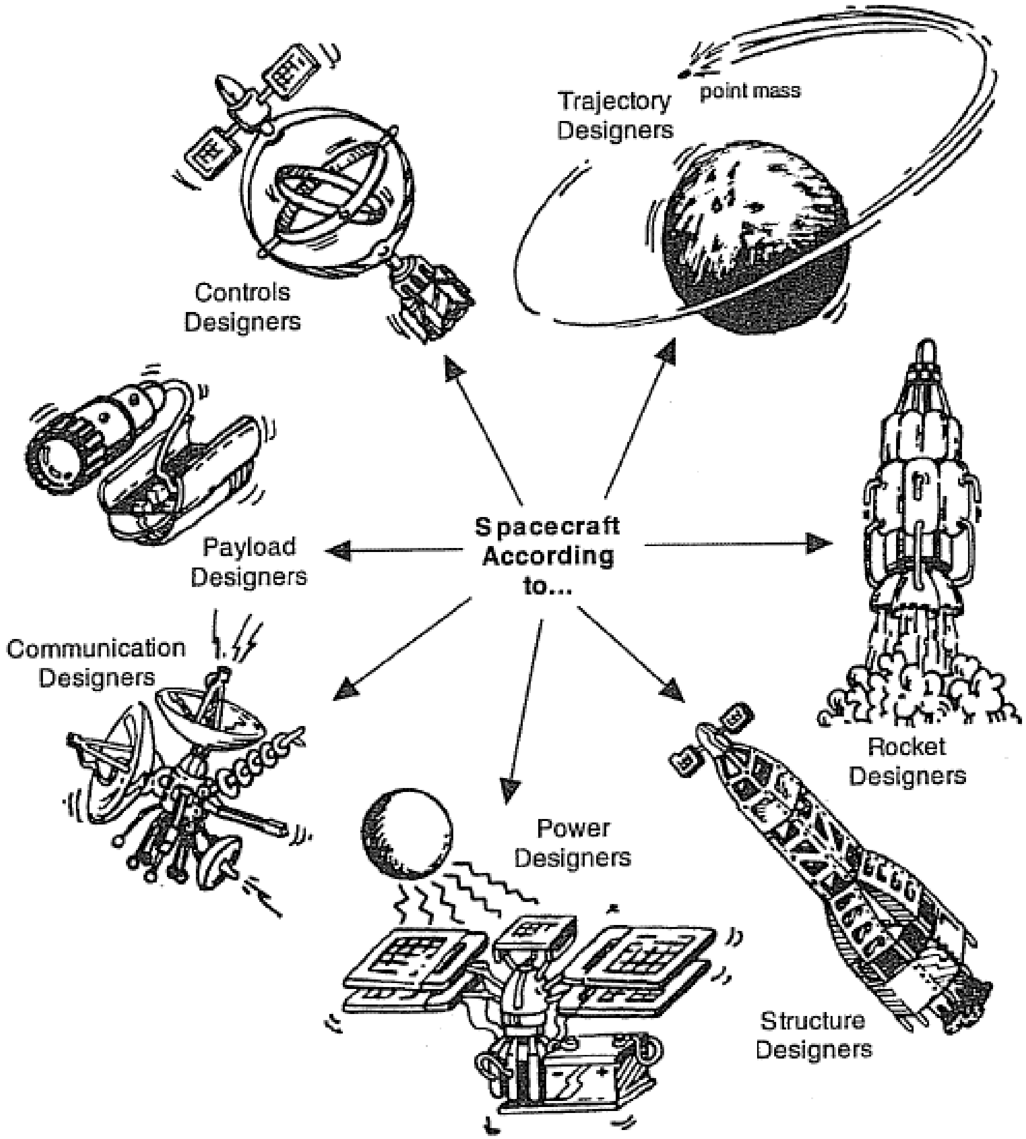
Redu: backup ground station

Safran aero: aestus engine valves

From Dreams to Technical Challenges



Challenge #1: Multidisciplinary Design



Solution: Multidisciplinary Design

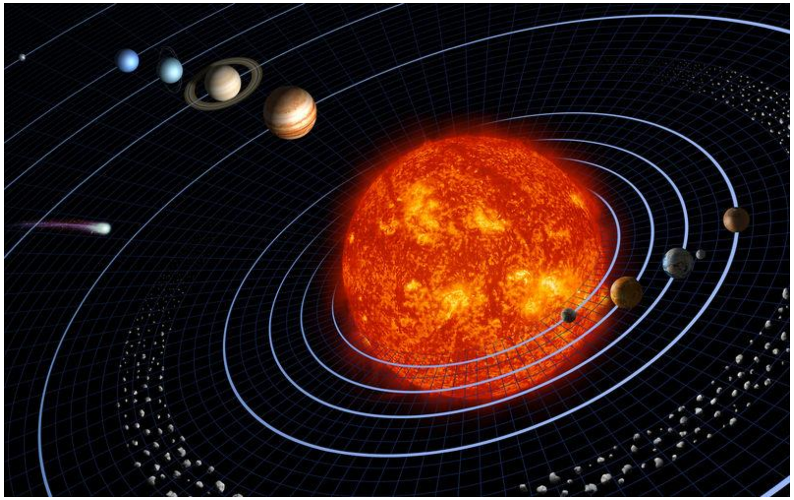
Look for the optimal solution for the entire spacecraft
(do not look for the optimal solution for your subsystem)

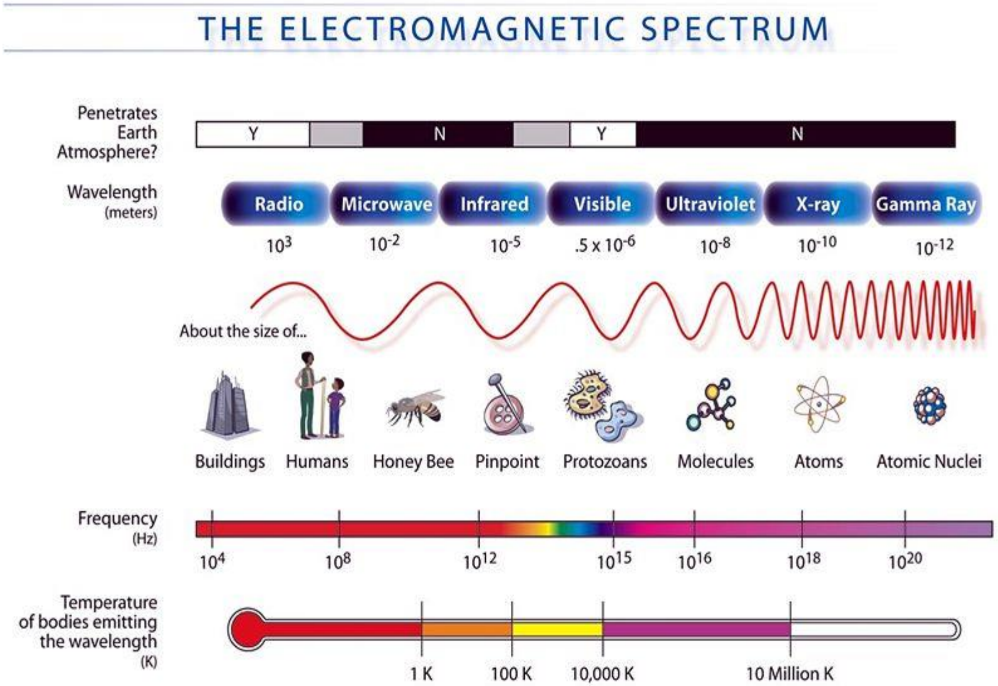
This course is intended to give you an overview of the different subsystems, so that you will understand the challenges faced by your colleagues who are expert in power systems telecommunications, etc

Concurrent Design Facility, ESTEC-ESA

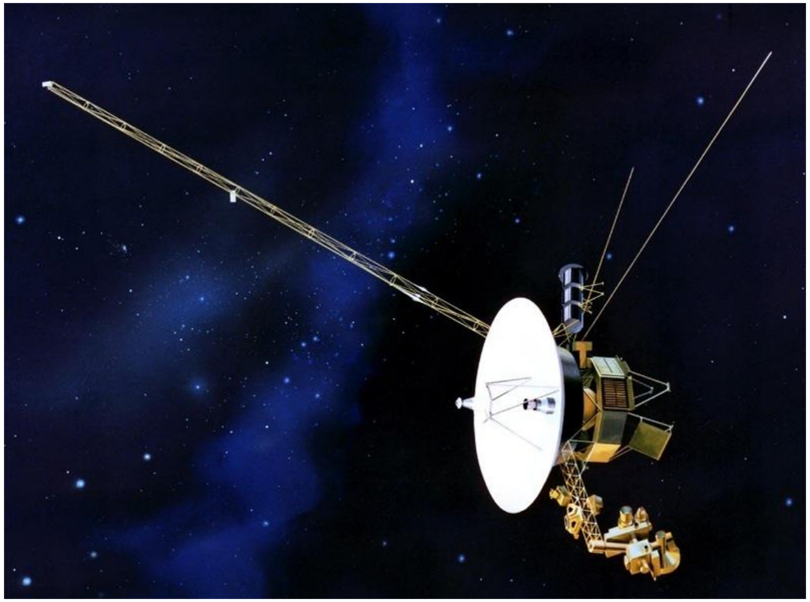
Challenge #2: Each Mission is Unique

Where ? & Why ?





Solution: Fit the Requirements



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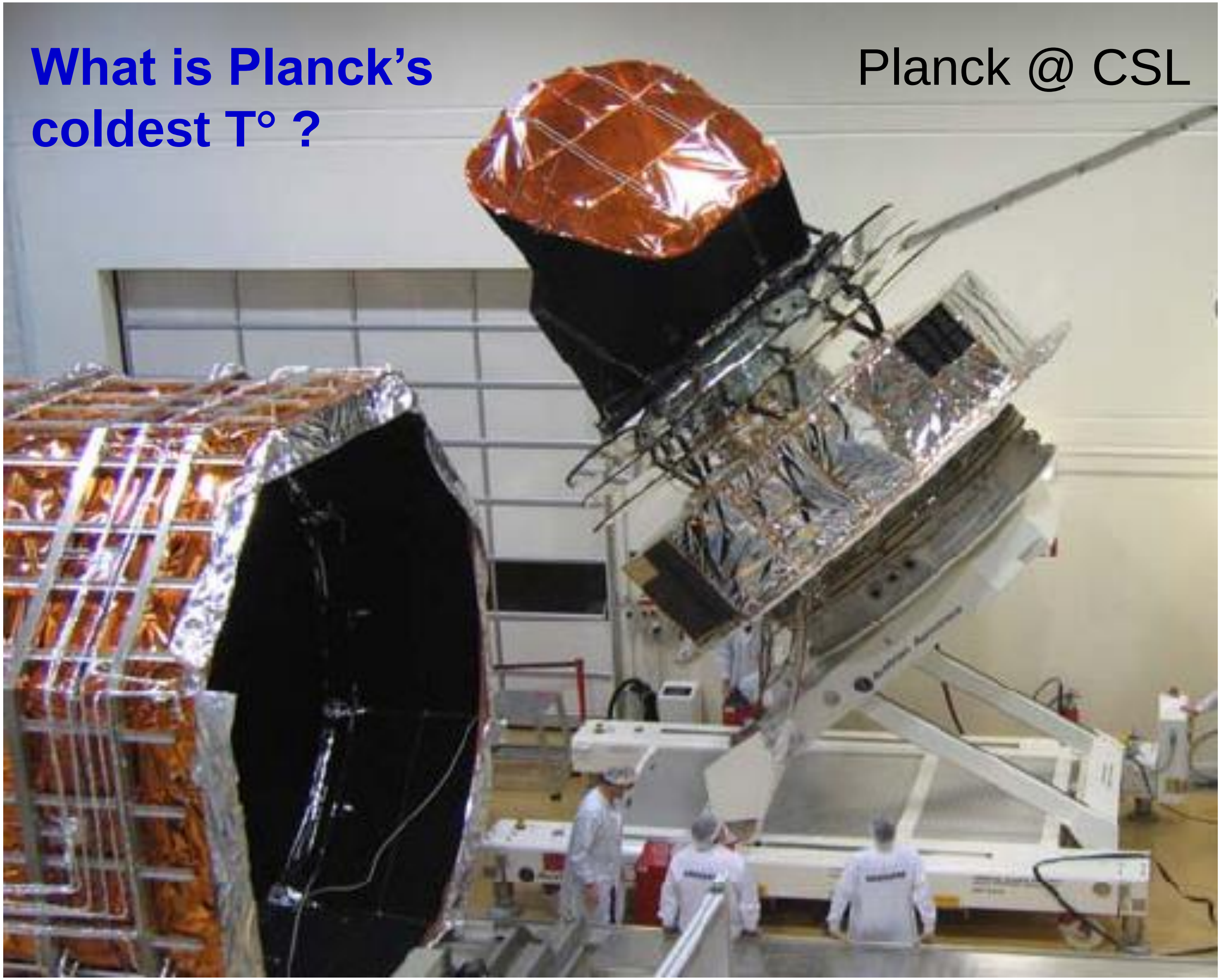
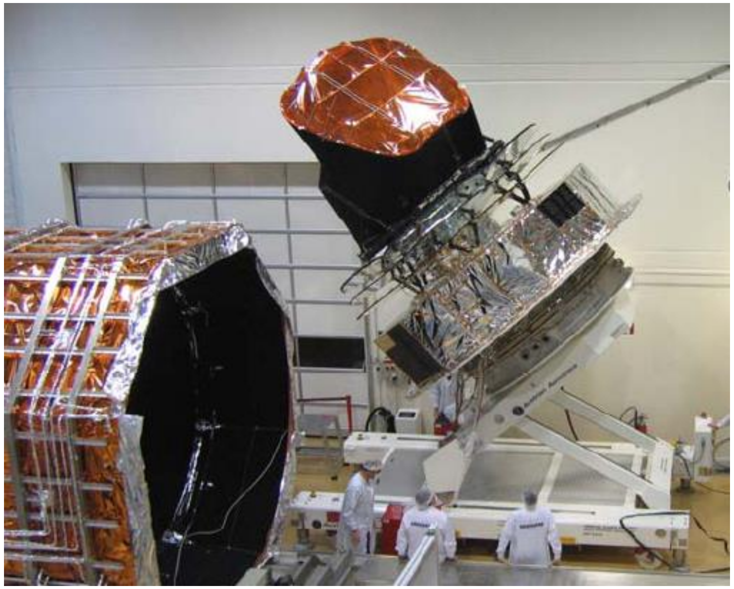
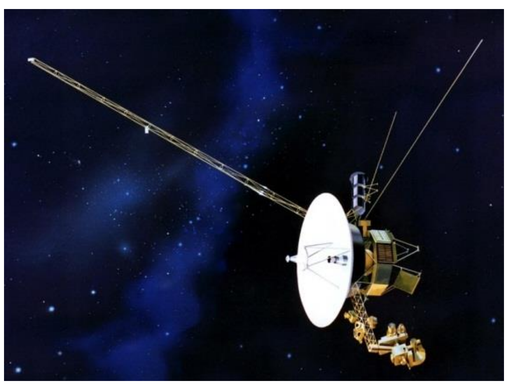
Challenge #3: Orders of Magnitude



Challenge #3: Orders of Magnitude



0.1°K (CSL) — the equivalent of the amount of energy exchanged between 2 people 400 kms from each other

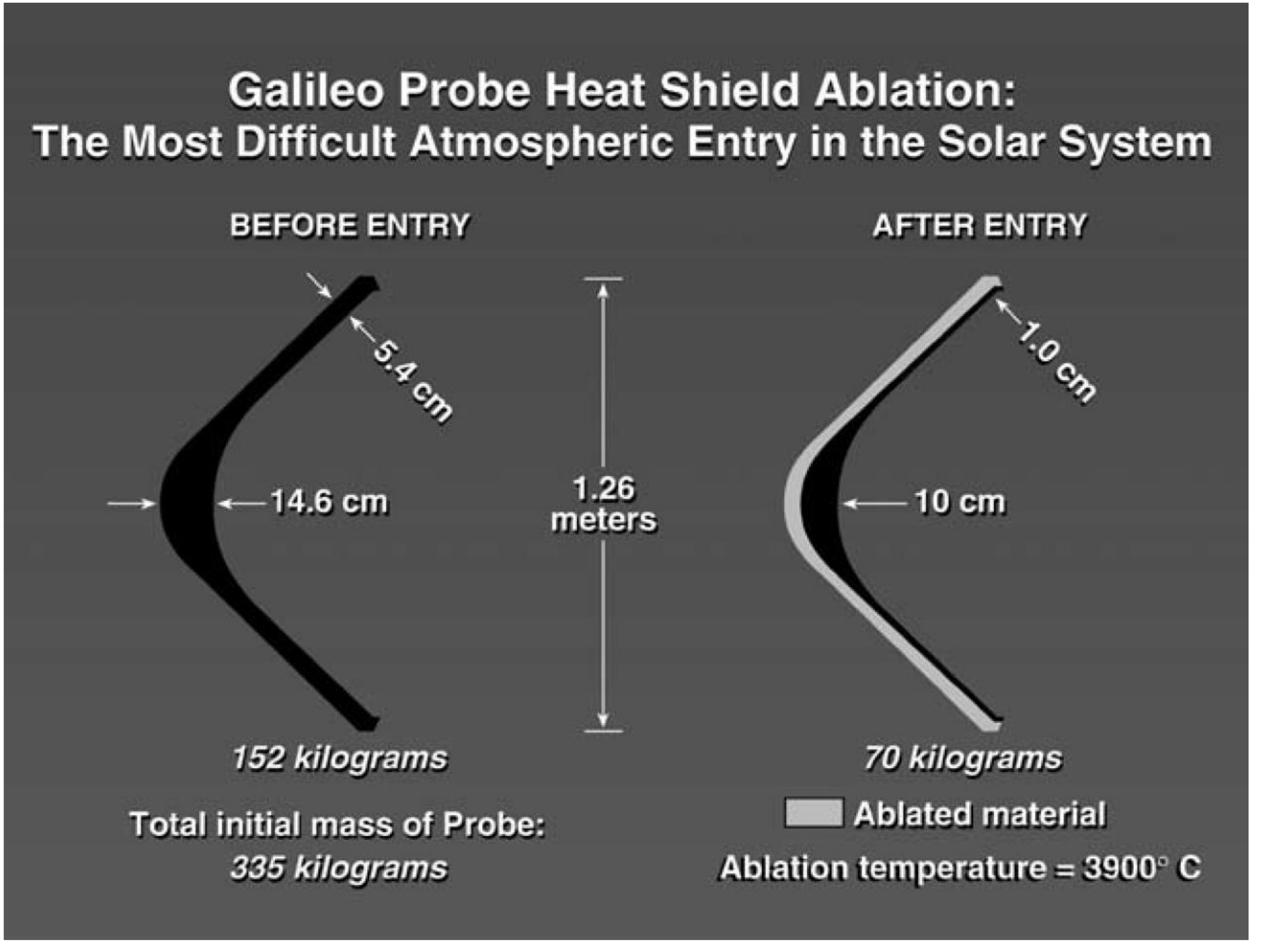


15.000.000.000 kms

10^{-16} W

0.007''

Challenge #3: Orders of Magnitude



171.000 km/h $\Rightarrow$ 1.600 km/h in 2 minutes

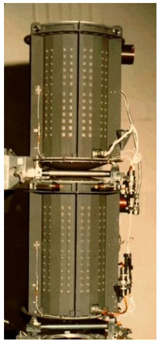
Solution: The Engineer Must Be Creative

15.000.000.000 kms

Power: 15W/m^2 (Saturne)

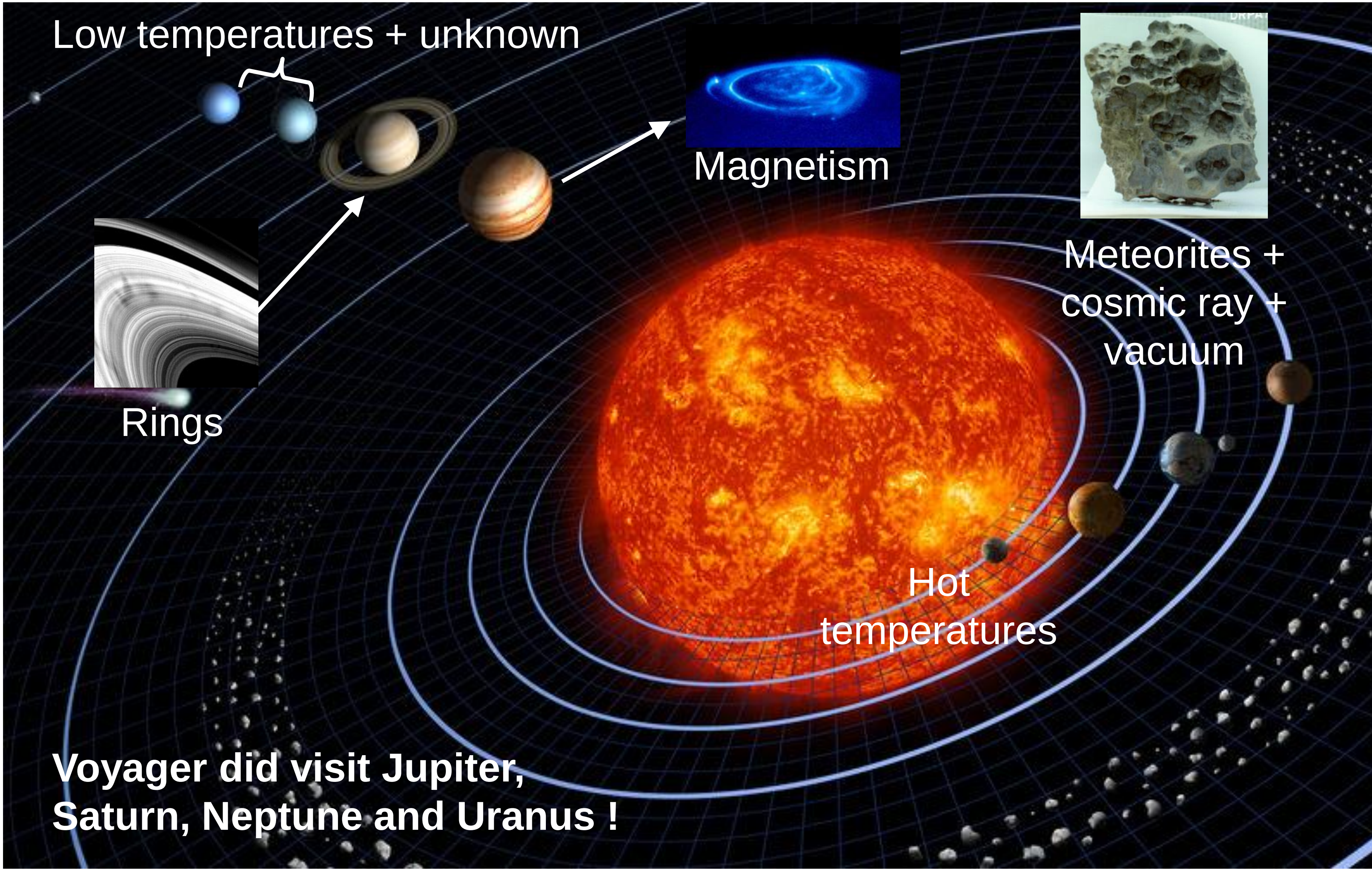
Communications: 10^{-16} W

70-meter antenna



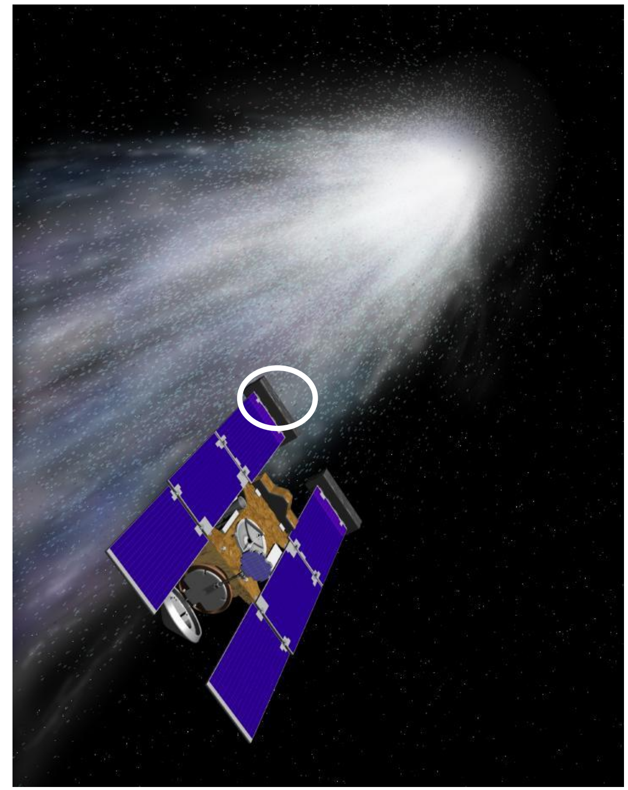
Nuclear materials

Challenge #4: Harsh Environment



Solution: Develop New Technologies

Thermal blanket
(temperatures)



Whipple shield against
comet projections

Challenge #5: No Maintenance !

Voyager 1

Voyager 2: backup
(ultimate redundancy !)

For each spacecraft:

3 RTGs
2 x 8 thrusters
2 transceivers
2 computers
2 magnetometers

In Summary

Use proven technologies

⇕

Be creative

Redundancy

⇕

Weight constraints (launch)

Conflict is the order of the day…

The resolution of such conflict in a productive manner is precisely the goal of systems engineering