Welcome !

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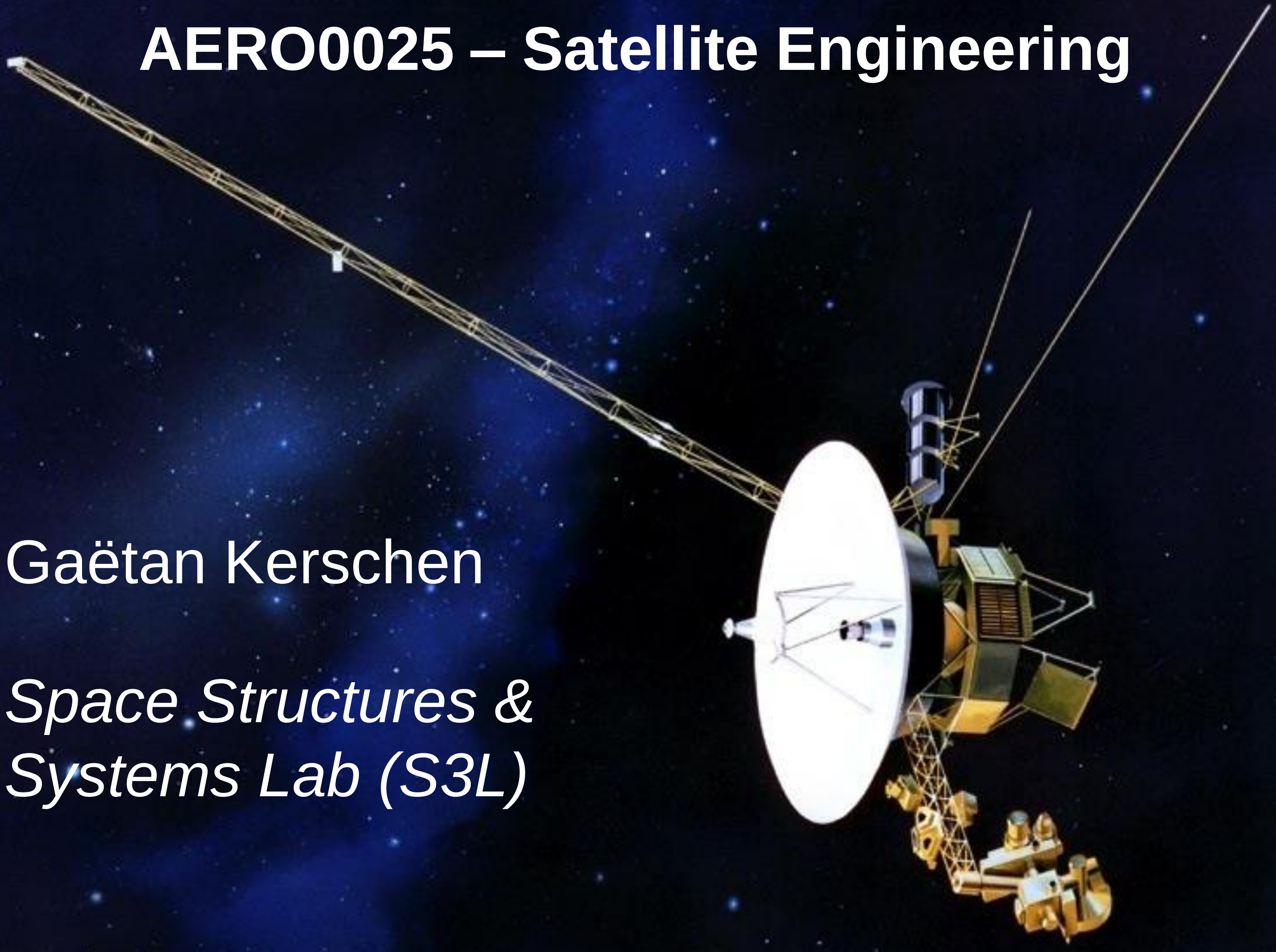
AERO0025 – Satellite Engineering



Gaëtan Kerschen

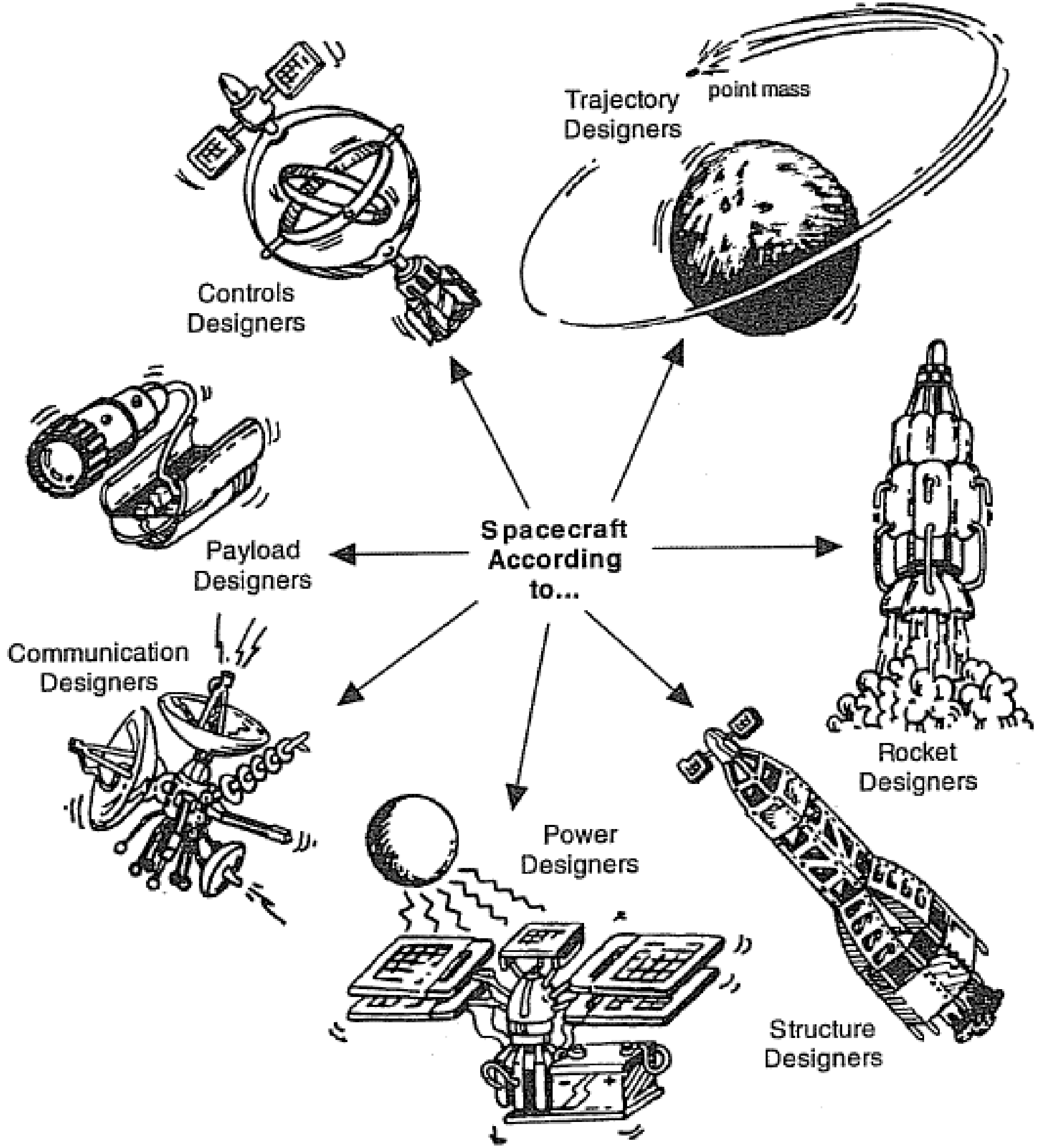
Space Structures & Systems Lab (S3L)

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


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

Astrophysics
Earth observation
Optics

Payload design

Telecommunications

Space environment

Vibrations

Space propulsion

Composites

Bus design

Astrodynamics
Reentry

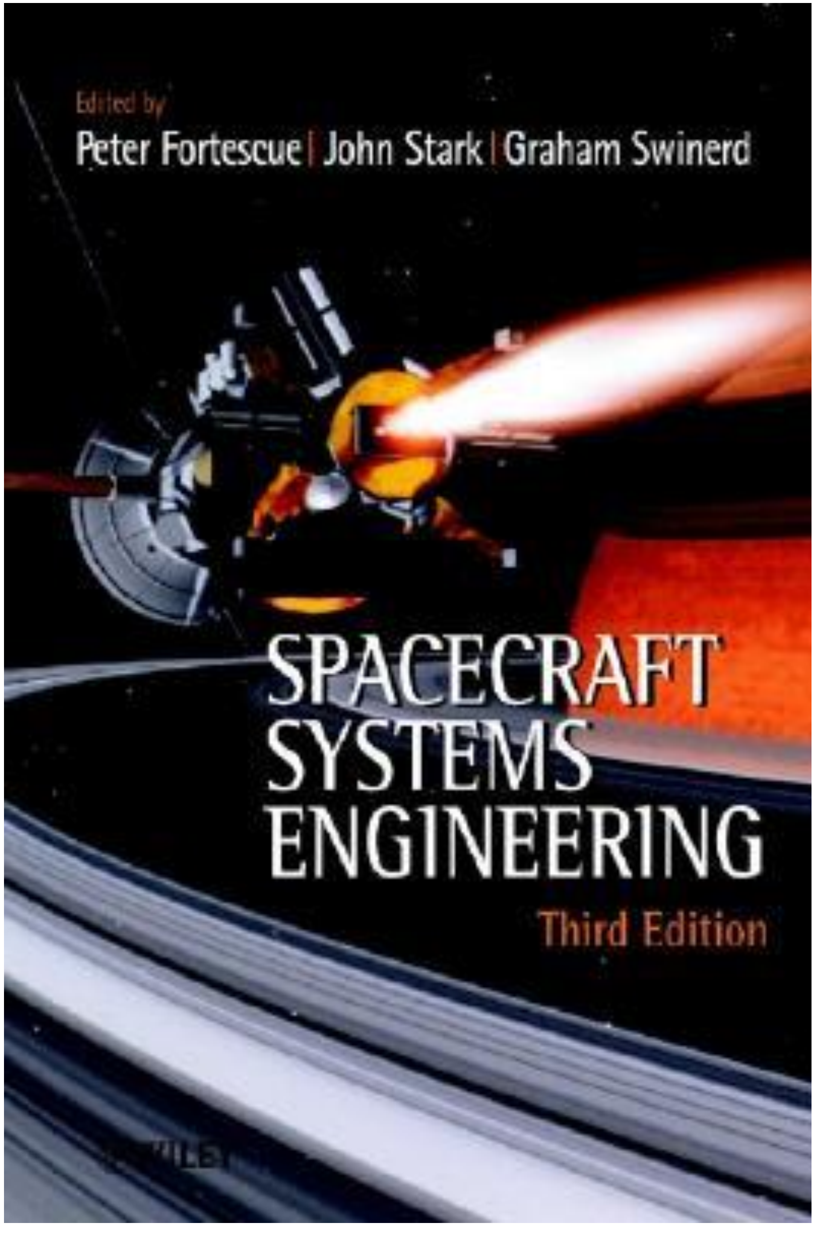
Mission analysis

Launch vehicle design

Launch vehicle

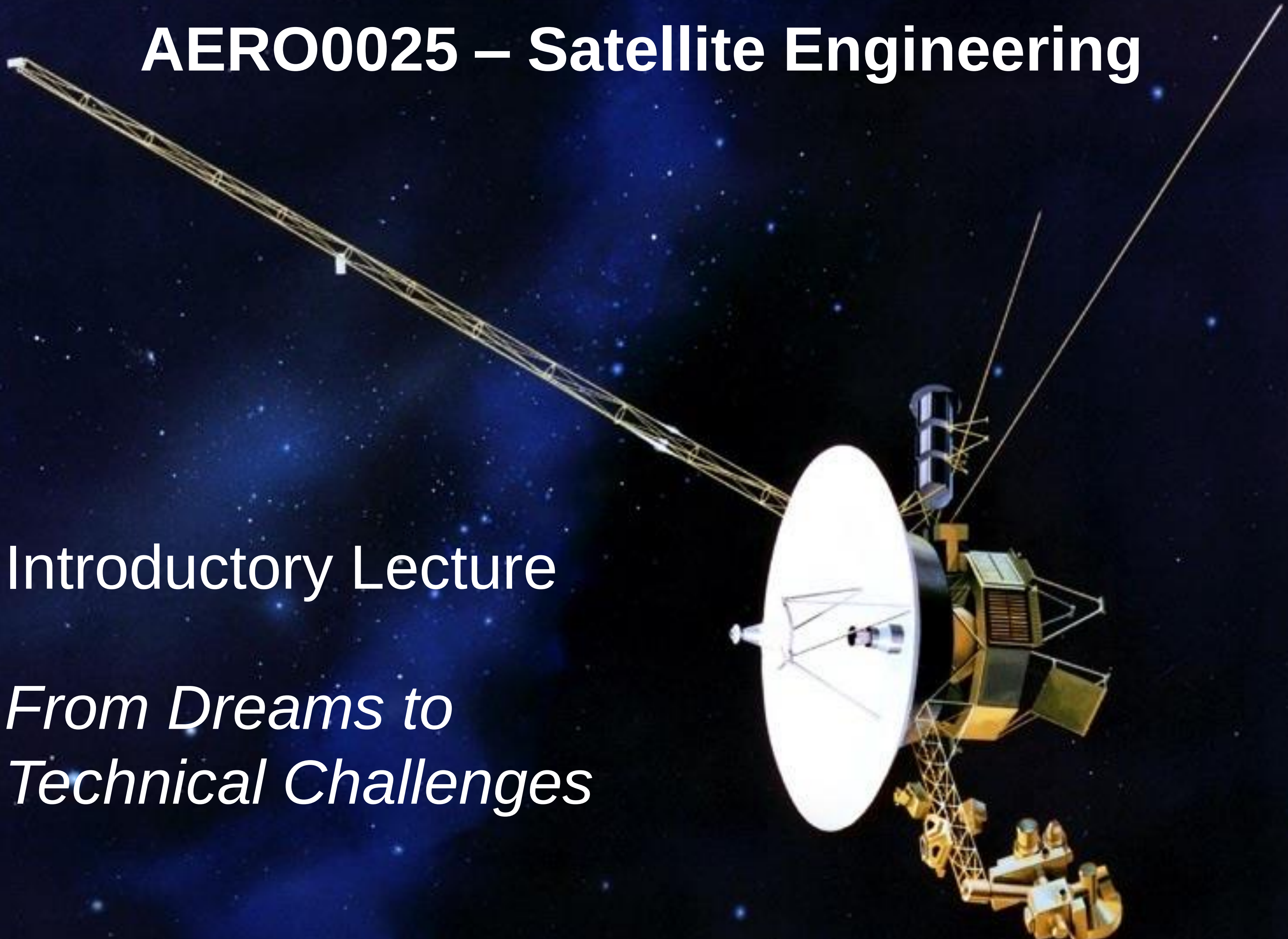
Course Details (See S3L Web Site)

Textbook



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

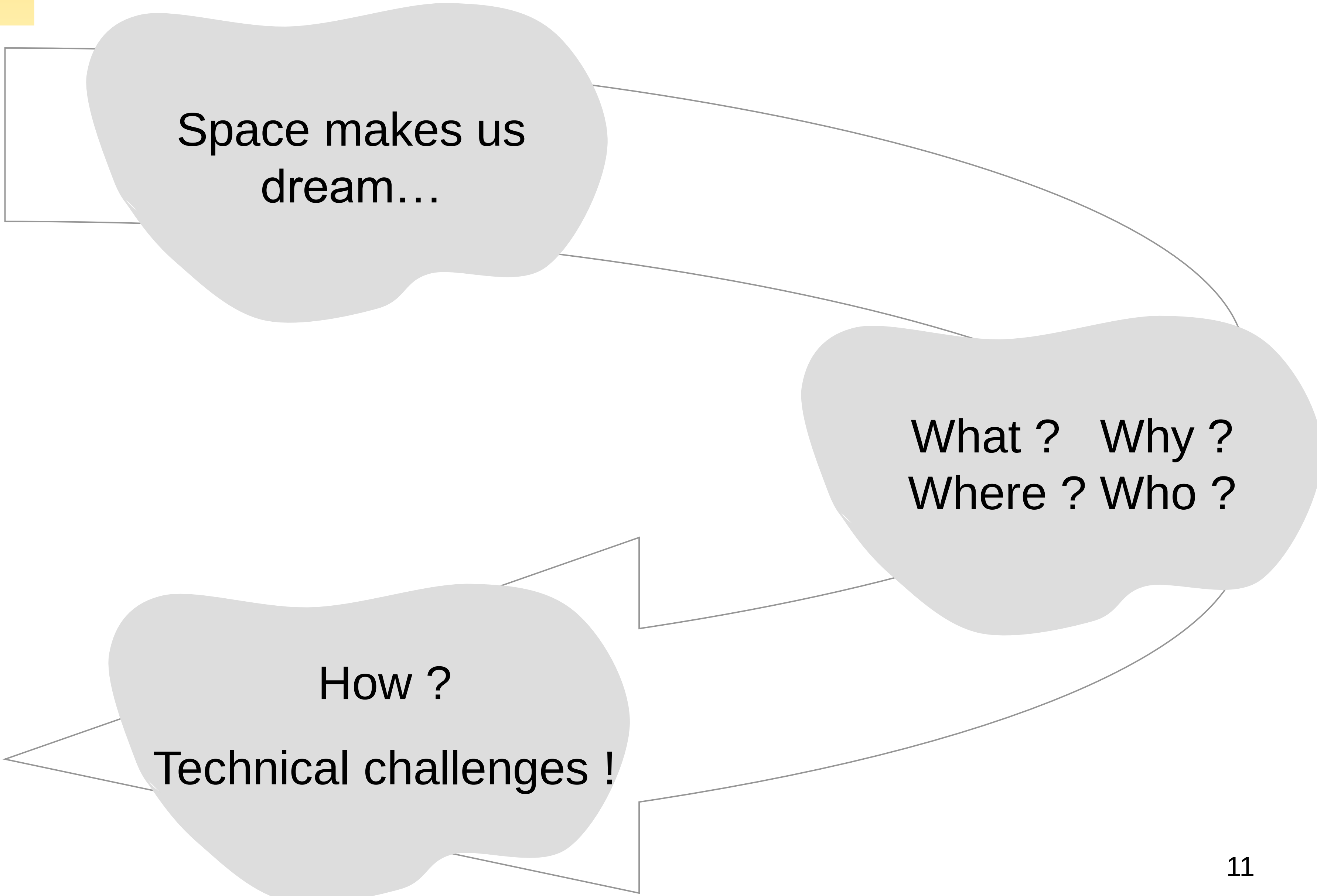
AERO0025 – Satellite Engineering

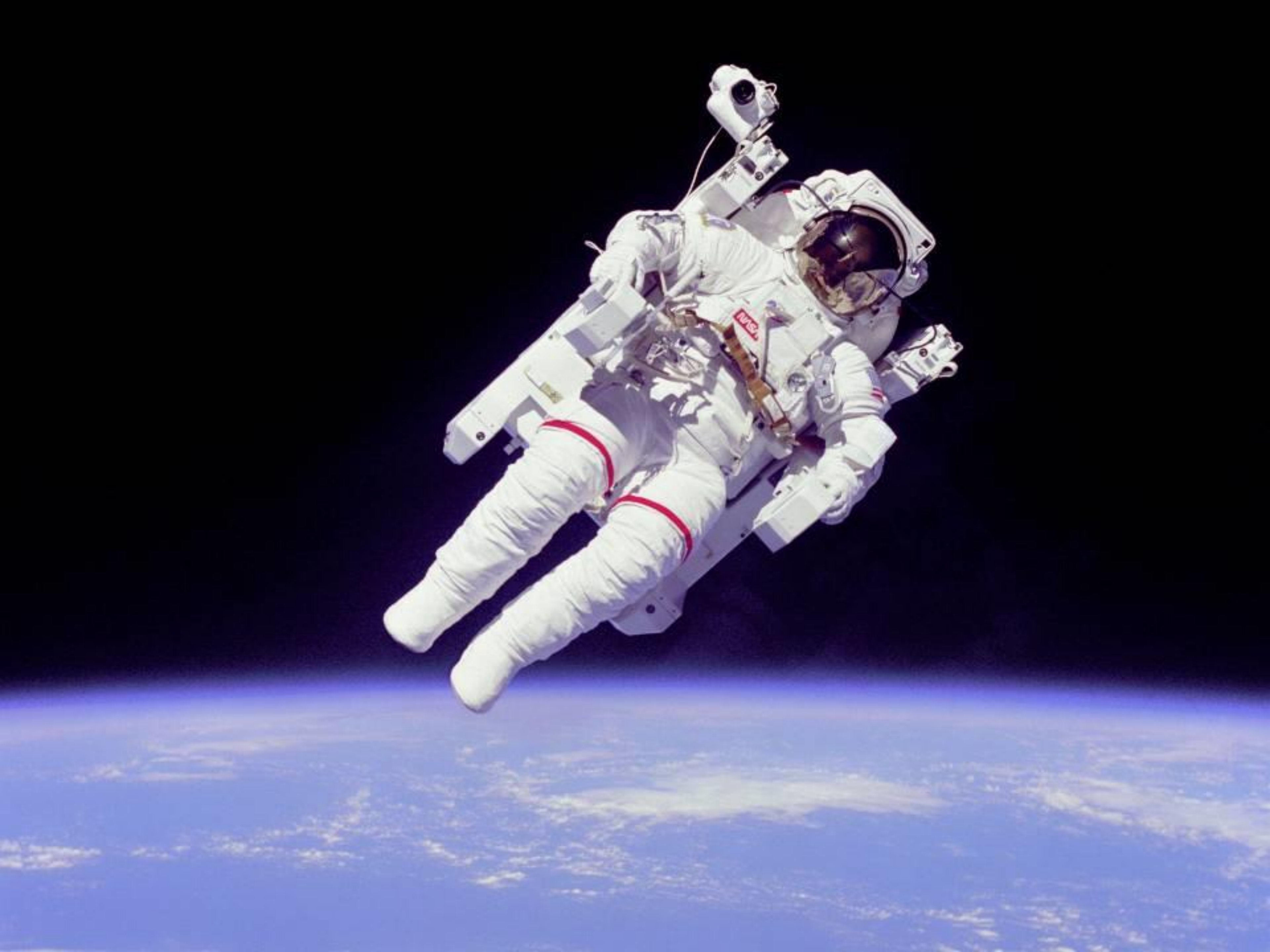


Introductory Lecture

From Dreams to Technical Challenges

From Dreams to Technical Challenges






Discovery

WHAT DO
YOU SEE ?


SPACE IMAGING

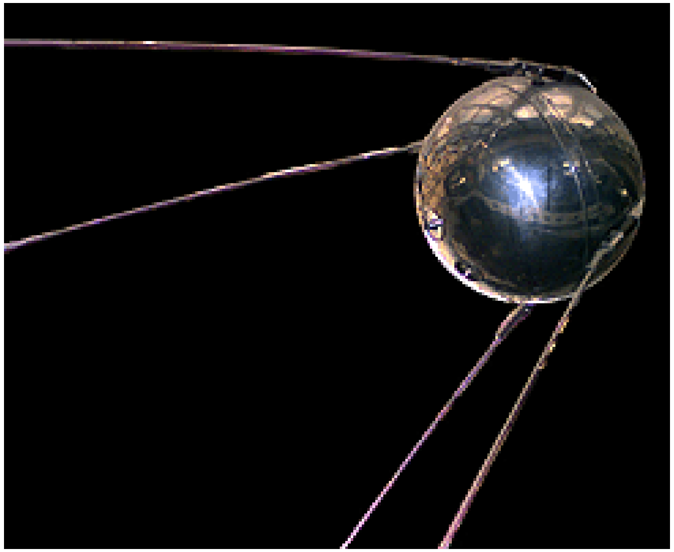
Emphasis of Some…

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)

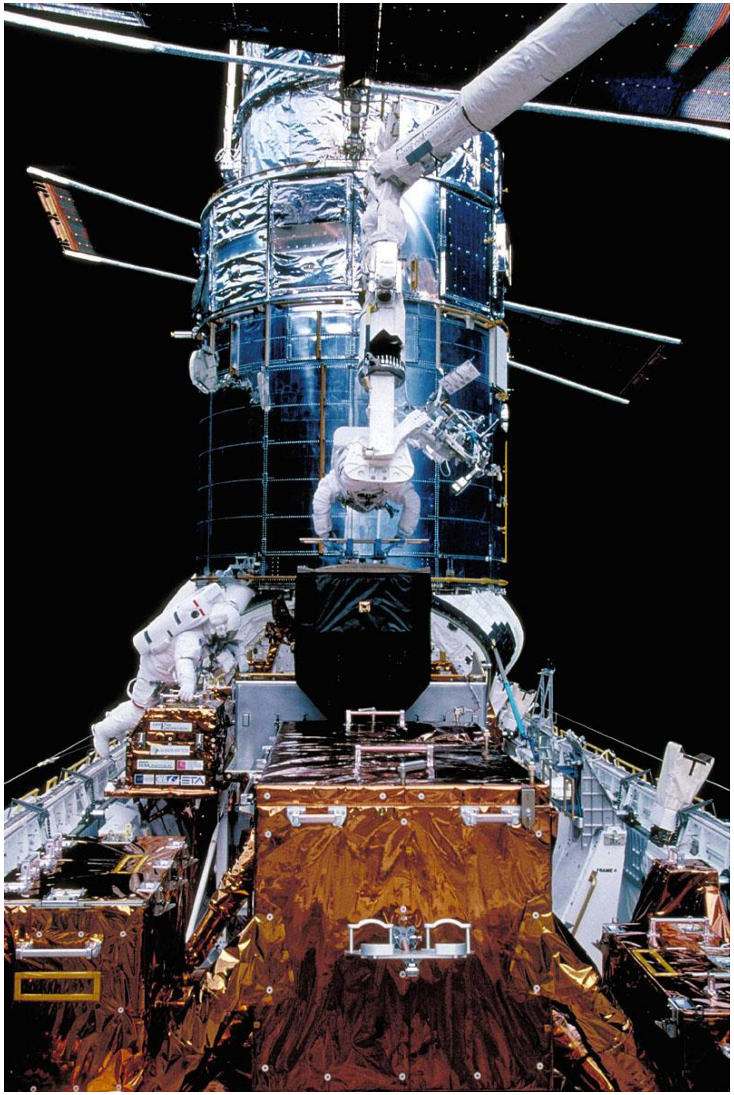
Satellite #2: ISS

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, N_2H_4 and N_2O_4) + 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

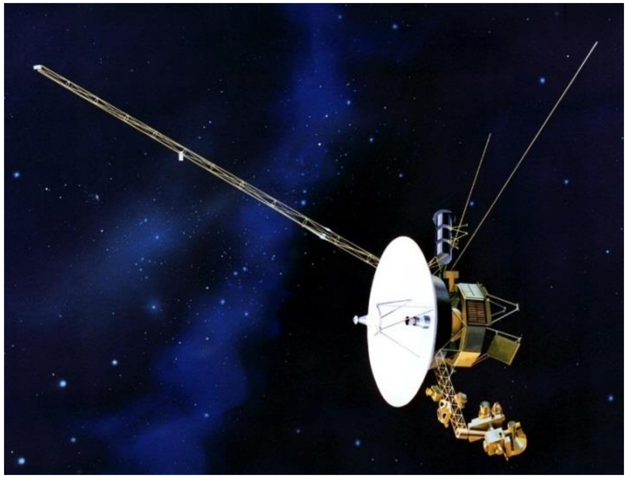
Pointing accuracy: 0.007”

Defective mirror and solar panels, recovery thanks to servicing mission

HST: Technical Data

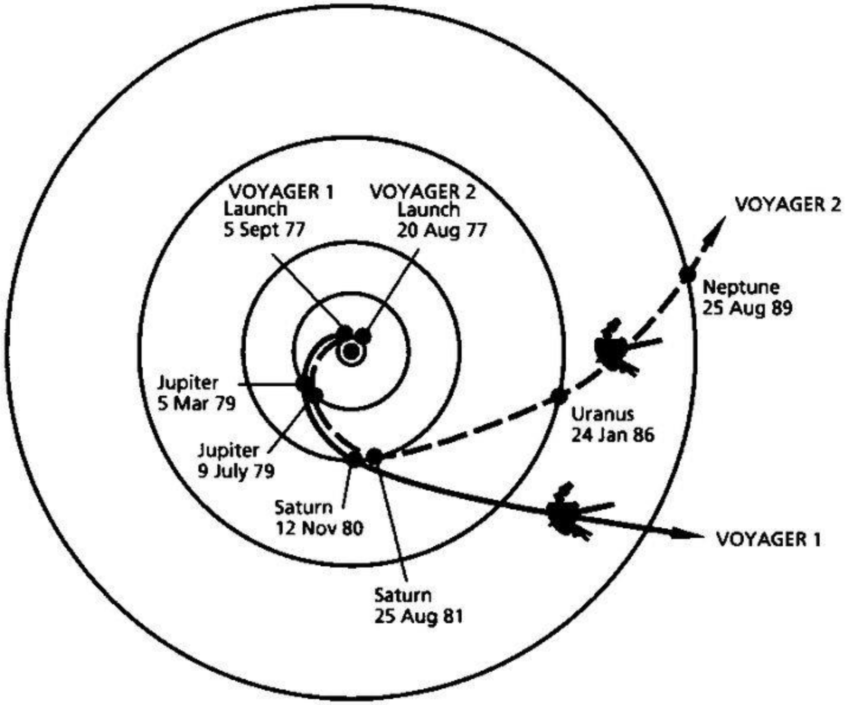
Weight	**11 tons**
Dimensions	13.2 m high, 4.2 m diameter
Power	4.5 kW, solar panels
Propulsion	-----
ADCS	**Reaction wheels, magnetometers, star trackers, gyroscopes, fine guidance sensor (lock onto guide stars), magnetic torquers**
Communications	**2 high-gain antennas (S-band)**
Orbit	LEO, 600 kms, 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: SOHO, 1995

Objective: Solar exploration and space weather prediction

http://www.space.com/php/video/player.php?video_id=sun_storm

SOHO: Technical Data

Weight	1850 kgs
Dimensions	4.3 x 2.7 x 3.7 m (bus) Solar panels: 9.5 m tip-to-tip
Power	1500 W, solar panels
Propulsion	Centaur + 16 N_2H_4 thrusters (4.2 N)
ADCS	3 reaction wheels + 16 N_2H_4 thrusters + 3 gyroscopes + sun sensors + star tracker
Communications	0.8 m high-gain and low-gain antennas (S-band)
Orbit	Halo orbit (L1)
Launch vehicle	Atlas II + centaur upper stage

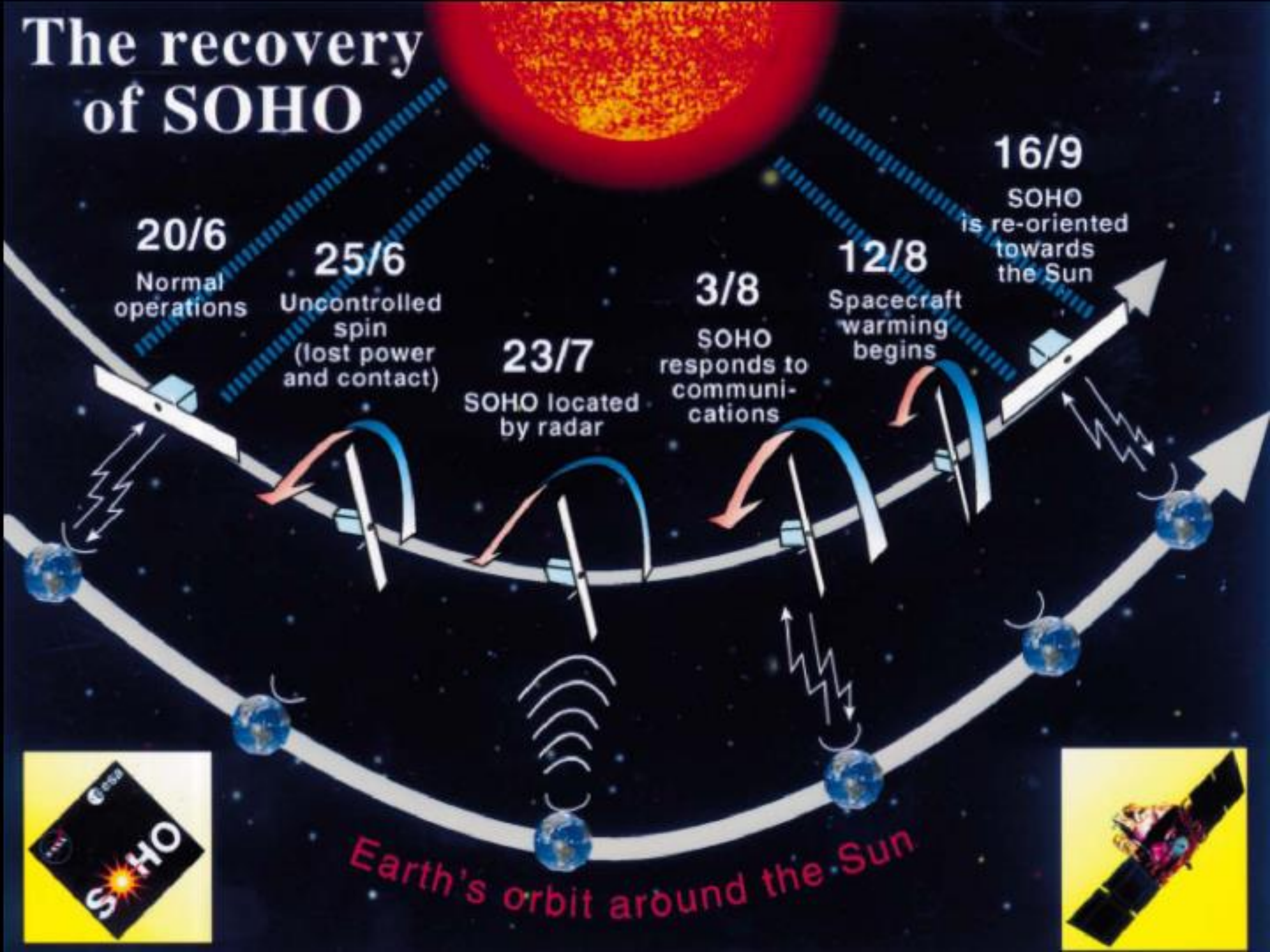
SOHO's Failure

1. All contact with SOHO was lost during a month !

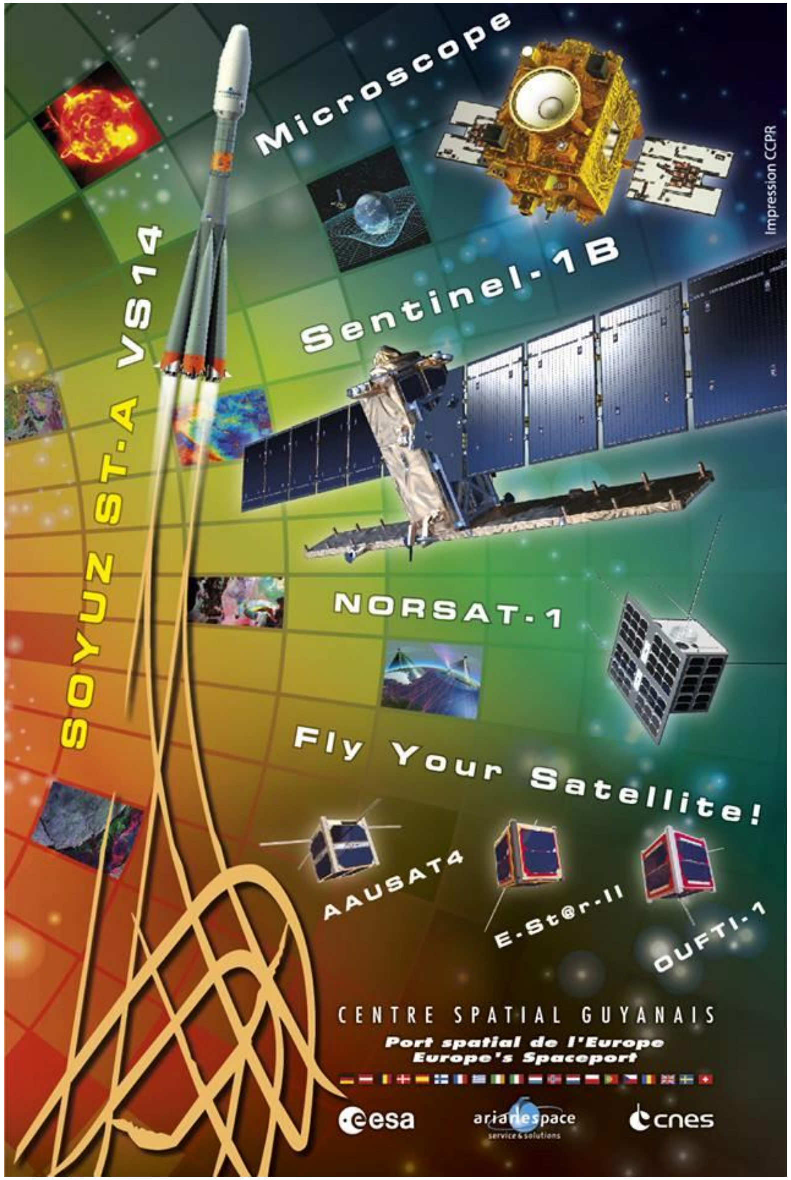
2. A telescope was used to transmit an S-band signal (580 kW !!!) towards SOHO. The radar echoes heard from Goldstone (Deep Space Network) confirmed its predicted location, and a spin rate of 1 rpm.

3. Telemetry showed that hydrazine in the tank, thrusters and pipes were frozen.

4. Thawing operation using heaters $\Rightarrow$ SOHO was recovered !


The recovery of SOHO
20/6
Normal operations
25/6
Uncontrolled spin (lost power and contact)
23/7
SOHO located by radar
3/8
SOHO responds to communi-cations
12/8
Spacecraft warming begins
16/9
SOHO is re-oriented towards the Sun
Earth's orbit around the Sun

Satellite #6: OUFTI-1, 2016



Objectives:

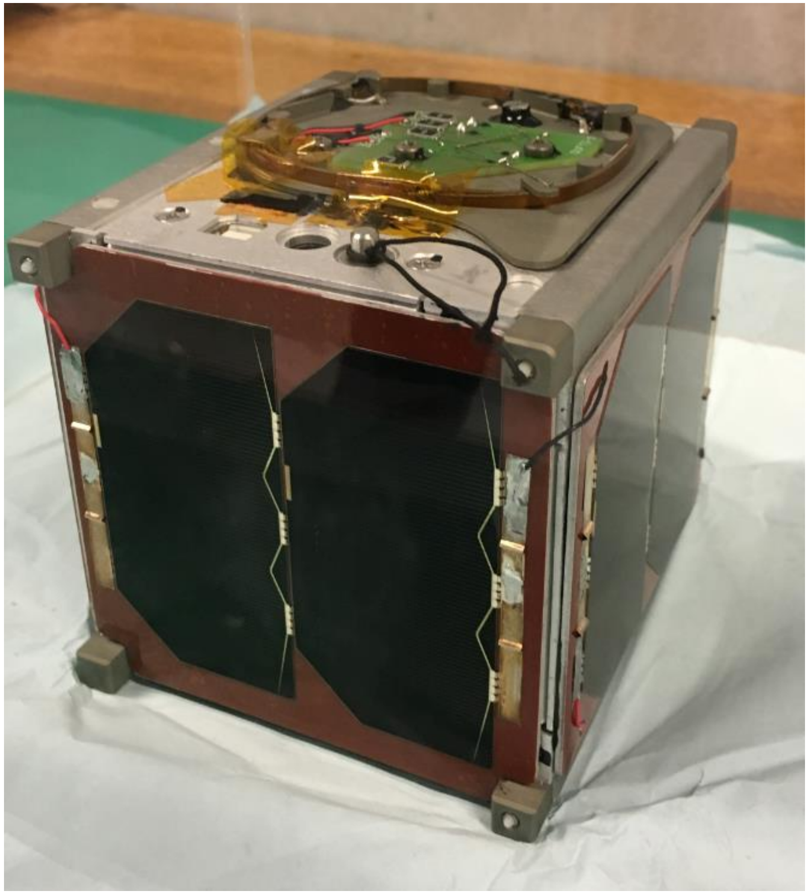
1. On-orbit validation of D-STAR
2. New solar cells

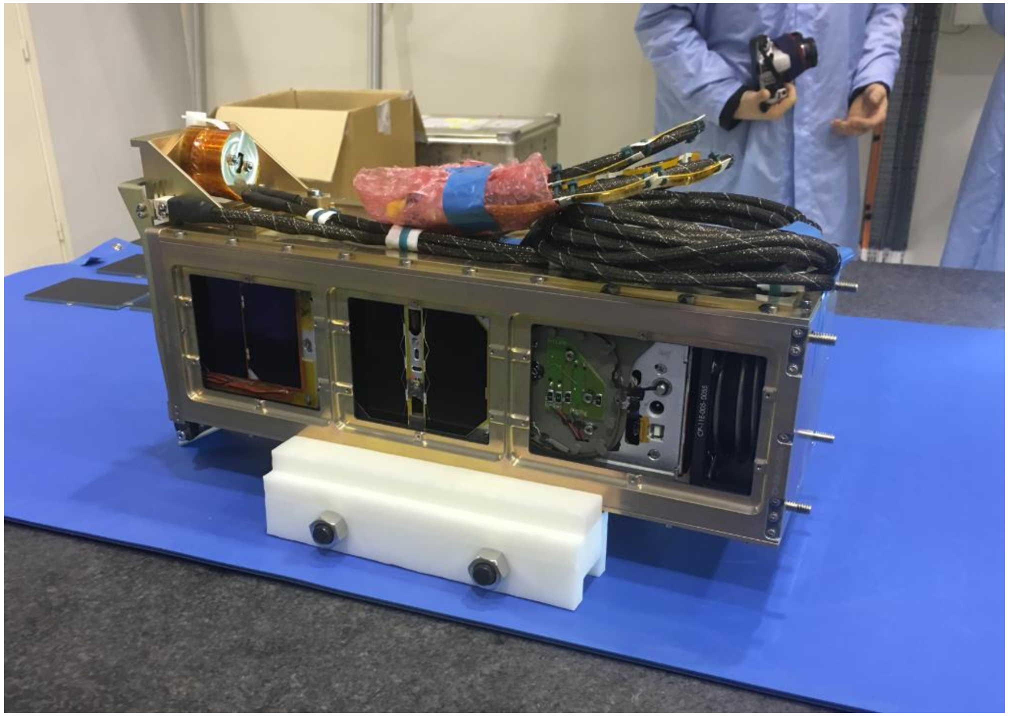
Entirely designed by students

Launched at the fourth attempt !

Unknown failure three weeks after launch.

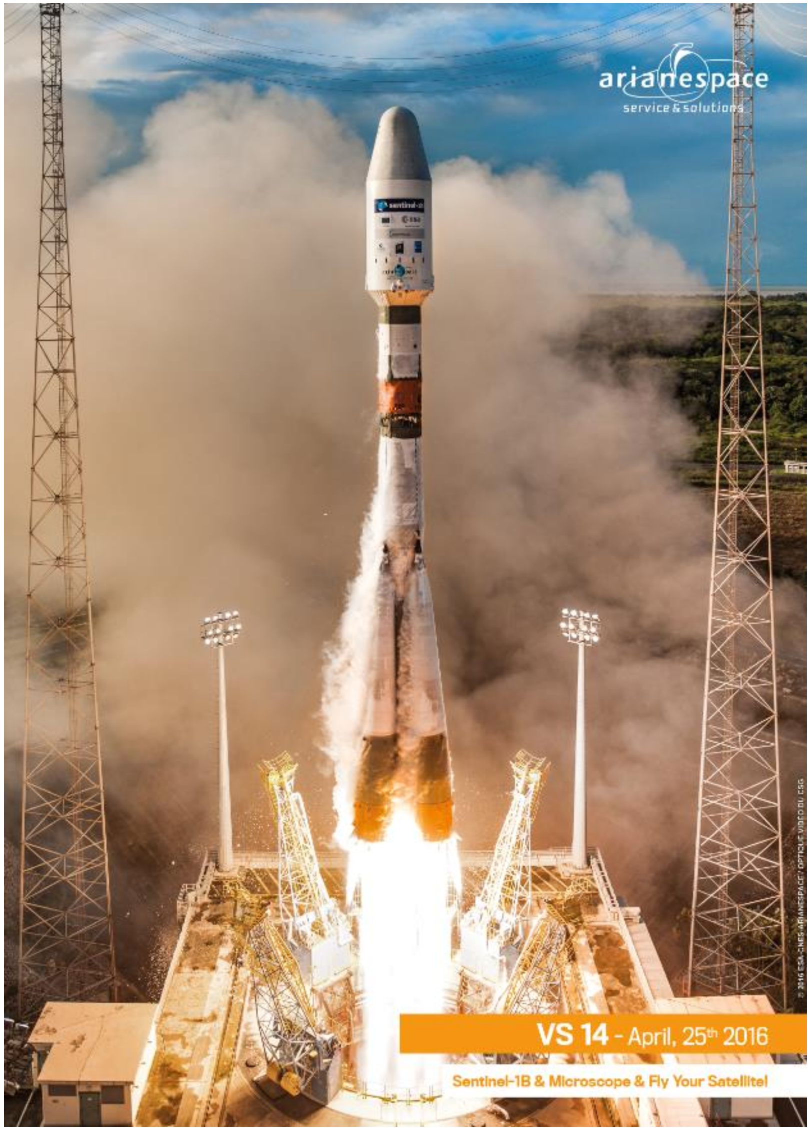
Satellite #6: Integration March, 2016





Satellite #6: Integration March, 2016

Satellite #6: Launch on April 25, 2016



OUFTI-1: Technical Data

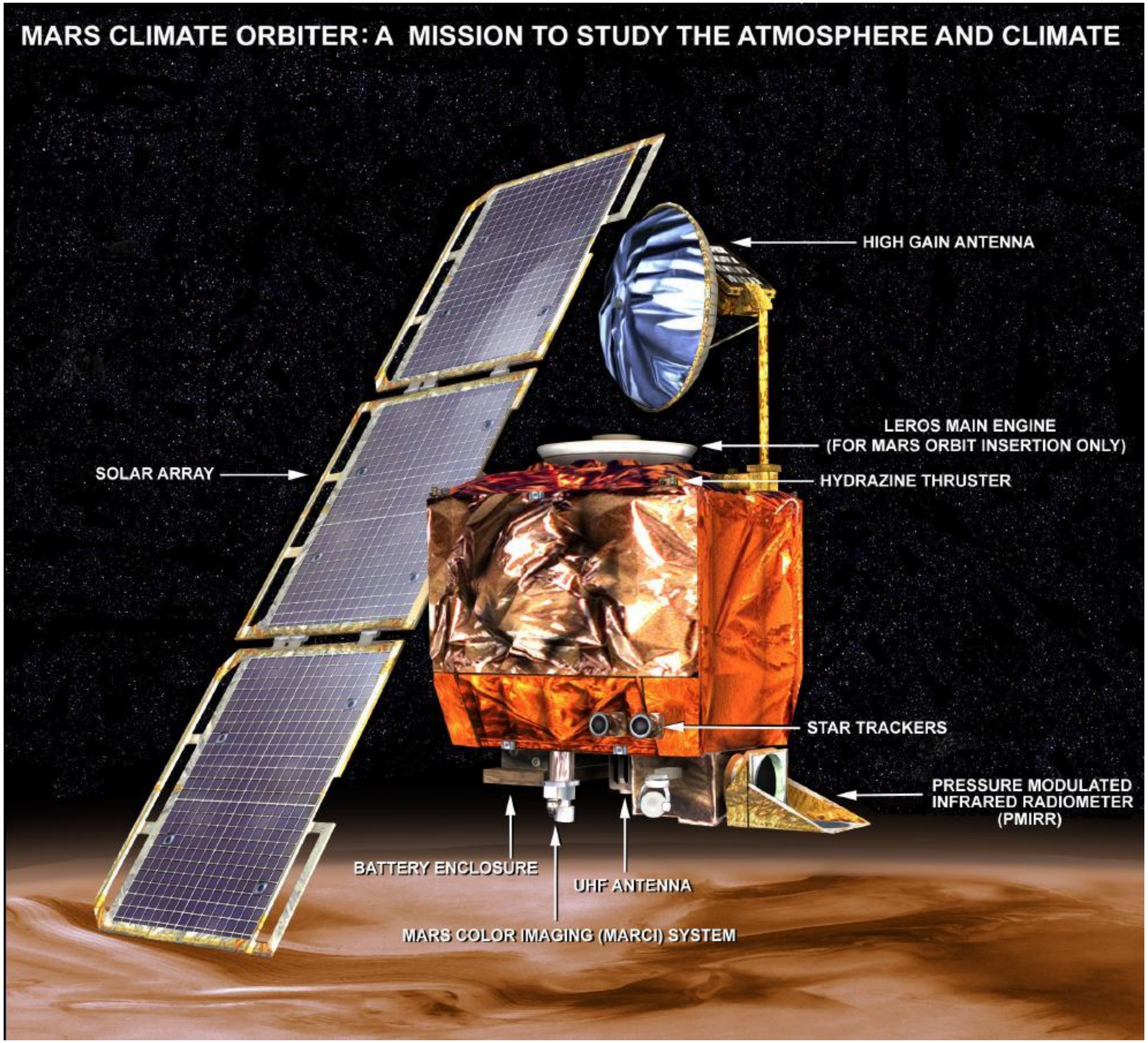
Weight	1 kg
Dimensions	**10 cm x 10 cm x 10 cm**
Power	**1 W**
ADCS	Passive (permanent magnets and hysteretic materials)
Propulsion	None
Communications	145 MHz + 435 MHz (Ham radio bands)
Orbit	LEO, 660 x 450 kms, i= 98°
Launch vehicle	Soyuz


THEY ALL
LOOK
DIFFERENT !!!

They Are All Different !

Weight	A few kgs → several tons
Dimensions	A few cms → several meters
Power	A few watts → several kW
ADCS	Many options
Communications	High gain, low gain UHF, X, S, Ku bands A few cms → several meters
Orbit	LEO, Halo orbit, asteroid pursuit, Martian, space exploration
Launch vehicle	Soyuz, STS, Delta II, Titan III, Atlas II

Failures Are Common ! Celebrated Example



Due to a navigation error, Mars Climate Orbiter was lost. The error arose because Lockheed Martin used imperial units instead of metric units as specified by NASA

The Launch Vehicle May Also Fail !

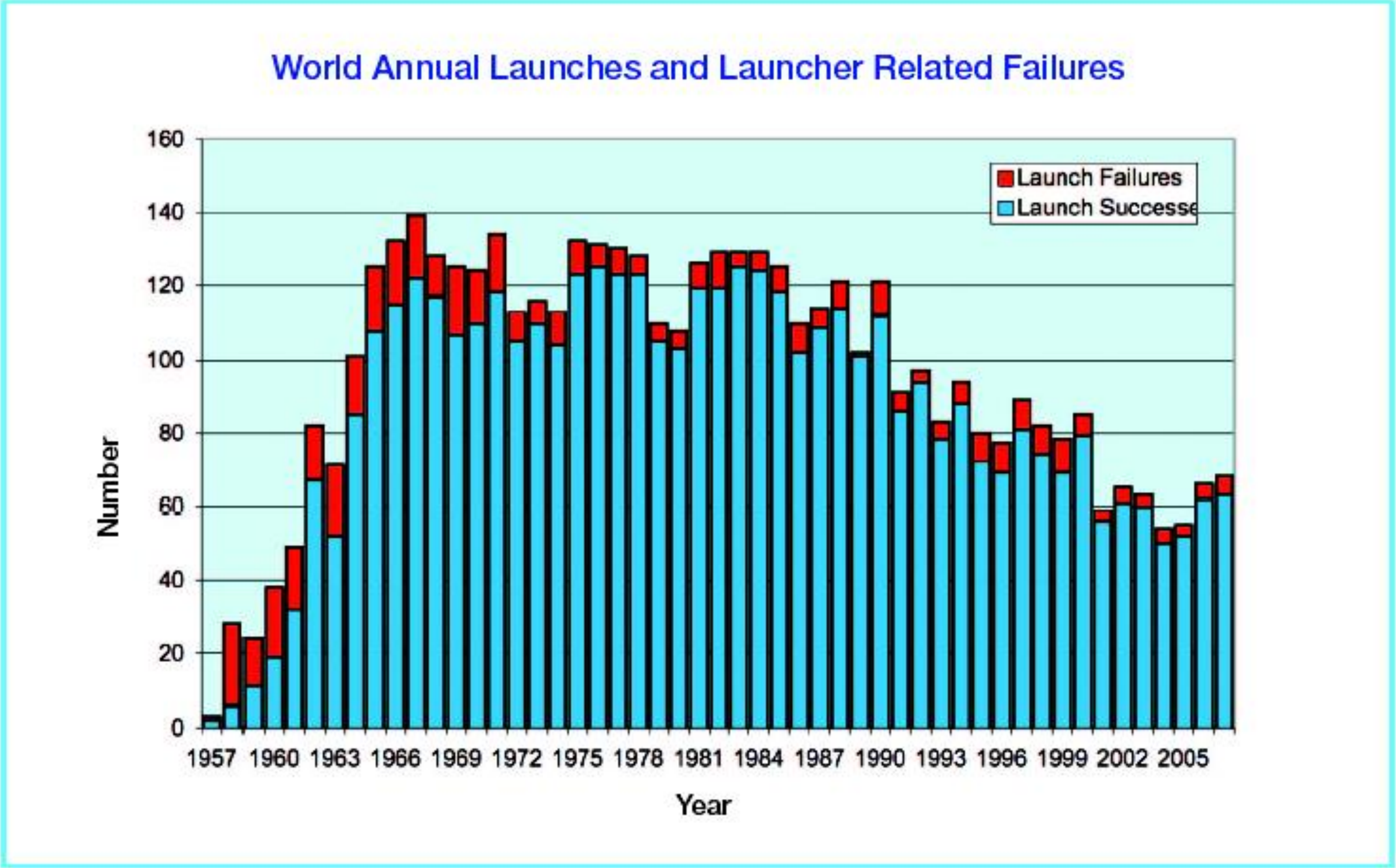
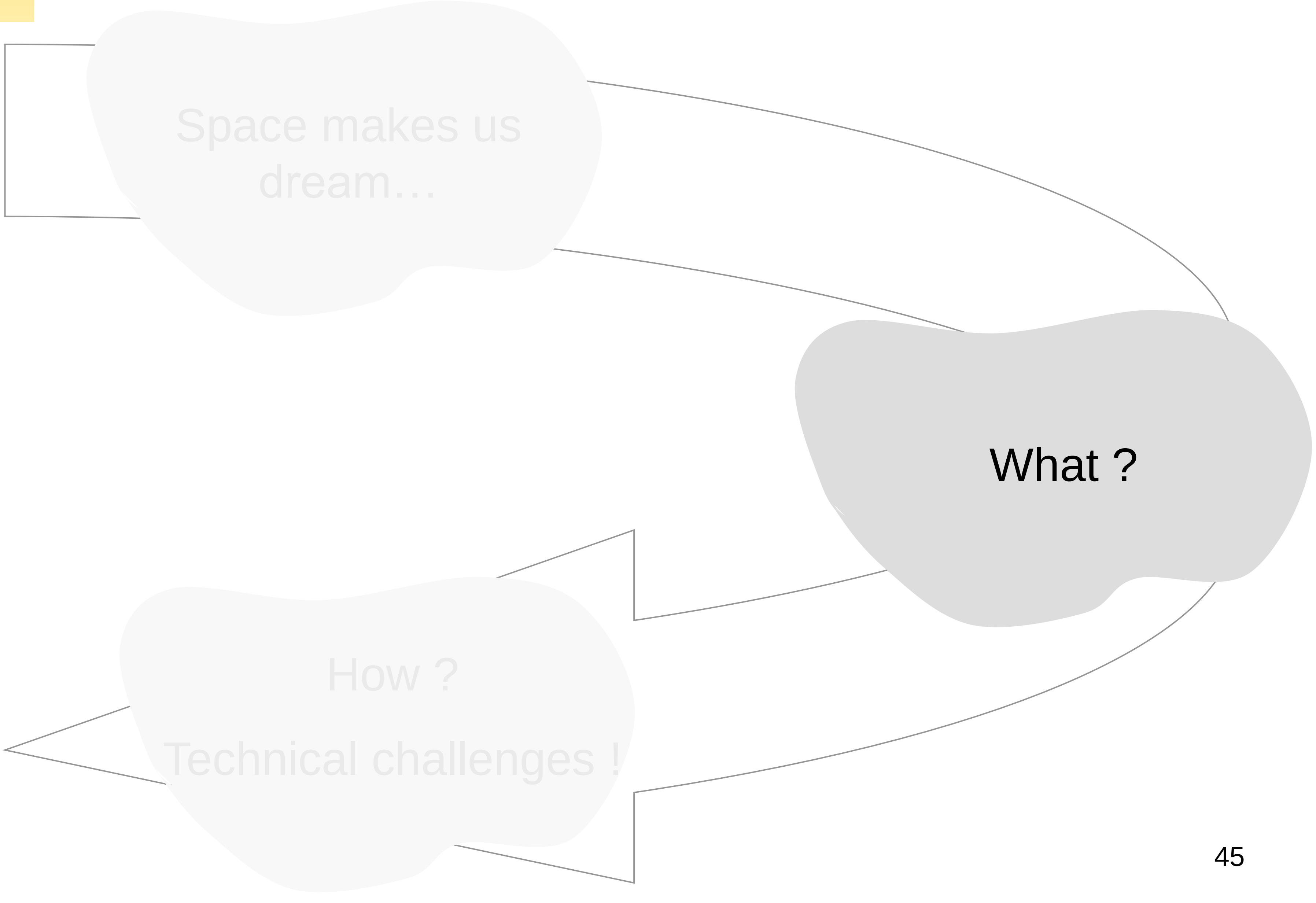
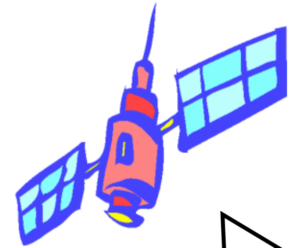


Chart 2: **Orbital launch attempts since 1957.** Source: Ascend Space Review

From Dreams to Technical Challenges

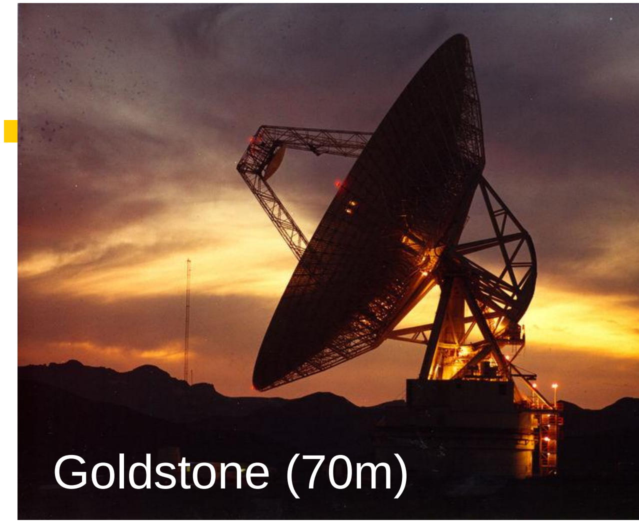


An Element Within a Larger System



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

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


Goldstone (70m)

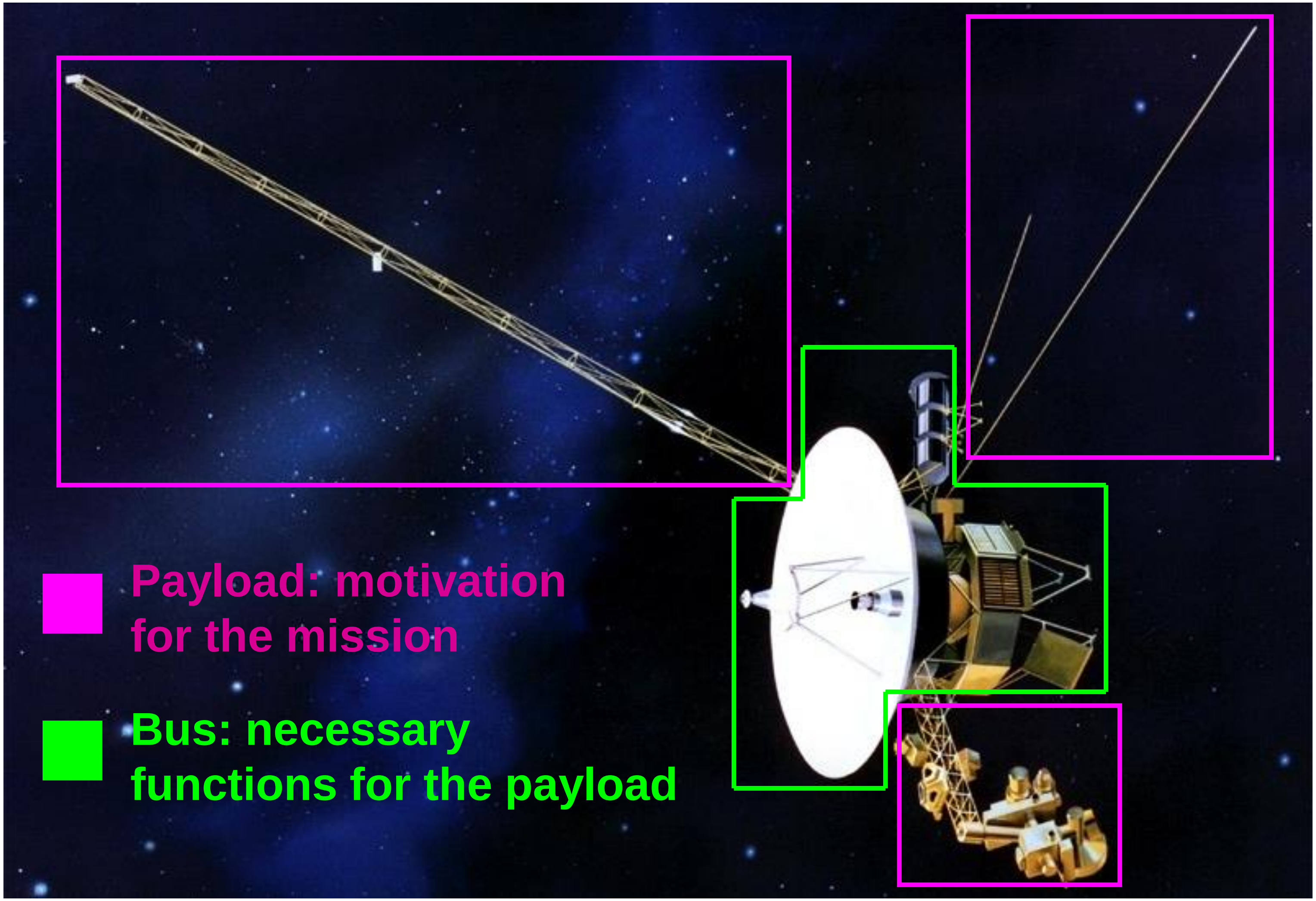
Madrid (70m)

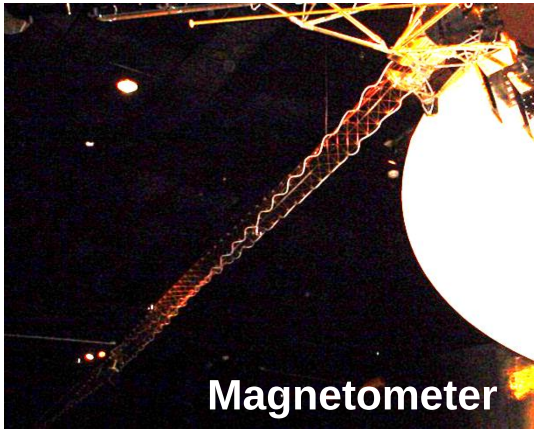

Canberra (70m)

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

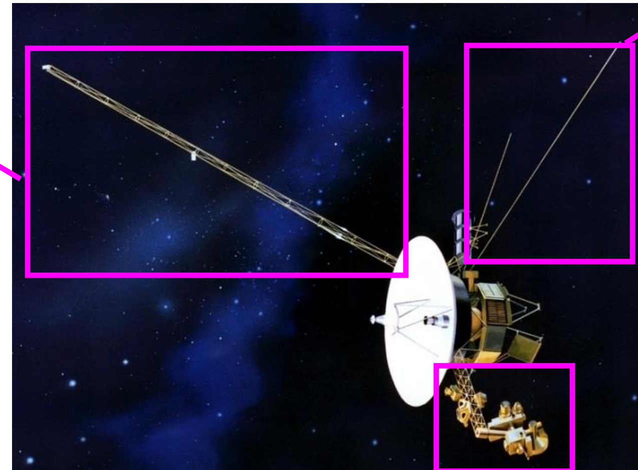

ESA Redu ground station (Belgium)

A Satellite Comprises Two Main Elements

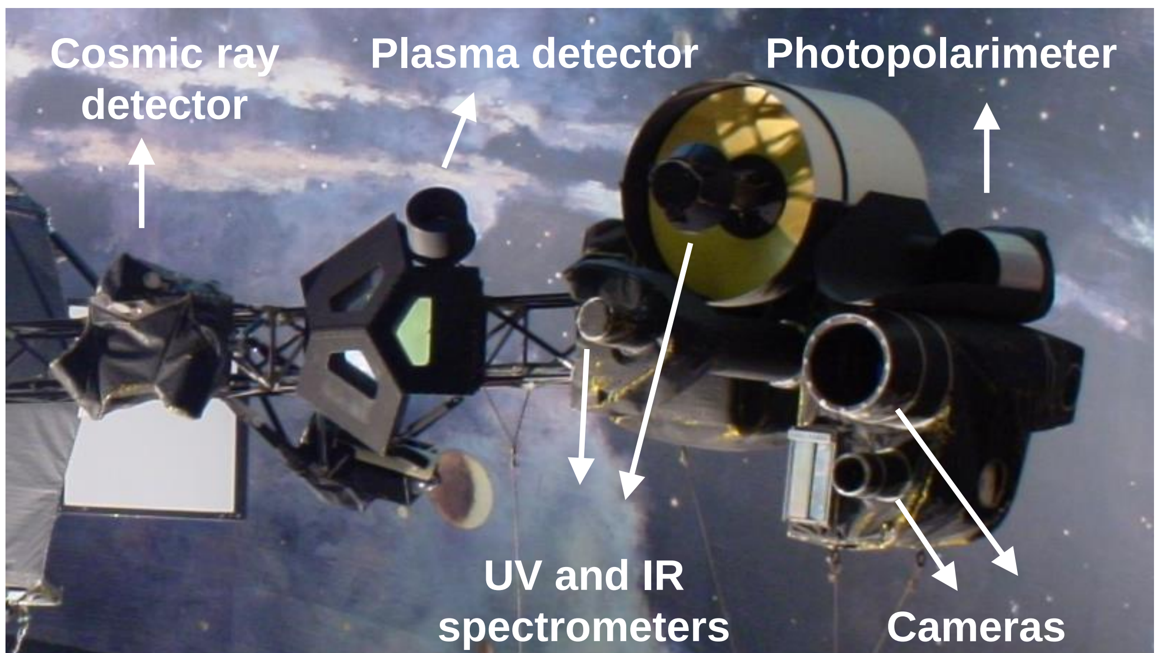




Antennas: planet radio emissions

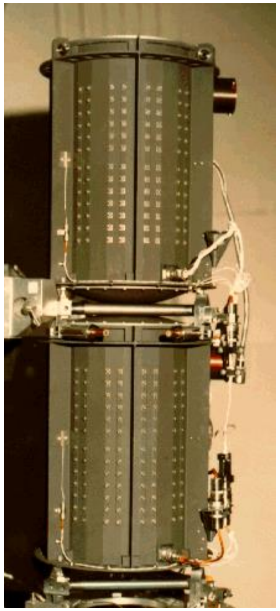


PAYLOAD



Bus: Complex Assembly of Subsystems

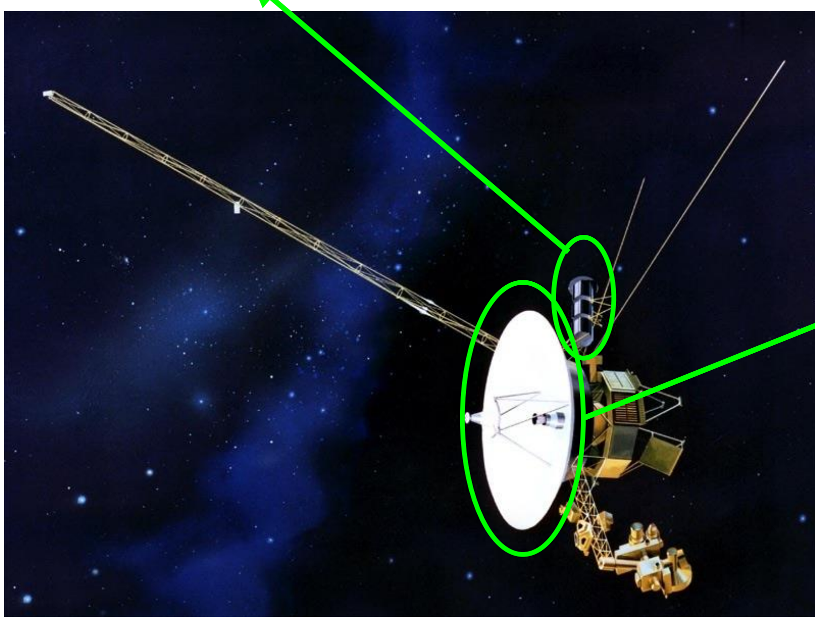
STRUCTURE & MECH.	Withstand launch and orbit loads + properly deploy and run mechanisms
PROPULSION	Spacecraft maneuvers and trajectory
THERMAL CONTROL	Withstand temperatures imposed by the harsh space environment
TELECOMMUNICATIONS	Communicate and exchange information with ground
ATTITUDE CONTROL	Ensure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

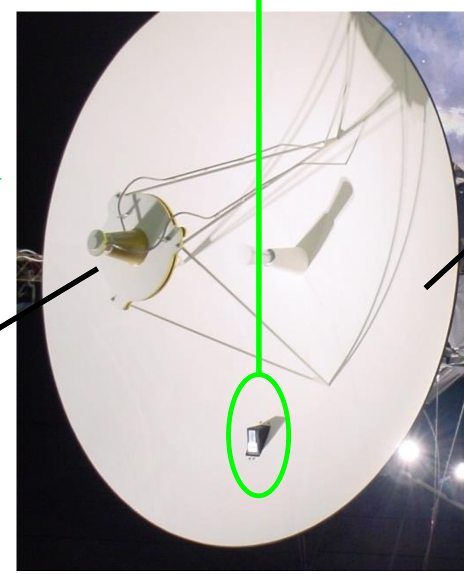


POWER

Radioisotope thermoelectric generator (RTG)

ATTITUDE CONTROL





High-gain antenna

Low-gain antenna

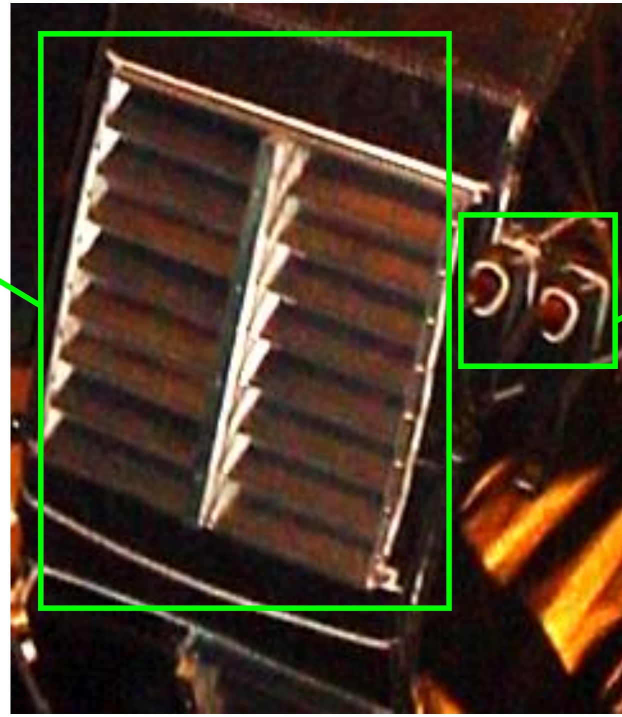
TELECOMMUNICATIONS

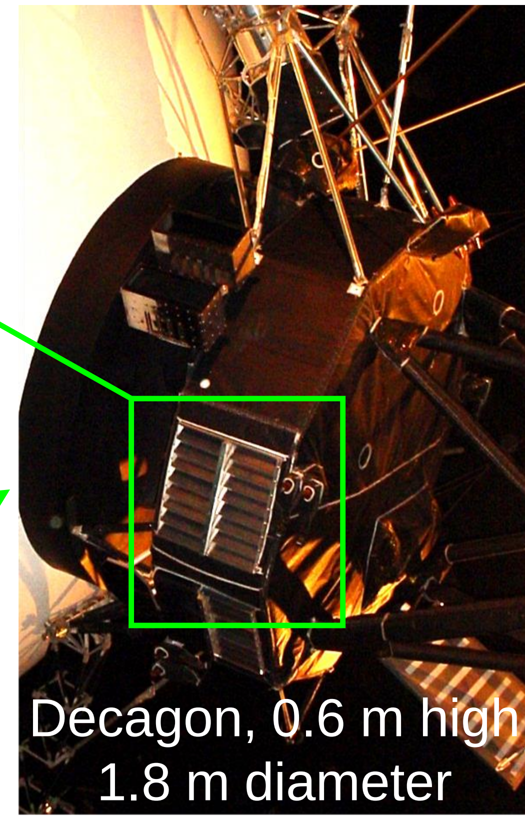
Louvers

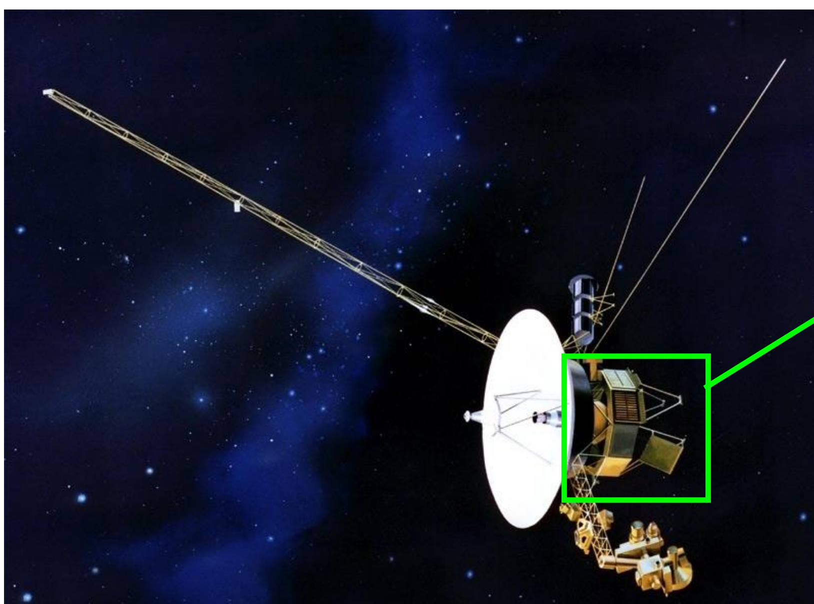
THERMAL CONTROL

N_2H_4 thrusters

PROPULSION

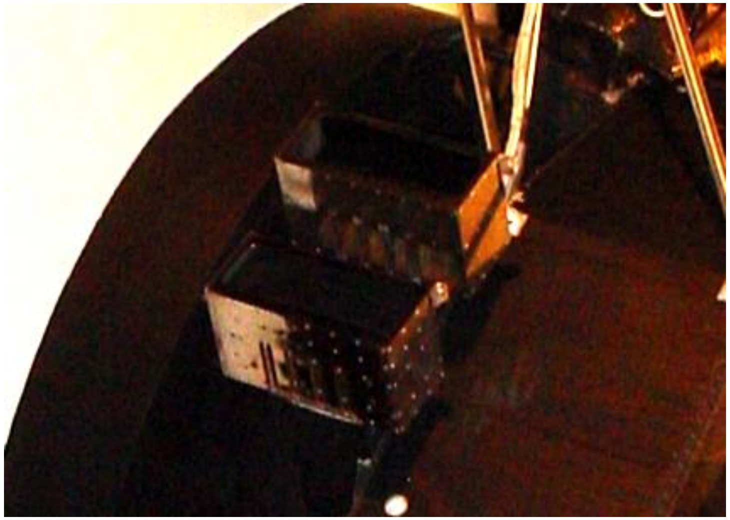




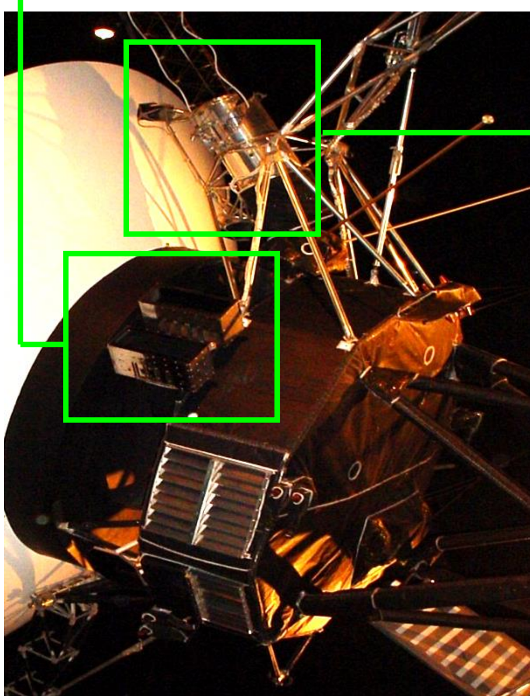


STRUCTURE

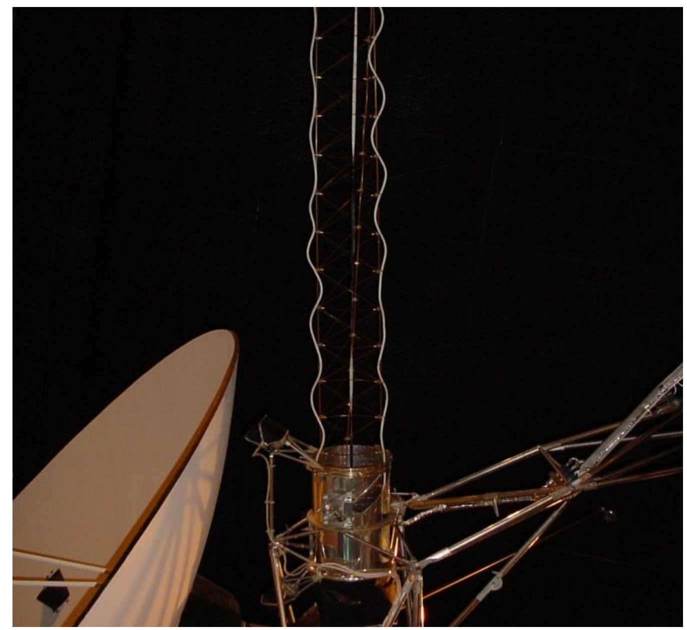
ATTITUDE CONTROL



Star tracker

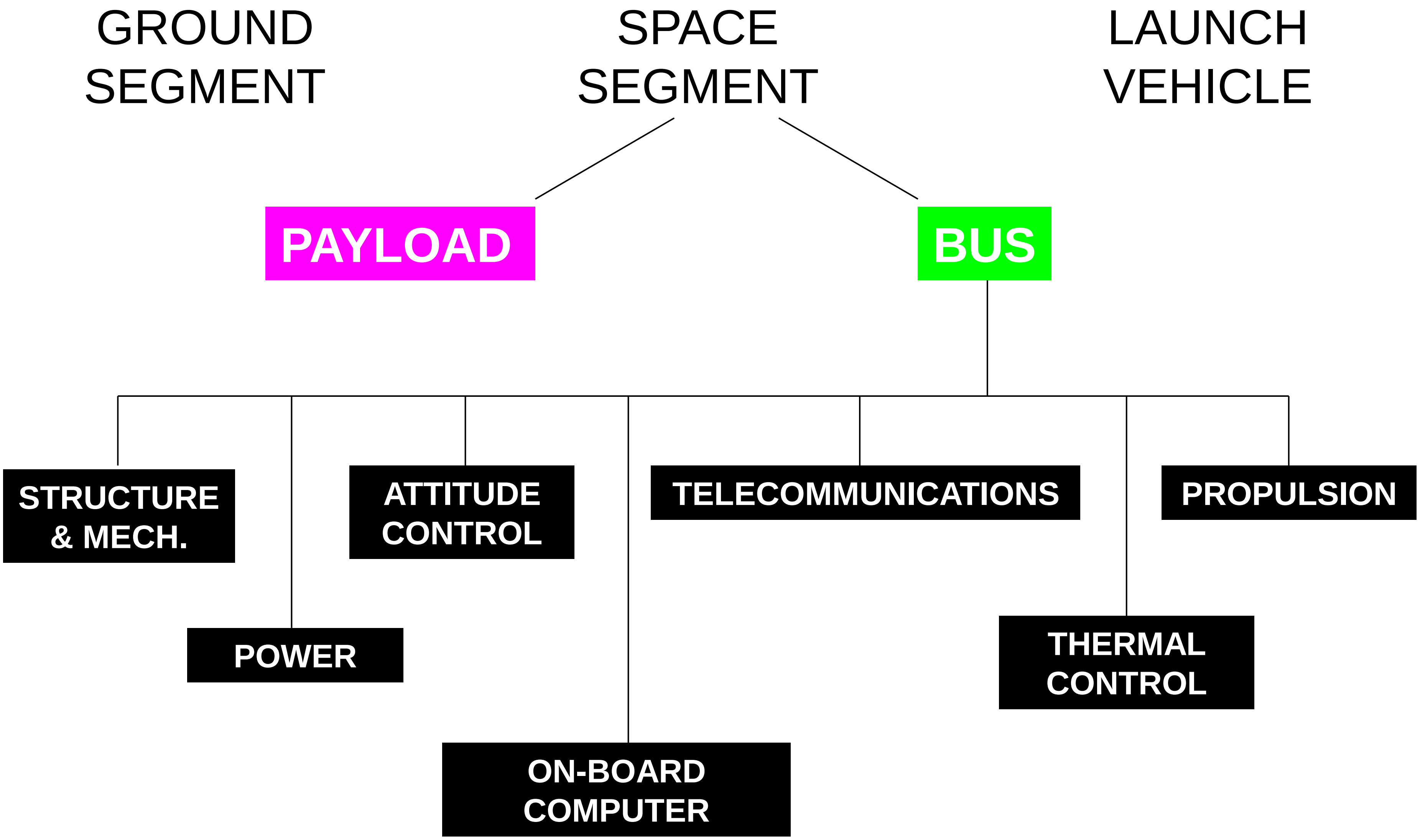


MECHANISMS

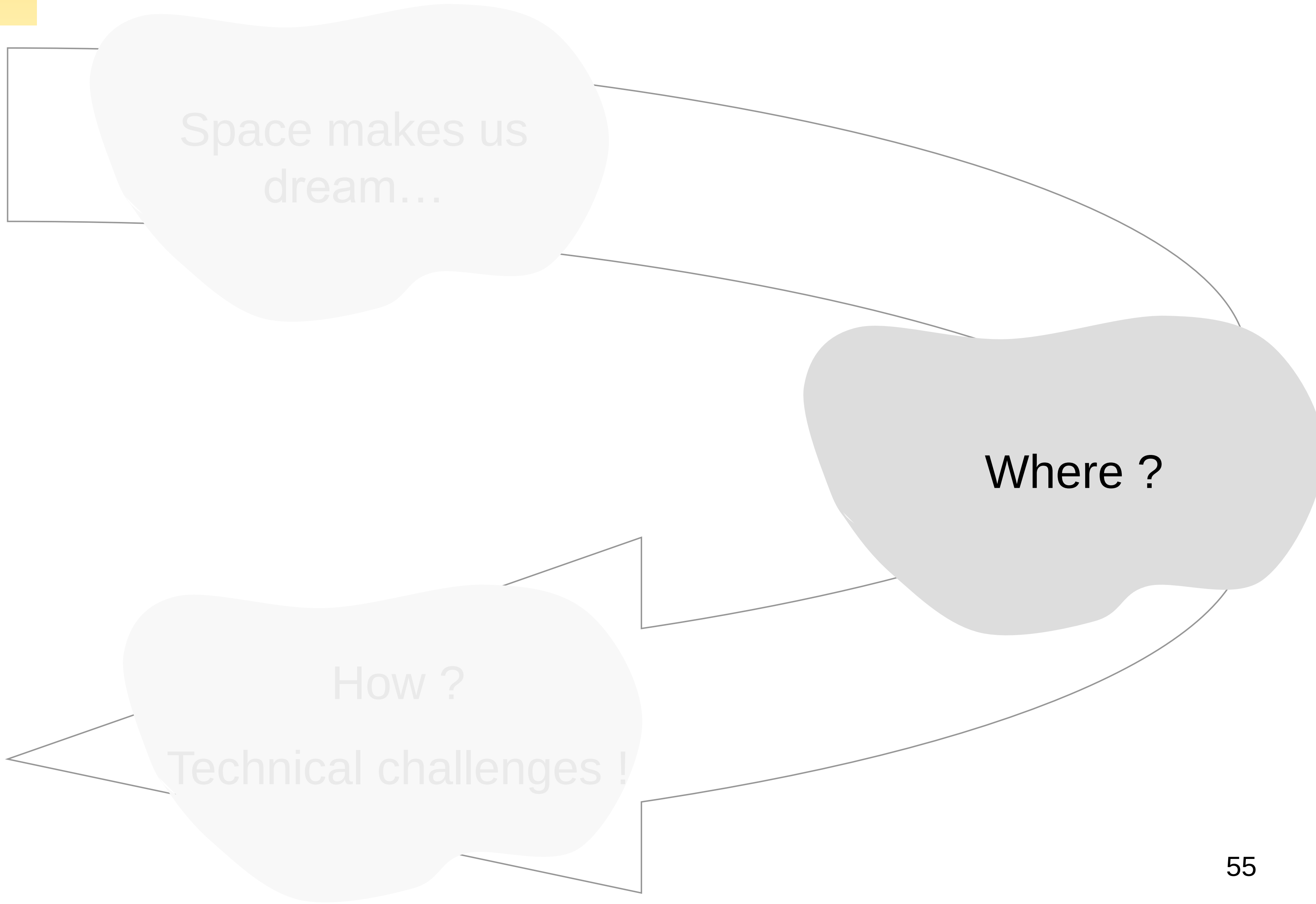


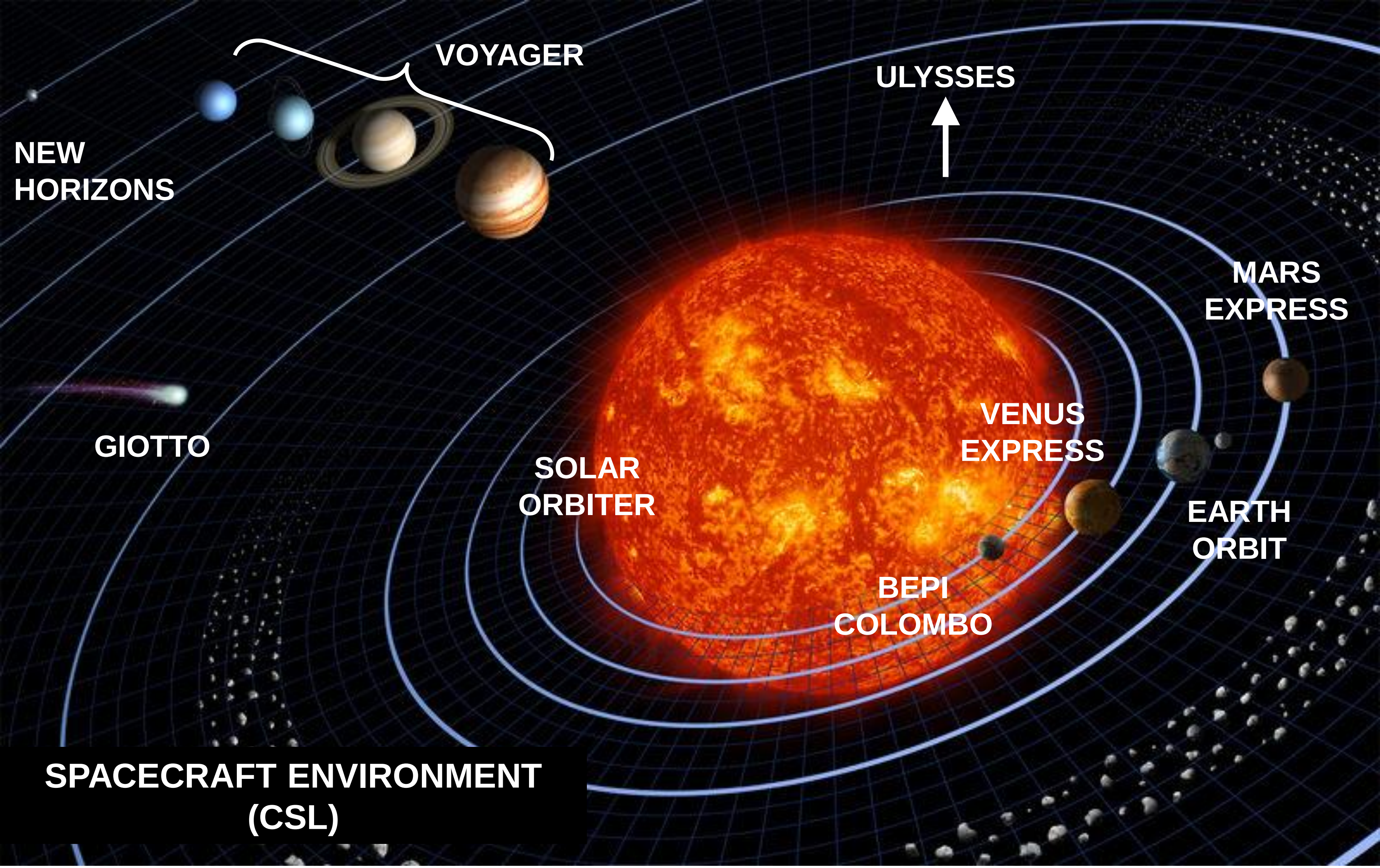
Box containing a deployable truss on which the magnetometer is mounted

In Summary


GROUND SEGMENT
SPACE SEGMENT
LAUNCH VEHICLE
PAYLOAD
BUS
STRUCTURE & MECH.
POWER
ATTITUDE CONTROL
ON-BOARD COMPUTER
TELECOMMUNICATIONS
THERMAL CONTROL
PROPULSION

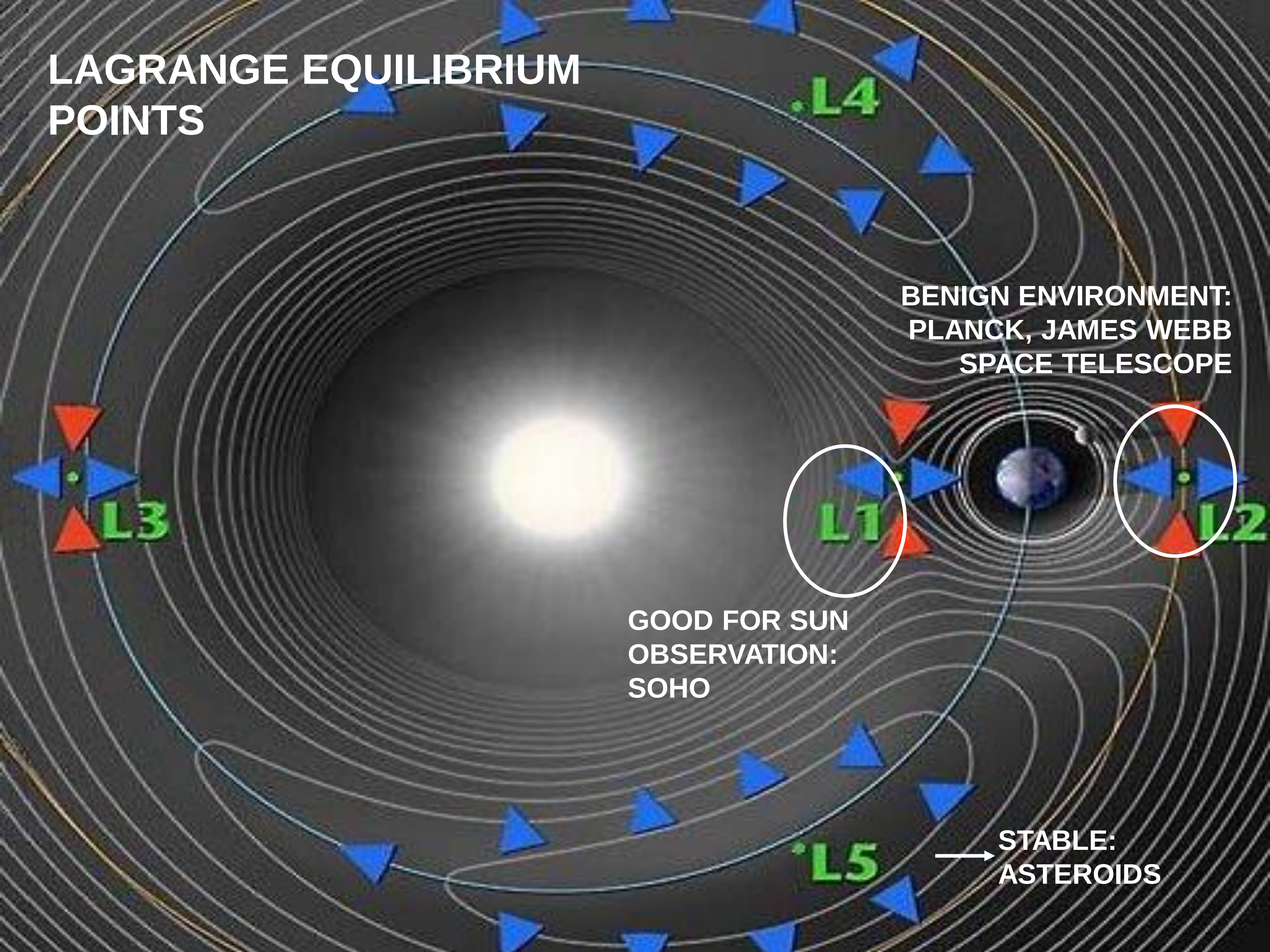
From Dreams to Technical Challenges

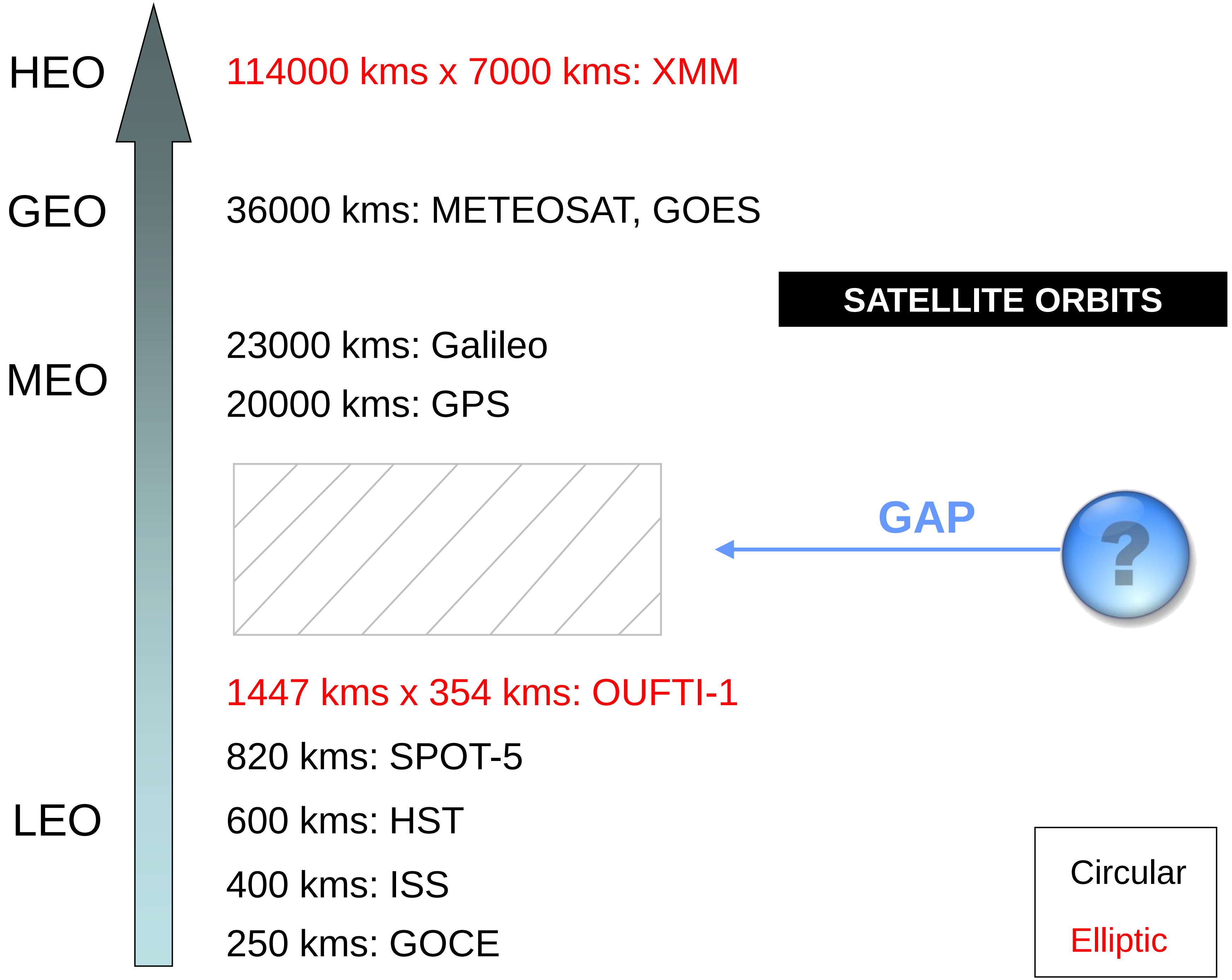




Severe constraints (magnetic field, temperatures, atmosphere, launch vehicle, ground station visibility, eclipse duration)

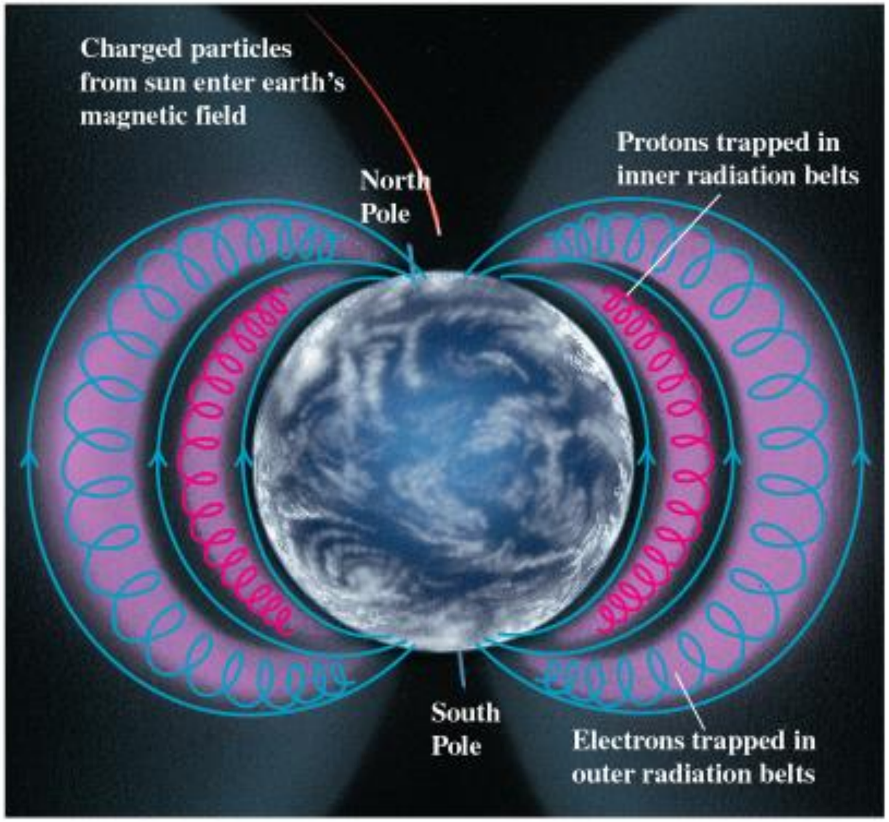
LAGRANGE EQUILIBRIUM POINTS



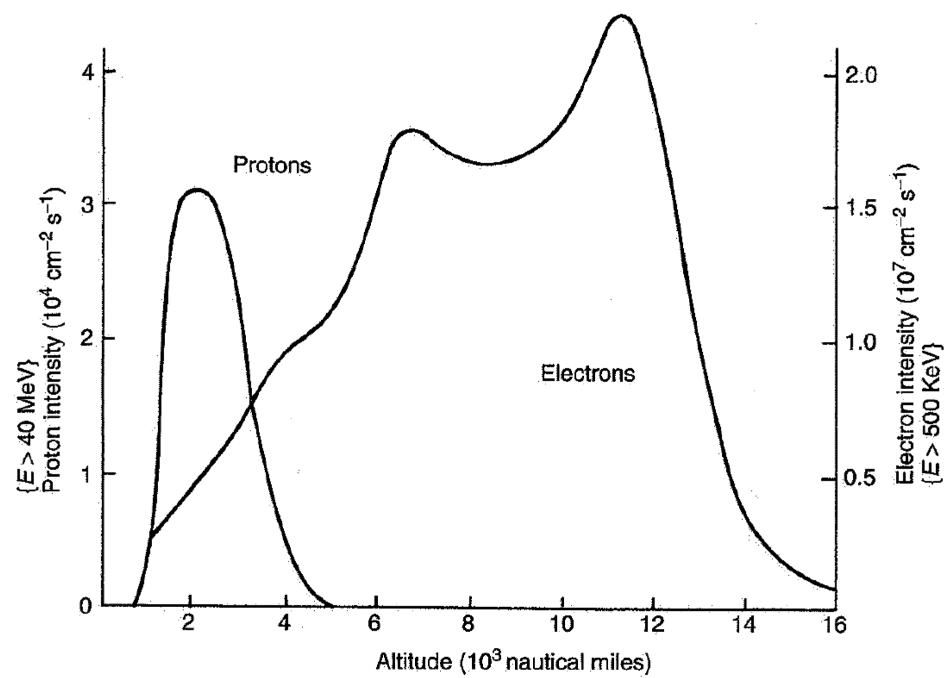


HEO
114000 kms x 7000 kms: XMM
GEO
36000 kms: METEOSAT, GOES
SATELLITE ORBITS
MEO
23000 kms: Galileo
20000 kms: GPS
GAP
1447 kms x 354 kms: OUFTI-1
820 kms: SPOT-5
LEO
600 kms: HST
400 kms: ISS
250 kms: GOCE
Circular
Elliptic

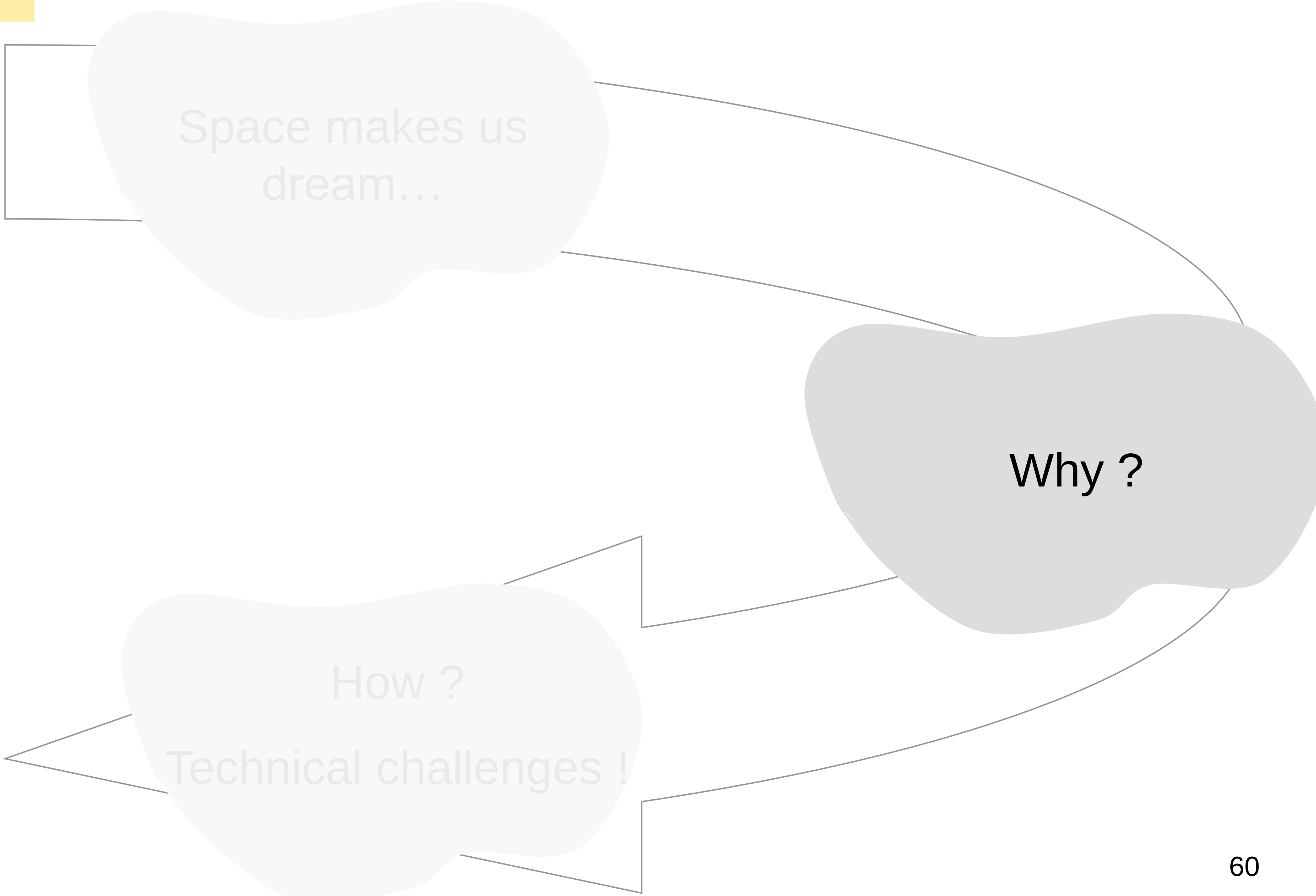
Gap ? Van Allen Belts



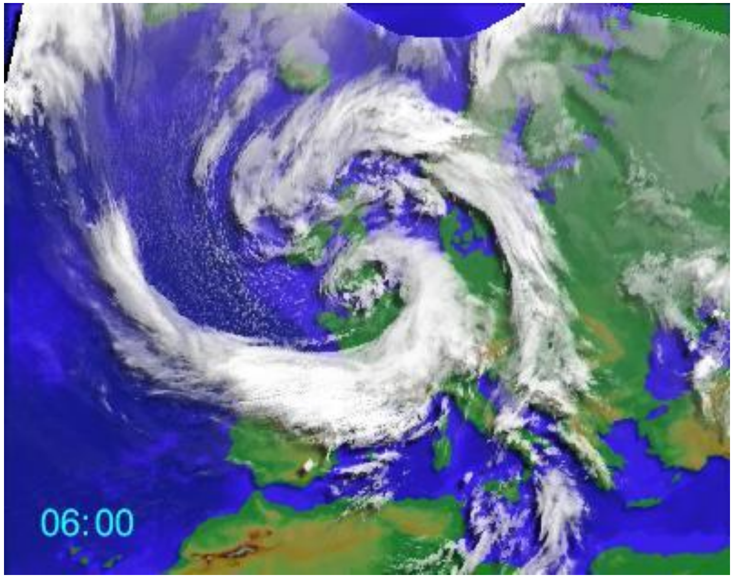
SPACECRAFT ENVIRONMENT



From Dreams to Technical Challenges



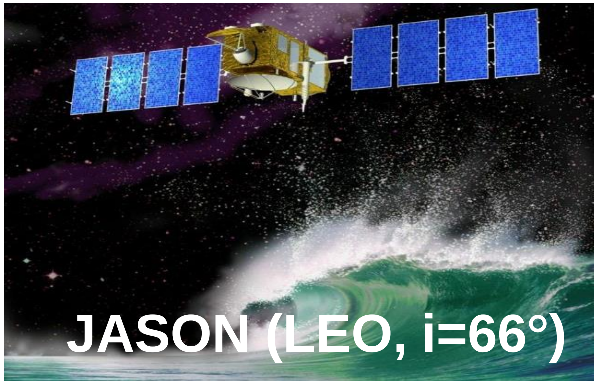
Earth Observation: Weather Satellites



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

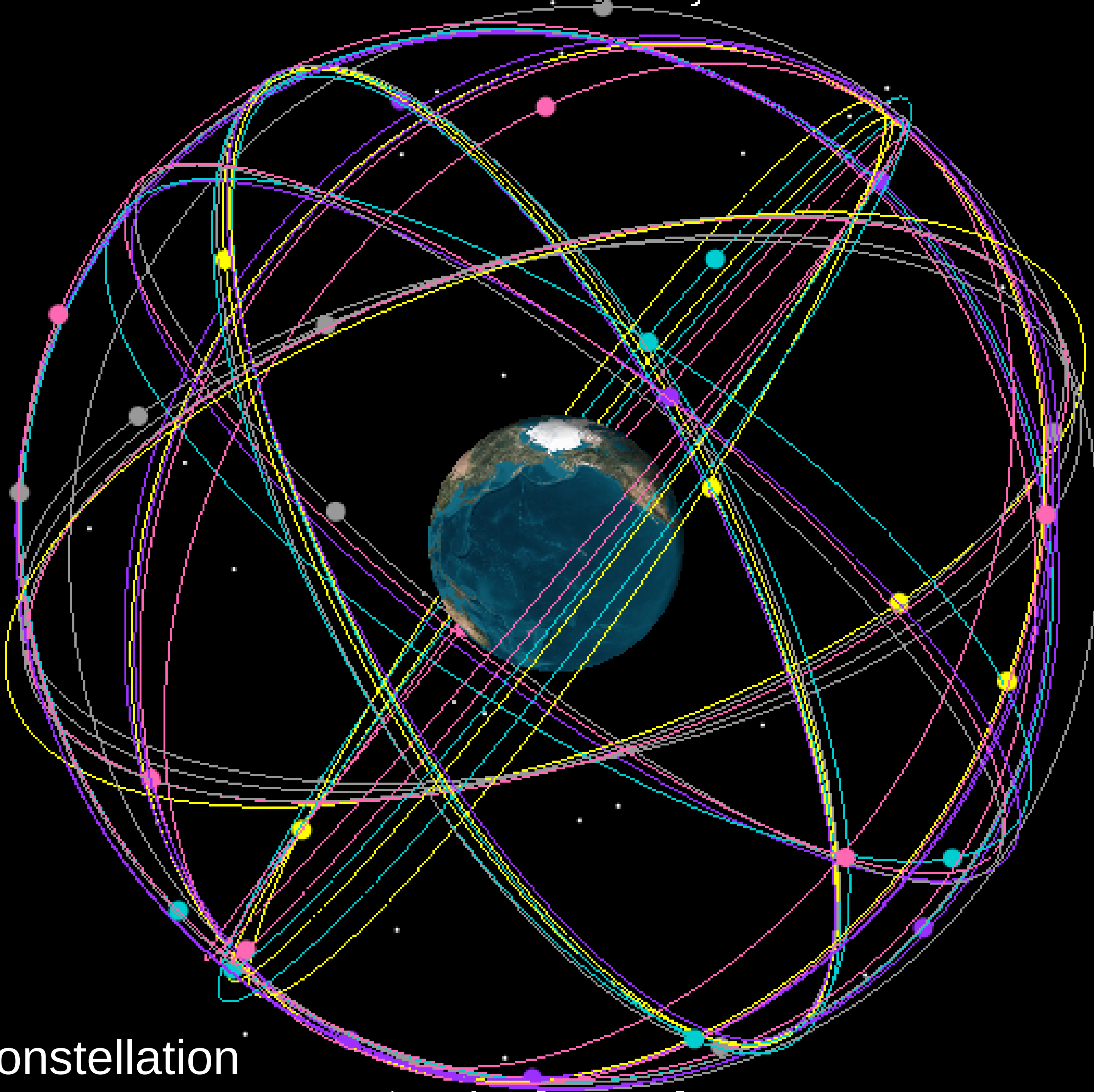
Communications and Navigation

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

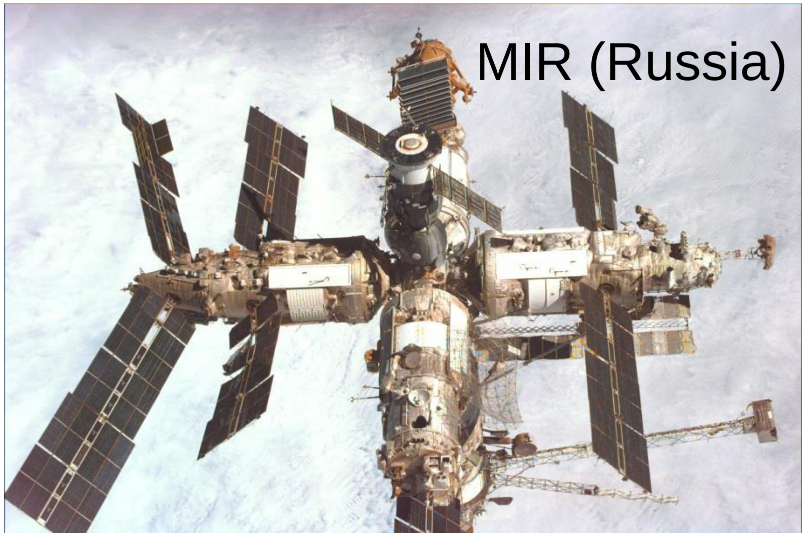
Too many examples !

- 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 Stations

Perform science experiments under microgravity conditions

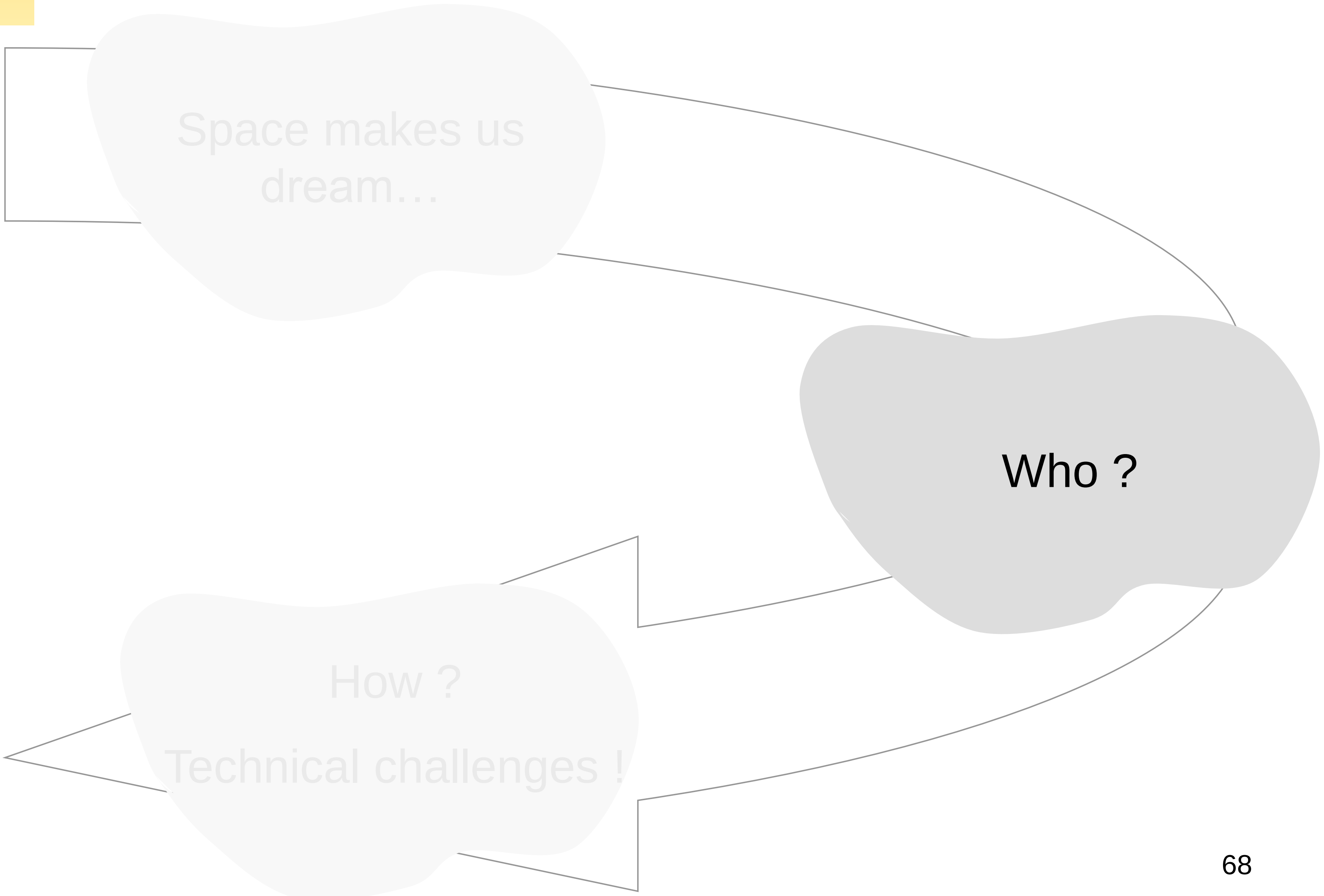


Space Tourism: Inflatable Hotel !

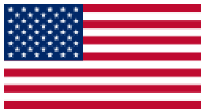
Experimental space habitat — GENESIS 1

http://www.bigelowaerospace.com/

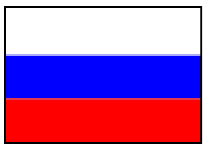
From Dreams to Technical Challenges



Key Players



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



Roscosmos, Energia

ESA,
CNES, DLR, ASI,
EADS-Astrium, Arianespace,Thales Alenia Space

Two emerging countries

Belgium ? A Truly Strong Expertise !

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

Euro Space Center and ESA Redu ground station

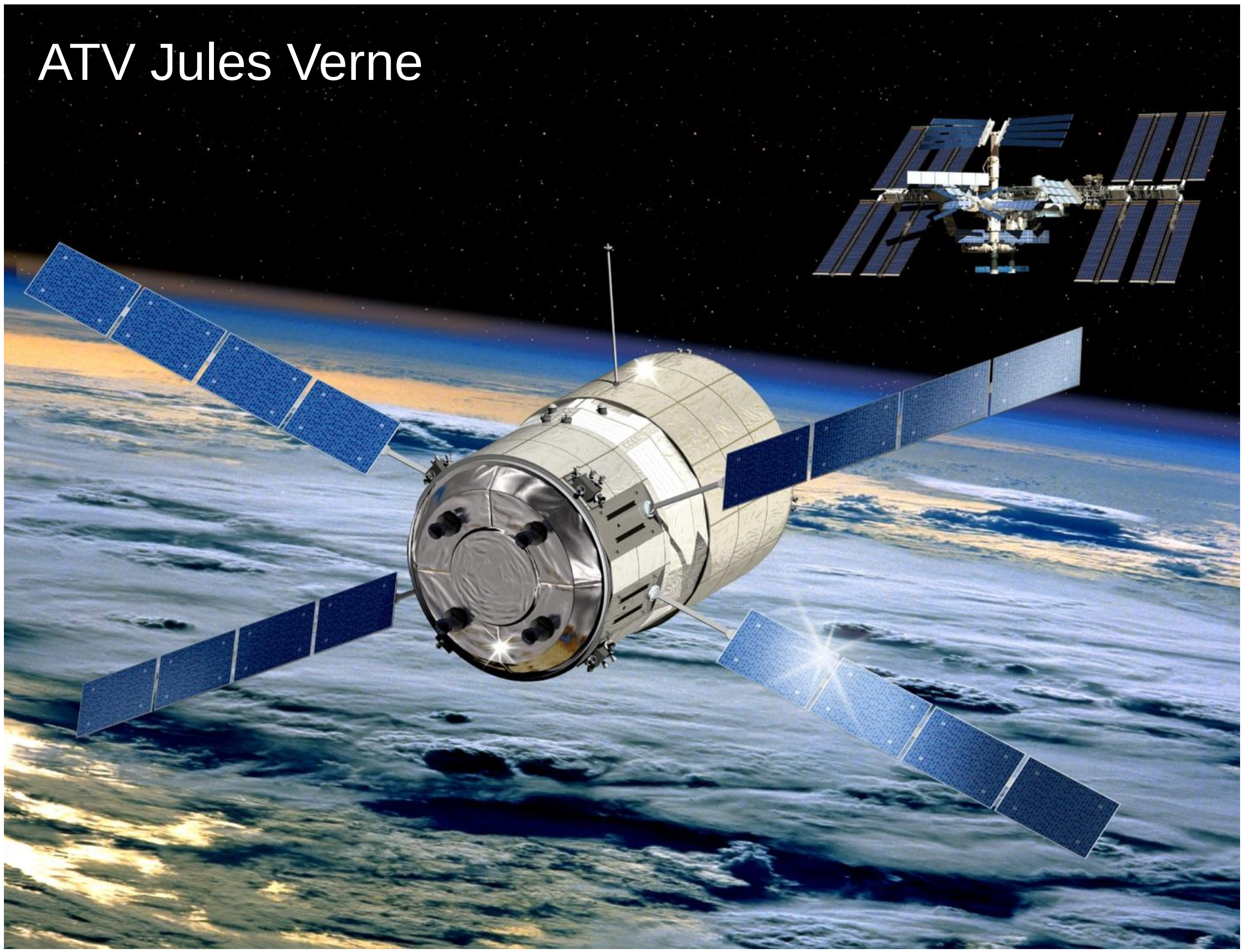
ULiege: 2 unique Masters + LTAS & AGO

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

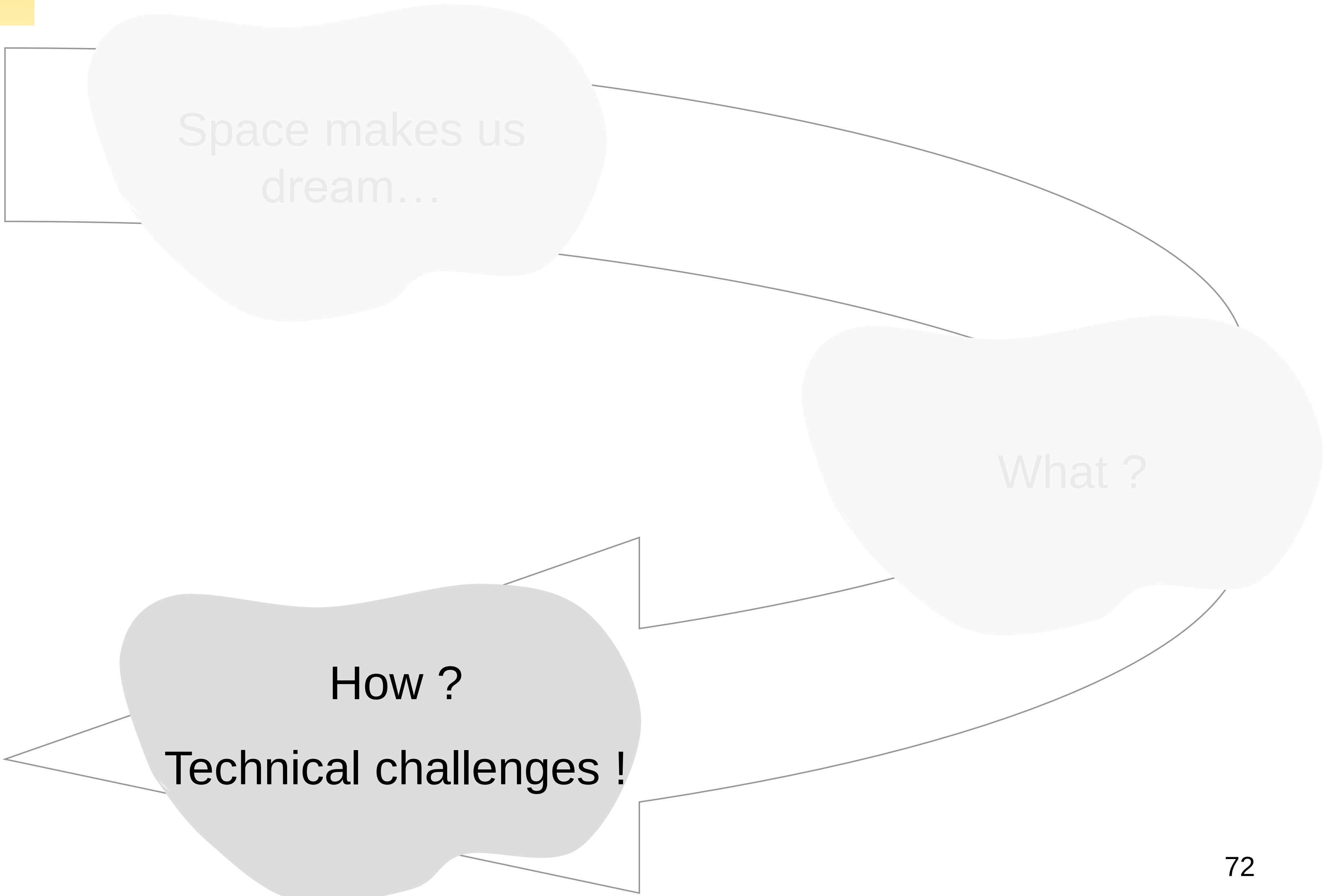
Spacebel: software

Rhea: software

Redu: backup ground station

Techspace aero: aestus engine valves

From Dreams to Technical Challenges



Satisfy Customer's Basic Goals

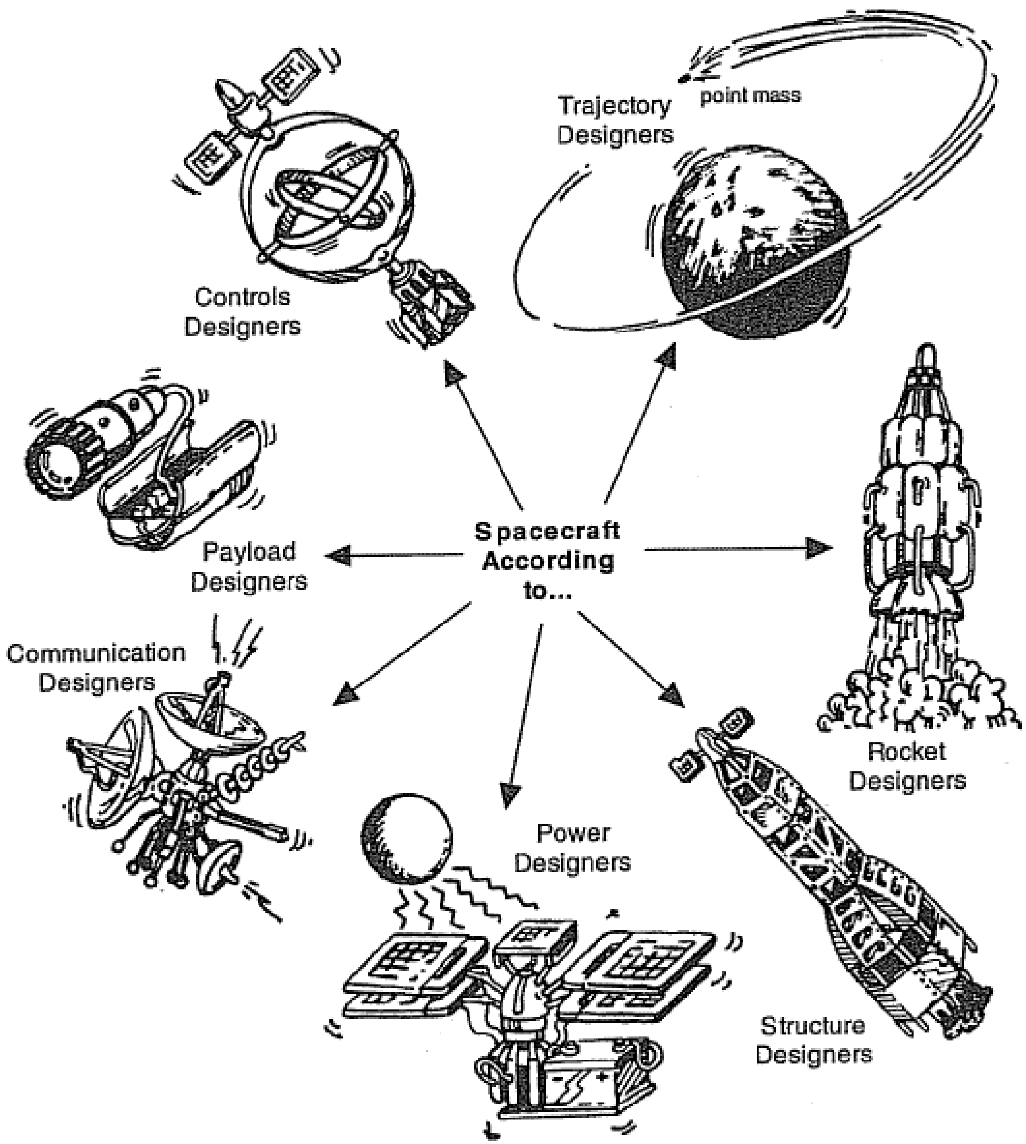
1. Payload design

2. Mission analysis (orbit design and environment)

3. Bus design

But the design of a satellite is associated with a number of ***unique challenges.***

Challenge #1: Multidisciplinary Design



Challenge #1: Voyager Example

Deep space mission

POWER USING NUCLEAR MATERIALS → POLITICAL PROBLEM

↓

ELECTRONICS (RADIATION)

↓

BUS (ADEQUATE CONFIGURATION)

Solution: Multidisciplinary Design

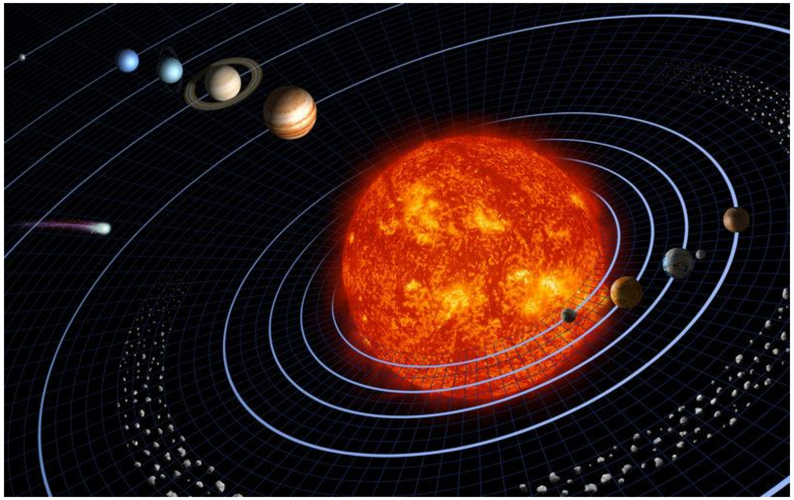
Look for the optimal solution for the entire spacecraft
(do not look for the optimal solution for your subsystem)

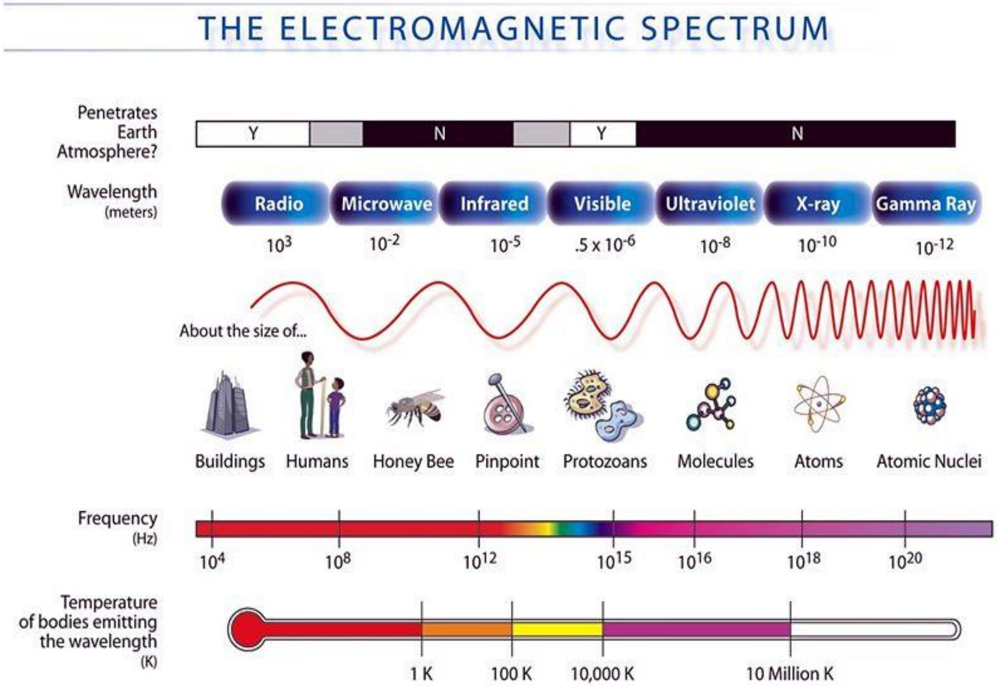
This course is intended to give you an overview of the different subsystems, so that you will understand the challenges faced by your colleagues who are expert in power systems telecommunications, etc

Concurrent Design Facility, ESTEC-ESA

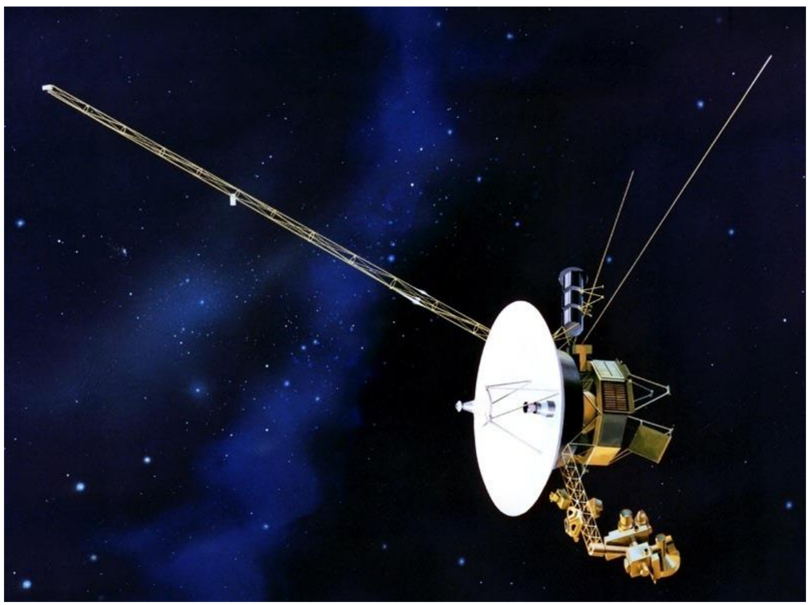
Challenge #2: Each Mission is Unique

Where ? & Why ?





Solution: Fit the Requirements



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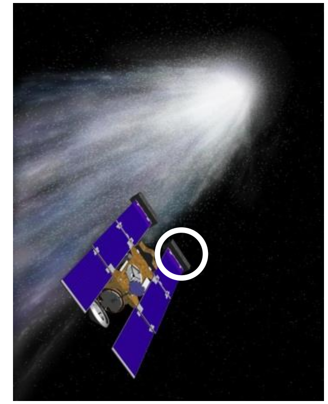
Solution: Fit the Requirements

Roll-out

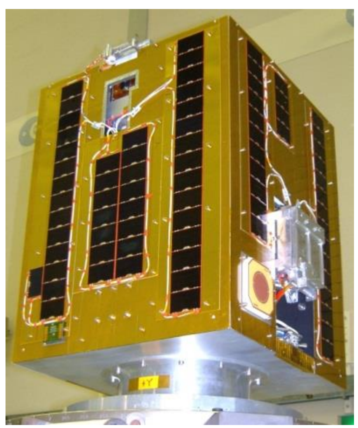
Hubble



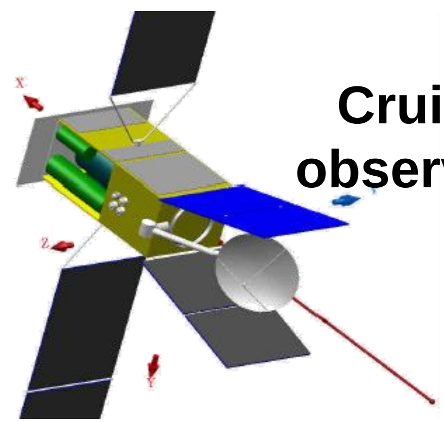
Whipple shield

Stardust

Body mounted



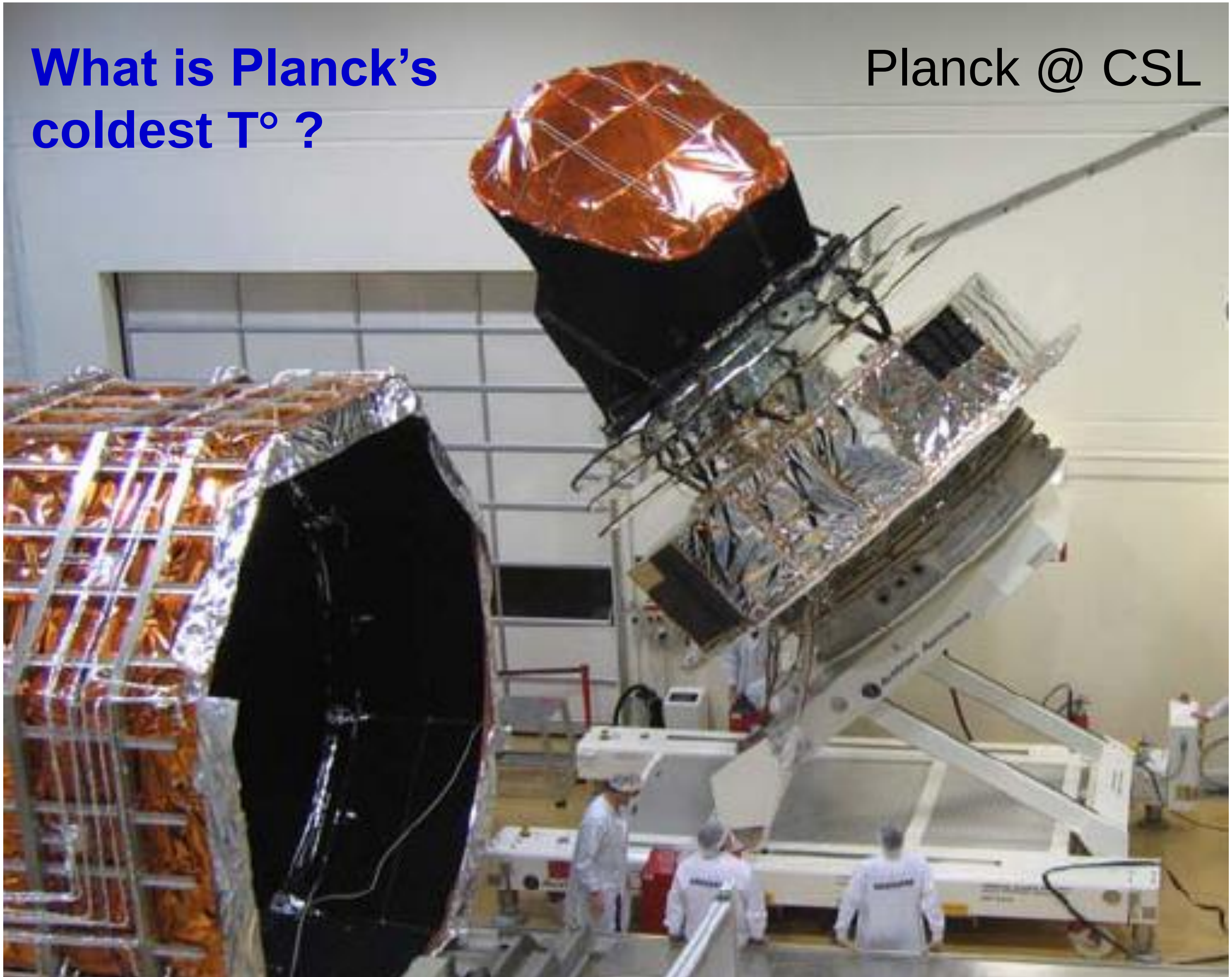
SSETI Express



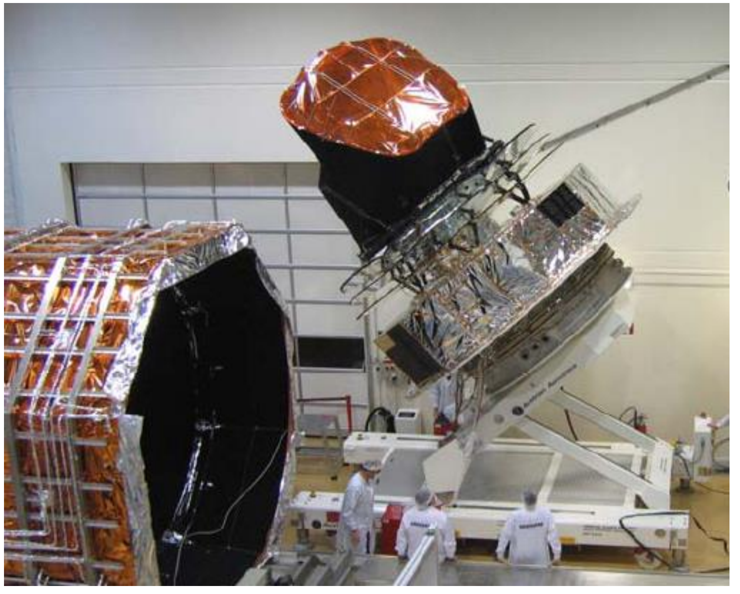
Cruise & observation

Solar Orbiter

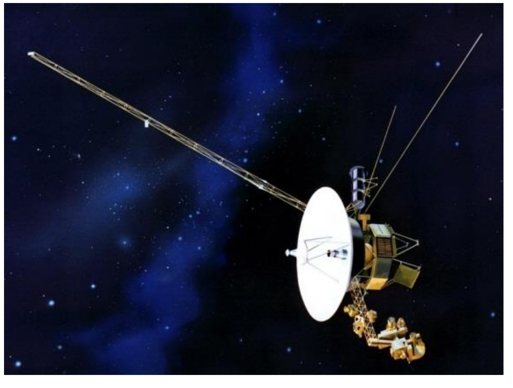
Challenge #3: Orders of Magnitude



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

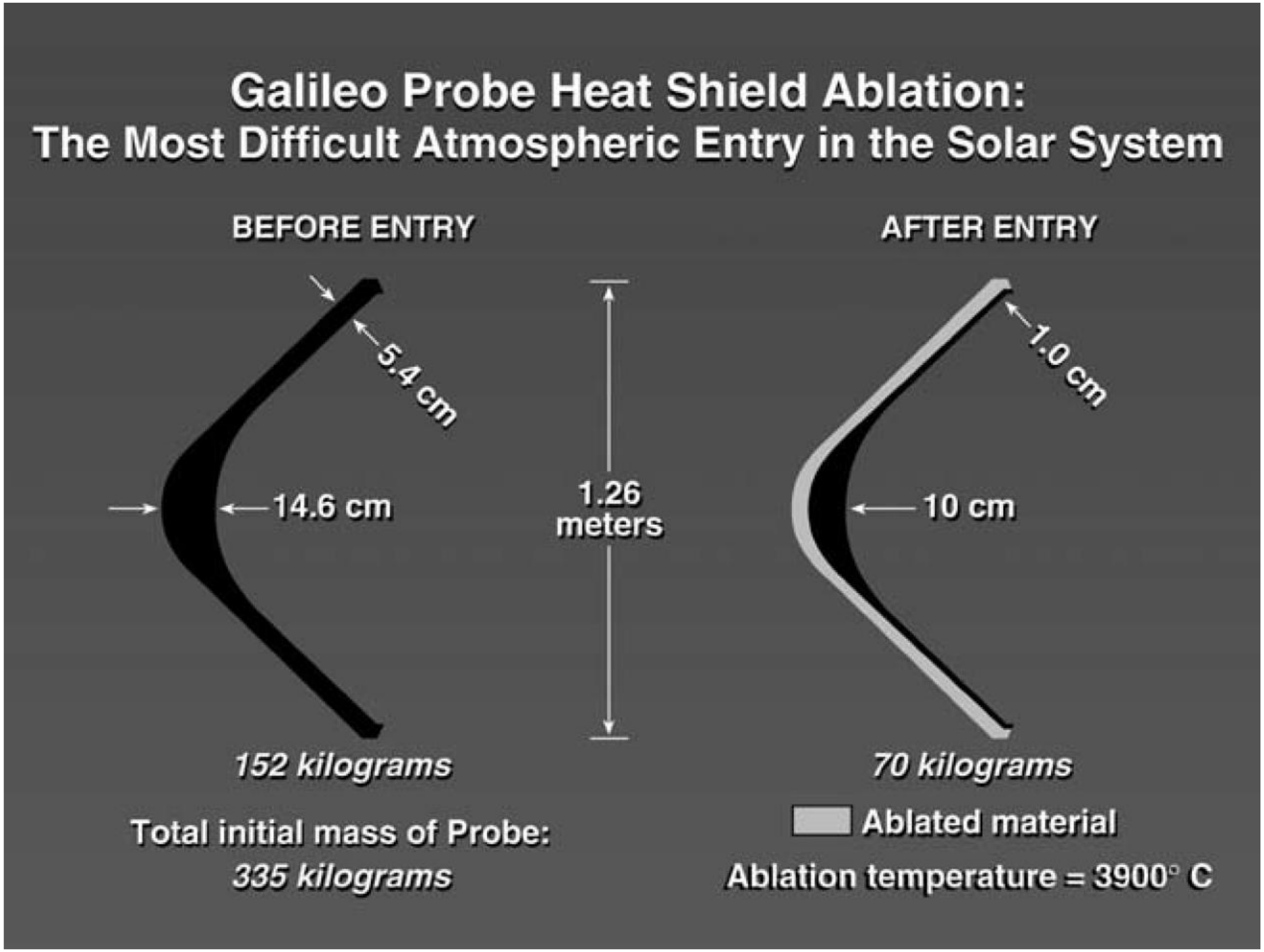


15.000.000.000 kms

10^{-16} W

0.007”

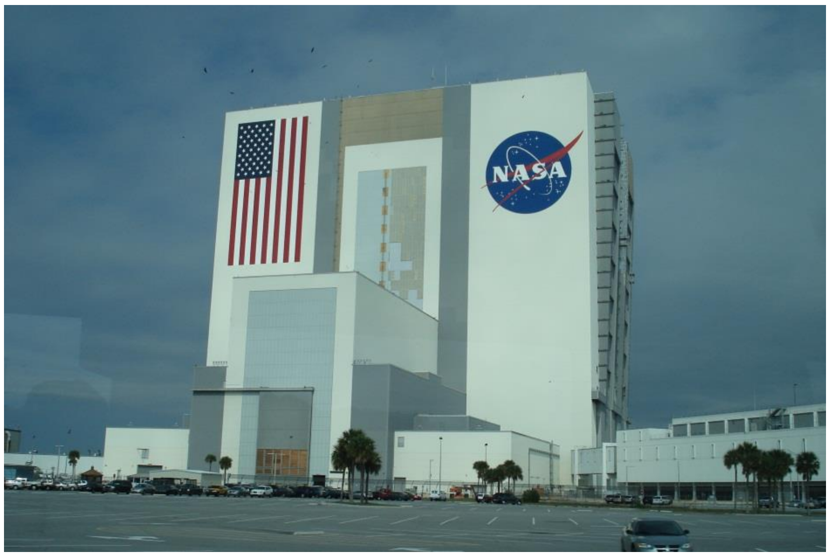
Challenge #3: Orders of Magnitude



171.000 km/h ⇒ 1.600 km/h in 2 minutes

Challenge #3: Not Only the Satellite…

Challenge #3: Not Only the Launcher…



Vehicle assembly building (KSC): 3.5 times the volume of the Empire State building

Largest self powered land vehicle in the world

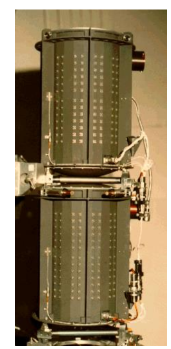
Solution: The Engineer Must Be Creative

15.000.000.000 kms

Power: 15W/m^2 (Saturne)

Communications: 10^{-16} W

70-meter antenna



Nuclear materials

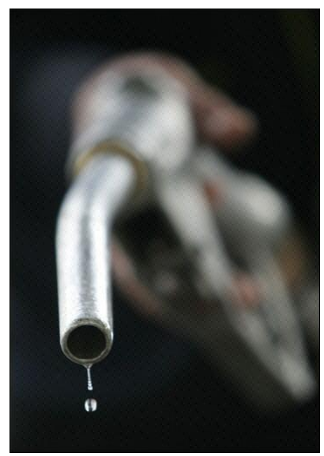
Challenge #4: Severe Constraints

25000 €/kg
Weight
Volume

January

Su	Mo	Tu	We	Th	Fr	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	**16**	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

Planning (Voyager: once every 176 years)



Fuel

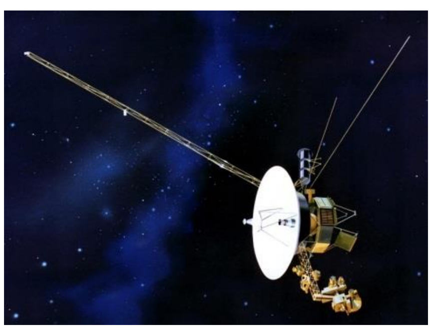
Power
(Voyager: 470 W)

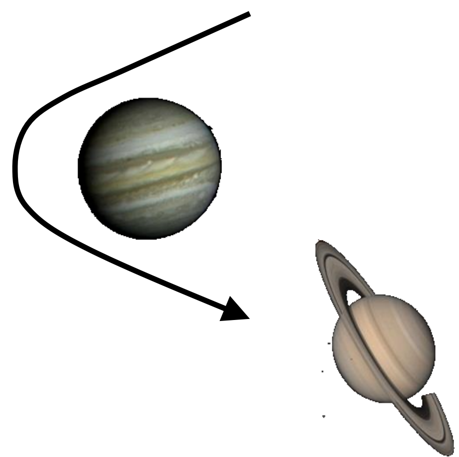
Solution: The Engineer Must Be Creative

Limited volume

Deployable boom (Voyager)

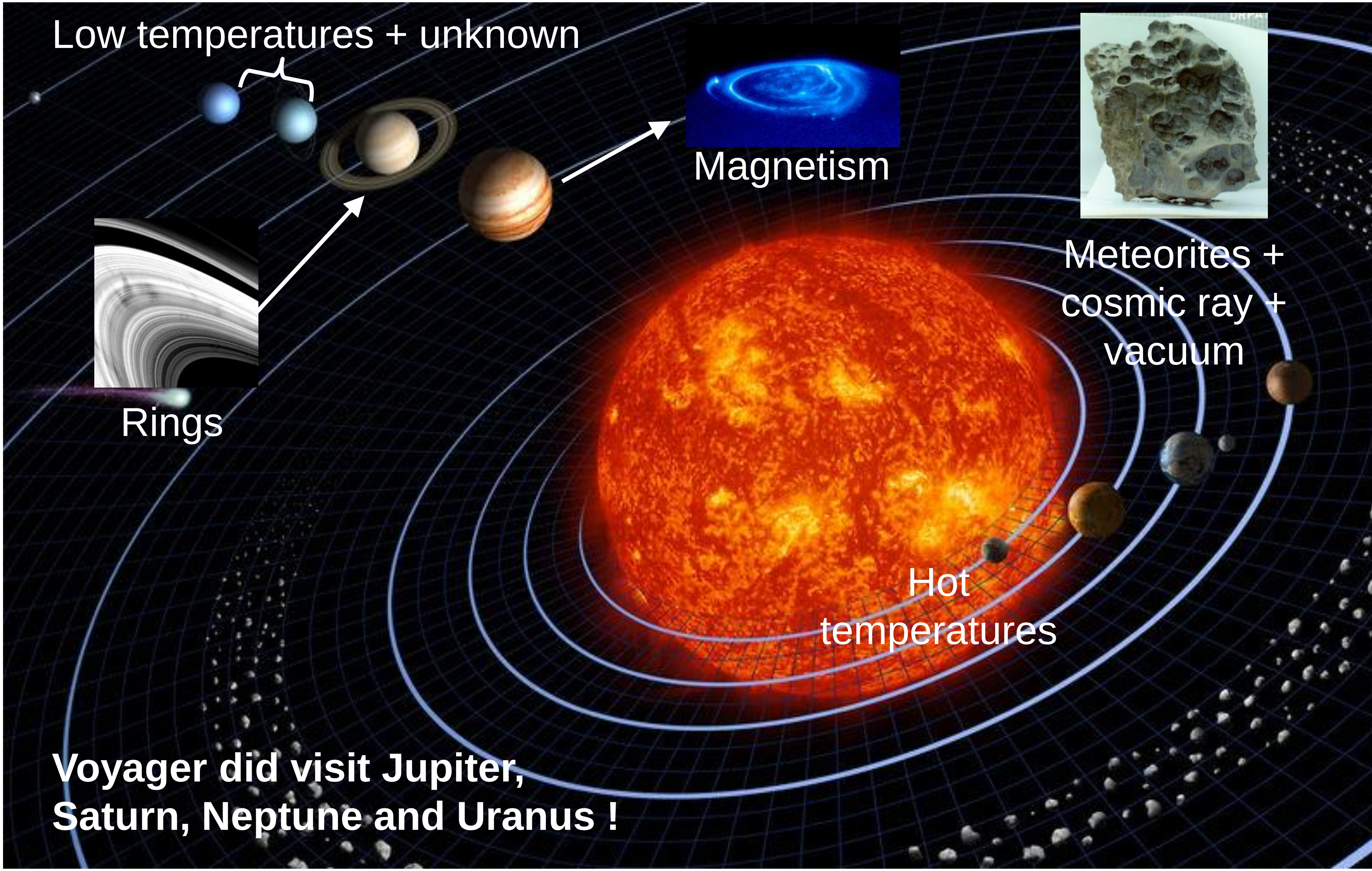
Propergols constraints





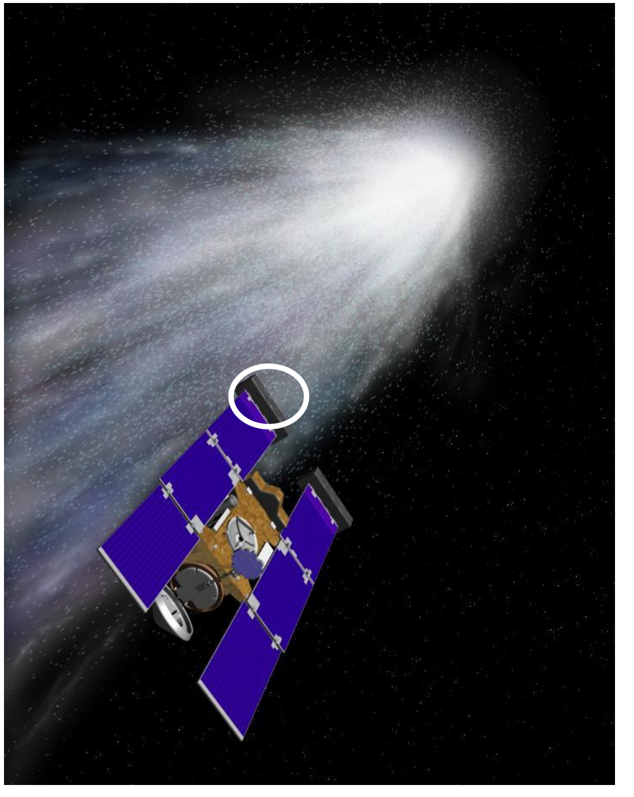
Gravity assist

Challenge #5: Harsh Environment



Solution: Develop New Technologies

Thermal blanket (temperatures)



Whipple shield against comet projections

Challenge #6: 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

AERO0025 – Satellite Engineering

Introductory Lecture

From Dreams to Technical Challenges