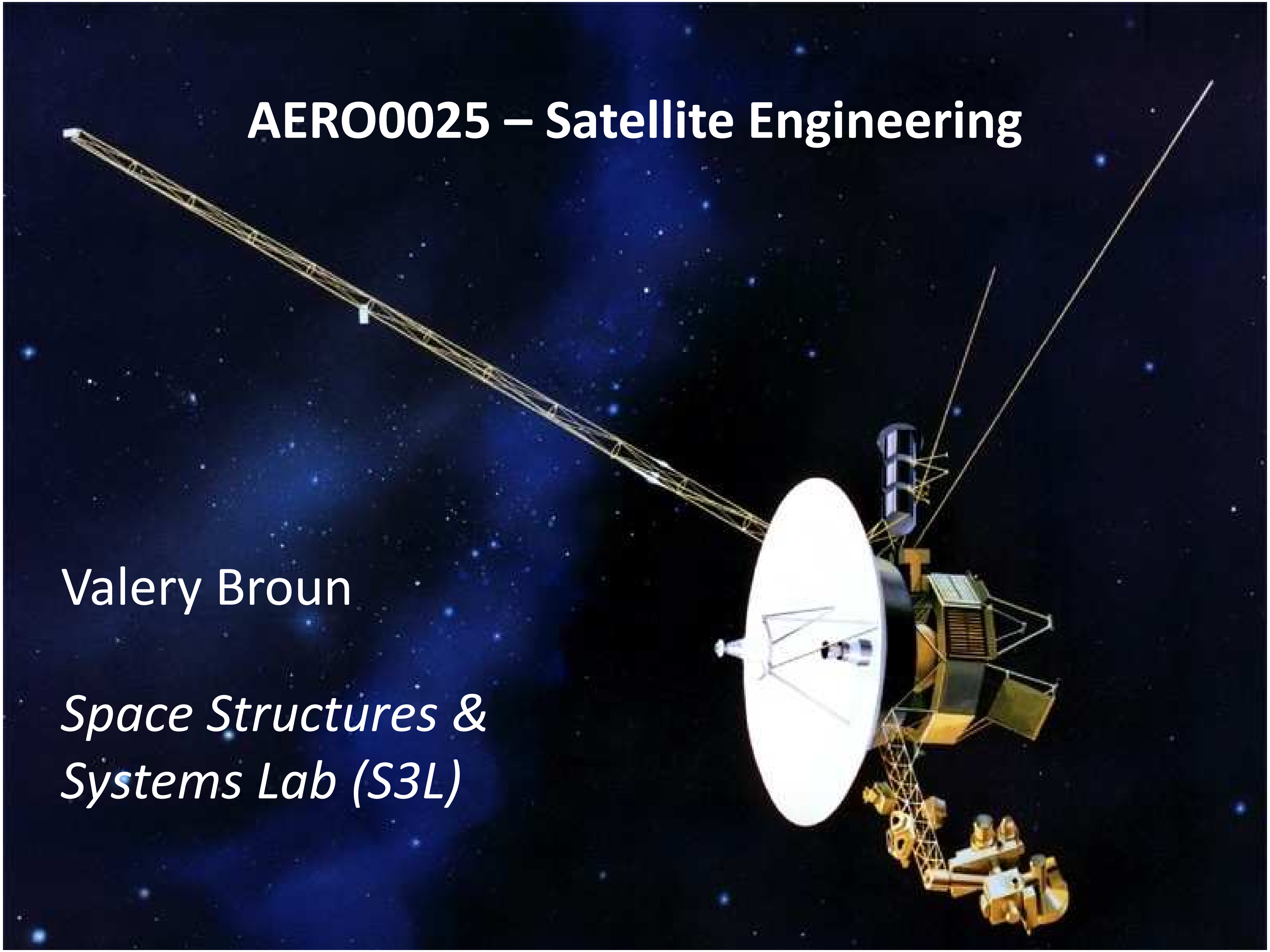
AERO0025 – Satellite Engineering



Valery Broun

Space Structures & Systems Lab (S3L)

Instructors

Instructor — Valery Broun

Contact details :

- valery.broun@uliege.be - valery.broun@help.be
- Space Structures and Systems Lab (S3L)
  Aerospace and Mechanical Engineering Department
- http://www.s3l.be

Former Instructor — Gaëtan Kerschen

Motivation

- ❑ An introduction to spacecraft systems engineering.

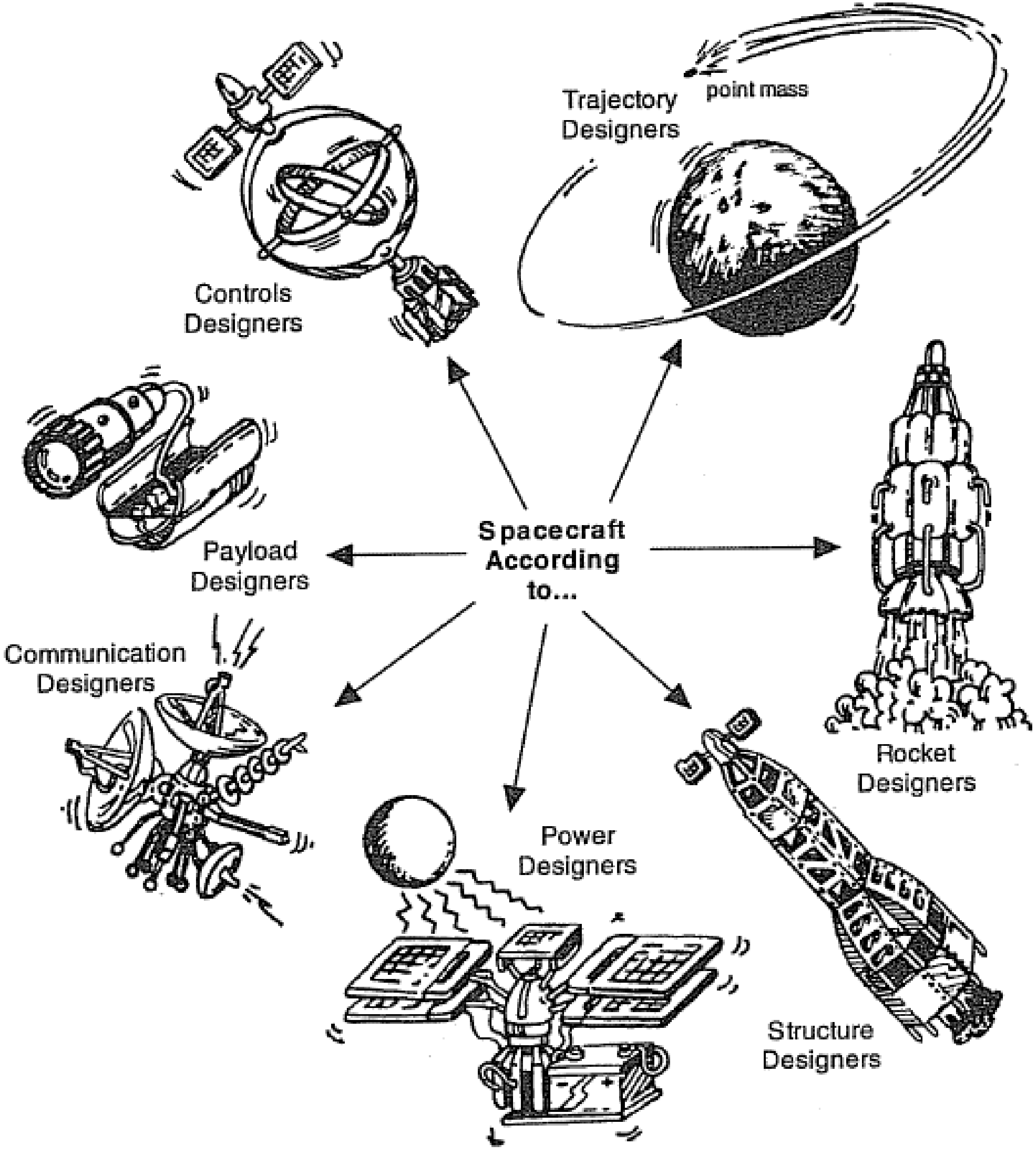
- ❑ Presentation of the fundamental subsystems of a satellite :
  - Propulsion
  - electrical power
  - Structure
  - thermal control
  - attitude control
  - Telecommunications
  - ….

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...
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

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 (http://www.s3l.be)

Date	14-16 h		16-18h	
	Sujet	Intervenant	Sujet	Intervenant
18-sept	Introduction	V, Broun (HEPL)	History	T. Pirard (Space Information Center)
25-sept	Satellite orbits	G. Kerschen (ULiege)	Earth observation	C. Barbier (CSL)
02-oct	Visite CSL			
09-oct	Astrophysics	O. Absil (ULiege)		
16-oct				
23-oct	Space environment	J. Loicq (CSL)		
30-oct	Thermal control	L. Jacques (CSL)		
06-nov	Telecommunications	M. Vandroogenbroeck (ULiege)		
13-nov	Attitude control	T. Delabie (KULeuven)		
20-nov	Spacecraft structures	A. Calvi (European Space Agency)		
27-nov	Nanosatellites	A. Denis (VKI)	Launch vehicles	A. Squelard (Arianespace)
04-déc	Propulsion	A. Squelard (Arianespace)	On board software	P. Parisis (Spacebel)
11-déc	Systems engineering	J. Tallineau (VEOWARE)		
18-dec	Electrical power	V. Lempereur (Thales Alenia Space)		

Visit of the CSL (Centre Spatial Liegeois)

Wednesday, 2nd October - 14:00 PM

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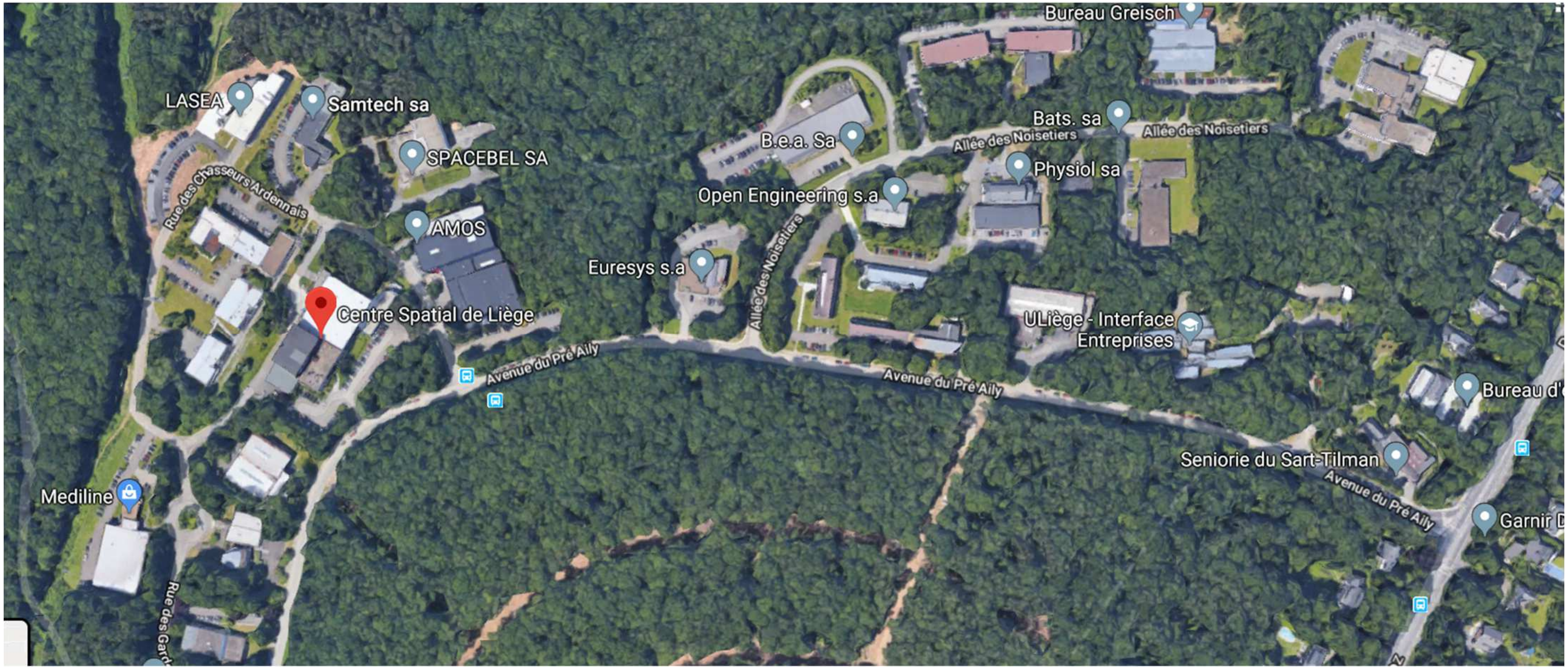


Adresse : Avenue du Pré Aily, 4031 Liège

Examination(s)

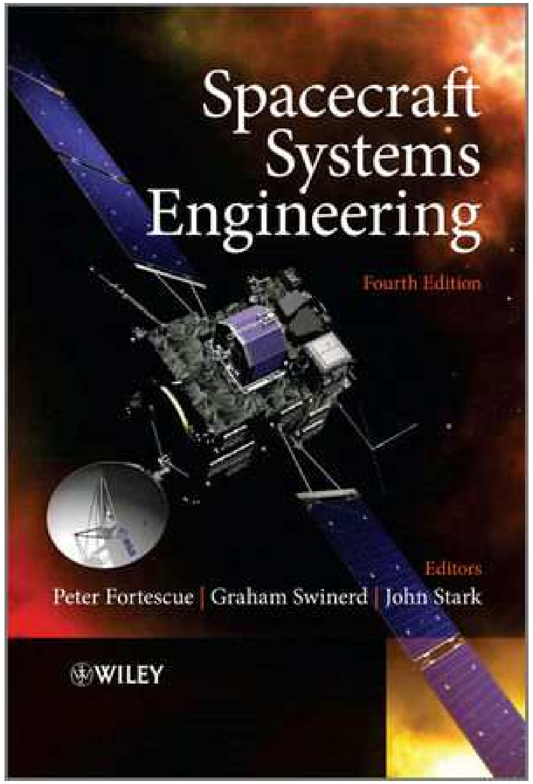
❑ **January :**

- Written examination
- Requires both a thorough knowledge and fundamental understanding of the material presented during the lectures.
- Closed book.
- 40 questions.

❑ **August :**

- Oral examination.

References



Spacecraft Systems Engineering

de Peter Fortescue, Graham Swinerd, et al. | 12 août 2011

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Relié

54,80€

prime Livraison GRATUITE d'ici **mercredi 21 août**

Autres vendeurs sur Amazon

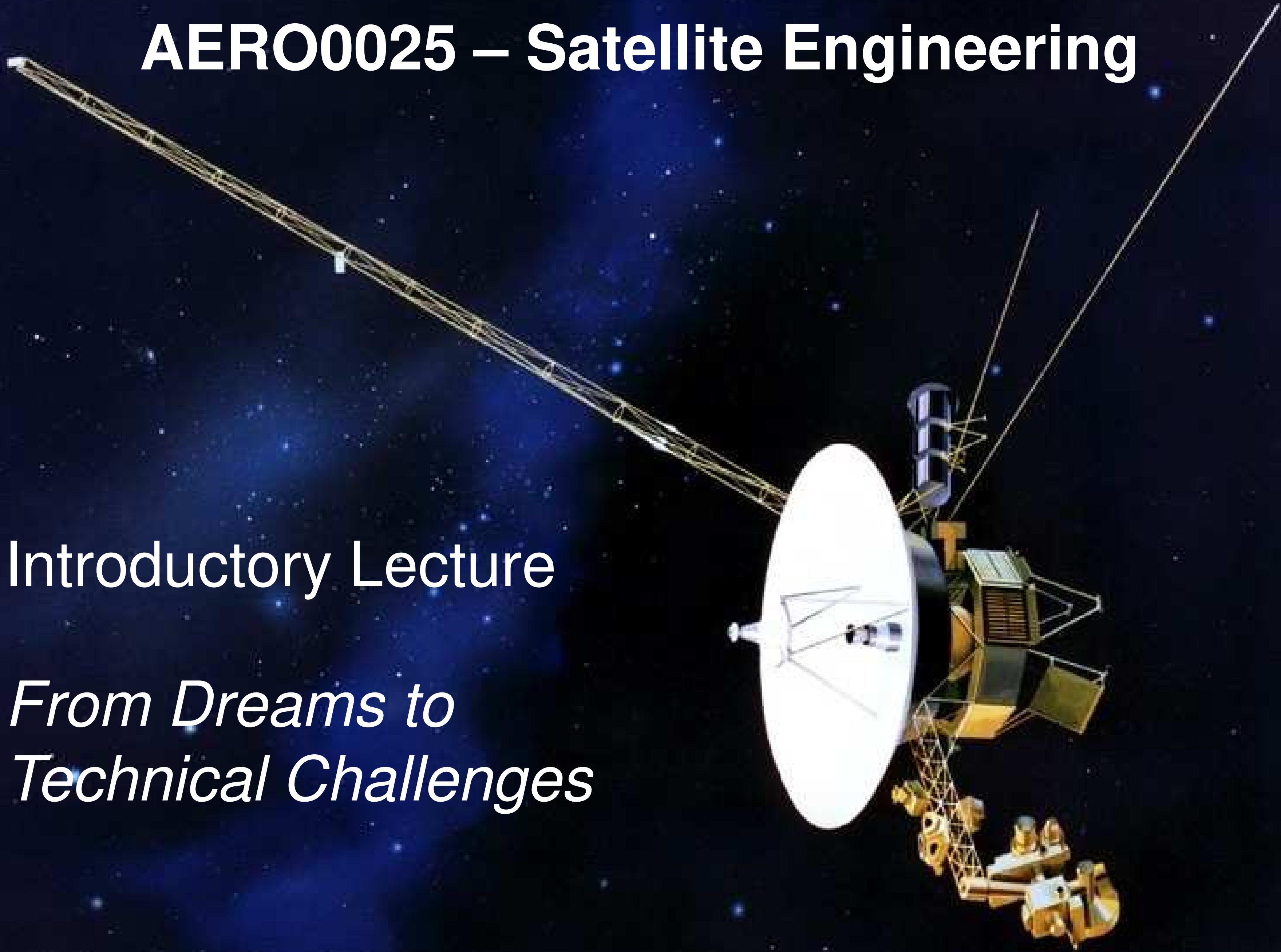
51,80 € (28 offres de produits d'occasion et neufs)

Format Kindle

37,09€ ~~64,70 €~~

Slides available on the website : http://www.s3l.be/en/education

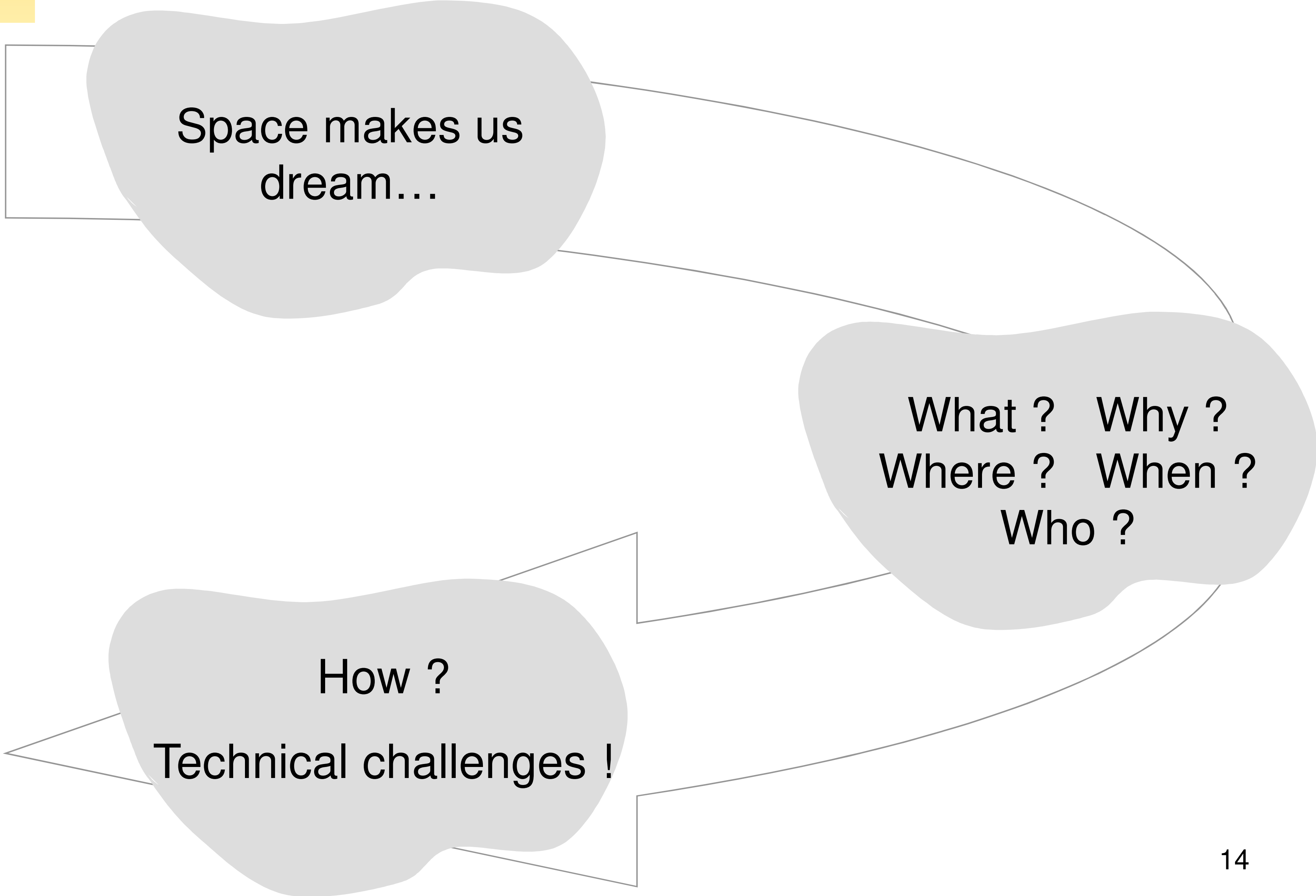
AERO0025 – Satellite Engineering

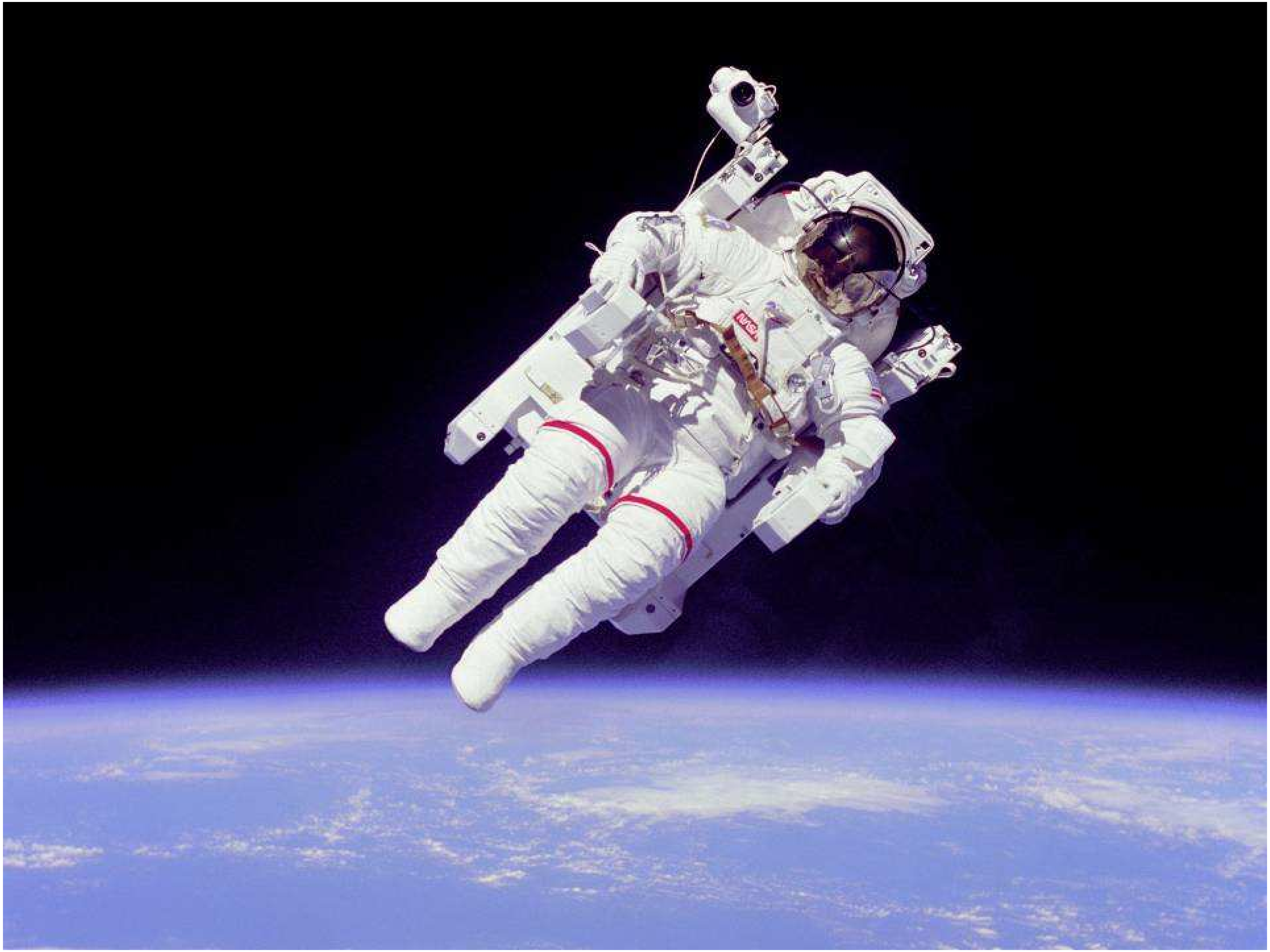


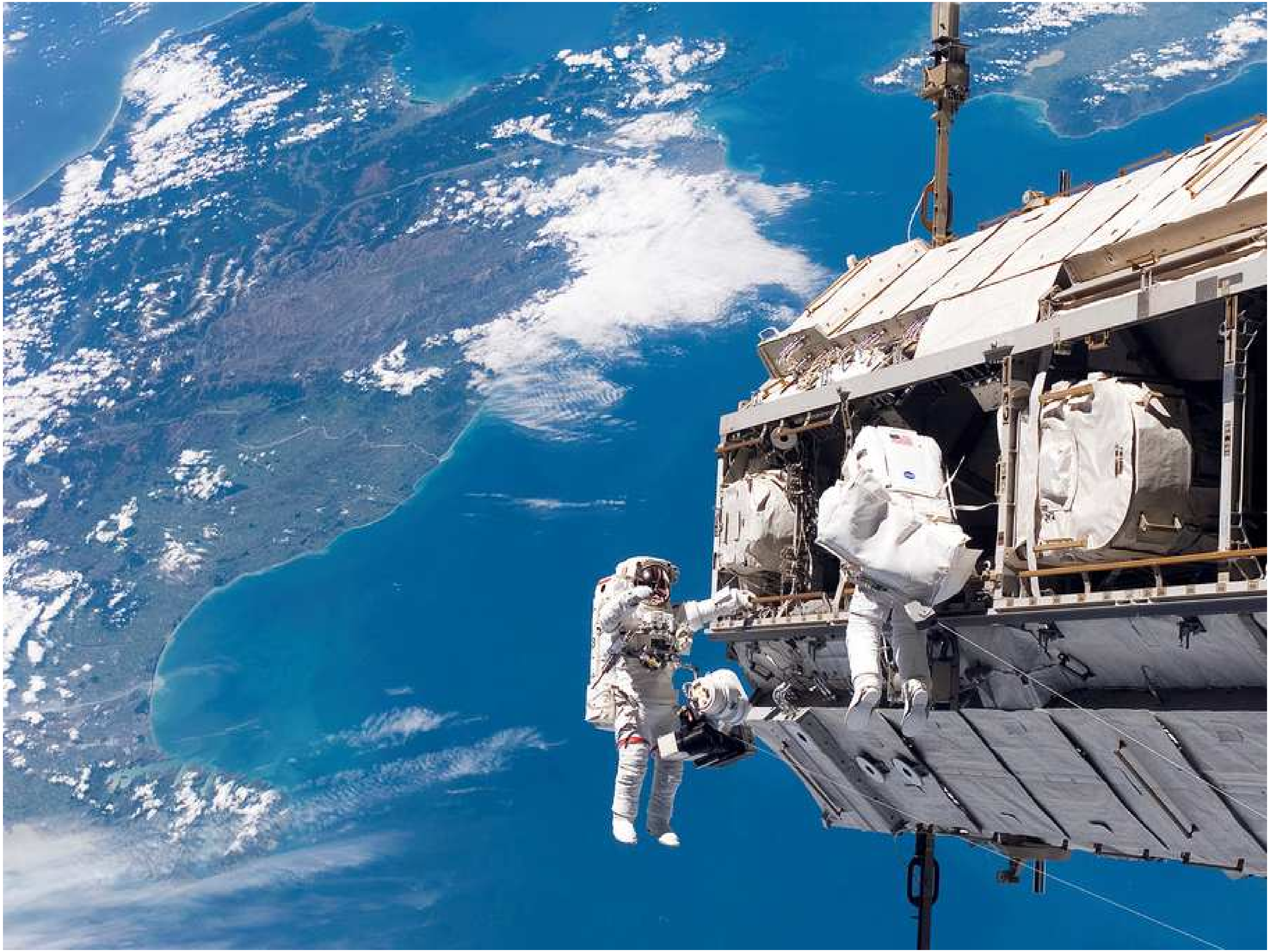
Introductory Lecture

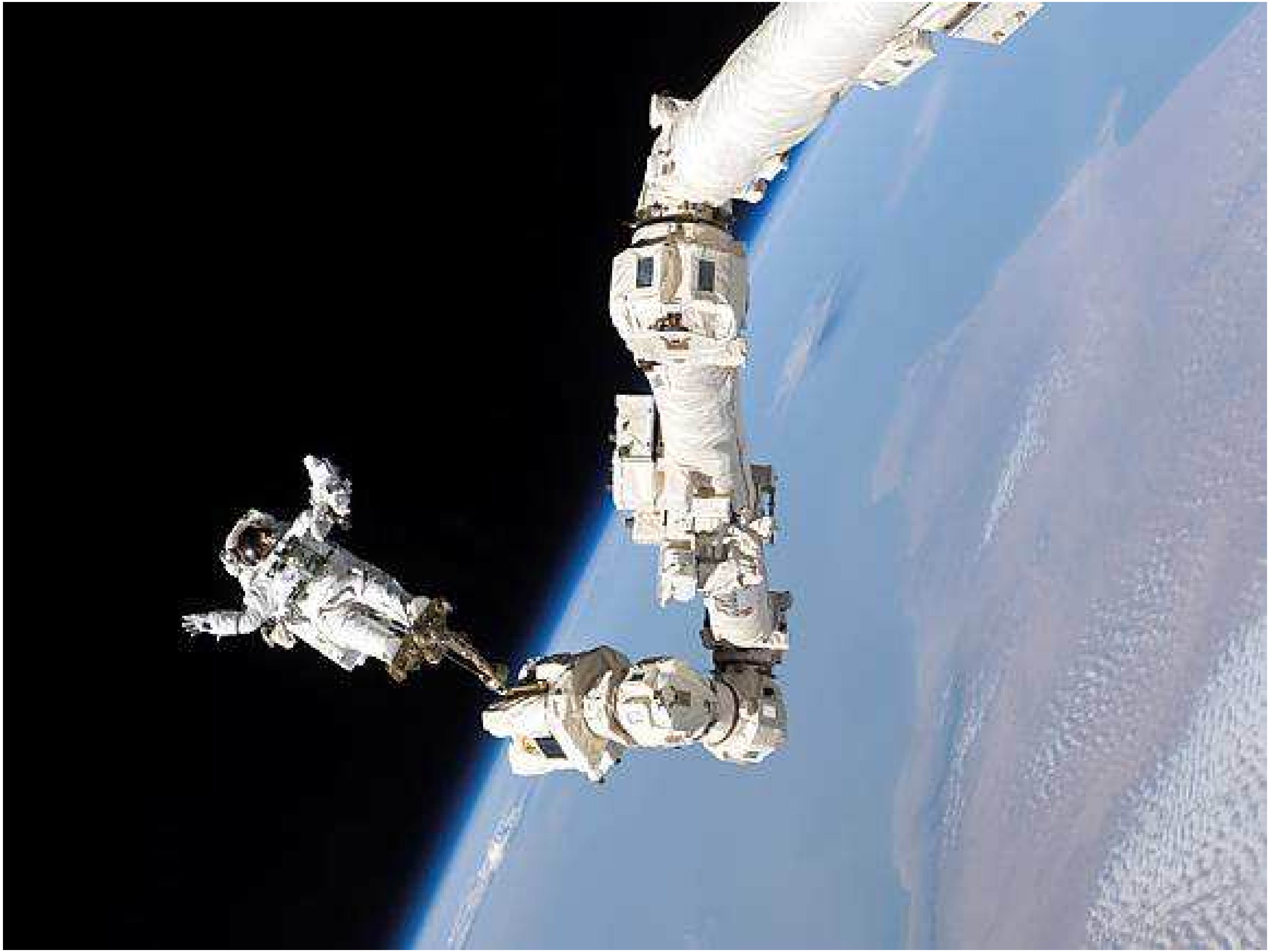
From Dreams to
Technical Challenges

From Dreams to Technical Challenges

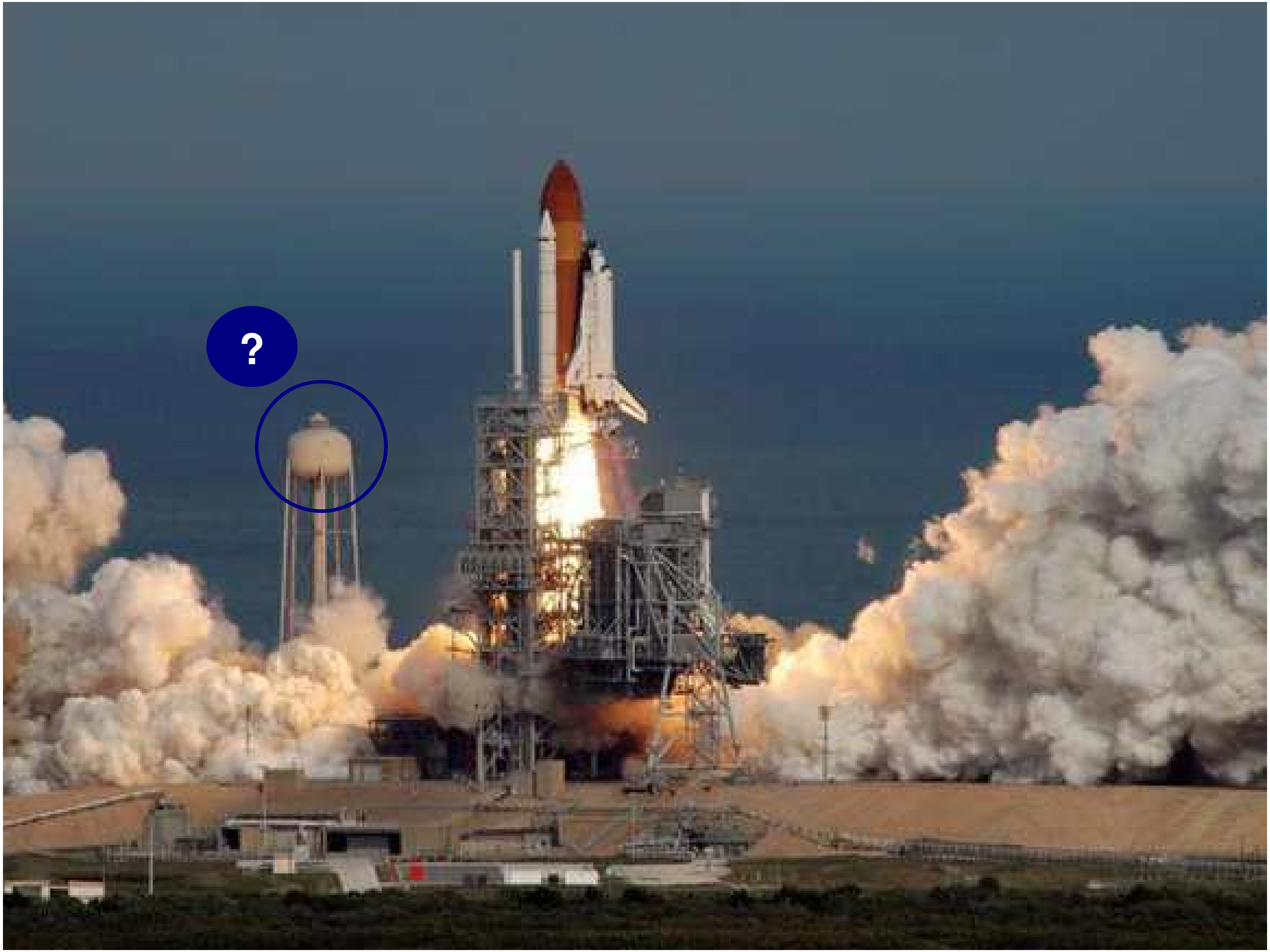









Discovery




WHAT DO
YOU SEE ?


CaughtOnTapeTV
CI7A 3 N TOWER


SPACE IMAGING

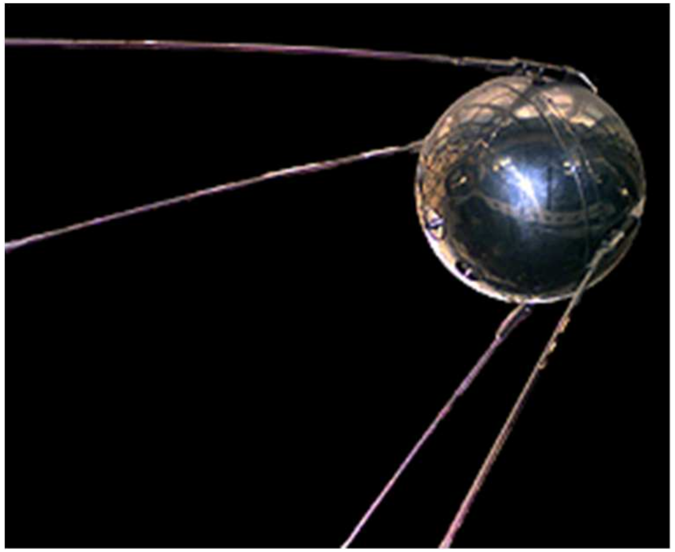
Emphasis of Some…

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)

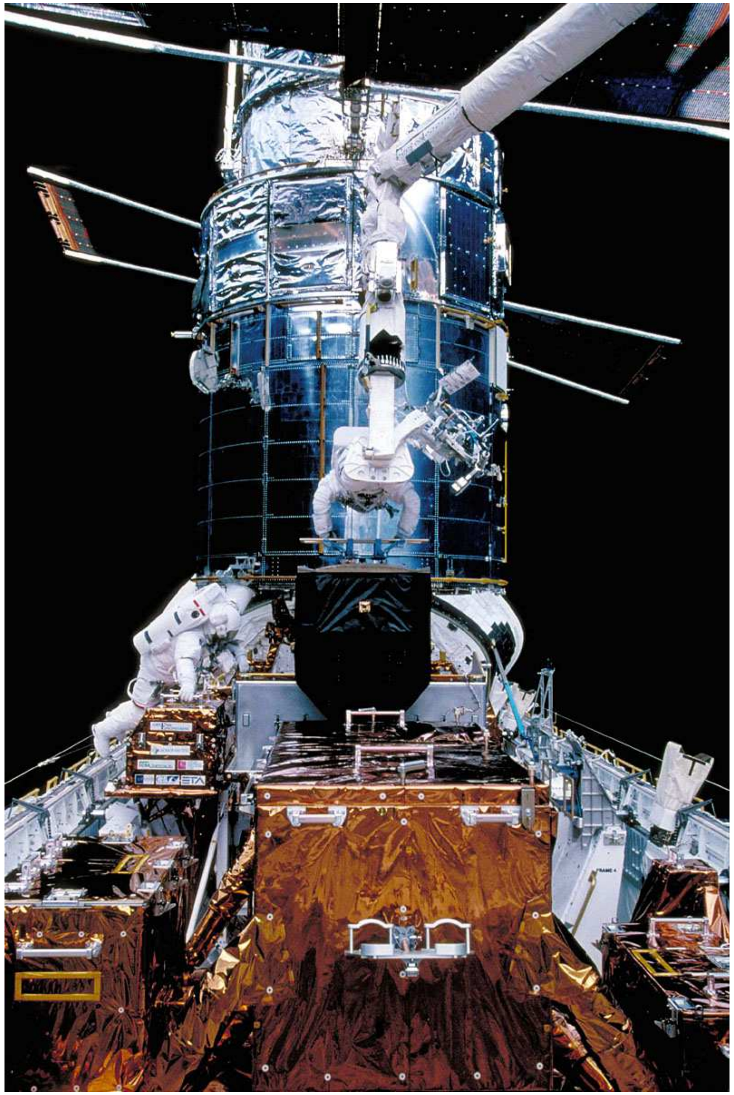
Satellite #2: ISS

Objective: Perform science experiments

ISS: Technical Data

Weight	470 tons (upon completion)
Dimensions	58m x 73m x 28m
Power	110 kW, solar panels
Propulsion	**Zvezda (2 x 3070 N thrusters, N_2H_4 and N_2O_4) + Progress + STS + ATV+? +Dragon**
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

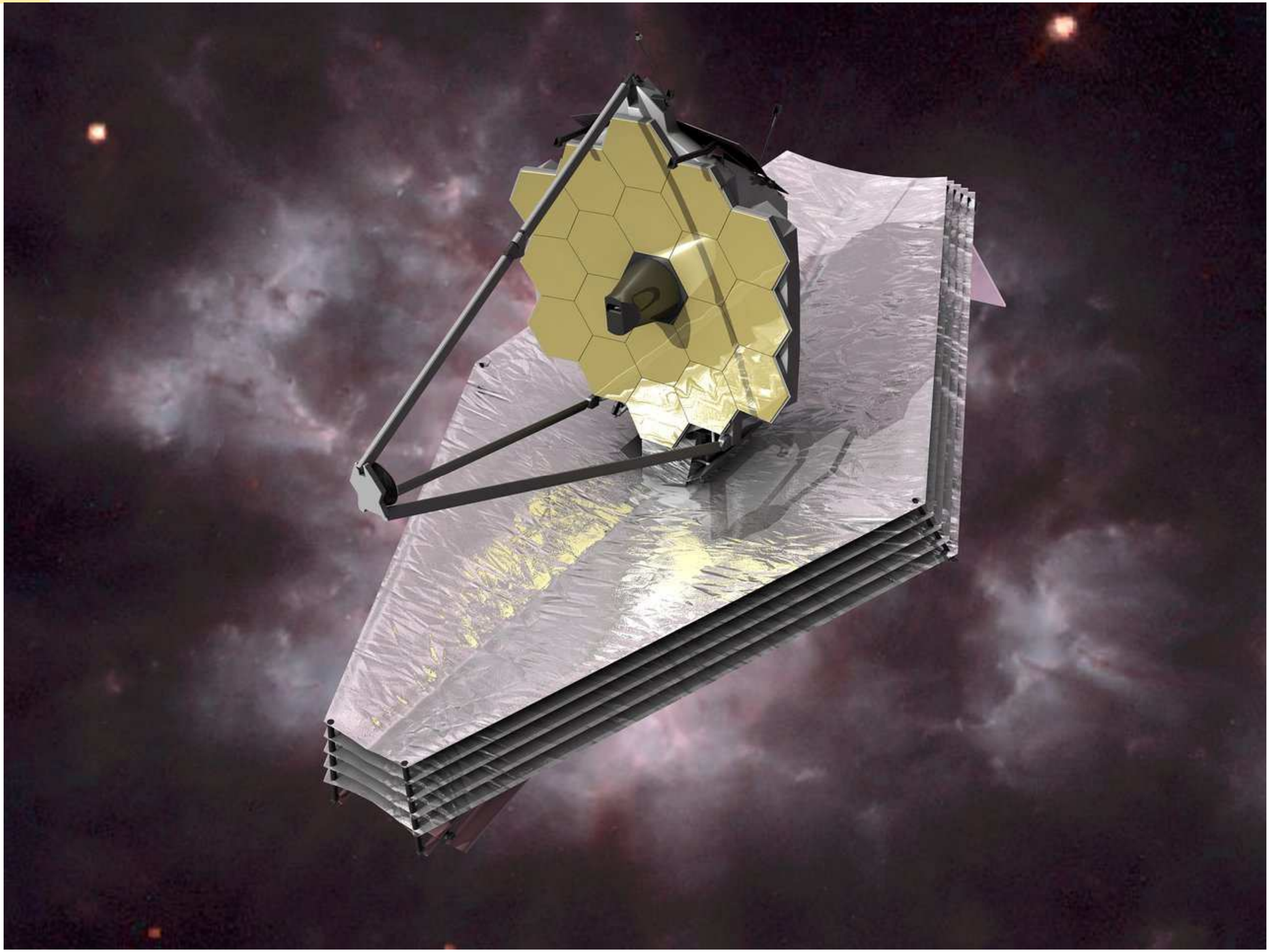
Pointing accuracy: 0.007”

Defective mirror and solar panels, recovery thanks to servicing mission

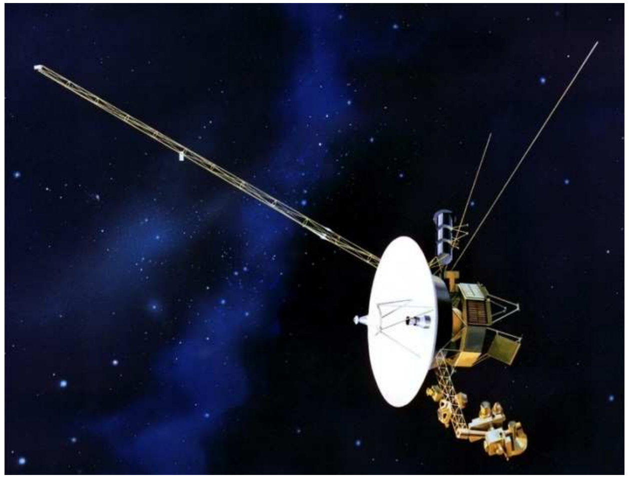
HST: Technical Data

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**

James Webb

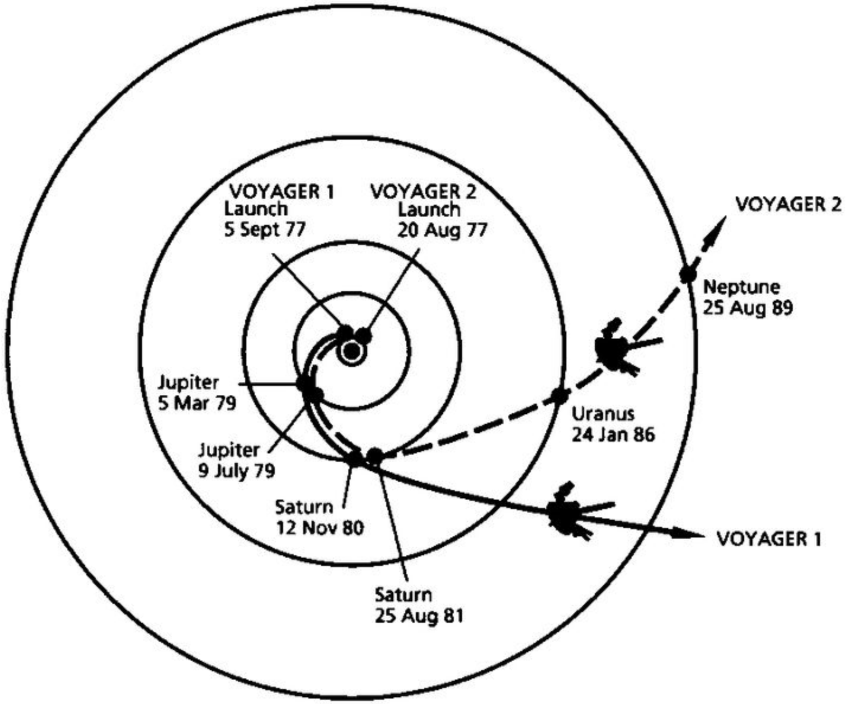


Satellite #4: Voyager, 1977



Objective: Space exploration (planets and their moons)

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



Jupiter, Saturn, Uranus, Neptune and their moons

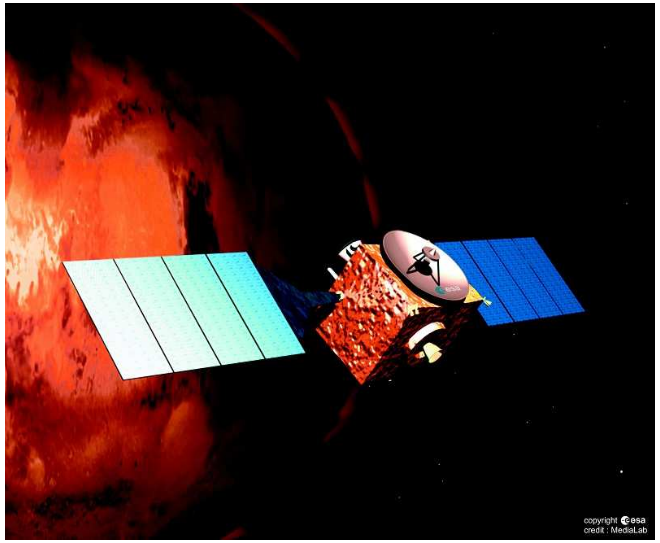
23 W radio could transmit data over a distance of 10^9 km

Alignment every 176 years + 12 years to meet Neptune

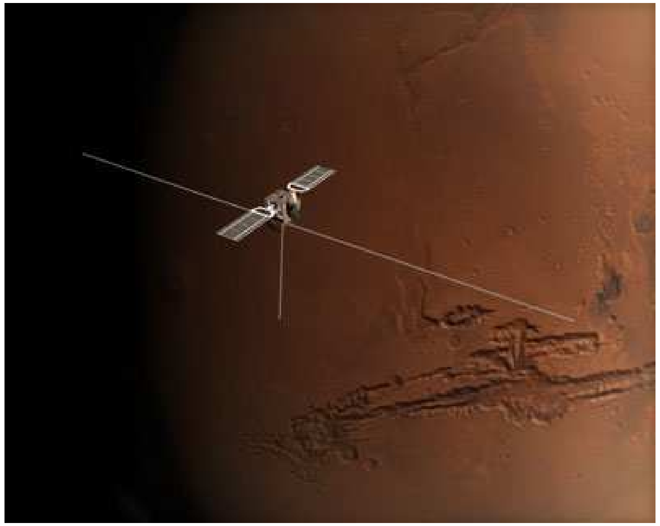
Voyager: Technical Data

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: Mars Express, 2003



Objective: Mars exploration



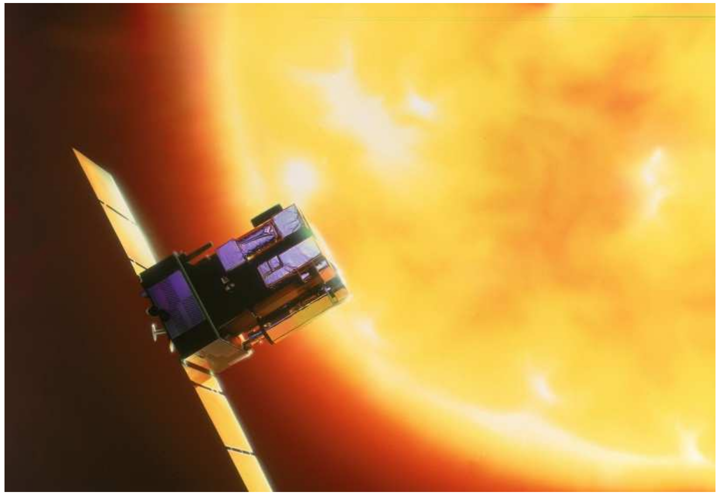
40-m radar to map the distribution of water

Beagle 2 failed to land (problem with the parachuting device)

Mars Express: Technical Data

Weight	1100 kgs
Dimensions	1.5 x 1.8 x 1.4 m (bus) Solar panels: 12 m tip-to-tip
Power	600 W, solar panels
Propulsion	Fregat + 400 N main engine with N_2H_4 and N_2O_4 (mainly for slowing down !)
ADCS	8 attitude thrusters (10 N each) + star trackers + gyros + sun sensors + 4 reaction wheels (12 NMs)
Communications	1.6 m high-gain antenna + 0.4 m low-gain antenna (X band – 7.1 GHz and S-band – 2.1 GHz) + UHF antenna (for Beagle 2)
Orbit	**Martian orbit, 259 x 11560 kms i= 86°**
Launch vehicle	**Soyuz + Fregat upper stage (4th stage)**

Satellite #6: SOHO, 1995



Objective: Solar exploration and space weather prediction

Satellite #6: SOHO, 1995

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

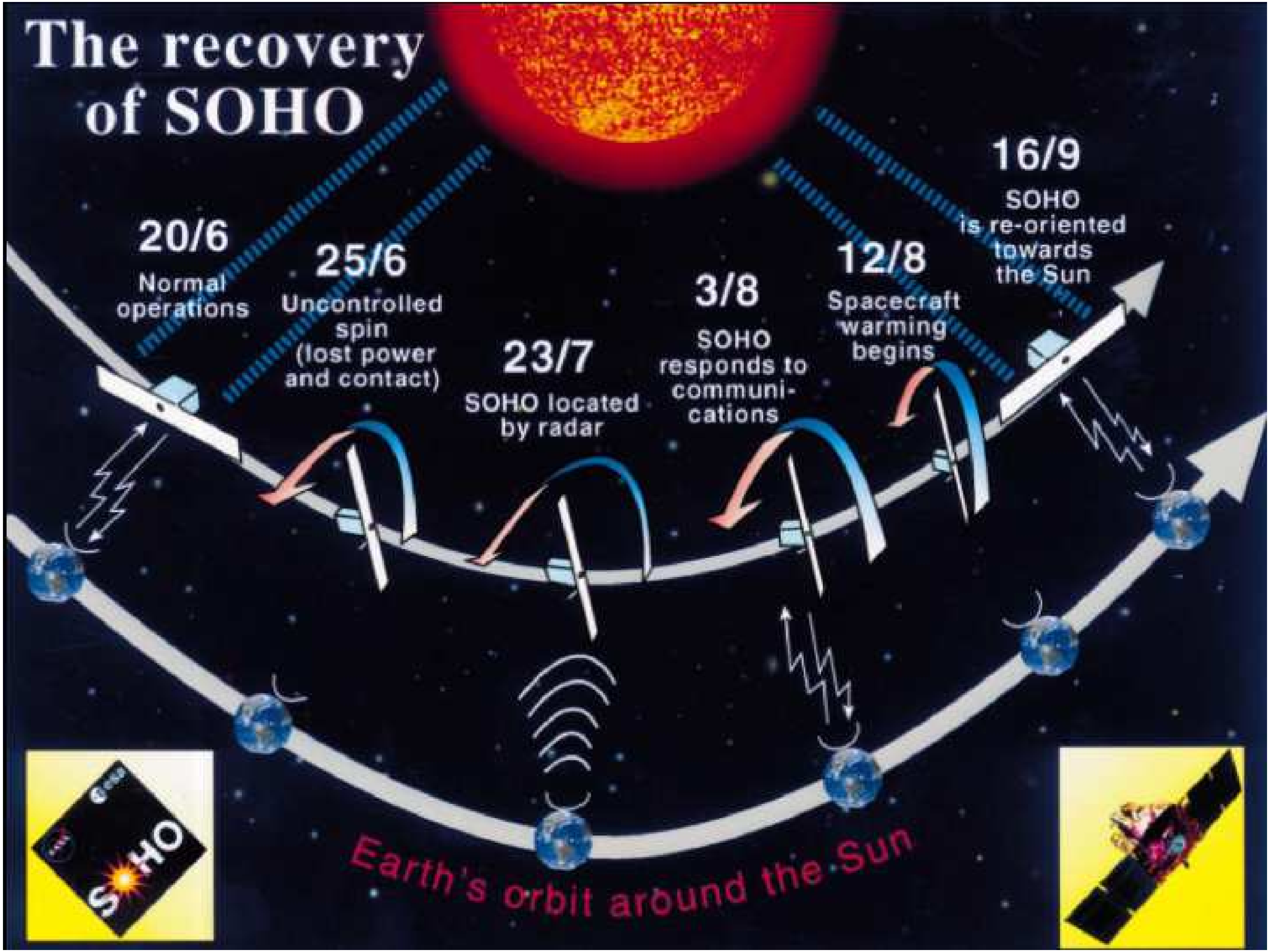
SOHO's Failure

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.

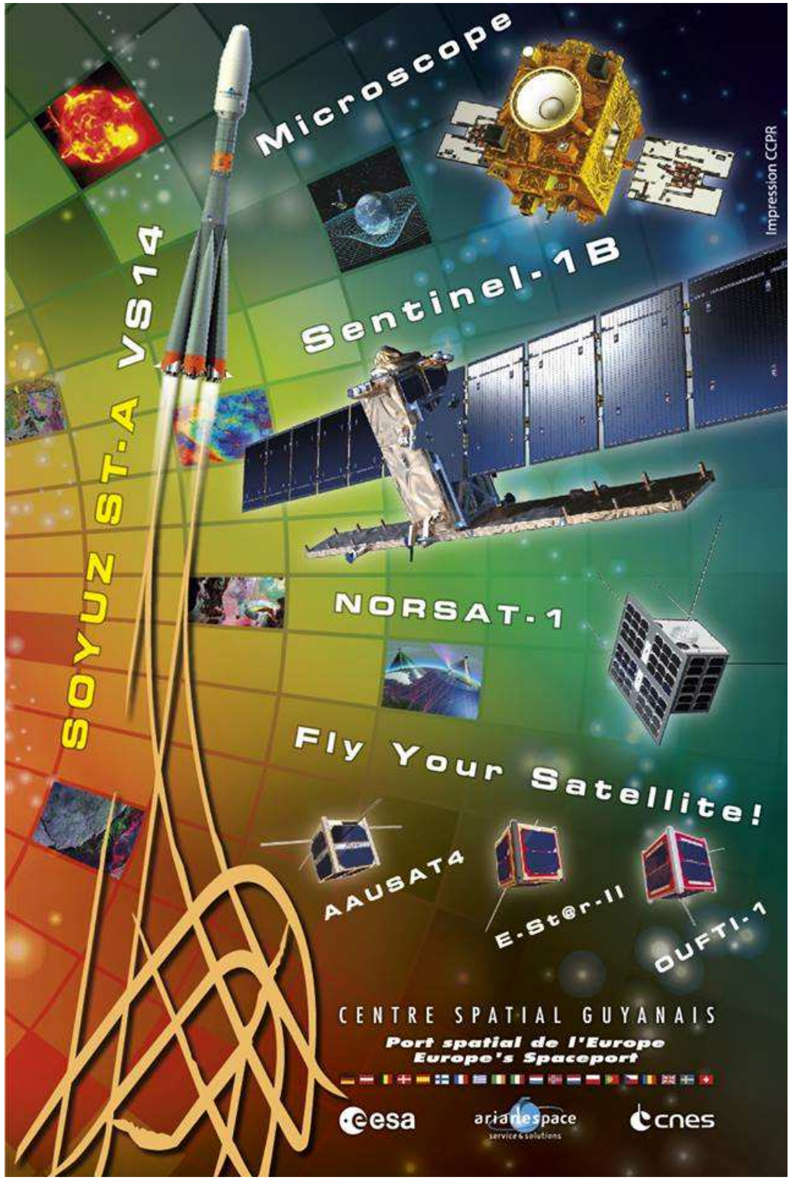
3. Telemetry showed that hydrazine in the tank, thrusters and pipes were frozen.

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
SOHO

Satellite #7: OUFTI-1, 2016



Objectives:

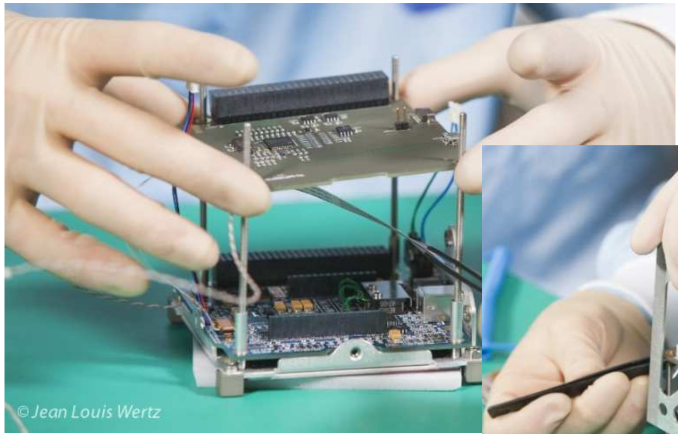
1. On-orbit validation of D-STAR
2. New solar cells

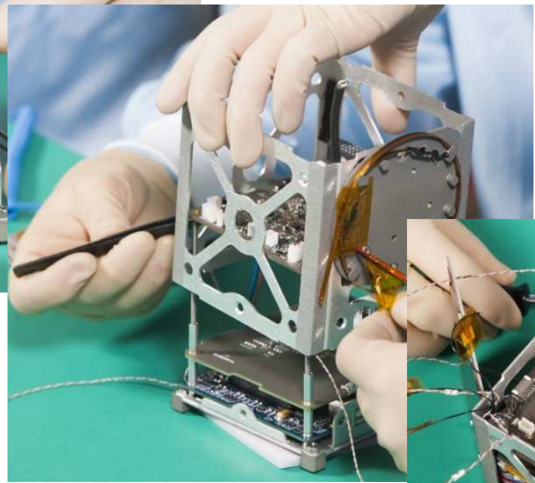
Entirely designed by students

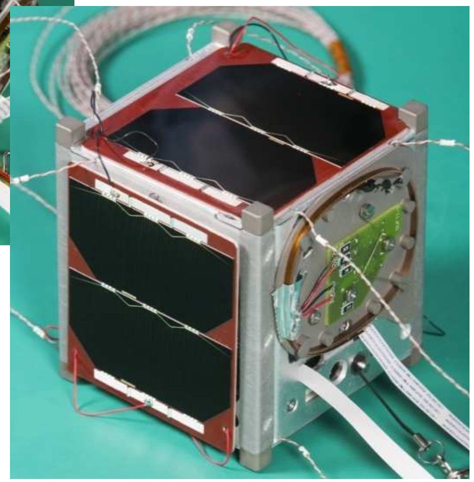
Launched at the fourth attempt !

Unknown failure three weeks after launch.

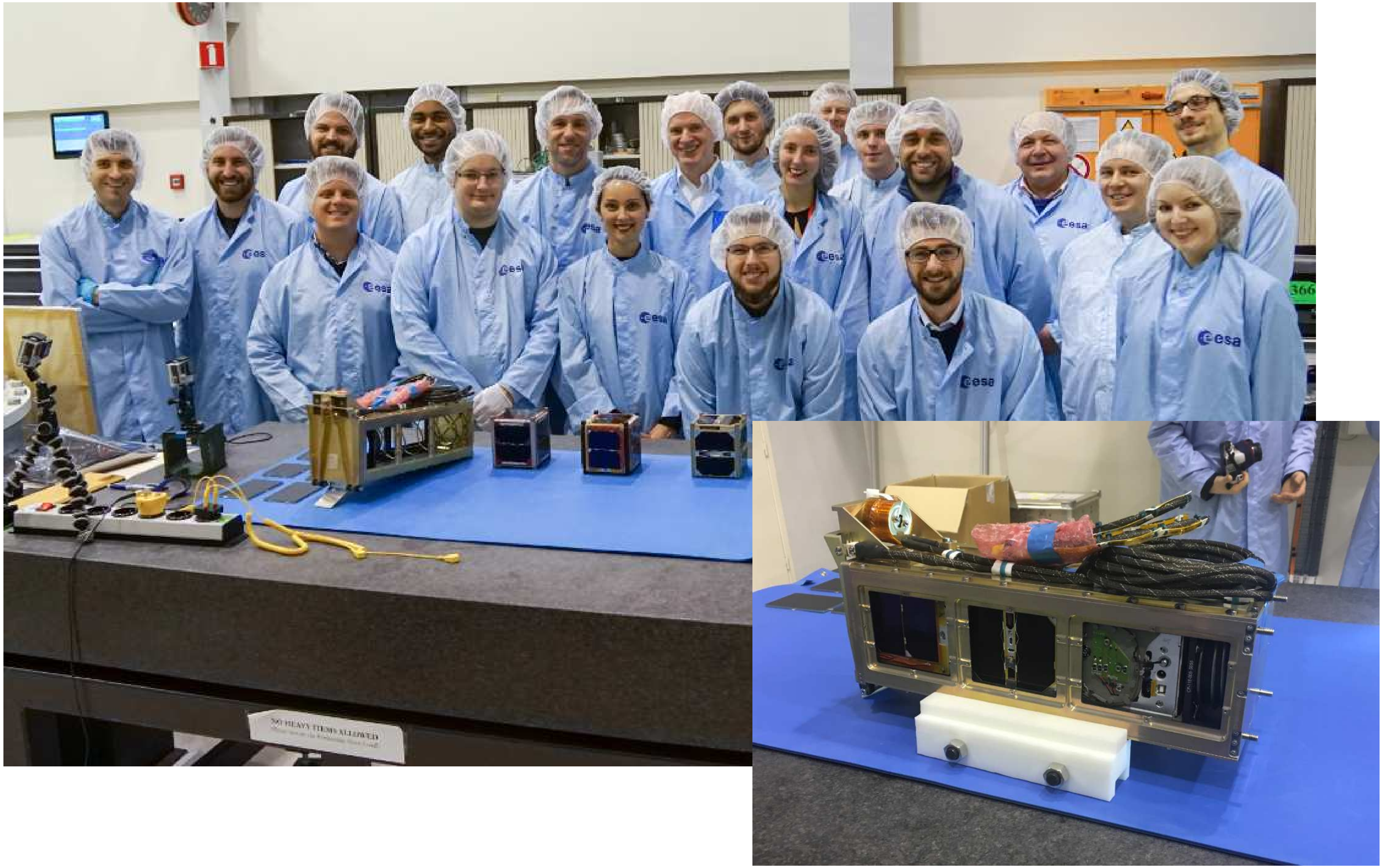
Satellite #7: Integration @ CSL (oct-2013)



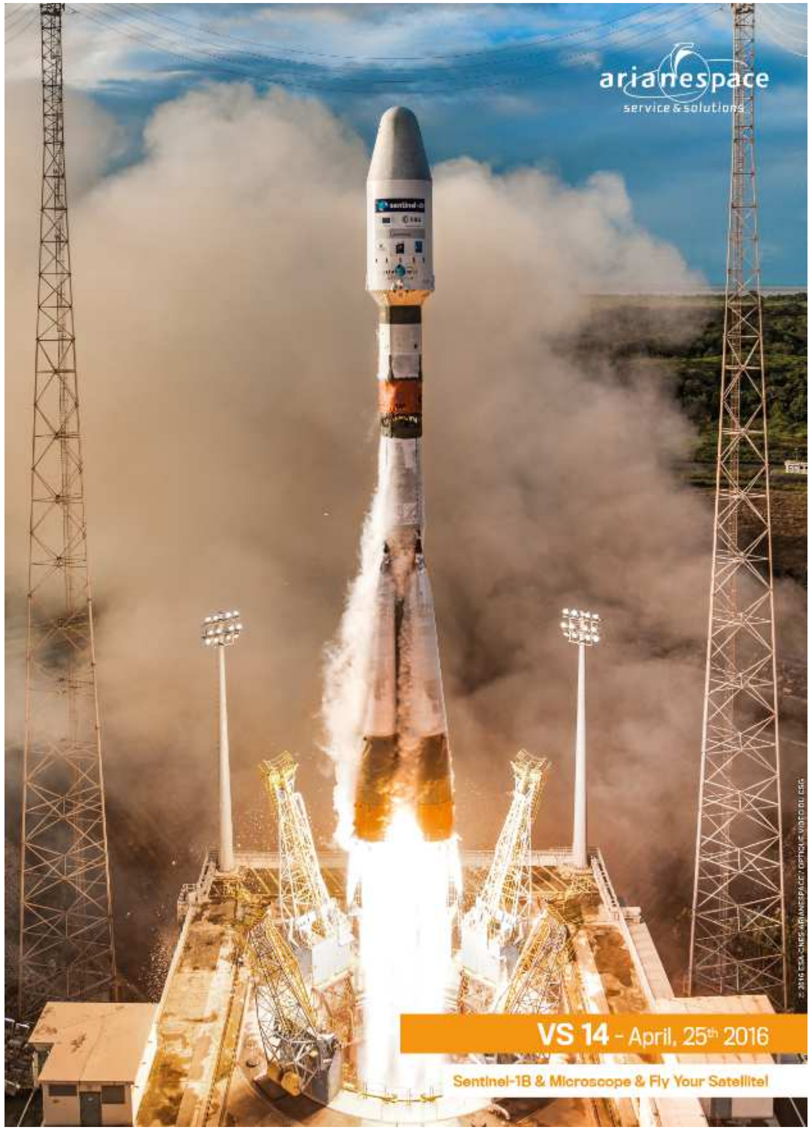





Satellite #7: Integration March, 2016

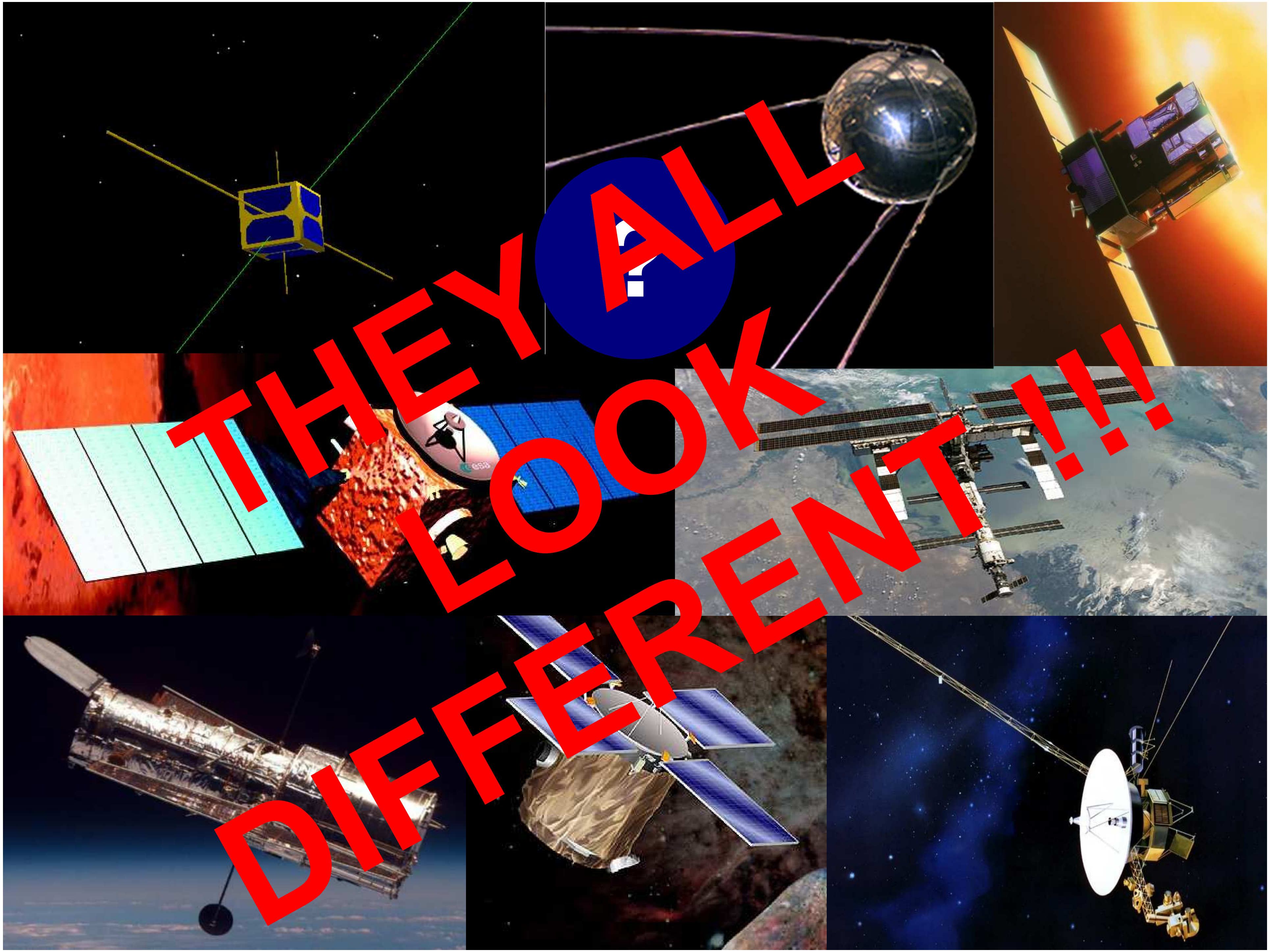


Satellite #7: Launch on April 25, 2016



OUFTI-1: Technical Data

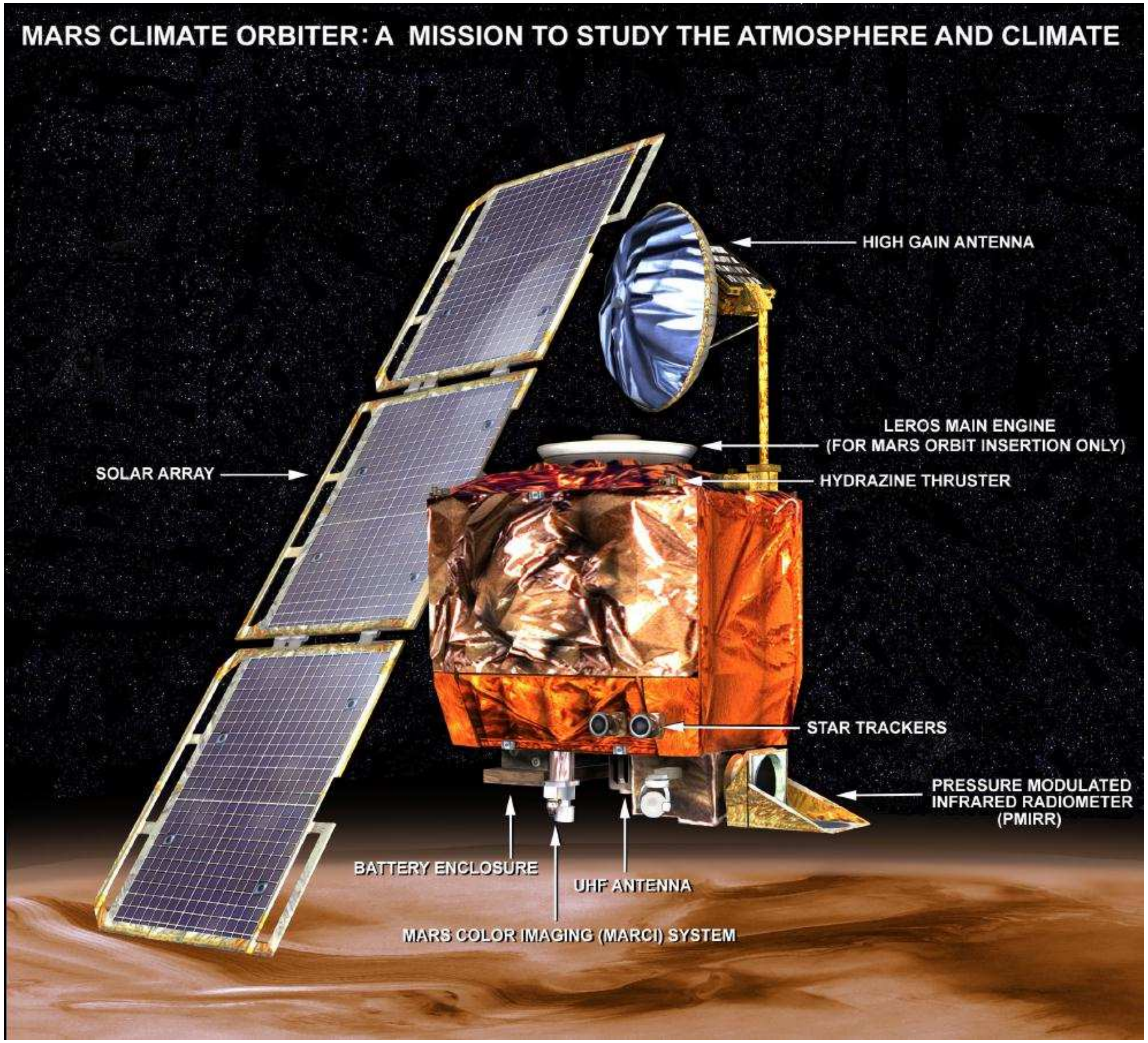
Weight	1 kg
Dimensions	**10 cm x 10 cm x 10 cm**
Power	**1 W**
ADCS	Passive (permanent magnets and hysteretic materials)
Propulsion	None
Communications	145 MHz + 435 MHz (Ham radio bands)
Orbit	LEO, 660 x 450 kms, i= 98°
Launch vehicle	Soyuz


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 ! Well knowed 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 !

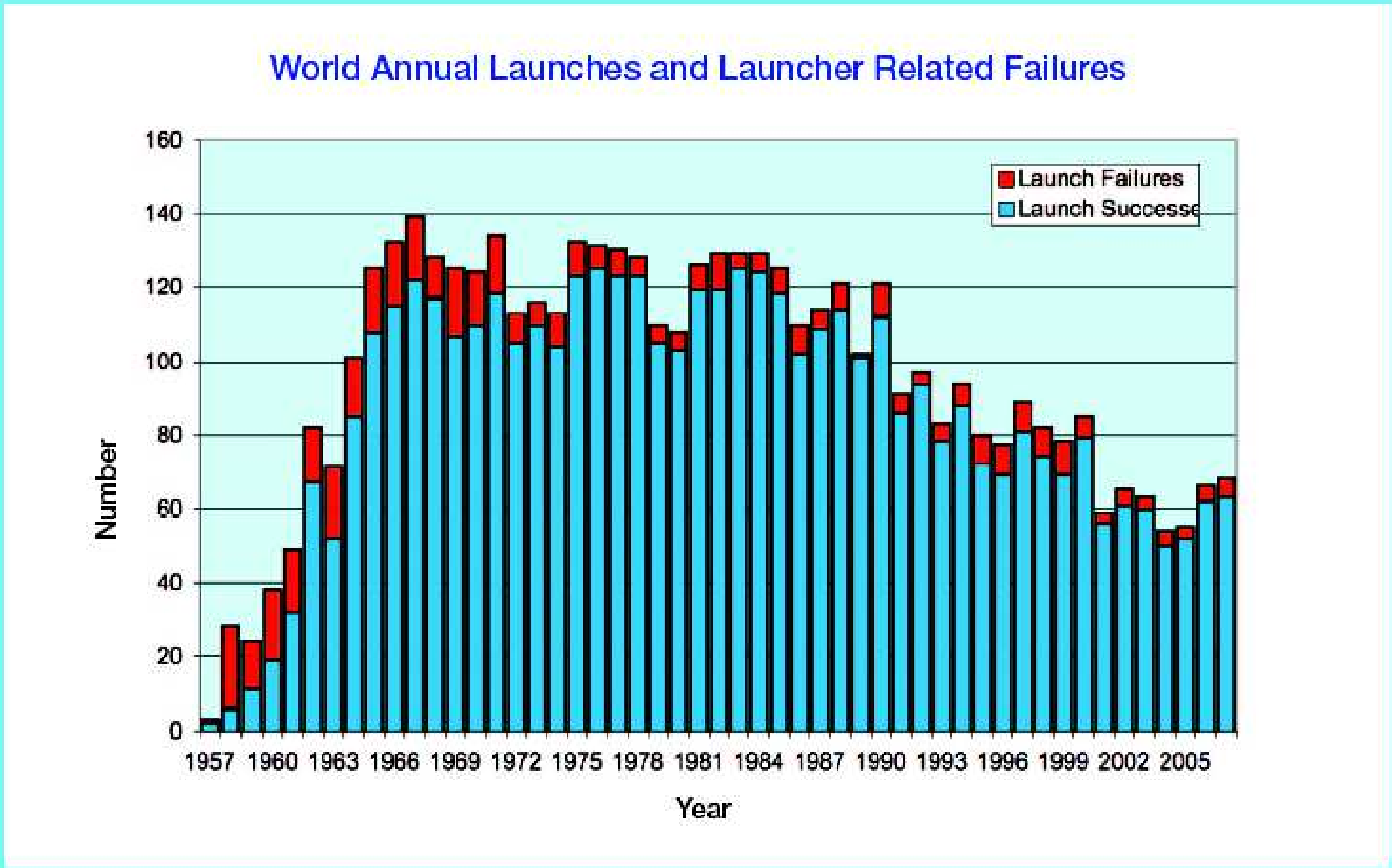
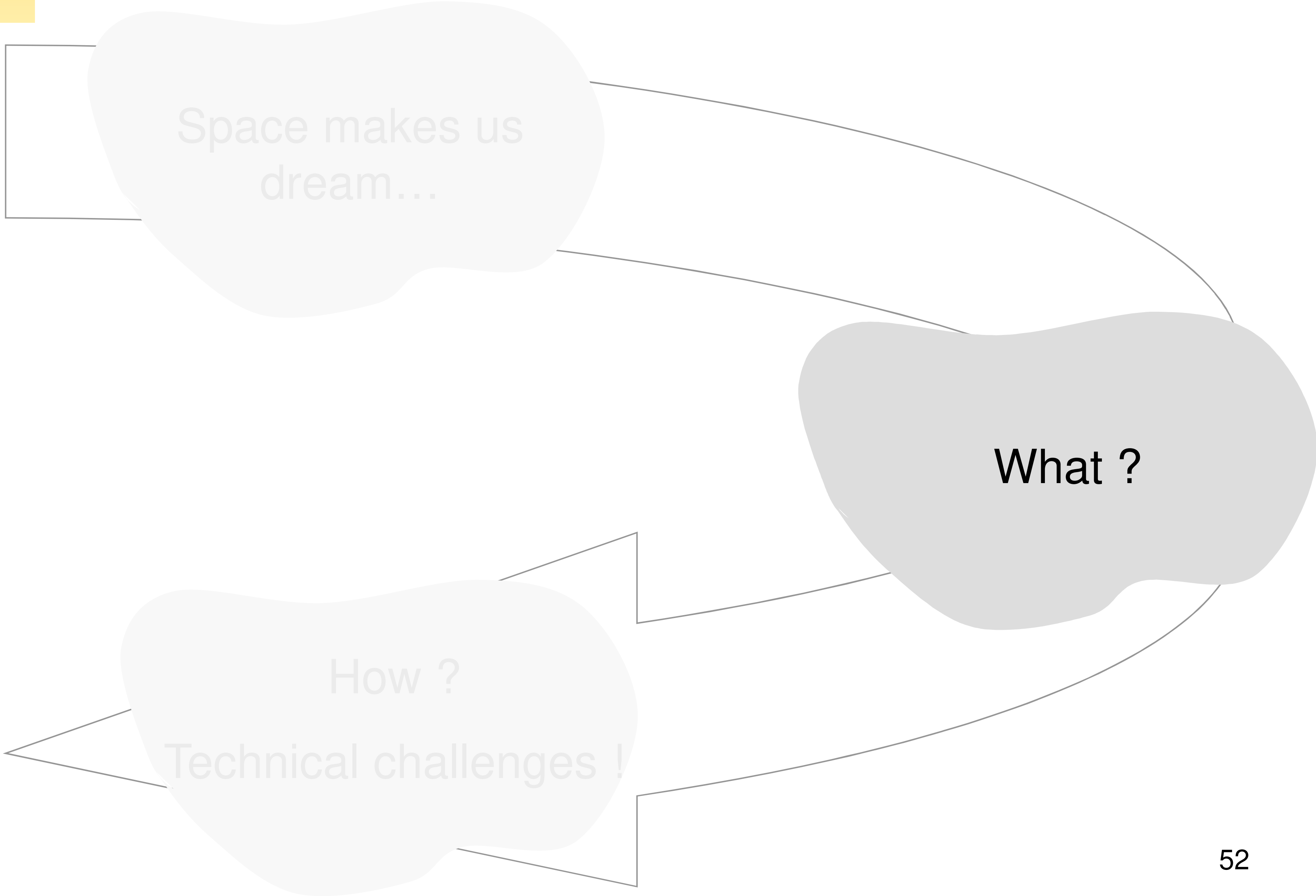
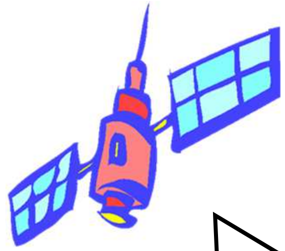


Chart 2: **Orbital launch attempts since 1957.** Source: Ascend Space Review

From Dreams to Technical Challenges

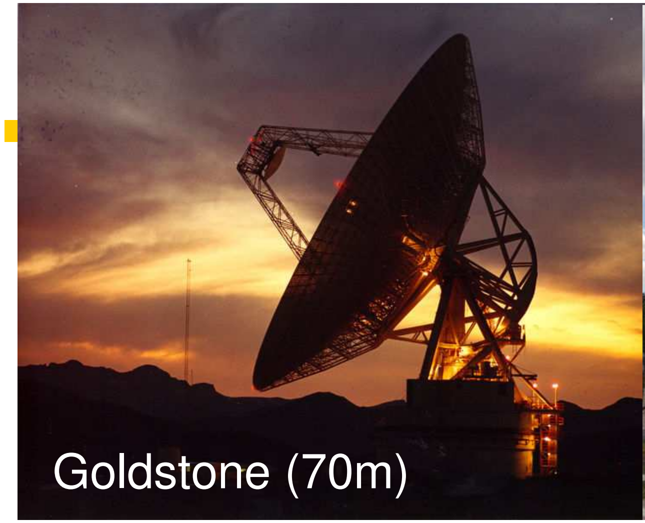


An Element Within a Larger System



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

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

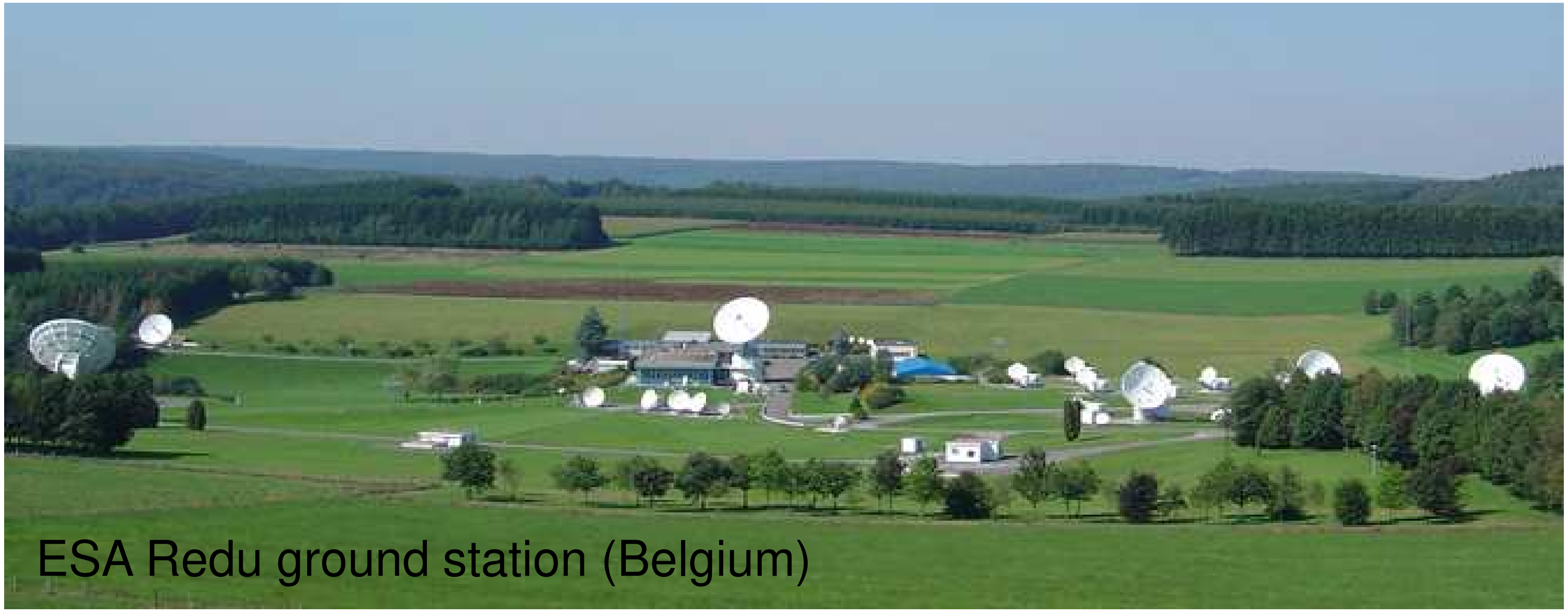


Goldstone (70m)

Madrid (70m)

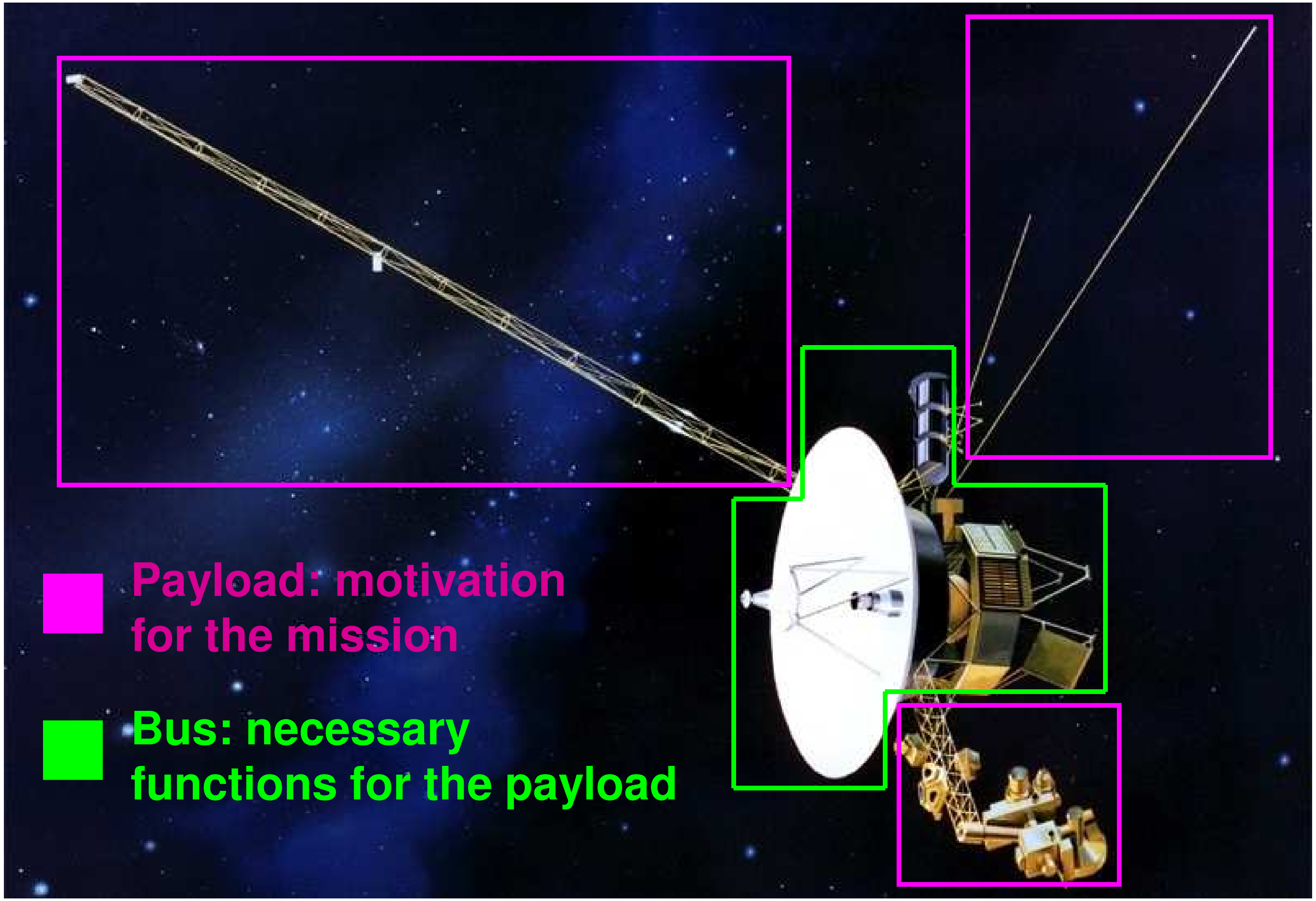
Canberra (70m)

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

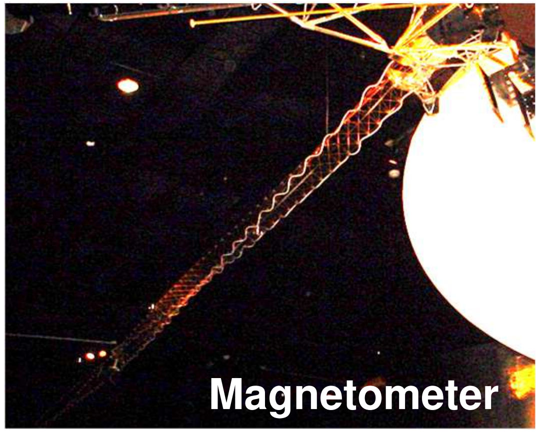


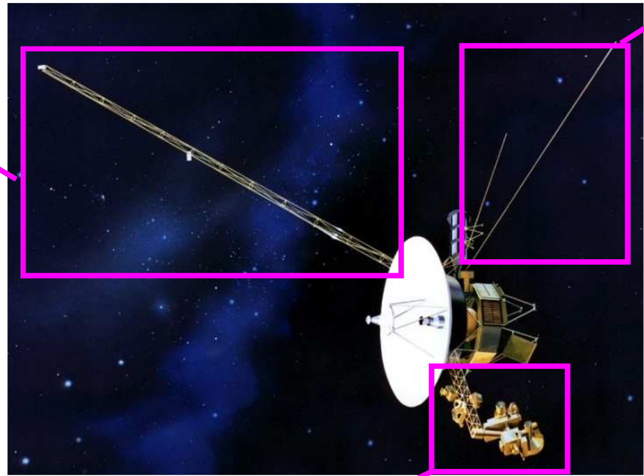
ESA Redu ground station (Belgium)

A Satellite Comprises Two Main Elements

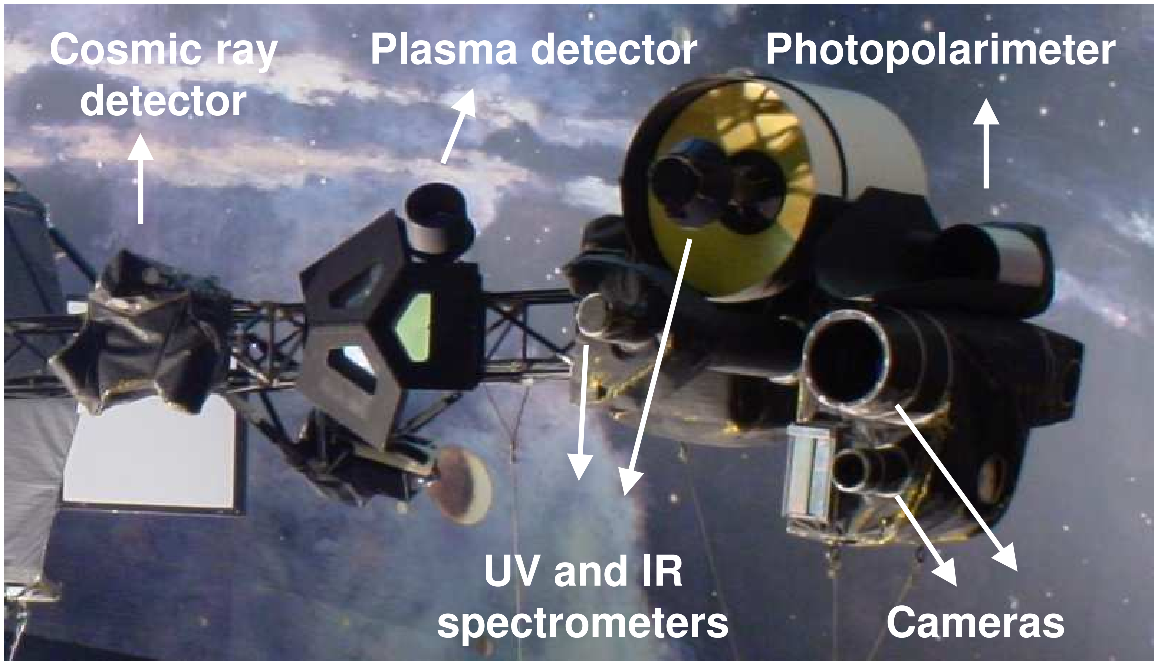


Antennas: planet radio emissions



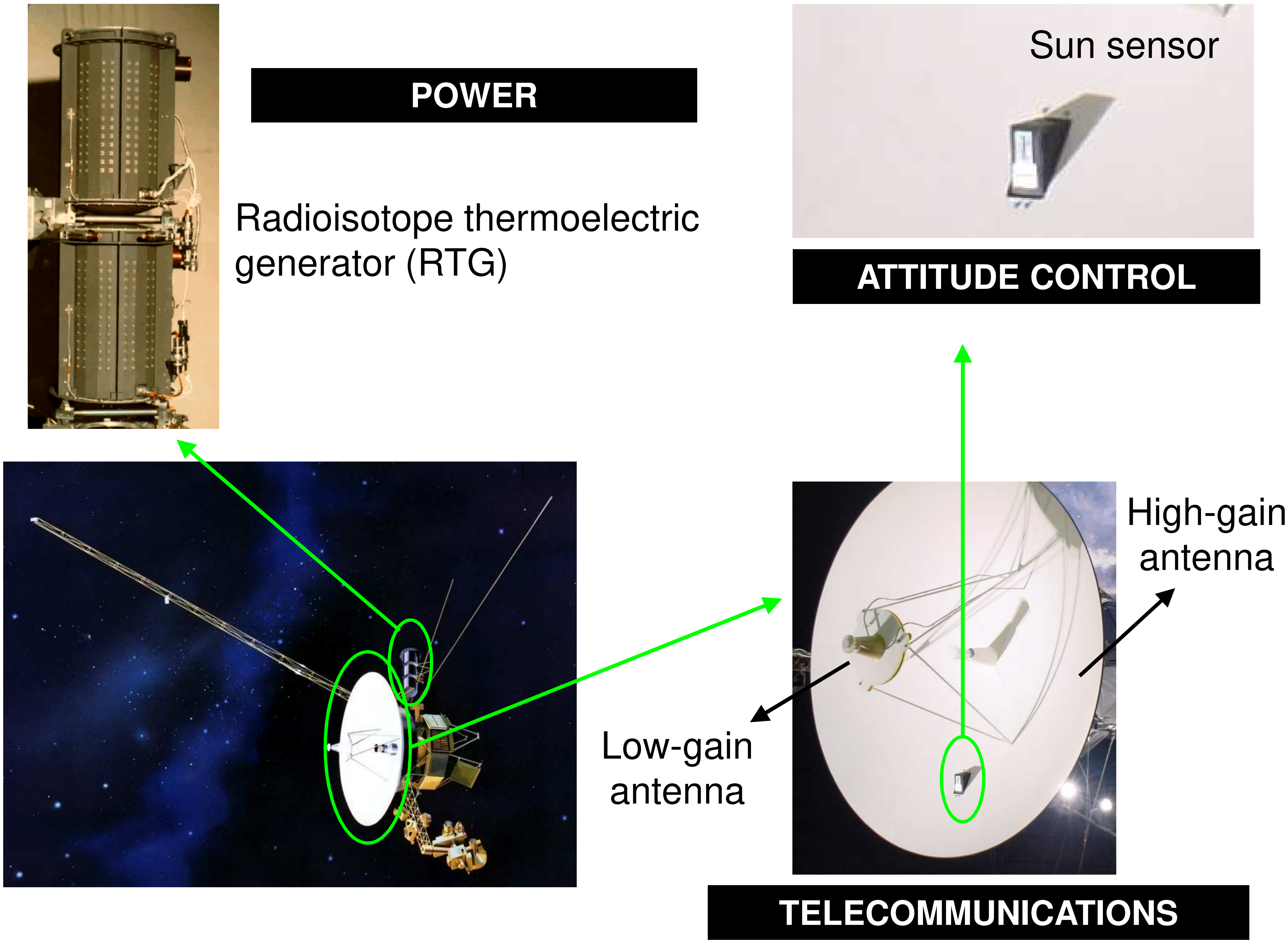


PAYLOAD



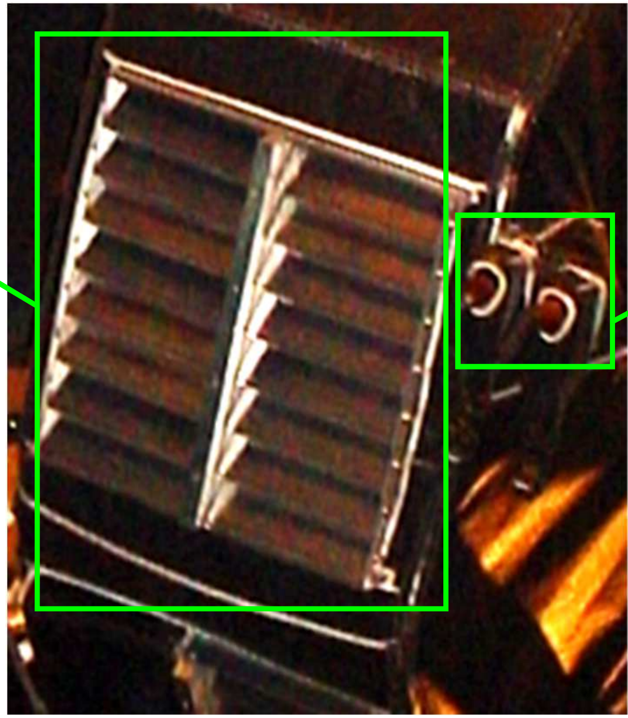
Bus: Complex Assembly of Subsystems

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)
Sun sensor
ATTITUDE CONTROL
High-gain antenna
Low-gain antenna
TELECOMMUNICATIONS

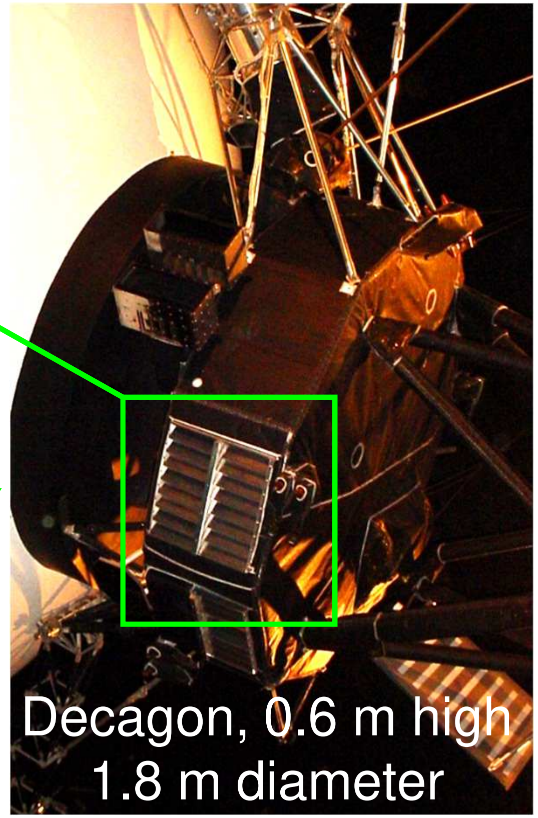
Louvers

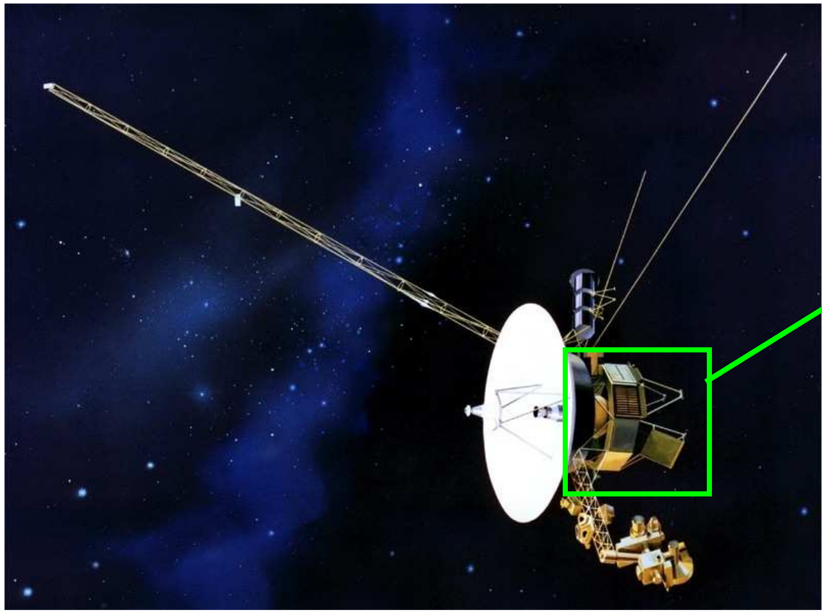
THERMAL CONTROL



N_2H_4 thrusters

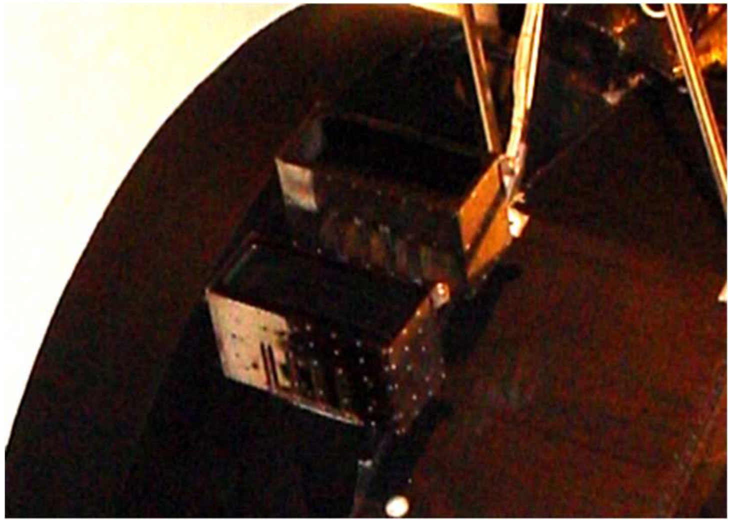
PROPULSION



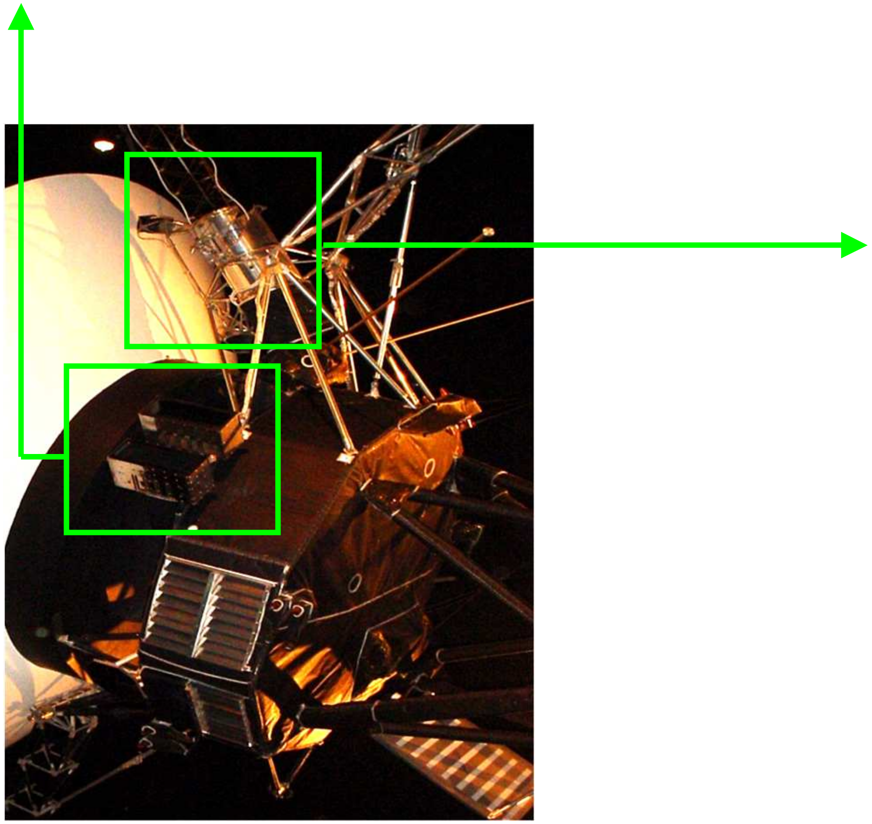


STRUCTURE

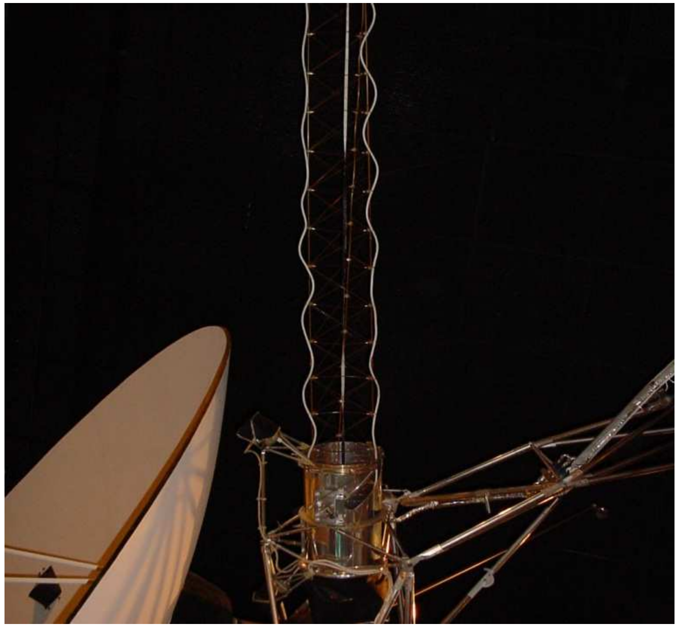
ATTITUDE CONTROL



Star tracker

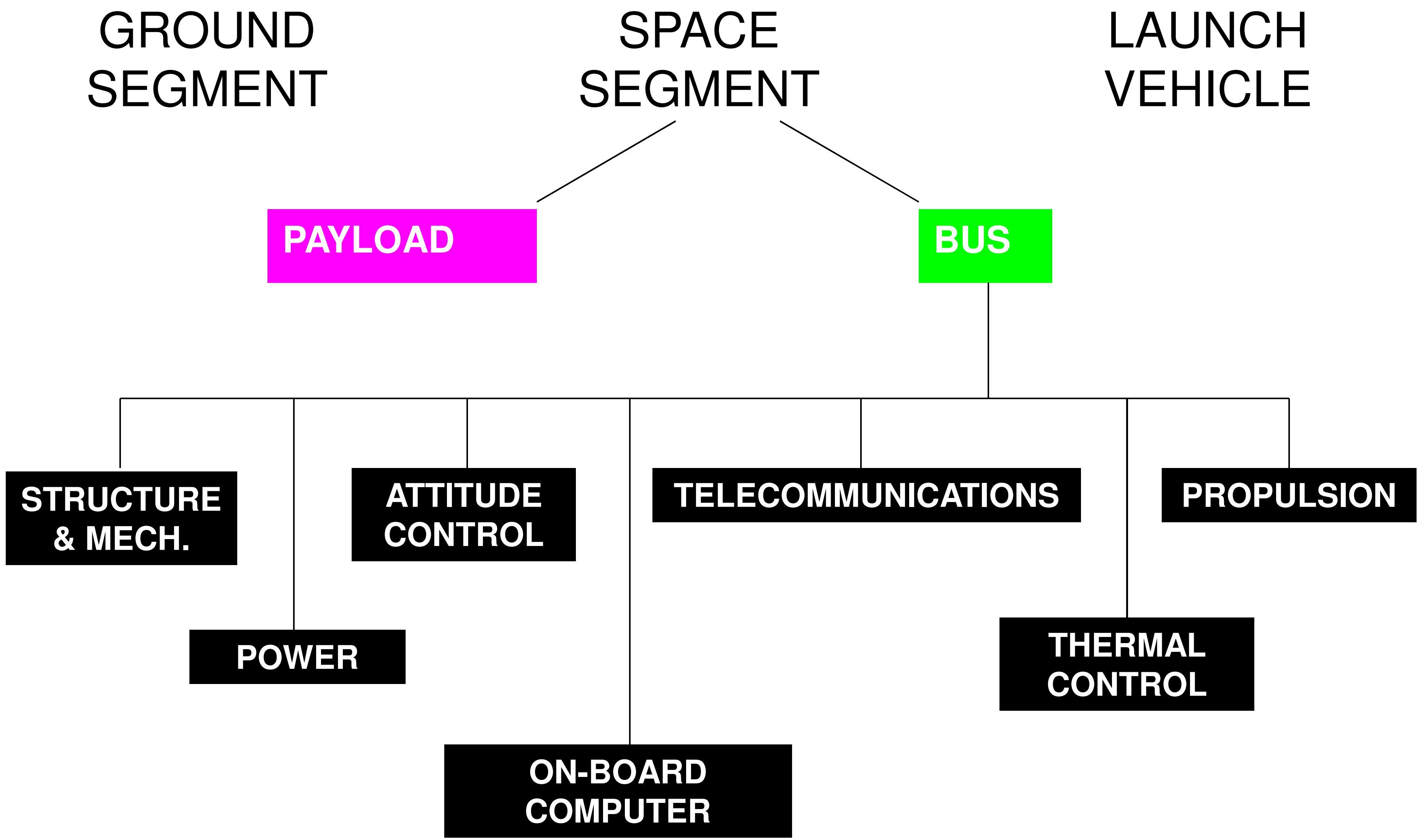


MECHANISMS

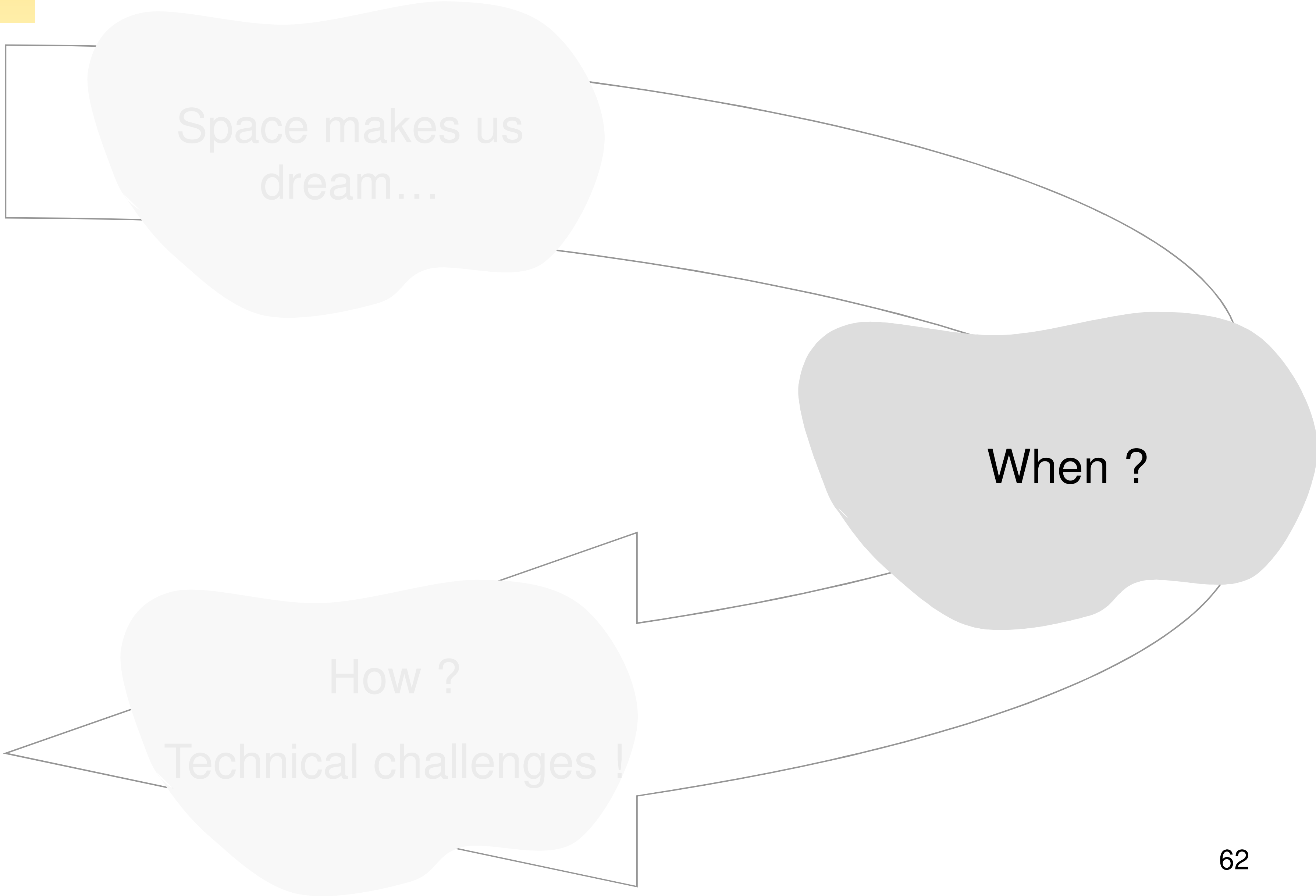


Box containing a deployable truss on which the magnetometer is mounted

In Summary


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

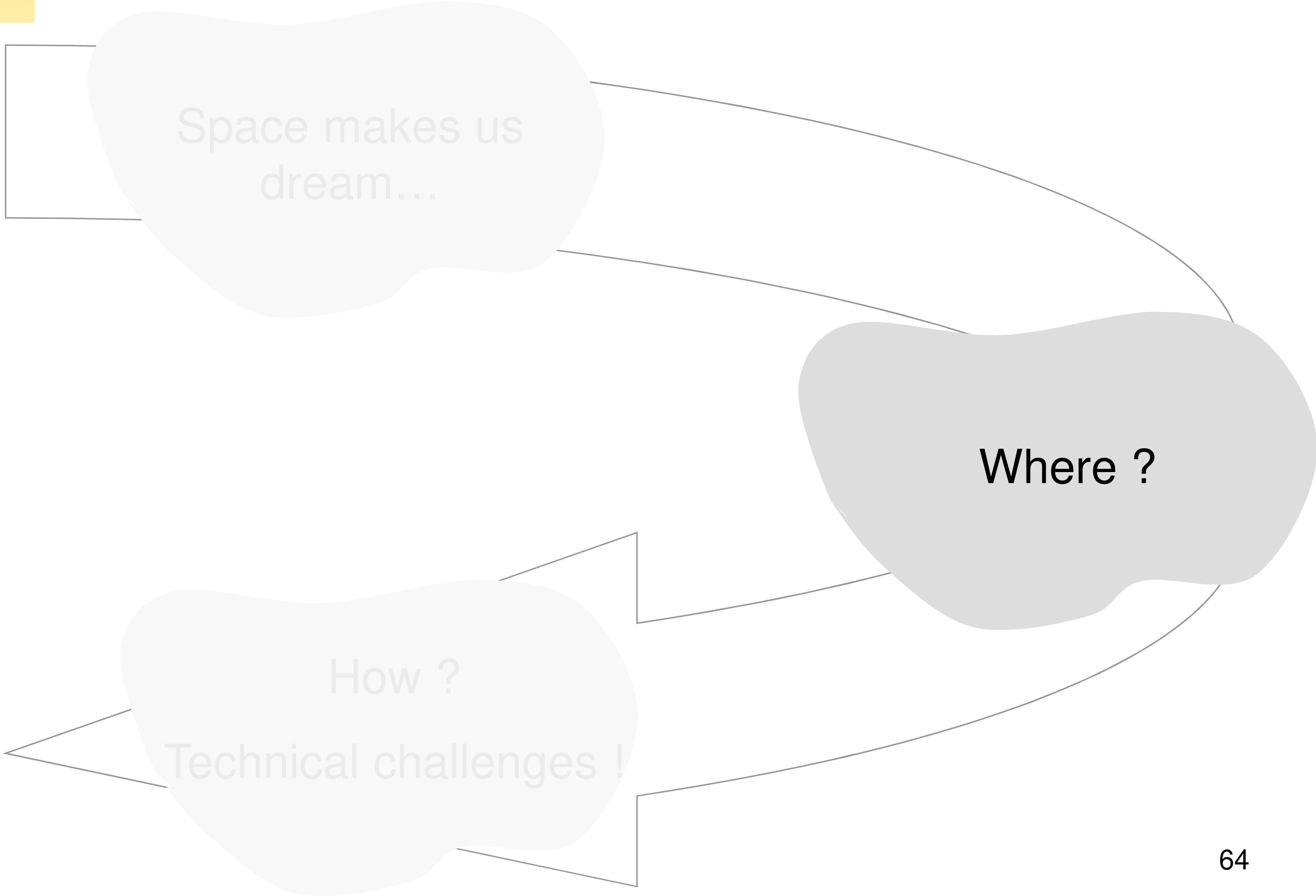
From Dreams to Technical Challenges

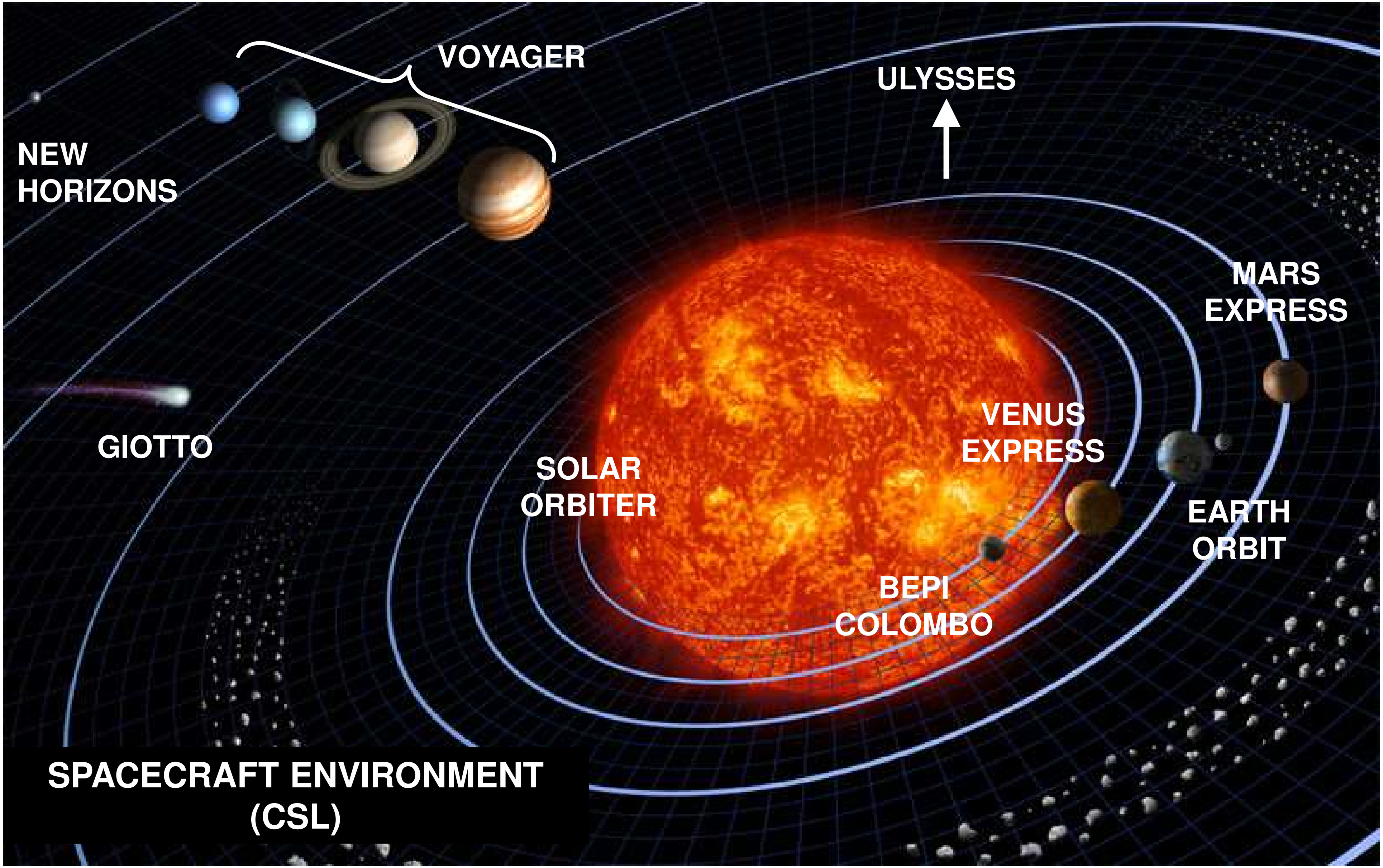


When ?

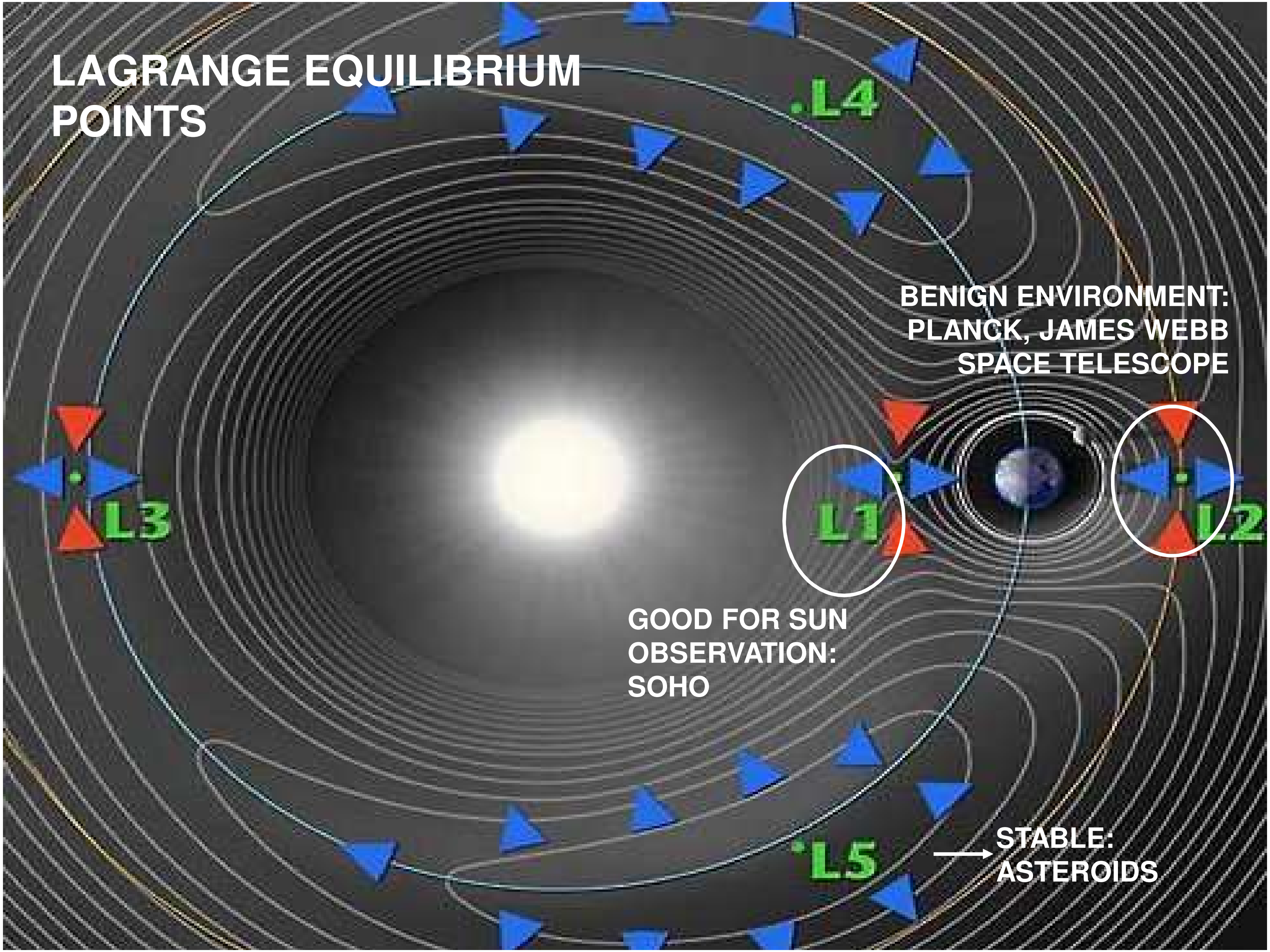
HISTORICAL PERSPECTIVE

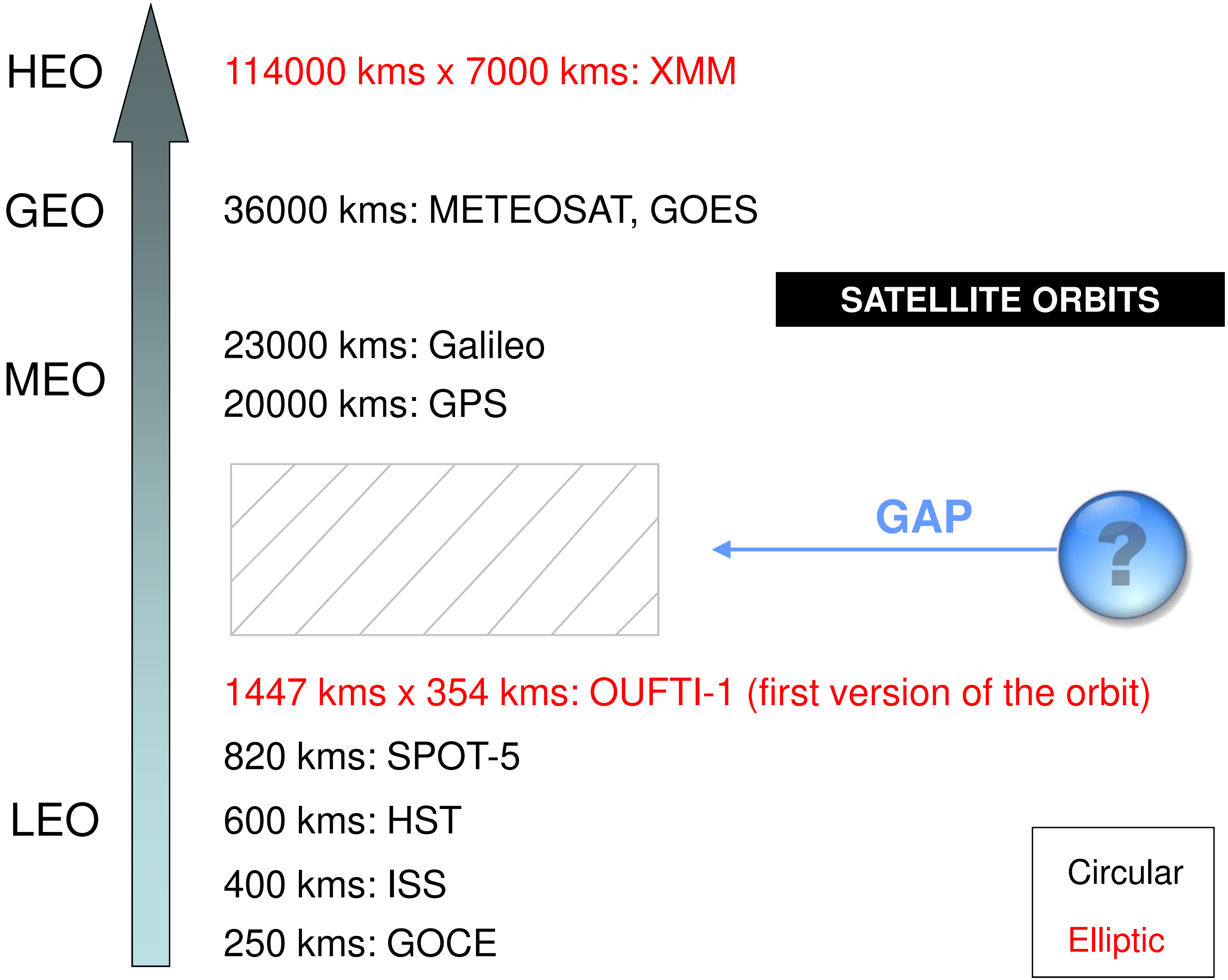
From Dreams to Technical Challenges





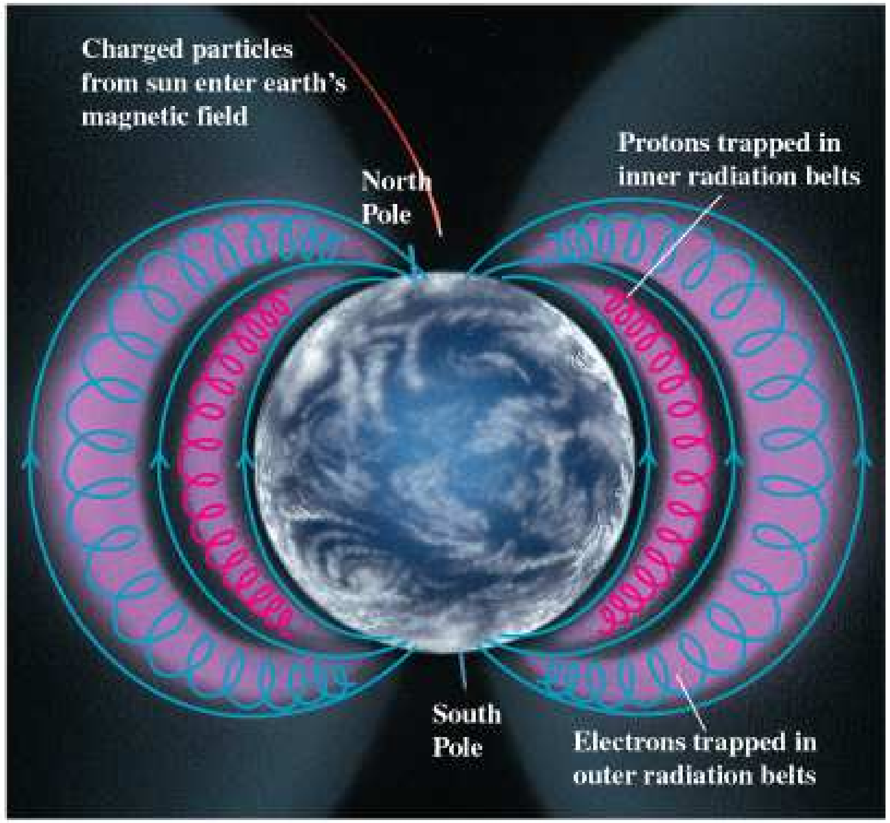
Severe constraints (magnetic field, temperatures, atmosphere, launch vehicle, ground station visibility, eclipse duration)


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

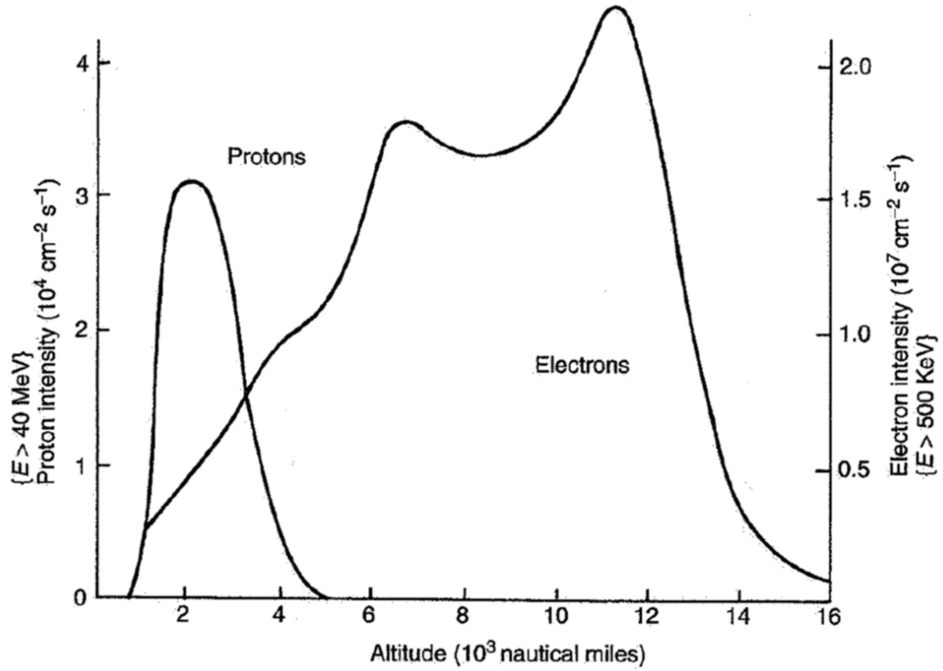


HEO
114000 kms x 7000 kms: XMM
GEO
36000 kms: METEOSAT, GOES
SATELLITE ORBITS
MEO
23000 kms: Galileo
20000 kms: GPS
GAP
1447 kms x 354 kms: OUFTI-1 (first version of the orbit)
LEO
820 kms: SPOT-5
600 kms: HST
400 kms: ISS
250 kms: GOCE
Circular
Elliptic

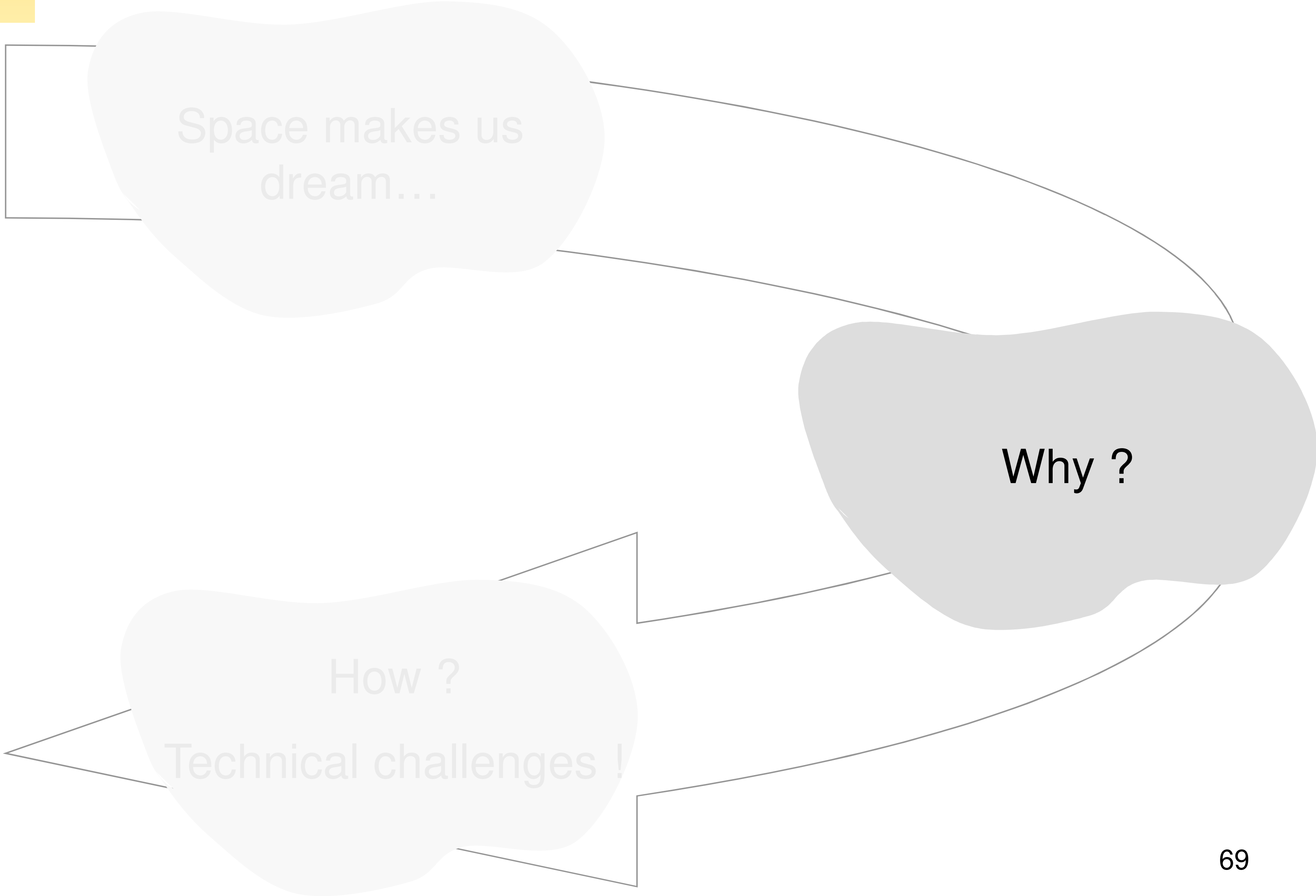
Gap ? Van Allen Belts



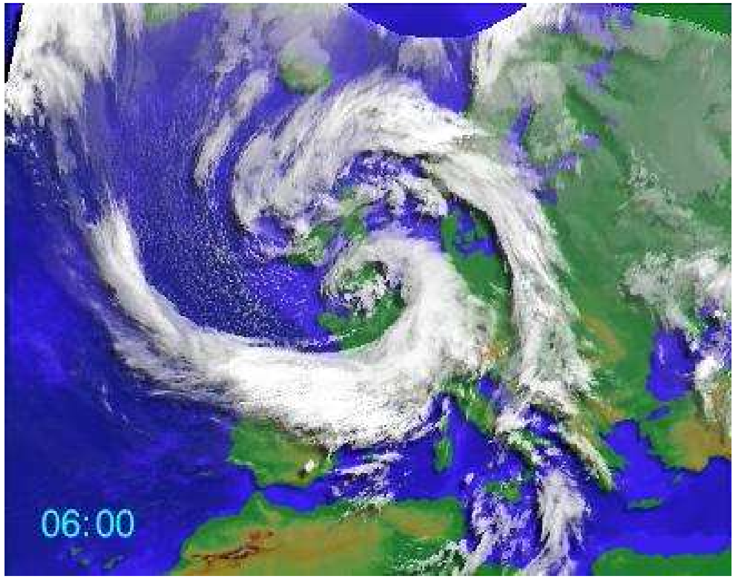
SPACECRAFT ENVIRONMENT



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

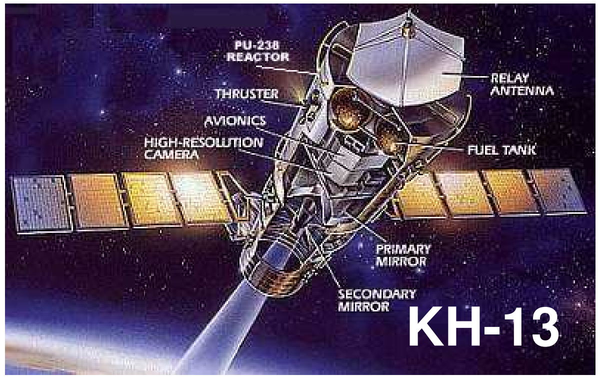
In-orbit configuration: 26 m x 10m x 5m (the size of a bus)

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



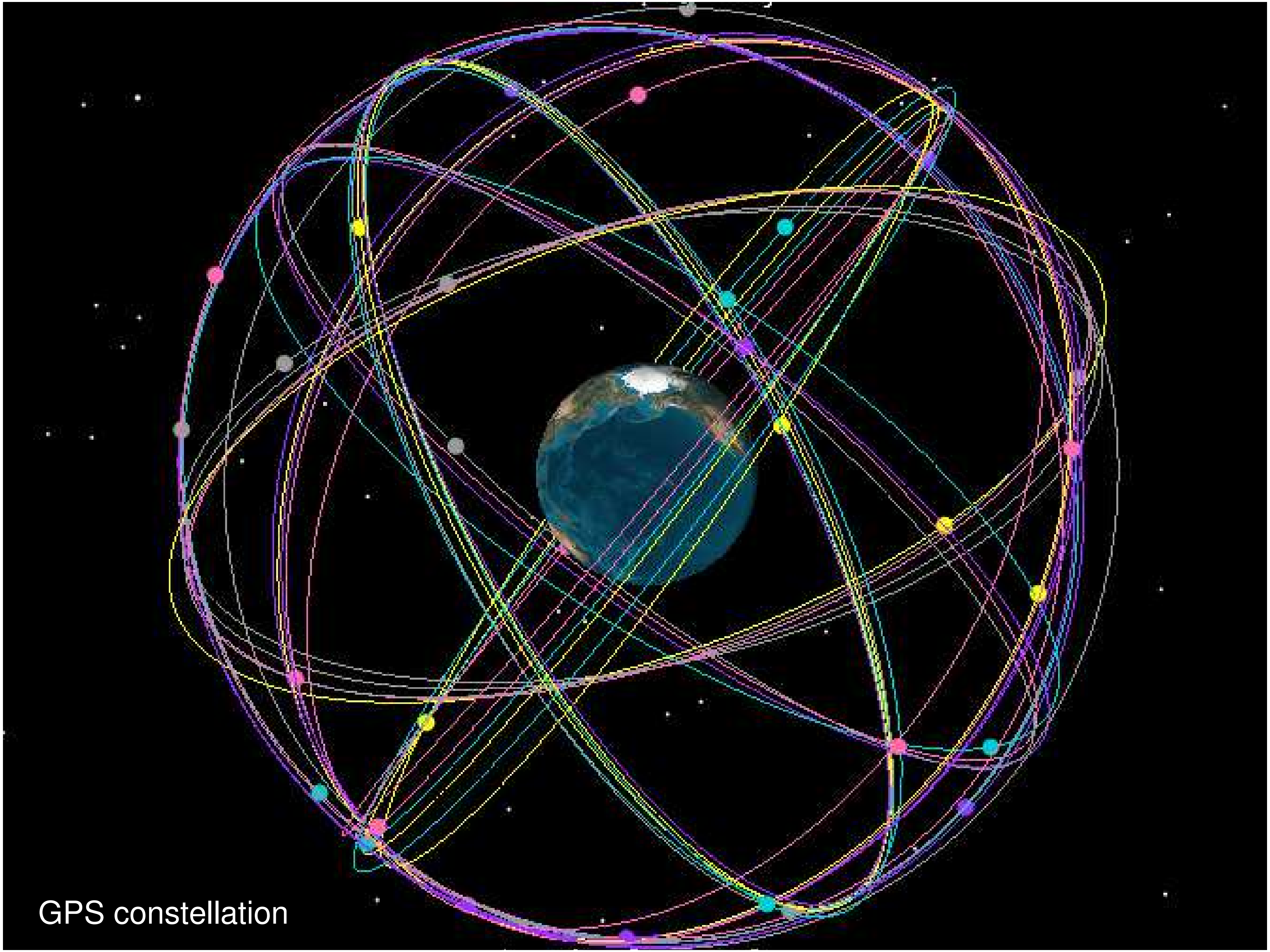
Communications and Navigation

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.

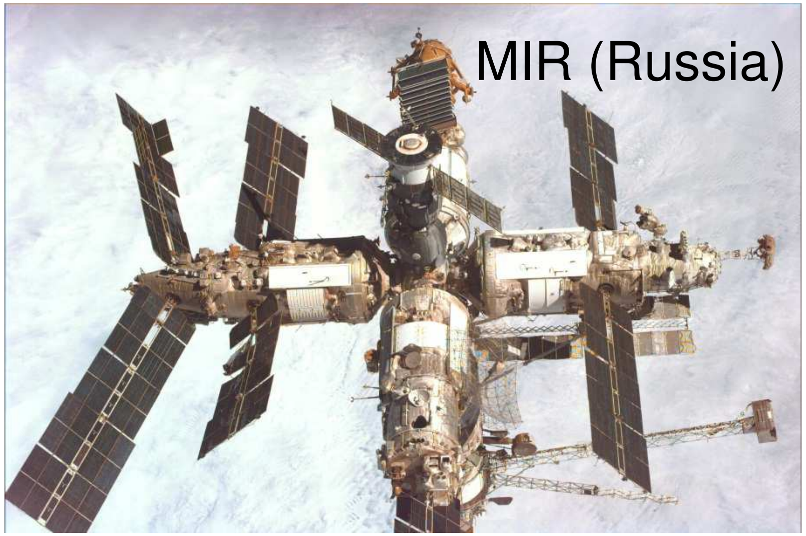
- Observation using different wave lengths (XMM $\Rightarrow$ X rays, IRAS $\Rightarrow$ infrared)

- A single mission has not a single instrument (e.g., more than 10 for Galileo)

ASTROPHYSICS

Space Stations

Perform science experiments under microgravity conditions

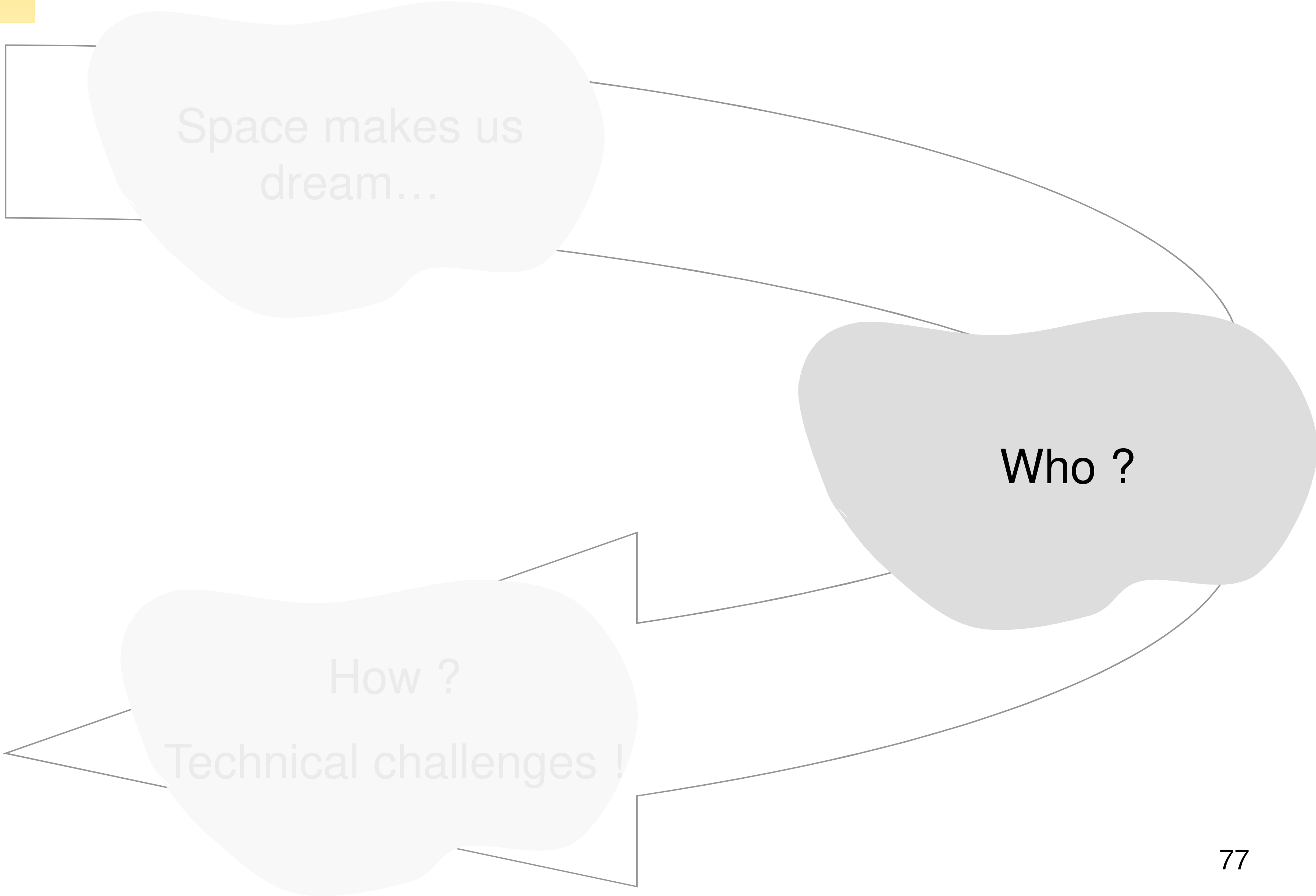


Space Tourism: Inflatable Hotel !

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

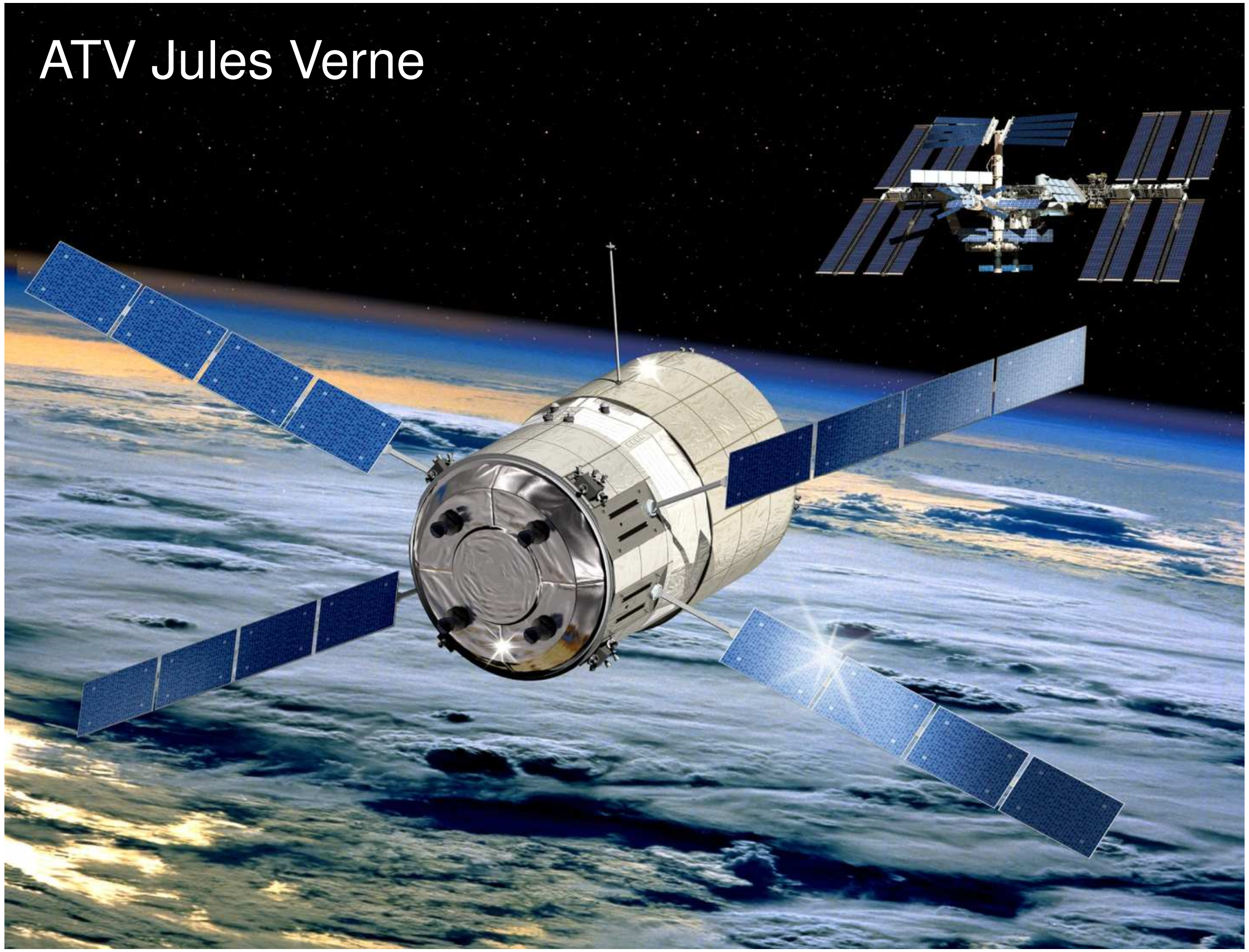
ULiege: 2 unique Masters + LTAS & AGO

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

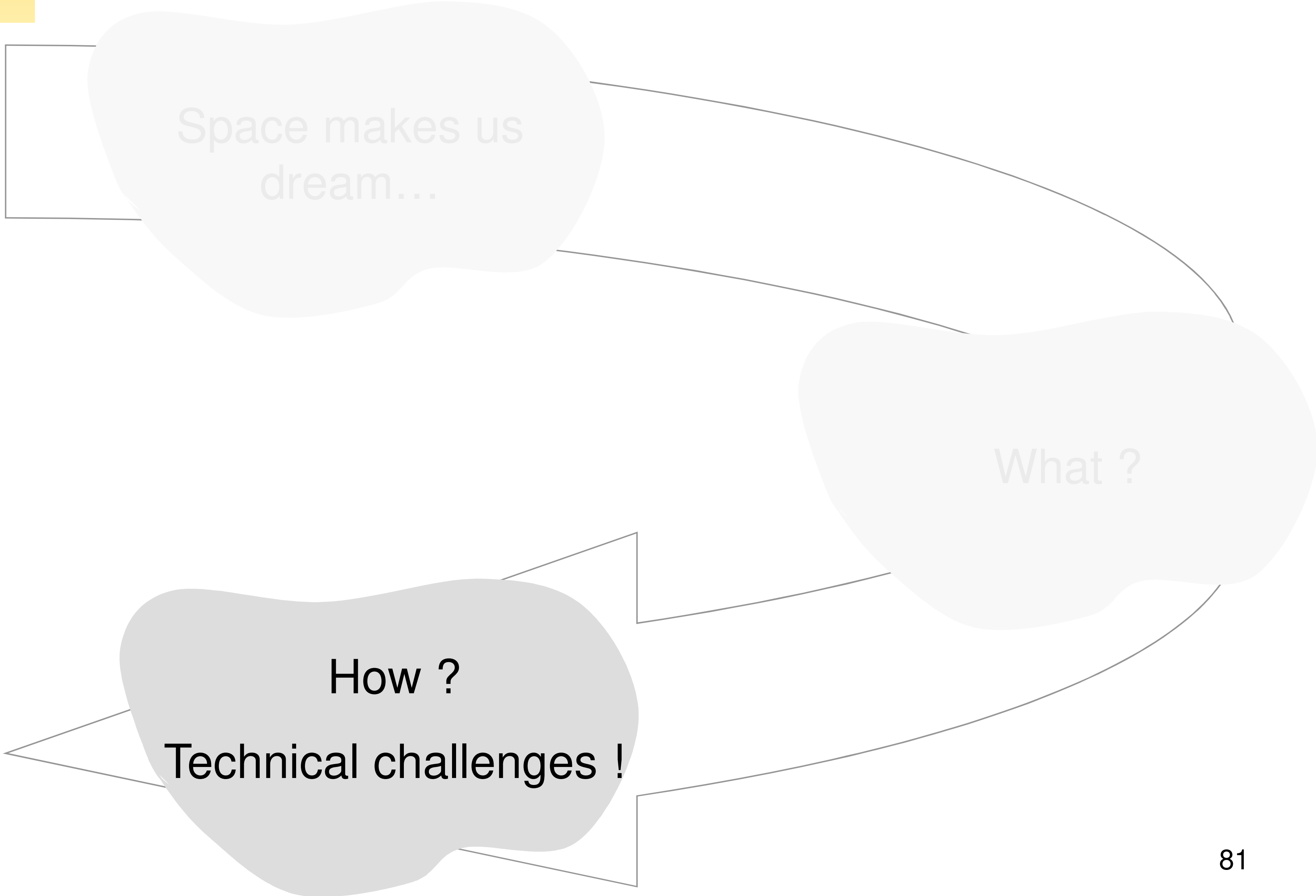
Spacebel: software

Rhea: software

Redu: backup ground station

Techspace aero: aestus engine valves

From Dreams to Technical Challenges



Satisfy Customer's Basic Goals

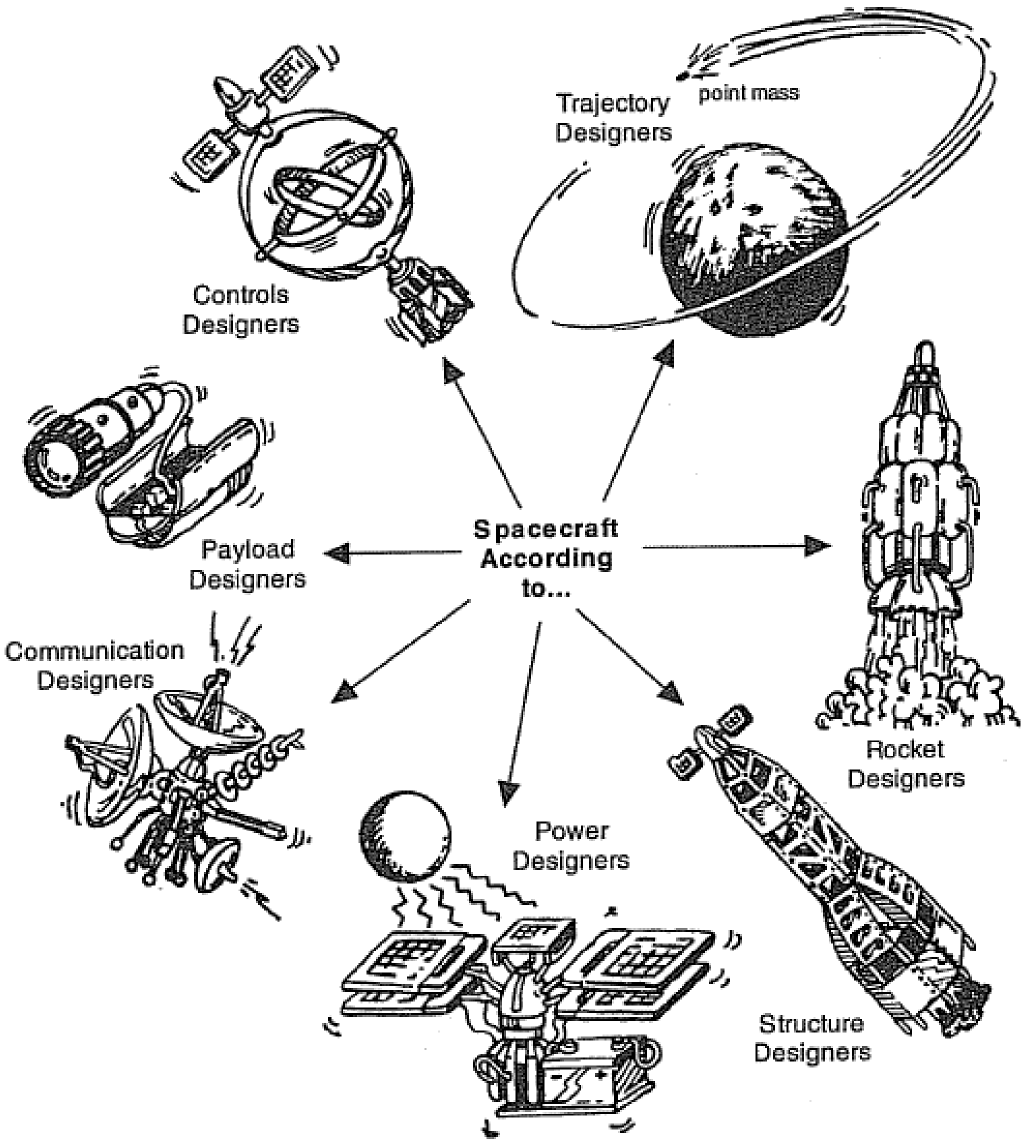
1. Payload design

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

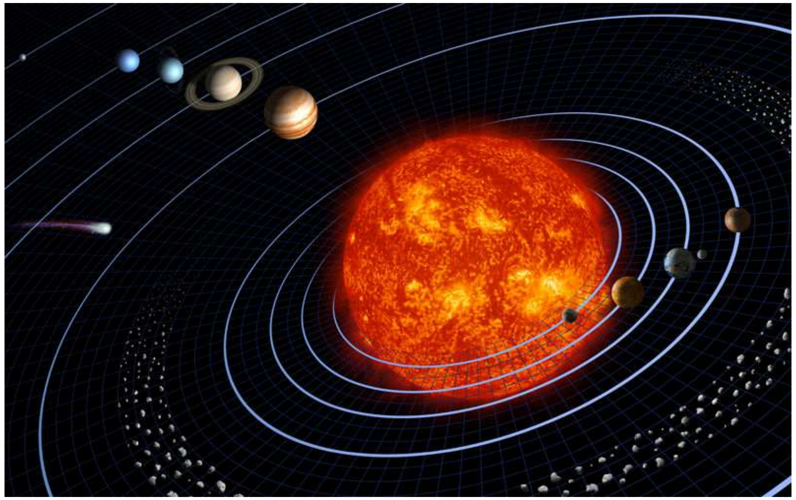
Look for the optimal solution for the entire spacecraft (do not look for the optimal solution for your subsystem)

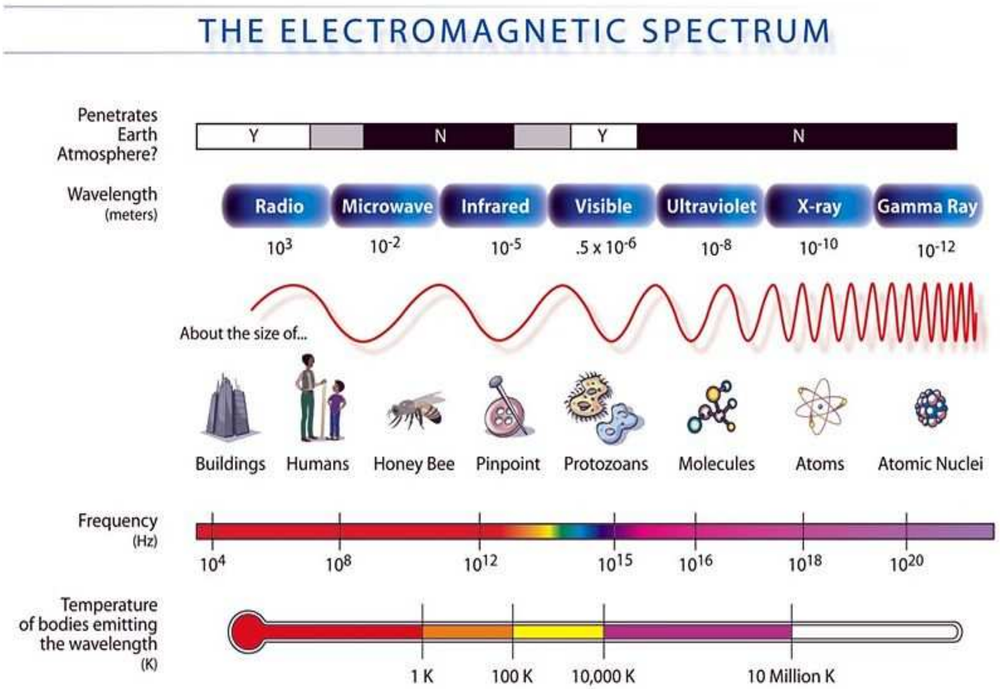
This course is intended to give you an overview of the different subsystems, so that you will understand the challenges faced by your colleagues who are expert in power systems telecommunications, etc

Concurrent Design Facility, ESTEC-ESA

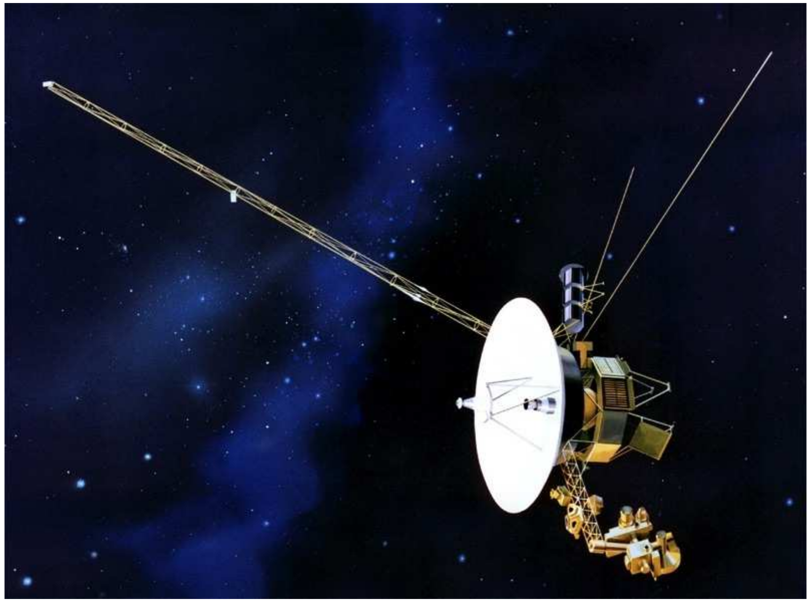
Challenge #2: Each Mission is Unique

Where ? & Why ?





Solution: Fit the Requirements



$\neq$

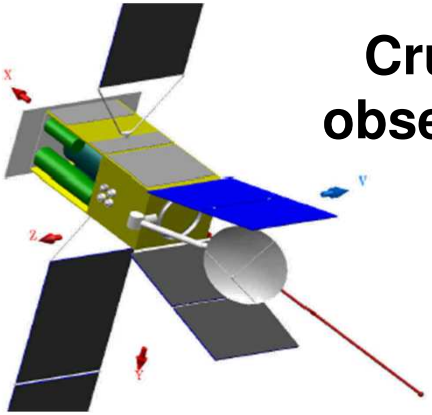
Solution: Fit the Requirements

Roll-out

Hubble

Whipple shield

Stardust

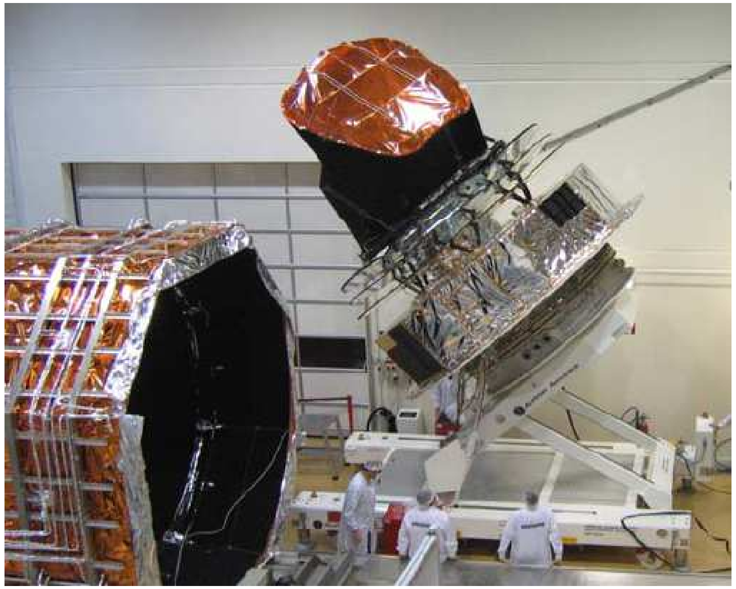


Cruise & observation

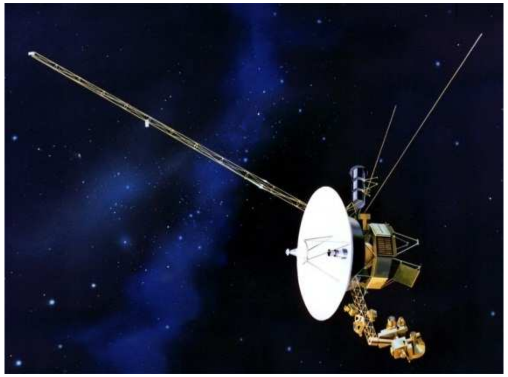
Solar Orbiter

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

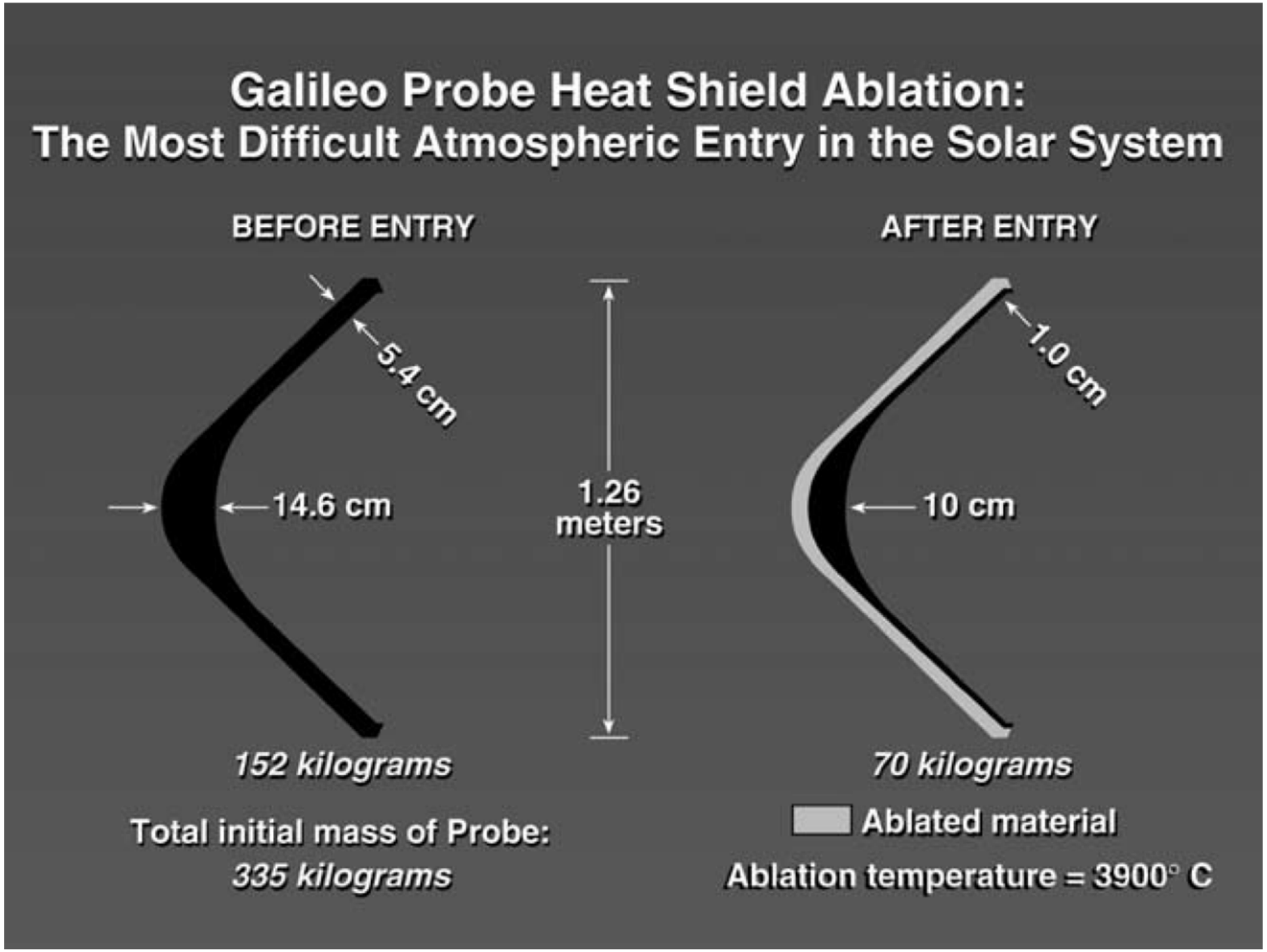


15.000.000.000 kms

10^{-16} W

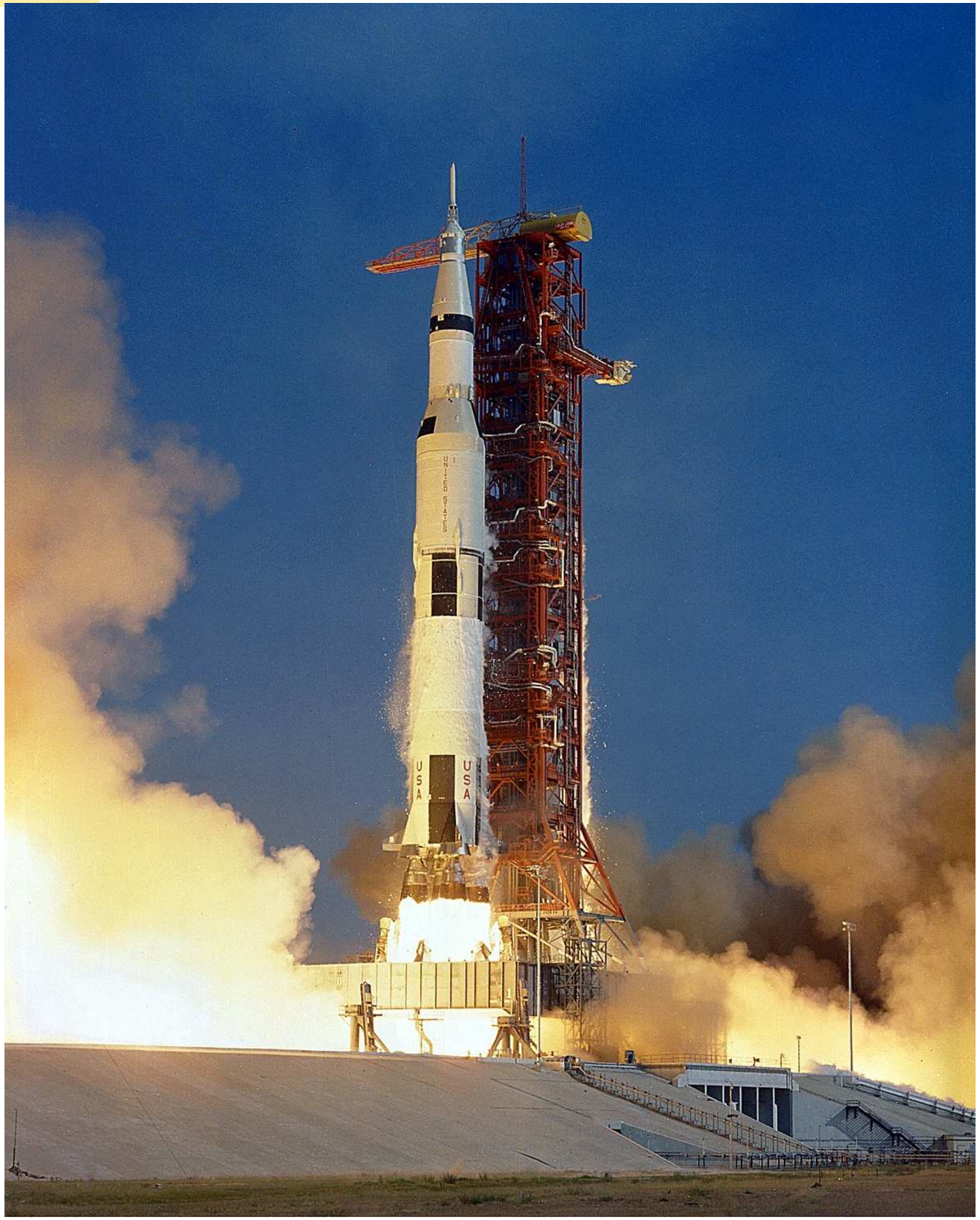
0.007''

Challenge #3: Orders of Magnitude



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

Challenge #3: Not Only the Satellite…



160.000.000 HP

120 billions Watt

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
(355 l/km)

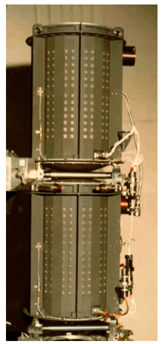
Solution: The Engineer Must Be Creative

15.000.000.000 kms

Power: $15 W/m^2$ (Saturne)

Communications:
10^{-16} W

70-meter antenna



Nuclear materials

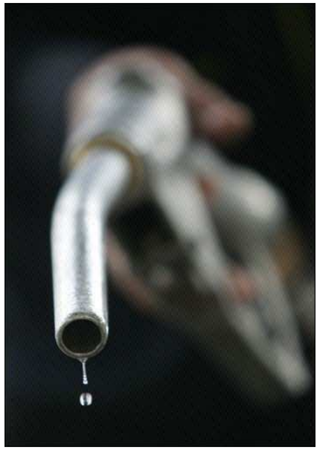
Challenge #4: Severe Constraints

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)

25000 €/kg
Weight
Volume



Fuel

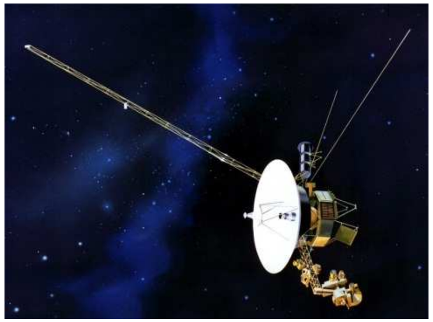
Power
(Voyager: 470 W)

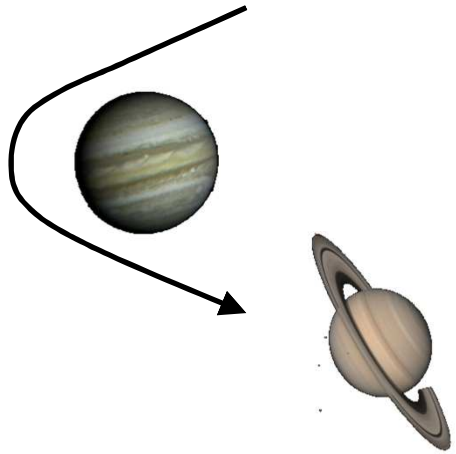
Solution: The Engineer Must Be Creative

Limited volume

Deployable boom (Voyager)

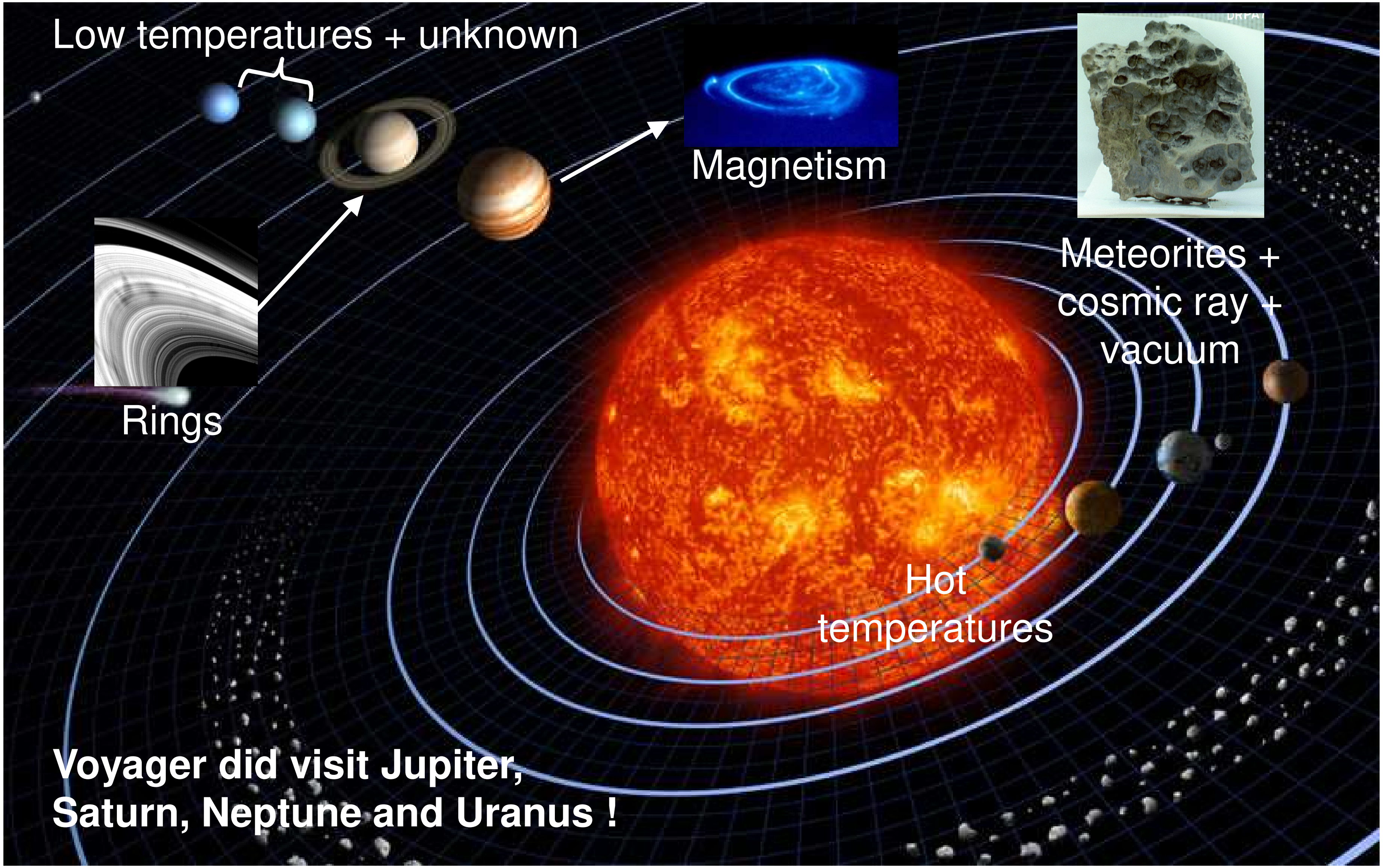
Propergols constraints





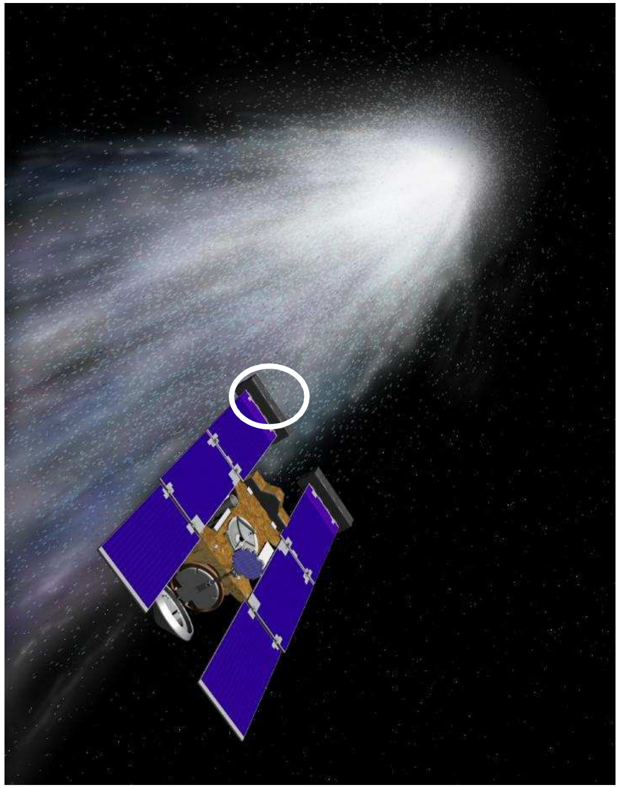
Gravity assist

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