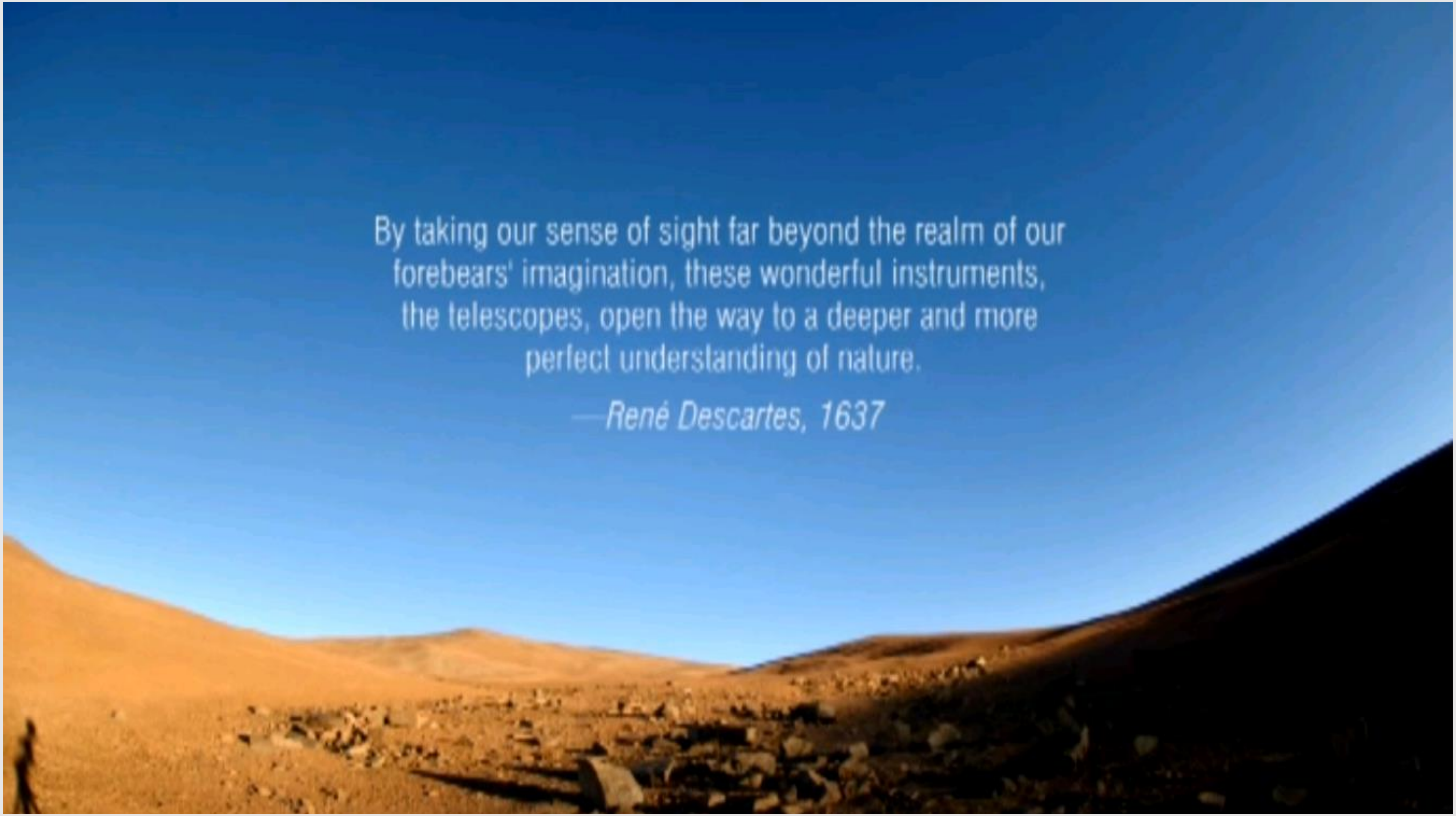
From science requirements

To the conception of a space mission


By taking our sense of sight far beyond the realm of our forebears' imagination, these wonderful instruments, the telescopes, open the way to a deeper and more perfect understanding of nature.
—René Descartes, 1637

Contents

A - Programmatic Context

- Proposals
- Call for ideas
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B - Space projects organization

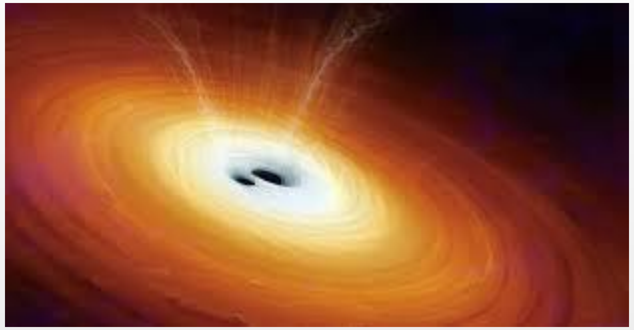
C - Defining a space mission: System approach

D - Constraints associated with an Astrophysical space mission

- Launcher, Satellite, Communication, ground segment
- Orbit, thermal environment, space environment

E – Defining an Instrument

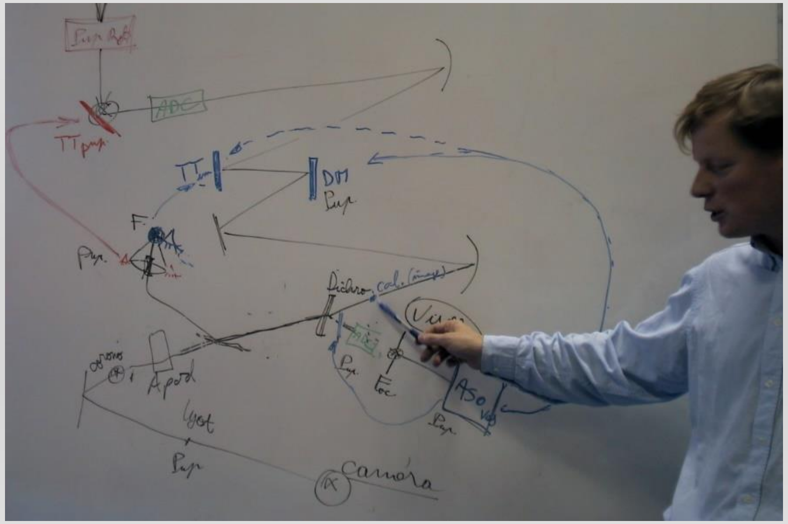
F – Example on the SVOM Mission



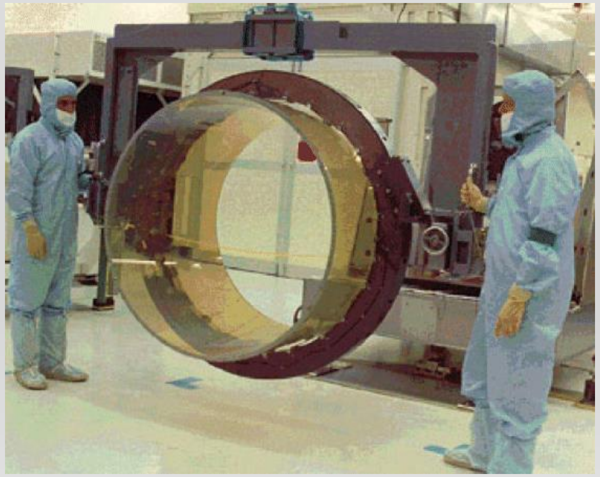
From a **science** objective

To a **Mission** concept...

From **Instruments** concepts ...



Design and realization of space instruments



A - Programmatic context

I - Astrophysical space mission proposal

Who do we answer to:

To the space agencies
(CNES; ESA, NASA, Others : China, Russia …)

What do we answer to:

ESA « Call for scientific ideas », « Cosmic Vision » call

Cosmic Vision 2015-2025 (**Astrophysics**, Fundamental physics, Solar system) : 50 European projects :
The missions are divided in three categories depending on the allocated budget :

- Large class missions (L): maximum cost 900 millions €.
- Medium class missions (M): maximum cost 470 millions €.
- Small class missions (S): maximum cost 50 millions €.

National agencies: for the payloads and laboratories activities

Example for CNES : « CNES prospective» that follows a « call for research projects »

- **Science of the universe**, planetary science, microgravity
- CNES participates financially to ESA programs
- CNES finances the national programs selected

NASA programs (considered as a « mission of opportunity »)

Missions of opportunity : depends on the national space agencies

Cosmic Vision 2015-2025 missions

Table 1: Building the science programme – missions in Cosmic Vision 2015-2025			
Date of Call	**Mission class**	**Candidate missions**	**Selected missions**
March 2007	Medium (M1)	Cross-Scale, Euclid, Marco Polo, PLATO, Solar Orbiter, SPICA	Solar Orbiter
	Medium (M2)		Euclid
	Large (L1)	IXO, Laplace (reformulated as JUICE), LISA	JUICE
July 2010	Medium (M3)	EChO, LOFT, MarcoPolo-R, PLATO, STE-QUEST	PLATO
March 2012	Small (S1)	CHEOPS	CHEOPS
January 2014	Large (L2)	Athena	Athena
August 2014	Medium (M4)	ARIEL, THOR, XIPE	ARIEL
January 2015	Mission in cooperation with CAS ([1])	SMILE	SMILE
April 2016	Medium (M5)	EnVision, SPICA, THESEUS	*M5 selection planned for 2021*
October 2016	Large (L3)	LISA	LISA
July 2018	Fast (F)	*Call is open until 20 March 2019*	*F candidate selection planned for 2019*

II – Call for ideas

- **Expression of the science case**
  - **Actual status of the research** in the field of the proposal
  - Detail of the "**added scientific value**" of the mission (improvements with respect to previous mission)
  - Field, energy domain, accuracy and so on not already covered by existing missions

- **Proposition of a mission concept**
  - **Description of the mission and instruments concept** (Mission concept, Orbit, payload (Instruments), Operational concept: Observation strategy)
  - **System performance requirements**:
    - Performances requirements (pointing accuracy, pointing stability etc …)
    - Operational constraints, ground segment

      $\Rightarrow$ technical challenges

      $\Rightarrow$ Risks ?

      $\Rightarrow$ Need for a Research and Technology ? (developing new detectors, new AOCs system to develop …)
  - **Project organization and agenda**
  - **Collaborations**
    - Technical collaboration (who is doing what part of the mission)
    - Scientific collaborations (Institutes involved in the research)

III Evaluation

- **ESA:**

Thematic groups (AWG: **Astronomy working Group**, Solar System Working Group, Fundamental Physics Working Group) …)

  - Science Advisory Committee (SSAC)
  - Science Program Committee (SPC)
  - ESA Executives

- **National space agencies (example CNES)**

Thematic groups

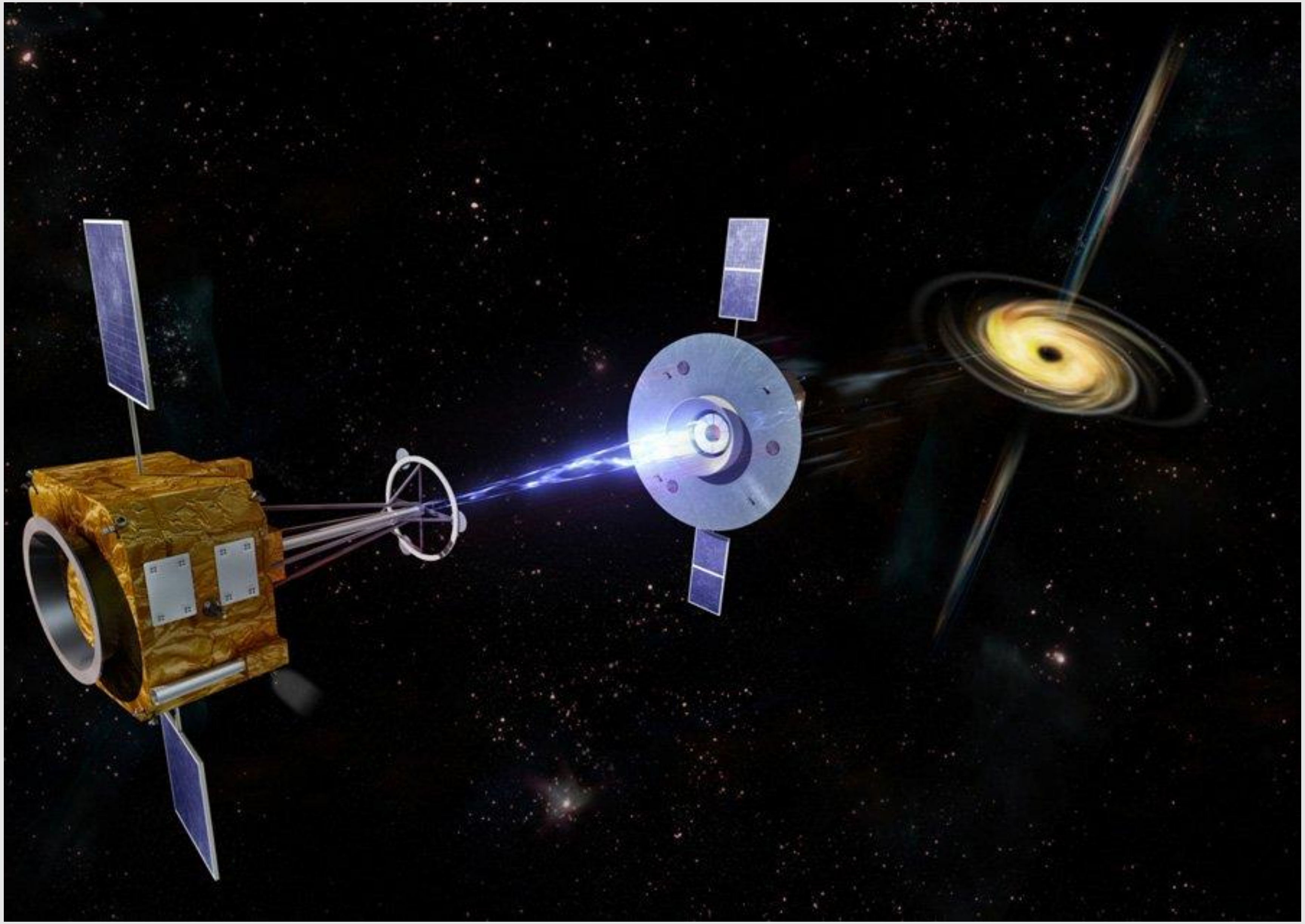
  - CERES (Comité d'Evaluation de la Rechercvhe et de l'exploration Spatiale) => internal evaluation of the projects (CNES)
    - Many thematic (planeto, Atro, Exobio, Fundamental physics …)
  - CPS : Comité des programmes scientifiques => Selection

  - Considerations
    - CPS recommendations
    - Equilibrium between thematic
    - Financial aspects

If selected, we follow the life cycle of a project :

Conception / Definition / realisation / Integration / validation / Qualification / Exploitation

Example of proposal: Simbol X, an advanced X ray mission (2005)



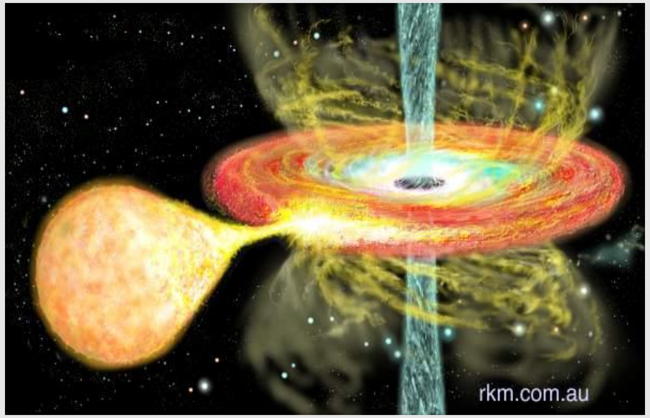
Science case : high energy Astrophisics (Symbol X)

Non thermal emissions in the X and gamma–ray domains reveal dynamical processes which involve very large transfers of matter and energy in a variety of astrophysical objects, at all scales from stars to clusters of galaxies

- ⇒ Hot plasmas in with very strong gravity fields
- ⇒ Strong variability
- ⇒ Particles accelerators, (electrons, protons)

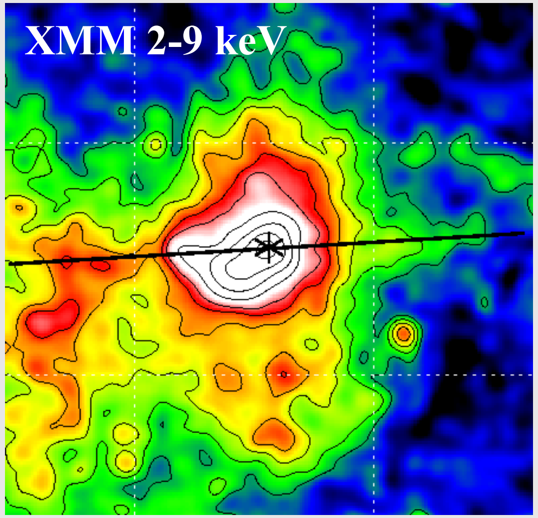
Characteristics: Non thermal X / γ rays electromagnetic emissions

Example : black holes astrophysics



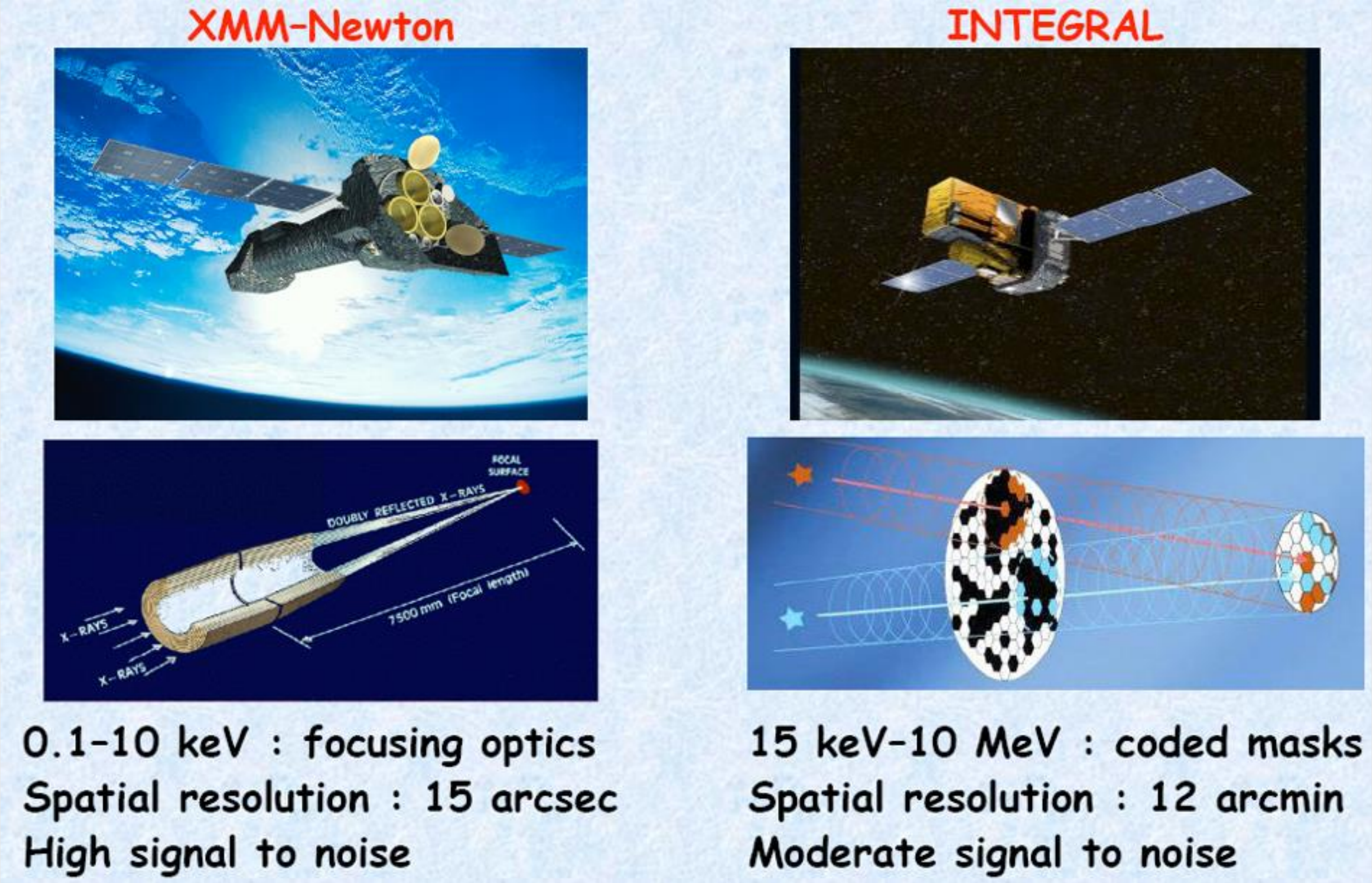
Binary systems with "stellaire" BH

AGN (active hyper massive BH)



Galactic centre

Previous missions



Below ~ 10 keV, astrophysics missions are using X–ray mirrors based on grazing incidence reflection properties.

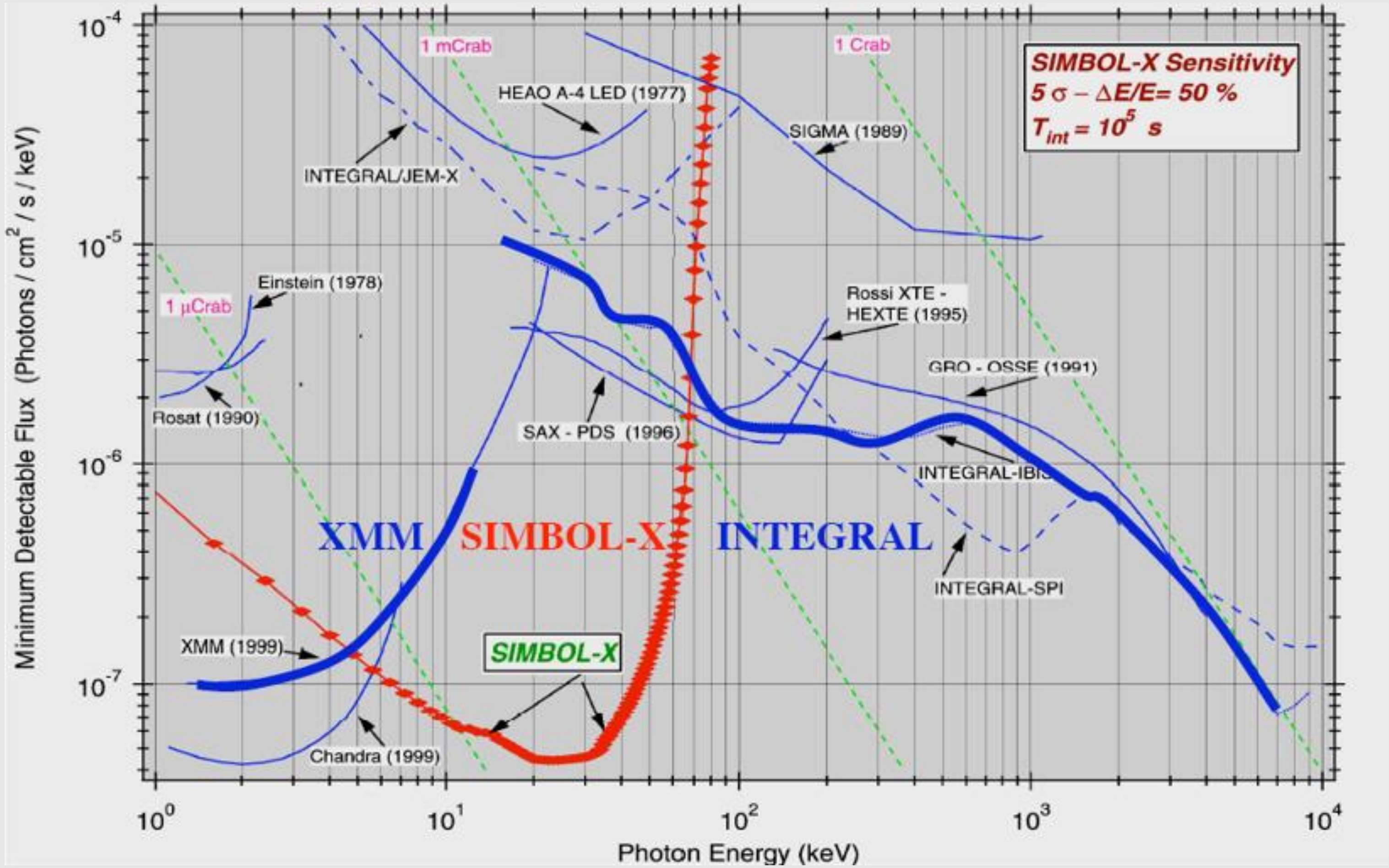
⇒ Extremely good angular resolution, down to 0.5 arcsec for Chandra,

⇒ Good signal to noise thanks to the focusing of the X–rays onto a small detector surface.

⇒ Technique has so far been limited to energies below ~ 10 keV because of the maximum focal length that can fit in a single spacecraft

⇒ **Extend the performance up to 70 keV**

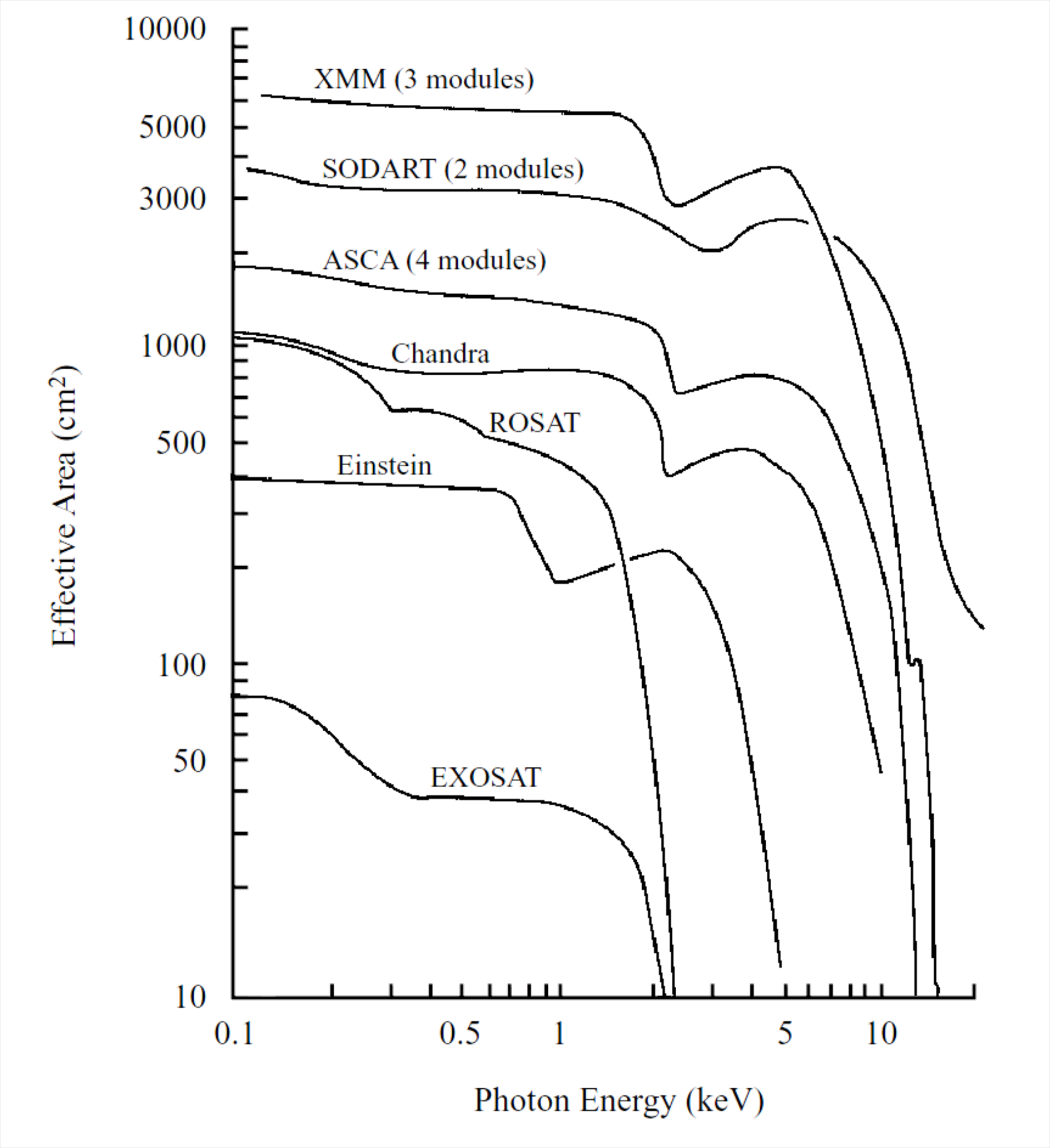
Enhanced sensitivity

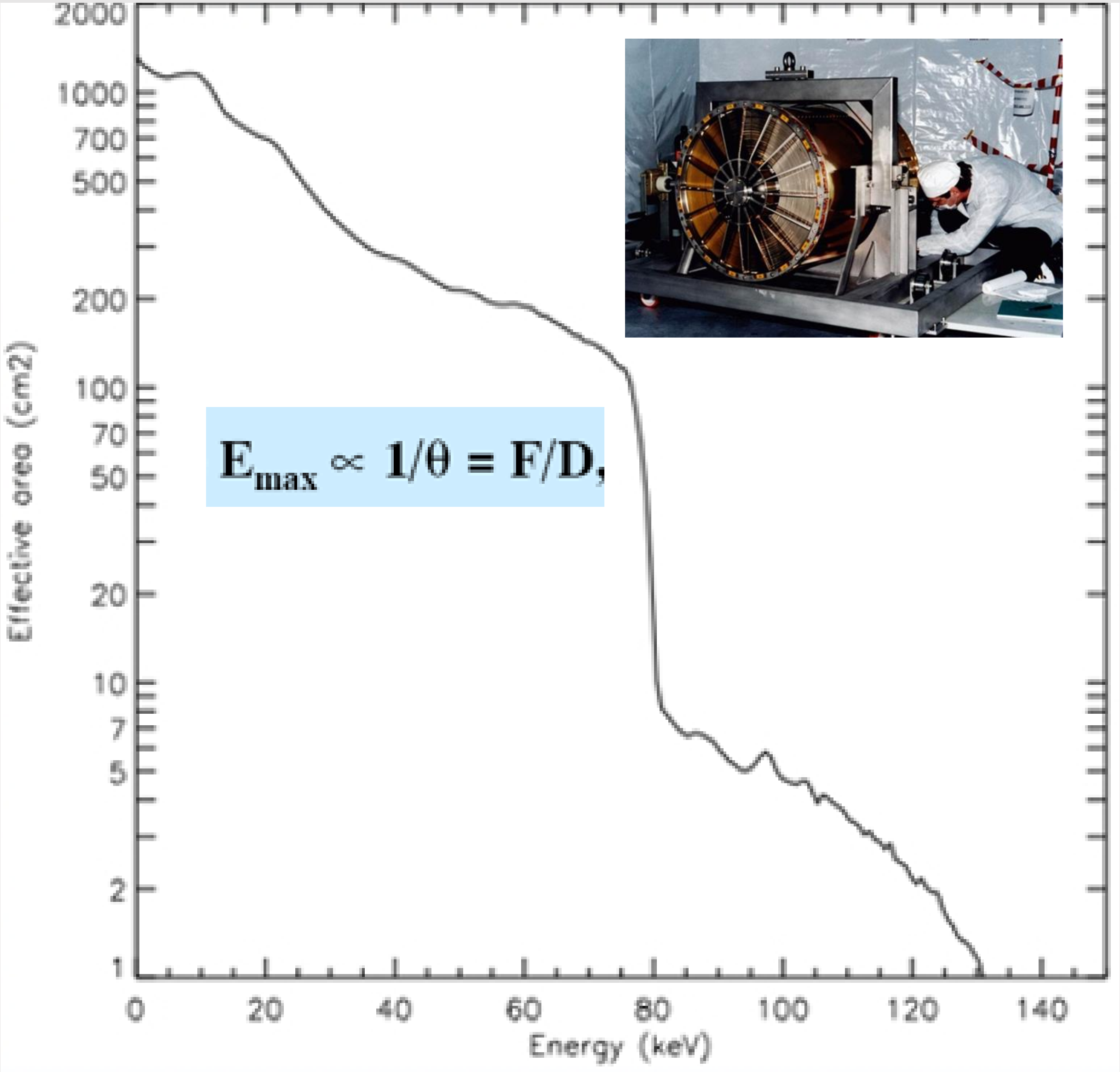


Large gap sensitivity between the X and gamma–ray domains.
Increase sensitivity by increasing effective area

Increase focal length => higher energy & resolution

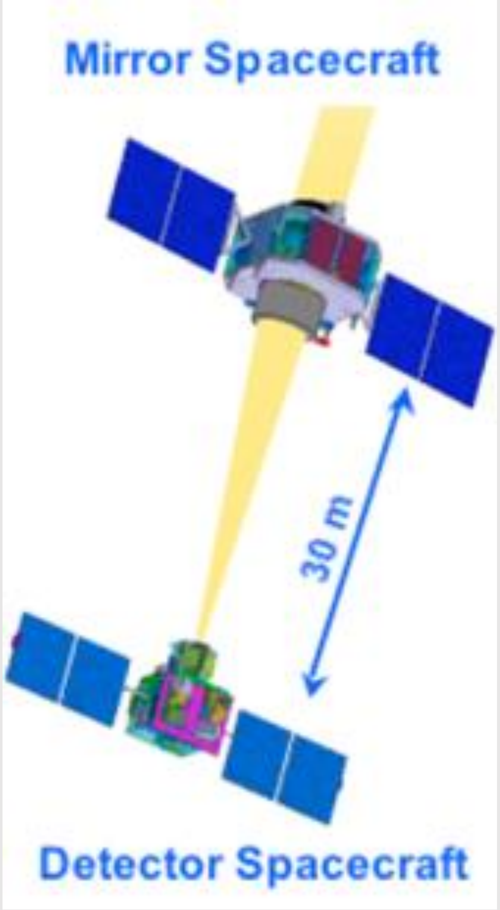
Effective area performance





Mission concept

Long focal length telescope, using grazing incidence X-ray optics, with mirror and detectors mounted on two different spacecraft in formation flying



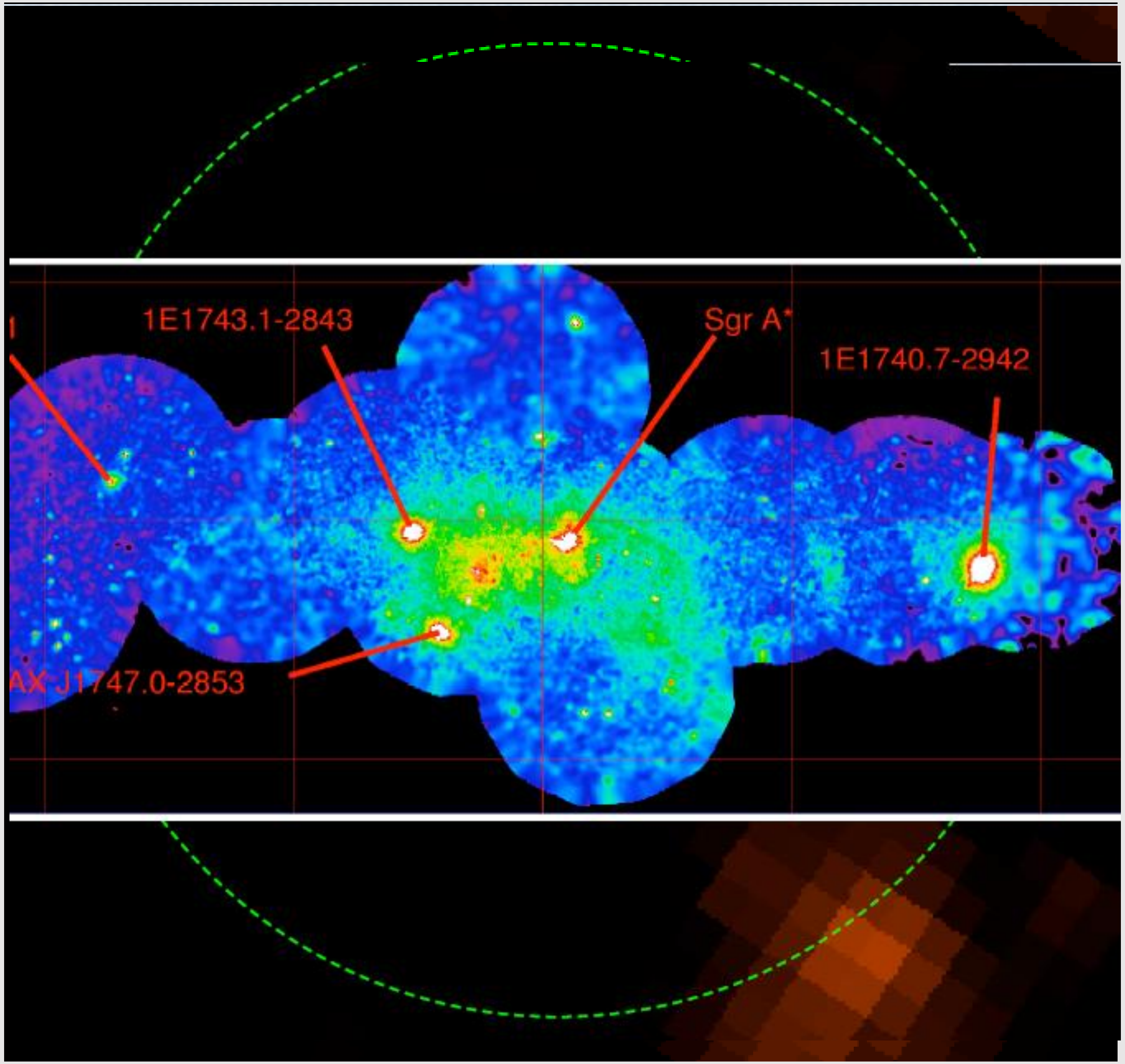
Expected characteristics

- Energy range: 0,5 – 70 keV
- Resolution: < 130 ev @ 6 keV, 1% @ 60 keV (CALISTE detector)
- Angular resolution: < 30 arcsec (localisation < 3 arsec)

Effective area : > 550 cm^2 @ E < 35 keV
150 cm^2 @ E = 50 keV

Sensitivity: 5.10^{-8} ph/cm^2/s (E < 40 keV)
(5 σ, 100 ks, $\Delta E = E/2$)

Comparison with XMM

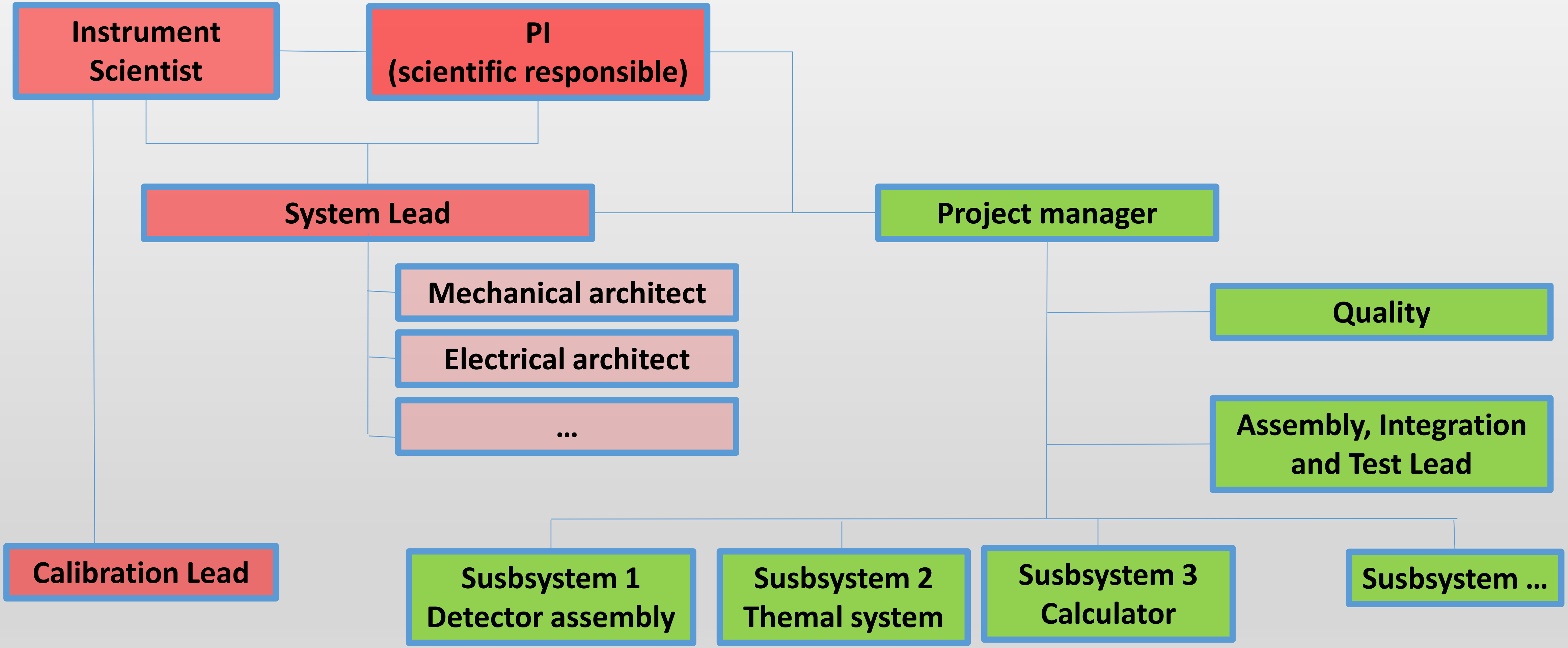


Expected performance

Simbol-X en chiffres	
domaine spectral	0,5-70 keV
résolution en énergie	< 130 eV @ 6 keV, 1% @ 60 kev
résolution angulaire	30 secondes d'arc
précision de localisation	3 secondes d'arc
champ de vue	6 minutes d'arc
surface efficace	550 cm^2 @ E< 35 keV, 150 cm^2 @ 50 keV, 10 cm^2 @ 67 keV
résolution temporelle	10 microsecondes
sensibilité	5 10^{-8} photons/cm^2/s/keV (E>40 keV) (5 sigma, 100 ks, dE=E/2)

B - Few words on space projects organization

Project team for astrophysical space missions



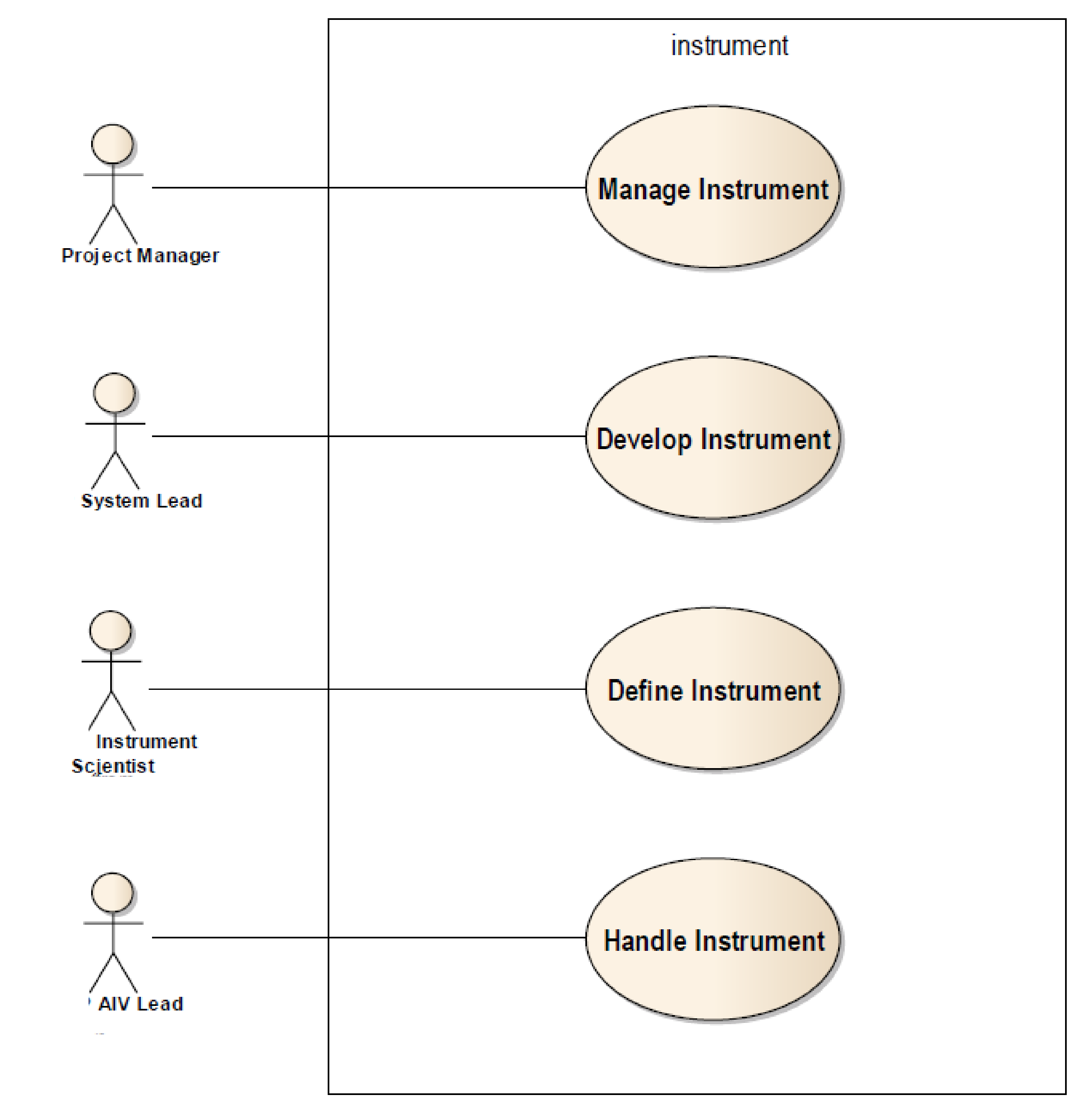
Main responsibilities

In charge of the planning, the budget, the human resources

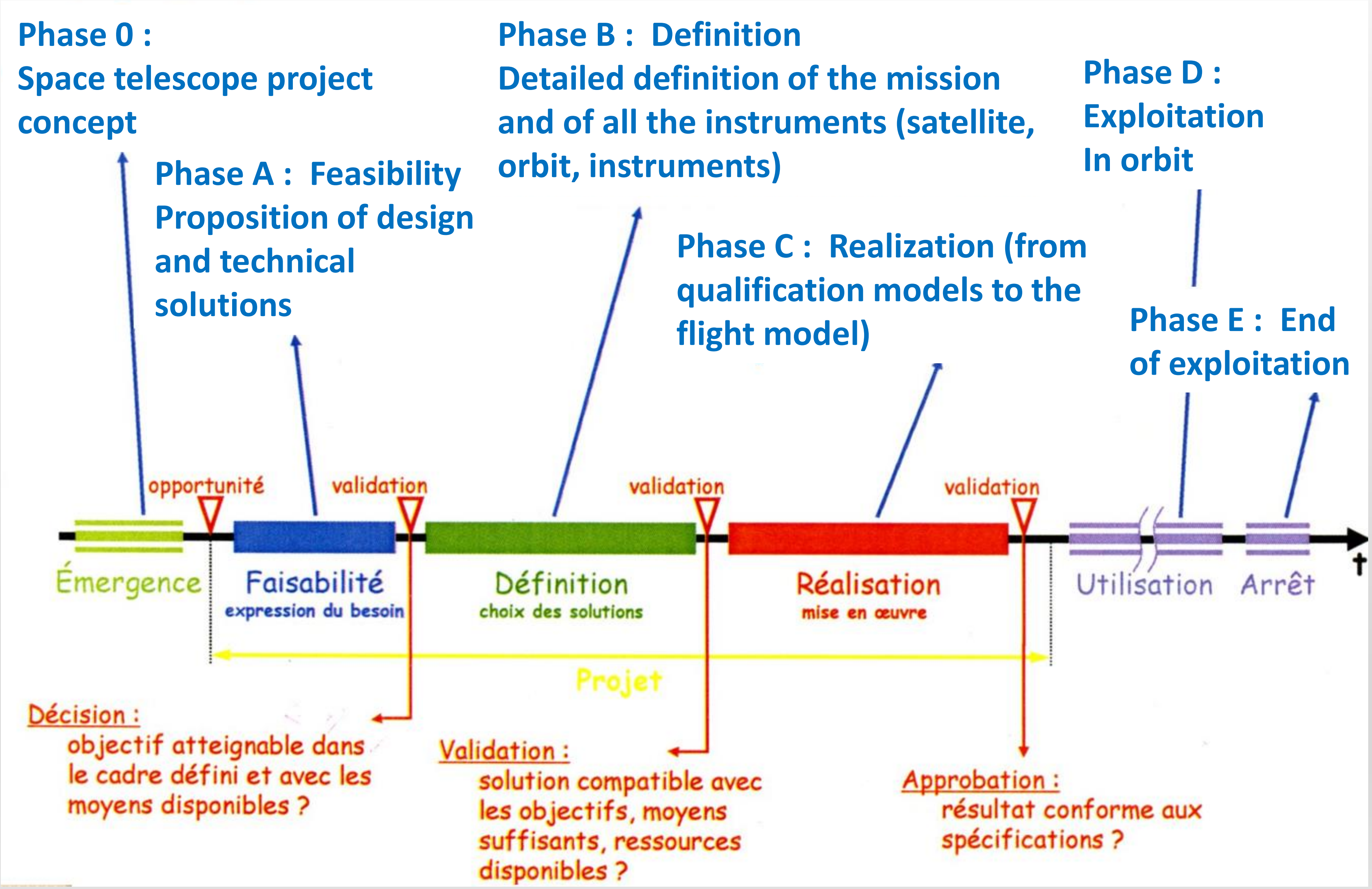
In charge of the performance of instrument and its subsystems

In charge of the definition of the instrument so that it is consistent with the science and takes into account the constraints associated with space environment

In charge of the integration of the instrument subsystems and the verification of the performance



Phases of a space project



C - Defining a space mission
Few words about the System methodology

System Approach to define a mission

SCIENCE

Focusses of the object to observe and to analyze

$\Rightarrow$ <u>Science objectives</u>

INSTRUMENT realization

Focusses on what is achievable

System ENGINEERING

Determines what must <u>be realized</u>

=> <u>Mission and Instrument</u>

Space systems Engineering

- **Complex System definition : (NASA Systems Engineering Handbook)**

  A system is a set of interrelated components which interact with one another in an organized fashion toward a common purpose.

- **System Engineering definition (Halligan 2003)**
  - Interdisciplinary and collaborative approach
  - Incorporates technical and management processes
  - Identify the requirements and constraints applicable to the project
  - Propose a solution that meets the scientific requirements and takes into account all constraints

To design a space mission and space telescopes from the scientific requirements, we use space systems engineering methods

System Approach to define a mission & Instruments

Mission Science objectives

Mission definition

Science Objectives of Instruments within the mission

Instrument definition and technical performance

Mission level:
Define the orbit, the Instruments,
The observation strategy

Instrument level:
Define the instruments and their subsystems

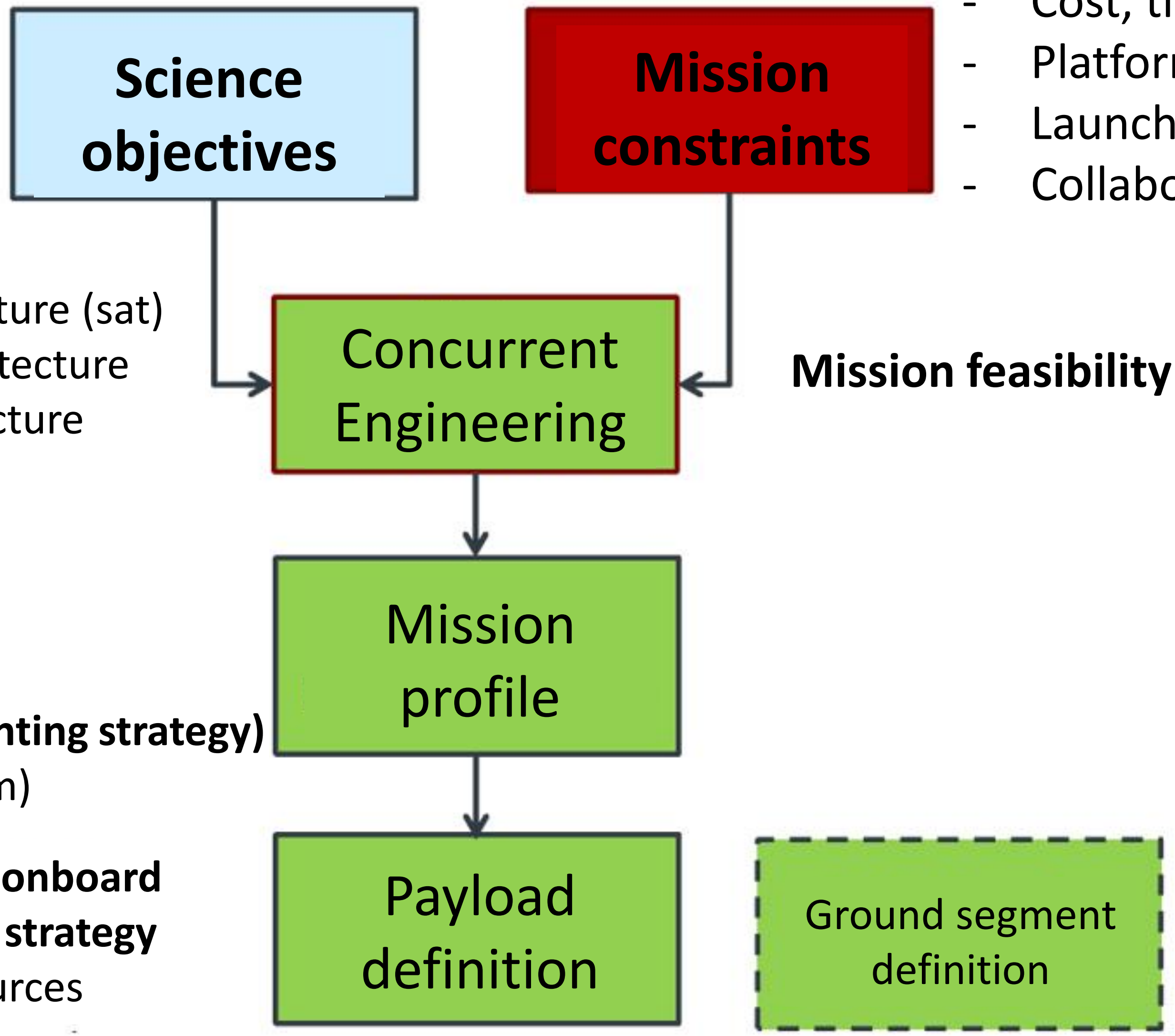
Definition of a mission

- Cost, time delay
- Platform resources (system)
- Launcher constraints
- Collaborations

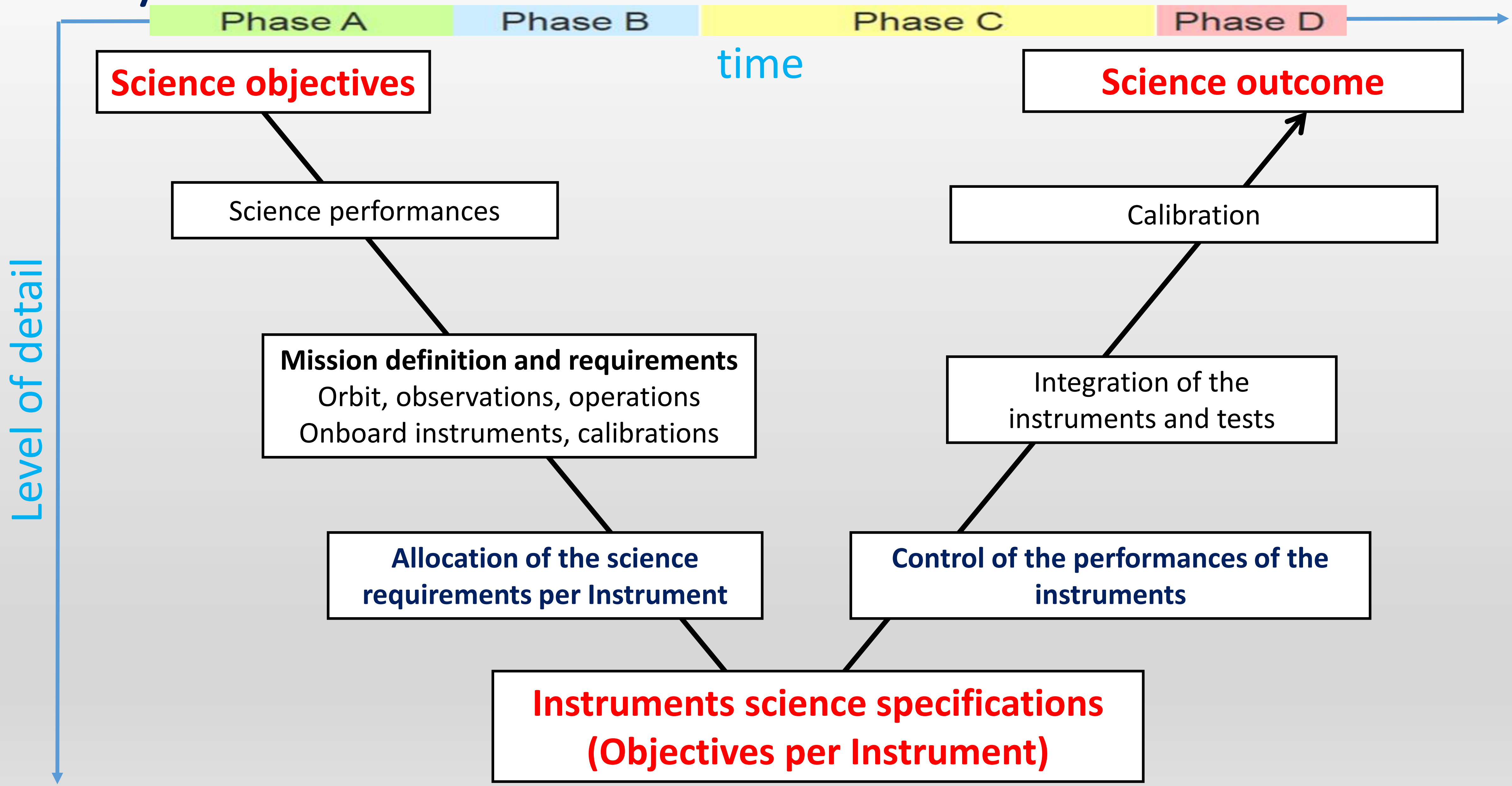
Satellite resources
- Thermal architecture (sat)
- Mechanical architecture
- Electrical architecture
- Orbit control

- Launcher
- **Orbit**
- Life duration
- **Attitude law (pointing strategy)**
- Data transfer (com)

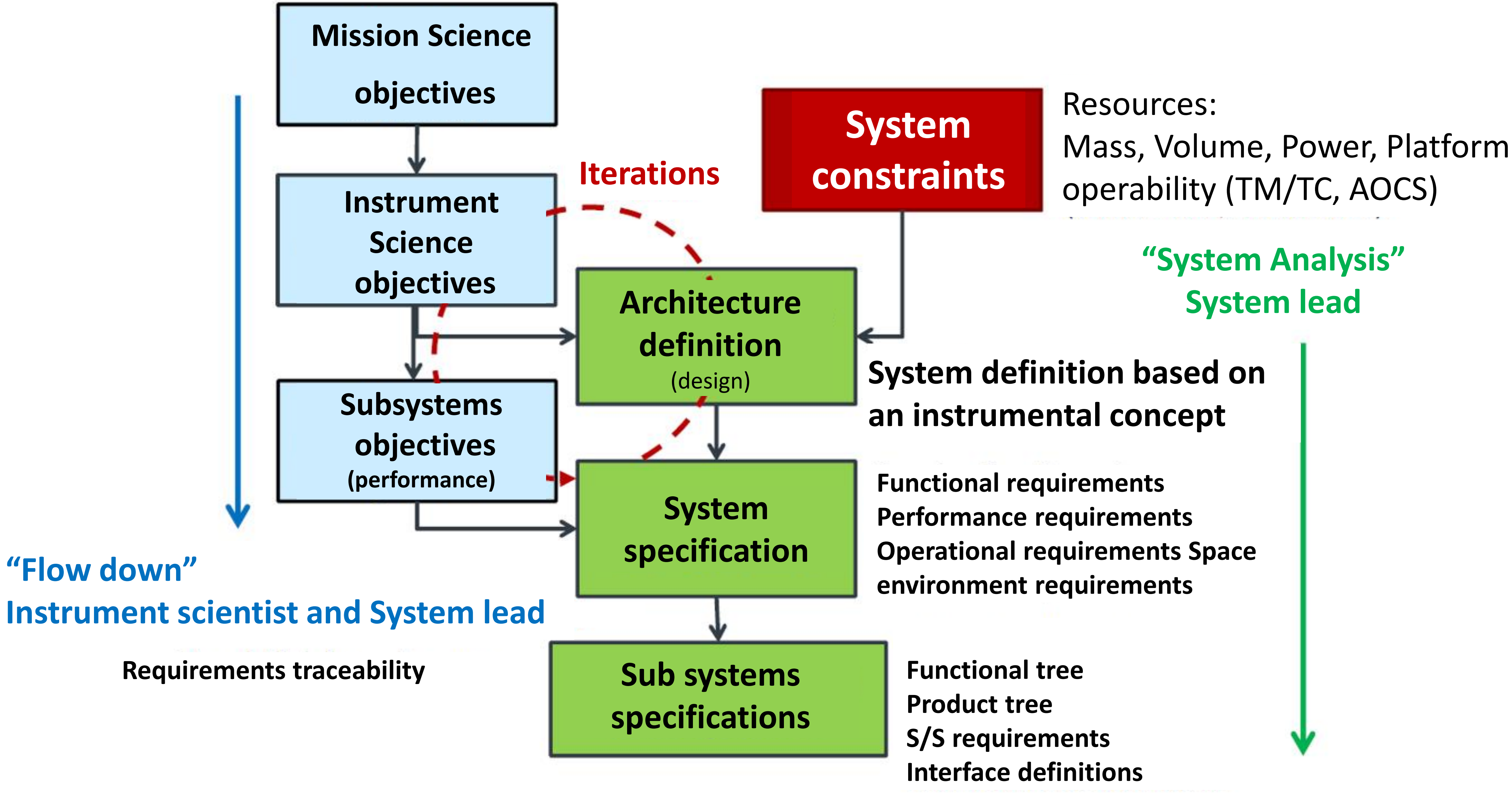
- **Instruments onboard**
- **Observation strategy**
- System resources



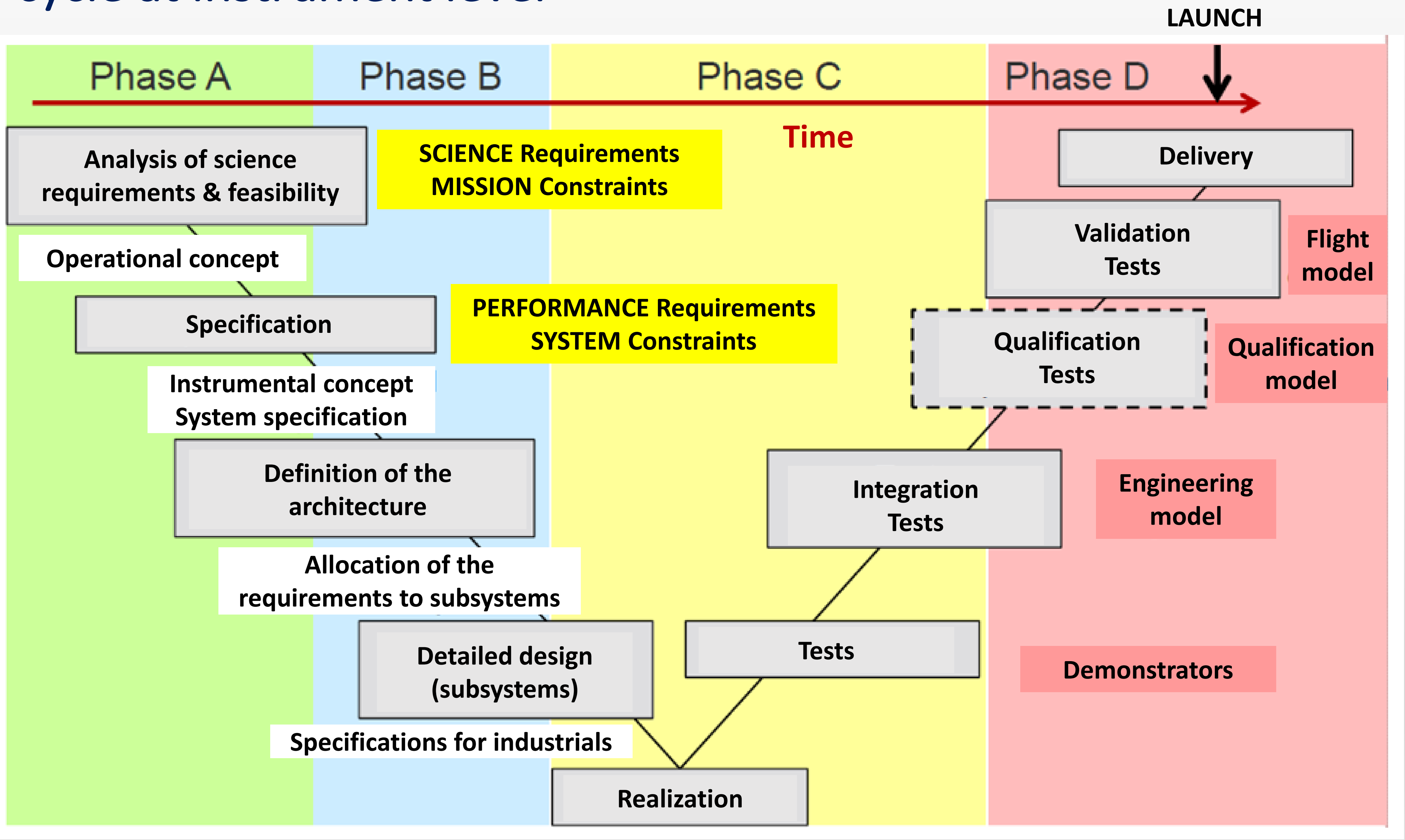
V cycle at mission level



Instrument definition



V cycle at instrument level



Defining a space mission

Perform a detailed analysis of the **mission science requirements** to define a **mission concept**

⇒ **Track all the requirements associated with the object you want to study** (angular size in the sky, magnitude, wavelengths, variability, redshift …),

⇒ Deduce from this analysis the **mission concept** and **Instruments you need** and their main characteristics

⇒ Need to identify which instrument within the mission contributes to each science performance

Perform a detailed analysis of the **instrument science requirements** to define an **instrument concept**

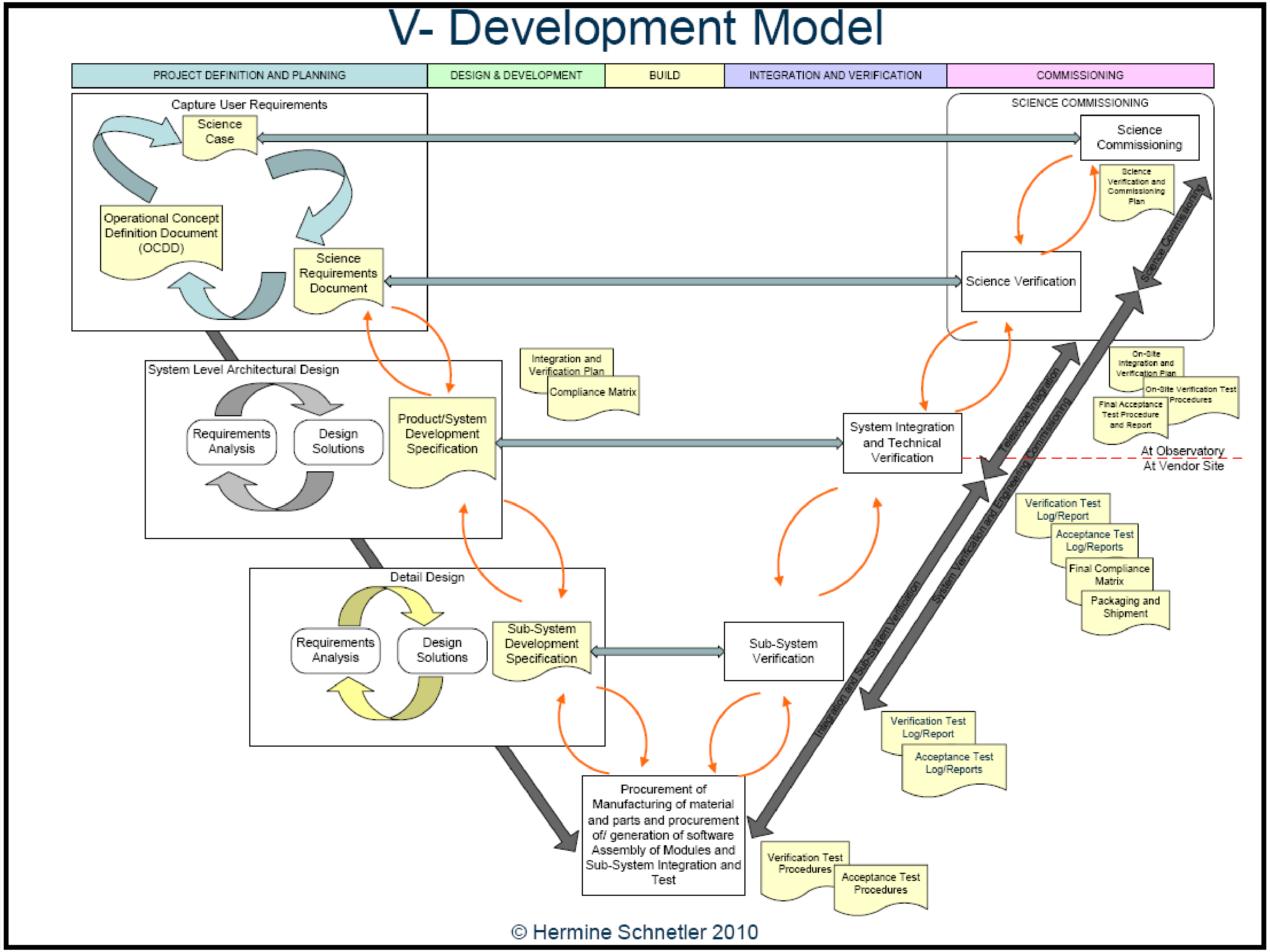
⇒ **Track all the requirements** and convert them into **instrument functions and performances**

⇒ Deduce from this analysis the **instrument concept and specification**

⇒ Need to identify which subsystem of an instrument contributes to the science performance

Process is non linear: many loops depending on feasibility, discussions on the science requirements …

⇒ Need to detail the science case and be a requirement hunter


V- Development Model
PROJECT DEFINITION AND PLANNING
DESIGN & DEVELOPMENT
BUILD
INTEGRATION AND VERIFICATION
COMMISSIONING
Capture User Requirements
Science Case
Operational Concept Definition Document (OCDD)
Science Requirements Document
SCIENCE COMMISSIONING
Science Commissioning
Science Verification and Commissioning Plan
Science Verification
System Level Architectural Design
Requirements Analysis
Design Solutions
Product/System Development Specification
Integration and Verification Plan
Compliance Matrix
System Integration and Technical Verification
On-Site Integration and Verification Plan
On-Site Verification Test Procedures
Final Acceptance Test Procedure and Report
At Observatory
At Vendor Site
Verification Test Log/Report
Acceptance Test Log/Reports
Final Compliance Matrix
Packaging and Shipment
Detail Design
Requirements Analysis
Design Solutions
Sub-System Development Specification
Sub-System Verification
Procurement of Manufacturing of material and parts and procurement of/ generation of software Assembly of Modules and Sub-System Integration and Test
Verification Test Log/Report
Acceptance Test Log/Reports
Verification Test Procedures
Acceptance Test Procedures
Integration and Sub-System Verification
System Verification and Engineering Commissioning
Telescope Integration
Science Commissioning
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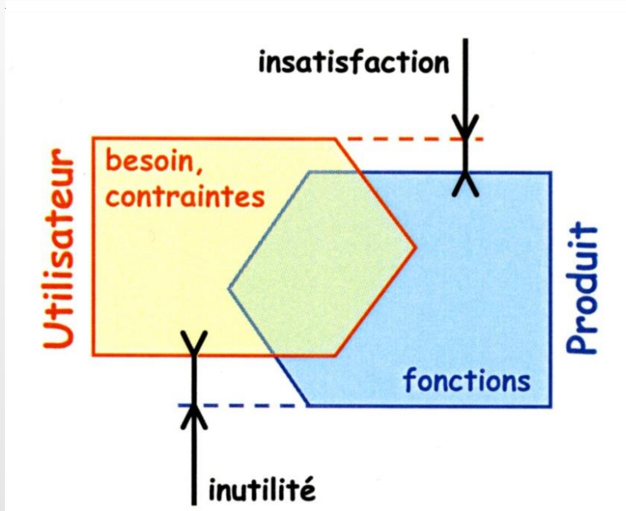
Systemic Approach: guarantee the performance

- Science requirements applicable to the instrument **(OBJECTIVE)**

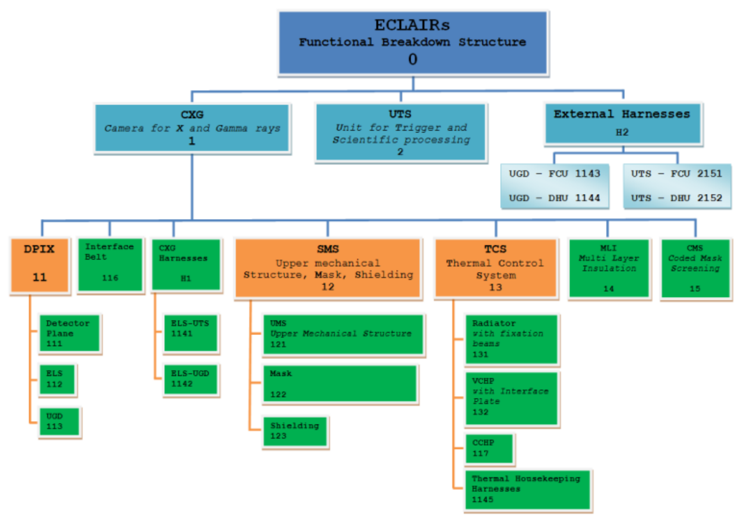


- Definition of the **Fonctions and Performances** of the instrument (functional architecture)

Convert science requirements into technical requirements: example sensitivity <-> choice of a detector, size of a mirror)

- **Proposal of an instrument concept**
  - **Make design choices**
  - **Define subsystems** (Product Breakdown Structure)
  - Allocate the performances to the subsystems

  (a performance can be met thanks to the contribution of various subsystems)



- Define the strategy for the **performance validation** of the instrument
  - Models to be developped
  - Planning associated with the project
  - Test strategy

D - Constraints to take into account when developing a space mission

Orbits, Satellite (Power, Mass, Thermal, Launcher, Telemetry …)

Main elements to define for each mission

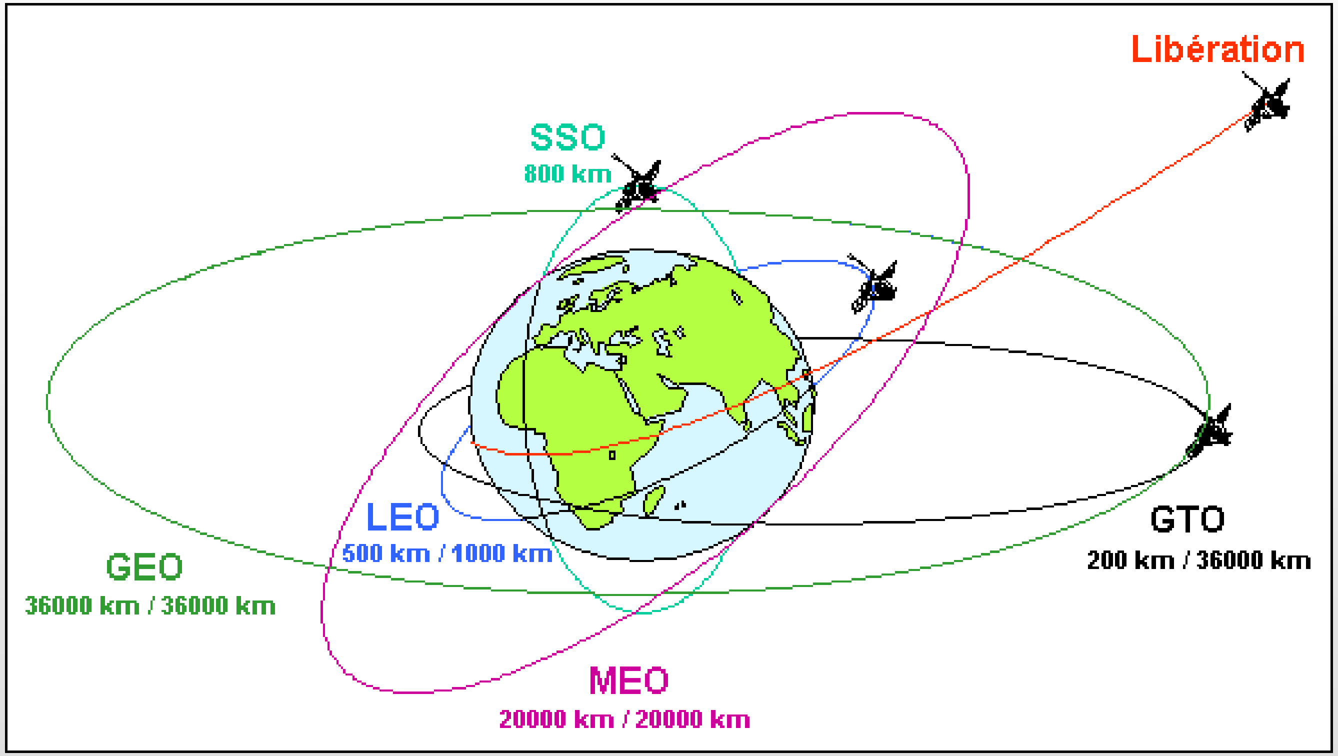
⇒ Mission Scientist and Mission System lead task

⇒ Specify all the following points so as to meet the mission science performance

- Observation strategy
  - Orbit & Launcher
  - Type of platform
- Instruments on board (And their science performance)
  - Contribution of each instrument to the science objective
- Ground instruments
  - Contribution of each instrument to the science objective
- Ground segment
- Operations, Calibrations
  - Required operations necessary to optimize the science
- **Mission performance budget to verify the mission science performance**

Different types of orbits

Science Requirements
$\Rightarrow$ Observation strategy
$\Rightarrow$ Choice of an orbit



Choose the best orbit that matches the observation requirements as well as the environment constraints on the orbit:

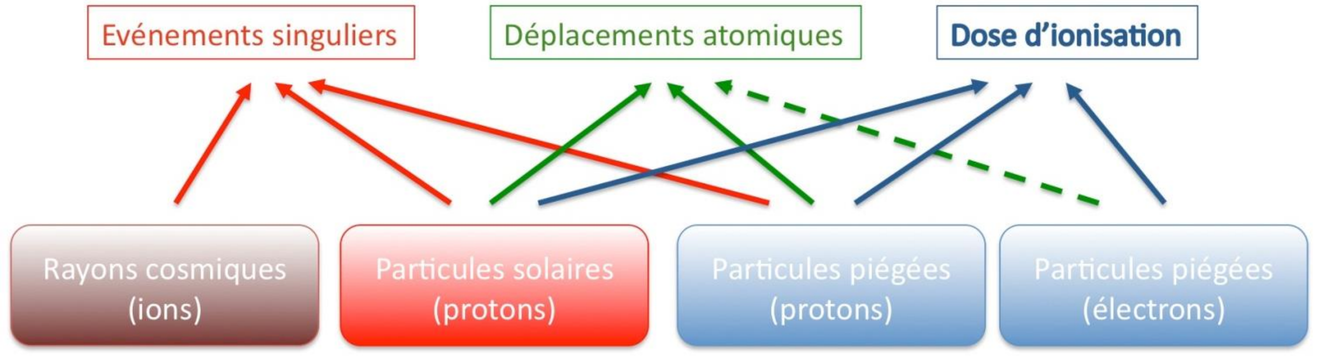
- Charged particles
- Cosmic rays
- Thermal environment (Earth albedo)
- Communication with Earth

Orbite	Période	Inclinaison	Périgée	Apogée
LEO	97 min	30°	600 km	
EOS	99 min	98°	705 km	
MEO	6 h	51°	10 000 km	
GEO	24 h	0°	36 000 km	
HEO	3 jours	51°	10 000 km	155 000 km

Choice of an orbit : charged particles

	Particules			
	Interplanétaires		Piégées	
Orbite	Cosmiques	Solaires	Protons	Electrons
GEO	++	++		++
MEO			++	++
LEO			SAA	SAA
EOS	cornets polaires	cornets polaires[1]	SAA	SAA
HEO	++	++	+	+
sonde	++	++		
L2	++	++		queue ?

[1] ions lourds principalement, pas les protons



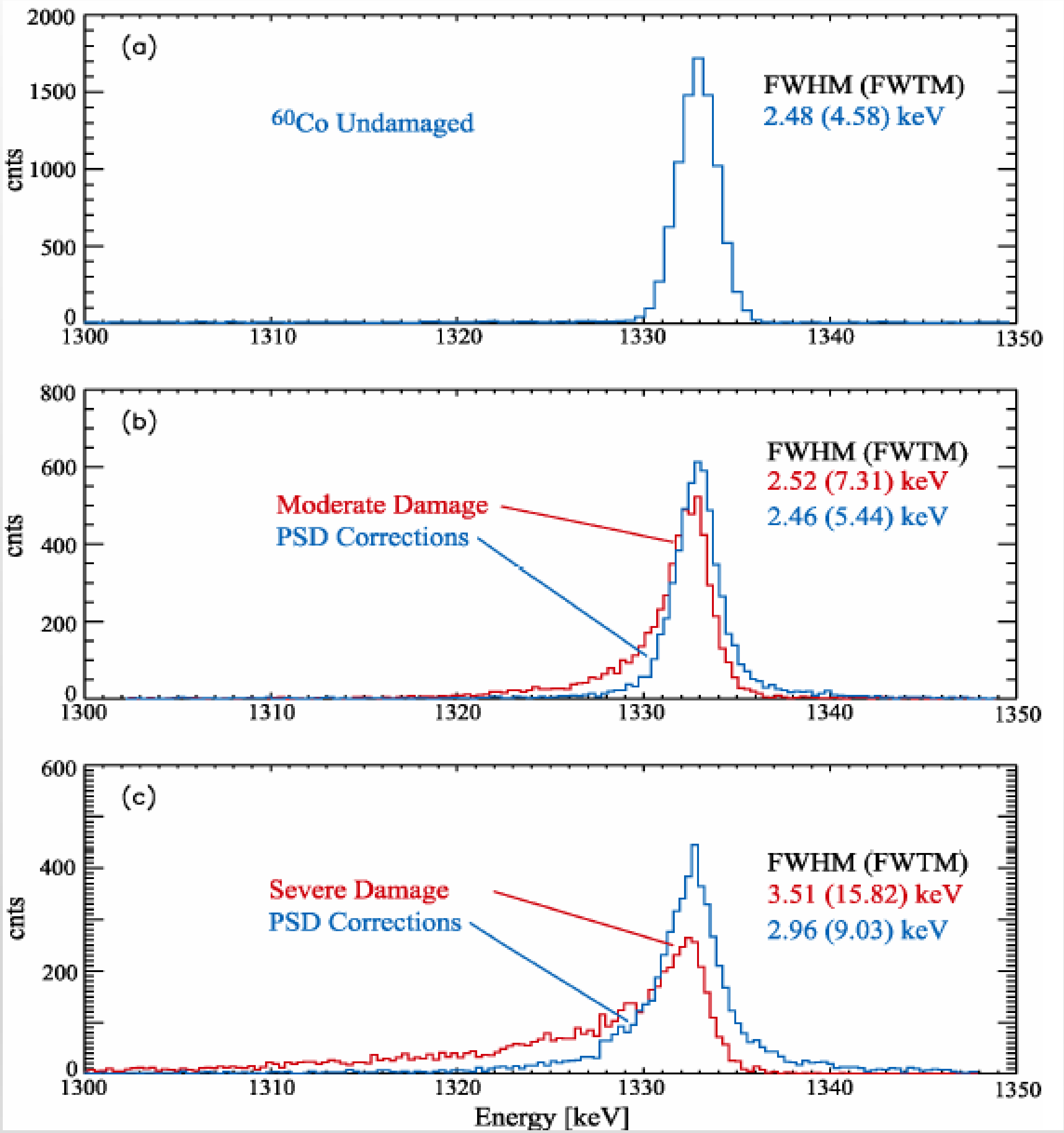
Cosmic ray difficulty

Cosmic rays affect electronic boards & semiconductor detectors because of lattice deformations (crystalline structures defaults) and ionization effects:

For detectors, causes more charge trapping, incomplete charge collection and **poorer energy resolution**. Require risky annealing's to fix the problem. PSD corrections can be applied in the meantime.

For electronic boards, even single effects can cause latchups and **noisy or unusable systems**. (some of the Ge detectors of INTEGRAL are dead!)

Radiation hardening techniques, both physical and logical, must be applied.
Redundancy is essential for space instrumentation !

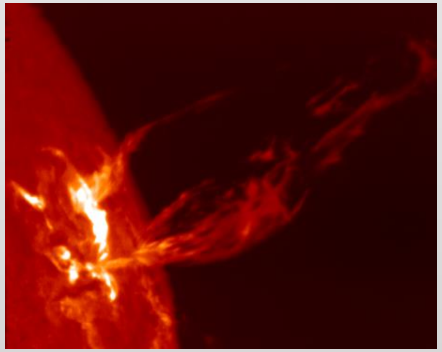


Single Event Effects: Source in Space

High Energy Particle Radiation

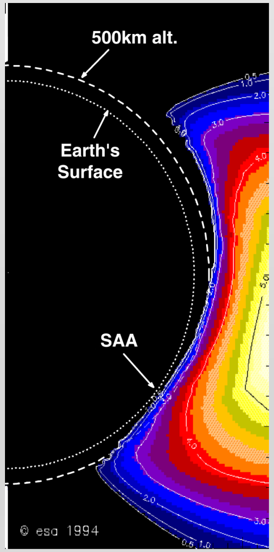
Galactic Cosmic Rays

Solar Particle Events (flare/CME)



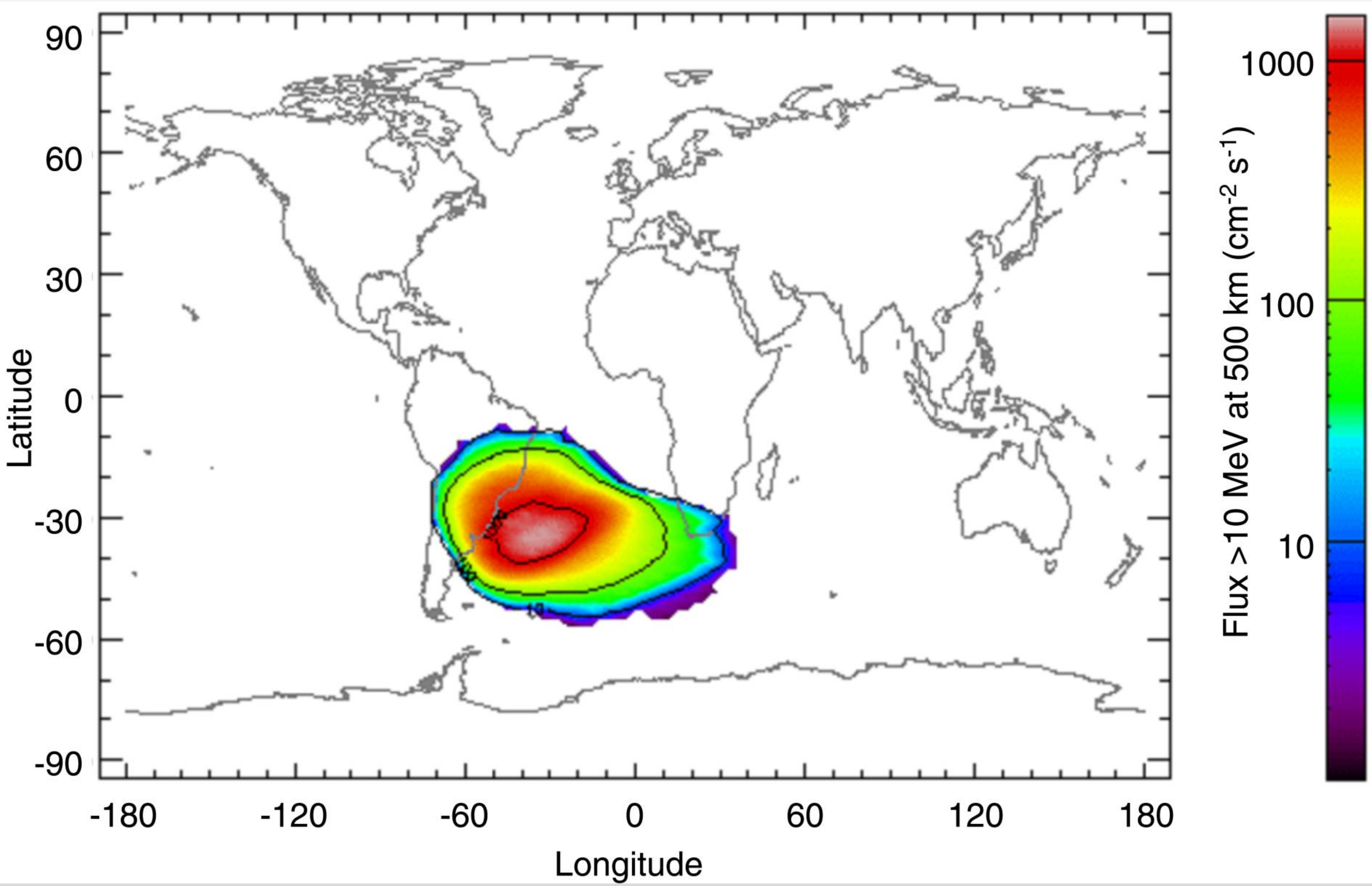
Most unpredictable

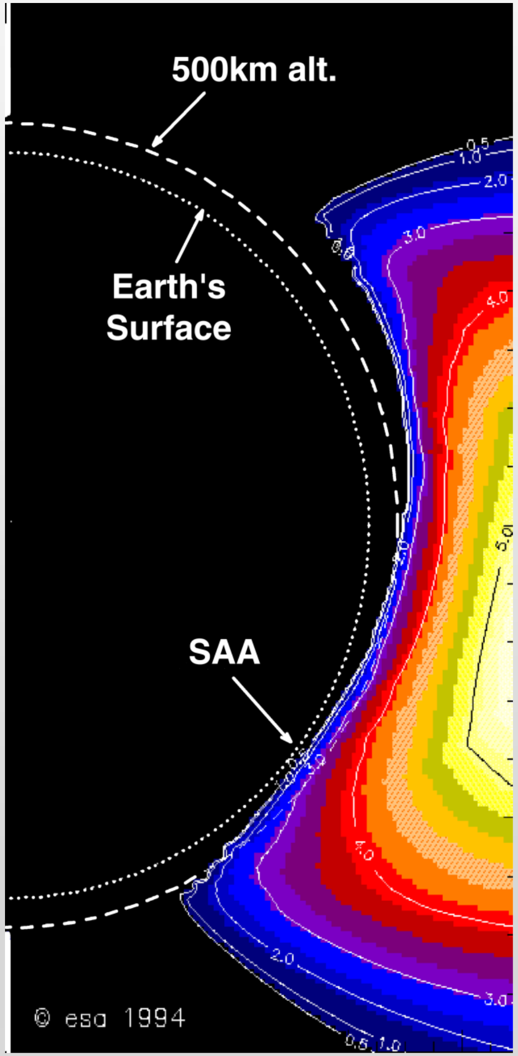
Trapped Particles (SAA)



High energy neutrons

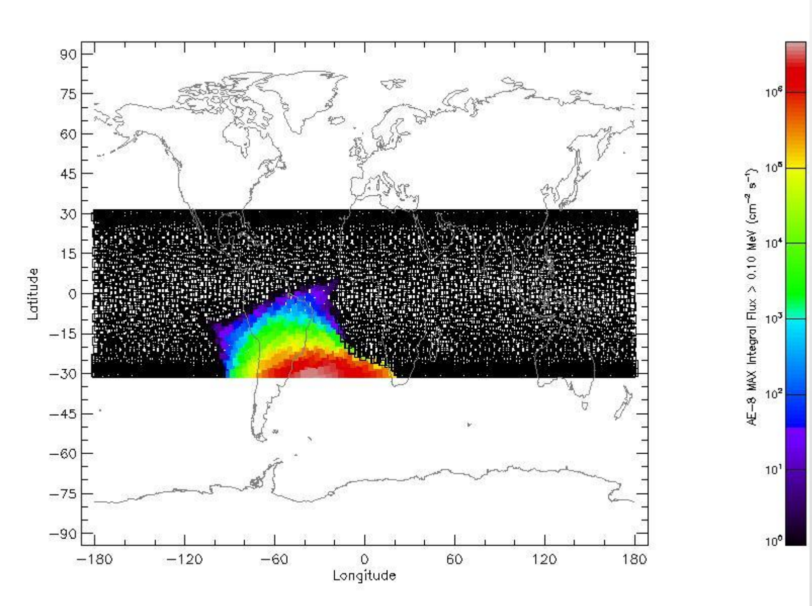
Choice of an orbit: South Atlantic Anomaly problem for LEO



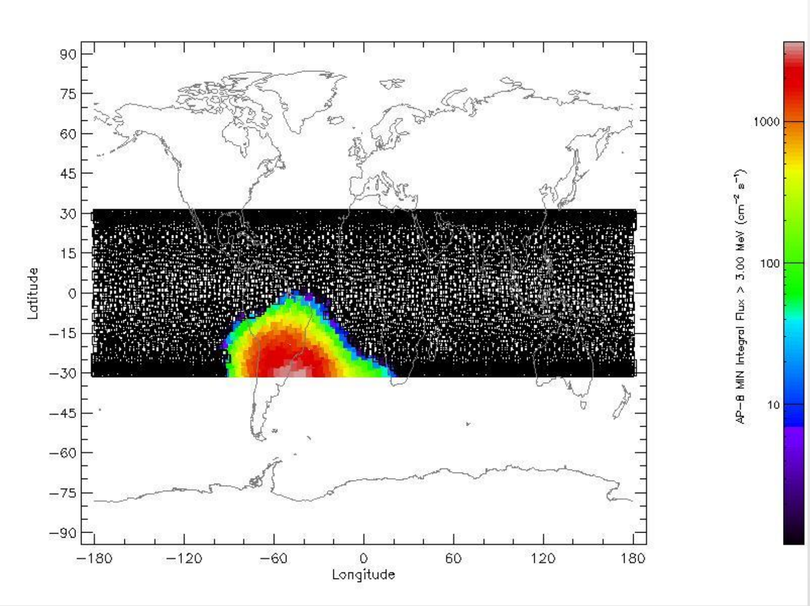


Choice of an orbit: South Atlantic Anomaly problem for LEO

Orbit : inclination 30° altitude 630-650 km

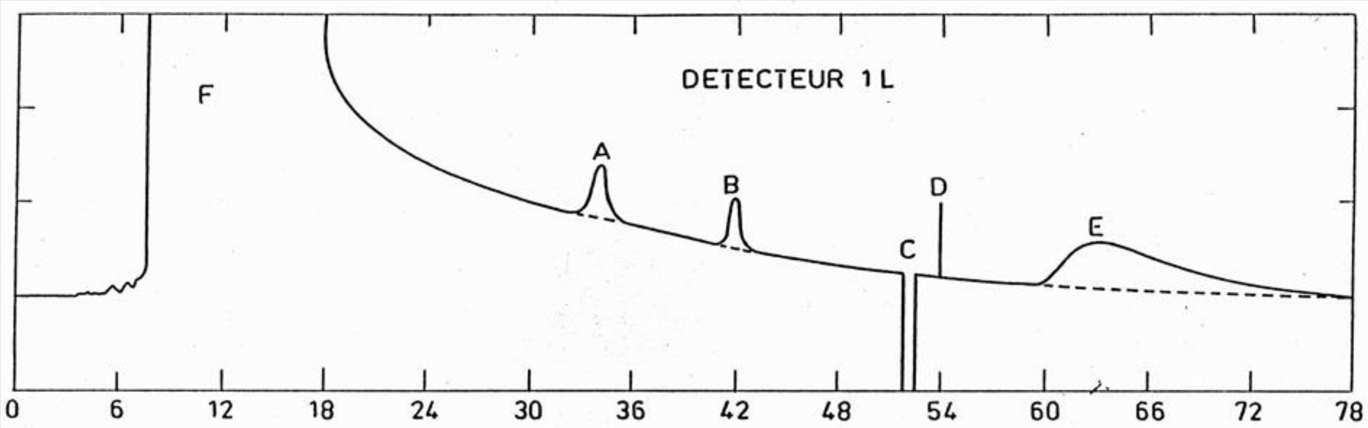


Electrons > 100 keV seuil 7000 e- cm-2 s-1



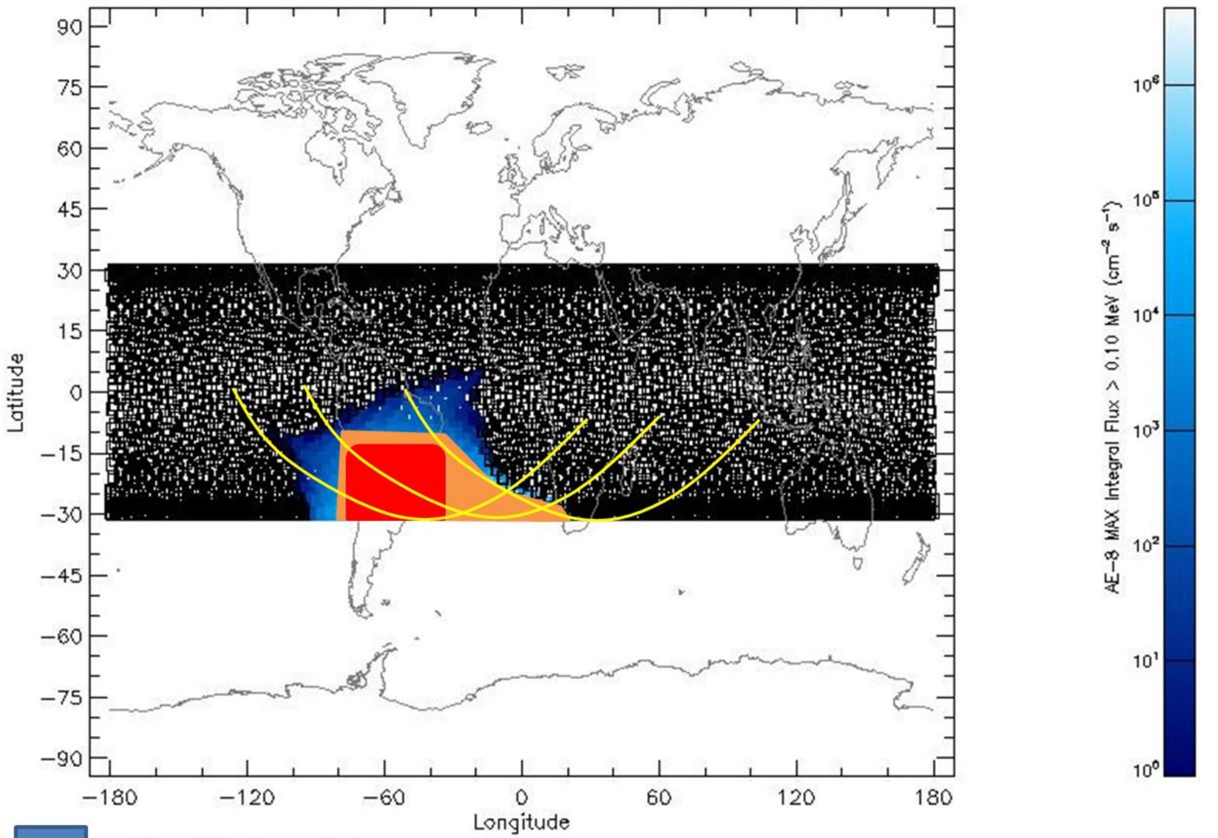
Protons > 3 MeV seuil 800 e- cm-2 s-1

Particules/s Echelle arbitraire



Temps en minutes

Choice of an orbit: SAA and Science performance of the mission



Specify an operating mode during SAA crossings

- Zone d'électrons piégés
- Zone saturation électrons
- Zone saturation protons (activation)

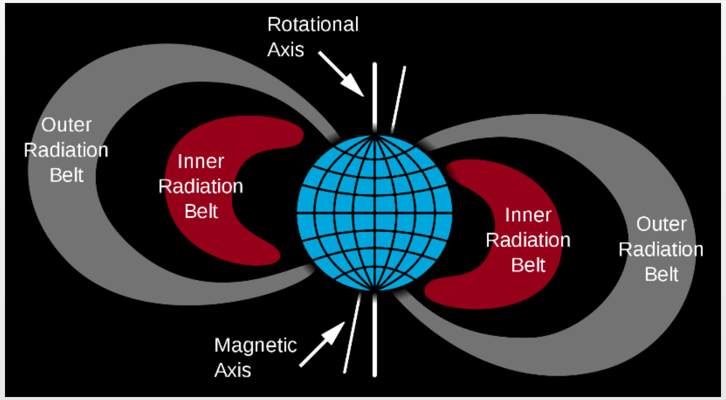
Swich off the detectors ?

Need to define a strategy to minimize the impact of charged particles on the life duration of detectors and on the quality of the scinetific data

Choice of an orbit for Astrophysic satellites

Why Low Earth Orbits

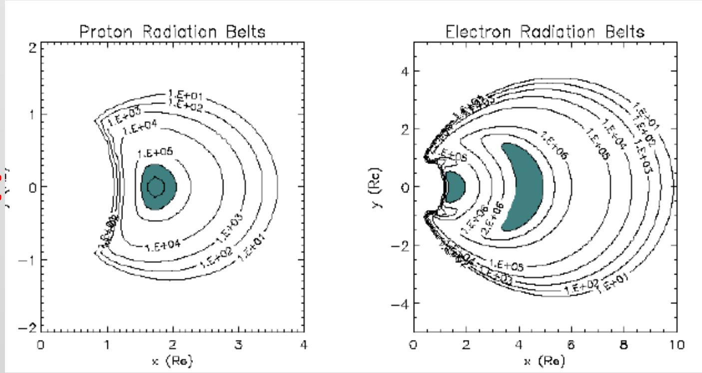
- Two harmful radiation belts exist: at ~7000 km (10 000 km thick) and 16000 km (~7000 km thick).
- Problems with radiation belts : within the belts, very high background due to energetic particles (protons, electrons).
- Particles affect semiconductors detectors and degenerate electronic circuits
- Above radiation belts, cosmic ray background very high



two radiation belts around Earth: the inner belt (red) dominated by protons and the outer one (blue) by electrons. Image Credit: NASA

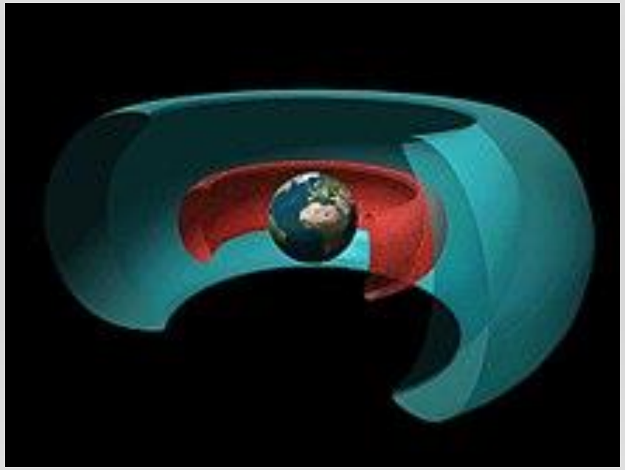
⇒ Below 1000 km is OK for satellites

⇒ Easy for maneuvers, easy to place in orbit



Why not low earth orbit

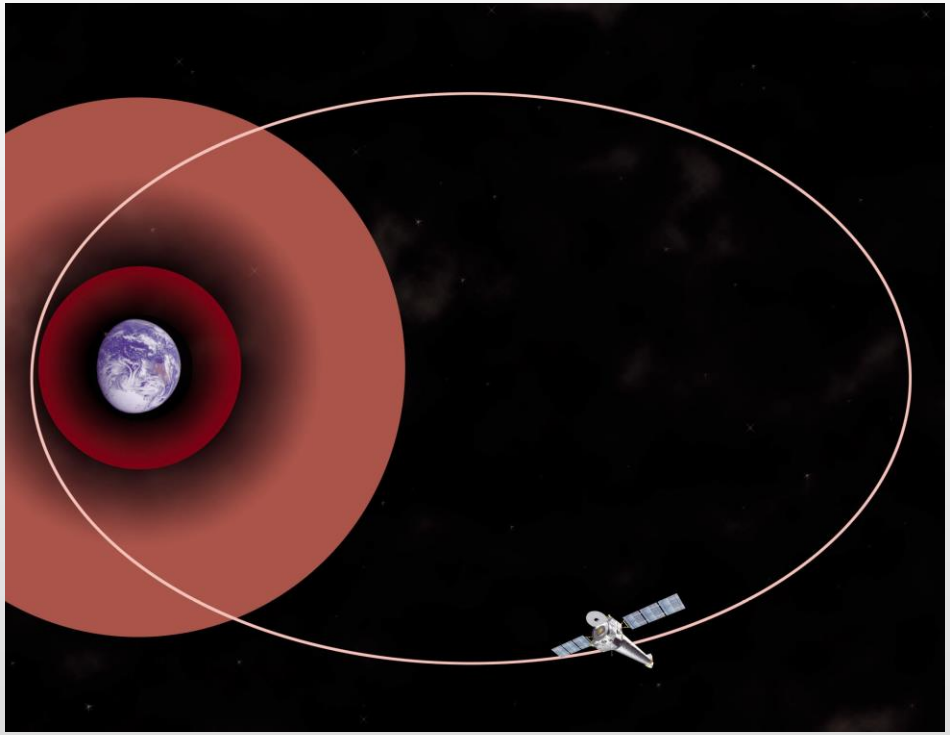
- Large eclipses due to earth. Impossible for continuous coverage
- (Efficiency 65-70%).
- Still particle problem with the South Atlantic Anamaly.
- Limited contact with ground bases.

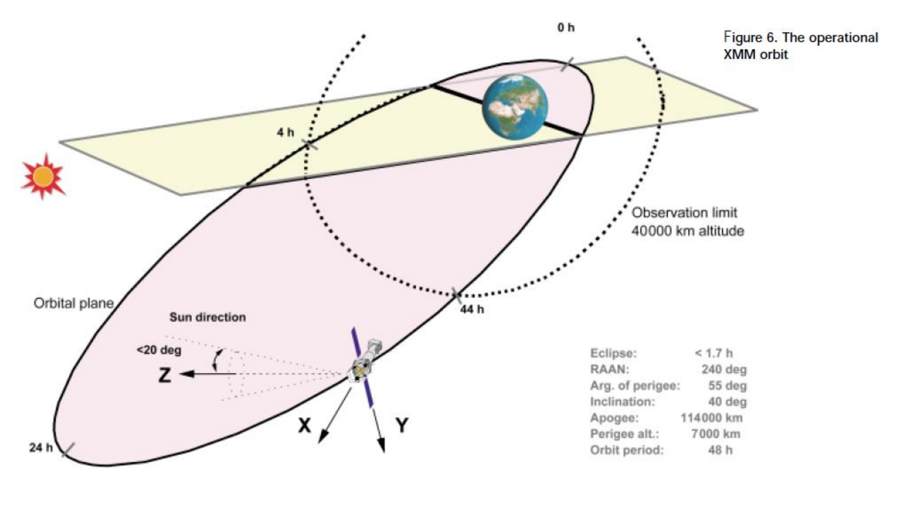


Choice of an orbit for Astrophysic satellites

Eccentric orbits (example XMM, Integral):

- Much better efficiency and coverage.
- Higher overall background
- Higher exposure to radiation belts
- 2 stage launch.
- Expensive

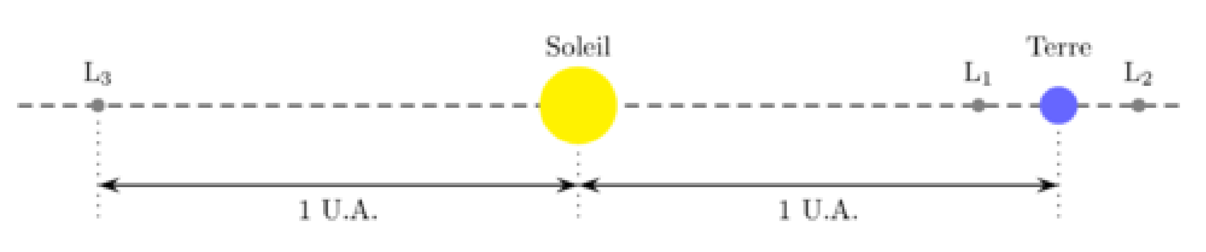




XMM

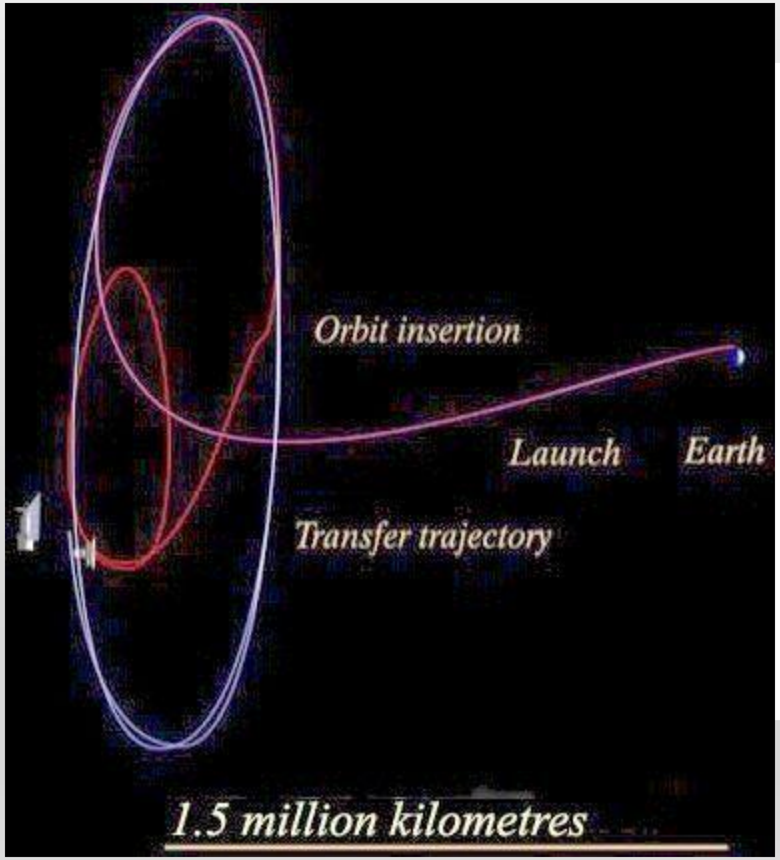
- perigee : 7 000 km
- Apogee : 114 000 km
- A revolution every 48 hours.
- Quasi continuous follow-up by Kourou and Perth ground stations

Choice of an orbit for Astrophysic satellites



Orbit around Lagrange point L1 or L2

- About 1,5 millions kilometers
- Stays at unstable Lagrange points L1 (like sun observing SOHO) or L2 (like WMAP).
- Need adjustments every 20 days
- no radiation belt,
- 100% efficiency
- Best location to observe deep space (far from the Earth)
- Easier for thermal control (IR satellites)
- A lot of Astro missions WMAP, Planck, Herschel, Gaia
- Expensive and long to reach the orbit



=> James Webb Space Telescope and Euclid.

Orbit selection drives supporting technology

- **Launch vehicle**
- **Launch sites/facilities**
- **Orbit Insertion Navigation & Station Keeping**
  - Tracking/ephemeris determination
  - Propulsion system
- **Communications**
  - Data rates (X band, S band, VHF)
  - Link requirements (BER & EIRP)
  - Spacecraft
    - Transmitter power
    - Antenna size and technology
    - Frequency domain
    - Data rates
  - Ground station
    - Antenna
    - Receiver sensitivities
    - Data rates

Lanceur	Masse totale	Masse Lancée (LEO)
AR 5 ECA	780 T	20 T
FALCON 9	550 T	22,8 T
AR 6	530 T	20 T
PSLV	320 T	3,25 T
Strato L (avion)	589 T	1,3 T
Véga	134 T	2,3 T
Rockot	107 T	1,9 T
Intrepid 1	24,2 T	600 kg

Mandatory elements of a space mission

Payload

- Telescopes onboard

Satellite Platform Subsystems

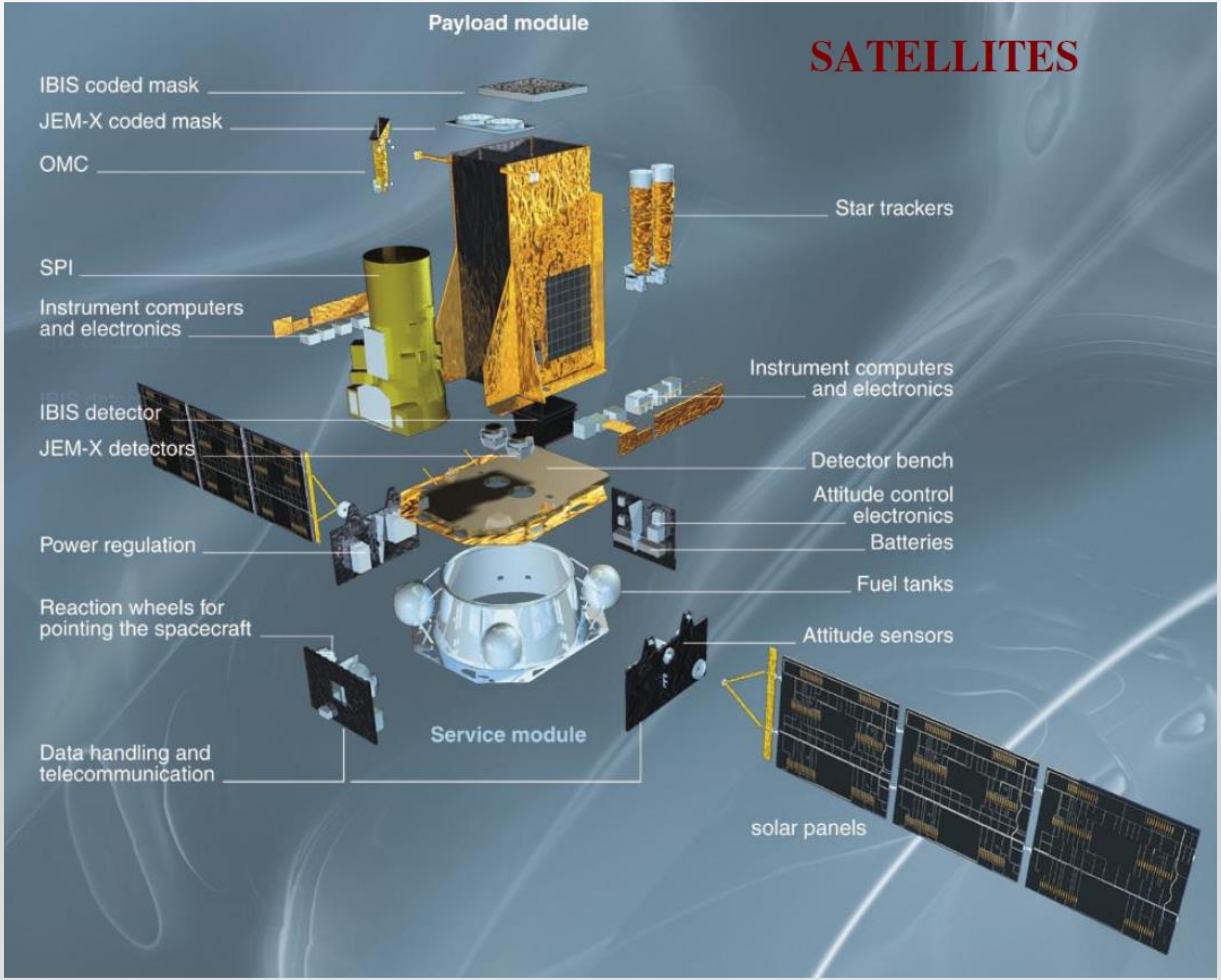
- Power
- Thermal
- Attitude
- Command & Data Handling
- Communications
- Structure
- Propulsion

Launch vehicle

Ground segment

- Science center
- Control center

Ground Antennas



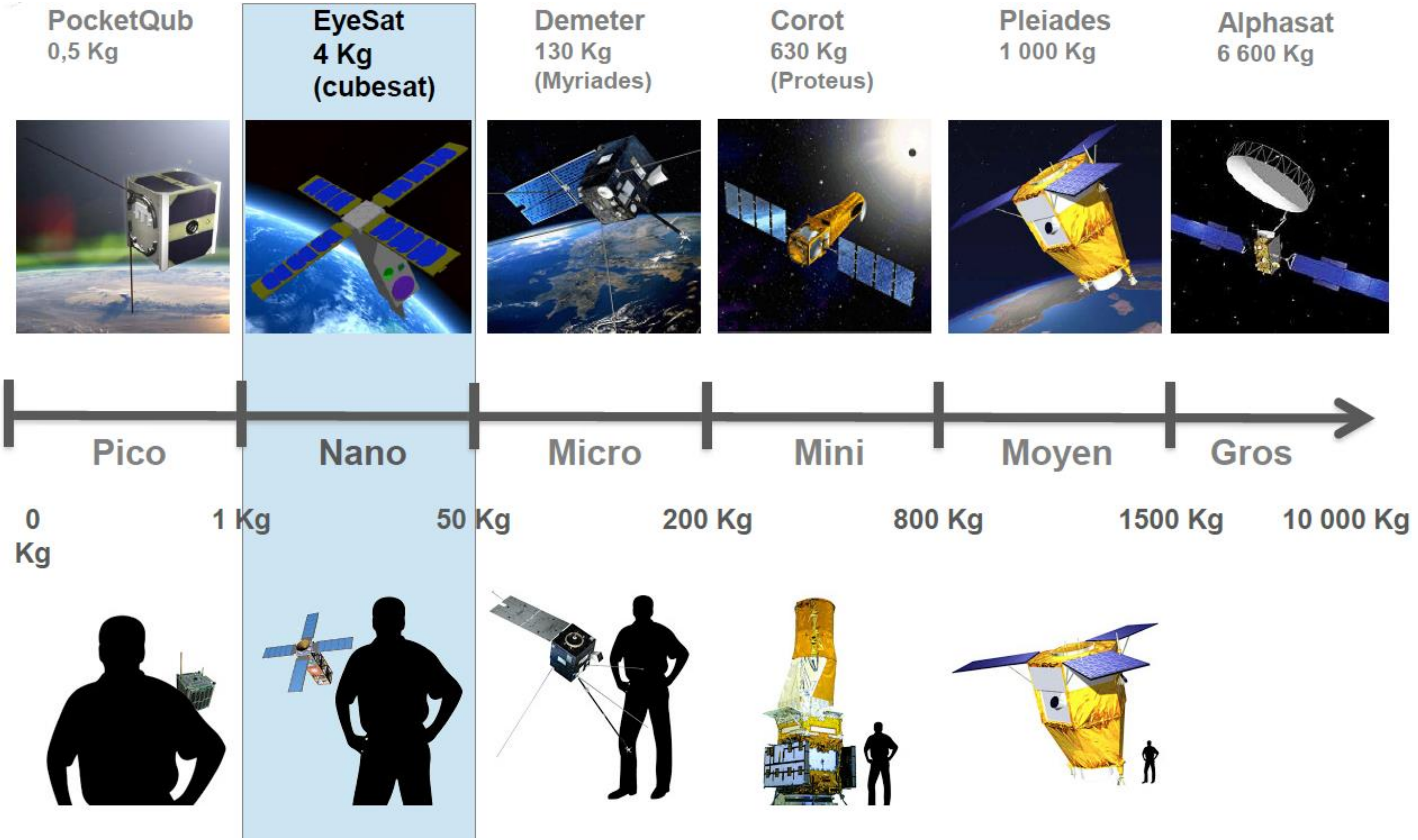
Choice of the platform: depends on the mass range

Classification	Mass Range [kg]
Femtosatellite	0.001 – 0.1
Picosatellite	0.1 - 1
Nanosatellite	1 – 10
Microsatellite	10 – 100
Minisatellite	100 - 1000

⇒ **Corresponds to different types of platforms that have specific capabilities in terms of resources: agility, pointing stability, telecommunication, life duration**

⇒ **Impact on the science performance of the mission**

Existing generic platforms



Resources for the telescope supplied by the platform

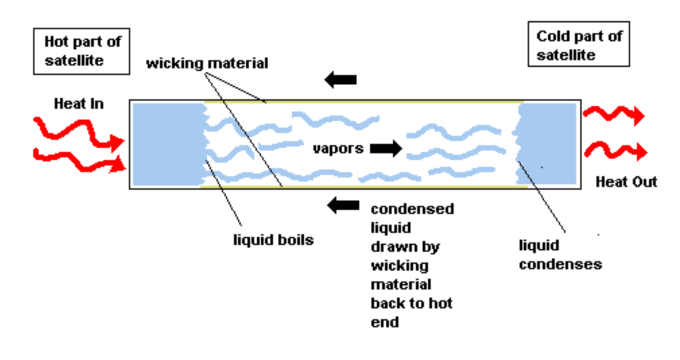
- Attitude Control & Navigation
- Communications
  - X band, S band, VHF
- Command & Data Handling
- Electrical Power and Power Distribution Systems
- Thermal control (can be ensured by the telescope itself)
  - Passive
  - Active
- Attitude Orbit and Control System (AOCS)
  - Pointing accuracy
  - Pointing stability
  - Agility

The platform performance have to be taken into account as constraints to estimate the instrument performance

Platform resources

Thermal Control

- Passive
  - Coatings (control amt of heat absorbed & emitted)
  - Multi-layer insulation (MLI) blankets
  - Radiators and Heat pipes (phase transition) connected to heat sources
- Active (Refrigerant loops, Heater coils)



Electrical Power

- Solar array: sunlight ➔ electrical power
  - max. efficiency = about 30 % (about 400 W/m^2 of array)
  - degrade due to radiation damage 0.5%/year
  - best for missions ≤ 1.53 AU (Mars' dist. from Sun)
- Radioisotope Thermoelectric Generator (RTG):

  Nuclear decay ➔ heat ➔ electrical power
  - max. efficiency = 8% (lots of waste heat!), best for missions to outer planets
- Batteries – good for a few hours, then recharge

Communications

- Transmits data to ground or to relay satellite (e.g. TDRS)
- Receives commands from ground or relay satellite

Platform resources

Command and Data Handling

- Commands
  - Validates
  - Routes uplinked commands to subsystems
- Data
  - Stores temporarily (as needed)
  - Formats for transmission to ground
  - Routes to other subsystems (as needed)

Structure

- Not just a coat-rack!
- *Unifies* subsystems
- *Supports* them during launch (accel. and vibrational loads)
- ***Protects* them from space debris**, dust, etc.

Propulsion

- Provides force needed to change satellite's orbit
- Includes thrusters and propellant

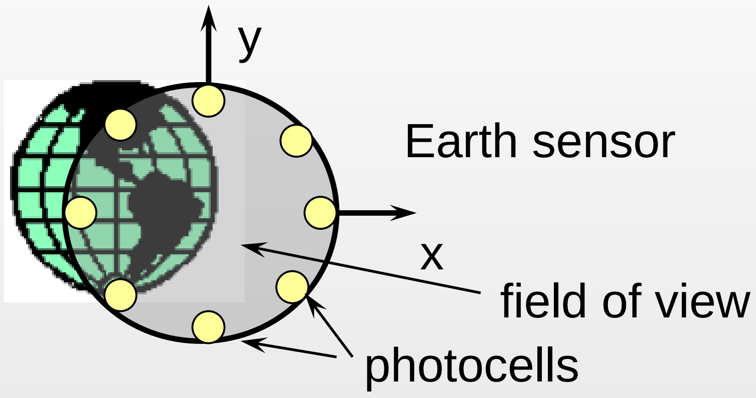
Attitude Determination and Control

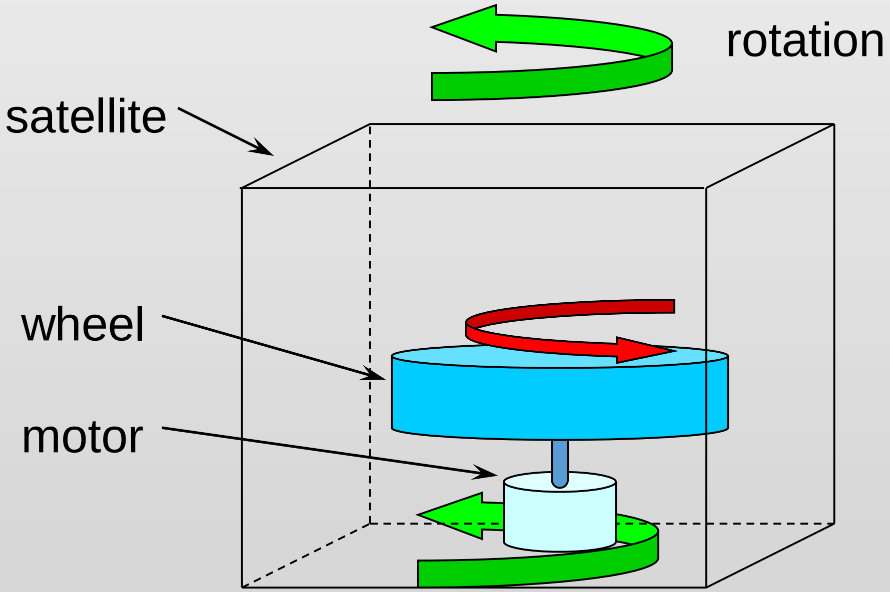
Defines the pointing accuracy of the sources

- **Sensors => attitude measurement accuracy**
    - Earth sensor (0.1° to 1°)
    - Sun sensor (0.005° to 3°)
    - star sensors (0.0003° to 0.01°)
    - magnetometers (0.5° to 3°)
    - Inertial measurement unit (gyros)

- **Active control (< 0.001°) => pointing stability**
    - thrusters (pairs)
    - gyroscopic devices
        - reaction & momentum wheels
    - magneto torqers (interact with Earth's magnetic field)

- **Passive control (1° to 5°)**
    - Spin stabilization (spin entire sat.)
    - Gravity gradient effect





- Motor applies torque to wheel (red)
- Reaction torque on motor (green) causes satellite to rotate

Elements of a space mission

Launch Vehicle

- Boosts satellite from Earth’s surface to space
- May have upper stage to transfer satellite to higher orbit
- Provides power and active thermal control before launch and until satellite deployment
- Creates **high levels of accel. and vibrational** loading

Ground Control

- MOCC (Mission Operations Control Center)
  - Oversees all stages of the mission (changes in orbits, deployment of subsatellites, etc.)
- SOCC (Spacecraft Operations Control Center)
  - Monitors housekeeping (engineering) data from sat.
  - Uplinks commands for vehicle operations
- POCC (Payload Operations Control Center)
  - Processes (and stores) data from payload (telescope instruments, Earth resource sensors, etc.)
  - Routes data to users
  - Prepares commands for uplink to payload
- Ground station – receives downlink and transmits uplink

E - Designing a space telescope (Instrument)

State of the art of existing technologies

Requirements and Constraints

SCIENCE REQUIREMENTS

INSTRUMENT

SPECIFICATION & DESIGN

STATE OF THE ART
Existing technologies
- Telescopes at different wavelength
- Detectors for different wavelength

Quality / Availability
- Electronic Components
- Methods

Assembly / Integration
- Available equipments
- Tests

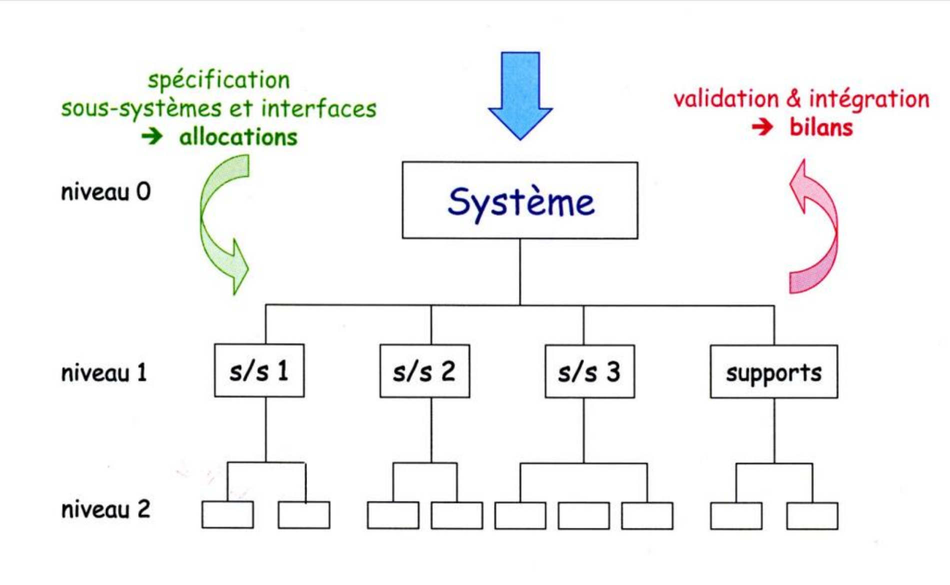
MISSION CONSTRAINTS
- Orbit
- Space environment (thermal, particles)

SATELLITE PLATFORM CONSTRAINTS
- Available resources (Mass, Power)
- Interfaces with Satellite
- Communication
- Control / Command
- Interfaces with satellite

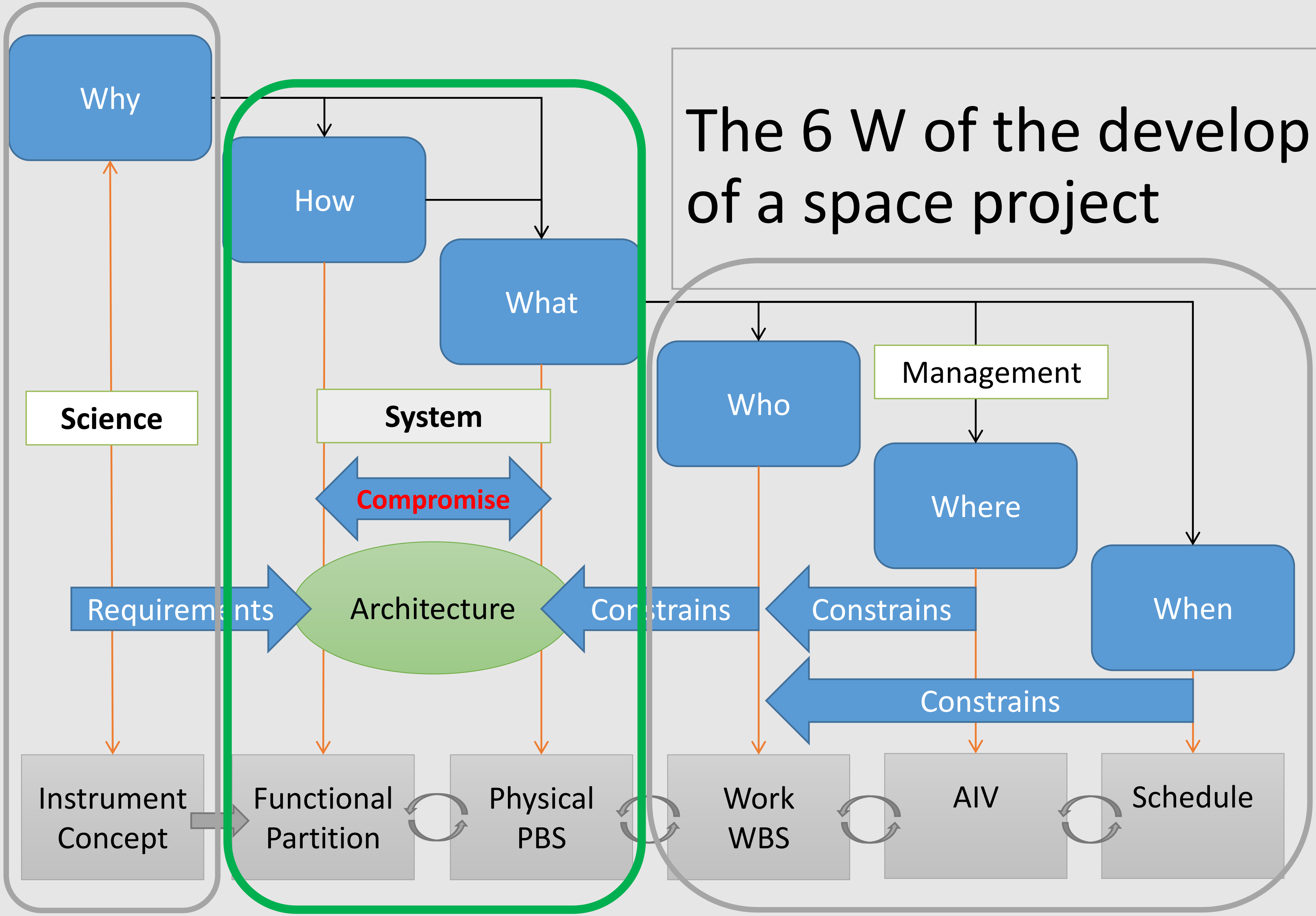
Parameters to specify for each instrument

⇒ To be done by the instrument scientist & system lead
⇒ Specify all the following elements so as to meet the science performance

- ❑ Instrument principle (Telescope, camera, detector, overall detection chain)
- ❑ Energy range
- ❑ Time scales, time resolution
- ❑ Sensitivity (SNR, sensor area …)
- ❑ Energy resolution (FWHM …)
- ❑ Localization accuracy (PSF
- ❑ Field of view
- ❑ Type of detector
- ❑ Calibration strategy
- ❑ Volume of science data
- ❑ **Instrument performance budget to verify the mission science performance**



The 6 W of the development of a space project



Detection chain elements & technologies for different wavelength

Telescope technologies (at different wavelength)

- ❑ Optical design (focusing technology)
- ❑ Materials
- ❑ Coatings
- ❑ Active/adaptive controls

Instruments (camera)

- ❑ Instrument type
  - ➢ (imager, spectroscopy, photometer, polarimeter)
- ❑ Bench/support technology
- ❑ Component technology
- ❑ **Detector technology**
  - ➢ Operational temperature
  - ➢ Effective area (for sensitivity)
  - ➢ Pixel size (resolution)
  - ➢ Associated electronics performance

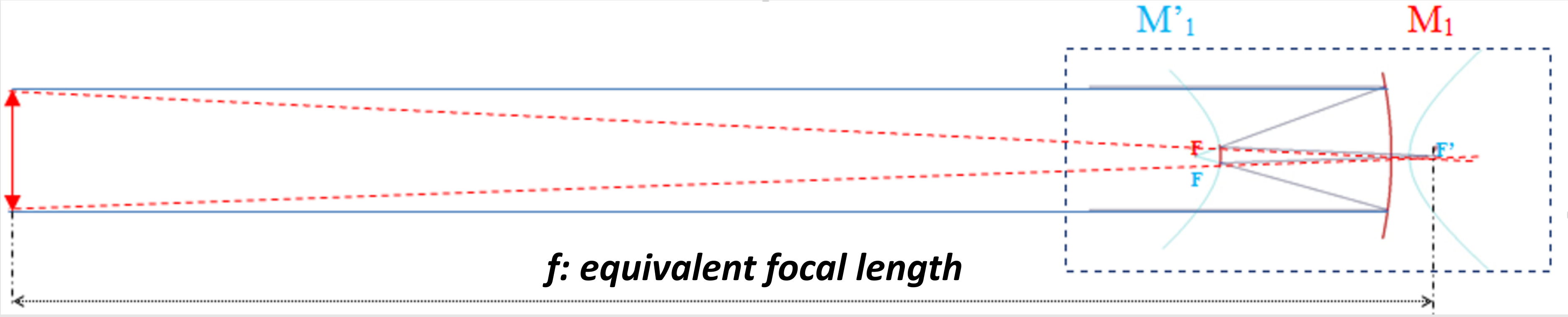
Command & Data Handling

- Signal conditioning
- Signal Processing (how much done on board)
- Data rates
- Storage capacity

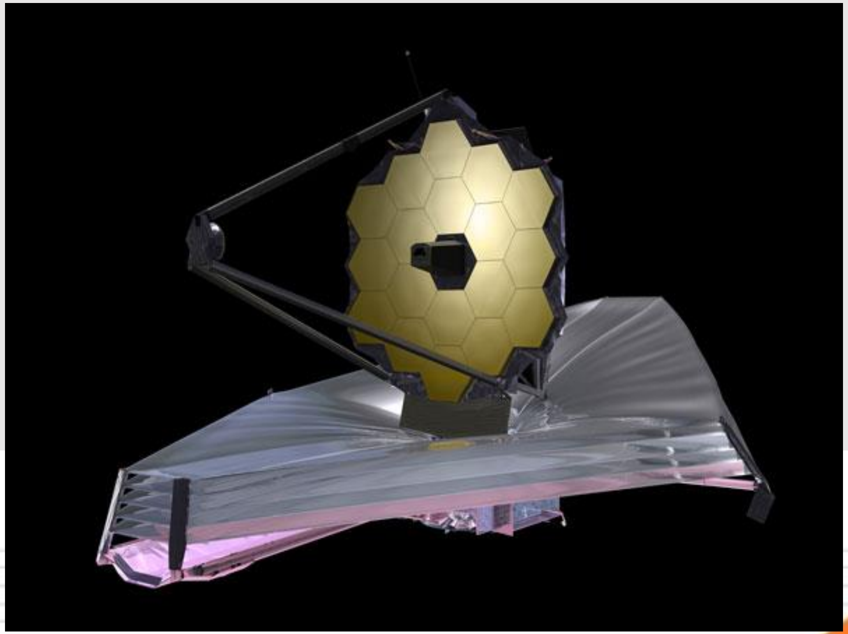
Need to know the « state of the art » of these elements that constitute the detection chain or to know who to get information about these elements

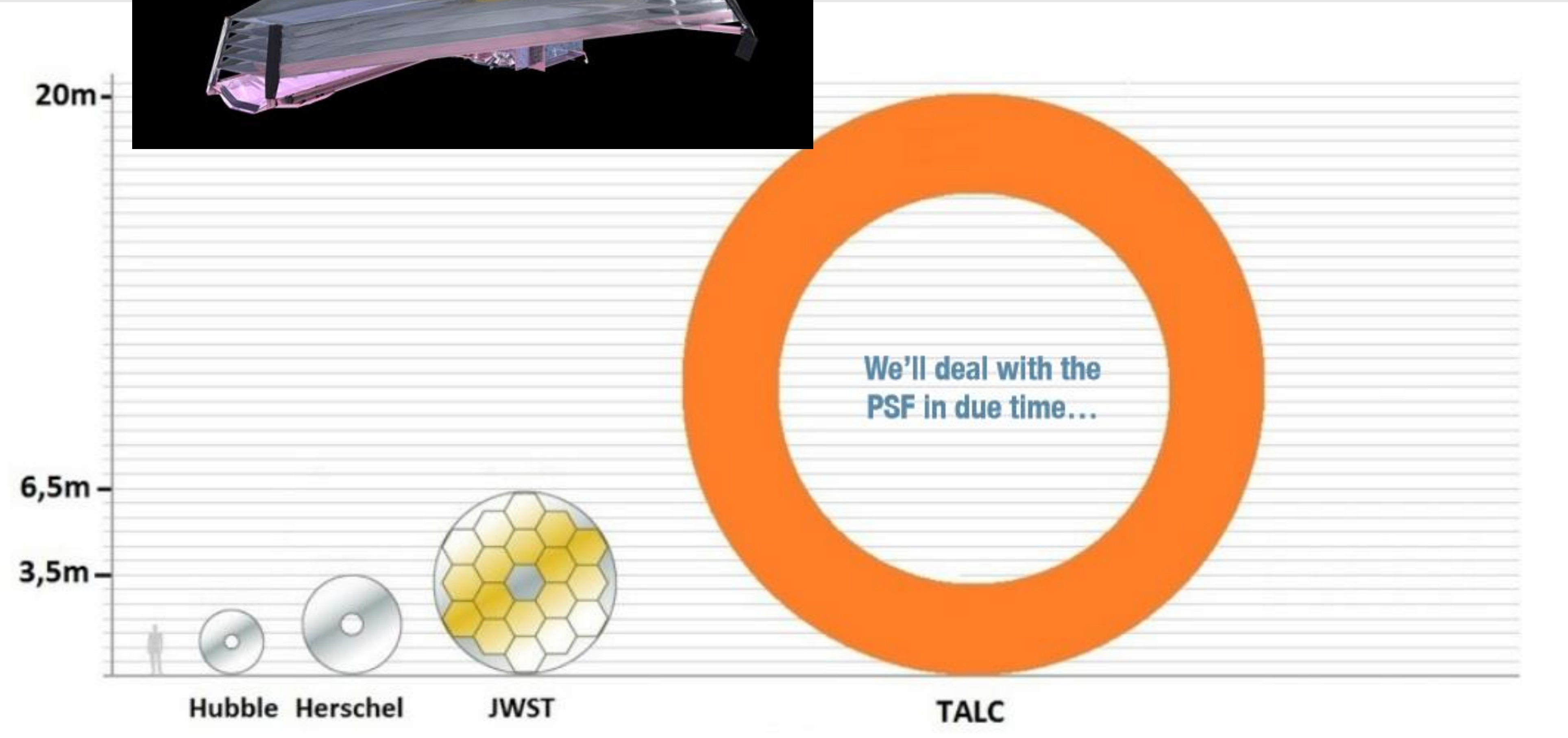
The instrument performance is supported by the performance of the elements of the detection chain

Optical resolution (best case)

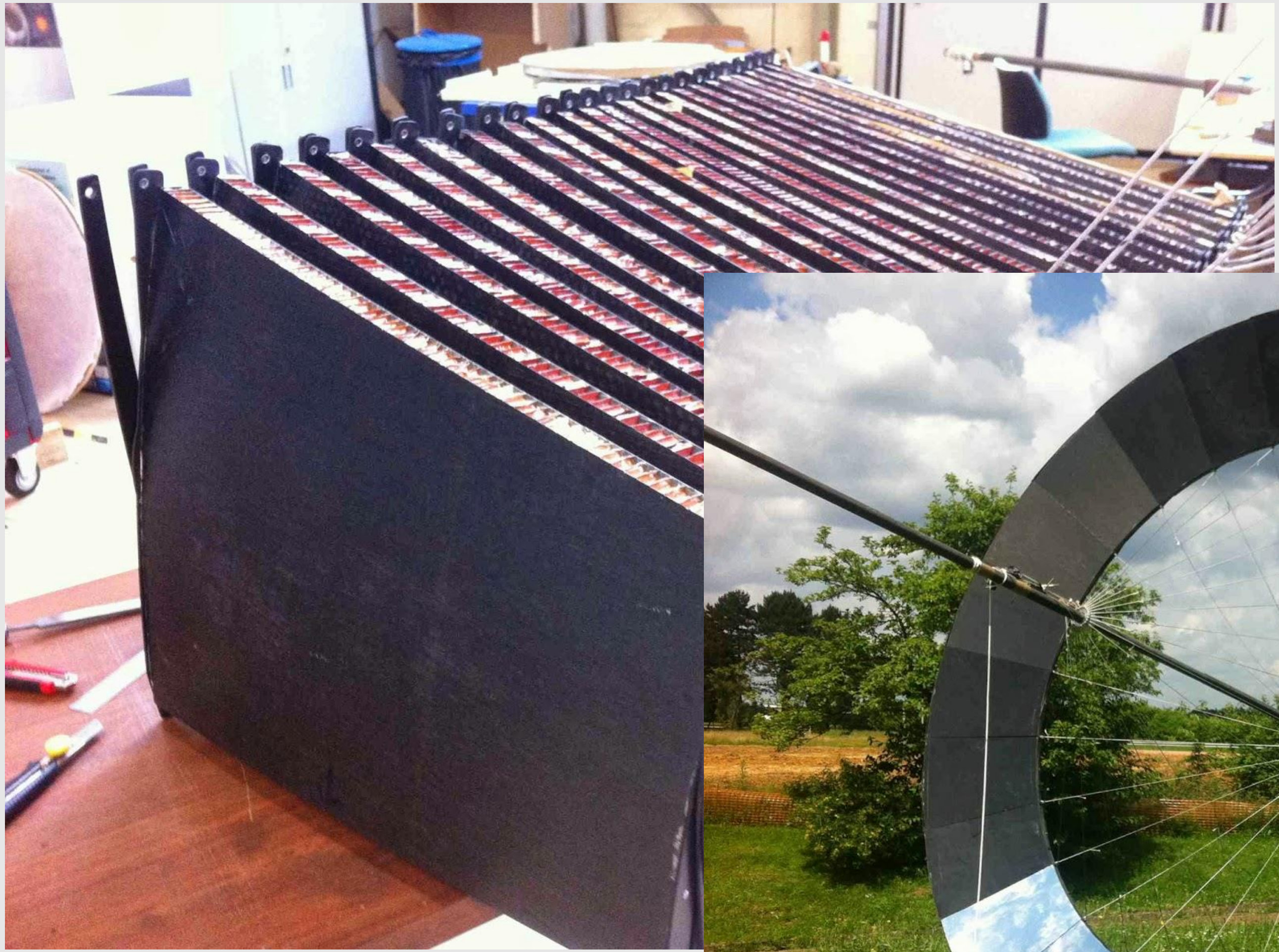
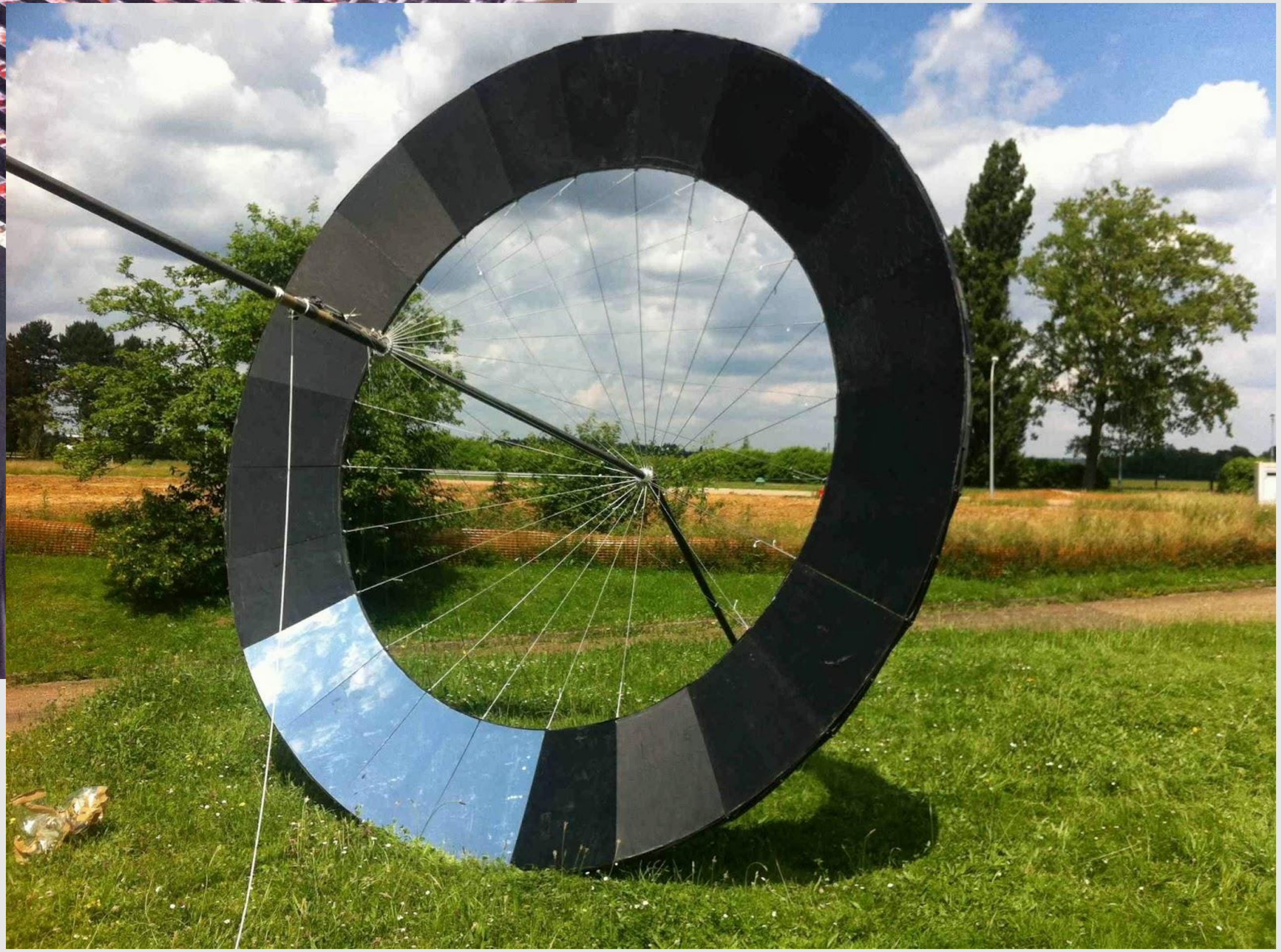


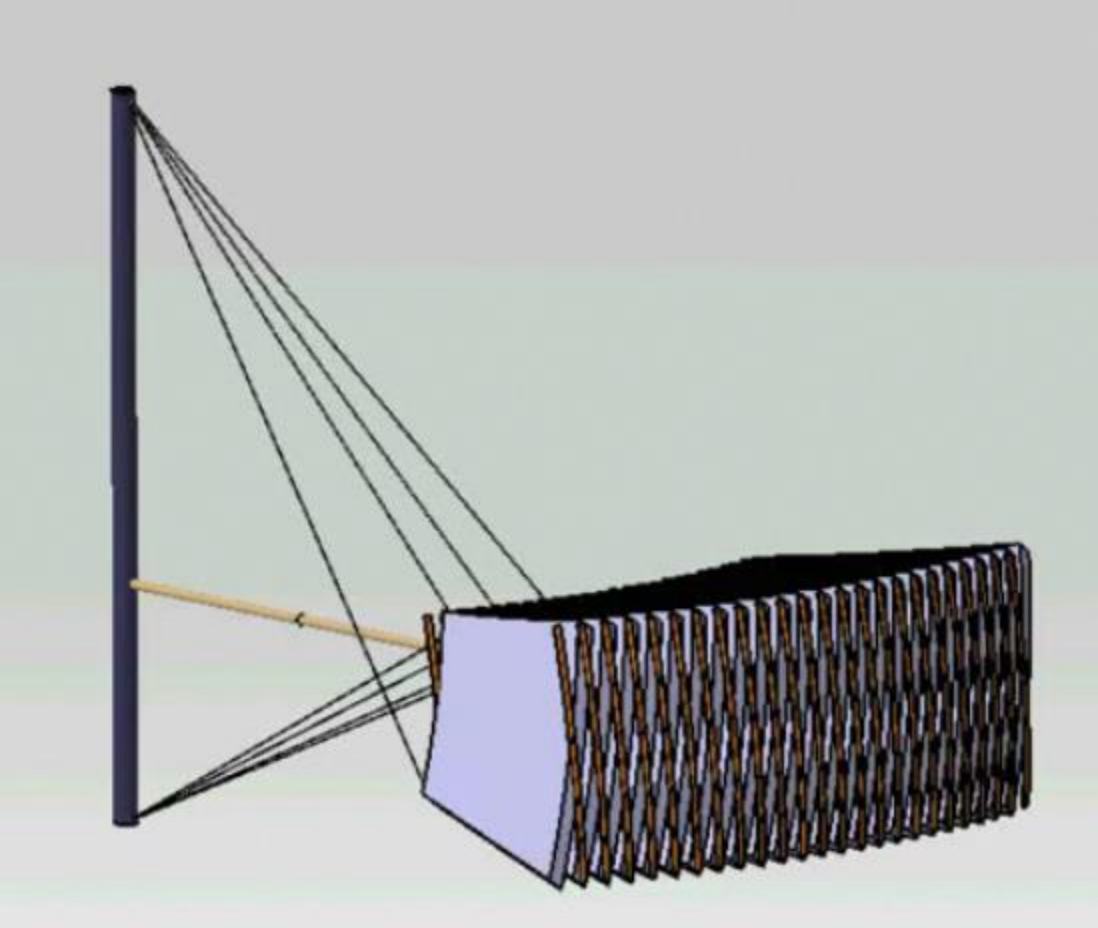
Outil	diamètre (m)	$\Delta\theta$ (rad)	$\Delta\theta$ (")	Détails sur la Lune	Détails à 200 km
Œil	0,0025	$2,7\times10^{-4}$	55	103 km	53 m
	0,010	$6,7\times10^{-5}$	13	25 km	13 m
Jumelles	0,050	$1,3\times10^{-5}$	2,8	5 km	2,7 m
	0,10	$6,7\times10^{-6}$	1,4	2,6 km	1,3 m
Télescope 150	0,15	$4,5\times10^{-6}$	0,92	1,7 km	89 cm
	0,20	$3,4\times10^{-6}$	0,69	1,3 km	67 cm
Télescope 1 m	1,0	$6,7\times10^{-7}$	0,14	260 m	13 cm
Hubble	2,4	$2,8\times10^{-7}$	0,058	110 m	55 mm
VLT	8,0	$8,4\times10^{-8}$	0,017	32 m	16 mm
Télescopes du Keck	10	$6,7\times10^{-8}$	0,014	25 m	13 mm
E-ELT (2024)	40	$1,7\times10^{-8}$	0,0035	6 m	3,3 mm

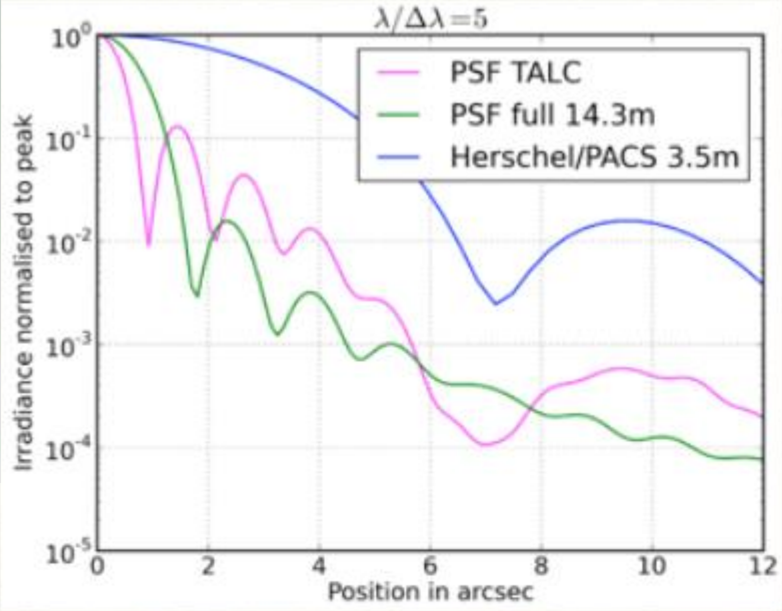




20m
6,5m
3,5m
We'll deal with the
PSF in due time…
Hubble
Herschel
JWST
TALC

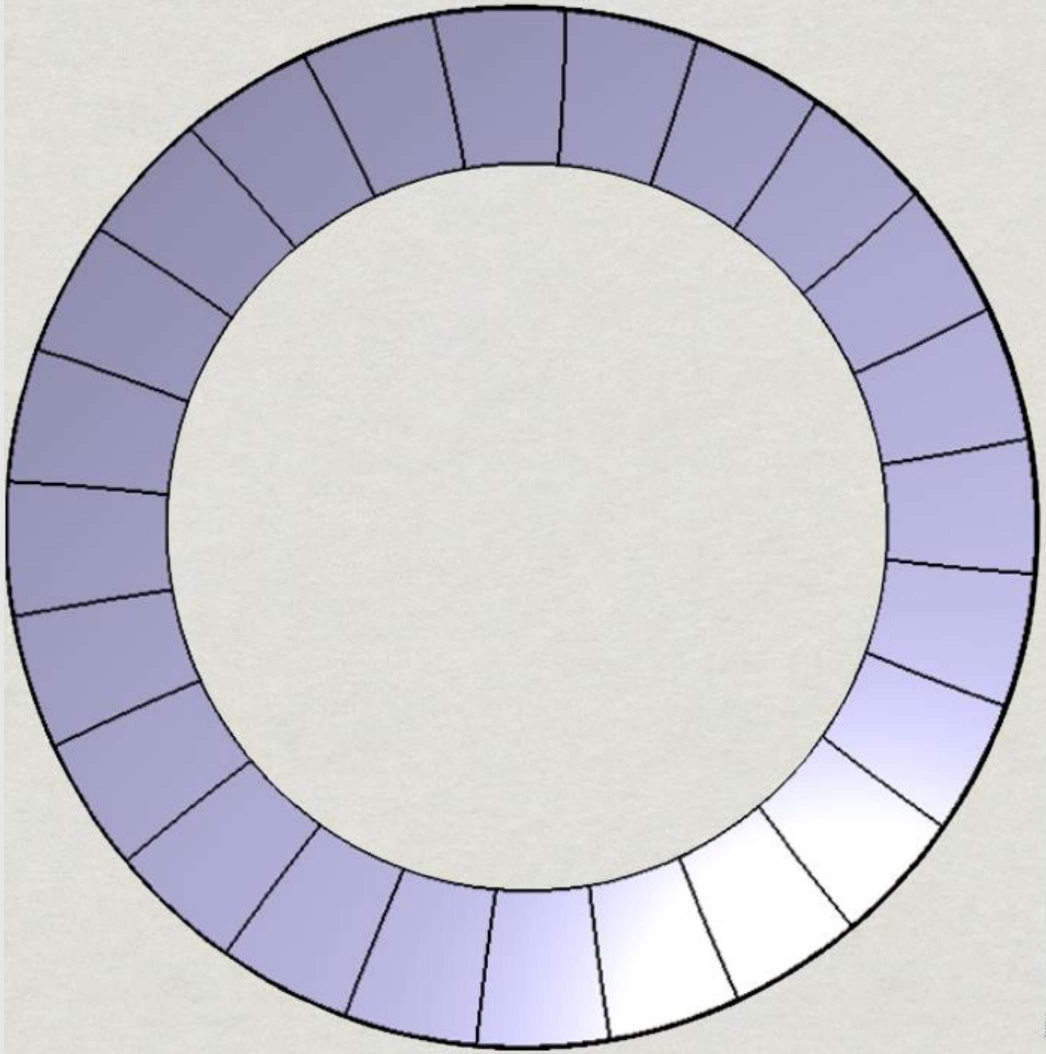



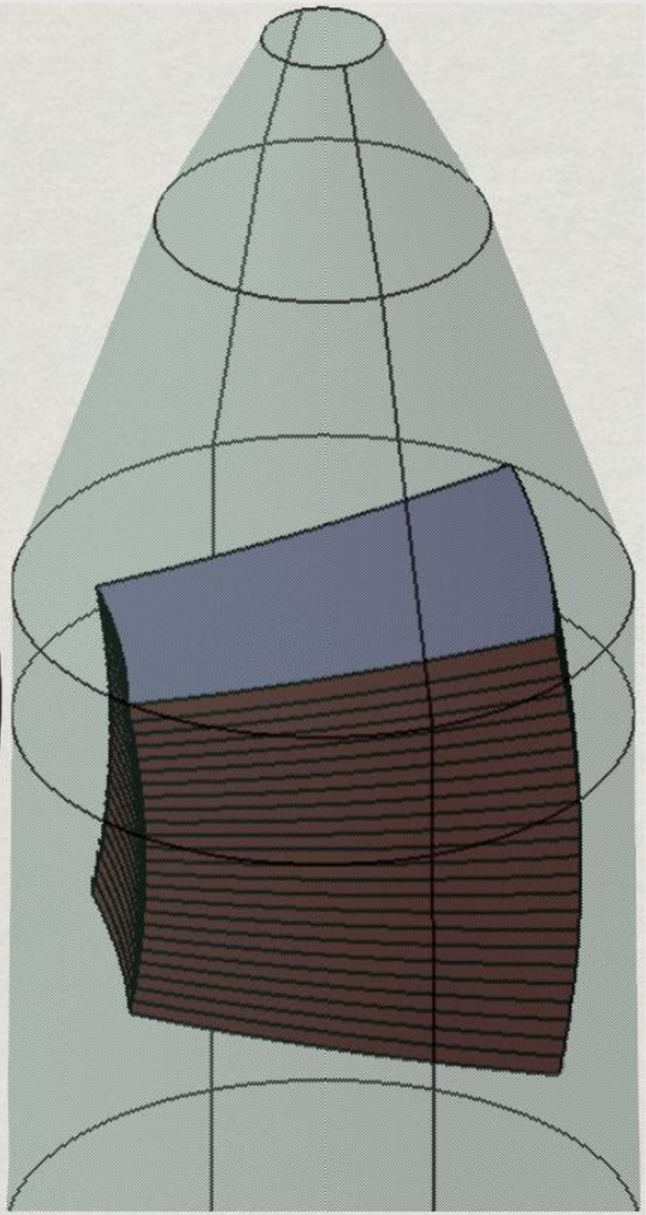


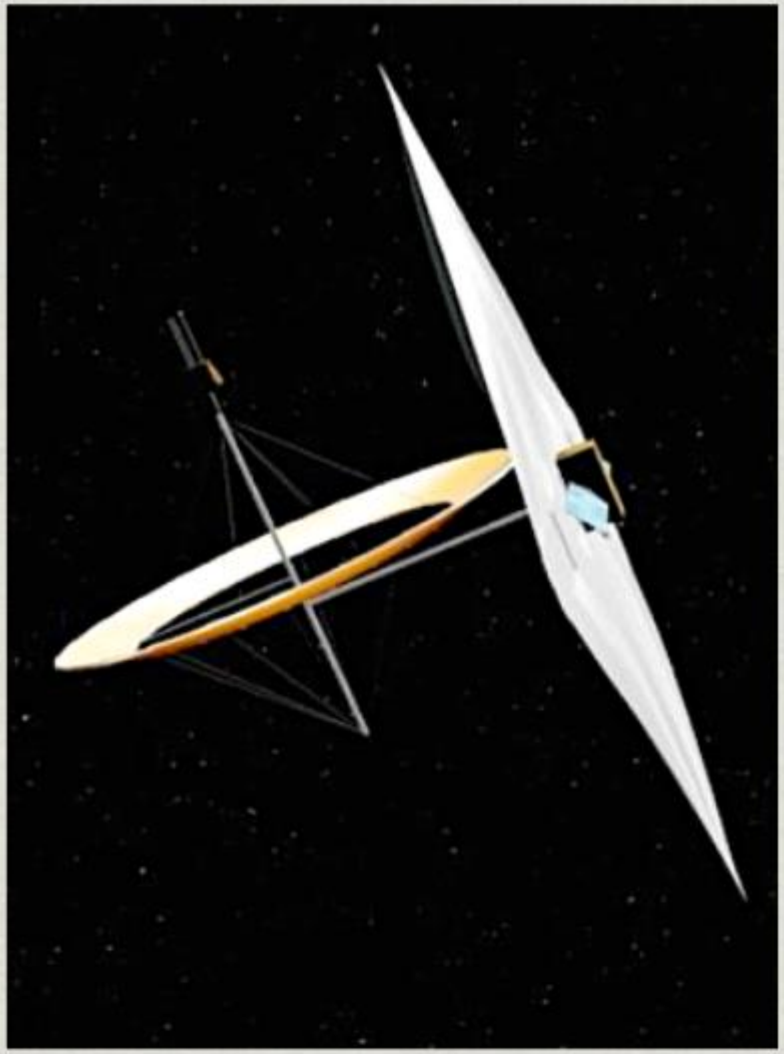
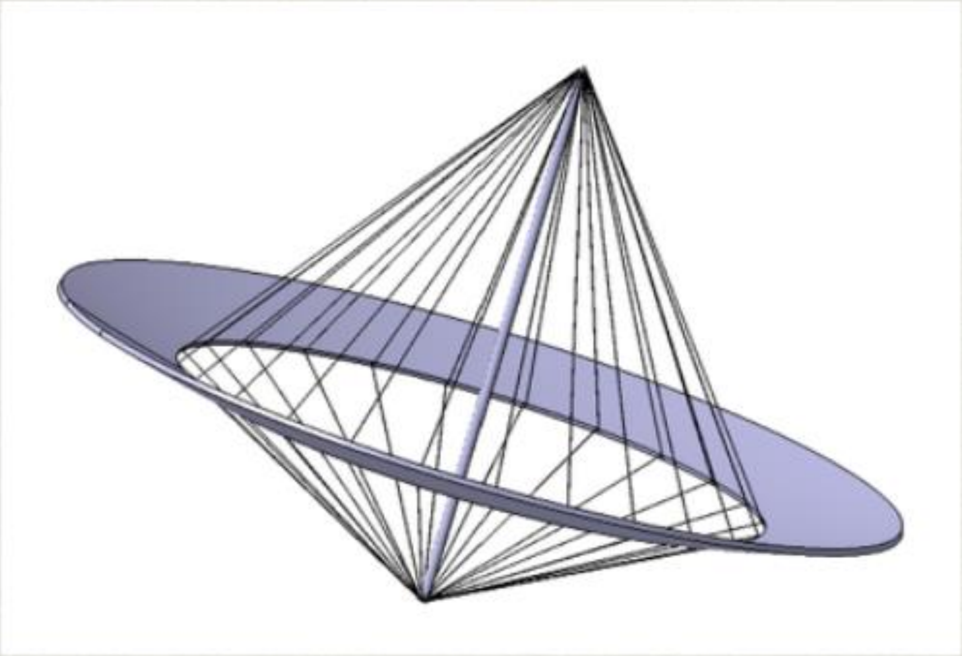


Beam profile for TALC (pink), a filled telescope of identical collecting area (green) and Herschel PACS, for a 100 µm filter of R=5.

How to fold a 20m ring…

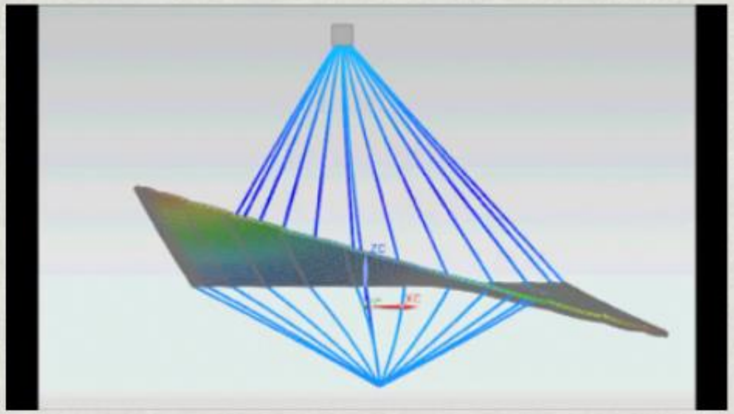




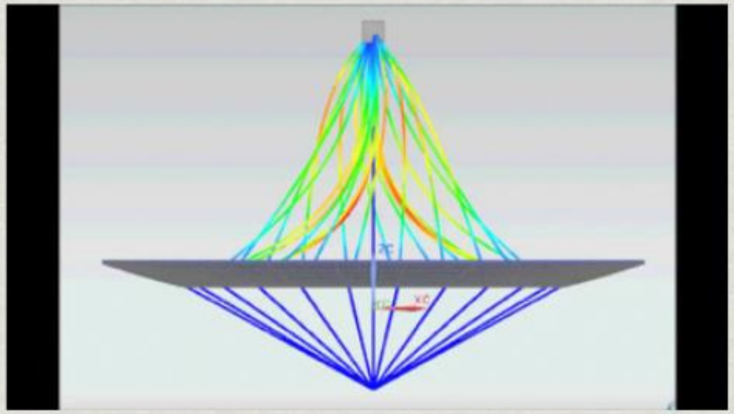




Stiffness demonstrated through vibration studies

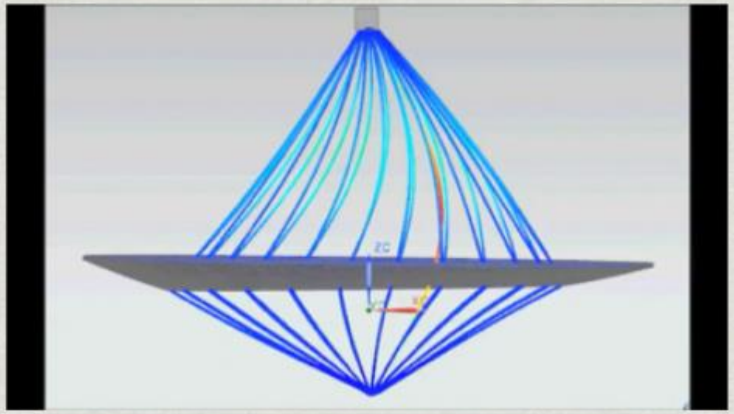
3.2 Hz



Vibrations can be dampened/controlled via the cables' tension, and the length of the mirror connecting rods.



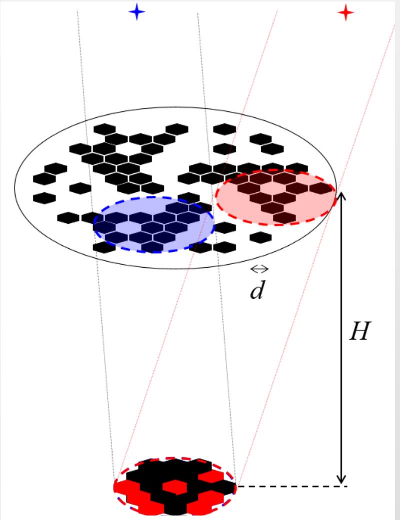
6.2 Hz



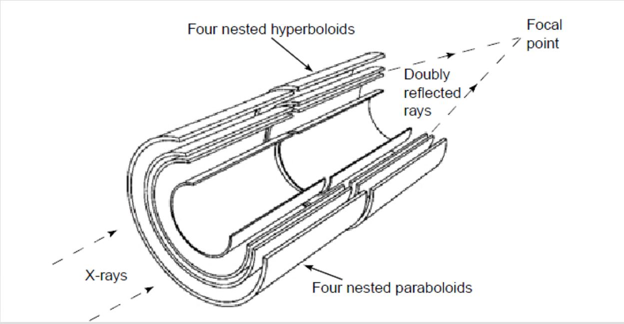
6.5 Hz

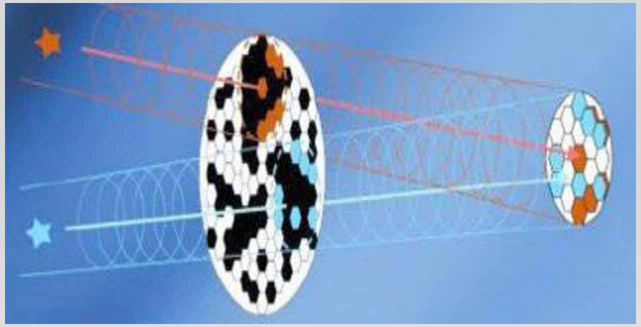
High energy telescopes

Paramètres	Miroirs en incidence rasante	Masque codé
Bande d'énergie	0,2-10 keV	10 keV-10 MeV
Résolution angulaire	10 arcsec	10 arcmin
Précision de localisation	1 arcsec	Arcmin pour sources fortes
Champ de vue	1° ∅	20° × 20°
Surface efficace de détection	PSF = 1 mm ∅	$A_{Det} \approx \frac{1}{2} A_{Coll} > 1000 cm^2$
Sensibilité	10^{-7} -10^{-8} ph.cm^{-2}.s^{-1}.keV^{-1} 0,1-1 µCrab	10^{-5} -10^{-6} ph.cm^{-2}.s^{-1}.keV^{-1} 0,1-1 mCrab



$$\theta = \arctan \frac{d}{H}$$





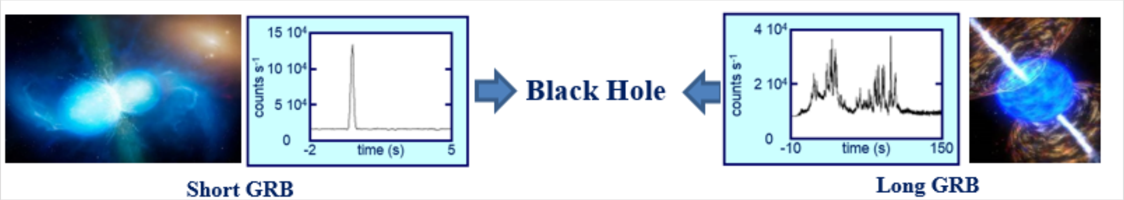
F - Application to the SVOM Mission

Scientific Rationale of the SVOM mission

The GRB science open questions

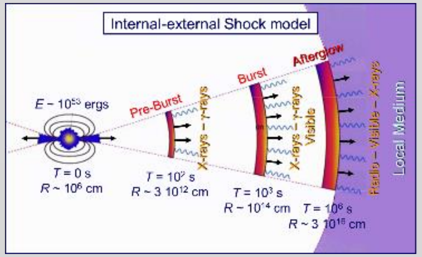
GRB phenomenon

- **Diversity of progenitors and unity of the GRBs phenomenon**



GRB physics

- Acceleration and nature of the relativistic jet
- Radiation processes
- **The early afterglow and the reverse shock**



GRB progenitors

- The GRB-supernova connection
- Short GRB progenitors

Cosmology

- Cosmological lighthouses (absorption systems)
- Host galaxies
- Tracing star formation
- Re-ionization of the universe
- Cosmological parameters
- **Detecting high redshift (low Epeak) GRBs (down to 4 keV)**

Fundamental Physics

- Origin of High-Energy Cosmic Rays
- Probing Lorentz invariance
- Gravitational waves induced by short GRBs

SVOM required Science Performance

- SVOM will provide ~80 GRB/yr during 3 years mission.
- SVOM will detect the GRBs in a wide spectral band (from 4 keV to 5 MeV) and observe the afterglow in Soft X rays, Visible, IR
- SVOM will detect short and long GRBs
- SVOM will measure the redshift for >50% of the SVOM GRBs
- SVOM will provide fast, reliable and accurate positions of GRBs, and send alerts to the community
- SVOM will measure the broadband spectral shape (from visible to MeV) and temporal properties of GRBs prompt emission
- SVOM will study the afterglows and provide quick arcsec positions of GRBs

SVOM GRBs will benefit from follow-up with a new generation of astronomical instruments: JWST, SKA, CTA, LSST…

SVOM will operate in the era of advanced GW detectors, providing the opportunity to search correlations between GW and GRBs

Main enhancements wrt previous mission (e.g. SWIFT)

⇒ **Enhanced synergy between space and ground observatories**

⇒ **Low energy threshold (4 keV) for GRB observation**

⇒ Mission Choice : SVOM is mini-satellite class mission (< 1000kg)

Chinese France Collaboration

The GRB science

CNSA (Chinese Space Agency)
CAS (Chinese Academy of Sciences)

- Launcher + launch service
- Satellite platform + payload module
- 2 space + 2 ground instruments

CNES (French space agency)

- 2 space + 1 ground instruments

Institutes

- **China (PI J. Wei, NAOC)**
  - SECM Shanghai
  - NAOC Beijing
  - IHEP Beijing
  - Nanjing University

- **France (PI B. Cordier, CEA)**
  - CNES Toulouse
  - APC Paris
  - CEA Paris-Saclay
  - CPPM Marseille
  - GEPI Meudon
  - IAP Paris
  - IRAP Toulouse
  - LAL Orsay
  - LAM Marseille
  - LUPM Montpellier
  - OAS Strasbourg

- **Germany**
  - MPE Garching
  - IAAT Tübingen

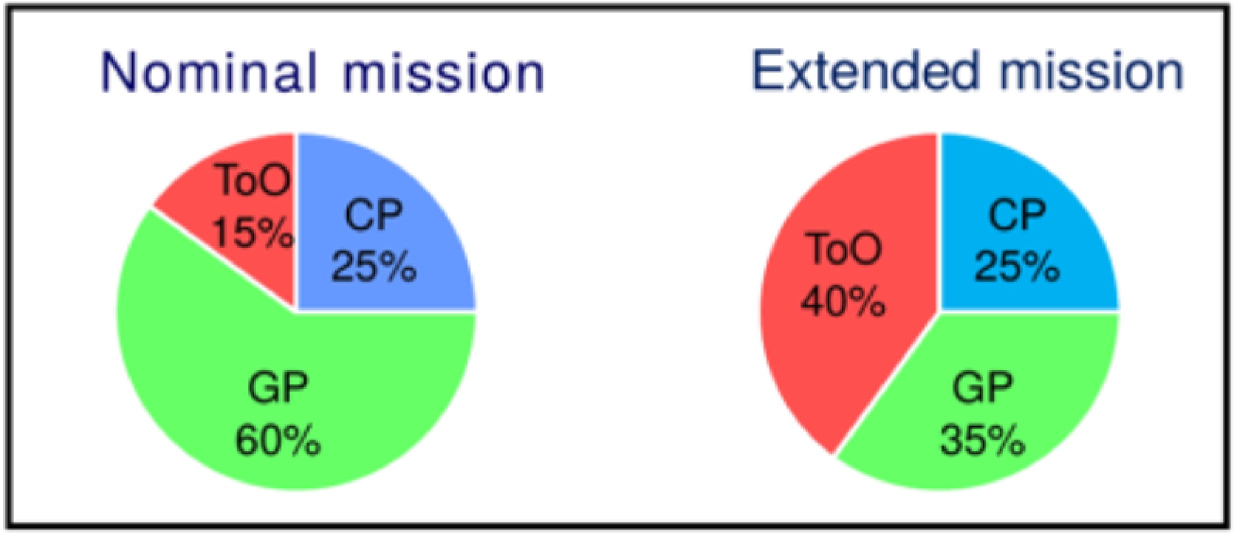
- **UK** Univ. Leicester

- **Mexico** UNAM

Scientific Programs of SVOM

- **Core Program (CP)** : follow-up GRB triggers of ECLAIRs
- **General Program (GP)** : AGN, ULX, TDE, Galactic sources (CV, XRB, pulsars, magnetars, TGF), background studies (CXB), etc
- **Targets of Opportunity (ToO)**, 1 / day: follow-up external triggers: multi-wavelength (SKA, LSST, CTA, HAWC) or multi-messenger (GW, neutrino)

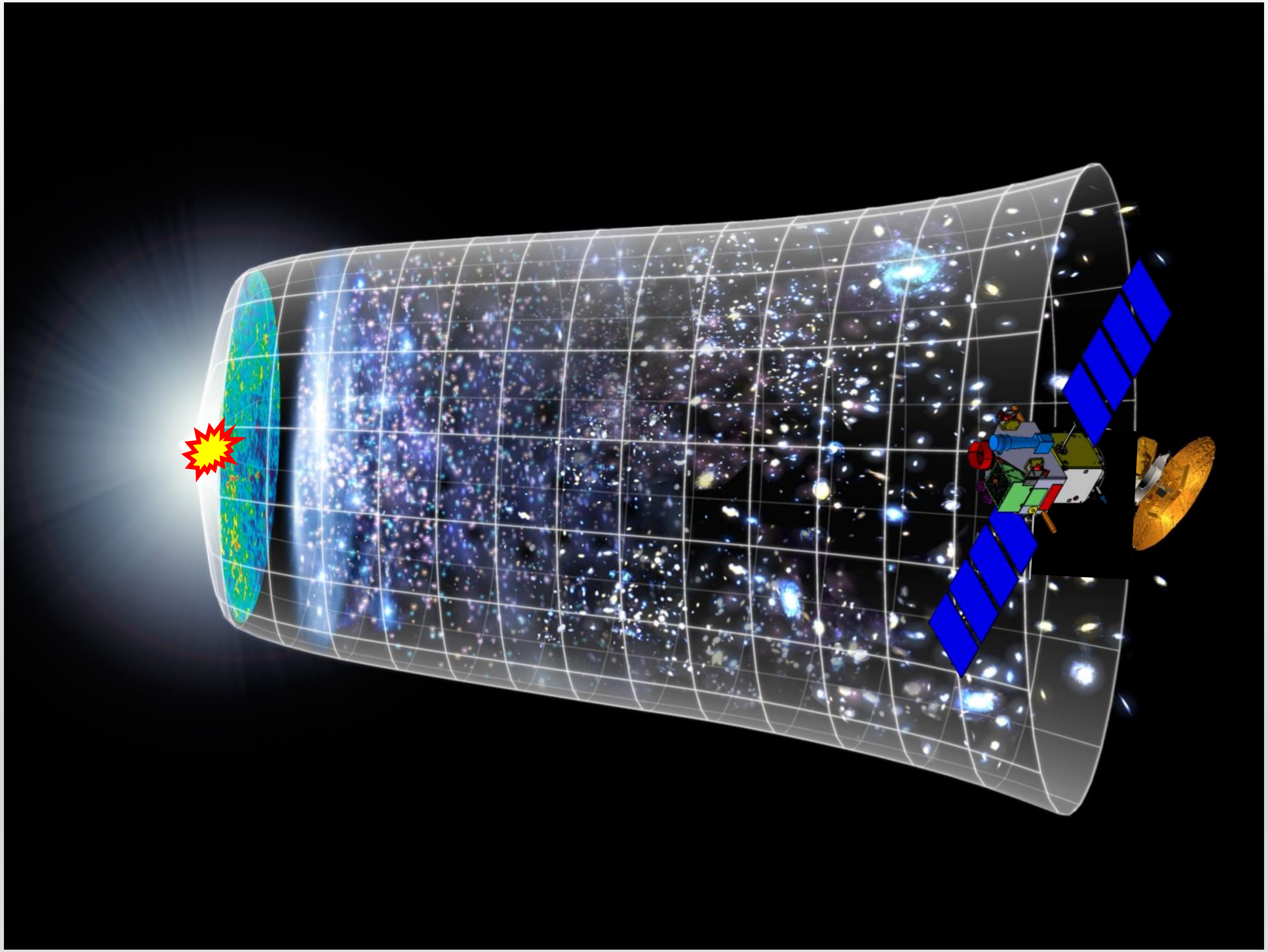
Observing time allocation



Extended mission (after 3 first years)

- ToO rate increased (up to 5/day)
- GP time outside the “B1 law” increased (10% → 50%)

SVOM Mission



Definition of a mission

Science objectives

Mission constraints

- Cost, time delay
- Platform resources (s
- Launcher constraints
- Collaborations

Concurrent Engineering

- Thermal architecture (sat)
- Mechanical architecture
- Electrical architecture
- Orbit control

Mission feasibility

Mission profile

- Launcher
- Orbit
- Life duration
- Attitude law (pointing strategy)
- Data transfer (com)

Payload definition

- Instruments onboard
- Observation strategy
- System ressources

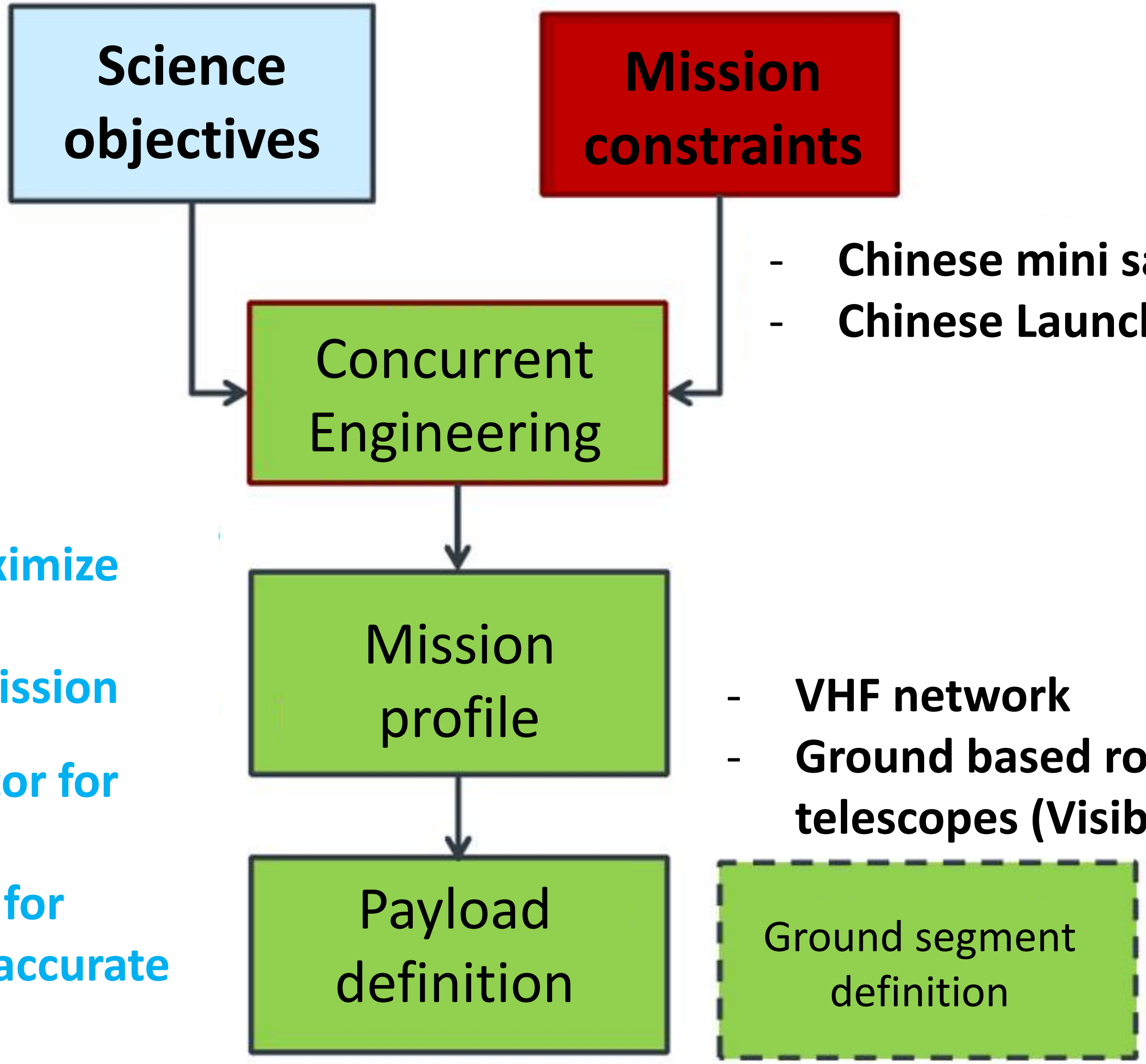
Ground segment definition

Analysis if the requirements => Definition the SVOM mission

Observe 200 GRB during the mission from γ ray to IR

- **Orbit 650 km**
- **Inclination of 30°**
- **Pointing strategy to maximize observing time,**
- **3years (+2 extension) mission**

- **Wide FOV gamma monitor for detection**
- **Visible and X telescopes for afterglow emission and accurate localization**



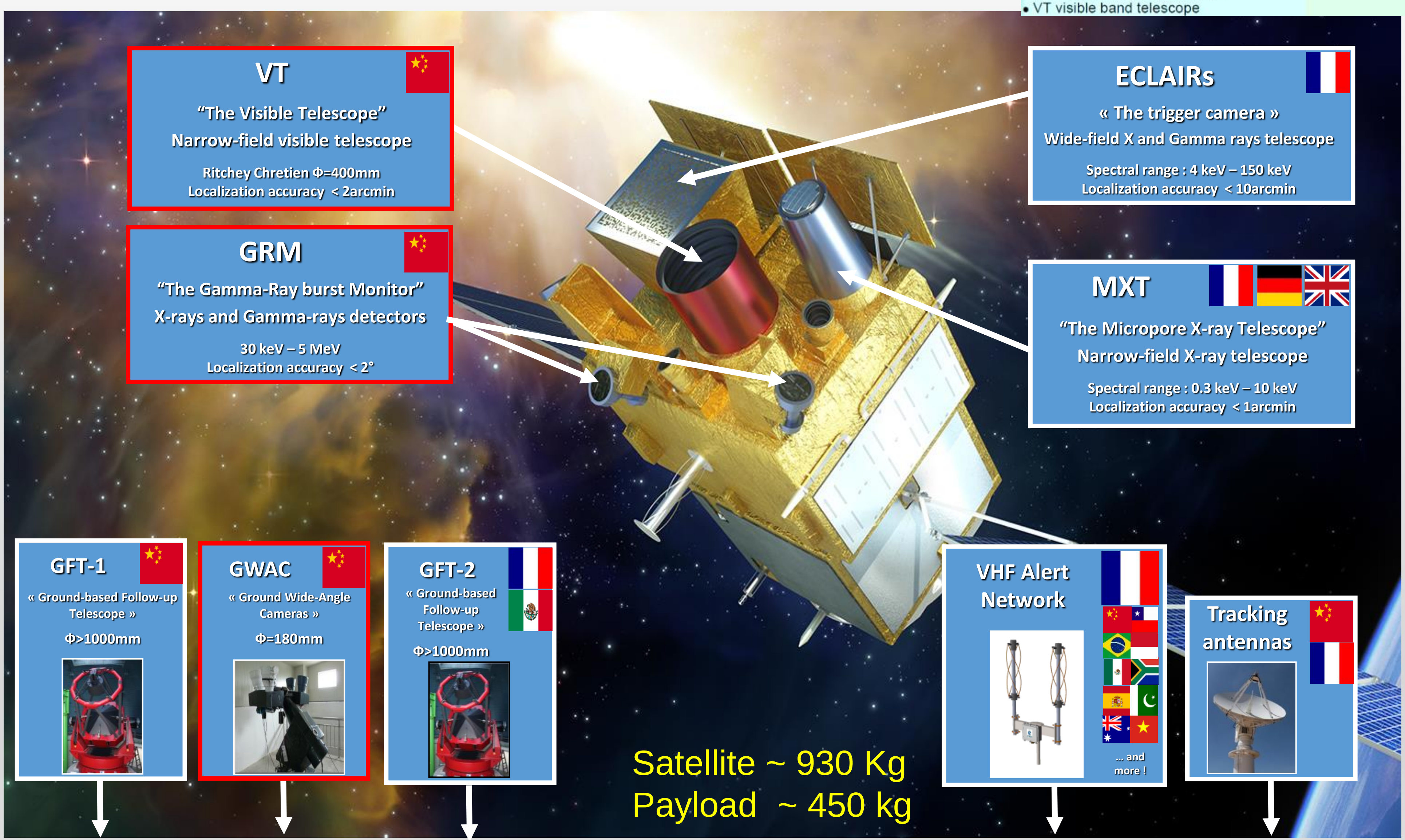
- **Chinese mini satellite**
- **Chinese Launcher**

- **VHF network**
- **Ground based robotized telescopes (Visible and IR**

SVOM INSTRUMENTS (board and ground)

4 space instruments:
- ECLAIRs gamma-ray imager & trigger
- GRM gamma-ray monitor
- MXT X-ray focusing telescope
- VT visible band telescope

3 ground telescopes
- GWAC ground wide angle camera
- F-GFT & C-GFT: ground follow-up telescopes



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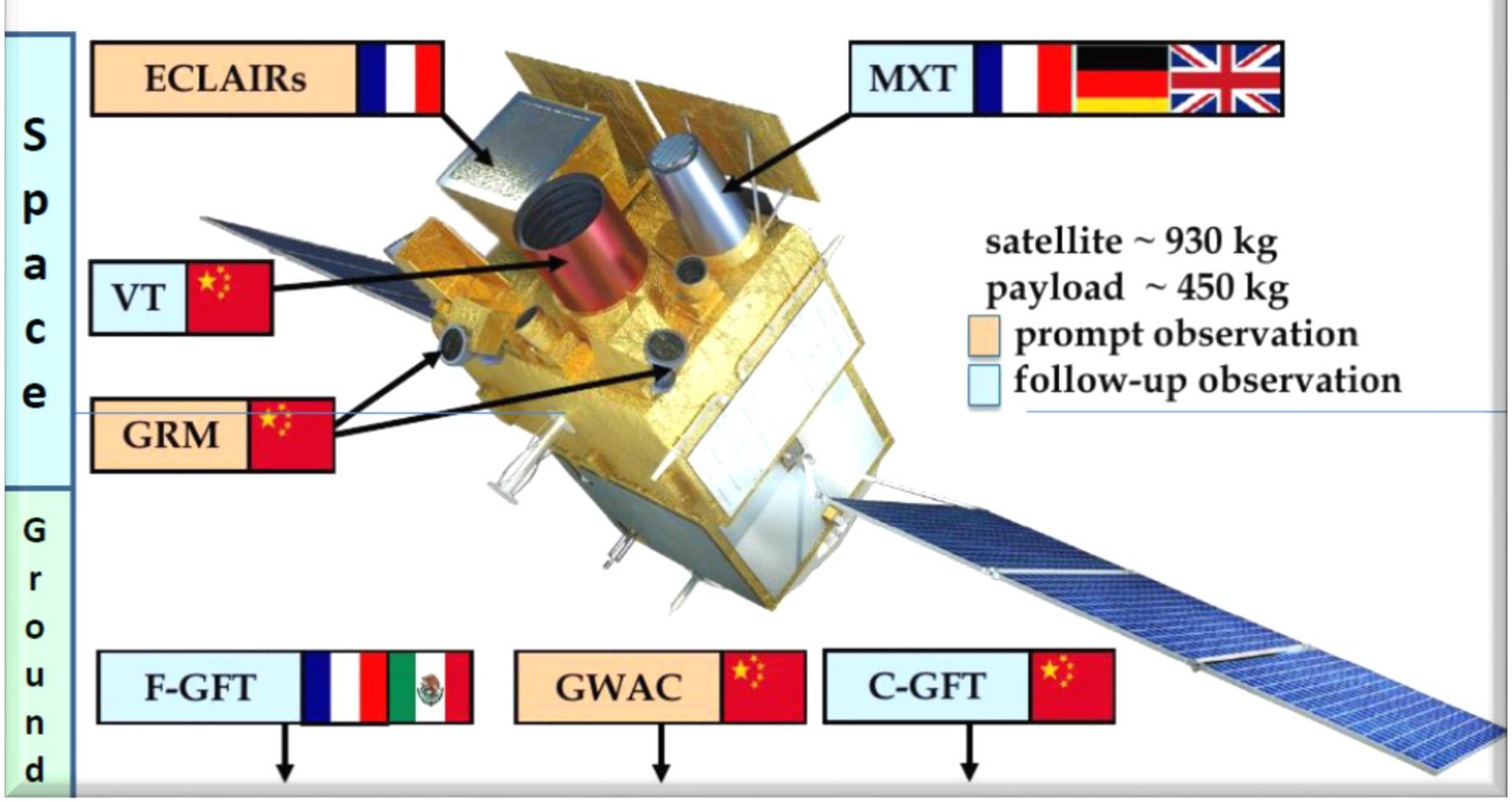
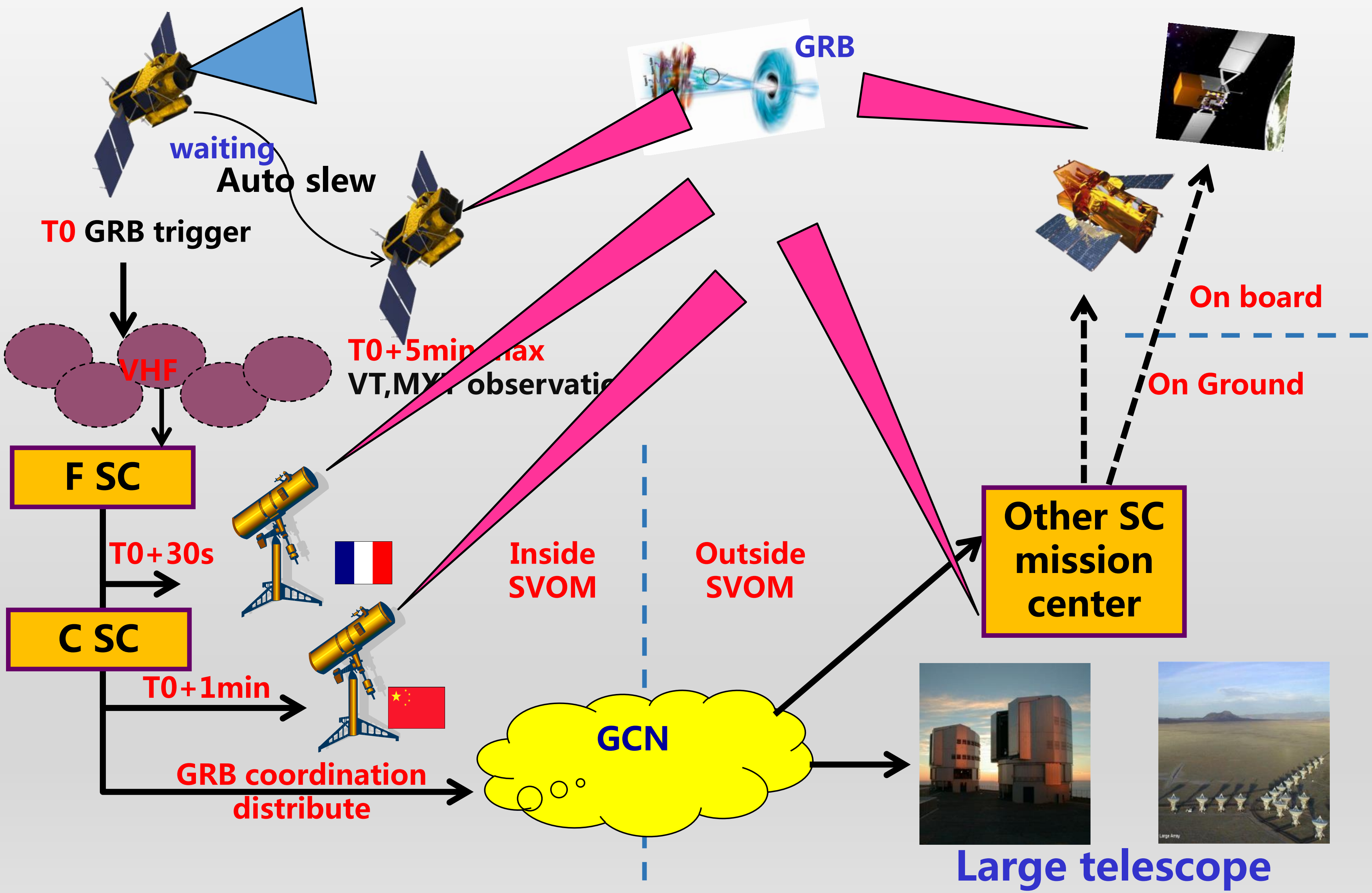
- GWAC ground wide angle camera
- F-GFT & C-GFT: ground follow-up telescopes



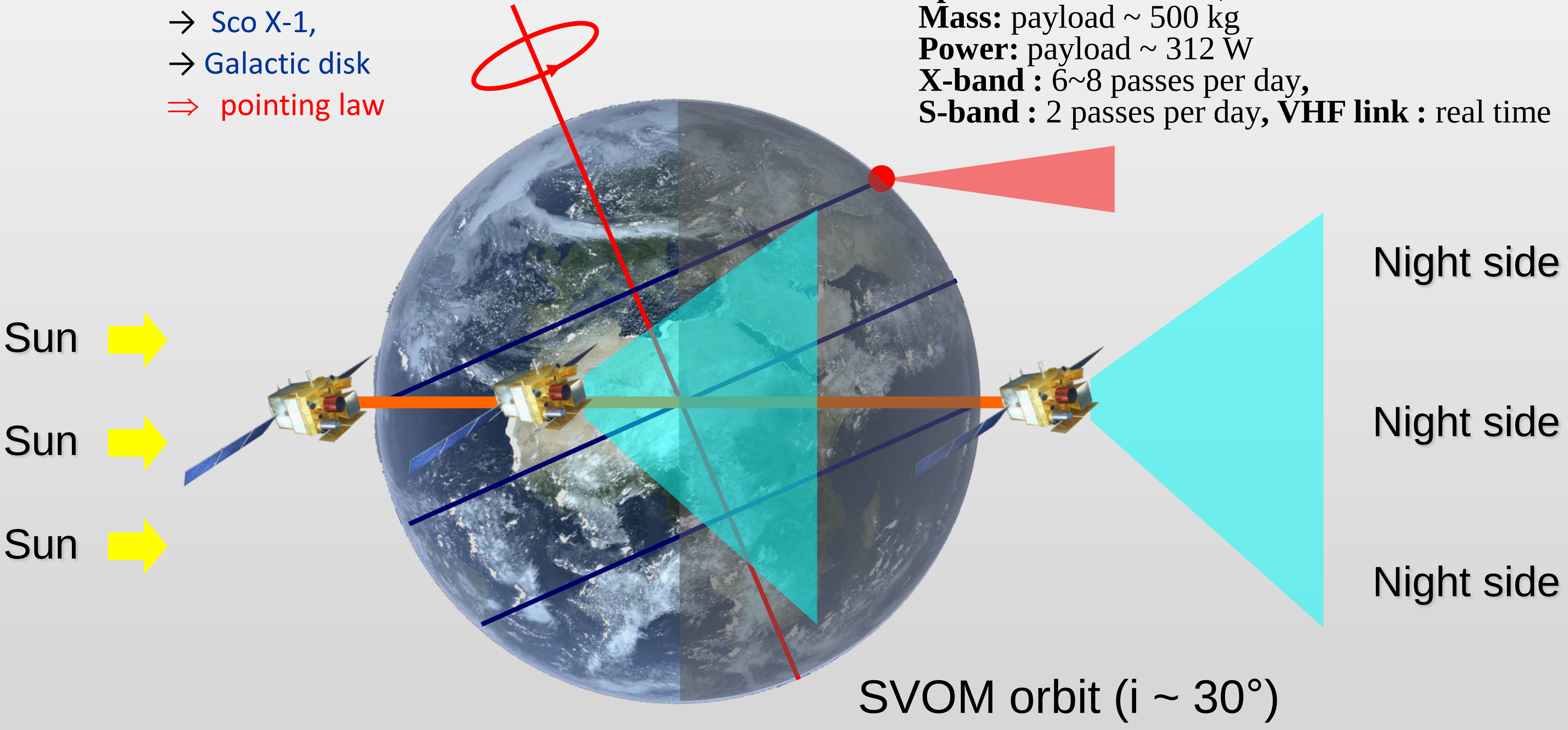
GRB Observation scenario



SVOM/ECLAIRs pointing strategy: anti solar

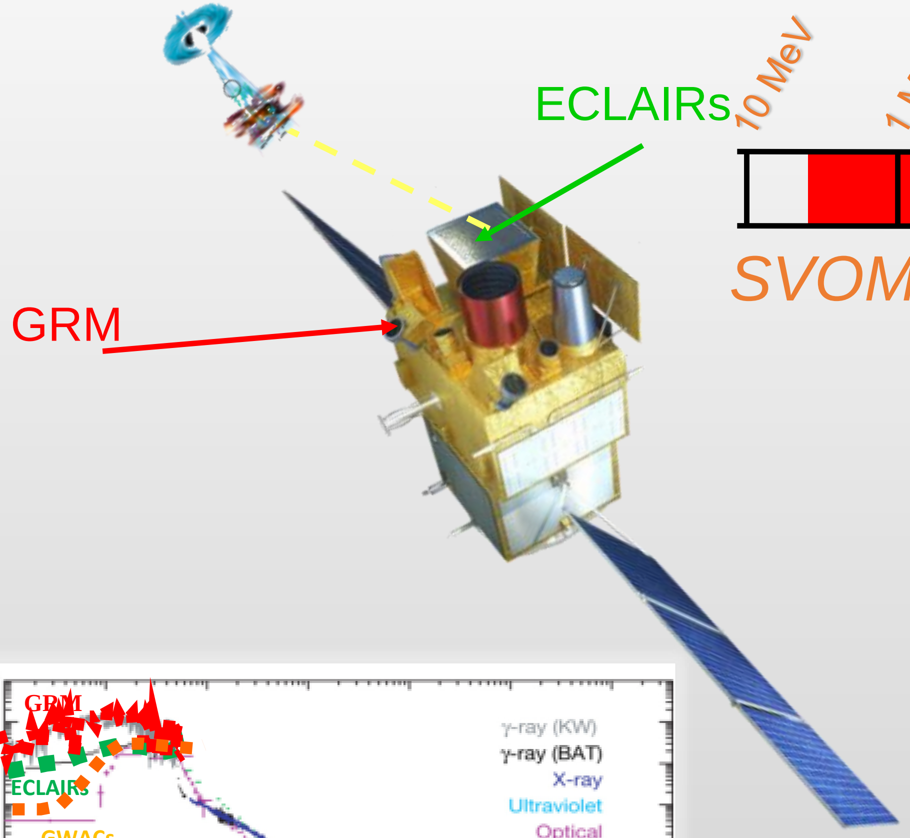
Pointing requirements
avoid strongest known X ray sources in the FoV
→ Sco X-1,
→ Galactic disk
⇒ pointing law

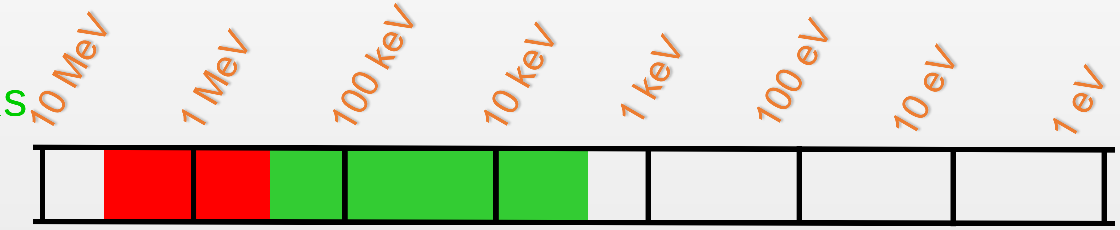
Orbit: 30 deg inclination, 600km altitude, circular
Mission lifetime: 3 years + 2 years (extend life time)
Pointing strategy : Anti-Solar
Spacecraft : Platform, 3 axis stabilized
Mass: payload ~ 500 kg
Power: payload ~ 312 W
X-band : 6~8 passes per day,
S-band : 2 passes per day, **VHF link :** real time



The center of the CXG field of view will be well above the horizon of large ground based telescopes all located at tropical latitudes

Multi wavelength Observation strategy





SVOM

ECLAIRs (CNES, CEA, IRAP, APC)

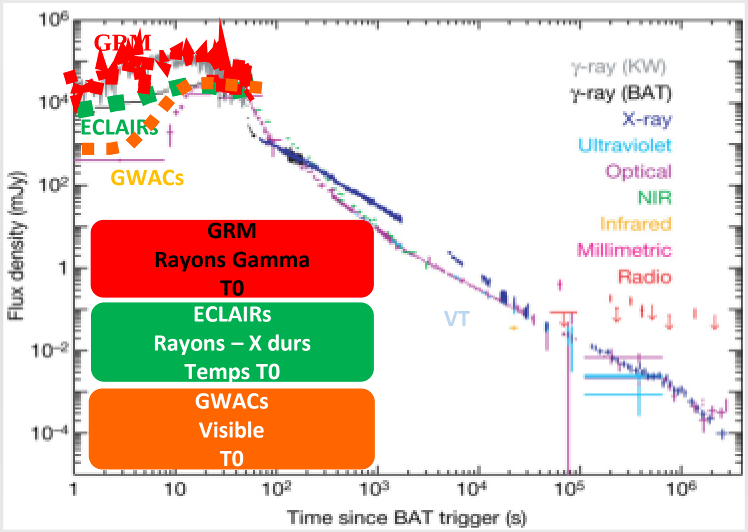
Camera for GRB detection +
real time trigger electronics

CdTe camera with coded mask, 4 – 150 keV
field 2sr, localizsation < 10 ’

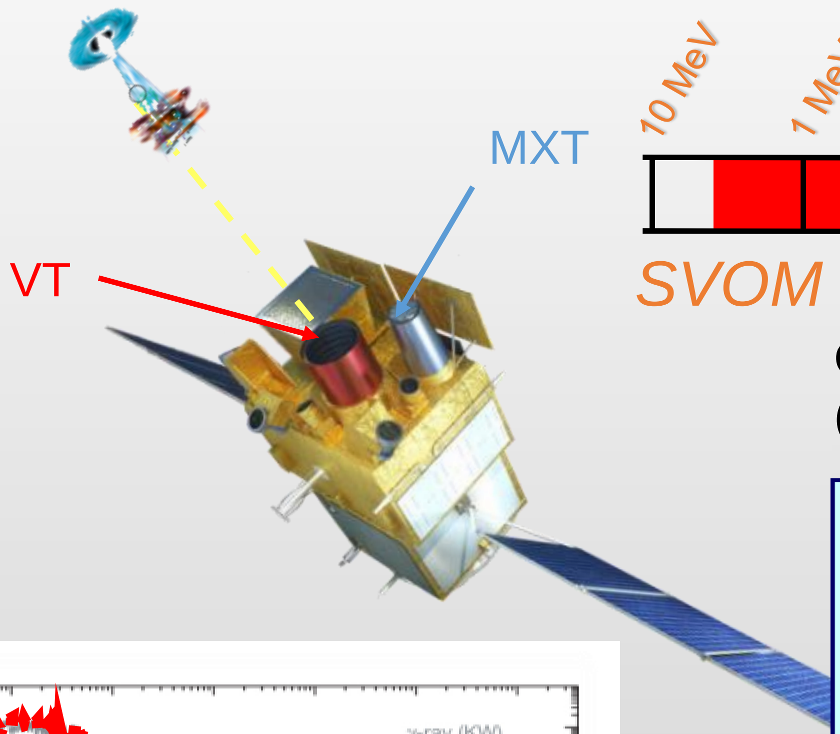
GRM (IHEP, Beijin)

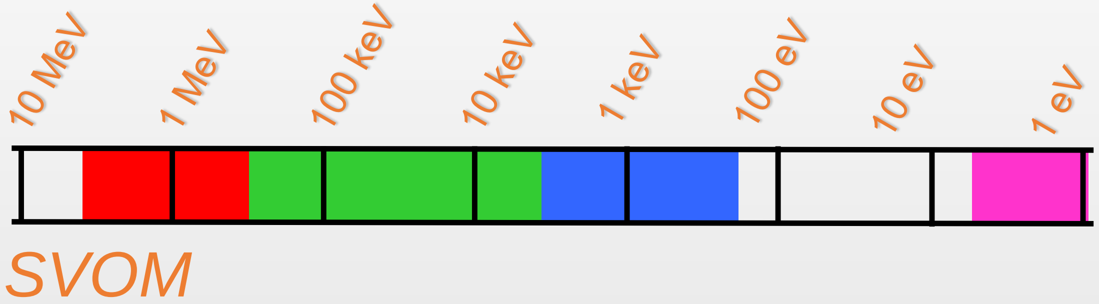
Gamma Rays monitor,
spectral parameter

NaI + CsI, 20 keV - 3 MeV,
field 2 sr, no localization

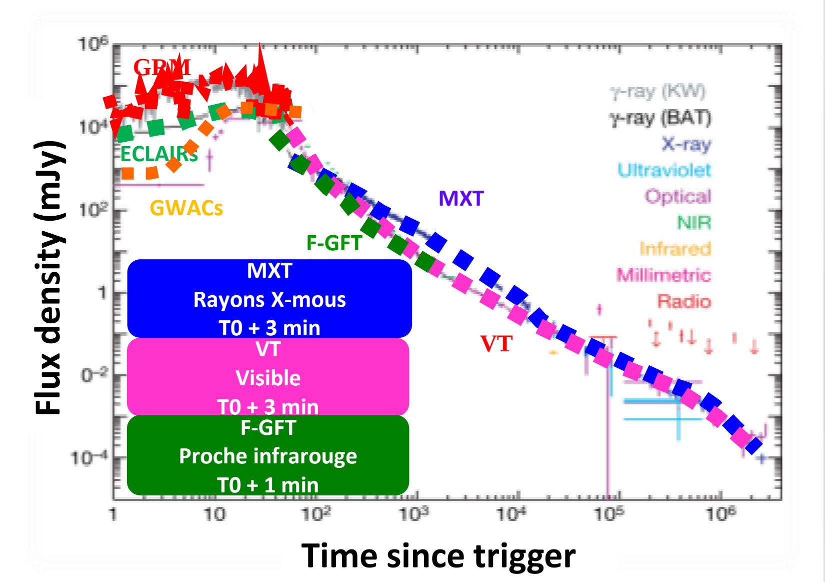


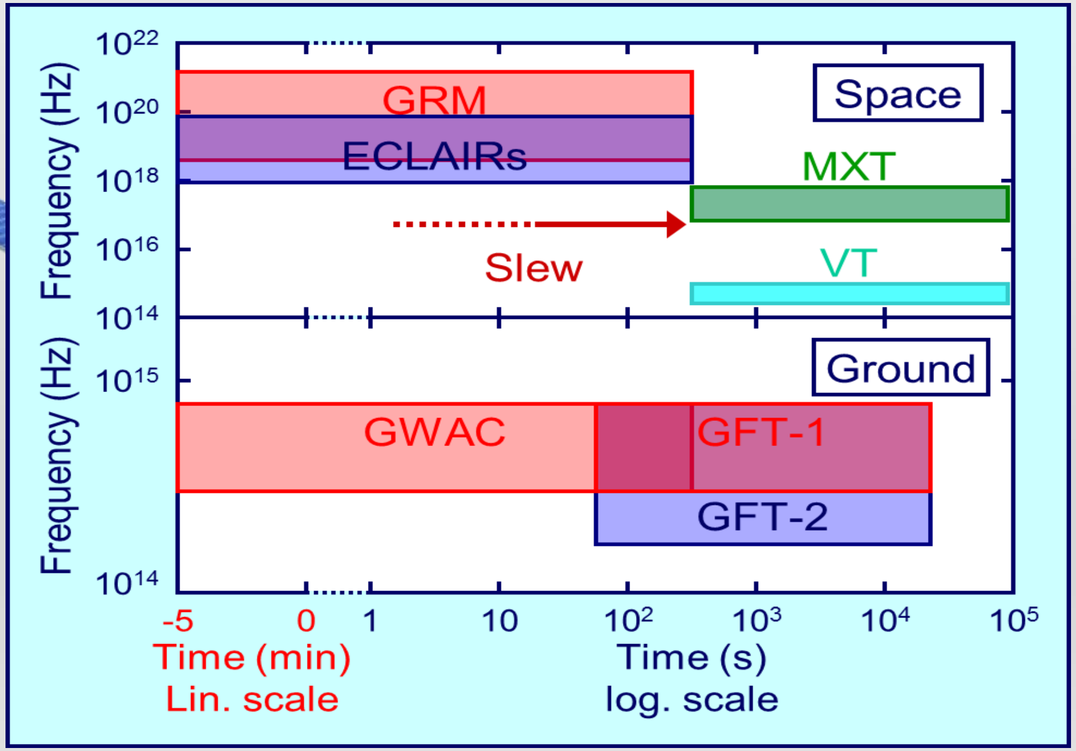
Multi wavelength Observation strategy





Observation of after glow after slew (rotation) of the satellite (~3 mn)





Towards the definition of each instrument

Once the mission is defined by the **mission scientist**:

- ❑ Collaborations
- ❑ Science programs,
- ❑ Orbit & pointing strategy,
- ❑ Operations,
- ❑ Principle of each instrument …,

⇒ **Each instrument has to be specified for the science it is responsible for** within the mission by the instrument scientist and the system lead.

- ❑ Instrument concepts and subsystems
- ❑ Sizing the instrument (Requirements)
- ❑ Performance allocation to its subsystems
- ❑ Performance budgets

ECLAIRs: GRB detection & Imaging

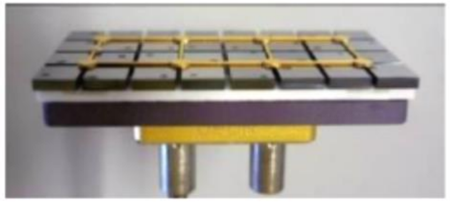
- **Detection plane**: 1024 cm²
- 6400 CdTe pixels (4x4x1 mm³)
- Energy range: 4-150 keV
- Aeff = 200 cm² @ 6 keV

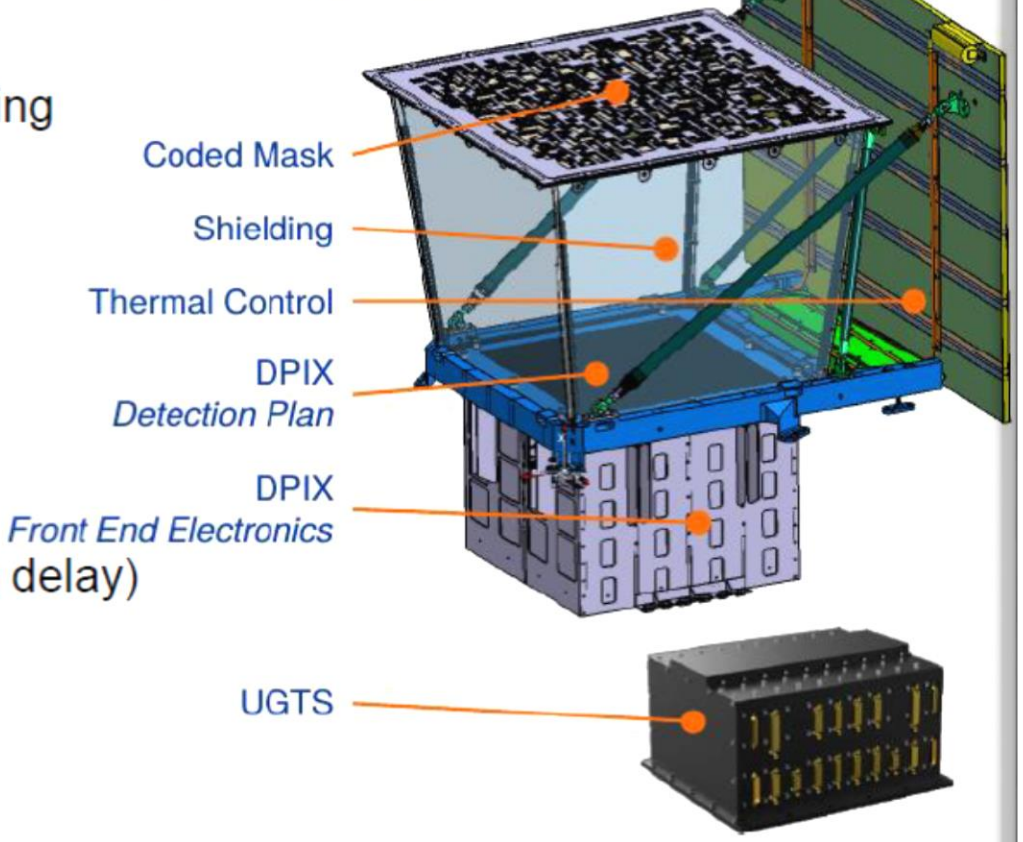
- **Mask**: Ta, 40% open, self supporting
- FoV = 2 sr (total)
- Localisation accuracy <12'

(at detection limit, 90% C.L.)

- **control and trigger unit UGTS**
- All photons sent to ground (6-12 h delay)
- GRB trigger & localization:
  - alert to ground via VHF
  - spacecraft slew for follow-up

CNES, IRAP, CEA, APC





Gamma Ray Monitor

IHEP

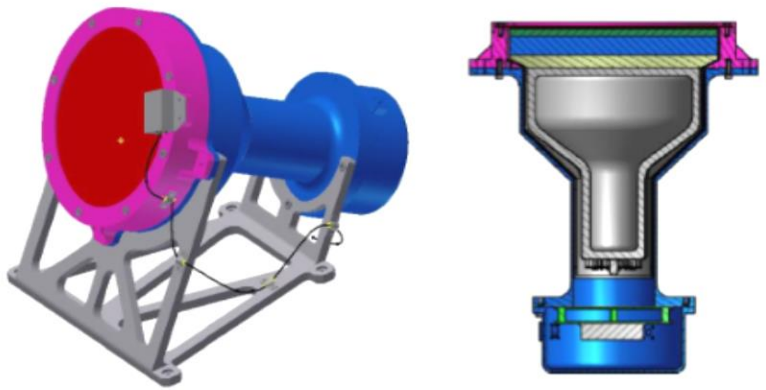
- **3 Gamma-Ray Detectors** (GRDs)
- NaI(Tl) (16 cm Ø, 1.5 cm thick)
- Plastic scintillator (6 mm) to monitor and reject particle events
- FoV = 2 sr per GRD

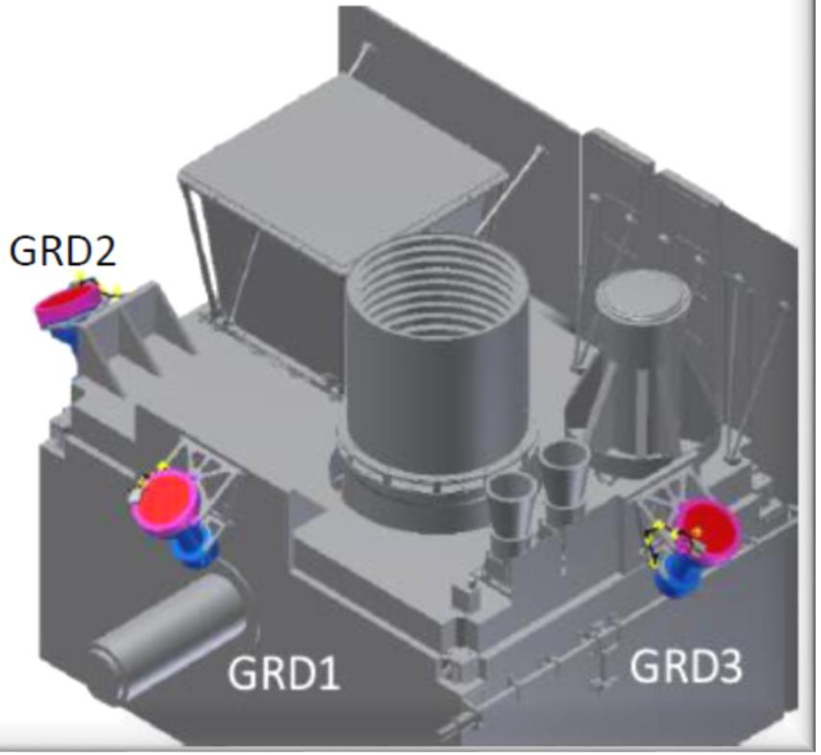
- Energy range: 15-5000 keV
- Aeff = 190 cm² @ peak
- Rough localization accuracy

- Expected GRD rate: ~90 GRB/yr

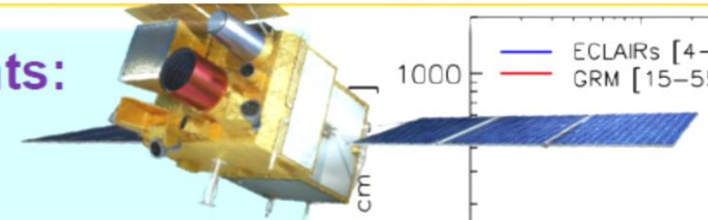
- GRM data sent to ECLAIRs

→ enhance Trigger sensitivity to short GRBs





SVOM: GRB prompt observation

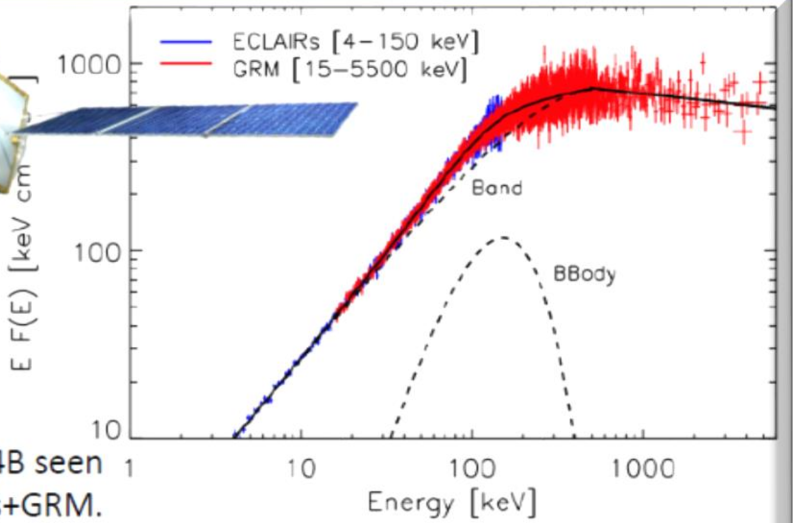


- **Space based instruments:**

ECLAIRs + GRM

- Broad-band coverage 4 keV – 5 MeV

➔ Well measured prompt gamma (Epeak, …



Multi-component spectrum of GRB100724B seen by Fermi/GBM imulated in ECLAIRs+GRM.

- **Ground-based Wide Angle Camera (GWAC)**

- dedicated to SVOM, partially operational in 2017
- sites: Ali (China) and CTIO (Chile)

- 36 camera units, 5400 deg², following ECLAIRs FoV
- band: 0.50-0.85 μm; sensitivity: M_V=15 in 10 s

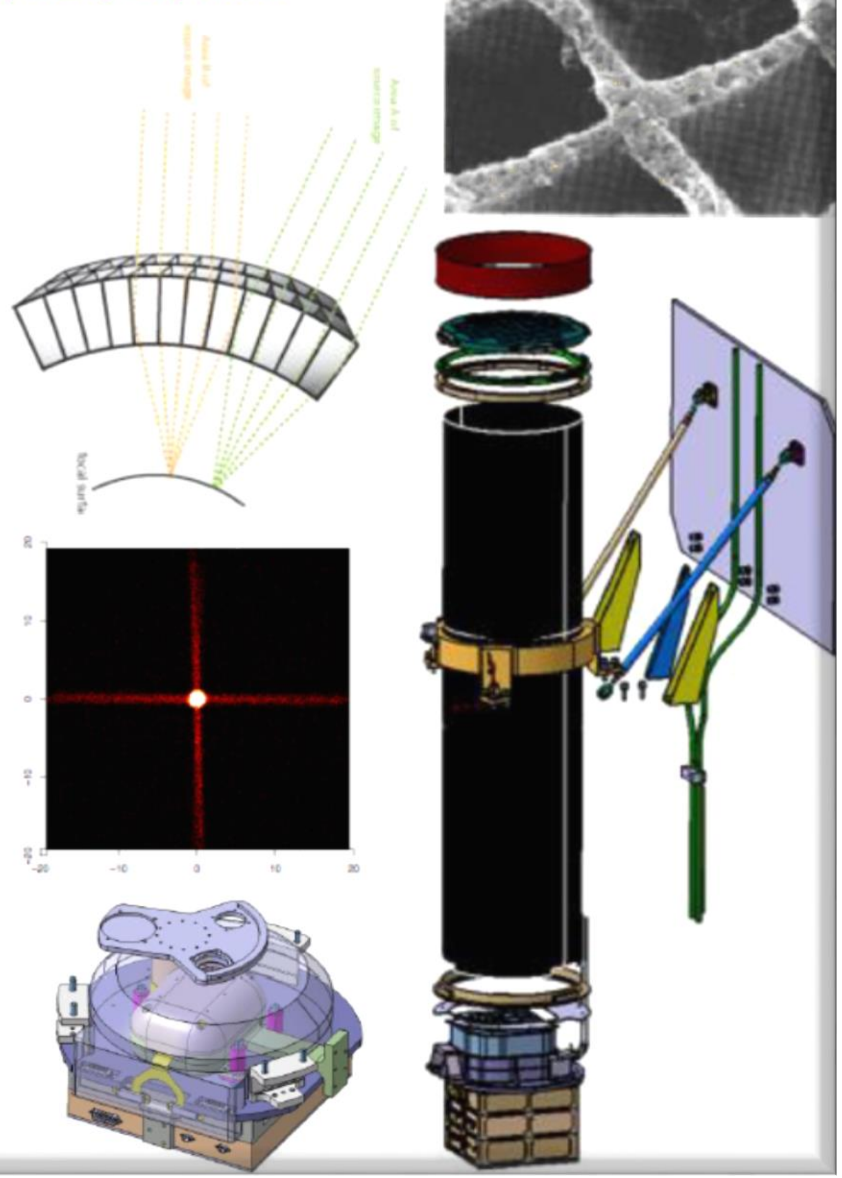
~16% of ECLAIRs-triggered GRBs observable by GWAC

MXT: Micro Channels X ray Telescope

- Micro-pores optics (Photonis) with square 40 µm-size pores in a "Lobster Eye" configuration
- Focal length: 1 m
- FoV = 64x64 arcmin²

- pnCCD camera
- Energy range: 0.2-10 keV
- Aeff = 27 cm² @ 1 keV (central spot)
- Energy resolution: ~80 eV @ 1.5 keV
- Localization accuracy <13" within 5 min (for 50% of GRBs)

CNES, CEA, UL, MPE

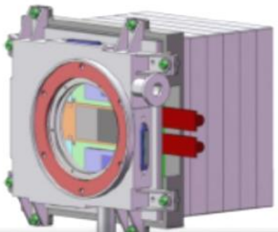


VT: Visible Telescope

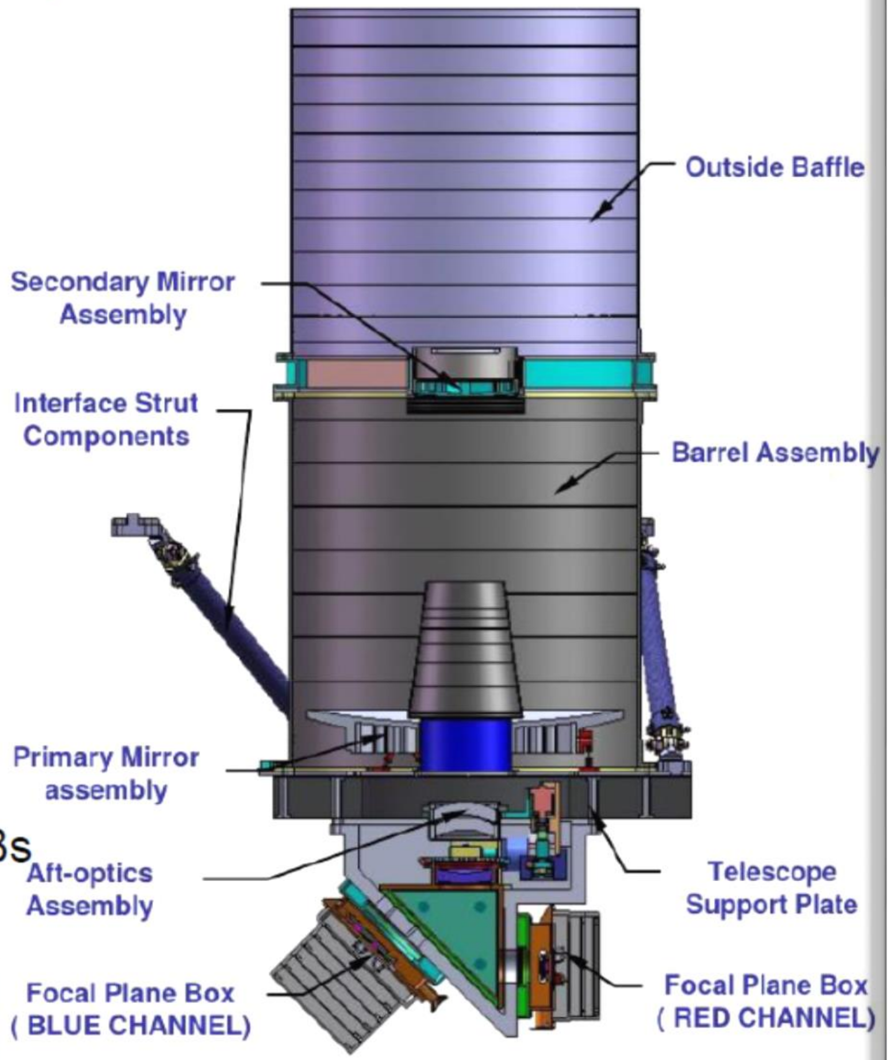
- Ritchey-Chretien telescope
- Ø=40 cm, f=9
- FoV = 26x26 arcmin² covering ECLAIRs localization error box
- Focal length: 3.6 m

- 2 channels: blue (400-650 nm) and red (650-1000 nm)
- Each channel: 2k x 2k CCD detector

- Sensitivity M_V=22.5 in 300 s
- Expect to detect ~80% of ECLAIRs GRBs
- Localization accuracy <1"

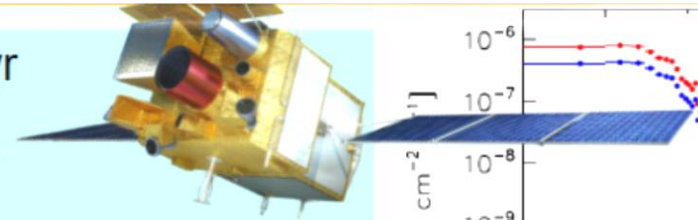


NAOC, XIOPM



SVOM: GRB afterglow observations

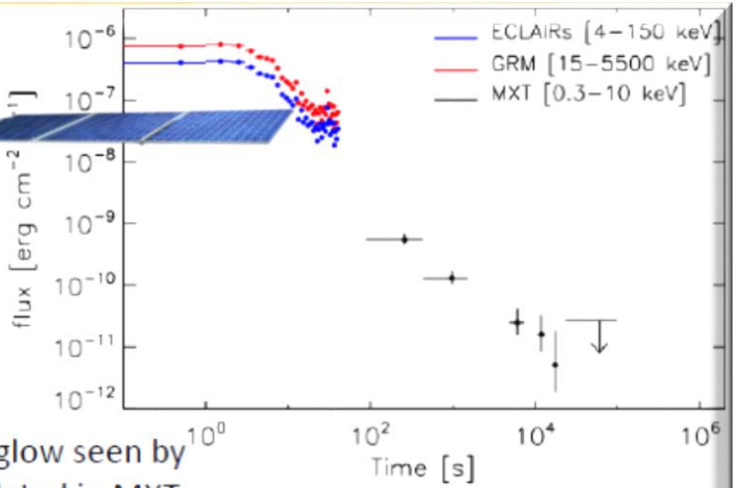
Spacecraft slew: 36-72 GRB/yr



- **Space-based follow-up:**

MXT X-ray afterglow for 90% of slewed GRBs

VT Visible/nIR afterglow + photometric redshift



GRB 091020 afterglow seen by Swift/XRT simulated in MXT.

- **Ground Follow-up Telescopes (GFTs)**
  - **Chinese Ground Follow-up Telescope (C-GFT)**
    - Robotic 1m class telescope, Xinglong observatory
    - FoV = 21x21 arcmin², 400-950 nm
  - **French Ground Follow-up Telescope (F-GFT)**
    - Robotic 1m class telescope, San Pedro Martir (Mexico)
    - FoV = 26x26 arcmin²
    - Multi-band photometry (400-1700 nm, 3 simultaneous bands)
  - **Contribution to LCOGT network** (12×1m + 2×2m tel.)

~75% of ECLAIRs-triggered GRBs immediately visible by one ground telescope (GFTs+LCOGT)

➔ Very large telescopes for redshift determination

SVOM spécifications applicable to ECLAIRs

*[R1] To localize **during the nominal duration of the mission at least 200 GRBs of all kinds**, including events of short duration (from few milliseconds to 1-2 s), long GRBs (duration up to 1,000 s), GRBs particularly rich in X-rays (e.g. events having most of their flux below 30 keV.).*

*[R2] To observe the GRB field in the X-ray and soft gamma-ray band (**4 keV** to 5 MeV) 5 min before and 10 min after the time of the localization T0.*

*[R3] To measure the GRB celestial coordinates with an accuracy better than **12 arcmin** (TBC) at the detection threshold **in the J2000 reference frame.***

[R1] 200 GRB during 3 years (1/3)

$N_{\text{GRB DETECTED}} = N_{\text{GRB SKY}} \times F_X \times \text{Exposition Factor} \times \text{Sensitivity} \times \text{Trigger } \epsilon\text{fficiency}$

F_x : apport des populations additionnelles (sursauts riches en RX)

Parameters
↑ Exposition Factor
↑**Sensitivity = Efficiency / √ Background**
↑Fx : X-ray range benefit
↑Efficacité Trigger (= 1)

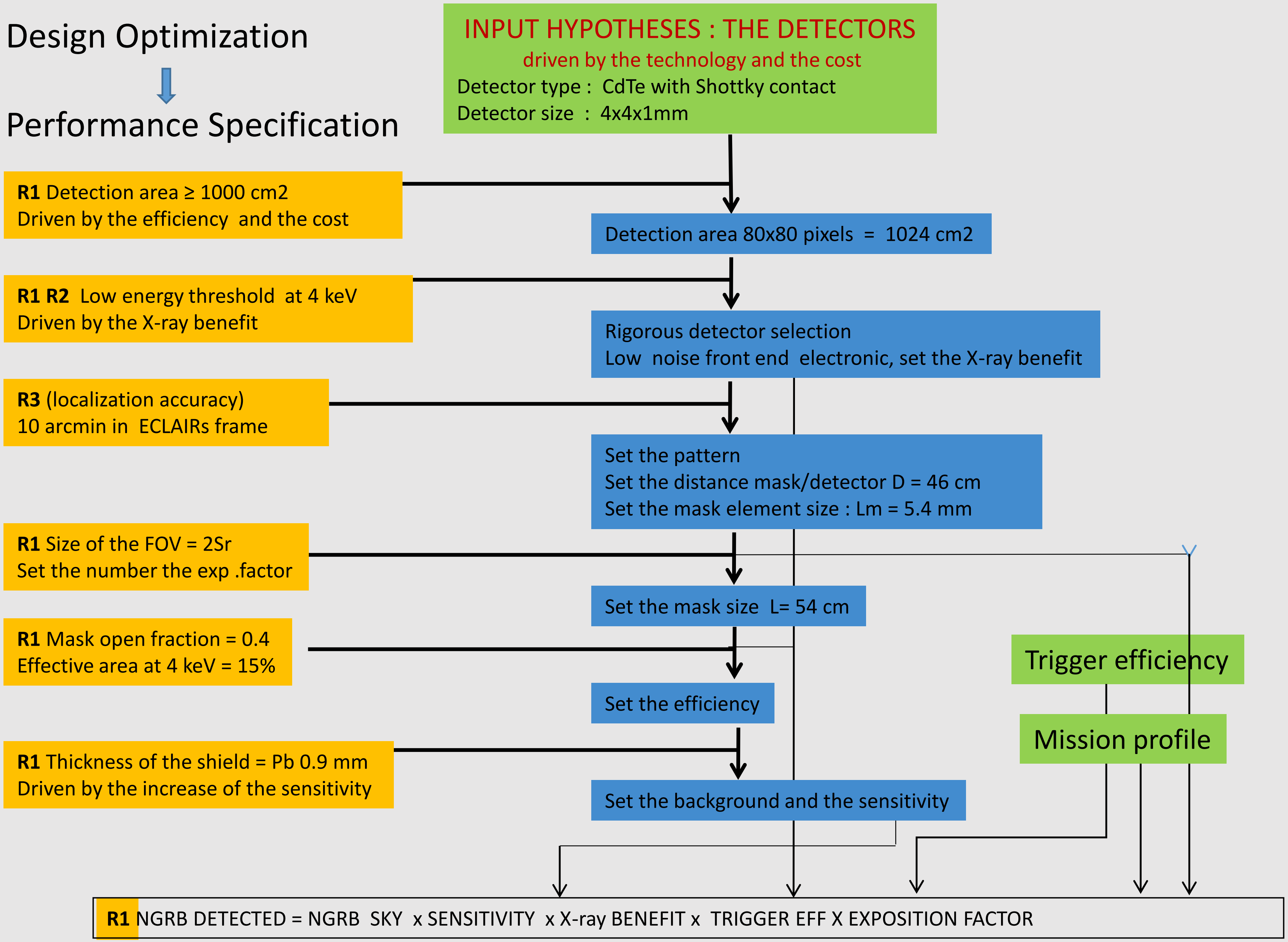
Impact on
↑Field of View
↑Efficiency
↓Background
↓Dead time
↑Effective FoV

SVOM/ECLAIRs Parameters
↑Mask size
↑Mask open fraction
↑Detector size
↓Absorption in the FOV
↑Shield thickness
↓Low energy threshold
Orbit parameter : ↓30°↓600km
Pointing strategy: antisolar

Goal : increase the number of GRBs detected

Design Optimization

Performance Specification



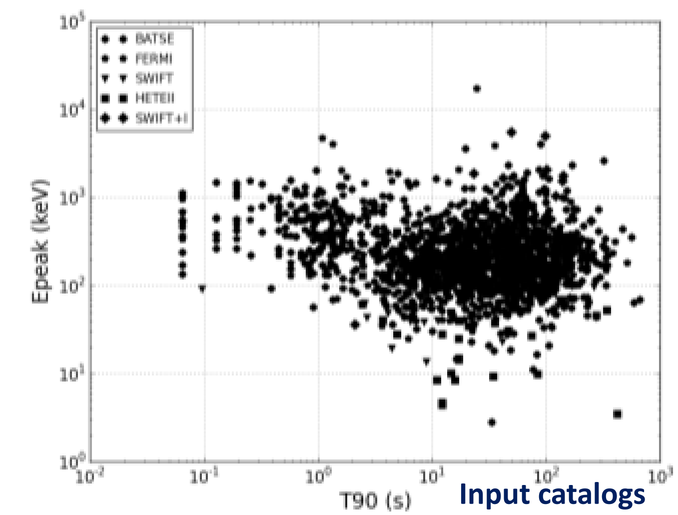
[R1] 200 sursauts pendant la durée de la mission (2/3)

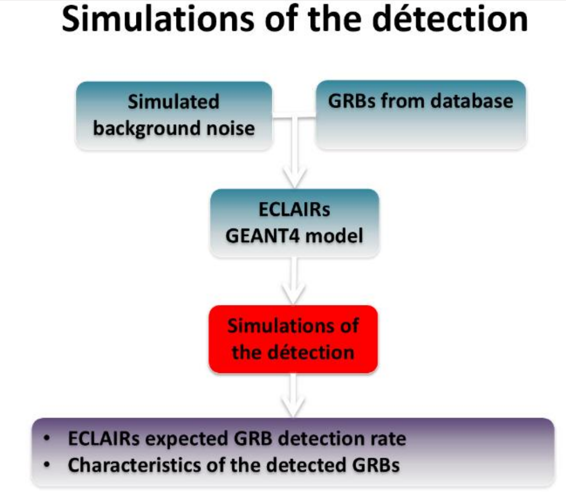
R1 - Requirements + technical input	Consequences	Paramètre impacté
To localize + energy range [R3]	Coded mask technique	
At least 200 GRBS + ECLAIRs resources allocation : Mass < 100 kg Power consumption < 120W	- FOV = 2 Sr - Effect of Mask self vignetting < 10% at the middle of the FOV Mask open fraction [0,3 – 0,4] - Geometrical detection area of at least 1000 cm2 - Noisy pixel management: switch-off pixels less than 3% of the geometric area - Low energy threshold as low as possible i.e.4keV - Good Energy resolution to monitor the low energy threshold : <2 keV at 6 keV - Effective detection area at 4 keV = 15% - Passive shielding transparency < 1% at [4-50 keV] ~50% at [200-250 keV] - Temporal (10µs) & spatial (5 up to 125 cm2) discrimination of particle shower - SAA flags to mark the beginning and the end of the perturbed area - Background modelisation with earth occultation correction - GRM data subset to manage the solar flares - Multi-pattern excess research in the deconvolved image	Exposition factor Sensitivity Sensitivity Sensitivity Sensitivity Fx Fx Fx , Sensitivity Sensitivity Trigger efficiency Trigger efficiency Trigger efficiency Trigger efficiency Trigger efficiency

Outcome of the instrument scientist analysis (ECLAIRs)

Parameter	**Value**
Energy range (low – high energy threshold)	Imaging : 4 keV to ~ 70 keV
	detection : 4 keV to ~ 150 keV
GRB duration detection range	from 10 ms to 1000 s
Field of view	2 sr : 89 x 89 deg (square)
Sensitive geometrical area	1024 cm² maximum
Localization Accuracy	< 13 arcmin (90%radius) in J_{2000} for SNR > 8 σ source (2 arcmin for brightest ones)
sensitivity :	0,7 ct/s/cm² [4 - 50 keV] *Function of the Extragalactic noise, detector characteristics and orbit*
Energy resolution	1.3 keV FWHM @ 60 keV
Photon timing resolution	~20 µs in standard mode
Expected GRB detection and localization rate	~ 80 per year with > 5,5 σ detection level

ECLAIRs: GRBs detection Performance (simulations)





Number of GRBs seen by ECLAIRs:

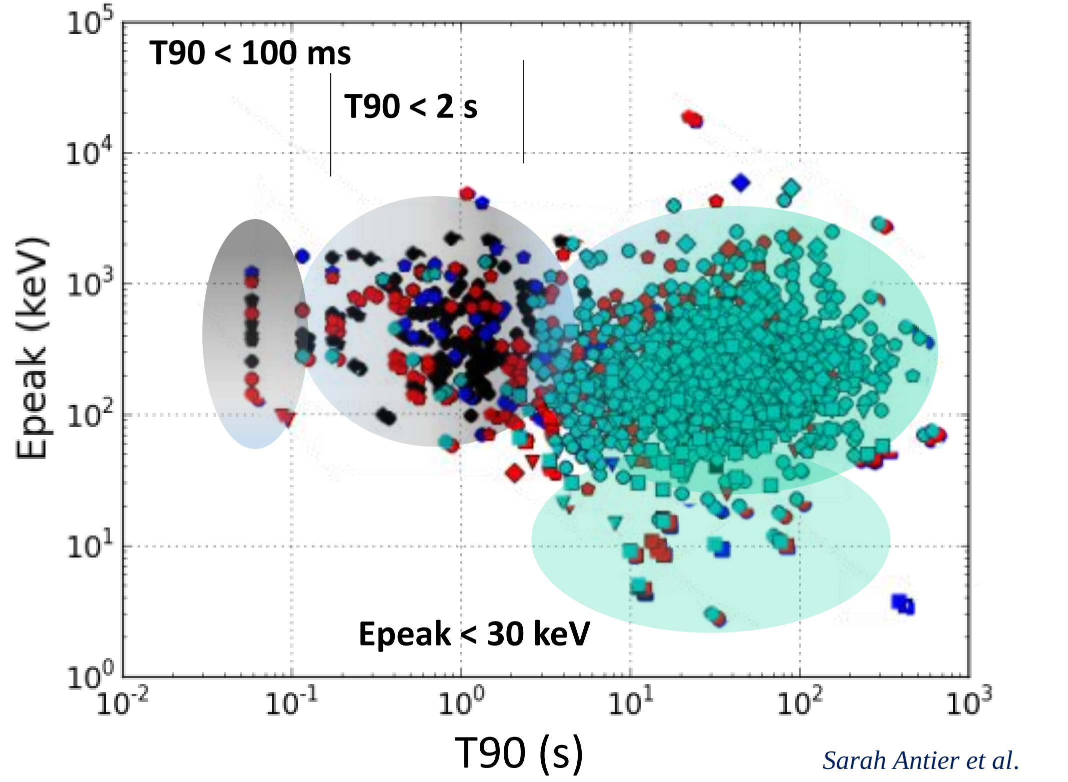
- 64 ± 18 GRBs/an for the alert threshold
- 56 ± 18 GRBs/an for the slew threshold
- About 10 % short GRBs

*Konus or GBM

Symbol
BATSE
FERMI
SWIFT
HETEII
SWIFT+*

ECLAIRs > ε_{GRB}
Black > 0.2
Blue > 0.5
Red > 0.7
Cyan > 0.9

ε_{GRB} (0-1) : ECLAIRs detection efficiency of a GRB
Given the properties of a GRB, it has a computed detection efficiency
It takes into account its detectability in all directions of the field of view



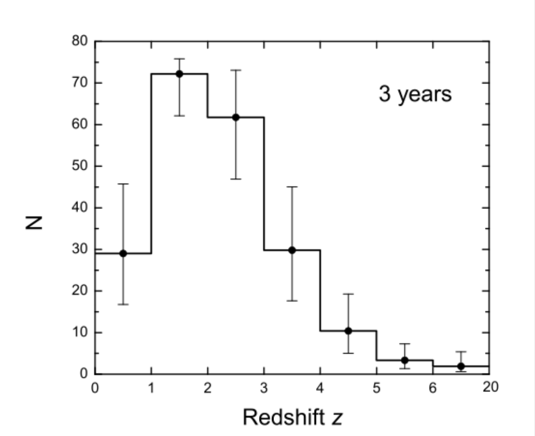
Sarah Antier et al.

ECLAIRs wil be sensitive to all known GRBs

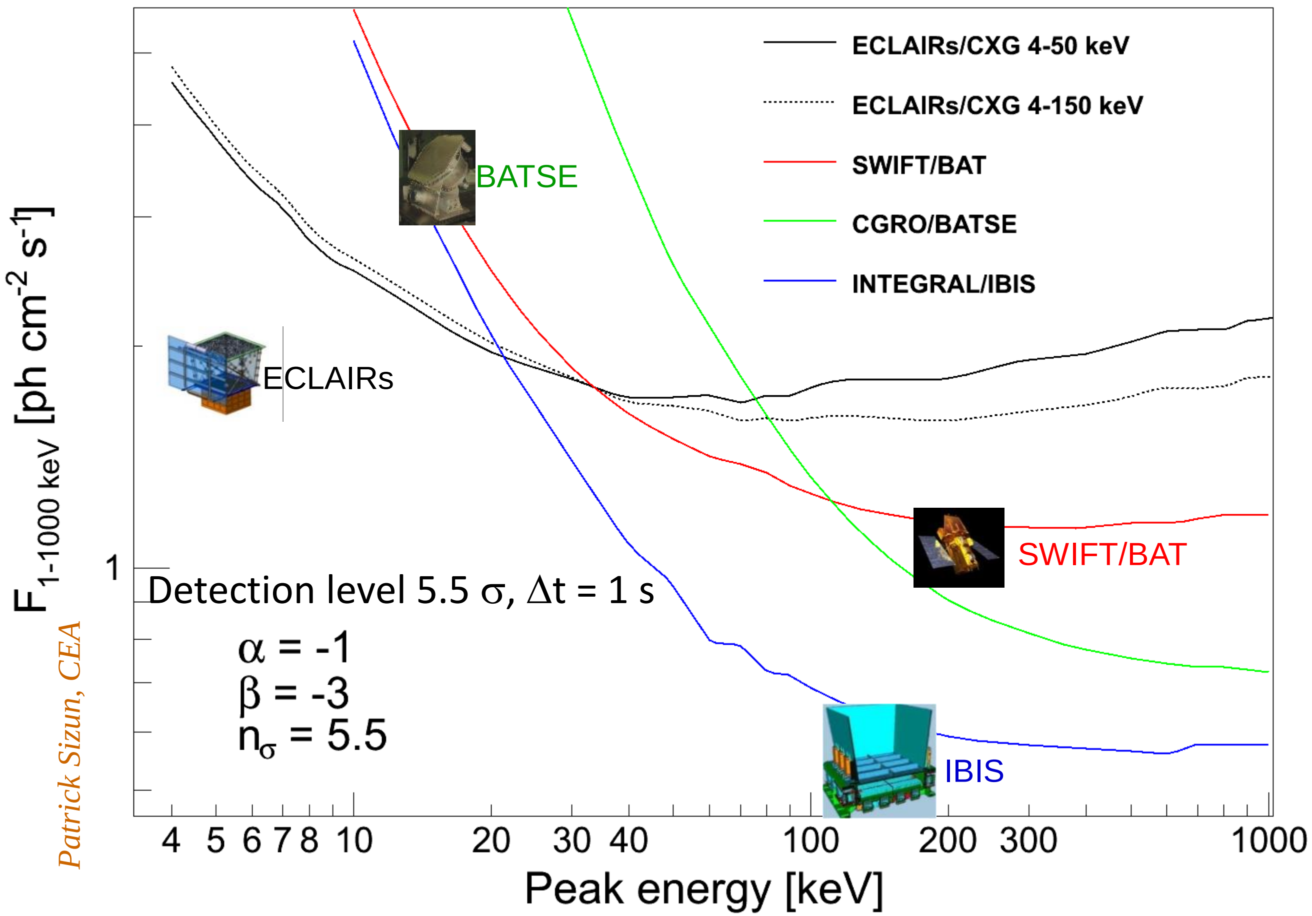
ECLAIRs Sensitivity Performance (simulations)

Energy : 4 – 150 keV (imagery 4 – 50 keV)

- Good sensitivity to cosmological events
- **Better sensitivity than Swift for Epeak < 20 keV (z>4)**
- Expected number of GRB : 80 / year
- **For z > 5 : ~3 / year**
  ~ 10 % of the GRBs



Instrument	Band (keV)	GRB/yr at z > 6
INTEGRAL/ IBIS	0.1	0.1 – 0.5
SWIFT/ BAT	15 - 150	1.3 – 4.0
SVOM/ ECLAIRs	4 - 150	2.0 – 4.0



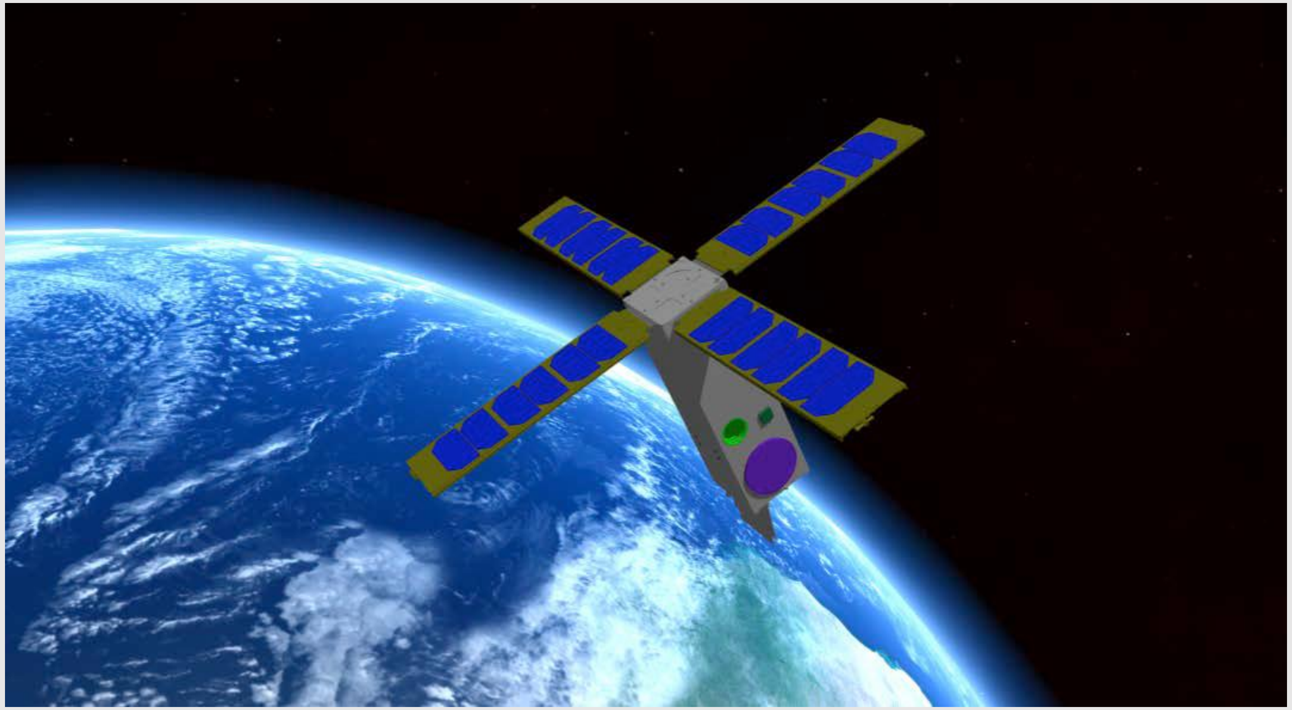
Simulations of the sensitivity and diffuse Xray background of ECLAIRs

Godet O, Sizun P, Barret D, Mandrou P, Cordier B, Schanne S, Remoué N :

G – Few words about nanostellites

Type of satellites

- **Fentosatellite: M < 100 g**
- **Picosatellite: M < 1 kg**
- **Nanosatellite: M < 10 kg**
- **Microsatellite : M < 100 to 500 kg**
- **Minisatellite: M < 500 kg**
- **Satellite : 500 kg to 5 T**
- **Bis satellites: > 5 T**



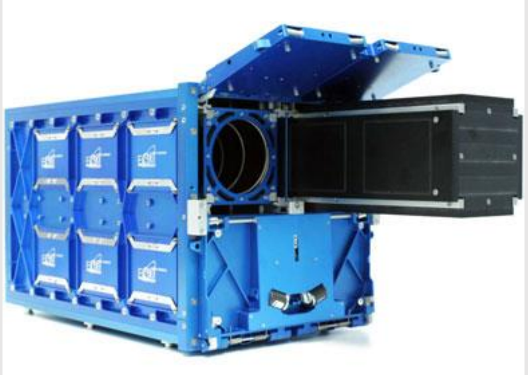
Nano satellites: what for ?

- **Miniaturization of technologies**
- **Training of students in aerospace Engineering**
- **Cubesat Concept**: generic nanosat invented byBob Twiggsat Stanford University (1999)

  First launched in 2003

  - 1 U: 10 cm x 10 cm x 10 cm 1,33 kg, 1 W
  - 2 U: 10 cm x 10 cm x 20 cm 2,66 kg, 2 W
  - 3 U: 10 cm x 10 cm x 30 cm 3,99 kg, 3 W
  - etc …

Size	Mass (before payload)	Available volume	Available payload power
1U	725 g	0.4U	1.3 W average
2U	1200 g	1.4U	2.48 W average
3U	1500 g	2.3U	3.68 W average



- **Standard interface with most Launchers**
  (P Pod deployment system) Miniaturization of technologies
- **More and more reliable for new applications**:
  - Technological validations in orbit (increase the TRL of components)
  - **Science mission** (space environment, space weather …)
  - New applications for the society (following of air planes, boats,)

Easy and cheap to launch

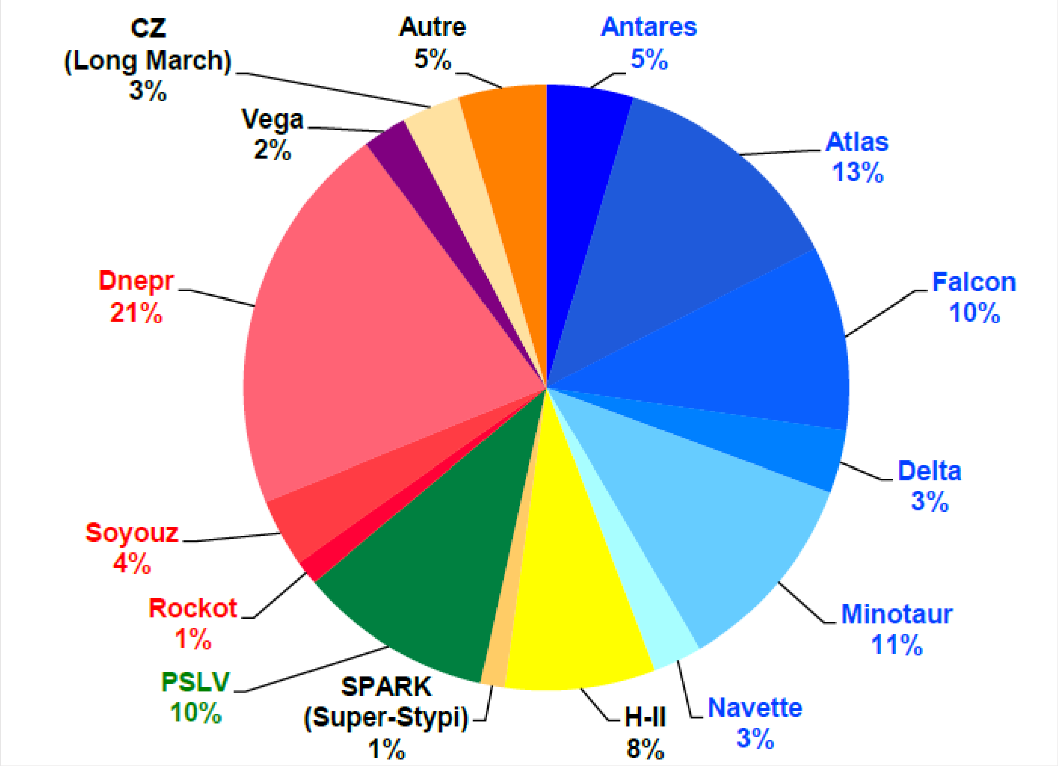
Orbits

- Mostly low earth orbit (often polar) between 350 and 800 km
- Law on space environment : must re-entry the atmosphere within less than 25 years

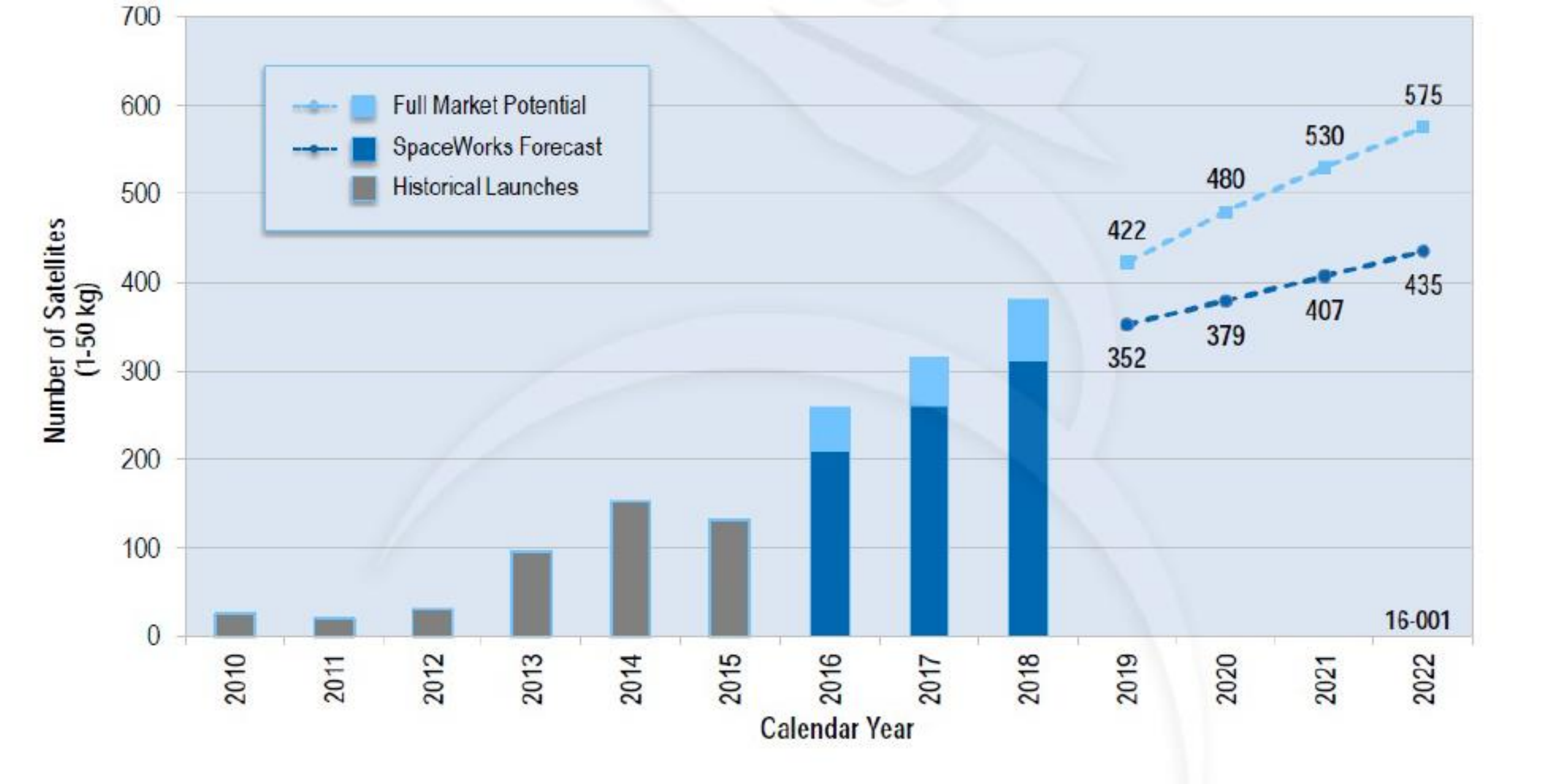
Launchers

Price : ~40 k€/kg launched (SSO)

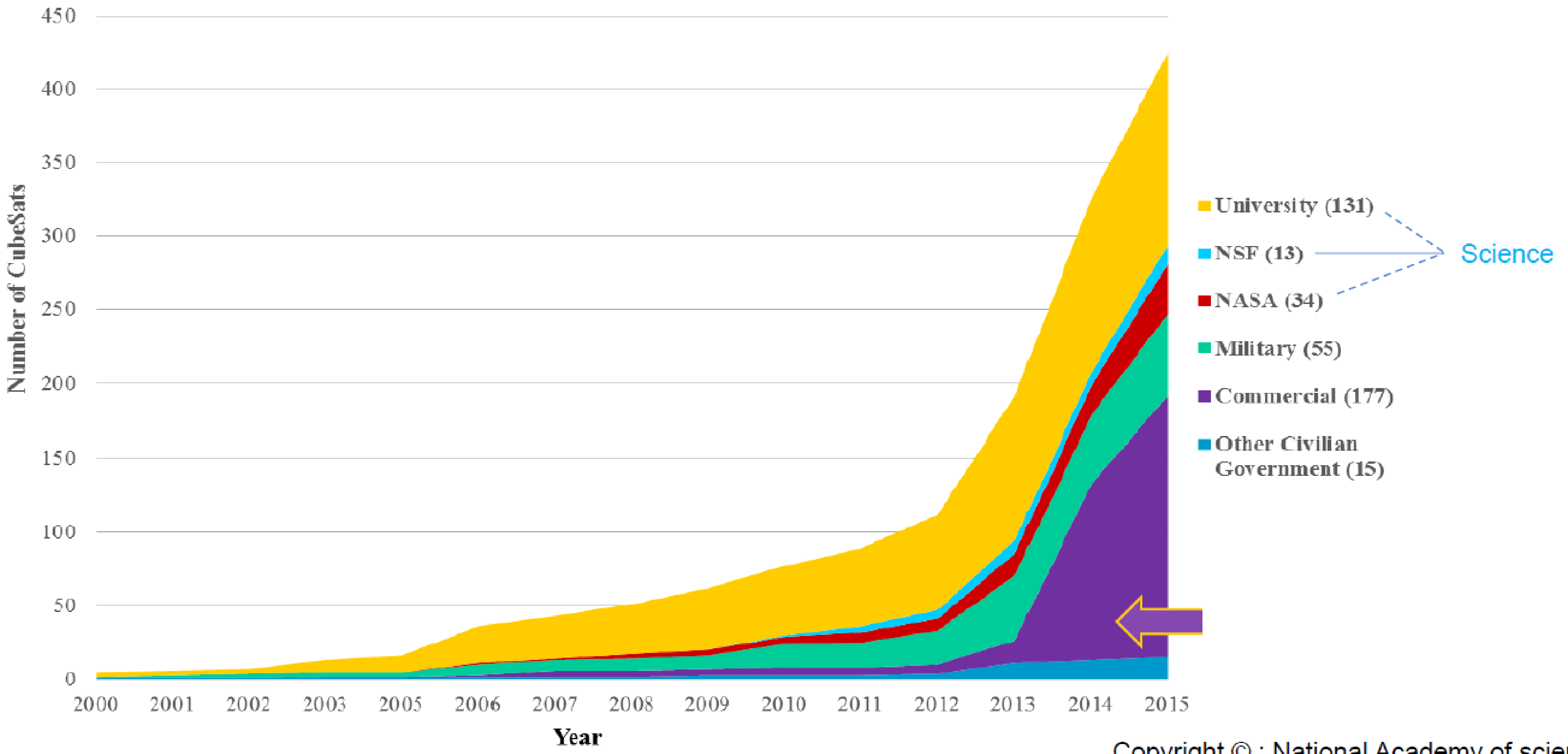
~60 kE/kg launched (LEO)



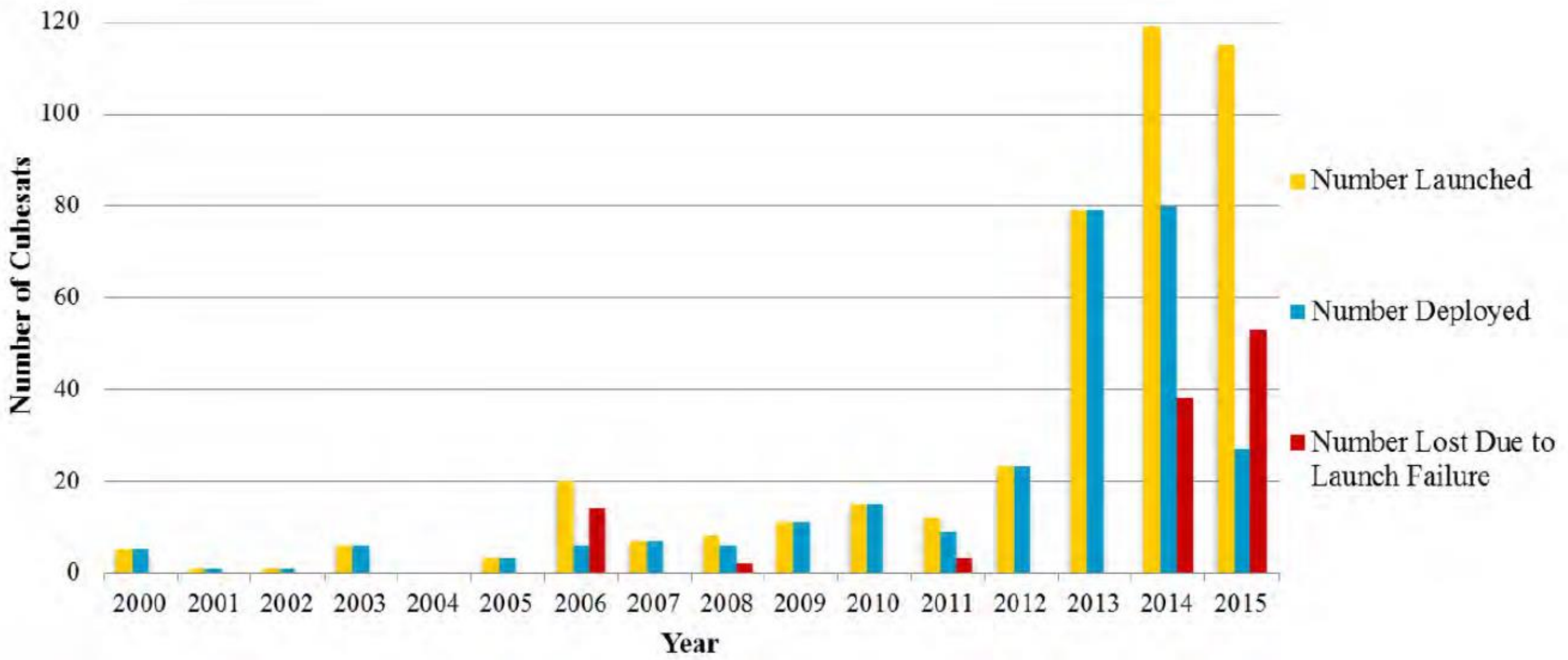
Evolution of the number of cubesats



Number of Cubesats

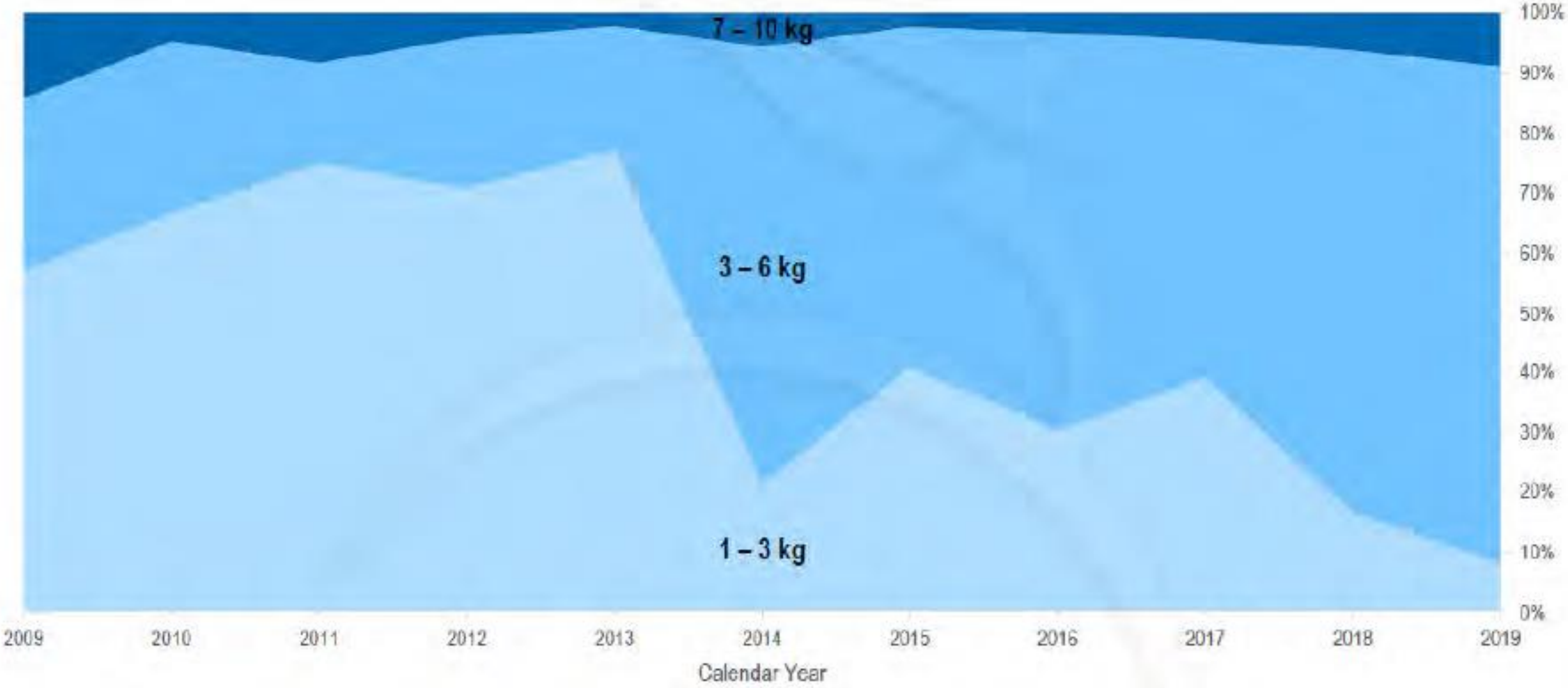


Reliability



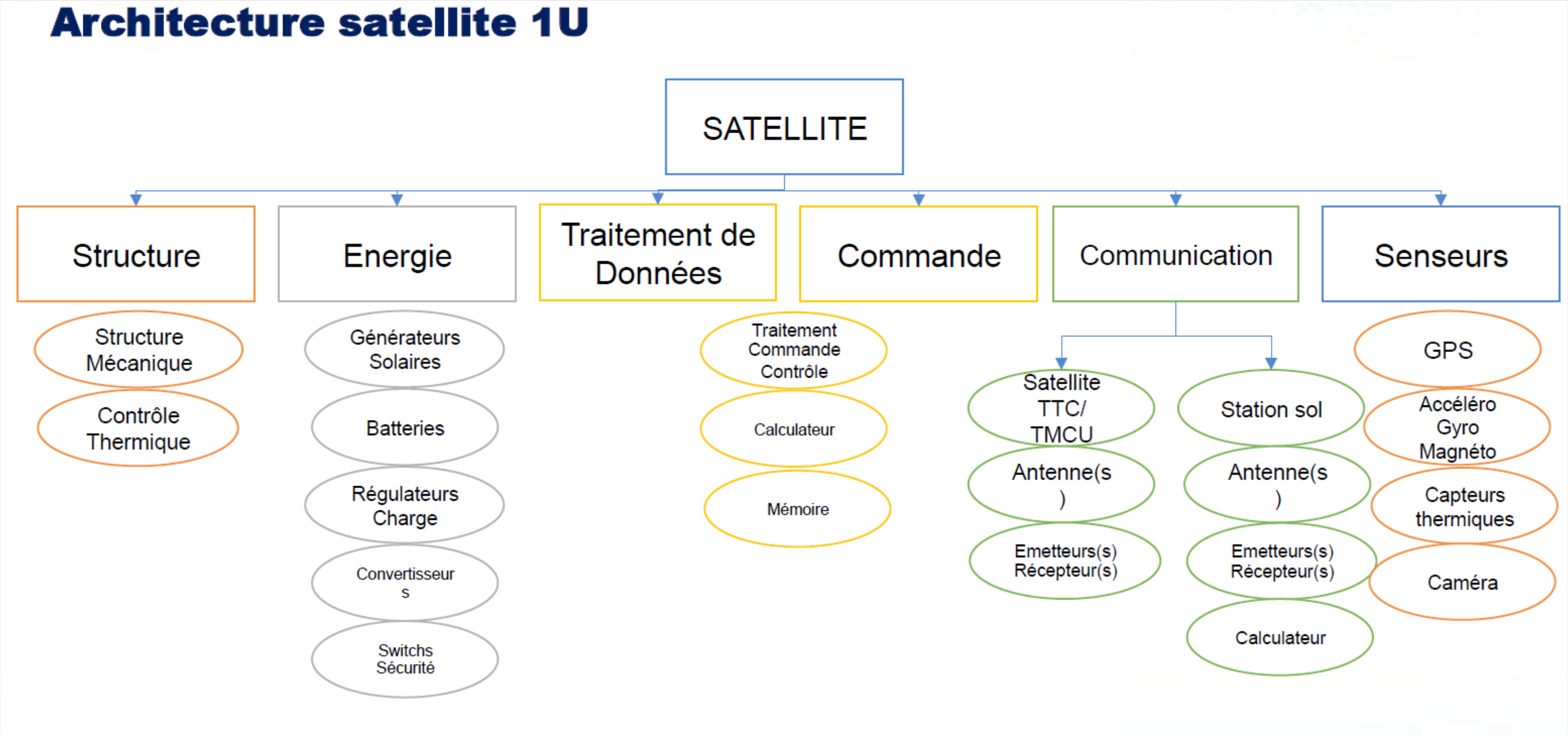
Nanosatellite Size Trends (1 - 10 kg)

The 3U form factor remains dominant in the market place as a result of its use by large Earth observation and remote sensing constellations



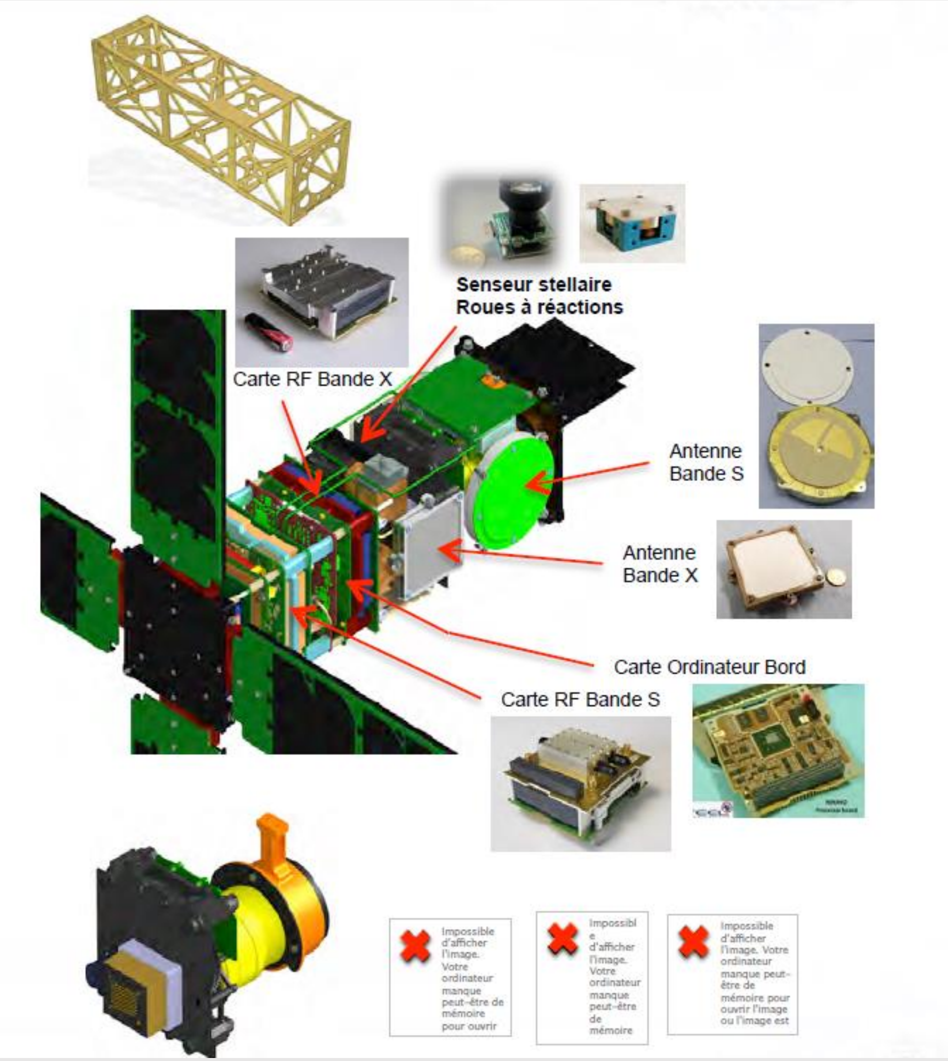
Overall growth is increasing in larger platforms (both CubeSats over 3U and non-CubeSats over 10kg) due to demand for additional payload capacity

Elements of Cubesats



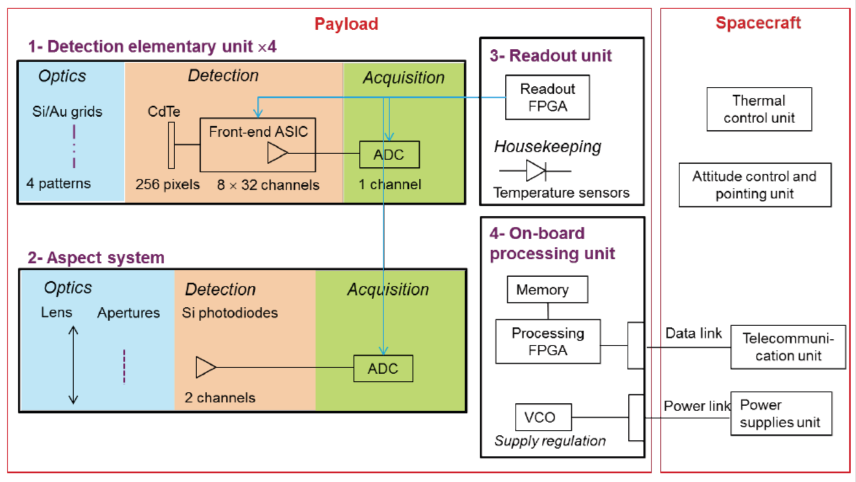
Architecture of Cubesats

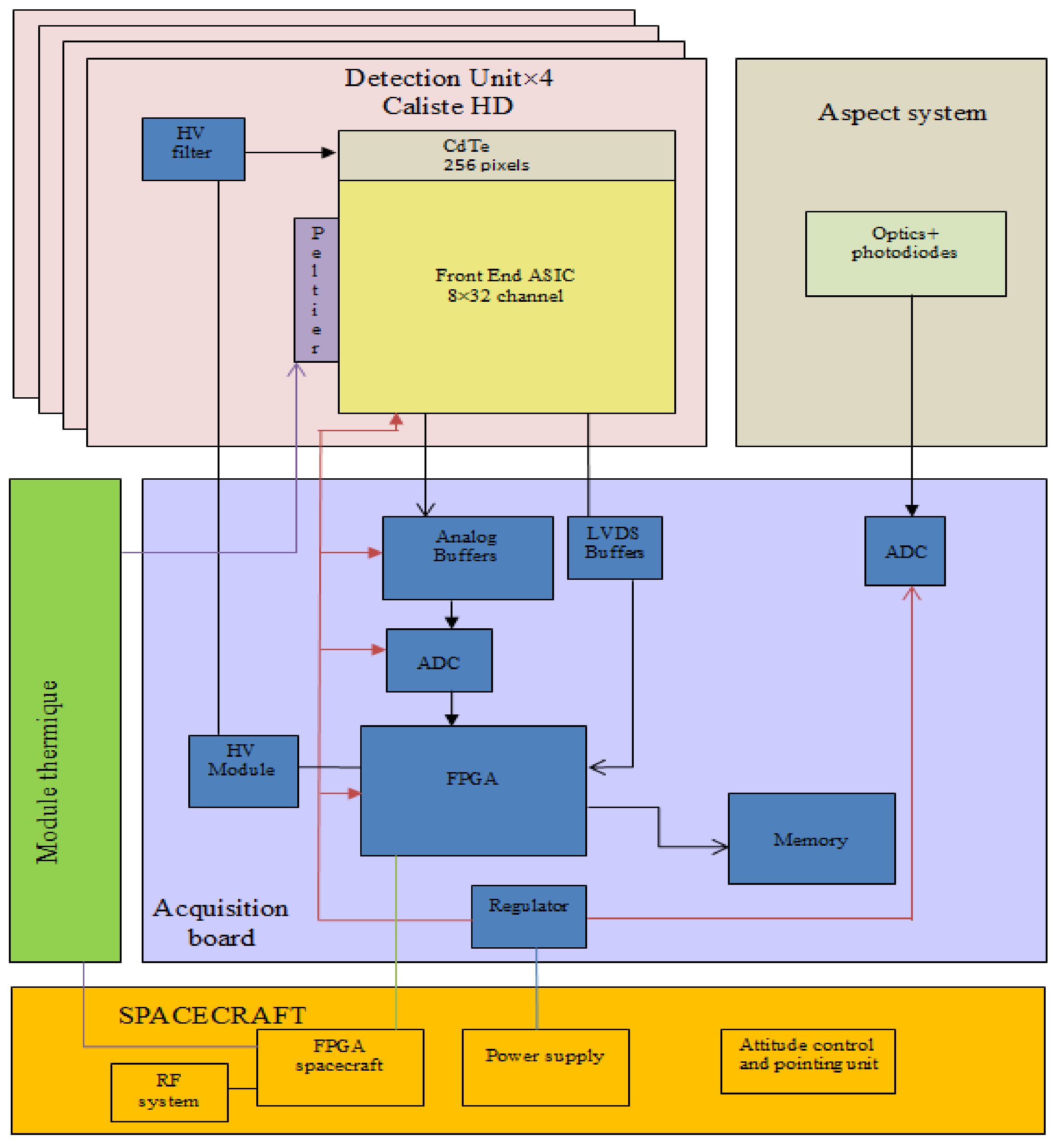
- Mechanical architecture
  - Thermal architecture
  - Radiator
  - Heaters
- Platform
  - Solar panels
  - Alimentation
  - Communication
  - On Board Computer with flight software
  - AOCS
  - Interfaces
- Payload
  - Telescope
  - Camera, filter wheel, optic, baffle



Example: BEEP nanosatellite

Unit	Unit name	Maximum Mass (g)	Maximum Power (W)
1	Detection units (4 Caliste HD) (based on ORIGAMIX design) **Detection unit developed for BEEP*	1200 **500*	0.81
2	Aspect system	100	0.2
3	Readout unit	200	0.8
4	On board processing unit	200	3
5	Structure: 2 mm Aluminum	400	0
6	Peltier devices	20	2.4
Total for the science payload (Max) ***With optimized detection unit***		**2120 g** ***1420 g***	**7.21 W**





Example: BEEP nanosatellite

Parameters	Typical value for 3U Cubesat	BEEP requirements
Overall dimensions	10 x 10 x 35 cm^3	~ 10 x 10 x 35 cm^3
Total mass	5 kg	~ 5 kg
Mission lifetime	1 year	6 months up to 2 years
Pointing knowledge accuracy	+/- 15 arcsec +/- 4 arcsec with ASPECT system	+/- 4 arcsec with ASPECT system
Attitude control accuracy	0.5 ° Reaction wheels, 3 axis	+/- 10° Sun remains in the field of view
Thermal control		Passive cooling (radiator) + active cooling at Caliste level (Peltier)
Total power of the nanosatellite	10 W (average) / 30 W (peak)	
RF datalink	S band (1 Mbits/s) or X band antennas (10 Mbits/s)	9.6 Mbits/s in X band (download)
De-orbiting system	YES	YES
ITAR free	YES	YES
Payload volume	2 L	1.5 L
Payload mass	3 kg	1.75 kg
Payload power (max)	8 W	7,2 W
Daily data transfer	2 Go	< 2 Go

Conference	Dates	Location
International Workshop on Lean Satellite 2018	January 22 - 24, 2018	Kitakyuhu, Japan
2018 SmallSat Symposium	February 5 - 8, 2018	Mountain View, California, USA
PocketQube Workshop 2018	March 22 - 23, 2018	Delft, Netherlands
15th Annual CubeSat Developers Workshop	April 30 - May 2, 2018	San Luis Obispo, California, USA
7th Annual Lunarcubes Workshop	May 3 - 4, 2018	San Luis Obispo, California, USA
Interplanetary Small Satellite Conference 2018	May 7-8, 2018	Pasadena, California, USA
4S Symposium 2018	May 28 - June 1, 2018	Sorrento, Italy
7th Interplanetary CubeSat Workshop	May 29 - 30, 2018	Paris, France
CubeSat Innovation Workshop 2018	July 10 - 11, 2018	Sydney, Australia
SmallSat 2018	August 4 - 9, 2018	Logan, Utah, USA
INSPIRE and Small Sat Workshop	August 27 - 29, 2018	Paris, France
From Quantum to KOSMOS	September 12 - 14, 2018	Berlin, Germany
Open Source CubeSat Workshop 2018	September 24 - 25, 2018	Madrid, Spain
69th IAC 2018	October 1 - 5, 2018	Bremen, Germany
1st Asian PocketQube Workshop	November 5, 2018	Singapore
1st China Microsatellite Symposium	November 18 - 20, 2018	Xi'an, China
10th European CubeSat Symposium	December 5 - 7, 2018	Toulouse, France