SCIENCE Mission Studies

Geoplanet Workshop on Planetary Missions

Peter Falkner

9/01/2018

The Tasks

- **prepare Science Missions** from proposal to Adoption (handover to Projects) within the D/SCI programmatic boundaries
- elaborate the mission concept and the requirements through Phase 0/A/B1 (feasibility, assessment, definition)
- iterate with the mission stakeholders (science teams, member states, international partners) as relevant (technical interface)
- the elaboration of the technical documentation for mission, the payload and ground segment elements
- contribution to definition and execution of the SCI technology work plan
- ESA Calls for Missions:
    - preparation of technical documentation for the call
    - technical and programmatic evaluation of mission proposals for selection of candidate missions
- prepare a smooth transition of the selected missions to Phase B2/C/D/E → Implementation, Handover to Project

Future Missions preparation

<u>**Science mission preparation include the following main activities:**</u>

1. **System studies:** for defining the mission space segment:
   - Parallel industrial studies,
   - Iterations with the science community,
   - Convergence on requirements and interfaces

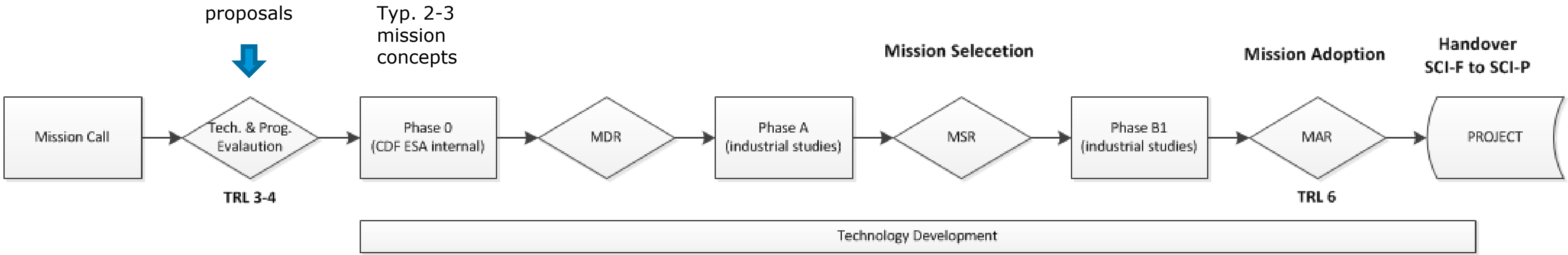
2. **Science and instrumentation related activities:**
   - Achieved by the science community, under Member States funding
   - Includes the Science Ground Segment

3. **Technology developments:** to reach TRL 5/6 prior to mission adoption
   - Mission driven technology work plans, in parallel to the studies
   - TRP-CTP joint work plan, with a yearly update (more if needed)

4. **Independent reviews:** to control the achievements and enable decisions
   - Assessment of the definition maturity, the technology readiness and cost/risks (Mission Adoption Review (MAR) ending Phase B1)

5. ***Calls***
   - M5 call currently
   - call for *New Science Ideas*

The Process



CDF … Concurrent Design Facility
MDR … Mission Definition Review
MSR … Mission Selection Review
MFR … Mission Formulation Review
MAR … Mission Adoption Review

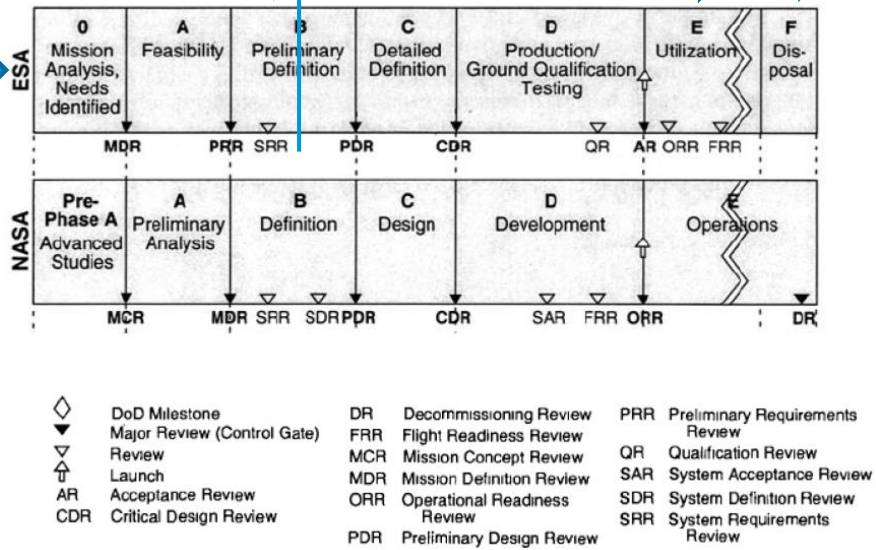
Project Phases

Studies

Project

Mission

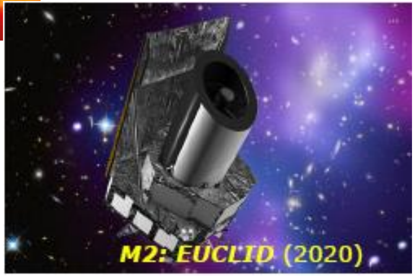
Call: proposals

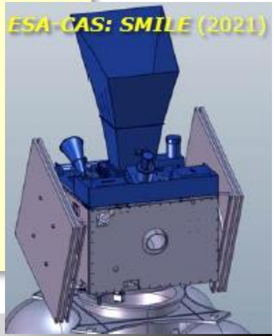


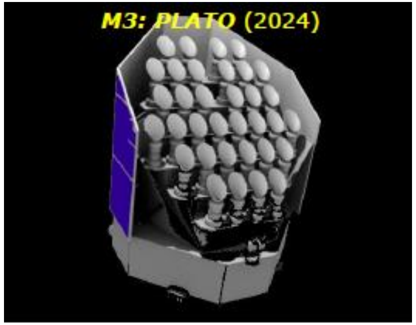
SMAD, p. 8

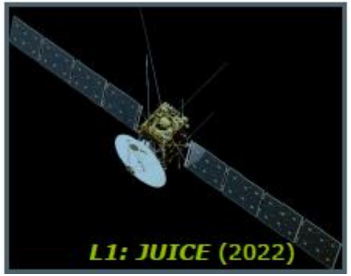
Mission Calls

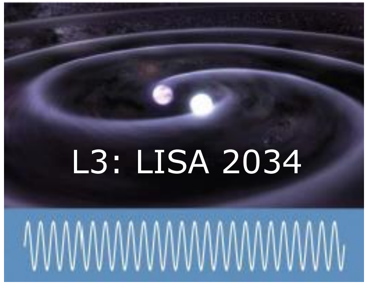
- M1/M2/L1 (2007) → Solar Orbiter (M1), Euclid (M2), Juice (L1)
- M3 (2010) → PLATO
- S1 (2012) → Cheops
- L2/L3 WP (2013) → The hot and energetic Universe & The gravitational Universe
- L2 (2014) → ATHENA
- M4 (2015) → ARIEL, THOR & XIPE (ongoing MSR)
- S2 (2015) → SMILE (ESA, CAS)
- M5 (2016) → under evaluation
- L3 (2017) → LISA











Mission Calls

- **Typically 20-30 proposals** from Scientific Community (30-60 pages)
  - Science
  - Mission description (launch, S/C, Payload, GS, Data center,…)
  - Programmatics (Team, management, cost, schedule, TRL,…)
- **Technical, Programmatic Evaluation** (SCI-F, Future Missions Department):
  - Evaluate feasibility, technical readiness, cost, schedule realism,…
  - → Typ. 20-40 % declared feasible within the call constraints
- **Scientific Evaluation** (external independent peer review)
  - Scientific Value of the mission
  - → 2-3 candidates recommended
- **2-3 selected for Phase 0/A**
- **1 selected for Phase B1** → Mission Adoption → Mission Implementation

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Cost	M€
ESA Project Team	54
Industrial Cost	172
Payload Contribution (ESA)	100
Mission Operations (MOC)	40
Science Operations (SOC)	42
Launcher	45
Contingeny (15%)	61
Total EaC	515

- 20-30 experts from SCI-F + 3-4 cost engineers from D-TEC involved in the evaluation → consolidation by SCI-F management

SCI-F … Future Missions department

Summary Evaluation		Comment
Mission profile	G	OK,except ΔV potentially underestimated significantly (altitude maintenance and re-entry).
Spacecraft design	Y	Very tight within Vega fairing, thermal and pointing error challenging.
Spacecraft TRL	G	OK.
Payload design	Y	Hardware design OK, software design seems challenging for on-board autonomy.
Payload TRL	Y	Some technology developments needed.
GS & Science Ops.	Y	OK but complicated autonomous science operations and constant ground contact required.
Programmatic / Cost	R	OK, but mass > M4 recommendation and cost unrealistic within M4.
Implementation Scheme	Y	OK, but ESA contributions to IRT un-clear.
General summary	R	Challenging design and too many payload elements for M4 cost.

Phase 0

- Typ. done in ESA **Concurrent Design Facility** (CDF)
- SCI-F customer
- CDF provides engineering specialists + system engineering + CDF Team leader
- Concurrent design: All experts + customer are in a room (or connected via VC) -> life iteration
- Typically 20-30 engineers involved + study team
- 8 sessions in 6 weeks
- Output Slides, report, model of the mission

- We (Science) run 3 - 7 CDF's per year …

Output:

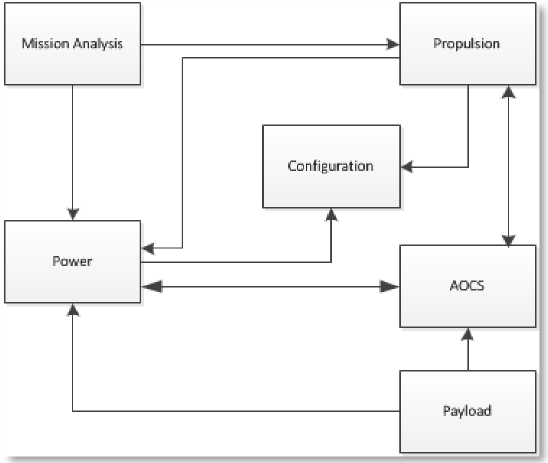
- → first global design (baseline) of the mission
- → refinement of requirements
- → definition of technology needs
- → programmatics (Cost & schedule)
- → input for industrial contracts Phase A

Study Phase 0:

- Analysis of Mission Objectives
- Analysis of Mission Constraints
- Definition of Science & Measurement Requirements
- Definition of Mission Architecture (s)
- Definition of payload / performance
- Analysis of Environment
- **Iteration / Trade phase !**
- Cost, Risk, Schedule, Technology Development

Goal:

- **feasible mission profile**
- **satisfying requirements and constraints**



…iterations needed

Phase A

- Industrial Studies (2 in parallel), 2-3 missions in parallel
- Duration: typically 18 to 24 month
- **Industrial Contract:**
  - Define Statement of Work (SoW) with all tasks, plus requirements: MRD, PDD, SciRD,…
  - pre TEB → Issue ITT → Proposals from Industry
  - Evaluation of Proposals (TEB) → contract
  - run competitive Studies
- **Parallel Activities:**
  - consolidate Payload with payload consortia (studies)
  - Update SciRD (science team, study scientist)
  - Define technologies (TECNET, technology plan) and execute Activities
- **ESA study team:**
  - Study Manager (SM) + System Engineer + Payload Study Manger (PSM)
  - Study Scientist + External Study Science Team
  - DTEC support as needed + ESOC + ESAC

Goals of Phase A

- Review and refinement of top-level requirements
- Investigation of alternative architectures, trade-offs, mission analysis and operations
- Identification and verification of design drivers and critical elements (especially those that have no or little heritage) with a corresponding mitigation plan (e.g. new technology developments)
- Identification of a feasible mission design and definition of a baseline
- Identification of suitable launcher(s)
- Definition, execution, and reviews of technology developments
- Transition of model P/L to selected P/L and system level update
- Risk assessment (identify all risks and mitigation measures)
- Establishment of a baseline master schedule
- Establishment of the Estimate-at-Completion (EaC) that must be reliable for the purpose of the Mission Selection by including adequate contingencies.

ITT … invitation to tender
DTEC … Technical Directorate
ESAC … European Space Astronomy Center
ESOC … European Spacecraft Operations Center
MRD … Mission Requirements Document
PDD … Payload Description (Definition) document
SciRD … Science Requirements document
TEB … tender evaluation board
TECNET … Technology Network (of experts)

Phase B1

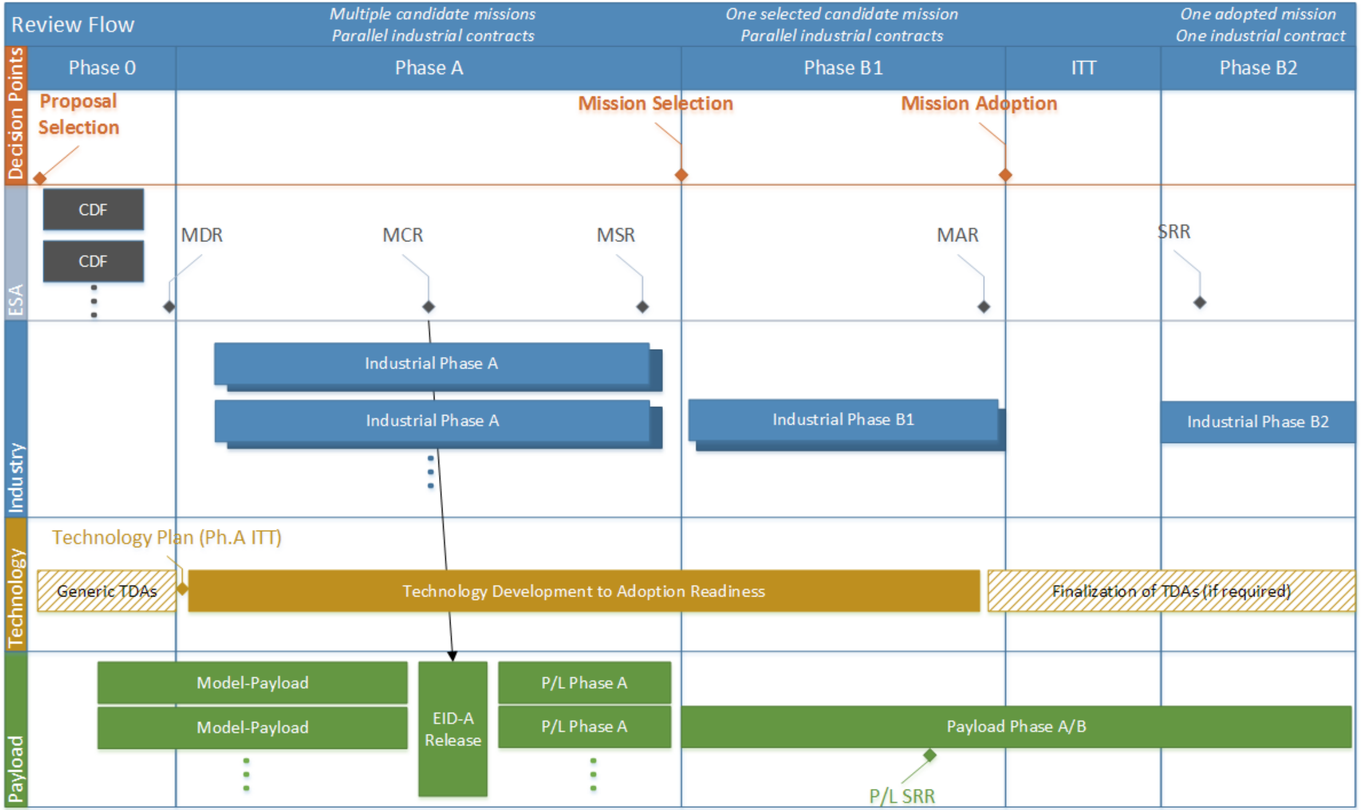
- Industrial Studies (2 in parallel), 1 mission
- Duration: typically 18 month to 24 month
- **Industrial Contract**:
  - Define Statement of Work (SoW) with all tasks
  - pre TEB → Issue ITT → Proposals from Industry
  - Evaluation of Proposals (TEB) → contract
  - run competitive Studies
    (progress meetings, dialog phase, final presentation)
- **Parallel Activities:**
  - consolidate Payload with payload consortia (studies and developments)
  - Complete technology developments

Goal of Phase B1

- Complete trade-offs
- Select ground and space system design and operations concept
- Consolidate requirements and interfaces, produce a system specification (to be frozen before the Implementation phase ITT)
- Conduct a dialogue phase with industry to consolidate implementation requirements, in support to the preparation of a realistic implementation phase offer
- Issue RFI's as needed
- Complete the technology development activities required for adoption
- Refine the risk assessment (identify all risks and mitigation measures)
- Establish/refine the baseline master schedule
- Refine the Estimate at completion (EaC)

- **ESA study team:**
  - Study Manager (SM) + System Engineer + Payload Study Manger (PSM)
  - Study Scientist + External Study Science Team
  - DTEC support as needed + ESOC + ESAC
  - Overlap with SCI-P (Projects) = soft transition / transfer of knowledge

The Review Process

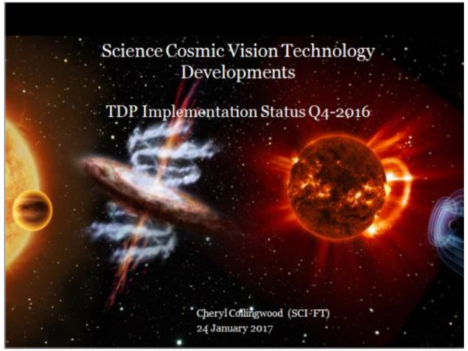


EID … Experiment Interface Document
SRR … System Requirements Review

Technology Development

- Identify lacking technology (from proposal, during CDF, Phase A…)
- Timely definition and implementation to bring it to TRL 6
  TRL6 = verified in relevant environment (at the right scale)
- Done with industrial developments (financed by CTP, TRP,…)
- Focus on ESA responsibility (payload often developed in Member States)
- Driven by the mission needs (requirements) !
- Must be ready in time ! (before Mission Adoption) … to minimize cost and schedule (=cost) risk

- Currently ~100 running, 110 finished, 50 in preparation…
  total ~260 TDA's (!)




Att.: Annexes
Paris, 24 October 2016
(English Only)

EUROPEAN SPACE AGENCY

INDUSTRIAL POLICY COMMITTEE

Science Programme
Technology Development Plan
Programme of Work for 2017 and Related Procurement Plan

SUMMARY

This document presents the activities in the Basic Technology Research Programme (TRP) and in the Science Core Technology Programme (CTP) supporting the implementation of ESA's Science Programme. The national initiatives activities of relevance to the Science programme are provided for information.

REQUIRED ACTION

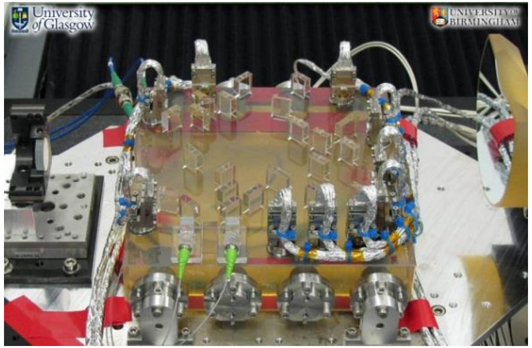
IPC is invited to approve this CTP/TRP work plan for the year 2017 and the connected procurement proposals and take note of activities envisaged for 2018, included for information.

VOTING RIGHTS AND MAJORITY REQUIRED

Simple majority of member States, present and voting.

Just an Example …

CV Prog.	Mission	TDA Ref	Activity Title	Actual Status Q4/2016	Status comment	Contract Duration
CTP	Gravitational Wave	C216-137FM	Optical Bench Manufacturing Industrialisation Study	Negotiation held	ITT closed. Negotiation held 14 Dec 2016	12
CTP	Gravitational Wave	C217-045FM	Phase Reference Distribution for Laser Interferometry	Negotiation held	Contract signature from Contractor pending internal VAT checks.	16
CTP	Gravitational Wave	C217-046FM	Gravitational Wave Observatory Metrology Laser	TEB held	Nego invite sent, nego date 17-01-16	36
TRP	Gravitational Wave	T217-064MM	Fine-structure of laser radiation in the far field	New	New approved activity IPC Nov 2016	12
TRP	Gravitational Wave Observatory	T219-001MP	Electric Micropropulsion System for a Gravitational Wave Observatory Mission	New	New approved activity IPC Nov 2016	24
TRP	Gravitational Wave Observatory	T205-033EC	Assessment and Preliminary Prototyping of a Drag Free Control System for the L3 Gravity Wave Observatory	New	New approved activity IPC Nov 2016	12

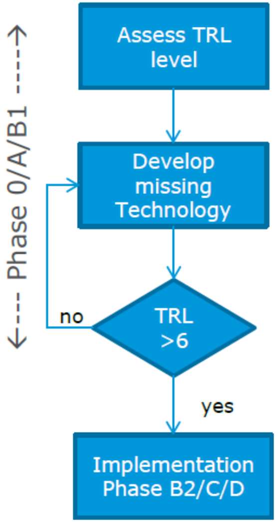


Technology Development

- Level of technology readiness is a key schedule (&cost) driver
- Assessment of efforts required to reach flight status is often difficult
- Assessment done according to the table below
- Non availability of technology can be detrimental to the schedule and cost

Technology Readiness Levels (TRL): **see also new ISO scale**

TRL	ISO definition	Associated model
1	Basic principles observed and reported	Not applicable
2	Technology concept and/or application formulated	Not applicable
3	Analytical and experimental critical function and/or characteristic proof-of-concept	Mathematical models, supported e.g. by sample tests
4	Component and/or breadboard functional verification in laboratory environment	Breadboard
5	Component and/or breadboard critical function verification in a relevant environment	Scaled EM for the critical functions
6	Model demonstrating the critical functions of the element in a relevant environment	Full scale EM, representative for critical functions
7	Model demonstrating the element performance for the operational environment	QM
8	Actual system completed and "flight qualified" through test and demonstration	FM acceptance tested, integrated in the final system
9	Actual system completed and accepted for flight ("flight qualified")	FM, flight proven



Technology Readiness Assessment

Space Mission Elements

(Science) Data Center

Launcher

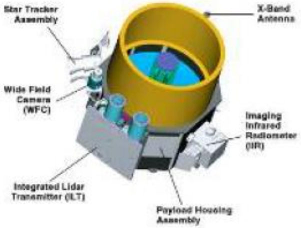
Orbit - Constellation

Space Mission

Spacecraft

Mission Operation

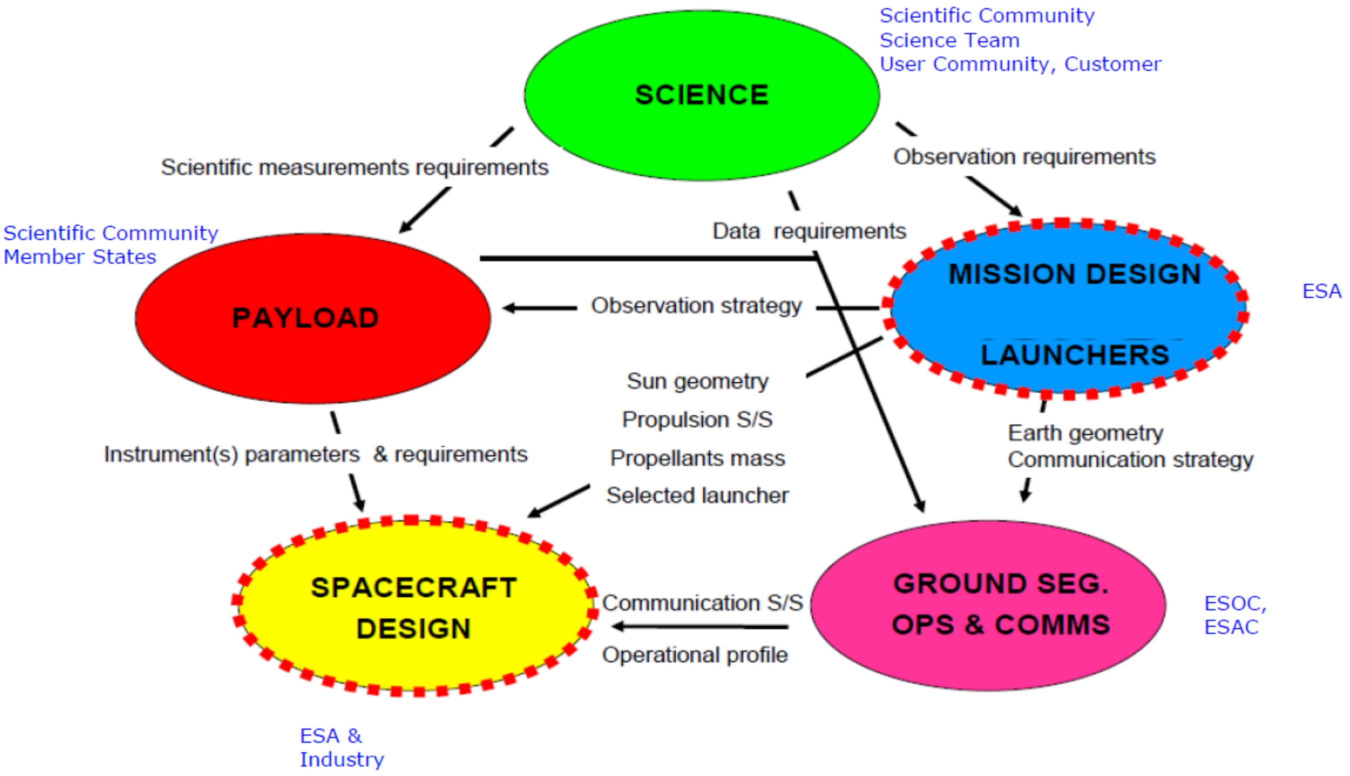
Ground Station



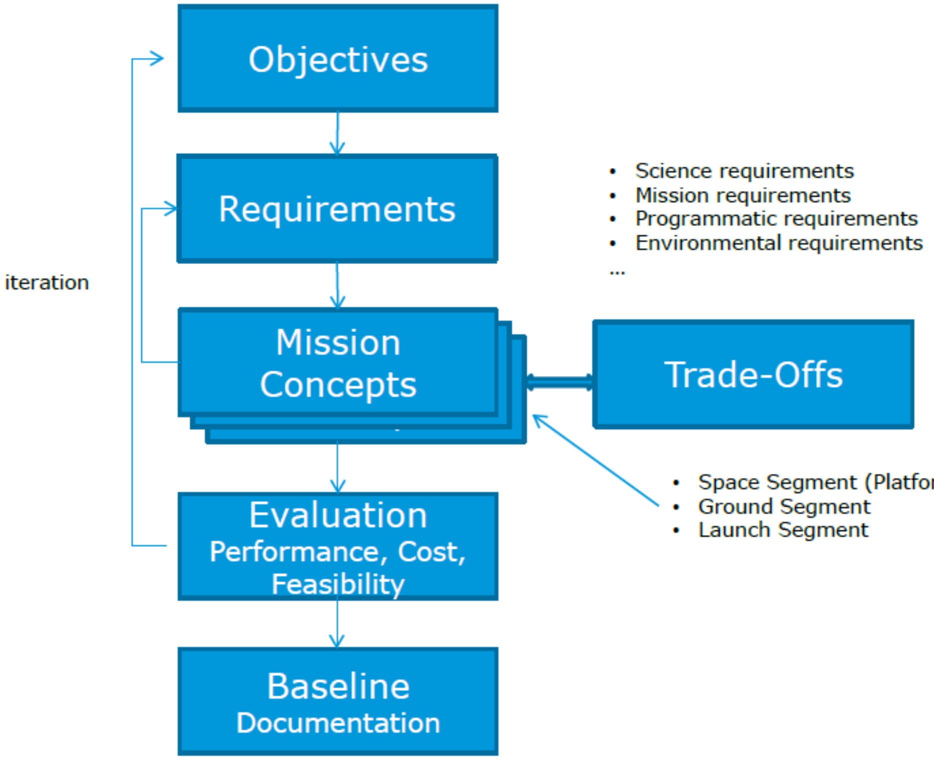
Payload

Mission Design Process

esa



Mission Design Process



Requirements driven…

- Science requirements
- Mission requirements
- Programmatic requirements
- Environmental requirements

…

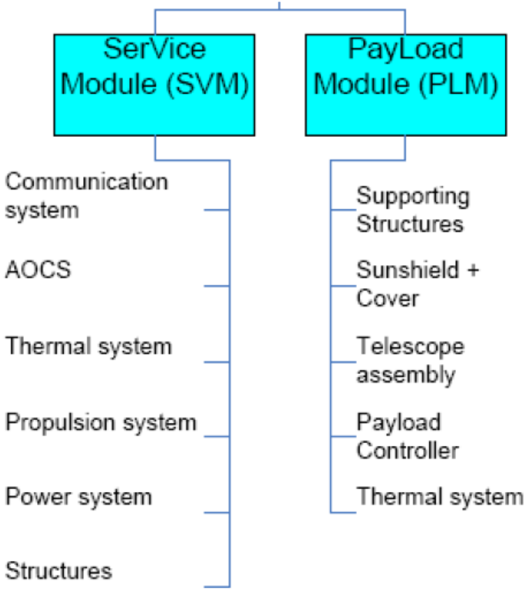
- Space Segment (Platform, Payload)
- Ground Segment
- Launch Segment

Spacecraft Subsystems

1. Structures & Mechanism
2. Propulsion
3. AOCS
4. Thermal Control System
5. Power
6. Data Handling
7. Communication (TT&C)
8. **Payload**

<u>Important:</u> Interrelation of Subsystems

⇨ concurrent design



Product tree

Cost, Risk and Schedule

Cost estimate is very difficult !

- **3 basic methods**: Bottom up approach, parametric analysis or by analogy with other missions
- Need cost model and data base with cost info
- Most difficult is the estimate on engineering, validation & verification cost, manpower etc. & **cost of technology TRL upgrade**
- Cost is driven by complexity of mission

Cost at completion comprises:

- Development cost
- Procurement cost of the space segment (industrial cost)
- Test facilities cost
- Launch cost
- Mission operation cost
- Science operations cost (Data analysis, distribution and archiving)
- Agency cost and margins
- Management costs
- Payload cost
- Contingency …

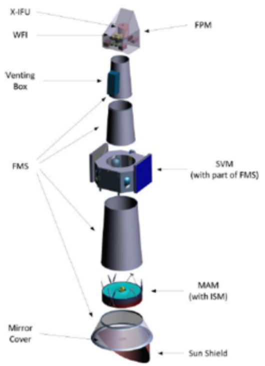
ESA science missions:
ESA: S/C, Launch, MOC,SOC, PM
M/S: Payload

#	Item	percent
1	Project Team	10% (2+3+4)
2	Industrial Cost	~40-50% of total
3	Mission Operations (MOC)	5-10% of total
4	Science Operations (SOC)	5-10% of total
5	Payload Cost	20-30 % of total
6	Launcher	see table
7	Contingeny (15%)	15% (1+2+3+4)
	total	sum (1-7)

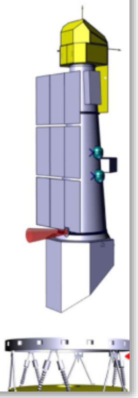
Mission Classes:
Ariane 6.4 > 1 B€ + P/L
Ariane 6.2 > 0.5 B€ + P/L
Vega C ~ 150 M€ + P/L

Missions currently under study

ATHENA Spacecraft



- Launch Mass: ~6.500 kg
- Two options: depending on Mirror size
- Mirror and Focal Plane separated by Carbon Fibre fixed metering structure
- Large LV I/F (3936) to fit the Mirror
- SVM positioned along the tube
- Mirror Assembly tilted by mechanism (hexapod) to switch between the two instruments
- Need of metrology system to comply with Relative Knowledge Error requirement

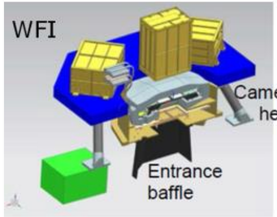


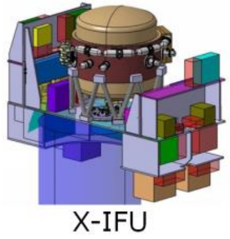
L2

ATHENA Payload

Two instruments:

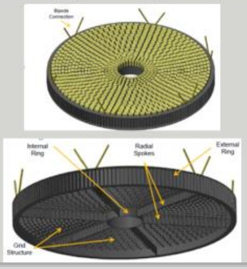
- **Wide Field Imager (WFI):** APS (DEPFET sensor) camera with 40' FoV (~270 kg mass)
- **X-ray Integral Field Unit (X-IFU):** cryo-cooler TES detector-based spectroscopy (~800 kg mass)



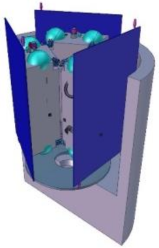


Mirror:
based on SPO technology

- 12 m focal length
- 2.4 m diam (3 m goal)
- 650 kg (1.200 kg for goal)

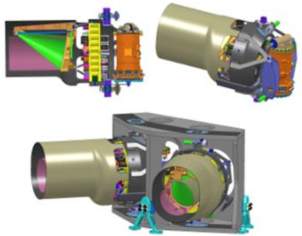


L3



LISA

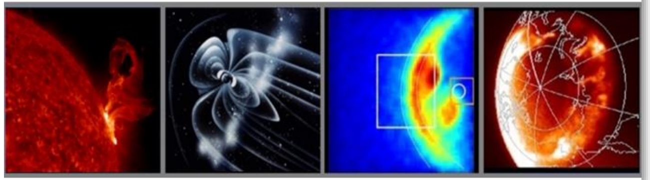
- Proposals received
- CDF's done (S/C+P/L)
- Selection (SPC June)
- Preparation of Phase A
- Baseline: SEP transfer, cold gas DFACS



SMILE

SMILE Mission Summary

- **Objective:** **Investigate the dynamic response of the Earth's magnetosphere to the solar wind impact**
- **Orbit:** Highly Elliptical Earth Orbit: 5.000 x 121.000 km
- **Spacecraft:** Service Module (220 kg dry), Payload Module (120 kg), Propulsion Module (315 kg dry), 480W, 3-axis stabilized
- **Payload:** 4 Instruments for X-ray and UV observations, magnetic field and ionized particles measurements



Missions currently under study

XIPE – Mission description

Science objective

Measurement of the light polarization for a large collection of X-ray sources

Mission Profile

LEO low inclination (6 deg), 550-600 km, launch with VEGA-C, 3 yrs operations, controlled re-entry at end of mission to comply with debris regulations

Mirror

3 Wolter-I Mirror Units, 4-m focal length, 30-Ni shell, on-axis total effective area @ 3 kV of 1650 cm^2 (> 1100 cm^2 required for polarimetry sensitivity), 20 arcsec HEW angular resolution

Payload Composition

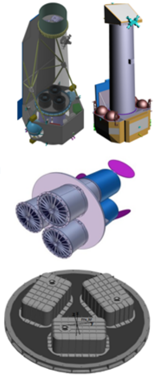
Focal Plane Assembly with three Detector Units

Detector Unit includes Gas Pixel Detector (GPD), Back End Electronics and Filter Wheel for Filters and Calibration Sources

Instrument Control Unit (onboard of SVM)

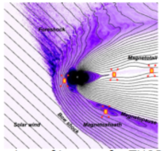
Spacecraft

- Configuration a' la XMM with Mirrors in the SVM and FPA on top of metering tube
- Mass at launch ~1.5 tons

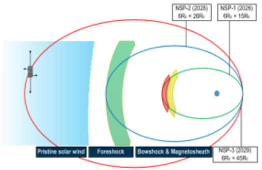


THOR - Mission description

- **Main Science Objectives :**
  - How are plasma heated & particles accelerated?
  - How is the dissipated energy partitioned?
  - How dissipation operates in ≠ regimes of turbulence?
- **Mission :** [3.5 yrs duration, 1 yr / science orbit]
  - 3 Science orbits, 6x15, 6x26 and 6x45 Re
  - probing 4 Key Science Regions (KSR)
  - Launch June 2026 by Ariane 62
- **Spacecraft :** [2.4 tons wet ; 1.2 tons dry ; 170 kg, 200 W P/L]
  - 10 instruments for Field (electric, Magnetic), Waves and Particles measurements, including two data processors
  - Sun-pointed slow spinner (2 rpm), ~4m diameter
  - 2 rigid deployable booms of > 6.5 m and 4 wire antennas of 50m in spin plane to support the most EMC-sensitive instruments



Regions of interest for THOR science in the near-Earth space.



M4

ARIEL mission

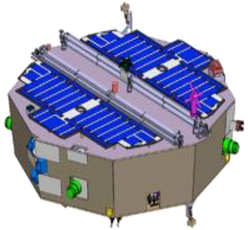
Science objective:

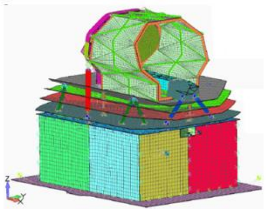
Measure the atmospheric composition and structure of ≥500 hot/warm transiting exoplanets around F to M-type stars, through IR (λ = 1.25-7.8 mm) spectroscopic observations.

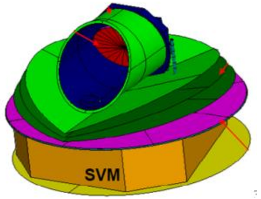
	VISPhot	FGS1	FGS2	NIRSpec	AIRS#0	AIRS#1
λmin	0.5	0.8	1.05	1.25	1.95	3.95
λmin	0.55	1	1.2	1.9	3.95	7.8
R	NA (photometry)			10	100	30

Baseline mission design (unchanged since 2016 MCR):

- ~1 t S/C dry mass, A62 launch to L2, 4 years nominal lifetime.
- 1100 mm x 730 mm M1, off-axis 3 mirror telescope.
- HgCdTe detector for all channels (US baseline, EU back-ups under development).
- PLM passive cooling (~55 K) + Ne JT cooler (~35 K) for AIRS#1 detector.
- AOCS: FGS and reaction wheels only (no micro-propulsion).







Summary

Study Phase: prepare missions from proposal to handover for implementation

Input: proposals from community

Process: Phase 0/A/B1 studies, technology developments + reviews

Output: mission ready for implementation – handover to Project team

Questions ?