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M4 Mission Selection Review Board Report (public)

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CHANGE RECORD

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Table of contents:

Abbreviations

AD	Applicable Document
AIV	Assembly, Integration and Verification
AOCS	Attitude & Orbit Control System
APS	Active Pixel Sensor
CaC	Cost at Completion
CDF	Concurrent Design Facility
CFI	Custom Furnished Item
DRB	Delivery Review Board
EaC	Estimate at Completion
FAR	Flight Acceptance Review
FTE	Full Time Equivalent
HW	Hardware
IOCR	In Orbit Commissioning Review
KO	Kick Off
LoI	Letter of Intend
MAR	Mission Adoption Review
MoM	Minutes of Meeting
MRD	Mission Requirements Document
MS	Member State
MSR	Mission Selection Review
P/L	Payload
PCP	Programmatic and Cost Panel
PLM	Payload Module
PMD	Propellant Management Device
PO	Project Office
RD	Reference Document
S/C	Spacecraft
S/S	Subsystem
SVM	Service Module
SW	Software
TBD	To Be Defined
TP	Technical Panel

REFERENCES

Ref.	Title
RD 1	Yellow Book: ARIEL Atmospheric Remote-sensing Infrared Exoplanet Large-survey, ESA/SCI(2017)2, March 2017
RD 2	Yellow Book: THOR Exploring plasma energisation in space turbulence, ESA/SCI(2017)3, March 2017
RD 3	Yellow Book: XIPE X-ray Imaging Polarimeter Explorer, ESA/SCI(2017)4, March 2017

1 INTRODUCTION

This report summarizes the findings of the Mission Selection Review (MSR) for the three ESA M4 candidates ARIEL, THOR and XIPE, conducted between February and April 2017 and concluded by the M4 MSR Board Meeting on 12 May 2017.

Following the call for M4 mission proposals ARIEL, THOR and XIPE have been selected as the candidates for Phase 0/A. The ESA internal Concurrent Design Facility (CDF) studies of the three candidates were conducted between July and September 2015, followed by industrial Phase-A studies between April 2016 and June 2017. The M4 timeline from call to MSR Board is summarized in Table 1 below.

M4 Timeline Call to MSR	
M4 Call	August 2014 – January 2015
Selection of M4 Candidates (SPC)	June 2015
Phase-0 CDF studies	July / September 2015
Industrial Phase A studies	April 2016 – June 2017
M4 Mission Selection Review (MSR)	Feb 2017 - April 2017
M4 MSR Board Meeting	12-May 2017

Table 1: M4 timeline from call to MSR

The MSR followed the M4 MSR procedure with the general objective to assess the technical readiness of the candidates to be selected for the M4 slot, by evaluating:

- the technical feasibility,
- the technology readiness,
- the development risks,
- the development schedule and ESA Cost at Completion

Composition of panels, scope of the review and detailed schedules were defined in the MSR procedure and are not repeated here. The flow-down from panel findings into to Board report is depicted in Figure 1.

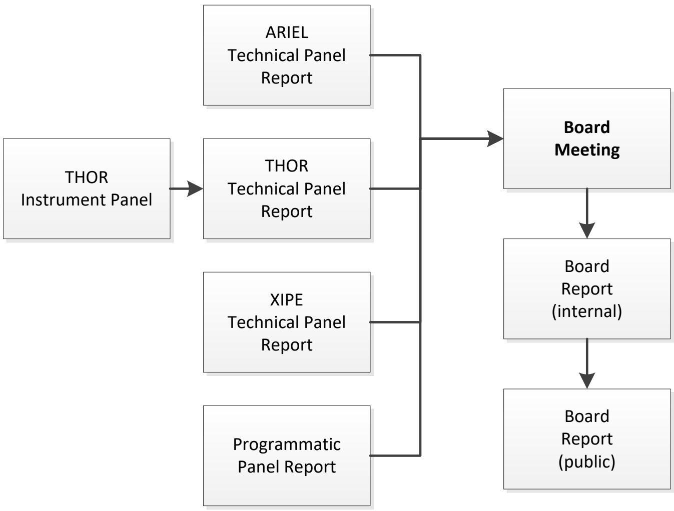

Figure 1: Flow down of information from Panels to Board Report

2 REVIEW SCOPE AND OBJECTIVES

2.1 M4 MSR Scope

The Mission Selection Review constitutes a Preliminary Requirement Review (PRR) as specified in ECSS and the Science QMS procedure *SCI Phase 0-A-B1 Studies and Technology Programme Implementation Procedure*, which outlines the wider scope of the MSR.

For each candidate mission, the MSR acts as a gate review intended to confirm the adequacy of the mission requirements and demonstrate the existence of a viable mission that is fulfilling the scientific and programmatic requirements. Therefore, a successful MSR means the mission is ready, from a sole technical and programmatic standpoint, for being selected for the M4 slot and for proceeding in the Phase B1.

At the same time, the Review assessed the acceptance of the Phase A documentation for the fulfilment of Industry contract obligations.

As developed later in this report, the three mission candidates have successfully passed the Mission Selection Review. Therefore, the M4 mission will be selected among the three candidates on the basis of the best scientific merit.

2.2 M4 MSR Objectives

The MSR objectives are re-called here for reference:

1. The correct flow down of mission requirements from the Science Requirements Document (SciRD) and other constraints to the MRD with relative traceability
2. Requirements maturity and adequacy to the current phase
3. The feasibility and suitability of the mission design (spacecraft, P/L, ground segment and launcher), including the correct identification of design drivers

4. The validity of trade-off results
5. The adequacy of technology readiness and relative maturation plan, for reaching TRL ≥ 5-6 by the time of the mission adoption
6. The completeness and appropriate definition of requirements and interfaces between spacecraft, P/L, ground segment and launcher
7. The completeness of the identification of the technical, programmatic and scientific risks linked to the proposed mission architectures, and the adequacy of the mitigation disposition
8. The compliance of the design to the space debris/planetary protection requirements
9. The correct identification of deviations in case of use of heritage hardware elements, including considerations on obsolescence
10. The realism of the mission Estimate at Completion (EaC) and its consistency with the allocated financial envelope
11. The realism of the mission schedule and its consistency with the programme requirements

3 REVIEW ORGANISATION

The reviews were implemented through a series of meetings held between February and May 2017. Towards the end of the review process, the major findings were presented to a common management board in the science directorate, who further challenged some findings and, in some cases, requested additional clarifications. A substantial effort was devoted to the harmonisation and cross-verification of the cost estimates.

This report provides a summary of the M4 MSR Board findings and is made public for the sake of transparency and for providing feedback to all teams who actively contributed to the mission assessment phase, namely: the study science team and the science community supporting the mission, the science instrument consortia, the industrial study teams, and ESA study team.

4 THE THREE CANDIDATES: ARIEL, THOR AND XIPE

<u>According to call the three mission candidates have to satisfy the M4 top level constrains:</u>

(1) TRL 5-6 at Mission Adoption
(2) Schedule compatibility for a launch in 2025/26 and
(3) ESA Cost-at-Completion (CaC) limit of 456 M€, which excludes the payload and science ground segment elements that are provided by ESA Member States and eventual international partners.

The three candidates are briefly described here, further details are given in the Yellow Books (RD1, RD2, RD3).

4.1 ARIEL

ARIEL studies exoplanets through transit/eclipse spectroscopy observations of their atmosphere (see Figure 3).

<u>ARIEL Mission requirements (summary):</u>

- A62 launch to L2 with ~1 ton S/C dry mass
- 4 years lifetime (6 years goal) including 6 months commissioning
- 85% observation efficiency (with slew ≥ 4.5°/min + 5 min) + 81% scheduling efficiency
- Survey: observation of 1 transit (time critical) → 70° average slew →next target →etc.
- 7.7 h average observation = 2.5x transit duration (10 h max & 3 days goal for bright targets)
- Scheduling gaps to be used for extended out-of-transit observations and (TBC) non-exoplanet science

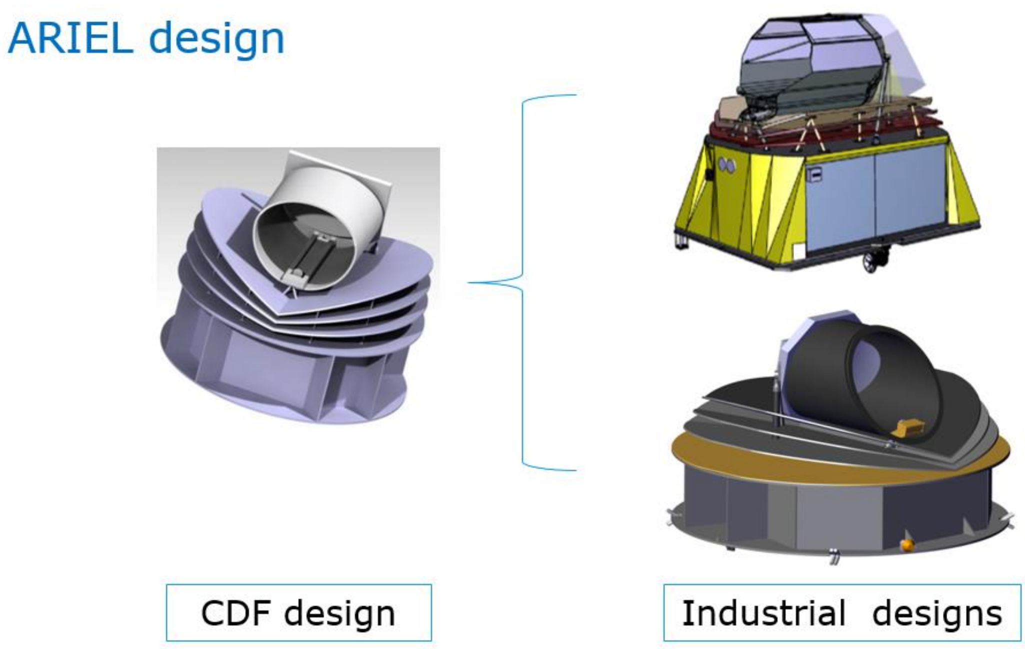

Figure 2: ARIEL spacecraft design impressions

ARIEL Science requirements (summary)

- ≥ 500 preferentially hot/warm transiting exoplanets
- Gas giants to Earth-sized planets, around hot F to cool M-type stars
- 4 VNIR photometric channels (3 photometers for FGS & stellar activity monitoring + 1 spectrometer) + AIRS spectrometer
- Survey type mission with 3 tiers of increasing quality in AIRS:
    - SNR~7 @ R=10 (~30% of time for all planets)
    - SNR~7 @ half R (~60% of time for half of the planets)
    - SNR~7 @ max R (~10% of time for ~10s of planets)
- 90% of targets and SNR completeness required
- Temporal resolution: 90 s (bright targets) to 300 s (faint targets)
- 30% sky observability at any time and full sky within a year
- Brightest/faintest targets: K=3.25/8.8 (flux ratio: 10^2 in IR and 10^3 in Vis)

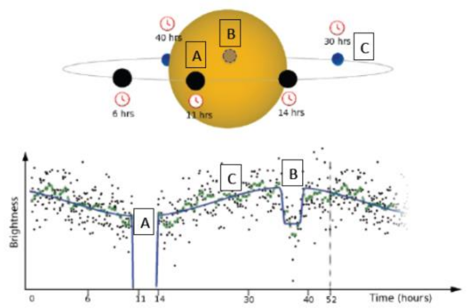

Figure 3 : ARIEL transit/Eclipse observation

	λ_{min}	λ_{max}	R
VISPhot	0.50	0.55	NA
FGS1	0.80	1.00	
FGS2	1.05	1.20	
NIRSpec	1.25	1.90	10
AIRS#0	1.95	3.90	100
AIRS#1	3.90	7.80	30

Table 2 : ARIEL observation channels

ARIEL Payload performance requirements (summary):

- Observation angles: Z=360˚; Y=±25˚ (V-groove cut angle): X =±1˚ (margin) & ±5˚ for X/Y (for FDIR)
- FoM: A_{eff}=0.6 m², η=40-50%, QE=55% (average in each band)
- Out of source pixels for background monitoring and calibration
- Noise and photometric stability (R-PERF-160) from temporal resolution up to 1 transit time. Implies:
    - Low/stable thermal background + dark current & low read out noise and astronomical noise
    - High pointing stability: APE ≤ 1"; PDE ≤ 100 mas [90s-10hrs]; RPE ≤ 200 mas over 90s; RPE stability ≤ 200 mas over 10 h; with FGS ≤ 20 mas [10 Hz] (half cone angles @99.7% for bright targets)

ARIEL Payload Design

- PLM passively cooled with GFRP bipods and V-grooves (telescope ≤ 70 K, OB / instrument boxes ≤ 55 K).
- Active cooling with Ne JT cooler (accommodated in SVM) for 2 AIRS detectors @ 35 K.

- Cut-off and QE optimization: 4 VNIR channels on 2 detectors (< or > 1 μm). AIRS split onto 2 detectors.
- 3 mirror off-axis afocal telescope diffraction limited at 3 μm with M2M. M1 is 1100 x 730 mm.
- Channels split with flat fold mirrors and dichroic mirrors.
- Internal calibration system included (integrating sphere with Tungsten filament or LEDs).
- Single optical bench supporting the telescope and the instrument boxes behind M1.
- All Aluminium design (back-ups studied during the industrial Phase A using ceramic materials).

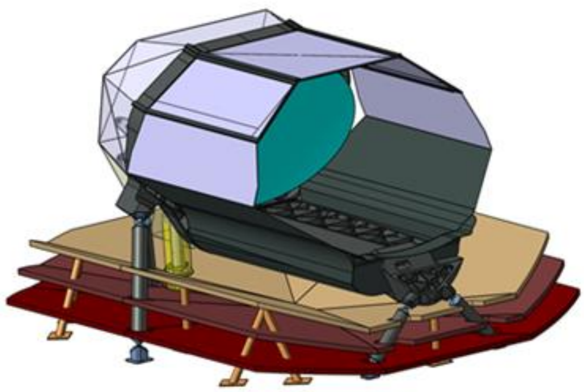

Figure 4: ARIEL Payload design (contractor A)

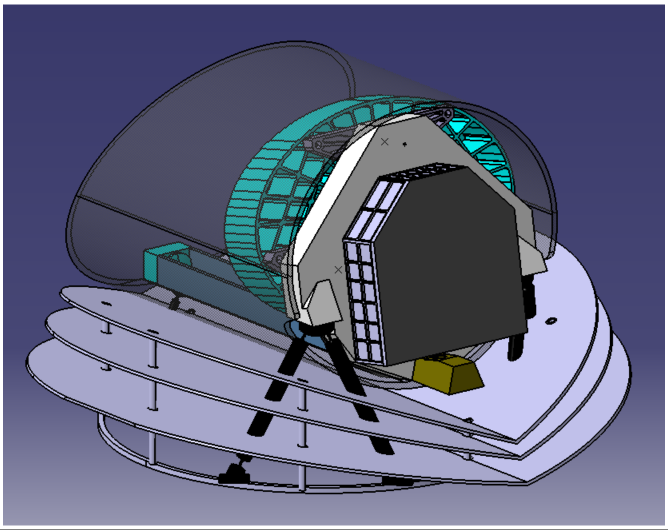

Figure 5: ARIEL Consortium Payload design

Figure 6: ARIEL Payload design (contractor B)

4.2 THOR

THOR will investigate the fundamental science theme "turbulent energy dissipation and particle energisation", which addresses the ESA Cosmic Vision question "How does the Solar System work?"

THOR Main Science Objectives

- How are plasma heated & particles accelerated?
- How is the dissipated energy partitioned?
- How dissipation operates in ≠ regimes of turbulence?

THOR Mission

- 3.5 years duration
- 3 science orbits to probe 4 Key Science Regions (KSR) @ 6x15, 6x26 and 6x45 R_E
- Launch June 2026 with A62 into a quasi-equatorial HEO
- Radiation: 100 krad behind 3 mm Al total dose
- Data: 15 Tbits of burst science data return
- "Scientist In The Loop" to select the relevant burst data
- Disposal via heliocentric or GEO graveyard

THOR Spacecraft

- Spacecraft: ~ 2.4 tons wet, 1.2 ton dry
- Sun-pointed slow spinner (2 rpm), >4m diameter
- EMC-driven S/C design: Conductive surface and active potential control
- Average use of ESA 35 m antenna of ~ 2.7 h/day

Figure 7: THOR spacecraft design – stowed configuration (contractor A)

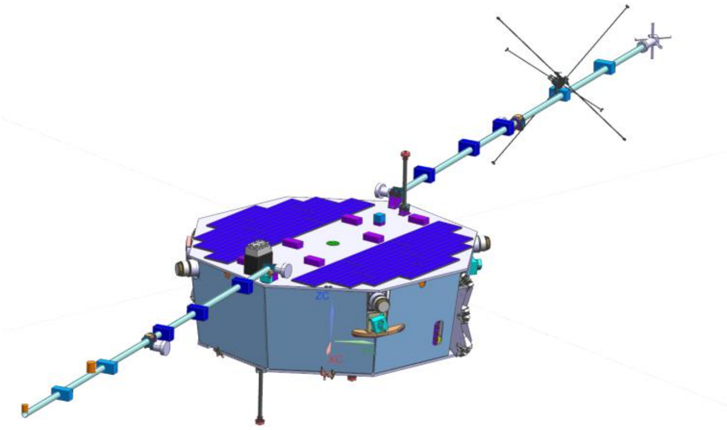

Figure 8: THOR spacecraft design – deployed configuration (contractor B)

THOR Payload

- Payload: ~ 170 kg, 200 W,
- Two rigid booms >6.5 m for magnetic field instruments
- Four 50 m wired booms for electric field instruments
- 10 instruments (magnetic, electric, particles, including 2 DPUs):

MAG	fluxgate magnetometer	B field, DC–64 Hz
SCM	search coil magnetometer	B field,1Hz–100kHz
EFI	electric field instrument	E field, 2D DC–100kHz, 3D 0.1–100kHz
FWP	field wave processor	E, B time series and spectral products
TEA	electron spectrometer	3D distr. function of electrons (5 ms)
CSW	cold solar wind analyser	3D distr. function of H^+(50 ms), He^{++}(300 ms)
IMS	ion mass spectrum analyser	3D distr. function of H^+(150 ms), He^{++}(300ms), He^+, O^+
PPU	particle processing unit	TEA, CSW, IMS, EPE data products
FAR	Faraday cup	cold solar wind ion moments, 32Hz
EPE	energetic particle analyser	3D distr. function energetic e^- & ions (15 s)

4.3 XIPE

XIPE will obtain unique physical and geometrical information on basically all classes of X-ray sources through two still unexplored observables – the degree and angle of polarization.

XIPE Science Objective and Measurement Principle

To measure (for the first time) polarization of a large number of X-ray sources in the 2-8 keV energy band:

- Incoming X-ray photons generate photoelectrons within the gas cell
- Each photoelectron track depends on polarization direction of incoming photons
- Reconstruction of (distribution of) main axis of photoelectron tracks allows to determine polarization direction.
- The technique requires a very large number (several 100.000) of X-ray photons

XIPE Mission

- VEGA-C launcher
- 550km, 6 deg inclination, LEO orbit
- 3 years nominal lifetime
- Controlled re-entry at end of life

XIPE Spacecraft

- Total wet mass between 1.400 kg and 1.600 kg
- “Standard” X-ray telescope configuration with Mirror Units inside Service Module and Focal Plane at the end of closed Metering Tube
- Service Module Avionics and EPS based on EO platforms
- Mirror Thermal Control with inner and outer thermal baffles and heaters
- Communication bands: S-up/down or S-up/X-down TT&C
- Slew by Reaction Wheels (de-saturated by magnetotorquers)
- Sandwich or CFRP monolithic Metering Tube

XIPE Payload

- Three identical Wolter-I Mirrors, 4 m focal length, 30 electroformed Ni shells (Ir+C coating) with XMM and eROSITA heritage
- Installed effective area on-axis: 1.620 cm^2 @ 3KeV > min required of 1.100 cm^2
- Angular resolution requirement of 30 arcsec HEW (20 arcsec as goal)
- Focal Plane Assembly with Detector Units including Gas Pixel Detectors and Back End Instrument Control Unit in SVM.
- Payload ~83 kg / 100W

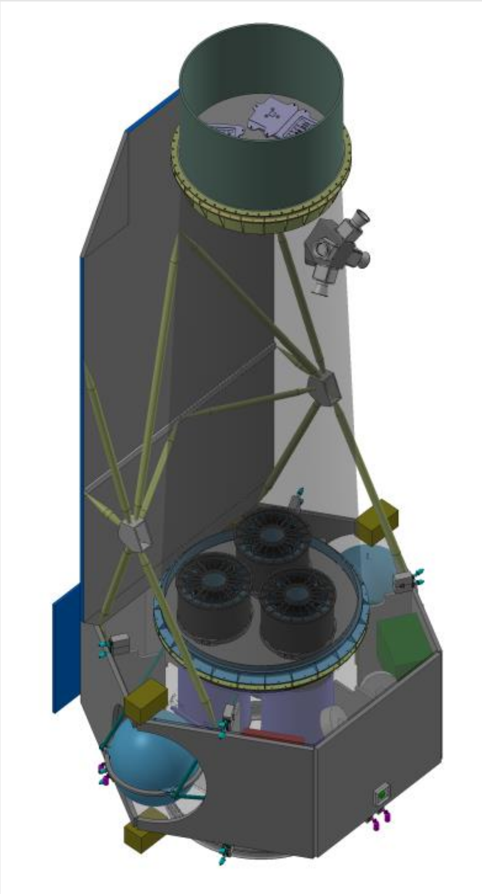	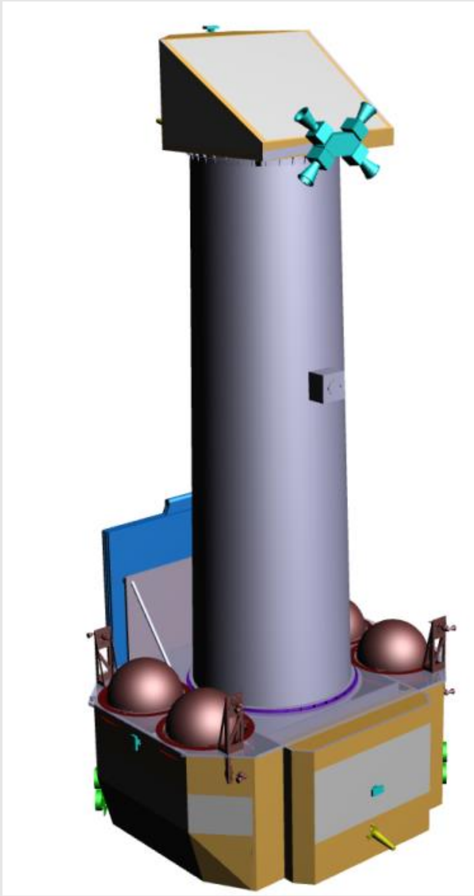
Figure 9: XIPE spacecraft design (hexagonal configuration)	Figure 10: XIPE spacecraft design (with units mounted on the outside, under MLI tent)

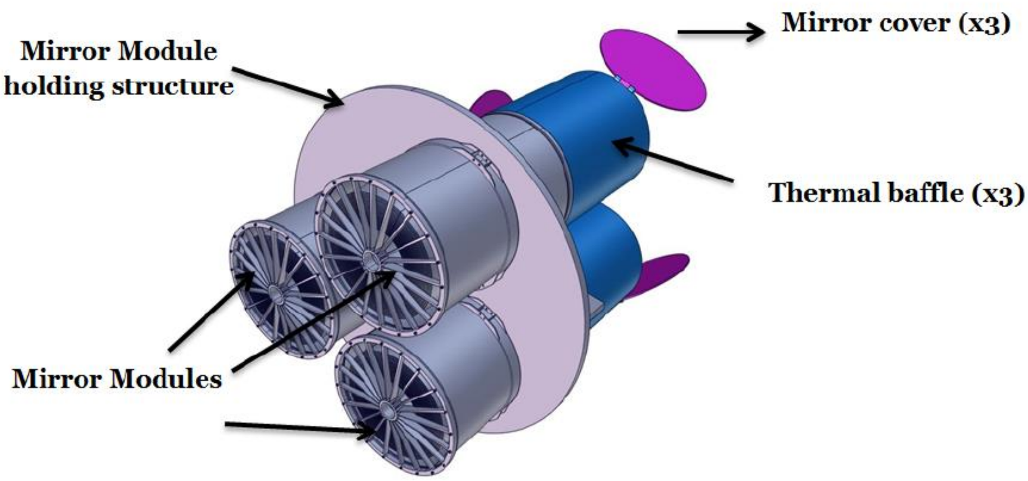

Figure 11: XIPE Mirror design

5 TECHNICAL REVIEW

The MSR technical evaluation was conducted by three separate Technical Panels (TP) for the three candidates ARIEL, THOR and XIPE. For THOR additional Instrument-subpanels were setup, due to the number of THOR instruments (10). Following the MSR procedure each of the three panels summarized their findings in their individual panel report.

5.1 ARIEL

The ARIEL Technical Panel concluded:

- Adequacy of requirements and flow-down:
    - In general, the requirements completeness and flow-down is suitable at this stage of the mission. Several detailed recommendations were issued by the Panel and are considered as normal work for Phase B1, and are hence not repeated here.
- Technical feasibility (incl. scientific performance):
    - SVM: The SVM design is seen as feasible and does not exhibit any particular complexity, apart for the AOCS subsystem that will require consolidation in the next phase, but is also expected to be feasible.
    - PLM: The PLM design is adequate to meet the performance requirements (incl. telescope, instruments, thermal shield assembly and active cooler). The weakest point of the design concept is its capability to survive direct Sun illumination, which was not considered in the study.
    - Sun illumination of the PLM following the launcher fairing jettisoning was not considered as a design driver by the Consortium, but its impact on the design/qualification/cost could be significant. Mitigation measures are identified (use of dual launch structure or thermal cover at system level, or PLM optimisation for this case with associated cost impact) and shall be consolidated in Phase B1.
    - In the nominal scenario (full PLM provided by the Consortium) the interfaces between SVM and PLM are well decoupled and allow parallel development and verification.
- Technology readiness:
    - SVM: All units have high TRL (excluding geo-return constraints).
    - PLM: Six payload units/systems have TRL < 6. Development plans are in place to reach TRL 6 by MAR and are considered credible by the Technical Panel if all recommendations are followed.
- Development risk:
    - SVM: Low risk, but micro-vibrations and impact on RPE budget will need to be closely monitored and might require additional characterisation of the system (as opposed to verification by system analysis combined with characterisation of units only).
    - PLM: Assuming all units reach an adequate TRL by the MAR, and the PLM is protected from direct Sun illumination, the subsequent development risk of the PLM is considered to be acceptable.
- Programmatic assessment (excluding cost):

- The schedule is driven by the development of the PLM (instruments on the critical path followed by the telescope) but is considered to be in line with the M4 constraints thanks to adequate margins. Nonetheless the Phase B1 should be strengthened to minimise the risk of development schedule slippage.
- The main programmatic risk resides in the overall scope of the work under the responsibility of the Consortium and to be supported by the Member States.

15 recommendations have been issued in the Technical Panel report for the Board's consideration. Overall, the Technical Panel does not see any technical show-stopper for the ARIEL mission.

5.1.1 Board Findings - ARIEL

The Board endorses the findings of the ARIEL Technical Panel and the conclusion above, in particular:

- The Board endorsed the recommended procurement of a NEOcam EM detector to test its performance and qualification status.
- To minimise the risk of a payload development schedule delay by strengthening the Consortium activities in the bridging Phase and subsequent Phase-B1.
- To continue the development of European IR detectors, although probably not ready for the need date for ARIEL.

<u>with addition of:</u>

- A risk concerning the overall complexity of the entire PLM to be designed, delivered and tested by the P/L Consortium under Consortium management shall be added to the risk register. Specifically, the risk of a timely delivery is of concern.
- The study of the telescope backup under ESA shall be terminated. The study of backup(s) to the Aluminium telescope should be made by the Consortium if needed.
- A decision concerning the choice of detectors (baseline or alternative) could be taken latest at the Mission Adoption Review (in case the European detectors would be ready by then or difficulties with the performance of the US detectors occur), following an assessment of the performance with respect to the ARIEL requirements and appropriateness of the technical readiness level.
- The risk associated with the timely funding of payload activities is to be addressed as normal work, by probing the Funding Agencies before the selection of the mission and actively requiring adequate funding for the payload activities already for the Phase B1.

5.2 THOR

5.2.1 *THOR Technical Panel findings*

The Technical Panel did not identify any mission feasibility issue with THOR. All objectives of the MSR have been met. The mission is overall mature, with high TRL equipment and subsystems, with the exception of the bi-propellant tanks for which a dedicated technology development activity for the propellant management device (PMD) has been identified (considered low risk). The mass budgets show a launch mass growth potential of more than 14%, which is considered as adequate at this stage. The Payload was found mature, with significant heritage, although some low payload TRL components have been flagged. For those elements adequate technology maturation effort is already on-going, and higher TRL back-up solutions exist (with some drawbacks).

The Panel recommends to remove the ASPOC and 2 TEA heads from the baseline design. The Panel noted that these are not needed to meet the scientific requirements.

The schedule is deemed credible, with the amendments and remarks discussed in this report.

The single launcher (Ariane 62), combined with the uncertainty of the launcher performance and characteristics, was considered by the Panel as one of the major risks of the mission, though adequate margins have been considered.

Programmatically, as for other science missions, a risk resides in the timely commitment of Member States for payload funding contributions.

5.2.2 *THOR Panel Recommendations*

- Recommendations for Mission and spacecraft design
    - The Panel recommends to add an exhaustive traceability matrix from SciRD to all applicable documents (not limited to the MRD).
    - The Panel recommends to provide a justification for all mission requirements like done for the science-derived requirements, including spacecraft and ground segment related requirements.
    - The Panel recommends reinstating the EMC working group to allow maturing further the EMC requirements and verification approach in preparation for phase B1.
    - The Panel noted that a relaxation of the E-field AC requirements could allow to relax the constraint on some equipment selection (or the need for modification), and could result in some cost savings. This should be investigated in the next phase in coordination with EMC working group activities.
    - Given the uncertainty on the launcher performance and capabilities the Panel recommends the study team to monitor closely the evolution of the launcher design.
    - The Panel recommends to remove ASPOC from the Mission requirements, being not justified to meet the science requirements based on industrial and ESA-internal charging analysis results.
    - It is recommended to study a potential early deployment of the MAG booms (just after the LEOP phase) such that in orbit calibration could be performed.
    - The Panel recommends that the study team monitors on-going mass memory developments in the coming months / years as their might be room for mass and/or cost reductions for THOR.

- Recommendations for Ground Segment
  - The panel recommends to further streamline the ground processing timeline (between GS, MOC, SOC and SITL) for survey data to make it more efficient (e.g. automatic transmission by GS to the Scientist-in-the-loop) and achieve reduction of the on-board memory unit size.

- Recommendations for Technology maturation
  - to implement in the Science Technology Plan a technology development activity for the bi-propellant tanks PMD adaptation, to raise the TRL from 4 to 6 before mission adoption.
  - to de-risk in a dedicated technology development activity the possible usage of APS star tracker for THOR, e.g. by improving the existing angular rate limitation. This would allow to relax the constraint on optical head line of sight angle with respect to the spin axis or to go for a gyroless design, which would reduce the HW cost for the mission.

- Recommendations for Payload
  - The Panel recommends to consolidate the payload contamination requirements in the coming phase due to the potential impact on AIV/T and launch campaign.
  - The Panel recommends to develop a preliminary frequency plan and discuss it in the EMC group especially with SCM and EFI instrument teams.
  - The Panel recommends to update the magnetic moments in the EIDA with numbers from hardware already measured in other projects instead of allocations.
  - The Panel recommends to remove the two additional TEA units from the payload baseline design as these were found not justified from a Science Requirements perspective.
  - The Panel recommends to establish a “Particle Instruments Suite” level as per phase B1 in the payload management plan to ensure proper coordination, interfaces specification, integration and testing of the PPU, and the timely delivery to the spacecraft of the tested PPU to mitigate the associated schedule risk.
  - The Panel recommends to consolidate with all instruments the thermal interfaces for all P/L units.
  - The Panel recommends to perform another iteration on the FAR thermal analysis in the bridging phase with the actual S/C configurations for this thermally-critical instrument that is located on the Sun-facing panel of the S/C.

5.2.3 Board Findings - THOR

The Board endorses the findings of the THOR Technical Panel as reported in its Technical Panel Report and the conclusion above, in particular:

- Endorses the recommended ASPOC removal, and requests a formal confirmation from the THOR Science Team and reflection in the SCI-RD.

- Endorses the recommended removal of 2 TEA heads and requests a formal confirmation from the THOR Science Team and reflection in the SCI-RD.

with exception of:
- Statement concerning the non-defined backup launcher. The Science Directorate will seek a waiver for having no backup launcher (except a potential change from A62 to A64), like done for other missions in the programme.

with addition of:
- Suggests to consider the reuse of the JUICE MAG boom, to eventually reduce cost and to increase EMC tolerance (with the longer boom from JUICE).
- Recommends the lead proposers to address a potential non availability of international partner funding for the three respective proposed instruments and define a minimum payload complement or a fallback solution, compatible with ESA Member State funding only and available technology.

5.3 XIPE

5.3.1 XIPE Technical Panel findings

The Technical Panel has not identified any major technical issue with XIPE. The mission has good technology maturity and overall low risk with the proposed mitigation approach on the Mirror coating and credible backup options exist.
The schedule is credible with the amendments discussed in the Panel Report, with a nominal development duration of 6.7 years to launch including 6 months of contingency.
The Panel recommended to simplify and streamline the interfaces and responsibilities for both the Mirror and the instrument: The Mirror development is proposed to be moved under Prime responsibility (instead of being ESA Customer Furnished Item to the Prime), and the whole Focal Plane Structure is proposed to be moved under the Instrument Consortium responsibility, including related verification (instead of sharing the structure with unclear verification responsibilities).

5.3.2 XIPE Panel Recommendations

Mission Requirements

- the Panel has noted the lack of a mirror specification document. The ESA study team has only produced a mirror ICD to control interfaces with the Primes. The Panel has recommended issuing a mirror specification for Phase B1.

Mission and SC design

- The Panel has noted positively the performed preliminary thermo-elastic analysis of the metering tube which has an important impact on the mission performance.
- Concerning AOCS, the Panel has raised minor issues on the design, e.g. AOCS during S/C re-entry was not sufficiently investigated.

Mirror

- The Mirror design of XIPE is based on proven technology flown on BeppoSAX, XMM, SWIFT and due to fly on eROSITA. However, the Science Team has proposed using a coating consisting of 30 nm Ir and overcoated by 10 nm C. This has not been used to date in any space mission and therefore, constitutes a technology risk. In addition, resistance of C overcoat to atomic oxygen present in XIPE orbit needs to be verified.
- After assessment of the issue, the Panel has recommended that the baseline Mirror coating shall be changed to Pt/C rather than Ir/C. The corresponding TRL can then be stated as ≥6. In addition, a TDA activity shall be started, if the mission is selected, to assess tolerance to atomic oxygen.

Instrument

- Overall, the design of the different Instrument elements is quite mature and low risk.
- The Panel has reviewed the AIV approach proposed by the Instrument Consortium, where this latter proposes to deliver the integrated Focal Plane (Detector Units plus structure) to the Prime only at STM level; while for the FM the units will be delivered separately (non-integrated). The Panel recommends to change this approach and to

receive the integrated Focal Plane from the Instrument Consortium in all cases for streamlining the respective responsibilities.

Ground Segment and Operations

- The Panel has noted a minor potential issue with S-band use in equatorial orbit linked to a phenomenon called Spread-F. Such phenomenon consists in disturbances to the propagating radio wave generated by plasma turbulence in the ionosphere. However, this effect is judged to be very limited for XIPE.

Technology readiness

- No technology maturity issue has been identified for XIPE, provided the recommendations on the mirror coating are implemented.

Schedule

- The ESA study team has updated the master schedule according to the Panel recommendations. The updated plan has been provided to the Programmatic Panel.

Specific Recommendation related to Management and Interfaces

- The Panel recommends the mirror contractor selection and kick-off to be made in Phase B1 by ESA and its management is transferred to the Prime in Phase B2/C/D. The Panel is also of the opinion that this change of responsibility will be cost neutral for the mission as the additional Prime overhead on the mirror activities will be compensated by the interface simplifications.
- The present share of responsibility of FPA, where the Instrument Consortium provides the FPA structure and the Prime provides the thermal control creates ambiguities in the definition of the interfaces and makes the overall AIV flow inefficient. Furthermore, there are no clear responsibilities on the thermal and alignment control and on the combined performance of the system.
  The Panel recommends that the respective responsibilities of the Prime and Instrument Consortium are streamlined, by moving the FPA structure to the Consortium including thermal control and verification.

5.3.3 Board Findings - XIPE

The Board endorses the findings of the XIPE Technical Panel as reported in its Technical Panel Report as summarized in the conclusion above, and in particular:

- Endorses the transfer of the FPA delivery and integration responsibility to the Instrument Consortium
- Endorse the change of Mirror coating to Pt/C

with exception of: None

with addition of: None

6 PROGRAMMATIC REVIEW

The programmatic MSR was conducted by a single panel (PCP) reviewing the three missions in parallel to guarantee equal treatment and similar underlying assumptions in particular for the cost estimate at completion (EaC). It followed the M4 MSR procedure and summarized the findings in the PCP panel report.

6.1 Cost

The PCP evaluated the EaC for each of the M4 candidates, which includes 10% margin for the elements ESA Project Office, S/C and P/L industrial cost (under ESA responsibility), and Operations cost. All three mission candidates are estimated to be close to the M4 cost target (slightly below or above), based on the current programmatic assumptions.

Also several cost saving options have been identified:

ARIEL:

- Dual launch on A62 with (significant TBD) savings,
- Removal of thermal cover, subject to a confirmation of a PLM design surviving sun illumination.

THOR:

- Gyroless AOCS (MMS-like): cost reduction, but at higher risk
- Reduction of Mass Memory Unit, with a science impact TBD. Following technical progress, it is likely that the cost difference of larger volume mass memory will decrease over time anyhow.

XIPE:

- Ground Station contribution by ASI (LoI provided) – savings TBD
- Use of standard platform avionics (e.g. reuse from Earth Observation platforms) – savings TBD
- Spacecraft development duration of currently 6.97 years could be reduced by 6 months based on the XIPE Technical Panel recommendations:
    - Initiate the mirror development in Phase B1, by implementing pre-developments and procuring the mandrels.
    - Instrument calibration only based on one pair and not each of the three pair as currently proposed.
    - Launch date in advanced to Q4/2025

6.2 Schedules

The figure below summarizes the underlying schedules for the three M4 candidates. All three candidates can be done within schedule (launch 2026), with 6 month margin included between P/L delivery (DRB) and P/L need date, and additional 6 month schedule margin between FAR and start of Phase E1. The assessment is based on the original M4 schedule and has to be shifted by ~6 month following the delay of the M4 Mission Selection (from July 2017 to November 2017).

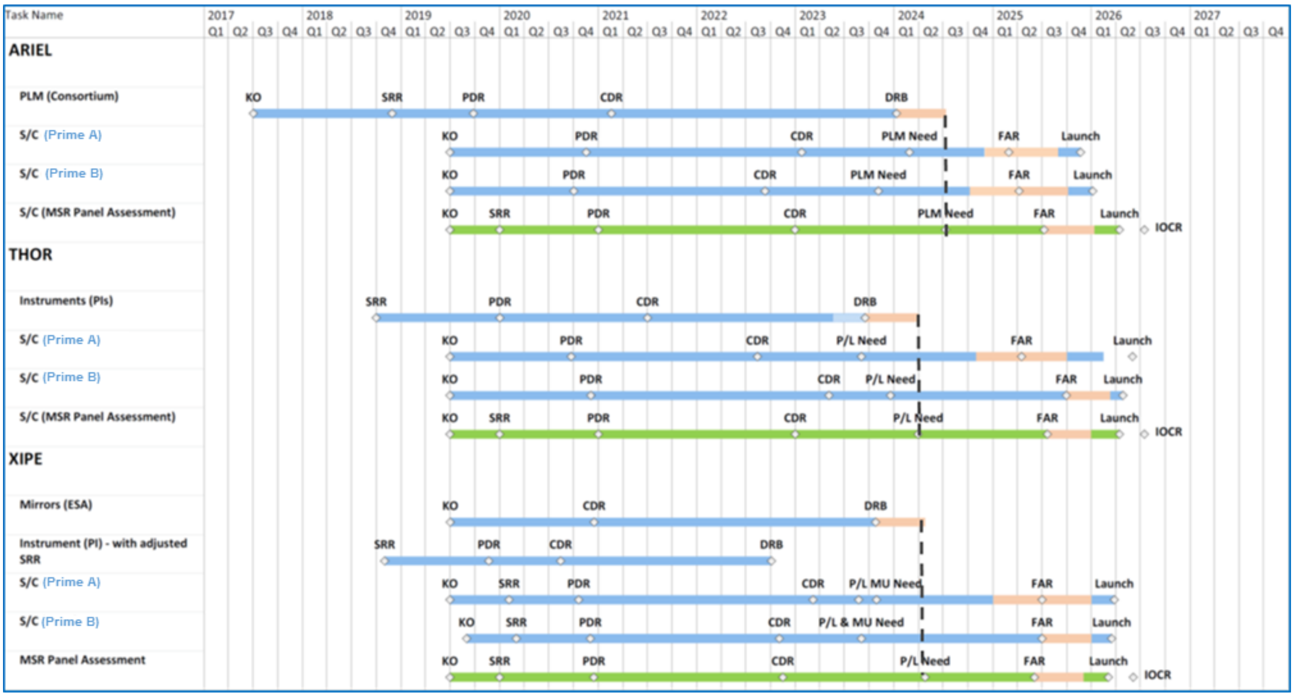

Figure 12: M4 schedules

Green: PCP estimated schedules for the S/C development. **Blue:** inputs provided by Industrial contractors. **Orange**: schedule margin. **Dotted black line**: Payload schedule margin of 6 months from P/L DRB proposed by the Consortia to P/L need date by the S/C.

6.3 Risk

The Risk assessment was performed in parallel by Technical Panels and the Programmatic Panel (PCP), with a final coordination by the PCP, followed by the Board. The details are in the TP and PCP panel reports, only a summary of the main risks is given here:

ARIEL

All main technical risks for ARIEL are related to payload elements, with the highest risk on the overall PLM complexity to be handled by the Consortium:

- high risk (C5): overall complexity of the PLM to be managed, designed, delivered and tested by the P/L Consortium under Member State funding.
- medium risk[1]: Aluminium telescope, NEOcam detector, M2 re-focusing mechanism, Ne JT cooler, PLM survival of Sun illumination, dichroic D1
- low risk: Silver coating on Aluminium mirrors in cryo, passive cooling concept with V-grooves and GFRP bipods, launcher availability.

[1] The Board concluded to elevate this risk from medium-low to medium

THOR

No high or very high risks were identified for THOR by the Technical Panel and PCP. Medium risks were found for:

- a significant proportion of the payload instruments rely on international partner funding (B5)
- schedule risk associated with the number of instruments and the potentially delayed commitment by some Member States for P/L funding (C2)
- Ariane 62 launcher performance and availability (B5).

XIPE

No high or very high risks were identified for XIPE by the Technical Panel and the PCP.

- Low risk: identification of S/C disposal region in the Pacific, failure of P/L CU affecting all three telescopes at the same time, use of small nuclear sources for P/L calibration, mirror coating technology.

6.4 Board programmatic conclusions

Following the Board Meeting conducted on 12 May 2017 the Board endorses the findings of the PCP as reported in its panel report:

with addition of:

- Increase of Phase E cost in the EaC, to reflect recent accrued costs for this phase.
- THOR should (1) have no ASPOC on board and (2) investigate a P/L simplification (e.g. in case international partner funding for the three instruments does not materialise)

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Board Conclusions

The Board concludes that all three M4 mission candidates are feasible, within the foreseen schedule and acceptable risks to ESA, and with the cost to ESA close to the M4 target.

Of the three candidates ARIEL has the highest risk due to the complexity of the PLM to be managed, designed, developed, tested and delivered by the P/L Consortium under Member State funding. The ESA provided SVM on the other hand is considered to be of low risk. Under the assumption that the PLM is provided under MS funding ARIEL is estimated to be within M4 cost, but with nominally no growth potential of ESA responsibility. Therefore, any ESA involvement in the PLM (e.g. provision of the telescope) would bring ARIEL above the cost target. On the other hand, a significant ESA cost saving could be achieved with a dual launch configuration.

THOR has heritage from Cluster and MMS and is feasible with acceptable risks. The main risk is due to the number of instruments and the associated possibility that funding is late or not sufficient and deliverables delayed. Three main instruments are provided by international partners (funding confirmation subject to a call). It is recommended to prepare a backup plan and science case with a set of (reduced) instruments taking the above risk into account. Furthermore, ASPOC has been removed from the baseline.

XIPE is considered feasible with low risk and within cost cap. The schedule could be somewhat advanced and the use of standard LEO platform equipment envisaged (e.g. avionics, subject to compatibility with implementation constraints such as industrial geo-return), both with potential positive impact on the ESA EaC. Also the proposed use of Malindi ground station as in kind provision could further reduce the ESA EaC.

For all three candidates the Board recommended to establish a list of actions to be executed in the bridging phase (extension of Phase A) and Phase B1 to further consolidate the definition of payload, anticipate related funding issues and establish reasonable consortia management schemes to reduce associated payload technical, schedule and cost risks.

For all three candidates a continued design-to-cost approach is necessary to remain within M4 envelope.

The Mission Selection Review is declared successful with its objectives achieved.