Theia: dark matter and exoplanets

ESA mission calls: M4 & M5

F. Malbet
University Grenoble Alpes

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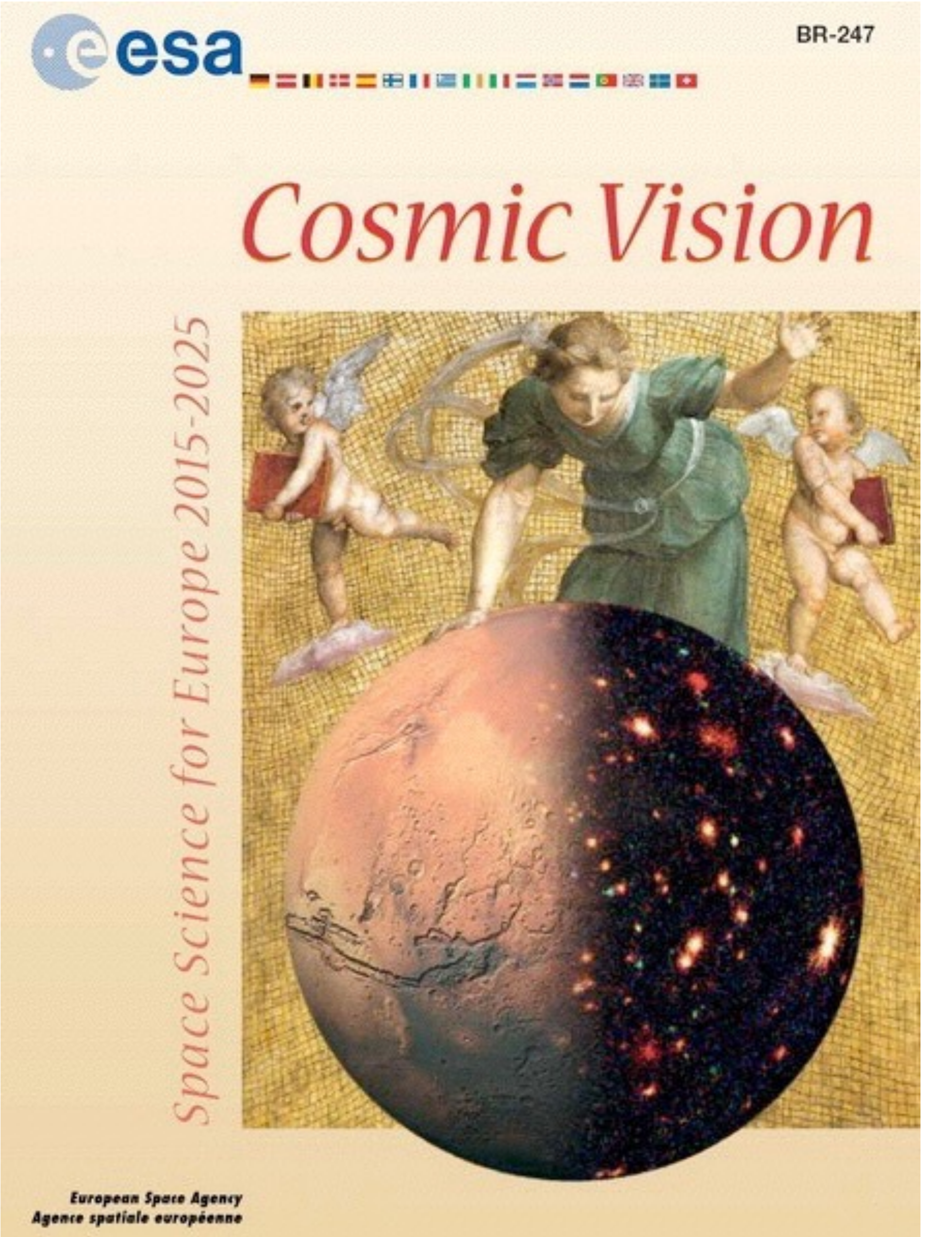
ESA Cosmic Vision



1. What are the Conditions for Planet Formation and the Emergence of Life?
2. How does the Solar System Work?
3. What are the Fundamental Physical Laws of the Universe?
4. How did the Universe Originate and What is it Made of?
5. Technology Requirements
6. Proposed Strategies and Their Implementation

- 2015-2025
- Mission calls
  - M1: Solar Orbiter
  - M2: Euclid
  - L1: Juice
  - S1: Cheops
  - M3: PLATO
  - L2: Athena-X
  - …. M4, M5, L3

S: 150 M€
M: 500-600 M€
L ≥1 G€

M3: NEAT
S1: microNEAT
M4: Theia

CV timelines

<< M missions

L missions

TIMELINE FOR M1/M2 CANDIDATE MISSIONS

Activity	Date
Call for proposals for Cosmic Vision missions	March 2007
Selection of M-class candidate missions for assessment studies	October 2007
ESA internal assessment phase of candidate missions	November 2007 - May 2008
Industrial assessment phase and parallel payload definition studies	June 2008 - August 2009
Open presentation of study results & Working Group recommendation for definition study phase	December 2009 - January 2010
SSAC down selection recommendation to 3 missions for the competitive definition phase	January 2010
SPC decision on 3 missions for the competitive definition phase	February 2010
Three missions in competitive definition phase	April 2010 - September 2011
Working group/SSAC evaluation and recommendation for adoption of 2 missions	September 2011
SPC selection of 2 missions for implementation	October 2011
Mission launch year targets (M1, M2)	2017, 2020

TIMELINE FOR M3 CANDIDATE MISSIONS

Activity	Date
Call for new M-class mission for M3 launch opportunity	July 2010
Selection of four M-class candidate missions for assessment studies	February 2011
ESA internal assessment phase of candidate missions	March 2011 - October 2011
Industrial assessment phase and parallel definition studies of model payload	February 2012 - December 2013
Call for proposals for scientific payload, including science ground segment elements, for the candidate missions	September 2012
SSAC recommendation on scientific payloads	Before February 2013
SPC selection of scientific payloads	February 2013
Definition studies on selected payloads	February 2013 - September 2013
SSAC down selection recommendation for one mission for the M3 launch opportunity	Before February 2014
SPC selection of one mission for the M3 launch opportunity	February 2014
Working group/SSAC evaluation and recommendation for adoption of mission	Before November 2015
SPC adoption of mission	November 2015
Mission launch year target	by 2024

TIMELINE FOR SELECTION OF L1 CANDIDATE MISSIONS

Activity	Date
Call for proposals for Cosmic Vision missions	March 2007
Selection of L-class candidate missions for assessment studies	October 2007
ESA internal assessment phase and identification of key technology areas	November 2007 - February 2009
Down selection of the two outer Solar System missions	February 2009
Industrial assessment phase and definition of technology development plan	September 2009 - September 2010
Start of European-led reformulation studies	March 2011
SSAC recommendation on the first Large-class mission (L1) selection	April 2012
Selection by SPC of L1: JUICE	May 2012
Planned launch date for JUICE	2022

TIMELINE FOR SELECTION OF L2 AND L3 CANDIDATE MISSIONS

Activity	Date
Call for White Papers to define science themes for L2 and L3 missions	March 2013
Selection by SPC of science themes for L2 and L3 missions	November 2013
Call for mission concepts for L2 mission opportunity	January 2014
SSAC recommendation on the second Large-class mission (L2) selection	June 2014
Selection by SPC of L2: ATHENA	June 2014
Planned call for mission concepts for L3 mission opportunity	2016
Planned launch date for ATHENA	2028
Planned launch date for L3	2034

Selection process

- Calendar:
  - Call for Mission (t0)
  - Letter of Intent (~t0+1m)
  - Deadline (~t0+4m)
  - Pre-selection (+2-3m)
- Call for mission:
  - letter gives the launch date, the cost cap and some specifics
  - selection committees includes AWG, SSWG,… then SSAC
  - M3: science selection first. NEAT was preselected by AWG, but rejected by SSAC
  - M4: technical and cost assessment first. The was not preselected.
- After the selection of mission candidates:
  - 3 to 4 candidates are studied
  - only 1 will be selected based on science and technical.
- Communities: Astrometry (Gaia), X-Ray (XMM, Athena), Cosmology (Planck, Core +), Exoplanets (PLATO, Cheops, Ariel,…), solar (Soho, Solar Orbiter), planeto (Mars, Pluto, Venus, Mercury,…), physics (LISA pathfinder, eLISA,…)

Proposal

- Topics to be addressed:
    - Science objective
    - Science cases
    - Science requirements
    - Mission (launch date, orbit, duration)
    - Instrument (principle, main characteristics, subsystems)
    - Mass budget, fuel budget, communication
    - Space segment, ground segment
    - Data processing
    - Cost analysis and management

- Community: astrophysicists, instrumentalists, data processing, industries,…

NEAT (1/2) - Proposal summary

<u>Main science objectives:</u>

• Detect and characterize planetary systems down to 1 Earth Mass in the habitable zone and further away, around nearby stars K, G, and F spectral types (pre-determined targets).

• Detect astrometric wobble of a star created by the gravitational effect of orbiting planets.

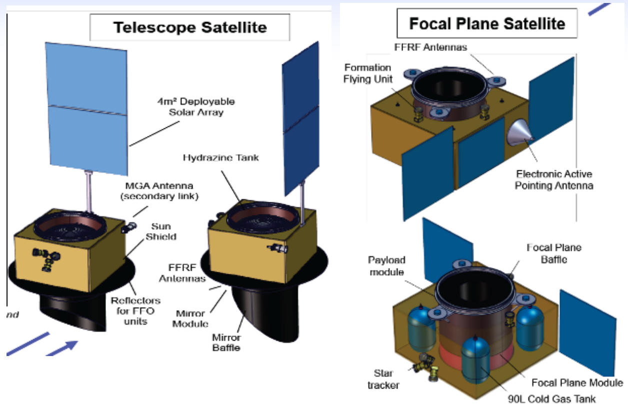
<u>Mission profile</u>

• Formation flying mission, driven by VIS telescope F=40m. Telescope S/C + Focal plane S/C.

• Soyuz Fregat (Kourou). Stacked launch but cruise separately to L2.

• At L2 S/C reconfigure into a large amplitude Lissajous or Halo orbit, 5 year lifetime.

• Re-pointing of formation every few hours, 50 revisits over mission, > 20,000 reconfigurations.



<u>Spacecraft:</u>

Telescope S/C (TSC):

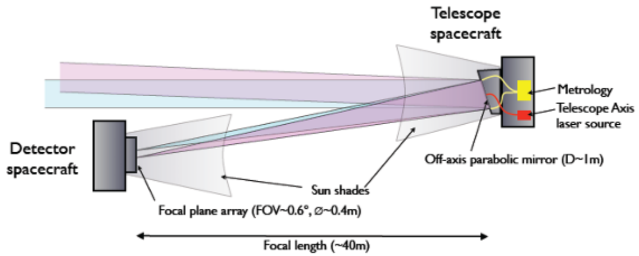
• 724 kg dry mass, 250 kg Hydrazine. X-band (cruise + secondary link); 4m^2 depl. Solar array.

• AOCS: RW's, 16x1N thrusters, star trackers + fine sun sensors, RF and optical FF metrology.

Detector S/C (DSC):

• 656 kg dry mass, 28 kg Hydrazine, 92 kg cold gas; 7 Gbit/day, X-band: = 4 hr/d (ESA 15 m g/s).

• AOCS: RW's, 4x1N thr, 8x10mN (cold gas), ST + fine sun sensors, RF & optical FF metrology



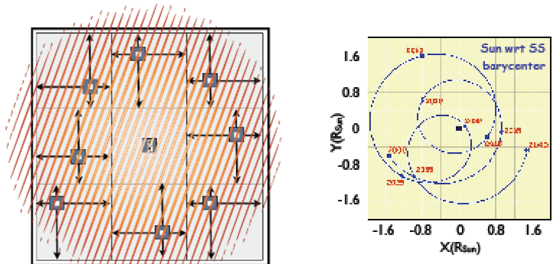
<u>Payload:</u>

• F=40 m, 1 m diameter, 0.6 degree FOV, diffraction limited, off-axis parabolic mirror on TSC.

• Focal plane (size 0.4m x 0.4m) consisting of 10 CCDs (2 fixed, 8 moving X,Y) on Detector S/C.

• Wobble of target star measured against set of 8 reference stars. Relative distance via OBM.

• Laser metrology system for stellar position determination. Tip/tilt on mirror in servo-loop.



g. E.5: Astrometric motion of the Sun due its planets. At 10pc, 1 R☉ translates into 0.46 mas. The effects of Jupiter and Saturn are dominating.

<u>International cooperation & European contribution/s:</u>

• Mission led by ESA – responsible for launch, 2 S/C and ground segment/ops

• Mirror and focal plane by Member States. Metrology from US (JPL, SIM heritage), fallback is EU.

NEAT (2/2) - Proposal evaluation

Major challenges & critical issues (System level & S/C):

- Formation flying: >20,000 S/C reconfigurations required, coupling of FF performance and P/L performance. Focal plane CCDs on translation stages.
- Challenging thermal stability control of mirrors and instruments (< 0.1K).
- Complexity of AIV/T (2x S/C, FF, 40 m focal length and metrology system verification)
- Complex S/C and payload interfaces – thermal and mechanical.
- Technology developments: FF delta developments and thruster qualification (ESA).

Major challenges & critical issues (Payload):

- Measurement principle at required precision (< 1 uas in 1hr, noise < 0.05 uas) not yet demonstrated – lab breadboard still one order of magnitude away.
- CCD/Metrology – ongoing national efforts to demonstrate: motions of CCD pixels to 3.10^{-6} pixels, and centroiding to 5.10^{-6} pixels. CCD development may be required.
- Complex focal plane design, with 8x CCD moving on translation stages.
- Metrology system – proposal baseline is for US technology. If European technology is required then national activities will be required, including bread-boarding of focal plane and metrology system with actuated primary mirror in the loop. Measurement principle must be validated at required performance level. Target star read at 500 Hz.
- No critical technology developments identified for mirror (actuated via mechanisms).

Programmatic aspects:

- Program schedule is risky: national TDAs on payload are a risk due to complexity and intrinsic coupling with performance of two S/C
- Qualification of two S/C independently and then together; payload and metrology difficult to test at full focal length. L=2020 unlikely, L=2022 more conservative.
- Metrology system: additional schedule risk if not US provided (+ additional cost to MS).
- Cost analysis to be performed, but mission complexity is too high for M class.

Evaluation summary

	Evaluation
Mission profile:	Y
Payload design:	R
Technol. Readiness P/L:	R
Spacecraft design:	Y/R
Technol. Readiness S/C:	Y
GS & Science Ops:	Y
Programmatic / Cost:	Y

Tech. maturity/ feasibility	Y
Overall programme risk	R

General summary:	R

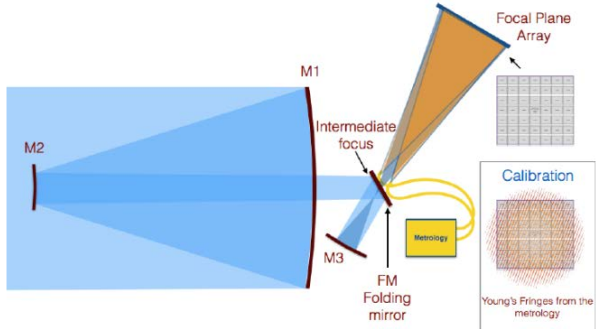
Overall technical complexity is too high for M class mission. Measurement principle requires further validation / testing.

Advanced Studies and Technology Preparation Division

44 – Theia (Description)

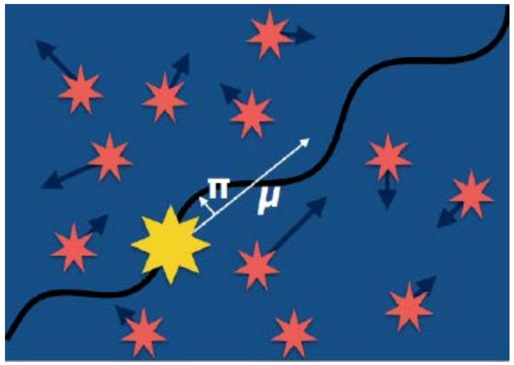
Main science objectives:
- Extremely high precision astrometry down to 2 orders of magnitude lower than Gaia (~µas).

Mission profile
- Launch with Soyuz-Fregat / Ariane 6.2, direct transfer to L2.
- ~6 months transfer and commissioning, 3 years lifetime + 1 year extension.
- De-commissioning from L2 required (but omitted).
- Bi-weekly ground contacts for data download, but daily contacts probably required for ranging/Doppler.



Spacecraft:
- SVM/PLM with vertical telescope and Sun shield "à la Euclid".
- Additional V-groove behind Sun shield for passive cooling to 130 K.
- 1 t (223 kg PLM), 9 Gbit/day @ 5 Mb/s in X band, 1240 W for the payload.

Payload:
- 0.8 m Ø 3 mirror telescope in Zerodur with Si3N4 structure, diffraction limited in Vis @ 130 K.
- FPA with 49 x H4RG HyVisi (Teledyne 4kx4k hybrid CMOS detectors, 4x H2RG size) @ 150 K.
- FPA also acting as FGS.
- Calibration system with laser metrology producing moving interference fringes for:
  - Fine detectors/pixels position calibration
  - Intra/inter pixel QE calibration
- 10^{-5} pixel centroiding accuracy required.

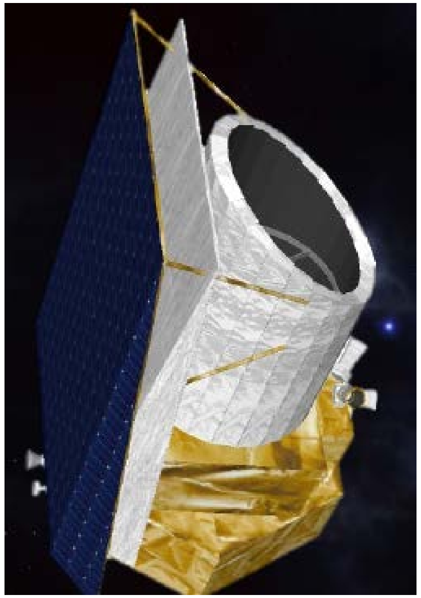


Implementation scheme & ESA contribution :
- Role of ESA: Launcher, S/C , GS and operations.
- Role of Member States: Instrument
- International cooperation and options: NA

44 – Theia (Evaluation)

S/C Major challenges & critical issues:

- Very large instrument => accommodation between telescope and SVM unclear, will probably require additional folding.
- 20 mas / 1 s RPE challenging (Euclid benchmark 25 mas / 700 s), with micro-propulsion (cold gas baseline).
- Thermal stability of 30 mK / 1 hr on telescope (for 27 nm M1/M2 stability) + FPA challenging with only passive cooling, fine thermistors and heaters. S/C slews will produce highest thermal variation, to be carefully designed and analysed.
- FGS interface management with S/C – AOCS control loop will be critical.



P/L Major challenges & critical issues:

- Calibration strategy is complex and 10^{-5} centroiding requirement is difficultly achieved even in controlled laboratory conditions on ground.
- FPA is huge, with non-flight qualified ITAR detectors, with un-known yield at required performance => long lead item with significant risk on schedule (49 H4RG vs 16 H2RG on Euclid).
- Telescope design OK, but need for on-axis design unclear and resulting in critical flat fold mirror with semi-transparent center, in double pass at both pupil and image planes with resulting complications.
- Aberration correction might require additional cryo-mechanism on e.g. M2.
- On-board processing and data storage capability insufficiently discussed to manage the huge amount of data produced by the FPA (e.g. on-board addition of calibrated roto-translated frames, data compression by factor 4 etc.).

Qualification status (S/C and P/L):

- Mostly TRL ≥ 5 except TRL 4 for FPA (detectors used on-ground, but no known flight experience and radiation/vibration testing) and TRL 3/4 for calibration strategy & autonomous data processing algorithms.

Programmatic aspects:

- TRL 5/6 by 2018 seems plausible, but procurement risk of FPA => 2025 launch unrealistic and cost > M4.
- Mass too optimistic (PLM mass is only 30% that of Euclid).

Clarity of implementation scheme, split of responsibilities and interfaces:

- No special issue.

44 – Theia (Summary)

esa

Cost	M€
ESA Project Team	53
Industrial Cost	217
Payload Contribution (ESA)	56
Mission Operations (MOC)	45
Science Operations (SOC)	40
Launcher	73
Contingeny (15%)	62
Total EaC	**546**

Summary Evaluation		Comment
Mission profile	G	OK, except ΔV for de-orbiting missing and more frequent ground contacts required.
Spacecraft design	Y	Challenging AOCS and thermal design, but not impossible.
Spacecraft TRL	G	OK.
Payload design	Y	Large and complicated payload,complex calibration required, critical flod mirror, and huge FPA.
Payload TRL	Y	Calibration strategy at TRL 3/4, detectors at TRL 4.
GS & Science Ops.	Y	OK, except complex on-board algorithms with high processing capability required.
Programmatic / Cost	R	2025 launch unlikely with FPA procurement and cost > M4.
Implementation Scheme	G	No specific issue, assuming MS provided PLM.
General summary	R	**TRL probably ok by 2018, but 2025 launch unlikely and high cost.**

Sharing of Responsibility

Element	ESA	MS / (SL)		Int. Partner / SL		comment
Launcher	X					
S/C	X					
P/L		X	X			MS assumed as PLM prime with ESA provided telescope only.
G/S & OPS	X					MS support to SGS not mentioned.
other						

Conclusion of Evaluation:

1: Payload is complex with very large instrument optics & FPA and complex calibration system requiring 10^{-5} pixel centroiding accuracy. Critical autonomous on-board algorithms required.

2: Instrument impacts on S/C are challenging, with 30 mK stability required around 130 K, 27 nm M1/M2 stability, 20 mas RPE with instrument acting as an FGS.

3: Overall, the payload is too demanding with significant risk on the schedule and a cost > M4.

From M4 to M5 ?

- ESA process is basically always the same…
- …but the rules always changes (tech/sci, cost cap,…)
- Astrometry might depend more on outcome from Gaia (compared to Core+ w/ Planck)
- Science impact is the important if Sci is evaluated first…
- However Theia has very few red flags and the cost might not be the issue for M5
- I would recommend to keep the same mirror size to have the same budget but improve the technical solutions…