Call for mission concepts for the Large-size “L2” mission opportunity in ESA’s Science Programme

1 INTRODUCTION

ESA’s Science Programme has for more than two decades been based on long-term planning of scientific goals. The first long-term plan was *Horizon 2000*, started in 1984, followed by *Horizon 2000+*, in 1995, and, subsequently, by the *Cosmic Vision 2015-2025* plan, published in 2005. The *Cosmic Vision* plan, established on the basis of a bottom-up process that started with a consultation of the broad scientific community, contains the wide-ranging and ambitious scientific questions that the ESA Science Programme should address. The plan (available as ESA BR-247[1]) describes science themes and topics, and leaves the definition of the actual space missions that will address the science themes in question to a series of competitive “Calls for Missions”.

The first call for mission concepts in the *Cosmic Vision* plan was issued in 2007 and resulted in the selection in 2011 of Solar Orbiter as the first Medium mission (M1) and Euclid as M2, followed by the selection in 2012 of JUICE as the first Large mission (L1). The second call for M-mission concepts was issued in July 2010 with the selection of the M3 mission expected in February 2014. In March 2012 the call for the first small mission (S1) in the *Cosmic Vision* plan was issued and resulted in the selection of CHEOPS.

The planning of the ESA Science Programme foresees the implementation of three L-class missions every 20 years (two decades being the planning horizon covered by the Programme's successive long-term plans). Considering that the JUICE mission was recently selected for the L1 launch opportunity in 2022, the two other L-class missions (L2 and L3) are planned for launch in 2028 and 2034.

Following discussions with the SPC in February 2013 the Director of Science and Robotic Exploration issued on 5 March 2013 a “Call for White Papers”, with the aim of selecting the science themes for the L2 and L3 launch opportunities. A total of 32 White Papers were received by the 24 May 2013 deadline, which were assessed by a Senior Survey Committee (SSC). The SSC’s brief was to recommend to the Director which science themes should be implemented for L2 and L3. Following an extensive interaction with the broad community, which included an open workshop that took place in Paris on 3-4 September 2013, as well as interaction with the Advisory Structure to the Science Programme, the SSC recommended the “The hot and energetic Universe” science theme for the L2 launch opportunity. At their 142nd meeting on 28-29 November 2013, the SPC approved the selection of “The hot and energetic Universe” science theme to be pursued by

---

[1] http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=38542

implementing a large collecting area X-ray observatory for the L2 opportunity, with a planned launch date of 2028.

In line with this decision, the present Call aims at selecting a mission concept able to fulfil the science goals given in "The hot and energetic Universe" science theme. The submitted proposals will be subject to technical and programmatic assessment by ESA and to peer review. As a result, a single mission concept will be defined, that will undergo an Assessment study (Phases 0 and A) to be carried out in parallel with nationally-funded payload study activities, for an approximate duration of 18-24 months. ESA will issue in due time an Announcement of Opportunity for the selection of Consortia who will eventually provide the nationally-funded payload and science ground segment elements, and who will be responsible during the Assessment Phase for the relative study activities. Following this phase and the confirmation of the necessary level of technological maturity, the selected mission concept will enter its Definition Phase. The mission's adoption is planned 10 years before launch date. This implementation approach may be modified depending on the evolution of the ESA Science Programme.

2 PURPOSE OF THE PRESENT CALL FOR MISSIONS

Through this Call for Missions the Director of Science and Robotic Exploration solicits proposals from the broad scientific community for the competitive selection of mission concepts to be candidate for the implementation of the second large mission (L2) of the *Cosmic Vision* Plan for a planned launch in 2028.

2.1 Scientific goals of the proposed mission concepts

The mission concepts proposed in response to the present Call must address the science goals described in "The hot and energetic Universe" science theme through the implementation of an X-ray observatory.

The science theme is focused on the relationship between the interaction, and feedback processes through their lifetime of galaxies and their central black holes. Massive black holes have been found to be present at the centres of most galaxies, with the associated accretion luminosity being an important component in the total energy balance of the galaxy. The central black holes influence the evolution of galaxies through different feedback processes and a full understanding of these processes is key to understanding galaxy formation and evolution and, more broadly, the formation of large-scale structure. This science theme will therefore provide a bridge connecting astrophysics and cosmology. It will allow the study of astrophysical processes that are fundamental to the large scale evolution of the Universe and address two key questions: (1) how and why does ordinary matter assemble into the large-scale structures that we see today and (2) how do black holes grow and influence the Universe?

The top-level science goals are:

- To find when and how the first structures of hot baryons assembled on the large scales which subsequently evolved into clusters of galaxies,
- To determine when the largest baryon reservoirs in galaxy clusters were chemically enriched, which stellar sources contributed to this enrichment, and find the missing 40% of ordinary matter in the local Universe.
- To investigate how AGNs, obscured or not, affect the evolution of galaxies, the amount of AGN energy deposited on very large (cluster) scales, and how that energy affects the evolution of the large-scale structure.

An X-ray observatory will also allow continuing progress in the study of distant transient phenomena, and in particular of gamma-ray bursts (GRBs), connecting high-energy astrophysics and cosmology. GRBs have become the most distant known energetic phenomena in our Universe. So far, the powerful diagnostics brought by high-throughput X-ray spectroscopy could not be systematically brought to bear on GRB counterparts. A powerful mission addressing the hot and energetic Universe should have the capacity to do science on GRBs, either having onboard the necessary burst alert system or by relying on external trigger inputs. In either case, the delay for pointing to the GRB source should be kept as short as possible.

In addition to the “core programme” associated with the fundamental questions mentioned above, the capabilities of the X-ray observatory should enable new “observatory science” to be performed for a wide range of sources, and in particular in Galactic science, such as the study of supernova remnants. More generally, this mission will return results for basically all classes of astrophysical sources as well as a wealth of serendipitous discoveries, enabled by the orders-of-magnitude improvement in key parameters, in particular throughput, energy resolution and field of view.

The SSC noted that the proposed tool for investigating the high-redshift hot Universe was of an X-ray observatory with high-throughput optics (of the order of 2 m^2 collecting area) with good angular resolution (5 arcsec), coupled with high spectral resolution (about 2.5 eV) and wide field of view in the focal plane.

The SSC also noted that the large throughput, coupled with a suitable reaction time for targets of opportunity would also open a new window on the transient Universe. Typically, an observation of a GRB afterglow could collect millions of photons, with a spectral resolution of few eV.

2.2 Allowed mission profile

Large missions are defined for the purpose of the present Call as space missions whose total cost to be covered by the ESA Science Programme does not exceed 1B€ at 2013 economic conditions and with an implementation schedule compatible with a potential 2028 launch. Experience shows that the funding ceiling mentioned above allows, in the ESA Science Programme, for the implementation of an Ariane 5-class mission.

The mission elements covered by the ESA Science Programme typically include the spacecraft, the launch services and the mission and science operations, with the science payload and ground segment elements being provided and funded by the ESA Member States. However, alternative payload funding schemes can be proposed.

Proposers must clearly discuss in their proposals the payload development and funding scheme they propose to adopt, together with the rationale for the approach. Letters of acknowledgement from proposed partner agencies are not required at this stage. Should proposers wish to provide letters of acknowledgment, these can be appended to the proposal, and will not count against the page limit.

ESA will discuss with the proposed international partners any proposal that includes international participation (as detailed in Sect. 2.3), to verify the programmatic status of the proposed cooperation and the partners' readiness to support the study phase of the mission under the proposed scheme.

The proposed mission must be compatible with a European launch vehicle using one of the currently existing launchers (e.g., Ariane V ECA, Soyuz), regardless of the possible international participation to the mission. The assumptions on launcher capabilities may be refined by ESA at a later stage depending on the evolution of the European launchers and on possible international cooperation schemes. Technical information on the European launchers can be found at http://www.arianespace.com.

The spacecraft operations must be compatible with the existing ESA ground stations (ESTRACK). Typical data rate capabilities vary from tens of kbit/s to tens of Mbit/s, depending on the spacecraft distance from Earth, the ground stations' size, the transmissions band and whether it is in down- or up- link. As an illustrative example, the downlink capability from a spacecraft at L2 Lagrange point using Ka band can be as high as 75 Mbit/s during the visibility period of the ground station (Malargue, Cebreros). Additional information can be found at http://www.esa.int.

2.3 International cooperation

Large missions are European-led missions, which are however open to international participation in the form of contributions from international partners. In principle any mission element (i.e. payload, spacecraft, launch, operations, etc.) is open to "international participation", i.e. to provision of such element from partner agencies from non-ESA member states. Any contribution from international partners will have to have a potential replacement that is based on European technology, and their total envelope will be limited to approximately 20% of the total mission envelope.

Proposers are welcome to suggest possible schemes for international participation, bearing in mind that the actual scheme for mission implementation will be the outcome of the phase A study activities, and will depend on direct negotiations between ESA and the partner agencies. At the present time both NASA and JAXA/ISAS have expressed a clear wish to participate to the phase A study activities in view of defining their potential participation to the mission implementation. For this purpose ESA plans to include US and

Japanese scientists in the Science Study Team (SST), whose functions are defined in Section 4.

Proposers are thus welcome to include US and Japanese scientists in the proposing teams, bearing however in mind that the composition of the SST will be decided by ESA in consultation with NASA and JAXA. Proposers are also welcome to suggest possible international cooperation schemes, including possible mission elements to be provided by international partners. Such suggestions are however non-binding, as the actual international cooperation scheme will be subject to direct inter-agency discussions with the potential partner agencies.

Throughout the present document, the term “nationally funded”, used to indicate mission elements (typically scientific instrumentation and science ground segment elements) not funded by ESA, must be understood to also potentially include elements funded by international partners.

2.4 Technological readiness

The adoption of the L2 mission is foreseen in 2018-2019, thus the overall time effectively available for mission preparation activities (including technology developments) is 5 to 6 years. The proposed mission concept must be compatible with the available preparation time, taking into account any study maturation activities that could be needed before initiating hardware technology developments. The minimum request is to reach TRL 5/6 prior to mission adoption (using the ISO TRL scale, see Sect. 7)

The selected mission concept will undergo Definition studies leading to the identification and implementation of technology developments where needed. A Science Study Team will be appointed by ESA and will be responsible for providing guidance on all scientific aspects. The implementation approach is further detailed in Sect. 4.

Since the technology requirements are often driven by the science payload, the technology development effort will likely be shared between ESA and the Member States (and, if applicable, international partners) according to the respective responsibilities of the parties. The actual details of the responsibility share will be defined once the spacecraft and payload have reached sufficient definition maturity and the instruments consortia are selected following the instrumentation Announcement of Opportunity. A coordinated technology development between ESA and the Payload consortium (or consortia) should be envisaged.

3 SCHEDULE FOR THE PRESENT CALL FOR MISSION CONCEPTS

The deadline for submission of proposals in response to the present Call for mission concepts is 15 April 2014, at 12:00 (noon) Central European Time. Late submissions will not be considered. Submissions are accepted exclusively in electronic form, in PDF format, using the interface available at http://sci.esa.int/2014_L2_Call. Proposals will be limited in length to 34 A4 pages (including any title page, appendices, bibliography, etc.), with a minimum font size of 11 pt, and a maximum file size of 50 Mbytes. A description of the expected proposal content is provided below. Any material in excess of the page limit will be removed and will not be submitted to the proposal reviewers. Proposals with file size in excess of the limit indicated above will be rejected by the submission system.

The overall schedule for the present Call is reported in Table 1.

Table 1. Overall Schedule for the present Call

Activity	Date
Letter of Intent submission deadline	17 February 2014 (12:00 noon CET)
Briefing meeting	5 March 2014 (TBC)
Proposal submission deadline	15 April 2014 (12:00 noon CET)
Proposal evaluation	April 2014 - June 2014

3.1 Letters of intent

Prospective proposers are required to submit, by 17 February 2014, at 12:00 (noon) Central European Time, a Letter of Intent stating their intention to submit a proposal in response to the present Call. Submission of a Letter of Intent is mandatory; proposals not preceded by a corresponding Letter of Intent will not be considered. The Letter of Intent should have a maximum length of 1 A4 page, minimum font size 11 pt. The letters should only contain the name of a contact point for the proposal and the proposal title. The purpose of the Letter of Intent will be to allow ESA to make the necessary preparation for the proposal evaluation process. No support or endorsement letters should be attached to the Letters of Intent.

3.2 Briefing meeting

Following the submission of a Letter of Intent, proposers will be invited to a briefing meeting, currently planned for 5 March 2014 (TBC), to be held at ESTEC (Noordwijk, The Netherlands). Confirmation of the date and of the logistical details for the briefing meeting will be communicated to the contact points indicated in the Letters of Intent.

4 IMPLEMENTATION APPROACH

The purpose of the present Call is to select a mission concept, with no pre-selection of teams or payload consortia.

Proposals received in response to the present Call will be subject to a technical and programmatic assessment by ESA, covering issues such as mission feasibility, technology readiness and proposed international collaboration scheme (if applicable).

The proposals will be subject to peer review, following which the Director of Science and Robotic Exploration intends to select among competing concepts (if applicable) a single mission concept that is able to fulfil the science goals given in “The hot and energetic Universe” science theme for further study. The recommended mission concept could contain elements from different proposals, should this be judged to provide the best overall science return to the European scientific community. All proposers will be notified of the evaluation of their proposals.

Contingent to this ESA will then assemble a Science Study Team (SST) to initiate the required study activities. The initial SST will be selected by ESA (in consultation with international partners, as applicable) to ensure broad expertise.

The selected mission concept will then undergo an Assessment Phase (Phases 0 and A) consisting of both ESA-internal and industrial study activities, to be carried out in parallel with nationally-funded payload study activities with an approximate duration of 24 months.

In due time during the Assessment Phase (i.e. when the spacecraft and payload interface definition will have achieved a sufficient maturity level), ESA will issue an Announcement of Opportunity for the selection of Consortia who will provide the nationally-funded payload and science ground segment elements.

Following successful completion of this phase and confirmation of the necessary level of technological maturity, the selected mission concept will enter its Definition Phase.

The mission’s adoption is foreseen to take place end 2018/early 2019, to be confirmed depending mainly on the evolution of the study activities.

The overall implementation timeline for the L2 mission is summarised in Table 2. The foreseen implementation approach described here is indicative only, and may be modified depending on the evolution of the ESA Science Programme.

Event	Date
Issue of the present Call	January 2014
Selection of L2 mission concept	June 2014
L2 internal Phase 0 studies completed	November 2014
AO for payload and science ground segment provision	Early 2015 TBC
Industrial Phase A studies start	Q2 2015

End of Phase A studies (PRR)	Q4 2016
Phase B1 completion (SRR)	Q4 2018
Mission adoption	Q4 2018/ Q1 2019
Industrial kick-off of Phase B2/C/D/E1	Q1/2020
Launch	2028

Table 2: Reference implementation timeline for the L2 mission

5 PROPOSAL OUTLINE

The proposal outline described below should be considered as a guide to proposers, with indicative page limits for each section. Table 3 summarises the content of the proposals.

Item	**Max No. Pages**
Cover Page	1
Proposal contact details	1
Executive summary	2
Introduction	1
Scientific performance necessary to achieve the “hot and energetic Universe” objectives	6
Mission profile proposed to achieve the scientific performance	2
Model payload	9
System requirements and spacecraft key issues	5
Science operations and archiving	2
Technology development requirements	2
Programmatic and cost analysis	2
References	1
Total	34

Table 3. Proposal Outline

5.1 Cover page

Free format, should contain the proposal’s title.

5.2 Proposal contact details

Must contain the proposal’s title, and name and contact details of the proposal’s contact person. It can also contain a list of proposers and their institutions. This will form the back of the cover page when the proposal is printed 2-sided.

5.3 Executive summary

Summary of the proposal (2 pages).

5.4 Introduction

1 page.

5.5 Scientific performance

The overall scientific objectives of the proposed mission concept are defined in the “The hot and energetic Universe” science theme. The proposal should show how the proposed mission concept is able to achieve these goals and what scientific performance is required to do so. The proposers may wish to elaborate briefly on other scientific issues that could be addressed by the proposed mission concept. The proposal should detail how the proposed mission concept will be able to achieve the necessary performance. This includes in particular:

1. Identification of the observable parameters that are relevant to the mission,
2. Identification of the tasks to be achieved for the mission success,
3. Clear description of the measurement objectives,
4. Measurement and operational requirements to be achieved, such as:
    i. Performance requirement of a mission-specific observable parameter,
    ii. Radiometric performance requirements,
    iii. Observation strategy requirements,
    iv. Spatial, spectral, temporal resolution,
    v. Stability and reproducibility requirements,
    vi. Timing requirements in the execution of the mission.

The measurement or operational requirements should be understandable by engineers and will constitute the skeleton for elaborating the Science Requirements Document and the Mission Requirements Document in the study phases. Examples are the duration of the observations, the required signal-to-noise ratio, the number of observations to be performed etc.

The proposal should summarise in tabular form the mission success criteria, which are associated with the minimum science requirements defined in “The hot and energetic Universe” theme.

5.6 Mission profile

The main requirements on the mission profile should be described, such as:

1. Launcher,
2. Preferred orbits,
3. Operational mode (Concept of Operations),
4. Mission lifetime,
5. Communication requirements,
6. Ground segment assumptions,
7. Etc.

Alternative mission scenarios (e.g., alternative orbit selection, alternative launcher) should be briefly presented in the proposal. The mission profile should not be assumed as definitive, as it will be subject to future analysis and optimisation.

5.7 Model payload

The model payload is the proposed set of instrumentation for achieving the science measurement objectives and the related science goals. Particular emphasis should be given to its definition and description. The model payload concept and its reference instrumentation should be clearly connected to the discussion on the science requirements.

The model payload description should include for each instrument:

1. Description of the measurement technique,
2. Instrument conceptual design and key characteristics,
3. Performance assessment with respect to science objectives,
4. Resources: mass, volume, power, on board data processing, data handling and telemetry,
5. Pointing and alignment requirements,
6. Operating modes,
7. Specific interface requirements: configuration needs, thermal needs (e.g. radiator for focal plane cooling),
8. Calibration and other specific requirements,
9. Current heritage and Technology Readiness Level (TRL, see Table 5)
10. Proposed procurement approach,

11. Critical issues.

The payload can include a telescope to be procured and funded by ESA, with focal plane instrumentation provided by nationally-funded consortia (possibly including international cooperation). In this case, the proposal should provide an overall payload conceptual design and address the specific design and performance requirements of the telescope. This includes provision of the main optical design parameters, performance requirements and discussion of accommodation and instrument operation principles in case of multiple instruments.

5.8 System requirements and spacecraft key factors

The system requirements applicable to the spacecraft platform design should be identified and discussed. These should be derived from the science measurement objectives and the proposed model payload. This includes requirements impacting on the subsystems necessary to support the payload, in particular:

1. Requirements on the Attitude and Orbit Control System including specific pointing requirements,
2. On-board data handling and telemetry requirements (data volume and rates),
3. Mission operations concept (Ground Segment),
4. Specific environmental constraints (EMC, temperature, cleanliness),
5. Other specific requirement(s) of relevance to the space and ground segment design (e.g. timing accuracy, on-board software).

The most challenging system requirements should be specifically outlined as design drivers. These requirements will be reviewed and used in future ESA study phases to further iterate the whole mission design, from the ground segment to the space segment, including launcher services and mission operations.

Supported by these system-level requirements and identified design drivers, a basic spacecraft concept should be proposed. It should contain a general description of the overall spacecraft configuration, highlighting how the design and spacecraft key factors meet the requirements. The overall necessary spacecraft resources should be estimated (mass, power) and their compatibility with the selected launcher and mission profile assessed. When relevant, similarity with previous missions or studies can be argued for the resource allocation.

5.9 Science operations and archiving

An overview of the envisaged science operations concepts should be provided. Topics to be addressed should include:

1. Community interfaces and interactions,
2. Need, if any, for support from ground-based observations,

3. Scientific mission planning, scheduling of observations,
4. Expected volume and format of the acquired data,
5. Quick-look assessment of data,
6. Ground data processing structure (pipelines, etc.) and challenges,
7. Data distribution and archiving.

The proposed approach to management of science operations should be outlined, including: proposed share of responsibilities for the operations, proposed funding source(s) (e.g. national institutes, national funding agencies, ESA Science Programme), and proposed data policy for the mission (e.g. what is the data return foreseen for all involved partners, what data would be publicly available, etc.), bearing in mind that the proposed mission must be an observatory serving as large a community as possible, while at the same time fulfilling the goals outlined in the “Hot and energetic Universe” science theme.

5.10 Technology development requirements

The proposal should identify the technological development needs (if any) that are required for both the payload and the spacecraft platform, and propose how these developments could be implemented. The aim is to give confidence that TRL 5/6 can actually be reached by the time of the mission adoption, by taking into account the technological steps to achieve but also other implementation constraints such as the maturation time for the technical definition, organisation aspects, funding and expenditure profile, etc.

TRL 5/6 does not require a full-scale demonstration of the spacecraft and payload elements. Conversely, it does require that the manufacturing processes of all the spacecraft components, including the science instrumentation, are demonstrated to meet the required performance in the expected environment in orbit. TRL 5/6 is also the minimum technology maturity level that enables the establishment of a meaningful development schedule for the payload and spacecraft development.

Therefore, the technology maturity assessment should start by identifying critical elements of the spacecraft platform and payload which are either new, or have never been demonstrated to meet the performance required for the mission success and in the relevant environment. The technology development activities should focus on these critical elements and remove the associated uncertainties through appropriate pre-developments.

The proposal should clearly address the consequences of the technology development activities failing to meet the requirements: back-up solutions relying on existing and demonstrated technologies should be identified whenever possible, and their impact on the science objectives discussed. Proposed check-points and milestones should be included in the discussion of a preliminary development plan.

5.11 Programmatic and cost analysis

A comprehensive view of the proposed mission implementation scenario(s) and overall management approach should be provided, including:

1. A basic programme management plan,
2. A basic integration and verification approach and model philosophy,
3. A basic programme schedule,
4. Preliminary risk analysis,
5. Preliminary cost analysis of the mission elements: technology developments, space segment, operations and ground segment,
6. International partners (if applicable) and their proposed role.

Information regarding specific capabilities and experience in the scientific institutes involved in the proposal and potential collaborative arrangements, expected funding sources outside of the ESA Science Programme and any other relevant programmatic or financial data should be included. The proposal should clearly identify tasks and cost elements that are proposed to be respectively under the responsibility of the ESA Science Programme, scientific institutes using Member States funding, and international partners, if any.

The overall implementation schedule should be based on the reference implementation timeline given in Table 2. This timeline is indicative and for reference purposes only. The actual timeline will be tailored to the selected mission, and may change depending on the Science Programme's programmatic evolution.

5.12 References

1 page.

6 FURTER INFORMATION

For any further information or questions about the present Call please contact:

Dr. Luigi Colangeli
Head of the Coordination Office for the Scientific Programme
Directorate of Science and Robotic Exploration
European Space Agency
Email: luigi.colangeli@esa.int

7 ANNEX

7.1 Technology Readiness Levels (TRL)

The new international ISO standard (Table 4) is applicable for the purposes of the response to the present Call. Table 5 provides the correspondence between the ISO TRL scale and the old ESA standard.

TRLs in old ESA scale		**TRLs in new ISO scale**	
TRLs 1 to 4		TRLs 1 to 4 are basically unchanged	
TRL 5	Critical functions verification in representative environment with representative scale breadboards	TRL 5	Same definition as TRL 5 old scale, but allowing reduced scale breadboard verification. Most useful for the development of large pieces (telescopes, structures) and for launcher developments.
		TRL 6	Same as TRL 5 old scale
TRL 6	Qualification through on ground verifications	TRL 7	Qualification level, through validation on ground or in orbit, as needed
TRL 7	Qualification through in-orbit demonstration		
TRLs 8-9		TRLs 8-9 are basically unchanged	

Table 5. Comparison of ISO TRL scale and ESA old TRL scale

It is worth noting the following:

- The TRL evaluation can be made for any element of the spacecraft: it can be an equipment, a full payload, a subsystem or the entire spacecraft
- TRL 5/6 require validation of the element critical functions in the relevant operational environment
- Up to and including TRL 6, the technology readiness level can be reached (most often) without building a fully representative model of the element. This is obviously applicable when the element is the entire spacecraft, but also for a sub-system or equipment. Exceptions are when the performance validation cannot be demonstrated without the development of a fully representative prototype, in which case the qualification level (TRL 7) is mandatory for mastering the performance and the development risks.

Technology Readiness Level	Milestone achieved for the element	Work achievement (documented)
TRL 1: Basic principles observed and reported	Potential applications are identified following basic observations but element concept not yet formulated.	Expression of the basic principles intended for use. Identification of potential applications.
TRL 2: Technology concept and/or application formulated	Formulation of potential applications and preliminary element concept. No proof of concept yet.	Formulation of potential applications. Preliminary conceptual design of the element, providing understanding of how the basic principles would be used.
TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept	Element concept is elaborated and expected performance is demonstrated through analytical models supported by experimental data/characteristics.	Preliminary performance requirements (can target several missions) including definition of functional performance requirements. Conceptual design of the element. Experimental data inputs, laboratory-based experiment definition and results. Element analytical models for the proof-of-concept.
TRL 4: Component and/or breadboard functional verification in laboratory environment	Element functional performance is demonstrated by breadboard testing in laboratory environment.	Preliminary performance requirements (can target several missions) with definition of functional performance requirements. Conceptual design of the element. Functional performance test plan. Breadboard definition for the functional performance verification. Breadboard test reports.
TRL 5: Component and/or breadboard critical function verification in a relevant environment	Critical functions of the element are identified and the associated relevant environment is defined. Breadboards not full-scale are built for verifying the performance through testing in the relevant environment, subject to scaling effects.	Preliminary definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Preliminary design of the element, supported by appropriate models for the critical functions verification. Critical function test plan. Analysis of scaling effects. Breadboard definition for the critical function verification. Breadboard test reports.
TRL 6: Model demonstrating the critical functions of the element in a relevant environment	Critical functions of the element are verified, performance is demonstrated in the relevant environment and representative model(s) in form, fit and function.	Definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Design of the element, supported by appropriate models for the critical functions verification. Critical function test plan.

Technology Readiness Level	Milestone achieved for the element	Work achievement (documented)
		Model definition for the critical function verifications. Model test reports.
TRL 7: Model demonstrating the element performance for the operational environment	Performance is demonstrated for the operational environment, on the ground or if necessary in space. A representative model, fully reflecting all aspects of the flight model design, is built and tested with adequate margins for demonstrating the performance in the operational environment.	Definition of performance requirements, including definition of the operational environment. Model definition and realization. Model test plan. Model test results.
TRL 8: Actual system completed and accepted for flight ("flight qualified")	Flight model is qualified and integrated in the final system ready for flight.	Flight model is built and integrated into the final system. Flight acceptance of the final system.
TRL 9: Actual system "flight proven" through successful mission operations	Technology is mature. The element is successfully in service for the assigned mission in the actual operational environment.	Commissioning in early operation phase. In-orbit operation report.

Table 4: Summary definition of the ISO TRL levels (*Courtesy of ISO. For further details, please refer to the ISO document "ISO 16290- Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment"*).

7.2 Indicative ESA cost breakdown

Reliable "Cost at Completion" estimates require a detailed definition of the ESA-funded elements and of the mission profile. Table 6 provides, for a typical ESA mission, the average range of fractional costs for the main building blocks which enter into the Cost at Completion models, assuming an overall cost to ESA of 1 B€ (2013 economic conditions). It should be used as a rough guide to assist in evaluating the realism of the costing of the proposed missions.

Activity	% of Total ESA CaC
Total spacecraft industrial activities	approx. 60%
Launcher services (assumes an Ariane V ECA launcher)	approx. 15 %
Ground segment and operations (MOC and SOC)	approx. 15 %
ESA project team	approx. 10 %

Table 6: ESA Cost at Completion reference building blocks.

.

8 LIST OF ACRONYMS

AGN	Active Galactic Nucleus
CaC	Cost at Completion
CHEOPS	CHaracterising ExOPlanet Satellite
DMM	Design Maturity Margin
ECA	Evolution Cryotechnique type A (Ariane 5)
EMC	Electro Magnetic Compatibility
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
eV	Electron Volt
GRB	Gamma-Ray Burst
ISO	International Standards Organization
JUICE	JUpiter ICy moons Explorer
MOC	Mission Operations Centre
S/C	Spacecraft
SOC	Science Operations Centre
SPC	Science Programme Committee
SSC	Senior Survey Committee
SST	Science Study Team
tbc	To be confirmed
TDP	Technology Development Plan
TRL	Technology Readiness Level