estec

European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
T +31 (0)71 565 6565
F +31 (0)71 565 6040
www.esa.int

DOCUMENT

EChO Preliminary Requirements Review (PRR) Technical Report

Prepared by	**EChO PRR team**
Reference	**ESA-ECHO-RP-0001**
Issue	**1**
Revision	**0**
Date of Issue	**25/11/2013**
Status	
Document Type	**RP**
Distribution	

APPROVAL

Title	
Issue 1	**Revision** 0
Author **EChO PRR Panel**	**Date** 25/11/2013
Approved by: Gerald CRONE	**Date** **17/12/2013**

CHANGE LOG

Reason for change	Issue	Revision	Date

CHANGE RECORD

Issue 1	**Revision** 0		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

Table of contents:

1 INTRODUCTION

1.1 M3 mission in ESA Cosmic Vision plan

Following the Call for M3 mission proposals that was issued in July 2010, five mission candidates are today competing for M3 nominal launch slot in 2024:

- EChO, an Exoplanet Characterisation Observatory,
- LOFT, a Large Observatory For X-ray Timing,
- MarcoPolo-R, a Near-Earth Asteroid (NEA) sample return mission,
- PLATO, an Exoplanet mission devoted to PLAnetary Transit and Oscillations of stars,
- STE-QUEST, a Space-Time Explorer and Quantum Equivalence Principle Space Test.

M3 timeline is recalled in Table 1. With the exception of PLATO, for which an assessment study was completed in 2011, the other missions have recently completed their Assessment Phase (phase A). A Preliminary Requirements Review (PRR) of all candidate missions has been performed to review their status in support of the M3 selection. This document reports the results of the technical and programmatic review for the EChO mission candidate.

Event	**Date**
Selection of M3 mission candidates	*Feb 2011*
Industrial studies kick-off	*Feb 2012*
Industrial studies mid-term reviews with model payload	*Jul 2012*
Instrumentation AO	*Sept 2012*
Selection of instrument teams	*Feb 2013*
Industrial Phase A studies data package delivery for PRR	*Sept 2013*
ESA technical and programmatic reviews completed	Dec 2013
Public presentations, Science Advisory Structure assessment and SSAC recommendation for M3 selection	Jan 2014
M3 mission selection by the SPC	Feb 2014
Phase B1 completion for the selected mission	Nov 2015
M3 mission adoption by the SPC	Q1 2016
Industrial Phase B2/C/D kick-off	Sept-Oct 2016
M3 nominal launch	by 2024 (*)

Table 1- Timeline for M3 selection and implementation

(*) Compatibility of M3 implementation with a launch by 2022 was requested

1.2 M3 Reviews: Process and Objectives

The independent reviews followed a common procedure and have several objectives:

1) Assess the design maturity of the mission at the end of Phase A
2) Evaluate ESA Estimate at Completion (EaC)
3) Provide recommendations for the next phases

While objectives 1) and 2) serve the M3 selection process, the third objective is actually applicable only to the mission that would be selected.
For each mission candidate, the reviews were chaired by an experienced project manager and supported by a number of senior engineers and technical experts across the Agency, involving typically about 20 people per mission, with a natural dispersion depending on the mission needs and the review Chairman requests. The reviewers are independent of the study team, and the latter was supporting the review process on the request of the Chairman e.g. by providing the historical background and answering questions raised by the reviewers. For practical reasons, the reviews were conducted in parallel for the five missions and the reviewers were distributed in two panels:

- A technical and programmatic panel (also called Review Panel), assessing all technical aspects for the mission implementation, including: mission requirements and flow down to engineering level; spacecraft definition and technology readiness; science payload definition and technology readiness; launch aspects and launcher compatibility; ground segment and operations; spacecraft development plan (model philosophy, schedule for the spacecraft and payload elements) and the associated development risks.
- A cost panel, in charge of assessing ESA costs (EaC), taking into account the technical and programmatic findings

The input documentation is constituted of:

- ESA requirement documents (e.g. Science Requirements Document, Mission Requirements Document, Experiment Interface Documents, etc)
- The data packages provided by the two industrial contractors
- The data package provided by the instrument consortia

The Review Panel was specifically tasked with the following activities:

a- Confirmation of the Mission and System requirements:
  - Adequacy and completeness of ESA Mission Requirements (MRD)
  - Adequacy, completeness and traceability of spacecraft, payload, ground segment and launcher requirements
  - Adequacy and completeness of interfaces definition

b- Confirmation of the mission technical feasibility:
  - Mission design justification and compliance with applicable requirements
  - Concept of operations, observing strategy and modes (where applicable), calibration aspects, driving requirements on mission, spacecraft and payload design
  - Validity and maturity of the spacecraft and payload design concept
  - Margin philosophy
  - Adequacy, completeness and credibility of system, spacecraft and payload budgets and

margins
- Availability of appropriate models and analyses in support to design definition
- Identification of critical technologies for the spacecraft and payload, identification of current technological maturity and availability of credible roadmap to achieve TRL 5 before adoption, critical review of ongoing technology development activities

c- Confirmation of the mission programmatic feasibility :
- Critical review of the spacecraft and payload development plans
- Adequacy and completeness of the proposed development and verification approach
- Model philosophy
- Realism and completeness of spacecraft and payload development schedule (incl. margins)
- Compatibility of payload need and delivery dates
- Critical path analysis
- Risk assessment and related mitigation plan
- Credibility and compatibility of technology maturation roadmap schedule with system schedule

The reviews were implemented through a series of meetings held throughout October and November. 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 Review Panel findings. It 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.

2 ECHO MISSION DESCRIPTION

2.1 Science overview

EChO - the Exoplanet Characterisation Observatory – is a survey-type mission dedicated to the characterisation of exoplanetary atmospheres. Using the differential technique of transit and eclipse spectroscopy, EChO will obtain transmission and/or emission spectra of the atmospheres of a large and diverse sample of known exoplanets covering a wide range of masses, densities, equilibrium temperatures, orbital properties and host-star characteristics. The instantaneous spectral coverage of EChO is unique in its breadth, spanning the visible to thermal infrared through a series of contiguous spectrometer channels that provide continuous spectral coverage. This broad range opens up the possibility to study exoplanets with physical temperatures ranging from a few hundred to over a few thousand degrees Kelvin. Importantly, broad instantaneous spectral coverage that includes the visible waveband provides an essential means by which to monitor and subsequently correct for the effects of activity of the host star, which could otherwise introduce significant uncertainty into the final exoplanet spectrum and its interpretation.

EChO will observe the combined light from the exoplanet and its host star. The transit and eclipse spectroscopy method, whereby the signal from the star and planet are differentiated using knowledge of the planetary ephemerides, allows atmospheric signals from the planet at levels of at least 10^{-4} relative to the star to be measured. Photometric stability rather than angular resolution is therefore key, and in fact the most stringent requirement of EChO, driving many engineering design and operational aspects of the mission. For the brightest targets it will be possible to obtain high quality spectra in a single visit; for fainter targets the necessary signal-to-noise will be built up through repeated visits over the mission lifetime.

EChO will address the following fundamental questions:

- Why are exoplanets as they are?
- What are the causes for the observed diversity?
- Can their formation and evolution history be traced back from their current composition?

EChO will allow scientists to study exoplanets both as a population and as individuals. The mission will target super-Earths, Neptune-like, and Jupiter-like planets, in the very hot to temperate zones (planet temperatures of 300 K - 3000 K) of F to M-type host stars. The spectroscopic information (at resolving powers of ~ 300 below 5 um and ~30 above) on the atmospheres of the large, select sample of exoplanets that EChO will provide will allow the compositions, temperature (profile), size and variability to be determined at a level never previously attempted. These in turn, will be used to address a wide range of key scientific questions relative to exoplanets:

- What are they made of?
- Do they have an atmosphere?
- What is the energy budget?
- How were they formed?
- Did they migrate and if so how?
- How do they evolve?
- How are they affected by starlight, stellar winds and other time-dependent processes?
- Weather: how do conditions vary with time?

And:

- Do any of the planets observed have habitable conditions?

2.2 Spacecraft and payload overview

The S/C is composed of a SVM and PLM (see Figure 1-1) which are thermally de-coupled.

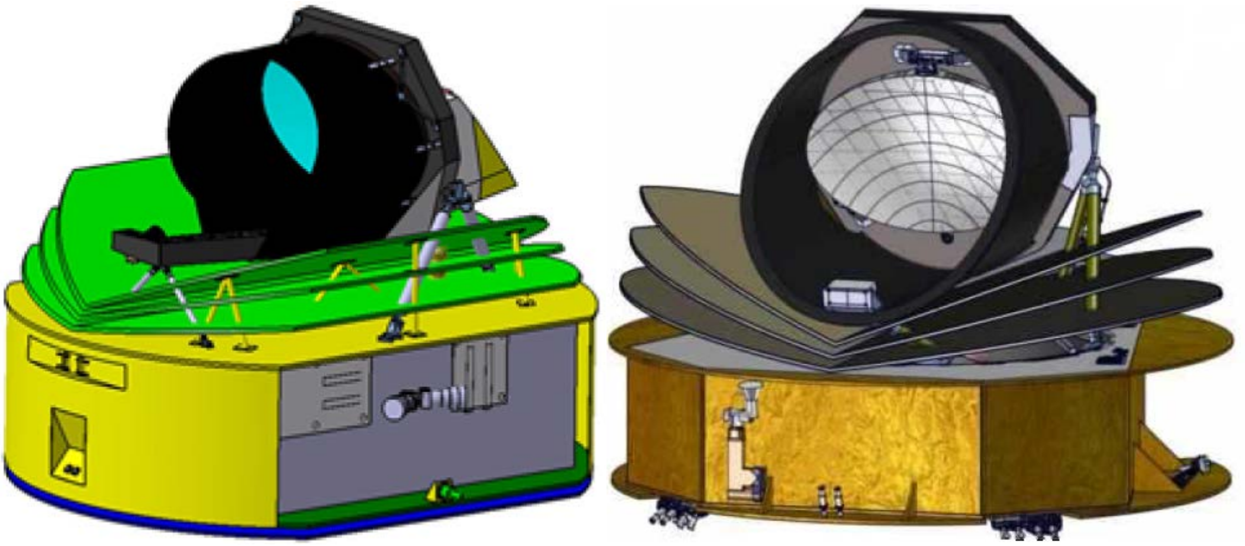

Figure 1-1: EChO S/C models from both industrial contractors, with SVM on the bottom and PLM on the top

The baseline operational orbit for EChO is an eclipse-free, large-amplitude quasi-halo orbit around the night-side Sun-Earth libration point, L2. This provides an environment that is benign with regard to radiation exposure and, critically for the photometric stability of EChO, is also thermally stable. The proposed orbit has the added benefits of being eclipse-free (Earth and Moon) and provides instantaneous visibility of a large number of EChO targets at any one time.

The baseline payload consists of an off-axis afocal telescope, accommodated horizontally on the SVM. The telescope feeds a single science instrument, covering the complete wave range using dichroic mirrors to split the band into several channels.

The critical requirements needed to achieve the science goals are:

- Wavelength coverage, implying several detector technologies are needed.
- Low noise, with many implications, including (major points, non-exhaustive list):
  - Complete PLM passively cooled to ~47 K to reduce the thermal background.
  - Low noise cryogenic detectors (from ~47 K down to ~30 K).
  - High photometric stability, resulting in stringent temperature and pointing stability.

3 APPLICABLE AND REFERENCE DOCUMENTS

[AD01] “PRR of candidate M3 missions in the ESA CV programme – Review procedure”, SRE-F/2013.042/ v2.0

[RD01] “M3 missions reference schedule”, SRE-F/2013.039 v1.0

4 TECHNICAL REVIEW OUTCOME

4.1 Confirmation of the mission and system requirements

Document tree

The current document tree (Figure 4-1) is well adapted for the needs of a Phase A study, with the MRD containing all the mission level requirements flowing down from the SciRD (with associated justification documents). The study team has gone one step ahead, whereby this MRD has been further flown down into a preliminary SRD with requirements applicable to the Prime Contractor only, while the performance requirements and budgets left for the instrument Consortia are highlighted in the RJBD. However, it is recommended that the instrument performance and design requirements are described in a dedicated document to be created during the next phase B1 (equivalent to the SRD for industry), while the EID-A could be streamlined to contain only interface requirements.

A FGS requirements document has also been created, flowing down from the SRD, as it will be used to ensure the performance of the FGS provided by the instrument Consortium meets the needs of the AOCS subsystem provided by industry. As such, this document will need to be reviewed and approved by industry in the next phases.

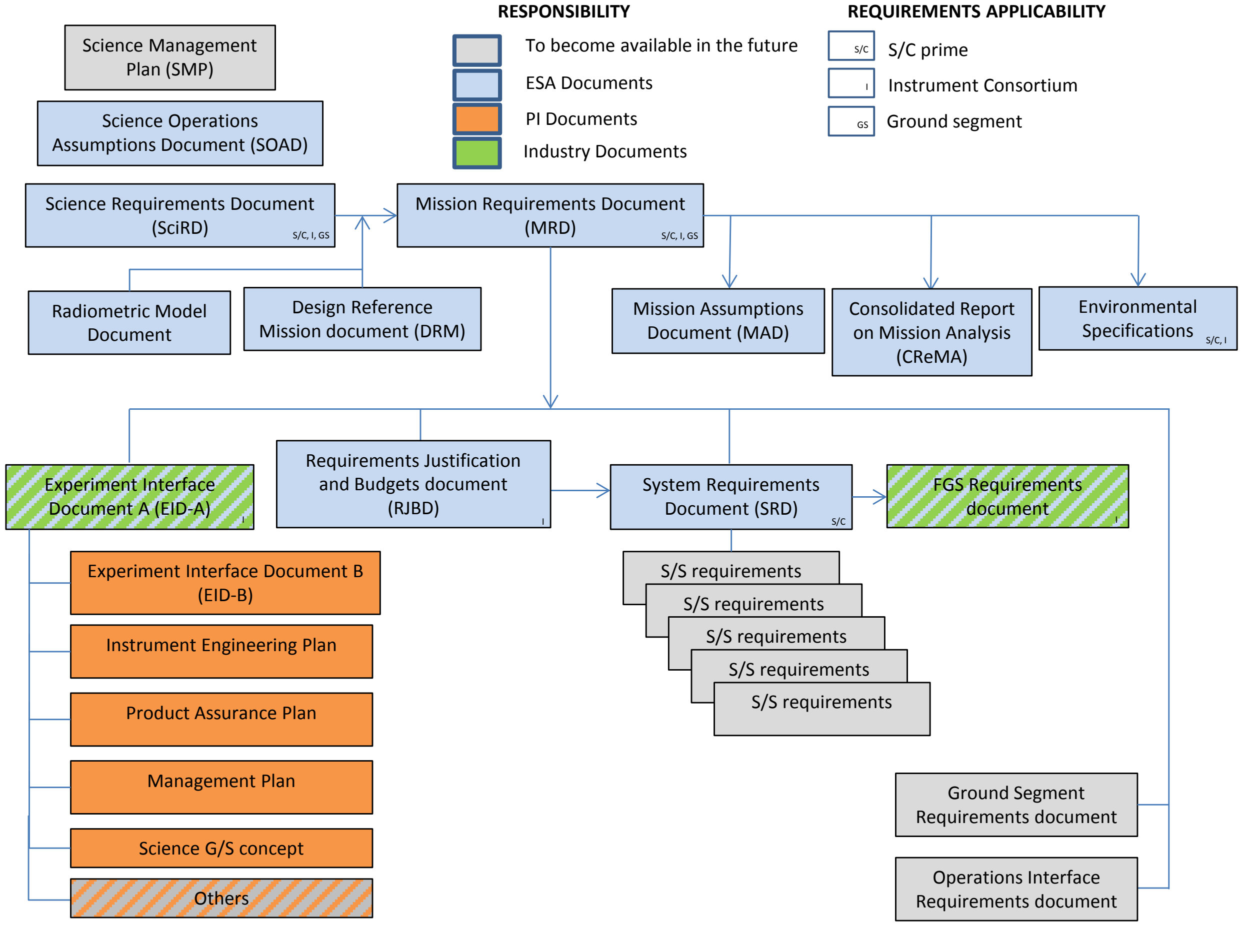

Figure 4-1: EChO document tree

A number of science TNs that support the SciRD exist and should also be referred to in this document tree. The baseline telescope optical prescription is also missing and should be added. The document tree structure is a good baseline to be adopted for the ITT of the phase B1 and should be tailored to the needs of the implementation phase to ensure that the documents produced in phase B1 are fully in line for the needs of the implementation phase ITT enabling a smooth and fast transition to the issue of the implementation phase ITT.

System, mission analysis and launch

The initial mission analysis-related requirements and constraints have been provided, but not yet fully consolidated. The CReMA was updated at the end of the Phase A study after the SRD was completed and was reviewed both by the study team and the review team during the review. Consequently, the MRD/SRD requirements are preliminary. For instance, the mission delta-V requirements are not consistent with the CReMA and need to be updated. Additionally, some aspects of the mission analysis are either based on assumptions from previous missions (e.g. post-mission disposal manoeuvre delta-V) or are not consistent with the spacecraft design baseline (e.g. manoeuvres in the Sun direction as well as anti-Sun). Whilst being worst case, these assumptions are not valid for the EChO baseline. Therefore, a dedicated work package for ESOC is recommended early in the next phase to perform the necessary detailed analyses in order to fully consolidate the mission design (delta-V budget, launch window) and flight dynamics (e.g. orbit determination accuracy, ground contact for Doppler tracking and station-keeping strategy). It is expected that delta-V savings could be achieved, e.g. for disposal and station-keeping. The latter would depend on the outcome of a plume contamination analysis, to be done in Phase B1 to confirm that thrusting in the Sun direction would not degrade critical optical surfaces.

The Soyuz Users' Manual is an applicable document, however its requirements for spacecraft qualification and acceptance are not fully consistent with the ESA applicable standards (e.g. sweep rate for sine test). It is recommended to negotiate in the next Phase B1 the full applicability of ESA standards with the Launcher authority to prevent lengthy discussions at a later stage.

It is also recommended to specify in the SRD the type of data encoding and more detailed constraints (i.e. Sun angle constraints with respect to the telescope and instrument FoV) associated to the Sun illumination during LEOP (see discussion in section 4.2).

AIV

The ESA top level documents are well structured and provide a complete set of requirements, although some edits and updates are required to specify the schedule boundaries for the contractors to perform their programmatic estimates in the next phase. Specifically this includes the kick-off of Phases B2/C/D and the launch date, the requirements for SOVTs, SVTs and RF compatibility and the deliverables from/to Instruments/Prime. In general terms a consistent approach shall be made evident at the level of the MRD, SRD and EID-A prior to the release of the ITT for Phase B1 .

Ground segment and mission operations

In review of the mission ground segment and operations requirements, it is acknowledged that the definition is both complete and appropriate for the current phase of the programme. The Mission and System requirements have been found to be adequate. There are no major findings to highlight. The issues that have been raised in the review will be carried forward into the Phase B1 as recommendations.

Nonetheless, several key recommendations are highlighted in the following:

- A specific agility requirement that sets a limit on the inter-observation slew rate should be added in the SRD.
- Spacecraft de-commissioning and disposal activities shall be better defined. This should cover the de-orbit strategy to achieve clean SEL2 departure, as well as spacecraft activities like transmitter chain deactivation, fuel depletion, battery passivation, cryo-cooler deactivation, etc.

Due to the relatively low downlink data rate, the X-band RF link is selected. The availability of the X-band communication link up to the year 2030 shall be investigated and confirmed by ESOC, as far as possible. In case ESA does not have X band by this time anymore, an external G/S (with cost impact of up to 30%) will have to be used. In any case it is not recommended to implement a K-band due to the resulting impacts on spacecraft design and operations (e.g. CFDP protocol).

AOCS

The system requirements related to pointing and AOCS have been reviewed and deemed adequate, although a justification of pointing requirements has not been systematically provided / or are scattered through too many documents. Some reformulations of the requirements have been recommended to avoid any ambiguity on their understanding. An alignment of the pointing requirements with the ECSS-E-ST-60-10 has been proposed.

4.2 Confirmation of the mission technical feasibility

System

The sizing of the propellant tanks for both industrial studies was based on an original delta-V requirement of 75 m/s based on the mission analysis conducted at the beginning of the Phase A study. The mission analysis was updated towards the end of the Phase A study after the industrial studies were completed, leading to an increase in the delta-V requirement to 125 m/s (SRD) and finally to 133 m/s (CReMA v1.1). The majority of this increase was caused by the addition of the EoL disposal manoeuvre. Consequently, the propellant tanks in both industrial designs do not have sufficient capacity to meet the current delta-V requirements. The risk is that a larger tank or two separate tanks will be required, resulting in cost impacts for the propulsion equipment and re-design of the spacecraft structure to accommodate this impact at the cost of increased mass (although this is not deemed critical due to the large launch mass margin). However, the mission analysis has not yet been consolidated (see above in section 4.1) and may find savings in delta-V. Therefore, the propellant tank selection needs to be completed after the mission analysis consolidation early in the next phase.

The current mission baseline looks to be feasible with low risk. However, it can be improved during Phase B1 and the improvements used to add robustness to the design. For instance, it is recommended to give ESOC a bigger work package (as already recommended above in section 4.1) to perform, in collaboration with the competing Phase B1 prime contractors and the study team, in-depth trade-offs of re-ignitable upper stage and inclination in order to use the full performance of the Soyuz launcher. Presently, there is a significant launch mass margin (~600 kg) which could be used to allow a two-burn parking orbit strategy or to target a more optimum inclination which would significantly increase the launch window.

AIV and launch

The Soyuz launcher has no roll law, which places constraints on the launch date to avoid illumination of the telescope. Therefore, it is recommended that a contract with Arianespace (as already mention in 4.1) is used in the next phase B1 to investigate what the rotation of the LV is around its roll axis. If the Sun can enter into the telescope and instrument FoV, dedicated mitigation measures should be investigated to prevent “thermal” damage to sensitive parts (e.g. the baffle, the mirrors or the FPAs). For instance, the addition of a telescope cover in the design is recommended as the simplest and safest solution.

In addition the qualification requirements requested by the Launcher may result on overstress and fatigue for structural elements (e.g. the STM/CQM which are re-furbished into PFM). The recommended contract with Arianespace in the next phase B1 should clarify these aspects as well, (i.e. a negotiation of the acoustic versus mechanical tests and fatigue issues, and requirements on random environment).

Mission operations

It is acknowledged that the commonality of the proposed EChO operations with that of recent missions with respect to the Sun-Earth L2 orbit, X-band communications, non-daily passes and off-line science operations, leads to the conclusion that there are no major issues to be highlighted for operations and ground segment.

Nonetheless, several key recommendations are highlighted in the following:

- The details of medium-term ground station planning at MOC for EChO, where scientific observations necessarily drive the scheduling of science downlink ground station passes, needs to be iterated with MOC scheduling office in the next phase (currently a flexibility of 10% in the exact time of the pass is requested, which will result in non-regular planning for the G/S scheduling).
- The current technical assumptions for the ground contact duration and frequency rely on Planck experience. The review team recommends performing a dedicated analysis for EChO in Phase B1 since this might have a cost impact.

AOCS

The two industrial designs are technically feasible from the AOCS perspective, and no major shortcomings have been identified. The pointing stability performance has been thoroughly assessed by both Contractors and requirements are expected to be met with adequate margins at this stage of the project with the baseline hybrid design solution (reaction wheels for slews + cold gas for fine pointing), except for the "coarse" absolute pointing error CAPE, which is only marginally met. Meeting this requirement is critical for the transition from coarse to fine pointing modes, and therefore, it is the opinion of the panel that an in-depth consolidation of this budget should be performed in phase B1. However a relaxation of this requirement can be easily done, as its only impact is on the required FoV of the FGS, which is currently specified as 10'' squared.

The baseline operations concept calls for reaction wheels frequently crossing 0 rpm and being frequently switched ON/OFF in transitions between coarse and fine pointing mode. Tests will need to be performed to validate this use of RWs and experience from the Euclid project can be re-used to this effect.

It should also be noted that for at least one industrial contractor, it is not clear how the Sun exclusion angle is guaranteed after launcher separation, based on the worst case tumbling rates coming from the LV user manual. This should be further investigated in the next phase B1 (e.g. AOCS system response time after detection of separation, spin-stabilised S/C at separation or mirror cover etc.).

Based on the baseline AOCS design (with cold gas) , potential cost savings options have been spotted and should be investigated in Phase B1: gyro-less design, and operating the cryo-cooler without isolator. These options are deemed to be potentially technically feasible, especially with the recent relaxation of the RPE and PDE requirements (respectively from 20 to 50 mas over 90 seconds, and 10 to 20 mas up to 10 hours, for the brightest targets only where the FGS performance is the highest, at 1 sigma).

A reaction-wheels only option has been investigated by both Contractors, as an alternative to the baseline cold-gas design, however the associated technical risk and cost impact have not been properly assessed. In particular, the panel notes that the impact of wheels spikes on the FAPE and the CAPE could be critical for science observation, as the associated requirement is already only marginally met without wheels. The amplitude of these wheels spike during the fine pointing mode could result in the target star exiting the FGS FoV, meaning the fine pointing mode would be lost, and time will be needed for this to be re-covered at the expense of the observation efficiency budget. As a consequence, the wheels-only option is not considered as a realistic alternative at this stage of the project.

Structures and configuration

The design as from a structural point of view is deemed reasonable for this phase. For further phases some detailed analysis will need to be performed using:

- More detailed FEM model.
- More adequate load cases coming from the launcher, with interfaces between the SVM and PFM and between the IOB and the TOB properly defined.

This will enable e.g. to derive launch loads at instrument interface level, which should be added into the EID-A early during the next phase B1. This will also enable to conduct proper micro-vibration analyses, which are required to confirm the possibility of meeting the RPE requirement with a cryo-cooler without an isolator (and with reaction wheels only as an alternative to cold gas).

Finally, bolt analyses also need to be performed for each bolts in the design, and fatigue life of the S/C has to be analysed taking into account that the Flight module is the refurbished STM/CQM.

Telescope

Regarding the telescope technology, the review Board noted a difference in readiness between the two proposed designs. Both contractors propose Silicon Carbide (SiC) technology, but one has flight proven technology (TRL 9), while the other is proposing a plan to reach TRL 5 by the mission adoption. This situation may require specific measures to be taken at Programme level for the spacecraft procurement and possibly in Phase B1.

As already mentioned (see “AIV and Launch section above), the absence of roll control for Soyuz launcher could be mitigated by adding a telescope cover. The review team noted that this cover would also be useful for the optics contamination control during AIT phases and in the launch fairing.

The review team noted a number of positive aspects of the telescope design. Both industries involved in the pre-development studies have converged on detailed optical designs which are very similar, and are fully compliant with requirements. This provides confidence that we are close to a stable configuration for the given performance requirements, boundary conditions set and assumptions made with respect to the trade-off between optical performance and the difficulties associated with manufacturing.

The telescope optical interface with the instrument is well defined and compliant with requirements. Both telescopes deliver an elliptical exit pupil at a specified location inside the instrument FPU volume. This is not constraining and its precise location is intended to be further fine-tuned in the next phase.

The telescope 3 micron diffraction limit requirement is well within the current state-of-the-art of large SiC mirrors and both contractors demonstrate compliant Wave-Front-Error (WFE) budgets. The dominant contributor to the WFE budget for both telescopes is the primary mirror, which is also on the critical path for the telescope procurement.

Mechanisms

A re-focussing mechanism behind M2 is required for both industrial designs. While such mechanisms exist in Europe, none are operational at EChO temperatures (~ 45K). A TDA has been put in place (imminent Kick-Off) to mitigate this risk, with no criticalities expected.

Thermal (SVM)

In both industrial studies, there are evidences that the SVM thermal subsystem does not present any significant risk. The active thermal control budget needs to be further justified/consolidated (which will most probably result in a non-negligible power increase, at least for Astrium), but this does not jeopardize the mission and will be done as normal work during the next phase.

Instrument

The instrument has evolved in a positive way during the last Phase, reducing the overall complexity of the system. The baseline design uses MCT detectors only up to 11µm, which requires only a single stage JT cooler. This cooling solution can draw the maximum heritage from Planck and it significantly reduces the development risks and system complexity compared with a 7K two stage cooling system which would have been required for Si:As detectors. For the optional LWIR channel (11-16µm), an initial design has been presented but no suitable detector has been identified which could operate with a single stage Ne JT cooler.

The instrument structure is proposed to be built in aluminum, drawing maximum heritage from previous instruments such as MIRI-JWST and SPIRE-Herschel. Nevertheless, to achieve a compact design, small refractive elements (lenses, prisms/grisms) are proposed, whereas reflective elements are normally preferred under cryogenic conditions. Supporting analyses to justify this solution (e.g. WFE budget, tolerance/sensitive analyses) have not yet been performed and are required early in the next phase B1 to fully justify this design approach. This should also include straylight and ghost image analyses. The performance of the dichroic mirrors, as presented in the Final Presentation by the Consortium, does not seem compliant with the 80% and 50% minimum throughput requirements. However, this is not reflected in the data pack, where only an " average" throughput is presented. Dedicated design and development activities are therefore required early in the next phase to ensure the coating of the dichroic mirrors can cope with the required wavelength range and minimum throughput. Overall, the design is considered feasible, but could add risks to the schedule (e.g. difficult alignment, complex mounting). For this reason it is strongly recommended to mitigate the risk as early as possible by undertaking some Bread Board activities on the lenses/Prisms (including mounting) in the next phase. This should include verification of the suitability of the selected elements and verification of their optical properties in the relevant environment (temperature, radiation). The consortium should investigate all reflective designs (for the optical train following the dichroïcs) since such design could ease manufacturing.

For the detectors covering 0.4-5µm, high TRL detectors from Teledyne (USA) have been baselined, but the actual predicted performance of these detectors in the EChO specific configuration (which is slightly different from the standard product) has not been provided. As an alternative solution, low TRL European Detectors from SELEX (UK) have been identified, but without supporting information. Since there are no public data available on European detectors for the EChO specific case (i.e. Quantum Efficiency as a function of wavelength range and operating temperature, noise etc.) some TDAs have been proposed to further characterize European detectors for the EChO conditions to better assess the risk of this solution.

For the MWIR channel (above 5 um), although some developments are on-going in Europe in this wavelength range, the initial results show that this is still at a very low TRL for being retained in the baseline design for EChO. The current baseline makes use of another Teledyne detector using HgCdTe technology (as was done for Euclid) with a tailored cut-off wavelength. Teledyne is currently developing a similar detector for a NASA mission (NEOCam) with requirements comparable to those for EChO. The measured performance on a detector prototype seems compliant with EChO needs, but no details are available on the further developments required for full qualification and whether these developments are financially covered by the Consortium. The review team recommends investigating whether the NEOCam developments can be used with no or minimum modification for EChO (e.g. without changing the cut-off wavelength) and with acceptable science performance, for minimizing the development effort and securing the development schedule. Specific actions should also be taken early in Phase B1 for confirming the performance acceptability of NEOCam detector and addressing early measures for qualification aspects.

Cryogenics

From the technical point of view, the following points shall be noted:

- There is no up-to-date (i.e. taking into account the higher cooler induced heat loads) end-to-end evaluation of the passive cooling performances. The effect of this higher heat load has been anticipated by the study team who relaxed the '45K stage' requirement to 47K, but the margin available on the passive cooling is therefore difficult to assess.
- The review team recommends taking all necessary measures in Phase B1 for further relaxing the passive cooling requirements towards industry (~ 55 K, including ~ 15 K margin), for easing the development and verification of the cooling system and securing the development schedule.

Even though no major technical challenge is foreseen in adapting the 2K/4K JT Cooler (from Planck) to obtain a 27K stage (filling it with Neon), the documentation does not provide sufficient data/evidence on the topic. The review team recommends initiating the pre-development of this cooler in Phase B1 for securing the development schedule.

It is important to highlight that if a 7K cooling stage were required, the risk and the overall complexity of the cryogenic subsystem would be dramatically increased: it adds an extra cooling stage (15K) which needs an extra cooler. This leads to an increase in cost, questions regarding the micro-vibration performances and additional non negligible programmatic risks. Even though European developments are on-going on the subject, there is no evidence that a sufficient maturity will be reached in time for EChO needs. The other concern relates to the configuration. To implement this with a Stirling/Pulse Tube pre-cooler, one has to route the 20K stage and the cold JT lines through the V-Groove system. This is not straightforward, requires quite some additional cooling power (see e.g. JWST) and there is no heritage in Europe (on cooler and system level) with such a configuration, which is considered a high risk (on the cooler and the performance of the V-Grooves).

Finally, it should be noted that the cryo-cooler is currently a single point failure. Redundant schemes could be further investigated in the next phase by the Consortium, depending on the criticality of losing the MWIR channel (instrument reliability budget for each channel is available in the RJBD) and its impact on science.

4.3 Confirmation of the mission programmatic feasibility

Industrial activities

The AIV and development plans are commensurate with what can be expected from a Phase A study. In the next phase, more emphasis shall be put to detail a number of points which have been partially addressed, such as e.g. consistency from Instruments to Spacecraft level activities, schedule granularity, facilities, GSE and the telescope mirror development program (including related TDA). The Industry schedule is based in a 6.5 years development and shows consistency with a launch date in December 2022 with a kick-off on 1 July 2016. Overall the estimated duration is considered realistic and no show-stoppers are identified at industry level. A launch date in 2022 is feasible and can be kept as a baseline, but is risky in view of the short development time available for the instrument (only 5.5 years, see next paragraph and Table 1) and the possibility to have the kick-off in July 2016. A launch in 2023 would be recommended instead as a safer assumption. This launch delay is not required for the industrial activities, but will be beneficial to relax the criticality of the industrial schedule.

Instrument activities

A development plan commensurate with what can be expected from a Phase A study has been provided by the instrument consortium. For the development of the EChO instrument 5.5 years are allocated. This development schedule is considered optimistic when compared to similar sized cryogenically cooled instruments and only limited details are available on bread boarding activities.

	JWST - MIRI		**PACS - Herschel**		**SPIRE - Herschel**	
	Dates	Durations since KO	Dates	Durations since ISVR	Dates	Durations since ISVR
SRR / IDCR / KO / ISVR	May-03	0	Feb-00	0	Oct-00	0
PDR / IIDR	Nov-04	1.4 y	Apr-01	1.2 y	May-01	0.5 y
CDR / IBDR	Dec-06 to Feb-07	3.7 y	Apr-02	2.2 y	Mar-02	1.4 y
SM/STM	Mar-05	2.8 y	Jan-04	3.9 y	Apr-04	3.5 y
VM/QM /EM ready	Feb-08	4.7 y	Dec-04	7.8 y	Nov-04	4.1 y
FM delivery	Nov-11	**7.5 years**	Apr-07	**7.3 y**	Feb-07	**6.3 y**

Table 1: Development time of various cold VIS/IR/FIR instruments

Based on this solid evidence, a development schedule of 6-6.5 years looks more realistic, taking into account that the complexity of the instrument and the instrument team structure are comparable to MIRI and SPIRE. Therefore, a mid-2023 launch date should be assumed as the baseline now, instead of a late 2022 launch.

Taking into account the limited experience with cryogenic-refractive optics in Europe, the PRR recommends that early breadboard tests should be performed in the next Phase to reduce the risk and modify the design if required. Tests on the dichroic chain are mentioned in the development plan to start early in the program and the PRR encourages the instrument team to already initiate these in the next Phase.

The development plan does not provide details on the European detector activities required to raise the TRL. If the European detectors are considered as a serious alternative a development plan needs to be established including early activities in the next Phase B1 to support the final detector selection at the time of Instrument SRR.

In the next phase, the Instruments Consortium shall work in cooperation with ESA on identified issues:

- Optimization and justification of the schedule of the EChO instrument with related details
- Coolers definition and development
- Detectors
- All instrument related TDAs

The panel also notes that the consortium is “under-powered” compared to what is deemed necessary for a successful phase B1, SRR and mission adoption. This should be improved on, especially when taking into account the technical recommendations on the instrument given above.

Risks

The procurement of the US detector is considered to be a low risk by the consortium, based on previous heritage with procurement of US detectors. Nevertheless, a timely initiation of the process (e.g. delta qualification if any, ITAR regulations) is required to ensure the schedule.

5 CONCLUSIONS AND RECOMMENDATIONS

In general, the mission and the system requirements have been addressed adequately by the ESA study team.

The use of reactions wheels and cold gas micro-propulsion enabled both contractors to be compliant with the AOCS requirements. Potential cost savings and simplifications are highlighted in this report.

Most budgets are consistent with Phase A margin requirements and contain some additional growth potential (mass, volume, power, pointing budgets). Data budget and link budgets are tight but mitigation measures exist. The delta-V budget currently requires an additional tank with respect to the baseline designs of industry, and needs to be consolidated in the next phase.

With respect to the mission analysis, the lack of a roll control of the Soyuz launcher puts constraints on the launch date and has the associated technical risk of Sun illumination of sensitive parts of the spacecraft and telescope. This risk should be assessed in the next phase and may imply the addition of specific hardware (e.g. telescope cover and/or instrument shutter).

The telescope design resulted from a trade-off led by ESA early in the study and relies on available technologies. The effective area is commensurate with the science requirements and the baseline design has converged to fix the optical interfaces with the instrument.

A conceptual design was produced for the instrumentation to be provided by the Consortium, but requires detailed design in the next phase (e.g. optical tolerances, ghost analysis, WFE budget, thermo-mechanical deformations etc.), and bread-boarding activities for critical optical elements.

With respect to the detectors and the impact on the spacecraft cryogenic system, the restriction of the wavelength range of the mission to 11 um not only alleviates the cost to the consortium but also allows the use of HgCdTe detectors with an operating temperature as high as 28K. Maintaining the goal requirement with the extended range to 16 um wavelength would require cooling the detector down to 7K and major changes in the instrument and spacecraft configurations. In view of the associated complexity and schedule risks, the Review Board strongly recommends considering in the next phase only the baseline configuration up to 11 micron.

With respect to technology readiness, there are a number of elements that are being addressed by dedicated predevelopments (see Appendix B for the details). However, they are all building on previous heritage, e.g. M2 re-focussing mechanism, detectors and cryogenic coolers for the instrument. The only exception is the instrument optics, where additional analysis and breadboards are recommended, and the MWIR channel detector from Teledyne, which requires specific actions to be initiated in Phase B1 .

With respect to the review objectives:

Confirmation of the availability of the Mission and System Requirements

The documentation set was adequate for the Phase A and has established a firm baseline on which to start the preparation of the ITT documentation package for the Phase B1. Many comments have been made which will result in updates to the ESA documentation for the Phase B1 ITT.

Confirmation of the mission technical feasibility

The mission is technically challenging and many issues have been raised in the report with associated recommendations for the Phase B1, however no showstoppers have been identified

Confirmation of mission programmatic feasibility

Overall the mission is programmatically feasible. The report has highlighted a launch by mid-2023 would be more realistic considering the nature of EChO instruments and previous experience. Timely initiation of instrument development within the consortium is recommended.

APPENDIX A - LIST OF ACRONYMS

AIVT	Assembly, Integration, Verification, Testing	MWIR	Mid Wave Infra-Red
AOCS	Attitude and Orbit Control System	NASA	National Aeronautics and Space Administration
(C/F) APE	(Coarse/Fine) Absolute Performance Error	PA	Product Assurance
AVM	Avionics Model	PACS	Photo-detecting Array and Camera Spectrometer
BB	Bread Board	PDE	Pointing Drift Error
CaC	Cost at Completion	PFM	Proto Flight Model
CAD	Computer Assisted Design	PLATO	Planetary Transits and Oscillation of stars
CDF	Concurrent Design Facility	PLM	Payload Module
CDR	Critical Design Review	PRR	Preliminary Requirements Review
CFDP	CCSDS File Delivery Protocol	QE	Quantum Efficiency
CQM	Cryogenic Qualification Model	RF	Radio Frequency
CReMA	Consolidated Report on Mission Analysis	RFI	Request For Information
CV	Cosmic Vision	RID	Review Item Discrepancy
EChO	Exoplanet Characterisation Observatory	RJBD	Requirements Justification and Budgets Documents
ECSS	European Cooperation for Space Standardisation	RPE	Relative Performance Error
EID	Experiment Interface Document	RW	Reaction Wheel
EO	Earth Observation	S/C	Spacecraft
ESA	European Space Agency	SciRD	Science Requirements Document
ESOC	European Space Operations Centre	SOAD	Science Operations Assumptions Document
FEM	Finite Element Model	SOC	Science Operations Centre
FGS	Fine Guidance Sensor	SOT	Science Operations Tool
FM	Flight Model	SOVT	Science Operations Validation Test
FoV	Field of View	SPIRE	Spectral and Photometric Imaging Receiver
FPA	Focal Plane Array	SRD	System Requirements Document
GSE	Ground Support Equipment	SRR	System Requirements Review
ICU	Instrument Control Unit	STE-QUEST	Space Time Explorer – Quantum Equivalence Principle Space Test
ICR	Intermediate Cost Review	STM	Structural Thermal Model
IOB	Instrument Optical Bench	SVM	Service Module

ITT	Invitation To Tender	SWIR	Short Wave Infra Red
JT	Joule Thomson	TBD	To Be Determined
JWST	James Webb Space Telescope	TDA	Technology Development Activity
LEOP	Launch and Early Operations Phase	TOB	Telescope Optical Bench
LFSA	Large Format Sensor Array	TRL	Technology Readiness Level
LOFT	Large Observatory For X-ray Timing	URD	User Requirements Document
LV	Launch Vehicle	VDA	Vapor Deposited Aluminium
LWIR	Long Wave Infra-Red	VNIR	Visible Near Infra Red
MAD	Mission Assumptions Document	WFE	Wave Front Error
MCT	Mercury Cadmium Telluride (HgCdTe)	WFEE	Warm Front End Electronics
MIRI	Mid Infra-Red Insturment		
MOC	Mission Operations Centre		
MRD	Mission Requirements Document		

APPENDIX B – LIST OF TDAS

The following ESA TDAs are currently on-going / planned to support EChO:

1. Required activities:

- M2 re-focussing mechanism. This mechanism is baselined by both Contractors. The activity aims at qualifying a re-focussing mechanism under the cryogenic operational conditions of EChO. The ITT is currently on EMITS, completion is planned for end 2015.
- 2 K JT cooler. The CDR is done, manufacturing and assembly is on-going, testing will start in February 2014. Expected TRL is 5 by the end of 2014. The same compressors (but only half required) and the same heat exchanger can be re-used on EChO. Back-up compressors from Astrium could also be used, as built on Sentinel 3 (similar to the Planck compressors), or the JWST MIRI compressors built by Hymatic (UK).
- Ne JT cooler. This activity is included in the December 2013 TECNET, and aims at modifying an existing JT Cooler to operate with Ne at ~ 30 K instead of He. It should be completed in 2015.

2. Back-up activities (i.e. technology not included in the baseline design):

- Cryogenic tip/tilt mechanism. As for the M2 re-focussing mechanism, this activity aims at qualifying a tip/tilt mechanism in cryogenic conditions. This mechanism is a back-up system for the cold gas micro-propulsion system used in the fine pointing mode. Testing is currently on-going, completion of the activity is planned in 2014.
- European HgCdTe detectors. A number of activities are currently on-going (and others planned to start in 2014). The most promising one is the LFSA for the Euclid Vis/NIR channel which is adequate for the EChO VNIR channel (some modifications required are being planned). Other activities for the SWIR/MWIR detectors are planned, but the likelihood of success with a TRL 5 by mission adoption in 2016 is low.

The following test activities are currently on-going within the consortium:

- European (Dutch) alternative to the Teledyne cold FEE (SIDECAR ASIC) is being further developed and tested.

- European (FR) alternative for the MWIR detector is still being pursued.

The following test activities are currently planned by the consortium in Phase B1:

- Breadboard tests of the dichroic chain
- Cryogenic tests of the VNIR optical fibers