DOCUMENT

EChO Mission Requirements Document

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Reference	**SRE-PA/2011.038/**
Issue	**3**
Revision	**0**
Date of Issue	**14/09/12**
Status	**N/A**
Document Type	**RQ**
Distribution	

European Space Agency
Agence spatiale européenne

APPROVAL

Title EChO Mission Requirements Document	
Issue 3	**Revision** 0
Author EChO Team	**Date** 14/09/12
Approved by	**Date**

CHANGE LOG

Reason for change	Issue	Revision	Date
Includes comments from instrument consortia and industry following kick-off of their respective studies.	2	6	27/01/2012
Contains update from June 2012 SST meeting and MBSR + MTR.	2	8	13/07/2012
Updates following SST meeting on 3/4 September 2012.	3	0	14/09/2012

CHANGE RECORD

Issue 3	**Revision** 0		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Update of noise and photometric stability requirements			
Addition of instrument performance verification and science demonstration phase			
Update of visible channel throughput			
Update of spectral resolution requirement			
Deletion of redundancy in definition of fine and coarse APE requirement vs instrument and FGS FoVs.			
New R-TT&C-080 and updated R-OGS-160 and 180			
Enhanced mission description in chapter 2.			
Updated launch date			
Formula for R-PERF-130			
Updated SOC requirements			
Updated list of ADs and RDs			
New R-MIS-240 and 250			

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1 INTRODUCTION

1.1 Scope of document

EChO (Exoplanet Characterisation Observatory) is an M-class mission candidate for the M3 slot within the Cosmic Vision programme, for a planned launch between 2022 and 2024. EChO, with 3 other science missions, was recommended by the Space Science Advisory Committee (SSAC) to enter an assessment study (Phase 0), starting by an ESA internal study followed by parallel industrial study activities.

Within the M3 boundary conditions, the readiness for launch by 2022/2024 is a severe requirement which in practice requires designing the space segment without major technology developments and with minimum developments risks. Therefore, only technologies with estimated Technology Readiness Levels (TRL) of at least 5 by the end of the Phase A (estimated at the end of 2014) may be used.

This document aims at providing a complete and comprehensive list of all high level mission requirements (including S/C and payload, launcher, ground segment and operations) necessary to achieve the science goals detailed in [AD1]. It is hence an applicable document that all mission design activities shall comply with. The MRD will be further reviewed matching the results of future study phases (e.g. definition phase) to finally evolve in the System Requirements Document at the start of the implementation phase.

1.2 Requirements identification

1.2.1 Requirements versus goals

Requirements are mandatory and must be complied with. They shall be verified by the Contractor using a verification method approved by ESA.

Goals are desirable in order to maximise the science return while keeping the impact on the cost and complexity to a minimum, but not mandatory. They are to be the subject of system trade-offs and analysis, and are to be fulfilled under restricted conditions to be defined and quantified.

Requirements are identified by the use of the term “shall”, as opposed to “should” for goals.

1.2.2 Requirement Identification

All requirements in this specification that require verification are marked with a unique reference, which is given as follows:

X-YYYY-nnn

where:
- X is the requirement type: “R” for a requirement or “G” for a goal
- YYYY is the requirement category consisting of 2, 3 to 4 letters
- nnn is the requirement identifier (sequential number of 3 digits).

Requirement categories are listed below:

AIV	Assembly, integration and verification requirements
AOCS	Attitude and orbit control subsystem requirements
CDMS	Control and data management subsystem requirements
ENV	Spacecraft environment requirements
EPS	Electrical power subsystem requirements
IF	Interface requirements
PERF	Instrument performance requirements
MECH	Mechanism requirements
MIS	Mission requirements
OGS	Operation and ground segment requirements
PA	Product assurance requirements
PROG	Programmatic requirements
PROP	Propulsion requirements
SFTW	On-board software requirements
STR	Structure and configuration requirements
SYS	System requirements
THER	Thermal control requirements
TT&C	Telemetry, tracking & command requirements

1.2.3 Explanatory Text

Supplementary text added to explain the source or reasoning behind a requirement shall be written after the requirement in *italics*.

1.3 Definitions

Channels: The different splits in wavelength within the science instrument.

Effective area (A_{eff}): True photon collecting area of the telescope. It is the geometrical area of the entrance pupil minus all the contributors that reduce this area, including M2 and its support structure obscuration, the central hole of M1 and obscuration by stray light baffles. It does not contain any assumptions on the reflectivity of the mirrors (contained within the total throughput).

Instruments: The science instrument (spectrometer) and the FGS (non-scientific instrument).

Instrument throughput: The throughput of the instrument only (for a point source target), from the first optical element after the telescope (e.g. a dichroic mirror) to the last optical element before the science detector. It is channel dependent, and equal to the total throughput divided by the telescope's throughput.

Observation efficiency: The percentage of time during science operations phases that is actually dedicated to collecting science data. Slews, settling times, communications (if not parallel to science observations), safe mode etc. all need to be deduced from the total time. Also referred to as the observatory's duty cycle.

Occultation: When the exoplanet passes behind its host star, along the line of sight to Earth (and hence to the EChO S/C). As such, the exoplanet is completely eclipsed by the star.

Payload: The telescope and the science instrument.

PLM: The physical PLM, containing the telescope and instruments but also some structural, thermal, cryogenic, power equipment etc. (e.g. Sun shield and thermal baffles, Solar cells etc.).

Primary transit: When the exoplanet passes in front of its host star, along the line of sight to Earth (and hence to the EChO S/C). As such, the exoplanet is between the EChO S/C and the star and partially eclipses it.

Resolving power : $R=\lambda/\Delta\lambda$.

SVM: The physical SVM, as opposed to the sum of all S/C platform subsystems (e.g. the FGS is not physically located in the SVM, although part of the AOCS subsystem).

System PSF: Image at detector level of a point source at infinity including all system contributors to its degradation (optical misalignments, optics quality and aberrations, pointing errors etc.).

Total throughput: Throughput of the complete system, including all optical elements from the telescope to the last element before the science detector. It includes diffraction and slit losses. It is channel dependent.

1.4 Acronyms

A/D	Analog/Digital
AOCS	Attitude and Orbit Control Subsystem
AIV	Assembly, Integration and Verification
APE	Absolute Performance Error
ASIC	Application Specific Integrated Circuit
BER	Bit Error Rate
BS	Beam Splitter
CCD	Charge Coupled Device
CDF	Concurrent Design Facility

CDMS	Control and Data Management Subsystem
CMOS	Complementary Metal-Oxide Semiconductor
DSN	Deep Space Network
DM	Dichroïc mirror
EChO	Exoplanet Characterisation Observatory
ECSS	European Cooperation for Space Standardisation
ESA	European Space Agency
ESOC	European Space Operations Centre
FEE	Front End Electronic
FER	Frame Error Rate
FGS	Fine Guidance Sensor
FW	Full Well capacity
GS	Ground Segment
GSE	Ground Support Equipment
ICC	Instrument Control Centre
I/F	Inter/Face
IOSDC	Instrument Operations and Science Data Centre
IV	Instrument Volume
ISEV	Instrument Support Equipment Volume
JWST	James Webb Space Telescope
LEOP	Launch and Early Operations Phase
LoS	Line of Sight
LV	Launch Vehicle
MAD	Mission Assumptions Document
MCT	Mercury Cadmium Telluride detector
MIRI	Mid Infra-Red Instrument on JWST
MOC	Mission Operation Centre
MRD	Mission Requirements Document
NASA	National Aeronautics and Space Administration
OBCP	On Board Control Procedure
PDD	Payload Definition Document
PLM	PayLoad Module
PSF	Point Spread Function
ROIC	Read Out Integrated Circuit
RPE	Relative Performance Error
RSS	Root Square Sum
S/C	Space/Craft
SciRD	Science Requirements Document
SI	International System of units
SOAD	Science Operations Assumptions Document
SOC	Science Operation centre
SoW	Statement of Work
SSAC	Space Science Advisory Committee
SST	Study Science Team

SVM	SerVice Module
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TC	TeleCommand
TM	TeleMetry
TRL	Technology Readiness Level
TT&C	Telemetry, Tracking & Command subsystem

1.5 Reference documentation

This document is supported by the documentation package described in the following sections. The mission document tree is given in Figure 1 for information.

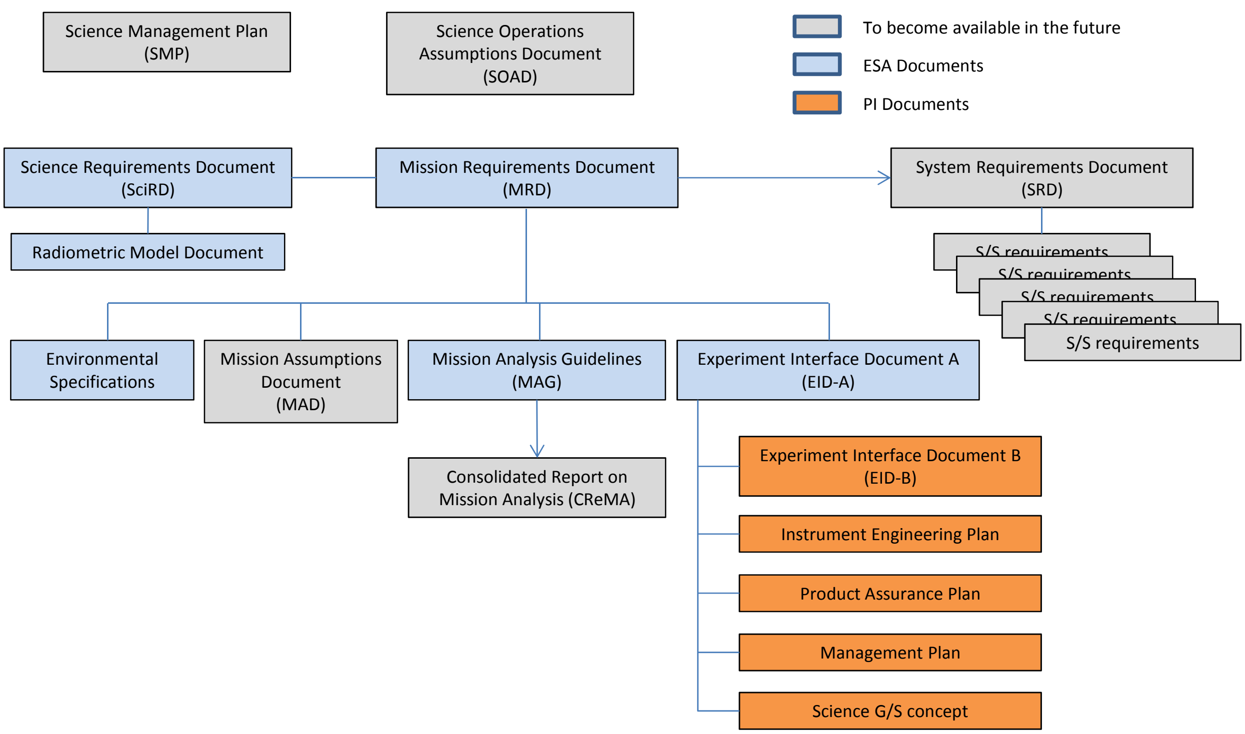

Figure 1: EChO document tree

In addition to those, all ESA approved standards (including relevant ECSS standards) are applicable documents as well.

1.5.1 Applicable documents

[AD1] EChO SciRD (Science Requirements Document), SRE-PA/2011.037/
[AD2] EChO radiometric model description, SRE-PA/2011.040/
[AD3] "Margin philosophy for science assessment studies", SRE-PA/2011.097/
[AD4] List of "ESA approved standards", Issue 3.5
[AD5] "Soyuz, from the Guiana space centre, user's manual", Issue 2

[AD6] "European Code of Conduct for Space Debris Mitigation", Issue 1
[AD7] EChO MAD (Mission Assumptions Document), TBW
[AD8] EChO SOAD (Science Operations Assumptions Document), TBW

1.5.2 Reference documents

[RD1] EChO PDD (Payload Definition Document), SRE-PA/2011.039/
[RD2] ESA pointing error engineering handbook, ESSB-HB-E-003
[RD3] Technology Readiness Levels handbook, TEC-SHS/5551/MG/ap, v1.6

2 MISSION OVERVIEW

2.1 Mission goals summary

The primary objective of the EChO mission is to study the physics and chemistry of the atmospheres of a representative sample of known exoplanetary systems found around nearby stars. The differential technique of transit spectroscopy will be used over the optical to thermal IR wavebands (0.4 to 16 μm) to determine the physical and chemical conditions of the atmospheres of a sample of several tens of known exoplanets, with masses ranging from Jupiter- to a few Earths- size, and equilibrium temperatures of 2000 K to 300 K respectively. Through detailed measurement of the spectral energy distribution and spectral features of exoplanetary atmospheres, it will be possible to establish the:

(a) chemical composition
(b) energy budget
(c) chemical abundances
(d) thermal structure
(e) optical albedo
(f) spatial and temporal variability of the atmospheric structure
(g) in the most favourable cases, determine all of the above, as a function of orbital phase

in a statistically significant sample of exoplanets, including those closest in mass and temperature to our own Earth.

By considering these goals across the sample as a whole, we will be able to start to determine the mechanisms driving the formation of exoplanets, including the role of the host star. For the most favourable sources, the cadence of sampling should allow accurate recovery of the shape of the ingress and egress, which in turn will require of order of 10 measurements across ingress/egress.

2.2 Measurement technique

Temporal variations in the observed signal from spatially unresolved observations of an exoplanet in orbit around its parent star, at different points in its orbit, will be used to determine the spectrum of the planetary atmosphere. This can be achieved using a single spectrometer and at least two measurement techniques:

- Secondary eclipse (occultation) spectroscopy. With this technique, a measurement is taken during secondary transit when the exoplanet is eclipsed by its parent star. Another measurement is then needed, just before or after the secondary transit, when the exoplanet's day side is in full view. The exoplanet's emission/reflection spectrum can then be recovered by making the difference between these two measurements.

- Transmission spectroscopy (primary transits). With this technique, a first measurement is taken just before or after the primary transit when only the night side of the exoplanet is in view (its emission is considered negligible). A second measurement is then taken during the primary transit, during which some of the star's light passes through the exoplanet's atmosphere before reaching the Earth. Making the ratio of both measurements then reveals the absorption features of molecules contained in the exoplanet's atmosphere.

2.3 System description

The EChO system consists of the complete end-to-end system (LV, space and ground segment), which fulfils the mission requirements according to the product tree below:

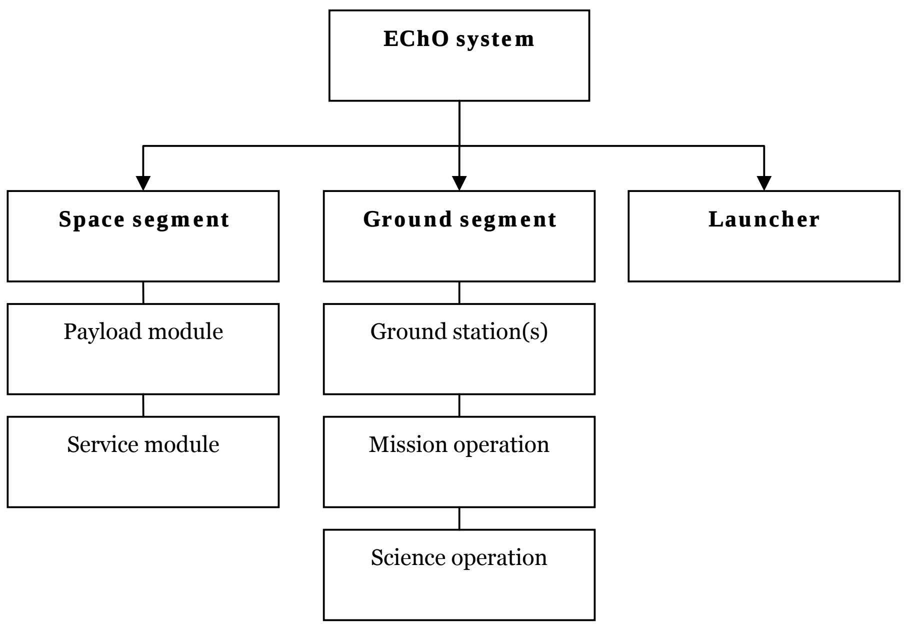

Figure 2: EChO system product tree

The EChO space segment consists of the Payload module (PLM) and the Service Module (SVM).

The PLM mainly consists of the telescope, the instruments and part of their support equipment. The instruments are:

- The scientific instrument, divided into several channels covering the required wavelength range.
- The Fine Guidance Sensor (FGS, non-scientific instrument), which is used to achieve the required pointing error and pointing stability.

The SVM holds all the hardware necessary to operate the spacecraft in-orbit and support the payload.

The ground segment provides the means and resources necessary to manage and control the mission via telecommands, to receive and process the telemetry from the satellite, and to disseminate and archive the generated products.

The Mission Operation Centre (MOC) is responsible for the operations of the spacecraft and instruments, for ensuring the spacecraft safety and health, for provision of flight dynamics support including determination and control of the satellite's orbit and attitude and for provision of auxiliary data to the Science Operation Centre (SOC). The MOC performs all communications with the satellite through the ground stations.

The scope of the Science Operation Centre (SOC) varies from one mission to another, depending on the scientific organisation of the mission, the responsibilities for each instrument and the partnerships to be put in place. For EChO, it is anticipated that the core function of the SOC will be the management of the observatory, including observations preparation, instrument performances follow-up and step-by-step science quality control of the measurements, in conjunction with an Instrument Operations and Science Data Centre (IOSDC).

The launcher refers here not only to the launch vehicle, but also to the means and facilities made available on site for the spacecraft preparation, fuelling (if any), encapsulation and launch operations. It is considered as a component of the system until the LV – S/C separation.

In addition, all of these sub-components of the EChO system also include EChO specific ground support equipment (e.g. equipment at the launch site facility, AIV and test facilities equipment etc.).

2.4 Spacecraft and payload overview

The S/C is composed of a SVM and PLM which are thermally de-coupled. In-orbit around the Sun-Earth L2 point for optimum thermo-mechanical stability, the EChO S/C will point at known transiting exoplanets distributed over the sky, with an expected bias towards targets closer to the ecliptic poles. This will enable an uninterrupted observation of the transits of these targets over longer periods of times within each year, as well as reducing the noise generated by the zodiacal background.

The baseline payload consist of an off-axis afocal telescope, accommodated horizontally on the SVM. This accommodation is illustrated in Figure 12. 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 defined in section 2.1 are:

- Wavelength coverage, implying several detector technologies are needed.
- Low noise, with many implications:
    - Complete PLM passively cooled to ~45 K to reduce the thermal background.

- Low noise cryogenic detectors (from 45 K down to potentially 7 K).
- High photometric stability, resulting in stringent temperature and pointing stability.
- Etc.

3 MISSION ANALYSIS REQUIREMENTS

3.1 Launch vehicle, site and date

R-MIS-010 The EChO S/C shall be compatible with a Soyuz Fregat-MT launch from Kourou, French Guiana.

R-MIS-020 The EChO mission shall be compatible with a launch date in 2022 (study baseline), with a launch in 2024 as study back-up.

The M3 mission is intended as a back-up candidate for the 2022 launch slot, depending on JUICE schedule. Although in the science programme the baseline launch slot for M3 is 2024, all current study planning should remain compatible with a 2022 launch. The final decision on the nominal launch date will be made following JUICE mission adoption.

3.2 Injection, transfer and operational orbits

R-MIS-030 The baseline injection strategy shall be to place the EChO S/C in an eclipse-free (Earth and Moon) direct transfer orbit to the Sun-Earth L2 point.

R-MIS-040 The science operations orbit shall be an eclipse-free (Earth and Moon) quasi-halo orbit around the Sun-Earth L2 point, with an amplitude no larger than 1 million km in all directions, restricting the Sun-S/C-Earth angle to ≤ 34 degrees.

3.3 Mission phases

R-MIS-050 The mission phases shall be defined as follows, chronologically following each other unless specified otherwise:

0	Pre-launch Phase (Launch Campaign)
1	Launch and Early Operations Phase (LEOP)
2	Transfer Phase
3	Commissioning Phase
4	Instrument Performance Verification and Science Demonstration Phase
5	Nominal Science Operations Phase
6	Extended Science Operations Phase
7	Decommissioning Phase

3.3.1 Pre-launch phase

R-MIS-060 Prior to lift-off the spacecraft shall be in an electrically active state and shall be able to perform the following tasks:

- power on/off only via umbilical and without physical access to the spacecraft

- receive telecommands
- handle telemetry packets
- perform on-board monitoring functions
- enter launch mode configuration

3.3.2 LEOP phase

R-MIS-070 The LEOP phase shall be from launch to the end of the 1st manoeuvre for launcher dispersion correction, occurring no later than 2 days after the LV – S/C separation.

R-MIS-080 From LV separation until Sun acquisition, the S/C shall be in a power mode using on-board batteries with all instruments switched off.

R-MIS-090 The S/C shall autonomously detect separation from the LV.

R-MIS-100 After separation from the LV, the S/C shall autonomously activate one of its transmitting and receiving channels to allow the ESA ground station network to establish the first contact.

R-MIS-110 After separation from the LV, the S/C shall autonomously re-orient itself to a safe attitude in order to:

- Start generating Solar power and terminate battery discharge
- Protect the instruments from the Sun
- Allow the ESA ground station network to establish the first contact as specified in R-MIS-100.

This manoeuvre is an attitude correction manoeuvre, not the 1st orbital correction manoeuvre defined in R-MIS-070.

3.3.3 Transfer, commissioning and performance verification phases

R-MIS-120 The transfer phase shall be from the end of LEOP to the insertion into the science operations orbit as defined in R-MIS-040.

R-MIS-130 The commissioning phase can be started during the transfer phase, and shall be completed within 3 months of the LV – S/C separation.

R**-MIS-131** The instrument performance verification and science demonstration phase shall be completed within 6 months of the LV – S/C separation.

R-MIS-140 The LEOP and transfer phases shall be completed within 3 months of the LV – S/C separation.

Although it will take about 1 month to arrive at a point 1.5 million km away from Earth, it will take about another 2 months before the amplitude and angle conditions expressed in R-MIS-040 are verified.

R-MIS-150 During the commissioning phase, check-out of the spacecraft functions and verification of all subsystems' performances shall be performed.

R-MIS-160 During the instrument performance verification and science demonstration phase, check-out and verification of the science instrument's performance shall be performed.

3.3.4 Science operation phases

R-MIS-170 The nominal science operations phase shall start from the end of the instrument performance verification and science demonstration phase.

R-MIS-180 The extended science operations phase shall start from the end of the nominal science operation phase.

3.4 Mission lifetime

R-MIS-190 The nominal mission lifetime, from LV (upper-stage) separation to the end of the nominal science operations phase, shall have a duration of 5 years.

R-MIS-200 The extended mission lifetime (the extended science operations phase), shall have a duration of at least 1 year.

R-MIS-210 During the nominal mission lifetime, all science performance requirements shall be fully met and include all specified margins.

G-MIS-220 During the extended mission lifetime, all science performance requirements should be fully met and include all specified margins.

R-MIS-230 All S/C consumables and radiation-sensitive units shall be sized to last from launch till the end of the extended mission lifetime.

R-MIS-240 The ground lifetime of units which degrade with usage or storage shall include a 50% margin (TBC).

R-MIS-250 All S/C units shall be designed to include a ground lifetime margin of 1 year (TBC) in addition to R-MIS-240.

This margin accounts for e.g. possible launch delays or late deliveries of specific units.

The following figure summarises the different phases (not to scale):

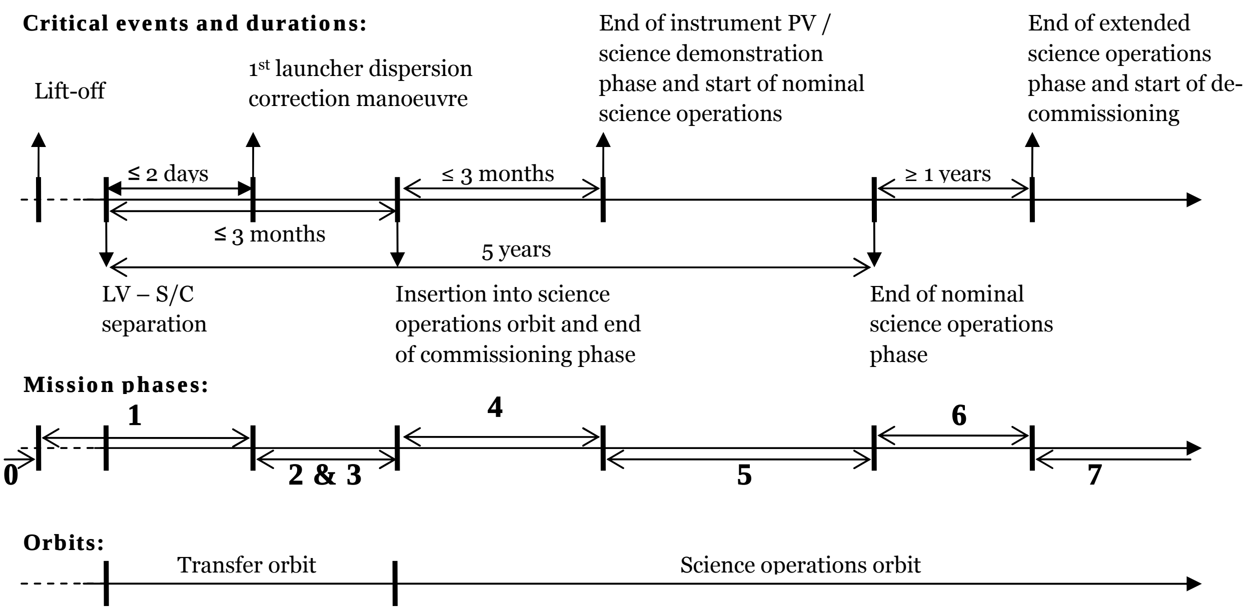

Figure 3: EChO mission critical events, phases and orbits

3.5 Delta V

R-MIS-240 The following geometrical delta-Vs shall apply (99% probability):

Reason	Delta V	Direction	Time line
Launcher dispersion correction manoeuvres	25.6 m/s	Close to the velocity vector, either directions possible.	Could be performed before day 2, but contains margin for additional manoeuvre at days 5 and 10 if necessary.
Perigee velocity correction manoeuvre	14.2 m/s	Executed in the same direction and simultaneously with the previous manoeuvre before day 2.	
Orbit maintenance	6 m/s/year	Parallel to the ecliptic plane, +28.6° away from the Sun-Earth axis, either directions possible.	Scheduled outage of 8 hours every 4 weeks.

Following margins defined by R-SYS-020, 5% are already included in the delta-V for launcher dispersion and perigee velocity correction manoeuvres, and 100% in the delta-V for orbit maintenance manoeuvres.

4 SCIENCE PERFORMANCE REQUIREMENTS

4.1 Observation requirements

Axes and references frames are detailed in section 5.1.2.

R-PERF-020 During phases 4 and 5, the EChO S/C shall have the ability to make a full 360 degrees rotation around Z_{ECHO} and observe a target from any of those attitudes.

R-PERF-030 During phases 4 and 5, the EChO S/C shall have the ability to make a rotation of 72 degrees around Y_{ECHO} and observe a target from any of those attitudes.

R-PERF-040 During phases 4 and 5, the EChO S/C shall have the ability to make a rotation of 2 degrees around X_{ECHO} and observe a target from any of those attitudes.

The rotation around X_{ECHO} is not a science need, it is only a safety margin that includes the Sun diameter.

R-PERF-050 The shields and baffles shall be designed to continuously cover the payload from the Sun, assuming the S/C can take any attitude as defined in R-PERF-020, 030 and 040.

R-PERF-060 The overall observing efficiency of the EChO S/C during science operation phases 4 and 5 shall be ≥ 85%.

R-PERF-061 Corruption or loss of science data during a science observation shall be deducted from the observation efficiency budget with a degradation factor of 2.

This loss can be due to e.g. reaction wheel spikes etc. The degradation factor is needed since a loss of X seconds during an observation out of transit means the equivalent X seconds in transit needed for the differential measurement are also lost.

R-PERF-070 An average observation shall be defined as the observation of a single science target for 5 hours, separated by 45 degrees from the previous and the next science targets (TBC).

R-PERF-080 Periodic calibration of the science instrument shall not be deducted from the observation efficiency budget (TBC).

1 hour per day are allocated (TBC) for calibration with external sources.

R-PERF-090 The faintest star to be observed by the EChO payload shall be defined as follows:

	Type	K magnitude	Comment
Under 3 microns	M5V	8.8	GJ 1214
From 3 to 8 microns	G0V	9.0	
Above 8 microns	G0V	8.0	

The flux from these targets can be evaluated using the appropriate SED from the library provided, and are based on the following parameters:

	T [K]	Radius [r_{Sun}]	Distance [pc]
Under 3 microns	3200	0.19	13
From 3 to 8 microns	6030	1.05	150
Above 5 microns	6030	1.05	94.6

G-PERF-100 The faintest star to be observed by the EChO payload should be defined as follows:

	Type	K magnitude	Comment
Under 3 microns	M5V	9.8	1 magnitude fainter than R-PERF-090
From 3 to 8 microns	G0V	10.0	
Above 8 microns	G0V	9.0	

The flux from these targets can be evaluated using the appropriate SED from the library provided, and are based on the following parameters:

	T [K]	Radius [r_{Sun}]	Distance [pc]
Under 3 microns	3200	0.19	20.6
From 3 to 8 microns	6030	1.05	238
Above 5 microns	6030	1.05	150

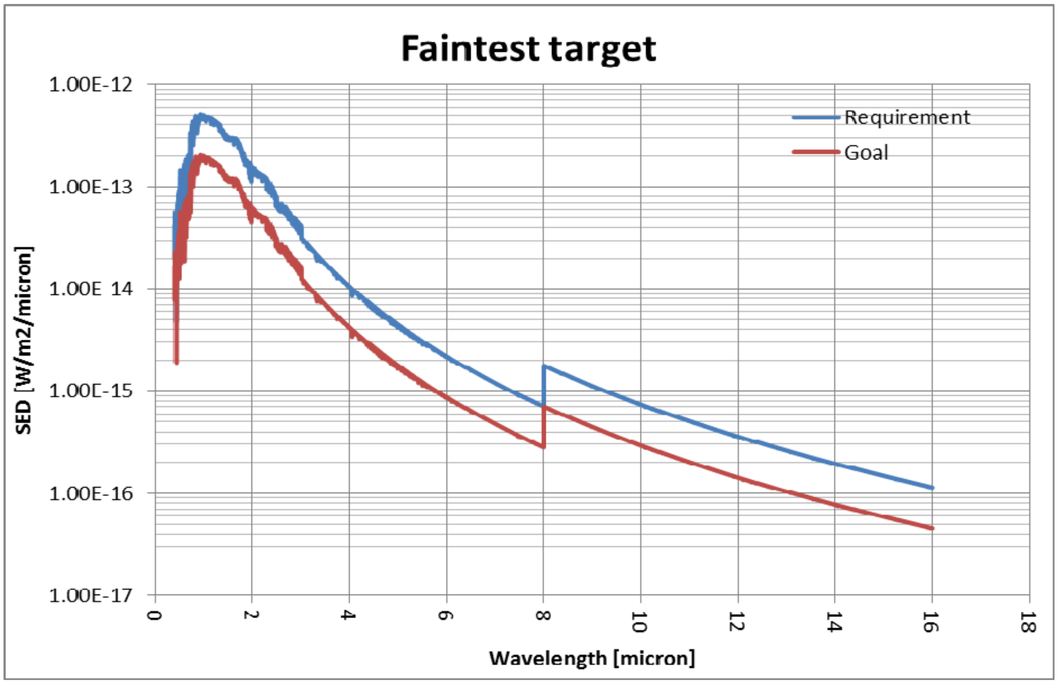

Figure 4: EChO faintest targets spectral irradiance at entrance pupil

This faintest flux corresponds to $N_{0\,\mathrm{min}}(\lambda)$ *as defined in [AD2].*

R-PERF-110 The brightest star to be observed by the EChO payload shall be defined as follows:

	Type	K magnitude	Comment
All wavelengths	K0V	4.0	55 Cnc

The flux from this target can be evaluated using the appropriate SED from the library provided, and are based on the following parameters:

	T [K]	Radius [r_{Sun}]	Distance [pc]
All wavelengths	5250	0.80	12.3

G-PERF-111 The brightest star to be observed by the EChO payload shall be defined as follows:

	Type	K magnitude	Comment
All wavelengths	F9V	2.9	υ And b

The flux from this target can be evaluated using the appropriate SED from the library provided, and are based on the following parameters:

	T [K]	Radius [r_{Sun}]	Distance [pc]
All wavelengths	6115	1.10	13.5

For phase-resolved observations of non-transiting planets (secondary science objective).

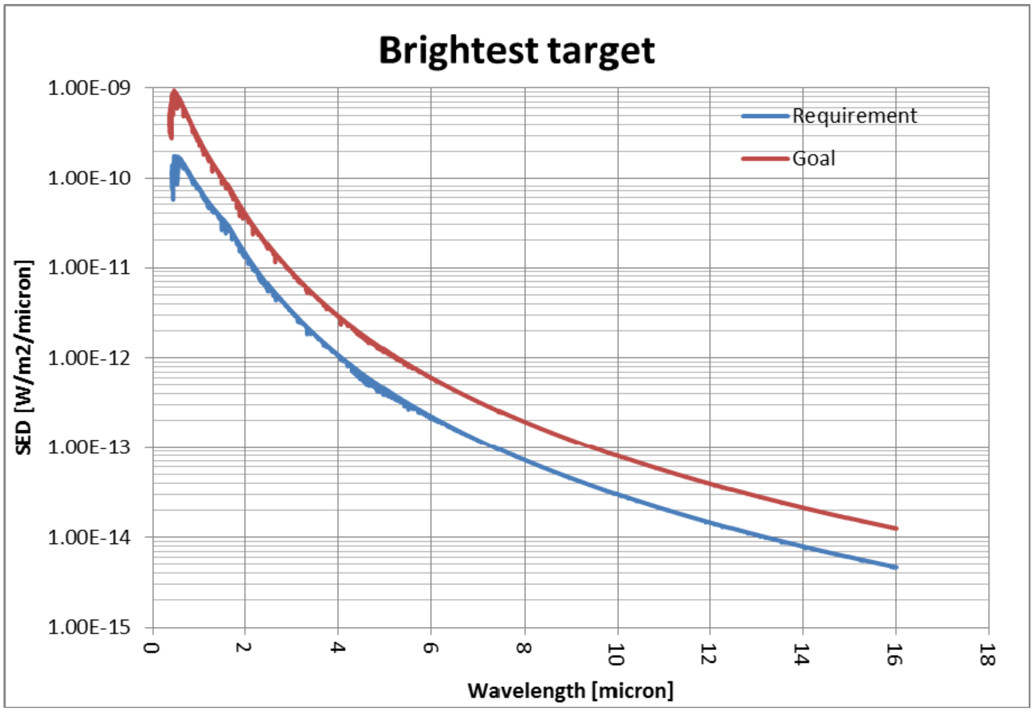

Figure 5: EChO brightest targets spectral irradiance at entrance pupil

The following operations are necessary to get a signal at detector level:

		[W/m²/micron]
Divide by the energy of a photon:	$\times \lambda / h \times c$	*[photons/s/m²/micron]*
Integrate over the spectral band corresponding to the resolving power required:	$\times \lambda / R$	*[photons/s/m²/spectral band]*
Multiply by the telescope's effective area, the total throughput and the detector's QE:	$\times Aeff \times \eta \times QE$	*[electrons/s/spectral band]*
Divide by the number of pixels per spectral band (assuming the PSF equally illuminates these pixels):	$\times 1/p$	*[electrons/s/pixel]*
Divide by the area per pixel:	$\times 1/d_p^2$	*[electrons/s/micron²]*

4.2 Telescope performance requirements

G-PERF-120 The effective area A_{eff} of the telescope (which defines the actual photon collecting area) should be ≥ 1.131 m².

R-PERF-130 The telescope shall feed into the FGS a FoV larger than the 1st Airy disk of a point source at infinity at the FGS's long cut-off wavelength plus twice the coarse platform APE (achieved without the FGS in the control loop):

$$FoV_{FGS}('') \geq \left(2 \times 1.22 \times \frac{\lambda_{\max}}{D_{tel}}\right) \times \left(\frac{180 \times 3600}{\pi}\right) + 2 \times APE_{coarse}('')$$

For example, the Airy disk is 0.34", assuming a cut-off wavelength of 0.8 µm and a 1.2 m diameter telescope. Assuming that the platform can provide a coarse APE of 3" (3 sigma) means the FoV of the telescope and FGS shall be larger than ~7"x7".

4.3 System performance requirements

Instrument requirements are derived for a classical dispersive/diffractive spectrometer design. In case alternative designs are proposed (e.g. FTS), equivalent requirements shall be derived.

R-PERF-150 The science instrument shall cover the 0.55 to 11 microns wavelength range without any gaps.

G-PERF-160 The science instrument should cover the 0.4 to 16 microns wavelength range without any gaps.

R-PERF-170 No-cut wavelength: R-SCI-030 in [AD1] is applicable.

G-PERF-180 No-cut wavelength: G-SCI-031 and 031a in [AD1] are applicable.

These requirements give the wavelengths at which no cut between channels is allowed. The complete wavelength range can be split into as many channels as necessary as long as all science performance requirements are met.

R-PERF-180 All science channels shall have an overlap in wavelength with their neighbouring channels to allow for cross-calibration between channels, of (TBC):

- ≥ 5 resolution elements for channels under 5 microns
- ≥ 1 resolution elements for channels above 5 microns

The width of the resolution element shall be taken from R-PERF-190.

R-PERF-190 For a point source at infinity, the science instrument shall have a resolving power:

- ≥ 300 under 5 microns
- ≥ 30 above 5 microns

The resolving power shall be defined by $R=\lambda/\Delta\lambda$ where $\Delta\lambda \geq$ FWHM of the monochromatic system PSF.

G-PERF-200 For a point source at infinity, the science instrument should have a resolving power:

- ≥ 300 in the complete wave range as defined in G-PERF-160

R-PERF-210 The science instrument post-processing shall allow binning of adjacent resolution elements together.

This should enable increasing the SNR at the expense of a reduced resolving power.

G-PERF-220 The average total throughput η (all optical elements along each science channel's optical path, from primary telescope mirror down to detector including losses due to apertures) should be:

- ≥ 0.25 for channels above 1 micron
- ≥ 0.10 for channels below 1 micron (TBC)

G-PERF-230 The average QE of the detectors should be:

- ≥ 0.50 e-/photons for channels above 5 microns
- ≥ 0.70 e-/photons for channels between 1 and 5 microns
- ≥ 0.60 e-/photons for channels below 1 micron

R-PERF-240 The figure of merit defined as A_{eff} x η x QE shall be (average value in each channel):

- ≥ 1.131 x 0.25 x 0.50 = 0.141 [m^2.e-/photons] above 5 microns
- ≥ 1.131 x 0.25 x 0.70 = 0.198 [m^2.e-/photons] between 1 and 5 microns
- ≥ 1.131 x 0.10 x 0.60 = 0.068 [m^2.e-/photons] for channels below 1 micron (TBC)

Any reduction in one of these parameters shall be compensated by a proportional increase of either of the other 2 parameters.

R-PERF-241 The minimum in-channel (i.e. not in the cut-off / overlap regions) figure of merit in any resolution element (as defined in R-PERF-190) shall be no less than 80% of the figure of merit defined in R-PERF-240.

R-PERF-242 The minimum out-of-channel (i.e. in the overlap regions between 2 adjacent channels) figure of merit in any resolution element (as defined in R-PERF-190) shall be no less than 50% of the figure of merit defined in R-PERF-240.

R-PERF-242 can be achieved by the individual channels or by summing the response from 2 overlapping channels.

R-PERF-250 The FoV in each science channel shall be larger than the 1st Airy disk of a point source at infinity at the channel's long cut-off wavelength plus twice the fine APE (achieved with the FGS in the control loop):

$$FoV_{science}('') \geq \left(2 \times 1.22 \times \frac{\lambda_{\max}}{D_{tel}}\right) \times \left(\frac{180 \times 3600}{\pi}\right) + 2 \times APE_{fine}('')$$

R-PERF-255 An extended FoV of ≥ 20" (half angle) in the spatial direction of each science channel shall enable the monitoring of the background (e.g. zodiacal and thermal background but also detector dark current) using off-source pixels (TBC).

R-PERF-260 Spectral sampling shall be commensurate with the Nyquist-Shannon criterion, i.e. at least two samples per spectral element defined in R-PER-190.

R-PERF-290 Photometric variations in the frequency band [2.8×10^{-5} – 4×10^{-3} Hz] shall be budgeted in and not raise the noise floor defined in R-PERF-350 after post-processing.

From 250 s to 10 hours (longest time required for the observation of a transit).

G-PERF-300 Photometric variations in the frequency band [3.8×10^{-6} – 16×10^{-3} Hz] should be budgeted in and not raise the noise floor defined in R-PERF-350 after post-processing.

From 60 s (2x goal temporal sampling) to 3 days (to enable orbital phase measurements).

All sources of photometric variations shall be accounted for in R-PERF-290 and 300, from astrophysical to system and instrumental effects.

R-PERF-310 Stellar variability (post-processing) shall make a negligible contribution to the noise budget defined in R-PERF-350 (<10% in RSS). Observation of stars with higher residual variability is TBD.

R-PERF-320 A 20% margin (in RSS) shall be kept in the noise budget until the end of the definition phase.

R-PERF-330 An absolute photometric calibration accuracy of 5% (TBC), post-processing, shall be achieved for all targets across the full waveband defined in R-PERF-150.

R-PERF-340 An absolute wavelength calibration accuracy better than 1/3rd (TBC) of the spectral resolution defined in R-PERF-190, post-processing, shall be achieved for all targets across the full waveband defined in R-PERF-150.

R-PERF-330 and 340 can be achieved by observations of reference celestial objects, which are the same observations as those defined in R-PERF-080.

R-PERF-341 The EChO satellite and science instrument shall provide TBD housekeeping, monitoring, calibration sources and reference detector data to enable the noise requirement R-PERF-350 to be met after post-processing.

R-PERF-350 The system level noise (after post-processing) shall be lower than X times the astronomical noise floor (defined by the square sum of the stellar and zodiacal background shot noises). The total noise $Noise_{TOTAL}$ shall then be less than:

$$
\begin{aligned}
Noise_{TOTAL} &\leq \sqrt{(N_0 + zodi)\times(1+X)} \\
&= \sqrt{(N_0 + zodi) + X\times(N_0 + zodi)} \\
&= \sqrt{N_0 + zodi} + (\sqrt{1+X} - 1)\times\sqrt{(N_0 + zodi)}
\end{aligned}
$$

Where:

- N0 is the flux from the target star being observed.
- The zodiacal background contribution shall be evaluated using a worst case FoV per spectral bin of 10''x10'' (TBC) and the average zodi value as defined in R-PERF-390.

X shall be equal to:

- 200% (TBC) under 1 micron.
- 30% between 1 and 5 micron.
- 30% above 5 micron.

The system level noise (post-processing) is given in Figure 6 (to be summed linearly with the noise floor):

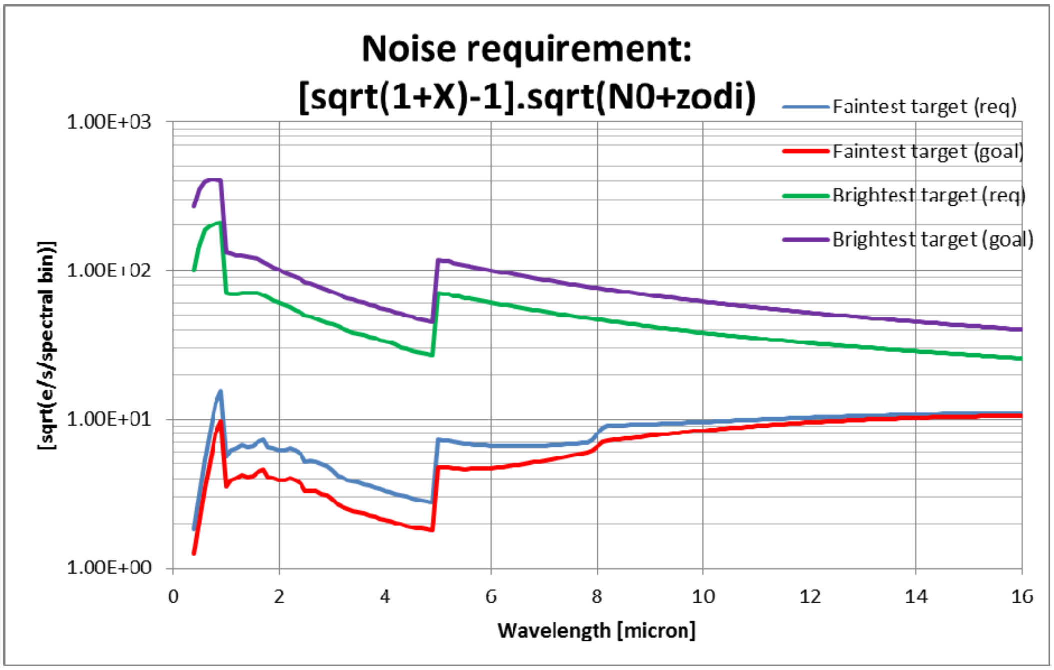

Figure 6: Noise requirement (to be summed linearly with the noise floor)

The square of the system level noise (post-processing) is given in Figure 7 (to be summed in RSS with the noise floor):

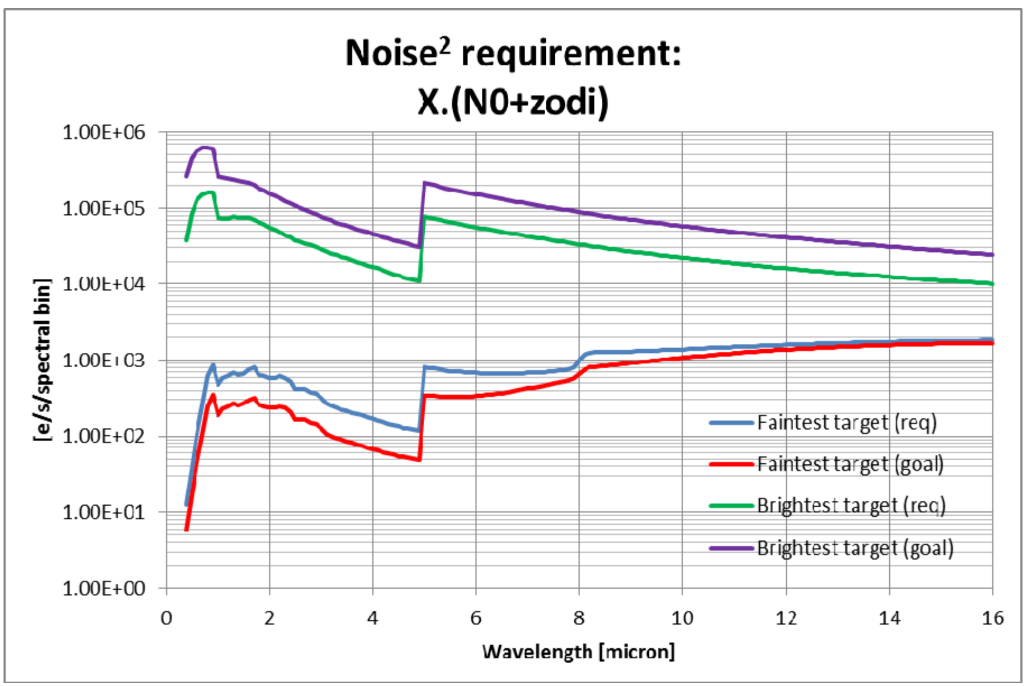

Figure 7: Square of noise requirement (to be summed in RSS with the noise floor)

The system level noise (post-processing) is given in Figure 8 relatively to the stellar flux:

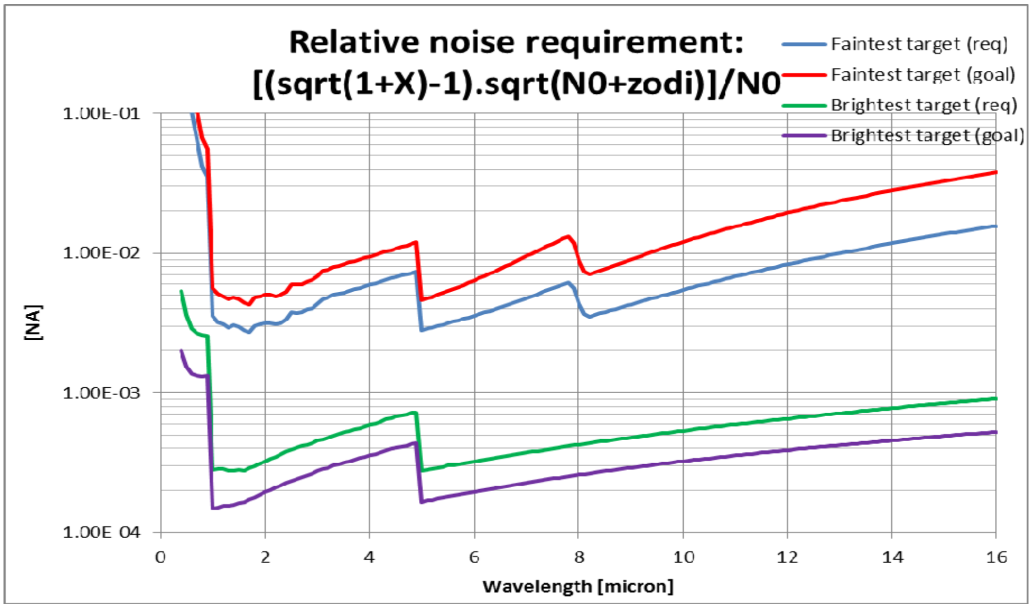

Figure 8: Relative noise requirement

These values has been derived using the performance parameters defined in R-PERF-190 and 240. Were R-PERF-240 to be exceeded, an equivalent relaxation to the noise requirement would be acceptable.

This noise definition is extensively detailed in [AD2].

G-PERF-351 Using the same noise definition as in R-PERF-350, X should be equal to:

- 200% (TBC) under 1 micron.
- 10% between 1 and 5 micron.
- 10% above 5 micron.

The system level noise (post-processing) is given in Figure 9 (to be summed linearly with the noise floor):

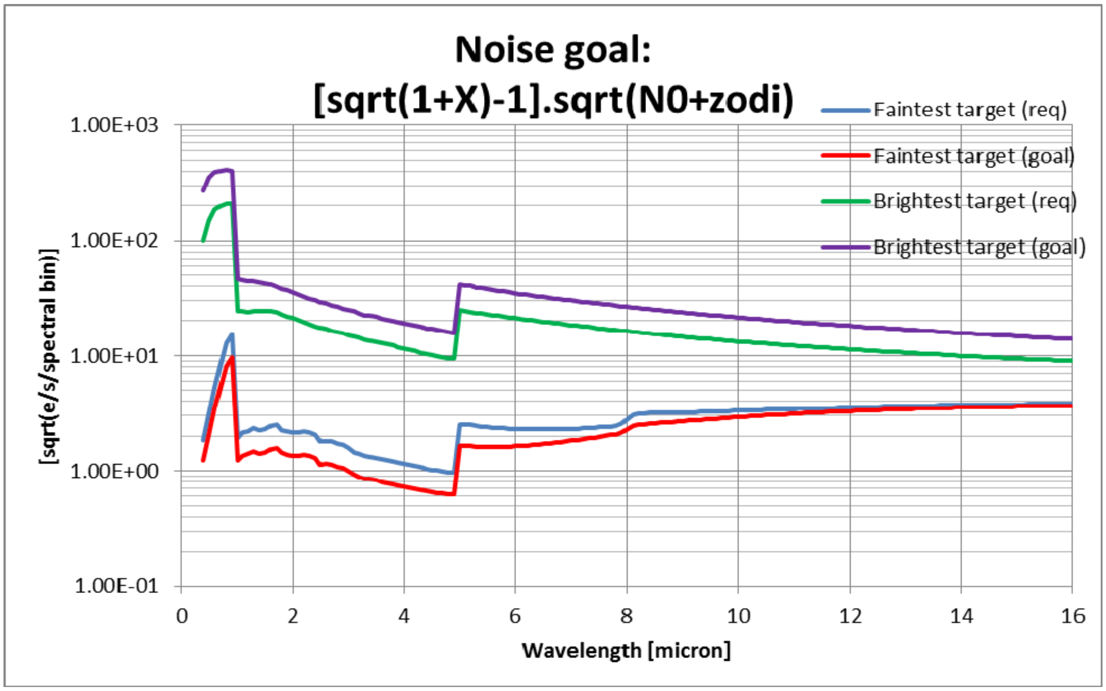

Figure 9: Noise goal (to be summed linearly with the noise floor)

The square of the system level noise (post-processing) is given in Figure 10 (to be summed in RSS with the noise floor):

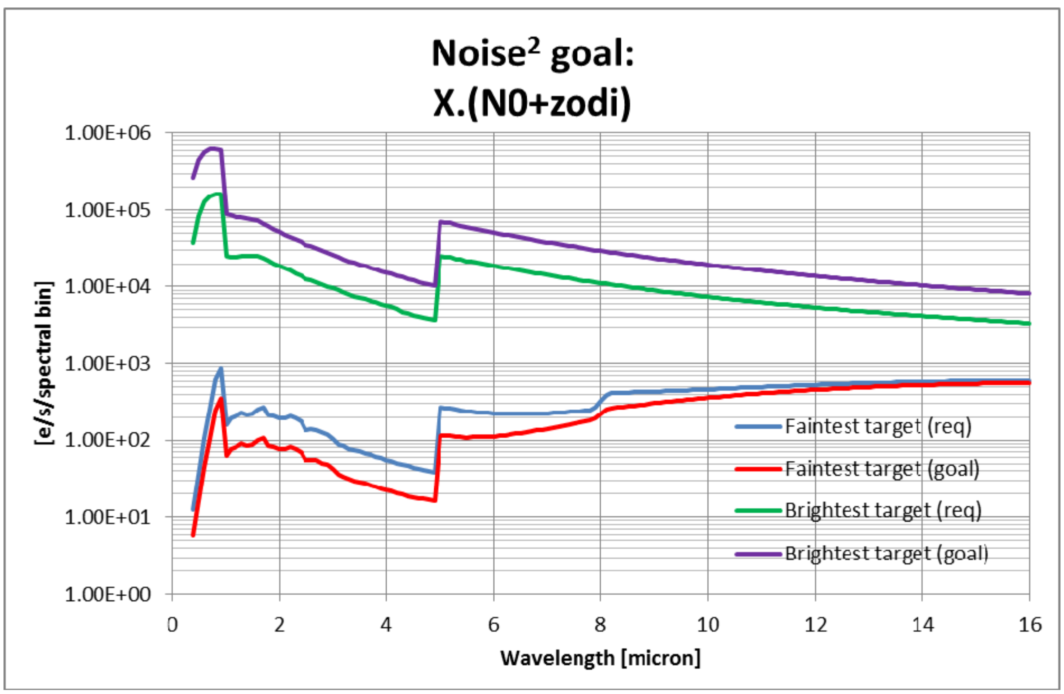

Figure 10: Square of noise goal (to be summed in RSS with the noise floor)

The system level noise (post-processing) is given in Figure 11 relatively to the stellar flux:

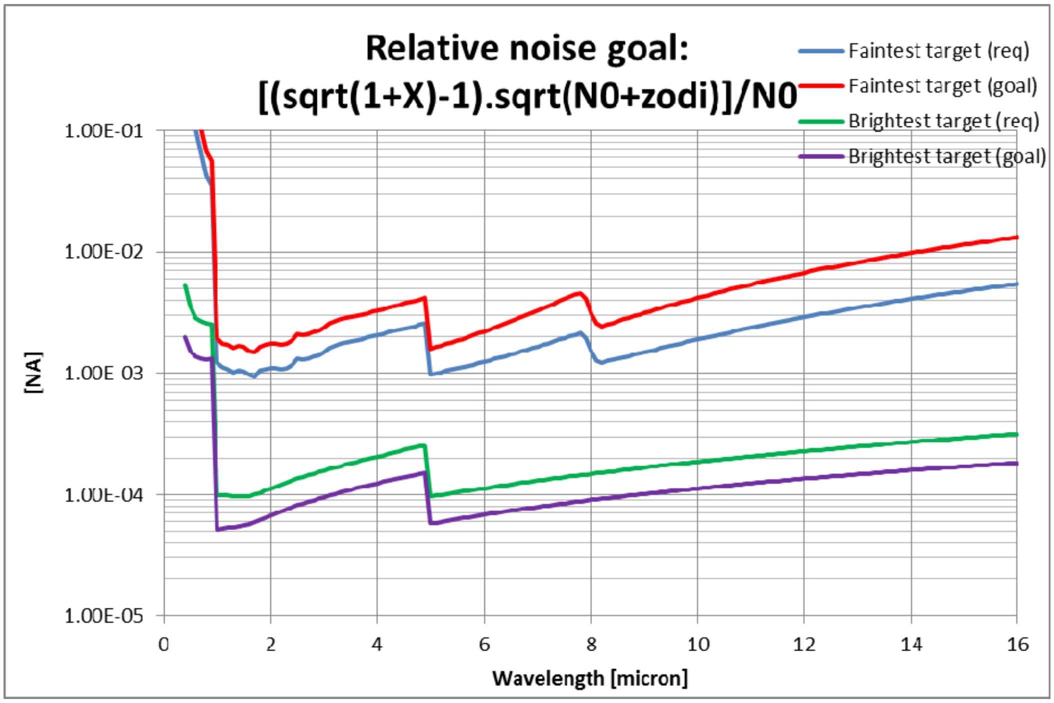

Figure 11: Relative noise goal

These values has been derived using the performance parameters defined in R-PERF-190 and 240. Were R-PERF-240 to be exceeded, an equivalent relaxation to the noise requirement would be acceptable.

Note that the noise requirement is relative to the target being observed, not absolute.

R-PERF-360 Neighbouring sources which fall within the instrument FoV around target stars shall make a negligible contribution to the noise budget defined in R-PERF-350. Observation of stars with neighbouring sources that make a larger contribution is TBD.

This means no additional budget needs to be apportioned to neighbouring sources in the total noise budget.

R-PERF-370 The interval between consecutive measurements of the host star/exoplanet system taken during a single transit/occultation shall be ≤90 s.

G-PERF-380 The interval between consecutive measurements of the host star/exoplanet system taken during a single transit/occultation should be ≤30 s.

R-PERF-390 The zodiacal background model which shall be used is defined by:

Zodi(λ)= B_λ (5500 K)x3.5.10-14 + B_λ (270 K)x3.58.10-8 I in units of [W/m2/sr/m]

where B_λ(X) is Planck's law written in terms of wavelength at a temperature of X [K].

As the zodi is a strong function of viewing direction, 3 cases shall be used for sizing purposes:

- Minimum zodi = 0.9 x expression above (value at ecliptic poles).
- Maximum zodi = 8 x expression above (Solar elongation angle of 55 degrees at an ecliptic latitude of 0 degrees).
- Average value = 2.5 x expression above.

The zodi model on which parameterization has been evaluated is based on the Hubble model out to 2.5 micron, and the DIRBE model at wavelengths beyond.

5 SPACECRAFT FUNCTIONAL REQUIREMENTS

5.1 System requirements

5.1.1 Standards

R-SYS-010 The SI international system of units shall be used. Radians, degrees and arcseconds are acceptable as angle units. All (sub)multiples by factors of 10 of any of the aforementioned units are also acceptable.

For instance, this implies [g], [microns] and [milliarcseconds] are acceptable.

R-SYS-020 The margin policy described in [AD3] shall be applied to the assessment study (Phase 0/A).

The margin philosophy and margin depletion scheme will be firmly defined at a later stage.

R-SYS-030 The list of ESA approved standards, including approved ECSS standards, shall apply throughout the ECHO study, and is detailed in [AD4]. Tailoring of specific standards is possible and shall be subject to formal approval by ESA on a case-by-case basis with a detailed rationale.

5.1.2 Coordinate systems

R-SYS-040 All reference coordinate frames shall be right-handed orthonormal triads.

The frames defined below are illustrated in Figure 12.

R-SYS-050 The EChO S/C reference frame shall be defined by three orthonormal axes (X_{ECHO}, Y_{ECHO}, Z_{ECHO}), with an origin at the geometrical centre of the separation plane between the LV adapter and the S/C.

R-SYS-060 The longitudinal axis $+Z_{ECHO}$ (roll axis) shall be coincident with the LV symmetry axis, and pointing in the positive direction from the LV – S/C separation plane up to the tip of the S/C.

R-SYS-070 $+X_{ECHO}$ shall be defined, in the separation plane between the LV adapter and the S/C, as pointing in the positive direction along the telescope pointing axis $Z_{E\text{-}TEL}$ projected in the separation plane.

R-SYS-080 $+Y_{ECHO}$ shall be defined to complete the right-handed orthonormal triad with $+X_{ECHO}$ and $+Z_{ECHO}$.

R-SYS-090 The EChO telescope pointing reference frame shall be defined by three orthonormal axes ($X_{E\text{-}TEL}$, $Y_{E\text{-}TEL}$, $Z_{E\text{-}TEL}$), with an origin in the vertex of the telescope's primary mirror.

R-SYS-100 The telescope's pointing axis $+Z_{E\text{-}TEL}$ shall be defined from the reference frame's origin, in the positive direction going towards the centre of the targeted FoV.

R-SYS-110 $+X_{E\text{-}TEL}$ shall be defined from the reference frame's origin towards the centre of the Sun shield (average Sun direction), projected onto the plane orthogonal to $+Z_{E\text{-}TEL}$.

R-SYS-120 $+Y_{E\text{-}TEL}$ shall be defined to complete the right-handed orthonormal triad with $+X_{E\text{-}TEL}$ and $+Z_{E\text{-}TEL}$.

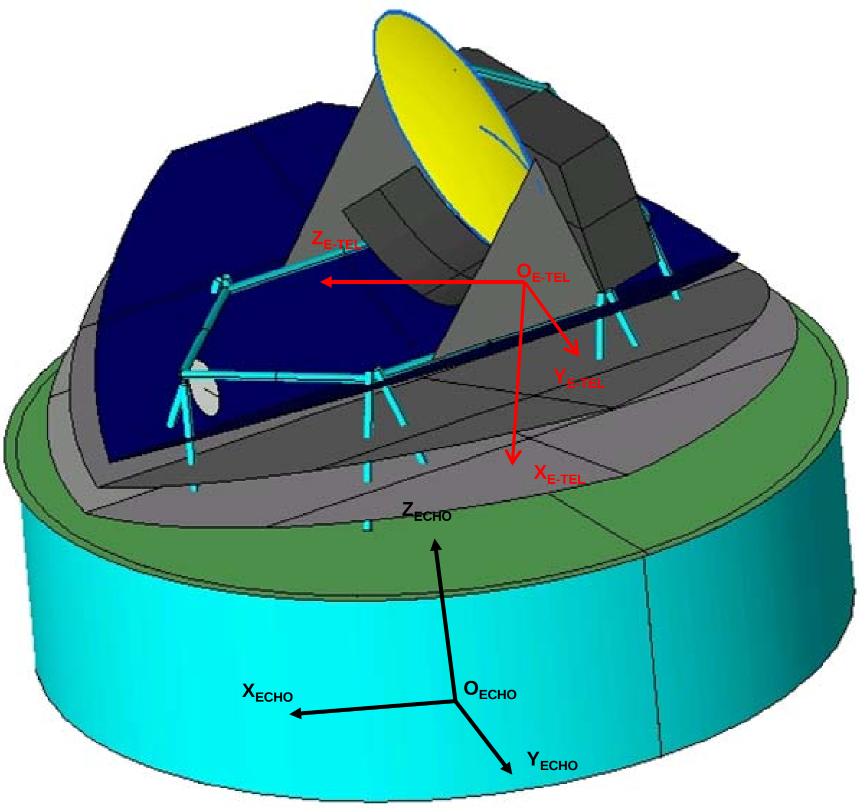

Figure 12: Illustration of the EChO reference frames

5.1.3 Spacecraft mass

R-SYS-130 The total wet mass of the EChO S/C (including all margins specified in [AD3] and the LV and S/C adaptors) shall be smaller than the LV baseline performance of 2200 kg.

5.1.4 Reliability and fault management

R-SYS-140 The overall reliability of the mission shall be > 85 % from after LV separation to the end of the nominal lifetime.

R-SYS-150 Single-point failures with a severity of catastrophic or critical (as defined in [AD4], ECSS-Q-ST-30C) shall be eliminated or prevented by design.

R-SYS-160 Retention in the S/C design of single-point failures of any severity rating is subject to formal approval by ESA on a case-by-case basis with a detailed retention rationale.

R-SYS-170 A failure of one S/C component (unit level) shall not cause failure of, or damage to, another component or subsystem.

R-SYS-180 The failure of an individual instrument channel shall not lead to a "Safe Mode" of the S/C.

R-SYS-190 Any hazardous situation, which will not cause immediate loss of but may develop into the loss of the S/C, shall be prevented by design or protected against.

R-SYS-200 The S/C shall respond to platform on-board failures by autonomously switching to a redundant functional path. Where this can be accomplished without risk to spacecraft safety, such switching shall enable the continuity of the mission timeline and performance.

This means the design of fault management systems shall intrinsically be fail-safe.

R-SYS-210 Where redundancy is employed, the design shall allow operation and verification of the redundant item/function, independent of nominal use.

R-SYS-220 In case of anomalies or failures from which the S/C cannot recover autonomously, the S/C shall enter a Safe Mode to ensure S/C and payload survival.

R-SYS-230 For design and analysis purposes, an average of 2 safe modes events of 4 days each per year shall be considered.

5.2 Structures and Configuration

R-STR-010 The S/C shall be configured in a modular way, with:

- The Payload Module (PLM), which mainly includes the telescope and the instruments, the optical bench(s), the supporting structures, the hardware related to passive thermal control of the PLM and some payload support equipment.

- The Service Module (SVM), which provides the spacecraft subsystems to support the PLM.

R-STR-020 The S/C shall be designed in a modular way so that the SVM and the PLM can be individually integrated and tested.

R-STR-030 The S/C design shall allow simple mounting and dismounting procedures so that the science instrument can be individually installed or uninstalled and tested throughout the integration process.

Structural and configuration compatibility with the launcher's constraints is already expressed in R-MIS-010, while I/F requirements are expressed in Chapter 6.

5.3 Mechanisms

R-MECH-010 The use of mechanisms shall be avoided as far as practicable. Proposed use of mechanisms is subject to formal approval by ESA on a case-by-case basis with a detailed rationale.

R-MECH-020 The use of units inducing mechanical vibrations during science observations shall be avoided as far as practicable. Proposed use of such units is subject to a formal approval by ESA on a case-by-case basis, after provision of a detailed rationale. If approved, the supplier of such units shall characterise the generated vibration disturbances, and provide means of reducing these disturbances when necessary to ensure compliance with R-MECH-030 and R-PERF-350..

R-MECH-030 The supplier of any unit whose performance is degraded by mechanical vibrations (e.g. star trackers, antennas, gyroscopes, the FGS etc.) shall provide a spectrum of maximum allowed micro-vibrations, at the unit's interface with the S/C's structure, under which the unit will still perform as required.

5.4 Thermal Control

R-THE-010 The thermal control subsystem shall provide a thermal environment suitable for nominal operation of all S/C systems and payload.

R-THE-020 The variations of the PLM (telescope and science instrument boxes) thermal background shall be compliant with the photometric stability requirements R-PERF-290.

R-THE-030 The temperature variations of the science detectors and associated electronics shall be controlled to ensure compliance with the photometric stability requirements R-PERF-290.

These requirements shall be derived from the photometric stability requirements and depend on the final budget allocation.

R-THE-040 The telescope and science instrument shall be sufficiently cooled to ensure the thermal background noise is compliant with the photon noise limit requirement R-PERF-350

5.5 AOCS

R-AOCS-010 During all mission phases, the AOCS shall acquire and control the attitude and orbit of the S/C within ranges allowing for nominal operation of all S/C systems and payload.

R-AOCS-020 During all mission phases, the AOCS shall ensure the spacecraft avoids "un-safe" attitudes, defined as attitudes where one of the following conditions exists:

- Insufficient power is generated for S/C survival
- Spacecraft thermal control is compromised
- Telescope or instruments are illuminated by the Sun, the Earth or any other bright source
- Other identified attitudes that impair the S/C and the nominal science operation plan

R-AOCS-030 After a major on-board failure or a violation of the attitude constraints, the AOCS shall maintain a "safe mode" attitude that:

- Allows a continuous and sufficient supply of power for S/C survival
- Allows communication with Earth
- Ensures a survivable thermal environment
- Prevents damage to the telescope, the instruments and any active cryo-cooler

R-AOCS-040 A redundant Fine Guidance Sensor (FGS) shall be implemented within the PLM, using the light focussed by the telescope, to meet the pointing stability requirement R-AOCS-070.

R-AOCS-070 The pointing stability between the instrument LoS and the science target with the FGS in the control loop shall be controlled to ensure compliance with the photometric stability requirement R-PERF-290.

This requirement shall be derived from the noise and photometric stability requirements and depends on the final budget allocation. RPE, PRE and PDE are possible ways of defining this pointing stability.

R-AOCS-080 The light shall be split between the first science instrument channel and the FGS, while ensuring the figures of merit defined in R-PERF-240 are not compromised.

R-AOCS-090 The star centroïding performance of the FGS shall allow compliance with the pointing stability requirement R-AOCS-070 for all possible science targets. The faintest signal to be considered by the FGS is the same as defined in R-PERF-090.

Integrating the faintest flux requirement given in R-PERF-090 from 0.4 to 0.8 micron gives 6.4E^{-14} W/m^{2}. With the faintest flux goal given in R-PERF-100, this falls to 2.1E^{-14} W/m^{2}.

5.6 Propulsion

R-PROP-010 The propulsion subsystem shall perform the following tasks:

- Provide the necessary propulsive actuators for the AOCS to meet R-AOCS-010.
- Perform the necessary correction manoeuvres during the LEOP and transfer phases.
- Perform the necessary orbital maintenance manoeuvres during the nominal and extended science operation phases.
- De-saturate reaction wheels (if equipped).

R-PROP-020 The characteristics of the thrusters and their accommodation on the spacecraft shall not cause any adverse effects on either the spacecraft or the instruments during the mission.

5.7 Electrical power subsystem

R-EPS-010 The EPS shall be able to generate and supply sufficient power to all instruments and subsystems during all mission phases.

R-EPS-020 The EPS shall be able to generate and supply sufficient power to all subsystems during contingency operations (Safe Mode).

5.8 Telemetry, Tracking & Command

R-TT&C-010 The TT&C subsystem shall be able to simultaneously perform the following actions throughout all the mission phases after launch and regardless of the spacecraft attitude:

- Receive and demodulate the uplink signal from the ground segment and transmit the telecommands to the data handling system.
- Receive all scientific and housekeeping telemetry data from the data handling system and transmit these data to the ground segment.
- Transpose the ranging signal.

R-TT&C-020 The TT&C subsystem shall be compatible with the ESA ground segment and the NASA Deep Space Network (DSN).

R-TT&C-030 The margins in the link budget calculations shall be:

- Nominal margin > 3 dB
- RSS worst-case margin > 0 dB
- Mean -3σ margin > 0 dB

R-TT&C-040 Uplink budget calculations shall be based on a BER of 10^{-5} at the input to the telecommand decoder.

R-TT&C-050 Downlink budget calculations shall be based on a FER of 10^{-7} after decoding.

R-TT&C-060 The downlink and uplink data rates shall be selected to be compatible with the data transmission requirements for all mission phases.

R-TT&C-070 Hot redundancy shall be provided for the receive function and cold redundancy for the transmit function.

R-TT&C-080 The nominal ground contact frequency shall be twice per week (TBC).

5.9 Control and Data Management System

R-CDMS-010 The CDMS shall collect and prepare all scientific and housekeeping data from the instruments and spacecraft for transmission to ground.

R-CDMS-020 The CDMS shall process the uplink signal received by the TT&C system, validate the commands and distribute them to the appropriate users/applications for execution.

R-CDMS-030 The CDMS shall perform the following general functions:

- Telemetry acquisition, encoding, and formatting
- Telecommand acquisition, decoding validation, and distribution
- Data storage
- Time distribution and time tagging
- Autonomy supervision and management
- On Board Control Procedure management (OBCP) functions

R-CDMS-040 The CDMS shall be able to store all science and housekeeping data from nominal science operation phase for the duration defined in R-OGS-160.

R-CDMS-050 The CDMS hardware shall be redundant.

5.10 On-Board Software

R-SFTW-010 The on-board software shall be able, in conjunction with hardware, to execute all the tasks identified for the CDMS.

R-SFTW-020 The S/C shall support replacement of the on-board software, either partially or totally, with software up-linked from the ground during any mission phase from end of LEOP.

6 EXTERNAL INTERFACES

6.1 Launcher interfaces

S/C compatibility (structural, acoustic and thermal loads, power and data I/Fs etc.) with LV and LV ground facilities and GSE is required from R-MIS-010.

6.2 Payload interfaces

R-IF-010 The S/C shall provide all the necessary interfaces (mechanical, thermal and electrical) and resources to the telescope and the focal plane instruments in all of their specified modes.

6.3 Ground facilities

R-IF-020 The S/C design shall be compatible with the proposed ground test and launch facilities. Proposed modifications and/or extensions to these facilities are subject to a formal approval by ESA on a case-by-case basis, after provision of a detailed rationale.

R-IF-030 The S/C shall have the necessary electrical/mechanical access for integration and testing.

R-IF-040 The S/C design shall allow transportation by standard commercial means, both with the PLM and SVM separate, and as a complete unit.

7 SPACECRAFT ENVIRONMENT

Application of ESA approved standards (including ECSS) related to the S/C environment is required in R-SYS-030.

7.1 Mechanical Environment

The spacecraft shall be designed to withstand all the mechanical static and dynamic loads encountered during its entire life. These include conditions arising from the LV selection (described in section 6.1), test facilities (R-IF-020) and transport (R-IF-040).

7.2 Thermal Environment

R-ENV-010 The S/C shall be compatible with the thermal-vacuum environment expected during all mission phases.

7.3 Cleanliness and Contamination

Cleanliness and contamination requirements are TBD. The need for a mirror cover shall be assessed in future study phases depending on mirror contamination constraints.

7.4 Stray light

Stray light requirements are TBD.

7.5 Radiation Environment

R-ENV-020 The S/C and its components shall be qualified to withstand twice the expected levels of radiation over the duration specified R-MIS-230.

R-ENV-030 Degradation of components due to radiation dose over the mission lifetime shall not degrade the S/C and payload performance beyond requirements.

7.6 Meteoroids

R-ENV-040 The spacecraft shall be designed to withstand and perform nominally taking into account the predicted meteoroids environment throughout the mission with a probability larger than TBD.

7.7 Electromagnetic Compatibility

EMC requirements are TBD.

8 ASSEMBLY, INTEGRATION AND VERIFICATION

Application of ESA approved standards (including ECSS) related to AIV is required in R-SYS-030.

9 OPERATIONS AND GROUND SEGMENT

Application of ESA approved standards (including ECSS) related to operations and ground segment is required in R-SYS-030.

9.1 Operations

R-OGS-010 The S/C design shall enable operational control by the ground segment during all mission phases and modes in both nominal and contingency situations.

9.2 Mission Operation Centre

R-OGS-020 The EChO mission shall have a single MOC. For the purpose of the assessment study, ESOC shall be assumed as the MOC.

R-OGS-030 The MOC shall be responsible for the spacecraft operations after launch, including mission planning, spacecraft monitoring and control, and orbit and attitude determination and control.

R-OGS-040 The MOC shall perform all communications with the S/C through the ground stations.

R-OGS-050 Orbit determination shall be conducted with the required accuracy to perform:

- All manoeuvres required to inject the S/C into L2
- All orbit maintenance manoeuvres during operation

R-OGS-060 The MOC shall provide all telemetry (science and housekeeping) to the SOC.

The definition of the roles and responsibilities of the MOC will be detailed in [AD7].

9.3 Science Operation Centre

R-OGS-070 The EChO mission shall have a single EChO SOC. For the purpose of the assessment study, ESAC shall be assumed as the SOC.

The definition of the roles and responsibilities of the SOC will be detailed in [AD8].

9.4 Ground Stations

R-OGS-110 All aspects of the EChO mission shall be compatible with the network of ESA ground stations.

9.5 Spacecraft Autonomy

R-OGS-120 The S/C shall support autonomous (without ground contact) operations according to a mission timeline uploaded from ground.

R-OGS-130 The S/C shall support re-scheduling of planned events in the mission timeline by ground command.

R-OGS-140 The S/C shall support interruption of the mission timeline execution by ground command.

R-OGS-150 During LEOP, the S/C shall be able to operate nominally without ground contact for at least 12 hours.

R-OGS-160 In all mission phases after LEOP, the S/C shall be able to operate nominally without ground contact for at least 7 days, without any loss of science data.

R-OGS-180 In all mission phases after LEOP, the S/C shall be able to survive without ground contact for at least 11 days.

10 PRODUCT ASSURANCE

Application of ESA approved standards (including ECSS) related to PA is required in R-SYS-030.

11 PROGRAMATIC

11.1 Technology Readiness

R-PROG-010 The TRL definitions shall be as from [RD3].

R-PROG-020 All mission related units (LV, space and ground segment) shall have a TRL 5 by the end of the definition phase (Phase A/B1).

End of Phase A/B1 is expected towards the end of 2014.

R-PROG-030 The mission design shall ensure a low development risk for phases B2 and beyond.

R-PROG-040 European equipment shall be preferred as far as practicable.

European equipment shall be preferred to non-European equipment with an equivalent performance. If European equipment does not meet the requirements, a non-European alternative can be sought.

11.2 Schedule

R-PROG-050 The mission plan shall be compatible with the launch date defined in R-MIS-020.

R-PROG-060 The flight units of the payload instruments shall be delivered at least 24 months before the start of the launch campaign.

These 24 months already include a 6 months ESA contingency.