DOCUMENT

EChO Mission Requirements Document

Prepared by	**EChO Team**
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APPROVAL

Title EChO Mission Requirements Document	
Issue 3	**Revision** 2
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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
MRD slimmed, with only proper mission requirements. All subsystem level requirements are moved to the SRD.	3	1	September 2013
Comments from the PRR have been incorporated.	3	2	December 2013

CHANGE RECORD

Issue 3	**Revision** 2		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Update of noise and photometric stability requirement with new values of X and Nmin	23/09/13		
Updated lifetime from 5 to 4 years	23/09/13		
Addition of subsection on modes	23/09/13		
Addition of post-operations phase	23/09/13		
Addition of DV for de-commissioning	23/09/13		
Addition of MR-MIS-041	23/09/13		
Update of reliability requirement	23/09/13		
Update of ground contact requirements	30/09/2013		
Addition of Standby mode	December 2013		
Addition of S/C design constraint from Sun illumination in LEOP	December 2013		

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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/B1 (estimated at the end of 2015) 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:

MX-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 Applicability

Each requirement is applicable to either the S/C prime industrial contractor, the instrument consortium or the ground segment (or a combination of these 3). This is indicated by S/C, I or GS.

Requirements applicable to the S/C only are flown-down into the SRD. Requirements applicable to the S/C and the instrument are budgeted into the RJBD. Requirements applicable to the ground segment will be flown-down into the Ground Segment Requirements Document, the MAD and the SOAD.

1.2.4 Explanatory Text

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

1.3 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.

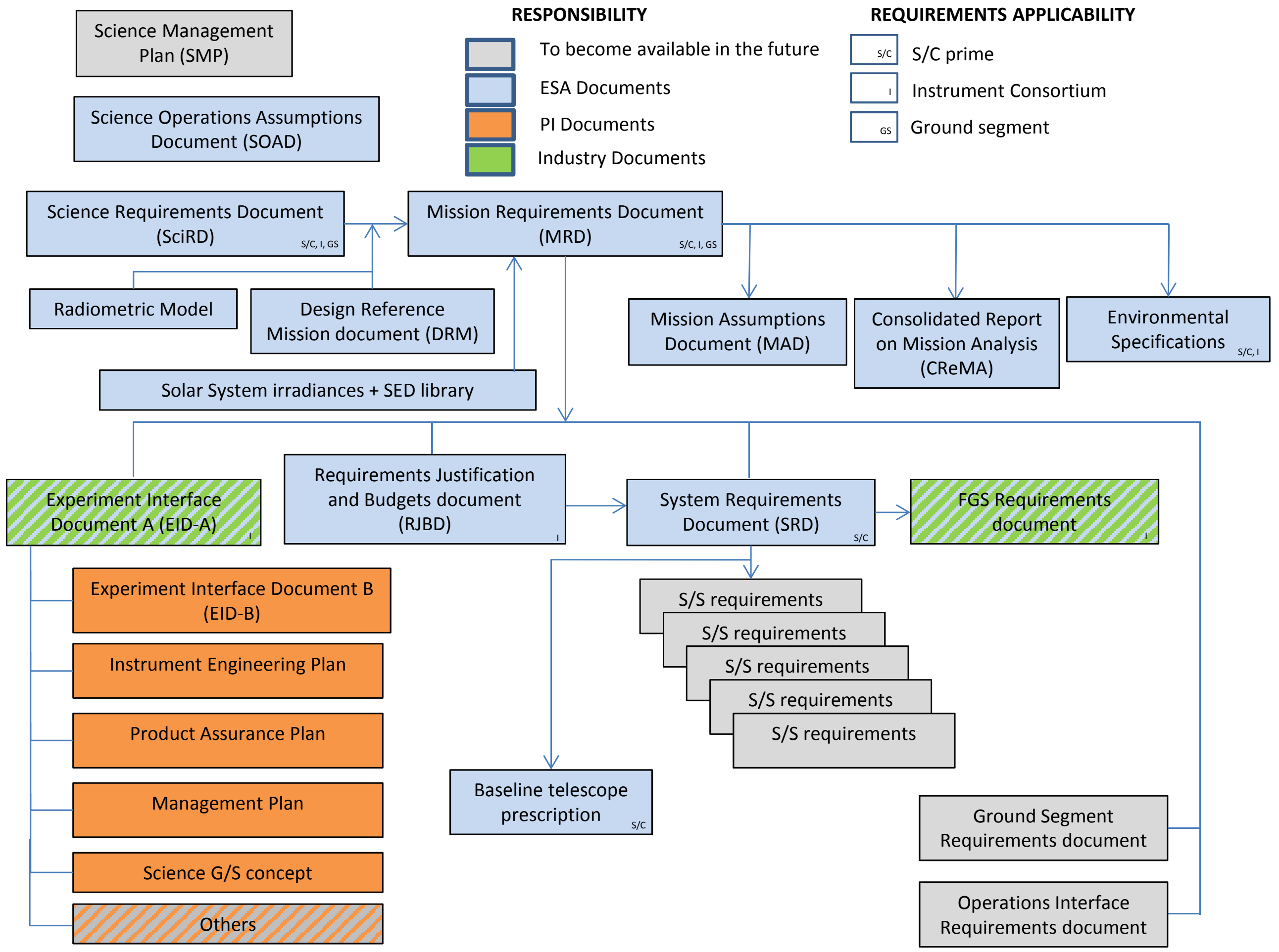

Figure 1: EChO document tree

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

1.3.1 *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), DHSO-MGT-MAD-1010-HSO-OSA
[AD8] EChO SOAD (Science Operations Assumptions Document), EChO-SA-Dc-0001
[AD9] EChO environmental specifications, JS-1-12
[AD10] Space debris mitigation for Agency projects, ESA/ADMIN/IPOL(2008)2
[AD11] EChO definitions and acronyms, SRE-F/2013.065/
[AD12] EChO CReMA, MAS working paper N 590

1.3.2 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 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 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 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 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:

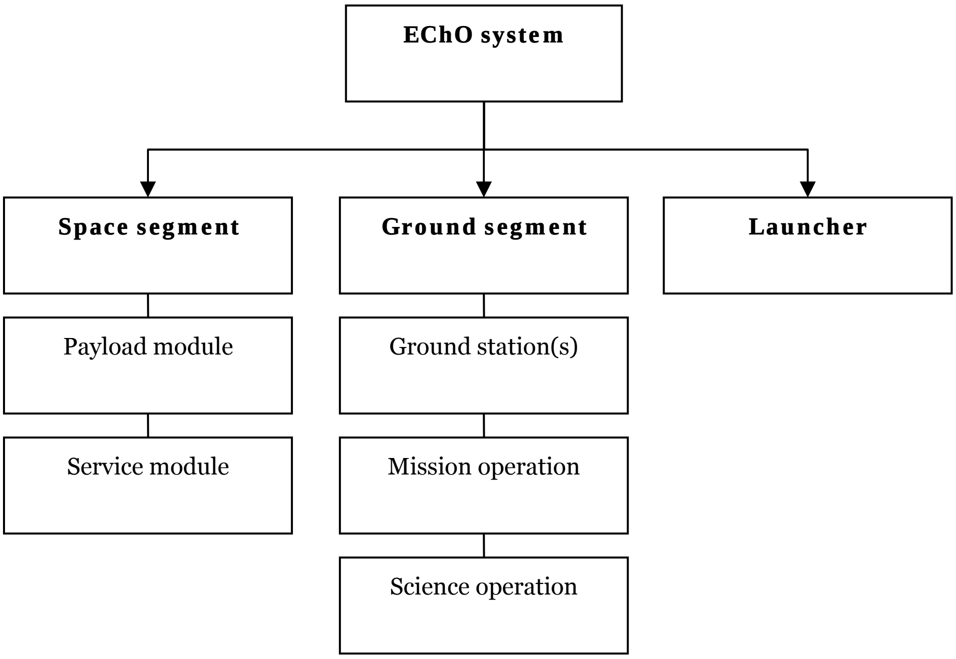

Figure 2: EChO system product tree

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

The PLM mainly consists of the telescope assembly, 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 data (science and S/C housekeeping) 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 planning and scheduling of observations, pointing re-construction, instrument performances follow-up, step-by-step science quality control of observations, pipeline data processing, user support and operation of the science archive. Several of these activities will be done 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.).

2.3 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 9. 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 **Error! Reference source not found.** 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 REQUIREMENTS

3.1 Launch vehicle, site and date

Applicability: S/C - I

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

Applicability: S/C – I - GS

MR-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

Applicability: S/C - I

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

Applicability: S/C – I - GS

MR-MIS-040 The science operations orbit shall be an eclipse-free (Earth and Moon) orbit around the Sun-Earth L2 point, with an amplitude no larger than 1.5 million km in all directions, restricting the Sun-S/C-Earth angle to ≤ 45 degrees.

Applicability: S/C – I - GS

MR-MIS-041 The launch window shall ensure that between fairing jettisoning and S/C – LV separation, the Sun does not remain:

- above the PLM (i.e. in the $+Z_{EChO}$ hemisphere) for more than 10 minutes
- in the exclusion angles defined in R-PERF-030 for more than 25 minutes

In practice, this requirement with MR-MIS-040 means that there are daily launch windows between 14h and 15h30, apart from a ~1 month period around both equinoxes.

3.3 Mission phases

Applicability: S/C – I - GS

MR-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
8	Post-Operations Phase

3.3.1 Pre-launch phase

Applicability: S/C - I

MR-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

Applicability: S/C - GS

MR-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.

Applicability: S/C - I

MR-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.

Applicability: S/C

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

Applicability: S/C - GS

MR-MIS-100 After separation from the LV, the S/C shall autonomously activate one of its transmitting channels and its 2 receiving channels to allow the ESA ground station network to establish the first contact.

Applicability: S/C – I

MR-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 MR-MIS-100.

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

3.3.3 Transfer, commissioning and performance verification phases

Applicability: S/C - GS
MR-MIS-120 The transfer phase shall be from the end of LEOP to the insertion into the science operations orbit as defined in MR-MIS-040.

Applicability: S/C - GS
MR-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.

Applicability: S/C – I - GS
MR-MIS-131 The instrument performance verification and science demonstration phase shall be completed within 6 months of the LV – S/C separation.

Applicability: S/C - GS
MR-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 MR-MIS-040 are verified.

Applicability: S/C - GS
MR-MIS-150 During the commissioning phase, check-out of the spacecraft functions and verification of all subsystems' performances shall be performed.

Applicability: S/C –I - GS
MR-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

Applicability: S/C - I
MR-MIS-170 The nominal science operations phase shall start from the end of the instrument performance verification and science demonstration phase.

Applicability: S/C - I
MR-MIS-180 The extended science operations phase shall start from the end of the nominal science operation phase.

Applicability: GS
MR-MIS-181 The post operations phase shall start from the end of the extended science operations phase and last for 2 years (TBC). In the case that there is no extended science operations phase, the post operations phase shall start at the end of the nominal science operations phases.

3.3.5 De-commissioning

Applicability: S/C - GS
MR-MIS-182 The decommissioning phase shall ensure compliance with the Space Debris Mitigation for Agency Projects [AD10].

3.4 Mission lifetime

Applicability: S/C - I - GS
MR-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 4 years.

Applicability: S/C - I - GS
MR-MIS-200 The extended mission lifetime (the extended science operations phase), shall have a duration of at least 2 year.

Applicability: S/C - I
MR-MIS-210 During the nominal mission lifetime, all science performance requirements shall be fully met and include all specified margins.

Applicability: S/C - I
MG-MIS-220 During the extended mission lifetime, all science performance requirements should be fully met, without margins.

Applicability: S/C - I
MR-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.

Applicability: S/C -I
MR-MIS-240 The ground lifetime of units which degrade with usage or storage shall include a 50% margin (TBC).

Applicability: S/C - I
MR-MIS-250 All S/C units shall be designed to include a ground lifetime margin of 1 year (TBC) in addition to MR-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):

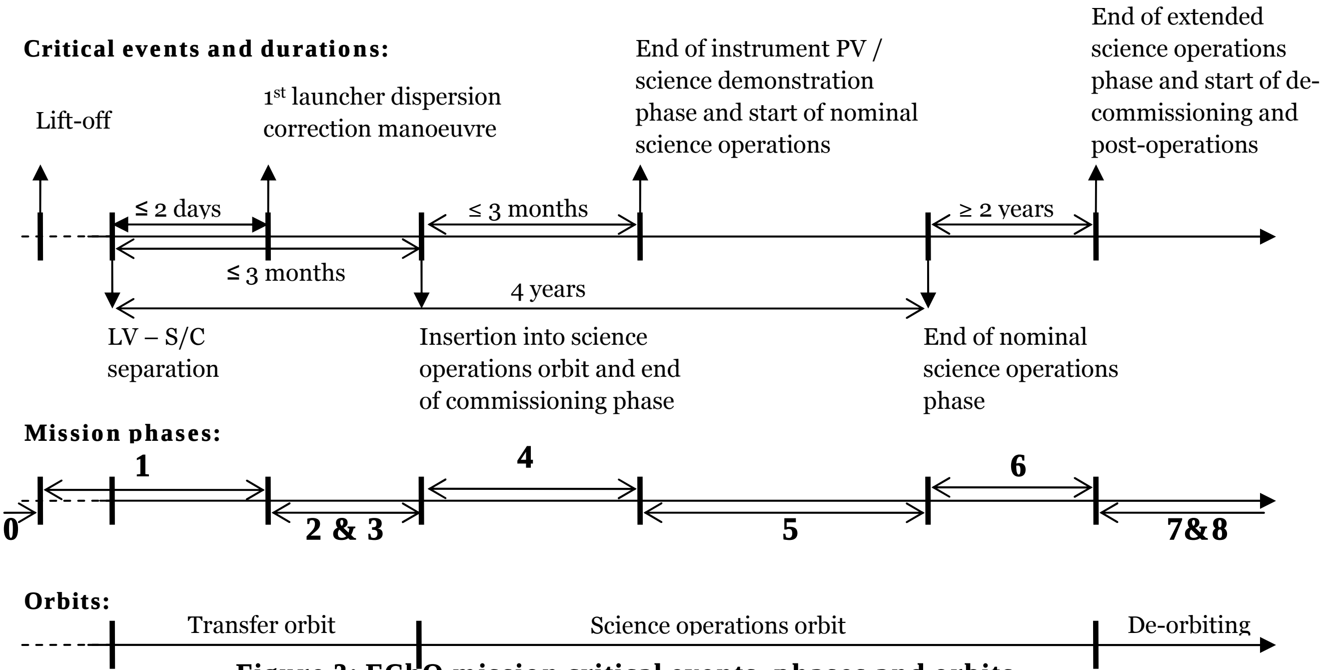

Figure 3: EChO mission critical events, phases and orbits

3.5 Delta V

Applicability: S/C

MR-MIS-260 The following geometrical delta-Vs shall apply (details in [AD12]):

Reason	Delta V	Direction	Time line
Launcher dispersion correction manoeuvres	32.4 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		Executed in the same direction and simultaneously with the previous manoeuvre before day 2.	
Orbit maintenance	8.5 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.
De-commissioning	40 m/s + 10 m/s	28.4° off the Sun direction in the ecliptic plane or opposite. In the direction of the velocity in the rotating frame.	Initial escape manoeuvre + 90 days later

Following margins defined by MR-SYS-020 (i.e. [AD3] R-DV-1), 5% are to be added to the delta-Vs above, apart for the 50 m/s for de-commissioning (no additional margin needed).

3.6 Operations and modes

Applicability: S/C - I

MR-MIS-270 The S/C shall be compatible with the operational space environment, as described in [AD9].

Applicability: S/C - I

MR-MIS-280 During all operational modes, the spacecraft shall autonomously avoid "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
- The telescope or the focal plane detectors are illuminated by the Sun or the Earth (which could cause permanent damage to the S/C)
- Other identified attitudes that impair the S/C and the nominal science operation plan

Applicability: S/C - I

MR-MIS-290 Safe mode:
After a major on-board failure or a violation of the attitude constraints defined in MR-PERF-020, 030 and 040, the S/C shall enter and maintain a safe mode that:

- keeps only the minimum number of units that are necessary to the S/C survival switched on
- 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

Applicability: S/C - I

MR-MIS-295 Standby mode:
The S/C shall enter / remain in a standby mode under the following conditions:

- if successive ground contacts are missed during the period defined in MR-OGS-160, or
- if minor anomalies are encountered which do not require entering into safe mode as defined in MR-MIS-290

This mode shall:

- keep only the minimum number of S/C units that are necessary for S/C survival and active coolers (if any) switched on
- allow communication with Earth

while keeping the attitude constraints defined in MR-PERF-020, 030 and 040.

This mode will ensure science operations can be re-initiated “quickly” (e.g. within few hours) when needed. Other instrument units (e.g. detectors and ICU) can be kept on if justified.

Applicability: S/C - I

MR-MIS-300 Fine pointing mode:
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 noise and photometric stability requirement MR-PERF-350.

Applicability: S/C - I

MG-MIS-310 Coarse pointing mode:
A coarse pointing mode shall allow:

- Acquiring the target star into the FGS before transitioning to Fine Pointing mode
- Observing secondary science targets without the FGS in the control loop. The maximum angular motion of these targets is 10 arcsec/min.

Applicability: S/C - I

MR-MIS-320 De-contamination mode:
A de-contamination mode shall ensure out-gassing and moisture release does not degrade the mission performance at any point during the mission.

This mode is necessary during LEOP and transfer to L2 to prevent contamination of the telescope and focal plane detectors during the initial out-gassing and moisture release of the S/C, but can also be re-used later during the mission lifetime to clean these units from any contaminants that might have accumulated since.

4 SCIENCE PERFORMANCE REQUIREMENTS

4.1 Observation requirements

Axes and references frames are detailed in section 5.1.2.

Applicability: S/C

MR-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.

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-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.

Applicability: S/C - I

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

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-PERF-070 An average observation shall be defined as the observation of a single science target for 3.7 hours, separated by 90 degrees from the previous and the next science targets (TBC).

Applicability: S/C - I

MR-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.

Applicability: I

MR-PERF-090 The faintest star that EChO shall be designed to observe is 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

Applicability: I

MG-PERF-100 The faintest star that EChO should be designed to observe is 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

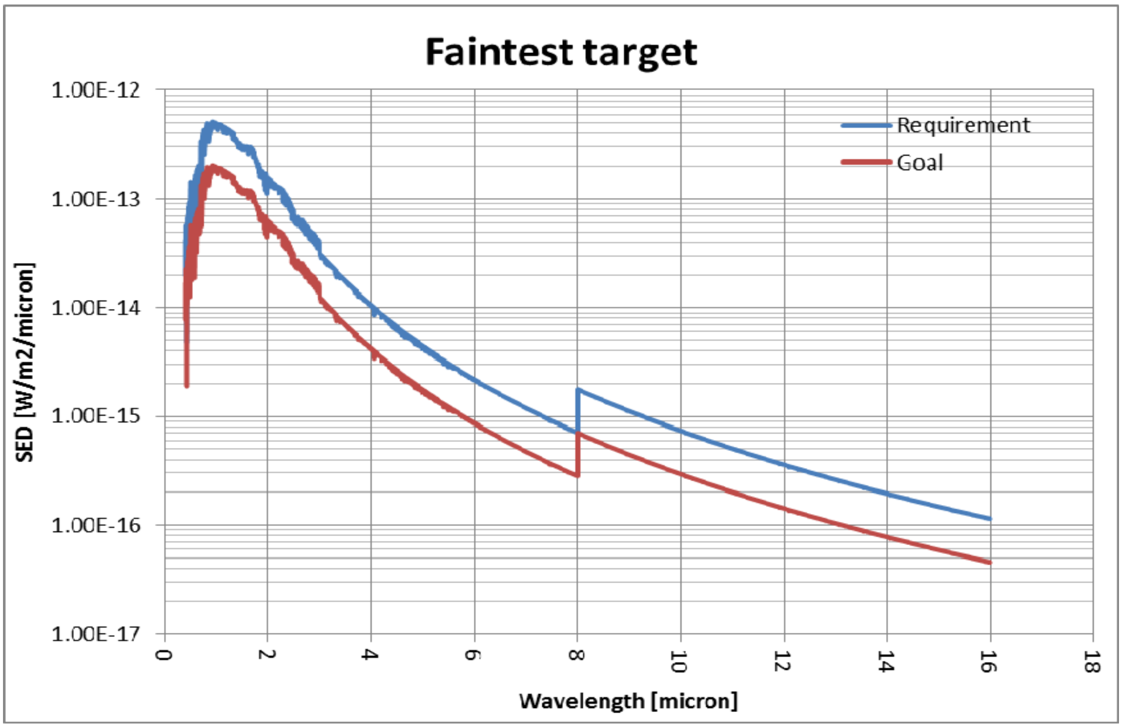

Figure 4: EChO faintest targets spectral irradiance at entrance pupil

Applicability: I

MR-PERF-110 The brightest star that EChO shall be designed to observe is 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

Applicability: I

MG-PERF-111 The brightest star that ECHO shold be designed to observe is 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

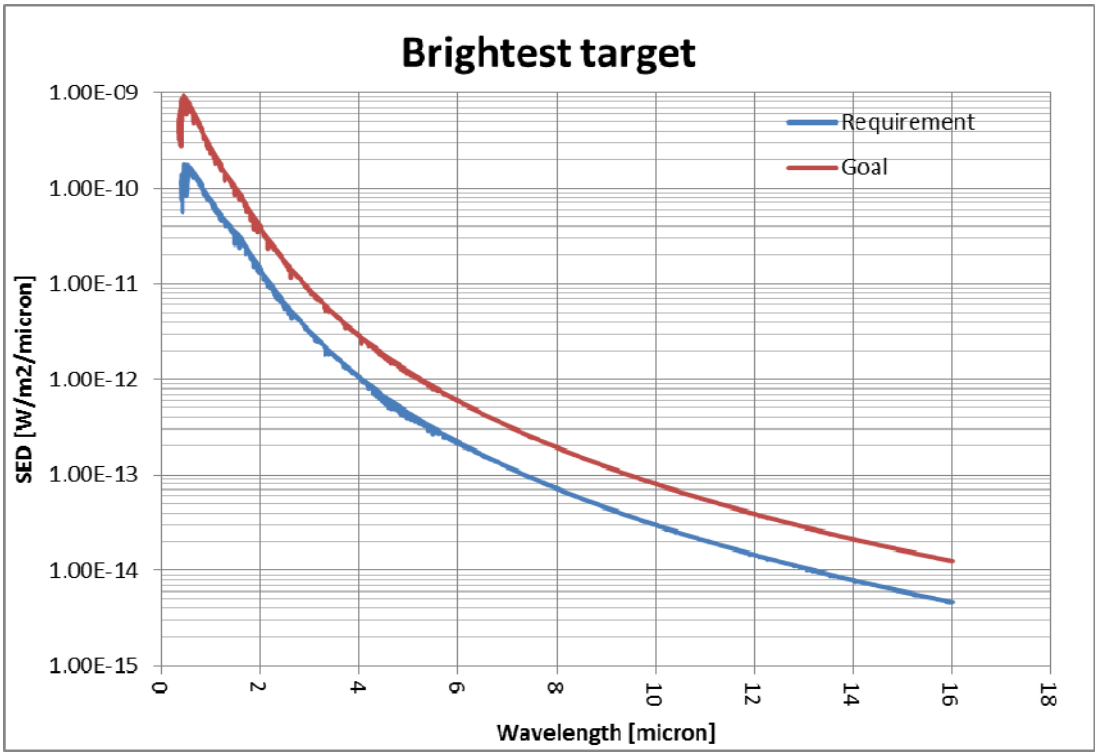

Figure 5: EChO brightest targets spectral irradiance at entrance pupil

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

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-PERF-150 The payload shall cover the 0.55 to 11 microns wavelength range without any gaps.

Applicability: S/C - I

MG-PERF-160 The payload should cover the 0.4 to 16 microns wavelength range without any gaps.

Applicability: I

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

Applicability: I

MG-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.

Applicability: I

MR-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 MR-PERF-190.

Applicability: I

MR-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.

Applicability: I

MG-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 MG-PERF-160

Applicability: I - GS

MR-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.

Applicability: S/C - I

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

- ≥ 1.131 x 0.23 x 0.50 = 0.130 [m^2.e-/photons] above 5 microns
- ≥ 1.131 x 0.23 x 0.70 = 0.182 [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.

Applicability: S/C - I

MR-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 MR-PERF-190) shall be no less than 80% of the figure of merit defined in MR-PERF-240.

Applicability: S/C - I

MR-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 MR-PERF-190) shall be no less than 50% of the figure of merit defined in MR-PERF-240.

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

Applicability: I

MR-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):

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

Applicability: I

MR-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).

This is only required where the background is not negligible.

Applicability: I

MR-PERF-260 Spectral sampling shall be commensurate with the Nyquist-Shannon criterion, i.e. at least two samples between adjacent resolution elements separated by $\Delta\lambda$ as defined in MR-PER-190.

Applicability: I

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

Applicability: I

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

Applicability: I

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

Applicability: I

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

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

Applicability: I

MR-PERF-350 The system level noise (after post-processing, taking into account all noise sources plus photometric variations in the frequency band [2.8x10^{-5} – 3.7x10^{-3} Hz]) shall be lower than X times the astronomical noise floor (defined by the square sum of the stellar and zodiacal background shot noises) plus an absolute noise floor N_{min}. The total noise $Noise_{TOTAL}$ shall then be less than:

$$Noise_{TOTAL} \leq \sqrt{(N_0 + zodi) \times (1 + X) + N_{\min}}$$
$$= \sqrt{(N_0 + zodi) + X \times (N_0 + zodi) + N_{\min}}$$
$$= \sqrt{N_0 + zodi} + \sqrt{N_0 + zodi} \times \left(\sqrt{1 + X + {N_{\min}}/{(N_0 + zodi)}} - 1 \right)$$

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 MR-PERF-390.

N_{min} shall be equal to:

- 20 [e-/s/spectral bin] below 5 micron
- 200 [e-/s/spectral bin] above 5 micron

and X shall be equal to:

- 200% (TBC) under 1 micron.
- 50% 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):

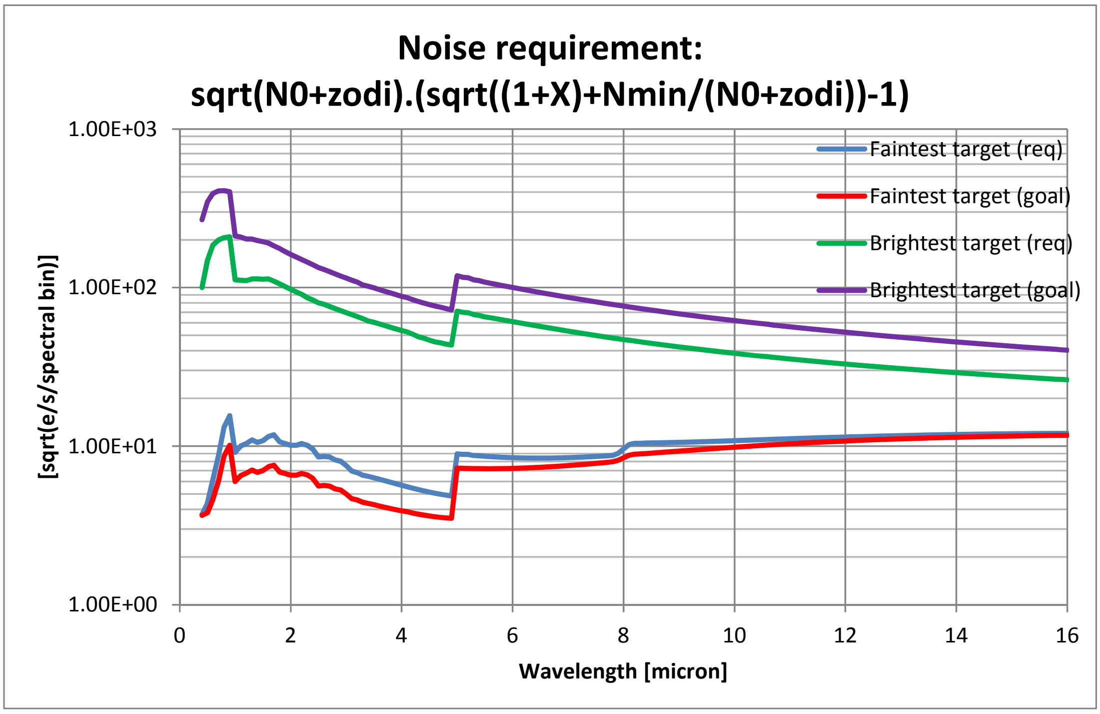

Figure 6: Noise requirement (to be summed linearly with the noise floor)

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

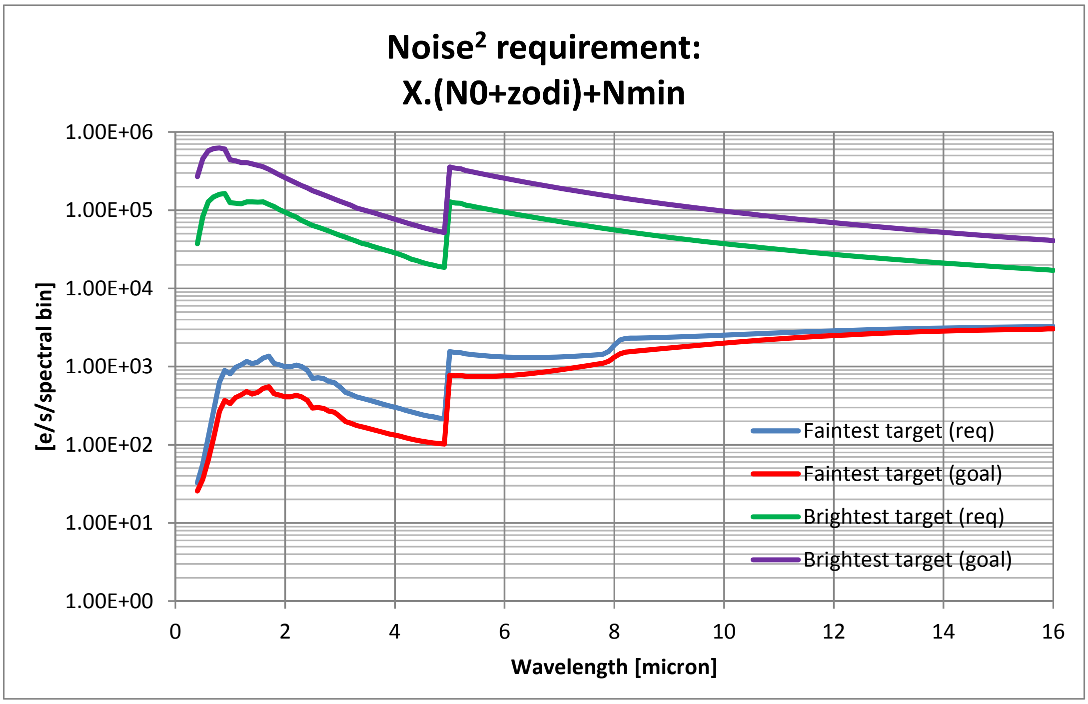

Figure 7: Square of noise requirement (to be summed in RSS with the noise floor)

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

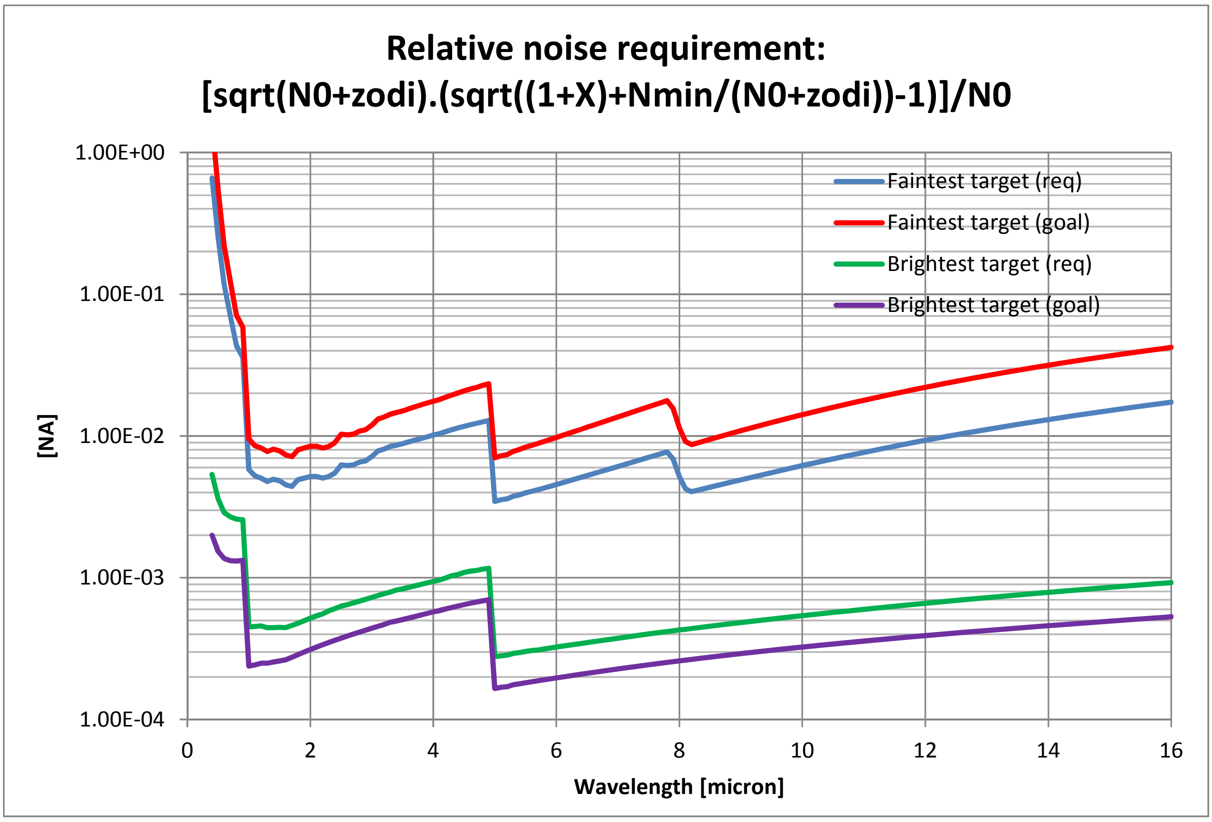

Figure 8: Relative noise requirement

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

This noise definition is extensively detailed in [AD2].

The frequency band is sized to contain all effects which vary within time scales of 270 s to 10 hours (longest time required for the observation of a transit).

Applicability: I

MG-PERF-351 As MR-PERF-350, with the frequency band for the photometric variations extended to cover [3.8×10^{-6} – 16×10^{-3} Hz].

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

Applicability: I

MR-PERF-360 Neighbouring sources which fall within the instrument FoV around target stars shall make a negligible contribution to the noise budget defined in MR-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.

Applicability: I

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

Applicability: I

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

Applicability: I

MR-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 DESIGN REQUIREMENTS

5.1 System requirements

5.1.1 Standards

Applicability: S/C - I

MR-SYS-010 The SI international system of units shall be used. Radians, degrees and arcseconds are acceptable as angular 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.

Applicability: S/C – I - GS

MR-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.

Applicability: S/C - I

MR-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

Applicability: S/C - I

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

The frames defined below are illustrated in Figure 9.

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-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.

Applicability: S/C - I

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

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-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 $+Z_{E\text{-}TEL}$.

Applicability: S/C - I

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

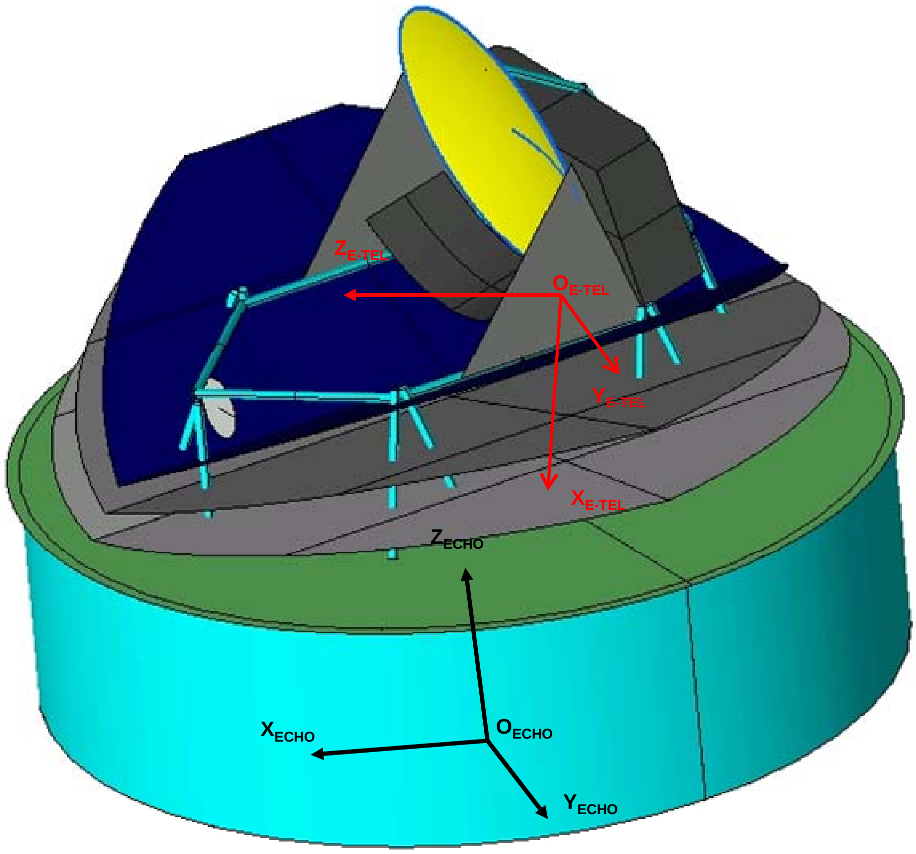

Figure 9:Definition of the EChO reference frames

5.1.3 Sun illumination constraints

MR-SYS-125 During the periods defined in MR-MIS-041, the S/C design shall be tolerant to the Sun in any possible direction in the X_{EChO}-Y_{EChO} plane.

5.1.4 Spacecraft mass

Applicability: S/C - I

MR-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 2160 kg.

5.1.5 Reliability and fault management

Applicability: S/C - I

MR-SYS-140 The overall reliability of the mission, from after LV separation till the end of the nominal lifetime, shall be:

- > 85 % including all science channels up to 1 micron (±0.1 micron)
- > 82 % including all science channels up to 5 micron (±0.3 micron)
- > 80% including all science channels up to 11 micron (±0.3 micron)

Applicability: S/C – I - GS

MR-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.

Applicability: S/C - I

MR-SYS-160 Retention in the 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.

Applicability: S/C - I

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

Applicability: S/C - I

MR-SYS-180 The failure of an individual instrument channel shall not lead to a safe mode of the S/C.

Applicability: S/C - I

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

Applicability: S/C - I

MR-SYS-200 The design shall allow the identification of on-board failures and their recovery by autonomously switching to a redundant functional path. Where this can be accomplished without risk to spacecraft and instrument 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.

Applicability: S/C - I

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

Applicability: S/C - I

MR-SYS-220 In case of anomalies or failures from which an autonomous recovery is not possible, the S/C shall enter a Safe Mode to ensure S/C and instrument survival.

Applicability: S/C - I

MR-SYS-230 For design and analysis purposes, an average of 2 safe mode events of 2 days (plus recovery time) each per year shall be considered.

These can be triggered by either S/C or instrument failures.

5.2 Mechanisms

Applicability: S/C - I

MR-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.

Applicability: S/C - I

MR-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 MR-MECH-030 and MR-PERF-350.

Applicability: S/C - I

MR-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.

5.3 FGS

Applicability: S/C - I

MR-AOCS-040 A Fine Guidance Sensor (FGS) shall be implemented within the PLM, using the light focussed by the telescope, to meet the pointing stability requirement defined in MR-MIS-300.

Applicability: I

MR-AOCS-050 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.

6 OPERATIONS AND GROUND SEGMENT

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

6.1 Operations

Applicability: S/C - I - GS
MR-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.

6.2 Mission Operation Centre

Applicability: S/C - GS
MR-OGS-020 The EChO mission shall have a single MOC. For the purpose of the assessment study, ESOC shall be assumed as the MOC.

Applicability: S/C - GS
MR-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.

Applicability: S/C - GS
MR-OGS-040 The MOC shall perform all communications with the S/C through the ground stations.

Applicability: S/C - GS
MR-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

Applicability: GS
MR-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].

6.3 Science Operation Centre

Applicability: S/C - I - GS
MR-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].

6.4 Ground Stations

Applicability: S/C - GS

MR-OGS-110 All aspects of the EChO mission shall be compatible with the network of ESA ground stations and the NASA DSN.

6.5 Spacecraft Autonomy

Applicability: S/C - I - GS

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

Applicability: S/C - I - GS

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

Applicability: S/C - GS

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

Applicability: S/C - I - GS

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

Applicability: S/C - I - GS

MR-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 or housekeeping data.

Applicability: S/C - I - GS

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

Applicability: S/C - I - GS

MR-OGS-190 During the science operations phase, the ground contact duration and frequency shall be 14 hours per week, spread over 4 ground contacts. Among these:

- The full 14h are required for Doppler tracking.
- 4 x 15 min are required for ranging.
- 3.5 hours shall be allocated to the telecommand/timeline uplink and downlink of science and housekeeping telemetry. In average conditions, this time shall be divided into 2 contacts per week that are to be scheduled with a ±5 hours flexibility in order to allow the optimisation of the scheduling of the science observations (i.e. time constrained exoplanet observations).

Doppler tracking can be done simultaneously with ranging or science TM, but ranging cannot be done simultaneously with science TM. In addition, Doppler tracking and ranging can be achieved with LGAs, but science TM requires a HGA. If done in this way, the only time to be taken out of the observation efficiency are the 3.5 hours of science TM (plus slew time), if done with a fixed HGA (and with LGAs that cover the full sky whatever the S/C attitude).

7 PROGRAMATIC

7.1 Technology Readiness

Applicability: S/C - I
MR-PROG-010 The TRL definitions shall be as from [RD3].

Applicability: S/C – I - GS
MR-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 2015.

Applicability: S/C – I - GS
MR-PROG-030 The mission design shall ensure a low development risk for phases B2 and beyond.

Applicability: S/C - I
MR-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.

7.2 Schedule

Applicability: S/C – I - GS
MR-PROG-050 The mission plan shall be compatible with the launch date defined in MR-MIS-020.

Applicability: I
MR-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.