DOCUMENT

ECHO Payload Definition Document

Prepared by	**ECHO Team**
Reference	**SRE-PA/2011.039/**
Issue	**3**
Revision	**0**
Date of Issue	**14/09/2012**
Status	**For information**
Document Type	**TN**
Distribution	

APPROVAL

Title ECHO Payload Definition Document	
Issue 3	**Revision** 0
Author ECHO Team	**Date** 14/09/2012
Approved by	**Date**

CHANGE LOG

Reason for change	Issue	Revision	Date
Update from MTR/MBSR	2	3	13.07.2012
Update for Instrument AO 2012	3	0	14.09.2012

CHANGE RECORD

Issue 3	Revision 4		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Updated reference design Update of Instrument allocation Remove MRD requirements Update of instrument budgets Derivation of S/C requirements with new reference design	20.01.2012		5 4 3 6 7/8
- Update I/F requirements with information available from ECHO MBSR and MTR - Change telescope description from Cassegarin to new baseline Off-Axis-Korsch afocal telescope - Replace ESA reference instrument design by MPIA led design and UCL/RAL lead design - Delete chapter 6&7, now included in chapter 5	12.07.2012		4 5.1 5.2 &5.3
- Remove I/F requirements in chapter 4 now covered in EID-A - Expand chapter 5 to include the generic description and structure of the EChO payload previously covered in chapter 4	14.09.2012		4 5, 5.1., 5.2. 5.3

Table of contents

1 INTRODUCTION

1.1 Scope

This document aims at providing the description of the EChO reference payload complement.

The payload complement comprises the following elements:

- The telescope.
- The common optics, common in the sense that all alternative instrument designs must use this same set of fore-optics.
- The instruments:
    - The science instrument, defined as a spectrometer covering the complete wavelength range required in [AD1]. This wavelength range is split into different science channels.
    - The Fine Guidance Sensor (FGS, acting as a non-scientific instrument), also required in [AD1] to answer the pointing needs of the spacecraft.

It is also important to highlight that not all elements of this payload complement are applicable to all partners: specificities are foreseen with each partner, i.e. industry and instrument team(s) will have different responsibilities.

1.2 Reference documentation

1.2.1 Applicable documents

[AD1] EChO MRD (Mission Requirements Document), SRE-PA/2011.038/
[AD2] EChO PDD (the present document), SRE-PA/2011.039/
[AD3] EChO radiometric model description, SRE-PA/2011.040/
[AD4] “Margin philosophy for science assessment studies”, SCI-PA/2007/022/
[AD5] List of “ESA approved standards”, Issue 3.1
[AD6] “Soyuz, from the Guiana space centre, user’s manual”, Issue 1.0

1.2.2 Reference documents

[RD1] EChO SciRD (Science Requirements Document), SRE-PA/2011.037/
[RD2] ESA pointing error engineering handbook, ESSB-HB-E-003
[RD3] Technology Readiness Levels handbook, TEC-SHS/5551/MG/ap, v1.6
[RD4] E2V website, imaging sensors datasheets, http://www.e2v.com/products-and-services/high-performance-imaging-solutions/space---scientific-imaging/imaging-sensor-datasheets/.
[RD5] Teledyne website, visible and infrared sensors, http://www.teledyne-si.com/infrared_visible_fpas/index.html.
[RD6] Raytheon website, vision systems, http://www.raytheon.com/businesses/ncs/rvs/Products/index.html.

[RD7] “JWST Near-Infrared Spectrograph (NIRSpec) Calculating the Nominal Sensitivity of NIRSpec”, ESA-JWST-AN-342
[RD8] ”JWST Prototype ETC User Manual”, jwstetc.stsci.edu/etcstatic/JWST_ETC_UG.pdf
[RD9] EChO baseline telescope for Phase 0, SRE- F/2012.069/
[RD10] ECHO EID-A, SRE-F/2012.097/

1.3 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
FW	Full Well capacity
GS	Ground Segment
GSE	Ground Support Equipment
ICC	Instrument Control Centre
I/F	Inter/Face
JWST	James Webb Space Telescope
LEOP	Launch and Early Operations Phase
LoS	Line of Sight
LV	Launch Vehicle
HgCdTe	Mercury Cadmium Telluride detector
MIRI	Mid Infra-Red Instrument on JWST
MPE	Mean Performance Error
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
PRE	Performance Reproducibility Error
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
SOC	Science Operation centre
SoW	Statement of Work
SSAC	Space Science Advisory Committee
SST	Study Science Team
SVM	SerVice Module
TC	TeleCommand
TM	TeleMetry
TRL	Technology Readiness Level
TT&C	Telemetry, Tracking & Command subsystem

1.4 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 bafflesc. It does not contain any assumptions on the reflectivity of the mirrors (contained within the total throughput).

Instruments: The science instrument 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 reflectivity (the reflectivity of M1, M2 and M3 combined).

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.

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 : $R=\lambda/\Delta\lambda$

Secondary eclipse: 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.

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.

2 SYSTEM ARCHITECTURE OVERVIEW

2.1 Spacecraft Architecture

Following the initial work during the industrial studies, a horizontal configuration has been adopted for the remaining part of the Phase 0, similar to the configuration studied by ESA and shown below.

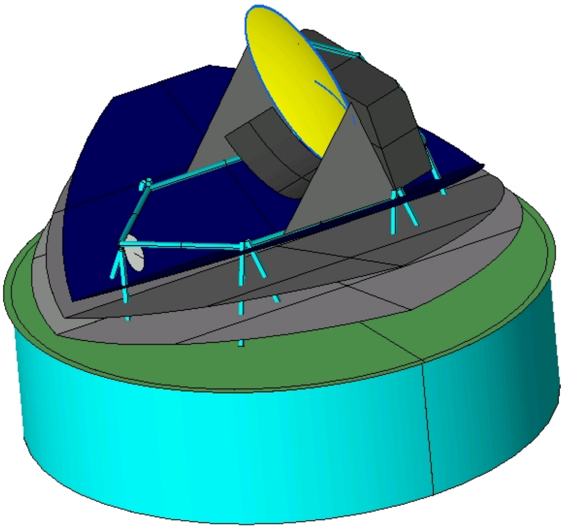


Figure 1 Example of a horizontal accommodation of the ECHO baseline off-axis telescope. The primary and secondary mirrors of the telescope are shown without any surrounding structure.

The volume left for the instrument boxes is behind M1, enabling late access and integration of the instruments and direct view to deep space to provide direct radiative cooling to deep space for critical elements such as the detectors. As an alternative, mounting the Instrument box on the side of the telescope might be considered. The Sun is located below the platform. The V-grooves and volumes are designed to accommodate a ±36 degree angle clearance with respect to the Sun vector.

To achieve the required photometric stability, a good pointing stability needs to be provided by the spacecraft during one observation. For this purpose, a Fine Guidance Sensor looking to the target star in parallel to the instruments will be accommodated on the payload and used by the AOCS.

2.2 Reference Payload complement

The EChO reference payload complement consists of:

- The reflective Off axis afocal Korsch telescope, which uses 3 mirrors M1, M2 and M3 plus flat folding mirrors to redirect the beam to the instrument compartment.
- The common optics, which include:

  - a 1st dichroïc mirror separating the wavelengths above and under 0.8 µm (later referred to as DM Vis)
  - a 1st Beam Splitter dividing the visible light into 2 optical paths for the science visible channel and the FGS.
- The instruments:
  - The science instrument, split into several channels
  - The FGS

The baseline design for each of those payload elements are detailed in the following chapters, with chapter 5.2 & 5.3 providing a generic overview of the Instrument. Chapter 5.4 and 5.5 provide the outcome of the two parallel instrument studies performed in Phase 0

While the extent of the wavelength range of the science instrument is a requirement (0.55µm to 11µm required and 0.4µm to 16µm as a goal) , the cut-offs between each successive channel are design dependent and hence subject to evolution. Each channel is isolated using dichroïc mirrors, while the FGS is separated from the 1st science channel thanks to a beam splitter.

On top of these payload elements, some payload support equipment is also necessary. Of critical importance is the cryogenic chain necessary:

- To sufficiently cool the telescope and the instrument box(es) for thermal background reduction. This is assumed to be achievable by passive means (or with a negligible amount of extra cooling power required by the active cryo-coolers.
- To sufficiently cool the detectors for dark current reduction. This is assumed to be achieved by a combination of passive/active cryo-cooling means.

3 INSTRUMENT PERFORMANCE REQUIREMENTS

The instrument performance requirements applicable to the design of the EChO payload complement are all defined in the EChO MRD [AD1].

4 PAYLOAD INTERFACE REQUIREMENTS

In addition to the instrument performance requirements described in the previous chapter, it is necessary to establish a set of payload interface requirements, which are described in the EChO EID-A [RD10]

5 REFERENCE PAYLOAD COMPLEMENT

The EChO reference payload complement is shown in the figure below:

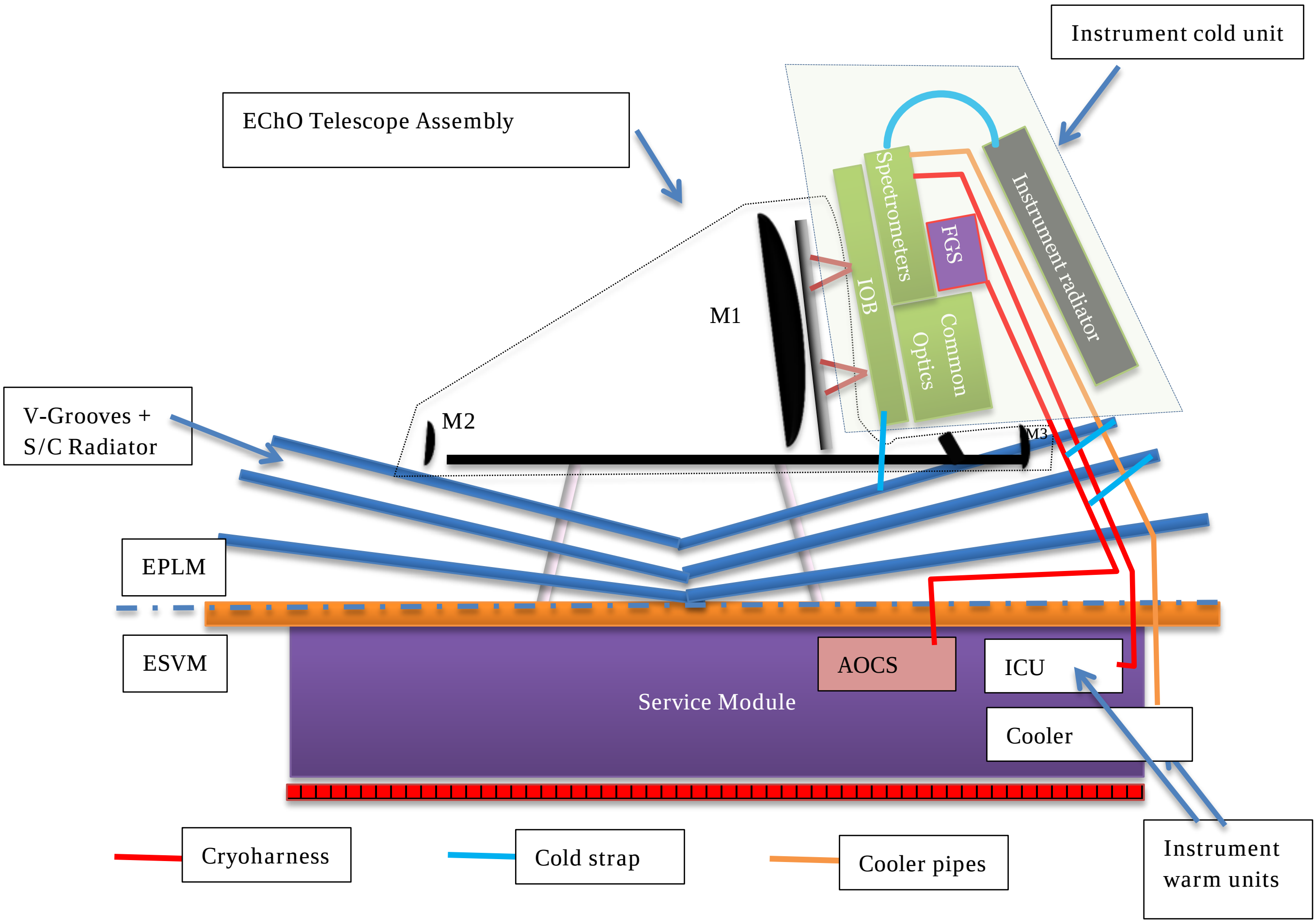


Figure 2 ECHO Reference Payload complement

Since EChO is observing in the infrared, the telescope and instrument needs to be cooled to cryogenic temperatures, which is achieved by passive cooling via a radiator, isolated from the warm spacecraft by V-Grooves shields similar to Planck.

In addition to the science instrumentation, A Fine Guidance Sensor (FGS) is included in the PLM to guarantee that the stringent pointing requirements of EChO can be achieved.

5.1 Baseline telescope

Following an internal trade-off at ESA, with the input from industries and instruments, an Afocal Korsch Off axis telescope has been selected as a baseline configuration for the EChO mission.

The main parameter of the telescope are as follows:

- Off axis Korsch
- Entrance pupil diameter 1286.5 mm
- Exit pupil diameter 36.5915 mm
- Effective focal length (for a 300mm focal length focusing lens) 10568.3055 mm

Figure 3 provides a scaled illustration of this telescope. An ideal focussing lens is included in the system to allow showing image quality in terms of spot diagrams in subsequent sections. In addition, two flat folding mirrors are added to accommodate the Instruments behind the primary mirror and to provide a dedicated mirror for fine steering. Pending the detailed accommodation and need for a Fine steering mechanism, the number and position of these flat mirrors can change.

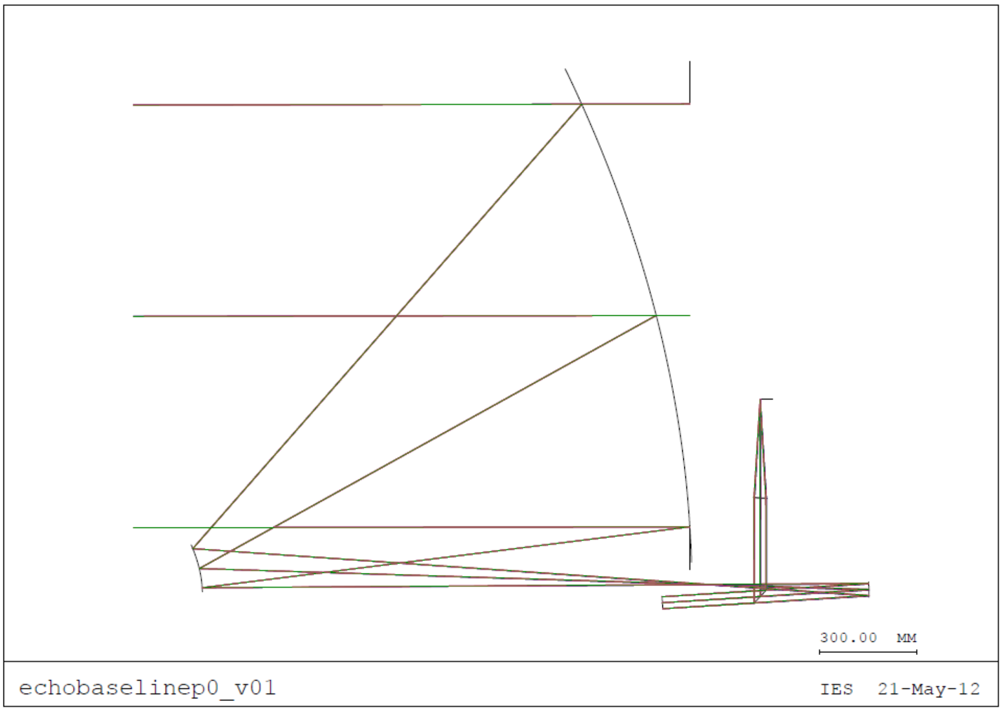


Figure 3: Scaled drawing of the baseline telescope for the Phase 0 study of EChO.

Figure 4 provides a 3D view of the telescope. The point of view is from the back of the primary towards the field of view of the telescope. The beam in blue corresponds to the light reflected by the pick-up mirror. This beam is displaced laterally from the vertical axis of symmetry of the telescope, as can be seen in the picture.

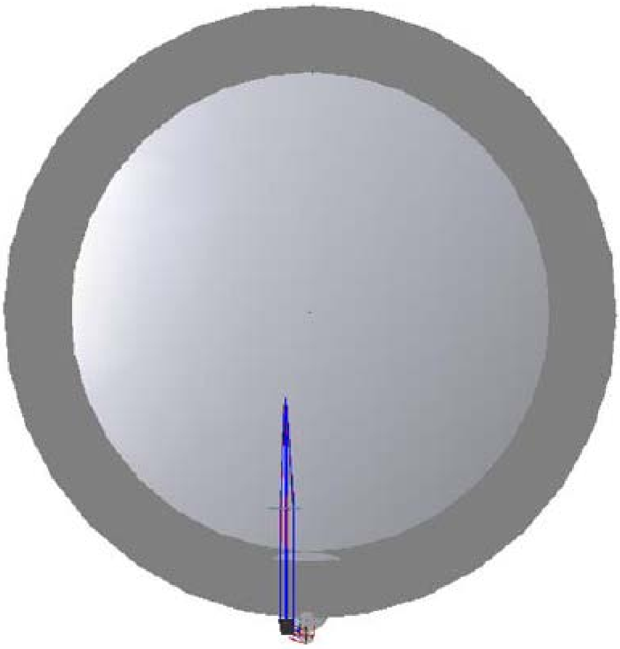


Figure 4: 3d view of the baseline telescope

A detailed optical description of the telescope is provided in RD9.

Taking into account that EChO is not an imaging mission and to limit the constraints on manufacturing and polishing of the telescope, a diffraction limited performance at 5µm should be considered for the optical design. The optical quality required at shorter wavelengths is still tbd.

The telescope is integrated into the EChO Telescope Assembly which include:

- primary Mirror M1
- secondary mirror M2
- tertiary mirror M3
- Telescope Mounting Structure (TMS) serving as:
  - An interface to the SVM.
  - A structural support on which to mount the telescope.
  - A structural support from which to mount the IOB.
  - Support structure for M1, M2 and M3
- If required, any mechanism on M2 (e.g. refocusing mechanism)
- Any flat fold mirrors (with eventual fine steering mechanism)
- Thermal control (e.g. decontamination heaters, radiators)
- Baffles for straylight and contamination control, if required

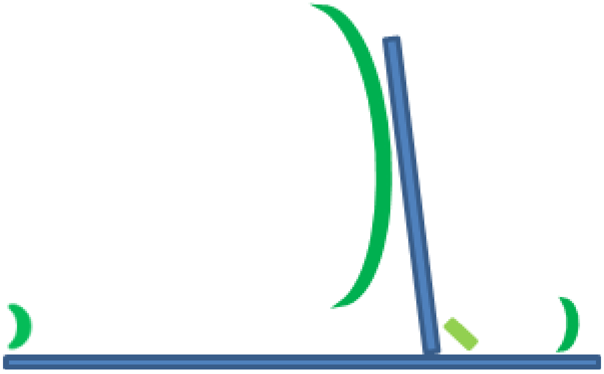


Figure 5 EChO Telescope Assembly (ECTA)

5.1.1 ECTA *Mass*

The preliminary mass allocation of the ECTA is:

Item	Mass [kg]	Margin (%)	Mass incl. Margins [kg]
TMS	Tbd	20	Tbd
Baffle (including stiffener and support)	Tbd	20	Tbd
Primary mirror support	Tbd	20	Tbd
Secondary Mirror support	Tbd	20	Tbd
Refocusing mechanism	Tbd	20	Tbd
Primary Mirror	40	20	44
Secondary mirror	2	20	2.5
Tertiary Mirror	2	20	2.5
Total	220	20	264

5.2 Instrument cold unit on the PLM

The instrument cold unit is mounted behind the primary mirror, including the following elements:

- The IOB, on which all cryogenic payload elements will be mounted:
  - Common optical elements to all channels (e.g. DM Vis and 1st beam splitter).
  - Dichroic chain to distribute the light between the various instrument boxes
  - The science instrument 'boxes' for the various wavelengths
    - Spectrometer (e.g. prism/gratings) and camera
    - Low noise Detectors (e.g. MCT/ Si:As) and FEE (or part of it)
    - Shielding/Baffling
    - Thermal control
  - Internal calibration system.
  - The FGS box.
- Instrument radiators to passively cool part of the instruments

- Active cooler elements mounted on the V-Grooves
- Thermal shielding
- IOB support structure to mount the IOB on to the TMS. The support structure has to consider that the ECTA and IOB might not be the same material.

The science instrument 'boxes' contain at least:

- The spectrometer (e.g. prism/grating)
- Camera(s) to image the spectrum onto the detector
- Baffling/ Field stops etc for straylight control
- The low noise focal plane detectors (e.g. MCT/Si:As) relative to each science channel.
- The FEEs (or part of it) of these detectors, taking into account the limited cooling power available at cryogenic temperatures
- The following interfaces:
    - Structural interface to allow mounting on the IOB.
    - Thermal interface at detector level on which to attach the thermal straps that will connect with the cold finger(s) of the cryogenic chain(s) or the dedicated instrument radiators.

5.2.1 *Mass of instrument cold unit*

The preliminary mass allocation of the elements is:

Item	Mass incl. Margins [kg]
IOB including support	≤30
Science Instrument Boxes	≤30
Common Optics (including support)	≤10
FGS	≤6
Thermal Shielding, Instrument Radiators, coldfingers	≤15
Cooler elements mounted on V-Grooves	≤10
Total	≤101

Table 1 Instrument mass budget

5.2.2 *Cryo-cooling*

For temperatures between 35K and 45K required by the instruments (e.g. detector cooling), an instrument provided radiator mounted on the IOB should be considered with a direct view to deep space. This radiator can be mounted on the backside of the IOB as shown in Figure 6.

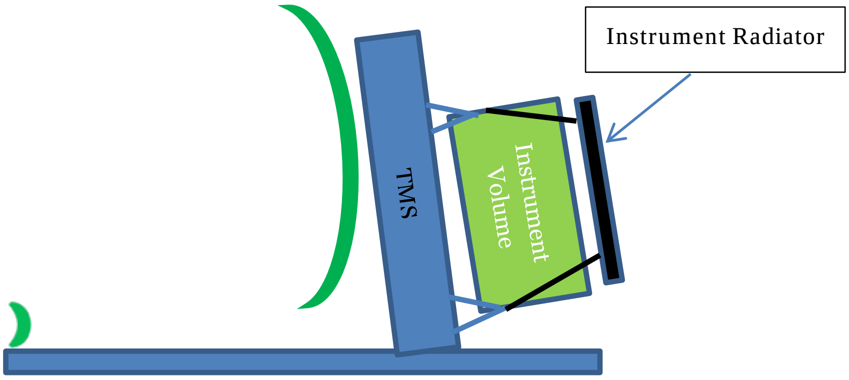


Figure 6 Example of Instrument Radiator accommodation

For temperatures below 35K , active cooling is strongly recommended, since passive cooling at such low temperatures is considered very challenging and has not been achieved by any European mission.
Considering available European cooler technology, the cooling powers available are:

- ≤ 20 mW at 4 K (requiring ~50mW pre-cooling at 18K)
  - Planck 4K JT cooler (RAL) using a compressor at room temperature
  - 4K sorption cooler (University of Twente), requiring large radiator area at 50K
- ≤ 100-200 mW between 18 K-35K
  - 2-Stage Stirling/Pulse Tube coolers using a compressor at room temperature
  - H2 sorption cooler (University of Twente) requiring radiator area at ~ 90-120K

In addition, the following should be considered:

- The different focal plane detectors and intermediate temperature levels that are actively cooled by a common cryo-cooler should be connected to a common I/F on the IOB (i.e. the cryo-cooler cold finger) by thermal straps,
- The cryogenic I/F's of any active cryo-cooler should be located on the IOB.
- The harness and JT cooler will be thermalised on the V-Groove radiator
- There is only limited passive cooling power available on the intermediate thermal shields of the V-Groove to thermalize harnesses, tubing and active coolers.

5.2.3 Calibration equipment

Since calibration requirements are still TBC in [AD1], additional hardware might be added within the instrument volume.

o

5.3 Instrument Warm Units on the SVM

5.3.1 Warm Electronics

Electronics which cannot be located inside the cryogenic part of the PLM will be located within one or several boxes located inside the SVM. As a minimum the following functionality should be included:

- Instrument Control
  - Main Bus power conversion
  - Housekeeping
  - Instrument control (data acquisition, thermal stabilisation, calibration ...)
- Digital Data processing, in case this cannot be performed by the S/C computer
- Detector Electronics (warm part)
- Cooler Drive Electronics (as a separate unit)

5.3.2 Cooler elements

Elements of the active cooling chain which might be required to cool part of the detectors to temperatures below 7K and which requires ambient temperatures for operation (e.g. JT mechanical compressors, Stirling/Pulse Tube pre-cooler) can be located inside the SVM.

5.3.3 Mass/Power Instrument warm units

The mass of the science instrument electronics should be ≤ 40kg, For the cryocoolers including the drive electronics, the total mass inside the SVM should be less than 75kg.

The power required by all EChO science instrument electronics should be ≤ 100 W
For the Cryocoolers including Drive Electronics, the required power should be less than 250W,

5.4 Reference science instrument MPIA

5.4.1 Science instrument

Figure 7 provides a block diagram of the optical path of the instruments and their accommodation inside the telescope.

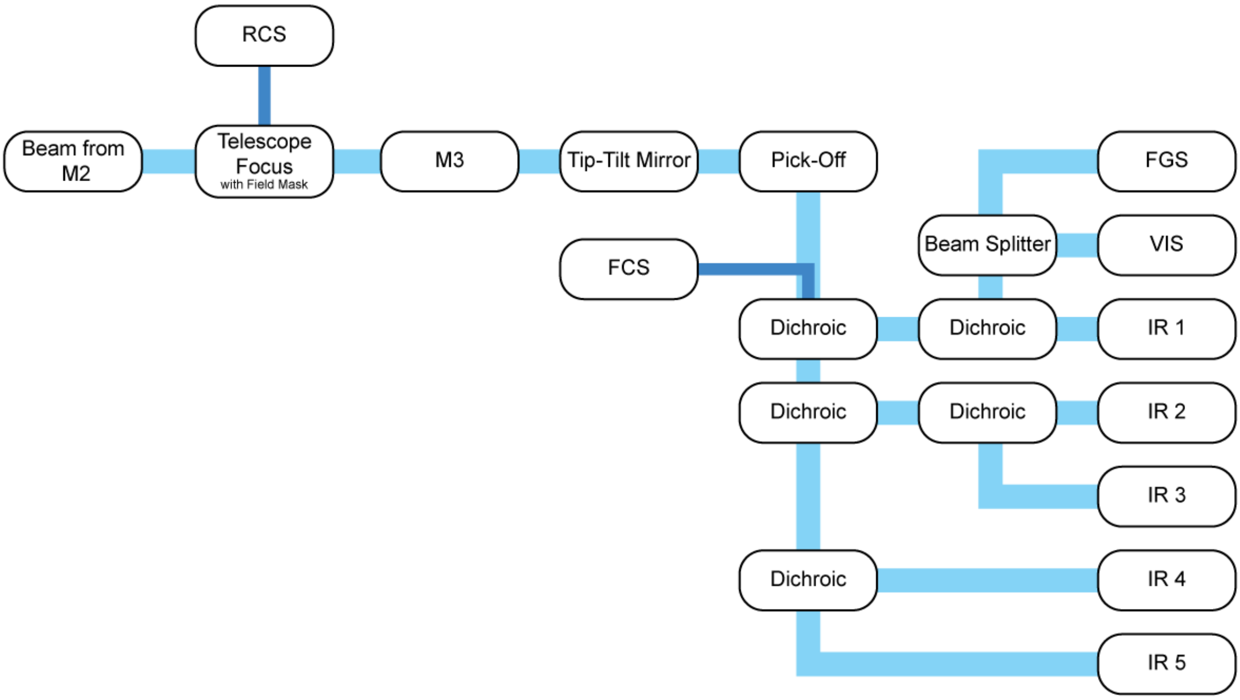


Figure 7: Block diagram of the optical path of the EChO instruments

Figure 8 shows the preliminary design for the optical assembly of the EChO science instrument. The instrument is designed as a multi-channel grating spectrograph with all-reflective optics. It is composed of six channels (one VIS and five IR) mounted on a common instrument optical bench. The wavelength regions of these six channels are listed in Table 2.

The instrument IOB also houses the FGS channel (as sketched in Figure 8) which is compatible with the volume allocation.

The field of view is 30” x 13” and is common for all channels as only one field mask is used. The spectral resolving power is at least 300 for all channels.

The baseline for the 0.4 µm to 8 µm wavelength range are passively cooled HgCdTe detectors. For the 9 µm to 16 µm range active cooled Si:As detectors are baseline. The pixel size is 15 µm for the VIS, 18 µm for the 0.7 µm to 5 µm and 30 µm for the 5 µm to 16 µm range. An oversampling of 2 pixel x 3 pixel (spectral x spatial) per FWHM is foreseen.

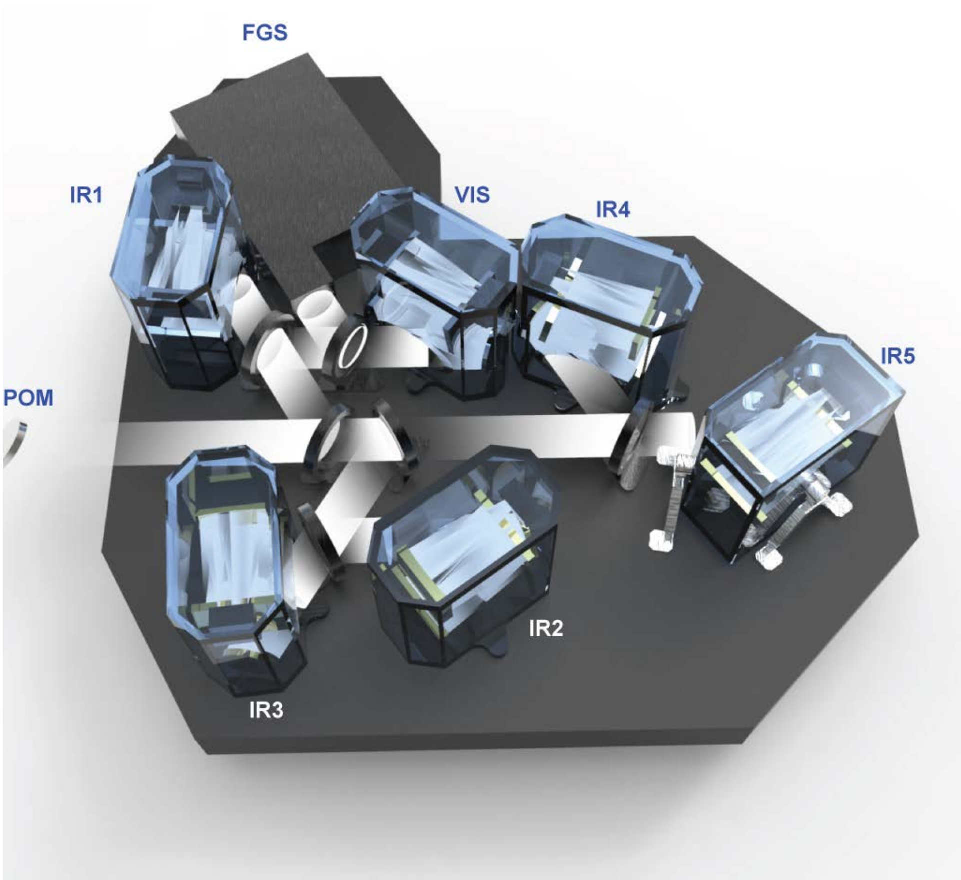


Figure 8: Overview of the optical assembly

Table 2 - Overview of wavelength regions

Channel	Lower limit	Upper limit
Vis	0.4 µm	0.8 µm
IR1	0.7 µm	1.4 µm
IR2	1.32 µm	2.64 µm
IR3	2.58 µm	5.16 µm
IR4	5.0 µm	9 µm
IR5	8.6 µm	11/16 µm

The Instrument is designed in all-aluminium (6061) which has the advantages of easy manufacturing, low cost, high-thermal conductivity and very high heritage.
Figure 9 shows – as an example – the visual TMA. In red the grating with vertical lines is shown. The dispersion direction is perpendicular to the TMA off-axis direction.

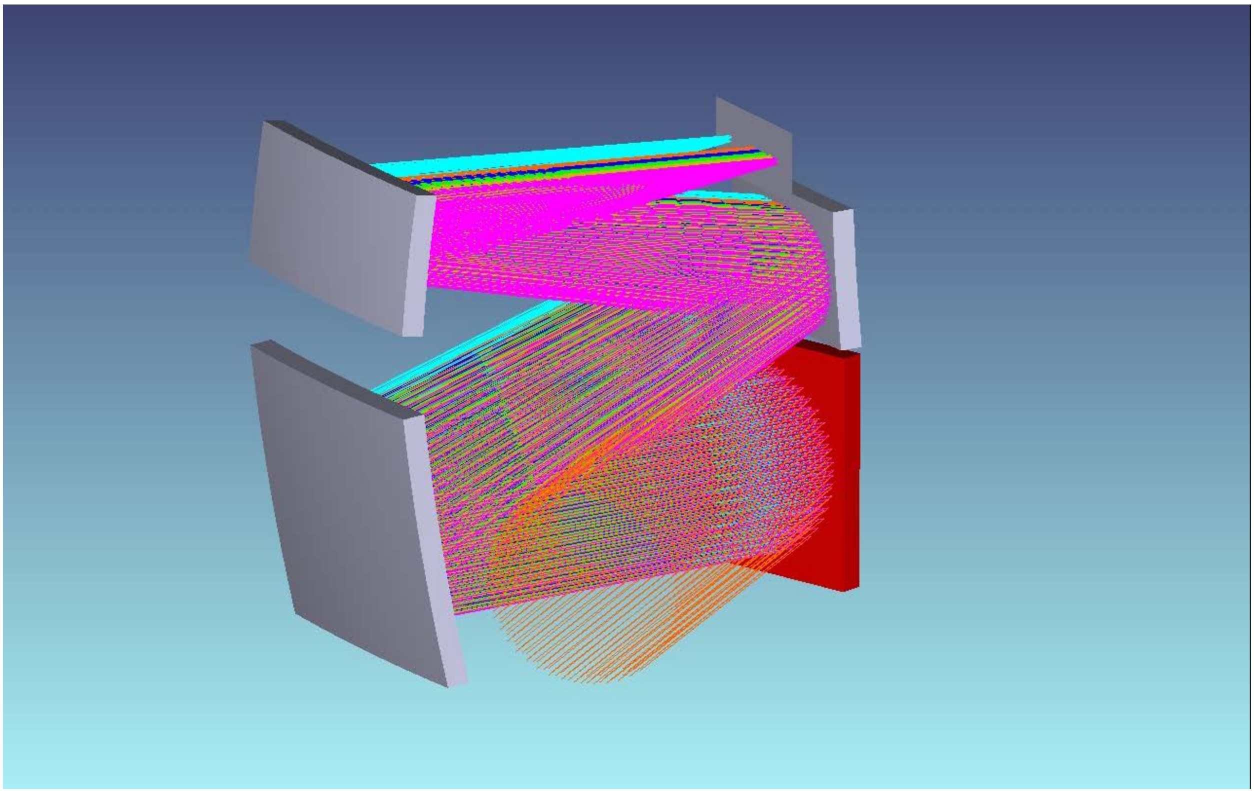


Figure 9 - Camera concept: As an example, the visual TMA is shown, in red the grating with vertical rools.

5.4.1.1 Instrument internal calibration system

The instrument requires an on-board calibration capability to characterize pixel gain variations, both spatially as well as temporarily. For this reason, a Flat-field Calibration Source (FCS) is needed which illuminates the detector arrays homogeneously. The FCS will be injected before the first dichroic mirror to allow a simultaneous illumination of all channels using one source only. The baseline concept I for the FCS is a blackbody source in combination with LEDs for the short wavelength range.

To monitor drifts in the read-out electronics and in the ADC process, a stable Reference Calibration Source (RCS) is required. This source will be imaged next to the sky field as a point source and simultaneous illumination by the science target and the RCS is anticipated, allowing the RCS to be a photometric reference. However, due to programmatic reasons and technical challenges, this source is not baseline but optional.

5.4.2 Cryogenic cooling (passive /active)

Figure 10 describes the thermal layout of the science instrument with active cooling of the IR5 channel with a combination of the RAL Joule-Thomson and the Twente hydrogen sorption cooler as pre-cooler. The 4.5 K stage of the cooler is connected to the detector unit and the 14.5 K stage is responsible for cooling the helium stage and the IR5 channel optics and structure. The 14.5 K stage of the cooler uses the radiators at the thermal shield as heat sink dissipating 5.5 W at 90 K. The MCT-detectors, the calibration unit and the FEE are connected to the instrument and IOB-radiator as shown in **Figure 10**..

The thermal interface is described in chapter **Error! Reference source not found.**.

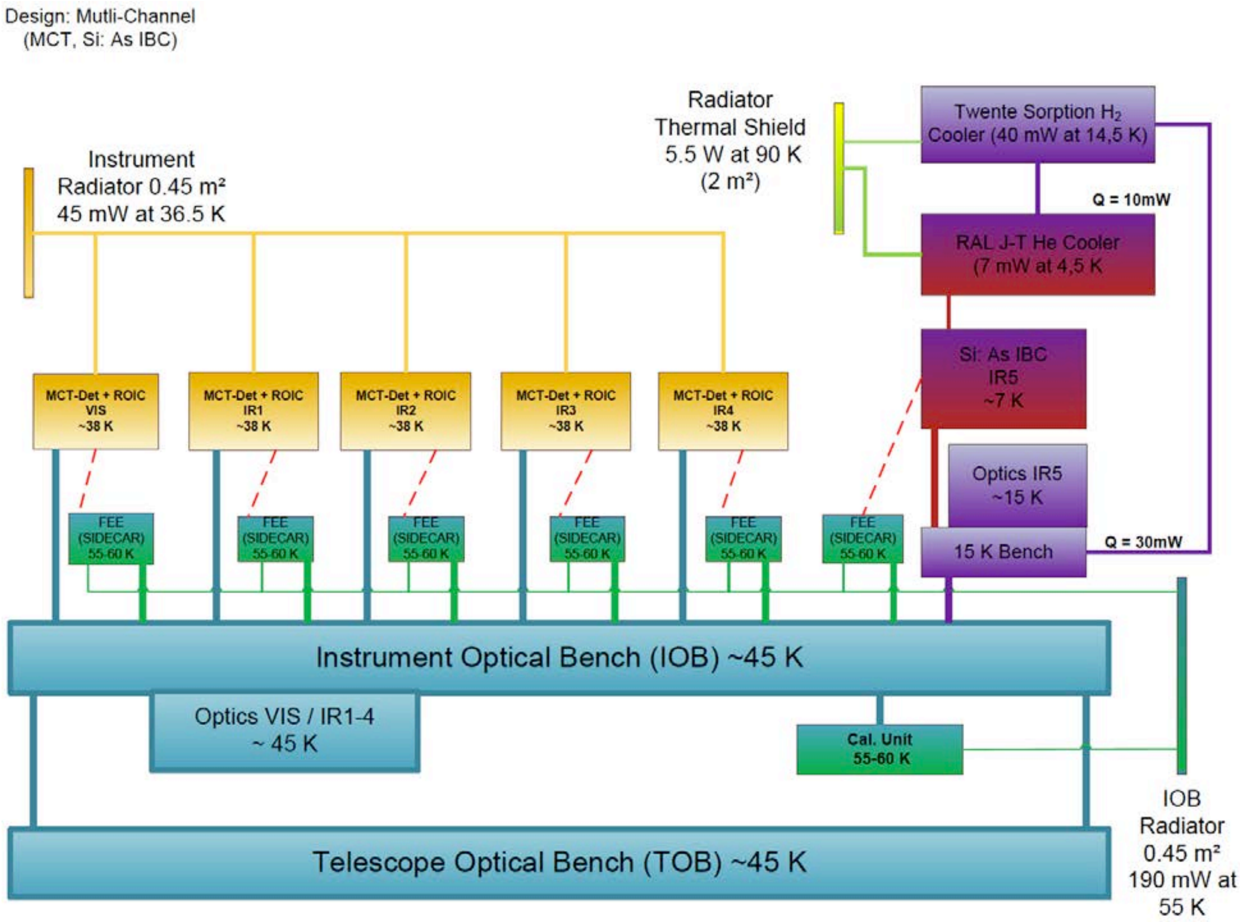


Figure 10: Thermal concept of the EChO science instrument

5.4.3 Instrument electronics/Data handling

Figure 11 illustrates the global instrument electronic architecture. The detector arrays are controlled and read-out through dedicated cryogenic front-end electronics (FEE) which also provides the analog to digital conversion. The digital signal are then further processed by the Instrument Control Unit (ICU), which also controls the house keeping sensors and heaters as well as the calibration sources. The ICU is then connected to the spacecraft computer via a 1355/Spacewire interface.

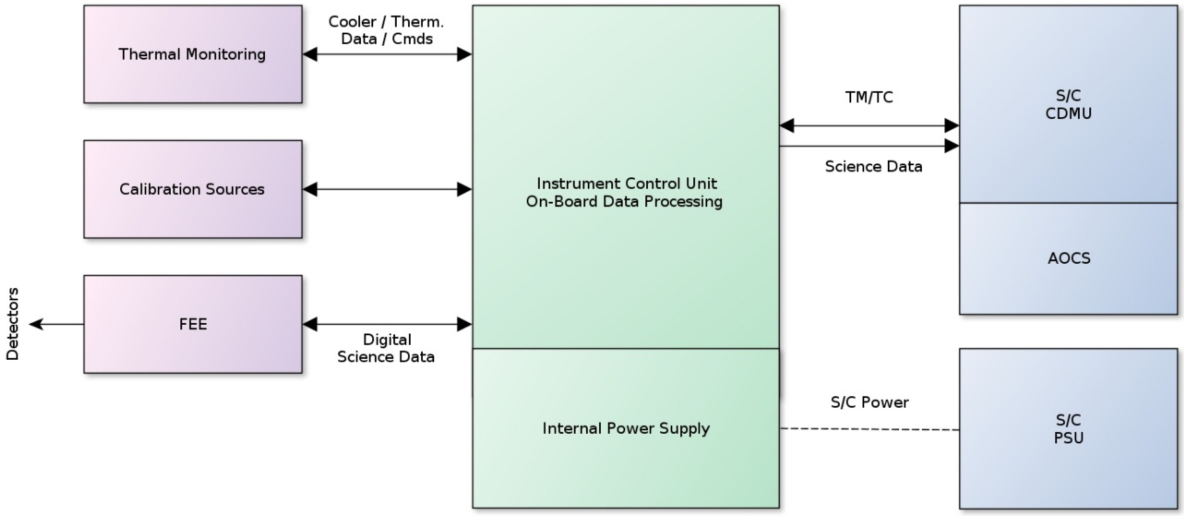


Figure 11 - Overview of the instrument electronics. The cold electronics are shown together with the detectors on the left side of the diagram, the ICU, which is shown at the centre and physically located at the SVM, provides all data handling and control functionality. The ICU is also the instrument interface to the spacecraft.

5.4.4 *Budgets/ Interfaces*

5.4.4.1 Common optics and instruments allocations on the PLM

The optical interface between the telescope and the ESI pre-optics has to be defined at two locations, the telescope focus and the collimated output beam from the telescope. Figure 12 indicates the location of the optical module inside the telescope.

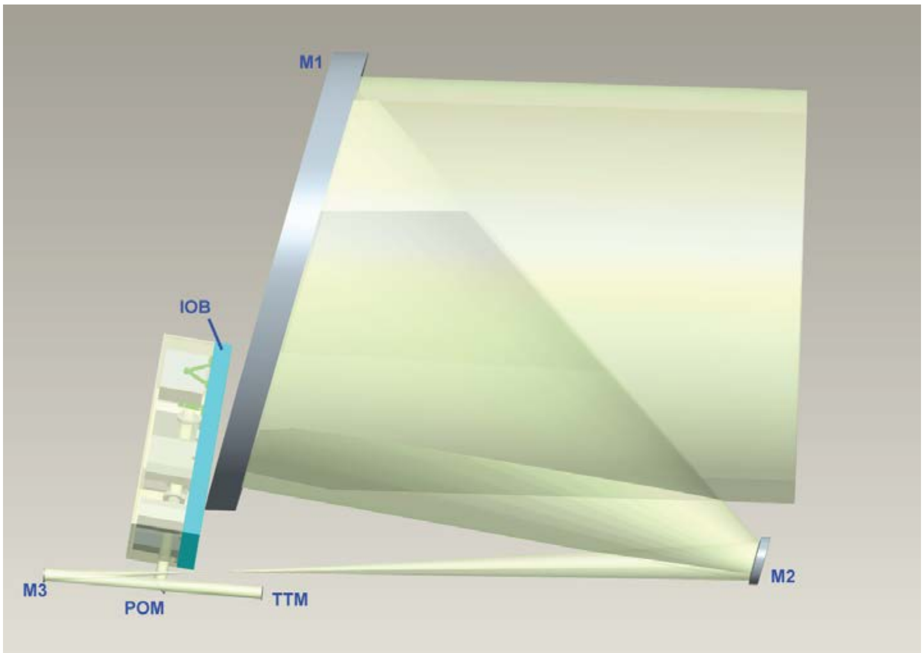


Figure 12: Location of the Optical Module in respect to the telescope

Telescope focus

The optical interface at the telescope focus is defined by the focal mask. The intermediate focus optical interface is described by the following parameters:

- f-ratio 14.365
- focal length: 17238.0 mm
- Pupil position: M2 1500 mm in front of the focal plane
- Central focus position: 116.0 mm in front of M1 (Center), 77.3 mm off axis
- Tilt angle: 2.84 deg

The field mask with its 13”x30” field corresponds to a field mask with 1.086 x 2.507 mm.
In addition, beside to the science beam there will be an interface to an optional calibration source (RCS), which is imaged as a point source to the telescope focus.

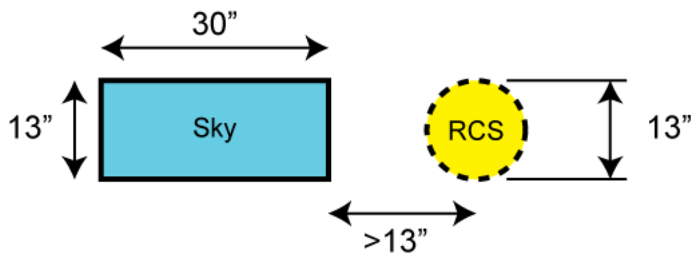


Figure 13 – Field of View of the sky beam and the optional calibration source (RCS).

Telescope output beam

The optical interface between pick-up mirror and first dichroic mirror of the EChO instrument is described by the following parameters:

- Diameter of the collimated beam: 40 mm
- Pupil position at the steering mirror 300 mm in front of the pick-up mirror.

As long as no re-imaging optics is used, the pupil position seen by the spectrograph is 300mm in front of the pick-up mirror.

In addition, the optical quality described in section **Error! Reference source not found.** is not deemed sufficient. Instead, we define the telescope quality required for ECHO in such a way, that the FWHM of the PSF is not significantly enlarged by telescope imperfections and that even for the shortest wavelength of 0.4 micron the scattered part it less than 10%.

Acceptable form errors:

For the shortest wavelengths the telescope is not used at the diffraction limit but the PSF is broadened by de-focussing (or any other low-pass filter). We have modelled the encircled energy for a slightly de-focussed instrument and run Monte Carlo simulations for 200 nm RMS form errors. Assuming 50% of the telescope wave front errors to be generated at M1, the rest being equally distributed over M2-M4, we deduce an acceptable preliminary form error of 100 nm RMS.

Acceptable micro roughness:

Even at 0.4 micron at least 90% of the radiation should go into the specular direction: $\mathrm{Exp}(-(2k\sigma)2) > 0.9$

For 0.4µm this implies $\sigma < 10$nm RMS

<u>FGS</u>
The FGS is currently implemented similar to [AD3] after a beam splitter dividing the 400 – 800 nm beam into two paths (see [AD1]). Therefore, the interface to the FGS can be described by a 40 mm collimated beam. Further details need to be established. In the case of the RCS being injected at the telescope focus, the source would also be imaged onto the FGS.

5.4.5 Volume

Since the telescope structure was not yet defined, mechanical interfaces to the telescope are not yet specified. In Figure 14 and Figure 15 we provide a volume envelope of the Optical Module (OM) compared with the allocated volume from the baseline telescope. Please note that this volume is an estimation for the optical channels only and an increase in volume is expected when the calibration sources, eventual relay optics and cold electronics are implemented.

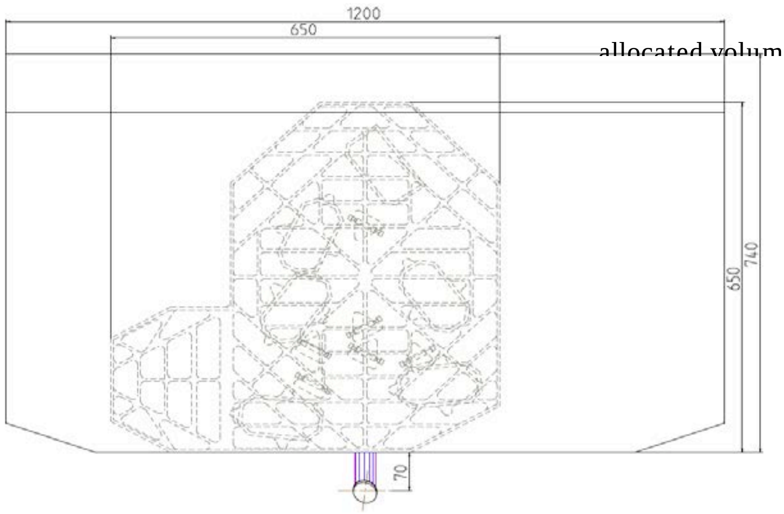


Figure 14: Top View of the OM Envelope compared with the allocated volume

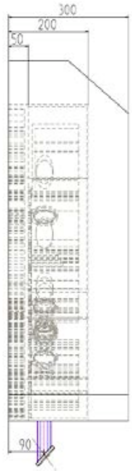


Figure 15: Side view of the OM Envelope compared with the allocated volume

5.4.5.1 Configuration

As shown in Figure 12, the Instrument Optical Bench (IOB) is located behind the M1 mirror. However, it has to be noted that with the current design, the structural interface between the telescope and instrument is challenging, as not much space is available for supporting structural elements of the primary mirror. As soon as the telescope structure is more established, a horizontal configuration of the instrument will be studied as this might allow more design flexibility for a rigid interface.

5.4.5.2 Mass

The preliminary mass allocation of the elements is:

Item	Mass [kg]	Margin (%)	Mass incl. Margins [kg]
IOB including support	27	20	≤60
Science Instrument Boxes	16	See AD4	≤30
Common Optics (including support)	2 / 10 (RD9)	20	≤15
Thermal	30	20	≤30
Active coolers	28	20	
Harnesses	5	20	
Electronic box	34	20	

5.4.6 Cryo-cooling

The thermal interfaces are illustrated in Figure 16. Internal and external interfaces are shown. These interfaces are further specified in Table 3. The thermal interface to the FGS is not yet discussed here.

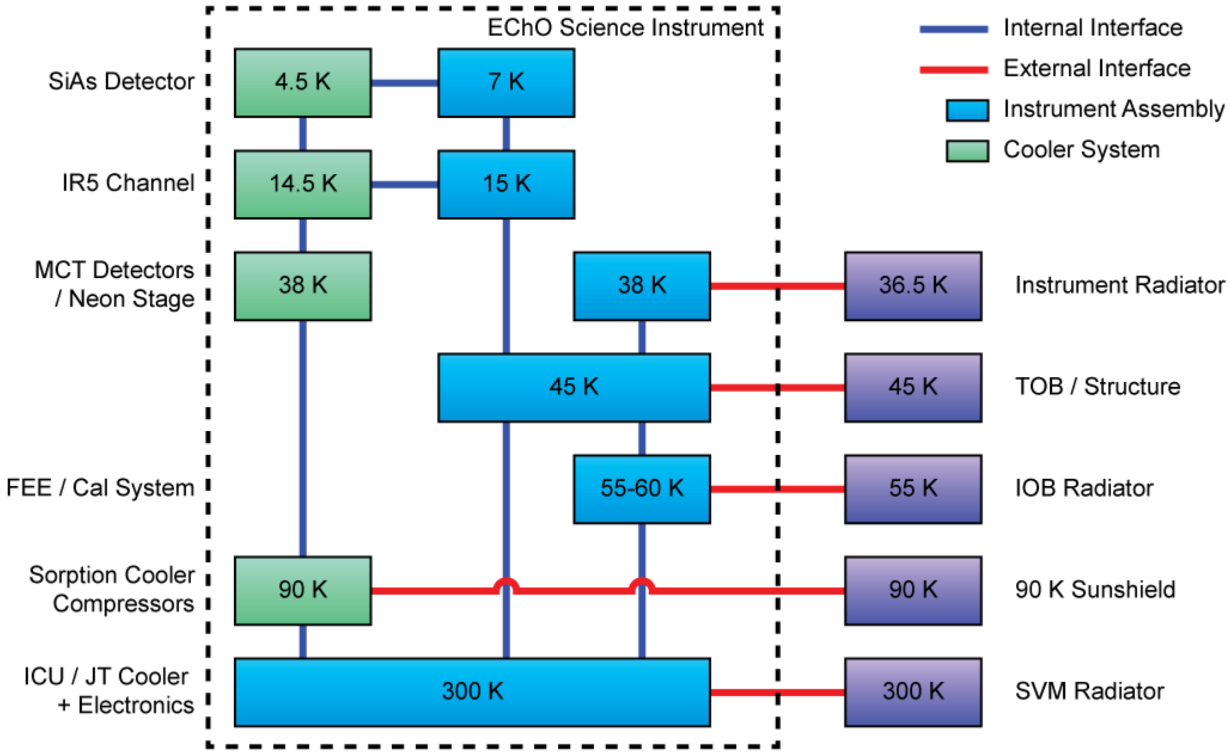


Figure 16 – Internal and external thermal interfaces of the ESI

Table 3 – Definition of ESI external thermal interfaces

External Interface	**Description**	**Thermal Requirement**			
		Q [mW]	T_{ESI} [K]	$T_{interface}$ [K]	$A_{radiator}$ [m^2]
Instrument Radiator	Cooling of MCT Detectors	45	38	36.5	0.45
TOB/Structure	Initial Cooldown / Parasitic heats	TBD	45	45	
IOB Radiator	Cooling of Cal System / FEE	233	55-60	55	0.45
Sunshield	Cooling of Sorption cooler and 90 K J-T heat exchanger	5500	90	~90	1.48
SVM Radiator	Cooling of Electronics	TBD	300	300	TBD

These thermal interfaces are outlined based on the assumption that active cooling will be required and the cooler system will be implemented by the RAL J-T cooler in combination with the H_2-Stage of the Twente Sorption cooler.

5.4.6.1 Calibration equipment

As discussed in Section5.4.1.1, an optional point-source-like calibration source signal is injected next to the science beam. A further calibration source is used (FCS) but without external interfaces.

5.4.7 Warm Instrument Electronics

Each Instrument Control Unit (ICU) – the nominal as well as the redundant unit – are connected with two interfaces with the S/C. One is the S/C power the other is the telecommand and telemetry (TC/TM) link. These are bi-directional synchronous serial links following the 1355/Spacewire standard. The clock speed is at 100 MHz and the interface to the S/C will be able to sustain a constant data rate of 100 Mbit/s (TBC).

Synchronisation of the internal timer with the S/C is TBD.

5.4.8 Data

The detectors are read by the FEE, their signals are digitized and sent to the DPU, where the raw data frames are processed. The raw data rates are of course the maximum amount of data that will be produced. Table 4 contains reduced rates, which correspond to a realistic rate (not all pixels in all optical channels have to be read out with the same sampling rate) which is still in line with the 30s cadence.

Table 4 - Compressed science data rates. The preliminary (*) rates are subject to change as the detector specifications and operational scenario changes.

Channel	**Active Pixels incl. zero order**	**Realistic science telemetry rate [bit/s]**
VIS	71641	12028*
IR1	63241	13568*
IR2	63241	13697*
IR3	63241	12477*
IR4	34505	9456*
IR5	33865	8489*
SCI total	329734	69715*
Per 22h		5,5* Gbit

In addition to the science data from the pixel arrays, other measures and parameters are acquired, which are essential for the interpretation of the science. These so-called “meterology” values contain timing and identification tags, detector, readout and on-board data processing configuration.

Housekeeping values are also produced at cyclic rates and included in the downlink. The total amount of instrument data without TM protocol overhead is given in Table 5.

Table 5 – Telemetry budget

Data Product	**Reduced / Compressed [bit/s] Minimum**
Science Data	69715
Meterology	1040
Nominal HK	632
Total rate	71387
Per 22h	5,65 Gbit

5.4.9 Power

From the primary S/C power, the PSU provides secondary voltages for the instrument sub-units. The PSU module is composed of the required filters and independent DC/DC converters. It provides the required secondary voltages to the ICU and DPU. The unit is housed in a separate flat enclosure beneath the ICU.

Table 6 – Power budget for the electrical subsystem. The Cooling System has its own power supply, all their subunits are powered by the PSU.

Unit	**Power**		
	Consumption	Overheads	Budget [W]
DPU	20 W	-	20
ICU	12 W	20% (harness)	14,4
Subtotal			34,4
DC/DC loss in PSU		+10 %	37,73
Contingency		+20 %	45,276
ICU Clients Total			**45,276**
Sorption Cooler	5,5 W	20 %	6,6
JT Cooler	110 W	10 %	121
Cooling Total			**127,6**
Instrument Total			**172,876**

5.5 Reference science instrument UCL/RAL

5.5.1 Payload Overview and Design Justification

The wide wavelength coverage required for EChO can best be met by dividing the input beam into a number of spectrally separated channels which can then be directed into physically separate spectrometers. Several options are possible for achieving this spectral channel division. We studied three options: dichroics, pupil division and pre-dispersion. In principle any of them could have achieved the required division. However, pupil division, i.e. using different sub-pupils for each channel, has the drawback of reducing the overall transmission of each channel and the use of a pre-dispersing element has proved difficult to design to efficiently cover such a large waveband. We have opted therefore for the simplest option of using dichroics more or less in series to provide the channel division. This method has the advantage of a long heritage in both astronomical (for instance JWST) and Earth observation missions. In consultation with suppliers of dichroics we have defined four spectrometer modules with wavelength coverage and nomenclature as follows:

VNIR: from 0.4 μm to 2.47 μm - internally sub divided into 0.4 μm to 0.8 μm and 0.2 μm to 2.47 μm

SWIR: from 2.47 μm to 5.3 μm

MWIR: from 5.3 μm to 11.25 μm – internally sub divided into 5.3 μm to 8.45 μm and 8.45 μm to 11.25 μm

LWIR: from 11.25 μm to 16 μm

The scheme is further illustrated in figure 1 showing how the dichroics, all used in short wavelength reflection, are ordered with respect to each other. Within the VNIR channel the visible part of the spectrum is divided by an amplitude beam splitter to provide light into the Fine Guidance Sensor (FGS): this is an imaging sensor used to feedback the stellar image into the spacecraft attitude control system to achieve the very high pointing accuracy required.

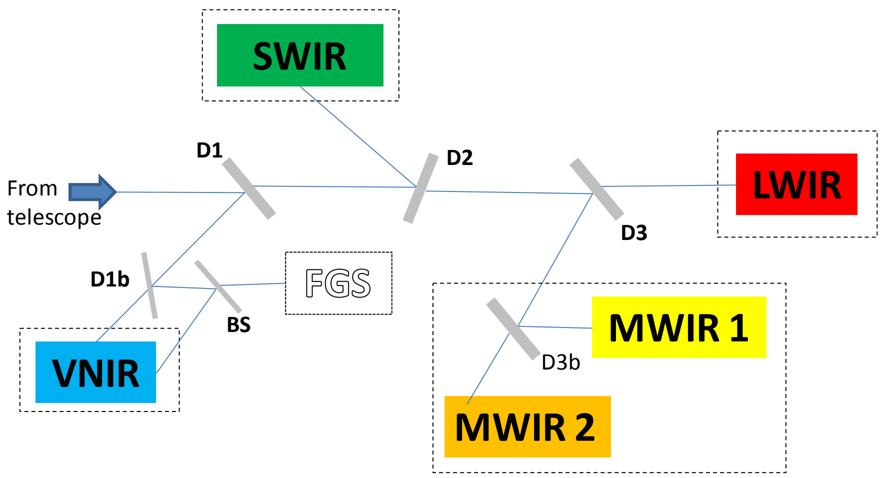


Figure 17: Baseline concept for the channel separation

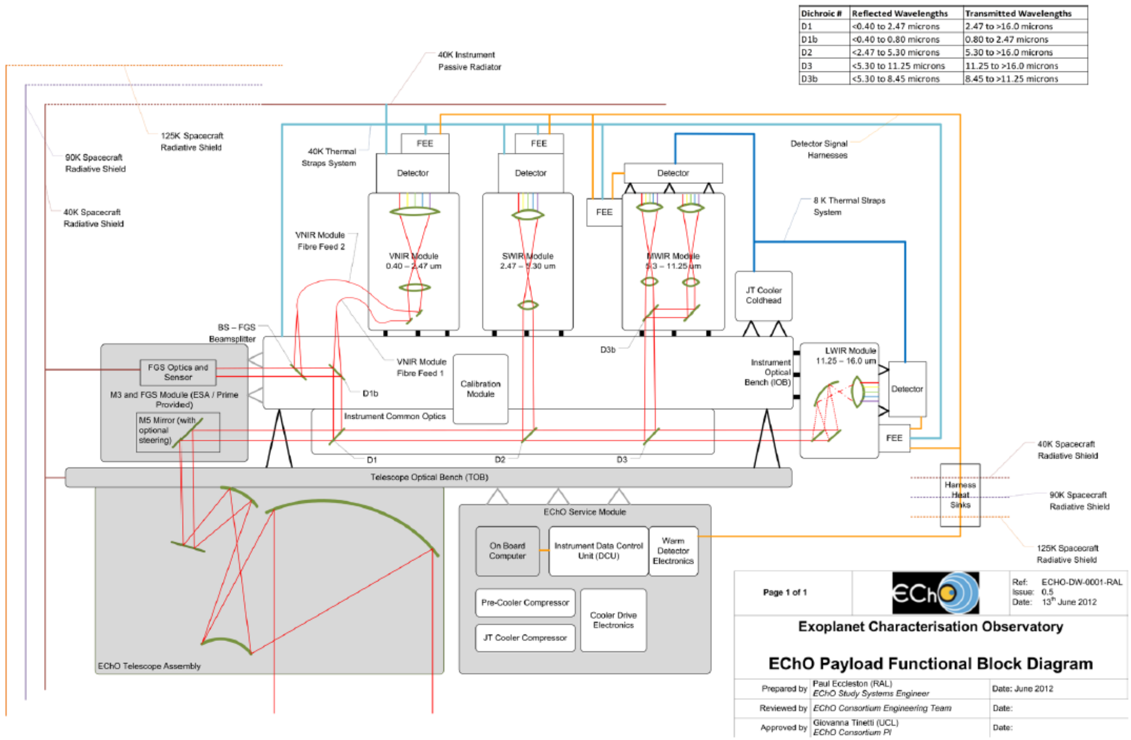


Figure 18 Overall system block diagram for the EChO integrated payload in relation to the spacecraft systems.

The payload design therefore consists of a set of common optics that condition the beam from the ESA provided telescope and direct it into each of the four modules via dichroics and fold mirrors. The operating wavelength, plus the common nature of the optical design, dictates that the payload must be cooled to below 50 K to prevent self emission from dominating the signal in the MWIR and LWIR ranges. In order to provide the stability required across the whole operating band we have also designed the payload as an integrated system by mounting the modules and common optics on a single optical bench with no moving parts, i.e. spectral scanning mechanisms etc, allowed in the spectrometer design. Although each module has its own

European Space Agency
Agence spatiale européenne

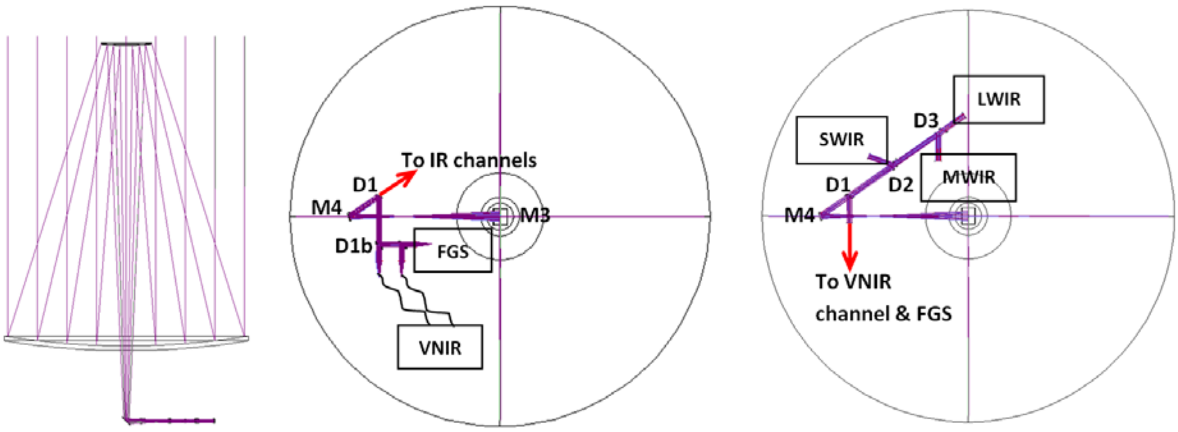


Figure 19 Common optics design shown for an on axis telescope design

internal optical train and detector system we treat the whole payload as effectively a single instrument that will be internally aligned and integrated with the spacecraft as a single unit meeting all the science requirements of the EChO mission. In the next section we discuss the design of the integrated payload in more detail.

5.5.2 Detailed Payload Design

5.5.2.1 System Design

Figure 2 shows the overall system block diagram for the EChO payload and how it is related to the spacecraft provided systems. In particular we note that, as discussed below, the various detector technologies chosen to cover the different wavelength ranges require different operating temperatures. The basic structure and optics of the payload can be strapped to a common thermal node on the spacecraft radiator system. However the MCT detectors (see 5.5.2.3 and 5.5.2.4] covering the VNIR and SWIR channels require a separate radiator to provide a highly stabilized 45-K stage and the current baseline Si:As detectors (see 5.5.2.5 and 5.5.2.6) for the MWIR and LWIR modules require a dedicated Joule-Thomson cooler to provide an <8-K stage pre-cooled using a Stirling cycle cooler. In line with the integrated nature of the payload, a single electronics unit will provide the power supplies, detector conditioning electronics and housekeeping electronics for all modules. The electronics unit will interface directly to the spacecraft on-board computer with processing and control tasks efficiently split between the payload processor and the spacecraft central processor. The division of tasks is subject to further study – see 5.5.2.9. The whole system design is based around providing as simple and robust design as possible compatible with the driving technical requirement for photometric stability and the need to avoid significant technology development in the context of an ESA medium mission due for launch in the 2020's.

5.5.2.2 Common Optics and Channel Division

The ESA provided telescope system design has evolved over the course of the current study period from an on-axis Cassegrain type to an off-axis three mirror design. The payload design we present here is compatible with either of these options but at the time of writing the detailed common feed optics assume an on-axis Cassegrain. The outline design for the common optics path is shown in relation to the original telescope design in figure 3. Here the 2-mirror telescope is followed by a flat folding mirror M3 located 2m below the telescope secondary (M2). M3 reflects the light into a plane orthogonal to the telescope axis to provide the telescope focal plane (TFP) at the interface with the instrument and the rest of the common path optics. In this configuration all instrument modules plus the FGS and M3 mirror are nominally accommodated on the instrument optical bench which is parallel to this plane. M3 could be used as the location for a fine steering mechanism in feedback with the FGS described above. At the TFP, a field stop is located to limit the flux from sources located near but outside the targeted sky area. The field aperture is sized to allow transmission of an oversized field of view with respect to the science target requirement. This outsized field is required for the FGS to allow tracking on non-target stars and to accommodate the baseline spacecraft pointing. That is, a target star needs to be “found” within the FGS field of view by blind pointing of the spacecraft before the fine guidance system can be activated. Given the nominal plate scale of 19.23 arcsec/mm a 1x1 mm aperture is found to meet the constraints. Locating the FGS on the same optical bench fed by the same common optics removes all common path errors and is another example of how the EChO payload is optimized for photometric stability.

After the TFP, an off-axis parabolic mirror M4 is used to achromatically re-collimate the beam before the spectral bands are split via a chain of dichroics. This re-collimation allows the provision an image of the telescope pupil at the entrance to the dichroic chain where a cold aperture stop can be located to shield against the emission from “warmer” elements in the telescope system, such as the thermal baffles. The collimation, and associated pupil demagnification, also controls the size of the beam intercepting the dichroics and restricts its angular spread to ~+/-0.2 degrees. The focal length of the collimator M4 is designed to give an output beam of 20mm diameter which is delivered to the 4 different science channels via the dichroics chain. The angle of incidence onto the dichroics is limited to 30 degrees maximum, and is typically adjusted to be between 20 and 30 degrees in order to help with the mechanical accommodation of the modules.

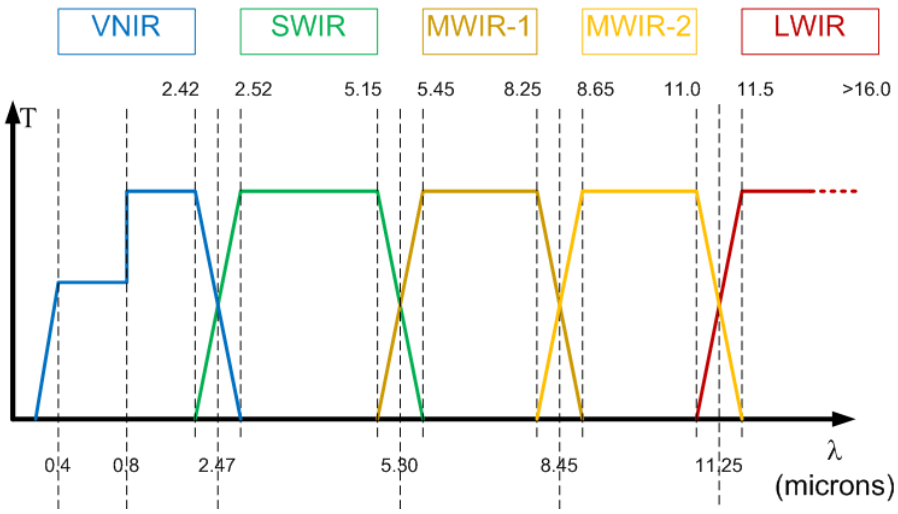


Figure 20 Detailed specification of the channel divisions. These are chosen respect the scientific requirement to avoid certain wavelength ranges for spectral features whilst providing some spectral overlap between the channels

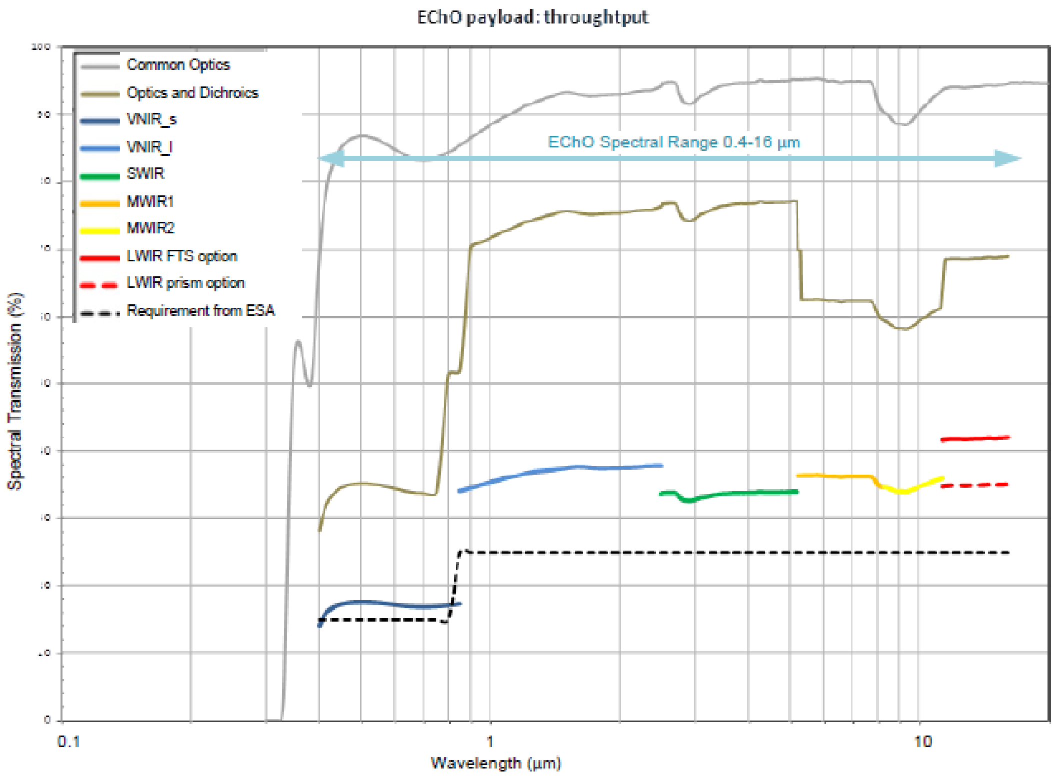


Figure 21 Calculated transmission efficiency for the EChO integrated payload based on measured and calculated efficiencies of the optical components in each module

Channel Name	Spectrometer type	Wavelength Range (μm)	Resolution	Nominal Detector Type	Detector operating temperature and stability
VNIR	Two fibre-fed cross-dispersed spectrometers	0.4 – 0.8 0.8-2.47	~330 constant across range	MCT	<45 ±0.05 K
SWIR	Grating-based dispersive spectrometer	2.47 – 5.3	380 (@ 2.45 um) – 835 (@ 5.3 um)	MCT	<45 ±0.05 K
MWIR-1	Prism-based dispersive spectrometer	5.3 – 8.45	40 – 110	Si:As	<7 ±0.038 K
MWIR-2	Prism-based dispersive spectrometers	8.45 – 11.3	40 – 85	Si:As	<7 ±0.038 K
LWIR	Static FTS or prism-based dispersive spectrometer	11.3 – 16.0	30 – 60	Si:As	<7 ±0.038 K

Table 7 Overview of the spectrometers type, wavelength coverage and design resolving power for each spectral channel

After each dichroic the collimated beams feed the respective channel modules. Inside each module and sub-modules the beam is focused onto an entrance slit sized to the specific module wavelengths. The combination of dichroics, band pass filters and detector spectral response will not have infinitely sharp edges, but we do require that there is some overlap between the module coverage in order to allow inter-module calibration. We therefore specify the detailed band pass of each module as being where the full transmission requirements must apply with a gap between the modules where the combined transmission of both modules must be at least 50% of the specification. The requirements are illustrated in Figure 20, the calculated overall transmission efficiencies for the modules are shown in Figure 21 and the module spectrometer types, wavelength coverage, resolving power and selected detector types are given in table 1. In the next sections we very briefly discuss the design of each module before describing the overall mechanical, thermal and electrical configuration of the integrated payload.

5.5.2.3 VNIR Module

Two echelle spectrometers are used to cover the wavelength range. The wide spectral coverage is achieved through the combined use of a grating with a ruling of 14.3 grooves/mm and blaze angle of 3.3° for wavelength dispersion in horizontal direction and an order sorting calcium fluoride prism (angle 22°), which separates the orders along the vertical direction. The prism is the only optical element used in transmission; all other optics are reflecting surfaces. The collimator (M1 – see Figure 22) and the prism are used in double pass. The light is fed to the spectrometer via two fibres positioned on either side of the M2 mirror. The fibres are commercial fused-silica with ultra-low OH content and core diameter of 0.050 mm. The fibres are separately fed by two identical off-axis parabolic mirrors which intercept the collimated light transmitted from the first dichroic (D1b) and reflected by the beam-splitter. The use of an optical fibre coupling gives a larger flexibility in the location of the VNIR spectrometer within the EChO payload module, if necessary the parabolic mirrors feeding these fibres could be part of the common optics and could be remotely located from the VNIR module itself.

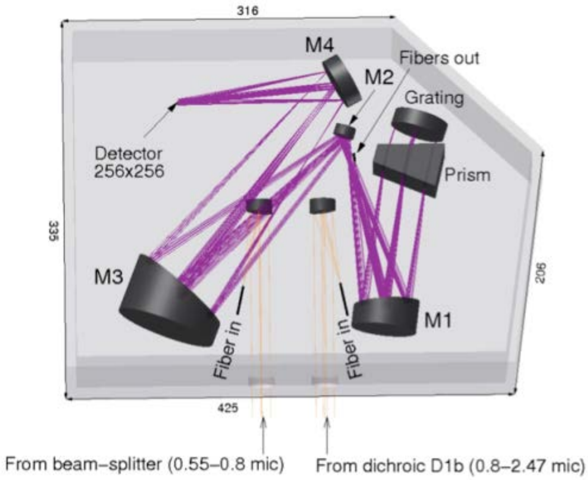


Figure 22 Outline optical design for the VNIR module.

In the current design the spectrum is spread on a 256 by 256 pixel detector which requires 3x3 pixel binning to obtain a spectral resolution of 300. An alternative design could have an output beam feeding a 512 x 512 detector. In this case the binning would be on 6x6 pixels. The detector technology of choice for the VNIR channel is based on Mercury Cadmium Telluride (MCT or HgCdTe). Detectors with good quantum efficiency over the full band are available from both US and European manufacturers. The advantage of using MCT detectors in this band is that, in common with the other EChO modules, the detector operates at temperature around 40-45 K, matching that of the optical bench of the modules and simplifying the thermal design of the payload.

5.5.2.4 SWIR Module

The spectrometer baseline design covering from 2.45 to 5.45 μm is based on the use of a two mirror relay which focuses the collimated beam from the common optics onto the slit location before re-collimating the beam onto a diffraction grating – see Figure 23. Following the dispersion the light is refocused onto the detector via a refractive camera. The detector baselined for the SWIR module is again an MCT array operating at 45 K.

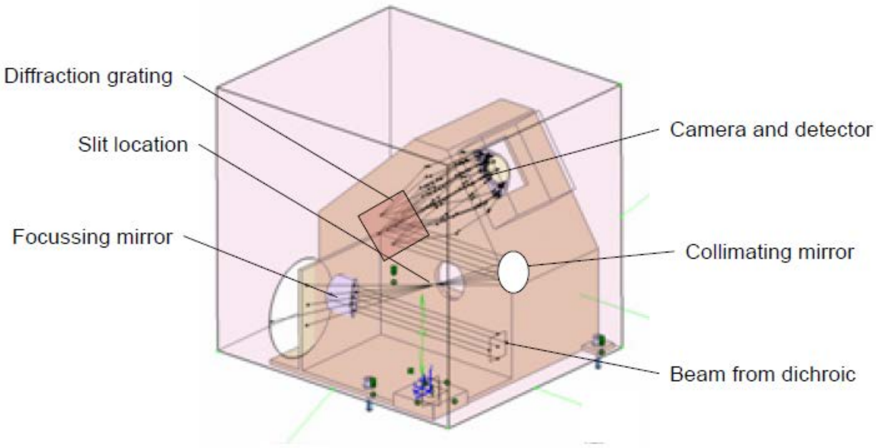


Figure 23 The SWIR module outline optical design shown in context with its mechanical envelope

5.5.2.5 MWIR Module

The entrance-collimated beam coming from the front-end optics is focused on a field stop and re-collimated by aluminum off-axis parabolas. An internal dichroic filter splits the bandpass in two sub-channels: MWIR1 and MWIR2. Both sub-channels use Cleartran prisms to perform the dispersion following which the spectra are refocused on detectors by means of three-lens objectives which use IG2/Cleartran/Ge for MWIR1 and IG2/Ge/Ge for MWIR2. A folding mirror is used in the MWIR1 channel in order to have both channels parallel along the path between the prism and the detector.

At the time of writing we have baselined the Raytheon Si:As Aquarius device as the detector of choice for the MWIR module. This has the advantage of a much higher high well capacity compared to the devices used on the JWST-MIRI whilst maintaining dark current and read noise values compatible with the photon noise expected from the EChO target stars. The disadvantage of using Si:As technology is that the arrays require an operating temperature <~ 8 K. This necessitates moderately complex thermal engineering and the use of Joule-Thomson and Stirling-cycle coolers (see 5.5.2.7). An alternative technology is being actively developed within Europe based on “n-on-p” and “p-on-n” photovoltaic MCT detector arrays. If these devices can be developed to provide a low enough dark current they will have the major advantage of operating at ~30-40 K removing the need for one and possibly both of the closed cycle coolers.

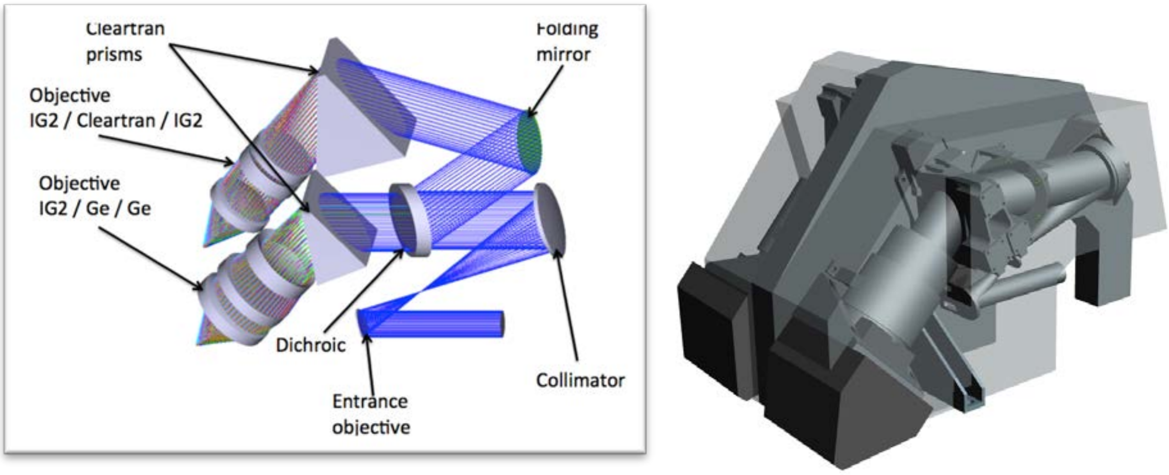


Figure 24: Left the optical layout of the MWIR module. Right the mechanical accommodation of the module.

5.5.2.6 LWIR module

We have studied two options for providing the wavelength coverage from 11 to 16 µm. The original design was based on a static Fourier Transform (FTS) design using a combination of lateral beam shearing KBr prisms with a germanium Fourier lens system to refocus the diverging beam from the prism, forming an interferogram at a pupil in the tangential plane (see Figure 25). The advantage of this design for EChO is that it is compact and has effectively variable spectral resolution by using different lengths of the interferogram depending on the brightness of the target. The full spectral band is seen by all detectors in this system therefore the photon noise is higher and the requirements on the detectors commensurately relaxed. When the target is bright enough for the photon noise in all pixels to outweigh the detector noise a higher spectral resolution can be achieved. The disadvantage of the system is that it requires a relatively large number of pixels (>512) and, to prevent phase errors, the pixels must be small, as evenly distributed as possible and their position known to very high accuracy.

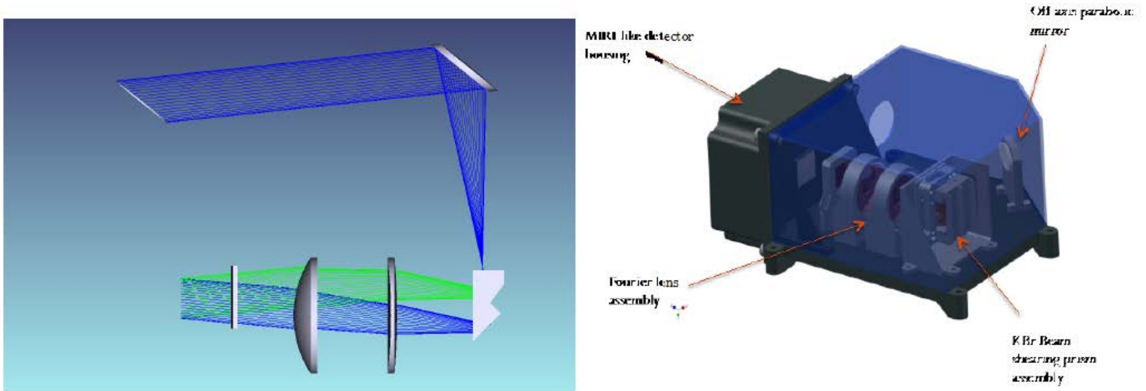
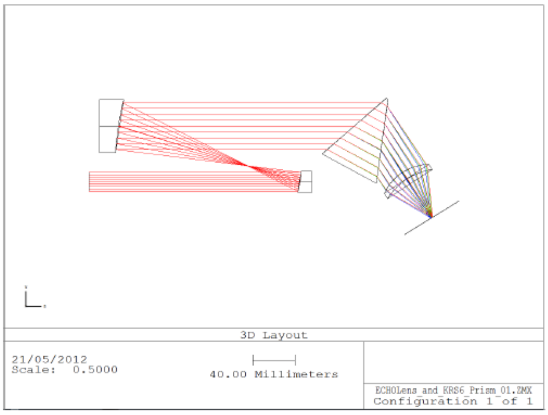


Figure 25 Optical layout of the Static FTS option shown here with a representative 17.7 mm diameter input and single focusing off axis parabolic reflector.

European Space Agency
Agence spatiale européenne



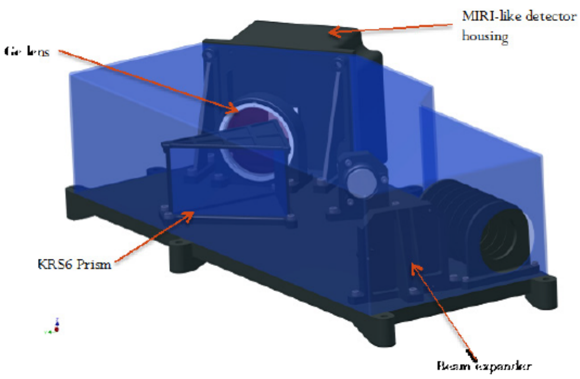


Figure 26 KRS6 prism design for the 11-16 úm channel with x2.5 beam expander

Given the possible issues associated with detector choice for the static FTS design we have pursued a parallel study into a much simpler prism based dispersive spectrometer. The basic design is based on a KRS6 glass prism and a coated germanium lens – see Figure 26. KRS6 is a thallium bromo-chloride glass that has excellent transmission in the LWIR spectral band, but its lower dispersion (e.g. 0.59) requires the use of an a-focal beam expander to achieve adequate spectral sampling using an assumed detector pitch of 30µm. The angle of incidence onto the prism is 48°, so care is required with AR coating designs etc.

We have modeled the performance of both designs for the LWIR module and find that they would both meet or exceed the majority of the requirements for EChO. However, this assumes that an Si:As detector is used in both. If a European MCT operating at e.g. 30-45K becomes available for the LWIR pass-band then replacing the ~7K detector is the obvious choice due to simpler thermal design requirements for the overall instrument solution. Using the current noise models, the static FTS performance is related to the accuracy of the detector array via the pixel position error noise, and this is currently unknown. The static FTS design also assumes a large (>512) number of pixels are available in the array to make maximum use of its programmable higher resolution mode and minimise noise contributions. The prism-based dispersive option is fixed at approximately 50 pixels. Both designs have a similar number of optical components and mechanical complexity.

Given the relative conceptual simplicity of the prism dispersive spectrometer and more predictable performance for different detector array technologies, the lowest risk option at this point favours the dispersive design. The prism design is least sensitive to the choice of detector, so has now been adopted as the baseline for the LWIR channel. However, the potential advantages in optical efficiency and flexibility for the static FTS should not be discounted if the detector array type becomes fixed using a Si:As detector.

5.5.2.7 Thermal Design

The design is based on a combination of passive and active cooling systems (see Figure 27). The first three temperature stages consist of passive radiators that exploit the favorable conditions of the L2 thermal environment to provide stable temperatures for the optical modules, for the detectors in the VNIR and SWIR channels and also to provide heat leak interception/rejection for the electrical harnesses. In our baseline design the MWIR and LWIR detectors need to operate at <8 K and we achieve this using 2 cryocoolers operating in series. Our baseline is to use a Joule-Thomson cooler based on the successful Planck design for the coldest (~7-K) stage with a two-stage Stirling cycle cooler based extensive European heritage to provide an 18-K stage. Alternative designs based on sorption coolers for the cold stage and pulse tube coolers for the intermediate stage are also under consideration.

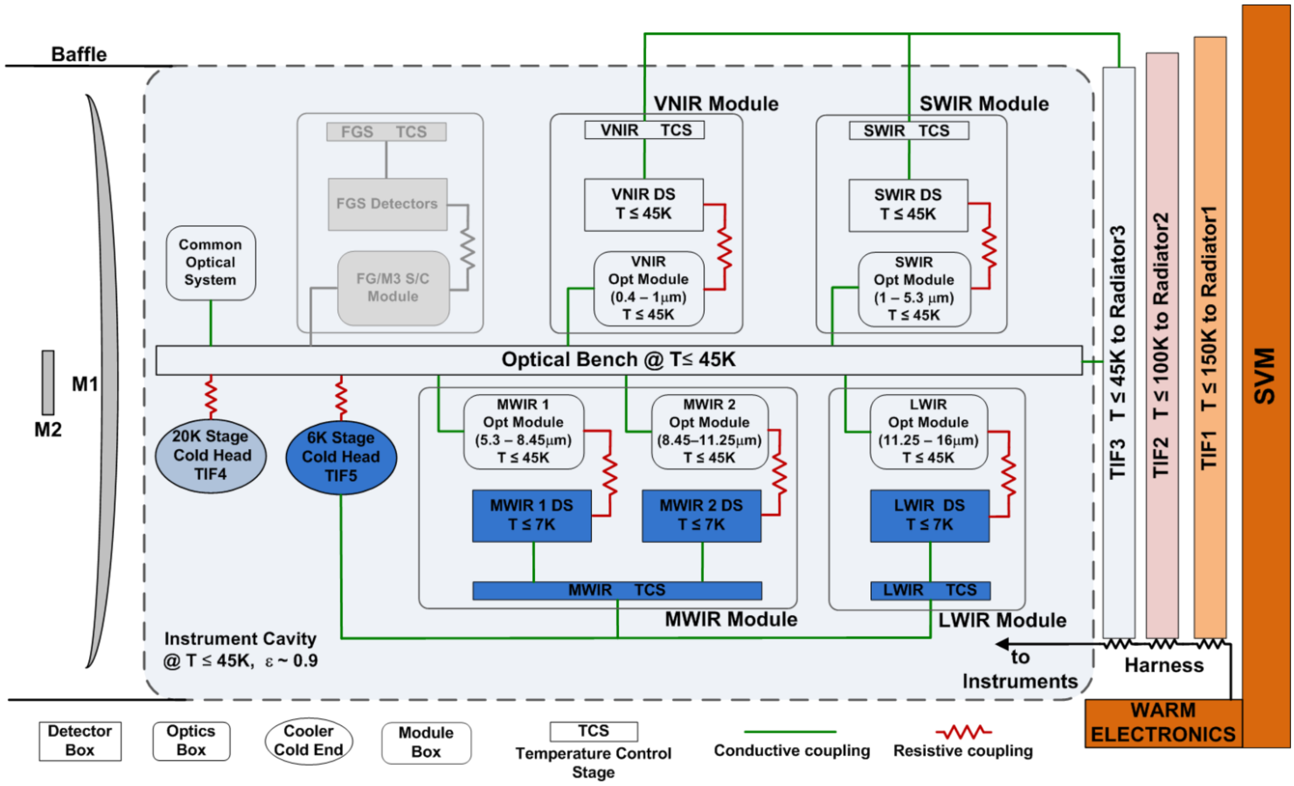


Figure 27 The thermal systems design for the EChO payload in the context of the EChO satellite thermal systems.

5.5.2.8 Mechanical Design

The mechanical design of the EChO payload is based on mounting all the common optical elements, the spectrometer modules and the fine guidance sensor on a common optical bench that interfaces directly to the EChO telescope optical bench. In this way we will provide a common structure that avoids induces differential optical path errors between the various elements of the payload giving the highest possible pointing and photometric stability. The preliminary design is shown in figure 11. The design will be isothermal as far as possible and manufactured from 6082 aluminium alloy except where thermal isolation demands other materials such as CFRP. The Instrument Optical Bench (IOB) will be shaped to the minimum area required for the common optics and modules and its mountings and will be pocketed out for minimum mass. It will be kinematically supported from the Telescope Optical Bench either by a hexapod or three “A” frames of aluminium alloy tubular struts each having universally flexible end fittings and mounted in a plane normal to the telescope optical axis to ensure alignment is maintained throughout the spacecraft temperature range.

Recently a new telescope lay-out has been adopted as baseline by ESA which is in effect an off-axis horizontal telescope. The ‘horizontal’ refers to the optical axis of the telescope being perpendicular to the launch direction of the spacecraft as opposed to longitudinal along the launch direction in the previous design. This configuration is very much in development at the moment and requires further study during the next phase of the project. The potential volume for the instrument optics in this case has been reduced compared to the classical Cassegrain telescope design, but the design shown in Figure 28 can still be accommodated in this new arrangement.

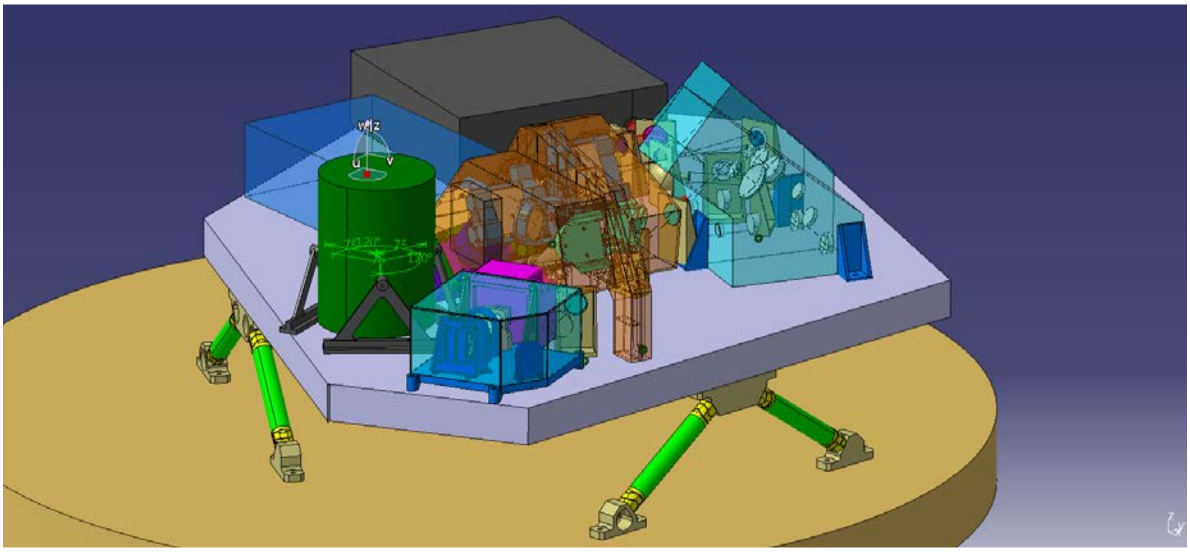


Figure 28 Illustration of the accommodation of the EChO common optics, spectrometer modules and cooling elements on the EChO Instrument Optical Bench (IOB). The dark green cylinder represents the J-T cooler head and the brown surface below the IOB represents the telescope optical bench(TOB). The IOB is kinematically mounted from the TOB

5.5.2.9 Drive electronics and communications

The EChO payload electrical architecture provides the signal conditioning, data and command transfer, clock/synchronization, power distribution, data processing and formatting. The architectural design assumes that the proximity electronics for each detector module provides very small heat load so that it can be located close to the cooled detectors. This proximity electronics is represented by the detector ROIC (Read Out Integrated Circuits) bonded to the MCT detector array for the VNIR and SWIR modules, and onto the Si:As array for the MWIR and LWIR modules. We further assume the cold electronics provide just the amplified analogue signal and house keeping to a set of the warm front-end electronics (FEEs) where further signal conditioning (filtering etc) and analogue to digital conversion and multiplexing will take place. The housekeeping signals (temperatures, voltages etc) and the any drive signals for calibration units are sensed and provided by a separate warm electronics unit termed the Instrument Control Unit (ICU). The warm FEE and ICU are interfaced to the spacecraft via a dedicated payload Digital Processing Unit (DPU) and a Power Supply Unit (PSU). The architecture is illustrated in Figure 29.

We envisage that the DPU will undertake most of the on board data processing required. The data rate limitations for EChO are such as to prevent the transmission of raw detector samples and some averaging and data compression is required before the data are sent to the ground. The detector data may be averaged temporally by combining all signal ramps in a 60-90 second period whilst retaining the number of spectral and spatial samples or the data may be averaged spatially by combining pixels within a single spectral element thus allowing a better overall temporal rate. In general we cannot know for certain which will prove the optimum method and it is desirable for the on-board processing to be as flexible as possible. For both scenarios it is clear that at the very least ramp slopes will need to be determined on-board and radiation induced glitches will need to be removed or accounted for.

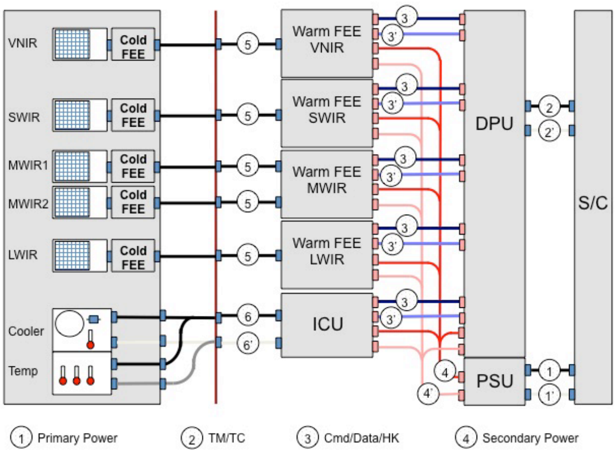


Figure 29 The proposed electrical architecture for the EChO integrated payload.

5.5.3 Budgets

5.5.3.1 Photometric stability budget

The proposed Photometric stability budget is shown below.

Budget Line Item	Photometric Stability		Criticality		Justification / Assumptions / Notes
	Required	Goal	Bright	Faint	
Overall Mission Post-processed Stability Target	1.01E-04	1.01E-05	red	red	
Science Target Variability Allowance	N/A	N/A			We can't control this, and is calibrated out by use of the out of absorption band detection, so are currently not going to account for this. We will meet requirements under ideal conditions.
Impact of Sunspots etc					Keep as line item – TBD impact to be studied
Other target based variations?					TBD
Data Processing Allowance	2.00E-05	2.00E-06	red	red	Should this be -ve as the DP will actually be removing a lot of the effects below?
EChO Spacecraft Overall	9.95E-05	9.95E-06	red	red	Addition in quadrature of identified budgets below - assumption is that they are independent
Telescope alignment / PSF shape	2.00E-05	2.00E-06	red	green	Allocation for telescope changes over period of transit
S/C Pointing Stability	3.00E-05	3.00E-06	red	red	Assessment using Herschel data shows that correction can be achieved using stellar lines
Background / stray-light stability	4.00E-05	4.00E-06	green	red	Row of background pixels to calibrate - then left as photon noise + field dependence
Dark Current stability	4.00E-05	4.00E-06	green	red	Needs measurement with blind pixels which are easily calibrated and non-target pixel
Thermal effect on detectors	TBD	TBD			Probably will translate directly into dark current variation. Direct measurement of the detector temperatures required with sufficient cadence and resolution.
Long term detector aging	TBD	TBD			To be monitored via observation of calibration stars
QE / Gain sensitivity	5.00E-05	5.00E-06	red	yellow	To be monitored vis observation of calibration stars and by use of the internal calibration source.
Linearity calibration accuracy	1.00E-05	5.00E-06	yellow	yellow	Includes accuracy of internal source for in-flight calibration
Thermal effect on warm electronics	TBD	TBD			Stabilised / measured temp of warm electronics. Electronics gains to be measured via electronic simulator - possibly injected in FEE.
Thermal effect on detectors	TBD	TBD			More likely to dominate the dark current - see above.
Calibration of persistence / latents	1.00E-05	1.00E-06	green	green	Likely to be small
Payload instrument opto-mechanical stability	1.00E-05	1.00E-06	green	green	Expected to be relatively small due to cold temp, monolithic build material etc. Also calibrated by the intra-pixel sensitivity
Calibration of Intra-pixel variability	5.00E-05	5.00E-06	yellow	yellow	Degree of oversampling will affect how much influence this has on the jitter and opto/mechanical stability. In turn this is critically connected to detector choice
Correction for SEE / Cosmic rays	1.00E-05	1.00E-06	green	green	Likely to be small as taken out in DP

Table 8 Proposed Baseline Photometric Stability Budget

5.5.3.2 Mass budget

Instrument Modules	Nominal Mass (kg)	Margin	Margined Mass [kg]	Requirement (from PDD)
VIS	5.00	20%	6.00	
SWIR	6.02	20%	7.22	
MWIR	9.74	20%	11.69	
LWIR	4.02	20%	4.82	
SubTotal	**24.78**		**29.73**	**30.00**
Cryogenic Instrument Infrastructure (with PLM)	**Nominal Mass (kg)**	**Margin**	**Margined Mass [kg]**	**Requirement (from PDD)**
Instrument Optical Bench (IOB)	20.25	20%	24.30	60.00
IOB Supports	1.89	20%	2.27	
Common Optics	2.00	20%	2.40	15.00
Harness	5.00	20%	6.00	
Calsource	1.70	20%	2.04	
Cooler (optical bench section)	1.50	20%	1.80	30.00
Thermal Straps	1.50	20%	1.80	
Blankets	0.10	20%	0.12	
SubTotal	**33.94**		**40.73**	**105.00**
Instrument Hardware Within SVM	**Nominal Mass (kg)**	**Margin**	**Margined Mass [kg]**	**Requirement (from PDD)**
2 stage pre cooler	18.50	20%	22.20	75.00
J-T cooler	19.50	20%	23.40	
Warm Electronics	15.00	20%	18.00	40.00
SubTotal	**53.00**		**63.60**	**115.00**
Total Instrument Mass	**Nominal Mass (kg)**	**Margin**	**Total Mass [kg]**	**Requirement (from PDD)**
Instrument Grand Total	**111.71**	**20%**	**134.06**	**250.00**

Table 9 Overall Instrument Mass budget

5.5.3.3 Thermal/Cryogenic Budget

The EChO PLM thermal budgets have been allocated on the basis of heritage from previous experience (e.g. MIRI, Planck) and checked/confirmed by thermal analysis and simulations with the reduced TMM. The budget values for each Thermal Interface are summarized in the following tables:

1) on TIF1 (Radiator 1) at T ≤150 (ΔTpp = 0.3K over exposure time; TBD over mission)

Heat load component	Load (W)
Heat leaks from SVM (harness, struts, piping, radiation)	15 (TBC)
Total	15
Total with 20% margin	18

2) on TIF2 (Radiator 2) at T ≤100 (ΔTpp = 0.3K over exposure time; TBD over mission)

Heat load component	Load (W)
Heat leaks from harness, struts, piping, radiation	3 (TBC)
Total	3
Total with 20% margin	3.6

3) on TIF3 (Radiator3) at T≤45K (with ΔTpp=0.1K over exposure time; TBD over mission)

Heat load component	Load (mW)
VNIR - DS (incl. FEE)	30
VNIR - TCS	5
SWIR - DS (incl. FEE)	2
SWIR - TCS	2
Leak to 6K stage	-15.8
Heat leaks from harness, struts, piping	31.75
Total	54.95
Total with 20% margin	65.94
Margin wrt PDD allocation (100 mW)	34%

4) on TIF4 (20K Cold End) at T ≤20K (ΔTpp = 0.1K over exposure time; TBD over mission)

Heat load component	Load (mW)
Precooling to 6K cooler + heat leaks from harness, struts, piping, radiation (TBC)	120 (TBC)
Total	120
Total with 20% margin	144

5) on TIF5 (6K Cold End) at T ≤6K (ΔTpp = 0.05K over exposure time; TBD over mission)

Heat load component	Load (mW)
MWIR1+2 - DS (incl. FEE)	0.5
MWIR - TCS	0.5

LWIR - DS (incl. FEE)	0.5
LWIR - TCS	0.5
Leak from 45K stage	15.8
Total	17.8
Total with 20% margin	21.36
Margin wrt PDD allocation (20 mW)	-1.36%

According to the TMM results the load expected on the 6K stage (including margin) is slightly over the PDD allocation. An optimized tuning of all thermal conductances could readjust the heat fluxes reducing the leak between the 45K and 6K stages. In any case, the 20K cold end reference can be used to intercept part of the thermal leakage from the 45K units, significantly reducing the load on the 6K cold end and lowering the total dissipation well within the allocated 20 mW.

5.5.3.4 Power Budget

The Power Budget of the DCU is 25W without margins (30W with margins)
The power budget for the active cooler is 200W (tbc)

5.5.3.5 Data Rate Budget

	VIS	NIR	MIR	LWIR
Detector Frame format	256 x 256	1200 x 20	80 x10	512 x 10
Number of detectors	1	1	1,5	1
Binning	3 x 3	NA	NA	NA
# bits/pixel	16	16	16	16
Observation time (min)				180
Acquisition time (s)				30
Gb/day				1.61
Efficency (R-perf-060)				85%
Contingency (HK+SpW)				25%
Gb/day				1.71

Masking procedure of the VNIR detector < 1Gb/day

Table 10 Estimated Payload Data Volume per day