An integrated payload design for the Exoplanet Characterisation Observatory (EChO)

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ABSTRACT

The Exoplanet Characterisation Observatory (EChO) is a space mission dedicated to undertaking spectroscopy of transiting exoplanets over the widest wavelength range possible. It is based around a highly stable space platform with a 1.2 m class telescope. The mission is currently being studied by ESA in the context of a medium class mission within the Cosmic Vision programme for launch post 2020. The payload suite is required to provide simultaneous coverage from the visible to the mid-infrared and must be highly stable and effectively operate as a single instrument. In this paper we describe the integrated spectrometer payload design for EChO which will cover the 0.4 to 16 micron wavelength band. The instrumentation is subdivided into 5 channels (Visible/Near Infrared, Short Wave InfraRed, 2 x

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Mid Wave InfraRed; Long Wave InfraRed) with a common set of optics spectrally dividing the input beam via dichroics. We discuss the significant design issues for the payload and the detailed technical trade-offs that we are undertaking to produce a payload for EChO that can be built within the mission and programme constraints and yet which will meet the exacting scientific performance required to undertake transit spectroscopy.

Keywords: Astronomy, Instrumentation, Exoplanets, Space

1. INTRODUCTION

The discovery and characterisation of extra-solar planets is one of the most rapidly changing and exciting areas of astrophysics. A combination of ground-based surveys and dedicated space missions have resulted in some 700 planets being detected up to the end of 2011, and over one thousand candidates that await confirmation. Since 1995, the number of planets known has increased by two orders of magnitude. NASA's Kepler mission is discovering many hundreds of new planets around some of the 100,000 stars it is surveying during its 3 to 4-year lifetime [1] and the ESA-Gaia mission is expected to discover thousands more. The detection techniques employed: radial velocity, transits, astrometry and micro-lensing, allow us to determine the basic parameters of the planets; that is their orbit, mass, size and basic nature (rocky or gaseous). However, to push our understanding of these worlds beyond these first steps, we must use spectroscopic techniques to probe for the presence of an atmosphere and, where one is present, to determine its physical nature and chemical constituents. Exoplanetary science stands on an exciting threshold, similar to our knowledge of the planets in our own Solar System before spectroscopic studies revealed their true nature and started to unravel the story of their formation and evolution. The observation of planetary atmospheres is at the cutting edge of exoplanet science, and in this context the Exoplanet Characterisation Observatory, EChO, has been proposed as an ESA "medium mission" for launch in the 2024 timeframe [2].

The basic mission concept is discussed in a number of papers in the current proceedings ([3], [4] and [5]). In brief it consists of a 1.2 m telescope passively cooled to below 50 K on a satellite in orbit around the second Lagrangian point (L2). The observation sequence consists of staring mode spectroscopic observations taken over the various phases of the target light curve as the planet transits in front and behind the host star (see for instance [6]). The spectrum of the planet is seen either in absorption against the stellar spectrum (primary transit) or in emission together with that of the star. The stellar spectrum is observed in the absence of the planet as the planet transits behind the star (secondary eclipse). The signal from the planet is isolated from the star by fitting a light curve to each observation. The contrast between the star and the planet spectra depends on the stellar type and the size and temperature of the planet and varies strongly with wavelength [7]. Typical contrasts range from $10^{-3}$for "hot Jupiters" in orbit around K0 stars to 10^{-5} for "temperate super-Earths" around M4 stars. To extract the spectrum of the planet therefore requires the co-addition of many transit observations in order to build up the total signal to noise ratio in the measurement. To achieve this to the level required demands a high level of stability in the detection system requiring, in turn, a payload design with a high degree of integration between the various components and with the satellite systems. All aspects of the system and payload design need careful attention to detail especially with regard to factors that can affect the photometric stability of the system and/or provide spurious signals that might mimic the light curve signature from the target planetary systems. In this paper we present such a design and show that, when integrated with the EChO satellite system, it will meet or exceed the requirements of the EChO mission.

The paper is organized as follows: In section 1.1 we recapitulate the basic scientific and technical requirements placed upon EChO in order to carry out its scientific mission. We go on to give an overview of the payload design and a brief justification for the design choices made. In section 2 we describe the system design in more detail and describe the detailed design of each of the system modules. In section 3 we discuss the performance of the payload and, briefly, describe the possible operational scenario and the performance of the instrument. In section 4 we draw some conclusions on the challenges presented for payload design by the EChO scientific mission and the challenges remaining for the instrument and systems design.

1.1 Scientific and Technical Requirements for the EChO payload

The typical temperature range of exo-planets detected to date varies from the very hot ~1000-1500 K through intermediate (500-1000 K) to temperate (100's K). In order to separate the spectrum of an orbiting planet from that of its host star it is therefore necessary to observe in the near to mid-infrared (~1 to 20 μm). Observing in this waveband not only increases the contrast between the emission from the star and planet, but it also contains very many of the most prominent spectroscopic features required for modeling planetary atmospheres ([3],[8]). The EChO mission is therefore designed to operate over as large a wavelength range as possible from the visible and into the mid-infrared. The baseline is that it shall cover 0.55 to 11 µm with a goal to cover from 0.4 to 16 µm. The payload design we have pursued will cover this goal. Such a large wavelength range demands that different spectrometer and detector technologies must be used to provide contiguous wavelength coverage. This, in turn imposes the need to divide the wavelength range by some means. A detailed evaluation of the spectral features of interest for exo-planet research shows that there are a number of wavelengths any division technique must avoid. Briefly, in the wavelength range above 3 µm we must avoid cutting between the following wavelengths, 3 to 3.6 µm, 4.1 to 5.0 µm, 5.7 - 8.3 µm, 9.2 - 11.0 µm and 13.5 to 16.0 µm. In the 0.4 to 3 µm range the situation is a little more complicated as there are a large number of features, an evaluation has been made that shows that placing a division at 2.47 µm will be scientifically acceptable. The scientific requirements also demand that the spectroscopic resolving power (λ/Δλ) shall be at least 300 for wavelengths up to 5 µm and 30 above 5 µm. The extremely large contrast between the star and the planet means that we must pay careful attention to the photometric stability achieved in the detection. The scientific requirements (see [5] and [9]) mean that, once we have applied sophisticated de-correlation algorithms, we must achieve a stability of one part in 10^4over a typical observing period of 10 hours. We set ourselves a goal of doing ten times better than this. The implications of each of the requirements set here on the design and operation of the payload are discussed in the following sections.

1.2 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 therefore chosen 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 [10], [11]) and Earth observation missions [12]. 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

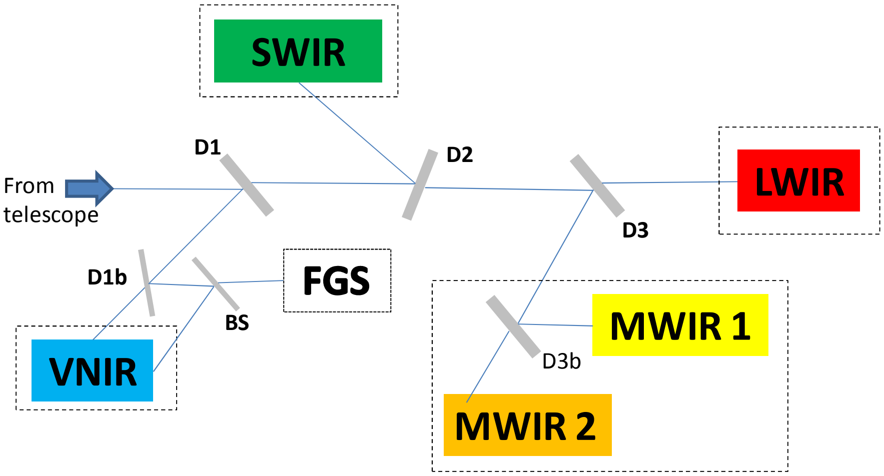
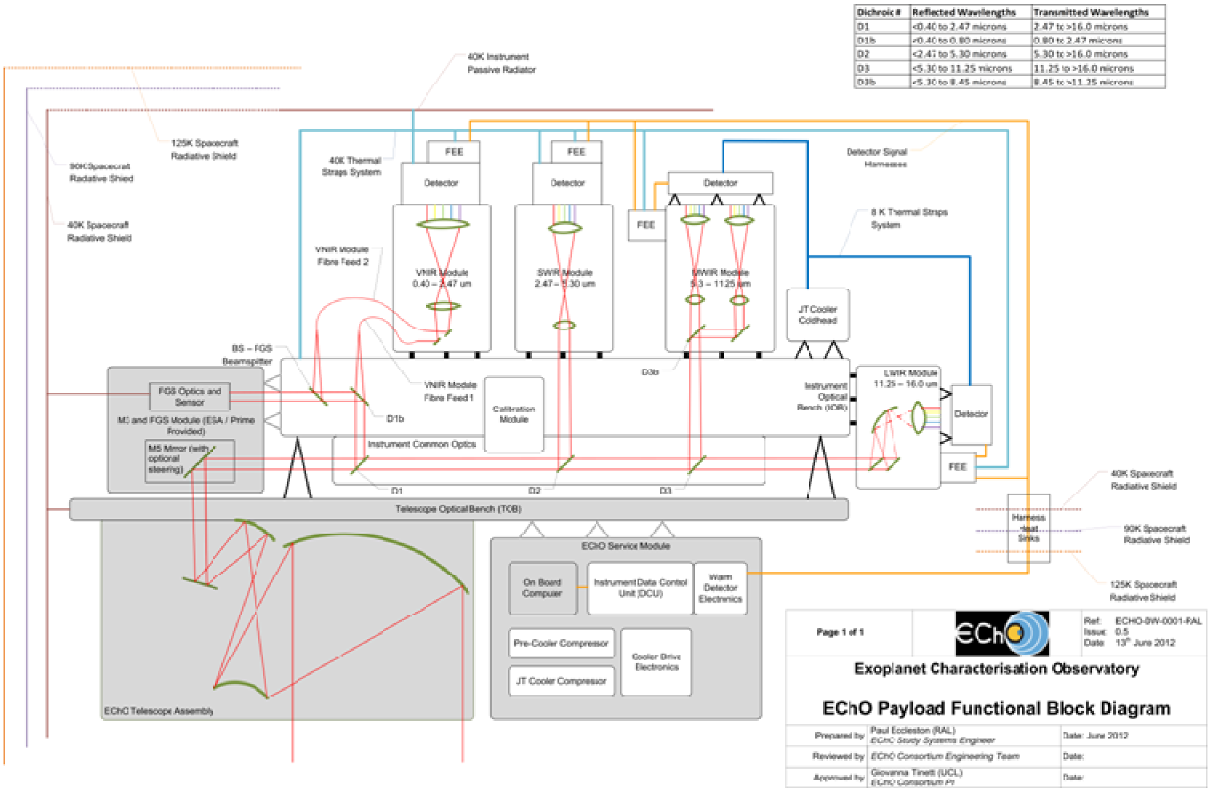


Figure 1: Baseline concept for the channel separation



Dichroic #	Reflected Wavelengths	Transmitted Wavelengths
D1	<0.40 to 2.47 microns	2.47 to >16.0 microns
D1b	<0.40 to 0.80 microns	0.80 to 2.47 microns
D2	<2.47 to 5.30 microns	5.30 to >16.0 microns
D3	<5.30 to 11.25 microns	11.25 to >16.0 microns
D3b	<5.30 to 8.45 microns	8.45 to <11.25 microns

Figure 2: Overall system block diagram for the EChO integrated payload in relation to the spacecraft systems. Note the telescope is shown as an off-axis three mirror design in accordance with the latest design evolution from ESA [4]

image into the spacecraft attitude control system to achieve the very high pointing accuracy required.

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 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.

2. DETAILED PAYLOAD DESIGN

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 Mercury Cadmium Telluride photo voltaic detectors (hereafter MCT see §2.3 and §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 Impurity Band Conduction (IBC) detectors (see §2.5 and §2.6) for the MWIR and LWIR modules require a dedicated Joule-Thomson cooler to provide a sub-8K 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

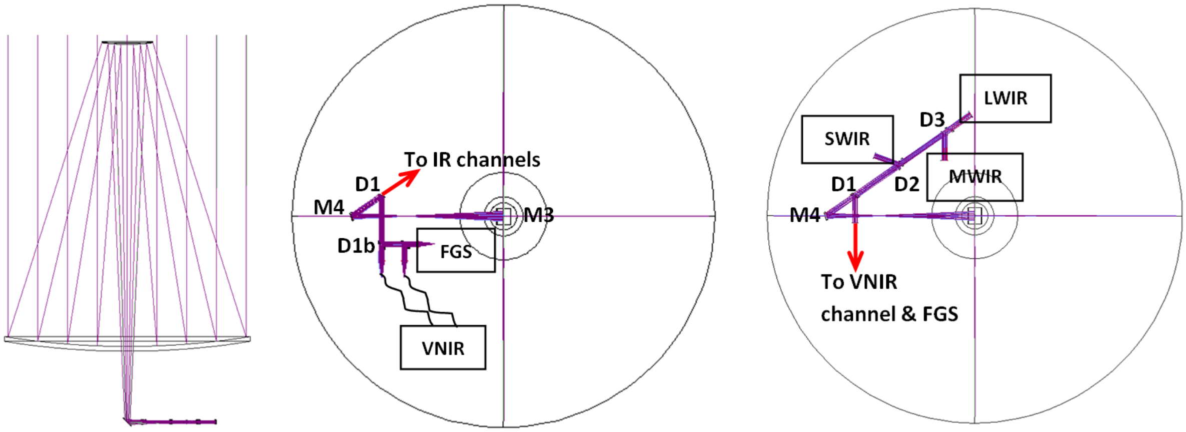


Figure 3: Common optics design shown for an on axis telescope design.

split between the payload processor and the spacecraft central processor. The division of tasks is subject to further study – see [13] and §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 class mission due for launch in the 2020's. The design presented here fulfils this ambition as we will show in the remainder of this section.

2.2 Common Optics and Channel Division

The ESA provided telescope system design has evolved over the course of the current study period (Phase A0 from mid-2011 to late 2012) from an on-axis Cassegrain type to an off-axis three mirror design [4]. 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 about +/-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.

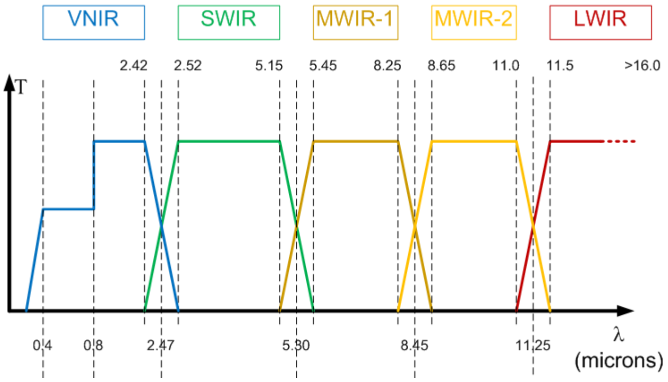


Figure 4a: Detailed specification of the channel divisions. These are chosen respect the scientific requirement to avoid certain wavelength ranges for spectral features whilst providing some spectral overlap between the channels

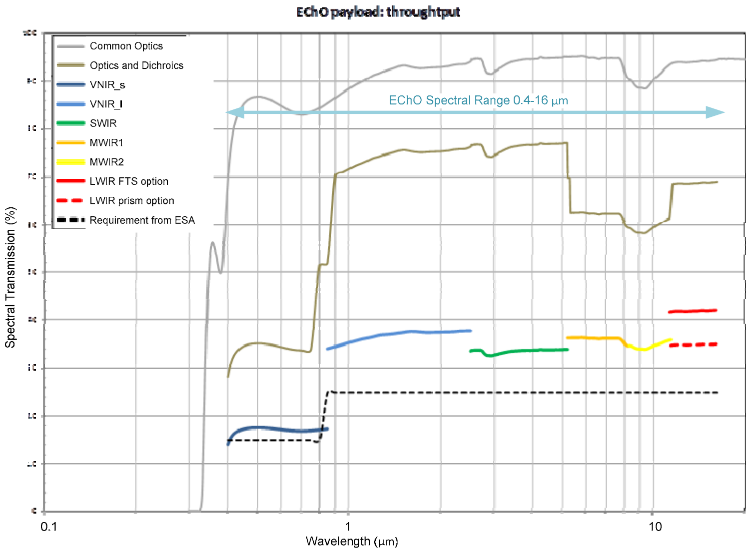


Figure 4b: Calculated transmission efficiency for the EChO integrated payload based on measured and calculated efficiencies of the optical components in each module

Table 1: Overview of the spectrometers type, wavelength coverage and design resolving power for each spectral channel

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

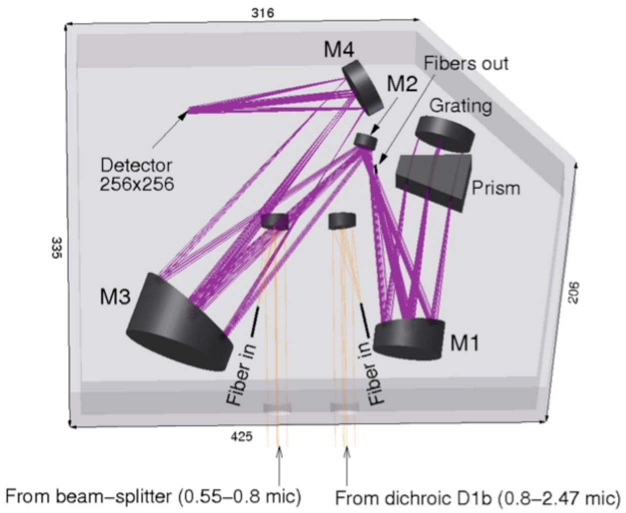


Figure 5: Outline optical design for the VNIR module.

After each dichroic the collimated beams feed the respective channel modules. Inside each module and sub-modules the 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 bandpass 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 4a, the calculated overall transmission efficiencies for the modules are shown in figure 4b 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.

2.3 VNIR Module

The detailed design of the VNIR module is described in [14]. 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 5) 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.

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

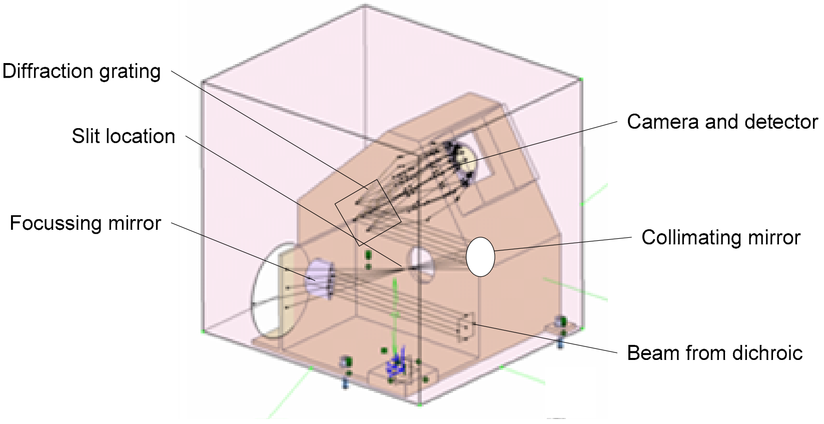


Figure 6: The SWIR module outline optical design shown in context with its mechanical envelope

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.

2.4 SWIR Module

The detailed design of the SWIR module is described in [15]. 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 6. 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.

2.5 MWIR Module

The detailed design of the MWIR channel is described in [16]. The optical and mechanical design of the module is illustrated in figure 7. 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 [17] 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 [18] whilst maintaining dark current and read noise values compatible with the photon noise expected from the EChO target stars (see [5]). The disadvantage of using Si:As technology is that the arrays require an operating temperature less than 8 K. This necessitates moderately complex thermal engineering and the use of Joule-Thomson and Stirling-cycle coolers (see §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 about 30-40 K removing the need for one and possibly both of the closed cycle coolers.

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

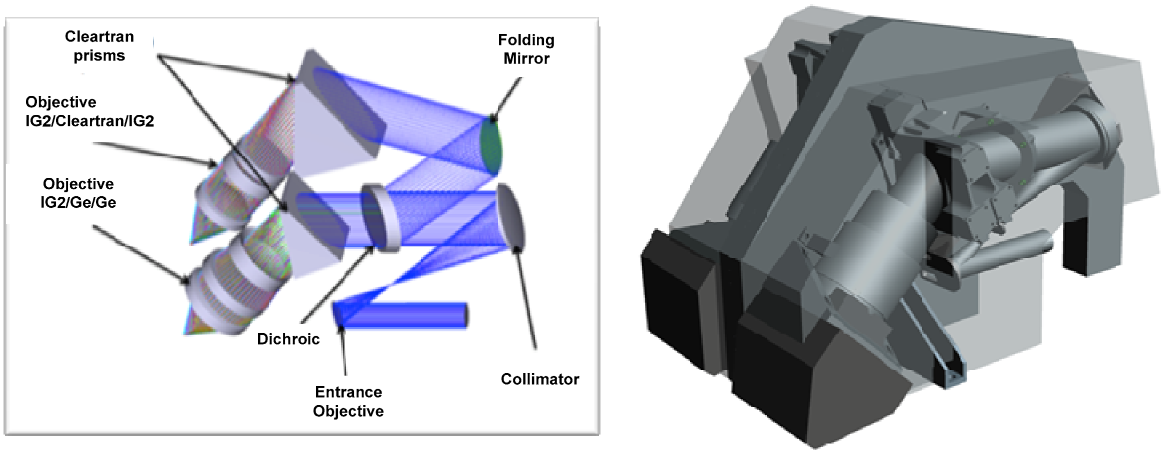


Figure 7: Left the optical layout of the MWIR module. Right the mechanical accommodation of the module.

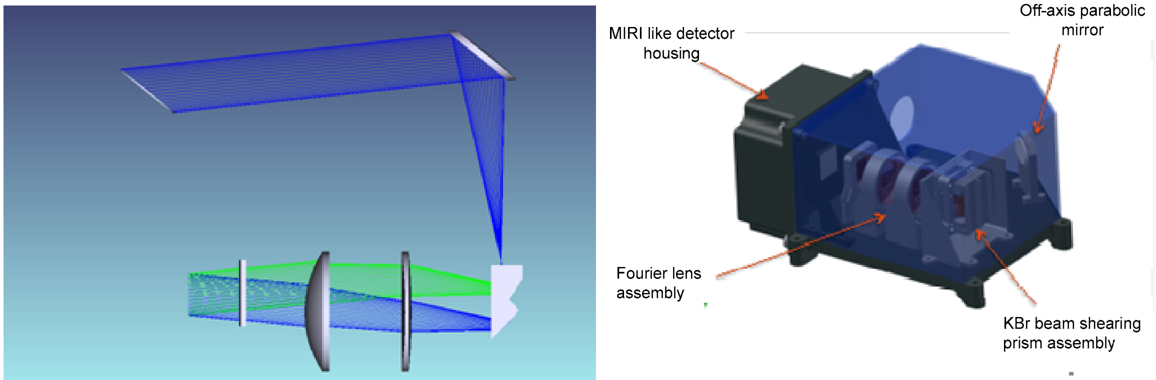


Figure 8: Optical layout of the Static FTS option ([19], [20]) shown here with a representative 17.7 mm diameter input and single focusing off axis parabolic reflector.

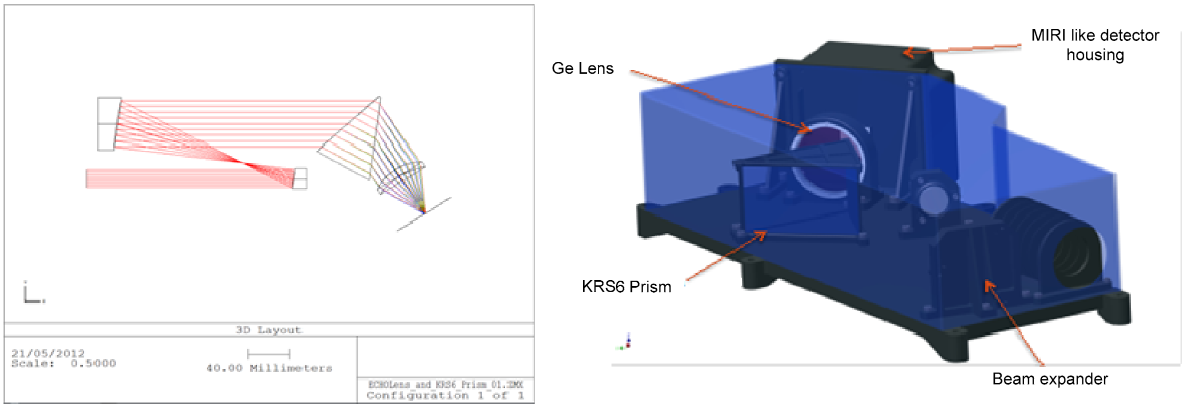


Figure 9: KRS6 prism design for the 11-16 µm channel with x2.5 beam expander.

plane ([19] - see figure 8). 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.

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 9. 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 30 µm. 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 30-45K becomes available for the LWIR pass-band, then replacing the 7-K 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

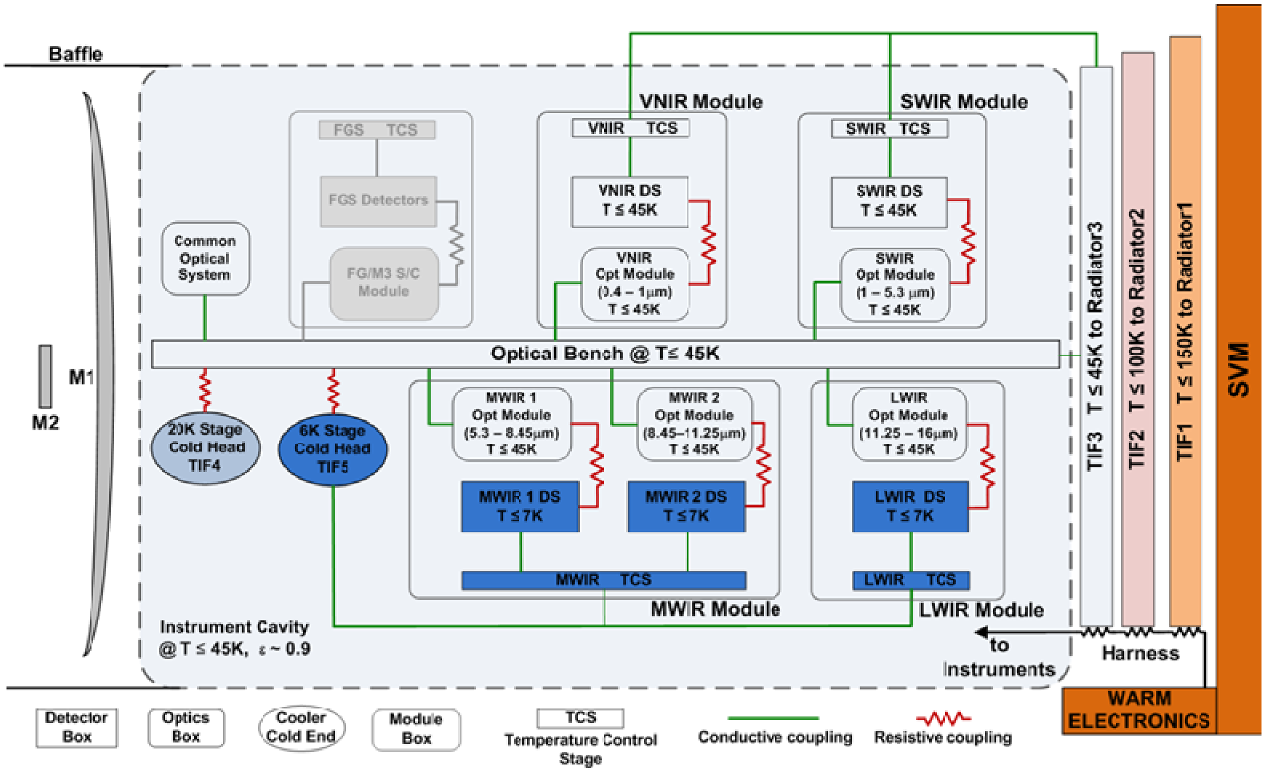


Figure 10: The thermal systems design for the EChO payload in the context of the EChO satellite thermal systems.

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.

2.7 Thermal Design

The thermal and mechanical design of the EChO payload is described in detail in Eccleston et al [21]. The design is based on a combination of passive and active cooling systems (see figure 10). 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. The choice of cooler technology is discussed extensively in [21]. Our baseline is to use a Joule-Thomson cooler based on the successful Planck design ([22], [23]) 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.

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

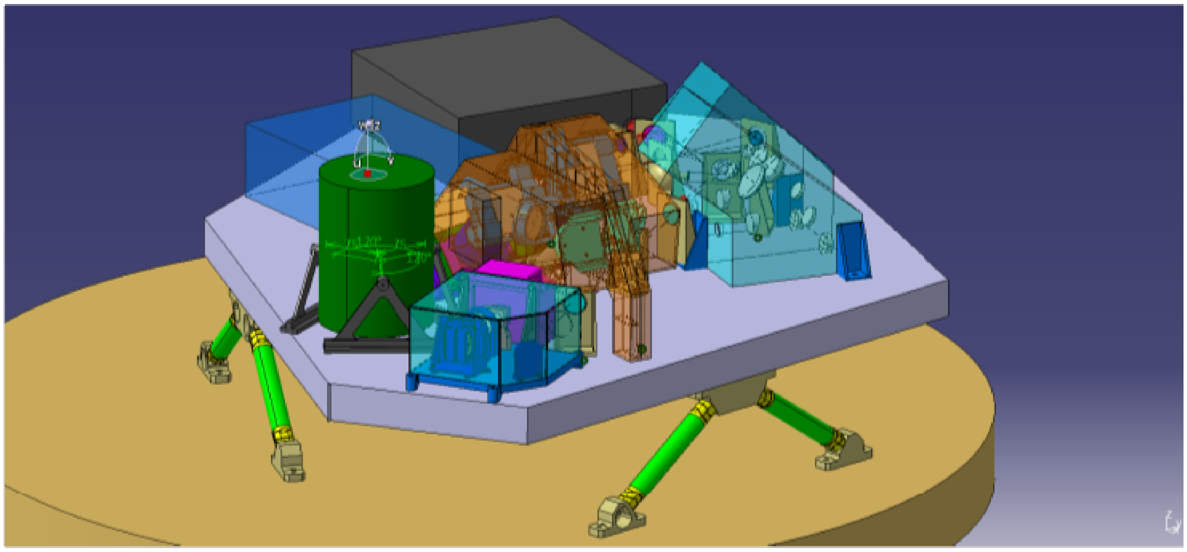


Figure 11: Illustration of the accommodation of the EChO common optics, spectrometer modules and cooling elements on the EChO Instrument Optical Bench (IOB). The dark green cylinder represents the J-T cooler head and the brown surface below the IOB represents the telescope optical bench(TOB). The IOB is kinematically mounted from the TOB

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, as shown in [21] the design shown in figure 11 can still be accommodated in this new arrangement.

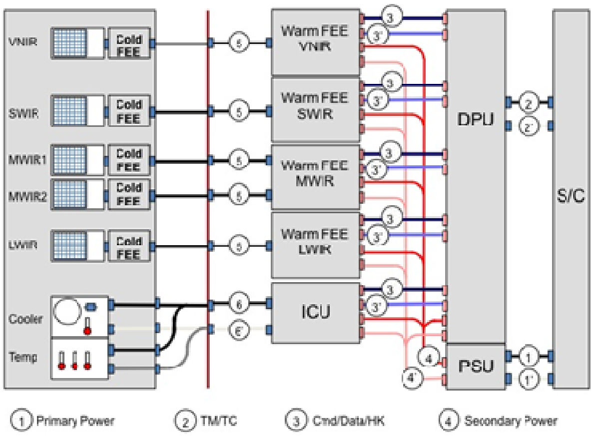


Figure 12: The proposed electrical architecture for the EChO integrated payload.

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 [13]. 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 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 12.

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.

3. OBSERVING SCENARIO AND PERFORMANCE

The operational scenario for EChO is to stare at a given target over the period of the transit of the planet around the star. In order extract the planetary emission or transmission spectrum the instrument and satellite must provide a high degree of photometric stability with as little induced signal and noise variation as possible. Ultimately the disturbance “signal” must be less than one part in 10^4 following processing of the data. This seems at first glance an extreme situation for the mission, however, we are assisted immensely by the fact that we have prior knowledge of the phase and period of the transiting planet such that we can extract the signals using what amounts to a matched filter. This greatly reduces the frequency space over which we need to achieve the stability requirements. A detailed discussion of the techniques involved is beyond the present work (see [24] for further details) but we estimate that the post processing stability requirements will apply for time periods between a few tens of minutes to a few hours. A detailed model of the effects of various influences on the signal such as pointing jitter, thermal drift, mechanical distortion, induced micro-vibrations, cosmic rays etc is now under way (see [9]). As an example of the methods that we might use for reducing the effects of spacecraft disturbances, we find that a pointing stability of 10 milliarcsec over a ten hour period is sufficient to provide the required photometric stability provided we track the correlated signal variation across the waveband using the observed variation in the line centres of stellar absorption features. A preliminary assessment of the ability to detect various planetary types around different stars has been conducted [5] and results are summarized in table 2. As we can see, with design assumptions described in this paper, the EChO integrated payload will be able to detect the spectra from the very faintest targets in times compatible with the mission lifetime in all infrared bands in the case of the hot planets and in the long wavelength bands in the case of the warm planets. For the extremely challenging case of attempting to measure the spectrum of a cool (300 K) super-Earth it will be just possible but only by co-adding several spectral elements to provide a lower resolution spectrum. This is all as expected from the emission characteristics of these objects. The estimates given here are for the case of the planetary emission spectrum only – the shorter wavelength channels are therefore not useful, however these channels come into their own when observing the Giant planetary atmospheric absorption spectra in the primary transit case. A detailed discussion of the two cases is beyond present work see [5], [7] and references therein.

Table 2: Estimated observing times for the EChO mission to achieve a signal-to-noise ratio of 5 in a single spectral element

Wavelength (microns)	**Resolving Power**	**K0V Star (mag 9 K-band) Hot Jupiter (1500 K)**	**M4V Star (mag 9 K-band) Warm sup-Earth (600 K)**	**55 CncE (mag 5.9 V-band) Hot super-Earth (2340 K)**	**M5.5V Star (mag 7 K-band) Cool super-Earth (300 K)**
3	300	8.2 hrs	N/A	8.2 hrs	N/A
7.5	30	0.5 hrs	119 hrs	1.4 hrs	Res 10 234 Hrs
13.5	30	2.2 hrs	169 hrs	4.6 hrs	Res 10 16 Hrs

4. CONCLUSIONS AND FUTURE CHALLENGES

We present in this paper an integrated instrument suite for the EChO exo-planet spectroscopy mission. The very high level of photometric stability required to detect exo-planet spectra has driven the design of the instrument and dictates the high level of integration required. For instance the different modules share a common optical interface with the telescope, are mounted on a common mechanical structure and share common thermal and electrical interfaces where at all possible. All these measures are designed to reduce the impact of differential disturbances to the signal across the wide operational waveband and ensure as much "common noise" rejection as possible. The design is shown by first order analysis to be compatible with the science requirements for EChO and the preliminary design is compatible with the spacecraft budgets. Much detailed design remains to be done to bring the mission and payload to fruition, but it is clear that the design can be realised with minimal technological development required. In some areas, particularly the detectors, we wish to pursue technological developments in order to reduce the cost and risk in other areas of the payload design: i.e. higher operating temperature detectors will remove the need for sophisticate cooling mechanisms. In all cases alternative high Technical Readiness Level (TRL) solutions exist and we have identified no major technical risks to the development of EChO. Major challenges remain in identifying and quantifying all sources of noise and disturbance in the EChO spacecraft and payload and ensuring that the design of all parts of the system are compatible with the photometric stability budgets. Overall the combination of a stable platform operating in a stable thermal environment and with a highly integrated payload and systems design will ensure an exciting future for exo-planet research in the 2020's.

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