Technical & Programmatic Annex

April 2004

EarthCARE - Earth Clouds, Aerosols and Radiation Explorer
SPECTRA - Surface Processes and Ecosystem Changes Through Response Analysis
WALES - Water Vapour Lidar Experiment in Space
ACE+ - Atmosphere and Climate Explorer
EGPM - European Contribution to Global Precipitation Measurement
Swarm - The Earth's Magnetic Field and Environment Explorers

European Space Agency
Agence spatiale européenne

REPORTS FOR MISSION SELECTION

THE SIX CANDIDATE EARTH EXPLORER MISSIONS

Annex to ESA SP-1279(2)
April 2004

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SPECTRA
Surface Processes and Ecosystem Changes Through Response Analysis
Technical and Programmatic Annex

European Space Agency
Agence Spatiale Européenne

Contents

1 Introduction

This document provides the technical description of the SPECTRA mission as derived from the preparatory activities at phase A level, for implementation as an Earth Explorer in the frame of ESA’s Living Planet Programme. It shows how feasible implementation concepts can respond to the scientific mission requirements defined in the Science Report. To this end, the expected system performance will also be described. A summary assessment of the programmatic framework is also provided.

The system description is mainly based on the results of work performed during two parallel phase A system studies by two industrial consortia. It is not possible to describe in this report all technical concepts, but where necessary, two concepts are described in order to present significantly different approaches to meeting the mission observation requirements. The description of particular concepts does not indicate special preferences.

After an overview of the mission architecture and the proposed orbit (in Chapters 2 and 3) the space segment will be described in detail (Chapter 4), followed by the ground segment and operations concept (Chapters 5 and 6). Following an overview of the data products (Chapter 7), the overall performance is described (Chapter 8). The report concludes with programmatic considerations (Chapter 9).

2 Mission Architecture Overview

The SPECTRA mission architecture is driven by the requirements for high-performance optical observations of selected target sites in the angular, spectral and radiometric domains.

The driving factor for the overall mission is the need to obtain hyperspectral directional observations of selected target sites that are distributed globally, under varying observation zenith angle (OZA, see Figure 2-1) to derive the Bidirectional Reflectance Distribution Function (BRDF). The pointing capabilities across track (ACT) and along track (ALT) are further constrained by the need to ensure a three-day revisit possibility per site.

The key requirements for the on-board instrumentation refer to the spectral, spatial and radiometric resolutions for the individual acquisitions, calling for observations in the Visible, Near-InfraRed (VNIR), and Short-Wave InfraRed (SWIR) bands, extending from 400 nm to 2.4 µm without gaps, with 10 nm spectral resolution, and two bands in the thermal infrared (TIR) range, between 10.3 µm and 12.3 µm. The spatial resolution is required to be 50 m at nadir, and to remain as constant as possible, not exceeding 100 m at large observation angles.

The target sites for the mission will be instrumented by the user community and the in-situ measurements will be made available to the science community together with the remotely sensed data for geophysical product generation.

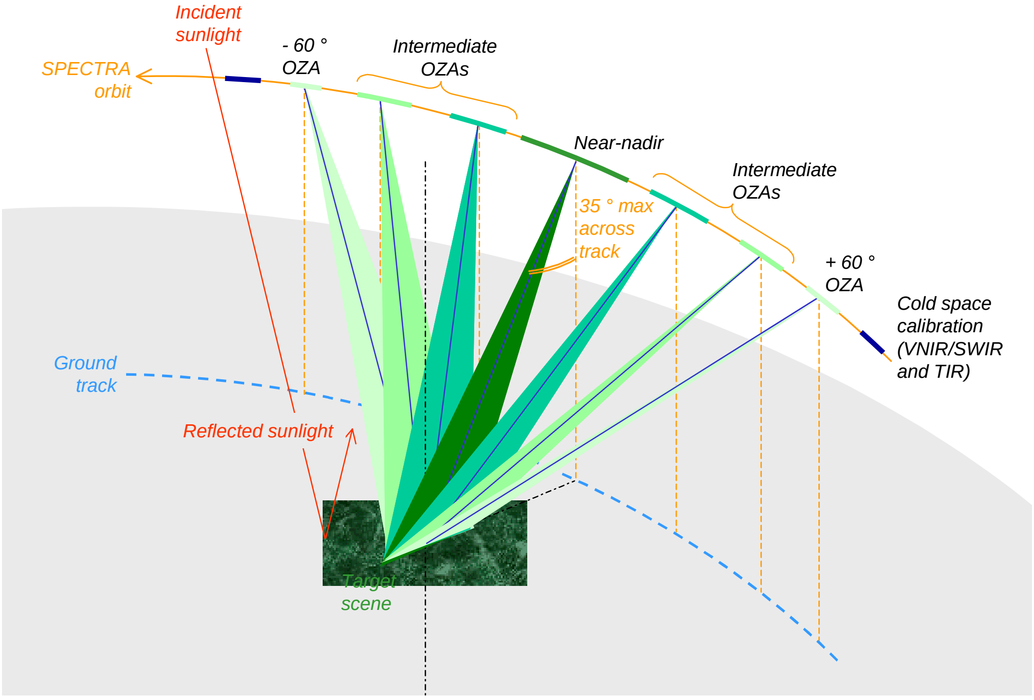


Figure 2-1: *Scene Acquisition Sequence*

In order to fulfil the above requirements, the SPECTRA mission includes the following elements (see Figure 2-2):

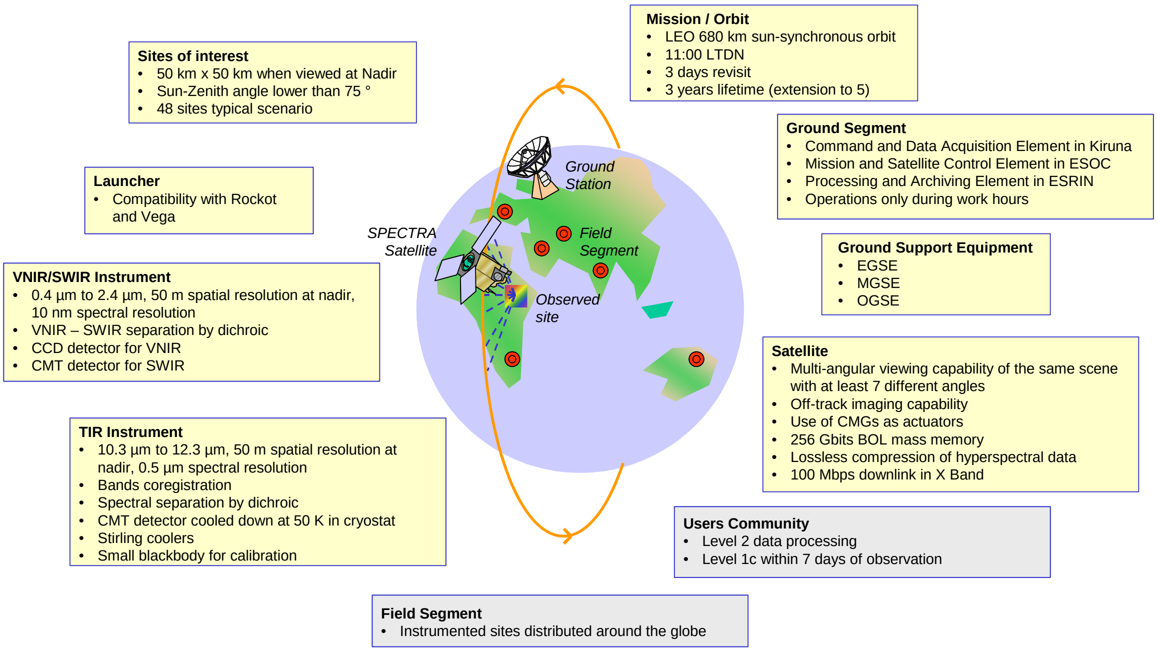
- A space segment, featuring an agile satellite carrying two instruments: A hyperspectral imaging sensor covering the VNIR/SWIR wavelength range, and a radiometer with two bands in the TIR region. The pointing function required to achieve the different viewing angles is entirely implemented at satellite level.

- A launch vehicle capable of injecting the SPECTRA satellite on its orbit with the required accuracy. Two reference launchers are identified.
- A ground segment in charge of satellite command and control operations, and of scientific data acquisition, processing, storage and distribution to the user community.
- A field segment, an essential element of the SPECTRA mission, consisting of a collection of well-documented and instrumented sites that are intensively studied by the user community.

The main observation requirements are summarized in Table 2-1:

Orbit, Spatial and Temporal Coverage	
Orbit	Sun-synchronous orbit Local time at descending node = 11.00 a.m.
Access time to any site on Earth	< 3 days
Orbit repeat cycle	To allow sites to be observed with varying ACT angles
Mission Principles	
Lifetime	3 years in orbit (goal : 5 years)
Directional requirements (daylight)	Near nadir 7 along track directions with -60° ≤ OZA ≤ 60°
Spectral bands acquisition	Nominal: 2 TIR + 60 bands (VNIR/SWIR) Full spectrum (on request)
Number of acquisitions	Average 25 BRDF sequences per day; Maximum 3 BRDF sequences per orbit
Pointing Requirements	
Pointing error	± 2% of largest diagonal dimension of the ground projection of each image (± 1.4 km nadir)
Localisation error	1 km (image center) - With processing :150 m
Spatial requirements	
Image swath / length	50 km nadir
Spatial sampling interval	≤ 50 m ACT nadir; ≤ 50 m ALT any angle
Spatial width at nadir (FWHM IPSF)	≤ 50 m ALT nadir; ≤ 65 m ACT nadir
Spatial width off-nadir (FWHM IPSF)	≤ 100 m for OZA=60° (no roll) in VNIR/SWIR ≤ 150 m for OZA=55° (no roll) in TIR
Spatial misregistration within each region	≤ 0.2 x pixel within VNIR/SWIR and within TIR
Spatial misregistration between regions	≤ 4 x pixels absolute; stable within 0.2 x pixels during a BRDF sequence
Spectral Requirements	
Acquisition range in VNIR/SWIR	0.4 to 2.4 µm
Sampling interval in VNIR/SWIR	≤ 10 nm
Misregistration in VNIR/SWIR	≤ 1.5 nm – Goal ≤ 0.5 nm in 400-650 nm range
Central wavelength knowledge in VNIR/SWIR	≤ 0.5 nm
Bandwidth knowledge in VNIR/SWIR	≤ 0.5 nm
Stability in VNIR/SWIR	≤ 0.5 nm over 1 year
Acquisition range in TIR	TIR1: 10.3-10.8 µm - TIR2: 11.8-12.3 µm
Spectral characterisation	According to template provided
Radiometric requirements	
Dynamic range	Radiance range specified in VNIR/SWIR 240 – 345 K TOA blackbody scenes in TIR
Radiometric resolution	≤ specified NedL envelope in VNIR/SWIR NEDT ≤ 0.1 K @ 300 K in TIR
Absolute radiometric accuracy	2% to 5% in VNIR/SWIR ≤ 1 K (270-345 K)

***Table 2-1:** Main observation requirements*



Mission / Orbit
- LEO 680 km sun-synchronous orbit
- 11:00 LTDN
- 3 days revisit
- 3 years lifetime (extension to 5)

Sites of interest
- 50 km x 50 km when viewed at Nadir
- Sun-Zenith angle lower than 75 °
- 48 sites typical scenario

Ground Segment
- Command and Data Acquisition Element in Kiruna
- Mission and Satellite Control Element in ESOC
- Processing and Archiving Element in ESRIN
- Operations only during work hours

Launcher
- Compatibility with Rockot and Vega

Ground Support Equipment
- EGSE
- MGSE
- OGSE

VNIR/SWIR Instrument
- 0.4 µm to 2.4 µm, 50 m spatial resolution at nadir, 10 nm spectral resolution
- VNIR – SWIR separation by dichroic
- CCD detector for VNIR
- CMT detector for SWIR

Satellite
- Multi-angular viewing capability of the same scene with at least 7 different angles
- Off-track imaging capability
- Use of CMGs as actuators
- 256 Gbits BOL mass memory
- Lossless compression of hyperspectral data
- 100 Mbps downlink in X Band

TIR Instrument
- 10.3 µm to 12.3 µm, 50 m spatial resolution at nadir, 0.5 µm spectral resolution
- Bands coregistration
- Spectral separation by dichroic
- CMT detector cooled down at 50 K in cryostat
- Stirling coolers
- Small blackbody for calibration

Users Community
- Level 2 data processing
- Level 1c within 7 days of observation

Field Segment
- Instrumented sites distributed around the globe

Figure 2-2: *SPECTRA Overall Mission Architecture*

3 Mission Profile

The definition of the mission profile for the SPECTRA mission involves mainly two aspects: the orbit selection proper and the mission planning and operations strategy.

The altitude of the operational orbit has been selected to provide access to any target on the Earth within three days, taking into account the pointing capabilities of the satellite. Furthermore, to ensure that the targets are observed under varying across track angles, a repeat period of 14 days has been selected. Lower altitude, still compatible with acceptable pointing angles across track (35°) is preferred to limit the instrument aperture and to increase the launcher compatibility. The local crossing time was chosen to optimise the target scene illumination, the sampling of the angle between the sun, the target and the satellite (the phase angle of the BRDF), and the minimisation of the statistical cloud coverage. The analysis leads to the parameters summarised in Table 3-1.

General Properties			
Orbit Type		Frozen Sun-Synchronous	
Altitude		673.613 km	
Period [s]		5 900.5 s	
Local Time at Descending Node		11:00	
Mean Elements		**Repeat Cycle Properties**	
Semi-major axis	7 051.749 km	Repeat Cycle Definition	14 + 9/14
Eccentricity	0.0010473	Repeat Cycle	14 days
Inclination	98.081 °	Orbits per day	14.643

Table 3-1: *Baseline Orbit Parameters*

The access and revisit time achieved with this orbit and with a maximum de-pointing of the satellite system of maximally 35° across track are depicted in Figure 3-1.

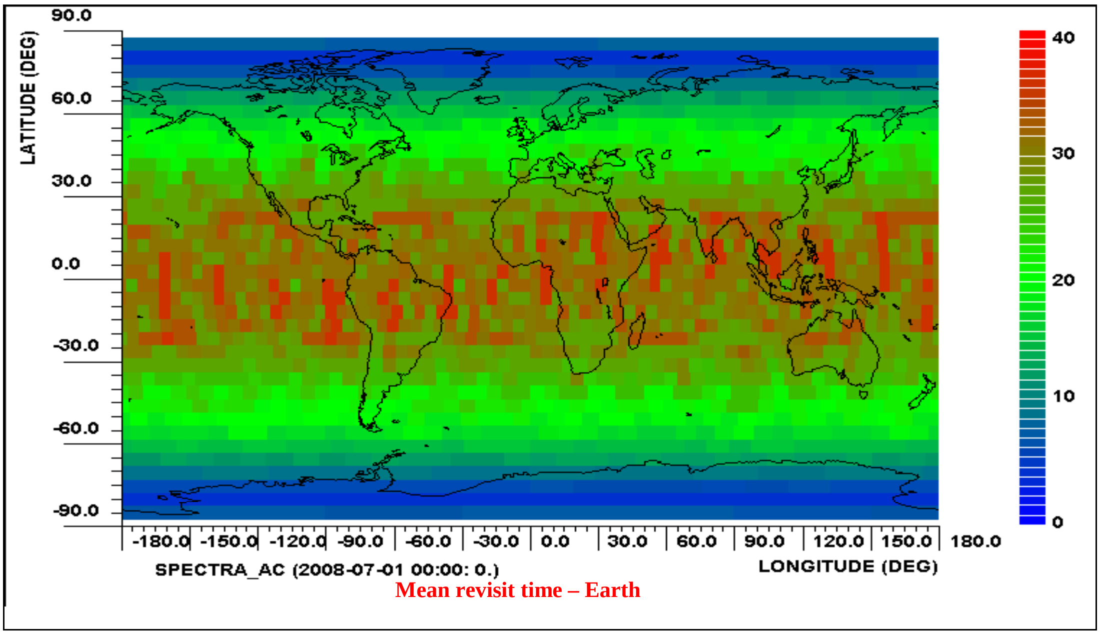


Figure 3-1: *Mean Acces Time (hours)*

In its operational orbit, the satellite can point across track to access a selected target of observation. During a pass the satellite is pointed to acquire the site under different observation angles. The acquisition is using a motion compensation (slowdown) pointing law for the line-of-sight in order to improve the radiometric performance of the instrument.

During the remaining time the solar panels are pointed towards the sun or towards the Earth (when in eclipse). This scenario is depicted in Figure 4-11.

The mission planning and the above operation strategy analysis were based on a mission scenario with around 50 sites, as illustrated in Figure 3-2. In addition, vicarious calibration sites over the ocean and deserts to validate the on-board calibration have been added. Observation requests have been established, taking into account the period of interest for observation and the minimum number of required directional measurements. Optimisation of parameters dependent on the geometry has been performed. Maximisation of acquisition of sites and repeating observations in case of cloudy target conditions have been taken into account.

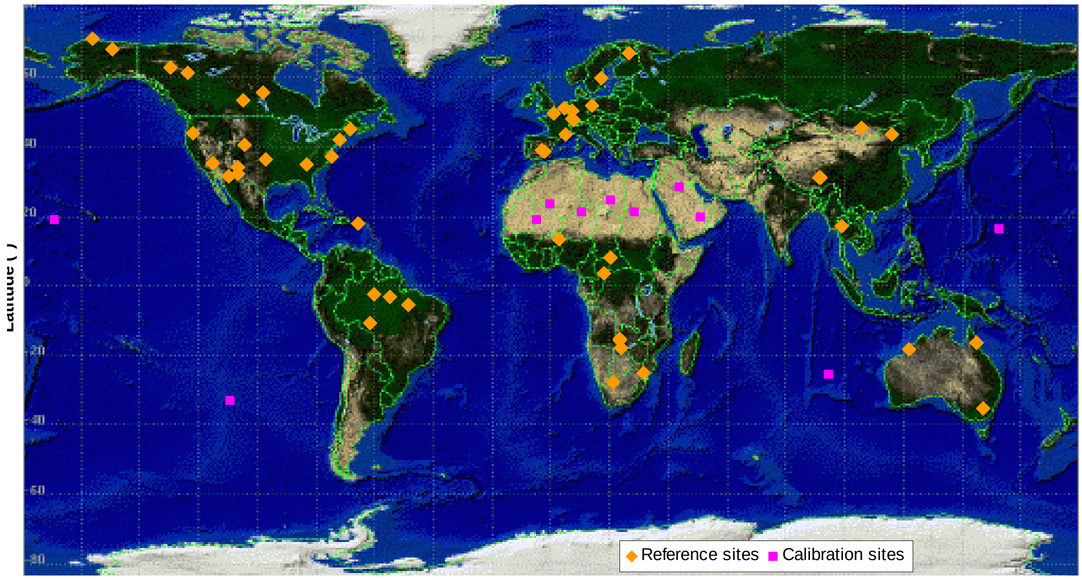


Figure 3-2: *Mission Scenario and Sites*

Extensive simulations, taking into account technical constraints such as satellite attitude control capabilities, mass memory resources, and downlink constraints to the selected ground station, have confirmed the viability of the chosen approach. The results demonstrate that the reference scenario can be met with the proposed technical and operational baseline, still demonstrating significant growth potential in terms of additional observations.

4 Space Segment

Modular satellite concepts have been proposed, with separation between the payload and the platform modules. The relevant technical descriptions are summarised in the following Chapters 4.1 and 4.2 and complemented with an overview of the overall satellite configuration in Chapter 4.3.

4.1 Payload

For the payload, two concepts have been proposed and are presented separately below. The performance is detailed in chapter 8 (Performance aspects). In both concepts, two push-broom instruments compose the SPECTRA payload: the VNIR/SWIR instrument and the TIR instrument.

Concept A

In this concept the instruments are accommodated on a common optical bench, which ensures their co-registration and their interface with the spacecraft.

4.1.1 VNIR/SWIR Instrument

The VNIR/SWIR instrument (shown in Figure 4-1) is an imaging spectrometer operating in the wavelength range from 0.4 to 2.4 µm, with a spectral resolution of 10 nm. The instrument reads out all the bands in the given spectral range and transmits them to the data handling sub-system. The optical subsystem is modular and involves two sub-assemblies: the telescope and the spectrometer. The telescope is a Three Mirrors Anastigmatic (TMA), providing a compact and efficient design, with an aperture diameter of 130 mm. The spectrometer is an innovative approach involving collimating/focusing all mirror optics, associated to spectral dispersion by a couple of fused silica prisms. A dichroic beam splitter, located at very low incidence on a quasi-parallel optical beam, ensures the spectral separation between VNIR and SWIR channels. To ensure spectral and spatial registrations performance, the spectrometer is mounted on a stable and thermally controlled optical bench, which is mechanically and thermally decoupled from external perturbations.

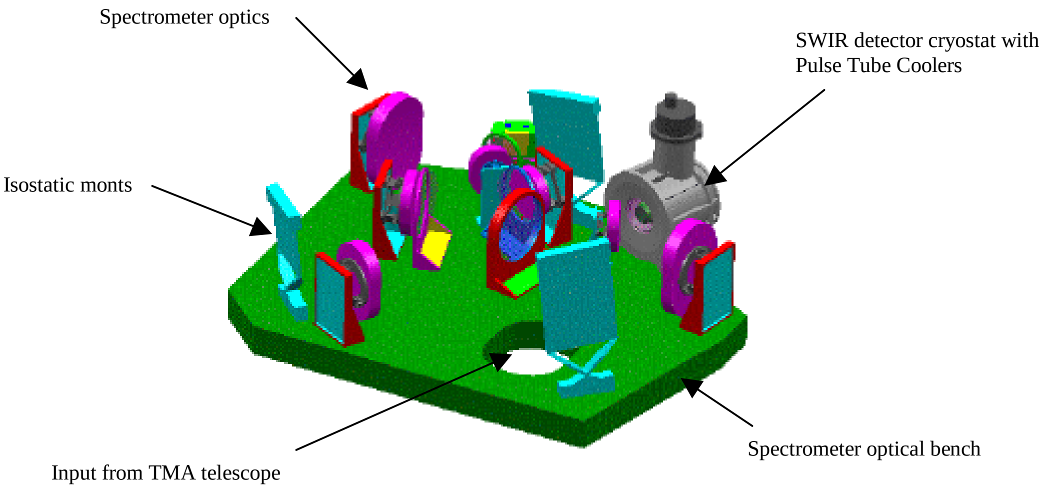


Figure 4-1: *Concept A VNIR/SWIR instrument*

The instrument images the scene onto two different bi-dimensional detector arrays, in which, according to the pushbroom mode, the columns represent the spatial dimension and the rows represent the spectral dimension.

The VNIR detector baseline is a back-illuminated Silicon CCD with four output ports. The image section consists of 1000 columns and 175 rows and is split so that an equal number of spectral bands are read-out from the top and the bottom of the device, accounting for the spectral binning performed in the low VNIR spectral region (see Figure 8-4). The detector operating temperature can be adjusted down to about 5° C, by means of a small passive radiator.

The SWIR detector baseline is the one currently under development by ESA in the frame of APEX/SPECTRA pre-development activities. This 1000 x 256 pixels detector is constituted of a Mercury Cadmium Telluride (MCT) detecting module hybridized on a monolithic CMOS multiplexer. From preliminary dark current measurements on the breadboard, the detector requires an operating temperature of about 175 K.

The SWIR detector operating temperature is achieved by using two mini-pulse tube coolers shown in Figure 4-2.

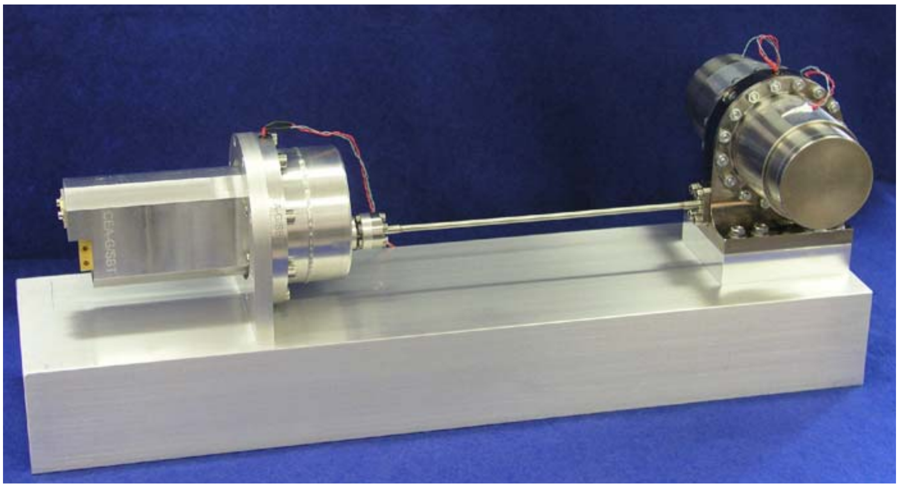


Figure 4-2: *Pulse-tube cooler configuration*

The radiometric and spectral calibration of SPECTRA in the VNIR/SWIR region directly capitalizes on the MERIS heritage. The full aperture calibration assembly involves three diffusers mounted on a rotating wheel: two white diffusers for radiometric calibration (one nominal used for radiometric calibration and one redundant to monitor degradation of the nominal diffuser), and a doped diffuser for spectral calibration (Spectralon doped with a mixture of Erbium, Holmium and Dysprosium). The calibration assembly includes, as well, a shutter for both dark signal calibration and contamination protection.

4.1.2 TIR Instrument

The TIR instrument (shown in Figure 4-3) provides images in two spectral bands with a width of 0.5 µm in the spectral range from 10.3 to 12.3 µm. A TMA telescope with an aperture of about 180 mm collects the light from the scene. Before the focal plane, a dichroic beam splitter performs the spectral separation of the two bands, and splits the optical path towards two detectors (TIR1 and TIR2). Both detectors and the dichroic beam splitter are housed in a cryostat. The detectors are cooled down to about 50 K.

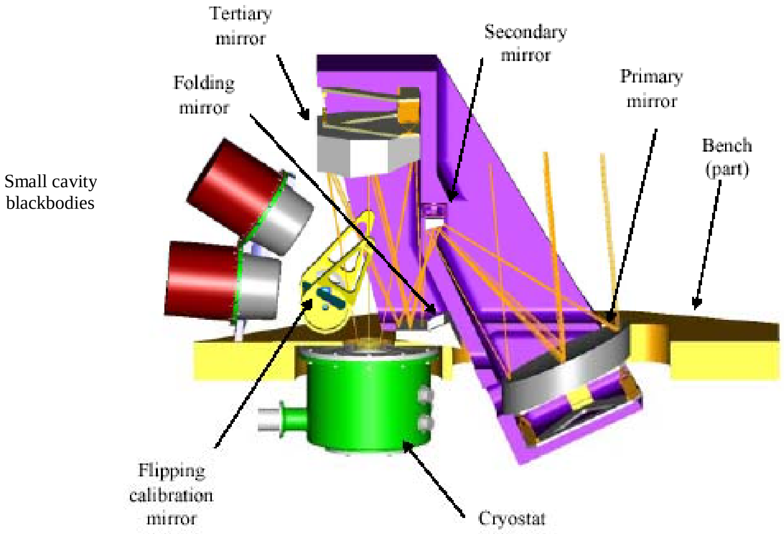


Figure 4-3: *Concept A TIR instrument*

The main characteristics of the TIR detector baseline proposed at the end of phase A are that for each band, a Mercury Cadmium Telluride (MCT) monolithic detecting module constituted of two or three lines (used for redundancy) of 1000 pixels will be used. The two modules are hybridised on a monolithic readout circuit based on the direct injection principle and a readout circuit constituted of two video outputs working at about 3 MHz.

In order to achieve the required operating temperature, two Stirling coolers are used, associated with a two-stage cryostat.

The radiometric calibration is achieved using two assemblies: 2 small cavity blackbodies, inserted before the cryostat by a flipping mirror, for frequent relative equalisation of the instrument response (relative spatial calibration), and a large plate blackbody for less frequent absolute calibration of the entire optical chain.

4.1.3 Payload Structural Architecture (Concept A)

The payload structural architecture involves three ensembles, as illustrated in Figure 4-4. The payload optical bench, which supports the instruments and the star trackers is directly interfaced to the platform through three bipods ensuring quasi isostatic mounting. The “cage” structure surrounds the optical bench, and provides in particular the mechanical support to the compressors and radiators of the coolers employed for the SWIR and TIR. This cage structure is mounted through six attachments to the platform and is covered with Multi-Layer Insulation (MLI) on non-radiative areas. The top panel closes the payload module and supports the antennas and the VNIR/SWIR and TIR calibration assemblies.

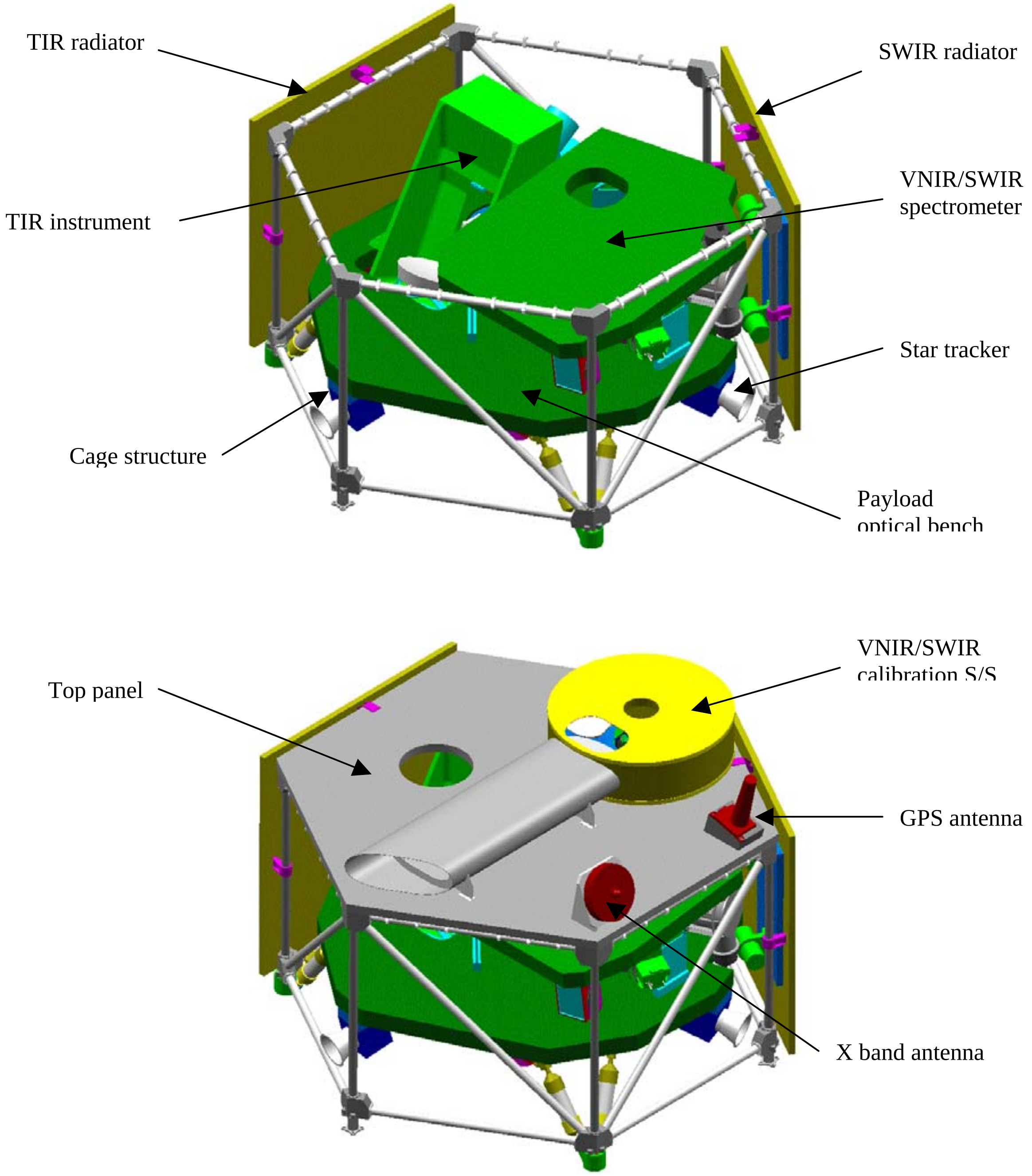


Figure 4-4: *Payload Module Configuration (Concept A)*

Concept B

In this concept the instruments are accommodated on the top panel of the spacecraft.

4.1.4 VNIR/SWIR Instrument

The VNIR/SWIR instrument is an imaging spectrometer operating in the wavelength range from 0.4 to 2.4 µm, with a spectral resolution of 10 nm. The instrument reads out all the bands in the given spectral range and transmit them to the data handling sub-system.

The optical subsystem consists of a telescope followed by a spectrometer (as shown in Figure 4-5). The telescope is a five mirrors Schaefer telescope, which provides easy alignment and excellent control of stray light, with an aperture of about 120 mm. The spectrometer is a compact Offner type unit, with 2 curved prisms for generation of the necessary spectral dispersion. A dichroic beam splitter provides VNIR and SWIR band separation. The spectrometer is mounted on an optical bench in order to ensure stability.

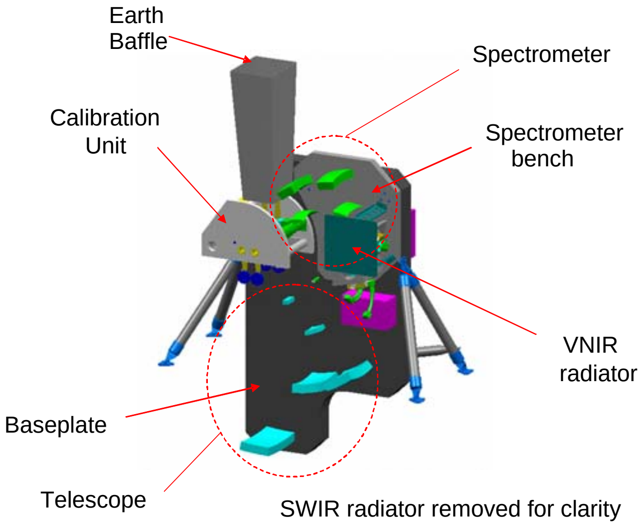


Figure 4-5: *Concept B VNIR/SWIR Instrument*

The VNIR and SWIR detectors are of the same type and characteristics of those described for concept A and are shown in Figure 4-6.

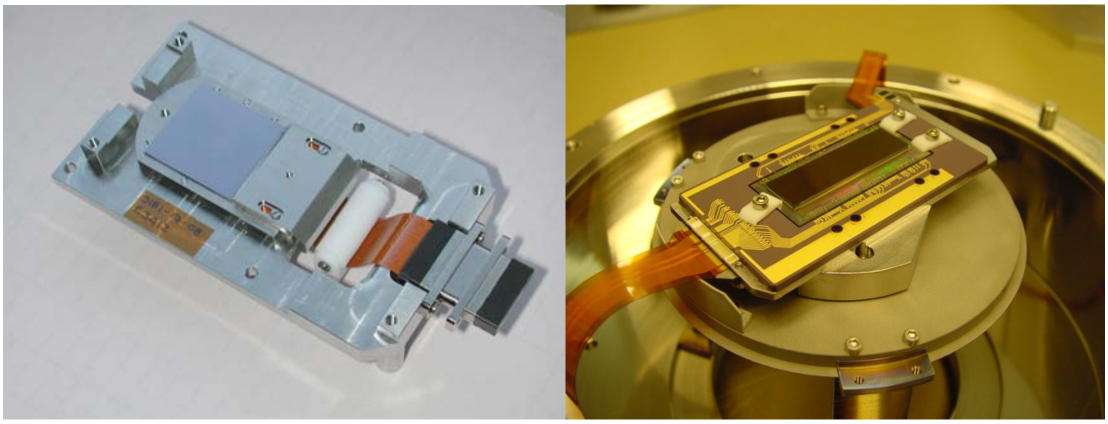


Figure 4-6: *CCD detector assembly (left) and SWIR detector assembly (right)*

The SWIR detector operating temperature is achieved using a passive cooling system. This radiator is a two stage device with a first stage designed as a compact parabolic concentrator for rejection of Earth and sun radiation and a second stage, disk like radiator with view to cold space.

The in flight calibration is performed by a unit located at the entrance pupil of the telescope. This system consists of a sun-illuminated echelle monochromator, for spectral calibration, and a rectangular diffuser moved stepwise at various positions in the entrance pupil for radiometric calibration. A second diffuser of the same shape is used to monitor in-flight degradation of the first one.

4.1.5 TIR Instrument

The TIR instrument provides images in two spectral bands with a width of 0.5 µm in the spectral range from 10.3 to 12.3 µm. The entrance scene is imaged by a Korsch-type telescope, with an aperture of about 180 mm diameter, and a cold imaging optics, made of Germanium lenses and housed inside the cryostat. The two spectral bands are separated by means of a dichroic beam splitter assembly located outside the cryostat near the intermediate focal plane of the telescope The TIR instrument is shown in Figure 4-7.

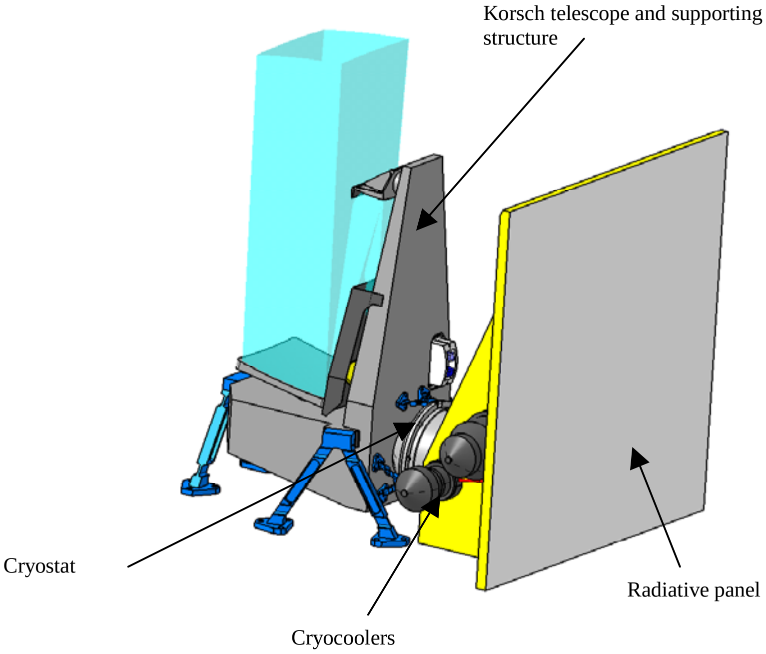


Figure 4-7: *Concept B TIR instrument*

The main characteristics of the TIR detector proposed in this concept are the same of those described for concept A. Figure 4-8 shows the breadboard of a detector with similar characteristic developed by the Agency in the frame of a previous study (HRTIR).

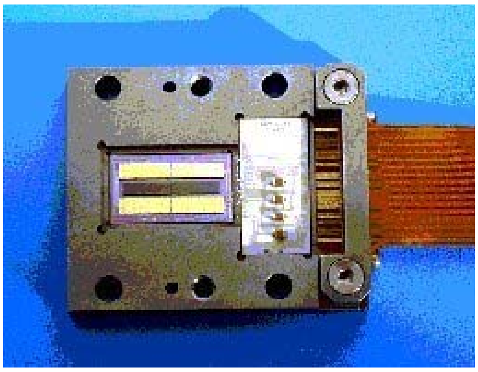


Figure 4-8: *Breadboard of HRTIR detector*

The cooling system is based on two recurring Stirling cryo-coolers. The cryostat assembly is a three thermal stage configuration, leading to an achievable temperature of 50 K at detector level.

The radiometric calibration in the TIR region is achieved using a small cavity black-body source, which a mechanism inserts in the optical path, in front of the beam splitter assembly. Heaters are implemented inside the black-body to allow for controlled variation of its temperature in order to perform the calibration over a large dynamic range. Full path calibration is achieved by monitoring the temperature of the optical elements before the black-body.

4.1.6 Payload Structural Architecture (Concept B)

The payload structural architecture is illustrated in Figure 4-9. The VNIR/SWIR instrument structure consists of an optical bench, which is mounted via isostatic mounts to the satellite top floor panel. This bench accommodates the telescope, the spectrometer bench, the two focal plane electronic boxes, the baffle and the calibration assembly. The spectrometer bench interfaces to the optical bench by isostatic mounts. It contains the spectrometer optical parts as well as the focal plane assembly and the support structure for the VNIR radiator. The TIR instrument is also mounted on the satellite top floor by three bipods, which provide an isostatic fixation.

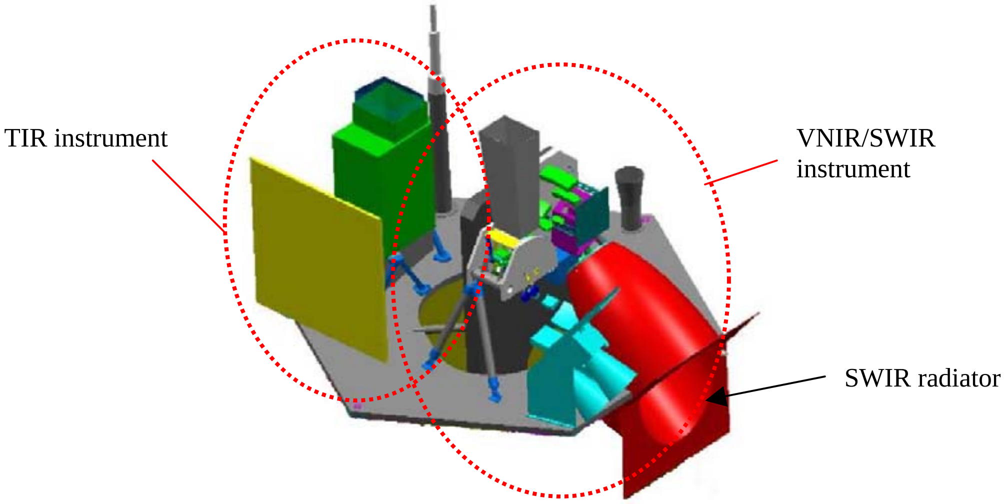


Figure 4-9: *VNIR/SWIR Instrument with parabolic SWIR radiator in the front and TIR instrument*

4.1.7 Data Handling

The SPECTRA payload data handling functions are very similar in the two concepts, and therefore only one generic technical implementation is described below. This subsystem performs both data processing and payload command control functions.

The video processing chains (VPCs) consist in highly integrated electronic modules which are close or attached to the instruments focal planes. They mainly process the analogue video signal and perform the digital conversion and the frame generation of the processed signal. The generated frame is then routed to the data storage unit through SpaceWire links. The VPCMM (Video Processing Chain Management Module) is in charge of the power and clock distribution to the VPC’s. It also provides the interface to control the video chains (parameter loading).

The observation data processing and storage is handled in the mass memory unit (MMU). The observation and calibration data is transferred by SpaceWire to the memory boards. The MMU includes off-line lossless compression capability, data reduction by the selection of the minimally required 62 spectral bands, file system management and a CCSDS formatting capability for data transmission. The MMU is as well responsible to operate the different modes and in particular for synchronising the image data storage with the video chain. The mode transitions are initiated by the spacecraft management unit through the MIL-1553 bus interface.

The payload command and control system gathers and supports the payload services, like the thermal control, the calibration mechanism control, the direct commanding and monitoring of the various payload units. It is composed of the Cooler Control Units (CCU) which are in charge of the control of the active coolers, and a Remote Terminal Unit (RTU) which offers standard channel I/O to make direct observation and commanding of the payload elements. The CCU and RTU are controlled by the Spacecraft Management Unit (SMU) through the MIL-1553 bus.

The overall data handling system of the system, comprising the payload and the platform part, is described in the overall avionics in chapter 4.2.3.

4.2 Platform

The platform provides the resources and services to operate the payload. The most salient element for SPECTRA is the required agility, which has been allocated to the satellite, requiring a high performance Attitude Determination and Control Subsystem (ADCS). All other subsystems are standard for LEO satellites.

4.2.1 Agility / ADCS

The ADCS of SPECTRA is driven by the requirements to slew across track to access the required sites, to slew in pitch to make the directional measurements with the required slowdown factor, and to perform yaw steering to compensate for the Earth motion and minimise geometric distortion. After a scene acquisition a fast re-pointing to the sun must be ensured. During the actual acquisition a very precise pointing must be maintained, ensuring the required stability for the geolocation of the observations.

In the proposed concepts the required agility is achieved using a cluster of four control momentum gyros (CMG’s) as attitude actuators. These devices, developed for the Pléiades mission (see Figure 4-10), provide the large torque needed for rapid re-orientation of the satellite. The attitude estimation is achieved by proper filtering of the star sensor and gyroscope data for the manoeuvre phases.

Figure 4-10: *CMG mock-up of technology development*

The normal ADCS operation mode is depicted in Figure 4-11. This routine mode ensures the attitude guidance for all the mission phases, except for the initial acquisition and the safe mode. The attitude estimator filters the star-tracker noise and estimates the gyroscope drift, permitting an accurate localisation of the line-of-sight on ground. The CMG off-loading is performed by magnetic torquer bars. The magnetic field is measured by magnetometers or is estimated on-board from GPS position measurements.

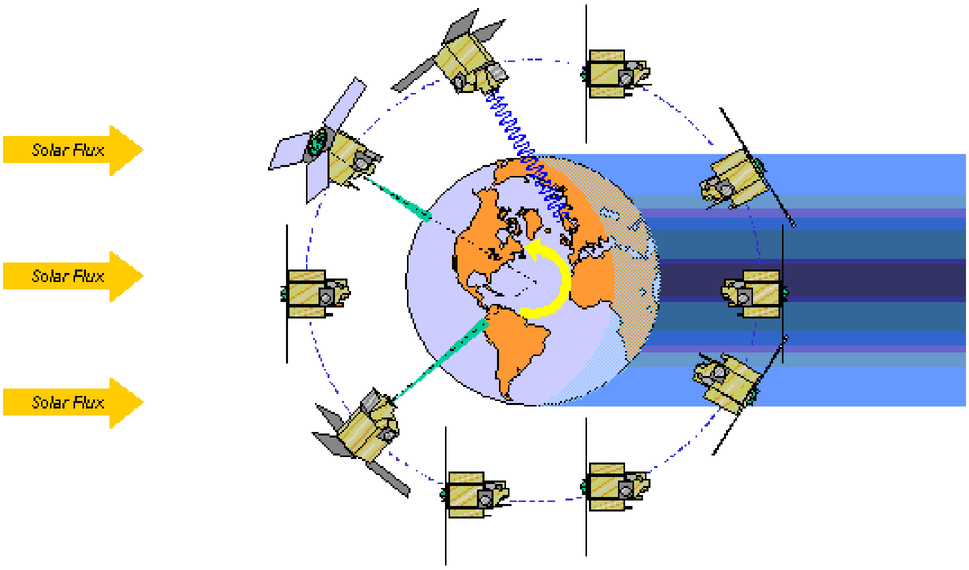


***Figure 4-11:** Pointing in Normal Mode (concept A)*

In the safe mode the satellite acquires and maintains a sun pointing attitude with magnetic actuation only to maximise the robustness of this mode.

The localisation accuracy, required to be 1 km in an Earth reference frame (without reference points), is achieved with ample margins.

4.2.2 Power

The electric power is generated by means of triple junction GaAs cells mounted on deployable solar arrays. Struts make these arrays stiffer after deployment, thus reducing the overall structural flexibility and improving the agility performance.

The energy is stored in a Li-ion battery and distributed via an unregulated power bus. The sizing of the power system has to take into account the agility of the platform, and has been verified by simulations with a typical operational scenario. This assumes an observation of 25 sites in one day, with all required manoeuvres and data download operations. The power demands of platform and payload are different, depending mainly on the payload cooling concept, and lead to different budgets. The results are summarised in Table 4-1.

Power Requirements	670 W (safe mode) to ~800 W (max)
Solar array size	5.9 m^2 (three panels) to 7.9 m^2 (six panels)
Battery	75 Ah to 150 Ah Li-ion battery

***Table 4-1:** Power System Characteristics*

4.2.3 Avionics

The Spacecraft Management Unit (SMU) is designed to command and control the satellite subsystems and the payload. The proposed concepts are based on the ERC-32 processor. Storage for the instrument data is provided by a 2x128 Gb solid state mass memory. The interfaces are based on the SpaceWire standard for the high data rates, and the MIL-1553 standard for command and control.

A representative architecture is depicted in Figure 4-12.

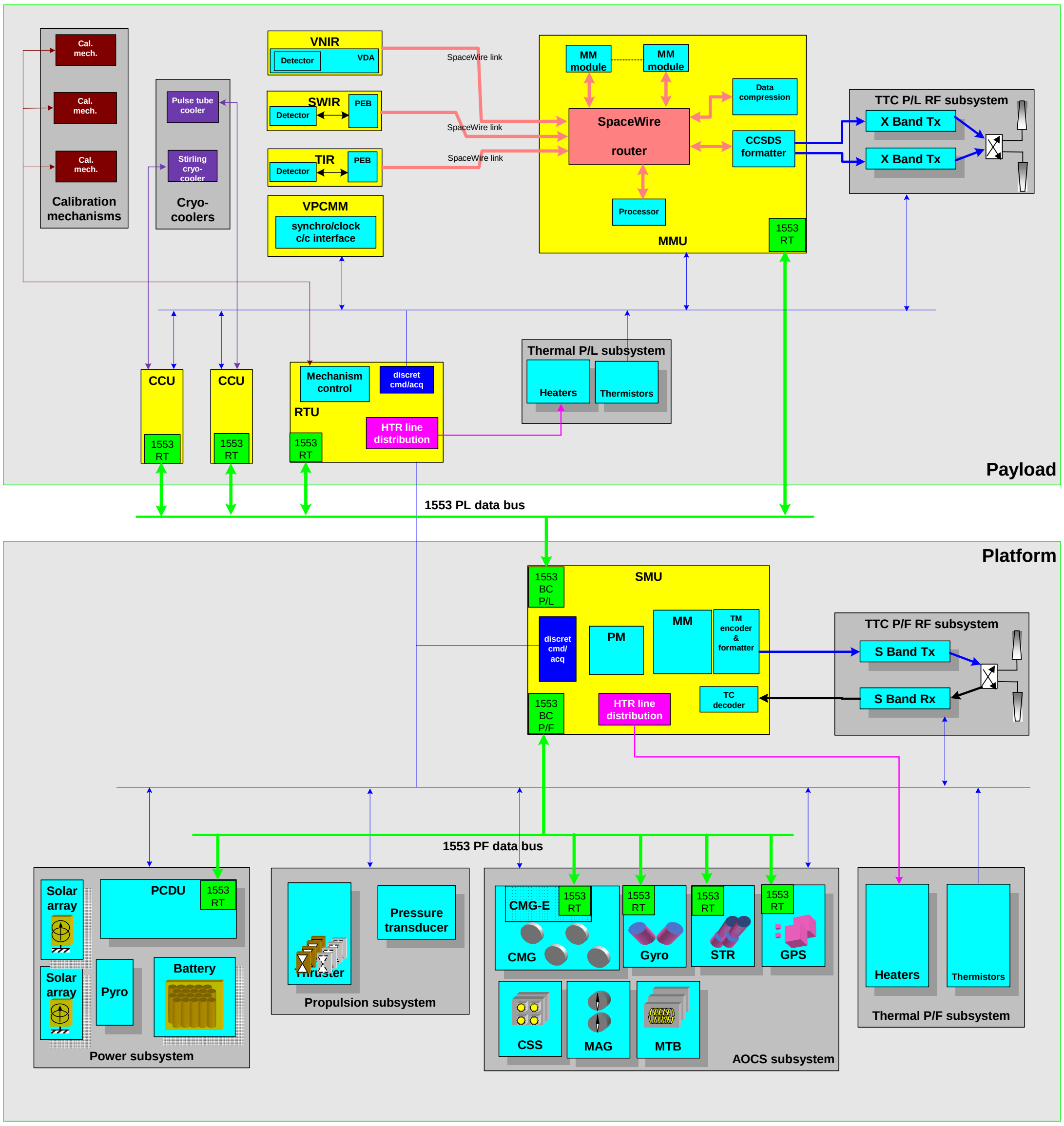


Figure 4-12: *Example Avionics Architecture*

4.2.4 Communications

The telecommand and housekeeping telemetry communication is based on redundant S-band transponders, ensuring a standard uplink rate of at least 4 kb/s and a downlink rate of at least 100 kb/s. Higher datarates will be possible if required by operational needs. Omnidirectional antennas ensure the coverage in any attitude.

The instrument data will be donwlinked by a redundant X-band transmitter operating with QPSK modulation at 100 Mb/s. An upgrade to higher datarates (150 Mb/s with 8PSK modulation) is possible in order to reduce the number of required contacts to dump the data.

The RF link budgets demonstrate sufficient margins for both bands using existing equipment.

4.2.5 Propulsion

The propulsion subsystem (Figure 4-13) is used for the initial orbit acquisition, orbit maintenance manoeuvres and the final de-orbiting manoeuvre. A monopropellant type system using hydrazine (N_2H_4) propellant, pressurised with nitrogen (N_2) gas is in the baseline design. It is equipped with a common diaphragm tank for both propellant and pressurant gas storage, with dedicated fill and drain valves for loading and draining, pressure transducer, filter and with four 1 N thrusters.

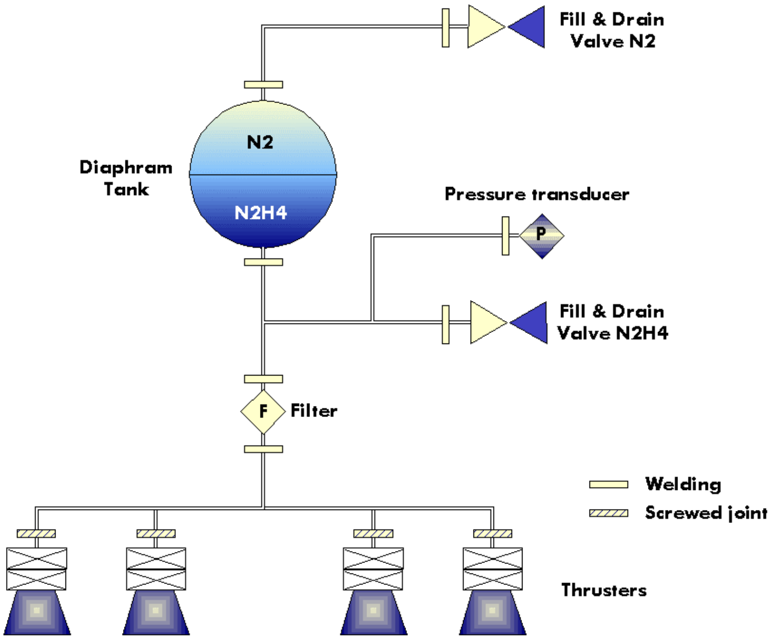


Figure 4-13: *Propulsion Assembly*

The maintenance of the orbit requires infrequent correction manoeuvres and the main contribution to the fuel budget is the de-orbiting manoeuvre at the end of the lifetime of the satellite. A representative fuel budget is summarised in Table 4-2.

	ΔV [m/s]	**Propellant mass [kg]**
De-orbiting	35.2	10.9
Space debris contingency (avoidance)	4.2	1.3
Orbit maintenance	19.1	5.7
Initial orbit acquisition	13.8	4.0
Total	**72.3**	**21.9**

Table 4-2: *Fuel Budget*

The tank capacity allows accommodation of 25 kg of hydrazine. The membrane minimises the sloshing induced by the satellite manoeuvres.

4.3 Satellite

4.3.1 Configuration

The configuration in the proposed concepts is driven by the agility requirement, which implies a compact and structurally stable design. This results mainly in fixed solar arrays and in the absence of further appendages to minimise the flexible modes.

The proposed concept A (Figure 4-14) shows a modular approach, allowing an easy separation of spacecraft bus and payload, although some electronic boxes of the payload are accommodated in the bus part of the satellite.

The mechanical architecture is based on a low cost structure concept without central tube, allowing easy electronic units accommodation while complying with launch vehicle stiffness requirements. The solar array design with stiffening devices responds to the AOCS requirements for agility and stability.

The unit accommodation has been designed in order to reduce loads on the most critical units (such as the CMG), simplify as far as possible the harness routing, and distribute the dissipating units according to the heat rejection capacity of each panel.

The thermal control of the platform is divided in distinct parts, each one thermally as much decoupled as possible from the others. Thermal decoupling between the payload module and the platform will further simplify the interfaces and consequently facilitate the development.

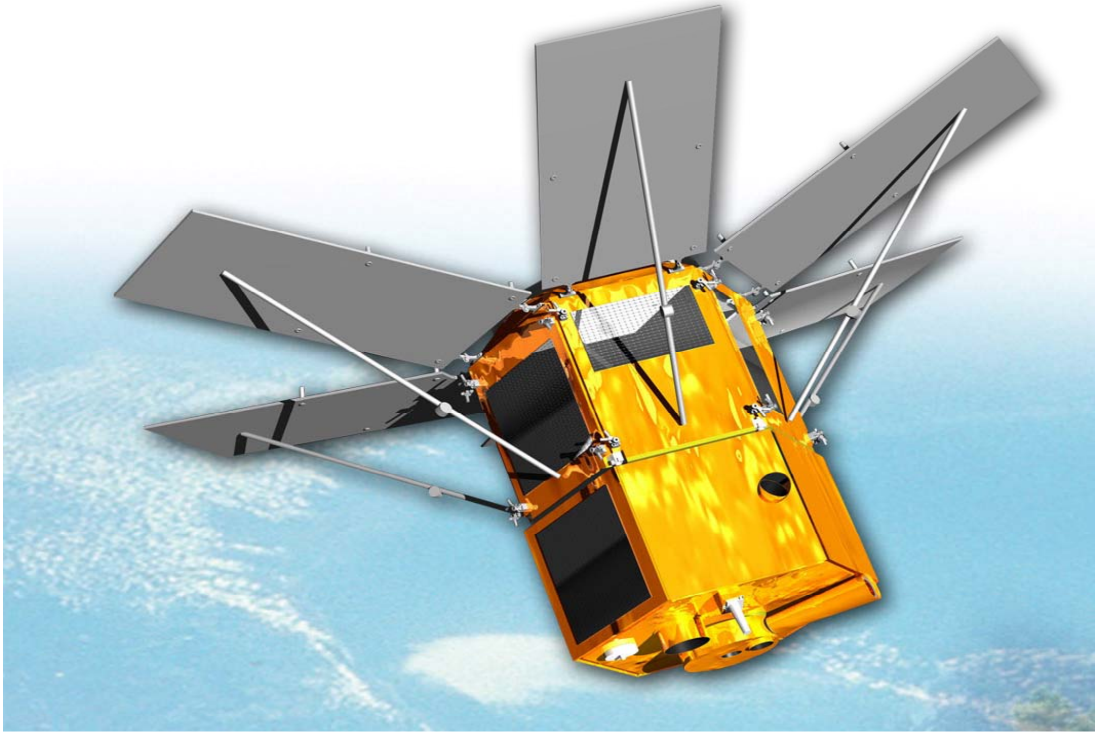


Figure 4-14: *Concept A Satellite*

The proposed concept B (Figure 4-15) shows very similar properties. The structural concept differs as it is implemented in the form of a light 1.4 meter-high hexagonal structure arranged around a central triangle made of three walls connected together by cleats and brackets. The hexagonal structure is fixed to the central triangle at each of the triangle vertices. The three hexagon faces parallel to the faces of the inner triangle are closure panels, the other three panels being fixed panels. This approach permits an easy access to the electronic boxes inside the platform, while ensuring the required stiffness. Thermal control of the internal units is ensured by radiative coupling with the external structure radiative walls.

The payload support structure is mainly comprised of the upper panel, upon which the two instruments and the SWIR radiator are mounted. The TIR instrument is flat mounted on the floor, while the VNIR/SWIR instrument opto-mechanical assembly is suspended on the top of the central triangle, and protrudes therein. This allows accommodating the large vertical instrument without increasing drastically the height of the satellite.

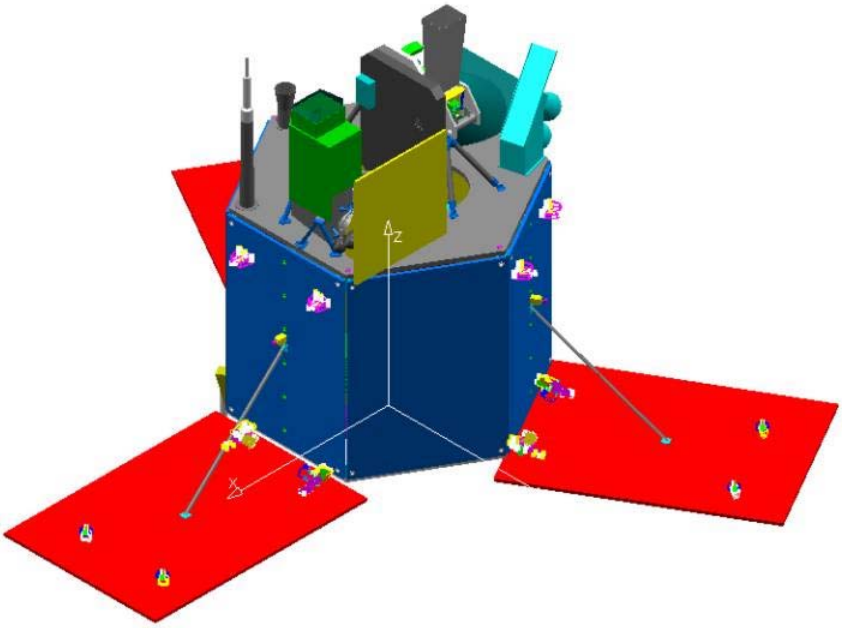


Figure 4-15: *Concept B Satellite (top view)*

4.3.2 Budgets

The resulting dry mass and power budgets of the proposed concepts are reported in Table 4-3 and Table 4-4. The hydrazine mass required amounts to 20-25 kg. For the power budget, the imaging mode has been assumed.

	Concept A	Concept B
Platform	384 kg	395 kg
VNIR/SWIR instrument	74 kg	83 kg
TIR instrument	50 kg	69 kg
Instrument electronics	67 kg	15 kg (ICU only)
Instrument Support	81 kg	Included in platform and instrument mass
Equipment contingency (according to development status)	81 kg	87 kg
System margin (10%)	77 kg	63 kg
Total satellite dry mass	**814 kg**	**712 kg**

Table 4-3: *Mass Budget*

	Concept A	Concept B
Platform	323 W	307 W
Payload	404 W	299 W
Margin	115 W	61 W
Total	**842 W**	**667 W**

Table 4-4: *Power Budget (imaging mode)*

4.4 Launcher

The proposed satellite concepts and the selected orbit are compatible with the Rockot launcher fitted with Breeze upper stage. This system has already been successfully flight proven three times.

It would also be compatible with the Vega launcher.

Figure 4-16: *Vega launcher (artists impression)*

5 Ground Segment

5.1 General

The ground segment will be based on the infrastructure being developed to support the Earth Explorer and other missions. The breakdown of the ground segment into its constituting elements and functions is outlined in Figure 5-1. It consists of three main elements:

- The Command and Data Acquisition Element (CDAE)
- The Mission Operations and Satellite Control Element (MSCE)
- The Processing and Archiving Element (PAE)

These three elements implement the Flight Operations Segment (FOS) and the Payload Data Segment (PDS) functions. The FOS will be developed and operated according to the concept of "family of missions" by which several missions share resources and staff for reduction of costs and reutilisation of expertise. Concerning the PDS, the principles and infrastructure developed for the open – operational, "oxygen" initiative will be reused as well as the infrastructure procured for previous Earth Explorer missions.

In Figure 5-1 the user communities are represented by notional Science Data Centres (SDC).

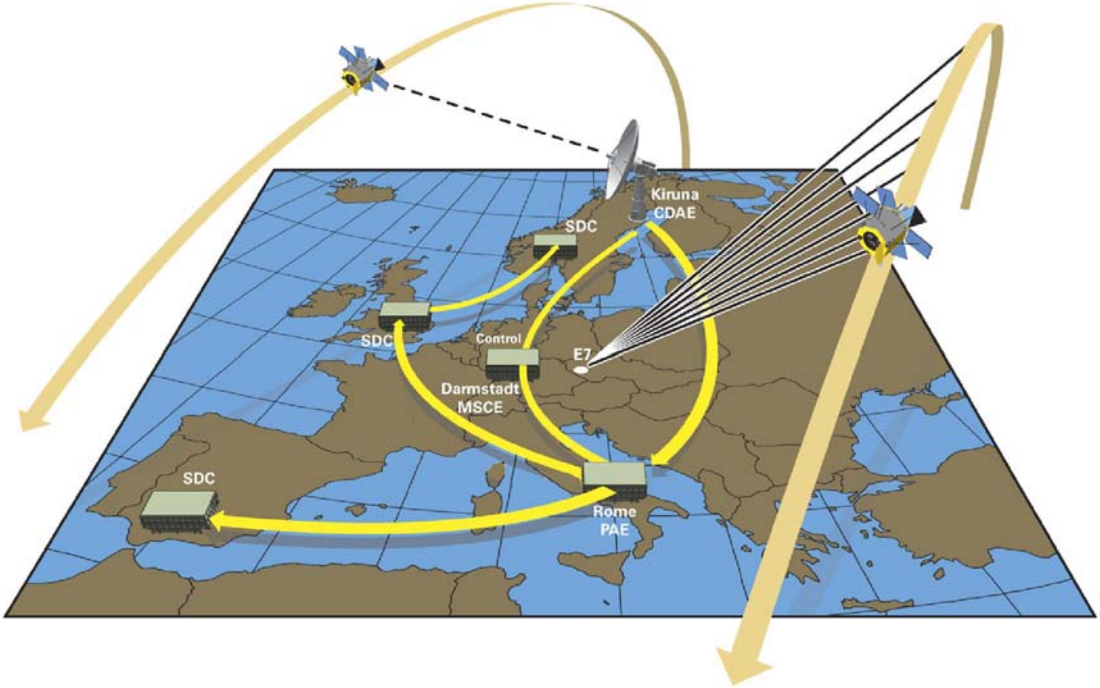


***Figure 5-1:** SPECTRA Ground Segment Elements*

5.2 Ground Segment Elements

The CDAE implements the following main FOS functions:

- Telemetry acquisition, telecommand uplink and satellite tracking (TT&C), and
- Transmission of telemetry to the MSCE.

For the PDS, it implements the following main functions:

- Payload data acquisition,

- Demodulation and formatting,
- Processing to appropriate level,
- Short-term archiving and
- Transmission to the PAE.

For the SPECTRA mission, the CDAE will be located in Kiruna. This station will implement the TTC functions in S-band and the payload data acquisition in X-band.

During Launch and Early Orbit Phase (LEOP), operations will be supported by additional suitable ground stations.

The MSCE will be located at ESOC and will provide the following main functions:

- Satellite operations planning in connection with the PAE
- Satellite monitoring and control
- Flight dynamics, derivation of attitude guidance profiles and manoeuvre planning,
- Telemetry analysis and telecommand generation
- On-board software maintenance
- Mission simulation
- FOS supervision
- Interface with the launch site for LEOP

Figure 5-2: *Flight Dynamics Room at ESOC*

The PAE will be located at ESRIN and will implement the following PDS functions:

- Acquisition of payload data (including platform ancillary data) from the CDAE
- Acquisition of the required auxiliary data, e.g. for cloud coverage,
- Acquisition of data from the field segment,
- Generation of products at level 1 and 2 by means of Instrument Processing (IPF) and High Level Processing facilities (HPF) respectively
- Long-term archiving (LTA) of mission products, including re-processing of archived data as needed
- Payload operations planning by means of a Reference Planning Facility (RPF) and transmission of plans to the MSCE, taking into account the availability of the field segment and the optimisation of observations as described in chapter 6,

- Mission and Payload Monitoring beside PDS performance monitoring by means of a Monitoring Facility (MF)
- Quality control (QC) for all products and media distributed to users.
- Distribution of mission products to the user communities,
- Provision of user services (USF) based on the existing EO Multi-mission User Services located at ESRIN, and
- Interface with the field segment, i.e. field sites,

An appropriate communication infrastructure will ensure the exchange of data flows between the elements of the ground segment and the interface with the users. The infrastructure being set-up within the "oxygen" initiative will be used as much as possible such as the high speed network (Figure 5-3) that connects the various ESA ground stations and centres.

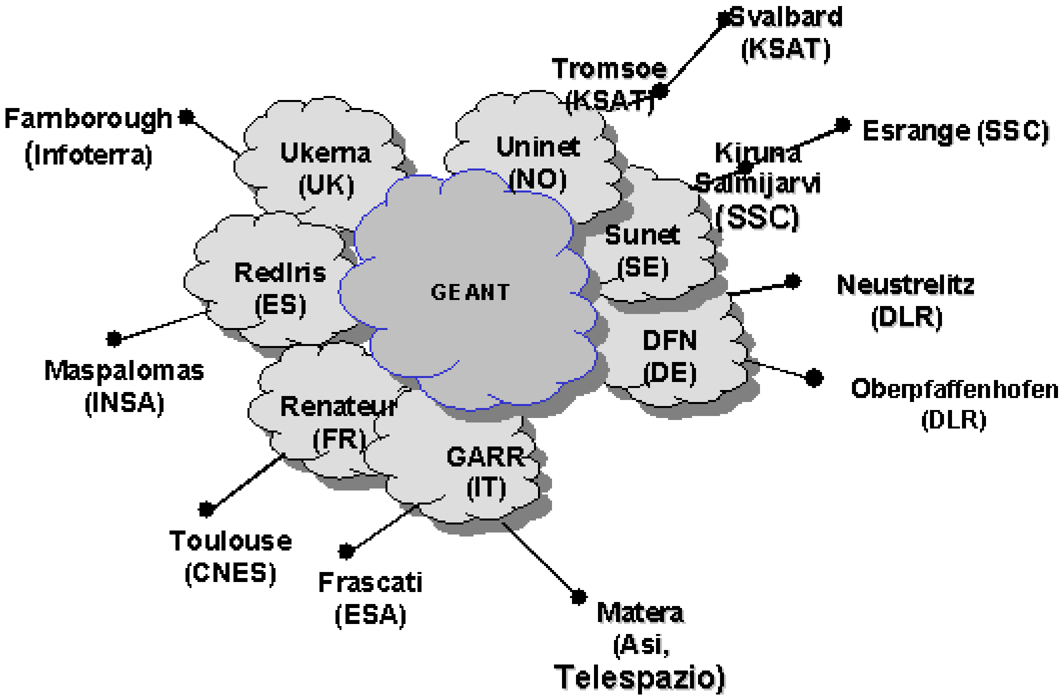


Figure 5-3: High Speed ESA EO Network based on the GEANT/NREN (Academic) Backbone

6 Operations and Utilisation Concept

The SPECTRA operation concept is driven by the user requirement to observe specific sites in a multi-directional sequence, in order to acquire information for BRDF modelling. To achieve this, both the angle of observation (the angle between the line of sight and the normal of the scene), and the solar incidence angle are to be considered.

The planning of an acquisition sequence induces a number of system constraints that have to be carefully addressed. Management of site acquisition conflicts is necessary over regions of dense site distribution, as well as the management of the satellite resources according to the mission profile. Analyses and simulations have demonstrated that the consideration of cloud coverage in the planning stage improves the overall acquisition performance only marginally, but significantly increases the planning complexity. Cloud information is therefore not taken into account during the planning phase.

The acquisition schedule is prepared on the basis of scientific requests and the availability of the corresponding field segment. It is nominally updated and uplinked three times per week. Additional targets can be planned in case time remains after the required scientific observations.

The housekeeping telemetry is acquired daily, whereas for the instrument data transmitted in X-band only 3-4 daily contacts during 6 days of the week are sufficient. The downlink is scheduled in order not to conflict with any data acquisition.

The satellite modes used in SPECTRA comprise non-operational modes (such as launch mode, safe mode…), support modes (where the system is not acquiring scientific data, such as the orbit control or data downlink mode), and finally the operational mode.

The operational mode consists of several sub-modes. The reason for defining sub-modes instead of distinct modes is that the bus activity in a given mode remains basically unchanged, the difference lying in the instrument modes.

In the instrument imaging mode, the ADCS follows a pre-defined attitude profile, aiming instruments line of sight at the scene of interest. During daytime this profile ensures that a target is observed with 7 distinct observation angles, controlling the line-of-sight in a way to ensure an effective slow-down of the push-broom motion by the factor of 2. The payload is fully switched on and delivers data to the data handling system, which performs the selection of the required spectral bands, compresses the data and stores them in the solid state mass memory. At night the profile will only ensure a single view to a selected target, since no directional measurements are being made and only the TIR instrument will be operational.

In the remaining periods the satellite is inertial pointing with its solar arrays towards the sun when being in the sunlit part of the orbit. In the eclipse part the satellite is Earth pointing.

In the instrument calibration mode all dedicated calibration activities for the VNIR/SWIR and TIR instruments outside an acquisition sequence are being performed. The platform is basically in the same configuration as in imaging mode, and the data generated by the calibrated instruments are stored by the data handling subsystem.

The optimisation of the site selection is done on ground taking into account the quality parameters as established by the scientific users. They include the phase angle to optimise the illumination conditions, the across track pointing angle to minimise the geometric distortion, the acquisition angles to optimise the sampling of the BRDF as well as the acquisition history of a site, previous cloud coverage and operational constraints such as avoidance of specular reflection and availability of downlink opportunities.

Figure 6-1 shows that the acquisitions required as the minimum to achieve the scientific objectives of SPECTRA only use a small part of the capacity of the proposed system. This analysis has been based on the reference scenario of about 50 sites, assuming cloud free conditions. The results show that there is spare capacity to allow a higher observation frequency per site (maximum scenario capability, depicted in red), thus ensuring appropriate coverage even for cloudy conditions, as well as room for a significant evolution of the number of sites or for other imaging purposes. On the other hand, a reduction of the system capacity to the bare minimum (on the basis of the present scenario) would lead to marginal savings only.

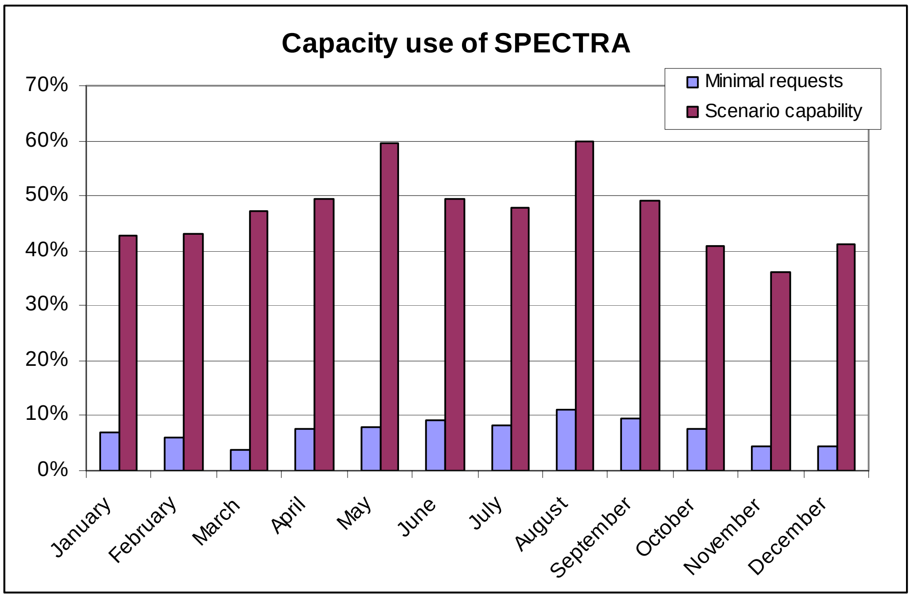


Figure 6-1: *Capacity use of the SPECTRA mission*

7 Data Processing

SPECTRA produces data at different levels, ranging from observed raw data to estimated geophysical parameters. In the following only the technical levels are described (see ***Figure 7-1***), whereas geo-physical products are dealt with in the science report.

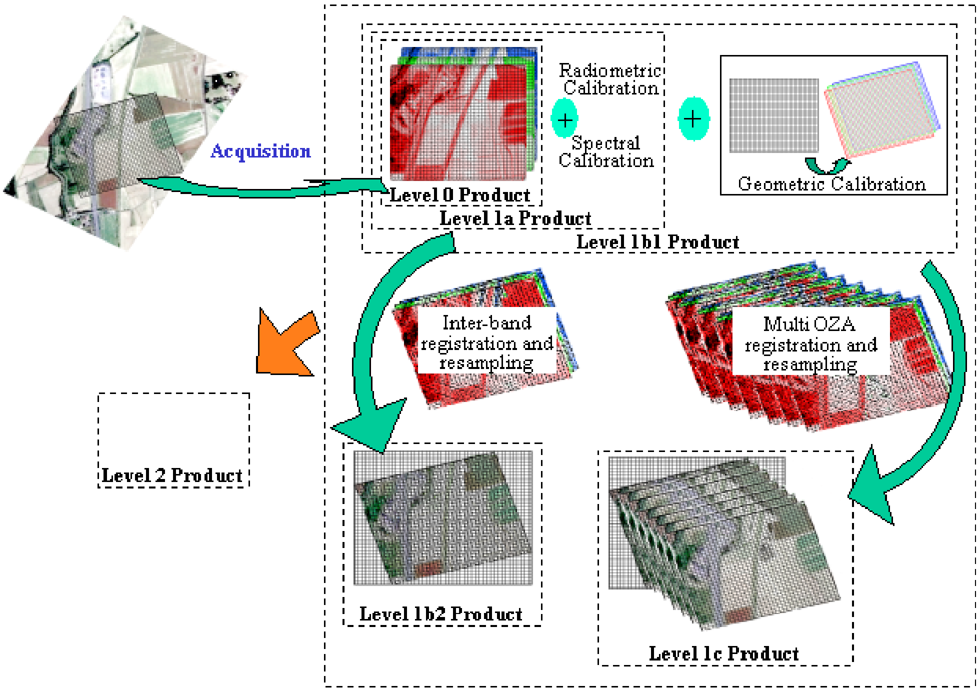


Figure 7-1: *Data Processing levels*

<u>Level 0:</u> The level 0 product is the sequential set of pixel data arranged in a three-dimensional data array (columns, lines, spectral bands).

<u>Level 1a:</u> Level 1a products are composed of level 0 data completed with the auxiliary parameters needed to determine for each pixel its radiometric absolute value, its spectral characteristics, and its geo-location. These auxiliary parameters are derived from calibration processes and from the mission plan. This means that the radiometric and spectral characteristics are established once per calibration process and that the geo-location is derived from the mission plan as a rough localisation of the centre of the scene. Neither LOS restitution process nor registration has run at this point.

<u>Level 1b1:</u> Level 1b1 represents the reversible product of highest possible quality. Each pixel is converted to the corresponding absolute radiance value (in W/m^2/sr/µm) through the radiometric calibration parameters. A geometric correction grid that converts image pixel coordinates to ground projected coordinates is estimated for each spectral band and appended to the image as auxiliary data, but not applied to the images.

<u>Level 1b2:</u> This product level is derived from the level 1b1 product, by resampling each spectral band of the image to a ground projected grid corresponding to the resolution of its acquisition. Inter-band registration algorithms are assumed to be necessary at least between spectral bands acquired by different sensor arrays.

<u>Level 1c:</u> This product basically has the same properties as level 1b2, but resamples the data to a common grid. The alignment between all the 7 OZA images of an acquisition is ensured. The level 1c correction grid permits resampling of all the 7 level 1b1 correction of all spectral bands to the same ground projected grid of coordinates. The fixed geometric grid is defined at a spatial resolution of 50×50 m^2.

8 Performance Aspects

8.1 Payload performance

The payload performance has been thoroughly analysed and full compliance with the observation requirements has been demonstrated. The following sections highlight the estimated performance.

8.1.1 Spatial

The spatial sampling interval at nadir is equal to 50 m on ground, for a 50 km x 50 km image. The spatial width, defined as the full width at half maximum of the instrument point spread function, is given in Figure 8-1, as a function of the OZA from 0° to ±60°. As shown, the spatial width remains very constant over a large range and within the required 100 m in the VNIR/SWIR domain, and below 150 m for a 50° OZA in the TIR range.

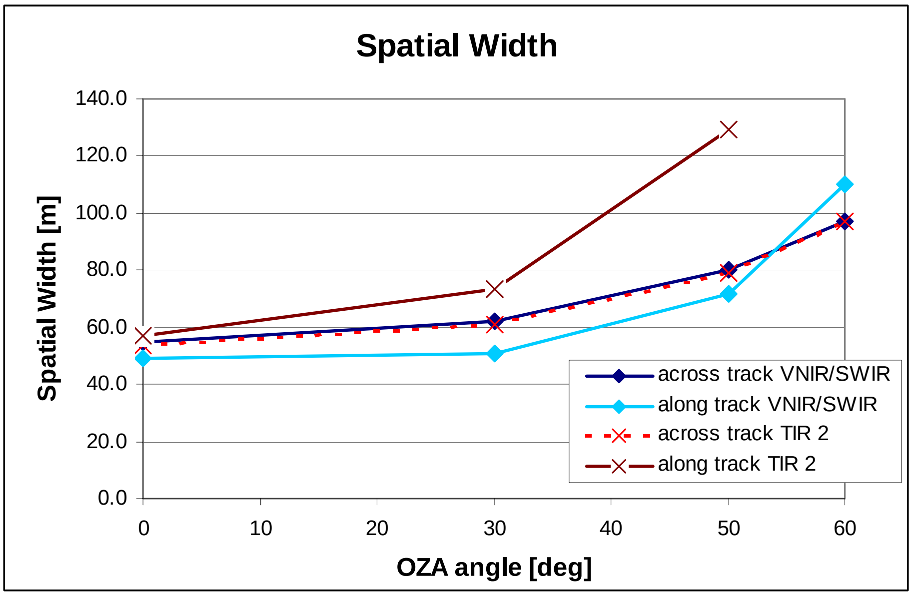


Figure 8-1: *Spatial Width Performance for a typical BRDF sequence*

The other key spatial performance concerns the spatial registration between the spectral bands in the different spectral ranges. In the VNIR/SWIR range, the misregistration is less than 20% of a pixel due to the excellent performance of the spectrometer design. In the TIR range, the registration between the bands is achieved after ground processing. Between the VNIR/SWIR and the TIR instruments, the use of a common optical bench or supporting structure ensures the absolute registration within the 4 pixels required. It also provides relative stability during a BRDF sequence, within 20% of a pixel.

8.1.2 Radiometric performance in VNIR/SWIR

Within the required dynamic range, the SPECTRA payload measures the top of atmosphere radiance with absolute radiometric accuracy between 2% and 5%. The radiometric resolution, estimated for a typical radiance case, meets with margins the requirement, as shown in Figure 8-2. This leads to SNR values as high as 300 to 700 in most of the VNIR, and in the 100 to 200 range in the SWIR. The oscillations in the instrument performance shown in Figure 8-2 reflect the spectral variation of the reference input radiance.

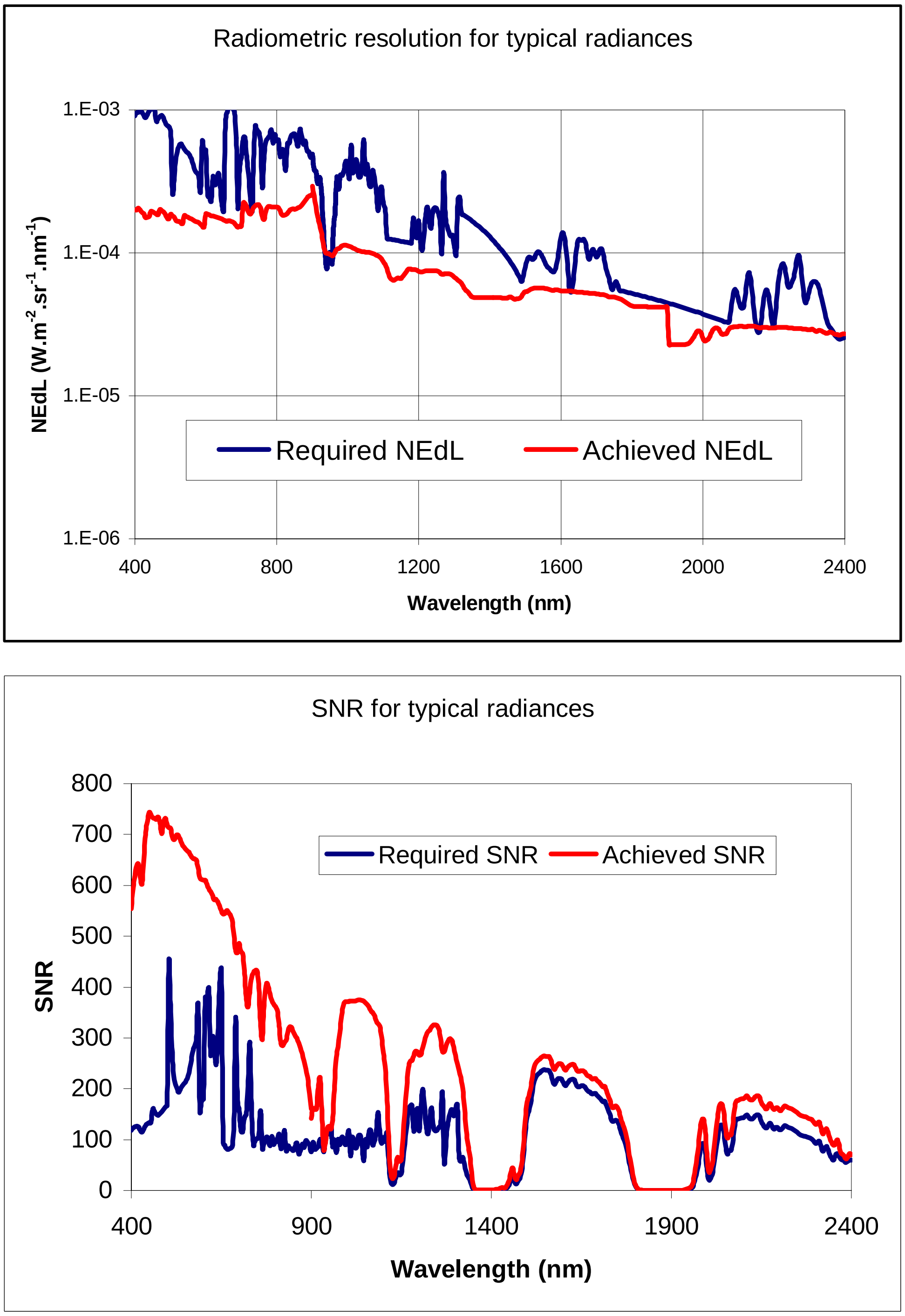


Figure 8-2: SPECTRA NeDL and SNR performance over a scene of typical radiance

8.1.3 Radiometric performance in TIR

In the TIR region, the SPECTRA dynamic range is specified for an input scene temperature ranging from 240 to 345 K (assuming top of atmosphere blackbody scene). In this dynamic range, SPECTRA provides an estimate of the temperature in each of its two channels with an absolute radiometric accuracy better than 1K, as shown in the Figure 8-3.

The radiometric resolution and the spatial radiometric accuracy are better than 100 mK for a blackbody scene at a temperature of 300 K, as required.

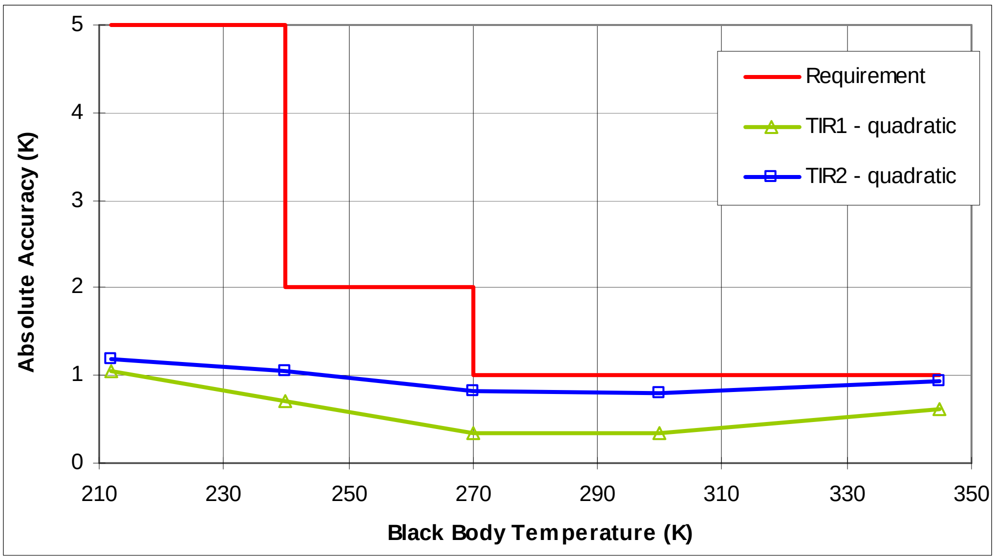


Figure 8-3: *TIR absolute radiometric accuracy*

8.1.4 Spectral performance

Figure 8-4 shows the spectral sampling interval of SPECTRA VNIR/SWIR instrument. The red curve shows the optical spectral sampling while the blue curve shows the actual performance after spectral pixels binning. The spectral width, i.e. the full width at half maximum of the instrument spectral response function is lower than the required 12 nm for any wavelength, and its value is expected to be stable within 0.5 nm between ground characterisation and end-of-life thanks to the optical bench on which the spectrometer is mounted.

The absolute location of the sampled wavelength is known with an accuracy estimated to be better than 0.5 nm after ground processing of the data provided by the on-board spectral calibration hardware.

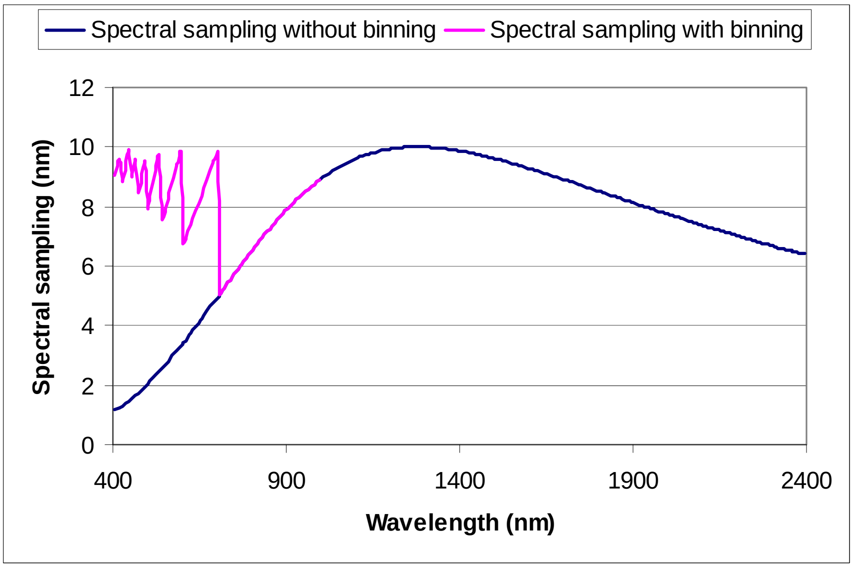


Figure 8-4: *Spectral sampling interval of SPECTRA VNIR/SWIR instrument*

The expected spectrometer performance, with very well corrected spectral registration across the field of view and very high mechanical and thermal stability will ensure that the spectral misregistration is well within the requirement of 1.5 nm, and meets even the goal of 0.5 nm in the 400-650 nm spectral range.

In the TIR region, preliminary spectral filters analysis shows that the typical spectral profiles that can be achieved are compliant with the required template.

8.2 System performance

8.2.1 Agility performance

The instrument line-of-sight (LOS) is pointed to the target by pointing the entire satellite. This achieves a great flexibility in choosing and programming the intermediate OZA, observation zenith angles. Figure 8-5 shows for different across track pointing angles the range of intermediate acquisition angles for a BRDF sequence. The orange bar shows the achievable range for 4 CMGs.

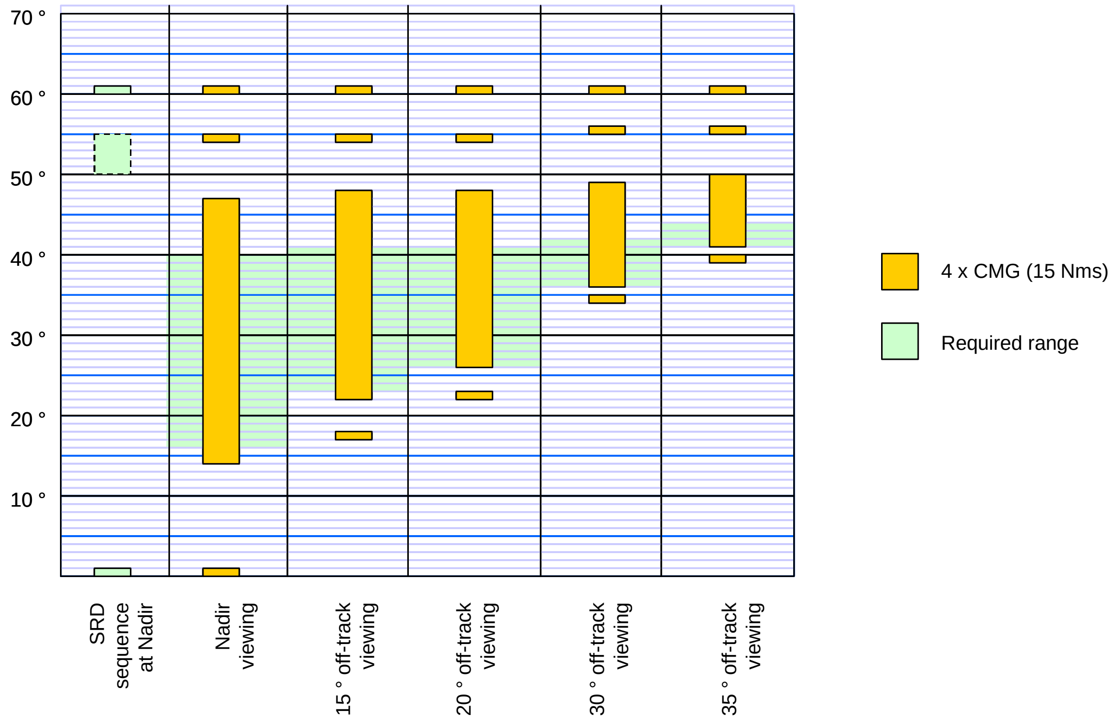


Figure 8-5: *Range of possible angle selection for BRDF sampling*

This large range can be exploited to optimise the sampling of the BRDF, by e.g. spacing the phase angles as equally as possible.

The pointing and stability requirements are fulfilled with margins. The pointing knowledge without ground processing is better than 1 km and can be significantly improved by matching ground reference points.

8.2.2 Site coverage

For analysis purposes, a mission scenario has been generated, based on a list of approx. 50 target sites, distributed around the Earth. A calendar has been established, reflecting the acquisition needs for these sites over the year. A high number of requests in Northern summer months (due to asymmetry of scenario) requires an optimisation of pass selection to increase acquisitions opportunities, where different quality parameters will be considered for this optimisation process (image geometry, illumination, priority, previous cloud coverage, sampling angles…)

Figure 8-6 shows the required number of acquisitions corresponding to the reference scenario. As shown in Figure 6-1 (above), the system can fulfil these required scientific observations and includes sufficient margins for additional observations.

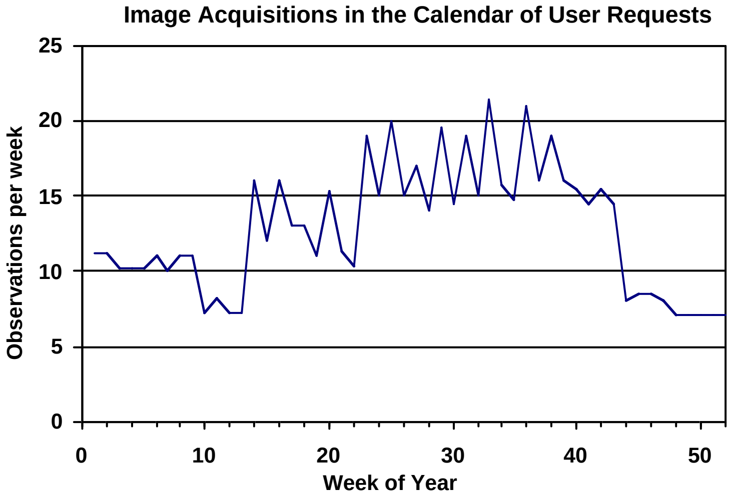


Figure 8-6: *Planned acquisitions required by scientific mission*

9 Programmatic Aspects

9.1 Schedule

The technical maturity of the mission has been assessed in detail in industrial phase A activities. The mission has a large heritage from previous and current programmes in Europe, both at preparatory level (e.g. the HRIS, HRTIR and PRISM instruments, the LSPIM mission), as well as in terms of instruments/missions in orbit or about to fly (e.g. the MERIS instrument on Envisat, the CHRIS instrument on PROBA, the APEX airborne demonstrator, Pléiades). The overall development schedule is driven by the instruments, and there in particular by long lead items such as the detectors which require a dedicated pre-development programme. The plans proposed by the phase A industrial teams include the elements in Table 9-1 and are consistent with launch in 2010/11.

Pre-development	~ 24 months
Phase B	12 months
Phase C/D	54 months
Launch	End 2010

Table 9-1: *Schedule elements for SPECTRA development*

The separation of the platform and the instrument permit the parallel development of instrument, platform and ground segment. The main schedule drivers are associated with the detectors, alternative coolers and the CMGs, covered in pre-development activities. Some overlap will be possible between the pre-development and the phases B and C with a careful definition of these activities.

9.2 Heritage, Critical Areas and Risks

There is strong heritage for almost every item for the implementation of the space and ground segment concepts, the novelties being in the spectrometer, the focal planes and the ADCS at satellite level. Table 9-2 summarises the areas of risk and the proposed or initiated measures to mitigate these risks.

Element	Critical areas	Risk reduction
Instruments		
Spectrometer	Manufacturing, alignment, stability	Opto-mechanical breadboard recommended
VNIR focal Plane	Buttressing	Breadboard recommended, fall-back solution available
SWIR focal plane	Long lead item, performance, single source	Development phase almost completed, breadboard to be enhanced
TIR focal plane	Long lead item, performance, single source	Development starting
Spectral Calibration VNIR/SWIR	Echelle monochromator novel implementation	Breadboard recommended
Video Processing Unit	Low noise implementation	Breadboard ongoing
Coolers	Life time of pulse tube cooler	Qualification programme needed
Platform		
ADCS	Novel implementation with CMGs	Breadboard equipment, agile control system development, backup possible with reaction wheels, with limited performance impact

Table 9-2: *Critical areas and risk-reduction measures*

For the SWIR detectors, the risk is being mitigated with the on-going ESA development of a hybrid HgCdTe-CMOS detector array. A similar version of such a detector will be tested on the APEX airborne hyper-spectral demonstrator. For the TIR detection, CMT linear arrays have already been developed in Europe, but have shown poor yields for long arrays. The technological efforts are therefore continued. The proposed CMGs are being developed for the Pléiades mission. Developments for alternative cooler concepts (heavy lift pulse-tube coolers and associated electronics) are being initiated.

For the ground segment and the field segment no critical areas have been identified.

The proposed implementation of SPECTRA has well defined critical areas for which measures have been started or are planned to mitigate these risks further, and in some cases alternative implementation options have been identified as backup solutions, with limited impact on the mission performance.