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RAPPORTO TECNICO - TECHNICAL REPORT

METIS INSTRUMENT PROPOSAL
for the Solar Orbiter Mission
Part 3: Engineering Plan

Ester Antonucci (P.I.), S. Fineschi, G. Naletto, M. Romoli, D. Spadaro, S. Solanski, P. Lami and the Co-I's Team

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Solar Orbiter Mission

Part III
ENGINEERING PLAN

Principal Investigator:

Ester Antonucci (1)

Co-Proposers:

S. Fineschi (1), G. Naletto (2), M. Romoli (3), D. Spadaro (4),
S. Solanki (5), P. Lamy (6), and the Co-I's Team

(1) INAF – Astronomical Observatory of Turin, Torino, Italy
(2) University of Padua, Padova, Italy
(3) University of Florence, Firenze, Italy
(4) INAF - Astrophysical Observatory of Catania, Italy
(5) Max-Plank-Institute fuer Sonnensystemforschung, Germany
(6) Laboratoire d'Astrophysique de Marseille, France,

Leading Funding Agency:

ASI – Agenzia Spaziale Italiana
(Ref. S. Di Pippo – (simonetta.dipippo@asi.it) - Viale Liegi 26 – 00198 Roma Italy
Phone: +390685671 Fax: +39 06 8567267)

In cooperation with:

CNES – Centre National d'Etudies Spatiale
DLR – Detuches Zentrum fuer Luft und Raumfahrt

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Simonetta Di Pippo	ASI – Osservazione dell'Universo Viale Liegi, 26 00198 Roma, Italia
Prof. Sergio De Julio	INAF Viale del Parco Mellini n.84 00136 Roma

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

1 METIS

Herein, a description of the proposed METIS Instrument is provided through a summary of the baseline design and an overview sheet containing the most relevant parameters of the instrument. More details on the instrument interface are contained in the following chapters.

1.1 System Design Justification

The proposed METIS Instrument for the Solar Orbiter is a suite performing imaging of the close solar corona in the visible and in the extreme ultraviolet (EUV) and spectroscopy, of both sun disk and corona in the EUV, by means of an integrated instrument suite located on a common optical bench, sharing main electronics, power supply, and a single aperture on the satellite heat shield. Details on the instrument design are given in the EID-B and reported in the following paragraphs for what concerns the purpose of this document.

The proposed instrument architecture is based on three different elements. The three elements form an Instrument Front End (IFE) and are identified as summarized in Table 1:

Acronym	***Name***	***Objective***
COR	Visible and EUV Coronagraph	Imaging of the close solar corona in the visible and in the extreme ultraviolet
EUS	EUV disk Spectrometer	Spectroscopy of sun disk in the EUV
SOCS	Solar Orbiter Coronal Spectrometer	Spectroscopy of the corona in the EUV

Table 1: Composition of the METIS Instrument

COR is an independent element, formed by optics, detector, thermal hardware (if needed), proximity electronics and electrical interface for power supply, telecommand / telemetry link. EUS and SOCS share the diffraction optics and the detectors, but have independent telescopes. All the three elements share a single aperture on the spacecraft (S/C) heat shield, and are mounted on a common optical bench. In addition, main electronics and power supply at suite level are common for all the IFE elements.

1.2 Instrument Overview Sheet

The instrument overview data sheet of the METIS is reported in Table 2, where the different elements are addressed separately as needed. More information can be found both in Chapter 2 of Scientific and Technical Plan and in the EID-B document of the present proposal.

Name / acronym	METIS / Multi Element Telescope for Imaging and Spectroscopy

Objectives	Visible and EUV coronography with the COR element
	Sun disk EUV spectroscopy with the EUS element
	Coronal EUV spectroscopy with SOCS

General description	Instrument suite consisting of three elements (COR, EUS, SOCS) mounted on a single optical bench, allocating common resources, and using a single aperture on the S/C heat shield.

Heritage	SCORE/HERSCHEL
	SUMER/SOHO
	UVCS/SOHO

Parameter		Units	Value / Description	Remarks
Sensor / detector				
COR visible detector		1	APS	Integration mode
	Format		2048 × 2048	
	Pixel size	µm	25	
	Dynamic range	bit	16	
	Operating temperature	°C	–50	
COR UV detector		1	IAPS	Photon counting mode
	Format		2048 × 2048	
	Pixel size	µm	25	On the focal plane. The actual pixel size of the APS for the IAPS is 12 µm (see section 4.6.1.1.4 of EID-B)
	Dynamic range	bit	N/A	This detector works in photon counting mode
	Operating temperature	°C	20	
SOCS/EUS detector		3	IAPS	Both analog and photon counting regimes
	Format		2048 × 2048	
	Pixel size	µm	12	
	Dynamic range	bit	14	When working in analog mode (N/A in photon counting mode)
	Operating temperature	°C	20	
Optics				
	Type			Different per each METIS element
	Unobstructed FOV	sr	2π	To be able to observe the very weak solar corona, no object can potentially scatter sun disk light inside the instrument aperture
	Energy passband		EUV to visible	
	Pointing		$+X_{Opt}$ S/C axis	
Configuration				
	Physical Units	No	1	
	Layout			
	Location S/C		±Z panel	See section 3.3.5 of EID-B.

Physical			
Sensor Mass	kg	2.7	Mass of the five METIS detectors, including housing, mounts and doors
Thermal Hardware Mass	kg	1.0	METIS total thermal H/W mass (conductive straps, thermal washers, thermistors)
Harness Mass	kg	1.2	
Electronics Mass	kg	8.2	METIS Processing & Power Unit (MPPU)
Detector FEE	kg	1.1	For five METIS detectors
Total Mass	kg	29.6	METIS total mass, without contingency
Sensor dimensions		∅70 mm × 55 mm	COR VD
		∅90 mm × 75 mm	COR UVD
		∅55 mm × 40 mm	EUS/SOCS
Harness Length	cm	~100	From the detector FEE to the MPPU
Electronics Dimension	cm^3	22 × 25× 35	MPPU box envelope
Power			
Average	W	40.2	Before margins (25%)
Peak power	W	TBD	
Stand-by	W	TBD	
Data rate / volume			
Average data rate	bits/sec	27 k	
Peak data rate	bits/sec	TBD	
Minimum data rate	bits/sec	TBD	
Data volume /orbit	GByte	32	
Data storage	GByte	31	
Thermal			
Electronics Dissipation	W	37	MPPU dissipation, including 25% margin
Sensor Dissipation	W	13.2	Dissipation of all the detector FEE, including 25% margin
Heat load to radiator	W	130	Thermal power to be dissipated from the sun disk rejection mirror M0 and the heat absorber behind the EUS M1
Operating T range	K	293 ÷ 323	
Non-operating range	K	TBD	
Other requirements		TBD	
Cleanliness			
EMC requirements		TBD	
DC magnetic		TBD	
Particulate		TBD	
Molecular		TBD	
Pointing			
APE	arcmin	< 2	ILS
RPE		< 1 arcsec/10 s < 0.5 arcsec/10 s goal	ILS
Miscellaneous			
Mechanisms	No.	6	COR mechanisms: 1. Extended external occulter insertion 2. Filter exchange 3. Internal occulter alignment (during commissioning phase only)

			EUS mechanisms: 4. Scanning mirror 5. Coronal telescope insertion 6. Slit selector
Detector doors	No.	4	Single shot (TBC) 1 for COR, 3 for EUS/SOCS
Orbit requirements		N/A	
AIT/AIV requirements		TBD	

Table 2: METIS overview sheet.

1.3 Instrument Baseline Design

In the present chapter, an overview of the baseline instrument design is given. More details both on each single channel and on the overall METIS suite, can be found in the EID-B document.

1.3.1 General Instrument Architecture

In an approach oriented to the best sharing of tasks between the imaging and the spectroscopic investigation of the Sun, and in particular of the solar corona, and to the best coordination between them, the proposed METIS suite is a highly integrated instrument, with an approach which seems to be the most effective to obtain the highest scientific return, while minimizing the overall resource allocation. In fact, the METIS architecture takes advantage of the commonality between the different elements that constitute the suite. Moreover the suite is aimed to provide a simplified interface to the spacecraft, by internally handling the needs of the various elements. A top-level architecture of the proposed METIS suite is sketched in Figure 1.

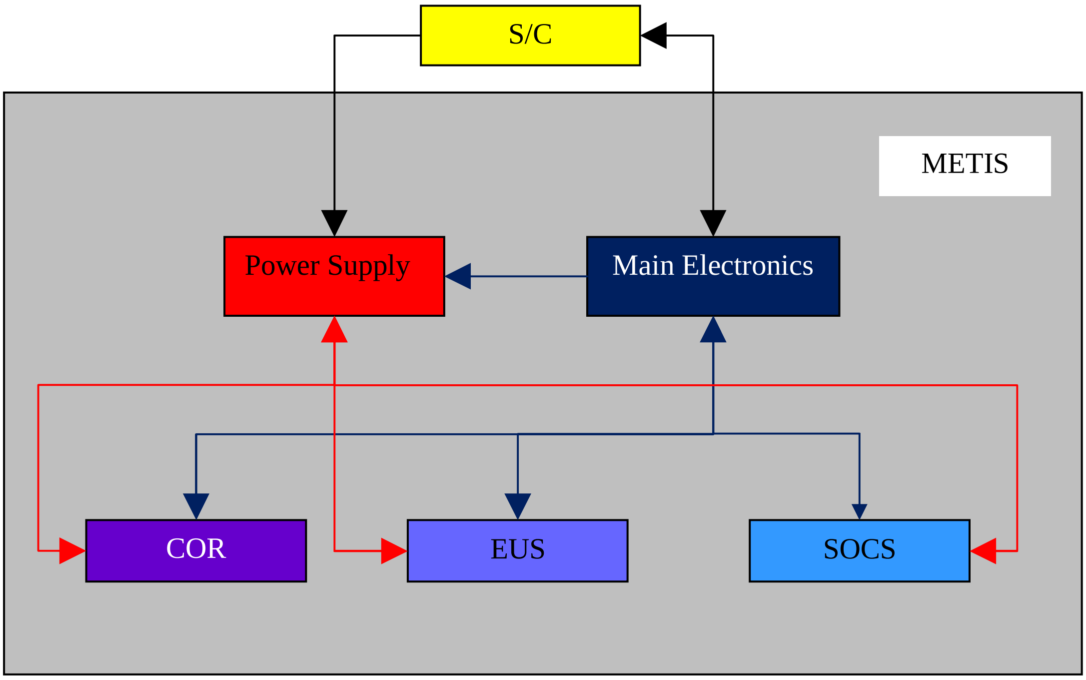

Figure 1. Overall METIS suite architecture.

1.3.2 Instrument Functional Design

The hardware configuration approach is based on a high level of integration between the three METIS elements. This means that duplication of common functions will be avoided whenever possible, in order to achieve maximum resource saving for the whole suite.
From a mechanical point of view, this means that each element is not intended to be designed as a self standing instrument, so requirements on the structure (e.g., stiffness, vibration performance) can be optimized. In fact, all the mechanical testing activities (including vibration and alignment) will be carried on at a suite level more than at an element level. In this way, global saving on mass can be obtained.
The METIS elements will be integrated on a common bench, that constitutes the mechanical interface towards the spacecraft. This is aimed also to guarantee the needed stability in co-alignment between the three elements, that is requested for best coordinated operations and data combined use.
From an electrical point of view, the proposed IFE approach allows the sharing of two main functions among the elements, that are implemented at suite level to avoid duplication, namely:
− main electronics function,
− power supply.
The first is mainly devoted to data management and compression, instrument control and telecommand/telemetry handling from/to the S/C interface. The second is optionally incorporated in the METIS capabilities and is devoted to supply all the subsystems with the required power, providing a common set of required voltages.
A schematic functional diagram of METIS is shown in Figure 2. The acronyms are reported in Chapter 4.1.

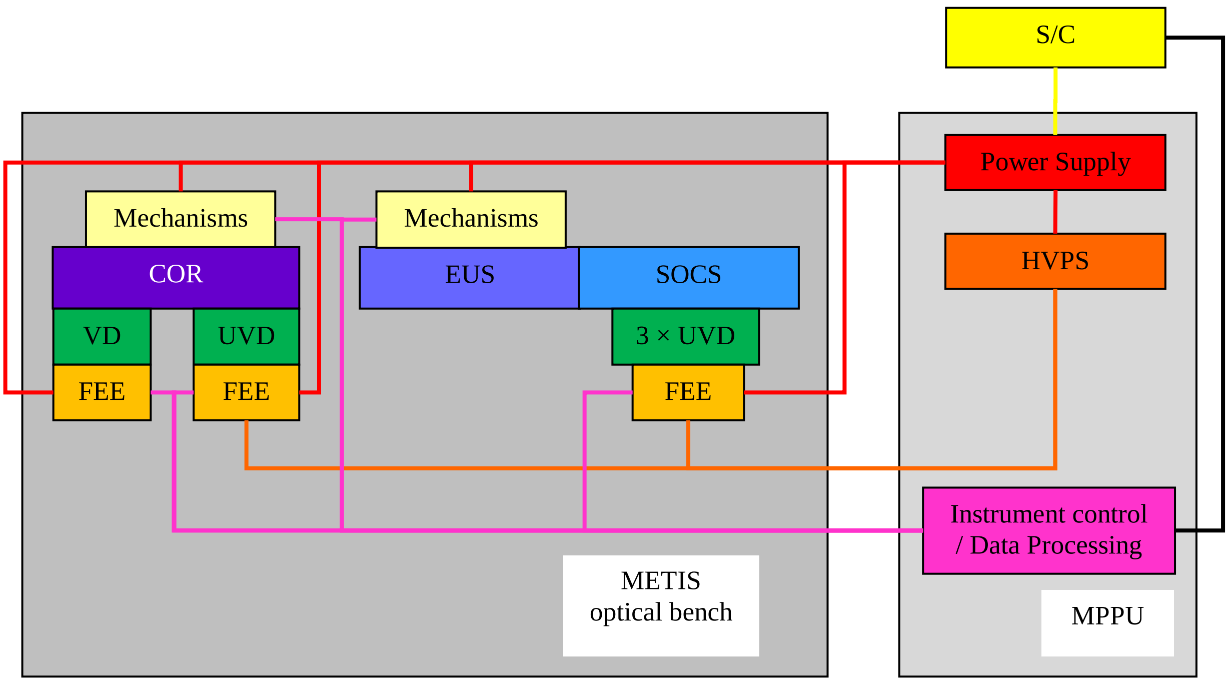

Figure 2. METIS functional block diagram.

1.3.3 Summary of Instrument Critical Items

The critical items of the METIS instrument front end are listed in Table 3. They are discussed in section 2.2.2, in which the technology preparatory program is outlined, and where the level of criticality of each of item is pointed out.

Item	**Risk level**
MULTILAYER vis-UV capped	1
IAPS DETECTORS	2
LCVR	2
RISK LEVEL	1: low (no technology development needed; space qualification required)
	2: moderate (minor technology development needed; space qualification required)
	3: high (major technology development needed; space qualification required)

Table 3: Critical items of the METIS instrument.

2 Design and Development

2.1 General

The design and development plan specifies the intended qualification approach and describes the adopted model philosophy, including also prototypes and other non-deliverable models, and the build standard relevant to each model. Critical items are also identified, and the required steps for their development are described.
The engineering plan describes all the engineering activities (mechanical, electrical, thermal, software, etc.) to be performed during the different programme phases.
The verification plan specifies all the activities to be performed at subsystem, unit and experiment levels; moreover, also the experiment most critical items will be verified as appropriate throughout their development (design and hardware production) to guarantee the fulfilment of their specific requirements. The methods of verification are also described.
All design, development and verification activities will be carried on following ECSS standards.

2.2 Development and Verification Plan

The instrument Verification Programme, will be defined in compliance with the EID-A requirements and will proceed through the following phases:

- Development, aimed to demonstrate that the design, manufacturing and test process are in line with the applicable requirements (scientific goals, mission environment, spacecraft performance, spacecraft interfaces and operational requirements).
- Qualification, aimed to demonstrate that the hardware and software, produced according to the established design, is compliant to the specification requirements, including proper margins.
- Acceptance, aimed to demonstrate that the deliverable models perform in agreement with the applicable requirements and are free of workmanship defects.

The requirement verification will be performed at different levels. In particular:

- Equipment level (i.e., detectors, optics, baffles, mechanisms, electronics, software)
- Assembly level (i.e. COR, EUS, SOCS)
- System level (the whole METIS instrument)

The verification methods will be:

- Test (functional, environmental, performance tests),
- Assessment (optical, structural, thermal, electrical analysis),
- Inspection (visual determination of physical characteristics),
- Review of Design (reference to validated design documents, approved design reports, technical descriptions, engineering drawings etc., showing unambiguously that the requirements are met),

or a combination thereof.

2.2.1 Model Philosophy

The instrument model philosophy, defined according to the satellite AIT philosophy and requirements (ref. EID-A) and to the METIS development and qualification program consists of:

- Breadboard Model (BB), already implemented during the instrument Phase B in support to the development of the METIS equipments (in particular: detectors, FEE, mechanisms, optics, baffles, electronics and software) and of the design of the thermal control and of the mechanical interfaces.
- Structural Thermal Optical Model (STOM), for the qualification by test of the METIS structure (including external occulter, baffles, optics), mechanisms, thermal control, the verification of the structural and thermal mathematical models, the verification of the instrument-S/C mechanical, thermal and optical interfaces. After the tests at instrument level, the STOM will be delivered to the Solar Orbiter Prime Contractor.
- Engineering Model (EM), for the verification of the electrical and software interfaces inside the instrument (between MPPU, FEE, detectors and mechanisms) and between the instrument and the S/C, verification of the operational modes and procedures, qualification of the instrument flight software, verification by test of the electromagnetic compatibility of the electronics, detectors and mechanisms. The MPPU and the FEE are planned to be realized at Engineering Qualification Model (EQM) level and subject to qualification tests before being used in the instrument EM. After the tests at instrument level, the STOM will be delivered to the Solar Orbiter Prime Contractor.
- Flight Model (FM), to be subjected to environmental and functional test campaign at acceptance level before the delivery the Solar Orbiter Prime Contractor.

Flight Spares (FS) for the replacement of failed or damaged equipment at integration and launch site will be also realized. The list of the items for which a FS will be realized will be defined during the instrument Phase A and discussed/agreed with ESA.

2.2.2 Technology Preparatory Program

In what follows, the potential critical items of the METIS instrument, identified in paragraph 1.3.3, are discussed together their technological developments and possible backup solutions.

2.2.2.1 Polarimeter

The Visible Light path of METIS/COR element consists of a polarimeter assembly for the measurement of linearly polarized visible-light brightness (pB) of the K-corona. The coronal electron density is the physical quantity derived from the pB measurements. The coronal electron density is fundamental for the Doppler Dimming analysis on the HI and HeII Lyman alpha emissions.
The baseline scheme of the polarimeter is based on electro-optically tuneable nematic Liquid Crystal Variable Retarder plates (LCVR). This device replaces the need for mechanically rotating retarders for polarization modulation. The LCVR driving electronics is compact, light-weight and with limited power consumption. A colour filter in front of the polarimeter assembly selects the spectral operation band. A LCVR based polarimeter will be tested in space during the suborbital experiment HERSCHEL/SCORE.
Classical methods of mechanical modulation by rotation of polarizing elements are the back-up design. This polarimeter concept is well consolidated and benefits from the SOHO/UVCS experiment heritage.

2.2.2.2 Multilayer

The baseline for the coating of the METIS/COR coronagraph mirrors is to use a SiC/Mg multilayer optimized for EUV. The visible-light and UV reflecting cap-layer has already been realized and tested, as shown in Figure 3. The obtained results show a behaviour corresponding to the expectation, allowing to be very optimistic on the possible use of this multilayer coating on the COR optics. Essentially, no further development is expected, and simple long term stability tests have to be performed, plus some typical environmental test (i.e. vibration and thermal test) to space qualify this coating.

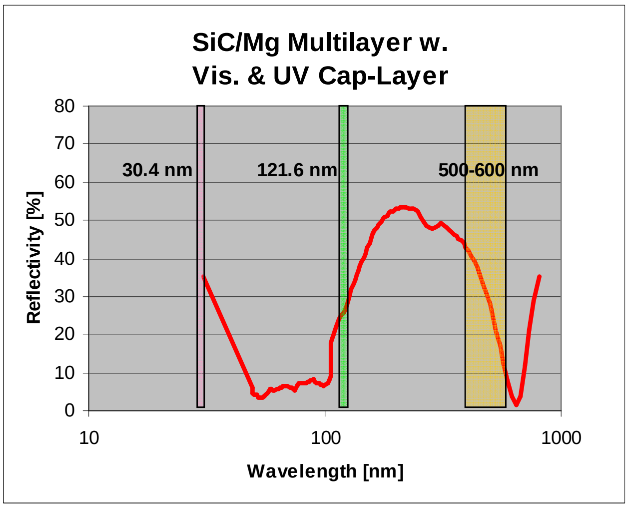

Figure 3: SiC/Mg Multilayer reflectivity

As a backup coating solution a Mo/Si multilayer is consider, which has been already well tested in several space experiments and provides long term stability. The structure is protected by 2 nm of additional SiO_2 cap-layer. In Figure 4 the measured performances of Mo/Si are shown.

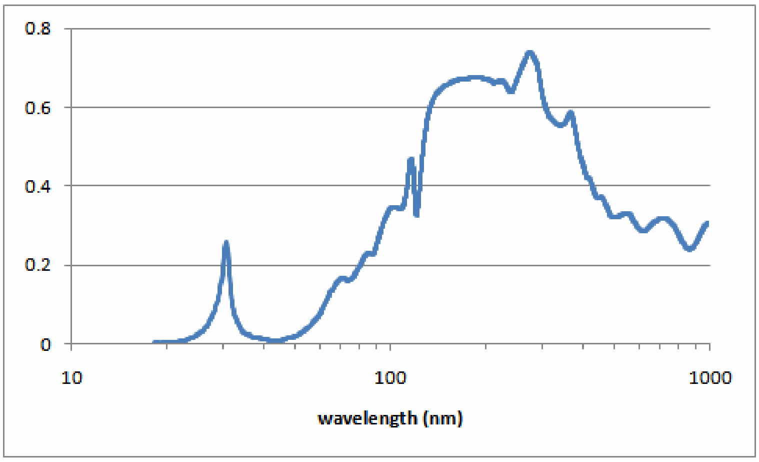

Figure 4: Reflectivity curve of a Mo-Si multilayer mirror. Parameters: 16.5 nm period, gamma 0.85, 25 periods, SiO_2 cap-layer.

2.2.2.3 Intensified APS Detectors

The METIS/EUS element present configuration foresees the use of three Intensified Active Pixel Sensor (IAPS). An IAPS consists of a microchannel plate (MCP) intensifier with phosphor screen output, optically coupled via fiber optic taper to an APS sensor. A photocathode deposited on the entrance MCP face converts the incoming photons in primary photoelectrons, which are then multiplied by the MCP plate and finally converted into optical photons by the phosphor screen. At the end of the process, the APS detects these optical photons. The schematic of the IAPS detector is shown in Figure 5.

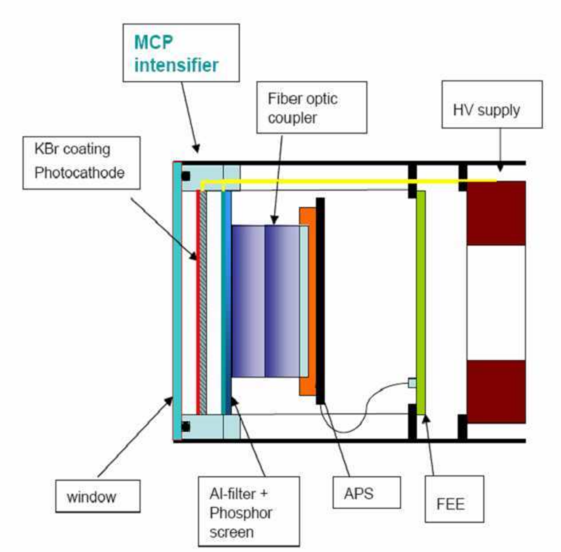

Figure 5: Schematic of the IAPS detector.

The final choice of the APS sensor to be used as readout device will be done in subsequent phases of the project. E.g., a space qualified version of the already available Cypress LUPA-4000 (presently under ESA technological development activity SO-DE-01) could meet basic requirements, even if the available dynamical range is rather limited (10 bits with respect to the 14 required).

The intensifier will be procured from Sensor Science – a commercial spin-off of the UC Berkley MCP activity of Prof. O. Siegmund. The METIS detectors are a straightforward adaptation of the New Horizons Pluto-Alice unit.

In order to have a flyable model of this detector, testing and the space qualification are necessary. Particular attention must be devoted to fully characterize the capability of maintaining the high spatial resolution in both photon counting and analogue modes on the same detector. All the other elements (APS, FEE, remote electronics, …) have significant heritage from other ASI spaceflight programs and do not need any specific development. If the early characterization of the engineering model IAPS performance indicates a fundamental engineering problem with significant schedule impact, a backup solution can be easily found changing the SOCS optical design, and increasing the grating-to-focal plane distance. In fact, in this case, a larger pixel size is necessary, and consequently a larger detector, but at the same time this greatly reduces the spatial resolution criticality. In practice, an IAPS with a larger APS pixel size would allow to maintain the foreseen scientific performance of the instrument, at the minor cost of some increase of the needed mass resource.

2.2.3 Backup Development Plan

TBW

2.2.4 Unit /assembly Development

The general development philosophy for units and assemblies is to qualify the design on the E(Q)M, STM and FM units and assemblies. Where it is considered necessary certain units will be breadboarded in order to verify the design concept.

2.2.5 Software Development

The on-board software will be developed under a specific PA Plan to be established for this purpose, in accordance with ESA software engineering standards.

2.2.6 GSE Development

In this paragraph, all the needed GSE equipment is addressed. Optical GSE, Electrical GSE and Mechanical GSE are discussed separately.

2.2.6.1 OGSE

An OGSE will be developed to fulfil the following tasks:

- to support alignment, testing and calibration of each METIS element
- to support the integration of the different elements within METIS suite.
- to test METIS suite, especially with respect to co-alignment between elements.

2.2.6.2 Optical Ground Support Equipment (OGSE)

The EGSE for METIS Instrument will be developed to fulfil the following tasks:

- to support the development of METIS Main Electronics
- to test METIS (integrated instrument) before the integration in the S/C
- to support the instrument OGSE at the calibration site
- to execute on ground calibration of METIS
- to test METIS after the integration in the S/C
- to support the Flight Operations of METIS.

2.2.6.3 Mechanical Ground Support Equipment (MGSE)

The following MGSE will be provided:

- transport container for the METIS Instrument (and/or its S/Ss, as necessary)
- gas purge equipment (if necessary)
- transport containers for MGSE items.

2.2.7 Assembly and Integration

Since the METIS suite is a composite instrument which includes different elements each characterized by its own specific scientific and operational task, plus some common parts, which functions are common to all the channels (MPPU, optical bench), the AIT / AIV activities at system level are of large relevance.
A diagram illustrating the flow of integration activities that shall be performed on METIS is shown in Figure 6. It includes all levels of integration from equipment (e.g. optics, detectors, mechanisms), through elements, up to system integration.

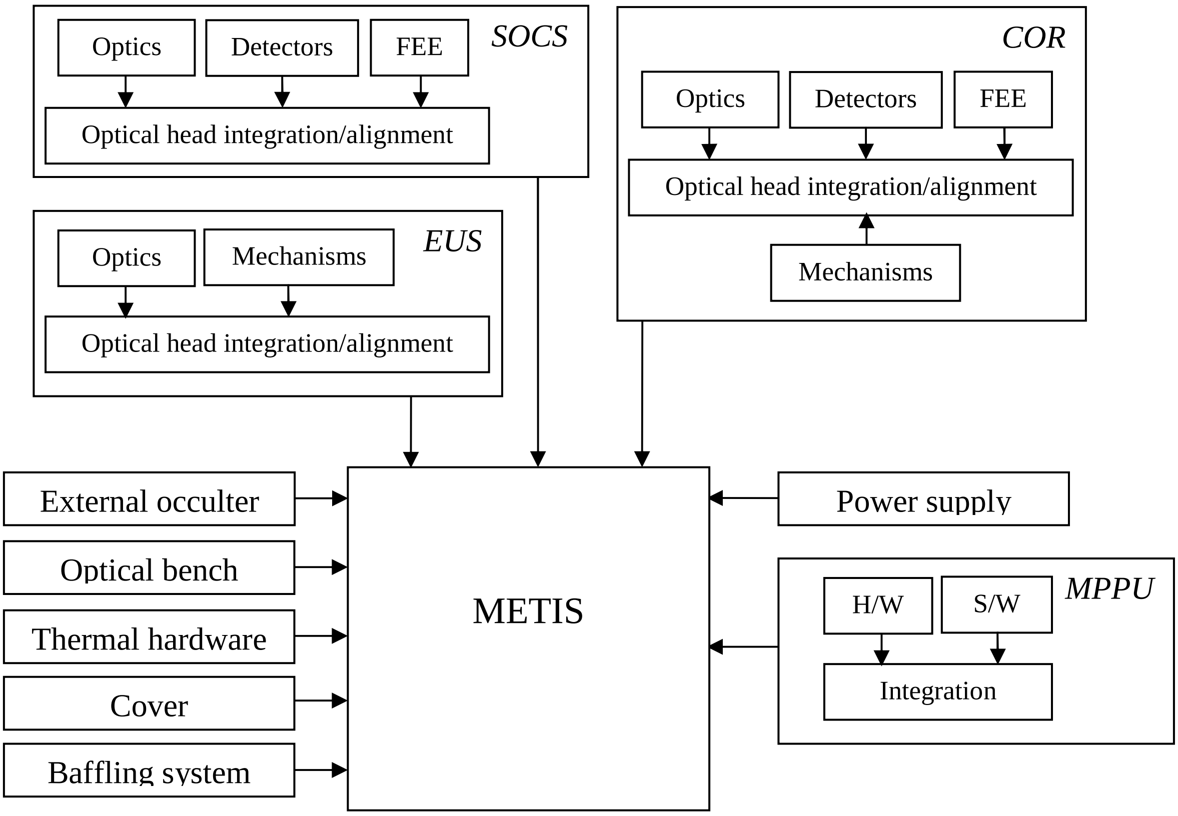

Figure 6: Flow diagram of the foreseen METIS integration activities.

The whole integration flux will be applied to the STOM, where only the representativeness of some parts will be modified as follows:

- Optical bench, cover and thermal hardware will have flight design
- Optics will be thermally representative of the flight model, but with no optical properties unless relevant for thermal analysis (for example, the heat rejection mirror M0 will be fully representative of the flight model)
- Detectors, FEE, main electronics and power supply will be substituted by dummies

While for the EM, integration will be limited to the electrical parts namely:

- Detectors
- FEE
- MPPU

To obtain the best scientific return from the chosen instrument suite approach, co-alignment and cross calibration of the different channels, as well as functionalities of the common main electronics, will be the subject of verification at a system level. The system level test flow is shown in Figure 7.
For those items that can be fully characterized at a lower level only performance tests shall be performed at a system level.

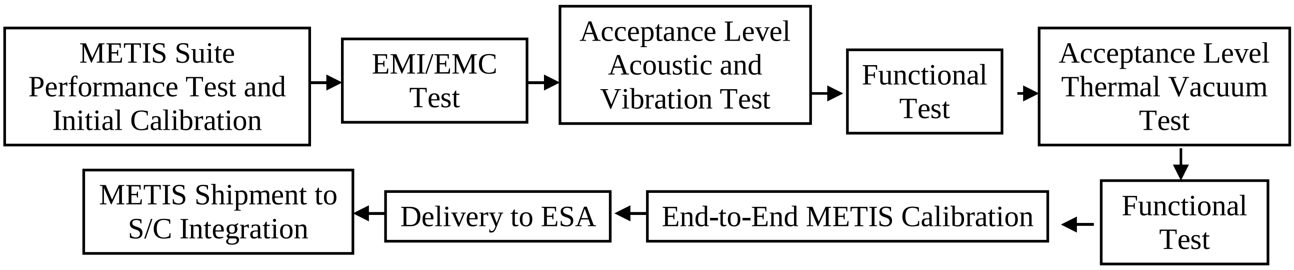

Figure 7: Flow diagram of the foreseen METIS system level test activities.

2.2.8 Phasing and Milestones

The development program of the experiment is divided into a number of phases during which specific activities will be performed. Table 4 reports the start and end events for each phase.

PHASE ACTIVITIES AND MILESTONES	START EVENT	END EVENT
Conceptual definition; functional breadboarding	Proposal Submission	ISRR
BB development and test	ISRR	IPDR
Detailed design; critical items verification and review; begin of STOM manufacturing.	IPDR	ICDR
Delivery of STOM. Development, testing and delivery of E(Q)M.	ICDR	IQR
Start of FM/FS manufacturing. Final testing and of FM.	IQR	IFAR
Delivery of FM/FS.	IFAR	FM/FS Delivery
Post-delivery support	FM/FS Delivery	Launch

Table 4: Instrument development phases.

3 Instrument Verification and Engineering Plan

3.1 General

The qualification approach selected for METIS follows the guidelines stated in Section 6 of the RD-1. The instrument verification plan specifies the intended qualification approach and describes the adopted model philosophy, including also prototypes and other non-deliverable models, and the build standard relevant to each model. Critical items are also identified. The verification plan specifies all the activities to be performed at subsystem. All design, development and verification activities will be carried on following ECSS standards.
The METIS Verification Programme will demonstrate to ESA and its selected Prime that the instrument design is fully compliant

- with the instrument scientific goals;
- with the mission environment;
- with the spacecraft performance;
- with the spacecraft interface requirements;
- with the operational requirements;
- with the provided operational documentation;

hence capable to contribute to the overall scientific goals.
The PI will verify the instrument design and build against each requirement specified in the EID-A and B [Qualification]. The PI will verify the FM instrument certification for flight against each requirement specified in the EID-A and B [Acceptance].

3.2 Verification

3.2.1 Verification Objectives and Control

The aim of the verification plan is to identify all the methods that collectively demonstrate that the produced hardware and software is qualified for flight on the Solar Orbiter spacecraft. This will be achieved by the end of phase C with the completion of the E(Q)M programme.
The subsequent test activity, performed on the FM, is still part of the verification plan and will certify that the PFM (and FS spare parts) is acceptable for flight in compliance with all the requirements called up in the EID-A.

3.2.2 Verification Concept

Instrument verification will be accomplished preferably by testing. But in certain cases, when testing is not possible, one or more of the following verification methods will be applied:

- Analysis (Structural, Thermal), when verification is achieved by performing theoretical or empirical evaluation by accepted techniques
- Functional Tests (FFT, AFT) or Environmental Tests (Vibration, TB/TV, EMC), when requirements have to be verified by measuring product performance and function under various simulated environments
- Inspection: Verification is achieved by visual determination of physical characteristics (such as construction features, hardware conformance to document drawing or workmanship requirements)

- Review-of-design (Similarity Assessment): Verification is achieved by validation of records or by evidence of validated design documents or when approved design reports, technical descriptions, engineering drawings unambiguously show the requirement is met.

3.3 System Analysis

Verification by analysis will be carried out extensively for the validation of the structural and thermal design at system and subsystem levels (optical bench, cameras and spectrometers optical heads and detectors, etc).
A radiation sensitivity analysis will be performed to evaluate the radiation impact on electrical components such as FPGAs, A/D converters, array detectors.
During the experiment development, breadboards of specific items and the STOM will be used to tie the results of analysis based on mathematical models with tests results, based on actual performance measurements under controlled environmental conditions.
In the overall, the numerical models which will be produced to guarantee analytical compliance to a given requirement will cover, whenever necessary, the following topics:

- Radiation sensitivity analysis
- Structural analysis
- Mechanisms analysis
- Thermal analysis
- Electrical performance evaluation
- Part stress analysis

Analysis reports will be generated for each analysis verification, and submitted to the SO Project Office.

3.3.1 Mechanical and Thermal Activities

3.3.1.1 Structural mathematical models

METIS mechanical performance will be calculated by means of structural mathematical models (SSMs). The PI will use models for his own design and will also provide model(s) to the Agency for use during spacecraft design and test results predictions. The PI will update the models according to instrument and system test results. The instruments SMMs will be delivered according to the dates TBD. They will comply with the detailed requirements for each model / analysis as listed in section 6.3.1 of RD-1.

3.3.1.2 Mechanisms functional analysis

A functional analysis of each mechanism will be carried out for all operational cases including worst case environmental conditions.

3.3.1.3 Thermal mathematical models

METIS thermal analysis will be performed to:

- verify that internal parts and materials are below their maximum allowed temperatures under acceptance/qualification testing;
- verify the ability of the thermal design to maintain the internal required temperatures and intended heat flow pattern that ensure performance requirements under the worst flight cases;
- verify the compliance with the spacecraft interface requirements under the worst flight cases.

METIS thermal analysis will comply with the requirements listed in section 6.3.2 of RD-1.

3.3.2 Electrical activities

Critical electrical systems will be breadboarded or prototyped to fully prove the design before start of the EM build-up.

3.3.3 Software Activities

Software activities are related to:

- the Main Electronics;
- the EGSE.

For both S/Ss the S/W will be provided by the same partner that is in charge of the electronics hardware. Appropriate analysis will be provided when needed to validate algorithms/functions.

3.3.4 Instrument Flight Operations

The development of the Flight Operations Plan will run in parallel with the Hardware design, under the direct control of the PI, of the Science Team and the Technical Manager. The state of the operation planning will be reviewed at each formal instrument review, and updated according to the technical and scientific requirements which should arise.

3.4 Testing

The verification activities will be divided in

- Qualification Programme
- Acceptance Programme
- Recertification
- Incoming Inspection

The test programme will be arranged in a way to best disclose problems and failures associated with the characteristics of the hardware and the mission objectives.

In the following, an overview is given of the tests that will be performed during the development of METIS to validate the design and qualify the hardware and software for flight.

3.4.1 Qualification Programme

METIS testing activities will comply with the requirements listed in section 6.4.1 of RD-1 and will include:

- Functional Testing at Instrument Level
- Functional Testing at System Level
- ECM testing
- Structural Testing
- Mechanism Testing
- Thermal Testing

Reference is made with respect to the general tests requirements and program as given in section 6.4 of RD-1.

3.5 Calibration and Science Performance Assessment Plan

A dedicated calibration plan will be issued to describe all the calibration activity to be performed to assess the science performance of the METIS.

3.5.1 Calibration Approach

This section deals with the description of the calibration activities to be carried out on ground during assembly and verification phases and in flight during commissioning, cruise and observational phases to fully characterize the instrumental response.
The knowledge of the instrument performance, needed for an optimized data reduction, requires to perform measurements at several stages:

- **Sub-system tests:** measurements performed on subsystems (H/W units to be integrated in any of the elements) before the integration of the three elements forming METIS;
- **Element ground calibration**: measurements performed on each of the three METIS elements;
- **Instrument ground calibration**: measurements on the IFE, as a single instrument, performed after integration of the entire flight unit, prior to its delivery for integration on the S/C;
- **S/C calibration**: measurements performed on METIS when integrated on the S/C, prior to its launch;
- **In-flight calibration**: calibration performed both during cruise and operations.

Preliminary to all the test activities, an analysis shall be performed of the performance of each element on the basis of S/W simulation.
Subsystems of the three elements for which tests shall be performed and documented are:

COR	EUS	SOCS
External occulter mechanism	Sun disk telescope	Coronal telescope
Heat rejection mirror	Sun disk telescope scanning mechanism	Grating
Telescope (with multilayer optics)	Coronal telescope insertion mechanism	UV detectors
Internal occulter mechanism	Slit selection mechanism	
Filters and filter mechanism		
Visible polarizer		
UV detector		
Visible detector		

Table 5: METIS elements and subsystems

For each subsystem the following documents shall be part of the FM delivery Data Package:

- Log Book of test activities;
- Data Book on the experimental set-up (e.g., lamps spectral and radiometric response, filters and windows transmittance, monochromator spectral resolution, collimator(s) optical quality and FOV, etc.)

- Data Book of the characteristics of subsystem under measure (e.g., mirror coating reflectance, sensor filter transmittance, etc.)

Considering the past experience of the Institutes and Industries involved in the project, a significant part of the required equipment for the tests described in the following is already available.

For all the sensors, which are different for the visible (APS) and UV (IAPS, in both analog and photon counting modes), standard measurements will be performed as: linearity, quantum efficiency, offsets and saturation level, spectral and radiometric photo-response, photo-response non-uniformity (flat field), dark current level, evaluation of damaged pixels location (out of linearity, fixed output). Many of the above tests shall be provided by the manufacturer, but in some cases tests shall be performed by Institutes/Industries as appropriate.

The optical subsystems for each element shall be properly aligned and their alignment verified prior to the final element integration.

A subset of the calibration activities, mainly geometric and radiometric cross-calibration, shall be performed on the integrated IFE to verify the instrument behaviour prior to the delivery.

The verification of co-alignment among the three elements is required to guarantee the correlation of observations taken by the different elements and to achieve the best scientific return from the combination of parallel and/or subsequent observations.

For the integrated suite of instruments the following activities are planned:

- co-alignment of the boresights of each element
- measurement of the relative spatial offsets
- spectral and cross spectral calibrations
- radiometric cross-calibration
- stray light evaluation

In flight calibrations will mainly consist of: a) internal calibration; b) radiometric calibration with stellar objects (within the nominal FOV at aphelion, without any S/C off-pointing, TBC); c) spectral calibration with reference chromospheric lines.

3.6 Final Acceptance

The acceptance process will demonstrate that METIS has been fully verified in terms of:

- scientific performance (including calibration and characterization)
- behaviour versus environmental conditions (including EMC)
- all functional interfaces

The acceptance of the Instrument will follow the sequence hereafter:

- completion of acceptance tests, including calibration/characterization at the Instrument supplier premises, in order to verify that the Instrument together with its ground support equipment meet all interface specifications and that the Instrument is ready, for integration onto the satellite
- acceptance review of the tests results and of the completeness of the acceptance data package at instrument manager premises and release of a consent to ship if the acceptability is stated by the review board
- delivery to the satellite AIT site of the Instrument together with the ground support equipment (including test software and documentation) and the acceptance data package
- performance - by the Instrument supplier - of a post shipment inspection and at an incoming test at the AIT site
- after successful completion of the incoming verifications by the Principal Investigator and formal incoming inspection by system level QA, the Instrument will be released for integration onto the satellite

- notwithstanding the mandatory Instrument level tests, the Instrument software will only be accepted after successful S/C level test.

4 Document References

4.1 Applicable Documents

AD-1

4.2 Reference Documents

RD-1 Experiment Interface Document – Part A Issue 1.0 – ref. SOL-EST-IF-0050 – October 2007

RD-2 Solar Orbiter Environmental Specification – issue 1.3 – ref. TEC-EES-03-034/JS – January 2006

5 Acronyms

ADC	Analog to Digital Converter
AFT	Abbreviated Functional Test
AIT	Assembly, Integration and Test
AOCS	Attitude and Orbit Control System
APS	Active Pixel Sensor
BB	Breadboard
BBM	Bread-Board Model
CCD	Charge Couple Device
CFRP	Carbon Fiber Reinforced Plastic
CME	Coronal Mass Ejections
CNR	Consiglio Nazionale delle Ricerche
CNRS	Centre National de la Recherche Scientifique
CoI	Co-Investigator
CoM	Center of Mass
CoPI	Co-Principal Investigator
COR	METIS Visible and EUV Coronagraphic imager
CTE	Coefficient of Thermal Expansion
DMS	Data Management System
ECSS	European Cooperation for Space Standardization
EEO	Extended External Occulter
EEOM	EEO Mechanism
EM	Electrical Model
EM	Experiment Manager
EO	External occulter
EOM	External occulter Mechanism
EQM	Electrical Qualification Model
ESA	European Space Agency
EUI	EUV Imager
EUS	METIS EUV disk Spectrometer
EUV	Extreme UltraViolet
EUVC	EUV Channel
FEE	Front End Electronics
FEM	Filter Exchange Mechanism
FFT	Full Functional Test
FM	Flight Model
FOV	Field Of View
FS	Flight Spare
FWHM	Full Width at Half Maximum
GSE	Ground Support Equipment
H/W	Hardware
HeF	Aluminum low-pass filter of the coronagraph
HELEX	Heliophysical Explorers
HERSCHEL	Helium Resonance Scattering in the Corona and Heliosphere
HF	Narrow-band multilayer filter of the coronagraph
HGA	High Gain Antenna

HVPS	High Voltage Power Supply
HWRP	Half Wave Retarder Plate
IAC	Instituto de Astrofísica de Canarias
IAPS	Itensified APS
IAS	Institut d'Astrophysique Spatiale
IASF	Istituto di Astrofisica Spaziale e Fisica cosmica
IDP	Instrument Development Plan
IFE	Instrument Front End
IFSI	Istituto di Fisica dello Spazio Interplanetario
ILS	Instrument Line of Sight
INAF	Istituto Nazionale di AstroFisica
INFM	Istituto Nazionale Fisica della Materia
IO	Internal Occulter
IOM	Internal Occulter Mechanism
IR	Infrared
LAM	Laboratoire d'Astrophysique de Marseille
LCL	Latching Current Limiters
LCVR	Liquid Crystal Variable Retarder
M0	Sun-disk rejection mirror of the coronagraph
M1	Primary mirror of the coronagraph
M2	Secondary mirror of the coronagraph
MCP	Micro Channel Plate
METIS	Multi Element Telescope for Imaging and Spectroscopy
MGSE	Mechanical Ground Support Equipment
ML	Multilayer
MOC	Mission Operation Center
MoI	Moment of Inertia
MPPU	METIS Processing & Power Unit
MPS	Max-Planck-Institut fuer Sonnensystemforschung
MSSL	Mullard Space Science Laboratory
N/A	Not Applicable
NASA	National Areonautics and Space Administration
NOM	Nominal Observing Mode
NRL	Naval Research Laboratory
OAA	Osservatorio Astronomico di Arcetri
OACN	Osservatorio Astronomico di Capodimonte Napoli
OACt	Osservatorio Astronomico di Catania
OAPa	Osservatorio Astronomico di Palermo
OAR	Osservatorio Astronomico di Roma
OATo	Osservatorio Astronomico di Torino
OATs	Osservatorio Astronomico di Trieste
OGSE	Optical Ground Support Equipment
OP	Off Pointing
PA	Product Assurance
PI	Principal Investigator
PoliTo	Politecnico di Torino
QE	Quantum Efficiency
RD-n	Reference Document n

S/C	Spacecraft
S/W	Software
SC	Sun Center
SCORE	Sounding-rocket Coronagraphic Experiment
SEP	Solar Energetic Particles
SMM	Structural Mathematical Model
SO	Solar Orbiter
SOCS	METIS Solar Orbiter Coronal Spectrometer
SOHO	Solar and Heliospheric Observatory
S/S	Subsystem
STOM	Structural Thermal Optical Model
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TEC	Thermo Electric Cooler
TM	Telemetry
TSOM	Time Share Observing Mode
TVLS	Toroidal Variable Line Space
UFOV	Unobstructed Field Of View
UniAq	Università di Aquila
UniCal	Università della Calabria
UniFi	Università di Firenze
UniPD	Università di Padova
UniPd	Università di Padova
UniPg	Università di Perugia
UniPv	Università di Pavia
UniRm	Università di Roma
UORF	Unit Optical Reference Frame
URF	Unit Reference Frame
UV	Ultraviolet
UVC	UV channel
UVD	Ultraviolet Detector
VD	Visible Detector
VIM	Visible Imager & Magnetograph
VLC	Visible Light Channel
VUV	Vacuum ultraviolet