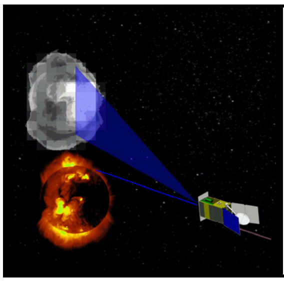
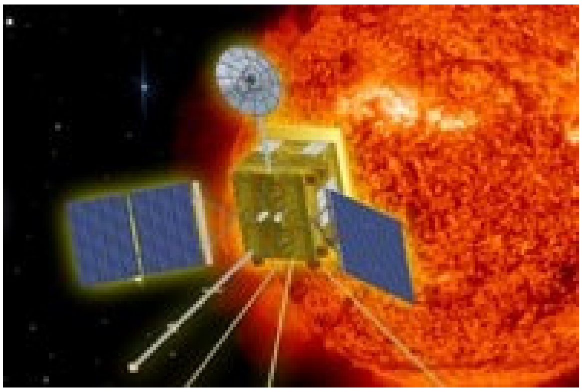


Istituto di Fisica dello Spazio Interplanetario

Engineering Plan

SCENARIO
NSWD
(Neutral Solar Wind Detector)

SOLAR ORBITER



prepared by	AMDL Team		
revised by	NSWD Team		
approved by	Stefano Orsini, Principal Investigator (INAF-IFSI)		
endorsed by	Enrico Flamini (Agenzia Spaziale Italiana)		
reference	SO-NSW-PL-003		
Issue	1	revision	0
date of issue	Dec 2007		

INAF IFSI
Area Ricerca Tor Vergata, Via del Fosso del Cavaliere 100, 00133 Rome - ITALY
Tel (39) 49.93.46.12   -   Fax   (39) 49.93.43.83

D I S T R I B U T I O N

Name	organisation
Solar Orbiter Project Office	ESA and related Solar Orbiter Program Science Panel & Industrial working team.

C H A N G E L O G

Date	Issue	Revision	Pages	Reason For Change
Dec 2007	1	0		1st Issue

Acronym List

ADC	Analog to Digital Converter
AI&V	Assembly Integration and Verification
AMU	Atomic Mass Unit
APE	Analog Proximity electronics
ASIC	Application Specific Integrated Circuit
BOL	Beginning Of Life
CBE	Current Best Estimation
CCEM	Ceramic Channel Electron Multiplier
CDMU	Command Data Management Unit
CEM	Channeltron Electron Multiplier
CM	Common Mode
CoM	Centre of Mass
CR	Collection Rate
DAC	Digital to Analog Converter
DC	Direct Current
DHSU	Data Handling Support Unit
DM	Differential Mode
DMA	Direct Memory Access

DPU	Data Processing Unit
DS	Document Specification
DSP	Digital Signal Processor
EBL	Electron Beam Lithography
EGSE	Electric Ground Support Equipment
ELS	Electron Spectrometer
EM	Electro Magnetic
EM	Engineering Model
EMI	Electro Magneti Interferences
EMC	Electro Magnetic Compatibility
EM	Engineering Model
ENA	Energetic Neutral Atoms
EOL	End Of Life
ESA	Electrostatic Analyser
FEE	Front End Electronics
FIFO	First In-First Out
FM	Flight Model
FOV	Field Of View
FPGA	Field Programmable Gate Array
FS	Flight Spare
GF	Geometrical Factor
HBR	High Bit Rate
H-ENA	High Energy Neutral Atoms
HK	Housekeeping
HPU	Hub Processor Unit
HRC	High Resolution Camera
HV	High Voltage
HVPS	High Voltage Power Supply
IBDR	Instrument Baseline Design Review
ICD	Interface Control Document
ICDR	Instrument Critical Design Review
IFAR	Instrument Flight Acceptance Review
IFE	Instrument Front End
IHDR	Instrument Hardware Design Review
IFOV	Intrinsic Field Of View
IPDR	Instrument Preliminary Design Review
IQR	Instrument Qualification Review
ISRR	Instrument Science Requirements Review
ISVR	Instrument Science Verification Review
LAN	Local Area Network
L-CAM	Limb Camera
LSB	Low Significant Bit
LUT	Look Up Tables
MBR	Medium Bit Rate
MCP	Micro Channel Plate
MGSE	Mechanical Ground Support Equipment
MICD	Mechanical Interface Control Document
MLI	Multi Layer Insulation
NSWD	Neutral Solar Wind Detector
OBDH	On Board Data Handling

PCB	Power Control Box
PDR	Preliminary Design Review
PEEK	PolyEthereEtherKetone
PCB	Printed Circuit Board
PG	Pulse Generator
PHA	Pulse Height Analysis
PMI	Piccola Media Impresa –(Italian Small/Medium size enterprise category)
PRS	Pseudo Random gate Sequence
PSD	Power Spectrum Density
QM	Qualification Model
RIE	Reactive Ion Etching
RPA	Retarding Potential Analyser
RTOS	Real Time Operating System
RTU	Remote Terminal Unit
SCENARIO	Solar Corona ENA Radiation Imaging Observer
SCU	Sensor Control Unit
SEL	Single Event Latch-up
SERENA	Search for Exospheric Refilling and Emitted Natural Abundances
SIS	Spacecraft Interface Simulator
SMD	Surface Mounted Devices
STM	Structural Thermal Model
SYS	System
TBC	To Be Confirmed
TBD	To Be Decided
TBW	To Be Written
TC	TeleCommand
TDC	Time to Digital Converter
TM	Telemetry
TOF	Time Of Flight
TRR	Test Readiness Review
UORF	Unit Optical Reference Frame
UPA	Ultrasonic Piezo Actuator
URF	Unit Reference
UVS	Ultra Violet Spectrometer

Applicable Documents

AD1: SOL-EST-IF-0050 “SOLO EID-A”, Version 1 Rev 0, 9 October 2007

TABLE OF CONTENTS

1 Neutral Solar Wind Detector

1.1 System Design Justification

The Solar Corona ENA Radiation Imaging Observer (SCENARIO) proposal foresees one Neutral Solar Wind Detector (NSWD) unit, being NSWD a neutral particle camera that investigates the neutral gas, strongly linked to solar wind origin, its dynamics and the processes responsible of such a population.

1.2 Instrument Overview Sheet

1.2.1 NSWD

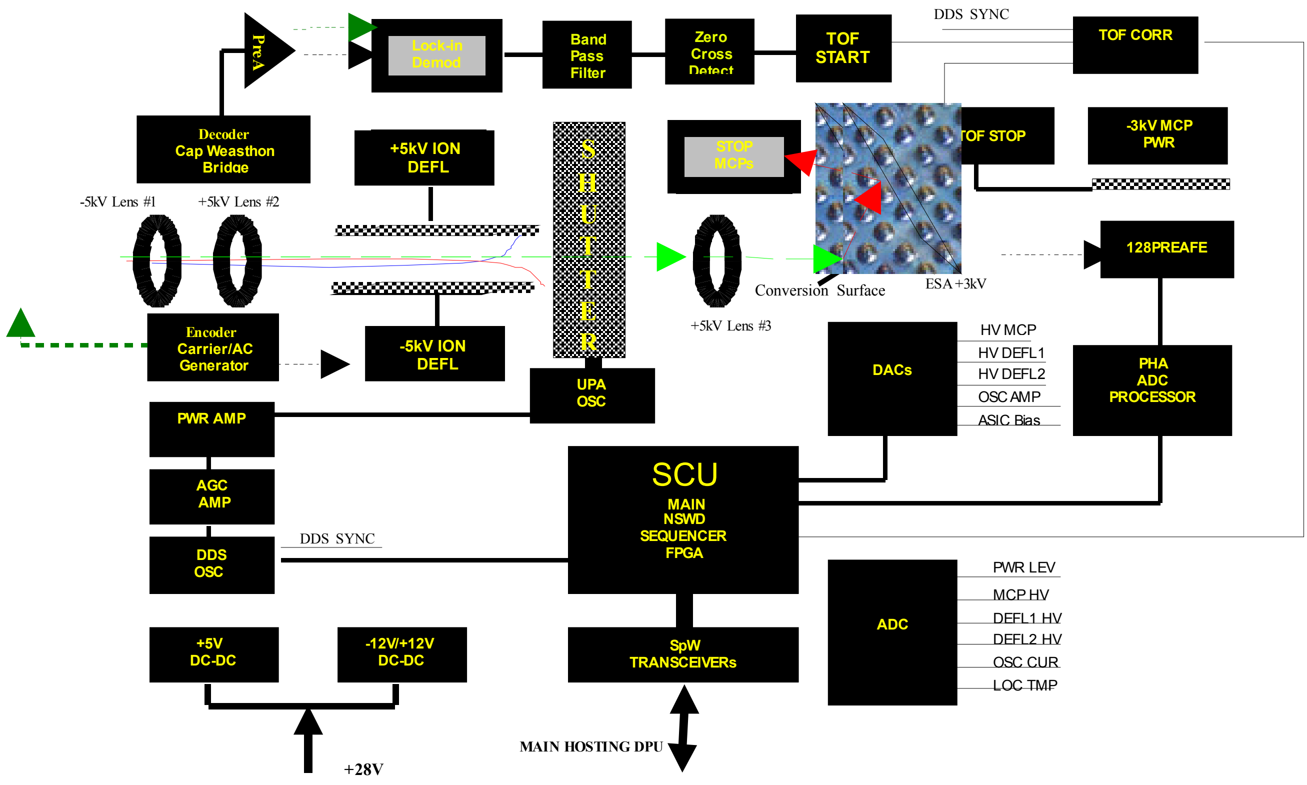


Figure 1.1. NSWD summary sheet.

1.3 Instrument Baseline Design

1.3.1 Instrument Hardware Design

The NSWD sensor concept is based on well flight proven design. Even though it addresses new methodology for the detection of neutrals, most of its architecture elements are based on design solution and detectors which come from the standard space particle spectroscopy practices.

The novel shuttering mechanism addressed by NSWD finds justification in the necessity to measure low energy particle distributions while keeping high directional and time correlation. This objective fits well with the idea to minimize the particle interaction with the detector up to the final stopping (MCP) element.

The electrostatic deflector and analyzers which are used within the sensor units are standard type devices used in particle instrumentation.
In the frame of the Instrument development also the following auxiliary subsystems shall be considered:

- Mechanical Ground Support Equipment
- Electrical Ground Support Equipment
- Spacecraft Simulator Software

There will be four formal models of NSWD
- Structure Thermal Model (STM)
- Engineering Model (EM)
- Qualification Model (QM) / Flight Spare (FS)
- Flight Model (FM)

The QM is not a deliverable model, but after the qualification tests it is suitably refurbished, upgraded and maintained as FS model ready to be delivered in place of the FM unit in the case of any major problem suffered by this unit.

NSWD unit is here shortly discussed, further design details are provided in the NSWD EID-B.

1.3.1.1 NSWD Architecture

NSWD sensor consists of the following subsystems (see Figure 1.1):

- Cover (not shown)
- Lens group #1 –5kV lens
- Lens group #2 +5kV lens
- Parallel plate collimator, balanced biased +5kV –5kV
- Shuttering system

- Lens group #3 +5kV lens
- Conversion Surface
- Parallel grids ESA +3kV
- MCP detector
- Proximity Electronics
- TDC Converter
- SCU - FPGA Sequencer
- DC/DC power converter
- HV power supplies
- ADC / Housekeeping I/F
- NSWD Box

1.3.1.1.1 Cover

It is protecting the instrument under all not operative conditions.

1.3.1.1.2 Lens group #1 –5kV lens

It is a not obstructing lens to suppress the lower energy incoming SW electrons.

1.3.1.1.3 Lens group #2 +5kV lens

It is a not obstructing lens to suppress the lower energy incoming SW ions.

1.3.1.1.4 Parallel plate collimator, balanced biased +5kV –5kV

It suppresses the higher energy ion/electron distributions, not filtered by the entrance lenses group, thus limiting the ion/electron leakage impacting onto the following shuttering element.

1.3.1.1.5 Ultrasonic shuttering system

It is a ultrasonic oscillator carrying a payload of grids which allows w.r.t. the neutral signal:

a) to operate a slow sliding 1° scanning within a 10° FOV
b) Optionally, to operate a fast (250 ns) shuttering of a 1° specific direction.

and w.r.t. the UV environment:

c) to blind the active detection system when operated in TOF mode
d) to filter Lyman-alpha when operated in sliding mode

The internal location of the shutter positioned after the biased collimator limits the background originated by the impact of unsuppressed ions/electrons leakage and minimize the focusing area of the conversion surface and at last extent of the final MCP detector dimension.

1.3.1.1.6 Lens group #3 +5kV lens

It is a not obstructing lens to suppress ions originated on/or closer the shuttering system and introduce a further defocusing element of the high energy ions/electrons leakage.

1.3.1.1.7 Conversion surface

It is the surface providing the neutral to ion conversion.

1.3.1.1.8 Parallel grids ESA +3kV

It is a high transmittivity electrostatic analyzer with the task to provide when operated at fixed biasing:

- the neutral energy dispersion within a range 100eV – 5keV focusing the output beam on the MCP target without the need of stepping energy

and when operated in on/off mode:

- to provide neutral energy dispersion combined with a TOF start information.

1.3.1.1.9 MCP Detector

It is the neutral particle detecting subsystem which releases an electron pulse onto a multi anode discrete system mapping the hit position on a 2D array. The MCP provides the STOP timing when ESA is operated in ON/OFF mode.

1.3.1.1.10 Proximity electronics

It utilizes a low noise, low power multi-channel front-end integrated circuits (ASICs), which processes in parallel the multi anode position detection system. Upon signal detection above the adjustable threshold, the circuits respond with sending out the energy- and position-information of the hit channel. Up to 128 CHs x chip are accommodated in a single device thus providing more than 10x10 mapping.

1.3.1.1.11 TDC converter

TOF measurement requires a tight control of 'start' time slot defined by the combination of the micro valves opening and the ultrasonic oscillator elongation, and the 'stop' signal produced by the impinging of the accepted neutral on the MCPs based end detector. The TOF electronics de-convolves the collected signal injected during the pseudo-random coded opening of the entrance slit into the real velocity spectrum of the incoming flux.

1.3.1.1.12 FPGA Sequencer

The event processing will be performed by a dedicated hi-rel FPGA which will provide the event tagging resources for classifying in time, spatial and energy domains all the incoming events. In nominal mode events will be accumulated into histogram cells and time to time downloaded to the SCU I/F. In calibration mode the single events will be time-tagged and transmitted at the maximum time, spatial, and energy resolution to the main unit.

1.3.1.1.13 DC/DC power converter

It provides the low voltage power supply (+5V, -5V, +12V) for the whole NSDW sensor.

1.3.1.1.14 HV power supplies

NSWD foresees several HV sources. Three are for lenses biasing (ranging -5kV to +5kV). Two are for biasing the charge particles suppresser plates (up to +5kV / –5kV biasing). One is for biasing the neutral stop MCP detector (<3kV). The last HV supply is for biasing ESA analyser (<3kV).

1.3.1.1.15 Ultrasonic oscillator control and motion actuation

The electronics foresees a Direct Digital Synthesis circuitry for programming the desired oscillator frequency, an ultrasonic piezo actuator driver and a motion control circuitry based on capacitive encoding.

1.3.1.1.16 ADC / Housekeeping I/F

Instrument monitoring will be implemented by measuring all the critical biases by means of a local multichannel ADC. Values will be reflected in the Housekeeping telemetry regularly provided by the sensor.

1.3.1.1.17 NSWD Box

It is the main NSWD box which houses the whole sensor elements, the local proximity and event processing electronics, and the external interface to the hosting system

1.3.2 Development of the instrument

1.3.2.1 NSWD Sensor

The NSWD sensor will be built within the NSWD consortium primarily as a collaboration between IFSI, AMDL and CESR. The fundamental components and subsystems utilized in NSWD have been successfully flown on previous missions. For the detector Cluster CIS-2 is the most recent example of particle detector sensor provided by IFSI on Cluster 1 & 2 in strict co-operation with CESR and AMDL.

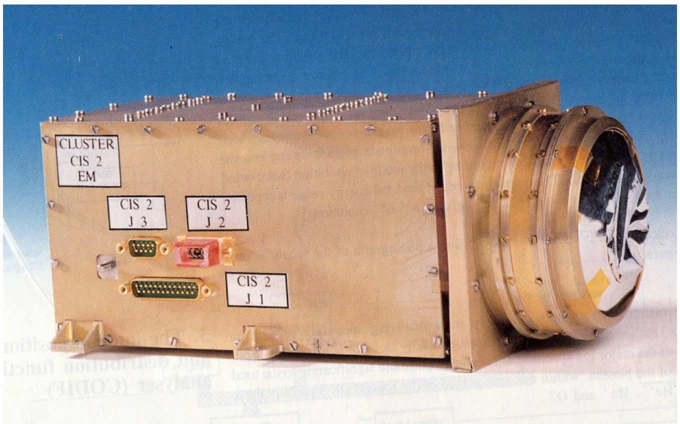


Figure 1.2. Cluster CIS-2 Detector

1.3.2.2 NSWD Electronics

This unit is essentially made by three parts:

- The power distribution subsystem
- The main controller FPGA

It will be inherited from well proven design solutions as those listed in the following.

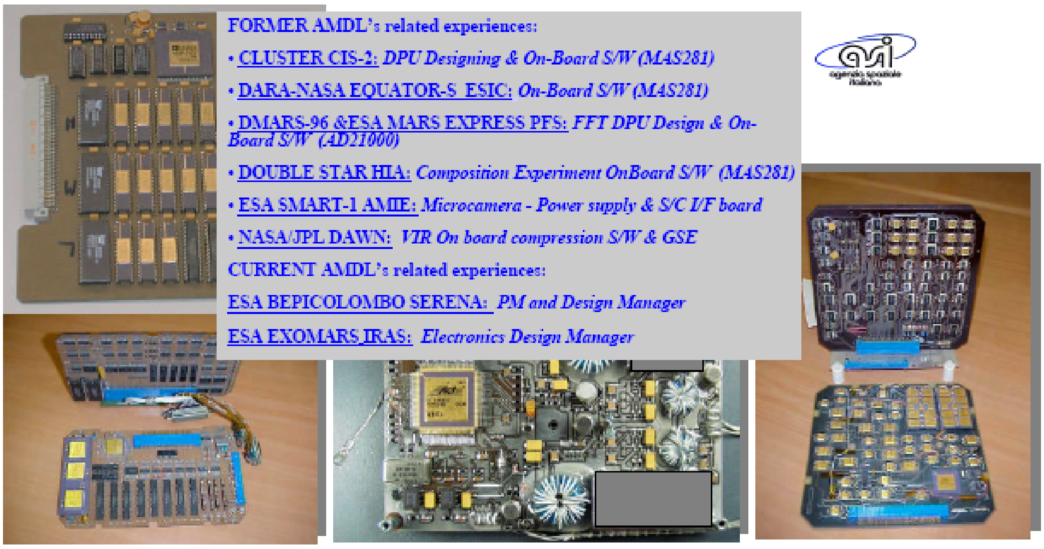


Figure 1.3. Flight DPU inheritance for SCU development. Collection of boards snapshots developed in the frame of space mission supported by AMDL Srl in cooperation with INAF/CNR Upper Left Panel: Engineering model of MARS96 and MEX Planetary Fourier Spectrometer FFT DSP board for which AMDL Srl supported H/W and S/W; Bottom Left Panel: Engineering model of CLUSTER Cis-2 Spectrometer CPU and I/F boards for which AMDL Srl supported H/W and S/W; Bottom Center Panel: SMART-1 AMIE Camera, Power Supply and S/C I/F board for which AMDL Srl supported H/W; Bottom Right Panel: Equator-S ESIC S/W development DPU boards (for which AMDL Srl supported software).

Moreover NSWD will be a strong inheritance of present BepiColombo / SERENA program from which the current developed technologies will be derived.

1.3.2.3 NSWD Sensor

The NSWD sensor concept is considered a new development only for what is concerning the shuttering system. As addressed in the development and verification section par. 2, top experts both for the manufacturing and the qualification of the ultrasonic oscillator and for implementing and verifying of the coupled shuttering payload have been involved. The implementation activity for the whole NSWD shuttering system has been anticipated and it is currently running. Different sets of representative ultrasonic oscillators have been procured for such purposes and four generations of shutter grids have been already realized by following the proposed nanotechnology manufacturing process.

1.4 Summary of Instrument Critical Items

The NSWD package has not major criticalities which could put in a risky situation the development. However a critical technology has been identified which may affect NSWD unit:

- The NSWD shuttering system based on the coupling of an ultrasonic oscillator carrying a payload of nanotechnology shuttering grids.

1.5 Summary data sheet

Sheet tables are provided in the NSWD EID-B.

2 Design, Development and Verification Plan

2.1 General

Starting from the ECSS-E-10 guidelines tailored to the NSWD System, the Design and Development Activities are detailed.

2.2 Technical Organization & Responsibility

Engineering activities are shared among the Industrial Team members of the NSWD Consortium:

System analysis is under responsibility of the system group at IFSI led by the NSWD PM. The main system analyses to be carried out are Mechanical, Thermal and the Electrical Worst Case Analysis.

For NSWD Unit and System level activities the following applies:

Institution	TASK
IFSI, Italy	Scientific Coordination
	Integration
	TV tests
	Harness
	System Functional Tests
	Ion optics collimator suppressor
	MCPs detector
AMDL, Italy	Technical Coordination
	Controller unit (Sequencer) Electronics
	Ultrasonic driver
	Sensor Electronics
	On-board Firmware and Software
	EGSE
	Mechanical design
	Electronics box housing
	Thermal, Radiation analysis
CESR, France	HV power supply boards

CB-PAN, Poland	Power Unit
Thales Alenia Space, Italy	Qualification Tests
ISC, Italy	Ultrasonic core payload design
	Ultrasonic core AIV
	Ultrasonic core testing & qualification
IFN, Italy	Nano gratings manufacturing
	Encoder pattern manufacturing
RMP, Italy	Mechanical analysis
FMI, Finland	EGSE

The NSWD Software is contained only into the NSWD Control unit and will be developed under AMDL responsibility.
NSWD Consortium will address the detailed user requirements. Real time kernel, synchronization procedures, compression routines will be mostly delivered from flown versions of the software procedures coded by AMDL.

EGSE software will be produced by FMI. Elements of the EGSE software in the part of the EGSE (the CCOE) that interfaces directly to the NSWD hardware will be written following the ECSS-E-40 Part1/2B standard. Software in the instrument analysis station will not necessarily follow the standard ECSS.

Software analysis will be provided by the NSWD Consortium for the utilization at the science operational centre of the mission. The instrument manual of software development meeting the requirements of ECSS-E-40 will be written and this manual will be used in all Consortium groups.

A detailed development plan for the analysis software will be issued when the interactions with the scientific entitled ESA entity for the science processing of the mission will be established.

The guiding principle for NSWD operations is that they should be as simple as possible. A small number of modes are envisaged. The flight operations plan will evolve in parallel with the hardware design, under the direct control of the PM and the Operational Manager of the System group. The state of Flight Operations planning will be reviewed at each of the formal NSWD instrument reviews.

2.3 Engineering Plan

In order to clearly identify the activities and the level of development of the NSWD System, it is useful to introduce a brief description of the Project Phases with the schedule requested by the Agency and the additional Meetings and Reviews foreseen at level of Equipments or Units.
The NSWD Instrument Performance Definition Approach is also reported, to allow the individuation of the correct Model Philosophy.

2.3.1 Phases Activities

Phase A-1 - This phase started in early 2005 and has been run until the preparation of the Solar Orbiter Preliminary Design Document and the Technical Interface Unique Document (TIUD) for the definition of the SOLO reference payload by half the 2007. The tasks of the phase were the following:

- Conceptual and laboratory studies on all the NSWD detector system
- Preliminary preparation of the Eid-B at the end of the phase.
- Performance simulations on the NSWD sensor including engineering trade-offs.
- Activate the process for applications for funding in all the Consortium nations

Phase A-2/B1 - This started by the time of the SOLO AO to the Instrument Science Verification Review (ISVR) throughout the instrument selection and national funding support milestones. The tasks of the phase are the following:

- Continue development programme on the NSWD ultrasonic shuttering system
- Start the radiation qualification programme
- Define the requirements of the system and subsystems
- Initiate detail studying of all instrument subsystems
- Initiate study contracts with industrial contractors
- Preliminary definition of internal interfaces
- Verify that the scientific objectives can be met
- Definition of long lead item procurement for the FM and FS programme

Phase B - This phase starts after the ISVR and continues until the Instrument Baseline Design Review (IBDR). The tasks of the phase are as follows:

- Produce the mathematical models required by ESA
- Continue the detectors development programme including building and testing of the development model detector units
- Initiate qualification of the detector units
- Complete detailed design of the subsystems
- Breadboard electronic units

- Define the software requirements on the sensor
- Define the calibration procedures
- Define the GSE requirements
- Carry out radiation tests of susceptible components
- Long-lead item procurement for the STM/QM instruments
- Final definition of all interfaces

Phase C - This phase begins with the NSWD IBDR and continues until the NSWD IHDR (Instrument Hardware Design Review). The main tasks are as follows:

- Manufacturing and qualification of STM, EM and QM subsystems
- Integration and test of STM, EM and QM instruments
- Qualification programme on QM instrument
- Delivery of STM and EM instruments

The main aim of this phase is to qualify the design of the instrument.

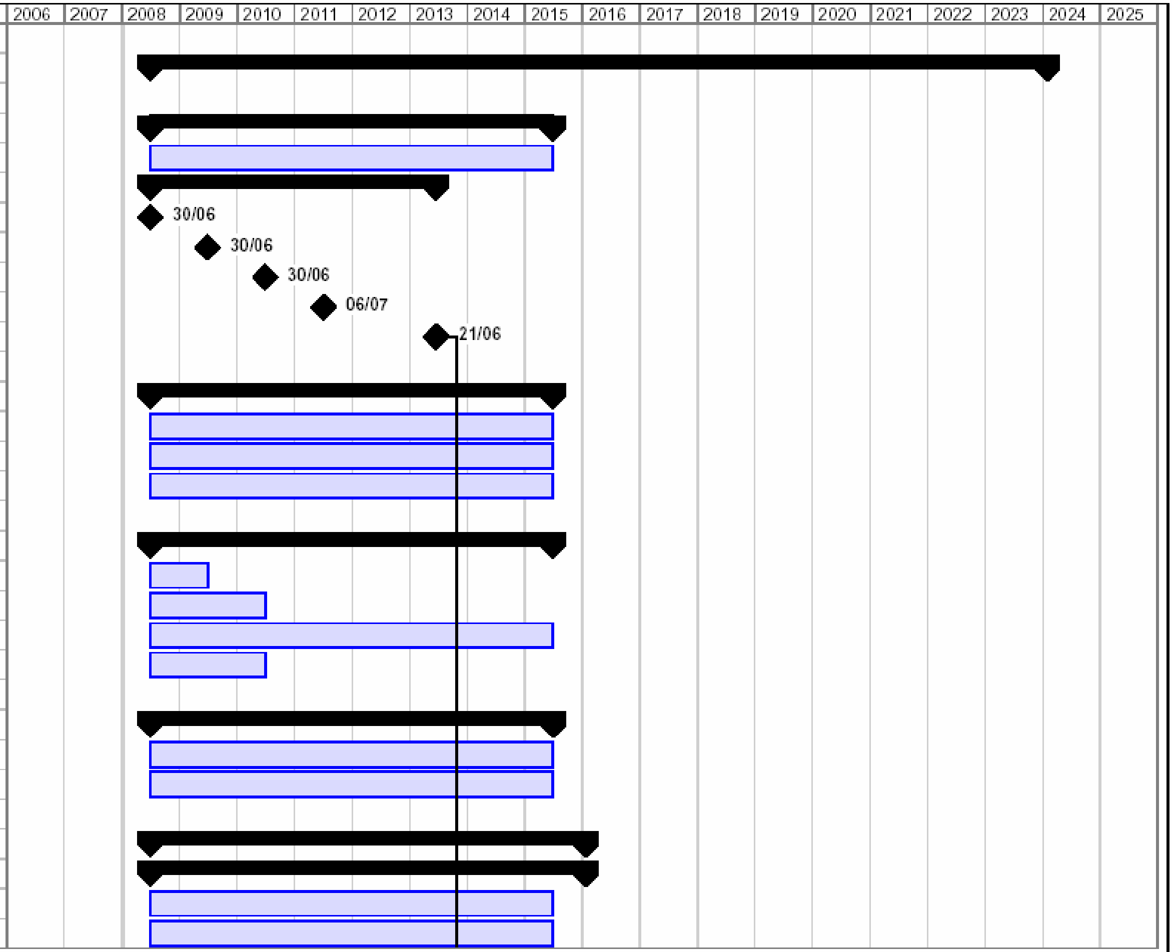
Phase D - This phase begins with the NSWD IHDR and continues until launch.

- Update the design of the QM subsystems for the FM programme
- Manufacturing and testing the FM and FS units
- Integration and functional test of the FM instrument
- Acceptance environmental tests of the FM instrument
- Delivery of the FM instrument to ESA
- Refurbish QM units to FS level

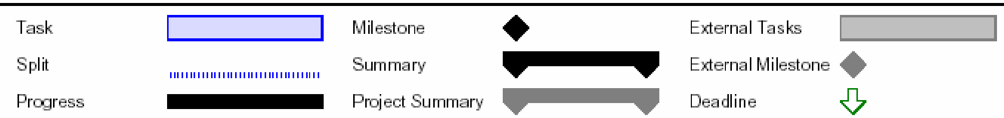
2.3.2 Master Schedule and Reviews

In the following the master schedule containing the requested Reviews and Meetings is reported.
In order to reach the scope of each meeting, additional reviews and meetings dedicated to the development of lower level units or equipment are foreseen and described.

ID	Task Name
1	
2	**MILESTONES**
21	
22	**1.0 Programme Management**
23	Project management
24	**1.2 Reviews**
25	Instrument Science requirements Review
26	Instrument Preliminary Design Review
27	Instrument Critical Design Review
28	Instrument Qualification review
29	Instrument Delivery Review
30	
31	**2.0 Science**
32	Science Theory, Modelling and simulation
33	Oversight Meetings
34	Science Team Meetings
35	
36	**3.0 Systems Engineering**
37	Special Trade Off Studies
38	Environment Derivation
39	General Systems Support
40	Interexperimental Link
41	
42	**4.0 Suite Product Assurance and Safety**
43	PA
44	Cleanliness
45	
46	**5.0 Instrument Development**
47	**NSWD**
48	NSWD Management
49	NSWD Performance Requirements

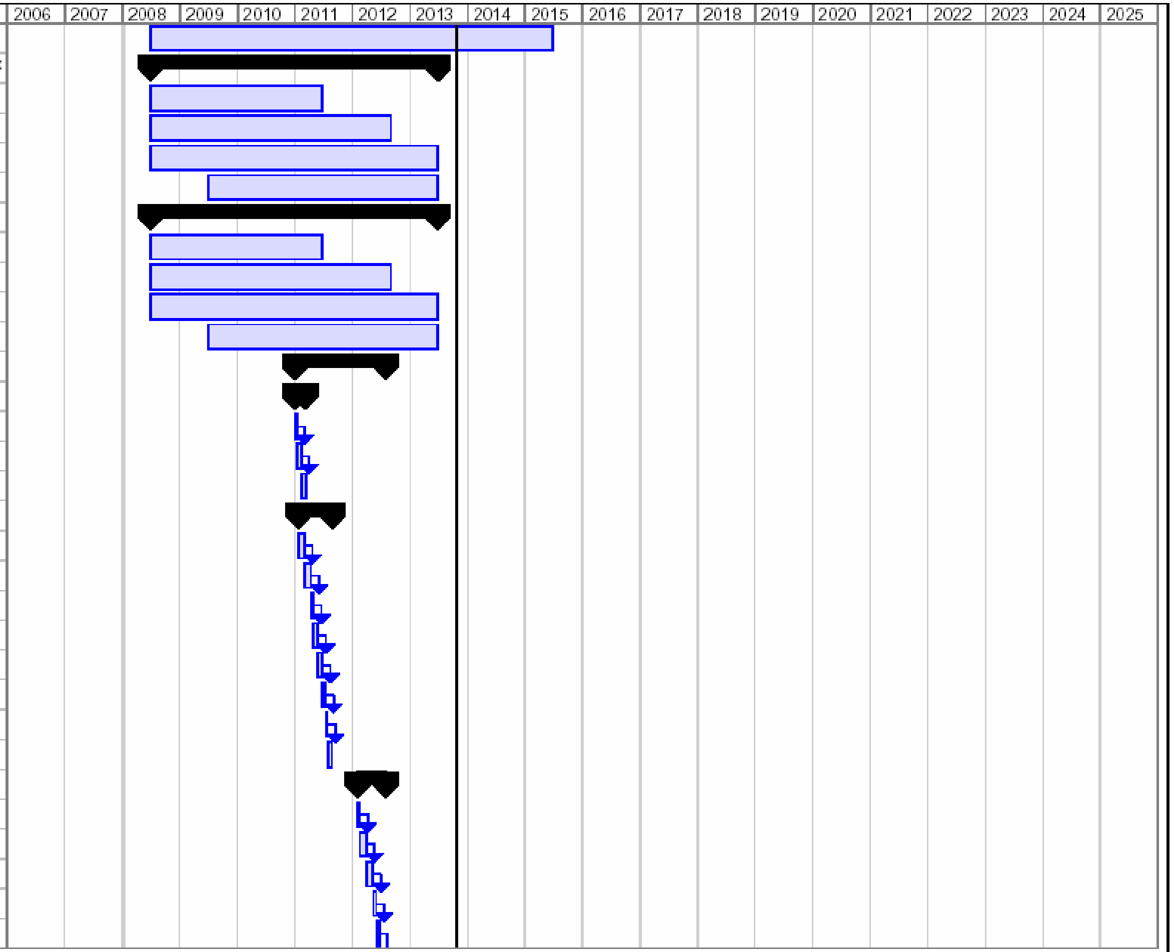


Project: Baseline Project Plan
Date: gio 10/01/08

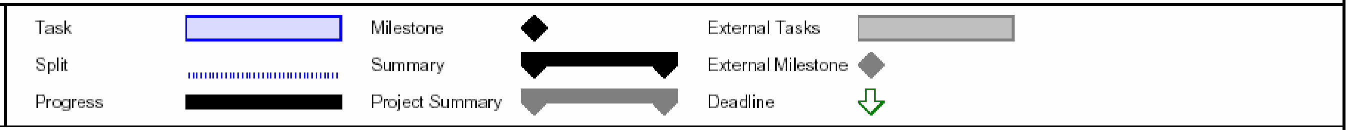


Page 1

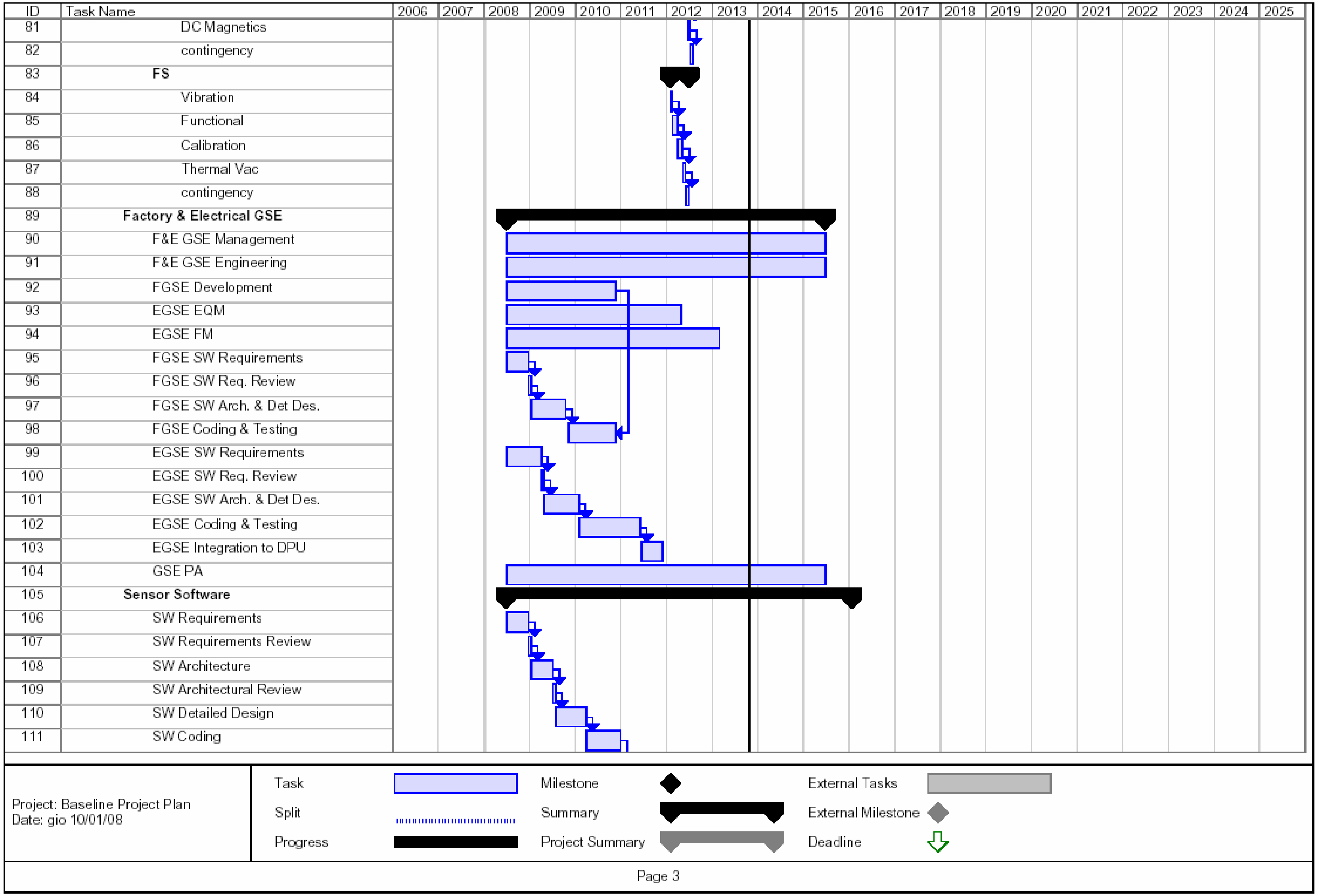
ID	Task Name
50	NSWD Systems Engineering
51	**Mechanical and Thermal design and buil**
52	STM
53	EQM
54	FM
55	FS
56	**Electrical Design and Build**
57	STM
58	EQM
59	FM
60	FS
61	**Integration & Test**
62	**STM**
63	Vibration
64	Thermal Balance
65	contingency
66	**EQM**
67	Functional
68	Calibration
69	Vibration
70	Thermal vac
71	Thermal balance
72	EMC
73	DC Magnetics
74	contingency
75	**FM**
76	Vibration
77	Functional
78	Calibration
79	Thermal Vac
80	EMC



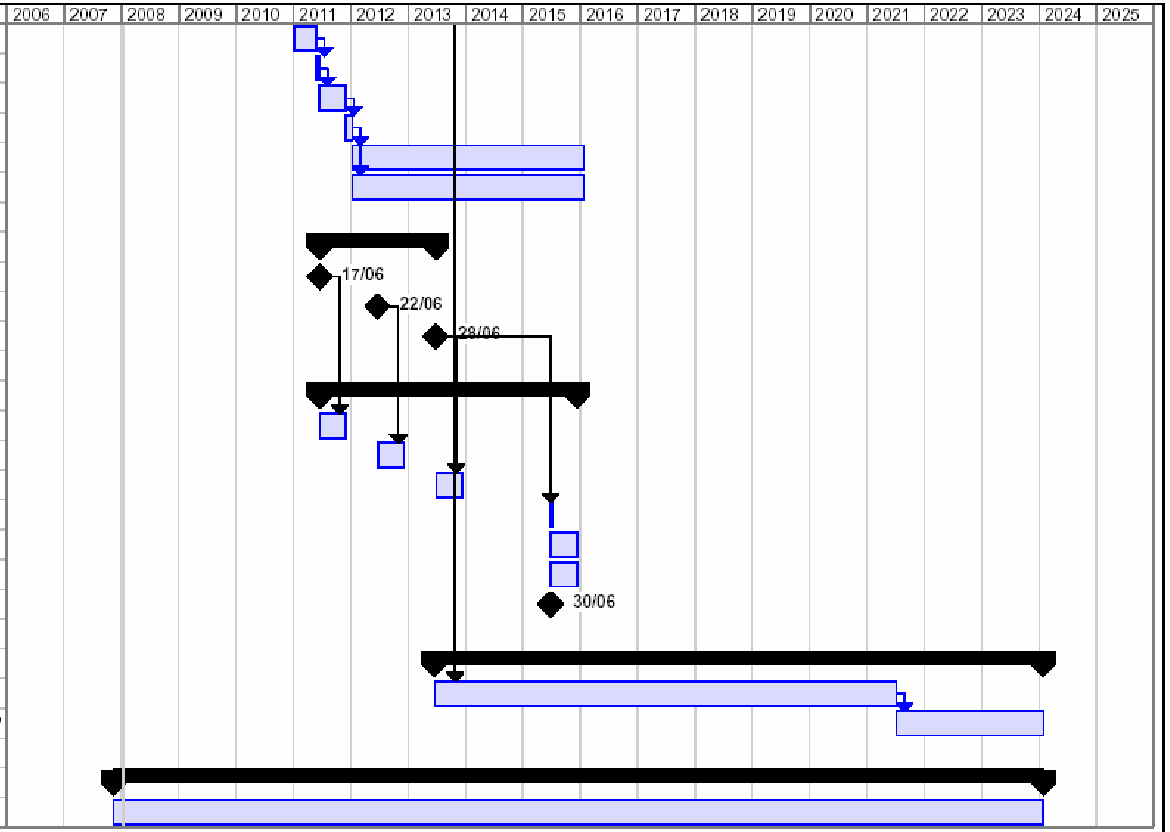
Project: Baseline Project Plan
Date: gio 10/01/08



Page 2


ID
Task Name
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
81 DC Magnetics
82 contingency
83 FS
84 Vibration
85 Functional
86 Calibration
87 Thermal Vac
88 contingency
89 Factory & Electrical GSE
90 F&E GSE Management
91 F&E GSE Engineering
92 FGSE Development
93 EGSE EQM
94 EGSE FM
95 FGSE SW Requirements
96 FGSE SW Req. Review
97 FGSE SW Arch. & Det Des.
98 FGSE Coding & Testing
99 EGSE SW Requirements
100 EGSE SW Req. Review
101 EGSE SW Arch. & Det Des.
102 EGSE Coding & Testing
103 EGSE Integration to DPU
104 GSE PA
105 Sensor Software
106 SW Requirements
107 SW Requirements Review
108 SW Architecture
109 SW Architectural Review
110 SW Detailed Design
111 SW Coding
Project: Baseline Project Plan
Date: gio 10/01/08
Task
Split
Progress
Milestone
Summary
Project Summary
External Tasks
External Milestone
Deadline
Page 3

ID	Task Name
112	SW Testing
113	SW Rediness Review
114	Transfer on Target
115	SW Acceptance
116	Calib&Oper Tab.Maintenance
117	SW Maintenance
118	
119	**6.0 MODEL DELIVERY**
120	STM
121	EQM
122	FM
123	
124	**7.0 Post Delivery Support**
125	Post Delivery STM Support
126	Post Delivery EQM Support
127	Post Delivery FM Support
128	Post Launch Management
129	Post Launch PA
130	Post Launch Engineering
131	Ground Segment Reviews
132	
133	**8.0 Science Ops and Data Analysis**
134	Science Ops and Data Analysis Mission
135	Science Ops and Data Analysis Extended Missio
136	
137	**9. Public Outreach**
138	Public Outreach



Project: Baseline Project Plan Date: gio 10/01/08	Task	Milestone	External Tasks		
	Split	Summary	External Milestone		
	Progress	Project Summary	Deadline		

Page 4

2.3.2.1 Phasing and Milestones

The NSWD development programme is structured under a number of phases. These are shown below.

Phase Name	Start Event	End Event
A-1	Initial Studies and Lab activity	Proposal Submission
A-2/B1	Proposal Submission	ISVR
B	ISVR	IBDR
C	IBDR	IHDR
D	IHDR	Launch

The NSWD review will be held prior to the formal instrument reviews required by ESA.

2.3.2.2 Other Meetings and Reviews

The following Equipment additional events are foreseen:

NSWD Plenary Team Meeting, including foreigners suppliers annual.
NSWD Team Meeting year quarterly
Pre-shipment reviews of major subassemblies for QM/FM/FS
Environmental Test Readiness Reviews for STM/QM/FM/FS
Acceptance reviews for STM/QM/FM/FS

2.3.3 Performance Definition

The scientific and technical plan that forms part of this proposal contains a definition of the expected scientific performance of the instrument. This is translated into requirement specifications on the units and the elements of the NSWD System. The key elements are:

- Particles detectors sensitivity
- Energy resolution
- M/DM resolving power
- Angular resolution
- FOVs / IFOVs

Achievement of these parameters has been actively reviewed during the Phase-A of the programme leading to a final definition of the requirements.

2.3.3.1 Performance Simulation

A key tool in assessing the requirements on the NSWD system are the software simulators developed for the monitoring of the different detector performances. These simulators are available at the sensor unit proposing Institute and they are used to quantify the effects of changing instrument parameters. This software tools will be actively maintained and used during all phases of the programme.

The simulated performance will be maintained as a performance budget and compared with data obtained from the tests of the hardware. Any differences will be made the subject of non-conformances which will be used to update the simulations or to correct the design.

2.3.3.2 Performance Calibration

NSWD Performance Calibration will be the subject of a full calibration programme. This will be done at unit level and at system level.

A full calibration programme will be carried out on the FM at unit level and it will be issued and discussed with the Agency during Phase C. A representative set of calibration procedure will be repeated at system level to produce a proof of right functionality of the entire system without unexpected problems caused by cross interferences between the units.

2.3.3.3 Calibration Database

The output of the calibration programme will be a large calibration database. This will be one of the items supplied to the scientific ESA entity entitled for the science processing of the mission for use in removing the instrument signature from the data.

2.3.3.4 UV rejection

The shutter system for Elena instrument, as defined within the mission BepiColombo, is based on moving Si_3N_4 gratings. Channel's widths of 100nm, inside 1μm thick double-assembled laminas, are indeed able to stop completely the Lyman-alpha line for both the electromagnetic polarizations.
Further involvement of the same instrument for other missions, like SCENARIO proposal for Solar Orbiter, claims for further refinements for a better rejection that has to include the He II line, the most important Sun emission line after the Ly-a.
The important improvements presented here are related to: a) geometrical factors; b) materials engineering; c) further dichroic mirror elements, able to divert neutral atoms and stops completely some specific wavelengths. Computational results are obtained by Finite Element Analysis (by COMSOL®

software running on a Linux double INTEL® XEON® quad-core platform equipped with 18GB RAM). Specifically:

1) The need to reject the 30nm He II line requires a smaller channel width of shutter grating. Because a channel width below 100nm is technologically problematic, a practical solution is the coverage by a suitable layer of Gold at both ends of a grating with 200nm wide channels. Other materials can be used. Rejection reaches at least seven orders (10^{-7}) of magnitude just at the end of the system. Note that the grating output can be represented as a new UV diffracting source. Because the $1/r^2$ decay of the electromagnetic intensity, at 1 cm distance the same radiation is depressed of at least the same factor. **Therefore 10^{-14} rejection can be safely expected at 1 cm back of the gratings**.

2) Multilayer techniques for EUV mirror preparation are now quite common, e.g. for synchrotron radiation experiments as well as for mirror designed for spatial missions. Therefore, critical part for the experiment, like sensors under intense EUV, can be protected by dichroic mirrors. Here, an example is designed to reject the He II line at 45°. The system is computed using a double Mo/Be layer over Silicon, quite a common choice. The Finite Element Analysis allows to fine tune the result. A rejection of 10^{-5} can be reached.

References

Zhanshan Wang et al., "*B4C/Mo/Si high reflectivity multilayer mirror at 30.4 nm*", October 10, 2006 / Vol. 4, No. 10 / CHINESE OPTICS LETTERS 611
David L. Windt, Soizik Donguy, John Seely, and Benjawan Kjornrattanawanich, "*Experimental comparison of extreme-ultraviolet multilayers for solar physics*", 20 March 2004 / Vol. 43, No. 9 / APPLIED OPTICS 1835.

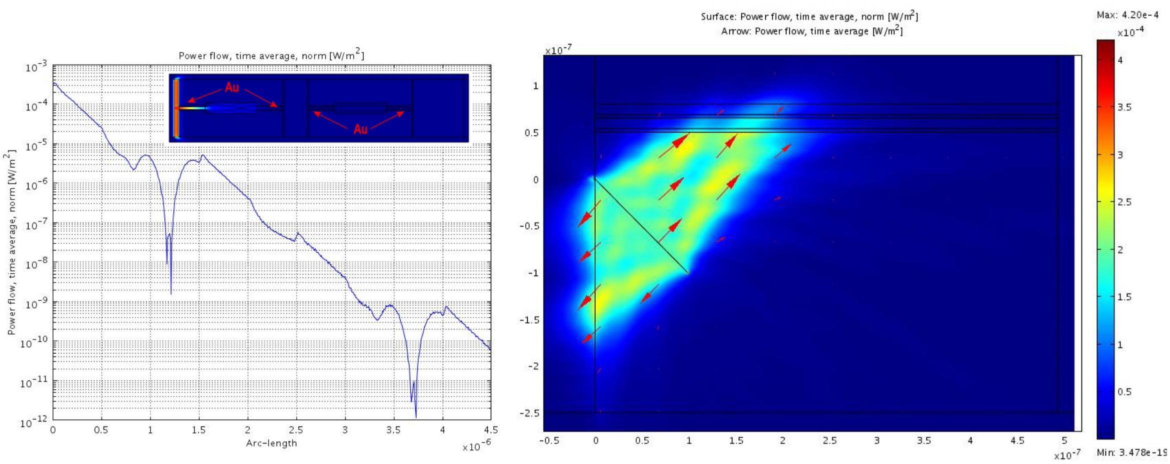


Figure 2.1 Si_3N_4 200nm gratings channel with evaporated Gold at each end (50nm residual diameter), He II line, TM.

2.3.4 Instrument Qualification Approach

The NSWD experiment system is composed by the NSWD experiment itself and its associated ground support equipment (GSE).

Although not deliverable, the NSWD experiment QM shall be used for a full performance test at H/W and S/W levels, under the environmental conditions defined in AD[1] It shall be subjected to a full qualification process, with two exceptions:

- the life test of the NSWD ultrasonic shutter that shall be already performed before starting the integration activities for the QM (see par. 2.4.3.5);
- the EMC tests that shall be reduced, provided the results on the EM are satisfactory.

The NSWD experiment QM will be fully flight representative. It will be composed by the QMs of all its five subsystems. Parts will be space qualified for interfaces with the S/C, while the other electronics components can be MIL-STD-883 B. The active parts are selected to withstand the radiation dose expected at the location of the subsystem, taking into account box thickness and radiation dose margins.

This QM model will be used to derive a Flight Spare (FS) model, after the end of its qualification and test campaign. The FS shall serve to ensure that in case of failure of the FM, a flight H/W is anyhow available. Refurbishment of the QM to become the FS shall thus start soon after the delivery of the FM and in order to have the FS unit available within 6 months after the delivery of the FM.

2.3.5 Derived Model Philosophy

The following NSWD models shall be assembled and subsequently integrated:

- Structural Thermal Model (STM)
- Electrical Model (EM);
- Qualification Model (QM);
- Flight Model (FM);
- Flight Spare (FS) as upgrade of QM

2.3.5.1 STM, Structural Thermal Model

The aim of the STM model programme is:

- To support mechanical and thermal tests of NSWD experiment on the SolO spacecraft
- Qualify the collimator and cover assemblies

- Qualify the detectors head structures

The STM system is mechanically and thermally representative with flight type electrical and mechanical interfaces. The STM thermal coating was only approximated to the flight standard.

2.3.5.2 EM purpose

The NSWD EM shall be fully representative of the flight model, and it will be used in particular to verify the adequacy of the design with respect to the electrical and functional requirements (according to its capabilities), to verify the compliance of its electrical interfaces to the specifications, and to qualify the experiment with respect to the EMC environment. Furthermore, the test programme on the EM will allow debugging of operational and test procedures and of the test S/W before actual use with the flight models. This aspect is extremely important, since it includes validation of high demanding modes.

Compliance of the interfaces with the S/C shall be verified in depth at unit level; a subset of the tests performed shall be repeated also at experiment level. This subset shall include at least verification of the electrical interfaces. The results of the tests performed at unit level, will be used to assess the compliance of the experiment by the "Assessment by Validation of Records" method.

During the EM test campaign, all the tests performed to verify the compliance with the EMC requirements shall be carried out, and the resulting test reports shall be used to partly qualify the NSWD QM by a combination of the "Assessment by Similarity" and "Assessment by Validation of Records" methods.

After successful completion of the test campaign, the NSWD EM with its EGSE will be delivered for EM S/C integration and test activities.

The EM physical dimensions are the same as for the FM. The EM is fully flight representative in terms of electrical I/F and functions, electromagnetic compatibility (EMC), harness and GSE. Internal and external connectors and electronic components will be MIL-STD-883 B grade as a maximum.

The EM will run a complete version of on-board S/W, that will be fully flight representative. All the functions that are relevant with respect to the S/C interfaces will be implemented: switching on/off of whole subsystems, operative mode transitions, and I/O data exchange with the S/C (execution of telecommands and generation of TM and HK data).

2.3.5.3 Qualification Model (QM)

Although not deliverable, the NSWD experiment QM shall be used for a full performance test at H/W and S/W levels, under the environmental conditions defined in AD[1] It shall be subject to a full qualification process, with three exceptions:

- the life test of all the cover mechanisms, that shall be already performed before starting the integration activities for the QM;
- the life test of the NSWD ultrasonic shutter that shall be already performed before starting the integration activities for the QM (see par. 2.4.3.5);
- the EMC tests that shall be reduced, provided the results on the EM are satisfactory.

The NSWD experiment QM will be fully flight representative. It is composed by the QMs of all its five subsystems. Parts grade shall be space qualified for interfaces with the S/C, while the other electronics components can be MIL-STD-883 B. The active parts are selected to withstand the radiation dose expected at the location of the subsystem, taking into account box thickness and radiation dose margins.

2.3.5.4 Flight Model (FM)

The NSWD experiment FM shall comply with all the requirements described in AD[1] and AD[2]. It shall be submitted to the full acceptance test programme, having the goals of verifying that the flight hardware is acceptable for flight and is free of workmanship faults, without overstressing it.

A full calibration program, shall be carried out by the PI, to ensure that the performance requirements of NSWD experiment are met. Results from the QM calibration programme shall be used to determine the extent of the FM calibration programme.

As for the EM and the QM, compliance of the electrical interfaces with the S/C will be verified in depth at subsystem level; a subset of the test performed shall be repeated also at this level. This subset shall include at least verification of the electrical interfaces, and of functional requirements during/after environmental testing at acceptance levels. The results of the tests performed at unit level, but not repeated at system level, will be used to assess the compliance of the experiment by the "Assessment by Validation of Records" method.

After successful acceptance test campaign completion, the NSWD FM shall be delivered, together with its EGSE, for S/C integration and test activities.

Standard FM built is done on the basis of the full qualification of the QM. Parts grade shall be space qualified for external interfaces, while the other electronics components can be MIL-STD-883 B.

2.3.5.5 Flight Spare (FS)

This model is derived from the QM, after the end of its qualification and test campaign. The FS shall serve to ensure that in case of failure of the FM, a flight H/W is anyhow available. Refurbishment of the QM to become the FS shall thus start after FM delivery.

The refurbishment of the QM will cover all the parts whose reliability can be affected by a full environmental testing at qualification level.

A recertification procedure shall demonstrate FS validity for flight; in case that one or more subsystems, already calibrated during the QM AIV activities, should be substituted during refurbishment, an appropriate calibration programme, derived from the one performed on the FM, shall be performed.

As the NSWD FS derives from the QM, it will be fully flight representative. It is composed by the opportunely refurbished QMs of all its three subsystems. FS parts grade shall be space qualified for external interfaces, while the other electronics components can be MIL-STD-883 B.

2.3.6 Criticalities and Recovery Plan

2.3.6.1 Critical Technology

The NSWD package has not major criticality which could put in a risky situation the development plan. However a potentially critical technology has been identified for a secondary mode of operating the instrument. This concerns the implementation of the NSWD shuttering system based on the coupling of an ultrasonic oscillator carrying a payload of nanotechnology manufactured shuttering grids. Top expert both for ultrasonic oscillator development and for grid manufacturing and AIV are participating to this development. Section 2.4.3.5.1 fully details the capabilities and the related development and verification program. By the way, the instrument in a primary operational mode can be operated even with shutter in a locked position

2.3.6.2 Schedule

The criticality identified in par. 2.3.6.1 is already under deep investigation. The developing/qualification programs for those related parts will end at the time of PDR and the achievements will be critically reviewed for a confirmation of the developments. For the general schedule of the program refer to the Management plan of this proposal and the annexed sheet for the master schedule.

2.3.6.3 Development Approach

NSWD sensor unit have been already prototyped at the time of this proposal.

2.3.6.4 Model Representativeness

Refer to par 2.3.5.

2.3.6.5 Backup Development Plan

Remove secondary operational mode which foresees motion actuation of the shutter.

2.3.7 Development Activities

Based on the system specification each of the Industrial Team of reference as in Team Organization Chart is asked to define the requirements on the system and the design solution. These will be reviewed by the system group under NSWD PM leading, but will remain under the full responsibility of the assigned group.

Subsequent detailed Unit or Assembly design, development, manufacture and testing is also the responsibility of the assigned group, reporting via the management structure described in the Management plan.

2.3.8 Software Development

The design and production of on-board software will be managed as part of the development of the units of which it is part. The requirements on the software will be defined as part of the design and development process of each unit and will be defined by the group responsible for that unit.

Requirements arising from other parts of the system will be fed into the unit design by interface documents and system design requirements documents. The requirements of PSS05 will be met as they are appropriate. There will be some level of Consortium organisation of this unit level code, but it will not be allowed to design the design process and escalate costs.

Critical points are foreseen to be:
- scientific computing demand (percentage of software cycle);
- program and data memory dimensioning;
- memory, input/output and interrupts sharing with basic software.

2.3.9 GSE Development

GSE will be dealt with as part of the instrument development. GSE is not a crucial area of the NSWD programme, no development hazards are foreseen.

2.3.10 Assembly and Integration

Manufacture and Test is broken down into several stages:

- Manufacture and testing by assigned sub-contractor.
- Manufacture and testing by IFSI Team.
- Integration.
- Thermal Vacuum and Functional Testing.
- Test Readiness Review (PA activity, verifies that the NSWD is ready for test programme).
- Thermal Vacuum, Thermal Balance, electrical testing where specified.
- Vibrations,
- EMC/EMI
- Full Functional Testing.
- Delivery Review Board (PA activity, demonstrates that the NSWD meets all the requirements).
- Delivery to ESA when required

All the integration activities will take place at the "Tor Vergata" Research Area at the INAF IFSI Facilities. This activity will be differentiated according to the model required to be integrated, and verified at System level before the delivery.

The qualification level activities with the exception of Thermal Vacum tests will be performed with the support of Thales Alenia Space.

2.3.11 Instrument Flight Operations

The guiding principle for NSWD operations is that it should be as simple as possible. A small number of modes are envisaged.
The NSWD has a good flexibility in order to cope with a fixed bandwidth and power budget.

The flight operations plan will be evolved in parallel with the hardware design, under the direct control of the PI group. The state of Flight Operations planning will be reviewed at each of the formal NSWD instrument reviews.

2.4 Verification Plan

The NSWD verification approach has the main goal of assuring the technical performance, safety and reliability of the project itself while keeping the total project costs and schedule under control.

2.4.1 Verification philosophy

The NSWD experiment belongs to the category of new design equipment, but with a strong inheritance on the adopted technical solutions and whose performance shall be fully demonstrated both by qualification and acceptance campaigns.

The verification plan has been designed taking in account the following points:

- EM and QM manufacturing processes shall proceed as much as possible as concurrent activities;
- whenever possible, verification of requirements that lead to long lasting tests at subsystem level (e.g. life test) shall be performed without blocking the AIV activities related to other subsystems;
- calibrations are more easily achieved at sensor unit and sub-system level rather than at experiment level;
- the kind of quantities that shall be measured to verify requirements by testing drives the choice on which level the related tests must be executed (unit, subsystem, experiment);
- early validation of analytical models is preferred.

Qualification and acceptance verifications are accomplished by testing whenever possible, and by assessment according to ESA definitions, as a support or as an alternative when testing is prohibitive or meaningless. Applicable verification levels have been identified:

- at experiment level;
- at sensor level;
- at subsystem level.

2.4.2 Verification methods

The standard ESA methods for verification are used throughout this document.

2.4.2.1 Verification by test:

- Measurement of Physical Properties;
- Electrical Test;
- Functional Test;
- Environmental Test.

2.4.2.2 Verification by assessment:

- Similarity;
- Analysis;
- Review of Design/Inspection;

- Demonstration;
- Validation of records.

2.4.3 Test philosophy

The objectives of the test campaign on the NSWD experiment are:

- confirmation of the functional characteristics of the sensor unit performances;
- verifying that the experiment is capable of surviving the environmental loads foreseen during the mission;
- indication of trend behaviours toward possible wear-out, non conformance and/or failures.

To meet these objectives, the following requirements must be satisfied first:

- use of standardised test configurations and set-ups;
- maximise use of automated test sequences;
- application of classified test procedures;
- use of specifically developed test S/W to allow evaluation, display and storage of both raw data and test results.

Tests will be carried out using the NSWD EGSE; more in detail, tests will be performed using dedicated EGSE Unit Testers and Stimulation/Simulation equipment (not deliverable) at unit level, while at system level they will mostly be accomplished using the NSWD EGSE and the Solar Orbiter Spacecraft Interface Simulator (SIS).

The extent of the functional or performance tests during the integration phase shall be increased according to the integration status of the experiment; after the integration activities, system functional tests will be performed using the same standardised test set-ups and equipment throughout all test phases, in order to ensure the maximum possible repeatability and traceability of all tests.
The experiment check-out equipment will be designed to meet the following requirements:

- limitation of human interaction, to minimise human errors;
- reduction of total check-out time;
- automate repetitive and complex test operations;
- real-time check on all data received from the experiment;
- safe operation.

The experiment check-out equipment features the following functional capabilities:

- allow manual application of input stimuli and/or simuli to the whole experiment or its subsystems;
- provide support for unit level testing and calibration;

- allow execution, both in interactive and in deferred mode, of test cases, either single or as a sequence;
- allow storage and retrieval of test results;
- allow storage and displaying of raw, processed and calibration data from the instrument, both in real time and in deferred mode;
- Allow management of NSWD on-board S/W configuration.

2.4.3.1 Qualification testing

Qualification testing consists in a series of functional and environmental tests having the purpose of demonstrating that the flight configured H/W (and, when applicable, S/W) will function within performance specifications under simulated conditions more severe than those expected from ground handling, launch and orbital operations. Deficiencies in design and/or workmanship are discovered with these tests; they are not intended to introduce unrealistic modes of failure or to exceed design safety margins.

2.4.3.2 Acceptance testing

Acceptance testing consists in a series of functional and environmental tests having the purpose of demonstrating that the flight configured H/W (and, when applicable, S/W) is acceptable for flight and that it performs satisfactorily at conditions equal to design specifications. It shall also serve as a quality control screen to detect deficiencies not uncovered by qualification tests.

2.4.3.3 Recertification testing

The recertification shall certify that modified/repaired units are acceptable for flight. It is applicable for any unit which has been disassembled from the spacecraft after the system environmental testing is refurbished in any way and then reintegrated to the flight spacecraft. The recertification is a limited acceptance certification and serves also as a quality control.

2.4.3.4 Verifications at Model level

The instrument is composed by one sensor unit. Verification by test will be the principle method of verification. That includes mechanical, thermal vacuum, and EMC tests:

Activity	TM[1]	STM	EM	FM	QM/FS	Responsible
Calibrations	A	N/A	N/A	A	A	PI
Visual Inspection	N/A	A	A	A	A	PI
Dimension verification	N/A	A	A	A	A	PI
Physical Properties	N/A	A	A	A	A	PI

Functional Test	A	N/A	A	A	A	PI
Low Level Sine	N/A	A	N/A	A	A	PI + Thales Alenia Space
Strength Test	N/A	TBD	N/A	TBD	N/A	TBD
Shock	N/A	TBD	N/A	TBD	N/A	TBD
Sine Vibrations	N/A	Q	N/A	AC	Q	PI + Thales Alenia Space
Low Level Sine	N/A	A	N/A	A	A	PI + Thales Alenia Space
Random Vibrations	N/A	Q	N/A	AC	Q	PI + Thales Alenia Space
Low Level Sine	N/A	A	N/A	A	A	PI + Thales Alenia Space
Functional Test	N/A	N/A	N/A	A	A	PI
Acoustic Noise	N/A	N/A	N/A	N/A	N/A	N/A
Functional Test	N/A	N/A	N/A	A	A	PI
TVAC	Q	N/A	Q	Q	Q	PI
Functional Test	A	N/A	A	A	A	PI
Grounding / Bonding / Isolation	N/A	A[2]	A	A	A	PI
EMC Conducted Emissions / Susceptibility	N/A	N/A	A	AC	Q	PI + Thales Alenia Space
EMC Radiated Emissions / Susceptibility	N/A	N/A	A	AC	Q	PI + Thales Alenia Space
DC Magnetic Properties	N/A	N/A	A	AC	Q	PI + Thales Alenia Space
Purging Rate Verification	N/A	N/A	N/A	N/A	N/A	N/A
Visual Inspection	N/A	A	A	A	A	PI

Table 2.4-1 The NSWD Sensor units verification matrix

[1] – non deliverable item
[2] – electrical board only
N/A - not applicable, *A* – applicable, *Q* – qualification, *AC* – acceptance

2.4.3.5 Specific Verifications at sub-system level

2.4.3.5.1 NSWD Ultrasonic shutter

To meet the requirements of the NSWD ultrasonic shuttering and the environmental conditions, we could use the UPD60 from CEDRAT TECHOLOGIES SA as ultrasonic generator, which uses the same concept that the UPA25 currently produced by the same firm. The UPD60 generator is not yet a standard product and has been developed and tested for a piezomotor, in the frame of an ESA funded Technology Research Program. In that frame, the UPD60 generator has been already evaluated.

2.4.3.5.1.1 NSWD Team qualified experience on piezo actuator 'payloads'

The experience at ISM-CNR (S. Selci) for piezomotors allows an optimal design, testing and qualification of the shuttering system. At the same time, the

Electron Beam Lithography facilities at IFN-CNR (S. Leoni, M. G. Castellano) allow the practical realization of the nano-grids.

In order to warrant against aging because of the high frequency motion of those small parts it is needed to realize special protection of surfaces. Diamond-like carbon (DLC) has been established as the best possible treatment. The various test benches and techniques for surface and covering characterization will be shown in the following with some details.

2.4.3.5.1.1.1 CONTROL METHODS AND FACILITIES FOR NANO-GRIDS ASSEMBLY.

There is availability of many non-contact techniques that are able to qualify the overall assembly working conditions as well to check the surface status of different components to understand thickness of protections coatings, wear, defects, just to cite few properties.

2.4.3.5.1.1.1.1 Laser scanning optical bench

An optical bench uses a diode laser, mechanical and piezoelectric general purpose translation tables, and optical detectors to perform many types of measurements.

In fact, with the same apparatus it is possible to perform quantitative optical modulation (e.g., to monitor very small movements of motors and other parts), scattering imaging (e.g., to qualify the roughness of surfaces), and many other useful techniques. Examples of uses will be given below for practical applications within this project.

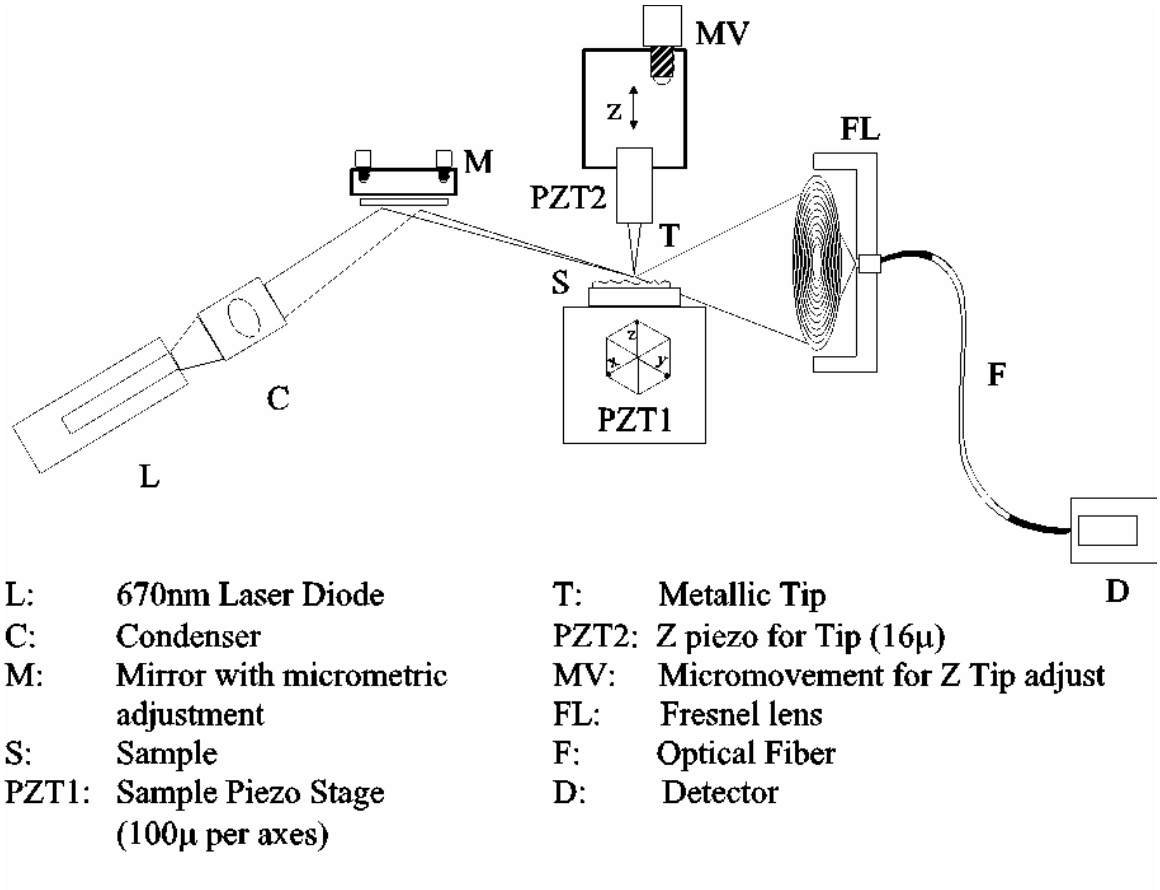


Figure 2.1. View of the optical test bench

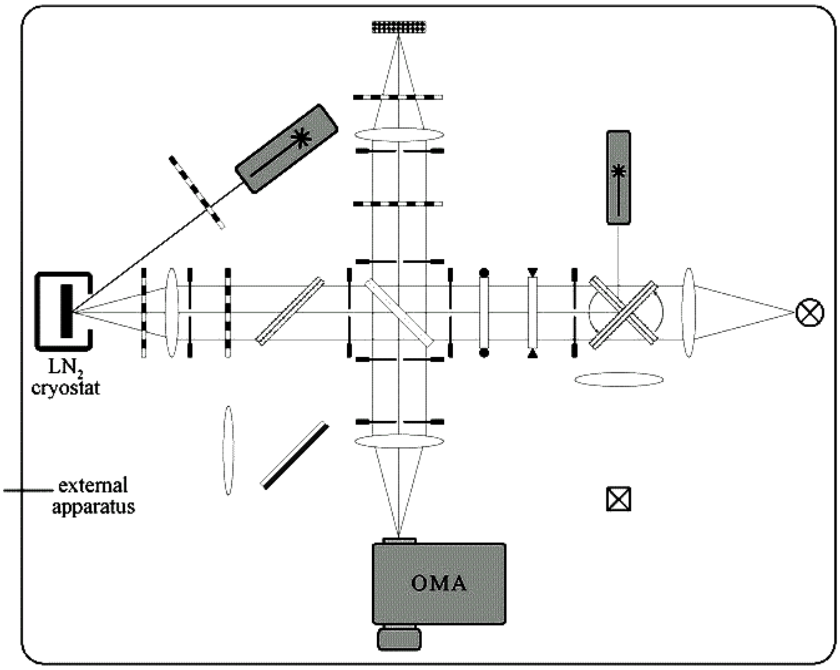


Figure 2.2. View of the optical layout for Reflectivity in the VIS and NIR range

2.4.3.5.1.1.1.2 Optical setup for Reflectivity measurements

Reflectivity in the VIS and NIR range can be used to accurately measure the thickness and the quality of coatings. For instance, making a comparison before and after tests, it is possible to understand wear processes suffered by protective layers. The optical layout is similar to a Michelson-Morley interferometer, and allows very precise relative reflectance measurements between the surfaces to be measured and some reference mirror. The entire optical spectrum can be measured with high accuracy and without moving parts using an Optical Multichannel Array (OMA), made by an array of 1024 Silicon diodes. If the alignment of the sample to be measured is careful reproduced (creating some laser reference signature, for instance) also the absolute reflectivity can be evaluated.

Moreover, a model is needed to decode from Reflectivity measurements thickness and properties of coating layers. Abelés matrix method can be used to analyze layer optical properties. This method defines a characteristic matrix for each discrete layer so that for the *m*th layer the corresponding matrix is:

$$c_m = \begin{bmatrix} \cos(\beta_m) & \left(-i/q_m\right)\sin(\beta_m) \\ -iq_m \sin(\beta_m) & \cos(\beta_m) \end{bmatrix}$$

where $q_m = n_m \sin(\vartheta_m)$ and $\beta_m = (2\pi/\lambda) n_m d_m \sin(\vartheta_m)$, with *d* the thickness of the *m*th layer of index of refraction (eventually complex) *n*, given the angle of incidence θ and the wavelength λ. Once matrices for each individual layer have been calculated, an overall sample matrix M is defined as the product of the individual matrices, so that for a sample with m layers the resultant matrix is defined as:

$$M = \prod_0^m c_m = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}$$

The reflectivity is then simply related to the matrix elements from M by the relationship:

$$r = \frac{(M_{11} + M_{12} q_{m+1}) q_0 - (M_{21} + M_2) q_{m+1}}{(M_{11} + M_{12} q_{m+1}) q_0 + (M_{21} + M_2) q_{m+1}}$$

where m+1 denotes the substrate and 0 the air. Moreover, when the protection layer is examined at an optical region when it is non absorbing, interference effects lead to rapid oscillations of reflectivity. Maxima visible in the resulting spectrum are related to the thickness *d* and the refraction index *n* of the layer by: $d(\mu m) = 0.62/n \Delta E(eV)$. Combining with the above equation for reflectivity, a very precise determination of film properties can results.

2.4.3.5.1.1.1.3 Scanning Probe Microscopy

The ultimate tool for surface analysis is the use of Scanning Tunnelling Microscopy (STM), the first available Scanning probe since its foundation by the famous group of Binning and Rohrer, who obtained the Nobel Prize in 1986 for their invention. At the CNR ISM site resides the first Italian group to have realized a homemade instrument and then contributed greatly to its diffusion in Italy. Whenever a detailed view of the surface is needed, it is necessary to measure the surface roughness down to sub-nanometers range. For this purpose, STM allows a detailed 3D map of the surface. Below, an example of the map resolution obtained with this technique is given.

2.4.3.5.1.1.2 DLC Nano-Grids coating for hardening and friction surface control.

There have recently been very important advances in the science of carbon such as the development of the chemical vapour deposition of diamond and the discovery of C_{60} and carbon nanotubes: there have been parallel developments in the field of disordered carbons. In particular, diamond-like carbon (DLC) is a

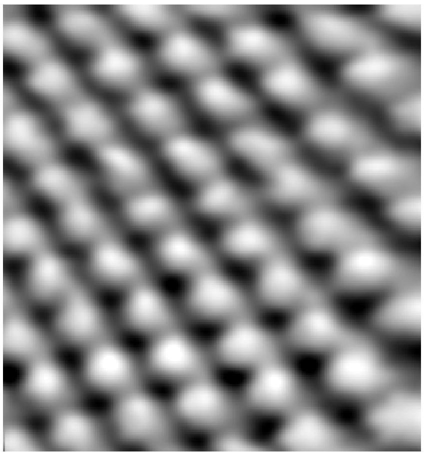


Figure 2.3. 20Å X 20Å X 8Å graphite STM image (by A.Gnoli, S. Selci, ISM-CNR, unpublished).

metastable form of amorphous carbon containing a significant fraction of sp^3 bonds. It is a wide band gap semiconductor with a high mechanical hardness, chemical inertness, optical transparency. DLC films have widespread applications as protective coatings in areas such as optical windows, magnetic storage disks, car parts, biomedical coatings and as micro-electromechanical devices (MEMs).

Carbon forms a great variety of crystalline and disordered structures because it is able to exist in three hybridisations, sp sp^2 and $sp^{3.}$ The extreme physical properties of diamond derive from its strong, directional σ bonds. Diamond has a wide 5.5 eV band gap, the largest bulk modulus of any solid, the highest atom density, the largest room temperature thermal conductivity, smallest thermal expansion coefficient, and largest limiting electron and hole velocities of any semiconductor. Graphite has strong intra-layer σ bonding and weak Van der Waals bonding between its layers. A single graphite plane is a zero band gap semiconductor, and in three dimensions it is an anisotropic metal.

The sp^3 bonding of DLC confers on it many of the beneficial properties of diamond itself, such as its mechanical hardness, elastic modulus, chemical and electrochemical inertness, and wide band gap. DLC consists not only of the amorphous carbons (a-C) but also of the hydrogenated alloys, a-C:H. It is much cheaper to produce than diamond itself. The ta-C (tetrahedral amorphous carbon) films are being studied for possible use in MEMs instead of polysilicon, mainly because ta-C is the hardest material known after diamond itself. A great advantage of DLC compared to CVD polycrystalline diamond is that it is amorphous with no grain boundaries. This means the films are extremely smooth. This has great advantages for many applications. A comparison table is reported below for some relevant parameters.

Material	***Vickers Hardness (kgf/mm2)***	***Thermal Conductivity □W/mK)***	***Friction Coefficient***
Diamond	7000-10000	900-2000	0.05-1
DLC	1000-2000	40	0.1-0.2
TiN	1500-2200	20	0.6-0.8

DLC is also deposited at room temperature, which is an advantage for temperature sensitive substrates such as plastic. DLC films also have extremely good coverage, so they act as good corrosion barriers. This is particularly useful in a major application, which is to coat disks and recording heads in the magnetic storage technology.

In this project, DLC coating will be used to protect the grid surfaces, realizing a calibrated spacing between the frame and active parts of the neutral atom spectrometers. In this way, protection of the moveable parts will be coupled to a substantial reduction of wear. Extensive tests will be used to evaluate in quantitative way duration of the surfaces for aging under prolonged use, as required by the mission.

2.4.3.5.1.1.2.1 Coating quality assessment.

The surface quality of Si/SiN of the first substrates prototype specifically developed for NSWD and DLC treated has been practically qualified using three independent methods:

a) Direct inspection by optical microscopy and CCD camera, for low resolution direct imaging;
b) Laser optical scattering with CCD sensing, for high resolution, integrated

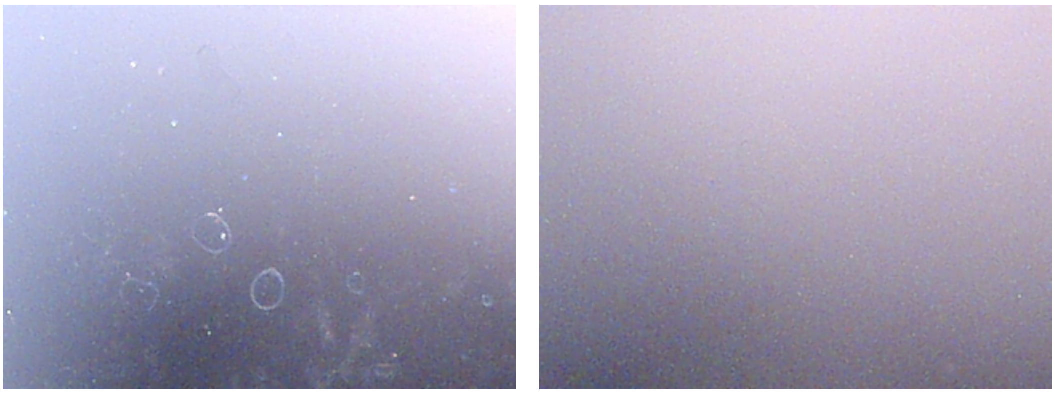


Figure 2.4. Optical Microscopy images, about 1mm X 0.75mm wide. On left the surface appears to be not perfectly clean, with solvents drops, while on the right the same surface appear to be perfectly clean after adequate treatment.Laser Optical Scattering.

information on the whole surface roughness;

c) Normal incidence VIS-NIR Reflectivity. By direct evaluation of interferential fringes (NIR) and entire optical spectrum, sure identification of protective layer (DLC) thickness and quality can be measured and compared at different test phases.

2.4.3.5.1.1.2.2 Direct inspection by optical microscopy

Below are optical images as recorded by the PC connected, QX3-Intel optical microscope, at 200X magnification, of the Si substrates used to realize the grids, just before to perform the tests on the surface duration.

Using the apparatus described above, scattering images have been recorded for the Si surfaces compared with reference mirrors for calibration purposes.

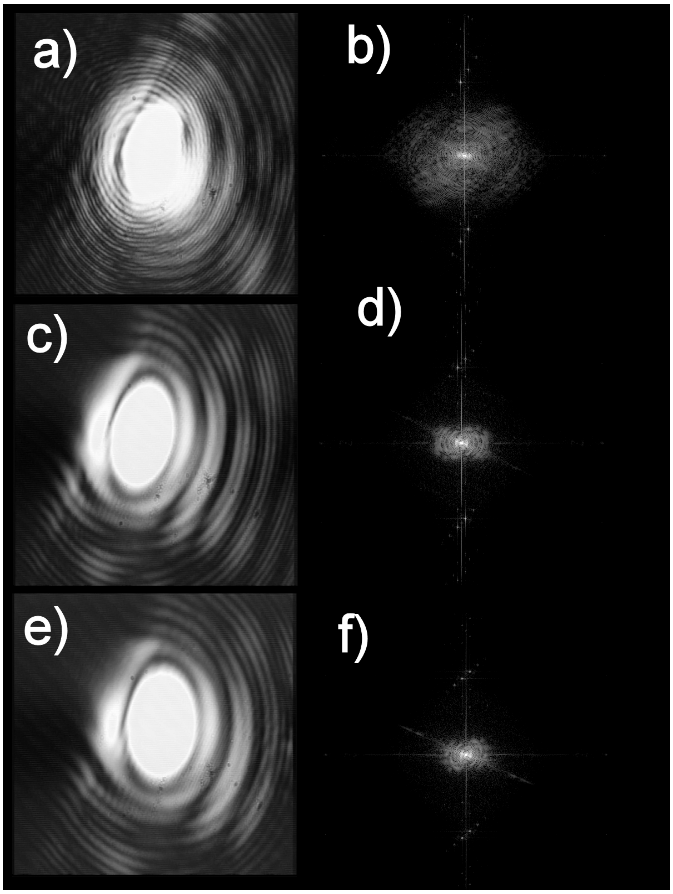


Figure 2.5. On the left, scattering images: a) aluminum covered glass (sample mirror); c) Thorlabs $\lambda/10$ mirror; e) Si substrate used for grids. On the right, Fourier transform of scattering showing the angular distribution: in b) the bad mirror shows much wider components than the good mirror in d), but the Silicon surface, in f), is also better than the $\lambda/10$ reference mirror.

In fact, the scattered intensity can be expressed by the following equation:

$$\frac{1}{I_0}\frac{dI_s}{d\omega_s}d\omega_s \propto 4k^4\cos(\theta_0)^2\cos(\theta_s)^2 W(p,q)\,d\omega_s$$

where *W(p, q)* is the power spectral density (PSD) of the surface roughness. This last quantity is related to the Fourier transform of the correlation function *C(R)* of the height probability distribution:

$$C(R)=\frac{\langle h(r)h(r+R)\rangle_s}{\sigma^2}$$

and things are defined in such a way that:

$$\langle h(r)\rangle_s=\int_{-\infty}^{\infty} hp(h)\,dh=0$$

being *p(h)* the height statistical distribution.
Therefore, the Fourier transform of the scattering spectrum reproduce directly the correlation function *C(R)*: the faster it goes to zero, the lesser is the content of sample roughness on the large scale and it can be considered flat.

2.4.3.5.1.1.2.3 Normal incidence VIS-NIR Reflectivity

As seen before, Reflectivity in the VIS and NIR range can be used to accurately measure the thickness and the quality of coatings.

Here, we show actual measurements of the DLC covered Si substrates. The normal incidence optical spectra are shown below, together with a simulated one.

The method allows accurately measuring the thickness of the layer as well as the optical constants (dielectric function) of DLC, because only the simultaneous determination of all parameters is able to reproduce the experimental results. The preliminary comparison between the theoretical curve and the experimental data shows the DLC thickness of 3.0μ and an index of refraction n_{DLC} of 2.05, with an overall accuracy of the order of 1%. After the tests for DLC duration, will be easy to measure again the thickness and n_{DLC} (that is roughly proportional to the presence of voids) in order to understand the superficial wear. A complete theoretical treatment will be completed and used during the whole program.

2.5 Assessment Plan

2.5.1 Crucial Parameters Definition

All the declared parameters in the sheet summary table are crucial being concerning angular resolution, covered dynamics, sensitivity. All this parameters presently achieved by instrument modelling will be cross verified and monitored throughout the whole programme until in-flight verification. Planned testing activity described in par. 2.4.3 and calibration activity described here after will be aimed to the achievements of the declared performances.

2.5.2 Calibration Approach

The sensor unit will be calibrated at Pi local facilities. This activity will be performed at the local class 100.000 clean room facilities of the "AREA di Ricerca di Tor Vergata" (Rome) in which a 1000 liters Ultra High Vacuum camera is equipped with a 0.1 – 5 keV ion beam source.

The calibration activity is organised to know the performances of the instrument, to verify the capabilities with respect to the specifications and mission objectives.

An high accuracy ion beam facility is available in Bern already used for these purposes on many space program (e.g. Cluster / Cis and Equator-S Esic for which A. M. Di Lellis is Co-Is for both experiments).

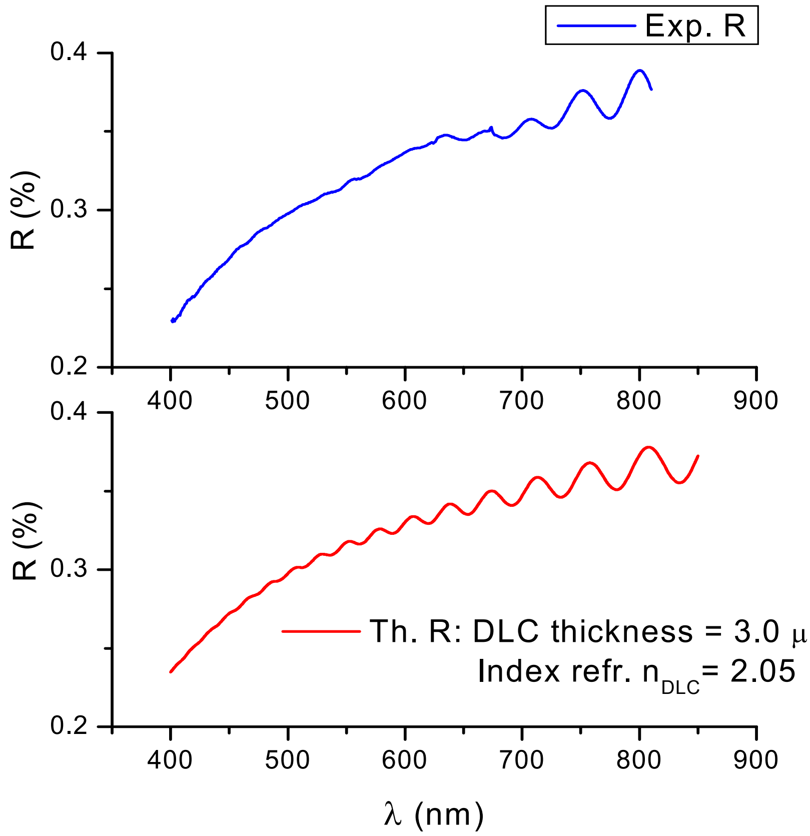


Figure 2.6. Preliminary evaluation of normal incidence Reflectivity spectrum**.**

2.5.2.1 NSWD Calibration approach

The NSWD instrument test plan foresees

- *Modular test*
- *Assembled instrument test*

The NSWD suite will be calibrated in its three peculiar objectives: capability of analysing the direction, the energy and the mass of the neutral atoms. The angular resolution has to be tested with a rotating platform allocated into the vacuum chamber. The instrument can be rotated with respect to the ENA beam at several angles and a set of measurements will be developed to test the capability of analysing different directions of the incoming particles. The energy of the beam will be varied from few eV up to 5 keV and different masses have to be used to calibrate the Time of Flight system. These kind of test will be performed in the ENEA facility (see hereafter) The same kind of tests will be repeated at the University of Bern with an ion beam. The NSWD modular test

The modular test consists of calibration of the several parts of the instrument.

- The ToF system is realised with START consisting in an ultrasonic oscillating choppers and mechanical gratings (for the stop a MCP detectors is used). A preliminary test is necessary for the hi-frequency mechanical oscillator and the hi-resolution grating, in particular to verify the stability and performance in time of this START module.
- MCP detector for the Stop and Position detection.
- Its efficiency at low energy and the discrete anode reading of the impinging position of the particles will be peculiar for the instrument to acquire the Stop of the particle an the incoming direction. Also the capability to distinguish the mass with its pulse-height will be verified.

2.5.2.1.1 The NSWD unit test

The instrument has to be verified in its functionality with all the modules assembled. Also two problems will be considered and tested: the UV counts and the environment ions entering in the instrument:

- UV rejection capability achieved with a grating has to be tested. A UV source is necessary to generate the photons fluxes and verify the transmission efficiency of this grating.
- Also the Ion rejection has to be tested. Deflection plates are used to remove the ions from the neutral direction in the NSWD instrument and this test is achievable with ion source at the ENEA and also at University of Bern in a vacuum chamber at the requested conditions.

After verification of its performances, the unit is brought to the University of Bern for final calibration.

2.5.3 Dedicated Facilities

The available facilities are listed in the following Sections

2.5.3.1 ENA Calibration Facility

2.5.3.1.1 General Description

A facility providing a beam of Energetic Neutral Atoms is allocated in the ENEA Research Centre of Frascati in Rome-Italy (Figure 2.7). The Scientific Technical Unit of Fusion at the FTU (Frascati Tokamak Upgrade) has realized this equipment to test and calibrate Energetic Neutral Atoms Analyser finalised to the plasma temperature study. During the last years a collaboration with the IFSI/CNR was started with the goal to realize an ENA instrument for the study of ENA generation in planetary environments.

The facility allows to generate an energetic neutral atoms beam of different energies and species. The interaction between ENA and the examining systems is possible in a dedicated vacuum chamber.

The laboratory equipment consists of an ion source generating an ion beam selected in mass by a cylindrical magnet. A post acceleration and focalization of the beam is possible with a system of electrostatic lenses. Then a neutralization cell allows realizing an energetic neutral beam. At the end of this chain a dedicated vacuum chamber is allocated with the characteristics adapted to the different experiments. In Figure 2.8 a scheme of the system is showed..

Figure 2.7. ENA laboratory at the ENEA research centre

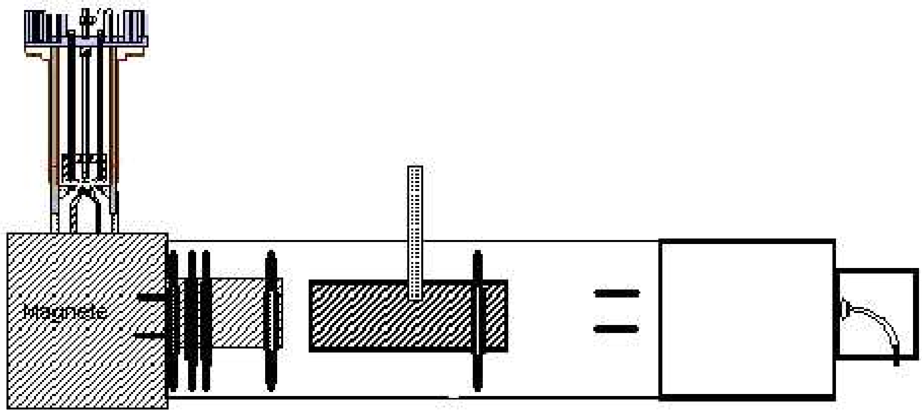


Figure 2.8. ENA source scheme.

2.5.3.1.1.1 Ion source

The ENA facility uses a filament ion source to produce its ion beam. The material of the filament is tantalum and a current I_f = 0-30 Ampere is achievable.

In the chamber a neutral is inserted to be ionised: the species available at the moment are Hydrogen, Deuterium or Helium. A discharge tension Vs between filament and the chamber is applied up to 200V to realize the electron emission able to ionise the gas. Then the generated ions are extracted with HV up to 10kV in the vertical direction. A picture of the ion source camera is showed in Figure 2.10 and the schematic of the system in Figure 2.11.

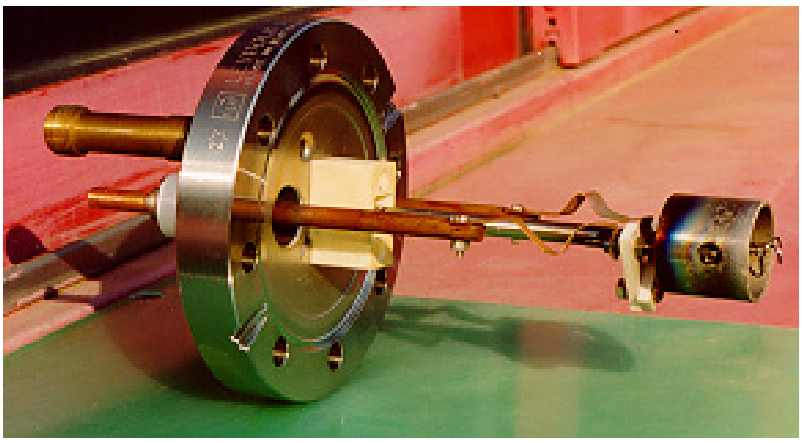
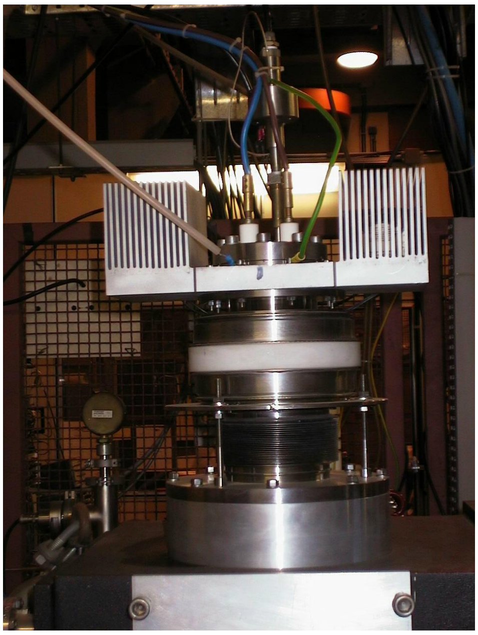


Figure 2.9. ENEA beam source



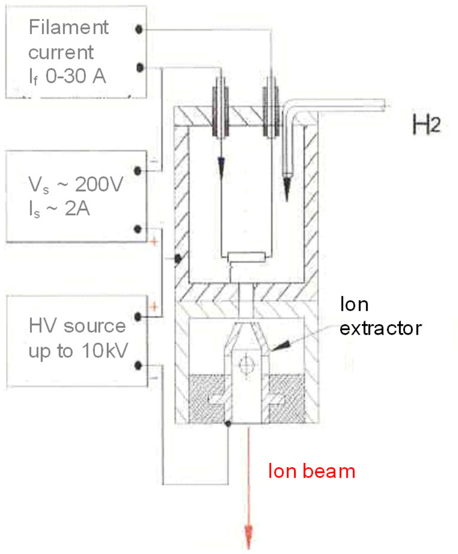


Figure 2.10. Ion source at ENEA

Figure 2.11. Schematic of Ion source

2.5.3.1.1.2 Magnet sector

The beam species are selected in momentum with a cylindrical magnet capable of selecting the different masses coming from the source (i.e. H+, H2+, H3+ for Hydrogen) using a magnetic field that can range from 0 to 2,5kgauss (Figure 2.12).

The magnet also turns the beam in the horizontal plane and its direction could be optimised by two electrostatic plate.

Figure 2.12. Magnet sector

2.5.3.1.1.3 Electrostatic lenses Accelerator neutralisation cell

A system of electrostatic lenses is used to focalise or de-focalise the beam. In this sector there is also the possibility to accelerate the beam up to 100keV.

In the same chamber the neutralization cell is allocated (Figures 2.13, 2.14). It is used to have a charge-exchange process between the ion beam and the gas. The neutral gas is injected in the cell and the energetic ions become Energetic Neutral Atoms. So this phenomenon produces a beam of neutral atoms with a part of residual ions that are deflected by a couple of electrostatic plates after this chamber (Figure 2.15).

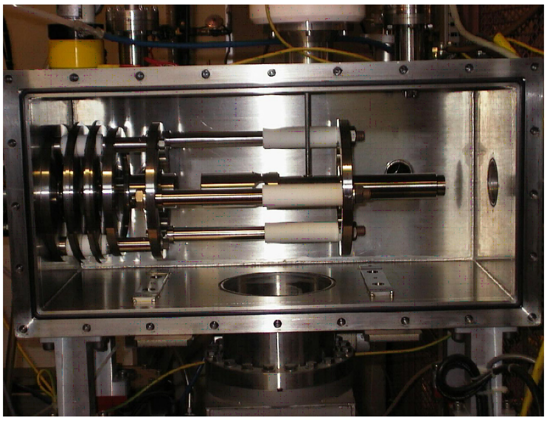


Figure 2.13. Electrostatic lenses-accelerator- neutralisation cell

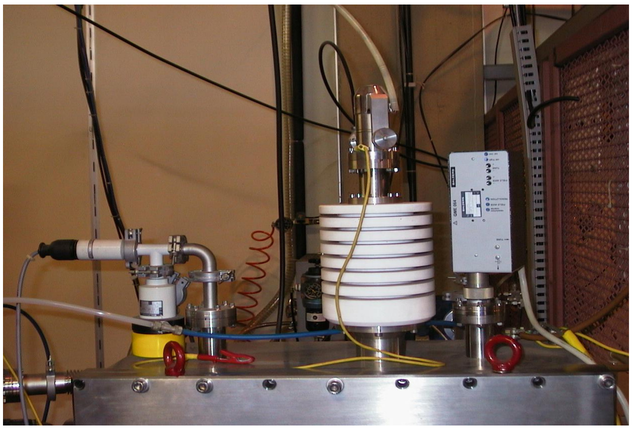


Figure 2.14. Neutral gas injector

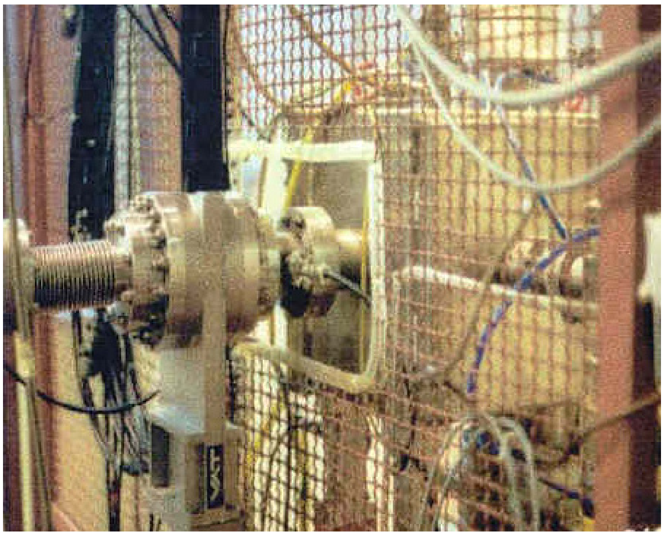


Figure 2.15. Deflection plate to suppress the residual ions in the ENA beam.

Facility carachteristics

Energy range	300eV-110keV
ION SOURCE	
filament	tantalum
If	0-30A
Is	0-2A
Vs	200V
HV	0.3-10kV
species	H - He - D
MASS SELECTION	
Magnet	0-2.5 kGauss
ACCELERATOR	
V accel.	0-100 kV
FOCALIZATION	
electrostatic lenses	
NEUTRALIZATION	
charge exchange	neutralization cell
IONS SUPPRESSION	
deflection plates	

Table **ENA facility characteristics**

2.6 Cleanliness and contamination control

2.6.1 Introduction

This section describes the cleanliness levels, controls and facilities needed for the programme. A detailed Contamination Control Plan (CCP) will be written identifying the requirements for cleanliness and the controls that shall be applied to achieve them. A brief summary follows.

2.6.2 Levels

ESA PSS-01-201 guidelines will be followed to ensure the required cleanliness levels are achieved and maintained throughout the Manufacture, Assembly, Integration and Verification (MAIV) phases. No cleanliness control will be provided for mechanical workshop machining operations. Optical components and mechanical items shall be cleaned before and during final assembly. Mechanical hardware will be assembled and handled in class 1000 (ISO class 6) environments or better. Additional cleanliness controls shall be implemented for assembly of the mechanisms. Final assembly of flight hardware will be conducted in a cleanroom, which is designated Fed Std class 100 (ISO class 5).

At delivery the NSWD will be verified to the following levels:

- Internal surface cleanliness levels:
- Molecular: _ 5.0 x 10-7 g/cm2 (TBC)
- Particulate: _ 50ppm (TBC)
- External surface cleanliness levels
- Molecular: _ 5.0 x 10-7 g/cm2 (TBC)
- Particulate: _ 150ppm (TBC)

2.6.3 Facilities

Test facilities for optical testing and vacuum testing shall be maintained to meet project requirements. External test facilities will be evaluated for compliance with requirements prior to use. Facilities shall be provided to control the environmental cleanliness of instrument flight hardware during assembly, integration and test phases. Facilities designated as clean will be monitored on a regular basis for particulate and molecular contaminates.

2.6.4 Materials

Materials shall be selected from ESA and NASA approved lists and processed in such a way as to minimize contamination. All materials shall be screened to either ECSS-Q-70-02 or ASTM-E595-93. Additional tests shall be conducted on materials that have surface areas greater than 1000cm2 to ASTM-E1559 or ESA VBQC. A Declared Materials List (DML) cataloguing the name of each material used in the design, where it will be used and how much will be used shall be maintained. In addition, a Declared Processes List (DPL) will be maintained, tracking each of the processes involved in the production of the instrument. All materials shall meet or exceed the following outgassing criteria:

- TML _ 1.0% (TBC)
- CVCM _ 0.1% (TBC)

All components will be required to undergo vacuum bake-out at piece part, sub assembly and system assembly levels. Residual Gas Analysers or TQCM shall be used to monitor outgassing levels and decay rates during vacuum bakeout. If this is not possible then materials shall be vacuum baked on elapsed time basis. As a general rule:

- Metallic materials: 100°C for 48 hours (TBC)
- Non metallic materials: 80°C for 72 hours (TBC)

For materials with lower working temperatures than 80°C, bake out durations shall be increased by 24 hours (TBC) for every 10°C drop in temperature.