D3S Aurora Oval Monitoring Mission Study Executive Summary

Aurora Oval Monitoring Mission

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TABLE OF CONTENTS

List Of Figures

List Of Tables

1. INTRODUCTION

This document provides the executive summary for the Auroral Oval Monitoring Mission Reorientation Phase A for ESA's Distributed Space Weather Sensor System (D3S). The full final report is provided in [RD1].

1.1 SCOPE OF STUDY

This Auroral Oval Monitoring (AOM) Phase A study was a reorientation after the previous Phase AB1, [AD4], with a simplified payload prioritizing auroral observation and a complete redesign of the mission.

The first part of the study was to update the mission architecture with an affordable, sustainable, and scalable solution resulting in a Mission Definition Review (MDR). For evaluation of the payload, the payload module prime from the previous Phase AB1, Thales Alenia Space UK (TAS-UK) was strengthened with a group of end-user advisors from UK Met Office and FMI will advise the consortium directly on the choice of orbit, instruments and help with the commercialization analysis.

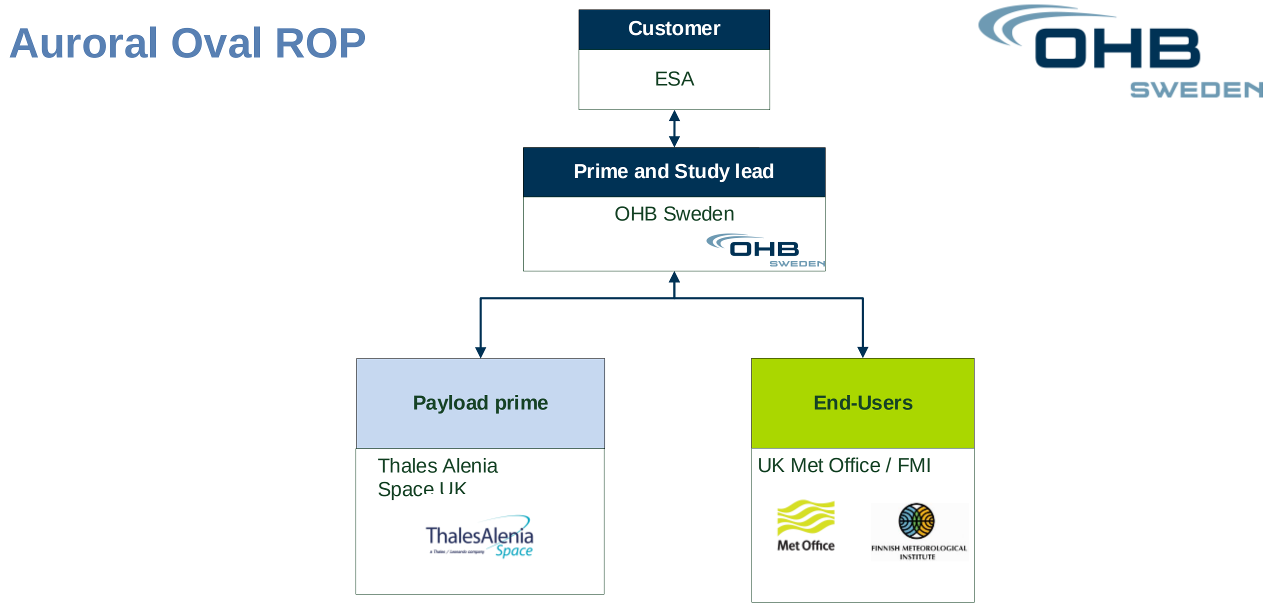

Figure 1-1: AOM industrial consortium

The second part of the study was to show feasibility resulting in a Preliminary Requirements Review (PRR).

The work logic from [AD3] is shown in Figure 1-2.

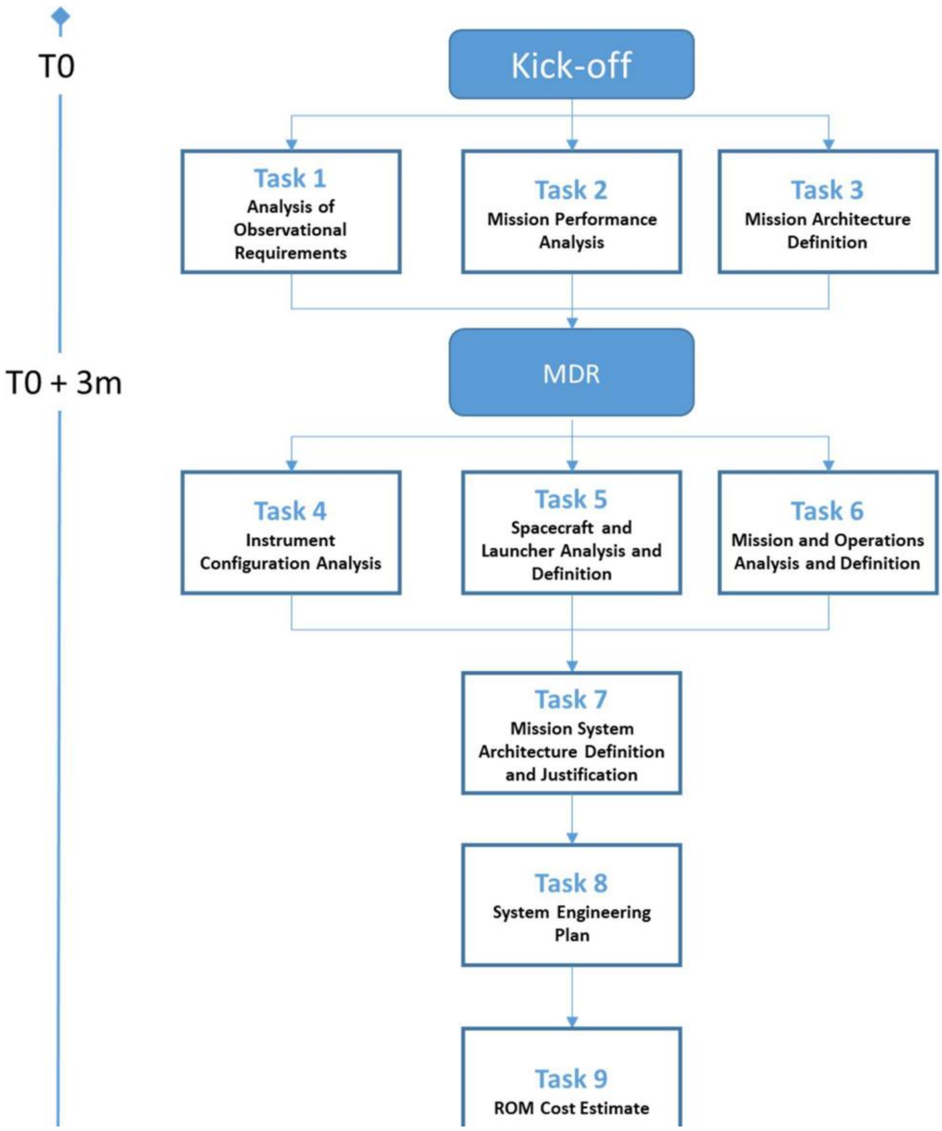

Figure 1-2: Work logic

Funding for Phases BCD was secured at CMIN22+ and Phase B1 starts in Q4 2023.

2. APPLICABLE AND REFERENCE DOCUMENTS

2.1 APPLICABLE DOCUMENTS

This document shall be read in conjunction with documents listed hereafter, which form part of this document to the extent specified herein. In case of a conflict between any provisions of this document and the provisions of the documents listed hereafter, the content of the contractually higher document shall be considered as superseding.

AD	Doc. Ref.	Issue	Title
[AD1]	ESA-S2P-SWE-RS-0008	01	AURORA MISSION REQUIREMENTS DOCUMENT
[AD2]	ESA-S2P-SWE-RS-0002	1	AURORAL OVAL MONITORING MISSION SYSTEM REQUIREMENTS DOCUMENT
[AD3]	ESA-S2P-SWE-SOW-0013	1	STATEMENT OF WORK AURORAL OVAL MONITORING MISSION REORIENTATION PHASE A
[AD4]	SWS-OSE-RP-0960	1	D3S Space Weather Smallsat Mission Study Final Report

Table 2-1: Applicable Documents

2.2 REFERENCE DOCUMENTS

The following documents contain supporting information and are referenced to throughout this document.

RD	Doc. Ref	Issue	Title
[RD1]	AOM-OSE-RP-1531	1	D3S Aurora Oval Monitoring Mission Study Final Report
[RD2]	AOM-OSE-RP-1109	4	Mission Analysis and System Performance Assessment
[RD3]	ESA-S2P-SWE-RS-0001	1	Distributed Space Weather Sensor System (D3S) Architecture and Observational Requirements Document (AORD)
[RD4]	AOM-OSE-RP-1122	2	Analysis of Mission Requirements and Payload Baseline Definition
[RD5]	AOM-OSE-VCD-0040	1	VCD to System Requirements
[RD6]	AOM-OSE-TN-1111	5	Mission Description Document
[RD7]	AOM-OSE-RP-1123	3	Radiation Analysis

Table 2-2: Reference Documents

3. ABBREVIATIONS AND DEFINITIONS

3.1 ACRONYMS AND ABBREVIATIONS

The list in [RD1] contains the general acronyms and abbreviations for this project. Additional, more specific abbreviations are listed in Table 3-1 of this document.

Acronyms and Abbreviations	

Table 3-1: Acronyms and Abbreviations List

3.2 DEFINITIONS

The list in [RD1] contains the general definitions for this project. Additional, more specific definitions are listed in Table 3-2 of this document.

Definitions	
AOM	Auroral Oval Monitoring mission
D3S	Distributed Space Weather Sensor System

Table 3-2: Definition List

4. PAYLOAD ANALYSIS

The Aurora reorientation phase explored the impacts of raising the operative orbit altitude on the payloads, in particular, the in-situ observational measurements in [RD4]. The analysis was carried out by TAS-UK to validate the selection of the secondary payload, in co-operation with subject matter experts from the UK Met Office and the Finnish Meterological Institute, as well as ESA and OHB Sweden.

Figure 4-1 shows the final recommended requirements prioritisation and associated instruments needed to deliver them for the baselined Scenario B with a 6500km circular orbit.

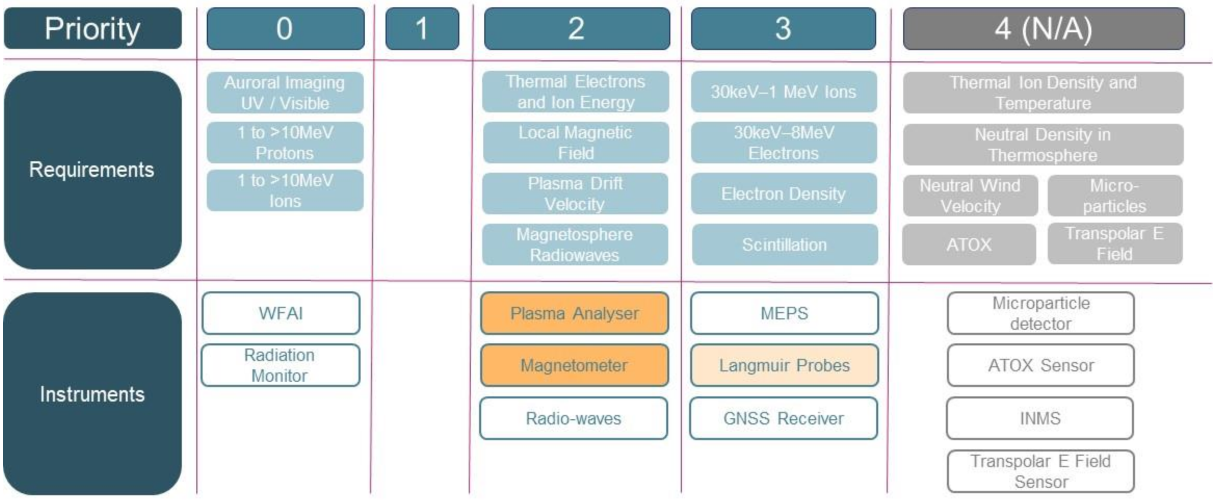

Figure 4-1: Requirement Prioritisation and instrument selection for the baseline orbit (Scenario B)

5. MISSION REQUIREMENTS

Mission analysis requirements have been extracted from Aurora Mission System Requirements [AD2] and Aurora Mission Requirements [AD1] and are presented in Table 5-1. "SRD-AUR-OBS-nnn" relates to [AD2]. Compliance statements refer to Circular Polar Orbit with Altitude 6500 km. Compliance justification is provided in [RD2]. The VCD [RD5] contains compliance statements with close-out references where possible for all requirements in [AD2].

Requirement	Text	Compliance	OHB Note
SRD-AUR-OBS-0020	The System shall observe during the Routine Phase the entire auroral oval over the North Pole (North and South) with a global average revisit time of less than 10 minutes.	C	Compliant considering an 60°x60° instrument with IFOV of 1 mrad.
SRD-AUR-OBS-0025	The System shall observe during the Routine Phase the entire auroral oval over the North Pole (North and South) with a global maximum revisit time of less than 45 minutes	C	Compliant considering 60°x60° instrument with IFOV of 1 mrad.
SRD-AUR-OBS-0030 / [AUR-007]	The System shall provide images of the entire auroral oval with a refresh rate of 20 (15) minutes (TBC).	C	Compliant considering 60°x60° instrument with IFOV of 1 mrad. Assuming 95% refreshed data of the entire AO required according to SRD-AUR-OBS-0065. Assuming AUI cadence of 3 minutes or less according to SRD-AUR-OBS-0140 Assumed worst case: 3 minutes cadence (2 min integration + 1 min wait) + max revisit time for 95% AO.

SRD-AUR-OBS-0080 / [AUR-010]	The spatial sampling distance of the Auroral Optical Spectral Imager shall be no more than 30 km for the NADIR viewing condition and less than 100 km for the complete nominal AO. Note: The spatial resolution of the optical imagers is considered as about twice the spatial sampling distance (SSD).	C	AOSI SSD Nadir = 26 km STK limit SSD < 100 km
SRD-AUR-OBS-0065	For the refreshed image of the entire Auroral Oval, the percentage of refreshed data of the samples shall be at least 95% (TBC).		See SRD-AUR-OBS-0030
SRD-AUR-OBS-0140 [AUR-008]	The Auroral Ultraviolet Imager shall provide image stacks of the AO with a cadence of 3 minutes or less.		See SRD-AUR-OBS-0030
SRD-AUR-OBS-0150 / [AUR-010]	The spatial sampling distance of the Auroral Ultraviolet Imager shall no more than 30 km for the NADIR viewing condition and less than 100 km for the complete nominal AO. Note: The spatial resolution of the optical imagers is considered as about twice the spatial sampling distance (SSD).	C	AUI SSD Nadir = 6.5 km
SRD-AUR-OBS-0520	The latency of the data of the samples that compose the image of the entire Auroral Oval shall be <15 minutes	C	Compliant considering 60°x60° instrument with IFOV of 1 mrad, 95% refreshed data of the entire AO and 1 minute instrument wait time after integration
SRD-AUR-OPS-0080	The System shall be designed to support the launch in any day of the year.	C	

Table 5-1: Mission requirements extract

6. MISSION ARCHITECTURE

6.1 BASELINE ORBIT

The orbit configuration consists of a constellation of four satellites in circular polar orbit in same plane at 6500 km altitude, each one separated by 90° in argument of latitude, see Table 6-1 and Figure 6-1. Orbit duration is typically 4 hours 2 minutes.

	Altitude (km)	Semi-Major Axis (km)	Inclination (˚)	Eccentricity	Argument of Latitude (˚)
AOM_000	6500.0	12878.1	90	0	0
AOM_090					90
AOM_180					180
AOM_270					270

Table 6-1: True of Date Classical Orbital Parameters Circular Polar Orbit 6500 km Altitude at Epoch 20 Mar 2024 12:00:00.000 UTCG

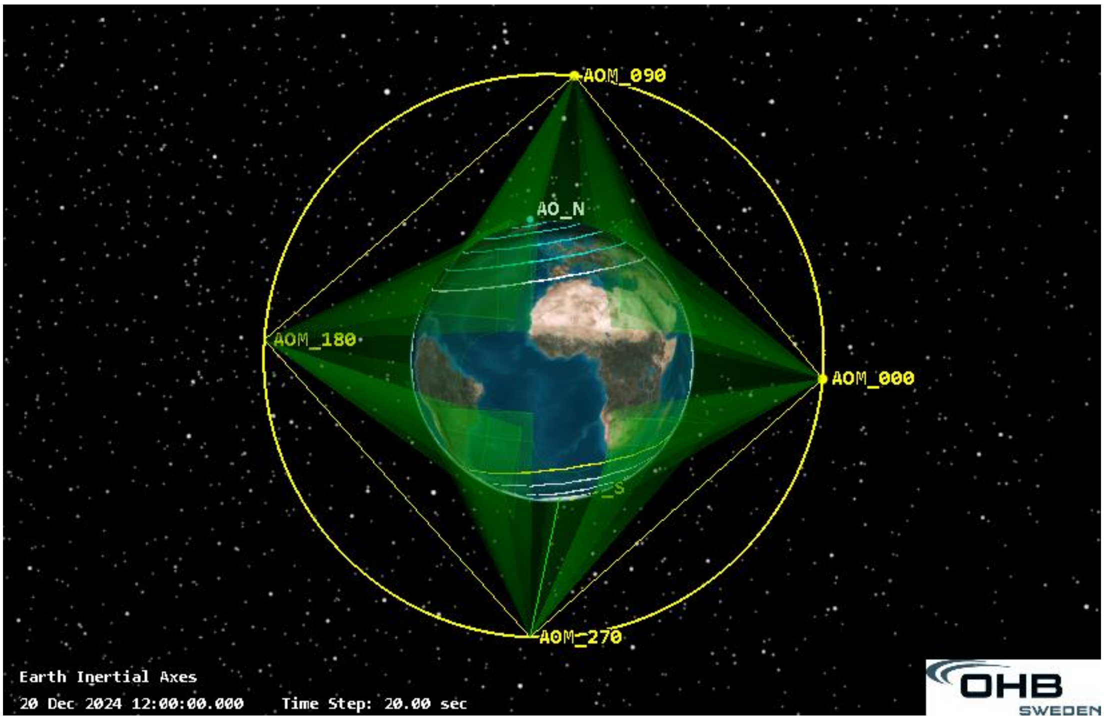

Figure 6-1: Satellites in Circular Polar Orbit at 6500 km Altitude with Nadir pointing instruments.

Other orbits considered in the study were 7000km circular and 350x2500km. See [RD2].

6.2 REFRESH RATE

SRD-AUR-OBS-0030 requires the system to provide images of the entire auroral oval with a refresh rate of 20 (15) minutes (TBC). Refresh rate is one of the key requirements for the feasibility of the operational Aurora constellation. The estimated refresh rate is derived from the revisit time and instrument cadence below.

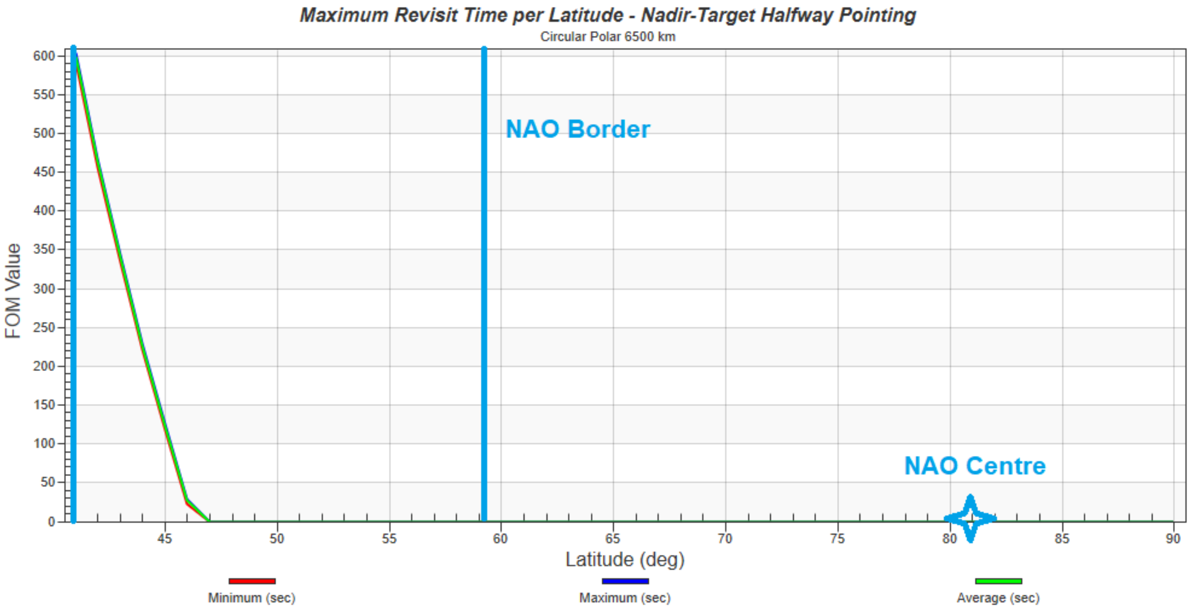

Figure 6-2: Maximum Revisit Time by Latitude of NAO Geomagnetic Latitude 50° for Satellites at 6500 km Altitude. Note that the “Minimum”, “Maximum” and “Average” curves relate to the statistics of the grid points at each latitude

The Maximum Revisit Time was also deduced for 95% of the NAO area, to determine if any sensor gaps would affect requirement SRD-AUR-OBS-0065, see Table 6-2.

IFOV	Geomagnetic Latitude Range	AO Range From Geo-magnetic Centre	Maximum Revisit Time (s)		
			Minimum	Maximum	Average
1 mrad	51.1°	38.9°	0.0 s	459.36 s	10.04 s
			0.0 min	7.7 min	0.17 min
4 mrad			0.0 s	2376.8 s	327.0 s
			0.0 min	40.0 min	5.5 min

Table 6-2: Maximum Revisit Time Statistics for 95% of the NAO over four (4) days for Satellites at 6500 km Altitude

Following is assumed as input for determining the AO data refresh rate:

- 95% refreshed data (see SRD-AUR-OBS-0065) of the entire AO is assumed sufficient as input for determining the refresh rate. Reducing the AO area to 95% gives approximately 7.7 min maximum revisit time.

- AUI Cadence of 3 minutes, whereof 2 minutes instrument integration time and 1 minute wait time

The refresh rate for 95% of the AO will therefore be < 11 minutes, well within SRD-AUR-OBS-0030 requirement of 20 (15) minutes.

6.3 SPACE DEBRIS MITIGATION

Specifically for the Aurora-D mission in Phase A, a Space Sustainability Rating has been obtained. The resulting score of Silver is considered high for this early phase and can be attributed to the expected high level of information sharing and the inherently low collision risk in the chosen MEO orbit.

For the general case of the Aurora-C constellation, at end of mission, the satellite will disconnect the Solar Array from the battery and deplete the remaining energy stored in the battery to limit the chance of internal breakup. The high-level end of life sequence is as follows:

- Transfer to graveyard
- Propulsion system passivation (detailed below)
- Battery passivation (detailed below)
- Confirm 0A is generated at all channels
- RF passivation

Finally, during the battery depletion the satellite will shut down automatically.

7. SPACECRAFT DESIGN CONFIGURATION

The Aurora spacecraft design reuses equipment from flying or soon to be flying InnoSat platforms, such as the Arctic Weather Satellite (AWS). Thus, by definition, the units TRL will be 9.

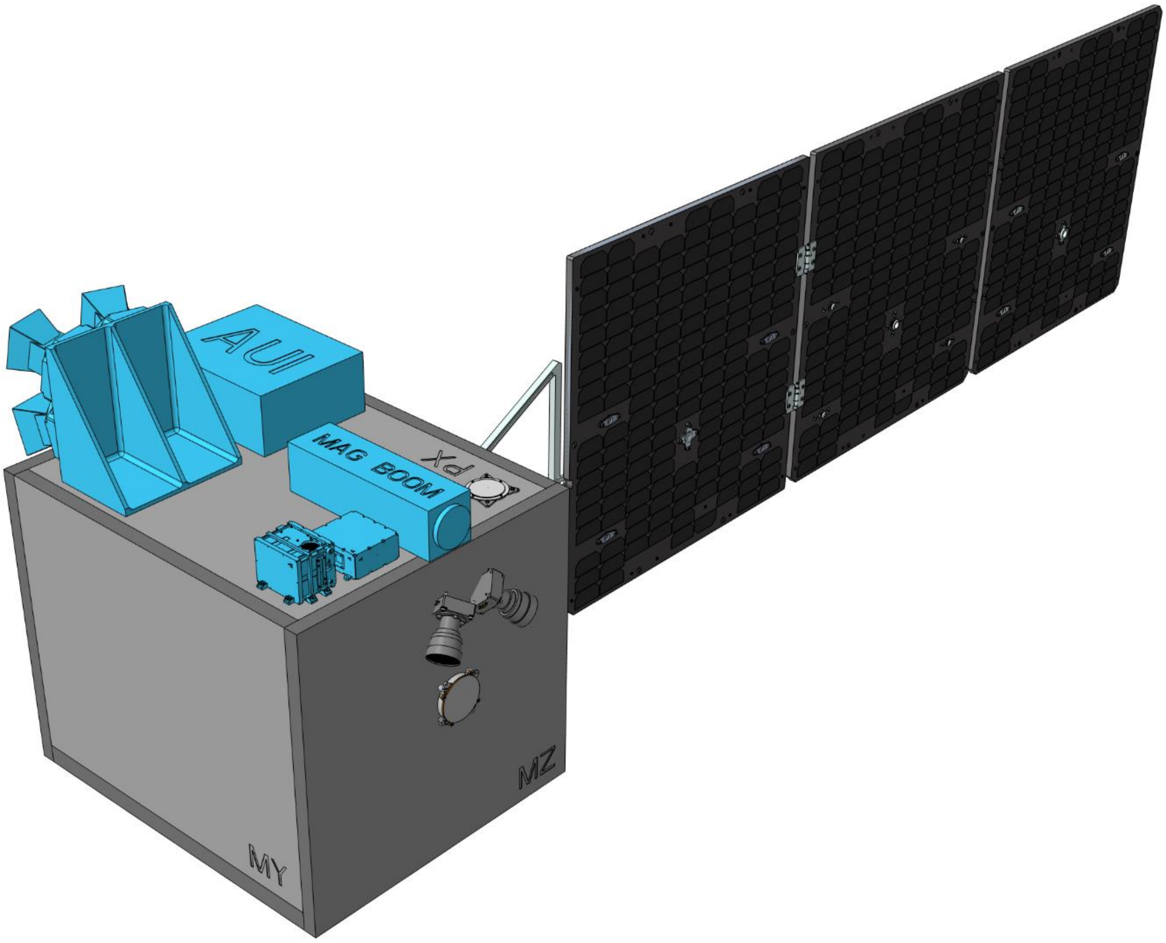

Figure 7-1: OHB Sweden Spacecraft Design Configuration

7.1 PAYLOAD ACCOMMODATION

As seen in Figure 7-1, the instruments are accommodated on the top panel of the spacecraft as individual equipment. There is no need for a separate Payload Module (PLM). Note that the CDPUs for AOSI and AUI are intended to be inside the spacecraft for sake of radiation shielding and then on the underside of the top panel. This also eases integration and test of the instruments.

The thermal decoupling required by some of the instruments will be achieved by means of insulating components for heat conduction and MLI covers for radiation.

A radiator is expected to be needed for the AOSI mounted on the AOSI bracket looking in the MY direction in the Spacecraft Body frame (SCB).

Instruments	Accommodation	Mechanical/Thermal/Radiation
AOSI, 4 sensor modules	Looking Nadir, PZ in SCB	Radiator mounted on AOSI bracket looking in MY in SCB. Thermal and mechanical decoupling to be achieved by means of insulating mounting feet and blades.
AOSI CDPU	Mounted underneath top panel inside spacecraft	Shielded by S/C
AUI, 2 sensor modules	Looking Nadir, PZ in SCB	Thermal and mechanical decoupling
AUI CDPU	Mounted underneath top panel inside spacecraft	Shielded by S/C
RadMag EU and radiation sensor 1	Looking in PX in SCB	Thermal decoupling TBC Mounted externally
RadMag radiation sensor 2 (and 3 TBC)	TBC separate units mounted orthogonally to radiation sensor 1	Thermal decoupling TBC
RadMag magnetometers and boom	At root and end of boom Boom deploys in MZ in SCB	

Table 7-1: Instrument accommodation

7.2 RADIATION ANALYSIS

The full radiation analysis with FastRad results is given in [RD7]. Spacecraft panels with only 4mm of equivalent Aluminium was shown to be sufficient. More radiation tolerant options in the standard InnoSat equipment catalogue have been chosen for Aurora.

8. CONCLUSION

The result of this study is a feasible mission and platform architecture for the Aurora Constellation (Aurora-C) for ESA's Distributed Space Weather Sensor System (D3S) that is a compromise between the platform limitations and the scientific goals to achieve a competitive overall cost.