CROSS SCALE

PAYLOAD DEFINITION DOCUMENT

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1 INTRODUCTION

This Payload Definition Document (PDD) is a compilation of the Cross Scale strawman payload requirements and of their related reference design. The PDD plays a key role in defining the resources required by the Cross Scale instruments and in providing the information necessary to conduct the mission assessment study and the preliminary spacecraft design.

The strawman payload described in this document originates from the scientific objectives of the Cross Scale mission as spelled out in the associated Scientific Requirements Document [AD 1]. In fact, each instrument addresses a part of the scientific goals of the mission with associated performance requirements.

Information on the strawman payload has been provided by selected experts of the Shocks, Turbulence and Reconnection Payload Working Groups (PLWG) of the Cross Scale SST. Additional information was incorporated based on the information received after a Call for Instrument Concepts for the Cross Scale mission was issued to the Cross Scale science community. All these provided inputs have led to the compilation of this PDD.

The descriptions of the instruments in the PDD shall be considered as general descriptions of a certain type of instrument. The final instrument selection for a Cross Scale mission will take place after a future Payload Announcement of Opportunity in 2009/2010. Therefore the instruments in the current PDD should not be taken as the final composition of the Cross Scale payload.

1.1 Changes since Cosmic Vision 2015-2025 Cross Scale proposal

Following the Cross Scale Cosmic Vision 2015-2025 proposal and the completion of the ESA Cross Scale CDF study, PDD v1 is a key reference document in support of the ITT release of the Assessment Studies to be performed by industry through two parallel contracts.

2 ACRONYMS

AC	Alternating Current
ADC	Analog to Digital Converter
AIV	Assembly, Integration and Verification
AO	Announcement of Opportunity
AOCS	Attitude and Orbit Control System
ASIC	Application Specific Integrated Circuit
BMI	Boom Mounted Instruments
BOL	Beginning of Life
CAN	Controller Area Network
CPPS	Centralized Payload Power Supply
CRB	Contamination Review Board
CSA	Charge Sensitive Amplifier
DAC	Digital to Analog Converter
DC	Direct Current
DPU	Digital Processing Unit
DSP	Digital Signal Processor
EAS	Electron Analyzer Sensor
EMC	Electromagnetic Cleanliness/compatibility
EMCB	Electromagnetic Cleanliness Board

EMI	Electromagnetic Interference
EOL	End of Life
EPD	Energetic Particle Detector
EPT	Electron and Proton Telescope
FFT	Fast Fourier Transform
FEE	Front End Electronics
FIFO	First In First Out
FPGA	Field Programmable Array
HGA	High Gain Antenna
HIS	Heavy Ion Sensor
H/W	Hardware
ICU	Instrument Control Unit
I/O	Input/Output
LEOP	Launch and Early Orbit Phase
LOS	Line Of Sight
MAG	Magnetometer
MCP	Micro Channel Plate
MLI	Multi Layer Insulation
PA	Product Assurance
PDD	Payload Definition Document
PDMU	Payload Data Management Unit
PMT	Photo Multiplier Tube
PZT	Piezo-Electric Transducer
RAM	Random Access Memory
RPE	Relative Pointing Error
RTC	Remote Terminal Controller
S/C	Spacecraft
SciRD	Scientific Requirements Document
SDT	Cross Scale Science Definition Team
SpW	Space Wire
SS	Solid state
SSMM	Solid State Mass Memory
SWT	Science Working Team
TBC	To Be Confirmed
TBD	To Be Determined
TC/TM	Tele-command / Telemetry
TDA	Technology Development Activity
TDP	Technology Development Plan
TOF	Time-Of-Flight

3 LIST OF TABLES AND FIGURES

4 APPLICABLE DOCUMENTS AND REFERENCE DOCUMENTS

4.1 Applicable Documents

[AD 1]	**Cross-Scale Science Requirements Document, [SCI-SM-2007-11-CPE], Document providing Science objectives and science requirements, including measurement specifications**
[AD 2]	**Cross-Scale Mission Requirements Document [SCI-PA/2007-020], Document providing the mission statement**
[AD 3]	**Not Applicable**
[AD 4]	**CDF Model Input Specification Issue 3 rev 1, Ref: CDF-IFS-001, and associated Excel workbooks 'Mission Input Issue 3 rev 1.xls' and 'data exchange.xls'**
[AD 5]	**"Margin Philosophy for SCI-PA Studies," [SCI-PA/2007-022]**
[AD 6]	**Cross-Scale Environmental Specification [SCI-PA/2007-021]**
[AD 7]	**ESOC WP510 Cross-Scale Mission Analysis Global Orbit Properties, Issue 1.0**
[AD 8]	**ESOC WP511 Cross-Scale Mission Analysis Transfer Using Moon Resonances, Issue 1.0**
[AD 9]	**ESOC WP522 Cross-Scale: Mission Analysis Guidelines, Issue 1.0**
[AD 10]	**European Code if Conduct for Space Debris Mitigation, Issue 1.0**
[AD 11]	**Support to Implementation of the Code of Conduct for Space Debris Mitigation, Issue 1.0**
[AD 12]	ECSS-E-10 series, available from http://www.ecss.nl
[AD 13]	ECSS-M-30A, available from http://www.ecss.nl

4.2 Reference documents

[RD 1]	**Cross-Scale Technology Reference Study Summary; SCI-PA/2007/155/CS**
[RD 2]	**Cross-Scale CDF study report CDF 69 (A)**

[RD 3] **Yuichi Tsuda et al., “Mission design of SCOPE – small satellites formation flying mission for magnetospheric tail observation,” presentation at AIAA International Conference on Low Cost Planetary Missions, Kyoto, 2005**
[RD 4] **Comic Vision Presentation to Industry, F. Safa**

5 CONTACT SCIENTISTS

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6 PAYLOAD OVERVIEW AND SUMMARY TABLES

Table 1 provides an overview of the payload characteristics. Three main scientific themes have been identified: the *reconnection* theme, *turbulence* theme and the *shocks* theme. All instrument requirements are compatible with the science goals described in the Scientific Requirement Document (SciRD) of the Cross Scale Mission [AD 1].

The Cross Scale Science Study Team (SST) has identified a baseline *strawman payload complement*. This payload will provide first-class science, while still being compatible with the constraints imposed by the resources - both technical and financial - that are likely to be available for implementation of the mission. Finally, it should be noted that while the reference payload described in this document demonstrates that the science requirements can be achieved within the resource constraints of the mission, it is not meant to preclude alternative concepts that could meet or improve on both the science return and the use of resources.

6.1 Strawman payload

The Baseline Mission could be accomplished by an instrument complement comprising the following generic types given in Table 1.

Instrument	Acronym	Measurement	Heritage	Nom. Mass (1) [kg]	TRL	Total Mass [kg]	Physical size of main units [cm]	Power (2) [W]	TM (3) [kbps]
Magnetometer (DC vector)	MAG	Boom mounted DC vector magnetic field	VEX, Double Star	0.6 (no harness and boom)	9	0.6 (0.3 kg in CPP	11×7×5 (×2 units) (sensors only)	1	12
AC vector magnetic field	ACB	Boom-mounted AC vector magnetic field (1Hz-2kHz, spectra and waveform)	Themis, Demeter	1 (no boom and harness)	8	1	10h×14d (cyl)	0.1	2
Electric field sensor 2D	E2D	30-50m wire double probe 2D electric field (DC & spectra), (0-100 kHz, DC & spectra)	Themis, MMS, Demeter	8	8	8	20×30×15 (×4 units)	3	TBD
Electron density sounder	EDEN	Electron density sounder	Cluster	0.2 in ACDPU	9	0.2 Tx +0.25 Rx	19.5x6.5x2cm Tx 19.5x9x2cm Rx	0.25 + 2.7 W (receiver)	1 kbytes/s
Processor / electronics	ACDPU	Common processor & electronics for ACB, E2D & EDEN)	Cluster	1.5 2kg from E2D only	7	1.5	23×19×6	2	TBD
Electron electrostatic analyzer	EESA	Dual head thermal 3D electron electrostatic analyzer (3 eV – 30 keV)	MMS	3	6	12	26×15×26 (x up to 4 units)	**7** **(28 total +5W for cards in DPU)**	**9.3Mbit/s**
Ion electrostatic analyzer	IESA	ion electrostatic analyzer	Cluster	1.5	6	1.5		1.5	130 kb over spin period 369 kbps
Ion Composition analyzer	ICA	3D ion composition < 40 keV	Cluster	3.5	8	3.5	20×30×20	3.5 ave	16 kby/s + 150 kbytes/s (msphere)
High Energy Particle	HEP	Solid State high energy particle detector > 30 keV	Themis, Demeter	1.0 (2D) 1.7 (3D)	9 (2D) 2 (3D)	2 (2D) 3.4 (3)	20×10×20 (2x3D ion scale 1x2D fluid)	1.3 (2D) 2 (3D) (without DPU)	26
Central payload processor	CPP	Centralised payload processor	Themis, SpaceWire	1.2 (TBC)	5	1.2 TBC	20×`2×7.5	2.9 TBC4-5 W for EESA processing.	Themis used 12 W for 5 instruments
Active Spacecraft Potential	ASP	Active spacecraft potential control	Cluster, MMS	2	9	2	19×16×17	4	0.1 kbps

Table 1: Strawman Payload Characteristics

No	1		2		3			4		5		6		7
Type of S/C	E1	#	e2	#	e3	#		i1/e4	#	i2	#	i3	#	i4
Instrument	ACB	1	ACB	1	ACB	1		ACB	1	ACB	1	ACB	1	ACB
	ASP	1	ASP	1										
			E2D	4				E2D	4	E2D	4	E2D	4	E2D
	E2Dincl	4			E2Dincl	4								
	EESA	4	EESA	4				EESA	2	EESA	2	EESA	1	EESA
								HEP	1			HEP	1	
														ICA
								IESA	2	IESA	4	IESA	2	IESA
	MAG	1	MAG	1	MAG	1		MAG	1	MAG	1	MAG	1	MAG
	ACDPU	1	ACDPU	1	ACDPU	1		ACDPU	1	ACDPU	1	ACDPU	1	ACDPU
	CPP	1	CPP	1				CPP	1	CPP	1	CPP	1	CPP

Table 2: Payload composition per S/C in the seven S/C constellation case

In Table 2 the composition of the payload is given in the 7 S/C case. The instruments are given and also how many of a particular kind of instrument is needed to fulfill the science requirements. However the total number of elements per instrument make up the complete instrument. In Table 3 the composition of the payload is given for the 5 S/C case in which it is assumed that the SCOPE mother and daughter will accompany the 5 s/c. Note that e stands for electron scale S/C and i stands for ion scale spacecraft. In both cases one spacecraft acts as an ion and electron scale spacecraft. Again note that the 5 ESA spacecraft option requires the 2 spacecraft from the JAXA SCOPE mission to be part of the constellation.

	2 (ESA1)		4 (ESA2)		5 (ESA3)		6 (ESA4)		7 (ESA5)	
Inst	e2	#	i1/e4	#	i2	#	i3	#	i4	#
	ACB	1	ACB	1	ACB	1	ACB	1	ACB	1
	ASP	1								
	E2D	4	E2D	4	E2D	4	E2D	4	E2D	4
	EESA	4	EESA	2	EESA	2	EESA	1	EESA	1
			HEP	1			HEP	1		
			IESA	2	IESA	4	IESA	2	IESA	2
	MAG	1	MAG	1	MAG	1	MAG	1	MAG	1
	ACDPU	1	ACDPU	1	ACDPU	1	ACDPU	1	ACDPU	1
	CPP	1	CPP	1	CPP	1	CPP	1	CPP	1

Table 3: Payload composition per S/C in the five S/C constellation case with JAXA SCOPE mission providing the e1 and e3 spacecraft defined in Table 2 and SCOPE providing one ICA unit.

7 MISSION PROFILE AND SCIENCE OPERATIONS SUMMARY

The current mission baseline consists of the following elements. A minimum of 7 s/c are required to meet the science objectives. The number of spacecraft will therefore up to 7. The operational orbit will be a 10 by 25 Re orbit with maximum time to be spend in the tailbox. Final mission analysis will be performed in a later stage to fix the final argument of apogee and Right Ascension of the Ascending Node of the orbit. The combination of 5 or 7 S/C will be launched by a SF-2b from Kourou in French Guyana. The mission will have a designed lifetime of 5 years, of which 1 year is reserved for deployment and commissioning of the complete constellation. The nominal science mission will be two years with a possible extension of two years. The S/C will have consumables onboard for the full 5 years. All of the S/C will have their own direct link to ground stations on Earth. A fair degree of autonomy is needed when S/C go into safe-mode, due to the relatively large number of S/C. The payload will consist of the core payload described in this document. The distribution of these instruments on each S/C is given in Table 2 and Table 3. Also the exact constellation configuration and how these up to 7 S/C will be combined in a larger international cooperation remains to be determined.

The science operations for the Cross Scale mission are important due to the large number of satellites and instruments. The S/C will have sufficient onboard memory to store data from two complete orbits. The total data rate of the complete constellation will be 800 kbps. All S/C will download their data to the ground. No mother S/C is currently foreseen to collect data from all spacecraft and send it to ground.

8 DESCRIPTION OF BASELINE INSTRUMENTS

8.1 Magnetometer (MAG)

8.1.1 Introduction

The MAG instrument will measure the DC magnetic field on all spacecraft with a dual sensor package.

8.1.2 Science goals and performance requirements

DC Magnetic field measurement is expected to be performed on all spacecraft, returning field vectors sampled up to 100 Hz. In the near-Earth space, this data provide a robust roadmap in the 3D space, i.e. the orientation within the solar wind-magnetosphere-system as well as the orientation within the area where shock, reconnection, turbulence take place. Simultaneously with these “position” information, multi-point magnetic field measurements at particular scales will provide current density (local gradient information) or wave properties that are essential for studying interaction with particles relevant to all the three science topics. Combining the multi-point magnetic field measurements from all scales, one can follow the variability across the shock, topology changes in the dynamic current sheet in the reconnection region, and overall turbulence spectrum across the important spatial ranges.

8.1.3 Instrument description

8.1.3.1 Instrument concept

The design of the dual sensor fluxgate magnetometer consists of two sensors, each consisting the sensor and near-sensor electronics. The sensor can have different shapes depending on the design as shown in Figures 1 and 2.

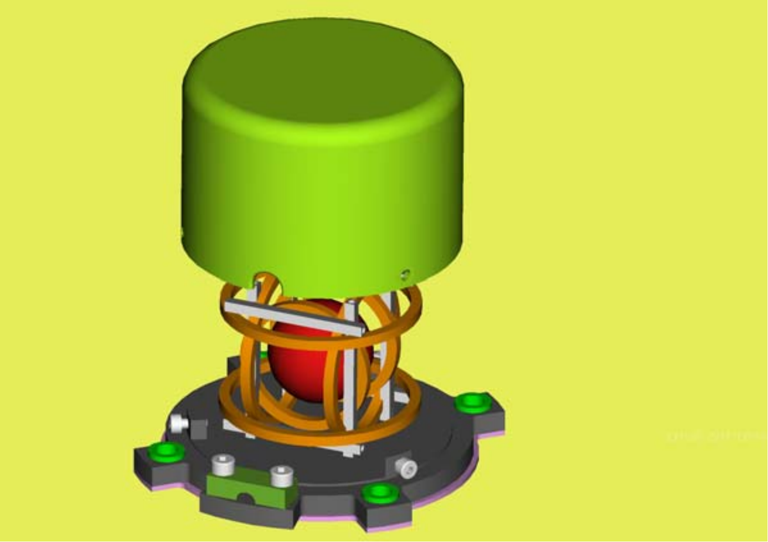

Figure 1: Fluxgate sensor with opened housing

Two entwined ring-cores are used to measure the magnetic field in three directions in the vector compensated sensor set-up. Via the smaller ring-core the magnetic field is measured in X and Z direction while the larger one is used for Y and Z. The ring-cores are equipped with two 3-D coil systems: an inner one to collect (pick-up) the magnetic field dependent second harmonic of the fundamental excitation frequency and an outer Helmholtz coil system to compensate the external field at the ring-core position. Figure 1 shows the sensor core with housing and mounting plate made from aluminum. Depending on the design, the ring-cores can be differently mounted so that the external envelope of the sensor is more rectangular, prism-shaped, as shown in Figure 2.

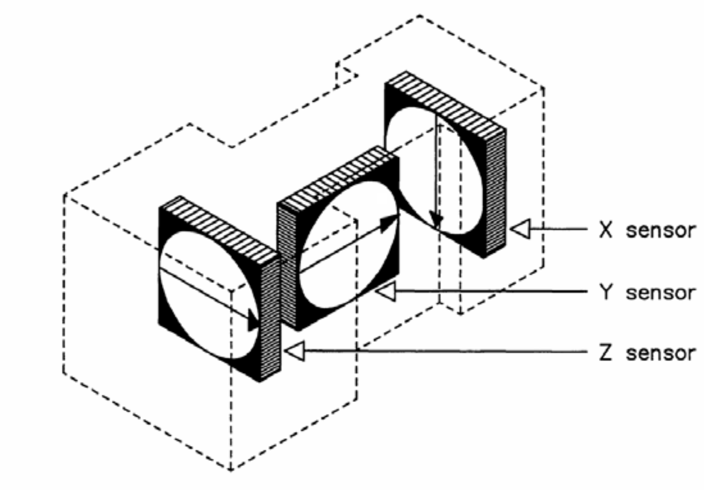

Figure 2: Schematic of a fluxgate sensor (rectangular prism shape)

The analogue output signal from each fluxgate sensor is processed in an electronics board as shown in Figure 3. The output field components are normally transmitted to a common data processing and data handling unit.

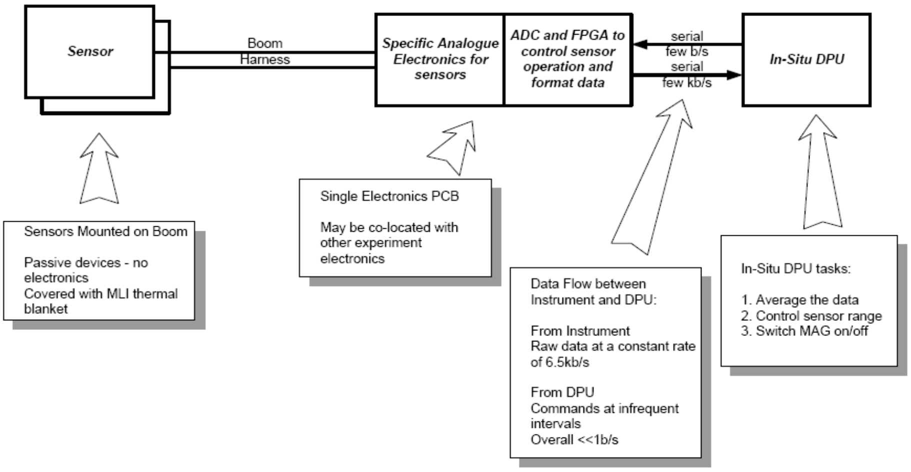

Figure 3: General block diagram of sensor electronics

8.1.3.2 Orbit, Operations and Pointing Requirements

The 10 by 25 Re orbit fulfils all science requirements. Pointing is not stringent and operations are assumed to be continuous.

8.1.3.3 Interface and Physical Resource Requirements

The outboard sensor shall be mounted on an interface board at the tip of a ≥2m long boom. The inboard sensor shall be mounted on the boom as well. The distance from the outboard sensor should be in the order of 1/3 of the total boom length, but not less than 50 cm.

8.1.3.4 Calibration

The calibration of the sensors needs to be performed regularly in-flight, but also before flight a calibration campaign is needed for all sensors. Cross-calibration (with ACB and other SC) is desirable.

8.1.3.5 Cleanliness, EMC issues and pre-launch activities

Magnetic cleanliness: The measured magnetic field stability at the location of the outboard sensor shall be less than or equal to 0.1 nT DC over a period of 4000 seconds during science mode while in the region of interest.

8.1.3.6 Critical Points

It is anticipated that the magnetometer electronics will be hosted in a common instrument electronics box and share data handling and power supply electronics with other TBD instruments. The current assumption is that the CPP will handle these issues.

Since a magnetometer is required for all spacecraft, combined efforts from several institutions are needed to build the required hardware will be essential to enhance the effectiveness of the flight-hardware production. A critical point in this case is the coordination and the interface definition, which need to be handled with care.

8.1.3.7 Heritage

The magnetometers have flown for example on Venus Express, THEMIS, Cluster II and Double Star. Furthermore a possible magnetometer deisgn is planned to be included in the payload of the BepiColombo mission to Mercury.

8.1.3.8 Instrument Data Sheet Summary

Element	Value/Range	Comments
Instrument Name	Fluxgate magnetometer	
Instrument Acronym	MAG	See CV Proposal
Description	Measurement of DC magnetic field vectors The magnetometer consist of two three-axial sensors, and associated electronic boards, harnesses, and thermal hardware	Here the following additional components necessary for magnetic field measurements are considered to be provided either by SC or shared with other instruments and therefore not regarded as “MAG”: (1) Boom (2) Box to mount on the electronic board (3) Common processor for interface and data handling (4) Power supply unit (±8V, 3.3V)
Heritage	VEX. Themis, Cluster, Double Star, etc.	
Detector type	Dual Flux-gate	
Measurement Range(s)	DC field, ±20000 nT ±8000 nT ±2000 nT ±500 nT ±100 nT	Necessary range can also depend whether magnetic field data are used for attitude determination
Measurement Resolution/Accuracy	< 10pT/ $Hz^{½}$ @1Hz 16 bit resolution: ±100 nT @ 4pT ±500 nT @ 16pT ±2000 nT @ 64pT ±8000 nT @ 256pT ±20000 nT @ 640pT	energy, angle, frequency, etc. Largest range allows attitude determination for low perigee
Field of View (per package)	N/A	FoV angle
Other detector characteristics		Characteristics like pixel size, QE, etc.
Cadence	128 Hz (e,ion-scale) 64 Hz (Fluid-scale)	
Volume per package	Following numbers are for	if orientation relevant, describe relation of

	each one sensor Sensor with housing: 11x 7 x 5 cm Electronics board:10x12x1.5 cm	each dimension to mounting requirements
Mass per package	Following numbers are for each system/sensor Sensor with housing: 100 g Electronics with PCB: 150 g Harness 70g/m, Thermal hardware 50g/sensor	
Power per package	Following numbers are for each system/sensor : Total 1W	
Power quality	±8 V, 3.3V Power should be provided within ±5% above numbers Ripple < 30 mV	spike, ripple, ... Only standard quality required
Detector thermal range and thermal stability requirements (operational and non-operational)	Sensor: (operational) -100 to 80 (non-operational) -100 to 80 Electronics: (operational) -40 to 80 (non-operational) -55 to 125	
Mounting and grounding requirements	The sensors are mounted on a boom stretching out from the satellite (one 'outboard' at the end, one 'inboard' closer to SC) in order to fulfil the EMC requirement (see below). The electronics box, where the electronic boards are mounted , is installed on the main platform	
Co-alignment requirements with respect to other P/L	N/A	
Special deployment & commissioning requirements	Turn-on required during boom deployment	
Attitude accuracy	Knowledge of sensor orientation with respect to spacecraft axes required to 0.1 deg.	
EMC requirement	The measured magnetic field strength at the location of the outboard sensor shall be less than 10 nT DC during science mode while in the region of	The requirement is taken from MMS value.

	interest. The measured magnetic field stability at the location of the outboard sensor shall be less than or equal to 0.1 nT DC over a period of 4000 seconds during science mode while in the region of interest.	
Special accommodation requirements	N/A	
Commanding/Modes of operation	Only data rate, range, and configuration change. Power consumption not mode dependent	
Inter-instrument links/dependencies	N/A	
Orbit, spin-rate, and related requirements	Boom shall be sufficiently stable to guarantee attitude knowledge (as given above)	
Calibration requirements	Cross-Calibration (with ACB, other SC)	
Data volume per package	Data-rate: i-e scale: 12kbit/sec Fluid: 6kbit/sec Data Volume: i,e-scale: 3.1Gbit/orbit Fluid: 1.5 Gbit/orbit	Data-rate: 2(sensors)x3(component)x16bitx 128 /s [or 64 /s]=12kbit/s or [6kbit/sec] Data-Volume for 3x24 hr orbit: 12kbit/s or [or 6kbit/sec] x 3 x 86400 s = 3.1 Gbit [or 1.5Gbit]
On-board data handling or storage requirements	Burst mode storage. Not required, but one useful process would be spin-fit calculation (THEMIS)	
Special requirements	N/A	
Radiation sensitive items	Sensor is not sensitive Electronics TD < 70krad SEL < 14,1 MeVcm2/mg	Dependent on detector design

8.2 AC search coil (ACB)

8.2.1 Introduction

The ACB instrument will measure three components of the AC magnetic field in space.

8.2.2 Science goals and performance requirements

AC search coil magnetometers are intended to measure the three components of the magnetic field from near DC to about 2 kHz. It will extend waveform measurements up to 500 Hz and will provide spectral information up to several kHz. These complete the characterisation of waves responsible for particle scattering and extend the turbulence analysis into the electron dissipation range. According to the Cross-Scale Science Priority Document, the measurements provided by ACB instrument are required to achieve the Cross-Scale Scientific objectives associated with shocks, reconnection and turbulence.

8.2.3 Instrument description

The ACB instrument is a tri-axial search coil based on designs for the CLUSTER, DEMETER and THEMIS missions. It is composed of 3 ELF/VLF antennas associated with a miniaturized preamplifier built in 3D technology.

The 3 orthogonal magnetic antennas are assembled in the most compact way as possible around a nut in a nonmagnetic material followed of a foot which acts as the interface with the body of the satellite. Both nut and foot are made of a special material (nonmagnetic) called PEEK KETRON.

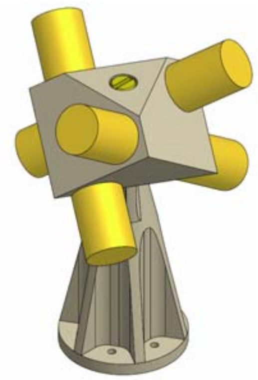

Figure 2: Sensor representation

The amplification electronic circuit is based on 3D technology.

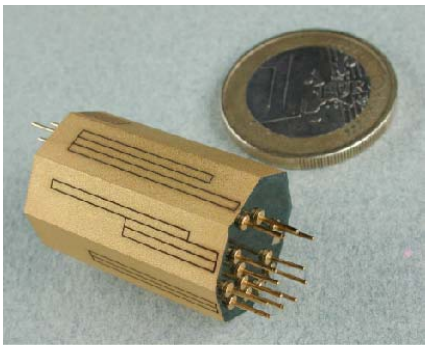

Figure 3: Miniaturized preamplifier and its pins

The amplification electronic circuit will be boarded in the sensors foot (close to the antennas) to reduce the signal-to-noise ratio. However if the thermal stresses are too important, the preamplifier can also be installed onboard the satellite

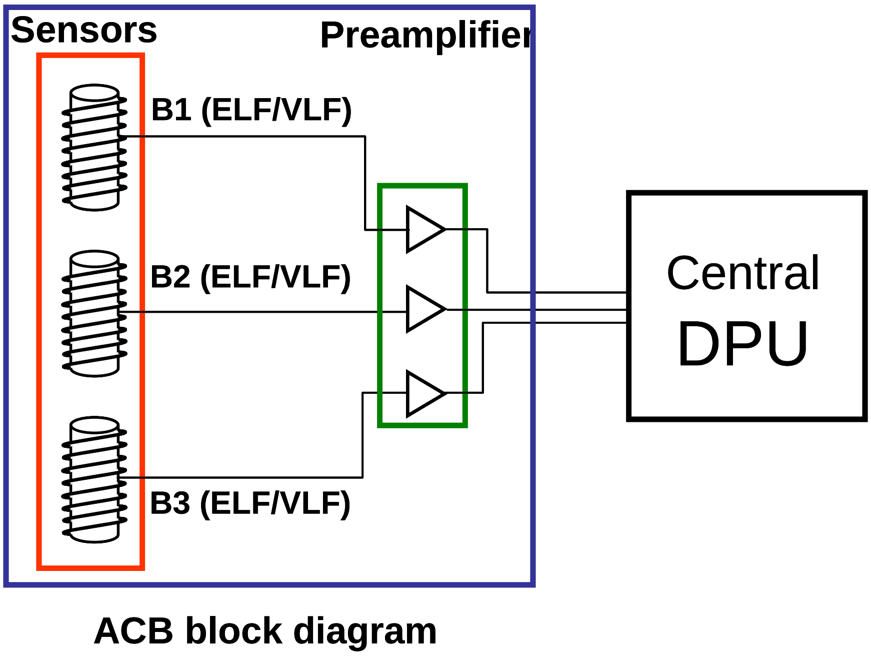

Figure 4: ACB block diagram including the three sensors, pre-amplifier and the central DPU (not part of the ACB assembly)

8.2.3.1 Orbit, Operations and Pointing Requirements

The 10 by 25 Re orbit fulfils all science requirements. Pointing is not stringent and operations are assumed to be continuous.

8.2.3.2 Interface and Physical Resource Requirements

To minimize noise interference from the spacecraft and other instrument subsystems, ACB instrument needs to be mounted on a boom extended away from the body of the spacecraft (at least 2 meters). To minimize the S/C interference on the sensor, the 3 antennas must be mounted such as none points directly the body of the satellite. Moreover, it should be mounted at least 1m from any other sensors including active electronics or magnetic materials (Fluxgate magnetometers for instance). The boom must be of a nonmagnetic material. These requirements are the same whatever the spacecraft type (Electron-scale, Ion-scale and Fluid-scale)

8.2.3.3 Calibration

TBD

8.2.3.4 Cleanliness, EMC issues and pre-launch activities

The intensity of the ELF/VLF magnetic fields generated by the spacecraft and other instruments at the location of ACB should be less or equal to its sensitivity: 10 fT/(Hz)$^{1/2}$ at 2 kHz and 2 pT/(Hz)$^{1/2}$ at 10 Hz

8.2.3.5 Critical Points

Magnetic cleanliness, electrodynamic cleanliness, see Instrument Data Sheet 8.2.3.7

8.2.3.6 Heritage

The ACB instrument concept has flown on missions like Cluster II, DEMETER and THEMIS.

8.2.3.7 Instrument Data Sheet Summary

Element	Value/Range	Comments
Instrument Name	AC Search Coil Magnetometers	
Instrument Acronym	ACB	see CV Proposal
Description	A boom-mounted system of three orthogonal magnetic antennas for ELF and VLF measurements	
Heritage	CLUSTER, DEMETER and THEMIS	
Detector type	Inductive magnetometer	
Measurement Range(s)	[1 Hz – 2 kHz]	
Measurement Resolution/Accuracy	10 fT/(Hz)$^{1/2}$ at 2 kHz 2 pT/(Hz)$^{1/2}$ at 10 Hz	energy, angle, frequency, etc.
Field of View (per package)		FoV angle
Other detector characteristics		Characteristics like pixel size, QE, etc.
Cadence	Fe = 5 kHz	
Volume per package	Cylinder : diameter = 10 cm height = 14 cm This volume includes the boom interface	if orientation relevant, describe relation of each dimension to mounting requirements
Mass per package	1 kg (including antennas + preamplifier+ boom interface) The boom and the harness are not included (a typical harness mass is 60g/m).	
Power per package	0.1 W (±12V)	
Power quality		spike, ripple, ...
Detector thermal range and thermal stability requirements (operational and non-operational)	Preamplifier: operational: -40°C to +80°C non-operational: -50° to +80° antenna: -50°C to + 150°C	

Mounting and grounding requirements	To minimize noise interference from the S/C and other instrument subsystems, ACB needs to be mounted on a boom (at least 2 meters) and the 3 antennas must be mounted such as none points directly the body of the satellite. Moreover, ACB should be mounted at least 1 meter away from any other sensors including active electronics or magnetic materials. The boom must be in a nonmagnetic material.	
Co-alignment requirements with respect to other P/L		
Special deployment & commissioning requirements		
Attitude accuracy	0.5° with respect to the main satellite axis	
EMC requirement	The intensity of the ELF/VLF magnetic fields generated by the spacecraft and other instruments at the location of ACB should be less or equal to its sensitivity: 10 fT/(Hz)$^{1/2}$ at 2 kHz 2 pT/(Hz)$^{1/2}$ at 10 Hz The boom must be in a nonmagnetic material.	
Special accommodation requirements		
Commanding/Modes of operation		
Inter-instrument links/dependencies	Synchronized Sampling with E2D	
Orbit, spin-rate, and related requirements		
Calibration requirements		
Data volume per package	2 kbytes/s	Waveform up to 500 Hz Spectra up to 2 kHz
On-board data handling or storage requirements	A/D converter FFT	
Special requirements		
Radiation sensitive items	Preamplifier. The miniaturized 3D preamp is already equipped with tantalum layers. It has a radiation tolerance level of 100 krad (Total Dose).	In accordance with the mission radiation specifications, a tantalum hood can be added to protect the whole preamplifier module

8.3 Electromagnetic fields 2D (E2D)

8.3.1 Introduction

The E2D instrument will measure the electrical field in space in two dimensions.

8.3.2 Science goals and performance requirements

The main goal of the E2D instrument is to measure the electric fields surrounding the S/C. By using four wire booms at the same time the full electric field in the spin-plane is measured. By inclining the spin axes of neighbouring S/C, it is possible to combine the E2D data from 2 s/c to provide full 3D electric field vector at least for frequencies consistent with the propagation and/or convective time sclses. The extent of the relative inclination is tbd. This configuration is referred to in Table 2 as E2Dincl.

8.3.3 Instrument description

A vector component of the electric field is measured by measuring the observed voltage between two spherical probes at the ends of two wire booms, extending radially from the spacecraft in opposite directions. By means of two such probe pairs (four wire booms), the 2 electric field components in the spin plane are obtained. Each probe is kept close to the local potential in the space plasma by application of a steady bias current. While the potential of any of the sensors with respect to the spacecraft will depend on plasma density, solar illumination and the emission and exchange of photoelectrons by all parts of the spacecraft, the voltage difference between opposite probes is dominated by the electric field due to the symmetry of the boom assembly. The long wire booms (order 100 m tip-to-tip) minimize perturbations from inevitable asymmetries on the spacecraft and maximize signal strength. The single-probe voltages provide the spacecraft potential, which in turn depend on the plasma density and also is necessary to monitor for the correct interpretation of particle data. To measure weak signals it is important to mount preamplifiers as close as possible to the sensors, i.e. near the boom ends.

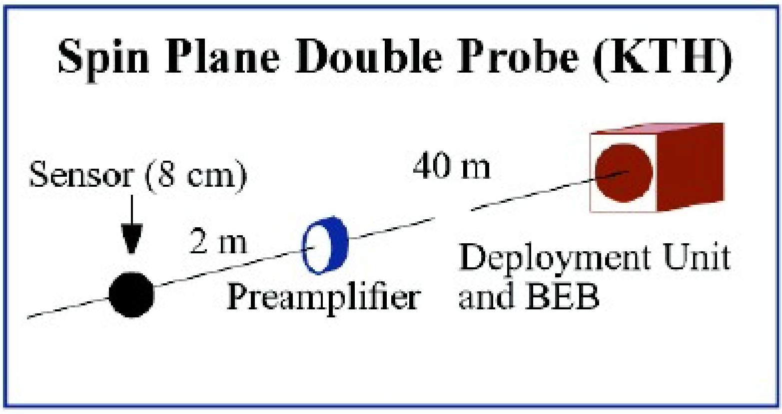

Figure 5: E2D antenna schematic

8.3.3.1 Orbit, Operations and Pointing Requirements

TBD

8.3.3.2 Interface and Physical Resource Requirements

The spacecraft surface should be conductive, so as to constitute an equi-potential surface minimizing perturbations and giving a well-defined spacecraft potential. The wire boom packets must be mounted symmetrically around the spacecraft at 90° separation, all of them in the same plane. The spherical sensors at the boom tips must all be illuminated for the technique to work, meaning that the spacecraft spin axis cannot be exactly perpendicular to the direction to the sun as this would put each sphere in shadow once per spin. It is desirable that the attitude is such that no more than half of the wire boom length is in shadow at any one time, and necessary that the outermost 5 meters are never eclipsed. However, as this relates to measurement quality, not to instrument safety, it is permissible to violate this attitude rule e.g. during s/c manoeuvres. The spacecraft must have good electrostatic cleanliness, preferentially using grounding of all units directly to the s/c chassis, which is then in contact with the conductive surface.

The wire booms are symmetrically deployed pair for pair, and no pair is deployed to its full length in one go as this probably would decrease the spacecraft spin intolerably and also waste an important opportunity for diagnostic data taking at different boom lengths: a sequence of two to four deployment/spin-up manoeuvres may be needed for each pair, with long intervals (days) of diagnostic data gathering between each step.

8.3.3.3 Calibration

TBD

8.3.3.4 Cleanliness, EMC issues and pre-launch activities

TBD

8.3.3.5 Critical Points

TBD

8.3.3.6 Heritage

The current design of the E2D has a large heritage in past missions.
The electronics have been used on GEOS, ISEE Viking, Freja, Astrid-2, Polar, Cluster and Themis.
The proposed sensors have flown in a similar configuration on Astrid-2, Cassini and Rosetta. The mechanical deployment is planned to be flown on missions like MMS and BepiColombo.

8.3.3.7 Instrument Data Sheet Summary

Element	**Value/Range**	**Comments**
Instrument Name	2D electric field Instrument	
Instrument Acronym	E2D	
Description	Measure E components in the satellite spin	

	plane. Measure satellite potential.	
Heritage	Electronics – GEOS, ISEE, Viking, Freja, Astrid-2, Polar, Cluster, Themis Sensors – Astrid-2, Cassini, Rosetta Mechanical deployment - MMS, BepiColombo	
Detector type	Double probe. 4 probe units. 30-50m wire. 60-100m tip-to-tip	
Measurement Range(s)	±100 V (potential) ±1 V/m (electric field) DC – 100kHz	
Measurement Resolution/Accuracy	0.1 mV/m DC E-field 2 uV/m AC E-field 20 bit resolution and/or different gain channels for DC and AC	energy, angle, frequency, etc.
Field of View (per package)	N/A	FoV angle
Other detector characteristics	Probe radius (few cm), probe surface coating (suggested TiN), boom length (60-100 m tip-to tip)	Characteristics like pixel size, QE, etc.
Cadence	Continuous measurements at few tens of Hz range. Shorter intervals of higher data rate regulated by instrument internal trigging and/or common s/c trigging and/or telecommand.	
Volume per package	4 boom units. The size of each unit: width 20cm height 15 cm	length direction points in the radial direcion orientation relevant, describe relation of each dimension to

	length 30cm	mounting requirements
Mass per package	7.5kg	
Power per package	2.5W peak 3.5W	
Power quality	28V low noise (10mV)	spike, ripple, ...
Detector thermal range and thermal stability requirements (operational and non-operational)	Operational -20C to 50C Non operational -40C to 90C	
Mounting and grounding requirements	Sensors around s/c periphery at 90° separation. Grounding see EMC.	
Co-alignment requirements with respect to other P/L		
Special deployment & commissioning requirements	Deployment: pairwise; sequential for each pair; see Section 8.3.3.2 above. Commissioning: tests for instrument integrity; days of diagnostic measurements between each deployment step; diagnostic tests for correct bias levels.	
Attitude accuracy	1°	
EMC requirement	E-field 15dBuV TBC max 100Hz TBC 500kHz Max 40dBuA 30Hz 500kHz Well defined s/c ground connected to conductive s/c surface.	
Special accommodation requirements	Last 5 m of wire must be in the same environmental conditions (solar illumination).	Requires a few degree tilt of spin axis.

Commanding/Modes of operation	ACDPU Regular (daily) commanding of e.g. bias levels.	
Inter-instrument links/dependencies	Synchronized sampling and modes with ACB, MAG	
Orbit, spin-rate, and related requirements	The maximum spin-rate the E2D antennae can handle is limitedm but TBD, i.e. possibility of breaking the wire booms shall be avoided.	
Calibration requirements	Simultaneous commissioning data from B-field and ion instruments	
Data volume per package		
On-board data handling or storage requirements		
Special requirements		
Radiation sensitive items	Max 30 krad TID	

8.4 Electron Density Sounder (EDEN)

8.4.1 Introduction

The EDEN instrument will measure the total electron density in space.

8.4.2 Science goals and performance requirements

The EDEN instrument, as a resonance sounder, can measure the total electron density in the range [0.2 cm^{-3} – 80 cm^{-3}] via active stimulation and subsequent detection of the resonances of the local plasma. It will provide a high time resolution, high quality total electron density measurement that is central to the shock and reconnection science objectives, and that underpins the calibration of the particle instruments. EDEN instrument is linked to the E2D antennas and, accordingly, measurements will be performed on board the spacecraft dedicated to Electron-scale and Ion-scale.

8.4.3 Instrument description

The EDEN relaxation sounder is linked to the electric field antennas of Cross-Scale (part of the E2D instrument) and consists of a transmitter and a receiver. The data acquisition and data processing will be performed by the central DPU system. The transmitter is connected to the braid of one pair of electric field antenna through the E2D experiment module. It remains inactive in (N) mode operations. In (S) mode a signal synthesiser delivers a pulse of sine waves, of either 1ms or 0.5ms duration. The successive frequency values in a sweep follow a table chosen by telecommand. The receiver is connected to the second pair of E2D electric antennas through the E2D experiment module. It is operated in each 13.3 ms listening step, after the transmission of the pulse (the receiver is inhibited during the pulse), during the acquisition slot.

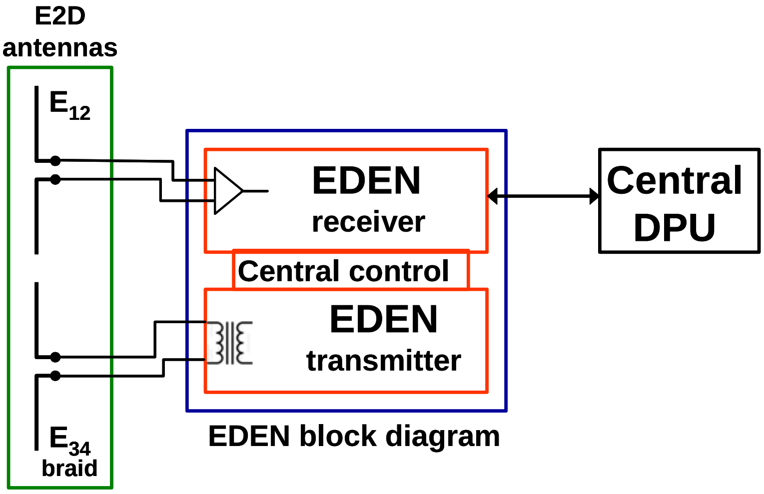

Figure 6: Blockdiagram of EDEN

8.4.3.1 Orbit, Operations and Pointing Requirements

The instrument EDEN is connected to the E2D instrument.. The electric signals from these antennas need to be sent to the EDEN receiver and likewise for the transmitter the signals need to be sent to the antennas. A clear interface between the two instruments is needed.

8.4.3.2 Interface and Physical Resource Requirements

The instrument heavily depends on the antennas of the E2D instrument. The signals from the EDEN electronic cards are sent and received from the antennas.

8.4.3.3 Calibration

TBD

8.4.3.4 Cleanliness, EMC issues and pre-launch activities

TBD

8.4.3.5 Critical Points

The EMC requirements are not seen as a critical point, but need to be taken into account at very early start of the design of the S/C.

8.4.3.6 Heritage

A similar instrument like EDEN has flown on Cluster.

8.4.3.7 Instrument Data Sheet Summary

Element	**Value/Range**	**Comments**
Instrument Name	Electron density sounder	
Instrument Acronym	EDEN	see CV Proposal
Description	Sounder for probing of e^- density by relaxation	
Heritage	CLUSTER	
Detector type	Resonance sounder. It measures the total electron density via active stimulation and subsequent detection of the resonances of the local plasma.	
Measurement Range(s)	Electron density : [0.2 cm^{-3} – 80 cm^{-3}]	
Measurement Resolution/Accuracy	Accuracy 1% (with a time resolution of 1.5s)	energy, angle, frequency, etc.
Field of View (per package)		FoV angle
Other detector characteristics		Characteristics like pixel size, QE, etc.
Cadence	Minimum duration of a complete sweep : 1.5 s	
Volume per package	Transmitter board: 19.5cm x 6.5cm x 2cm Receiver board: 19,5cm x 9cm x 2cm	if orientation relevant, describe relation of each dimension to mounting requirements
Mass per package	0.2 kg (transmitter board) 0.250 kg (receiver board) (only electronic, boxes are not included)	
Power per package	Transmitter: 0.25 W Receiver: 2.7 W	Average power
Power quality		spike, ripple, ...
Detector thermal range and thermal stability requirements (operational and non-operational)	Operational: -20°C to +40°C Non-operational: -50°C to +60°C	
Mounting and grounding requirements	The elements of the EDEN instrument are all within the ACDPU	

Co-alignment requirements with respect to other P/L		
Special deployment & commissioning requirements		
Attitude accuracy		
EMC requirement		
Special accommodation requirements		
Commanding/Modes of operation	N mode (transmitter is inactive). S mode (transmitter is active)	
Inter-instrument links/dependencies	Connected to E-field antennas through E2D module.	
Orbit, spin-rate, and related requirements		
Calibration requirements	On ground calibration. No flight calibration, only integrity check.	
Data volume per package	1 kbytes/s	
On-board data handling or storage requirements		
Special requirements	An extensive inter-instrument test will have to be done to identify potential interference problems	
Radiation sensitive items	Electronics : A/D converter (no problem for an orbit with 12 krad/year)	

8.5 Common processor and electronics for field instrument (ACDPU)

8.5.1 Introduction

The ACDPU is proposed as the DPU and wave processor for all the AC field instruments. The decision to implement this DPU depends on whether all AC instruments will be put on the S/C. When only one AC field instrument is implemented on the S/C such a common DPU might not be necessary. The ACDPU will control and combine the output of the following instruments:

- E2D
- E3D (when applicable)
- EDEN
- ACB

A similar wave processor and DPU flew on Cluster (Wave Experiment Consortium) and processed data from the instruments, STAFF (tri-axial search-coil magnetometer and spectrum analyzer), WHISPER (relaxation sounder for probing electron density), the Electric Field and Wave Experiment (EFW), the wideband receiver system for generating wideband waveform data (WBD) and the digital wave-processing experiment (DWP).

8.5.2 Science goals and performance requirements

The science goals are described by the sections of each instrument controlled by the ACDPU.

8.5.2.1 Instrument description

The necessity for an ACDPU has not yet been confirmed by the SST, nor have specific concepts for Cross scale been put forward by the community. To have at least some information available on how such a DPU could look, like we present some particular features of the WEC from Cluster.

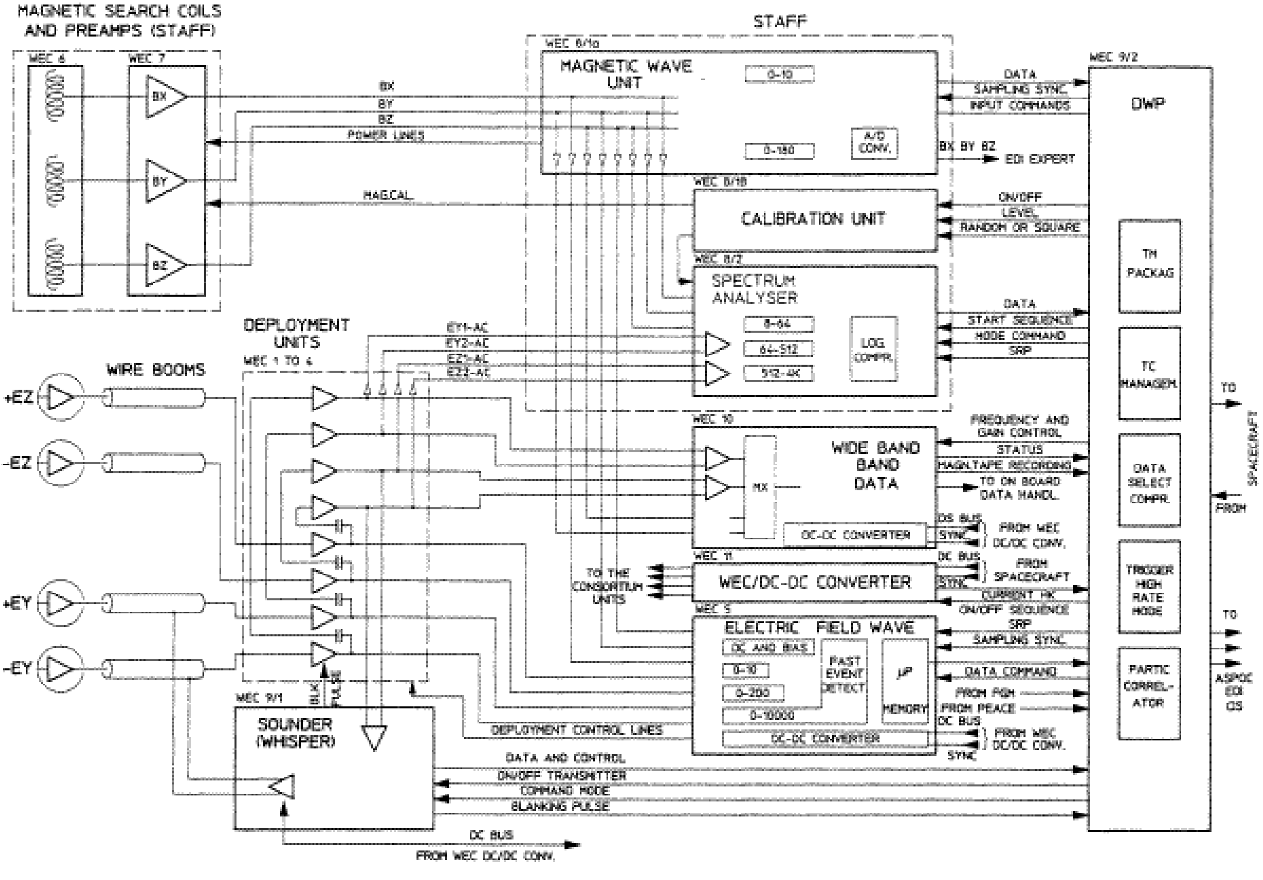

Figure 7: Block diagram for WEC in the Cluster II payload

Figure 7 is the general block diagram of the WEC and shows the interfaces between the five experiments described in previous section. In the Cross Scale case EFW can be replaced by E2D and E3D, STAFF can be replaced by ACB and WHISPER is now EDEN. The other two instruments are completely embedded into the complete WEC system and might have their counterparts in the ACDPU, but completely integrated.

The five sensors in Figure 7 are the three magnetic search coils (STAFF) and the two electric double-probe antennas.

8.5.2.2 Orbit, Operations and Pointing Requirements

TBD

8.5.2.3 Interface and Physical Resource Requirements

This instrument needs interfaces (data lines) to the instruments controlled by it.

8.5.2.4 Calibration

TBD

8.5.2.5 Cleanliness, EMC issues and pre-launch activities

TBD

8.5.2.6 Critical Points

Complete integration with the connected instruments and the testing of the combined set will demand a stringent programmatic approach.

8.5.2.7 Heritage

Heritage is coming from the WEC instrument onboard Cluster

8.5.2.8 Instrument Data Sheet Summary

TBD

8.6 Electron Electrostatic Analyser (EESA)

8.6.1 Introduction

The EESA instrument will be capable of measuring electrons and their energies at a very fast rate.

8.6.2 Science goals and performance requirements

Electrostatic particle detectors of various designs need to be carried on all spacecraft. On the electron scale, fast (~50 Hz) measurements of the full 3D electron velocity distribution function need to be made at sufficiently high energy and angular resolution to identify electron beams, temperature anisotropies, multiple populations and other features that may drive the collisionless plasma processes (i.e. reconnection, shocks, turbulence) which are the target of the Cross Scale mission. The velocity distribution functions can provide the basic electron parameters or moments: density, velocity, temperature, etc. However many of the features described above are hidden in the low-order moments. Thus there is a need for the mission to telemeter also the full 3D electron velocity distribution functions in order to fully address the science goals.

8.6.3 Instrument description

Modern electrostatic analysers utilize a top-hat design which has a narrow field of view in one angular dimension. With a single sensor, full 3D velocity measurements therefore can only be obtained using a full satellite spin period. This tying of the basic instrument time resolution to the spacecraft spin period (usually a few seconds) is adequate at the fluid scale. However, higher time resolutions are needed on the ion and electron scale spacecraft to increase the resolution and provide full 3D capability at the corresponding ion or electron time scales demanded by the science objectives. Multiple sensors, as either dual-heads within a single unit or multiple units, must therefore be deployed. Additionally, on the electron scale, deflector plates need to be employed to increase the field of view for sub-spin resolution and reduce the number of sensors required. Thus the electron electrostatic analyser system described here for use on the electron scale is base-lined as a set of 4 ‘dual-head’ sensors, with each of the 8 heads covering 180° in elevation, and through the use of the aperture deflection system (ADS), ±22.5° in azimuth. The combined heads thus provide 360° coverage in azimuth, or complete 4π steradians of the sky. Electrons from a chosen azimuth are deflected into the hemispherical analyser section (which has 180° acceptance in elevation) of each head by applying a voltage across the ADS system. Electrons are selected in energy by the applied voltage across the concentric hemispheres and are recorded by the MCP or CEM detectors. Sweeping of the ADS and hemispherical voltages allows electron fluxes of the full angular and energy range for each sensor to be obtained. Note that fewer units could be deployed per electron scale spacecraft if larger acceptance angles for the ADS system are used. However, this has drawbacks in the form of irregular angular coverage, potentially large gaps in that coverage and also means the instrument will not be able to cover the full energy range since higher energies cannot be deflected through the larger angles.

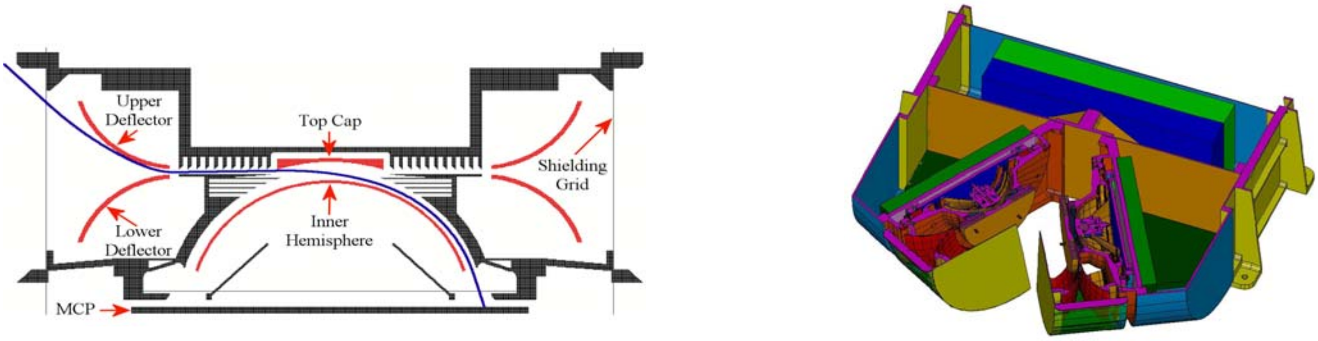

Figure 8: Left: Electro-optical model of one of the sensor heads of the Dual Head system, right; Dual head unit as used in the design for the MMS mission

8.6.3.1 Orbit, Operations and Pointing Requirements

The full compliment of EESAsensors will be deployed only on the Electron-scale spacecraft. On ion scale spacecraft, where lower time resolutions are acceptable, a reduced numbe rof sensor units can be deployed.

The full EESA instrument consists of multiple, dual head units, the fields of view of which have to be distributed around the spacecraft body in order to provide the complete 4π sr coverage at high time resolution on the electron scale. In the base-line 4 dual-head units scenario for this scale, this implies the 4 units must be separated by 90 degrees from each other, such that the centre of the instantaneous, un-deflected fields of view of each head is perpendicular to the spacecraft spin axis. The unit heads must protrude from the body of the spacecraft in order that there is no spacecraft obstruction to the field of view.

The low-energy electron measurements are susceptible to modification by the spacecraft potential, and by contamination by photoelectrons and secondary electrons emitted by the spacecraft. An EMC cleanliness program is therefore required to minimise the spacecraft potential, or at least any sources of differential potential, especially in the vicinity of the instrument heads. If resources allow, deployment of a Cluster ASPOC-type device would be advantageous to the EESA measurements.

8.6.3.2 Interface and Physical Resource Requirements

The power and data services from the spacecraft to/from the EESA sensors are TBD, but may need some careful optimisation. The thermal interface is not expected to be unusual (cf. Cluster, etc.)

8.6.3.3 Calibration

TBD

8.6.3.4 Cleanliness, EMC issues and pre-launch activities

8.6.3.5 Magnetic cleanliness:

- The magnetic field due to the spacecraft and payload (with the solar panels in sunlight) measured along the line of sight of a sensors should be less than 25 nTm
- Some electronic components inside the instrument may be magnetic, but magnetostatic emission will be less than 1 nT at 1m.

8.6.3.6 Electrostatic cleanliness:

- Minimise any exposed voltages; i.e. care must be taken to ensure that the spacecraft surfaces are all at spacecraft ground potential, particularly in the vicinity of the sensor apertures.
- Eliminate non-conductive areas on the spacecraft surface, particularly close to the sensor apertures.
- Spacecraft surfaces exposed to the plasma environment need to be conductive and grounded to minimise differential charging potential to less than 1 Volt (design goal) between any two points of the spacecraft external surfaces.
- Ideally, the potential of the exposed surfaces of the sensors should always be within 10% of the average potential of the whole spacecraft.

8.6.3.7 Critical Points

Critical issues concern the data rates generated, and how the spacecraft systems (central DPU, on board mass memory, telemetry, etc.), handle such rates.

Further development is essential to demonstrate the capability of flight-representative miniaturised, fast sweeping, high voltage generators.

The sensor geometric factors may need to be addressed to avoid counting statistic issues. The plasma sheet count rates obtained by Cluster PEACE HEEA ranged from low 100s to < 10 per 3.95 milliseconds bin. On the electron scale, we need a bin sample time of 0.15 milliseconds, which is a factor of 26 faster. This implies similarly lower counts per bin, even without the smaller geometric factor implied by a scaled-down sensor. The expected counts are then something of order 10 in the peak and 0.25 for typical lobe flux levels.

8.6.3.8 Heritage

The current design of the EESA is also being developed for a NASA mission; MMS.

8.6.3.9 Instrument Data Sheet Summary

Element	**Value/Range**	**Comments**
Instrument Name	Electron Electrostatic Analyser	
Instrument Acronym	EESA	see CV Proposal
Description	Dual-head thermal 3D electron electrostatic ‘top-hat’ analyser 3eV–30keV , with aperture deflection system (ADS). Use of 4 dual head sensors provides full FoV of 4π steradians (and thus full 3D f(v)) in a time period set only by the sweep rates (i.e. independent of spacecraft spin rate).	MMS concept assumes 4 dual-head analysers (i.e. a total of 8 sensors), each covering 180° in elevation and each with ADS providing ±22.5° azimuthal range for combined 360° coverage in azimuth. Could be reduced to 3 dual-head analysers with ADS providing ±30°, or even 2 with ADS with ADS providing ±45°, but this implies uneven angular coverage, probably large gaps in coverage and a reduced energy range for the instrument. These descopes most likely reduce angular coverage at high energy for a given HV generator upper voltage, or else they require a higher power HV system that will not be able to sweep as fast.
Heritage	Cluster, Cassini, MEX,VEX, Stereo, MMS, Solar Orbiter (?)	Based on long line of similar sensors flown e.g. on Cluster, Cassini, etc. Cross-Scale needs an aperture deflection system (ADS) which has heritage from STEREO, is being deployed on MMS and proposed for Solar Orbiter. A fast sweeping high voltage system is needed which lacks heritage apart from MMS development.
Detector type	Electrostatic particle detector with aperture deflection system;	Electrons from a chosen azimuth are deflected into the hemispherical analyser section (which has 180° acceptance in elevation) of each sensor. Electrons of the selected energy then pass around the hemisphere and are recorded by the MCP or CEM detectors. Sweeping of the ADS and hemispherical voltages allows electron fluxes of the full angular and energy range for each sensor to be obtained.
Measurement Range(s)	Electron scale: 3 eV to 30 keV, 30 energy bins, 12 elevation bins, 32 azimuthal bins, 50 Hz	Dimensions as in proposal Table 7.

	Ion Scale: 1 Hz Ion Scale: part of CESA or reduced number of sensors?	
Measurement Resolution/Accuracy	Electron scale: ΔE/E ~ 30% if 30 energy bins are used to cover full range; 12 elevation bins and 32 azimuth bins implies angular resolution of 15°and 11.25° across both angular ranges.	ΔE/E is rather large here compared to previous missions. Floating the sweep voltage to start at the spacecraft potential (as high as tens of volts in the lobe, available from electric field instrument) could improve this. Angular resolution also quite coarse, but improving either has a significant effect on the dominating data rate for the electron scale.
Field of View (per package)	Electron scale: 4π steradians for full 3D f(v)	FoV angle
Other detector characteristics	Electron scale: Deflector plates on aperture; possible use of variable geometric factor;	Characteristics like pixel size, QE, etc.
Cadence	Electron scale: As fast as 20 ms for a full scan	
Volume per package	Electron scale: Sensor Units 26x15x26 cm^3; electronics box TBD (should share DPU with other instruments)	Assume deployment of 4 such units on electron scale (as in proposal); Units will then need to be mounted at 90° to each other with centres of each FoV perpendicular to the spacecraft spin axis.
Mass per package	Electron scale: 3kg per package, 4 per spacecraft; DPU TBD.	2 kg per dual sensor given in proposal may be a little optimistic. We may also need more radiation protection in the magnetosphere. There is however some potential for optimisation so the value given here is a worst case number. It could come down somewhat with clever engineering.
Power per package	Electron scale: 7W per unit, 28W per s/c	For a worst case power estimate and sweep rates etc consistent with the proposal, we need a fast high voltage flyback for the deflector plate system even if the sensors sweep up-sweep down for energy sweeps (and thus avoid fly-back). We assume a bin time of 150 microseconds, but could go a bit quicker using two optocouplers in parallel. This increases the power demand and also the mass a little. In a DES there are 8 optocouplers per head or 128 per spacecraft. These are expensive (~$2000 each), and we would double this for

		the fast flyback, in the worst case. In this latter case the mass penalty is estimated roughly at a further 50 g per head, or 800 g per spacecraft We recommend a maximum flyback rate of 8 kV/millisec The flyback needs to do 5 kV and we need 4 of them in 20 millisec. Data collection is given 18/4 = 4.5 millisec per energy sweep, so for a 30 bin sweep the desired accumulation bin is 150 microsec. This is fairly consistent with the 5 millisec energy sweep/200 microsec bin/40 Hz 3D data of MMS We also assume a 80 MOhm MCP. With no contingency; the assumptions give 2.9 Watts per head with FPGA, A111, sweep generators, 80 Mohm MCP. With recommended 20% contingency that is 3.47 W; multiply by 8 for a full EESA to get 28 W. Note this does not cover power in DPU. Likely that 4-5 W would be required to handle EESA data processing and compression requirements alone.
Power quality	28V spacecraft primary power inc DC-DC efficiency	spike, ripple, ...
Detector thermal range and thermal stability requirements (operational and non-operational)	Maximum operating temperature 25 °C in order to avoid thermal runaway of the MCP detectors. Ideally, the sensors and the electronics would be operated at 15 °C +/- 10 °C at all times. For non-operating times, this may be extended to the range -20 °C to +50 °C.	
Mounting and grounding requirements	Multiple sensors mounted around spacecraft, perpendicular to spin axis, to provide 4π FOV in measurement time.	
Co-alignment requirements with respect to other P/L	None	
Special deployment & commissioning requirements	Allow outgassing period (~3 weeks from launch) before turn on.	
Attitude accuracy	<< angular resolution (~5 deg)	
EMC requirement	- The magnetic field due to the spacecraft and payload (with the solar panels in sunlight) measured along the line of sight of a sensors should be less than 25 nTm.	

	- Some electronic components inside the instrument may be magnetic, but magnetostatic emission will be less than 1 nT at 1m. Electrostatic cleanliness: - Minimise any exposed voltages; i.e. care must be taken to ensure that the spacecraft surfaces are all at spacecraft ground potential, particularly in the vicinity of the sensor apertures. - Eliminate non-conductive areas on the spacecraft surface, particularly close to the sensor apertures. - Spacecraft surfaces exposed to the plasma environment need to be conductive and grounded to minimise differential charging potential to less than 1 Volt (design goal) between any two points of the spacecraft external surfaces. - Ideally, the potential of the exposed surfaces of the sensors should always be within 10% of the average potential of the whole spacecraft.	
Special accommodation requirements	Unobstructed FOV. Sensitive to s/c differential charging. S/c surface should be conducting, equipotential, especially near instrument apertures	
Commanding/Modes of operation	Onboard moments/compressed 3D distributions/pitch angle distributions in normal mode? Full 3D distribution at highest cadence in burst (primary science) mode?	Note that these operations assume some considerable capability of a centralised DPU, with resultant resource requirements.
Inter-instrument links/dependencies	Magnetometer data if onboard pitch angle distributions required. s/c potential from E-field instruments to control sweep?	
Orbit, spin-rate, and related requirements	None other than EMC issues above. Instrument in proposed configuration is not dependent on s/c spin. Assume spacecraft spin axis is perpendicular to the Earth-Sun line to avoid some parts of sensors being permanently sunlit.	
Calibration requirements	Regular MCP test/monitoring; cross calibration between sensors and with other instruments (e.g. density sounder).	
Data volume per package	576050 words/sec ~9.3 Mbits/sec	From proposal Assuming 16 bit words Experience with Double Star PEACE suggests that compression factors of 10 may be useable – again depending on DPU capability. The numbers quoted above are worst case. For the typical counts rates that will be

		encountered per bin, 8-bit data words may be sufficient. Also, the system over-samples the 4-pi solid angle and with intelligent data handling, this could be removed.
On-board data handling or storage requirements	Onboard compression and/or moment calculations	
Special requirements		
Radiation sensitive items	May need radiation shielding to reduce background signal to MCP's. Or turn off in radiation belts.	

8.7 Combined ion/electron electrostatic analyzer (CESA, IESA and ICA)

8.7.1 Introduction

The following three instruments described are all electrostatic analysers. The first CESA is an electrostatic analyser for ions and electrons combined. The other two are electrostatic analysers either ions without time-of-flight mass analysis or ions with time-of-flight mass analysis (ICA). The science goals for these electrostatic analysers are rather interconnected and therefore are given in single chapter. The description of the instruments is also given in a combined section. All three instruments have their own datasheets.

8.7.2 Science goals and performance requirements

Electrostatic analysers measure the 3D distribution functions of low energy ions and electrons, at energies from a few eV to a few 10 keV. These measurements are essential to determine the fluid parameters (density, flow velocity, temperature, composition...) as well as the kinetic properties (anisotropies, fluctuations with respect to maxwellians, particle beams...) of the plasma. They thus play a central role in any studies regarding the dynamics of collisionless plasmas and their fundamental processes.

Distribution functions. For a given species, the velocity distribution function is defined as the density of particles in elementary domains of the velocity space phase. The measurement of this physical object is fundamental for the Cross-Scale science. At the fluid scale, the 3D distributions will be used to derive the MHD parameters of the plasma (density, flow velocity, mean energy, temperature...), using an averaging procedure:

$$n = \int f(\vec{v}) d^3\vec{v}\,; \quad < \vec{V} > = \int \vec{v}.f(\vec{v}) d^3\vec{v} / n \; ....$$

This will characterize the general context and contribute to quantify the overall energetic importance of detailed microscopic processes. This will be crucial to answer 'Cross-Scale' questions as: What is the fraction of incoming kinetic energy converted into thermal energy at a shock? What is the part of magnetic energy converted into kinetic and thermal energy during a reconnection? They will also be used to measure the plasma turbulence cascade from the large to the dissipation scales. At the ion and electron scales, the measurements of the distributions will be critical to identify and quantify the key kinetic processes that drive the intrinsic dynamics of the plasma. Together with magnetic and waves measurements, they will be pivotal to identify the various plasma instabilities and understand their role in complex energy dissipation processes, at the different scales.

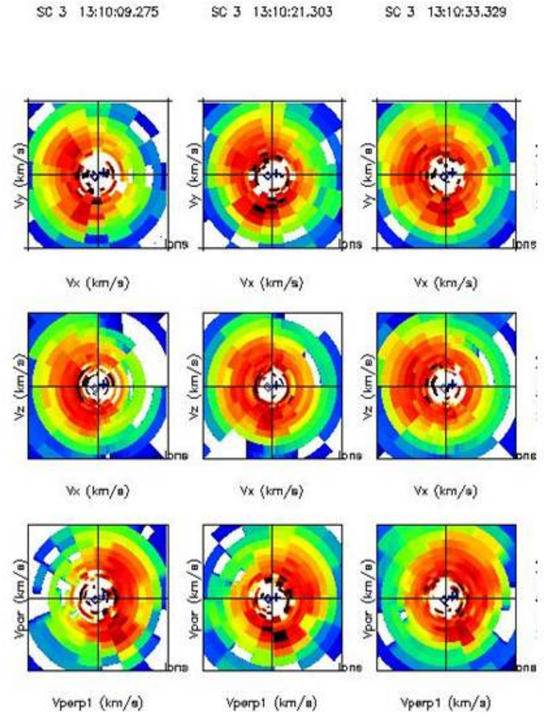

Figure 9 : **Examples of ion distribution measurements (from Cluster HIA).**

In practice, f(v) is determined by measuring the flux of particles having a defined velocity. This is made by selecting the energy (E) and the direction of arrival of the particles (angles: Θ and Ψ). For most scientific purposes, a resolution of ~ 10% in energy and ~10°x10° (or ~ 20°x 20°) in azimuth and polar angles is sufficient. A measurement of a 3D distribution function thus corresponds to a 32x16x32 or 16x8x32 matrix. Examples of measured ion distribution functions (from Cluster-HIA) are shown in Figure 12 . On these cuts of the distribution functions in the planes Vx/Vy, Vx/Vz and Vy/Vz (here in the GSE frame), the angular/energy pixels corresponding to the sampling of the velocity space are well apparent. The average value of f(v) in each pixel is colour coded.

Time resolution

In their simplest version, the particle instruments measured the distribution functions in a plane. The third dimension is sampled thanks to the spacecraft spin. The time resolution of 3D measurements is then directly related to the spin period. Depending on the number of sensors and their mounting on the spacecraft, the resolution could be 1, ½, ¼... of the spin period.

For Cross-Scale, the time resolution will depend on the considered scale. Electrons have the largest velocities and shortest characteristic time/length scales (gyrofrequency, plasma frequency, electron skin depth...). Their distributions must be measured at a particularly high temporal cadence - especially at the electron scale - to really access the finest structures of the plasma (cadence of 10 Hz and more). The solution is to multiply the number of sensors. In practice, with 8 sensors and some deflection capabilities at their entrance, it is possible to span the whole 3D space at very large cadences (see description of the Dual Electron Electrostatic Analyser).

At the ion scales, measurements at about the ion gyrofrequency (~1 Hz) for both electrons and ions are sufficient to identify the key dynamical processes. At the fluid scale, a resolution of the order of the inter-spacecraft distance divided by the ion thermal velocity or Alfven velocity, is adequate. The spin period (~4s) is then largely sufficient for most studies.

Ion composition.

More complex instruments, with mass spectrometry capabilities, are needed to provide the distribution functions of the main ion species (H^+, He^{++}, and O^+). This is crucial for the study of plasma processes that are mass dependent. For example, the knowledge of the low-order moments for each ion species will allow an accurate study of mass, momentum and energy transfers across plasma boundaries and current sheets. The heavy ions play also an important role in various tail processes as the formation of multiple current sheets or high-speed flows, and may contribute significantly to the density and pressure of plasmasheet. During substorms, the energy inputs to the plasmasheet and their releases have different impacts on particles with different mass. For reconnection, the exact scale of heavy-ion and of proton decoupling from the magnetic field is most certainly mass dependent. The cascade turbulence through the different ion scales (O^+ , P^+ Larmor radius) and the associated dissipation is also a subject of great interest. Their global effect on processes taking place at the global MHD scale will be investigated.

8.7.3 Instrument description

8.7.3.1 Electrostatic Analyser

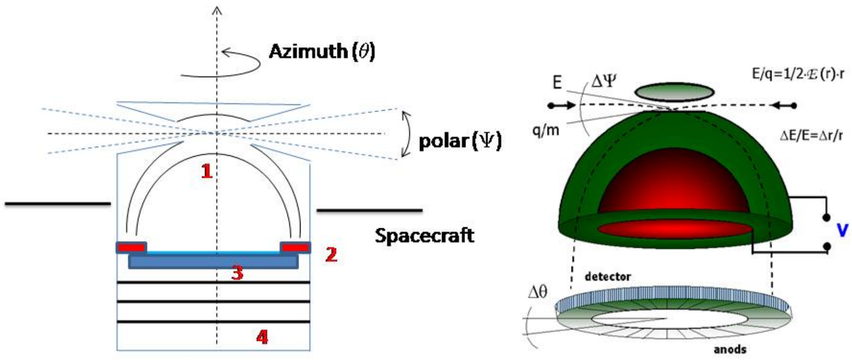

Figure 10: Principle of a top hat analyser. (1)Electron Optics element: top-hat analyser system. (2)Detector and readout element consisting of an MCP mounted onto an anode and readout board, including HV coupling capacitors and readout electronics. (3)LV and HV boards (4) FPGA-based electronics board/boards for instrument control, position processing, interfaces, counters, etc

To determine the distribution function f(v) of particles, systems able to select the velocity of incoming particles and to measure their flux must be designed. The universal solution uses an electrostatic optics that only allows particles with a given energy (E) and arrival directions (defined by an azimuth θ and a polar angle ψ to hit a detector. The detector itself is a charge amplifier, generally multi-channel plates (MCP). The flux is determined by counting the particles that hit the detector during a given time interval. This flux is linked to the value of distribution function in the considered domain of phase spaceby a simple function of the energy, the angular and energy acceptance of the sensor and, the surface of its entrance aperture. Figure 2 shows the principle of a very common type of analyser: the 'top-hat'. This design will be used for all electrostatic analysers of Cross-Scale. A 'top-hat' is a symmetrical electrostatic analyser which has a uniform 360° field of view. It consists of three concentric spherical elements: an inner hemisphere, an outer hemisphere which contains a circular opening, and a small circular top cap which defines the entrance aperture. In the analyser, a potential is applied between the inner and outer plates and only charged particles with a limited range of energy and an initial polar angle are transmitted. The particle exit position, usually identified by the use of ring-shaped MCP, is a measure of the incident azimuth angle. Usually, when mounted on the s/c, the top-hat analyser has 2 × 180° FOV sections parallel to the spin axis and 2D "instantaneous" distributions are sampled at the sweep rate of the voltage applied to the inner plate of the electrostatic analyser. A full 3D distribution of the particles is obtained every ½ spin of the spacecraft. When two different sensitivities are used for each of the 2 × 180° FOV sections of the instrument, or when the FOV of the sensor is limited to a 180° section, a full 3D distribution of the particles is obtained every spin.

An electronic system consisting of a sectorized anode (16 or 32 sectors), and a read-out electronics (ASIC or classical amplifiers) record the electric pulses corresponding to each particle impact in each sector in azimuth. For most system, a few ten's of ms is sufficient to record a statistically significant number of count per pixel and, thus, to perform the analysis at a given energy, at a given polar angle and for 360° in azimuth. By sweeping the potential of the plates, from a few V to a few keV, measurements are performed at successive energies. Generally, 32 or 64 logarithmically spaced energy channels are chosen, from a few eV to a few 10 KeV, which offers a typical 10% energy resolution.

The coverage in polar angle is performed thanks to the spin of the spacecraft, with 16 or 32 spectra made during a spin period. It is also possible to use deflector plates at the entrance of the detector to widen the polar FOV and to select particles coming from an extended polar domain. This solution leads to more complex instruments and is not considered as a baseline for Cross-Scale measurements, except if a very high resolution is required, as electrons at the electron scale.

A typical measurement of a 3D distribution, with a 11°x11° angular resolution and 10 % energy resolution, consists in 32 azimuth x 16 polar x 32 energy flux measurements. They are generally logarithmically coded on 8 bits which corresponds to about 130 kb.

8.7.3.2 Mass composition measurements

To measure the distribution functions of various ion species, the electrostatic analyser (EA) already described has to be complemented with a mass spectrometer (figure14). The most popular solution is the electrostatic time-of-flight (TOF) although magnetic mass spectrometer could also be used.

After their direction/energy selection, the particles are focussed by the EA onto an ultra-thin carbon foil (~0.5 μg cm^{-2}) polarized at a voltage of ~ -15 kV, at the entrance of the TOF section. Due to collisions and charge exchange during their interaction with the carbon foils, ions experience angular and energy diffusion, and exit as neutrals, positive or negative ions. Also, upon ion impact, the carbon foils emit one or several secondary electrons. These electrons are deflected and focused by a dedicated electrostatic optics toward a ring MCP. In figure 14, it is at the bottom of the TOF section but it can also be located at the top of the TOF. This provides a START pulse, while the position of the electron impact indicates the azimuthal sector of the incoming ion. Measurements of the START rate in the azimuthal channels thus yield the three-dimensional angular and energy distributions without mass identification but with a high temporal resolution. In this respect, ICA also acts as a classical ion sensor without mass identification.

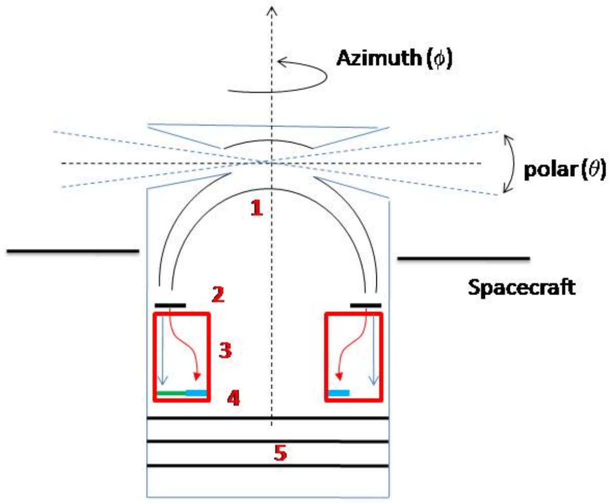

Figure 11: Principle of a mass composition analyser. Electron Optics element: (1) top-hat analyser system. (2) Carbon foils. (3) TOF section. (4) Start and Stop MCP. (5) LV and HV boards.

After drifting in the TOF section, the incoming particles are detected on the MCP at the bottom end which provides the STOP signal. The corresponding times of flight display some spreading due to the above mentioned angular and energy diffusion of the particles upon crossing of the carbon foils. To increase the mass resolution, the collector of the MCP at the bottom end is divided into two parts, viz., a small central disk and a large outer ring. Particles collected on the central disk have a reduced spread in path length as well as in energy because they exit in the direction nearly normal to the carbon foil. This significantly improves the mass resolution which is of the order of 10 at the 10% level. The outer ring with a large useful surface (thus, a larger count rate but with a larger spread in the length of ion trajectories and in ion energy) provide a reduced mass resolution of $m/\Delta m \approx 8$ at the 50% level.
The time-of-flight measurement along the flight path length is used to determine the velocity v of the incident ion. Knowledge of the E/q and the velocity of an individual ion allows to determine its mass/charge (m/q) and hence separate the dominant ion species: protons (m/q = 1), alpha particles (m/q = 2), and heavier ions (m/q > 2.5).

Time resolution, sensor with multiple heads.

An 360° azimuth FOV is achievable if the plane of analysis of the sensor is tangent to the external surface of the spacecraft. However, to minimize perturbation of the particle trajectory or to avoid FOV obstruction, it may be preferable to choose a FOV perpendicular to the spacecraft surface. The FOV is then restricted to 180°. This reduces the time resolution by a factor 2.
To increase the time resolution, a classical solution is to multiply the sensor heads. In principle, a 360° analyser measures a full 3D distribution in ½ spin period. With 2 sensors, the resolution is ¼ spin period. With 8 sensors equipped with electrostatic deflectors, one may consider that the time resolution is independent from the spin period. Extremely high time resolutions can be achieved (3D f(v) at a few 10 Hz), the limiting factors being the electronics and statistical limitations.

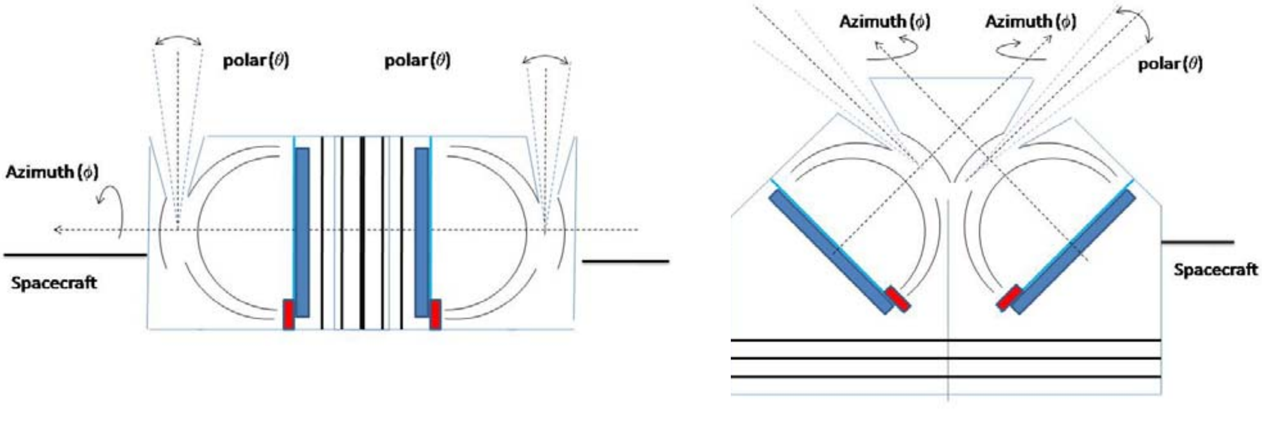

Figure 12: **Possible configurations of dual sensor head. Case 1(on left) is convenient for Combined Electron Ion system (CESA). Case 2(on right) is more adapted to Dual Electron Electron or Ion-Ion sensor. DEEA and DIEA.**

It may be useful to combine different sensor heads in a single instrument to save mass and power. We present in Figure 12 possible arrangements, tested and flown on projects as Cassini, Astrid, MMS. The combination can be 2 electron or ion heads: EESA and IESA for dual Electron (or Ion) Electrostatic Analyser or combined electron/ion heads: CESA (Combined Ion Electron Electrostatic Analyser).

A CESA may consist of two top-hat analysers packed back-to-back, with a common entrance aperture and opposite voltages applied to the two internal hemispheres. Therefore, this instrument is capable of measuring electrons and ions fluxes simultaneously.
As for the single top-hat, the full 3D distributions are obtained at spin resolution. When multiple detectors are installed on the spacecraft, the time resolution of the measurements increases. It should be note that, if needed, appropriate deflector plates, mounted at the top-hat apertures and increasing the sensor field of view, allow for sub-spin resolution with a reduced number of detectors (see figure 16).

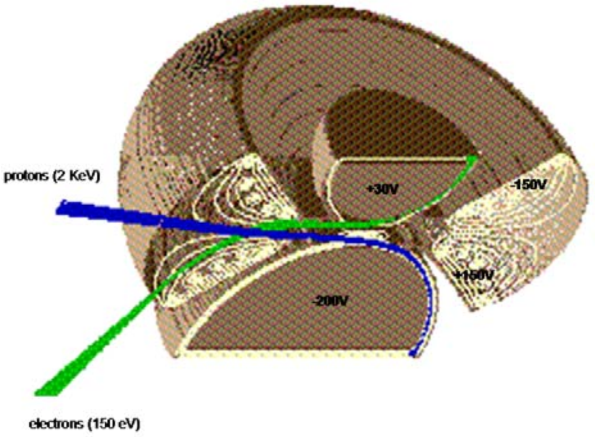

Figure 13: **An example of CEIA geometry, with deflector plates at the entrance**

8.7.3.3 Orbit, Operations and Pointing Requirements

TBD

8.7.3.4 Interface and Physical Resource Requirements

FOV. For all electrostatic sensors the following restrictions need to be taken into account: An obvious requirement is to limit obstructions of the FOV. This is easy to perform if the plane of analysis of the sensor contains the spin axis of the spacecraft and is perpendicular to the surface of the spacecraft. However, the FOV is then limited to ~180° for each sensor. To have a 360° FOV, the plane of analysis must be almost tangential to the surface of the spacecraft. To avoid perturbation effects associated to the proximity of the spacecraft surface, the sensor head needs to protrude (10 cm) out of the spacecraft body. Obstacles (antenna, other instruments, solar panels) must be excluded from the FOV.

Adaptable geometric factor. The sensor will make measurements in very different plasma regions so that the sensor dynamic range must be large, with the need for different geometric factors. To accomplish this, without increasing the number of sensors, an electrostatic reduction of the geometry factor can be implemented.

Alignment. The alignment requirements are not critical. It is a fraction of the angular resolution of the measurements, then of the order of 1 °, which is easy to achieve.

Spacecraft perturbation. As charged particles are measured, it is important to minimize electrostatic disturbances in the vicinity of the sensors. This requires that the external surfaces of the spacecraft, including instruments, are conductive and at a uniform electric potential. This requirement is particularly important for the measurements of electrons.

Thermal. Particle detectors have no specific thermal requirements. The most sensible components are the electronics and the MCP. The typical operating temperature range is -10°C to +40°C, the survival range is -40°C to +50°C.

Radiation. Particle detectors are sensitive to particle radiation. Their electronics, as for any other spacecraft electronic system, can be affected by the cumulative dose of radiation. More specifically, because of saturation effects and progressive degradation of the detectors, the system should be in survival modes during the crossing of the radiation belts, if there are any. The degradation effects will be accounted for in the design. This is to ensure that at the end of the mission, the accumulated effects will not affect the performance of the electronics. To accomplish this, the final parametric degradation effects must be used in the worst-case circuit analysis. In addition, a Radiation Design Margin (RDM) will be used to cover uncertainties in the environment. Latchup resistant electronic components must be used to reduce damage from single event upsets.

8.7.3.5 Calibration

TBD

8.7.3.6 Cleanliness, EMC issues and pre-launch activities

TBD

8.7.3.7 Critical Points

TBD

8.7.3.8 Heritage

The heritage of the three instruments is given in their own datasheets in the following sections.

8.7.3.9 Instrument Data Sheet Summary (CESA)

Although the combined Ion and Electron Analyser is not part of the payload, it represents a possibility to reduce the amount instruments by combining two. A more detailed study is needed whether this combined instrument is capable of performing the same measurements compared to the single instruments measuring ions and electrons separately. For completeness the CESA datasheet is still given.

Element	Value/Range	Comments
Instrument Name	**Combined Electron Ion electrostatic Analyser**	
Instrument Acronym	CESA	
Description	Combined measurements of 3D distributions of ions and electrons.	No determination of ion composition. If TOF section is added, Ion composition determination

		would be possible.
Heritage	Astrid Medusa	
Detector type	A Package is constituted by 2 heads (Top-Hat), one for ions the other for electrons.	
Overall characteristics and performance. How instrument matches Science Requirement, including s/c on which it needs to be deployed.		
Measurement Range(s)	10 eV – 40 KeV two heads with 180° (in azimuth) FOV	
Measurement Resolution/Accuracy	ΔE/E=10%, 22.5 ° or 11°	
Field of View (per package)	2x180°x 5°	
Other detector characteristics		
Cadence	32 energy steps in 0.25 s (or 1/16 of spin period)	
Volume per package	15 x 20 x 20 cm^3	
Mass per package	2.5 kg	
Power per package	2.5 W (3 W in burst modes)	
Power quality	28V spacecraft primary power. Power quality is arranged in the instrument.	The sensor produces and controls its own high voltages.
Detector thermal range and thermal stability requirements (operational and non-operational)	Operating temperatures -10°C +40º C Non-operating: -40°C to +50°C	Too high temperature (above 50°) could produce thermal runaway of the MCP detectors.
Mounting requirements	The plane of analysis is perpendicular to the surface of the spacecraft -> 180° FOV To have 360°, the instrument must protrude (~ 10 cm).	To increase the time resolution, 2 CESA can be mounted on the same spacecraft. they must be at 180° one to the other (1/2 spin resolution).
Co-alignment requirements with respect to other P/L	None	
Special deployment & commissioning requirements	After launch, an outgassing period before turn on (a few days).	
Attitude accuracy	Not critical	The tolerance is a fraction of an angular pixel (1°)
EMC requirement	Electrostatic Minimise any exposed voltages; - Care must be taken to ensure that the spacecraft surfaces are at spacecraft ground potential, particularly in the vicinity of the sensor apertures. - Eliminate non-conductive areas on the spacecraft surface, particularly close to	Small localized electrostatic charging is acceptable if they do not significantly perturb the energy of the particles at the lowest energy range. ~ 1V is acceptable.

	the sensor apertures.	
Special accommodation requirements	Minimized obstructions of the FOV. Sensitive to s/c differential charging: the instrument apertures must be as far as possible from possible electrostatic charged area	
Commanding/Modes of operation	Three mode: 1) Onboard moments/compressed 3D distributions/pitch angle distributions. 2) Full 3D distribution at highest cadence (burst mode?). 3) Calibration/Engineering mode.	
Inter-instrument links/dependencies	Magnetometer data if onboard pitch angle distributions required.	
Orbit, spin-rate, and related requirements	Time resolution directly proportional to the spin rate.	
Calibration requirements	Regular MCP test/monitoring;	cross calibration between sensors and with other instruments (on ground)
Data volume per package	~ 130 kb for a 3D (32x16x32) distributions -> ~ 260 kb for 1 electron and 1 ion distribution.	
On-board data handling or storage requirements	Onboard compression and/or moment calculations	
Special requirements		
Radiation sensitive items	MCP are radiation sensitive items (generation of noise, spurious signals, degradation of performance). Turn off in radiation belts.	Most critical items must be 100 krad qualified. (TBC)

8.7.3.10Instrument Data Sheet Summary (ICA)

Element	**Value/Range**	**Comments**
Instrument Name	**Ion Mass Analyser**	
Instrument Acronym	ICA	
Description	Electrostatic energy Analyser + Time-Of-Flight analyser	The instrument is intended to measure the proportion of heavy ions (CNO group) in the plasma, not to precisely determine the exact proportion each minor species.
Heritage	Cluster: CODIF Cassini: CAPS-IMS Bepi Colombo: MSA	
Detector type	Electrostatic energy/angle analysis (Electrostatic Analyser: EA) followed by a	Top-Hat analyser. Simple TOF system (no

	Time-Of-Flight (TOF) analysis	reflectron)
Measurement Range(s)	10 eV/q – 40 keV/q	
Measurement Resolution/Accuracy	Energy resolution : 10 % Mass resolution : 8-10	
Field of View (per package)	8 deg x 360 deg	
Other detector characteristics	Variable 10^{-3} – 10^{-4} geometrical factor depending on measurements	
Cadence	full 3D distributions in half-spin	
Volume per package	20 x 30 x 20 cm^3	
Mass per package	3.5 kg	
Power per package	3.5 W (average)	
Power quality	28V spacecraft primary power. Power quality is arranged in the instrument.	The sensor produces and controls its own high voltages.
Detector thermal range and thermal stability requirements (operational and non-operational)	Operating temperatures -10°C +40º C Non-operating: -40°C to +50°C	Too high temperature (above 60°) could produce thermal runaway of the MCP detectors.
Mounting and grounding requirements	The plane of analysis can be: - tangent to the surface of the spacecraft -> 360° FOV - perpendicular to the surface -> 180° FOV To have 360°, the instrument must protrude (~ 10 cm).	To increase the time resolution, 2 ISA can be mounted on the same spacecraft. If 360° FOV, they must be at 90° one to the other (1/4 spin resolution). If 180° FOV, they must be at 180° one to the other (1/2 spin resolution).
Co-alignment requirements with respect to other P/L	Possibly coordinated measurements with other ion sensor to improve time resolution	Describe the needed co-alignment accuracy and stability with respect to other instruments, which data will help to analyse the data from this instrument
Special deployment & commissioning requirements	After launch, an outgassing period before turn on (a few days).	
Attitude accuracy	Not critical	The tolerance is a fraction of an angular pixel (1°)
EMC requirement	Electrostatic Minimise any exposed voltages - Care must be taken to ensure that the spacecraft surfaces are at spacecraft ground potential, particularly in the vicinity of the sensor apertures. - Eliminate non-conductive areas on the	Small localized electrostatic charging is acceptable if they do not significantly perturb the energy of the particles at the lowest energy range. ~ 1V is acceptable.

	spacecraft surface, particularly close to the sensor apertures.	
Special accommodation requirements	Minimized obstructions of the FOV. Sensitive to s/c differential charging: the instrument apertures must be as far as possible from possible electrostatic charged area	
Commanding/Modes of operation	Main modes: 1) Onboard moments/compressed 3D distributions/pitch angle distributions. 2) Full 3D distribution at highest cadence (burst mode ?). 3) Calibration/Engineering mode.	
Inter-instrument links/dependencies	Magnetometer data if onboard pitch angle distributions required.	
Orbit, spin-rate, and related requirements	Time resolution directly proportional to the spin rate.	
Calibration requirements	Regular MCP test and monitoring.	cross calibration between sensors and with other instruments (on ground)
Data volume per package	150 kbytes/s (msphere) 16 kbytes/s (sw) Why is it so different between magnetosphere and solar wind	
On-board data handling or storage requirements	sufficient data memory (~1Gbit) and processing power to compute ion TOF, mass and handle compression	
Special requirements		
Radiation sensitive	MCP are radiation sensitive items (generation of noise, spurious signals, degradation of performance). Turn off in radiation belts.	Most critical items must be 100 krad qualified. (TBC)

8.7.3.11 Instrument Data Sheet Summary (IESA)

Element	Value/Range	Comments
Instrument Name	**Ion Electrostatic Analyser**	
Instrument Acronym	IESA	
Description	Single-head 3D ion electrostatic analyser 3eV–40keV	No mass determination
Heritage	Cluster – Themis	
Detector type	Top-Hat Electrostatic detector	
Overall characteristics and performance. How instrument matches Science Requirement, including s/c on which it needs to be deployed.		
Measurement Range(s)	At electron and ion scales: 3 eV - 40	

	keV, 32 energy bins, 16 polar bins, 32 azimuth bins	
Measurement Resolution/Accuracy	ΔE/E ~ 10% for 32 energy bins ~11°x11° angular resolution	
Field of View (per package)	360°x5° or 180°x 5°	Major obstructions of the FOV must be avoided. Obstruction by a thin boom or an antenna is acceptable. It should be less than an angular pixel (< 5°, typically)
Other detector characteristics		
Cadence	Full energy scan in 1/16 spin period (0.25 s)	If 360° coverage in azimuth, ½ spin period is needed to span 4π str. If 180° coverage in azimuth, 1 spin period is needed to span 4π str.
Volume per package	15x15x25 cm^3	
Mass per package	1.5 kg	
Power per package	1.5 W	
Power quality	28V spacecraft primary power. Power quality is arranged in the instrument.	The sensor produces and controls its own high voltages.
Detector thermal range and thermal stability requirements (operational and non-operational)	Operating temperatures -10°C +40º C Non-operating: -40°C to +50°C	Too high temperature (above 50°) could produce thermal runaway of the MCP detectors.
Mounting requirements	The plane of analysis can be: - tangent to the surface of the spacecraft -> 360° FOV - perpendicular to the surface -> 180° FOV To have 360°, the instrument must protrude (~ 10 cm).	To increase the time resolution, 2 ISA can be mounted on the same spacecraft. If 360° FOV, they must be at 90° one to the other (1/4 spin resolution). If 180° FOV, they must be at 180° one to the other (1/2 spin resolution).
Co-alignment requirements with respect to other P/L	None	
Special deployment & commissioning requirements	After launch, an outgassing period before turn on (a few days).	
Attitude accuracy	Not critical	The tolerance is a fraction of an angular pixel (1°)
EMC requirement	Electrostatic Minimise any exposed voltages; -	Small localized electrostatic charging is acceptable if they

	Care must be taken to ensure that the spacecraft surfaces are at spacecraft ground potential, particularly in the vicinity of the sensor apertures. - Eliminate non-conductive areas on the spacecraft surface, particularly close to the sensor apertures.	do not significantly perturb the energy of the particles at the lowest energy range. ~ 1V is acceptable.
Special accommodation requirements	Minimized obstructions of the FOV. Sensitive to s/c differential charging: the instrument apertures must be as far as possible from possible electrostatic charged area	
Commanding/Modes of operation	Three mode: 1) Onboard moments/compressed 3D distributions/pitch angle distributions. 2) Full 3D distribution at highest cadence (burst mode ?). 3) Calibration/Engineering mode.	
Inter-instrument links/dependencies	Magnetometer data if onboard pitch angle distributions required.	
Orbit, spin-rate, and related requirements	Time resolution directly proportional to the spin rate.	
Calibration requirements	Regular MCP test/monitoring;	cross calibration between sensors and with other instruments (on ground)
Data volume per package	~ 130 kb for a 3D (32x16x32) distribution	
On-board data handling or storage requirements	Onboard compression and/or moment calculations	
Special requirements		
Radiation sensitive items	MCP are radiation sensitive items (generation of noise, spurious signals, degradation of performance). Turn off in radiation belts.	Most critical items must be 100 krad qualified. (TBC)

8.8 High Energy Particle detector (HEP)

8.8.1 Introduction

The High Energy Particle instrument is focused on the detection of high energy ions and electrons. The current baseline concept is based on Cluster HEP

8.8.2 Science goals and performance requirements

The supra-thermal component of particle distributions is a ubiquitous feature of non-equilibrium, collision-less plasmas including those observed in the near-Earth environment. These populations are most readily described in terms of a kappa function representing a combination of a thermal Maxwellian distribution and a power-law tail. The non-thermal population and rapid field aligned transport, provide the unique capability to remotely sample the acceleration processes and mechanisms taking place within boundaries, shocks and regions of magnetic reconnection. Within the near-Earth plasma environment the non-thermal tail of the distribution is most commonly observed from a few tens of keV and above. The HEP instrument on CrossScale will measure the full 3D ion and electron particle distributions, at high temporal resolution (~16Hz) in the energy range from ~20 to 1000 keV, though telemetry constraints are likely to mean that only an onboard calculated pitch angle distribution (PAD) can be returned at the full time resolution.

Some of the areas of investigation to be undertaken using HEP will include:

- Addressing the fundamental question about the physical acceleration mechanisms and processes that give rise to the supra-thermal part of the particle distributions (e.g. at shocks and reconnection sites)
- Investigating the transport mechanisms that link the transfer of energy between the different scales. For example the effect at the different scales of percolation of energetic particles through a structured magnetic topology and the processes that maintain quasi-neutrality in a rapidly changing plasma environment.
- Understanding the loss of magnetic ordering within the X-line diffusion regions using the fast field aligned transport of the energetic particles.
- Plasma turbulence (with a particular emphasis on the transport between the different scales)
- Plasma instabilities (those driven by and those modifying the energetic particle distribution)
- Using the energetic particle observations to probe remote boundaries and their motions (e.g. using ion gyro radii effects), trace the magnetic topology at the different scales and to determine the temporal and spatial variations in the magnetic structures and connectivity (e.g. determining the magnetic connectivity to shock boundaries).

A key design feature of the HEP-3D is the ability to provide fast acquisition of the 3D energetic electron and ion distributions. This capability is vital for remote sensing of boundaries and in identifying fast changes in the magnetic field topology where continuous monitoring of the field aligned directions is required. The current strawman payload for Cross Scale does not include the HEP on the electron scale. While the electron and ion gyro radii for the energetic particles are larger than the spacecraft separation (of the order 50km and 3000km respectively) we note that continuous monitoring of the field parallel and anti-parallel directions, particularly for the fast energetic electrons, would be extremely valuable for the remote sampling of thin sheets related with reconnection sites. In the case of counter-streaming beams it might be possible to use differences observed at the electron scale to assess the convection of the beam between the original and return directions (though modelling will be required to assess the feasibility of this). As a minimum there is a requirement to have a HEP on at least one spacecraft at the electron scale so that the link and magnetic topology within the different scales can be determined. This could be achieved if the electron and ion scales share a spacecraft (TBD).

8.8.3 Instrument description

A prospective instrument concept consists of a simple ‘pin-hole’ design utilising ion implanted silicon solid state detectors to measure supra-thermal ion and electron distributions in the energy range from ~20-1000 keV. The sensor unit comprises a set of detector modules that are similar in design to those adopted for the

Imaging Electron Spectrometer (IES) instruments flown on the NASA/Polar and ESA/Cluster spacecraft both of which are still operating successfully after ten and six years respectively. Each energetic electron detection module incorporates a 'pin-hole' aperture, foil and Silicon Solid State Detector (SSD) segmented to provide the desired angular resolution within each modules overall field of view. Multiple modules are mounted in order to provide either a 2D coverage (HEP-2D) which measures a full 3D distribution over the course of a spin, or two oppositely mounted sensor units, each providing FOV (Figure 1), which are combined to measure a full 3D distribution at sub-spin resolution (HEP- 3D).The ion module operates in a similar way but without the foil. Development of a combined electron/ion module is currently under investigation.

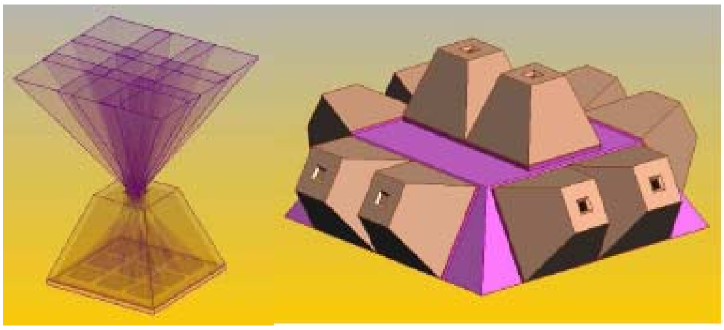

Figure 14: Schematic of the modular detector unit, segmented detectors and fly's eye concept used to provide 2 FOV per sensor unit within a HEP-3D instrument

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The signals from each SSD element are fed to a front-end, low noise, multi-channel pre-amp with multiplexed digitisation and data readout Application Specific Integrated Circuit (ASIC). This requires minimal external components and is fundamental to the miniaturisation and simplified modular design of the instrument. A next generation of ASIC is planned for use in this instrument which is expected to have its first flight opportunity in the IEPS instrument on the Chinese KuaFu mission, 2012/13 launch. The new ASIC, which incorporates an on-chip 12bit ADC, is to be adapted from an existing design which in turn is a major advance on the MX/RP used in the previous generation of IES instruments flown on Cluster and Polar. The remaining sensor unit electronics consist of data buffering, interface to a dedicated or central data processing unit, and power converters for the SSD bias voltage. For Cross-Scale instruments based on two instrument configurations could be considered. The modular detector design simplifies the provision of a 2D and 3D configuration although there is clearly development and cost benefits if the same 3D unit could be accommodated across all spacecraft scales.

For the ion scale length two oppositely mounted units that together provide full 3D coverage at sub-spin resolution (HEP-3D) and therefore allow continuous monitoring of the field parallel and anti-parallel directions which is important for detection of short bursts of energetic particles that are expected from reconnection sites. For the fluid scale a single sensor unit is proposed with modules oriented to provide 2D coverage in the plane of the spin axis (HEP-2D) with a full distribution accumulated over the course of a spin.

8.8.3.1 Orbit, Operations and Pointing Requirements

- The accommodation of the sensor units is assumed to follow the baseline specified in the Cross-Scale Cosmic Vision proposal. Units will be mounted on universal plates with the detector modules protruding from the spacecraft such that they have an unobstructed view of space.

8.8.3.2 Interface and Physical Resource Requirements

TBD

8.8.3.3 Calibration

TBD

8.8.3.4 Cleanliness, EMC issues and pre-launch activities

TBD

8.8.3.5 Critical Points

A key issue for the HEP instrument will be the capabilities of the CPP and the link between the CPP and HEP sensor units. The HEP instrument assumes that the CPP will:

- Handle all inter-experiment link and spacecraft interfaces such as sun sensor and clock.
- Deal with data processing/compression/storage
- The HEP to CPP will be able to handle the transfer of full 3D distributions at rates up to 16Hz.
- Have sufficient processing power to combine magnetic field information obtained from the magnetometer and particle distributions from HEP to generate pitch angle distributions at 16Hz and averaged 3D particle distributions at 2Hz.

It is not definite whether all interfaces (power, data etc) to the HEP sensor units are handled through the CPP. It is assumed that the power converters will be required within each of the sensor heads in order to generate the ~200V bias voltage for the solid state detectors. Information on the available voltages available shall be required.

8.8.3.6 Heritage

A possible two-dimensional HEP instrument has flown on Cluster. A 3D design would be a new development.

8.8.3.7 Instrument Data Sheet Summary

Element	Value/Range	Comments
Instrument Name	High Energy Particles	
Instrument acronym	HEP	See CV proposal
Description	A medium energy (~20keV to ~1MeV) electron and ion spectrometer. The instrument uses a set of detector modules to provide the desired angular coverage required to meet the science requirements. Two configurations are considered which could be applied to the different spatial scales though having a single configuration that could be used on all scale lengths would simplify the development, build and AIT. The 2D configuration takes an azimuthal slice that is built up into a full distribution over the course of the spin. The 3D configuration uses a fly's-eye arrangement of modules, and two oppositely mounted sensor units, to provide a full 4 pi FOV. This will be vital for scales shorter than the fluid length where rapid (sub-	

	spin) acquisition of the full energetic particle distribution and continuous monitoring of the field aligned directions are required.	
Heritage	The instrument design is building on the heritage of the 2D electron spectrometer (IES) instrument that has successfully operated on Polar (1996 to present) and Cluster (2000 to present). The current development is a new instrument (hence the low TRL described above) but is based on the same, conceptually simple and robust pin-hole, and solid state detector design that has been used on numerous magnetospheric missions. The first version of this instrument, called the IEPS), is currently in the early design phase as part of the payload for the Chinese KuaFu-B spacecraft due for launch in 2012/13. It will incorporate all the key technology developments including fast acquisition of full 3D distribution and low mass/power electronics based on existing hybrid ASIC development work at RAL.	
Detector type	Silicon solid state detector. The incident energetic particles generate electronhole pairs that are collected to form to produce a signal pulse proportional to the energy of the incident particle. The signal from each particle event is amplified by the front end electronics, digitised and counted to form a pulse height distribution corresponding to the energy spectrum of the measured particles. Electrons: ~1000um Ions: ~150us Detector thickness optimised for energy range and to minimise contamination from more energetic particles. Electron detectors use a metalized layer/foil for photon and proton rejection.	
Measurement Range (s)	Energetic electrons and ions: Electrons ~20keV to ~800keV Ions: ~40keV to ~1MeV	*HEP Note:* *1) There is some flexibility in the top energy range by selection of appropriate detector thickness.* *2) The ion instrument does not distinguish between different ion species.*

Measurement Resolution/Accuracy	Energy resolution 6keV or ~ 30-40%	energy, angle, frequency, etc.
Field of View (per package)	Fast 3D instrument makes use two oppositely mounted units each with 180x180º FOV allowing full 3D distribution to be accumulated at subspin resolution. Suitable for ion scale. The 2D configuration uses a single sensor unit with ~20x180º (fan oriented perpendicular to the spin plane). A full 3D distribution is accumulated over spin. Suitable for fluid scale.	FoV angle
Other detector characteristics	Sensor size to be optimised to the measurement requirements. Each detector will be ~0.75cm2 in order to provide the geometric factor required for low flux regions. Depending on detailed measurement requirements the individual detectors can be sub-divided to provide enhanced angular resolution. Level of sub-division is constrained by signal to noise and number of available input channels on the ASIC.	Characteristics like pixel size, QE, etc.
Cadence	Ion and Electron Scale: With the proposed two 180x180 FOV sensor units a full 3D distribution can be accumulated continuously and with short integrations. The major constraints are obtaining sufficient counts within the integration period and telemetry handling limitations. Realistic goals would be full 3D distribution at 2Hz with enhanced sampling of the field parallel aligned and perpendicular directions at 8-16Hz. Fluid Scale: The optimal solution would be to use the same configuration as for the ion scale thus allowing continuous monitoring, and therefore remote sampling, of the field aligned distributions. The strawman does not have sufficient resources (mass, power and accommodation) to support this scenario. Instead the baseline would be to use the 2D, single unit, instrument configuration which will obtain a full 3D distribution over a spin (~ 0.5 Hz assuming a 30 rpm spin)	
Volume per package	3D configuration: 20x10x20cm 2D configuration: 20x10x20cm X, Z is the footprint, Z	if orientation relevant, describe relation of each dimension to mounting requirements *HEP Note: These sizes assume the unit just with*

	spin axis direction, Y is the depth.	*fewer detector modules in the case of the 2D instrument. There is a possibility of reducing the X dimension to ~10cm which would result in a small mass use of the same modular saving but additional development costs/risks.*
Mass per package	3D configuration: ~1.7kg +20% 2D configuration: ~1kg +20%	*HEP Note: Strawman configuration is 2x3D units on the Ion scale and 1x2D unit on the fluid scale. See comments in the main text for alternative configurations and justification.*
Power per package	3D configuration ~2.0W 2D configuration ~1.3W	*HEP Note: Unit consists of N x detector modules power ~100mW plus ~1W for power conversion (inc ~160V for SSD bias voltage), FPGA and CPP interface.* *HEP Note: These figures assume that all the instrument DPU functionality including, sensor unit control, data formatting, interexperiment link with the magnetometer and spacecraft interface, is handled by the separate CPP.*
Power quality	Spike <+/-2.5V for < 8ms Ripple < 1%	spike, ripple, ...
Detector thermal range and thermal stability requirements operational and non-operational)	-30 to +40 Operational -40 to +50 non-operational	
Mounting and grounding requirements	(As per strawman) I2-4, C and G Fluid, H	*HEP Note: Having Identical instruments on all scales would be preferred. In particular having a HEP-3D on at least one electron scale spacecraft. Having HEP-3D rather than HEP-2D on the fluid scale would also be beneficial.*
Co-alignment	For HEP-3D the two	

requirements with respect to other P/L	sensor units should be mounted 180q apart with alignment accuracy <1º (Sun sensor information?)	
Special deployment & commissioning requirements	No special deployment requirements. Commissioning should take place after the magnetometer to allow verification of on board field direction	*HEP Note: On the ground, magnetic field (MAG) data used for production of pitch angle distribution and thermal plasma electron and ion (CESA) used to produce ion and electron distribution over full energy range.*
Attitude accuracy	<1°	
EMC requirement	No special requirements	
Special accommodation requirements	For HEP-3D configuration need unobstructed 180x180º field of view. For the HEP-2D configuration need ~20º azimuthal by 180 º polar FOV. I.e. the modules on each sensor unit protrude from body of spacecraft	
Commanding/Modes of operation	TBD Off None (0 W) Standby HK (2.0 W) Science mode HK (2.0W) Science (2.0 W) Burst mode? HK (2.0W) Science (2.0W) Calibration HK (2.0W) Calib (2.0W)	*HEP Note: these modes need to be coordinated with the CPP modes. Different modes are unlikely to have large impact on power consumption.*
Inter-instrument links/dependencies	Inter-experiment link with the magnetometer required for field direction determination. Sun sensor information. This will most likely be handled by the CPP and so there is not requirement for this information to be passed to the HEP sensor units.	*HEP Note: The main reason for this is so that telemetry can be reduced by extracting most scientifically interesting parts of the distribution. An alternative is to return the full 3D distribution at maximum resolution but this requires more telemetry!*
Orbit, spin-rate, and related requirements	The baseline spin rates of 20-40 rpm are fine.	
Calibration requirements	Cross-calibration with combined electron/ion analyser needed	
Data volume per package	Ion/Electron scales: 3D distribution: 18 az,	*HEP Note: These values are currently in*

	9 po, 10E, 2s @ 2Hz ~ 13.5kB/s Par, anti-par, perp: 3dir ,10E, 2s @ 16Hz ~2KB/s (assume 2 byte words. Az=azimuthal, po=polar, E=energy, s=species, dir=directions) We note that there appears to be an error in the calculation of the data volume for HEP given in the cross-scale strawman.	*kBytes/s not kbits.* *HEP Note: Data volumes per orbit will require further information on orbit duration and operations strategy. HEP Note: A better option to the direction product would be onboard calculation of the full PA distribution (e.g. in 9 rather than 3 directions). This would increase the size of the itch angle product to 6KB/s. To provide this would place a bigger load on the CPP.*
On-board data handling or storage requirements	Depends on capabilities of CPP. Default would be one each of 3D electron and 3D ion per sensor unit per spin (2D instrument). 3D instruments can produce more data which would require further processing in the CPP to reduce to manageable size (see comments above).	
Special requirements	None specified	
Radiation sensitive items	TBD but instruments such as Cluster RAPID which is in a somewhat similar orbit has operated for 6 years, Polar /CEPPAD which has a lower perigee/apogee has operated successfully for 10+ years	

8.9 Common Payload Processor (CPP)

8.9.1 Introduction

This section illustrates how the problem of optimizing and reducing resources might be addressed by adopting a common on-board processing unit. The case shown here refers to a plasma suite which includes EESA, CESA, CEIA and ICA instruments, but it may be transferred to other groups of instruments onboard Cross-Scale S/C. A similar structure has been adopted on SERENA particle suite on the Bepi-Colombo spacecraft and proposed on SWA plasma suite for Solar Orbiter spacecraft.

8.9.2 Science goals and performance requirements

The CPP will be requested to provide instrument functionality control, memory and computational capability in order to perform the following functions:

1. Receive and decode commands from S/C via the Main and Redundant SpaceWire dedicated link.
2. Control and managing all the EESA, CESA CEIA, and ICA functions. Possibly also for HEP and maybe ECA
3. Buffer for the S/C On Board Data Handling (OBDH) a certain number of complete spectra records received from the sensors;
4. Compress / scale, arrange in pitch-angle (and therefore requires information of the MAG measurement), format & transmit sensors spectra according to the available S/C TLM allocation;
5. For lossy compression, verify the full functionality of the local DSP compressor, send to / retrieve from DSP raw data / compressed blocks.
6. Provide power supplies for DPU itself, and distribute power by latching current limiters to EESA, CESA, CEIA and ICA units.
7. Verify continuously the health status of the DPU both from H/W point of view (sensing of the power supplies lines, critical temperatures e.g. DC-DC converter) and from S/W point of view (continuous checking of consistency of the checksum appended to all critical tables: operational tables, context tables, RTOS parameters, etc).

Time to time the particle suite package would be operated in calibration mode or in high resolution timing mode, thus transmitting raw time tagged events. Each event will be represented by a stream of bits. The data rate in this case will depend on the incoming flux.

8.9.3 Instrument description

The DPU will be equipped with a FPGA based processor, in this case a Leon 3 FT (FT: i.e. Fault Tolerant) derived processor, able to provide instrument operations control and perform loss-less data compression. The Leon 3 FT represents, at present, the top DPU reference design for FPGA based space applications and its validity is not further discussed here. The ancillary customized resources block will be developed to guarantee a similar security standard as for example the embedded EDAC (Error Detection Automatic Correction) already developed in the frame of the SWA DPU design. Apart for the nominal operation, it will be optionally possible to switch to loss controlled DSP based compression operation by a dedicated configurable error parameter.
The basic sensor interfaces to the DPU core architecture are shown in the following Figure 15.

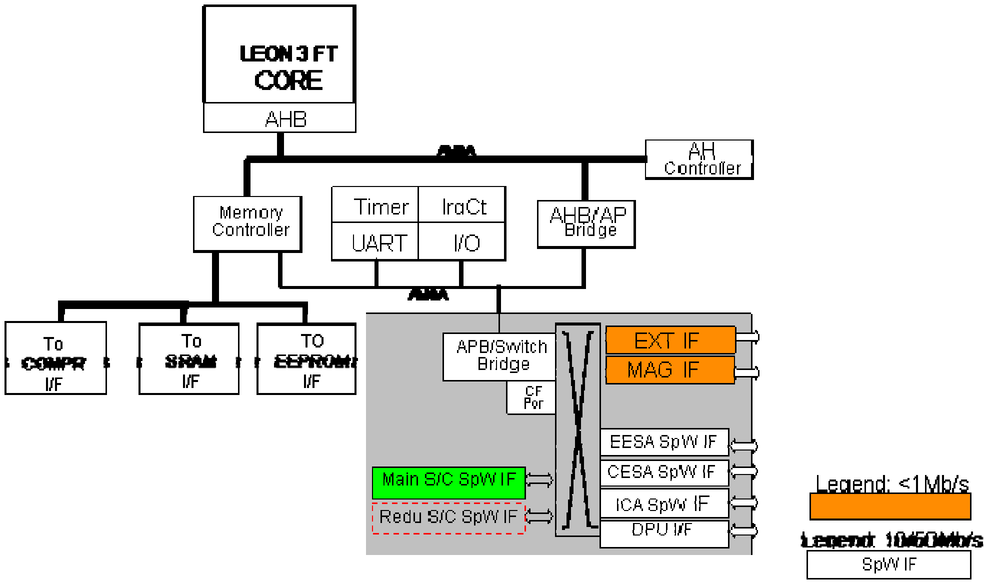

Figure 15: DPU Core architecture

Instrument Software Architecture

The on board management and processing of data is performed by a combination of the HW (FPGA) resident in detectors peripherals and the SW and the HW processing units (FPGA, DSP Compressor), resident in the CPP. The Data Handling System (SDHS) consists of:

- A Virtual VHDL microprocessor (custom LEON 3 CPU based) with its related instrument application firmware. This is the main high-reliability processor, which will work as main particle suite interface
- A DSP data compressor and its related DSP compressor application firmware for demanding data rate compressions.

In general, the software will be divided into an execution-software (a) and into an application software (b).

8.9.3.1 Instrument concept

Common Payload Processor concept is based on combining the requirements for data handling, processing and storage into one single unit.

8.9.3.2 Orbit, Operations and Pointing Requirements

CPP Telemetry Operating Modes

- In Stand-by state only housekeeping telemetry would be supported;
- In Diagnostic TM mode the unit will go into a minimum performance and operability state. No science TM would be provided;
- In Low TM mode the unit would be set to its nominal state to provide science support and allowing for loss-less data compression;
- In Burst TM mode the system will power up and initialize the DSP compressor. The nominal performances of the DPU will be increased, so as to exploit the DSP performances in order to support also lossy data compression.

The possible operation of cross-scale is to get BM data all the time, compress it in survey data, download the survey data and then from these select period where BM should be downloaded. Is it compatible?

8.9.3.3 Interface and Physical Resource Requirements

TBD, see datasheet

8.9.3.4 Calibration

TBD

8.9.3.5 Cleanliness, EMC issues and pre-launch activities

TBD

8.9.3.6 Critical Points

The critical point of a CPP is the testing of the interfaces with all other instruments. When one instrument is delayed the CPP is also automatically delayed. From a programmatics point of view this could become a problem.

The logistics of having elements of all instruments connected to the CPP can become troublesome too. A detailed schedule shall be determined to ensure a smooth testing period of the CPP.

8.9.3.7 Heritage

INAF-IFSI has a long experience in DPU H/W and S/W development thanks to synergistic collaboration with the AMDL srl, a spinoff company originated from INAF/IFSI. The proposed DPU (CPP) is essentially made by three parts:
(1) The power distribution subsystem
(2) The main controller FPGA hub
(3)The Compressor Unit

FORMER AMDL's related experiences:

- CLUSTER CIS-2: *DPU Designing & On-Board S/W (MAS281)*
- DARA-NASA EQUATOR-S ESIC: *On-Board S/W (MAS281)*
- DMARS-96 &ESA MARS EXPRESS PFS: *FFT DPU Design & On-Board S/W (AD21000)*
- DOUBLE STAR HIA: *Composition Experiment OnBoard S/W (MAS281)*
- ESA SMART-1 AMIE: *Microcamera - Power supply & S/C I/F board*
- NASA/JPL DAWN: *VIR On board compression S/W & GSE*

CURRENT AMDL's related experiences:

ESA BEPICOLOMBO SERENA: *PM and Design Manager*

ESA EXOMARS IRAS: *Electronics Design Manager*

Figure 16: Family of processors flown by INAF-IFSI

For the first two items well proven design solutions will be inherited, e.g. the recent AMIE experiment, successfully flown in the frame ESA SMART-1 mission, for which AMDL srl implemented the experiment power and S/C I/F unit. Concerning the compression unit, AMDL srl already produced and tested the second generation of the 3^{Cube} Processor family and this class of devices has been already assessed and used in the frame of the ESA Dalomis Planetary Microprobes ITT. Moreover the first generation of the the 3^{Cube} family was also presented in the frame of the ESA EXOMARS / Pasteur rover . A list of projects contributing to form the heritage for CPP is given below:

(2) Experiment	CIS/ESA-Cluster I	4xOn board DPU and on board S/W
(1) Experiment	CIS/ESA-Cluster II	4xOn board DPU and on board S/W
(2) Experiment	PFS/SovietUnion-Mars’96	On board FFT- DPU and on board S/W
(1) Experiment	PFS/ESA-MEX	On board FFT- DPU and on board S/W
(2) Experiment	ESIC/ DLR-ESA-Equator-S	On board S/W, Ground Support Equipment
(1) Experiment	Ibis-/ESA-INTEGRAL	Management of Operations (EM/QM)
(2) Experiment	Amie/ESA-SMART1	Power system and on board communication
(1) Experiment	CIS2/China Republic-DoubleStar	On board DPU and on board S/W
(1) Experiment	VIR/NASA-DAWN	On board scient. S/W & GSE
(4) Experiment	NPA/ESA-BepiColombo	Instrument designer & Experiment Manager.
(4) Experiment	Exomars/ESA-MARE	Instrument designer & Experiment Manager.

(1) In flight & Operative, (2) Flown in the past (3) To be flown in a short while, (4) to be built

It is unclear whether there is any experience on handling more than one instrument by this particular CPP. More information TBD.

Table 4: Overview of missions with DPUs from INAF-IFSI

8.9.3.8 Technology Reference Level (TRL)

At the present, the CPP TRL is difficult to estimate for the complete definition on what the CPP should is not defined.

8.9.3.9 Instrument Data Sheet Summary

Element	**Value/Range**	**Comments**
Instrument Name		
Instrument Acronym	CPP	see CV Proposal
Description	Common DPU for plasma suite experiment	
Heritage	CIS/ESA-Cluster I (CIS/ESA-	

	Cluster II PFS/SovietUnion-Mars'96 PFS/ESA-MEX ESIC/ DLR-ESA-Equator-S Ibis-/ESA-INTEGRAL Amie/ESA-SMART1 CIS2/DoubleStar VIR/NASA-DAWN NPA/ESA-BepiColombo Exomars/ESA-MARE	
Detector type		
Measurement Range(s)		
Measurement Resolution/Accuracy		energy, angle, frequency, etc.
Field of View (per package)		FoV angle
Other detector characteristics		Characteristics like pixel size, QE, etc.
Cadence		
Volume per package	**200x120x75 mm**	if orientation relevant, describe relation of each dimension to mounting requirements
Mass per package	**1.2 kg TBC (depends on number of instruments controlled by CPP)**	
Power per package	**2.85 W TBC (depends on number of instruments controlled by CPP)**	
Power quality		spike, ripple, ...
Detector thermal range and thermal stability requirements (operational and non-operational)		
Mounting and grounding requirements		
Co-alignment requirements with respect to other P/L		
Special deployment & commissioning requirements		
Attitude accuracy		
EMC requirement		
Special accommodation		

requirements		
Commanding/Modes of operation	**DPU TM Modes:** 1- **Diagnostic** **2- Low TM** 3- **Burst TM**	
Inter-instrument links/dependencies		
Orbit, spin-rate, and related requirements		
Calibration requirements		
Data volume per package		
On-board data handling or storage requirements		
Special requirements		
Radiation sensitive items		

All values are per "package" unless otherwise indicated. Total on any s/c depends on number of "packages" per s/c, which may be different depending on which s/c.

8.10 Active Spacecraft Potential Control (ASPOC)

8.10.1 Introduction

The ASPOC instrument measures and counteracts the effect of charging of the S/C.

8.10.2 Science goals and performance requirements

In order to perform exact plasma observations at energies close to the satellite potential a satellite potential control device is needed. ASPOC reduces the positive spacecraft potential by emitting an ion beam of a few keV energy. The beam current sets an upper limit to the potential which corresponds to the lower end of the energy band measured by the plasma instrumentation.

8.10.3 Instrument description

The instrument ASPOC emits a beam of positive ions (species is indium) at energies of about 4 to 10 keV and currents up to 50 μA in order to control the electrical potential of the spacecraft. The emission of positive charges from the spacecraft balances the excess of charge accumulating on the vehicle from interactions with the environment in the presence of photo-emission. By adjusting the positive emission current, the spacecraft potential can be adjusted to single-digit positive values. The resulting potential is a function of spacecraft size and shape, the photo-emission properties of the surfaces, the emitted ion beam current, and the characteristics (mainly the density) of the ambient plasma. For a spacecraft of half the sunlit area of the Cluster spacecraft and similar surface parameters, a beam current of 10 µA will be sufficient to set an upper limit to the spacecraft potential of about 5 V. Using up to 50 µA beam current, potentials as low as 2 V are feasible.

The ion emitters are "solid needle" - type liquid metal ion sources using indium as charge material. A solid needle, made of tungsten, is mounted in a heated reservoir with the charge material. A potential of 4 to 10 kV is applied between the needle and an extractor electrode. If the needle is well wetted by the liquid metal, the electrostatic stress at the needle tip pulls the liquid metal towards the extractor electrode and a cone with a tip diameter of a few nm is formed. Field evaporation takes place at the tip and and ion beam is formed. Indium has extremely low vapour pressure, preventing contamination of the source insulators and ambient spacecraft surfaces.

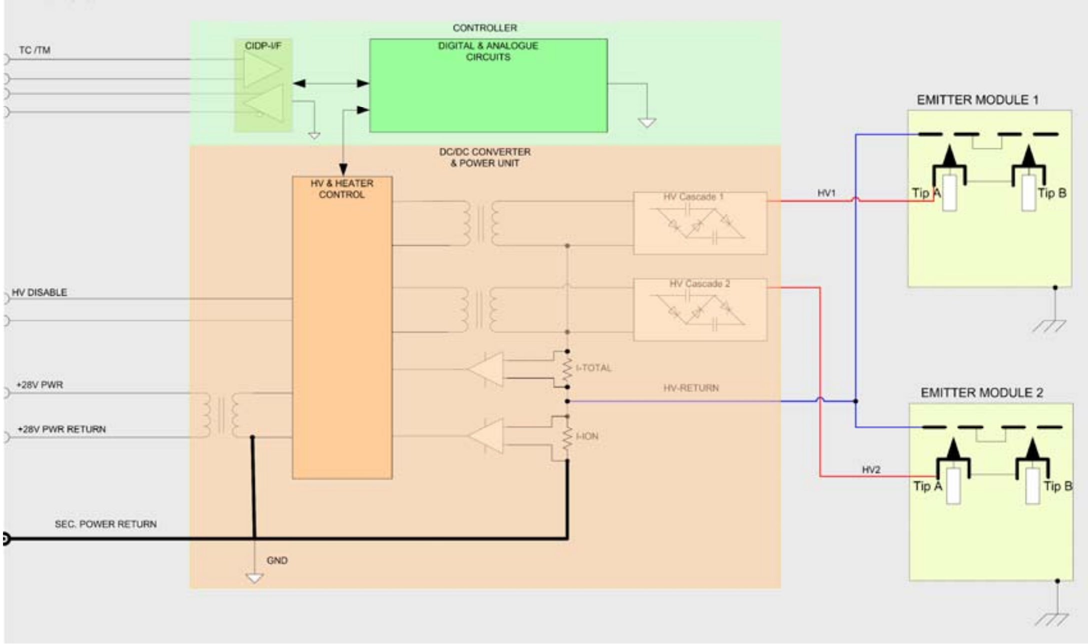

Figure 17: Block diagram of ASP instrument

The main constituents of the ASPOC instrument are shown in the block diagram (Figure 17).
- There are two pairs (in total 4) individual ion emitters. Each pair is connected to a dedicated high voltage supply. The ion emitters have heater elements (typical power 0.5 W) to bring the indium in the small reservoir (about 0.5 g) of the active emitter into liquid state (melting point at 156 C). Only one emitter is active at a time. Four emitters are present for lifetime and redundancy reasons. Heritage emitters have demonstrated to achieve up to 100,000 µAh. If necessary to fulfil lifetime and/or redundancy requirements, additional emitters can be added with only small impact on overall mass.
- A low voltage power converter provides the necessary secondary voltages and power to the heater element of the active ion emitter.
- Two high voltage converters provide the extraction voltages of typically 4 to 10 kV.
- A controller based on a microprocessor core running in an FPGA provides the interfaces to the spacecraft data and command system and controls the power supplies.

8.10.3.1 Orbit, Operations and Pointing Requirements

TBD

8.10.3.2 Interface and Physical Resource Requirements

The ion beam emitted by the ASPOC instrument has an opening angle of about +/-30 deg (depending on beam current). The direction of the ion beam axis should be as far as possible away from the electric field probes. A boresight direction of about 45 deg off the spin plane would be a possibility. The near vicinity of the low energy plasma sensors and spacecraft thrusters should be avoided.
The emitter modules (the front end) and the electronics box form a single mechanical unit in order to reduce mass and complexity. The ion emitter modules are two cylinders of about 6 cm diameter. They shall protrude through the spacecraft skin. A possible location is the top or bottom panel of the spacecraft.

8.10.3.3 Calibration

TBD

8.10.3.4 Cleanliness, EMC issues and pre-launch activities

TBD

8.10.3.5 Critical Points

There are no known critical issues. Trade-off studies might be made as to whether the instrument electronics (DPU and low voltage power converter) can be merged with another unit. The high voltage supplies will in any case have to be dedicated to ASPOC. The mass and power requirements depend to some extent on the radiation situation and the requirement on the level of spacecraft potential and emitter lifetime. For all these, the experience from the Cluster mission was used as a baseline.

8.10.3.6 Heritage

The instrument has been flown in several missions: Geotail, Equator-S, Cluster, and recently Double Star TC-1. It has also been selected for the NASA MMS mission.

8.10.3.7 Instrument Data Sheet Summary

Element	Value/Range	Comments
Instrument Name	Active Spacecraft POtential Control	
Instrument Acronym		see CV Proposal
Description	Emitter of high-energy positive ions (indium) to clamp the spacecraft potential to low values.	
Heritage	Geotail, Equator-S, Cluster, Double Star TC-1, MMS	
Detector type	Liquid metal ion sources using indium. A beam of 4 to 10 keV ions is extracted from a needle covered wiht liquid indium	
Measurement Range(s)	Typical ion beam current: 10 to 20 µA. Maximum current: 50 µA.	

	Lifetime is determined by size of indium reservoir. The instrument as described supports the mission lifetime using typical currents. The resulting upper limit to the spacecraft potential is determined by spacecraft parameters. Expected values are 4 to 5 V for typical currents.	
Measurement Resolution/Accuracy	Beam current: 0.1 µA	energy, angle, frequency, etc.
Field of View (per package)	Ion beam width typically +/-30 deg full width. Unobstructed field of view of 45 deg is recommended.	FoV angle
Other detector characteristics	Nominal lifetime at 20 µA beam current is 16,000 hours with 4 individual emitters.	Characteristics like pixel size, QE, etc.
Cadence	1 unit per electron spacecraft	
Volume per package	Emitters: 2 cylinders each 60 mm high, 60 mm diameter. Box (attached to emitters): 200x120x100mm	if orientation relevant, describe relation of each dimension to mounting requirements
Mass per package	2 kg (includes two emitter modules with 160 g each)	
Power per package	4 W (current best estimate at 20 µA beam current, after derating)	
Power quality	no particular requirements	spike, ripple, ...
Detector thermal range and thermal stability requirements (operational and non-operational)	-20 to +40 C op -30 to +50 C nonop	
Mounting and grounding requirements	Ion beam axis shall point at least 45 deg away from radial and axial booms. Location at top or bottom panel. Conductive spacecraft surfaces are required.	
Co-alignment requirements with respect to other P/L	Ion beam axis shall be at least 45 deg away from radial and axial booms. Accuracy is uncritical.	
Special deployment & commissioning requirements	Allow 4 weeks for outgassing after launch before high voltage turn-on	
Attitude accuracy	no particular requirements	
EMC requirement	no particular requirements	
Special accommodation requirements	no particular requirements	
Commanding/Modes of operation	active mode: 4 W power, extended housekeeping data including emitter and beam parameters, ca. 100 bps standby mode: 2.5 W power, minimal housekeeping, ca. 10 bps	

Inter-instrument links/dependencies	Link from electric field probes with spacecraft potential data allows to control the potential more accurately than by emitting a constant ion beam	
Orbit, spin-rate, and related requirements	no particular requirements	
Calibration requirements	no particular requirements	
Data volume per package	data rate: 0.1 kbit/s in active mode	
On-board data handling or storage requirements	Monitoring of out-of-limits	
Special requirements	no particular requirements	
Radiation sensitive items	typical requirements for electronics. The mass quoted above includes about 1 mm minimum wall thickness of the electronics box.	

9 PAYLOAD SUPPORT ELEMENTS (PSE)

The Payload Support Elements (PSE) are instrument specific items required for a proper accommodation of the instruments on-board the spacecraft. They include thermal control units whose characteristics and procurement is strictly linked to the design of the spacecraft heat shield (*e.g.,* instrument covers/doors, heat rejection windows, thermal straps).

The resource required by the PSE items is accounted for in addition to the payload units. To date the following items are included in the PSE:

Payload Support Element	**Description / justification**	**Nominal Mass (kg)**	**Maturity Margin (%)**	**Total Mass (kg)**
Boom	ACB and MAG need booms to reduce S/C magnetic field influence	TBD (THEMIS discussion)		
harness	All instruments	TBD		