The Detection System of the Double Focusing Mass Spectrometer (DFMS) for the ROSINA Experiment on the Rosetta Mission

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ABSTRACT

The Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (ROSINA) is one of the key instruments on board the Rosetta spacecraft, fulfilling several of the main scientific objectives of this mission to comet Wirtanen. It will analyze the composition and different interactions in the cometary atmosphere by means of three sensors, one of which is the Double Focusing Mass Spectrometer (DFMS). This paper describes the detection system of DFMS.

INTRODUCTION

Rosetta is the third cornerstone mission in ESA's Horizon 2000+ programme. The mission is named after the Rosetta stone, which was the key that unlocked the secrets of ancient Egyptian hieroglyphics. A rendezvous with Comet 46/P Wirtanen is the destination of ESA's Rosetta mission. The prime scientific objective is to study the origin of comets, the relationship between cometary and interstellar material and its implications with regard to the origin of the solar system. Rosetta will study the fabric of the comet and land a small probe (Rosetta Lander) on its surface.

Cometary nuclei, the prime target bodies of the Rosetta mission, represent the most primitive solar system bodies. They are assumed to have kept a record of the physical and chemical processes that prevailed during the early stages of the evolution of the solar system.

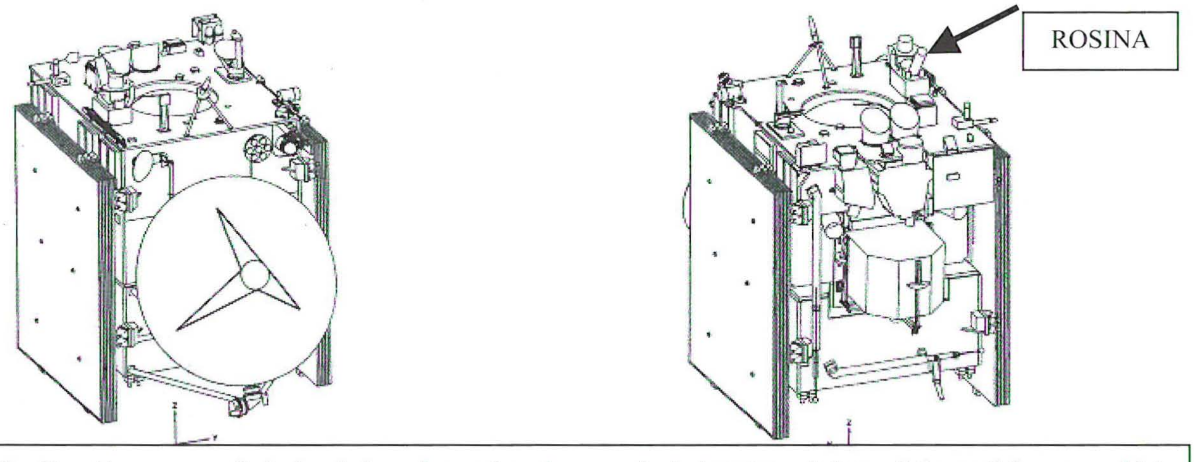
It is the abundance of volatile material in comets that makes them particularly important and extraordinary objects : they demonstrate that comets were formed at large heliocentric distances and have been preserved at low temperatures since their formation. Cometary material therefore represents the closest we can get to early condensates in the solar nebula. The tremendous potential of cometary material for providing on the constituents and early evolution of the solar nebula has yet to be exploited.

One of the instruments in the Rosetta payload is ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis). ROSINA consists of three separate subsystems, one of which is the DFMS, a Double Focusing Mass Spectrometer. DFMS is developed under the responsibility of the University of Bern (Switzerland) (Principal Investigator). BIRA-IASB and CETP are co-investigators in the ROSINA experiment and responsible for the construction of the detection system and its corresponding electronics for the DFMS spectrometer.

The Rosetta mission and spacecraft

The Rosetta mission has specifically been designed to achieve this important scientific goal by focusing on in situ investigations of cometary material. The surface-science package will provide information on the chemical and physical properties of a selected area. It should also be possible to determine the isotopic composition. This information will be used as ground-truth for high-resolution coverage of the nucleus by state-of-the-art remote-sensing investigations. Sophisticated in situ analyses will be performed on the dust grains and the gas flowing out from the nucleus. The physico-chemical processes that link material in the coma to volatile and refractory species in the nucleus will also be investigated. To achieve these goals, the spacecraft will remain most of the mission within a few tens of kilometers of the nucleus. Here the analyzed dust and gas is likely to present minimal alterations relative to surface material and it can be traced back to specific active regions on the cometary nucleus. The physics of the outer coma and the interaction with the solar wind will also be studied.

Rosetta is scheduled for launch from the Kuru base in French Guyana in January 2003 on board an Ariane-5 rocket. It will take eight years to reach comet Wirtanen. Rosetta will then orbit it for the next two years. In order to get there, Rosetta needs to pass by Earth (2005 and 2007) and Mars (2005) for gravity-assisted swingby's. On its long journey it will also encounter a pair of asteroids (Ottawara in 2006 and Siwa in 2008). Rosetta will study the nucleus of comet Wirtanen and its environment in great detail for a period of approximately 18 months, the near-nucleus phase starting at a heliocentric distance of about 3.25 AU, with far-observation activities leading ultimately to close observation (from about 1 km distance). The nominal end of the mission is then foreseen on July 9th 2013.



The Rosetta spacecraft design is based on a box-type central structure, 2.8 m x 2.1 m x 2.0 m, on which all subsystems and payload equipment are mounted. Two solar panels, each of 32 square meters, extend outwards, giving a total span of about 32 m tip to tip.

The ROSINA instrument

One of the instruments of the Rosetta payload is ROSINA. ROSINA is the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis. It is dedicated to the study of the composition and interactions in the cometary atmosphere and ionosphere. It consists of three sensors: RTOF (Reflectron Time Of Flight mass spectrometer), DFMS (Double Focusing Mass Spectrometer) and COPS (COmetary Pressure Sensor).

In determining the composition of the atmospheres and ionospheres of comets, the following prime scientific objectives will be achieved :

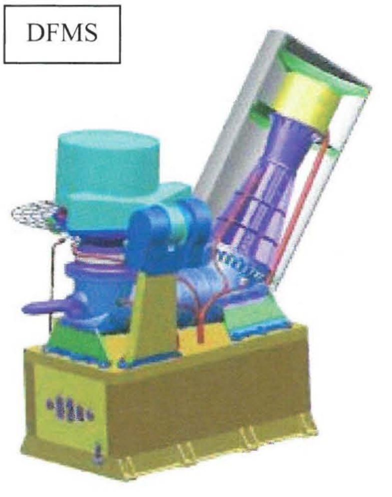
- to determine the global molecular, elemental and isotopic composition and the physical, chemical and morphological character of the cometary nucleus;
- to determine the processes by which the dusty cometary atmosphere and ionosphere are formed and to characterize their dynamics as a function of time, heliocentric and cometocentric position;
- to investigate the origin of comets, the relationship between cometary and interstellar material and the implications for the origin of the solar system;
- to investigate during flyby's possibly asteroid outgassing and establish what possible relationship exists between comets and asteroids.

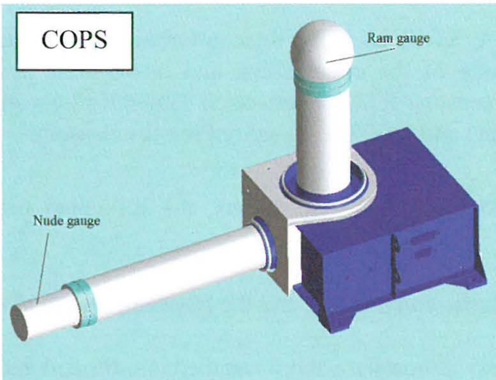
In order to accomplish these very demanding objectives, ROSINA will have unprecedented capabilities, including :

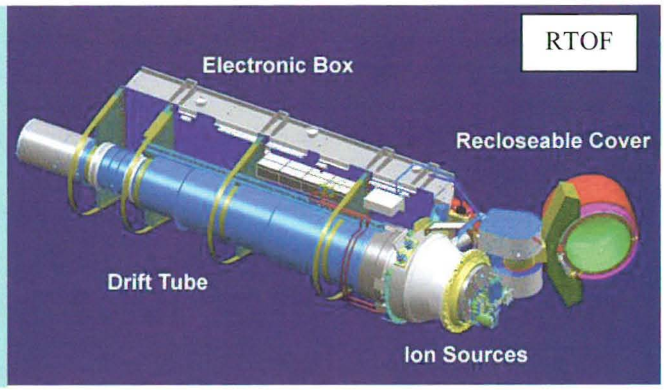
- very wide mass range from 1 amu (Hydrogen) to more than 300 amu (organic molecules);
- very high mass resolution (ability to resolve CO from N_2 and ^{13}C from ^{12}CH);
- very wide dynamic range and high sensitivity to accommodate very large differences in ion and neutral gas concentrations and large changes in the ion and gas flux as the comet approaches its perihelion;
- the ability to determine the outflowing cometary gas (and possibly ion) flow velocities and temperatures.

The necessity for the unusual high capabilities of this experiment stems from the fact that it is one of the key instruments which is able to give meaningful data during the whole mission and thus by monitoring and characterizing the different phases of comet activity from apogee through perigee will lead to a full understanding of cometary behavior. No single instrument could have the capabilities required to accomplish the science objectives of the gas and ion mass spectrometer.

Therefore ROSINA has three sensors each of which is optimized for part of the scientific objectives, while at the same time complementing the other sensors. In view of the very long mission duration they also provide the necessary redundancy. DFMS, the Double Focusing magnetic Mass Spectrometer, has a mass range from 1 to 100 amu and a mass resolution of 3000 at 1% peak height. This sensor is optimized for very high mass resolution and large dynamic range. RTOF, the Reflectron Type Time Of Flight mass spectrometer, has a mass range from 1 to 300 amu and a high sensitivity. The mass resolution is better than 500 at 1% peak height. This sensor is optimized for high sensitivity over a very broad mass range. COPS, the Cometary Pressure Sensor, consists of two pressure gauges providing total pressure and ram pressure.





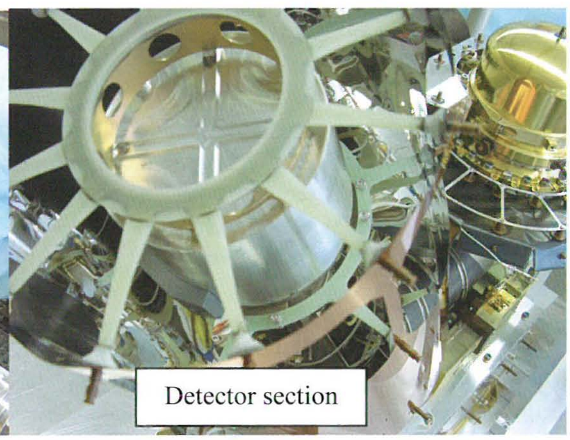


DFMS – ROSINA's double focusing mass spectrometer

Scientific overview

The Double Focusing Mass Spectrometer (DFMS) is a state of the art high resolution mass spectrometer (resolution m/Δm equal to 3000 at 1% peak height) with a high dynamic range and a good sensitivity. It is based on well proven design concepts that were optimized for mass resolution and dynamic range using modern methods for calculating ion optical properties. Striving for fulfilling the overall scientific objectives of the ROSINA instrument, the DFMS has two basic operation modes: a gas mode for analyzing cometary gases and an ion mode for measuring cometary ions. The three main parts are the ion source, the analyzer and the detector system.

Ion source



Detector section

Sector magnet (left) and main chamber (right) of the mass analyzer

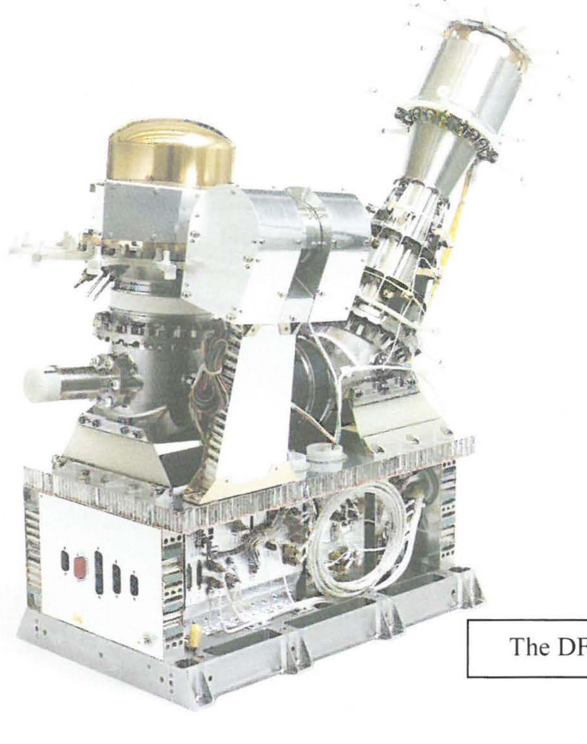
Collaboration

Several industrial and scientific partners collaborate in the development of DFMS. The principal investigator is the Physikalisches Institut of the Universität Bern (Bern, Switzerland). They subcontract as prime instrument builder the company Contraves Space (Zürich, Switzerland). Nevertheless a number of scientific institutions which are co-investigators in the DFMS team are also responsible for the manufacturing of parts of the DFMS instrument. E.g. the Lockheed Martin Advanced Technology Center (LMATC) (Palo Alto, USA), the Belgian Institute for Space Aeronomy (BIRA-IASB) (Brussels, Belgium), the Space Physics Research Laboratory of the University of Michigan (Ann Harbour, USA), the Centre d'Etude des Environnements Terrestre et Planétaires (CETP) of the Institut Pierre Simon Laplace (IPSL) (Saint-Maur, France), the Max Planck Institut für Aeronomy (MPAe) (Lindau, Germany) and the Institut für Datenverarbeitungsanlagen (IDA) of the Technische Universität Braunschweig (Braunschweig, Germany).

BIRA-IASB contribution

BIRA-IASB is participating in the ROSINA instrument as a scientific co-investigator but is also responsible for the construction of a part of the DFMS sensor. In fact the main detector system, the Linear Electron Detector Array (LEDA) is designed and manufactured under the responsibility of BIRA-IASB. Also the proximity electronics for both the LEDA and the Faraday Cup detector are under BIRA-IASB's responsibility. Besides that, BIRA-IASB is also in charge of the construction of part of the remote LEDA and Faraday Cup detector electronics. Finally BIRA-IASB is responsible for the cabling between proximity and distant electronics and assists in the mechanical integration of the detectors and the electronic modules in the instrument.

It is clear that for all the mentioned items BIRA-IASB has the lead throughout the complete build up, i.e. from the first stage of the design, through the prototyping phase to the construction of qualification and flight models. For a number of elements BIRA-IASB uses Belgian industrial partners as subcontractors. The two main subcontractors in this project are IMEC (manufacturing of the LEDA detector) and OIP (production of space qualified PCBs). This consortium watches over the quality of the delivered models by means of appropriate control and testing.



The DFMS without MLI

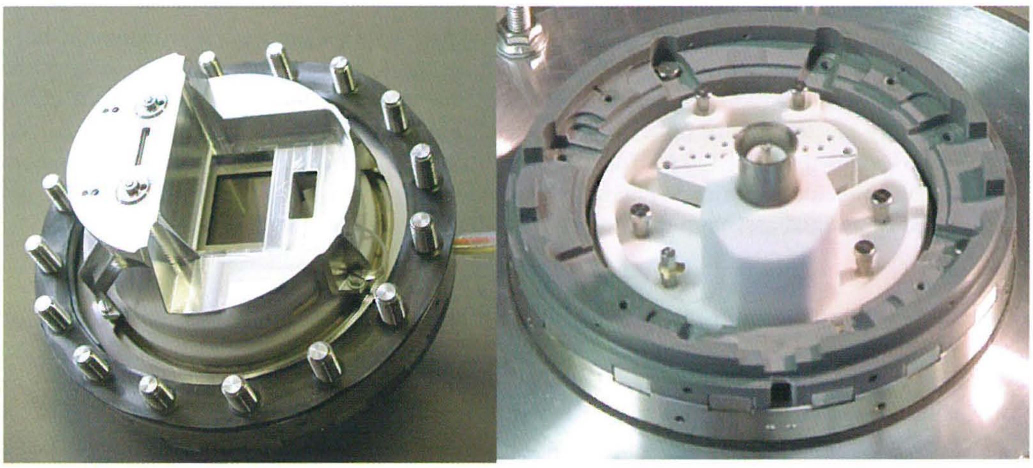
The detector assembly

The detector flange

The DFMS detects ions by means of three different detectors, located near the focal plane of the spectrometer :

- a Faraday cup detector for absolute ion current measurements;
- a multi-anode detector, a combination of a Micro Channel Plate (MCP) and a 512 double anode Linear Electron Detector Array (LEDA) chip;
- a Channel Electron Multiplier (CEM).

The three detectors are mounted on the DFMS detector flange. This flange forms the physical interface between the high vacuum mass analyzer section (front side) and the proximity electronics section (back side). It has been designed and manufactured by CETP.



Detector flange front side (left) and back side (right)

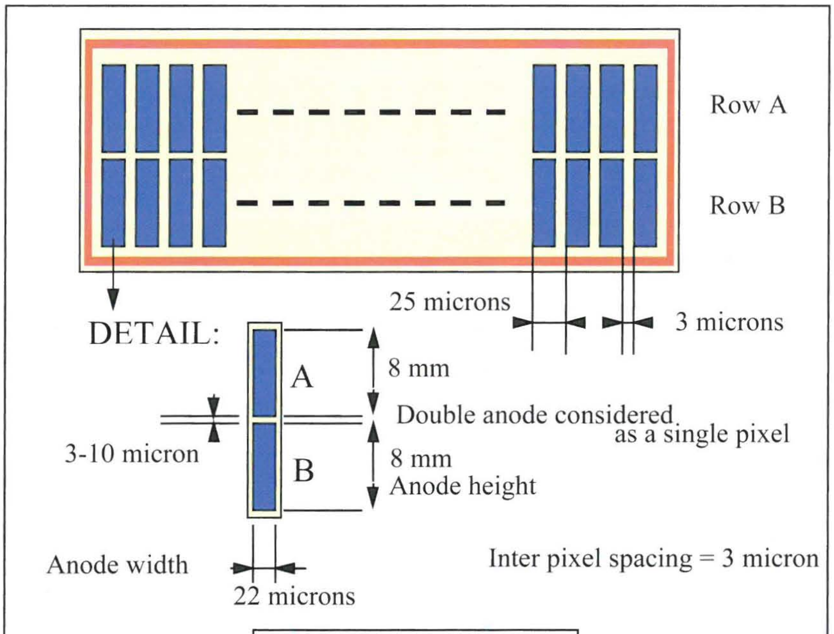
The DFMS detector flange : front side (left) and back side (right)

The flange consists of two main elements :

- an titanium outer ring which is mounted with 16 special auto-locking screws at the output (focal plane) of the mass analyzer. Special attention is paid to the vacuum tight sealing between the flange and the mass analyzer;
- a central ceramics part with a very complex shape, accommodating the three detector systems. At the mass analyzer side this ceramic piece is shaped such that the detectors are situated at the exact position in the analyzer beam. At the rear side interfaces are foreseen towards the proximity electronics (LEDA and Faraday Cup) and electrical connections for MCP and CEM high voltages.

The Linear Electron Detector Array

The Linear Electron Detector Array (LEDA) has been designed and fabricated in a close cooperation between BIRA-IASB and IMEC (Interuniversity Micro Electronics Centre, Leuven, Belgium).



Lay-out of the LEDA-chip

The LEDA chip consists of a linear array of 512 anodes each having an identical nominal size of 16 mm by 25 µm and having an inter-anode spacing of less than 3 µm. Each anode strip will collect negative charge consisting of electrons produced by a micro channel plate. This charge is stored on a capacitor associated with the anode. For redundancy reasons the anode array is split in two independent rows of anodes (A and B). In each row individual anodes have a size of 8 mm by 25 µm. Both rows have separate supplies, clocks, inputs and outputs and are from an electrical point of view totally independent from each other. Their respective anodes are in line and located as close as possible to each other.

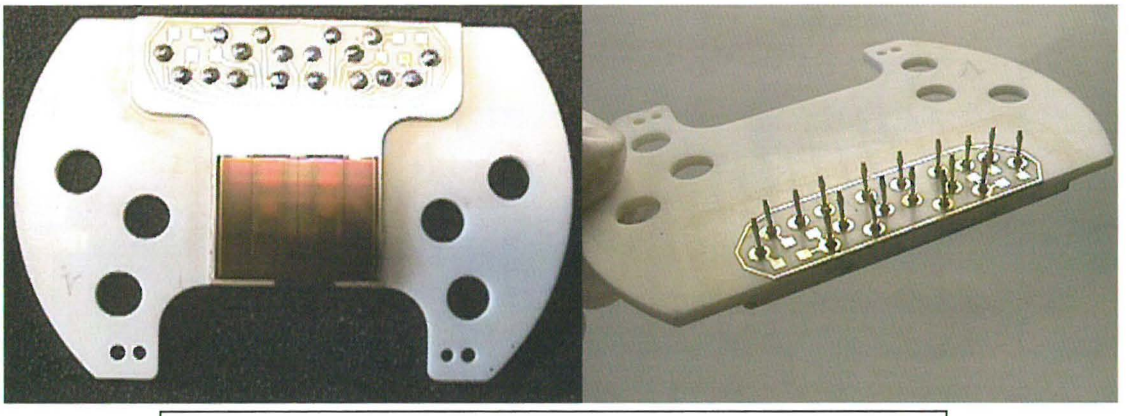
Each individual anode strip is etched in the top Al layer of the circuit. An interface (bonding) zone is foreseen for connecting the LEDA chip to a ceramic support. The analog supply voltage for the LEDA chip is fixed at 5 V. This allows for a maximum of 3 V on the anodes and for a linear operation in the 3 V to 0 V range.

Each anode cell is equipped with protection circuitry. Additionally an anti-blooming device is incorporated in each anode cell in order to avoid that excess charge impacting on an anode would influence nearby anode cells.

The LEDA ceramic support

The LEDA chip is mounted on a ceramic Al_2O_3 support in order to have identical thermal expansion characteristics as the other parts in the DFMS. It is shaped such that an optimal integration with the DFMS instrument is possible. It is equipped with a rounded top side border that is used as mounting reference. The ceramic surfaces are subject to severe finish, flatness, parallelism and perpendicularity limitations.

The ceramic support acts primarily as the LEDA chip carrier but serves also as electrical interface between the LEDA512 detector and the detector's proximity electronics. The connection between LEDA chip and ceramic support is made by means of bonding wires. They connect the bonding pads on the chip with a set of metallized bonding pads on the ceramics. From these bonding pads a metallization pattern, printed on the ceramics, leads to the physical connector : a zone with 18 plated through holes in which pins are soldered. These pins form the interface connector to the proximity electronics. The LEDA ceramic was designed by CETP.



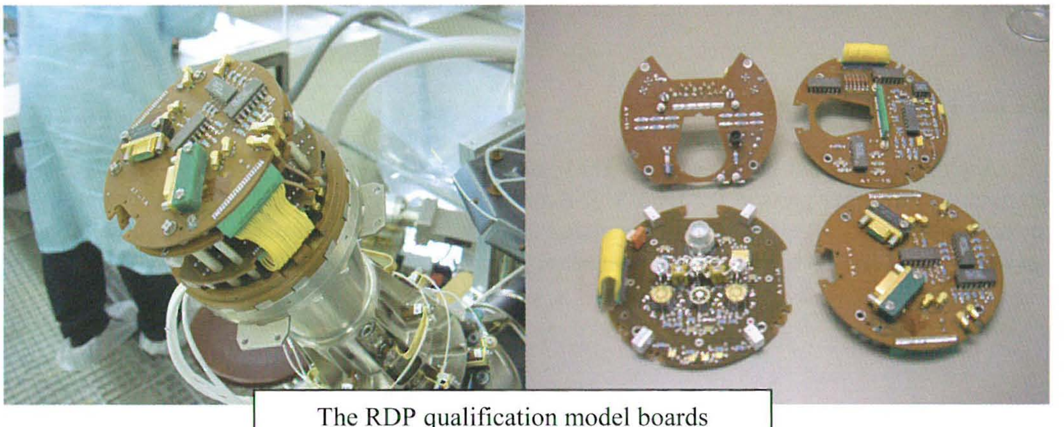
LEDA ceramics structure with LEDA 512 chip and connector pins

The microchannel plate

A pair of chevron type MCP's with 6 μm pore diameter is used in front of the LEDA. Proximity focusing with a potential difference of several hundred volts is used between the exit of the MCP and the LEDA. The gain of the MCP's can be changed from more than 10^7 to less than unity by adjusting the MCP voltage. Changing the MCP gain results in a total dynamic range of the detector of the order of 10^{10}. The microchannel plate was supplied by CETP.

The detector proximity electronics

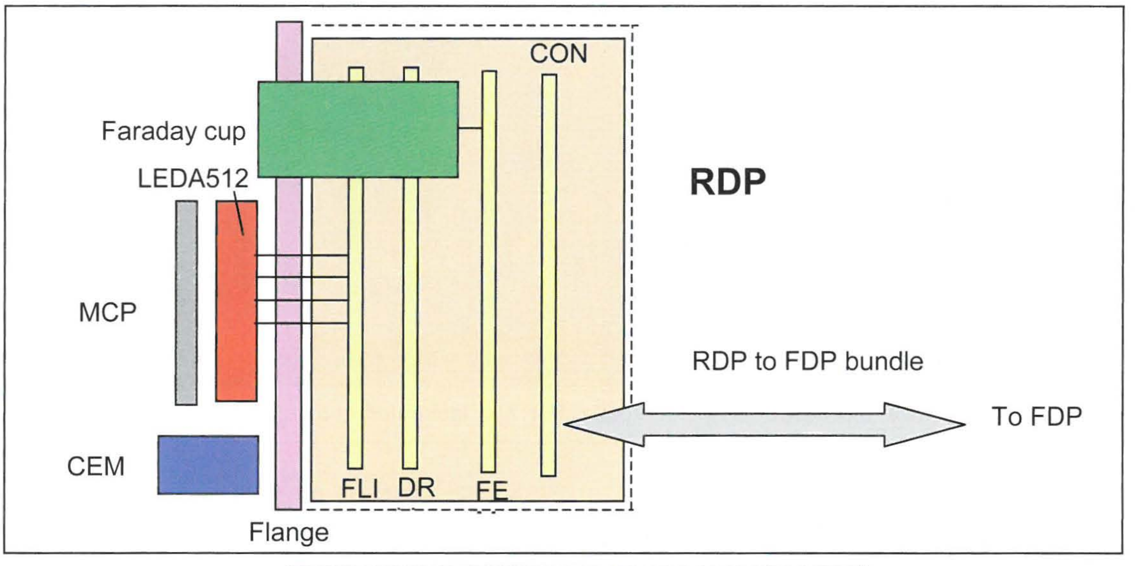
At the backside of the DFMS detector flange a set of four electronic boards is mounted. These electronic boards form the proximity electronics for the Faraday Cup and LEDA detectors. The three detectors (Faraday Cup, LEDA and CEM) together with these proximity electronics boards are called the Remote Detector Package (RDP) (since they are mounted "remote" from the main electronics package).



The RDP qualification model boards

The RDP pack contains four boards :

- RDP-FLI : the LEDA detector interfaces directly with the RDP-FLI board. The LEDA signals are passed directly towards RDP-DRV. The board contains a heater for better temperature control of the LEDA.
- RDP-DRV : contains drivers for the LEDA signals and stabilized short circuit proof LEDA power supplies. The analog outputs of the LEDA are passed towards RDP-CON.
- RDP-FEM : the Faraday cup detector is connected to the RDP-FEM board. This board contains a three-range electrometer circuit. The FC output signal is passed towards RDP-CON.
- RDP-CON : buffers the analog LEDA output signals and filters the FC electrometer output before transmission to the main detector electronics for further analog-to-digital conversion.



Schematic representation of the RDP electronics

The RDP boards are designed and manufactured by BIRA-IASB. The manufacturing of the space qualified versions was in close cooperation with OIP (Optronic Instruments and Products, Oudenaarde, Belgium).

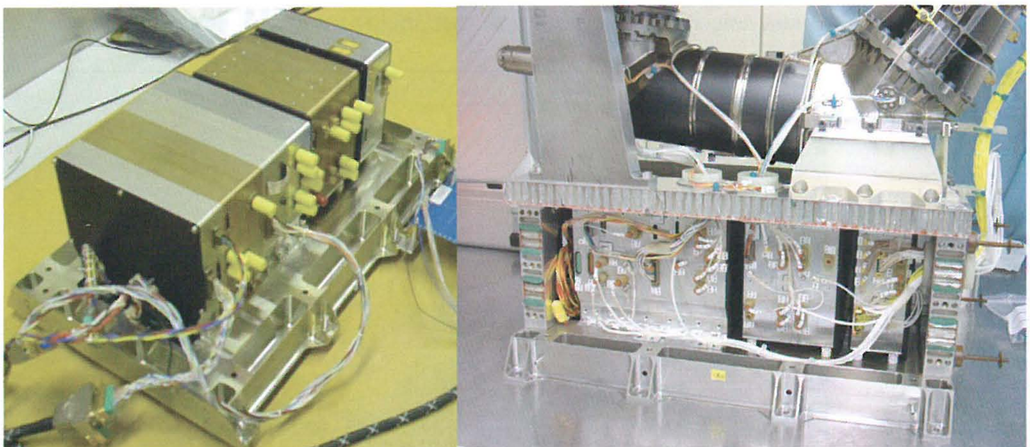
The detector main electronics

The DFMS baseplate carries the whole of the DFMS main electronics. We can distinguish three different sets of modules :

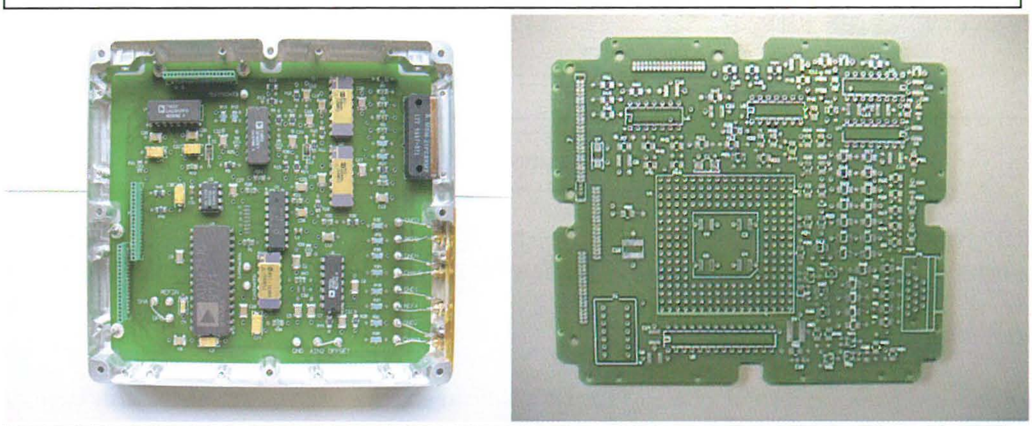
- the Main Electronics Package (MEP) (nine boards, a motherboard and a low voltage supply board). MEP receives commands and primary power from the DPU, controls the ion source, the in flight gas calibration system and the mechanisms (cover). It also controls the CEM detector and provides primary power to the Acceleration Supply Package (ASP). Finally, it communicates with the ASP and the Floating Detector Package (FDP), i.e. sending commands and retrieving data, routing it back to the DPU.
- the Acceleration Supply Package (ASP) (five boards). ASP provides the primary high voltage to the sensor to operate the optics (excluding the ion source and the detector). ASP communicates with MEP across its high voltage interface.
- the Floating Detector Package (FDP) (three boards). This pack contains in fact the detector main electronics. It consists of the analog processing, digital control and interface power for the Remote Detector Package (RDP) which is situated close to the detector flange. FDP receives signals from RDP (Faraday Cup and LEDA, not CEM), provides power for LEDA and Faraday Cup and transfers the signals received from RDP towards MEP across a high voltage interface.

In the FDP pack three boards are sandwiched together :

- FDP-A : high-speed analog-to-digital conversion of the LEDA signals coming from RDP. Analog-to-digital conversion of the FC electrometer output signal and supplementary housekeeping measurements.
- FDP-B : performs the LEDA timing and spectrum accumulation.
- FDP-C: produces the MCP Front and MCP Back high voltages, that are wired directly towards feedthroughs on the DFMS detector flange. They are controlled via commands sent to the FDP-A,B combination. This board produces also the necessary low voltages for the FDP and RDP packs.

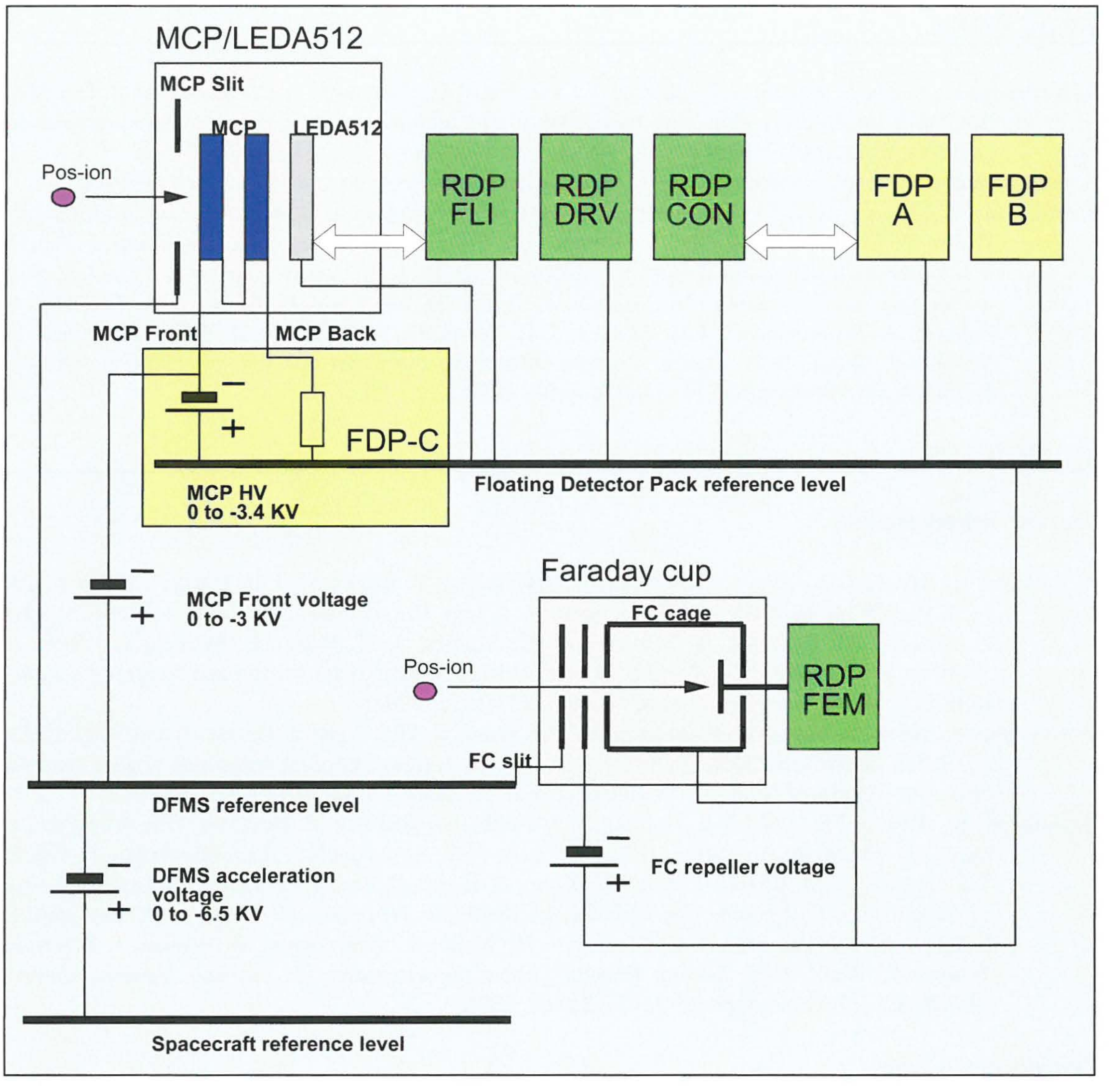


The DFMS main electronics on the baseplate (left) and integrated in the instrument (right)



FDP-A populated prototype board (left) and FDP-B unpopulated prototype board (right)

The FDP-A and FDP-B boards are designed and manufactured by BIRA-IASB. The manufacturing of the space qualified versions was in close cooperation with OIP (Optronic Instruments and Products, Oudenaarde, Belgium). The design and manufacturing of the FDP-C board was in the hands of LMATC (Lockheed Martin Advanced Technology Center , Palo Alto, USA).



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