Specific Technologies for Planetology, Space Weather and Gravitation oriented instrumentations

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Miniaturized Lab-on-Chip to extract and detect biogenic compound from Planetary Surfaces

The main goal is to develop a miniaturized lab-on-a-chip, to provide a highly-integrated multiparametric *in situ* platform utilizing immuno-assay to detect, identify and assess biogenic compounds at parts-per-billion sensitivity from samples extracted from planetary surfaces

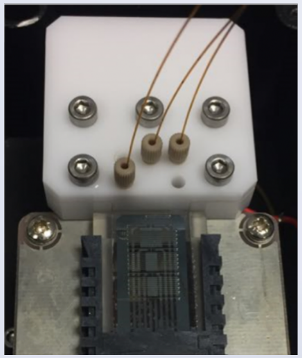
The concept is based on two main subsystems

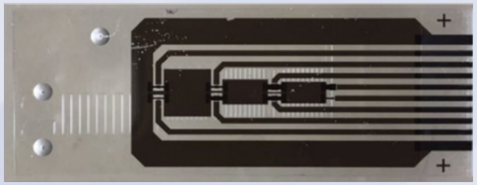
"***SAMPLE PREPARATION***" AND "***SAMPLE ANALYSIS***"

Sample Preparation Subsystem will contain the sample melting, the filtration to separate particulates from an aqueous slurry, the sample concentration and desalination to obtain sample volumes adequate to introduce to the lab-on-chip (in order of mm^3)

Sample Analysis Subsystem, consisting of integrated Lab-on-chip(s), it is a core element of the proposed technology.

It consists in:
1) a microfluidic network for the handling of samples and reagents; **2)** a set of detection sites using immunoassays; **3)** an array of thin-film photosensors for the detection of the analytical signal and **4)** a set of on-chip thin-film heaters for accurate and efficient control of local chip temperature.





Micro-thermogravimeters

Leader Institute INAF Co-I's Institutes POLITECNICO DI MILANO

- INAF-IAPS Team
  - **PI: E. Palomba**
  - **CoI:** A. Longobardo, F. Dirri, D. Biondi, A. Boccaccini

The instrument core is a Quartz Crystal Microbalance (QCM), whose oscillation frequency linearly depends on the mass deposited on its sensible area

Innovations:

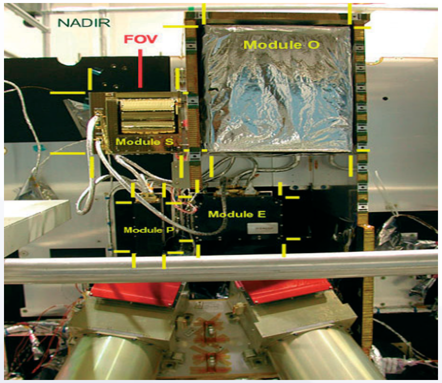
- Extreme accuracy in temperature control and measurement (< 0.1°C)
- Thermomechanical structure

Micro-thermogravimeters

- Projects:
  - ***ESA projects***: development of a detector for monitoring space and laboratory contamination
    - CAM (Contamination Assessment Microbalance; 2014-16)
    - CAMLAB (CAM for LABoratory; 2017-19)
  - ***VISTA*** (Volatile In Situ Thermogravimetry Analyser): measurement of volatile (water/organics) content in planetary dust and regolith and monitoring of dust fluxes.
  - *Selected by ESA* for the scientific payload of MarcoPolo-R (ESA M3)
  - *Studied* for the Phase A of many planetary space missions (e.g. ESA L1, M2)
  - *Included* in other proposed planetary space missions

- Awards:
  - *WIRE Innovation Award* Frascati Scienza/ESA-ESRIN 2016 (winner)
  - *StartCup Lazio* 2018 (winner)
  - *Premio Nazionale Innovazione 2018 (Finalist)*
  - *4th edition Unirsi per l'Impresa* 2019 (Finalist)

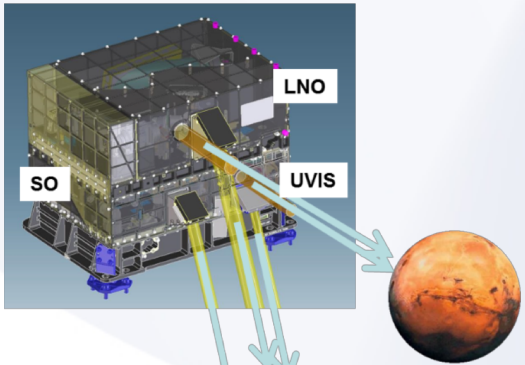
SPECTROMETERS IN THE VIS-IR FOR SPACE MISSIONS



PFS Flight Model integrated on MEx

- **PFS (Planetary Fourier Spectrometers) on MARS EXPRESS:** an infrared FT spectrometer formed by two spectral channels SWC (1.2÷5.0 μm) and LWC (5.5÷45 μm), res 1.3cm^{-1}. PFS is the **first instrument** on Mars **covering** the wavelength range **1-50 μm**. The spectrometer is optimized for atmospheric studies in particular, provided unique data necessary to improve our knowledge of the atmospheric properties, composition and dynamics, as well as of the polar ices, the surface Phobos, the non-LTE processes, etc.
Highest Spectral Resolution in such a broad spectral range…still after 15 years!

- **NOMAD (Nadir and Occultation for MArs Discovery) on the ExoMars Trace Gases Orbiter (TGO):** a spectrometer designed to perform high-sensitivity orbital identification of atmospheric components, concentration in a wide range of wavelengths (infrared, ultraviolet and visible). This broad coverage of the instrument enables the detection of the components of the Martian atmosphere, even in low concentrations. In addition to identifying the constituents of the Martian atmosphere, NOMAD will also map their locations.



NOMAD
High resolution occultation and nadir spectrometers

Atmospheric composition
(CH_4, O_3, trace species, isotopes)
dust, clouds, P&T profiles

UVIS (0.20 – 0.65 μm)	λ/Δλ ~ 250	SO	Limb	Nadir
IR (2.3 – 3.8 μm)	λ/Δλ ~ 10,000	SO	Limb	Nadir
IR (2.3 – 4.3 μm)	λ/Δλ ~ 20,000	SO		

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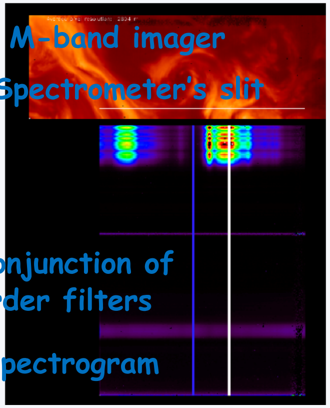
SPECTROMETERS IN THE VIS-IR FOR SPACE MISSIONS

- **JIRAM (JOVIAN INFRARED AURORAL MAPPER) ON BOARD JUNO:** CAMERA AND A SPECTROMETER:

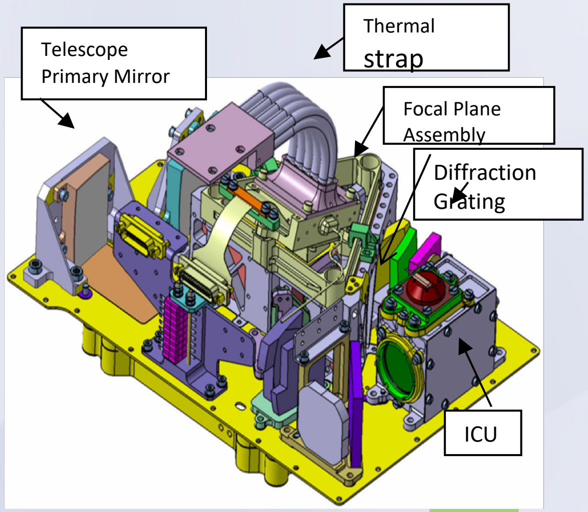
- ✓ Camera for auroral emissions, fwhm 3.32-3.60μm
- ✓ Camera for thermal emissions, fwhm 4.54 5.03 μm
- ✓ Spectrometer 2-5 μm, resolution 9nm, av. fwhm 12.5 nm.
- ✓ Instrument design, modes, and observation strategy is optimized for operations **on board a spinning satellite** in polar orbit around Jupiter. Where the atmosphere has less opacity JIRAM can sound deeper among the clouds and measure concentration of species like water, ammonia and phosphine.



- **VIHI/SIMBIO-SYS (VIS-NIR HYPERSPECTRAL IMAGER) ON BEPICOLOMBO.**

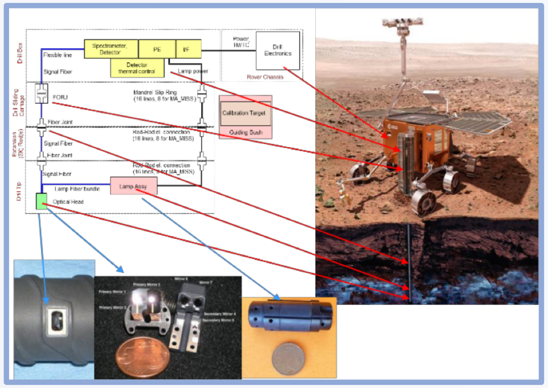
Major technological challenges:

- ✓ First MgCdTe detector on a interplanetary mission with spectral sensitivity to 400nm.
- ✓ Fully integrated Detector package (FPA, cold shield, Light trap, TEC)
- ✓ Limited onboard resources (mass less than 2Kg)
- ✓ Mechanically ruled plane grating with UV enhancement to cover a very wide spectral range (400-2000nm);



FUTURE PROJECTS

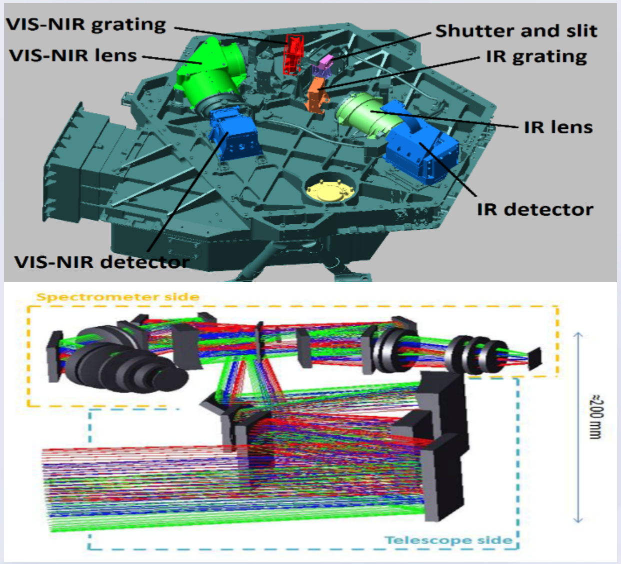
➢ **Ma_MISS on Exomars 2020:** is a **miniaturized** spectrometer based on optical fibers that permit to have a modular instrument.



- ✓ Optical Head inside the DRILL TIP
- ✓ The spectrometer is at 0.5-2 metres distance from the optical head
- ✓ The Spectrometer, the detector and Proximity Electronics in a box placed on the external wall of Drill Box.
- ✓ Extremely small, modular and light (<1kg)

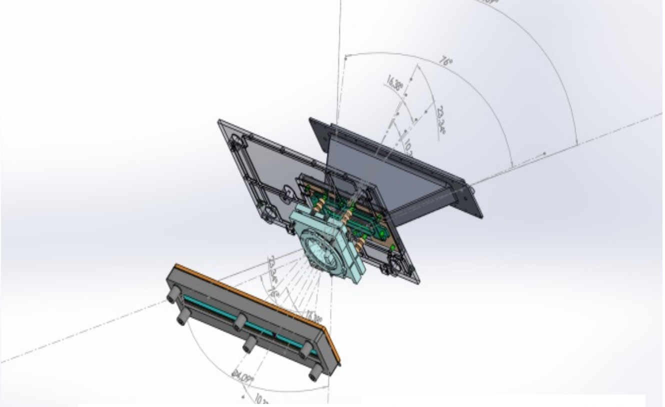
➢ **MAJIS (MOONS AND JUPITER IMAGING SPECTROMETER) ON JUICE:**

an hyperspectral imager operating in the 0.50-5.54 µm spectral range.

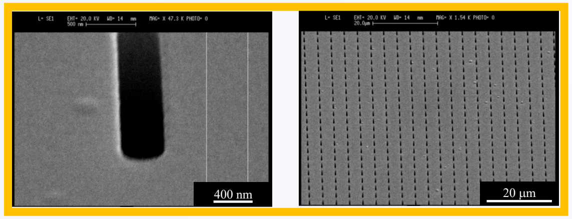


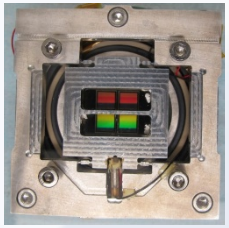
The architecture is driven by **unique design challenges**:
- ✓ Passive cooling to cryogenic temperatures (T<90K for IR detector-T<140 K for o.b.)
- ✓ Harsh radiation environment (up to 50 Mrad on the scan mirror)
- ✓ Limited mass allocated to the OH (< 45kg)
- ✓ Advanced optical performances:0.5-5.54 µm spectral range, 150 µrad/px IFOV (75m from 500 km altitude), 3.4° FOV (30km swath)
- ✓ Two large format detectors (508x400px, spectral x spatial)

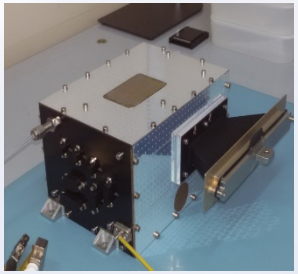
ENA- Energetic Neutral Atom detection system

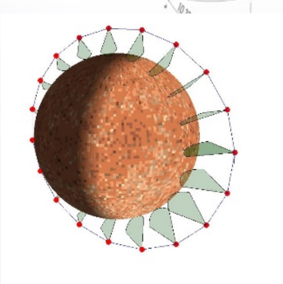


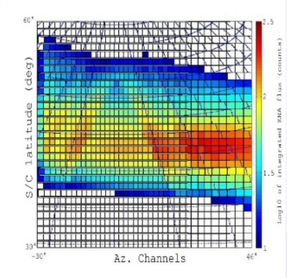
Innovative instrumentation -> Direct atom detection technique
ELENA/SERENA on board BepiColombo mission is the first in flight ENA instrument with direct detection technique using several innovations
Innovative technolgies:
- nanoslits Si3N4 membranes as UV grating filter
- shutter system as new ToF system with low consumption and weigh
- MCP detector at low energy











New detection technique-> Gas detector for Neutral Atoms
SWEATERS-project for Earth SpaceWeather
Innovative technologies:
A new micro-pattern gas detector for ENA detection based on m-megas detector
(in coll with INFN and CERN R&D)

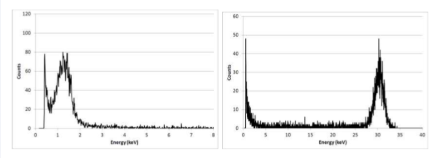
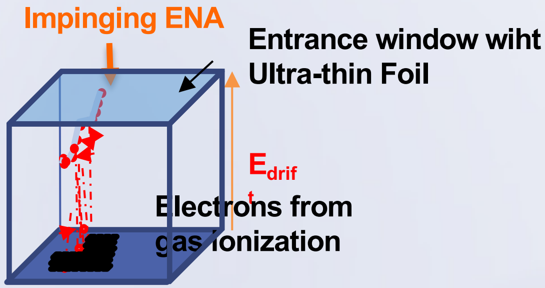


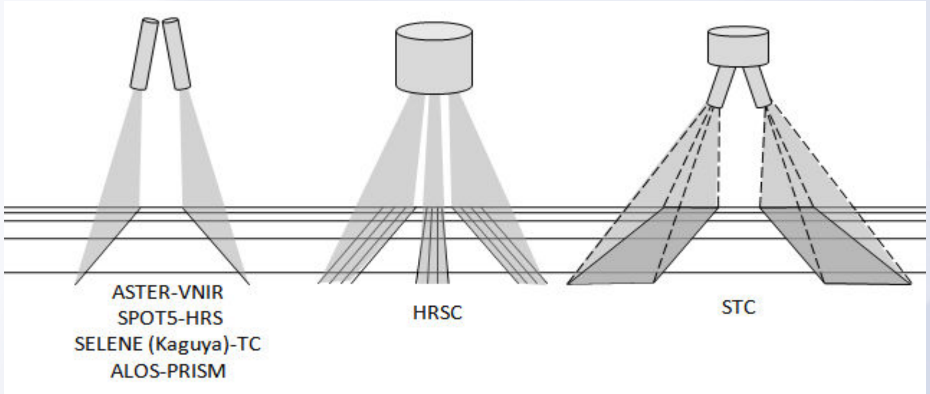
Fig. 6. Spectra of 3 keV (left) and 40 keV (right) kinetic energy ^{4}He in $^4He + 5\% C_4H_{10}$ mixture at 350 mbar.



Development capability and testing:
ION-ENA beam in high vacuum chamber @IAPS-INAF
-for development testing and validation
-for laboratory simulation of particles-surface interaction in space

NEW CONCEPT OF STEREO CAMERA
STC/SIMBIO-SYS

- original optical design
- the stereo camera has two sub-channels that share most of the optical elements and the detector
- the stereo angle is 40°
- the stereo acquisition is based on the push-frame



STEREO CAMERAS

BepiColombo mission

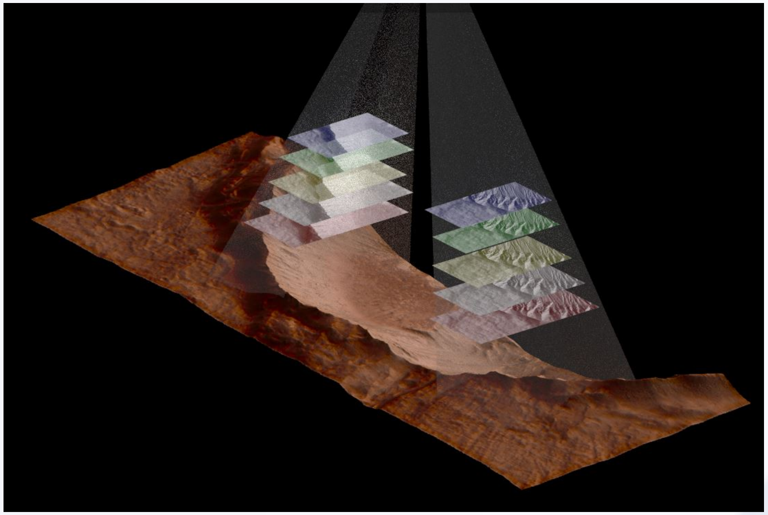
- ESA/JAXA to Mercury (launch 2018)
- MPO (Mercury Planetary Orbiter)
- SIMBIO-SYS: Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem
- Orbit: polar, three axis stabilized
- Altitude: less then 480 km.

ExoMars mission

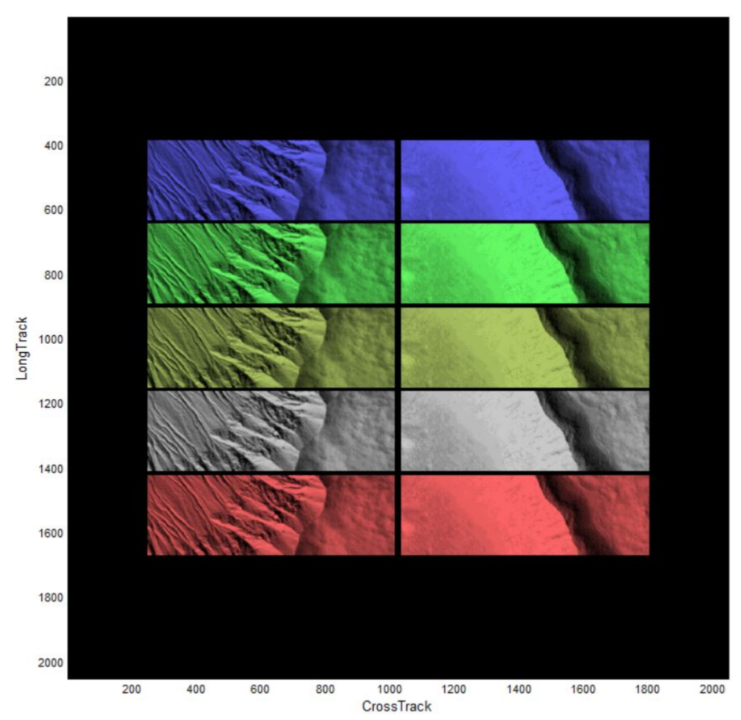
- ESA/Roscomos to Mars (launch 2016)
- Trace Gas Orbiter (TGO) 2016
- CaSSIS: Colour and Stereo Surface Imaging System
- Orbit: circular orbit (inclination of 74°)
- Altitude: 400 km

HYPerspectral Stereo Observing System (HYPSOS)

The evolution of the stereo camera



Two channels observing the surface



One stereo pair for each spectral channel focused on a single detector.
The spectrograph allows to have more than **100 stereo pairs on the same chip (HYPerspectral)**

HYPSOS provides 4D data

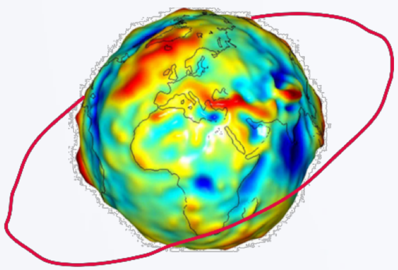
Italian patent n.102016000097439, M.Tordi (EIE), G.Cremonese, G.Naletto, C.Re

TECHNIQUES FOR EXPERIMENTAL GRAVITATION

Two approaches

Gravity field provides invaluable capability to **understand planets interiors, dynamics and evolution**

Gravimetry



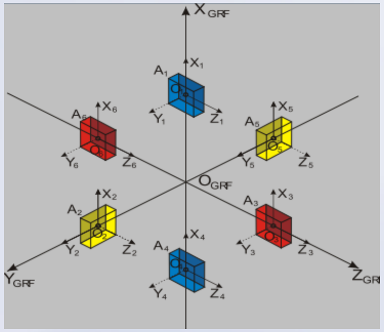
- ✓ Tracking of a spacecraft
- ✓ Measurement of Non-Gravitational accelerations (solar radiation pressure, drag, fuel sloshing, etc.) by means of an **accelerometer**

Gravity Field coefficients are solved-for parameters in the Precise Orbit Determination (POD) process.

more accuracy in forces knowledge = more accuracy in the gravity field determination

Gravity Gradiometry

$$\begin{pmatrix} \partial g_x/\partial x & \partial g_x/\partial y & \partial g_x/\partial z \\ \partial g_y/\partial x & \partial g_y/\partial y & \partial g_y/\partial z \\ \partial g_z/\partial x & \partial g_z/\partial y & \partial g_z/\partial z \end{pmatrix} = \begin{pmatrix} V_{xx} & V_{xy} & V_{xz} \\ V_{yx} & V_{yy} & V_{yz} \\ V_{zx} & V_{zy} & V_{zz} \end{pmatrix}$$



- ✓ Direct measurement of gravity gradients, by means of a **Gravitational Gradiometer**: in principle coupling of accelerometer pairs, whose output are differenced (differential accelerometry)
- ✓ Precise Orbit Determination (POD) is needed (only) for measurements georeferentiation.

It means **direct measurement of gravity field**

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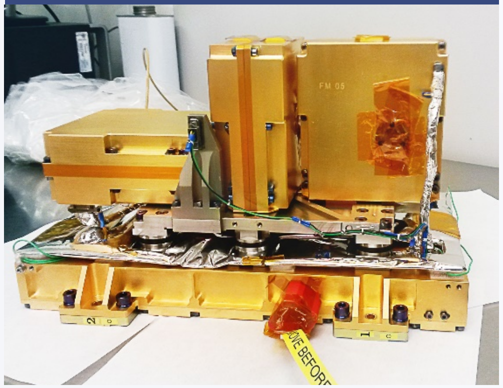
TECHNIQUES FOR EXPERIMENTAL GRAVITATION

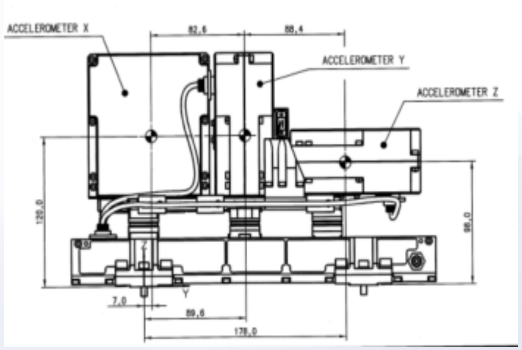
ISA accelerometer



ISA (Italian Spring Accelerometer) accurately **measures** non-gravitational accelerations flying on-board **BepiColombo** towards Mercury.

First high sensitivity accelerometer on interplanetary mission (PI@IAPS-INAF)

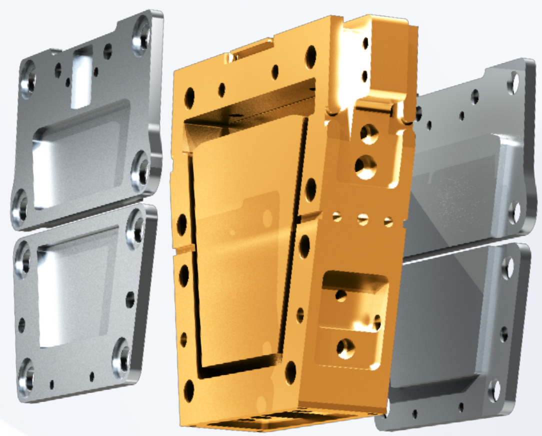
HAA accelerometer



HAA (High Accuracy Accelerometer)

will measure accurately non-gravitational accelerations on-board **JUICE** at Jupiter and its Moons.

Sensing element



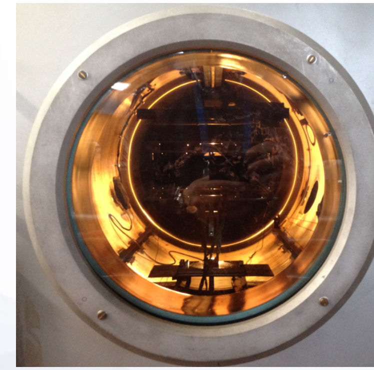
Performance parameters

- Accuracy: $<10^{-8}$ m/s^2
- Noise floor: $<10^{-8}$ m/s^{2}Hz$^{-0.5}$
- Frequency band: $3{\cdot}10^{-5}$-10^{-1} Hz

Key Points/Technologies

- Sensing technology of very small displacements ($< 10^{-11}$ m)
- High performance thermal control system ($< 10^{-4}$ K)
- Capability of on-ground calibration
- Specific radiation-hardened electronics
- High accuracy metrology (alignments, positioning, etc.)

SOLAR WIND AND IONOSPHERIC PLASMA SIMULATOR



The plasma chamber developed at INAF-IAPS is a facility capable to reproduce a large volume of both the ionospheric and the solar wind plasma.

The plasma generated by the source is accelerated into the chamber at a velocity that can be tuned to simulate both the relative motion between an object orbiting in space and the ionosphere ($\cong$ 8 km/s) and the velocity of solar wind (> 300 km/s). This feature, in particular, allows laboratory simulations of compression and depletion phenomena typical of the ram and wake regions around ionospheric satellites

Instrument development, test and calibration performed in the IAPS Plasma Chamber SWIPS are carried out in the framework of Space Missions, Bilateral Scientific Cooperation, and Third Parts services.

These concern:

- calibration of plasma diagnostic sensors (Langmuir probes, Retarding Potential Analyzer, Ion Drift Meter, …);
- characterization and compatibility tests of components for space applications (materials, satellite paints, photo-voltaic cells, etc.);
- functional tests of experiments envisaged to operate in an ionospheric environment (sensors exposed to space plasma);
- tests on active experiments which use cathodes and/or plasma sources (ion thruster, ion beam neutralizers, hollow cathodes).
- basic plasma physics experiments such as interaction of neutral, charged, and magnetized bodies with plasma for the evaluation of thrust, etching or any kind of plasma-bodies interaction.

Plasma Chamber will host the development of the Electric Field Detector (EFD) for the Chinese satellite CSES in the framework of CNSA-ASI collaboration