Spectrometers and imaging cameras for planetary remote sensing

Spectrometers And Imaging Cameras For Planetary Remote Sensing

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Abstract

The paper is an overview of some instruments for remote sensing and in-situ planetary exploration already developed or under study by SELEX Galileo (SG, formerly Galileo Avionica) Space Line of Business for both the Italian Space Agency (ASI) and for the European Space Agency (ESA).

Introduction

Several missions for planetary exploration, including Moon, comets and asteroids, are ongoing or planned by the European Space Agencies: Aurora and the Mars program, Bepi Colombo, Dawn and Juno (contributions), the Moon program, Rosetta, Venus Express, are good examples. The satisfaction of the scientific request for the mentioned programs calls for the development of advanced technologies for new instruments and facilities devoted to investigate the body (planet, asteroid or comet) both remotely and by in-situ measurements.

The paper is an overview of the spectrometers and imaging cameras developed by SELEX Galileo for planetary exploration programs.

Part 1: SELEX Galileo contribution to in-orbit missions for Planetary Exploration

In the last ten years, the first and most important contribution for ASI (and NASA) has been for the NASA/ASI "Cassini" mission to Saturn and its moon Titan. Under ASI contract, SELEX Galileo provided two Principal Investigator (PI) instruments: the Visible Infrared Mapping Spectrometer (VIMS) shown in Fig.1 and the Huygens Atmospheric Structure Instrument (HASI), a suite of instruments for atmospheric sensing on the Huygens Lander.

VIMS, which is located in the Cassini Orbiter, has the primary objective to provide two dimension, multi-spectral high resolution images for detailed study of the composition and structure of Saturn's ring system, dark materials and atmospheric composition.

VIMS makes use of a reflective telescope in a Shafer configuration and pushbroom imaging with a pointable primary mirror. The spectral range is from 325 to 1025 nm, with spectral resolution of 1.46 nm.

Fig.1 - VIMS spectrometer (on Cassini)

VIMS-V has been able to observe Saturn and it's rings from geometries unusual for Earth-based observers, including the south pole vortex and the shadows of the rings casting on the Saturn's atmosphere. The rings have been imaged at unprecedented spatial resolutions, showing in great details their structures (ringlets, gaps, divisions) and allowing a detailed analysis of their composition (water ice and contaminants like dust and organic compounds).

The scientific activities on VIMS-V are carried out by the Institutes INAF-IFSI and INAF-IAS.

The evolution of VIMS spectrometer has been the Visible IR Thermal Imaging Spectrometer (VIRTIS), shown in Fig. 2; VIRTIS is an hyper-spectral imaging spectrometer in the Visible (VIS) and Mid-Infrared (MIR) bands, designed for remote sensing in deep space missions.

VIRTIS has been selected by ESA for two missions:

- one VIRTIS instrument is flying on board of Rosetta, the mission to comet 67P/Churyumov-Gerasimenko; launched in February 2004, after the fly-by of the asteroids Steins and Lutetia, Rosetta will meet the comet around May 2014;
- one VIRTIS instrument is flying on board of Venus Express (VEX), the mission launched on November 2005 for studying Venus atmosphere and its interactions with the planet surface.

The VIRTIS instrument is composed by two optical heads, VIRTIS-M (mapper) and VIRTIS-H (high spectral resolution), both passively cooled to 130 K to limit background radiation. VIRTIS-M includes a VIS and a single IR channel using the same all-reflective optical system, while VIRTIS-H has a single IR channel. All VIRTIS instruments are using IR detectors cooled to 80 K by miniature Stirling cycle cryo-coolers.

VIRTIS makes use of a reflective telescope with Offner spectrometer and pushbroom imaging with a pointable primary mirror. The main characteristics of VIRTIS-M are spectral range from 250 to 5000 nm, with spectral resolution of 3 nm for VIS and 15 nm for IR. The main characteristics of VIRTIS-H are spectral range from 2000 to 5000 nm, with spectral resolution of 2-10 nm.

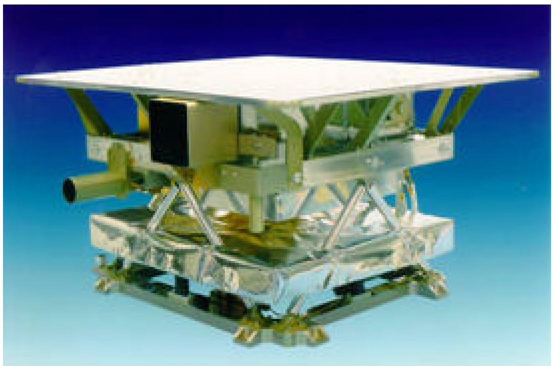

Fig. 2 - VIRTIS spectrometer

During the Earth swing-by, VIRTIS has taken several hyperspectral images, shown in Fig. 3. Later on, the satellite has been placed into hibernation.

In July 2008, the instruments on Rosetta have been awoken from hibernation to prepare the satellite for its encounter with asteroid Steins (2867) on September 5th, 2008. ESA's comet chaser will study this asteroid as it flies by on its way to comet 67/P.

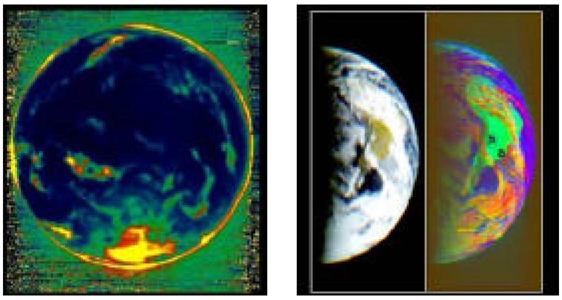

Fig. 3 - The Earth imaged from 250,000 Km by VIRTIS in VIS & IR bands (Courtesy: ESA/ASI/VIRTIS Team/INAF)

Left: IR image of the Earth showing details of the atmosphere (emission of carbon dioxide is shown in yellow)

Right: Earth (South America) in real colours and false colours

VIRTIS on VEX is looking through the dense atmosphere of Venus at different depths, by probing it at different infrared wavelengths. VIRTIS is providing a valuable contribution to the investigation of Venus' atmospheric layers to solve the riddle of the causes for such turbulent and stormy atmosphere; some examples are shown in Fig. 4, by courtesy of ESA and the PI's scientific Team (INAF-IFSI).

The scientific activities on VIRTIS for Rosetta and VEX are carried out by the Institutes INAF-IFSI and INAF-IAS.

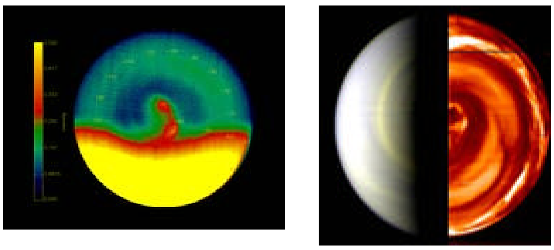

Fig. 4 - Venus images by VIRTIS on VEX (Courtesy of ESA/INAF-IAS)

Rosetta spacecraft has on board a navigation camera, shown in Fig. 5, realized by SG. This camera has three operating modes: 1) a target detection mode, for first target detection (comet/asteroid) 2) a star & target tracker mode, with a capability of up to 10 simultaneous targets 3) an imaging mode, to be used during close comet approach.

Main camera characteristics are FOV 6.4°x6.4°, IFOV 22.5 arcsec, a focal length of 129 mm; the camera operates in the VIS (450 to 850 nm) with a 1K x 1K CCD.

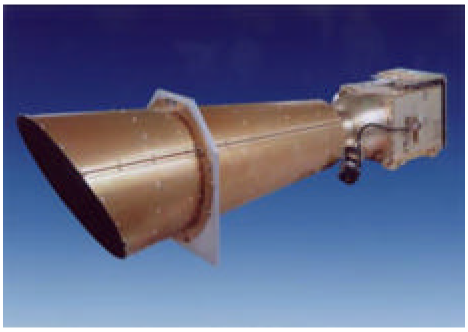

Fig. 5 - Rosetta Navigation Camera

The camera, in the imaging mode, has provided interesting images during Earth and Mars fly-by. On Fig. 6 is shown the image of Mars during a swing-by approach on February 2007.

Fig. 6 - Mars seen by Rosetta NavCam on swing-by approach 24 February 24th, 2007 (Courtesy of ESA)

More recently, Galileo Avionica have provided to ASI/NASA the VIR-MS imaging spectrometer (a VIRTIS like spectrometer) for Dawn mission. Launched on September 2007, VIR-MS will perform the VIS/NIR remote sensing of the asteroids Vesta (on 2011) and Ceres (on 2015).

The scientific activities on VIRTIS for Rosetta and VEX are carried out by the Institutes INAF-IFSI and INAF-IAS; the VIR-MS PI is from INAF-IFSI.

Part 2: running studies at SELEX Galileo for Planetary Exploration programs

2.1 Mars exploration and Exomars

Since 1999, SG is studying for ASI on Mars Exploration. Studies and critical bread-boarding activities have been performed on the drilling system DEEDRI, on the Sample Preparation and Distribution System and on some instruments for in-situ Mars exploration. Within Exomars program, SG's responsibility include three optical instruments: the spectrometers Ma_MISS and MIMA and the dust analyzer MEDUSA. All of them are PI-lead instruments, the first two from INAF-IFSI and the last from INAF-OAC.

MA_MISS (MArs Multispectral Imager for Subsurface Studies) is a spectrometer integrated in the Drill & SPDS (Sample Preparation and Distribution System), thus forming the experiment DIBS (Drill-Integrated Borehole Science). MA_MISS Instrument is extremely miniaturized (mass < 450g) and complex, as required to fit into the Drill. MA_MISS is devoted to the observation of the lateral surface of the borehole created by the Drill during its operation for the acquisition of subsurface soil samples.

MA_MISS main requirements are: spectral range 0.4-2.4 µm, spectral resolution 20nm, spatial resolution <0.1 mm, typical S/N ratio ~ 100.

MIMA (Mars Infrared MApper) is a Fourier spectrometer operating in the IR spectral range devoted to the observation of soil (mineralogy) and atmosphere. MIMA is placed on masthead of Rover and is co-aligned with PanCam cameras.

MIMA Instrument is miniaturized and complex (allocated mass < 1kg). Its main features are: spectral range 2 to 25 µm, spectral resolution 5 cm-1 for atmospheric sounding and 10 cm-1 for geologic mapping, FOV 3.2° and S\N greater than 40 (SW channel) and 100 (LW channel).

MEDUSA (Mars Environment and DUSt Analysis) is a suite dedicated to Dust and Water Vapor analysis, fitted in Humboldt Payload on Exomars Landing Module. The instrument is able to perform simultaneously measurements on dust characteristics (with a laser system), dust deposition (with an electric sensor), water vapor monitoring (with a microbalance).

MEDUSA Instrument is extremely miniaturized and complex, as required to all Exomars instruments.

2.2 ASI Moon programs

Since July 2006, ASI has started a number of studies having the Moon as target or as the operating site; SELEX Galileo have contributed to ASI vision by leading two studies:

• "Moon in-situ sensing", with the aim to select possible instruments for experiments to be performed on the Moon and from the Moon, in the range from UV up to far IR and millimeter waves;

• "Study of Electro-Optical P/Ls for Moon surface remote sensing", with the aim to select instruments to be installed on board of a Moon orbiting spacecraft for passive remote sensing operating in the range from UV up to far IR and millimeter waves.

2.3 Bepi Colombo mission

As a contribution to ESA Bepi Colombo mission to Mercury, ASI will provide many PI instruments on the MPO Orbiter. Between them, under ASI contract SELEX Galileo have been selected to develop a suite of optical instruments called SIMBIO-SYS, shown in Fig. 7, that includes three PI instruments: two cameras HRIC (INAF-OAC) and STC (Uni. of Padova) and one spectrometer VIHI (INAF-IFSI).

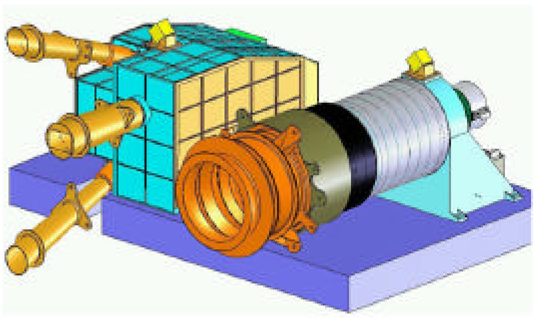

Fig. 7 - 3D view of SIMBIO-SYS on Bepi Colombo mission

HRIC (High Resolution Imaging Channel), is a high resolution VIS multi-band camera for high resolution Mercury mapping. Main features are: spectral range 400 to 900 nm, 4 spectral channels, focal length 800 mm, FOV 1.47°, S\N ~ 150.

STC (STereo imaging Channel), is a stereo and multi-band camera with a maximum resolution of 50m for Mercury topography and 3D reconstruction. Main features are: stereo camera, spectral range 530 to 900 nm, 4 spectral channels, focal length 90 mm, FOV 4°, S\N > 200.

VIHI (Visual and Infrared Hyperspectral Imager), an imaging spectrometer for global mineralogic mapping. Main features are: spectral range 400 to 2000 nm, FOV 3.7°, spectral resolution 6.5 nm, spatial resolution 100m, S\N > 100.

SIMBIO-SYS Phase C1 activities are going to start. The mission has put severe constraints on mass and power dissipation; to meet the requirements, a strong integration between the three instruments has been necessary, as shown in Fig. 7.

2.4 Juno mission

Since 2007, ASI has initiated a cooperation with NASA/JPL on the Juno mission to Jupiter. Juno is the second NASA mission of New Frontiers Program having a primary goal of improving the understanding of the formation and structure of Jupiter.

SELEX Galileo has been requested as the industrial partner for the PI (INAF-IFSI Institute) instrument Jovian Infrared Auroral Mapper (JIRAM), an instrument which performs spectroscopy and imaging in the 2 – 5 µm band simultaneously by the use of a double focal plane.

The instrument, shown in Fig. 8, has a single telescope which feeds both focal planes through a beam splitter: one beam is used for images, while the second, after passing through a slit, performs a spectra.

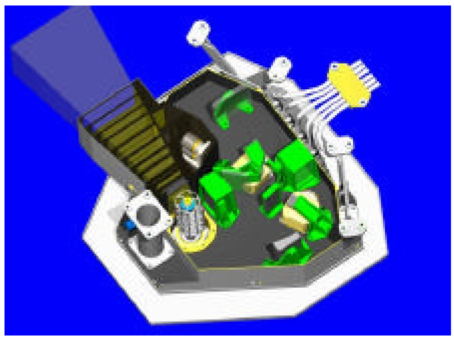

Fig. 8 - JIRAM instrument on Juno mission

Main features of the imaging channel are: spectral range 3.6 to 4.8 µm, FOV 3.5°x6.2°, IFOV 237 µrad.

Main features of the spectral channel are: spectral range 2 to 5.2 µm, spectral resolution 10 nm, IFOV 237 µrad.

JIRAM compensate the spacecraft rotation by de-spinning track scanning capability.

2.5 SELEX Galileo design guidelines

Planetary exploration requirements for payloads are very severe, in terms of mass, power and environment: the instruments must be designed by using state-of-the-art technologies, and, whenever possible, trying to integrate common parts between several instruments as well as their electronics. Examples can be found in the integrated package of SIMBIO-SYS and in the dual function JIRAM instrument.

Mass and planetary protection (PP) are instead the main drivers for the in-situ Exomars instruments. Space materials and components must undergo PP requirements, including cleanliness protection, which often implies high temperature sterilization.

SELEX Galileo's experience includes 360 degrees knowledge and capability of designing, manufacturing and testing in the technological fields of optics, focal plane assembly, detector and reading electronics, precision mechanics, mechanisms.

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