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IMAGING SPECTROMETERS DEVELOPMENTS IN ITALIAN SPACE AGENCY

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ABSTRACT

The imaging spectroscopy is a very powerful tool for the Remote Sensing of the Solar Planets and, in particular, of the Earth. This technique permits to get not only the geometrical information but also the spectral information of the scenario under observation. The number of potential data-products obtainable in this way could be very high, useful and of benefit in several fields of Earth Observation. If these are the advantages on the other side the new dimension will increase the number of data by the number of spectral band, and for this it will increase the technical requirements, mainly, on the Instrument Optical Design, Focal Plane Array, Storage/Compressor Data Unit, Data Transmission etc.
The instruments able to produce 3-dimensional data (cube image) are the imaging spectrometers, which depending on the way how the spectral contents is obtained, can be divided in two main categories:

- The Fourier Imaging spectrometers
- The Dispersing Imaging spectrometers

Each one of the above categories of spectrometers has advantages and disadvantages and a choice between the two types can be made only performing a trade-off with the mission requirements.
The Italian Space Agency (ASI) from long time is promoting and funding, to industrial and scientific levels, several activities covering almost all the aspects related to the imaging spectroscopy: from the applications to the instruments, from the data compressors to future hyperspectral missions.
Purpose of this paper is to present the main results of the activities supported by ASI in this field with particular emphasis on the activities related to the studies and developments of new instruments.

1. INTRODUCTION

To improve the knowledge of Complex Physical Systems, like the Earth System, it is required to have together with the geometrical data also a complete knowledge of the spectral signature. At present, by the space based remote sensing instruments, the geometrical knowledge is accompanied only by a few spectral data: this fact leading possible ambiguities is the reason of a specific and limited number of applications of the remote sensing data.
The imaging spectroscopy is a very powerful tool for the remote sensing of the Earth able to overcome the above limitations. This technique permits to get not only the geometrical information but also the spectral information of the scenario under observation, giving, in this way, to the data another dimension: that of the wavelengths. A complete knowledge of the spectral signature of a pixel in many cases can be more useful than the knowledge of its very detailed geometrical property.
The knowledge of the complete spectrum over a large spectral range (typically 0.4-2.5 μm) instead of few spectral bands, as shown in the Table 1, give the possibility to obtain a very high number of data–products useful and of benefit in several fields of Earth Observation: Vegetation, Geology, Oceanography, Atmosphere.
In the case of Defence Application more requirements could be necessary to cope with the specific application (i.e. extension to the Middle and Thermal bands, better GSD, PAN data etc.) .
Besides , the spectral dimension, increasing the number of the pure geometrical data by the number of spectral band, will require more demanding performance, mainly, on the Instrument Optical Design, Focal Plane Array, Storage/Compressor Data Unit, Data Transmission etc.

2. IMAGING SPECTROMETERS

An Imaging spectrometer is, mainly, made up of the following blocks, as shown in Figure 1.

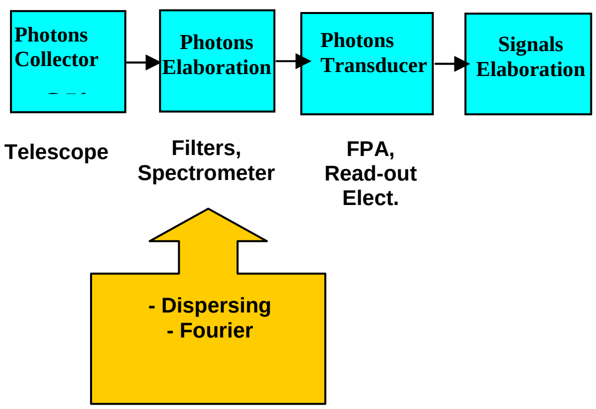

Fig. 1. Imaging Spectrometer Blocks Diagrams

The Imaging Spectrometers, depending on the way how the spectral contents is obtained, can be divided in two main categories:

- The Dispersing Imaging Spectrometers: based on dispersing elements like grating, prism, tunable filters etc.
- The Fourier Imaging Spectrometers: based on the capability to divide the incoming radiation in two beams and then to permit to the two beams to interfere after that they have recurred different optical paths.

Each one of the above categories of spectrometers has advantages and disadvantages and a choice between the two types can be made only performing a trade-off with the mission requirements.

3. DISPERSIVE HYPERSPECTRAL CAMERAS

The Imaging Spectrometers based on dispersing elements are generally very light in weight and very reliable. The previous characteristics make these hyperspectral cameras suitable also for Planetary Missions. ASI has participated to the CASSINI and ROSETTA Mission with the VIMS-V [1] and VIRTIS [2] cameras respectively. These cameras are working in the spectral range 0.3- 1 μm and are using as dispersing elements diffraction gratings in the Offner configuration. .
For Earth Observation applications, where a very high spatial resolution and S/N ratio are required, the Italian Company SELEX Galileo, under ASI contract, is responsible of the design and development of the Hyperspectral camera of the PRISMA Mission [3].
The PRISMA (PRecursore IperSpettrale della Missione Applicativa), heritage of previous hyperspectral program like HypSEO (Hyperspectral Eatrh Observatory) and JHM (ASI-CSA Joint Hyperspectral Mission), mission is a preoperational mission with the intent to qualify the Hyperspectral Camera (HYP/PAN) and to test and validate the associated hyperspectral data products.
The driven applications of the PRISMA data are:

- Vegetation mapping
- Geological Mapping
- Crop Health diagnostics
- Environmental assessment
- Sea coastal zones
- Homeland security
- Hot spots

The phase B of PRISMA started in January 2008 and the launch is foreseen for the end of 2011. All the activities until the commissioning phase have been fully funded by ASI.
HYC/PAN Camera [4], based on the pushbroom concept, is utilizing as dispersing element a prism. The Instrument provides hyperspectral images of the Earth in the Visible and Near Infrared (VNIR) and Short Wave Infrared (SWIR) bands with a GSD of 30m, swath width of 30 km, and with a spectral resolution better than 10 nm. A third panchromatic, 400-750 nm, with a of GSD (5 m), will cover the same swath. The Hypesrspectral and Panchromatic images are co-registered to the to allow testing of images fusion technique.
The optical system of the HYC/PAN consists of three channels sharing a common telescope and a pointing mirror. Two channels perform spectroscopy in the VNIR and SWIR bands and the third channel is the panchromatic camera PAN (Figure 2).

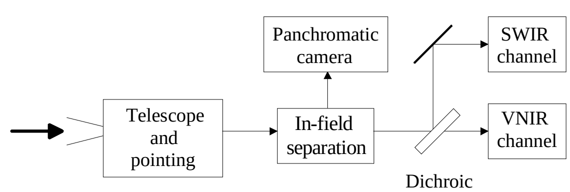

Fig. 2. Block diagram of HYC optics.

The telescope has a TMA (Three Mirror Anastigmatic) design, constituted by three aspherical mirrors realized in Schott Zerodur ™,

with an entrance aperture of 210 mm and an effective focal length of 695 mm.
The PAN and VNIR/SWIR optical paths are in-field separated by a mirror, then the light to be spectrally analysed is sent, through a dichroic plate, to the two VNIR and SWIR channels, respectively.

The purpose to have an entrance pupil so large is to meet the demanding requirements on the S/N ratio for the entire operative life and to meet the requirements of very demanding applications products.
The main performance of HYP/PAN are in the Table 1.

Table 1: Summary of the main HYP/PAN instrument performance

	VNIR channel	*SWIR channel*	*PAN channel*
Spectral range (nm)	400-1010	920-2505	400-750
Spectral resolution (nm)	≤ 10	≤ 10	-
Swath width (km)	30	30	30
Ground SampleDistance (m)	30	30	5
Spectral bands	92	157	1
S/N ratio	200:1 on 0.4–1.0 µm 600:1 @ 0.65 µm	200:1 on 1.0–1.75 µm 400:1 @ 1.55 µm 100:1 on 1.95–2.35 µm 200:1 @ 2.1 µm	240

A solar port allows sun light to enter in the telescope for radiometric calibration. Spectral calibration is performed by using internal lamps, while “dark calibration” is possible by using a shutter mechanism placed in front of the slit located after the in-field separation.
The 3 FPA (Focal Plane Array) are passively cooled by means of a suitable radiator.

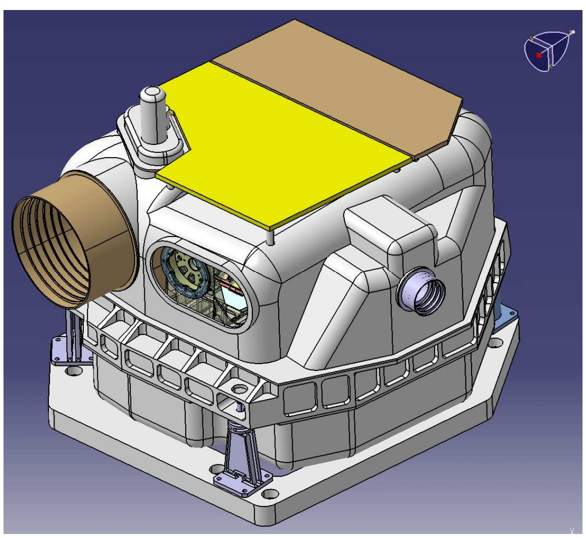

Fig. 3. Courtesy SELEX Galileo : HYP/PAN Camera Layout

4. FOURIER IMAGING SPECTROMETERS

The future space missions require always to the sensors more demanding performance in terms of resolution, S/N ratio and weight. For this reason, ASI has started, with some National Research Labs, study activities with the intent to realize and to test prototypes of Imaging Spectrometers based on Fourier Interferometers in different configurations : Mach Zehnder and Sagnac-like .
The Fourier Interferometers[5] have several important advantages with respect to Dispersing Spectrometers, mainly :

- Jacquinot-Felgett advantages, that means very high S/N ratio
- the spectral band and the spectral resolution can be changed by acting on the sensor sampling steps, the Optical Path Difference (OPD) and on the instrument Field of View.

The above advantages are dicreased by a more complex data analysis; in fact, in order to have the spectrum, it is necessary to apply a Fourier Transform to the interferograms.

4.1 Mach-Zehnder MicroInterferometers

This instrument, developed using the MOEMS[6] (Micro Opto-Electro-Mechanical System) technologies, works in the spectral band 0.4-4.5 µm, with an expected spectral resolution of about 0.1 nm. It is made up of an array of 3 Mach-Zehnder micro-interferometers integrated on the same hybrid chip together with the driving electronics (Figure 4). Arrays of a larger number of micro-interferometers are "easily" achievable. The substrate material is $LiNbO_3$.

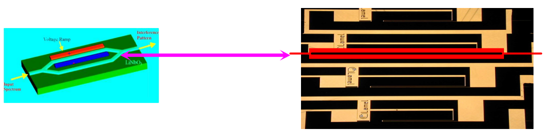

Fig.4. The 3 Mach-Zehnder micro- interferometers

An Optical Path Difference is achieved changing the refractive index of one arm of the interferometer using a linear electrical ramp. The weight, the dimension and the power consumption of the device are negligible, the input optics and the Peltier Cooler of the detectors are the heaviest and largest components of the instrument. This kind of instrument was developed having in mind a possible installation on board of nano-satellite and for future planetary missions.

4.2 ALISEO a Sagnac-like Interferometer

The so-called Static Michelson Interferometers are suitable instruments for Planetary and /or Earth Observation.
Of particular interest are those in the Sagnac configuration as the imaging interferometer ALISEO[7] (Aerospace Leap-frog Imaging Stationery Interferometer for Earth Observation). As in the Sagnac interferometer, in ALISEO (see in Figure 5 a layout of the prototype) a collimated beam is divided by a Beam Splitter inside a common triangular path with a tilt introduced between the two interfering image wavefronts. The two beams are focused on a 2D array where will be formed a fixed (stationary) pattern of interference fringes of "equal thickness".
The Beam Splitter is a fundamental component in this kind of interferometer because it will provide the phase delay between the two interfering beams so that the OPD changes linearly by varying the angle of the incoming ray with respect the instrument optical axis.

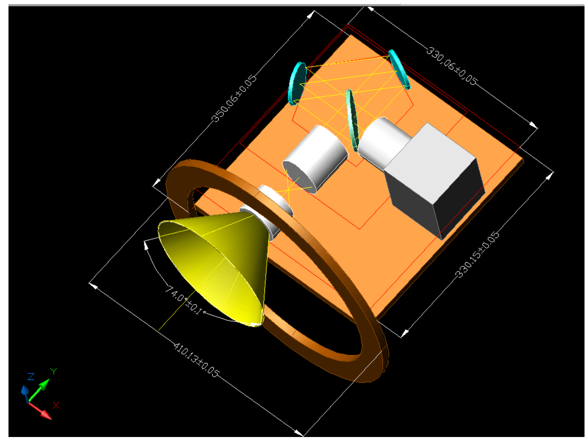

Fig.5. Layout of the prototype of ALISEO.

Differently from the HYP/PAN camera, where the energy from each observed element is dispersed spectrally and every frame is a monochromatic image of the scene, in ALISEO every frame contains the observed scene superimposed to the stationary interference pattern and the interferogram related to the same observed element is dispersed along the diagonal of the data-cube (Figure 6).

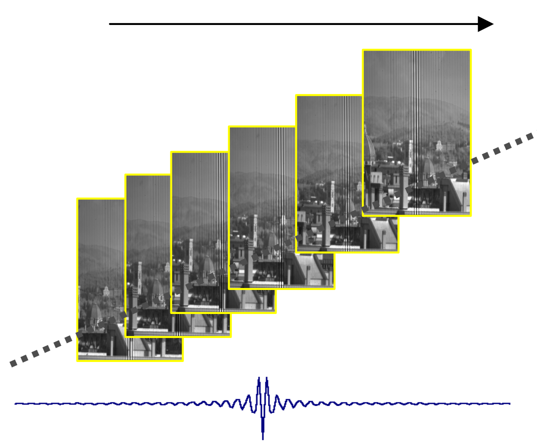

Fig. 6. The interferogram along the diagonal, the arrow is the direction of movement .

Currently ALISEO is using a CCD matrix of 1024*1024 pixels working in the spectral band

0.4-1.0 µm and with a resolution of less than 7 nm .

4.3 The MIOSAT Mission

The Mach-Zehnder Interferometer and the ALISEO imaging spectrometer are two of the payloads which will be installed on board of the ASI technological mission MIOSAT (Small Optical Mission based on Microsatellite). The main goal of MIOSAT is the qualification in the space of several instruments, mainly devoted to the Earth Observation, developed during the Technological Programs funded by ASI.
The main features of the MIOSAT Mission are in the Table 2

Table 2: Summary of the main features of the MIOSAT Mission

Satellite launch mass	~120 kg	
Pointing capability	Nadir pointing with rapid repointing capability,	
Orbit type	Circular heliosyncronous	
Orbit Height	~500 km	
Mission lifetime	2 years	
Launcher	Compatibility with VEGA and other launchers	
Launch date	2011	
Technological suit		
	Pancromatic Camera	0.4-0.75 µm / GSD: 2m
	ALISEO Camera	0.4-1.0 µm / GSD: 10m/ $\Delta\lambda$:̃ınm
	Mach-Zehnder coupled to a deployable Telescope	0.4-4.5 µm / $\Delta\lambda$:̃ınm
	Data Storage /Compression Data Unit	
	SW Radio GPS	

5. CONCLUSION

The imaging spectroscopy is a very powerful tool for the remote sensing of the Solar Planets and, in particular, of the Earth. This paper presents the main results of the activities supported by Italian Space Agency (ASI) in this field with particular emphasis on the activities related to the studies and developments of the new instruments which will be installed aboard of the next technological and preoperative space missions MIOSAT and PRISMA.

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