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MINIATURISATION OF IMAGING SPECTROMETER FOR PLANETARY EXPLORATION

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ABSTRACT

Future planetary exploration on telluric or giant planets will need a new kind of instrumentation combining imaging and spectroscopy at high spectral resolution to achieve new scientific measurements, in particular for atmospheric studies in nadir configuration.
We present here a study of a Fourier Transform heterodyne spectrometer, which can achieve these objectives, in the visible or infrared. The system is composed of a Michelson interferometer, whose mirrors have been replaced by gratings, a configuration studied in the early days of Fourier Transform spectroscopy [1], but only recently reused for space instrumentation, with the availability of large infrared mosaics.
A complete study of an instrument is underway, with optical and electronic tests, as well as data processing analysis. This instrument will be proposed for future planetary missions, including ESA/Bepi Colombo Mercury Planetary Orbiter or Earth orbiting platforms.

1. SCIENTIFIC DESCRIPTION

The following description corresponds to scientific objectives of an infrared imaging spectrometer developed for the Bepi Colombo/ESA mission to Mercury. Other applications are foreseen in planetary explorations [2]

1.1 Scientific objectives: mineralogy

The mineralogic objectives of the Mercury Planetary Orbiter (MPO) mission correspond to the objectives of the generic infrared spectrometer (IMS) whose characteristics are aimed to fit the payload description. An important objective is to understand the repartition of iron in the planet, from a mapping of its abundance in surface layers; the spectral signature of ferrous compounds as Fe^{2+} feature, or FeO contents in silicates, is achievable through the detection of spectral signatures around 1 micron. Disk average reflectance spectra show no absolute evidence of the presence of FeO in mafic silicates, although broadband characteristics of these spectra suggest its presence as a surface material with a percentage lower than 8%. The characterisation of such spectral bands with an imaging infrared spectrometer would be of great interest to trace the abundance of iron on Mercury, and to provide clues on the origin of the planets. Mapping other minerals across the surface would give an understanding of the processes at work on the surface of Mercury. Of particular interest is also the study of the bright radar features, to understand the mineralogic origins of these features, in particular to discriminate between the origin of these backscattering radar component, for which different interpretations have been given, as water ice [3] or sulfur [4]. Even if a direct spectral detection of these constituents is problematic on Mercury (cold hidden domain for ice and lack of spectral signatures for the second), trace of alteration or of mineral deposits could provide indirect evidence for their presence.
To achieve the science objectives of mineralogic mapping, it has been suggested to add to a “standard” IR mapping spectrometer, at the usual spectral resolution of ~200 a channel centered at 1 μm with a higher spectral resolution, to help discriminating the iron bearing silicates. As discussed below in the technical part, these two options can in fact be combined together in one unique channel.

1.2 Scientific objectives: atmosphere

Mercury possesses a tenuous atmosphere, which poses several important scientific questions, related to its characteristics and relation with the surface and magnetosphere [5]. Na, K, H, He, O, and, more recently, Ca, have been identified so far in the exosphere. As the heavy elements are related to sputtering mechanisms on the surface, the lighter ones are supposed to come from the solar wind, or from ices present on Mercury. Temporal and spatial variations of Na and K are related to the variability of the atmosphere, which is known to be large, from ground based observations. Important questions are to understand the mechanisms responsible for the origin of atmospheric compounds, and of their interaction with the solar wind.
The Na abundance can vary by two orders of magnitudes between 10^{10} to 10^{12} atoms/cm^{-2}, with a suggested dependence related to surface features. A mapping of these variations, and especially, a correlation with the mineralogic variations would be of high interest to track the origin of the sodium atmosphere. Moreover, surface sputtering by precipitating particles is a potential source of

atmospheric emission; such phenomena would be related to magnetosphere/surface interaction, and to solar wind variability. The monitoring of atmospheric variability could therefore be related to magnetospheric observations provided by the MMO to study the correlation between magnetospheric and atmospheric activity.

2. TECHNICAL DESCRIPTION

To achieve the two different objectives, different concepts are under study, in particular with the use of modified Michelson interferometers. Such instrument have been studied for space mission in particular in the group of Kiev University for Earth observation satellites [6].

2.1 <u>High resolution spectrometer for Sodium lines nadir imaging</u>

For this science objective, ideally a mapping spectroscopy in the Na lines at 589 nm with a resolving power of 50,000 is foreseen. The spatial resolution can be degraded compared to the mineralogic channel, at ~ 1mrad FOV, as atmospheric features are not expected to vary at very small scale.

Spectral resolution ($\lambda/\Delta\lambda$)	50000
Spectral bandwidth	0.588 – 0.591µm
IFOV	1 x 1 mrad

Table 1 General specifications of the static FTS.

The optical principle is a static imaging Fourier transform spectrometer based on a Michelson interferometer in "corner" configuration. The light is collected on an entrance slit by a two-lens telescope and collimated by another two-lens collimator. A beamsplitter cube associated with gratings performs the Fizeau fringe pattern, which is re-imaged on the FPA using an objective. The Fourier transform of the imaged interferogram gives the spectrum of the observed scene. The fringes being parallel to the interferometer corner, a toroidal lens is used to flatten the pattern. The perpendicular direction is then freed and can be used to image the entrance slit on the detector. The objective has therefore two perpendicular optical powers, one that images the fringes and the other one that images the entrance slit. The FPA then records parallel interferograms of the different field directions.
For a spectral resolution of 50000, gratings working under Littrow conditions are used. This kind of configuration is called heterodyned FTS as it reduces the fringe frequency seen at the detector while retaining high spectral resolution.

OPTICS	
Type	**Heterodyned FTS**
Entrance pupil diameter	**10mm**
Beam etendue	**$1.5.10^{-11}m^2.sr$**
Interferometric pupil diameter	**42mm**
Optical transmission	**0.35**
FPA	
Number of pixels	**512x256**
Pixel size	**30µm**
Read out noise	**630 e-**
Quantum efficiency	**0.6**
Capacity	**1.10^7e-**

Table 2 Optical characteristics

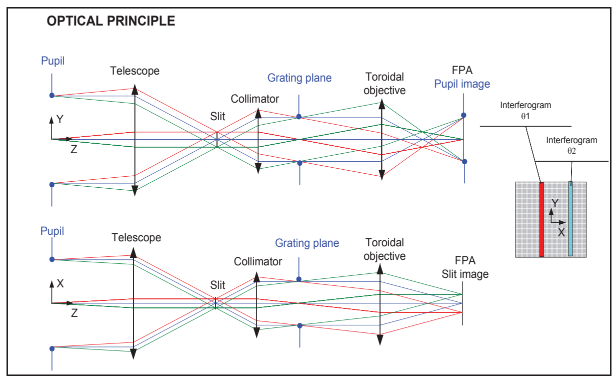

Fig.1 Optical concepts of heterodyne imaging spectrometer

Optical principle of the instrument with a toroidal objective lens. The pupil is imaged in the YZ plan (top figure) The slit is imaged in the plan (bottom figure)

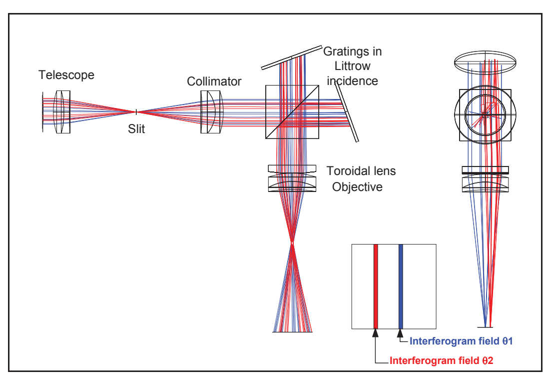

Fig.2 Optical design

Instrument performances

In the following simulation, a Mercury spectrum around the sodium emission lines is used (fig 3.c). This spectrum is first Fourier transformed to obtain the interferogram (fig 3.a). Some photon noise and readout noise is added to get the interferogram that will be recorded on the detector. This noised interferogram is then Fourier transformed again to get the reconstructed spectrum of Mercury (fig 3.D).

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A mass budget for this instrument channel has been estimated at 275 g, optical bench excluded.

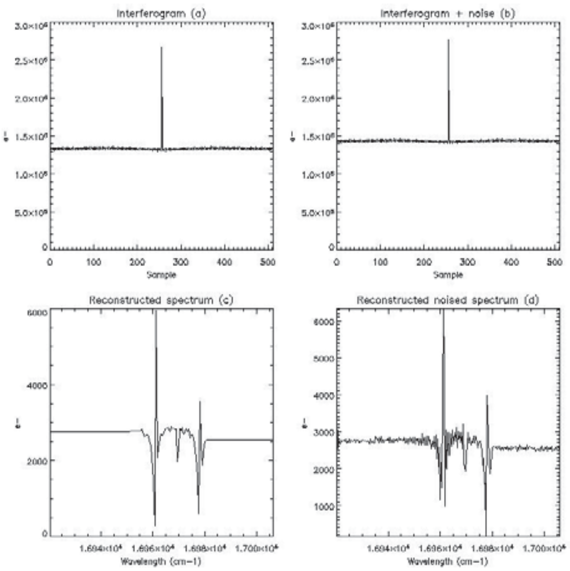

Fig.3 Initial spectrum (c) and its interferogram (a). Reconstructed spectrum (d) and its interferogram (b).

2.2 Low resolution imaging spectrometer

A mapping spectrometer in the range 0.4 – 2.0 µm is foreseen; the spectral resolution for discriminating some of the iron features in the 1 µm silicate band should ideally be higher than 200. The spatial resolution should be 0.25 mrad for satisfying the science objectives.

Two concepts are investigated: a wedge filter spectrometer and a Fourier Transform Spectrometer (FTS), similar to the channel at high resolution, described above, but with mirrors instead of gratings.

The wedge filter techniques permits to have the minimum number of optical components. A contract has been signed with Institut Fresnel in Marseille to develop a customized component on our specification.

The total mass is estimated at 200 g, The Signal to Noise Ratio for an albedo of 0.1 and an integration time of 0.1 s is included in 100 ÷ 500.

As for the FTS, its main advantages are its high luminosity and its compactness. Its total mass should be the almost the same as the equivalent high resolution channel

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