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LAND-SURFACE PROCESSES AND INTERACTIONS MISSION

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ABSTRACT - For the post 2000 time frame, the European Space Agency (ESA) is defining candidate missions for Earth Observation. In the class of the Earth Explorer missions, dedicated to research and demonstration missions, the Land-Surface Processes and Interactions Mission (LSPIM) involves a dedicated satellite carrying a single optical payload named PRISM (Processes Research by an Imaging Space Mission). PRISM is a multispectral imager providing high spatial resolution images (50 m over 50 km swath) in the whole optical spectral domain (from 450 nm to 2.3 µm with a resolution close to 10 nm, and two thermal bands from 8.2 to 9.2 µm). The mission provides multi-directional observations for measurement of Land Surface BRDF (Bi-Directional Reflectance Distribution Function) and an access to any site on Earth within 3 days. This paper presents the results of a study awarded by ESA, led by AEROSPATIALE and concerning the design of the Land Surface Processes and Interactions Mission.

I. INTRODUCTION

This paper presents the results of a pre-feasibility study awarded to AEROSPATIALE by ESA concerning the Land-Surface Processes and Interaction Mission (LSPIM). It details the main mission requirements, the results of the mission analyses and the description of the instrument and satellite design.

LSPIM features an optical payload named PRISM (Processes Research by an Imaging Space Mission), a push broom multispectral imager providing high spatial resolution images (50 m over 50 km swath when looking at nadir) in the whole optical spectral domain (from 450 nm to 2.3 µm with a resolution close to 10 nm, and 2 thermal bands from 8.2 to 9.2 µm). This payload is implemented on a dedicated, small class satellite.

The mission provides an access on any site on Earth within at maximum 3 days and is designed to perform BRDF (Bidirectionnal Reflectance Distribution Function) measurements of the sites of interest. The Land-Surface Processes and Interactions Mission is one of the candidates for the ESA post ENVISAT « Earth Explorer » missions, to be launched in the post 2000 time frame.

2 MISSION REQUIREMENTS

Three types of missions are defined for the Land-Surface Processes and Interaction satellite :

- the Principal Mission provides systematic BRDF acquisition over a number of essential sites.
- the Exceptional Mission provides on request, BRDF acquisition on high priority sites.
- the Secondary Mission envisages direct delivering of data to local users, if spare capabilities are available.

The nominal measurement mode is the BRDF acquisition mode, which consists in acquiring images of the same site from a number of different directions, to provide directional sampling of the surface BRDF. Two temporal scales are involved in this acquisition :

- a sequence of 7 acquisitions using different Along-Track angles during a single satellite pass, that is, lasting about 400 seconds,
- a series of similar sequences from several satellite passes, using different Across-Track (ACT) angles, in a time frame of a few days.

The required depointing range for the mission is typically ±35° in the ACT direction, and ±55° in the ALT direction.
For each angular acquisition, the instrument produces a set of spectral images of the selected Earth sites, measured simultaneously in different wavelength regions. When looking at nadir, the image dimension is 50 km x 50 km, and the spatial sampling interval is 50 m. The images in all bands are spatially and spectrally co-registered for accurate exploitation of data. The instrument covers two main spectral regions. Region 1 covers Visible-Near InfraRed (VNIR) and the Short-Wave InfraRed (SWIR). In this region, the instrument works as an imaging spectrometer with a spectral resolution of about 10 nm. Region 2 covers the Thermal InfraRed (TIR), with two bands (8.2 -8.7 µm and 8.7-9.2 µm).

The physical parameters directly measured by the instrument are the top of the atmosphere radiances of the selected ground sites. The images are calibrated to assign an absolute radiometric value to each of its picture elements. The main instrument requirements are given in the following :

SPATIAL REQUIREMENTS	
Swath width	50 km
Spatial sampling interval	50 m
Spatial registration within region 1 and region 2	< 0.2 spatial sampling interval
System Point Spread Function (PSF)	< 1.75 spatial sampling interval
SPECTRAL REQUIREMENTS	
Spectral range region 1	0.45-1.11 / 1.16-1.40 / 1.49-1.79 / 2.02-2.35 µm
Spectral sampling interval	< 15 nm, < 10 nm in range 680 ÷ 769 nm
Spectral registration	< 0.15 spectral sampling interval
Center line accuracy - Spectral width accuracy	0.5 nm - 0.5 nm
Spectral range in region 2	8.2-8.7 µm / 8.7-9.2 µm
RADIOMETRIC REQUIREMENTS	
Signal dynamic range in region 1	Specified Max. And Min. Radiance
Signal resolution in region 1	12 bits
Absolute radiometric accuracy in region 1	Goal : $< \sqrt{(NedL^2 + (0.02 \times \text{Input radiance})^2)}$
Radiometric dynamic range in region 2	200 - 360 K
Radiometric resolution in region 2	NedT < 0.1 K
Absolute radiometric accuracy in region 2	1 ÷ 3 K
Polarisation sensitivity	< 0.03 (450 nm), < 0.1 (700 nm), < 0.3 (1 µm)

3. MISSION ANALYSIS

The goal of the mission analysis was to consolidate the mission profile (orbit selection, depointing requirements, satellite resources) and assess the performance of the systems, assuming a realistic mission scenario.

3.1 Reference sites

A preliminary set of sites has been defined as a reference for the analysis of the Principal mission and are given in Fig.1. They corresponds to sites within IGPB (International Geosphere-Biosphere Programme) transect areas, or to typical calibration sites (such as la Crau, White Sands, Dunhuaung etc...). The number and localisation of sites is indicative and will be refined in further phases, but they correspond to sites of particular scientific interest.

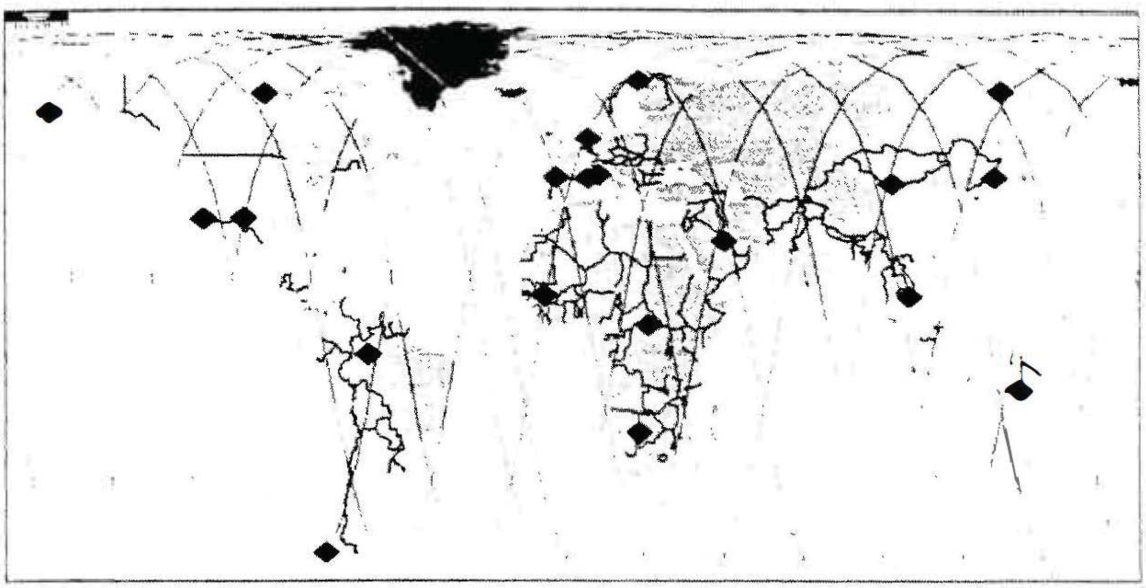


Fig. 1 : Reference sites for the Principal Mission Analysis

3.2 BRDF measurement mode

The main goal of the mission is to perform an efficient sampling of the BRDF of each of the selected sites, within a time frame compatible with the time frame of the processes to be analysed, namely, a few days.

The sampling is provided by sequential acquisitions with different angles. Each satellite pass provides 7 measurements with different Along-track angles, several satellite passes are involved to complete the 2D BRDF sampling.
The geometrical characteristics of each acquisition can be described in a polar representation as illustrated in Fig. 2. A convenient representation uses the principal plane as a reference (the sun's plane of incidence). Indeed, the sampling of the BRDF in this plane is of high interest, in particular in the direction of incidence of the sun (so-called hot spot direction).

Several candidate orbits have been traded-off against their BRDF sampling capability. A promising 14 days, 767 km orbit has been recommended, which allows an efficient theoretical 2D sampling of the BRDF on any site in about 2 weeks.

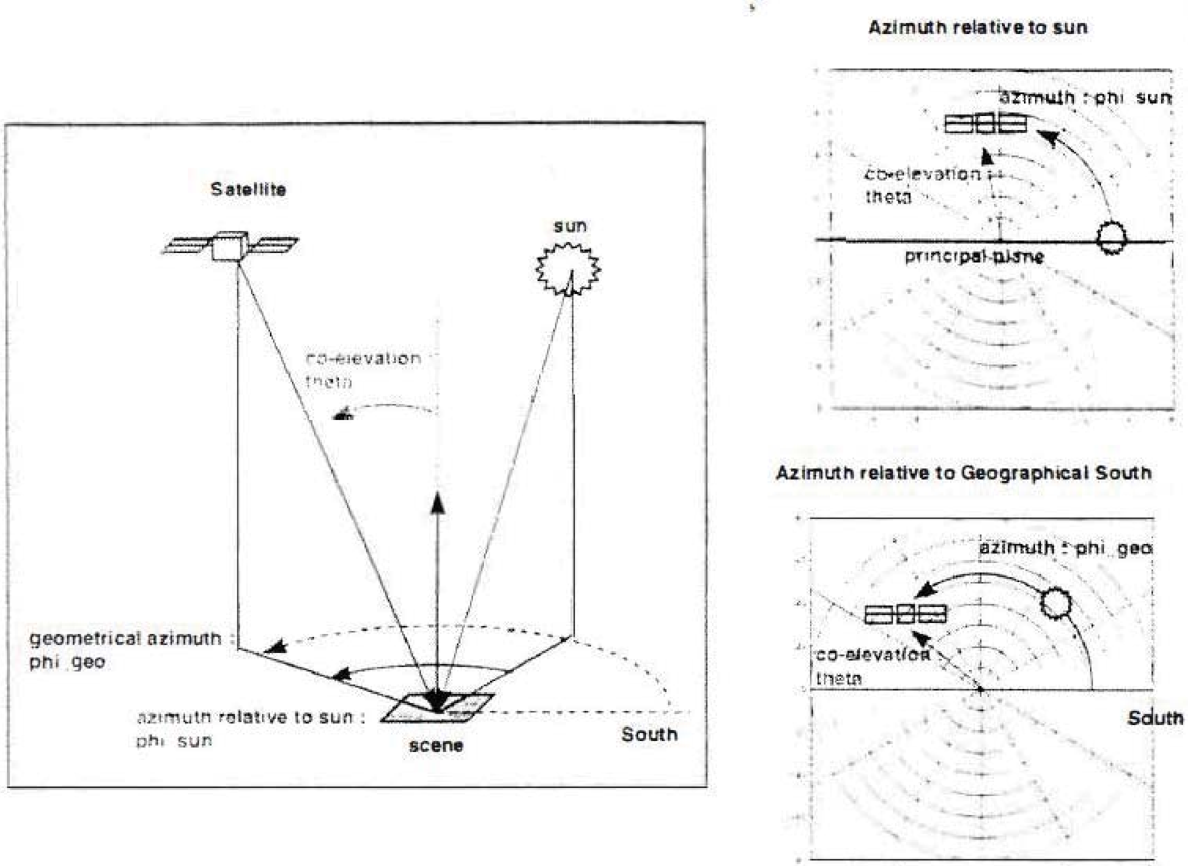


Fig. 2 : BRDF Measurement principle

3.3 Mission performance simulation

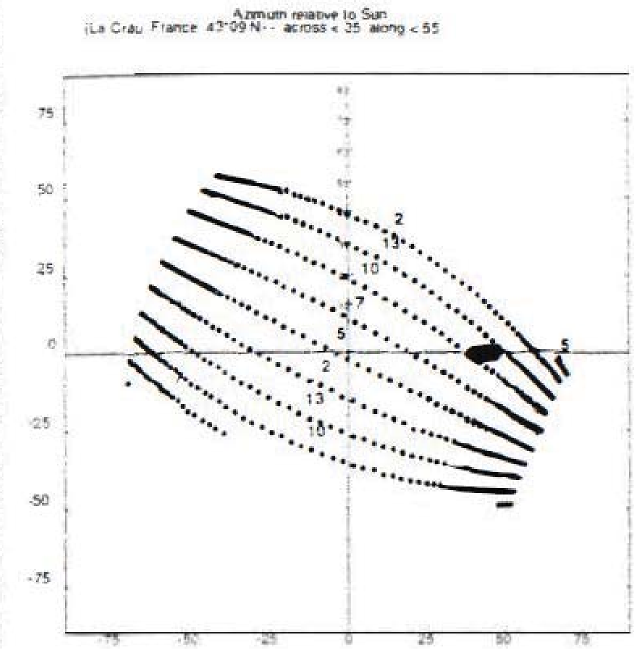
A simulation of the mission performance has been performed featuring :

- the assessment of the theoretical BRDF sampling capability of the satellite for the selected orbit, and for each site of interest,
- the simulation of mission planning using AS3_M tool (AEROSPATIALE Space System Simulator_Mission), which accounts for image acquisition request scenario and satellite resources such as on board storage, Attitude and Orbit Control System (AOCS) constraints, etc..
- the accounting of typical meteorological constraints (cloud coverage statistics from International Meteorological Organisation) for realistic performance assessment.

Typical achievable performance have been calculated for all the reference sites, giving the theoretical BRDF sampling, and the number of days required to get a certain probability of performing from 1 to 6 sets of BRDF sequences. Each BRDF sequence is composed of 7 acquisitions during a single pass with different Along-Track angles.
Fig.3 gives typical results calculated for La Crau site.

The results that were obtained show that an overall optimisation of the Principal Mission profile is possible, accounting for the orbit definition, the sites location, the seasonal effects on the sun position and on the meteorological conditions. Such optimisation will allow an efficient definition of the satellite resources

BRDF Sampling in Sun Azimuth Reference

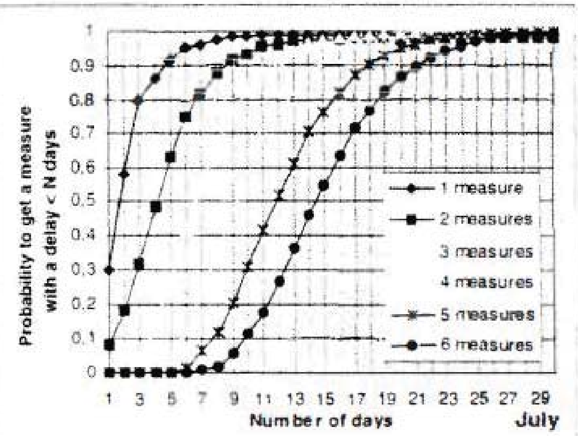


This plot gives the BRDF sampling that could be provided in 2 weeks on La Crau site with a satellite having a depointing capability of ±35° in the Across-Track direction, and ±55° in the Along-Track direction.

The numbers indicated on each curve is the day of the pass.
The horizontal axis represents the principal plane. The plots on this axis correspond to the hot spots location during the orbit cycle of 2 weeks.
These performance do not account for cloud coverage.

The calculation is performed for a 2 weeks cycle in Spring.

Probability to get measures within n days accounting for cloud coverage - Best Case



Probability to get measures within n days accounting for cloud coverage - Worst Case

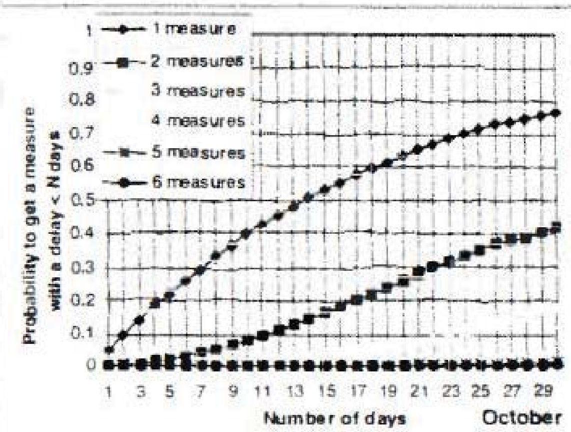


Fig. 3 : Example of BRDF measurement performance - La Crau calibration site

In the best case of July, when cloud coverage is minimum, the probability to get 6 sequences of BRDF sampling (42 sampling points of the BRDF), in less than 2 weeks is about 45%. A single pass sequence providing 7 sampling points can be acquired in less than 3 days with a probability of about 80%. The performance is strongly degraded in october, due to higher cloud coverage . In this worst case, a single pass sequence of 7 sampling points can be acquired in less than 2 weeks with a probability of 50%. These result show the interest of optimal planning of the sites to be observed to get the best performance.

4. INSTRUMENT DESIGN

4.1 Introduction : optimisation of payload and platform interactions

A main feature of the Land-Processes and Interaction Mission is the need for a high depointing capability of the system, both in the Along-Track and the Across-Track directions, to provide the required BRDF measurement capability.
An exhaustive trade-off has been performed on the possible solutions to provide this pointing capability, from complete depointing by the instrument, to a fully agile satellite.

The solution that has been retained provides an optimum interaction of payload and platform, and guarantees the highest flexibility of the mission. The selected concepts involves :

- a highly agile small class satellite, whose AOCS is optimised to provide high manoeuvre capability in all axes,
- the pointing capability is further improved in the Along-Track direction by involving a so-called « line-stop » depointing mirror at the instrument level, which provides an additional flexibility in the pointing capabilities. In particular, it allows a high flexibility on the angular sampling sequence that can be performed, and on the projected scan rate during push broom imaging. Furthermore, this mirror is used to address the radiometric calibration sources required to achieve the high level radiometric performance.

Other considerations have been taken into account in the optimisation of the interactions between the payload and the platform :

- the overall mechanical architecture is optimised, involving the platform, a payload service module, and the optical instrument,
- the electrical architecture is also optimised, with a mastering by the platform calculator, and an efficient dialogue with the instrument control unit. Such unit has been implemented to allow an efficient parallel development and testing of the platform and the payload.

A overview of the satellite design and budgets is provided in the section 5.

4.2 Payload design

Fig. 4 gives the functional block-diagram of the payload. The technical choices made for each sub-system are detailed in the following. The main features of the instrument are :

- a single common TMA telescope (Three Mirrors Anastigmat), for the whole spectral range,
- an in field separation between region 1 (VNIR & SWIR) and region 2 (TIR),
- a refractive relay optics in region 2,
- an innovative spectrometer covering the full region 1 spectral range,
- two 2D arrays of detectors in region 1 where the instrument is a spectro-imager,
- two 1D arrays of detectors in region 2,
- a single mirror, rotating around the optical axis, providing both a small range Along-Track depointing capability (a few degrees), and addressing the radiometric calibration sources.

The instrument is fully compliant with the requirements recalled in section 1.

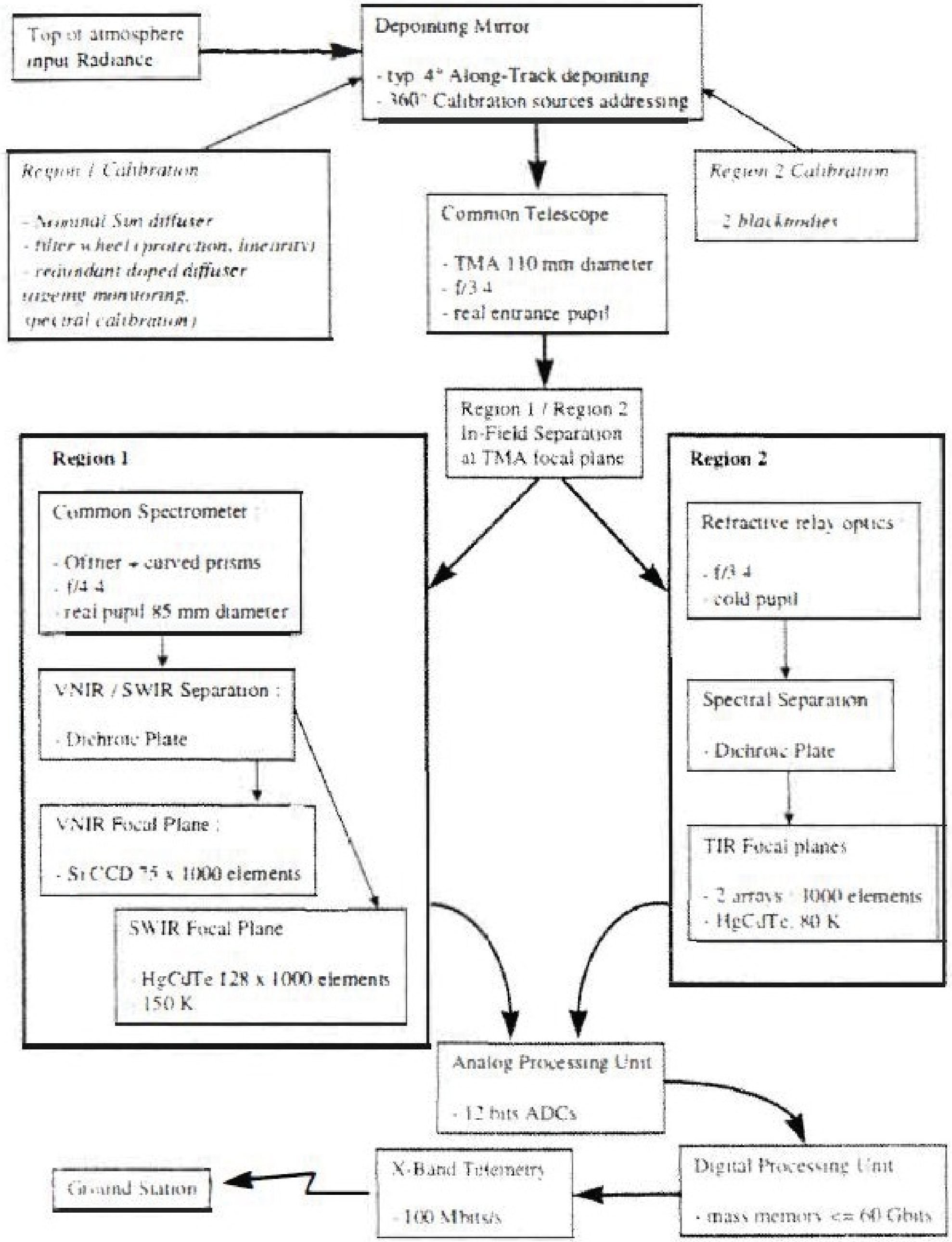


Fig. 4 : Payload functional block diagram.

4.2.1 Depointing mirror

The depointing mirror has two functions :

- a small range (a few degrees), accurate depointing in the Along-Track direction,
- a wide range, low accuracy depointing towards the calibrations sources.

The mirror is rotating around the optical axis, which minimises its size and allows a potential 360° depointing capability. The mechanism is a brushless motor, with a fine depointing mode, the accuracy of which is ensured by accurate driving current control. The calibration sources addressing involves a second operating mode with higher angular range and lower accuracy.
In the Along-Track depointing mode, the few degrees rotation of the detector line's projection on Earth can be efficiently corrected by satellite yaw steering

4.2.2 Telescope

The telescope is a Three Mirror Anastigmat (TMA) with a real entrance pupil, and covering the full spectral range. Its focal length is 375 mm, its across track field of view is ± 1.8°. Its diameter is 110 mm which leads to a f number of 3.4.

4.2.3 Separation bet een region 1&2

The separation between region 1 and region 2 is performed at the telescope focal plane. This in-field separation device reflects the region 2 while the region 1 is transmitted through a slit.

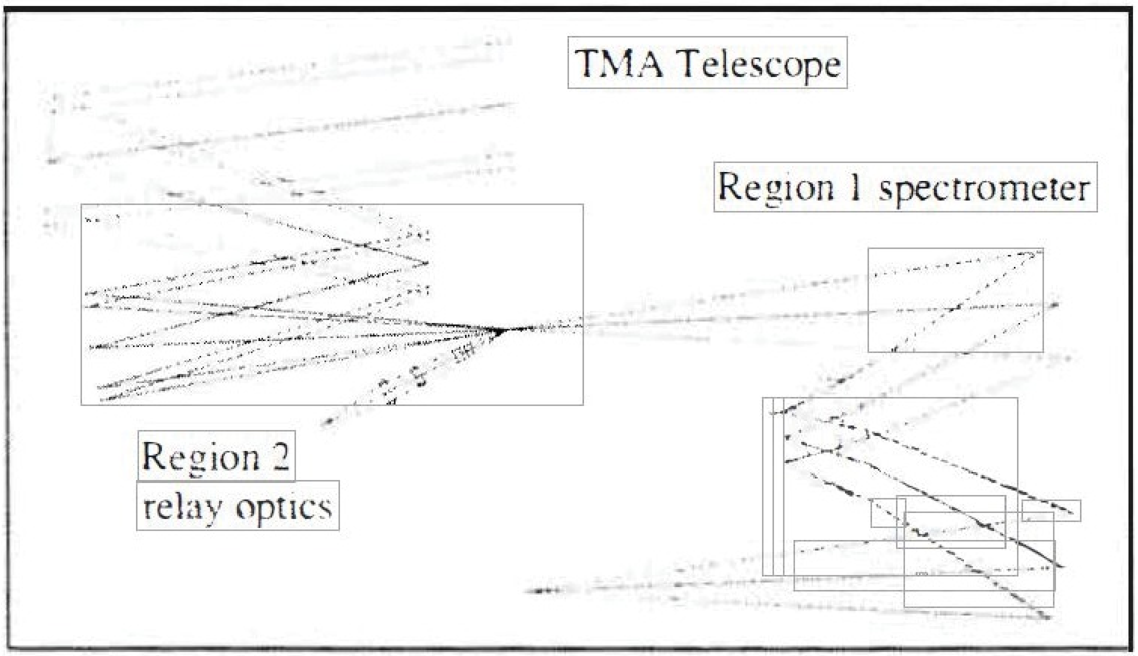
4.2.4 Region 1 spectrometer

Considering the required number of bands and their spectral width, the principle of a spectrometer involving a disperser element and a 2D focal plane array was selected, one direction defining the spatial swath, the other defining the spectral range. The spectrometer covers the whole spectral range, and features an Offner layout and curved prisms with spherical surfaces. The separation between SWIR and VNIR is performed by a dichroic plate, located after the disperser element. This provides a very good registration within region 1.

4.2.5 Region 2 optics

The region 2 relay optics layout is fully refractive, using Ge and ZnSe lenses. Its f number is 3.4, and it provides a real pupil just before the focal plane, allowing the implementation of a cold pupil.

The optical layout is given in the following figure.



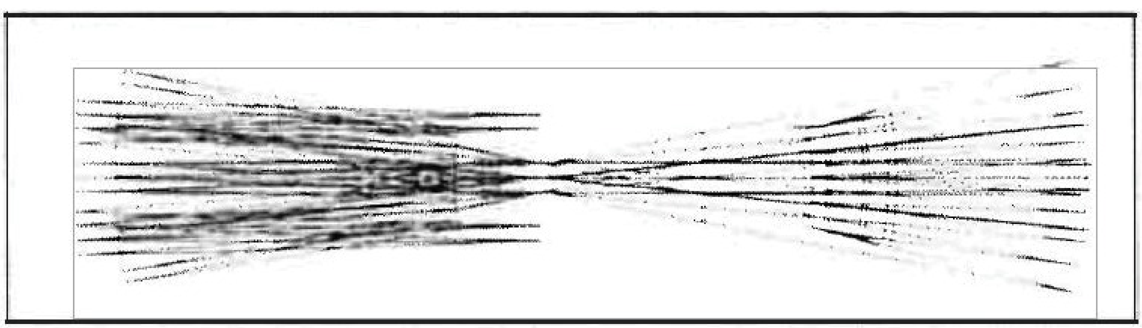


Fig. 5 : Optical layout

4.2.6 INIR focal plane

A Silicon thinned back illuminated array is preferred due to its better responsivity in the blue region. This array is hybridised on a CCD MUX, provided with a four frame transfer to reduce the read out frequency. The CCD has 1000 x 75 sensitive elements, the pitch is 28 µm x 22 µm. Conrnlering the spectral response of Silicon, the spectral range will be limited to 450-1000 nm.

4.2.7 SWIR focal plane

The SWIR focal plane baseline is using HgCdTe detectors and CMOS multiplexer as readout circuit. The array is made of 128 x 1000 elements of 28 µm pitch. The array is made of several smaller arrays butted in the spatial (and possibly spectral) direction(s). It is actively cooled to 150 K.

4.2.8 Thermal Infrared focal planes

The sensitive material in all bands is HgCdTe hybridised on CMOS read-out and multiplexer. The operating spectral range is from 8.2 µm to 9.2 µm, well within the capability of state of the art HgCdTe focal planes The 1000 elements required to cover the swath are obtained by butting smaller arrays in the spatial direction. A staggered focal plane configuration can be envisaged. The focal plane is actively cooled to about 80 K.

4.2.9 Calibration principles

In region 1, two sun diffusers are implemented : a nominal one for absolute and relative calibration, a redundant, doped one for monitoring of the nominal diffuser and spectral calibration. A shutter wheel filters the sun entrance (linearity check, full aperture and shutter).
In region 2, the nominal calibration is based on the use of two direct view blackbodies.
Fig. 5 shows the instrument 3D implementation (the shutter wheel is not represented for clarity)

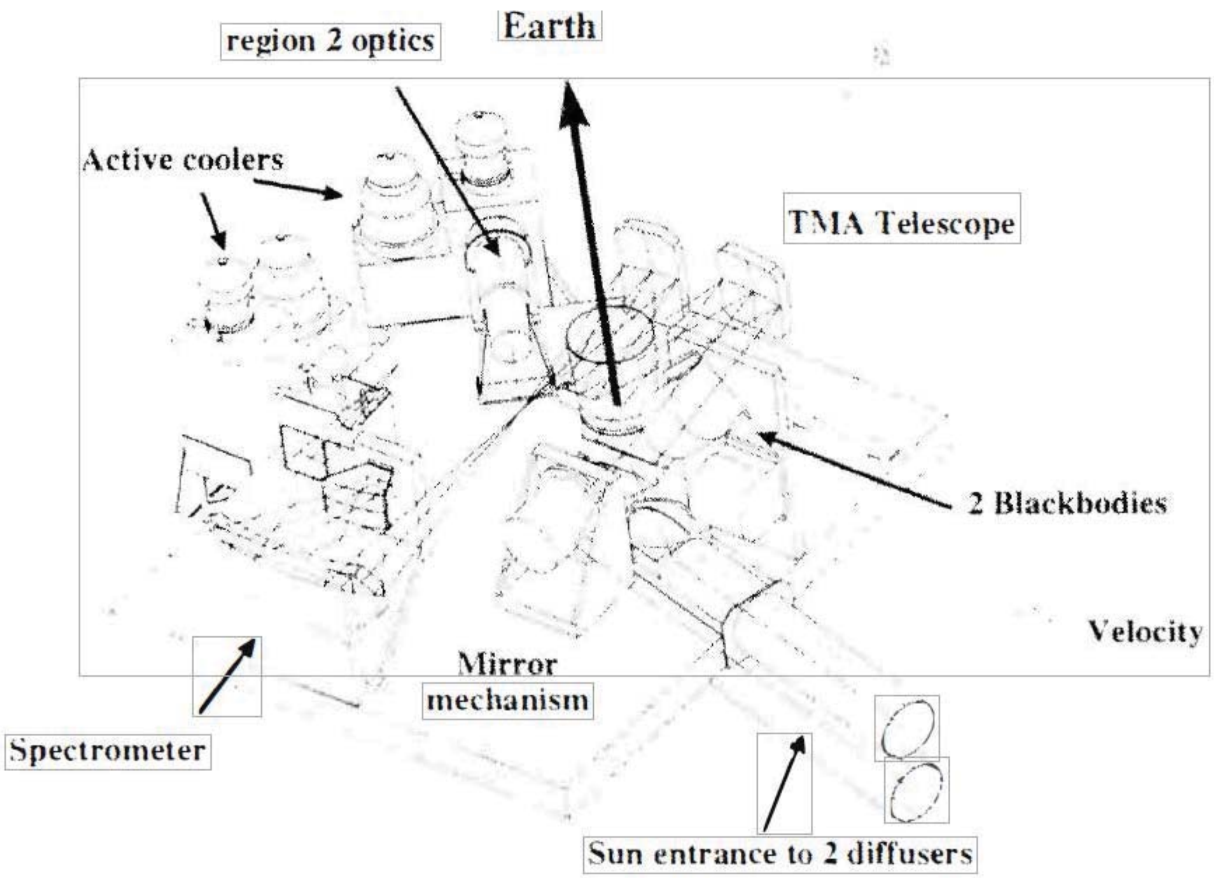


Fig. 6 : Instrument implementation

5. SATELLITE DESIGN

As illustrated in the Fig.6. the satellite design is modular featuring the optical bench (perpendicular to nadir). a payload service module and a platform. The satellite is agile thanks to a rigid concept (fixed solar arrays). and an optimised AOCS design (0.2 Nms wheels are used in an optimised skewed configuration). It typically provides a O to 30° depointing capability in the pitch direction in less than 50 seconds (stabilisation included). Between BRDF measurements. the satellite is pointing towards the sun. which optimises the solar arrays surface.

The satellite mass is 642 Kg. including 337 Kg for the payload. 278 Kg for the platform. and 27 Kg for the propellant.

The power is 663 W. including 395 W for the payload and 268 W for the platform.

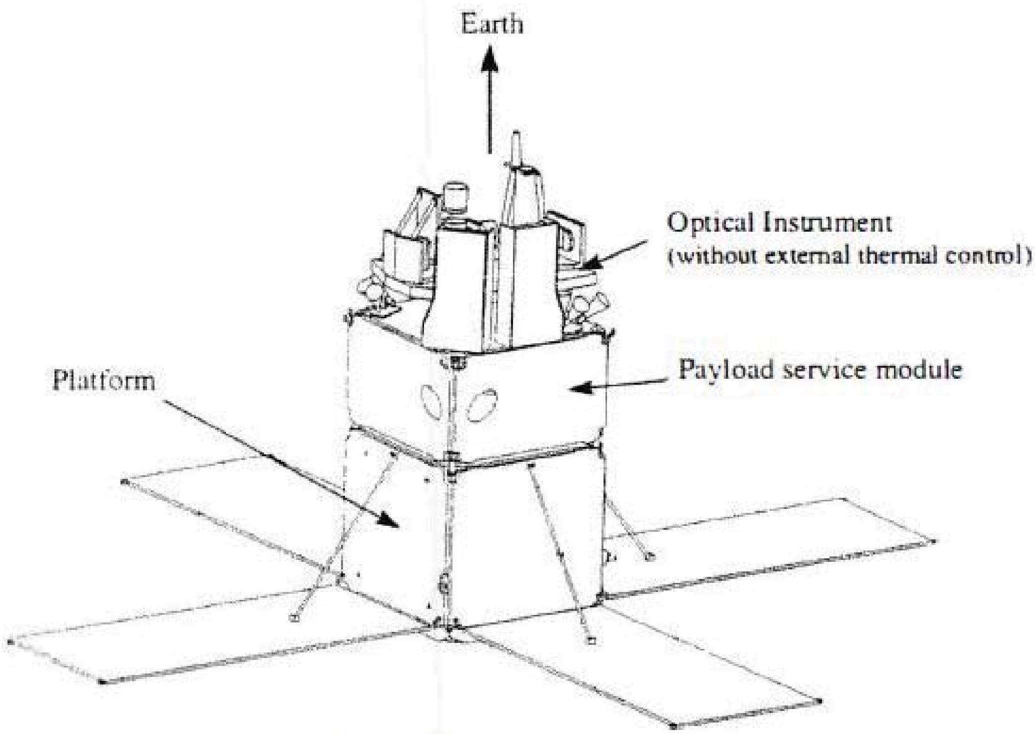


Fig. 7 : Satellite configuration

6. CONCLUSION

This pre-feasibility study has allowed a consolidation of the Land-Surface Processes and Interaction Mission profile. and led to the definition of an optimised and cost efficient design for the satellite, providing high mission flexibility and performance.

7. ACKOWLEDMENTS

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