CENTRE NATIONAL D'ÉTUDES SPATIALES

Preparing the future: the HYPXIM mission

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With the collaboration of
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EARSeL SYMPOSIUM 2016 – BONN, JUNE 20-24 th,

1. SATELLITE MISSION HYPXIM CURRENT STATUS
2. PREPARING THE USES OF HYPXIM DATA /TOSCA PROGRAM
3. AN ENLARGED EUROPEAN TEAM CONSOLIDATE THE MISSION REQUIREMENTS
4. ESA CALL “EE9”: AN OPPORTUNITY FOR HYPEX-2, A DEMONSTRATOR DERIVED FROM HYPXIM

HYPXIM MISSION & EVOLUTION

- The HYPXIM satellite mission proposes a “second generation” of European imaging spectrometer with a high spatial resolution (<10m) and flexibility (revisit: 3-5 days), that would be better suited for quantitative estimation of biogeophysico-chemical parameters at a local scale

- After 2 preliminary studies (ie phase 0) conducted by CNES and its institutional and industrial partners (2009-2010 / 2011-2012), A phase A based on a very performant instrument took place mid-2012 but was frozen in early 2013 for financial reasons. An option of demonstrator was also considered in 2015, studying the interest of very low orbits (VLEO).

- In March 2014 the Scientific Prospective Seminar of CNES (SPS) decided to plan this mission at “middle term horizon (2023-2025)” and recommended to focus this hyperspectral mission, in priority around the needs for a few environment scientific problematic and their social benefits

- At the same time our scientific program called TOSCA prepares the uses of this data with in situ and aerial campaigns, physical modelizations based on mock ups, space data simulations, algorithms and product studies.

- 2016: HYPEX-2 proposal for Earth Explorer 9 (ESA Call) with an enlarged team

SOME WORDS ABOUT THE TOSCA PROGRAM FOR HYPERSPECTRAL DATA USES

HYPXIM

- **MAIN OBJECTIVES:**

  6 projects covers the main topics which prepare the uses of Hyperspectral data. They are based on field studies, physical modeling, thematic algorithms and experimental airborne campaigns,…

NAME	*TOPICS*	MAIN OBJECTIVES	LABORATORIES
HYPERTROPIK	*FOREST BIODIVERSITY*	Consolidation of Hypxim mission for the theme "Biodiversity of Tropical Forests' contribution of 3D radiative transfer model (DART).	CESBIO, CIRAD, AMAP/IRD, ECO&SOL/INRA, TETIS/Irstea et ESE/Paris Sud
SAMSAT2	*RIVER SEDIMENTOLOGY*	Bio-optical properties analysis of Amazona delta water from hyperspectral data, in order to modelize the signal of the matters in suspension (MES).	GET (Geoscience & Environment lab of Toulouse)
HUMPER	*SOILS DEGRADATION*	Spatial resolution needs for the study of soil texture. Setting up a complete simulation chain to compare with different hyperspectral cameras.	ONERA, LISAH/IRD, CESBIO
MiHySpecSol		Impact of Spectral resolution for perennial properties of Mediterranean soils mapping	LISAH/IRD, ITAP/IRSTEA
HYPERCORAL	*COASTAL BIOTOPES*	Physical environmental parameters extracted from airborne hyperspectral images for mapping and monitoring of fragil habitats reef (Coral reef area -Reunion Island)	LDO, IFREMER, LETG, LPG, SEAS-OI, ESPACE-DEV, ECOMAR
URBHYP	*URBAN PLANIFICATION*	Hypxim requirements, to provide relevant information with the complexity of the environment for urban development and planning	LIVE, ONERA, in coordination with ANR project HYEP

TOSCA Scientific Committee - Annual selection of studies preparing Space Missions

SOIL STUDIES
URBAN
COAST
BIODIVERSITY

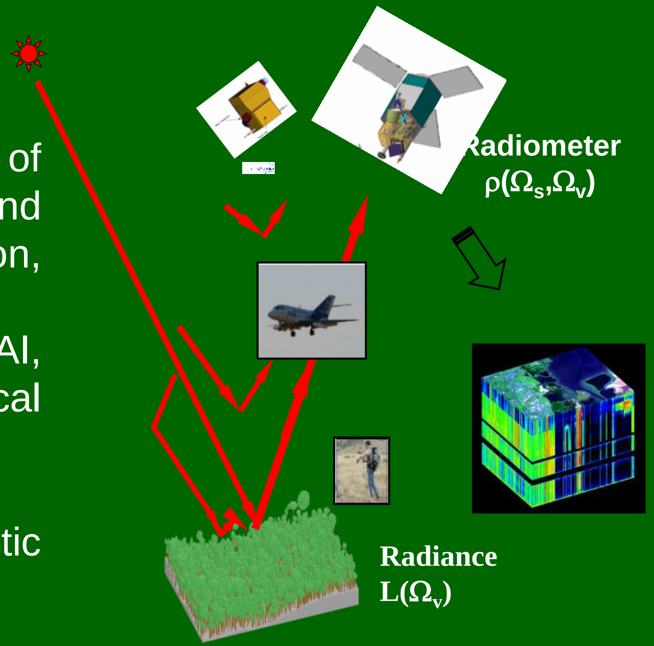
« END TO END » PHYSICAL MODELING & VALIDATION

- **DART model step: from a 3D Radiative transfer model to simulated hyperspectral images:**

DART is based on the 3D representation of various components of the scene (mock-up, atmosphere, DEM, solar direction) and instrumental characteristics (spectral domain, spatial resolution, view direction, ...).

The vegetation is simulated by the juxtaposition of turbid cells (LAI, LAD, ...) and / or as a collection of triangles with translucent optical properties and specific orientations, etc.

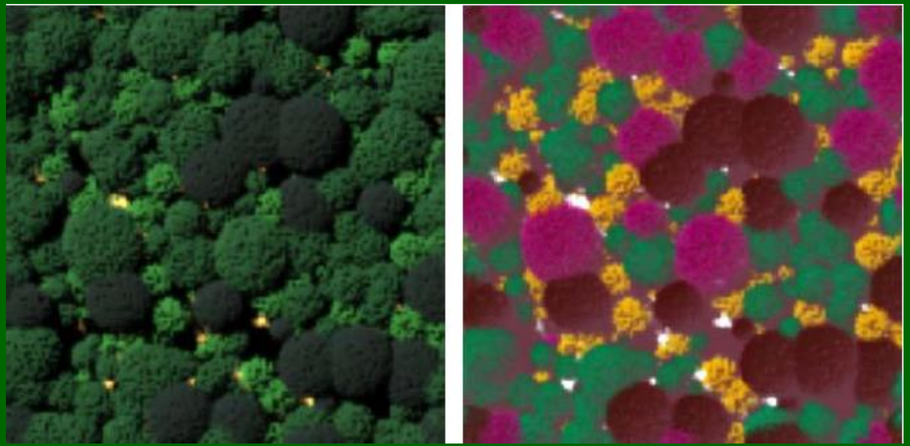
DART generate hyperspectral images of radiance and realistic HYPXIM simulations.



- **Airborne validation Campaign :**

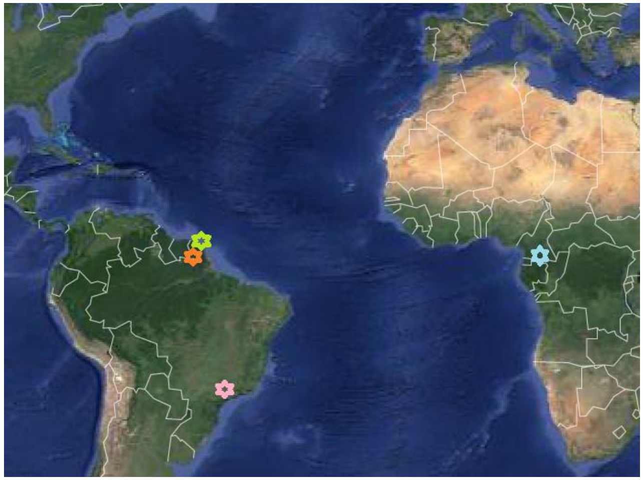
Critical for the validation of DART simulations and preparation HYPXIM acquisitions.

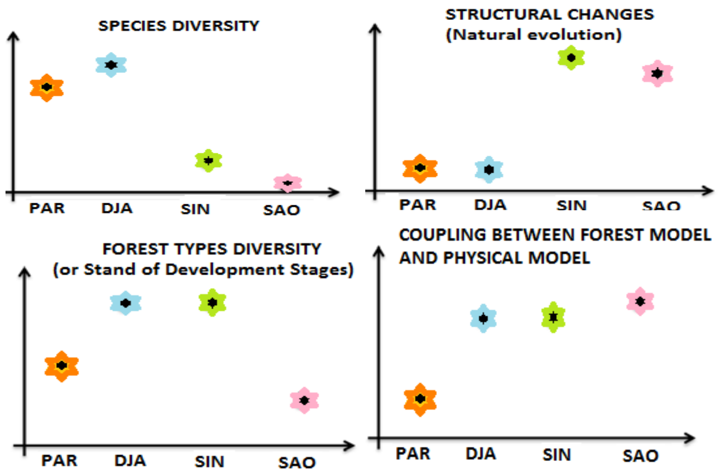
The aim is to compare the images of radiance generated by DART with airborne/satellite hyperspectral images of local species diversity (α-diversity), and changes in forest species communities (β-diversity) (Féret & Asner 2014)..



OIL STUDIES | URBAN | COAST | BIODIVERSITY

4 test-sites are selected as representing different stages of forest biodiversity





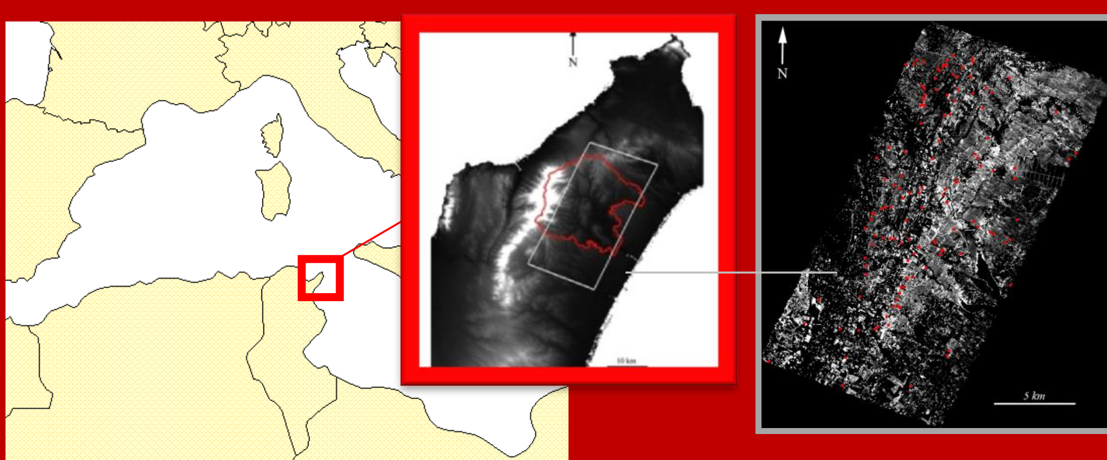
- **Dja test-site (Cameroon):** a dense and fragile rainforest characterized by a high diversity (species, architecture) and limited topographical variations.
- **Paracou / Nouragues test-sites (French Guiana):** a dense rainforest characterized by high species diversity, a structural variability TBD and a complex topography.
- **Sinnamary test-site (French Guiana):** mangrove consisting of only two dominant species, but, with a soil frequently flooded (tidal or rainy season), a high growth rate and fast changes.
- **São Paulo test-sites(Brazil):** eucalyptus plantations characterized by very low species diversity but with significant structural variability among clones and among growth stages

French Guyane: Hyperspectral /Lidar validation campaign (in september 2016)

Parametric Analysis of soil property prediction to :

1- Spatial resolution and **Atmospheric impacts**
(HUMPER Project 2013-2014)

2- Spectral resolution and **Signal Noise Ratio**
(MiHySpecSol Project 2014-2015)



AISA-DUAL airborne data (300km²)

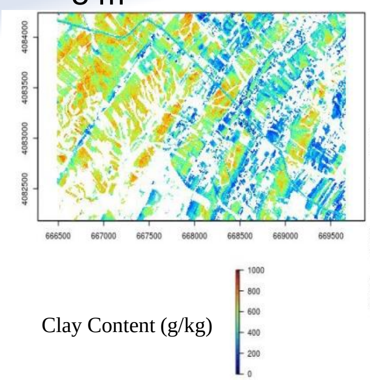
- Spectral domain: 400-2500 nm
- Number of Spectral Bands: 290
- Spatial resolution: 5 m
- Spectral resolution:
  - 4.67 nm between [400 - 960 nm]
  - 6.28 nm between [960 to 2450 nm]

RESULTS

Sensitivity to spatial resolution

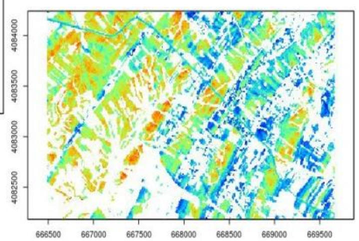
Gomez et al., 2015

5 m

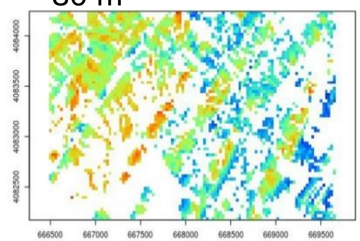


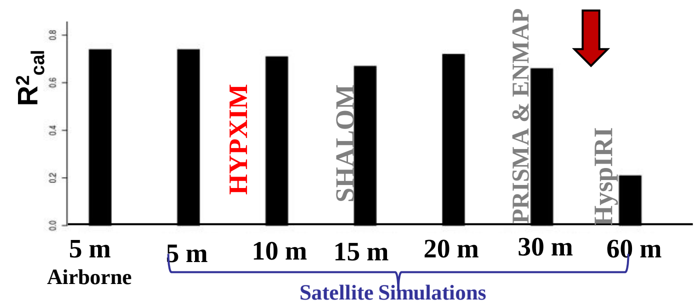
=> HYPXIM is very close to Airborne data

10 m



30 m

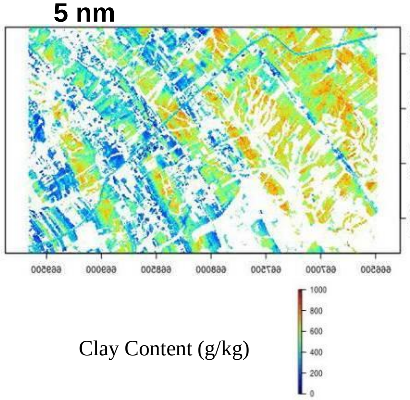




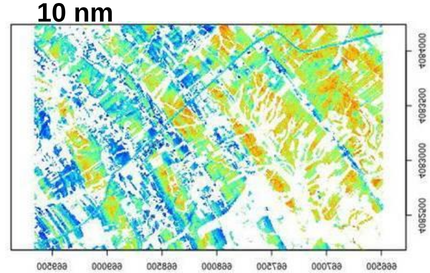
Sensitivity to spectral resolution

Adeline et al., in revision

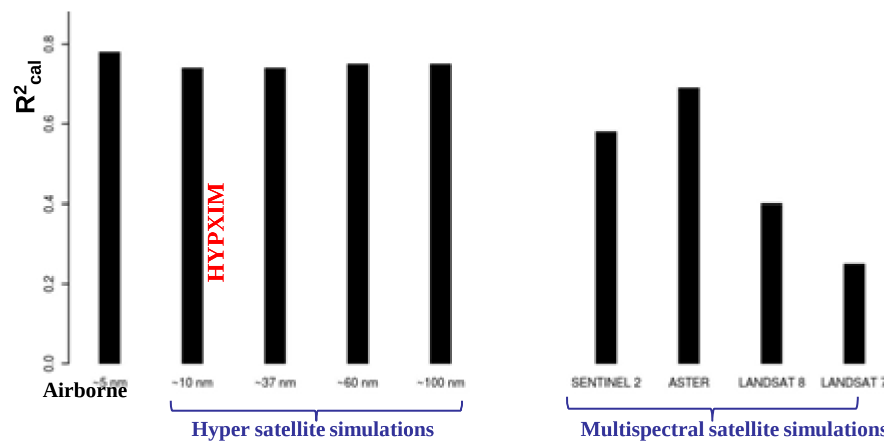
5 nm



10 nm



=> No significant changes between the 2 maps



1 km

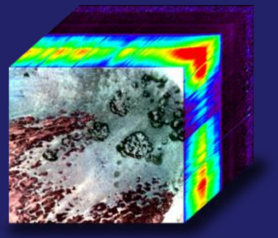
WHAT CAN BE EXPECTED FROM HYPXIM FOR COASTAL ENVIRONMENTS ?

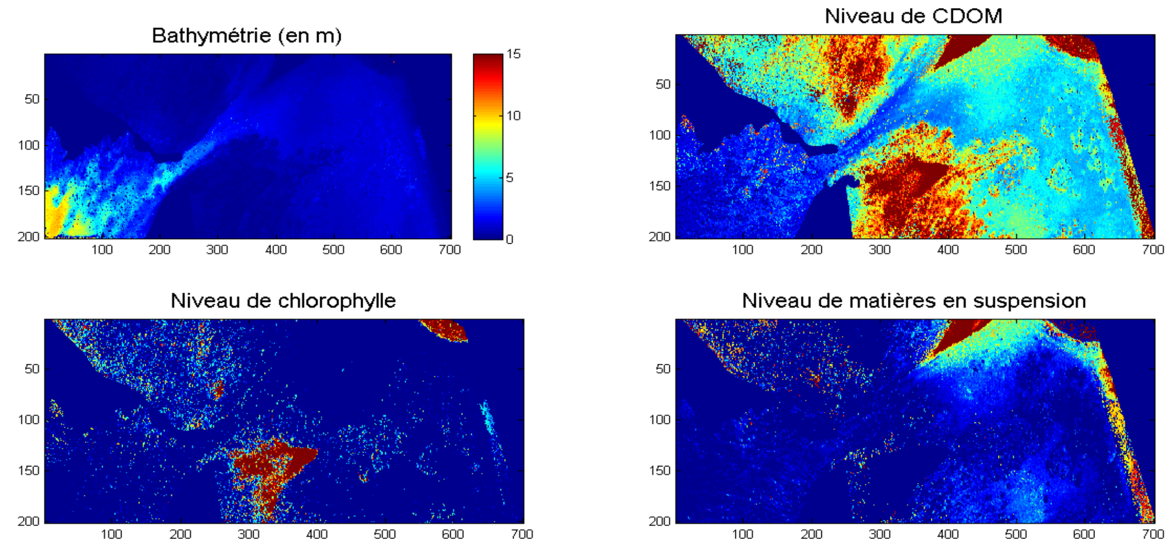
Hypercoral project Goal :

To assess the potential of hyperspectral imaging and spatial complementarity with existing optical satellites for extracting physical parameters of the environment (bathymetry, Backgrounds, Water Column), mapping and monitoring habitat reef area.

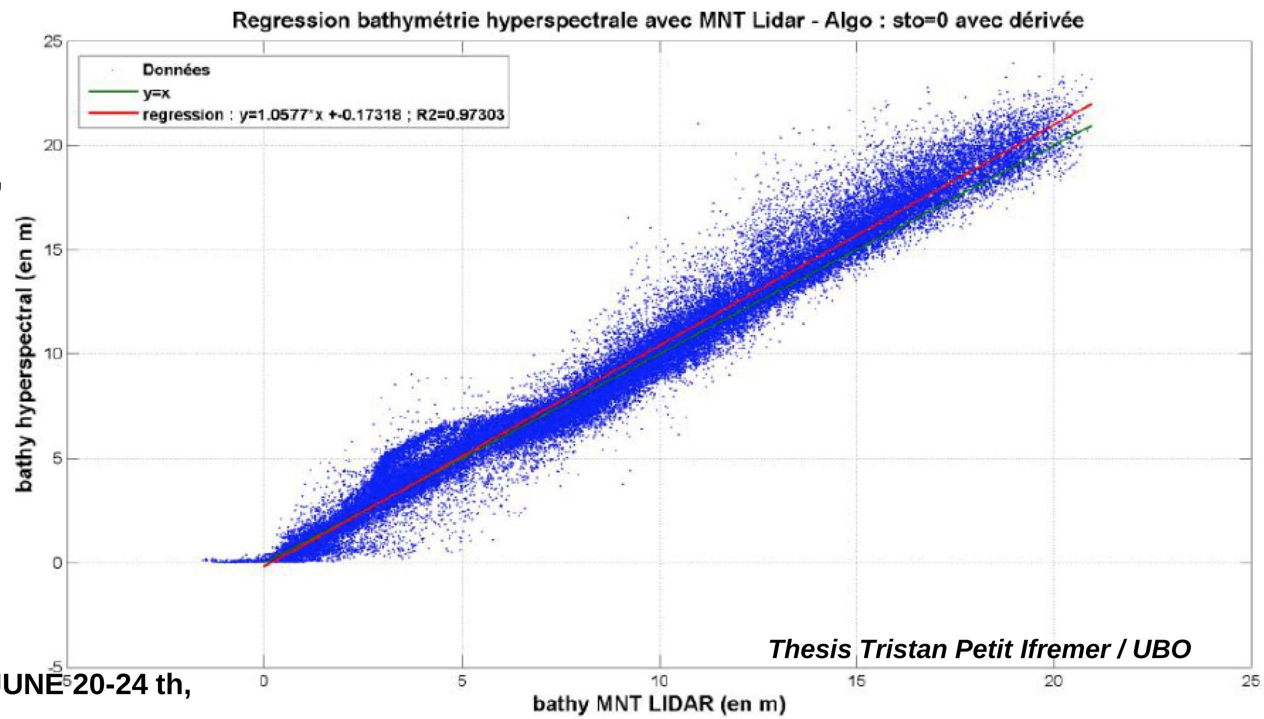
Approach:

- Development of a direct model , then inversion to extract the hyperspectral signal: bathymetry / background reflectance and optical properties of the water column
- Campaigns acquisitions multi platforms (satellite / aircraft / UAV) and multi sensors (multi and hyperspectral) at different spatial resolutions) and ground truth





Preliminary results on the hyperspectral inversion signal, for bathymetry,
but also the water column content and the substratum



Thesis Tristan Petit Ifremer / UBO

URBAN AREAS: MODELIZATION & ALGOS

SOIL STUDIES
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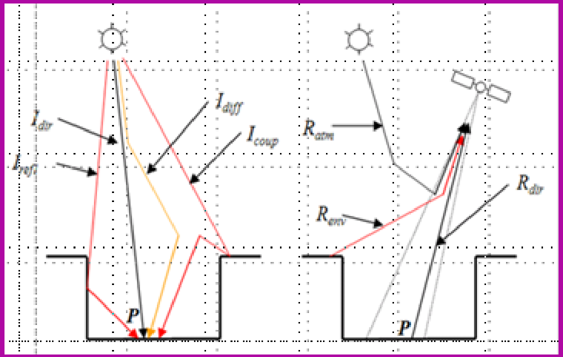
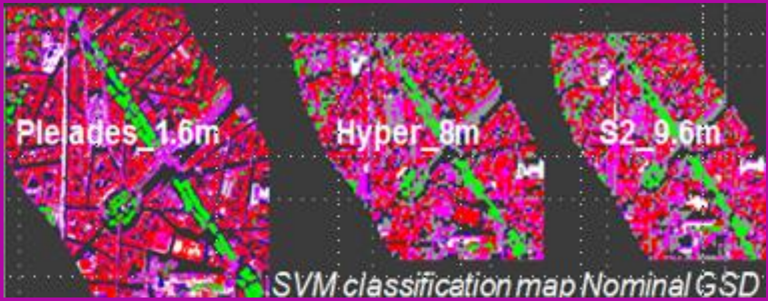
- **Atmosphere compensation in shadows**

  => *Different atmosphere correction tools are compared as a function of the spatial resolution*



- **Parametric study on the Impact of spatial resolution vs spectral domain**

  => Classification performances comparison of existing sensors (Pleiades, Sentinel-2 and HYPXIM) in radiance unit



- **Fusion algorithm**

  => *HYPXIM : PAN/Hyperspectral products*

Authors:

- ***Rosa Oltra-Carrio (ONERA)***
- ***Guillaume Roussel (LIVE, ONERA)***
- ***Briottet Xavier (ONERA)***
- ***Laetitia Loncan (ONERA, GIPSA-Lab)***

HYEP
Hyperspectral imagery for Environmental urban Planning

SOIL STUDIES
URBAN
COAST
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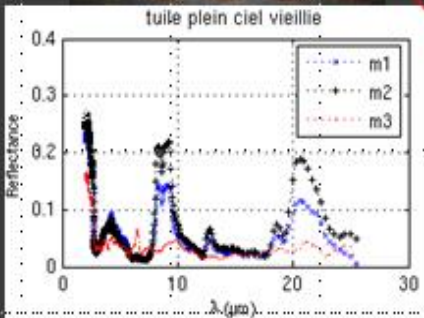
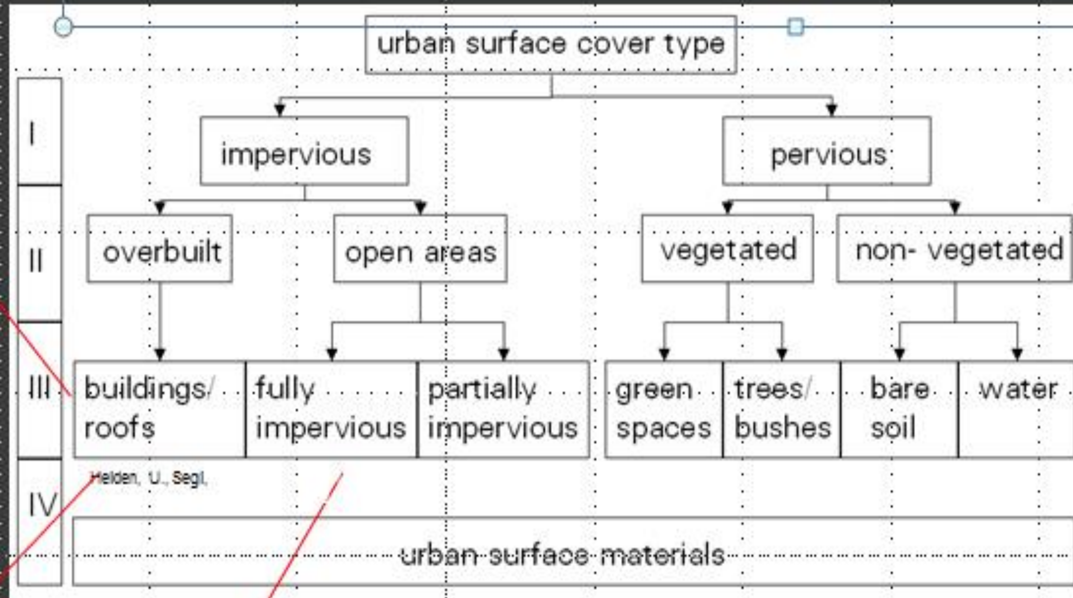
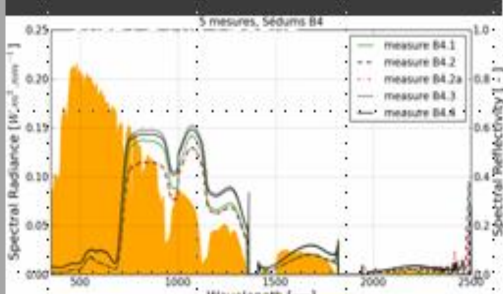
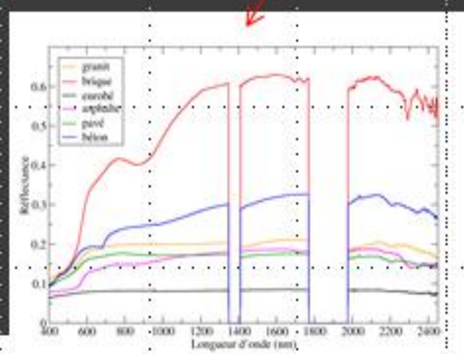
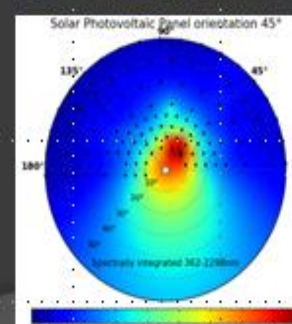
Taxonomy and data base

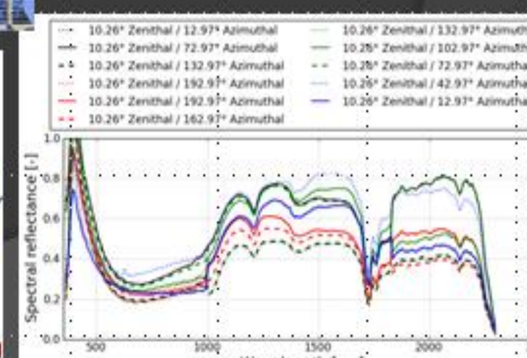












MISSION REQUIREMENTS CONSOLIDATION BY AN ENLARGED EUROPEAN TEAM

HYPXIM

2016: THE MISSION GROUP PREPARING THE ESA CALL « Earth Explorer -9 »

	Name	*Affiliation*
VEGETAIONS & BIODIVERSITY	FERET J.-B.	Irstea, France
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	SCHAEPMAN M.	Univ. of Zurich, Remote Sensing Laboratories, Switzerland
	SHEEREN D.	ENSAT, France
	SKIDMORE A.	ITC, Netherlands
	SOMERS B.	KULeuven, Belgium
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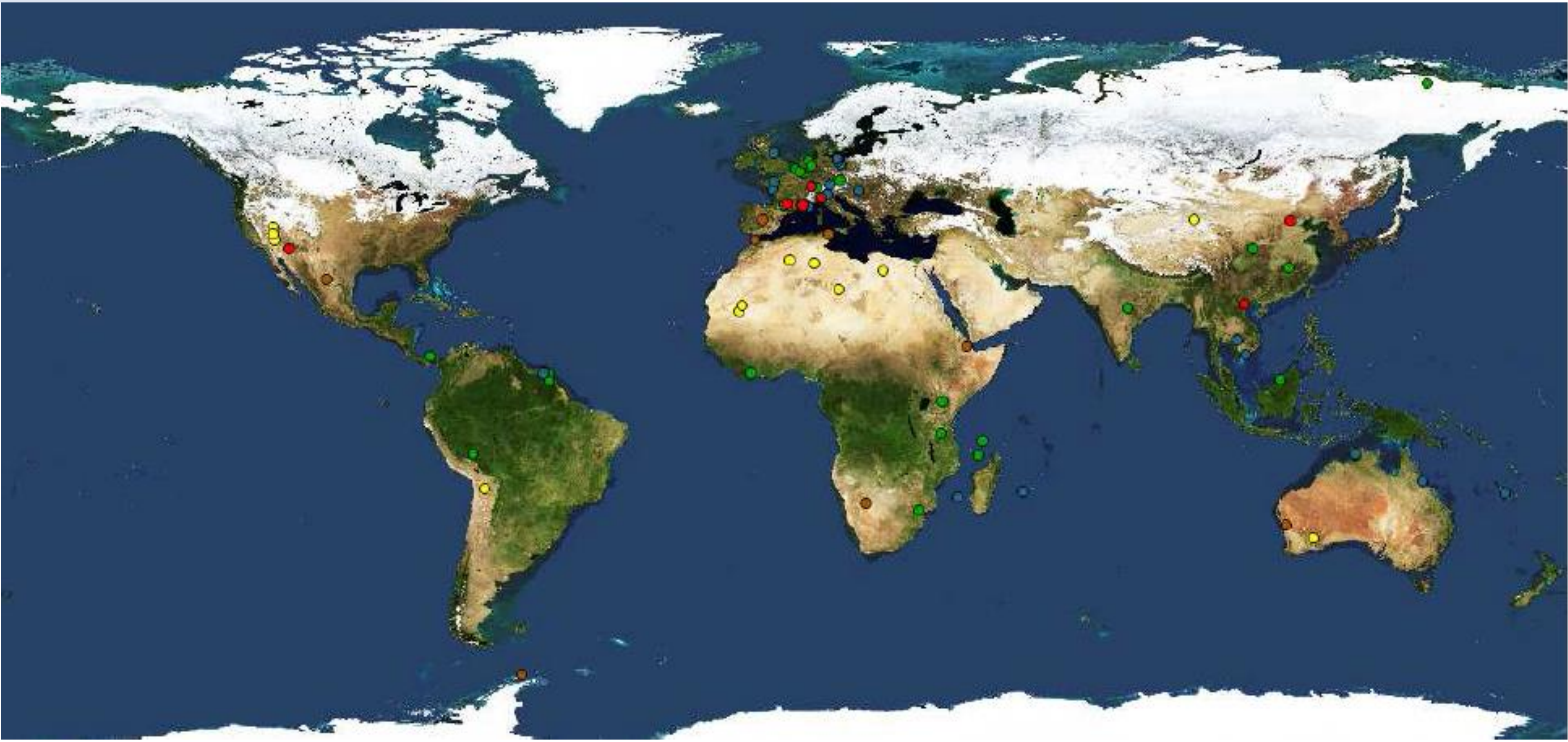
	CHABRILLAT S.	GFZ, Germany
	SCHMID T.	CIEMAT, Spain
	STENBERG B.	Swedish Univ. of Agricultural Sciences, Sweden
	MARION R.	CEA, France
	CARRERE V.	LPGN, France
COASTAL & INLAND WATER	DELACOURT C.	Institut Universitaire Européen de la Mer Univ. Brest, France
	CHAMI M.	Laboratoire d'Océanographie de Villefranche, France
	McKEE D.	Univ. of Strathclyde, Scotland
	BAJOUK T.	IFREMER, France
	LUBAC Bertrand	EPOC, France
	GEGE P.	DLR, Germany
	MINGHELLI A. (	LSIS, Univ. Toulon, France
URBAN ECOSYSTEM	GAMBA P.	Univ. of Pavia, Italy
	WEBER C.	CNRS LIVE Univ. of Strasbourg, France
	SHIMONI M.	RMA, Belgium
	MARION R.	CEA, France
	FOUCHER P.-Y.	ONERA, France

- **NEW TEST-SITES**
- **NEW PARAMETERS**
- **NEW APPROACHES**

HYPXIM

SITES OF INTEREST LOCATION



- Vegetation & biodiversity (30)
- Bare continental surfaces (15)
- Coastal zones & Inland water (23)
- Urban ecosystem areas (11)
- Inflight calibration sites CEOS IVOS recom. (16)

→ ~ 100 sites

MAIN MISSION REQUIREMENTS (2/4)

HYPXIM

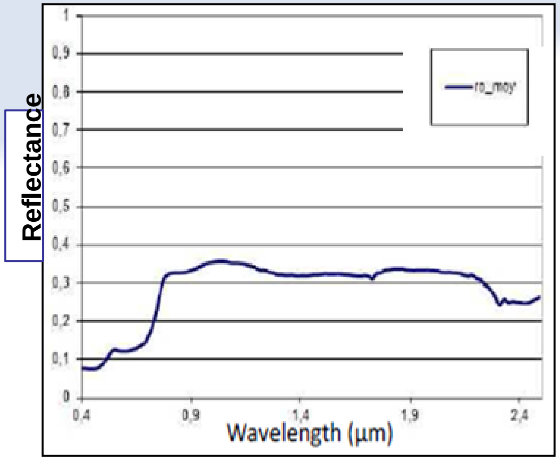
NEW OBSERVABLES ➔ INCREASED NEEDS IN VIS-NIR SNR

	Spectral range (µm)	Spectral resolution (nm)	SNR	Revisit period (days)	Area size (km²)	GSD (m)
Vegetation	VIS [0.4-0.7]	A: 15 G:10	A > 250	10	50-100	A < 10 G: 8
	NIR [0.7-1.0]]	A: 15 G:10	A > 250			
	SWIR [1.0-2.5]	A: 15 G:15	A: > 100 G: > 150			
Bare Continental Soil	VIS [0.4-0.7]	A: 15 G:10	A > 200 G > 200	10	60	A-G~10
	NIR [0.7-1.0]]	A: 15 G:10	A > 200 G > 200			
	SWIR [1.0-2.5]	A: 15 G:10	A > 100* G > 150-200**			
Coastal zones and inland waters	VIS [0.4-0.7]	A > 15 G > 10	A > 250 G > 400	A ~15 G ~10	60	A ~15 G ~10
	NIR [0.7-1.0]]		A > 250 G > 400			
	SWIR [1.0-2.5]	-	-	-	-	-
UrbanAreas	VIS [0.4-0.7]	A: 15 G:10	A > 250 G > 300	10	60-150	A < 10 G < 5
	NIR [0.7-1.0]]	A: 15 G:10	A > 250 G > 300			
	SWIR [1.0-2.5]	A: 15 G:10	A: > 100 G: > 150			

G= GOAL **A= ACCEPTABLE**

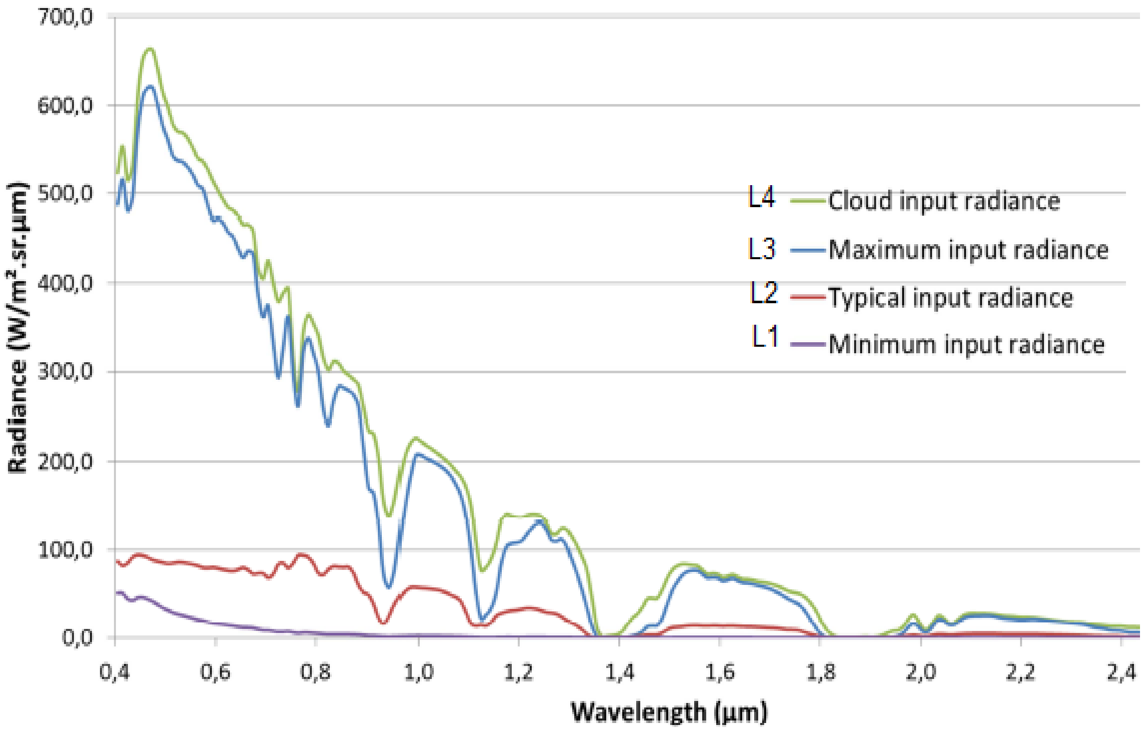
MAIN MISSION REQUIREMENTS (3/4)

HYPXIM



For L2 definition:

- Very low levels of reflectances has been taken into account in VIS (see fig)
- Sun illumination: SZA= 60°
- Atmosphere model : midlatitude winter
- Aerosol model: continental, visibility: 50 km



L2 near a worst cases in order to be compliant with SNR requirements

MAIN MISSION REQUIREMENTS (4/4)

HYPXIM

IN SYNTHESIS

Type of HX Requirements	Goal Values	Acceptable values
Spatial resolution (m)	5	10
Spectral range (µm)	0.4 – 2.5	
Spectral resolution (nm)	10	15
SNR@L2 (reference scene)		
VIS [400-700 nm]	300 (*)	250
NIR [700-1000 nm]	250 (**)	200
SWIR [1000-2500 nm]	150	100
Revisit time (day)	3-5	10
Geolocalisation (with amers)	< 1pixel	
Scene size (km2)	150	50

(*) SNR 400 (VIS) for a part of water observables => the binning of pixels will be possible to reach this requirements
(**) SNR 300 (NIR) for shadows conditions in Urban areas => possibilty to enhance the pitch slow

HYPXIM MISSION: 3 DESIGNS COULD MEETS THE REQUIREMENTS

	MICROSAT CLASS (200Kg) (15m / 15 km)	MINISAT CLASS (600kg) (8m / 16 km)	DEMONSTRATOR (350Kg) (8m / 8 km)
	HX-Challenging	HX-Performance	HX-Demonstrator
Altitude	650 km	650 km	360 km
Payload	TMA telescope Φ150 mm	TMA or Korsch telescope Φ450 mm,	TMA telescope Φ150 mm
	Detector VNIR-SWIR 1000 x 256 pixels (off-the-shelf)	Detector HgCdTe 2000 x 360 pixels (to be developed)	Detector VNIR-SWIR 1000 x 256 pixels (off-the-shelf)
Resolution/Swath	15 m / 15 km	8 m / 16 km	8 m / 8 km
Panchromatic band	Resolution: 3.75m	Resolution: 1.85m	Resolution: 1.85m
Spectral bandwidth	400 – 2500 nm / < 14 nm	400 – 2500 nm / 10 nm	400 – 2500 nm / < 14 nm
Payload budget	Mass 70 kg	Mass ~115 kg	Mass 70 kg
	Power 110 W (imaging),	Power < 150 W (imaging)	Power 110 W (TBC)
Satellite	195 kg (at launch)	600 kg (at launch)	350 kg (chemical propulsion)
Revisit period	+/-20° across-track imaging : 15 days	+/-20° across-track imaging : 15 days	+/-20° across-track imaging : 3 days/5 days (*)
(+/-60° in latitude)	+/-35° across-track imaging: 3 days (2 satellites)	+/-35° across-track imaging: 3 days (1 satellite)	+/-35° across-track imaging: 3 days/5 days (*) 1 satellite)
Imaging capacity (for one satellite)	~ 63 000km2 per day (280 images/day)	~100 000 km2 per day (270-450 images)	~7000 km2 per day (~110 images)
Link to Ground	X-band link at 160 Mbps (with ground or mobile stations)	X-band link at 620 Mbps (with ground or mobile stations)	X-band link at 160 Mbps (with ground or mobile stations)
Launcher compatib.	Soyuz, Vega, Ariane 5	Soyuz, Vega, Ariane 5	Vega (double)
Expected lifetime	5 years (incl. end-of-life operations)	10 years (incl. end-of-life operations)	3 years (incl. end-of-life) 5 years (if electric propu.)
	NOK (GSD > 10m)	OK for all requirements	OK for all requirements

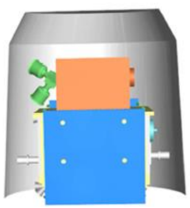
(*) impact on image quality and acces

HYPEX-2 DEMONSTRATOR (PREPARING ESA CALL « EE-9 »)

HYPEX-2
orbit@ 380 km
Pupil diam: 15-20cm

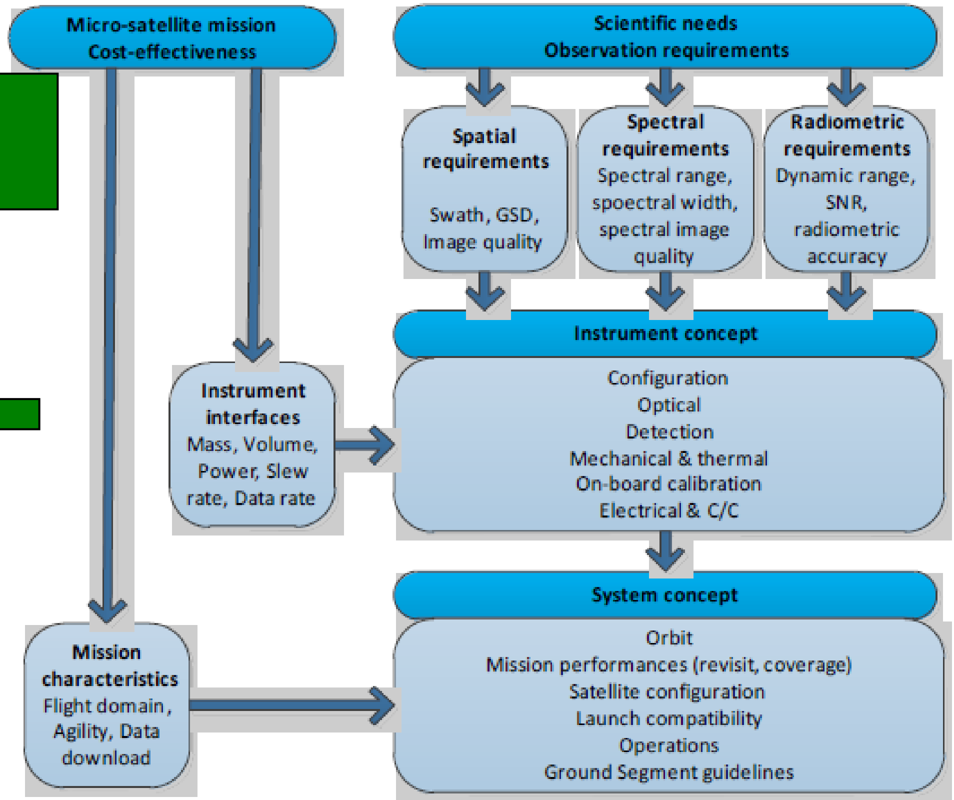
Instrument:: 70 Kg/ <110W
Satellite wet mass~ 380 kg
Launch : ½ VEGA

Courtesy of ThalesAlenia Space



Spacecraft in LV

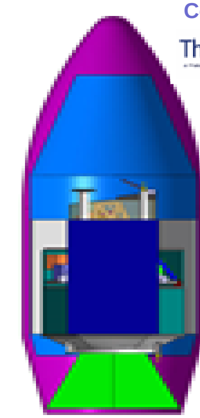
IN THE EE-9 CONSTRAINTS OF TRL & COST



HYPXIM-P
orbit@ 700 km
Pupil diam: 45cm

Instrument:: 115 Kg/ 150W
Satellite wet mass ~ 600kg
Launch: ½ VEGA

Courtesy of ThalesAlenia Space



BEST PERFOS BUT OUT OFTHE EE-9 CONSTRAINTS (COST)

SAME SPATIAL, SPECTRAL & RADIOMETRIC RESOLUTION BUT LESS COVERAGE
100 000 km2 /day FOR HYPXIM-P => 7000km2 / day FOR HYPEX-2 DEMONSTRATOR

MATURITY & COST ARE COMPLIANT WITH EE-9 CRITERIA

HYPEX-2 DEMONSTRATOR

Observation requirements

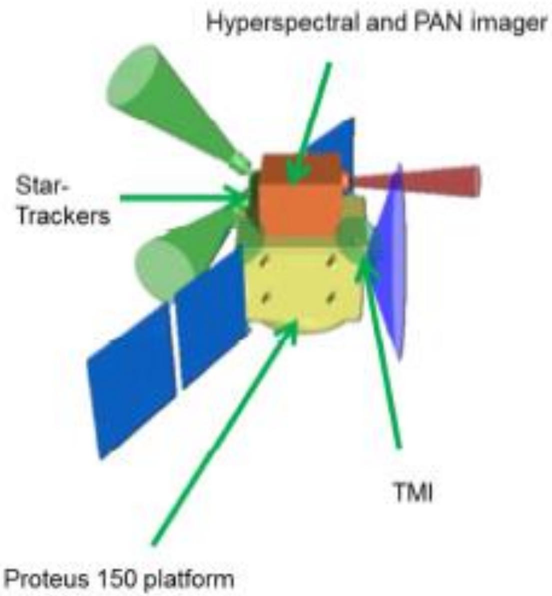
- Hyperspectral imagery VNIR/SWIR
- PAN imagery
- Up to 100 images per day

Satellite

- Roll +/-20° (need for mission and capacity up to 35°)
- Slowdown factor of ~9 in pitch
- 4 solar panels 20s4p, NeXt Triple Junction
- 2 battery modules
- 160Mbps downlink in X band capacity
- 370 kg launch mass
- Compatible with TAS product like Proteus 150 platform

Instrument

- 200mm pupil
- TMA telescope
- Double paths TMA spectrometer with prism
- 8m spatial sampling distance, 8km swath
- Spatial resolution <14nm
- Spectral range 400-2500nm
- 1000x256 detector matrix 30µm pitch
- 175K active cooling focal plane
- Additional PAN sensor
- 57kg max without margin, 64W max



Courtesy of ThalesAlenia Space

Mission

- VLEO 360km sun-synchronous orbit (or 500km)
- 10:00 local time
- 3 days revisiting capability
- 3 years lifetime
- Launch in 2024

Launcher

- ASAP-S Soyuz as central passenger
- VEGA auxiliary payload
- Dedicated launch on alternative commercial launcher

Ground segment

- Flight Operation Segment in ESOC
- Payload Data Ground Segment

Ground support equipment

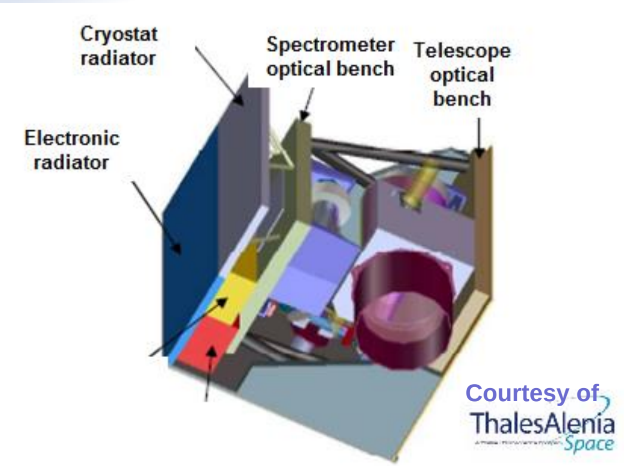
- OGSE
- MGSE
- EGSE

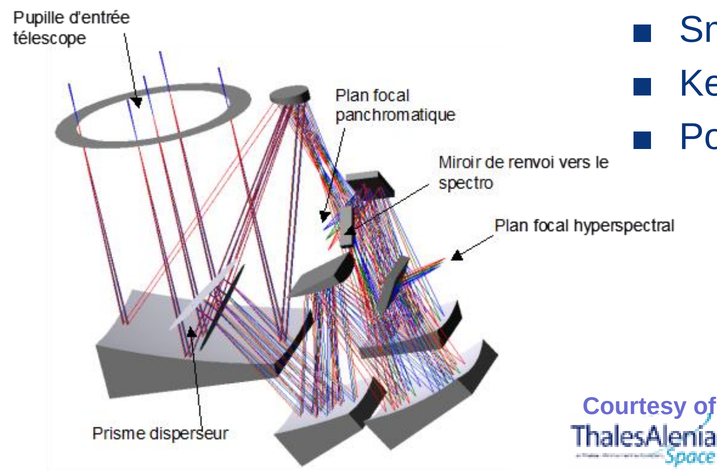
Figure 6 : General description of HYPEX-2

HYPEX-2 DEMONSTRATOR

HYPXIM

■ COMMITS WITH ALL THE IMAGE QUALITY REQUIREMENTS @ 8m

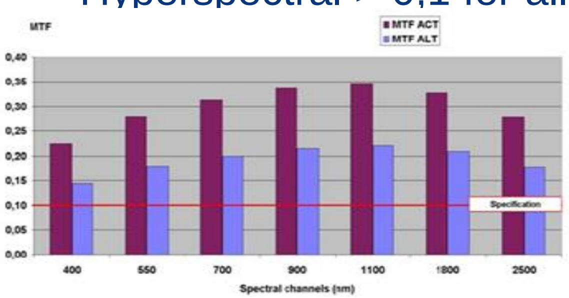




- Smile < 1 μm
- Keystone < 5 μm
- Polarisation < 2,4%

■ MTF

- Hyperspectral > 0,1 for all bands

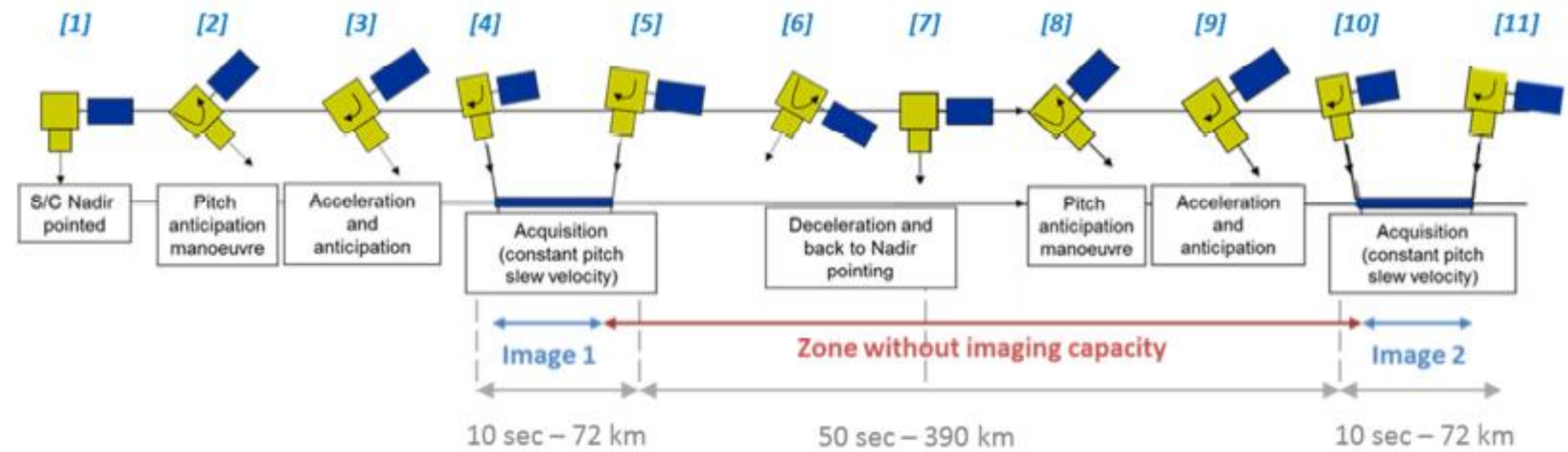


- PAN : 0,09 (X) et 0,10 (Y)

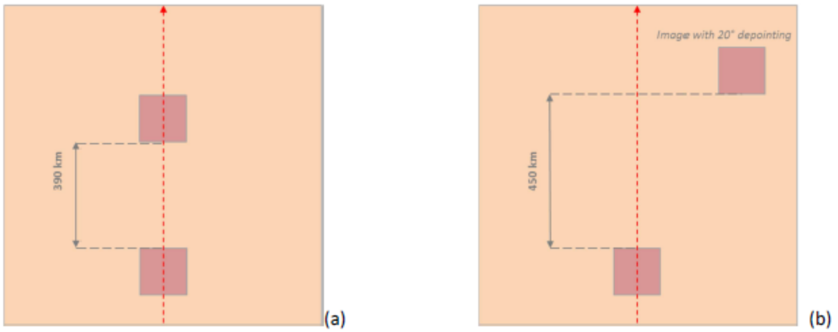
■ SNR & SPECTRAL RESOLUTION

Spectral bands	VIS (0.4-0.7μm)	NIR (0.7-1.1 μm)	SWIR (1.1-2.5μm)
Requirement of mean SNR	>250	>200	>100
Mean SNR	250	306	149
Slow-down		9	
Mean spectral resolution (nm)	12.5	10.8	11.7

■ LIMITATION OF THE COVERAGE DUE TO HIGH LEVEL OF SNR => SLOW MOTION (9)



On the left (a), acquisition scenario with two successive images on the spacecraft ground-track, the minimum distance between the two images is then of 390 km along track. On the right (b), acquisition scenario with the second image being 20° depointed from the spacecraft ground track. The along track distance between the two is at least of 450 km



HYPEX-2 DEMONSTRATOR

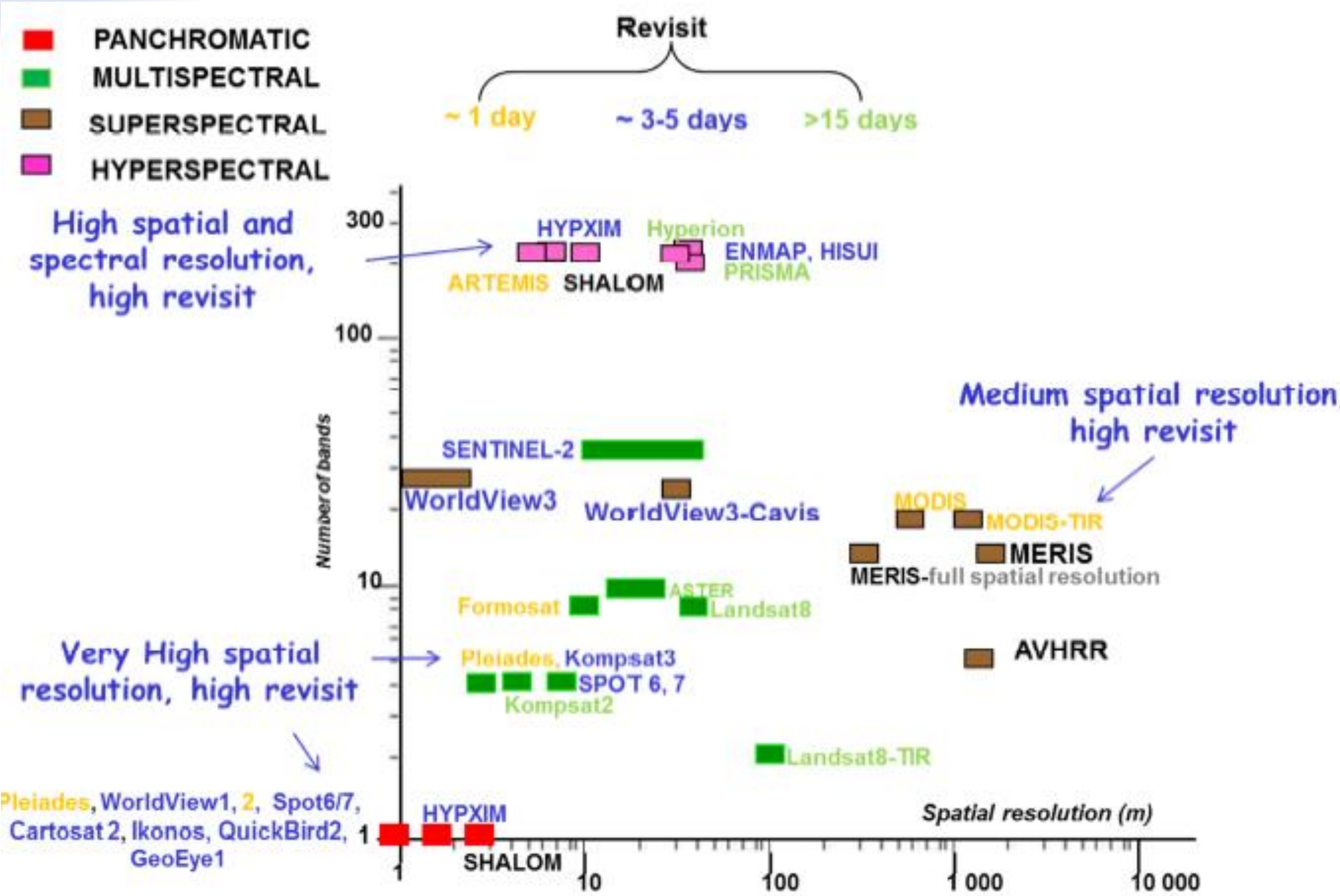
HYPXIM

■ OVERVIEW

Satellite (at launch)	Mass: 380 kg, Power: 180 W Date Rate: 320 Mbp/s Helio-synchronous phased orbit: 362 km (VLEO)
Launch compatibility	Vega (Vespa low)
Payload (marged)	Mass: 70Kg ; Power <110 W TMA telescope F200 mm High slow motion capabilities ~9
Hyperspectral sensor **Spectral resolution / spectral range**	Detector VNIR-SWIR 1000 x 256 pixels (existing detector) GSD: 8 m / Swath: 8 km / SNR @L2 : VIS > 250, NIR > 300, SWIR > 100 <14 nm / 0.4 – 2.5 µm
Panchromatic sensor :	GSD: 1.85 m / Swath 8 km / SNR> 90
Revisit period (+/- 60° in latitude)	3 days
Depointing capability (Image quality)	± 20° across-track imaging (possible ± 35° for better access)
Link to Ground	X-Band link at 160 Mbps (with ground or mobile stations)
Lifetime	3 years including end-of-life operations – 5 years with electric propulsion

HYPEX-2 DEMONSTRATOR

HYPXIM



SYNTHESIS & PERSPECTIVES

THE PREPARATION OF THE INNOVATIVE HYPERSPECTRAL DUAL MISSION HYPXIM CONTINUES IN THE FOLLOWING DIRECTIONS:

1. THEMATIC PRIORITIES ARE CURRENTLY STUDIED WITH EXPERIMENTAL APPROACHES AND DEMONSTRATIONS

2. AN IMPORTANT EFFORT IS ALSO GIVEN TO THE SIGNAL MODELIZATION AND TO ALGORITHM VALIDATIONS, IN ORDER TO PREPARE THE SCIENTISTS & USERS COMMUNITY FOR THE USE OF NEW *HIGH SPECTRAL & HIGH SPATIAL RESOLUTION* SATELLITE DATA

3. THE HYPXIM REQUIREMENTS (RESOLUTION, SNR, BANDWITH, ..) ARE BEING CONSOLIDATED, FOCUSING ON A “JUST NEED” BASIS

4. A LOW COST MICROSAT DEMONSTRAT, HYPEX-2 IS PROPOSED TO THE EARTH EXPLORER 9 CALL WITH A LAUNCH IN 2024

HYPXIM

Thanks for your attention