Introduction to Hyperspectral Remote Sensing of Vegetation

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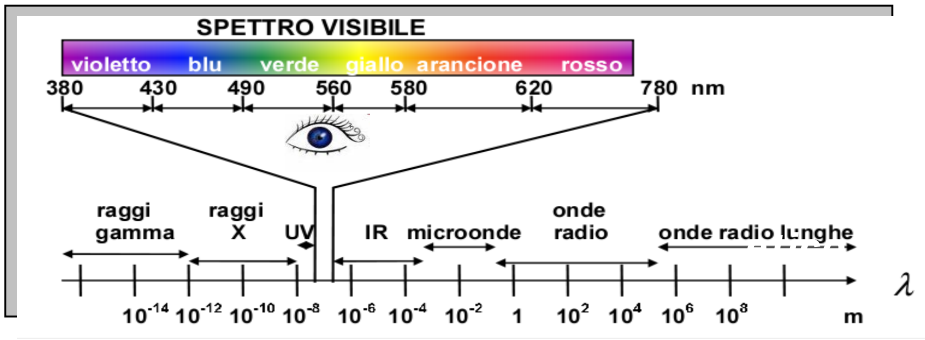
Aim and Contents

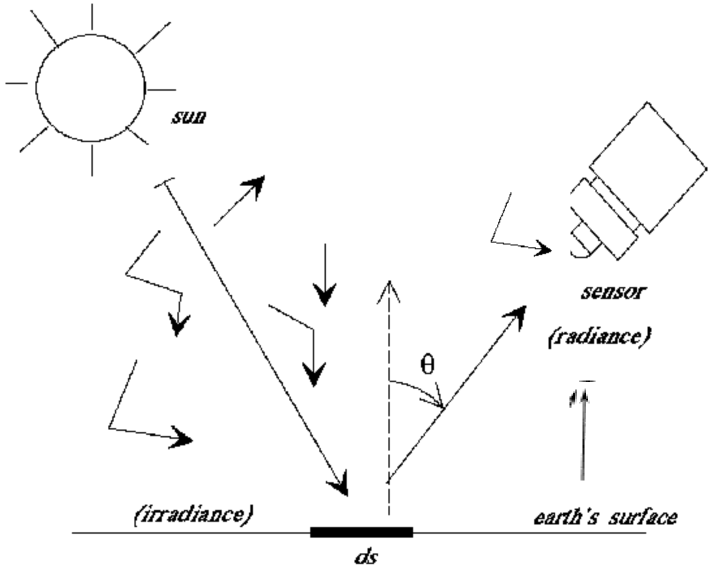
To introduce the concept of using hyperspectral data for monitoring vegetation properties and dynamics

- **Basic concepts of remote sensing**
- **Vegetation parameters from optical RS and their assimilation in environmental models**
- **New perspectives: sun-induced chlorophyll fluorescence**
- **Conclusions**

Definition of Remote Sensing

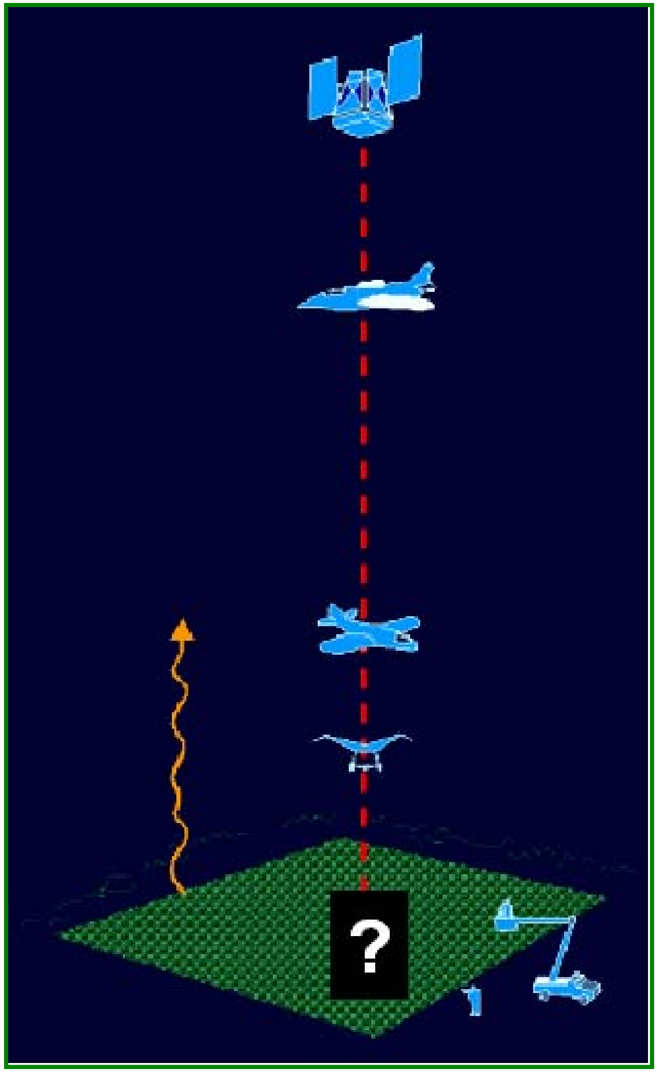
The science of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation

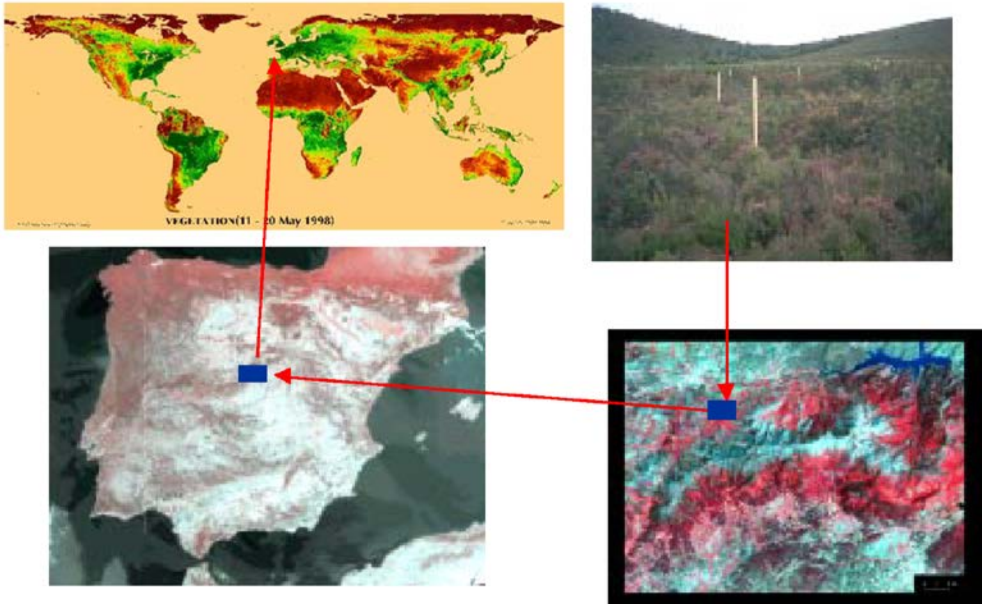




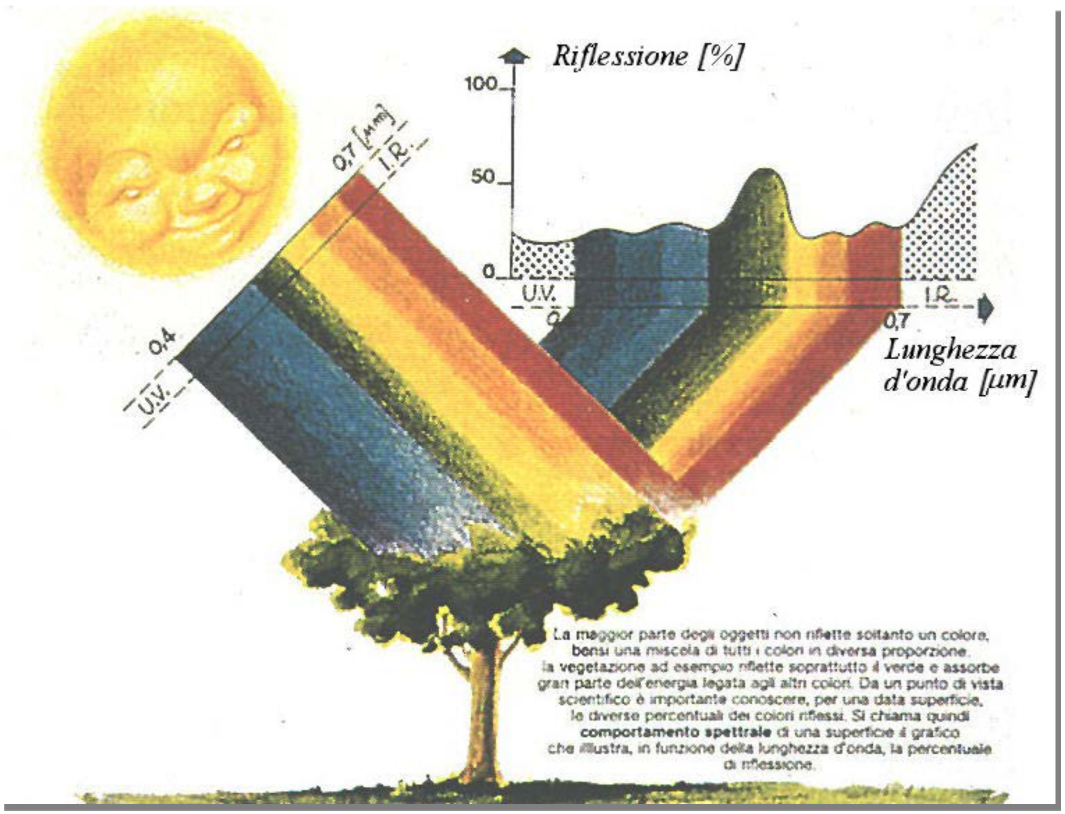
Optical and thermal classic configuration

Multi-source and multi-scale approach

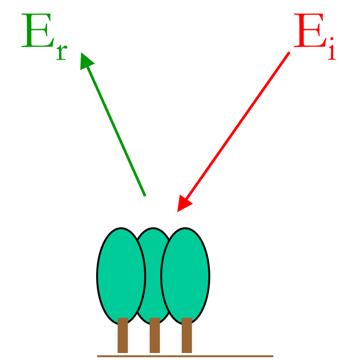




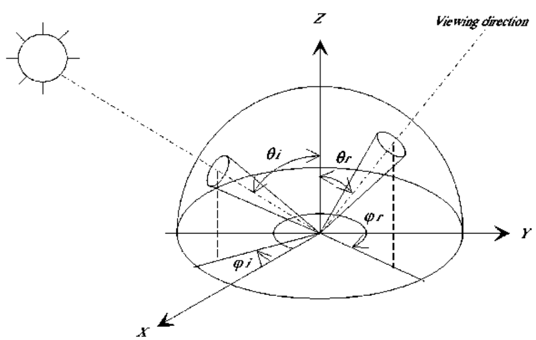
What we compute (after a processing chain)



Credit: Zilioli et al., 2001



$$\rho(\lambda) = E_r(\lambda) / E_i(\lambda)$$

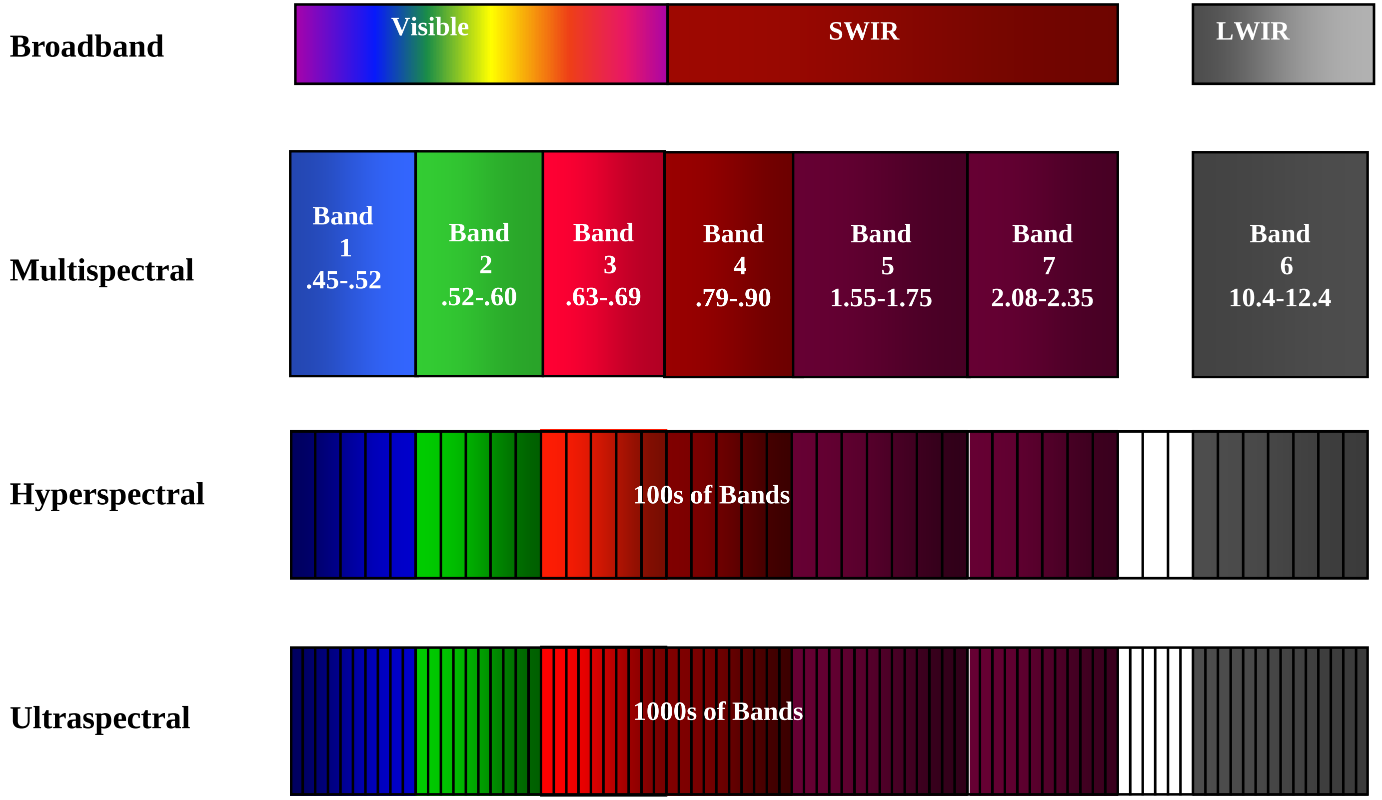


In spatial and temporal domain

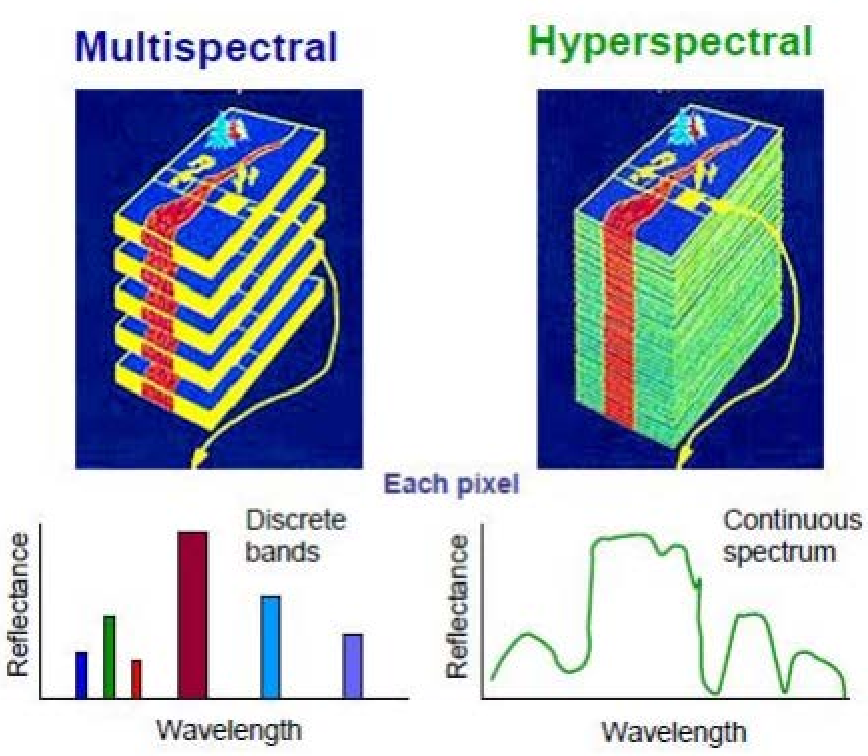
Hyperspectral Remote Sensing

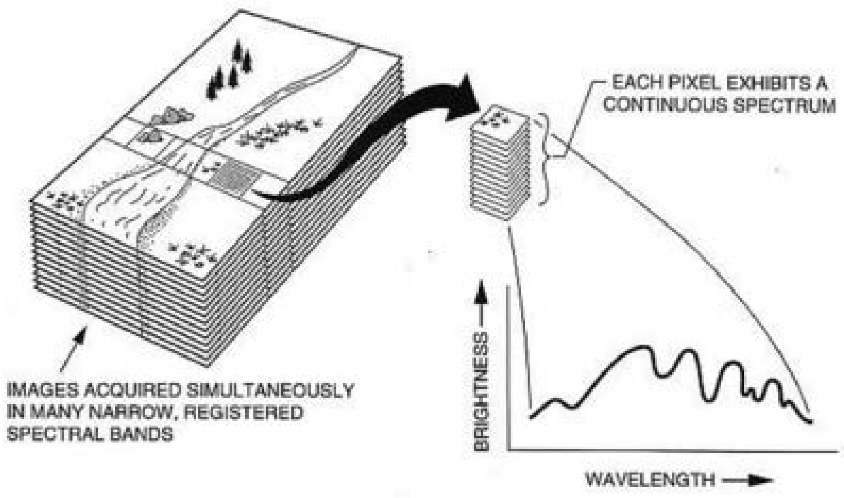
- Quantitative measurements of the spectral characteristics of materials using a remote sensing system having greater than 60 spectral bands with a spectral resolution less than 10 nm producing a contiguous portion of the light spectrum which defines the chemical composition of the material through its spectral signature

- Hyperspectral sensing allows the analyst to perform reflectance, emittance, or fluorescence spectroscopy on each pixel (spatial element) of the image scene

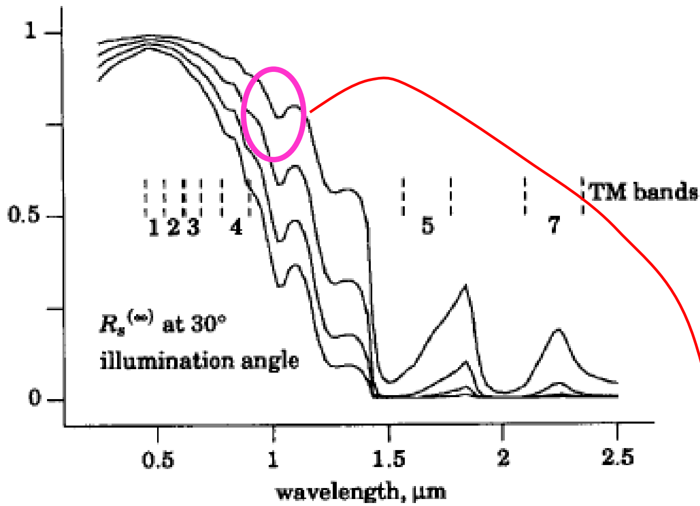


Multispectral vs hyperspectral Remote Sensing





Why Hyperspectral Remote Sensing?



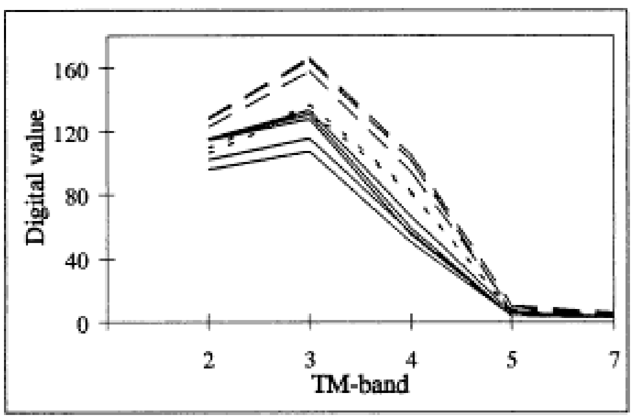
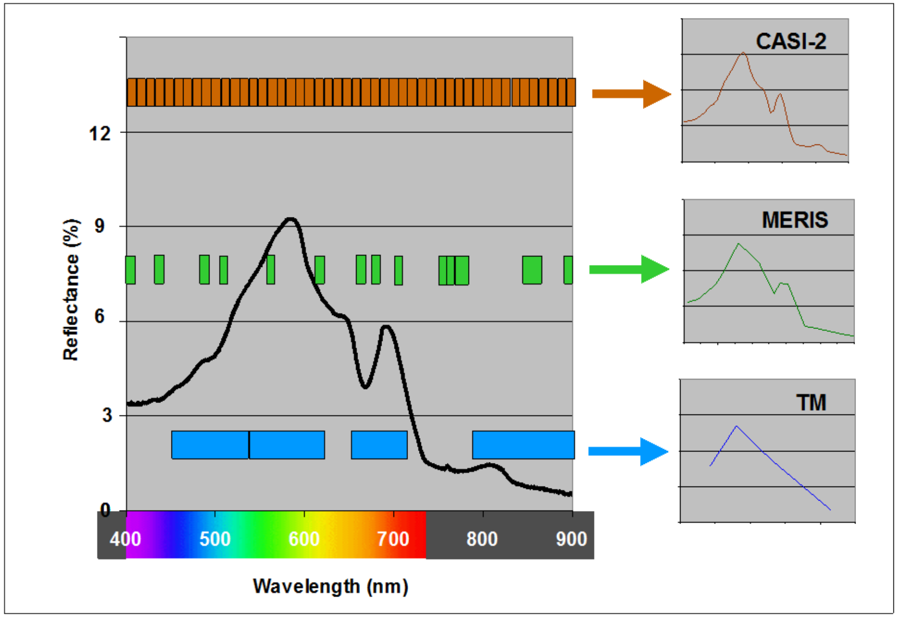


Fig. 3. Landsat TM spectral signature curves of blue-ice compared to snow.
——— Blue-ice.
- - - - - - - Old metamorphosed snow.
— — — — Snow at a low degree of metamorphosis.



For example, we lose this absorption feature

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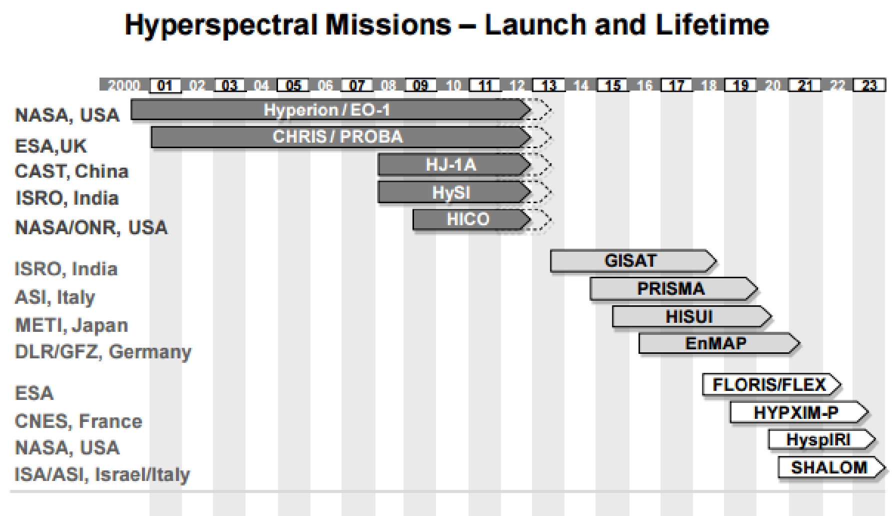
Spaceborne imaging spectroscopy mission

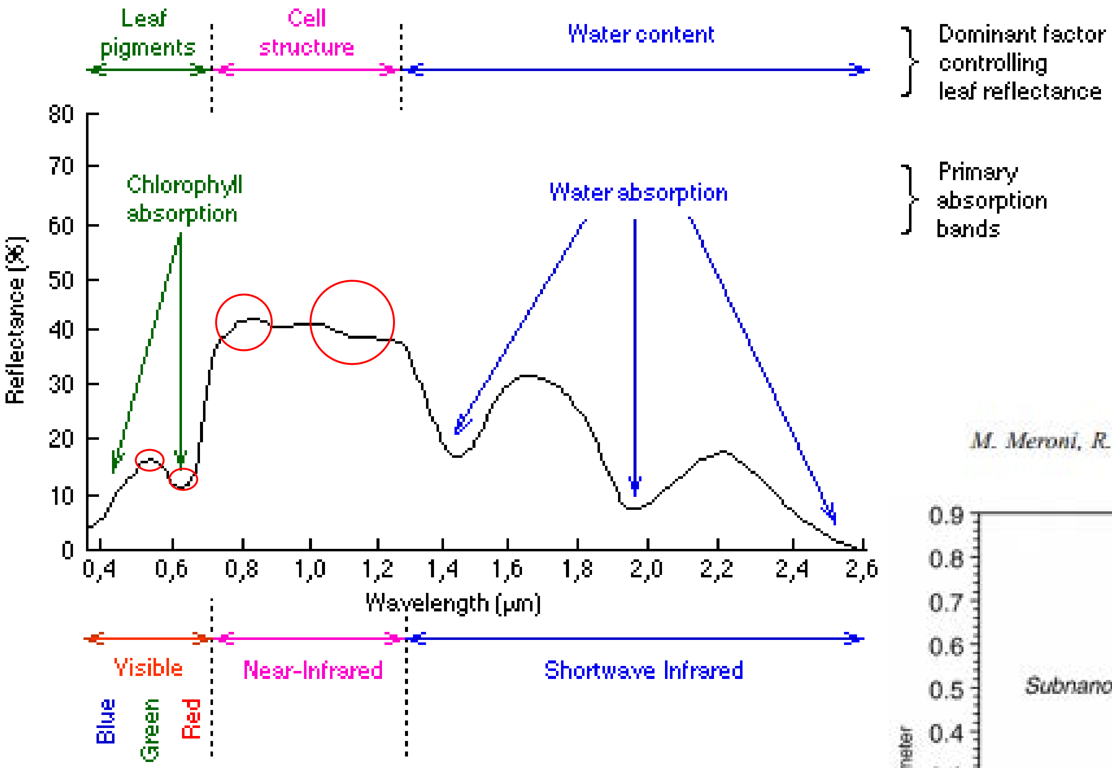
Sensor	Organization (Country)	GSD (m)	Swath at Nadir (km)	Wavelength Coverage (nm)	Number of Bands	Spectral Res. (nm @ FWHM)	Launch Date
Hyperion	NASA (USA)	30	7.65	357-2576	242	10	2000
CHRIS	ESA (UK)	17/34	13 (nominal)	400-1050	6/18/37	5.6-32.9	2001
HJ-1A	CAST (China)	100	≥ 50	450-950	110-128	5	2008
HySI	ISRO (India)	506	129.5	400-950	64	~ 10	2008
HICO	NASA/ONR (USA)	90	42	353-1081	128	5.7	2009
GISAT	ISRO (India)	500	NA	NA	210	NA	≥ 2013
PRISMA	ASI (Italy)	30	30	400-2500	237	~ 12	2014/15
HISUI	METI (Japan)	30	15	400-2500	185	10 (VNIR) 12.5 (SWIR)	≥ 2015
EnMAP	DLR/GFZ (Germany)	30	30	420-2450	218	5/10 (VNIR) 10 SWIR	2016
FLORIS/ FLEX	ESA	300	100-150	500-780	NA	0.3 – 3.0	~ 2018
HYPXIM- P	CNES (France)	8	16	400-2500	> 200	≤ 10	~ 2019
HyspIRI	NASA (USA)	60	145	380-2500	> 200	10	~ 2020
SHALOM	ISA/ASI (Israel/Italy)	10	10	400-2500	200	10	TBD

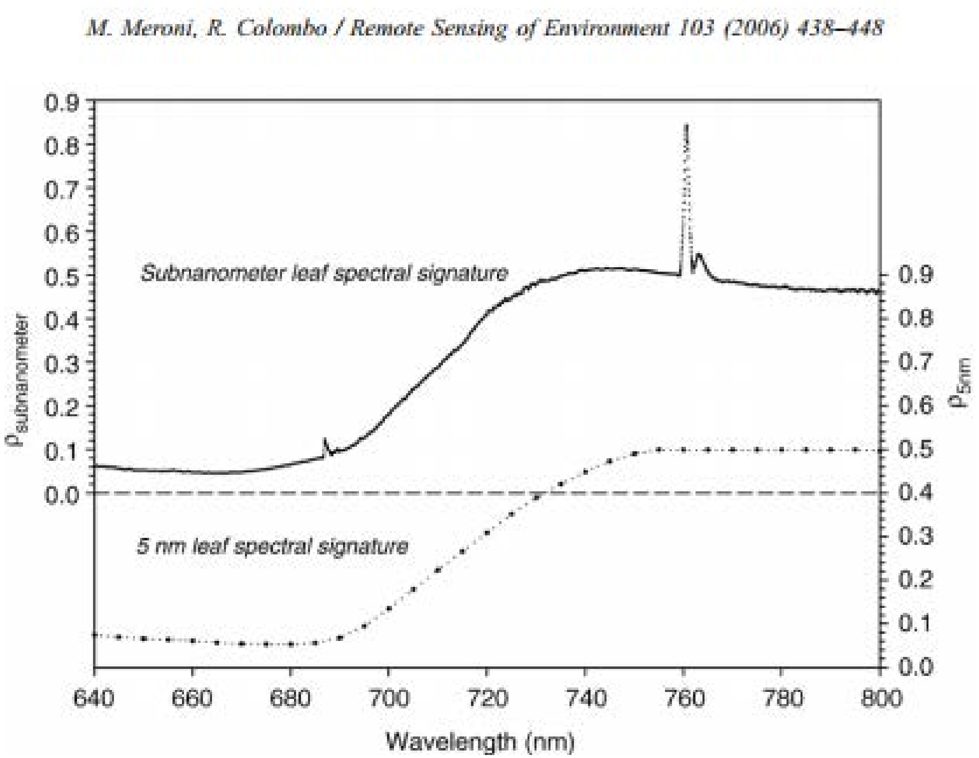
Missions currently in operation, Missions under construction, Missions in a planning stage



International Spaceborne Imaging Spectroscopy (ISIS) Working Group

Spectral signature of green vegetation canopies





"Hyperspectral features"

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So that, what RS cannot do and what can do?

- **Remote Sensing Sensors never measure ecological properties of the canopy;**

- **We can measure only *electromagnetic signals* in certain bands reflected or emitted from bodies;**

- **We need to convert the electromagnetic signal into ecosystem variables (e.g. biophysical parameters) and then incorporate them in environmental models. It is an inverse problem, that can be solved using different approaches** ***Semi-empirical vs physical models***

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The canopy characteristics of interest (and potentially accessible from RS data)

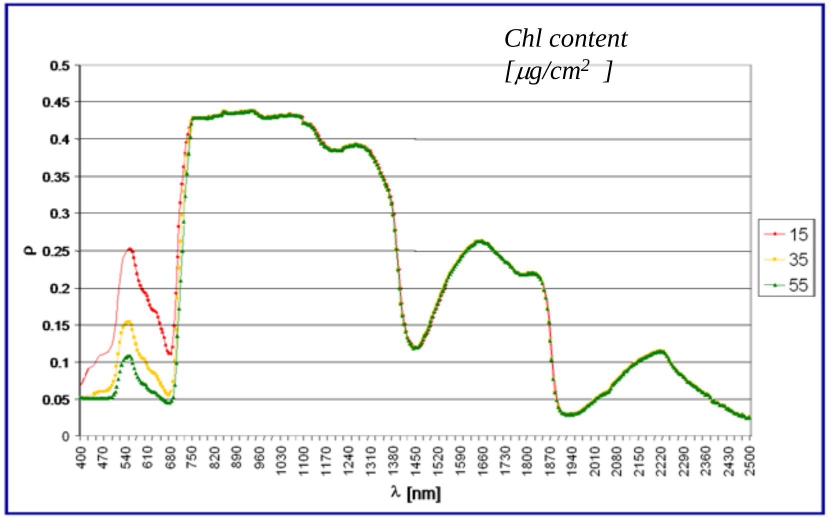
Biophysical Variables	Solar	Thermal infrared	µ-waves active	µ-waves passive	Process Models
Albedo	++				SVAT
fCover	++	+			SVAT
fAPAR	++				FC
LAI	++	+	+	+	SVAT & FC
Water content (canopy)			++	++	FC
Temperature		++		+	SVAT & FC
Pigments	++				FC
Water content (leaves)	++		+	+	FC
Soil moisture (surface)	+		++	++	SVAT & FC
Canopy height	(+)		++		SVAT & FC

Sun Induced Fluorescence ++

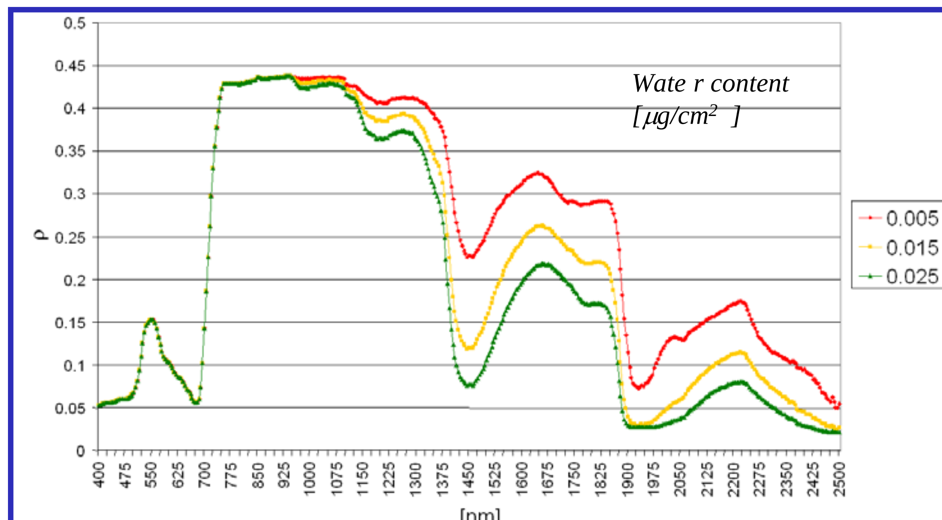
FC: Canopy functioning models
SVAT: Soil vegetation Atmosphere Transfer models

→ **The optical domain is privilegiated**

Physical models. Forward scheme

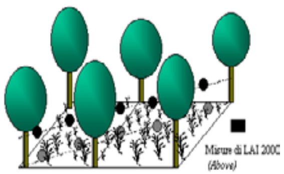


Example of PROSAIL model for simulating spectral reflectance at different concentration of pigments and water



Designing an experiment

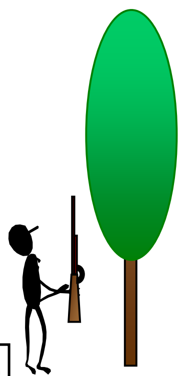
Field data



Licor LAI2000 PCA, HC

Sunscan, SPAD, PEA, Fc

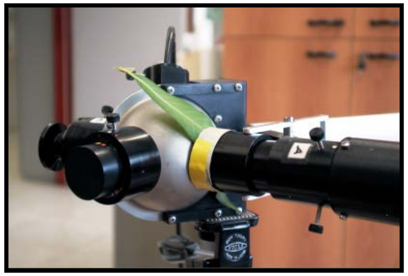
Field radiometric measurements

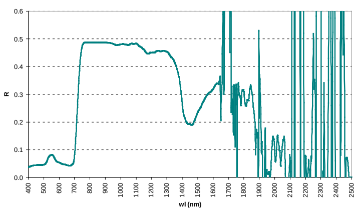


Leaf samples, biomass (NPPa/b)

Lab. data

Pigment, water, dry matter content and N (PROSPECT)





Spectroscopy

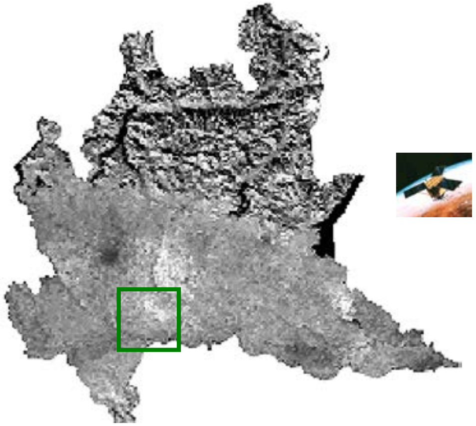
and

chemical extraction

Remote Sensing

Hyperspectral data

Satellite data



Regional scaling up

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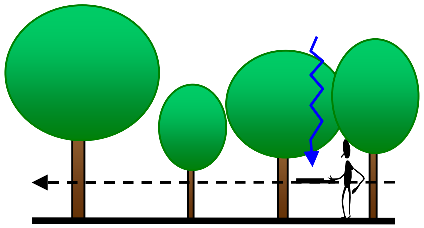
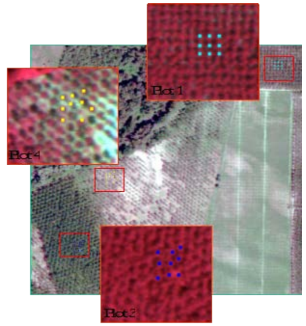
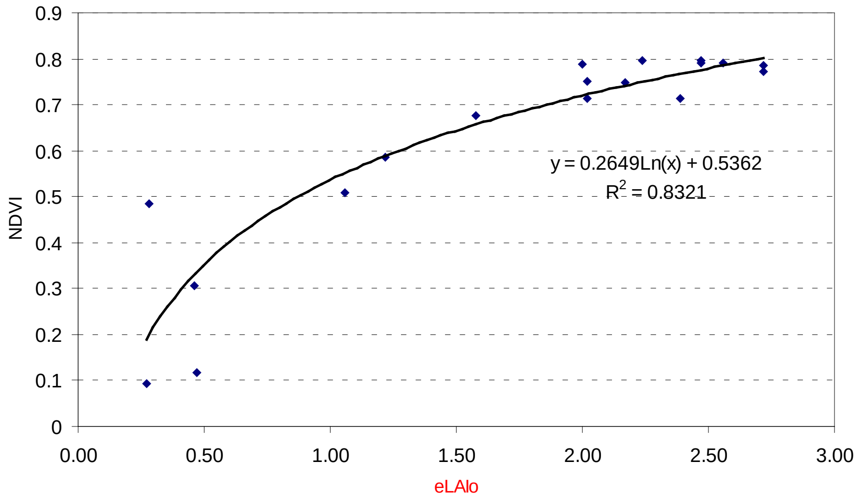
Relating canopy properties to hyperspectral observations

Semi-empirical models



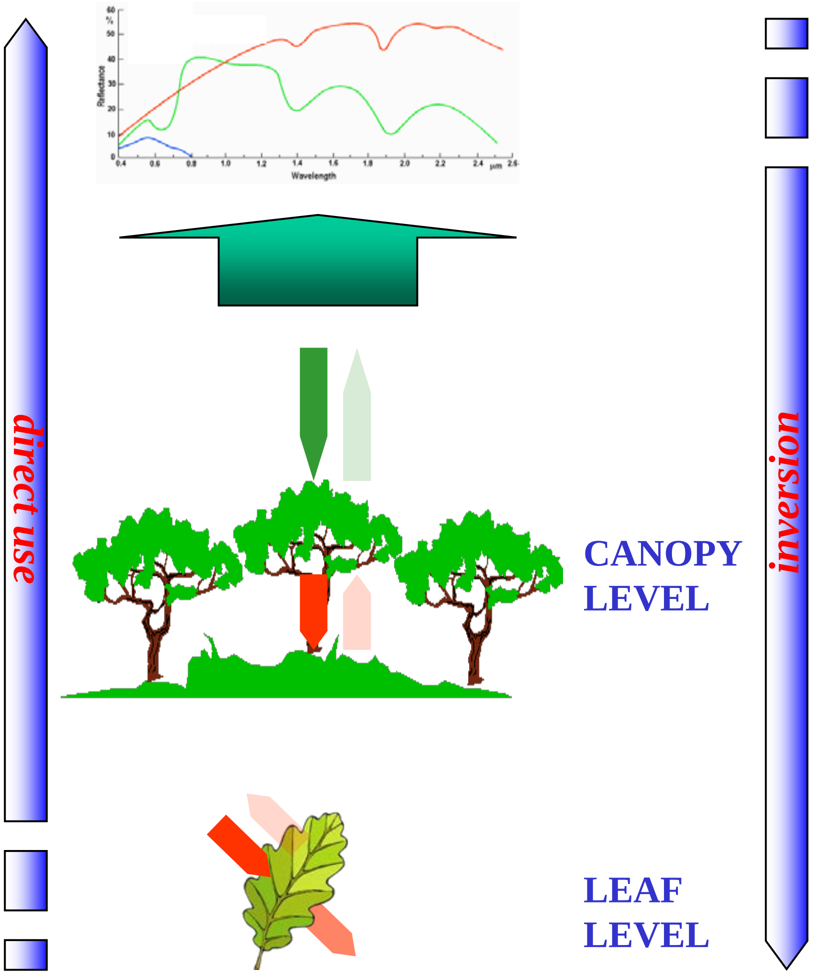


Field data *VS* hyperspectral data



Regression model between NDVI and LAI

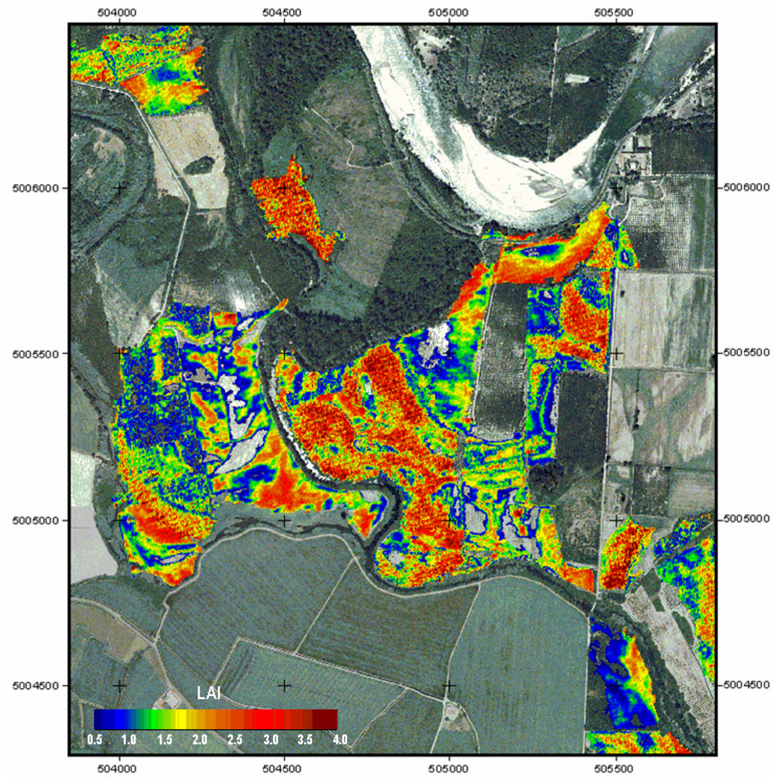
Physically based models



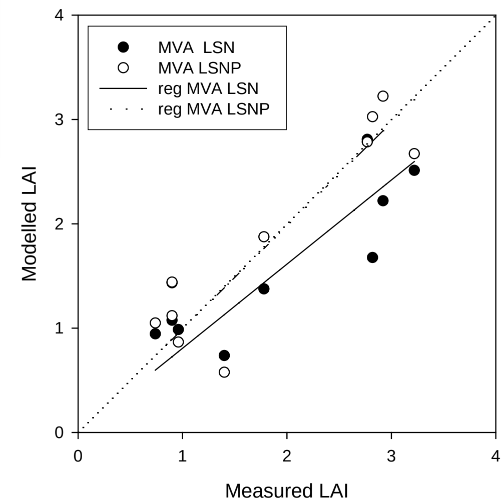
LAI retrieval with inversion of CR models

Retrieval approach:

PROSAIL inversion with stepwise procedure for optimal spectral sampling selection & exploitation of prior knowledge about model variables.



Accuracy in LAI estimation (n=20) achieved with different cost functions and different spectral sampling sets (LSNP & MVA=0.40 m^2/m^2)



Cost function	Retained spectral data set		Optimal spectral sampling set	
	RMSE (m^2m^{-2})	Band number	RMSE (m^2m^{-2})	Band number
LSN	0.76	36	0.60	21
LSNP	0.57	36	0.47	18

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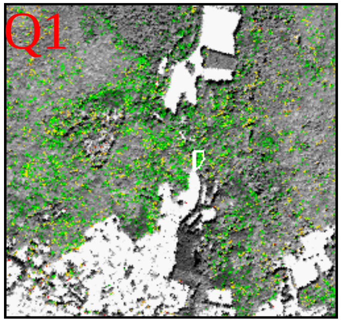
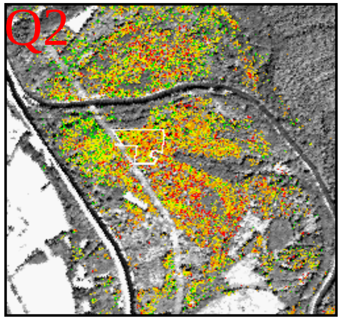
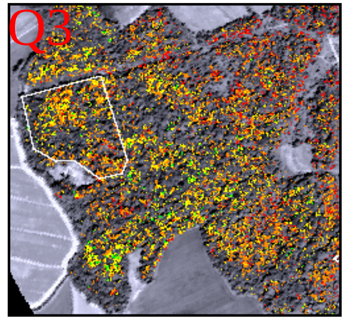
Example of applications. Chlorophyll and plant status



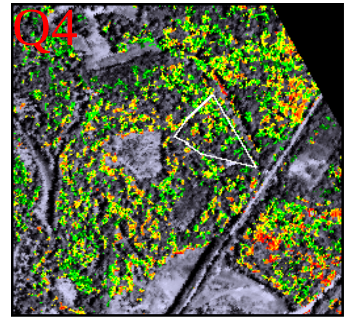
Class 0
Healthy site



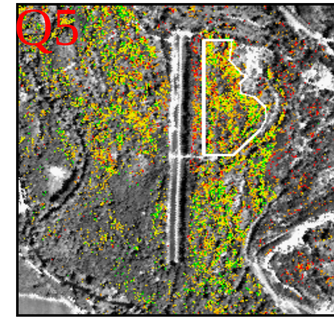
Class 2
Medium stressed



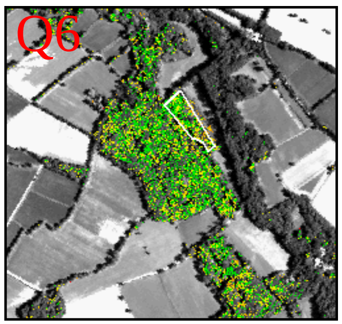
Class 1
Low stressed site



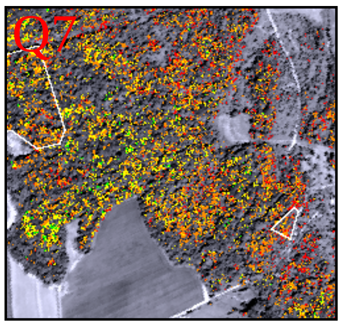
Class 2
Medium stressed



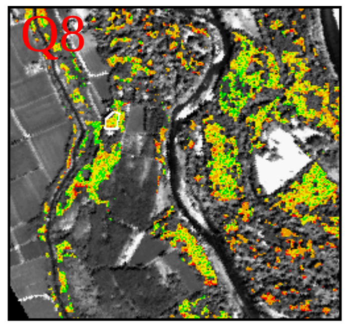
Class 2
Medium stressed



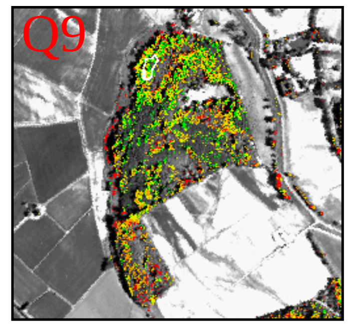
Class 0
Healthy site



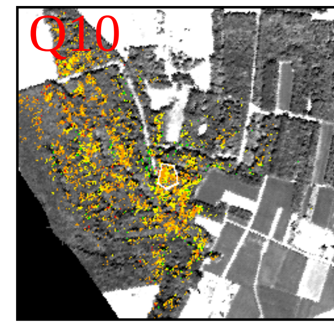
Class 3
Strongly stressed



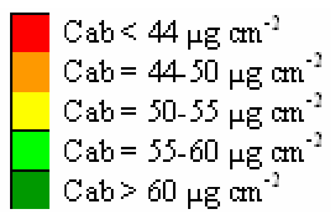
Class 0
Healthy site



Class 2-3
Strongly stressed

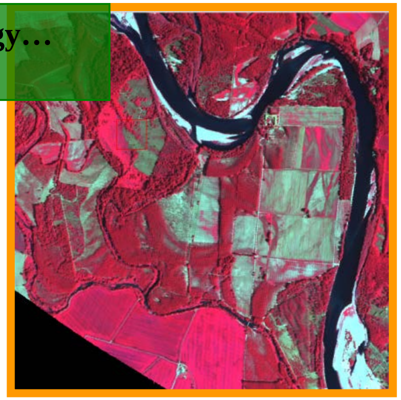


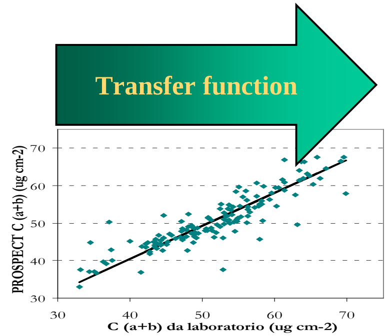
Class 1
Healthy site

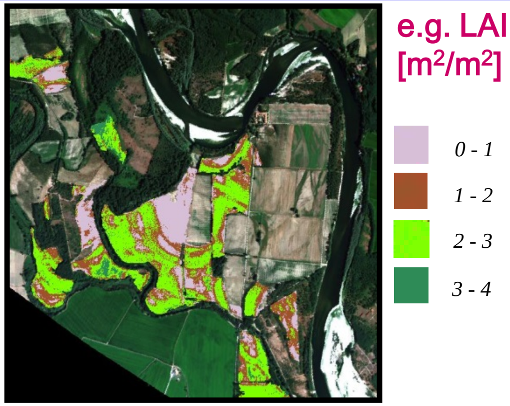


A lot of applications…..

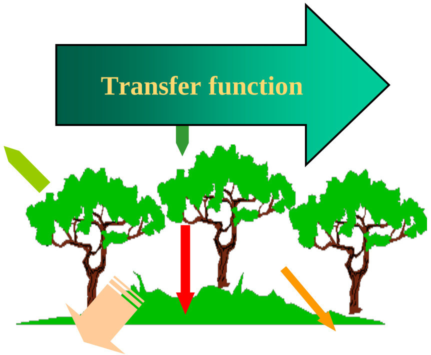
Carbon, Phenology… (NPP)

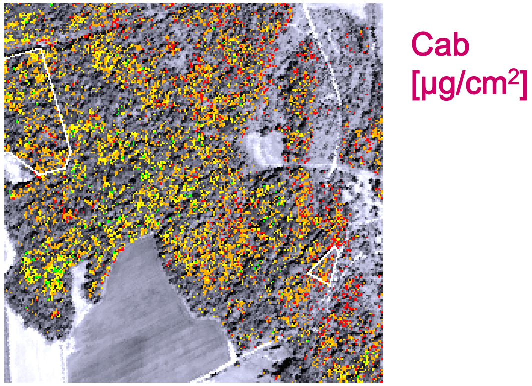




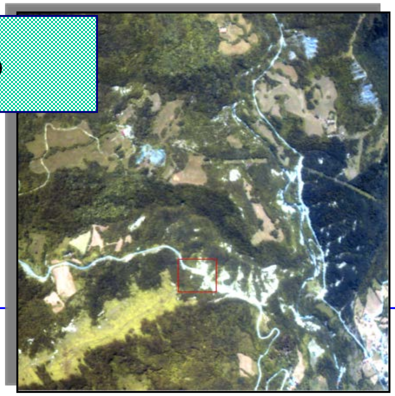


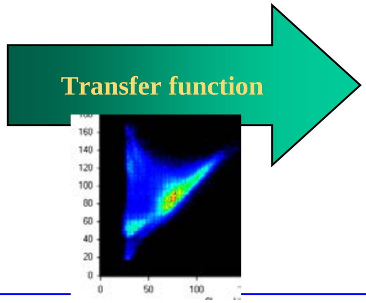
Plant status

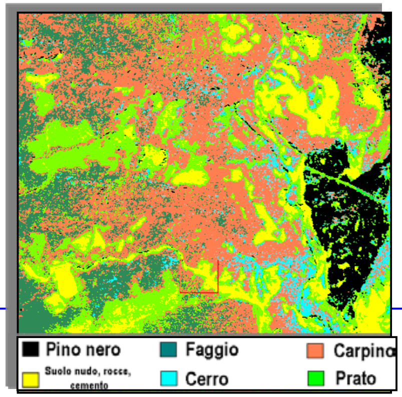




Vegetation map

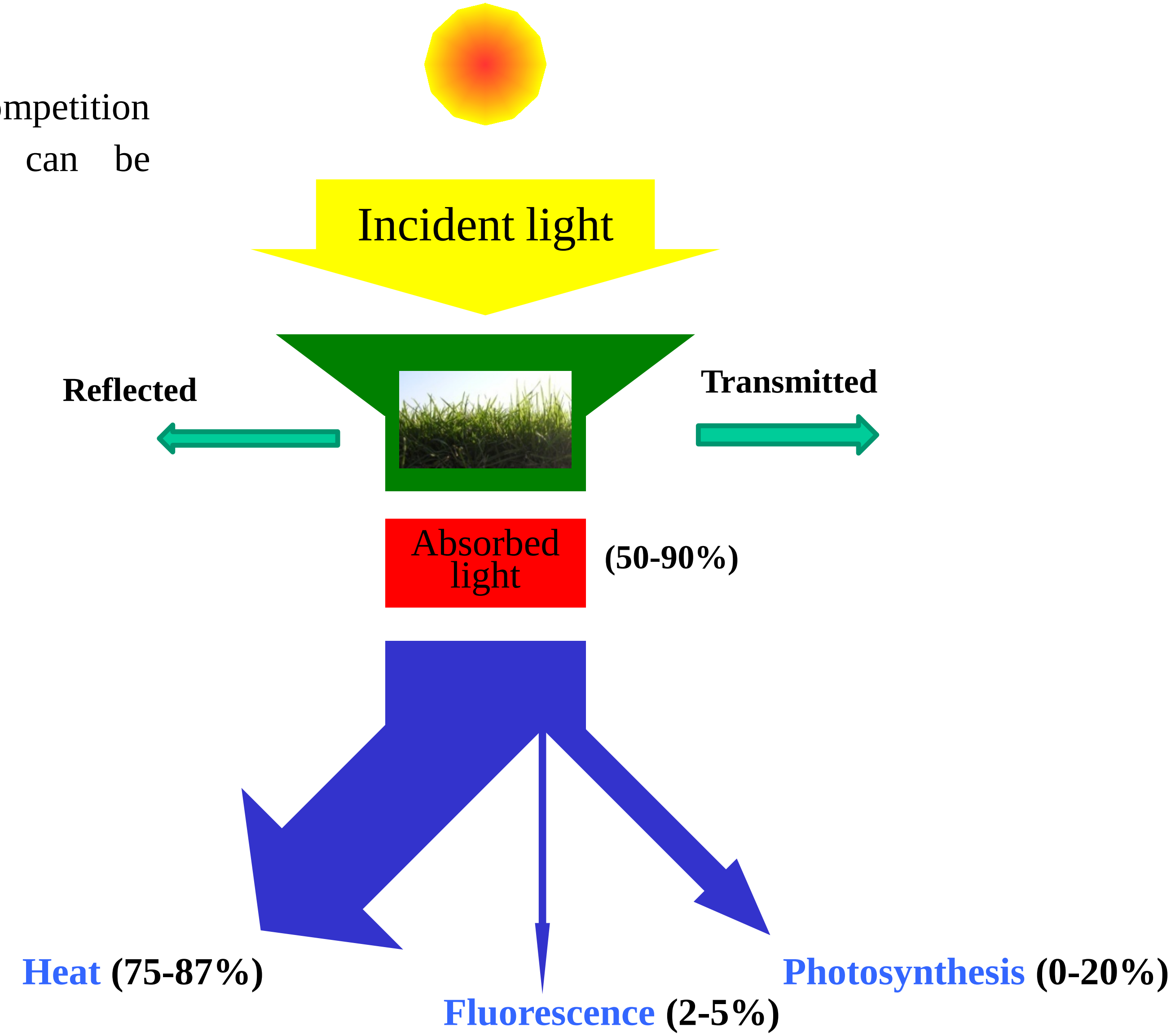






New perspectives of hyperspectral RS of vegetation

Fluorescence is in direct competition with **Photosynthesis** and can be measured remotely.



This link can be exploited for:

- **Stress detection;**
- **GPP estimation.**

FLEX Mission, tandem with Sentinel-3

Hyperspectral mission

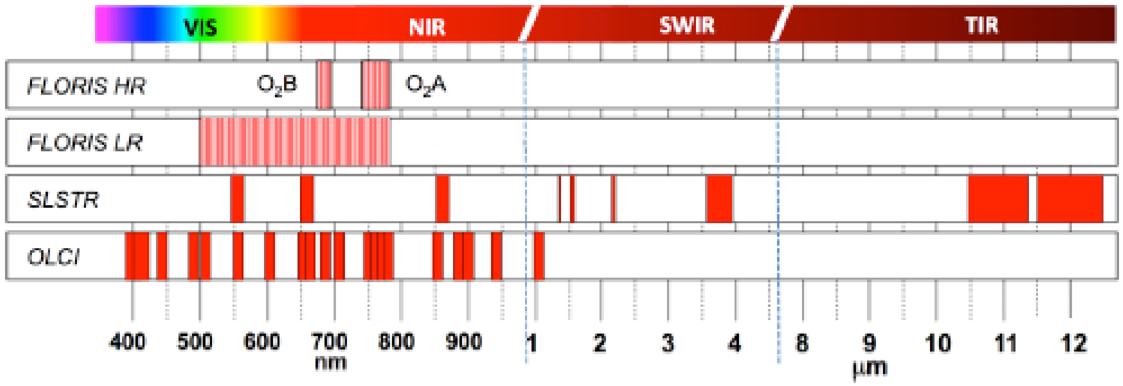
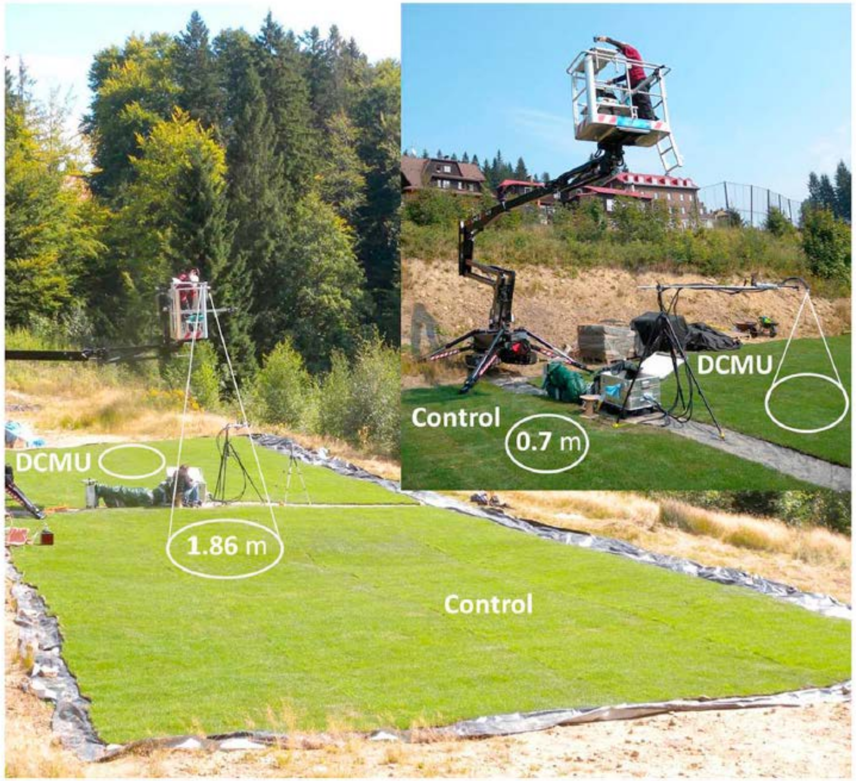


Table 1
Technical characteristics of the FLORIS spectra in terms of spectral resolution (SR), spectral sampling interval (SSI), and signal to noise ratio (SNR) for the different spectral regions.

Spectral region	Visible	SIF_{red}		Red-edge			$SIF_{far\text{-}red}$		
λ (nm)	500–677	677–686	686–697	697–740	740–755	755–759	759–762	762–769	769–780
SR (nm)	3.0	0.6	0.3	2.0	0.7			0.3	0.7
SSI (nm)	2.0	0.5	0.1	0.65	0.5			0.1	0.5
SNR	245	340	175	425	Linear from 510 to 1015	1015	115	Linear from 115 to 455	1015

Stress/manipulation experiment: demonstration test



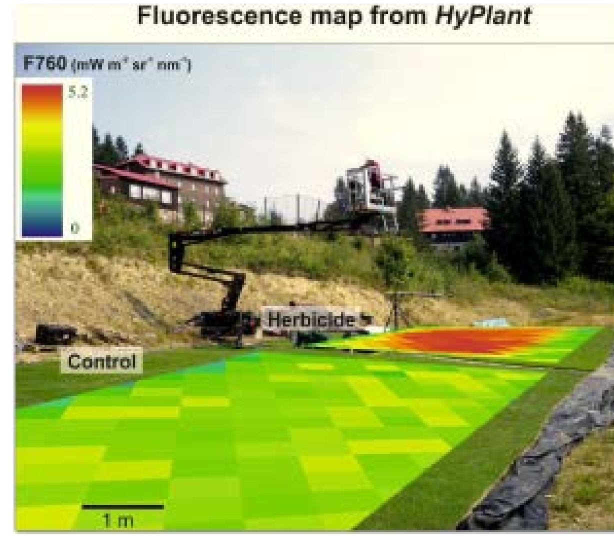
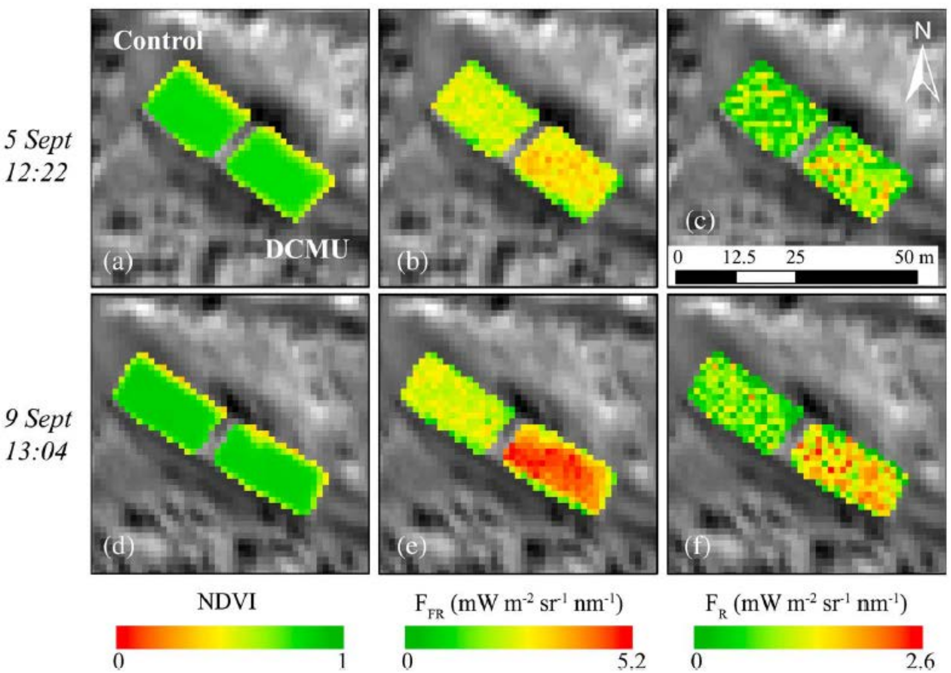
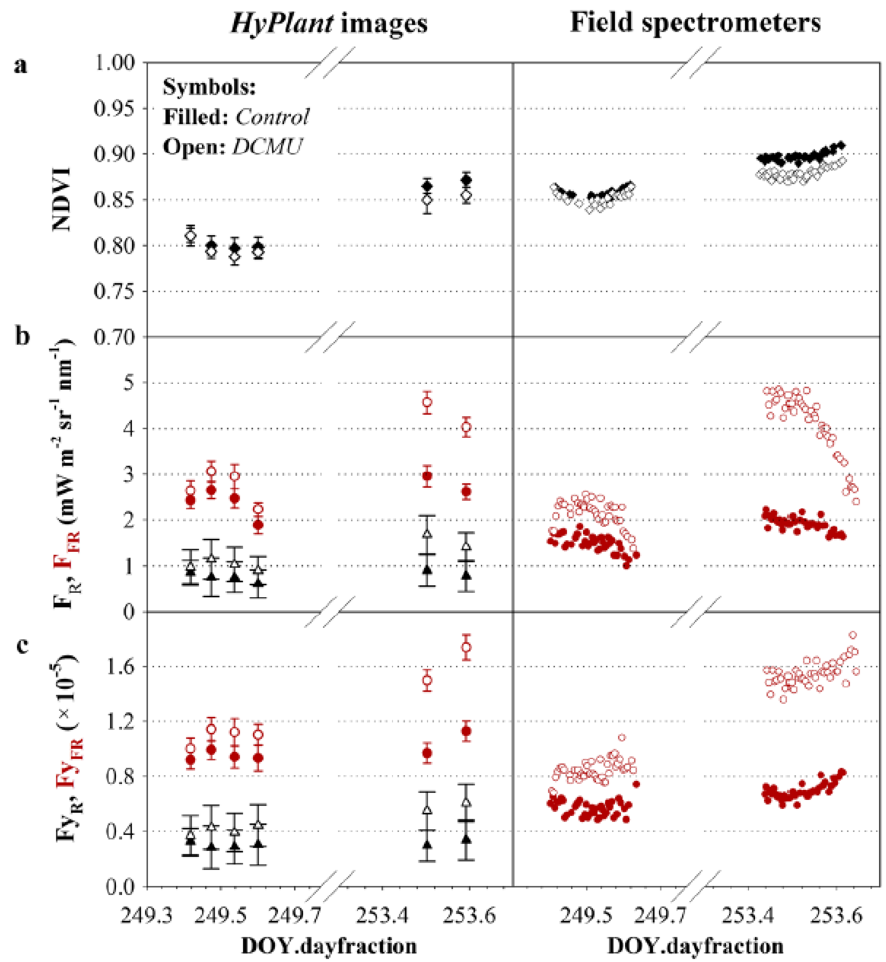


Figure 1. Experimental site with a treated (DCMU) and an untreated (control) grass carpet. Ground spectral data were collected in circular areas (approximately 1.86 m in diameter) in both the treated (3-(3′,4′-dichlorophenyl)-1,1-dimethylurea (DCMU)) and the control plot using an ASD field spectrometer. The ASD instrument was installed on a hydraulic platform that allowed moving the fore optic and measuring both plots sequentially. Additional high-resolution spectral measurements were collected (inlet at the top right corner) by a Multiplexer Radiometer/Irradiometer consisting of two portable OceanOptics spectrometers equipped with optical fibers and mounted on a mobile arm swinging over both plots. The measured area covers a circular area (approximately 0.7 m in diameter) of both grass carpets.

sVI and SIF

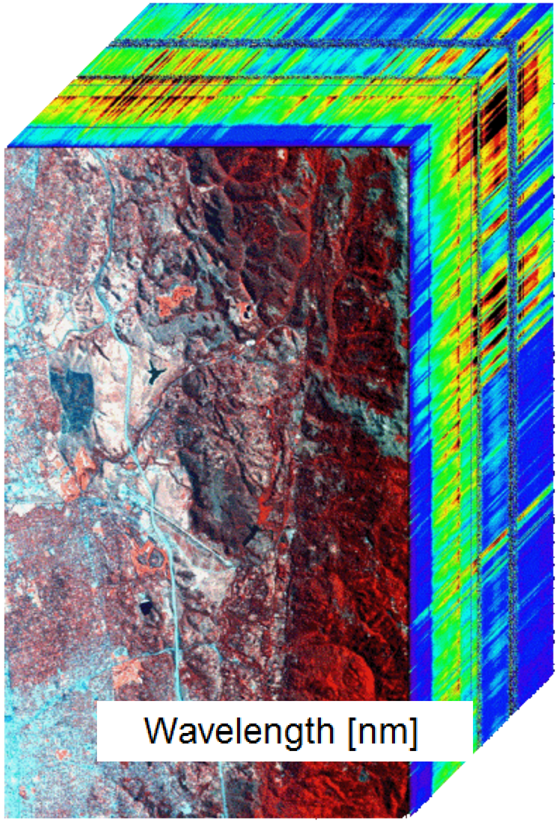


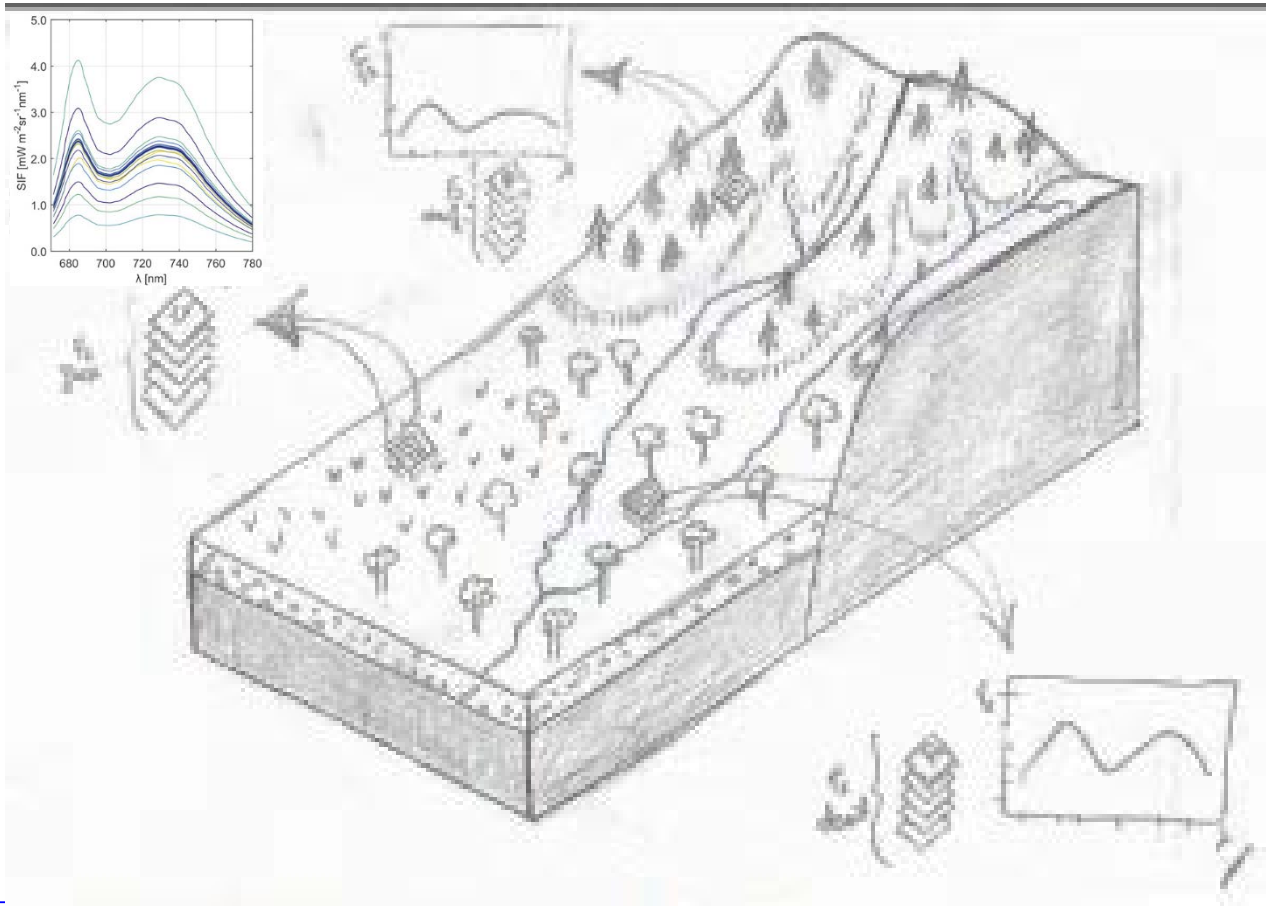


Rossini et al., 2014

Fluorescence spectra

Reflectance cube *and* fluorescence cube





Conclusions

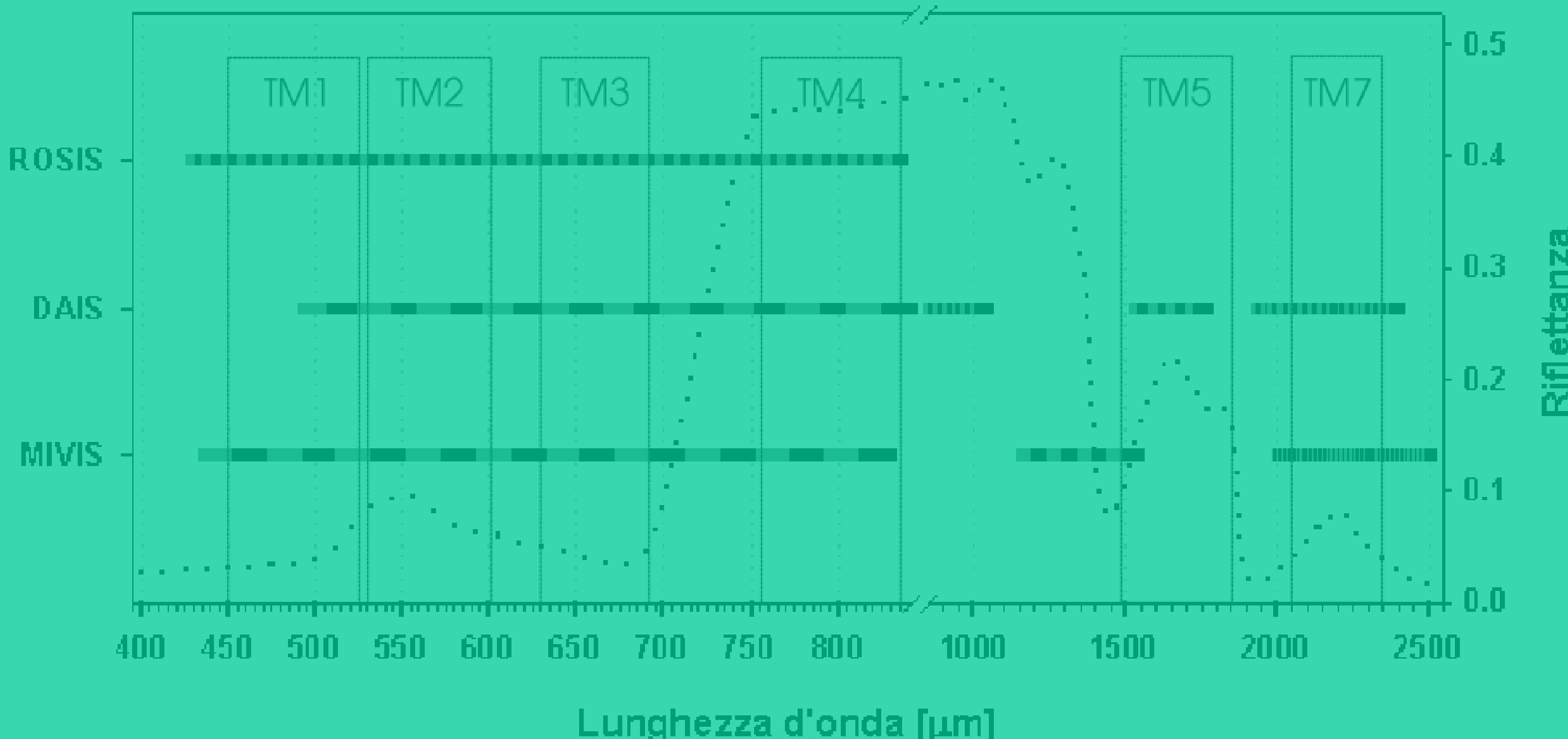
- RS is a powerful tool for obtaining spatial and temporal information of vegetation parameters at different scales

- Spaceborne imaging spectroscopy mission is still in a development phase and we expect a lot of missions in near future

- Fluorescence is a promising technique that can be used for different purposes,(e.g. early stress detection, GPP estimation..) and it represents the novelty in hyperspectral remote sensing


Thank you

Landsat *vs* Airborne instruments



What can we obtain from RS measurements?

- **Conceptual basis of remote sensing research**
  - ***Continuous variables***
    - Biochemical and biophysical vegetation parameters
  - ***Nominal variables***
    - Classification techniques

Incorporating in space and time vegetation related parameters in environmental models