Education & Training

Hyperspectral instrumentation and the process of measuring

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HyperTeach
Training in Imaging Spectroscopy

Content

- Imaging spectroscopy
- Sensor calibration
- Atmospheric correction: Land

Imaging Spectroscopy

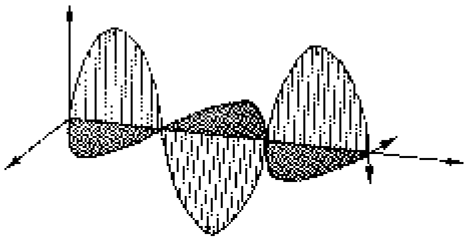
Content

- The electromagnetic radiation EMR
  - Source of EMR: Planck's law
  - Interaction of EMR with matter
    - Transmission
    - Absorption
    - Reflection

- Imaging spectroscopy
- Spectral reflectance measurements
  - Radiance and reflectance
  - Atmosphere
- Imaging spectroradiometers
  - Airborne
  - Spaceborne

The electromagnetic radiation EMR

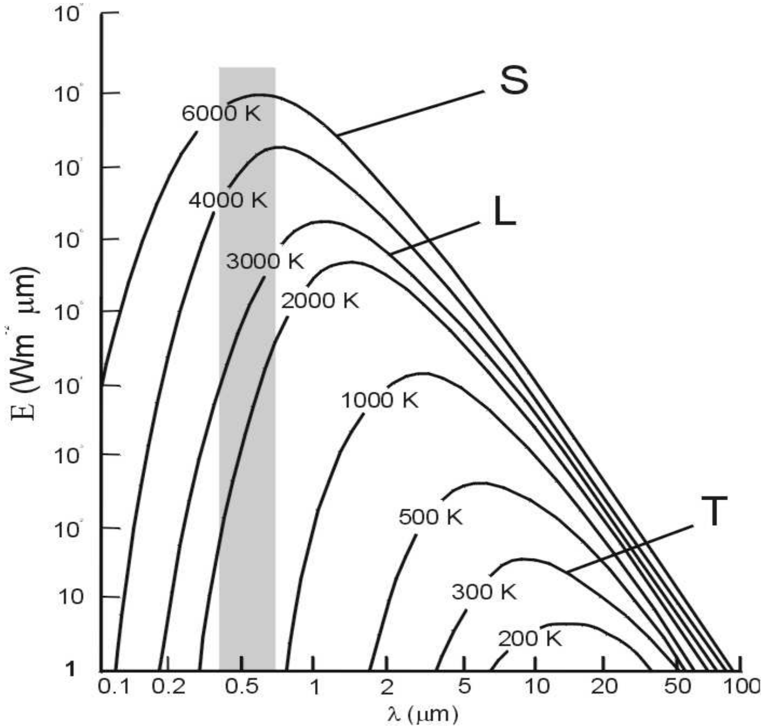
Electromagnetic radiation (EMR) propagates as a harmonic sinusoidal wave. EMR consists of oscillating electric and magnetic fields that are perpendicular to each other and perpendicular to the direction of travel. EMR can affect the electronic, vibrational and rotational properties of atoms or molecules.



•Source of EMR

Planck's law

$$E(\lambda,T)= C_1 \frac{\lambda^{-5}}{e^{\frac{C_2}{\lambda T}}-1}$$



λ in meters, T in °K

C_1=3.74x10-16 W m2 ($2\pi hc^2$)

h: Planck's constant = 6.6256×10^{-34} Js

c ≈ 3×10^8 m/s

C_2=1.44 10^{-2} m K (hc/k)

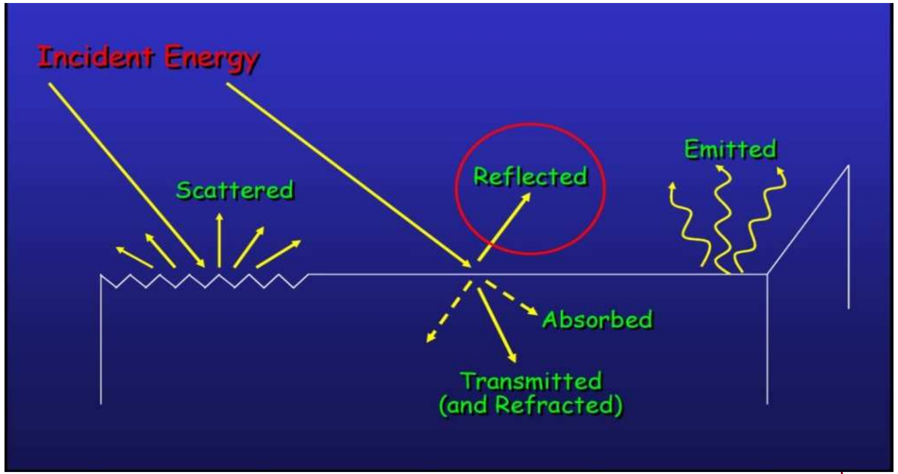
k: Boltzmann's constant

S sun

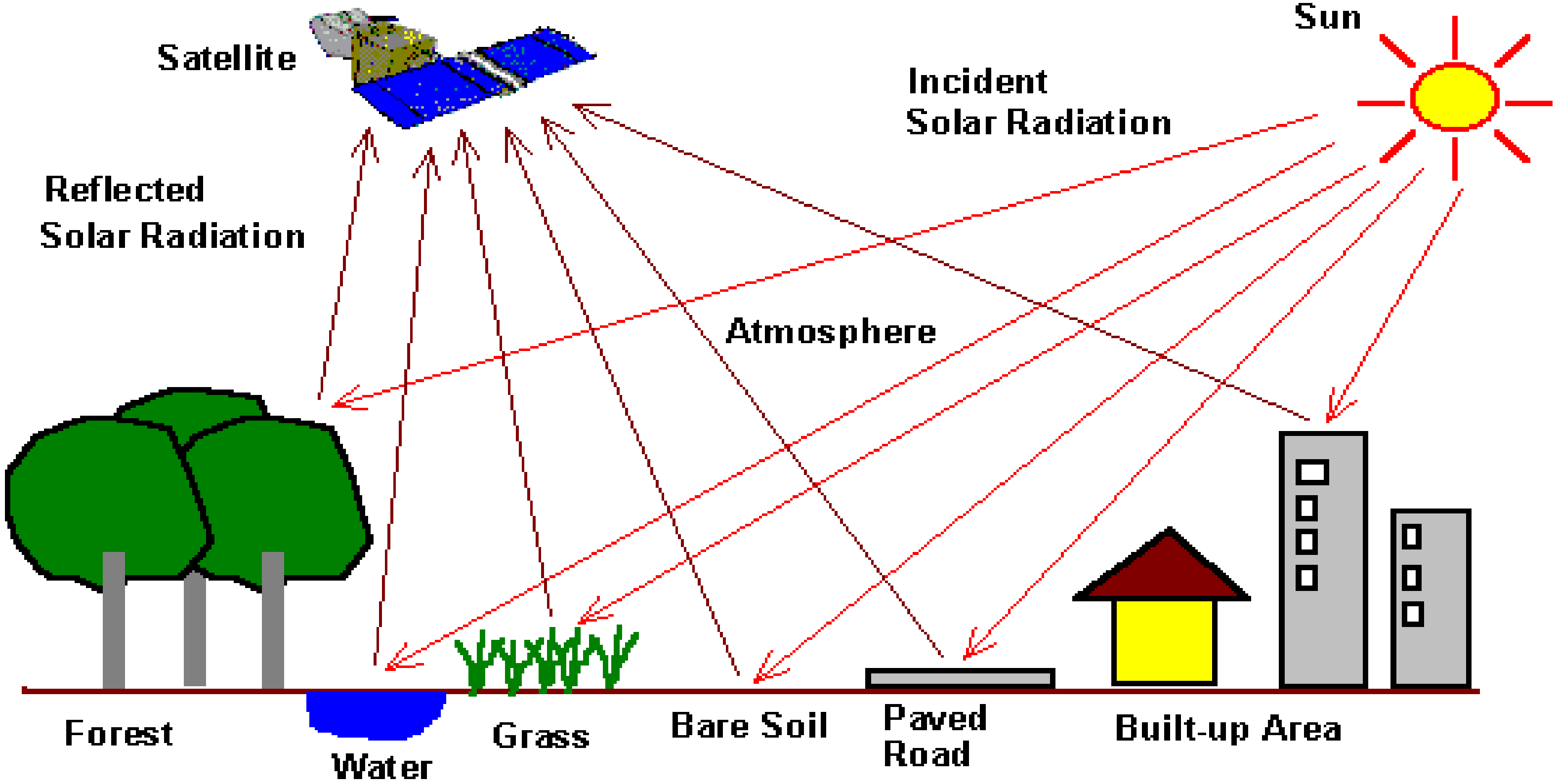
L lamp

T earth

Interaction with matter



Concept of remote sensing



The principle of energy conservation states that the incident radiant flux (E_i) is totally distributed between reflected (E_r), transmitted (E_t) and absorbed (Ea) energy.

$E_i = E_t + E_a + E_r$

Dividing all variables of this equation by the incident radiant flux E_i results in

$1 = E_t/E_i + E_a/E_i + E_r/E_i$

Defining three new parameters:

transmittance (τ) E_t/E

absorptance (α) E_a/E

reflectance (ρ) E_r/E_i

$$1 = \tau + \alpha + \rho$$

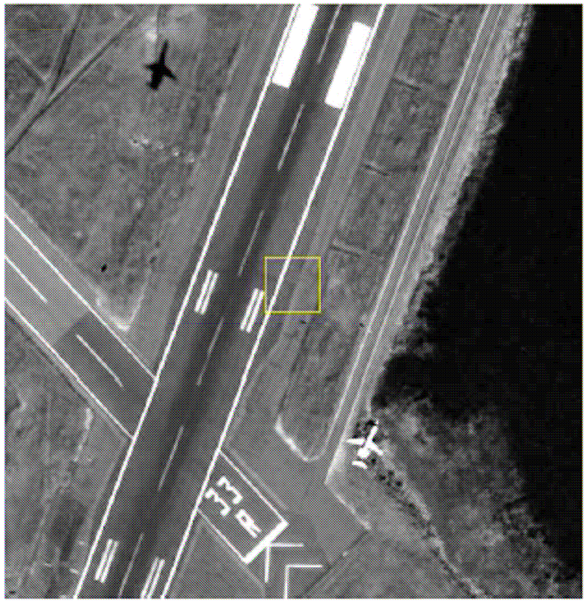
Imaging spectroscopy

Imaging spectroscopy is the acquisition of images in hundreds of registered, contiguous spectral bands such that for each picture element of an image it is possible to derive a complete reflectance spectrum (Goetz, 1992).

Each picture element contains a unique reflectance spectrum which can be used for the identification of Earth's surface materials.

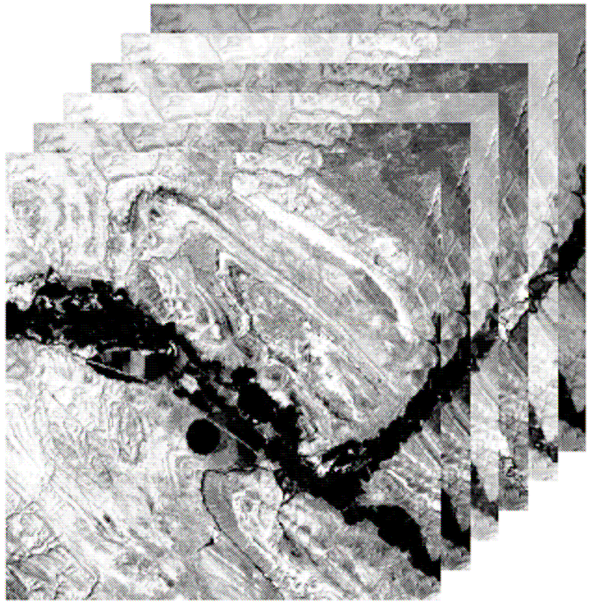
Typical wavelength region: 400 nm - 2500 nm (VNIR-SWIR)

Panchromatic



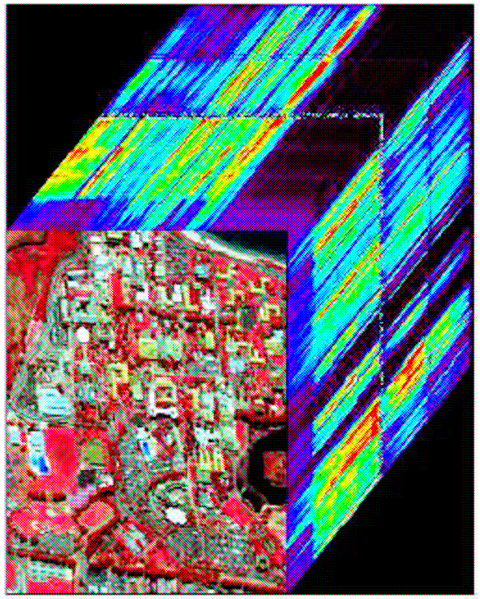
1 Band

Multispectral

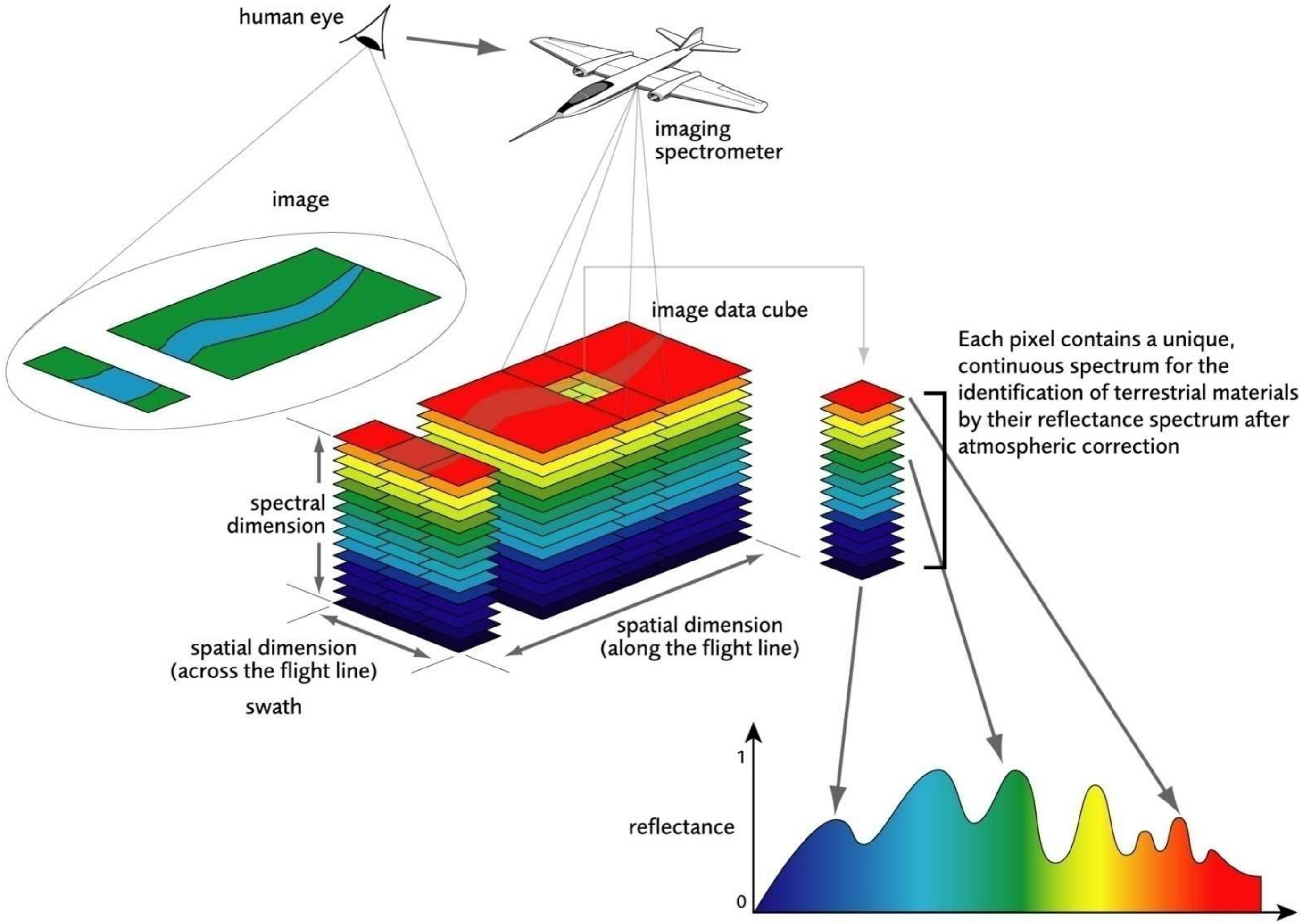


Several Bands

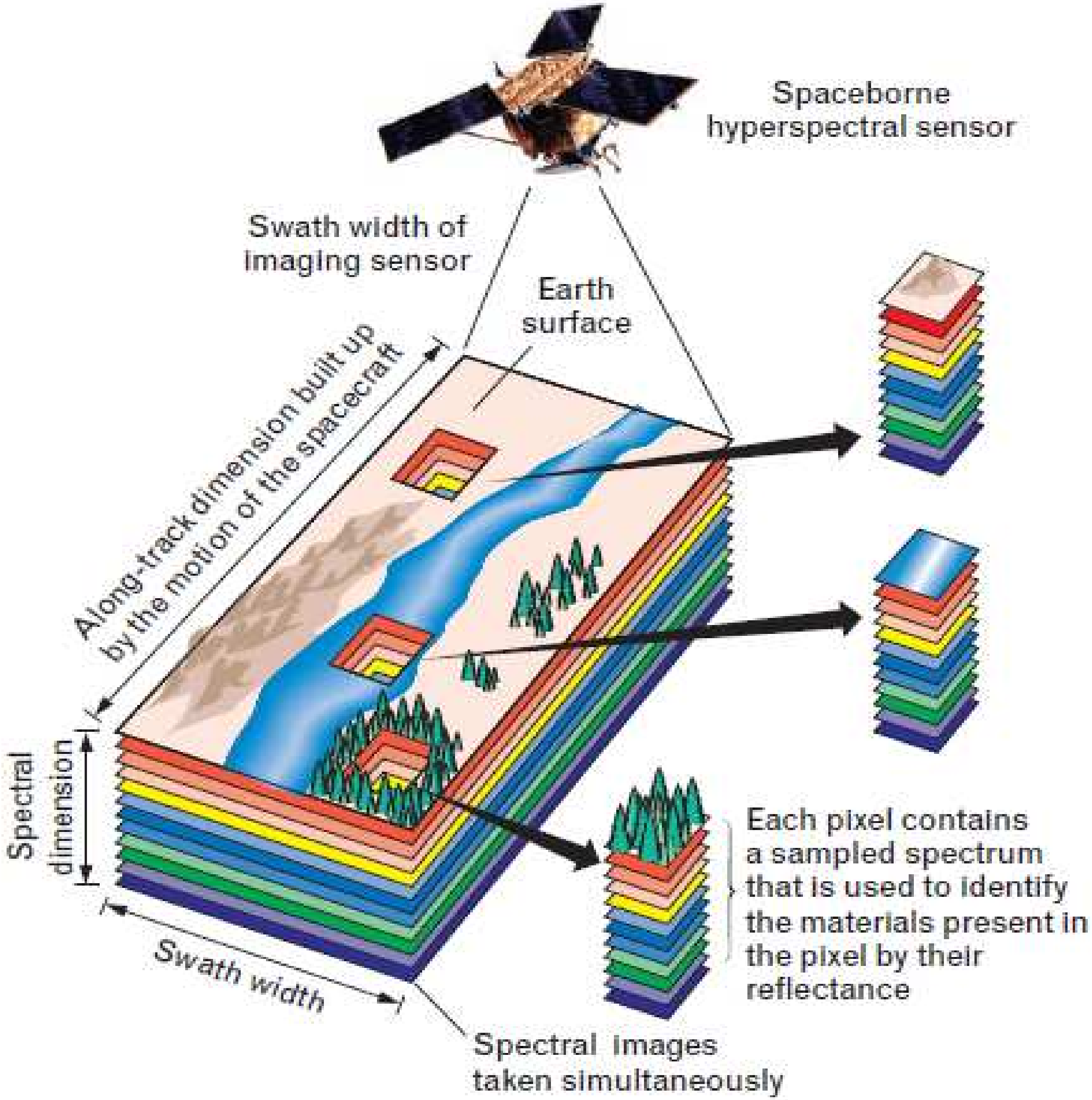
Hyperspectral

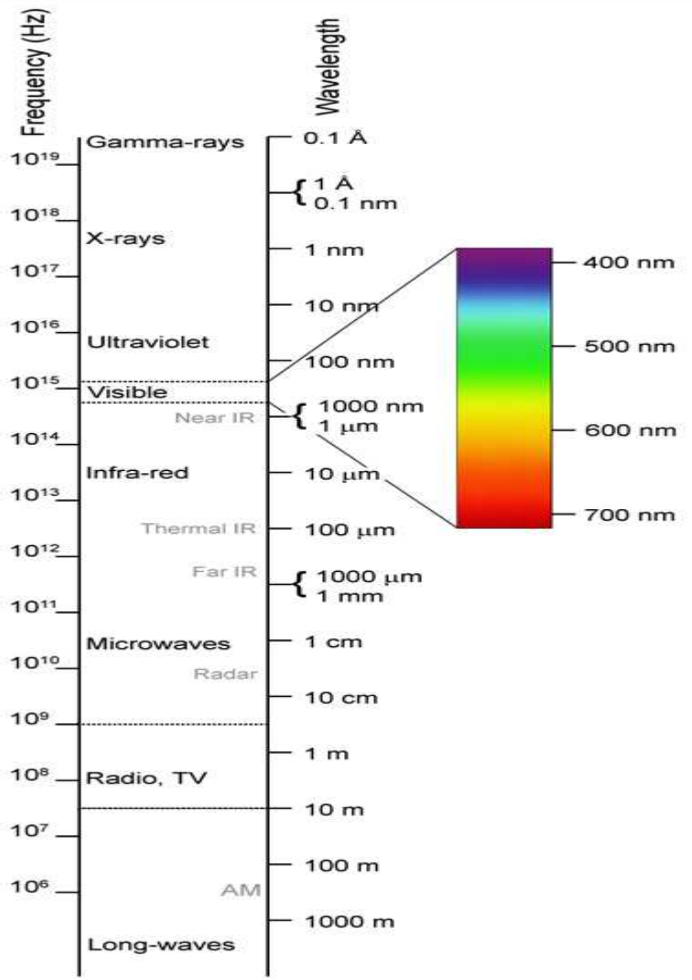


Tens to hundreds of Bands

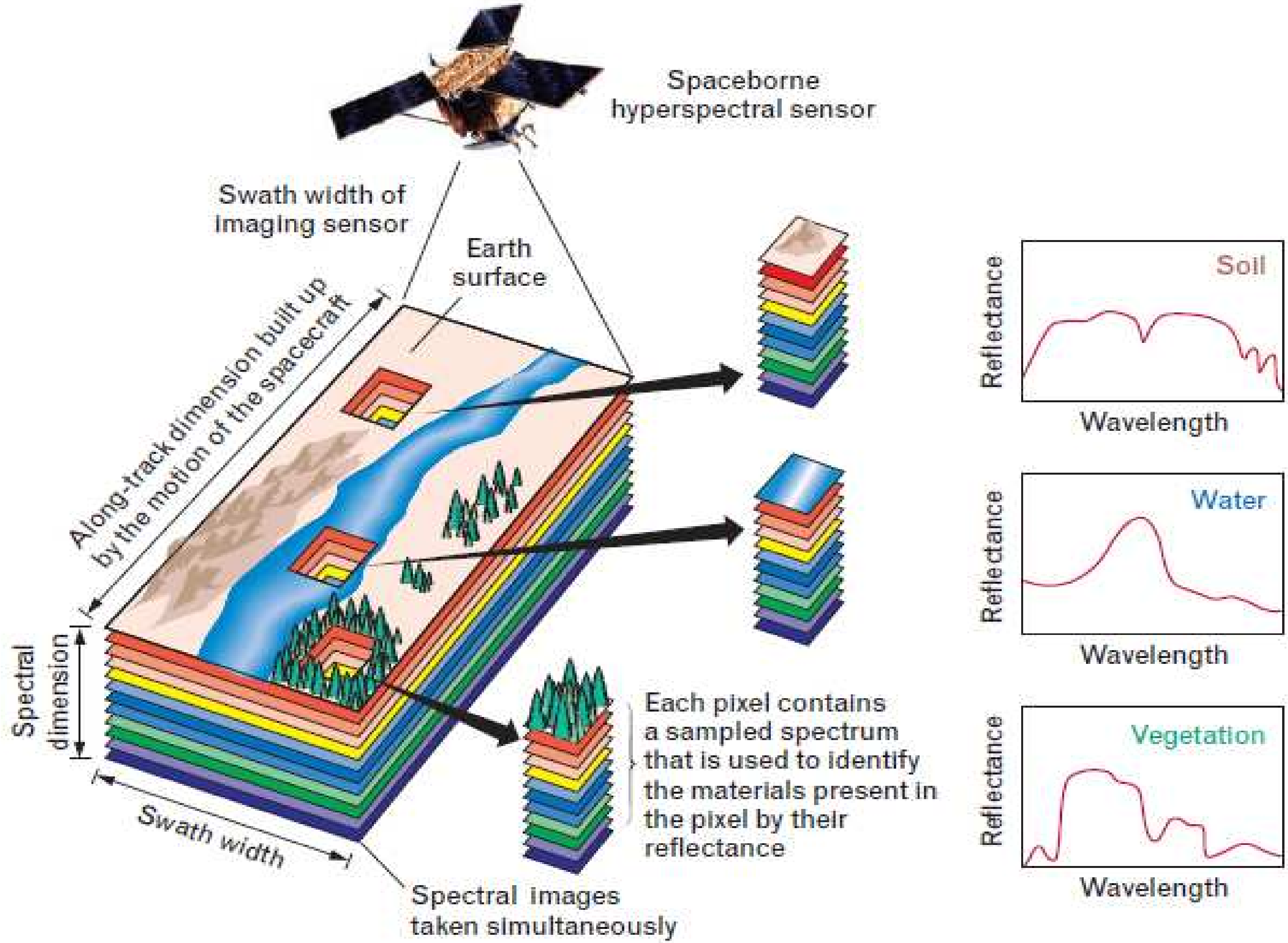

human eye
imaging
spectrometer
image
image data cube
Each pixel contains a unique, continuous spectrum for the identification of terrestrial materials by their reflectance spectrum after atmospheric correction
spectral
dimension
spatial dimension
(across the flight line)
swath
spatial dimension
(along the flight line)
1
reflectance
0

The concept of hyperspectral remote sensing





Spectral signature
Reflectance spectrum

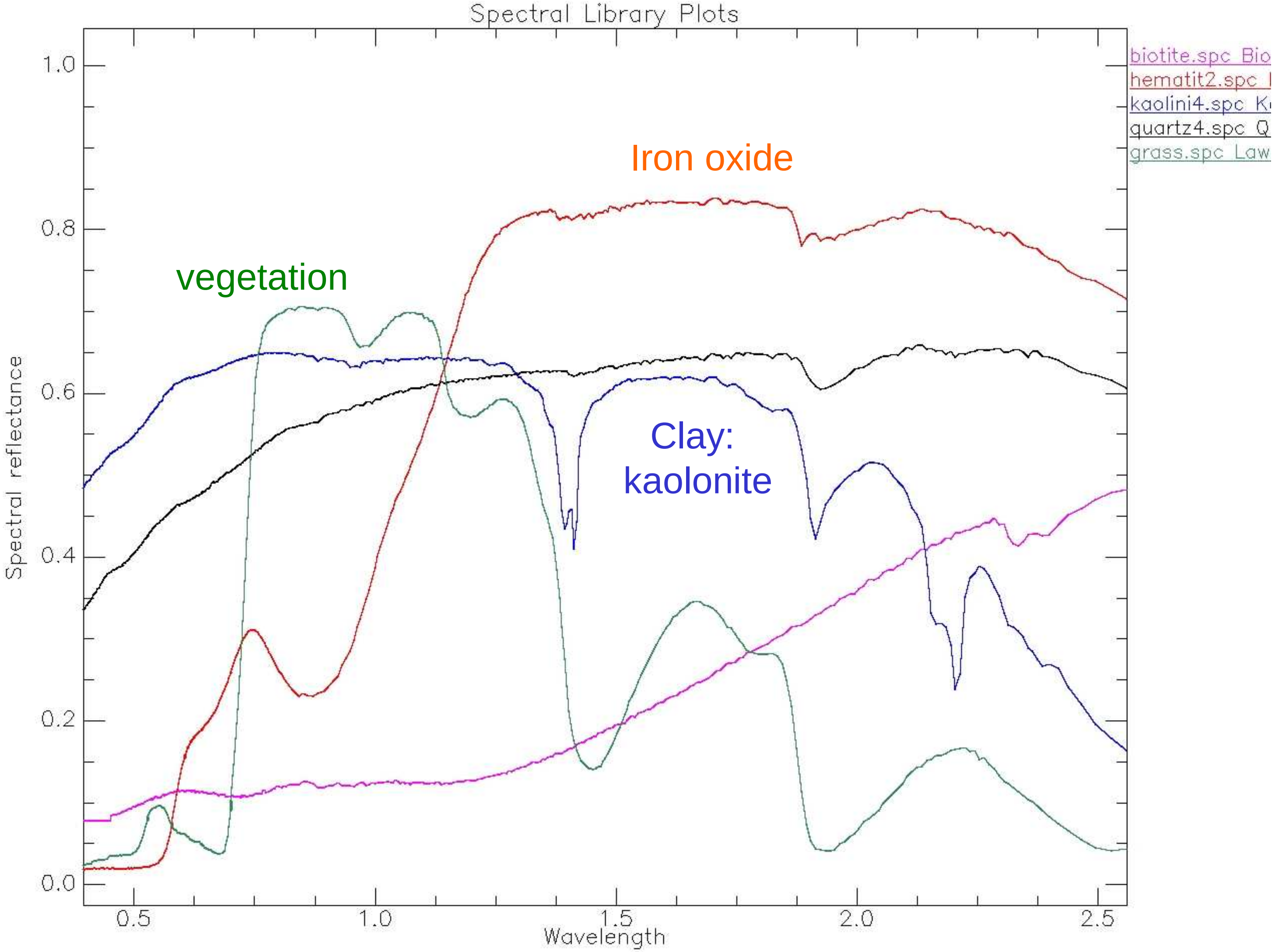


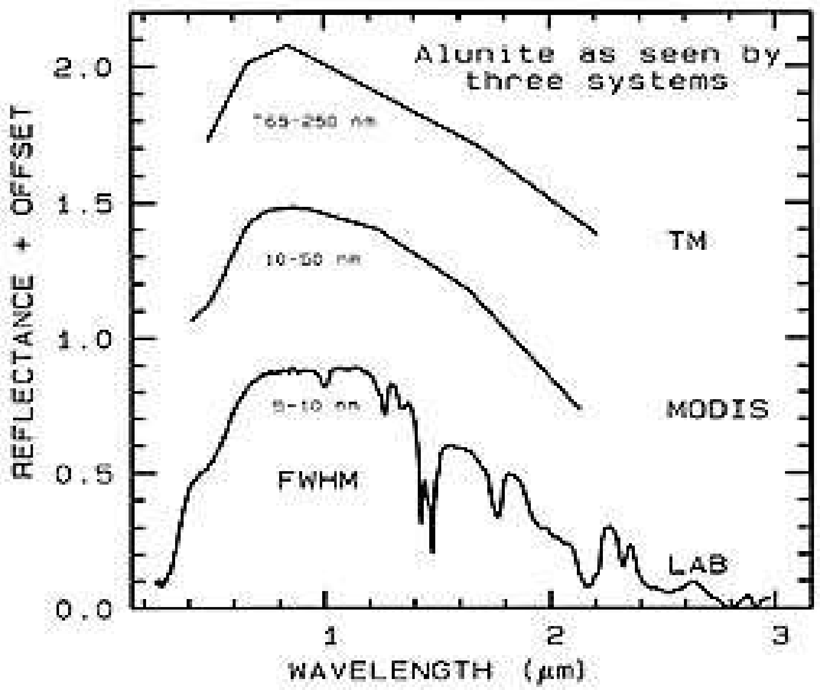
Spectral reflectance measurements

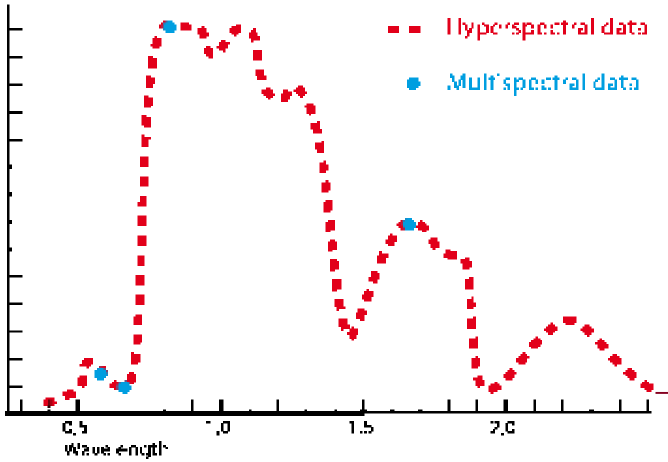
Each material has its own spectral identity by which it can be identified. This *“<u>spectral signature</u>”* depicts the reflectance of a material as a function of the wavelength and is as characteristic for the material as a fingerprint is for a human being.

It is independent of the light source or the environment. At some wavelengths sand reflects more light than vegetation while at other wavelengths the opposite may be true.

Examples of spectral signatures







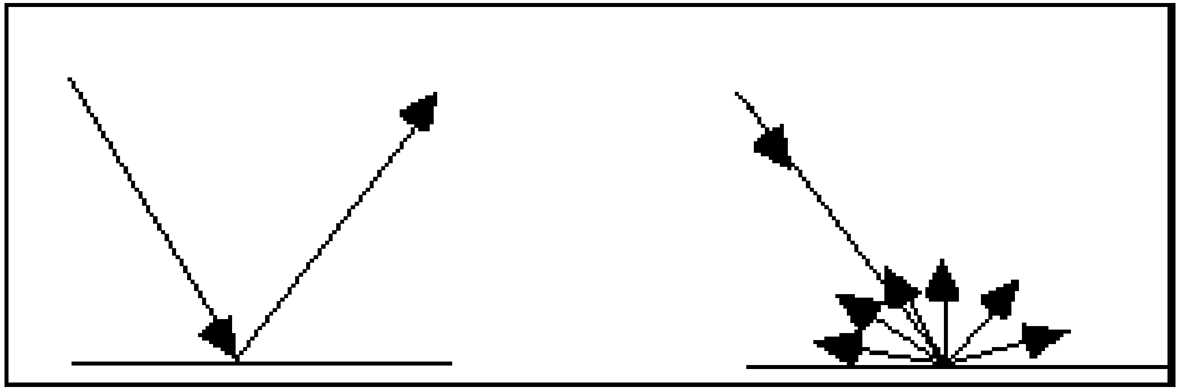
Advantage(s) of hyperspectral remote sensing

- Specular and diffuse (Lambertian) reflection

There are two extreme cases of scattering surfaces: the smooth surface (specular surface) and the rough surface (Lambertian surface). A surface is rough (smooth) when its texture is comparable or larger (smaller) than the wavelength of the incident radiation.

A *Lambertian* surface reflects the incident radiation homogeneously in all directions, while a *specular* surface reflects the radiation in a single direction. In the latter case the angle of reflection equals the angle of incidence. Most surfaces are a combination of perfectly specular and perfectly Lambertian.

Surface reflection



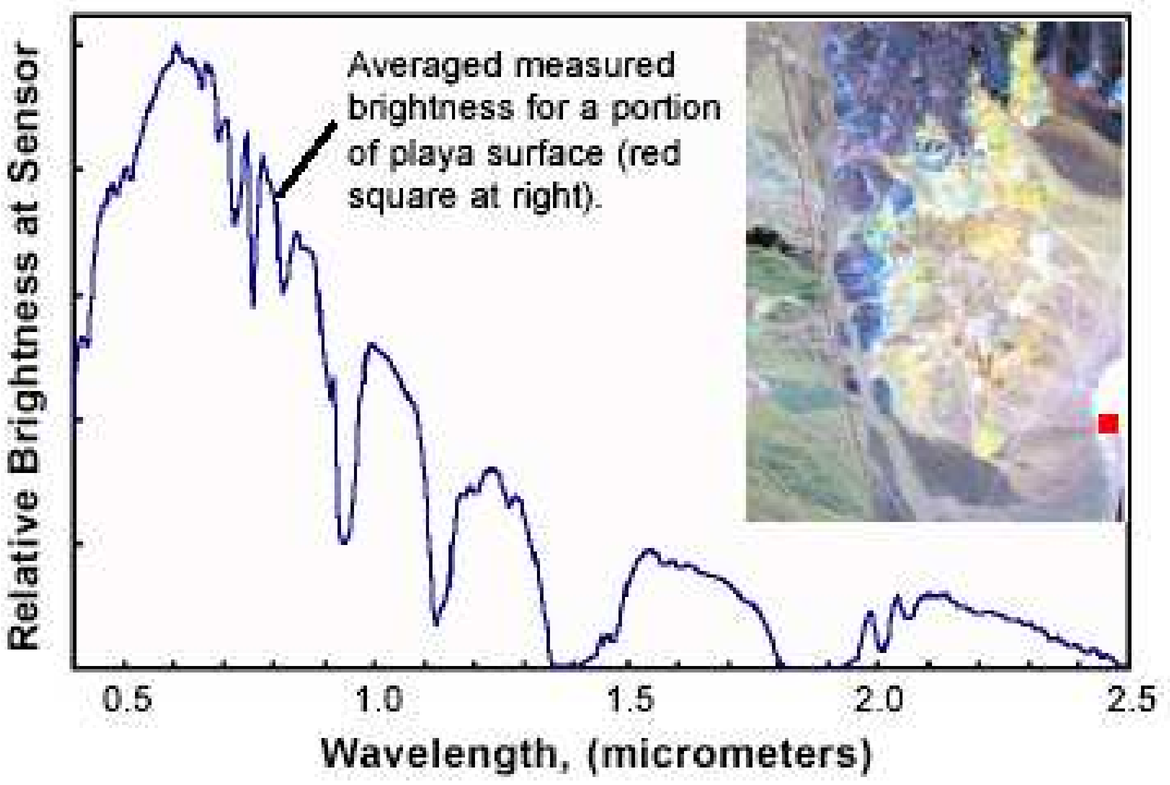
specular diffuse(lambertian)

•Radiance and reflectance

The spectral **reflectance** of an object at the Earth’s surface is an intrinsic property that we would like to measure precisely and accurately using an airborne or spaceborne hyperspectral sensor.

The sensor measures **radiances** that have to be calibrated to “apparent” reflectance.

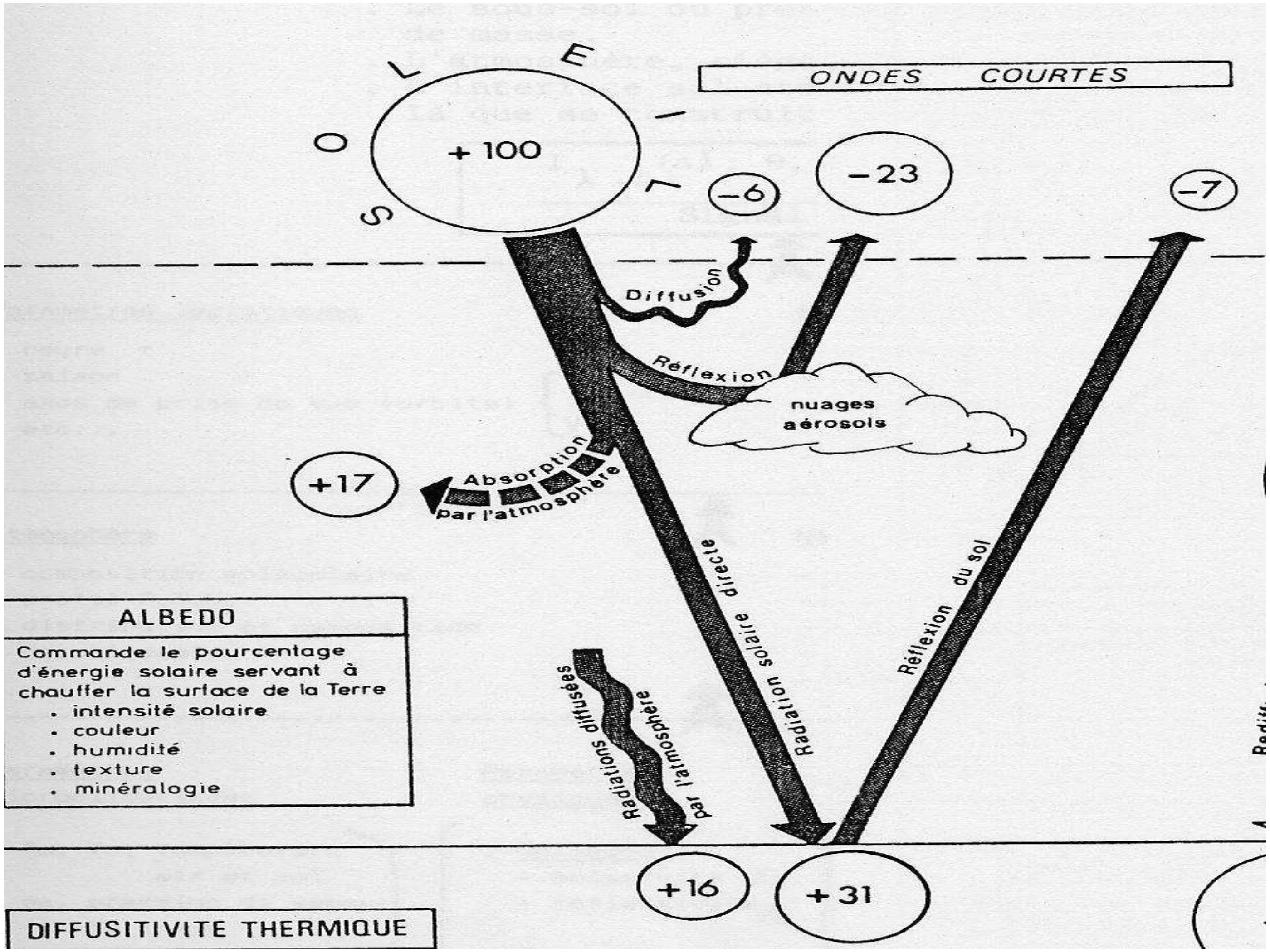
Radiance at sensor

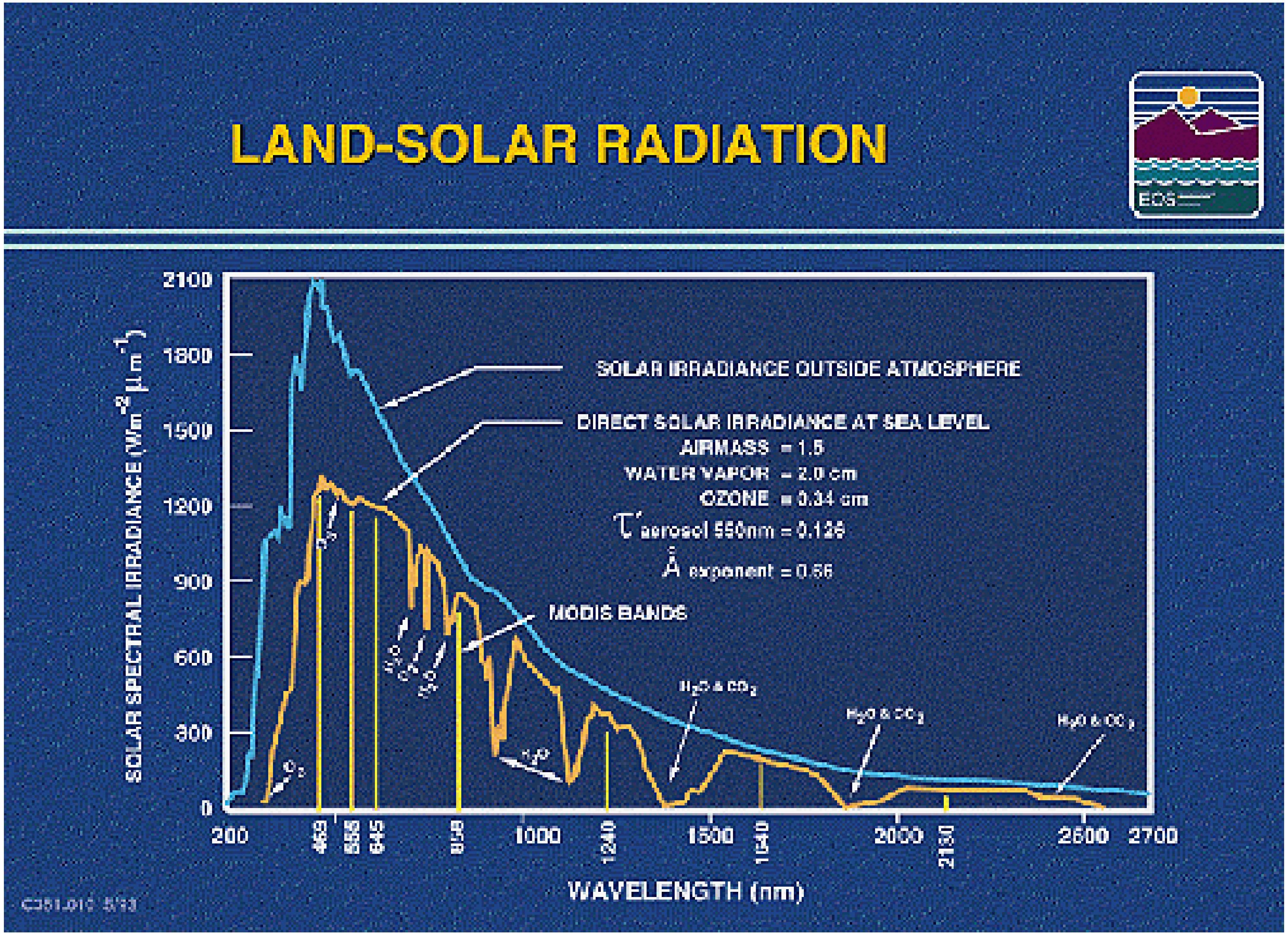


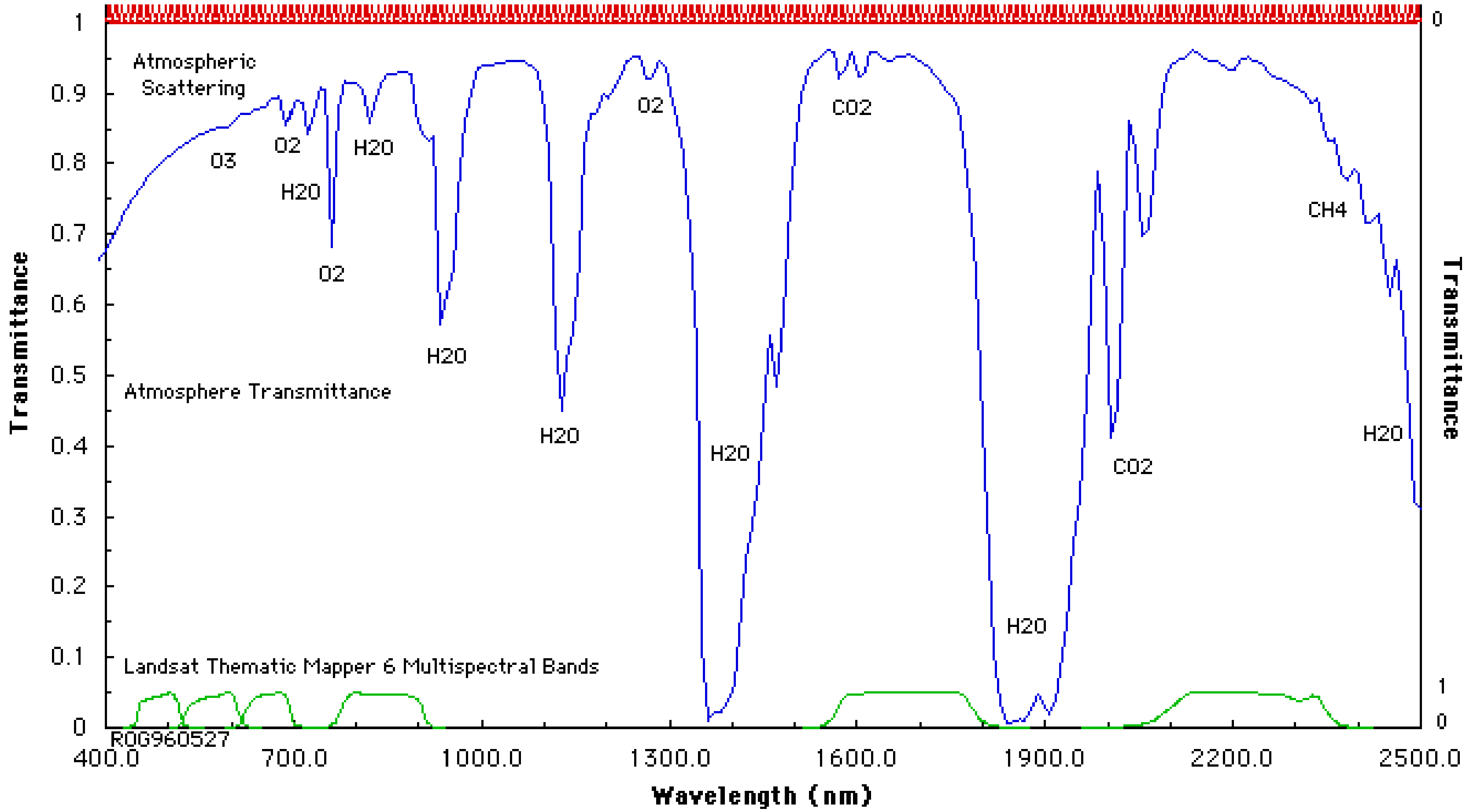
•Atmosphere

Scattering and **absorption** in the atmosphere have a profound effect on the radiation detected by the remote sensor.

The effect of the atmosphere depends on the distance the radiation has to travel through the atmosphere, the atmospheric conditions and the wavelength of the radiation. More details on the atmospheric effects and how to correct for it can be found in Section 8.


SOLEIL
+100
ONDES COURTES
-6
-23
-7
Diffusion
Réflexion
nuages
aérosols
+17
Absorption par l'atmosphère
ALBEDO
Commande le pourcentage d'énergie solaire servant à chauffer la surface de la Terre
. intensité solaire
. couleur
. humidité
. texture
. minéralogie
Radiations diffusées par l'atmosphère
Radiation solaire directe
Réflexion du sol
+16
+31
DIFFUSITIVITE THERMIQUE

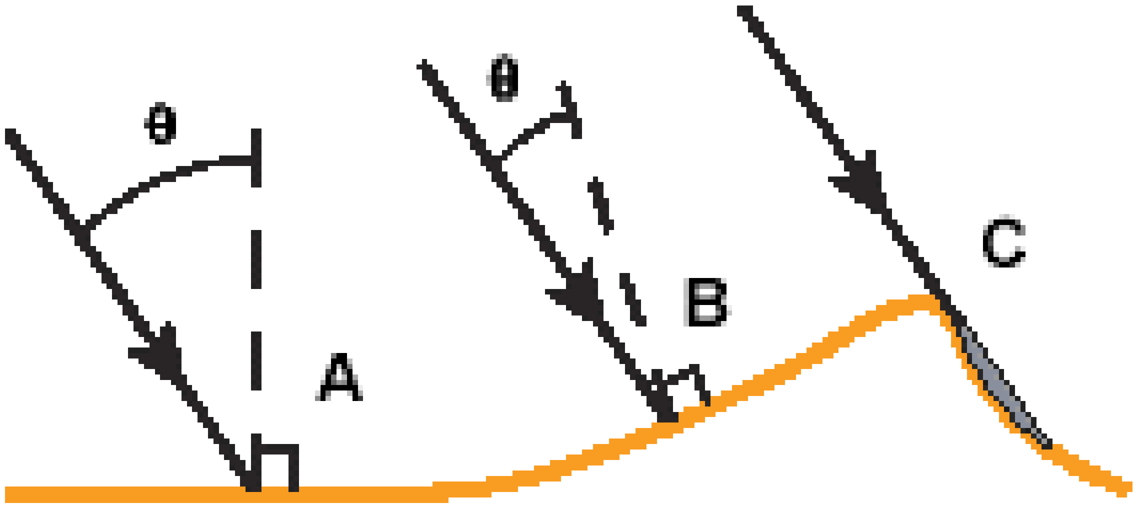

LAND-SOLAR RADIATION
EOS
SOLAR SPECTRAL IRRADIANCE (Wm-2 μm-1)
2100
1800
1500
1200
900
600
300
0
SOLAR IRRADIANCE OUTSIDE ATMOSPHERE
DIRECT SOLAR IRRADIANCE AT SEA LEVEL
AIRMASS = 1.5
WATER VAPOR = 2.0 cm
OZONE = 0.34 cm
τ aerosol 550nm = 0.126
Å exponent = 0.56
MODIS BANDS
H2O & CO2
H2O & CO2
H2O & CO2
O3
O3
H2O
200
469
555
645
858
1000
1240
1500
1640
2000
2130
2500
2700
WAVELENGTH (nm)


Atmospheric Scattering
O3
O2
H2O
O2
H2O
O2
H2O
H2O
O2
CO2
H2O
H2O
CO2
CH4
H2O
Atmosphere Transmittance
Landsat Thematic Mapper 6 Multispectral Bands
Transmittance
Wavelength (nm)
ROG960527
400.0
700.0
1000.0
1300.0
1600.0
1900.0
2200.0
2500.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

- Illumination geometry

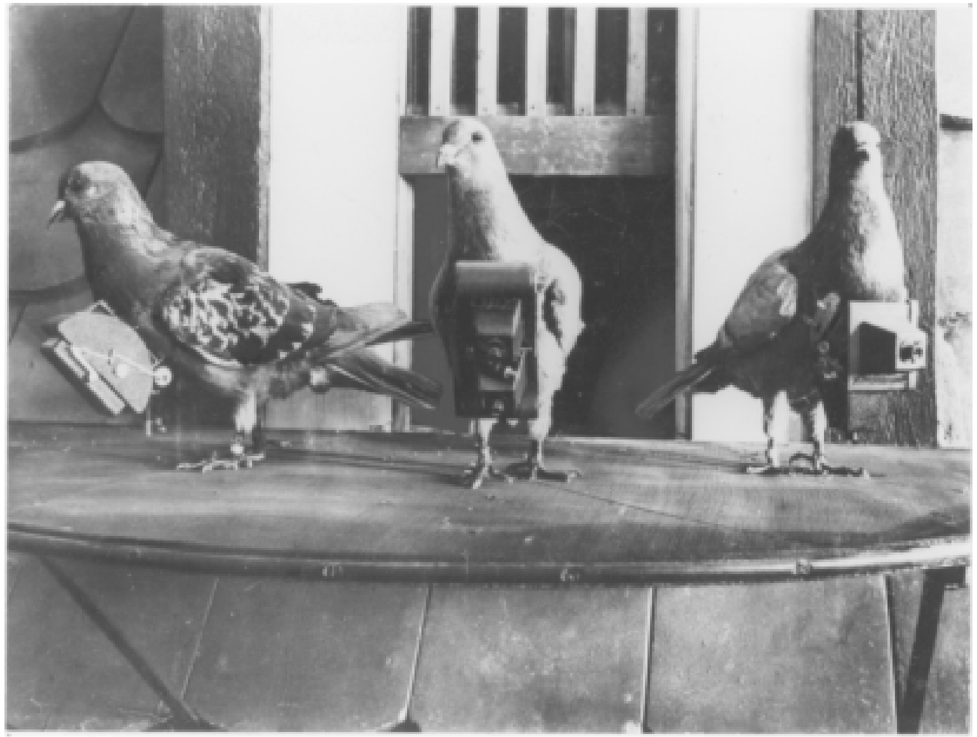
The amount of energy reflected by an area on the ground depends on the amount of solar energy illuminating the area, which in turn depends on the *angle of incidence*: the angle between the path of the incoming energy and a line perpendicular to the ground surface.

Specifically, the energy received at each angle $E(\theta)$ varies as the cosine of the angle of incidence (θ): $E(\theta) = Eo \times \cos \theta$, where Eo is the amount of incoming energy.



Illumination differences can arise from differing incidence angles (θ) as for A and B, or from shadowing (C).

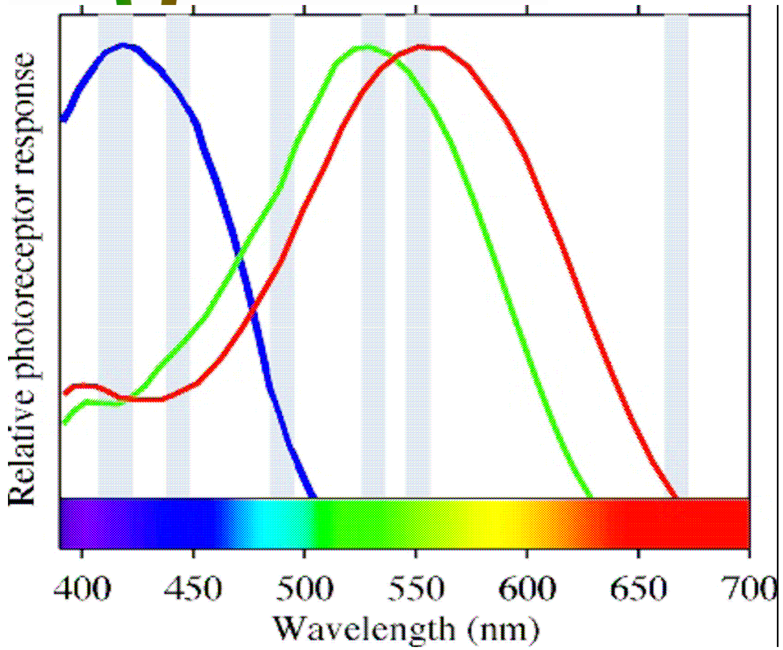
Imaging spectroradiometers



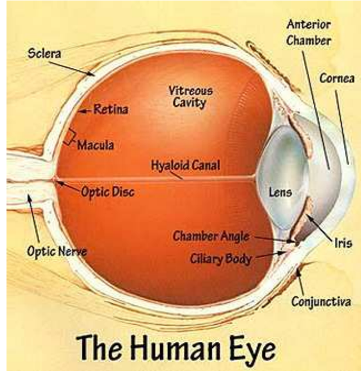
•Introduction

The human eye has three sensors ((Rho), (Gamma), (Beta)) which are sensitive in three broad spectral bands centred around 580 nm, 540 nm and 450 nm respectively.

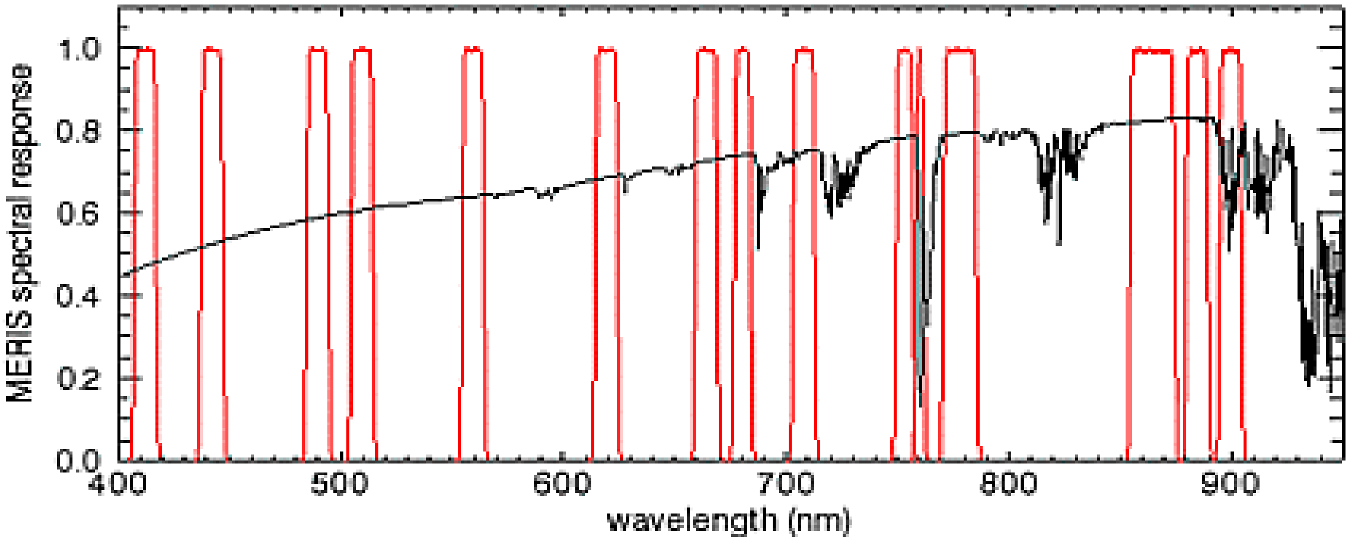
Our eye can detect visual light from 400 nm (blue) to 700 nm (red). Light within this range will excite one or more of the three sensors. Our perception of colour is determined by the combination of the proportional excitation of the three sensors.



human color vision



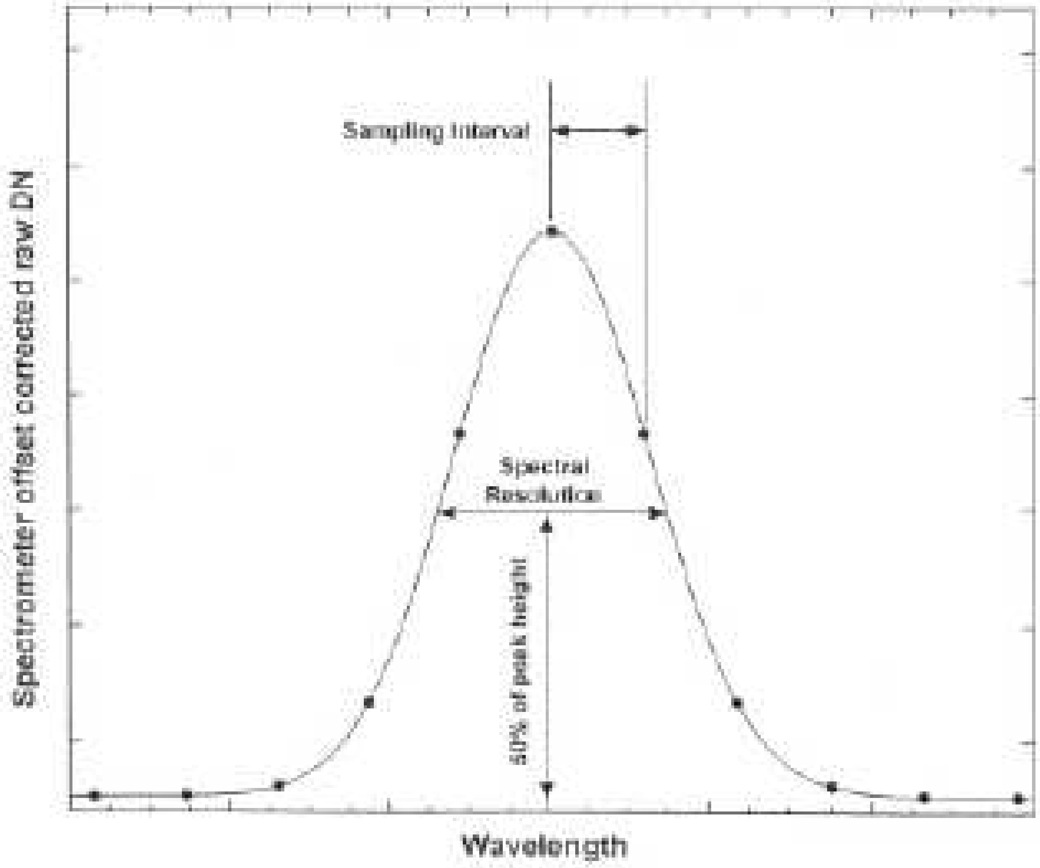
Response of the three cone classes (short, middle, and long) in the human eye to different wavelengths of light (scaled to the same range, Livingstone 2002).



Imaging spectroradiometers have often more than hundred sensors which are sensitive in narrow spectral bands and can detect not only the visual light (400-700 nm) but also near-infrared (700-1000 nm) and short wave infrared radiation (1000-2500 nm).

The **spectral sampling interval** is the spacing between two sample points in the spectrum and is independent of the **spectral resolution** of a sensor. The spectral resolution is defined as the Full Width at Half Maximum (FWHM) of a sensor's response to a monochromatic source.

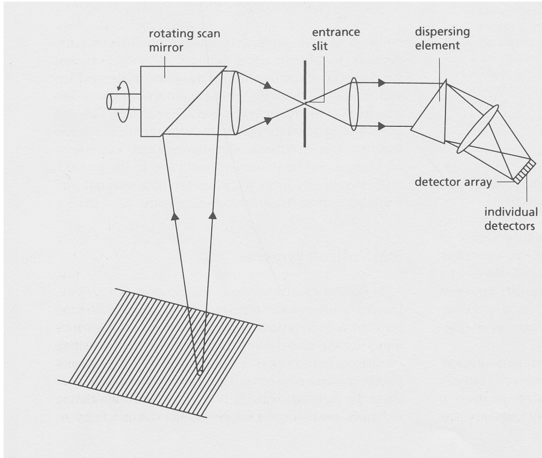
The Full Width at Half Maximum (FWHM) of a sensor is defined as the full width at 50% of the peak height of the spectral response of the sensor to a monochromatic source. The FWHM is the definition of spectral resolution we use in the HyperTeach Syllabi.



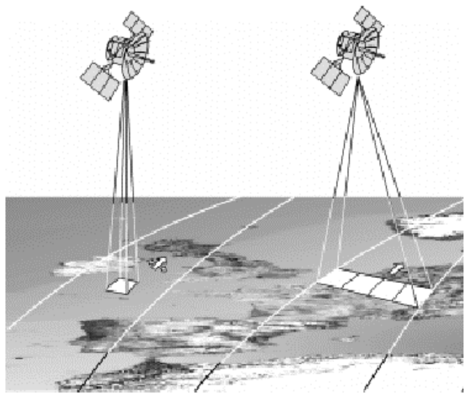
Sampling Interval
Spectral
Resolution
50% of peak height
Spectrometer offset corrected raw DN
Wavelength

•An imaging spectrometer consists of:

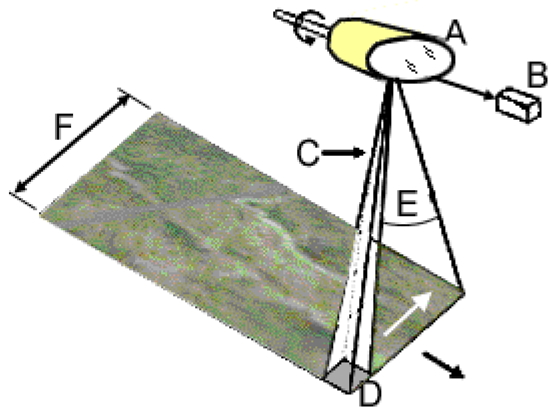
A prism or grating to disperse the incoming light into different wavelengths



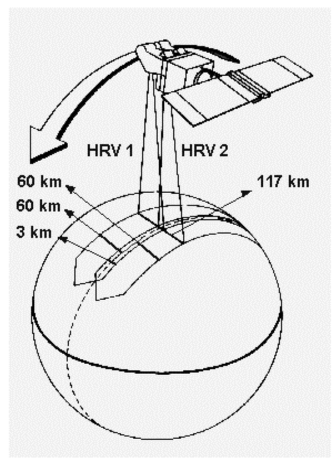
A spatial scanner system: 1-dimensional (**whiskbroom**) or 2-dimensional (**pushbroom**) sensor array.



A *whiskbroom* sensor registers the reflected solar radiance of one ground cell in the different wavelengths and scans the landscape below from side to side using rotating mirrors.



A *pushbroom* sensor does not use scanning mirrors and registers the reflected solar radiance of the landscape below for the entire swath at once in the different wavelengths using a 2-dimensional array. (SNR, calibration!)



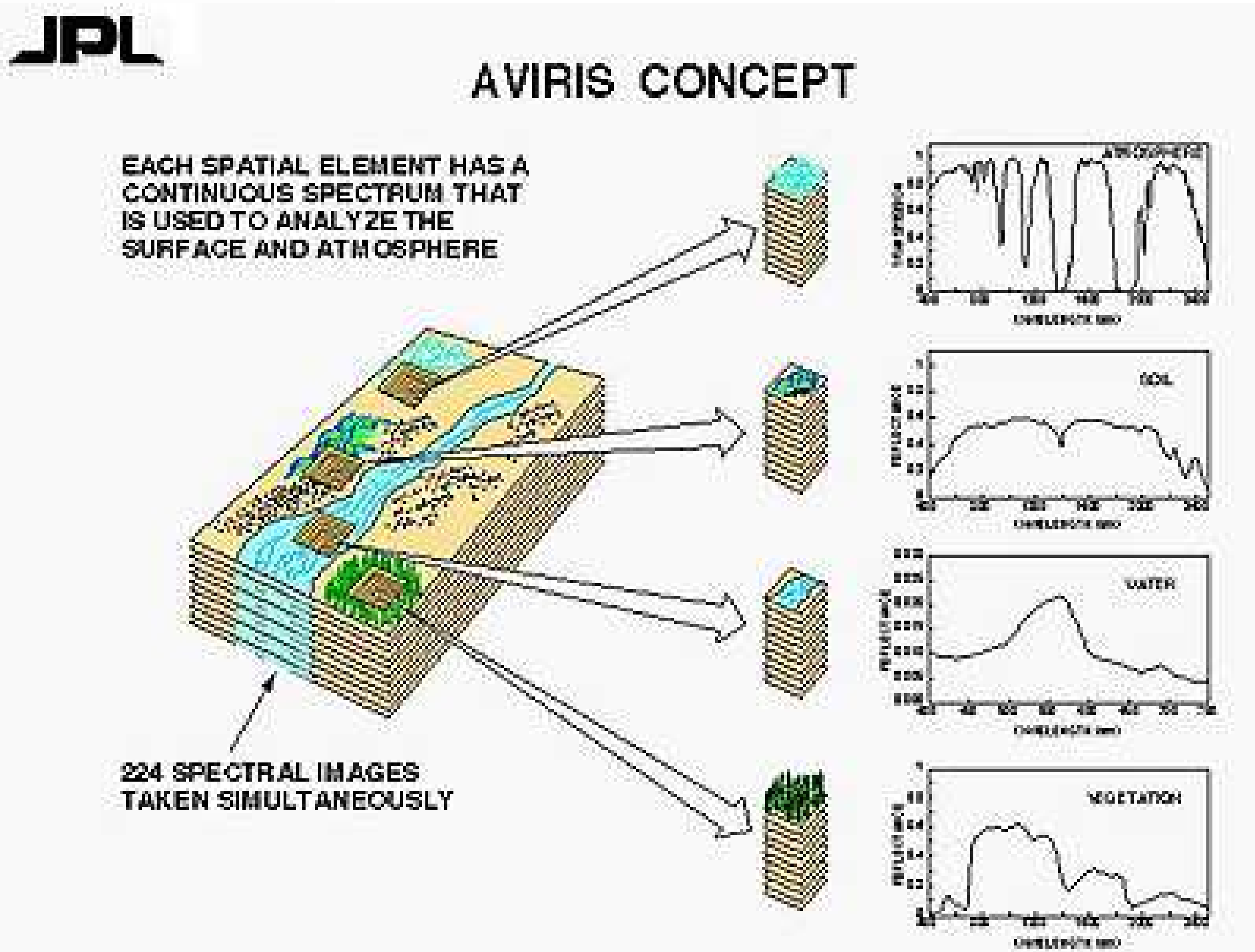
HyperTeach
Training in Imaging Spectroscopy

• Airborne sensors

Scanning Imaging Spectroradiometer (SIS) constructed in the early 1970s for NASA.

Airborne Imaging Spectrometer (AIS) developed by NASA, operational from 1983 onward.

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), the successor of the AIS sensors, operated by NASA since 1987until now.


JPL
AVIRIS CONCEPT
EACH SPATIAL ELEMENT HAS A CONTINUOUS SPECTRUM THAT IS USED TO ANALYZE THE SURFACE AND ATMOSPHERE
224 SPECTRAL IMAGES TAKEN SIMULTANEOUSLY
ATMOSPHERE
SOIL
WATER
VEGETATION

•Nowadays: around 80 instruments commercially available worldwide.

–*Compact Airborne Spectrographic Imager* (CASI), by ITRES Research Ltd

–Geophysical Environmental Research Corporation (GER) developed the GERIS, the *Digital Airborne Imaging Spectrometer* (DAIS) and the Environmental Protection Systems (EPS).

– *Hyperspectral Mapper* (HyMAP) constructed by Integrated Spectronics is operated by HyVISTA.

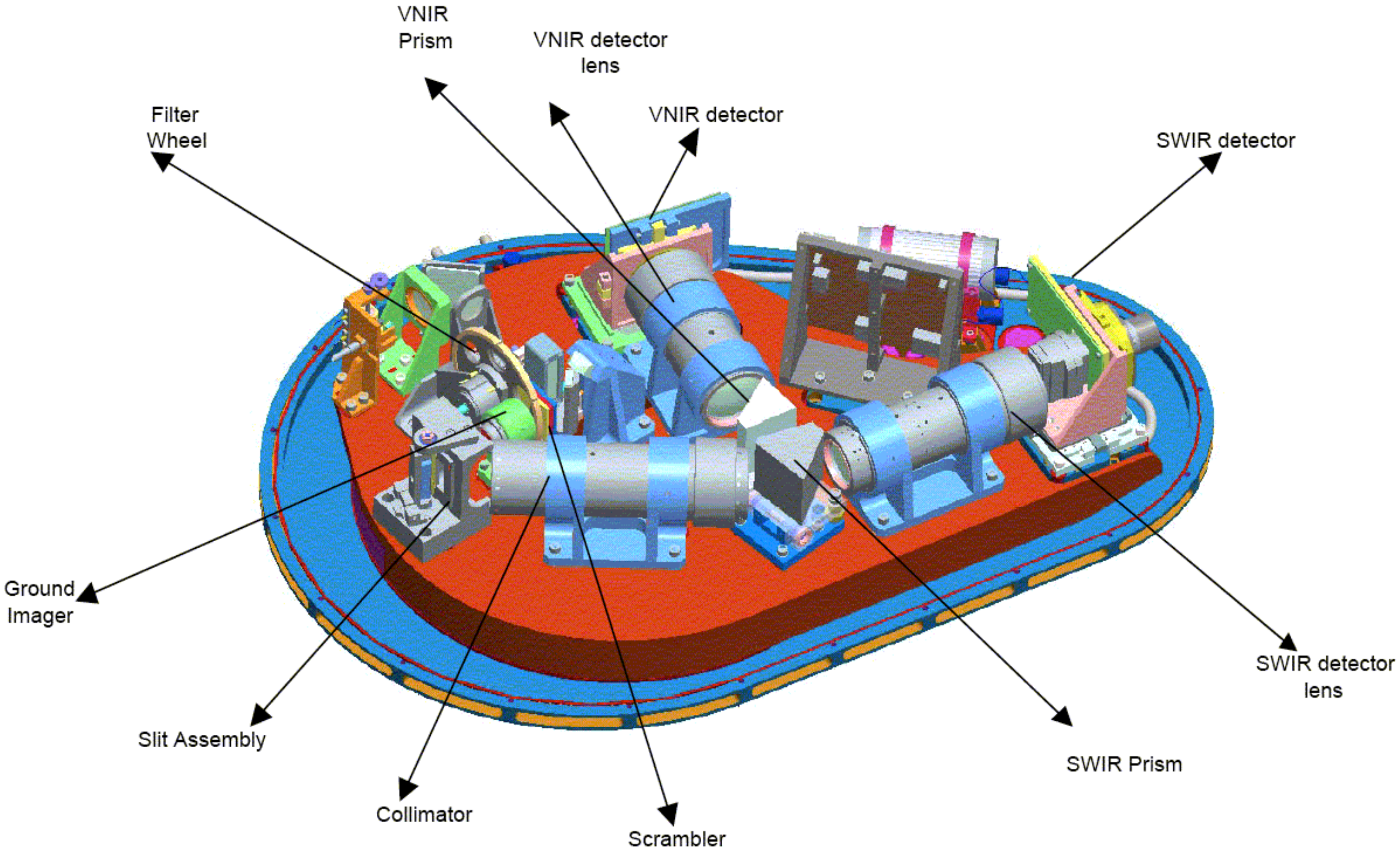
–*Airborne Imaging Spectrometer* AISA by SPECIM.

–*The Reflective Optics System Imaging Spectrometer* (ROSIS) developed by Dornier Satellite Systems, GKSS Research Centre and the German Aerospace Center.

– HYSPEX (Norsk Elektro Optic).

• Soon:

–*Airborne Reflective Emissive Spectrometer* (ARES) and the *Airborne Prism EXperiment* (APEX). Available in 2011-2012.


VNIR Prism
VNIR detector lens
VNIR detector
Filter Wheel
SWIR detector
Ground Imager
SWIR detector lens
Slit Assembly
SWIR Prism
Collimator
Scrambler

The APEX sensor

Airborne pushbroom imaging spectrometer under development by a Swiss-Belgian consortium on behalf of the European Space Agency (ESA).

Intended as a simulator, calibration and validation device for future spaceborne imaging spectrometers.

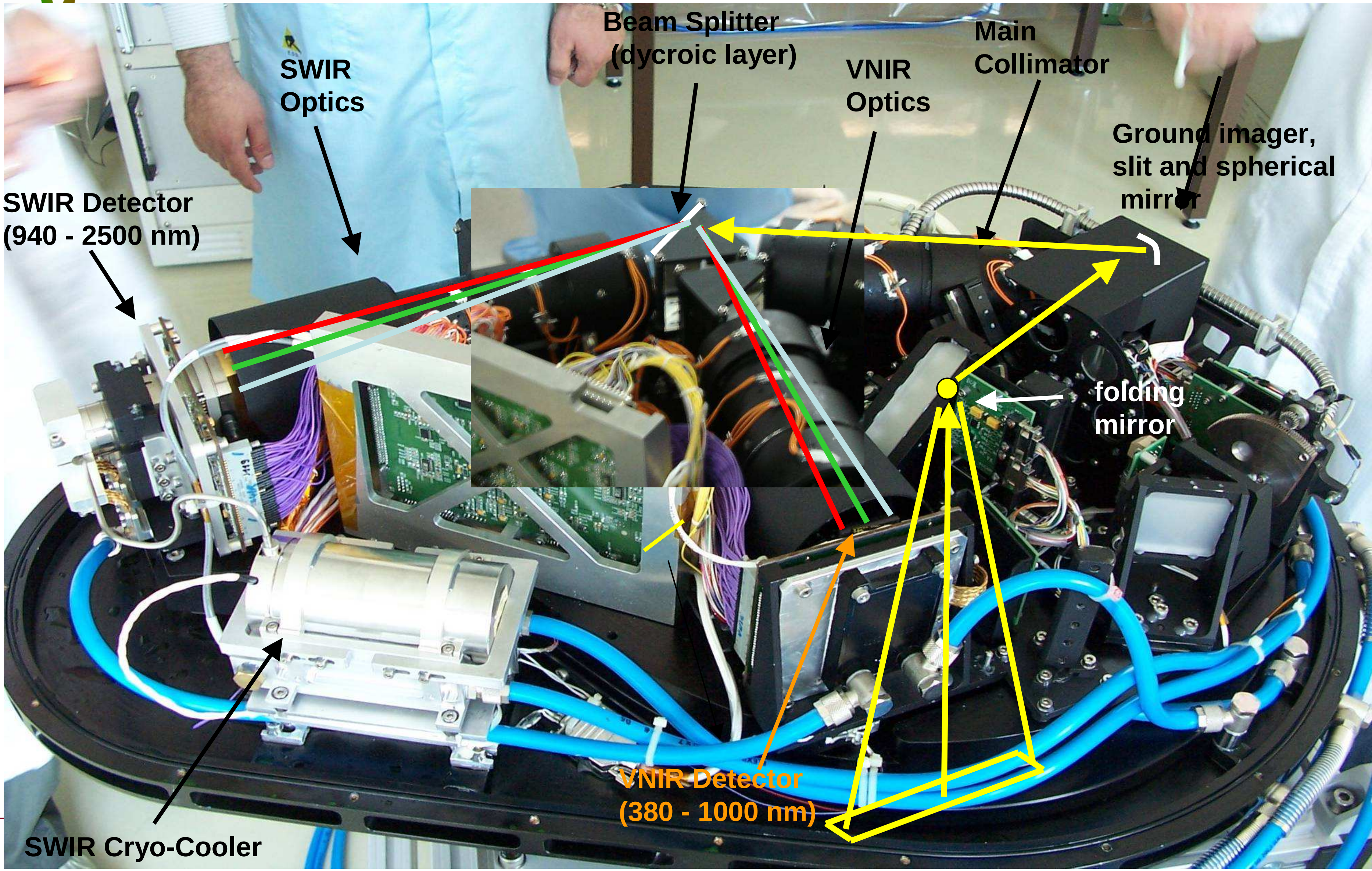
Advanced scientific instrument for the European remote sensing community,

- approximately 300 spectral bands between 380 nm and 2500 nm.
- 1000 pixels across track
- field-of-View of 28 degrees.
- spectral sampling interval is less than 10 nm. (less than 5 nm in the 560-780 nm range).

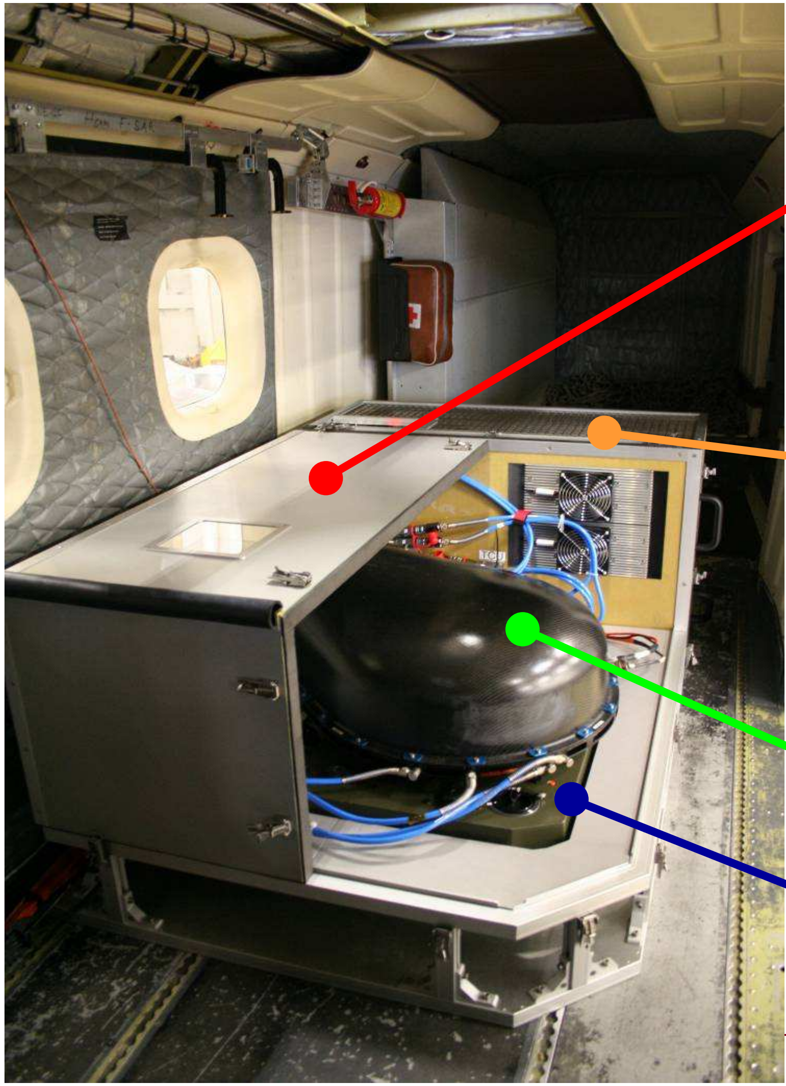
APEX Performance

	VNIR	SWIR
Spectral Performance	**VNIR**	**SWIR**
Spectral Range	380.5 – 971.7 nm	941.2 – 2501.5 nm
Spectral Bands	Up to 334 (default: 114) (number of VNIR spectral rows programmable via binning pattern upload)	198
Spectral Sampling Interval	0.5 ÷ 8 nm (default: 11 ÷ 8 nm)	5 ÷ 10 nm
Spectral Resolution (FWHM)	0.6 ÷ 6.3 nm	6.2 ÷ 11 nm
Spatial Performance		
Spatial Pixels (acrosstrack)	1000	
FOV	28°	
IFOV	0.028° (ca 0.5 mrad)	
Spatial Sampling Interval (across track)	1.75 m @ 3500 m AGL	
Sensor Characteristics		
Type	CCD	CMOS
Dynamic Range	14 bit encoding	13 bit encoding
Pixel Size	22.5 µm x 22.5 µm	30 µm x 30 µm
Smile	Average, less than	0.35 pixel
Keystone (Frown)	Average, less than	0.35 pixel
Co-Registration	Average, less than	0.55 pixel
Other Information		
Data Capacity	500 GB on SSD	
Data Transfer	Spectral frames	30 MB/s via Optical Link
	Housekeeping Data	20 kB/s via Serial Cable
Data rate for default configuration	0.4 GB/km (1250 km max)	

APEX Optical Sub-Unit



APEX Aircraft Installation



Environmental Thermal Control (ETC) Box

Thermal Control Unit (TCU)

Optical Subsystem Unit (OSU)

Stabilising Platform (Leica PAV30)

APEX Aircraft Installation

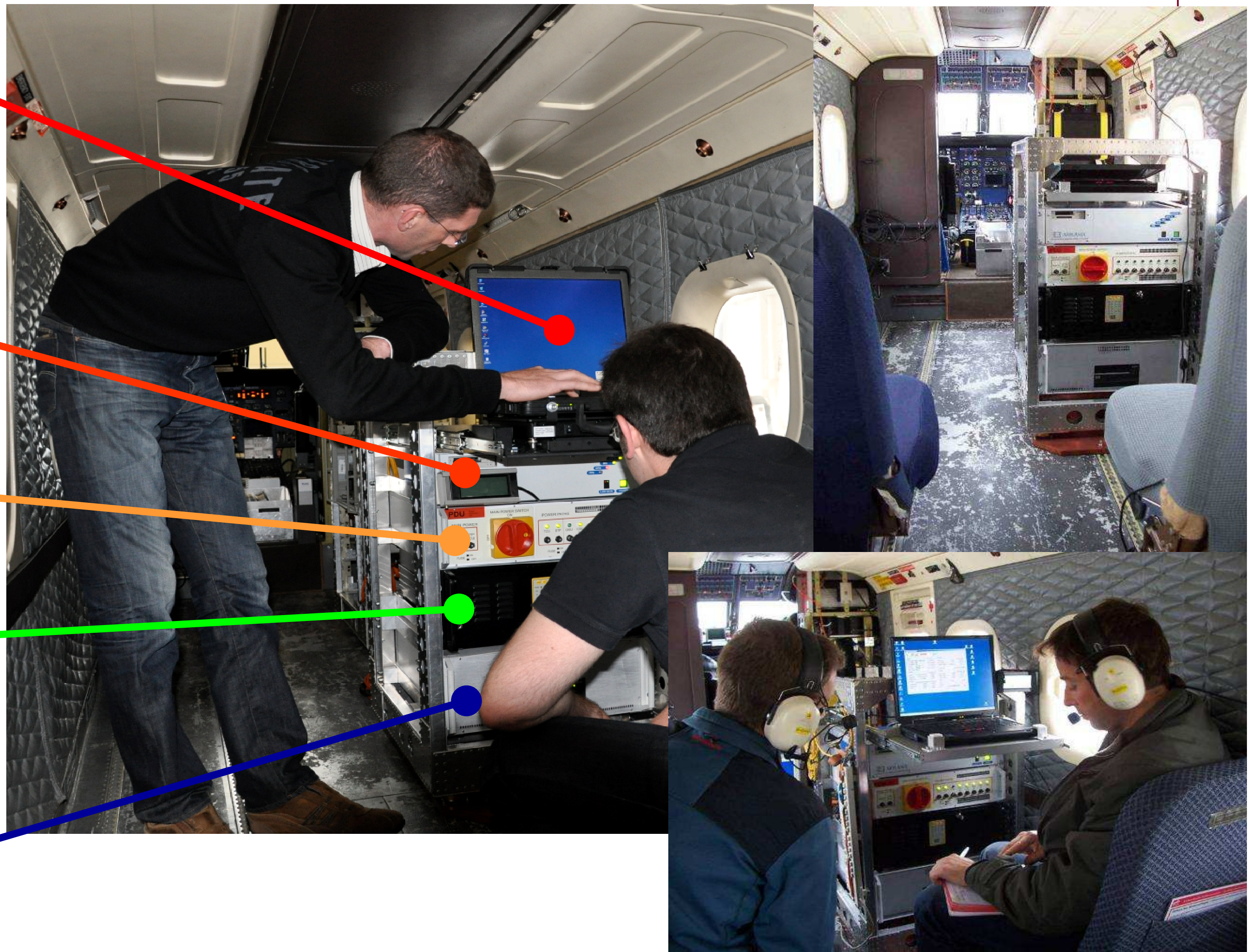
Operator’s Interface
Flight Management System
(FMS, TrackAir)

Navigation Sub-System
(Applanix POS/AV)

Power Distribution Unit

Main Control
Computer (CSU)

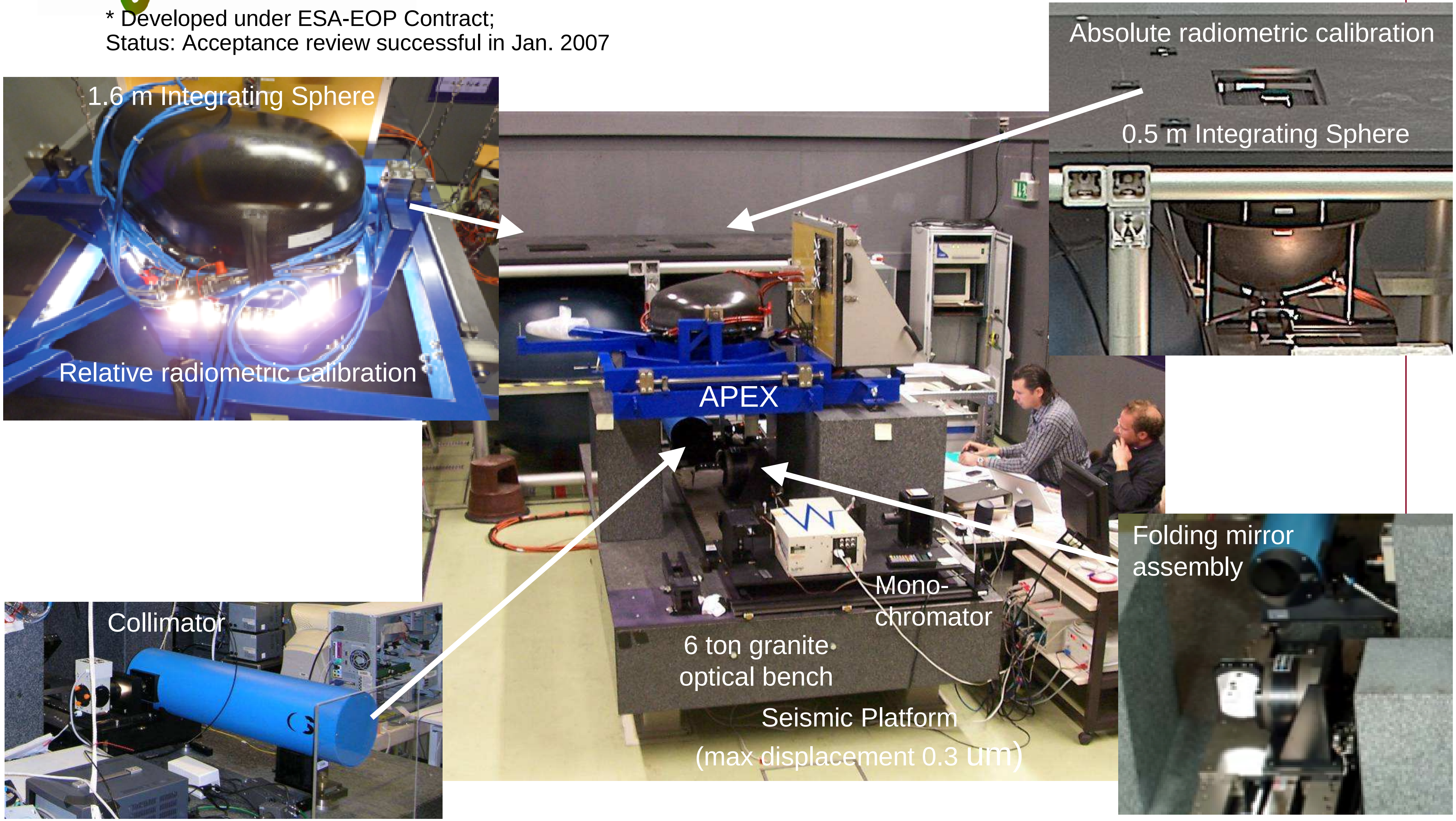
Storage Unit
(SSD and tape)

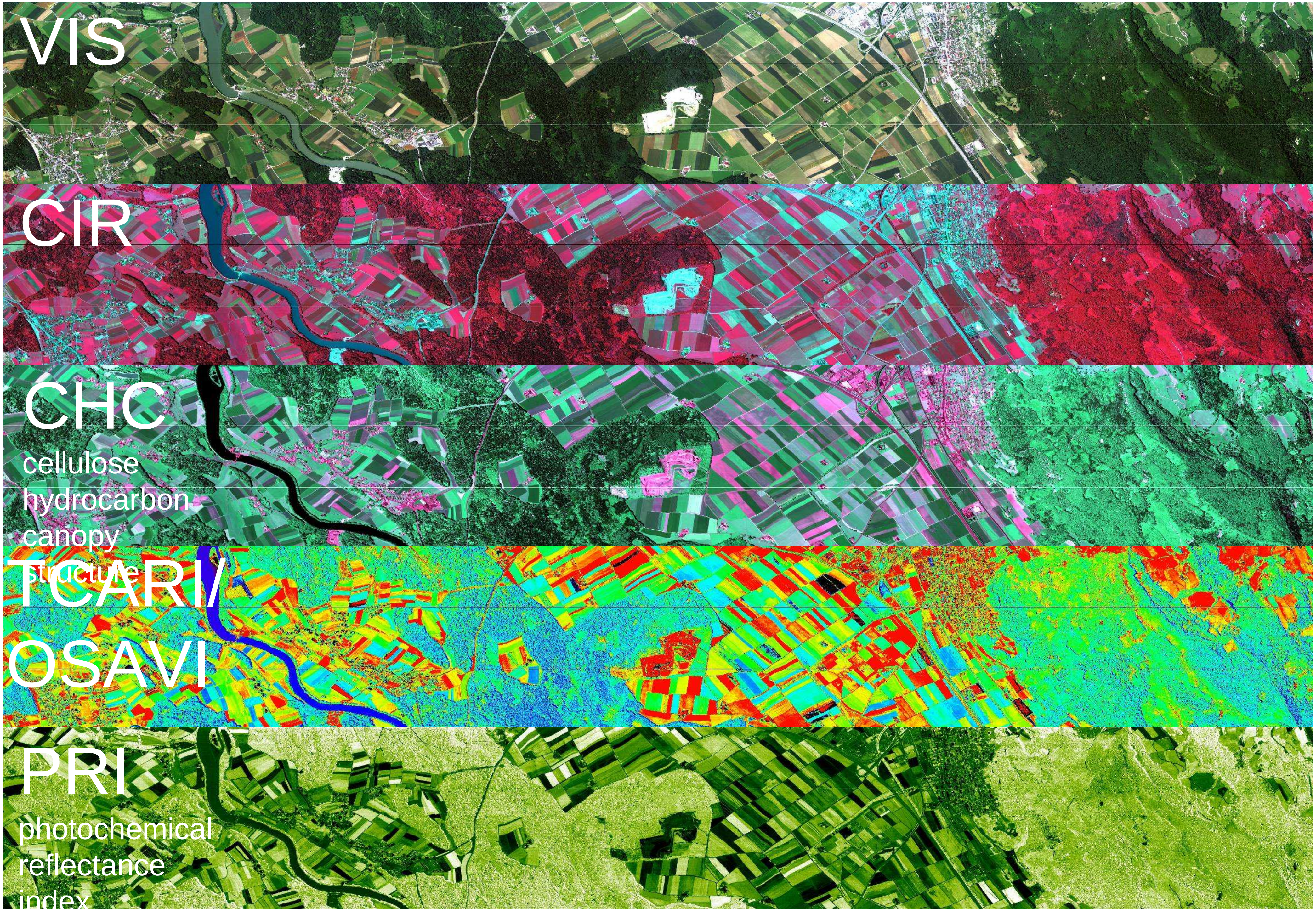


HyperTeach
Training in Imaging Spectroscopy

The Calibration Home Base @ DLR München*

* Developed under ESA-EOP Contract;
Status: Acceptance review successful in Jan. 2007




VIS
CIR
ĆHC
cellulose
hydrocarbon
canopy
structure
TCARI/
OSAVI
PRI
photochemical
reflectance
index

- Spaceborne sensors

Dominated by systems based on multispectral radiometers with a limited number of bands

HyperTeach
Training in Imaging Spectroscopy

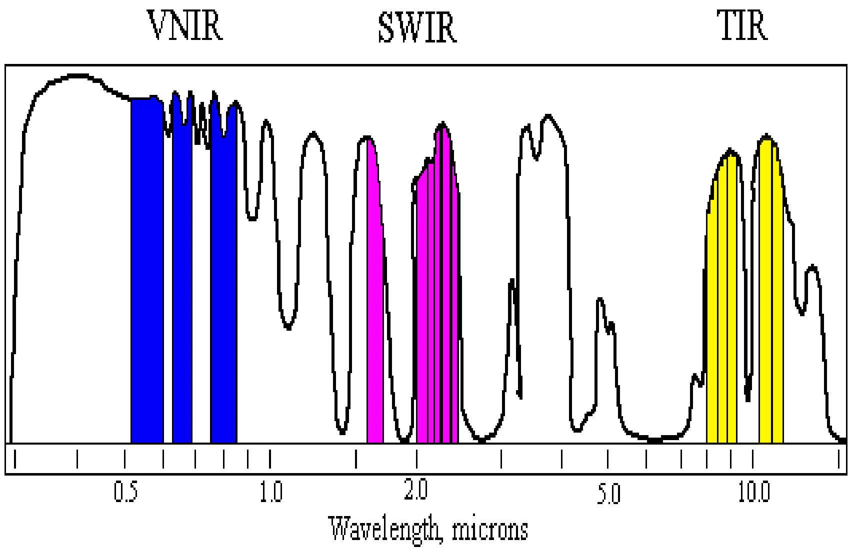
Advanced Spaceborne Thermal Emission and Reflection Radiometer: ASTER

ASTER is a cooperative effort between NASA and the Japanese Ministry of Economy Trade and Industry (METI).

The performances of the ASTER channels makes it a good spaceborne tool for geology:
- good spatial resolution in the VNIR range (15 m)
- stereographic capabilities
- 6 spectral bands in the SWIR range, allow the identification of carbonates and good discrimination between alteration mineral, including clays
- 5 bands in the TIR range allow to map SiO_2 content.

ASTER

Spectral bands



Key Features: high spatial resolution, multi-spectral, stereo coverage

Three Instruments:

Instrument Name	Bands	Resolution
Visible and Near Infrared (VNIR)	1-3 (3)	15-meters
Short-wave Infrared (SWIR)	4-9 (6)	30-meters
Thermal Infrared (TIR)	10-14 (5)	90-meters

The first real spaceborne hyperspectral instrument: HYPERION (after 2012 less acquisitions)

On board of NASA’s EO1 satellite

High resolution hyperspectral imager
- 220 spectral bands (from 0.4 to 2.5 µm)
- 30 meter spatial resolution.
- 7.5 km by 100 km land area per image

The focus of the HYPERION instrument is to provide high quality calibrated data that can support evaluation of hyperspectral technology for Earth observing missions.

MEdium Resolution Imaging Spectrometer Instrument MERIS

MERIS on ENVISAT (ESA) is a programmable, medium spectral resolution pushbroom imaging spectrometer

Technical characteristics:
•Accuracy Ocean colour bands typical S:N = 1700
•Spatial Resolution Ocean: 1040 m x 1200 m, Land & coast: 260 m x 300 m
•Swath Width 1150 km, global coverage every 3 days
•Spectral range VIS-NIR: 15 bands selectable across range: 390 nm to 1040 nm (bandwidth programmable between 2.5 and 30 nm)

Applications:
•Ocean and Coast (Ocean Colour/Biology)
•Land (Vegetation)
•Atmosphere (Clouds, Precipitation)

HyperTeach
Training in Imaging Spectroscopy

CHRIS/PROBA

CHRIS (the Compact High Resolution Imaging Spectrometer) is an *imaging spectrometer* that was launched in October 2001 on board a novel space platform called PROBA (Project for On Board Autonomy)

Spatial sampling interval **18 m on ground at nadir**

Image area **14 km X 14 km (748 X 748 pixels)**

Number of images **Nominal is 5 downloads at different view angles (nadir, +/- 55 degrees, +/-36 degrees)**

Data per image (for a 14 X 14 km^2) **131 Mbits**

Spectral range **410 nm to 1050 nm**

Number of spectral bands **19 bands at a spatial resolution of 18 m, 63 at 36 m**

Spectral resolution **1.3 nm @ 410nm to 12 nm @ 1050nm**

Planned HSI missions (1/3)

- PRISMA - PRecursore IperSpettrale della Missione Applicativa (Italian Space Agency) (launch 2012)
  - Global coverage
  - < 7 days re-look time
  - 30 km swath
  - Spatial GSD < 30 m
  - Spectral resolution: < 10 nm
  - Spectral ranges (contiguous)
    - VNIR: 400-1010 nm
    - SWIR: 920-2505 nm

Planned HSI missions (2/3)

- ENMAP (German Space Agency) (launch 2014)
  - **Swath width 30 km**
  - **Ground sampling distance (GSD) 30 m x 30 m (at nadir; sea level)**
  - **VNIR:**
    - Nominal band width: 6.5 nm
    - Range: 423.7 nm – 994.4 nm
    - Total number of bands: 89
  - **SWIR:**
    - Nominal band width: 10 nm
    - Range: 905 nm – 2446 nm
    - Total number of bands: 155
- ENMAP2 (launch 2017)

Planned HSI missions (3/3)

- HYSPIRI (NASA JPL) (launch approx. 2016)
  - global coverage 19 days revisit time
  - 60 m spatial resolution
  - Spectral range 380-2500 nm
  - 10 nm channels
  - All land and coastal areas will be downloaded
  - 150 km swath
  - **Free** for everyone!