TITLE OF PRESENTATION

ESA–MOST China Dragon 4 Cooperation

2019 ADVANCED INTERNATIONAL TRAINING COURSE IN LAND REMOTE SENSING

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Hyperspectral Remote Sensing Technology and Applications

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Definition of remote sensing

ASPRS adopted a combined formal definition from *photogrammetry* and *remote sensing* (Colwell, 1997) as:

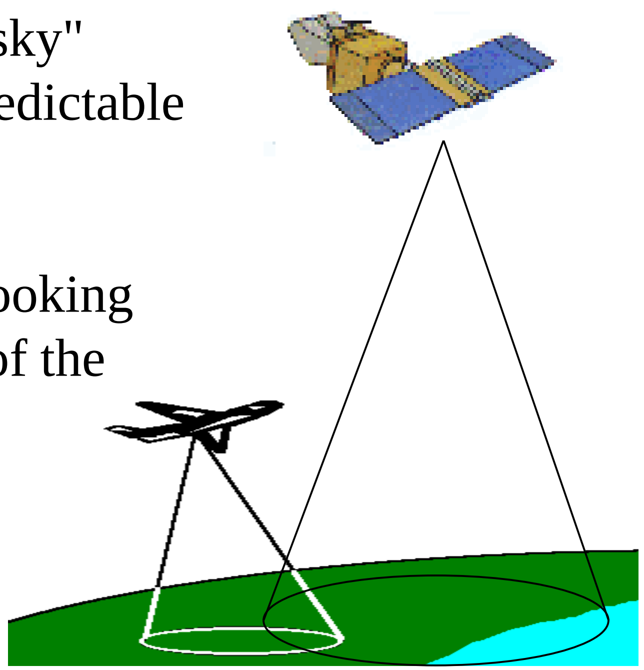
> "the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensor systems".

What is Remote Sensing?

In a more restricted sense, remote sensing usually refers to the technology of acquiring information about the earth's surface (land and ocean) and atmosphere using sensors onboard **airborne** (aircraft, balloons) or **spaceborne** (satellites, space shuttles) platforms.

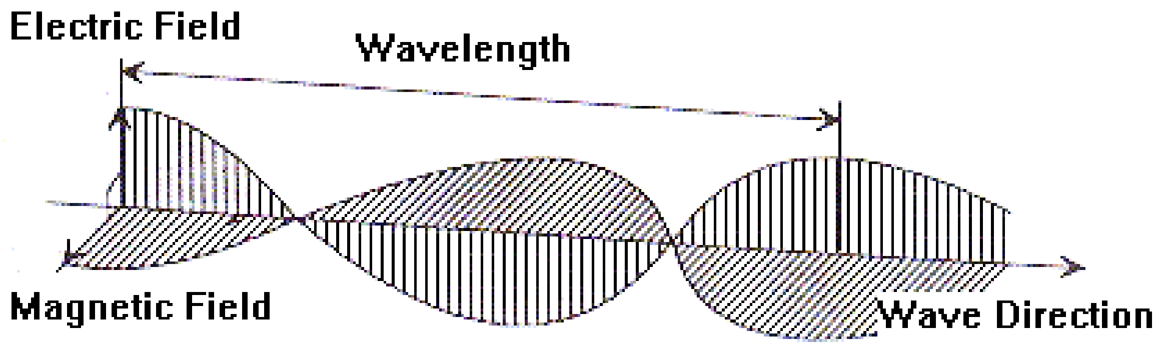
These remote sensing satellites are equipped with sensors looking down to the earth. They are the "eyes in the sky" constantly observing the earth as they go round in predictable orbits.

In airborne remote sensing, downward or sideward looking sensors are mounted on an aircraft to obtain images of the earth's surface.



The Electromagnetic Spectrum

The electromagnetic radiation is normally used as an information carrier in remote sensing. An electromagnetic wave is characterized by a frequency and a wavelength.



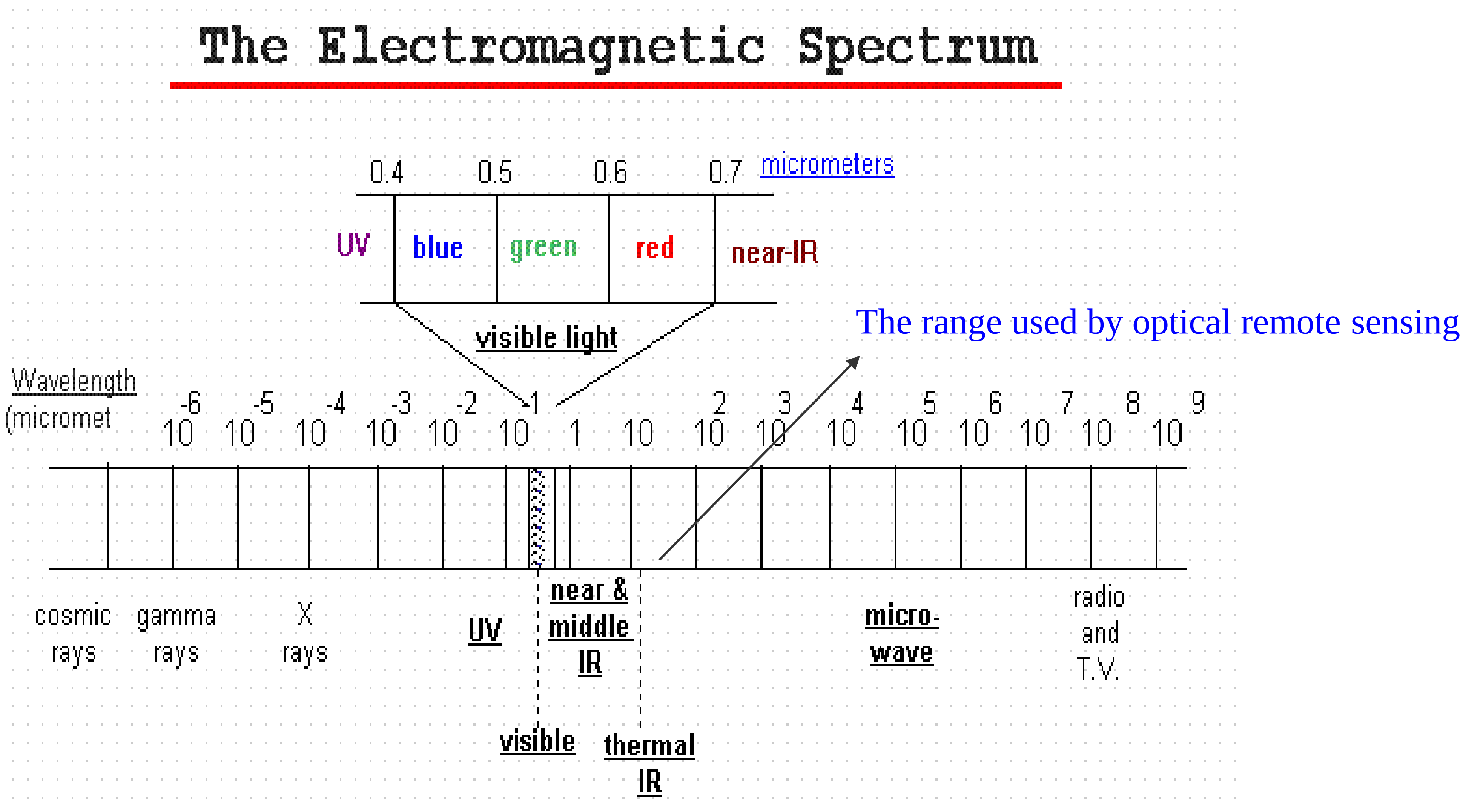
Wave $$v = f\lambda$$

Particle $$E = hf = \frac{hc}{\lambda}$$

E is Energy
f is the period
c is the speed of light
λ is the wavelength
V is the frequency
h is Planck's constant

The Electromagnetic Spectrum

The electromagnetic spectrum can be divided into several wavelength (frequency) regions.



The Electromagnetic Spectrum

Electromagnetic spectral regions for remote sensing :

Optical R.S.

Visible :

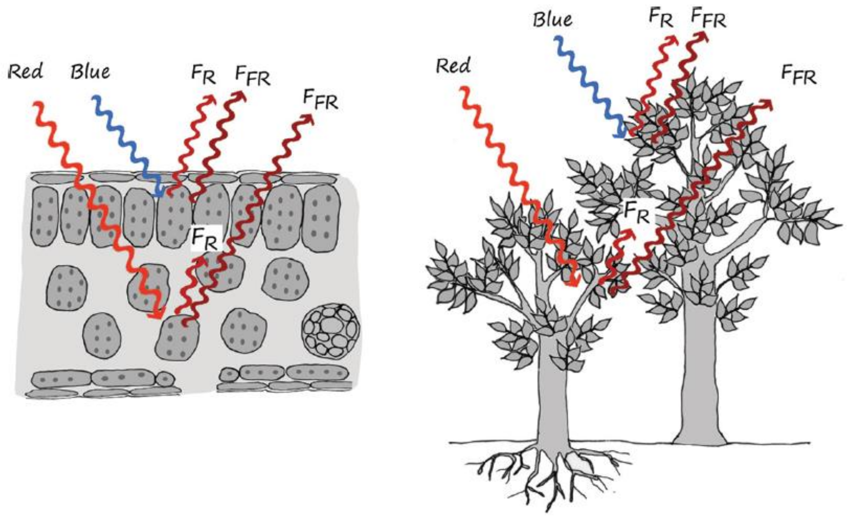
- **Red**: 610 - 700 nm
- **Orange**: 590 - 610 nm
- **Yellow**: 570 - 590 nm
- **Green**: 500 - 570 nm
- **Blue**: 450 - 500 nm
- **Indigo**: 430 - 450 nm
- **Violet**: 400 - 430 nm

Infrared:

- **Near Infrared (NIR)**: 0.7 to 1.5 µm.
- **Short Wavelength Infrared (SWIR)**: 1.5 to 3 µm.
- **Mid Wavelength Infrared (MWIR)**: 3 to 8 µm.
- **Long Wanelength Infrared (LWIR)**: 8 to 15 µm.
- **Far Infrared (FIR)**: longer than 15 µm.

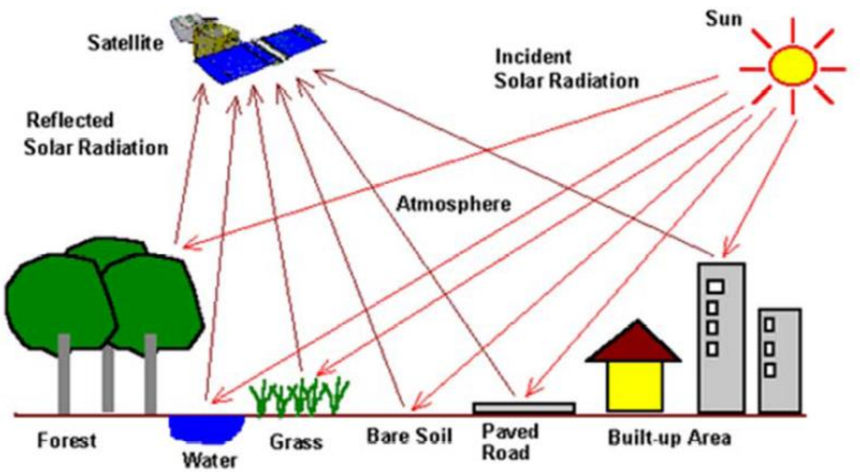
Microwaves: 1 mm to 1 m wavelength.

Interaction of Radiation with Matter



In reflected radiation region, only reflected radiance at view direction is recorded.

How does light interact with matter to create the measurement?



Reflectance :

$$L_\lambda = \frac{\rho_\lambda E_\lambda}{\pi} \; Wm^{-2}sr^{-1}\mu m^{-1}$$

$$\rho_\lambda = \frac{\pi L_\lambda}{E_\lambda}$$

Reflectance curve is a curve which illustrate the variety of object reflectance at different wavelengths. It shows spectral signatures of surface materials.

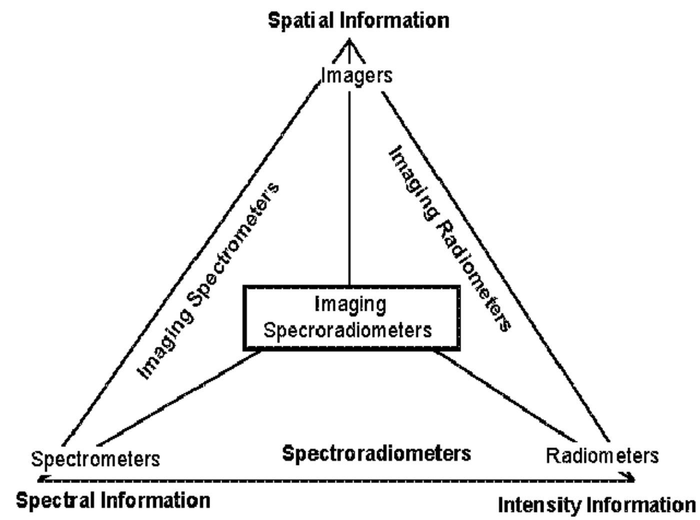
Definition of hyperspectral remote sensing

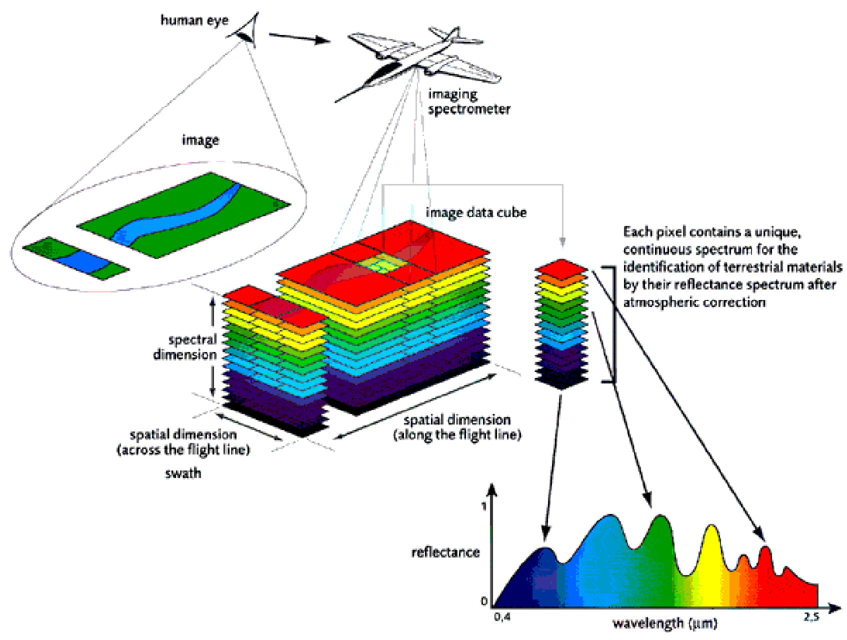
Hyperspectral remote sensing (HRS), or imaging spectroscopy (IS), is a technology that can provide detailed spectral information from every pixel in an image. Whereas HRS refers mostly to remote-sensing means (usually from far distances), the emerging IS technology covers all spatial-spectral domains, from microscopic to telescopic.

In general, being a technology that provides spatial and spectral information simultaneously, HRS-IS improves our understanding of the remote environment. It enables accurate identification of both targets and phenomena as the spectral information is presented on a spatial rather than point (pixel) basis.

Furthermore, it provides a new capability—to quantitatively assess chemical and physical aspects of the pixel(s) in question. The IS-HRS technology is well accepted in the remote-sensing arena as an innovative tool for many applications, such as in geology, ecology, soil, limnology, pedology, plant biology and atmospheric sciences, especially for cases in which other remote-sensing means have failed or are incapable of obtaining additional information.

—Prof. Dr. Eyal Ben-Dor





Definition of hyperspectral remote sensing

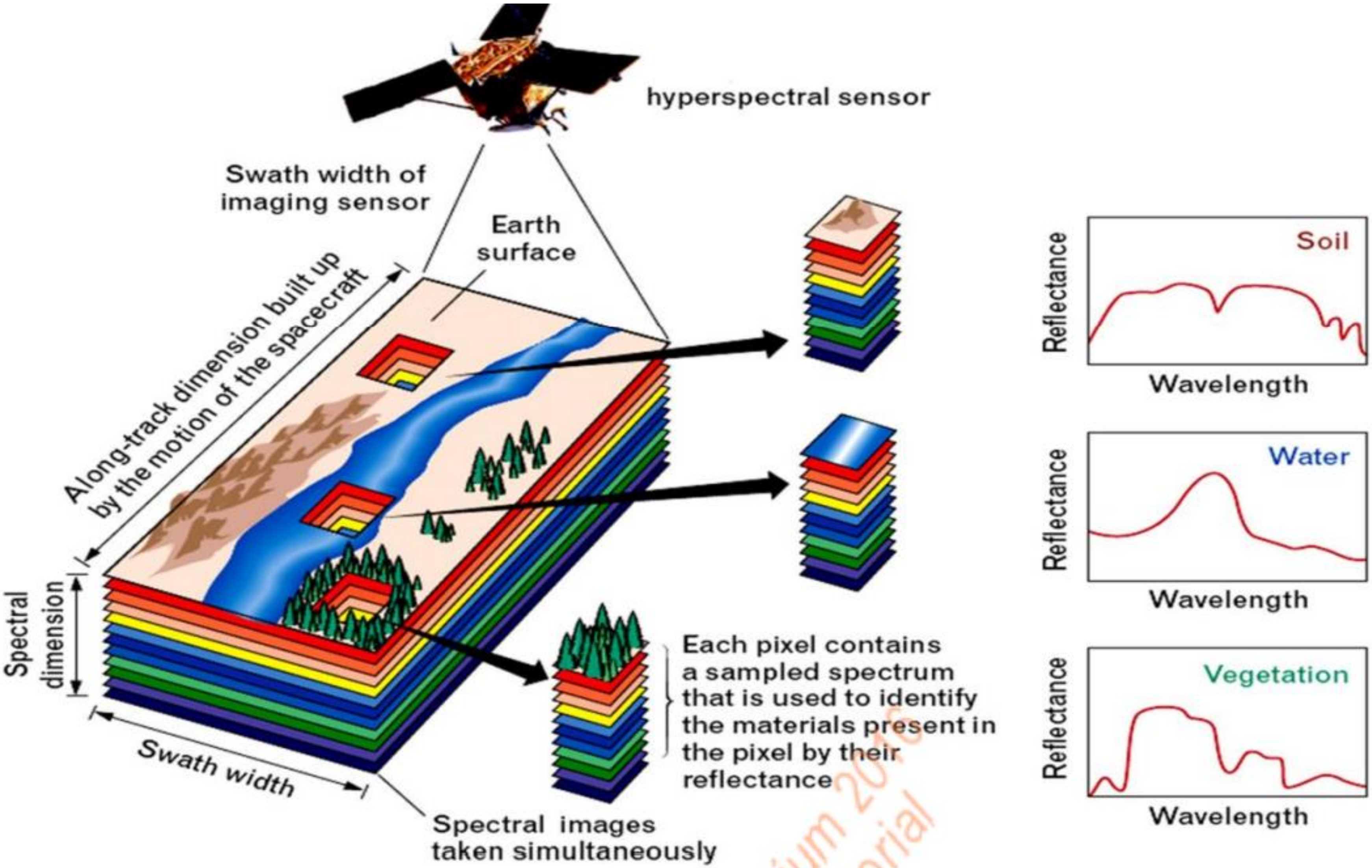
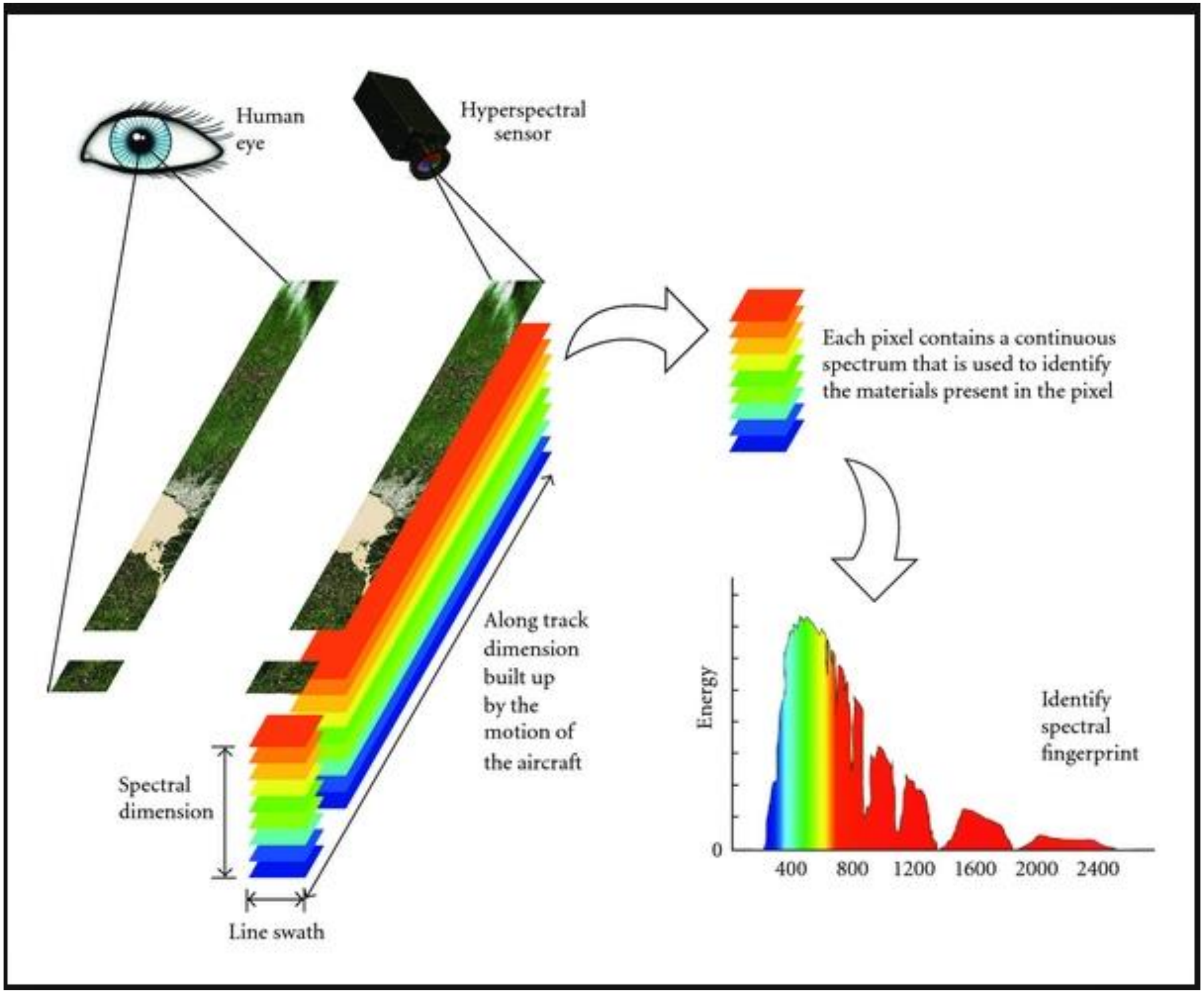


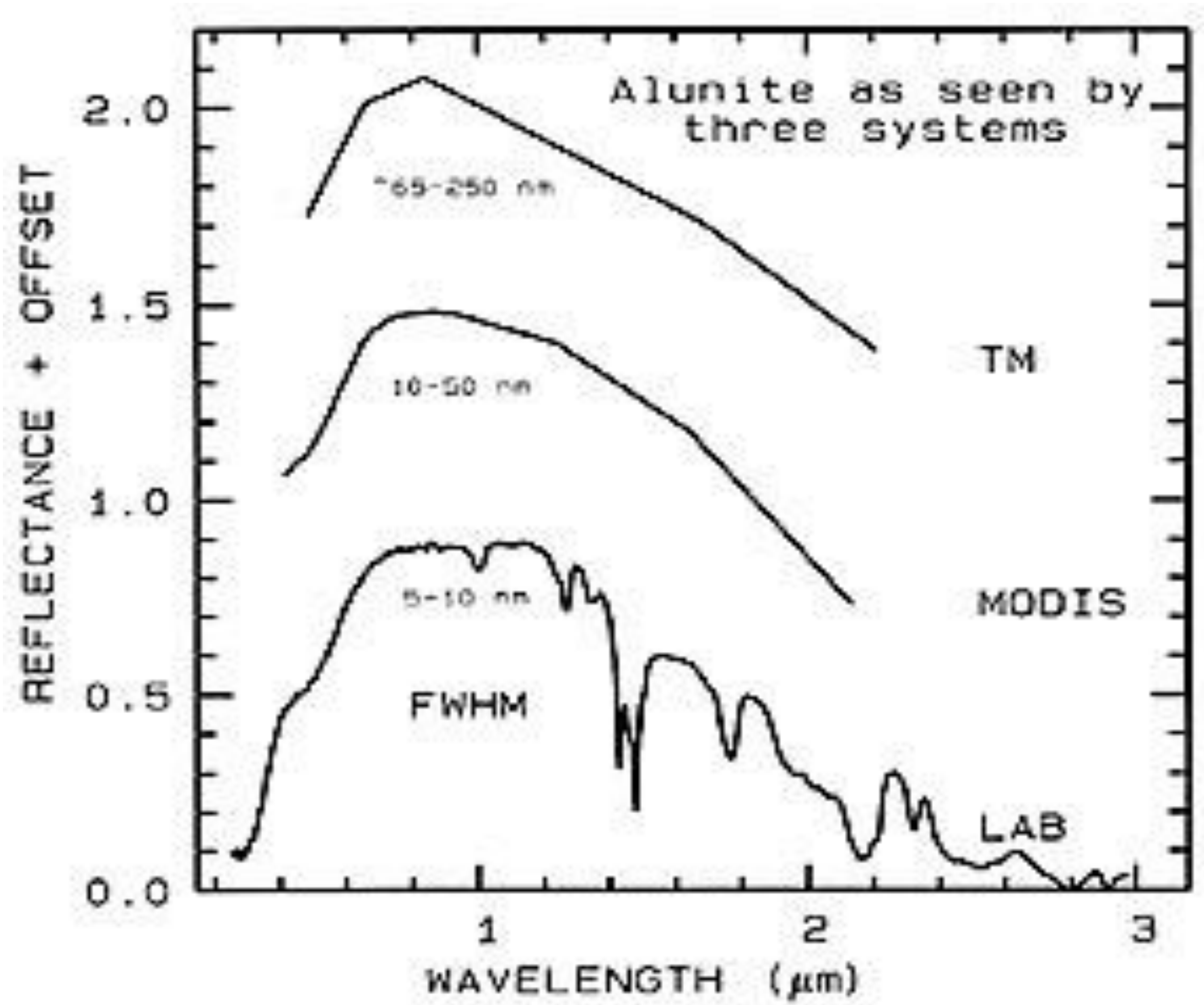
Figure 3. Hyperspectral Remote Sensing (*Source*: NEMO)

Definition of hyperspectral remote sensing

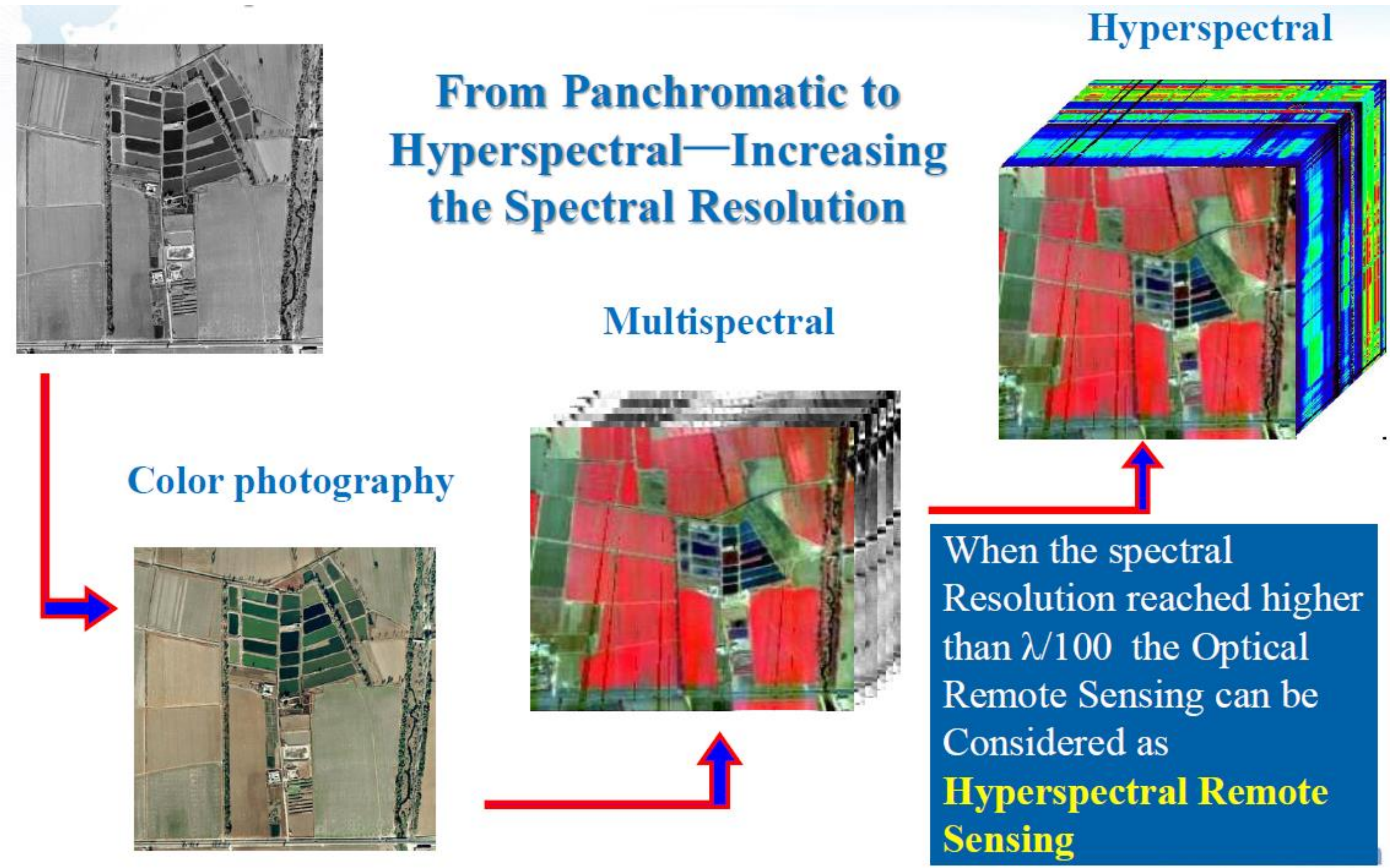
Characteristics of HRS： a combination of image and spectra information



Spectral curves and spectral resolution



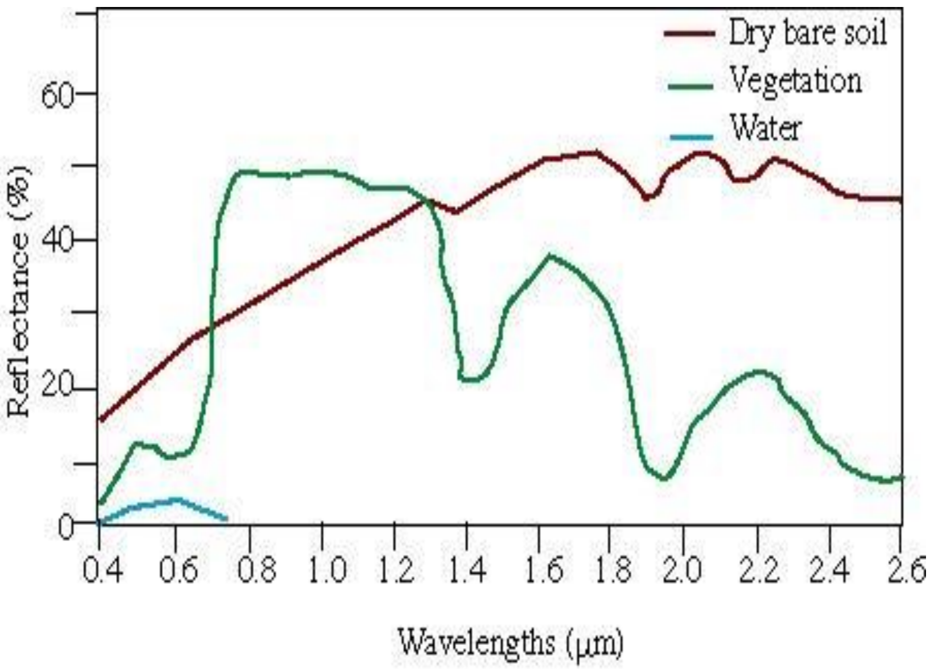
Definition of hyperspectral remote sensing

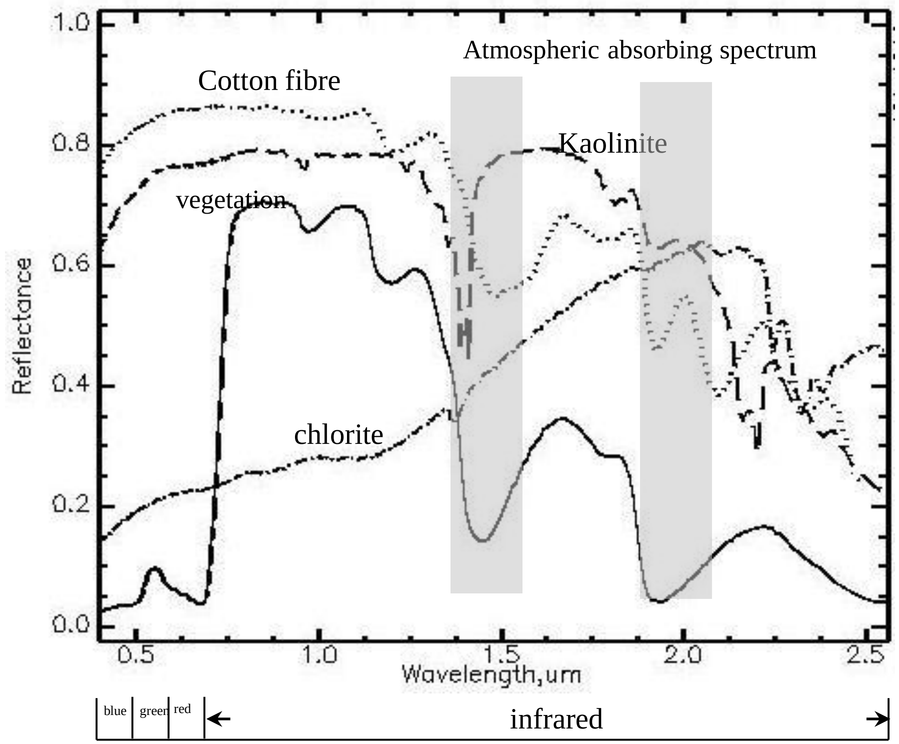


2. Spectral Properties of Earth Materials

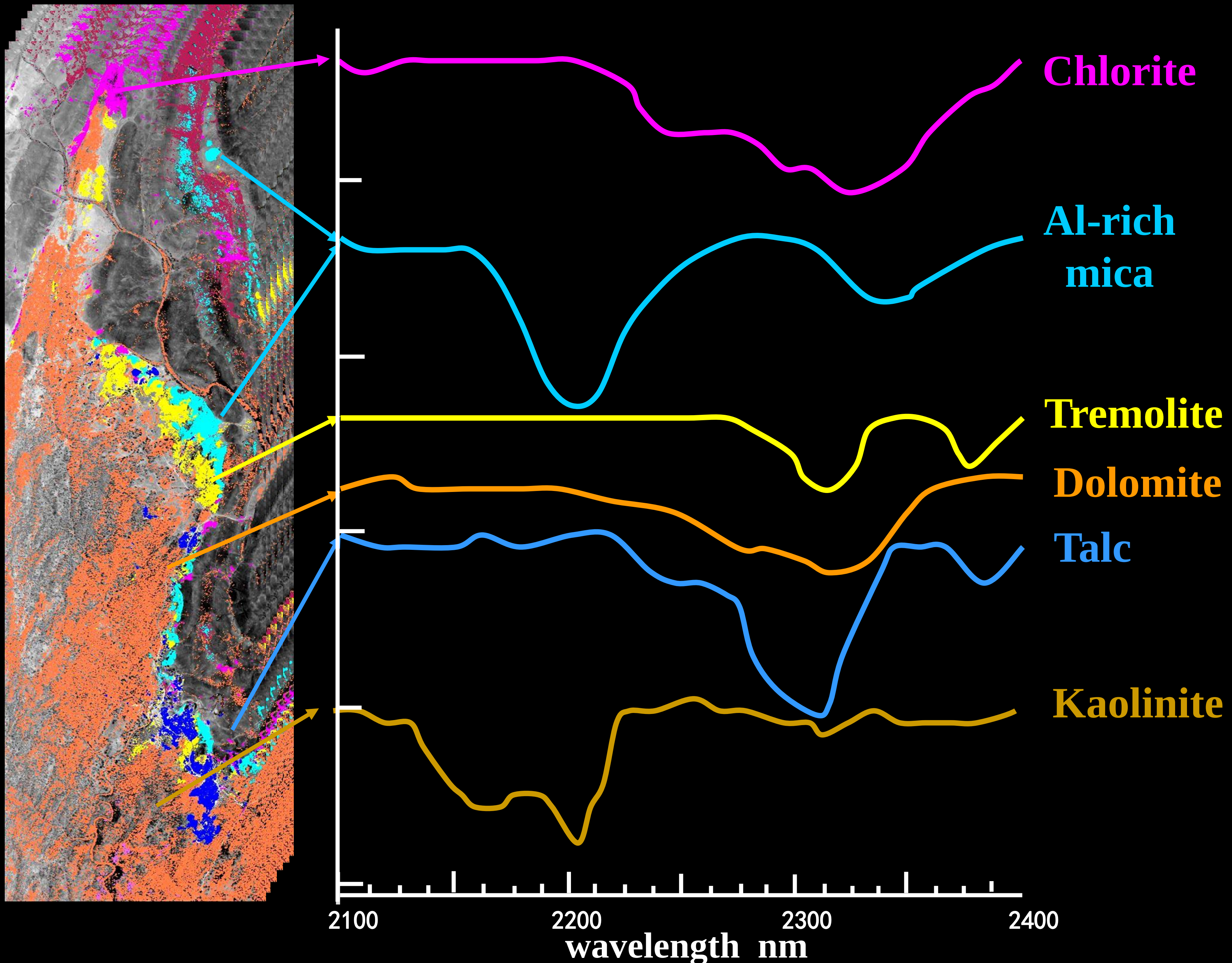
Spectral Features

Typical Reflectance Spectrum



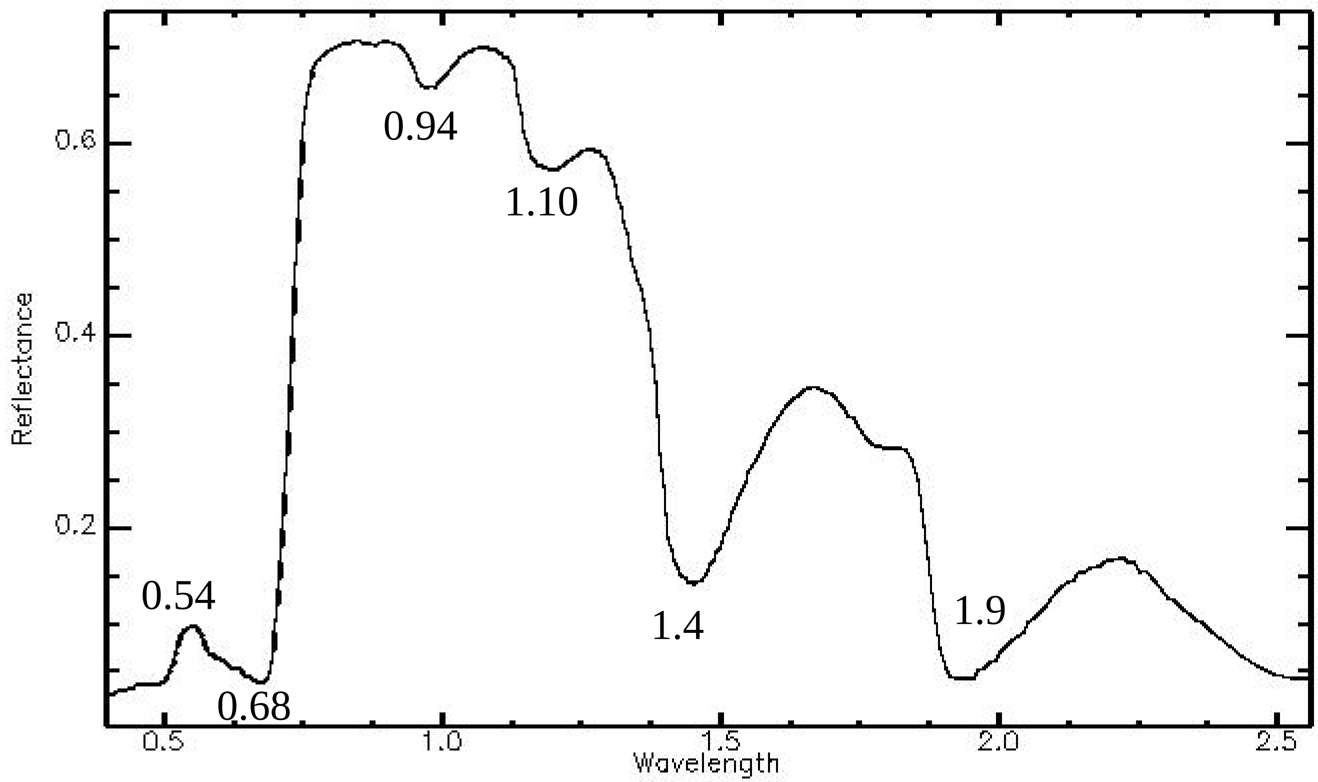


SPECTRAL LIBRARY


Chlorite
Al-rich mica
Tremolite
Dolomite
Talc
Kaolinite
2100
2200
2300
2400
wavelength nm

Spectral Feature

Vegetation is sensitive to optical radiation from the ultraviolet through infrared spectral range and is optimized to absorb solar energy in the visible spectrum to drive the biological process of photosynthesis necessary for plant growth.

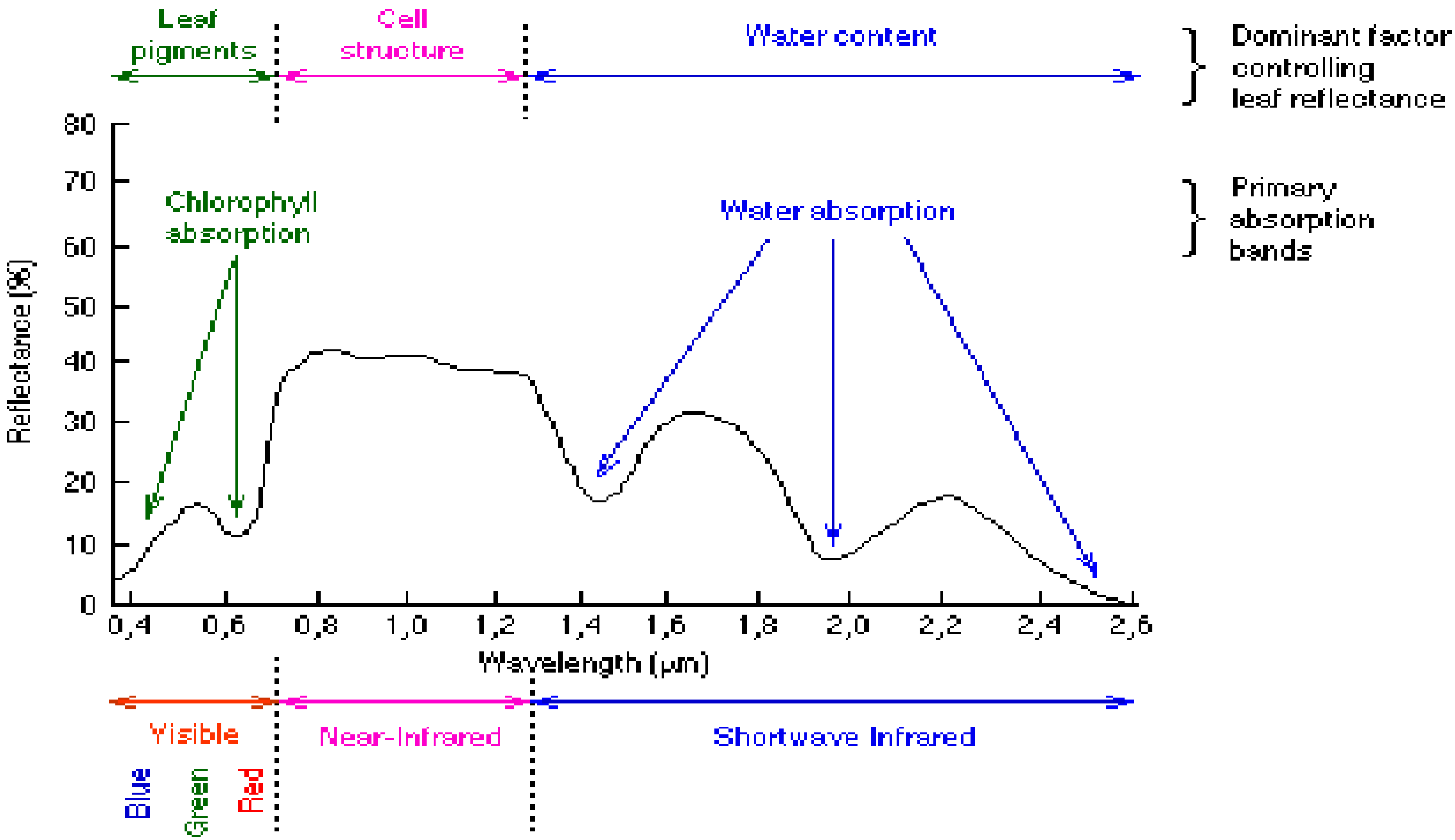


Transpiration
Photosynthesis
fluorescence

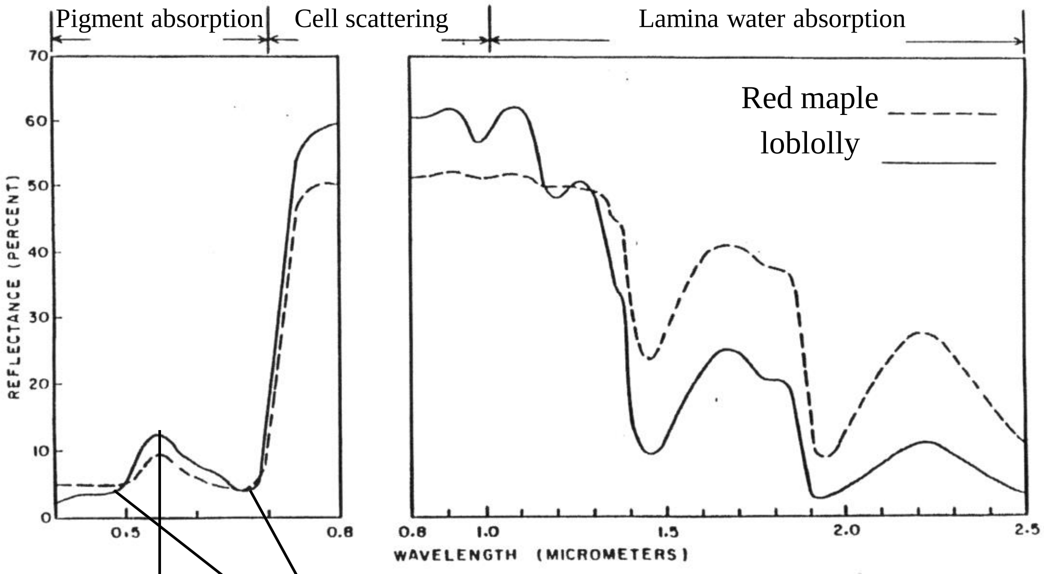
2.7

Typical spectral curve of vegetation

Spectral Feature



Spectral Feature

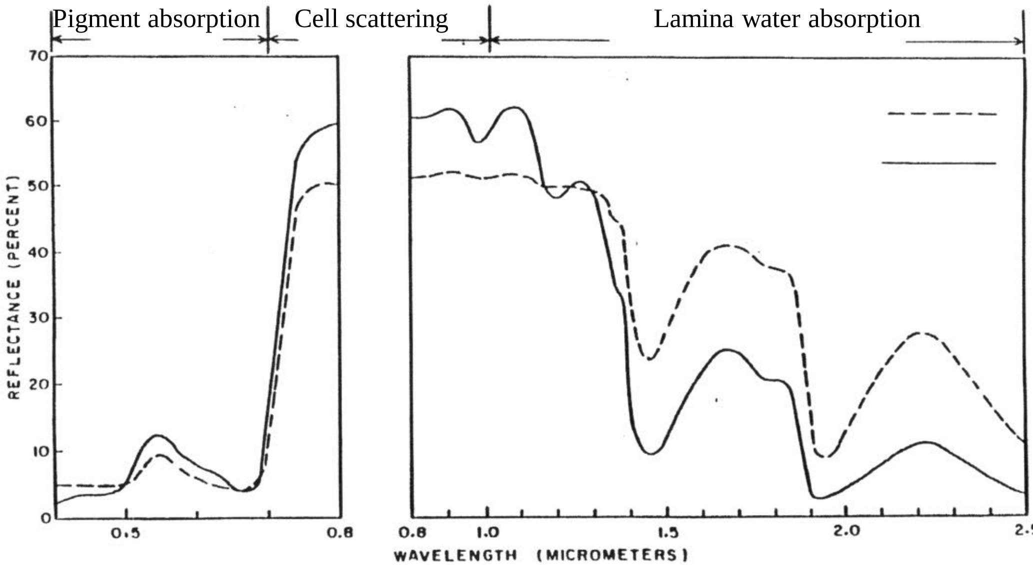


Chlorophyll absorption

Absorption decrease- vegetation is green

When plants get ill, Chlorophyll absorption intensity will get weaker and reflectance will get higher especially in red light region. For this reason, ill plants are often in light yellow color.

Spectral Feature

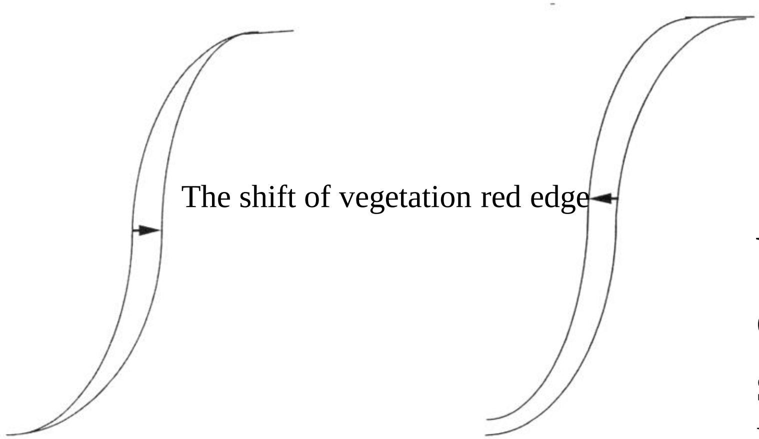


Spectral characteristics of healthy plants in NIR region:

High reflectance（45%～50%)

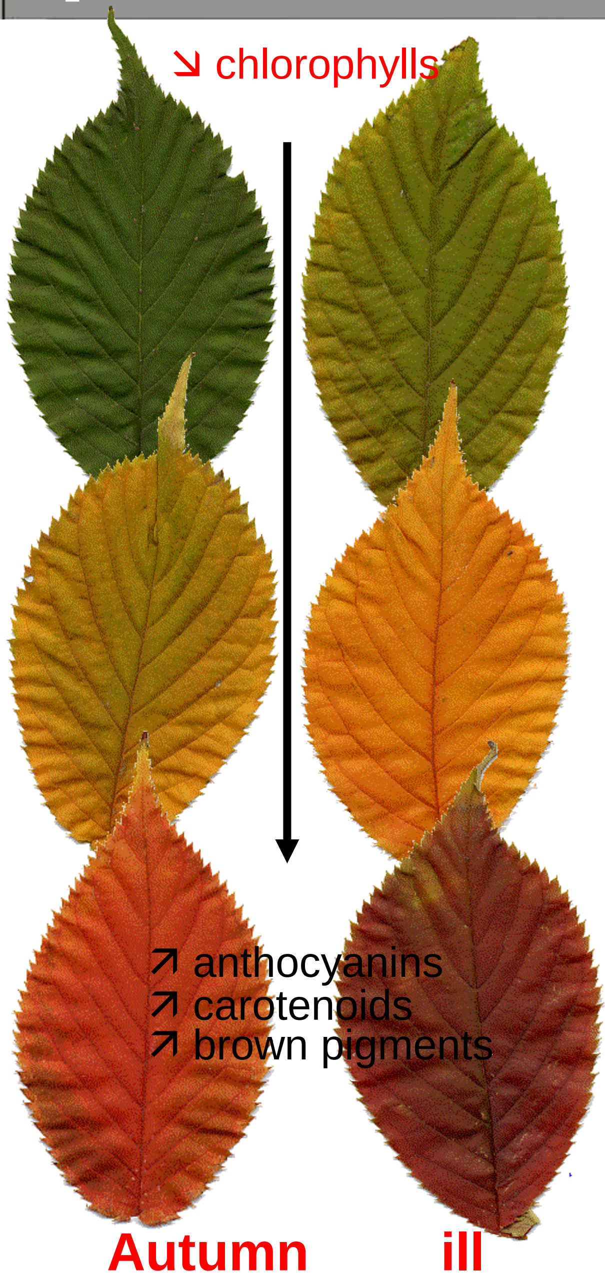
High transmittance（45%～50%)

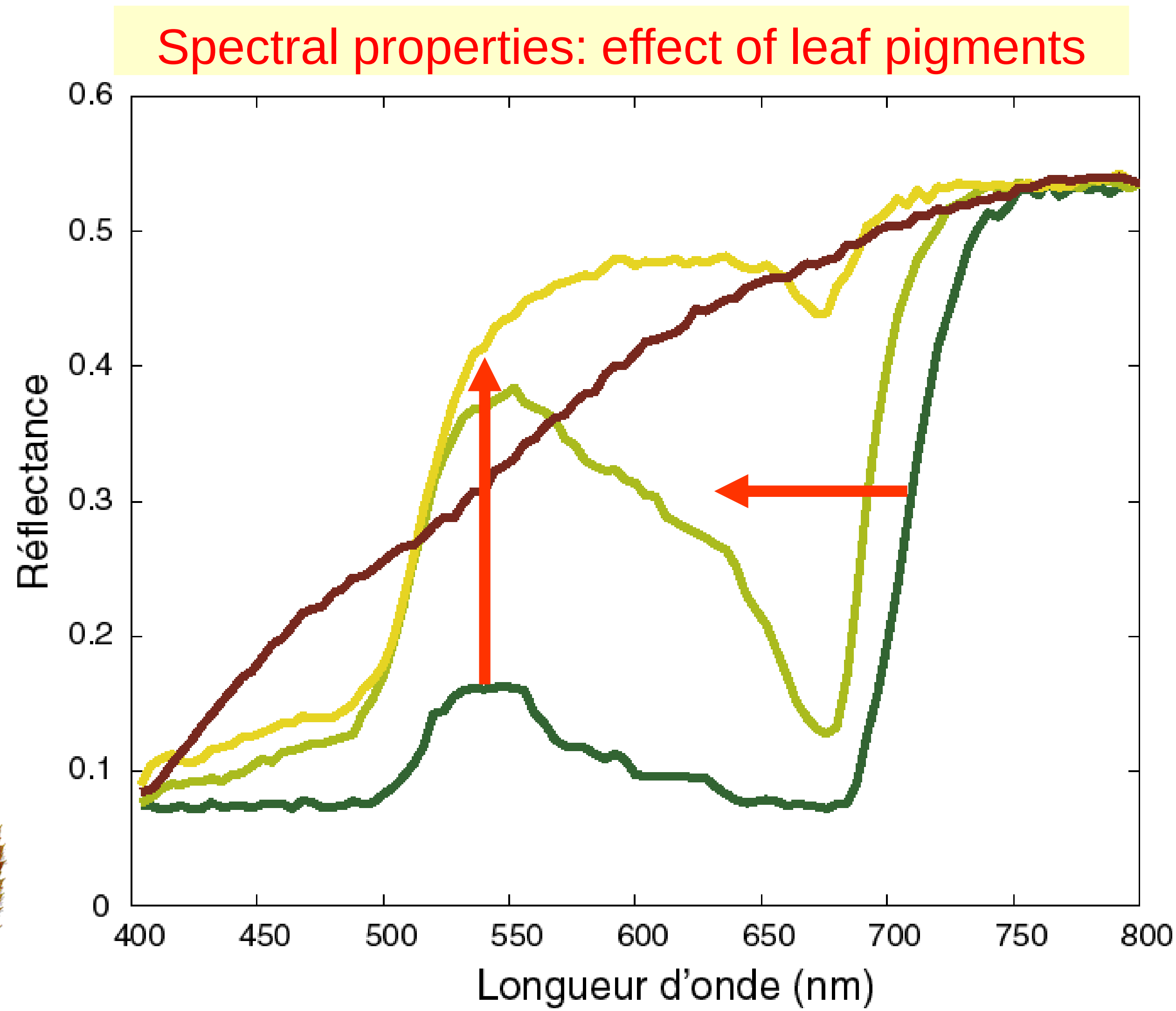
Low absorptance （<5%）



With the increase of Chlorophyll consistency , photosynthesis will be strengthened and more photons in long wavelength will be consumed

Spectral Feature





Spectral Feature

NDVI =[R(860nm) - R(660nm)] / [R(860nm) + R(660nm)]

Red-edge reflectance:

$$R_{red} = [R(670nm) + R(780nm)] / 2$$

Red-edge inflection:

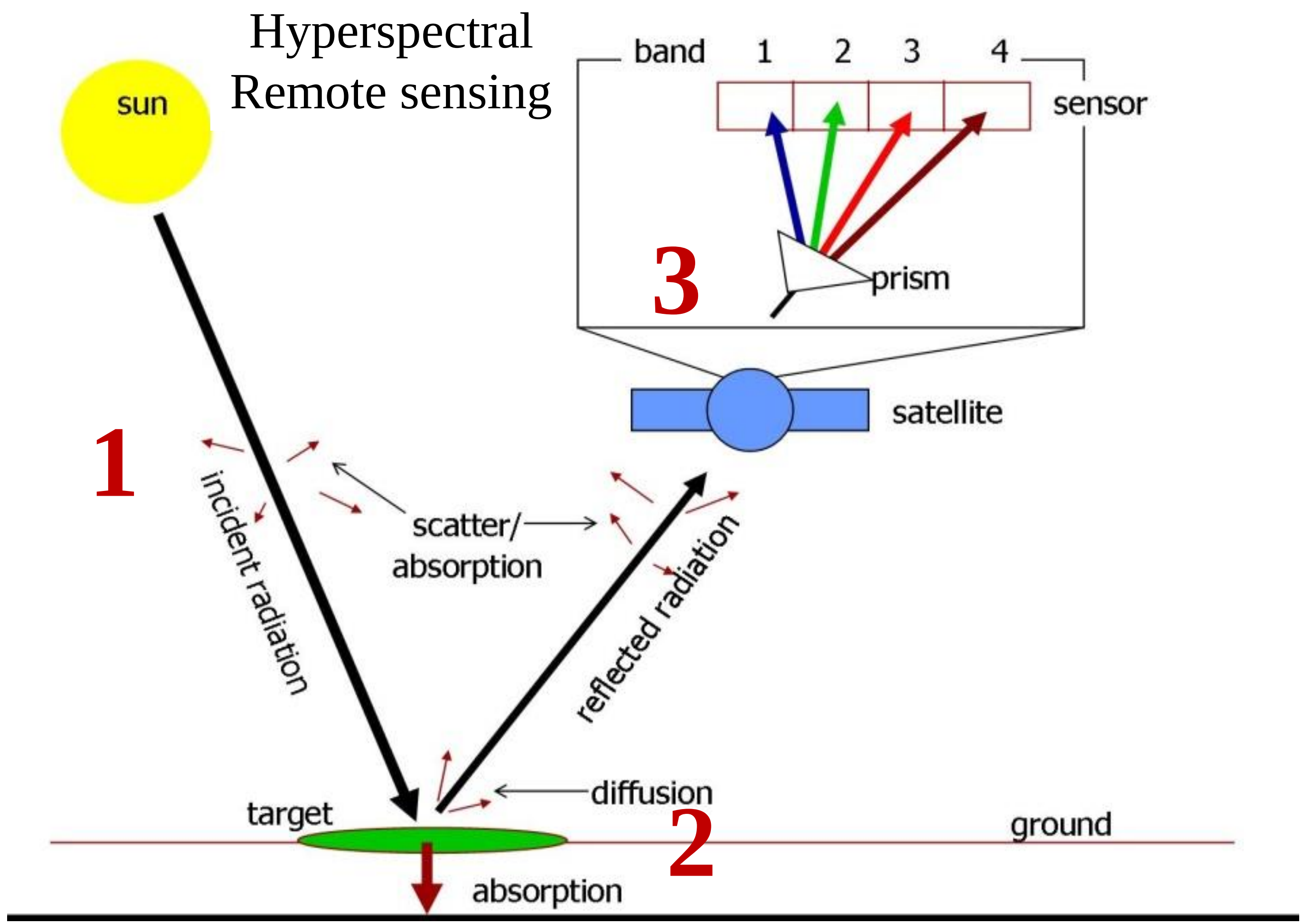
$$\lambda_{red} = 700nm + [R_{red} - R(700nm)] / [R(740nm) - R(700nm)] * 40nm$$

Spectral bands selection → color composition
→ index image

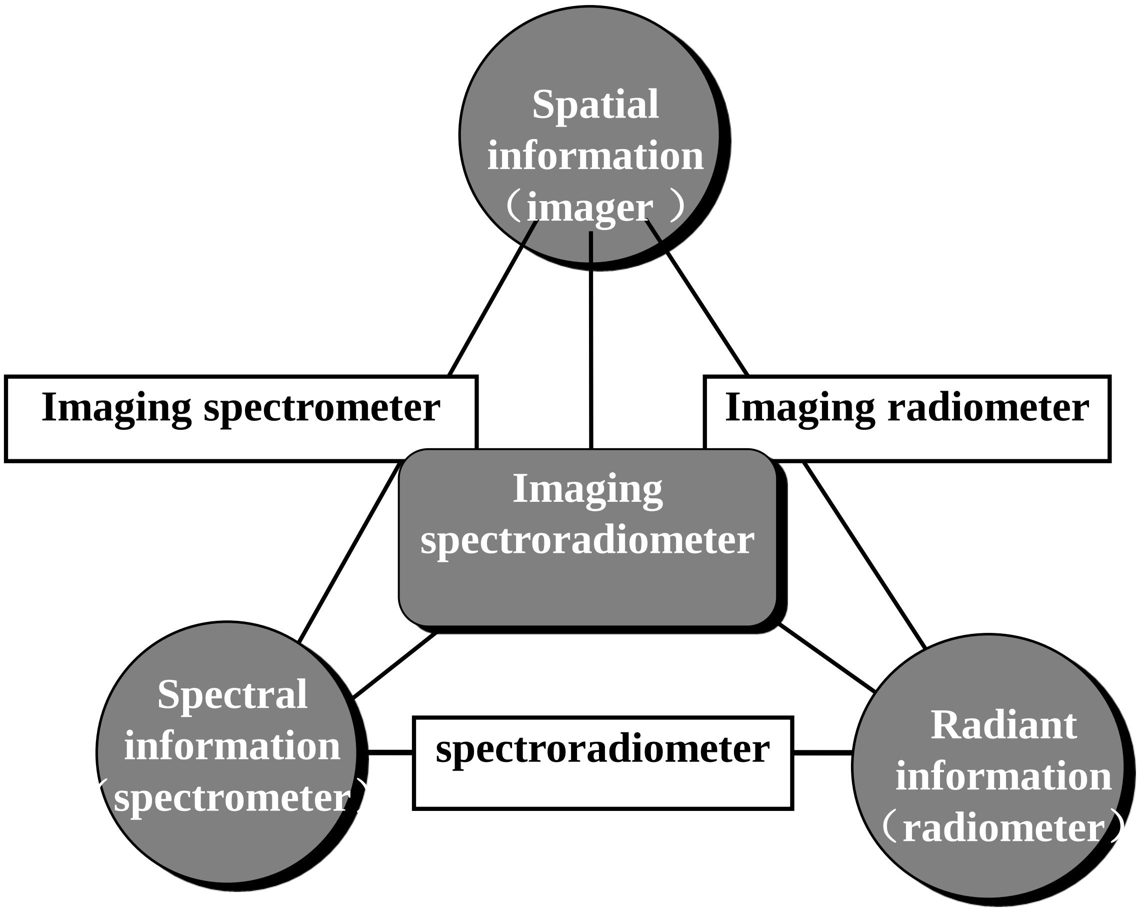
3. Sensor Technology

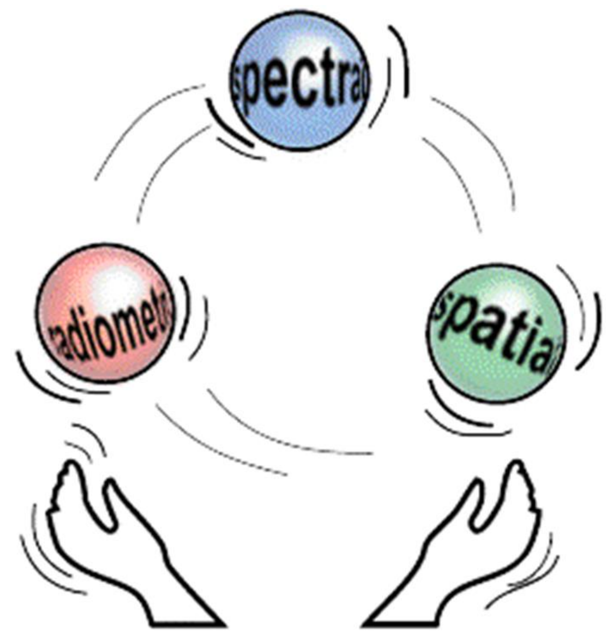
Hyperspectral RS Imaging process—Reflectance bands

Energy source -> Atmosphere -> Target -> Atmosphere -> Sensor -> Images



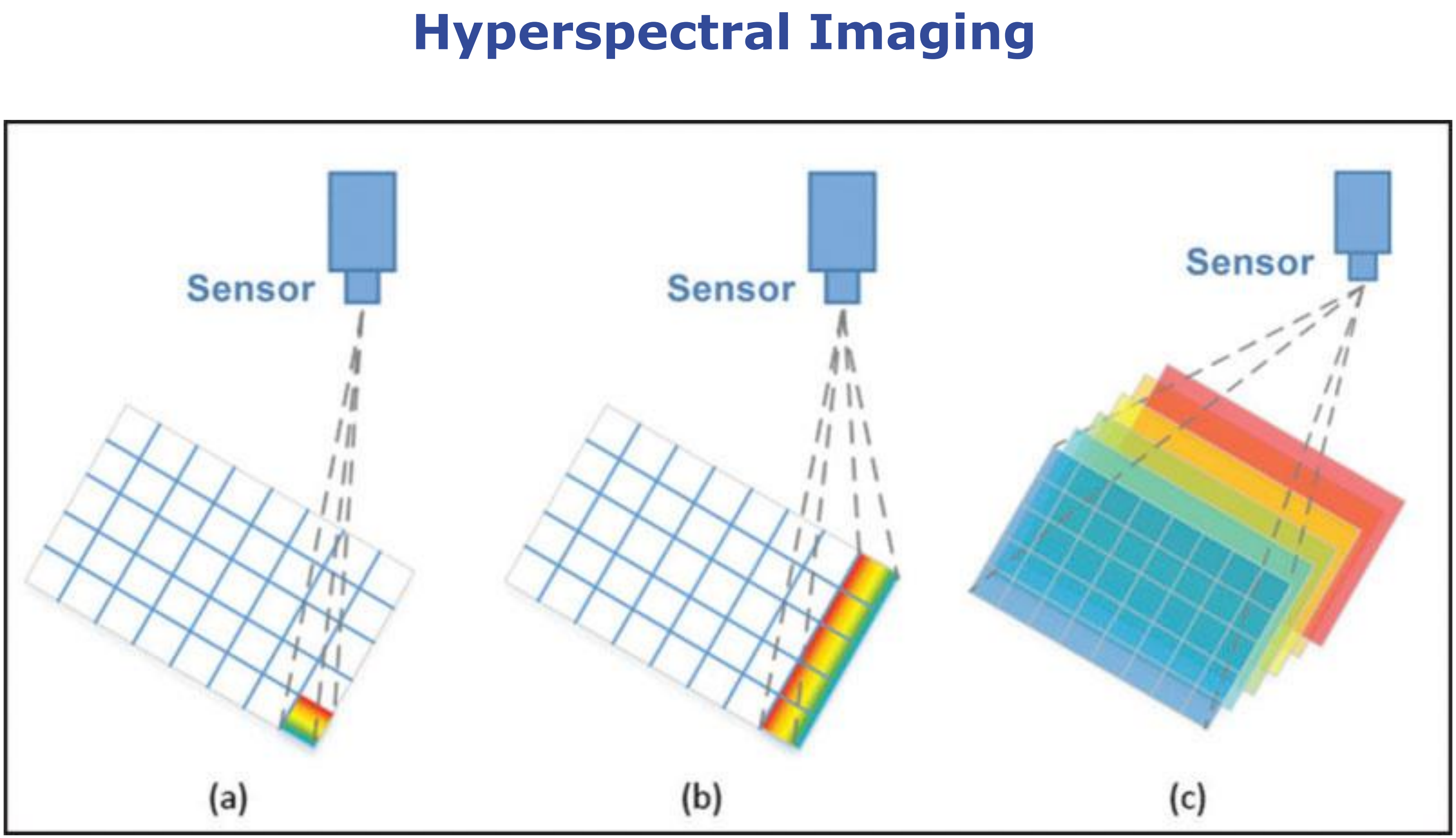
Characteristics of HRS： a combination of image and spectra information





3.2 Imaging Characteristics of HRS

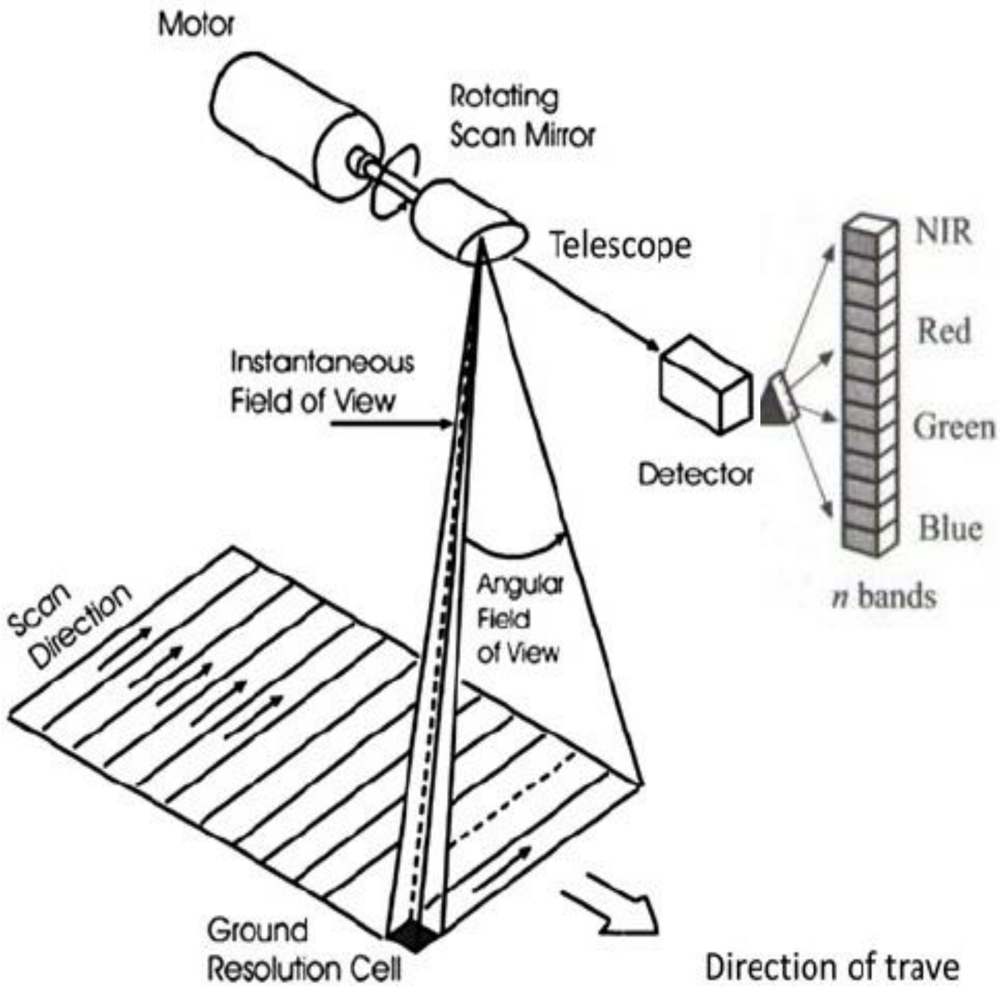
Characteristics of HRS： a combination of image and spectra information



whiskbroom pushbroom Frame camera

3.4 Spatial Imaging Models of Imaging Spectrometer

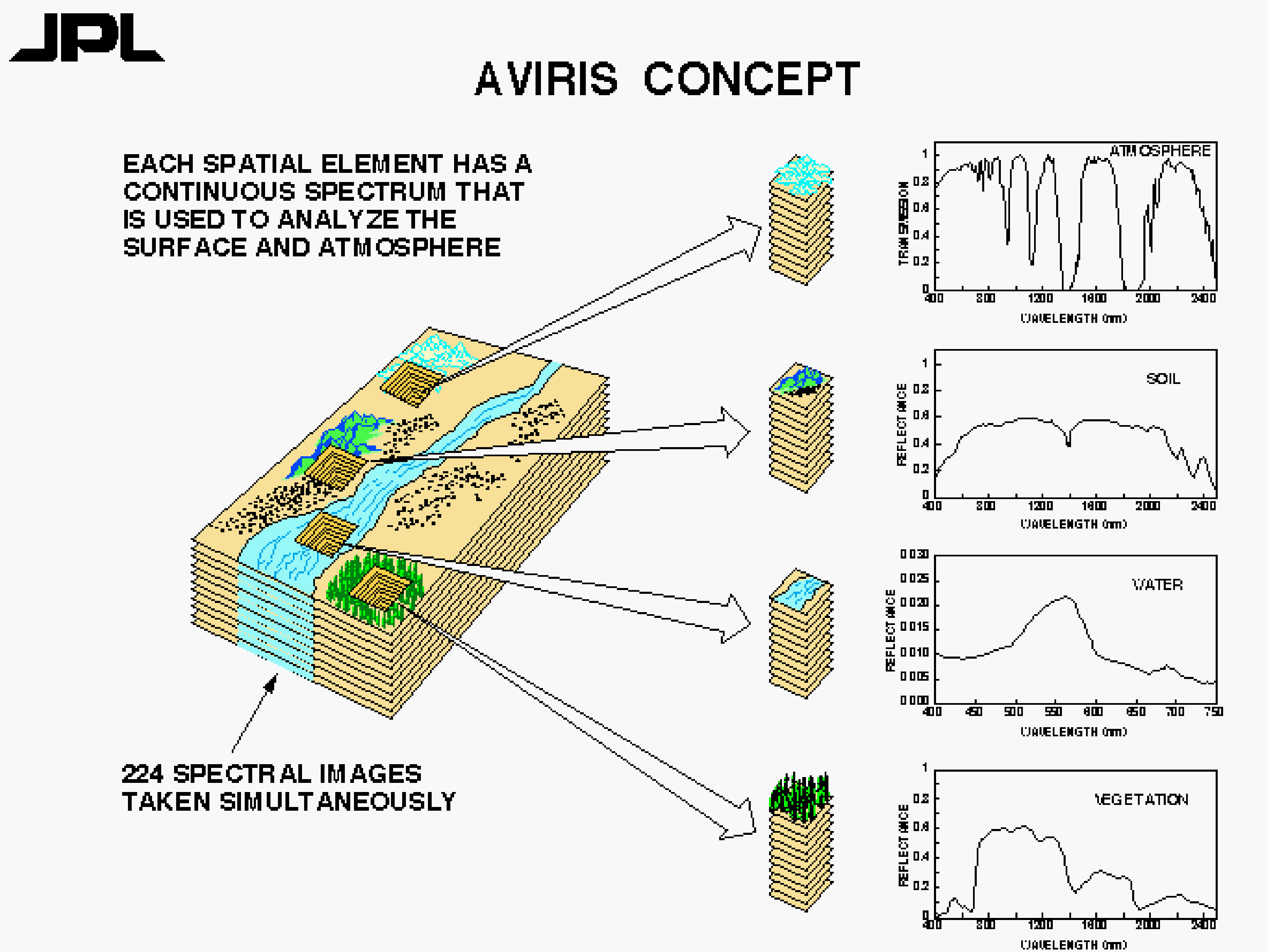
（1）Whiskbroom Imaging Spectrometer



A whisk broom or spotlight sensor (also known as an across track scanner) is a technology for obtaining satellite images with optical cameras. A mirror scans across the satellite's path (ground track), reflecting light into a single detector which collects data one pixel at a time. Whisk broom scanners have the effect of stopping the scan, and focusing the detector on one part of the swath width.

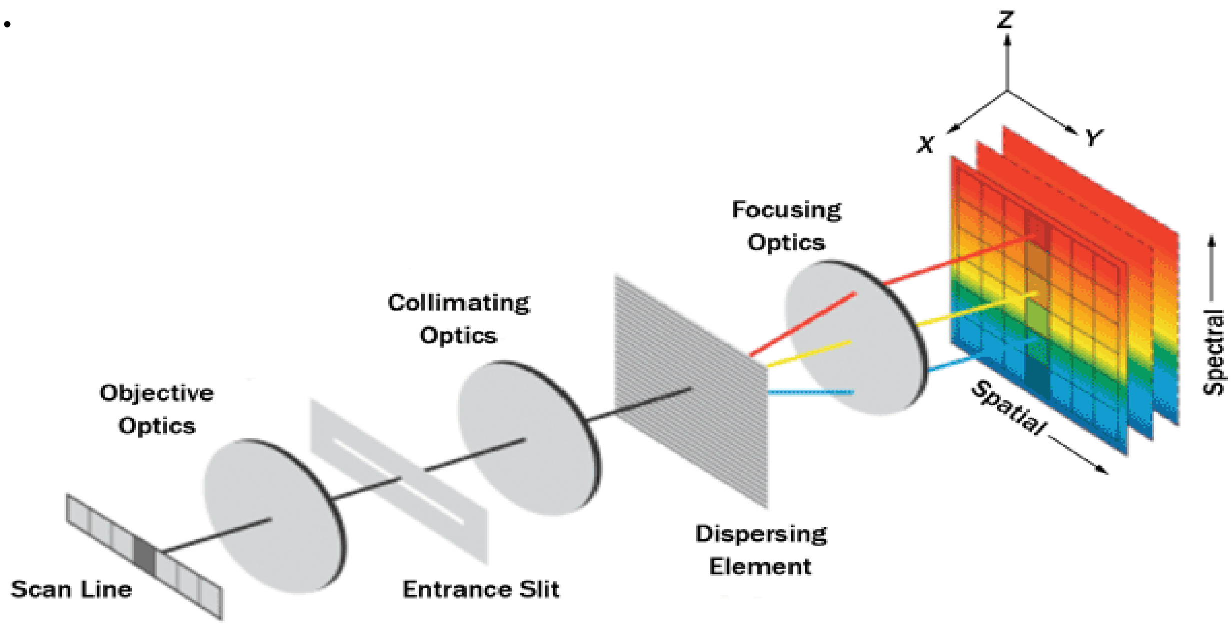
3.4 Spatial Imaging Models of Imaging Spectrometer

（1）Whiskbroom Imaging Spectrometer



（2）Pushbroom Imaging Spectrometer

A push broom scanner (also known as an along-track scanner) is a device for obtaining images with spectroscopic sensors. In orbital push broom sensors, a line of sensors arranged perpendicular to the flight direction of the spacecraft is used. Different areas of the surface are imaged as the spacecraft flies forward. A push broom scanner can gather more light than a whisk broom scanner because it looks at a particular area for a longer time, like a long exposure on a camera. One drawback of pushbroom sensors is the varying sensitivity of the individual detectors.



（2）Pushbroom Imaging Spectrometer

(i) ***Hyperspectral pushbroom line scanners*** use a CCD area array – which is however operated in a pushbroom mode as with a linear array.

(ii) The remaining detectors in the area array collect the spectral (colour) data for that line in hundreds of narrow spectral channels.

(iii) The spectral data is generated using a dispersive prism or grating – that acts as an imaging spectrometer.

(iv) The final result is an image "cube".

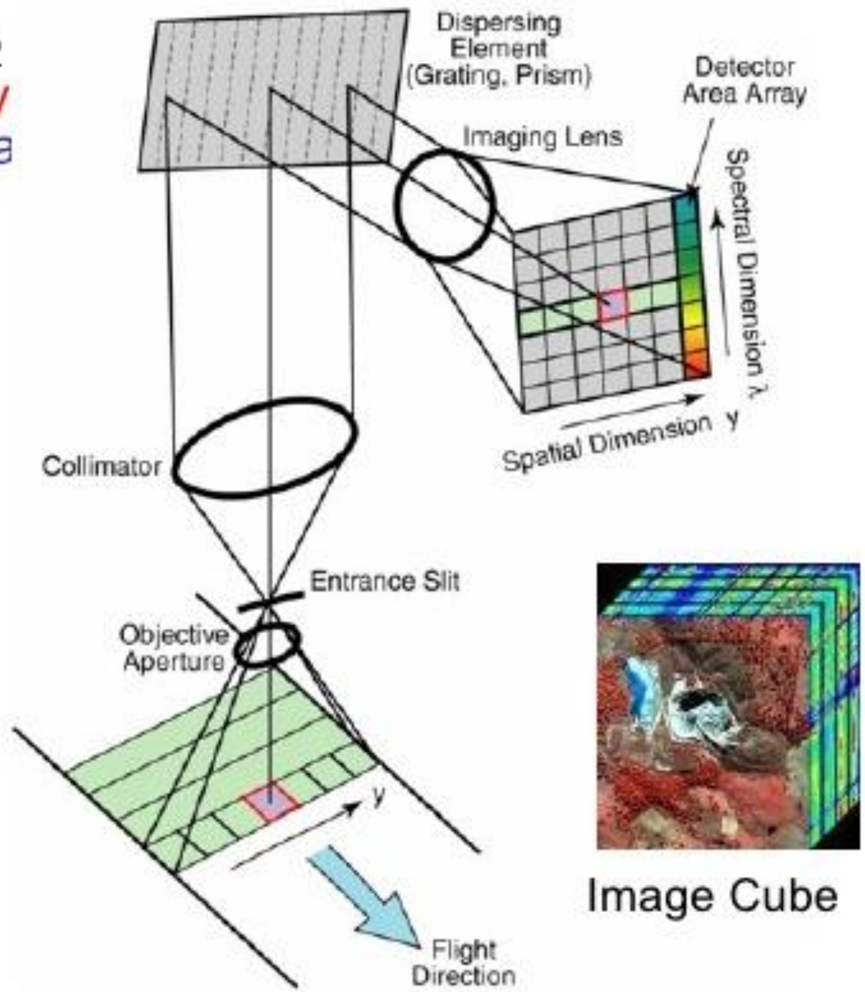
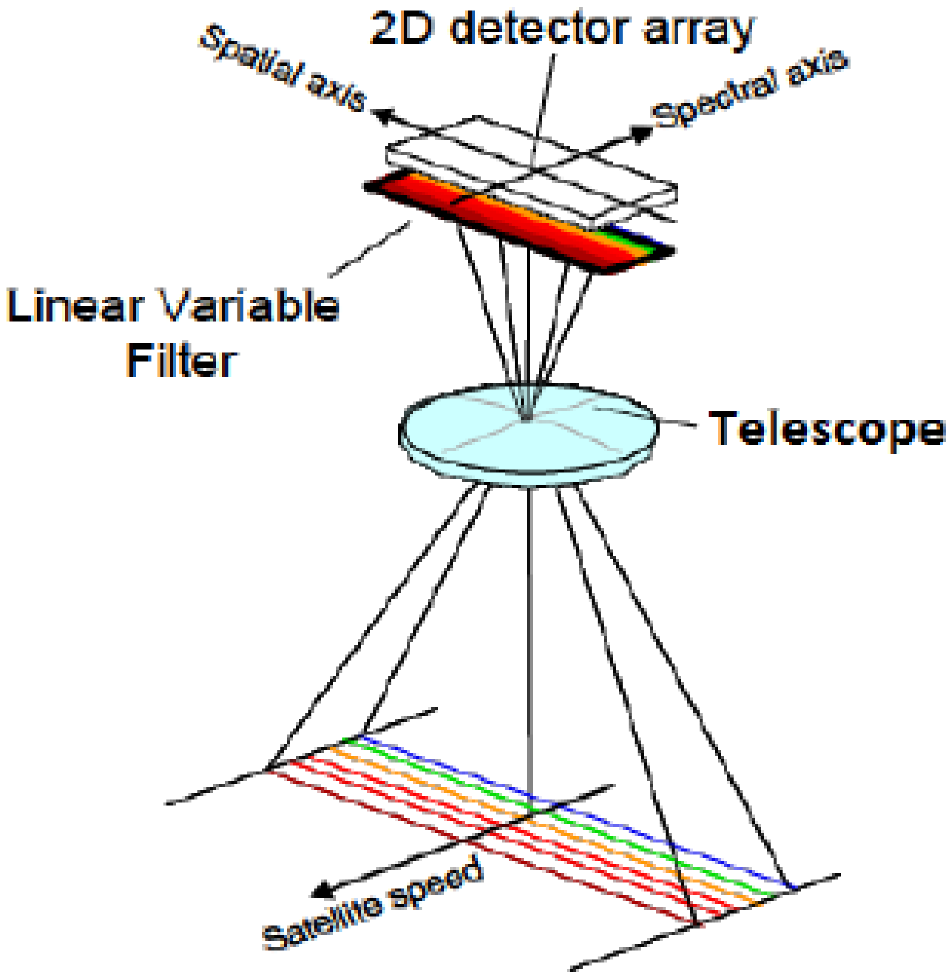


Image Cube

（2）Pushbroom Imaging Spectrometer



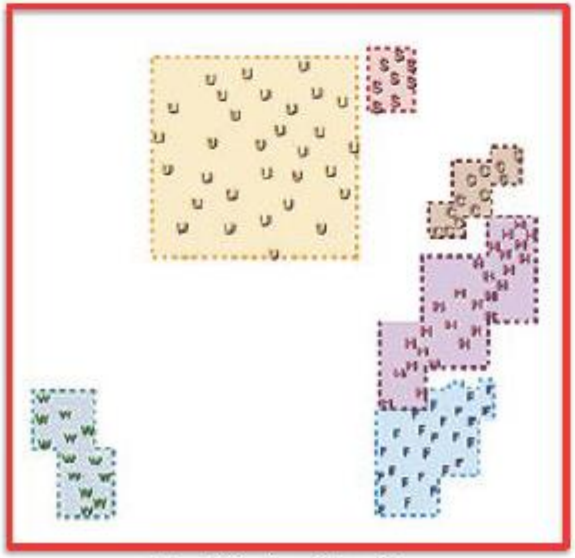
The geospectral camera: A compact and geometrically precise hyperspectral and high spatial resolution imager

Figure 1: Sentinel-5/GF-5 imaging principle

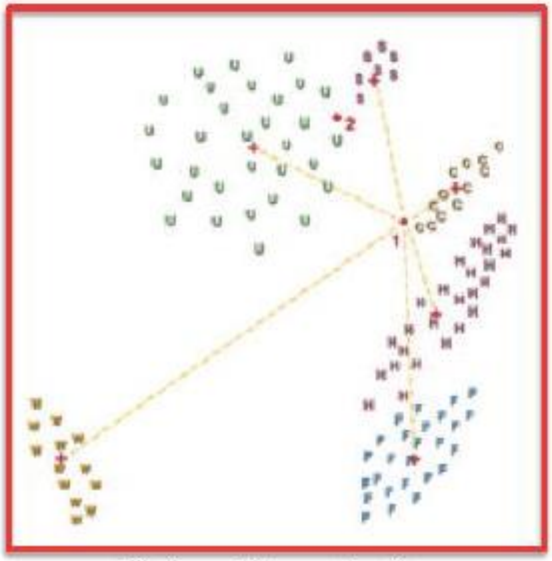
4. Hyperspectral Remote Sensing Applications

Classic supervised classification

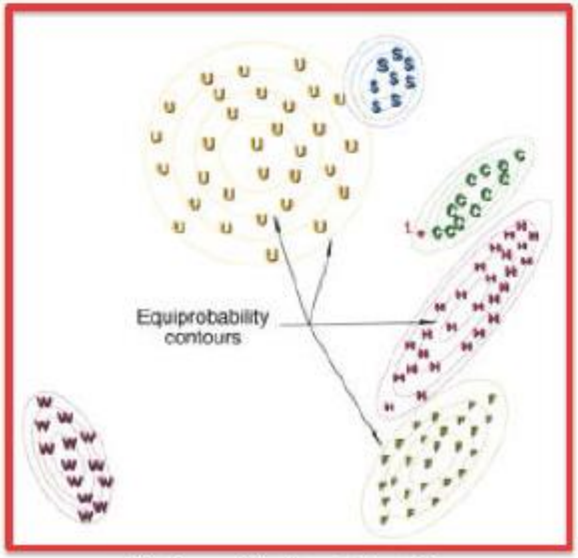
- There are many other strategies for supervised classification of hyperspectral data.
  - ✓ The parallelepiped classifier constructs multidimensional boxes for each class using class mean and standard deviation and the pixel is tested to determine membership.
  - ✓ The minimum distance classifier assigns a pixel to the class with the closest mean.
  - ✓ The maximum likelihood classifier evaluates the likelihood of assigning a pixel to a class using both the variance and the covariance of the available training samples.



Parallelepiped classifier

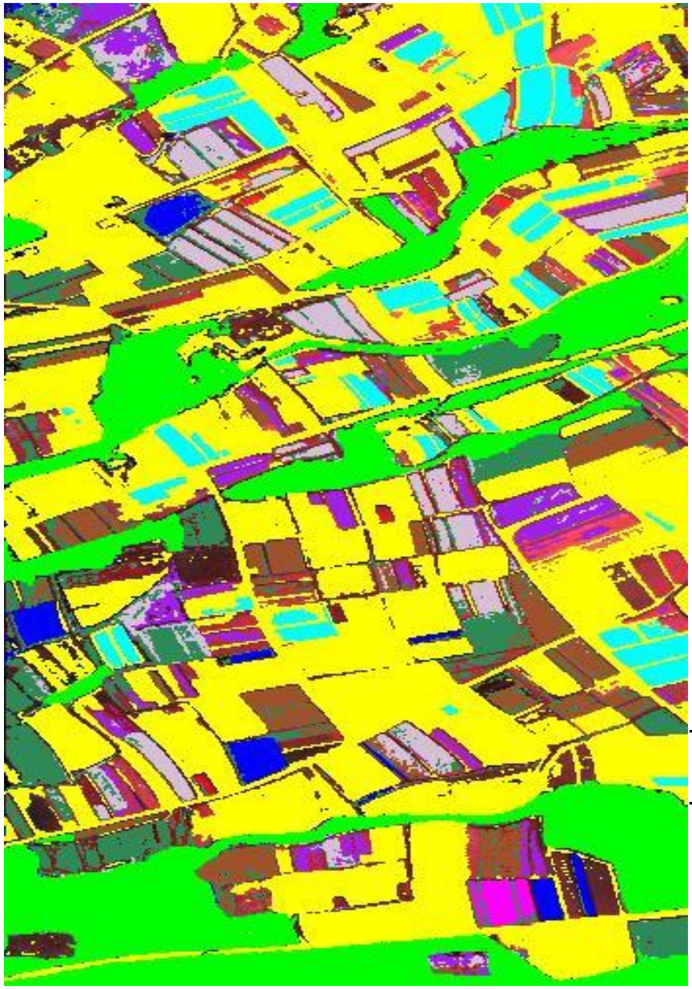


Minimum distance classifier



Maximum likelihood classifier

Image Classification



Japanese cabbage (midseason)
Chinese cabbage (midseason)
Radish
Lettuce (midseason)
Pasture
Yam
Forest
Plastic film
No_vegetation cover area

LANDCOVER IN MINAMIMAKI, JAPAN
August 23, 2000

The roles of H.R.S in precision agriculture:

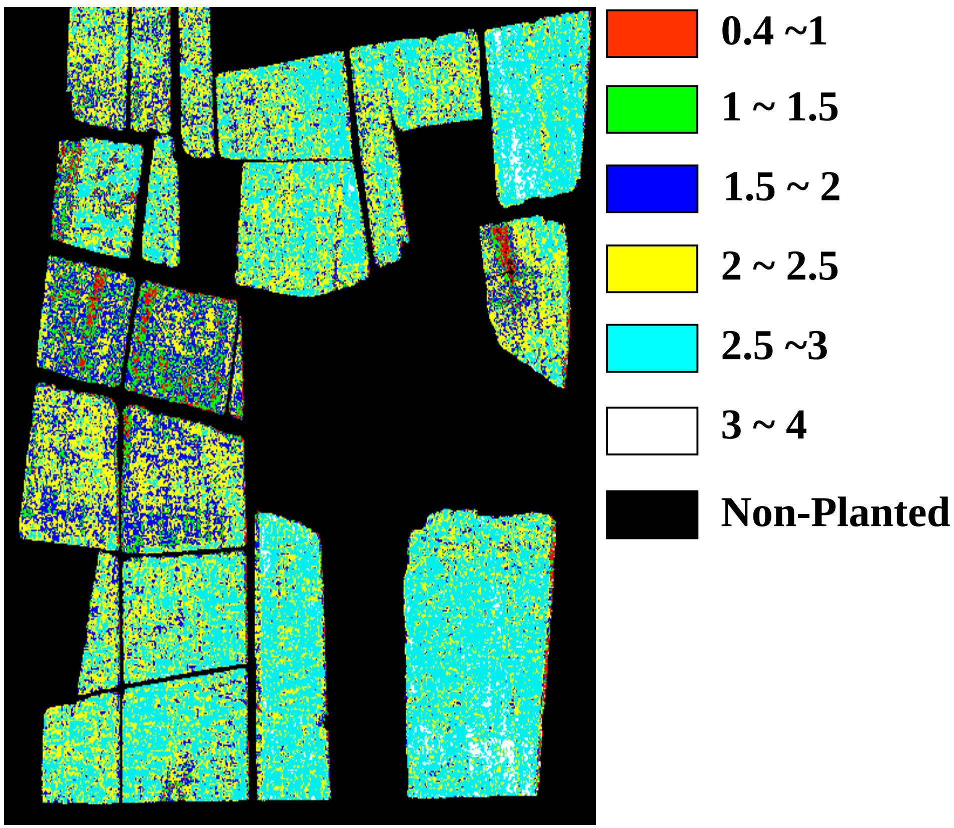
(1) Where and what kind of agricultural products will be produced
---- Crop Identification

(2) What quality of agricultural products will be provided for the market
---- Spectral analysis models for the extraction of Crop biochemical parameters

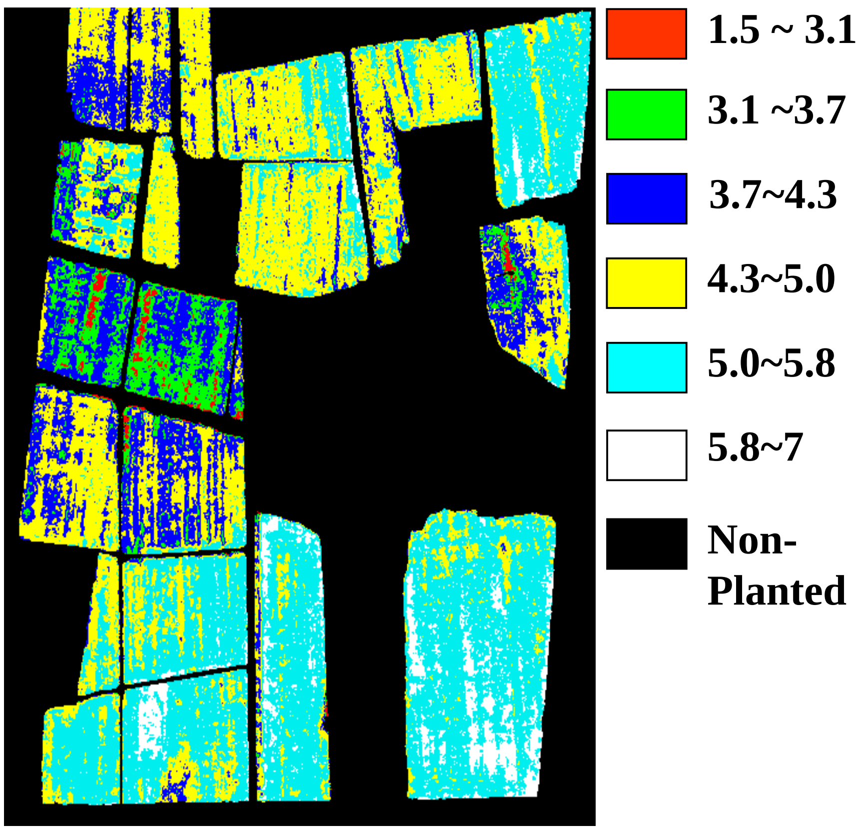
Precision agriculture: "Do the right thing at the right place and at the right time“. Hyperspectral R.S.: Providing relevant and reliable agronomic indexes to farmers

Bio-chemical parameter mapping

Chlorophyll (mg/g)



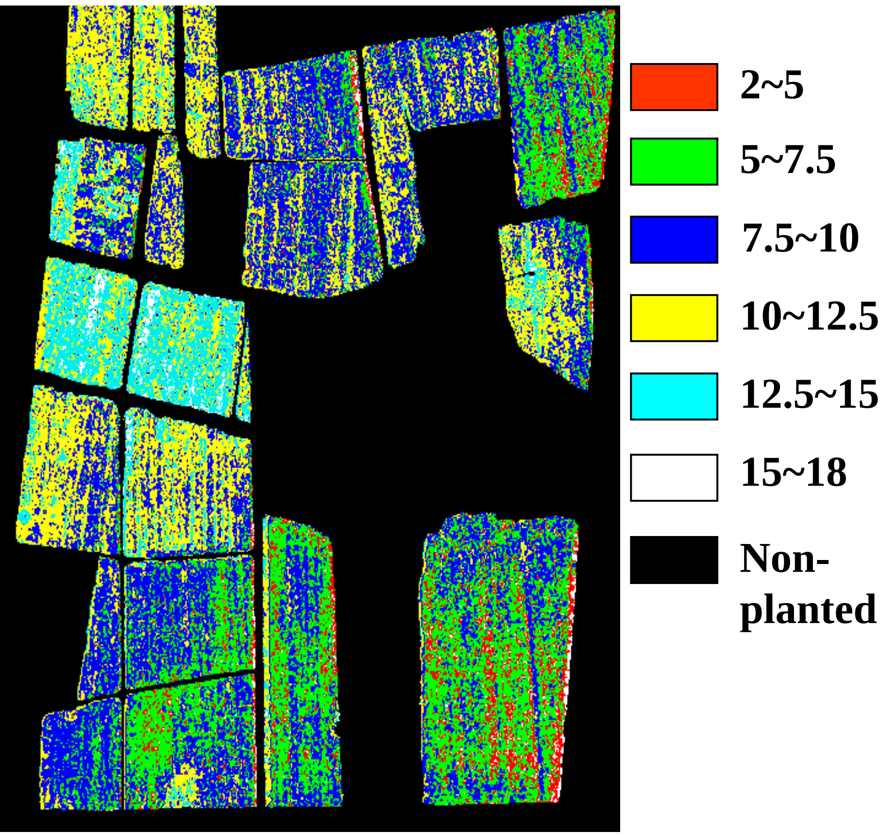
Nitrogen (%)



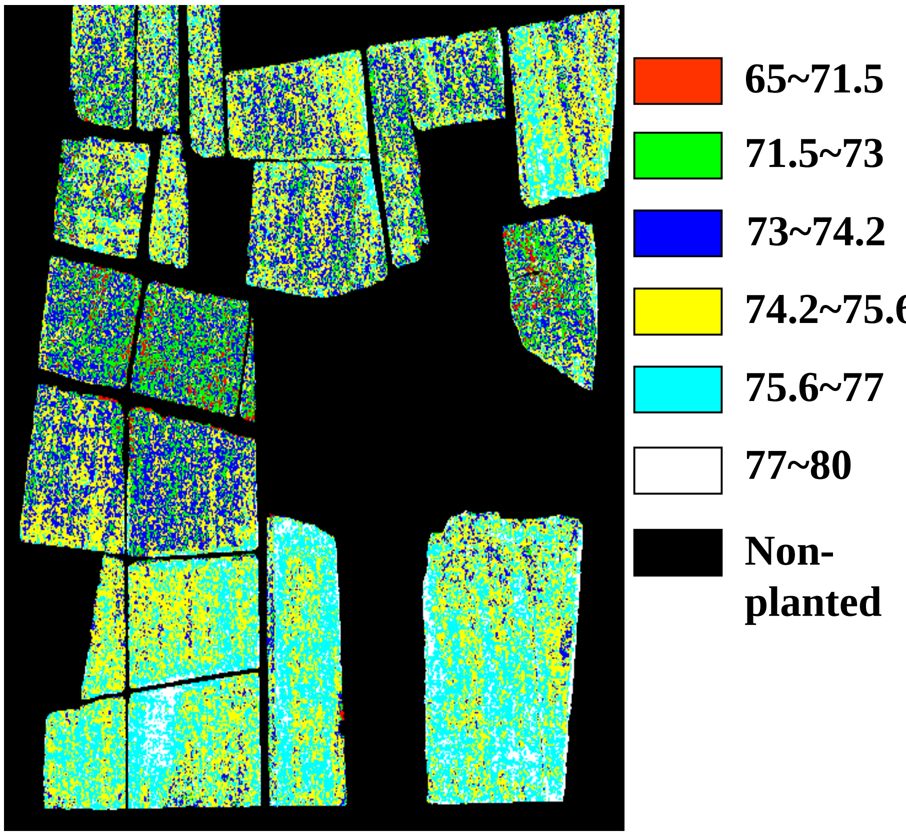
April 26, 2001

Bio-chemical parameter mapping

Dissolved sugar(%)



Leaf water contents(%)

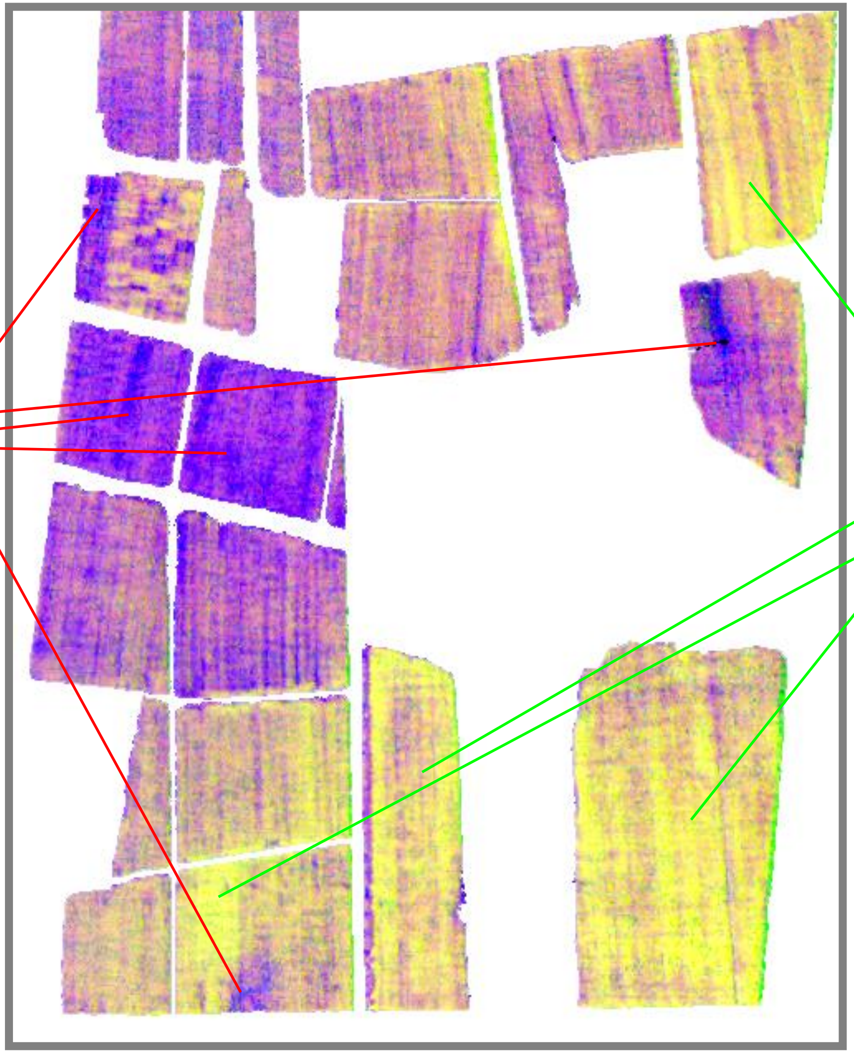


April 26, 2001

Color-composed analysis by Chl., TN, Dissolved sugar bands

Low protein content

Bad growing area
High sugar
Low TN
Low Chl.



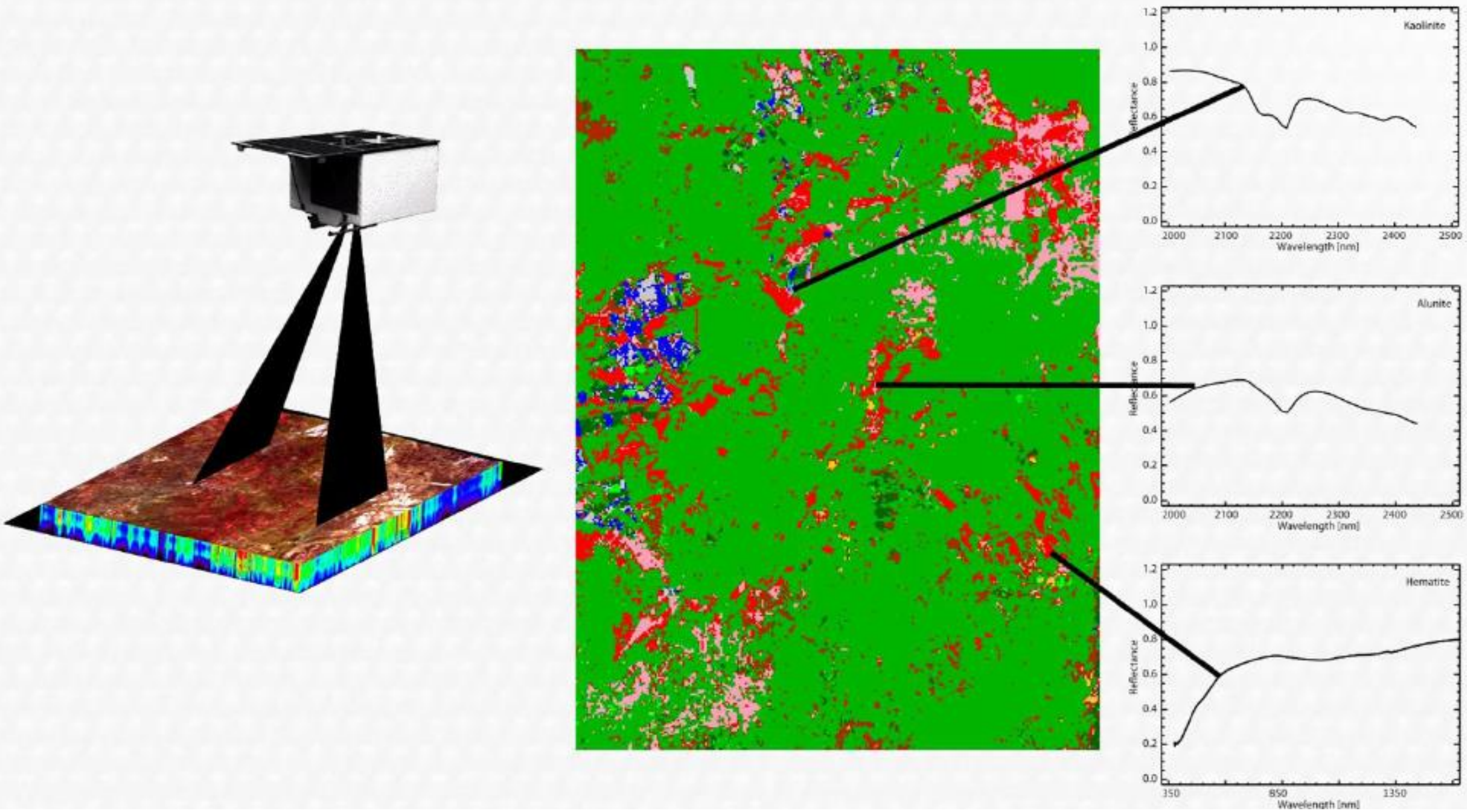
High protein content

Better growing area
Low sugar
High TN
High Chl.

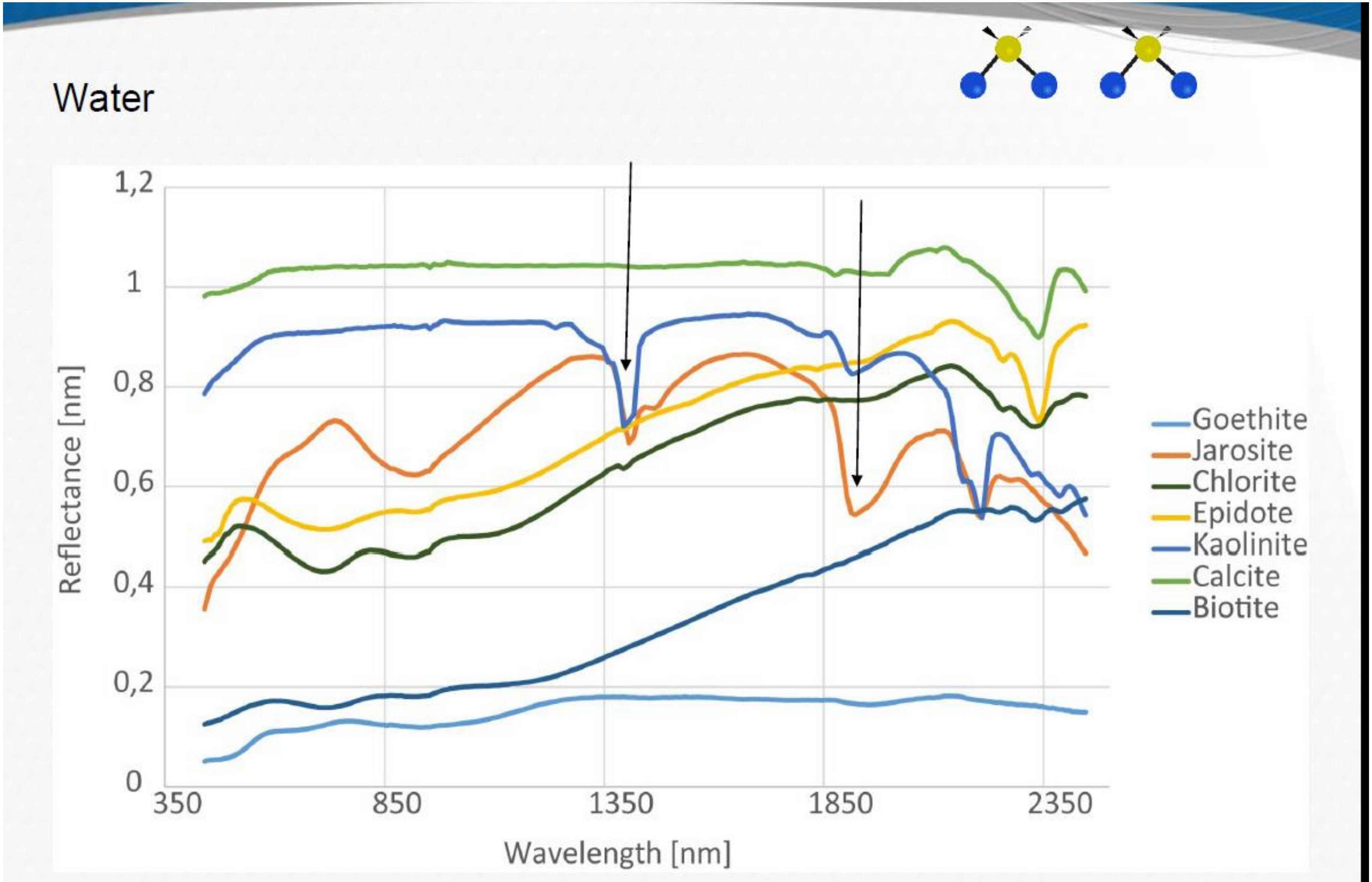
April 26, 2001

Mineral Exploration

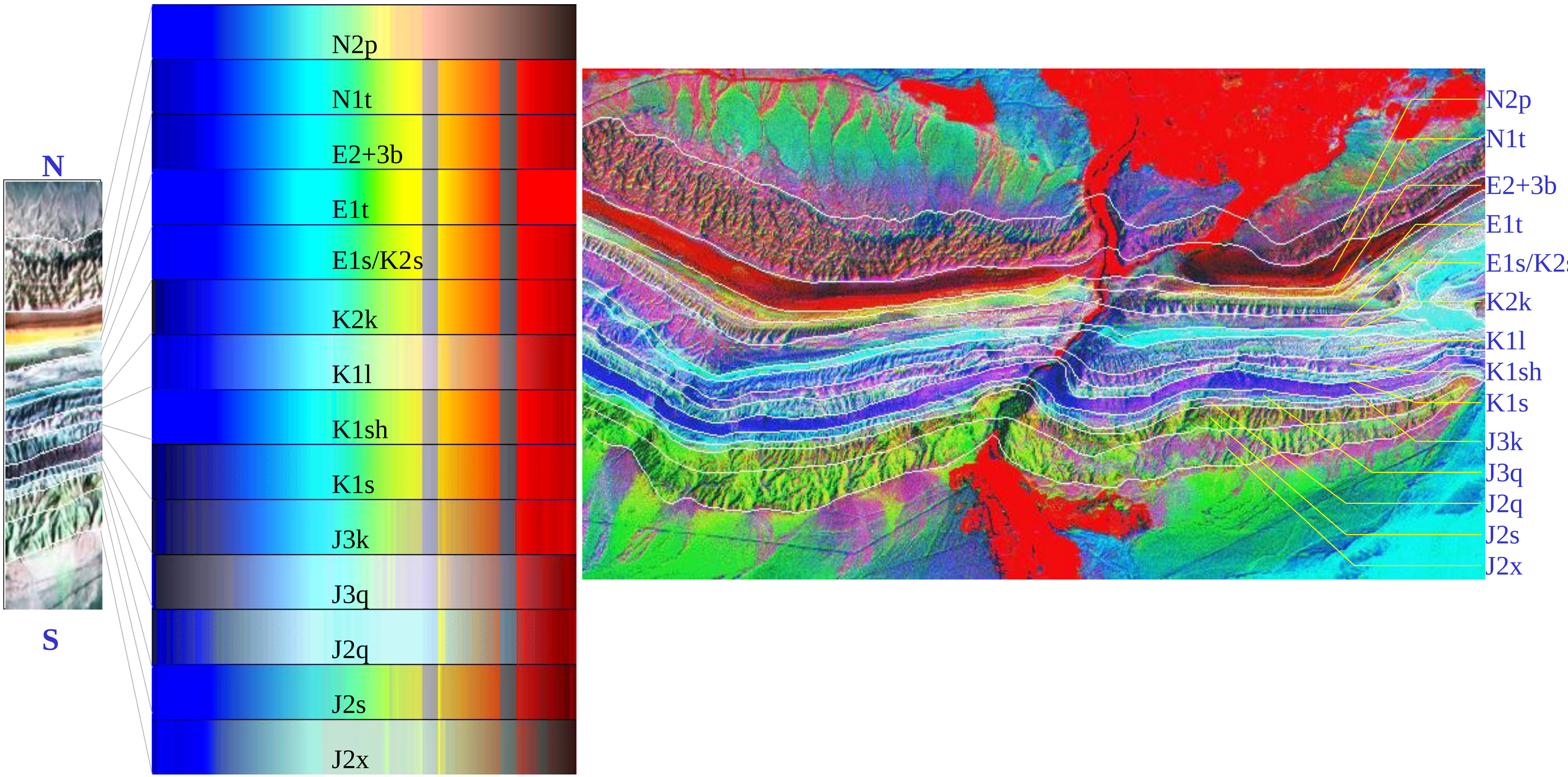
Spectroscopy → study of the interaction between matter and radiated energy specifically looking at what wavelengths of light are emitted or absorbed by an object in order to characterize materials.



Absorption bands of rock forming minerals



Mineral Exploration



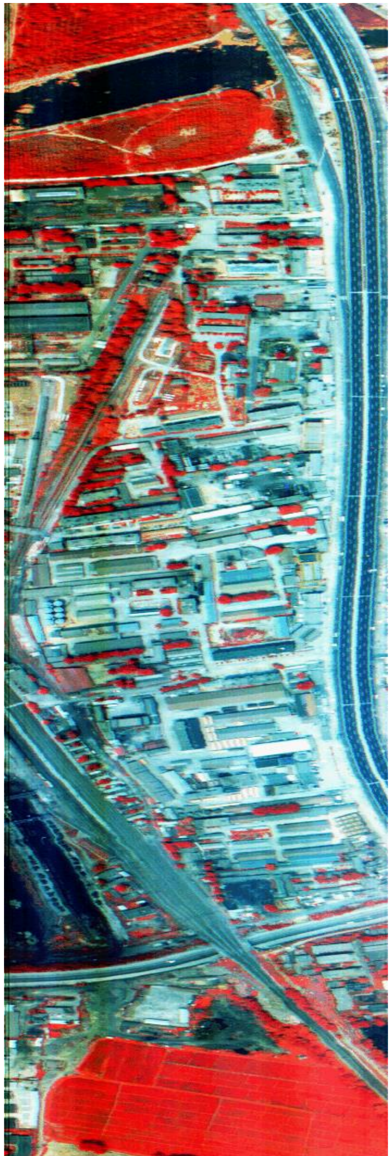
400 wavelength (nm) 2500

Spectral Histogram of Stratum

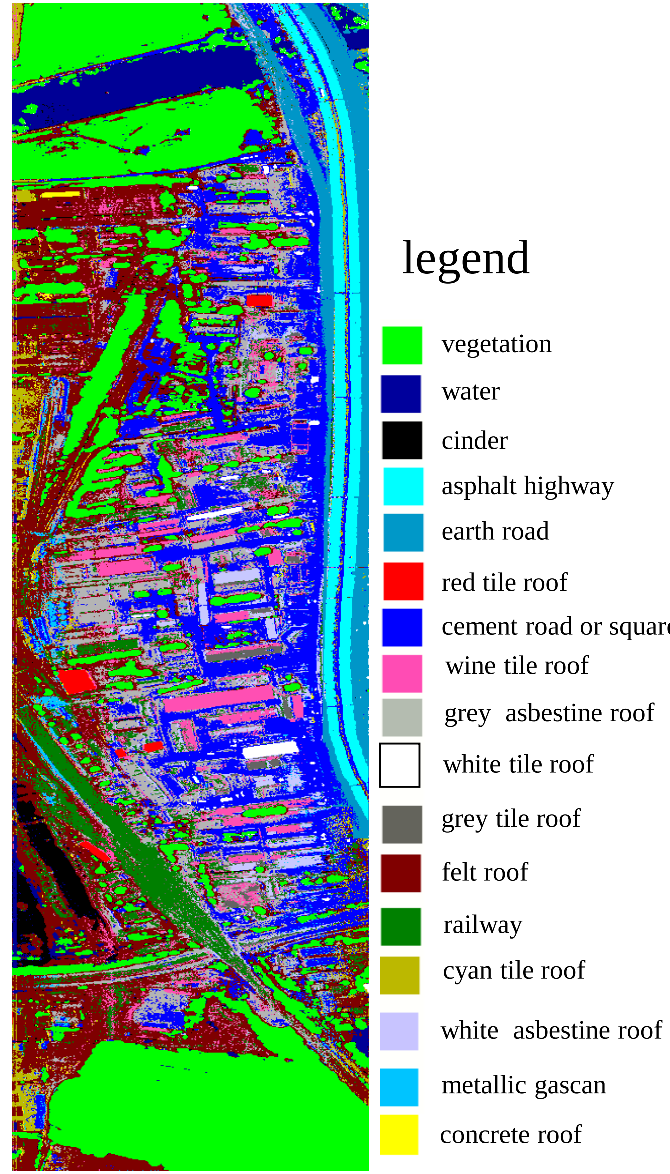
Urban and Artificial objects detection

HRS data in the north part of Beijing City

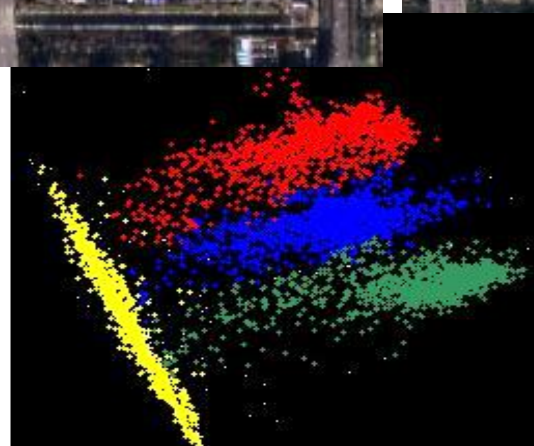
Urban and Artificial objects detection

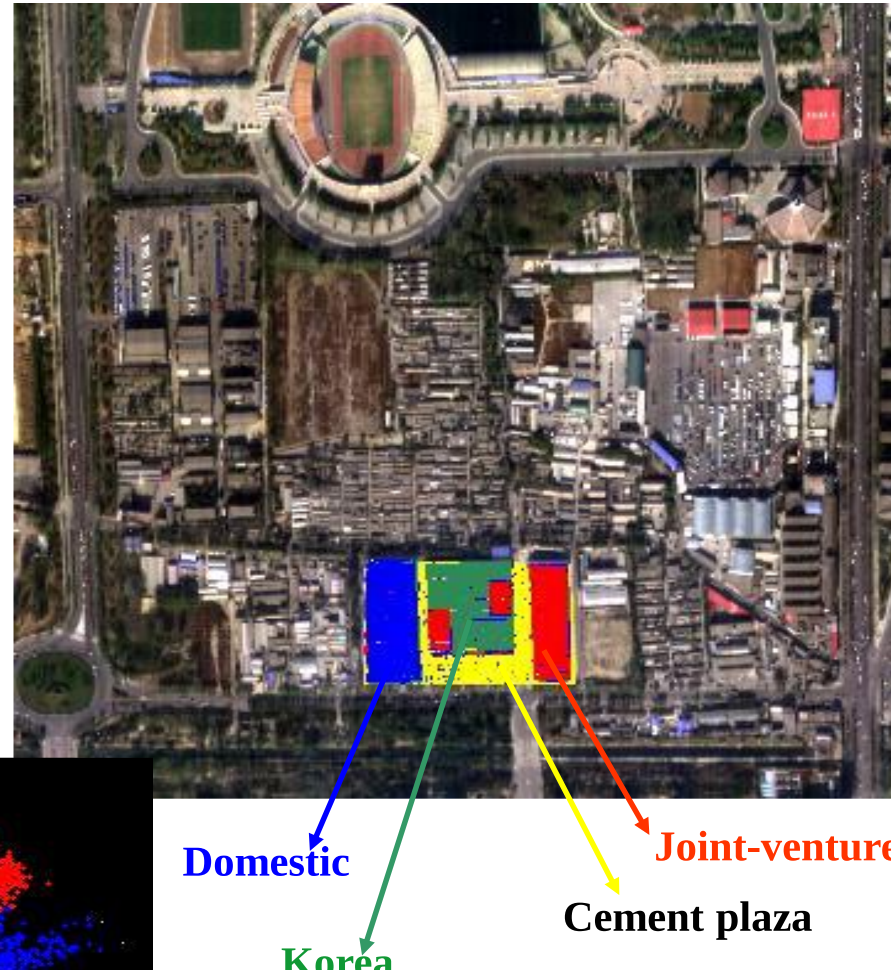


CLASSIFICATION



True color



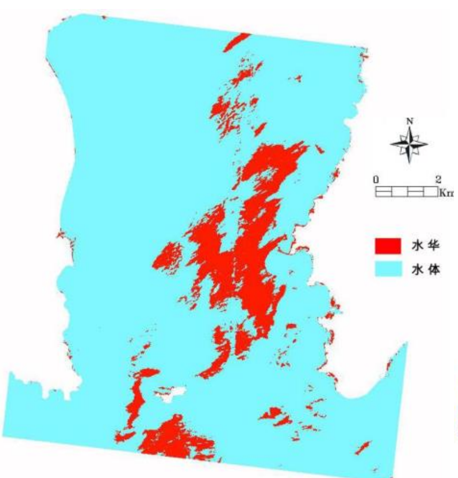


Three kinds of Aluminum alloy plate

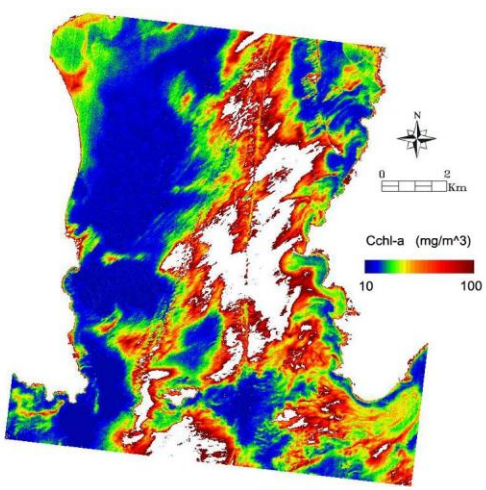
Hyperspectral remote sensing models to monitor inland water quality

In 2014, the project “Hyperspectral remote sensing technology and application in monitoring eutrophication of inland waters” won the prize of Science and Technology Award of Beijing.

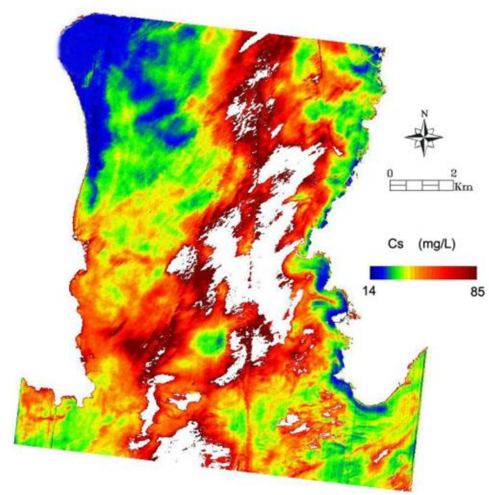
Retrieval of water constituents from Hyperspectral images (PROBA/CHRIS)



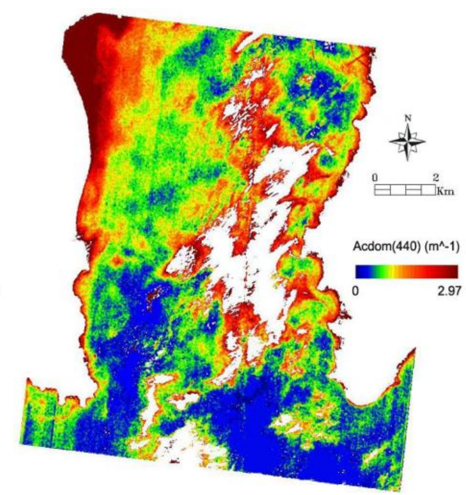
Algae bloom



Chlorophyll-a

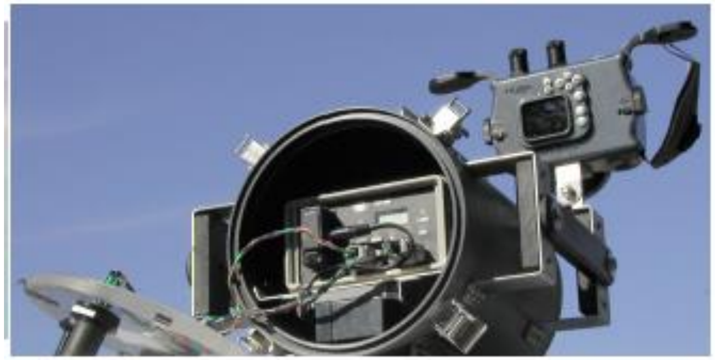


Suspended matter

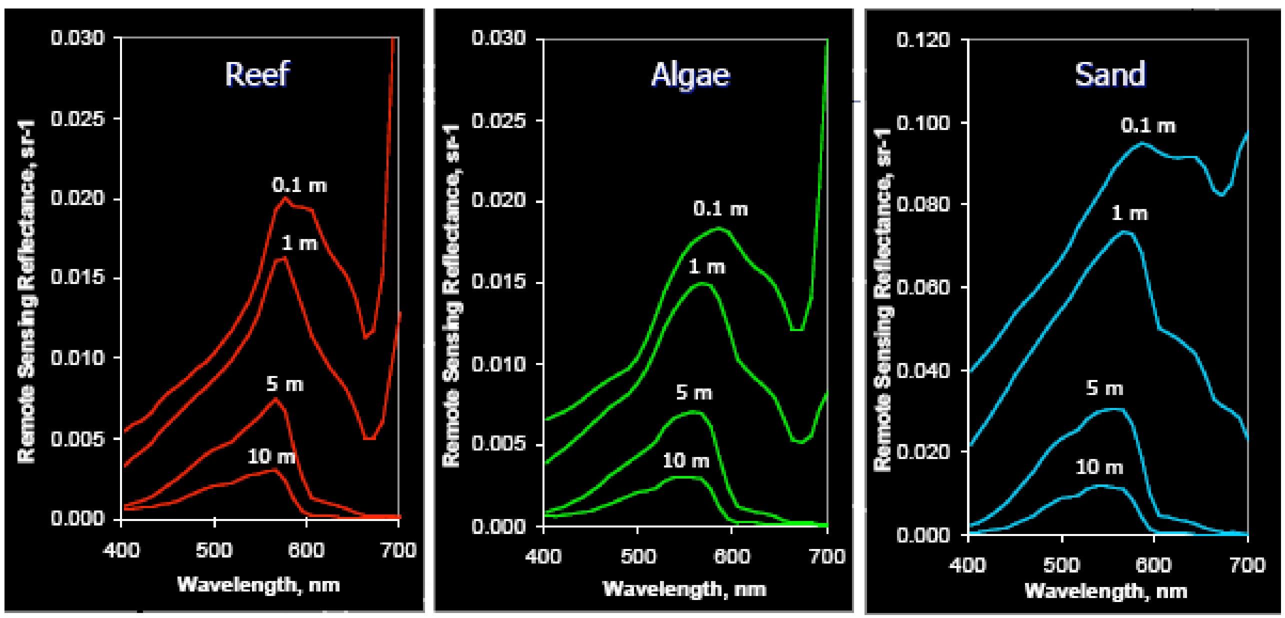


CDOM

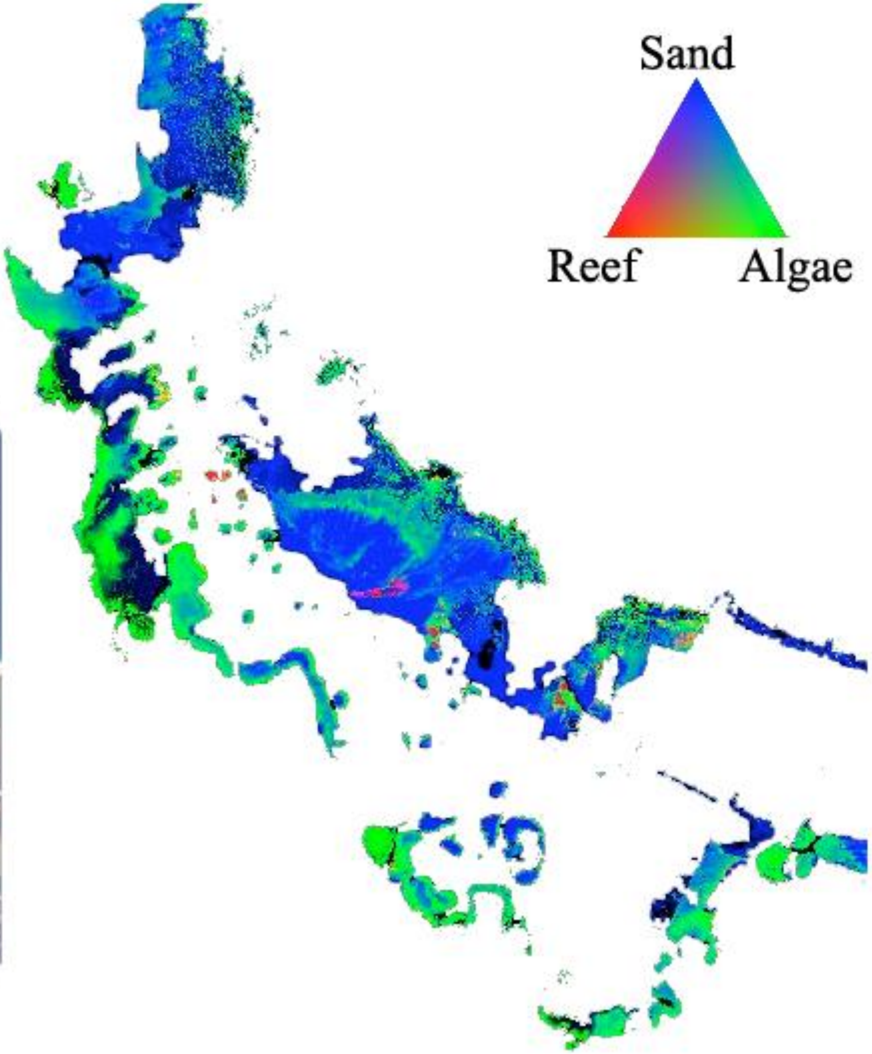
Sea ecosystem monitoring



Sea ecosystem monitoring

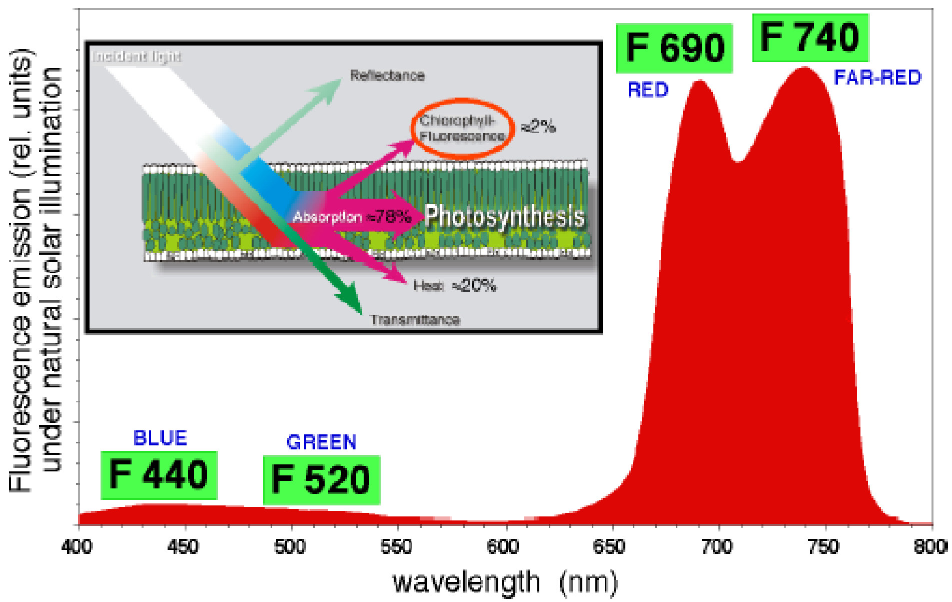


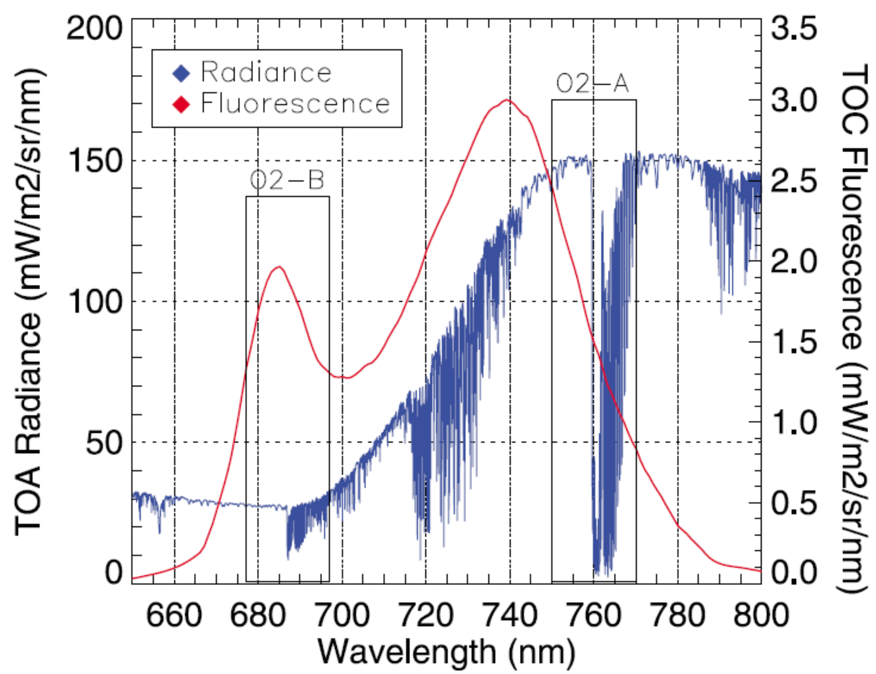
Sea ecosystem monitoring



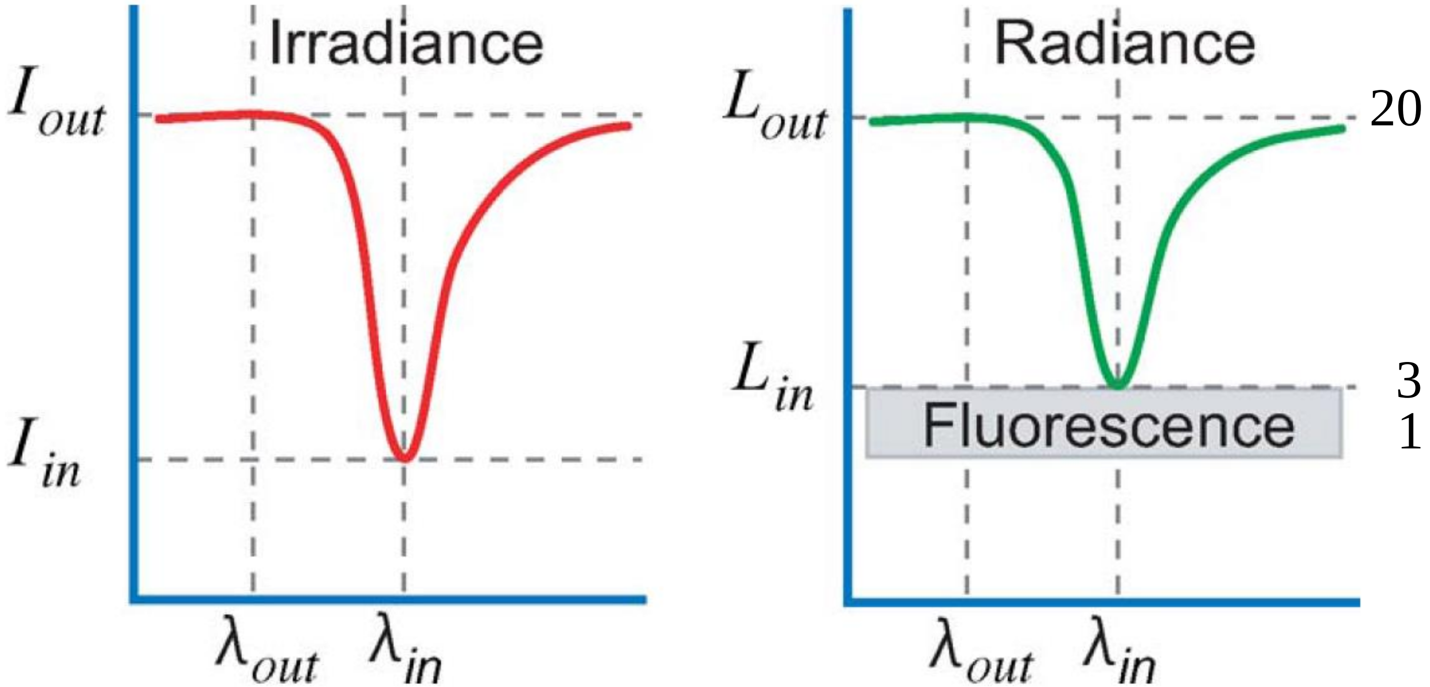
Solar-Induced Chlorophyll Fluorescence

- **Under natural conditions, fluorescence and photosynthesis are correlated** → a measurement of fluorescence can be interpreted as a proxy for instantaneous photosynthesis
- **Challenge for the retrieval:** SIF is a small signal (~1-2%) with respect to the reflected solar radiation in the red and near-infrared part of the spectrum





SIF retrieval principle: in-filling of absorption lines



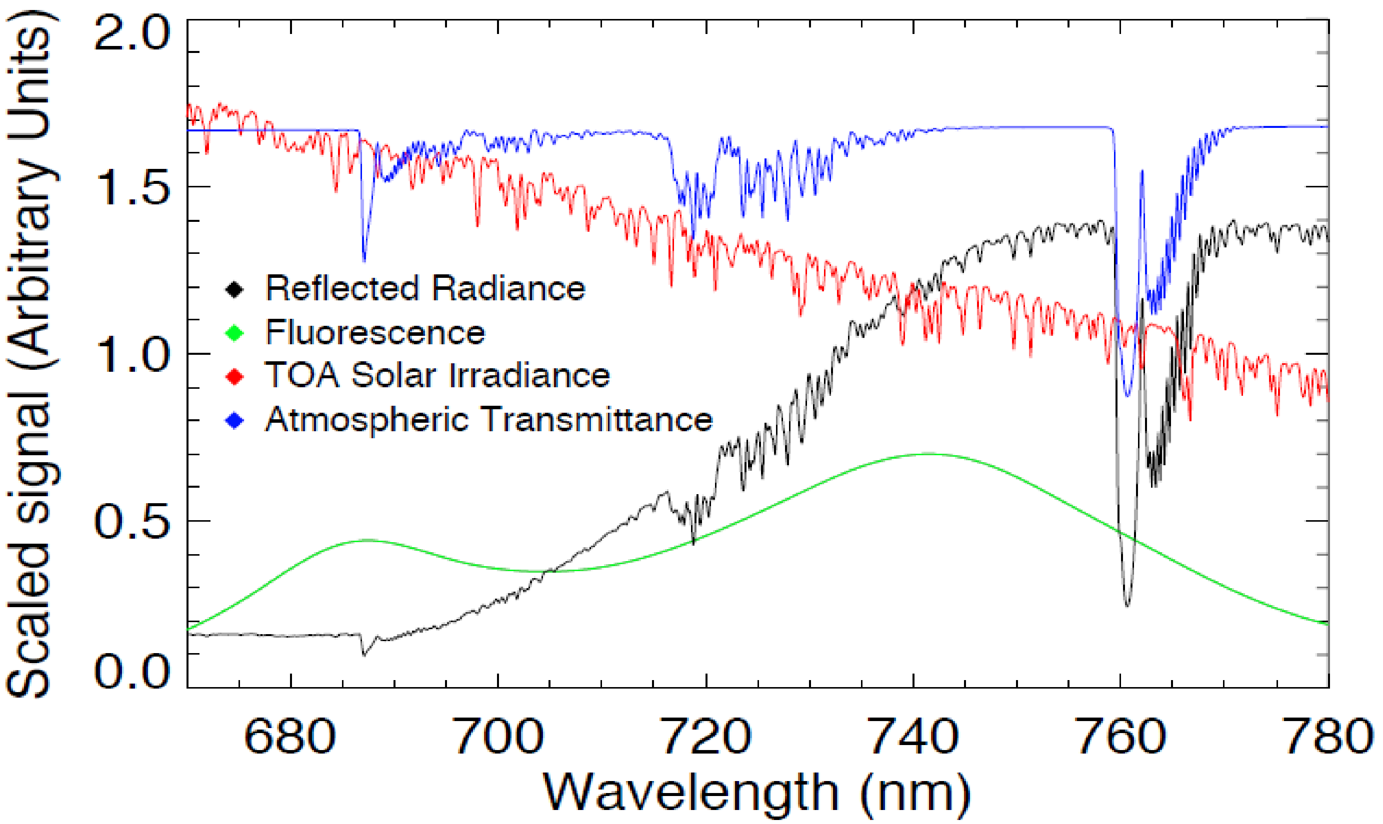
Example (FD = Fractional depth, bottom/continuum ratio)

FD(Fs=0)=Li/Lo =3/20 = 0.15

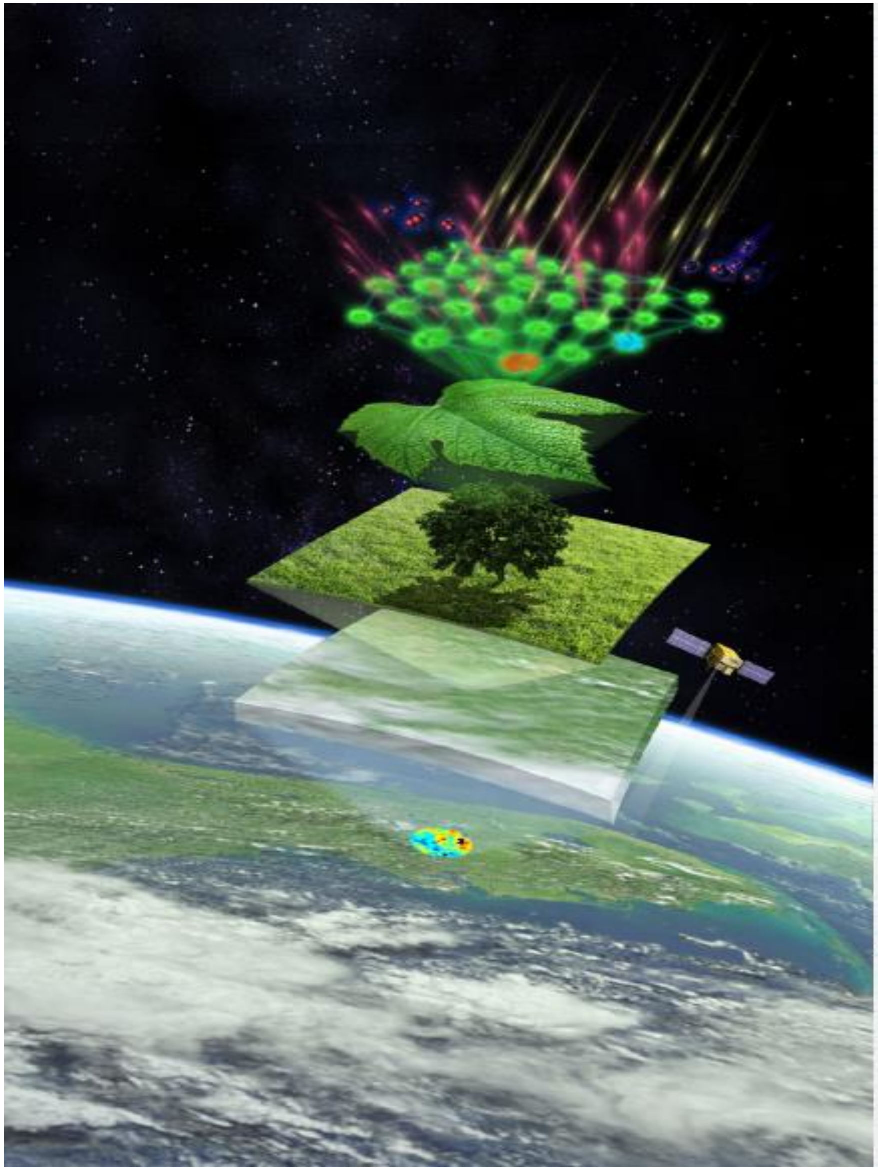
FD(Fs=1)=(Li+Fs)/(Lo+Fs) =4/21 = 0.19

Solar-Induced Chlorophyll Fluorescence

- **The SIF spectrum (650-850 nm) overlaps**
  - Atmospheric bands: O2B (690 nm), water vapor (730 nm), O2A (761 nm)
  - Solar Fraunhofer lines: everywhere



Solar-Induced Chlorophyll Fluorescence



Equation Chain:
Molecules to the Globe

From PAM fluorometry

$$F_t = F'_m\left(1 - \frac{J_e}{a\mathrm{PAR}_{(PSII)}}\right)$$

$$\mathrm{SIF} \approx F_t \cdot a\mathrm{PAR}$$

Non-photochemical quenching to the "tipping point"

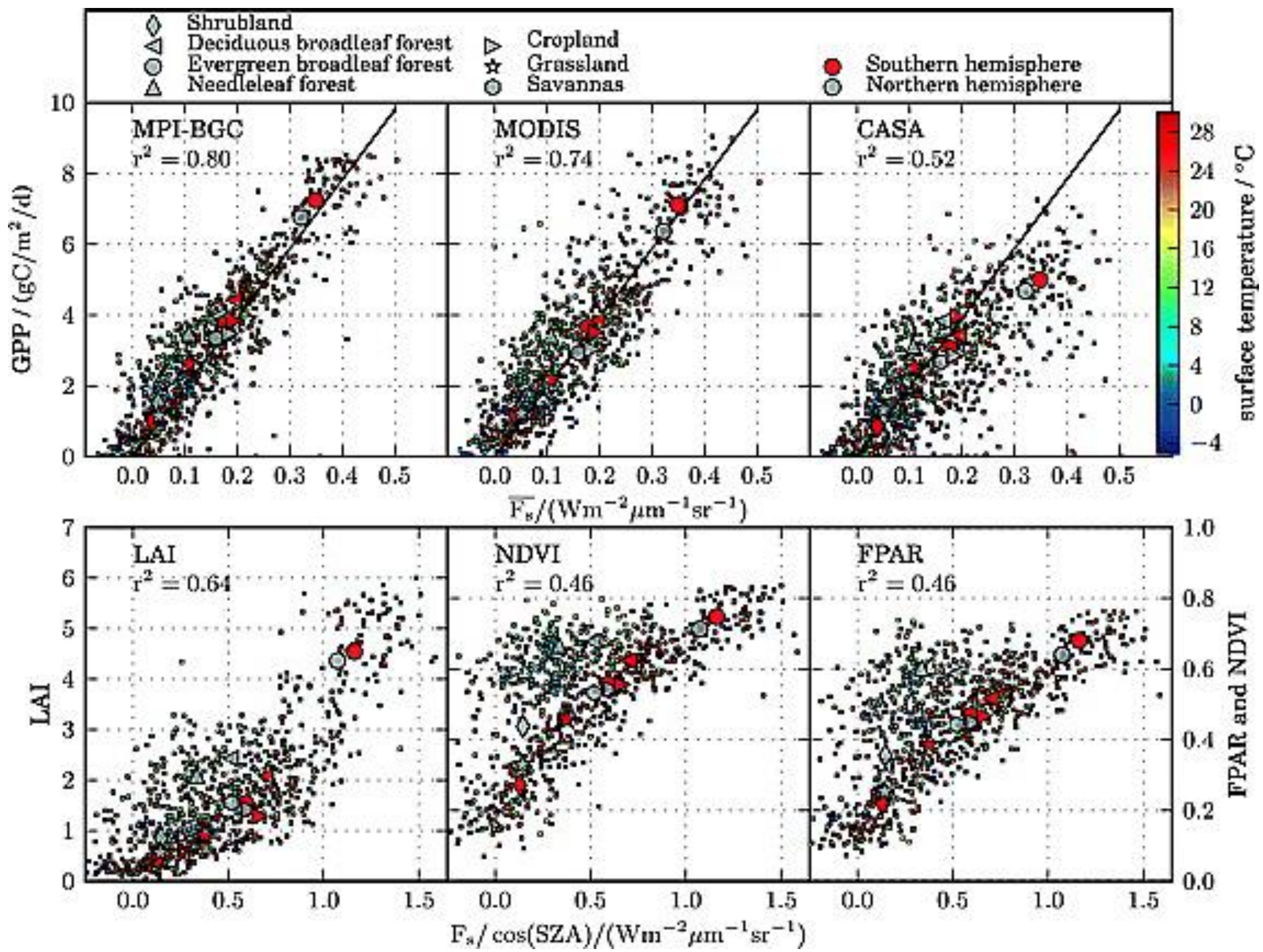
$$k_{NPQ} = f(x), x = 1 - \frac{J}{J_o}$$

SIF to GPP; from flux sites and satellites

$$\begin{cases} \mathrm{GPP} = \mathrm{PAR} \cdot \mathrm{fPAR} \cdot \epsilon_P \\ \mathrm{SIF} = \mathrm{PAR} \cdot \mathrm{fPAR} \cdot \epsilon_F \\ \mathrm{GPP} = \frac{\epsilon_P}{\epsilon_F} \cdot \mathrm{SIF} \end{cases}$$

Solar-Induced Chlorophyll Fluorescence

Frankenberg, C., Fisher, J. B., Worden, J., Badgley, G., Saatchi, S. S., Lee, J. E., ... & Yokota, T. (2011). New global observations of the terrestrial carbon cycle from GOSAT: Patterns of plant fluorescence with gross primary productivity. *Geophysical Research Letters*, *38*(17).



1. The TanSat satellite

TanSat is the first Chinese satellite and the third satellite after the GOSAT of Japan and OCO-2 of the US dedicated to the monitoring and detection of carbon dioxide (CO_2) from space, which was launched on December 21, 2016.

The characters of TanSat satellite

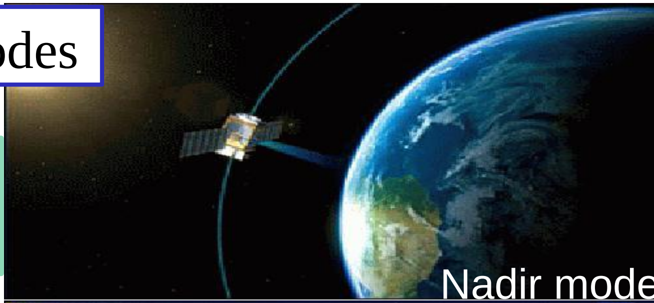
Name	Characters
Orbit type	Sun-synchronous
Altitude	700 km
Inclination	98^0
Local time	13:30
Weight	620 kg
Revisit period	16 days

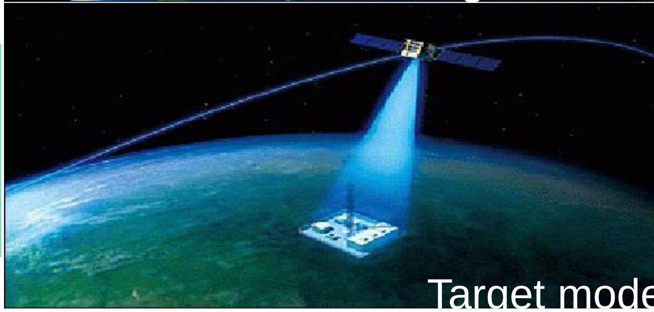
3 observation modes

Observation over land;
Push broom;

Observation over ocean;
Sun glint track;

Observation validation;
Surface target track;





1. The TanSat satellite

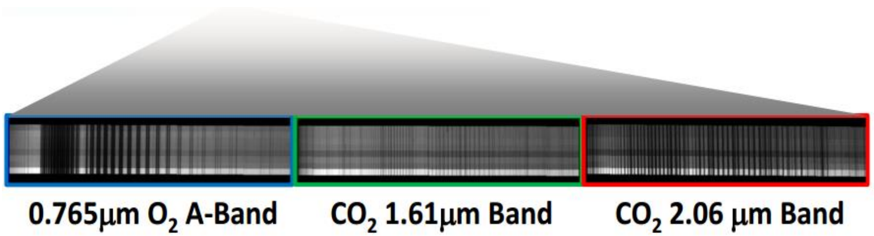
- **Main payloads of TanSat:**

Atmospheric Carbon dioxide Grating Spectroradiometer (ACGS)

Cloud and Aerosol Polarimetry Imager (CAPI).

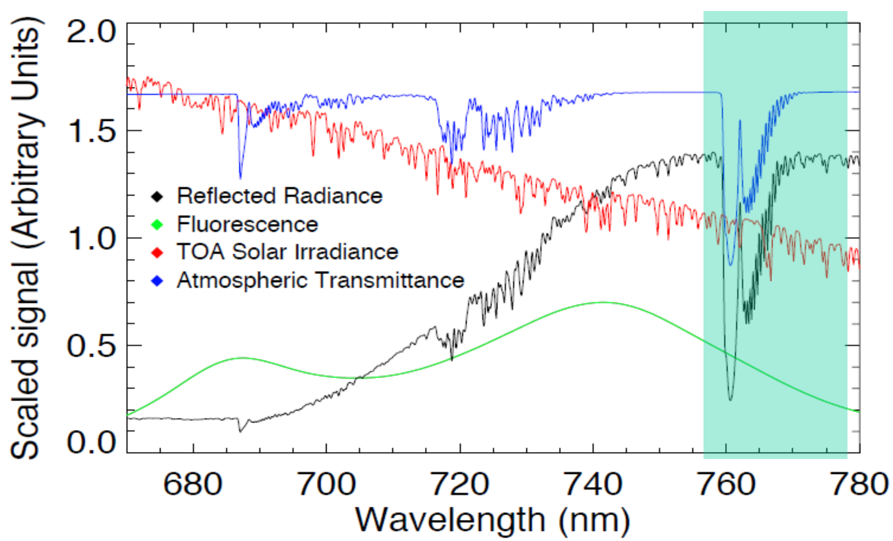
Specification of TanSat-ACGS

Band	**O_2-A**	**Weak CO_2**	**Strong CO_2**
Spectral Coverage (nm)	758-778	1594-1624	2042-2082
Spectral Resolution (nm)	0.044	0.12	0.16
SNR	360@15.2	250@2.6	180@1.1
Spatial Resolution	2 km × 2 km		
Swath	20 km		



Specification of TanSat-CAPI

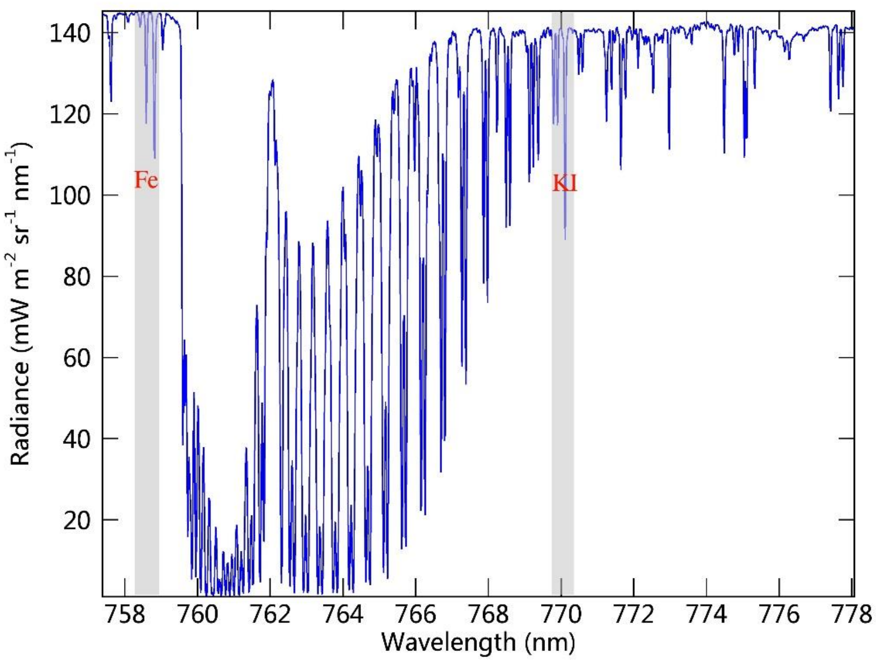
Band	**Range**	**SNR**	**FOV**	**pixels**
1	365-408	260		1600
2	660-685	160		1600
3	862-877	400	400km	1600
4	1360-1390	180		800
5	1628-1654	110		800



1. The TanSat satellite

- **Fe Frannhofer line at 758.8 nm, KI Fraunhofer line at 770.1 nm for SIF retrieval**

The Fe Fraunhofer lines around 758.8 nm, KI Fraunhofer line at 770.1 nm and the atmospheric absorption band around 760 nm all have potential for use in SIF retrieval. Here, a spectral window covering several Fe Fraunhofer lines around 758.8 nm, which is marked in gray shadow, was selected for SIF retrieval.



TanSat-ACGS L1B Radiance at O_2-A band

$$Radiance = \sum_{i=0}^{6} c_i (Dn - Dn_{dark})^i$$

- Radiance-ACGS radiance in Level 1B data;
- c_i - Radiometric calibration gain;
- Dn-The digital number of ACGS's response in observational model;
- Dn_{dark} - The digital number of dark signal of ACGS;

$$\lambda = \sum_{i=0}^{5} C_i \cdot P^i$$

- P refers to the pixel number
- Ci refers to the dispersion coefficients

2. SIF Retrieval method for Tansat

- **SVD data-driven algorithm for SIF retrieval**

The Singular Value Decomposition (SVD) data-driven algorithm, which was firstly used for **global SIF retrieval by Guanter et al. (2012),** was employed to retrieve SIF from the TanSat–ACGS data.

$$L_{TOA} = I_0^{\lambda}\mu[\rho_0^{\lambda} + \frac{\rho_s^{\lambda} \cdot T_{\downarrow\uparrow}^{\lambda}}{\pi}] + SIF_{TOA}^{\lambda}$$

$$M = U\,\Sigma\,V^T$$

$$R_{TOA} = \sum_{i=1}^{n_v} \omega_i v_i + F_s^{TOA} \cdot I$$

$$\boldsymbol{Ax} = \boldsymbol{L_{TOA}}$$

$$A = [V, I] \quad x = [\omega_i, SIF_{TOA}]^T$$

The following rules were designed for the selection of the training samples:

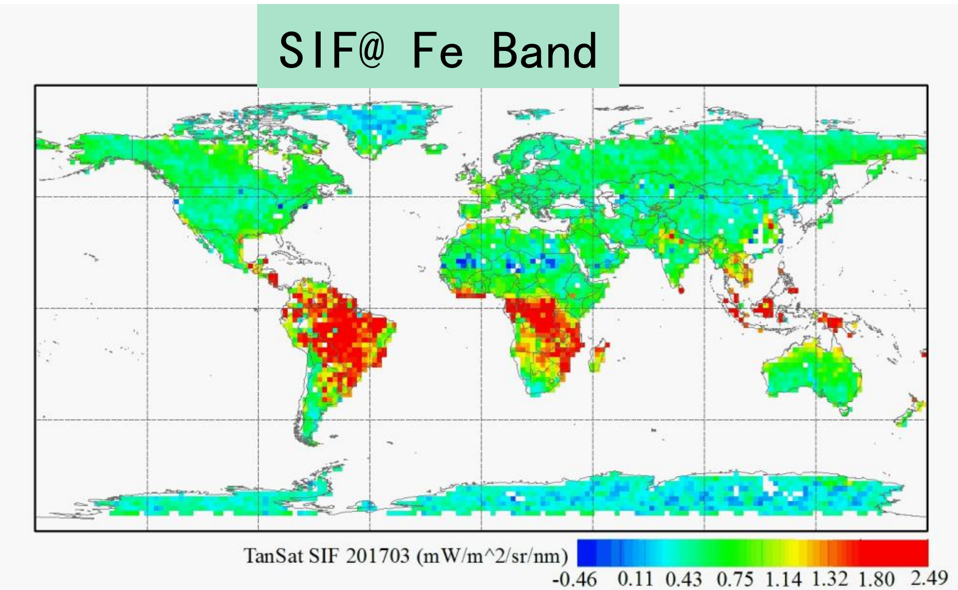
(1) Non-vegetated surface (bare soil or snow)

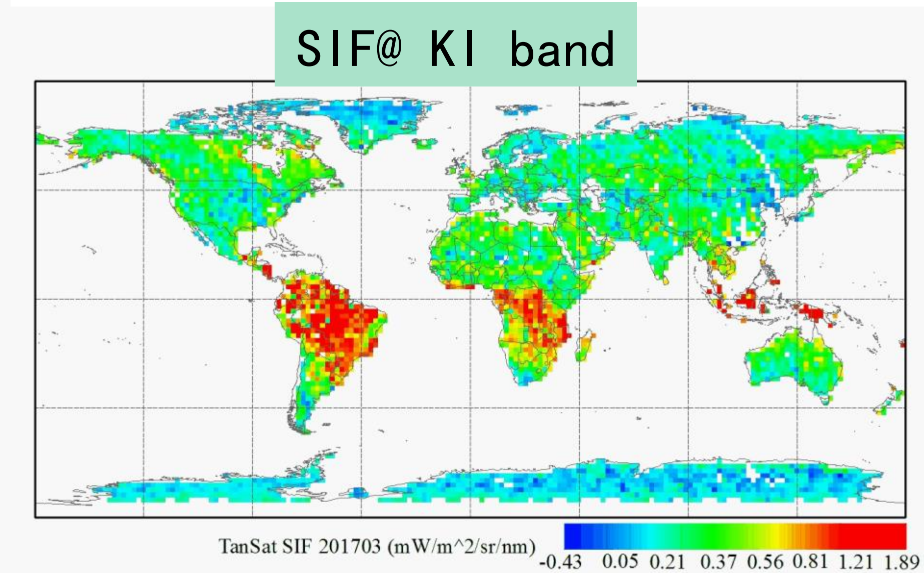
(2) Normalized and averaged at-sensor radiance at O_2-A band within the range 25 to 200 mW m^{-2} sr^{-1} nm^{-1}

(3) Uniform distribution with latitude to guarantee the representativeness of the sun zenith angle (SZA) for the training samples

3. The results of TanSat SIF retrieval

- **Global SIF retrieved from TanSat (2017.3-2019.8)**

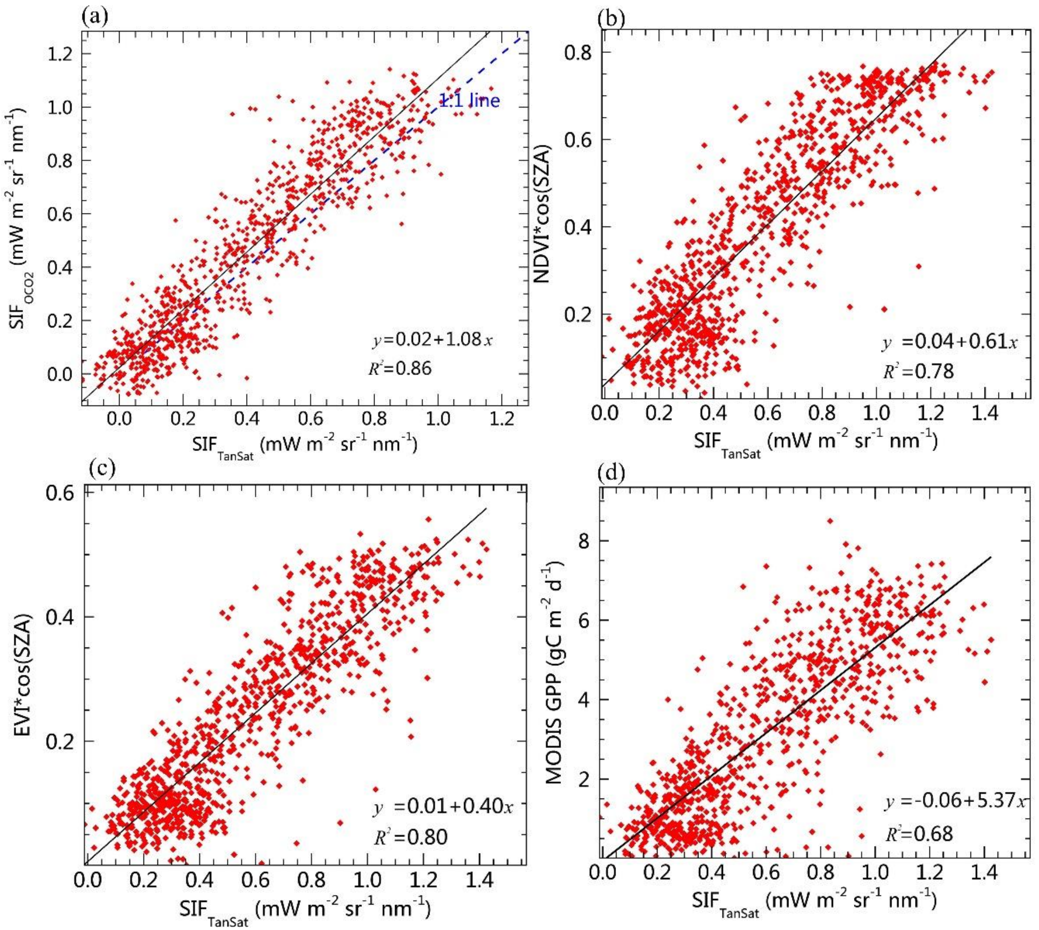




Du, S., Liu, L., Liu, X., Zhang, X., Zhang, X., Bi, Y., & Zhang, L. (2018). Retrieval of global terrestrial solar-induced chlorophyll fluorescence from TanSat satellite. Science Bulletin, 63(22), 1502-1512.

3. The results of TanSat SIF retrieval

- **Quantitative comparison of TanSat SIF with OCO-2 and MODIS Vegetation indices**



The high consistency between TanSat and OCO-2 SIF products (R^2=0.86) and the consistency between the spatial patterns in the TanSat SIF and MODIS vegetation indices increase the confidence in the potential and feasibility of TanSat data for SIF retrieval

5. The Hyperspectral Imager on China's GF-5 Satellite

Introduction

- GF-5 Satellite

Introduction

- AHSI is the main payload of GaoFen-5(GF-5) satellite of China’s High Resolution Earth Observation System.
- Application in monitoring and investigation of ecologies, environments, resources, agricultures, forestry, and soil, etc.

Development Timeline

- 2008～2012: Prototype
- 2013～2015: Engineering Model
- 2016～2018: Flight Model
- 2018.05.09: Launched at Taiyuan Satellite Centre

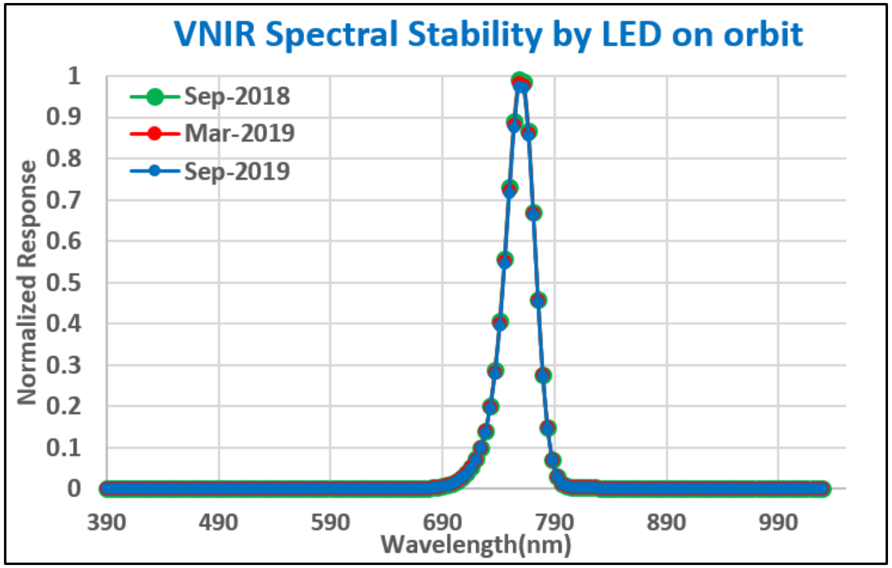
Key Performance

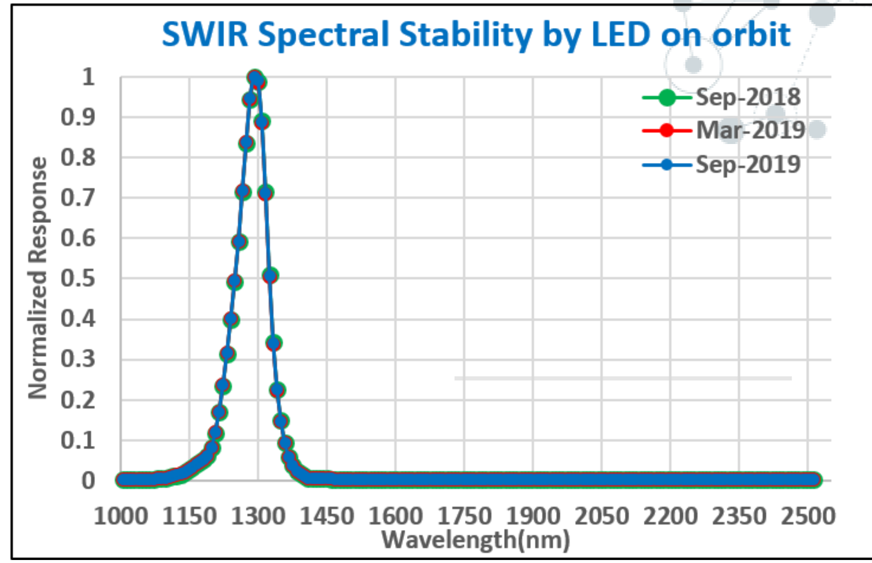
Characteristic	On orbit performance
Spectral Range /μm	0.39~2.513
Spectral Resolution /nm	4.31 (VNIR); 7.96 (SWIR)
Spectral Channels	330
Ground Sampling Distance /m	29.76~29.95
Swath Width /km	59.75
Accuracy of Absolute Radiation Calibration	<2.59% (VNIR); <2.68% (SWIR)
Accuracy of Relative Radiation Calibration	0.35% (VNIR); 0.43% (SWIR)
Accuracy of Spectral Calibration /nm	0.32 (VNIR); 0.55 (SWIR)
X-track spectral error /nm	0.23 (VNIR); 0.20 (SWIR)
SNR	686(600nm); 369(900nm); 452(1200nm); 460(1500nm); 405(1700nm); 194(2400nm)
MTF	~0.3

Key Performance

Paylaoad	Country	F#	Slit length	Dispersion width	Spectral distortion
Hyperion	**USA**	**12**	**15mm**	**9.6mm**	**<1/5 pixel**
CRISM	**USA**	**4.4**	**~20mm**	**10.02mm**	**<1/5 pixel**
CHRIS	**ESA**	**6**	**~18mm**	**3.38mm**	**<1/10 pixel**
M3	**USA/India**	**~4**	**16mm**	**6.21mm**	**<1/10 pixel**
ALOS3	**Japan**	**/**	**30mm**	**1.71mm**	**<1/10 pixel**
ENMAP	**Germany**	**3**	**24mm**	**3.84mm**	**<1/5 pixel**
AHSI	**China**	**2.83**	**60mm**	**30mm**	**<1/10 pixel**

Key Performance



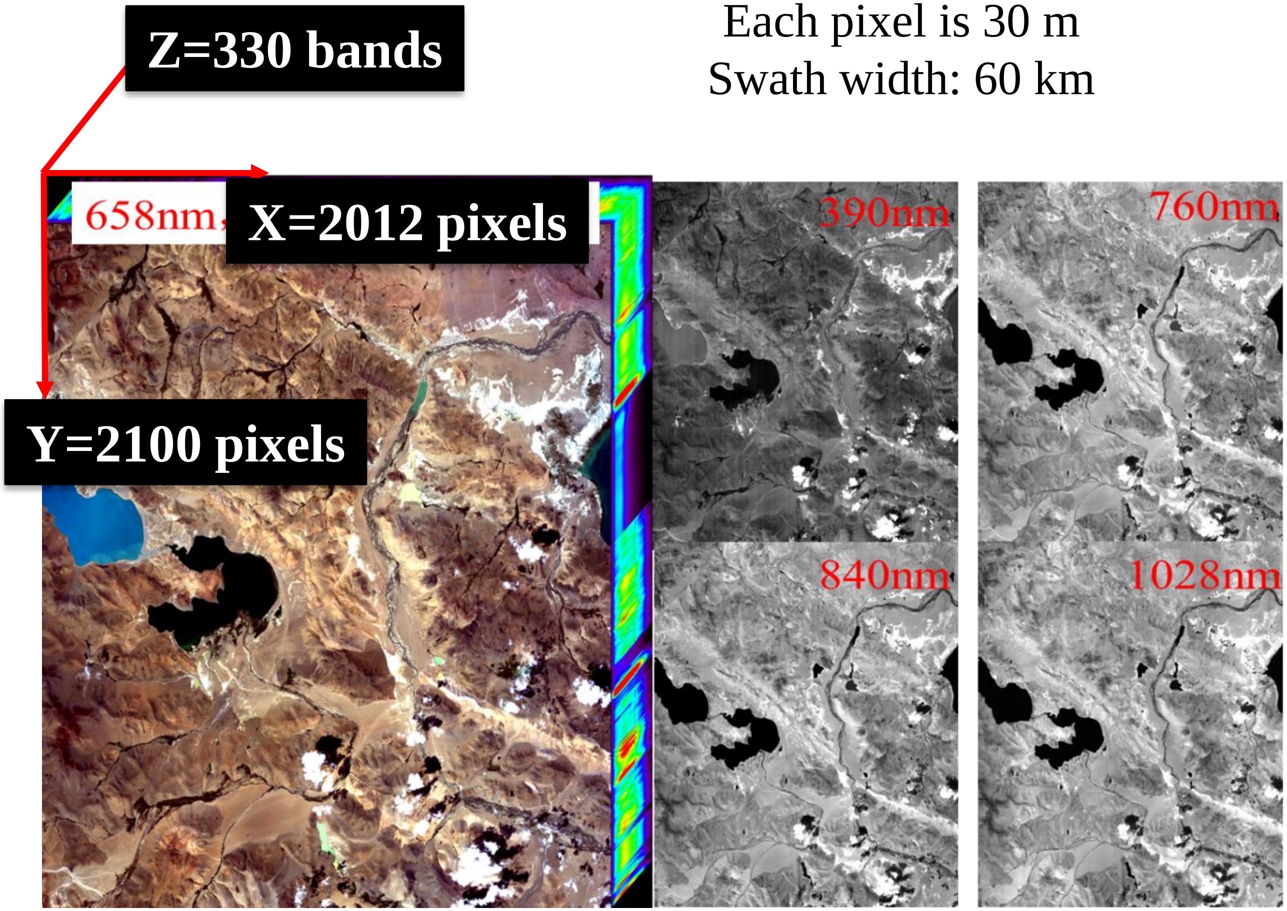


Center Spectral of Typical Band（Band87）	
Sep-2019	758.08 nm
Mar-2019	758.05 nm
Sep-2018	758.01 nm

Center Spectral of Typical Band（Band185）	
Sep-2019	1291.11 nm
Mar-2019	1290.95 nm
Sep-2018	1291.25 nm

Key Performance-Images

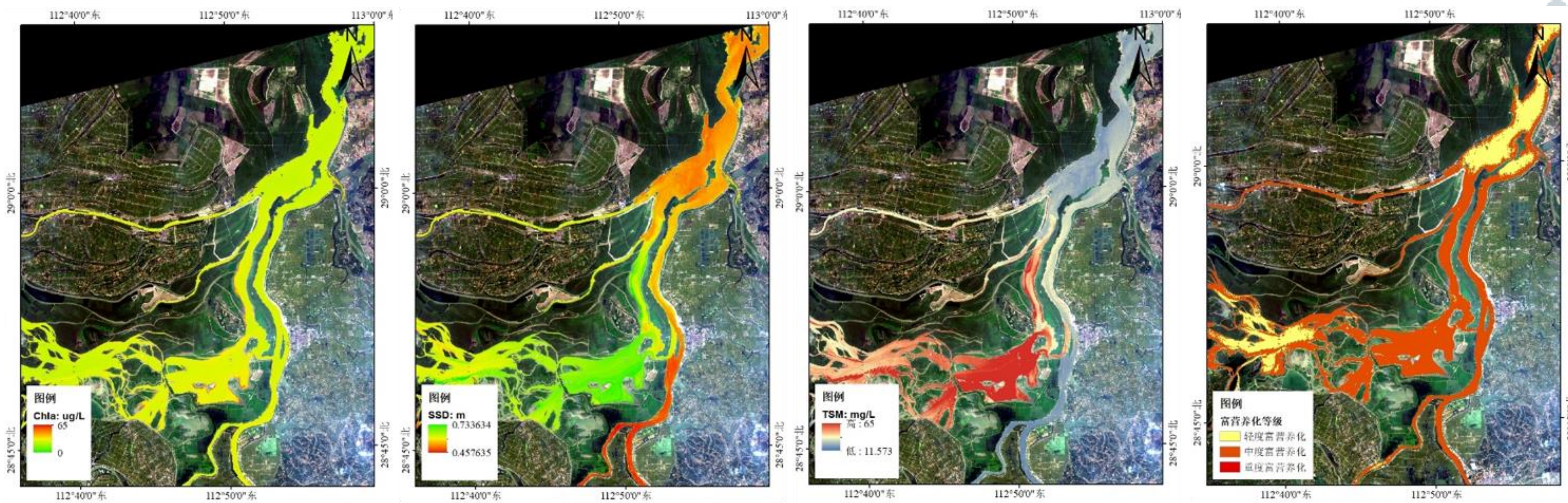
Data Cube



Each pixel is 30 m
Swath width: 60 km

- VNIR Images of Shigatse, Tibet, China, acquired by AHSI in September 11th, 2018

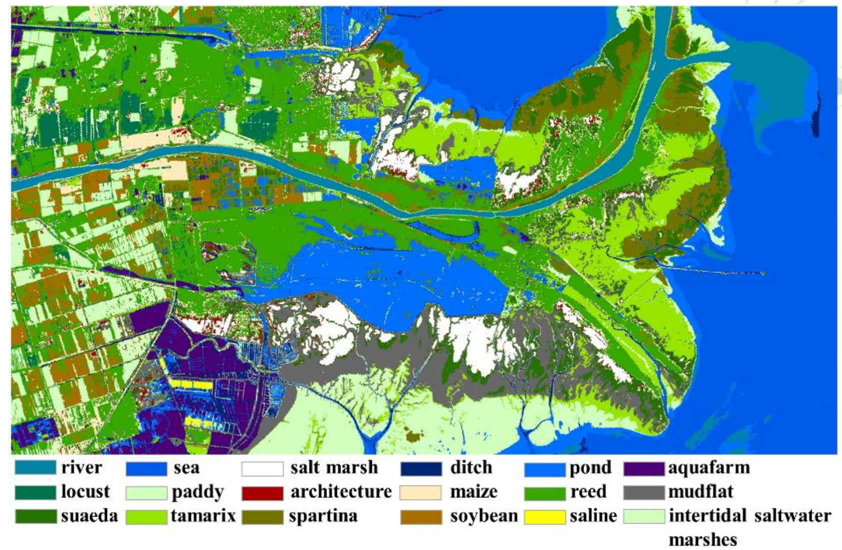
Sample Applications-Water environment monitoring

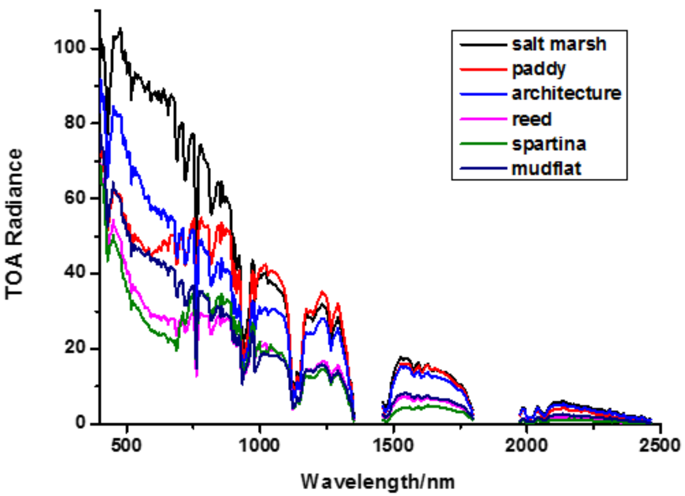


Chla ssd tsm

- Water quality monitoring in Dongting Lake by GF-5/AHSI, 05/10/2018

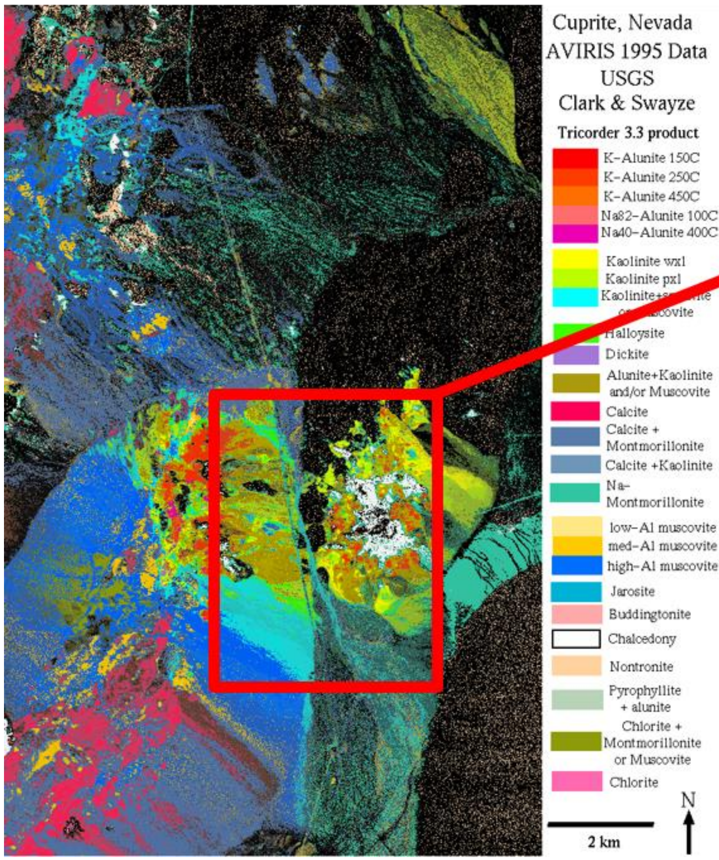
Sample Applications-Classification

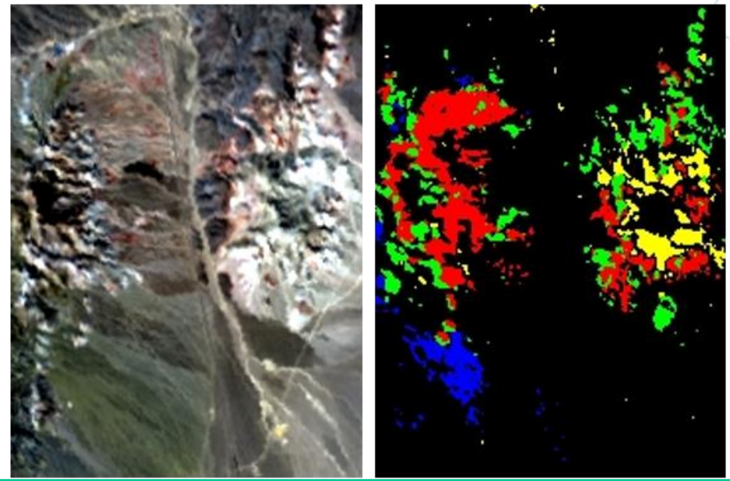




- Yellow River delta, China, 2018/11/01

Sample Application-Mineral Information Extraction





矿物名称Name	SAM（光谱角匹配）		SFF（光谱特征匹配）	
	AHSI	Hyperion	AHSI	Hyperion
明矾石Alunite	91.17%	87.89%	89.78%	80.95%
高岭石 Kaolinite	69.32%	59.56%	78.92%	56.42%
白云母 Muscovite	70.14%	50.68%	70.59%	58.37%
玉髓 Chalcedony	82.71%	46.54%	76.46%	67.74%
结论 Conclusion	Accuracy: AHSI >Hyperion by 17.17%		Accuracy: AHSI >Hyperion by 13.07%	

- Cuprite, Nevada, USA

Summary

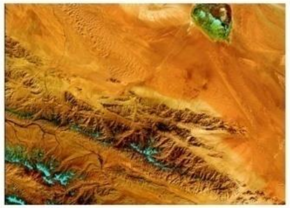
- AHSI is a visible/ short-wave infrared hyperspectral imager aboard China's GF-5 satellite, launched in May 9th, 2018

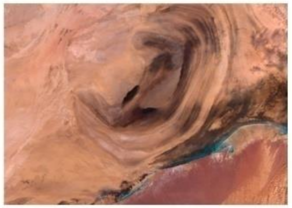
- It has 330 spectral bands, 60 km swath width, and 30 m spatial resolution.

- It features a large FOV telescope, a low-distortion large flat-field fine spectrometer, a large-size infrared focal plane detector, a long-life large cooling capacity cryocooler, a high-precision calibration system, and a high precision image compensation mechanism.

- On orbit test results show that it has stable and good performance(high SNR, low Smile, high calibration accuracy), high image quality, and high quantitative application capability.

Thanks!



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