Introduction to Remote Sensing

Physical principles: Image characteristics and surface properties

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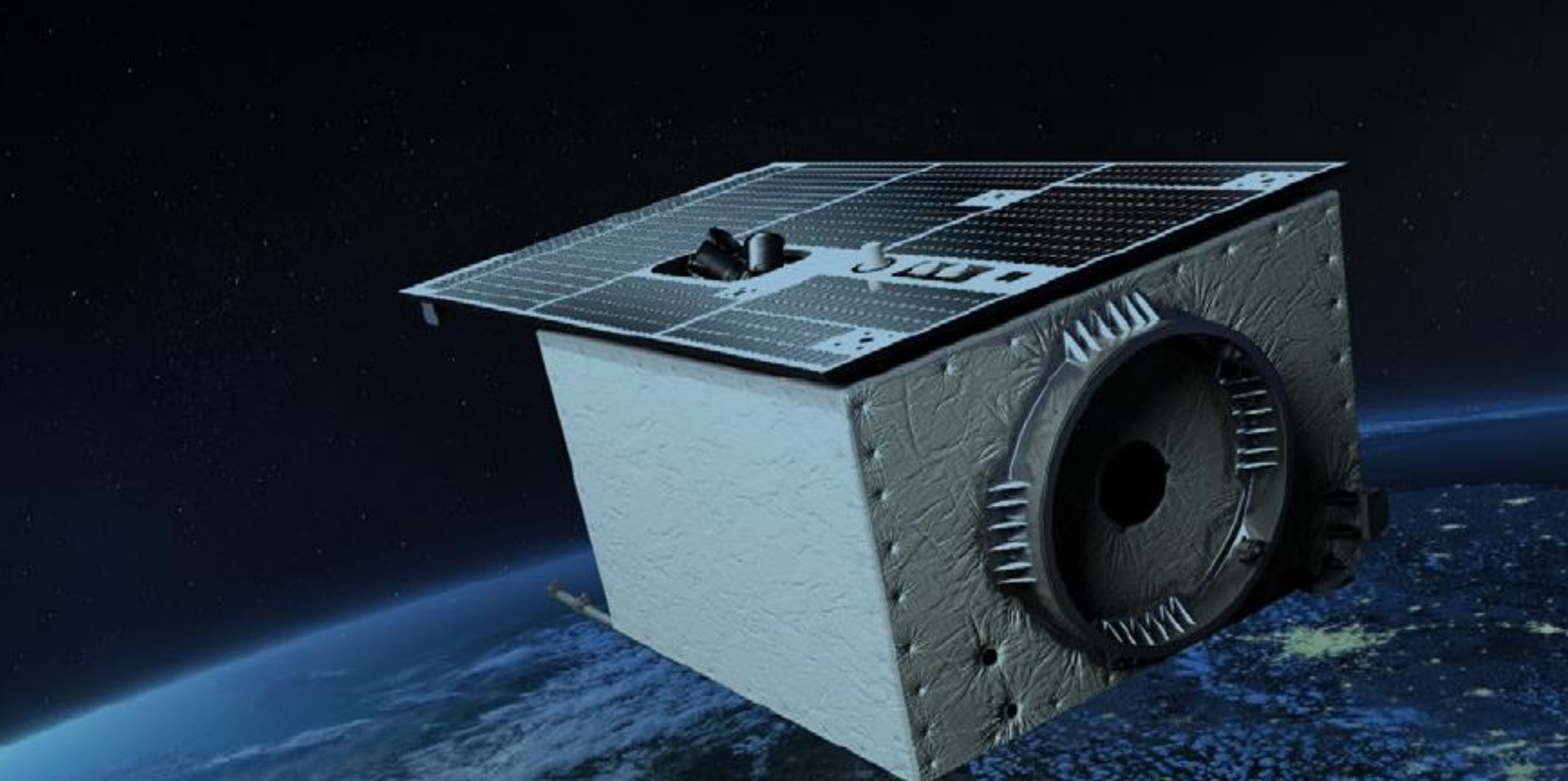
Recapitulation from last week

(1) Name 3 phenomena that illustrate the different resolutions in Google Earth. Which factors drive these phenomena?

(2) Why can we not assume that there will ever be the „ideal remote sensing device" in respect to all the different resolutions?

(3) Which size (in MB) will the following dataset have:
- 5,000 x 7,000 pixels
- 16-bit radiometric resolution
- 9 spectral bands

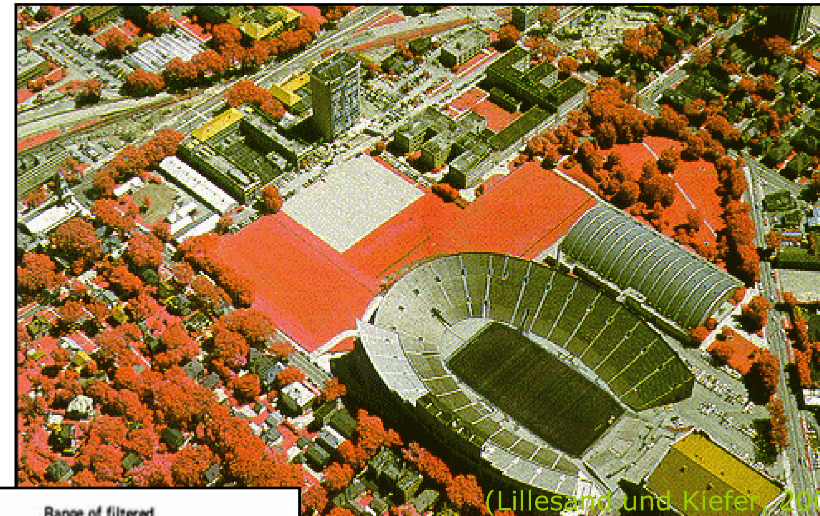


Content

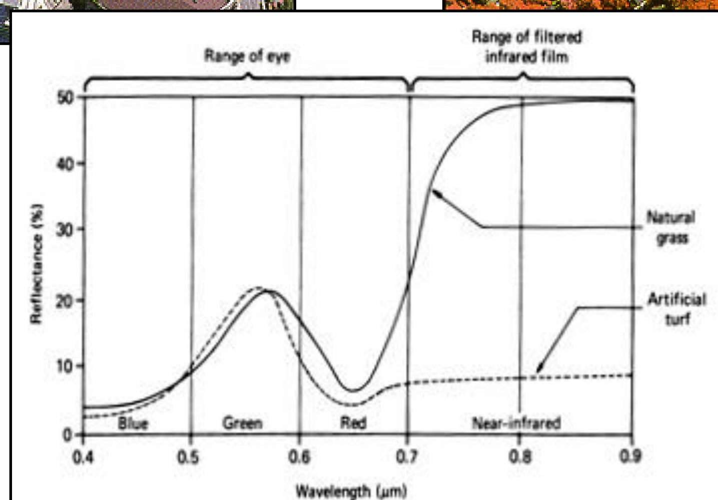
- Wavelengths and spectral properties
- Spectral surface characteristics
- Imaging spectrometers
- Spectral measurements: Demo ASD

The spectral dimension of remote sensing data

True color image of the stadium on the Wisconsin-Madison university campus, US (Lillesand, Kiefer and Chipman, 2008)



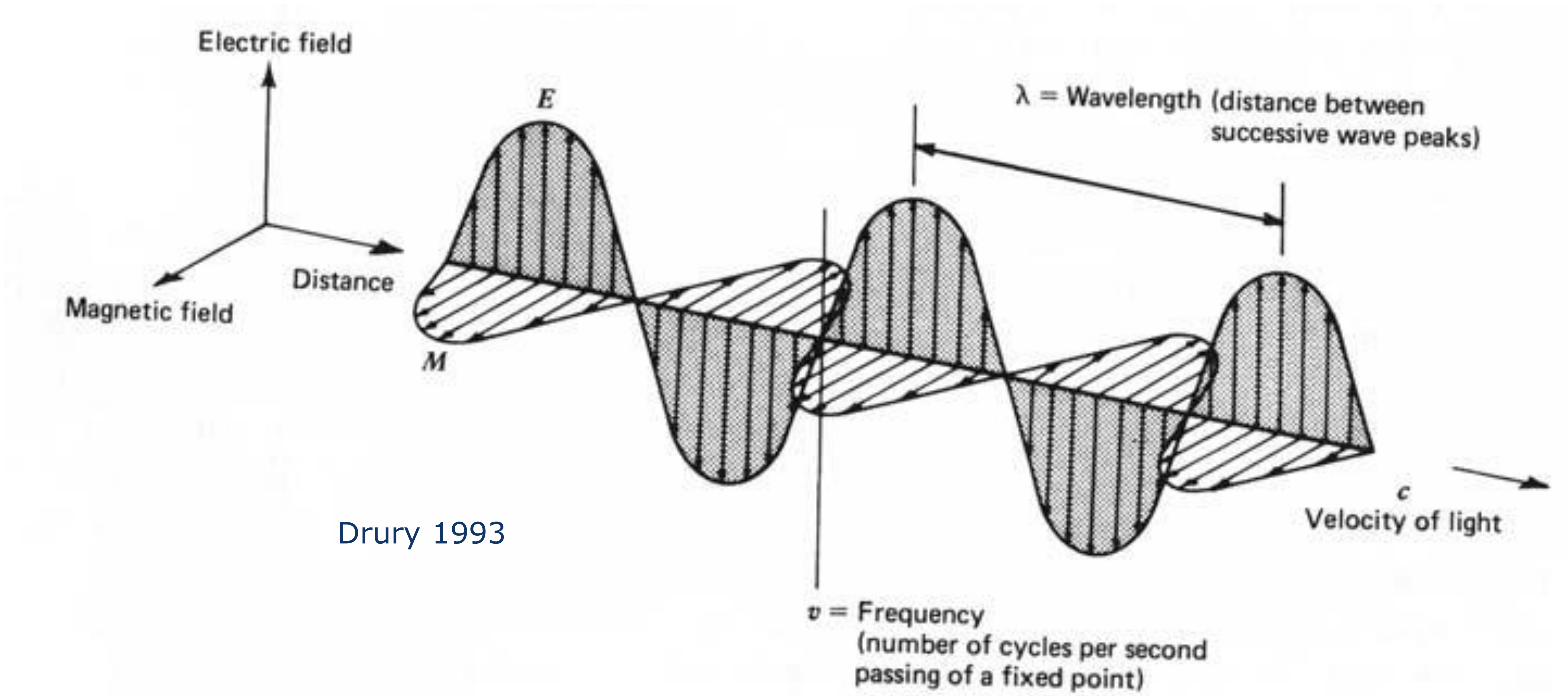
False color infrared image of the stadium on the Wisconsin-Madison university campus, US (Lillesand, Kiefer and Chipman, 2008)



(Lillesand, Kiefer and Chipman, 2008)

- How do we produce such measurements that allow differentiating different surfaces or monitoring changes of surfaces over time?

Basics – what is electromagnetic radiance, what do we measure?
The nature of electromagnetic energy

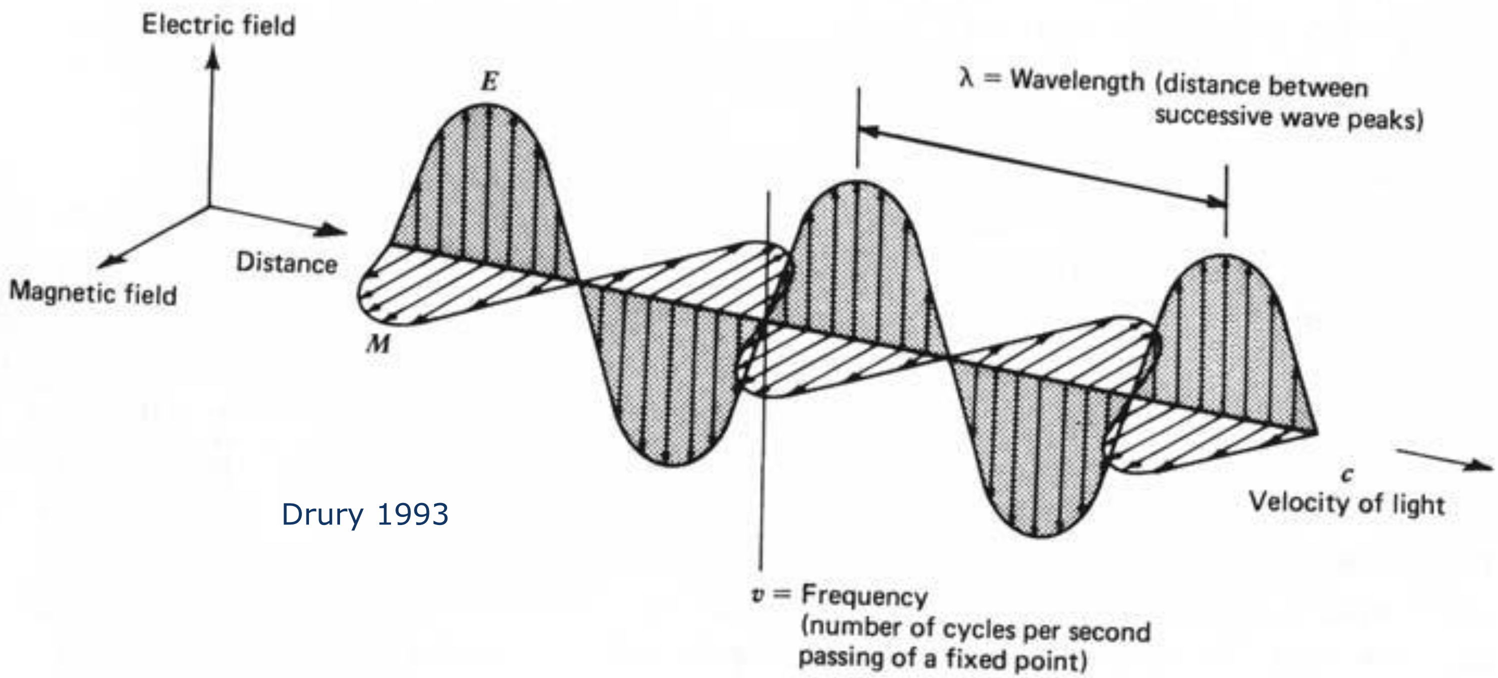


Drury 1993

- Energy (or light) travels as a periodic electromagnetic field (sinusoidal wave)
- Light travels with – surprise! – **speed of light *(c)***
- Relevant characteristics are ***wavelength*** λ ***[nm]*** and ***frequency*** ν ***[Hz]***

- The wavelength is hence defined according to: $\lambda = c / \nu$

Basics – what is electromagnetic radiance, what do we measure?
The nature of electromagnetic energy



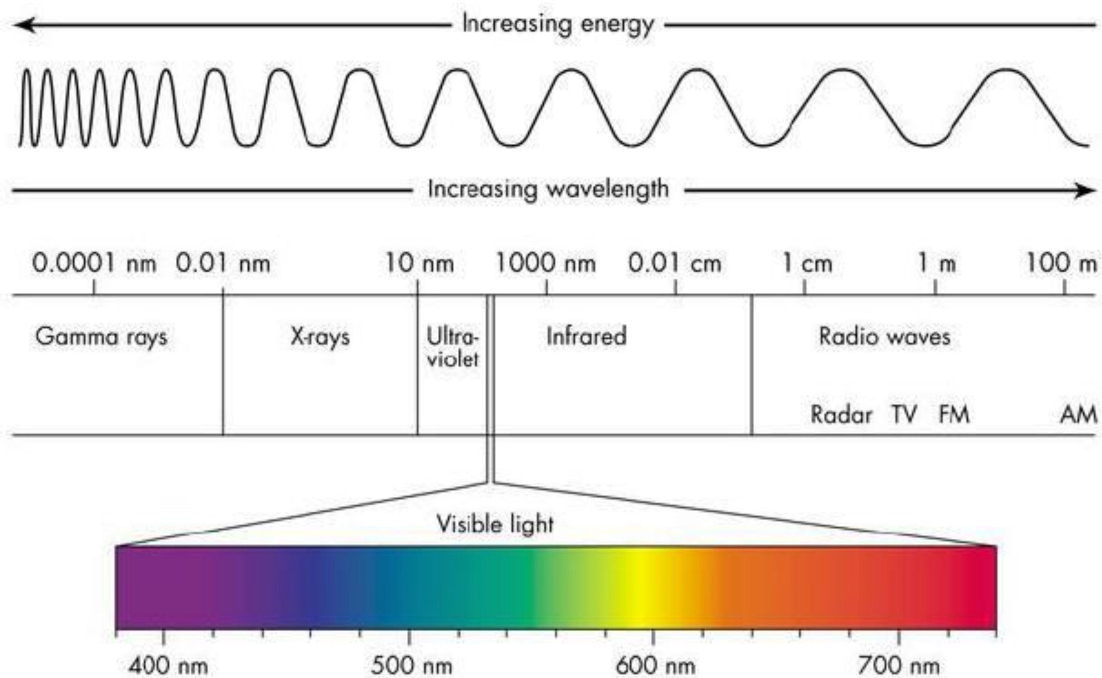
Drury 1993

- In remote sensing, wavelength is the common unit
  1 nm (Nanometer) = 1×10^{-9} m
  1 µm (Mikrometer) = 1×10^{-6} m
  1 mm (Millimeter) = 1×10^{-3} m

- In remote sensing, a target's spectral properties are measured across a wavelength region and in several or even many distinct bands

Basics – what is electromagnetic radiance, what do we measure? Electromagnetic spectrum

- Spectrometers are sensitive to wavelengths beyond the human eye's sensitivity
- optical remote sensing makes use of the visible light (~400-700 nm), and the near and short-wave infrared (0,7-~3 µm)
- thermal remote sensing detects thermal infrared radiation (5-15 µm)
- radar remote sensing detects microwave radiation (1 mm-1 m)



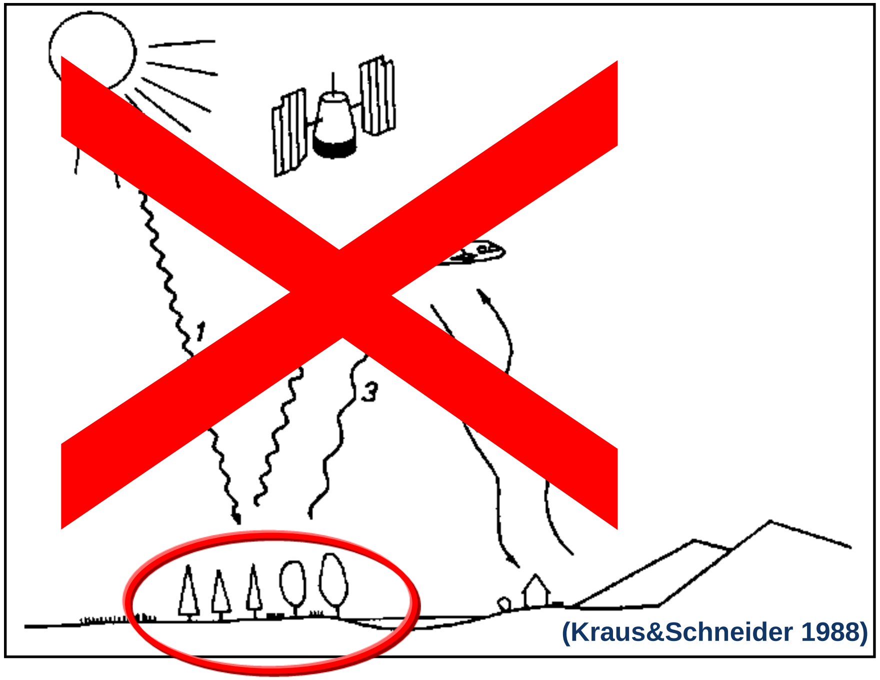
http://www.arm.gov/news/facility/post/5946

Abbreviations:

VIS = visible: 400-700 nm
nIR = near infrared: 0.7-1.3 µm
SWIR = short wave infrared: 1.3-3 µm
tIR = thermal infrared: 5-15 µm

Basics – what is electromagnetic radiance, what do we measure?
Measuring surface properties

- Geo- and environmental sciences are primarily interested in processes at the Earth's surface
- From the interaction between radiation and surface we can draw conclusions on the surface's characteristics
- Each surface's interaction with radiation depends on it's physical and chemical properties and varies with wavelength
- That's the **basis for the entire remote sensing process**

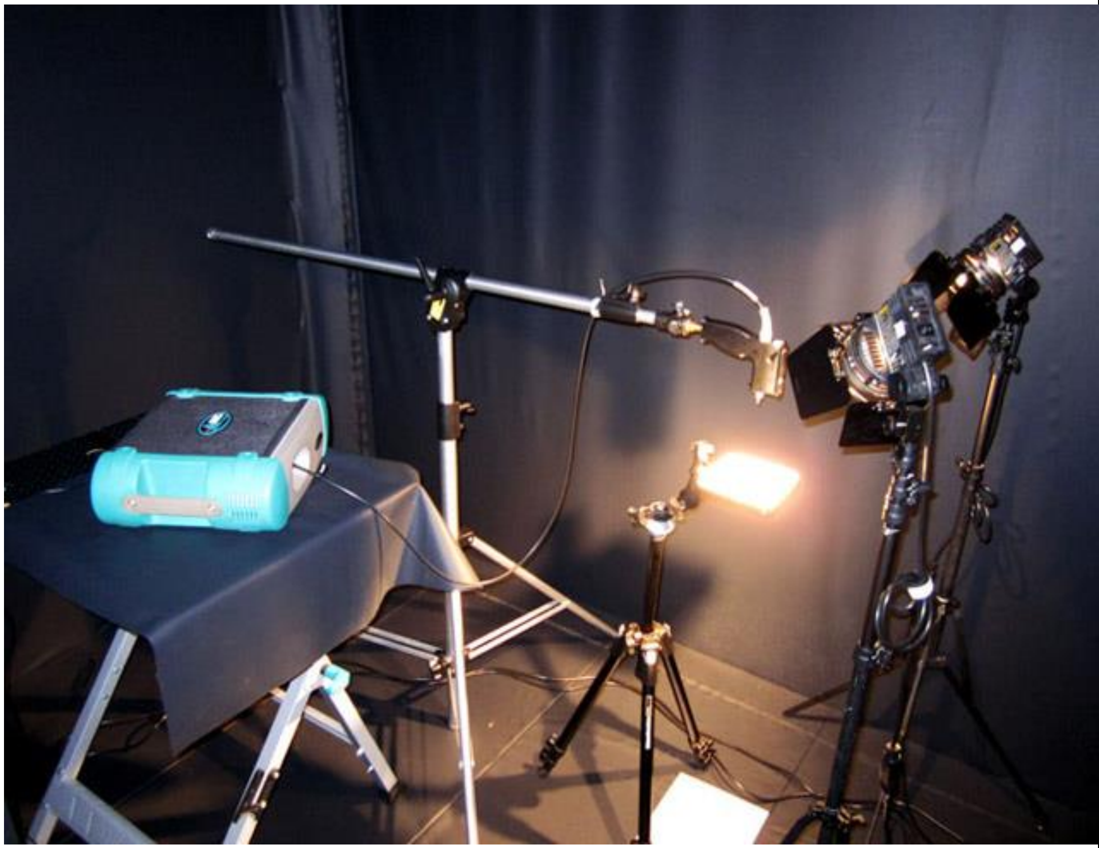


(Kraus&Schneider 1988)

- to start with: let's control illumination and ignore the atmosphere
- Let's assume laboratory conditions (using an artificial light source instead of the sun)

Basics – what is electromagnetic radiance, what do we measure? A laboratory setup

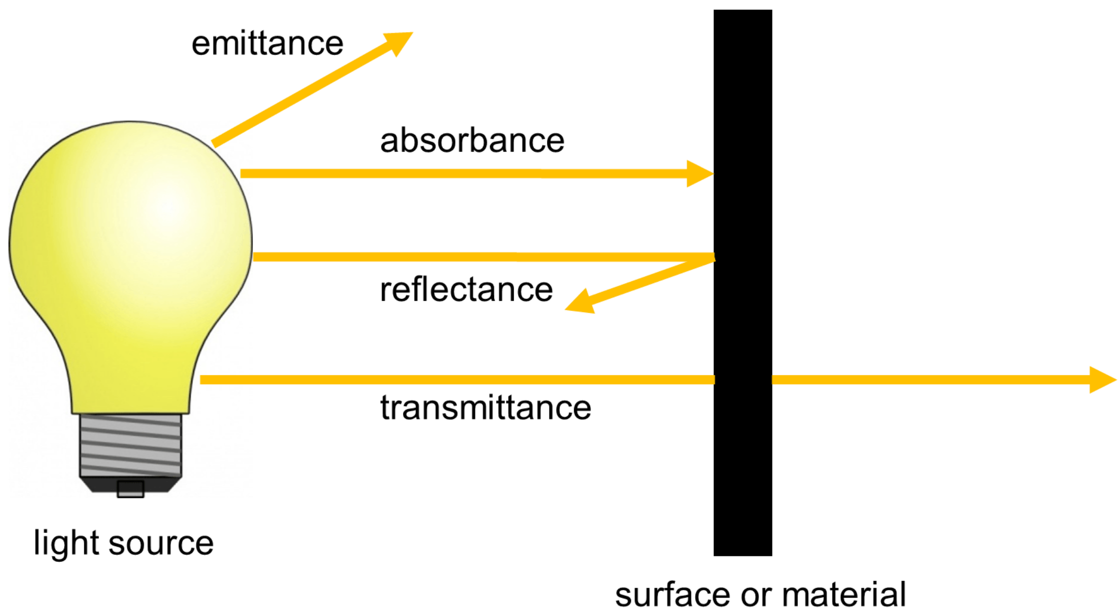
- Lab measurements are performed with a spectrometer and allow an exact characterization of a surface
- We control illumination by using a lamp
- We control the distance and angle to the surface to be measured (usually nadir measurement)
- We control the instrument calibration, i.e. we measure and eliminate the noise from the signal



Typical laboratory setup with an ASD spectrometer (in blue), the fiber optics ending in a pistol grip mounted on a tripod and a video spot as articial illumination source. The bright target on the smaller tripod is a calibration panel.
http://www.lineas.cchs.csic.es/biospec/methods/laboratory

Basics – what is electromagnetic radiance, what do we measure?
Measuring target radiance

- In Earth remote sensing, we perform measurements from above, i.e. we are interested in the reflected portion of the energy
- At any surface, incoming radiation is either partially or fully:
  - reflected (ρ)
  - absorbed (α)
  - transmitted (τ)
- The sum of all three terms is always 100% of the in-coming radiance:
  $\boldsymbol{\rho + \alpha + \tau = 1}$
  (Law of conservation of energy)

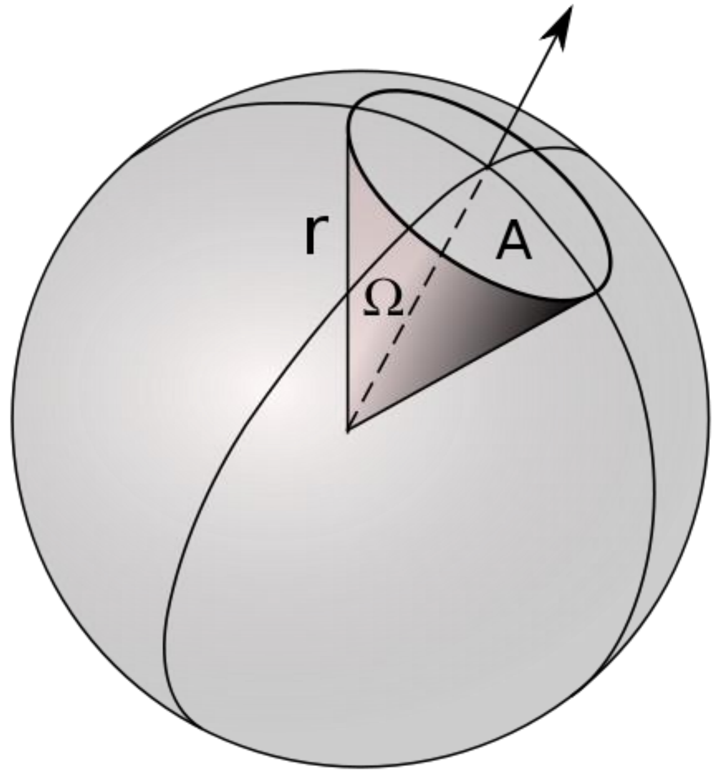


http://www.edaphic.com.au/emittance-absorbance-reflectance-transmittance/

- the physical quantity measured by the sensor is **radiance**
- The unit of radiance is watts per square meter per steradian: $W \bullet m^{-2} \bullet sr^{-1}$

Basics – what is electromagnetic radiance, what do we measure?
Excursus – solid angle

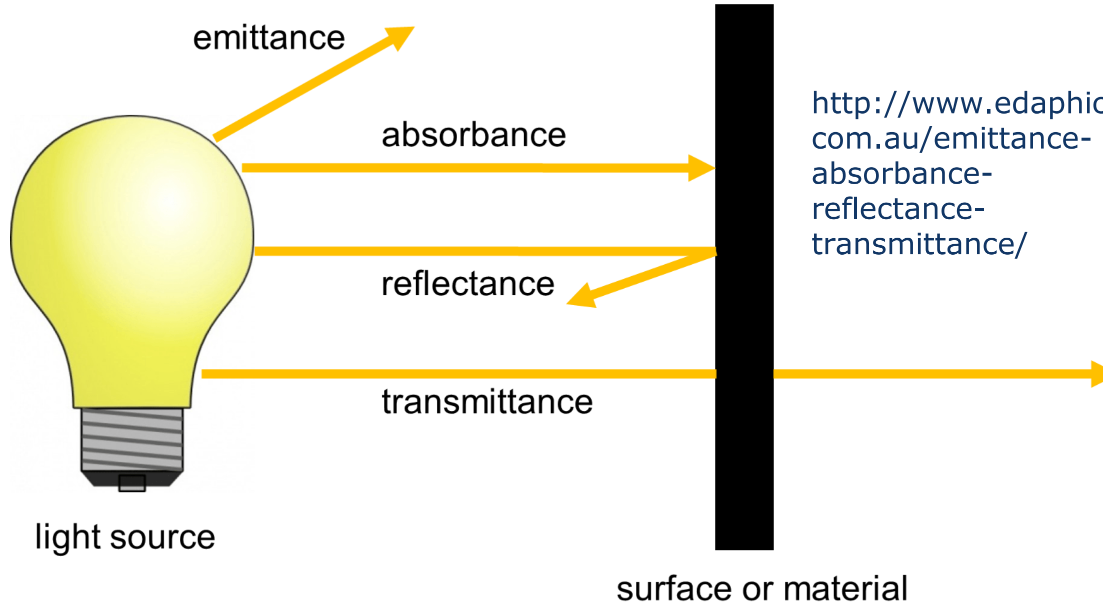
- A three-dimensional angle is called ***solid angle Ω***:
- Definition *Ω:* the area A cut out from a sphere with the radius r
- unit: ***steradian [sr]***
- Ω = 1 sr if a conus cuts an area A of 1 m^2 from a sphere with the radius r=1m



https://de.wikipedia.org/wiki/Raumwinkel

Basics – what is electromagnetic radiance, what do we measure? From radiance to reflectance

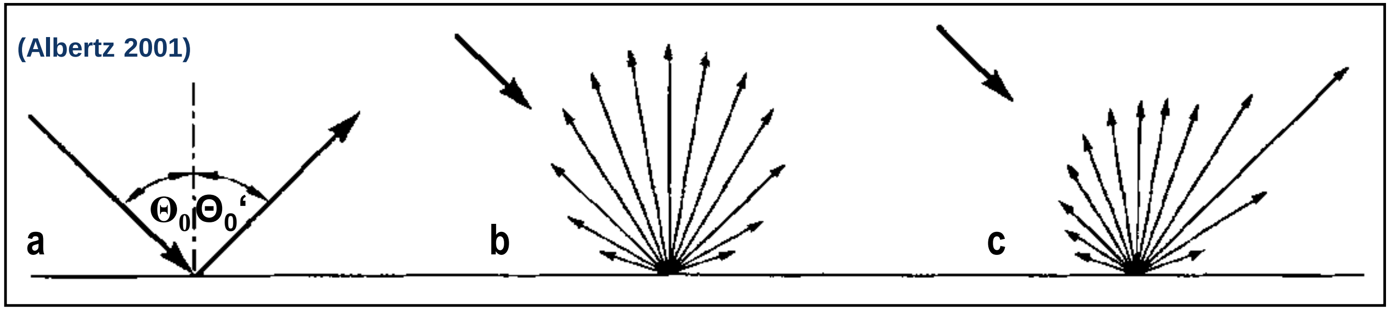
- The problem with radiance as the unit of measure: it varies with illumination
- Needed: a stable measurement over time, independent of illumination, to avoid introducing changes when measuring unchanged surfaces



http://www.edaphic.com.au/emittance-absorbance-reflectance-transmittance/

- Solution: normalize the measurement relative to the irradiation
- The ratio between radiance reflected at the Earth's surface and the incoming radiation is called ***reflectance***
- Reflectance = $Rad_{reflected}/Rad_{incoming}$
- reflectance is the percentage of the total measurable radiation, which has not been absorbed or transmitted

Basics – what is electromagnetic radiance, what do we measure? Diffuse und direct reflectance



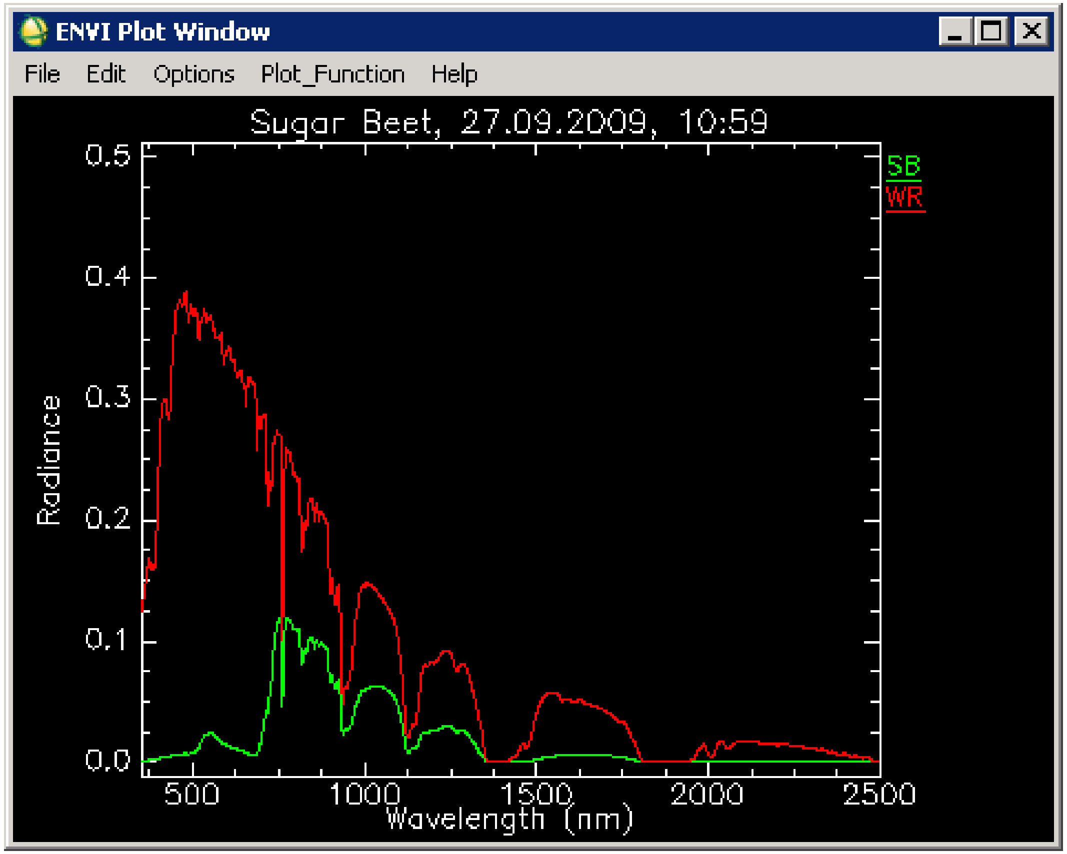
a) direct
b) Lambert
c) mixed

- The observation direction influences the measured signal
- In most cases, surfaces reflect the incoming radiation diffusely
- A special case is ***Lambert reflectance*** that is often assumed in remote sensing for the sake of simplicity
- Lambert reflectance: the measured signal is independent of the observation direction (no directionality effects in the reflected signal)
- In reality, most surfaces reflect in a mixed way, which can be described by the so called **Bidirectional Reflectance Distribution Function (BRDF)**
- Spectral reference panels (e.g. Spectralon®) are almost Lambert reflectors

Spectral surface characteristics

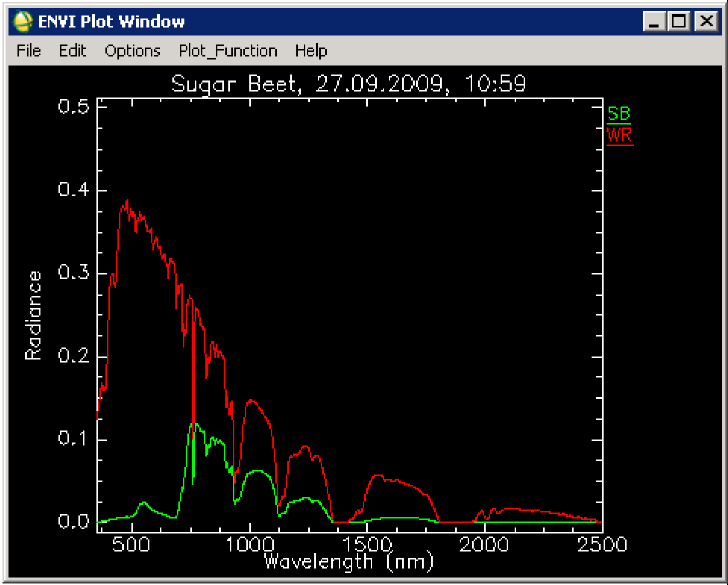
Reflectance Spectra
Introduction

- Example of a vegetation measurement (green) in the field



Reflectance Spectra
White Reference

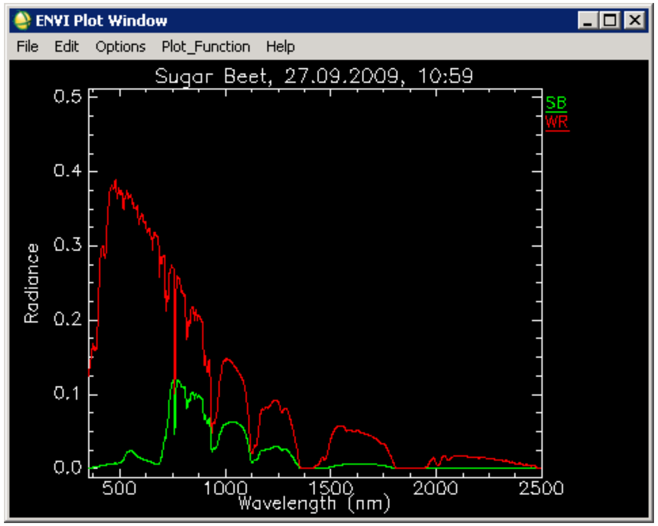
- In addition to the target surface, a white surface is measured
- This so-called ***White Reference*** is a surface with a reflectance of almost 100% across the entire wavelength spectrum
- Spectralon®, alternatively $BaSO_4$
- Reference panels allow measuring the maximum backscatter for a particular point in time and position on Earth
- If a panel reflects 100% across the spectral region of interest, its radiance is the same as the incoming radiance, i.e. it can serve for normalizing to reflectance

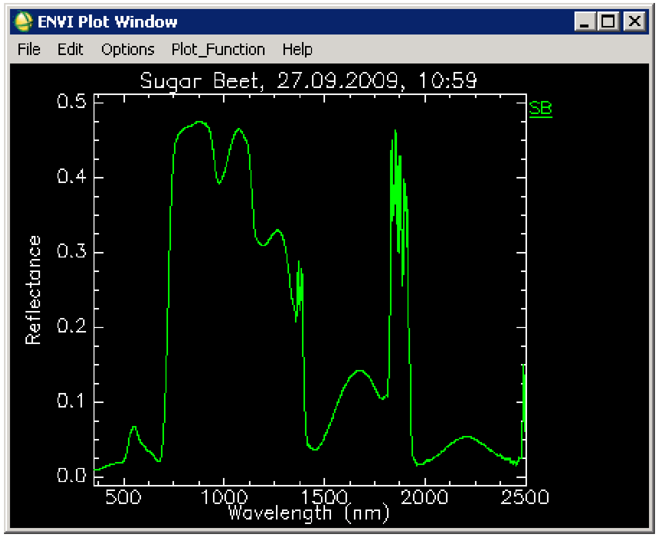


Reflectance Spectra
Reflectance

- The ratio between the target radiance measured and the reference panel (white reference) is hence ***reflectance***
- ***reflectance = Rad_{target}/Rad_{WR}***
- reflectance is the percentage of the total measurable radiation, which has not been absorbed (or transmitted)

- Note: The division by Rad_{WR} can result in considerable noise in wavelength regions with poor signal-to-noise-ratio





Reflectance of Different Surfaces and Materials

Introduction

https://nau.edu/lci/isl/

http://oceanoptics.com/application/agricultural-measurements-monitoring/

http://gallery.usgs.gov/photos/08_11_2010_a1Uh83Jww6_08_11_2010_1#.VipK0n41-Ht

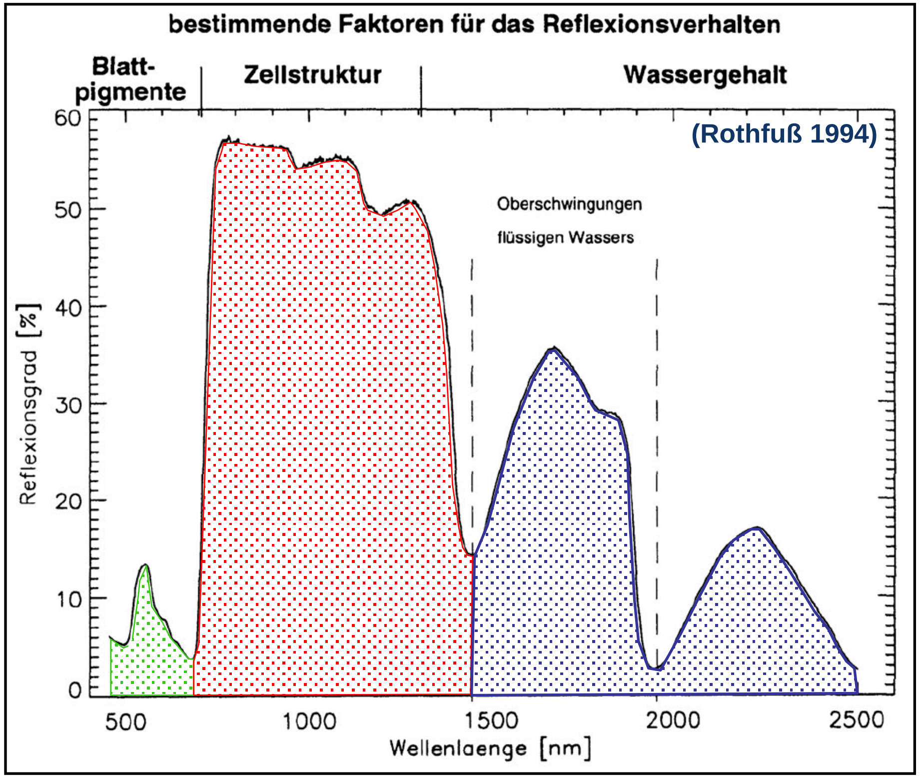
Reflectance of Different Surfaces and Materials
Introduction

- The object-specific influence determines object-specific patterns in the spectrum of recorded electromagnetic radiation
- The change of irradiation at the Earth’s surface results from material-specific absorption
- We distinguish between absorption features due to electron transitions, molecular vibrations und molecular rotation

- Electron transitions require a high amount of energy
  → they occur mostly in the VIS
- Vibration and rotation can lead to narrow absorption bands also in the nIR and SWIR

Reflectance of photosynthetic active vegetation

- Vegetation produces a distinct spectral reflectance pattern due to its leaf and cell structure, its physiognomy, and complex stand structure
- The reflectance of photosynthetically active vegetation is characterized by different factors in the VIS, nIR and SWIR:
  - VIS – leaf pigments
  - nIR – cell structure
  - SWIR – water content



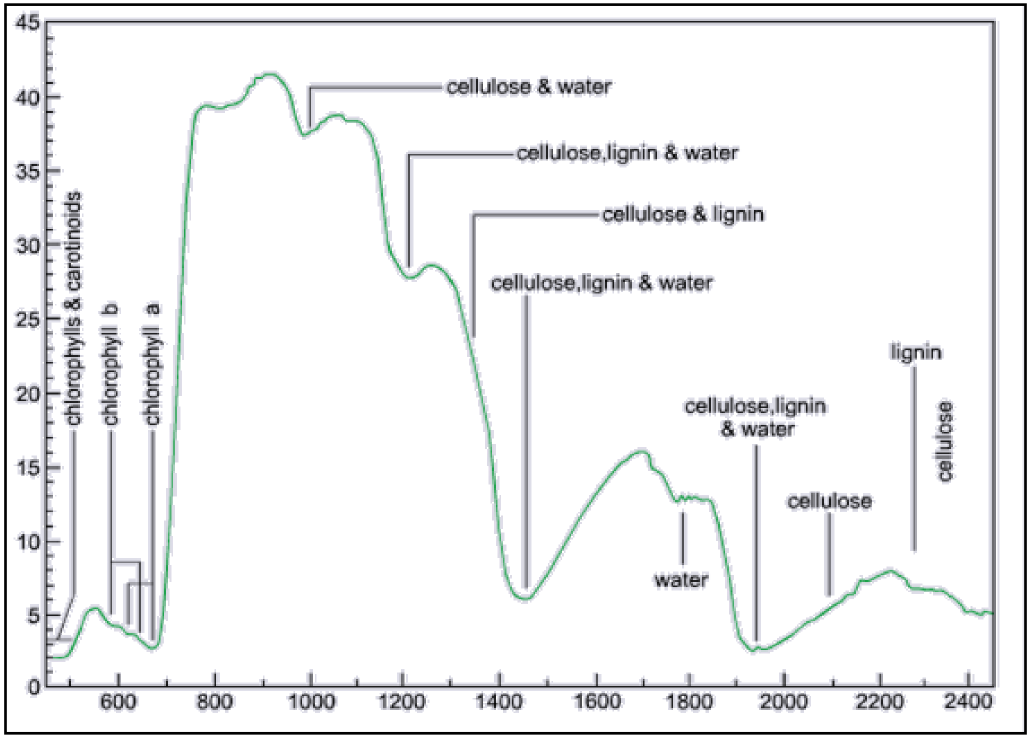
- Photosynthetically inactive plant parts differ considerably from active ones across different wavelength regions

Reflectance of photosynthetic active vegetation Single leaf reflectance

- The reflectance of a single leaf or needle is determined by various absorption, transmission and reflectance characteristics

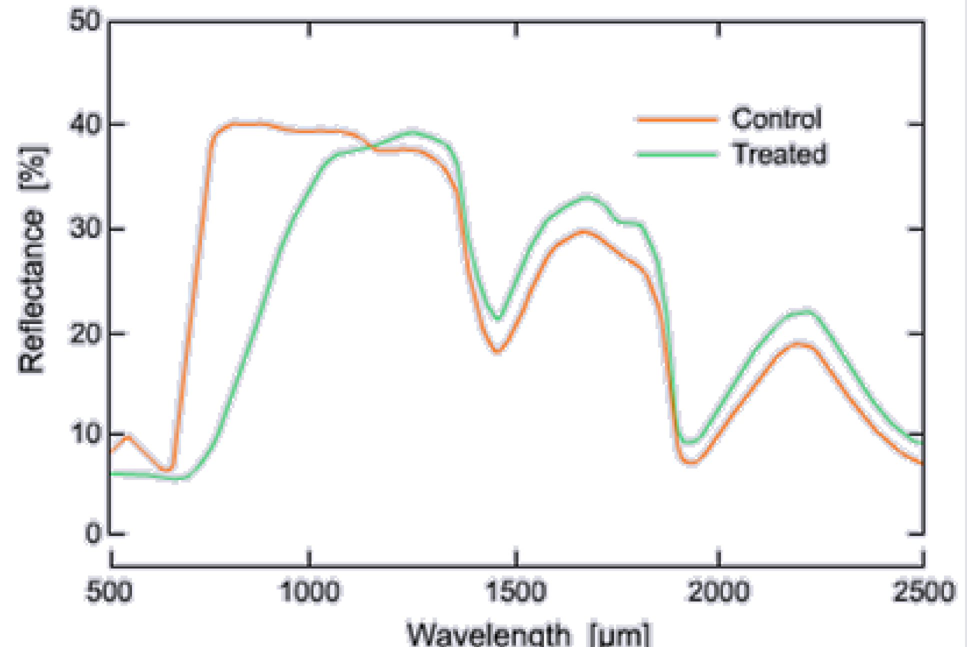
Important characteristics are:

- The local reflectance maximum in the VIS (green peak) is small
- The high reflectance in the nIR results in the so-called "red edge"
- Thus, transmission in the nIR is very high, in the VIS very small
- Lignin and cellulose, and particularly water, lead to high absorption, especially in the SWIR



Reflectance of vegetation – plant stress

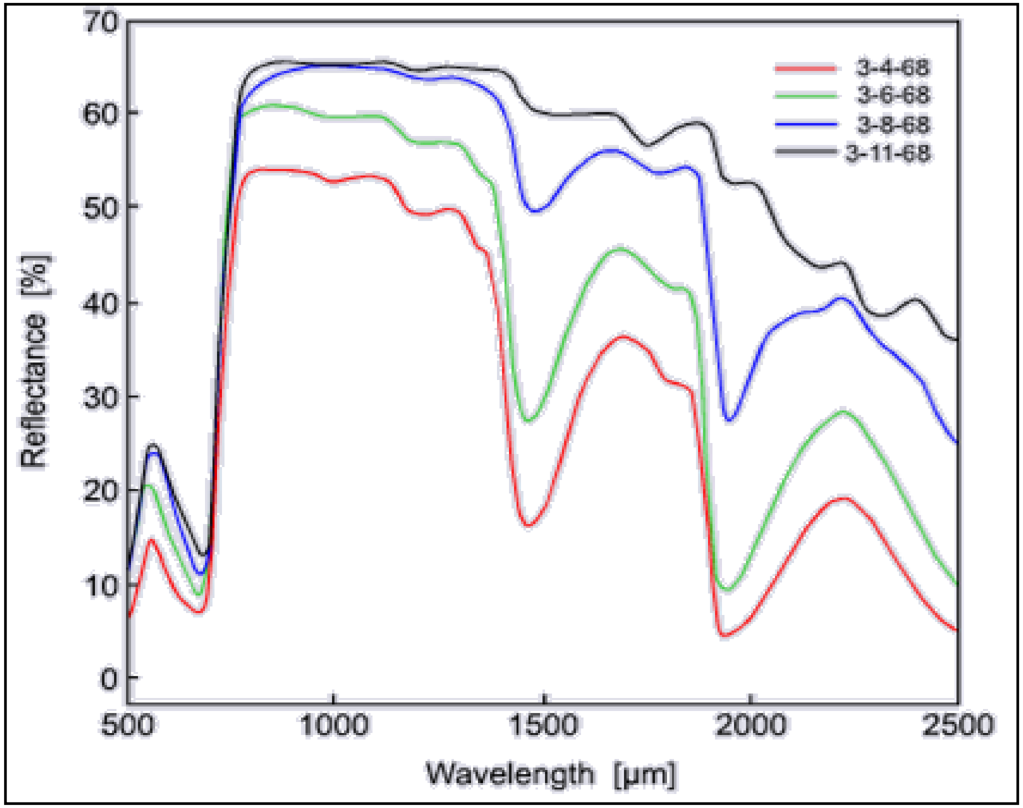
- Accordingly to the factors determining reflectance, there are also three determining damaging factors
  - Pigments
  - Cell structure
  - Cell water
- Destruction of chlorophyll causes a flattening of the C_{ab}-specific absorption bands
- Destruction of the cell structure causes a shift of the red edge towards the nIR and a flattening of the nIR-plateau
- Both effects can be detected with remote sensing systems



(Gausman 1974)

Reflectance of vegetation – water stress

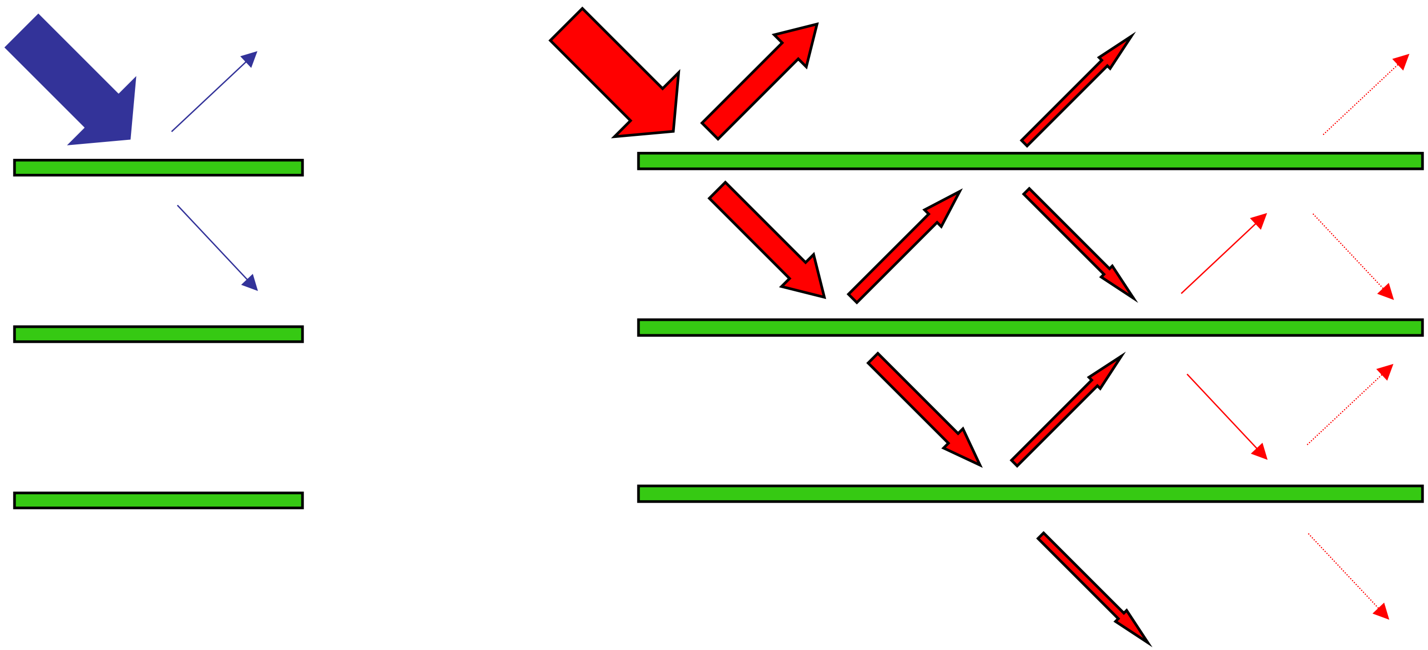
- Dehydration of the cell leads to a flattening of absorption bands that depend on water content
- Additionally, albedo increases considerably
- Absorption bands of cellulose and lignin appear more clearly
- Heavy water stress ultimately leads to a destruction of the cell structure and a decrease in plant metabolism



Reflectance of vegetation

Multi-layered leaf reflectance

- The plant's leaf organs produce complex reflectance patterns
- In the VIS, one leaf layer is enough to absorb almost the entire radiation
- In the nIR, complex radiation paths relate to multiple transmission



Reflectance of vegetation

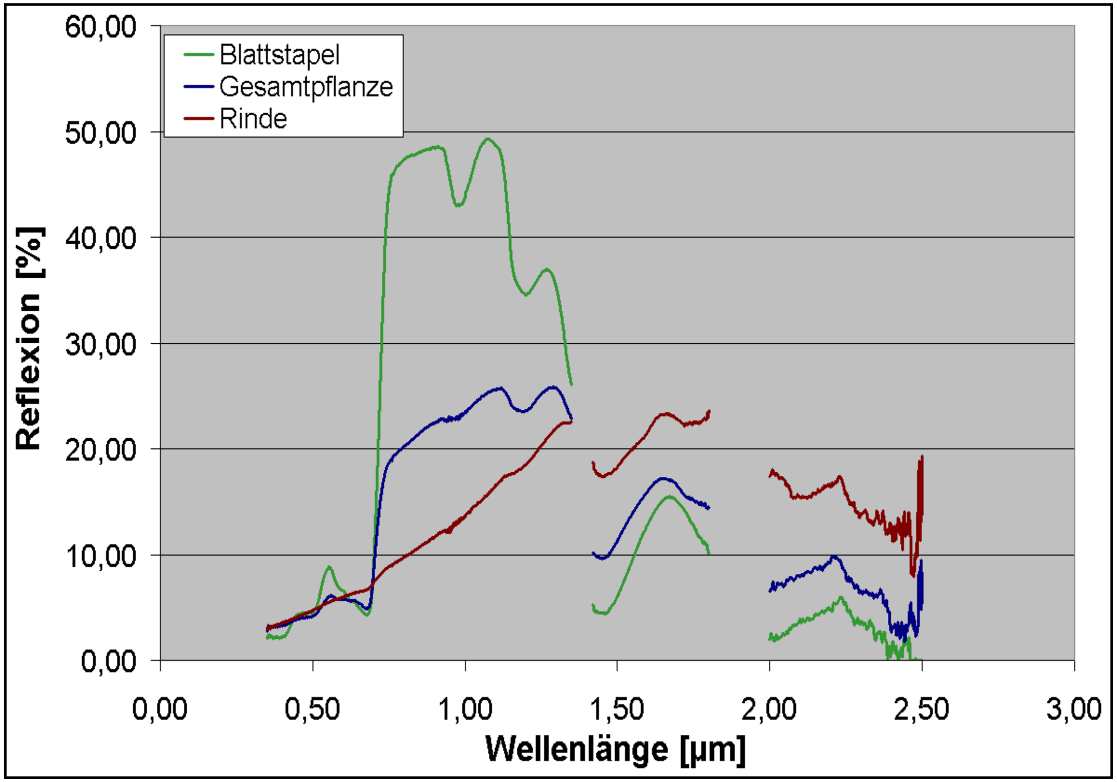
Multi-layered leaf reflectance

- As the degree of transmission varies greatly in different wavelength regions, non-linear changes of the reflectance behaviour occur with an increasing number of leaf layers
- A saturation of the reflectance in the nIR is – depending on the character of the respective leaves or needles – reached with 6 to 7 leaf layers
- A commonly used measure for the number of leaf layers is the so called “leaf area index” (LAI), measured in $[m^2 \bullet m^{-2}]$

Reflectance of vegetation

Plants as a system

- plants do include photosynthetically inactive parts
- fruits, spines, flowers, bark, and dead parts of the plant affect the reflectance
- Also structural factors affect the signal
- Aircraft or satellite based methods detect an integral signal
- In remote sensing, the analysis often focuses on the green parts of the plants only

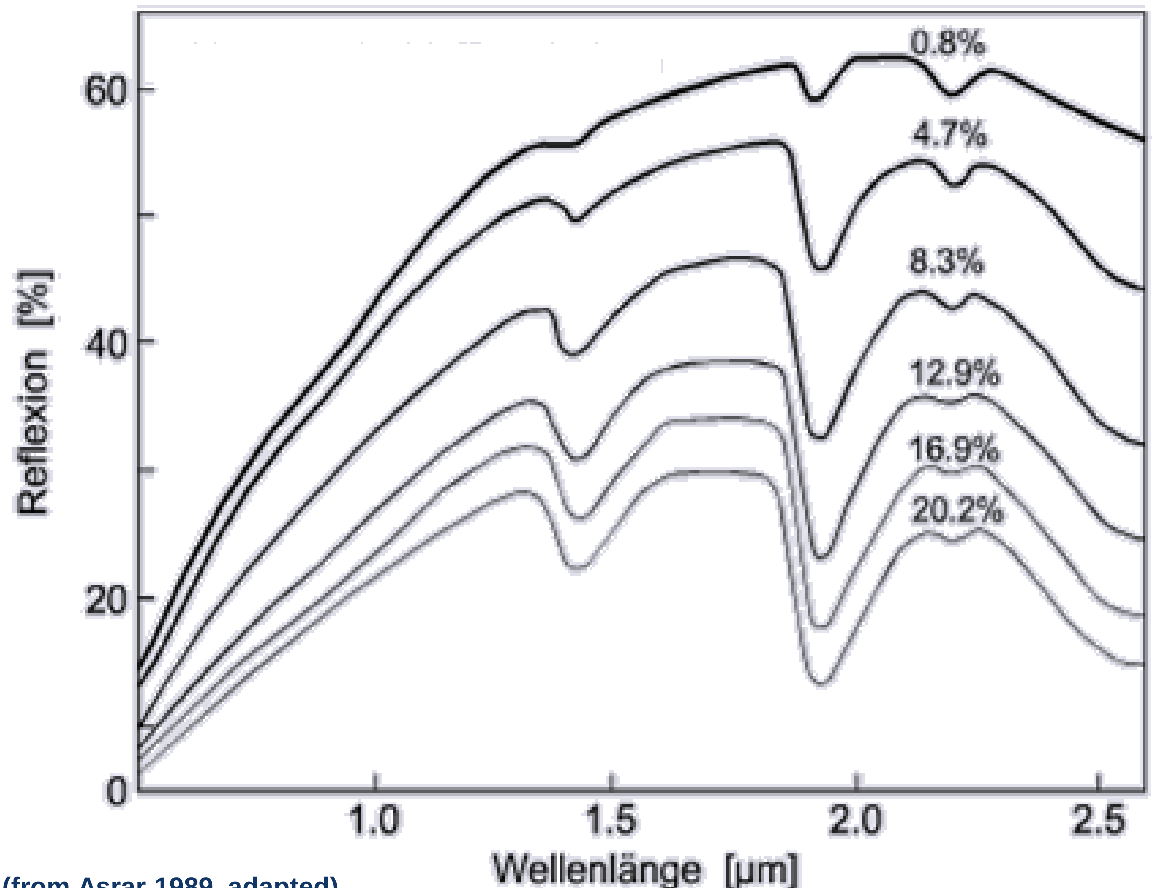


Reflectance of soils
Soil moisture

Example: silty loam

Alteration of

- Form of the reflectance curve
- Albedo
- Absorption depth
- FWHM (here: maximum absorption depth, similar to sensitivity function of sensors -> compare slides on spectral resolution)



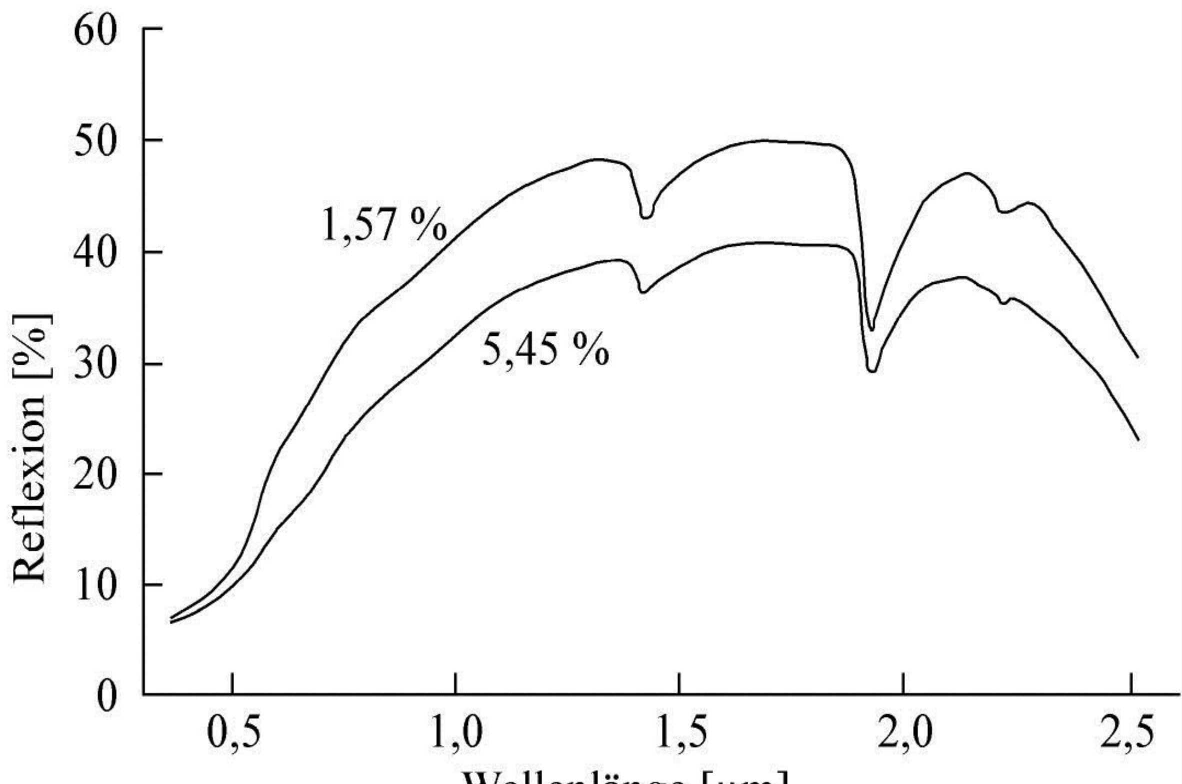
(from Asrar 1989, adapted)

Reflectance of soils
Organic material content

- Figure shows difference between low and very high organic content

With increasing portion of C_{org}

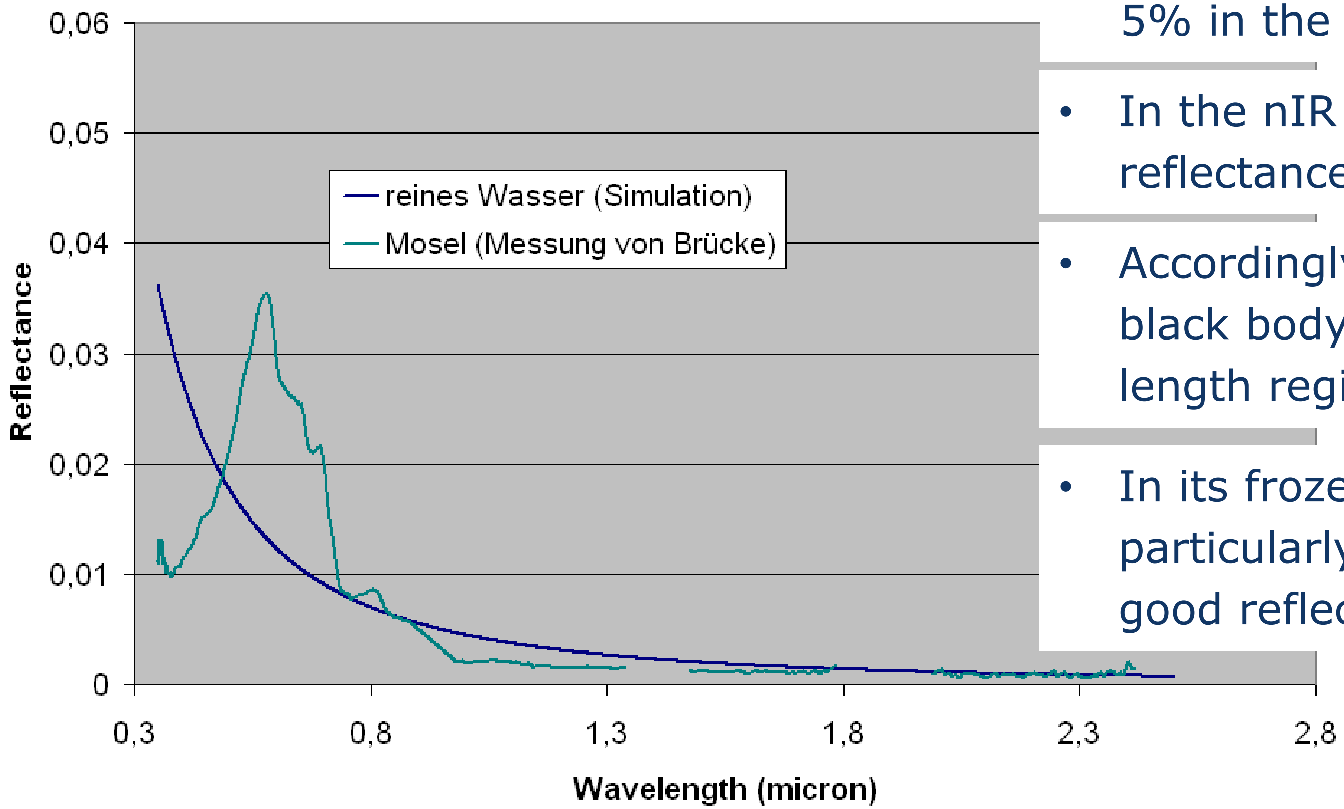
- the total reflectance decreases
- particularly the reflectance at 0.6 µm decreases
- the depth of the water-dependent absorption bands decreases



(from Asrar 1989, adapted)

Reflectance of water

- Water, in its fluid phase, is an excellent absorber (especially in the infrared)



- Clear water reflects less than 5% in the VIS
- In the nIR and SWIR, reflectance is close to 0
- Accordingly, water is almost a black body in these wave-length regions
- In its frozen form of ice, and particularly as snow, water is a good reflector

Imaging spectrometers

Imaging spectrometers

- Field / lab spectrometers measure a point on Earth on the ground, ideally similar to measuring a single pixel from an airborne or satellite platform
- Imaging spectrometers allow measuring continuous images in 100s of bands (also referred to as “hyperspectral remote sensing”)

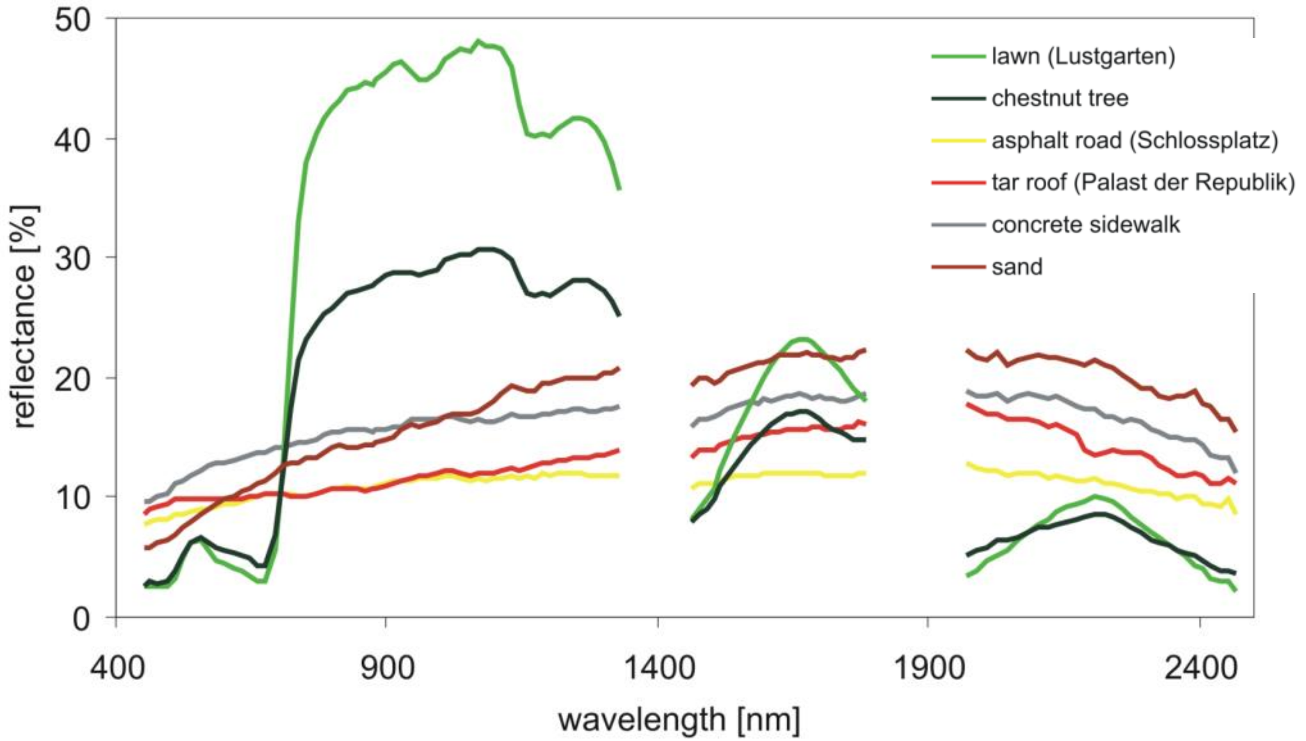
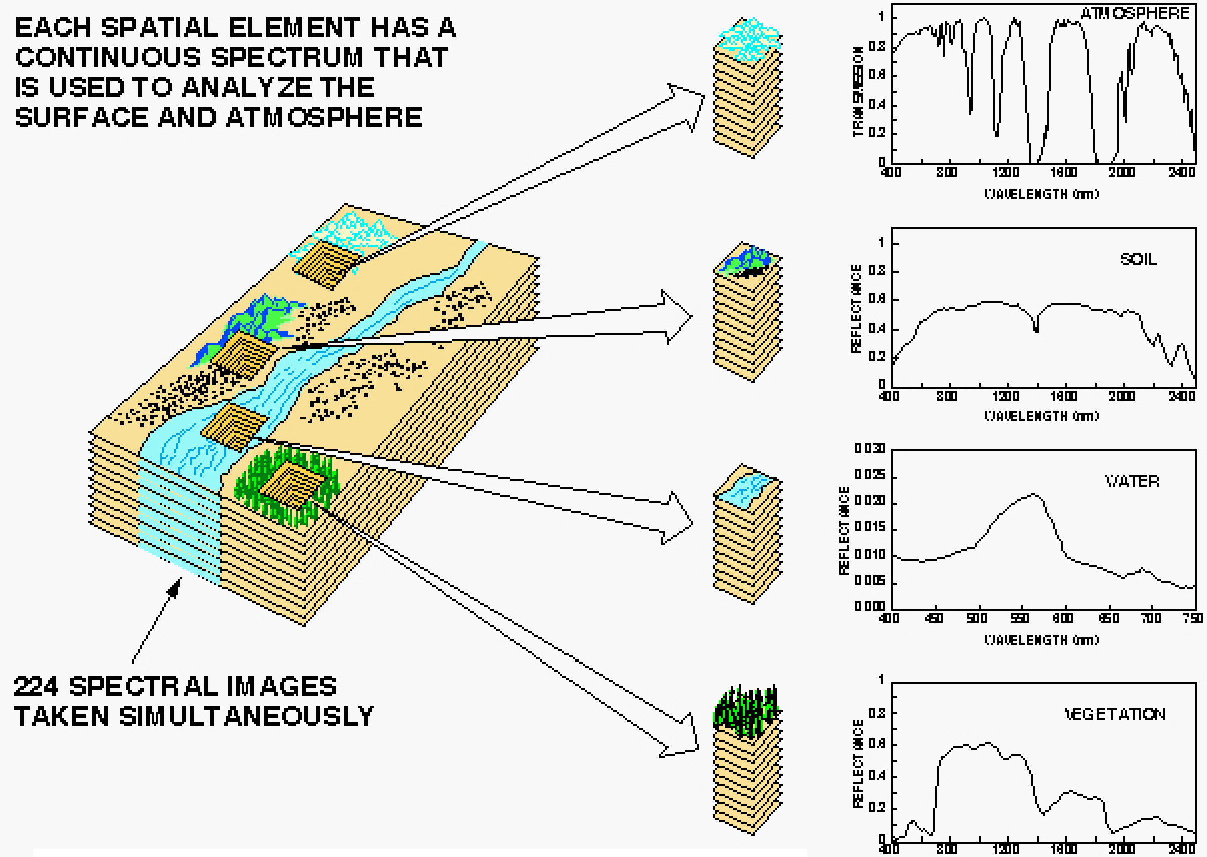


Image subset (left) and reflectance spectra from airborne HyMap image over Berlin (right). Colored circles in the close-up on the „Lustgarten“ correspond with colors of spectra. Gaps in spectra around ca. 1,400 nm and 1,900 nm result from atmospheric water vapor absorption.

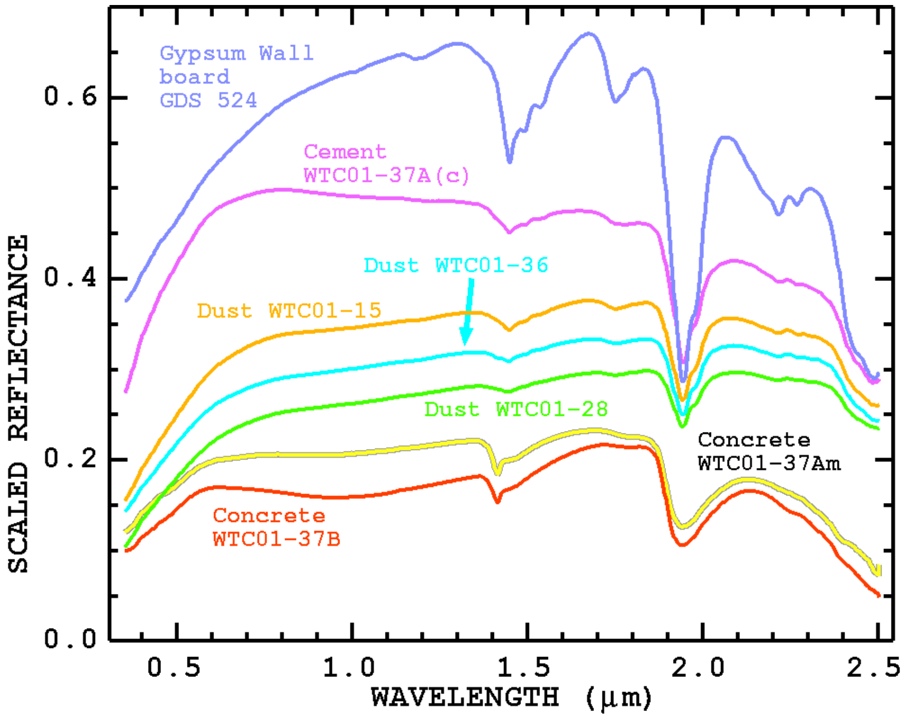
Imaging spectrometers



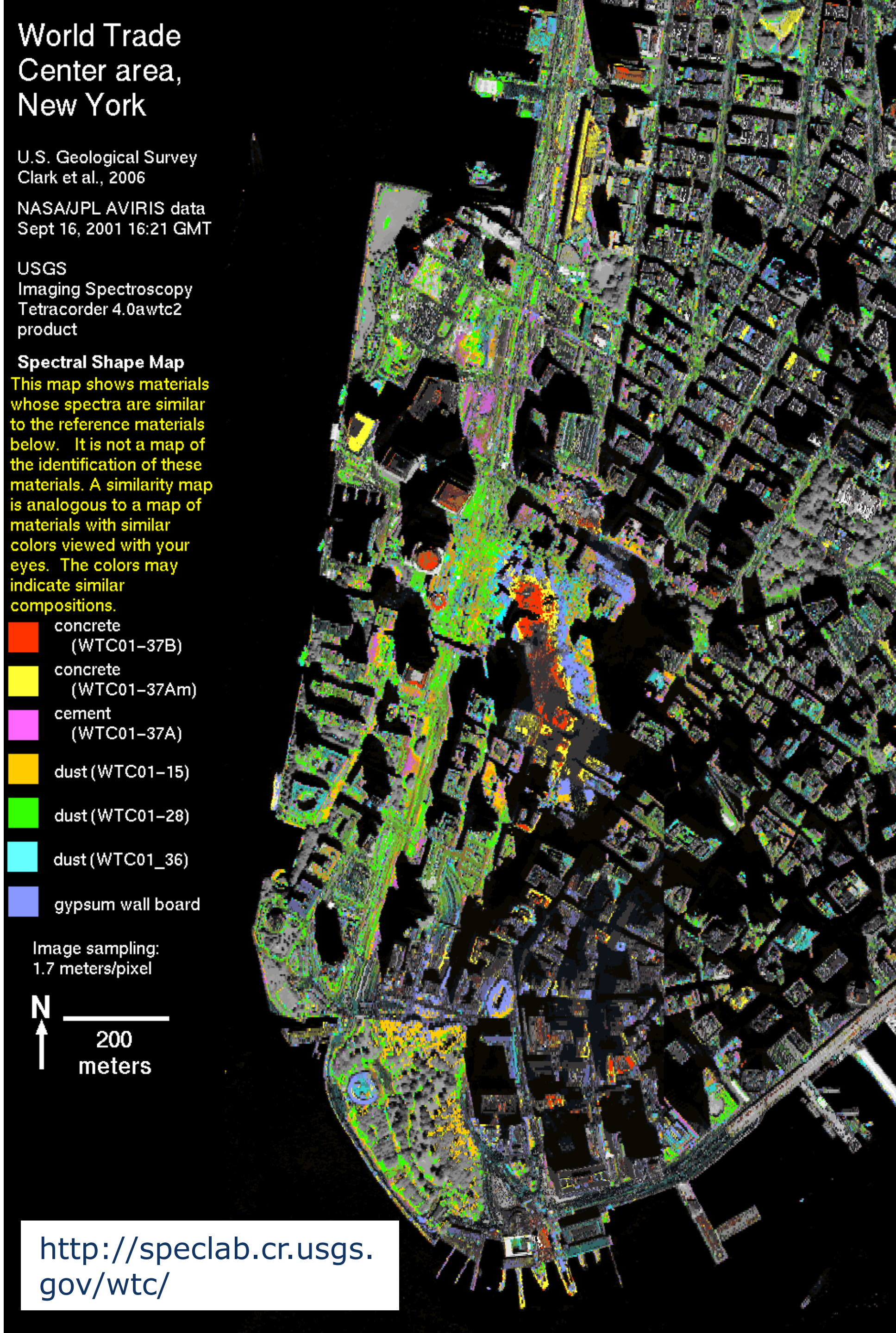
http://aviris.jpl.nasa.gov/aviris/concept.html

- NASA/JPL Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) continuously improved since the late 1980s
- Measures 224 bands from 400 to 2,500 nm
- Each pixel is a spectroscopic measurement from an airborne platform that needs thorough calibration and atmospheric correction to become a reflectance spectrum
- As of today, there is no operational imaging spectrometer on a satellite platform
- Reason: spectrometers need fine spectral resolution and sampling interval -> low irradiance input compared to broadband instruments -> poor signal-to-noise-ratio -> signal retrieval from space not trivial (IFOV, atmospheric influence)

Imaging spectrometers Applications



- Next slides from 2 presentations by Guanter et al.:
  - Overview of the Science Perspectives of EnMAP. ISRSE Berlin 2015
  - Overview of the EnMAP Imaging Spectroscopy Mission, IGARSS Milan 2015

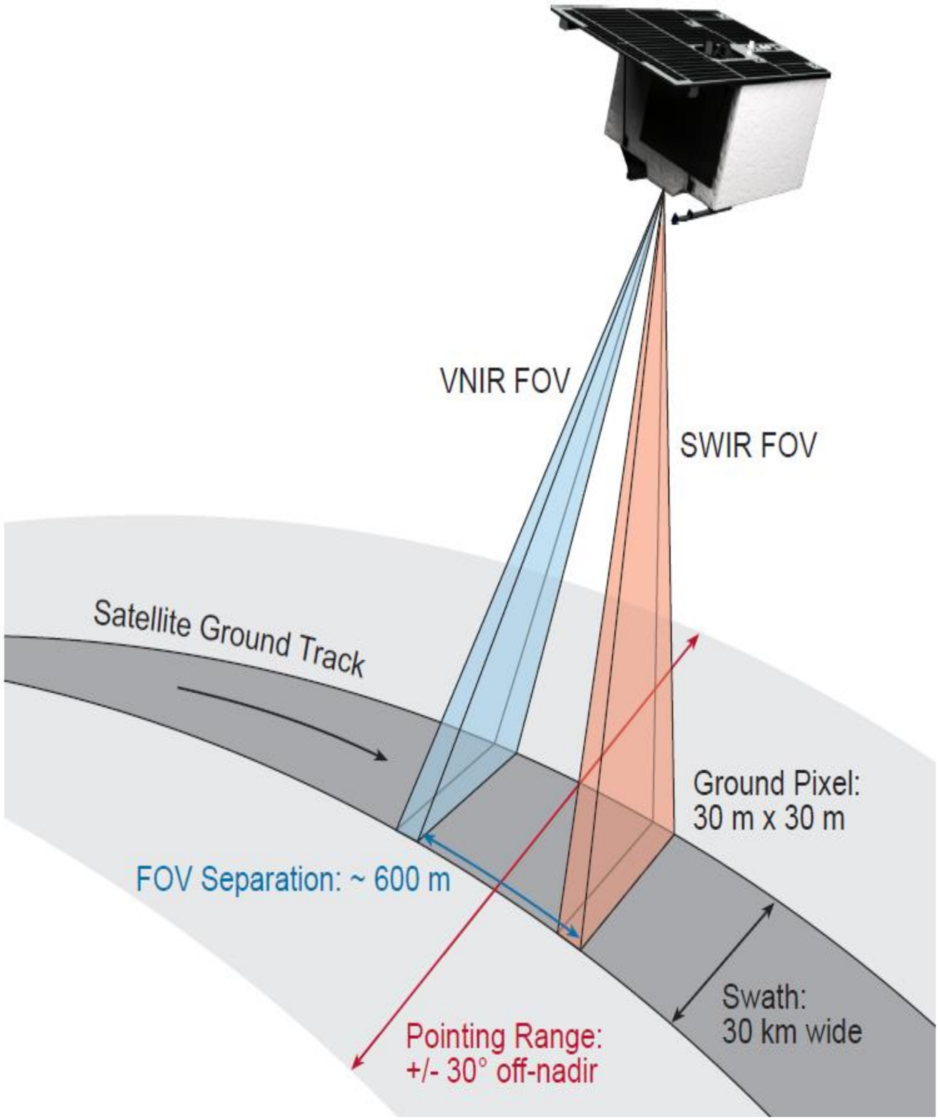


International Scenario of Spaceborne Imaging Spectroscopy

- **The not-so-happy story of spaceborne imaging spectroscopy for Earth observation:**
  - Current missions → So-called "technology demonstrators"
    - Low data quality and limited acquisition capability
    - Examples: EO-1 Hyperion (USA NASA, 2000) & CHRIS/PROBA (UK/ESA, 2001), designed for a 1-year lifetime!
  - There are more imaging spectrometers for planetary observation than for Earth observation!
  - Most of imaging spectroscopy applications rely on airborne spectrometers → heritage from AVIRIS (NASA-JPL, since 1987)

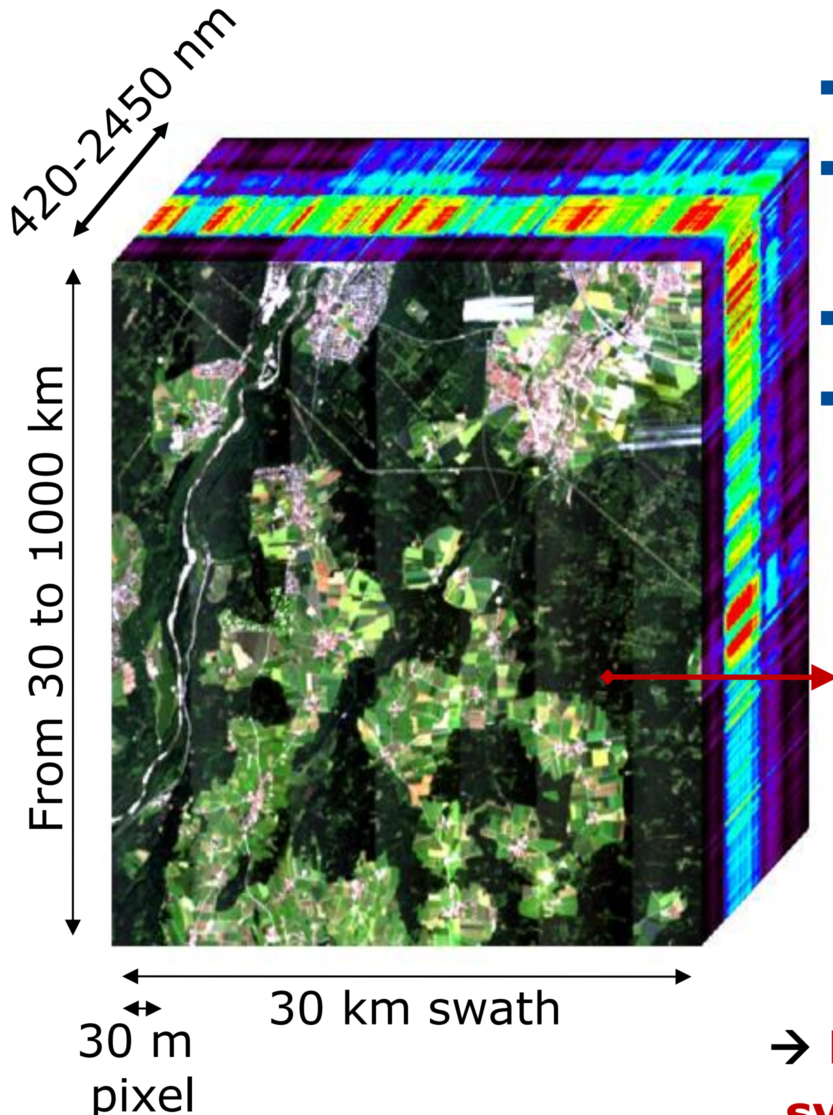
→ **EnMAP (launch 2018) expected to fill this gap in operational spaceborne imaging spectroscopy**

EnMAP – Main Mission Parameters

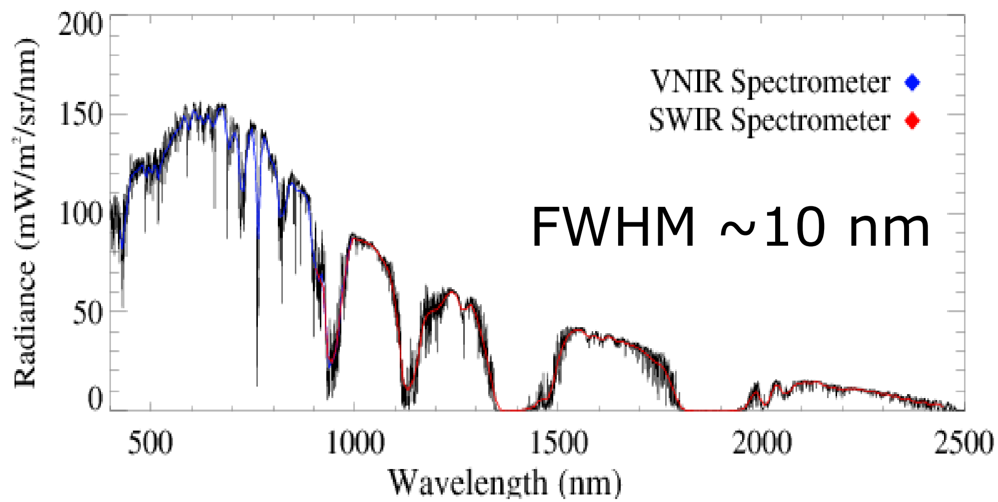


- Push-broom imaging spectrometer
- Sun-synchronous orbit, 11h LTDN
- Spectral range
  - VNIR: 420 nm to 1000 nm
  - SWIR: 900 nm to 2450 nm
- Spectral sampling distance
  - VNIR ~6.5 nm
  - SWIR ~10 nm
- Data acquisition
  - 1000 km/orbit
  - 5000 km/day
- Swath width 30 km
- Ground sampling distance 30 m
- Revisit time
  - 27 d nadir
  - 4 d with 30º across-track pointing
- Mission lifetime ≥ 5 years

Key mission characteristics for scientific use of EnMAP



- Up to 4 days revisit time with tilted obs.
- Ground segment distributing geometrically-corrected reflectance data
- Co-existence with Sentinel-2 & Landsat-8
- Open data policy

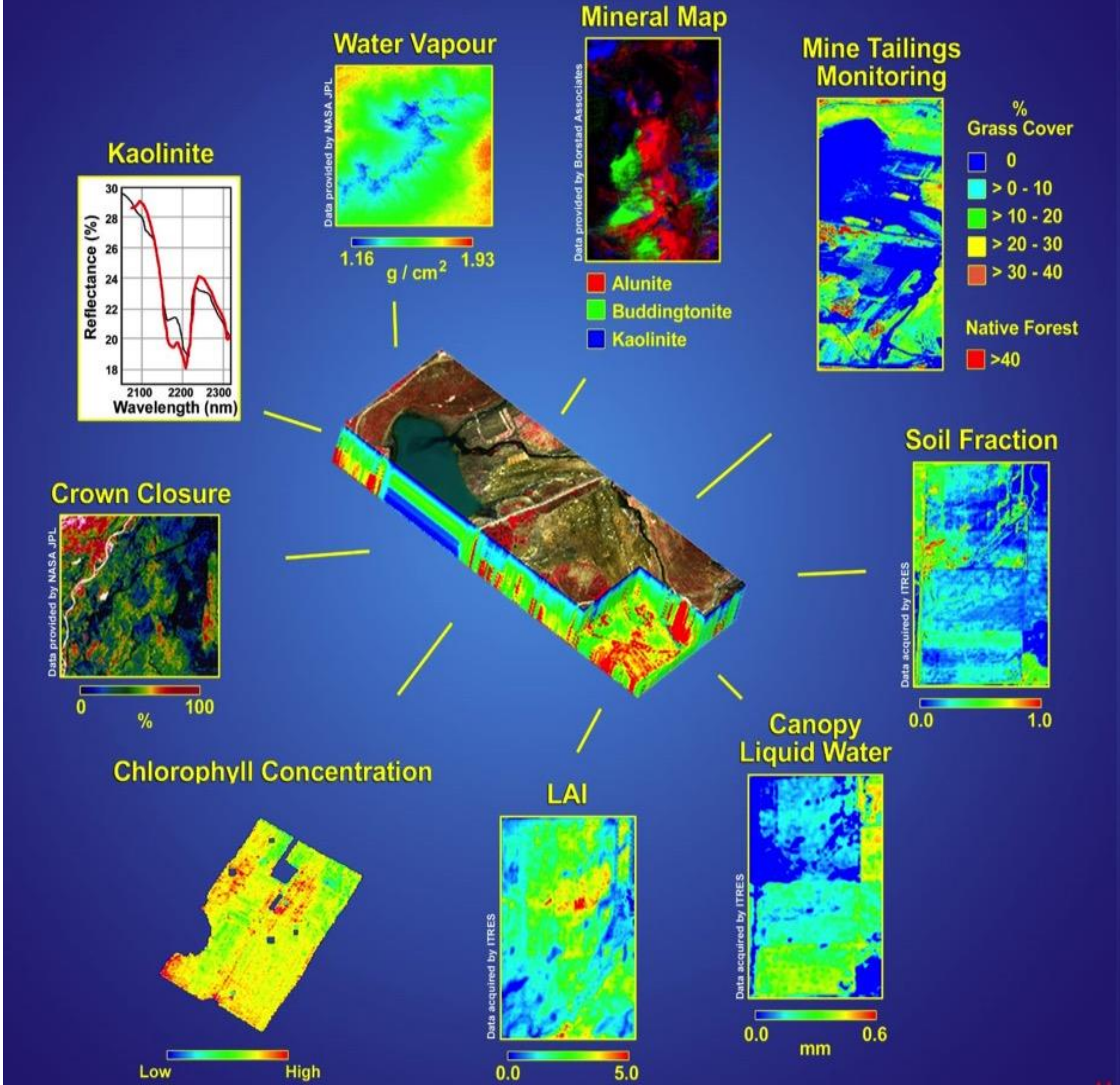


→ **High-performance imaging spectroscopy system for Earth observation**

Imaging Spectroscopy & Science

→Quantitative mapping for a wide range of research fields

→Great potential for new (and unexpected!) applications

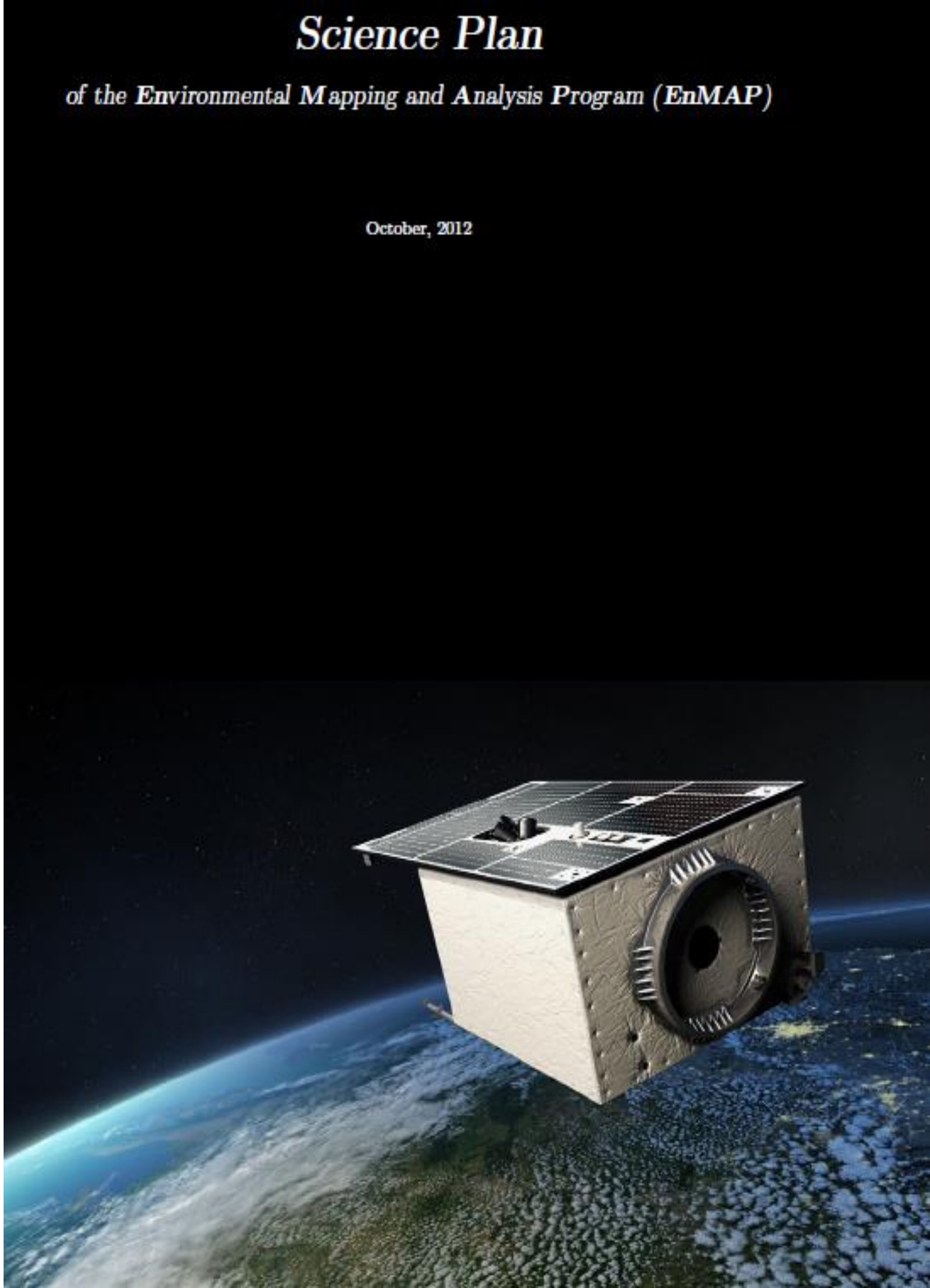


EnMAP Science Plan

Content

- Research context and significance
- General mission framework
- EnMAP perspectives and impact
- Scientific exploitation strategy

www.enmap.org



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HZG Geesthacht


Hajo Krasemann


Roland Doerffer


Hong Yan Xi

Coastal and inland waters

ESA


Mike Rast

Uni Lethbridge

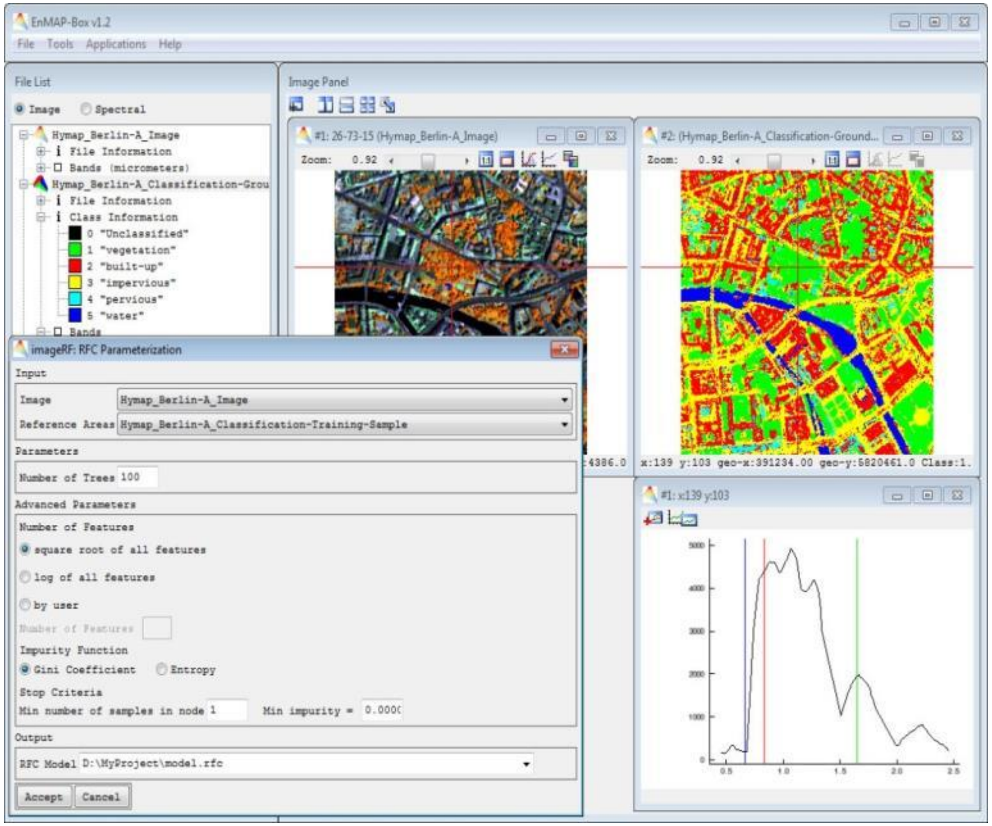

Karl Staenz

Scientific advisory

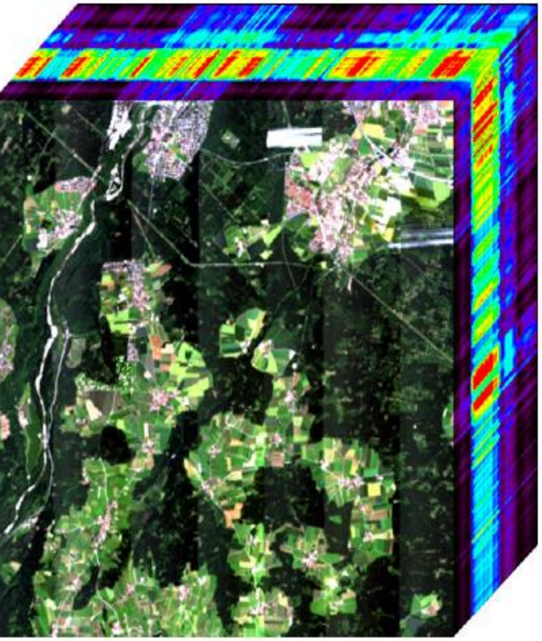
EnMAP-Box

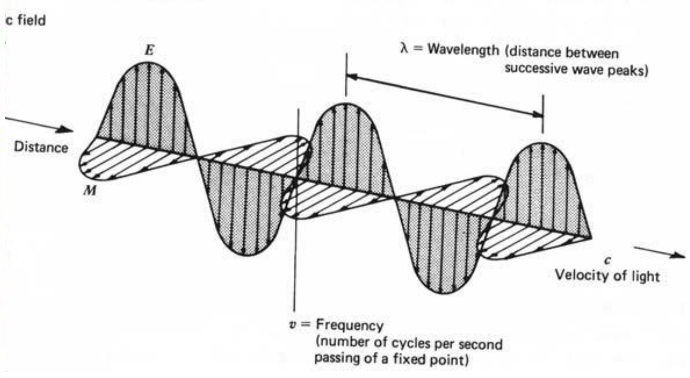
Download from
www.enmap.org/?q=enmapbox

- Software for the scientific exploitation of EnMAP data
- Also contains pre-processing tools for EnMAP data
- Free, open source and platform independent
- Reference algorithms for different application fields being developed by EnSAG partners

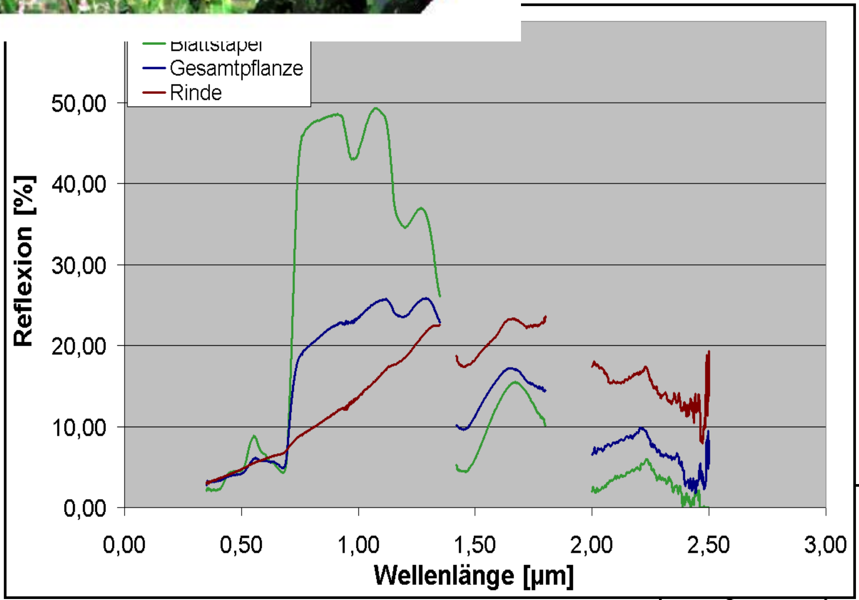


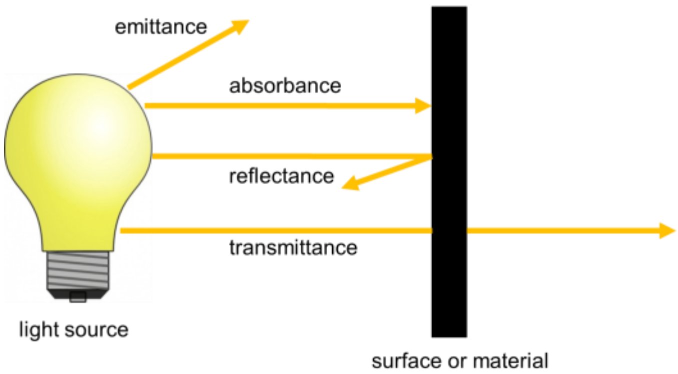
van der Linden, S., Rabe, A., Held, M., Jakimow, B., Leitão, P., Okujeni, A., Schwieder, M., Suess, S., & Hostert, P. (2015). The EnMAP-Box—A Toolbox and Application Programming Interface for EnMAP Data Processing. *Remote Sensing, 7, 11249*

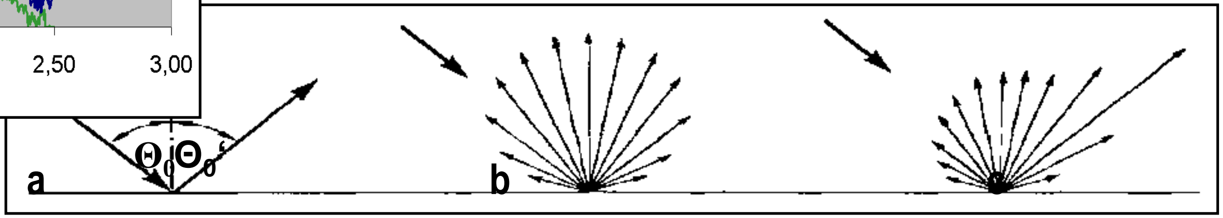



c field
E
M
Distance
λ = Wavelength (distance between successive wave peaks)
c
Velocity of light
ν = Frequency (number of cycles per second passing of a fixed point)

Summary


Blattstapel
Gesamtpflanze
Rinde
50,00
40,00
30,00
20,00
10,00
0,00
Reflexion [%]
0,00
0,50
1,00
1,50
2,00
2,50
3,00
Wellenlänge [µm]


emittance
absorbance
reflectance
transmittance
light source
surface or material


a
b

Recapitulation for next week

(1) Read chapters 2.1.2 and 2.1.3 in „Albertz (2007): Einführung in die Fernerkundung. Wiss. Buchges., Darmstadt.“ The pdf is provided in Moodle. 2.1.2 is preparatory for next week, 2.1.3 is a summary of today‘s lecture.

(2) Name the most important influence factors of the atmosphere on the signal that we measure with satellite or airborne sensors.

Outlook

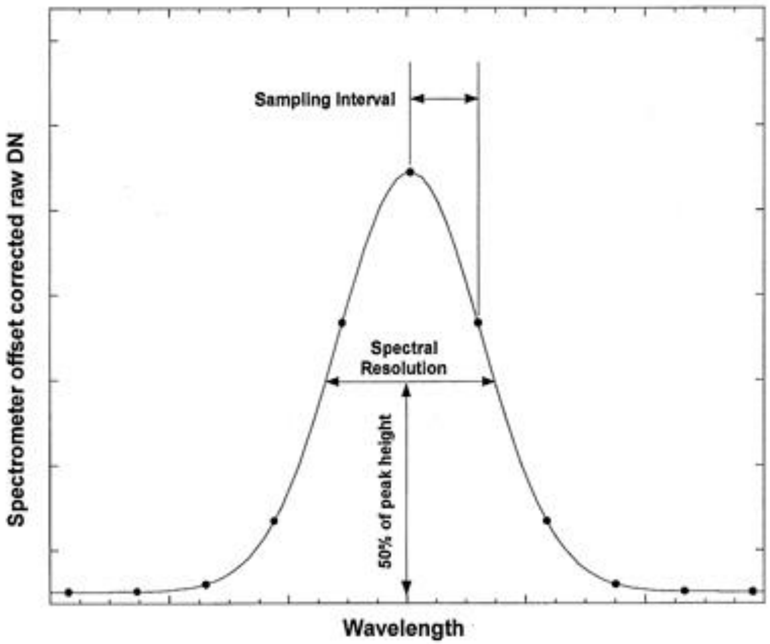
Next week we will focus on:

From Sun to Earth – and back into space

Thanks for your attention!

Excursus:
Lab and field spectrometers

- Spectrometers: large number of detectors
- ASD Fieldspec: 512 detectors within the range of 350-1,000 nm
- 750 bands sequentially sampled with one detector in the range of 1,000-2,500 nm
- sensitivity of individual detectors can be displayed as a function of a Gaussian distribution
- shape of the distribution determines resolution of each wavelength range

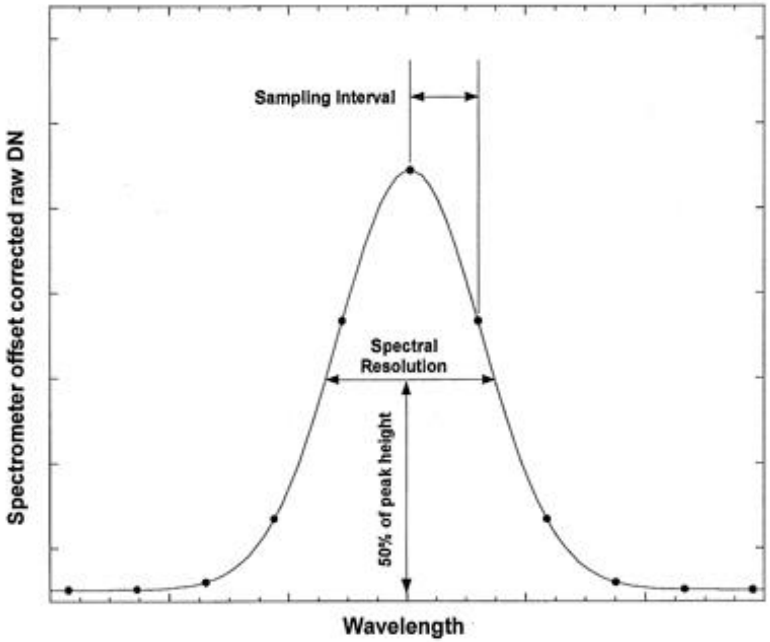


http://www.asdi.com/mining-ore-properties/faq/what-is-spectral-resolution

- The ***spectral resolution*** is the width of the sensitivity function at half maximum height (FWHM – Full Width at Half Maximum)

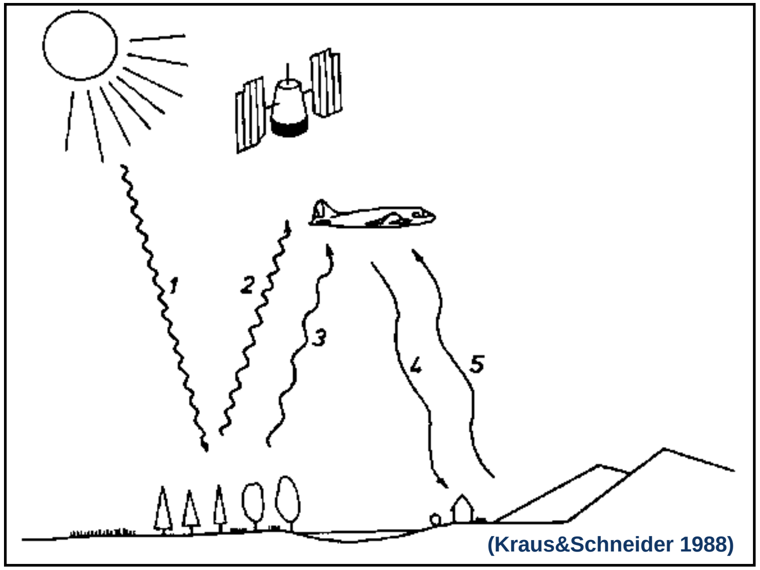
Excursus:
Lab and field spectrometers

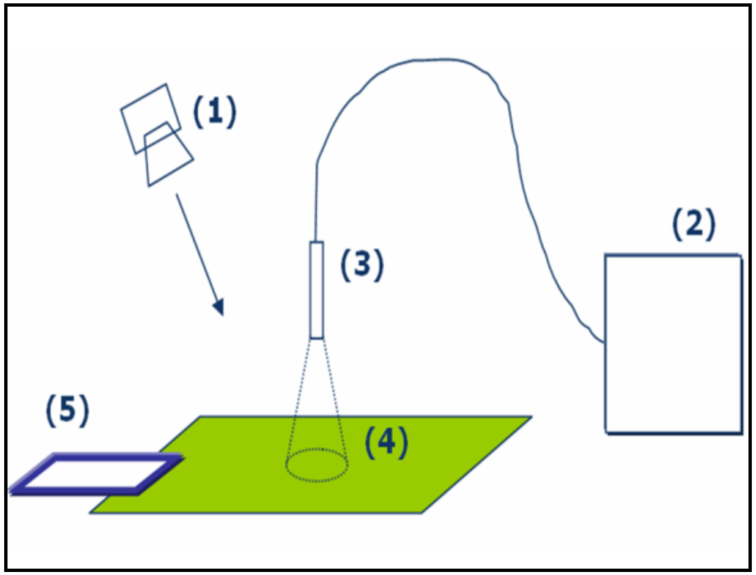
- The sensitivity functions of single detectors cover different wavelength intervals
- The ***spectral sampling interval*** is the number of wavelengths between the wavelength of maximum sensitivity of two neighbouring detectors



http://www.asdi.com/mining-ore-properties/faq/what-is-spectral-resolution

Excursus:
Lab spectroscopy



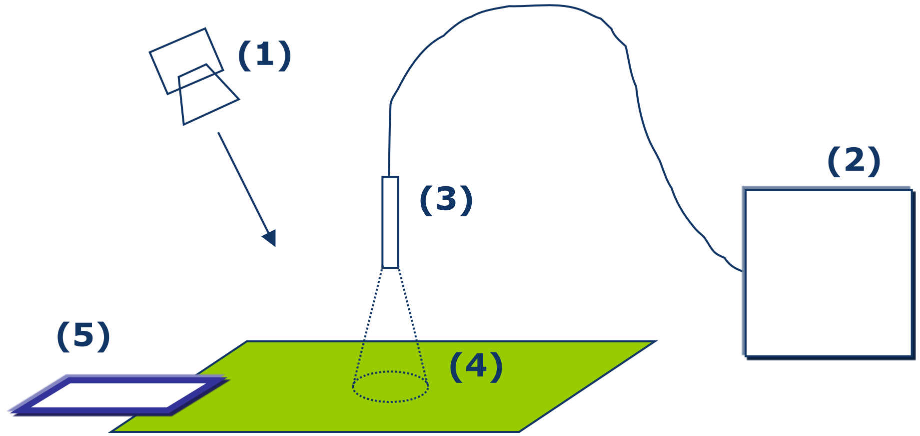


- Data in Google Earth™ show that many factors affect remote sensing data
- In order to explain interactions of irradiation and a particular surface, we eliminate disturbing factors under lab conditions

- **Laboratory conditions**: constant measurement geometry (angles & distances), nadir view (no displacement), no atmosphere, reduction to a point measurement

Excursus:
Lab spectroscopy

-
- **Lamp (1)** as an energy source with constant radiation
- Calibrated **spectrometer (2)**
- **Sensor (3)**
- **Target (4)**
- **White reference (WR) (5)** for calibration (adjustment to illumination conditions), by measuring the incoming radiance

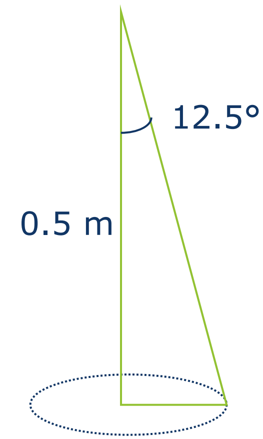


- → The spectrometer allows radiance measurements as well as reflectance measurements

- **Reflectance** = Rad_{Target} / Rad_{WR}

Excursus:
Lab measurement setup

- Angular aperture of the spectrometer: 25°
- Measurement height: ~0.5 m
- Aperture radius : 0.108 m
- Area: 0.0368 m² = 368 cm²
- Calculation of area depends on measurement height



r = 0.5 m * sin(12.5°)

r = 0.108 m

- The solid angle of our ASD Lab/Field Spectrometer is 0.149 sr, i.e. it measures 0.149 of a half sphere of 2π (~2.4%)