>>> **Introduction to hyperspectral remote sensing imagery**
>>> **GRSS Summer School**

Name: Mathieu Fauvel (UMR Dynafor)
Date: *[2017-04-26 Wed 08:30]–[2017-04-26 Wed 10:00]*

Outline

>>> Mathieu Fauvel

- Short CV
  - 2004-2007: PhD GIPSA-lab & University of Iceland
  - 2007-2008: Assistant Professor Grenoble INP
  - 2008-2010: Post-Doc position INRIA Mistis Team
  - 2010-2011: Assistant Professor INP Toulouse
  - Since 2011: Associate professor at ENSAT - INP Toulouse & University of Toulouse
- Director of the Engineering and Digital Sciences Department at the National Institute of Agronomy of Toulouse (ENSAT).
- Associated to the DYNAFOR lab
- IEEE GRSS:
  - Senior Member
  - Member of the *GRSS Chapter Committee*
  - IEEE JSTARS Associated Editor

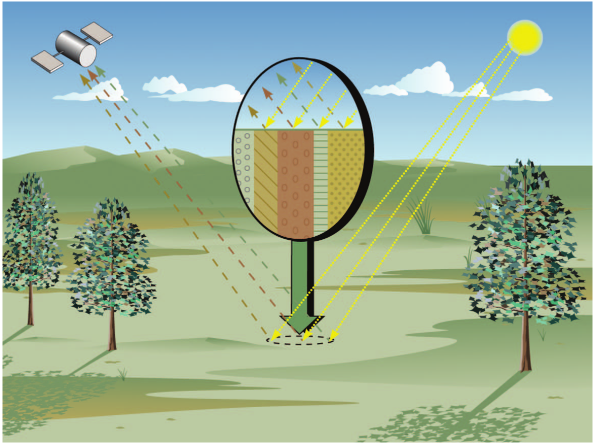
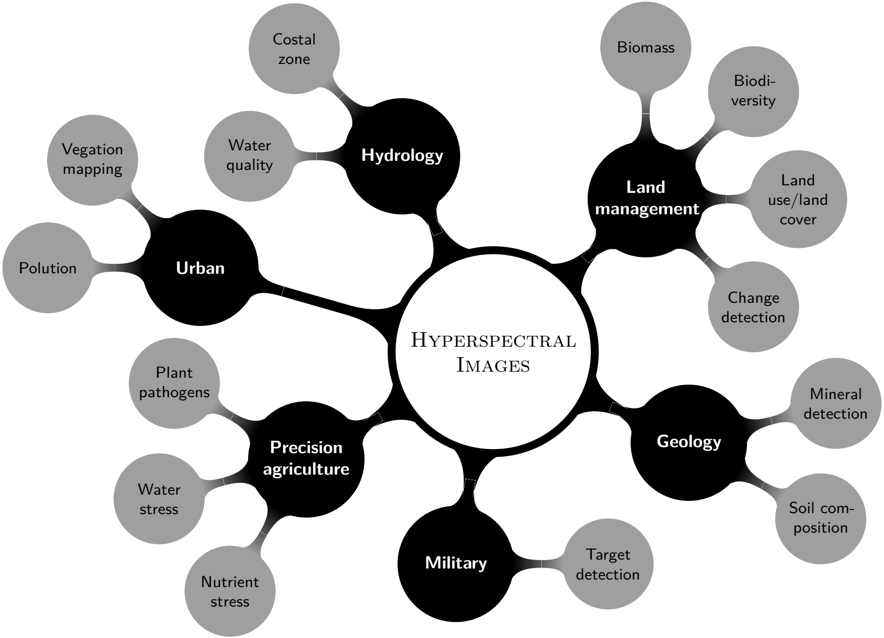
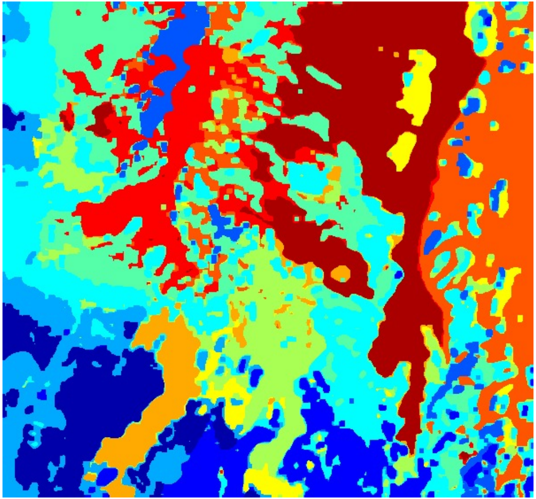


Image taken from [KM02].

- Remote sensing provides information about landscapes.
- This information is carried out by the *electromagnetic energy* and is usually formated in terms of *digital image data*.
- This information can be used
  - To *update* and to *supervise* landscapes in known areas,
  - To *get prior* information about landscapes of unknown areas.

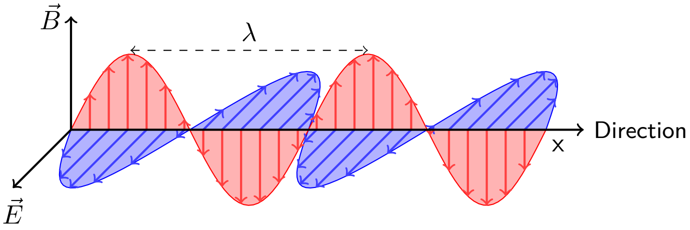
>>> Fields of application



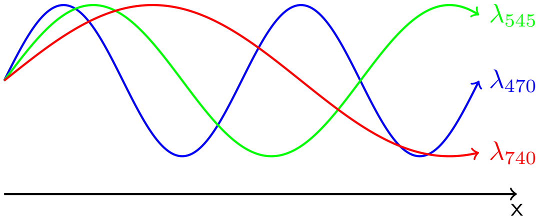


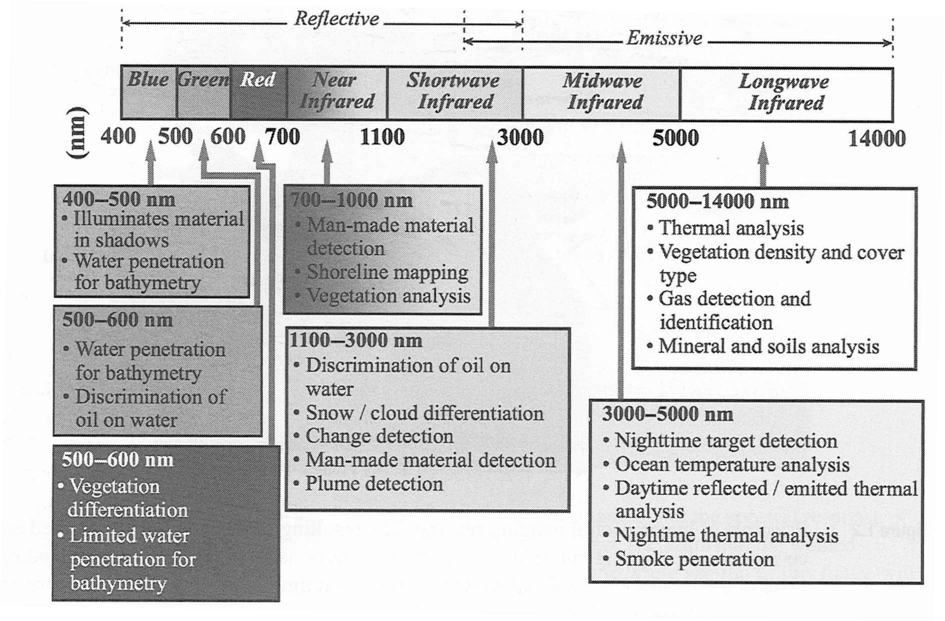
Classes

Lava 1970, Lava 1980 I, Lava 1980 II, Lava 1991 I, Lava 1991 II, Lava moss cover, hyaloclastite formation, Tephra lava, Rhyolite, Scoria, Firn-glacier ice, Snow.



- An electromagnetic wave is a pertubation of the electric and magnetic field which propagates throught space.
- $\vec{E}$: Electric field. $\vec{B}$: Magnetic field.
- Wavelength (λ): *Minimal distance between 2 points of the space for which $\vec{E}$ and $\vec{B}$ recover the same values.*

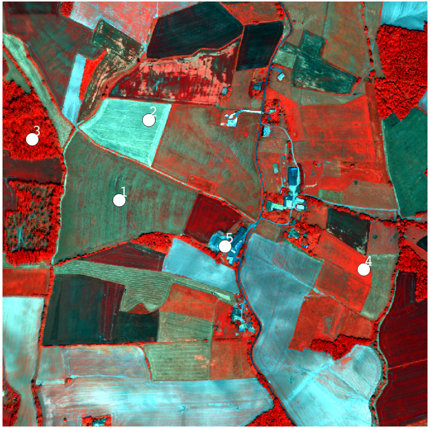


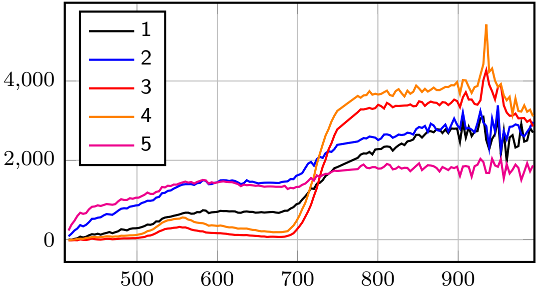

Reflective
Emissive
Blue
Green
Red
Near Infrared
Shortwave Infrared
Midwave Infrared
Longwave Infrared
(nm)
400
500
600
700
1100
3000
5000
14000
400–500 nm
• Illuminates material in shadows
• Water penetration for bathymetry
500–600 nm
• Water penetration for bathymetry
• Discrimination of oil on water
500–600 nm
• Vegetation differentiation
• Limited water penetration for bathymetry
700–1000 nm
• Man-made material detection
• Shoreline mapping
• Vegetation analysis
1100–3000 nm
• Discrimination of oil on water
• Snow / cloud differentiation
• Change detection
• Man-made material detection
• Plume detection
5000–14000 nm
• Thermal analysis
• Vegetation density and cover type
• Gas detection and identification
• Mineral and soils analysis
3000–5000 nm
• Nighttime target detection
• Ocean temperature analysis
• Daytime reflected / emitted thermal analysis
• Nightime thermal analysis
• Smoke penetration

From [MLC16].

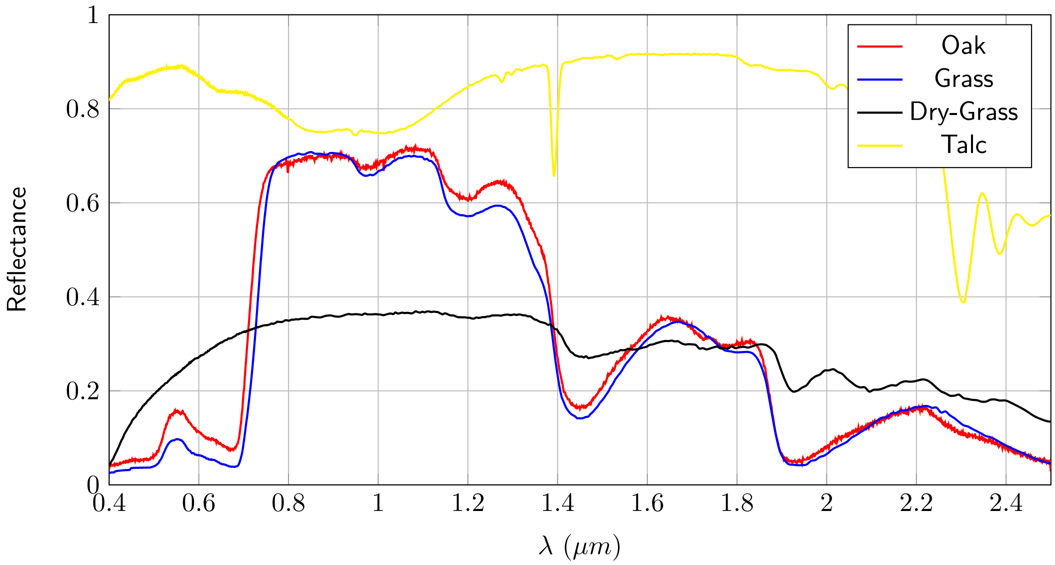
Reflectance:

- ⋆ Capacity of a given surface to reflect the incident light,
- ⋆ It is specific to each material.

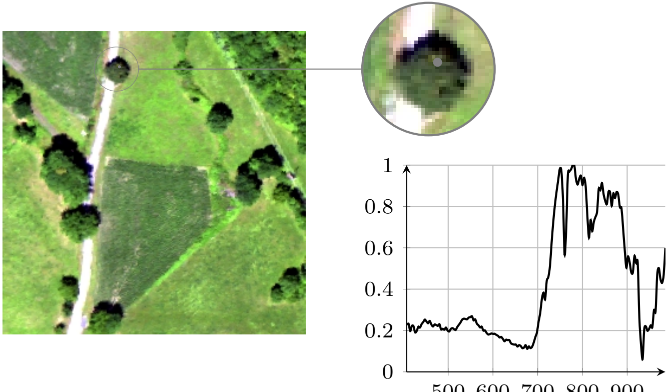




Spectral reflectance curves or spectral signature: Radiometric identity card



A remote sensing image is a sampling of a spatial, spectral and temporel process.



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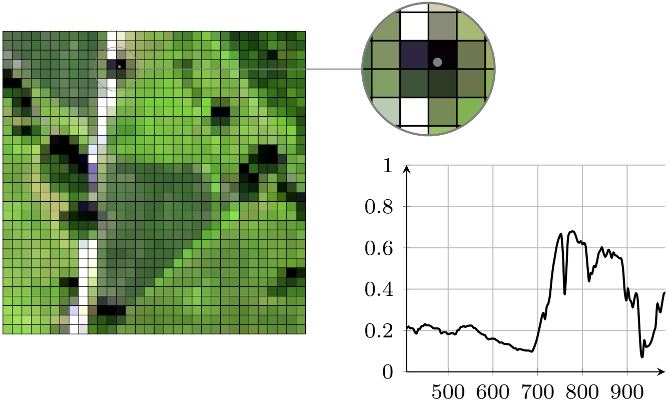

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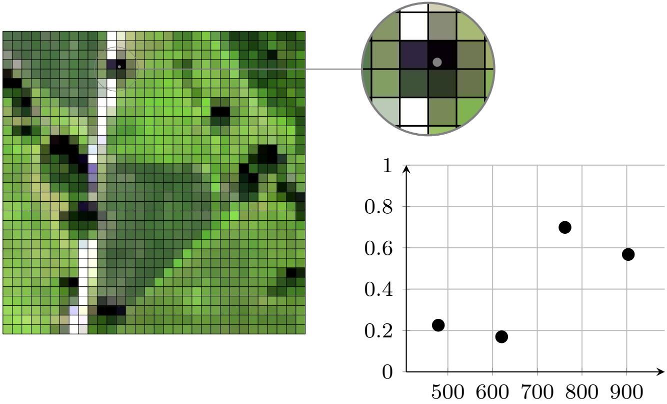

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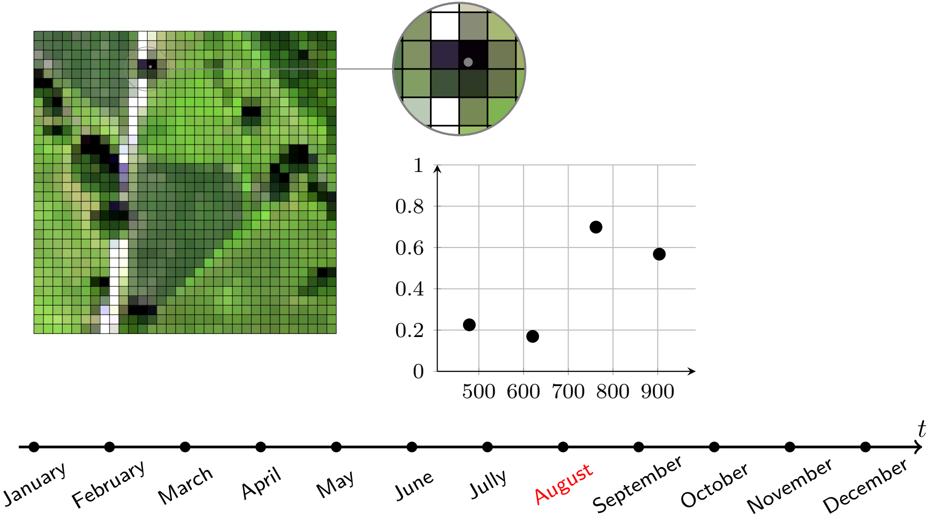
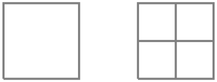


>>> Characteristics of remote sensing images

- Spatial resolution: *Ability to distinguish two closed objects*.



2 m/pixel   1m/pixel

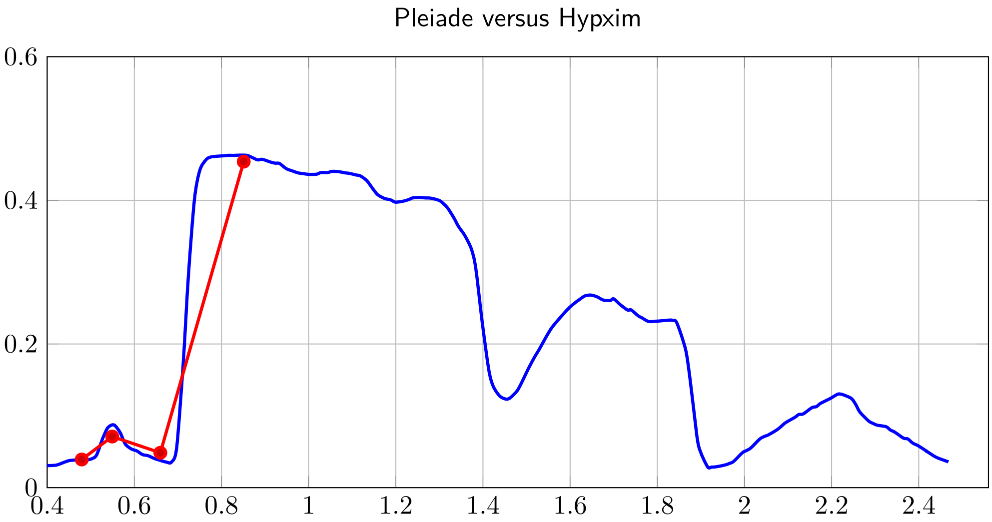
- Radiometric resolution: *Smallest difference in intensity that the sensor can record*.

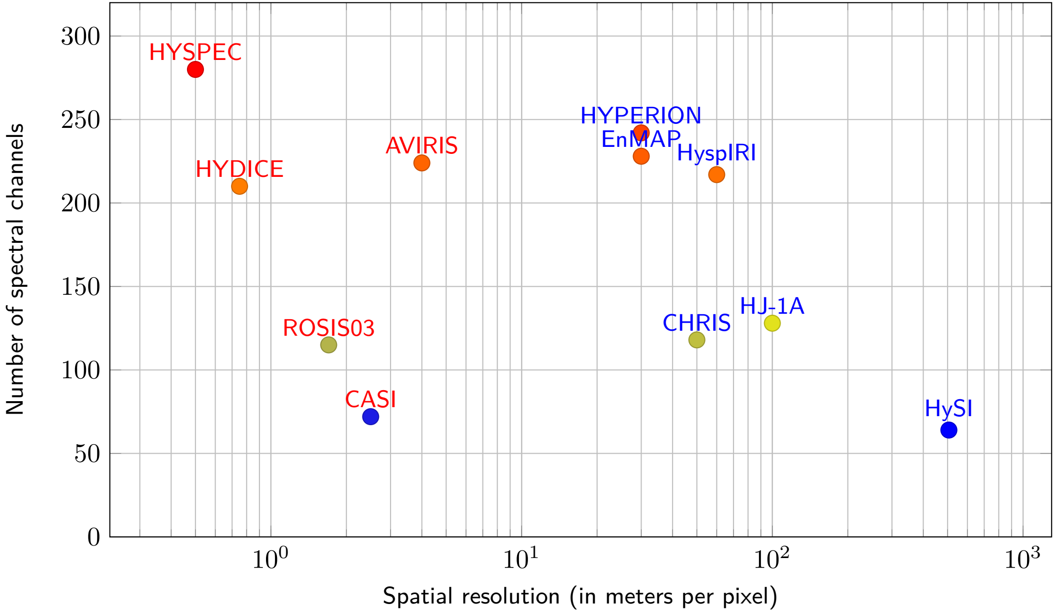
Coding	Quantification	Exemple: 6.666666
8 bits	256	7
16 bits	65536	6.67

- Spectral resolution: *Width of each band of the spectrum that can be collected*.

Image Type	Number of bands
Panchromatic	1
Multispectral	~ 10
Hyperspectral	> 100
Ultraspectral	> 1000

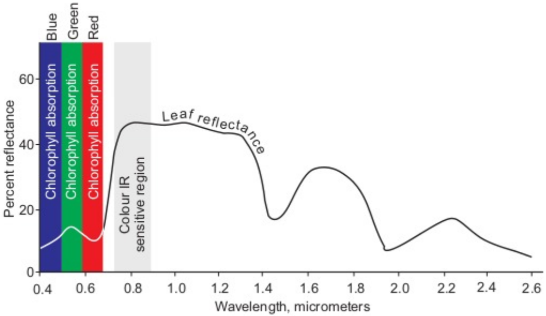
- Spatial and spectral resolution are linked: difficult to have high spatial *and* spectral resolution at the same time.


Pleiade versus Hypxim
0.6
0.4
0.2
0
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4


HYSPEC
HYDICE
AVIRIS
ROSIS03
CASI
HYPERION
EnMAP
HyspIRI
CHRIS
HJ-1A
HySI
300
250
200
150
100
50
0
Number of spectral channels
10^0
10^1
10^2
10^3
Spatial resolution (in meters per pixel)

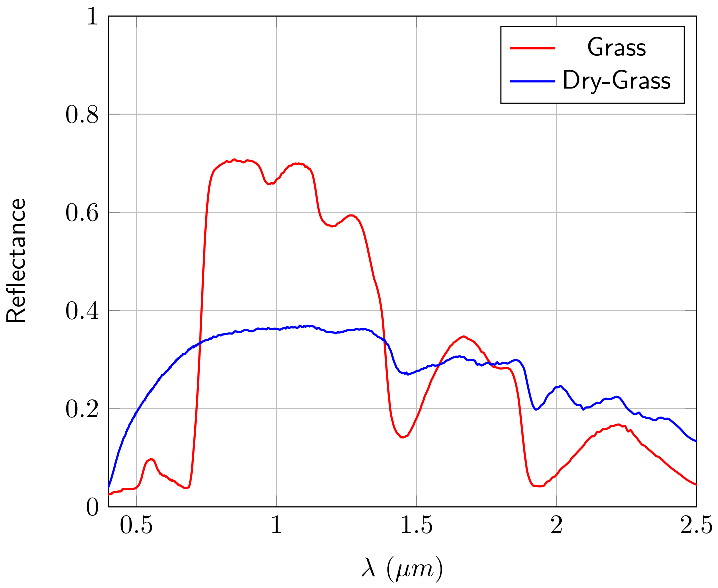
Healthy vegetation (high photosynthesis)

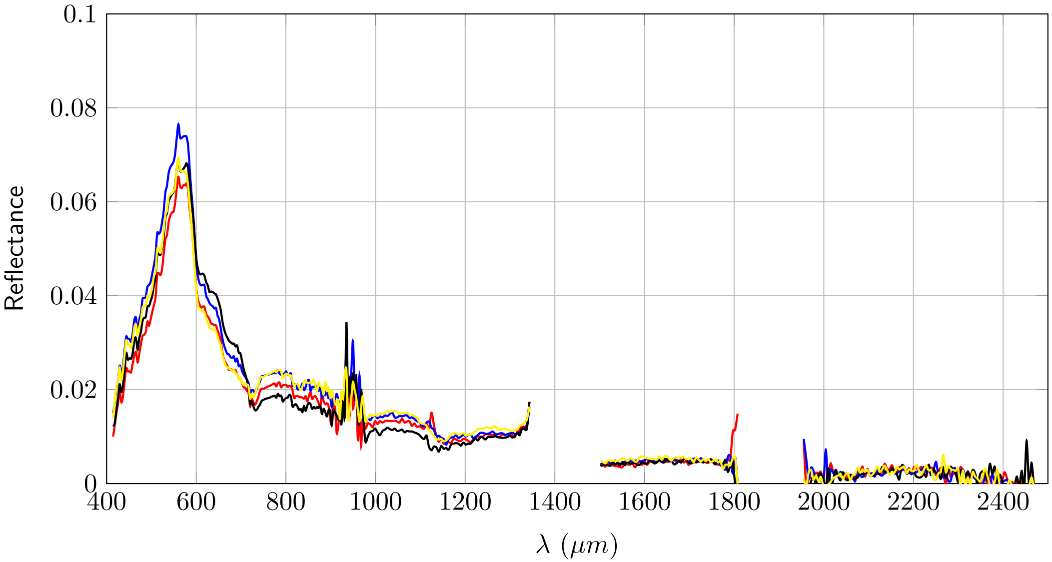
- Absorption in *blue* and *red* domain,
- *Visible* to *near infrared*: increase of the reflectance,
- *Mid infrared*: depends on the free water in the leafs.

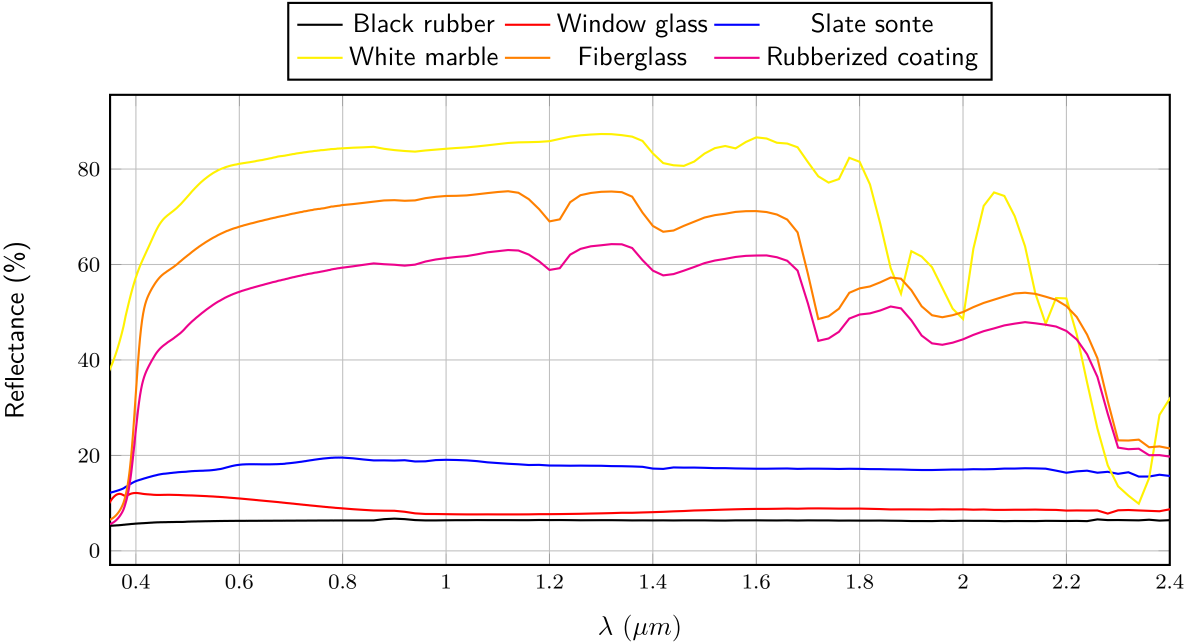


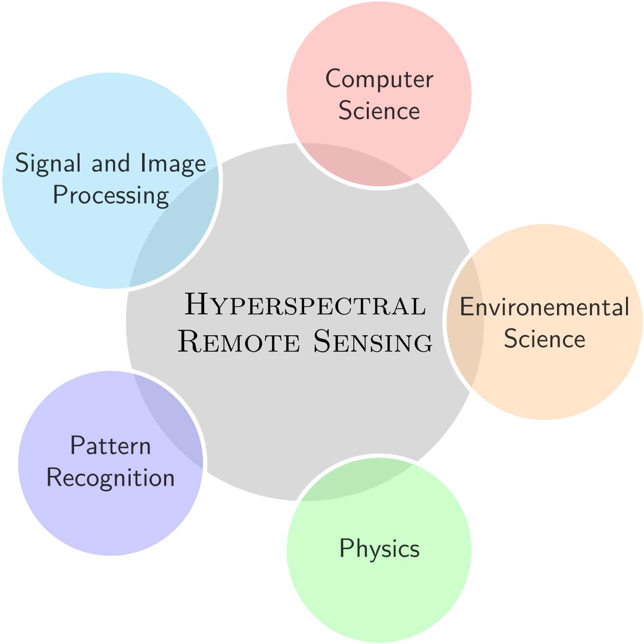
Factor modifying the reflectance

- ⋆ Leaf thickness,
- ⋆ Leaf age,
- ⋆ Water content,
- ⋆ Nitrogen content,
- ⋆ Health condition,
- ⋆ . . .




0.1
0.08
0.06
0.04
0.02
0
Reflectance
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
λ (μm)

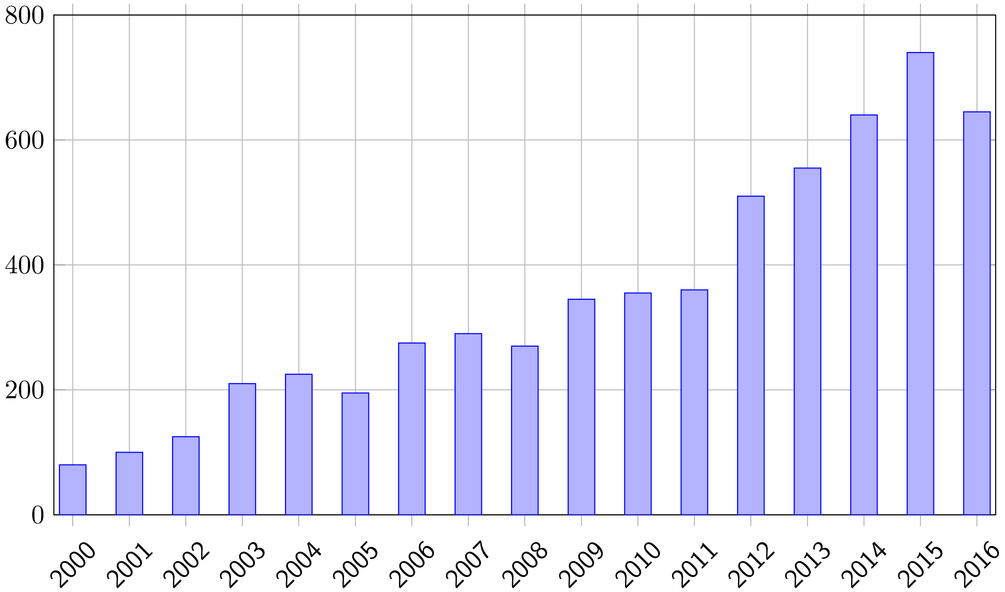

Black rubber
Window glass
Slate sonte
White marble
Fiberglass
Rubberized coating
Reflectance (%)
0
20
40
60
80
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
λ (μm)


Computer Science
Signal and Image Processing
Hyperspectral Remote Sensing
Environemental Science
Pattern Recognition
Physics

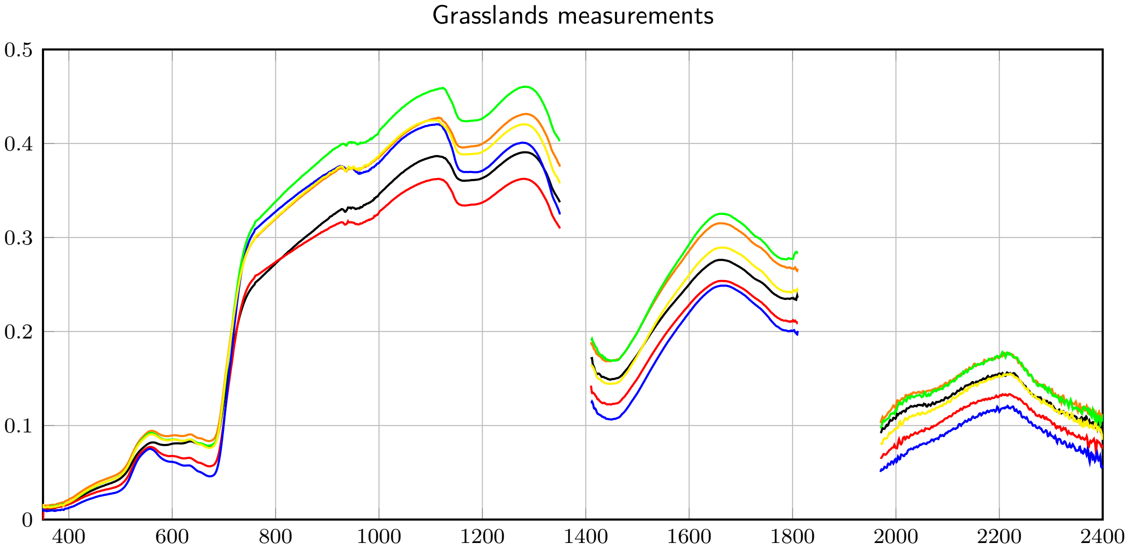
>>> Processing chain

- Transmission:
  - Compression.
- Pre-processing:
  - Geometric and atmospheric corrections,
  - Data fusion,
  - Feature extraction.
- Information extraction:
  - Classification/inversion,
  - Unmixing,
  - Target detection.

Number of published papers per year about "hyperspectral remote sensing" (*ISI Web of science*)

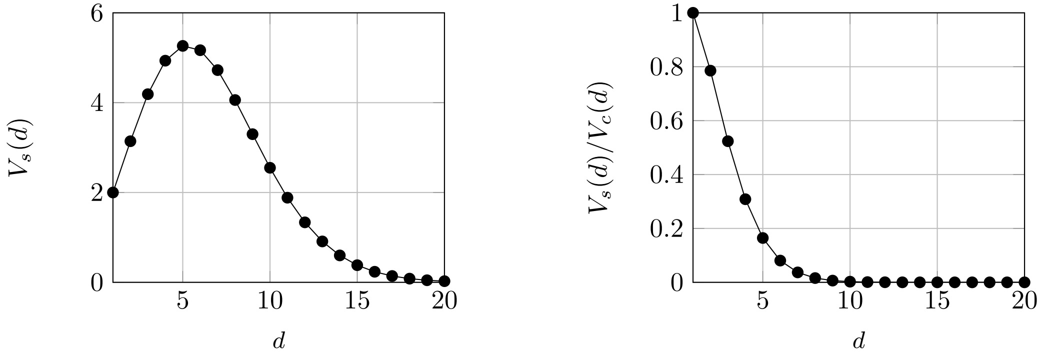


- Pattern recognition:
  - High dimensional data,
  - Spectral variability,
  - Reduce ground-thruth.
- Computer science:
  - Large volume of data,
  - Real time constraints.
- Thematic application:
  - Environmental issues,
  - Military issues,
  - Astrophysical issues.


Grasslands measurements
0.5
0.4
0.3
0.2
0.1
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

>>> Outline

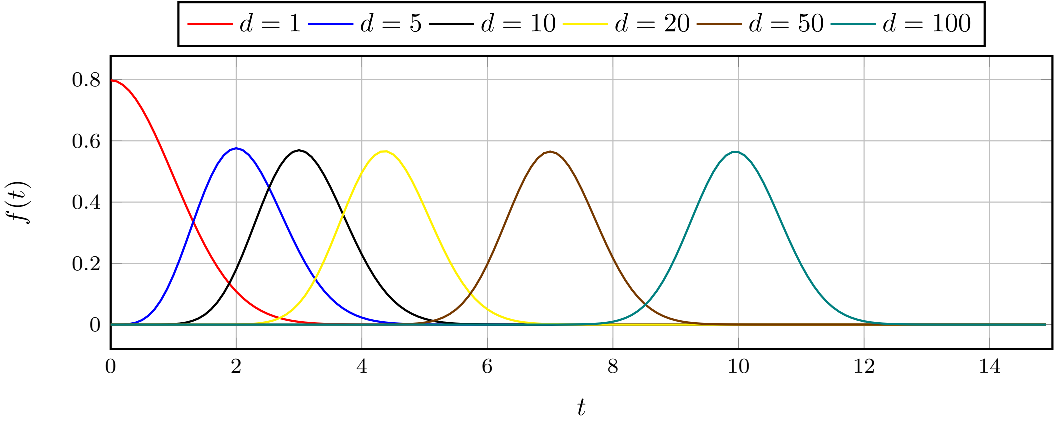
- High number of measurements d but limited number n of samples.
- High dimensional space do not behave as low/moderate dimensional space [JL98]:
  - Volume of an hypersphere: $V_s(d, r) = \frac{\pi^{d/2}}{\Gamma\left(\frac{d}{2}+1\right)} r^d$,
  - Volume of an hypercube: $V_c(d, r) = (2r)^d$.



Consider a r.v. $\mathbf{x} \sim \mathcal{N}(\mathbf{0}, \mathbf{I})$. The likelihood of $t = \|\mathbf{x}\|$ is given by

$$f(t) = \frac{t^{d-1}\exp(-t^2/2)}{2^{(d/2)-1}\Gamma(d/2)}$$

which is maximum for $t^* = \sqrt{d-1}$ [JL98].



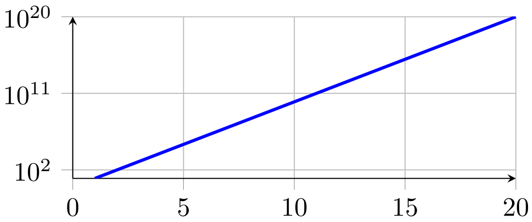
- Concentration of measure phenomenon [AHK01]: if $\mathbf{x}$ r.v. with i.i.d variables

$$\frac{d_M(\mathbf{x}) - d_m(\mathbf{x})}{d_M(\mathbf{x})} \rightarrow_p 0$$

for all Minkowski norm: $\|\mathbf{x}\| = \left(\sum_{i=1}^{d} |x_i|^p\right)^{1/p}$.

- From [Don00]:
  - Rate of convergence of estimators decreases when d increases,
  - The number of model parameters increase w.r.t d.

- Curse of dimensionality: Number of points to uniformly sample a unit hypercube (step=0.1)



- Method based on *nearest neighbors* fail (with Euclidean distance)
- Hughes phenomenon [Hug68]:

> *"With a fixed design pattern sample, recognition accuracy can first increase as the number of measurements made on a pattern increases, but decay with measurement complexity higher than some optimum value."*

- Ill-posed problem:
  - Matrix inversion,
  - Determinant,
  - Overfitting . . .

>>> Is there a fake ?

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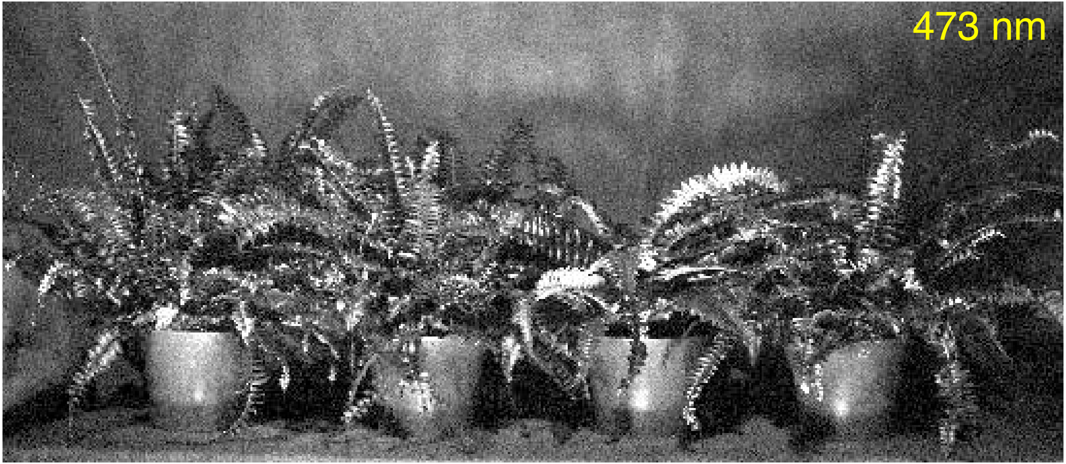

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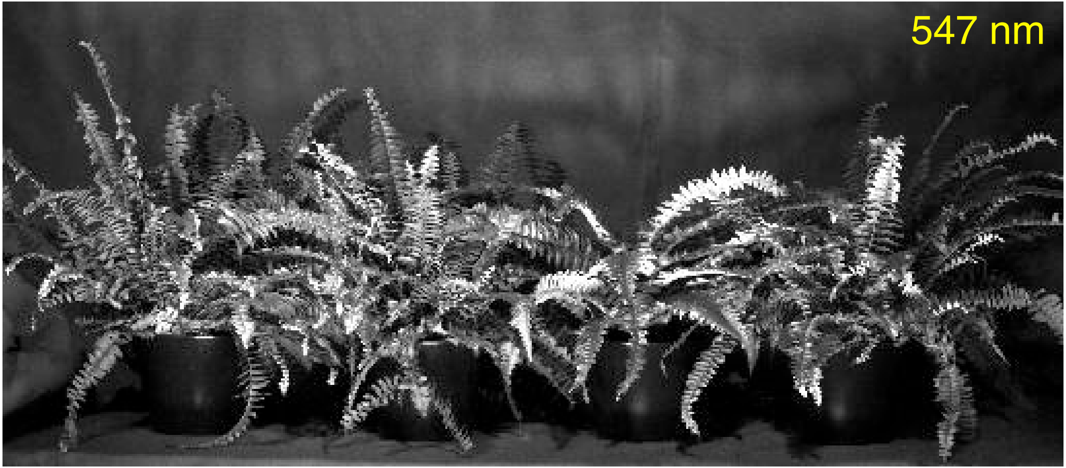

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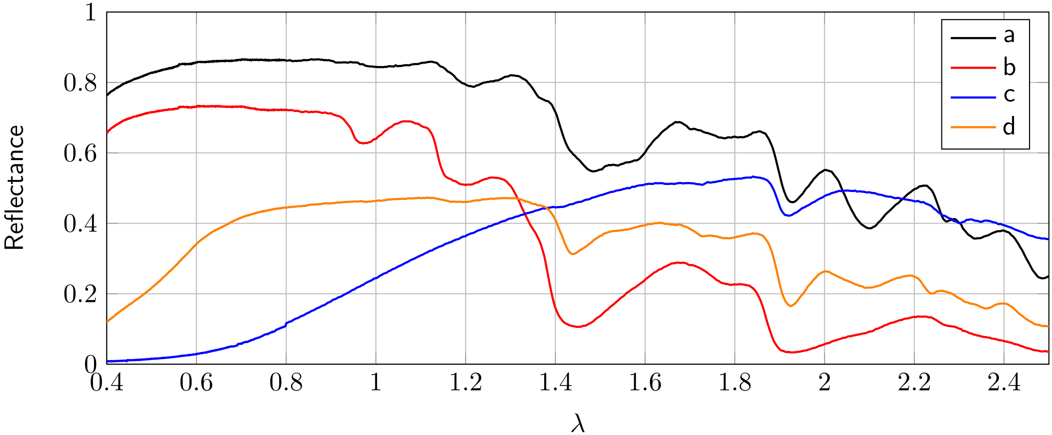

There are two spectra of the same material (cotton), before and after drying. Which are they ?

What is the number of parameters to estimate for a Gaussian distribution

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- The mean: d

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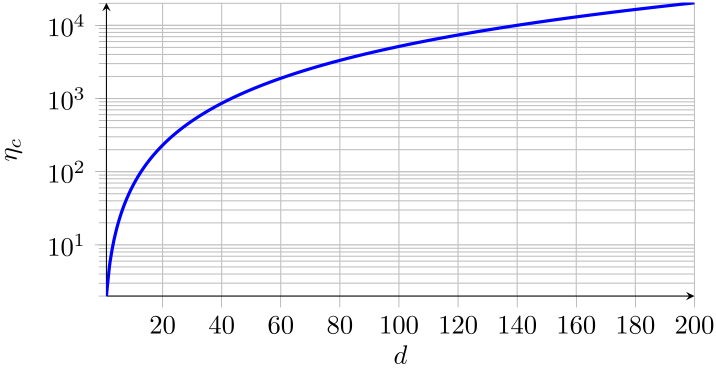
- The mean: d
- The covariance matrix: $d(d+1)/2$

What is the number of parameters to estimate for a Gaussian distribution

- ⋆ The mean: d
- ⋆ The covariance matrix: $d(d+1)/2$

Total: $d(d+3)/2 \approx d^2/2$



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Donoho, D.L. "High-dimensional data analysis: the curses and blessing of dimensionality". In: *AMS Mathematical challenges of the 21st century*. 2000.

Hughes, G.F. "On the mean accuracy of statistical pattern recognizers". In: *IEEE Trans. Inf. Th.* IT-14 (Jan. 1968), pp. 55–63.

Jimenez, L.O. and D.A. Landgrebe. "Supervised classification in high-dimensional space: geometrical, statistical, and asymptotical properties of multivariate data". In: *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on* 28.1 (Feb. 1998), pp. 39–54.

Keshava, N. and J. F. Mustard. "Spectral unmixing". In: *IEEE Signal Processing Magazine* 19.1 (Jan. 2002), pp. 44–57.

Manolakis, D., R. Lockwood, and T. Cooley. *Hyperspectral Imaging Remote Sensing: Physics, Sensors, and Algorithms*. Cambridge University Press, 2016. ISBN: 9781316033401. URL: https://books.google.fr/books?id=Zeg8DQAAQBAJ.