

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

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Date: [2017-04-26 Wed]–[2017-04-27 Thu]

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2. Hyperspectral imagery

Element of physics

Digital remote sensing images

Spectral signatures

3. Current challenges in hyperspectral

What is remote sensing made of ?

Current challenges

High dimensional data

4. Questions

5. References



★ 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

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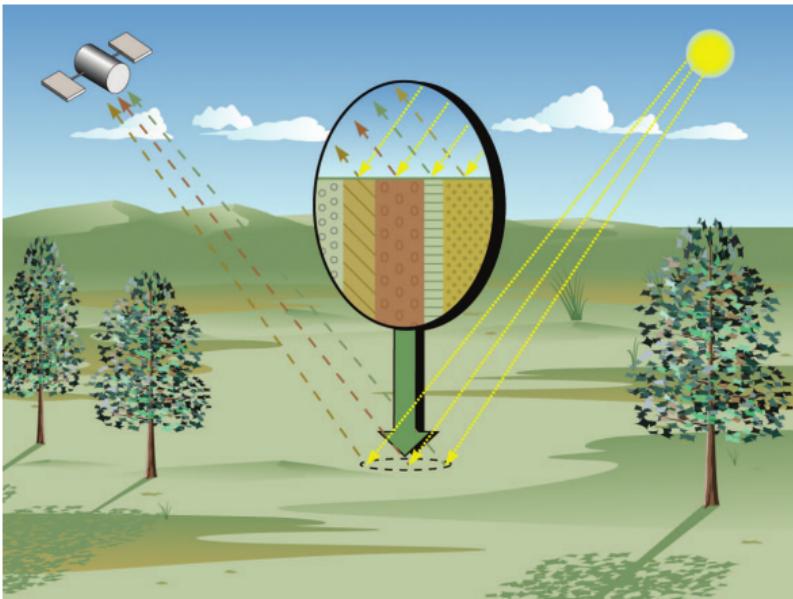
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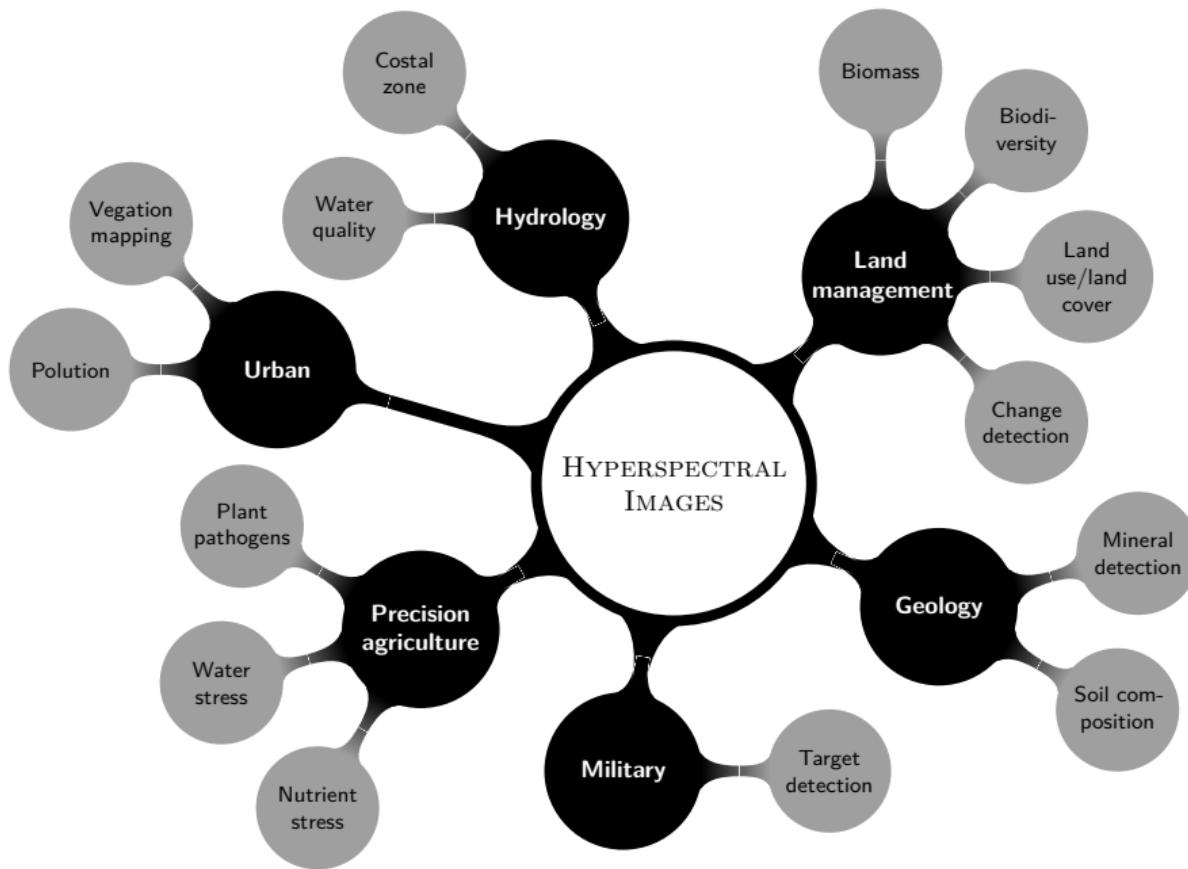
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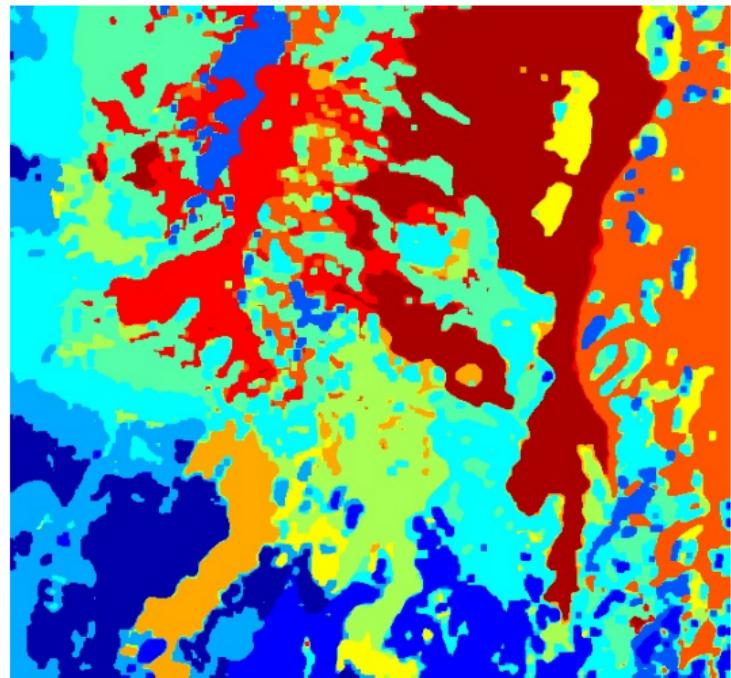
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- ★ Remote sensing provides information about landscapes.
- ★ This information is carried out by the *electromagnetic energy* and is usually formed in terms of *digital image data*.
- ★ This information can be used
  - ★ To *update* and to *supervise*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

Image taken from [KM02].





### 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.

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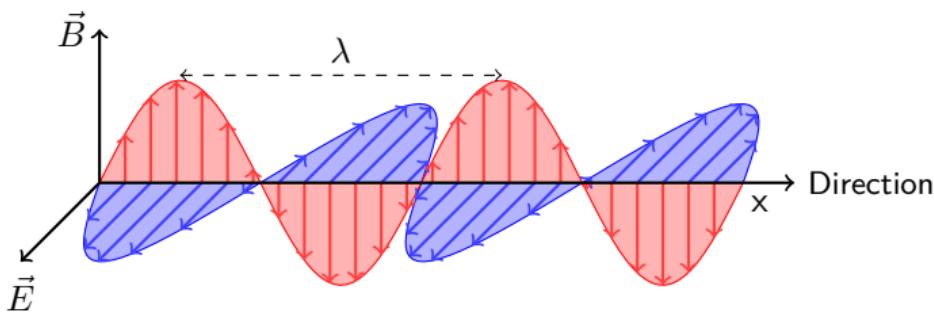
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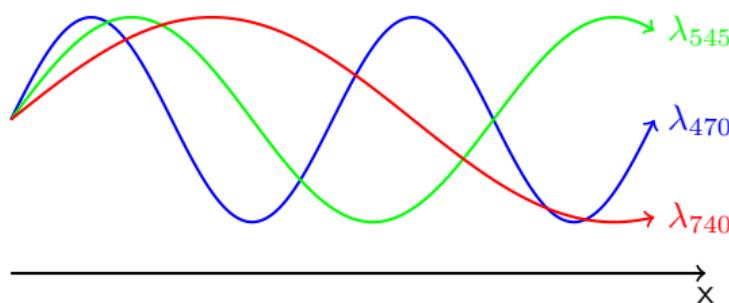
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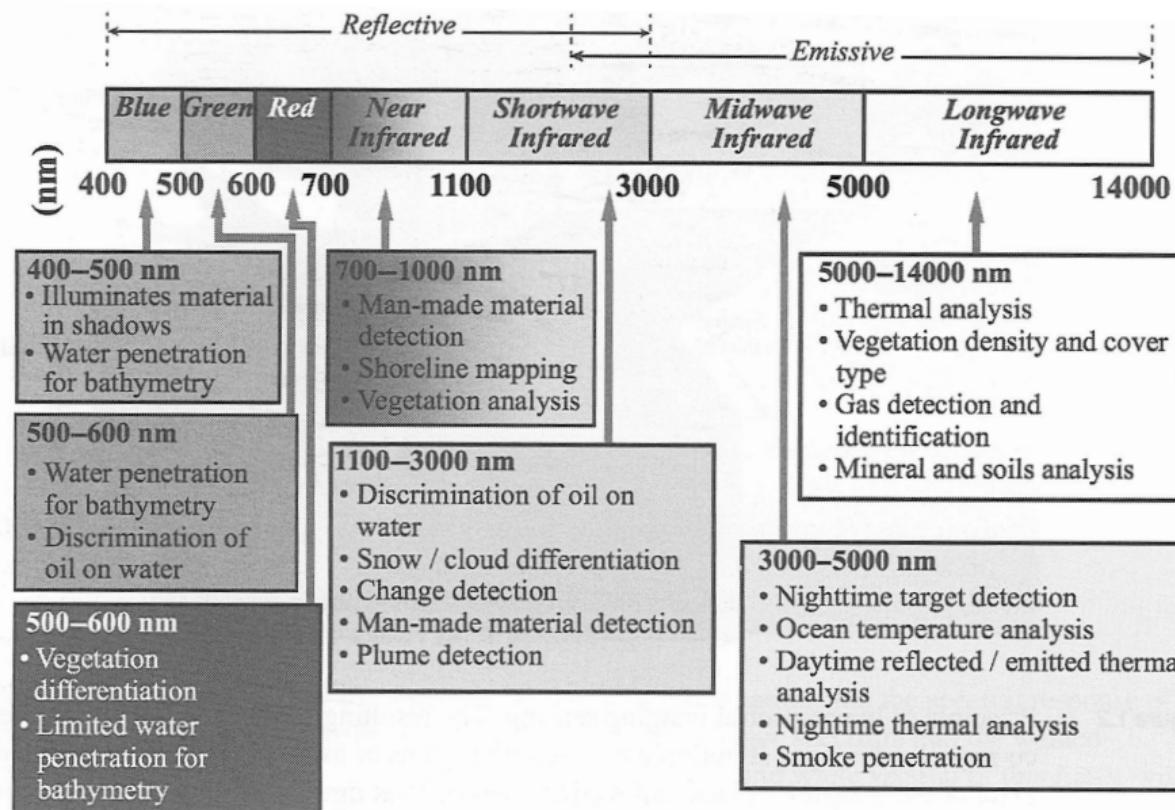
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- ★ An electromagnetic wave is a perturbation of the electric and magnetic field which propagates through space.
- ★  $\vec{E}$ : Electric field.  $\vec{B}$ : Magnetic field.
- ★ **Wavelength ( $\lambda$ )**: Minimal distance between 2 points of the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

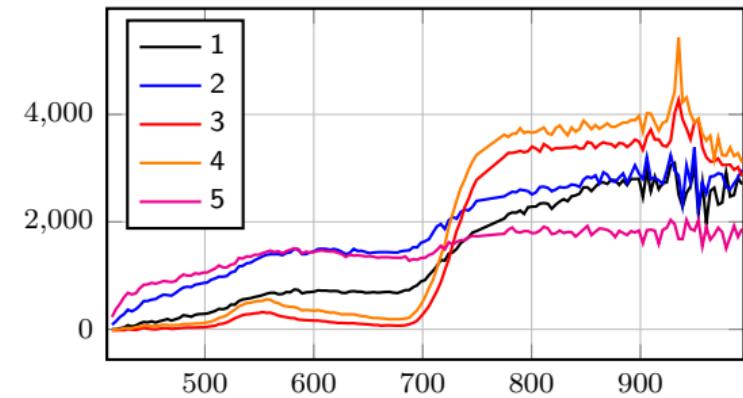




From [MLC16].

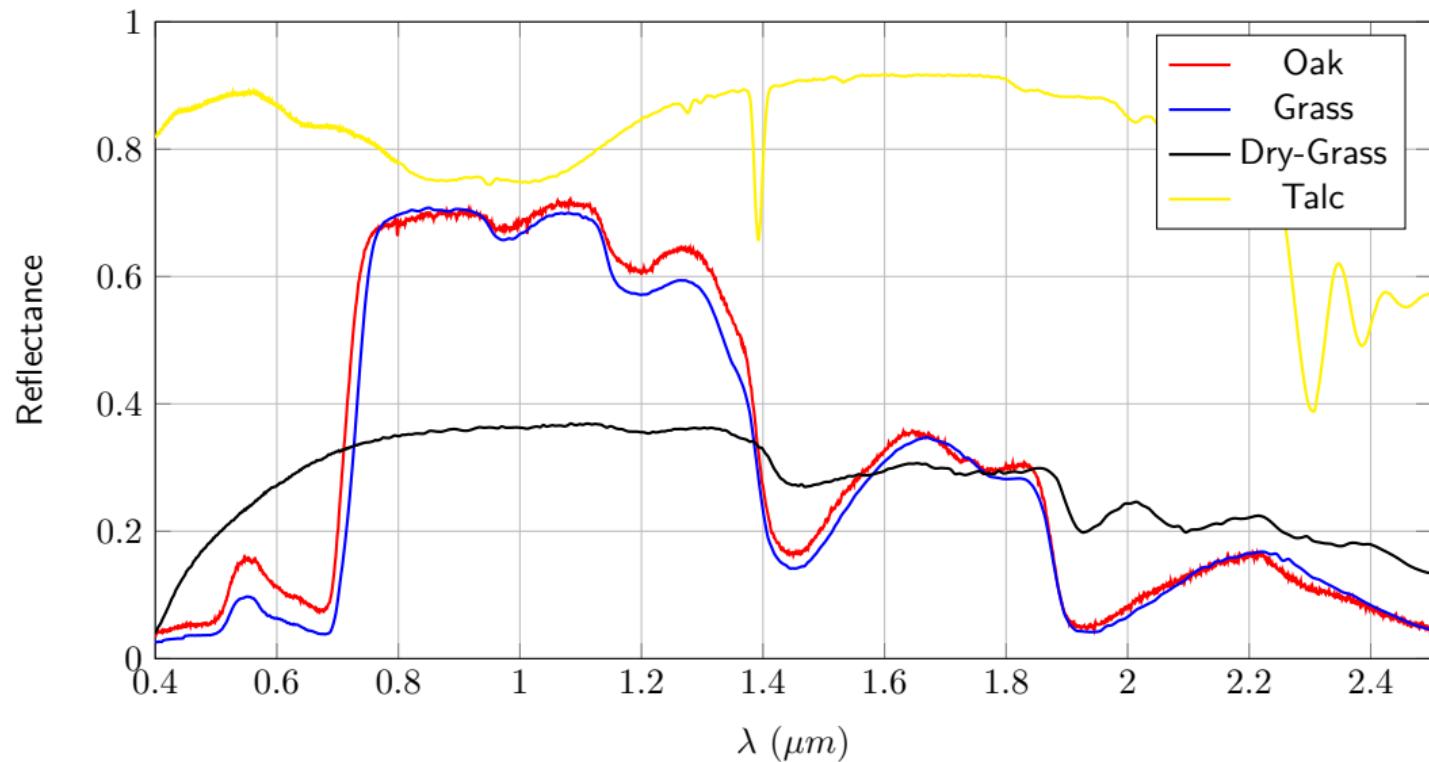
## Reflectance:

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



>>> Spectral reflectance curves

Spectral reflectance curves or spectral signature: Radiometric identity card



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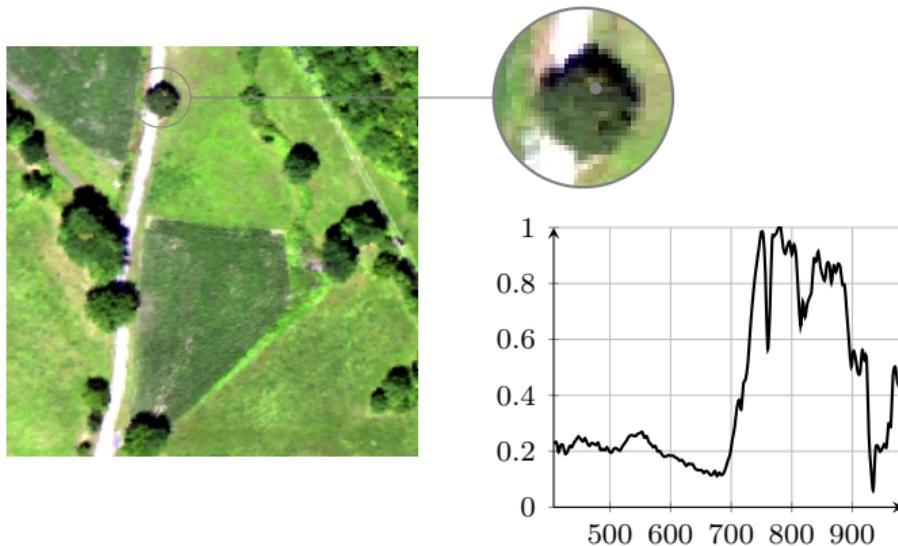
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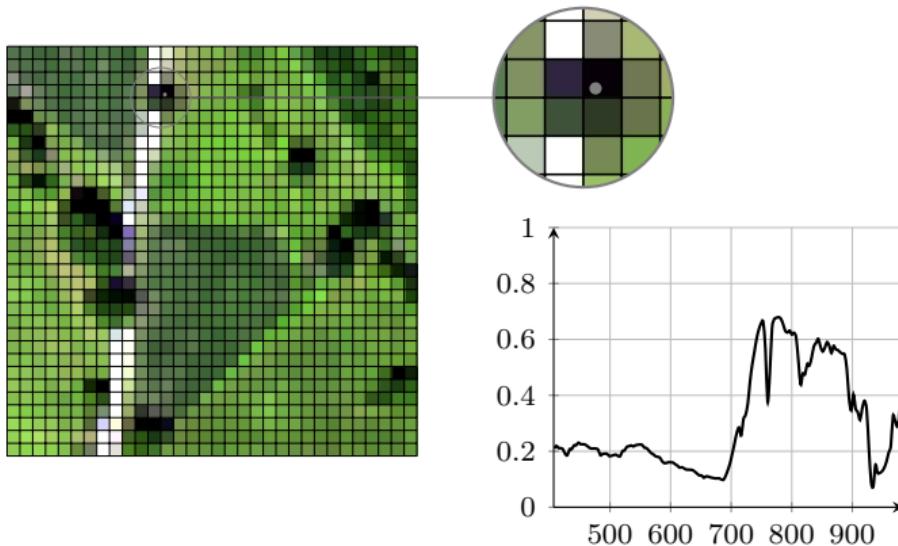
>>> Remote sensing images

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



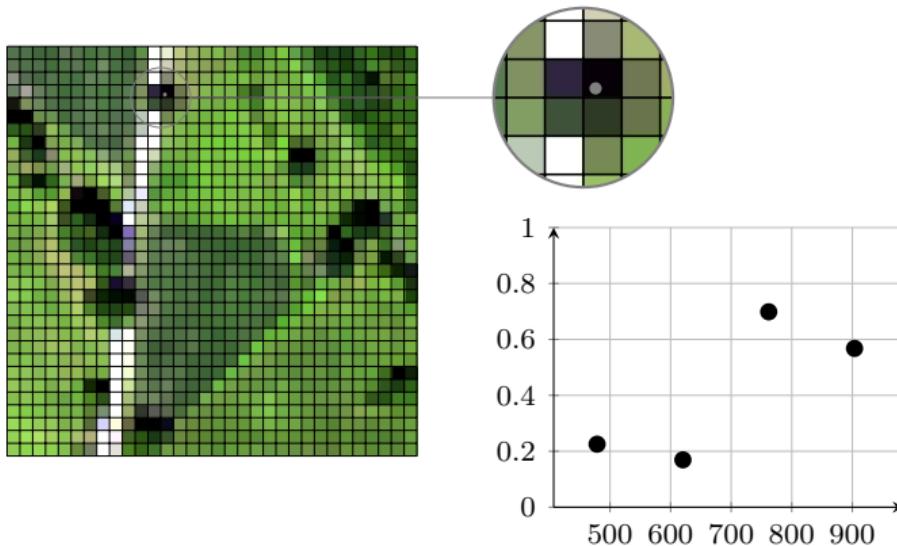
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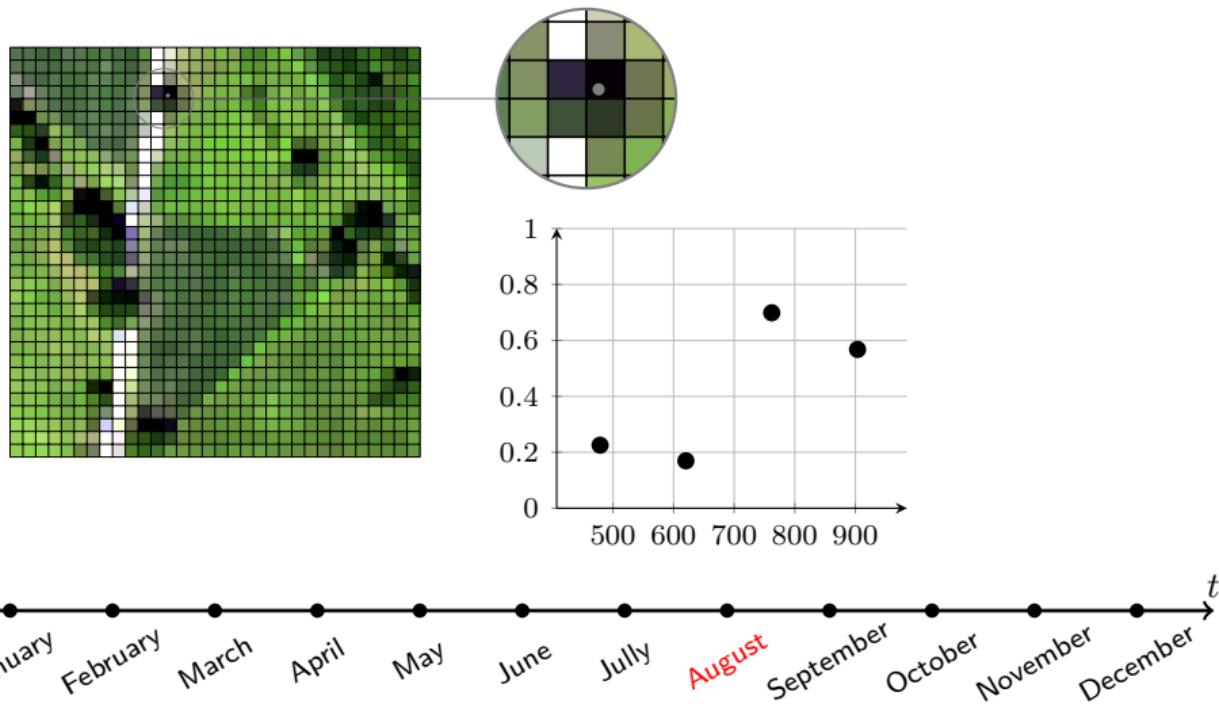
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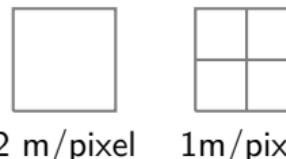
>>> Remote sensing images

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



>>> Characteristics of remote sensing images

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



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

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

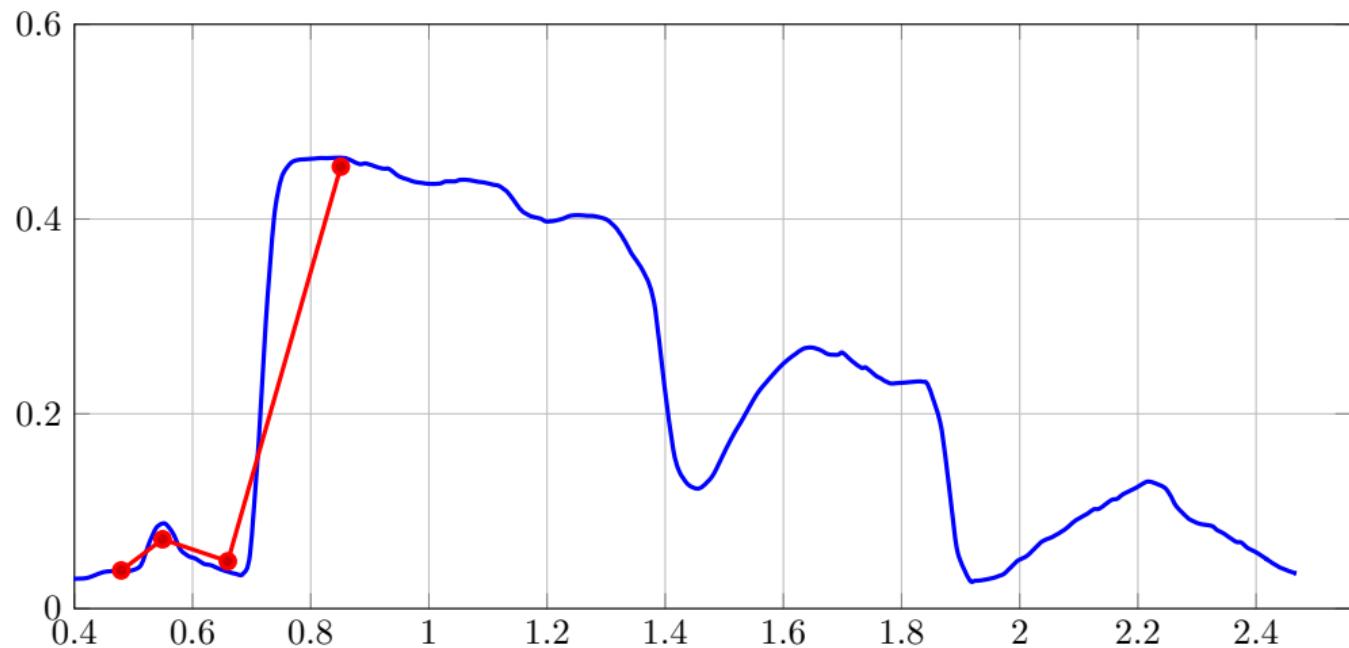
- \* Spectral resolution: *Width of each band of the spectrum that can be collected.*

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

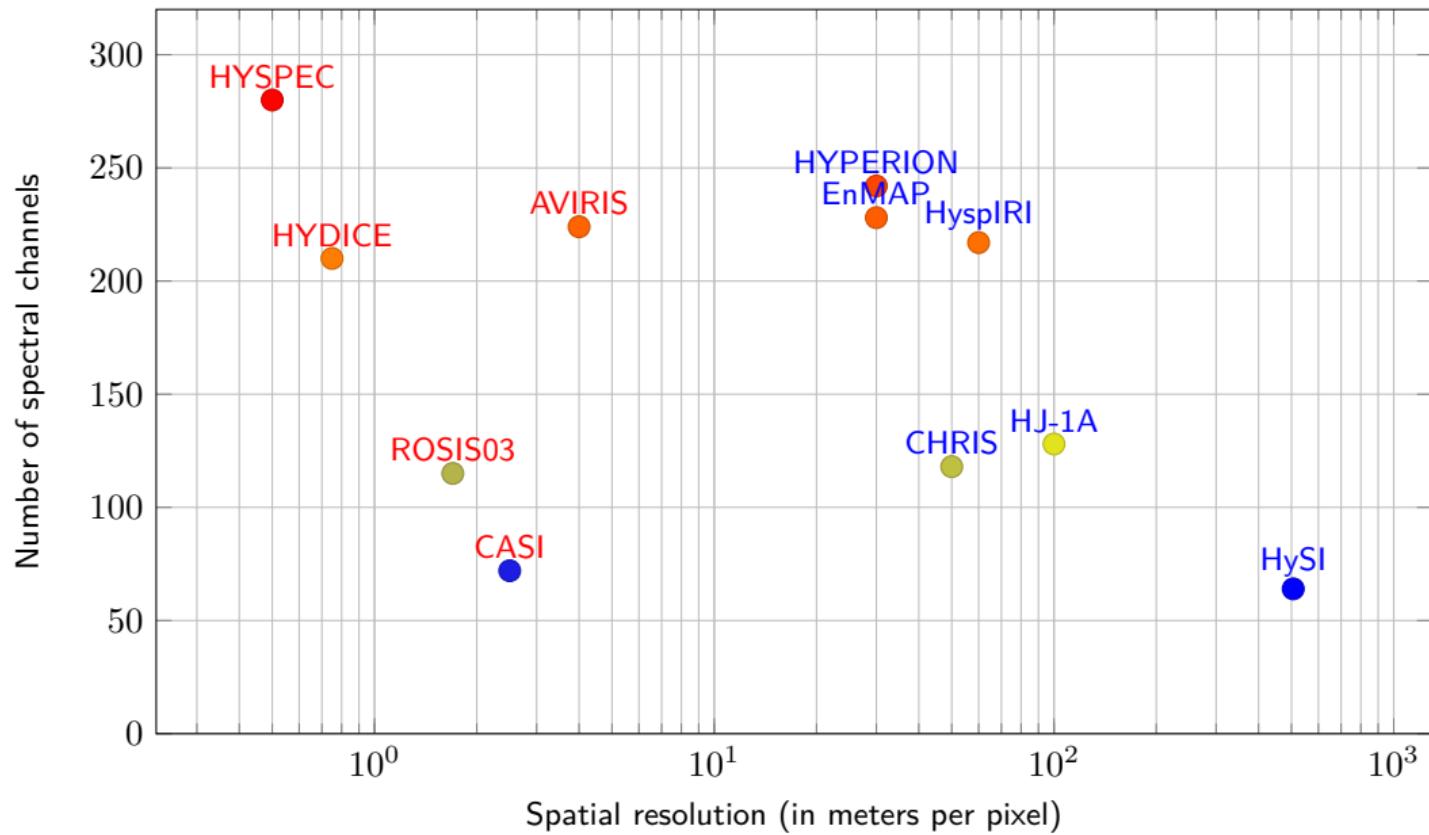
- \* Spatial and spectral resolution are linked: difficult to have high spatial *and* spectral resolution at the same time.

>>> Multispectral versus hyperspectral

Pleiade versus Hypsim



>>> Hyperspectral sensors



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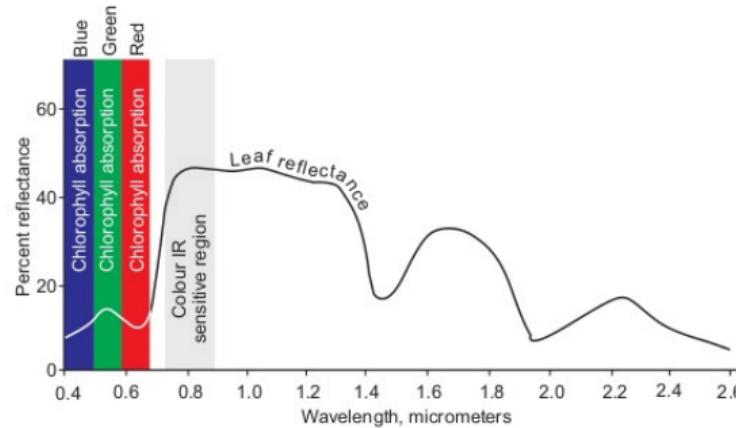
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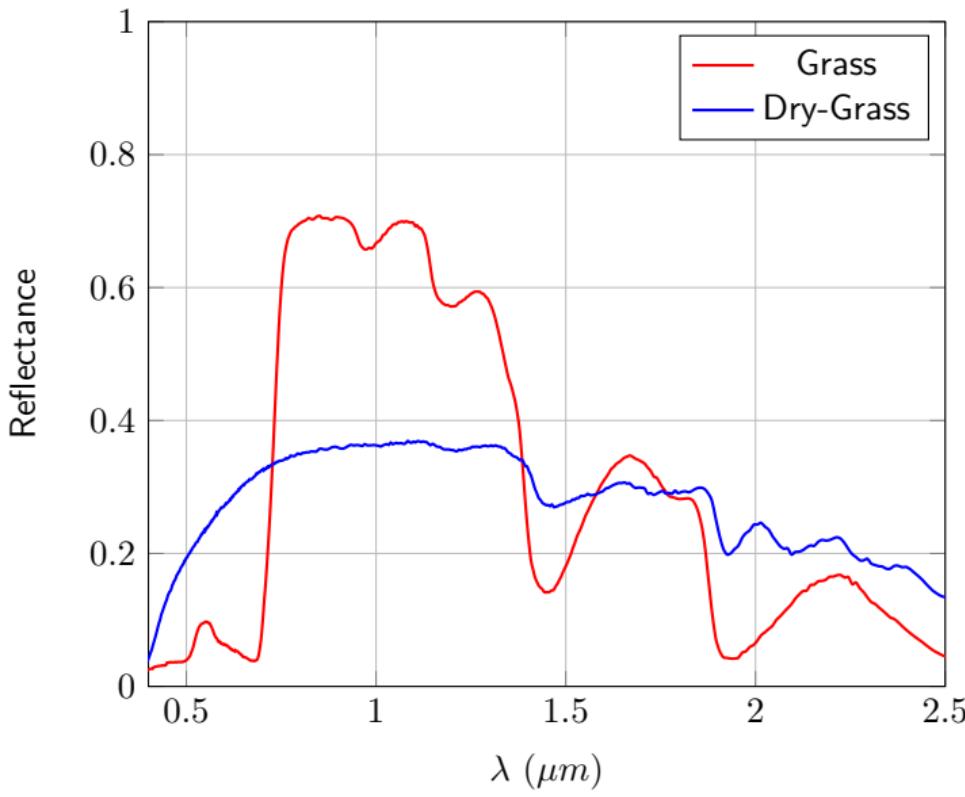
## Healthy vegetation (high photosynthesis)

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

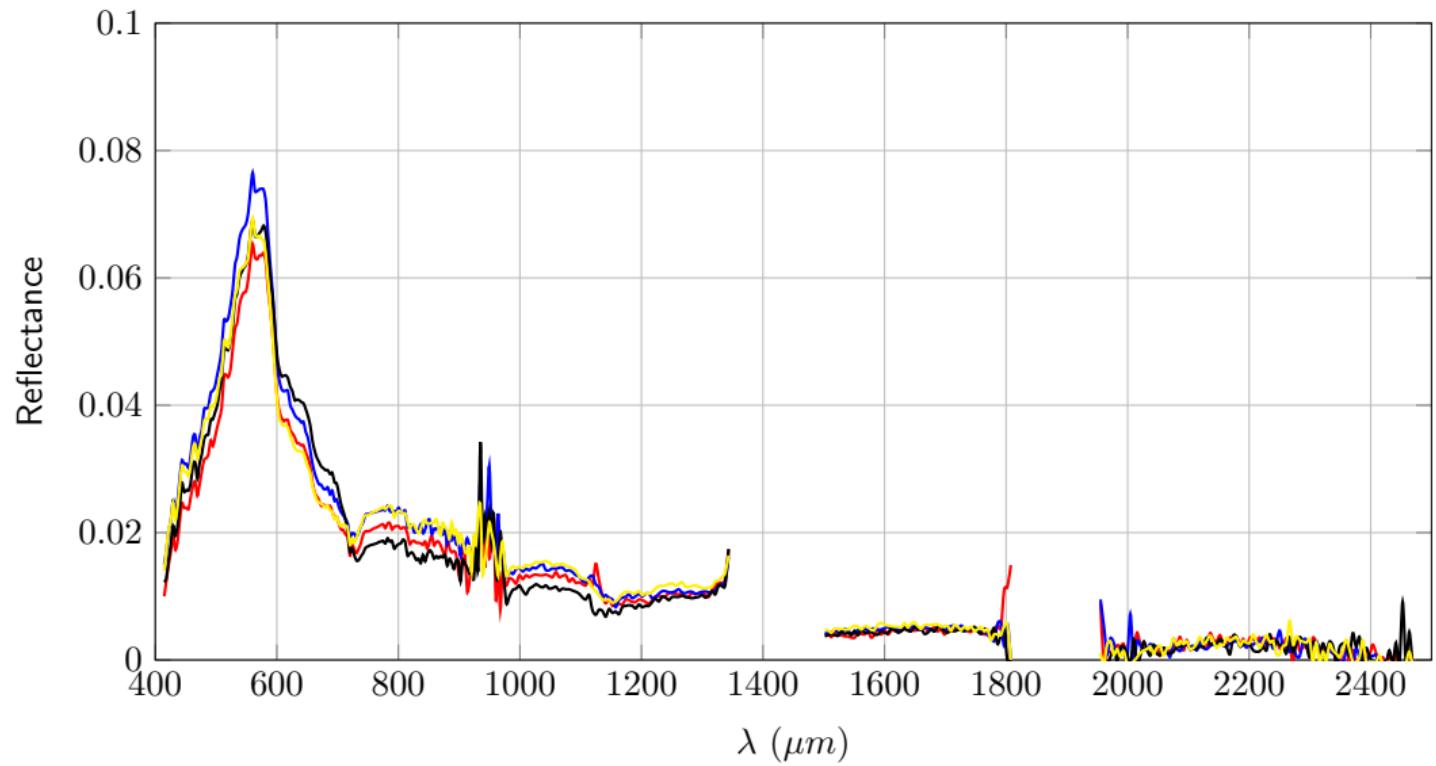


Factor modifying the reflectance

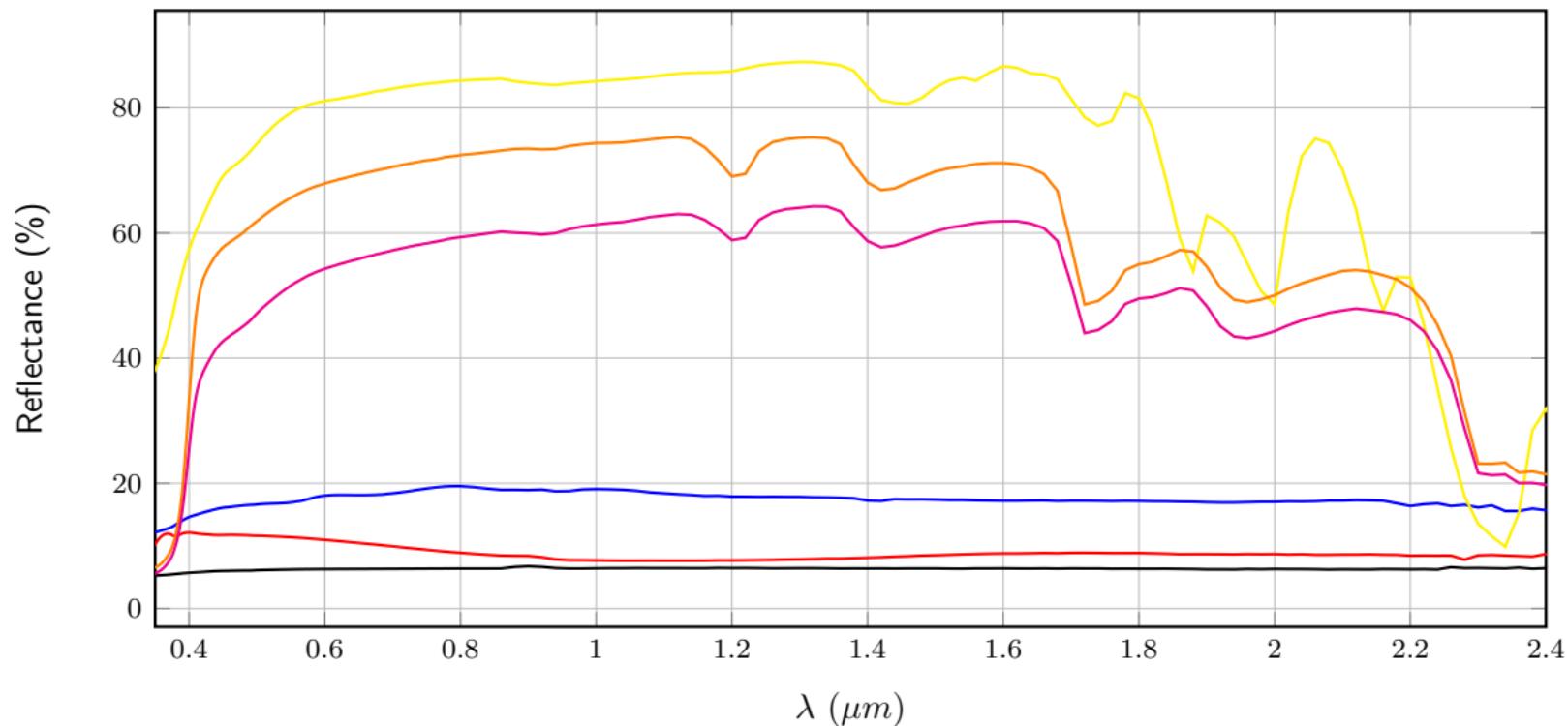
- \* Leaf thickness,
- \* Leaf age,
- \* Water content,
- \* Nitrogen content,
- \* Health condition,
- \* ...



>>> Water



— Black rubber — Window glass — Slate sonte  
— White marble — Fiberglass — Rubberized coating



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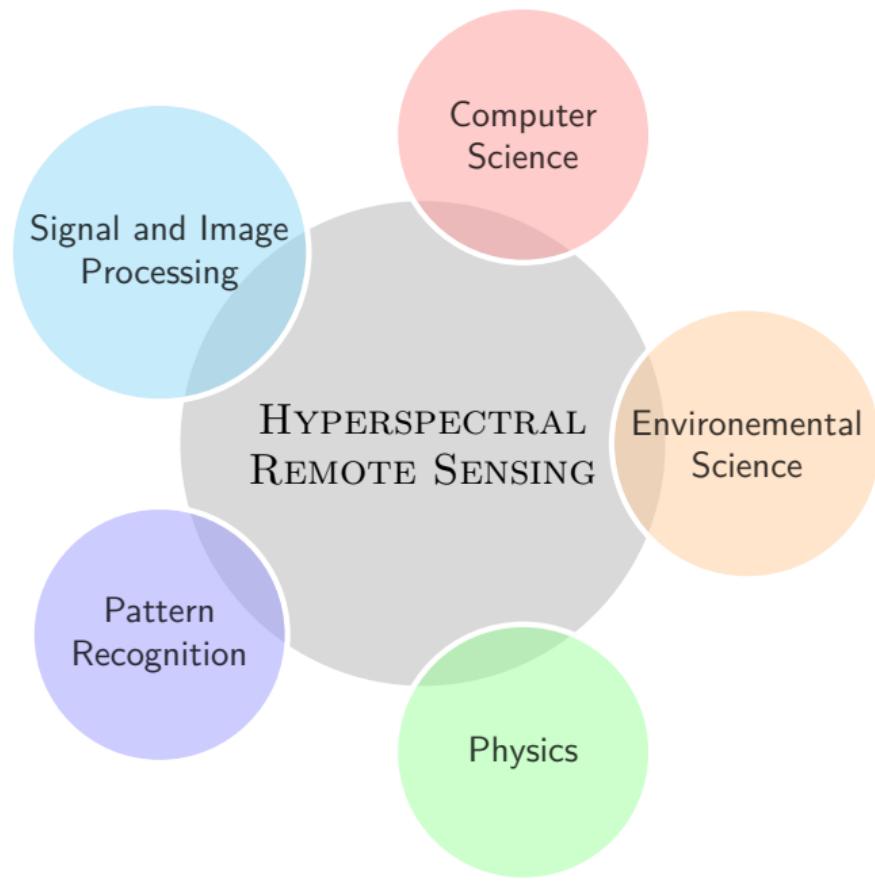
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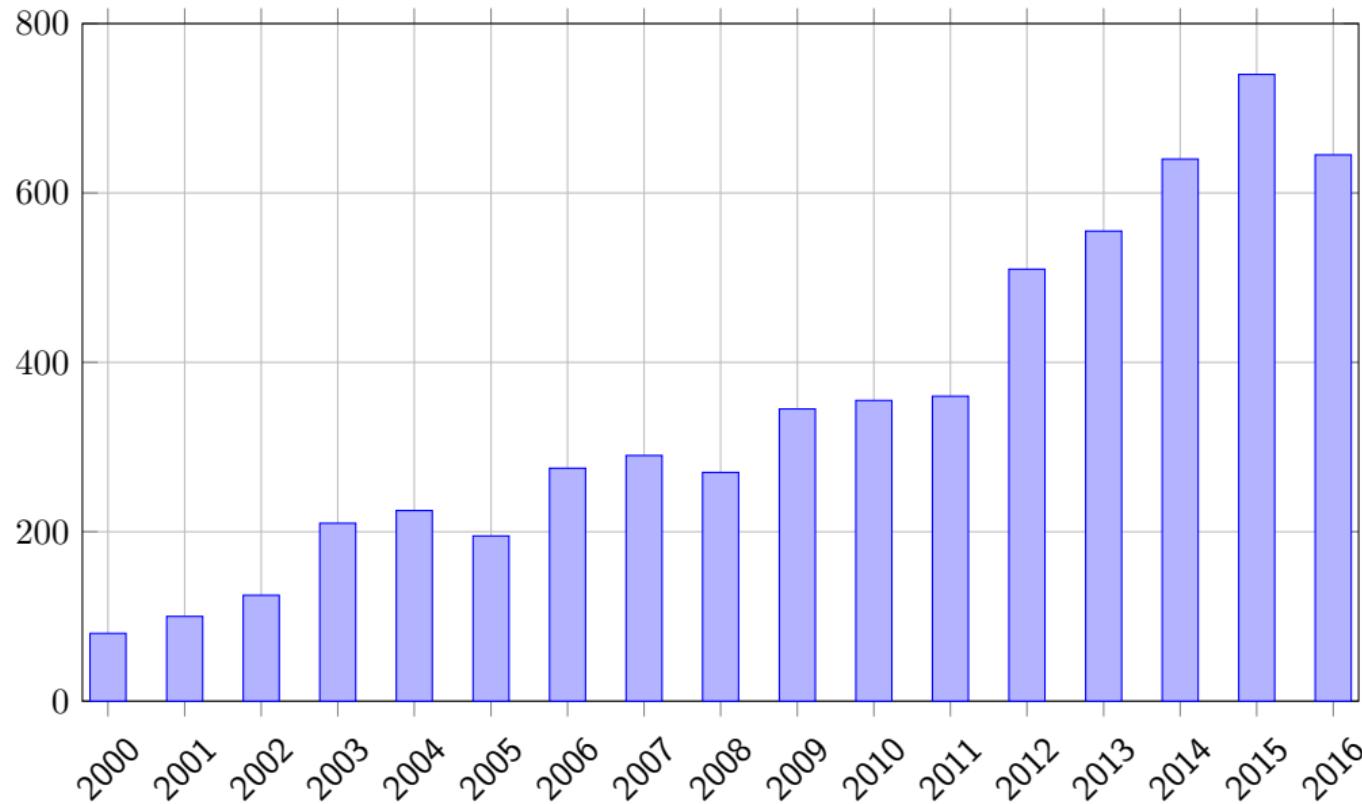
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- ★ Transmission:
  - ★ Compression.
- ★ Pre-processing:
  - ★ Geometric and atmospheric corrections,
  - ★ Data fusion,
  - ★ Feature extraction.
- ★ Information extraction:
  - ★ Classification/inversion,
  - ★ Unmixing,
  - ★ Target detection.

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



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\* Pattern recognition:

- ★ High dimensional data,
- ★ Spectral variability,
- ★ Reduce ground-truth.

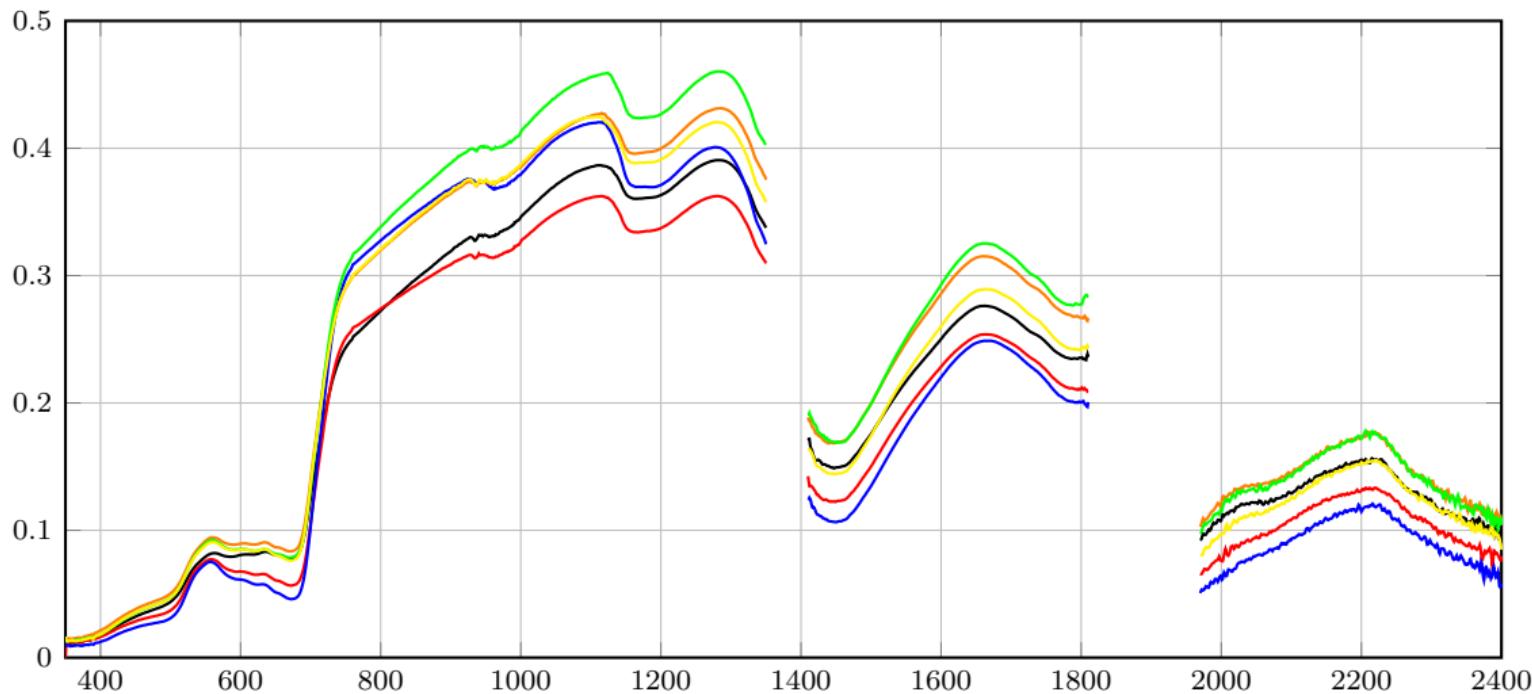
\* Computer science:

- ★ Large volume of data,
- ★ Real time constraints.

\* Thematic application:

- ★ Environmental issues,
- ★ Military issues,
- ★ Astrophysical issues.

### Grasslands measurements



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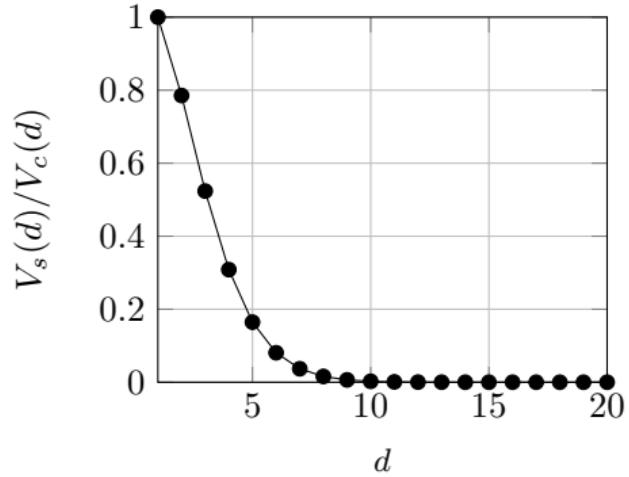
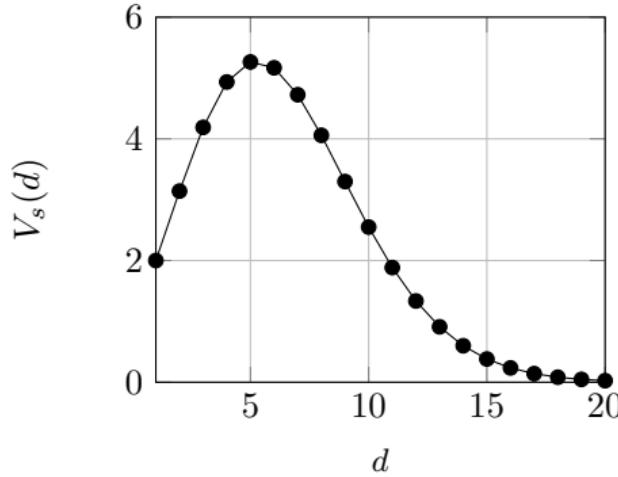
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- ★ High number of measurements  $d$  but limited number  $n$  of samples.
- ★ High dimensional space do not behave as low/moderate dimensional space [JL98]:
  - ★ Volume of an hypersphere:  $V_s(d, r) = \frac{\pi^{d/2}}{\Gamma(\frac{d}{2}+1)} r^d$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

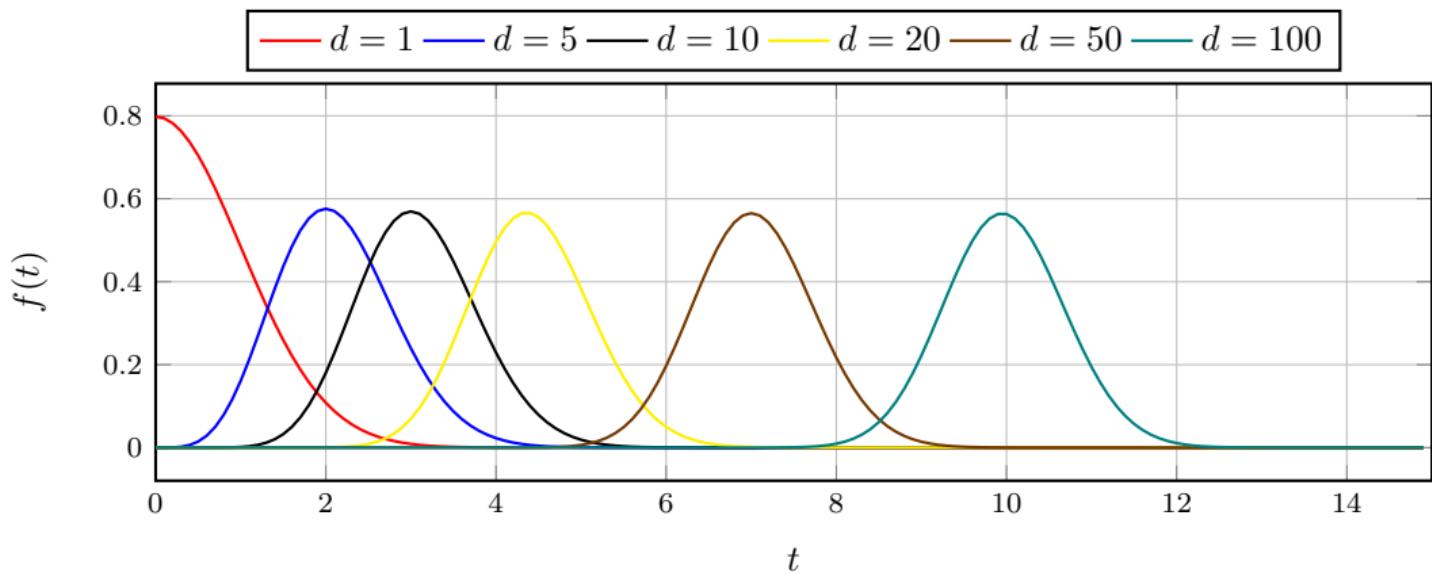


>>> Properties of HD spaces 2/3

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].



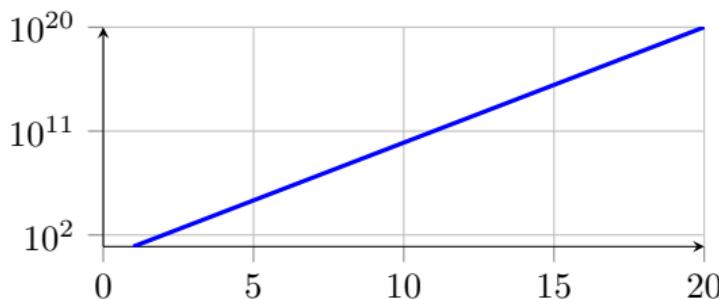
- ★ Concentration of measure phenomenon [AHK01]: if  $\mathbf{x}$  r.v. with i.i.d variables

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

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 ...

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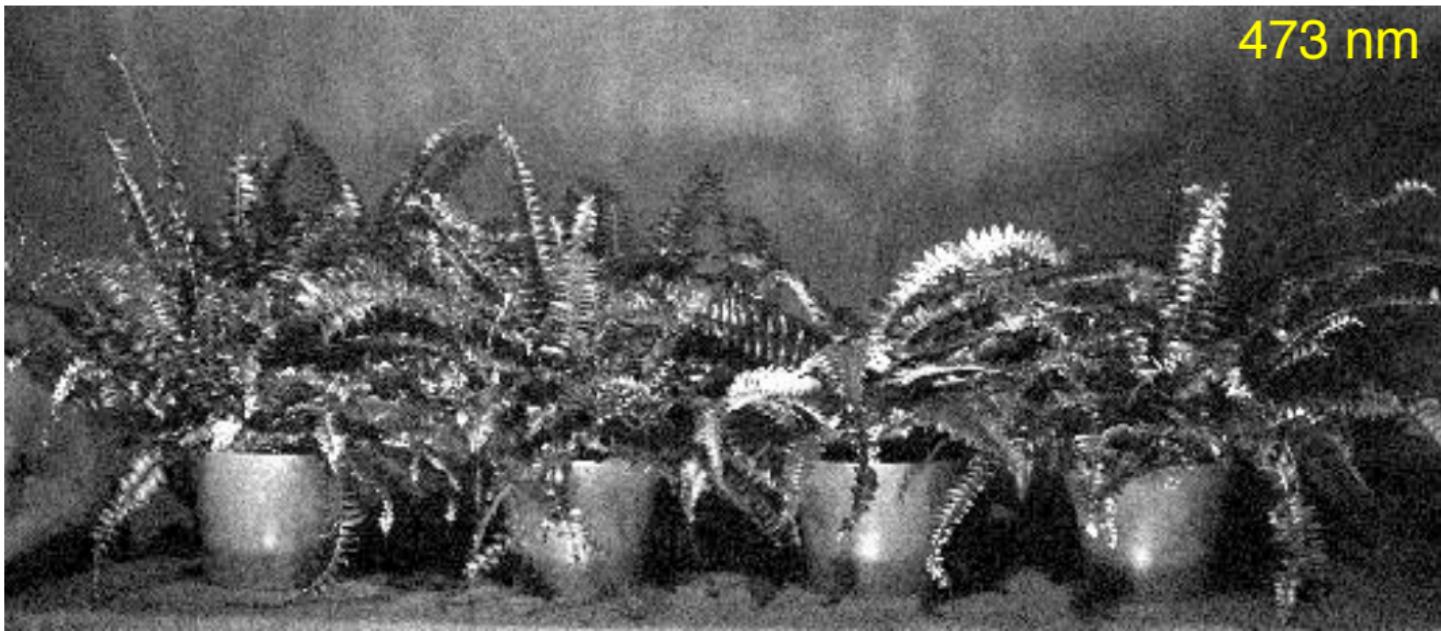
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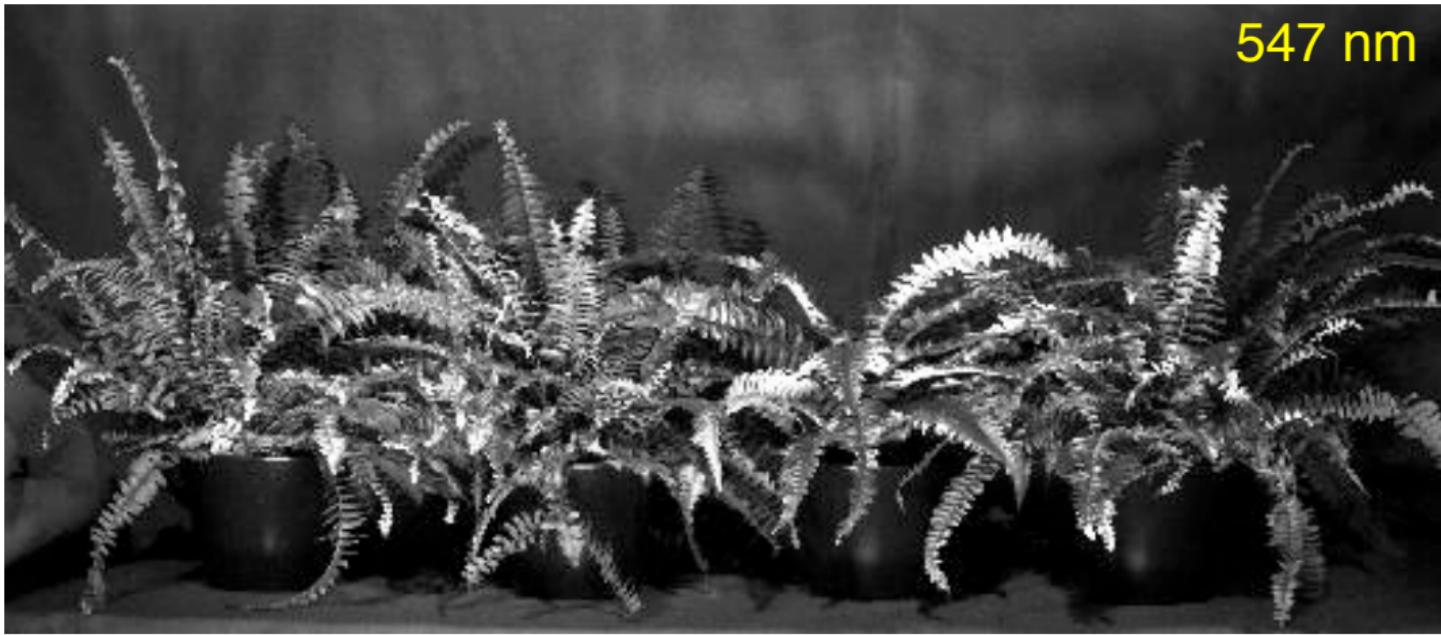
>>> Is there a fake ?



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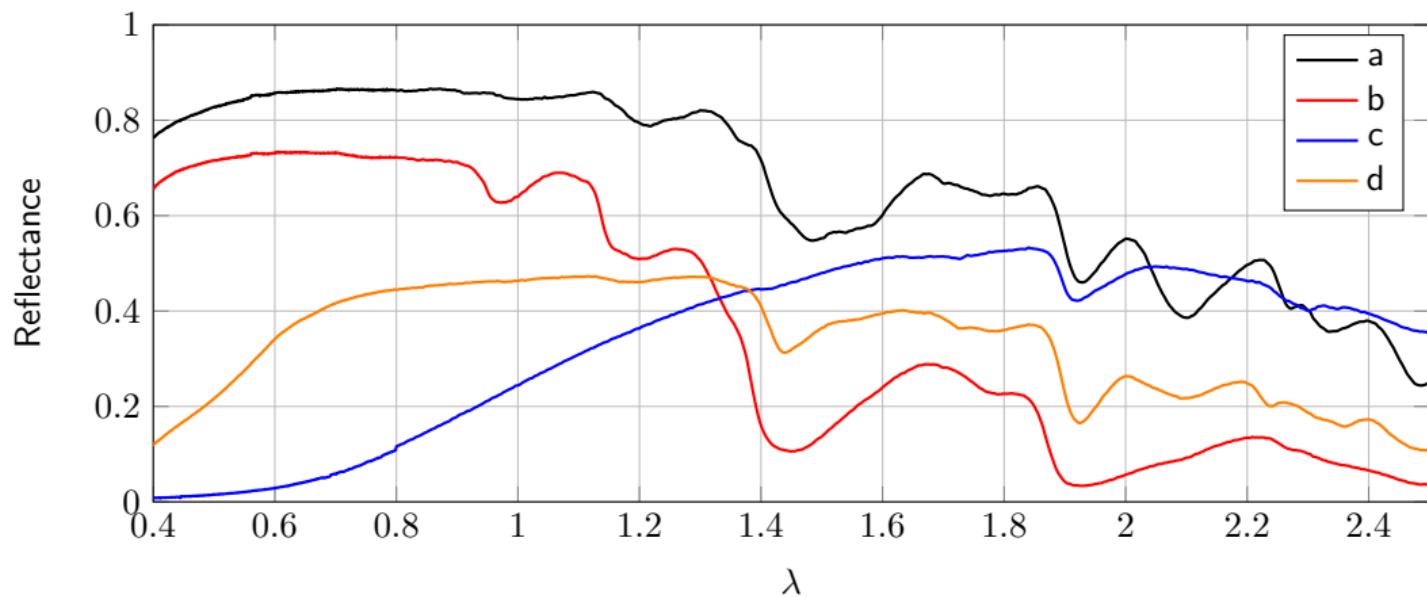


>>> Is there a fake ?



>>> Is there a fake ?





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

>>> Gaussian distribution

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

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- ★ The mean:  $d$

>>> Gaussian distribution

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

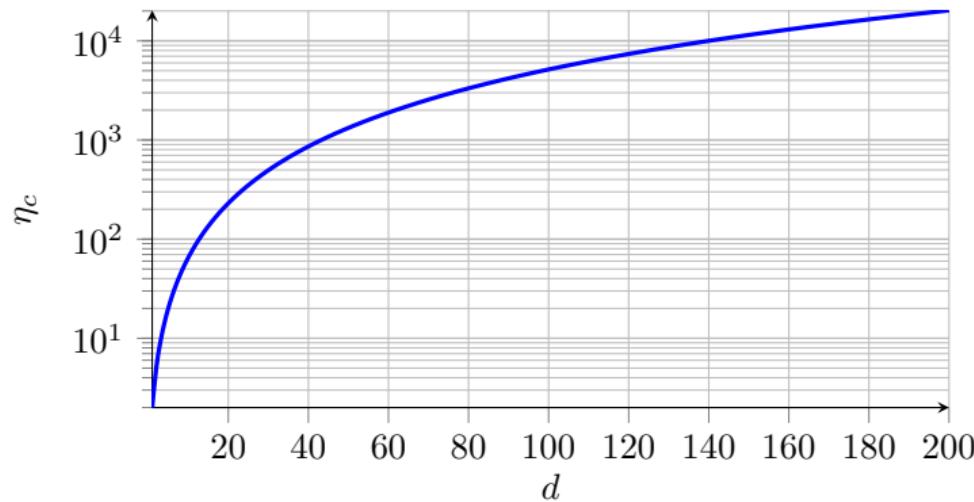
- ★ The mean:  $d$
- ★ The covariance matrix:  $d(d + 1)/2$

>>> Gaussian distribution

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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<https://books.google.fr/books?id=Zeg8DQAAQBAJ>.

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