IA@SISU, AI or not AI ?

Hervé Carfantan

- What kind of AI are we talking about?
  Generative AI, CNN, deep learning, random forest, ML...
  Regression, Classification, Estimation ?
- Approaches? Model-based versus data-driven
- Examples of some problems studied in the SISU group:

1. Correction of pushbroom detectors
2. Spectral unmixing of hyperspectral images
3. Spectral unmixing for EUCLID
4. Super-resolution through data fusion
5. Unsupervised classification for a coded mask hyperspectral imager

1. Correction of pushbroom detectors

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Jérôme Idier
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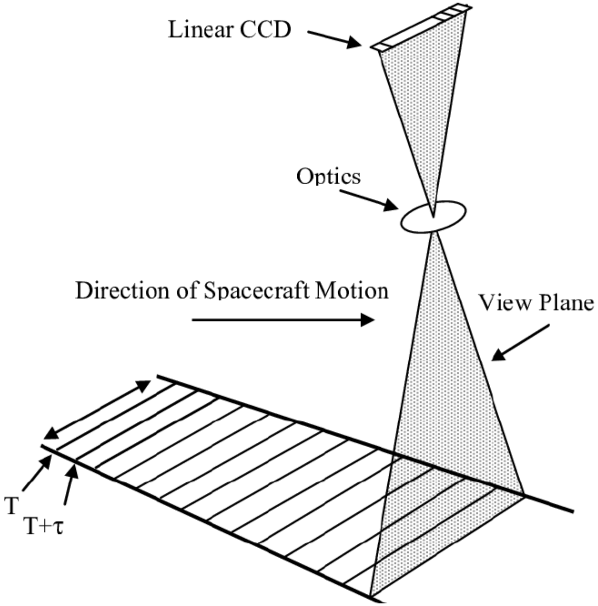
- Pushbroom satellite imaging

  - 1D array detector

  - Acquisition of one image row at each acquisition



  - The motion of the satellite scans all lines

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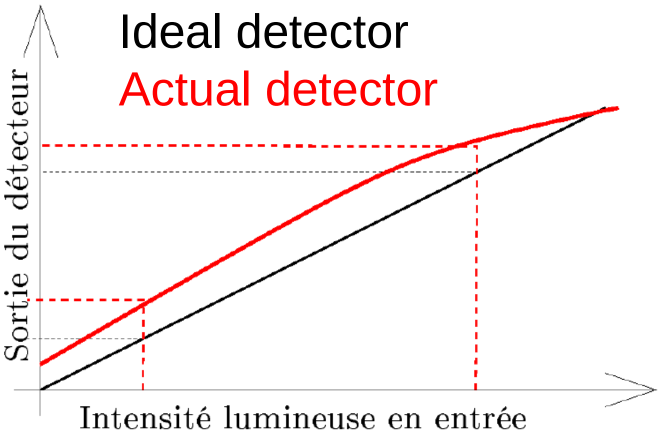
- ## Pushbroom satellite imaging

- Response of one detector



- Each detector of the 1D array has a different response !

Effect of vertical stripes on the image

- ## Detector calibration/image correction

- Ground-based qualification
- Calibration during flight acceptance testing

- Residual correction from any image

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- Model-based approach: Affine response model of detectors

For each column c : gain g_c & offset o_c

$$I_{\ell,c} = g_c S_{\ell,c} + o_c \quad \Rightarrow S_{\ell,c} = a_c I_{\ell,c} - \gamma_c$$

Correction gain and offset a_c & γ_c

Independant, Gaussian $a_c \sim \mathcal{N}(1, \sigma_a^2)$ $\gamma_c \sim \mathcal{N}(0, \sigma_\gamma^2)$

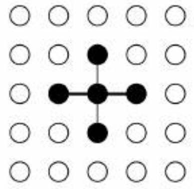
- Model for the observed scene

Gibbs random fields : probability density $f(\boldsymbol{S}) \propto \exp\left(-\frac{1}{T} \sum_{(\ell,c)\sim(\ell',c')} \phi(S_{\ell,c} - S_{\ell',c'})\right)$

Rq : For quadratic function ϕ: Gaussian process
Better results for non-quadratic ϕ

$(\ell, c) \sim (\ell', c')$

4 nearest neihhbours



- Maximum a posteriori estimator

Minimizes the cost function :

$$K_{\text{MAP}}(\{a_c, \gamma_c\}_c) = \frac{1}{T} \sum_{\ell,c} \phi((a_c I_{\ell,c} - \gamma_c) - (a_c I_{\ell,c+1} - \gamma_c)) + \frac{1}{\sigma_a^2} \sum_c (a_c - 1)^2 + \frac{1}{\sigma_\gamma^2} \sum_c \gamma_c^2$$

1. Correction of pushbroom detectors

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- Other methods without detector response models

Method	Year	Input	Imaging	Brief Description	Direction	Estimation
Horn [1]	1979	Single Image	Landsat MSS	Histogram Matching	No	Image
Wegener [2]	1990	Single Image	Landsat MSS	Histogram Matching	No	Image
Corsini [3]	2000	Single Image	MOS-B	Moment Equalization	No	Image
Gadallah [4]	2000	Single Image	Landsat TM	Moment Matching	No	Image
Meza [5]	2016	Multispectral	Hyperspectral	Equalization	No	Image
Simpson [6]	1998	Single Image	GOES-7	Finite Impulse Filters	No	Image
Chen [7]	2003	Single Image	CMODIS	Filtering	No	Image
Chen [8]	2006	Single Image	CMODIS	Wavelet+ FFT	Yes	Image
Liu [9]	2006	Single Image	Landsat-7	FFT + Adaptive Filtering	Yes	Image
Rakwatin [10]	2007	Single Image	MODIS	Moment Matching + Facet Filtering	No	Image
Gómez [11]	2008	Multispectral	CHRIS	Filtering	Yes	Image
Rakwatin [12]	2009	Multispectral	MODIS Band6	Moment Matching + Facet Filtering	No	Image
Münch [13]	2009	Single Image	Medical	Wavelet + FFT	Yes	Image
Wang [14]	2008	Multispectral	MODIS Band6	Interpolation	No	Image
Jung [15]	2010	Multispectral	SPOT4	Detection + Interpolation	No	Image
Chhetri [16]	2011	Single Image	Hyperspectral	Wavelet + FFT	Yes	Image
Gladkova [17]	2011	Multispectral	MODIS Band6	Multivariate Regression	No	Image
Duan [18]	2014	Single Image	Hyperspectral	Reference Calibration + Filtering	No	Image
Cao [19]	2016	Single Image	Infrared	1D Guided Filtering	Yes	Image

Histogram Maching

Image filtering

1. Correction of pushbroom detectors

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- Other methods without detector response models...

Shen [20]	2009	Single Image	MODIS	MAP Framework with Huber-Markov Prior	No	Image
Bisceglie [21]	2009	Single Image	MODIS	Least Squares Minimization	No	Image
Carfantan [22]	2010	Single Image	SPOT3	MAP Framework with Markov field Prior	No	Stripe
Bouali [23]	2011	Single Image	MODIS	Unidirectional Variational	Yes	Image
Fehrenbach [24]	2012	Single Image	Medical	MAP Framework with Huber-Markov Prior	Yes	Stripe
Yuan [25]	2012	Multispectral	Hyperspectral	Spectral-spatial Adaptive Total Variation	No	Image
Chang [26]	2013	Single Image	General	Framelet + Unidirectional Variational	Yes	Image
Chang [27]	2014	Single Image	General	Sparse + Unidirectional Variation	Yes	Image
Chang [28]	2015	Multispectral	General	Anisotropic Spectral-Spatial Total Variation	Yes	Image
Liu [29]	2015	Single Image	General	Sparse + Unidirectional Variational	Yes	Stripe
Aggarwal [30]	2016	Multispectral	Hyperspectral	Spectral-spatial Total Variation	No	Image
Fitschen [31]	2017	Single Image	Medical	Framelet + Unidirectional Variational	Yes	Image
Liu [32]	2018	Single Image	General	Oriented Variational	Yes	Image
Liu [33]	2018	Single Image	General	Feature based Unidirectional Variational	Yes	Image
Acito [35]	2011	Multispectral	Hyperspectral	Orthogonal Subspace Learning	No	Stripe
Lu [36]	2013	Multispectral	Hyperspectral	Graph-regularized Low-rank Representation	No	Both
Zhang [37]	2014	Multispectral	Hyperspectral	Low-rank Matrix Recovery	No	Both
Zhao [38]	2015	Multispectral	Hyperspectral	Sparse + Low-rank Matrix Recovery	No	Image
Wang [39]	2016	Multispectral	Hyperspectral	Group Low-rank Representation	Yes	Both
He [40]	2016	Multispectral	Hyperspectral	Total variation based Low-rank Representation	No	Both
Chang [41]	2016	Multispectral	General	Low-rank Image Decomposition	Yes	Both
Chen [42]	2017	Single Image	General	Group Sparsity + Unidirectional Variational	Yes	Stripe
Chang [43]	2017	Single Image	General	Transformed Low-rank Matrix Recovery	Yes	Image

Image denoising

Image and stripes estimation

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Jérôme Idier
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- Other methods without detector response models...

Xie [46]	2016	Multispectral	Hyperspectral	Intrinsic Tensor Sparsity	No	Image
Chang [47]	2017	Multispectral	Hyperspectral	Unidirectional Low-rank Tensor Recovery	No	Image
Fan [48]	2017	Multispectral	Hyperspectral	Low-rank Tensor Recovery	No	Both
Chen [49]	2018	Multispectral	Hyperspectral	ASSTV + Low-rank Tensor Decomposition	Yes	Both
Cao [50]	2018	Multispectral	Hyperspectral	SSTV + Low-rank Tensor Recovery	No	Both
Fan [51]	2018	Multispectral	Hyperspectral	SSTV + Low-rank Tensor Recovery	No	Both
Wang [52]	2018	Multispectral	Hyperspectral	SSTV + Low-rank Tensor Decomposition	No	Both
Kuang [53]	2017	Single Image	Infrared	CNN	No	Image
He [54]	2018	Single Image	Infrared	CNN	No	Image
Xiao [55]	2018	Single Image	Infrared	Local-global CNN	No	Image
Xie [56]	2018	Multispectral	Hyperspectral	Residual Deep CNN	No	Stripe
Zhang [57]	2018	Multispectral	Hyperspectral	Spatial-spectral Gradient CNN	No	Stripe
Chang [58]	2019	Multispectral	Hyperspectral	Residual Deep CNN	No	Stripe
Chang [60]	2019	Single Image	Infrared	Multiscale Residual Deep CNN	No	Stripe

Image & stripes estimation

Data-Driven (CNN)

- Data-driven approach

$$D = I + S$$

Data Image Stripes

Retrieve image I or stripes S from D :
- Generation of an image database
- Simulation of stripes (model?)
- Training a CNN

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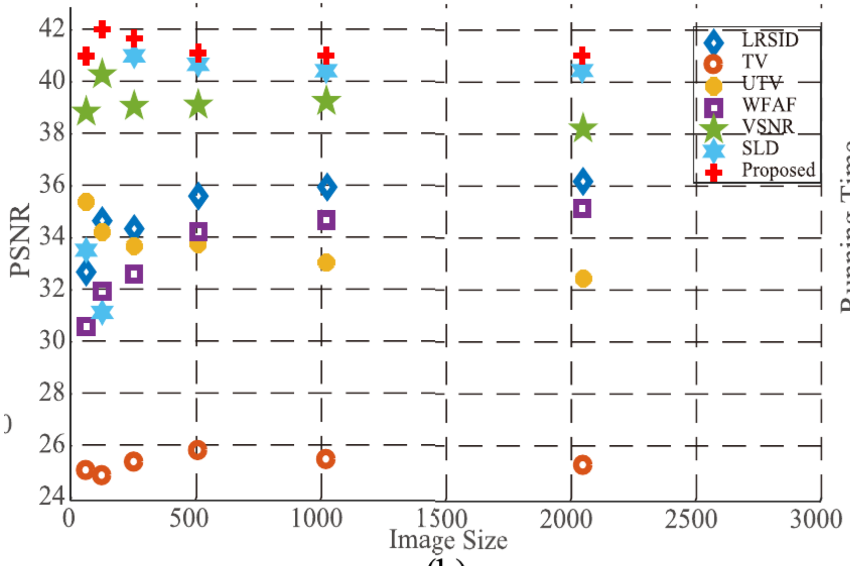
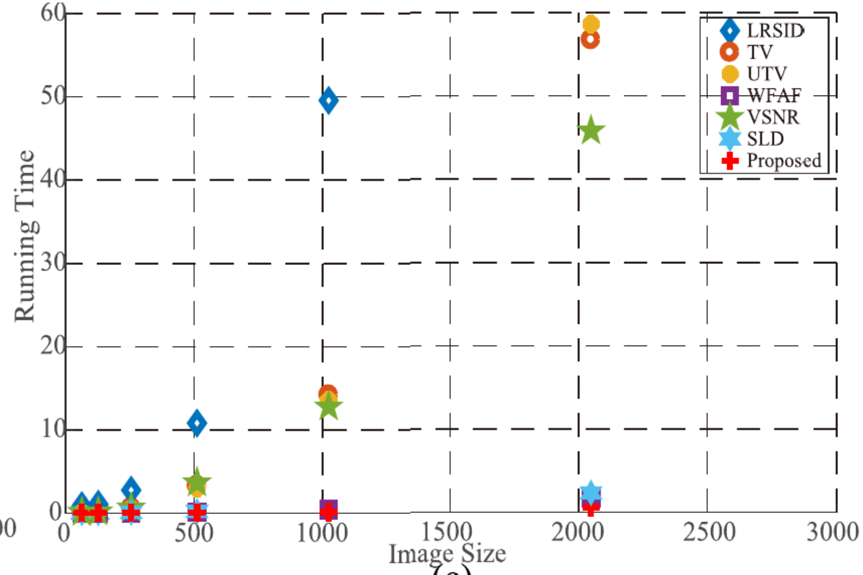
- Comparison to other methods



(b)



(c)

- Our model-based method

- Estimation of 2N parameters
  (N number of columns of the image)
- Number of rows can be >>N

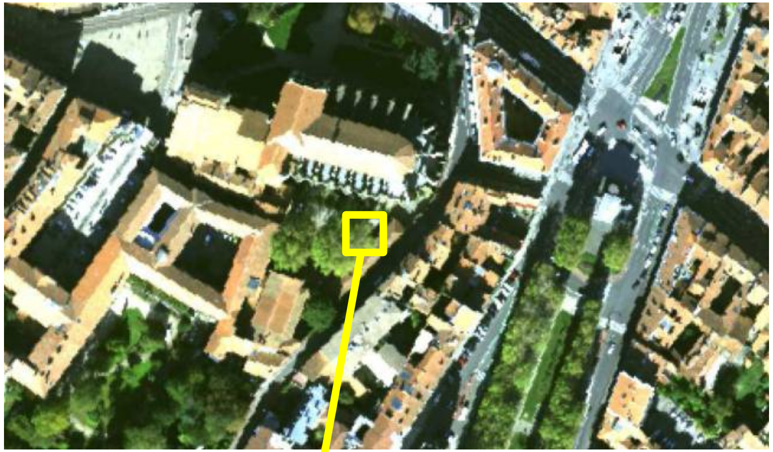
- *Data-driven approach*

- Requires training (image data base)
- Estimation of N^2 parameters
  (number of pixels of the image)

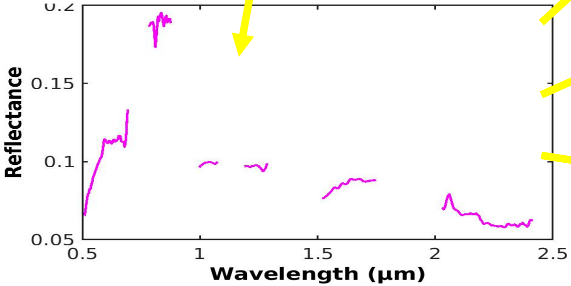
2. Spectral unmixing of hyperspectral im.

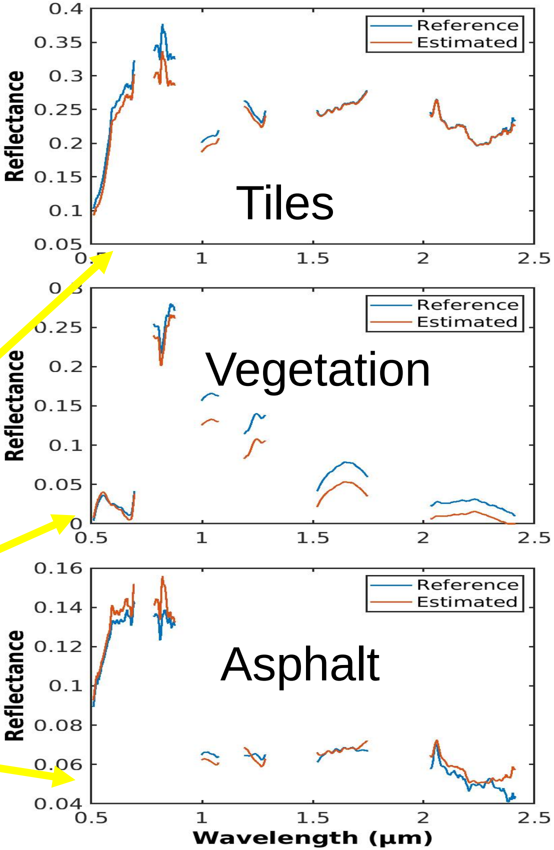
Guillaume Faury
Yannick Deville
Charlotte Revel et al.

- Spectra mixing in hyperspectral images due to spatial resolution



In one pixel : mixing of spectra





Spatial resolution creates mixing!

Problem:

- Which materials?
  A material does not have a single spectrum!

- Which spectra?

- What proportions?

Guillaume Faury
Yannick Deville
Charlotte Revel et al.

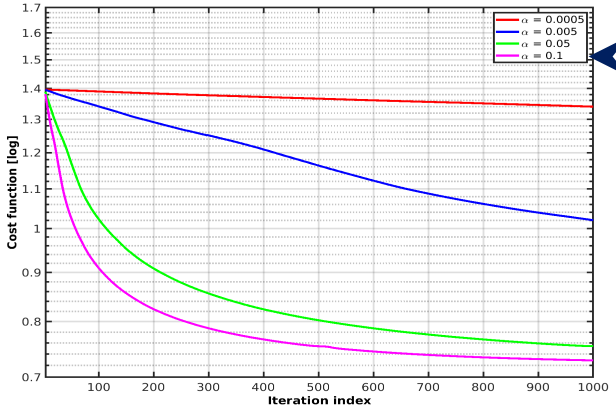
- NMF-type unmixing method
  (Non-negative Matrix Factorisation)

$$Y = A.X$$

Data — Proportions — Spectra

- Hybrid method: linear and non-linear mixing models
- Spectral variability of materials
- Optimisation by fixed-step gradient descent

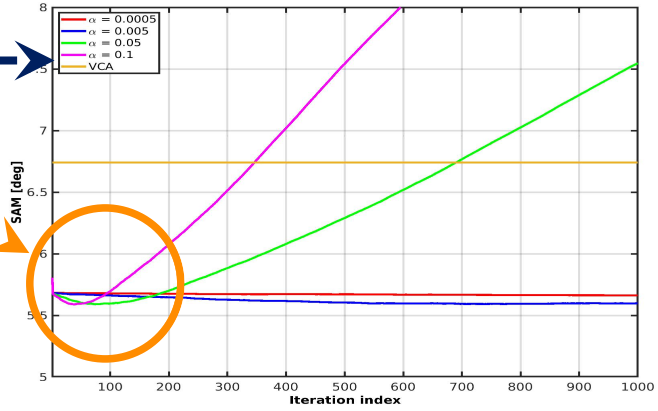
Choice of descent step / learning rate?



Cost function vs iteration

Learning rate

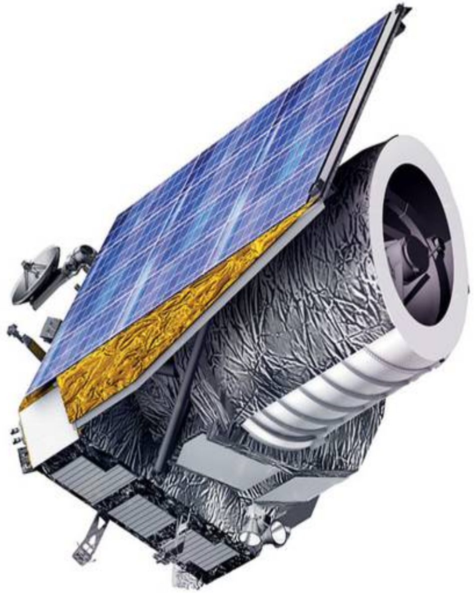
overfitting!



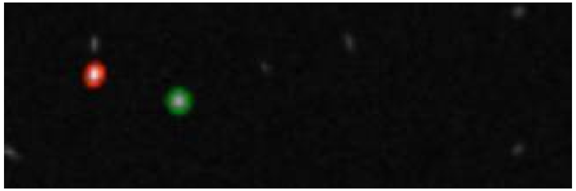
SAM performance vs iteration

Mostafa Bella
Shahram Hosseini

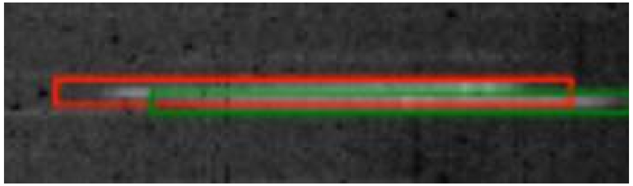
- EUCLID Mission



- VIS Wide-field imager in the visible spectrum
- NISP Infrared slitless spectro-imager

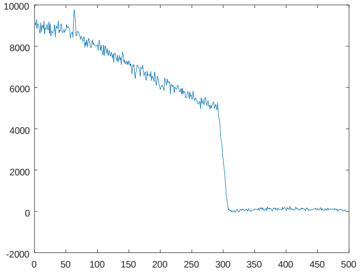


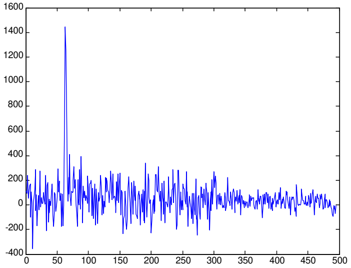
VIS Direct image



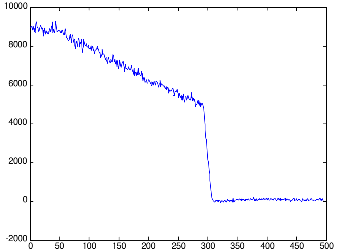
NISP Dispersed image

- Spectra unmixing





+



Better spectral line detection → redshift

3. Spectral unmixing for EUCLID

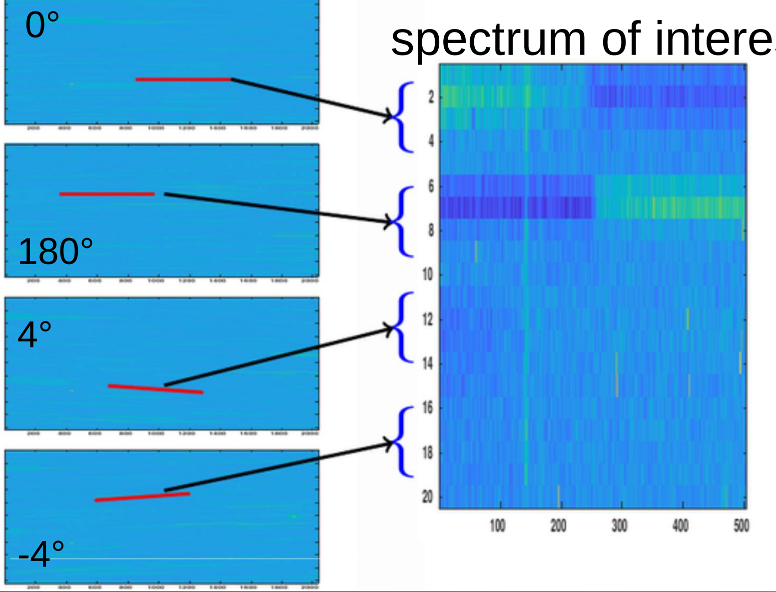
Mostafa Bella
Shahram Hosseini

- From raw image to decontaminated and denoised spectrum

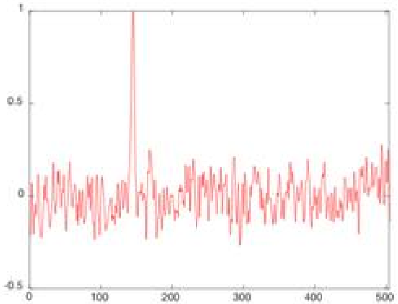
Extraction of contaminated spectra → (Instrument model / Source separation method) → Decontamination (model-based) → (Autoencoder / Trained on simulated data) → Denoising (data-driven)

Raw Images
4 directions

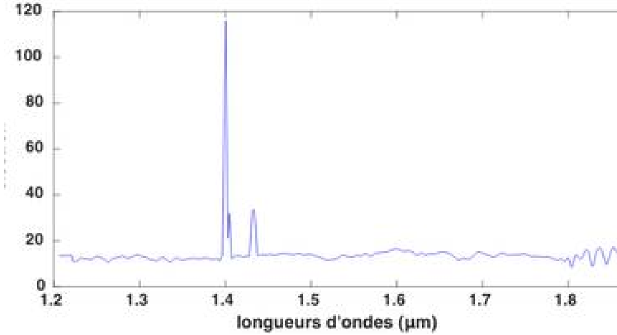
Extraction for a spectrum of interest



Unmixed spectrum

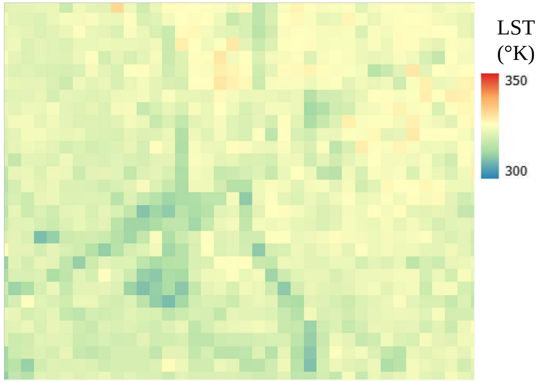


Denoised spectrum



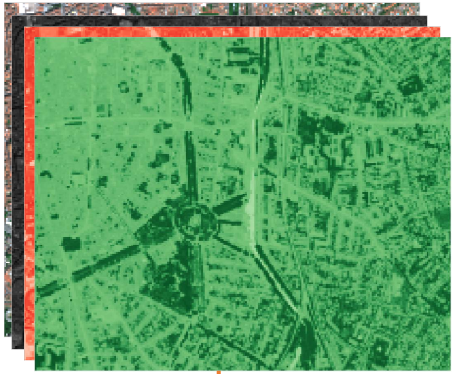
Raphaël Delair
Aurélie Michel
Hervé Carfantan

- Low resolution Land Surface Temperature



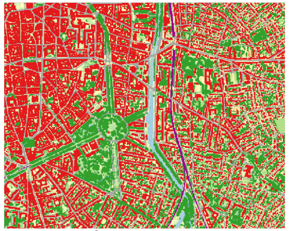
Land Surface Temperature
(60 m)

Multi-spectral data (10m)



Spectral Indices :
NDBI
NDVI...

Morphological data (10m)



Land Cover Map
Rochel et al. 2023

Digital Elevation Model
Youssefi et al. 2020

Pléiades © CNES 2021

Land Surface Temperature
(10 m)

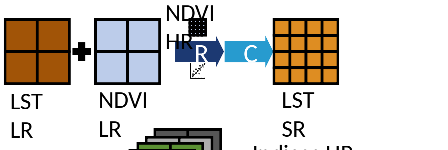
Raphaël Delair
Aurélie Michel
Hervé Carfantan

- Variable selection

Is it always better with more variables?

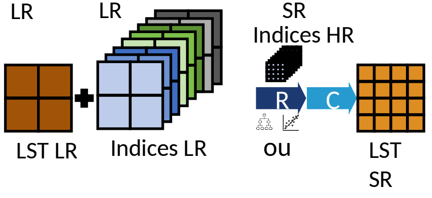
- Regression, Correction & Fusion

Baseline



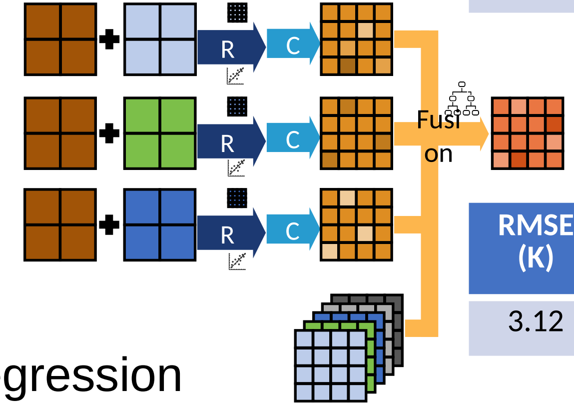
RMSE (K)	SSIM
3.77	0.65

Improved Regression



RMSE (K)	SSIM
3.51	0.78

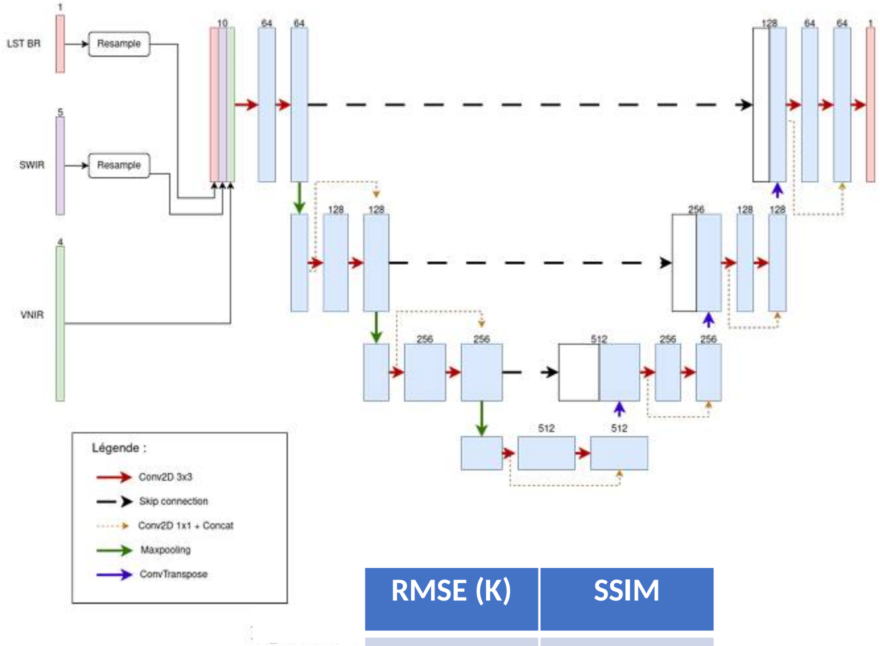
Post-Correction Fusion



RMSE (K)	SSIM
3.12	0.75

- Lineaire regression
- Correction : Kriging / Gaussian Process

- *Deep Learning approach*

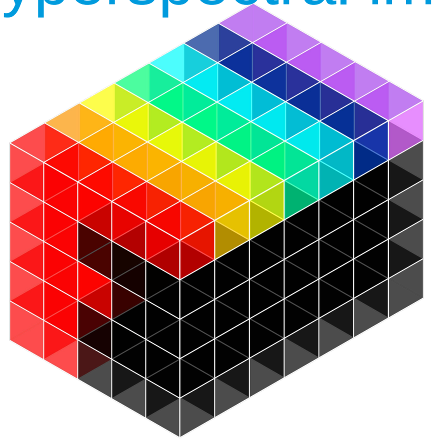


RMSE (K)	SSIM
3.77	0.65

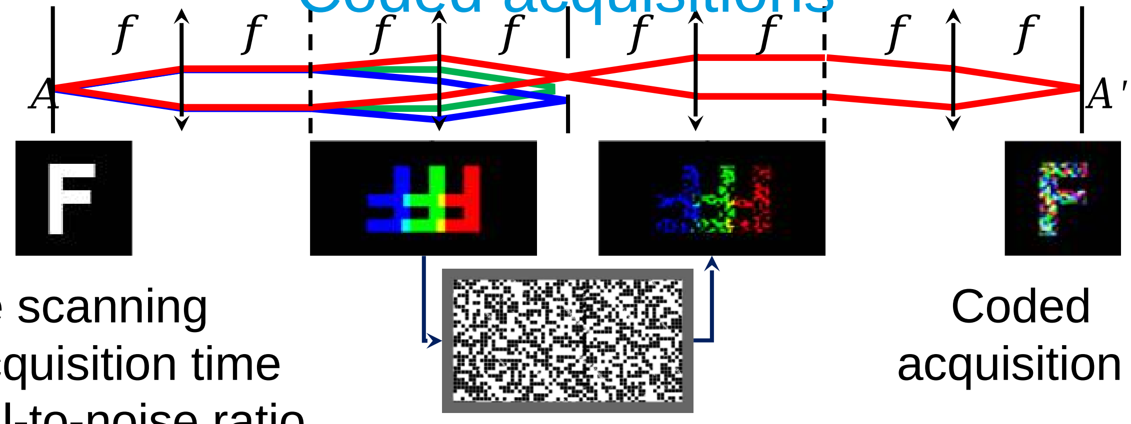
Trung Tin DINH
Hervé Carfantan
Antoine Monmairant

5. Coded mask hyperspectral imager

- Hyperspectral image



- Coded acquisitions

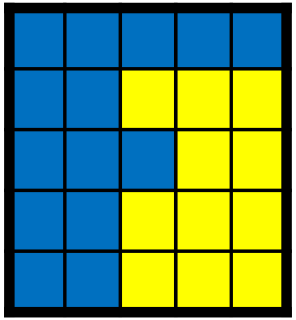


- Avoids cube scanning
- Reduced acquisition time
- Better signal-to-noise ratio

- Unsupervised classification

Low number of coded acquisitions

- Unknown spectra
- Number of materials unknown



Labels Map

5. Coded mask hyperspectral imager

Trung Tin DINH
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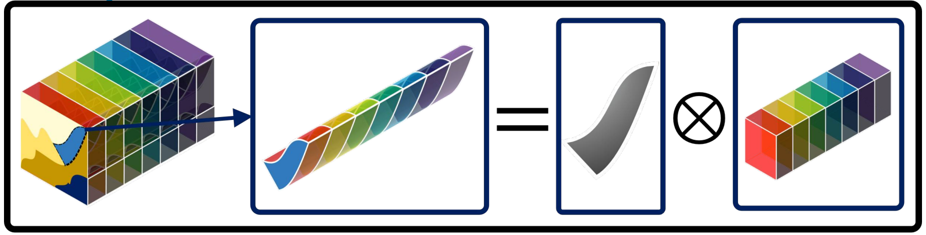
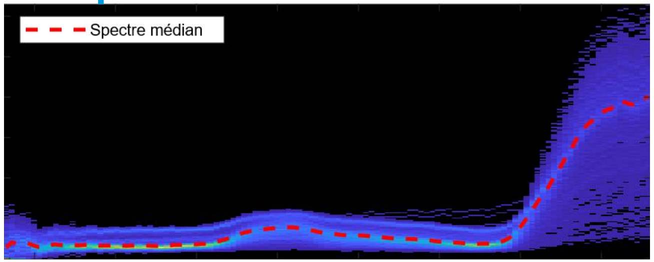
Antoine Monmairant

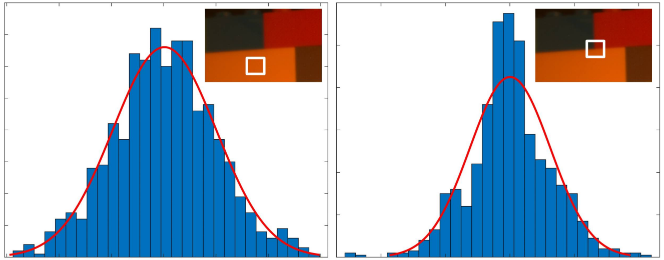
- Simplified model of a class

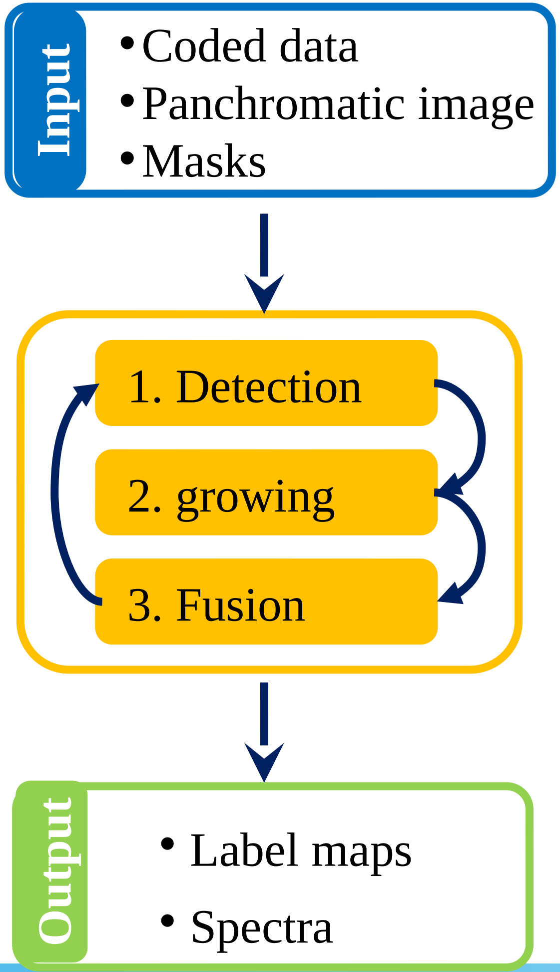


- Simplified model of intra-class spectral variability



- Statistical tests





Conclusion IA@SISU

- Development of various methods

  HCERES themes:

  Inverse problems
  Unmixing / Source separation
  Machine Learning

- For a wide range of problems

  Applications :

  Astrophyc, remote Sensing,
  Quantum Processing,...

- Taking into account instrumental models and of observed objets

- Model-based and data-driven approaches

If you have a data processing problem, come and talk to us...