LAAS Days
Research & Technology

An adaptive hyperspectral imager: design, control, processing and applications

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What is color?

- Color: “The property possessed by an object of producing different sensations on the eye as a result of the way it reflects or emits light”

What is color?

- “The property possessed by an object of producing different sensations on the eye as a result of the way it reflects or emits light”
- Which eye ?

Human eye?

Insect eye?

Mantis shrimp eye?

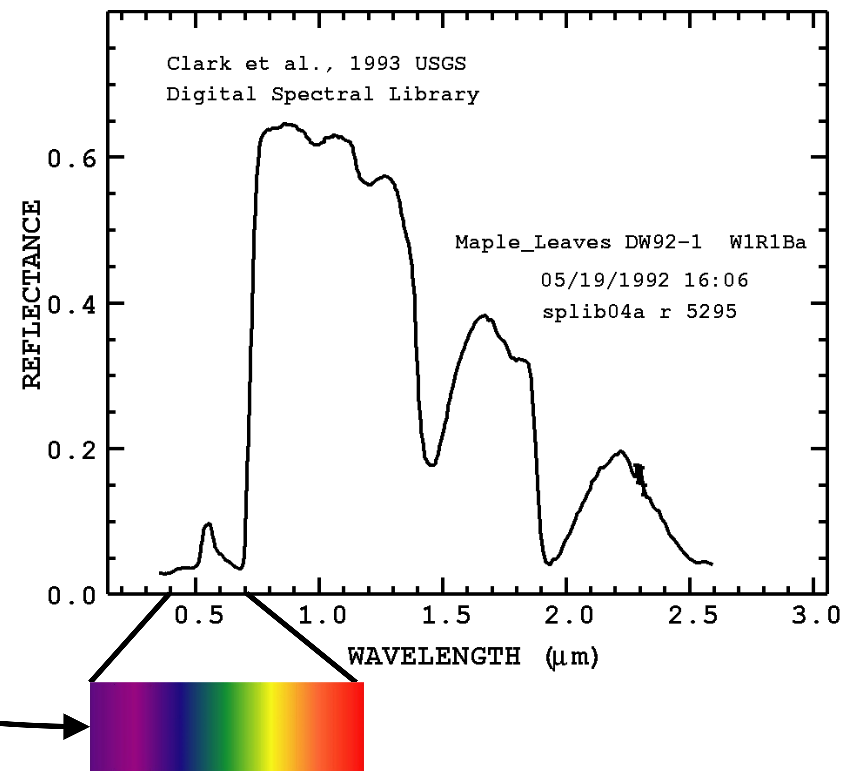
What is color?

> “The property possessed by an object of producing different sensations on the eye as a result of the way it reflects or emits light”

> Light: “Electromagnetic radiation within a certain portion of the electromagnetic spectrum”

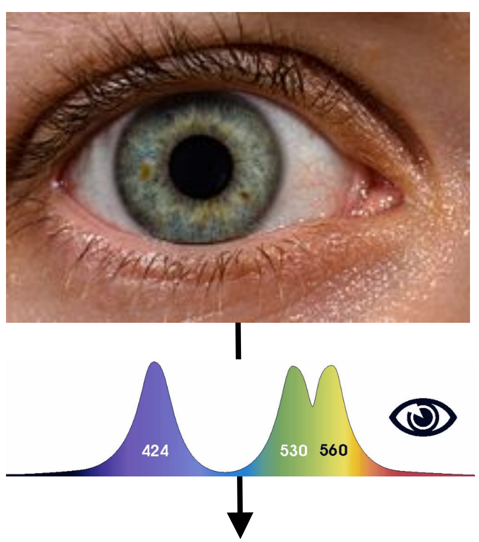
An energy spectrum:

The human portion

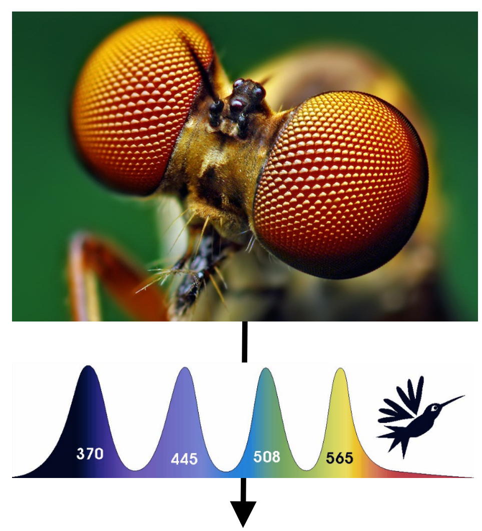


What is color?

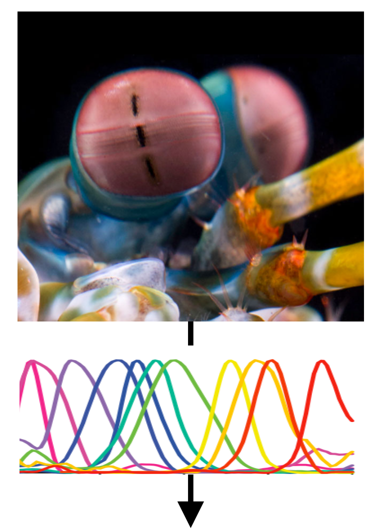
- Color: “The property possessed by an object of producing different sensations on the eye as a result of the way it reflects or emits light”
- Light: “Electromagnetic radiation within a certain portion of the electromagnetic spectrum”
- Light through eyes



3 numbers



4 numbers



12 numbers!

Hyperspectral images: “true colors”

- B&W image (aka intensity image): every pixel encodes the integral of energy over a given wavelength interval
- Color image: every pixel encodes the energy captured along three wavelength intervals (“3 image planes”)
- Multi-spectral images: up to a dozen image planes
- Hyperspectral images: hundreds of image planes

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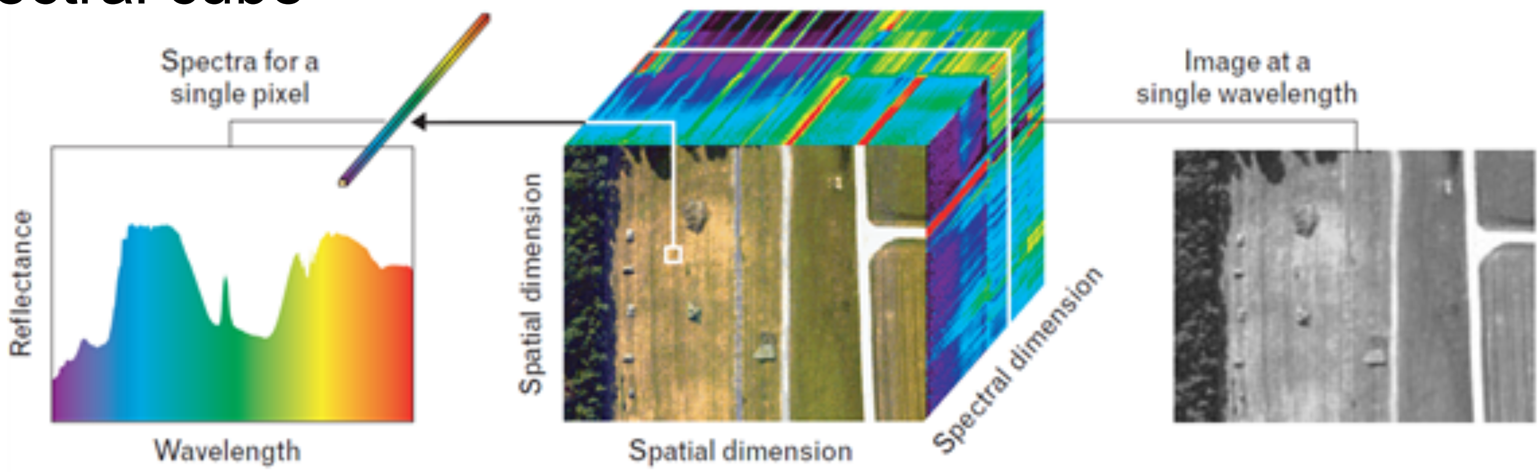
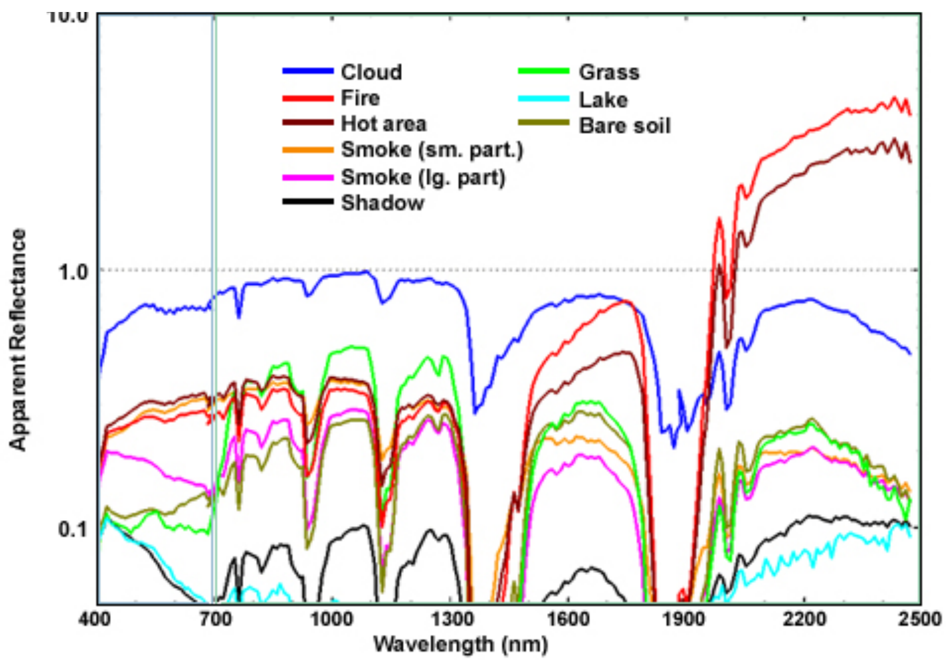
➤ Hyperspectral cube”

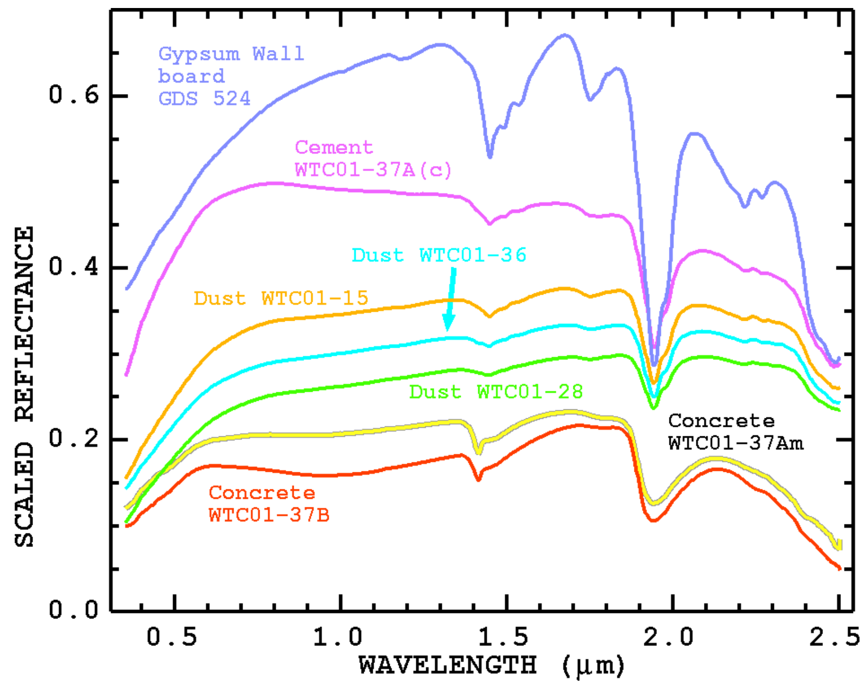


What for?

> The reflected spectrum of a surface is characteristic of its physical nature



Various materials



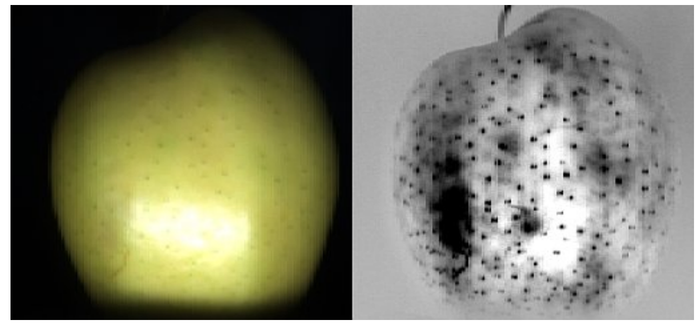
Various minerals

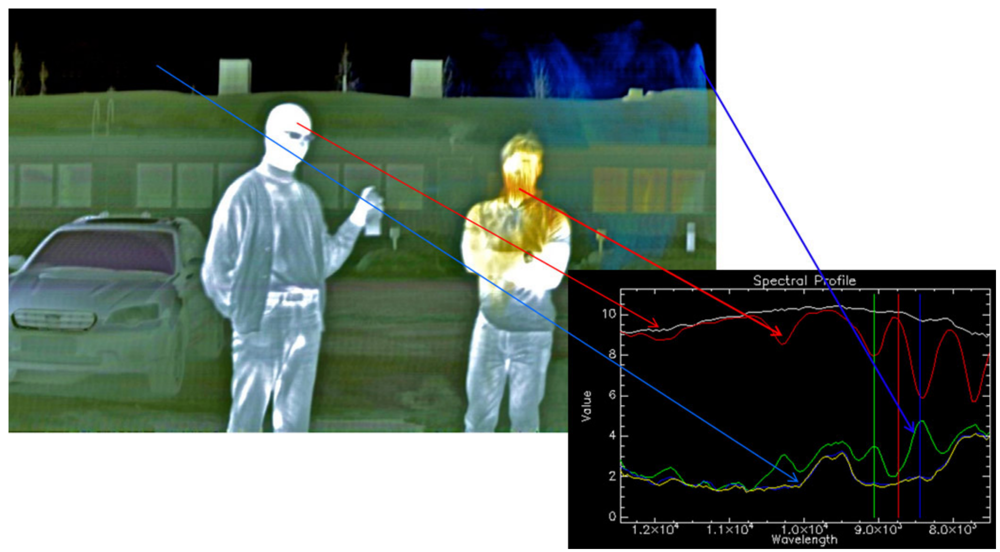
What for?

> The reflected spectrum of a surface is characteristic of its physical nature

☛ A wide spectrum of applications

- Astronomy
- Earth observation
- Agriculture
- Gaz detection
- Forensic
- Medicine
- Art paint analysis
- Microscopy
- ...





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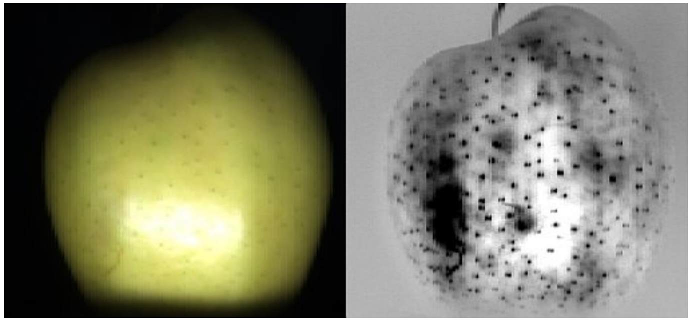
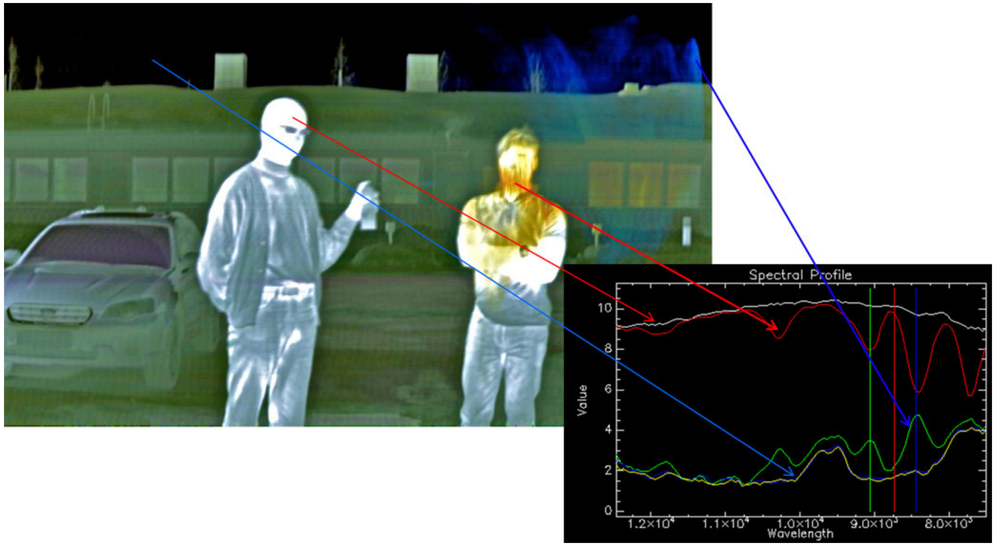
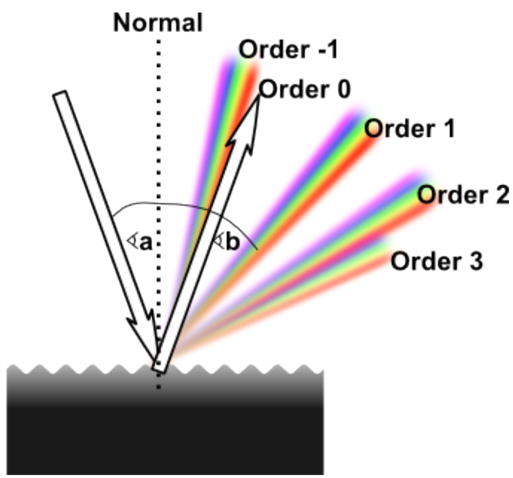
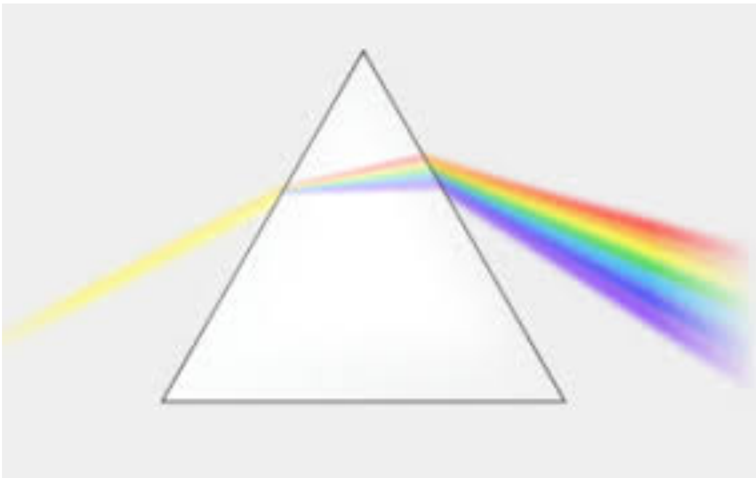




> Core component: dispersing element



Grating (diffraction)

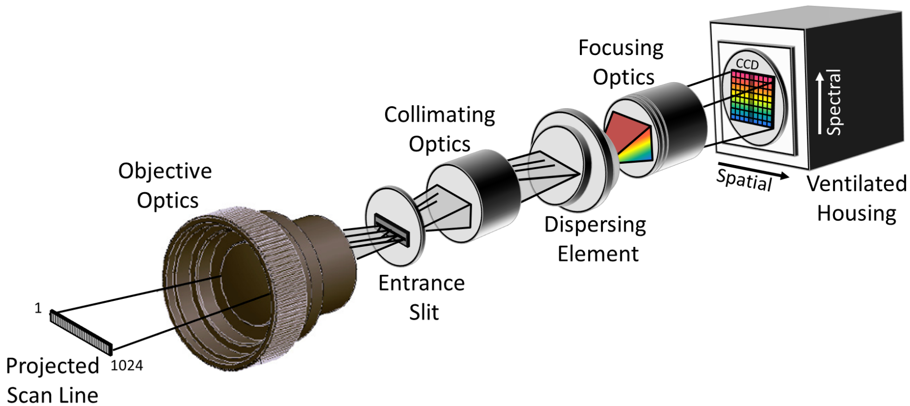


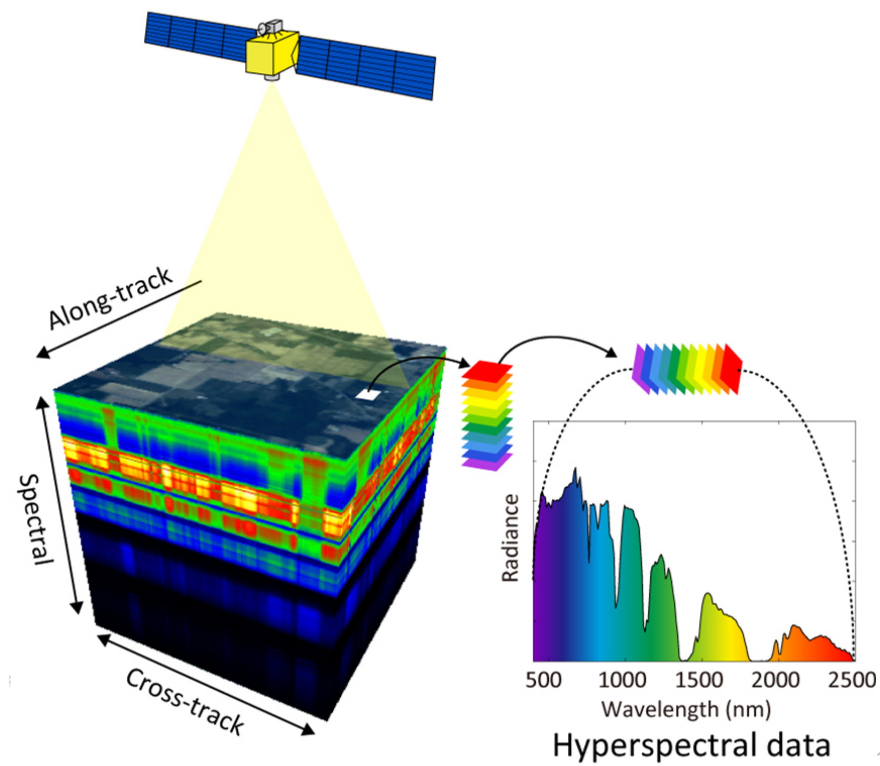
Prism (refraction)

> Main difficulty: recovering a 3D data cube with a 2D sensor

Hyperspectral cameras

> Classic technology: imaging a slit through a disperser



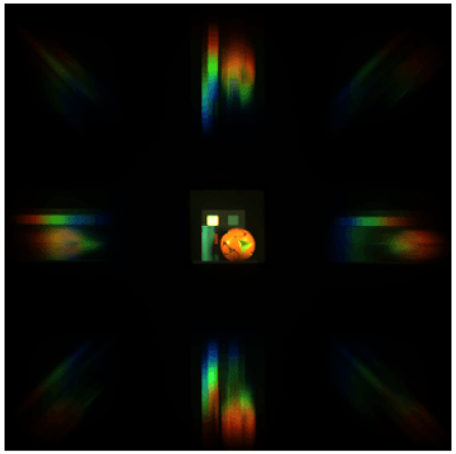


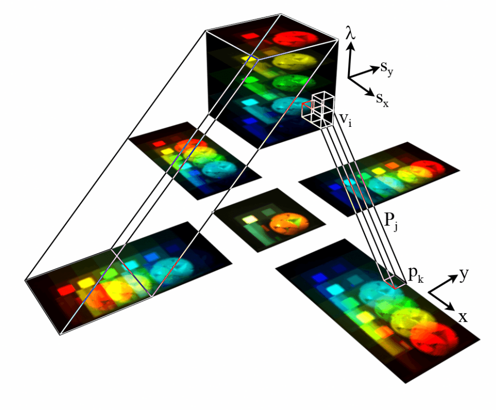
Hyperspectral cameras

> Classic technology: imaging a slit through a disperser

> Alternative technologies: snapshot hyperspectral imaging

- Imaging several orders of diffraction
- + tomography-like reconstruction





Hyperspectral cameras

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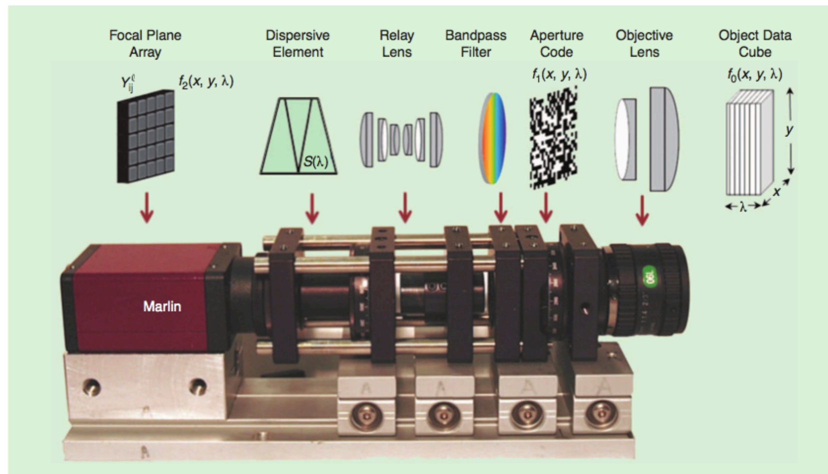
> Alternative technologies: snapshot hyperspectral imaging

- Coded aperture snapshot spectral imaging (CASSI)
- Compressed sensing reconstruction



Hyperspectral cameras

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☛ Main issue: sequential acquisition

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☛ Several issues

- High CPU load to produce the HS cube
- Performances fixed by design
- Tough calibration issues

Hyperspectral cameras

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☛ All approaches produce heavy data (~ 1 Gb):

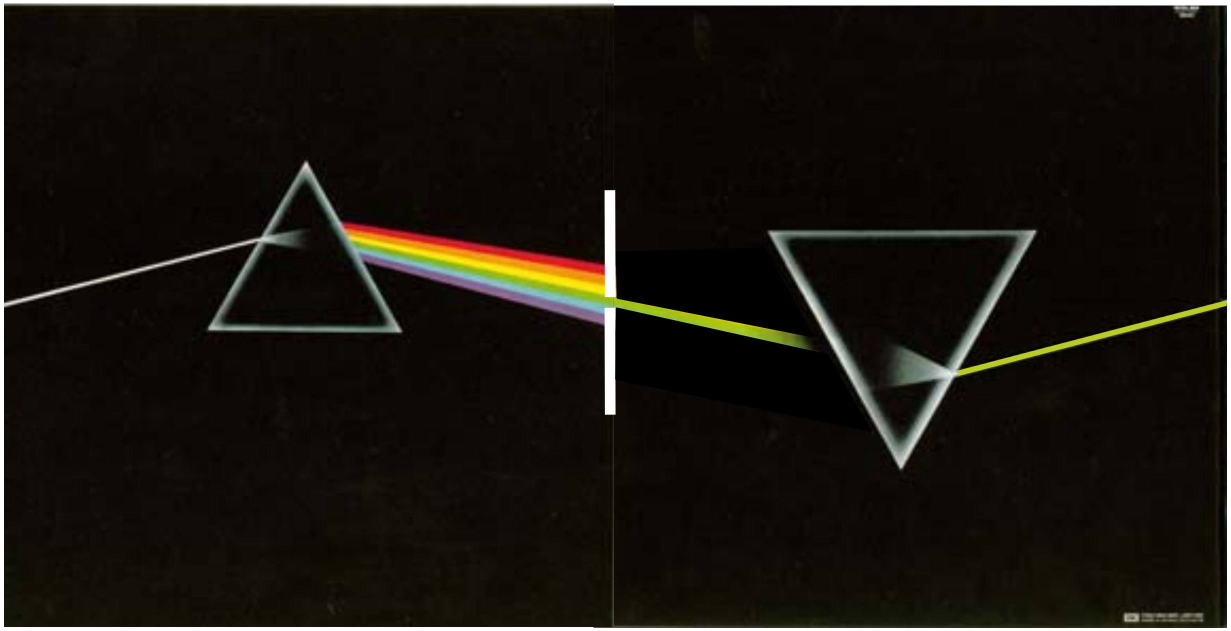
- To acquire
- To process
- To transmit

An adaptive hyperspectral imager

> Principle

An adaptive hyperspectral imager

> Principle (illustration)



A partial masking of the signal
defines a spectral filter

An adaptive hyperspectral imager

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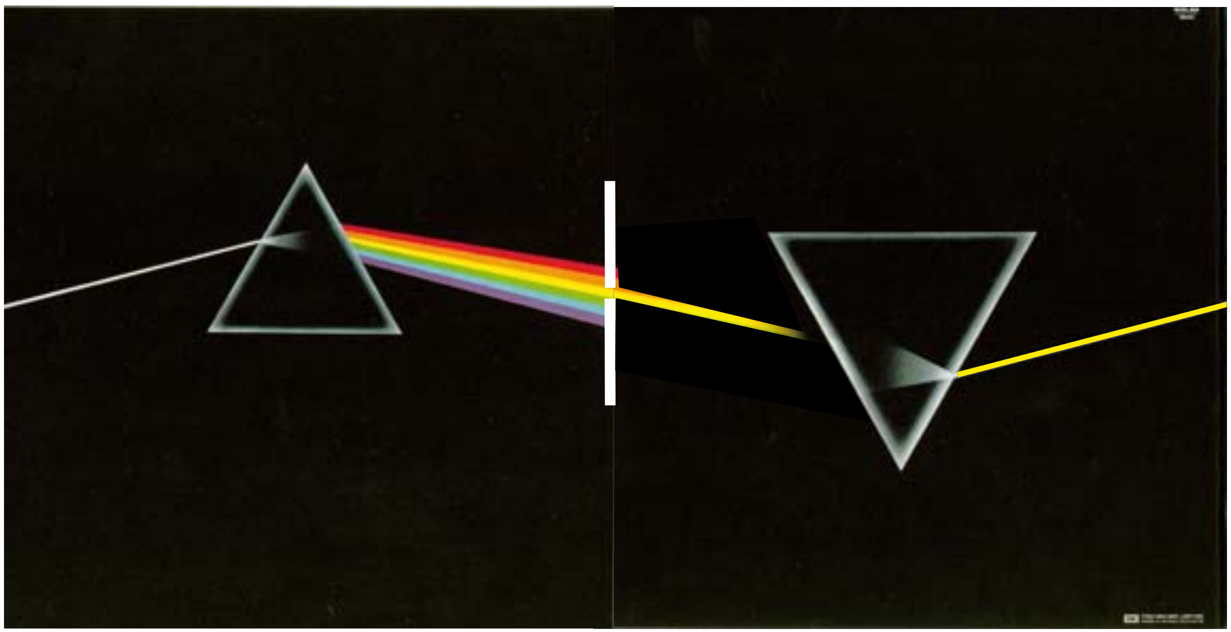

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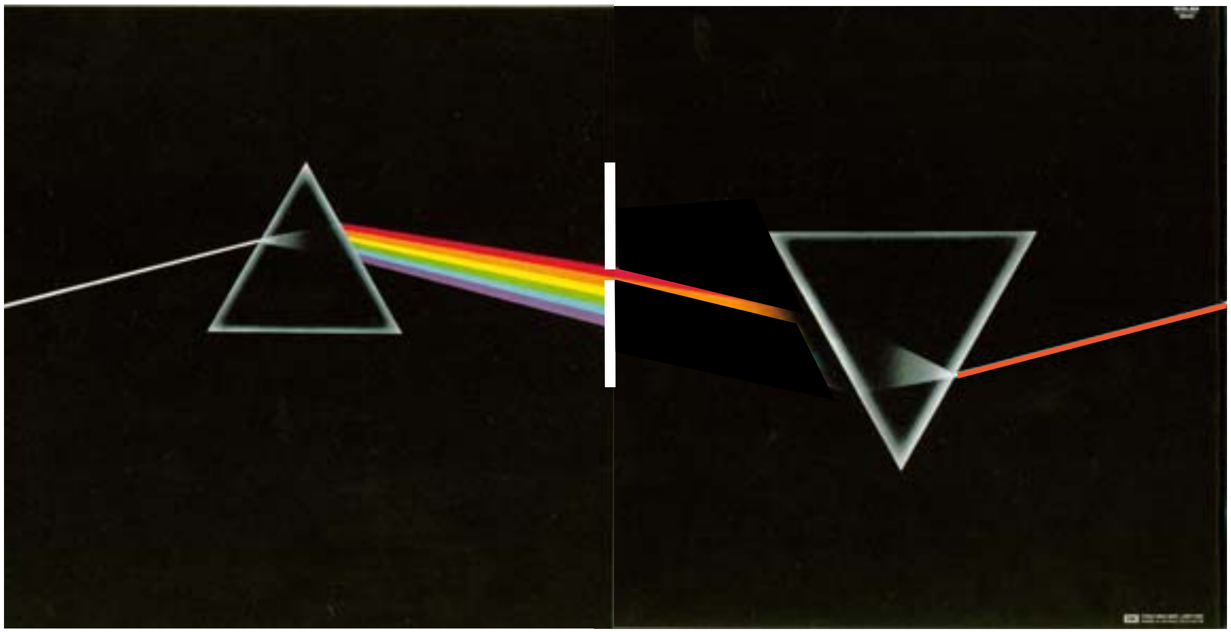

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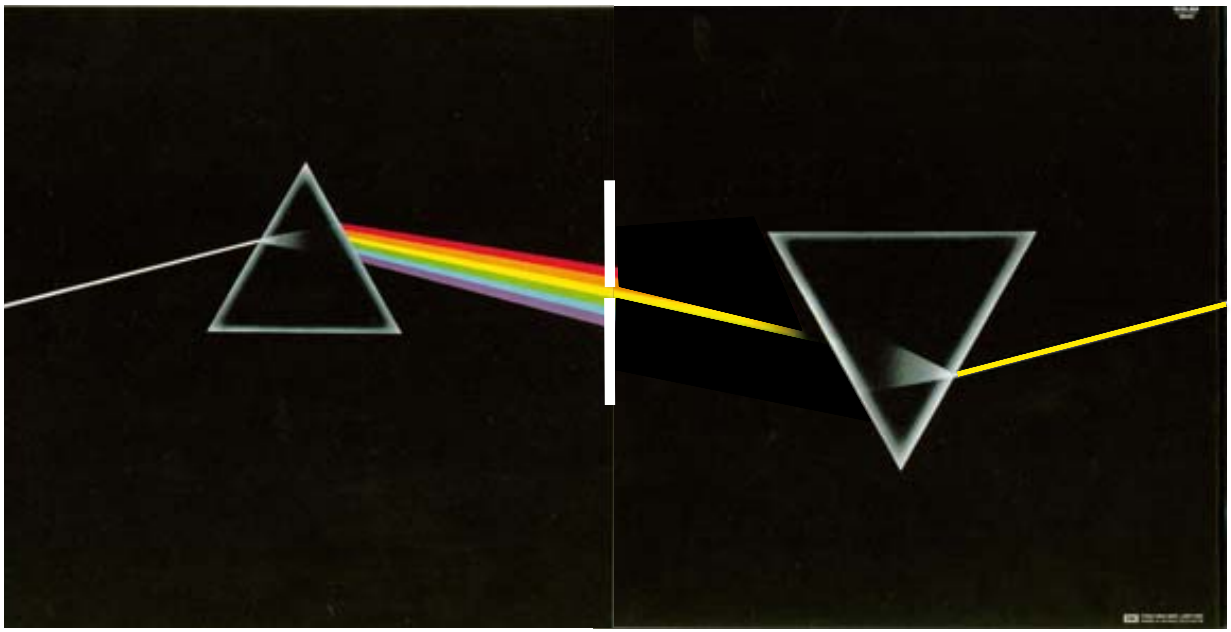

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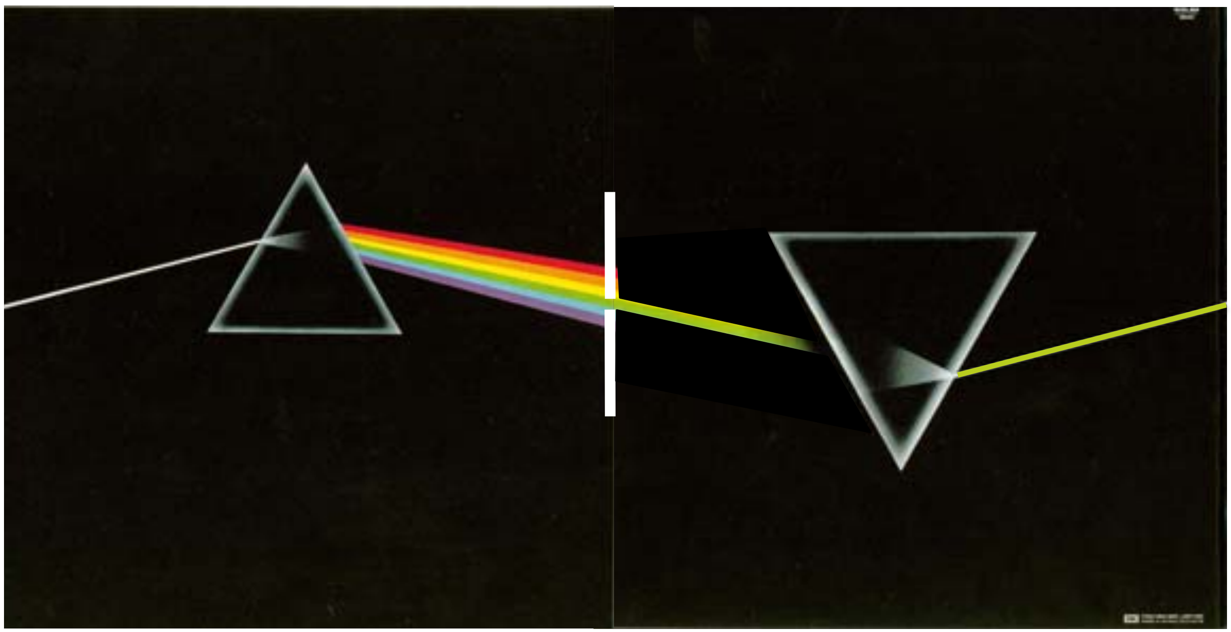

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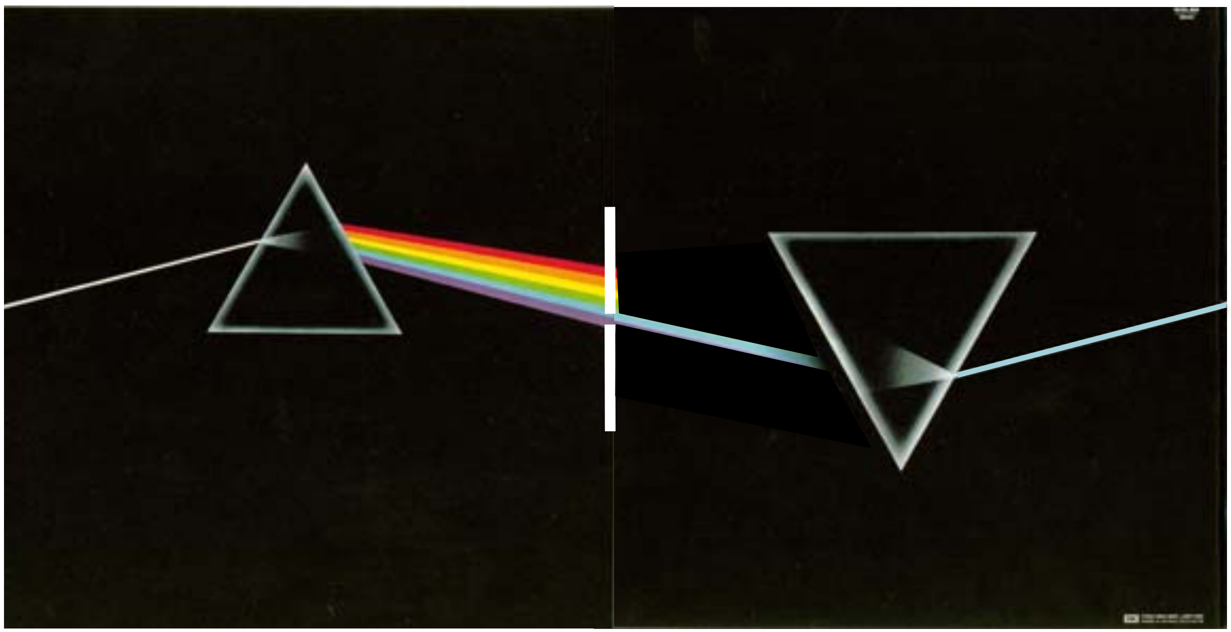

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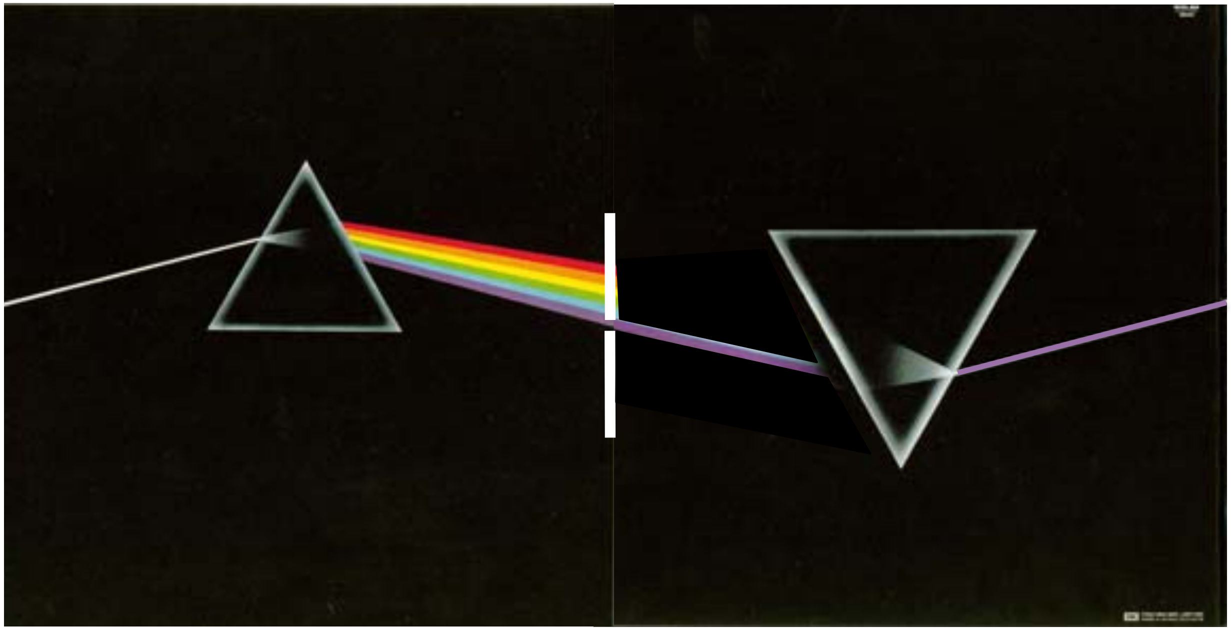

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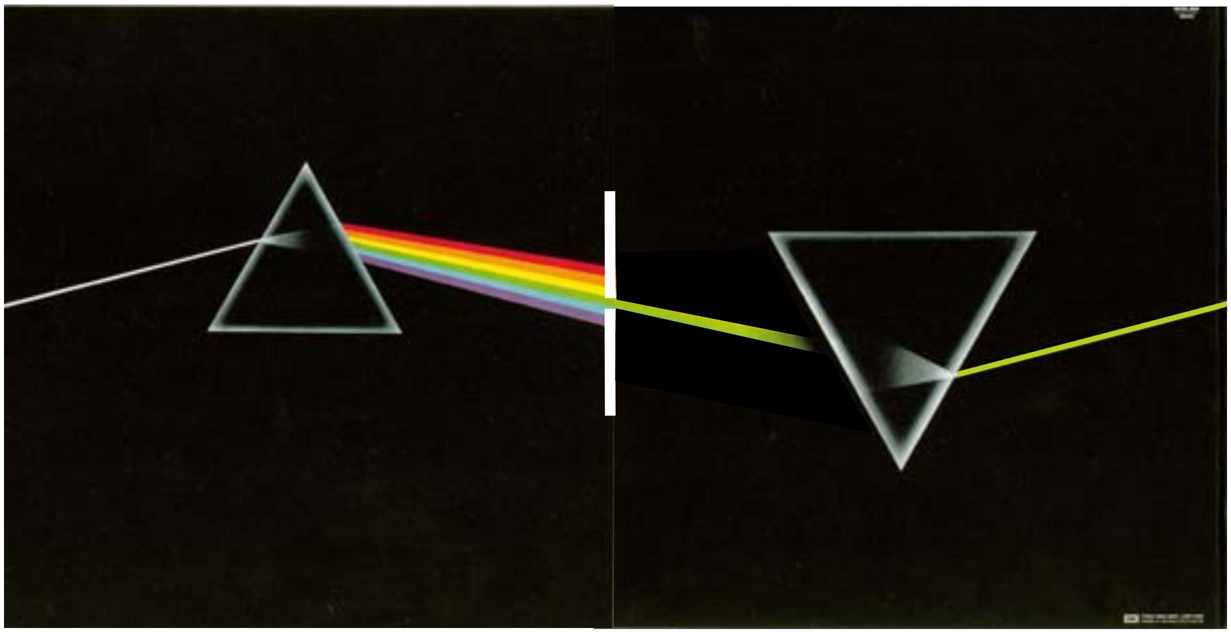

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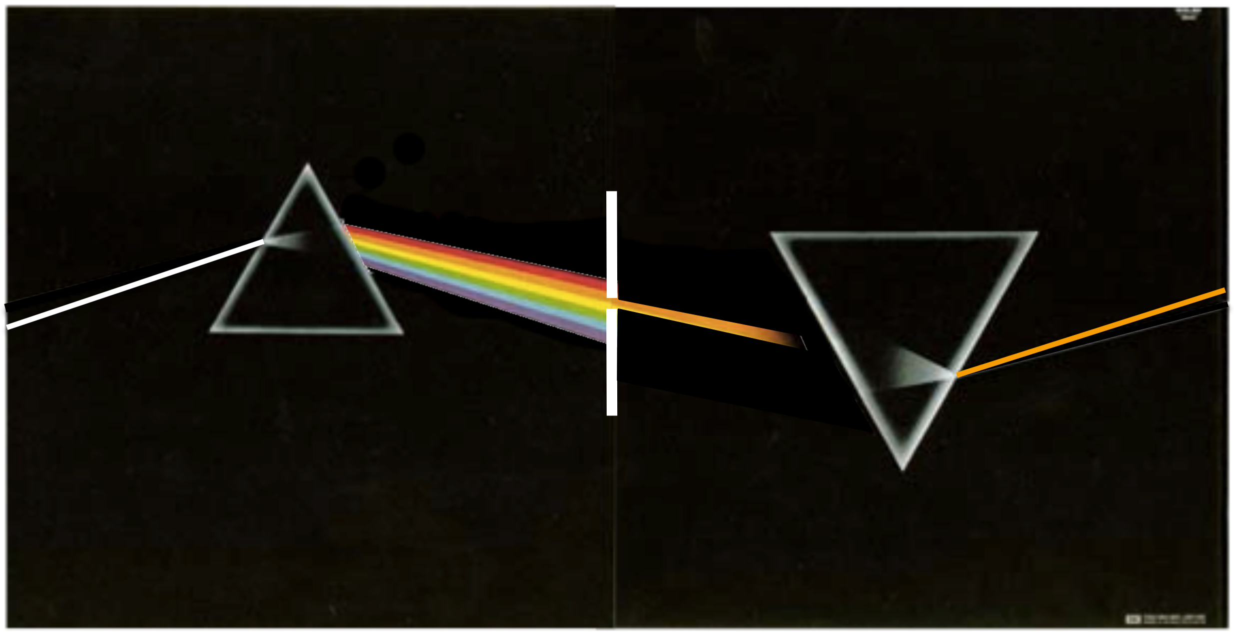

For the same mask, different spatial rays are differently spectrally filtered

An adaptive hyperspectral imager

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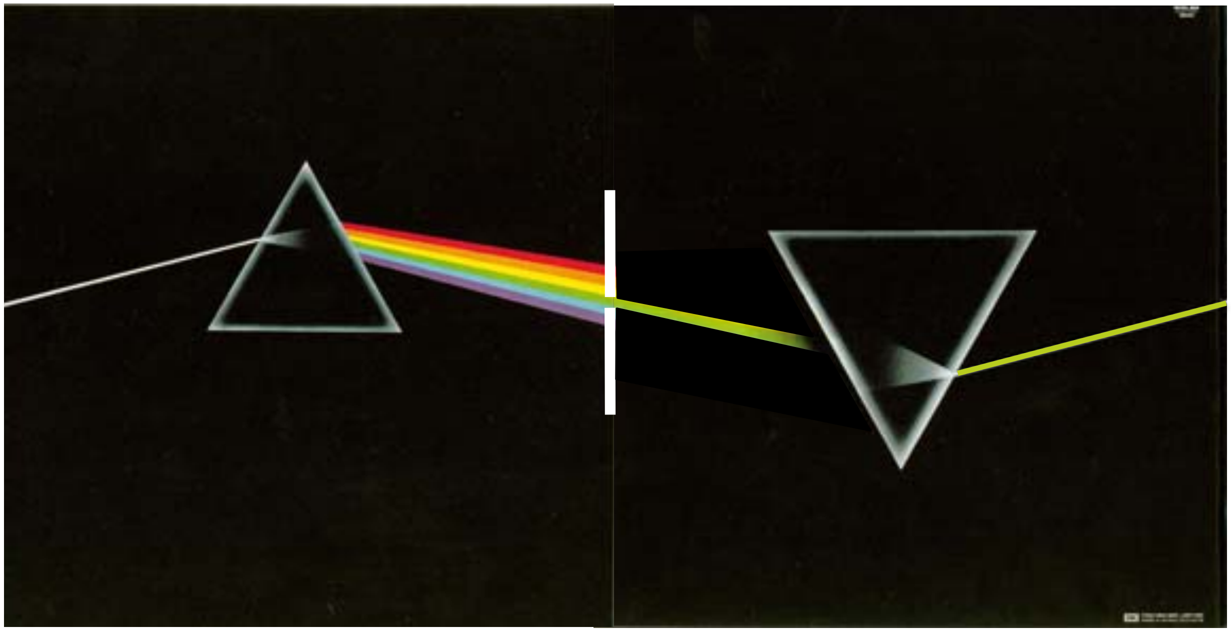
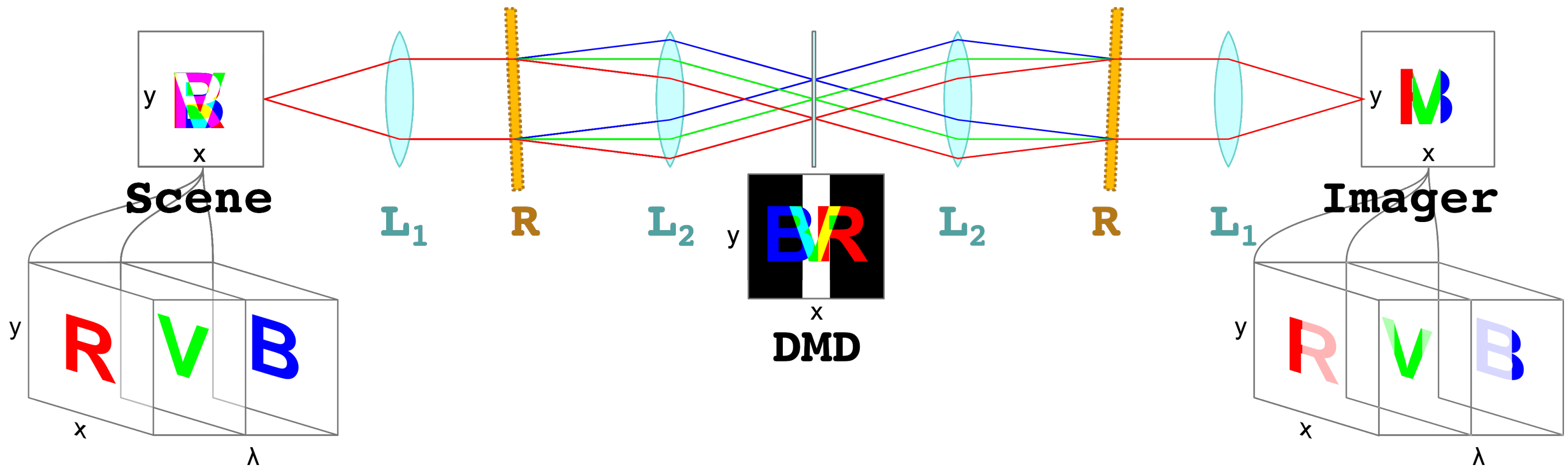


For the same mask, different spatial rays are differently spectrally filtered

An adaptive hyperspectral imager

> Design: dual 4f-line



"Single-shot compressive spectral imaging with a dual-disperser architecture", Ghem *et al.* Optics Express 2007.

An adaptive hyperspectral imager

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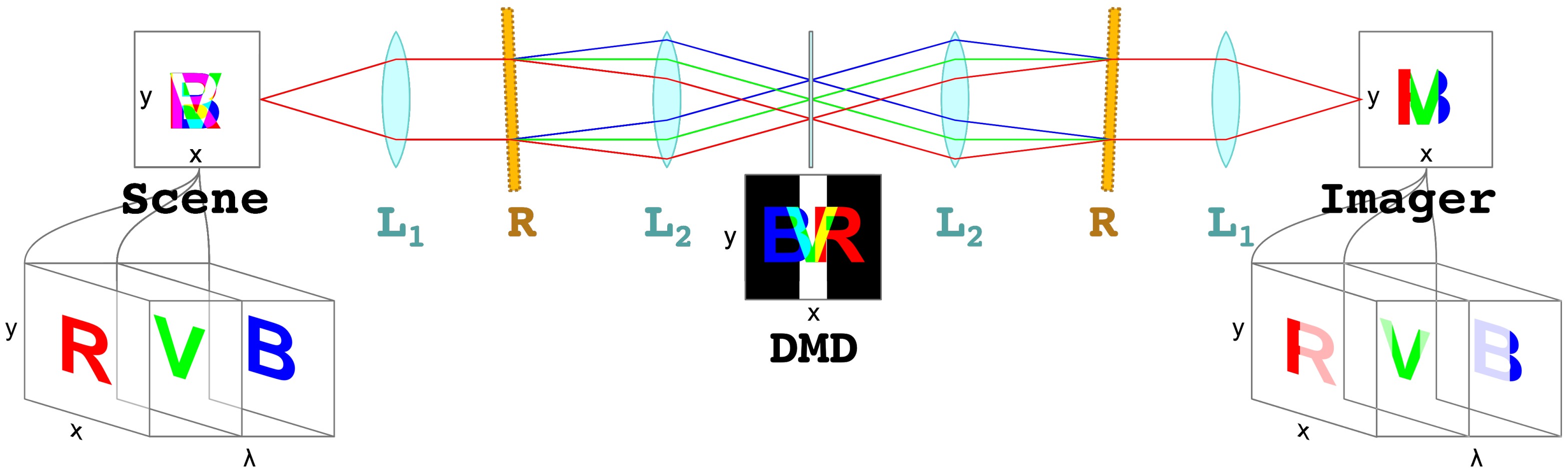

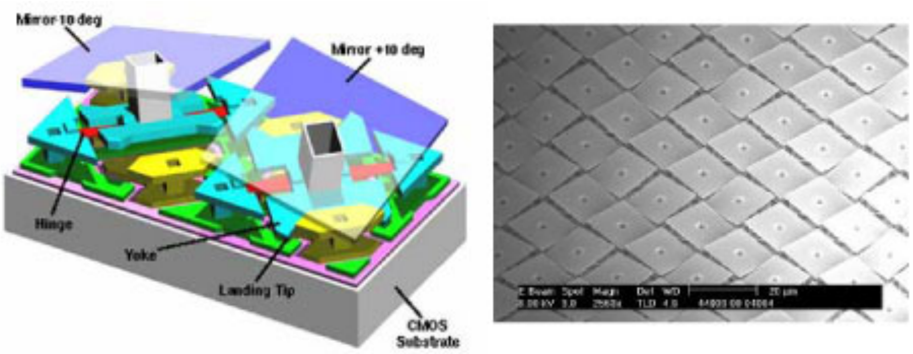

Digital Micro-mirror Device

An adaptive hyperspectral imager

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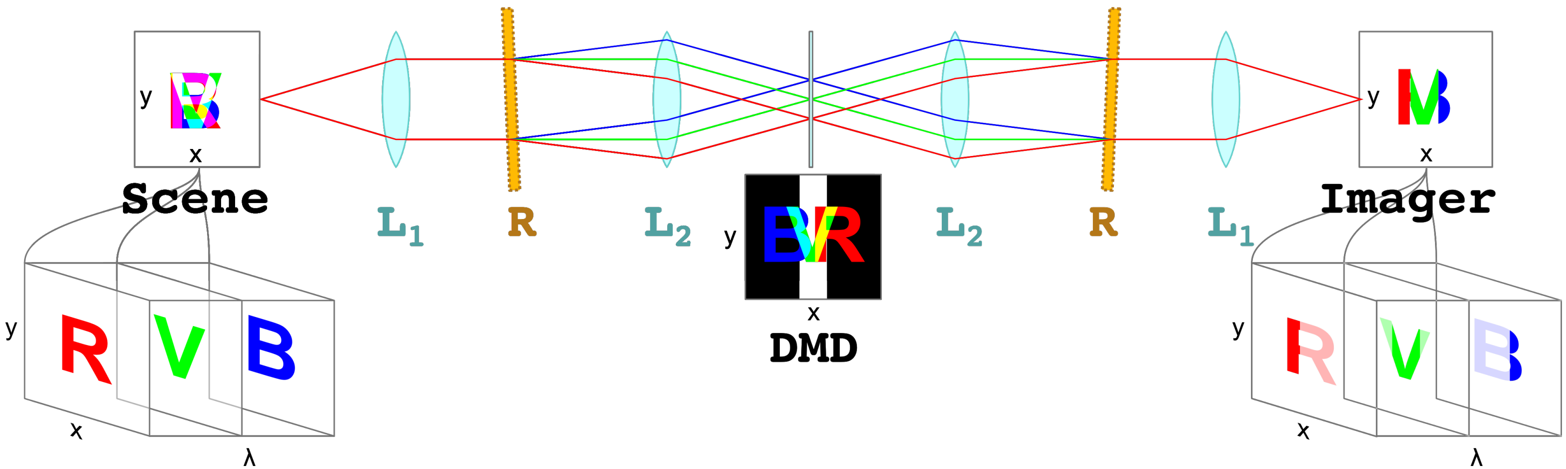
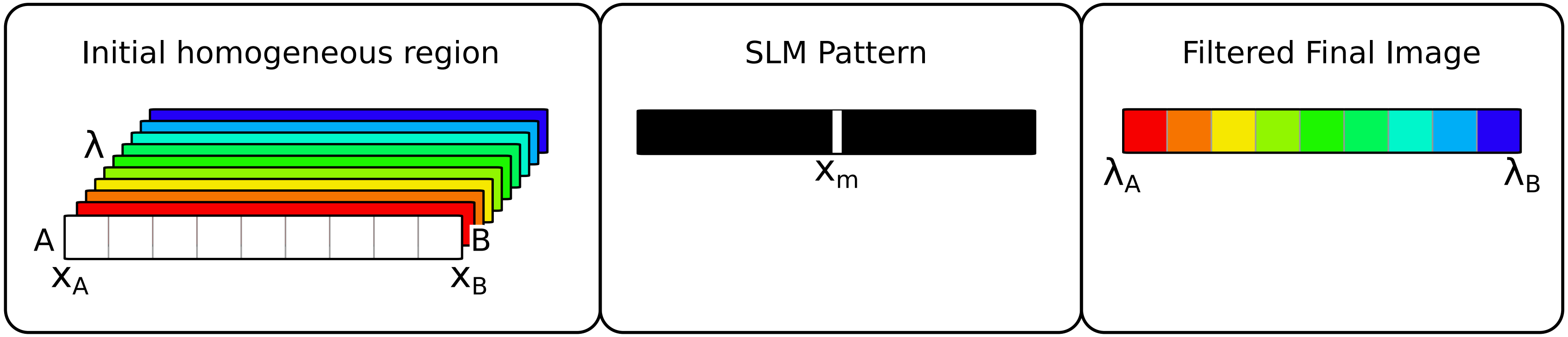
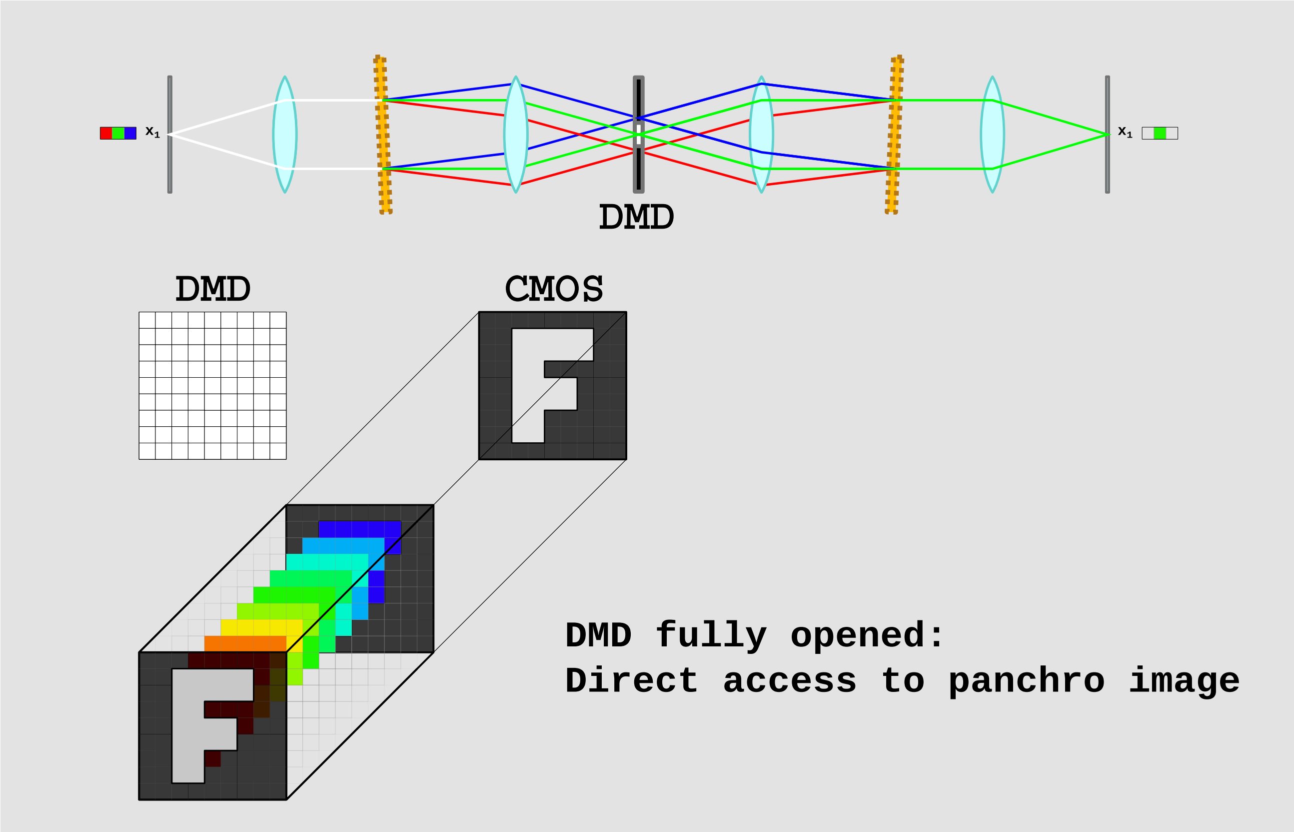




An adaptive hyperspectral imager

> Properties

- Possibility to acquire an intensity image



An adaptive hyperspectral imager

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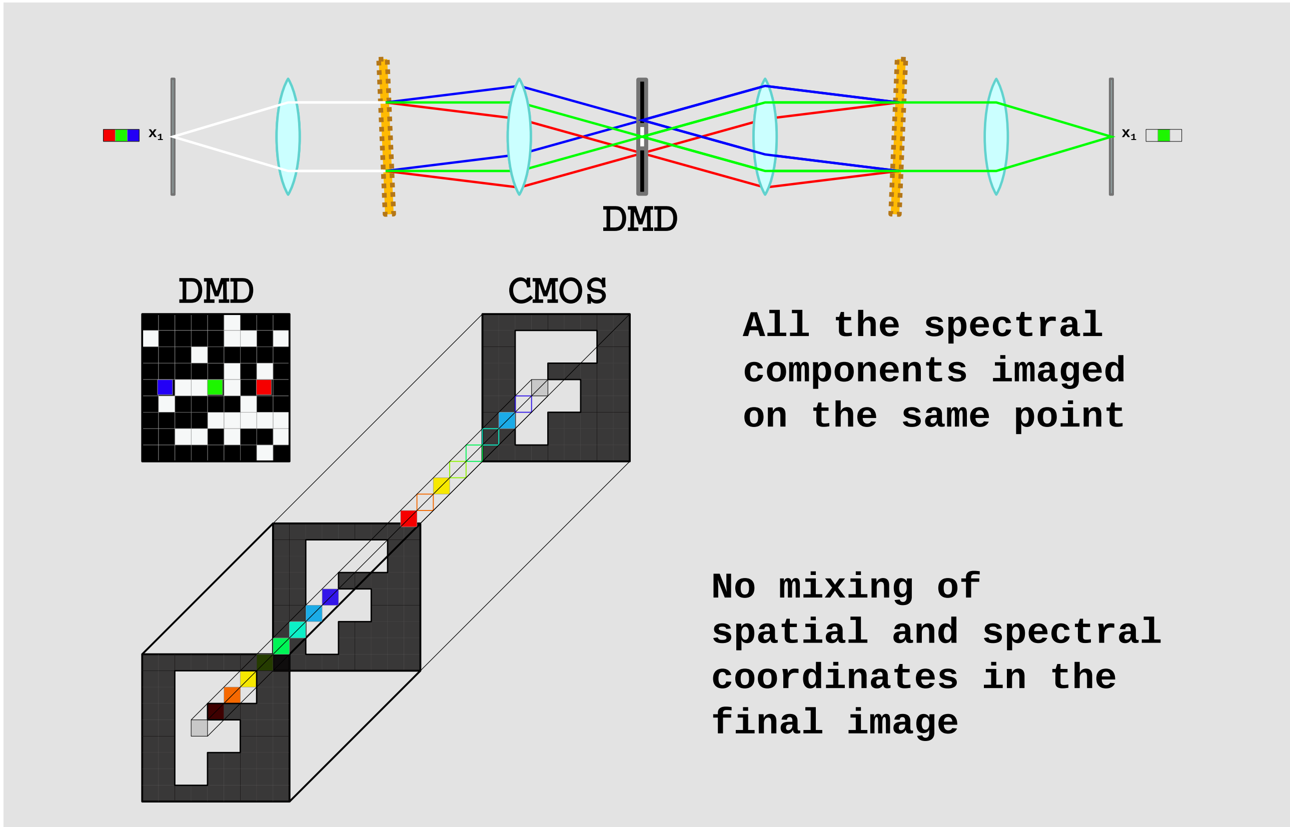
- Possibility to acquire an intensity image
- "Colocation"



An adaptive hyperspectral imager

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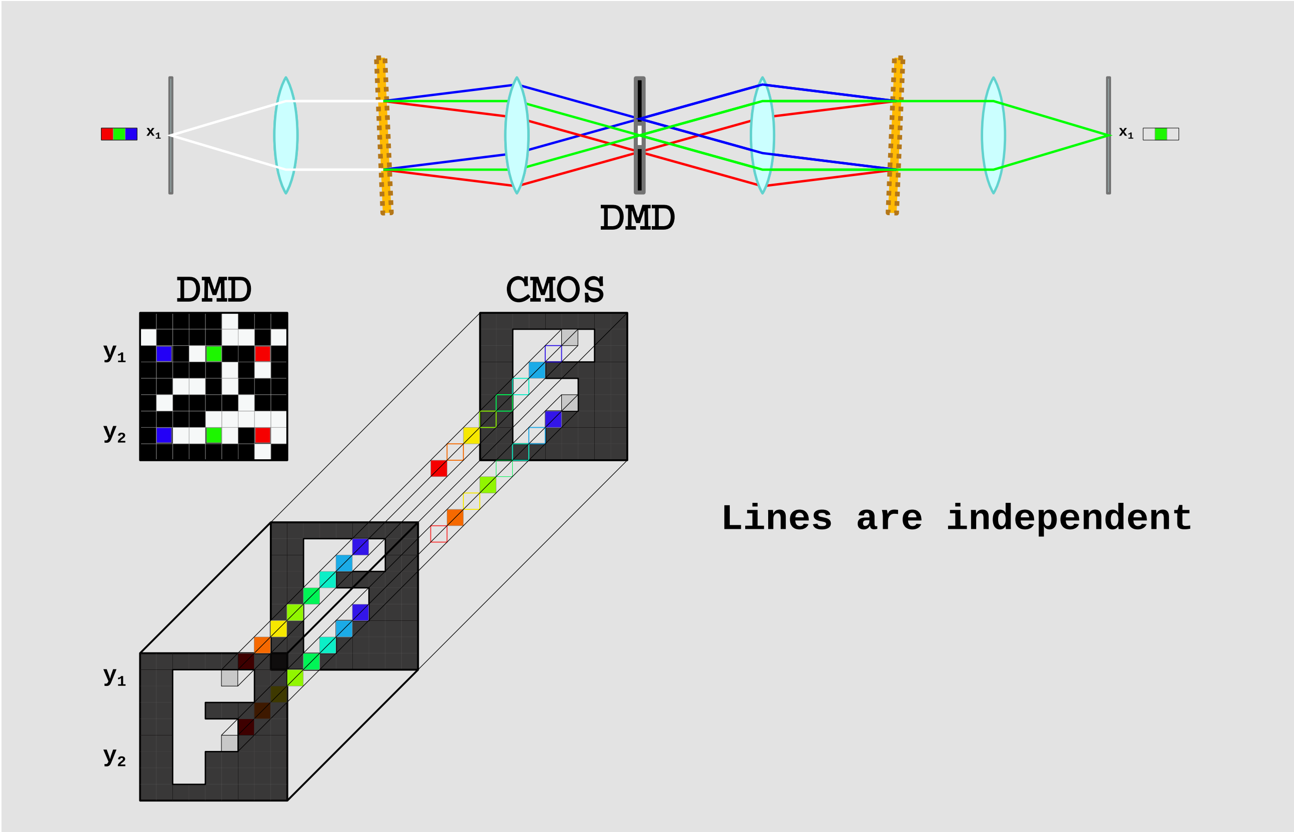
- Possibility to acquire an intensity image
- “Colocation”
- Independence of lines



An adaptive hyperspectral imager

> Properties

- Possibility to acquire an intensity image
- "Colocation"
- Independence of lines
- Simplicity of the model

$$\lambda(x_f, x_m) = \lambda_c + x_f/(\beta\alpha) - x_m/\alpha$$

An adaptive hyperspectral imager

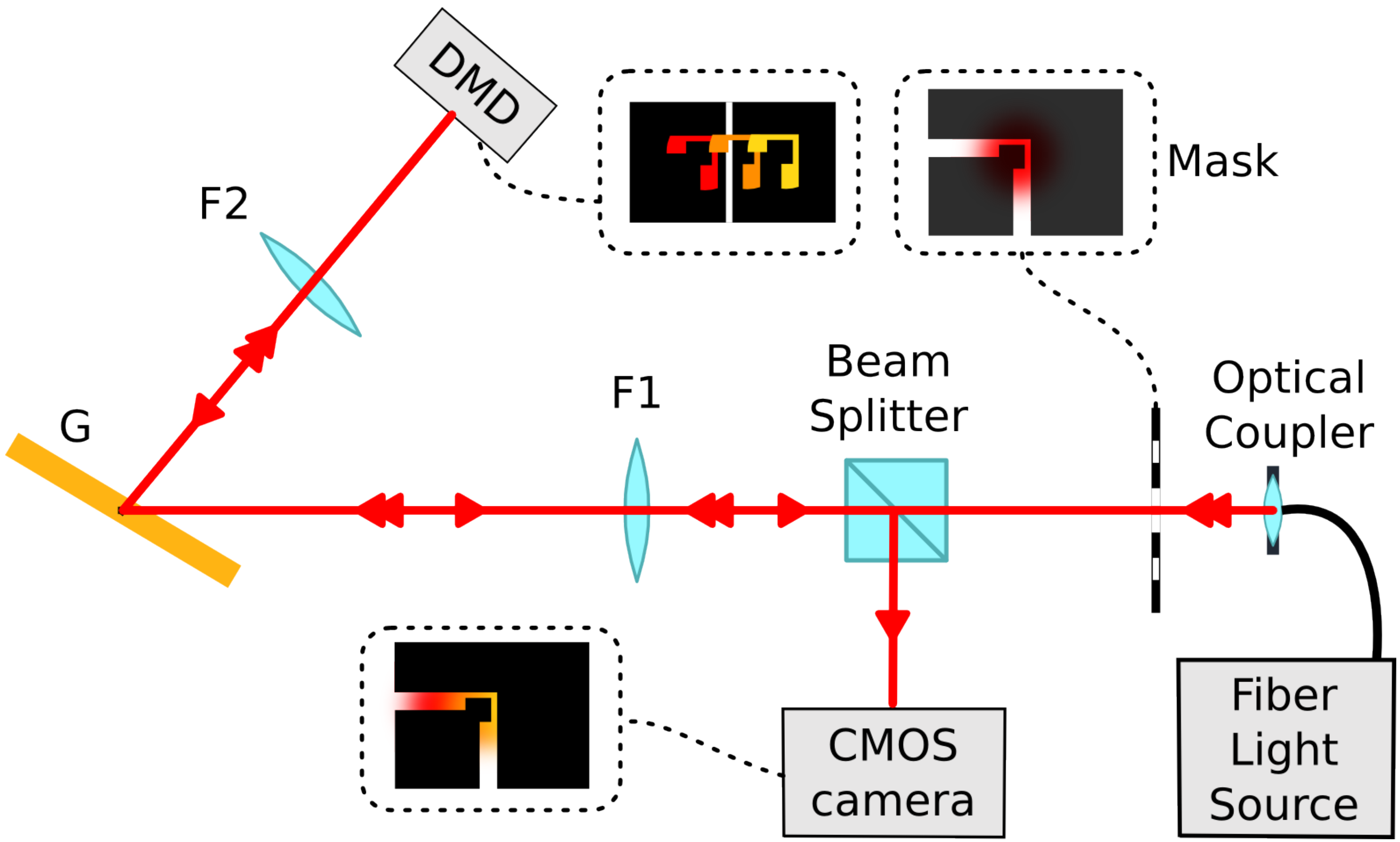
> Properties

- Possibility to acquire an intensity image
- "Colocation"
- Independence of lines
- Simplicity of the model $$\lambda(x_f, x_m) = \lambda_c + x_f/(\beta\alpha) - x_m/\alpha$$
- Programmable acquisition

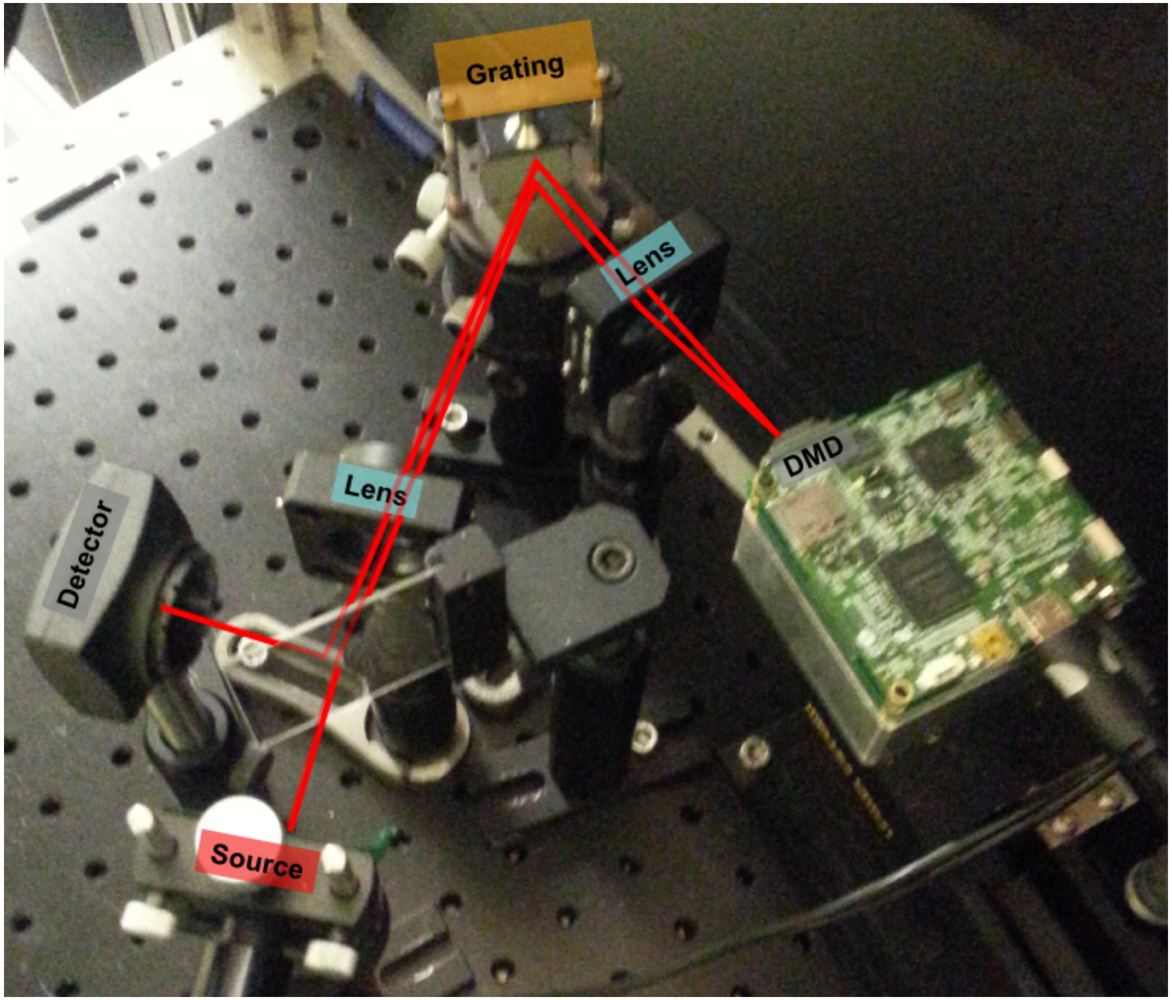
➤ Various acquisition schemes

First proof of concept

> Design implementation

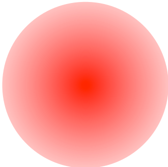


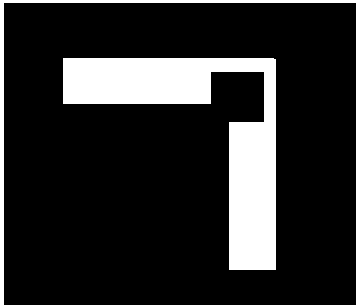
First proof of concept



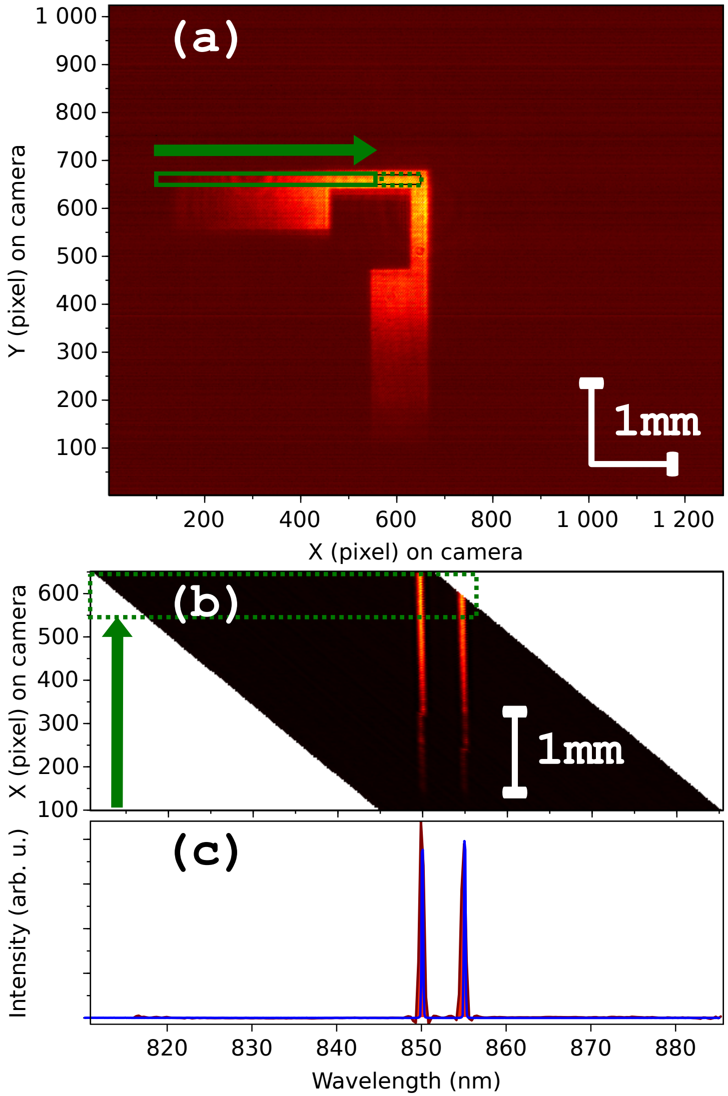
First proof of concept

> Scanning a slit on the DMD





Imaged object: known light source through a mask



“bi-λ” illumination

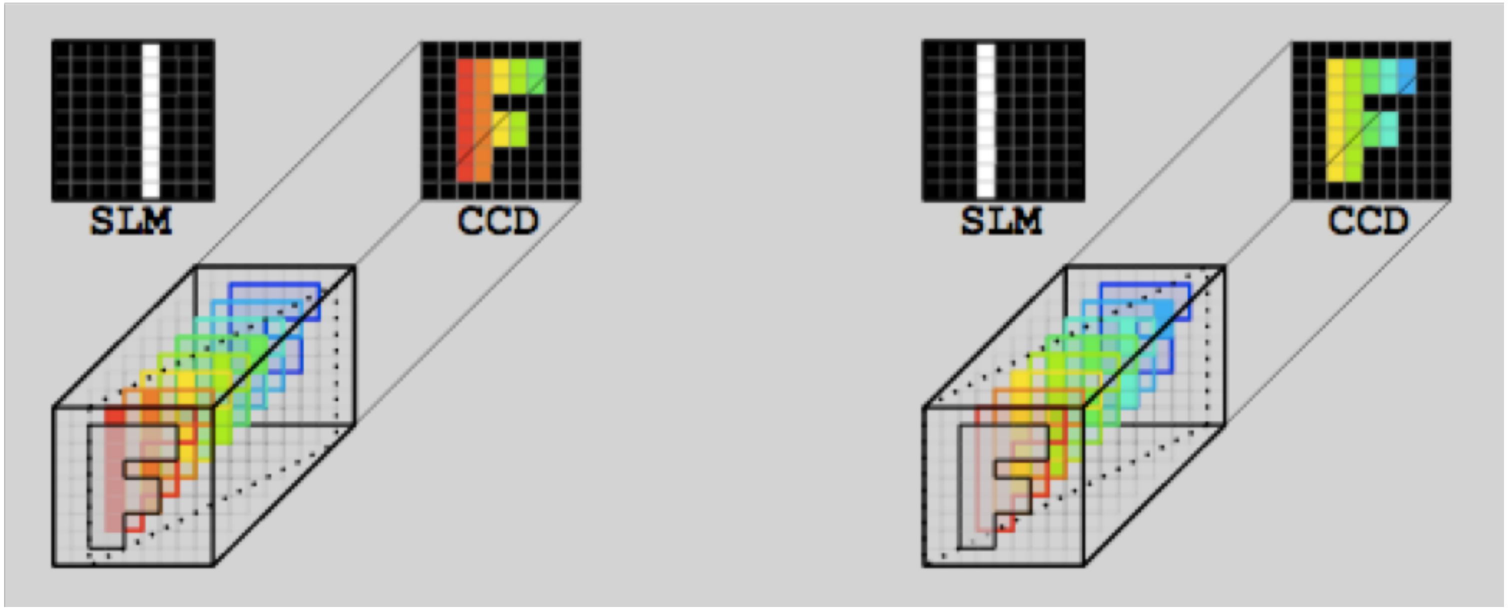
Overview of the system possibilities

- The control of the DMD allows to:
  - *Configure* the system for a given purpose / characteristic
  - *Control* the system to optimize its output (*active perception* paradigm)
- Taxonomy of acquisition schemes, along 2 “dimensions”
  1. Type of recovered information (defined by operational goals)
     - Full HS cube
     - Specific information (*e.g.* a set of given spectra)
  2. Way to control the system
     - Pre-configured DMD patterns
     - *On-line* controlled / adapted patterns
- Criteria to consider for application contexts:
  - Number of acquisitions
  - Computational load to recover the information
  - Quantity/quality of recovered information

Overview of the system possibilities

> Example 1: scanning slit

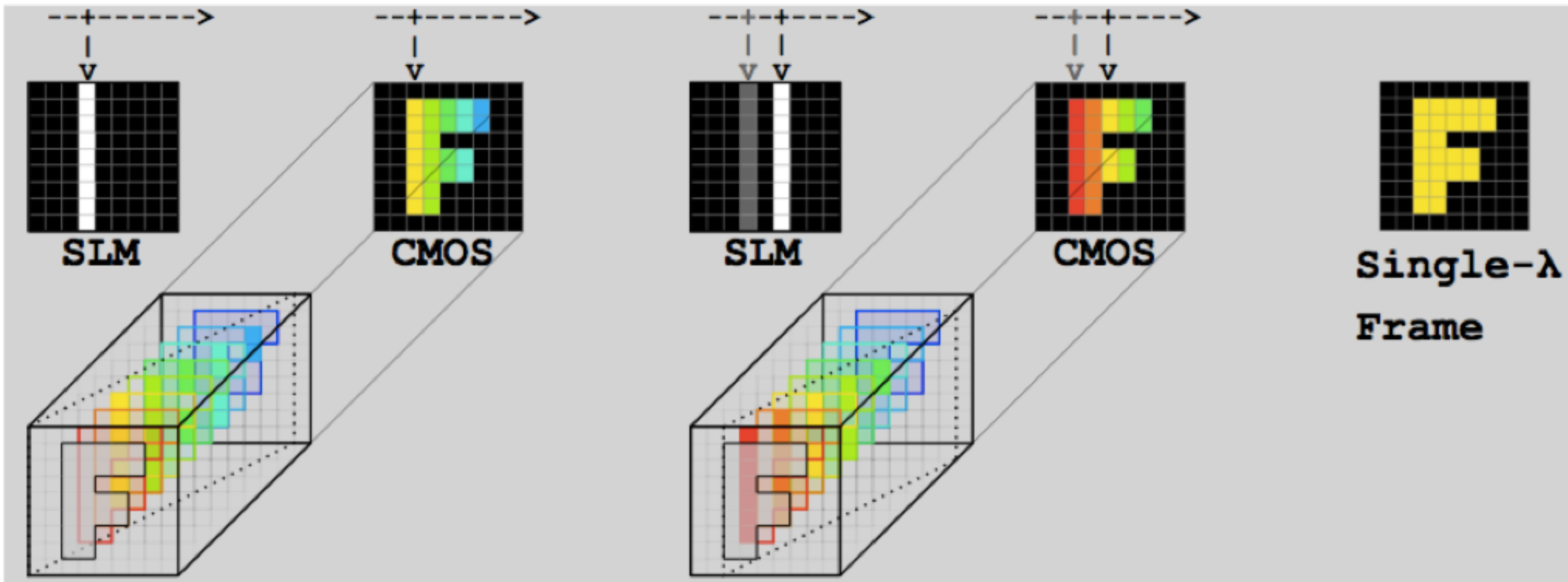
- Fills the whole cube



Overview of the system possibilities

> Example 2: monochromatic imager

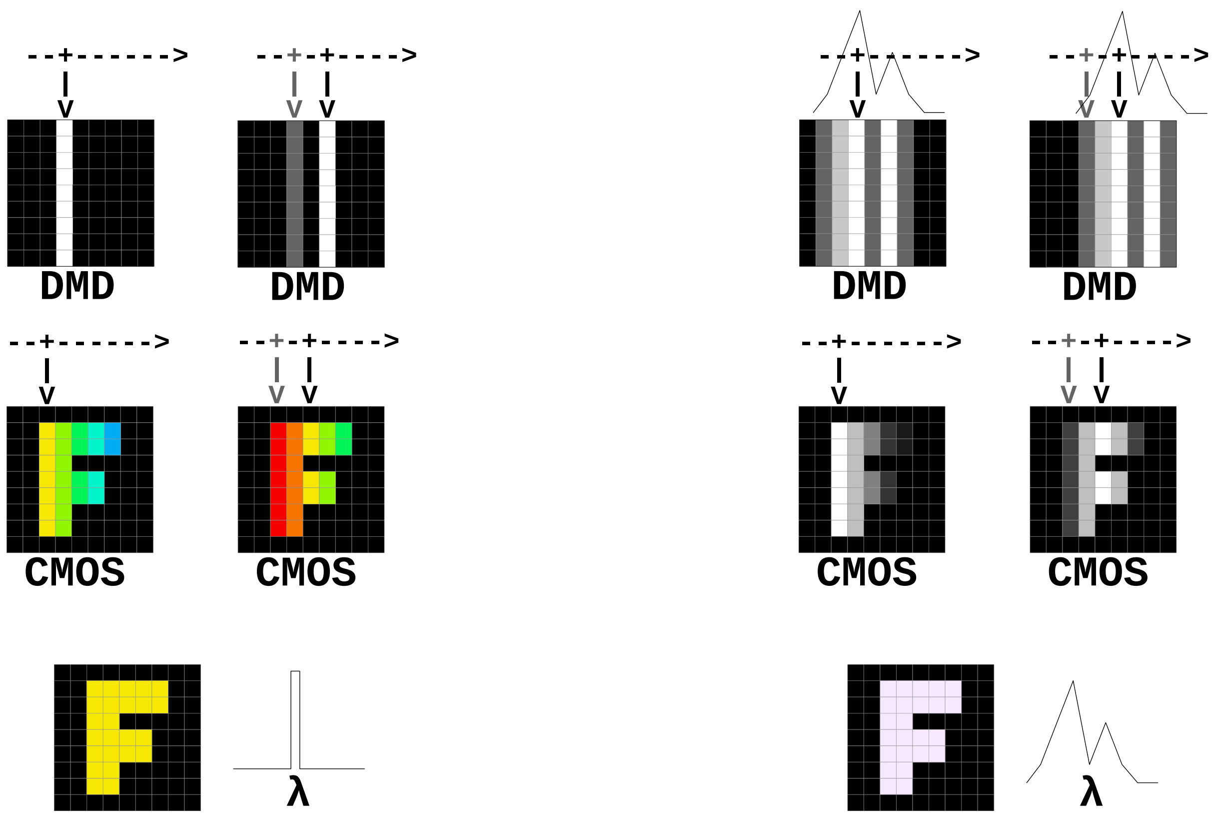
- Random access to any spectral plane in one acquistion



Overview of the system possibilities

> Example 3: spectrum response image

- Exhibits the presence of a given spectrum in one acquisition



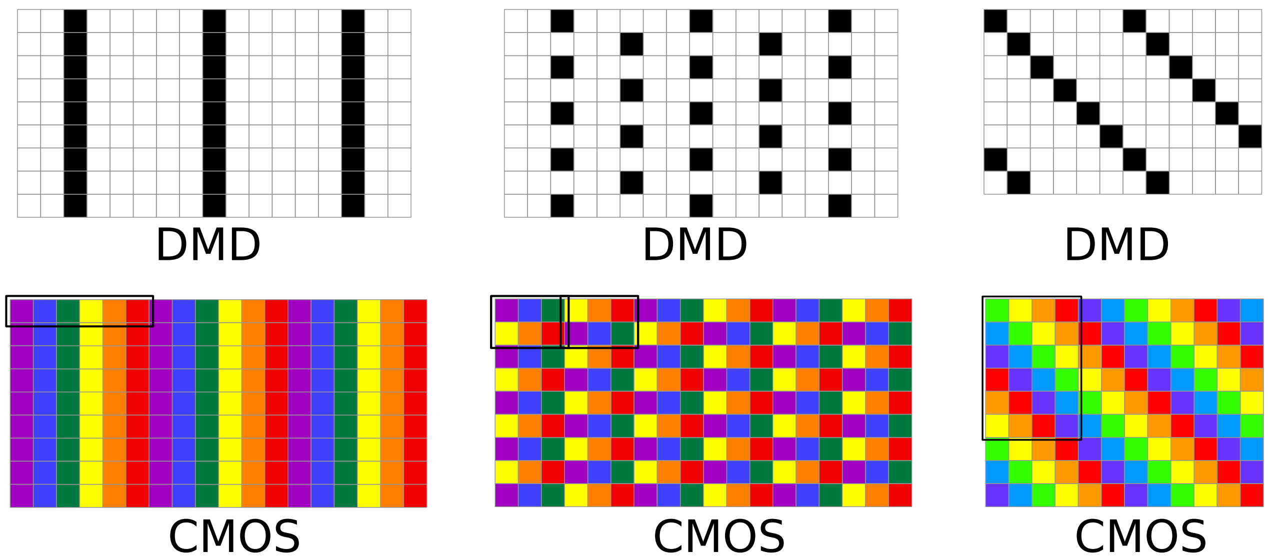
Monochromatic image

Spectrum correlation

Overview of the system possibilities

> Example 4: generalized bayer mosaics

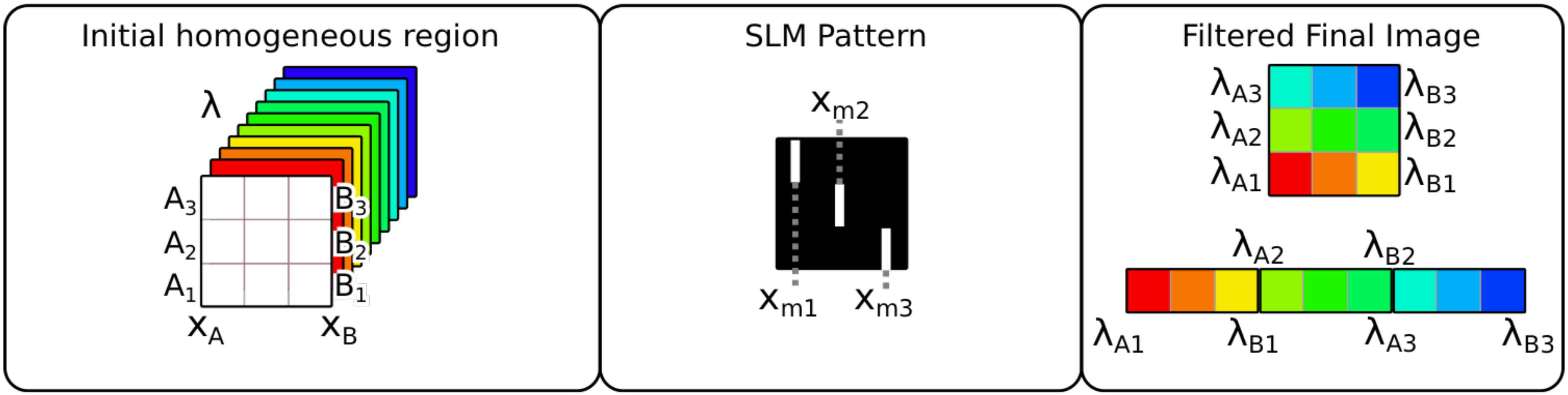
- Numerous possible patterns



Overview of the system possibilities

> Example 5: near-snapshot partitioning

- 2 acquisitions: 1 panchro, 1 controlled

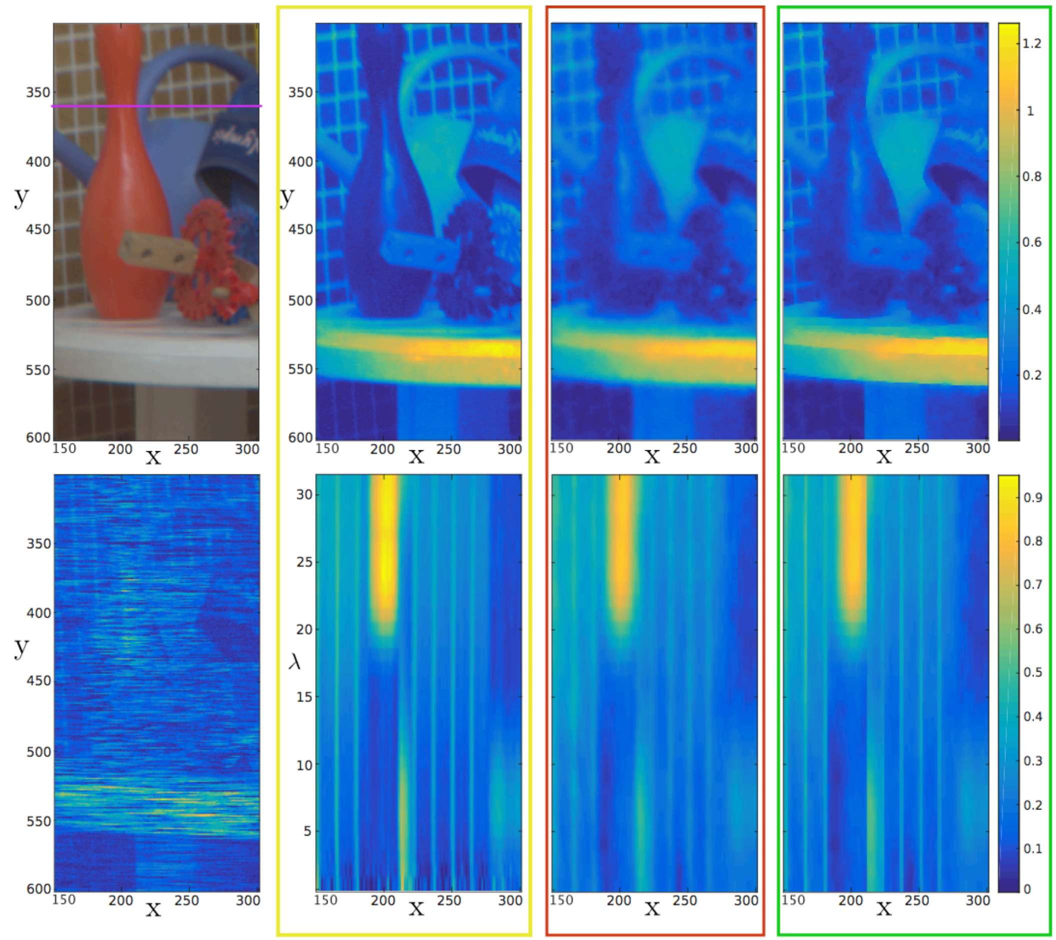


Overview of the system possibilities

> Example 6: quadratic regularization

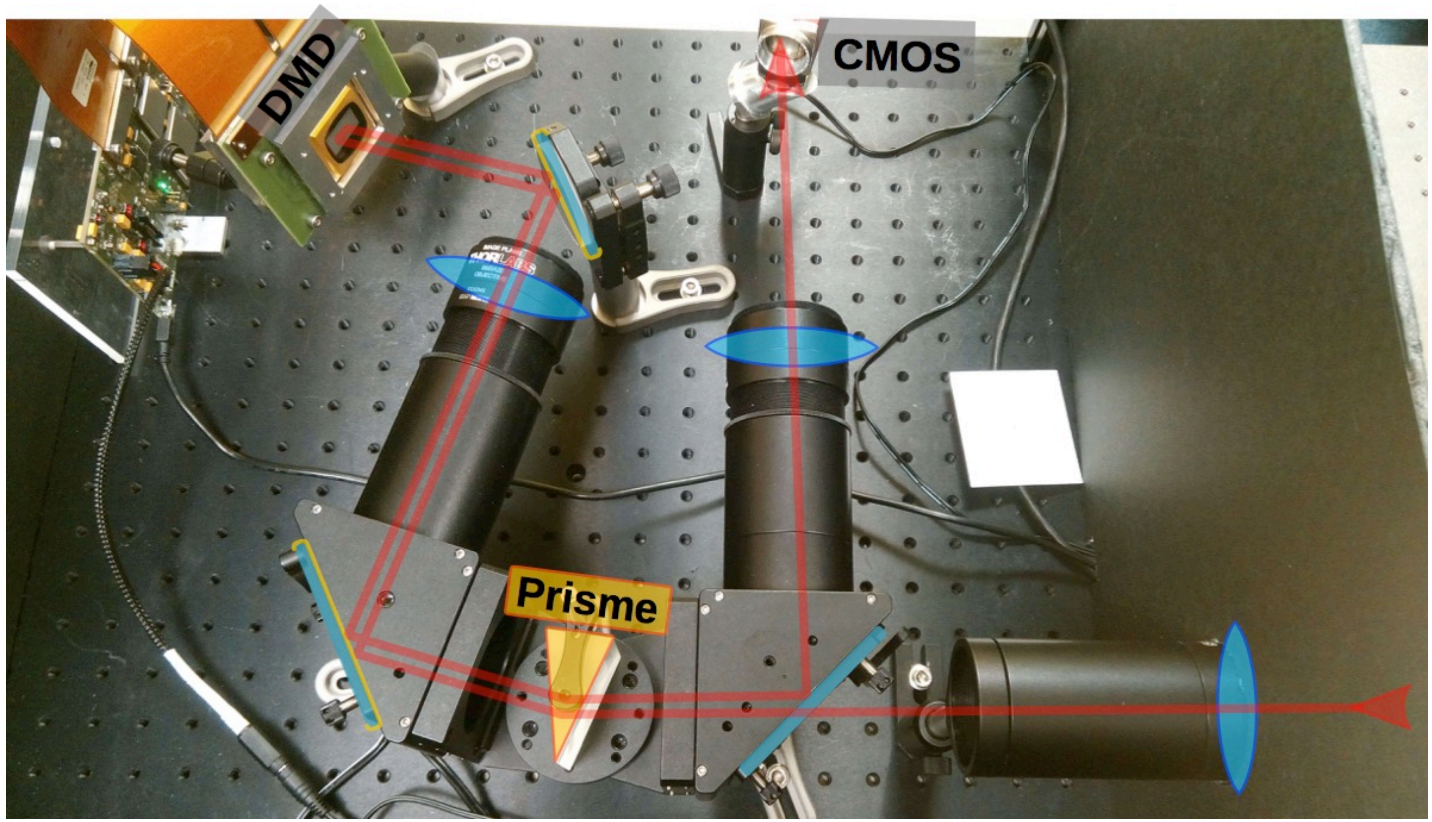
- Recovering the full cube from a small set of random DMD acquisitions (PhD of Ibrahim Ardi, IRAP/LAAS)

Reconstruction of a 31 wavelengths cube from 5 images



Latest prototype

- Really engineered
- Images the visible 500-700 nm
- Integrated acquisition & DMD control



Earth observation applications?

- Configurability yields a series of trade-offs in terms of:
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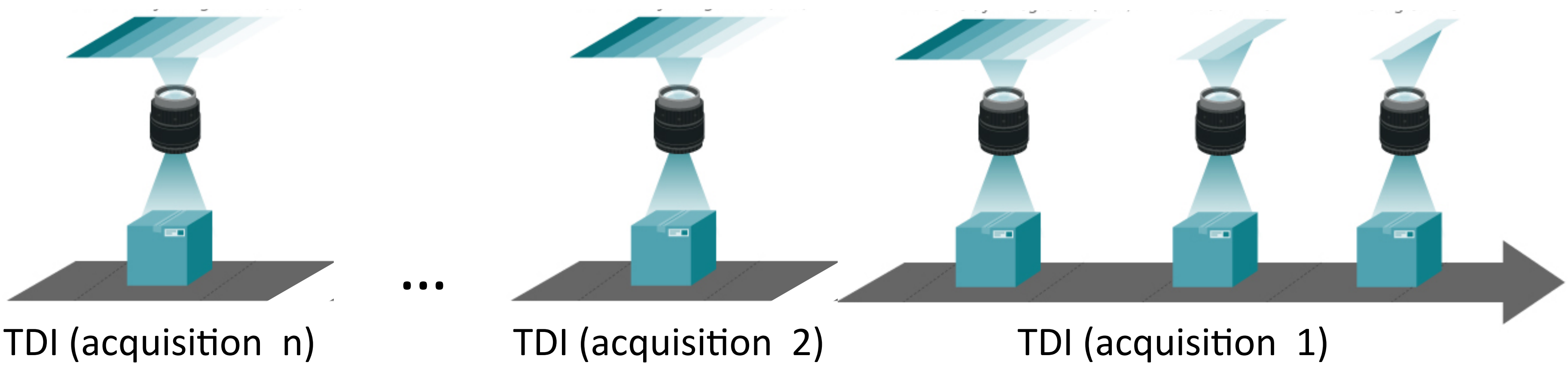
- Matrix sensor in a push-broom configuration:
  - Time delayed integration
  - Real-time adaptive control of the acquisitions



As a conclusion

> Co-design: interdisciplinary cross fertilization