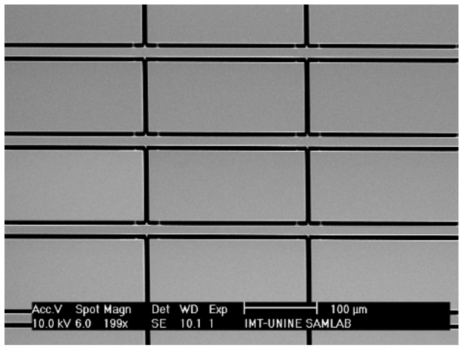
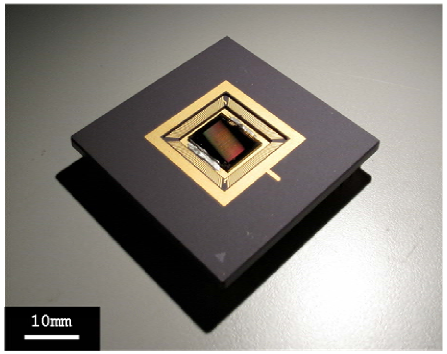
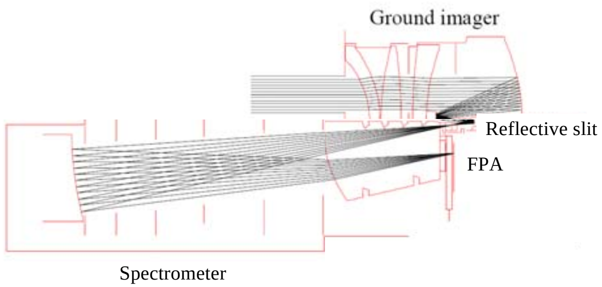
Optical MEMS for Earth Observation: an efficient optical cloud removal technique

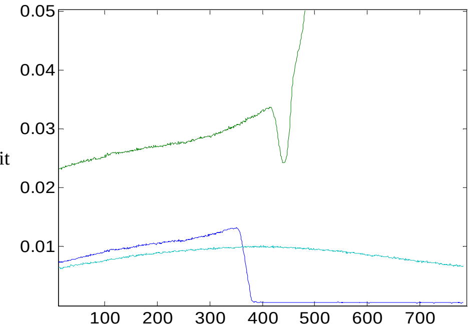
Frederic Zamkotsian[1], Arnaud Liotard[2], Patrick Lanzoni[1], Thierry Viard[2], Wilfried Noell[3], Benedikt Guldimann[4], Marco Freire[4], Stefan Kraft[4]

Laboratoire d'Astrophysique de Marseille, France
Thales Alenia Space, France
EPFL, Switzerland
ESA / ESTEC, Netherlands









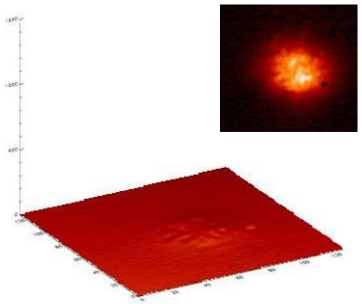
Instrumental needs

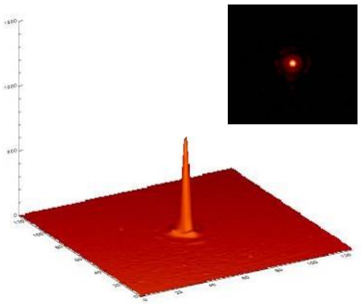
♦Instrumental needs using micro-opto-electro-mechanical systems (MOEMS)

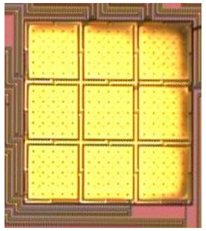
❑ Wavefront control

- Deformable mirrors

Phase



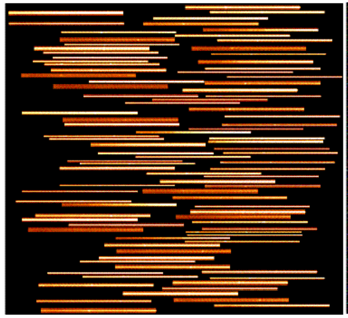


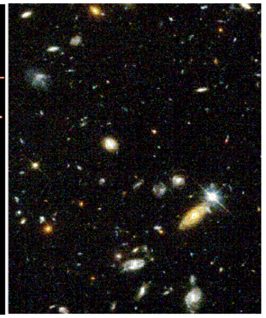


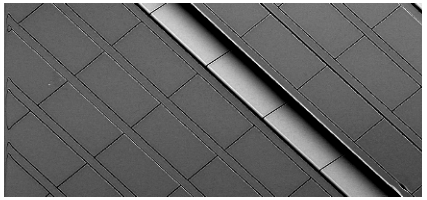
❑ Object selection

- Programmable slits

Intensity



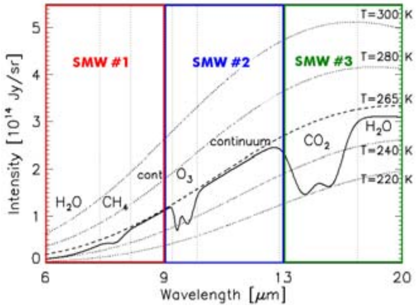




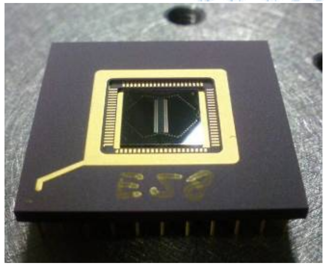
❑ Spectral domain application

- Programmable gratings

Wavelength



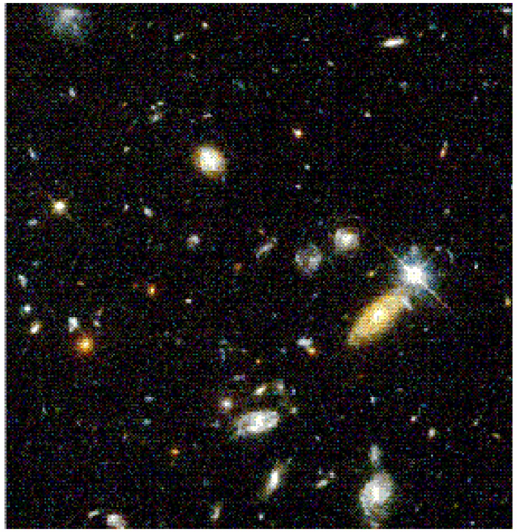
csem

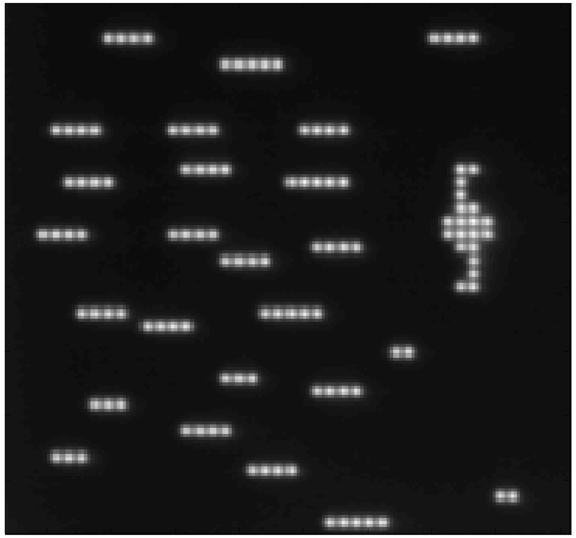


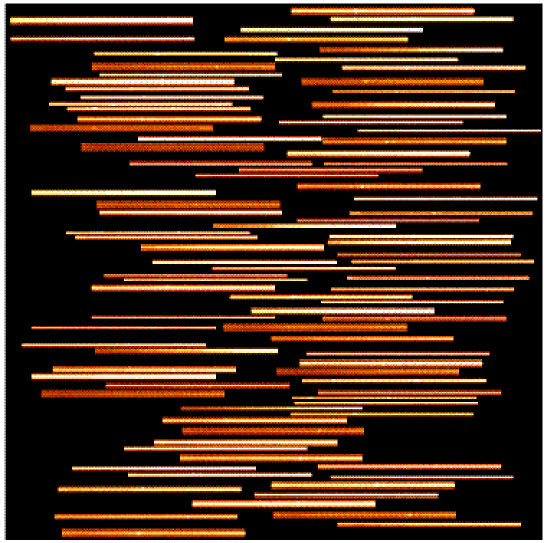
- **First phase: collecting all necessary data**
  - Earth observation instruments or payloads
  - Existing and potential optical MEMS components
- **Second phase**
  - Pre-selection of at least 6 optical payloads following three different philosophies
    - pre-selection of 2 market-pull concepts
    - pre-selection of 3 techno-push concepts
    - pre-selection of 1 concept coming from outside Earth Observation
  - Final selection of the 2 most promising optical payload
- **Third phase**
  - Detailed design of the 2 promising concepts
  - Synthesis of the study

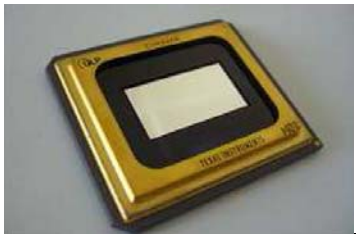
Tiltable micromirror arrays

- Tiltable micromirror array
  - Active on intensity
  - High contrast
  - Digital mode only : light is switched between ON and OFF positions



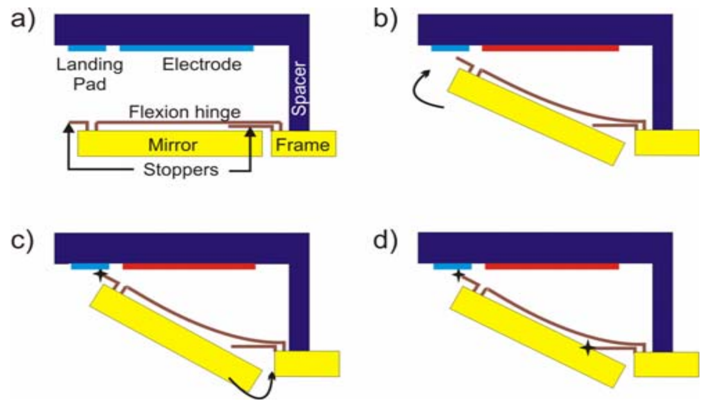


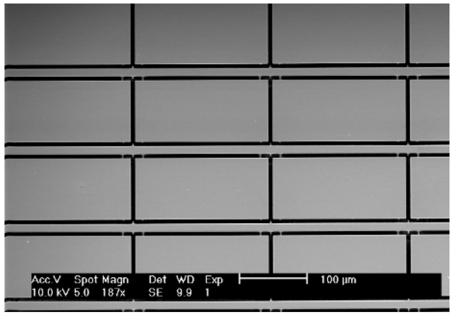


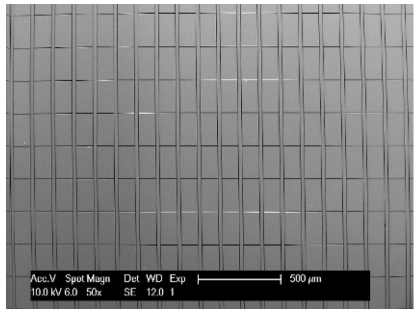


MIRA

- Single crystalline micromirror array for next generation IR multi-object spectrograph
- Collaboration between LAM and EPFL
- Goal: high contrast 1500:1
- Fill factor > 90 % obtained
- Concept
  - Electrostatic actuation
  - Precise tilt angle (landing beams)
- Realization
  - Combination surface and bulk micromachining
  - Wafer level bonding of two wafers: one for th mirrors, one for the electrodes

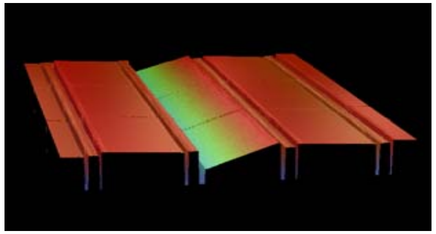


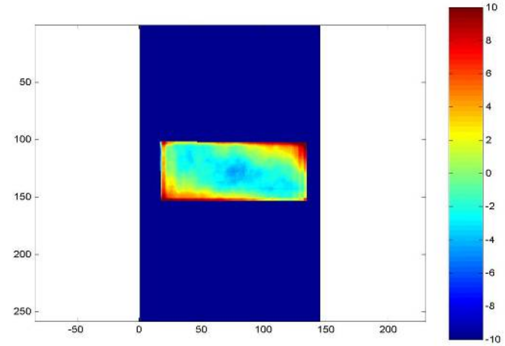




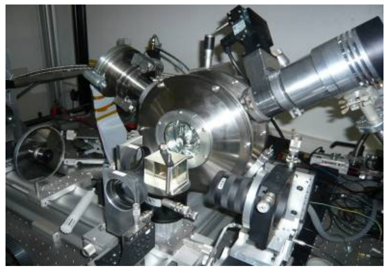
MIRA

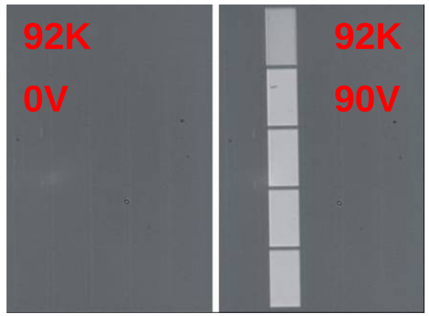
- Surface quality
  - On 100µm x 200µm micromirrors: deformation < 10 nm
  - Tilt angle precision < 1 arcmin
  - Actuation voltage < 100 V





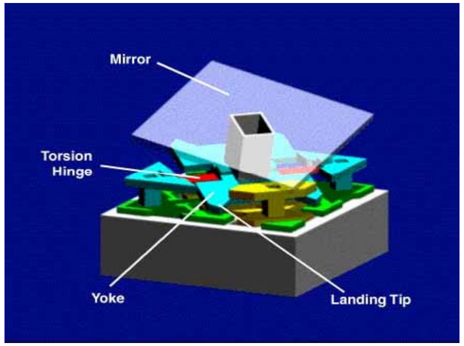
- Environmental tests
  - Vacuum (10^{-6} mbar)
  - 92K and 162 K
  - Mirrors tilt
  - Surface quality < 30 nm PtV in cryo

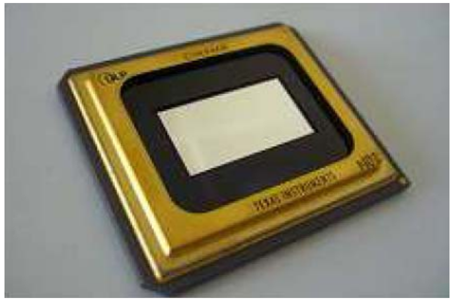


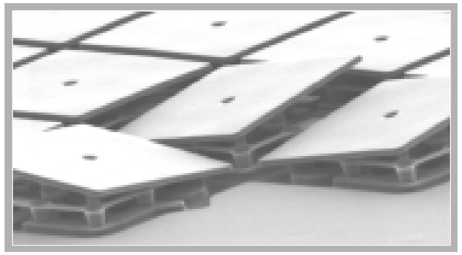


DMD from Texas Instruments

- Most popular MOEMS device
- Micromirrors
  - 2048x1080 mirrors individually adressables
  - Pitch 13,68µm
  - Tilt angle: 12°
- Numerous applications
  - Main application: image display
  - Design modification not possible
- Spatial qualification test (ESA contract)
  - -40°C in vacuum (10^{-5} mbar)
  - Micromirrors hold in position during > 1500 s
  - DMD fully operational
  - Life test during 1038h, radiations, vibrations
  - No showstopper for space use

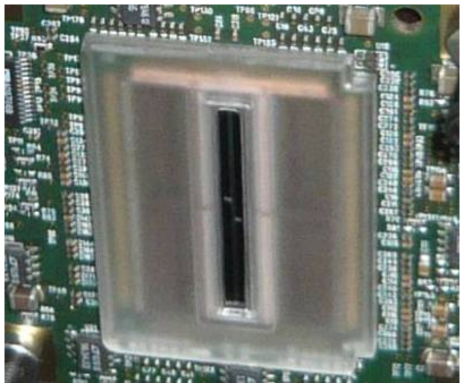


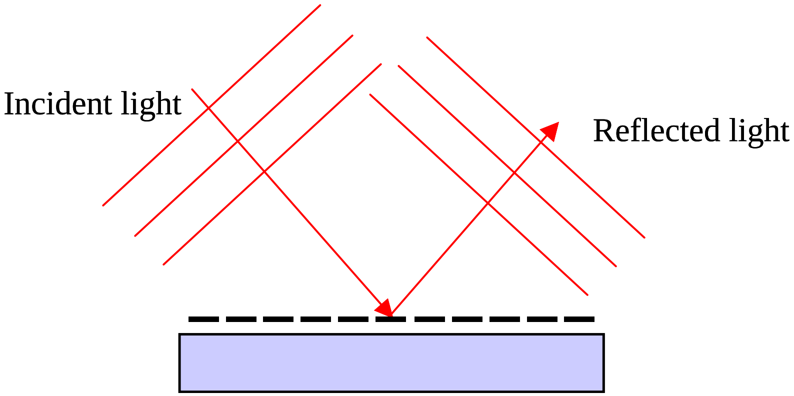


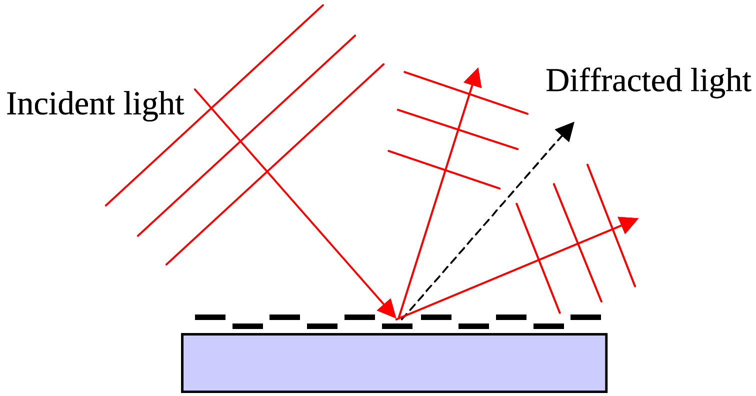


PMDG

- Programmable micro-diffraction gratings (PMDG)
  - Action on phase
  - Based on 200µm x 4µm ribbons, with piston mouvment
  - Digital mode: light modulated between ON and OFF positions
  - Analog mode: ribbons move in order to cancel partially the input light ("gray" scales)

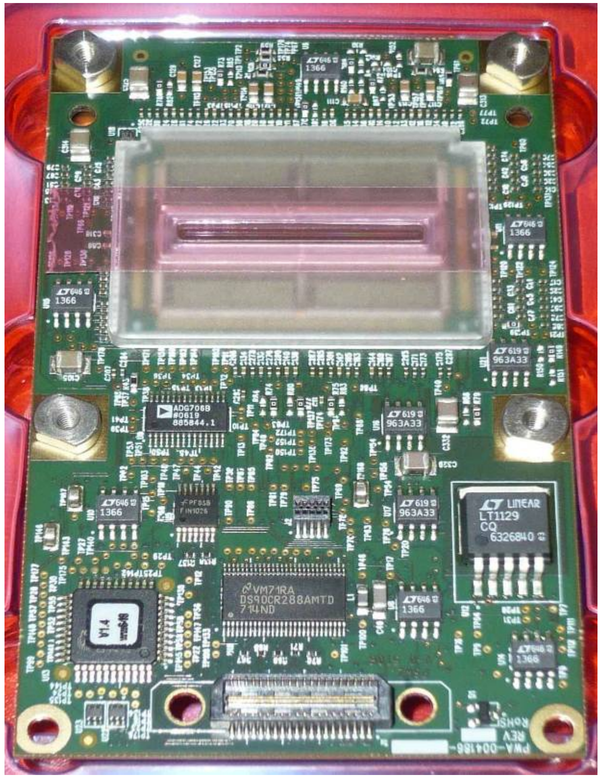




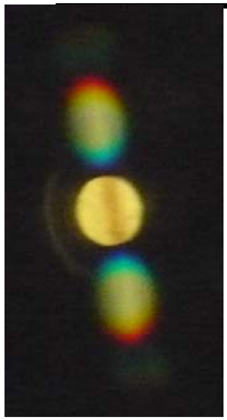


PMDG from SLM

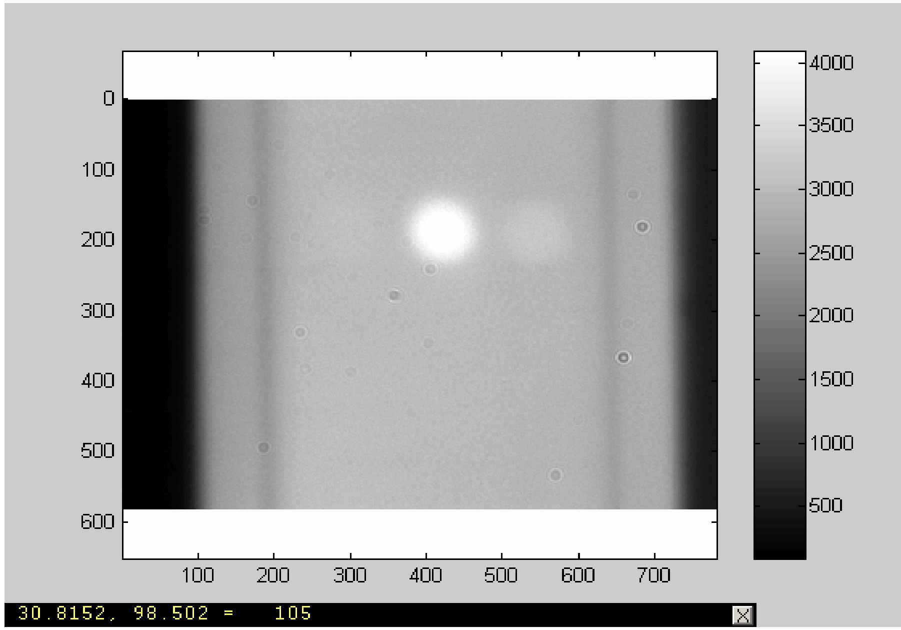
- PMDG from Silicon Light Machines (ESA study)
  - 1086 pixels
    - → 6 ribbons (3 pairs) / pixel
    - → 3 fixed ribbons / 3 piston ribbons
    - → Pixel pitch 25.5µm
    - → Ribbon width / gap: 3.775µm / 0.475µm
    - → Ribbon length 220µm
    - → Active area 75 x 28254 $µm^2$
  - Window with visible coatng
  - Monted on PCB
  - Heat sink on the back
  - V_{max} = 385V
  - Coded on 1024 levels (10 bits)

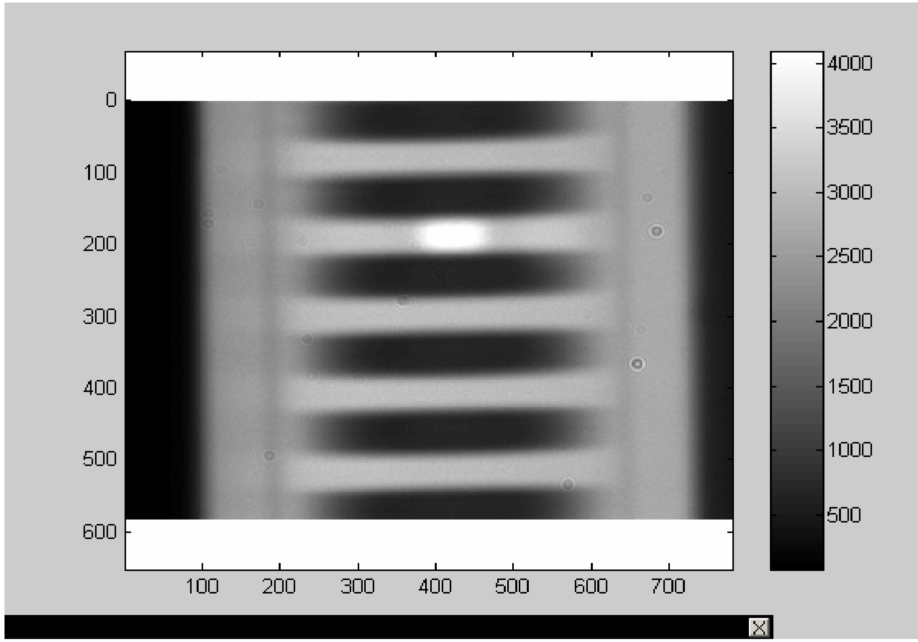


PMDG in operation



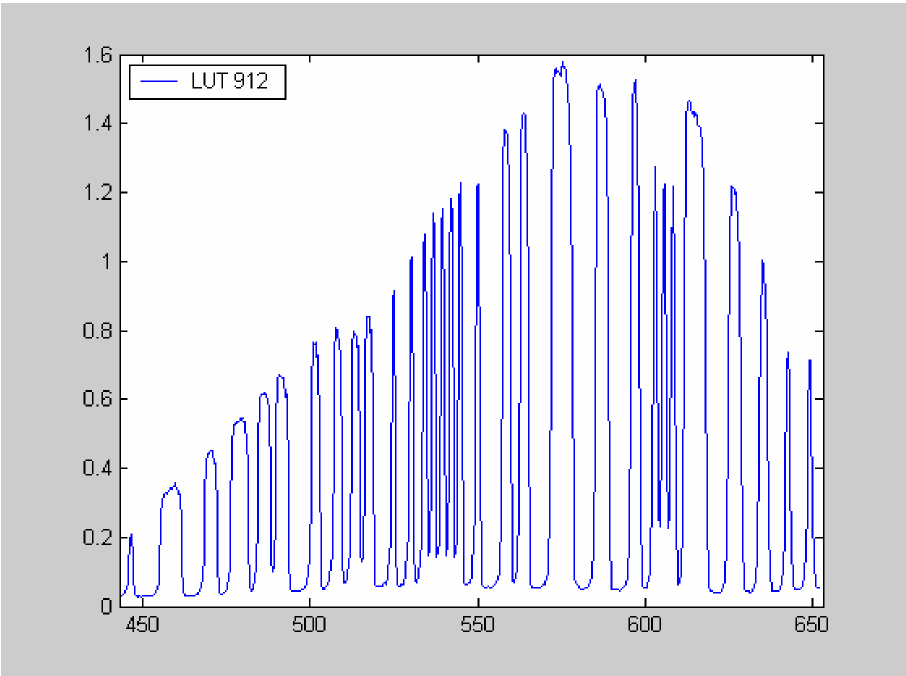
- Ribbons images / localized source
  Filtering in Fourier plane

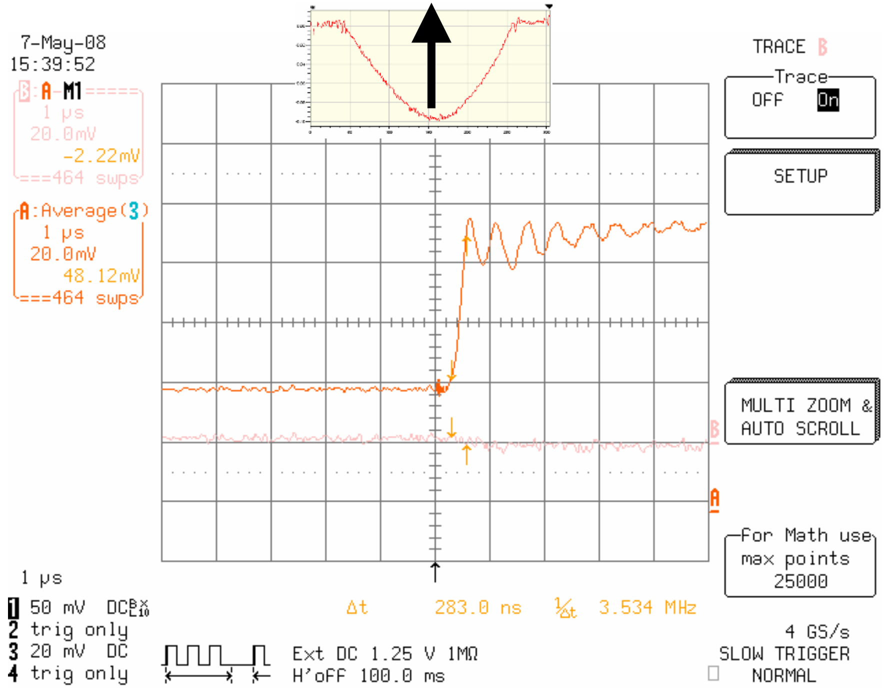




PMDG performances

- Device for wavelength selection
  - Fully programmable
  - Steep edge filters, contrast > 30
  - Long term stability and reproducibility
  - Dynamical response (1 MHz)



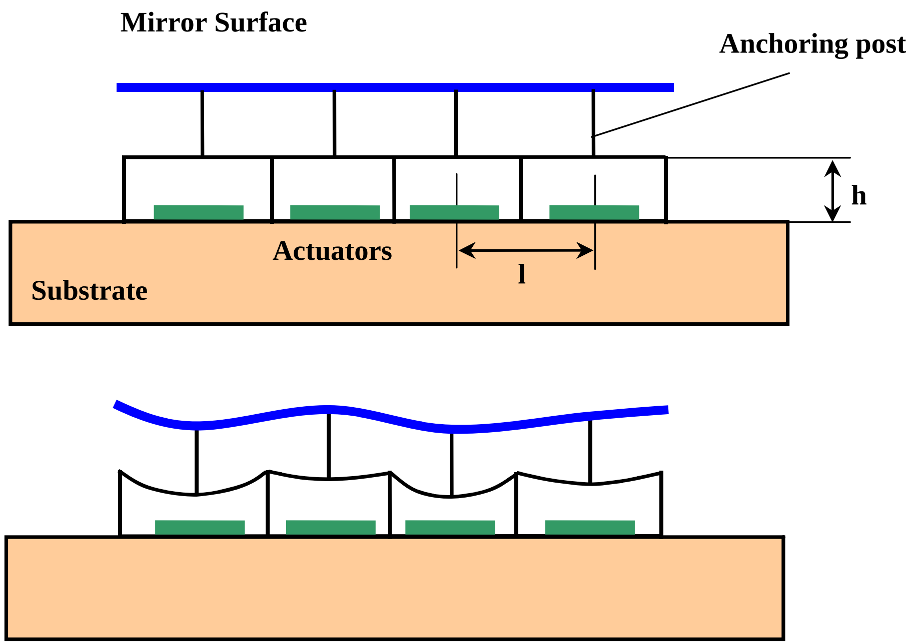


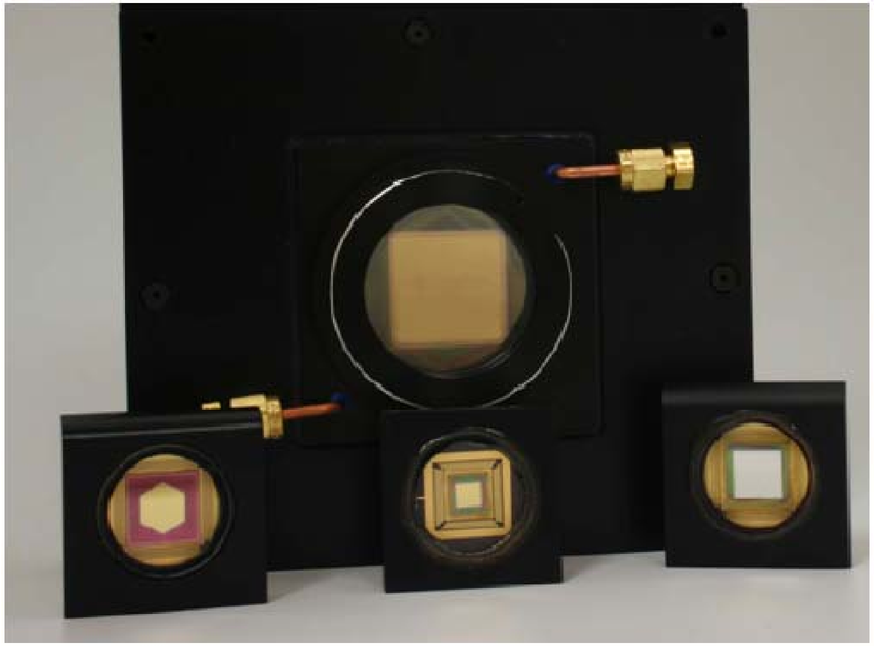
MDM

♦ Micro-deformable mirrors (MDM), action on wavefront (phase)

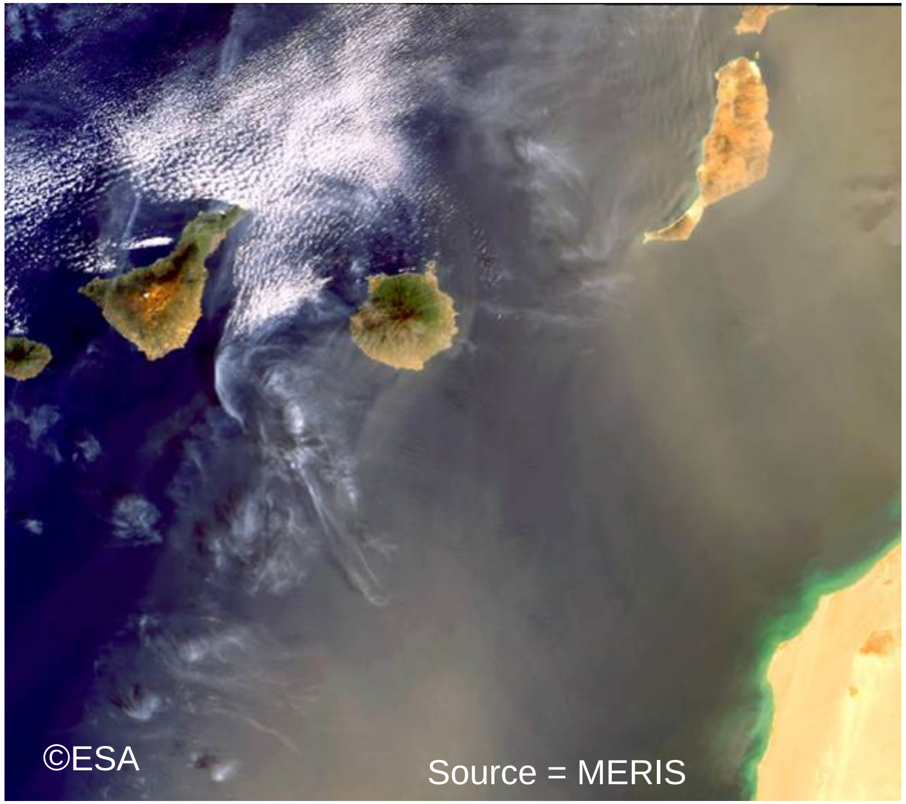
- Actuators array
- Continuous mirror
- Boston Micromachines devices

  Up to 4096 actuators, up to 5µm stroke.





First promising concept based on MOEMS : Cloud remover

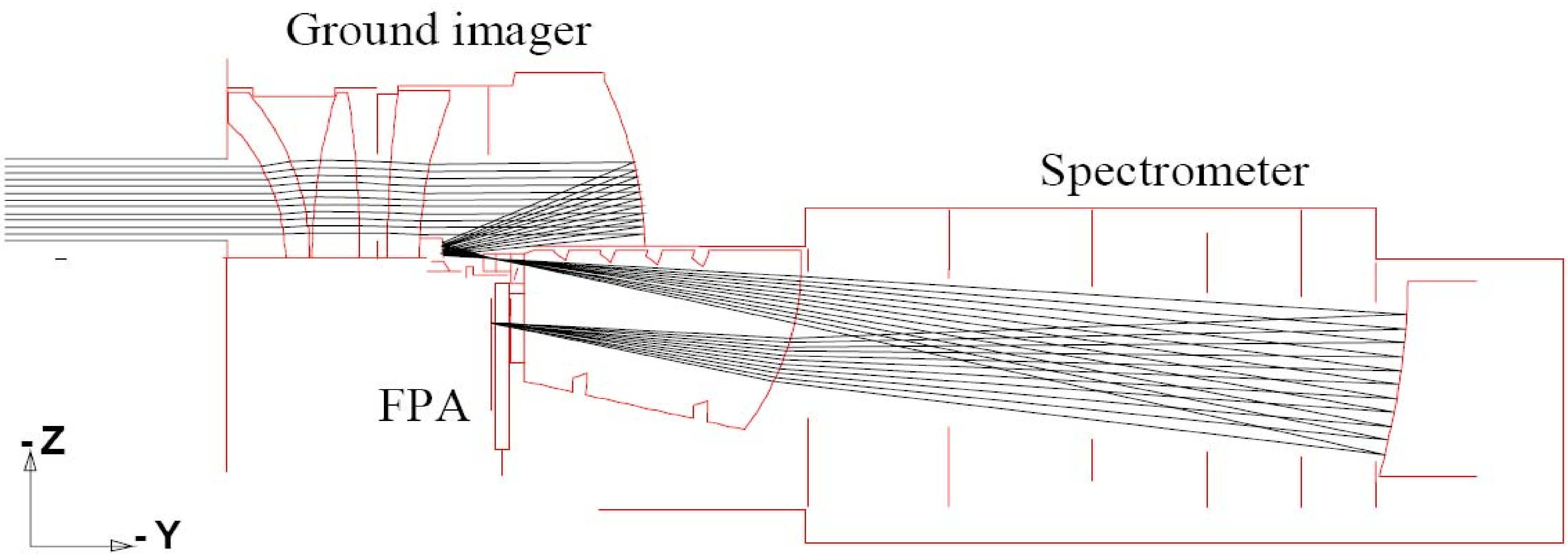


Cloud remover

MERIS return of experience :

Push-broom spectro-imager for Earth monitoring

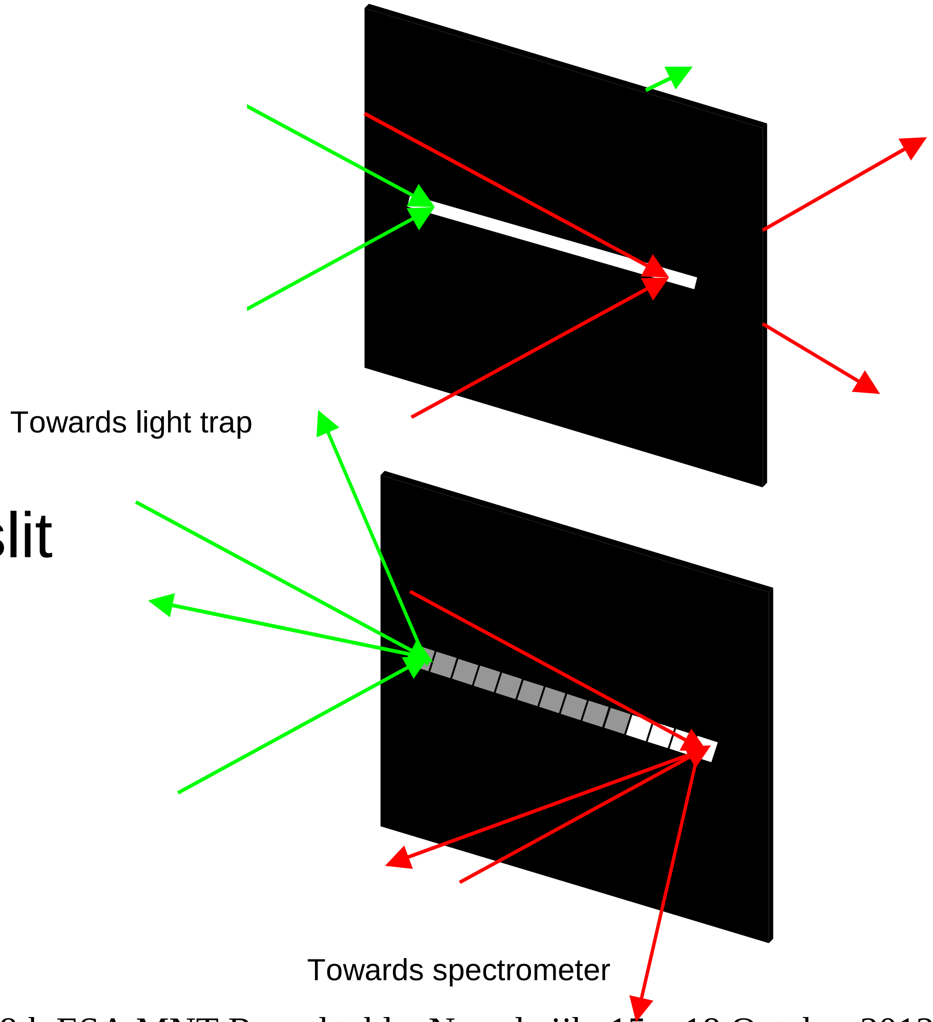
- Clouds in the field-of-view generates massive straylight
- Sun-glint completely saturates the detector.



Cloud remover

Spectrometer characteristics (spectrum : 400 nm -> 1020 nm)

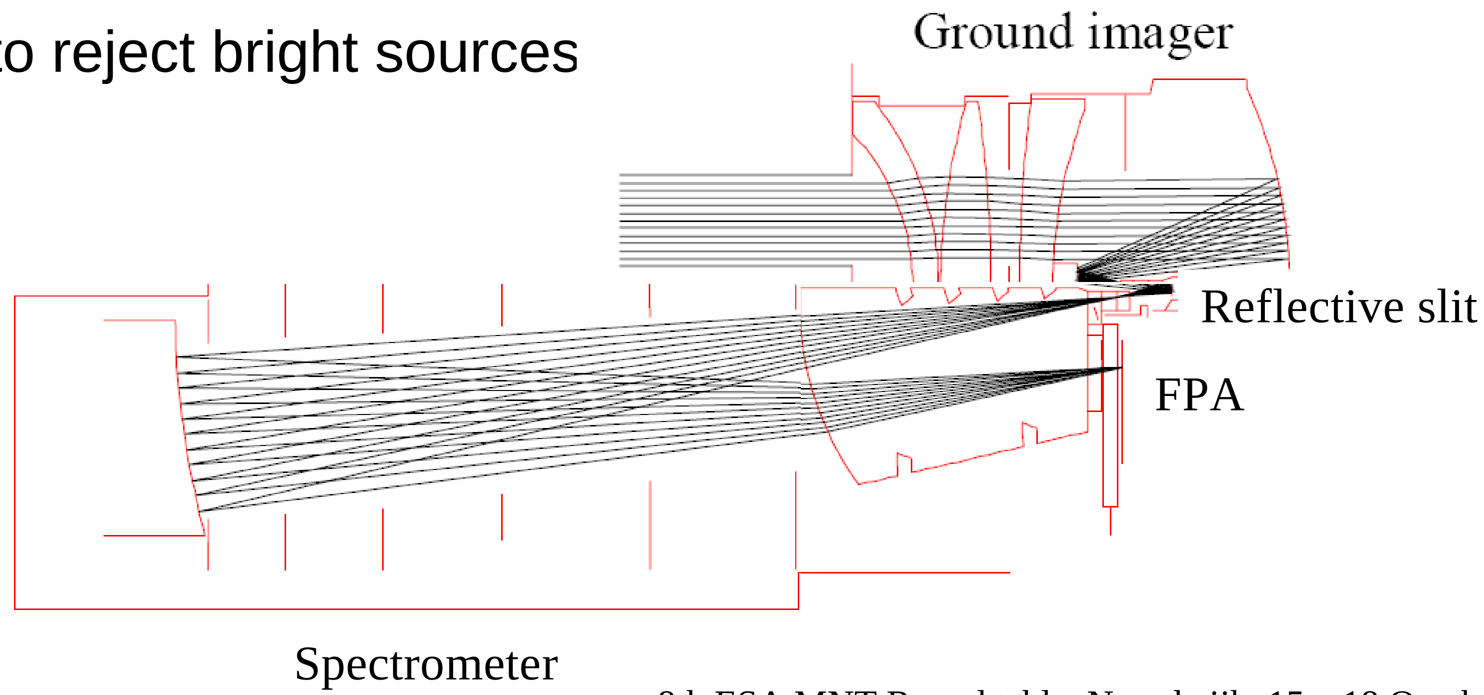
- Classical design : slit dimensions
  - 17mm x 20 microns
  - 740 columns
- New design : dynamical reflective slit
  - Based on a micro-mirror array
  - Enable to reject bright sources



Cloud remover

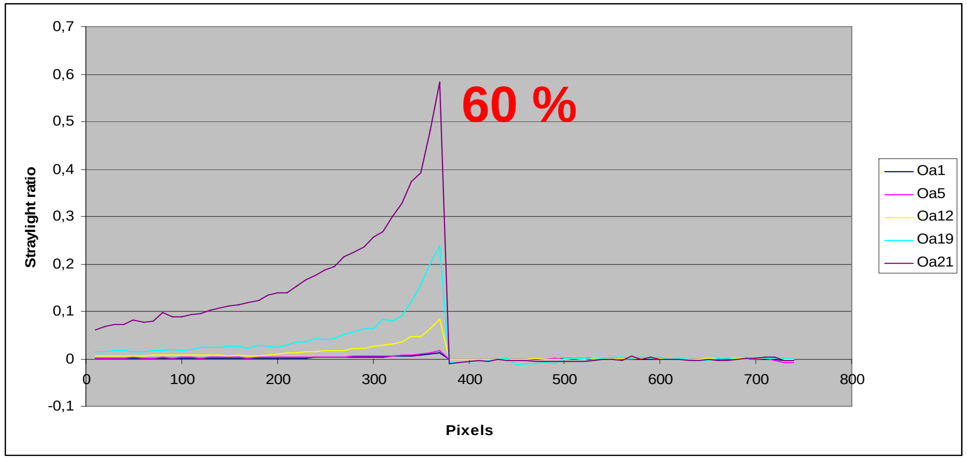
Spectrometer characteristics (spectrum : 400 nm -> 1020 nm)

- Classical design : transmissive slit
- New design : reflective slit
  - Compliant with the opto-mechanical design
  - Enable to reject bright sources

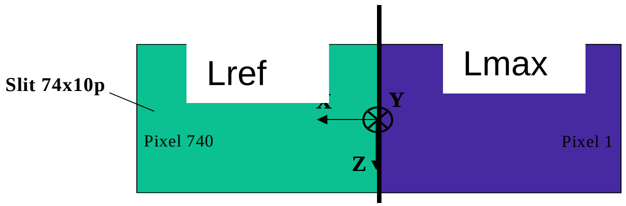


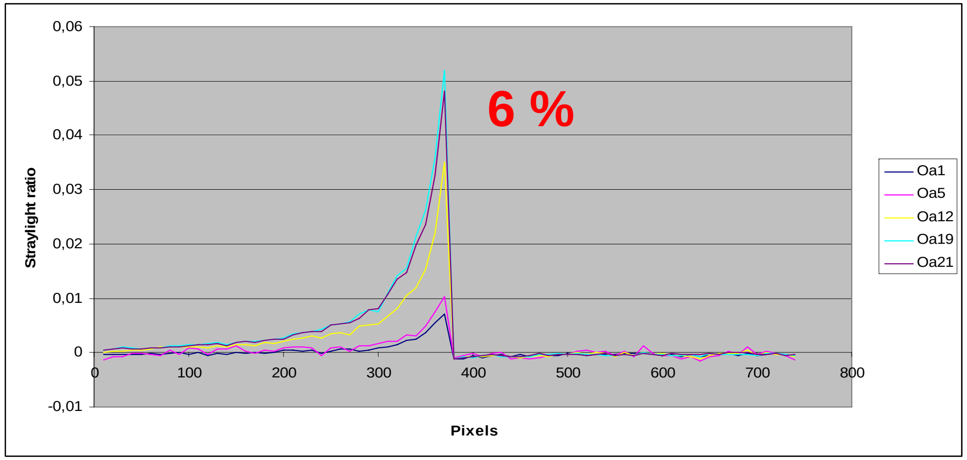
Straylight analysis

- Complete simulations with ASAP
- Spectrometer nominal design
- Straylight ratio :
  - ➔ Straylight level / useful signal



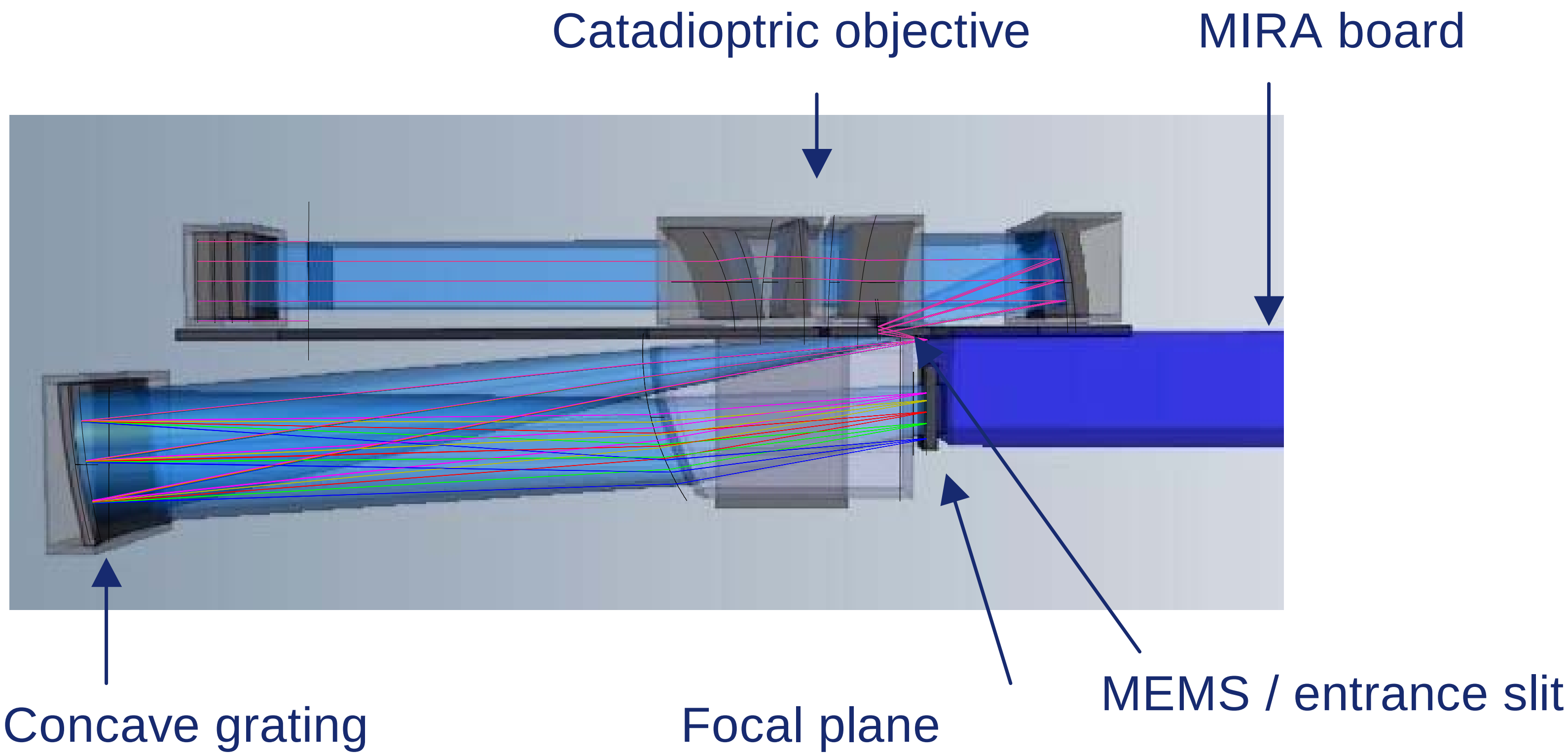
Straylight without bright sources remover



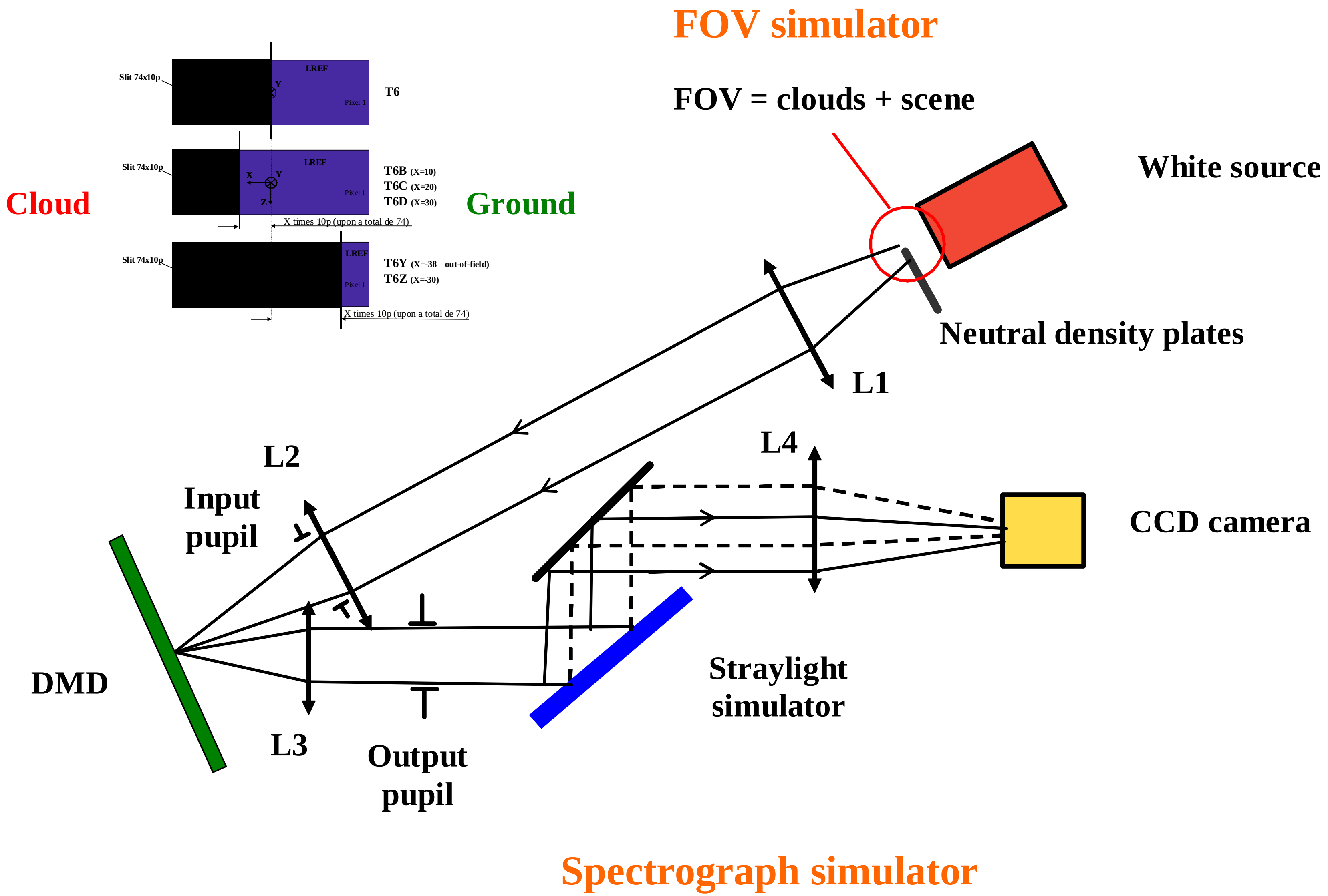


Straylight with bright sources remover

CAD view


Catadioptric objective
MIRA board
Concave grating
Focal plane
MEMS / entrance slit

Cloud remover: demonstration @ LAM

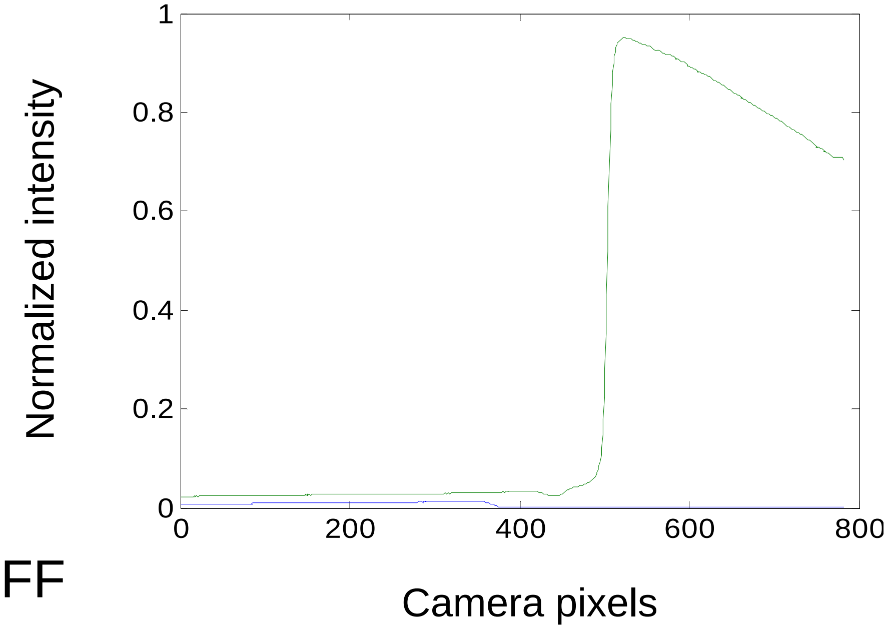


Cloud remover: demonstration @ LAM

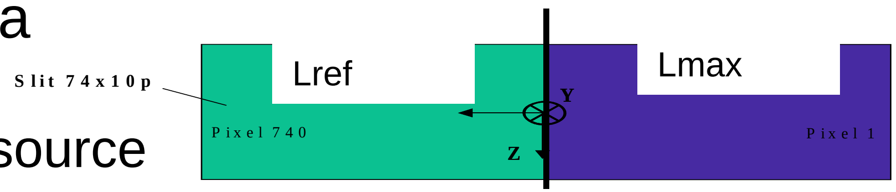
Bright sources remover experiment results

- Profile of the field-of-view
  - Scene @ Lref (left part)
  - Bright source @ Lmax (right part)

  - green curve:
    programmable slit is all ON
  - blue curve:
    the micro-mirrors located
    on the bright area are switched OFF



- Close-up view of the transition area
  - Light blue curve:
    perfect scene without the bright source



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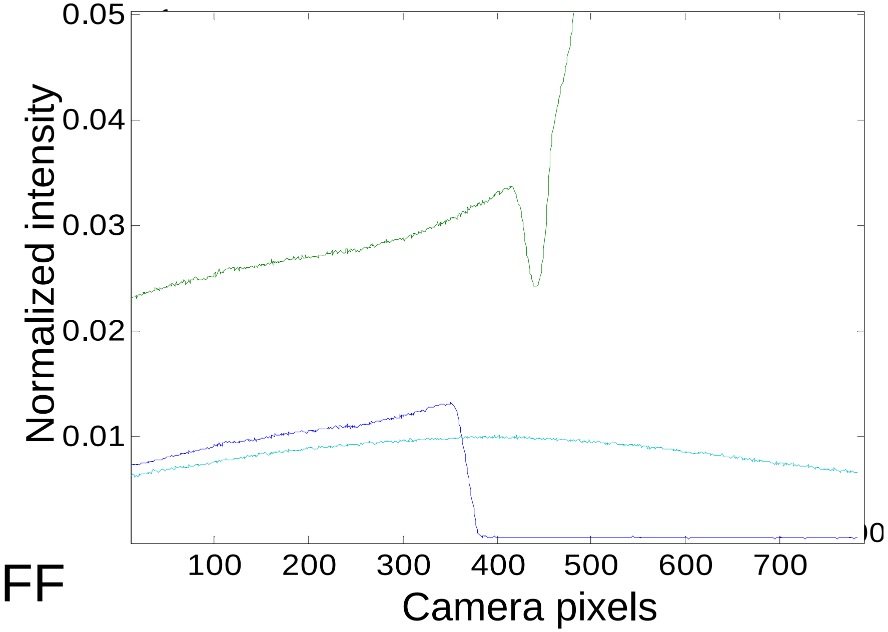

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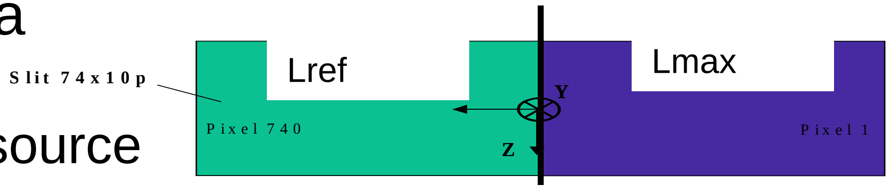

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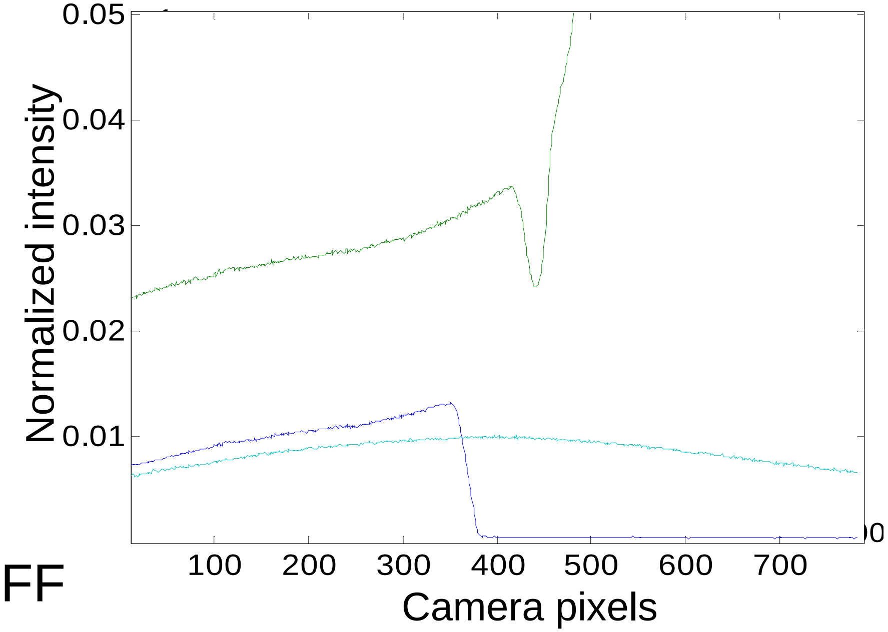

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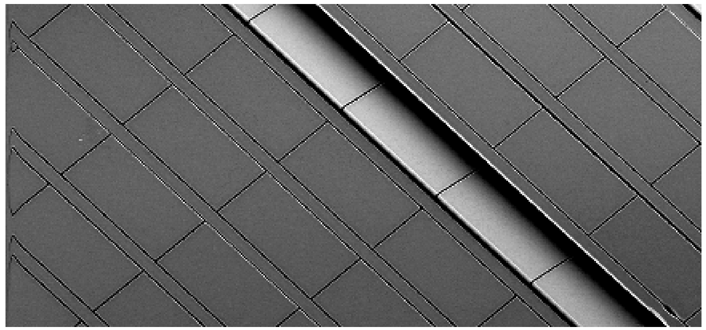
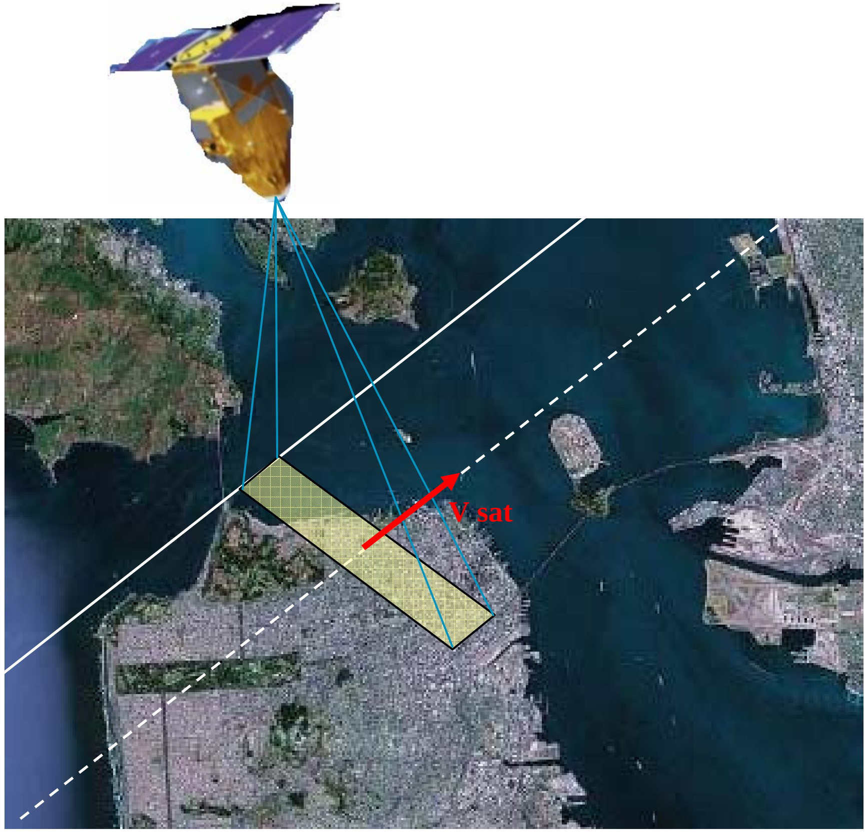
MIRA



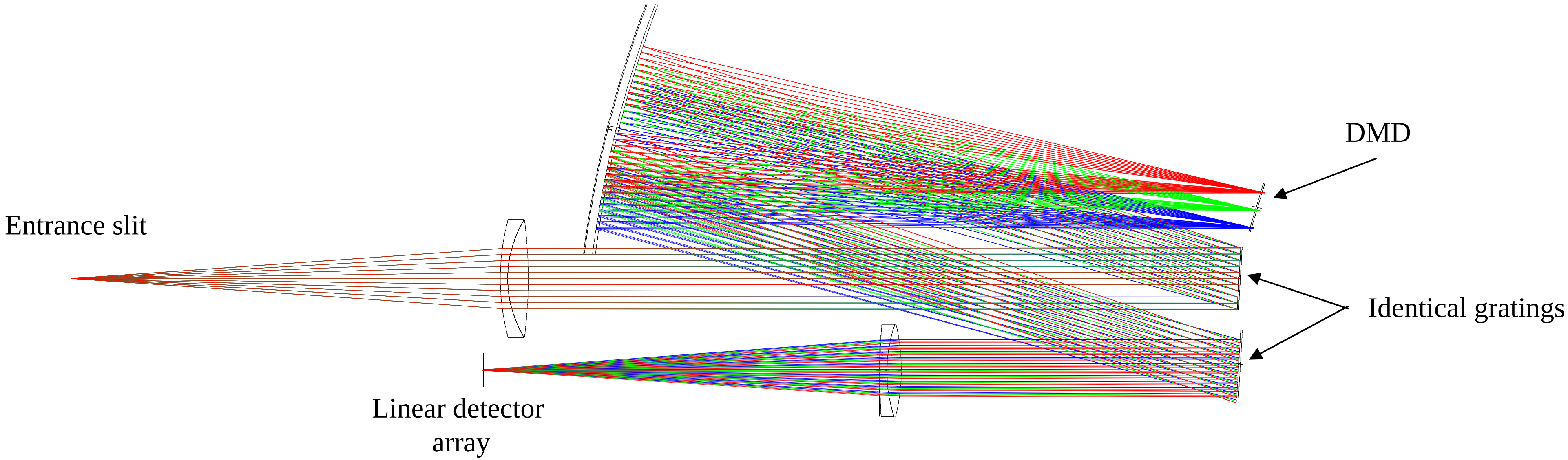
Second promising concept based on MOEMS : Tuneable spectrometer with field of view



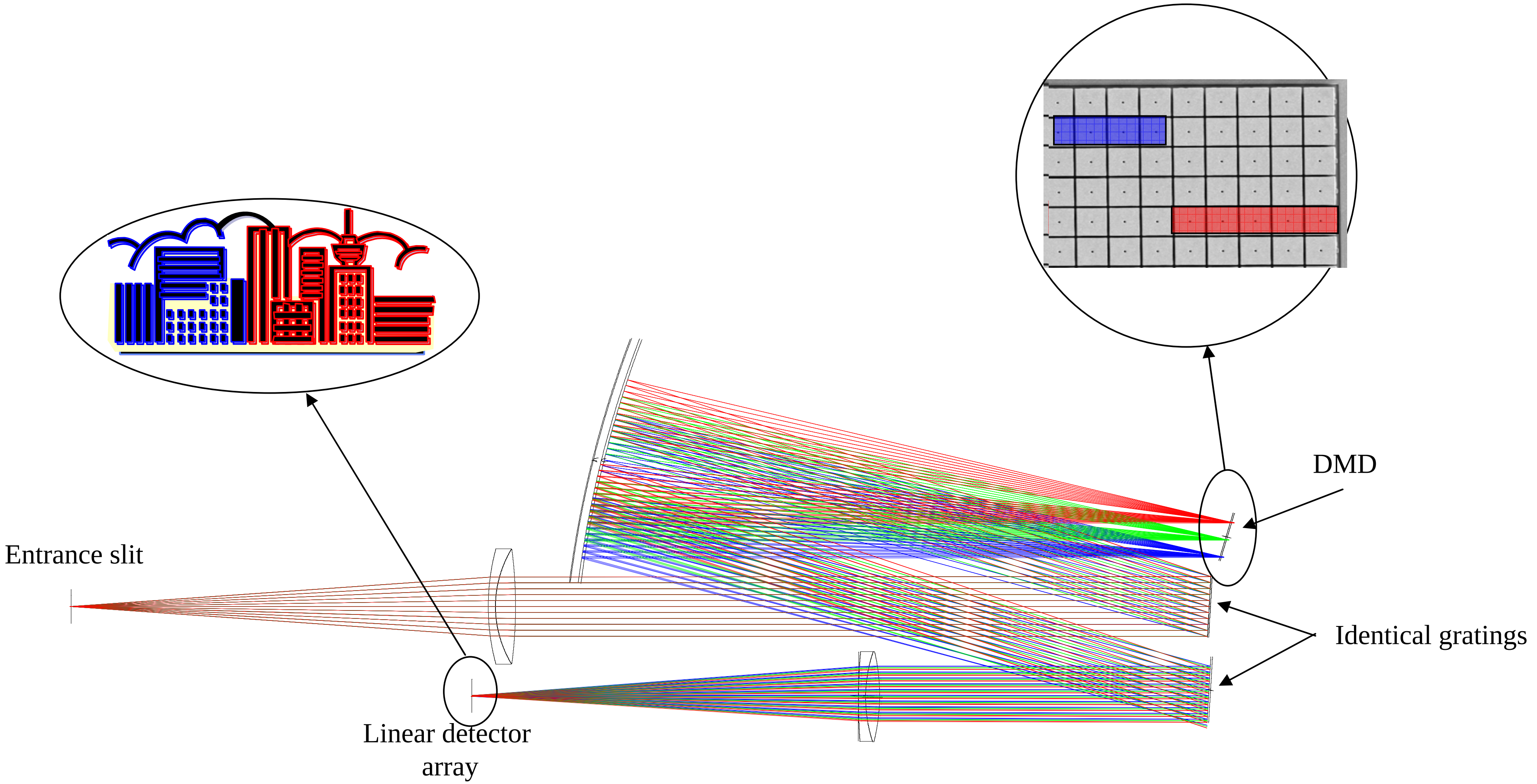
DMD for spectral tailoring with FOV

Spectrometer concept for push broom acquisition

- Use of a micro mirrors array
  - One dimension for the FOV
  - One dimension for the spectral dispersion



DMD for spectral tailoring with FOV



DMD for spectral tailoring with FOV

MOEMS (DMD) characteristics

- Micro mirror dimension around 15 µm x 15 µm
- Number of micro mirrors in spectral direction around 1000
- Number of micro mirrors in spatial direction around 2000

Design parameters (other operating points are possible)

- Spatial resolution = 5 m (for altitude = 700 Km)
- Total field = 10 Km (2000 pixels)
- Total bandwidth = 200 nm (ex : from 400 nm to 600 nm)
- Theoretical spectral resolution can be tuned from 0,2 nm to 200 nm

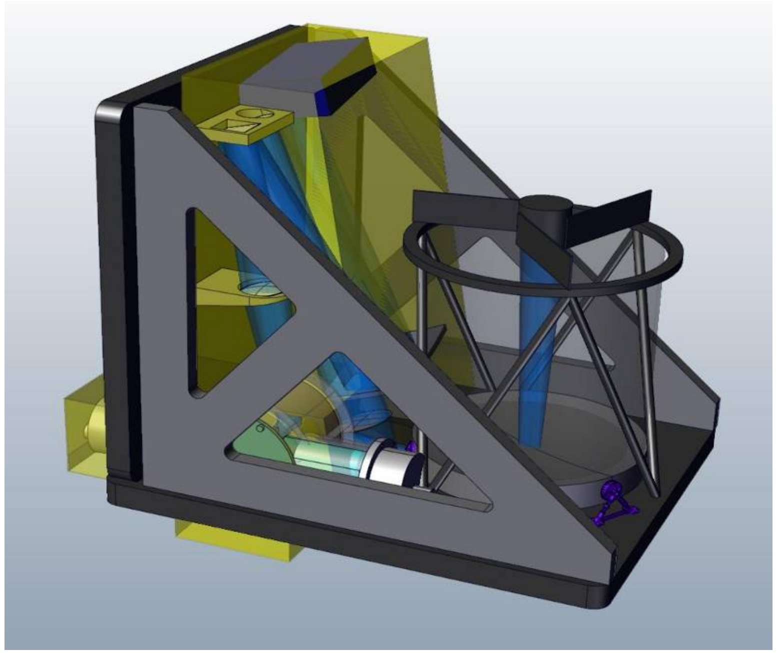
Instrument characteristics (for here above operating point)

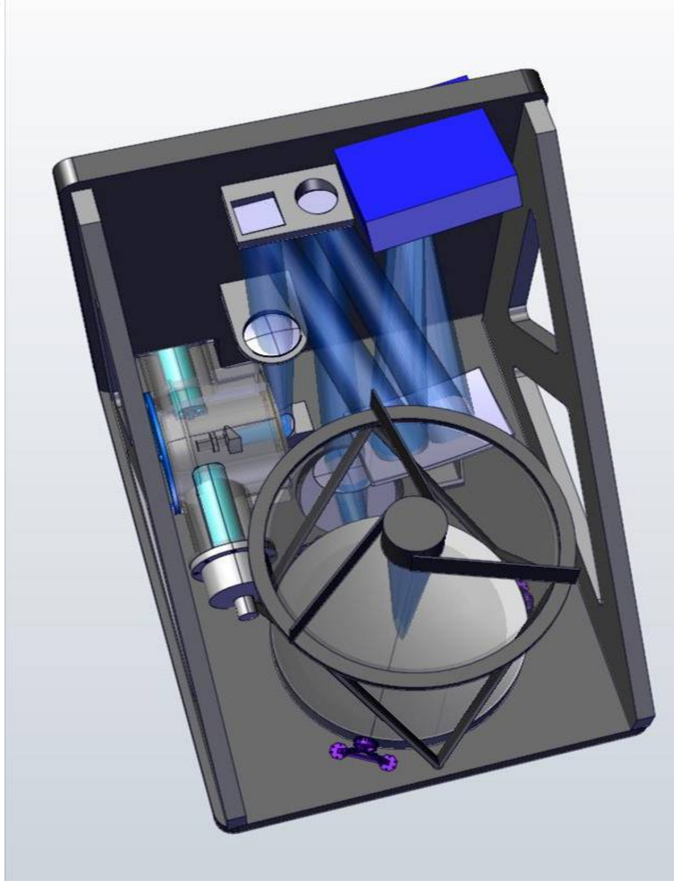
- Entrance pupil dimension Φ_{PE} = 270 mm
- Afocal magnification ratio G around 5 (grating size = 54 mm)
- Focusing focal length f_{FOC} = 380 mm (F-number 7.6)
- Grating period around 300 lines/mm for visible range

DMD for spectral tailoring with FOV

Volume

- X :669 Y : 480 Z : 568.





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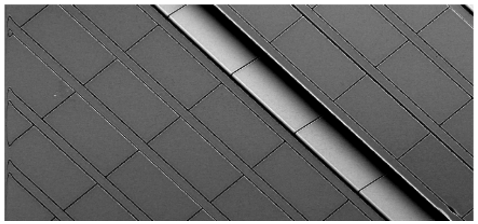
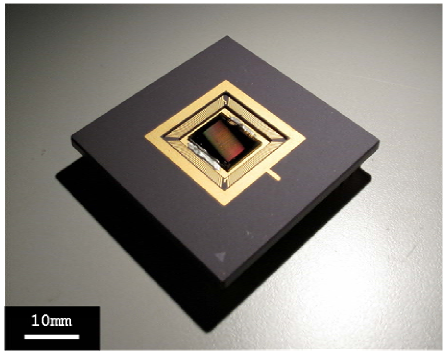
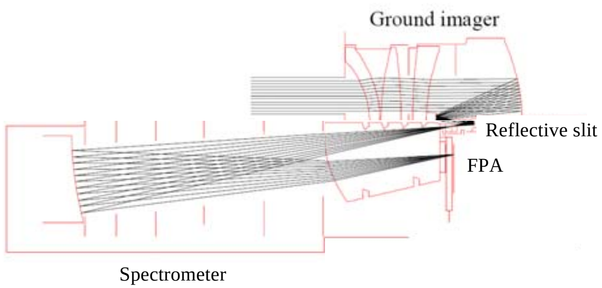
Bench demonstrator will be developed within a CNES study

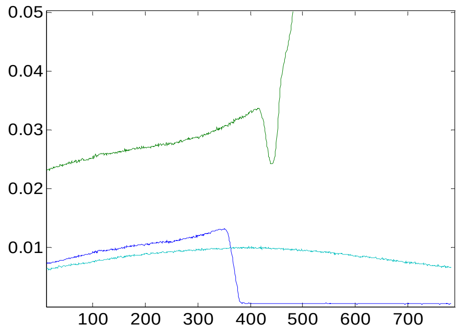
MOEMS for Earth Observation

- Space optical payloads can benefit from MOEMS technology
- Optical MOEMS can bring new services/functionalities in Earth Observation
- Two promising concepts have been proposed and studied:
  - Cloud removal based on Digital Micro-mirror Array
  - Tunable spectrometer with field-of-view based on TI's DMD









frederic.zamkotsian@oamp.fr