Applications of SLMs for advanced optical instrumentation in space

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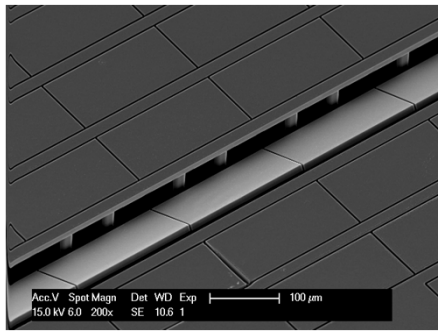
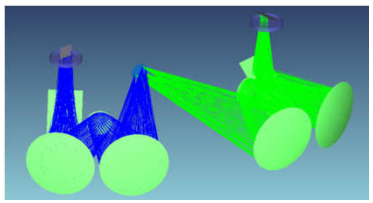
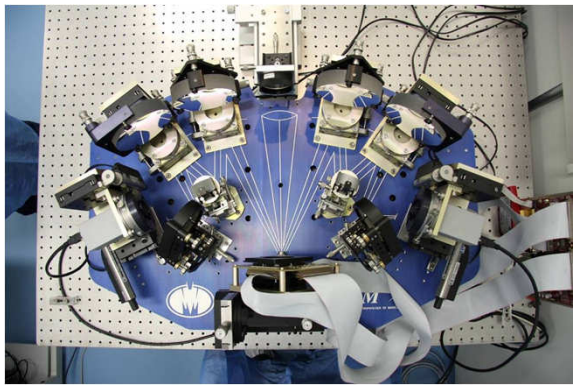
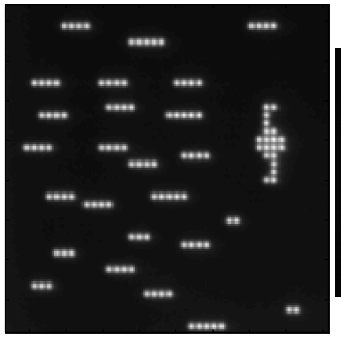
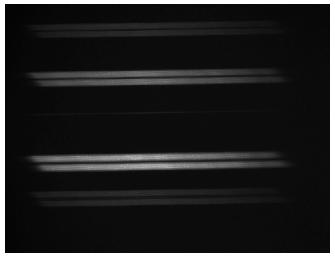


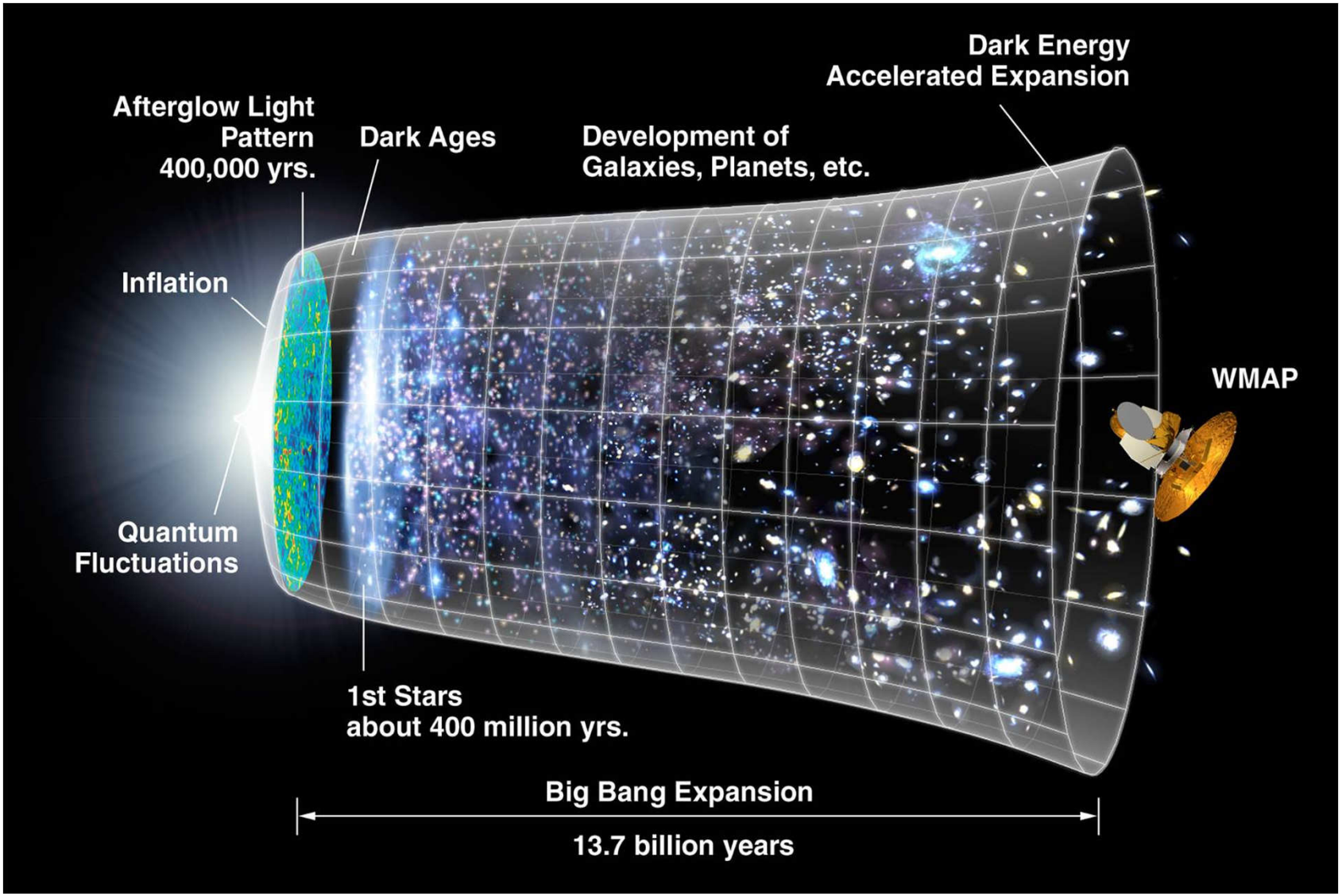






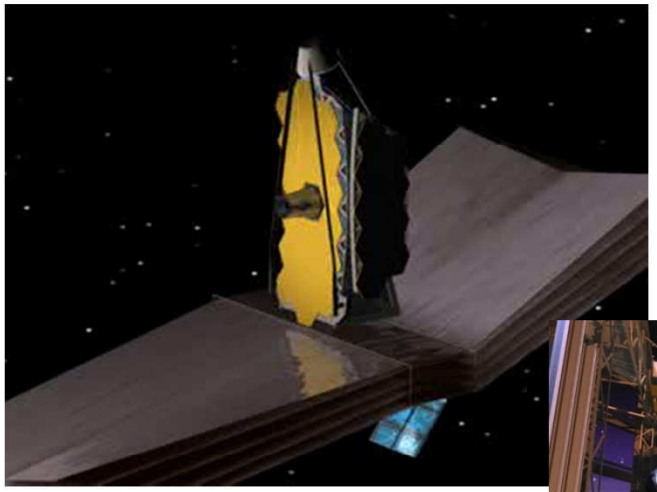


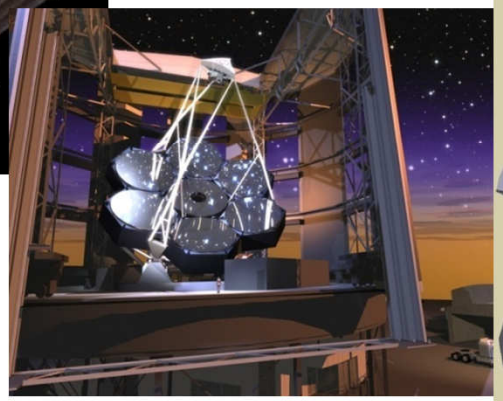
The Universe

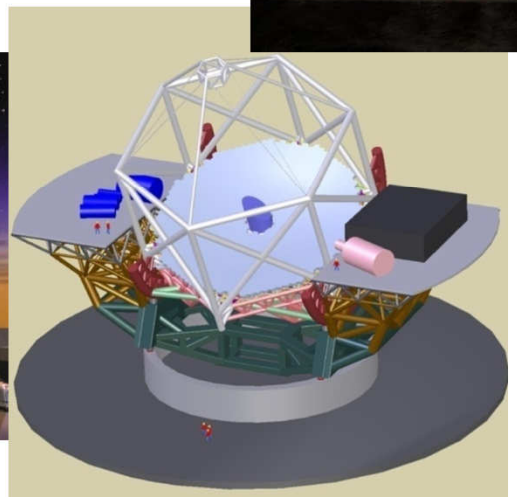


Future needs

- MOEMS devices designed/operating at cryo temperature + vacuum
  - Space instruments
  - Ground-based IR instruments





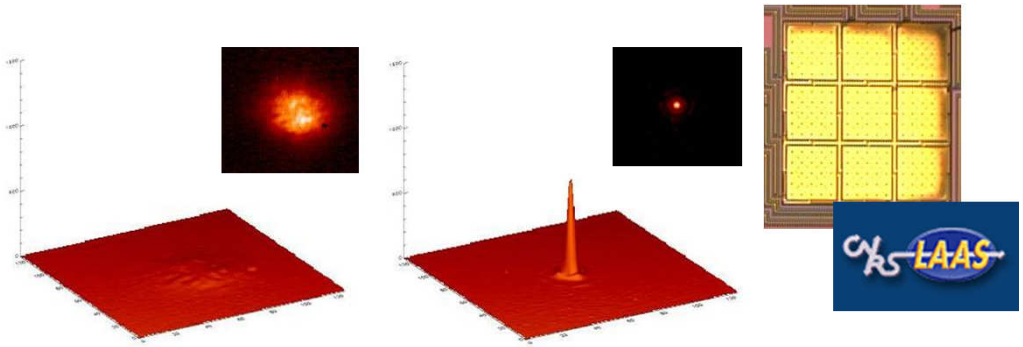


Instrumental needs

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

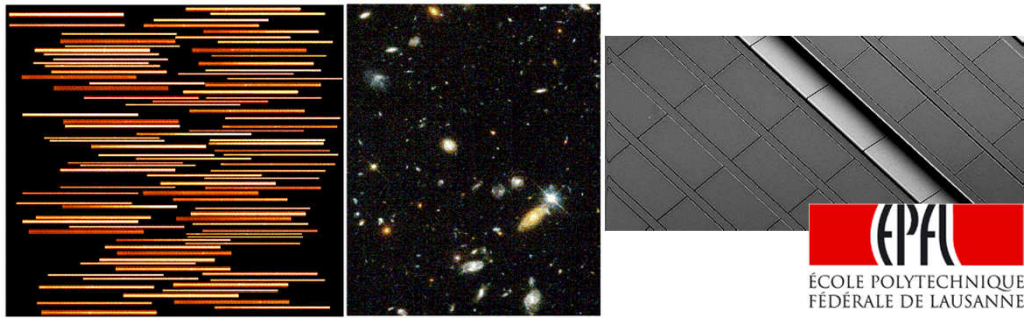
Phase

- Wavefront control
  - Deformable mirrors



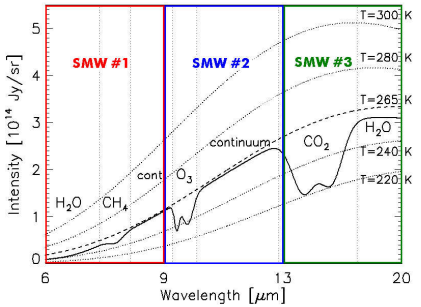
Intensity

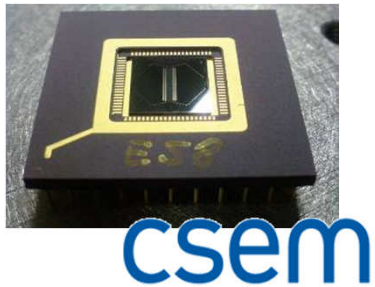
- Object selection
  - Programmable slits



Wavelength

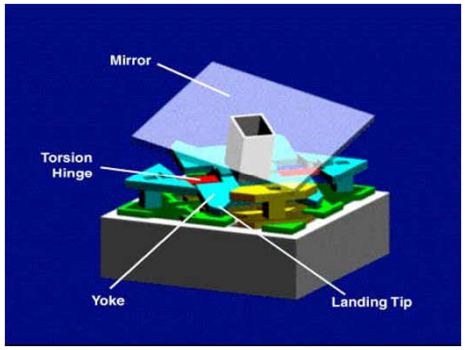
- Spectral domain application
  - Programmable gratings

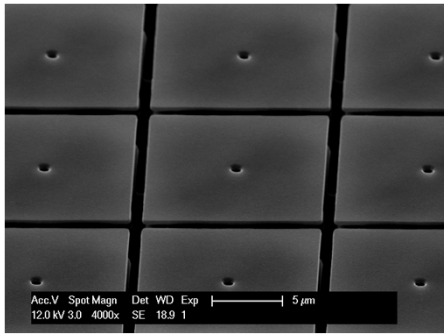


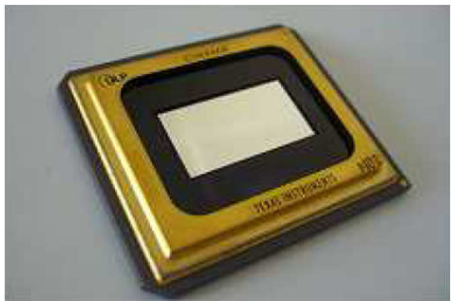


Texas Instruments DMD

- Most popular MOEMS devices available
- Micro-mirrors
  - 2048x1080 individually tiltable
  - 13.68µm pixel pitch,
  - Tilt angle of 12°
- Numerous applications
  - Prime use displaying images
  - No customization possible
- Space qualification tests (ESA contract)
  - -40°C in 10^{-5} mbar vacuum
  - Micro-mirrors in position for > 1500s
  - DMD fully operational
  - 1038 hours life test, radiations, vibrations
  - **No show-stopper for space application**



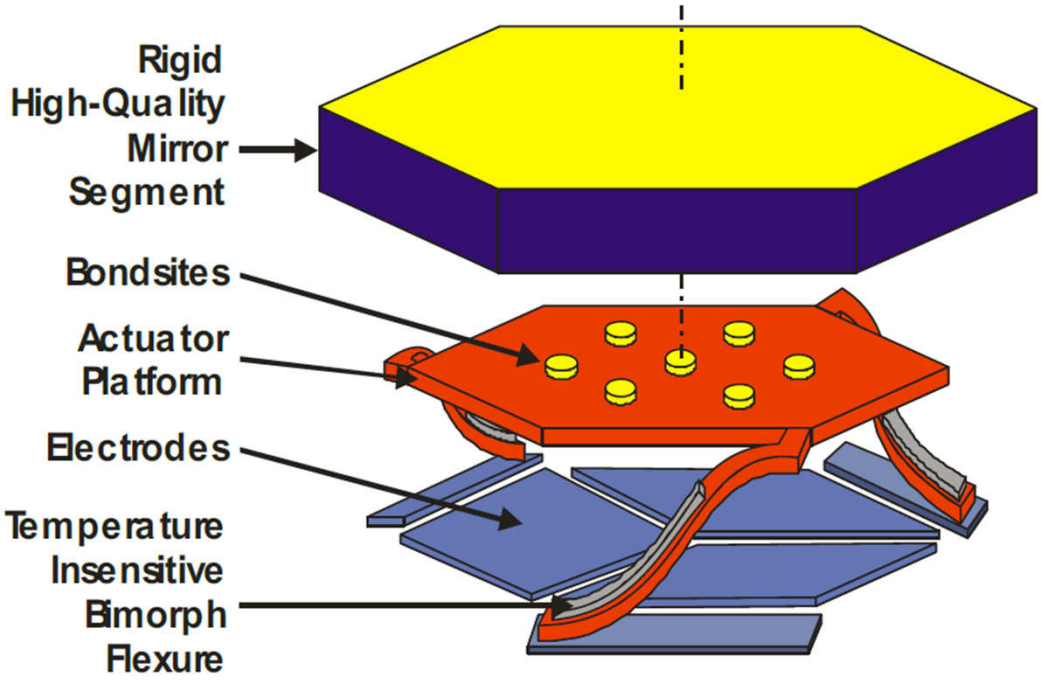


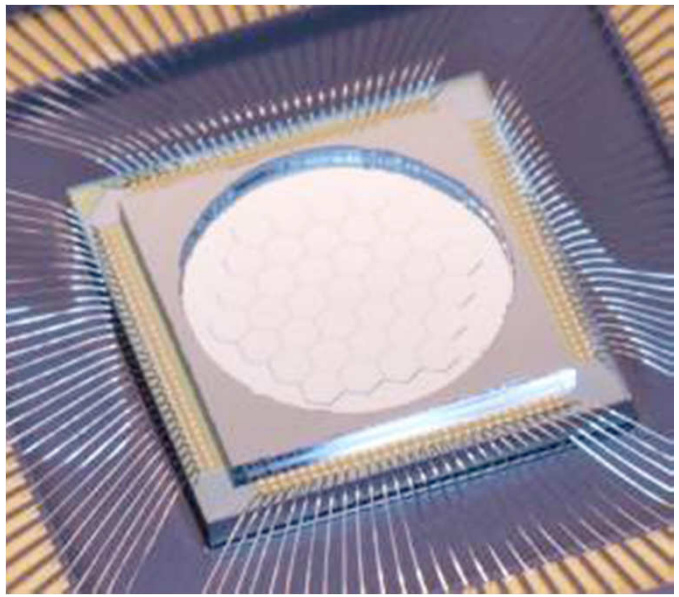


Zamkotsian et al., SPIE 6884, 2008

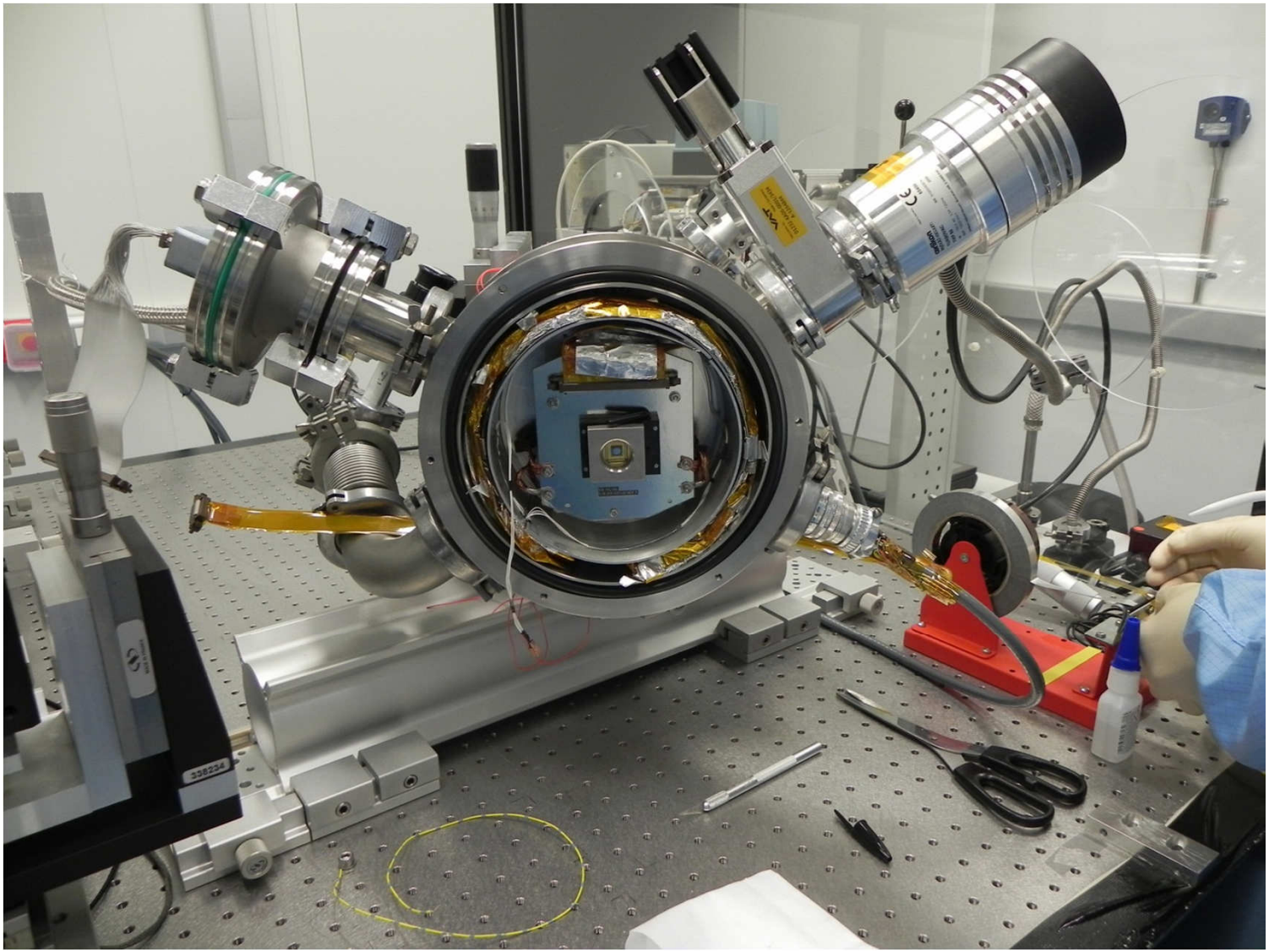
Micro Déformable Mirror 2

- PTT 111 DM
  - 111 actuators, 37 piston-tip-tilt segments
  - Segment pitch 606µm (segment size 700µm)
  - Stroke 5 to 7 µm; Tilt angle ±4 or ±5.6 mrad
  - Optical coating: protected silver, gold, protected alu, dielectric

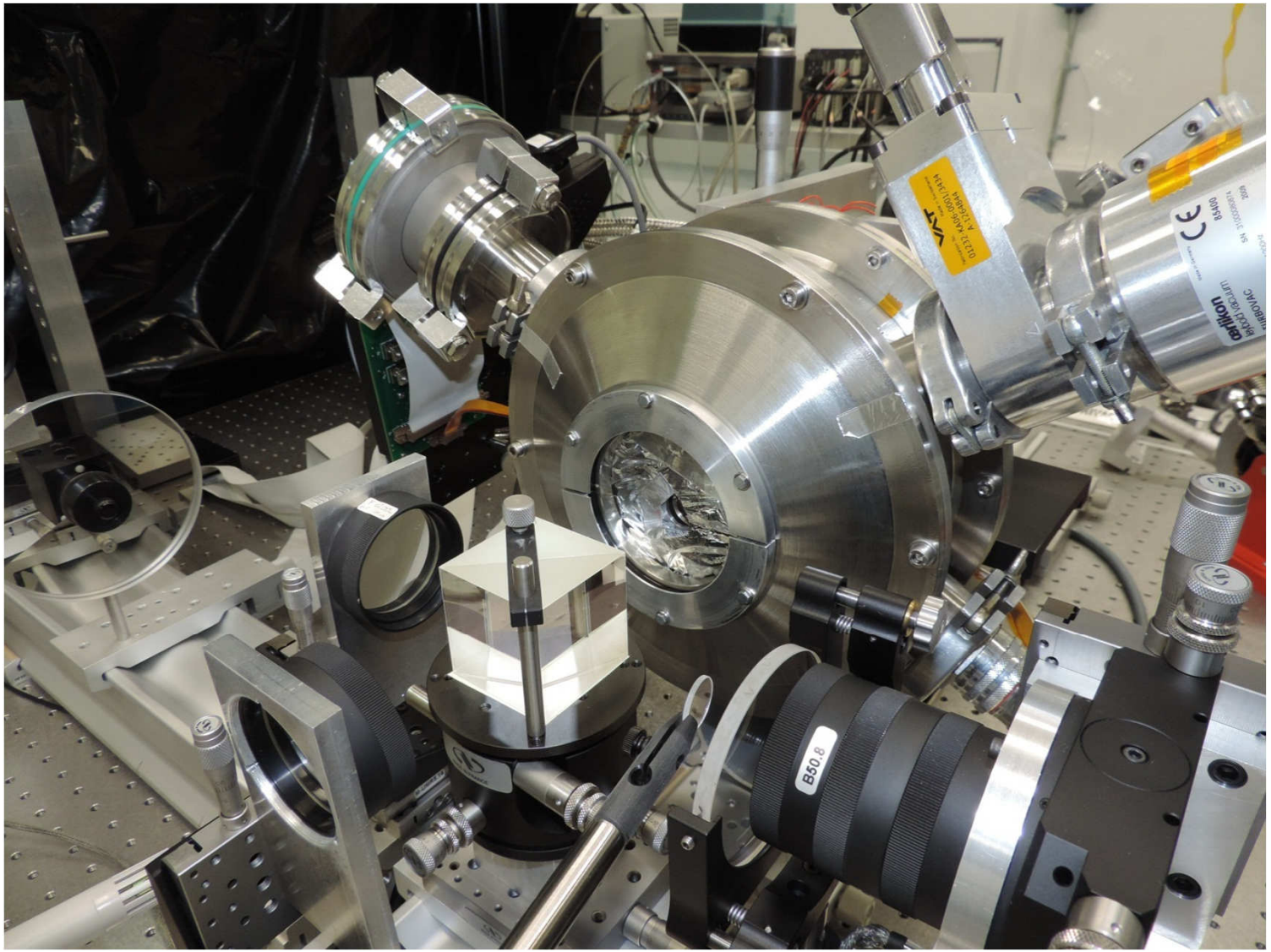




PTT111 integration

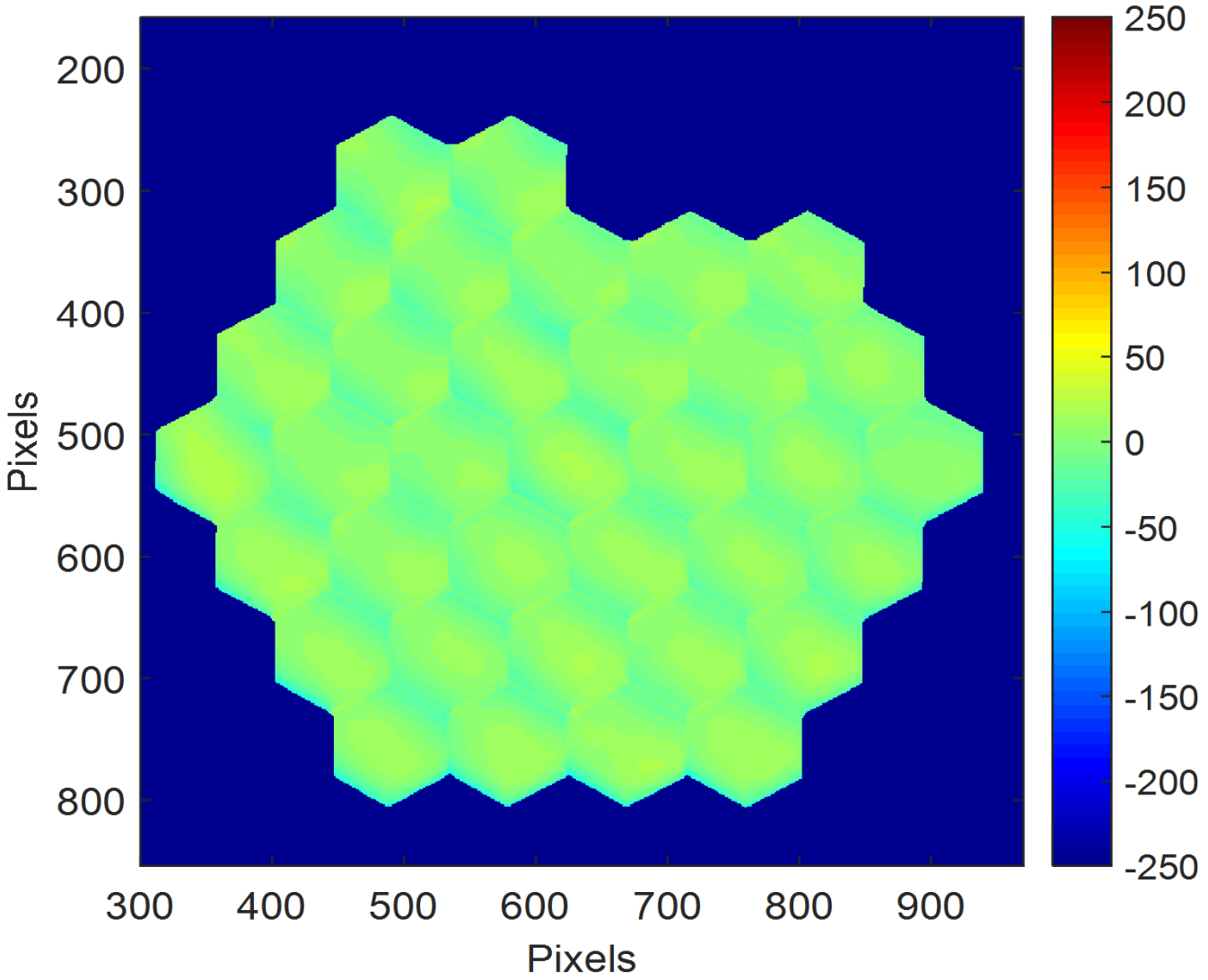


PTT111 integration



Improved Best Flat 293K

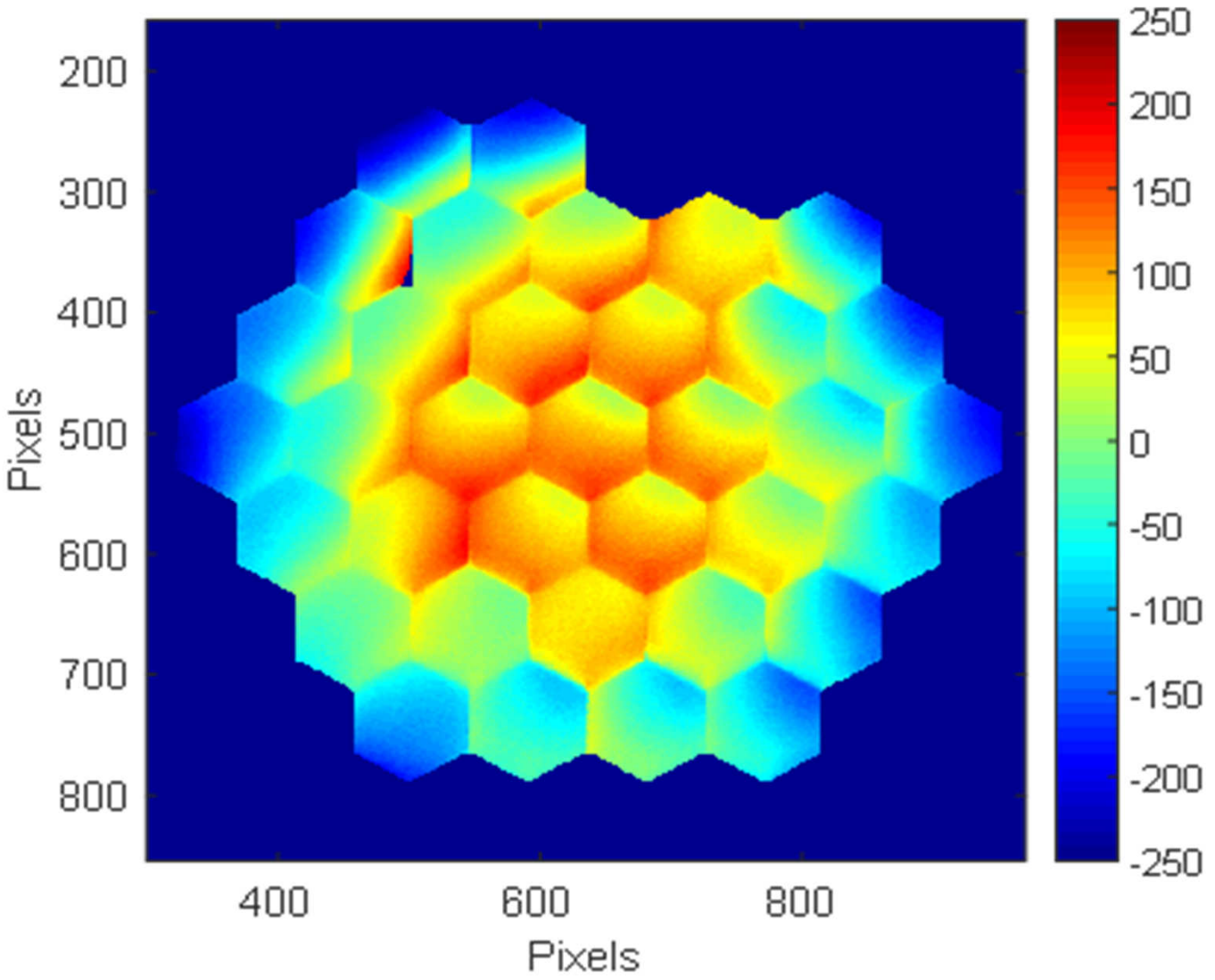
- **Best flat**
  10nm RMS
  79nm PtV



Zamkotsian et al.,
Micromachines , 8, 233; 2017
doi:10.3390/mi8080233

PTT111 down to 160K

- **Best flat**
  86nm RMS
  501nm PtV



Zamkotsian et al.,
Micromachines , 8, 233; 2017
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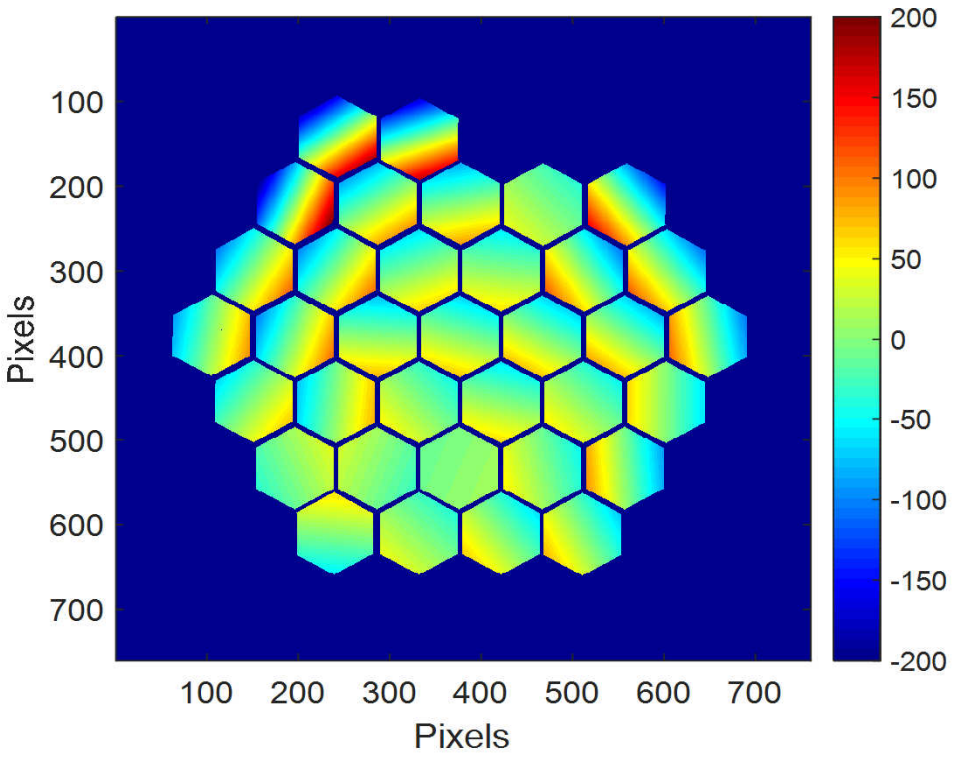
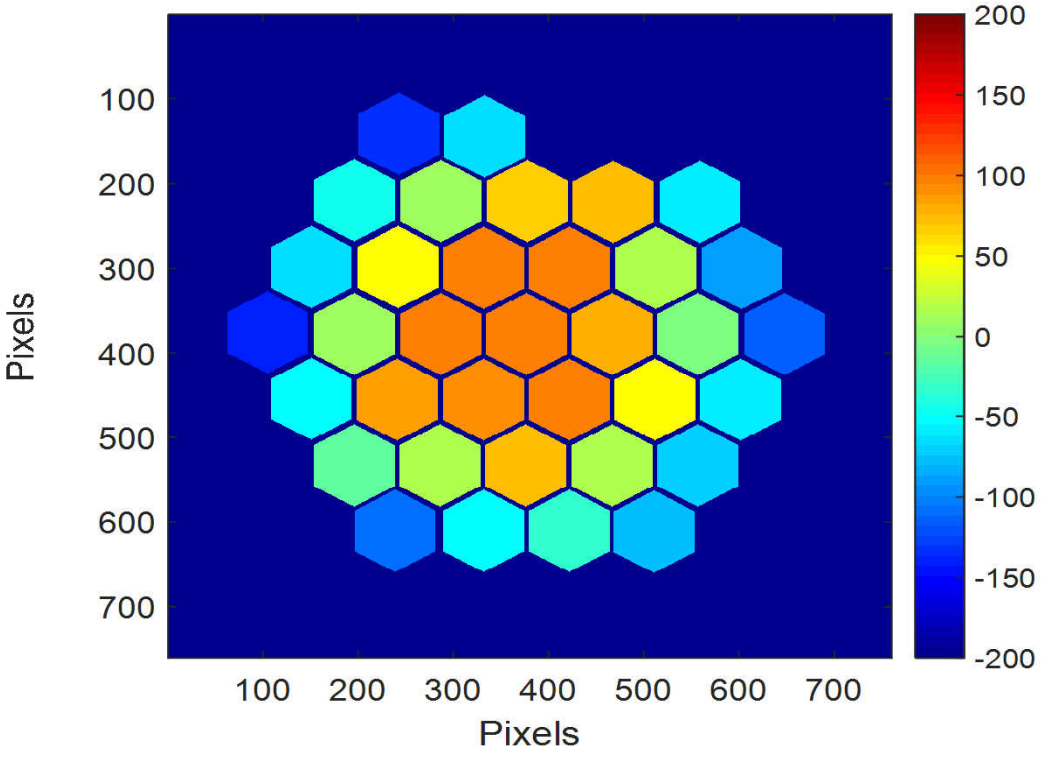
PTT111 down to 160K



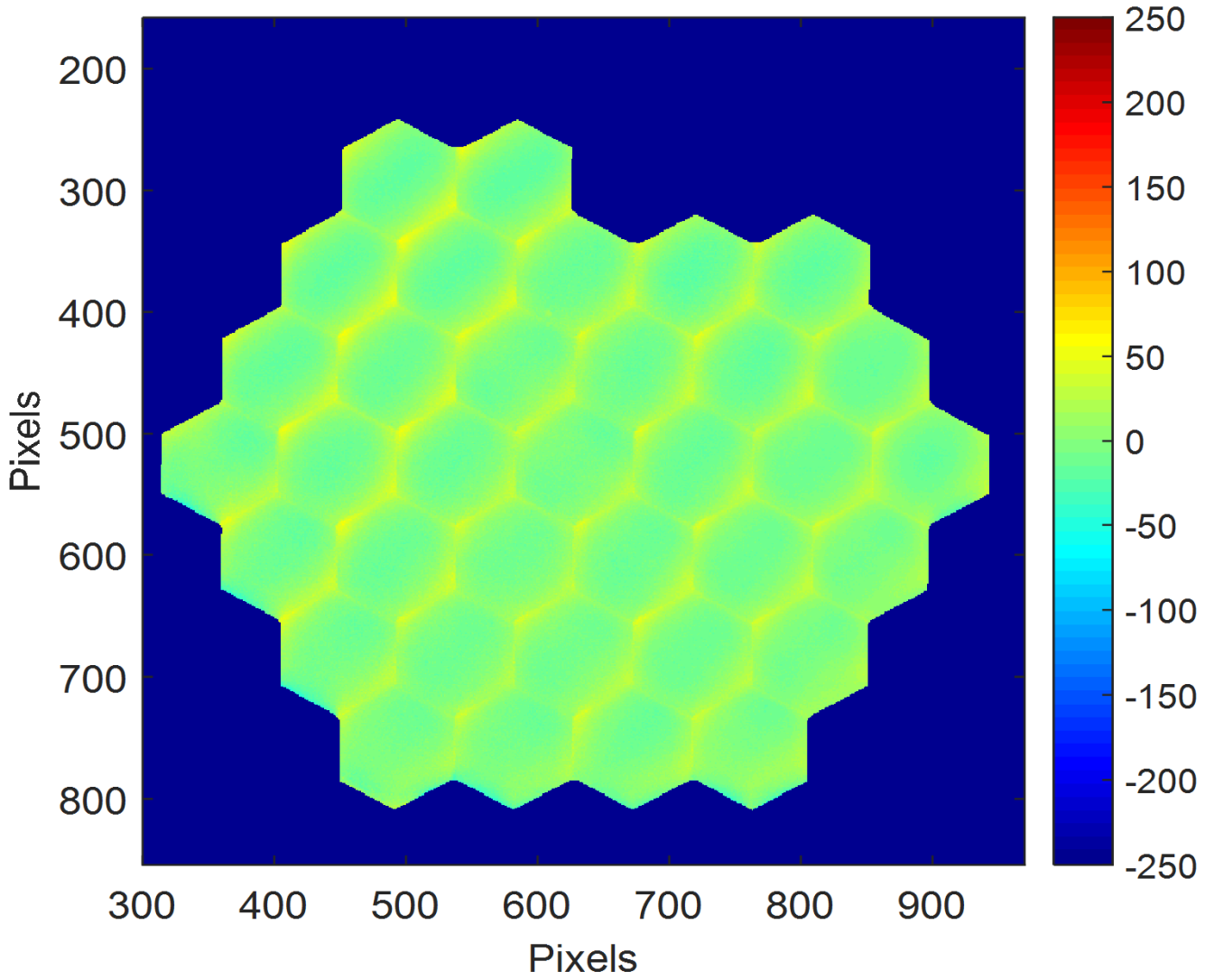
Tilt



Piston

Cryo Best Flat 160K

- **Best flat**
  12nm RMS
  113nm PtV

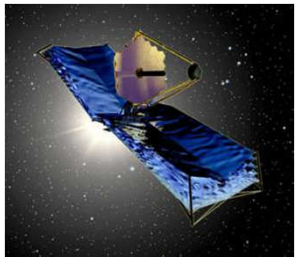


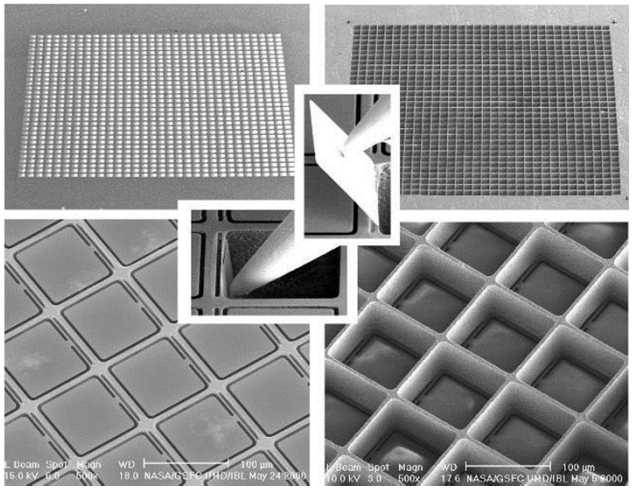
Zamkotsian et al.,
Micromachines , 8, 233; 2017
doi:10.3390/mi8080233

MOEMS developments for cryo

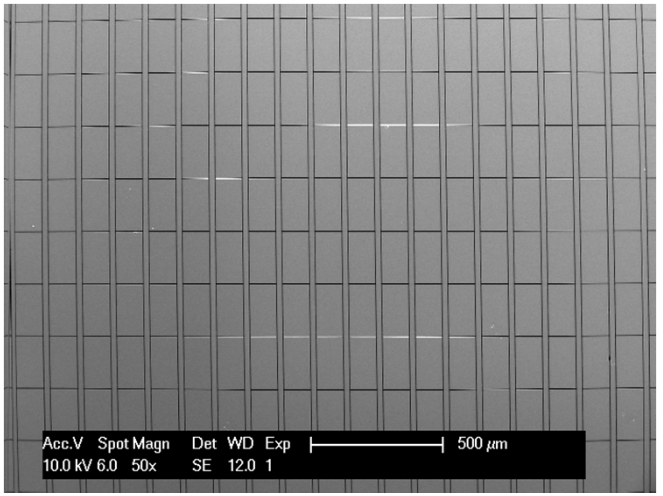
- NASA-GSFC Micro-shutters (USA)

Selected for JWST NIRSpec





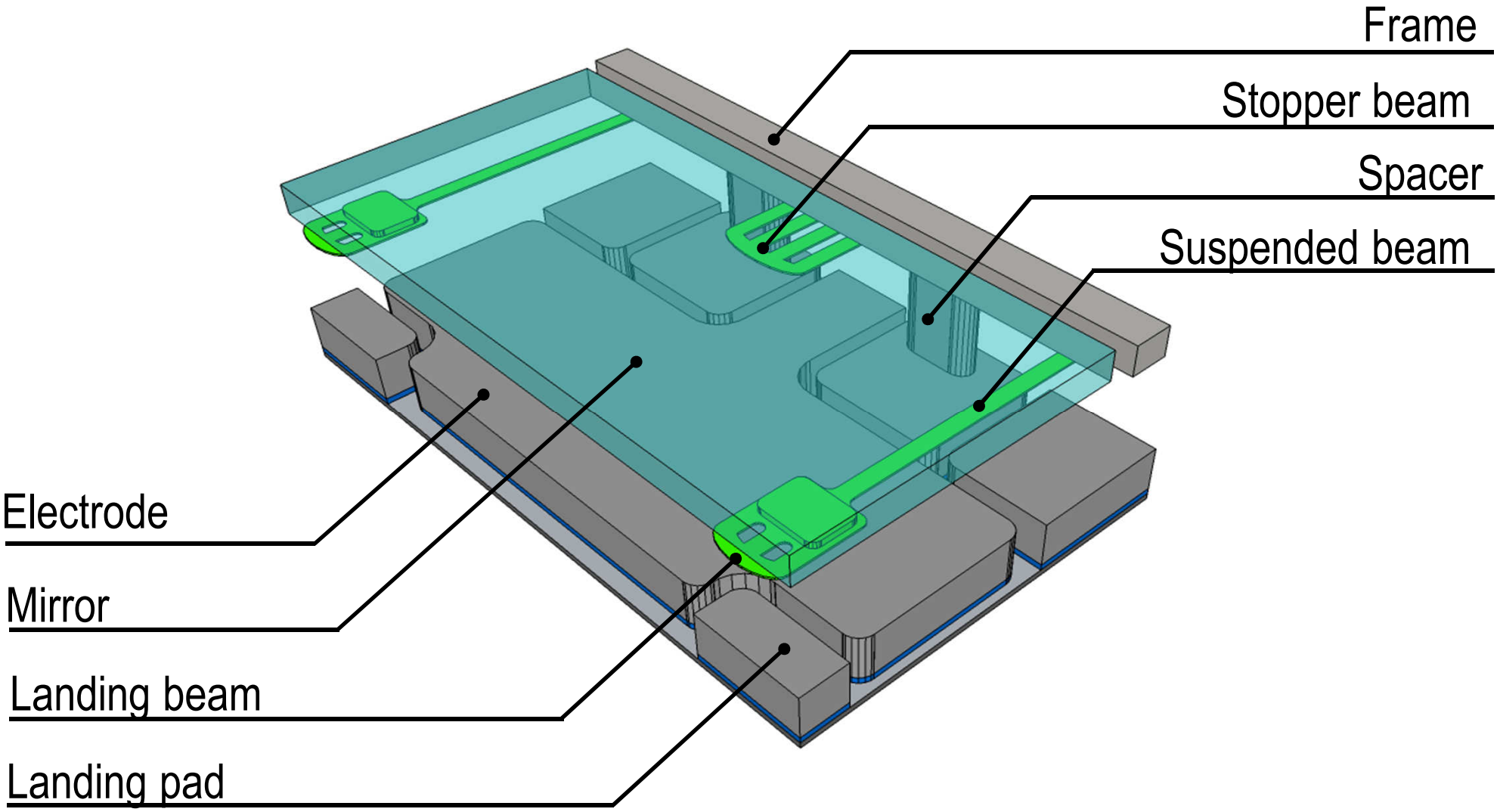
- LAM-IMT Micro-mirrors (Europe)



MIRA: the requirements

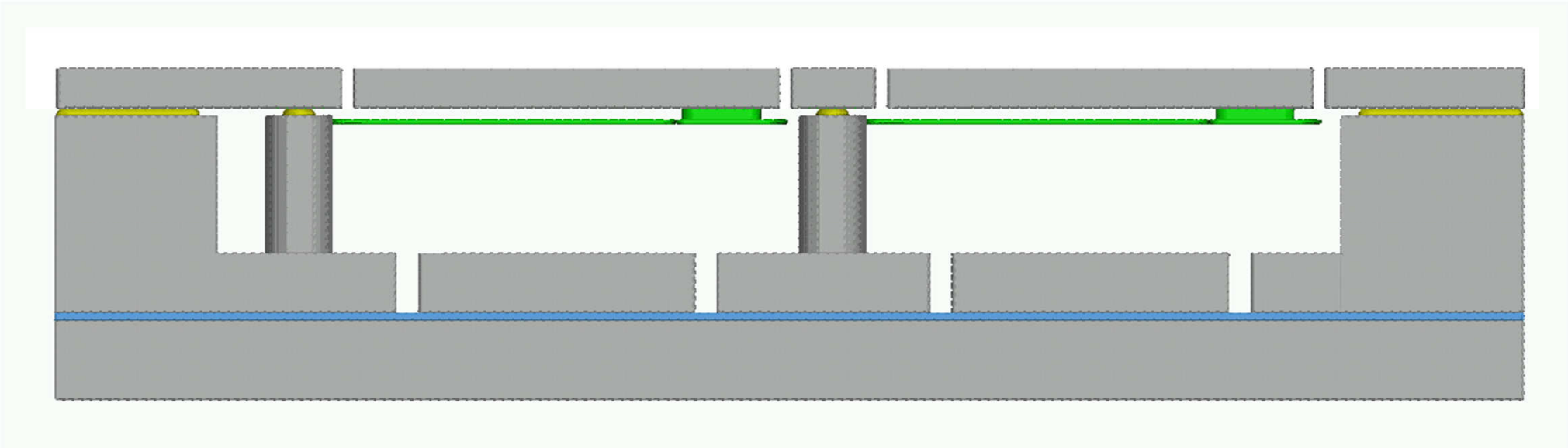
- LAM – EPFL micromirror array development: MIRA project
- Requirements
  - Mirror size of 100 x 200 μm^2
  - Individual addressing of the micromirrors
  - High contrast of at least 1000:1
  - 20° mechanical tilt angle
  - Uniform tilt angle over the whole array
  - Fill factor of more than 90% (if possible >95% in one direction
  - Wavelength range from visible to infrared
  - Optically flat mirrors in operation < $\lambda/20$ with λ = 1 µm
  - Cryogenic operating temperature (<100K, 30K goal)

MIRA: concept



MIRA: the realization

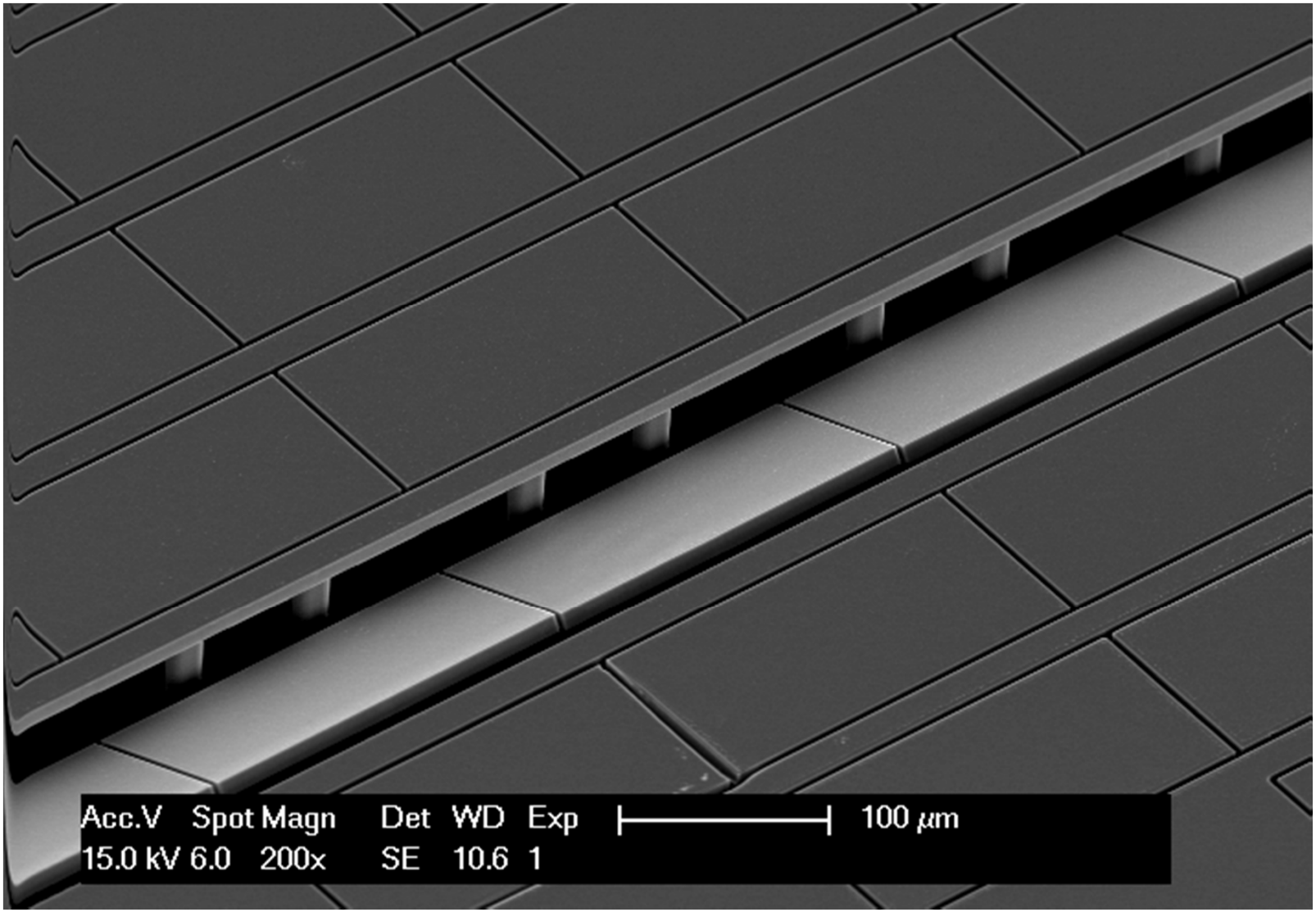
- Three SOI wafer process
- Two wafer-level bonding steps



Waldis et al., SPIE 6887, 2008

Canonica et al., JMM, 2013

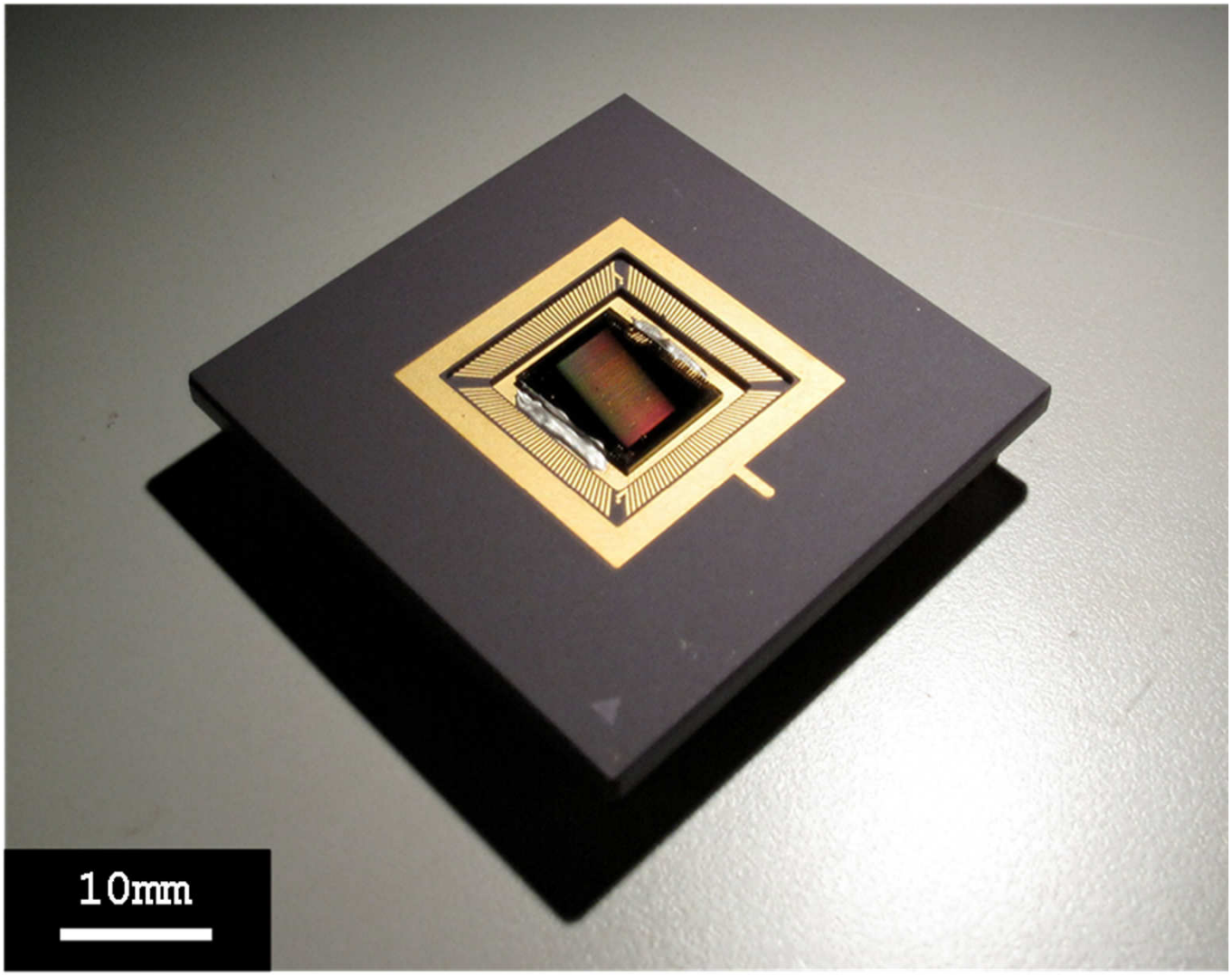
MIRA: the realization



MIRA: the realization

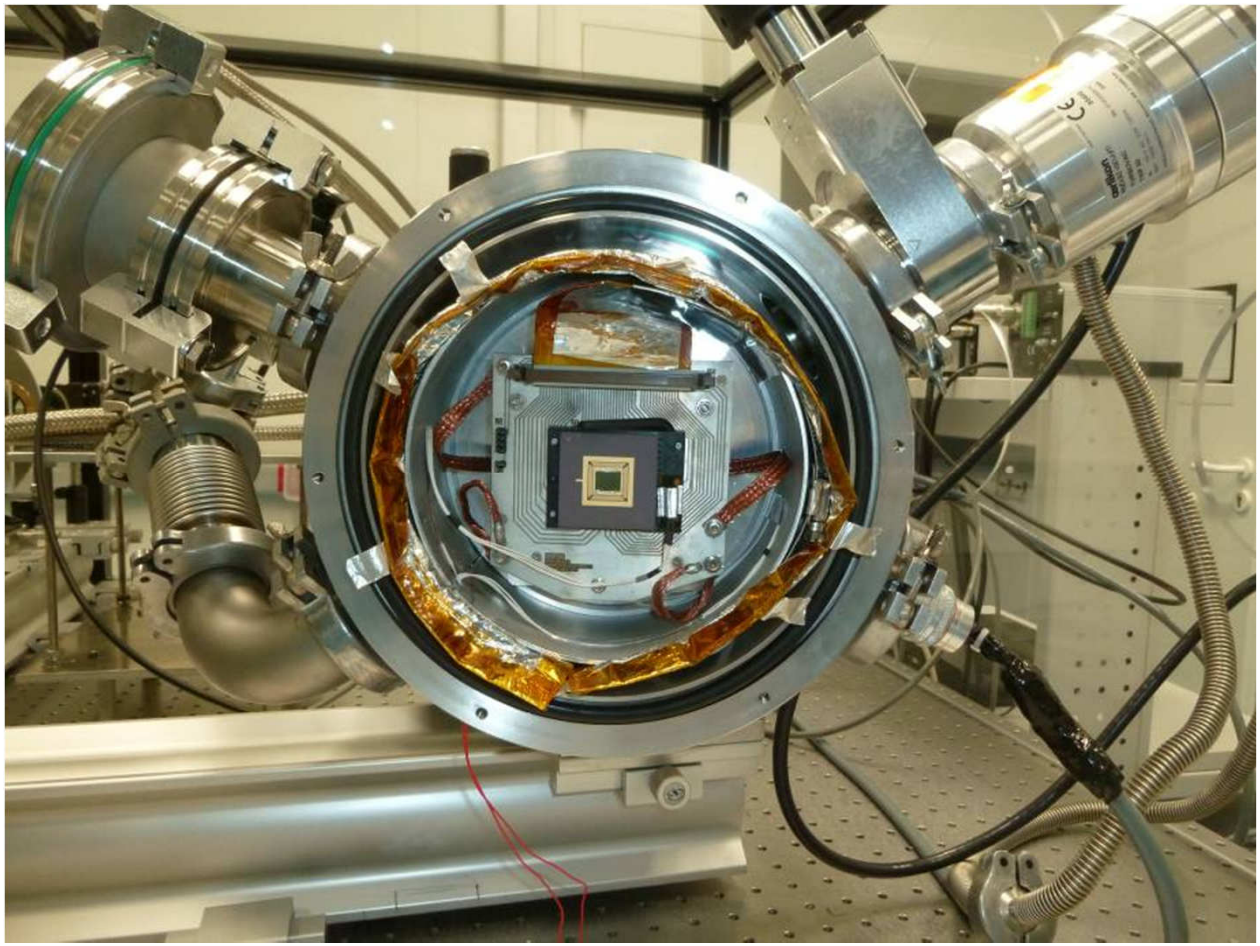
2048 mirrors

(64 x 32)



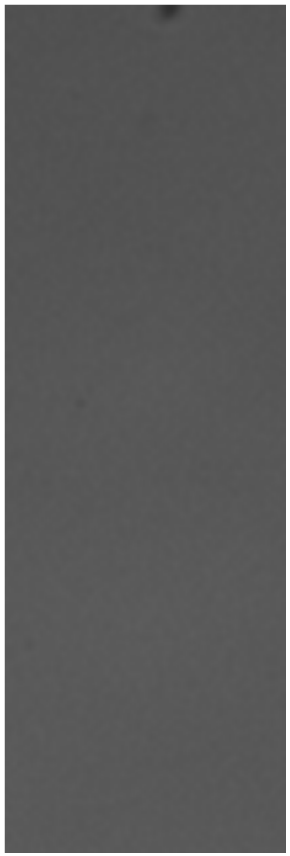
MIRA: cryogenic test

- Specific cryo chamber developped, compatible with our interferometric bench
- Vacuum 10^{-6} mbar
- Cryogenic temperatures



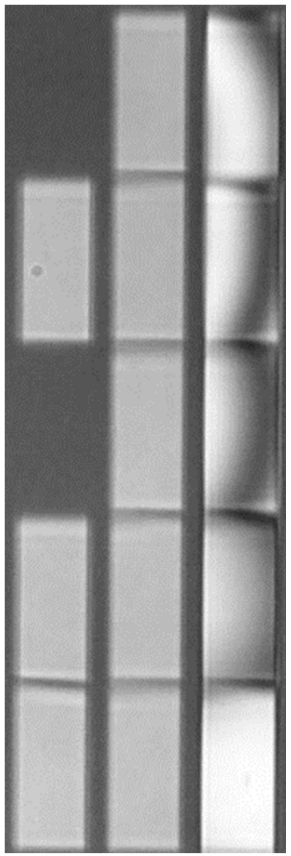
MIRA: cryogenic test

300K
0 V

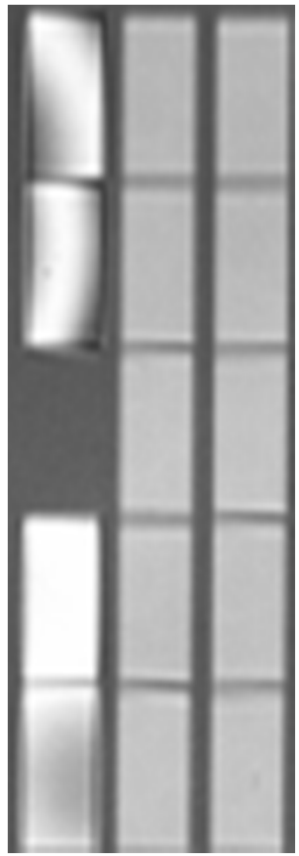


300K
130V

162K
130V



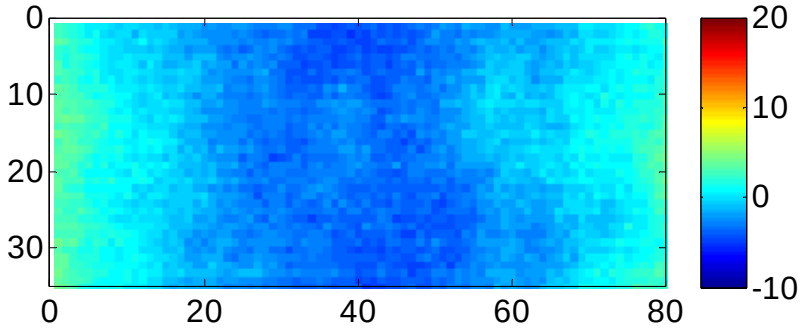
162K
148V



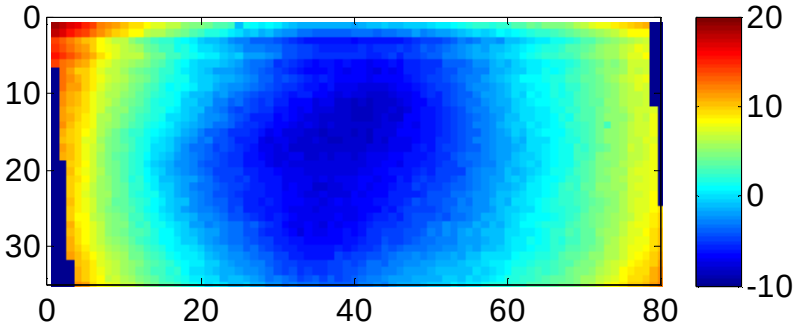
Cryogenic test: mirror surface

Surface quality measurement in the ON position

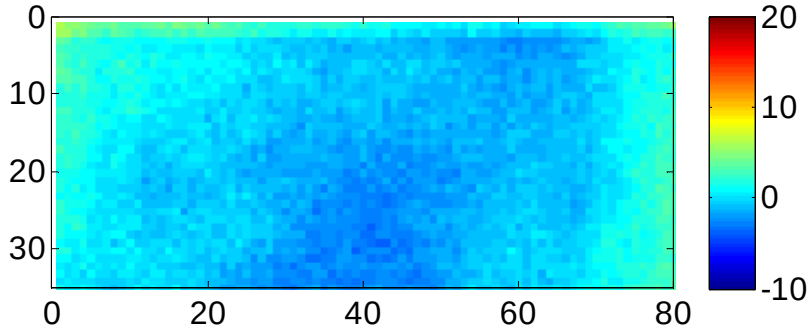
293 K
135 V
9.8 nm PtV



162 K
148 V
27.2 nm PtV

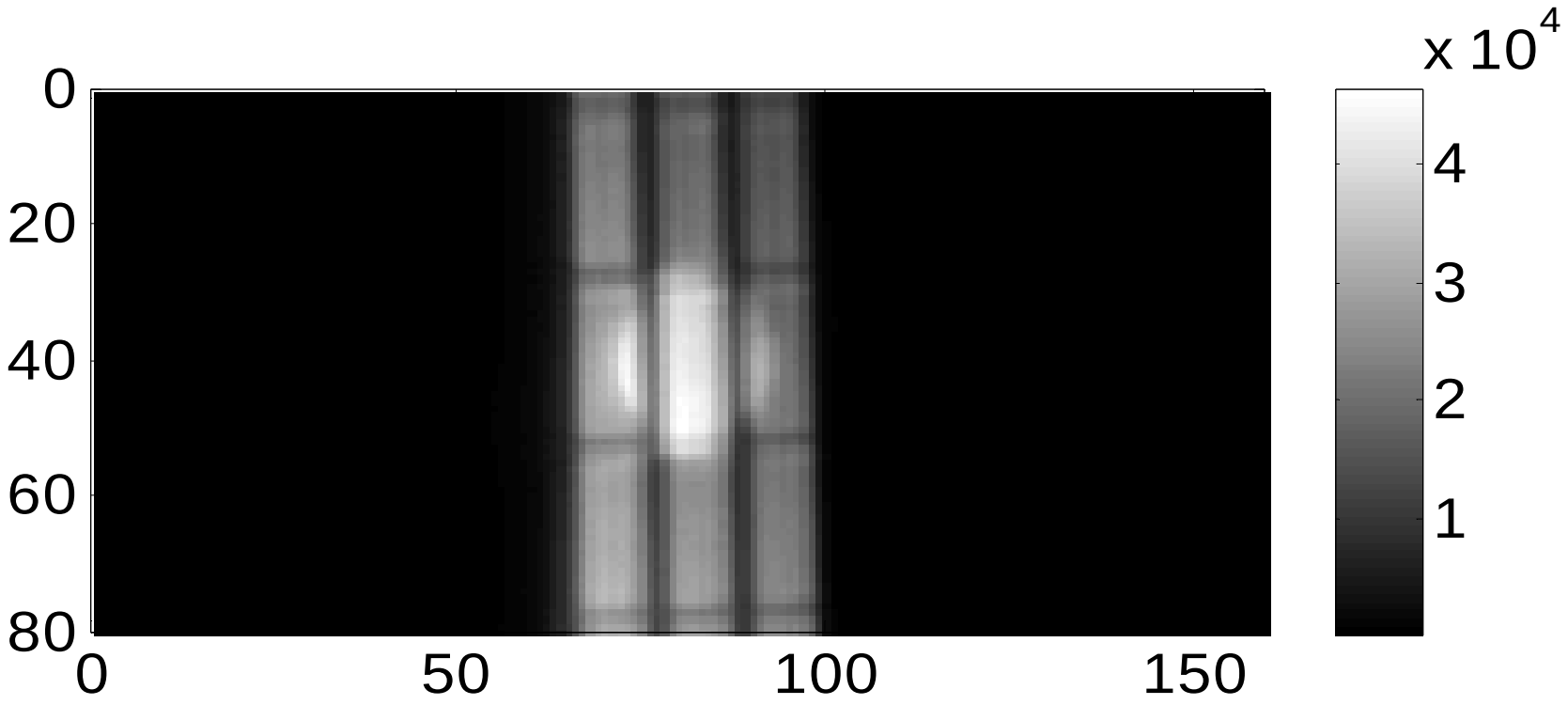


293 K
135 V
9.9 nm PtV



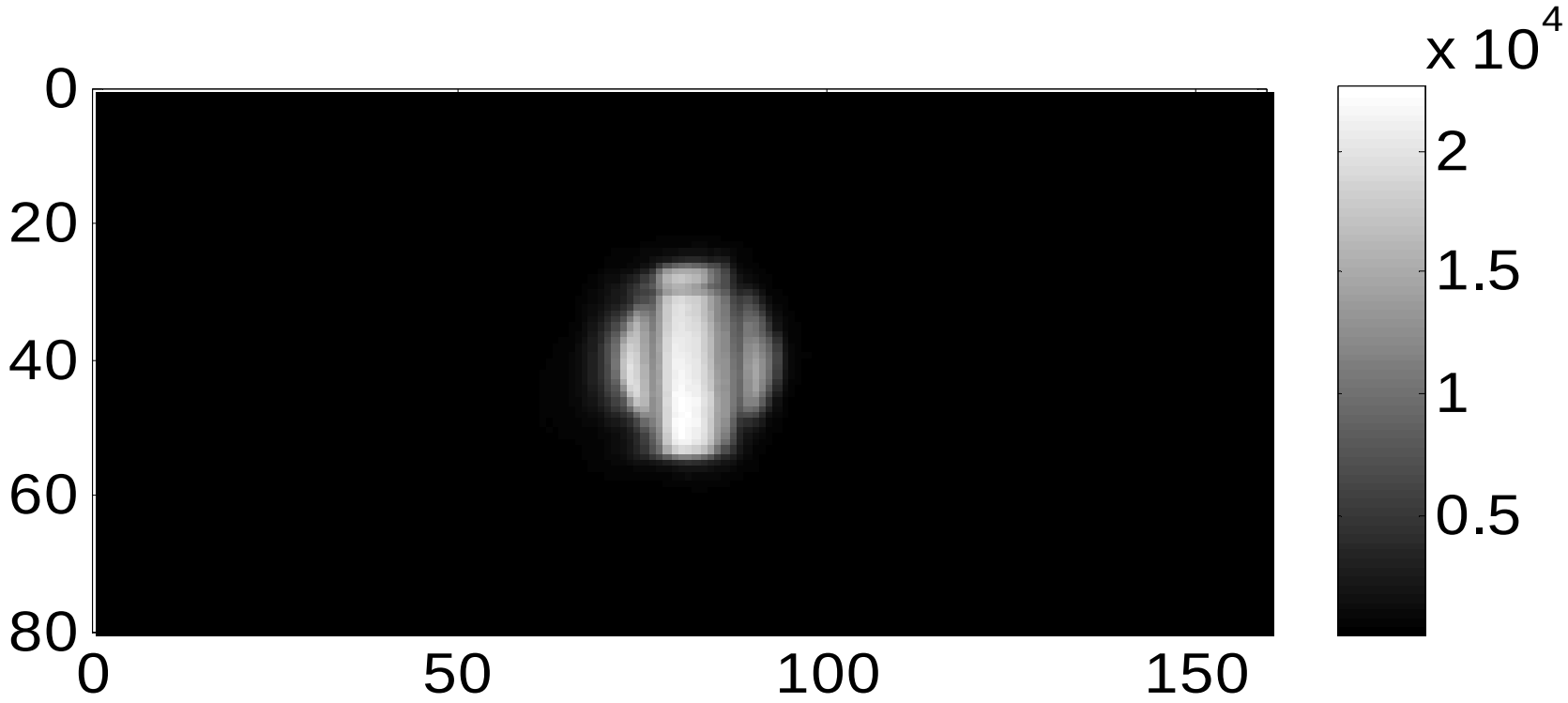
Object tailoring

- Device with lines tilting only
- 200µm object projected on the 100 x 200 µm^2



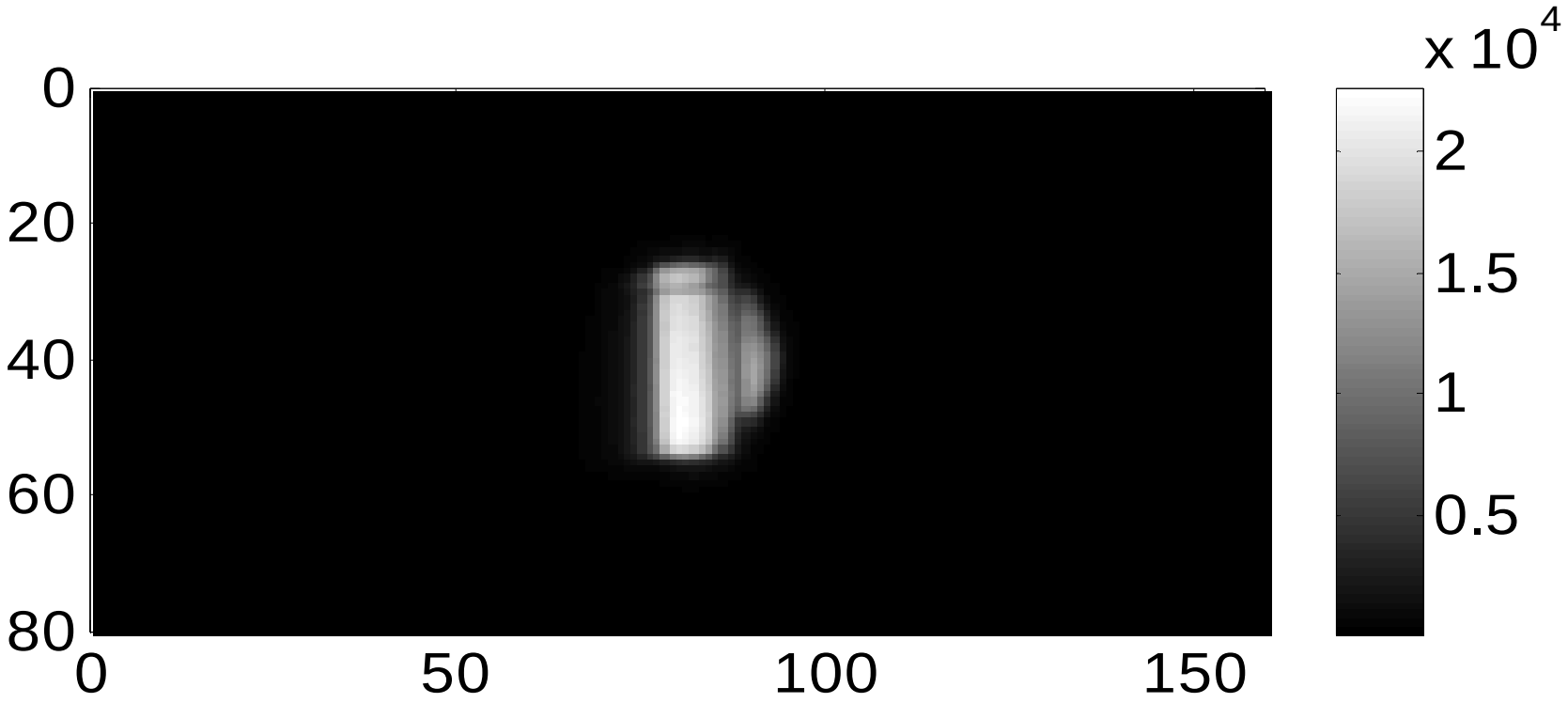
Object tailoring

- PSF slicing



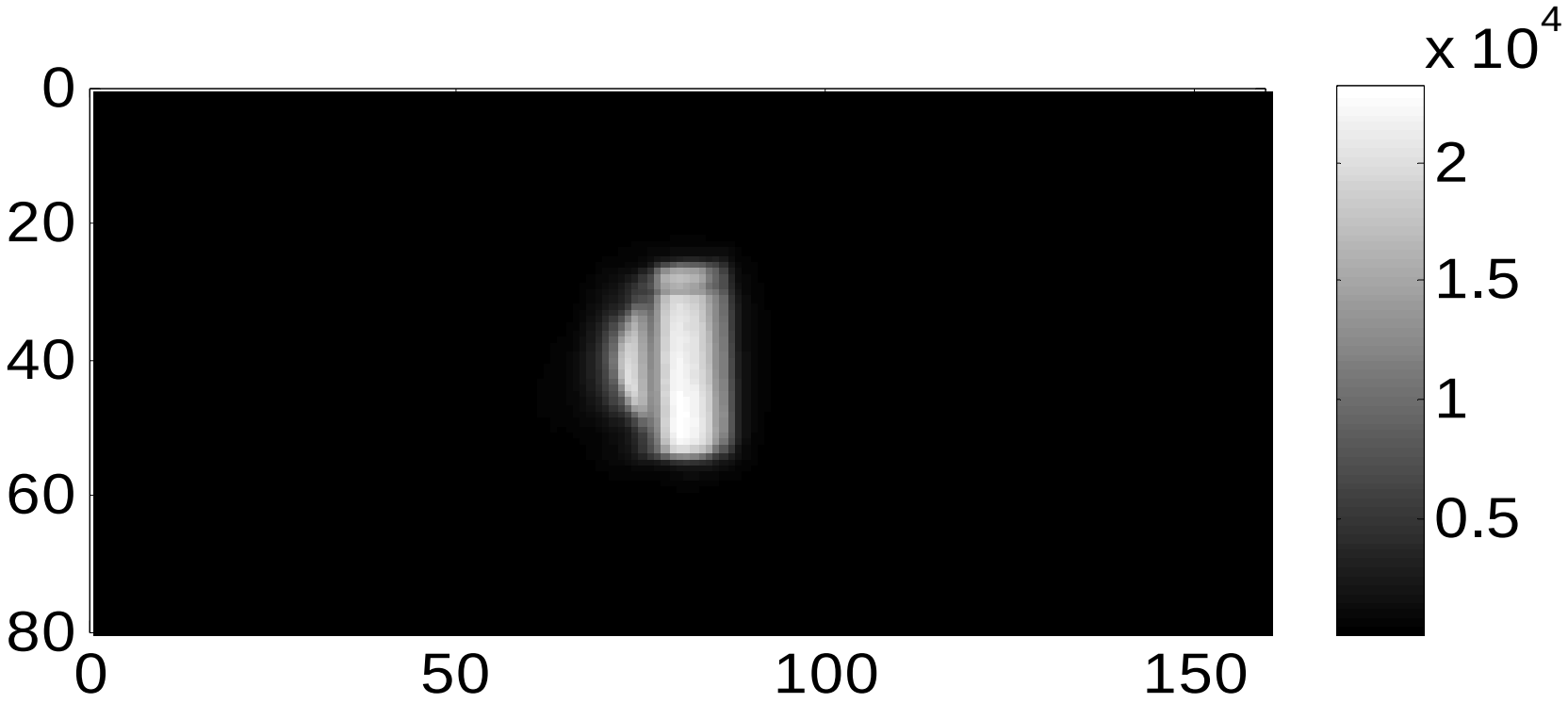
Object tailoring

- PSF slicing



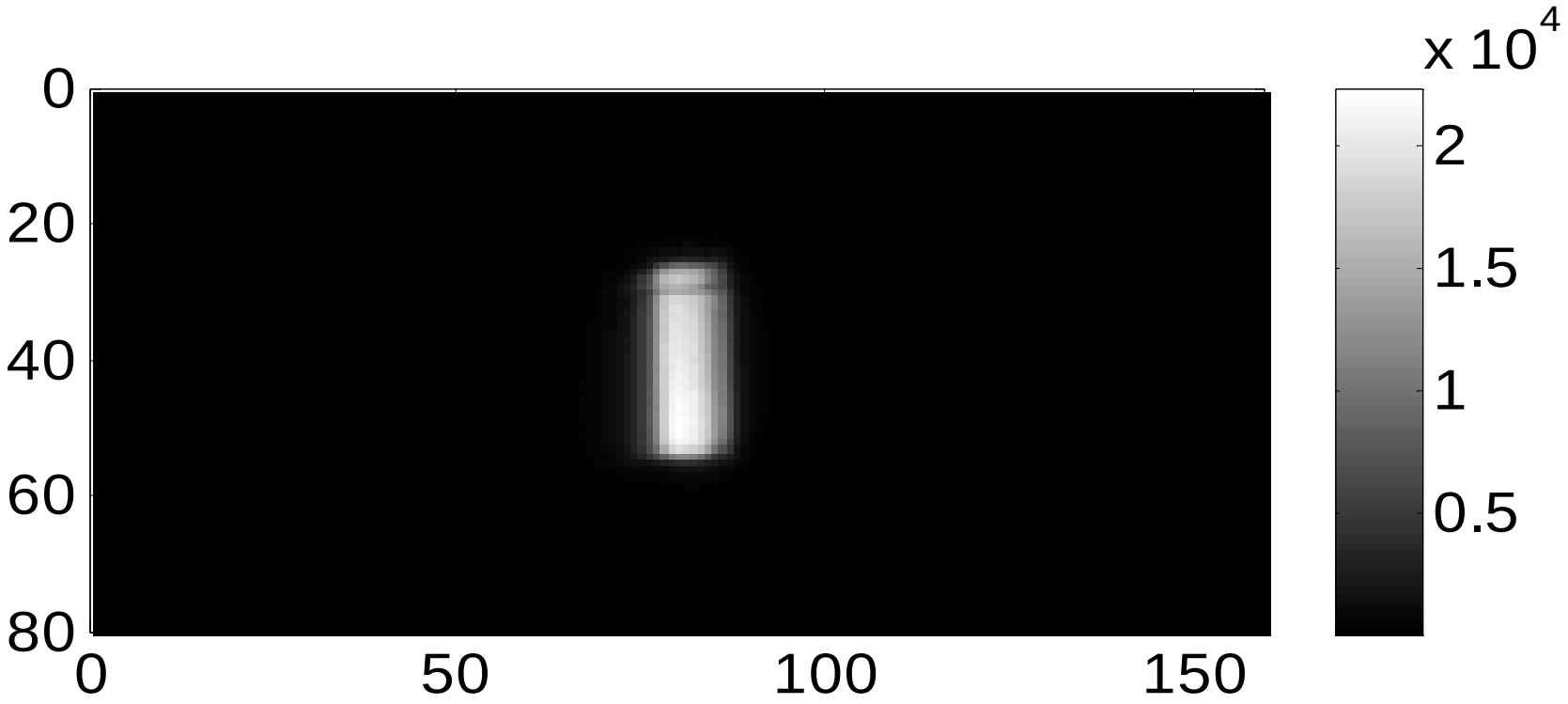
Object tailoring

- PSF slicing



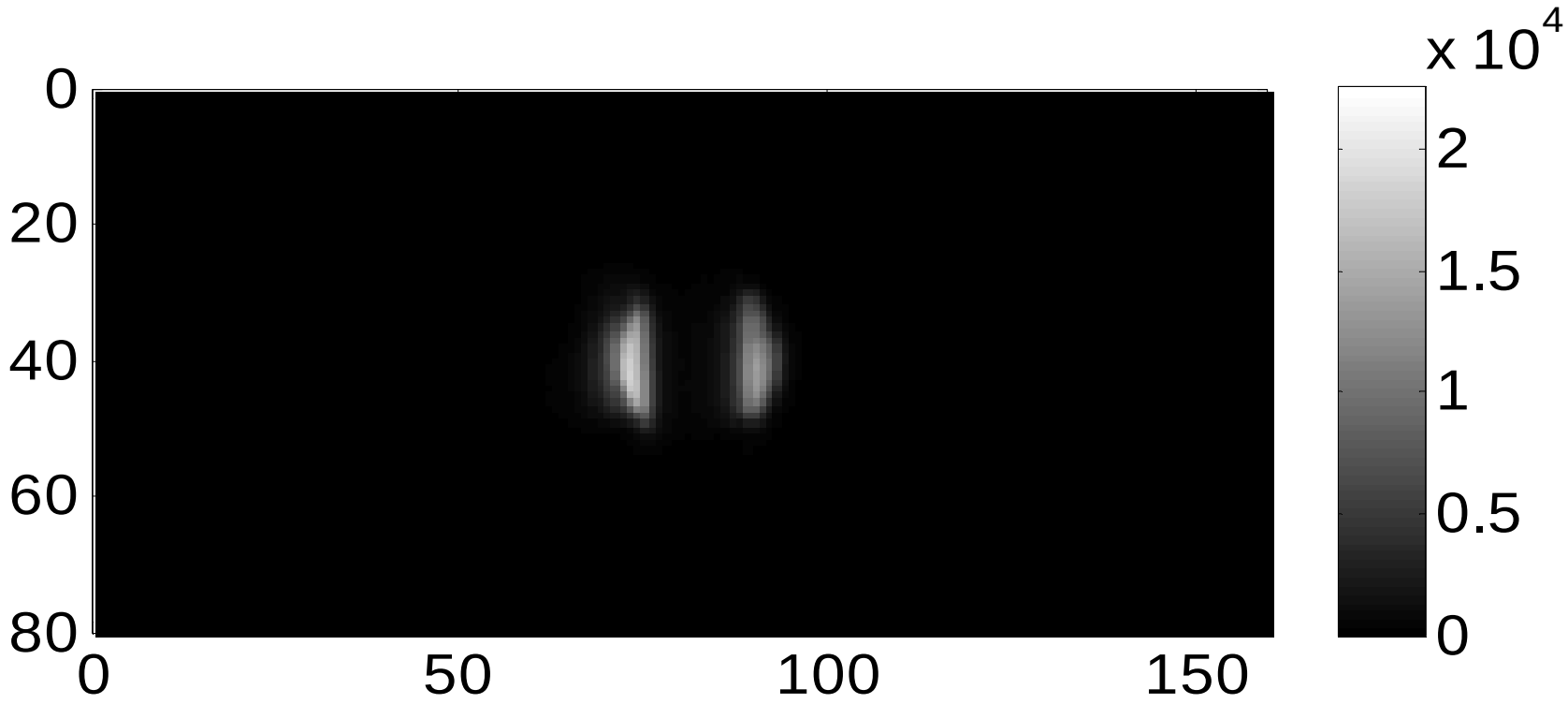
Object tailoring

- PSF slicing



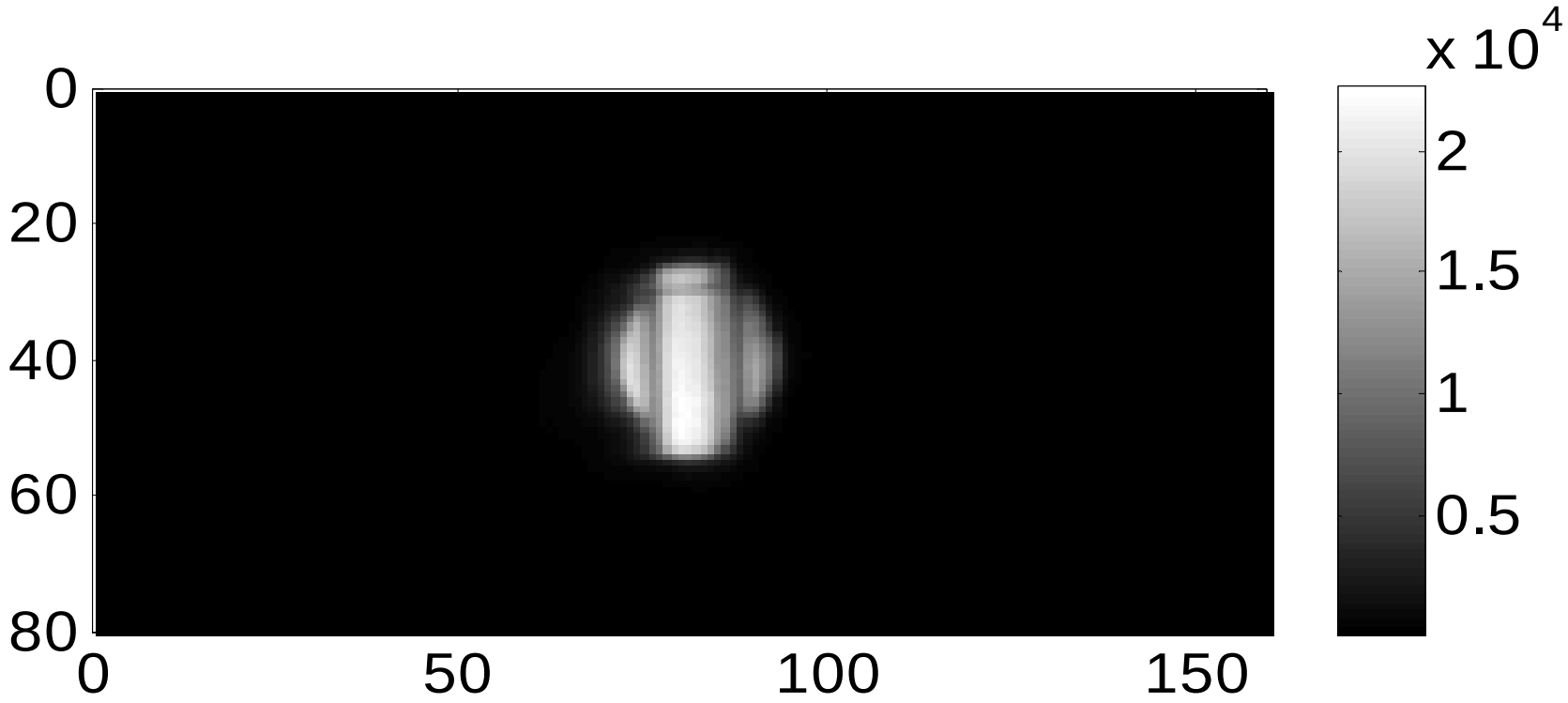
Object tailoring

- PSF slicing

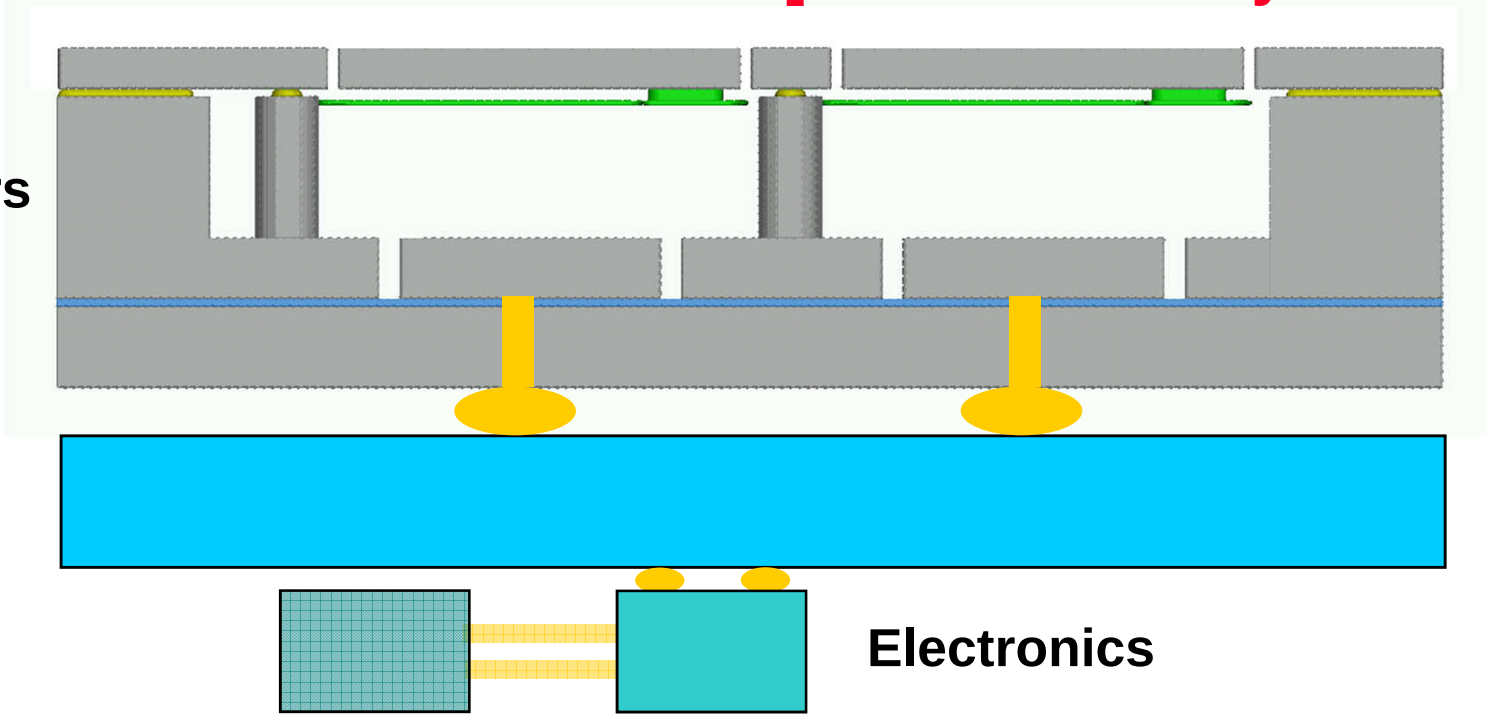


Object tailoring

- Contrast measurement integrated over the micromirror surface
- Contrast value: **1000:1**



MIRA 4 project
[MIRA + hardened electronics] : buttable arrays in FOV



Applications: Universe and Earth Observation, Physics, Biology

Funding

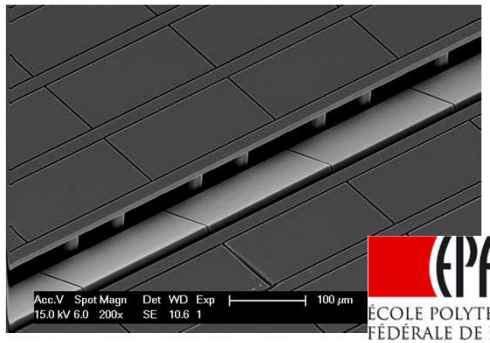
MOEMS characterization platform

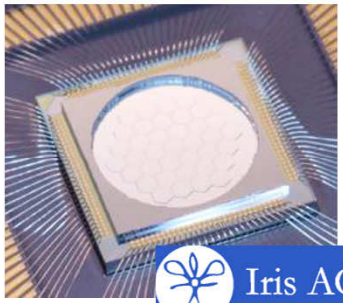
- Operational bench (completed 2002)
  - MOEMS components operational performances measurement (tilting micromirrors, programmable diffraction gratings, …)
  - Modular bench: multi-sources, multi-detectors and adjustable pupil
- Interferometric bench (completed 2004)
  - Surface quality, deformation static and dynamical measurement
  - Small and large FOV with sub-nanometer resolution (z-direction)
- Cryogenic bench (completed 2013)
  - Performances measurement under vacuum and at cryo. temp. (30K - ambient)

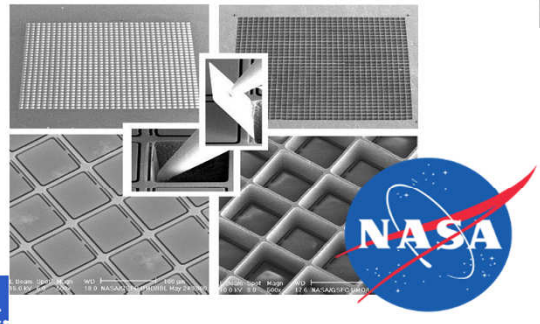
MOEMS characterization platform

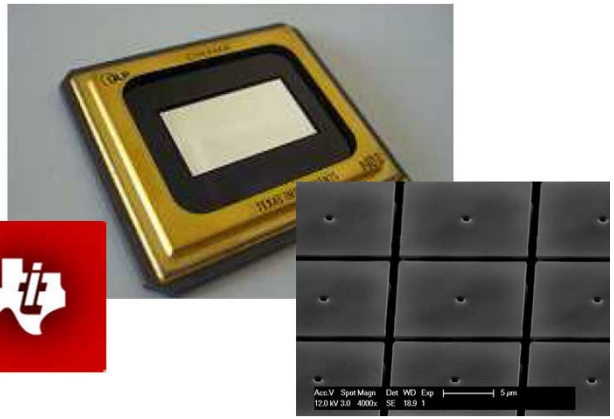
Tests on multiple devices: TI, EPFL, NASA, LAAS, MEMSCAP, OKO, ALPAO, BMC, CSEM ...

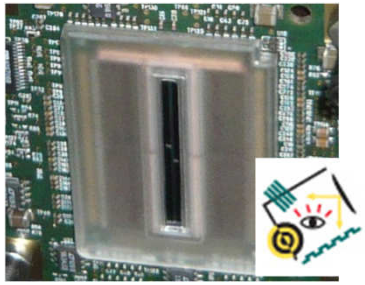
in cryo: MIRA project (with EPFL), TI-DMD for EUCLID, PTT111 from Iris-AO

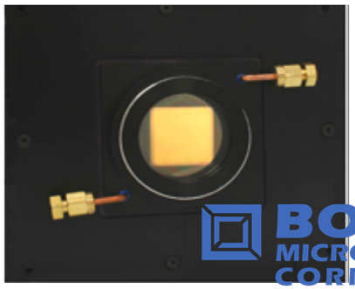












ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

csem

FLEXIBLE OKO OPTICAL

NASA

Iris AO, Inc.

SILICON LIGHT MACHINES

BOSTON MICROMACHINES CORPORATION SHAPING LIGHT

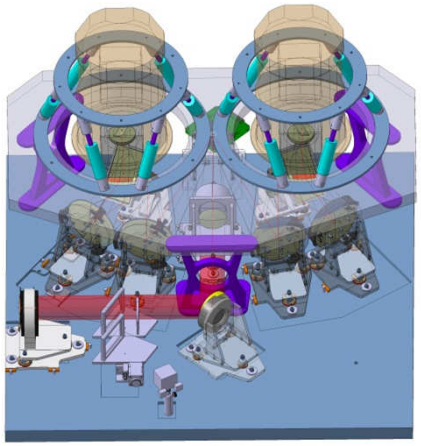
ALPAO

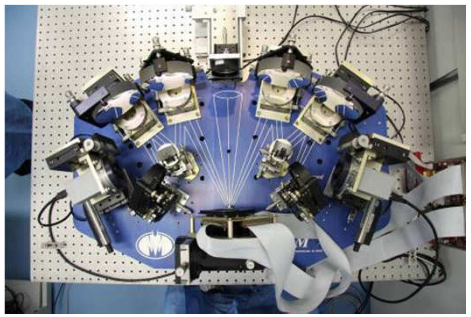
Instrument developments

- Instrument developments using MOEMS: **the BATMAN family**

Universe Observation

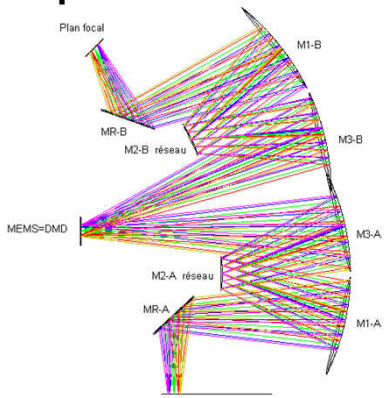
- Multi-Object Spectrograph
  - BATMAN
  - ROBIN
  - BATMAN flies

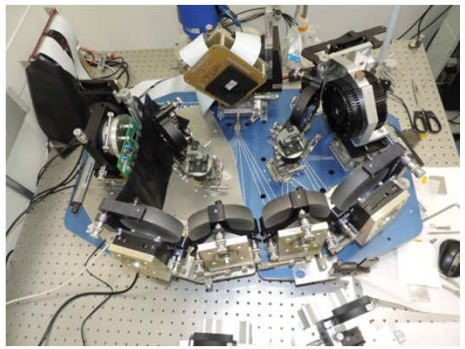




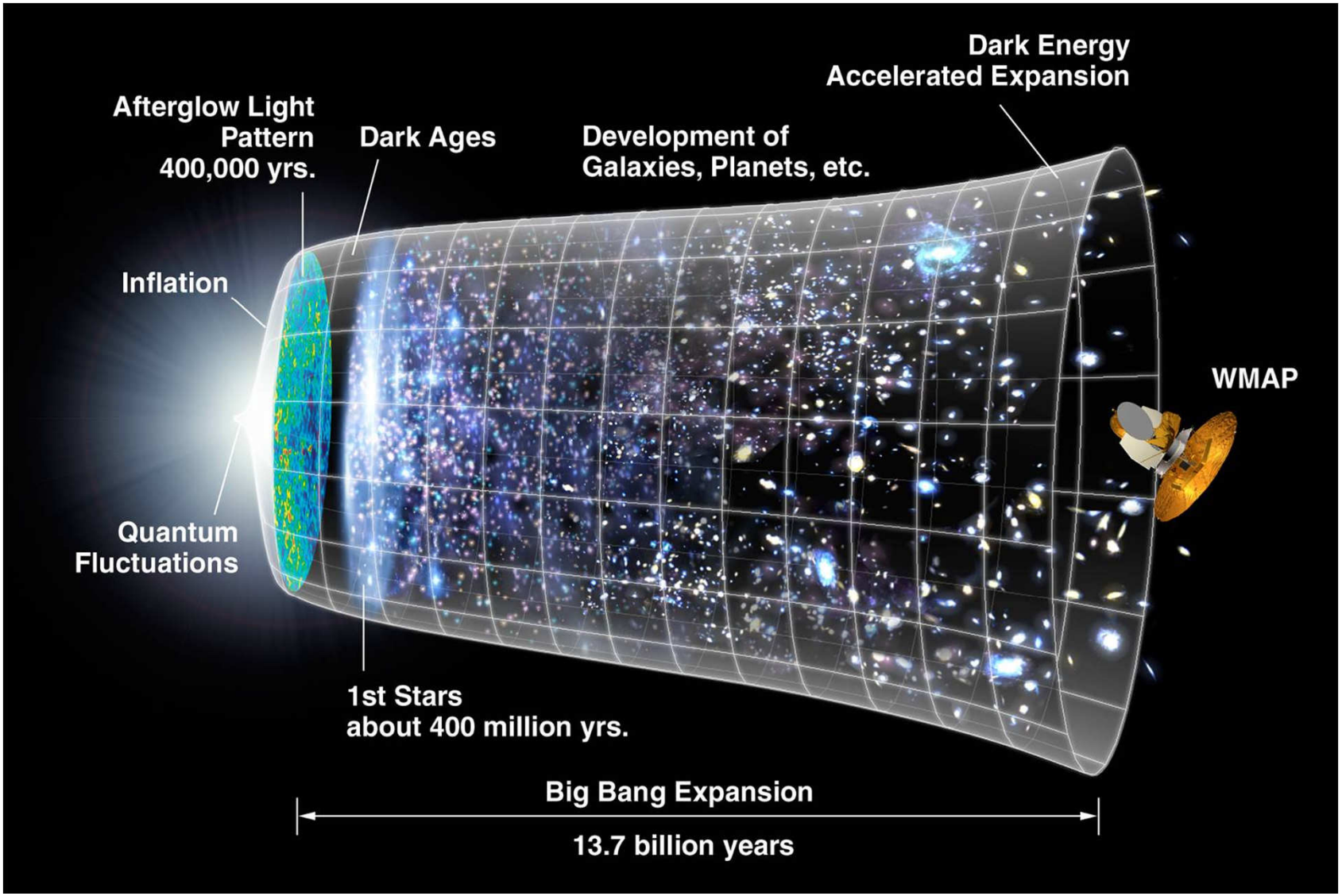
Earth Observation

- Programmable wide field spectrograph
  - Flight model design
  - Full scale breadboard

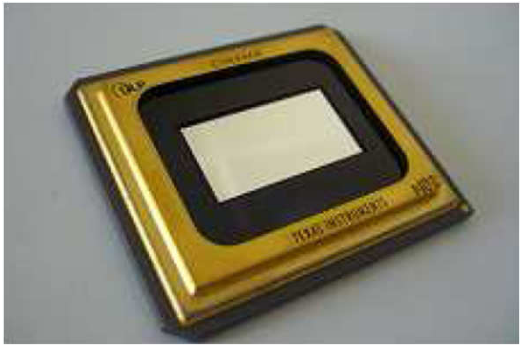


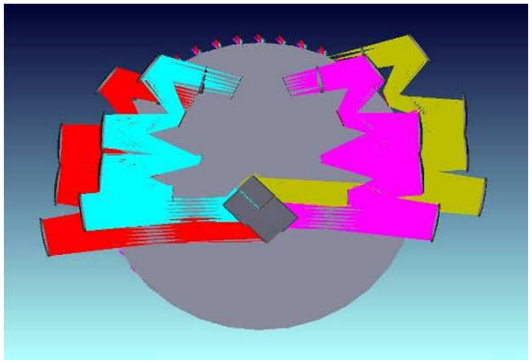


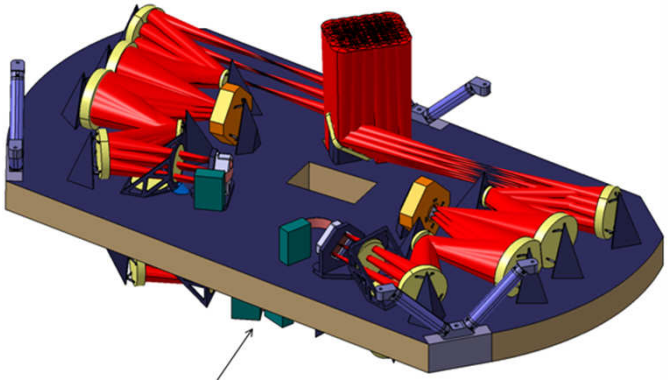
The Universe

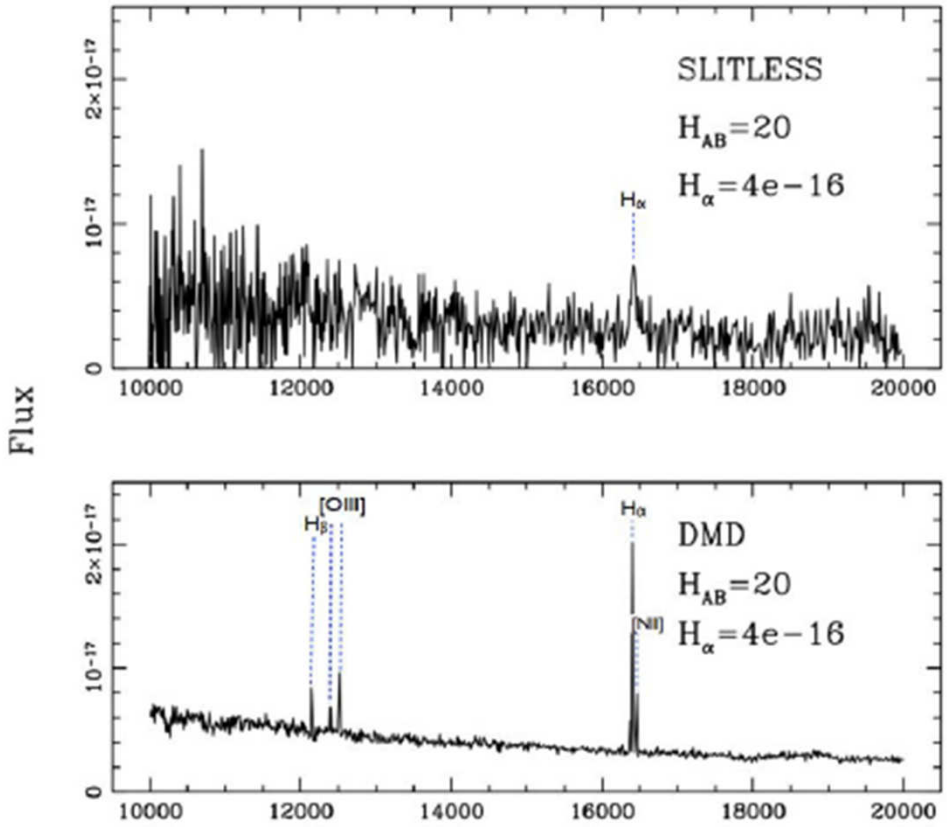


EUCLID-NIS: the DMD option

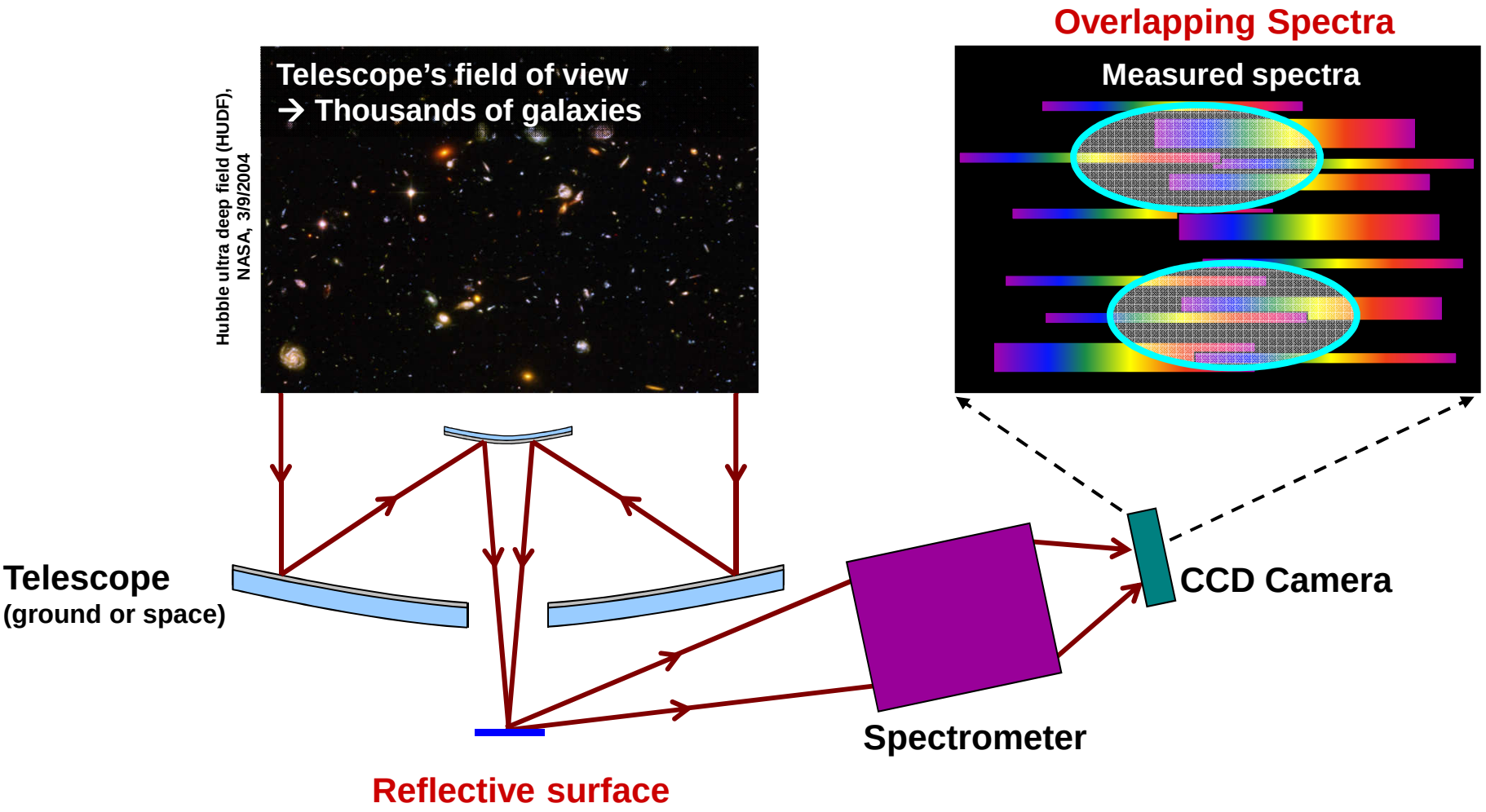




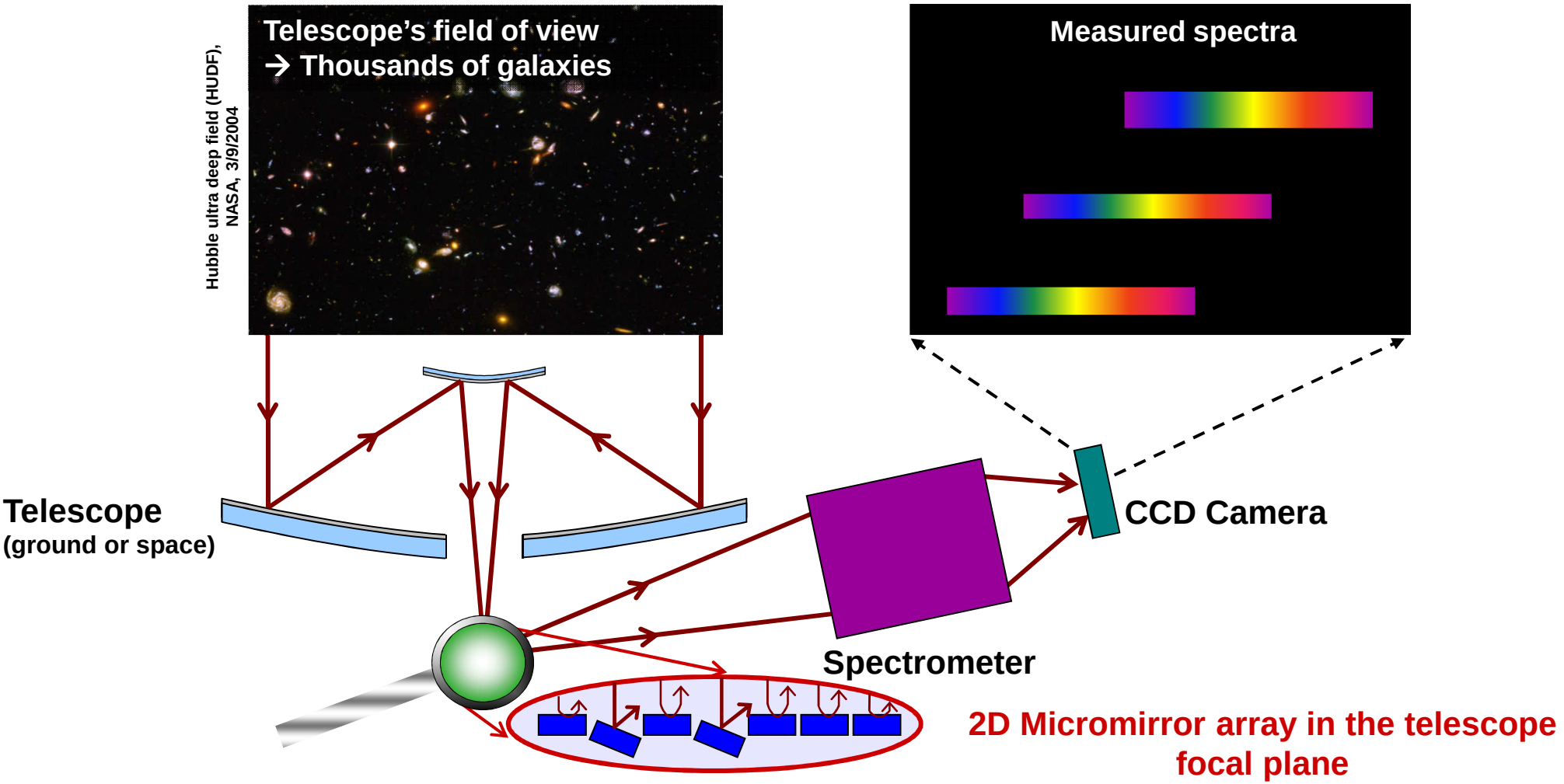




Multi-Object Spectroscopy (MOS)

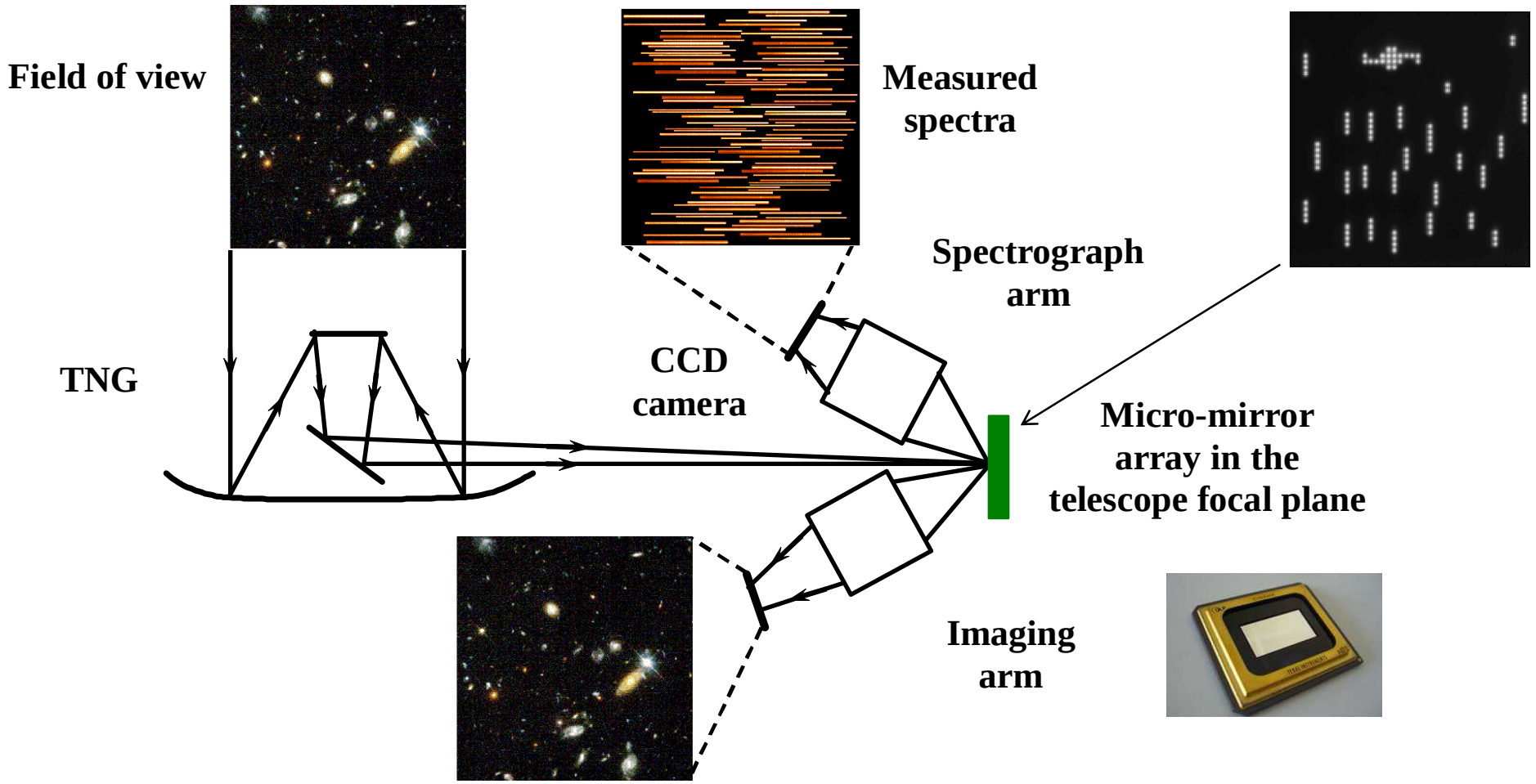


Multi-Object Spectroscopy (MOS)



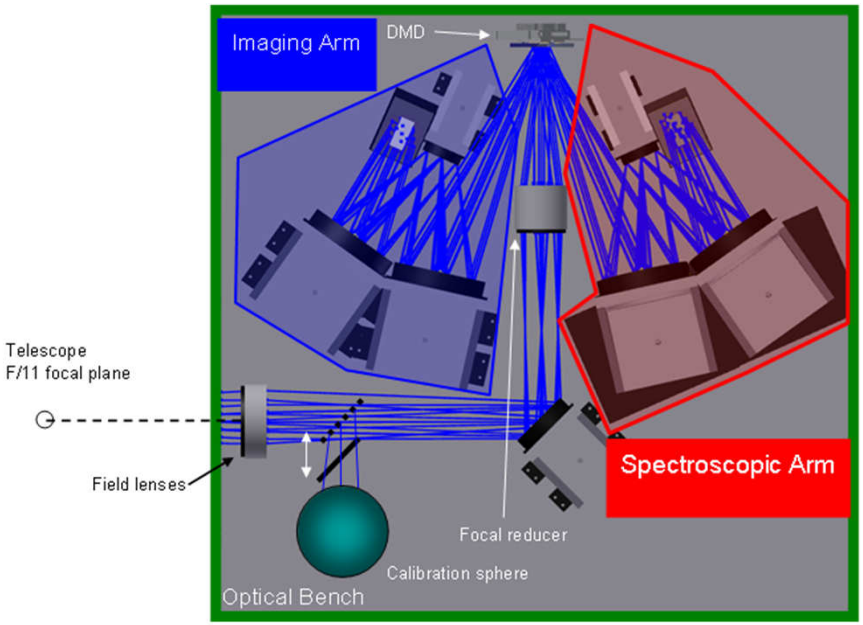
MOEMS-based Spectro-Imager

- Universe Observation: Multi-Object Spectrograph + Imager

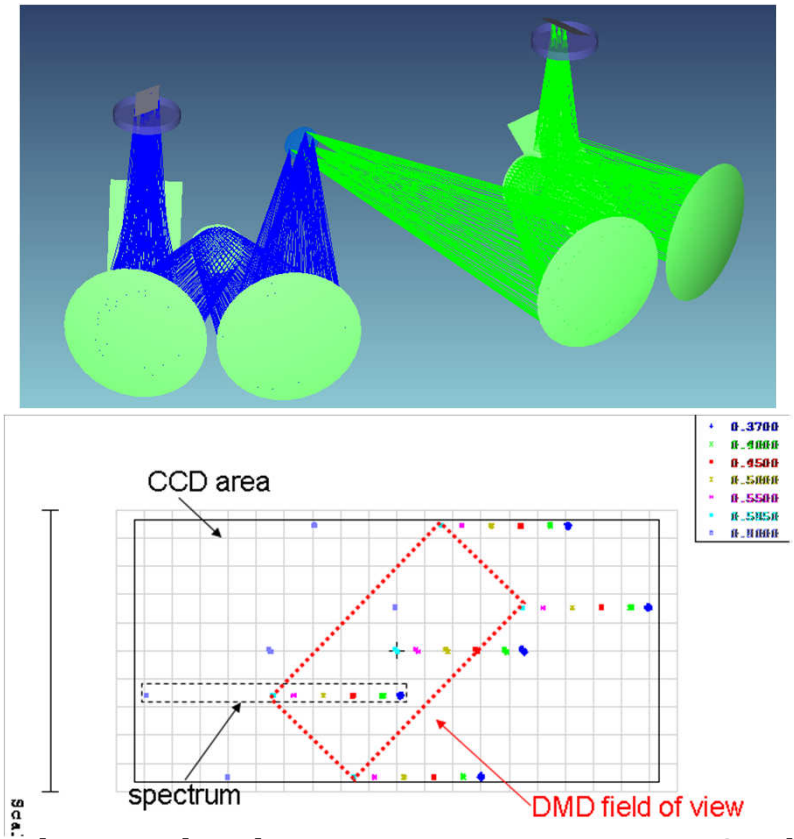


BATMAN

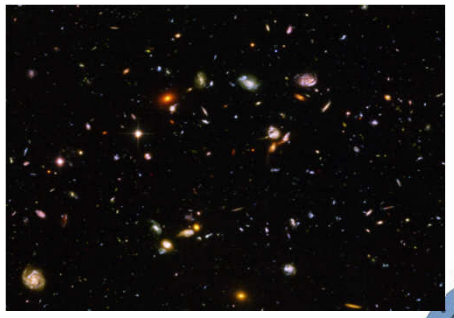
Spectro-Imager on Galileo telescope (3,6m)

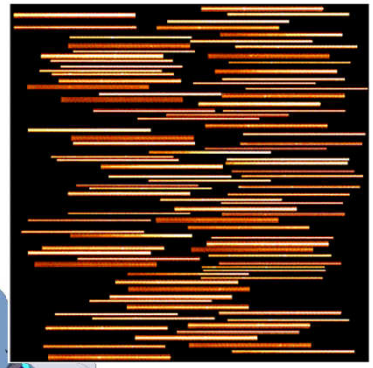


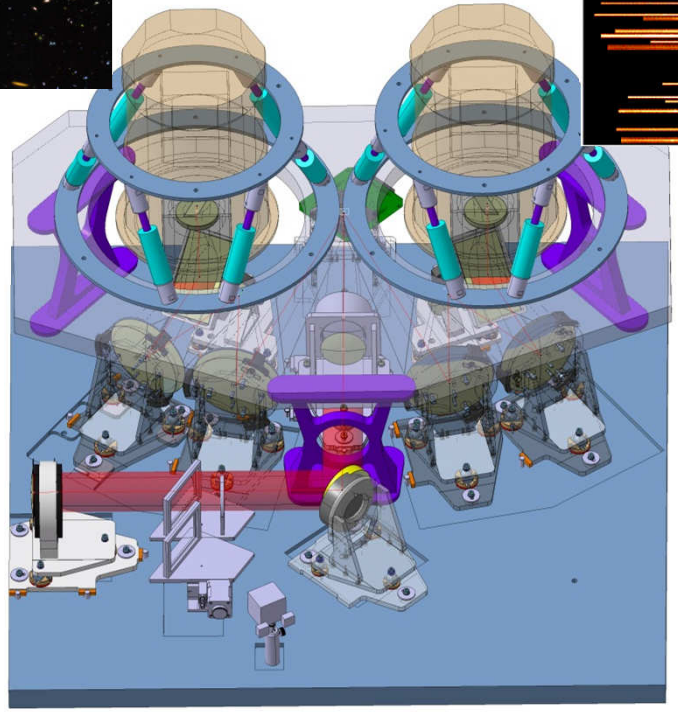
Zamkotsian et al., SPIE 9908, 2016



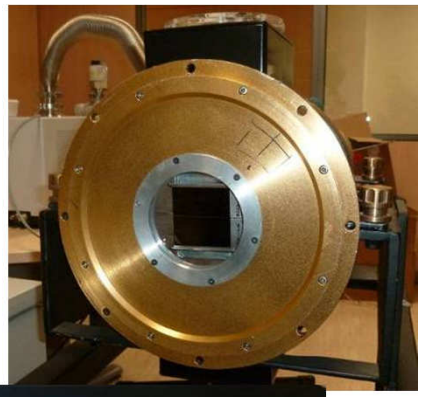
BATMAN

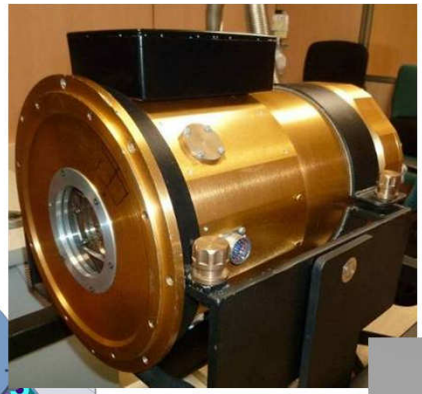


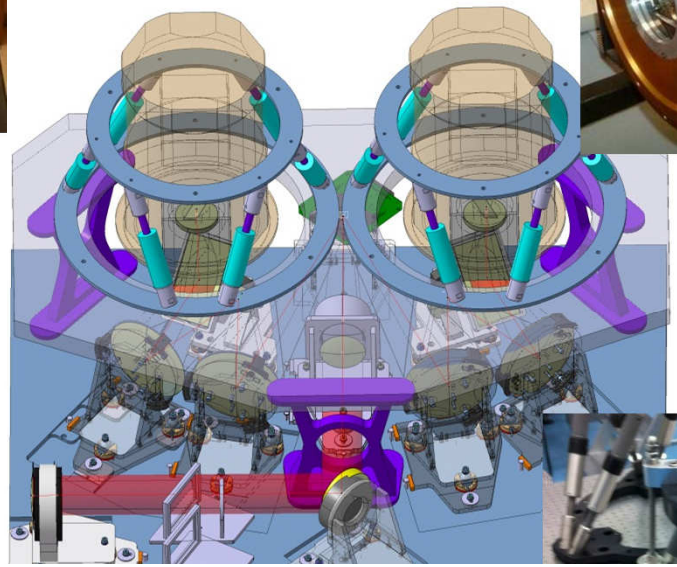


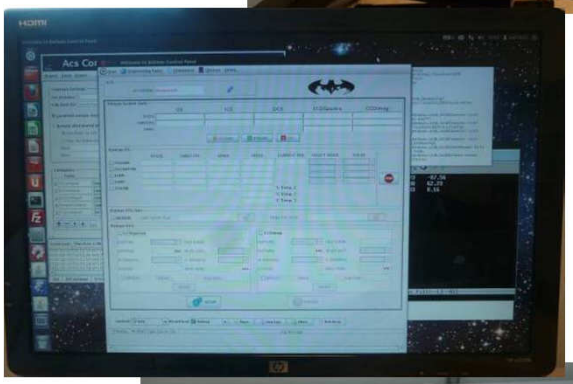


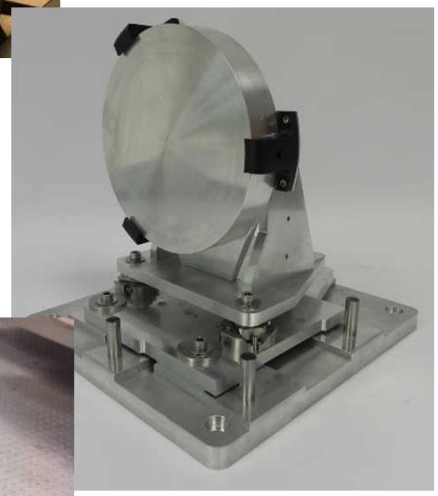
BATMAN





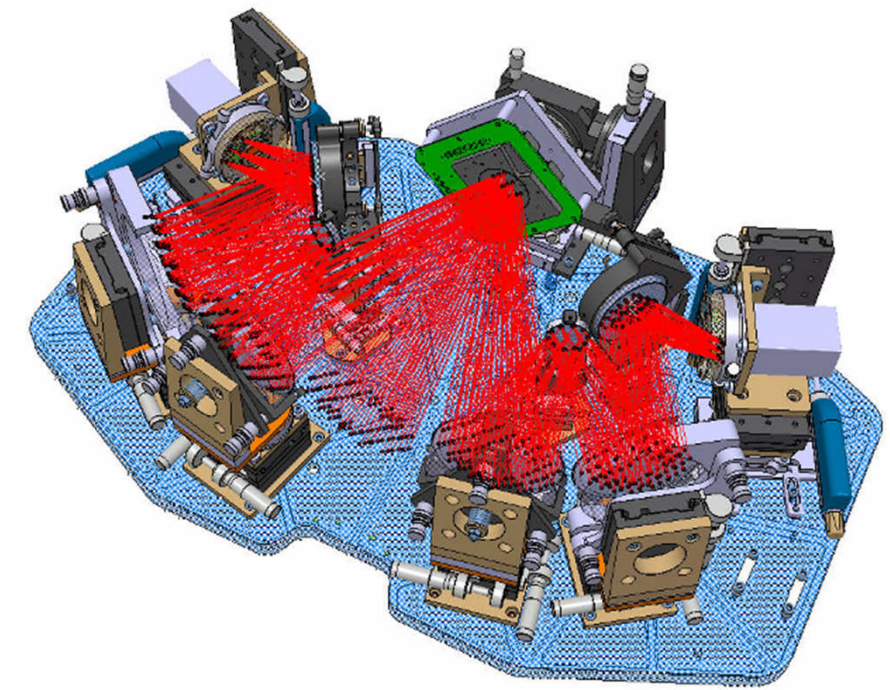


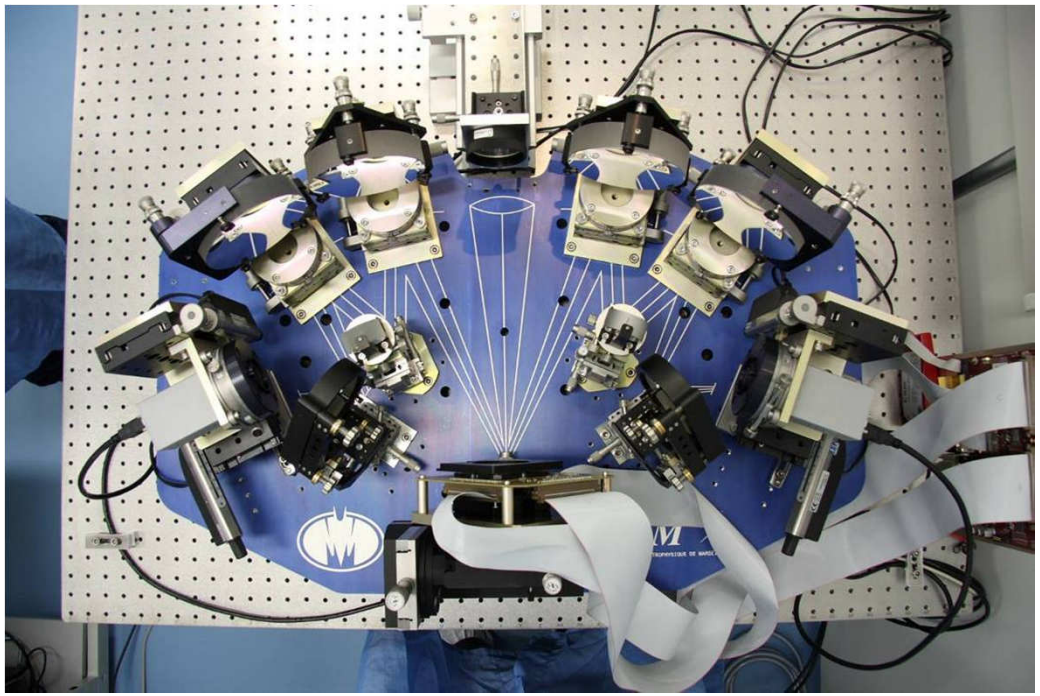




On-sky by end 2018

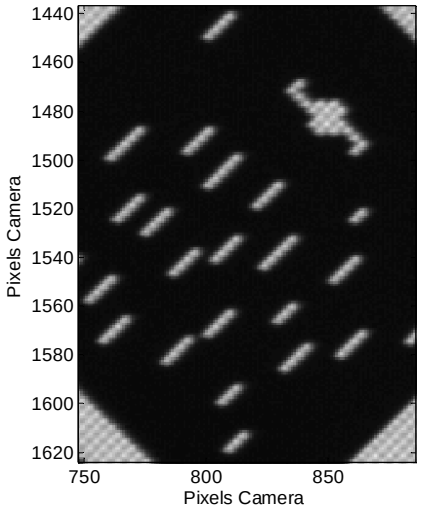
ROBIN



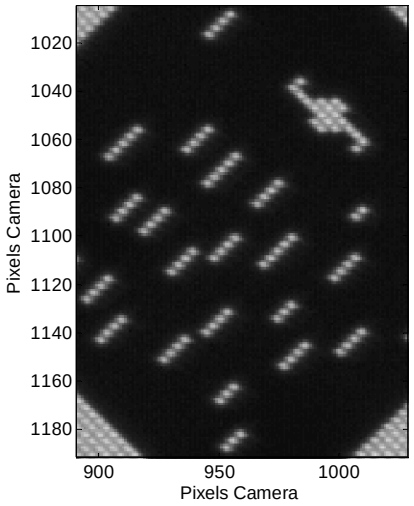


Imagery

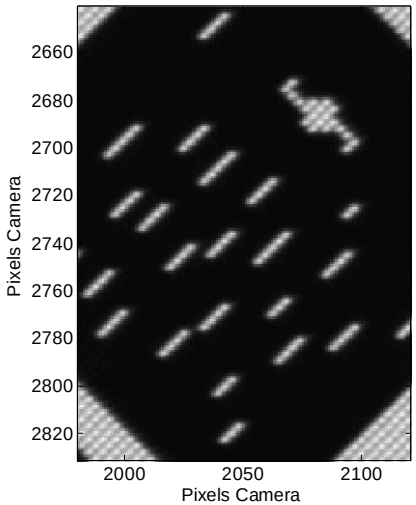
z00 pattern2



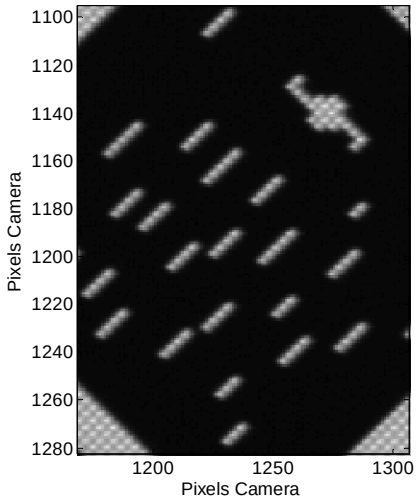
z09 pattern2



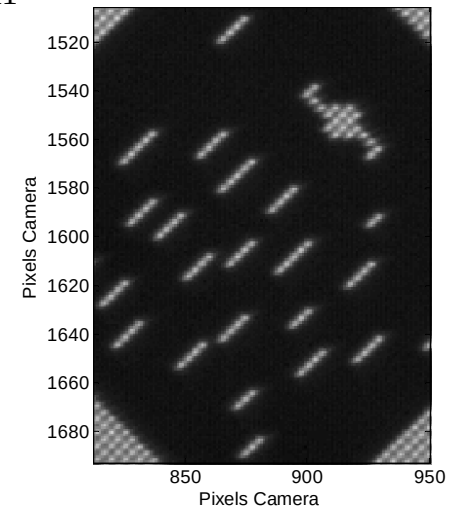
z20 pattern1



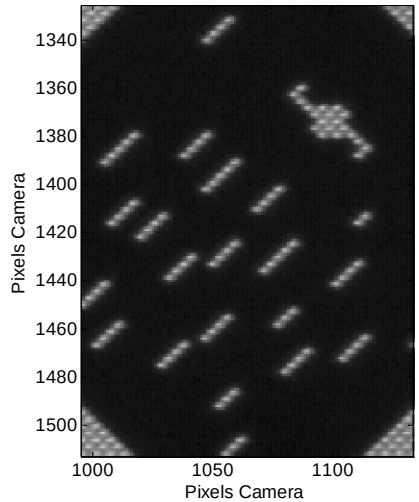
z25 pattern1



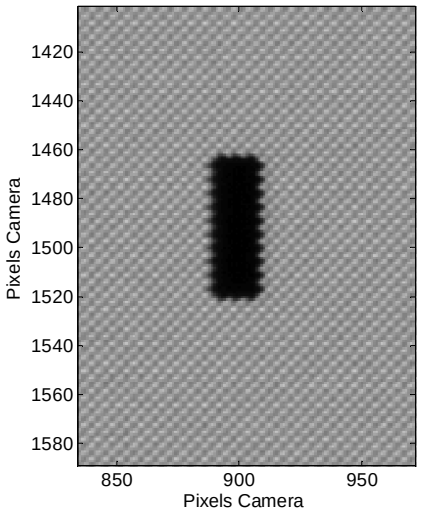
z40 pattern1



z49 pattern2



Slits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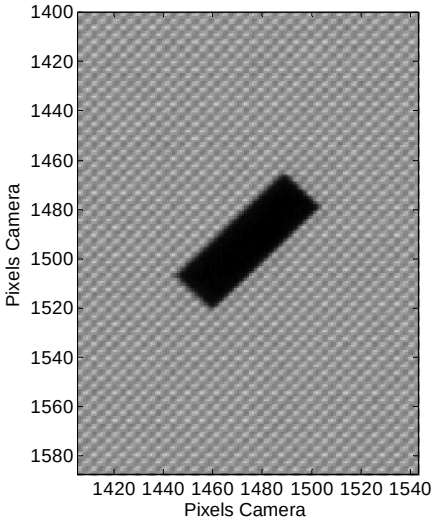
Pixels Camera


Pixels Camera
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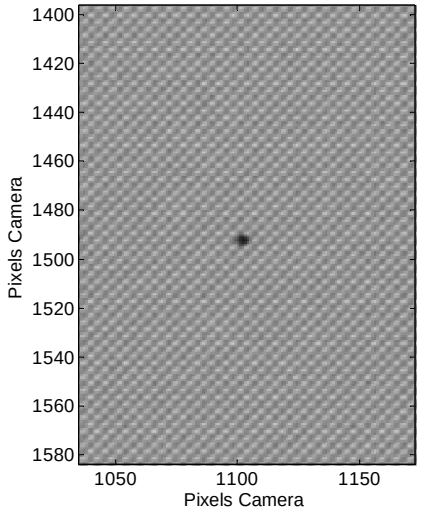
Pixels Camera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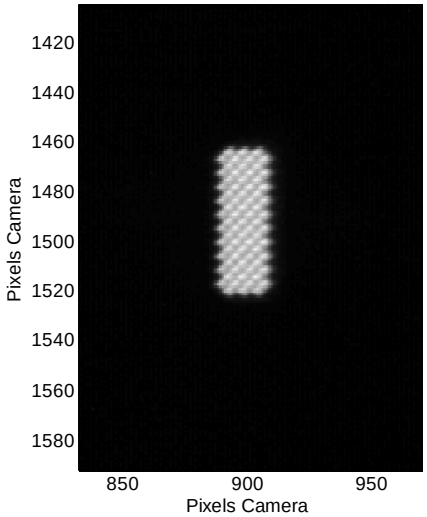
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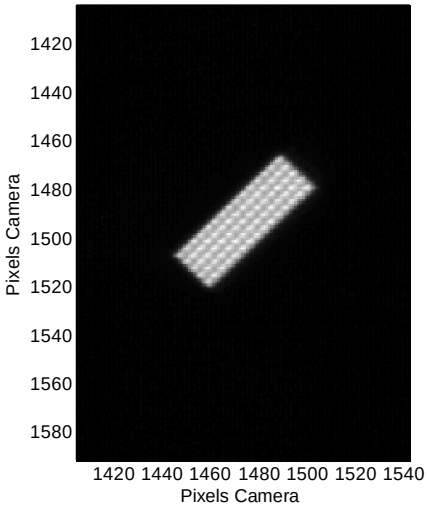
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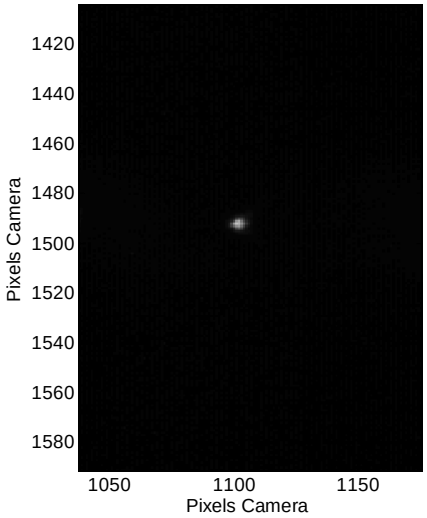
Pixels Camera
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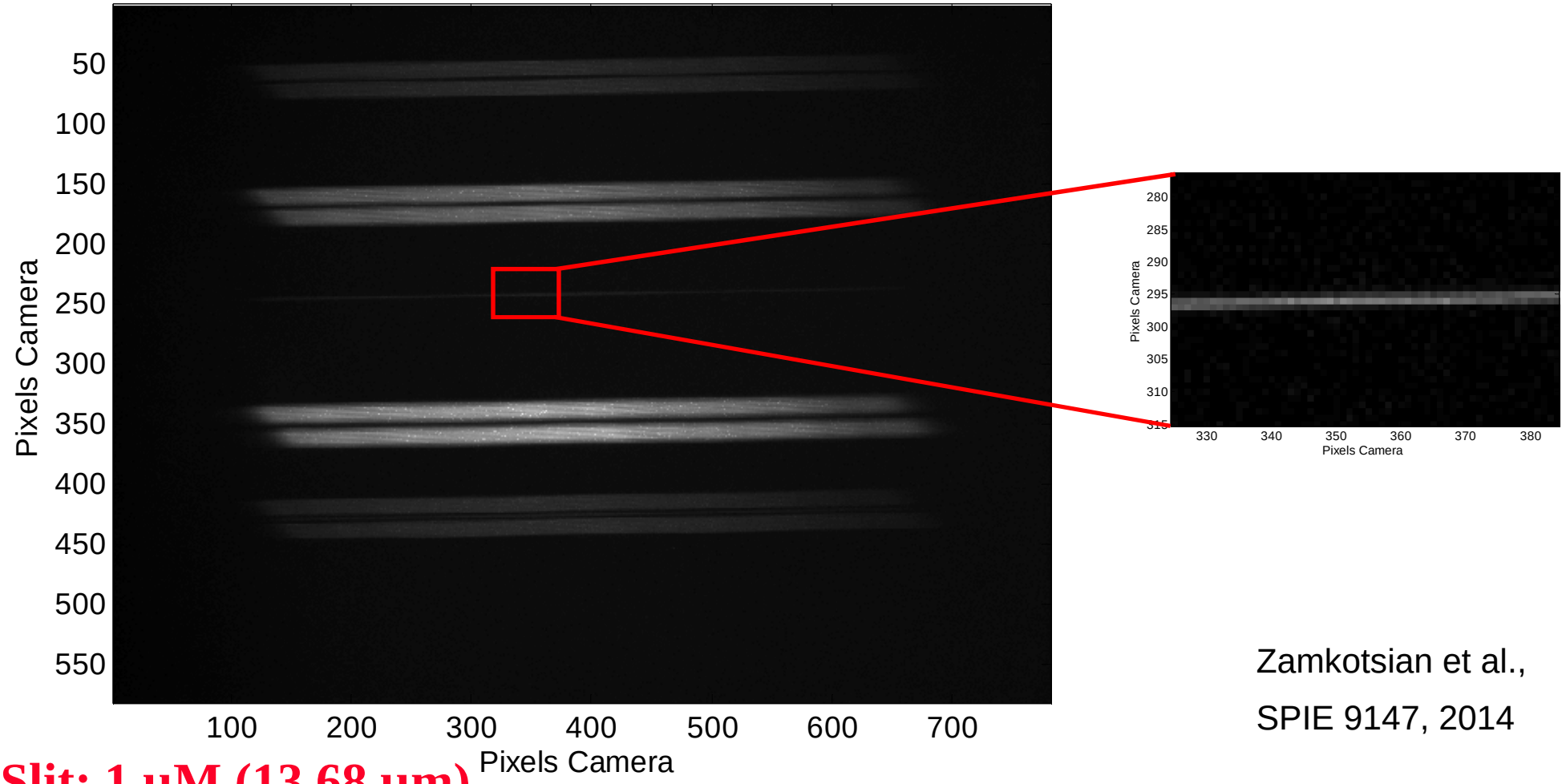
Spectra



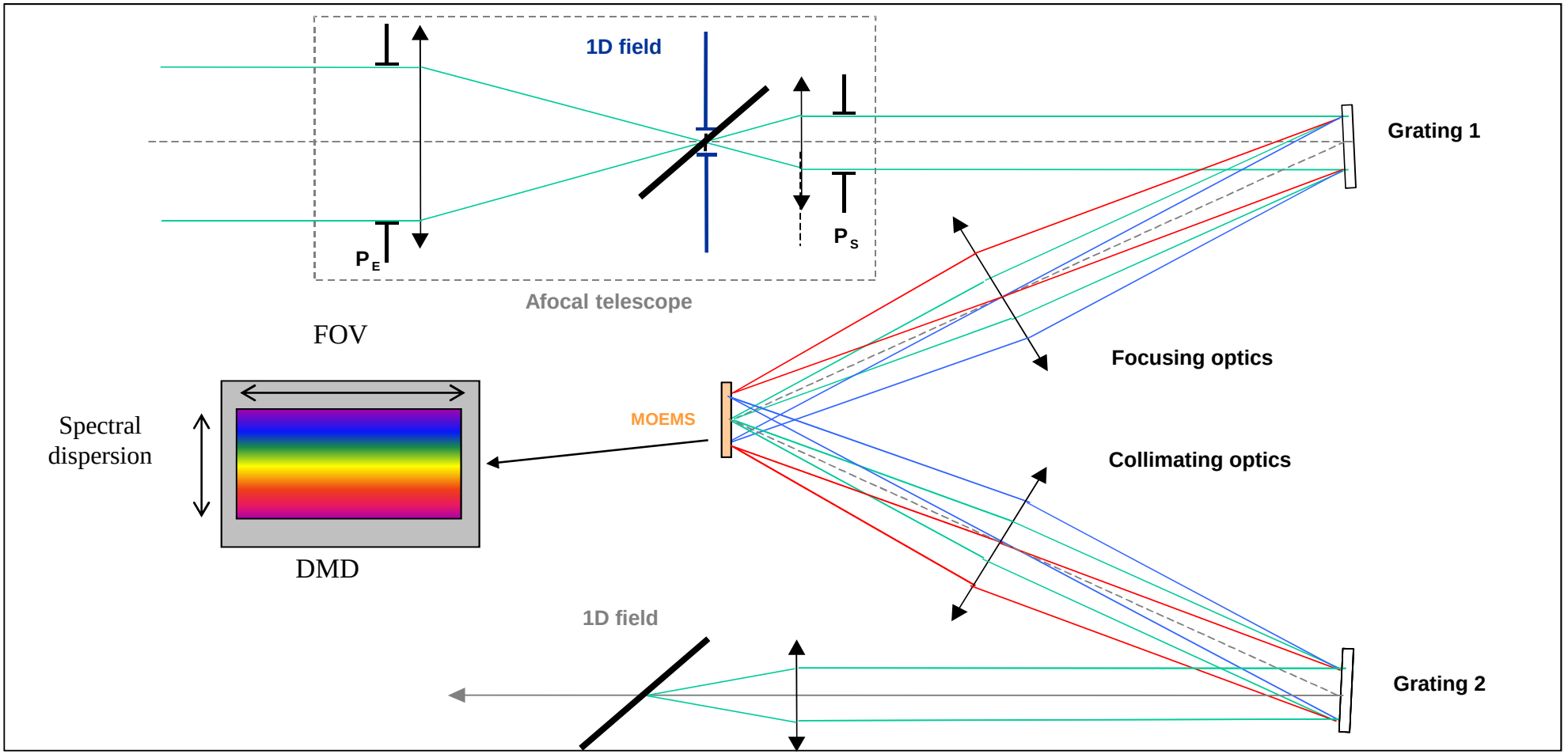
Zamkotsian et al.,

SPIE 9147, 2014

Slit: 1 µM (13.68 µm)

Spectrum on 1.5 detector pixel (8,3µm) in 450-650nm wavelength range

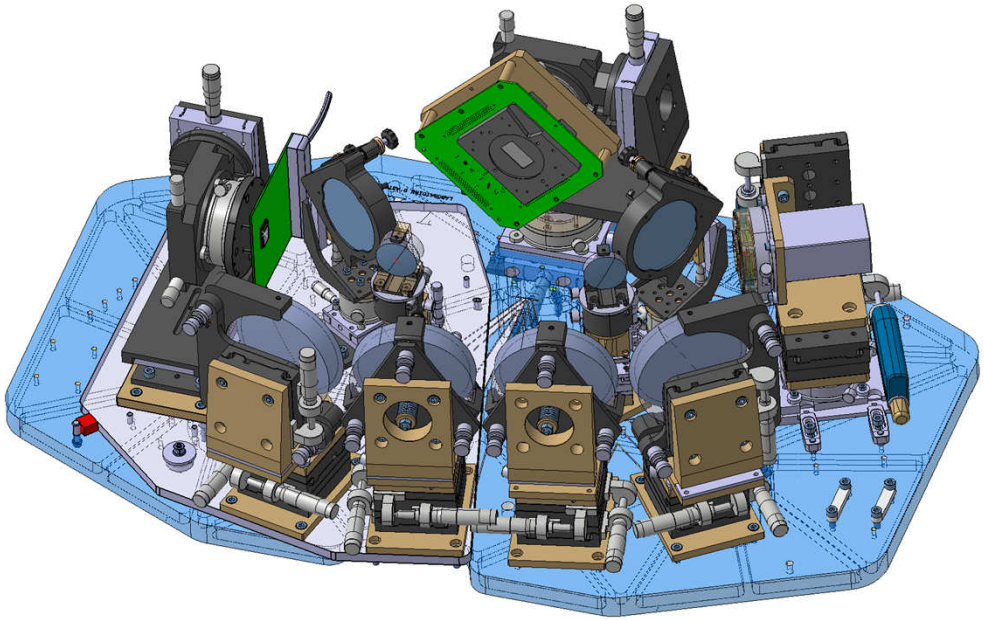
Wide field programmable spectrograph

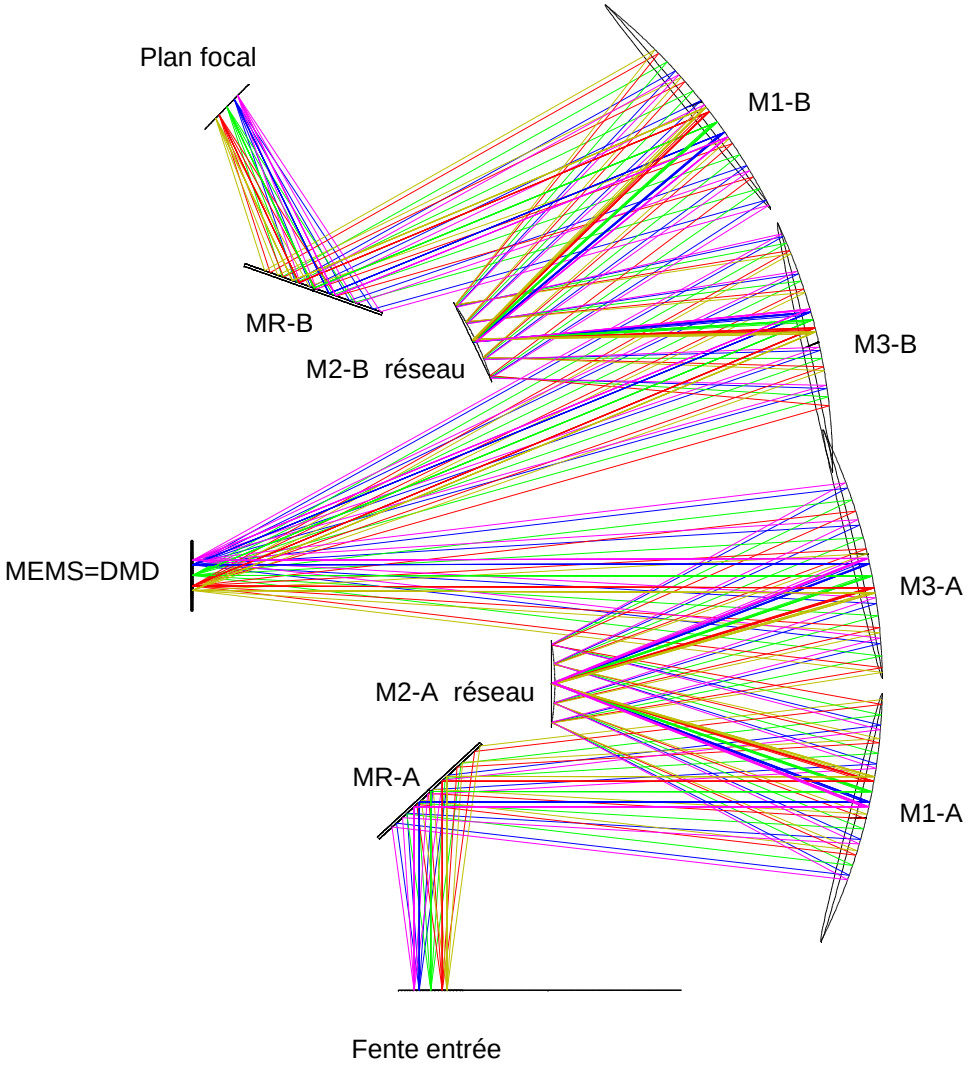


Zamkotsian et al., SPIE 9376, 2015

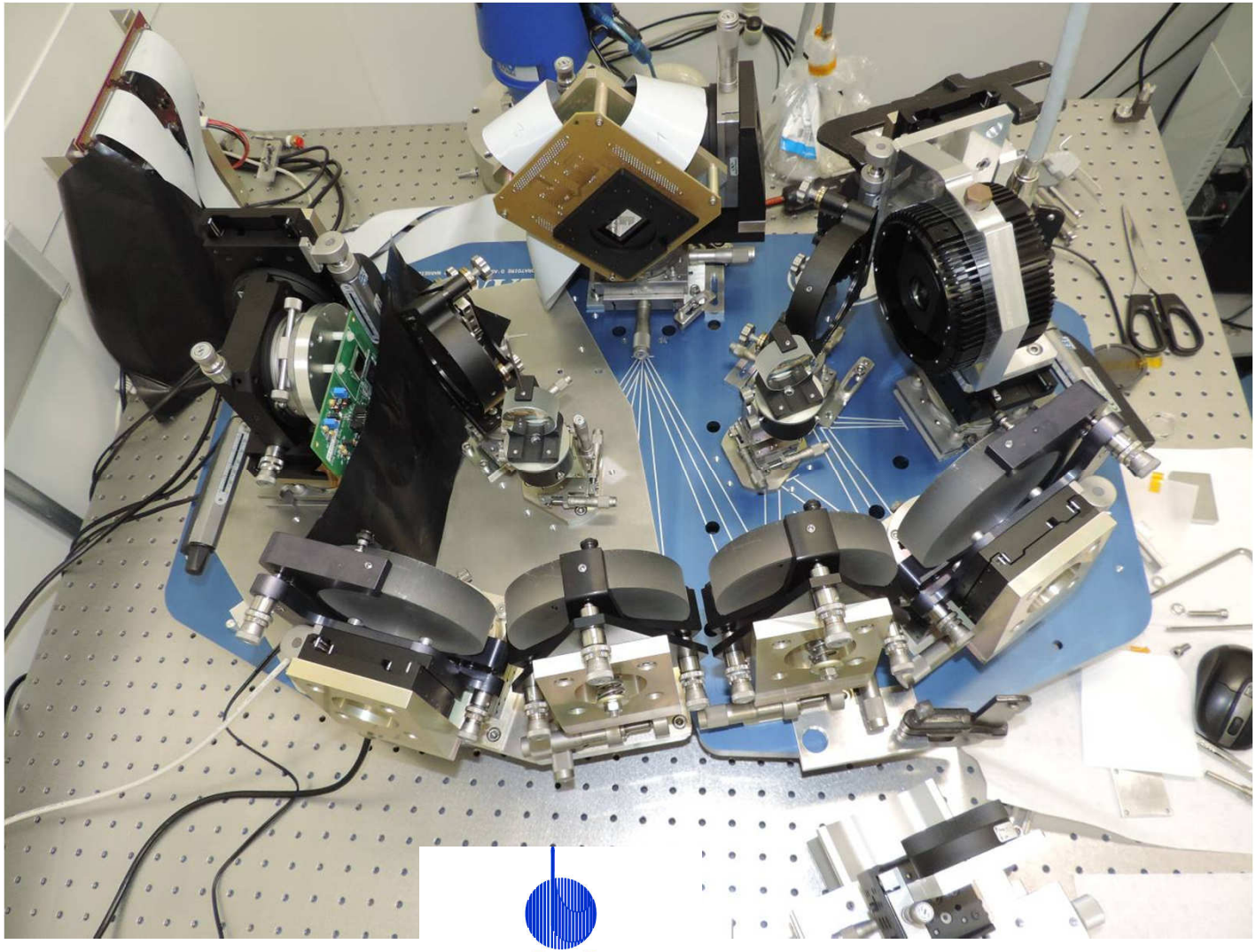
Demonstrator

- Optical and opto-mechanical design



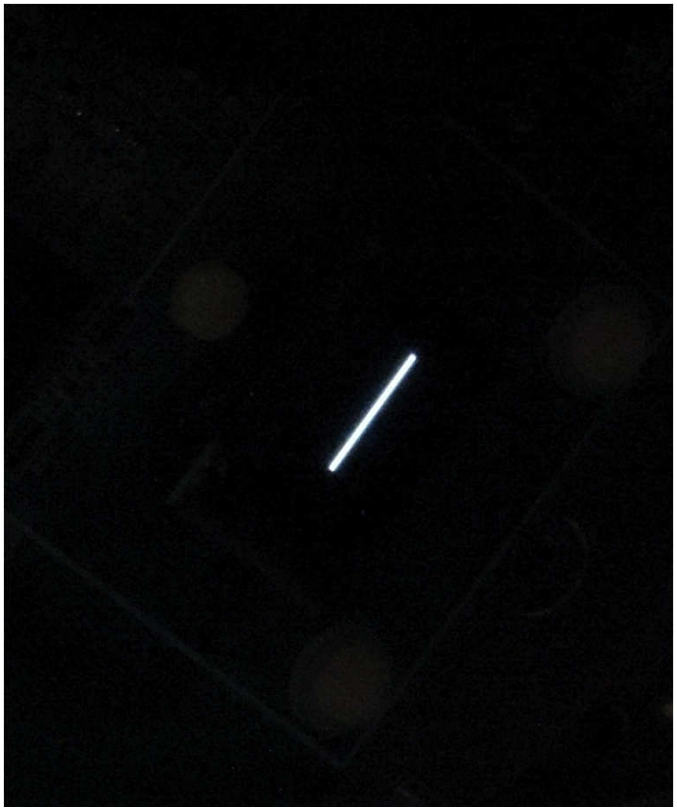


Demonstrator

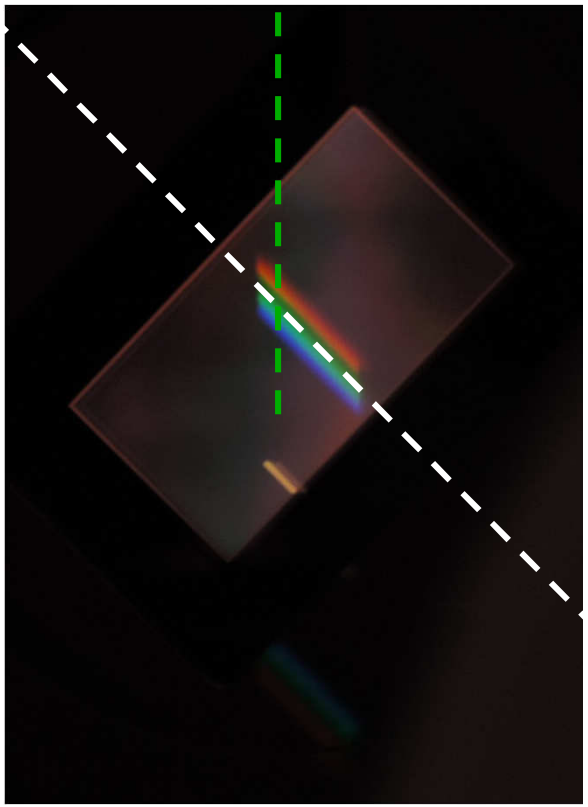


Demonstrator: in the DMD plane

- Images at DMD surface, spatial / spectral behaviour
  - OLED: white slit at 45°
  - DMD: order 1, order 0, order -1



OLED

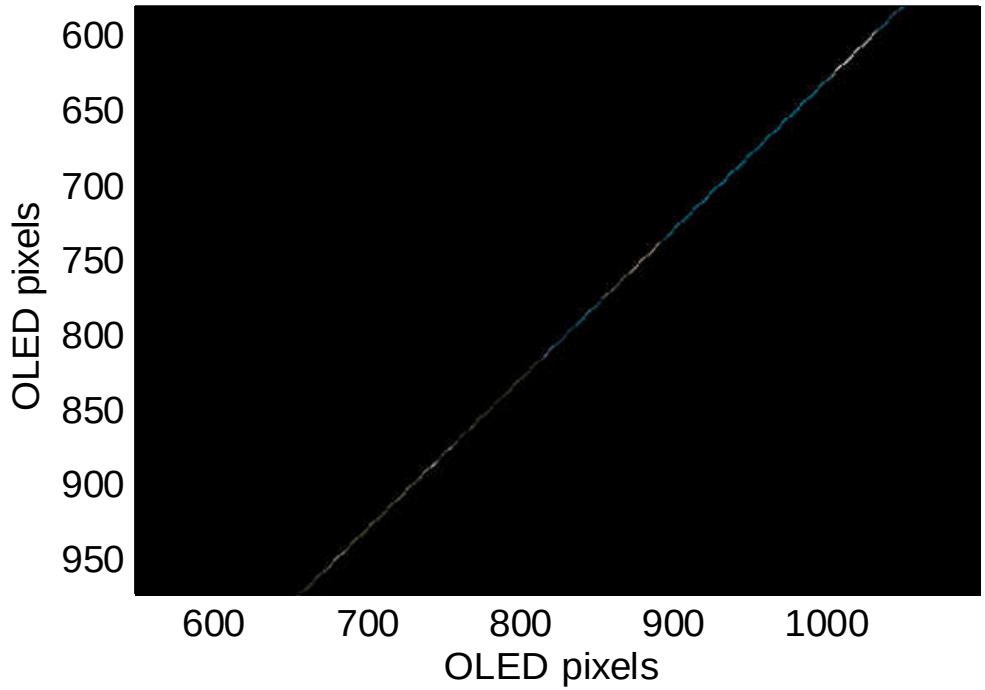


DMD

Demonstrator

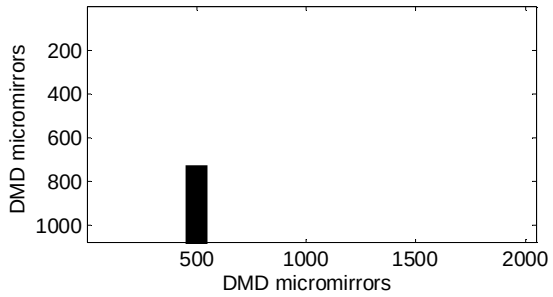
- End-to-end measurement
  - Input: OLED scanning slit, width 1 pixel
  - DMD: 0-order removed
  - Output: recombined slit

Input

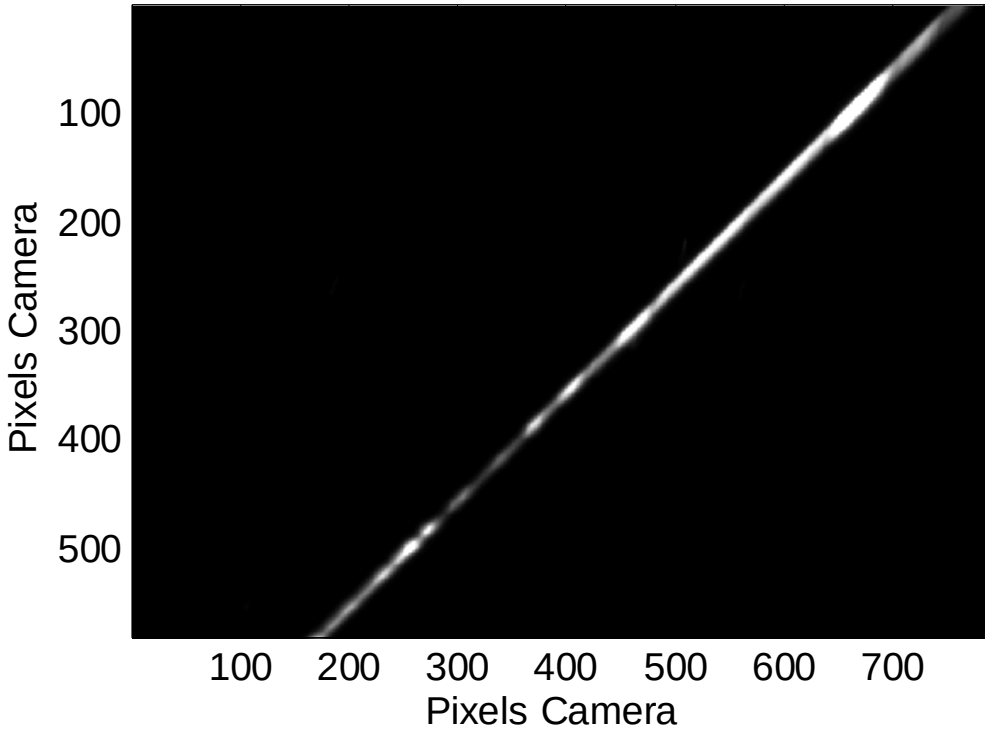


Demonstrator

- End-to-end measurement
  - Input: OLED scanning slit, width 1 pixel
  - DMD: 0-order removed
  - Output: recombined slit

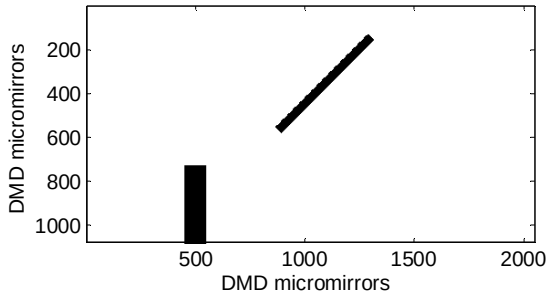


Output

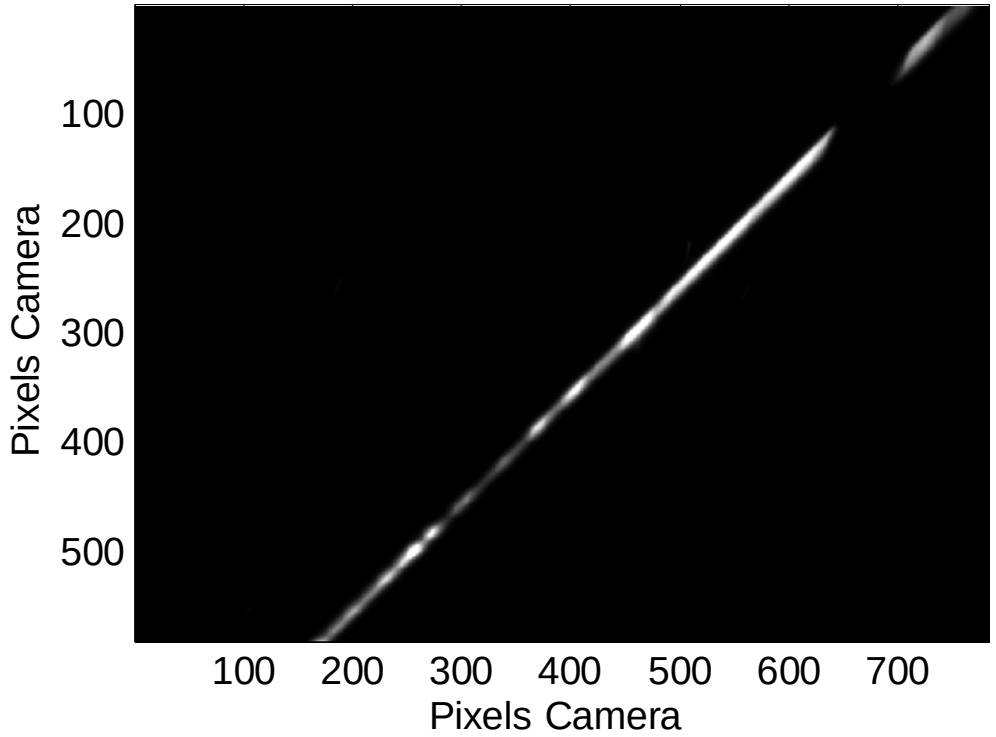


Demonstrator

- End-to-end measurement
  - Input: OLED scanning slit, width 1 pixel
  - DMD: 0-order + object removed
  - Output: recombined slit

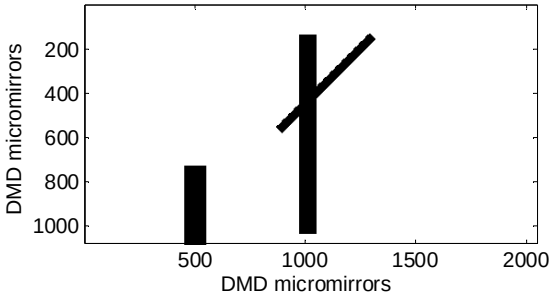


Output

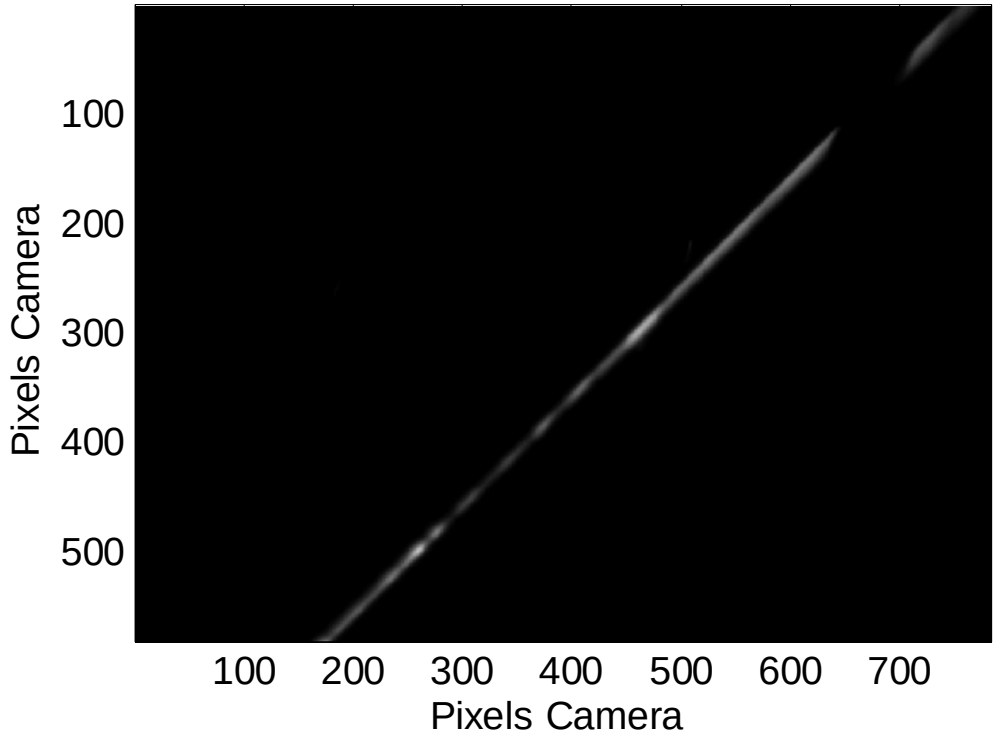


Demonstrator

- End-to-end measurement
  - Input: OLED scanning slit, width 1 pixel
  - DMD: 0-order + object + blue removed
  - Output: recombined slit



Output



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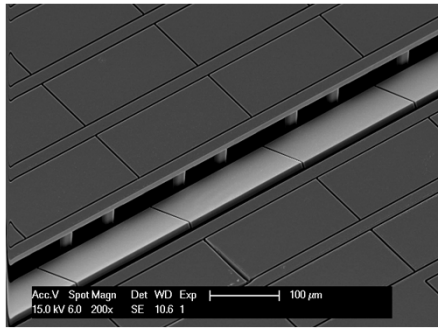
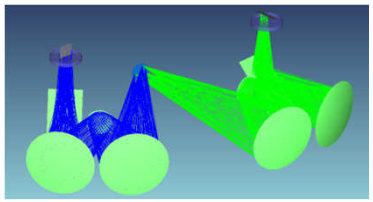
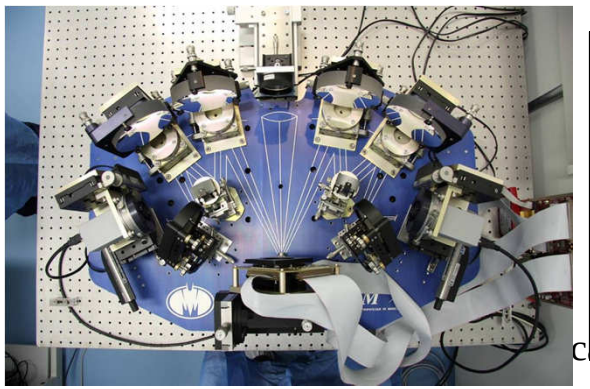
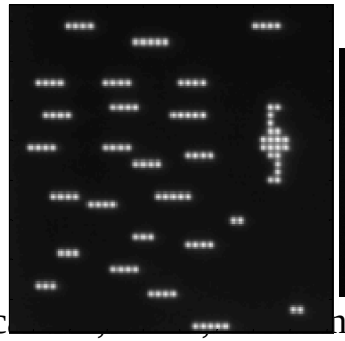
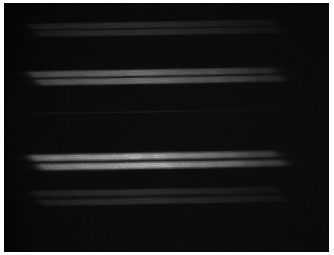
BATMAN team, France-Italy
Manuele Moschetti, Paolo Spano, Marco Riva, Emilio Molinari, Rosario Cosentino, Adriano Ghedina, L. Nicastro, M. Gonzalez, P. Di Marcantonio, I. Coretti, R. Cirami, Filippo Zerbi, Luca Valenziano





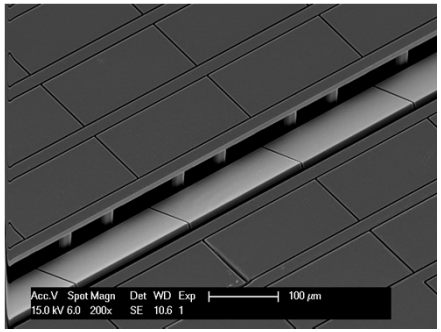


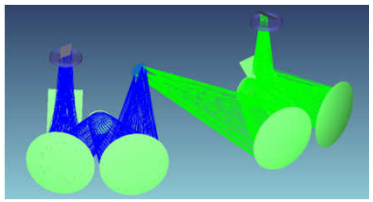
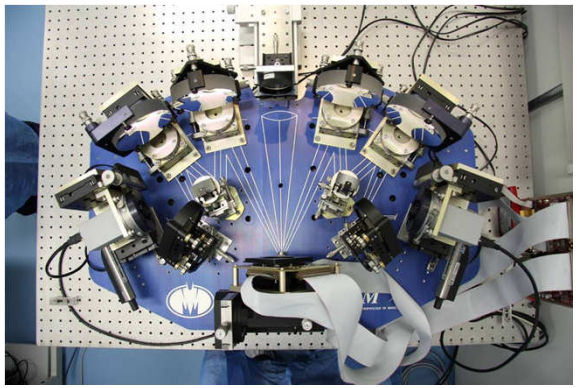
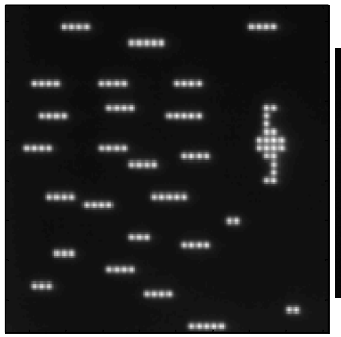
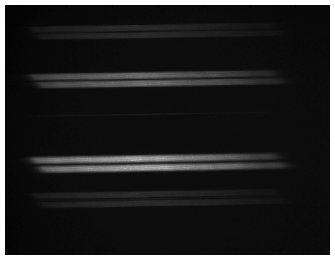




SLM for space

- Large micro-mirror array with large tilt angle, excellent surface quality, high contrast and operation at cryo temperature are requested for spectro-imagery applications in space
- MIRA project is under way for the realization of large arrays dedicated to spectroscopy (next step: integration with hardened electronics)
- Spectro-imager for Universe Observation
- Programmable spectrograph for Earth Observation



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