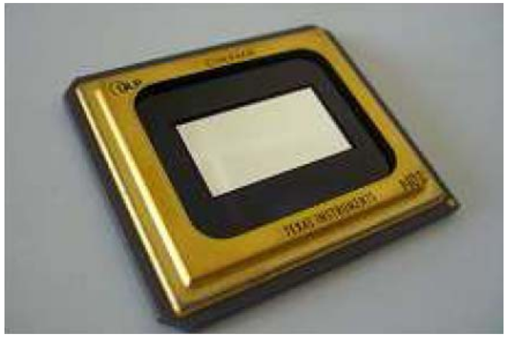
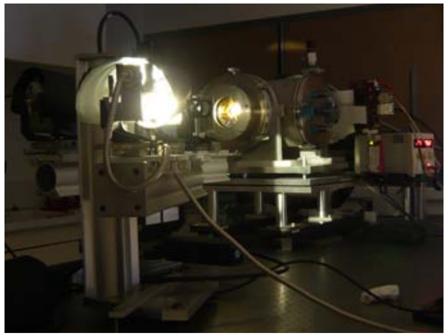
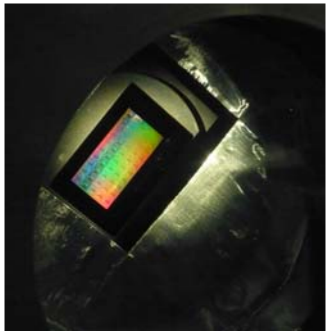
# MOEMS for space: DMD chip evaluation

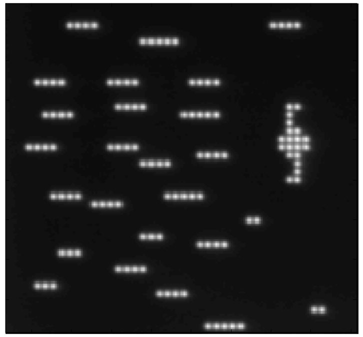
**Frederic Zamkotsian[1], Kyrre Tangen[2], Rudy Barette[1], Patrick Lanzoni[1], Emmanuel Grassi[1], Christophe Fabron[1], Luca Valenziano[3], Laurent Marchand[4], Ludovic Duvet[4]**

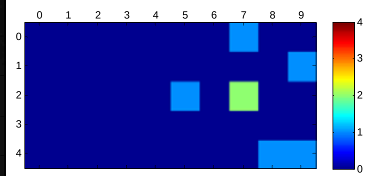
*Laboratoire d'Astrophysique de Marseille, France*
*Visitech, Norway*
*INAF / IASF, Bologna, Italy*
*European Space Agency, The Netherlands*



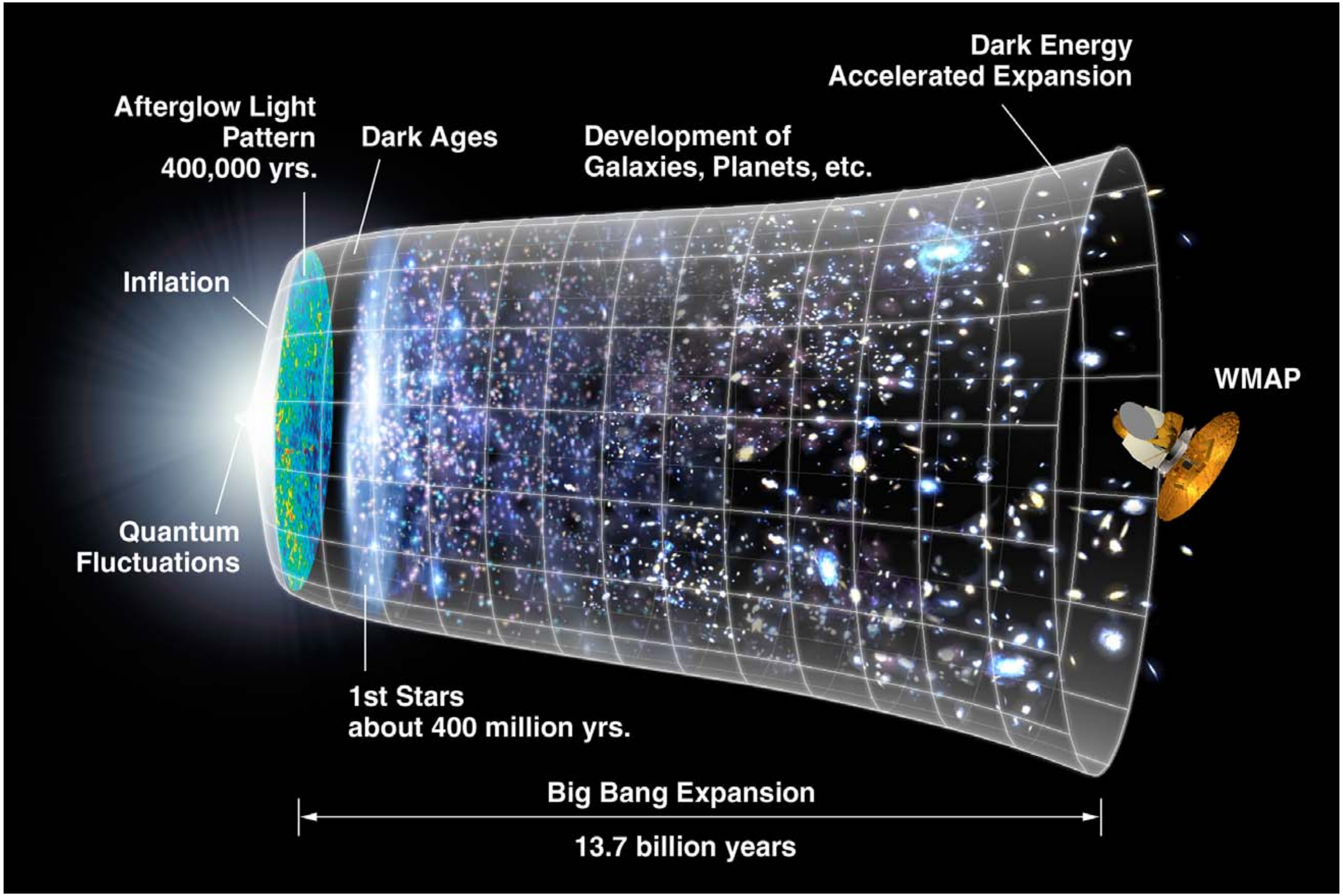








# Universe expansion



# EUCLID

## ♦EUCLID

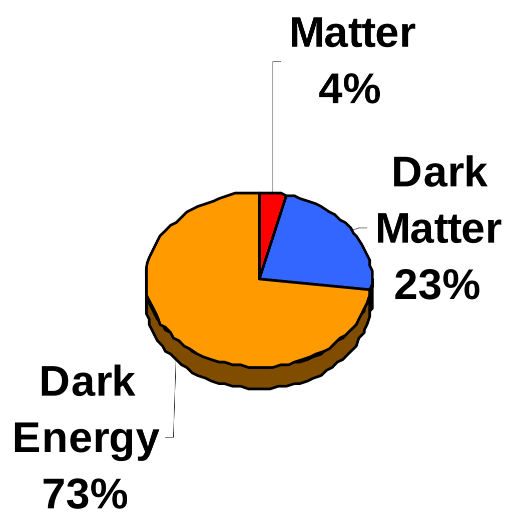
- Mission for ESA Cosmic Vision Program
- Looking for Dark Energy and Dark Matter
- 2 instruments for imagery and spectroscopy

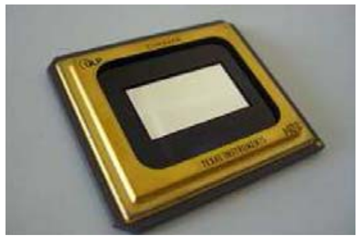
## ♦EUCLID - NIS

- Near–Infrared Spectrograph
- Measurement red-shifts of galaxies
- Huge sample of 50 – 100 millions galaxies

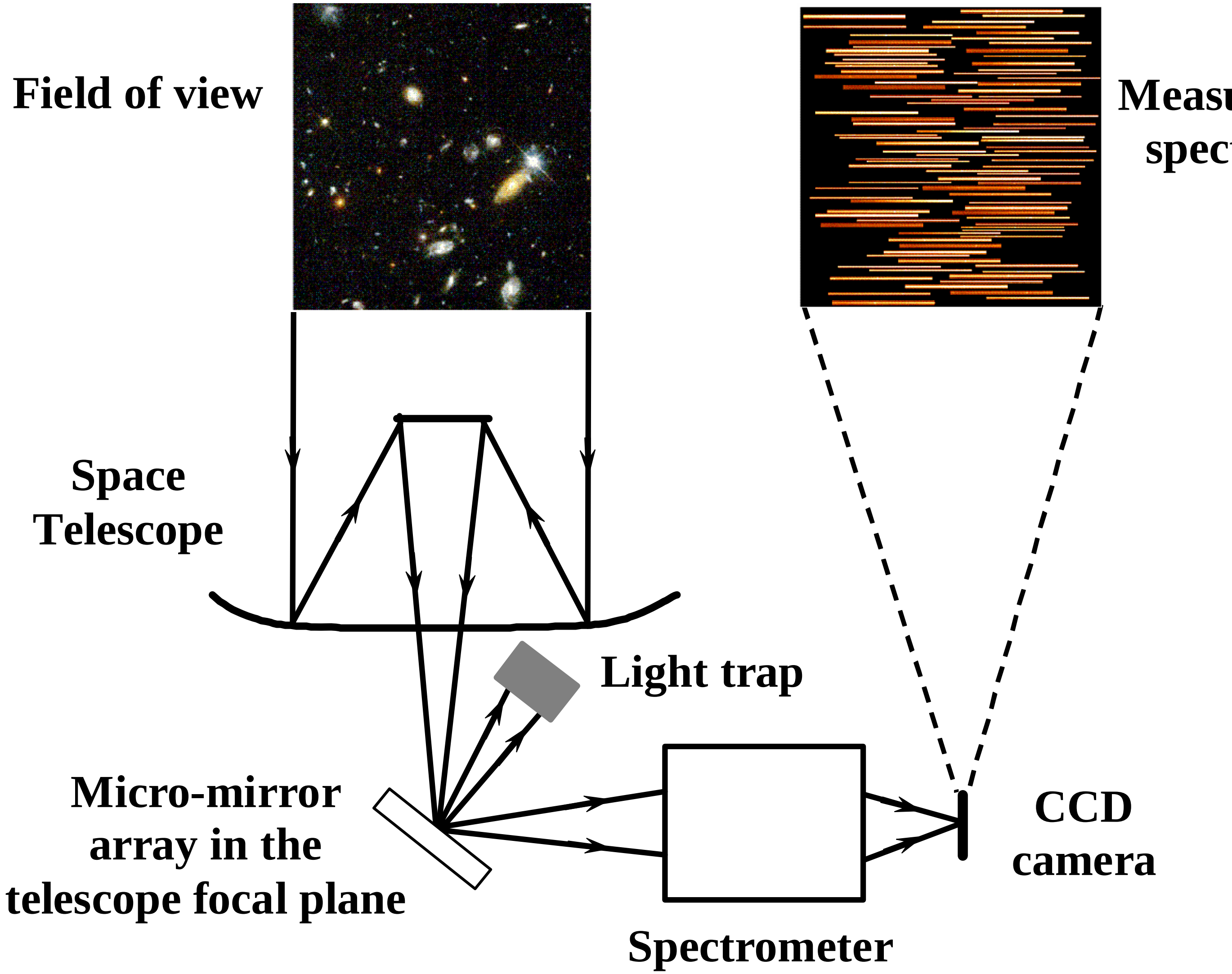
## ♦DMD - option

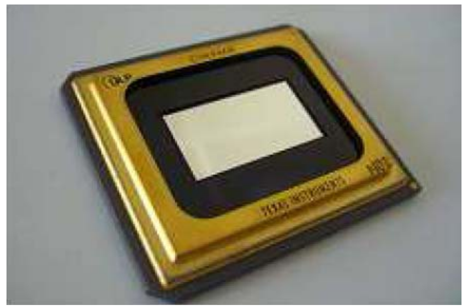
- Multi-Object Spectrograph option based on DMD
- DMD 2048x1080 Micromirrors made by TI
- DMD space evaluation (Visitech - LAM)



# Multi-Object Spectroscopy (MOS)

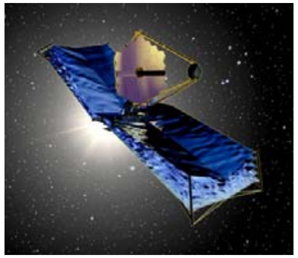


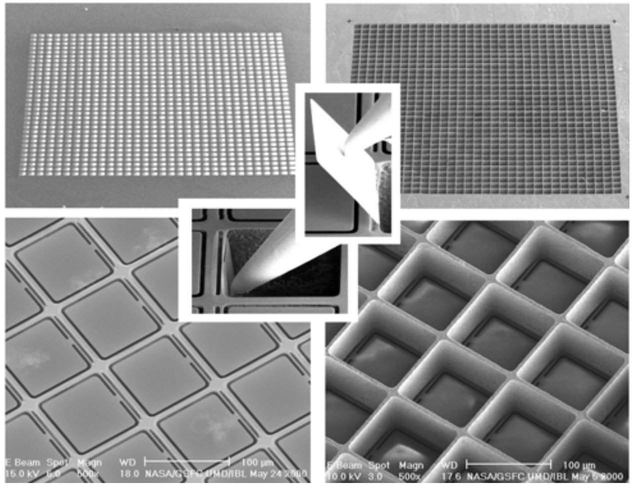



# MOEMS developments

♦NASA-GSFC Micro-shutters

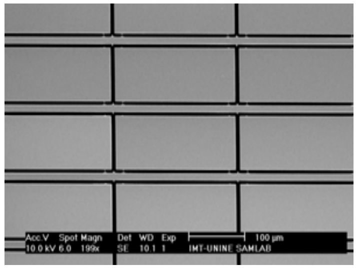
**Selected for JWST NIRSpec**

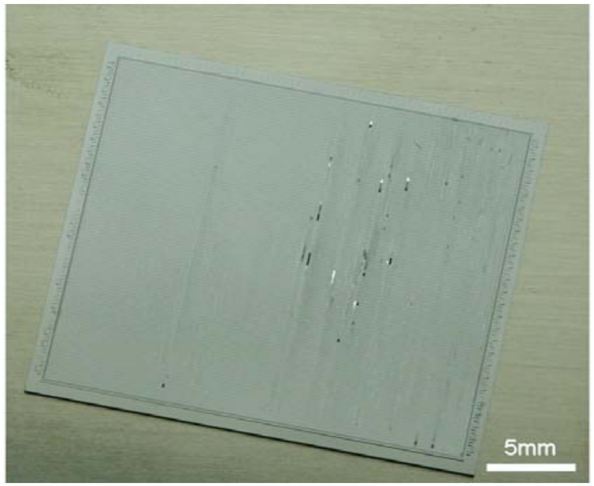




♦LAM-EPFL Micro-mirrors

**100 x 200 mirrors**



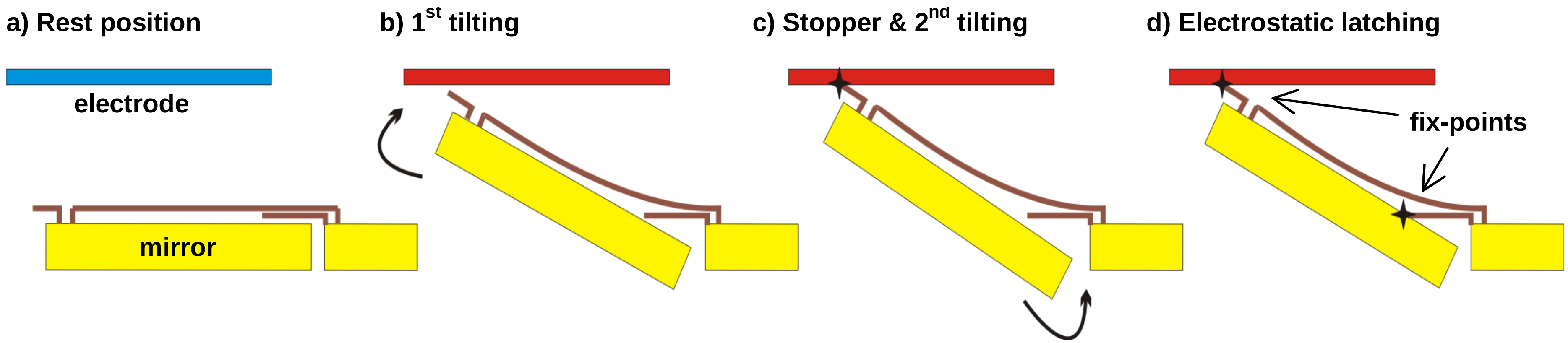



LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

# Programmable slits in Europe (1/2)

## Principle of the micro-mirror array

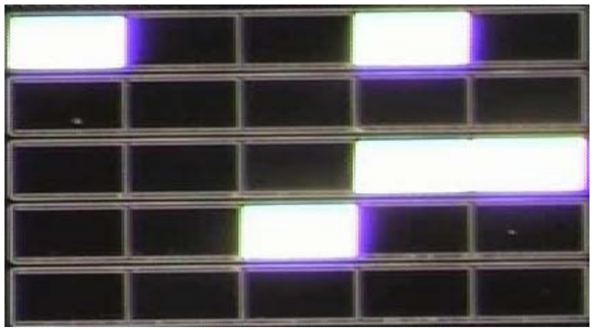



## Realization

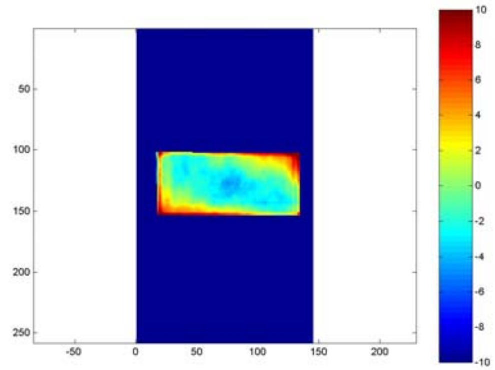
Bulk and surface micro-machining
2 wafer assembly

5x5 µM array

µM: 100 x 200µm$^2$



## Surface quality (in operation)

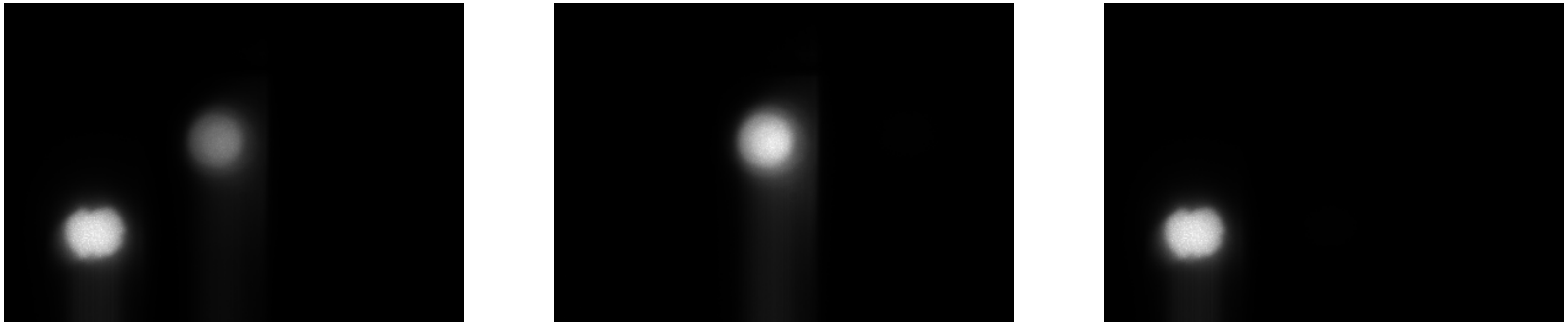



**< 10nm PtV**

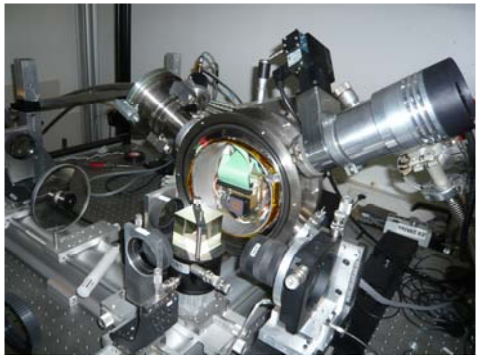
# Programmable slits in Europe (2/2)

## Multi-Object Spectroscopy: bench demonstration

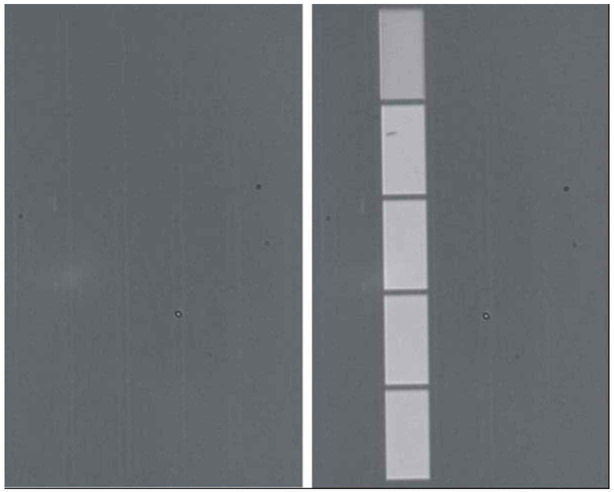
- Object selection



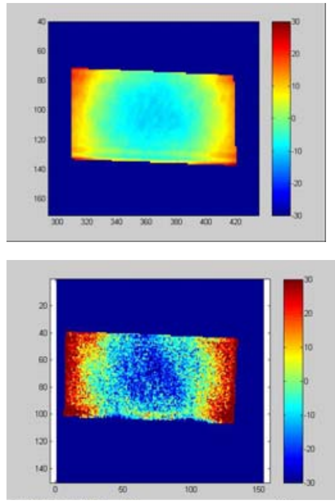
## Operation at cryogenic temperature (92K)



92K
0V

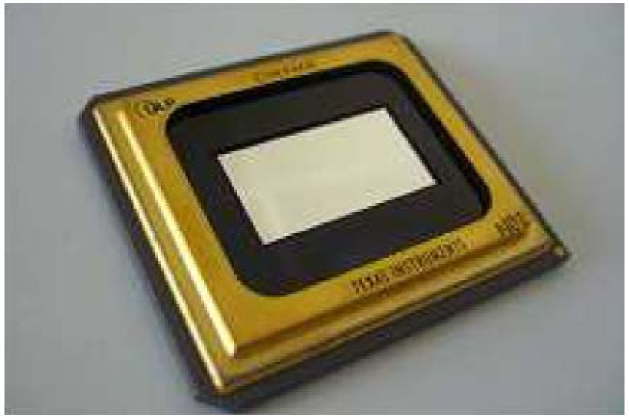


92K
90V



# DMD 2048 x 1080 micromirrors

- DMD chip
  - 2048 x 1080 micromirrors (13.68 µm pitch)
  - Designed for use at ambient temperature, at atmospheric pressure and to be actuated several thousand times per second,
- DMD operation in EUCLID
  - Vacuum, -40°C, static patterns for 1500s
  - Device evaluation: under vacuum, at cold temperature, life test, thermal cycling, physical analysis, radiations, vibration & shock



# Outline

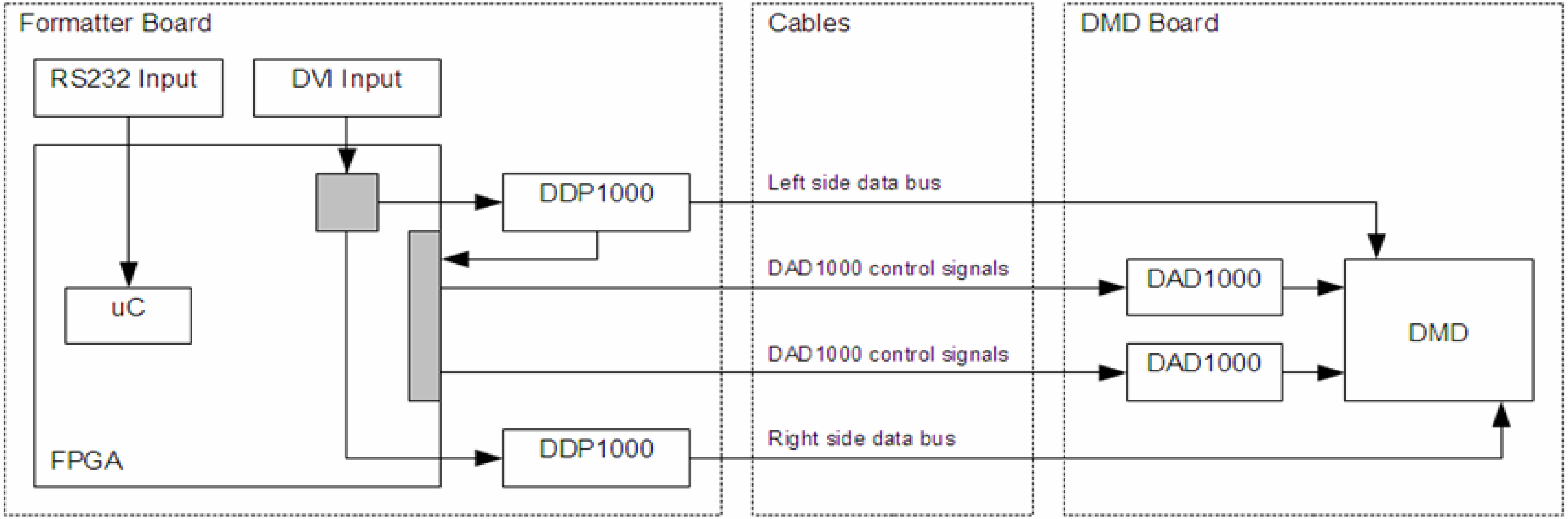
| DMD tag | Test |
|---|---|
| **DMD #20** | Low temperature stress test |
| **DMD #11** | Vacuum in DMD package |
| **DMD #20** | Thermal chamber (LAM) |
| **DMD #10** | Low temperature nominal test (3 cycles) |
| **DMD #5** | Life test (1038 hours) |
| **DMD #22** | Thermal cycling (550 cycles) |
| **DMD #xx** | Physical analysis |
| **DMD #12** | Preliminary room temperature: Problem |
| **DMD #13** | Preliminary room temperature: Problem |
| **DMD #16** | Total Ionising Dose |
| **DMD #21** | Total Ionising Dose |
| **DMD #15** | Protons |
| **DMD #19** | Preliminary room temperature: Problem |
| **DMD #7** | Vibrations |
| **DMD #6** | Shocks |
| **DMD #17** | MOS tests |
| | |
| **Total: 16 DMDs tested at LAM** | |

# Electronic test vehicle

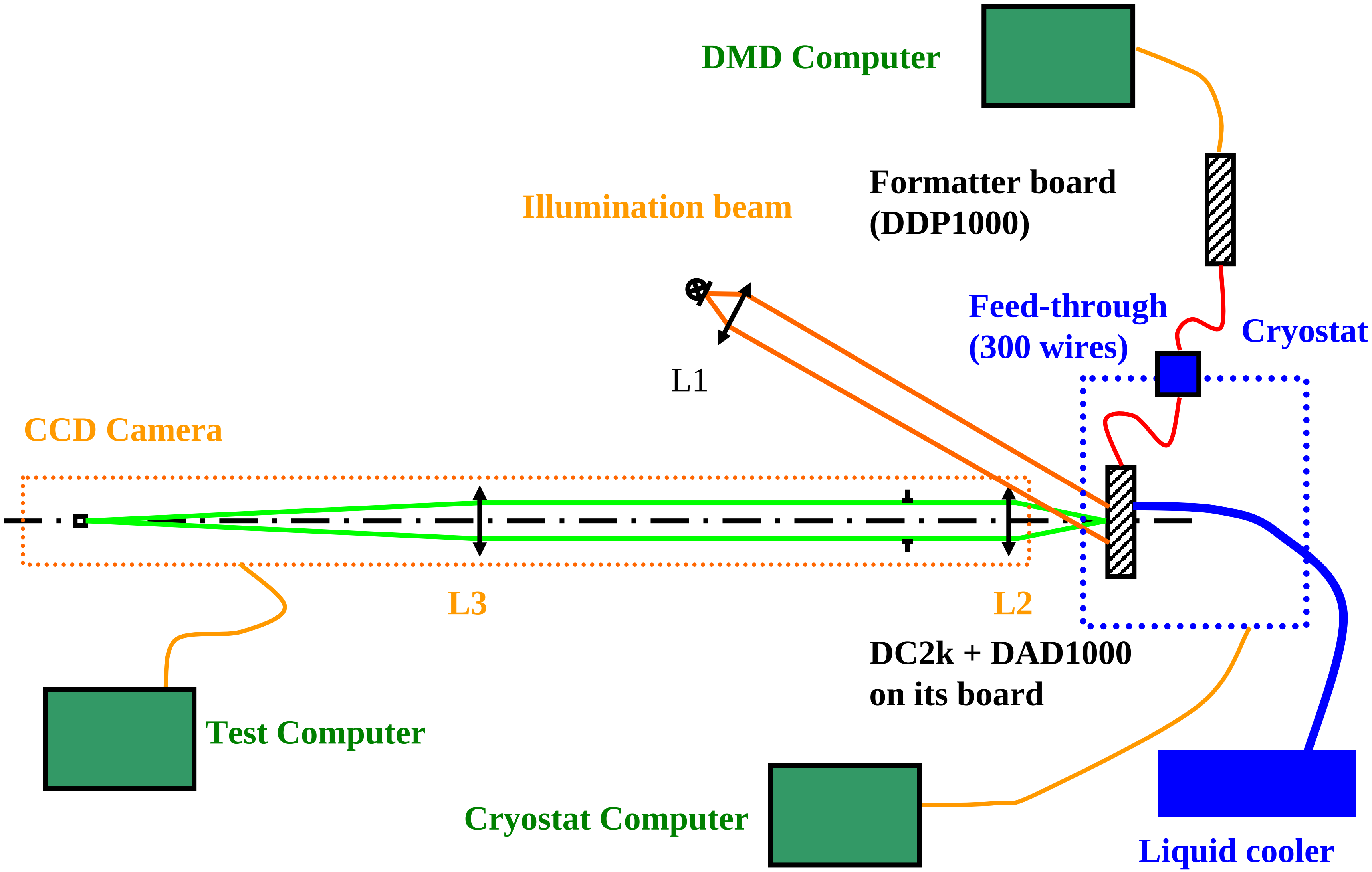
# Electronic test vehicle



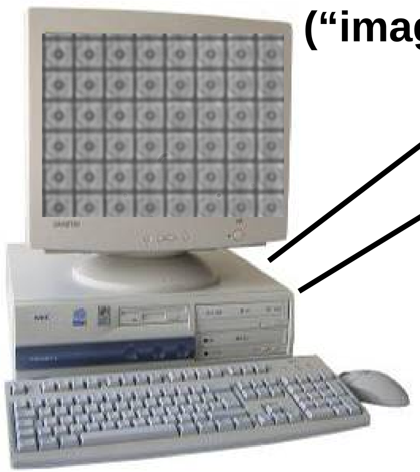
- The electronic test vehicle consists of a formatter board and a DMD board
- The main components includes 2 DDP1000, 2 DAD1000 and 1 high resolution DMD
- The FPGA handles simple image processing and some very important modification to the DAD1000 control signals



# Optical tests

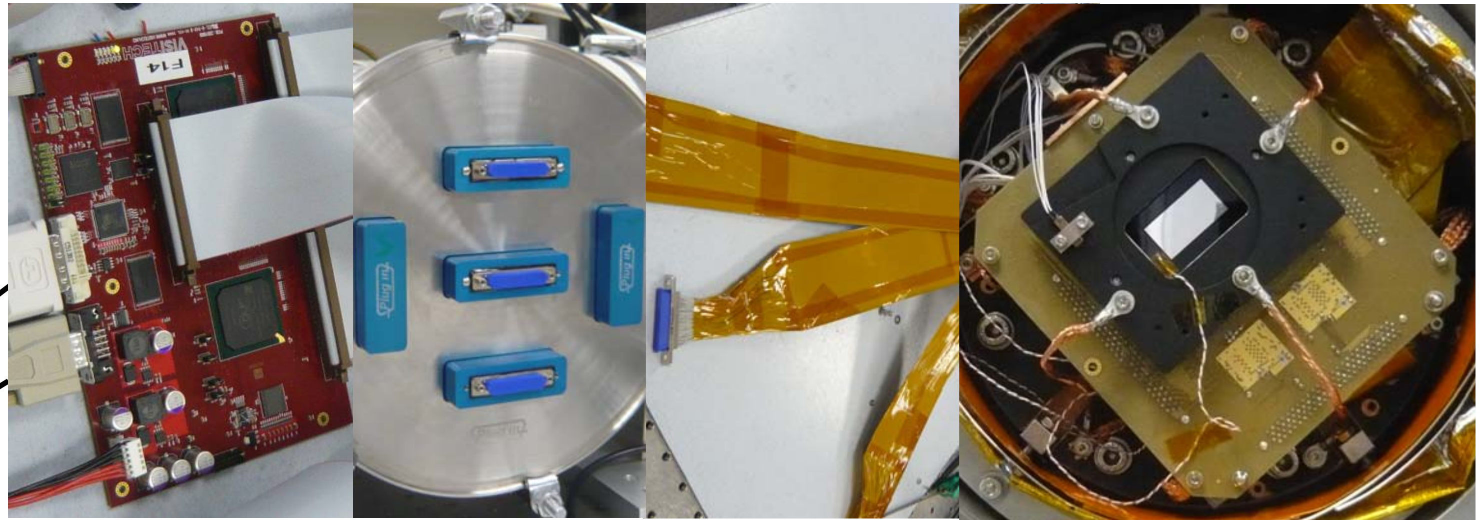


# Cold temperature test set-up



DVI link
("images")

Serial link
(RS 232)

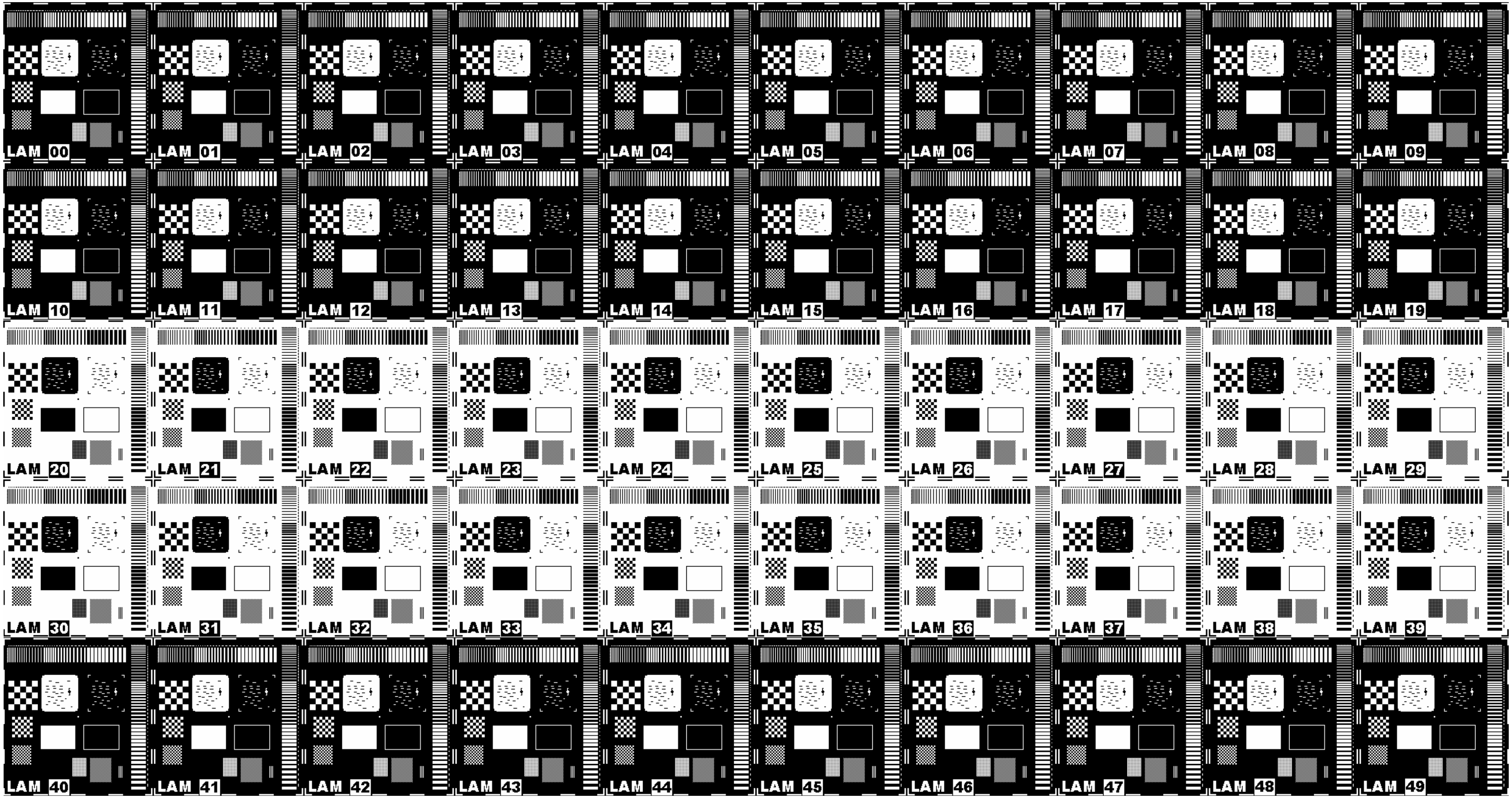


# Cold temperature test set-up

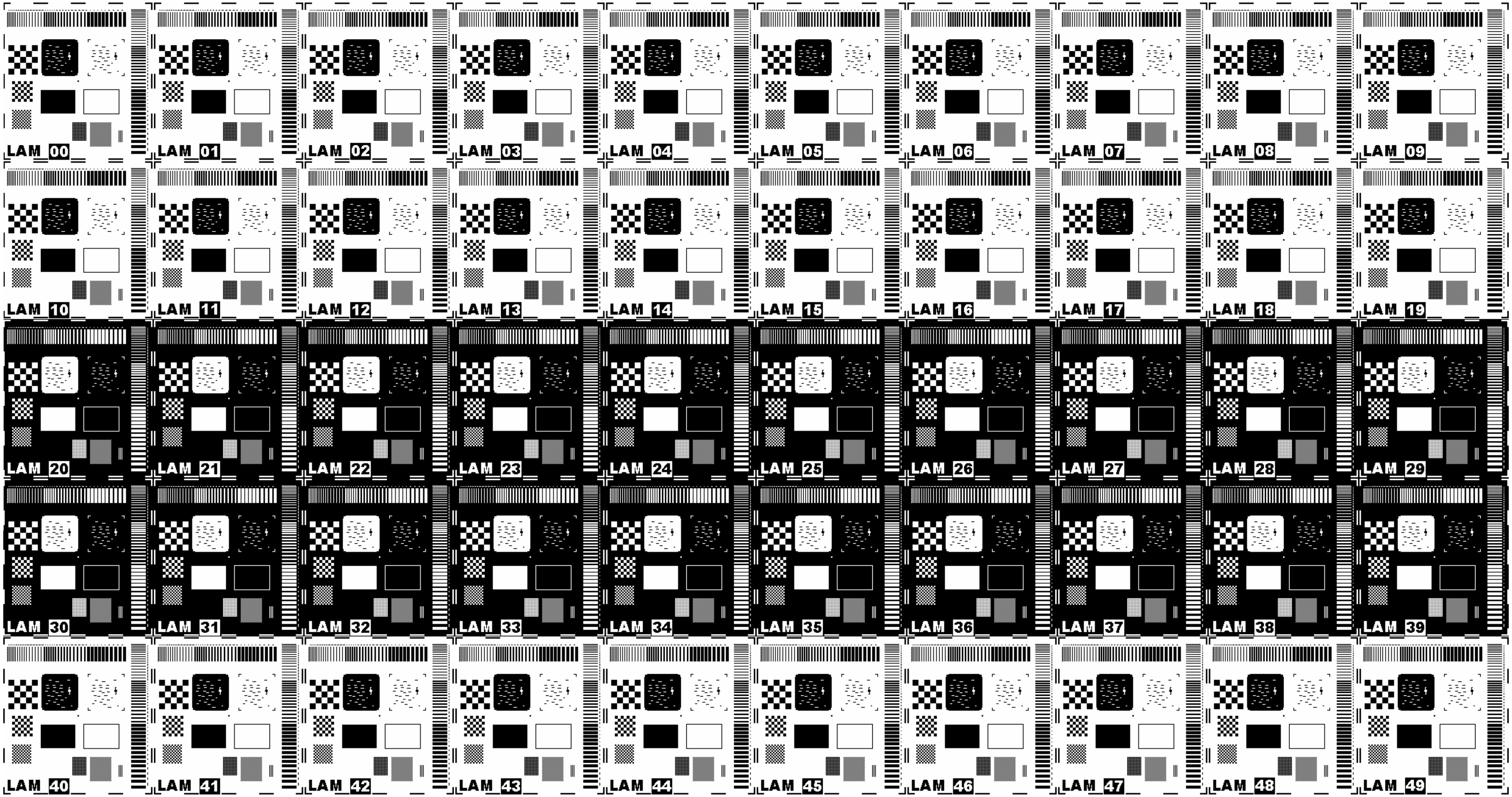
# Optical bench

- Optical parameters
  - 50 zones to be imaged
  - 1 zone = 205 x 216 µM
  - 1 zone = 44280 µM
  - 1k 1k camera
  - 4.07 x 4.07 pixels / µM
  - Illumination by a collimated beam
  - Imagery: two doublets (200mm – 400mm)
  - Device scanning using Newport – MicroContrôle motorized stages (XYZ)

# Pattern 1


LAM 00
LAM 01
LAM 02
LAM 03
LAM 04
LAM 05
LAM 06
LAM 07
LAM 08
LAM 09
LAM 10
LAM 11
LAM 12
LAM 13
LAM 14
LAM 15
LAM 16
LAM 17
LAM 18
LAM 19
LAM 20
LAM 21
LAM 22
LAM 23
LAM 24
LAM 25
LAM 26
LAM 27
LAM 28
LAM 29
LAM 30
LAM 31
LAM 32
LAM 33
LAM 34
LAM 35
LAM 36
LAM 37
LAM 38
LAM 39
LAM 40
LAM 41
LAM 42
LAM 43
LAM 44
LAM 45
LAM 46
LAM 47
LAM 48
LAM 49

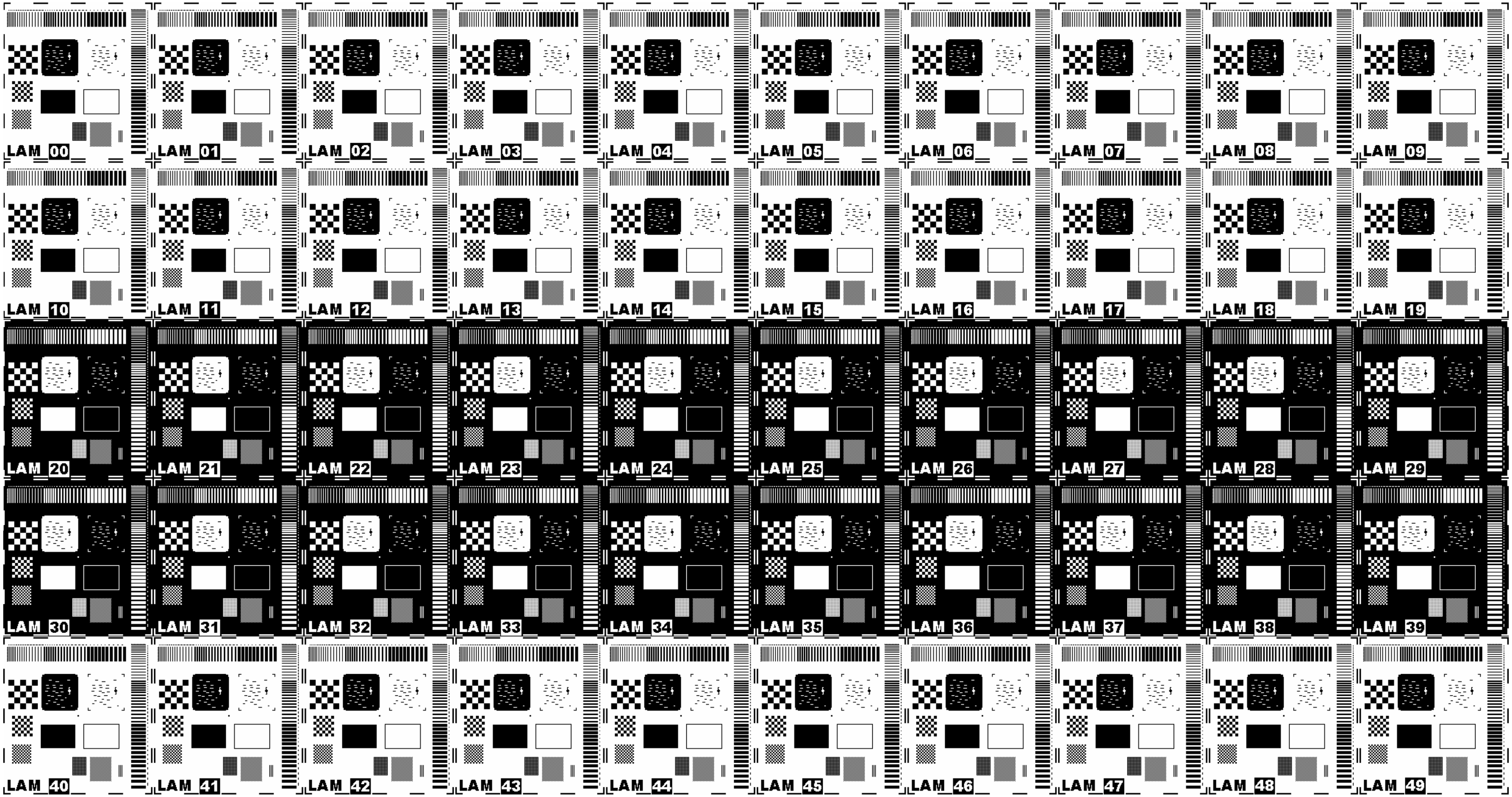
# Pattern 2


LAM 00
LAM 01
LAM 02
LAM 03
LAM 04
LAM 05
LAM 06
LAM 07
LAM 08
LAM 09
LAM 10
LAM 11
LAM 12
LAM 13
LAM 14
LAM 15
LAM 16
LAM 17
LAM 18
LAM 19
LAM 20
LAM 21
LAM 22
LAM 23
LAM 24
LAM 25
LAM 26
LAM 27
LAM 28
LAM 29
LAM 30
LAM 31
LAM 32
LAM 33
LAM 34
LAM 35
LAM 36
LAM 37
LAM 38
LAM 39
LAM 40
LAM 41
LAM 42
LAM 43
LAM 44
LAM 45
LAM 46
LAM 47
LAM 48
LAM 49

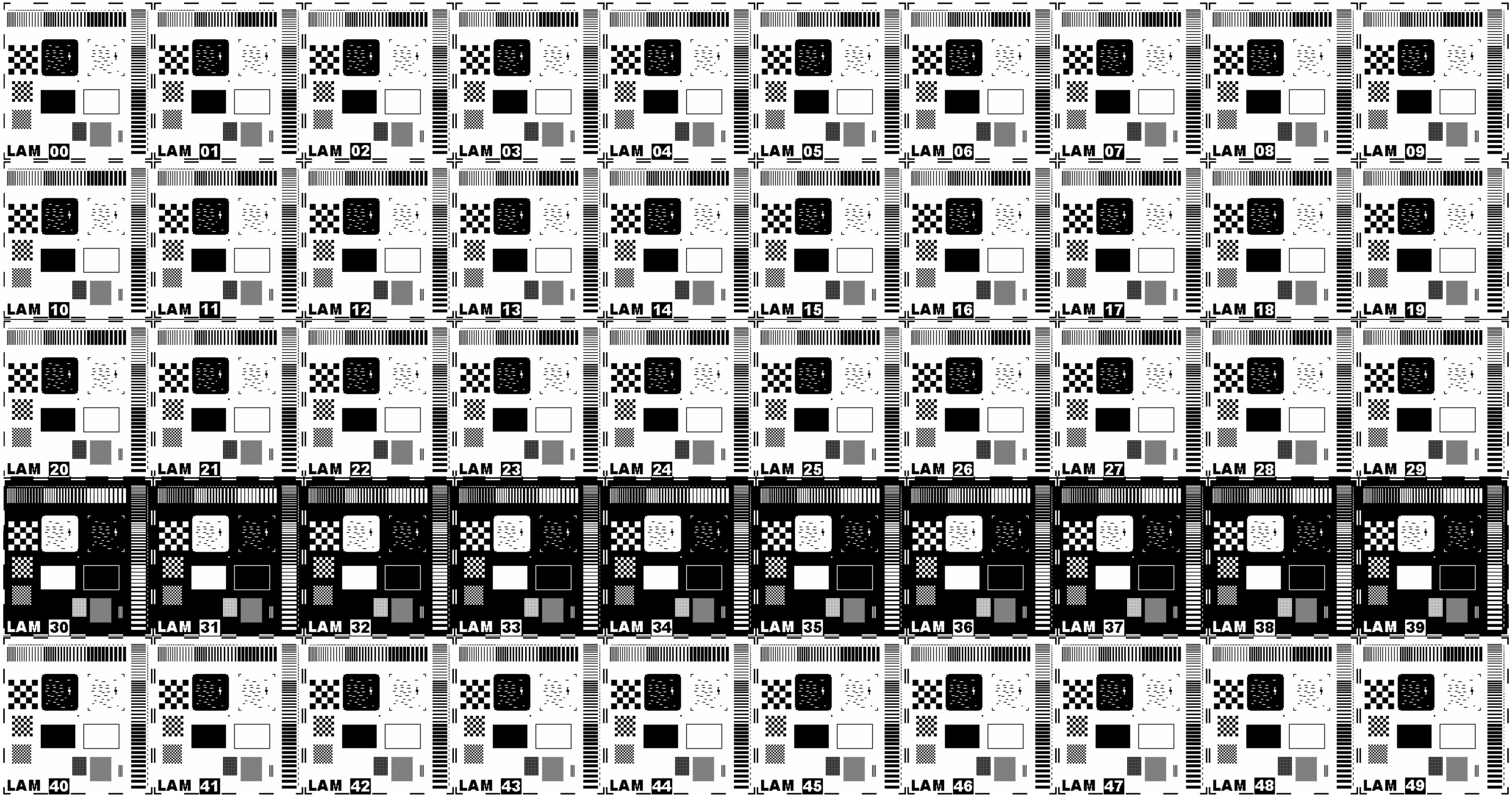
LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

# Test patterns for EUCLID

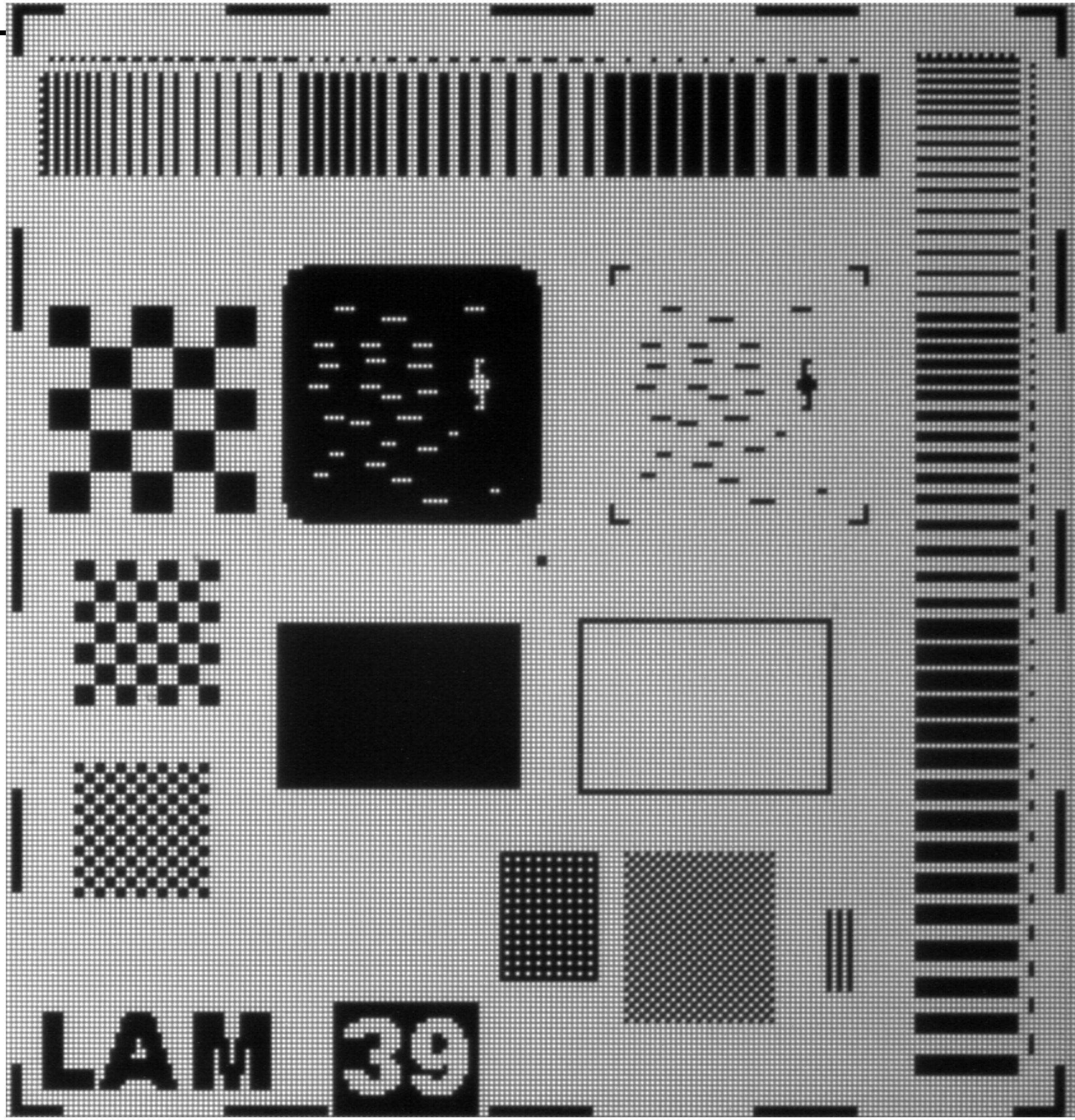
VISITECH



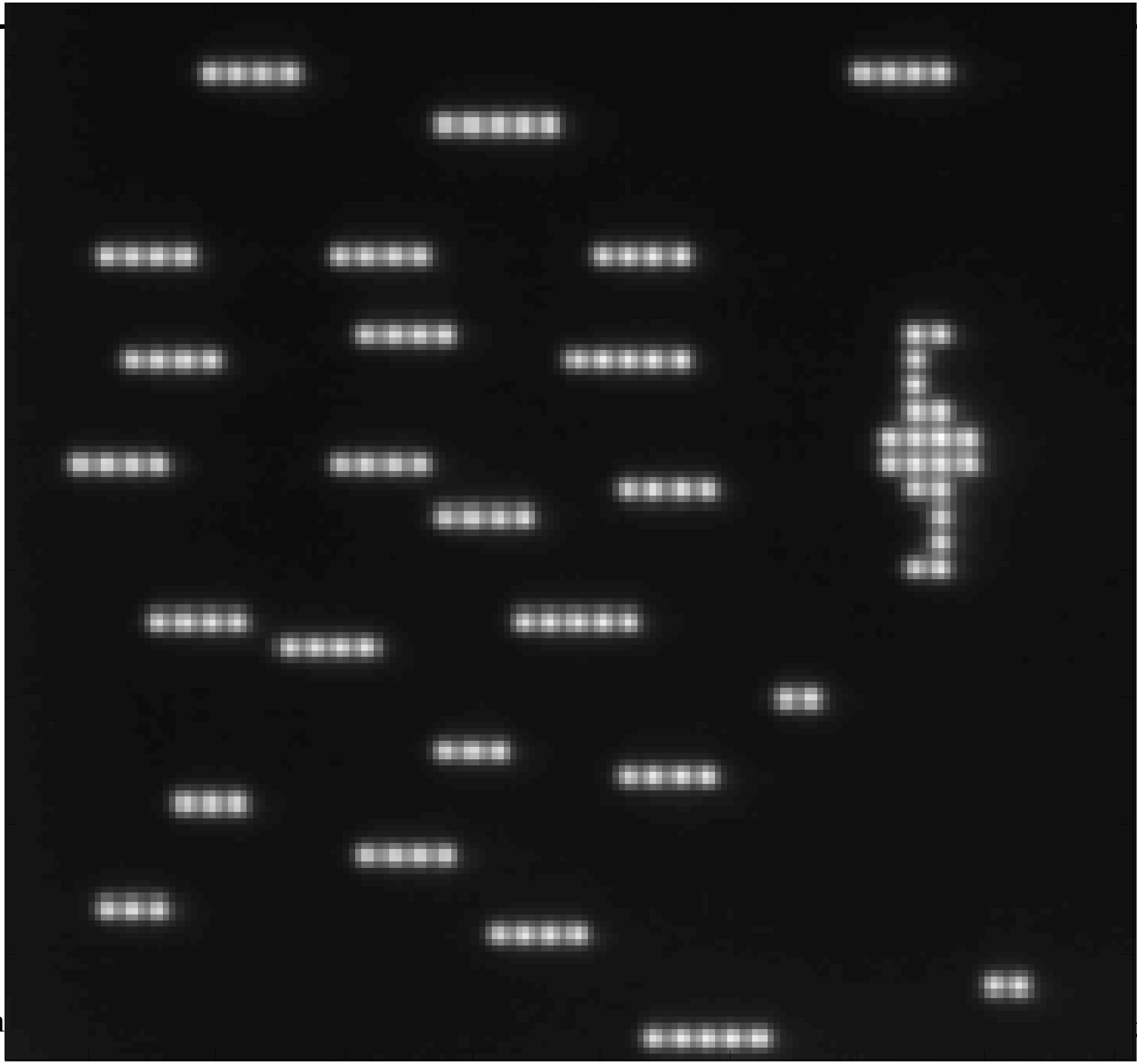
# Test patterns for EUCLID



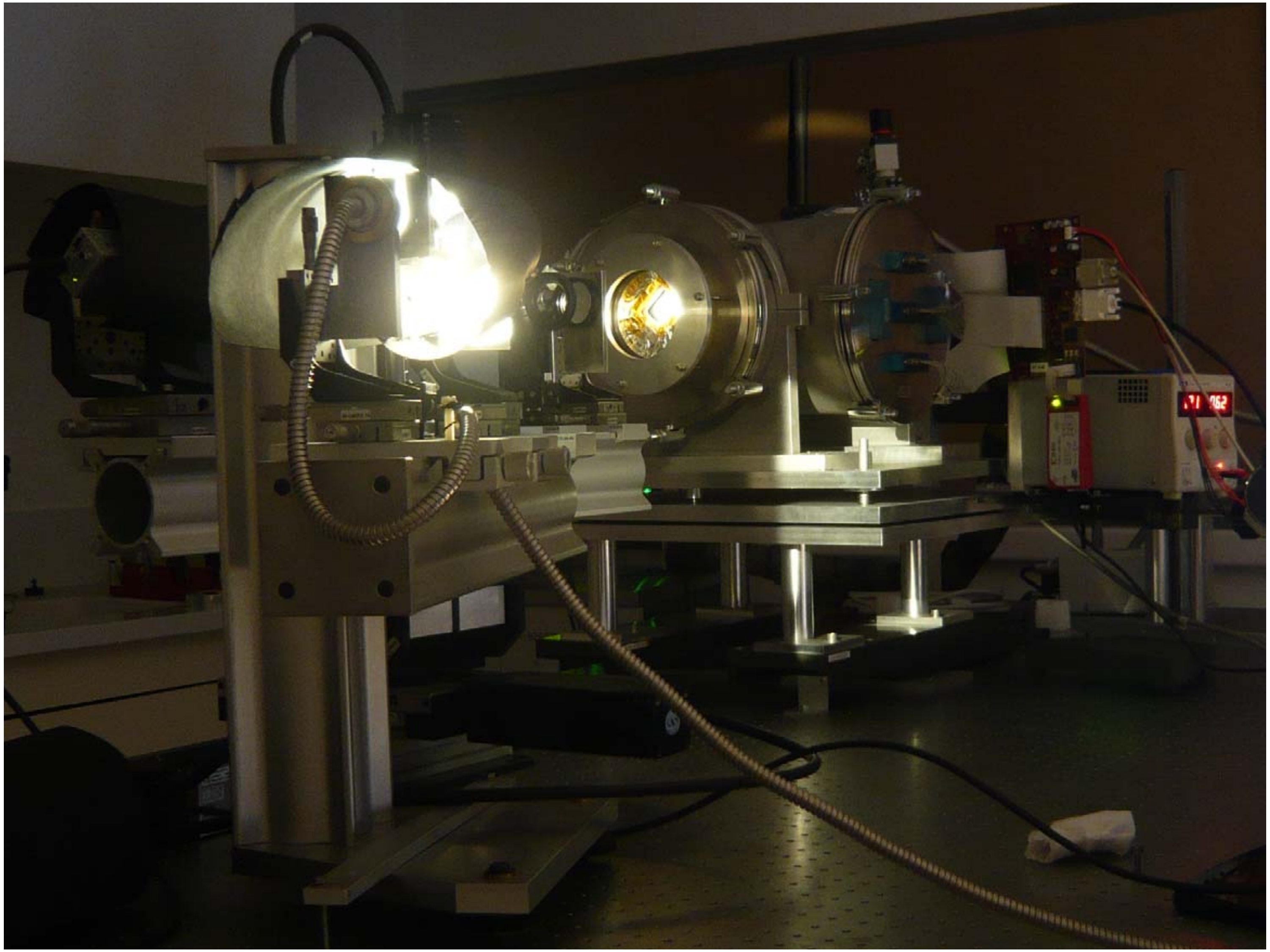
# Patterns



# Patterns



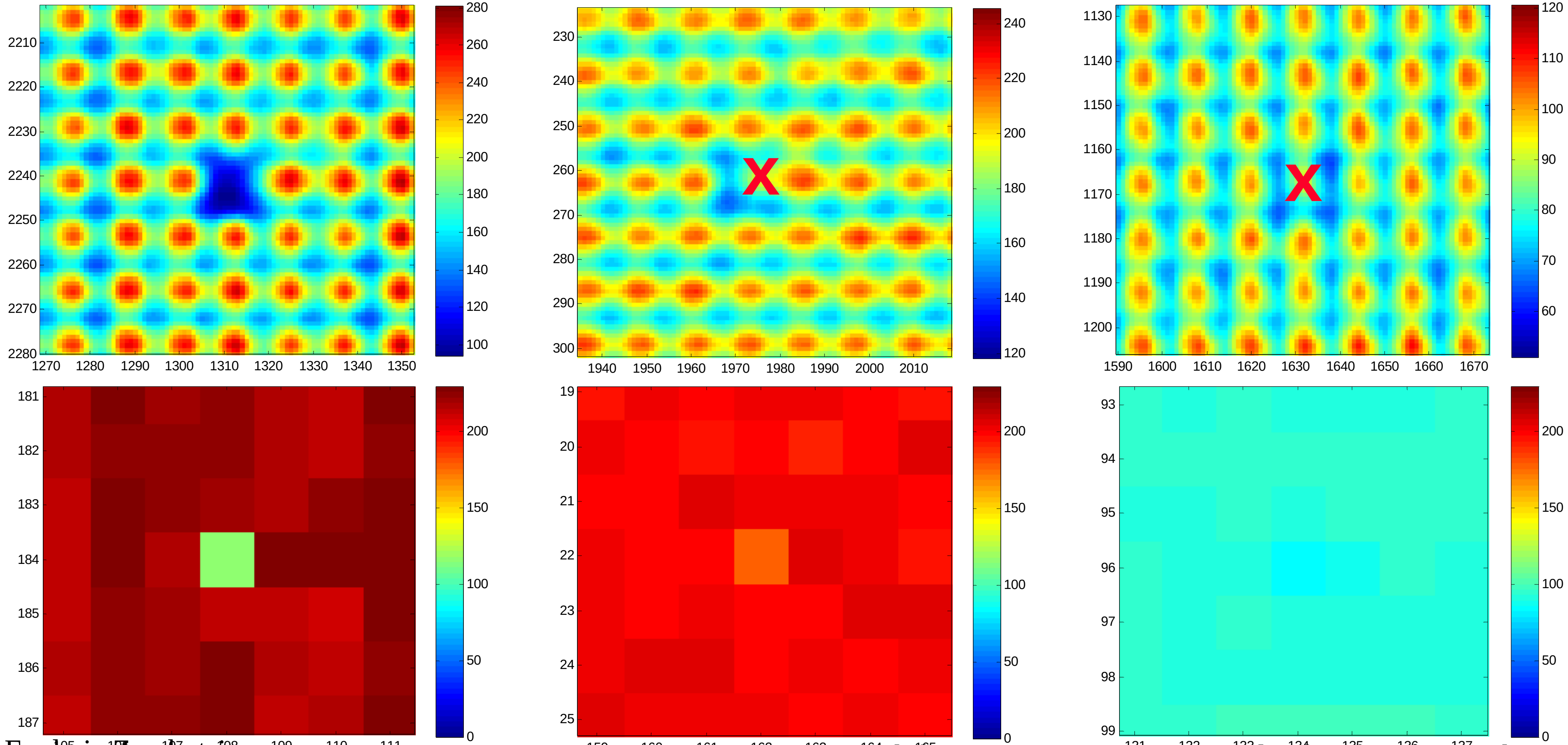
# DMD under test



# Results analysis

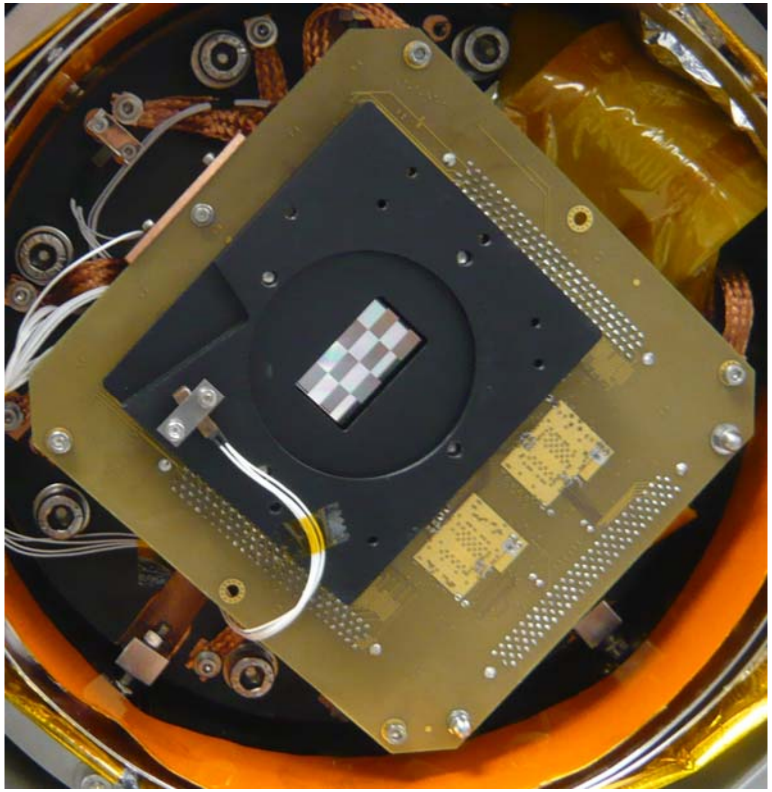
VISITECH

- Mirrors behaviour: fine analysis
  - Affected mirrors are blocked, lossy or weak mirrors
  - Average throughput and Centroid calculation

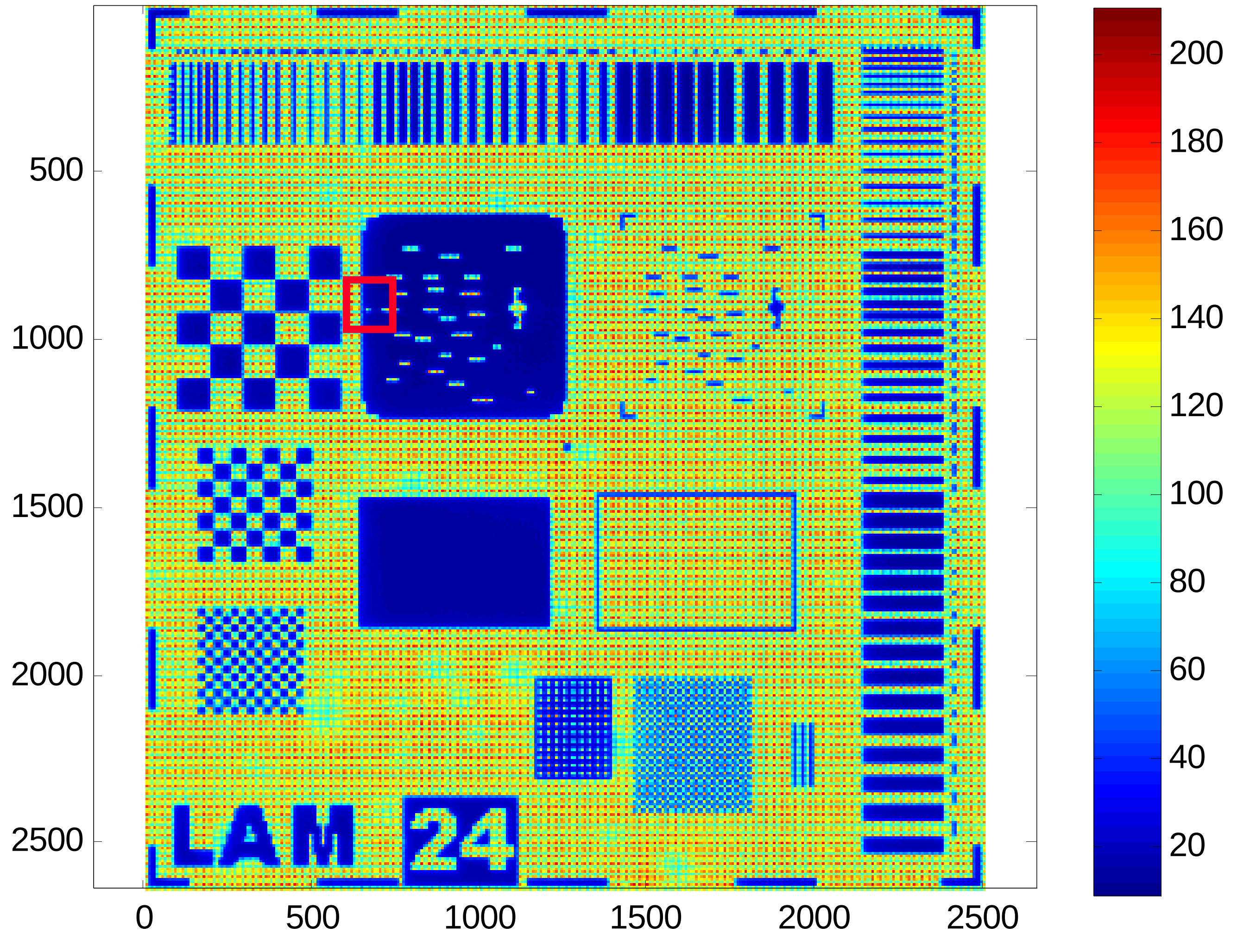


# Cold temperature test

- Cold temperature step stress test
  - First tested device
  - 12 temperature steps **(+20, +10, 0, -10, -20, -30, -35, -40, -45, -50, -55, -60)**



# DMD #20



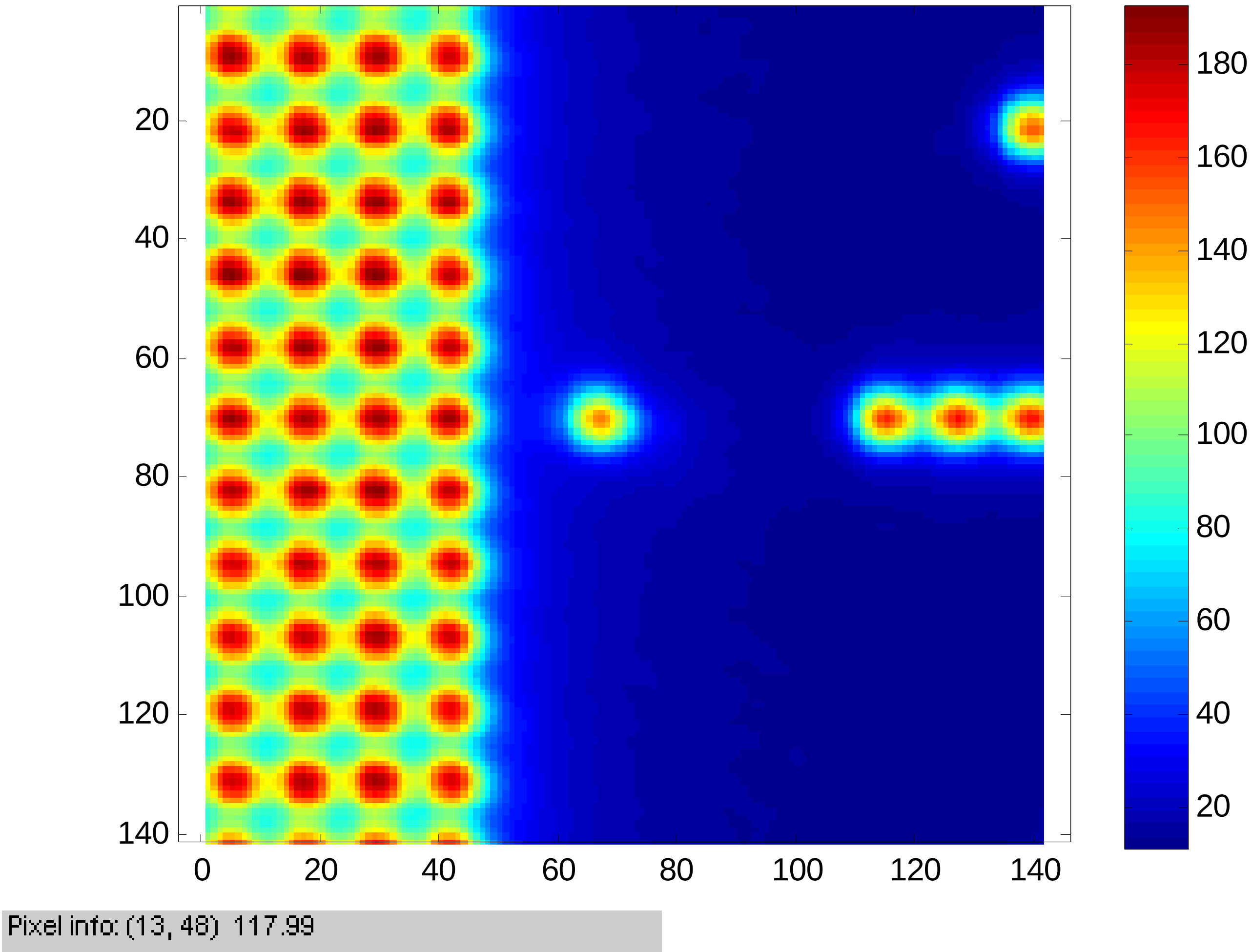
500
1000
1500
2000
2500
0
500
1000
1500
2000
2500
LAM
24
200
180
160
140
120
100
80
60
40
20


T°
+ 24°C

LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

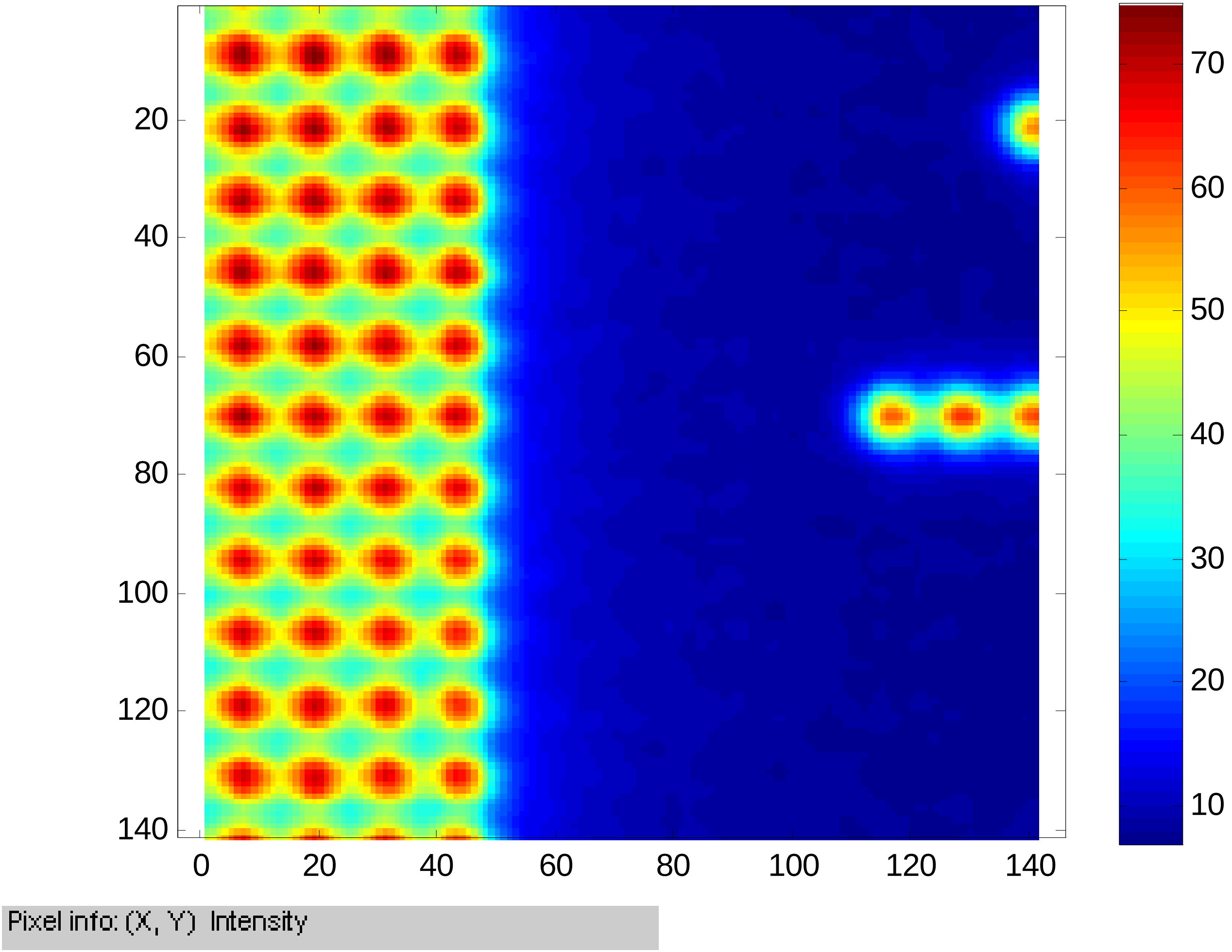
# DMD #20

VISITECH



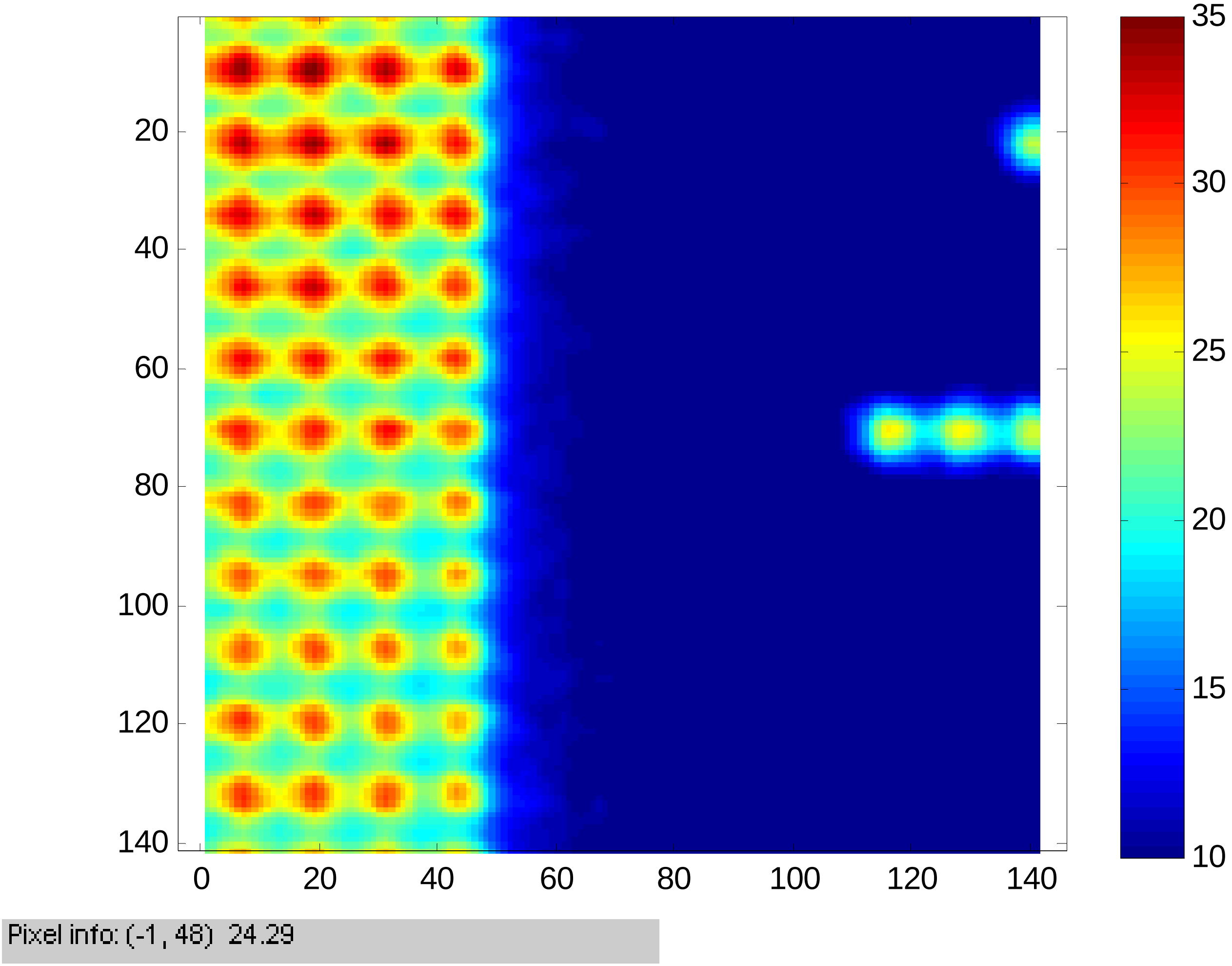

T°
+ 24°C

# DMD #20


20
40
60
80
100
120
140
0
20
40
60
80
100
120
140
70
60
50
40
30
20
10
Pixel info: (X, Y) Intensity

**T°**
**- 41°C**

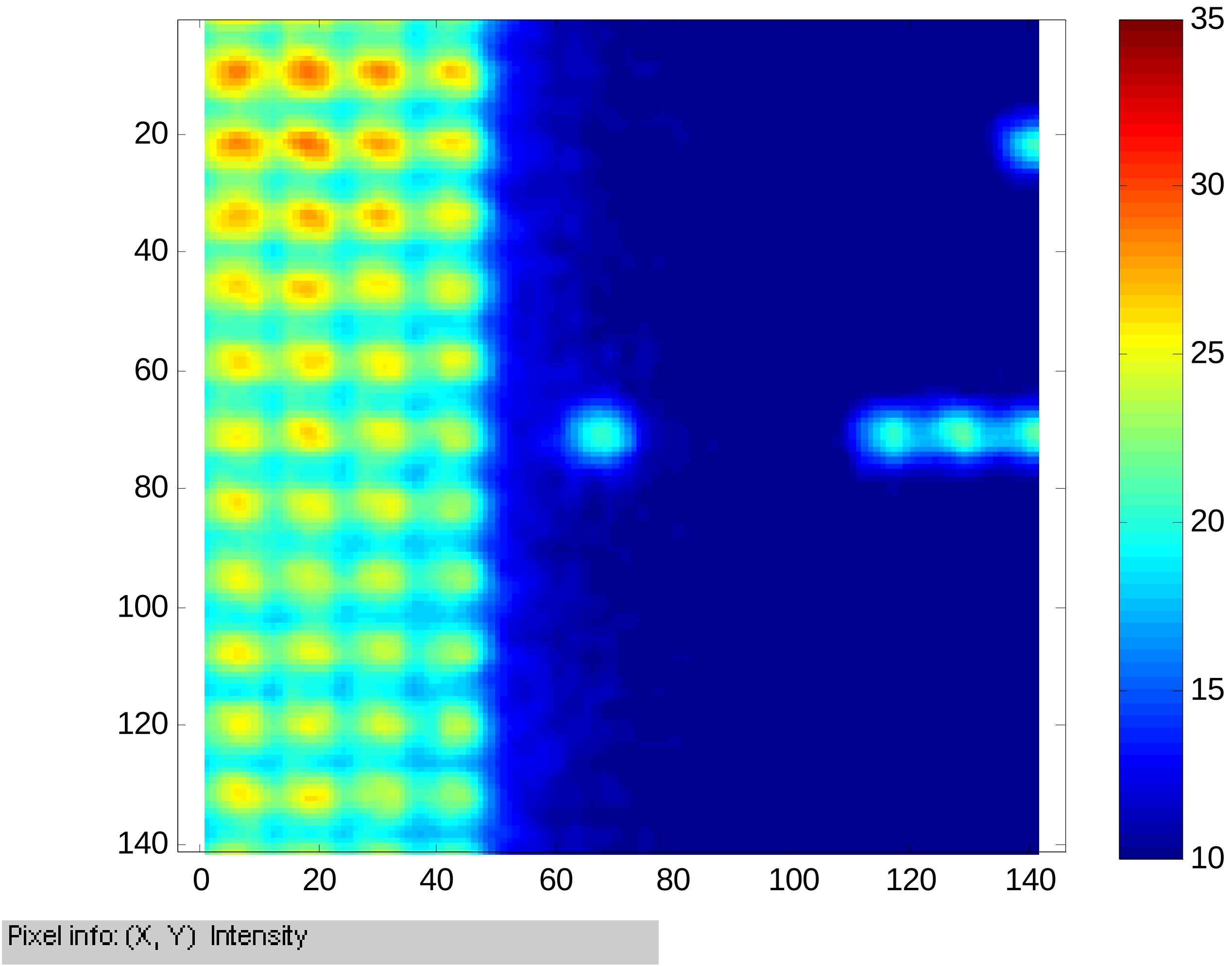
# DMD #20



20
40
60
80
100
120
140
0
20
40
60
80
100
120
140
35
30
25
20
15
10
Pixel info: (-1, 48) 24.29


**T°**
**- 50°C**

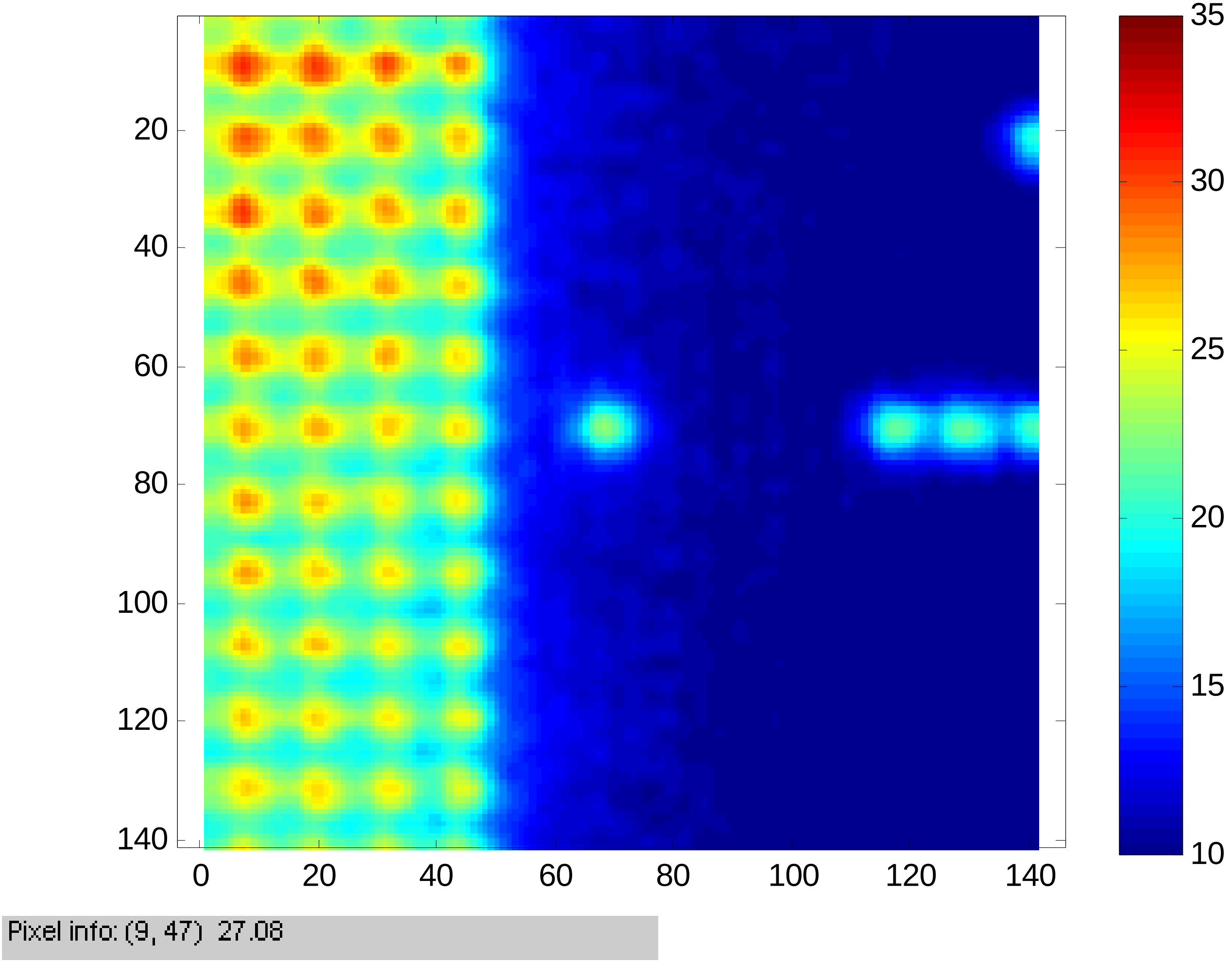
# DMD #20


20
40
60
80
100
120
140
0
20
40
60
80
100
120
140
35
30
25
20
15
10
Pixel info: (X, Y) Intensity

**T°**

**- 55°C**

DMD #20

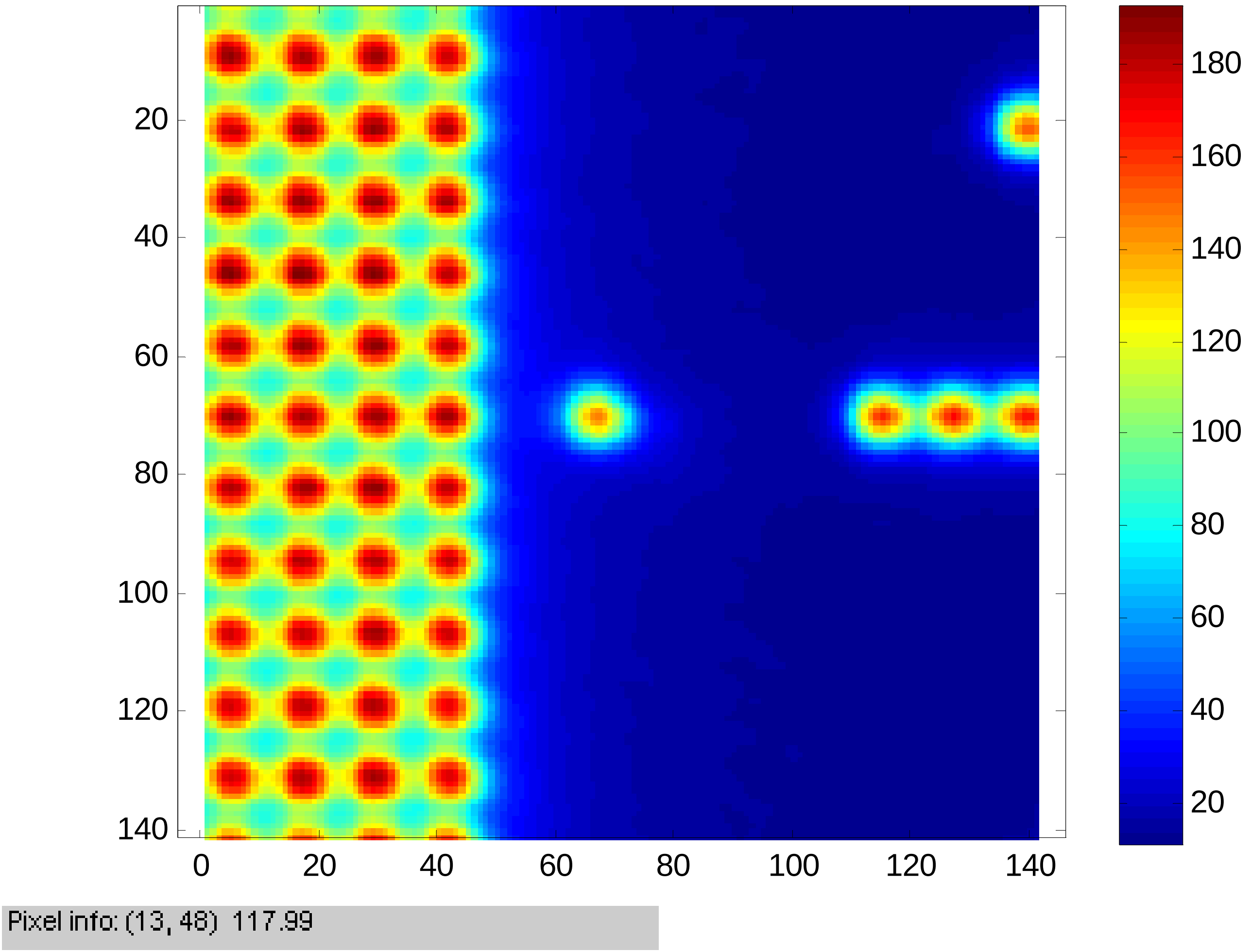

20
40
60
80
100
120
140
0
20
40
60
80
100
120
140
35
30
25
20
15
10
Pixel info: (9, 47) 27.08

**T°**

**- 60°C**

# DMD #20



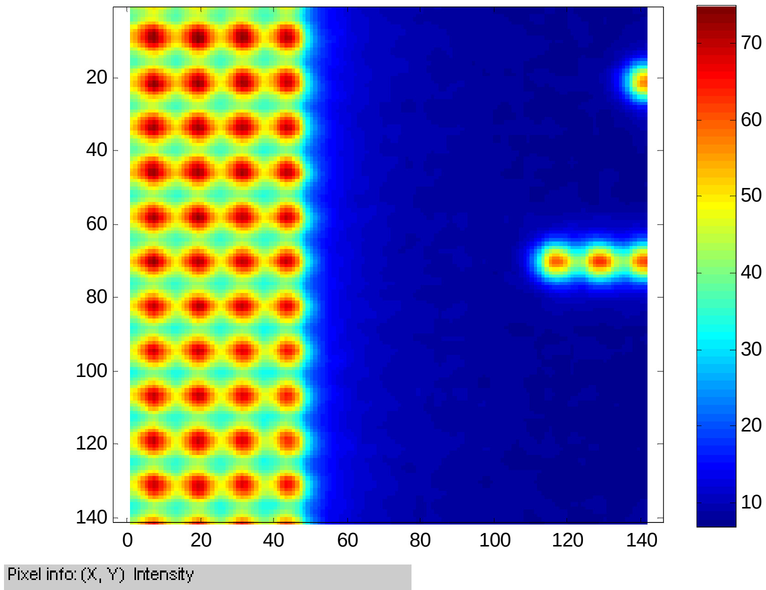

20
40
60
80
100
120
140
0
20
40
60
80
100
120
140
180
160
140
120
100
80
60
40
20
Pixel info: (13, 48) 117.99

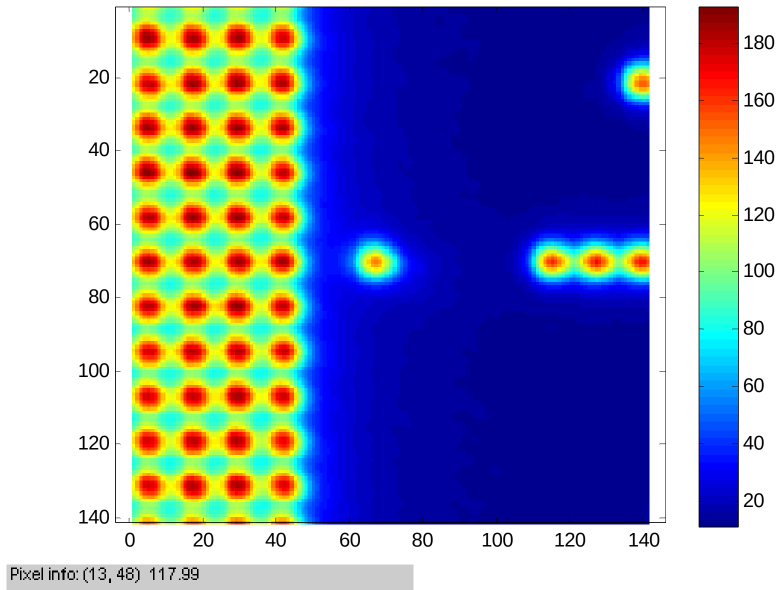
**T°**

**+ 24°C**

# DMD test analysis

- DMD
  - Permanent failure on some micro-mirrors
  - Failure starts at -55°C
  - Safe operation at -40°C



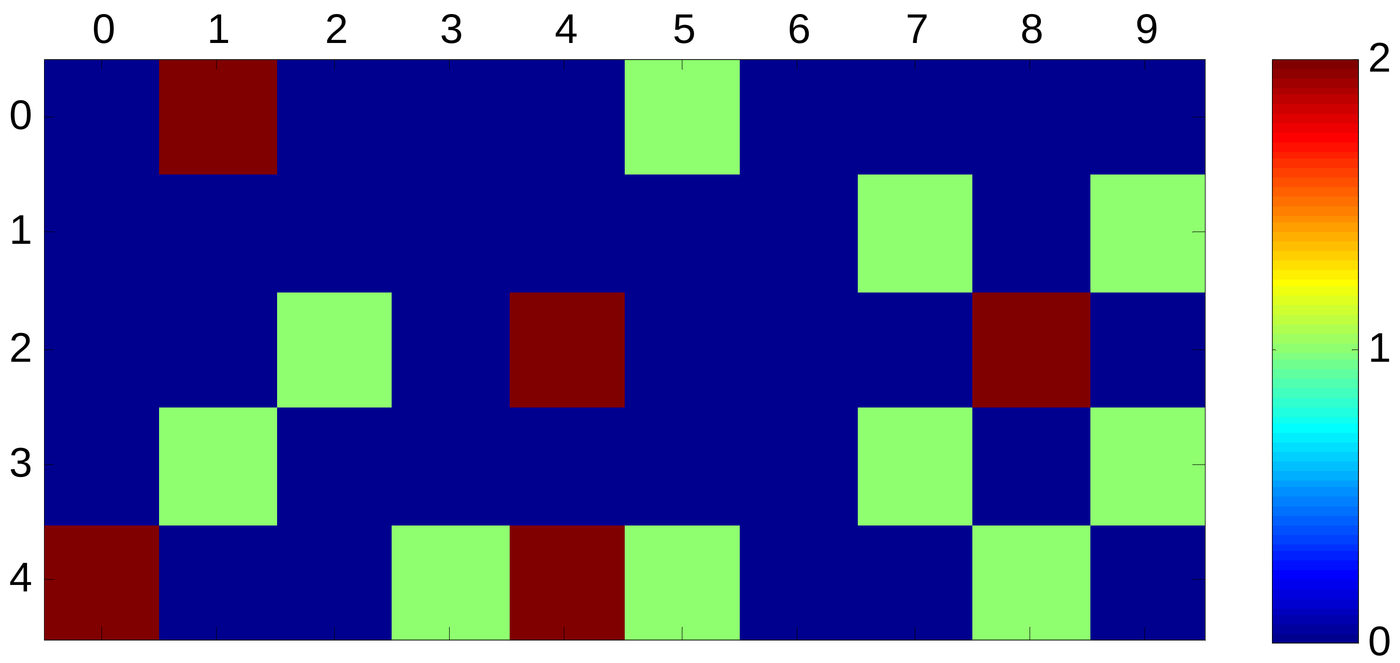



# Outline

| DMD tag | Test |
|---|---|
| **DMD #20** | Low temperature stress test |
| **DMD #11** | Vacuum in DMD package |
| **DMD #20** | Thermal chamber (LAM) |
| **DMD #10** | **Low temperature nominal test (3 cycles)** |
| **DMD #5** | Life test (1038 hours) |
| **DMD #22** | Thermal cycling (550 cycles) |
| **DMD #xx** | Physical analysis |
| **DMD #12** | Preliminary room temperature: Problem |
| **DMD #13** | Preliminary room temperature: Problem |
| **DMD #16** | Total Ionising Dose |
| **DMD #21** | Total Ionising Dose |
| **DMD #15** | Protons |
| **DMD #19** | Preliminary room temperature: Problem |
| **DMD #7** | Vibrations |
| **DMD #6** | Shocks |
| **DMD #17** | MOS tests |
| | |
| **Total: 16 DMDs tested at LAM** | |

## Results analysis

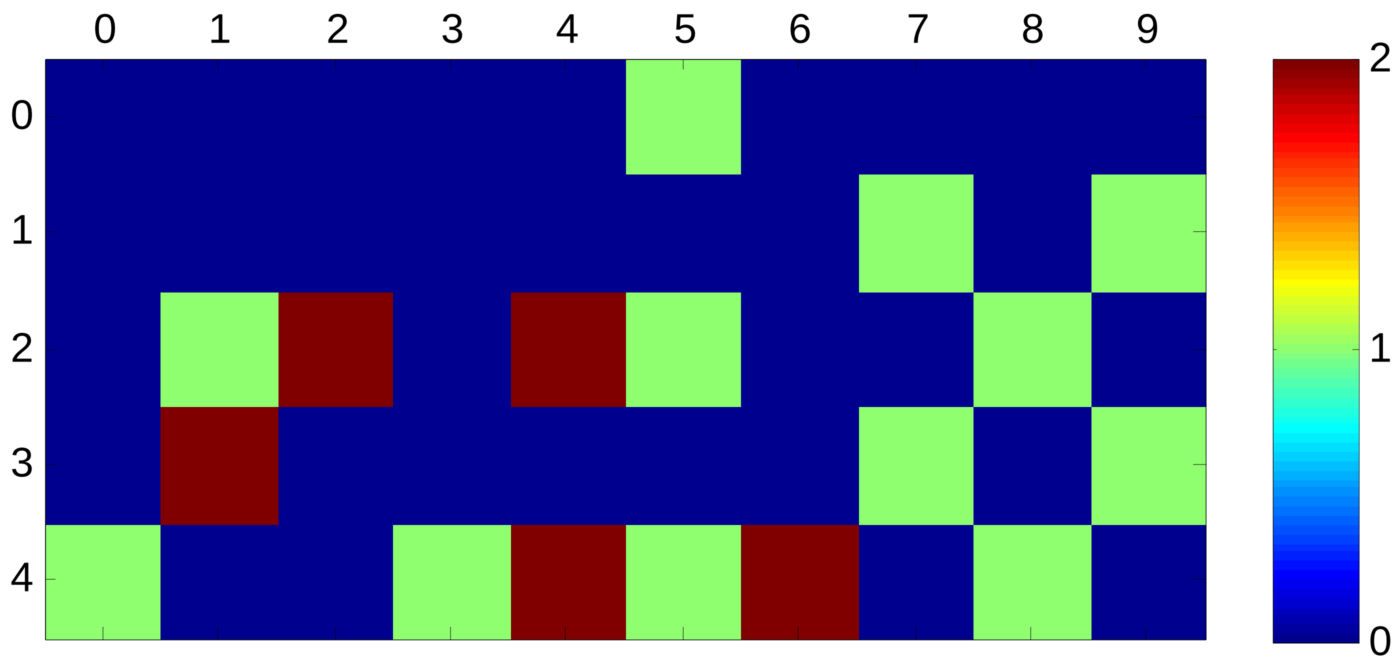
- Detection at +20°C
  - Lossy micro-mirrors + weak micro-mirrors: 19




**No blocked mirror**

# Results analysis

- Detection at -38°C
  - Lossy micro-mirrors + weak micro-mirrors: 22

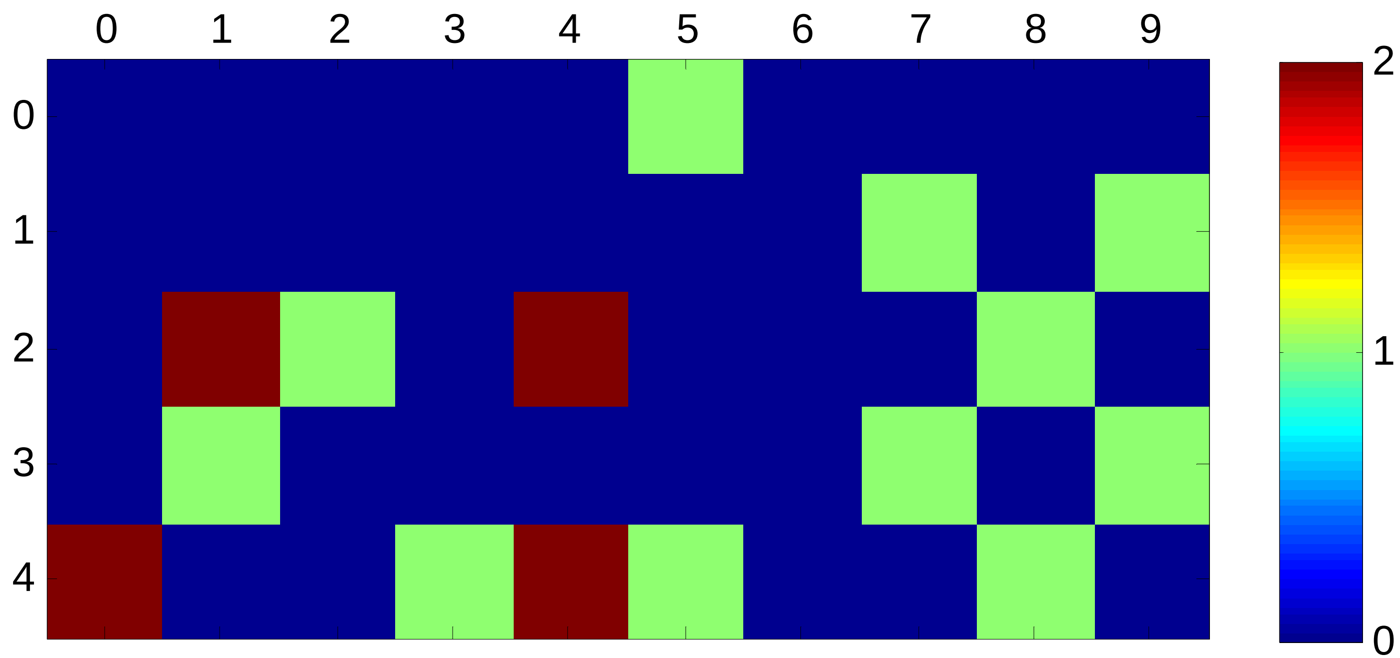



**No blocked mirror**

# Results analysis



- Detection at -40°C
  - Lossy micro-mirrors + weak micro-mirrors: 18

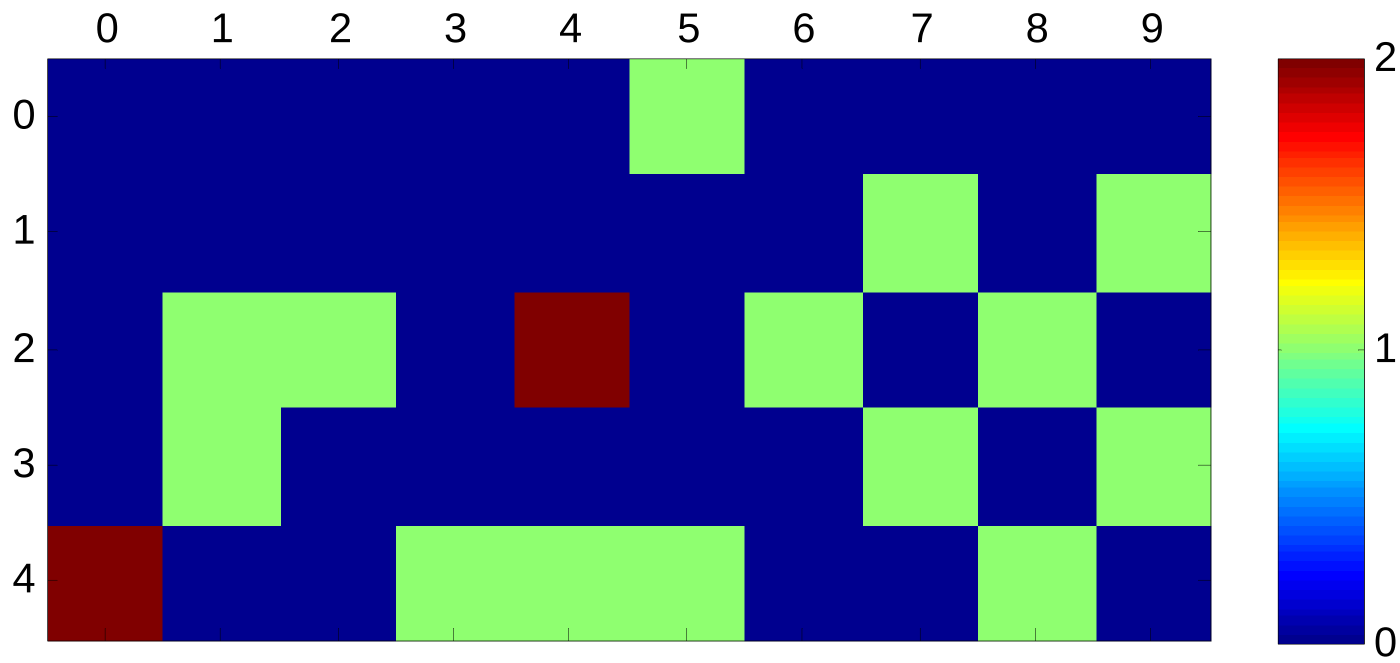



**No blocked mirror**

# Results analysis



- Detection at -40°C
  - Lossy micro-mirrors + weak micro-mirrors: 18




**No blocked mirror**

# Results analysis

- The micro-mirrors are tilting at -40°C
  - ➔ No blocked mirrors, 15 lossy mirrors
  - ➔ Differential affected mirrors between ambient and cold, in EUCLID mode, as low as: **3 to 5 of 2 million mirrors**
- Same behavior for mirrors tilting frequently or fixed in a position as for EUCLID mission (duration 1500s)
- If lossy mirrors are detected at ambient, they stay lossy at cold temp.
- Additional affected mirrors are only in the weak position

# Outline

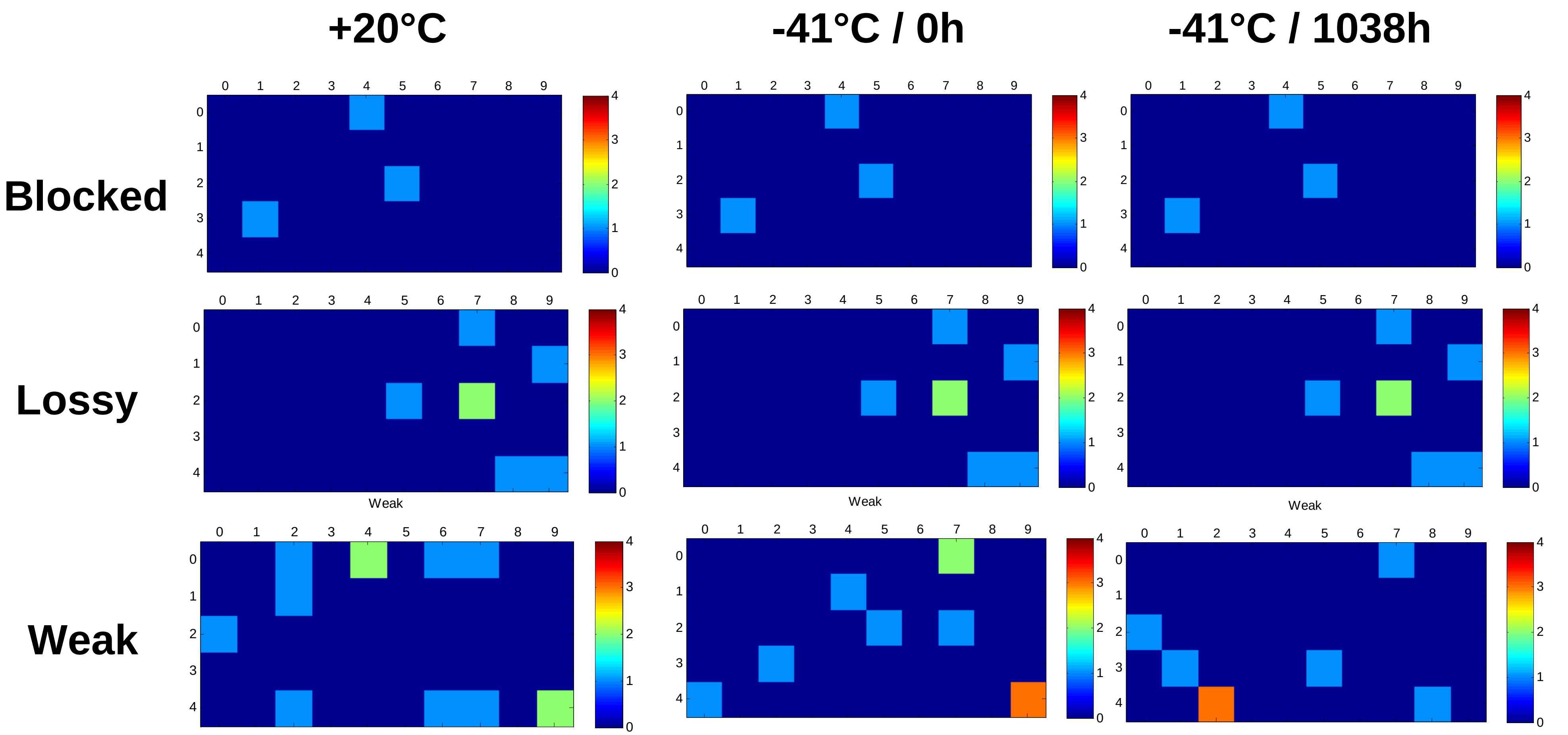
| DMD tag | Test |
|---|---|
| **DMD #20** | Low temperature stress test |
| **DMD #11** | Vacuum in DMD package |
| **DMD #20** | Thermal chamber (LAM) |
| **DMD #10** | Low temperature nominal test (3 cycles) |
| **DMD #5** | **Life test (1038 hours)** |
| **DMD #22** | Thermal cycling (550 cycles) |
| **DMD #xx** | Physical analysis |
| **DMD #12** | Preliminary room temperature: Problem |
| **DMD #13** | Preliminary room temperature: Problem |
| **DMD #16** | Total Ionising Dose |
| **DMD #21** | Total Ionising Dose |
| **DMD #15** | Protons |
| **DMD #19** | Preliminary room temperature: Problem |
| **DMD #7** | Vibrations |
| **DMD #6** | Shocks |
| **DMD #17** | MOS tests |
| | |
| **Total: 16 DMDs tested at LAM** | |

## Test procedure for the life test

- Life test concept
  - EUCLID-type patterns applied during whole life test
  - Identical duty cycle for all mirrors
  - Optical tests done during whole life test
- Actual test cycle
  - Pattern 1 during 1500s (central line tilting)
  - Tilting of the whole device between pattern 1 and pattern 2: 60s
  - Pattern 2 during 1500s (central line tilting)
- Life test dates
  - Lasted for **1038 hours**
  - 13 full device measurements during the life test

# Failure analysis (life test)

♦ No degradation of DMD performances after 1038 h of life test



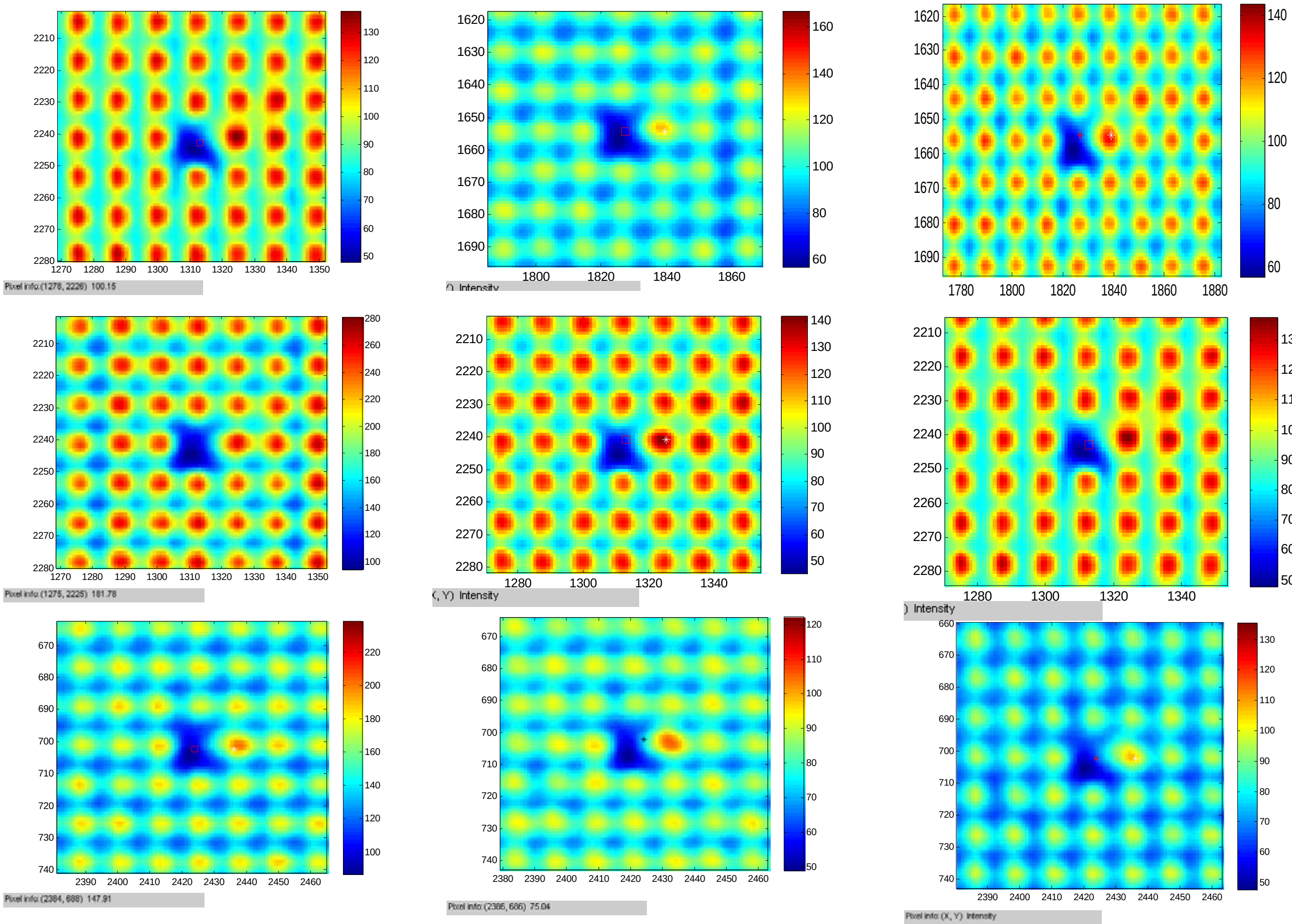
# Failure analysis (life test)

- Life test, 3 blocked mirrors, +20°C, -41°C/0h, -41°C/1038 hours

**Zone 4**

**Zone 25**

**Zone 31**



# Outline

| DMD tag | Test |
|---|---|
| **DMD #20** | Low temperature stress test |
| **DMD #11** | Vacuum in DMD package |
| **DMD #20** | Thermal chamber (LAM) |
| **DMD #10** | Low temperature nominal test (3 cycles) |
| **DMD #5** | Life test (1038 hours) |
| **DMD #22** | **Thermal cycling (550 cycles)** |
| **DMD #xx** | Physical analysis |
| **DMD #12** | Preliminary room temperature: Problem |
| **DMD #13** | Preliminary room temperature: Problem |
| **DMD #16** | Total Ionising Dose |
| **DMD #21** | Total Ionising Dose |
| **DMD #15** | Protons |
| **DMD #19** | Preliminary room temperature: Problem |
| **DMD #7** | Vibrations |
| **DMD #6** | Shocks |
| **DMD #17** | MOS tests |
| | |
| **Total: 16 DMDs tested at LAM** | |

# Thermal cycling

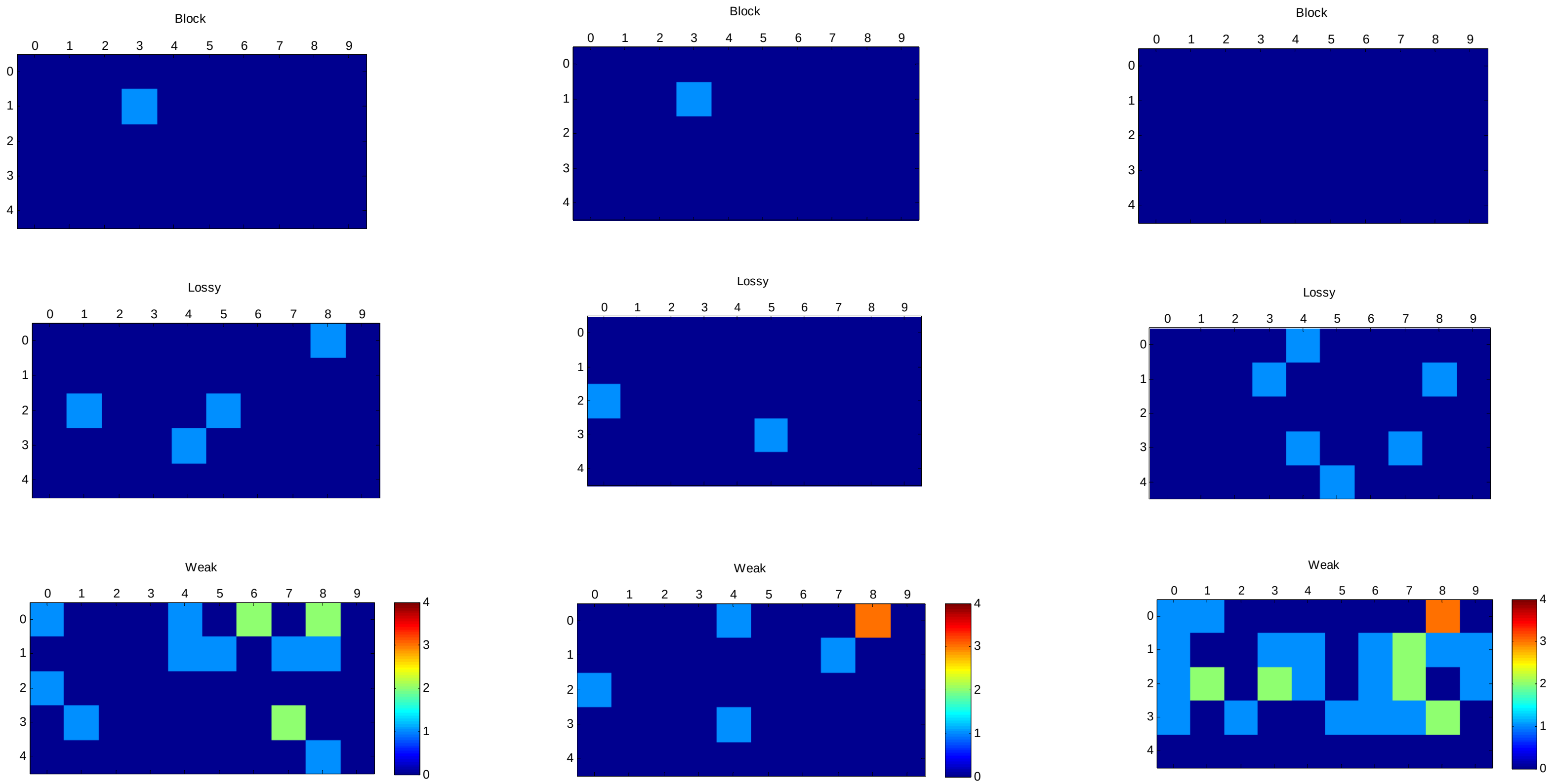
- Thermal cycling of DMD #22
  - Pre-test at room temperature
  - First test at cold temperature, -40°C
  - Five cycles [room temperature / -40°C], device non operating
  - Test at cold temperature, -40°C
  - Shipping to INAF/IASF
  - 249 cycles [room temperature / -40°C], device non operating
  - Shipping to LAM
  - Test at cold temperature, -40°C, at LAM
  - 313 cycles [room temperature / -40°C], device non operating
  - Shipping to LAM
  - Test at cold temperature, -40°C, at LAM

# Failure analysis (thermal cycling)

VISITECH

- **No degradation of DMD performances after thermal cycling**

| | +20°C | -41°C /249 cycles | -41°C / 562 cycles |
|---|---|---|---|
| **Blocked** | | | |
| **Lossy** | | | |
| **Weak** | | | |

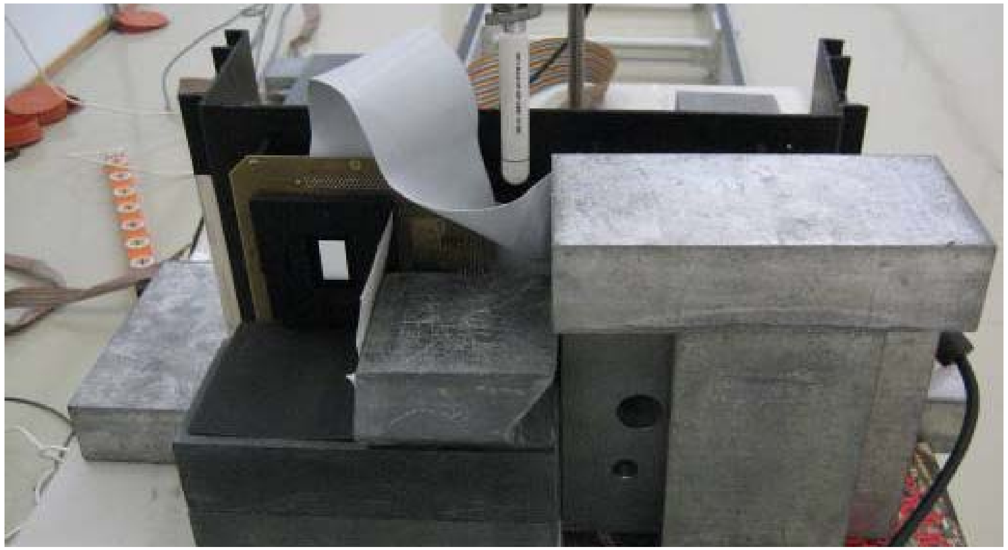


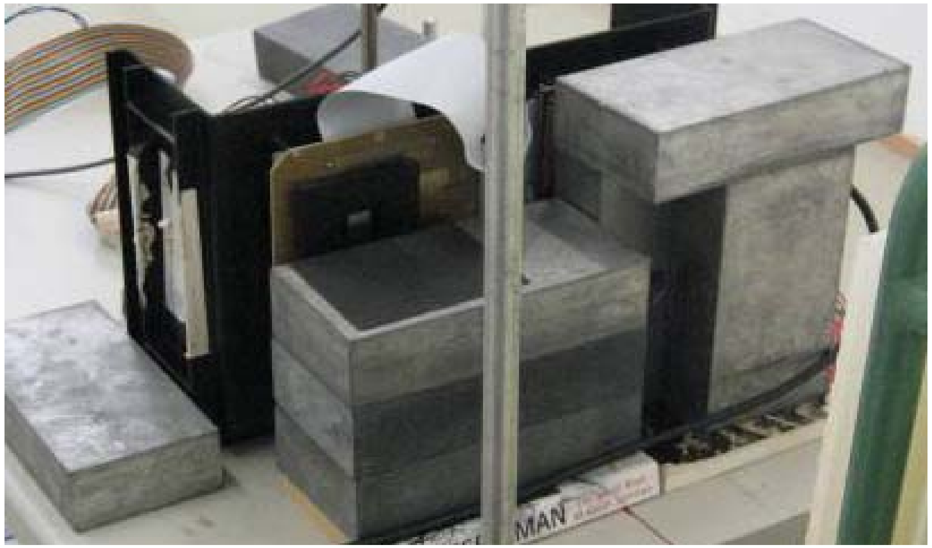
# Outline

| DMD tag | Test |
|---|---|
| **DMD #20** | Low temperature stress test |
| **DMD #11** | Vacuum in DMD package |
| **DMD #20** | Thermal chamber (LAM) |
| **DMD #10** | Low temperature nominal test (3 cycles) |
| **DMD #5** | Life test (1038 hours) |
| **DMD #22** | Thermal cycling (550 cycles) |
| **DMD #xx** | Physical analysis |
| **DMD #12** | Preliminary room temperature: Problem |
| **DMD #13** | Preliminary room temperature: Problem |
| **DMD #16** | **Total Ionising Dose** |
| **DMD #21** | **Total Ionising Dose** |
| **DMD #15** | **Protons** |
| **DMD #19** | Preliminary room temperature: Problem |
| **DMD #7** | Vibrations |
| **DMD #6** | Shocks |
| **DMD #17** | MOS tests |
| | |
| **Total: 16 DMDs tested at LAM** | |

# Radiation test

- Radiation test: Total Ionizing Dose (TID), done at ESTEC
- All measurements and visual observations show that
  - The DMD starts to get affected at a dose rate of approximately 10 Krads
  - The DMD will work with only minor artifacts up to a dose rate of about 16 Krads



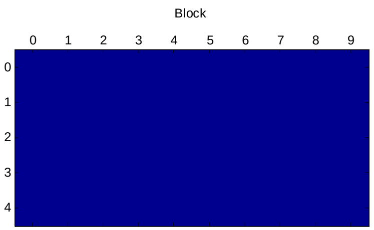


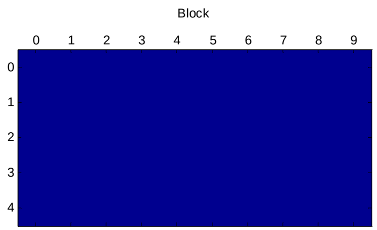
## Failure analysis (TID radiation)

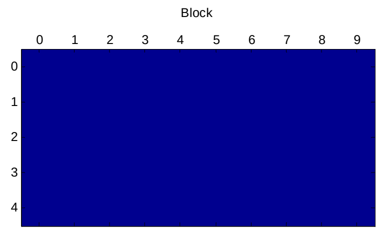
### ♦No degradation of DMD performances after TID radiation

+20°C / before TID | +20°C /after TID | +20°C /after TID + 1 week

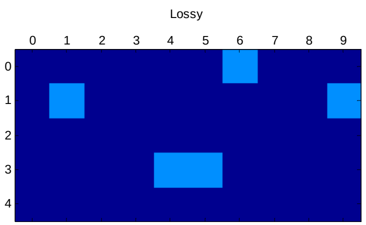
**Blocked**

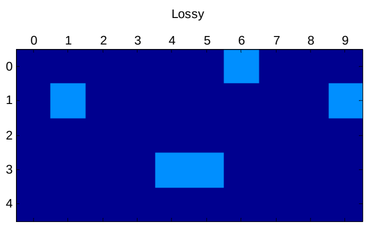


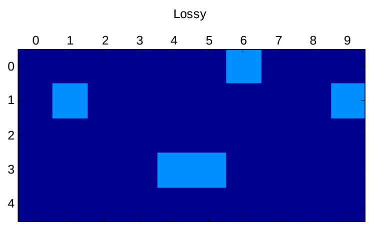



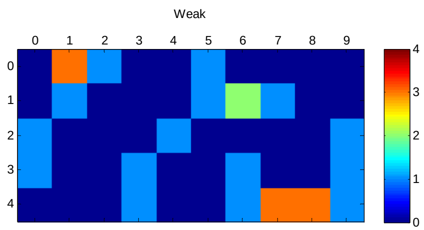

**Lossy**

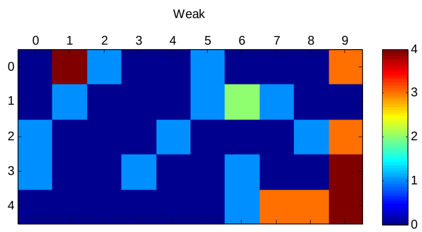


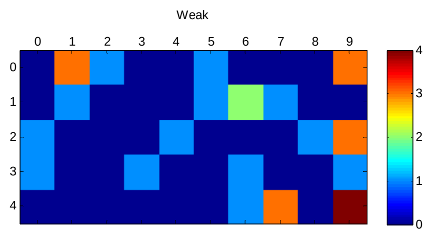




**Weak**



# Protons at KVI

# Protons test

- Protons tests done at KVI (Netherlands)
- Optical tests (irradiated area: half DMD)
  - Pre-test and post-test at room temperature (LAM)
  - Optical measurement during protons flux on DMD
- Energy
  - Energy on silicon after crossing the DMD window: 34.7 MeV
  - Beam FWHM: 6.2mm
- Two radiation regimes
  - Low flux at 6 $10^5$ p/cm$^2$/s during 300s
  - High flux at 5 $10^7$ p/cm$^2$/s during 896s in order to reach a total dose of 10 Krad on DMD
- Experiment results
  - Failure of the protons beam (low flux during 120s)
  - During the irradiation, no transient effect observed

# Outline

| DMD tag | Test |
|---|---|
| DMD #20 | Low temperature stress test |
| DMD #11 | Vacuum in DMD package |
| DMD #20 | Thermal chamber (LAM) |
| DMD #10 | Low temperature nominal test (3 cycles) |
| DMD #5 | Life test (1038 hours) |
| DMD #22 | Thermal cycling (550 cycles) |
| DMD #xx | Physical analysis |
| DMD #12 | Preliminary room temperature: Problem |
| DMD #13 | Preliminary room temperature: Problem |
| DMD #16 | Total Ionising Dose |
| DMD #21 | Total Ionising Dose |
| DMD #15 | Protons |
| DMD #19 | Preliminary room temperature: Problem |
| DMD #7 | **Vibrations** |
| DMD #6 | **Shocks** |
| DMD #17 | MOS tests |
| | |
| **Total: 16 DMDs tested at LAM** | |

# Failure analysis (vibrations)



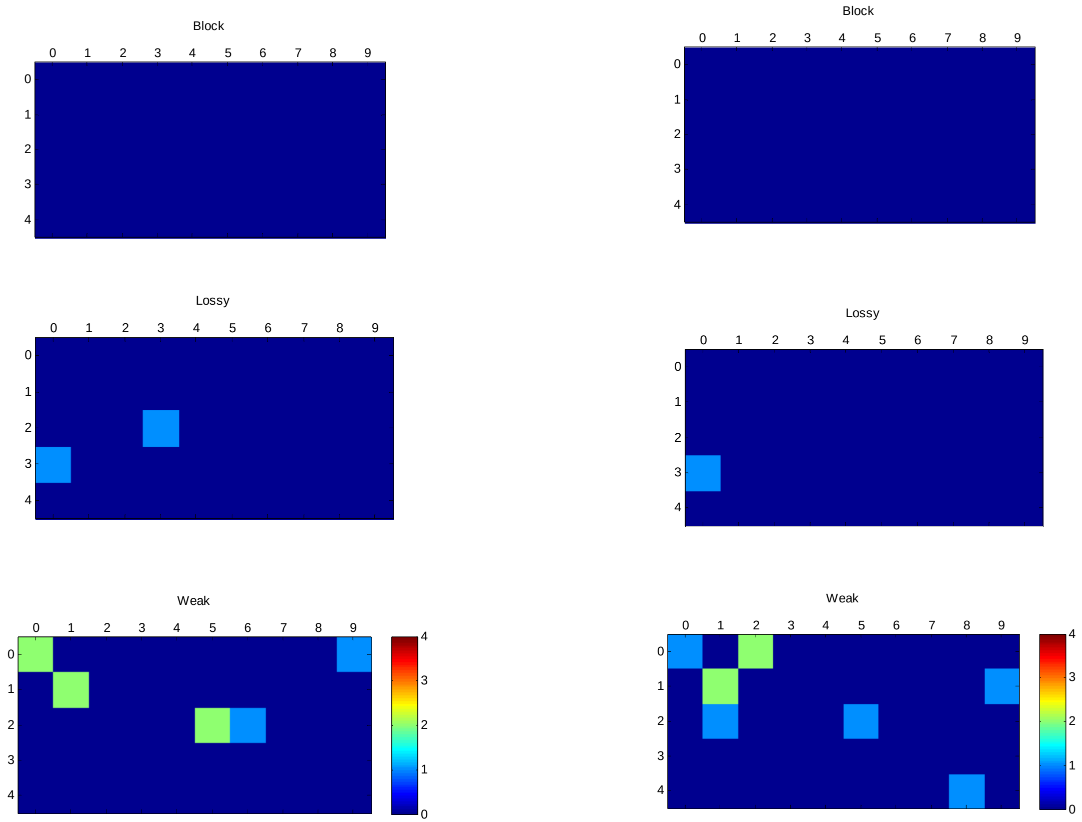
## ♦No degradation of DMD performances after vibrations

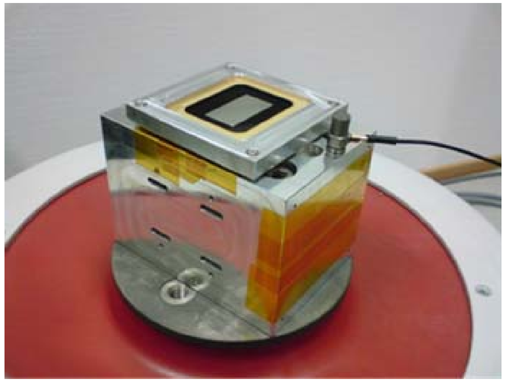
**+20°C, before vibrations** **-40°C, after vibrations**

**Blocked**

**Lossy**

**Weak**



**Done at ESTEC**

**MIL-STD-883F,**
**- method 2005 (vibration fatigue)**
**- method 2007 (vibration at variable frequency)**

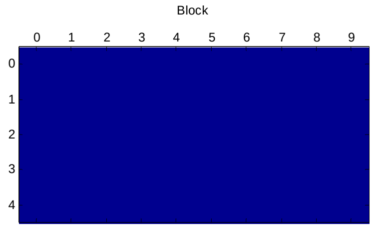
# Failure analysis (shocks)

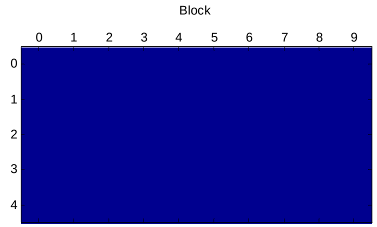
VISITECH

## ♦No degradation of DMD performances after shocks

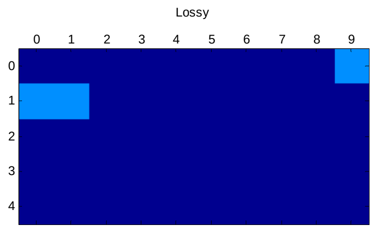
**+20°C, before shocks** **-40°C, after shocks**

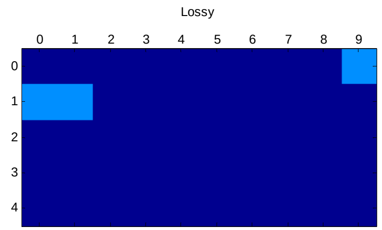
**Blocked**



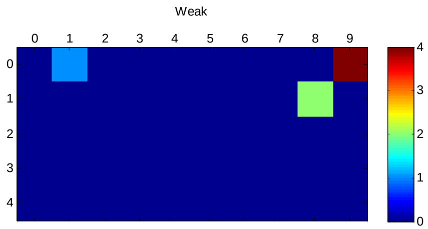



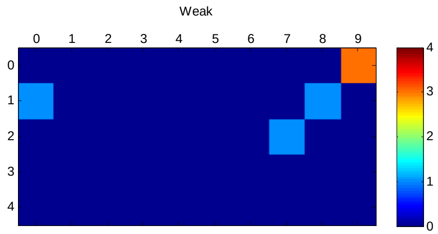

**Lossy**

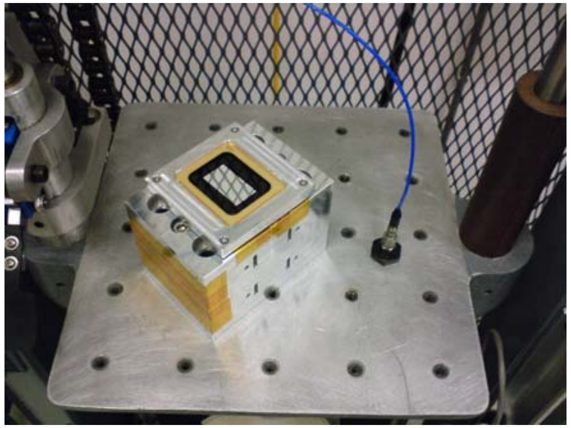



**Weak**



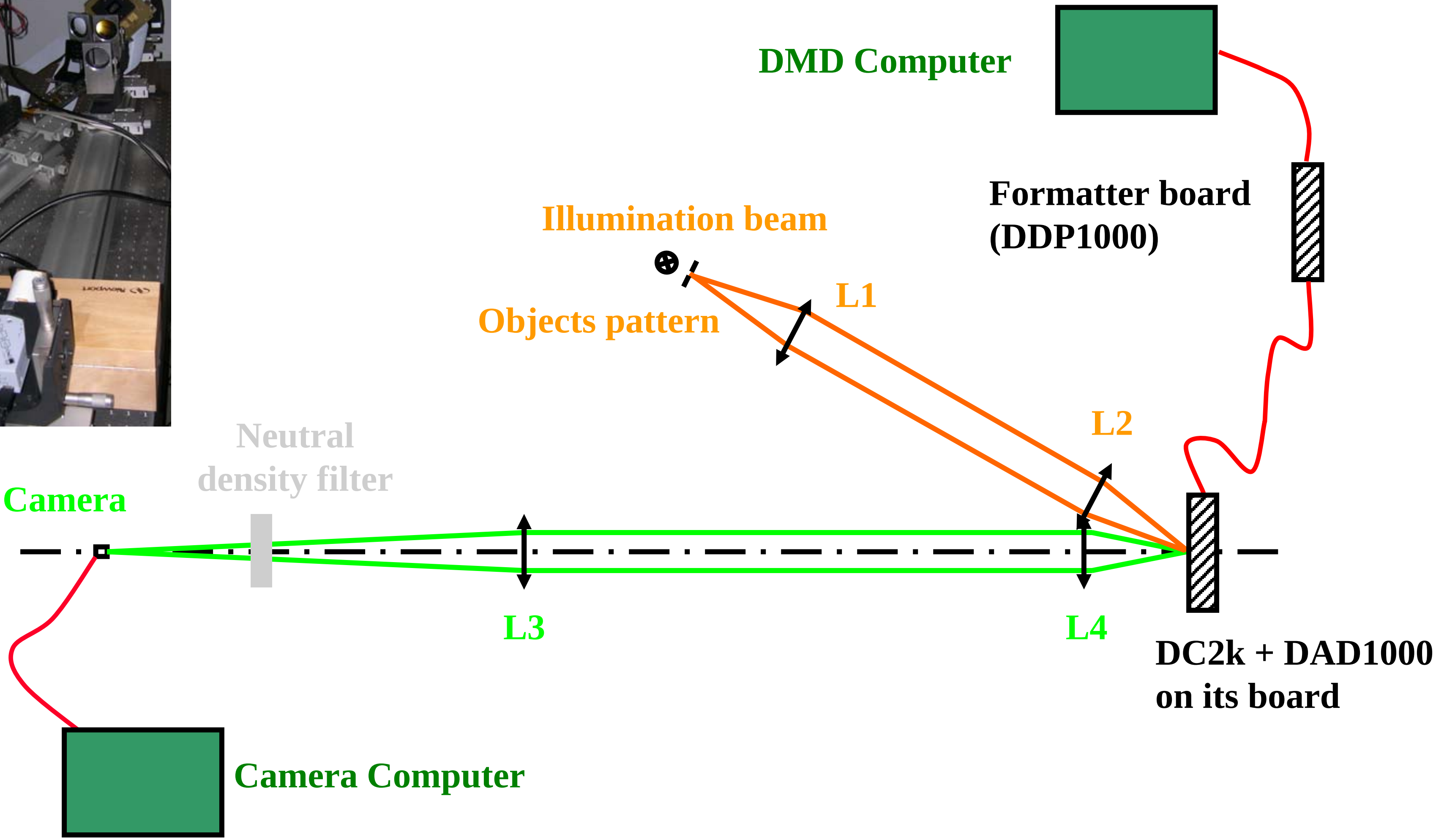



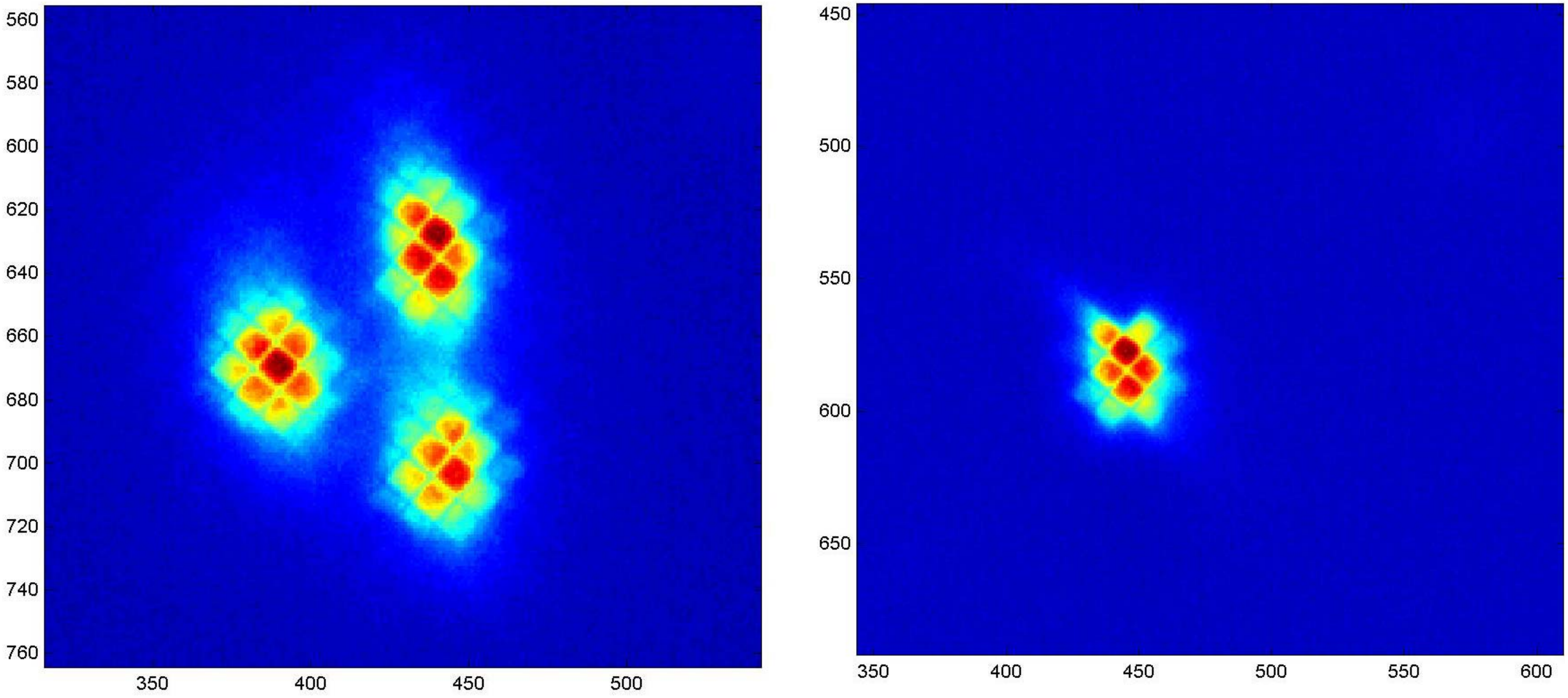
**Done at ESTEC,**

**MIL-STD-883 Method 2002, condition B: 1500g, 0.5ms, 5times each axis**

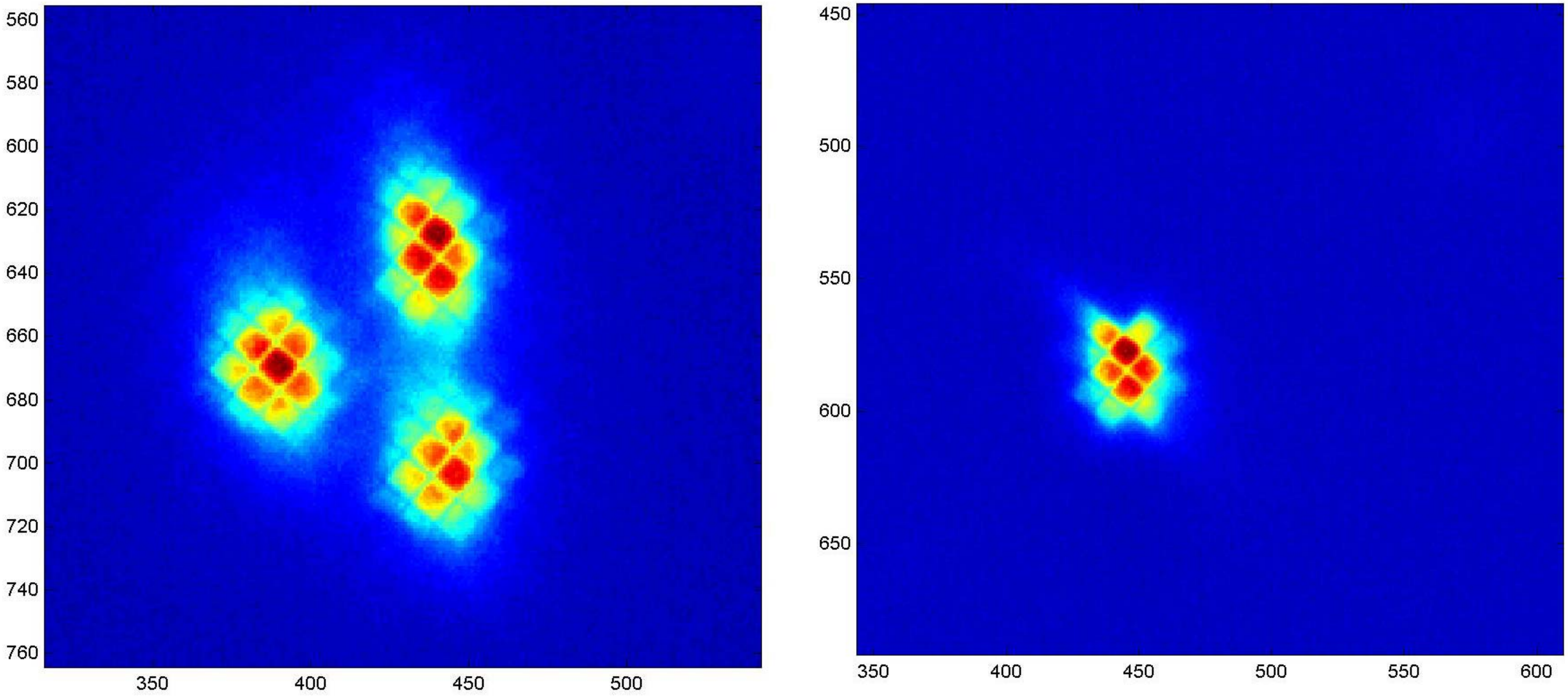
# MOS tests


DMD Computer
Formatter board
(DDP1000)
Illumination beam
Objects pattern
L1
L2
Neutral
density filter
CCD Camera
L3
L4
DC2k + DAD1000
on its board
Camera Computer

# MOS tests: object selection



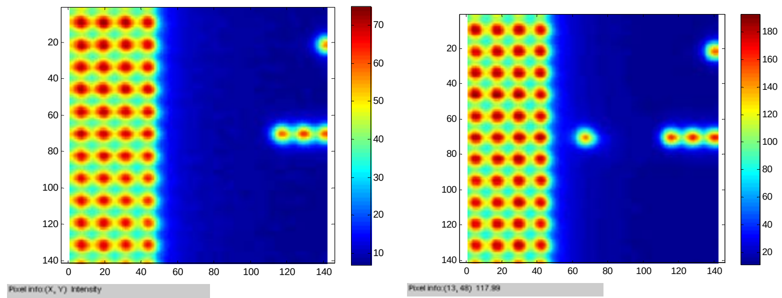
# MOS tests: object selection

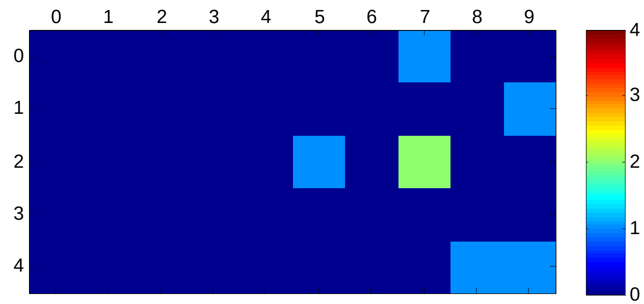



**Contrast = 2250**

# DMD for space

- Under vacuum and low temperature
  - Operating device vacuum, -40°C, pattern set for 1500s
  - No additional blocked mirror, minor defects for 19 mirrors
  - Few blocked mirrors at -55°C
- Life test
  - Space environment for 1038 heures
  - No major failure
- Thermal cycling
  - 550 cycles
- Radiations
  - TID and protons
  - Electronics OK
  - DMD memory cells affected above 10 Krads
- Vibration & shocks





**No major failure in space environment**

# DMD for space

- Cold temperature test, life test, thermal cycling, radiation tests, vibrations tests and MOS-like tests have been completed:
  - ➔ **The DMD chip presents no major failure in the ESA specified space environment**
- Strong interest of the consortium to continue this development
- Issues
  - Space compatible electronics has to be developed
  - DMD window with IR coating is highly recommended
  - TI support is important