# Polarimetric study of the liquid crystal panels. Optimization for diffractive optics

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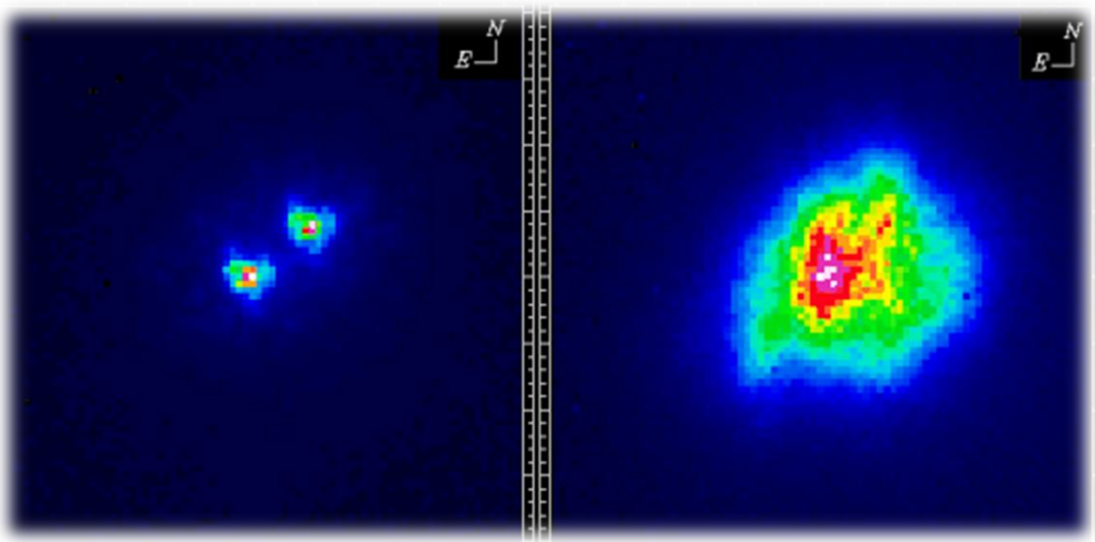
Department of Physics
Universitat Autònoma de Barcelona (Spain)

Vice President ICO Bureau (International Commission for Optics )
SPIE 2009 President

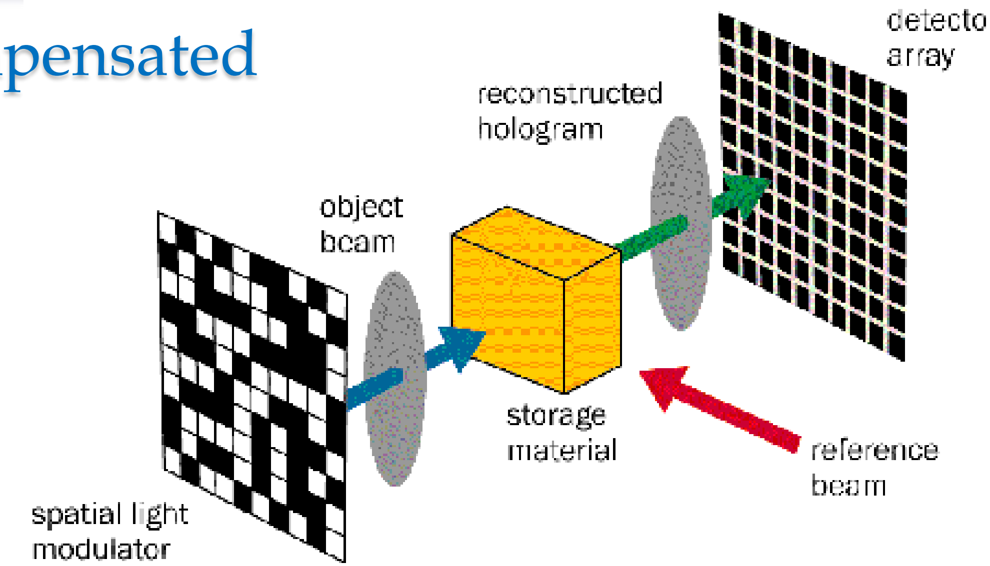
# LCDs applications




Compensated Uncompensated

- **Adaptive Optics: Binary Stars**

- **Holographic data storage**




Basic holographic data storage set-up

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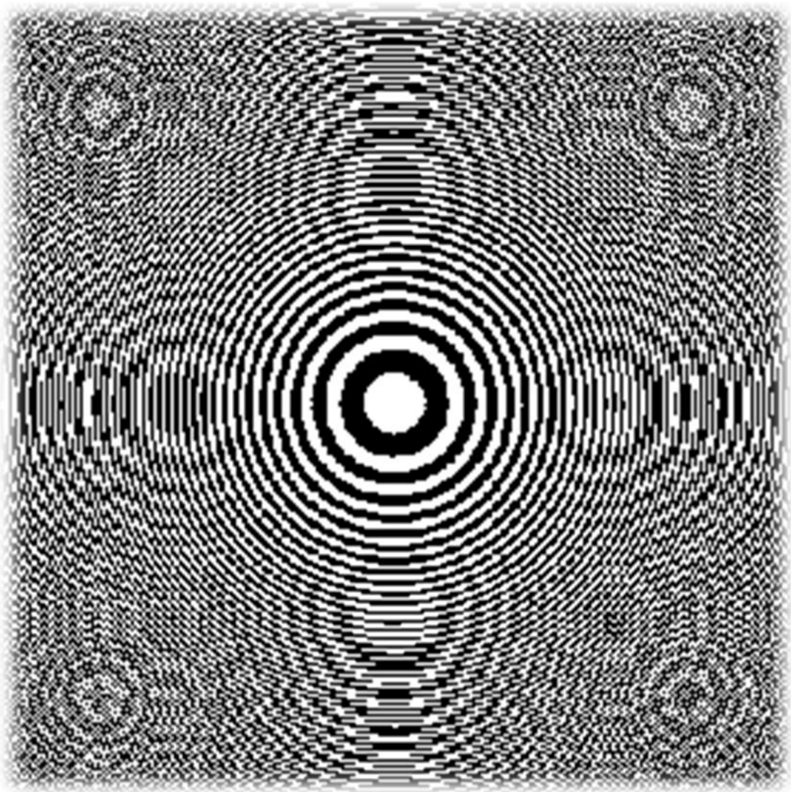
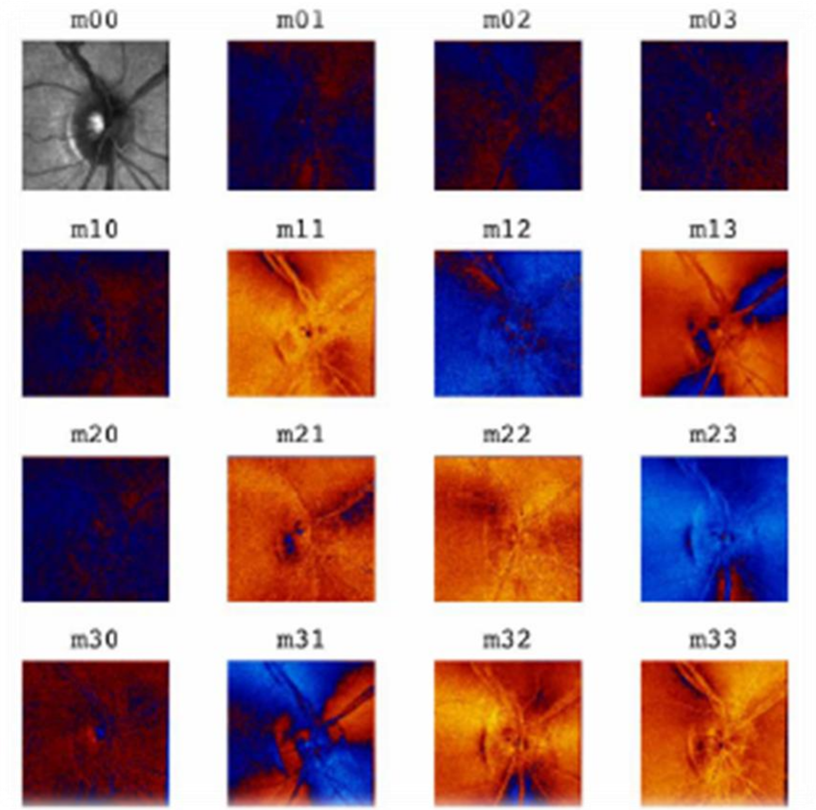
# LCDs applications

- **Diffractive Optics**



- **Medical Optics: Polarimeters**




Mueller matrix images of the optic nerve head.

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# LCD from Video projectors

Transmission Twisted  Nematic Liquid Crystal devices

TN-LCSLM: Sony Model LCX012BL;
VGA (640 x 480)
Videoproyector Sony VPL-V500

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# LCoS display

## Reflective Liquid Crystal on Silicon devices

**Twisted Nematic**
kit LC-R2500 by Holoeye


**Parallel Aligned**
kit Pluto by Holoeye

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# CONTENTS

- **Polarimetric study of the liquid crystal panels**
  - Non Depolarizing devices
  - Depolarizing devices
  - Modulation Optimization

- **Use of commercial LCDs in diffractive Optics**
  - Color Pattern Recognition
  - Apodization
  - Lens multiplexing

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- **Polarimetric study of the liquid crystal panels**

Non Depolarizing devices

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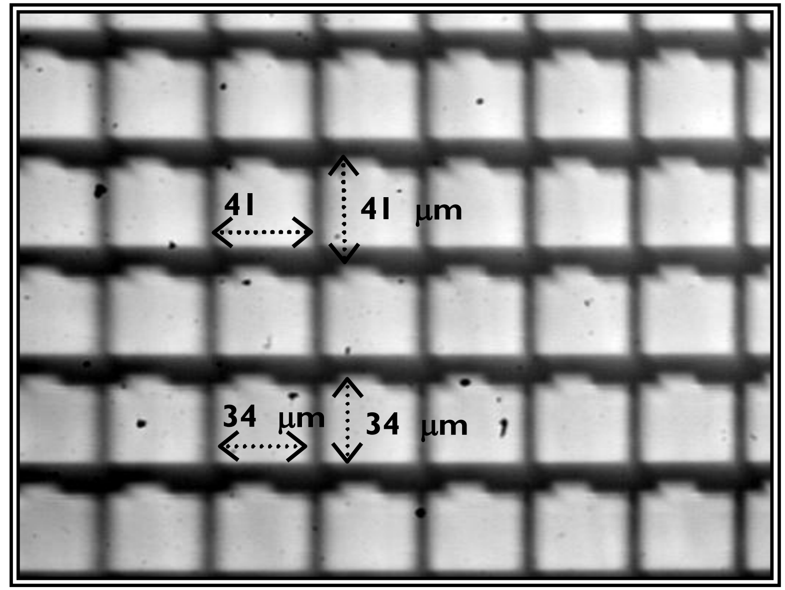
# Polarimetric study of the liquid crystal panels




**Transmission Twisted Nematic Liquid Crystal devices**

TN-LCSLM: Sony Model LCX012BL;
VGA (640 x 480)
Videoproyector Sony VPL-V500

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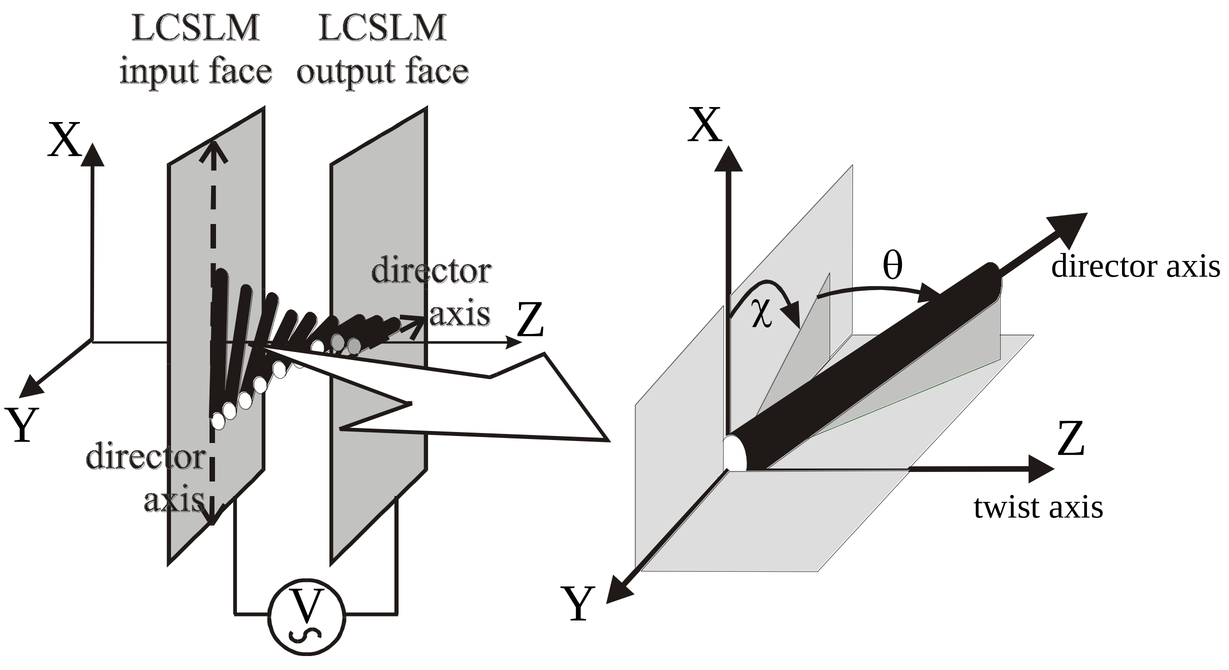
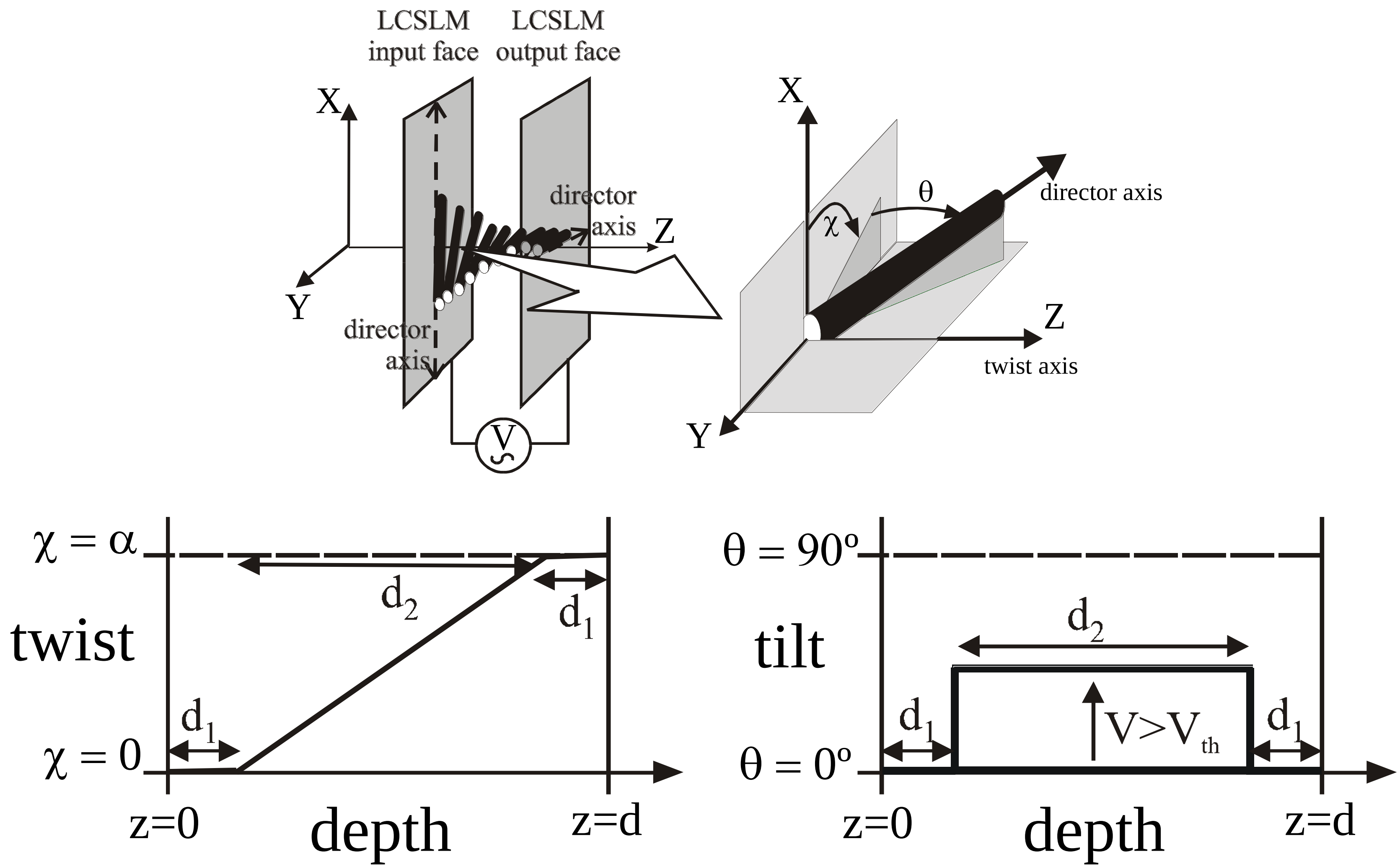
# Simplified model




$$\frac{1}{n_e^2(\theta)} = \frac{\cos^2(\theta)}{n_{\parallel}^2} + \frac{\sin^2(\theta)}{n_{\perp}^2}$$

# Simplified model



# Jones Matrix

$$M'_{LCSLM}(\alpha,\beta,\delta) = exp(-i(\beta + 2\delta))R(-\alpha)\begin{pmatrix} X'-iY' & Z \\ -Z & X'+iY' \end{pmatrix}$$

$$X' = X\cos 2\delta - Y\sin 2\delta$$

$$X = \cos\gamma$$

$$Y' = X\sin 2\delta + Y\cos 2\delta$$

$$Y = \frac{\beta}{\gamma}\sin\gamma$$

$$Z = \frac{\alpha}{\gamma}\sin\gamma$$

$$\gamma = \sqrt{\alpha^2 + \beta^2}$$

$$\delta(V) = \pi\, d_1(V)\Delta n_{max}/\lambda$$

$$\beta(V) = \pi\, d_2(V)\Delta n(V)/\lambda$$

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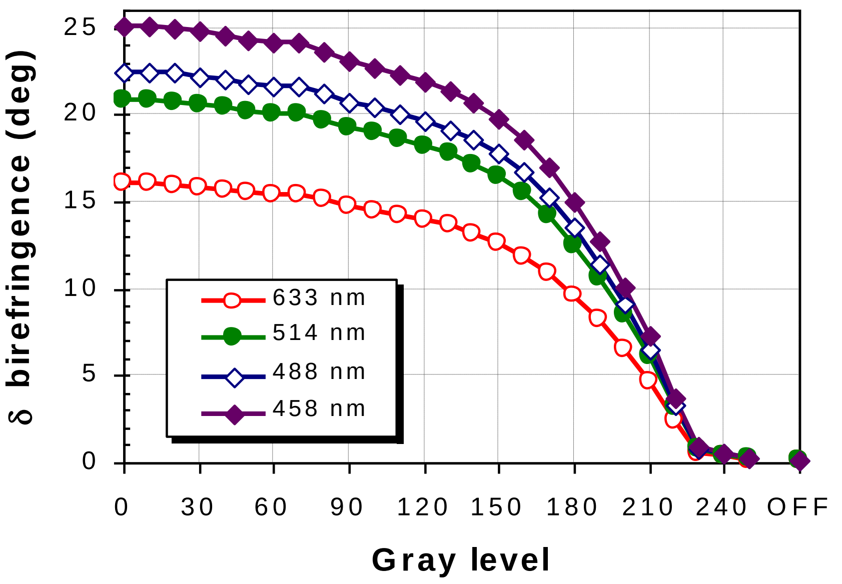
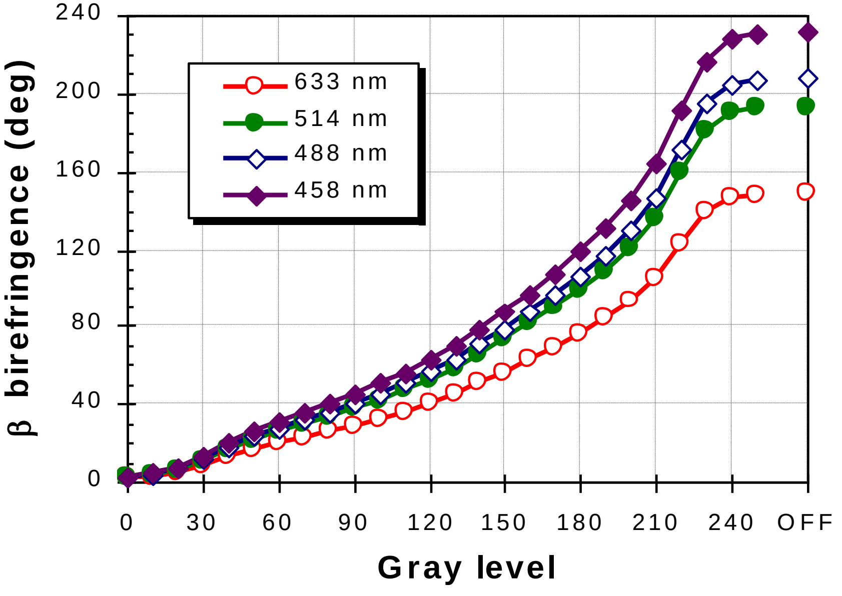
# Measured Parameters

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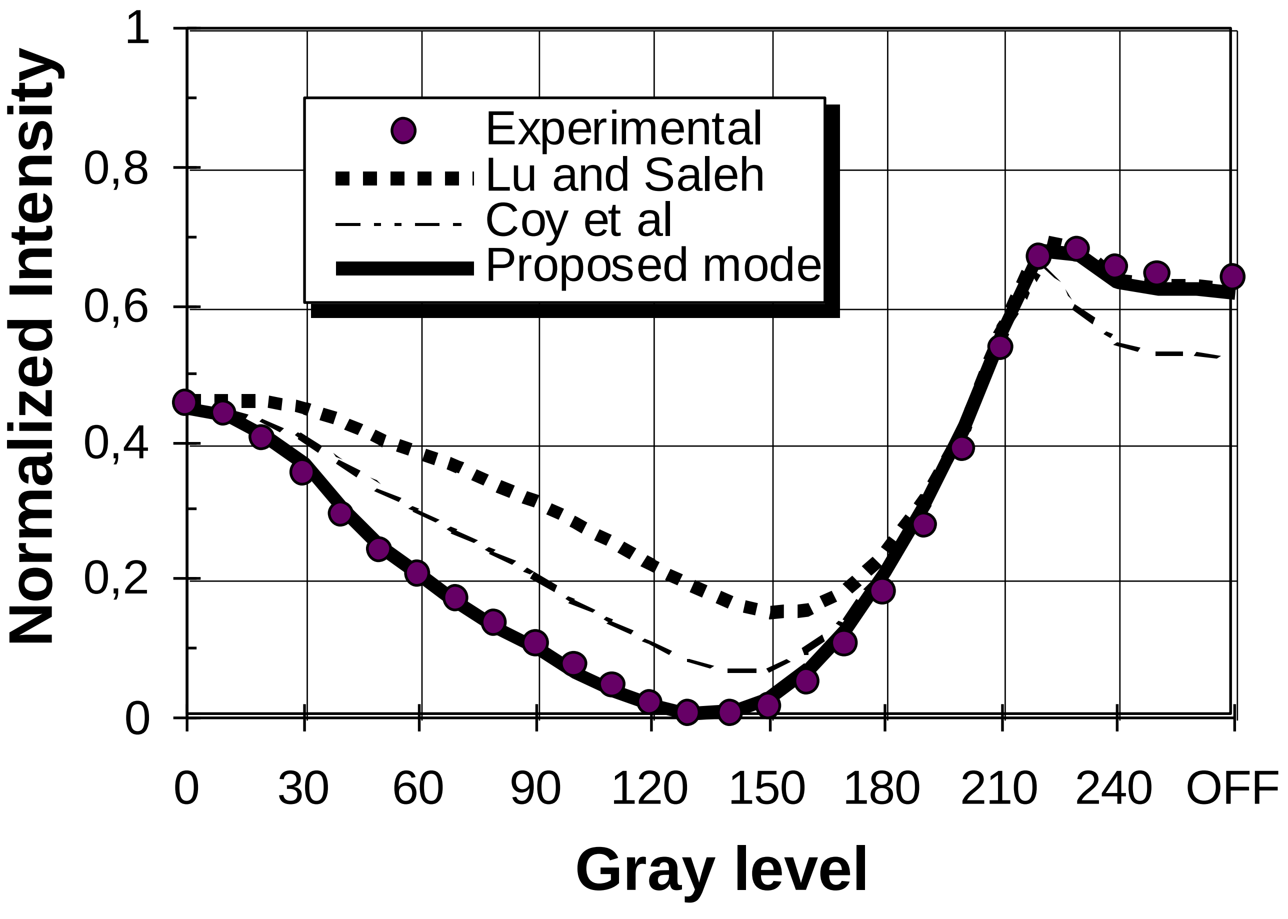
# Predictive capability of the model

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- **Polarimetric study of the liquid crystal panels**

Depolarizing devices

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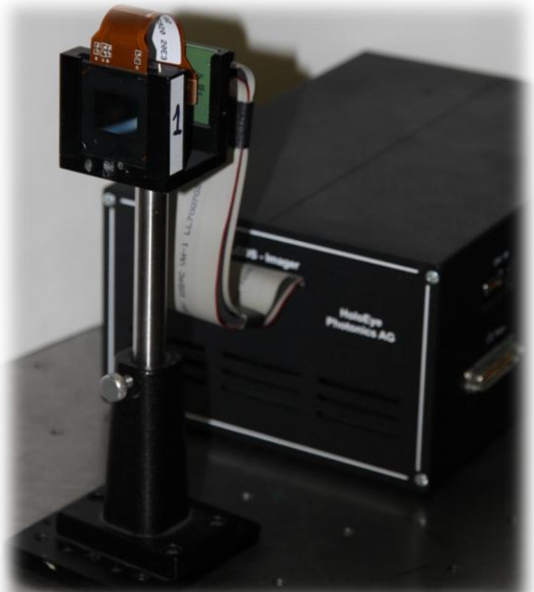
# Technical features of the used TNLCoS

## Twisted Nematic LCoS display



- Philips model X97c3A0.
- Kit LC-R2500 by Holoeye
- 2.46 cm diagonal reflective LCoS display of the 45º twisted nematic type.
- XGA resolution (1024x768)
- Digitally controlled gray scales with 256 gray levels.
- Square pixels with a center to center separation of 19mm.
- 93% fill factor.

*Twist of the LC molecules director along the cell*

# Technical features of the used PALCoS

## Parallel Aligned LCoS display

- PLUTO Spatial Light Modulator (SLM) distributed by Holoeye.
- Diagonal display of 1.8 cm.
- High resolution: 1920 x 1080.
- Small pixel size : 8µm.
- Fill factor of 87%.
- Different gamma corrections and electrical sequences available.

*LC molecules parallel aligned*

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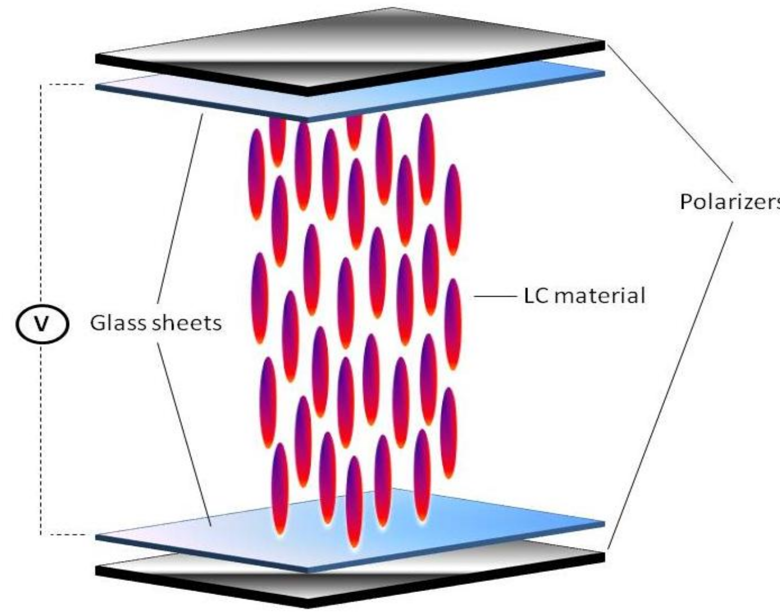
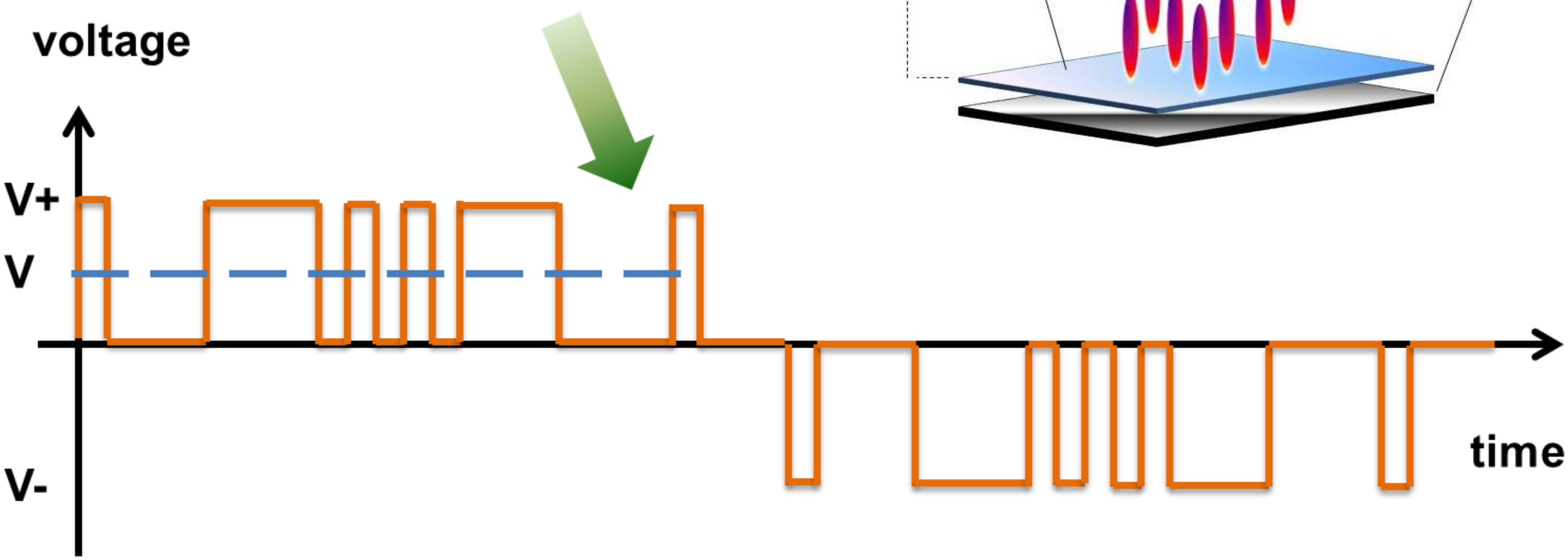
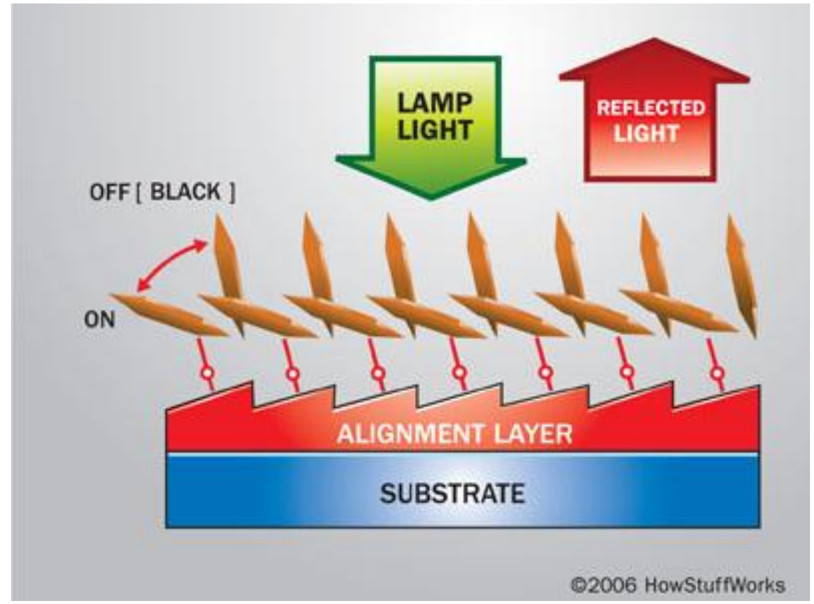
# Time-fluctuations in LCoS displays



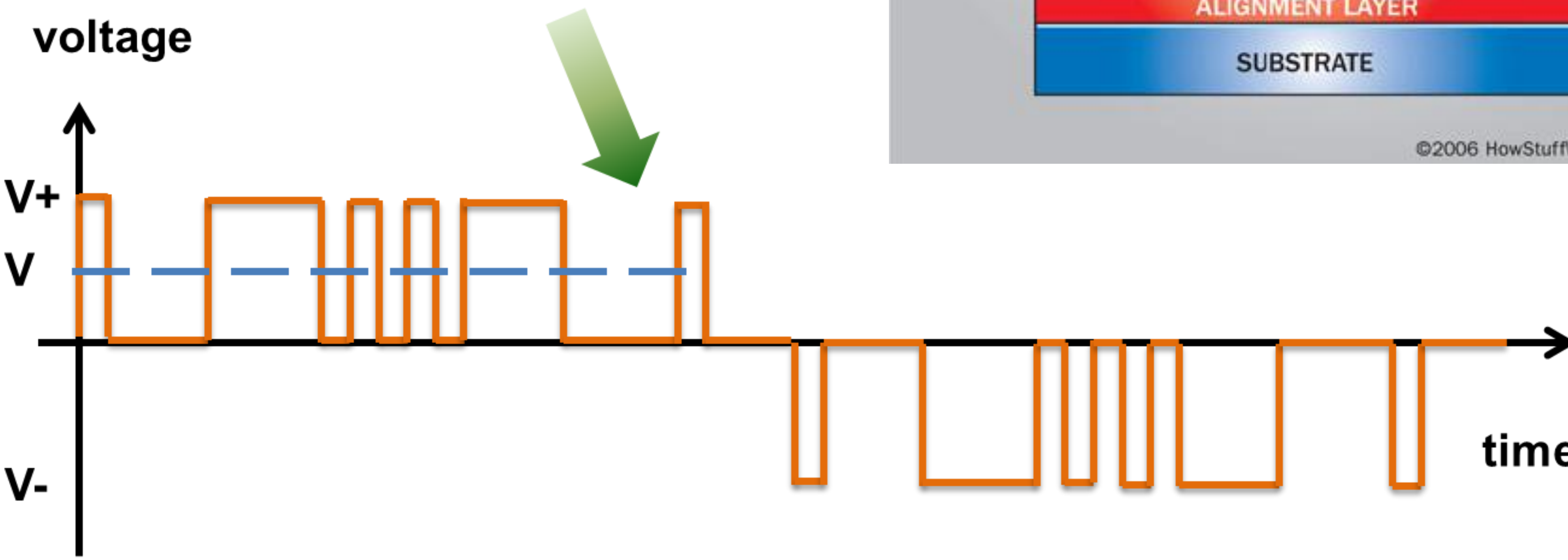

**Digital addressing schemes :**
***Pulse Width Modulation***



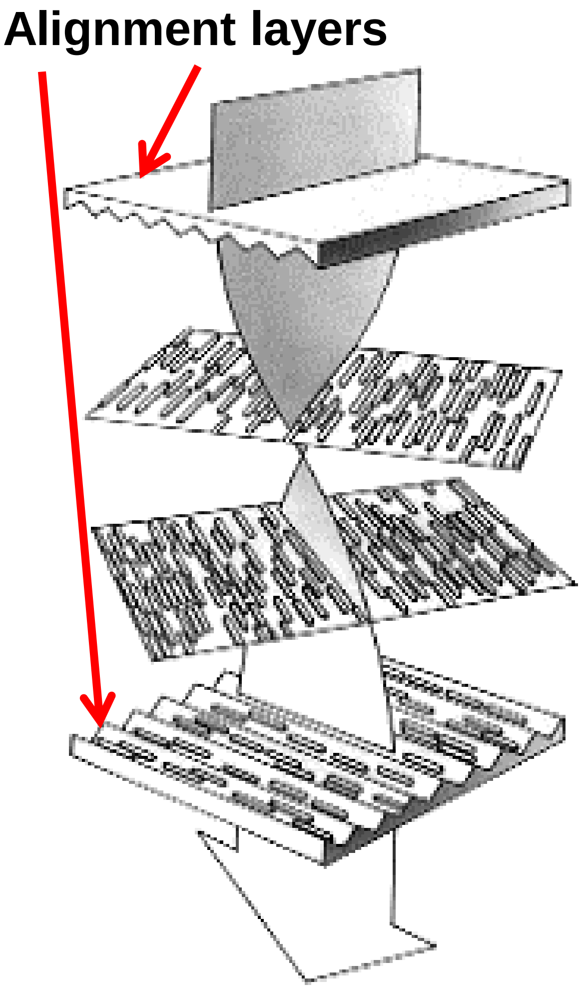
# Time-fluctuations in LCoS displays

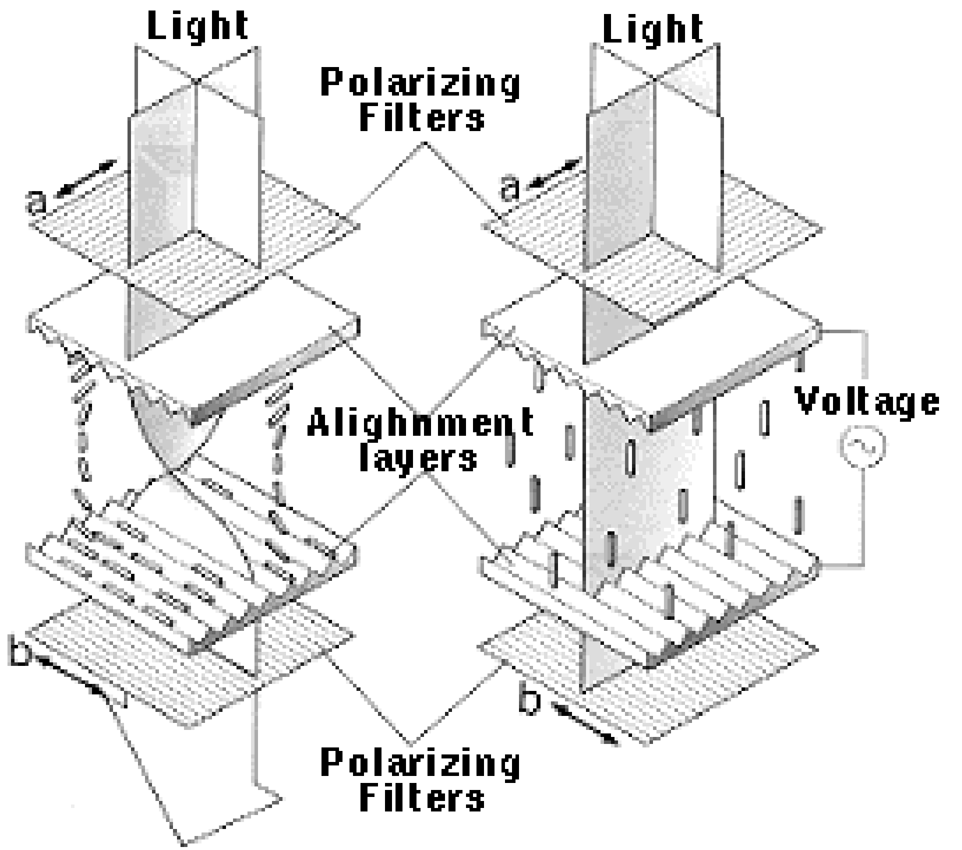



**Digital addressing schemes :**
***Pulse Width Modulation***

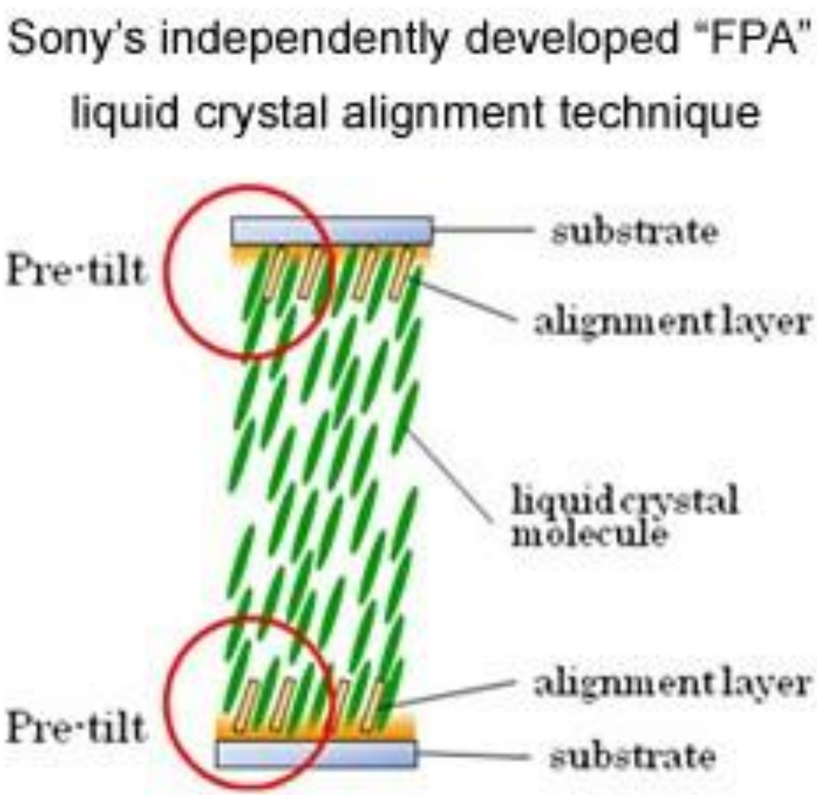


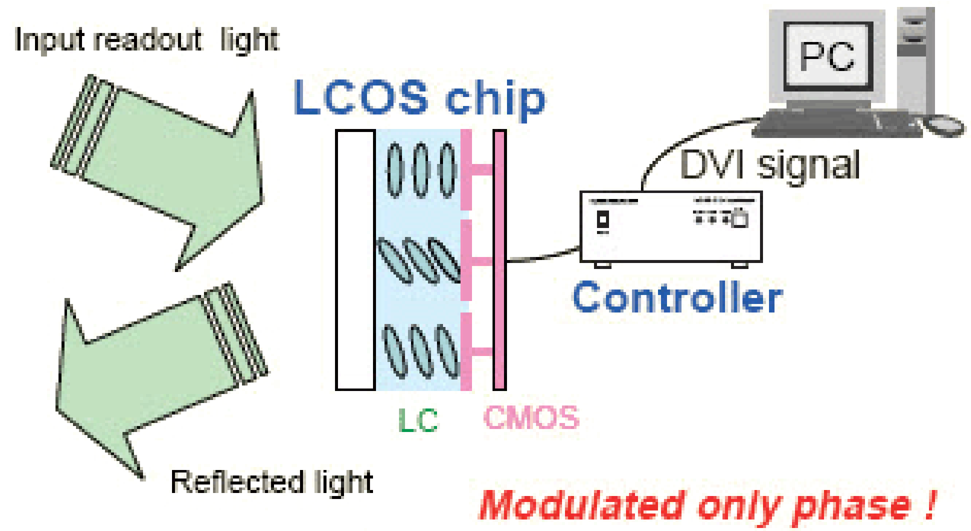
# Twisted Nematic



# Parallel Aligned

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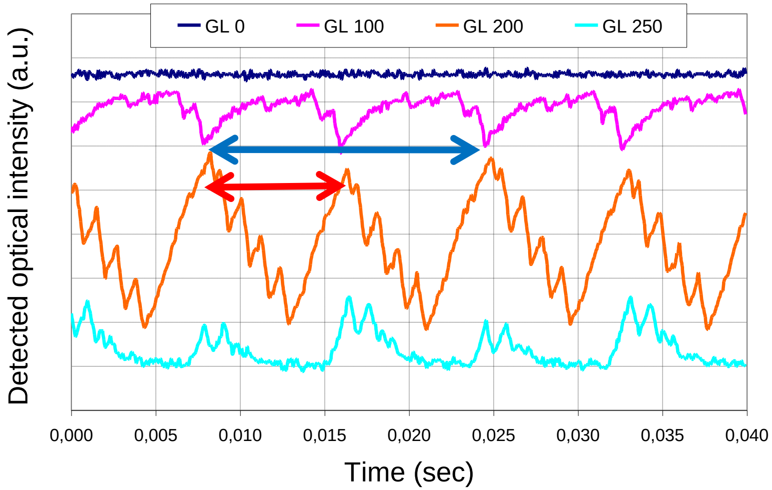
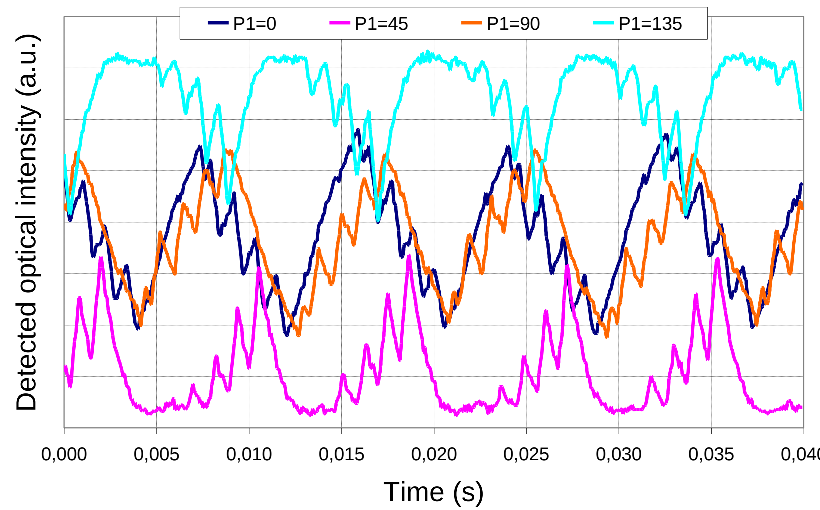
# Time-fluctuations in LCoS displays

- **Reflected intensity measurements (incident angle equal to 2º) acquired with a Tektronix TDS3012B Digital Oscilloscope**




- ○ Fixed polarizers (at 0º with respect to the vertical of the lab)
- ○ Fixing gray level (at 200) and output polarizer (at 0º Vertical-Lab)

- **Intensity oscillates with a period of ~17 ms (~60 Hz), with a sub period of ~8 ms (~120 Hz)**

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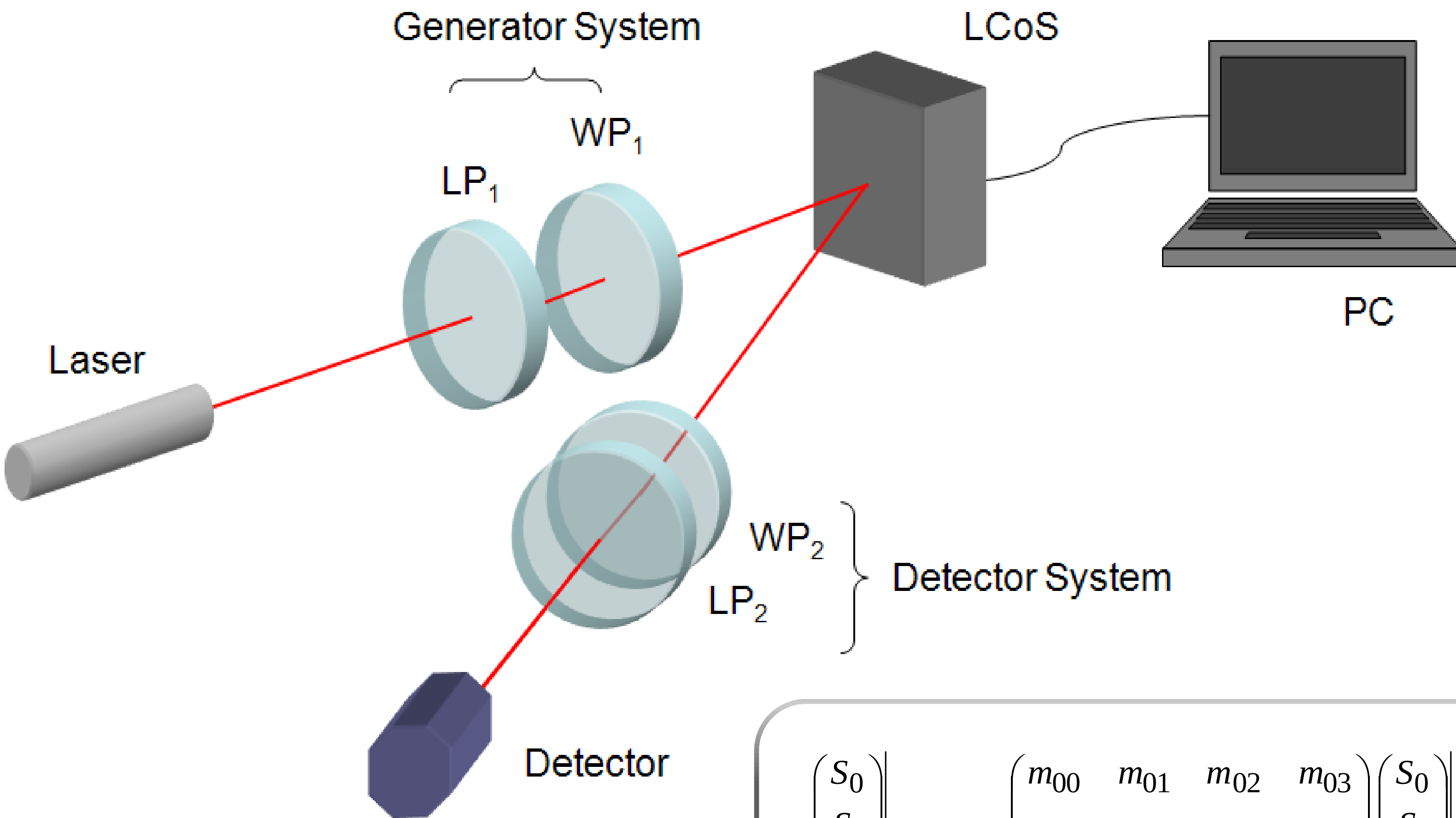
# LCoS display characterization set-up




$$\begin{pmatrix} S_0 \\ S_1 \\ S_3 \\ S_4 \end{pmatrix}\Bigg|_{Output} = \begin{pmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{pmatrix} \cdot \begin{pmatrix} S_0 \\ S_1 \\ S_3 \\ S_4 \end{pmatrix}\Bigg|_{Input}$$

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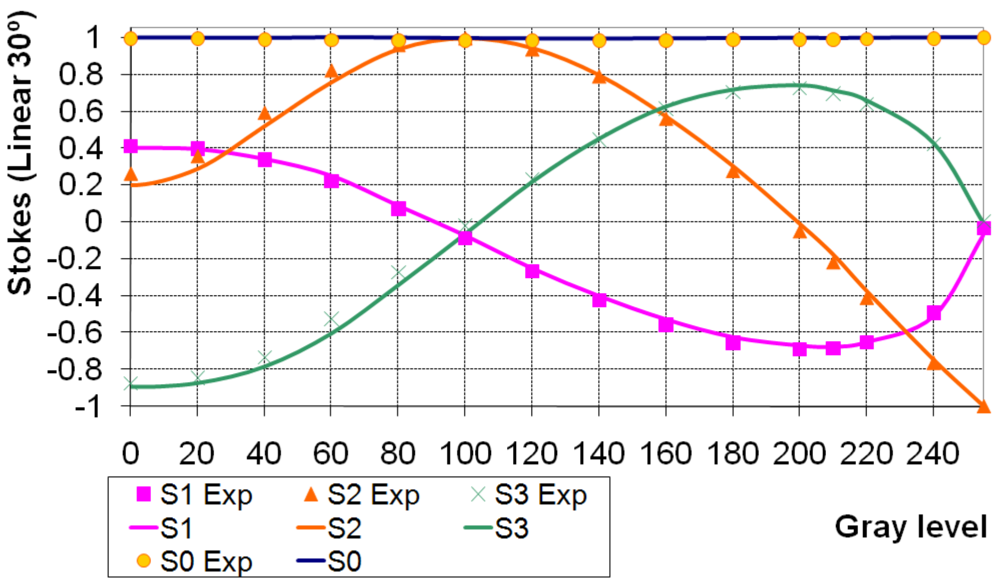
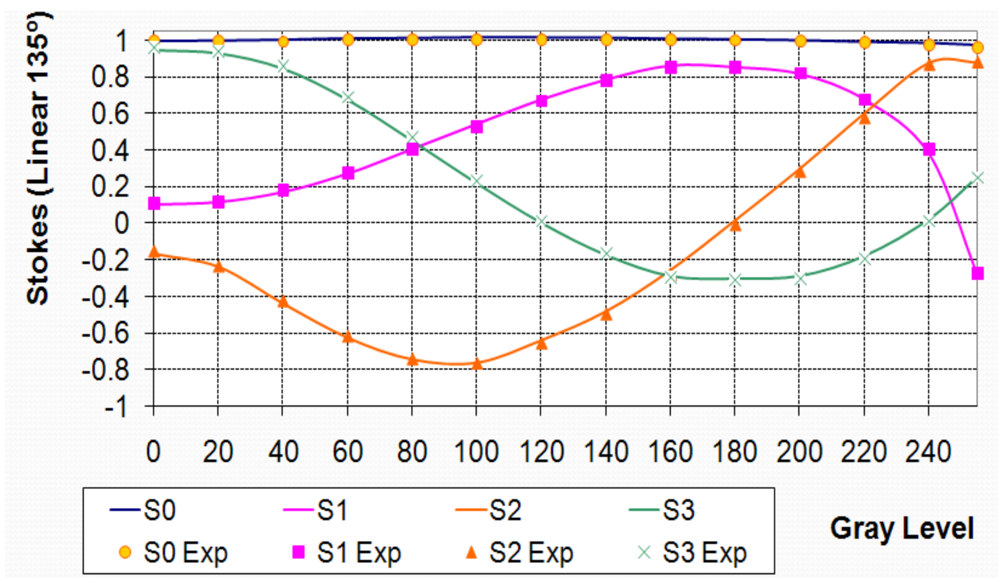
# LCoS Mueller matrices validation



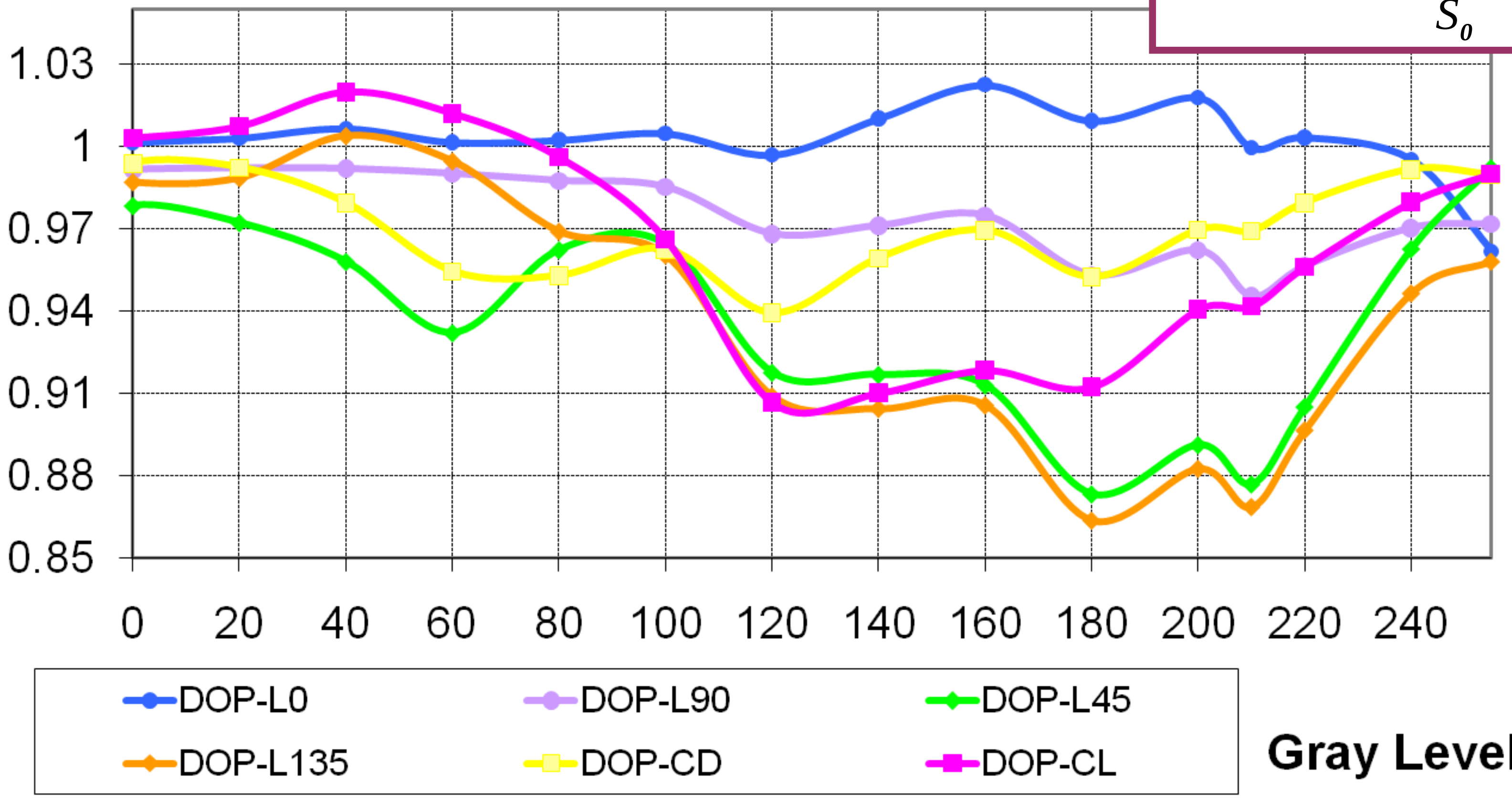

- Non Synchronous characterization method.




- Synchronous characterization method.

# Degree of Polarization (DOP)

$$DOP = \frac{\left(S_1^2 + S_2^2 + S_3^2\right)^{1/2}}{S_0}$$




Degree of polarization as a function of the gray level and the incident state of polarization for quasi-normal incidence.

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# Polar decomposition of the Mueller matrix

$\mathrm{M}=\mathrm{M}_{\Delta}\mathrm{M}_{\mathrm{R}}\mathrm{M}_{\mathrm{D}}$ Depolarization, retardance, and diattenuation

$$\mathbf{M}=\mathbf{M}_{\Delta}\mathbf{M}_{\mathbf{R}}=\begin{pmatrix}1 & \vec{0}^{T}\\ \vec{P}_{\Delta} & m_{\Delta}\end{pmatrix}\cdot\begin{pmatrix}1 & \vec{0}^{T}\\ \vec{0} & m_{R}\end{pmatrix}=\begin{pmatrix}1 & \vec{0}^{T}\\ \vec{P}_{\Delta} & m_{\Delta}m_{R}\end{pmatrix}$$

The Jones matrix of a non-absorbing polarization element

$$\mathbf{J}_{\mathbf{R}}=e^{-i\beta}\begin{pmatrix}A & B\\ -B^{*} & A^{*}\end{pmatrix}=e^{-i\beta}\begin{pmatrix}A_{\mathrm{Re}}-iA_{\mathrm{Im}} & B_{\mathrm{Re}}-iB_{\mathrm{Im}}\\ -B_{\mathrm{Re}}-iB_{\mathrm{Im}} & A_{\mathrm{Re}}+iA_{\mathrm{Im}}\end{pmatrix}$$

$$A_{\mathrm{Re}}^{2}+A_{\mathrm{Im}}^{2}+B_{\mathrm{Re}}^{2}+B_{\mathrm{Im}}^{2}=1$$

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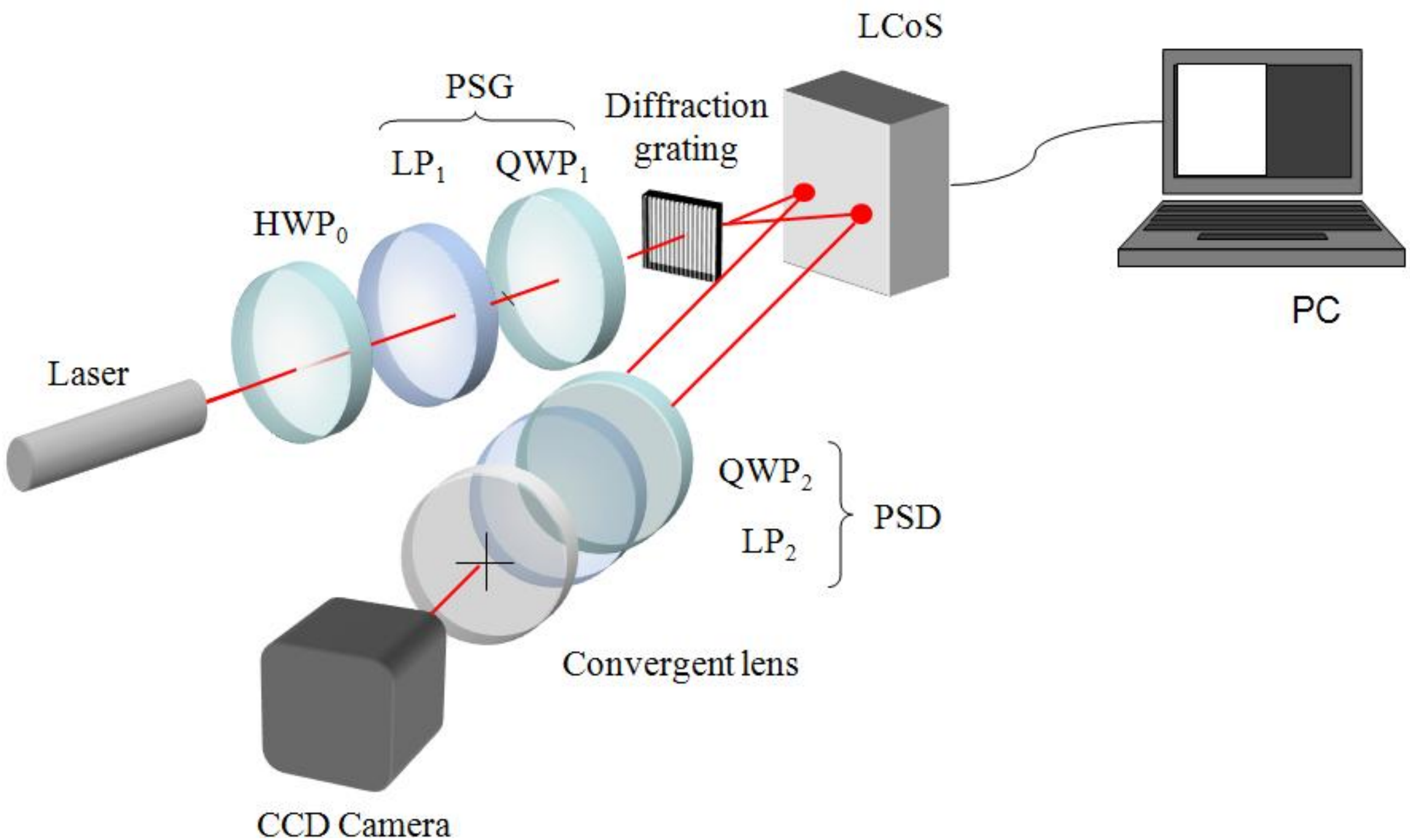
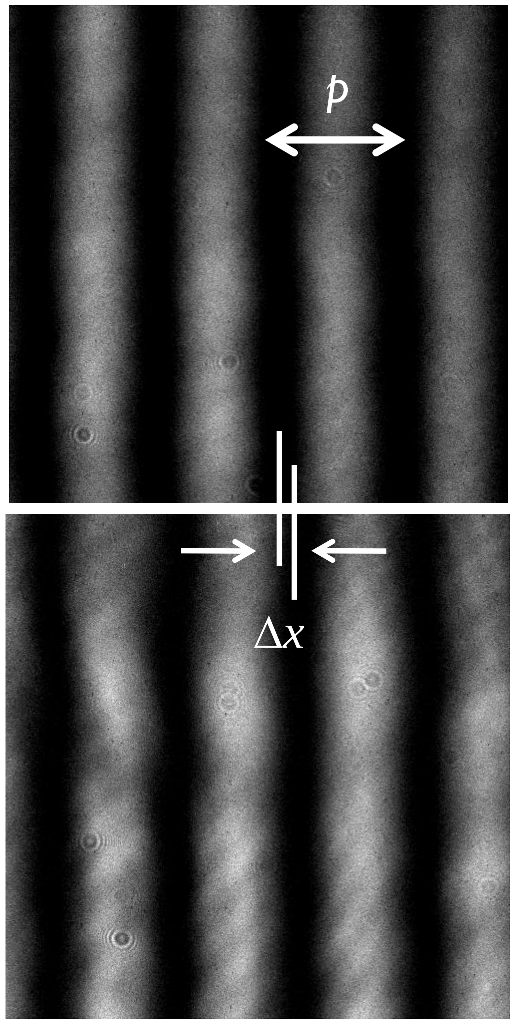
# Phase measurement set-up




- Interference method based set-up for experimental phase measurements.

# Phase measurement set-up




$$I(x) = 2I_0\left(1 + \cos\left(2\pi p x + \Phi\right)\right)$$

- **Interference method based set-up for experimental phase measurements.**

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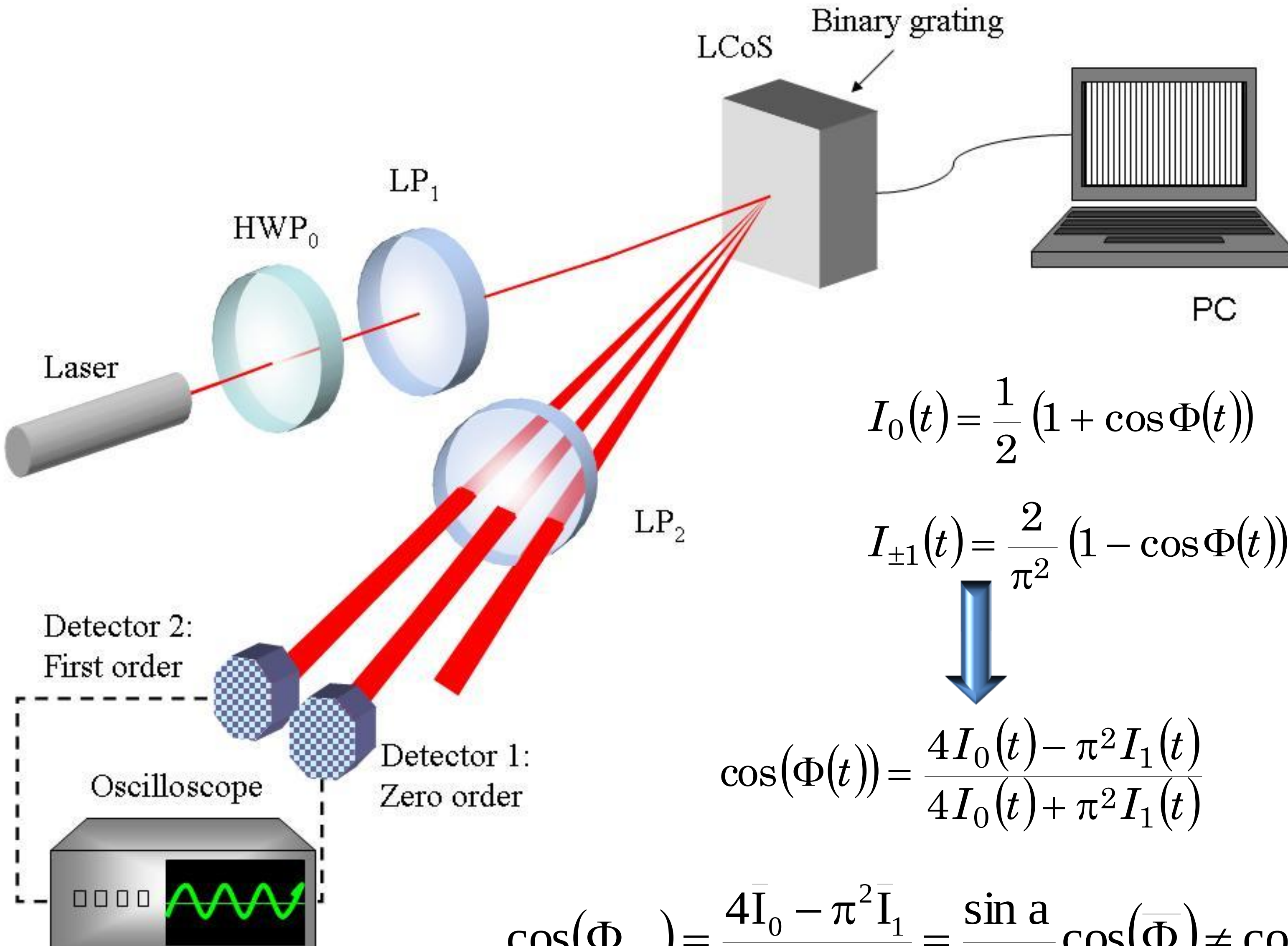
# Time-fluctuations of the phase




$$I_0(t) = \frac{1}{2}\left(1 + \cos\Phi(t)\right)$$

$$I_{\pm 1}(t) = \frac{2}{\pi^2}\left(1 - \cos\Phi(t)\right)$$

$$\cos(\Phi(t)) = \frac{4I_0(t) - \pi^2 I_1(t)}{4I_0(t) + \pi^2 I_1(t)}$$

$$\cos(\Phi_M) = \frac{4\bar{I}_0 - \pi^2 \bar{I}_1}{4\bar{I}_0 + \pi^2 \bar{I}_1} = \frac{\sin a}{a}\cos(\bar{\Phi}) \neq \cos(\bar{\Phi})$$

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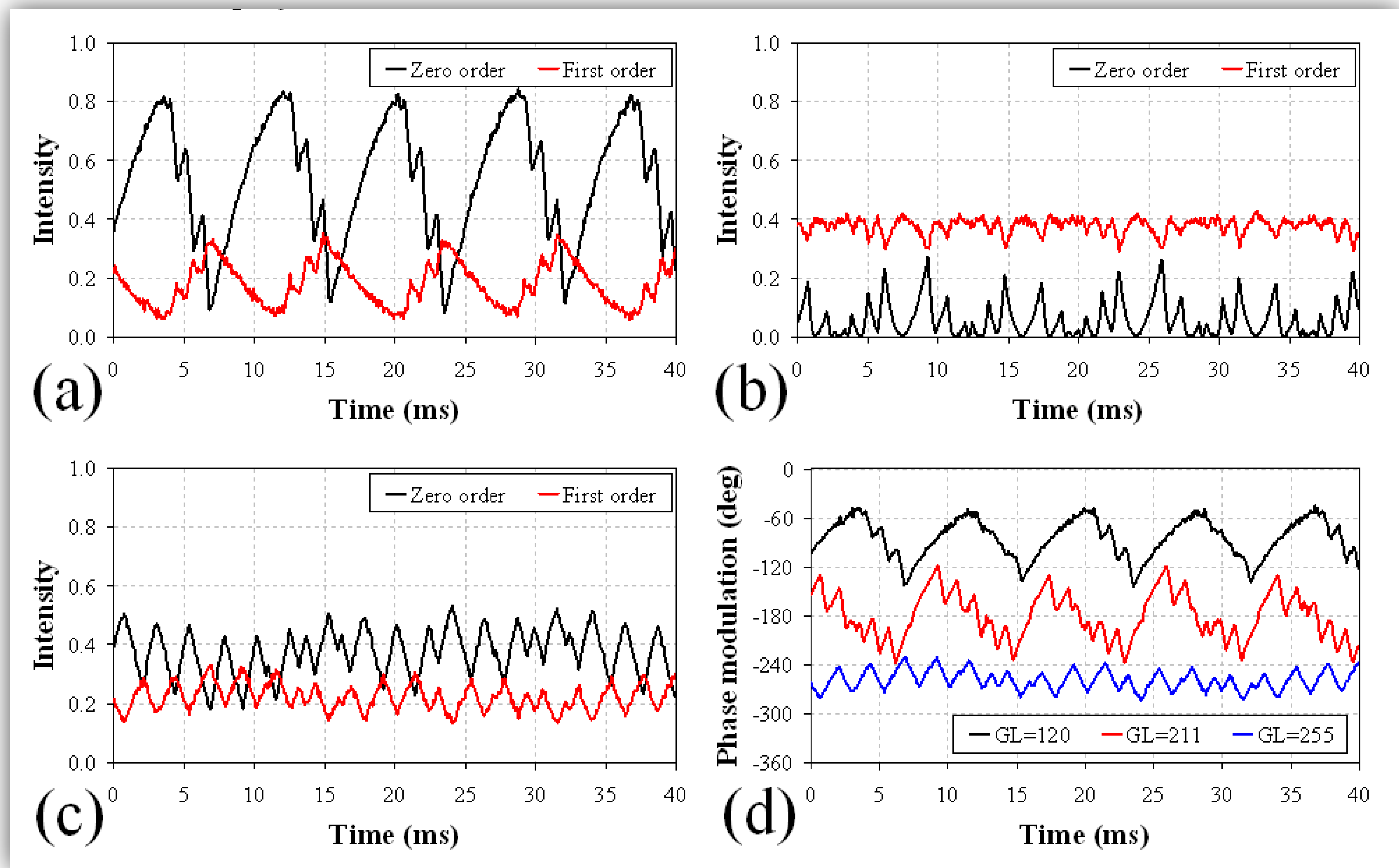
# Phase fluctuation phenomenon

- **Intensity measurements at the zero and first diffraction orders for binary diffraction gratings with two different gray levels:**




(a) (0,120), (b) (0,211) and (c) (0,255). (d) Instantaneous phase values as a function of time for different grey levels

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- **Polarimetric study of the liquid crystal panels**

Modulation Optimization

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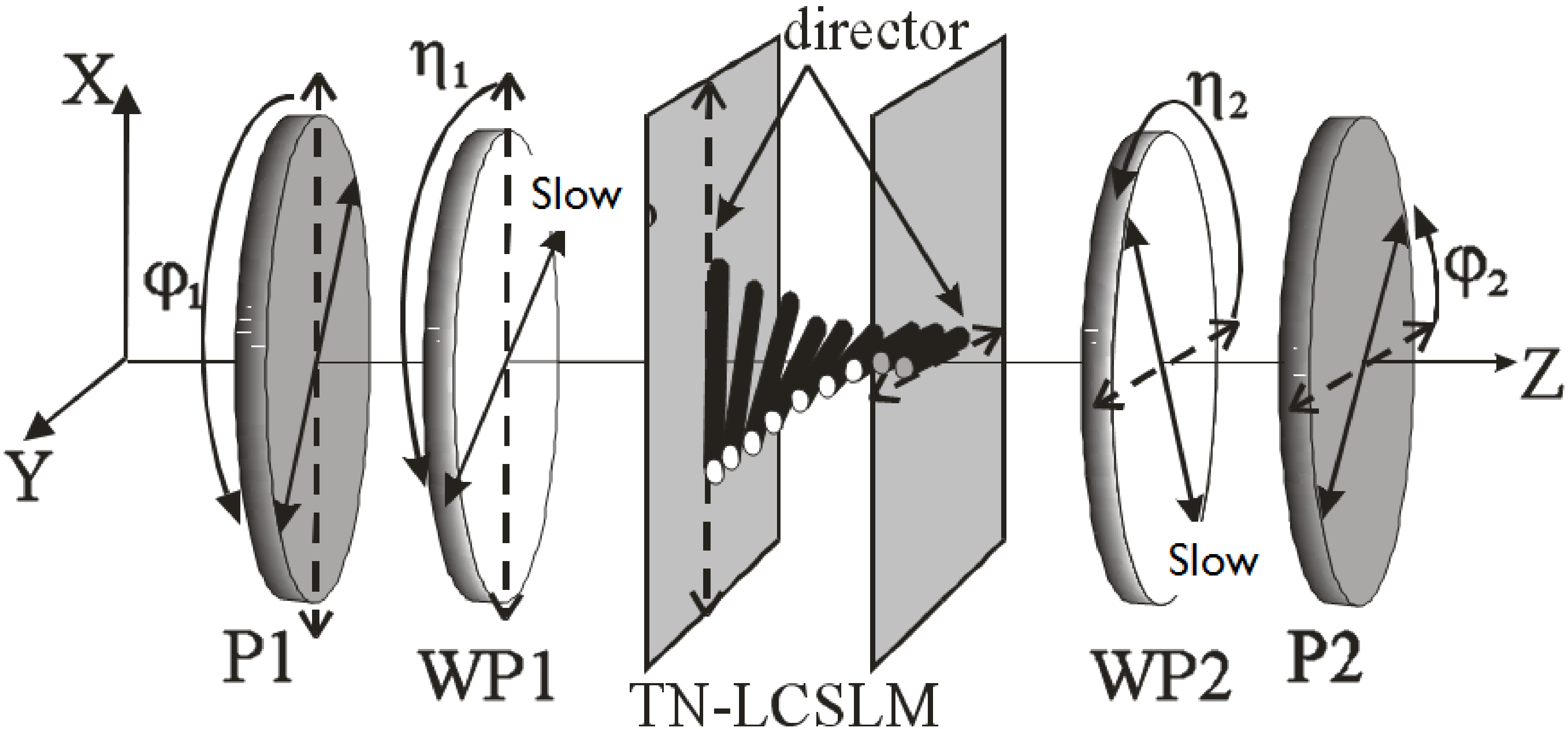
# Modulation Optimization

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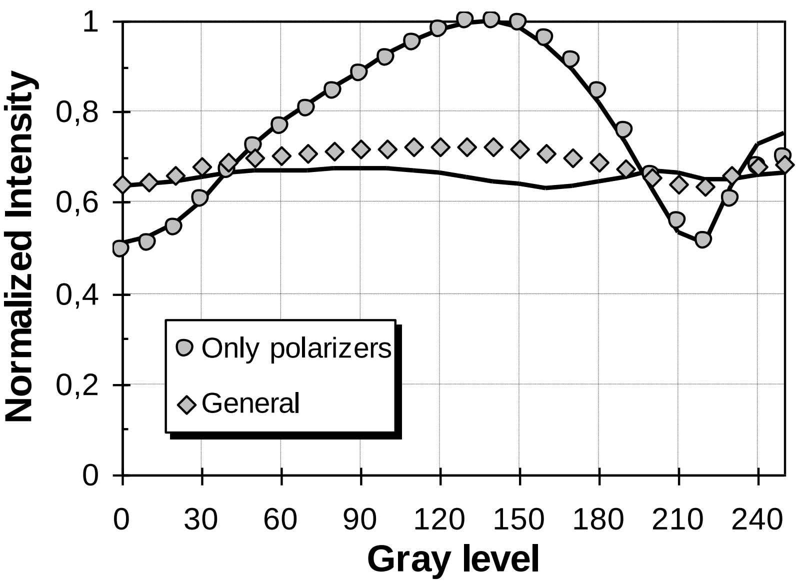
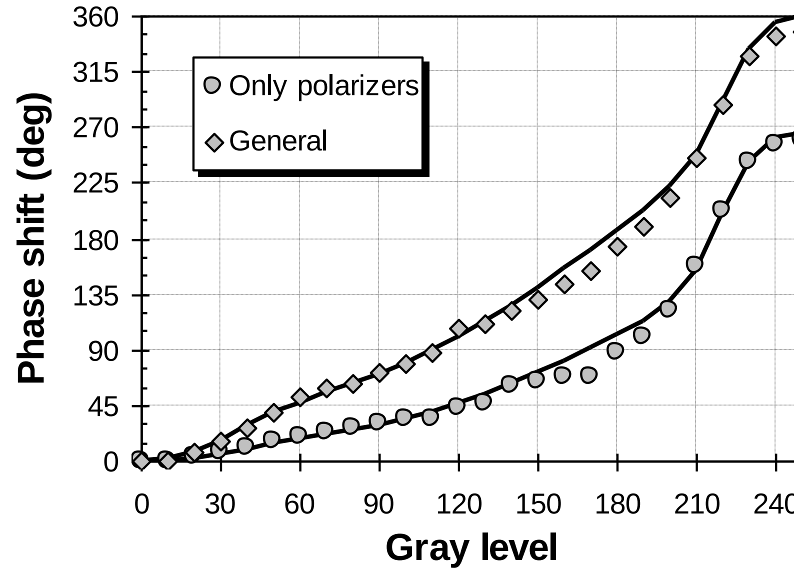
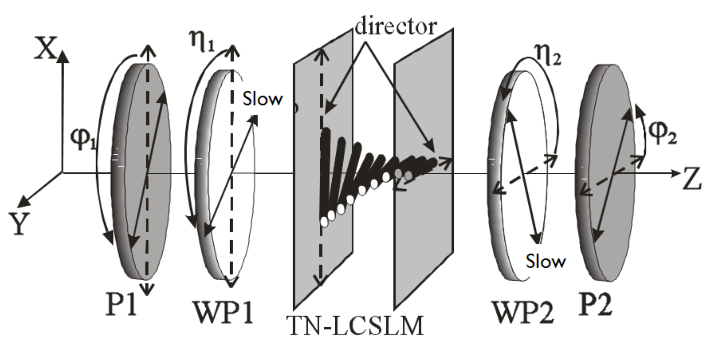
# Modulation Optimization

- **Phase-only modulation**

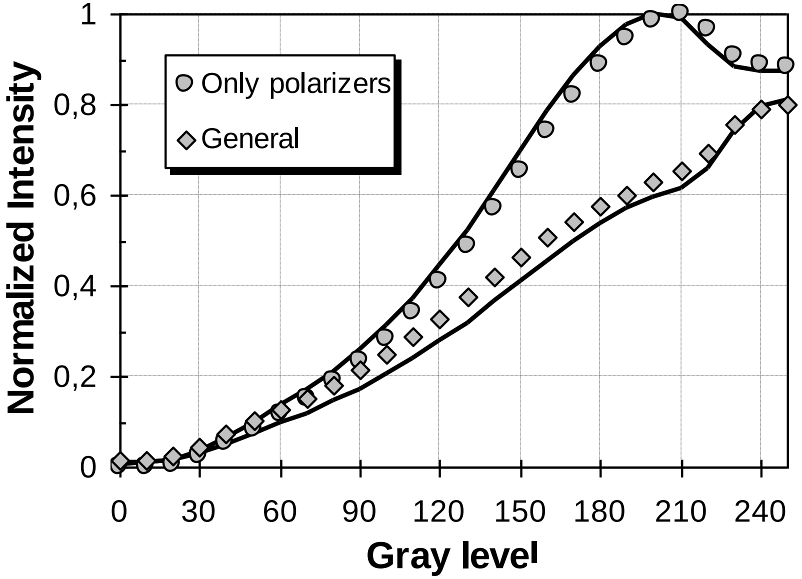


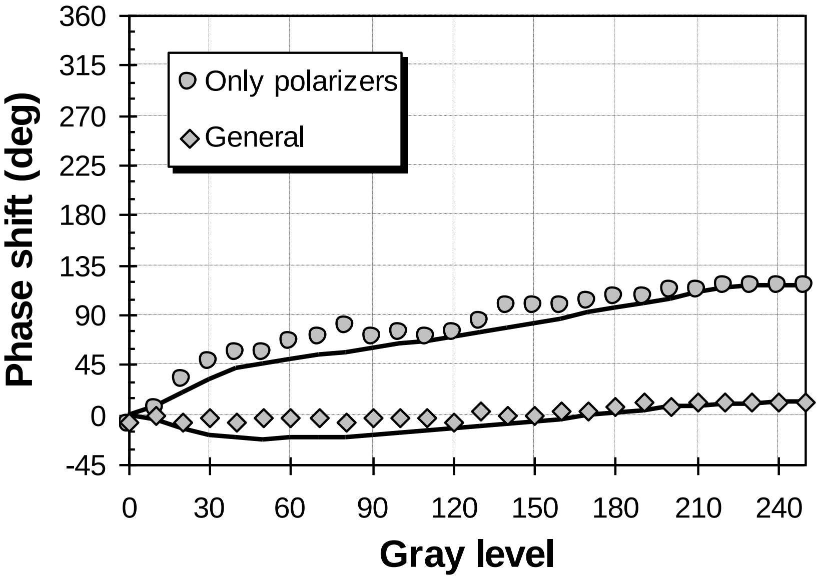



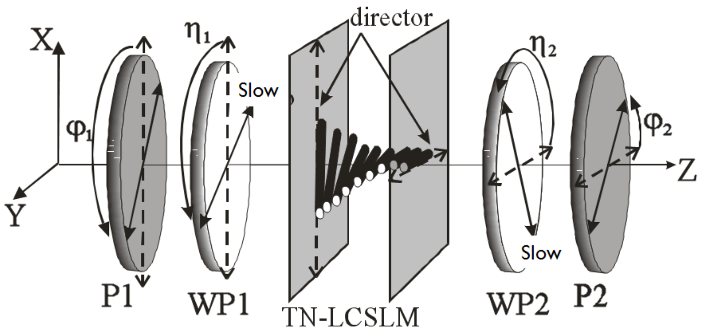



# Modulation Optimization

- **Amplitude-only modulation**

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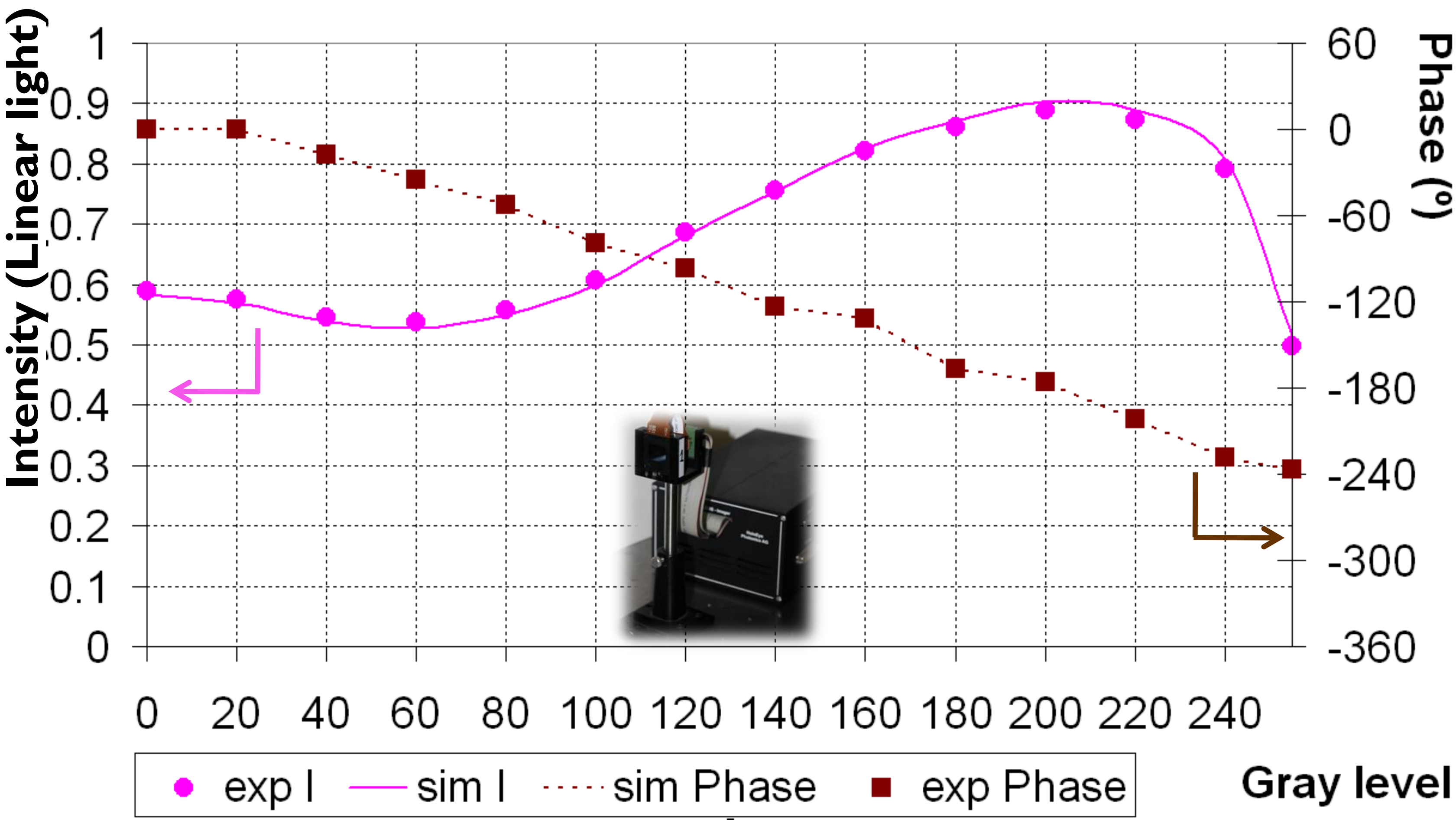
# LCoS display response optimization

- Optimized results for : 633 nm; Only polarizers and 2° incident angle.

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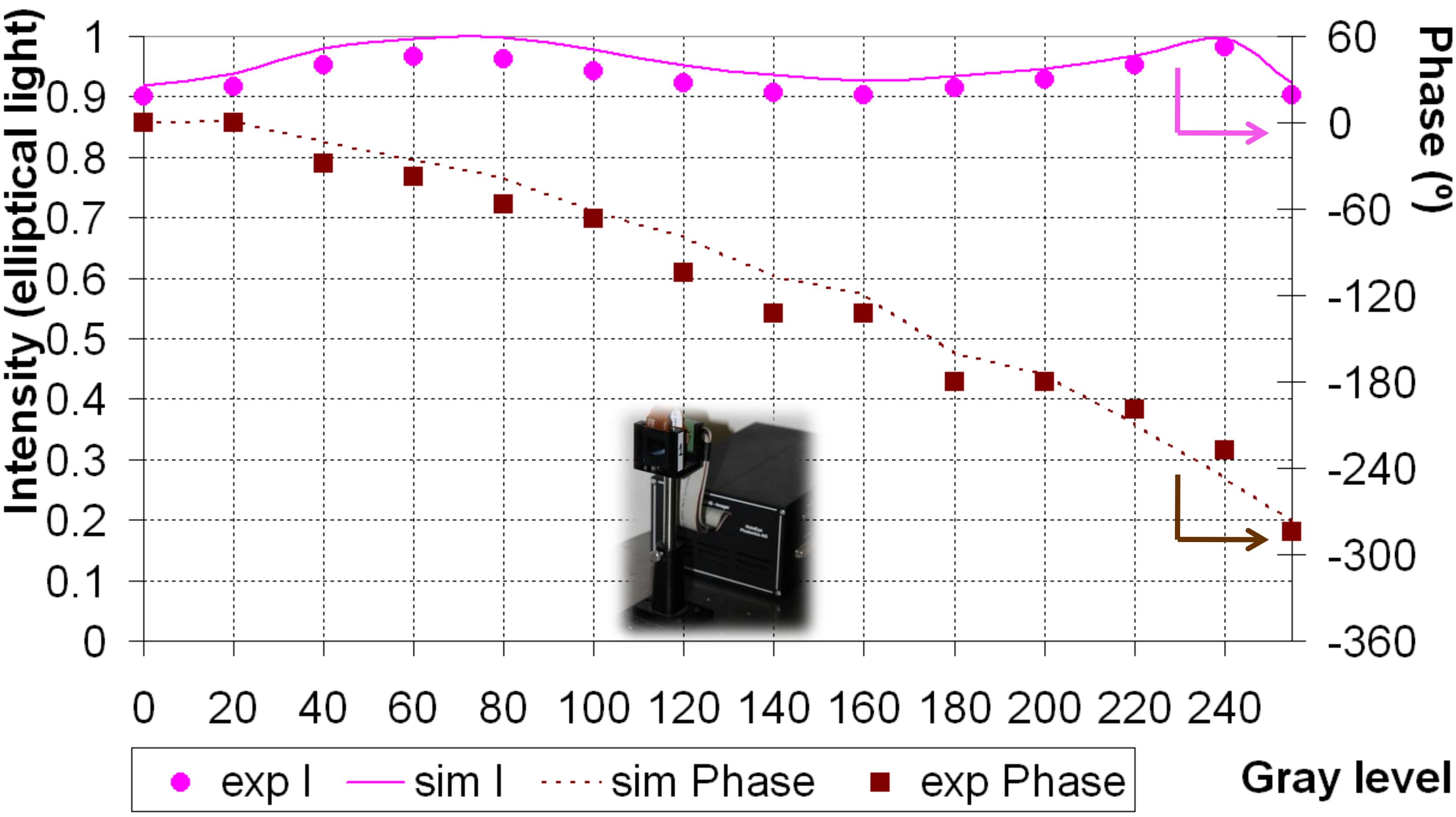
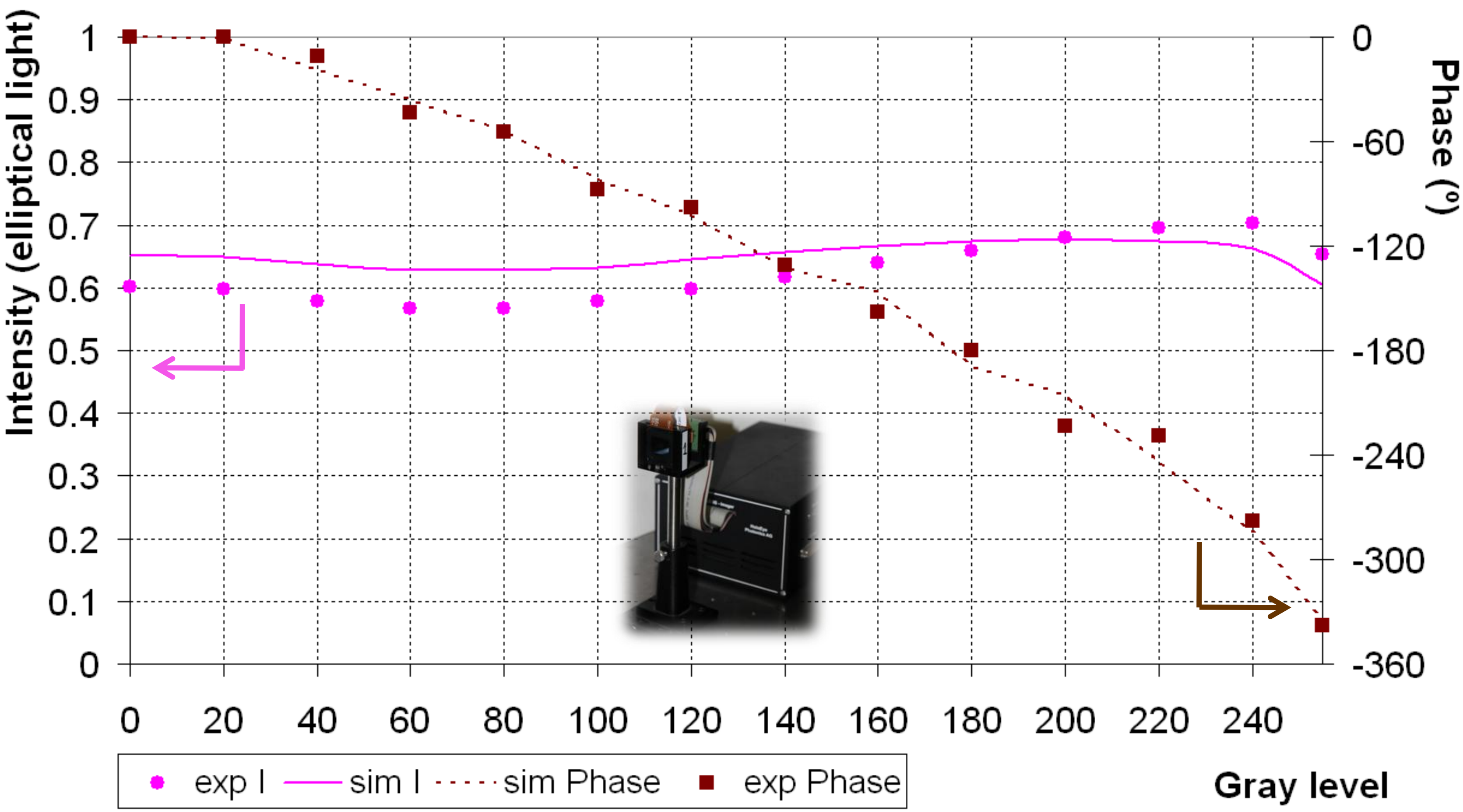
# LCoS display response optimization

- Optimized results for : 633 nm; Polarizers and Wave plates and 2° incident angle.



# LCoS display response optimization

- Optimized results for : 633 nm; Polarizers and Wave plates and 2° incident angle.

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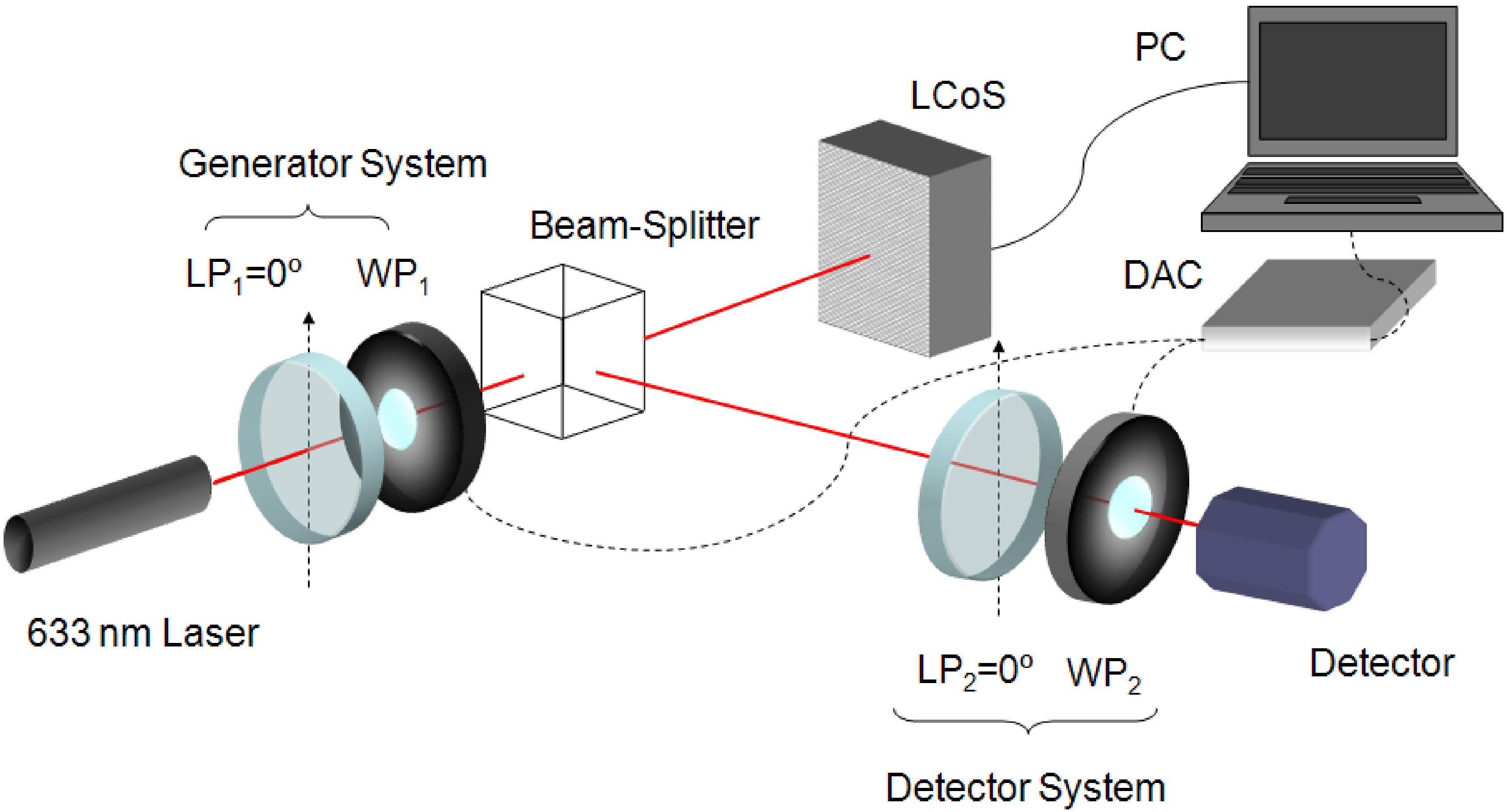
# LCoS display response optimization




- **Beam-splitter based set-up.**

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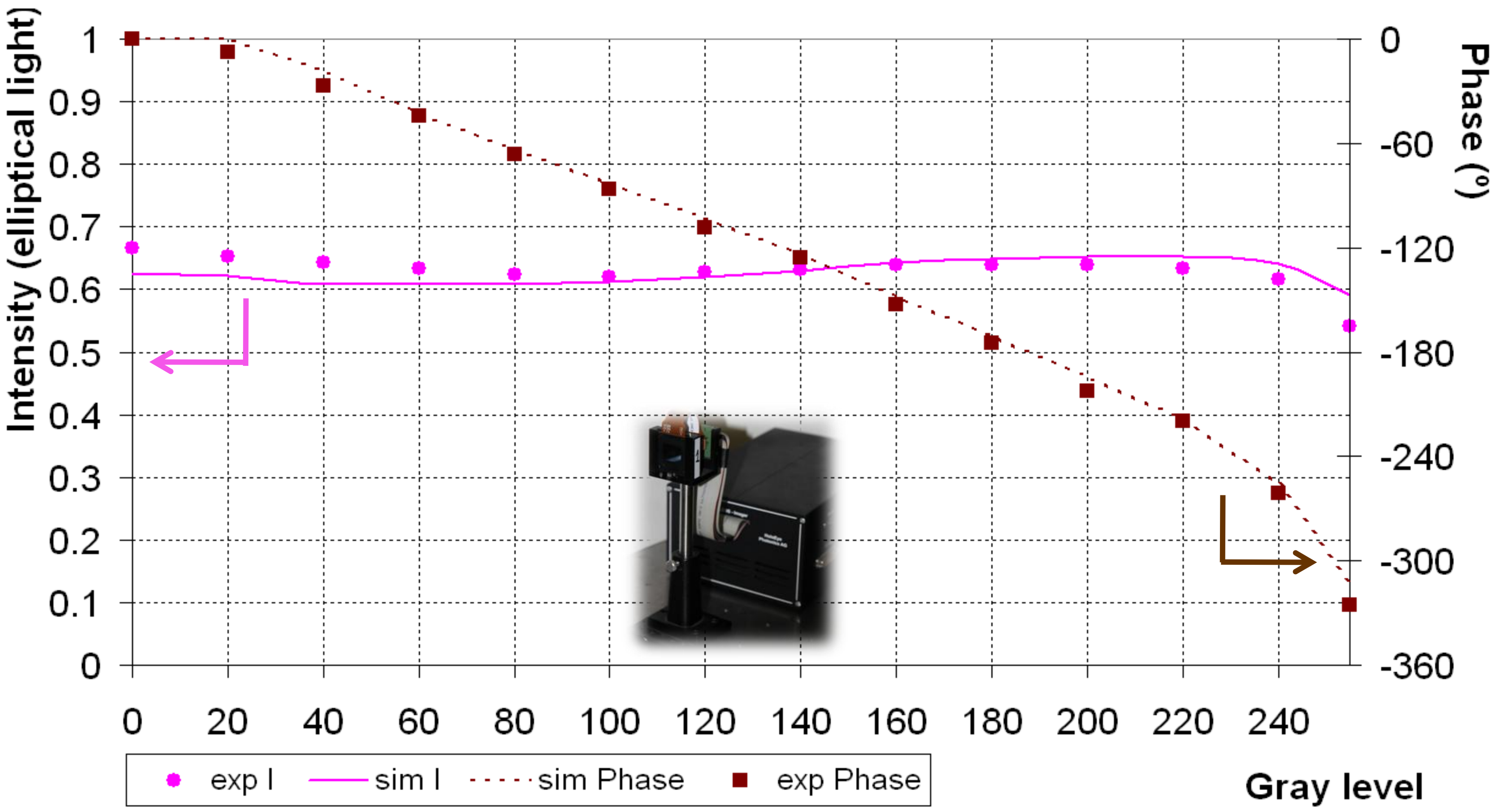
# LCoS display response optimization

- Optimized results for : 633 nm; Polarizers and Wave plates and Beam-splitter.



# Use of commercial LCDs in diffractive Optics

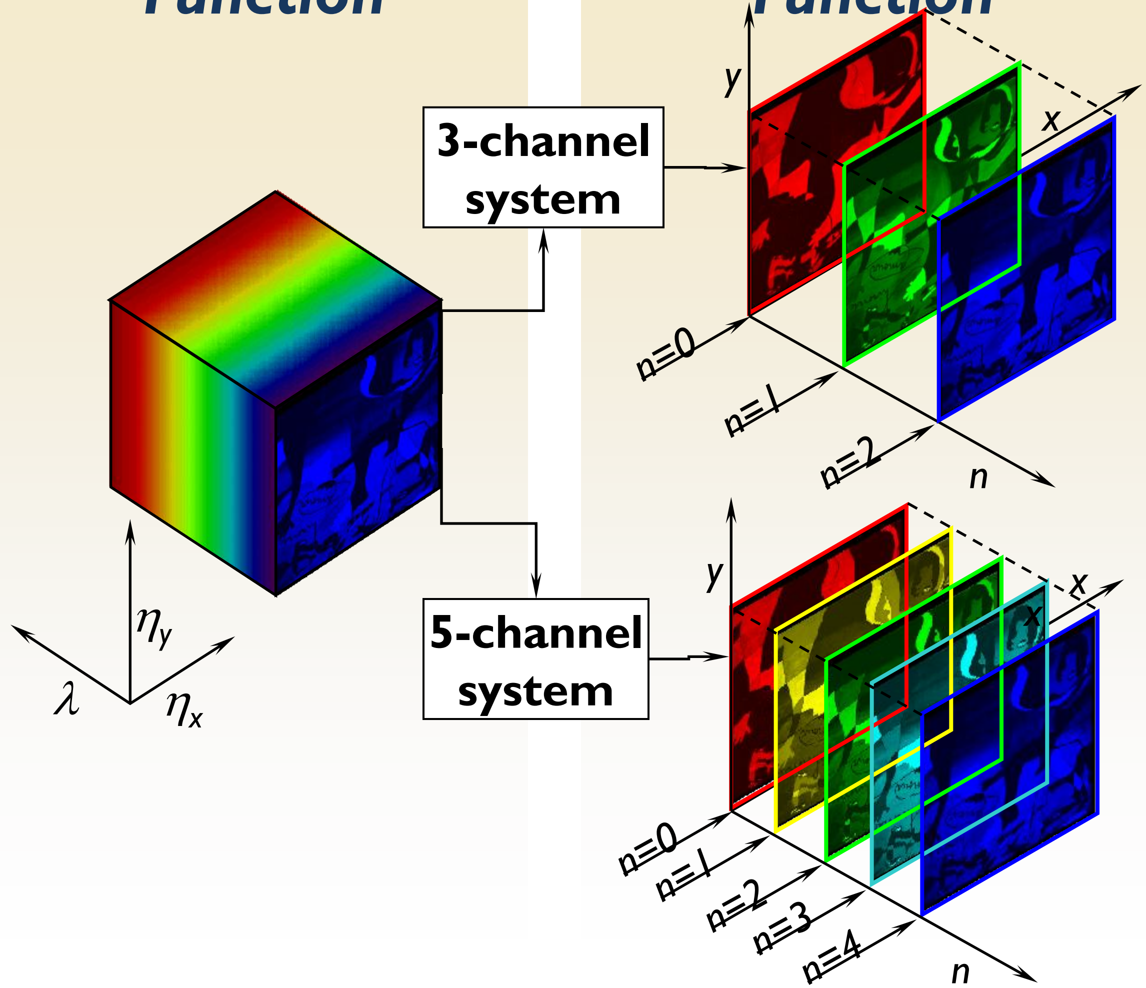
## Pattern recognition

# Color Pattern Recognition

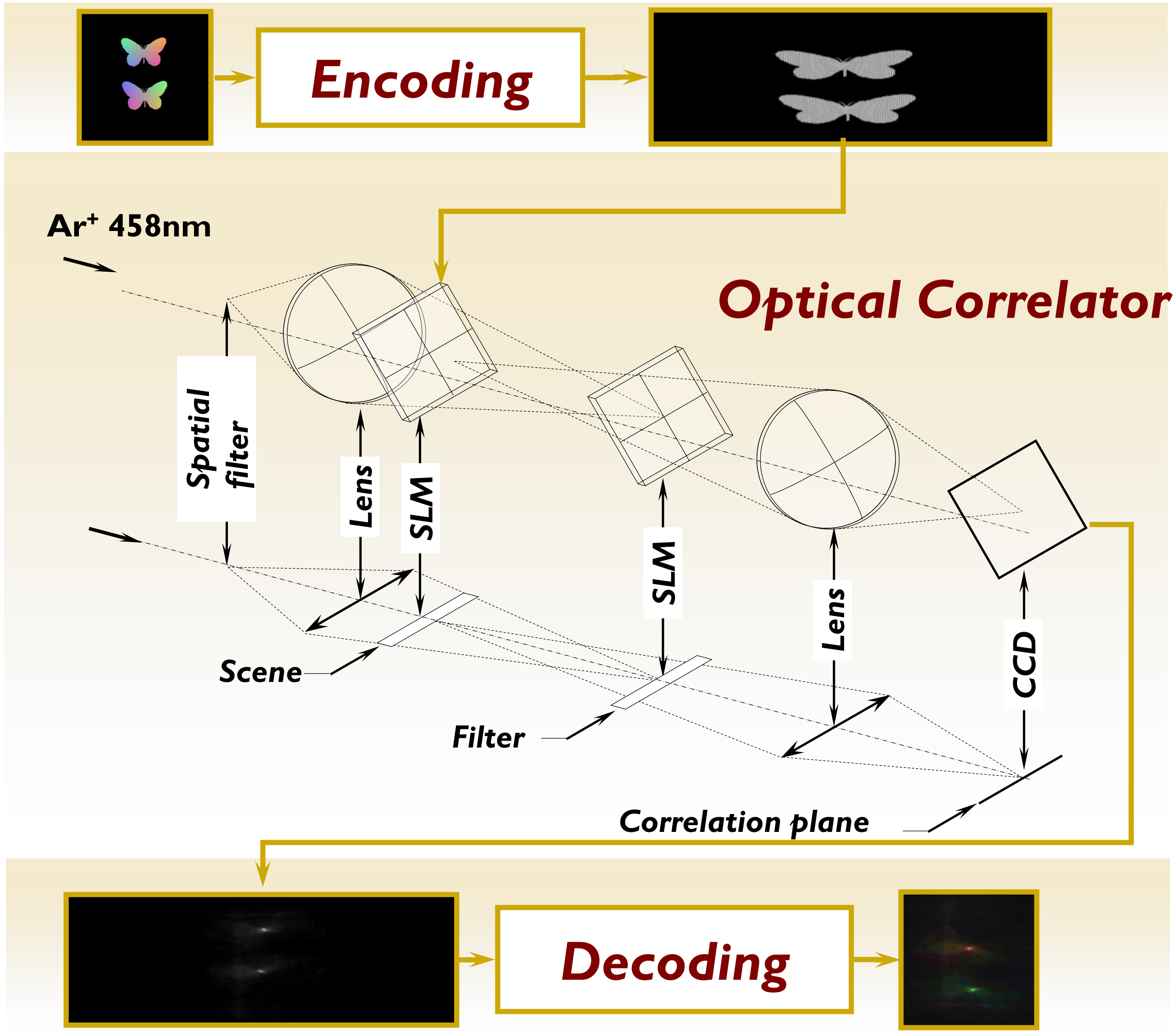
## Color Image

## 3D Continuous Function

## 3D Sampled Function



# Color Pattern Recognition

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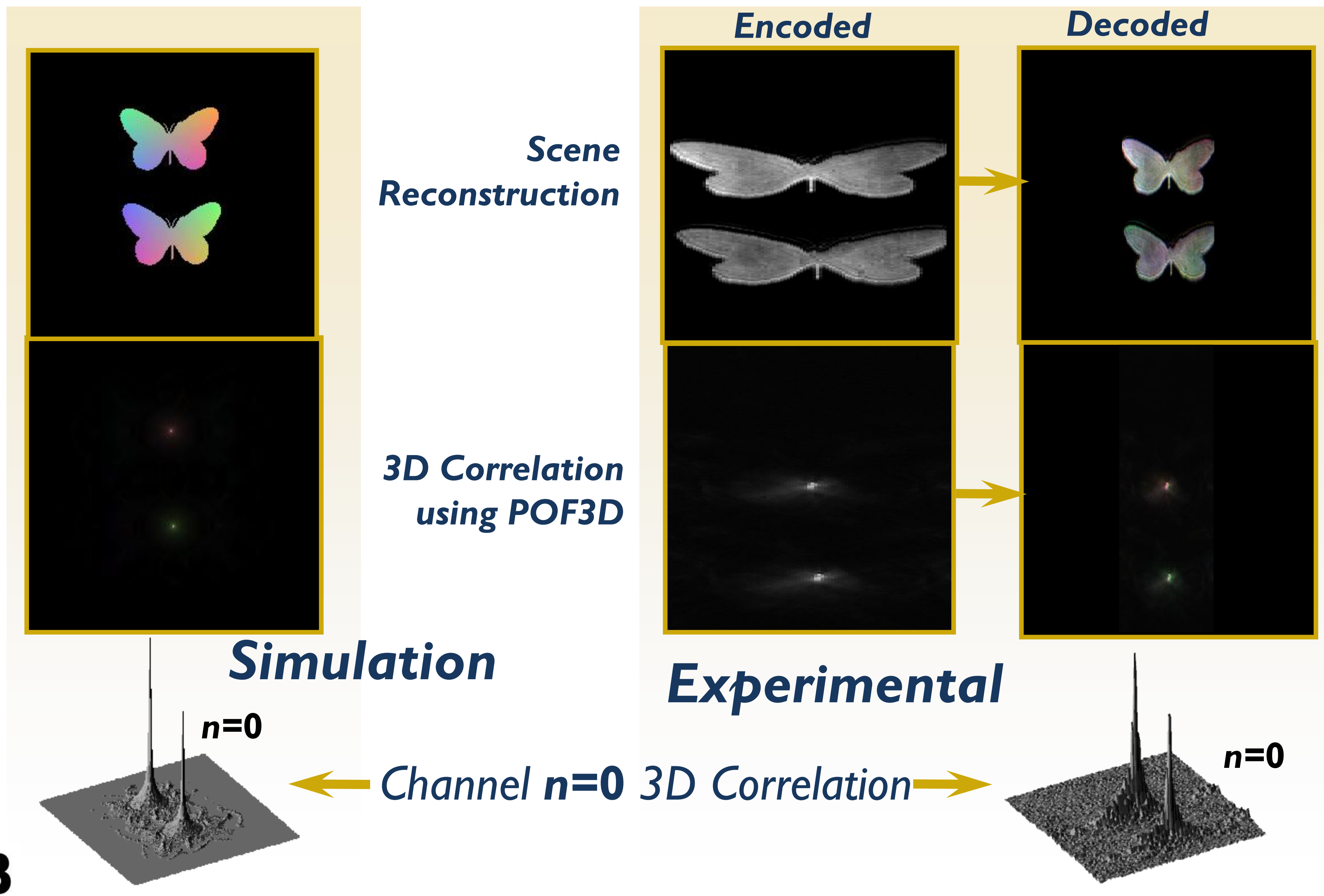
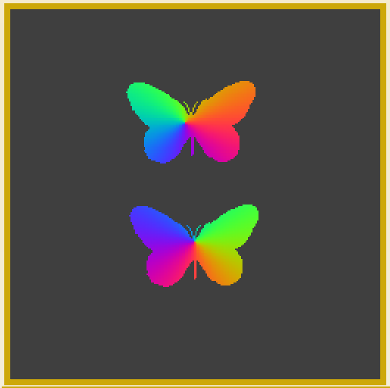
# Color Pattern Recognition

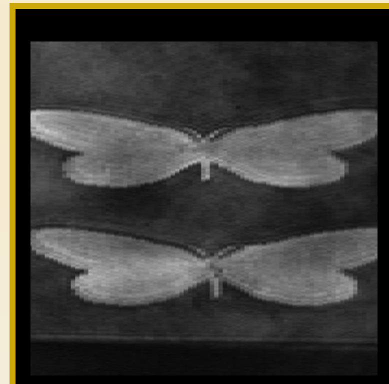


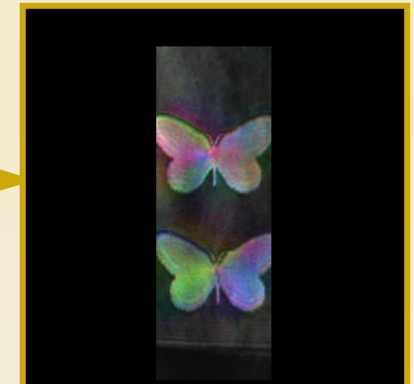
# Color Pattern Recognition



Encoded

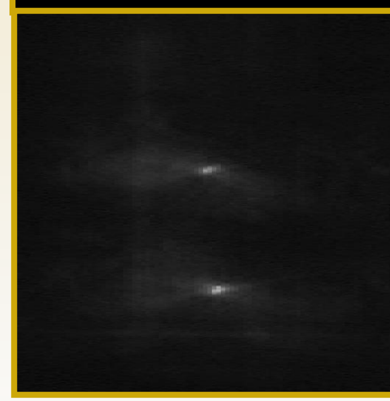
Decoded

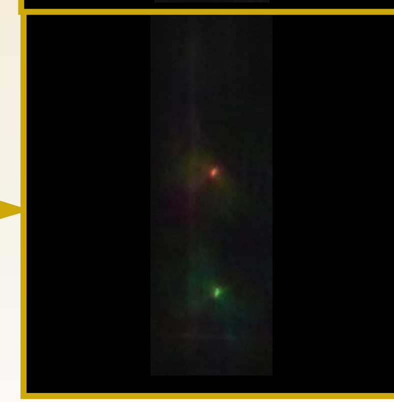




*Scene Reconstruction*

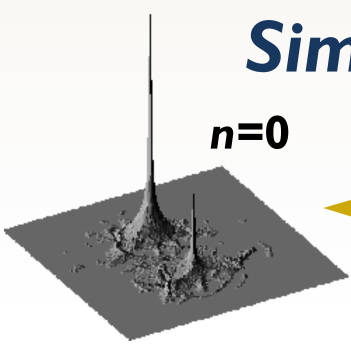
*3D Correlation using POF3D and preprocessed scene*



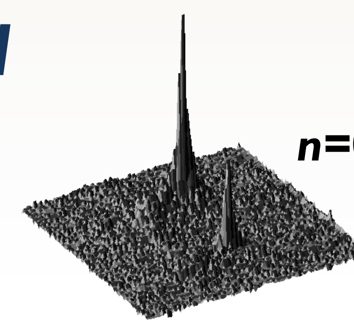


**Simulation**

**Experimental**




*Channel* ***n*=0** *3D Correlation*

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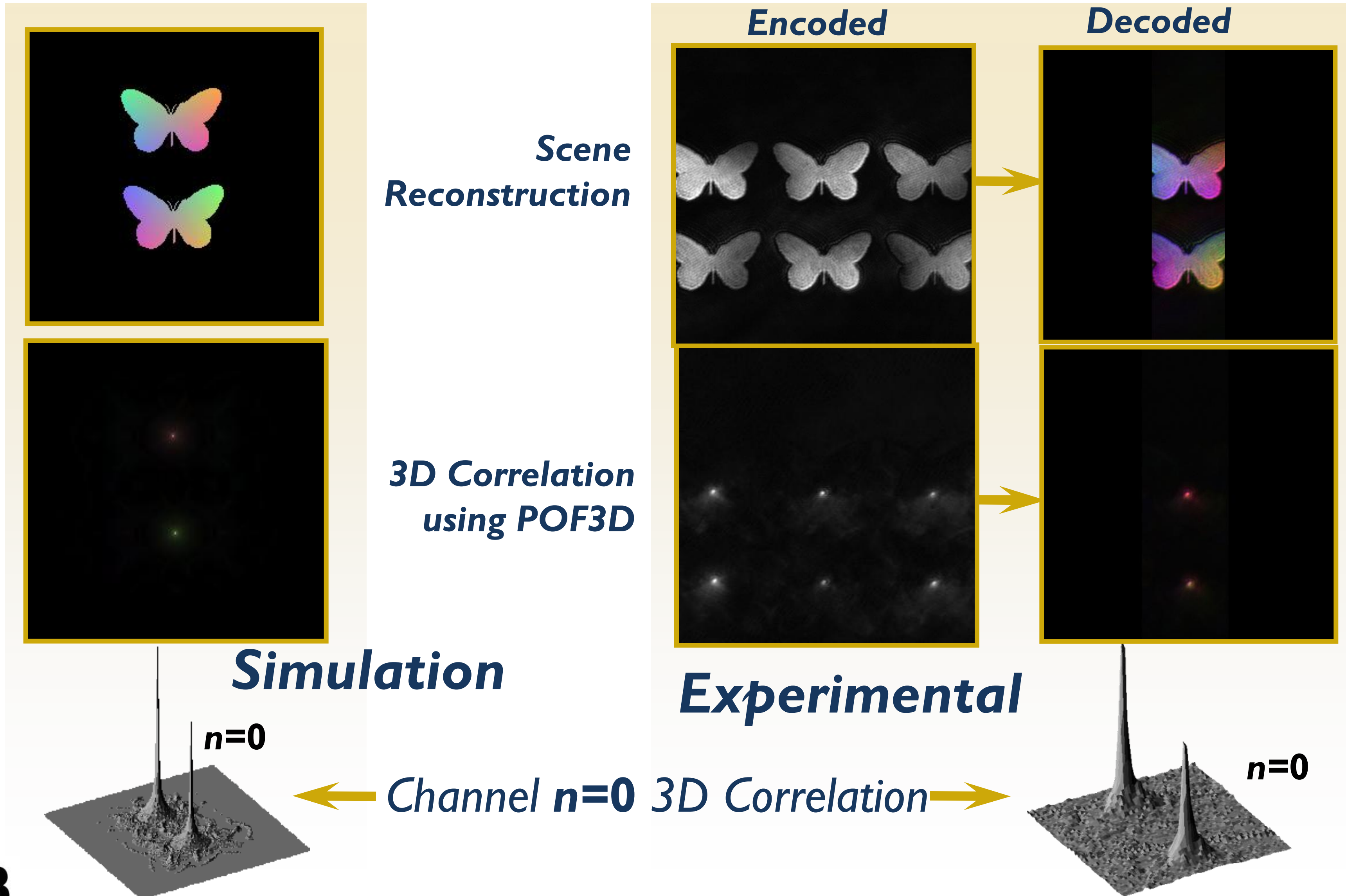
# Color Pattern Recognition

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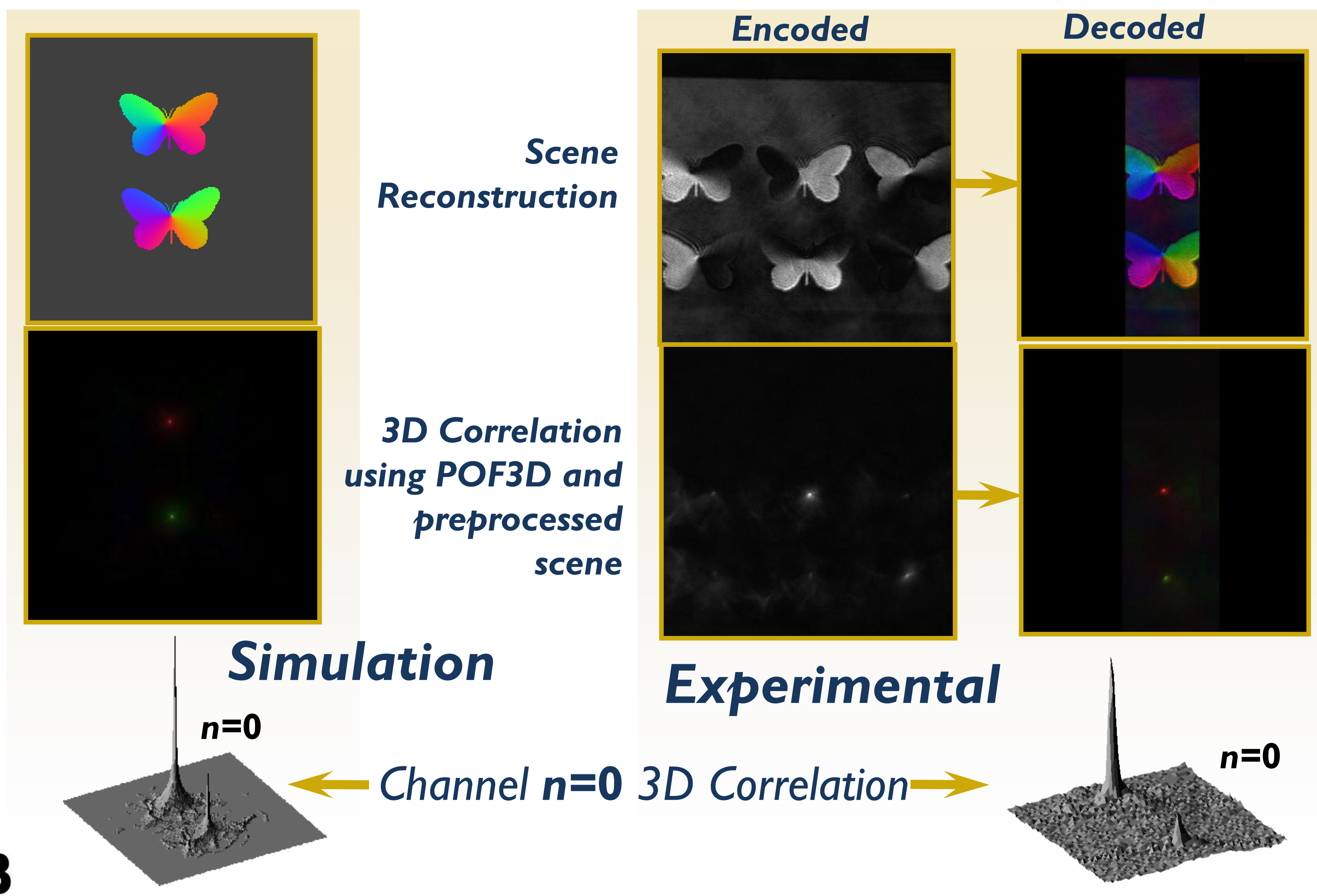
# Color Pattern Recognition



# Use of commercial LCDs in diffractive Optics

## Apodizing filters

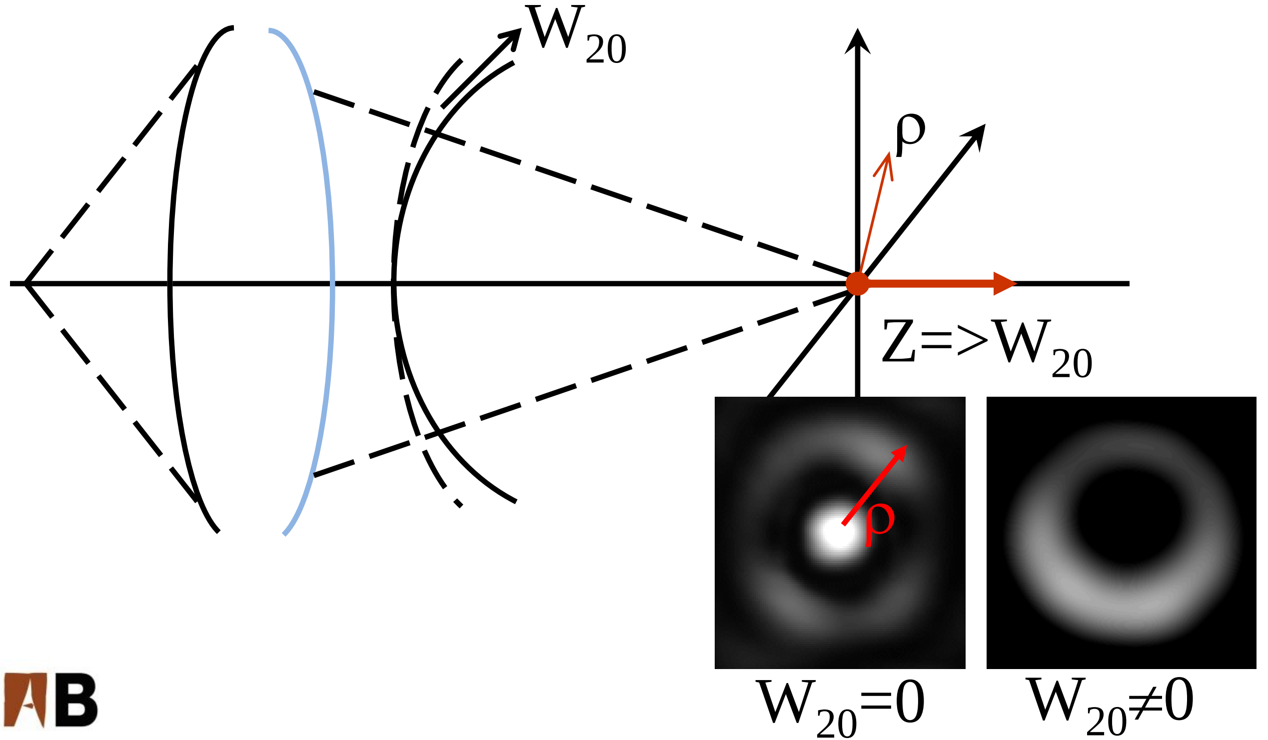
# Apodizing filters

The **3-D Point Spread Function** (PSF) of an optical system is given by:

$$G(\rho, W_{20}) = \left(1/\lambda^2\right) \left| F_\lambda(\rho, W_{20}) \right|^2$$

***$F(\rho, W_{20})$*** **monochromatic amplitude** (optical system with radial symmetry) :

$$F_\lambda(\rho, W_{20}) = 2\pi \int_0^1 t(r) \exp\left[i\, 2\pi\, W_{20} r^2\right] J_0\left(2\pi\, \rho\, r\right) r\, dr$$

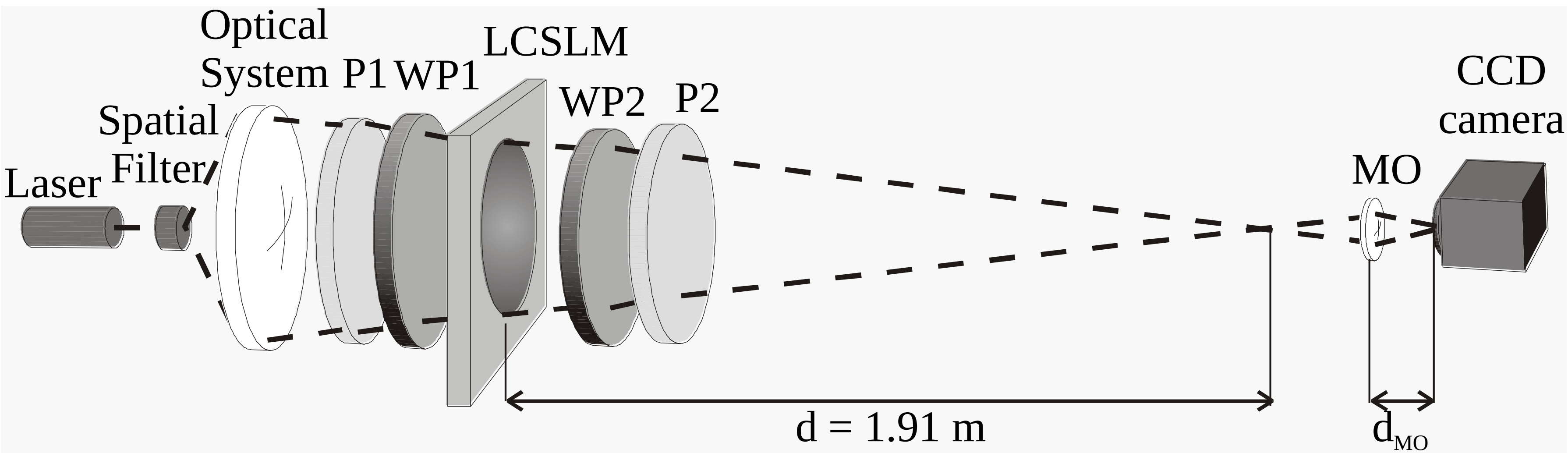



$$s = \frac{\lambda}{NA}\rho$$

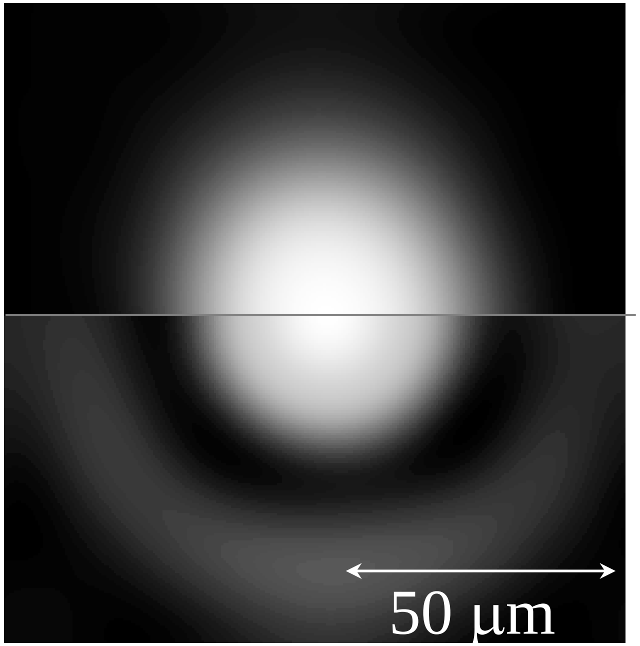
$$z = \frac{2\lambda}{NA^2} W_{20}$$

UAB

# Apodizing filters

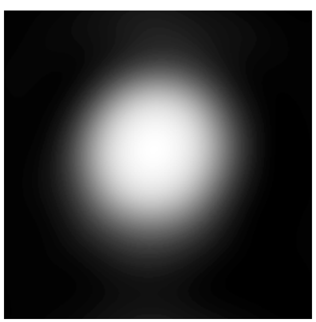


# $\tau(r) = 1 - r^2$ and $\tau(r) = r^2$

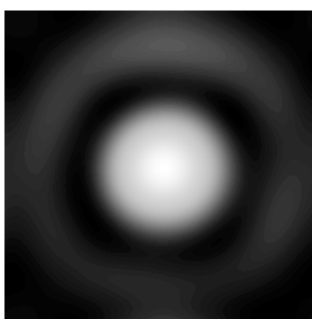



| $t(r) = 1 - r^2$ (transverse response) | | | | |
|---|---|---|---|---|
| Position | $\rho'$ ($\mu m$) (theory) | Intensity N2 | $\rho'$ ($\mu m$) (exper) | Intensity N2 |
| Center | **0** | **1** | **0** | **1** |
| 1rst min. | **84.1** | **0** | **88.3** | **0** |
| 1rst max. | **105.9** | **0.004** | **---** | **---** |

| $t(r) = r^2$ (transverse response) | | | | |
|---|---|---|---|---|
| Position | $\rho'$ ($\mu m$) (theory) | Intensity N2 | $\rho'$ ($\mu m$) (exper) | Intensity N2 |
| Center | **0** | **1** | **0** | **1** |
| 1rst min. | **49.8** | **0** | **54.3** | **0** |
| 1rst max. | **74.7** | **0.08** | **79.9** | **0.07** |



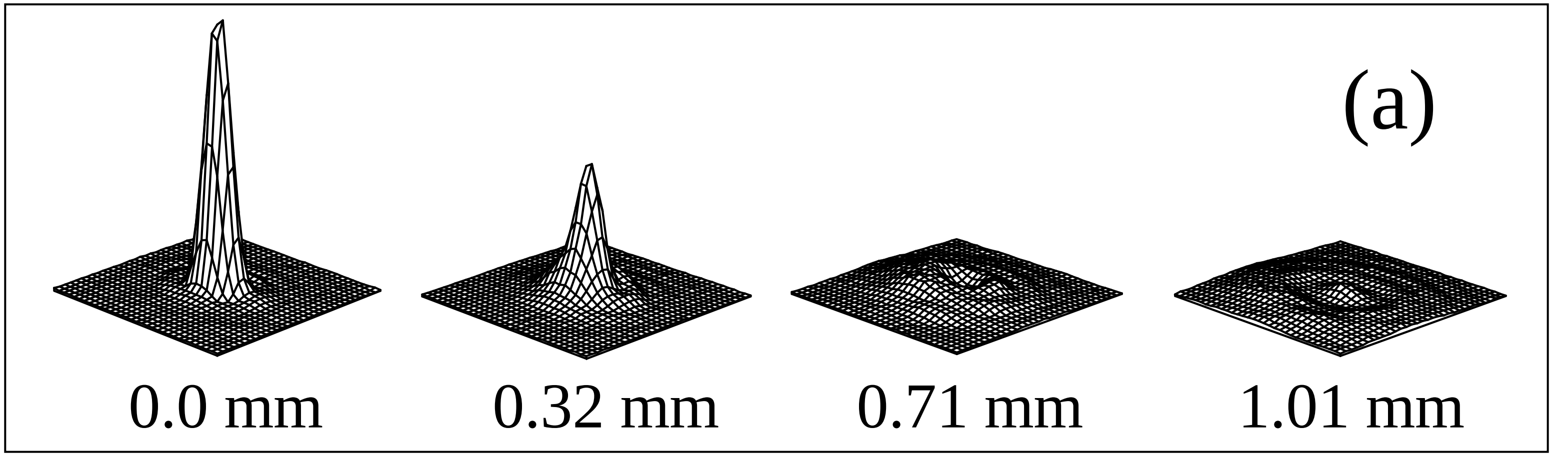
$\tau(r) = 1 - r^2$

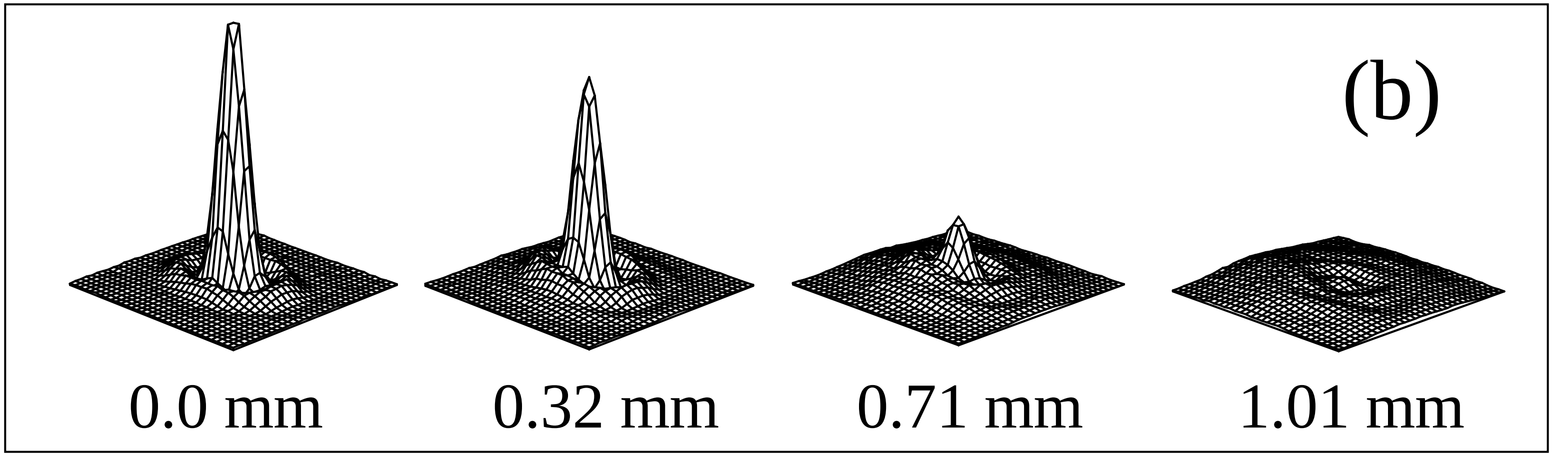


$\tau(r) = r^2$

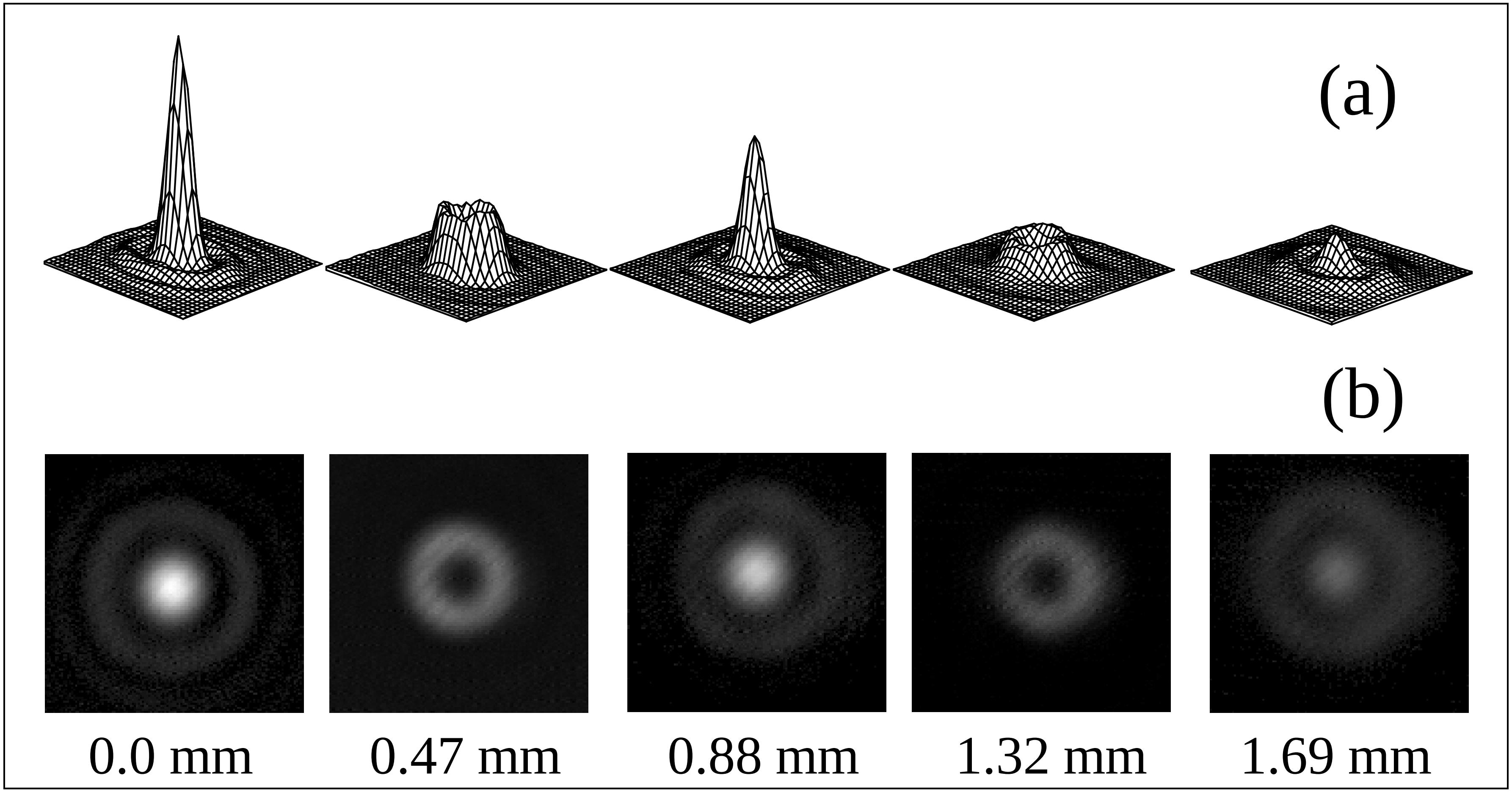
**Clear aperture**

**Axial apodizing filter:** $\tau(r) = 6.75\, r^2 - 13.5\, r^4 + 6.75\, r^6$



# Axial hyperresolving filter: $\tau(r) = 1 - 4r^2 + 4r$

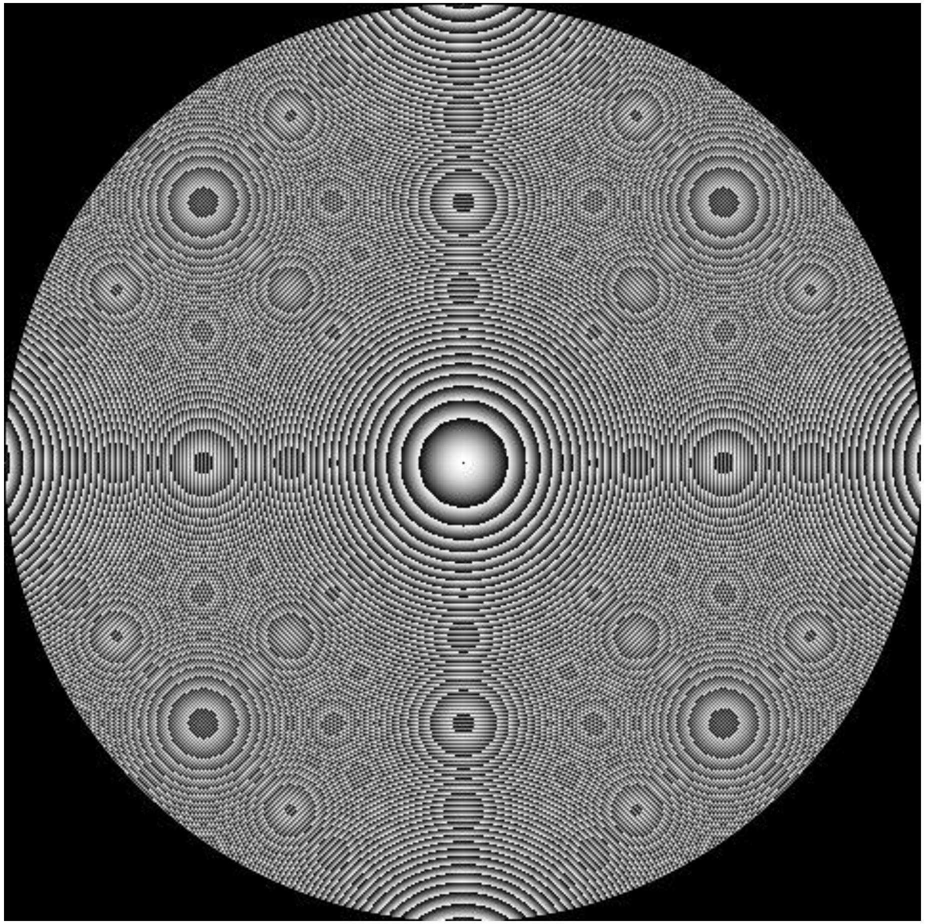


# Use of commercial LCDs in diffractive Optics

## Multiplexed lenses

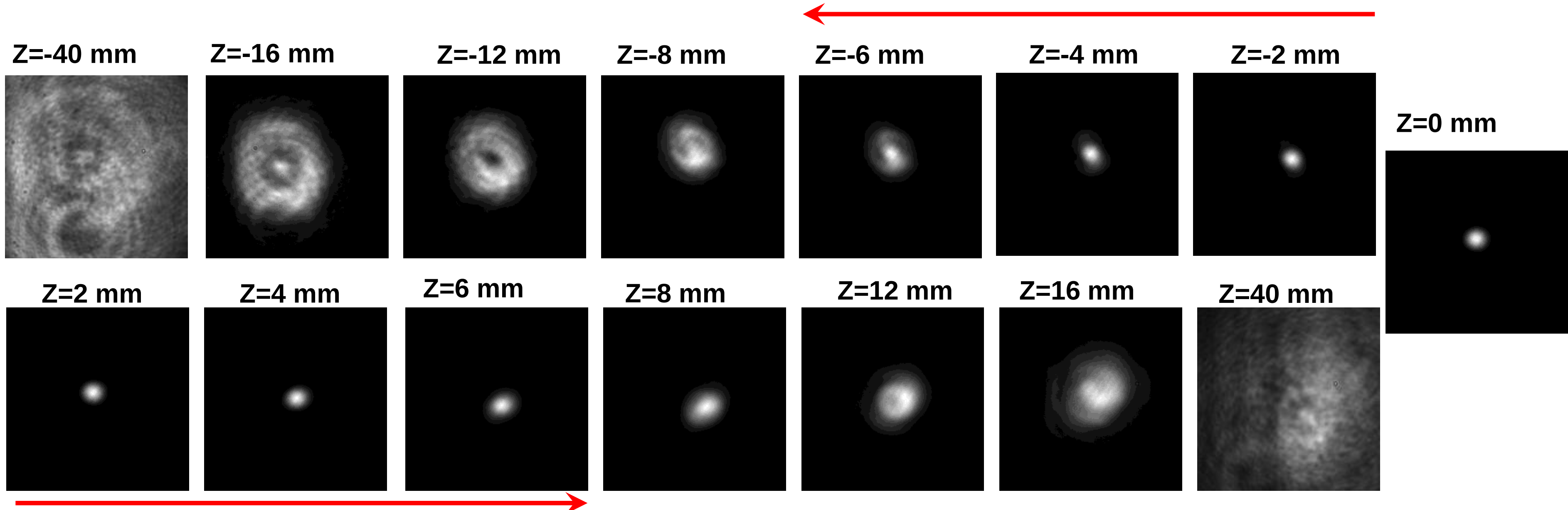
# Single lens

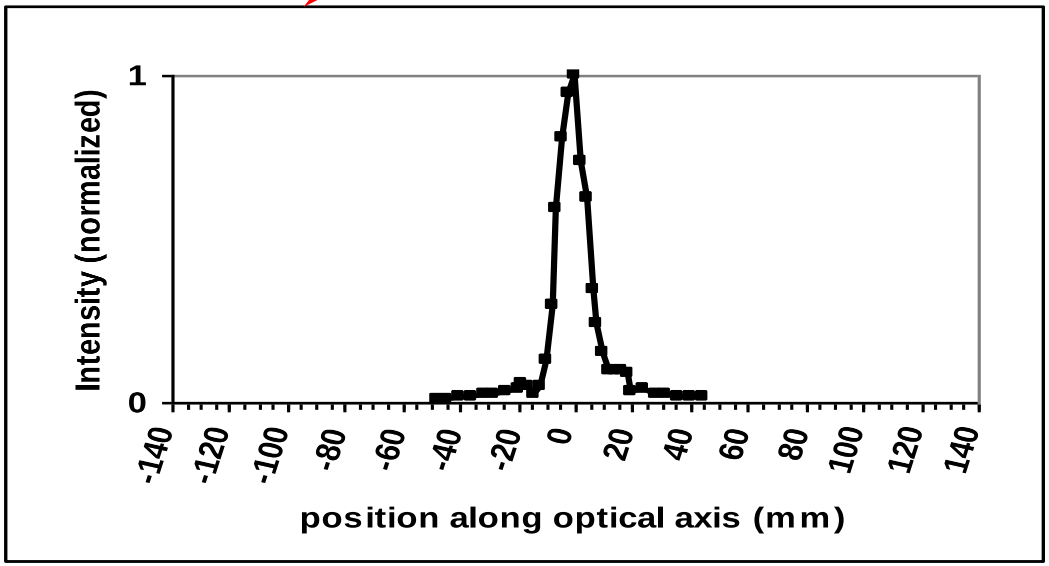
- Lens with a focal length of 1000 mm for the blue line of an Ar laser ($\lambda$ = 458 nm)



UAB

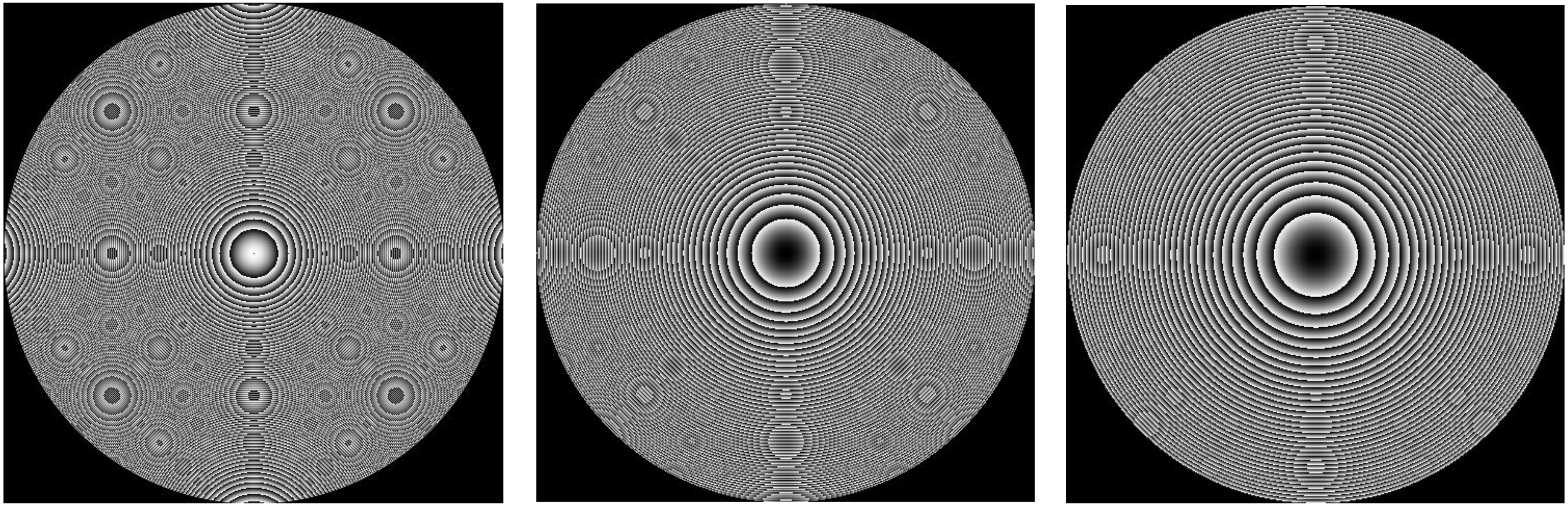
# Single lens

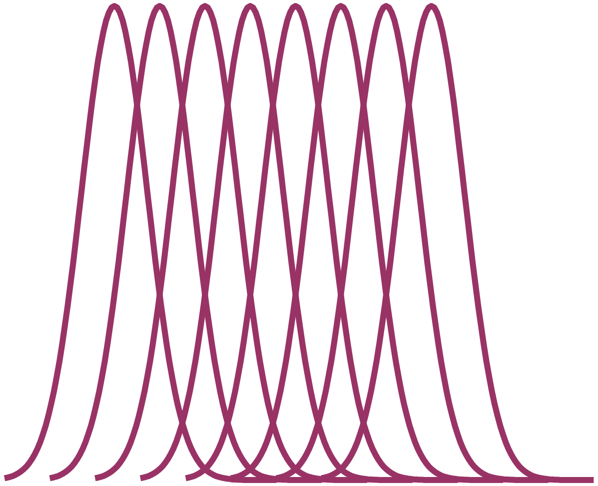


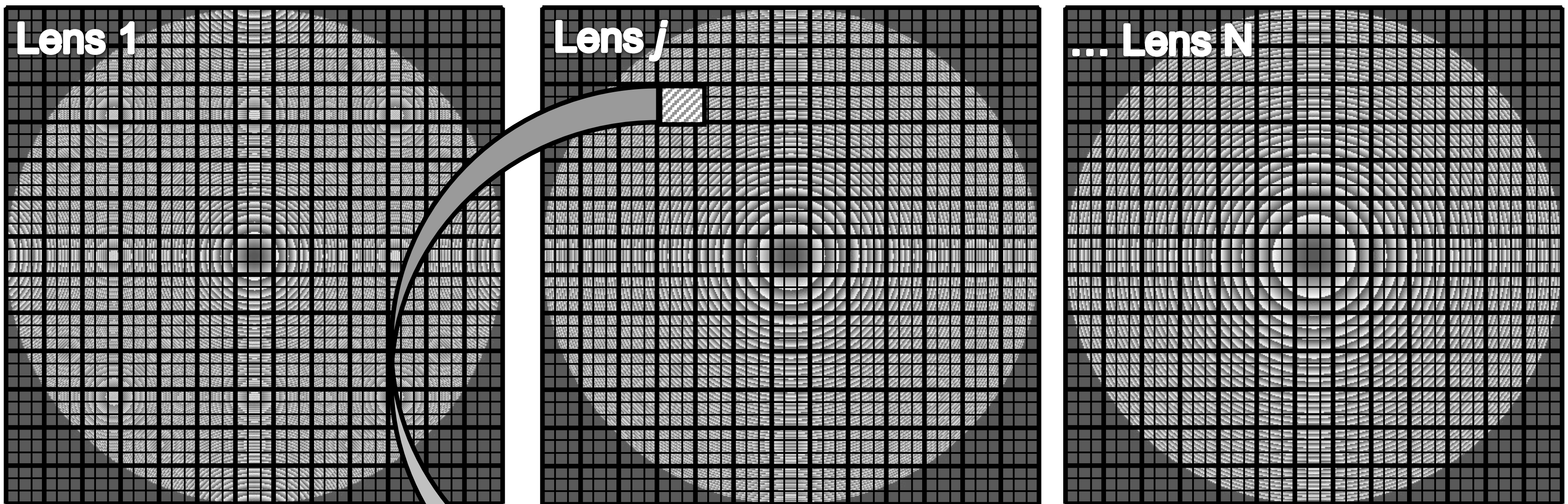

UAB

# Multiplexed Lens





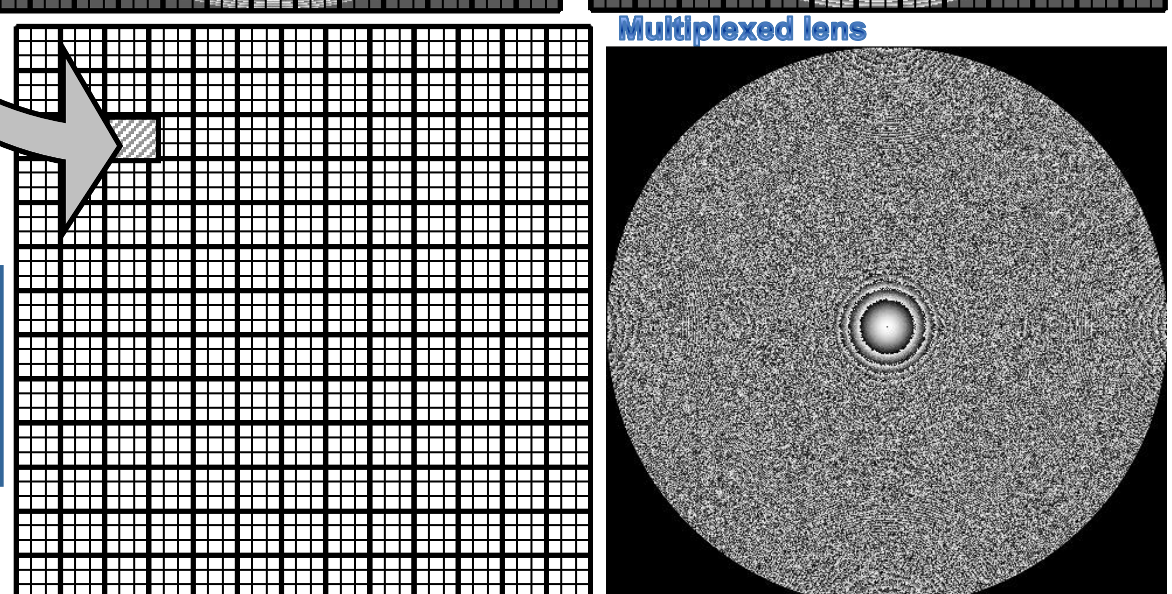
# Randomly multiplexed lenses



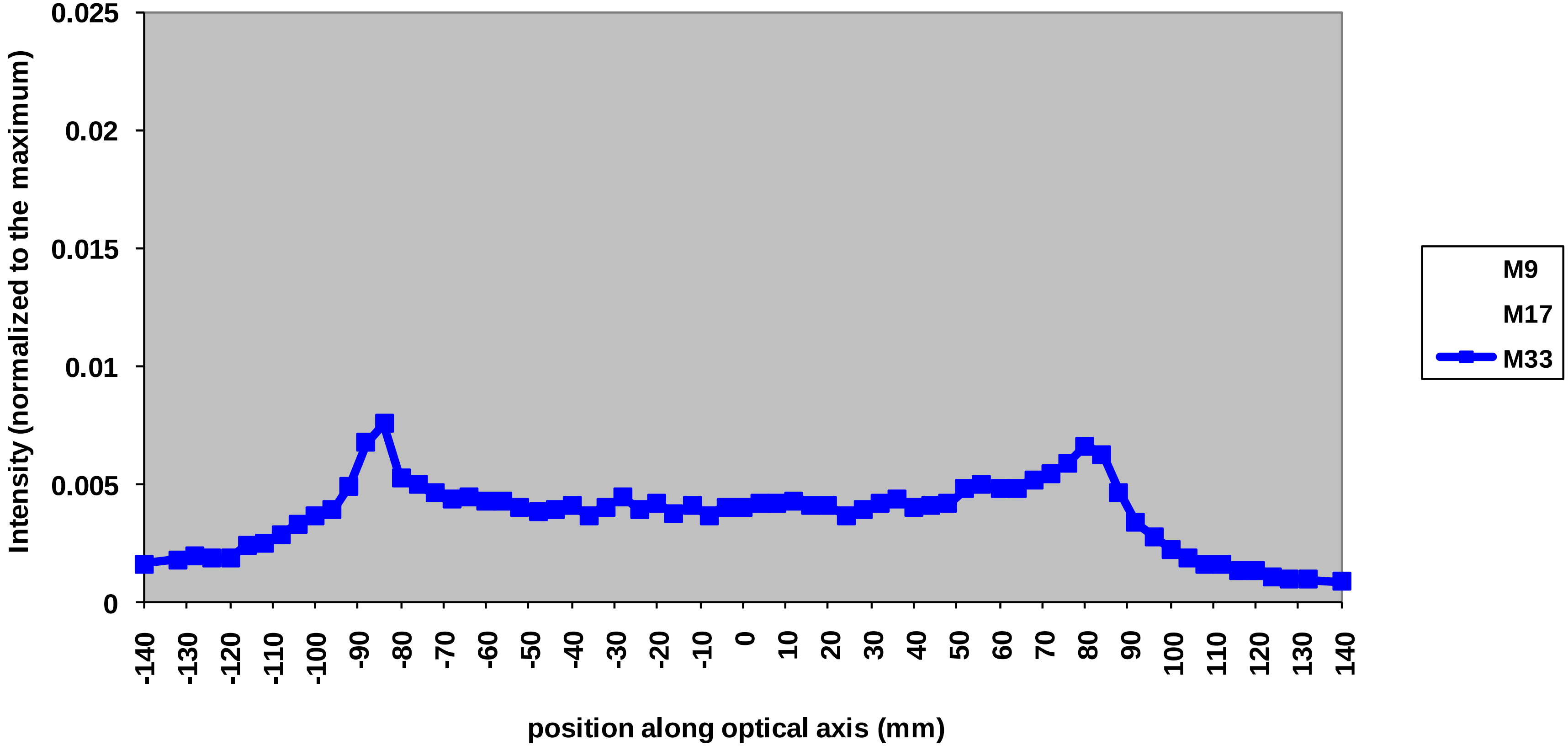

N: Number of lenses
P: Number of pixels for each lens

K random number (0,N]

j-1 < K <= j



# Randomly multiplexed 33 lenses

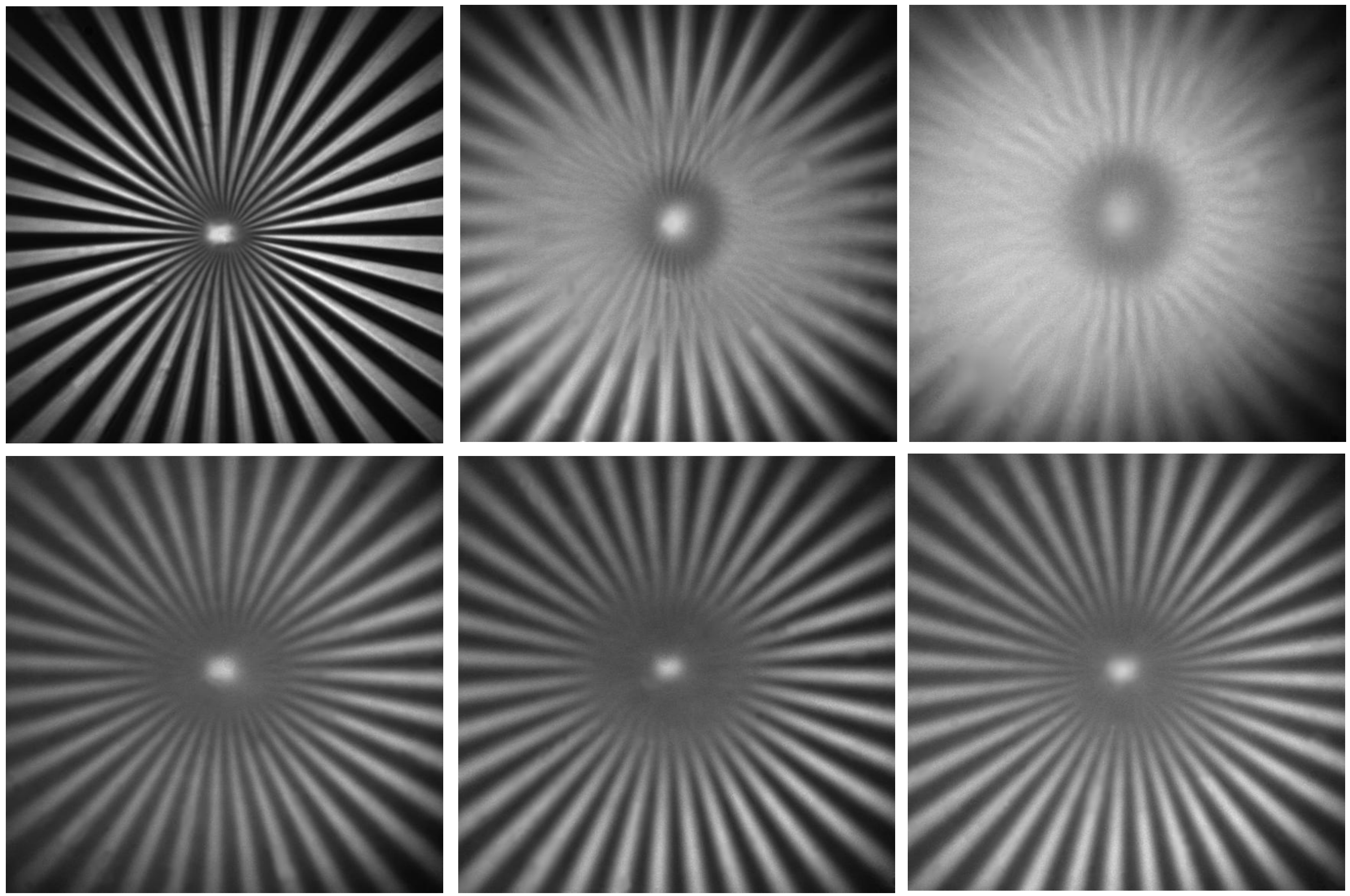


# Randomly multiplexed 33 lenses

Z = 0 cm. | Z = -6 cm. | Z = -10 cm.

Single lens

Multiplexed lens



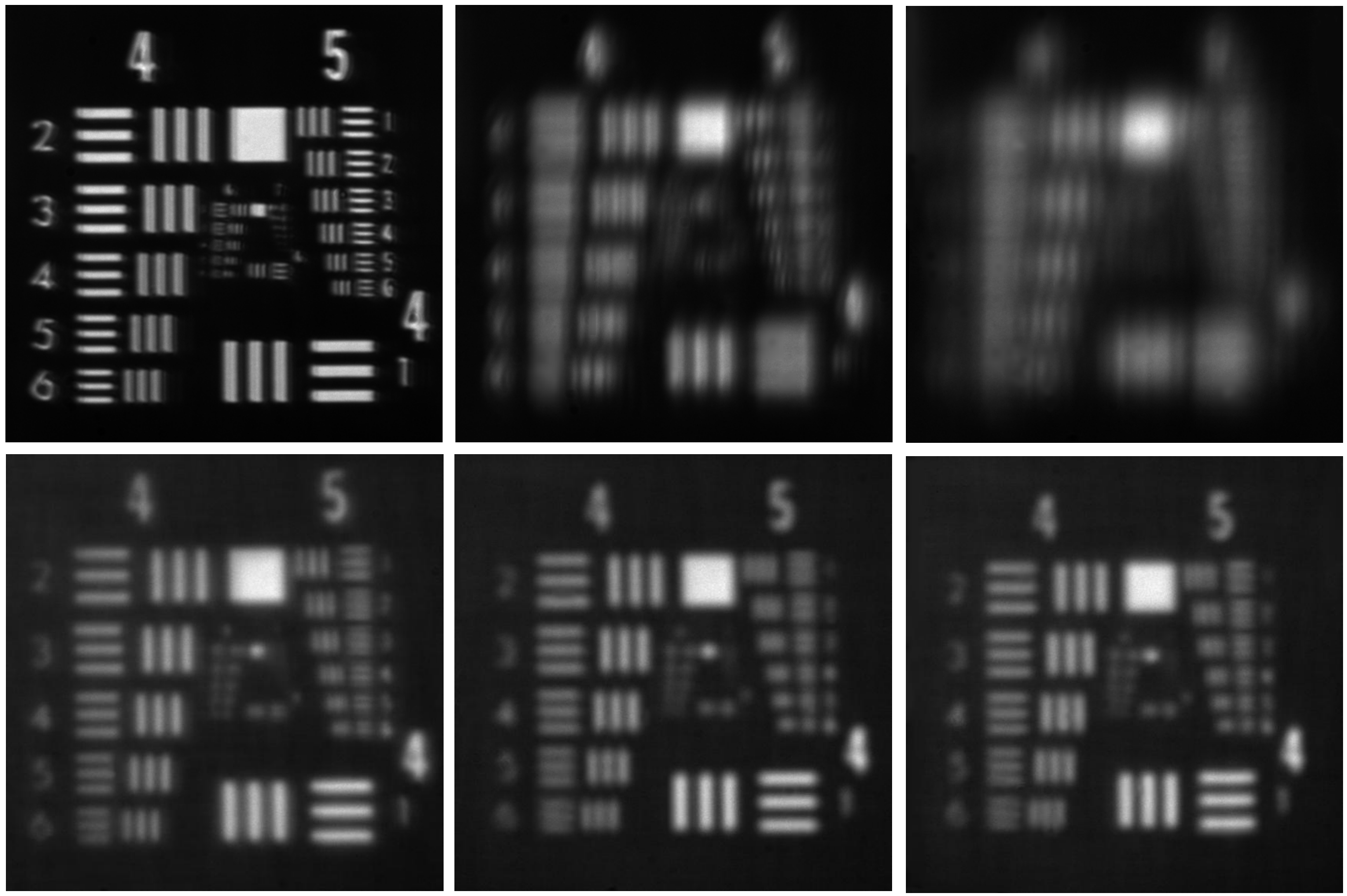
UAB

# Randomly multiplexed 33 lenses

Z = 0 cm. | Z = -6 cm. | Z = -10 cm.

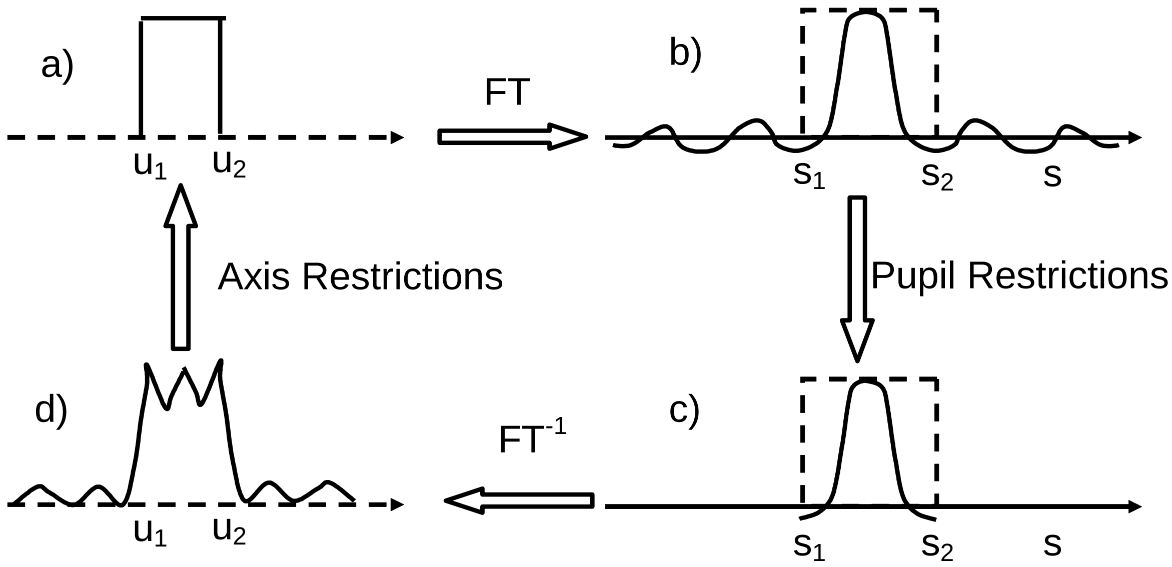
Single lens

Multiplexed lens



# Tailoring the axial response

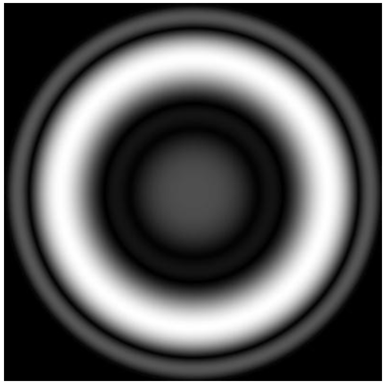
$$E(u) \propto \int_{-\infty}^{\infty} p(s)\exp(-i2\pi us)\,ds = P(u)$$



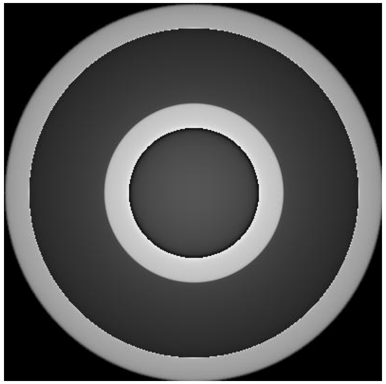
# Tailoring the axial response

## Encoding Complex pupils in Phase Only SLMs

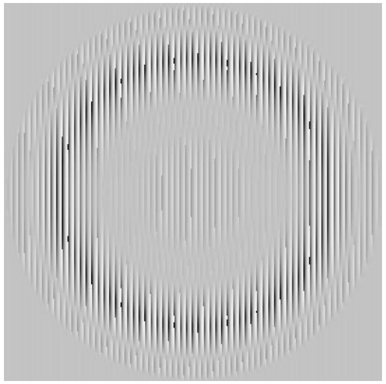
NARROW RECTANGLE



modulus

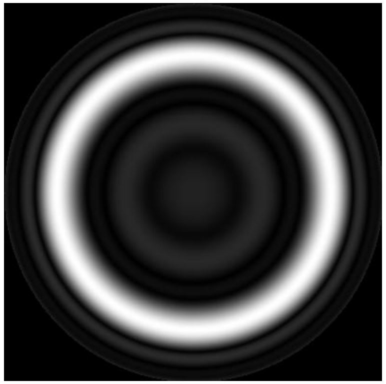


phase

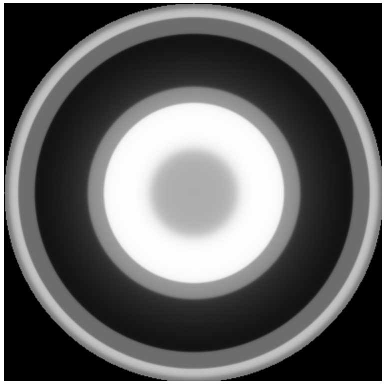


encoded pupil

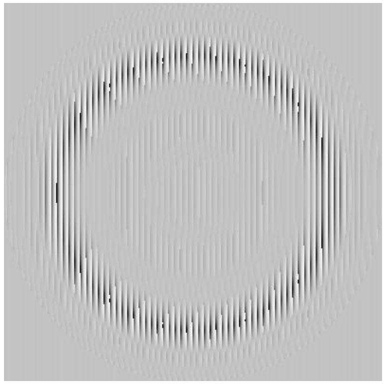
TRIANGLE



modulus



phase

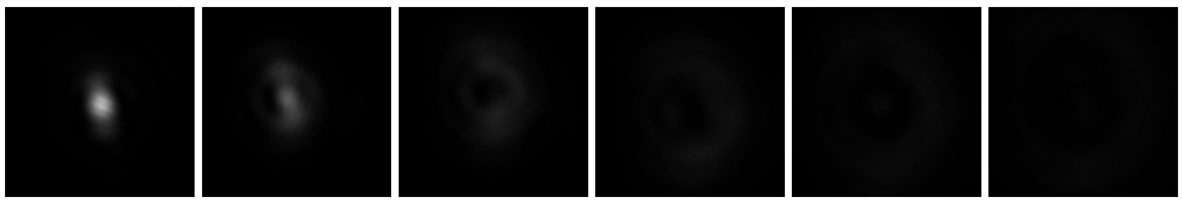


encoded pupil

UAB

# Tailoring the axial response

Z = -12 Z = -10 Z = -8 Z = -6 Z = -4 Z = -2 Z = 0

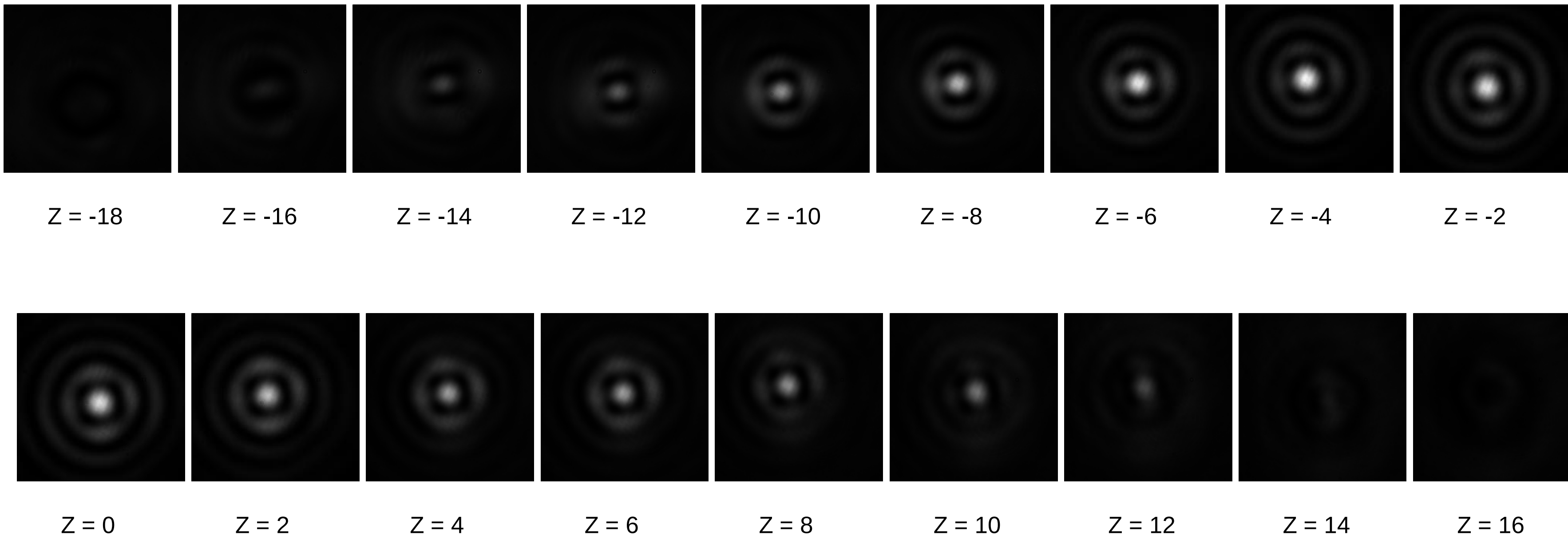


Z = 2 Z = 4 Z = 6 Z = 8 Z = 10 Z = 12

UNIFORM PUPIL

UAB

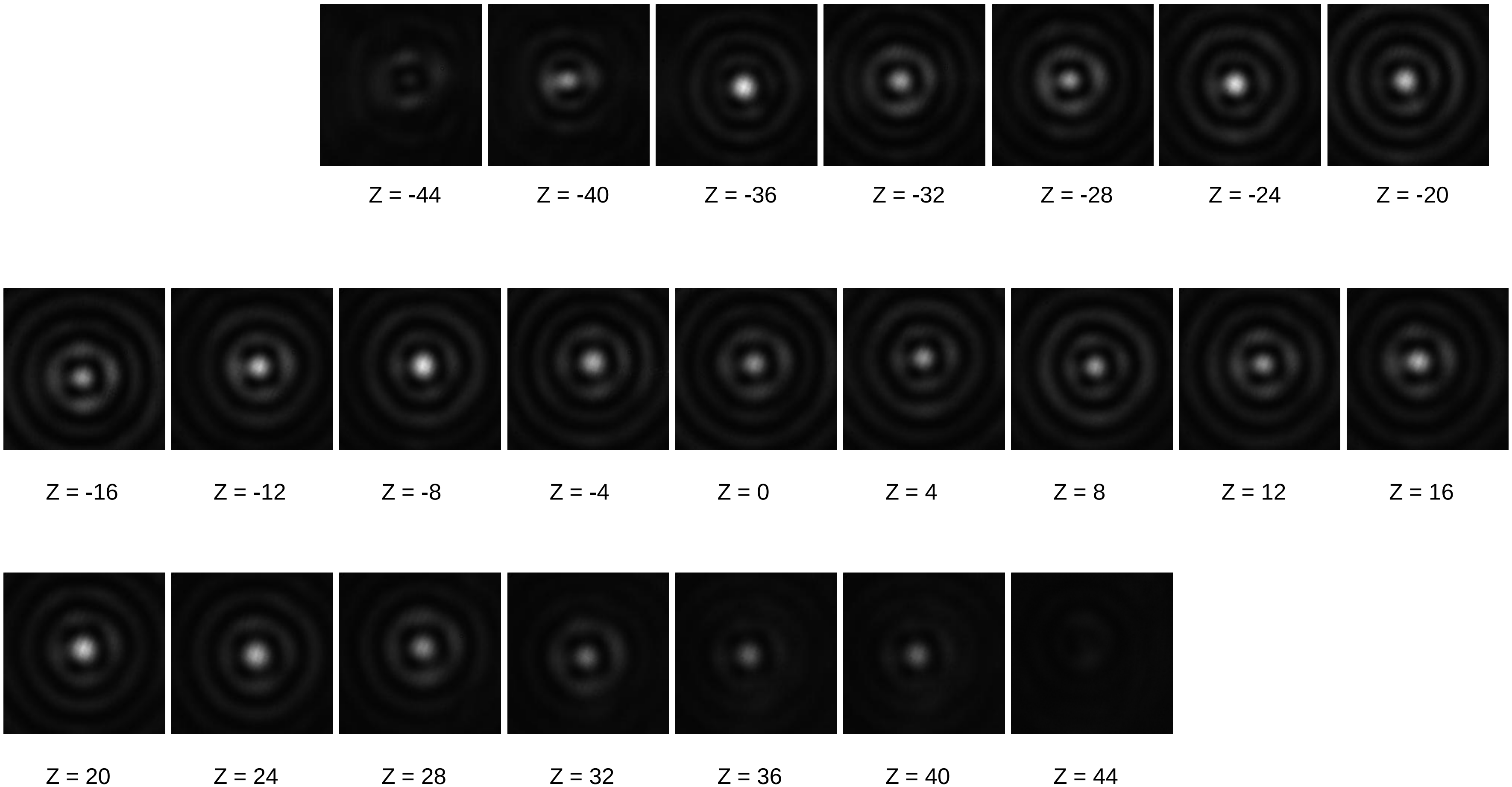
# Tailoring the axial response




NARROW RECTANGLE

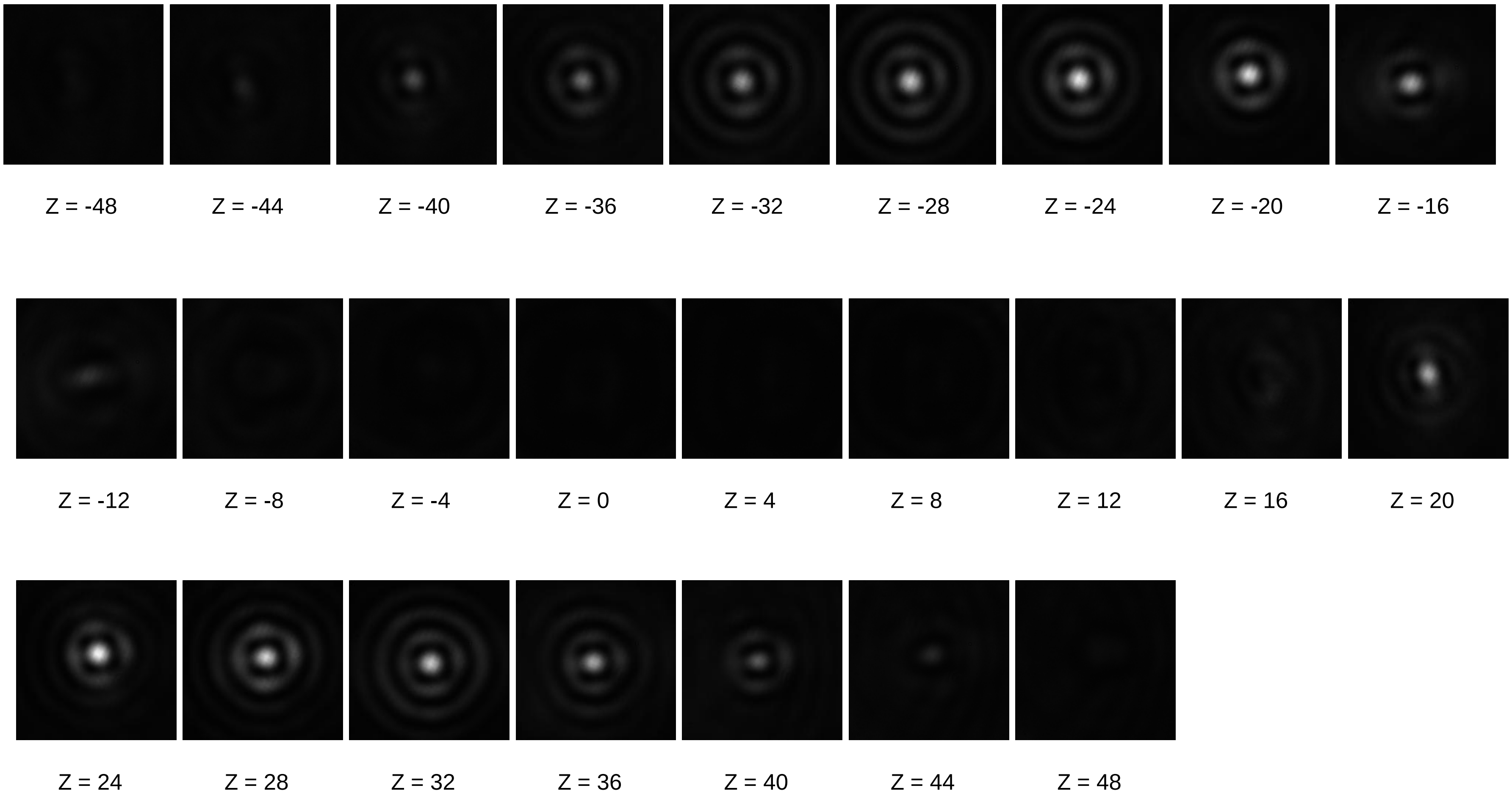
UAB

# Tailoring the axial response




WIDE RECTANGLE

# Tailoring the axial response




TWO RECTANGLES

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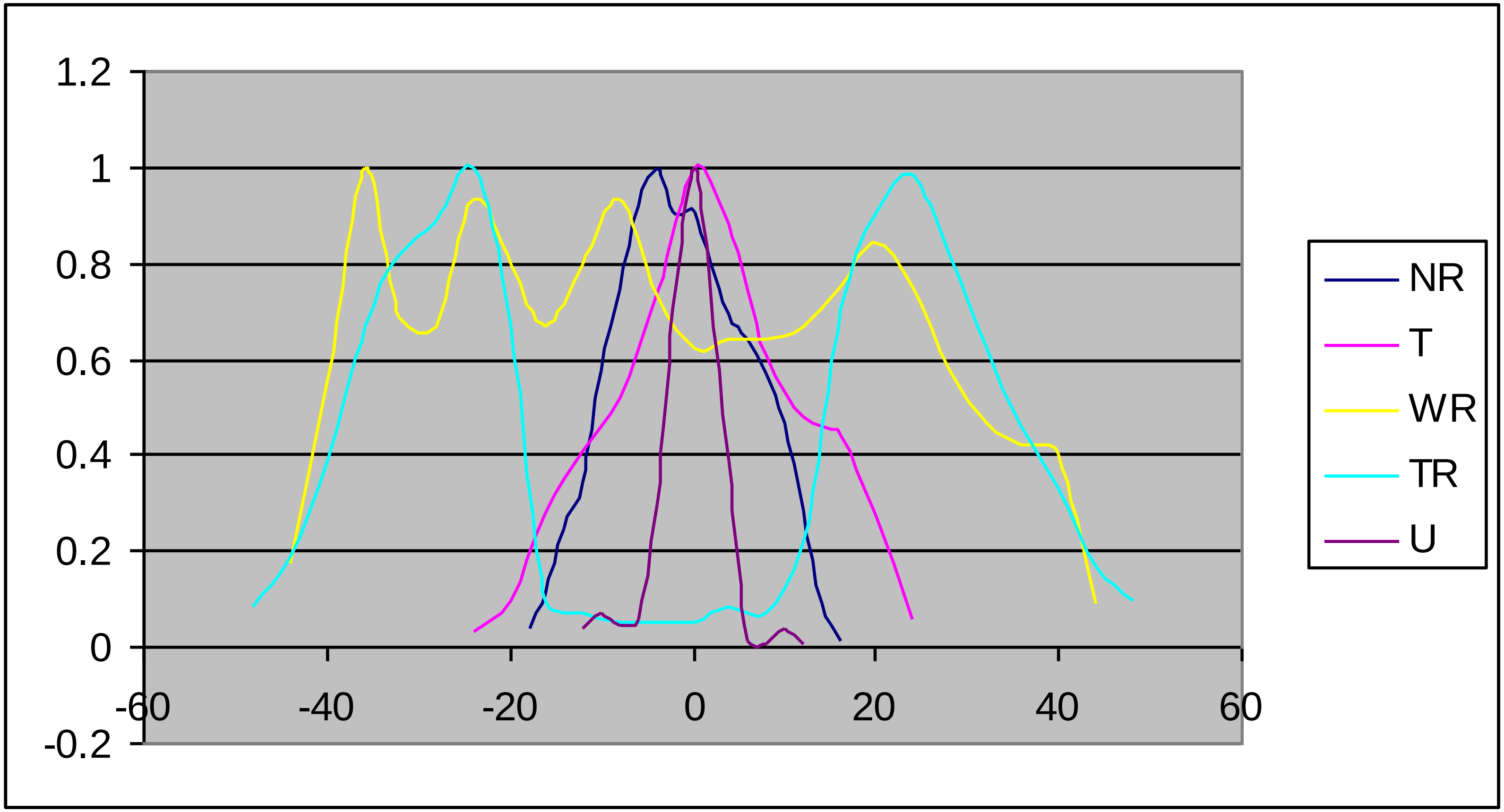
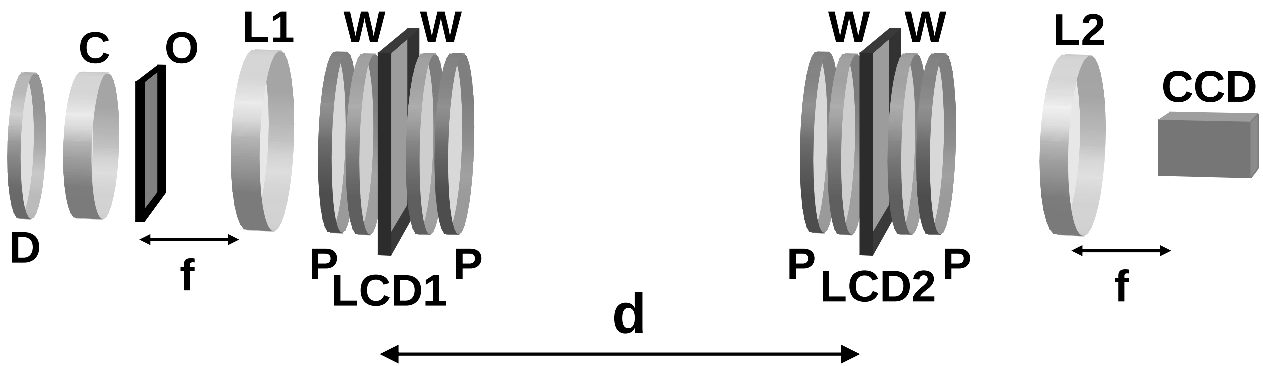
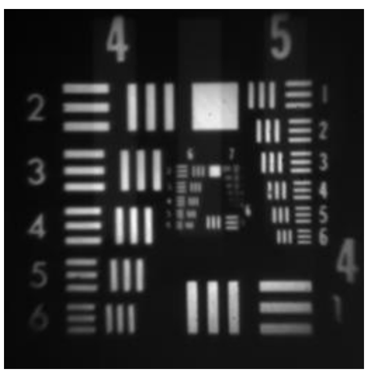
# Tailoring the axial response



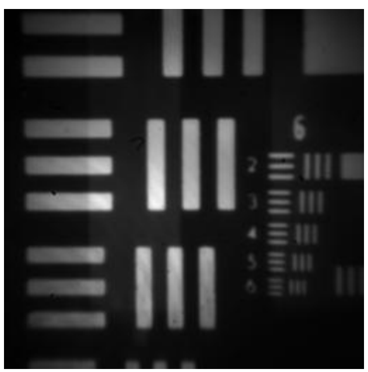
# Anamorphic Zoom



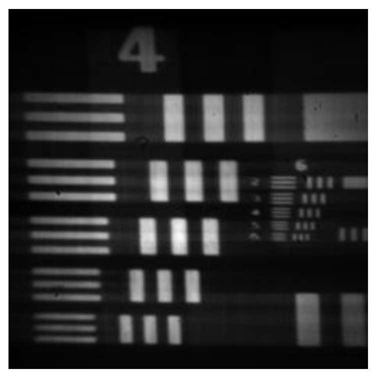

Without Zoom



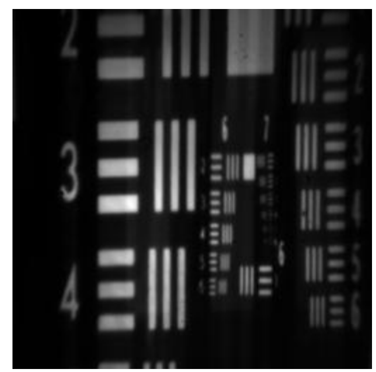
Zoom (x=y)



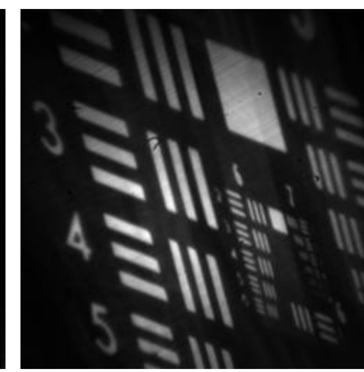
Zoom (x)



Zoom (y)

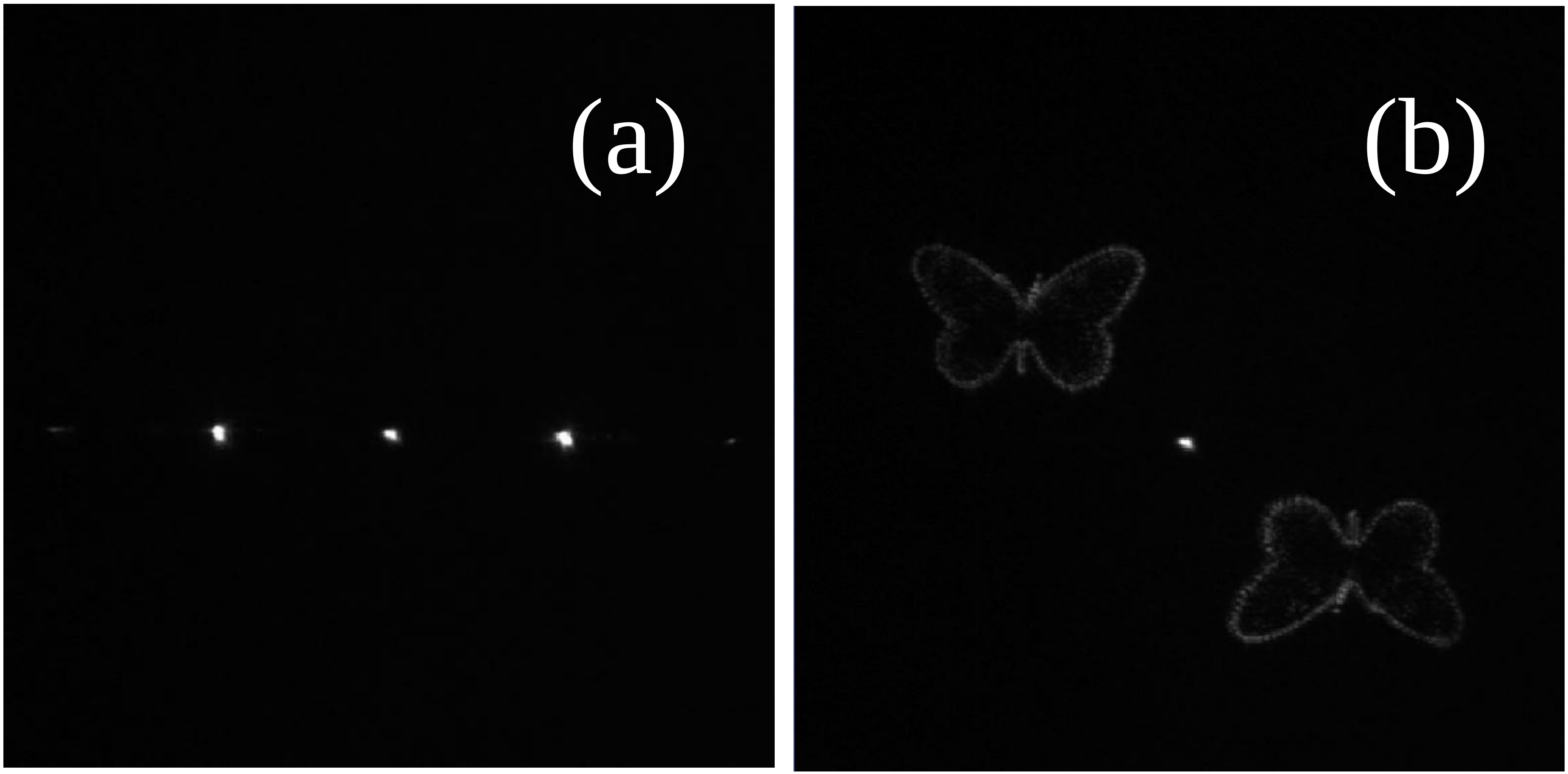


Anamorphic Rotated



# Phase fluctuation phenomenon

## Effects on Diffractive Optics

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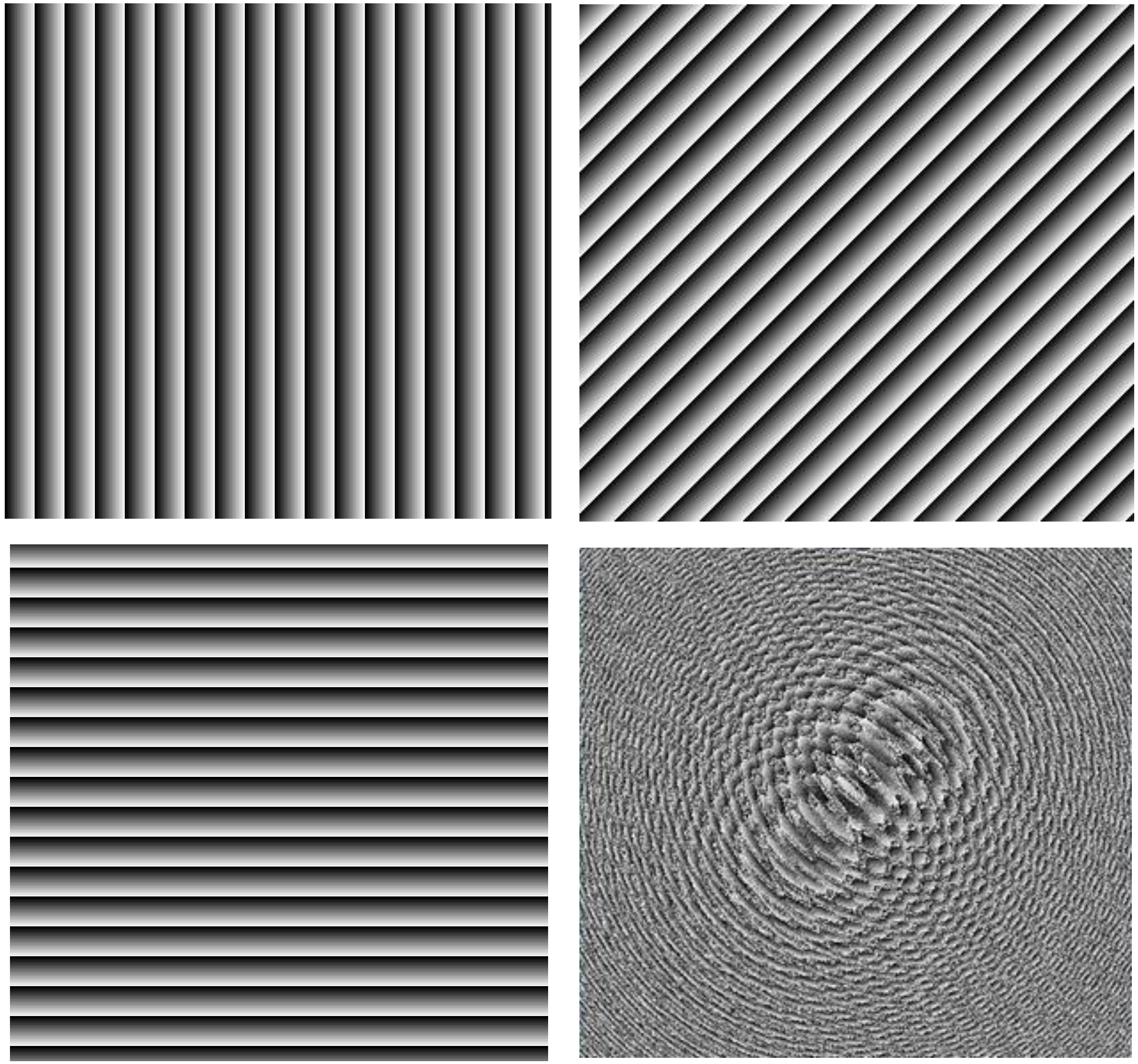
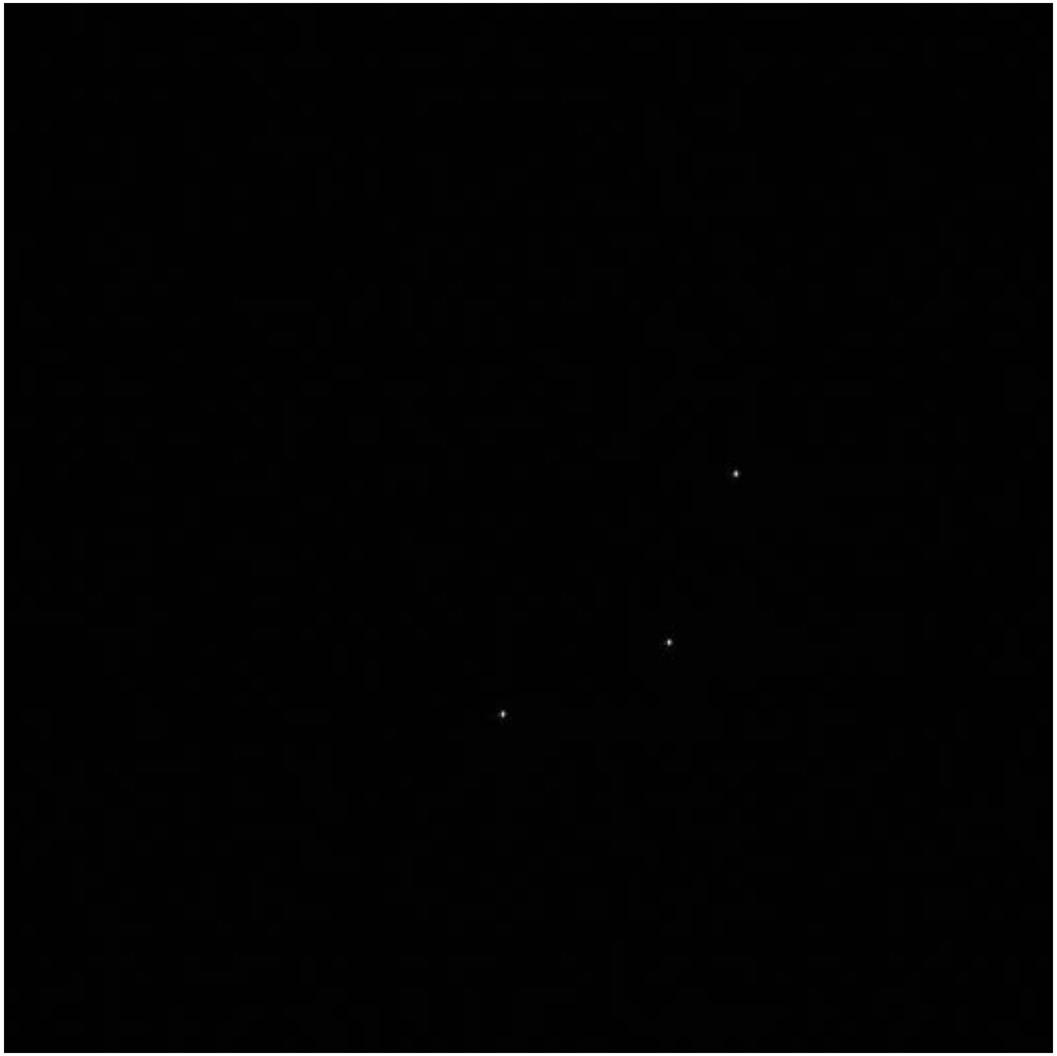
# 3 multiplexed Blazed grating



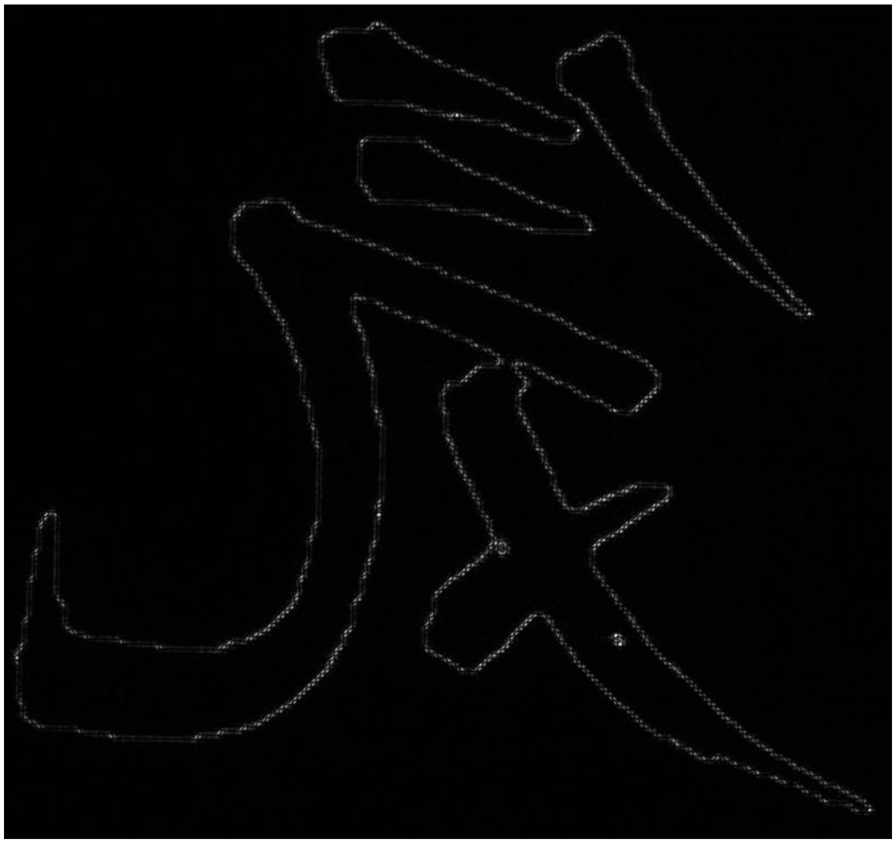
# 3 multiplexed Blazed grating

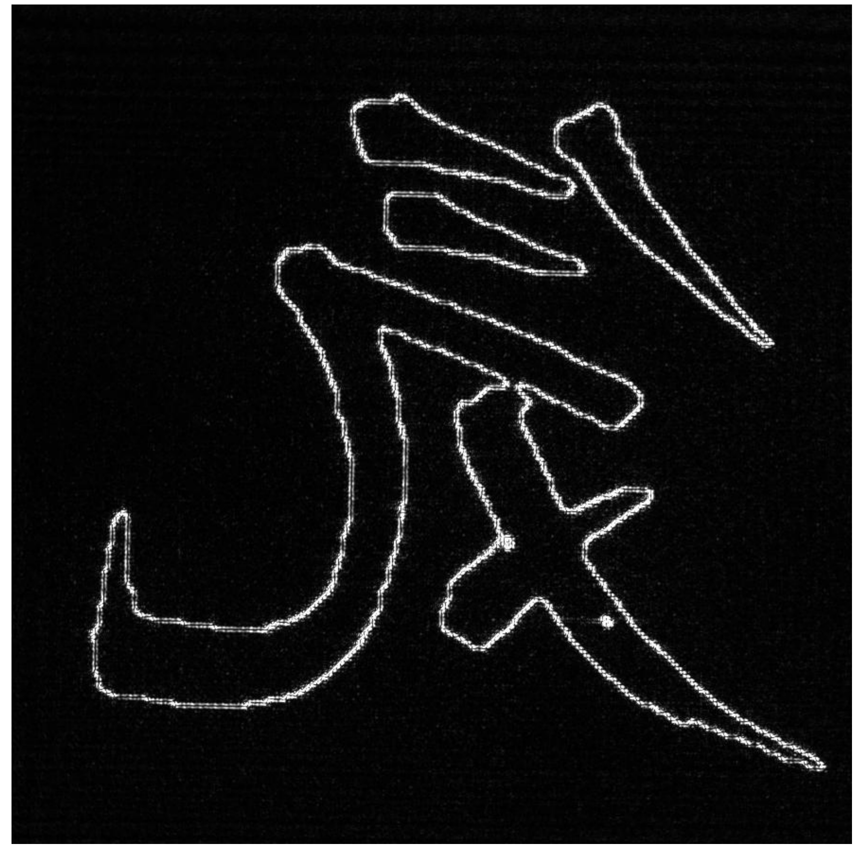
- Period (18), angle (0,45,90), focal spherical lens (200)

**Random Multiplex**



# Phase hologram





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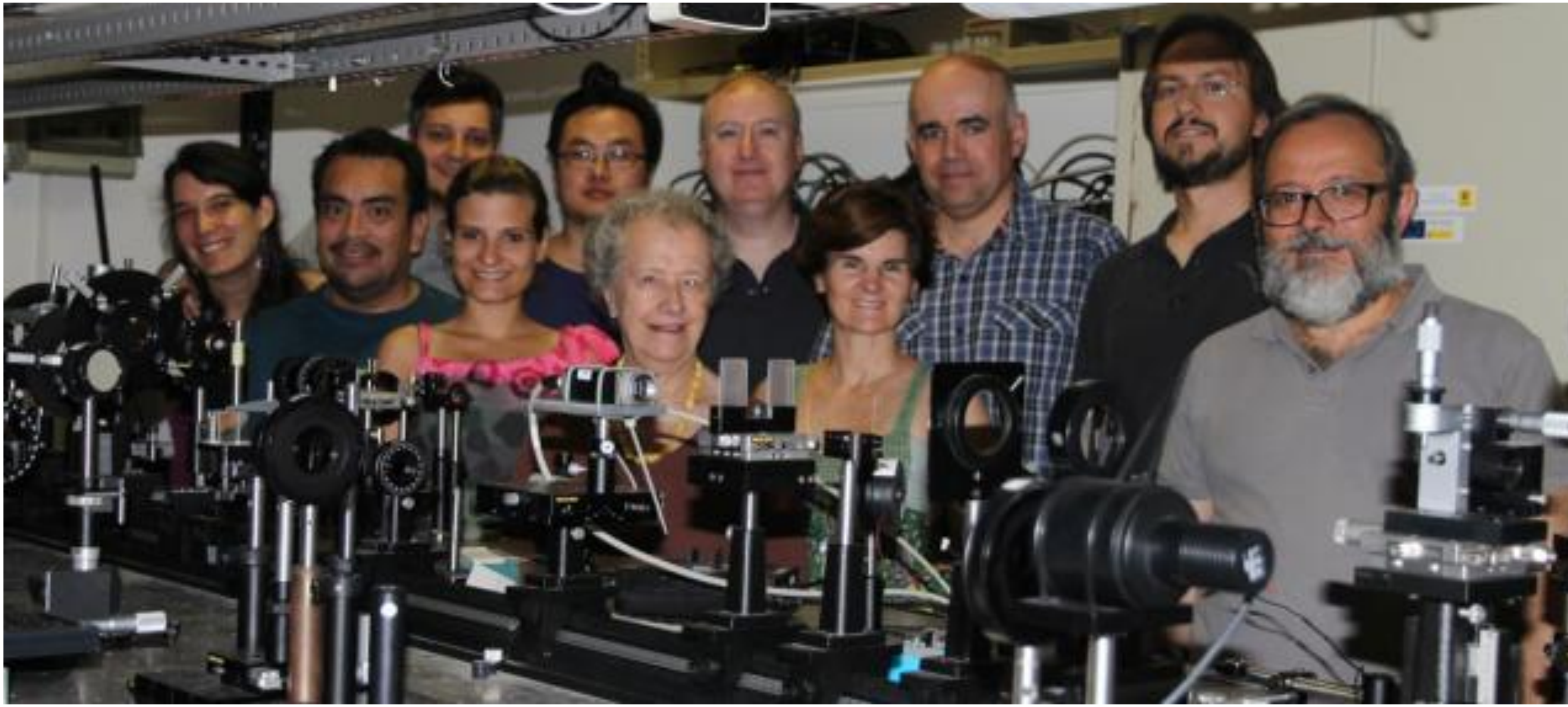
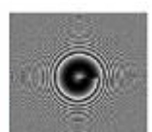
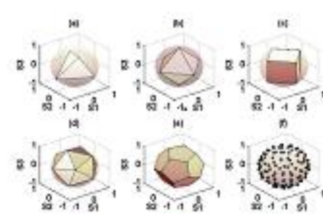
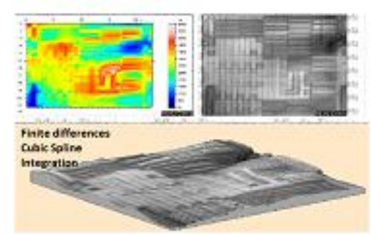


http://grupsderecerca.uab.cat/mipoptilab/

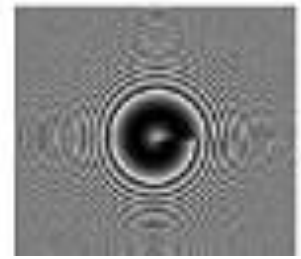


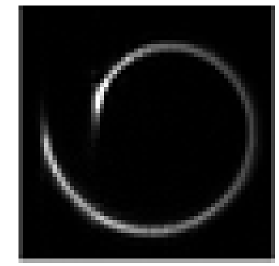


MIP

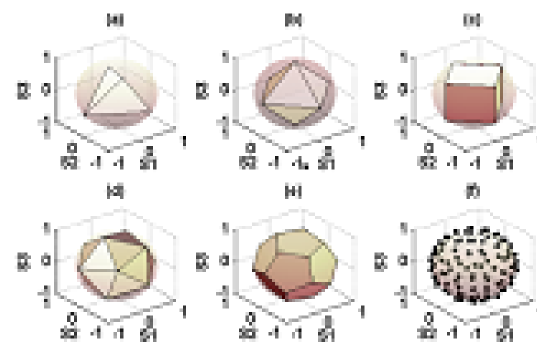
Group of Optics

## 1) LCD characterization and Diffractive Optics

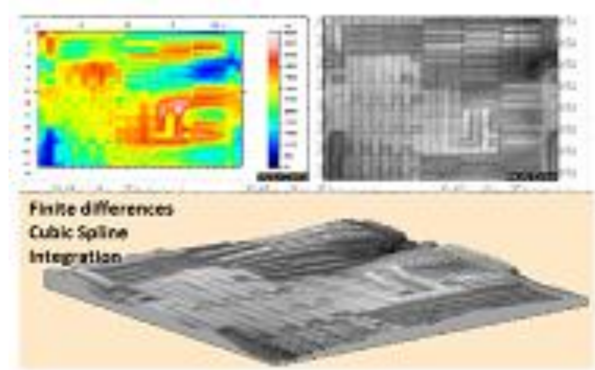




## 2) Polarization control, polarimeters and applications



## 3) Optical metrology



# SPIE

# The international Society for Optics and Photonics

www.spie.org

# SPIE at a Glance

**264,000**
Constituent

**19,000**
Members

**166**
Countries

**20**
Annual Conferences

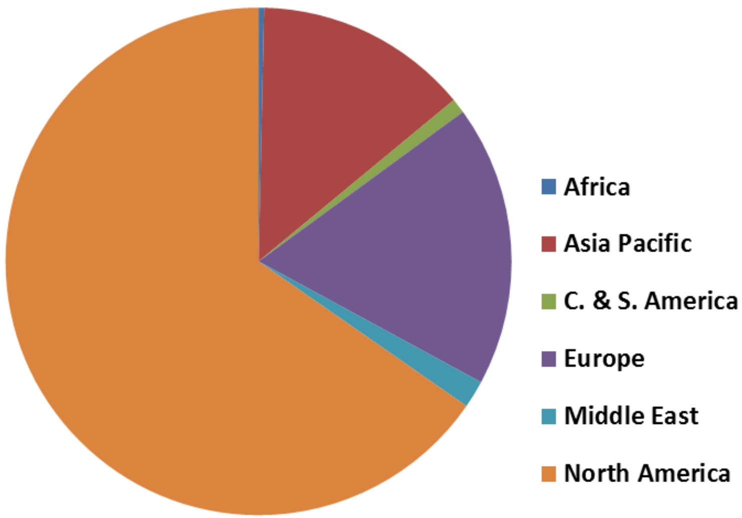
**650**
Corporate Members

**300**
Student Chapters

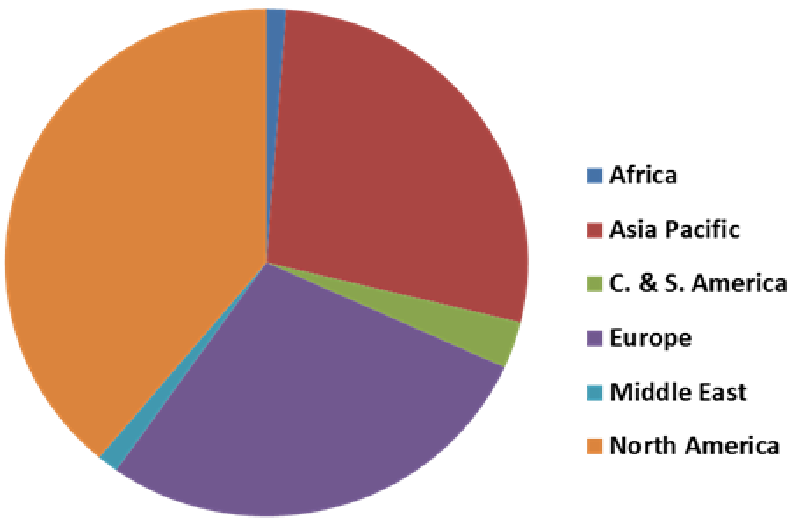
# SPIE in Russia

**Russia:**
14 Student Chapters
239 Student Members
80 Regular Members
6 Senior Members
5 Fellows
3 Corporate Members

**18,500 Total Members**
**80 in Russia**




**7,500 Student Members**
**239 in Russia**

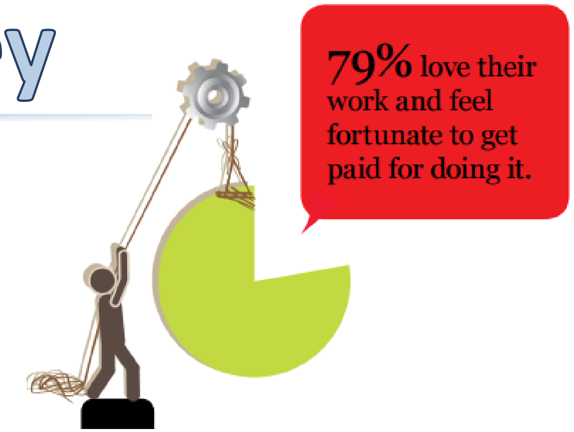


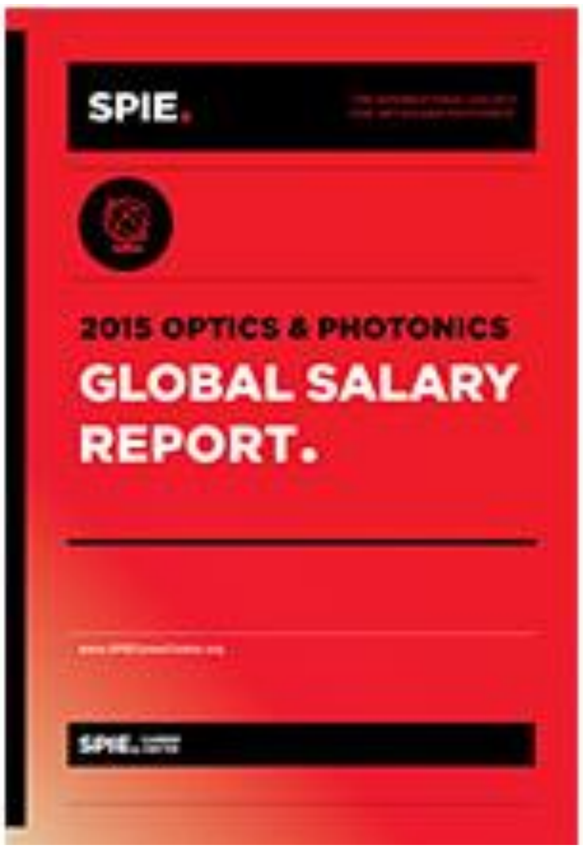
# SPIE Student Chapters in Russia

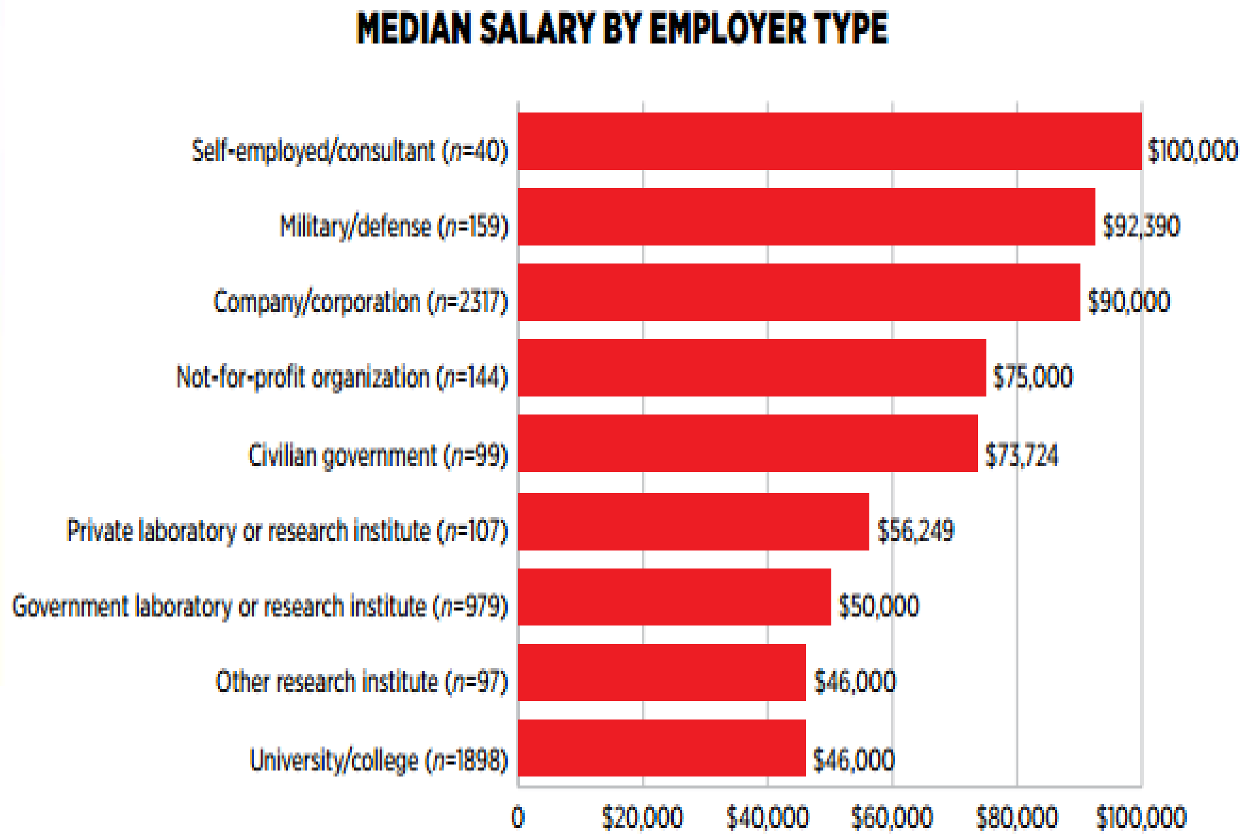
- Saint–Petersburg Acad Univ Russian Acad of Science
- Kazan National Research Tech Univ
- Bauman Moscow State Technical Univ
- Lomonosov Moscow State Univ Chapter
- ITMO University Chapter
- Saratov State Univ
- V.E. Zuev Institute of Atmospheric Optics
- Vladivostok Student Chapter
- Samara Student Chapter
- Saint-Petersburg State Univ of Aerospace
- Institute of Automation and Electrometry
- Nizhny Novgorod Student Chapter
- Povolzhskiy State Univ of Telecommunications and Informatics Chapter
- National Research Univ. of Electronic TechNational Research Univ. of Electronic Tech

# SPIE Student Chapter Map

# SPIE Salary Survey

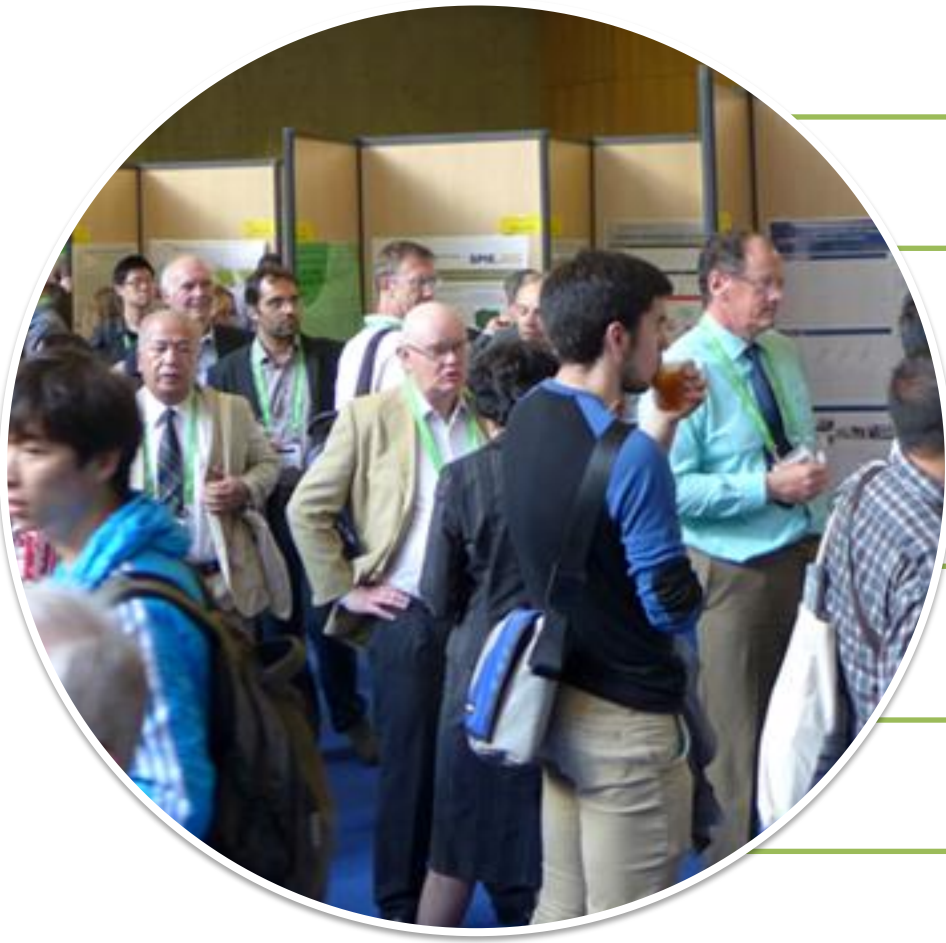


# Major SPIE Conferences

**P**lus many smaller meetings



SPIE. REMOTE SENSING

SPIE. PHOTONICS WEST

SPIE. PHOTONICS EUROPE

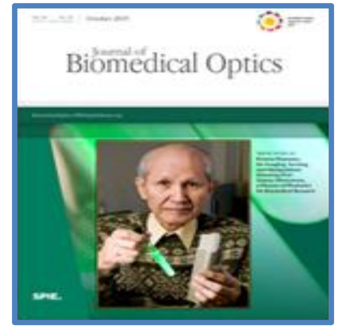
SPIE. OPTICS+ PHOTONICS

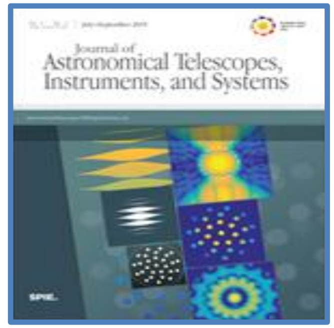
SPIE. SECURITY+ DEFENCE

SPIE. ASTRONOMICAL TELESCOPES + INSTRUMENTATION

# SPIE Digital Library

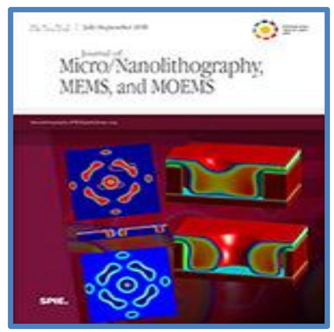
## 10 peer-reviewed journals, ebooks and 430,000 papers

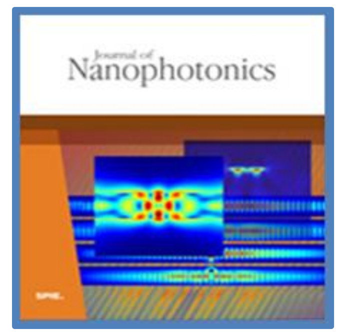


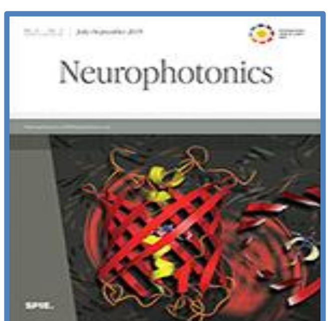



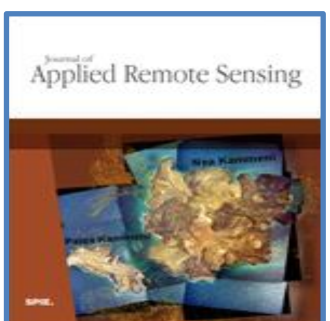


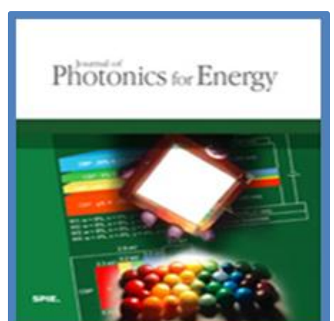




# SPIE Altruistic Activities

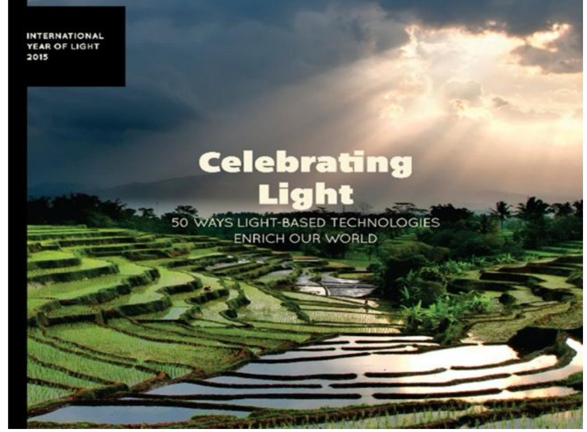
INTERNATIONAL YEAR OF LIGHT 2015

## Over $5.2 million USD in support in 2015

- $350,000 USD in Scholarships
- $90,000 USD in Education Outreach Grants
- Educational outreach kits, posters and videos
- Summer schools, science fairs & best paper prizes
- Free SPIE Digital Library for developing nations
- UNESCO Active Learning in Optics and Photonics (ALOP) teacher training for developing nations
- Women in Optics events and planner
- International Year of Light Founding Partner

**Your Membership Makes a Difference!**

Light Painting World Alliance




25,000 SPIE IYL books distributed

IYL New Years in Australia

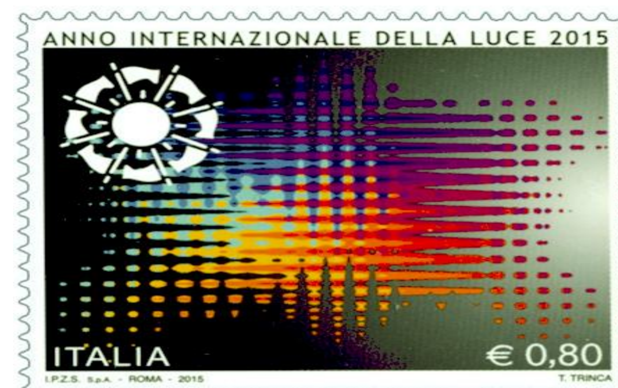
Story of Light Festival in India

UK IYL patron, Duke of York

IYL song competition in Europe

IYL at CERN

Amsterdam rainbow train station




IYL stamps issued in 17 countries

# Get Involved! www.spie.org


- Become an SPIE member
- Start a student chapter
- Apply for an outreach grant
- Educate the next generation
- Nominate a Fellow or Senior Member
- Present your research at a conference
- Become a reviewer
- Join a planning committee

# ICO

## International Commission for Optics

## www.e-ico.org

# ICO
# Is organized in Territorial Committees

# Russian Federation Committee

# ICO

General Congress every 3 years
Next one in 21-25 August, 2017 in Japan

The General Assembly meets every 3 years.

# ICO

## Organizes Topical conferences

## Sponsor of meetings and schools

# ICO Prizes and Awards

- ICO Prize
-ICO and IUPAP Optics Prize
ICOand ICTP Galieno Denardo Prize
-ICO Galileo Galilei Award

# Thank you for your attention