Snapshot Ellipsometer Based on Linear Algebra Demodulation

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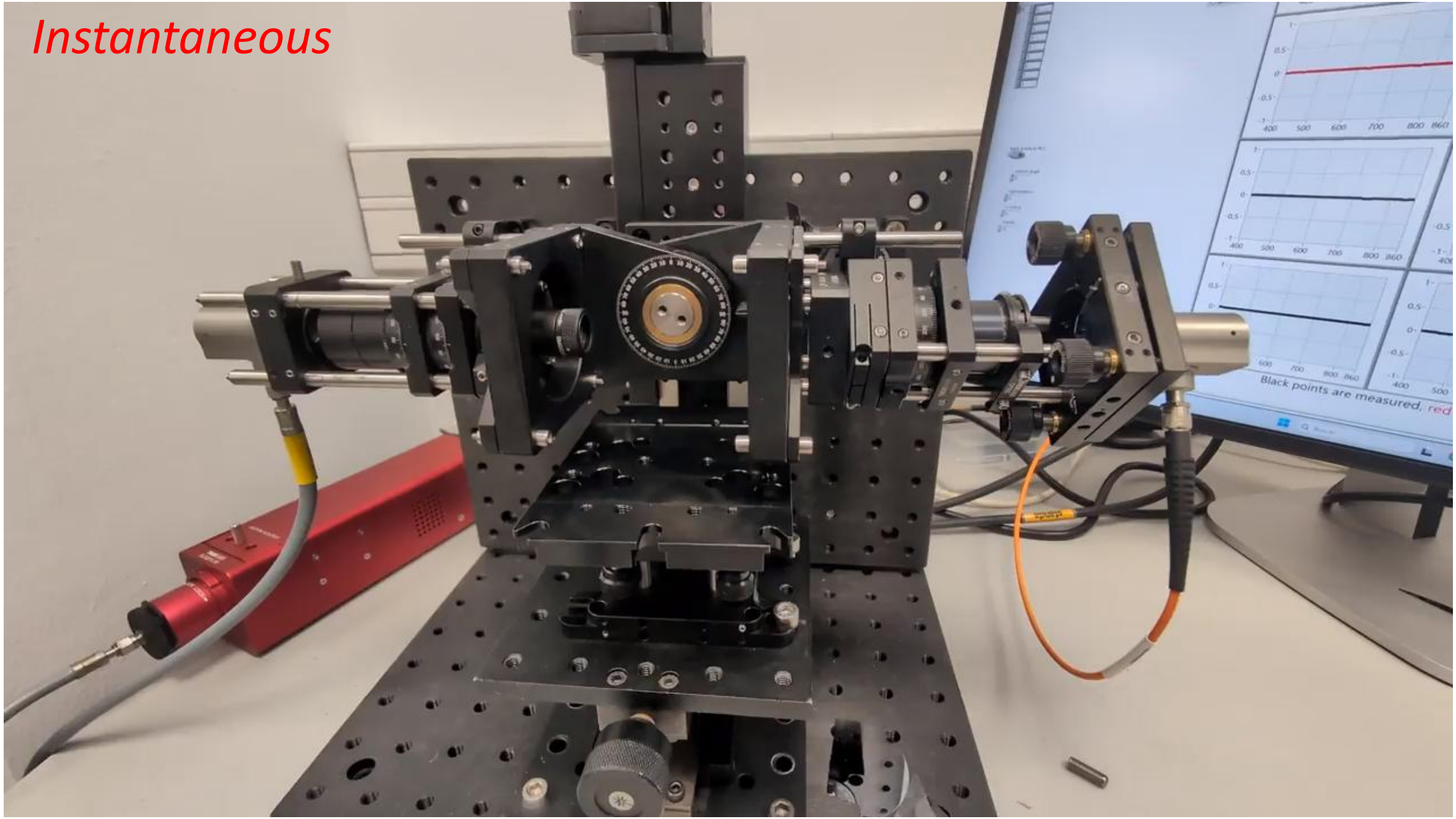
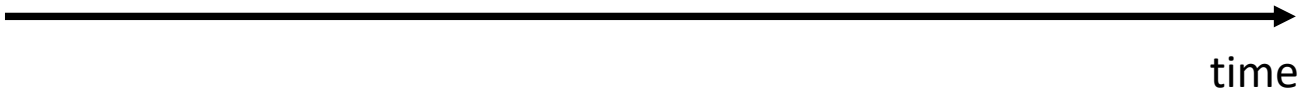

Instantaneous
Black points are measured, red

Not posible with “standard ellipsometers”

Polarization modulation in the **time domain**

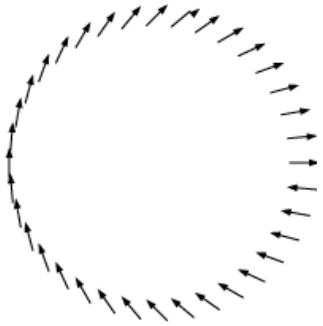


Temporal response limited by the speed of motors, photoelastic modulators, liquid crystals, etc

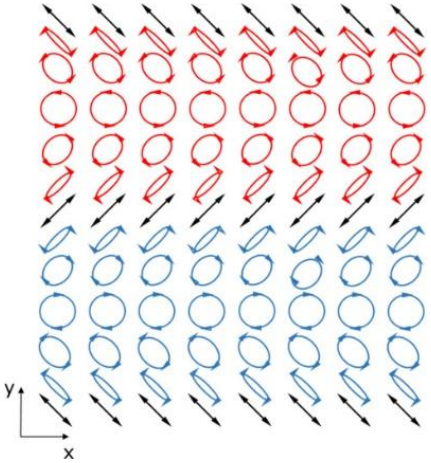
Snapshot ellipsometers (main types)

1.Polarization modulation in <u>spatial domain</u>

m = 1 Vortex Retarder



The fast-axis orientation of the m=1 vortex retarder.



2D-Vortex retarder

2D

1D

space

2. Polarization modulation in *spectral domain*

$d \gg \lambda$

- *Very non-achromatic (multi-order)* crystal retarders (this presentation)
- Interferometric module (Prof. D. Kim presentation)

wavelength

Temporal response limited only by the detector

Spectral modulation → <u>Hardware</u> is very simple

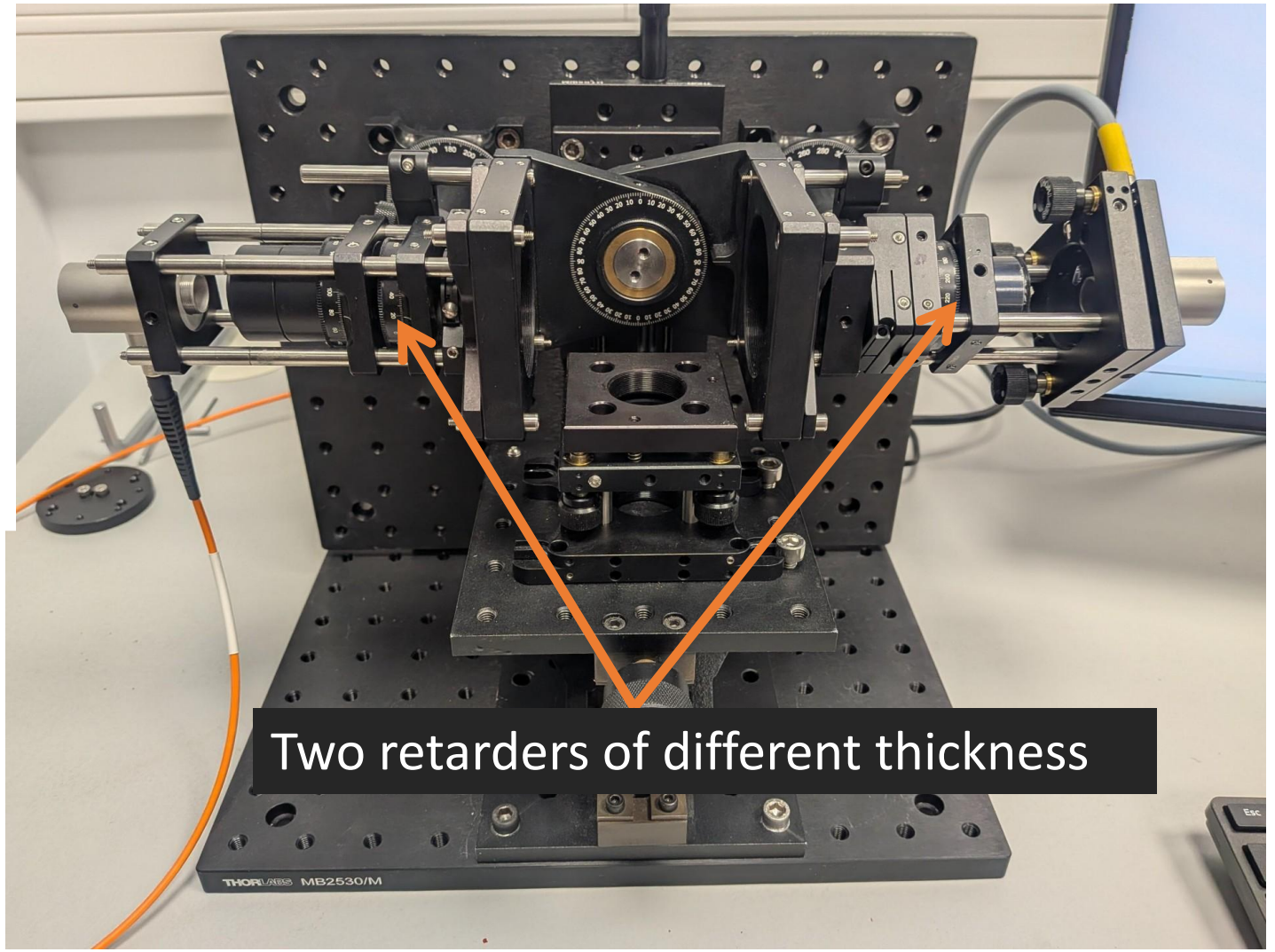
- Multi-order crystal retarders are widely available
- High resolution 1D CMOS spectrometer

Cheap parts

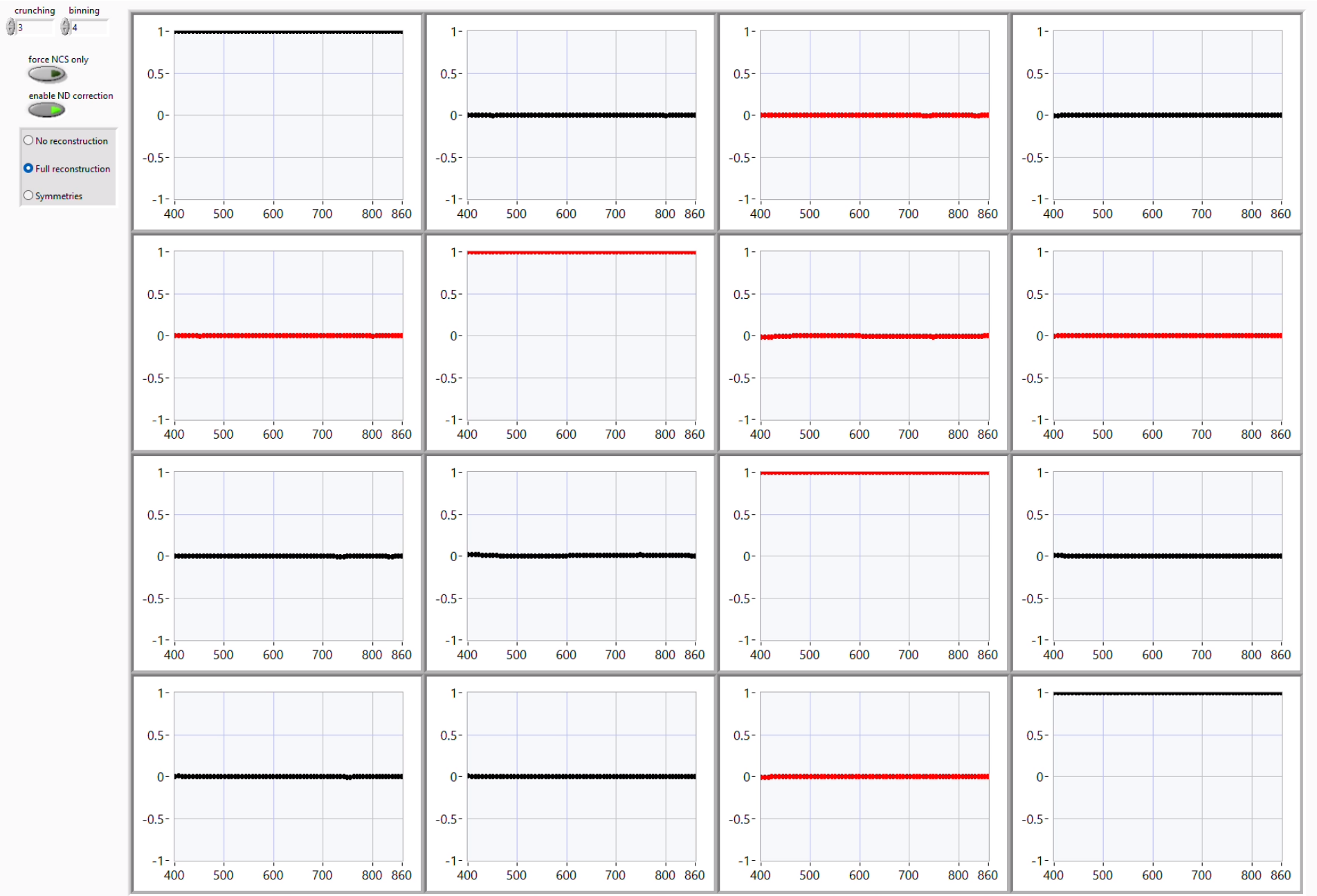
$$\begin{bmatrix} m_{00} & m_{01} & \bullet & m_{03} \\ \bullet & \bullet & \bullet & \bullet \\ m_{20} & m_{21} & \bullet & m_{23} \\ m_{30} & m_{31} & \bullet & m_{33} \end{bmatrix}$$

In this presentation I show reconstructed elements with the method in

R. Ossikovski and O. Arteaga, "Completing Experimental Non-Depolarizing Mueller Matrix with Both a Row and a Column Missing," J. Opt. Soc. Am. A accepted (2026)

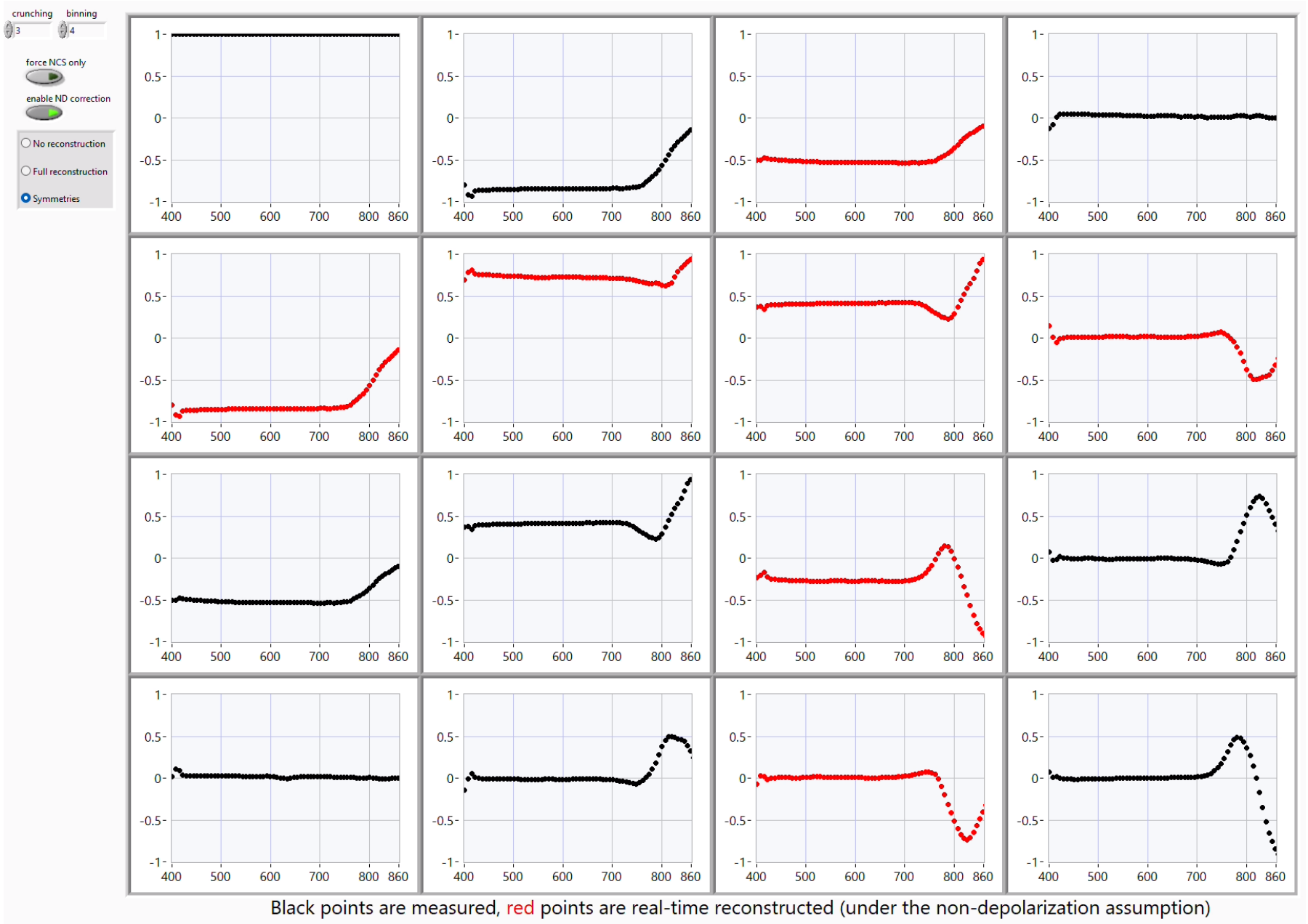


BLANK



Black points are measured, red points are real-time reconstructed (under the non-depolarization assumption)

CHEAP FILM POLARIZER



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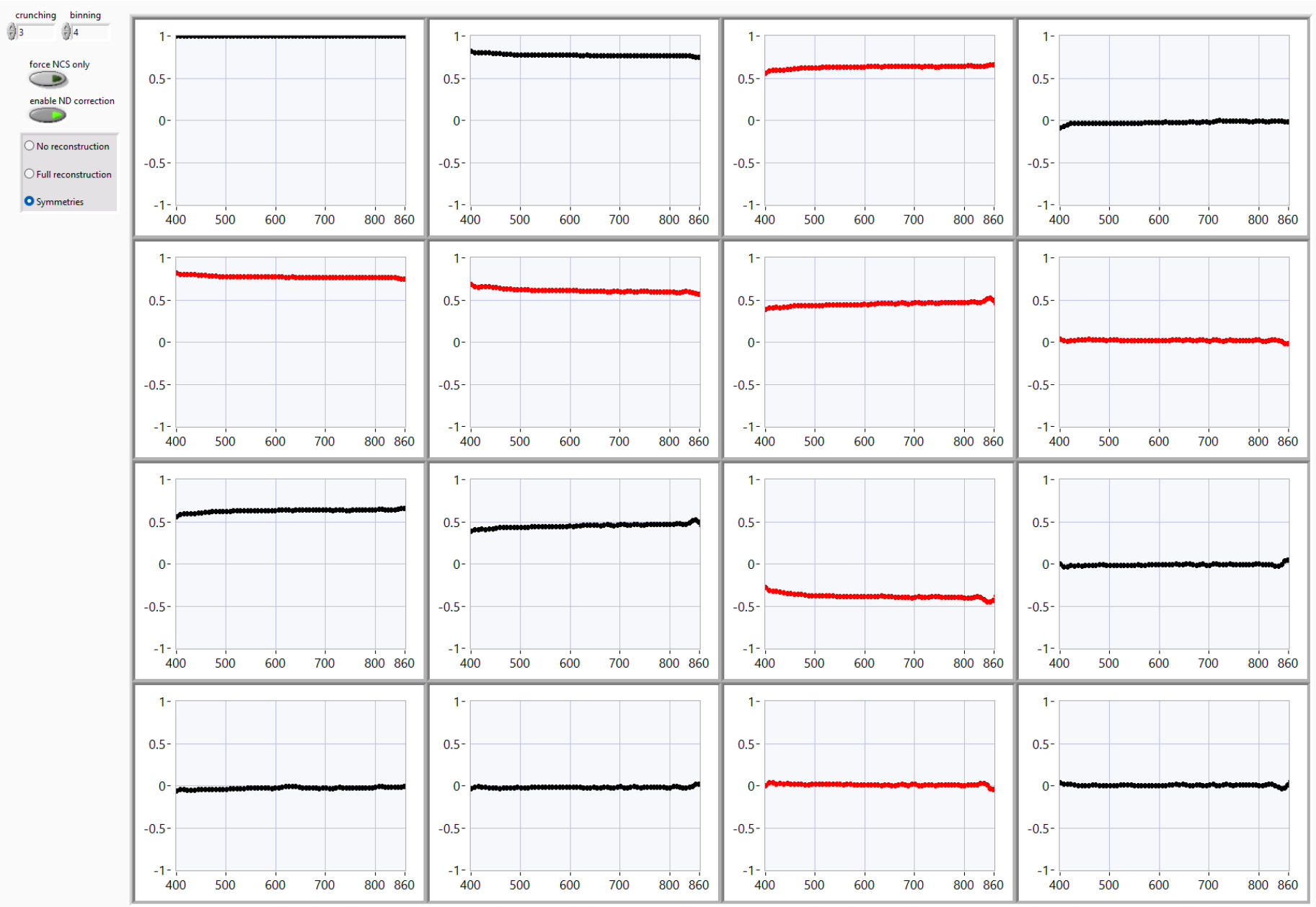
EXPENSIVE FILM POLARIZER



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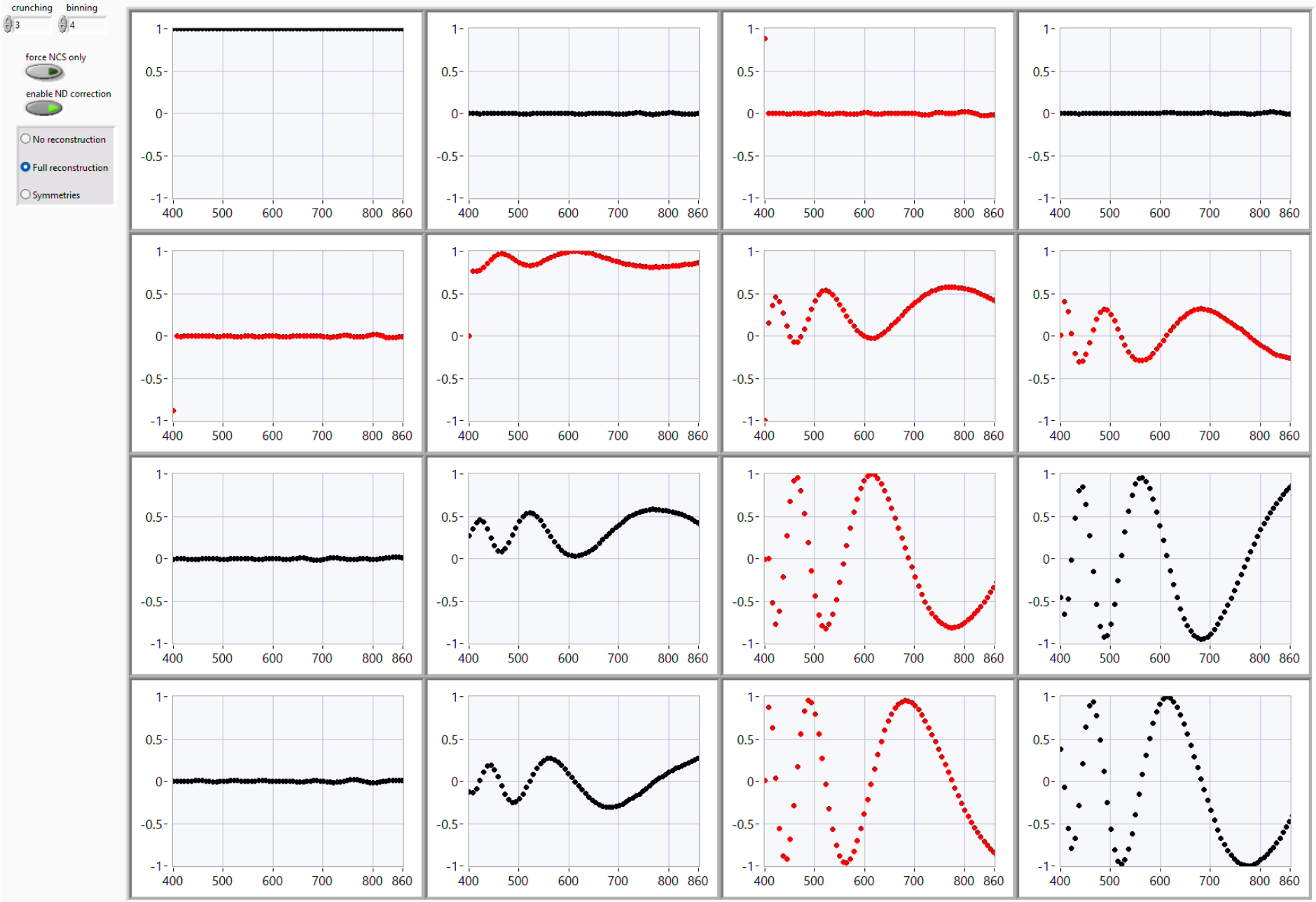
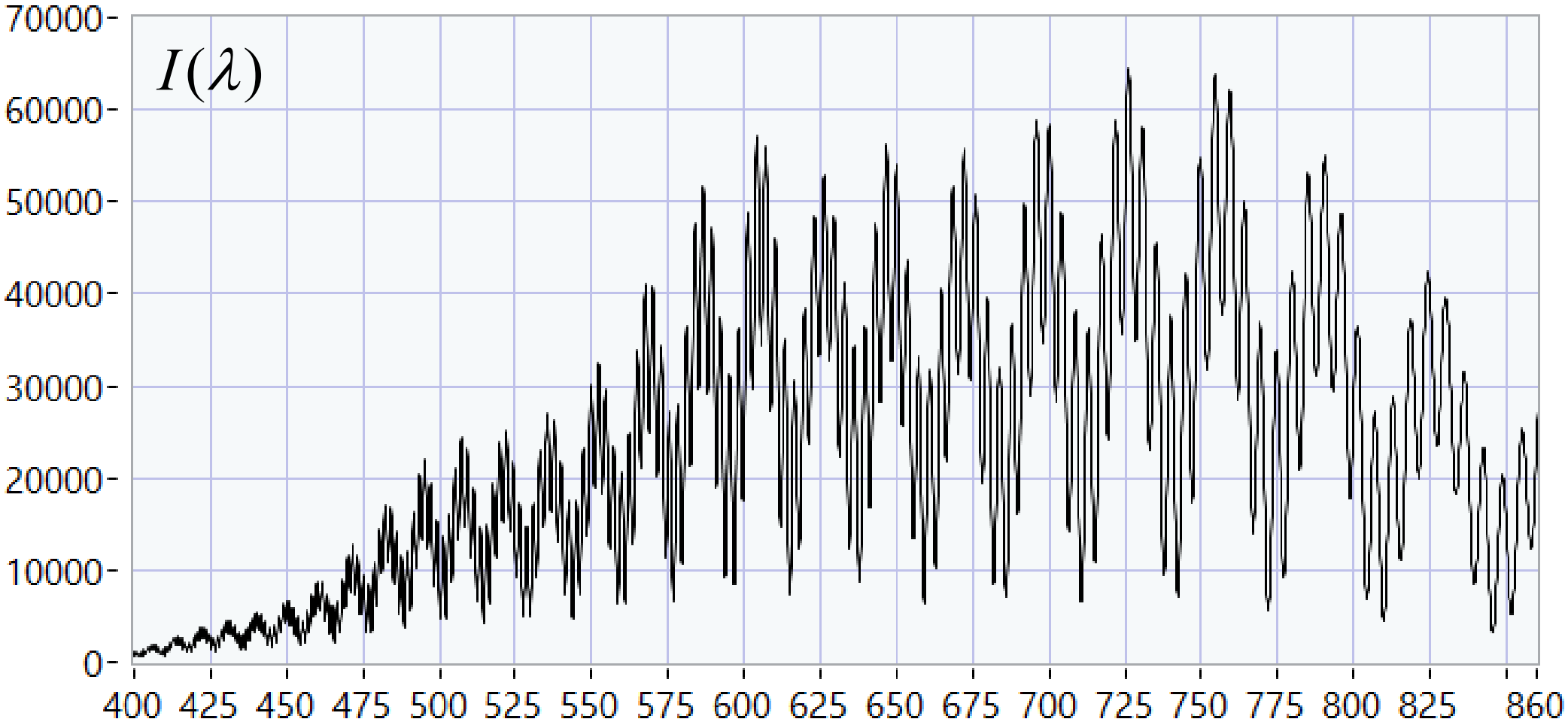
PLASTIC FILM



Black points are measured, red points are real-time reconstructed (under the non-depolarization assumption)

Spectral modulation → Data processing is not so simple



Noise in the data below 450nm comes from the halogen lamp (has very weak output there)

Spectral modulation → Software (data analysis) challenging

"Channeled approaches" do the data processing in **wavenumber** but have **two serious problems:**

1. Spectra are NOT periodic in wavelength and only *approximately* periodic in wavenumber

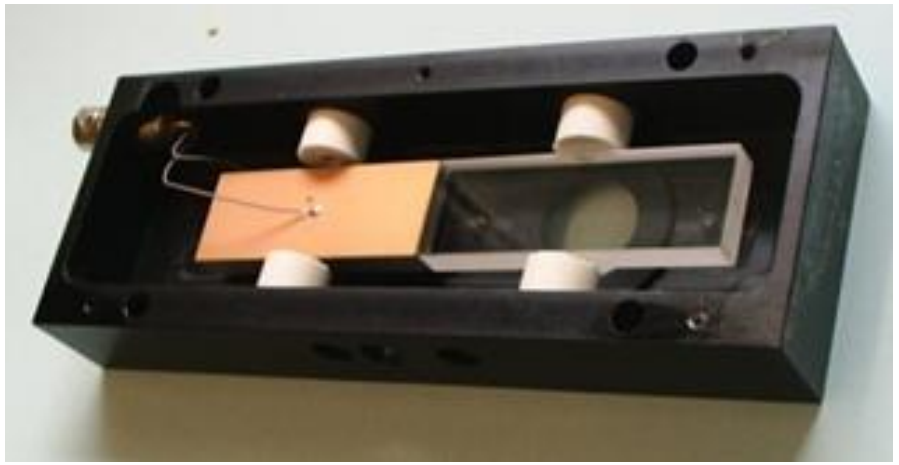
$$\delta_\lambda = \frac{2\pi\Delta n_\lambda d}{\lambda}$$

$$\Delta n_\lambda = A + \frac{B\lambda^2}{\lambda^2 - C^2} + \frac{E\lambda^2}{\lambda^2 - F^2}$$

2. Dispersive spectrometers do not provide evenly spaced data in the wavenumber domain

Spectral modulation Our Approach

Strategies we have applied for years in **photoelastic modulators**



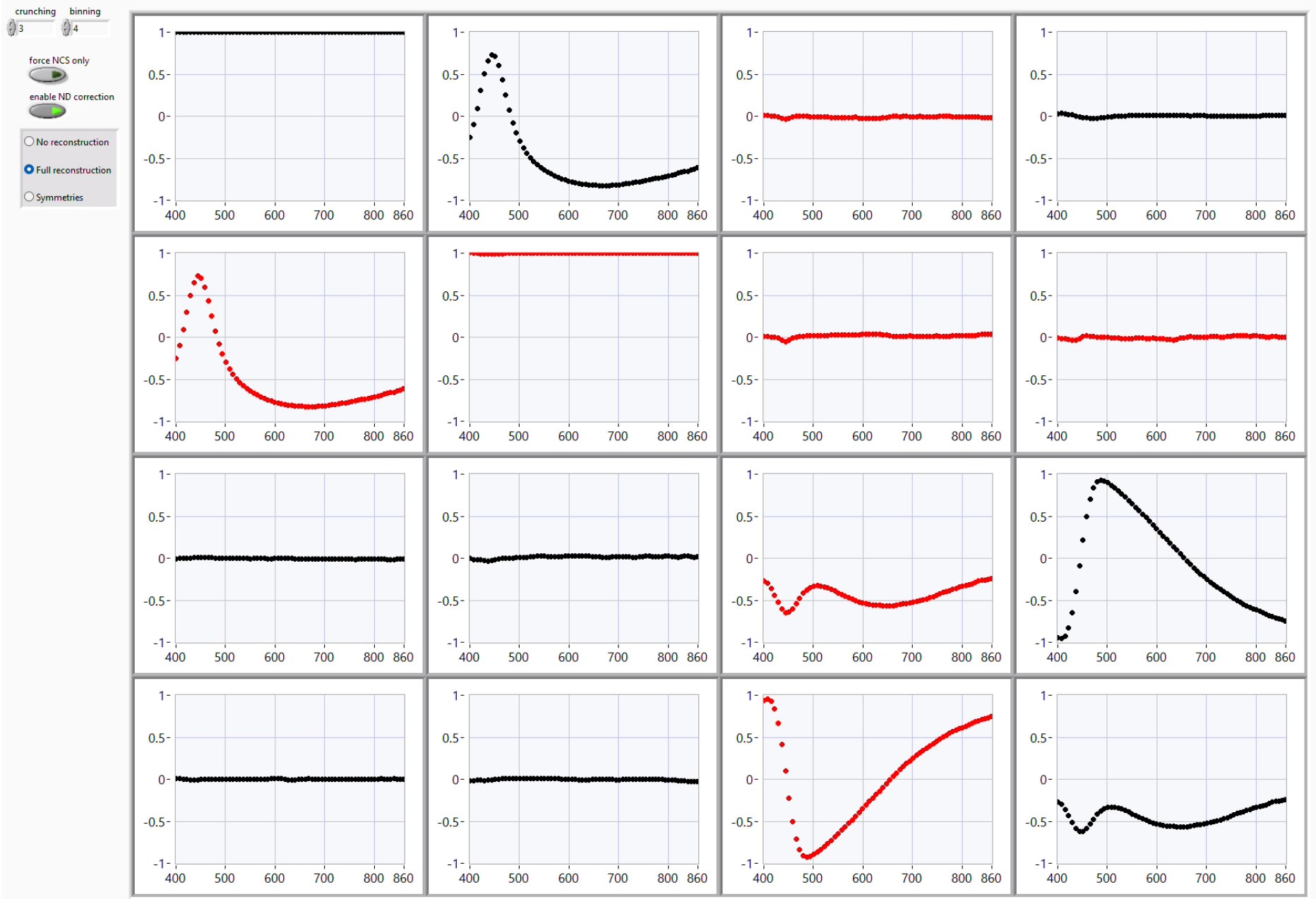
A PEM changes retardance in time
Azimuth is fix

A multi-order crystal retarder changes retardance in wavelength
Azimuth is fix

No periodicity required
Data processing based on **linear algebra**

Patent: A SNAPSHOT ELLIPSOMETRY SYSTEM AND METHOD, EP25382555

SiO_2 on Si



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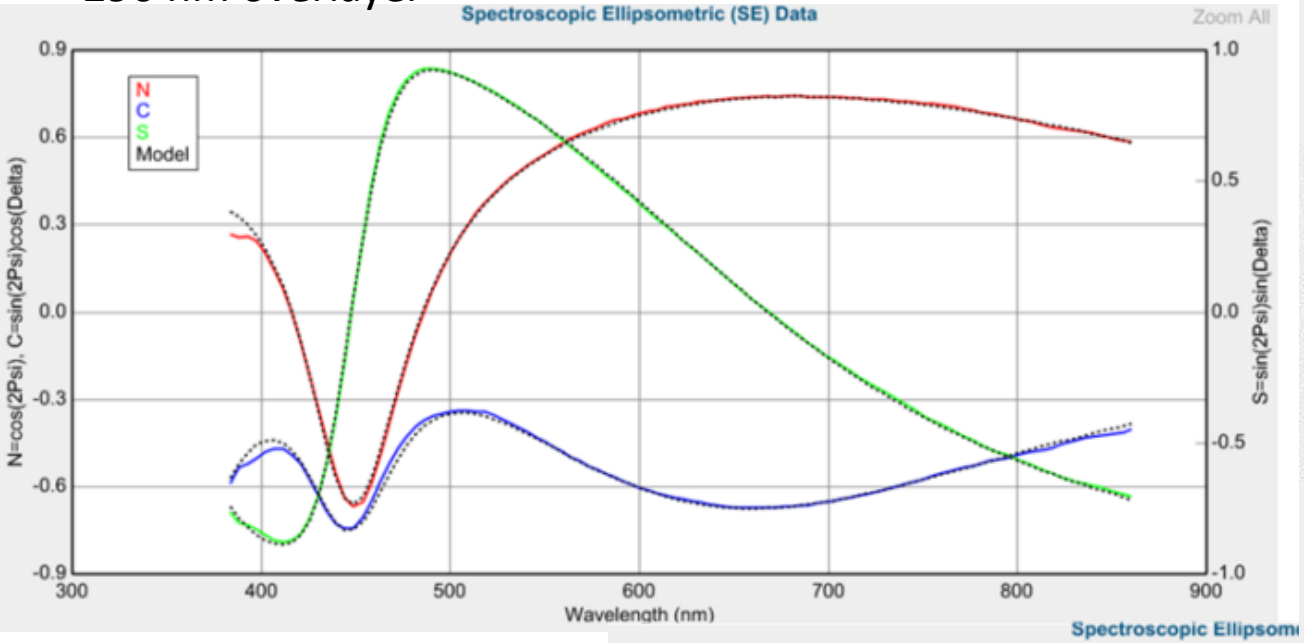
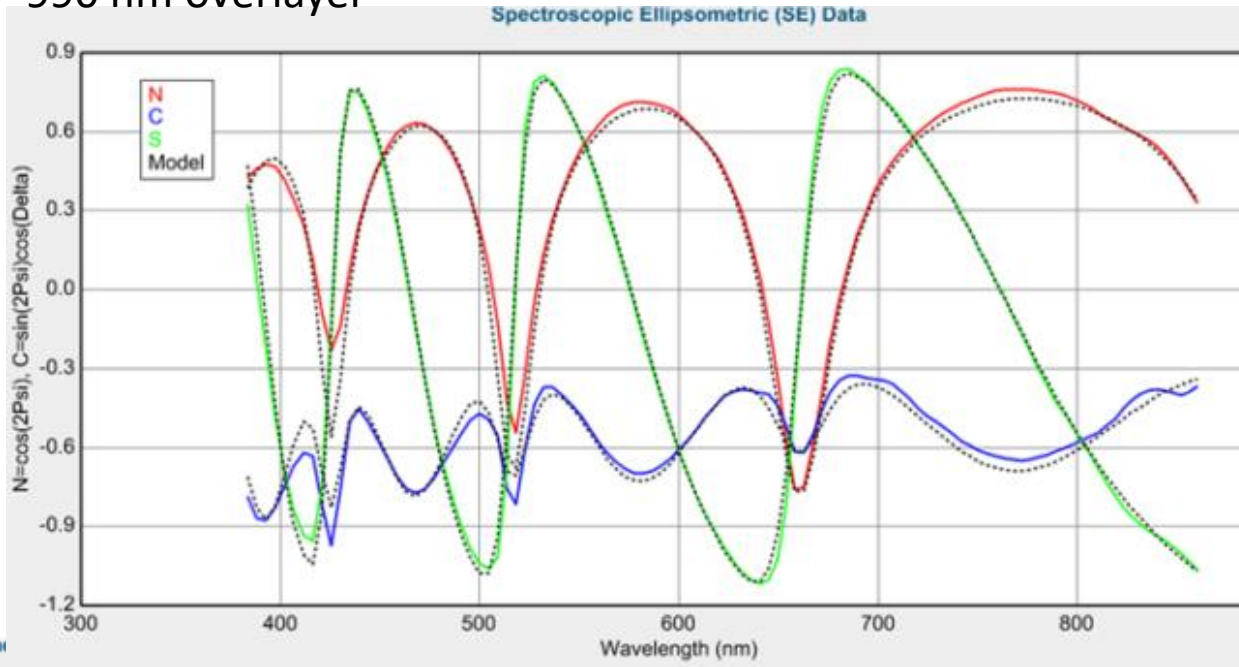
SiO_2 on Si (Fits on Woollam's CompleteEase. Prototype=> WVASE=> CompleteEase)

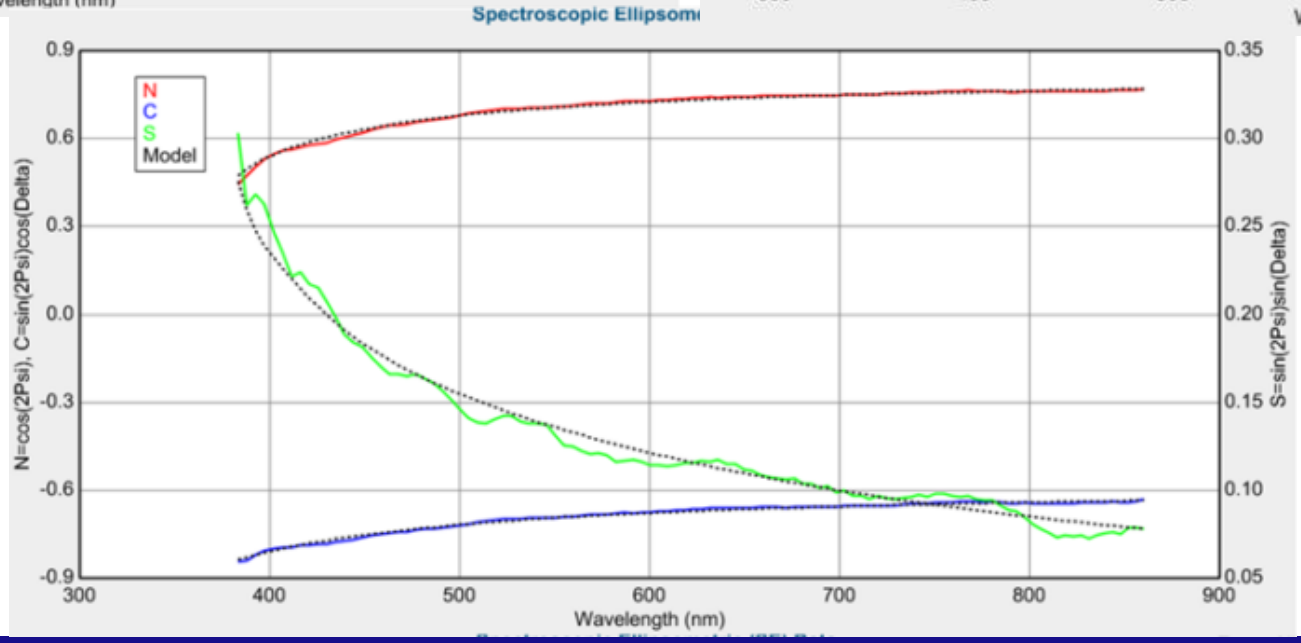
290 nm overlayer

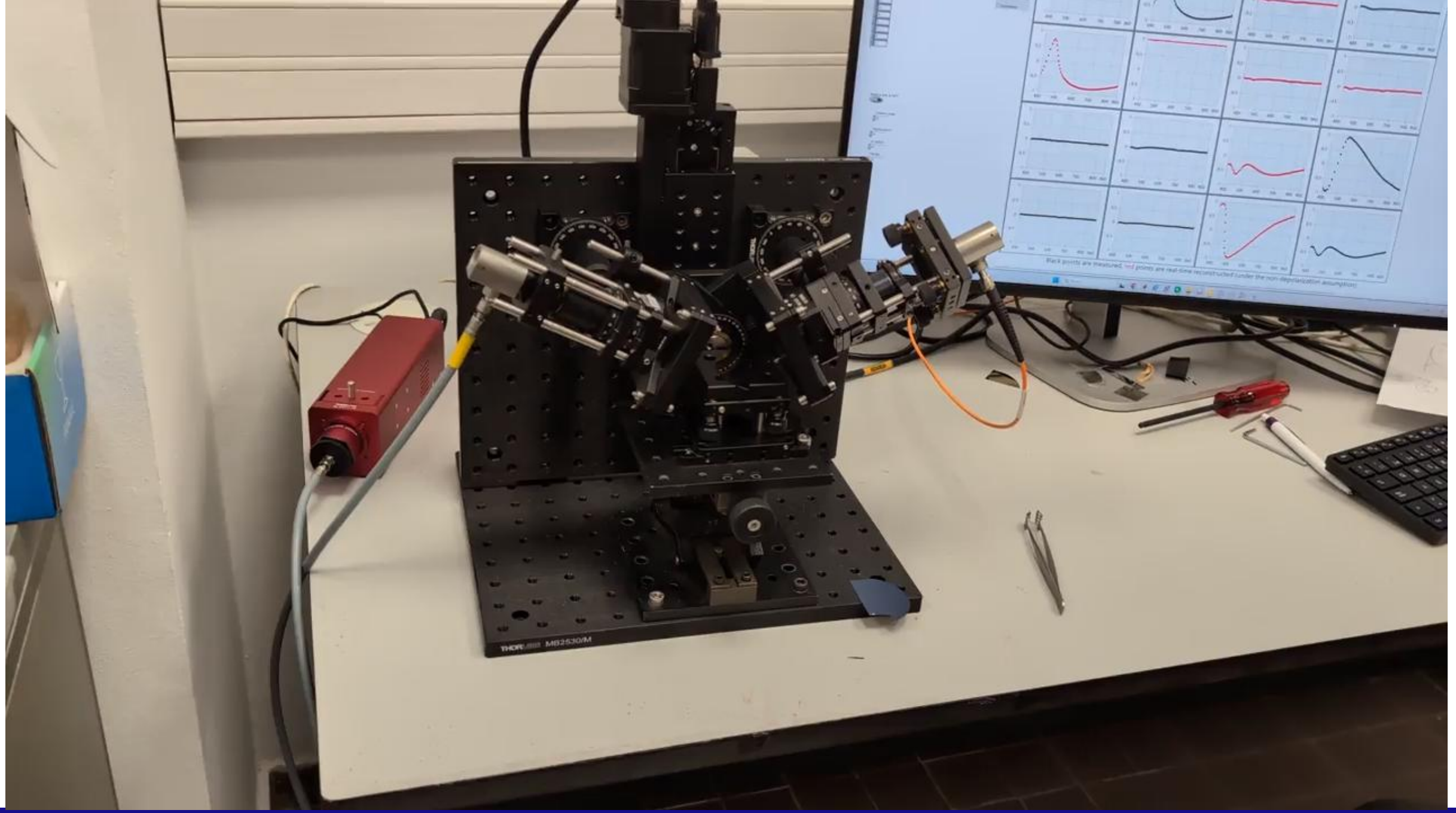


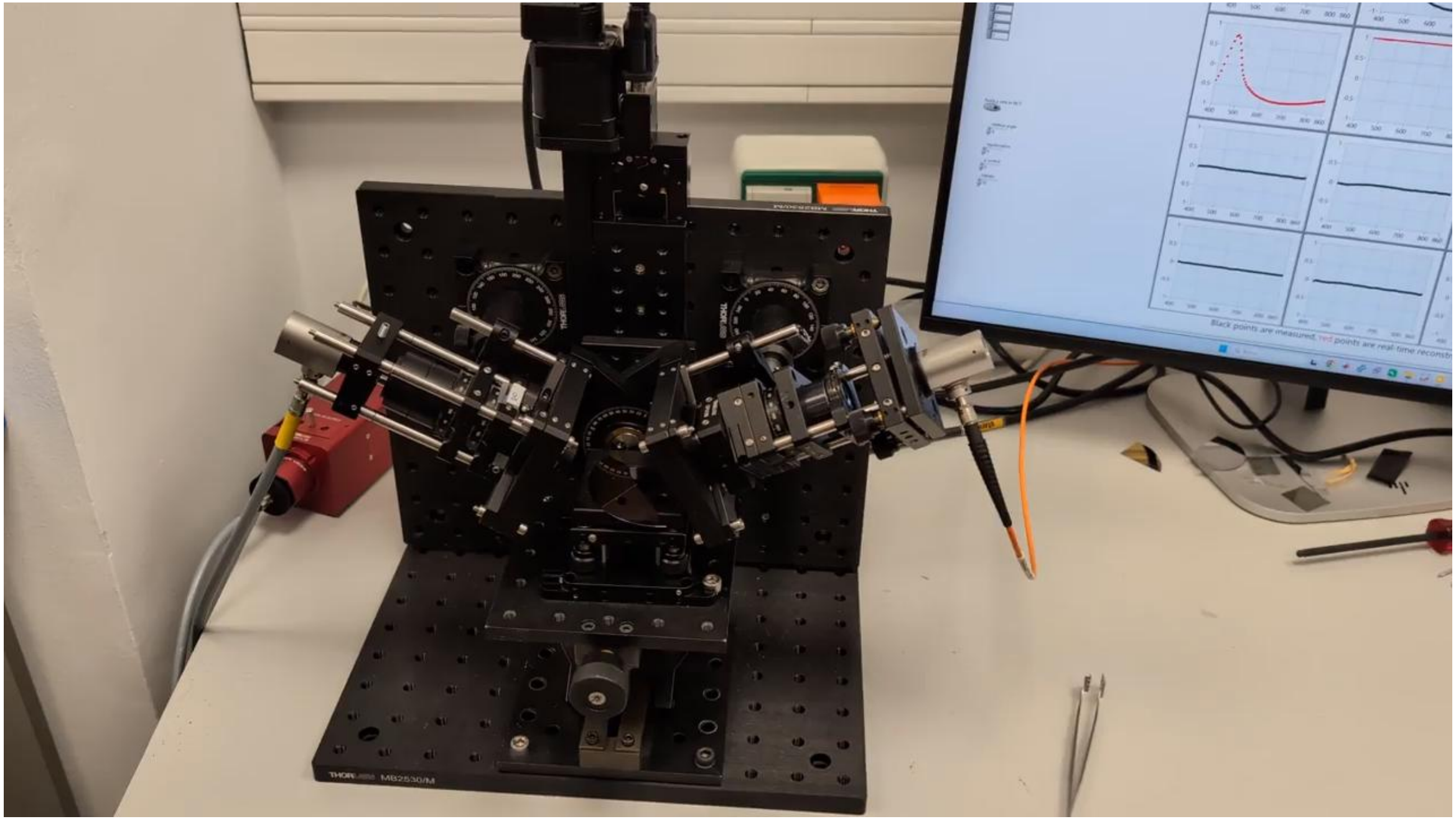
990 nm overlayer



Native oxide




THORLABS MB2530/M


MB2530/M

Good

- Instantaneous!
- Simple & small hardware
- Highest mechanical stability
- Small random errors
- New applications:

  - Quick ellipsometric imaging by rastering (seconds instead hours)
  - Ultrafast measurements if combined with pulsed LEDs or in pump-probe experiments

Not-So-Good

- Limited spectral resolution
- **Caution with Systematic errors** (in samples with sharp spectral features)

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Thank you for your attention