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A fiber-based endomicroscope designed for full Mueller endoscopic polarimetric imaging

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Context and objectives

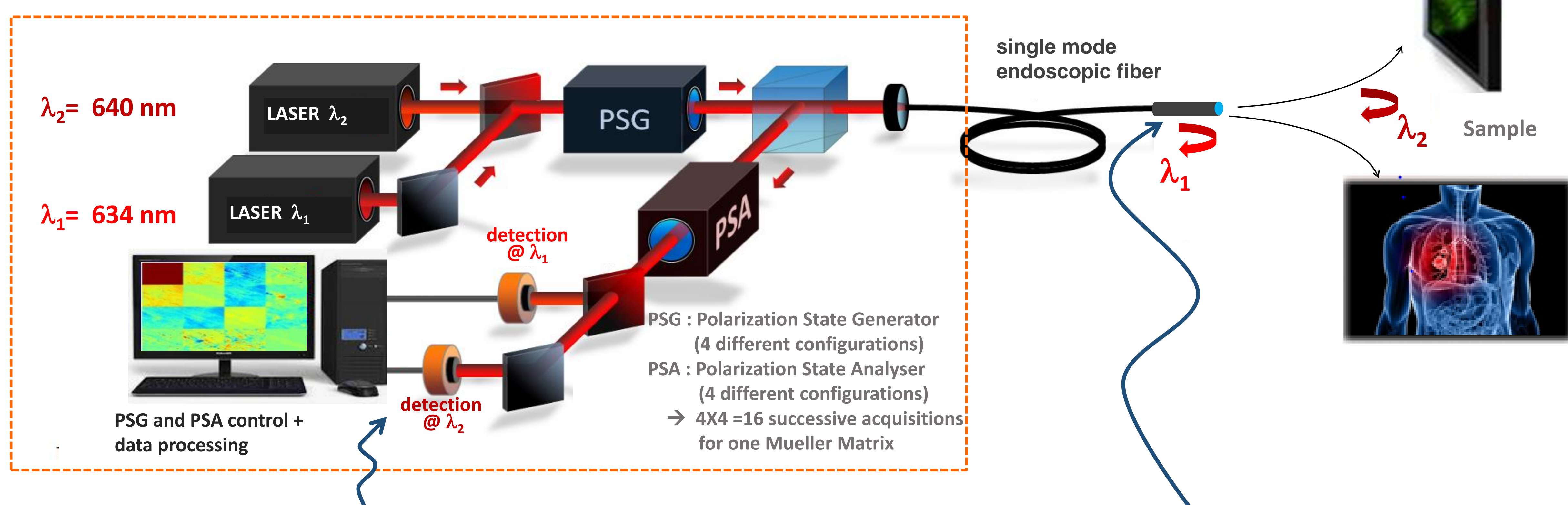
Mueller polarimetry: a powerful technique allowing the determination of all the polarimetric characteristics of a sample from a 4x4 Mueller matrix (M_{sample}).

A promising application...: early diagnosis of diseases affecting biological tissues [1].

... but a serious limitation: since an optical-fiber-based endoscope behaves as an uncontrollable time dependent polarization scrambler, the use of such an instrument seems incompatible with polarimetric imaging: polarimetric imaging is limited to external tissues or biopsies.

The challenge to overcome: how to get rid of the harmful polarimetric effects of the fiber for allowing polarimetric endoscopic imaging of inner tissues?

A novel technique for achieving endoscopic polarimetric Mueller imaging



Two-wavelength differential method (TWDM) based on a simultaneous measurement at two close wavelengths [2]

$$@\lambda_1 \rightarrow M_{\lambda_1} = \text{matrix "fiber only"} = M_{\text{Back}1} \cdot M_{\text{Forth}1}$$

determination of $M_{\text{Back}1}$ and $M_{\text{Forth}1}$

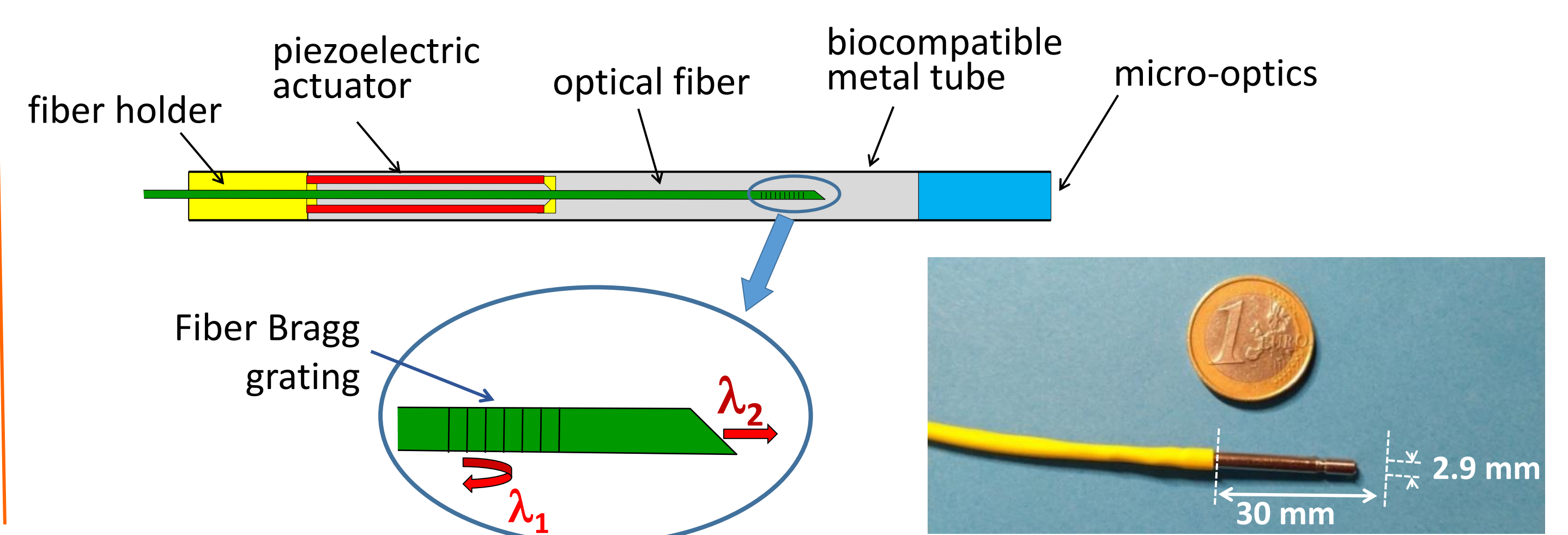
$$@\lambda_2 \rightarrow M_{\lambda_2} = \text{matrix "fiber + sample"} = M_{\text{Back}2} \cdot M_{\text{Samp}} \cdot M_{\text{Forth}2}$$

If λ_1 and λ_2 are close enough ($\Delta\lambda < 1\%$), thus:

$$M_{\text{Forth}1} \sim M_{\text{Forth}2} \text{ and } M_{\text{Back}1} \sim M_{\text{Back}2}$$

$$\rightarrow M_{\lambda_2} \sim M_{\text{Back}1} \cdot M_{\text{Samp}} \cdot M_{\text{Forth}1} \rightarrow M_{\text{Samp}} \sim M_{\text{Back}1}^{-1} \cdot M_{\lambda_2} \cdot M_{\text{Forth}1}^{-1}$$

Specially designed microprobe making it possible to implement the TWDM [3]

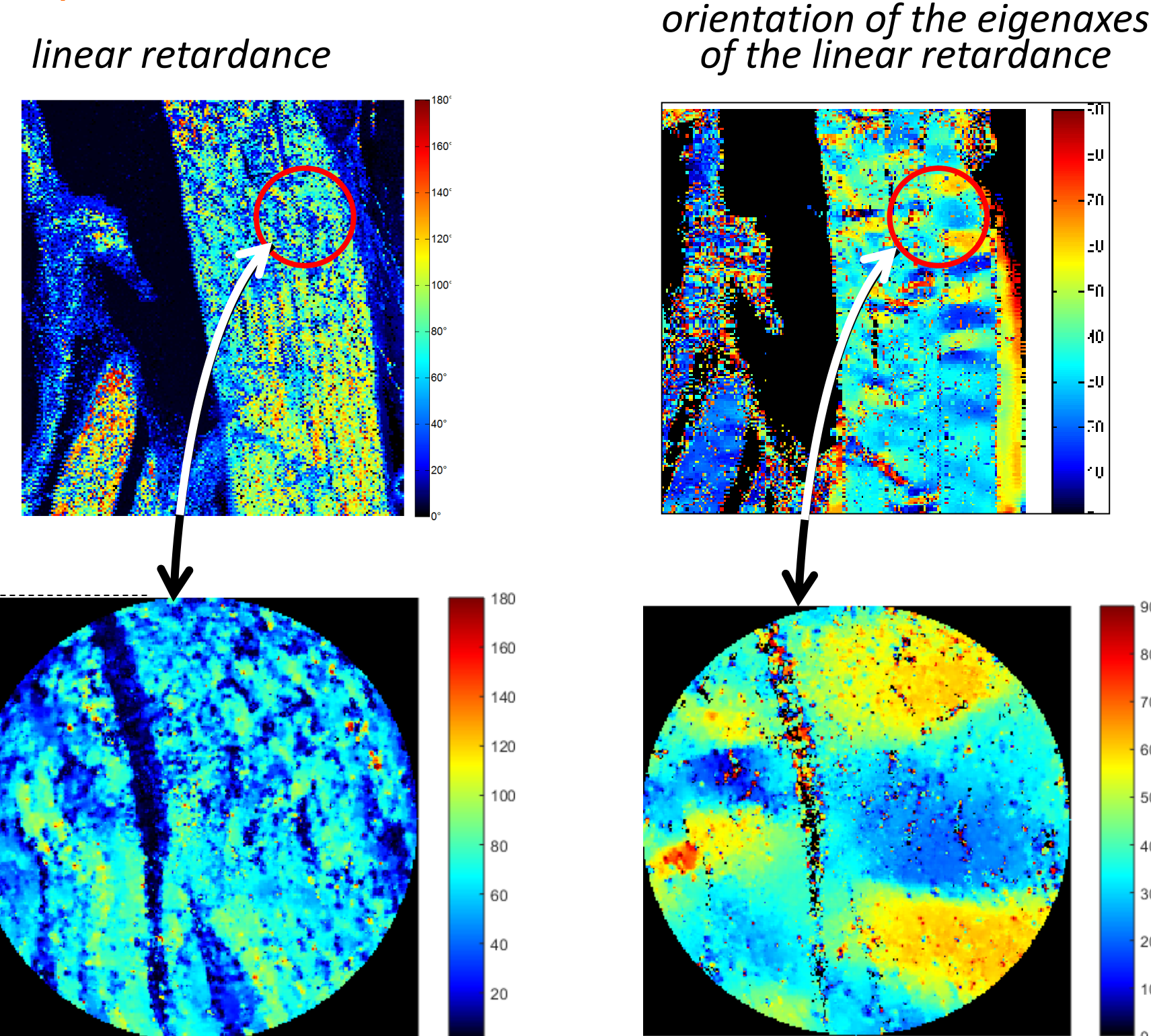
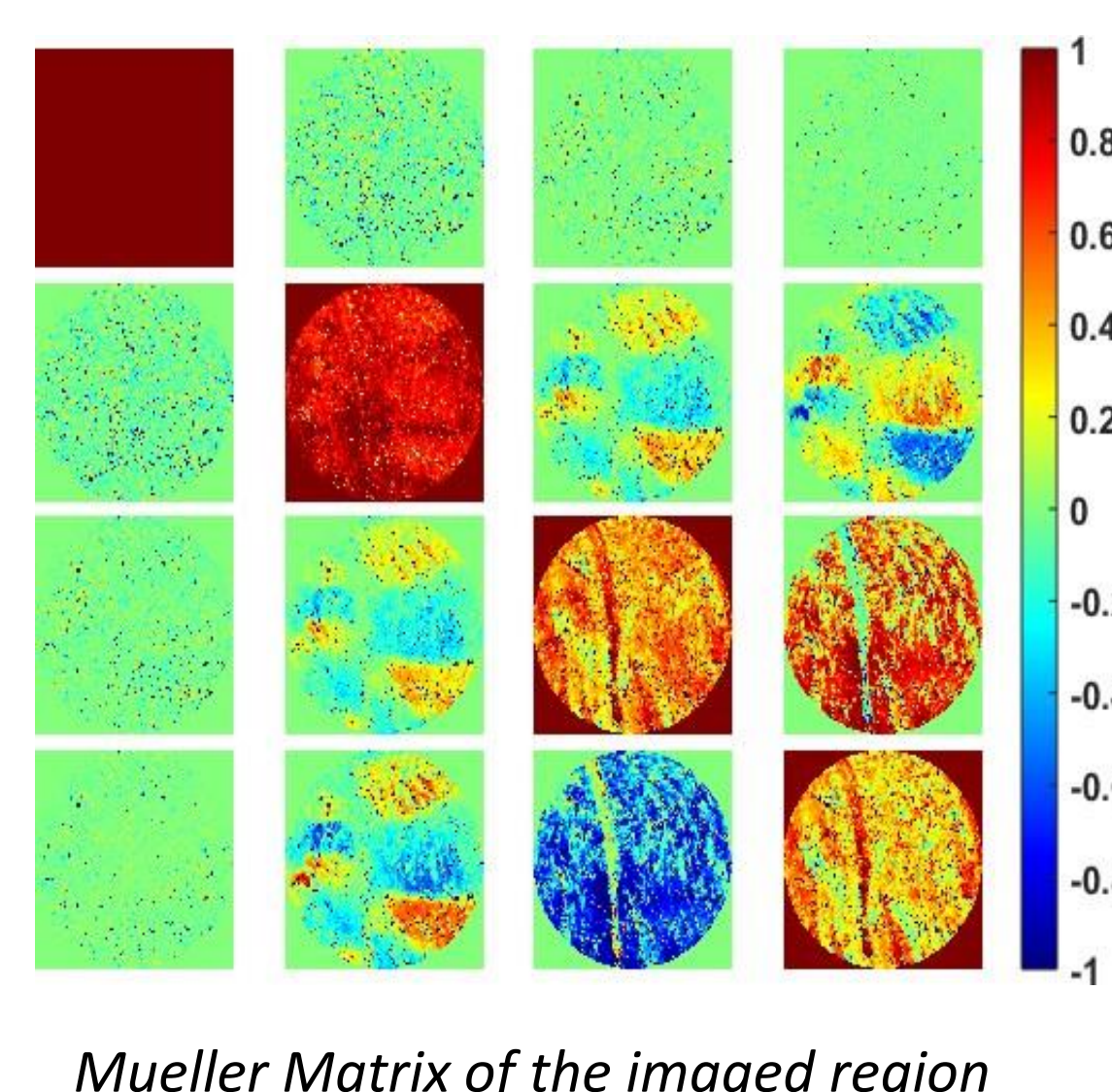
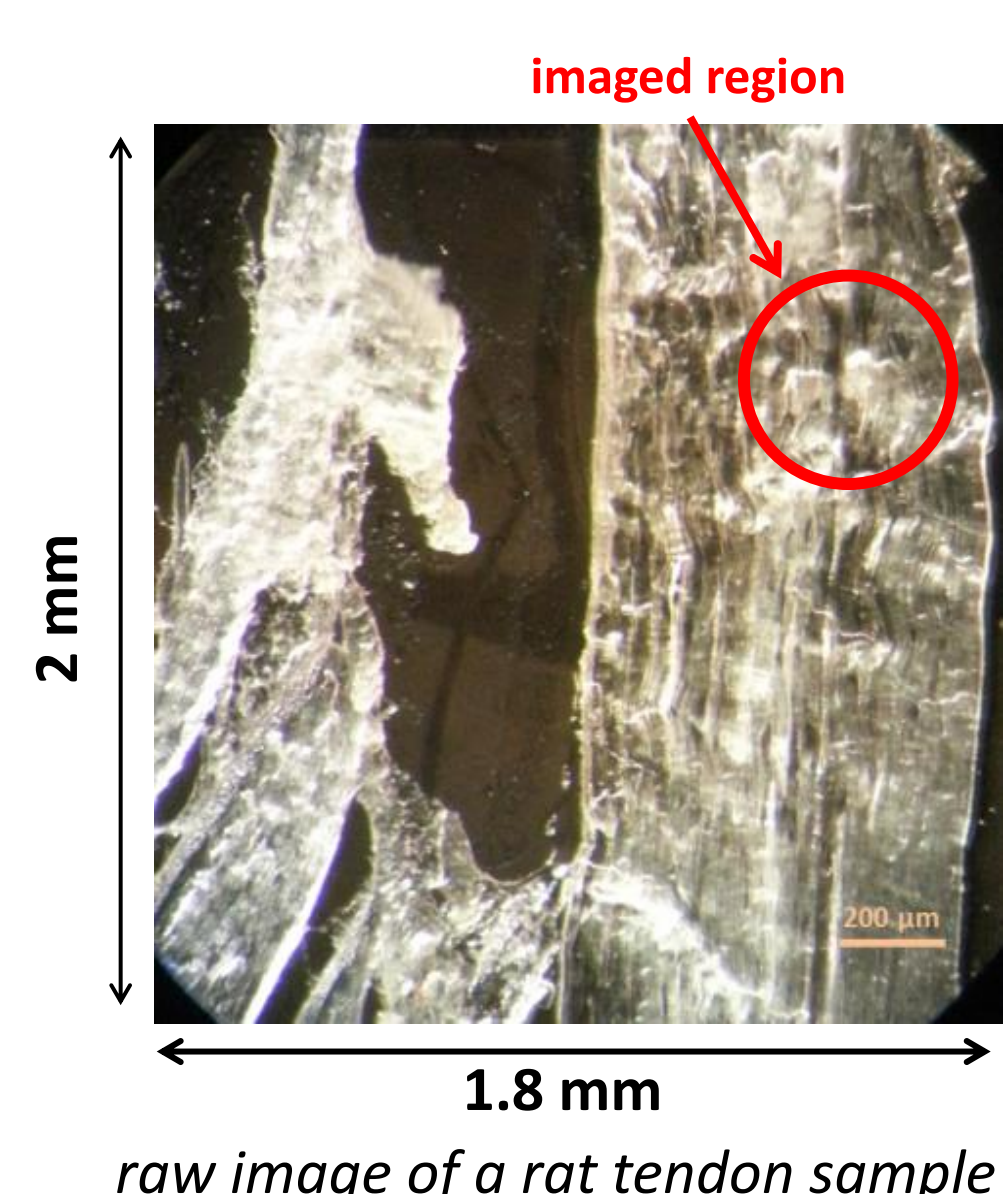
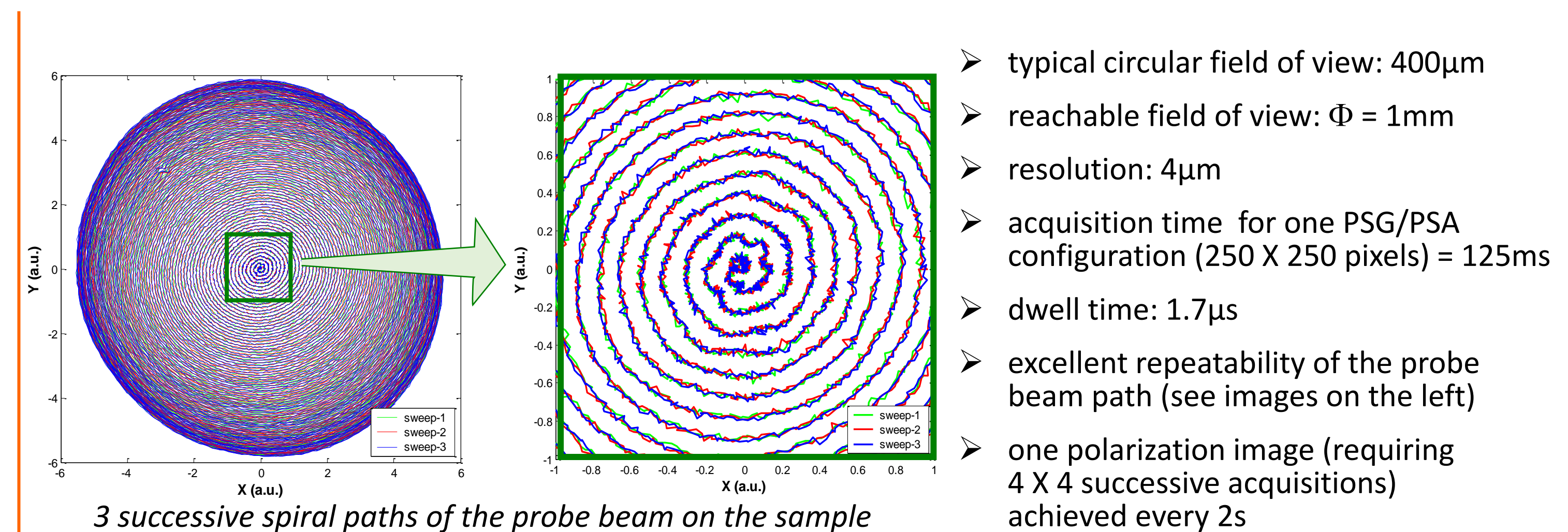


Experimental performances and example of polarimetric endoscopic image

For each pixel of the sample \rightarrow determination of the associated Mueller matrix M_{sample} by means of the TWDM \rightarrow Lu-Chipman decomposition of M_{sample} \rightarrow remote determination of all the polarimetric characteristics of this pixel:

- linear retardance (precision of +/- 3°): effect of birefringence in fibrillar tissues
- depolarization rate (*): effect of volume scattering of light in the tissue
 - diagnosis of diseases like fibrosis or certain cancers which affect the structure of the tissue at the submicronic scale, inducing changes in retardance and /or depolarization.
- diattenuation (precision < 0.02): effect of anisotropic absorption or diffusion of light
 - detection of specific biomolecules
- relative direction of the birefringence/diattenuation eigenaxes (precision of +/- 1°)
 - precise topological characterization of collagen fibers and fibrils

(*): concerning the depolarization measurement, the precision depends on the measuring conditions



with a point by point bulk imaging scanner
180 X 200 pixels
production time = 20min [2]

with the microprobe shown above
250 X 250 pixels
production time = 2s [3]

References

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- Vizet et al., J. Biomed Optics 21, 7, 071106 (2016).
- Buckley et al., Biomed Opt Express 11, 12, 7032 (2020).

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