Nanostructured substrates for surface enhanced spectroscopy

Hamid Keshmiri (VBCF), Michal Urbanek (CEITEC), Kareem Elsayad (VBCF)

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EUROPEAN UNION

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Interreg
Austria-Czech Republic
European Regional Development Fund

Pilot project introduction

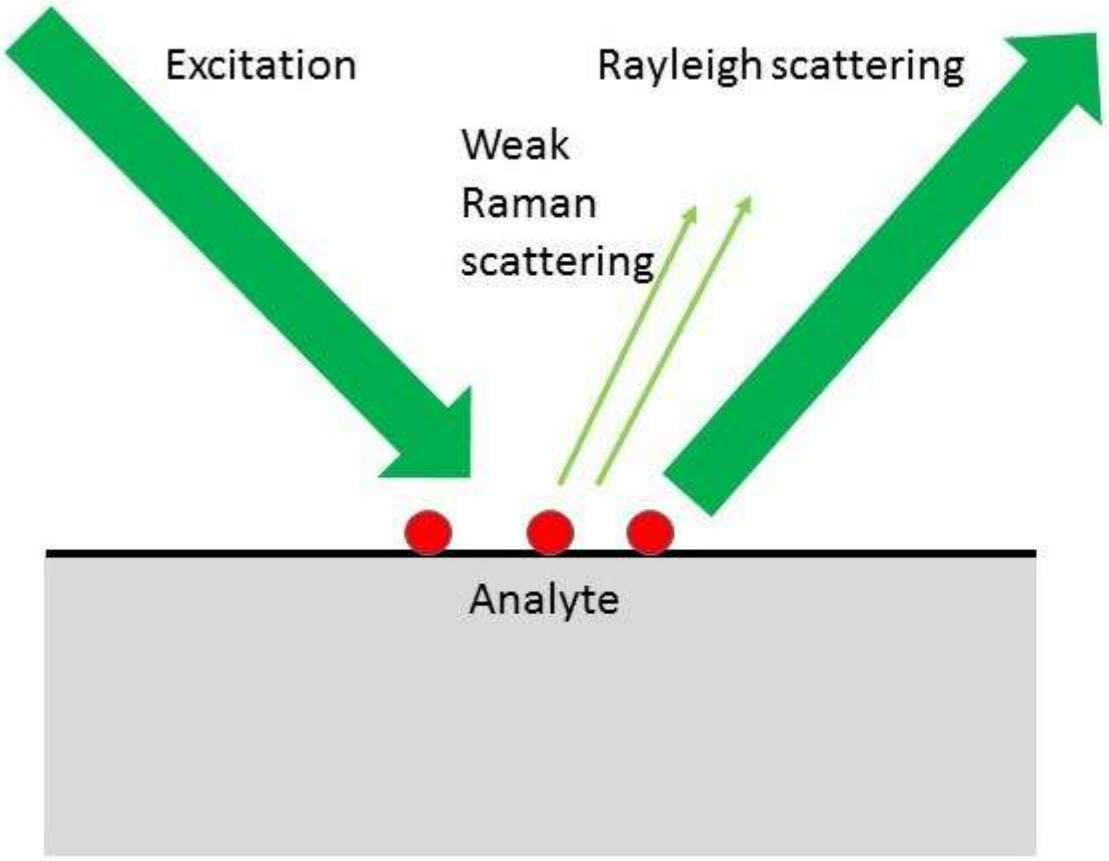
Project partners:
Hamid Keshmiri (VBCF), Michal Urbanek (CEITEC), Kareem Elsayad (VBCF)

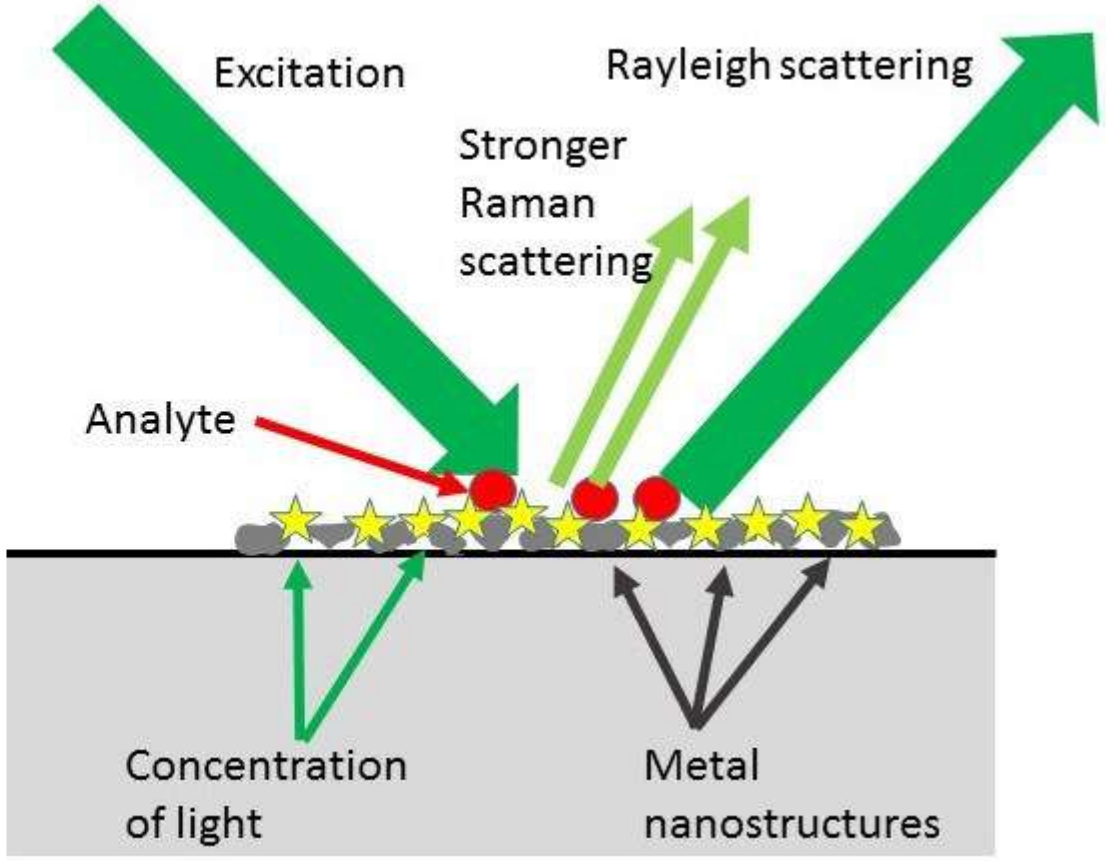
Goal:
Most micospectroscopy (fluorescence and non-fluorescence) techniques suffer from poor signal-to-noise, which limit their acquisition speeds and efficiency. Optimization thereof can allow for the study of dynamic biological processes otherwise not possible. By fabricating and employing suitable nanostructures this can be enhanced.

***Dynamic* microspectroscopy in many projects we get is highly desirable but currently not possible due to finite acquisition time**

Pilot project introduction

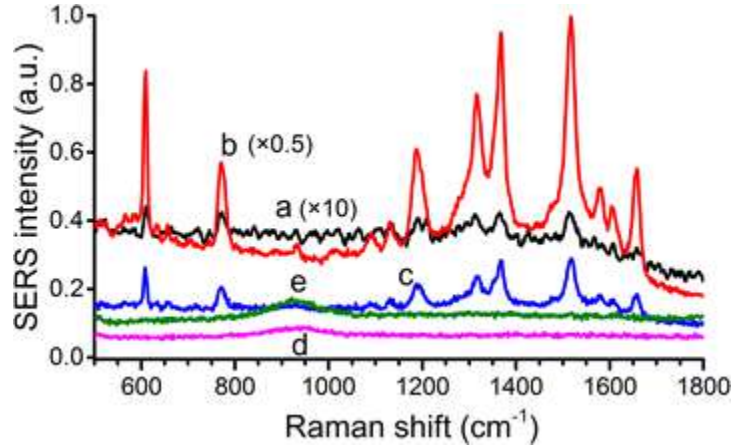
Surface enhanced spectroscopy

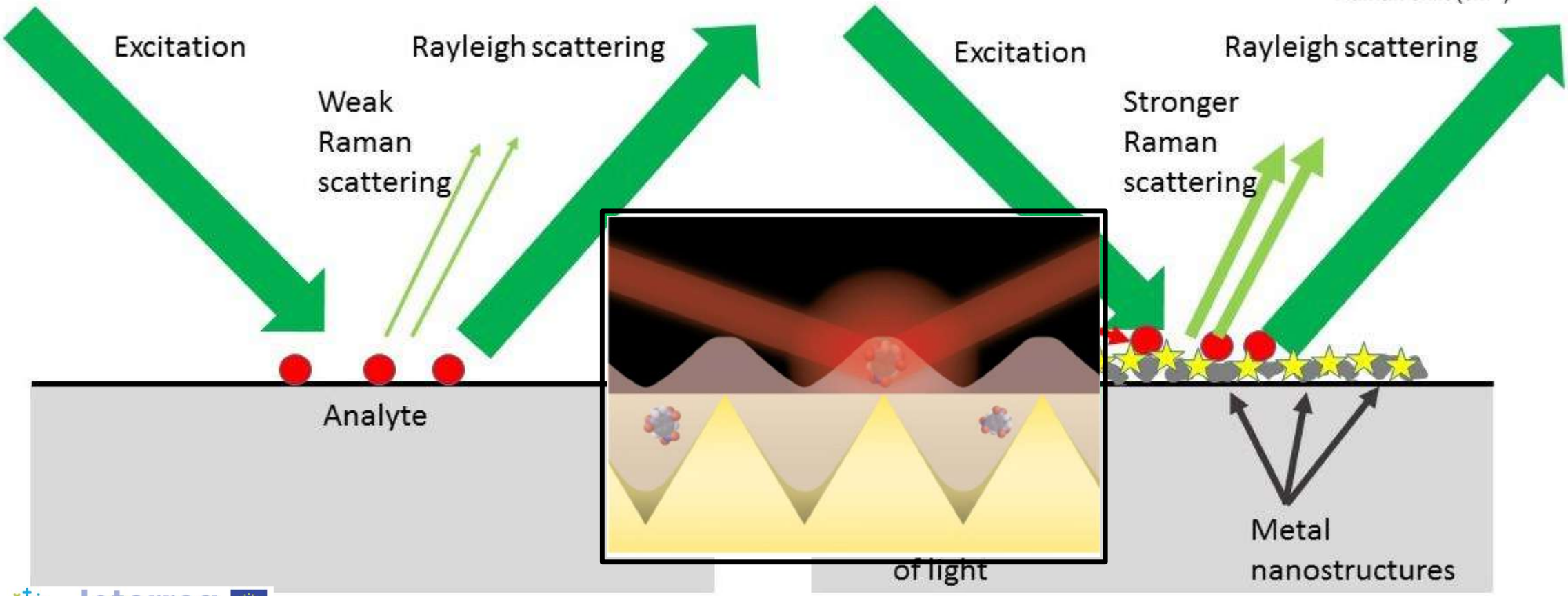




Pilot project introduction

Surface enhanced spectroscopy



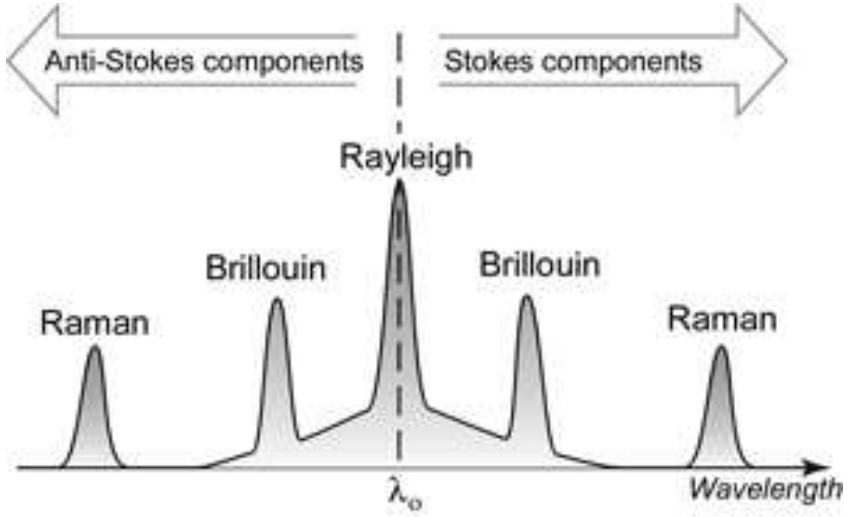


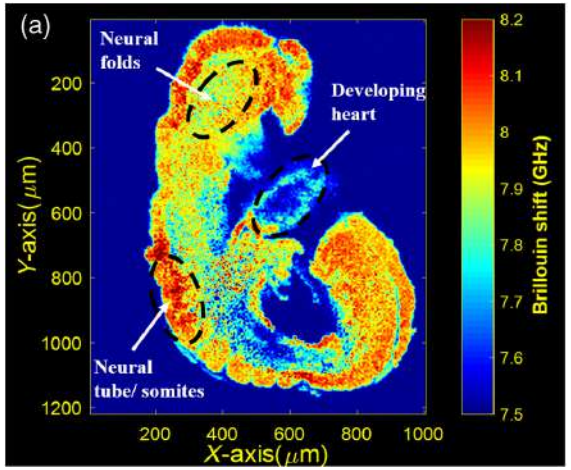
Pilot project introduction

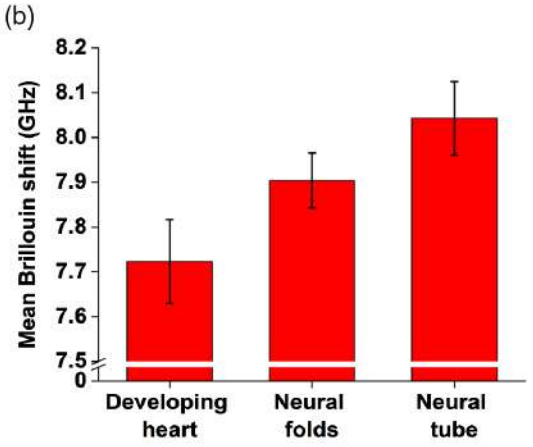
Brillouin Microscopy (VBCF)

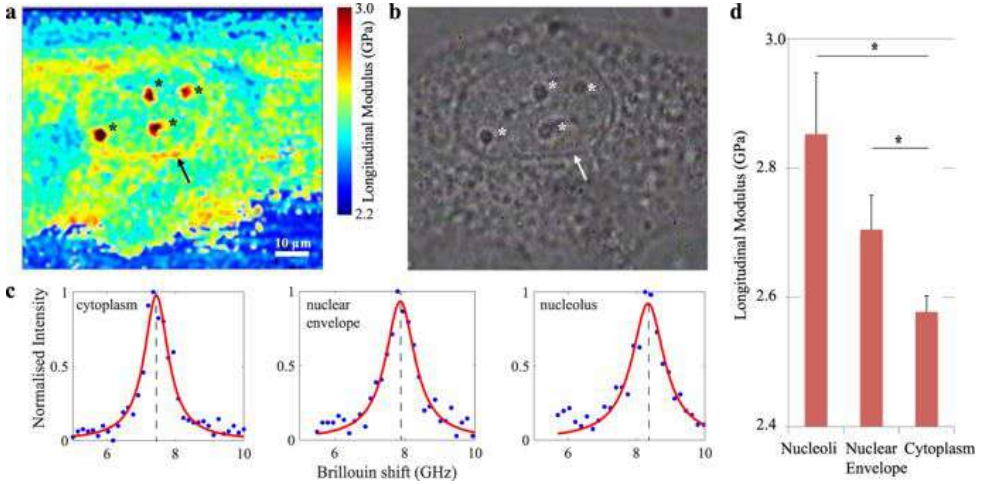
All optical measurement of mechanical properties
via VERY small (~1/1000 nm) spectral shift – challenging

Long acquisition times / high laser powers



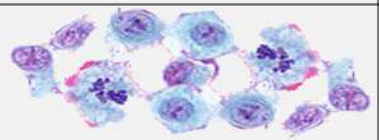
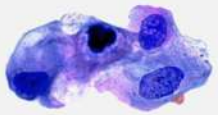
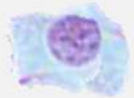






Pilot project introduction

Mechanical properties are important!

Normal	Cancer	
		Large, variably shaped nuclei
		Many dividing cells; Disorganized arrangement
		Variation in size and shape
		Loss of normal features

http://sphweb.bumc.bu.edu

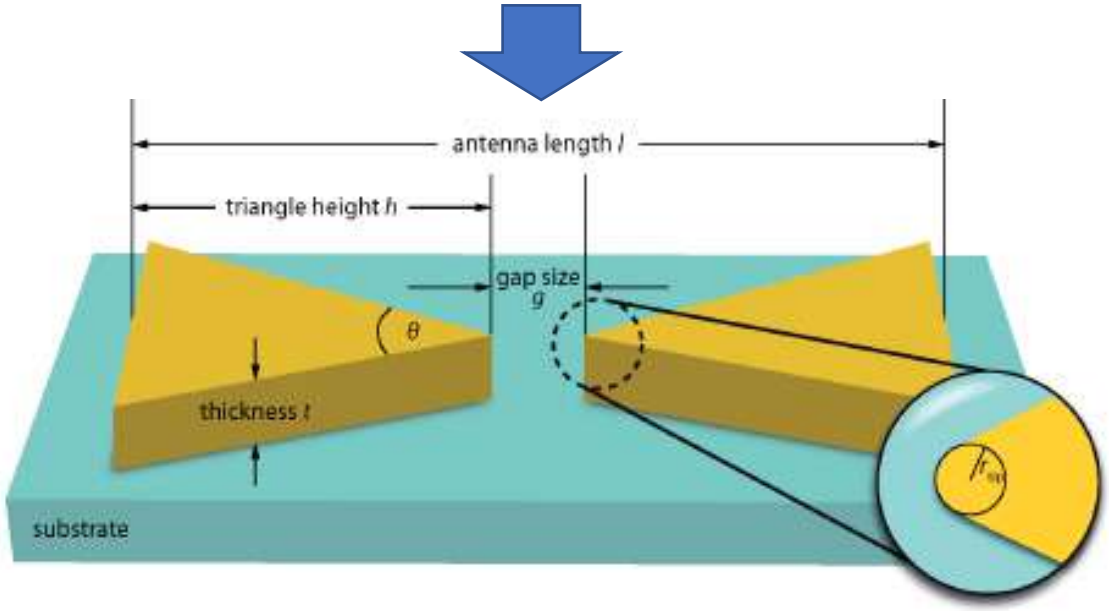
- **Potential end-users:**

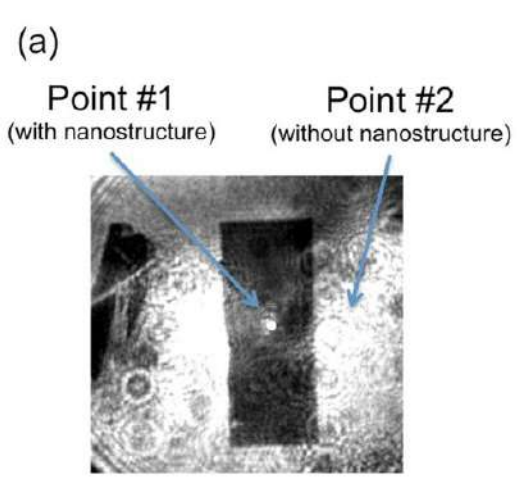
  Mostly academic users – possible candidates:

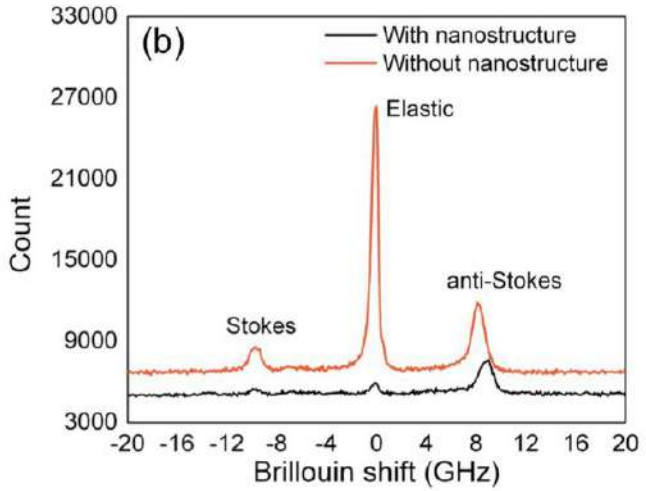
- *Alexander Dammerman, MFPL, Vienna*
- *Peter Schloegelhofer, MFPL, Vienna*
- *Andrea Pauli, IMP, Vienna*
- *Josef Penninger, IMBA, Vienna*
- *Sabine Eichinger, Medical University, Vienna*
- *Robert Konrad, MFPL, Vienna*
- *…*

Pilot project introduction

Field (signal) enhancement







Surface-enhanced Brillouin scattering in a vicinity of plasmonic gold nanostructures

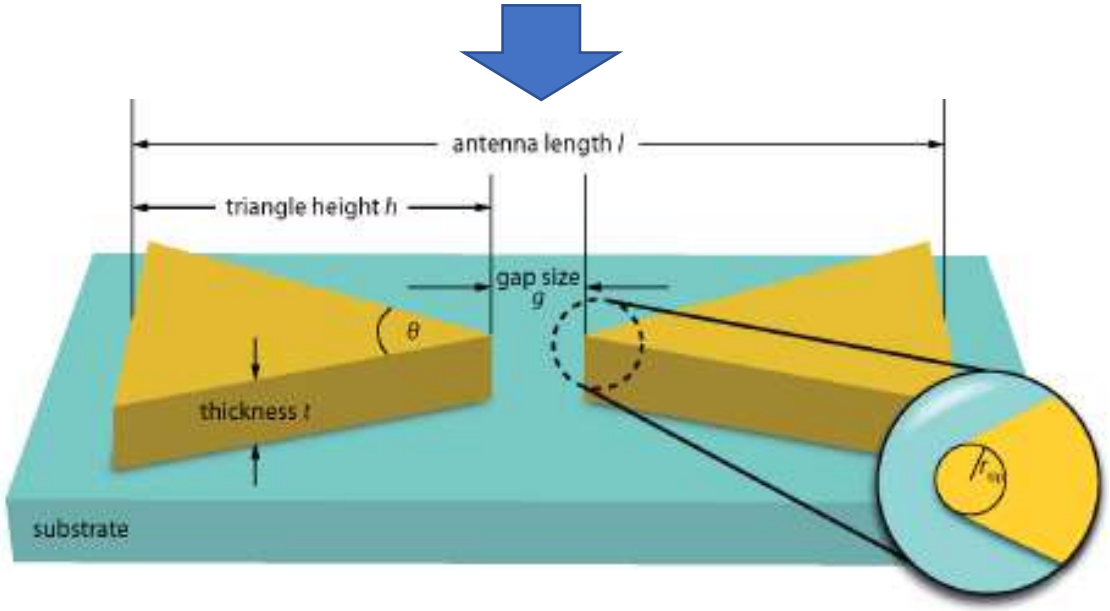
Zhaokai Meng; Vladislav V. Yakovlev; Zhandos Utegulov

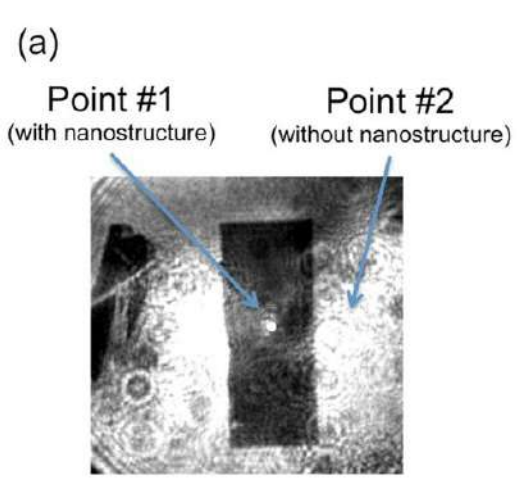
Only very small effect ☹

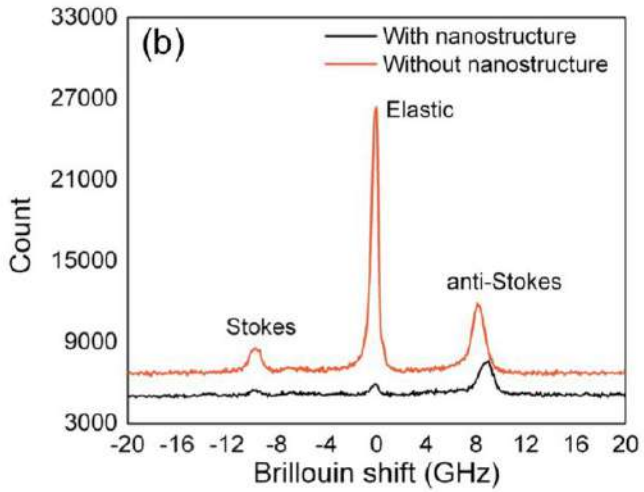
Due to length scales of acoustic phonons one is scattering from

Pilot project introduction

Field (signal) enhancement







Surface-enhanced Brillouin scattering in a vicinity of plasmonic gold nanostructures

Zhaokai Meng; Vladislav V. Yakovlev; Zhandos Utegulov

Work on engineering *phonon density of states*

TRICKY

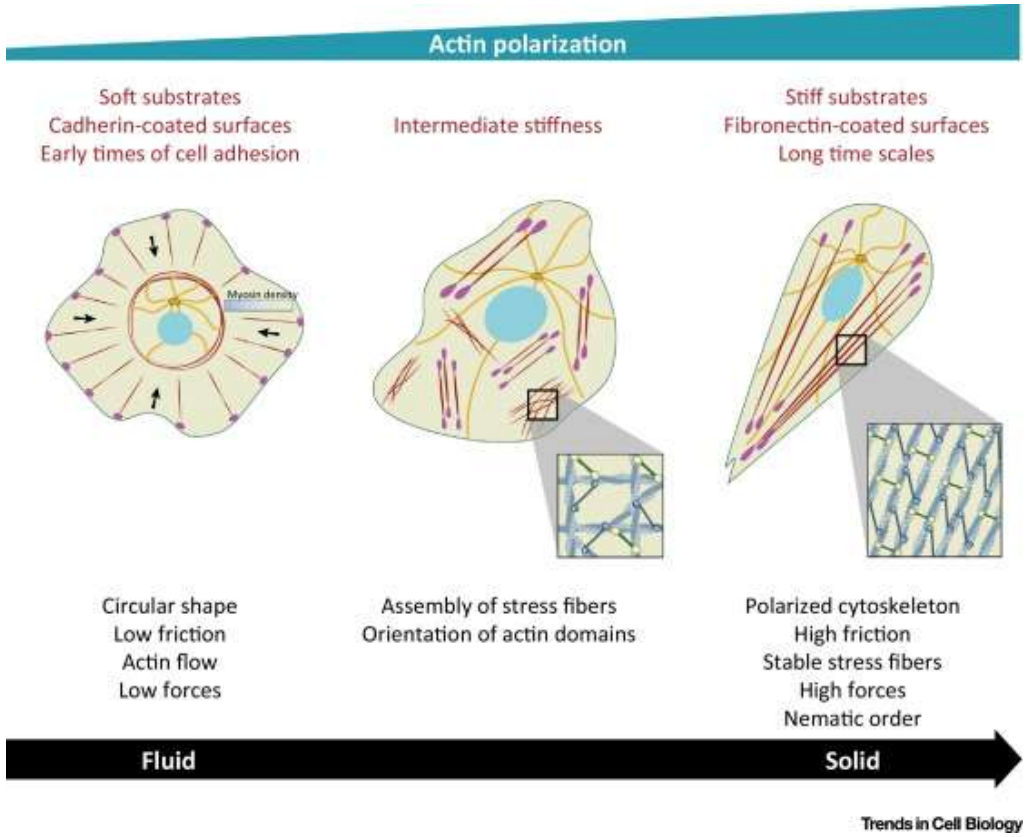
(planned collaboration with Bert Hecht, Wuerzburg)

Only very small effect ☹

Due to length scales of acoustic phonons one is scattering from

Pilot project introduction

Mechanical properties are rarely isotropic



"Would be great to know anisotropy!!"

- **Potential end-users:**

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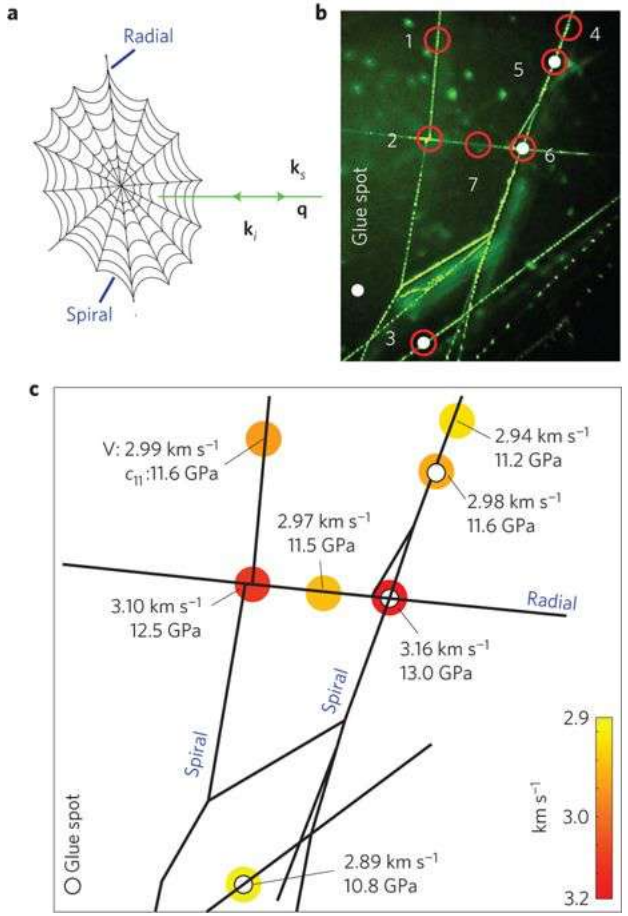
- *Andrea Pauli, IMP, Vienna*
- *Josef Penninger, IMBA, Vienna*
- *Sabine Eichinger, Medical University, Vienna*
- *Robert Konrad, MFPL, Vienna*
- *…*

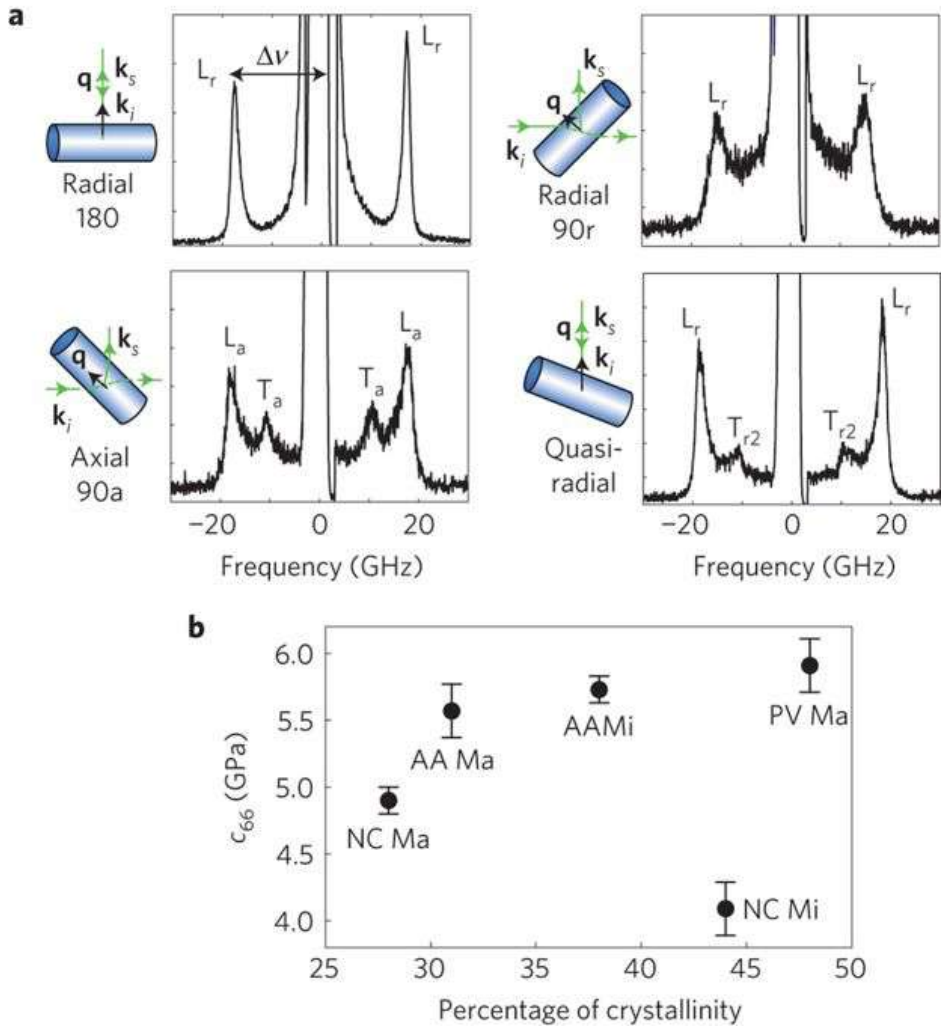
“Stiffness tensor”

Can be obtained from Brillouin Scattering measurements*

$$[C] = \begin{bmatrix} c_{1111} & c_{1122} & c_{1133} & c_{1123} & c_{1131} & c_{1112} \\ c_{2211} & c_{2222} & c_{2233} & c_{2223} & c_{2231} & c_{2212} \\ c_{3311} & c_{3322} & c_{3333} & c_{3323} & c_{3331} & c_{3312} \\ c_{2311} & c_{2322} & c_{2333} & c_{2323} & c_{2331} & c_{2312} \\ c_{3111} & c_{3122} & c_{3133} & c_{3123} & c_{3131} & c_{3112} \\ c_{1211} & c_{1222} & c_{1233} & c_{1223} & c_{1231} & c_{1212} \end{bmatrix} \equiv \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{12} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{13} & C_{23} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{14} & C_{24} & C_{34} & C_{44} & C_{45} & C_{46} \\ C_{15} & C_{25} & C_{35} & C_{45} & C_{55} & C_{56} \\ C_{16} & C_{26} & C_{36} & C_{46} & C_{56} & C_{66} \end{bmatrix}$$



Koski et al. Nature Mat. 2013



<u>Tricky</u> *sequential* measurements from different angles and polarizations

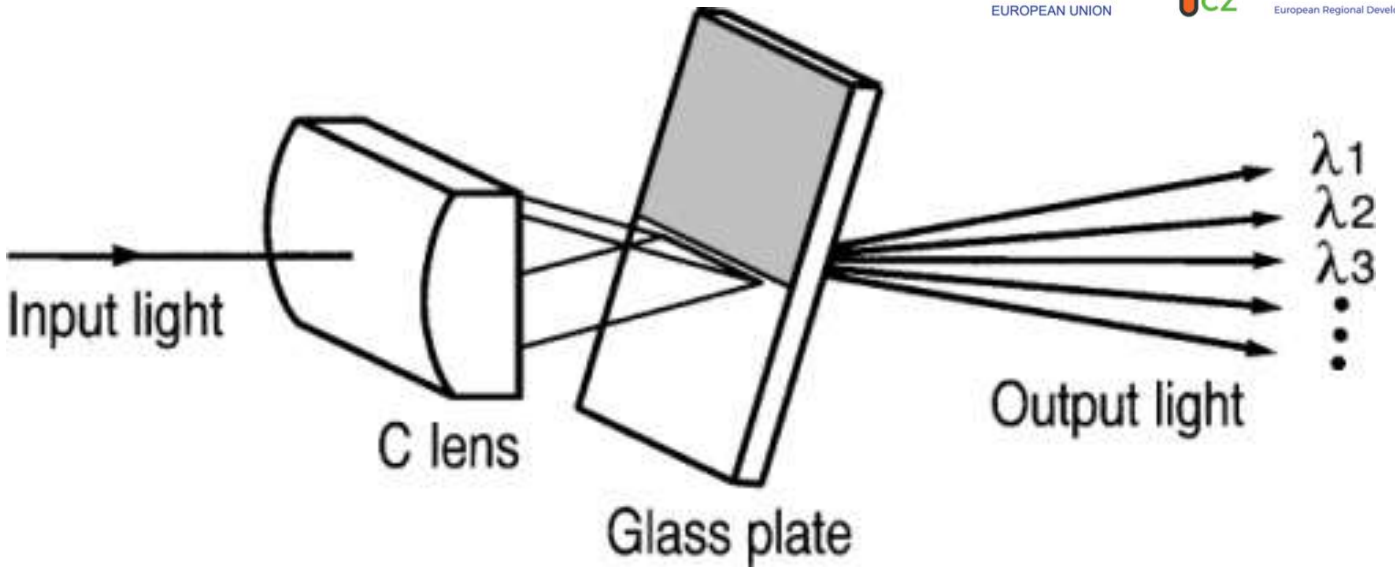
Most groups who are measuring anisotropic structures and fibers would be very interested in getting this!

*No other technique is capable of this!

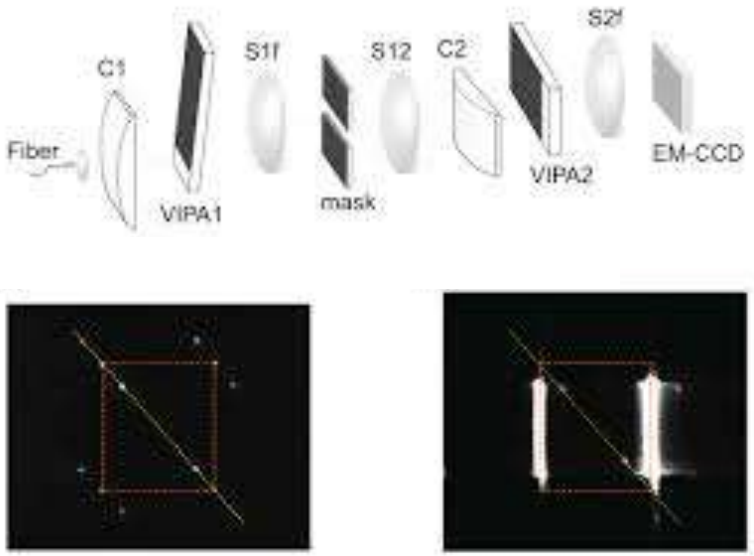
Current imaging-spectrometer designs used for Brillouin Microscopy

“VIPA”

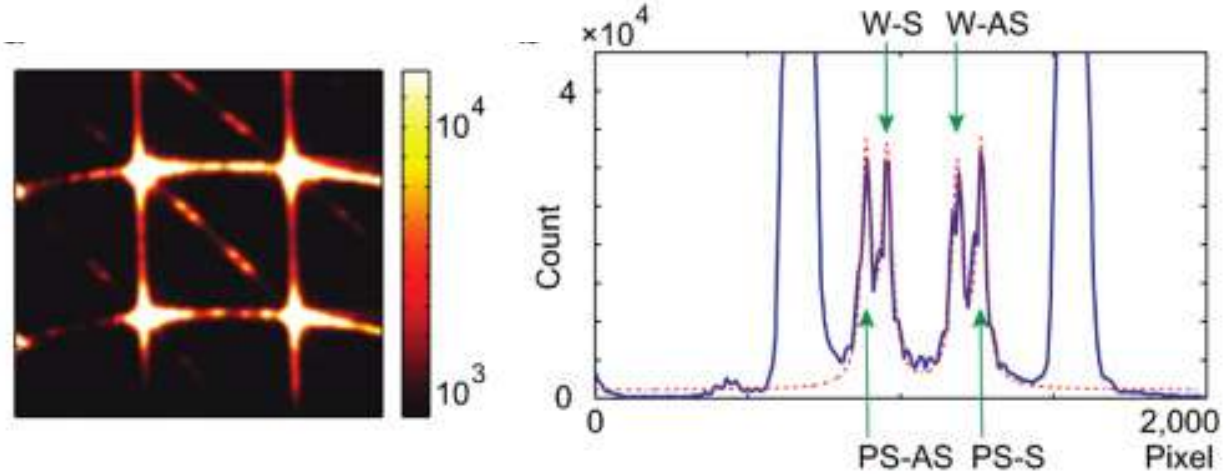
Can only obtain spectra from
a single measuring configuration
(angle and polarization)



Cross-dispersion

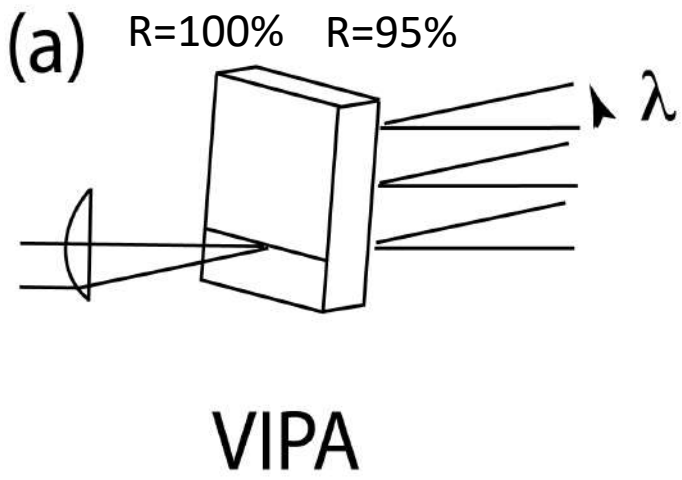


Shear modulus (non-cross-terms)

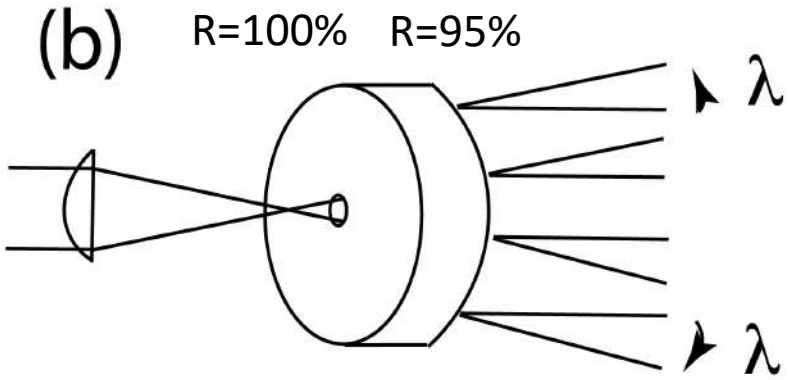


But life is 3D…

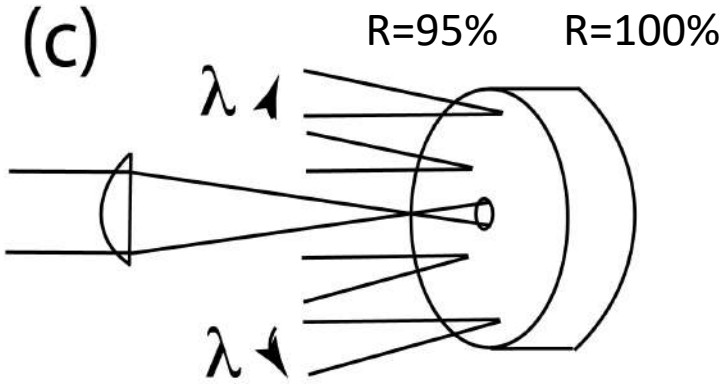
Can we use the extra degree of freedom?



VIPA



radial VIPA



reflective radial VIPA

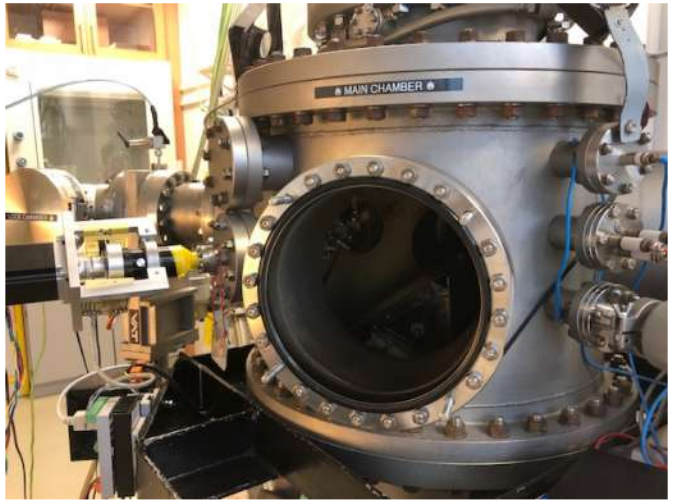
Can purchase

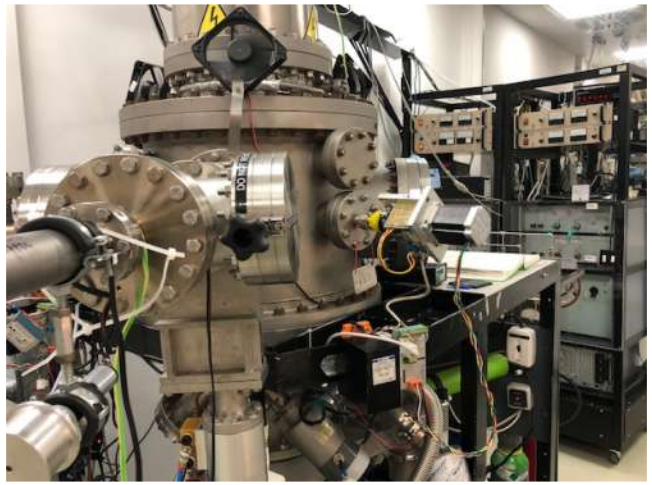
Fabricate at CEITEC

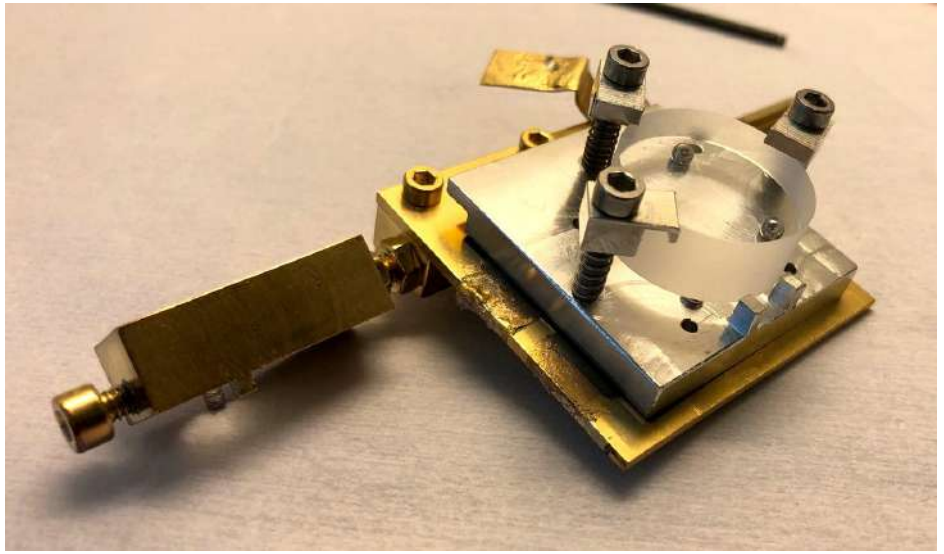
Super flat (etalon) substrates

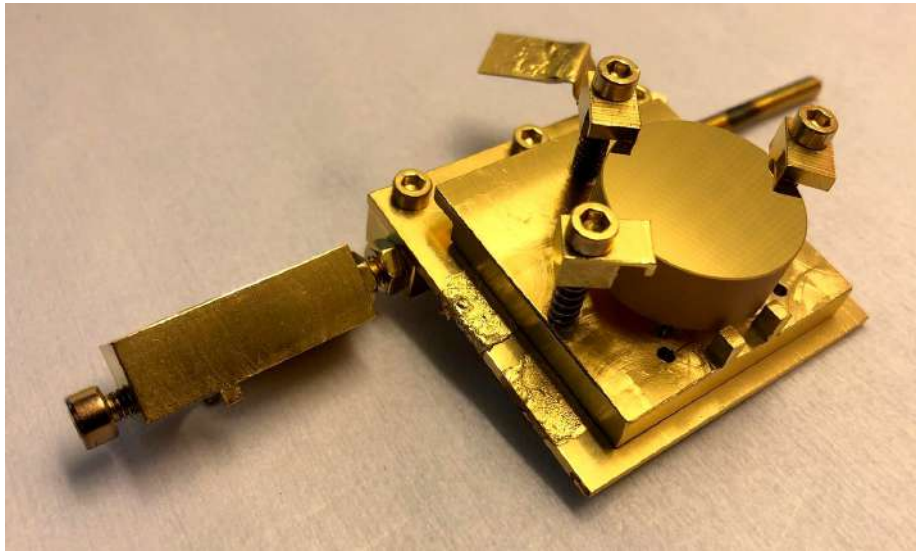
Thin film deposition:
Device: Ion beam sputter with a Kaufman source
Materials: Ti (t=2 nm) / Au (t=70 nm)
Chamber pressure: $1.5 \cdot 10^{-6}$ mbar

Patterning (ion milling):
Device: Focused ion beam scanning electron microscope (TESCAN dual-beam FIB/SEM LYRA3 system)
Structure: a microhole pattern with 100 µm in diameter etched through the 70 nm thick gold film at the center of the etalon substrate.
(Conditions: 30 kV accelerating voltage, 660 pA probe current)









The coating of etalon substrates was realized by Ion Beam Sputtering (IBS) technique in an in-house developed sputter equipped with a Kaufman-type argon ion source.

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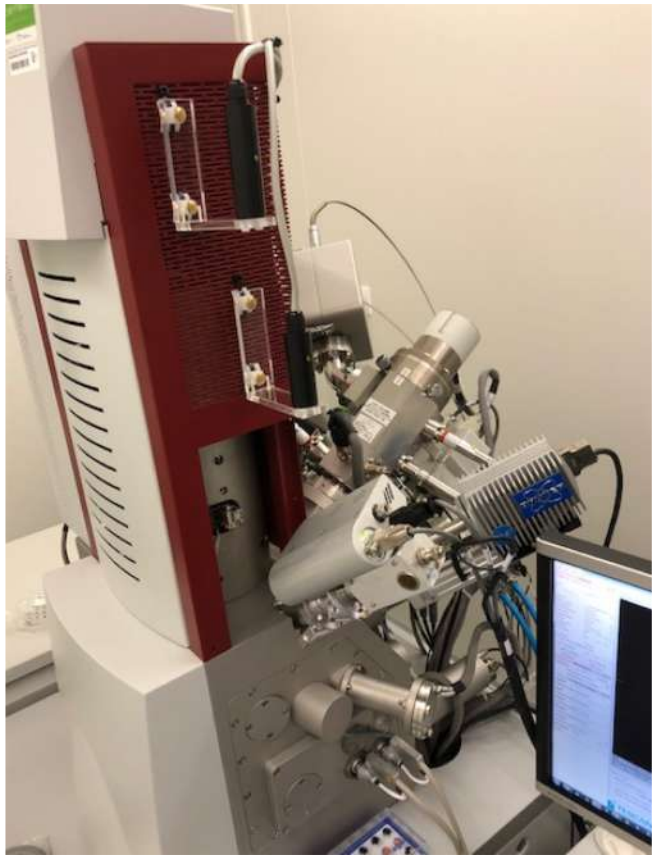
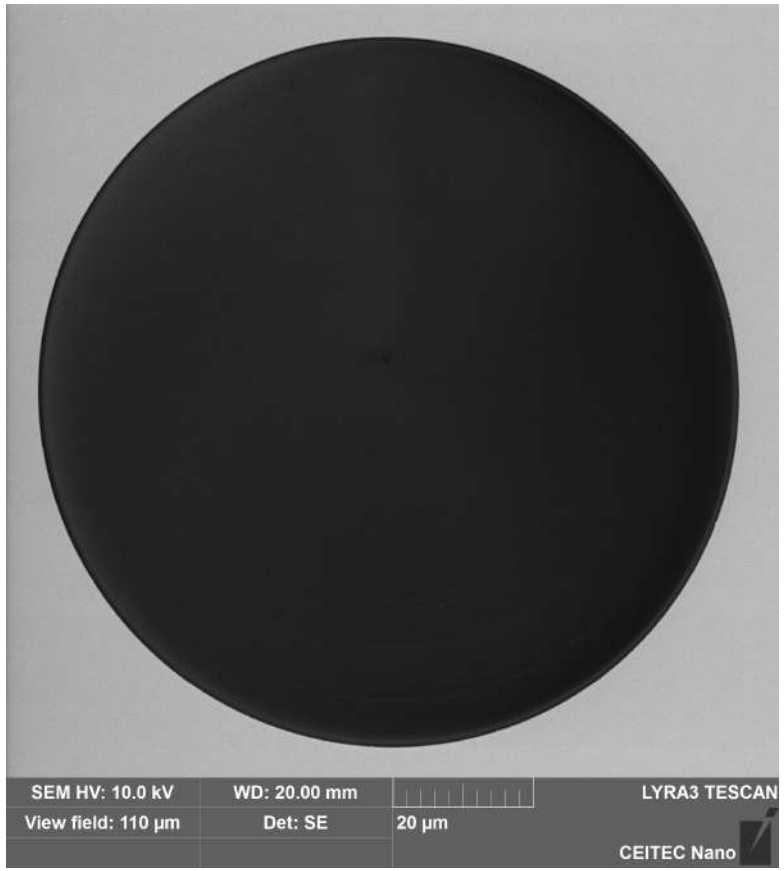
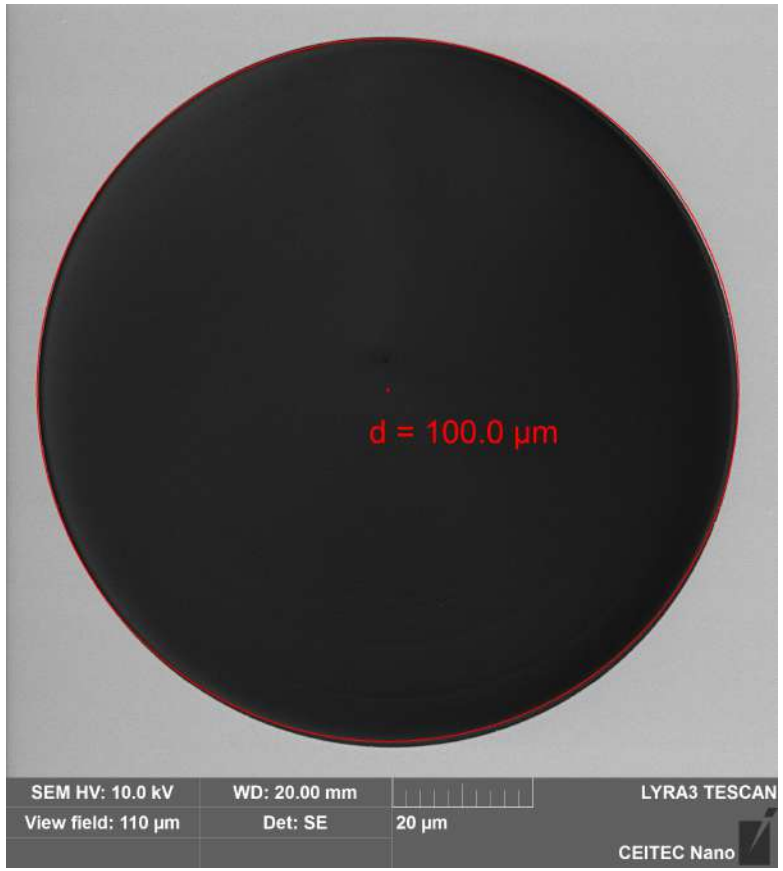
*TU Brno Institute of Physical Engineering

Michal Kvapil, Hamid Keshmiri



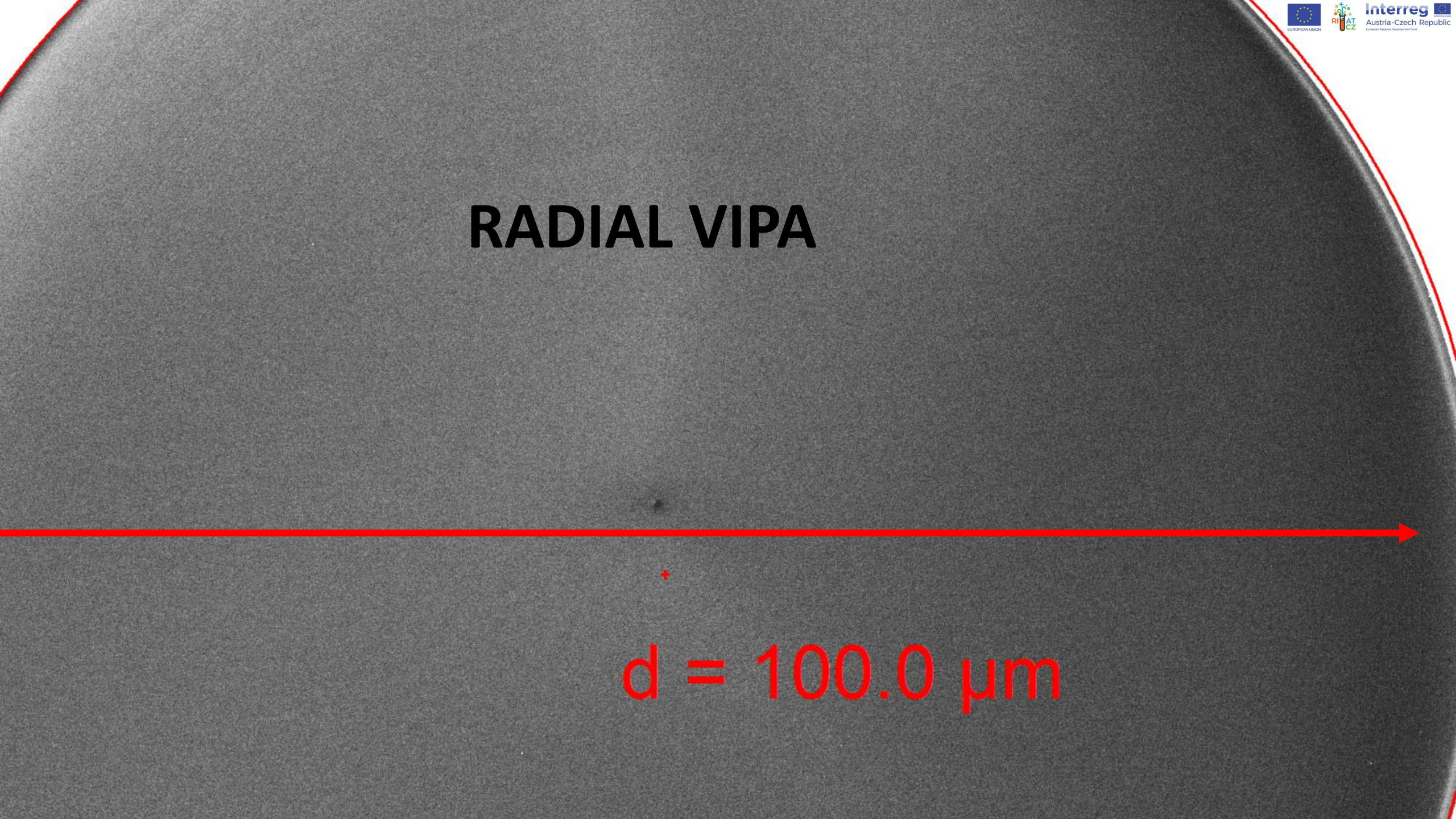


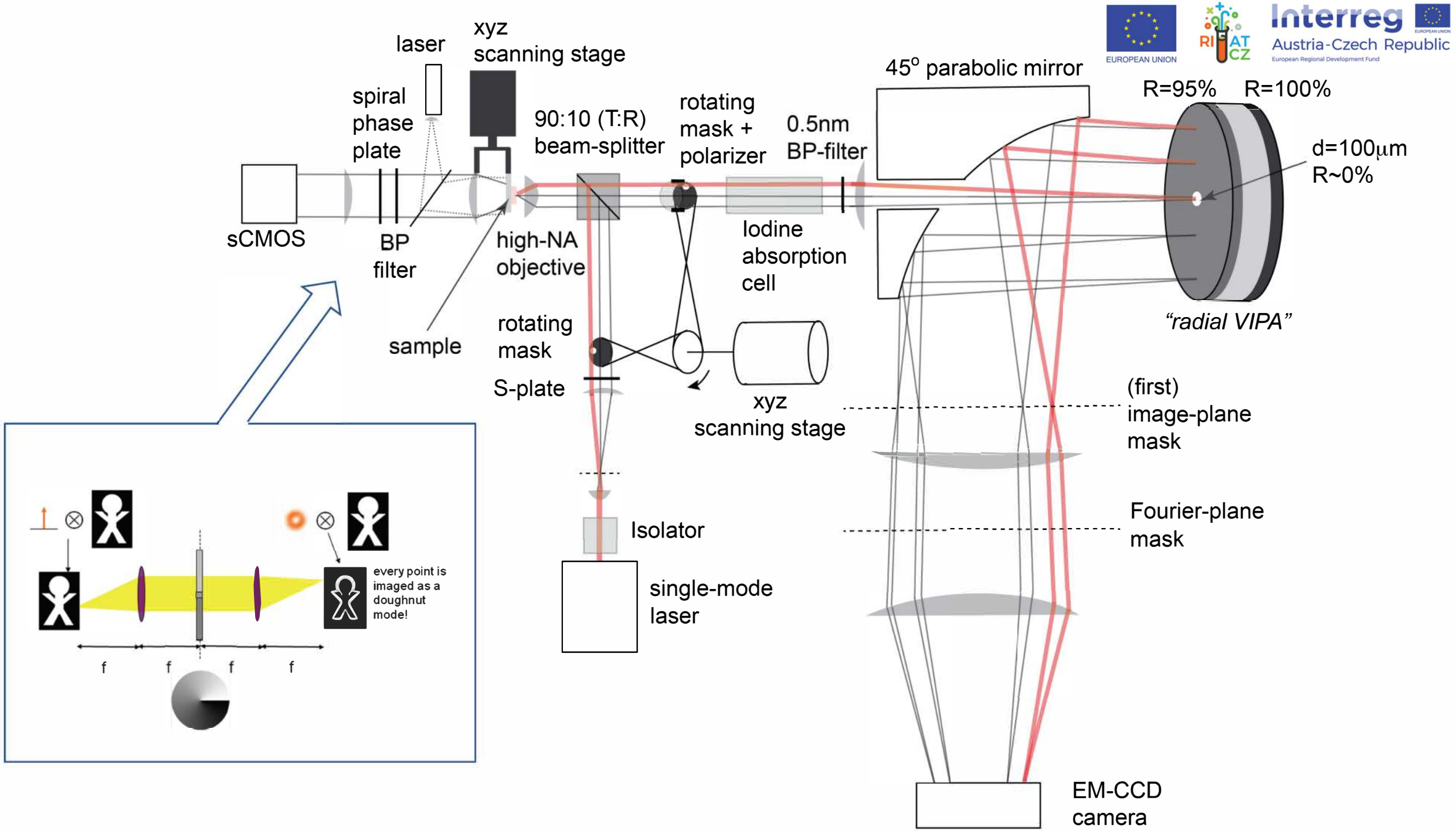


A microhole with 100 *µm* in diameter was patterned by TESCAN dual-beam FIB/SEM LYRA3 system under 30 *kV* accelerating voltage and 660 *pA* probe current.

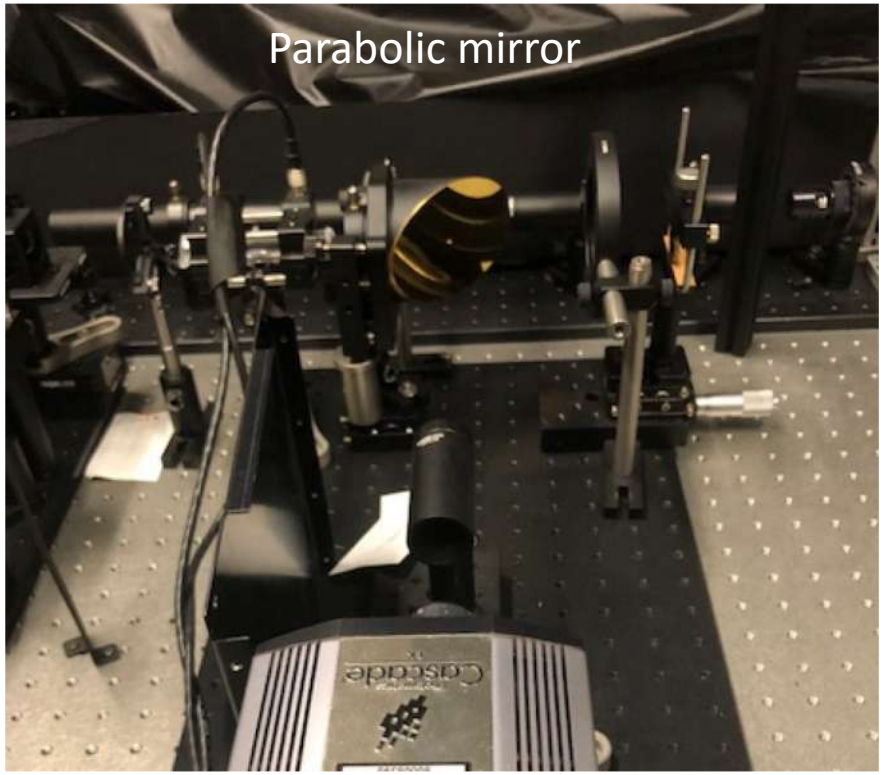
*CEITEC Nano

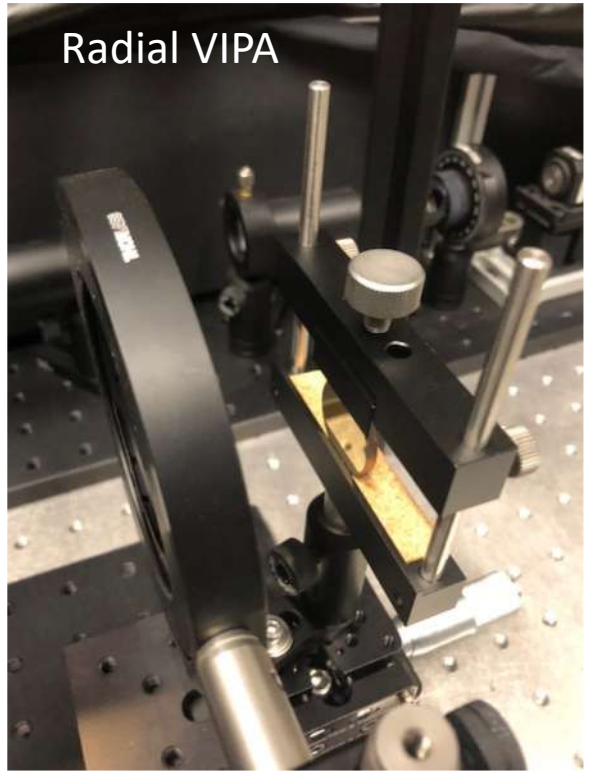
Tomas Samoril, Hamid Keshmiri

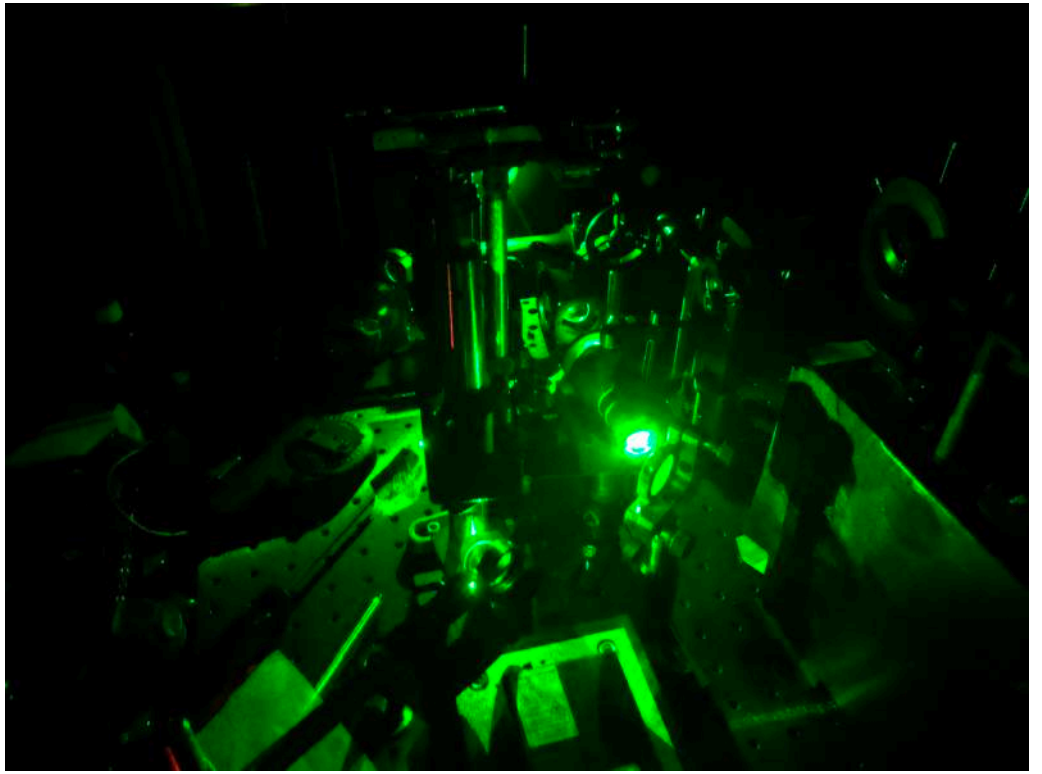

RADIAL VIPA
d = 100.0 µm

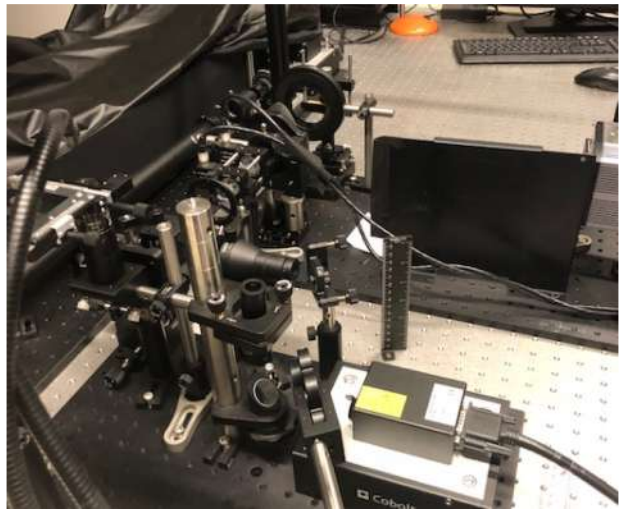

laser
xyz
scanning stage
spiral
phase
plate
90:10 (T:R)
beam-splitter
rotating
mask +
polarizer
0.5nm
BP-filter
45° parabolic mirror
R=95%
R=100%
d=100μm
R~0%
sCMOS
BP
filter
high-NA
objective
Iodine
absorption
cell
"radial VIPA"
sample
rotating
mask
S-plate
xyz
scanning stage
(first)
image-plane
mask
Fourier-plane
mask
Isolator
single-mode
laser
EM-CCD
camera
every point is
imaged as a
doughnut
mode!
f
f
f
f

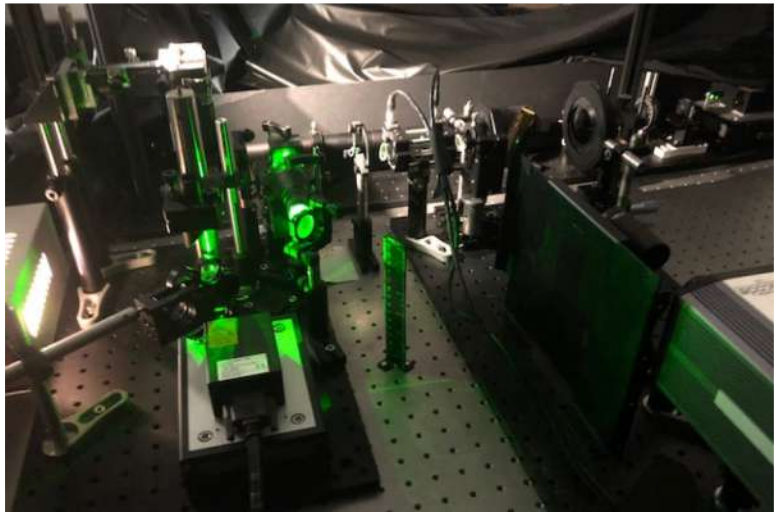
Radial Dispersion Imaging Microspectroscopy



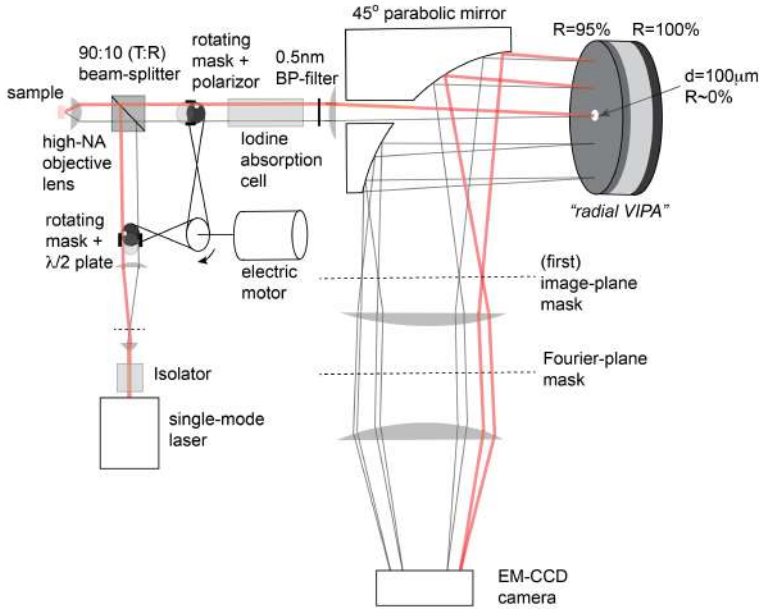








Can simultaneously measure all components of stiffness tensor



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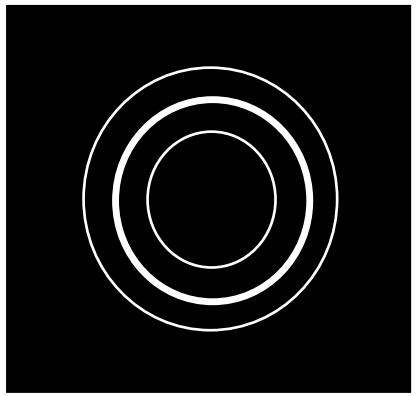
Radial dispersion…

muscle fiber

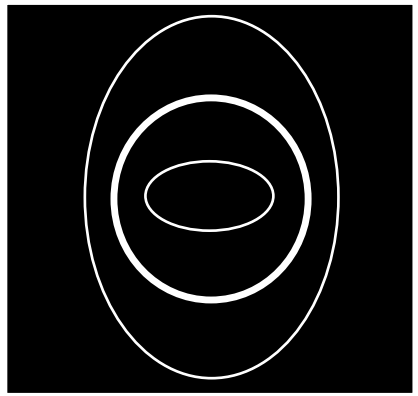
Each angular segment of the circlular Projected dispersion probes the sample from a different angle…
…can get all components of tensor at once!!

$$\sigma_i = C_{ij}\epsilon_j$$

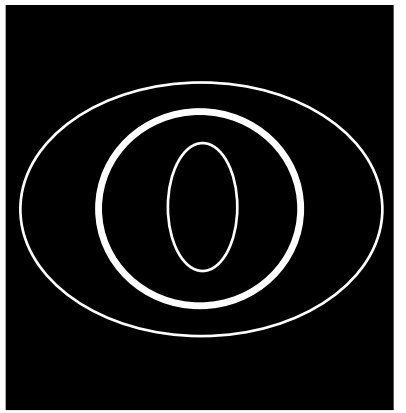
Isotropic "stiffness"



"Stiffer" in vertical direction



"Stiffer" in horizontal direction



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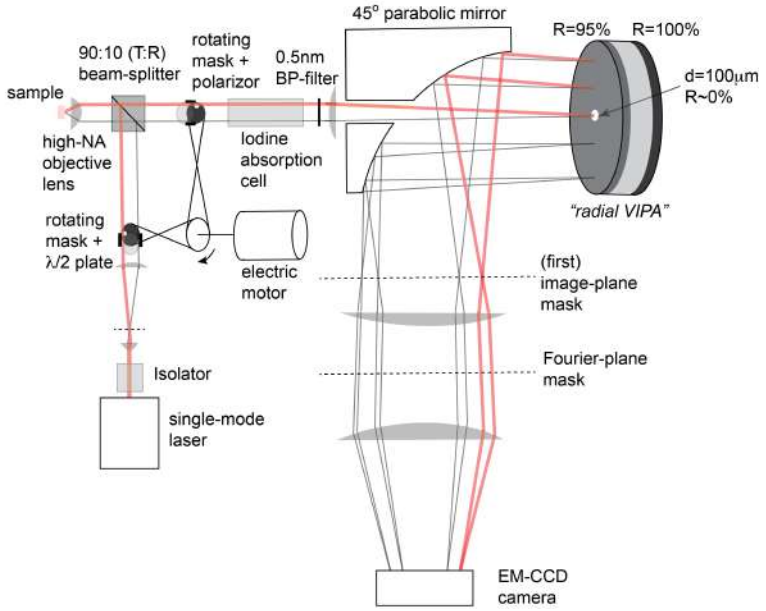
Austria-Czech Republic
European Regional Development Fund

Can simultaneously measure all components of stiffness tensor



$$[C] = \begin{bmatrix} c_{1111} & c_{1122} & c_{1133} & c_{1123} & c_{1131} & c_{1112} \\ c_{2211} & c_{2222} & c_{2233} & c_{2223} & c_{2231} & c_{2212} \\ c_{3311} & c_{3322} & c_{3333} & c_{3323} & c_{3331} & c_{3312} \\ c_{2311} & c_{2322} & c_{2333} & c_{2323} & c_{2331} & c_{2312} \\ c_{3111} & c_{3122} & c_{3133} & c_{3123} & c_{3131} & c_{3112} \\ c_{1211} & c_{1222} & c_{1233} & c_{1223} & c_{1231} & c_{1212} \end{bmatrix} \equiv \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{12} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{13} & C_{23} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{14} & C_{24} & C_{34} & C_{44} & C_{45} & C_{46} \\ C_{15} & C_{25} & C_{35} & C_{45} & C_{55} & C_{56} \\ C_{16} & C_{26} & C_{36} & C_{46} & C_{56} & C_{66} \end{bmatrix}$$

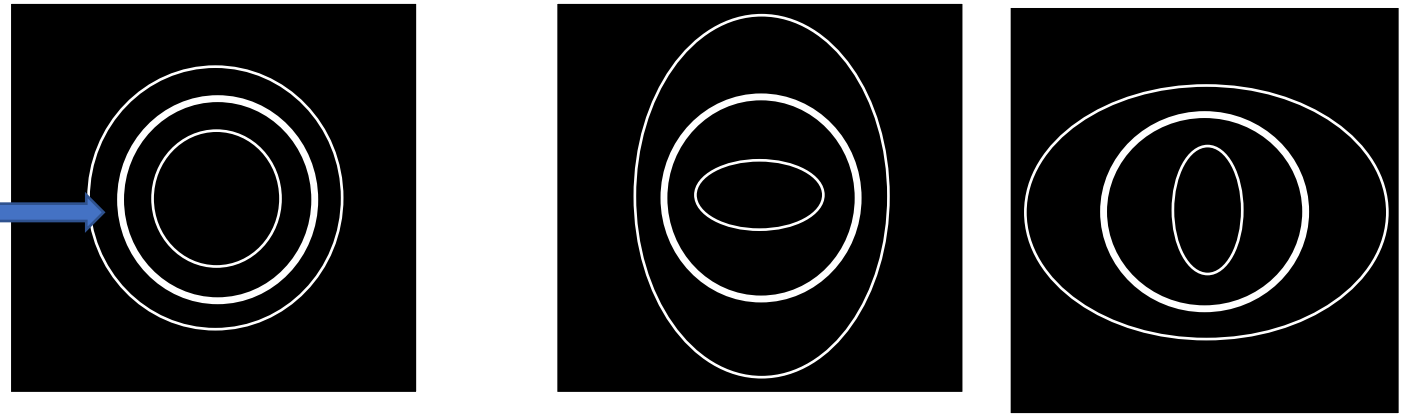
Radial dispersion…

muscle fiber

Isotropic "stiffness"

"Stiffer" in vertical direction

"Stiffer" in horizontal direction

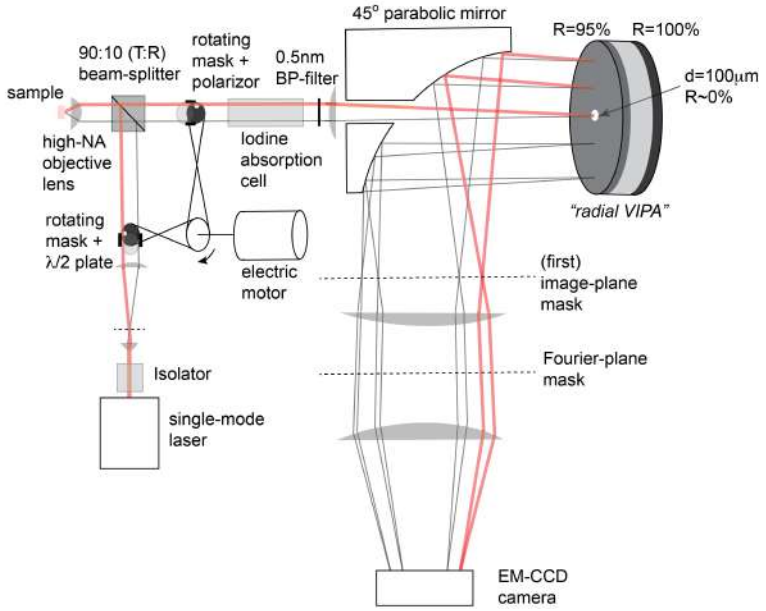


Rayleigh peaks overwhelming
(since no cross dispersion)

⇩

Limits how well you can measure weak/small scattering spectra

Can simultaneously measure all components of stiffness tensor



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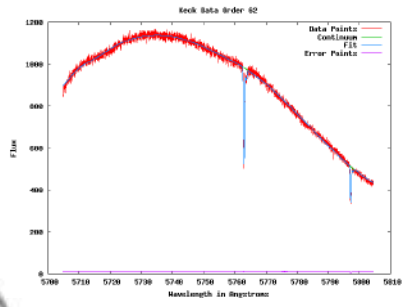
Radial dispersion…

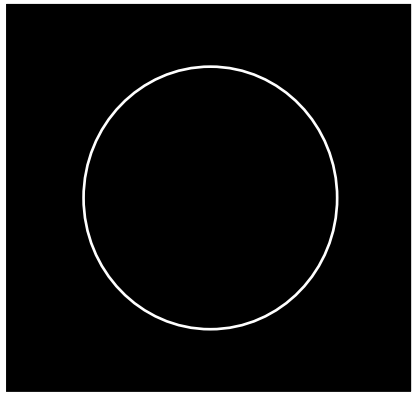
muscle fiber

Iodine absorption cell

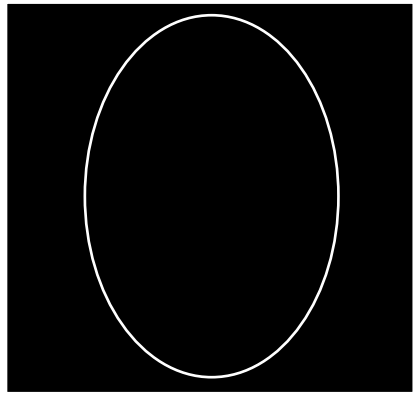


Currently fixing issues
With absorption cell stability

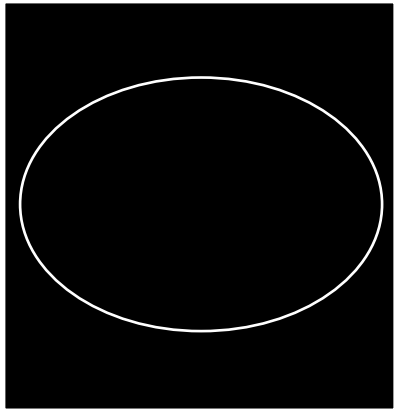
Isotropic "stiffness"



"Stiffer" in vertical direction



"Stiffer" in horizontal direction



Conclusions

- **First experiments with users currently being planned**
- **Expected to offer full open access later this year**

- Fabrication of modified (“gradient”) coating for better contrast imaging and different spectral ranges

- Student expected to start later this year to optimize analysis code

Thank you for your attention