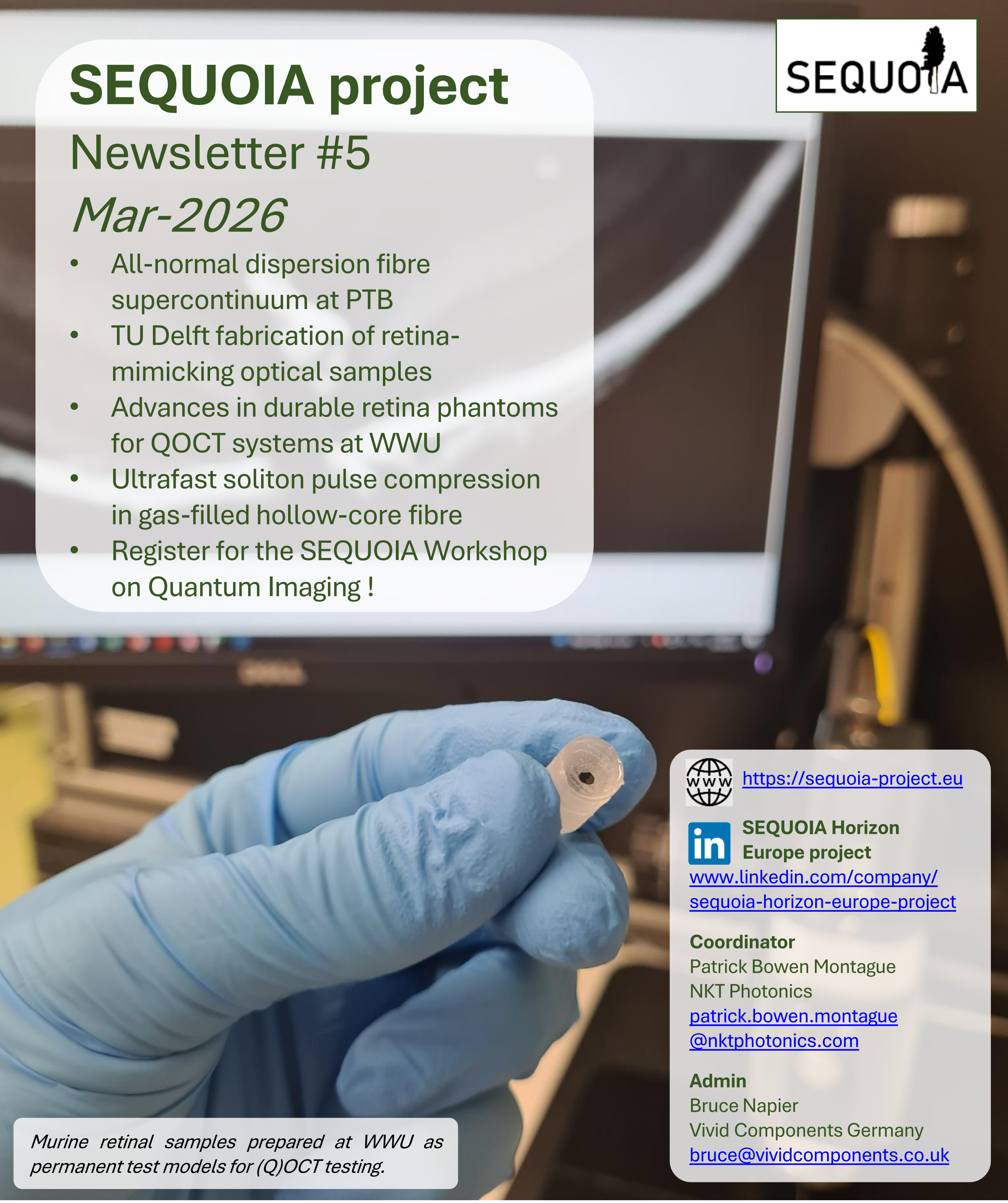
# SEQUOIA project

## Newsletter #5

*Mar-2026*

- All-normal dispersion fibre supercontinuum at PTB
- TU Delft fabrication of retina-mimicking optical samples
- Advances in durable retina phantoms for QOCT systems at WWU
- Ultrafast soliton pulse compression in gas-filled hollow-core fibre
- Register for the SEQUOIA Workshop on Quantum Imaging !



*Murine retinal samples prepared at WWU as permanent test models for (Q)OCT testing.*


https://sequoia-project.eu

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Funded by the European Union

*This project has received funding from Horizon Europe, the European Union's Framework Programme for Research and Innovation, under Grant Agreement No. 101070062 (SEQUOIA). Funded by the European Union.*

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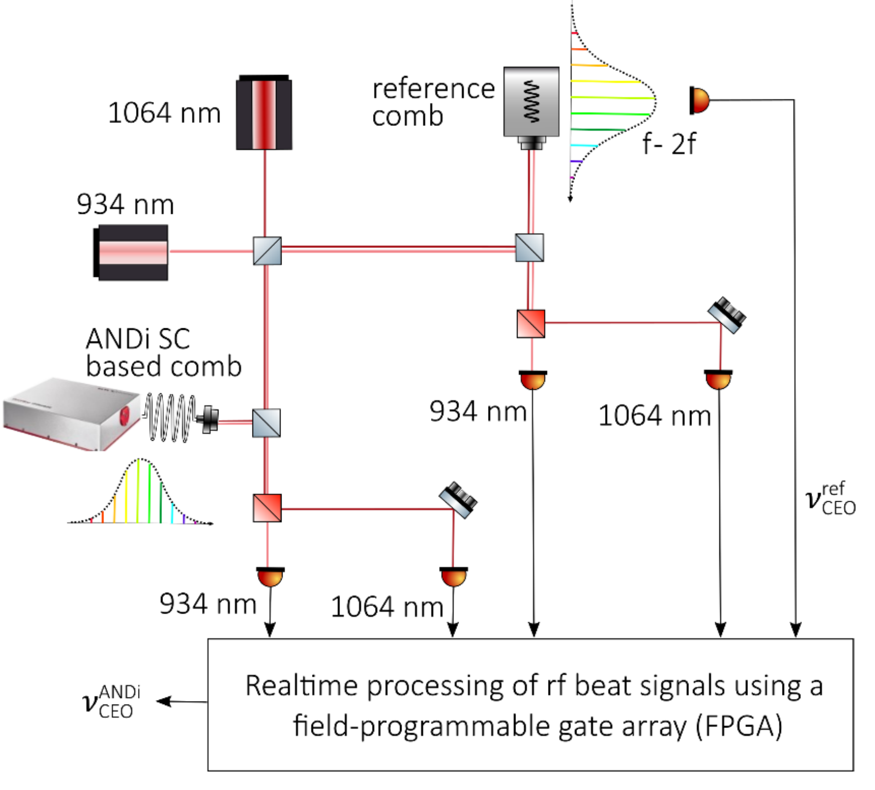
# All-normal dispersion fibre supercontinuum
## *A high-quality optical frequency comb*

PTB

As a spin-off from the main project goal of quantum optical coherence tomography, the pump laser for the single-photon source employed in the SEQUOIA project has been investigated by partner PTB regarding its capabilities as an optical frequency comb, which could also be employed in all kinds of precision metrology applications such as the comparison of optical clocks.

The frequency comb extending from 700 nm to 1400 nm is generated in an all-normal dispersion (ANDi) fibre (designed by partner NKT Photonics) which is pumped by a 1050 nm mode locked laser. A well-known signature of a precision optical frequency comb is the so-called carrier-envelope offset (CEO) beat signal, which is usually generated using a nonlinear f-2f interferometer relying on an octave-broad supercontinuum.

Recently, PTB developed an alternative approach for the measurement of the CEO beat signal, which does not require an octave bandwidth. Instead, it processes in real-time the radio-frequency beat signals of two single-frequency lasers with the frequency comb under investigation and simultaneously with an ultra-stable reference frequency comb (see figure). The processing of the beat signals is performed in a field-programmable gate array (FPGA) and directly yields the CEO beat signal of the comb under investigation.




*A schematic of the novel CEO measurement techniques developed at PTB, which does not require an octave bandwidth source.*

Using this novel method, a CEO beat with a linewidth below 100 kHz was observed with the free-running SEQUOIA ANDi supercontinuum comb. Furthermore, the ANDi supercontinuum has an extremely flat spectral envelope, rendering this source a high-quality optical frequency comb which is suitable for precision optical frequency metrological applications at all wavelengths within its spectrum.

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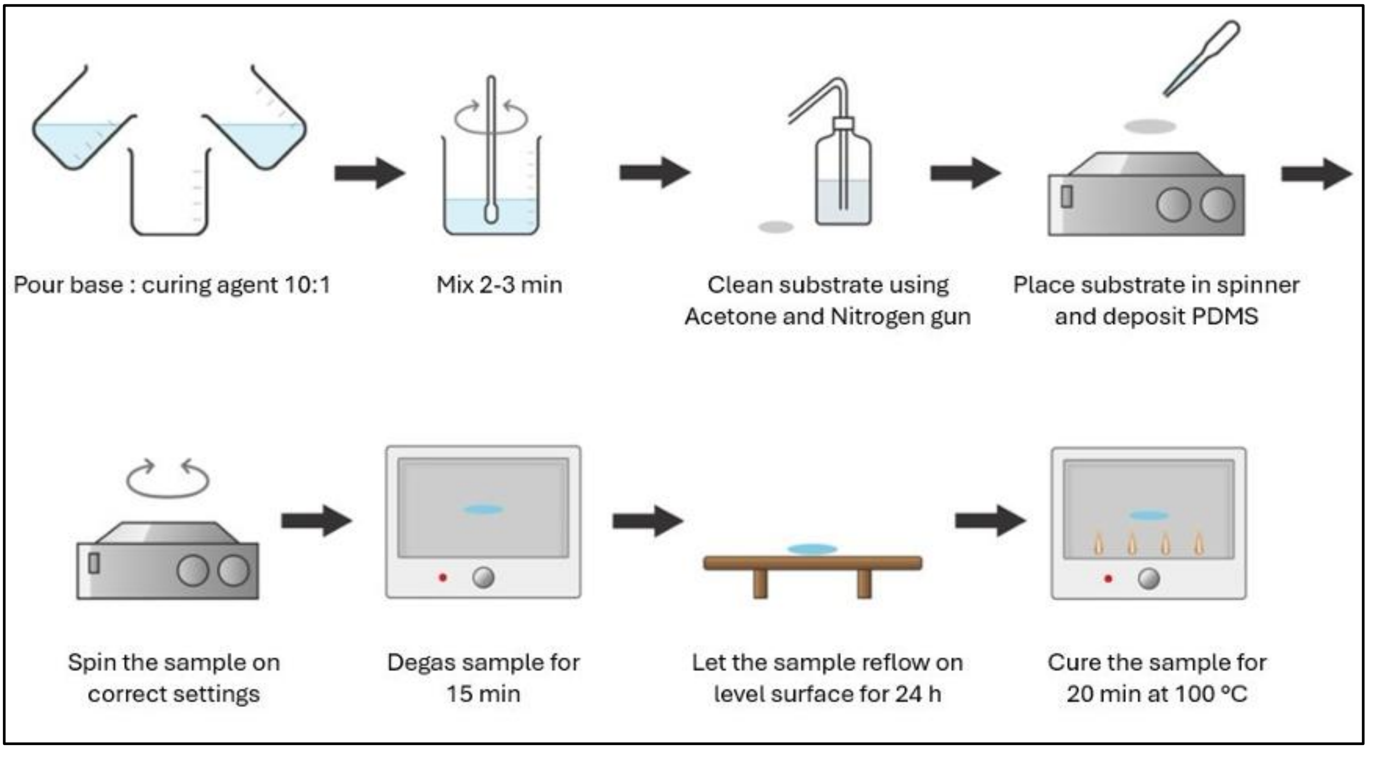
## Fabrication of retina-mimicking optical samples

Understanding and replicating the optical properties of the human retina is essential for advancing optical imaging techniques, particularly optical coherence tomography (OCT). The SEQUOIA team at TUD fabricated retina-mimicking samples with controlled thickness, layering, and scattering properties, enabling realistic optical phantoms for system characterisation and validation.

### *Materials and fabrication workflow*

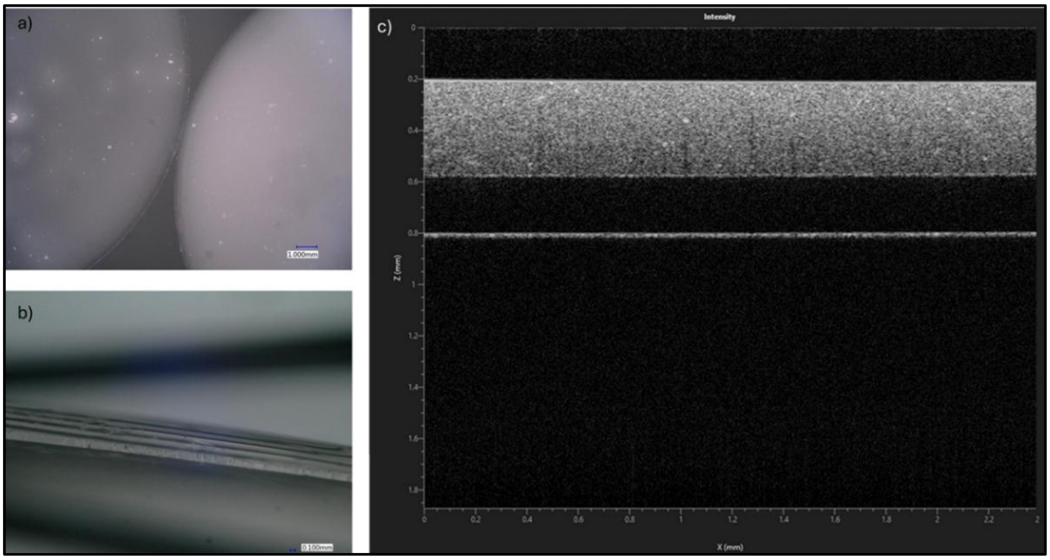
At the core of this work is polydimethylsiloxane (PDMS), chosen for its excellent optical transparency, mechanical stability, and compatibility with spin-coating. To reproduce retinal light scattering, titanium dioxide ($TiO_2$) nano-powder was incorporated as a controllable scattering agent. To achieve this $TiO_2$ was dispersed in IPA before adding it to the PDMS. All samples were fabricated on 25 mm glass coverslips using a spin-coating process, with Sylgard 184 Elastomer Kit used for PDMS preparation.




*Fabrication workflow for retina-mimicking samples. Schematic showing PDMS preparation, spin-coating on glass substrates, curing, and final inspection.*

### *Optical characterisation with microscopy and OCT*

Following fabrication, samples were inspected under an optical microscope and characterised using a commercial OCT system. OCT measurements were used to extract the group refractive index of the fabricated phantoms. (See images on following page.)




*OCT images illustrating layer structure of PDMS and glass and scattering contrast.*

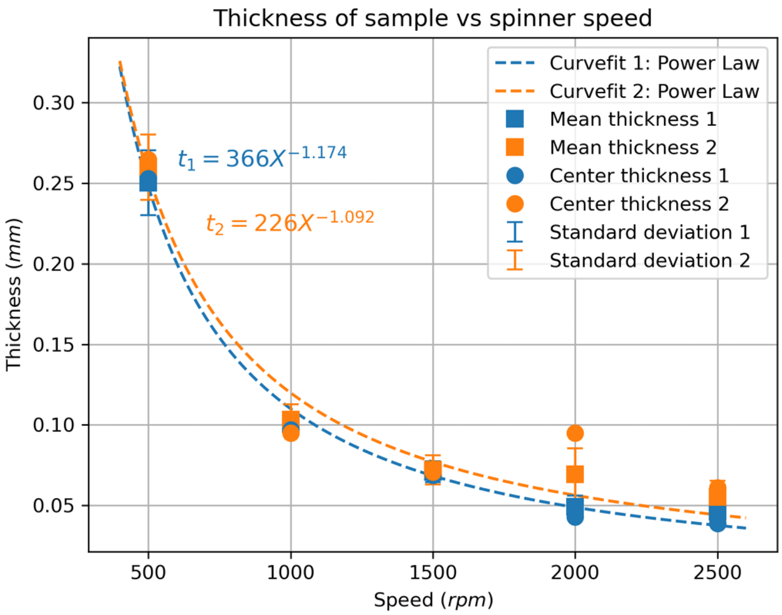
*a) Top-view*

*b) Side-view microscopy*

*c) Cross-sectional.*

## *Thickness control*

At approximately 500 rpm, the process consistently produced single-layer thicknesses in the range of 200–300 µm, closely matching the physiological thickness of the human retina. Increasing the spin speed resulted in thinner individual layers, enabling the fabrication of sub-200 µm layers that can be stacked to construct controlled multi-layer retinal phantoms.




*Spin speed as a tuning parameter for retinal-scale thickness control. Measured thickness as a function of spin speed with fitted power-law trends*

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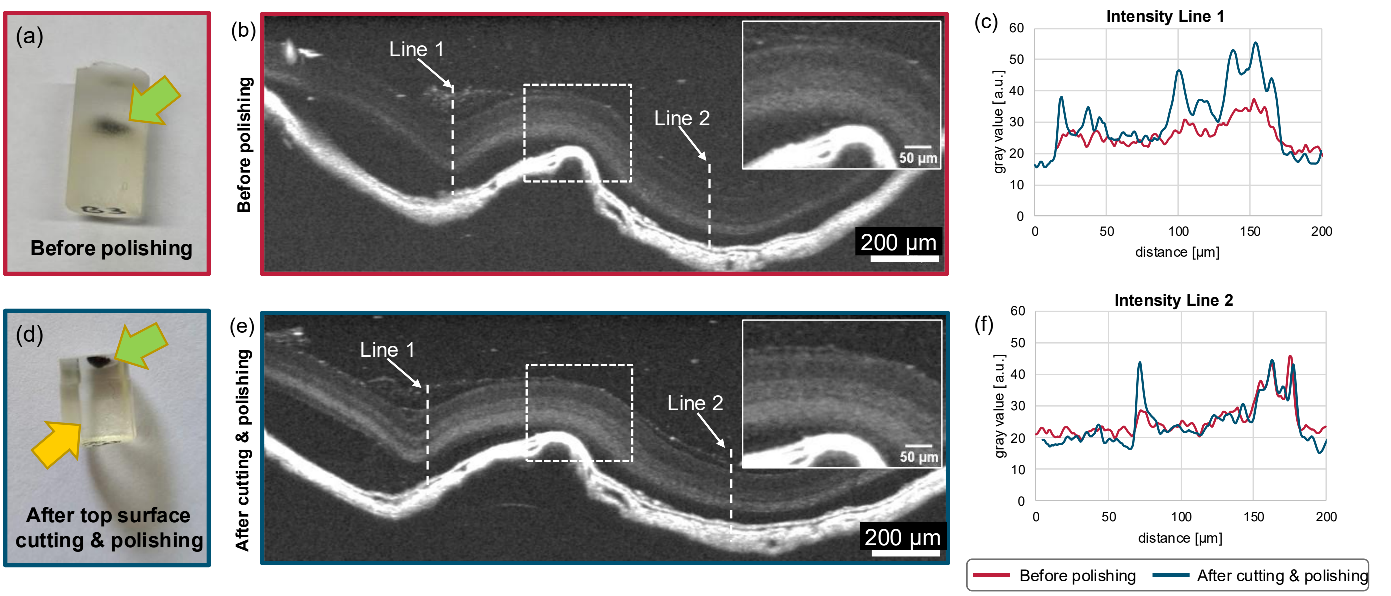
## Advances in durable retina phantoms for QOCT systems

Durable and standardised phantoms that replicate the structural and optical properties of native healthy biological tissues are essential for reliable performance testing and comparative benchmarking of novel QOCT systems, as developed in SEQUOIA. To demonstrate the advances of the quantum optic concept and its application potential under realistic conditions for the example of retinal imaging, project partners from the Biomedical Technology Center of the University of Münster (WWU) focus on the establishment of durable 3D retina models with optical properties similar to native tissue and tiny layered structures, near the resolution limits of high-resolution OCT and QOCT systems, such as the nerve fibre layer (NFL) and ganglion cell layer (GCL).

Funded by the European Union

To achieve high stability, *ex vivo* dissected mouse retinas are embedded with refined preparation procedures in resin and adapted to the sample shape using moulds with defined geometrical shapes. Among the moulds tested by WWU for the fabrication of new durable retina samples, cylindrical silicone moulds showed the advantage of reusability and ease of sample removal compared with disposable polymer moulds, which allows sample placement in various commercial optical mounts. However, the manual casting process has the limitation of creating slightly convex surfaces due to the meniscus effect, which affects the quality of the OCT B-scan images. Furthermore, the rough lateral faces of the samples prevented visual localisation of the sample within the resin.




*Evaluation of resin-embedded retina interlayer contrast before and after cutting and polishing. (a)-(b) Photos and representative B-scans of the Gedeo-embedded retina sample (a)-(b) before and (d)-(e) after cutting and polishing. (c), (f) B-scan intensity distribution along the lines depicted in the B-scans.*

To overcome these issues, WWU has developed a mechanical adaptation process using a turning machine to precisely control the distance between the sample and the surface. This process reduces the amount of scattering media above the retina, leading to a significant increase in contrast, particularly for the first retinal layers, as seen in the figure. This is especially of interest for novel QOCT systems developed by the SEQUOIA partners which operate with high numerical aperture imaging optics in the visible spectral range and short working distances.

Current and future activities of WWU focus on the further improvement of the optical quality of the generated samples and their adaptation to the evolving needs of the SEQUOIA QOCT systems. These advances pave the way for reliable performance testing and comparative benchmarking of the QOCT systems developed in SEQUOIA. (More information is available in the reference below.)

*Á. Barroso, S. Ketelhut, P. Heiduschka, R. del Amor, F. García-Torres, S. Morales-Martínez, V. Naranjo, B. Kemper, J. Schnekenburger, "Resin-embedded murine ex vivo retina as durable models for optical coherence tomography," Proc. SPIE **13571**, Optical Methods for Inspection, Characterization, and Imaging of Biomaterials VII, 135711H (1 August 2025); https://doi.org/10.1117/12.3062588*

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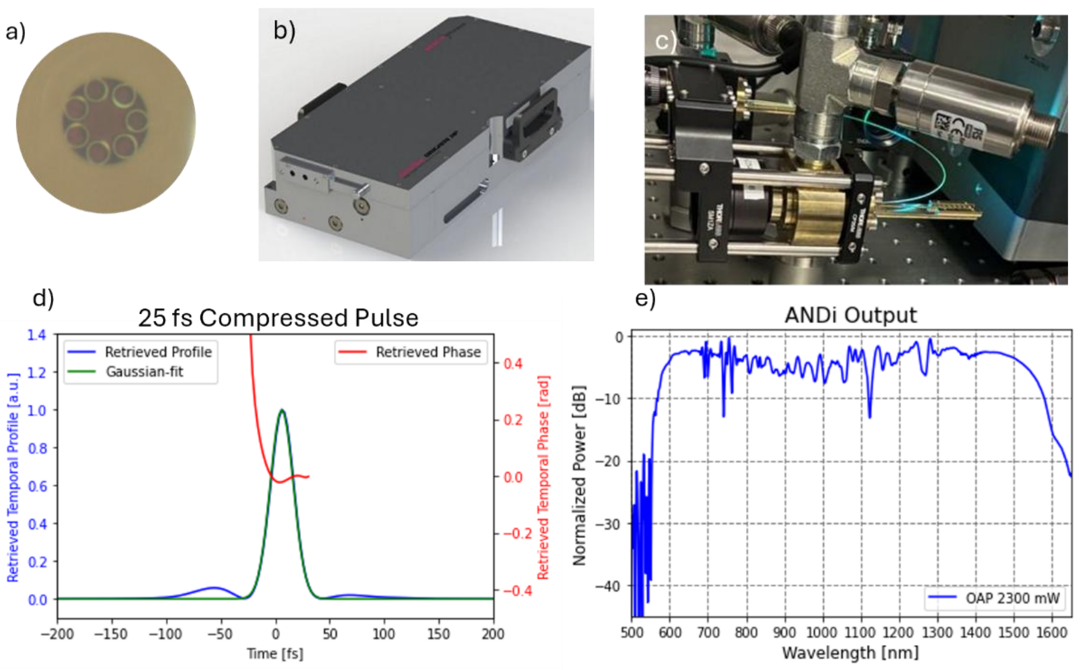
# Ultrafast soliton pulse compression in gas-filled hollow-core fibre

An important technical goal within the SEQUOIA project is to develop a supercontinuum (SC) source with two essential properties: low-noise and a wide bandwidth. This SC source will subsequently be frequency doubled and used to pump the spontaneous parametric down conversion process – a critical stage of the quantum OCT system. Traditionally, SC generation involves pumping optical fibers with anomalous dispersion, which leads to efficient spectral broadening but unacceptably high noise. To achieve low-noise performance, NKT Photonics opted to generate the SC spectrum in all-normal dispersion (ANDi) fibres. When pumped with ultrafast laser pulses, these special fibres support a coherent nonlinear broadening process resulting in a low-noise SC spectrum. However, this approach requires the pump pulses to have a very high peak power to achieve a sufficiently wide SC bandwidth.




*a.) NKT Photonics in-house fabricated anti-resonant hollow-core fibre*

*b.) NKT Photonics Origami 10HP laser*

*c.) Developed gas-cell systems*

*d.) Measured duration and phase of the 25 fs compressed pulse used to pump the ANDi fibre*

*e) Hero experiment output SC spectrum from the ANDi fibre covering 570-1580 nm.*

To achieve the necessary high power pump pulses, NKT Photonics has developed a compact and robust pulse compression architecture based on soliton self-compression (SSC) in gas-filled hollow-core fibre (GF-HCF). This simple system has been implemented on a range of ultrafast pump lasers to achieve high-quality pulse compression. The approach utilises several key advantages of GF-HCF, namely that the non-linearity and dispersion properties of the fibre can be tuned by controlling the species and pressure of gas within the core. With a suitable balance of non-linear and dispersive properties, an initial pulse can undergo SSC during propagation along the fibre length. This was implemented in the SEQUOIA project to compress the NKTP Origami 10HP laser from a pulse duration of 116 fs to just 25 fs, leading to a more than 4× increase in peak power. These ultrashort pulses were subsequently used to pump a section of ANDi fibre in a hero experiment, generating an extremely broad, and importantly low-noise, SC bandwidth covering 570-1580 nm.

The successful implementation of this pulse compression system involved the combination of several key technologies at NKTP. On the hardware side, this included in-house manufactured ultrafast laser systems, hollow-core fibre and gas-cell technology to allow control of the gas filling pressure. On the theoretical side, this involved an in-depth knowledge of soliton dynamics (supported by numerical modelling), which acted to guide the experiments. Additionally, understanding ultrashort pulse propagation was critical to manipulating the <30 fs pulses used to pump the ANDi fibre. Results relating to this pulse compression system were presented at the recent Photonics West conference in San Francisco.

**For more information see: https://lnkd.in/dYQUp4y8**

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## SEQUOIA Workshop on Quantum Imaging
## *WED 27-May-2026; PTB Braunschweig*

The SEQUOIA Horizon Europe project will hold its final Workshop on Quantum Imaging on WED 27-May-2026 at the German national metrology institute PTB.

This in person workshop will cover a range of topics relating to quantum imaging, from hardware (comb sources, SPAD-based imagers) to practical issues (noise, experimental approaches). The workshop aims to bring together people from quantum imaging research, industry and stakeholders from other disciplines including medicine and ophthalmology. After the presentation sessions there will be a tour of PTB for those who are able to stay.

In addition to five presentations from SEQUOIA researchers, the consortium is very pleased to host several prestigious guest speakers who will present in person on key quantum imaging themes and capabilities:

*Remote quantum imaging: Achieving super-resolution and imaging below background noise*
Dr. Carsten Pitsch, Fraunhofer IOSB

*Quantum OCT based on nonlinear interferometers*
Prof. Juan P. Torres, ICFO

*Rapid mid-IR sensing with undetected photons*
Dr. Sven Ramelow; Humboldt-University Berlin

*PTB Quantum Technology Competence Centre*
Nicolas Spethmann; Physikalisch-Technische Bundesanstalt (PTB)

**Please register for this free event on the event webpage:**

**https://forms.gle/L8zyFk2FppKBhuZ4A**