SEQUOIA project

Newsletter #2

Jan-2024

- *Record low supercontinuum RIN measurement at PTB*
- *Retinal standard models from Universität Münster*
- *OAM control at TU Delft*

https://sequoia-project.eu

SEQUOIA Horizon Europe project
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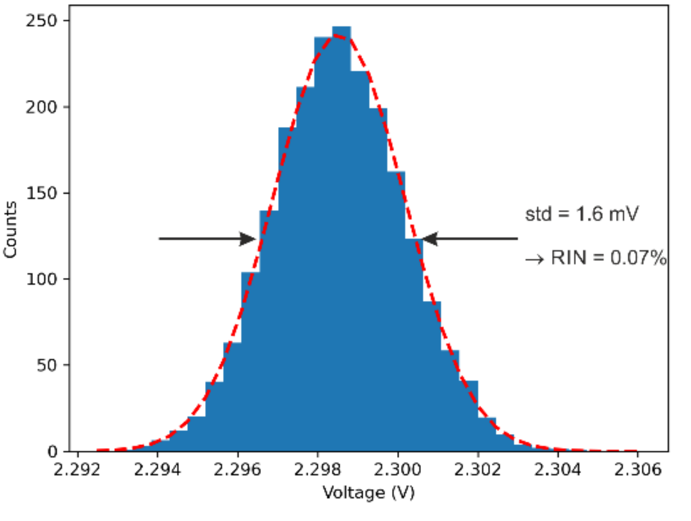
Record low relative intensity noise of NKT supercontinuum source measured at PTB

The main role of the German national metrology institute (PTB) in the SEQUOIA project is to analyse, model and measure the various influences of noise, which ultimately determine the quality of QOCT images. As part of this work, the noise of the laser and supercontinuum sources and in the Hong-Ou-Mandel (HOM) interferometer, being at the heart of QOCT set-ups, is investigated. After the delivery of a pulsed supercontinuum source by consortium partner NKT Photonics to PTB, its relative intensity noise (RIN) has been measured. The excellent low noise properties of this light source required that the measurement chain from the photodiode via RF filters and amplifiers to an oscilloscope or electrical spectrum analyser had to be carefully optimised to achieve optimum operation parameters, such that the measurement noise floor is minimised. As a preliminary result (which despite the optimisation still comprises a significant contribution from the photodiode and its transimpedance amplifier) ***a record low RIN of 0.07 %*** has been observed.



Distribution of peak values measured at PTB from the NKT supercontinuum source pulse train. The peak values are proportional to the individual pulse energies and normalisation of the standard deviation to the mean value yields the RIN.

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Besides the noise characterisation of the NKT supercontinuum source for the QOCT experiments, its noise properties relevant for application as an optical frequency comb in frequency metrology are examined. For this purpose, a novel technique for the measurement of the carrier envelope offset (CEO) beat and its noise has been developed which, unlike the standard f-2f interferometer technique, does not require an octave-spanning supercontinuum. Instead, the radio frequency beat notes of two single-frequency lasers with the comb under investigation as well as with a fully stabilised reference comb are processed in an FPGA. A first analysis shows a CEO linewidth of the free-running supercontinuum source in the low 10 kHz range, demonstrating its potential as a low-noise comb for frequency metrology.

Modelling noise in Hong-Ou-Mandel interferometers for QOCT experiments

A simple model has been developed by PTB, which considers RIN as the main relevant noise source in a HOM interferometer. The RIN can be either due to “technical” noise processes, such as the RIN of the supercontinuum source pumping the spontaneous parametric down conversion (SPDC) crystal for correlated photon-pair generation, or quantum noise, *i.e.* RIN due to shot noise of the photons. Using the model with realistic experimental parameters, PTB can now estimate that the quantum noise will dominate the RIN in the SEQUOIA QOCT experiments.

Establishment of durable retina models for QOCT performance testing

Universität Münster

For performance testing of high-resolution label-free optical coherence tomography (OCT) systems, durable test standards with optical properties similar to native biological tissues are highly desirable. Hence, in SEQUOIA, Universität Münster explores the establishment of *ex vivo* 3D samples from dissected mouse retinae. To achieve high stability dissected tissue, parts are embedded in resin. Therefore, comparative investigations on samples prepared with different fixing and resin embedding protocols are performed to achieve durable 3D models with adequate refractive index properties like native tissue and tiny layered structures near the resolution limits of high-resolution OCT and QOCT systems. The figure below illustrates the preparation procedure for the generation of the 3D models and demonstrates the visibility of tiny rodent retinal layers such as the nerve fibre layer (NFL), ganglion cell layer (GCL), inner plexiform layer (IPL); inner nuclear layer (INL), outer plexiform layer (OPL) and outer nuclear layer (ONL) as well as the sclera in OCT B-scan images.

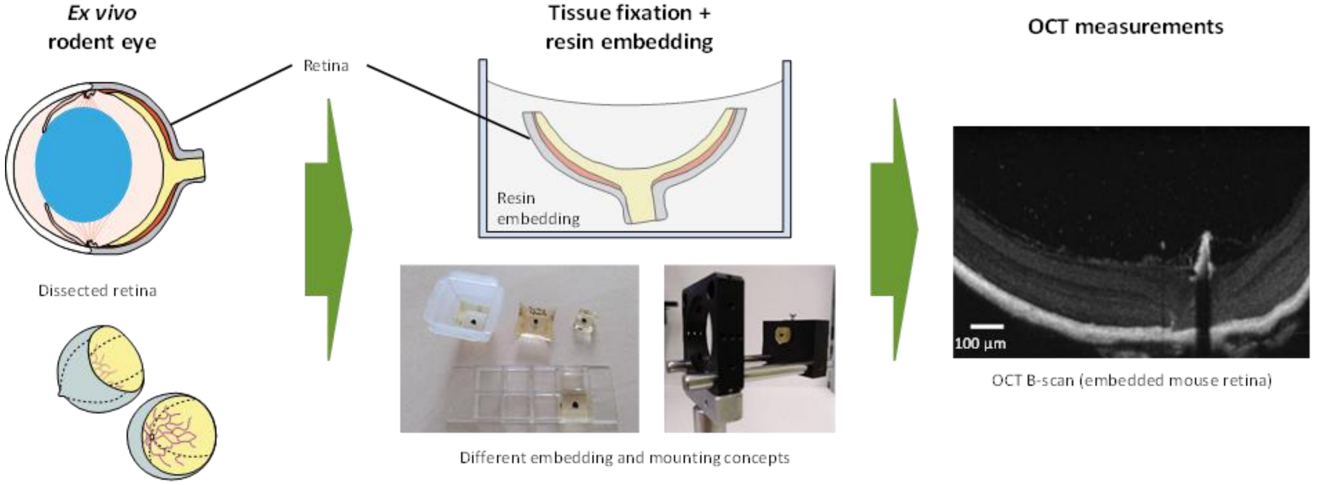

Illustration of the preparation procedures for generation of 3D retina models from mouse eyes for OCT system testing. Left panel: Sketch of an initially extracted mouse eye (upper left panel) and the separated eye-cup after removal of undesired structures (lower left panel); middle (upper panel): schematic cross-section of the dissected eye-cup prepared in an embedding medium for durable tissue preservation; middle (lower panel): photos of various established and evaluated 3D models from dissected mouse retinae embedded in resin achieved by moulds with different shapes and a tube-shaped 3D model mounted to an optical cage system; right panel: representative OCT B-scan image of a resin embedded mouse retina (modified from [1]).

Results from OCT imaging of resin embedded tissues, as illustrated in the right panel of the figure, are in good agreement with data from comparatively performed investigations on agarose and phytagel embedded native dissected tissues and with previously reported *in vivo* OCT studies [1]. Current activities focus on refined and further standardised resin-based sample embedding procedures, research on the better understanding of the underlying mechanisms of the embedding processes, the characterisation of the optical sample properties and their further adaptation to the needs of the SEQUOIA QOCT systems. In addition, the established 3D mouse retina models are utilised to generate ground truth and reference data for training and evaluation of machine learning-based retinal layer segmentation algorithms that are being developed at UPV.

[1] Á. Barroso *et al.*, "Durable 3D murine ex vivo retina glaucoma models for optical coherence tomography," Biomed. Opt. Express **14**, p. 4421-4438 (2023). https://doi.org/10.1364/BOE.494271

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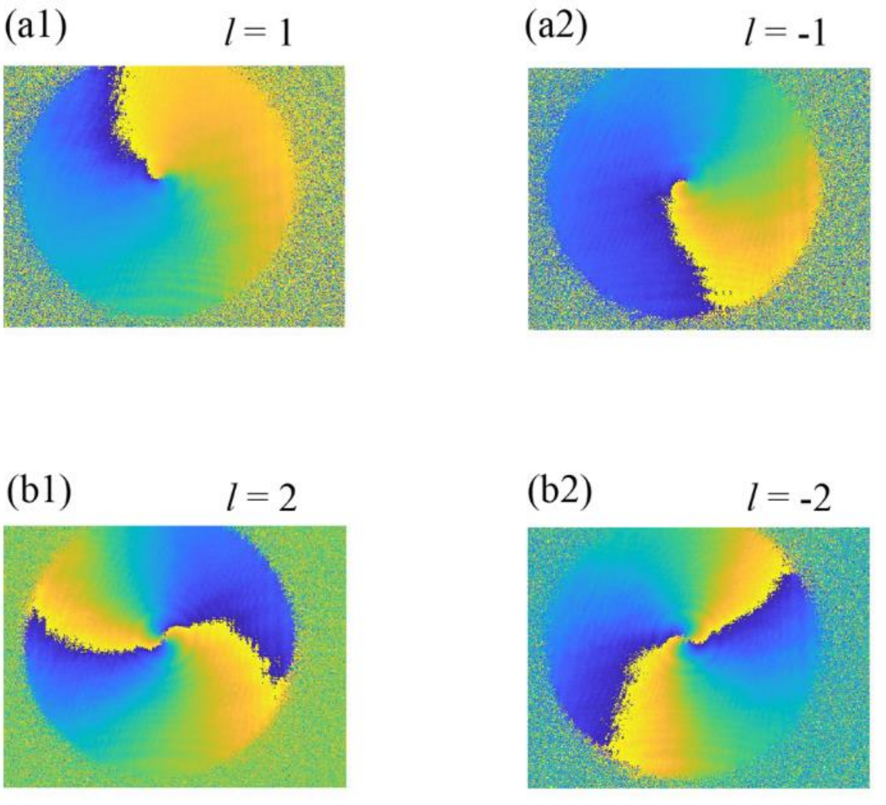
Orbital angular momentum control at TUD

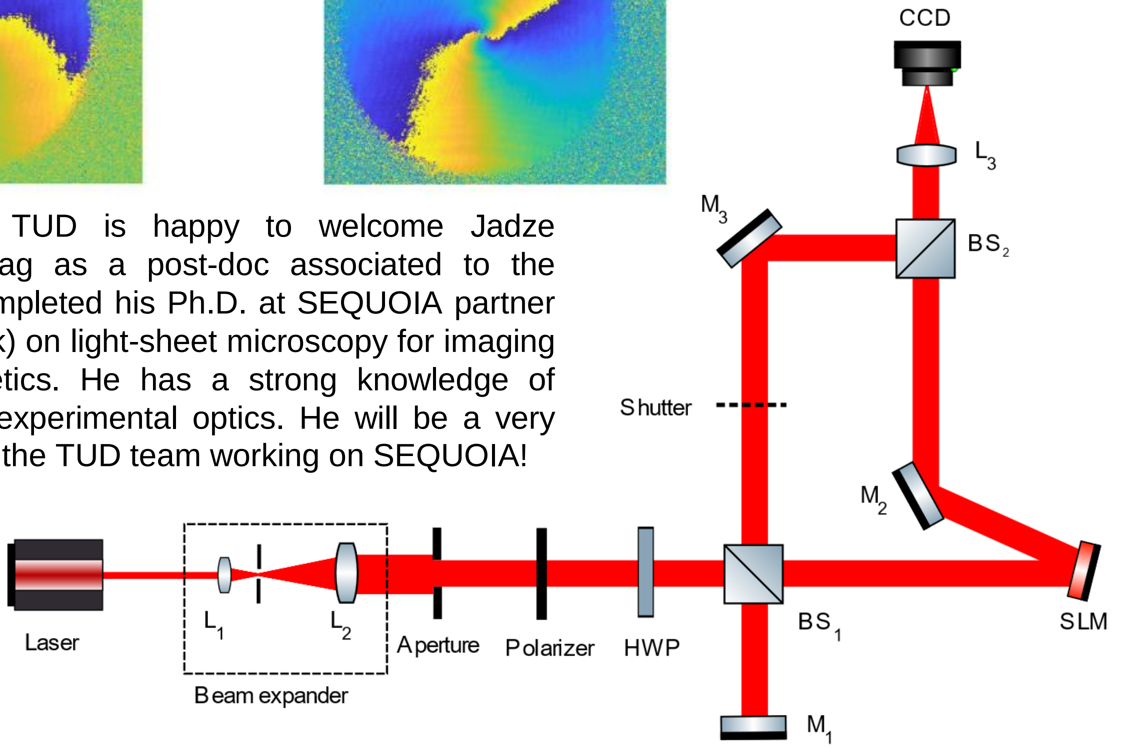
TU Delft

TUD is very pleased and proud to share progress on the project SEQUOIA. With the help of two students from our Master Programme, Yuchen Ye and Ke Han Wang, it has been possible to generate the first examples of target OAM states and study the properties, as shown in the image below. The work continues with the design of optical elements that will spatially separate the different OAMs on the detectors.



Left: Retrieved phase OAM profile achieved for different target OAM states (1,2,-1,2).

In Jan-2024, TUD is happy to welcome Jadze Princeton Narag as a post-doc associated to the project. JP completed his Ph.D. at SEQUOIA partner DTU (Denmark) on light-sheet microscopy for imaging living biomimetics. He has a strong knowledge of OAM and on experimental optics. He will be a very good asset for the TUD team working on SEQUOIA!



Schematic view of the set-up to generate OAM using an SLM.

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