# GALAHAD project newsletter #3

*Jun 2018*

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**Welcome to the third GALAHAD project newsletter!**

In this newsletter we present:

- 3D tissue models for OCT from WWU
- Breakthroughs in polarised supercontinuum sources from NKT Photonics
- Record-breaking broadband components for OCT from G&H (Torquay)
- A look-ahead to some upcoming GALAHAD-related events

*More info is available on the website (www.galahad-project.eu).*


*In GALAHAD G&H has set new standards for ultra-wideband fused couplers: see pg 4.*

## Four GALAHAD papers at Photonics West

SPIE. PHOTONICS WEST BIOS

27-Jan to 01-Feb-2018
San Francisco, USA

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In the previous newsletter we mentioned that a poster from the GALAHAD team at Westfälische Wilhelms-Univ. Münster (WWU) was presented at Photonics West:

*Developmental approach towards high resolution optical coherence tomography for glaucoma diagnostics.* http://dx.doi.org/10.1117/12.2290984

The WWU team also presented a paper on the DHM work in GALAHAD which is exploring the phase imaging of tissue using different polarisation states:

*Multi-spectral digital holographic microscopy for enhanced quantitative phase imaging of living cells* *http://dx.doi.org/10.1117/12.2291071*

At the same event, DTU presented two papers on the use of supercontinuum for OCT:

*Ultra-low noise supercontinuum source for ultra-high resolution optical coherence tomography at 1300 nm* *https://doi.org/10.1117/12.2282412*

*In-vivo detection of the skin dermo-epidermal junction by ultrahigh resolution optical coherence tomography* *https://doi.org/10.1117/12.2289880*

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# 3D tissue models for OCT evaluation

In GALAHAD WWU develops model systems and 2D and 3D test standards that represent glaucoma related tissue structures for performance characterisation of the GALAHAD high resolution OCT systems as well as for training numerical algorithms for automated glaucoma recognition. These test standards include defined micro-particles, simple 2D or enhanced 3D cell culture systems as wells as 3D tissue models. Fig. 1 shows a B-scan that was retrieved at WWU from a 3D tissue model, established from mouse eyes, during its characterization with a state-of-the-art OCT system. Different retinal layers are clearly resolved. Current research focuses on the improvement of the stability and quality of the developed standards as well as on the generation of glaucoma related tissue structures.

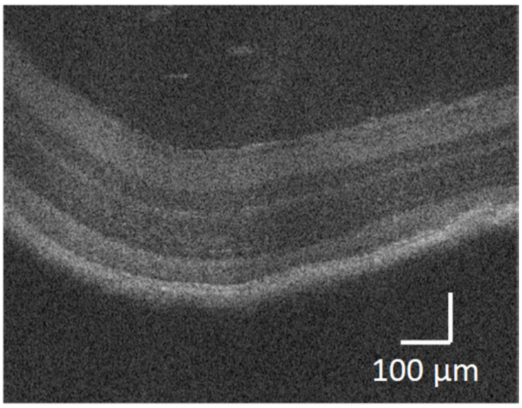


*Fig. 1: Example of a 3D tissue model developed at WWU from dissected mouse retina for UHR-OCT system performance testing and algorithm training. In the shown B-scan during characterisation at WWU with a state-of-the-art OCT system, different layers of the retina are clearly resolved.*

In parallel GALAHAD research activities, WWU characterises the refractive index (RI) properties of the developed test standards utilising quantitative phase imaging with digital holographic microscopy (DHM). A multispectral DHM set-up based on a tuneable super-continuum laser source for ultra-high resolution (UHR) wavelength dependent RI sensing of cells and tissues in the spectral range of the GALAHAD UHR-OCT systems has been established. The acquired data provide parameters to quantify the quality of the achieved test standards, for system optimisation and validation as well algorithm testing and training.

Fig. 2 illustrates RI sensing with DHM for the example of dissected mouse retina tissue. The unwrapped quantitative phase image (QPI) in Fig. 2d quantifies the sample induced optical path length delay (OPD). The detected refractive index distribution reflects the layer structure of the retina that is visible in Fig. 1. This technique will be explored in GALAHAD to assess the information provided by the birefringence of retinal tissue in the development of glaucoma.

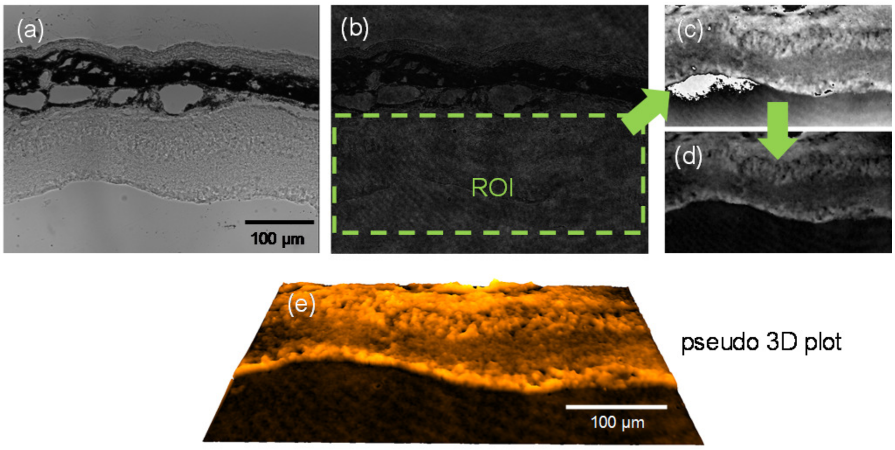


*Fig. 2: Tissue RI sensing with digital holographic microscopy.*
- *(a) Bright field image of dissected mouse retina on a glass carrier.*
- *(b) Digital off-axis hologram of the sample.*
- *(c) Corresponding quantitative phase image (QPI) modulo $2\pi$ reconstructed in the ROI marked with a dashed box in (b).*
- *(d) The unwrapped QPI retrieved from (b) quantifies the optical path length delay caused by the sample and reflects the refractive index distribution inside the tissue.*
- *(e) Pseudo 3D plot of the QPI in (d).*

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## Polarised supercontinuum source development

Polarised supercontinuum sources (SCSs) have found widespread use in a range of areas across all kinds of imaging and sensing applications, as many materials have polarisation sensitive properties. The use of a polarised SCS allows these properties to be exploited or suppressed, depending on the application, allowing for greater information specificity. However, in all current implementations of a polarised SCS, the SCS itself is unpolarised and a filter is used to polarise the output radiation after the SC process, thus halving the efficiency. This means that high power applications are usually limited by their ability to inject light into a fibre without damaging it, and even SCs with lower power levels have shorter lifetimes and require more expensive pump diodes.

From this, it is clear that developing a SCS that produces polarised light directly is of great value. This has been attempted in past, and with good results, providing 15 dB polarisation extinction ratio (PER) between the orthogonal axes. However, the lifetime of these systems was limited to <1000 h, as the off-axis light was of sufficient power to cause a photo-induced change in birefringence. Over time, this change accumulates, and eventually causes a complete depolarisation of the SCS.

To avoid this, NKT in the GALAHAD project has developed a novel method that considerably improves the input PER of the system and in doing so, induces a large increase in output PER across the entire spectrum (see Figure 3). Not only is the "background" level of polarisation in this system above 25 dB, but significantly, NKT has managed to suppress the presence of off-axis Raman and polarisation modulation instability.

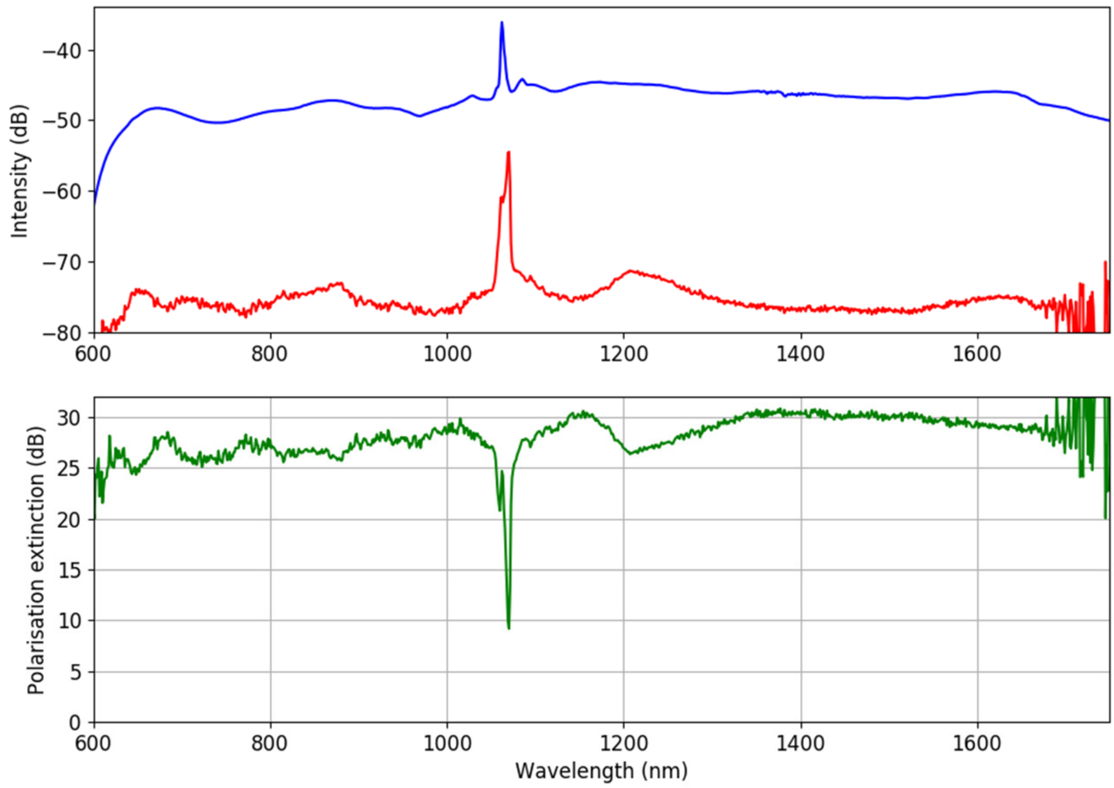


*Figure 3: Graphs showing the output intensity and PER of the GALAHAD NKT SCS which has been operating successfully for >2200 h.*

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Having achieved this objective, it was important to ensure that the laser could maintain this PER over a long period of time. The target lifetime was 2000 h, and the laser has already been tested >2200 h demonstrating its durability against the material degradation of the nonlinear fibre. The PER remains stable within an average range of 23-27 dB. The fluctuations observable in the bottom panel of Figure 4 showing the long-term power tests correspond directly to the room temperature in the lab, which varied from 18-24 °C on a regular basis. It is emphasised that while these power fluctuations appear significant due to the scales of the two graphs they correspond to a variation in total power of just ±0.2 %.

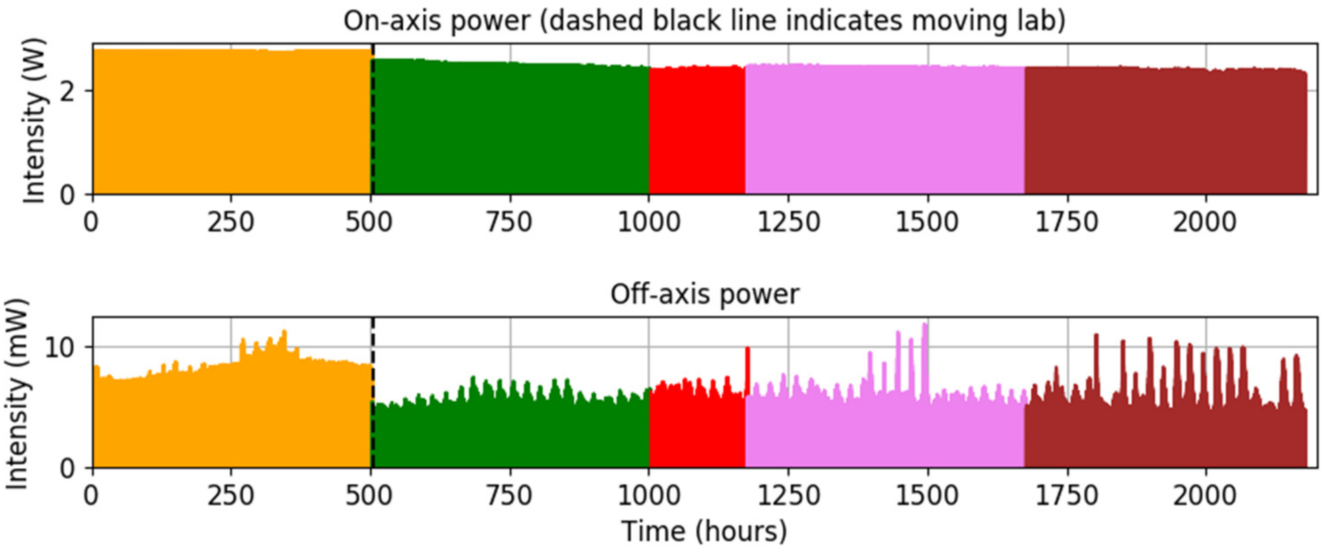


*Figure 4: Showing the output power stability of the two axes of the polarised SCS over >2200 h. During this period the laboratory was moved to another location, which resulted in the step between the yellow and green regions. Note that the on-axis power is shown in watts, and the off-axis power in milliwatts. The deviations in off-axis power represent ±0.2 %.*

## Ultra-wideband components for OCT

Gooch & Housego

Within the GALAHAD project, G&H is developing a range of state-of-the-art components for the final demo system. Some of the latest highlights are presented below.

### Record >300 nm broadband SM fibre coupler

Ultra-wideband single-mode fibre couplers with >300 nm bandwidth centred at 800 nm have been fabricated at G&H's Torquay site. This newest addition to the G&H fibre optic components portfolio will enable the next generation of the fibre-based ultra-high resolution (UHR) OCT systems.

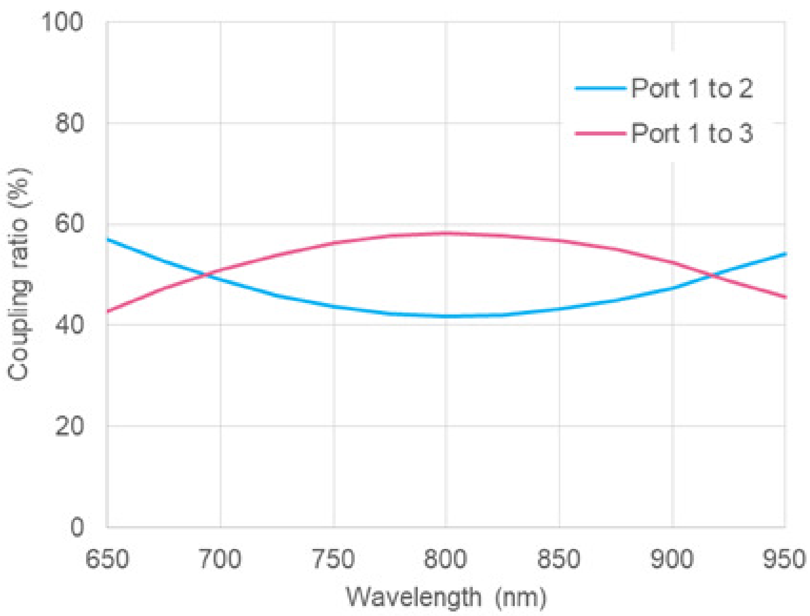


*Figure 5 Graph showing the wavelength performance of G&H GALAHAD 50:50 single-mode fibre coupler.*

## Compact OCT interferometer

Compact fibre interferometer designs enable UHR-OCT due to the low loss transmission over a broad spectral range and accurate path length matching. The modules are meticulously designed for low cost, high-reliability and to minimise noise along with other unwanted artefacts affected OCT.

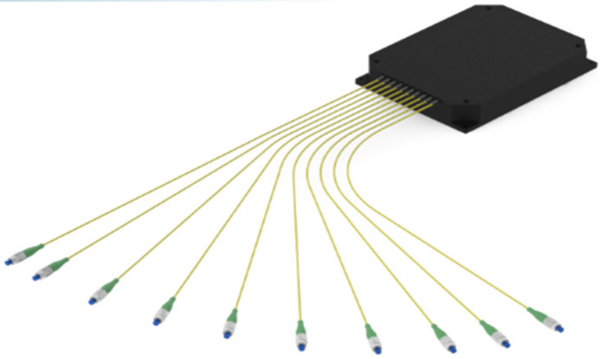

*Figure 6: G&H GALAHAD broadband fibre interferometer.*

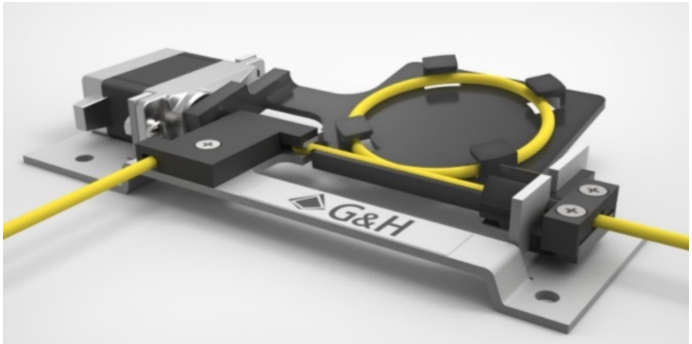


*Figure 7: G&H GALAHAD active polarisation controller.*

## Active polarisation controller

The G&H active polarisation controller developed for GALAHAD is a flexible and low cost option for standard and polarisation sensitive (PS-) OCT. The low profile design can be easily integrated into any optical fibre system for use in OCT, gas detection and many other industrial, medical or scientific applications.

## Ultra-wideband motorised optical delay line

This 300 nm bandwidth optical delay line provides fast and accurate optical path length control in a compact housing. Based on a customisable chassis that can be adapted to incorporate a variety of adjustment ranges and additional optical components (*e.g.* Faraday rotator, quarter waveplate and dispersion compensating glass) it is ideal for next generation UHR-PS-OCT systems.


*Figure 8: G&H GALAHAD ultra-wideband motorised optical delay line has 300 nm bandwidth.*

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# Upcoming GALAHAD events

Digital Holography & 3-D Imaging (25-28 Jun-2018; Orlando, Florida, USA)
WWU will present *Enhanced Quantitative Imaging of Living Cells and Dissected Tissues Utilizing Multi-Spectral Digital Holographic Microscopy* (DW3F.3)

OSA Advanced Photonics Congress (02-05 Jul-2018; Zürich, Switzerland)
DTU will present two papers in the session on Applications of Supercontinuum (NpTh2I; THU 05-Jul-2018 10:30-12:30; E1.1).

Speckle 2018 (10-12 Sep-2018, Janów Podlaski, Poland)
WWU will present on GALAHAD topics: more info soon!