			ALC–ICFO Frontiers Research School: Modern Trends in Photonics	
Thursday 27 November 2025				
			Registration 08:00 Wallenberg Research Centre STIAS	**Speaker**
	08:30	08:35	Welcome	
1	08:35	09:35	Time-domain ptychography: Principle and applications	Pieter Neethling
2	09:35	10:35	Long-Distance Free-Space Quantum Key Distribution for Secure Communication	Yaseera Ismail
	10:35	**11:00**	**Tea**	
3	11:00	12:00	Quantum enrichment for producing lifesaving medical isotopes	Leerin Perumal
4	12:00	13:00	Bosonic network architectures for quantum simulation and thermodynamics	Federico Centrone
	13:00	**14:30**	**Lunch**	
5	14:30	15:30	Near-infrared diffuse optics for biomedicine: from physiology to optical principles and back	Anika Pretorius
	15:30	16:00	Tea	
	16:00	17:00	Careers in Photonics: Different Beginnings, Endless Opportunities Enabled by Photonics	Lydia Sanmarti-Vila
	17:00	18:00	Poster Session	
	18:00	**20:00**	**Dinner. Wallenberg Research Centre STIAS**	
Friday 28 November 2025				
6	08:30	09:30	Homemade single pixel imaging enhanced by Artificial Intelligence	Adam Vallès
7	09:30	10:30	Quantum topologies take shape	Andrew Forbes
	10:30	**11:00**	**Tea**	
8	11:00	12:00	Photonic flatband systems	Verònica Ahufinger
9	12:00	13:00	Silica optical fibers functionalized with nanoparticles and quantum materials	Alex Heidt
	13:00	**14:00**	**Lunch**	
10	14:30	14:30	Analysing broadband Mie scattering from optically trapped aerosol droplet	Anneke Erasmus
11	14:30	15:00	The European X-ray free electron laser	Thomas Feurer
12	15:00	15:30	Temporal shaping of supercontinuum pulses for improved axial resolution in optical coherence tomography	Eugene Fouche
	15:30	**16:00**	**Tea**	
13	16:00	16:30	Seeing through randomness with topological light	Kelsey Everts
14	16:30	17:00	Making the Quantum Visible: An Automated Toolbox for Quantum Education Using Classical Light	Cathy Maaku
	17:30	**20:00**	**Dinner. Wallenberg Research Centre STIAS**	

Time-domain ptychography: Principle and applications

PH Neethling*
** Stellenbosch Photonics Institute, Department of Physics, University of Stellenbosch, Stellenbosch, South Africa*

Keywords: Time-domain ptychography, CARS spectroscopy, nonlinear microscopy

Time domain ptychography, developed in our laboratory, provides a unique way to characterise the amplitude and phase of a temporal object, such as an ultrashort laser pulse, with unprecedented fidelity. Recently time-domain ptychography was generalised for laser pulse characterization to utilize phase-only transfer functions, without the need for a probe pulse, simplifying its implementation and making it more applicable in most ultrafast laboratories. This generalisation was termed i2PIE, referring to the fact that the square of the signal is measured and that a set of known transfer functions (intrinsic knowledge) is used. The full characterization of the laser pulse allows for its optimal compression, thereby improving signal strength and contrast in nonlinear optical experiments. Example of improvements CARS spectroscopy and nonlinear imaging will be presented. It has recently also been illustrated that time-domain ptychography can be applied to any temporal signal, not only laser pulses, highlighting its broad applicability.

Yaseera Ismail

Title: Long-Distance Free-Space Quantum Key Distribution for Secure Communication

Quantum Key Distribution (QKD) is a secure communication method that uses the principles of quantum mechanics to exchange encryption keys safely. It relies on single photons, which change state if intercepted, making eavesdropping immediately detectable. Free-space QKD is based on sending photons through air or space instead of optical fibres, reducing signal loss over long distances. This technology forms the foundation of the emerging quantum internet. A recent breakthrough in QKD has been achieved by establishing a 12,900 km quantum satellite link between Beijing and Stellenbosch. This experiment achieved over 1 million secure bits in one satellite pass using China's Jinan-1 satellite. It marks a crucial step toward a functioning, global quantum communication network.

Federico Centrone

ICFO

Lecture

Bosonic network architectures for quantum simulation and thermodynamics

In this talk I build on the CV toolbox introduced in the tutorial and show how networks of bosonic modes – the same harmonic oscillators underlying light fields, mechanical resonators, and microwave cavities – can be used as a unified platform for simulating quantum many-body systems and exploring quantum thermodynamics. Using a photonic variational approach, we design and optimize continuous-variable circuits that approximate ground states and dynamics of infinite-dimensional bosonic models, going beyond simple Gaussian states while still keeping the computations efficient. I will explain how phase-space and symplectic geometry methods let us tame the complexity of non-Gaussian operations and structured entanglement in these networks. On the thermodynamics side, I will show how one can derive practical bounds that link noise, fluctuations, and work extraction to genuinely quantum features such as squeezing and Wigner negativity. These results highlight how the same bosonic architectures can serve both as programmable quantum simulators and as platforms to demonstrate concrete thermodynamic advantages, all within reach of current and near-term photonic technology.

Anika Pretorius

ICFO

Lecture

Near_infrared.diffuse.optics.for.deep.in.vivo.microvascular.measurement¿From. energy.metabolism.physiology.to.optical.principles.and.back

Near Infrared diffuse optics can provide powerful noninvasive tools to measure microvascular- perfusion (blood flow) and -O2 utilization in vivo. Using as theoretical framework equations first delineated by Adolph Fick, these parameters can further be used to derive local energy metabolism (metabolic rate of oxygen consumption). In this talk we will discuss: (1) Some of the Energy metabolism Physiology theory from my background as a Sport Physiologist. Then we will (2) briefly discuss how we can use Near-Infrared Diffuse Optics principles to measure in vivo microvasculature, and (3) What we’ve learned so far about muscle energy metabolism from a blood flow restriction study.

Adam Vallés

ICFO

Lecture

Homemade single pixel imaging enhanced by Artificial Intelligence

This talk presents a simple way to perform high-quality imaging using only a single pixel detector (bucket detector) and a rotating disk patterned with random holes. This homemade approach works even in difficult wavelength regions - such as terahertz - where conventional cameras struggle, yet still achieves high-resolution, broadband imaging [Ref. if needed: oe-28-20-28868]. We will then show how artificial intelligence further boosts performance: by training neural networks to interpret the measured signals, we can reconstruct clear images using far fewer measurements and much faster acquisition times, enabling real-time identification of unknown objects. Together, these results demonstrate how simple hardware combined with smart algorithms can open new possibilities for low-cost, high-performance imaging and even quantum communications through turbulent media.

Quantum topologies take shape

Andrew Forbes
School of Physics, University of the Witwatersrand, Johannesburg, andrew.forbes@wits.ac.za

Abstract

Light can be tailored in its many degrees of freedom for so-called structured light. This opens many exciting avenues in seeing smaller in imaging, enhanced precision in manufacturing, and in optical communication and information processing, where the many forms of structured light can be used as an information alphabet. Here I will outline a new direction in structured light, where the usual degrees of freedom are ignored in favour of a global topology, with the promise of in-built robustness to noise and an interface between topologically structured matter and structured light. Using examples bulk and on-chip quantum optics, I will highlight the recent progress made in this field and the exciting future prospects.

Verònica Ahufinger

ICFO

Lecture

Photonic.flatband.systems

In this talk, we will discuss photonic flatband systems. First, we will consider the propagation of light carrying orbital angular momentum (OAM) in a lattice of optical waveguides arranged in a diamond configuration. We will show that the OAM degree of freedom induces phases in certain coupling amplitudes, effectively generating a net flux through the plaquettes and giving rise to a topologically non-trivial band structure with flat bands and protected edge states. Furthermore, we demonstrate, both theoretically and experimentally, the appearance of Aharonov–Bohm caging in the system. In the second part of the talk, we will decorate the diamond chain with constant magnetic flux per plaquette with several controlled onsite impurities in a patterned arrangement, generating an effective system that emerges from the flat band. Finally, we will outline a route to implement the system experimentally using optical waveguides that guide orbital angular momentum (OAM) modes.

Prof Alexander Heidt

Bern University

Title: Silica optical fibers functionalized with nanoparticles and quantum materials

Abstract: Silica optical fibers have transformed modern technology, yet emerging applications increasingly require specialty fibers functionalized with dopants such as rare-earth ions, semiconductors, and nanoparticles. I will present our unique fiber fabrication approach that enables the incorporation of heat-sensitive quantum materials directly into silica. These capabilities open a new pathway to engineer the nonlinear response of silica, bringing fibers with enhanced, suppressed, or potentially even negative Kerr nonlinearity into reach. I will also discuss our recent realization of the first semiconductor quantum-dot fiber laser operating directly in the visible, with emission wavelength tunable via the quantum-dot size.

The European X-ray free electron laser

Thomas Feurer, Managing Director

European XFEL GmbH, Holzkoppel 4, 22869 Schenefeld, Germany

X-ray Free Electron Lasers (XFELs) have greatly enhanced our ability to observe transient nuclear and electronic motions in real time at atomic resolution, thereby deepening our fundamental understanding of matter across different disciplines. Moreover, XFELs offer several significant advantages in High Energy Density (HED) science, which deals with matter under extreme conditions of temperature and pressure. For instance, XFELs can probe structure and ionization dynamics in warm dense matter, a regime between solid and plasma states, investigate material response to ultra-high pressures, help refine models of radiation transport at extreme conditions, and recreate and study conditions inside gas giants or white dwarfs.

Most XFELs today generate pulses that consist of amplified noise, leading to significant shot-to-shot fluctuations. While these pulses exhibit high transverse coherence, their longitudinal coherence remains very low. In this talk, I will present two methods for controlling longitudinal coherence and demonstrate their application in X-ray spectroscopy. Such experiments are made possible only by the resulting exceptional spectral brilliance of XFEL sources. Specifically, I will discuss a nuclear clock transition in one of the scandium isotopes. By controlling the nonlinear phase-space dynamics of ultrashort electron bunches, undulators can be made to emit pulses as short as attoseconds. Such pulses are ideal for probing electron dynamics on their natural timescales. In this presentation, I will highlight applications where attosecond pulses are used to create transient population inversion in inner-shell electrons. Lastly, I will discuss several applications of XFELs in the area of high energy density science. For example, I will present the first experimental evidence of liquid carbon, formed by shock-compressing graphite with a high-energy laser and probing it transiently using ultrashort XFEL pulses. Additionally, I will show the first experimental observation of plasma compression driven by relativistic currents in a cylindrical geometry; this effect was predicted over two decades ago but never confirmed until now. These experiments underscore the transformative impact of XFELs on advancing inertial fusion energy research.

Analysing broadband Mie scattering from optically trapped aerosol droplets

A Erasmus[1], A D Ward[3], E G Rohwer[1], G W Bosman[1,2], P H Neethling[1,2,*]

[1]Stellenbosch Photonics Institute, Physics Department, Stellenbosch University, South Africa
[2]National Institute for Theoretical and Computational Sciences, Stellenbosch, South Africa
[3]Central Laser Facility, Research Complex at Harwell, Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0FA, UK

*pietern@sun.ac.za

Aerosol droplets exist at equilibrium with a constant diameter and refractive index. When the droplet's environment changes in temperature or relative humidity, processes such as evaporation and growth of the droplet occur (processes which are relevant in atmospheric studies). To study the change of an aerosol droplet's size and refractive index over time, these properties can be determined by analysis of the backscattering of broadband light from the droplet. In this work, NaCl-water droplets (diameters of 3 µm to 5 µm) were isolated with a counter-propagating optical trap. Using Mie scattering theory, the diameter and refractive index of the droplets were determined simultaneously as a function of changes in the trap laser power. The counter-propagating optical trap system enabled the study of individual droplets as a function of changes in their local environment over time. The incident trap laser power was varied by approximately 1 mW, and shifts in the spectrum were measured, indicating changes in the droplet's diameter and refractive index. These changes induced in the droplet were measurable, controllable, and reversible. Such studies are applicable to aerosol droplets in the atmosphere, where surface-to-volume ratios and droplet curvature are important (which are neglected in bulk sample studies). Advantageous to this system is the high temporal resolution, which allowed the temporal evolution of the droplet to be observed as it equilibrates when the laser power is changed.

Temporal shaping of supercontinuum pulses for improved axial resolution in optical coherence tomography

Eugene E. Fouche,[1,*] Gurthwin W. Bosman,[1,2,**] and Pieter H. Neethling[1,2,***]
[1]Stellenbosch Photonics Institute, Physics Department, Stellenbosch University, Private Bag XI, Matieland, 7602, Stellenbosch, South Africa
[2]NITheCS (National Institute for Theoretical and Computational Sciences), Stellenbosch, South Africa
*21598835@sun.ac.za
**gwb@sun.ac.za
***pietern@sun.ac.za

Abstract

Optical coherence tomography (OCT) is an interferometric imaging technique used to image samples such as the human eye in 2 or 3 dimensions, with micrometer resolution and millimeter penetration depths. A broad bandwidth pulsed laser is scanned across the sample, and for each laser beam position a depth profile of the sample is obtained. These depth scans are stitched together to create a 2D or 3D image of the sample. However, the axial resolution in traditional OCT systems is limited by the bandwidth of the illumination source.

Recent work in super-resolving radar has shown how to improve the depth resolution of radar systems beyond the bandwidth limitations of the source by using temporally structured radar pulses. Using these concepts from radar, we will show how a temporal pulse shaping setup for laser pulses (using a 1-dimensional spatial light modulator) can be used to create temporally structured pulses that allow us to improve the axial resolution of our imaging setup beyond the limitations imposed by the bandwidth of the laser pulses. Simulations, practical aspects with regards to temporal pulse shaping and experimental results will be shown.

Seeing through randomness with topological light

Kelsey Everts, Cade Peters, Tatjana Kleine, Pedro Ornelas, Andrew Forbes
School of Physics, University of the Witwatersrand, Private Bag 3, Wits 2050, South Africa
andrew.forbes@wits.ac.za

Topological light has recently gained interest due to its robustness against external perturbations. Even in situations where a beam's spatial or phase structure is severely distorted, the topology remains intact minimizing the need for aberration correction through noisy channels. However, topological protection through scattering media remains mostly unexplored. Here we engineer several optical skyrmion topologies using superpositions of orthogonally polarised Laguerre-Gaussian modes. We demonstrate their resilience first to digitally simulated randomness of varying strengths and secondly to real samples with varying composition and distortion strengths such as fly wings, cork and bubble wrap. We illustrate an example of noise-free communication in strongly distorting regimes with skyrmions showing 97% fidelity in cases where OAM has a poor fidelity of only 25% due to modal crosstalk. This work thus highlights the power of topological light for seeing through complex random media thus paving the way for error-free communication and imaging.

Making the Quantum Visible: An Automated Toolbox for Quantum Education Using Classical Light

Cathy Maako [1], Brian Green [2], and Andrew Forbes [1]

1. University of the Witwatersrand, 1 Jan Smuts Drive, Johannesburg 2050, South Africa 2342774@students.wits.ac.za, andrew.forbes@wits.ac.za
2. Tshwane University of Technology, 175 Nelson Mandela Drive, Arcadia, Pretoria, 0083 224252927@tut4life.ac.za

Abstract

Amidst the current second quantum revolution, much work has been done to advance quantum-based technologies such as quantum communication, quantum computing, quantum sensing and metrology, just to name a few. It is therefore of utmost importance to build a quantum-ready workforce by equipping undergraduate and postgraduate students with solid quantum foundations. Although foundational quantum physics theory is taught from an undergraduate level, it is very seldom that students are given an opportunity to engage with quantum experiments due to their complex and costly nature. In contrast, classical optical experiments are easier to implement and are relatively cheaper than traditional quantum experiments.

In this work we exploit the conceptual parallels between quantum systems and classical systems with an experiment that bridges this gap in the learning of quantum physics. We investigate in detail the concept of quantum entanglement, that is when two spatially separated particles are correlated and thus said to be non-separable. We use vector light fields, a form of classical light whose spatial degree of freedom is coupled to its polarization degree of freedom, therefore also non-separable, to emulate quantum entangled particles. We present an automated and compact experiment, based on Digital Micromirror Device (DMD) technology, where we demonstrate the use of quantum measurement techniques like quantum state tomography to characterize classical vector light fields. We believe that such low-cost technology can effectively facilitate the study of quantum mechanics in undergraduate laboratory settings.