Optical Sciences Centre 2025 Physics Honours Projects

1. Advanced Silicon Photonic Integrated Chips

Supervisors: Prof. D.J. Moss, Dr. J. Wu
Contact: jiayangwu@swin.edu.au

Project Description: This project will focus on theoretical designs of high performance optical filters in integrated silicon photonic nanowire resonators [1]. It will use mode interference in formed by zig-zag waveguide coupled Sagnac loop reflectors (ZWC-SLRs), tailored to achieve diverse filtering functions with good performance. These include compact bandpass filters with improved roll-off, optical analogues of Fano resonances with ultrahigh spectral extinction ratios (ERs) and slope rates, and resonance mode splitting with high ERs and low free spectral ranges. The project will verifies the feasibility of multi-functional integrated photonic filters based on ZWC-SLR resonators for flexible spectral engineering in diverse applications.

[1] H.Arianfard, J.Wu, S.Juodkazis,D.J. Moss,"Spectral Shaping based on Integrated Coupled Sagnac Loop Reflectors Formed by a Self-Coupled Wire Waveguide", IEEE *Photonics Technology Letters* 33 (13) 680 (2021).

2. Nonlinear Photonic Chips with 2D Graphene Oxide Films

Supervisors: Prof. D.J. Moss, Dr. J. Wu
Contact: jiayangwu@swin.edu.au

Project Description: This project will investigate enhanced nonlinear optics in complementary metal-oxide-semiconductor (CMOS) compatible photonic platforms through the use of layered two-dimensional (2D) graphene oxide (GO) films [1]. It will investigate the integration of GO films with silicon-on-insulator nanowires (SOI), high index doped silica glass (Hydex) and silicon nitride (SiN) waveguides and ring resonators, to demonstrate an enhanced optical nonlinearity including Kerr nonlinearity and four-wave mixing (FWM). The GO films are integrated using a large-area, transfer-free, layer-by-layer method while the film placement and size are controlled by photolithography. In SOI nanowires we will observe a dramatic enhancement in both the Kerr nonlinearity and nonlinear figure of merit (FOM) due to the highly nonlinear GO films. Self-phase modulation (SPM) measurements will show significant spectral broadening enhancement for SOI nanowires coated with patterned films of GO. The dependence of GO's Kerr nonlinearity on layer number and pulse energy will be investigated to show trends of the layered GO films from 2D to quasi bulk-like behavior. This project will help to demonstrate the strong potential of GO films to improve the nonlinearity of silicon, Hydex and SiN photonic devices.

[1] J. Wu, L. Jia, Y. Zhang, Y. Qu, B. Jia, and D. J. Moss,"Graphene oxide: versatile films for flat optics to nonlinear photonic chips", *Advanced Materials* 33 (3) 2006415, pp.1-29 (2021).

3. Applications of Kerr Frequency Microcomb Chips

Supervisors: Prof D. Moss dmoss@swin.edu.au

Project Description: Integrated Kerr micro-combs will be investigated as a powerful source of many wavelengths for photonic RF and microwave signal processing as well as optical neural networks [1,2]. They are particularly useful for transversal filter systems and have many advantages including a compact footprint, high versatility, large numbers of wavelengths, and wide bandwidths. This project will investigate photonic RF and microwave high bandwidth temporal signal processing based on Kerr micro-combs with spacings from 49-200GHz. It will consider a range of possible functions from integral and fractional Hilbert transforms, differentiators, integrators as well as optical neural networks. The potential of optical micro-combs for RF photonic applications in terms of functionality and ability to realize integrated solutions will be explored.

[1] M. Tan, X. Xu, J. Wu, R. Morandotti, A. Mitchell, and D. J. Moss, "RF and microwave photonic temporal signal processing with Kerr micro-combs", *Advances in Physics X* 6 (1) 1838946 (2021).
[2] X. Xu, M. Tan, B. Corcoran, J. Wu, A. Boes, T. G. Nguyen, S. T. Chu, B. E. Little, D. G. Hicks, R. Morandotti, A. Mitchell, and D. J. Moss, "11 TOPs photonic convolutional accelerator for optical neural networks", *Nature* 589 (7840) 44-51 (2021).

4. Satellite Ocean Polariscopy

Supervisors: Dr S. H. Ng (data processing), Prof S. Juodkazis (polariscopy), Dr A. Codoreanu (high performance computing & Earth observation), Prof A. Duffy (high performance computing)

Contact: soonhockng@swin.edu.au

Project description: Observations of ocean waves, their orientation, and height play an important role in the study and modelling of the climate. This information can be used to track the effects of climate change or help with the prediction of severe weather events. This project will investigate adapting a polariscopy method developed for use at the Australian Synchrotron to satellite applications. The method involves taking transmission measurements at 4 different linear polarisations (0°, 45°, 90°, and 135°) and is able to determine orientation of a sample, even when the structures are far below the diffraction limit.

The project will involve processing of currently available altimeter, synthetic aperture radar, and scatterometer satellite data to determine the feasibility of applying this technique to Earth observation and in reflection. It will seek to understand how the low-level data can be processed to extract the required polarisations and if not, how this data can still be utilised. There is the possibility of experimentally validating the method in reflection (subject to easing of restrictions), and future prospects include design and implementation of an instrument for validation in space.

5. Micro-optics for Astro-Photonics (@ Optical and Astronomy Centers)

Supervisors: Dr V. Anand (optical design), Prof K. Glazebrook (astronomy devices), Dr S-H Ng (nanofabrication), Prof S. Juodkazis and T. Katkus (fs laser fab)

Contact: sjuodkazis@swin.edu.au

Project description: This project is set up to establish the modeling of micro-optical elements for observational astronomy. Coupling of light from the sky into a fiber-optical element for spectral measurement has to meet stringent constraints for angular light acceptance, collection, high efficiency of light transmission, and simplicity/robustness of design for fabrication of micro-optical elements. In this 1 year project, we will establish the design and optimize for the collection of light by 5-m-diameter lens into an optical fiber with a 0.5 mm core. What micro-optical element(s) made out of pure silica or sapphire (for high UV-IR transmission) is(are) required will be established. The project will prepare a design that is amenable by femtosecond laser fabrication (3D printing). The optical design or laser fabrication can have the main focus of the project.

6. Laser ablation of nanoparticle for biomedical applications

Supervisors: A/Prof. James W. M. Chon, Prof. Saulius Juodkazis

Contact: jchon@swin.edu.au

Project description: Metallic and semiconductor nanoparticles have tunable interaction ability in the visible and near-infrared range with size and shape. This provides a wealth of choice for resonant modes, ideal for enhancing any light scattering/absorption/emission processes in the range. Such is very attractive for linear or nonlinear biomedical imaging modalities, as well as for photodynamic therapy. Recently fabrication methods of silicon nanoparticles have greatly improved with femtosecond pulsed laser irradiation. In this project, we use amplified femtosecond pulsed laser to synthesise nanoparticles and characterise them using multiphoton microscopy and spectroscopic technique. In particular we utilize dynamic light scattering (DLS) and high-order fluorescence correlation spectroscopy (H-FCS) to characterize the size and shape distribution of nanoparticles produced inside solution and be able to separate monodisperse silicon nanoparticles with controlled sizes from 50 -250 nm. This project involves experimental (laser fabrication and spectroscopies), theoretical (Light scattering theory) and numerical simulations (T-matrix and finite element methods in EM). Students will be able to learn nonlinear optics, plasmonics, and correlation spectroscopies.

7. Understanding and controlling exciton-polaritons to realise new quantum phases of matter.

Supervisors: Professor Jeff Davis jdavis@swin.edu.au

Project description: A polariton is a quasi-particle that is part light and part matter, which can arise where there is strong light-matter coupling, such as is the case where 2D semiconductor is incorporated within a light cavity formed by two mirrors. Alternative means of trapping the light involve photonic crystals, or metamaterials, which allow more flexibility to tune the properties of the trapped light [1]. These polariton systems offer great flexibility to control the properties of and interaction between polaritons with the potential to form condensed phases of matter that cannot be achieved with material physics alone. This ability to control the properties of these hybrid light-matter systems opens the door to a range of novel applications. In this project, you will use femtosecond (10-15 s) laser pulses and state of the art multidimensional coherent spectroscopy experiments to measure the dynamics and interactions between polaritons in different situations. Depending on interest and aptitude, there is also the potential to model the metamaterial/photonic crystal structures, determining the bandstructure and affect of the strong light-matter coupling.

8. Understanding High-Temperature Superconductivity (and Other Strongly Correlated Electron Systems)

Supervisors: Professor Jeff Davis jdavis@swin.edu.au

Project description: Understanding the mechanisms of high-temperature superconductivity has been one of the great challenges in condensed matter physics over the past 30 years since superconductivity was first observed in cuprate materials. We have recently been able to successfully realise the first measurements of coherent dynamics in these materials, which we expect will help to provide great insight into the mechanisms responsible for superconductivity in these materials[1]. This project will expand upon that work, measuring the coherent dynamics of cuprate superconductors and/or other strongly correlated electron systems, using femtosecond (10-15 s) laser pulses and state of the art multidimensional coherent spectroscopy experiments. The aim of these measurements is to disentangle and quantify the interactions between electrons, phonons, magnons, and any other degrees of freedom (and the interplay between them), which are ultimately responsible for the macroscopic properties inherent in these strongly correlated systems, including superconductivity, charge density waves, excitonic insulators, the “strange metal” and “pseudogap” phases, and more!

[1] Novelli, Tollerud, Davis Science Advances 6, eaaw9932 (2020), https://doi.org/10.1126/sciadv.aaw9932

9. Coherent Dynamics and Interactions in Atomically Thin 2D Semiconductors and Stacked Heterostructures

Supervisors: Professor Jeff Davis jdavis@swin.edu.au

Project description: Since the Nobel Prize winning discovery of graphene (a 2D sheet of Carbon atoms, 1 atom thick) in 2006, there has been rapid growth in research on graphene and other 2D materials with remarkable properties. More recently, the ability to stack layers (of either the same or different material) with carefully controlled twist angles has opened the door to a range of new and controllable quantum phases. Interactions between electrons, phonons, photons, and more, are responsible for the properties and functionality of all molecules, materials and devices, including these monolayer and stacked monolayer semiconductors. Understanding and quantifying these interactions is therefore essential for optimising and controlling the properties and functionality of these new material systems. In this project you will utilise various ultrafast spectroscopy techniques, including multidimensional coherent spectroscopy, to reveal, identify and quantify the dominant interactions in these material systems under different conditions (see eg[1]). This will help develop a detailed understanding of the physics in these 2-dimensional systems and validate or contradict existing models.

[1] Muir … Davis Nature Communications **13**, 6164 (2022),https://www.nature.com/articles/s41467-022-33811-x

10. Dysprosium Quantum Gas Laboratory

Supervisors: Dr Sascha Hoinka shoinka@swin.edu.au

Project description: We are setting up a quantum gas microscope for ultracold dysprosium atoms, creating a versatile platform for quantum simulation, fundamental tests of quantum physics, and precision measurement. This hands-on project will give you the opportunity to contribute to various aspects, depending on your interests and our progress at the time you join. Cold atom experiments are typically built from the ground up, requiring a broad range of skills. You could work on laser cooling of atoms, including characterisation and simulations, laser and experimental control, customised RF electronics, or the imaging system, with potential overlap between tasks. This project provides practical experience in building complex quantum gas experiments while allowing you to learn the underlying physics involved in ultracold atoms, quantum mechanics, and atomic physics.

11. Fermi Gas Laboratory

Supervisors: Dr Paul Dykes pdykes@swin.edu.au

Project description: Ultracold atomic gases can display remarkable quantum behaviours at nanoKelvin temperatures such as superfluidity or flow with zero resistance. Understanding the motion of particles and impurities in strongly correlated superfluids represents a key challenge in modern physics.

Project 1 Developing a homogenous Fermi-Gas: In this project you will design, construct, and implement a homogeneous Fermi gas in a flat-bottomed optical potential that will overcome resolution limits imposed by our current harmonically trapped ultracold Fermi gas. This will be the first step towards the production of a definitive map of the dynamical properties of an ultracold Fermi gas superfluid with resonant interactions, using two-photon Bragg spectroscopy.

Project 2 Vortex dynamics in a two-dimensional Fermi gas: This project aims to produce a single vortex in a superfluid Fermi gas cooled to nanoKelvin temperatures confined to a pancake shape potential. Using two photon Bragg spectroscopy we will probe the vortex and produce a definitive map of the spectral properties.

12. Quantised Vortices and Quantum Turbulence (theory/computation)

Supervisors: A Prof Tapio Simula tsimula@swin.edu.au

Project description: Quantum turbulence occurs in superfluids and is associated with chaotic dynamics of quantised vortices. These non-equilibrium quantum systems feature remarkable behaviours such as absolute negative temperature states and large scale Onsager vortex flows. A broad range of publication-worthy problems on these topics can be tailored to suit the candidates' skills and interests. You will also have an opportunity to present your results at an international research conference at the end of the year. Please contact Tapio to discuss the details of your personalized Honours Project.

13. Droplet Time Crystals and Superwalkers (experiments/theory/computation)

Supervisors: A Prof Tapio Simula tsimula@swin.edu.au

Project description: Millimeter sized droplets can be made to bounce on the surface of a periodically driven fluid. For suitably Floquet engineered parameters these droplets begin to "walk" at speeds exceeding tens of millimeters per second. Furthermore, these curious wave-droplet entities have been shown to allow creation of classical time crystals and to mimic the behaviour of various quantum systems. A broad range of publication-worthy problems on these topics can be tailored to suit the candidates' skills and interests. You will also have an opportunity to present your results at an international research conference at the end of the year. Please contact Tapio to discuss the details of your personalized Honours Project.

14. Topological Quantum Computation (theory/computation)

Supervisors: A Prof Tapio Simula tsimula@swin.edu.au

Project description: The future of computing inevitably involves quantum computers. Topological quantum computation is a novel decoherence resilient way of performing quantum information processing and may be achieved using novel particles called non-Abelian anyons, which are neither bosons or fermions. A broad range of publication-worthy problems on these topics can be tailored to suit the candidates' skills and interests. You will also have an opportunity to present your results in an international research conference at the end of the year. Please contact Tapio to discuss the details of your personalized Honours Project.

15. Crystallizing Time in a Bose-Einstein Condensate

Supervisors: Prof Peter Hannaford and Prof Andrei Sidorov phannaford@swin.edu.au

Project Description: This project involves the creation of a Bose-Einstein condensate of ultracold potassium-39 atoms bouncing under the action of gravity on an oscillating atom mirror. The experiment is a forerunner to creating a "time crystal", which is a new form of quantum matter in which a periodically driven many-body system spontaneously evolves with a period longer than the driving period, allowing the periodic structure to resist external perturbations and, in principle, to persist indefinitely in time. Such a time crystal has potential applications in extending condensed matter physics to the time dimension and in quantum technology.

16. Development of Novel Radiation Detectors and Signal Processing Algorithms

Supervisor: A/Prof. Jeremy Brown jmbrown@swin.edu.au

Project Description: Over the last decade one of the most significant technological advances made in the field of nuclear instrumentation and detector physics was the development of Silicon Photomultipler (SiPM) sensors. These compact novel optical photosensors have enabled significant gains in radiation detector performance, whilst also reducing unit size and power consumption. Swinburne's Applied Nuclear Physics Laboratory specialises in the development of scintillator-SiPM based radiation detectors, and possesses the required production and experimental infrastructure in-house to support development through the full development cycle:

Phase 1: initial concept and in-silico optimisation.

Phase 2: desktop prototyping and performance assessment.

Phase 3: real-world field trials in collaboration with industry partners.

The following list outlines a selection of potential projects topics offered which can be tailored to specific student interests (computational, experimental, or a combination of both):

1. Novel Scintillator-SiPM Based Radiation Detectors and Position Read-Out Algorithms for Nuclear Medicine (PET and SPECT) [1,2]
2. Dual End Scintillator Crystal Readout to Maximise Depth of Interaction and Time of Flight Performance in PET Radiation Detectors
3. Dual Mode Gamma Ray/Neutron Radiation Detectors and Signal Processing Algorithms for Stand-Off Radiation and Nuclear Threat Detection [3]
4. Large Area Fast Neutron Radiation Detectors and Signal Processing Algorithms for Stand-Off Detection
5. Development and Validation of Geant4 Monte Carlo [4] Simulation Applications of In-Service Radiation Detectors at ANSTO [5], ARPANSA [6], and DSTG [7]

[1] J. M. C. Brown et al. (2019), A high count-rate and depth-of-interaction resolving single-layered one-side readout pixelated scintillator crystal array for PET applications, IEEE Transactions on Radiation and Plasma Medical Sciences 4(3): 361-370.

[2] J. M. C. Brown (2021), In-silico optimisation of tileable philips digital SiPM based thin monolithic scintillator detectors for SPECT applications, Applied Radiation and Isotopes 168: 109368.

[3] J. M. C. Brown et al. (2023), Modelling the Response of CLLBC (Ce) and TLYC (Ce) SiPM-Based Radiation Detectors in Mixed Radiation Fields with Geant4, arXiv:2303.09709.

[4] Geant4 Monte Carlo Radiation Modelling Toolkit, https://geant4.web.cern.ch/

[5] Australian Nuclear Sceince and Technology Organisation (ANSTO), https://www.ansto.gov.au/

[6] Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), https://www.arpansa.gov.au/

[7] Defence Science and Technology Group (DSTG), https://www.dst.defence.gov.au/

17. Design, Modelling, and Development of Novel Materials, Extra-Terrestrial Exploration Vehicles, and Modular Habitation Structures for Space Exploration

Supervisor: A/Prof. Jeremy Brown jmbrown@swin.edu.au

Project Description: High performance materials and tightly controlled fabrication processes are critical for the development of next-generation satellites, extra-terrestrial exploration vehicles, and modular habitation structure systems key to humankind's plans to explore and settle on objects other than earth. These satellites, vehicles, and structures will need to endure extreme temperatures, unpredictable radiation events, high speed debris impacts, and near perfect vacuums with little or no opportunity for repair. Even if these materials/structures can tolerate the extremes of space, further refinement will be required to ensure that human passengers and their supply payloads are sufficiently protected to survive the planned mission span. To meet these challenges, engineers, scientists and manufacturers need innovative components, shielding and repair solutions that deliver sustainable performance in space without compromising vehicle weight/cost. The following list outlines a selection of potential projects topics offered within the Swinburne Space Technology and Industry Institute [1] that can be tailored to specific student interests (computational, experimental, or a combination of both):

1. Development of new material systems and fabrication techniques to mitigate the impact of radiation, temperature extremes and collisions with debris
2. Additive manufacturing repair processes and developing light weight, thermally protected structures for vehicle components to survive the temperature extremes of space
3. Modelling radiation exposure associate risks to food supplies, electronics, humans, and structures on long-term missions

[1] Swinburne Space Technology and Industry Institute, https://www.swinburne.edu.au/research/institutes/space-technology-industry/

18. Developing serial macromolecular crystallography at MX3, Australian Synchrotron

Supervisor: A/Prof. Nadia Zatsepin nzatsepin@swin.edu.au

Project Description: Macromolecular X-ray crystallography (MX) is the leading method for atomic-resolution structure determination in biology. Structure and dynamics of macromolecules determine their function, so MX provides mechanistic insights into life-enabling biochemical processes like photosynthesis, all our senses, the molecular basis of infection and disease, and structure-based pharmaceutical drug discovery [1]. The new MX3 beamline at the Australian Synchrotron promises to provide the high flux, microfocus beam required to push the frontiers of MX to static *and time-resolved* studies of tiny microcrystals of weakly-diffracting and/or radiation-sensitive macromolecules at room temperature (not currently possible in Australia [2]). This project aims to test the limits of MX3 capabilities through optimising *serial* macromolecular crystallography (SMX) by exploring the influence of experimental parameters on data quality (e.g. X-ray energy, bandwidth, focus size, exposure time/crystal, and various sample delivery approaches: standard goniometer, fixed target, in-tray screening, high-viscosity extrusion). The project involves X-ray physics, protein crystallography experiments, structural biology, high-performance computing, and close collaboration with the MX3 team [3].

[1] Pearson & Mehrabi, *Curr. Op. Struct. Bio*. 2020, 65:168-174.
[2] Martin-Garcia *et al. IUCrJ* (2017). 4, 439-454, and J*. Synch. Rad*. (2022), 29(3), 896-907.
[3] https://www.ansto.gov.au/high-performance-macromolecular-crystallography-beamline#content-capabilities

19. Investigating radiation damage in DsbA to enable studies of protein dynamics and development of antimicrobials.

Supervisor: A/Prof. Nadia Zatsepin nzatsepin@swin.edu.au

Project Description: Time-resolved serial macromolecular crystallography (TR-SMX) is a recently invented technique for direct visualisation of biomolecules in action, aka experimental “molecular movies”. X-ray free-electron laser (XFEL) serial crystallography enables femtosecond-scale dynamics to be imaged in lightactivated biomolecules [1], while reactions initiated by chemical binding are (currently) limited by microfluidic mixing and diffusion rates to ~ ms time scales [2]. This project is the beginning of a long-term goal to image structural dynamics of small molecule binding in an enzyme involved in protein folding: disulphide bond-forming enzyme A (DsbA). DsbA is a key target for a new type of antibacterial drug to fight antimicrobial resistance, which is increasing worldwide [3]. However, DsbA is particularly sensitive to X-ray induced radiation damage at room temperature, so pursuing TR-SMX on DsbA requires a thorough understanding of local and global radiation damage. To this end, this project will determine the first room-temperature structures of DsbA in reduced and oxidised states, in two different crystal forms, and compared with "undamaged" structures obtained with an XFEL (where "diffraction before destruction" outruns structural X-ray-induced damage by using extremely brilliant femtosecond-scale X-ray pulses) [1,2]. The project involves X-ray physics, crystallography experiments, structural biology, high-performance computing, close collaboration with Prof Begoña Heras' lab (La Trobe University, [3,4]) and might include opportunities for experiments overseas. The project also forms an excellent introduction to a PhD focusing on XFELs or synchrotron-based TR-SMX (e.g. to understand DsbA interactions with small molecule inhibitors, substrates, and other enzymes to aid structure-based drug discovery based on DsbA inhibition [4]).

[1] Tenboer, Basu, Zatsepin *et al.* 2014. *Science* 346 (6214), 1242-1246.
[2] Stagno *et al.* 2017. *Nature* 541(7636), 242-246.
[3] Heras *et al.* 2009. *Nature Reviews Microbiology* 7 (3), 215-225.
[4] Smith, Paxman, Scanlon & Heras 2016. *Molecules* 21 (7), 811.

20. Simulations of serial crystallography with a Compact X-ray Light Source: new source, new capabilities, new problems!

Supervisor: A/Prof. Nadia Zatsepin nzatsepin@swin.edu.au

Project Description: The ASU Compact X-ray Light Source (CXLS) is a novel, compact, hard X-ray source being constructed at Arizona State University based on inverse Compton scattering [1]. The CXLS aims to deliver synchrotron undulator-like capabilities on a table-top scale, with pulsed hard X-rays (100's fs in duration at 1kHz), with a widely tuneable beam that will be usable for ultrafast spectroscopy, micro-crystallography and phase contrast medical imaging. CXLS will also comprise phase I of the construction of a recently-funded room-sized Compact X-ray free-electron laser (CXFEL) [2], and both are being considered as potential next-generation X-ray sources to build in Australia.

In this simulation project you will simulate serial crystallography data (X-ray diffraction from protein microcrystals with stochastically varying size, orientation, mosaicity) using *nanoBragg* [3] to (a) explore the capabilities of CXLS for serial macromolecular crystallography (SMX), and (b) compare the performance of *CrystFEL* [4] and *Careless* [5] on difficult data (e.g. beam divergence, polychromaticity & crystal mosaicity and weak diffraction, limited detector dynamic range). *CrystFEL* is the most widely used suite of programs for serial crystallography data analysis [4], while *Careless* is a new tool for merging crystallography data that uses deep learning and variational inference [5]. The project is in collaboration with the CXLS/CXFEL team. This work will contribute to a pipeline for planning future experiments at CXLS as well as a science case for Australia to pursue such powerful and flexible sources. You might also have an opportunity to participate in the world-first SMX experiments at CXLS if feasible.

[1] https://news.asu.edu/20230205-discoveries-firstofitskind-instrument-officially-ushers-new-era-xray-science
[2] Graves et al. "ASU Compact XFEL" 2017. Proc. 38th Int. FEL Conference; https://biodesign.asu.edu/cxfel/
[3] *nanoBragg*. https://bl831.als.lbl.gov/~jamesh/nanoBragg/ and Sauter et al. 2020, Acta Cryst D 76(2), 176-

192.
[4] White et al., Zatsepin & Chapman. 2013 Acta Cryst D. 69 (7), 1231-1240.
[5] Dalton, Greisman & Hekstra. 2022. Nature Comm. 13 (7764), 1-13.