Cavendish GSC 2019- Student Talks

10:00-10:15: Alexandra J Zhou (BSS)

ajz28@cam.ac.uk	Alexandra J Zhou	ajz28	a Graduate	Biological and Soft Systems

Investigating the Biophysical Properties of FUS Using Microfluidics and Laser Tweezers

Fused in sarcoma (FUS) is an RNA-binding protein that contributes to protein synthesis at neuron axon terminals [1]. Past research on FUS focused on its biological function and structural composition, while recently it was discovered that FUS can undergo liquid-liquid phase separation and this intracellular process leads to the formation of membraneless organelles in the cell. Under certain conditions, phase-separated proteins can develop into aberrant hydrogel form and such dysfunction is associated with neurodegenerative diseases such as familial amyotrophic lateral sclerosis (fALS) and frontotemporal lobar degeneration (FTLD) [2].

To better understand the transition of FUS protein from its droplet state to the hydrogel state, we aim to investigate some biophysical properties of FUS droplets through microrheology using microfluidics and laser tweezers. The liquid-like property of the FUS droplets was confirmed by Patel et al. with laser tweezers [3], making it possible to study the behaviour and property of FUS droplets using rheological methods and analyses. In addition, Taylor et al. were able to coalesce individual droplets of several proteins that undergo liquid-liquid phase separation using the technique of microfluidics and obtain both velocity profile and viscoelasticity of the droplets, which suggested a novel method to examine the physical properties of larger populations of protein droplets [4].

With more knowledge on the phenomenon of liquid-liquid phase separation in proteins being explored, we will be able to reveal the pathology underlying neurodegenerative diseases due to the abnormal protein hydrogels as well as develop more effective therapies.

[1] Weber, S. C., & Brangwynne, C. P. (2012). Getting RNA and protein in phase. Cell, 149(6), 1188-1191.
[2] Qamar, S., Wang, G., Randle, S. J., Ruggeri, F. S., Varela, J. A., Lin, J. Q., ... & Meadows, W. (2018). FUS Phase Separation Is Modulated by a Molecular Chaperone and Methylation of Arginine Cation-π Interactions. Cell, 173(3), 720-734.
[3] Taylor, N., Elbaum-Garfinkle, S., Vaidya, N., Zhang, H., Stone, H. A., & Brangwynne, C. P. (2016). Biophysical characterization of organelle-based RNA/protein liquid phases using microfluidics. Soft Matter, 12(45), 9142-9150.
[4] Patel, A., Lee, H. O., Jawerth, L., Maharana, S., Jahnel, M., Hein, M. Y., ... & Pozniakovski, A. (2015). A liquid-to-solid phase transition of the ALS protein FUS accelerated by disease mutation. Cell, 162(5), 1066-1077.

10:15-10:30: Pedro Vianez (SP)

pmtv2@cam.ac.uk	Pedro Vianez	pmtv2	a Graduate	Semiconductor Physics

Flatland: An Experiment of Many Dimensions

Much like the book, life (and physics) gets rather more exciting when confined to lower dimensions. At low excitation energies and infinite size, a system of interacting one-dimensional (1D) electrons can be well described theoretically as a Tomonaga-Luttinger liquid. However, it is only in the last few years that theoreticians have started to develop models for finite-sized systems at energies comparable to the Fermi energy, where new physics involving 'replica' parabolic dispersions at higher momenta or with negative effective mass is predicted to occur. Our work focuses on the experimental detection and quantification of these higher-order modes. We measure momentum-resolved tunnelling of electrons to and from an array of 1D wires formed within a GaAs heterostructure and use a 2D electron gas as a spectrometer in order to map their dispersion both in and away from equilibrium. We have recently fabricated a series of very short-length wire devices where both first- and second-order 'replica' modes can be observed, even when multiple subbands are occupied, taking us beyond the regime of the current models. In this brief talk I will clarify how insights into this new physics could pave the way for new era of quantum electronics applications.

10:30-10:45: Dominic Anstey (Astro)

da401@cam.ac.uk	Dominic Anstey	da401	a Graduate	Astrophysics

Detecting the first stars with REACH: Data analysis via physics-rooted models

The first stars that formed in the universe have never been directly detected, and so the circumstances of their formation are poorly understood. These early stars are almost impossible to detect with visible light telescopes due to their extreme age. However, one of the most promising channels by which they could be detected is through the 21cm line.

Neutral hydrogen, which filled the universe at early times, has a hyperfine transition at a wavelength of 21cm. When illuminated by visible light, hydrogen gas will absorb photons from background radio emissions at 21cm, with a strength dependent on the properties of both the gas and the starlight. The change in this absorption strength can therefore provide a trace of the development of the first stars.

Here, I will present REACH, a new experiment being developed in the astrophysics group aiming to detect this 21cm signal from the first stars. I will first discuss the design of REACH, then the new data analysis processes that are vital to the experiment. The 21cm signal must be separated from radio foregrounds that are 10^4 times brighter than it, and the ability to do so is greatly limited by distortions arising from frequency dependence in the antenna pattern. REACH is developing a novel way to tackle this issue via detailed physical modelling, allowing the first stars to be seen from beneath these bright foregrounds.

10:45-11:00: Max McGinley (TCM)

mm2025@cam.ac.uk	Max McGinley	mm2025	a Graduate	Theory of Condensed Matter

Topological Aspects of Quantum Systems Far From Equilibrium

Although topology has been a topic of research in pure mathematics for centuries, it is only recently that its relevance to physics has been widely appreciated. In disciplines including high energy, optical, and atmospheric physics, physical systems can be characterized by topological invariants, i.e. quantities that cannot not change as the underlying system is continuously deformed. In the context of condensed matter, or more generally, many-body quantum physics, these invariants have been used to identify new `topological phases of matter', corresponding to topologically distinct equilibrium configurations of the relevant system. These exotic phases of matter give rise to fascinating effects that are intrinsically quantum mechanical, some of which are of potential technological use, e.g. in quantum computation architectures.

In this talk, I discuss how a similar approach can be used to understand many-body quantum systems far from equilibrium. I will discuss how the topological properties of non-equilibrium wavefunctions can impose constraints on the dynamics of these systems. Despite the increased complexity that arises when departing from equilibrium, we are able to identify universal features of many-body systems in non-equilibrium scenarios through this formalism. More practically, I will show how this understanding can be used to identify whether or not the features of topological systems that are of potential technological use will persist in non-equilibrium regimes.

11:30-11:45: Farhan Nur Kholid (ME)

fnk23@cam.ac.uk	Farhan Nur Kholid	fnk23	a Graduate	Microelectronics

Ultrafast Spin Seebeck Effect in an Antiferromagnetic Heterostructure

Thermoelectric effects are essential for harnessing heat energy. Among them that are useful for spintronics is spin Seebeck effect (SSE). In a heterostructure consisting of a magnet/non-magnetic metal, a temperature gradient generates spin current which is collected by the non-magnetic metal. With inverse spin-Hall effect, the spins are converted to charge current. This talk will outline the progress in understanding the origins of SSE, and the recent research directions including using femtosecond pulsed laser techniques. We show that SSE in the ultrafast regime deviates from the models developed based on thermal fluctuations.

11:45-12:00: William Wood (OE)

waw31@cam.ac.uk	William Wood	waw31	a Graduate	Optoelectonics

Organic Charge Transport: Bendy Conducty Things

Organic semiconductors are quite exciting: they can be inkjet printed, they're "nice" to use in fabrication and, if they're a polymer, they're often flexible and who doesn't want bendy things? In OE-FET we tend to focus on these polymer systems, attempting to glean details of how charges exist and move inside these far-from-ideal structures and how this ends up affecting their (semi)-conducting properties.

Things in these materials are often complicated by the fact that there's normally at least two mechanisms competing with each other over how charges move through them. My work focuses mostly on trying to figure out which mechanisms are at play and in what proportions across a variety of different polymer systems. To this end I employ every Physicist's favourite effect: the Hall effect. However, because this is rather difficult to measure in these sorts of materials, I have built a new set-up that uses an alternating field (and looks like a freaking spaceship, I might add) to measure to a fine enough resolution so that valuable information on charge delocalisation can be ascertained.

In essence, bendy conducty things are complicated and we don't entirely know how they work, but we're getting there. Promise.

12:00-12:15: Ed Carter (AMOP)

eac65@cam.ac.uk	Ed Carter	eac65	a Graduate	Atomic, Mesoscopic and Optical Physics

A four-dimensional crystal of light

Quasicrystals are a class of materials that are ordered without being periodic. This has many implications, including no unit cell and no Bloch's theorem, but perhaps the most interesting is that every quasicrystal can be considered as part of a higher-dimensional periodic "parent" crystal, making them a window into higher-dimensional physics that can't normally be seen in a lab. Despite these unique features, however, quasicrystals are still quite poorly understood.

In our group we use ultracold atoms in an optical lattice to study quasicrystals. We create our lattice by interfering laser beams in a pattern with eightfold rotational symmetry, which works because this symmetry is forbidden for periodic systems (octagons can't tessellate). We can use this system to simulate a quasicrystalline material by loading it with ultracold atoms, which play an equivalent role to electrons in real materials but are heavier, slower and easier to see. Because our two-dimensional quasicrystal has a four-dimensional parent, this allows us to observe physics that requires four spatial dimensions.

12:15-12:30: Catriona Murray (Astro)

cam217@cam.ac.uk	Catriona Murray	cam217	a Graduate	Astrophysics

SPECULOOS - Search for habitable Planets EClipsing ULtra-cOOl Stars

The SPECULOOS survey is an international network of 1m-class robotic telescopes established to search for transiting terrestrial planets around the nearest and brightest ultra-cool dwarfs. Our unique Southern Hemisphere facility, SPECULOOS-South, is an observatory located at ESO Paranal, Chile. To deal with the specialised photometric requirements of ultra-cool dwarf targets and the challenges of ground-based observations, an automatic pipeline and novel differential photometry methods were developed. We show the exceptional photometric performance of the facility and assess its detection potential. By comparing simultaneous observations with SPECULOOS-South and TESS, we show that, using these new methods, we readily achieve high-precision, space-level photometry for bright, ultra-cool dwarfs, highlighting SPECULOOS-South as the first facility of its kind.