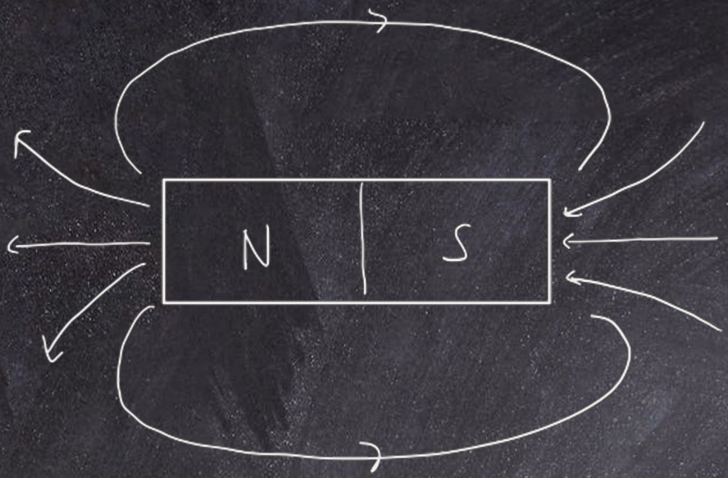
Physics Department Newsletter

Volume 1, Issue 04

Heriot Watt University

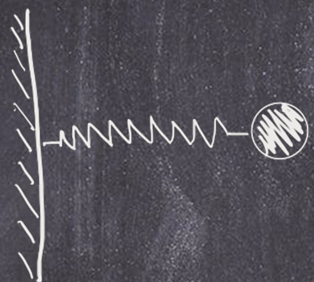


$$\nabla \cdot \vec{E} = \frac{1}{\varepsilon_0} \rho$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial}{\partial t} \vec{B}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial}{\partial t} \vec{E}$$



$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{x}}\right) = \frac{\partial L}{\partial x}$$

$$m\ddot{x} = -kx$$

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HERIOT WATT UNIVERSITY
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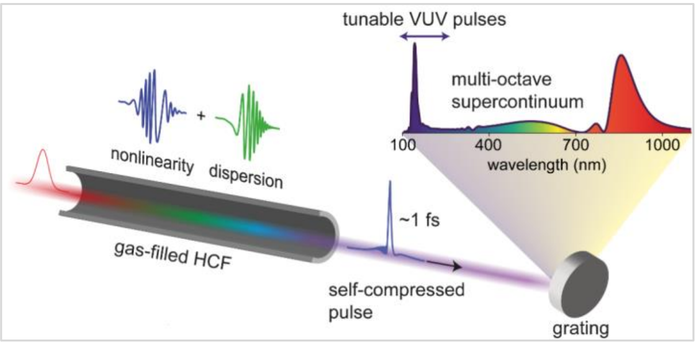
High Energy Soliton Dynamics – Generating Ultrashort Pulses

*Miss **T. F. Grigorova** & Prof. J. Travers* – LUPO Lab

Two years ago, the group of Prof. John Travers demonstrated the brightest ultrashort pulses in the vacuum ultraviolet region (VUV, covering the range from 100 to 200 nm) and the highest energy sub-cycle transient pulses in the near-infrared (NIR) through scaling soliton effects in gas-filled capillary fibres. Recently, he received further funding from ERC, the European Research Council, for an ambitious project that will demonstrate even further scaling of these effects and use them as a driver for secondary sources, which would generate high-brightness X-ray attosecond pulses and accelerate electrons.

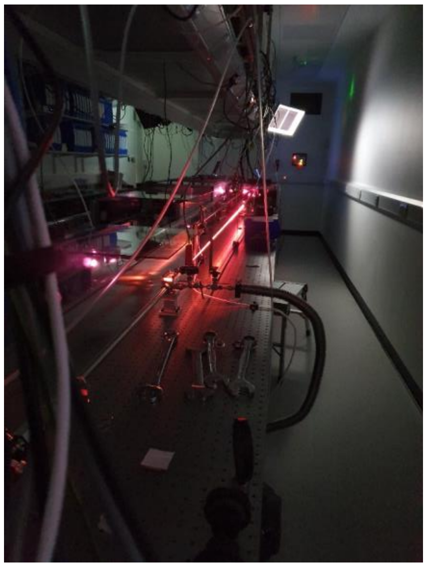
Solitons, which are the basis of these advances, are a type of nonlinear wave with special properties, which was first observed as water waves in 1834 on the Union Canal, not far from our campus. Similar light waves can form during the propagation of laser pulse through a fibre.

In the original demonstration by Prof. Travers' group, this was experimentally achieved by using 10 fs-long pulses, centered at 800 nm, coupled into a 3 m-long, large-core size (250 um diameter) capillary fibre filled with helium.



The principle of soliton effects in a gas-filled fibre; HCF: hollow capillary fibre.

In this way, it was possible to demonstrate optical attosecond pulses duration of 412 as (this is the duration of the central field transient of the pulse, the duration of the envelope is 1.2 fs) and energy of 340 μJ (in contrast to previous demonstrations, in which the energy was on the order of 20 μJ). In addition to this, a short-duration pulse in the UV region is emitted through phase-matching, called a dispersive-wave. What makes this a particularly useful source is its versatility—by choosing the parameters, e.g., gas pressure, pulse energy, duration and wavelength, fibre length and core-size, etc. it is possible to generate pulses that are tunable over the entire visible and ultraviolet region.



Lab view of the current system.

In this next project, the group is aiming to demonstrate even further energy scaling, up to 20 mJ. Reaching these energies will create a unique source for strong field physics, which will be used for a series of exciting applications:

- High-harmonic generation (HHG): HHG a process by which intense pulse ionises an electron and accelerates it away and back to its parent ion within one optical cycle. On returning to the parent ion, the electron may recombine with it, emitting its excess energy, leading to extreme ultraviolet or soft x-ray generation. A novelty in these experiments would be the use of dispersive-waves in the ultraviolet region for pumping HHG – something demonstrated only once previously by another group and showing unexpected and surprising increase of the energy of the emitted photons. While this goal of the project is using a gas target, another option is to use a solid target, called relativistic plasma mirror, for the generation of x-rays, promising even better conversion. Additionally, the tunability of the dispersive-waves would allow to study the frequency-dependence of these processes.

- Electron acceleration: this project will aim to demonstrate direct laser acceleration of electrons using vector beams, which have a longitudinal component of their electric field. This was one of the first proposals for achieving electron acceleration with laser pulses, but has been mostly abandoned, due to the difficulties of producing such beams. However, this type of beam electric field distribution is a mode of the guiding capillary fibre, and it is expected that soliton self-compression can be achieved by pumping in this mode. This technique offers the promise of very good quality, energetic electron beams.

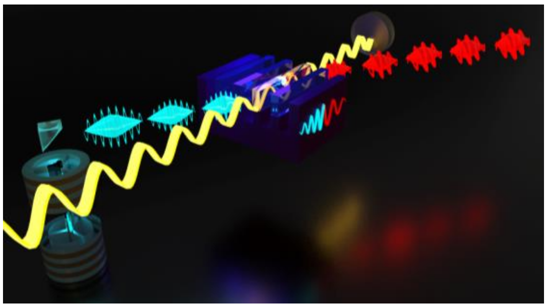
The new project will commence in July 2021. There will be positions for PhD students, as well as projects for UG and PG students. If you are interested in taking part in this work, please get in contact with Prof. John Travers at J.travers@hw.ac.uk.

Bridging the Gap – Converting an Infrared Single-Photon Source to Telecommunication Wavelengths with Quantum Frequency Conversion

Mr. Z. X. Koong, Mr. C. Morrison – Quantum Photonics Laboratory

Quantum information processing requires deterministic, high purity single-photon sources. However, for these sources to be compatible with existing telecommunication infrastructure they need to emit photons at 1550 nm, where attenuation in optical fibre is lowest. Currently the best deterministic single-photon sources are semiconductor quantum dots embedded in microcavity [1]. Their major drawback lies in the fact that their emission wavelength of these sources is around 900 nm.

It is possible to get around this drawback by converting the frequency of photons from these sources to telecommunication wavelengths. The heart of the mechanism lies in the interaction between the single photons and a strong pump beam in a waveguide fabricated out of nonlinear crystal. This interaction annihilated a photon at the original frequency and produces a photon a new frequency given by the simple relation,



Artist illustration of quantum frequency conversion process: converting single photons from a micropillar quantum dot (blue) into the telecommunication wavelength (red) via nonlinear three-wave mixing with a strong pump (yellow).

$$\omega_{out} = \omega_{in} - \omega_{pump}.$$

This mechanism can be in principle noiseless, has been proven a success in the past in converting non-classical light from a variety of different sources [2-5] telecommunication wavelengths. This allows one to utilize the vast catalogue of telecom components in addition to the access to the existing ultra-low-loss fibre infrastructure.

In our recent paper published in APL [6], we demonstrate near noiseless frequency conversion from near IR to telecom C-band via difference frequency generation. We report on bright, pure and indistinguishable single photons, generated from a InGaAs quantum dots embedded in a micropillar cavity. With this source, this enables immediate application in quantum networking protocols, with ongoing works on exploring the feasibility of this source for secure quantum communication.

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For more information you can read the full article here: https://doi.org/10.1063/5.0045413

Shared Experiences – Life After Graduation

Sean Keenan, 5th Year MPhys Physics

The summer is finally ahead of us, and with the continuing rollout of vaccines and the easing of restrictions it seems like a return to "normality" is just around the proverbial corner! It has been a challenging year to say the least and I don't particularly want to go on about "you know what" as I am sure everyone has had just about had enough of it. Yet, there is a lot to be said for the speed and efficiency at which the science community has pulled together a viable vaccine – a "saving grace" if you will, and the road out of this nightmare.

I know most of us students are glad the semester is over, and we will all be looking forward to some much-deserved time off. For those of us graduating however, it signals the next step in our journey and I am certain that some will still be a little unsure as to what the next step is / will be. Lockdown has shown us that the world of work and the way we do work—working from home and flexitime less of a perk and more of a necessity—is rapidly changing and with that brings new opportunities. As the world economy starts to get moving again there should be an increase in job opportunities and options out there – which is something to be thankful for at least.

Next in this series we have Douglas Arbuckle who has just recently taken up employment at Coherent Scotland (congratulations Douglas!). Here he gives us his experience and some of the struggles of "life after graduation".

What inspired you to get into Physics?

I am not entirely sure in all honesty. I think I have always liked science, specifically building things. My Granda was a radio and television engineer, and his house was full of circuit boards and cathode ray tubes which always fascinated me. Physics and Chemistry seemed like the kind of things you did to do what I was interested in, so I picked them at school. I was decent at both and ended up getting sent to an interschools quiz competition and made it to the finals both times I went, gaining two pretty good mugs out of it. By the end of school, I had realised Chemistry wasn't for me (I had failed at Advanced Higher quite convincingly) but that I'd loved doing practical Physics work. So, I grabbed my chance at UCAS clearing and appeared at Heriot-Watt.

What is your current role and what steps did you take to get there?

I am currently a Laser Systems Engineer at Coherent Scotland. Getting this chance did involve a fair bit of floating around in the doldrums after University. I started at the end of April this year, which puts it almost 10 months to the day I should've been at the graduation ceremony getting my 2:1 in Physics. The time from leaving university to getting this role involved a pretty ridiculous number of applications, all in all about 60 I think, with a grand total of 4 replies. I wasn't the fastest off the mark in starting up applying but I had quite a strong routine by mid-July of applying to any role that I could spin my degree as being relevant for.

The effort per application for no response gets pretty crushing after a while and I'd got a temp job at a supermarket that had me working long hours in evenings, nights and early mornings which is the hardest work I've ever done. I just didn't have the energy to keep up the application/rejection cycle as I had a job. It wore me down enough to get applying again as much as I could in February. Finally, I got a reply, an interview, an alignment test and then a job at Coherent. Now I build Lasers.

What is your favourite part of your current work / what do you find most interesting about physics?

I absolutely love all of it in all honesty. I'd say the building of lasers just beats the testing despite the potential of both to frustrate you endlessly. I build fibre lasers and when you get a perfect splice between two different kind of fibres, it really hits different. Soldering is very relaxing too, can't get enough of it.

This all fits with my enjoyment of practical work in physics, hands on work is very much the best. My module grades speak for themselves on that matter.

How has your degree helped you in your current role / what has been the most useful aspect of your degree?

The thing that's been at the front of my mind recently is that the small bit of soldering with Bill MacPherson in 1st year was really handy, it's essential to know a bit of soldering at least to do anything practical in Physics in my opinion. Also, there's no chance I'd have got my job without knowing how to align a laser, so that's something to give huge thanks to Marius Rutkauskas and Derryck Reid for. As well, I used my old notes from Richard Carter's Laser Physics course to revise for my interview so to those three – cheers for getting me a job!

Has your degree in physics helped you in any way that isn't explicitly linked to science?

I'd say it's good at drawing out skills you didn't know you had. I was never a big fan of writing essays or any long form text at school but if it's a report for Physics I'd throw myself into it and I usually came out with pretty decent stuff. The whole time at university was pretty transformative and I've came out a good bit more confident, understanding and level-headed… and I now know how to draw a picture of Nicholas Cage in MATLAB. I also had a great chance to develop some folk music skills and form a fantastic group that will hopefully meet up for a tune again when we get the chance. If that sounds good to you, get in touch and I'll let you know when they start playing at the Uni again!

What have been the biggest challenges in your degree / career so far?

Probably leaving University and looking for a career was up there. I don't think I took as much of an advantage of the careers service as I should have towards the end of my degree and worked out how to get a job through trial and tonnes of error.

But tied at the top for big challenges, going into my 3rd year exams, which is already a big step up from the year before, and having some pretty significant challenges in my personal life was very rough, but I'd have to thank the Physics department for accommodating me through that. Circumstances just flat out don't go your way sometimes, but life goes on and along the road you'll make it through.

Is there anything you dislike about physics / disliked in your degree?

Maths! Pierre-Simon Laplace has caused untold suffering to me. I hated Maths but loved MATLAB, why not just let the computers do the Maths?

If there was one piece of advice you wish someone gave you in 1st year – what would it be?

Join everything! Go to everything! There are loads of societies that I wish I'd joined up with and engaged in much earlier that introduced me to some great people. I would echo what Jake said in Issue 3 that you should go to all your lectures and tutorials, he has a far greater knowledge and understanding of physics than I do so just go and get into the habit of it, you'll end up getting way more out of your time at Heriot-Watt. Plus, joining and running a society is a great way to get examples for of things they ask you about in applications. Join something and plan overambitious events! They might not be successful! They will be a good laugh!

List of Latest Research Output

High-speed object detection using SPAD sensors.
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In: Y. Soskind, & L. E. Busse (Eds.), Photonic Instrumentation Engineering VIII [116930L] (Proceedings of SPIE; Vol. 11693). SPIE.
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Ahmed, J., Xie, S., Liang, B., Yi, X., Jin, X., Kesaria, M., David, J. P. R., & Huffaker, D. L.
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Simultaneous multi-spectral, single-photon fluorescence imaging using a plasmonic colour filter array.
Connolly, P. W. R., Valli, J., Shah, Y. D., Altmann, Y., Grant, J., Accarino, C., Rickman, C., Cumming, D. R. S., & Buller, G. S.
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Polarization-resolved supercontinuum generated in a germania-doped photonic crystal fiber.
Couture, N., Ostic, R., Reddy, P. H., Kar, A. K., Paul, M. C., & Menard, J. M.
Journal of Physics: Photonics, 3(2), [025002].
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Resonance Fluorescence from Waveguide-Coupled, Strain-Localized, Two-Dimensional Quantum Emitters.
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In: npj Quantum Information, 7, [56]. https://doi.org/10.1038/s41534-021-00389-z

Improved insights in time-resolved photoelectron imaging.
Kotsina, N., & Townsend, D.
In: Physical Chemistry Chemical Physics. https://doi.org/10.1039/d1cp00933h

Systematic study of the emission spectra of nanowire quantum dots.
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