IOP | Institute of Physics
Plasma Physics Group

# UK Plasma Physics News – Summer 2021.

*Welcome to the UK IOP Plasma Physics Group (PPG) e-newsletter. If you have items for inclusion in future newsletters e.g. any meeting announcements or reports, research achievements, new appointments, facilities, projects, buildings etc. please contact: ken.mcclements@ukaea.uk.*

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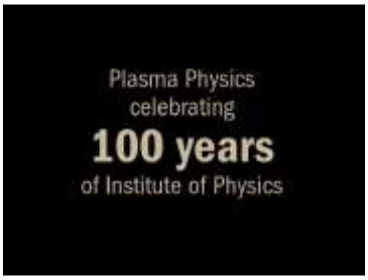
## COMMITTEE NEWS

There have been two committee meetings and one AGM since the last newsletter. Further details of committee activity and actions are available on the Group website.

## RECENT MEETINGS

### 47th IOP Plasma Physics Conference


Plasma Physics
celebrating
100 years
of Institute of Physics

Animated image (double click for it to work) produced by IOP last year for the conference and for 100 years of the IOP. It is also on the IOP PP Conference website.

The 47th IOP Plasma Physics Conference took place online from 6-9 April 2021 having been postponed from 2020 due to the pandemic. A total of 30 talks were given including the Rutherford Prize talk given by Cara Hawkins and Dr Laura Corner of the University of Liverpool for an episode of the *Liverpool Scientific* podcast, two Culham thesis prize talks given by Dr Ben Chapman of the University of Warwick (for a thesis on modelling of ion cyclotron emission in tokamak plasmas) and Dr Stefan Mijin of Imperial College London (for a thesis on modelling of parallel transport in tokamak scrape-off layer plasmas), and the second Malcolm Haines prize talk given by Dr Rob Shalloo, also of Imperial College (for a paper on automation and control of laser wakefield accelerators using Bayesian optimisation). Participants enjoyed an excellent programme of talks and posters covering all aspects of plasma physics including magnetic confinement fusion, laser-plasma interactions, warm dense matter, technological plasmas and space plasmas. Prizes sponsored by the PPG and the IOP Publishing journal *Plasma Research Express* were awarded for the best two posters presented by students, the winners being Wei Wu (Imperial College London) for a poster on pair production in a thermal bath, and Will Fuller (University of Warwick) for a poster on optimizing the design of a new turbulence probe for MAST Upgrade. The conference also included a session on equality, diversity and inclusion (EDI), organised and chaired by PPG committee member Dr Kirsty McKay, and an online social evening which was centred around a pub-style physics-themed quiz hosted by PPG committee member Greg Daly. The PPG committee thanks Dr Francisco Suzuki Vidal (Imperial College London), Dr Josie Coltman (AWE and IOP PPG secretary), Dr Lauren Hobbs (AWE) and Ana Santos (IOP) for all the hard work they put in to organising and running this conference. We are also very grateful to the IOP, CCFE, STFC and AWE for their sponsorship and to those who exhibited during the conference (Appleyard Lees, IOP Publishing, The Royal Society Publishing and Quantum Design UK and Ireland).

## FORTHCOMING MEETINGS

TPW 2021: December 2021 in Liverpool, UK. Please contact Dr Mohammad Hasan for any queries.

48th IOP Plasma Physics Conference: 11-14 April 2022 at Merseyside Maritime Museum, Liverpool, UK.

## COMMUNITY NEWS

### AWE

#### NIF-ARC Demonstrates High-Resolution 100 keV X-ray Radiography Source (Matt Hill)

A joint AWE-LLNL team have doubled the resolving power of the hard x-ray radiography used in dynamic material strength experiments in two demonstration shots using the Advanced Radiographic Capability laser at the National Ignition Facility (NIF-ARC).

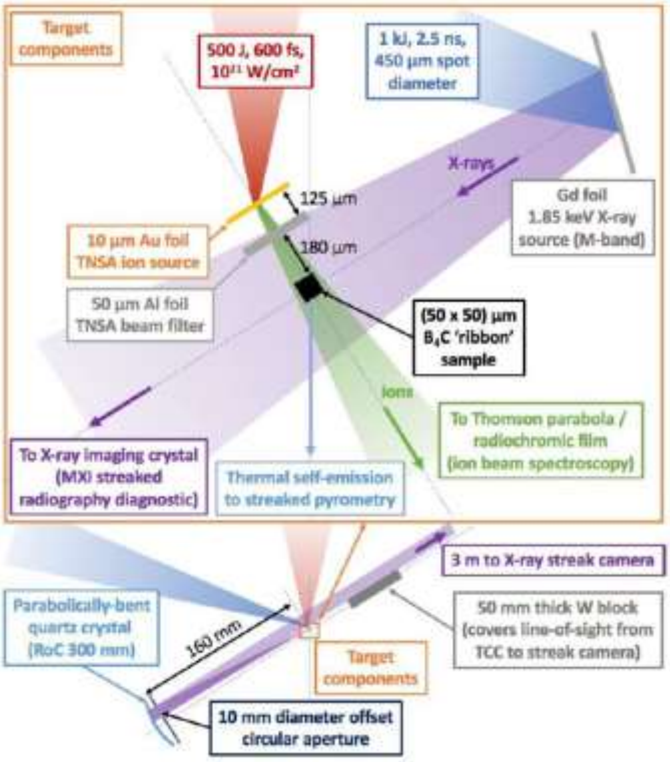
Analysis of the ~100 keV x-ray source, capable of radiographing high-opacity samples such as lead at a resolution of better than 35 µm, was presented at the High Temperature Plasma Diagnostics and APS Division of Plasma Physics virtual conferences at the end of last year and has now been published in the journal Review of Scientific Instruments (M. Hill *et al.*, Rev. Sci. Instrum. 92, 033535 (2021)).

The microscopic Rayleigh-Taylor instabilities that will be imaged using this source at NIF are generated by precisely tuned ramped compressions from either x-ray or direct, shaped-pulse laser ablation. Features evolving at kilometres per second require a fast shutter speed as well as fine imaging resolution and the laser pulse duration of only 10 picoseconds ensures that the NIF-ARC source will suffer no motion blurring in the data it produces. The high intensity of the 2.5 kJ laser pulse (1018 W/cm2) onto a 5 µm-thick dysprosium 'flag' target also ensures that this brief exposure reliably delivers enough hard x-ray dose to study hydrodynamic instabilities in solid materials at pressures exceeding 1 Mbar. Since these experiments only require high resolution along one imaging axis the source is extended in the other axis to increase brightness, clearly visible in the radiograph, although future work may study more compact targets such as microwires to deliver high resolution in both axes.

These shots are an evolution of previous work by the LLNL team led by Hye-Sook Park at the Omega-EP and JasUSP laser facilities in the US and the Vulcan 100 TW and Petawatt lasers at RAL in the UK. Plans are underway to deploy a similar source for experiments at Orion, exploiting the facility's unique super-high-contrast, dual-short-pulse capabilities to further improve performance in both temporal and spatial resolution.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52- 07NA27344. UK Ministry of Defence © Crown Owned Copyright 2021/AWE*

## WDM Campaign in Orion (Colin Brown, Tom Hodge and Emma Floyd)



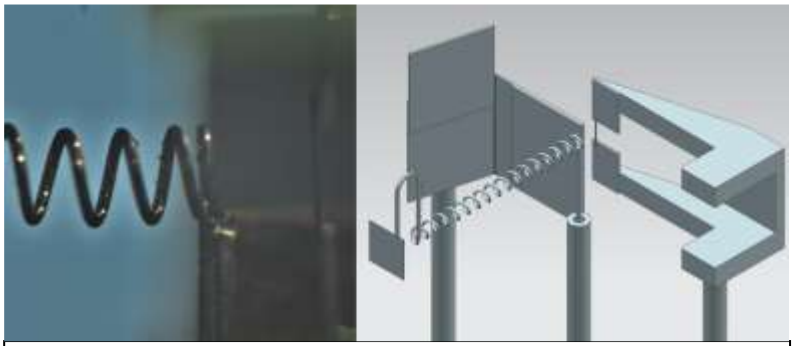
Top-down view of the experimental layout in the Orion target chamber.

The latest campaign in a series of experiments exploring the properties of materials in the “Warm Dense Matter (WDM)” regime, characterized as materials at around solid density and temperatures of a few eV (1 eV ~ 11,000K) was completed at Orion during April 2021.

These experiments exploit the short-pulse/long-pulse capabilities of Orion, using the short-pulse to generate an intense proton beam that is used to heat a sample to the required temperature, rapidly enough that the sample does not expand during the heating phase.

After the material heating, the sample is allowed to expand adiabatically. This expansion is diagnosed through the technique of streaked x-ray radiography, using a spherical crystal imager coupled to an x-ray streak camera. The source of x-rays is generated using three Orion long-pulse beams. Measurement of this expansion is then used to infer the equation of state of the material along an adiabat defined by the initial temperature and density of that material.

The initial density is determined by pre-shot metrology, whereas the initial temperature is measured during the experiment using ultrafast streaked optical pyrometry with picosecond temporal resolution, which was improved on for this campaign by modifying the viewing angle with a redirection mirror. This modification was largely successful, providing clean pyrometry data that was much easier to interpret. Together the initial density and temperature measurements can then be used to compare with models developed by the high-temperature material modelling team.



Left: Coil target as fired in the WDM campaign.
Right: Isometric view of the WDM target assembly with coil target.

The campaign changed the proton generating source to incorporate a focussing coil, building off the work of Kar et al. Such an addition provides a mechanism to both focus the protons at a specific energy, tailoring the characteristics of the proton beam and increase the separation between the laser target and sample, reducing the observed background on the pyrometry diagnostic.

Early results from the campaign look promising with high quality data from the streaked optical pyrometry system recorded along with a number of x-ray radiographs. The coil targets also demonstrated heating of the sample; the first time this technique has been used to heat a secondary sample. Further analysis of these results will be required to interpret the results before assessing the captured data and providing that data to the modelling team.

## UKAEA

### JET defies pandemic to have record-breaking year

In 2020 plasma physicists and engineers worked around the clock to achieve high performance in Europe's flagship fusion device, the Joint European Torus (JET), despite ongoing challenges posed by the global pandemic. Early on in 2020, prior to the pandemic, a number of engineering upgrades on JET were successfully completed. Work then followed on JET experiments, with the focus on developing high performance plasma scenarios ahead of experiments using tritium fuel, but this was halted because of the first national lockdown.

When work on JET restarted it was with the good news that months of painstaking work to rectify problems with JET's new Exhaust Detritiation System (EDS) had been successfully completed. The EDS is a safety system which detritiates exhaust gases, and was required for subsequent tritium experiments. This major EDS achievement meant that for the first time in three years the system was now connected to JET's Active Gas Handling System (AGHS), which enables tritium to be recovered from the plasma exhaust, processed, measured and stored for re-injection, crucial to allow plasma scientists to experiment with tritium.

Further uplifting news followed as the experimental campaigns posted record plasma performance and heating power with scientists able to call upon the required 30+ MW of Neutral Beam Injection (NBI) heating power from the very first day of experiments after the outage earlier in the year (unprecedented in the history of JET). This meant that records for the total heating power into JET were quickly broken – another accomplishment to celebrate.

Another key success of these campaigns was demonstration that the newly installed Shattered Pellet Injector (SPI) could be an effective part of the ITER protection systems, in particular to mitigate disruptions (very high electromagnetic loads on the tokamak) and runaway electrons which can significantly damage internal structures if not suitably controlled.

The next significant step was completion of commissioning in AGHS, thus meeting a major contractual milestone – that of being 'ready to expand the tritium boundary'. Essentially this ensures that tritium can be moved from the AGHS to the torus and to the neutral beam injection boxes. Before expanding the tritium boundary, the scientific team on JET moved on to the DT rehearsal phase – a point at which systems and procedures for moving tritium to the torus were tested and trialled.

In September, new JET plasma scenarios achieved levels of deuterium fusion power, measured by the production of deuterium-deuterium (DD) fusion neutrons, that were comparable with the best previously reported for pure deuterium plasmas in JET. The previous DD fusion record had stood for many years and this was the first time that such high performance had been achieved with a metal (beryllium and tungsten) first wall – the same materials that will be used in ITER.

In December 2020 JET was then able to start to experiment with tritium pulses in the machine. This was the first time since 1997 that significant quantities of tritium have been used in JET plasmas. Further tritium commissioning of the neutral beams heating system was then carried out. Joe Milnes, JET Operating Contract Senior Manager, said: "Achieving most of these very challenging milestones while figuring out how to remotely operate the biggest and most complicated tokamak in the world, and doing this safely with less than a tenth of the JET workforce based on site, is something the team should be immensely proud of."

**First results from MAST Upgrade point to solution to one of fusion's most challenging problems**

Plasma physicists at UKAEA have successfully tested a world-first concept that could clear one of the major hurdles in developing fusion energy. Initial results from UKAEA's MAST Upgrade experiment have demonstrated the effectiveness of an innovative plasma exhaust system designed to make compact fusion power plants commercially viable. A key challenge in getting tokamaks on the electricity grid is removing excess heat produced during fusion reactions. Without an exhaust system that can handle this intense heat, materials will have to be regularly replaced, significantly affecting the amount of time during which a power plant could operate.

The new system, known as a 'Super-X divertor', was invented by researchers at the University of Texas and is being trialled for the first time on MAST Upgrade. It could allow plasma-facing components in future commercial tokamaks to last for much longer, greatly increasing the power plant's availability, improving its economic viability and reducing the cost of fusion electricity. Tests on MAST Upgrade, which began plasma operations in October 2020, have demonstrated at least a tenfold reduction in the heat flux on materials with the Super-X system. This is a game-changer for achieving fusion power plants that can deliver affordable, efficient electricity.

UKAEA is planning to build a prototype fusion power plant – known as STEP (Spherical Tokamak for Energy Production) – by the early 2040s. The success of the Super-X divertor is a huge boost for engineers designing the STEP device, as it is particularly suited to the spherical tokamak. The results were announced at the official opening of the MAST Upgrade facility on May 26 2021, where guest of honour, British astronaut Tim Peake, ran a plasma test on the machine.

UKAEA's Lead Scientist at MAST Upgrade, Andrew Kirk, said: "These are fantastic results. We built MAST Upgrade to solve the exhaust problem for compact fusion power plants, and the signs are that we've succeeded. Super-X reduces the heat on the exhaust system from a blowtorch level down to more like you'd find in a car engine. This could mean it would only have to be replaced once during the lifetime of a power plant. It's a pivotal development for the UK's plan to put a fusion power plant on the grid by the early 2040s – and for bringing low-carbon energy from fusion to the world."

### General Fusion to build Fusion Demonstration Plant at Culham

In June 2021 UKAEA and General Fusion announced an agreement under which General Fusion will build and operate its Fusion Demonstration Plant (FDP) at UKAEA's Culham Campus. General Fusion will enter into a long-term lease with UKAEA following construction of a new facility at Culham to host the FDP. The FDP will demonstrate General Fusion's proprietary Magnetized Target Fusion (MTF) technology, paving the way for the company's subsequent commercial pilot plant. The MTF approach is different to the tokamak approach used, for example, in JET, MAST Upgrade and ITER, but UKAEA and General Fusion expect to collaborate on a range of technologies of mutual interest.

General Fusion will benefit from the cluster of fusion supply chain activities in the UK, centred on UKAEA's globally recognised expertise and presence in the field. This is also an exciting and very positive development for UKAEA and the Culham site, strongly aligned with UKAEA's mission and the development of the Culham site as a leading location for developing fusion energy. The announcement was made by Amanda Solloway MP, Science Minister for the UK Government, who said: "This new plant by General Fusion is a huge boost for our plans to develop a fusion industry in the UK, and I'm thrilled that Culham will be home to such a cutting-edge and potentially transformative project. Fusion energy has great potential as a source of limitless, low-carbon energy, and today's announcement is a clear vote of confidence in the region and the UK's status as a global science superpower."

The Fusion Demonstration Plant at Culham is the culmination of more than a decade of advances in General Fusion's technology and represents a major milestone on the company's path to commercialisation. Construction is anticipated to begin in 2022, with operations beginning approximately three years later. "Coming to Culham gives us the opportunity to benefit from UKAEA's expertise," stated Christofer Mowry, CEO, General Fusion. "By locating at this campus, General Fusion expands our market presence beyond North America into Europe, broadening our global network of government, institutional, and industrial partners. This is incredibly exciting news for not only General Fusion, but also the global effort to develop practical fusion energy."

"This is a great development for UKAEA, very much in line with our mission to lead the development of sustainable fusion energy, and builds on our long heritage of hosting major fusion facilities such as the Joint European Torus," said Ian Chapman, CEO of UKAEA.

## IMPERIAL COLLEGE/CLF

### Artificial intelligence improves control of powerful plasma accelerators (Haley Dunning)

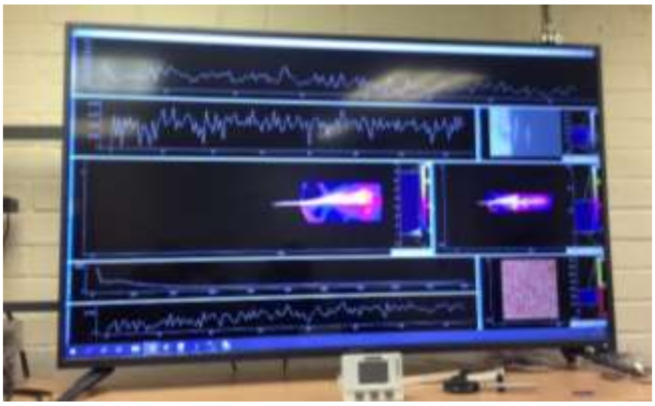


Image of live data being taken on the experiment, with optimization algorithm live in action!

Researchers have used artificial intelligence (AI) to control and optimise the performance of a laser plasma accelerator – a novel particle accelerator with a promising future as a smaller, cheaper alternative for accelerator-based research, as well as for applications in medicine and industry.

Experiments led by researchers at Imperial College London, using the Science and Technology Facilities Council's Central Laser Facility (CLF), showed that an algorithm was able to tune the many parameters involved in controlling the next generation of plasma-based particle accelerators to improve their performance.

The algorithm was able to optimise the accelerator much more quickly than a human operator, and could even outperform experiments on similar laser systems. Several facilities using these new accelerators are in various stages of planning and construction around the world, including the CLF's Extreme Photonics Applications Centre (EPAC) in the UK, and this new development could help to quickly optimise these systems in the future, increasing beam time for applications.

The results are published in *Nature Communications*. The first author of this paper, Dr Rob Shalloo, who was awarded this year's Malcolm Haines Prize for this work, said: "The techniques we have developed will be instrumental in getting the most out of a new generation of advanced plasma accelerator facilities under construction within the UK and worldwide. Plasma accelerator technology provides uniquely short bursts of electrons and X-rays, which are already finding uses in many areas of scientific study. With our developments, we hope to broaden accessibility to these compact accelerators, allowing scientists in other disciplines and those wishing to use these machines for applications, to benefit from the technology without being an expert in plasma accelerators."

Because wakefield accelerators operate in the extreme conditions created when lasers are combined with plasma, they can be difficult to control and optimise to get the best performance. Both the laser and plasma have several parameters that can be tweaked to control the interaction, such as the shape and intensity of the laser pulse, or the density and length of the plasma. While a human operator can tweak these parameters, it is difficult to know how to optimise so many parameters at once. Instead, the team turned to artificial intelligence, creating a machine learning algorithm to optimise the performance of the accelerator. The algorithm set up to six parameters controlling the laser and plasma, fired the laser, analysed the data, and re-set the parameters, performing this loop many times in succession until the optimal parameter configuration was reached. Lead researcher Dr Matthew Streeter said: "Our work resulted in an autonomous plasma accelerator, the first of its kind. As well as allowing us to efficiently optimise the accelerator, it also simplifies their operation and allows us to spend more of our efforts on exploring the fundamental physics behind these extreme machines."

The team demonstrated their technique using the smaller Astra laser system at the CLF, but have already begun to use it in further experiments on the larger Gemini laser facility to help improve the performance of the electron beams that will be used in a wide range of different experiments.

## UK PLASMA PHYSICISTS CONDUCTING RESEARCH IN CHINA

UK scientists have gained academic access to Chinese high-power laser facilities and have published results demonstrating successful collaboration between UK and China on the Shenguang-II (SG-II) laser facility.

A team from Imperial College London has been investigating the formation of radiative shocks on the SG-II laser at the Shanghai Institute of Optics and Fine Mechanics (SIOM). These experiments are relevant to the formation of these types of shocks in astrophysical scenarios involving supersonic flows such as supernova remnants and protostellar jets. This collaboration is supported by The Royal Society and includes researchers from the UK, France, Czech Republic and China with expertise in experimental plasma physics, theoretical physics and laser science, together with data analysis carried out by students at Imperial College London.

A recent publication in the journal *High-Power Laser Science and Engineering* presents the first results from two campaigns in 2018 and 2019 showing experimental data on the evolution of the shock with point projection X-ray backlighting together with comparison with numerical simulations. The team plans to return to SG-II in early 2022 to build on these first results.

The collaboration has been led by Dr Francisco Suzuki-Vidal who said: “It has been an amazing experience to collaborate with our colleagues from SIOM. They have made us feel very welcome in their lab and have worked very hard to make our experiments happen. Personally, this has been a very rewarding experience not only scientifically but also culturally.”

A team from Queen’s University Belfast (QUB) has also accessed the SG-II laser facility in collaboration with colleagues from the Beijing Normal University and SIOM. They carried out experiments to calibrate X-ray sources for use in photo-ionised plasma experiments and then applied them to gas-cell targets filled with Ar. A recent publication in *Plasma Sources and Technology* shows the results of this initial campaign, which they hope to extend after travel restrictions are lifted.

Professor David Riley (QUB) said: ‘We very much enjoyed working with our Chinese colleagues from the Beijing Normal University and SIOM in Shanghai. We were hugely impressed by the speed and comfort of the train from Beijing to Shanghai and the hospitality of our hosts allowed us to very much enjoy a taste of Chinese culture, history and of course the excellent cuisine!’.

## NEW BOOK ON WARM DENSE MATTER

Professor David Riley has recently produced a new book on Warm Dense Matter (WDM), which covers topics on the generation of WDM via laser driven shocks and x-ray sources, explosives, gas guns and ion beams, as well as x-ray free electron lasers. He also discusses principal optical and x-ray diagnostics. The book can be found online here and is part of the IOP Series in Plasma Physics.

## ROYAL SOCIETY SPECIAL ISSUES

Royal Society Publishing has published special issues of *Philosophical Transactions A* entitled **Prospects for high gain inertial fusion energy** (part 1) and **Prospects for high gain inertial fusion energy** (part 2) organised and edited by P A Norreys, C P Ridgers, K L Lancaster, M Koepke and G Tynan. The articles can be accessed directly at www.bit.ly/TransA2184 and www.bit.ly/TransA-2189. Print issues can be purchased at the reduced price of £35 each by contacting Debbie.vaughan@royalsociety.org. They are also looking for new themed issues: if you are interested in submitting any, please visit the website or contact the Editorial Office for more information at philtransa@royalsociety.org.

## PRIZES AND AWARDS

### Rutherford Prize for the Communication of Plasma Physics 2021 (sponsored by STFC)

The Rutherford Plasma Physics Communication Prize is an annual award sponsored by STFC Central Laser Facility and hosted by the IOP Plasma Physics Group.

The award recognises those who exemplify excellence in outreach to the general public through the communication of plasma physics to those that are non-experts and is open to ALL members of the plasma physics community, whose application is judged by a distinguished panel of scientists and communicators (including one plasma physicist, one non-plasma physicist and one non-physicist).

This year's winner is an episode of ‘The Liverpool Scientific’ created and hosted by Cara Hawkins and featuring Dr Laura Corner as guest interviewer.

The episode was S1 E7: Accelerator Science with Laura Corner. The podcasts can be found on Spotify and there is also an account on twitter. They received a prize of £500 and gave an invited talk at the annual IOP plasma physics conference.

### Culham Thesis Prize (sponsored by CCFE) 2021

The Culham Thesis Prize is an annual award sponsored by Culham Centre for Fusion Energy (CCFE) and jointly coordinated by CCFE and the IOP Plasma Physics Group.

The Culham Thesis Prize is awarded to the candidate who has displayed the highest degree of excellence in the execution of the scientific method as witnessed by the award of Doctor of Philosophy in plasma science from a UK or Irish university in the last two calendar years.

The thesis content should exhibit significant new work and originality, clearly driven by the nominee, be well explained and demonstrate a good understanding of the subject.

This year's winner is Dr Stefan Mijin from Imperial College London for his thesis on modelling of kinetic effects in parallel transport in the tokamak scrape-off layer.

He received a prize of £500 plus gave an invited talk at the annual IOP plasma physics conference. Congratulations Stefan!

**Malcolm Haines Prize 2021**

The Malcolm Haines Prize is a biennial award funded by Malcolm Haines' widow, Polly Haines and hosted by the IOP Plasma Physics Group, which has been awarded for the second time.

The Malcolm Haines Prize was created in honour of the late Malcolm Haines, an outstanding plasma physicist at Imperial College London. It recognises early researchers for outstanding research carried out in the UK or Ireland, leadership and/or innovation in any area of experimental or theoretical plasma physics. A panel of experts is appointed to act as judges for the prize.

The winner of the second Malcolm Haines Prize is Dr Rob Shalloo from Imperial College London.

The award is in recognition of his research on the automation and control of laser-wakefield accelerators using Bayesian optimisation. He received a prize of £500 and gave a talk at the annual IOP plasma physics conference. Congratulations Rob!