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FUSING DIFFERENT AREAS OF PLASMA RESEARCH

In probing the fourth state of matter, researchers found **SURPRISING CROSS-OVERS IN DIFFERENT BRANCHES** of plasma research.

Ninety-nine per cent of visible matter in the Universe is plasma. This fourth fundamental state of matter is important not just because it is so commonly found, but also because plasma technologies are in such ubiquitous use, including electrical engineering, industrial machinery, food security, and biomedical and ecological applications.

The Advances and Applications in Plasma Physics conference at the St Petersburg Polytechnic University (SPbPU) in September 2019 was the first *Nature* conference to be held in Russia. It was also unusual in combining the different strands of plasma research. “The conference is intended to provide a platform for experts from different fields of plasma physics and from different regions and countries,” said Pavel Goncharov, one of the organizers from SPbPU. “I hope this event will contribute to push the front lines of plasma research.”

Fusion

Nuclear fusion provides the Sun’s energy, and recreating nuclear fusion on Earth is anticipated to be a future source of cheap, clean energy. But there are many challenges to overcome before we can realize a viable commercial fusion reactor.

In order to get the atomic nuclei to fuse, the plasma ‘fuel’ must be confined at high temperature and pressure, typically achieved with powerful magnetic fields. There are two leading designs of experimental fusion reactor, tokamak and stellarator, which have different configurations.

Vladimir Rozhansky, head of the Laboratory of Controlled Thermonuclear Fusion at SPbPU, and a conference organizer, described one of the most challenging engineering problems presented by tokamaks. The plasma is confined by magnetic fields in a doughnut-like torus shape, but heavier ‘exhaust’ elements from the so-called scrape-off layer (SOL) hit the divertor plate. “Plasma generates in the order of 100 MW of power, but the divertor plates can only cope with 10 MW per square metre,” he explained. “At the moment it’s unclear how to organize the edge of the reactor so that it can work in real situations.”

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VITALY SERGEEV

Rozhansky said he is looking to the Sun for inspiration. “In the main part of the chromosphere, plasma is only very slightly ionized. Then there’s a transition region, where temperature increases dramatically. We can try to use this as a model.”

Stellarators are also doughnut-shaped, but use magnetic fields generated by twisted coils, meaning they are not symmetrical around their central axis. Josefine Proll, an assistant professor in the Department of Applied Physics at Eindhoven University of Technology in the Netherlands, explained that stellarators’ advantage is that the magnetic field created by the coils is sufficient to confine the plasma, so they can operate in a steady state, unlike the pulses required by tokamaks. But the asymmetry means that some stellarators have issues with trapped particles drifting radially outwards.

Proll outlined a variety of stellarator field designs that can address particle drift. Germany's Wendelstein 7-X, which has been running since December 2015, uses a quasi-isodynamic configuration. “It's performing really well,” said Proll. “It's a large, complicated machine, with a diameter of around 11 metres. Theoreticians calculated the design specifications down to the millimetre range in order to get the magnetic field right.” Building the W7-X was a triumph of physics, theory and engineering. “The magnetic field is as-calculated, and the particle drifts are low. The results are impressive,” she added.

Private firms are also interested in fusion. Tokamak Energy Ltd is one of around 19 companies racing to develop a commercial reactor. Mikhail Gryaznevich, chief scientist at Tokamak Energy, based in Oxfordshire UK, described the seven-year-old company's ST40 spherical tokamak as “an apple without a core”. ST40 has a diameter of only 0.8m and a toroidal field of 1 Tesla. Its next tokamak will get to 3T. Tokamak Energy aims to demonstrate controlled fusion power by 2025.

By contrast, the International Thermonuclear Experimental Reactor (ITER) — a multi-billion dollar collaboration to build a tokamak reactor in France — started in 2007, broke ground in 2013, and is “65% of the way towards ‘first plasma’,” said the head of ITER's Tokamak Engineering Department, Alexander Alekseev. The plan is to reach full fusion power in 2035.

Clockwise from top: the opening of the Advances and Applications in Plasma Physics conference at St Petersburg Polytechnic University; Vladimir Rozhansky outlines progress with tokamaks; Clare Watt talks about plasma and space weather; Hubertus Thomas examines a poster; and Josefine Proll, describes stellarator designs.

Tokamak Energy has the potential to move faster than ITER, but some are sceptical. “We've heard this before,” said Proll. “There are a lot of small companies who have said they can do it faster, and most have yet to deliver. But it's great that other promising concepts are being explored.”

Beyond fusion

There is more to plasma research than fusion, however. Paul McKenna, professor of Laser-Plasma Physics at the University of Strathclyde, Glasgow, explained that plasmas can be used as a medium for particle acceleration. A conventional radio-frequency particle accelerator involves a potential difference between electrodes, creating an acceleration field. The field strength is limited by the electrical breakdown and therefore long accelerators are required to reach high particle energies. Plasma structures can be produced that sustain higher electric fields, by 3–4 orders of magnitude, opening the possibility for compact particle accelerators to be created, he explained.

Hubertus Thomas, group leader at the Institute of Materials Physics in Space at the German Aerospace Center, talked about creating ‘plasma crystals’, which seems counter-intuitive. “You have the most disordered state of matter, that is plasma,” he said, “and then you're talking about the most ordered state — crystals.”

Compared with the atoms in traditional crystals, the nodes in plasma crystals are relatively large dust particles. “The plasma surrounds the crystal structures and forms a charge-neutral medium,” he explained. At such a macro level, plasma crystals can be useful models for otherwise unobservable processes. “You can see crystals at the individual particle level.” Studying dusty plasmas on Earth is extremely difficult as gravity interferes. Consequently, most insights have come from experiments on the International Space Station.

Still in space, Clare Watt, an associate professor in the Department of Meteorology at the University of Reading, UK, investigates how space weather affects the plasma in the Van Allen belts. These are where the Earth's protective magnetosphere traps energetic charged particles from the Sun. This type of plasma is different from the others discussed, she said. “My plasma is natural, not in a box. There are very few collisions, and it does not contain much dust or other contaminants. It's a very good, textbook plasma.” Understanding it is also important for the world's increasing use of satellite technology. “If you're designing a satellite, then you will want to know about the climate of the region it will be in.”

Combining all the plasma specialities had several advantages. “It was really nice to see lots of engagement from young physicists and their interaction with world's best researchers in the field,” said SPbPU vice-rector for research, Vitaly Sergeev.

And it was not just students who enjoyed exposure to the range of plasma research. “Quite often you are in a talk about something slightly outside your area, and you see a technique being applied in a certain way,” said McKenna, “and you think ‘I can adopt and apply that in my science’.”

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