Unprecedented level of insight into plasma edge phenomena

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Credit: AI-generated image (disclaimer)

Producing energy and heat using plasma fusion is one of the promising technologies for the transition to sustainable energy sources. One of the challenges is managing the temperatures in the plasma edge. Ph.D. researcher Artur Perek has built an imaging system known as MANTIS to image and monitor temperature in the plasma edge, and he has

improved the software performance to enhance control of plasma edge temperatures. Perek defended his thesis at the department of Applied Physics on April 13th.

Low-carbon power generation is one of the challenges of the 21st century. Nuclear fusion, the sun's energy-producing process, is one of the envisaged solutions for base-load power generation independent of weather conditions.

On Earth, the conditions for fusion can be recreated in magnetic confinement devices. When the right conditions are met, the heat generated by fusion reactions can maintain the plasma temperatures. Once successful in generating fusion power, the safe power exhaust becomes a challenge.

Plasma edge temperature challenges

The plasma edge is shaped to create a Scrape-Off Layer (SOL) around the plasma core, which diverts heat and charged particles escaping the core to a dedicated part of the machine called the divertor. Unmitigated heat-fluxes will melt the divertor target surfaces within seconds of operation at full power. The SOL must be operated in a detached regime in which heat and particle fluxes reaching the divertor target are reduced to protect those components. The divertor detachment can be achieved by increasing the neutral gas pressure in the divertor and enriching the plasma with impurities to radiate the power away.

Overcooling of the SOL can negatively affect core plasma performance. On the other hand, undercooling can damage the plasma-facing components. Between those extremes, there is an optimum in which both the core and the divertor requirements are satisfied. To find this optimum, Artur Perek built a Multispectral Advanced Narrowband Imaging System (in short, MANTIS) within a collaboration between

DIFFER, EPFL and MIT.

"My Ph.D. involved solving problem after problem. Luckily, I really enjoy solving problems," Perek adds. "When I started my Ph.D., the components of the camera were ordered and piling up. My goal was to build it, install it on the Swiss TCV Tokamak of EPFL (École Polytechnique de Lausanne), and enable its use for control."

It can simultaneously image ten spectrally narrow bands of light through a single pupil. The bands were selected to capture photons originating from atoms in the plasma edge that correspond to transitions between their excited states.

Vision-in-loop reactor control

Combining those measurements with the camera view geometry and the state-of-the-art modeling of the plasma emission yielded 2D maps of plasma parameters such as the electron density and temperature. These maps provide insights into the state of the Scrape-Off Layer (SOL) and the physics behind it. The data allowed for comparisons between SOL models and experiments in unprecedented detail, pinpointing where the models deviate from experiments and vice-versa.

The MANTIS camera is a high quality, high-performance apparatus, but the software that came with it was not designed to match this performance. "We analyze the plasma 800 times per second. The software turned out to be too slow to keep up with this, so I decided to improve it." Perek built a software exploit that bypassed the original software and improved microsecond stability.

MANTIS is not just a camera; it is also part of the real-time reactor control system. It can provide controllers with information about the plasma edge state to balance the SOL cooling while avoiding

unnecessary degradation of the plasma core performance. Perek explains: "MANTIS actually has ten cameras, not just the one we use. Using them all would drastically improve detachment control, but it requires far faster models."

The images provided an unprecedented insight into the plasma edge phenomena used for model validation. Therefore, this research is essential for validating 2D SOL models with 2D diagnostics to strengthen their predictive power for future machines. It also shows that vision-in-the-loop can be used to control the power exhaust of a nuclear fusion reactor.

More information: Development and application of quantitative multispectral imaging in nuclear fusion research. research.tue.nl/en/publication … ultispectral-imaging

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