Scientists develop a new tool for measuring radio waves in fusion plasmas

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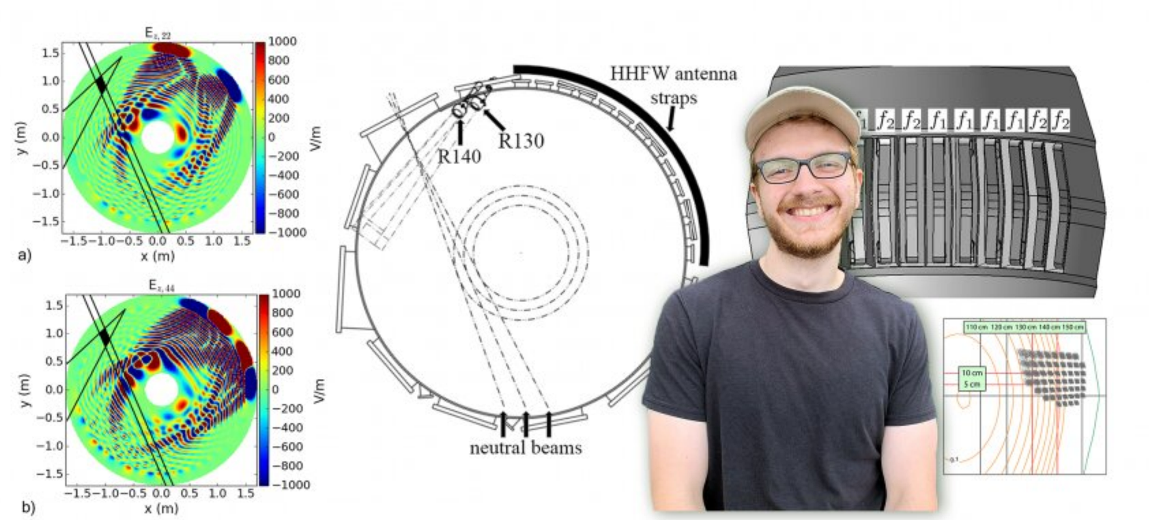

Physicist Grant Rutherford with images from his paper. Credit: Natalie Rugg, collage by Elle Starkman/Office of Communications

Scientists seeking to bring to Earth the fusion energy that drives the sun and stars use radio frequency (RF) waves—the same waves that bring radio and television into homes—to heat and drive current in the plasma that fuels fusion reactions. Scientists now have developed a path-setting way to measure the waves that could be used to validate predictions of their impact, setting the stage for enhanced future experiments that could result in bringing energy from fusion to Earth.

Potential breakthrough

The potential breakthrough, led by researchers at the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL), could lead to follow-up experiments on the National Spherical Tokamak Experiment-Upgrade (NSTX-U), the flagship fusion experiment at PPPL that is undergoing repair, as well as other fusion facilities around the world. "If our method turns out to work it would be a very useful tool for many fusion reactors," said Grant Rutherford, a first-year graduate student at the Massachusetts Institute of Technology (MIT) and lead author of a paper in the *Review of Scientific Instruments* that he wrote as a Brown University DOE Science Undergraduate Laboratory Intern (SULI) at PPPL.

Key to predicting the impact of RF waves is measuring the fluctuations, or swings, they create in the density of fusion plasmas. "Once we have those fluctuations we would be able to work backwards to see what those RF fields were that created the fluctuations," Rutherford said.

However, the high frequency of RF waves causes the swings to occur too rapidly to measure. So the researchers created a "beat wave" by launching two waves at different frequencies, a technique that produced measurable swings. "If we were able to both create a beat wave fluctuation and measure it, we would have a new tool for validating predictions for RF heating and current drive," Rutherford explained.

Such measurements would have wide-ranging benefits. For example, they could facilitate study of the performance of RF wave actuators, said PPPL physicist Nicola Bertelli, a co-author of the paper, and could enable validation of RF calculation tools developed throughout the fusion community. Moreover, said David Smith, a University of Wisconsin physicist and co-author of the paper, "Our calculations provide an initial assessment of the technique and motivate follow-up experiments on NSTX-U."

Fusion reactions combine light elements in the form of plasma— the hot, charged state of matter composed of free electrons and atomic nuclei that makes up 99 percent of the visible universe—to generate massive amounts of energy. Reproducing and controlling this process on Earth would create a virtually inexhaustible supply of safe and clean power to generate electricity. Fusion could become a major contributor to the U.S. transition from fossil fuels to a low-carbon source of electrical generation.

Testing the technique

Rutherford and co-authors tested their technique by creating a synthetic version of a 2D beam emission spectroscopy (BES) diagnostic to evaluate simulated RF injections into the plasma. Their aim was to understand and improve the ability to measure the RF field waves that create the swings.

Going forward, "We're hoping that by increasing our ability to measure, we will increase our ability to understand heating and current drive processes, but we're leaving that to future work," Rutherford said. Such work could also show whether the BES diagnostic the scientists based their model on could measure the density swings in actual fusion plasmas, or whether some other diagnostic would do the critical job better.

More information: Grant Rutherford et al, Scoping study of detecting high harmonic fast waves in NSTX-U hot core plasma directly using

beam emission spectroscopy, *Review of Scientific Instruments* (2021).
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