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Fusion Scientists Find Inspiration in Earth's Ionosphere

Electromagnetic whistling shows promise for relieving an ailment of fusion-energy experiments.

MILWAUKEE, Wis.—For more than a century, mysterious electromagnetic waves that are generated naturally in the Earth's ionosphere have been detected over telephone lines, antennas, and radios. They are named "whistlers" from the fact that when converted into sound, the signals are in the human auditory range and sound like someone whistling with varying pitch. The natural whistler waves are now extensively studied in-situ by satellites. They play important roles in space weather and in the regulation of the Earth's Van Allen belts.

Recently, scientists at General Atomics in San Diego, California created whistler waves in the DIII-D fusion-science facility (Figure 1). Dr. Donald Spong of Oak Ridge National Laboratory and colleagues analyzed the laboratory observations with the help of computer simulations. The experiments are supported under the U.S. Department of Energy Frontier Science program, which focuses on connections between the physics of natural and laboratory plasma. Here, "plasma" refers to gas so hot that atoms dissociate into electrons and ions.

Like ionospheric whistler waves, DIII-D's whistlers are driven by very energetic electrons. These electrons, known as runaways, can be produced in donut-shaped "tokamak" plasma configurations, like DIII-D, by electric fields that arise during rapid transient thermal events.

Plasmas have an unusual feature—collisional drag decreases with increasing velocity, which allows energetic electrons to freely accelerate to nearly the speed of light. According to Spong, "One might think of this decreasing drag with increasing velocity as a skydiver's worst nightmare, since the skydiver depends on increasing drag with speed to provide a terminal velocity."

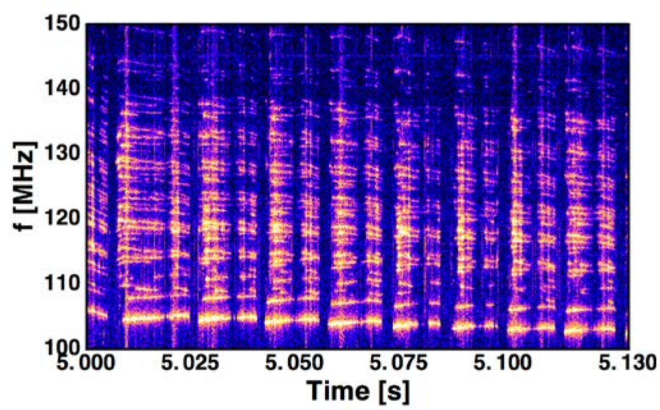

Figure 1: Spectrogram of whistler wave activity measured in the DIII-D device. Intermittent bursts of activity indicate that whistlers are interacting with relativistic electrons in a cyclic manner. [Courtesy of General Atomics]

Runaway electrons in fusion reactors only reach a terminal velocity due to Einstein's theory of relativity. If they were to escape the plasma in an energy grade fusion reactor, they could cause damage to the surrounding material walls. The DIII-D experiments show that whistler waves driven by runaway electrons modify the runaways in such a way as to redirect some of their energy. An analogous issue underlies ionospheric studies of whistler waves; the ionosphere also contains directed energetic electron components that can damage satellites. The presence of whistler waves is predicted to mitigate these effects.

These experiments demonstrate the excitation and diagnosis of energetic electron driven whistler waves in a new plasma parameter regime. Although the magnetic field, plasma density, and temperature of tokamaks are in a quite different range from ionospheric plasmas, many of the same physical mechanisms are relevant. Producing whistlers in laboratory plasmas allows for more controllable, repeatable studies to be made than is possible for ionospheric plasmas. This feature and the new plasma regime will facilitate validation of whistler models and lead to a deeper physics understanding of whistler wave phenomena.

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Abstract

YI3.00006	First direct observation of runaway electron-driven whistler waves in tokamaks
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