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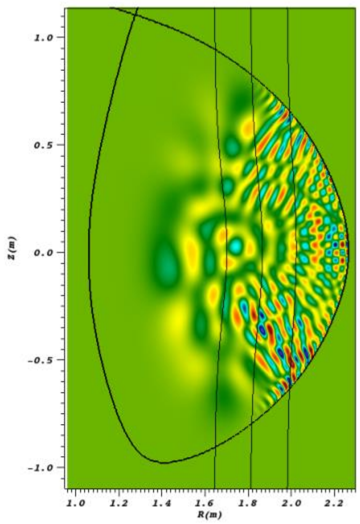
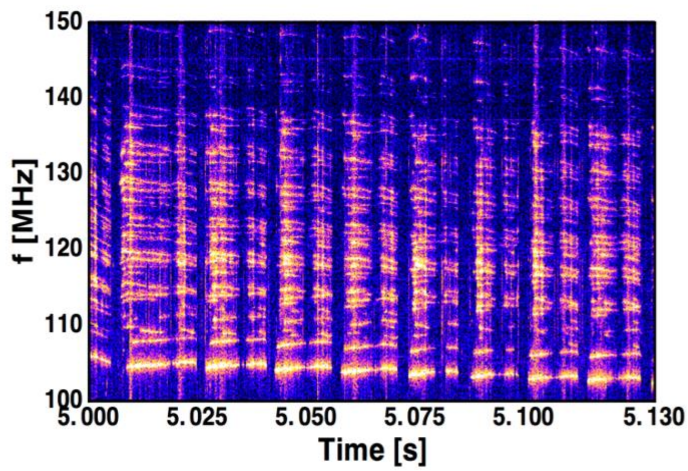
Whistling While You Work: Fusion Scientists Find Inspiration in Earth's Ionosphere

Electromagnetic whistler waves were measured for the first time at the DIII-D National Fusion Facility, which could lead to better control of damaging relativistic electrons in tokamaks.



Cross-section of the tokamak plasma, with colors indicating the predicted intensity and shape of the electric fields arising from a whistler wave.



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.

Images courtesy of the DIII-D Team

The Science

The challenge of fusion energy is often equated to capturing – and holding – lightning in a bottle. The analogy is apt because lightning and a fusion energy plasma have a lot in common, including very high temperatures, massive electric charges and extremely complex fluid dynamics. Researchers at the DIII-D National Fusion Facility recently found another characteristic shared between the two types of plasmas: an odd electromagnetic wave known as a whistler. If their theories are correct, the whistler discovery could help better understand runaway electrons in tokamaks and could even help control these destructive particles.

For more than a century, mysterious electromagnetic waves that occur naturally in the Earth's ionosphere – generally caused by lightning – have been detected over telephone lines, antennas and satellites. They were named "whistlers" because of their characteristic time-varying frequencies, which are unmistakable when the signals are converted into sound.

Theorists have for years predicted that whistlers could exist in a tokamak, but experimentalists were never able to directly observe the waves. Recently, however, a team at DIII-D was able to generate extremely diffuse plasmas with a low magnetic field that yielded the characteristic whistling of the electromagnetic oscillations. The researchers believe the whistlers are driven by runaway electrons and may play a role in regulating their generation and evolution.

Runaway electrons develop due to an unusual feature of plasmas – a collisional drag that decreases with increasing velocity. This allows energetic electrons that are in the presence of an electric field in a tokamak to freely accelerate to high energies. Runaway electrons in fusion reactors only reach a terminal velocity as they approach the speed of light, per Einstein’s theory of relativity. These electrons are thus called “runaway” electrons.

To illustrate the oddity of this characteristic, if skydivers experienced the same phenomenon, jumping out of an airplane would always be fatal, since the skydiver depends on increasing drag with increasing speed to provide a terminal velocity.

The Impact

Runaway electrons are a significant concern for future large tokamak devices such as ITER and must be mitigated due to their potential to cause significant wall damage. Multiple approaches for controlling runaways are being explored at DIII-D and other fusion facilities.

Runaway electron-driven whistler instabilities and the wave-induced scattering observed at DIII-D demonstrate that the evolution of runaway electrons may involve more than just classical collisional and radiative processes. This is an important mechanism to include in predictions of runaway generation. It also raises the possibility that externally driven waves in the whistler frequency range could be used to suppress and control runaways. The team intends to pursue this concept by exploring whether a planned high-frequency helicon can be used at DIII-D to stimulate whistler waves. While much work remains to be done, the team thinks there is a possibility that injecting whistlers or similar waves into a plasma could prevent or control runaway electrons by bleeding energy from the particles, which move at relativistic speeds.

Summary

Researchers at DIII-D were able to measure the presence of whistler waves in a tokamak for the first time and are planning to explore how these waves can help understand and potentially control the generation of runaway electrons. If large fluxes of runaways were to escape the plasma in a 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.

A similar idea is being explored in ionospheric studies of whistler waves. Directed energetic electron components are also present in the ionosphere and can damage satellites. Whistler waves are predicted to mitigate these effects in a manner similar to that being explored in tokamaks. Whistlers also play an important role in space weather and the regulation of Earth’s Van Allen belts. The DIII-D experiments provide the first direct evidence that such waves exist in a tokamak and open an exciting new field of exploration that could have critical importance to ITER and other large tokamaks.

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Publications

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Related Links

DIII-D user facility: https://diii-d.gat.com/diii-d/Home