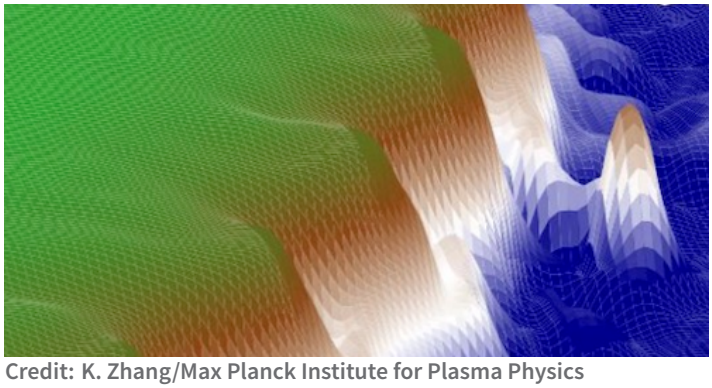
Tapping Tokamak Turbulence

Supercomputer simulations reveal how turbulence supports a Goldilocks regime for operating a fusion reactor.

By **Charles Day**

The type of fusion reactor known as a tokamak uses a doughnut-shaped magnetic field to trap burning plasma. Although high temperatures are needed to sustain fusion reactions, excess heat can threaten the tokamak's metal walls and its other plasma-facing components. Four years ago, researchers at the medium-sized ASDEX Upgrade tokamak at the Max Planck Institute for Plasma Physics in Germany identified a regime—quasicontinuous exhaust (QCE)—that removes excess heat while keeping the plasma tightly confined. Now Kaiyu Zhang and other members of the ASDEX Upgrade team have run simulations on a supercomputer to dissect the physical processes responsible for QCE [**1**]. Zhang says that the team's insights could aid long-term plasma confinement by making it easier for ITER and other larger tokamaks to attain QCE.

Zhang and his colleagues knew that QCE relies on a quasicoherent mode—a wave-like plasma oscillation—that extends across the separatrix, the magnetic boundary between toroidal, plasma-confining field lines and open field lines. To understand how the mode forms and persists, the team ran an electromagnetic turbulence code called GRILLIX on a supercomputer at the High-Performance Computing Center Stuttgart in Germany. Turbulence turned out to be crucial. In the simulations it organized itself into a centimeter-scale oscillation—the quasicoherent mode—at the outer edge of the confined plasma. The wavy pattern extended beyond the separatrix, launching blobs of plasma that carried away heat. The simulations revealed an intricate interplay of two distinct smaller-scale instabilities underlying the turbulent quasicoherent mode. One caused the mode to appear, while a second, acting with the first, caused the blobs to be launched.



Credit: K. Zhang/Max Planck Institute for Plasma Physics

Charles Day is a Senior Editor for *Physics Magazine*.

REFERENCES

1. K. Zhang *et al.*, "Turbulent nature of the quasicontinuous exhaust regime for fusion plasmas," **Phys. Rev. Lett. 137, 055102 (2026).**