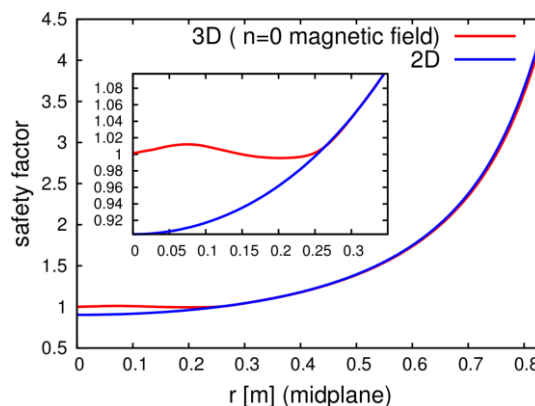
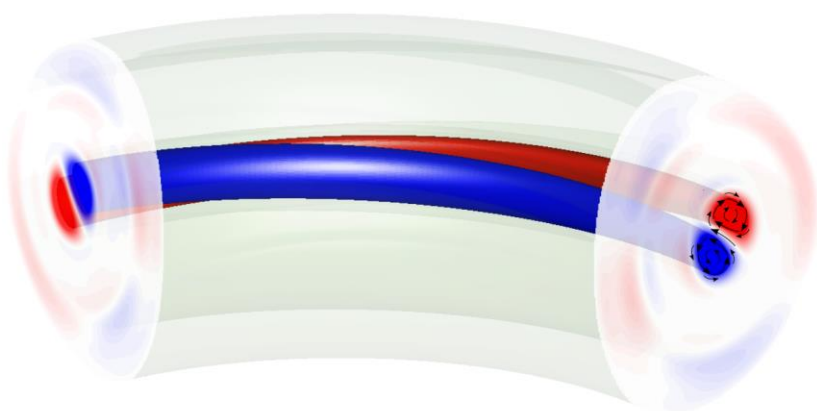


[January] [2018]

Nonlinear simulations of magnetically confined plasmas reveal a self-regulating stabilizing mechanism

[High-performance numerical simulations of magnetically confined plasmas suggest that a mysterious mechanism that prevents instabilities might result from a similar process as that maintaining the earth's magnetic field.]



[Left: Helical plasma flow in the core of a tokamak in a nonlinear simulation. Red depicts positive values and blue depicts negative values of the poloidal velocity stream function. The black arrows are added to illustrate the direction of the plasma flow within a toroidal cross section. (Figure shows a quarter of the torus.) Right: The safety factor profile - which is approximately inversely proportional to the electrical current density - is modified by a 3D effect. (The radial coordinate extends from the center to the edge of the plasma.) Fig. taken from [1].]

The Science

The hot ionized gas called a plasma is confined in a particular kind of doughnut-shaped nuclear fusion experiment called a tokamak by a strong magnetic field, part of which is generated by a strong electric current flowing through the plasma itself. It is very common that a periodically recurring instability, the so-called sawtooth instability that causes the temperature of the plasma to abruptly drop and then recover in a sawtooth pattern limits how much current can be concentrated in the center of the plasma. However, there are types of tokamak plasmas for which a previously unknown mechanism, called “magnetic flux pumping,” limits the current in the plasma center so that it stays precisely just below the sawtooth threshold. Scientists have been puzzled by exactly how this self-regulating mechanism works. The results of highly complex numerical simulations performed by a group of scientists at the Princeton Plasma

Physics Laboratory (PPPL) in collaboration with scientists at the Max Planck Institute for Plasma Physics (IPP) in Germany, now suggest a possible answer.

The Impact

The sawtooth instability can trigger other plasma instabilities, which can lead to the deterioration or even termination of the plasma confinement. This is why so-called hybrid scenarios for tokamaks in which magnetic flux pumping prevents the sawtooth instability are of particular interest, especially for future large-scale fusion experiments like ITER. In order to extrapolate the accessibility and properties of hybrid scenarios to ITER, it is essential to understand the physics behind magnetic flux pumping. With the help of elaborate nonlinear magnetohydrodynamic simulations on high-performance computers, scientists are now able to find a possible explanation for this phenomenon.

Summary

The mechanism behind the magnetic flux pumping in the numerical simulations works as follows: If the central current profile is flat, and if the central plasma pressure is sufficiently high, a so-called quasi-interchange mode develops in the core of the plasma. The quasi-interchange mode generates a large-scale helical flow of plasma that – almost like a mixer – constantly stirs the central plasma. At the same time, the magnetic field in the plasma core is deformed.

This is where a so-called dynamo effect comes in. The dynamo effect is known to play an important role for many astrophysical phenomena as well as for the mechanism that maintains the earth's magnetic field. It describes how a particularly swirly movement of an electrically conducting fluid can reinforce an existing magnetic field. In the case of the earth's magnetic field, the fluid is the liquid part of the earth's iron core. In the case of the hybrid tokamak scenario, the fluid is the hot plasma in the center of the tokamak. In the latter case, it is through a dynamo effect that the helical plasma flow and the helical deformation of the magnetic field combine to give a negative voltage that keeps the central current flat. By keeping the current in the plasma center flat, the sawtooth instability is prevented.

The numerical simulations also explain how this magnetic flux pumping regulates itself: The quasi-interchange mode is known to work best if the central current is at a certain threshold – which coincides with the threshold for the sawtooth instability. Whenever the flux pumping mechanism becomes too strong, it weakens the quasi-interchange mode, and therefore its own drive. This is how the strength of the flux pumping is limited so that it keeps the central current just below the threshold for the sawtooth instability.

Contact

[Isabel Krebs]

[Princeton Plasma Physics Laboratory]

[ikrebs@pppl.gov]

Participating Institutions

[Princeton Plasma Physics Laboratory]

[P.O. Box 451]

[Princeton, NJ 08543]

[Max Planck Institute for Plasma Physics]

[Boltzmannstr. 2]

[D-85748 Garching, Germany]

[Rensselaer Institute of Technology]

[Scientific Computation Research Center]

[110 8th St., Troy, NY 12180]

Funding

[

- DOE Office of Science, Fusion Energy Science DE-AC02- 09CH11466

- DOE Office of Advanced Scientific Computing Research DE-SC0006618

- SciDAC Center for Extended-Magnetohydrodynamic Modeling

- Max-Planck/Princeton Center for Plasma Physics

- The research used resources of the National Energy Research Scientific Computing Center, a DOE Office of Science user facility supported by the DOE Office of Science under contract DE-AC02-05CH11231.

]

Publications

[1]

I. Krebs, S.C. Jardin, S. Günter, K. Lackner, M. Hoelzl, E. Strumberger, N. Ferraro, "Magnetic flux pumping in 3D nonlinear magnetohydrodynamic simulations." *Physics of Plasmas* **24**, 102511 (2017).

[<https://doi.org/10.1063/1.4990704>]

[2]

S.C. Jardin, N. Ferraro, I. Krebs, "Self-organized stationary states of tokamaks." *Physical Review Letters*

115, 215001 (2015). [<https://doi.org/10.1103/PhysRevLett.115.215001>]

Related Links

[--]