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Tearing a magnetic field to heat a fusion plasma

Tearing and reconnection of magnetic field lines, usually counter to the goal of harnessing fusion as an energy source, has been utilized beneficially to heat plasma ions to nearly 30,000,000 °F.

It has long been observed in both laboratory and astrophysical plasmas that the magnetic field lines responsible for confining the plasma can tear apart and reconnect. It has also been observed that tearing and reconnection (usually referred to simply as reconnection) is sometimes accompanied by strong heating of the plasma ions. Reconnection occurs during solar flares, and ion heating caused by this reconnection might explain why the solar corona, the sun's outer atmosphere, is hotter than expected. The physics of reconnection and ion heating is not yet wholly understood, so its occurrence in laboratory plasmas provides a valuable research tool. Substantial ion heating is a key ingredient to harnessing plasma fusion as an energy source, but ion heating by reconnection has not generally been useful for fusion given the relatively small degree of ion heating observed combined with the degradation of plasma confinement accompanying the reconnection. Now, however, scientists have learned how to harness this natural process in a way beneficial for fusion energy research.

In the MST[1] (Madison Symmetric Torus) experiment at the University of Wisconsin-Madison, ion heating by reconnection has been exploited to achieve a nearly six-fold increase in the ion temperature (*see figure*). There are two key steps in this process.[2] First, one produces short-lived, intense reconnection that lasts for only about 1/10,000 of a second but generates millions of watts of ion heating power. Second, one quickly suppresses the reconnection in order to magnetically capture much of the ion heat, resulting in an ion temperature of nearly 30,000,000 °F.

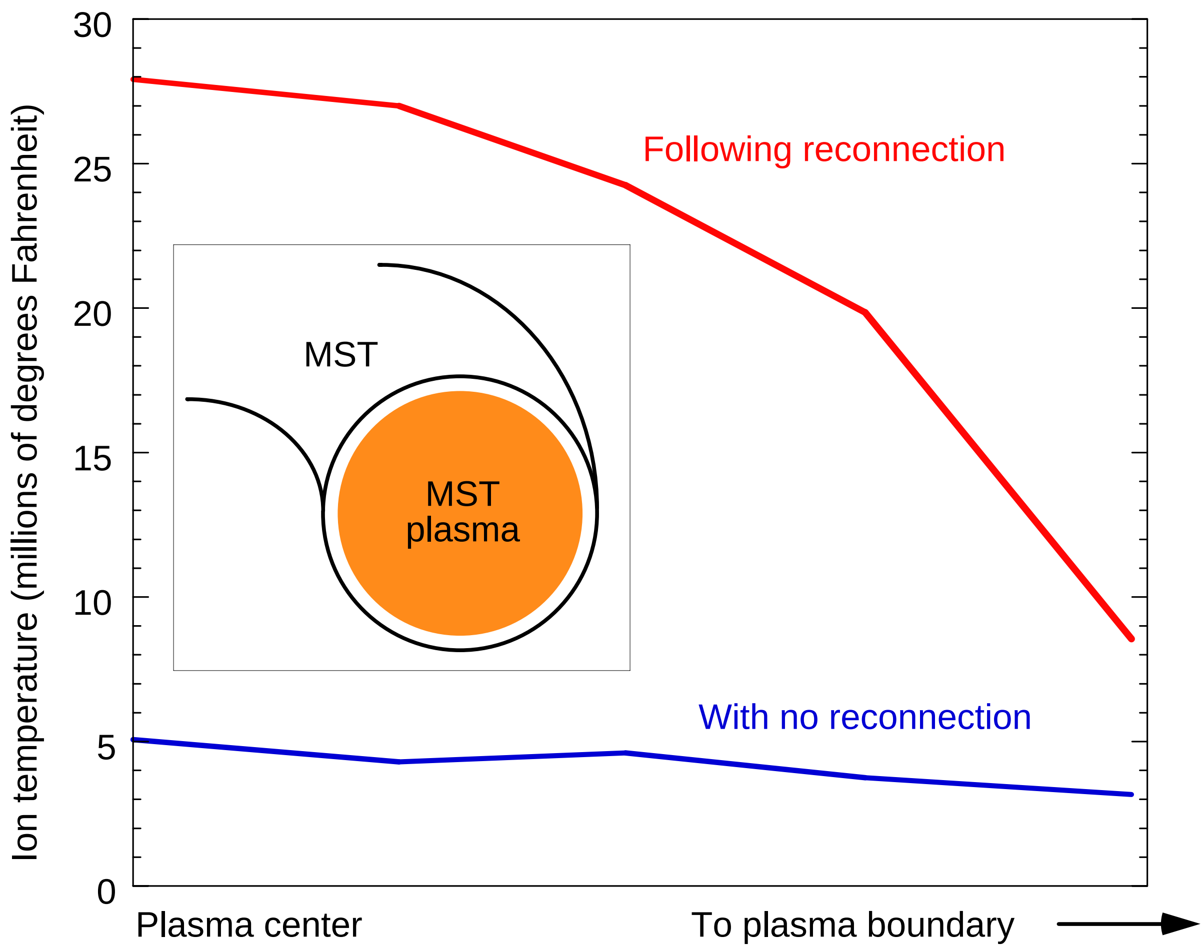
In an actual fusion reactor, the plasma must be heated to around 200,000,000 °F for sufficient fusion to occur. Ions at this temperature travel at about 1% of the speed of light (very fast), so that when two ions approach one another they can overcome their mutual repulsion and fuse. But while the plasma is heated, it must be confined, else the plasma particles would rapidly be lost.

In MST, the plasma is normally heated by passing electrical current through it. This is the same resistive heating technique that warms the coils in a toaster. As the MST plasma is heated it is confined by a magnetic field, which can trap the charged plasma particles. Magnetic reconnection is both triggered and suppressed through manipulation of the plasma current and magnetic field. The plasma can more readily escape during reconnection, but the reconnection lasts for such a short time, and the heating of the ions is so intense, that reconnection-based ion heating is beneficial. Equally important is that the reconnection suppression following the heating phase is achieved to a degree unprecendented in devices like MST. This allows the trapping of the added ion heat for a relatively long time.

While these results are encouraging, it is by no means clear that reconnection-based ion heating can be extended to the temperature needed for fusion. Work is underway not only to try to extend this technique but to better understand the science behind it as well.

[1]*The MST program combines fusion energy research with fundamental studies of reconnection and is thus jointly supported by the DOE and the NSF Physics Frontier Centers program through the Center for Magnetic Self-Organization in Laboratory and Astrophysical Plasmas.*

[2]*A paper describing this work in more detail will be submitted to Physical Review Letters.*



Shown here is the ion temperature measured across two MST plasmas, one in which reconnection is suppressed at all times (blue line) and one in which reconnection is utilized to strongly heat the ions (red line). The MST device and plasma are donut-shaped with a circular vertical cross section, as partially illustrated in the inset cartoon.