Statistically speaking, Indus script is a language

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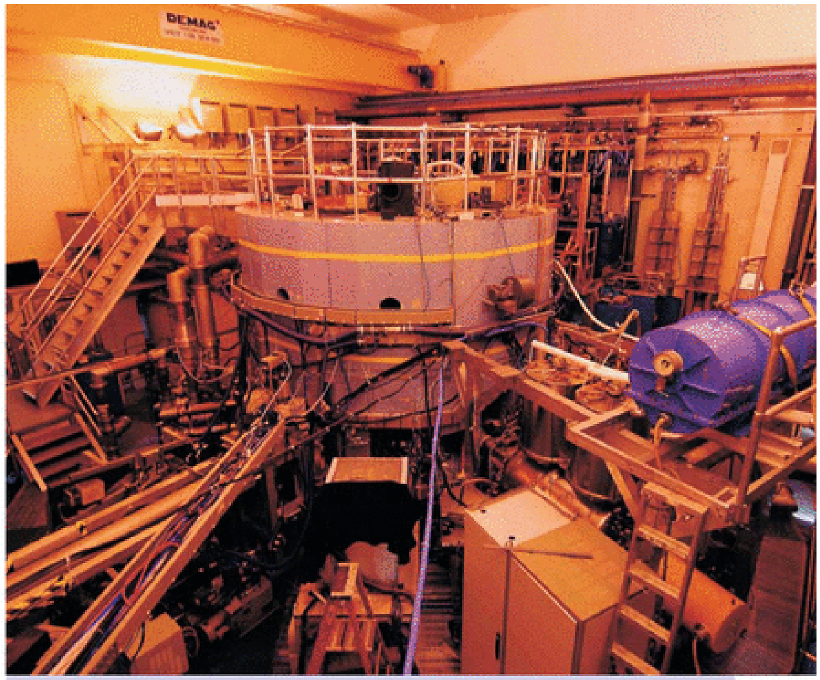
(~100 MHz), electron cyclotron (~100 GHz), and an intermediate frequency called the lower hybrid band (~5 GHz).

Once the 200-MK fusion temperature is reached, energetic byproducts of fusion act as heat sources. In the case of D–T fuel, 3.5-MeV alpha particles heat the plasma, whereas the other byproduct, 14-MeV neutrons, escapes. If the neutrons are caught in a blanket, their energy can ultimately be converted to electrical energy using a conventional steam-powered generator. Steep gradients in the plasma's pressure and density provide enough free energy to drive as much as 80% of the plasma current; microwaves of particle beams can provide the remaining 20%.

No tokamak has ever reached the so-called burning plasma regime, in which the plasma heats itself. Scaling laws derived from past and present tokamaks imply that an ITER-sized device will reach the burning plasma regime. But to sustain that regime—and maybe just to attain it—plasma instabilities must be suppressed. That's where rotation might come into play.



The fusion chamber at MIT's Alcator tokamak is located inside the gray, hot-tub-shaped, concrete-clad structure.

Ion cyclotron mode conversion

Rotating a plasma is akin to stirring soup: You need a spoon and energy. Lin, Rice, and their colleagues seeded their deuterium fuel with a small admixture of helium-3 ions to serve as a spoon. For the stirring energy, they used radio waves tuned to the helium ions' cyclotron resonance, which, for Alcator's 5-tesla magnetic field, is around 50 MHz.

Because of their significantly different mass-to-charge ratio, the $^3He^{2+}$ ions can be in resonance with the waves when the majority D^+ are not. And because the magnetic field has a gradient, the frequency of the radiation can be adjusted to resonate with $^3He^{2+}$ ions at specific locations in the plasma.

The ability to target the radiation is crucial. Where the waves' momentum ends up and whether it's dissipated before it can rotate the plasma depend on which of several magnetohydrodynamic processes the waves trigger. And that depends on local conditions. The theoretical picture is incomplete, but the MIT researchers believe their input waves are converted into another type of wave that entrains the $^3He^{2+}$ ions, which then impart some of their momentum to the D^+ ions.

Another minority species, argon, provides the diagnostic for measuring flow. Under the temperatures and pressure that prevail in Alcator, argon is stripped of all but one or two of its electrons. The spectra of hydrogen- and helium-like Ar ions are characterized so well that departures from their rest-frame values serve as accurate Doppler probes of motion. Line widths probe temperature.

The MIT team tested a range of minority concentrations and found that a 10% admixture of ^3He provides the biggest rotational boost—from 10 km/s to 70 km/s using 3 MW of VHF power.

Proving that rotation does indeed suppress turbulence requires probing the velocity field on small scales. That goal awaits future experiments, but the MIT team did find indirect evidence. In general, turbulence mixes momenta and flattens gradients. Line widths indicate that the temperature gradient of the optimally seeded plasma was steeper than that of an otherwise similar plasma.

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Reference

1. Y. Lin et al., *Phys. Plasmas* **16**, 056102 (2009).

physics update These items, with supplementary material, first appeared at http://www.physicstoday.org.

Statistically speaking, Indus script is a language. The Indus Valley civilization, in what is now eastern Pakistan and northwestern India, flourished circa 2500–1900 BCE. To this day its writing, as in the figure, has not been deciphered. Indeed, scholars are unsure if the Indus script represents a language. Other, superficially similar ancient texts are thought to be either rigidly prescribed strings, such as a hierarchical list of deities, or nonlinguistic strings in which order is unimportant. Now computer scientist Rajesh Rao (University of Washington) and colleagues from several Indian institutions have studied the correlations of neighboring tokens (symbols or words) with a statistical tool—the conditional entropy—that reliably distinguishes natural languages from token strings in which the ordering is rigid or unimportant. The Indus script, they conclude, has the structure of a language. Like the conventional entropy, the conditional entropy involves the logarithm of a probability—in this case the conditional probability that a specified token appears, given its