SOLAR PHYSICS

Does Magnetic Twist Crank Up the Sun's Outbursts?

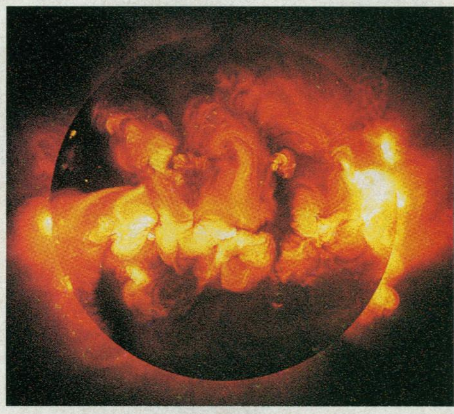
To solar physicists, the dense interior of the sun, its wispy corona, and the far reaches of space aren't as disparate as they look. They share a common thread: The sun's magnetic field, which is generated by a "dynamo" of churning plasmas in the sun's interior, erupts through its surface at sunspots and bright patches called faculae and is swept into space by the sun's thin wind of plasma and by larger outbursts of material called coronal mass ejections (CMEs). But researchers don't know exactly how the magnetic field links all these phenomena. "There are lots of theories and models and suggestions about virtually all of those steps," says David McComas, a space physicist at Los Alamos National Laboratory, but "we're not yet sure how all the connections go."

David Rust of Johns Hopkins University thinks he has a way to weave these magnetic links more tightly. A key factor shaping them, he thinks, is the twist, or helicity, of the sun's field. In a series of papers this year, Rust has drawn on 20-year-old studies of hot laboratory plasmas to argue that helicity is conserved from its cradle in the depths of the solar dynamo to its grave in the wilds of interstellar space. Along the way, it puts its mark on phenomena as disparate as the screwlike twist of field lines arching over the surface of the sun and the winding of the solar wind's magnetic field where it encounters Earth.

And because a field with a large enough twist can go unstable, like a twisted rubber band that suddenly knots up, helicity may also help account for the sudden eruption of CMEs, which can disrupt communications and damage satellites when the magnetized plasma reaches Earth. The work, says McComas, could yield "a quantitative way to look at how new [magnetic] flux emerges from the sun and gets transported out into space"—and possibly insight into the workings of the mysterious solar dynamo itself.

What twists the magnetic field lines in the first place is the internal churning of the sun, whose plasma carries the field lines as if they were "frozen" into it. Among other things, the sun spins faster at its equator than at its poles. As a result, some field lines that initially run north-south in the sun's outer layers get wrapped around the sun during the course of its 11-year cycle of activity. The process squeezes the lines together, strengthening the field, and twists them up. By the peak of the activity cycle, these twisted hoops of field bob above the solar surface, forming great magnetic arches, rooted in sunspots and faculae.

For the sun to complete its activity cycle and return to quiescence, it has to lose these strong, toroidal fields. In the standard picture, arches meet up and reconnect in an arrangement that allows the sun's differential rotation to unwind the field. But many solar physicists have been uneasy with the slow pace most theories predict for reconnection. "You have a terrible problem dissipating [the toroidal field] in place," says Rust.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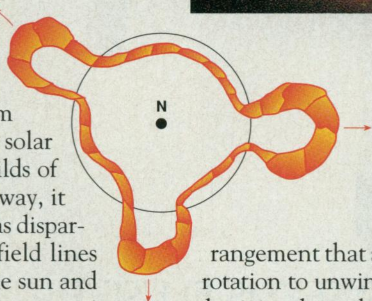

SOURCE: D. RUST

Twist of fate. The twist in a rope of magnetic field may be what drives it to break free of the sun in great arches. The S-shaped structure in the x-ray image above may be an arch wriggling free.

Last year, however, Rust thought he saw a hint that something else might be happening to the toroidal hoops of field. John Bieber and co-workers at the Bartol Research Institute of the University of Delaware, he learned, had made satellite measurements of the "pitch" of magnetic field lines in the solar wind. Because the sun rotates with one end of the lines frozen into it, the solar wind's magnetic field twirls outward from the sun like water from a garden sprinkler. Bieber's measurements of the winding's pitch, or tightness, showed that it is about 10% greater than predicted from the sun's rotation—just the amount expected if the sun were sloughing off its toroidal field in the solar wind rather than dissipating it.

And by combining other observations with a principle discovered in laboratory work, Rust thought he saw how the sun might shed those magnetic rings. Observing the sun at wavelengths of light that are sensitive to details of the magnetic field, Sara Martin, then at Caltech's Big Bear Observatory, and her colleagues saw a fine-scale twist in field lines at the solar surface. Theorists might have expected this twist to be dissipated within the sun, but it was accumulating at the surface—and the same twist also seemed to be showing up in certain satellite measurements of the solar wind. The correspondence, he and Johns Hopkins collaborator Ashok Kumar thought, implies that what J. B. Taylor of Culham Laboratories in the United Kingdom found was true of laboratory plasmas 20 years ago applied to the sun as well: Once twisted up by turbulent processes like those in the sun's interior, a magnetic field never loses its helicity.

Rust, Bieber, and Kumar then found that this conservation of helicity was just what they needed to explain how the sun could shed its toroidal field. They knew from previous theoretical work that any twist in a toroidal field within the sun would tend to bunch up wherever the field arched above the solar surface—and, because total helicity is conserved, they reasoned, it would accumulate there until the tube suddenly "kinked," or went unstable, and broke away from the sun. This process could be the mysterious driver behind CMEs, they thought. As an arch pinches off, moreover, it could reconnect with adjacent arches, which could then do the same, piecing together a "daisy chain" that becomes a toroid of field expanding away from the sun.

Support for this mechanism came from x-ray images made by the Japanese Yohkoh satellite, which reveal the hot gases trapped in the magnetic arches. Seen from above, the arches have just the sort of S-curves expected if the twist in the magnetic field were causing them to kink. "There is a tremendous unity to this [theory] that tells me it's right," says Rust.

B. C. Low of the High Altitude Observatory at the National Center for Atmospheric Research in Boulder, Colorado, agrees that such comprehensiveness "is what makes this whole picture so enchanting," although he thinks fields can tear loose, producing CMEs, even without a kink. Some solar physicists have deeper reservations, however, among them Eugene Parker of the University of Chicago, who predicted the existence of the solar wind in 1958. Parker calls the picture "rather interesting" but says, "I don't think they have proved their point yet."

But even researchers who are withholding judgment on the whole picture are excited by the prospect that, as Norbert Seehafer of the Universität Potsdam puts it, "observations of helicity above the sun can tell us something about the solar dynamo," yielding a novel tool for revealing the invisible churnings below.

–James Glanz