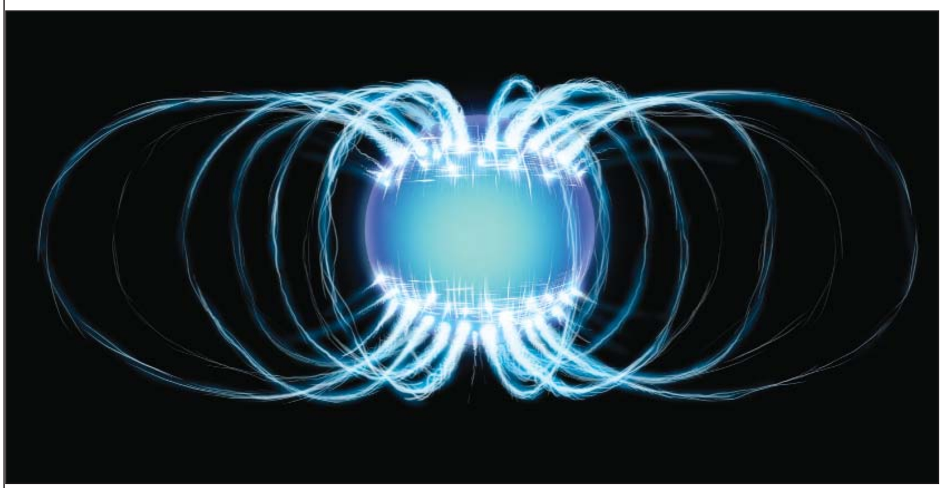
NEWS

Crushed by Magnetism

The strongest—and strangest—magnetic fields in the galaxy stop some pulsars dead in their tracks and literally fracture their surfaces

Mutations are the spice of life, but the most freakish mutants usually die at a tender age. This biological rule holds true in astrophysics: Some of the strangest mutations in space create superenergetic but short-lived cousins of pulsars, called magnetars.

Like a pulsar, a magnetar is a neutron star forged at the center of a supernova when a massive star explodes. But something odd happens during a magnetar's birth. An unknown process—perhaps ultrafast rotation within the dying star's collapsing core—endows each magnetar with a crushing magnetic field. This magnetism, up to 1000 times more intense than that of a typical pulsar, is the strongest known in space.



Feel the force. Ultramagnetized neutron stars, called magnetars, unleash powerful flares spawned by the most extreme magnetic fields known.

As the magnetic forces subside, they rupture the brittle crust of the neutron star and drive fierce bursts of gamma rays and x-rays. But the pyrotechnics takes a toll. The magnetism acts as a brake, grinding each magnetar to a near-halt within thousands of years and short-circuiting its spin power. In contrast, an ordinary pulsar can sweep the galaxy with rotation-powered beams of radio waves for millions of years.

Astrophysicists have found just 11 magnetars, but their brief lives and sporadic tantrums point to a far larger population that we can't see. "There probably are hundreds of thousands of these dead relics, undetected and undetectable, now spinning in our galaxy," says x-ray astronomer Chryssa Kouveliotou of NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama. Indeed, some proponents think the objects might not be mutants at all but common offspring of supernovas. "It's quite possible that a majority of neutron stars are magnetars rather than radio pulsars," says astrophysicist Robert Duncan of the University of Texas, Austin.

A hundred billion MRI scans

That's a grand claim, but Duncan and fellow theorist Christopher Thompson of the Canadian Institute for Theoretical Astrophysics in Toronto, Ontario, have swayed skeptics before. They first calculated that powerful magnetic fields could lace through newborn neutron stars in 1987, when Duncan was a postdoctoral researcher at Princeton University and Thompson was a graduate student. But their solution for the strengths of such fields—10^{15} gauss—was so startling that they weren't sure what to make of it for several years.

For perspective, Earth's global magnetic field is about 0.6 gauss. Magnetic resonance imagers for medical scans attain 10,000 gauss. Radio pulsars cluster around 10^{12} gauss, a deduction based on magnetism's gradual braking effect on their spins. Such fields are impressive, but a radio pulsar's main power comes from its rotation, not its magnetism. The magnetic fields act as conveyor belts to carry radiation spawned as the neutron star slows down and sheds rotational energy. No one expected the fields to soar much higher.

But Thompson and Duncan realized that ultrastrong fields could explain some mysteries. Notably, astrophysicists were puzzled by soft gamma repeaters (SGRs). These unidentified objects emitted erratic flares of soft gamma rays—a notch above the most piercing x-rays—then fell quiet. In 1979, an SGR in a neighboring galaxy unleashed a giant flare that packed as much energy into its first 0.2 seconds as the sun produces in 10,000 years. The source was close to the remains of a recent supernova. However, the flare ebbed and flowed just once every 8 seconds as it gradually subsided, seemingly far too slow to come from a pulsar.

The theorists postulated that the bursts arose from a slow-spinning neutron star that had spun breathtakingly fast at birth. Astrophysicists Adam Burrows of the University of Arizona in Tucson and James Lattimer of the State University of New York, Stony Brook, had shown that during a neutron star's first 10 seconds of existence, its hot nuclear fluid would convect about 100 times every second. If the neutron star whirled between 100 and 1000 times each second during those birth pangs, Thompson and Duncan calculated, it would spark a furious dynamo—a self-sustaining generator of an intense magnetic field, 10^{15} gauss and beyond.

Once magnetism suffuses the dense superfluid of a neutron star, it's tough to disperse. Still, the magnetic fields and the electric currents that support them try to shift into patterns that are less taut with pent-up energy. "The magnetic field is strongly wound up in a tight spiral inside the star," Thompson explains. "It is the progressive unwinding of the field that drives the [SGR] flares." Each shift strains the solid crust of the neutron star. At a critical point the crust snaps, creating faults that may span a kilometer. Once the surface cracks, the magnetic fields above it whip into new positions as well. The violent motions blast particles along the magnetic fields, triggering gamma rays and x-rays.

Duncan and Thompson published this scenario in 1992, discarding their initial "burstar" term for the more descriptive "magnetar." Three years later, they noted that the magnetic fields should confine a burst's energy in a fireball lasting a few minutes, exactly the pattern observed.

Still, their notions were too fantastic for most colleagues. As recently as January 1998, Duncan was relegated to the last talk of the last session at a meeting of the American Astronomical Society (AAS)—just after a speaker who explored alternatives to Ein-

CREDIT: CAMERON SLAYDEN

stein's general theory of relativity.

But later that year, observations won the day. First, a team led by Kouveliotou used NASA's Rossi X-ray Timing Explorer (RXTE) satellite to measure pulsations once every 7.47 seconds in an SGR with frequent outbursts. The periodic fluctuations were visible only during bright bursts; at other times the SGR did not emit ordinary pulsar-like beams. The object's rotational "clock" was slowing down by an astonishing 0.26 seconds per century—an effect that could result only from the strong drag of a magnetic field around 10^{15} gauss.

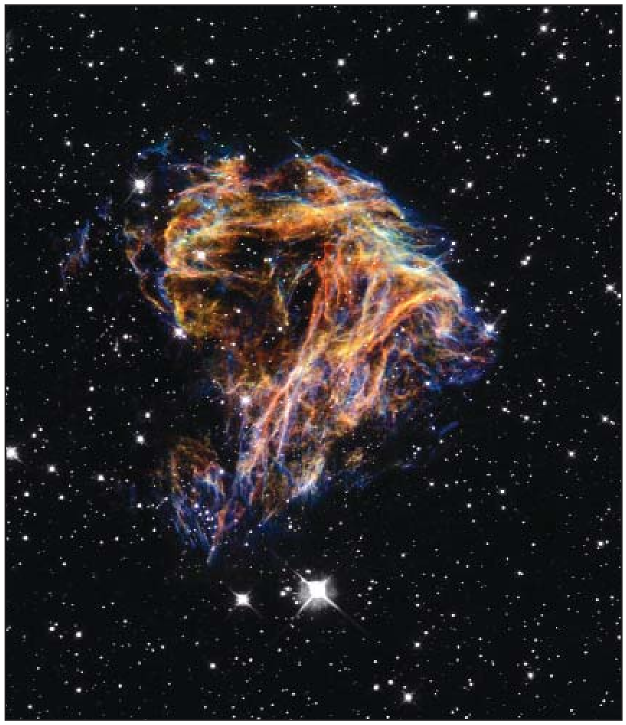
Then on 27 August 1998, a wave of gamma rays and x-rays more intense than the 1979 flare swept through the solar system. The source was an SGR across the Milky Way. Despite the distance, the radiation was powerful enough to affect radio transmissions on Earth by strongly ionizing the upper atmosphere. Slow, 5.16-second pulsations modulated the flare. Kouveliotou's team also studied it with RXTE to show that the SGR's spin decelerated at a magnetar-like clip.

With those findings, magnetars passed into mainstream science. Peers honored the work last year when Duncan, Thompson, and Kouveliotou jointly received the 2003 Bruno Rossi Prize, the top research award from the AAS High-Energy Astrophysics Division. It was a stark contrast to the theory's early years, Duncan recalls: "There was resistance, and a whole bunch of people thought it was crazy. But I view it all as a normal part of the scientific process."

Transients and nuclear bombs

In recent years, astronomers have broadened the magnetar family. Most now agree that objects called anomalous x-ray pulsars (AXPs), which pulsate slowly in x-rays but not in radio waves, are another flavor of magnetar. Astronomer Victoria Kaspi of McGill University in Montreal, Canada, and her colleagues have shown that AXPs can spew impulsive bursts, although not quite as vehemently as SGRs.

Curiously, the 11 known SGRs and AXPs all spin at nearly the same rate: between 5 and 12 seconds for each rotation. Magnetic fields stifle a young magnetar's spin so severely that its rotation stutters from a few milliseconds down to a few seconds within centuries—such a brief interval that astronomers would have to get lucky to see a furiously spinning magnetar. "And if they were active for more than a few thousand years, we'd expect to see some with periods of tens of seconds, but we don't," says astronomer Peter Woods of MSFC. "So it appears to be a very short life cycle when they are x-ray bright."



Flare for the dramatic. A suspected magnetar in the supernova remnant N49, in the Large Magellanic Cloud galaxy, hurled a giant burst of gamma rays in 1979.

CREDIT: NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

Two new studies to appear in the *Astrophysical Journal* suggest that magnetars are more common than their measly statistics indicate. In one report, astronomers led by Woods describe an AXP that flickered intensely for 4 hours in June 2002, then just as quickly faded. Similar outbursts elsewhere in the galaxy might go undetected by current instruments, says Woods, because telescopes that monitor the whole sky aren't yet sensitive enough. In another study, astronomers led by Alaa Ibrahim of NASA's Goddard Space Flight Center in Greenbelt, Maryland, exposed a "transient" magnetar. The object was too faint to attract attention throughout the 1990s, but it suddenly grew 100 times brighter in early 2003.

In their quiet states, these misbehaving magnetars bear some resemblance to faint sources of x-rays in supernova remnants, called central compact objects. They also look similar to another mysterious class of bodies called dim isolated neutron stars. Kaspi, a collaborator on both studies, agrees that the magnetar family tree may include some of these branches. "Dim isolated neutron stars could be dead magnetars with some residual heat," she says. "I think the numbers are consistent with half the neutron star population being born as magnetars." But better counts—and a firmer handle on the strengths of magnetic fields—are needed before anyone accepts that logic.

On the theoretical side, several groups are probing possible links between magnetars and gamma ray bursts (GRBs), the most energetic explosions in the cosmos. Many astrophysicists now think the most viable triggers of long-duration GRBs, lasting seconds to minutes, are powerful supernovas that create newborn black holes. However, a magnetically dominated wind from a new magnetar makes more sense as a coherent driving force, says astrophysicist Maxim Lyutikov of McGill University. "The dissipation of magnetic energy can be very efficient," he notes. In contrast, blasts of matter from close to a black hole might lose too much energy within violent shocks.

In related work, modeling by Hubble postdoctoral fellow Todd Thompson of the University of California, Berkeley, shows that a brand-new magnetar will sling matter into space along stiff magnetic "spokes" at nearly the speed of light. This outpouring of mass expels so much momentum that if the magnetar spins 1000 times per second at birth, it takes merely 10 seconds to slam the brakes down to about 300 spins per second. That deceleration releases a whopping 90% of the object's energy. Thompson thinks all that energy can propel a hyperenergetic supernova or, under the right conditions, a GRB.

The heaviest elements in nature could arise in this turbulent setting as well, Thompson adds. Astrophysicists haven't yet identified a convincing site for the "r-process," the creation of heavy atomic nuclei by rapid bombardment with a fierce wind of neutrons. Ultrastrong magnetic fields might keep a hot bath of neutrons and protons close enough to a new magnetar to push element synthesis up the periodic table to uranium and beyond.

Duncan, advocate of all things magnetar, loves the idea. "It's possible that all elements heavier than bismuth are synthesized in magnetar winds," he says. "If that's true, nuclear bombs and reactors are running on magnetar energy." Since supernovas supply the iron in our blood, it's only fair that magnetars get in on the action as well.

–ROBERT IRION