more confusion. SS433's emission lines show that the jet streams outward at one-quarter of the speed of light—fast, but not as fast as theory predicts. And there is another problem: Some astronomers suspect that SS433 is an anomalous object that contains not a black hole but a neutron star—"the worst example" of a microquasar, Margon says.

Help may come from Chandra, which has recently turned up encouraging hints of line pairs in several other microquasars. "We found suggestive evidence for the lines in the microquasar 1E1740.7-2942," says astrophysicist Wei Cui of Purdue University in West Lafayette, Indiana. "We now have 10 times more telescope time, so we should have a definitive answer next year."

Until that answer comes, researchers can only speculate as to whether microquasars truly are miniature quasars. Dimitrios Psaltis, for one, is beginning to suspect that the answer isn't a simple yes or no. Psaltis, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, in collaboration with van der Klis and Tomaso Belloni of the AIAP, has found evidence that the pattern of QPOs varies smoothly from neutron stars to black holes. The result suggests that microquasars are not exactly the same as either neutron stars or quasars, but instead form a link in a chain of jet-producing compact objects that extends from stellar-mass neutron stars all the way to the supermassive quasars.

Van der Klis acknowledges that the proposal is tentative and needs further investigation. "Some say this is just a coincidence, and others build entire theories out of it," he says. "That is just the way it is in this field right now." —**MARK SINCELL**

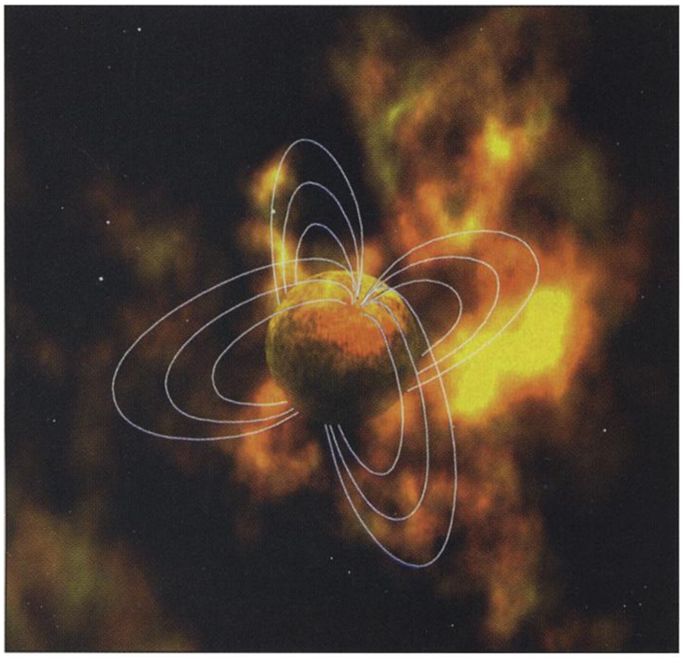
Mark Sincell is a science writer in Houston.

NEWS

Astronomical Odd Couple? Or Alter Egos?

While theorists try to bring them under one explanatory umbrella, the cosmic rarities known as SGRs and AXPs seem to insist on their differences

To high-energy astrophysicists, the calm beauty of the night sky is the world's grandest illusion. "It's a wild animal park out there," says Chryssa Kouveliotou of NASA's Marshall Space Flight Center in Huntsville, Alabama. Kouveliotou should know. She and a handful of colleagues worldwide study two of the wildest, most elusive creatures in the universe. Known as soft gamma repeaters and anomalous x-ray pulsars—SGRs and AXPs for short—the two classes of objects have teased astronomers for years with tantalizing similarities that may, or may not, be family resemblances. For the sake of simplicity, astrophysicists would love to show that SGRs or AXPs are special cases of the same theory, or different stages in each other's life cycle. So far, though, attempts to establish such an evolutionary link have run up against equally frustrating differences between the two enigmatic objects. And some recent evidence indicates that they may not be related at all.



Dynamic. Whirling fluid inside a young neutron star generates a magnetar's intense enormous field—the probable powerhouse behind soft gamma repeaters.

CREDIT: NASA

The likenesses are clear: Both types of objects are rare; astronomers know of only four SGRs and six AXPs. Both are found alone, apparently in association with young supernova remnants. From variations in their x-ray output, astronomers know that both spin with periods of between 5 seconds and 12 seconds, and both are slowing down considerably.

The main differences between them are that SGRs have a "harder" spectrum (one containing more high-energy radiation), and, unlike AXPs, they erupt into bursts of explosive activity. But those distinctions may not be hard and fast. The first identified SGR—an object known as SGR 0526-66 in the Large Magellanic Cloud—would be classified as an AXP if it were discovered today, Kouveliotou says. No one has detected a burst from 0526-66 since 1983, and a team led by Shrinivas Kulkarni of the California Institute of Technology in Pasadena, which recently observed the object using NASA's Chandra X-ray Observatory, reports that its spectrum turns out to be very soft.

"The similarities of SGRs and AXPs argue that they are one kind of beast," says Robert Duncan, a theoretical astrophysicist at the University of Texas (UT), Austin. And the heart of the beast, everyone agrees, is a neutron star—the whirling, superdense corpse of a massive star that exploded as a supernova at the end of its short life. Beyond that, though, confusion begins. At issue is how the two objects generate the powerful radiation in their spectra. The reigning model of SGRs says that it comes from starquakes on the star's intensely magnetic surface. A popular model for AXPs holds that the radiation emanates from gas sucked in by the star's enormously powerful gravity. If the beasts are indeed related, at least one of the models must be wrong. Which one? The experts disagree, often sharply.

Surging starquakes

The SGR saga began in 1979, when orbiting satellites and interplanetary space probes registered a couple of powerful bursts of energetic x-rays and gamma rays. No one knew what they were. Most astronomers classified them as gamma ray bursts. (See the Review by Peter Mészáros on p. 79.) One of those explosions, however, was special. Observed on 5 March 1979, it appeared much brighter than any other gamma ray burst detected so far, it contained more low-energy radiation, and it went off again and again, producing 16 bursts over a 4-year period. What's more, whereas "normal" gamma ray bursts occur in "empty" spots on the sky, this one—called SGR 0526-66, after its position in the sky—resided in a young supernova remnant in the

Large Magellanic Cloud, a companion galaxy of our Milky Way, some 170,000 light-years away.

By 1986, gamma ray burst researchers had identified two more sources with the same characteristics: multiple short bursts, first observed in 1979; a "soft" spectrum (one with relatively high levels of low-energy radiation); and a possible association with a supernova remnant. The three eccentrics were christened "soft gamma repeaters," although Duncan says "hard x-ray flashers" would have been more descriptive. (In the electromagnetic spectrum, hard x-rays grade into soft gamma rays.)

UT's Robert Duncan, together with Christopher Thompson of the Canadian Institute for Theoretical Astrophysics in Toronto, speculated that the repeating bursts were caused by starquakes on highly magnetized neutron stars. They had predicted on theoretical grounds that such bizarre objects ought to exist; in a landmark 1992 paper in the *Astrophysical Journal*, they named them "magnetars."

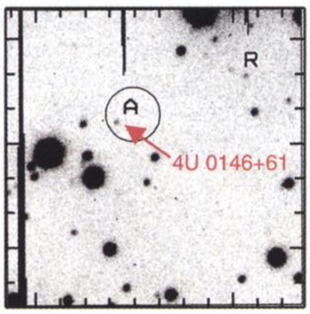
Like other neutron stars, magnetars are born after a massive star explodes into a supernova. The core of the star collapses into a rapidly rotating ball of densely packed neutrons, surrounded by a kilometer-thick crust of solid iron. The result is the densest object in the universe—the mass of a star packed into a ball no larger than Washington, D.C., every cubic centimeter of which weighs 100 million tons.

As their rapid radio pulsations show, neutron stars spin madly, some of them hundreds of times per second. In magnetars, the initial rotation rate of the progenitor star is high enough to turn the conductive liquid interior of the neutron star into a dynamo that can create a magnetic field on the order of 10^{15} gauss. That's 1000 times as strong as the field of a radio pulsar, or as powerful as 10 trillion refrigerator magnets. According to Duncan and Thompson's magnetar model, such a superstrong field would periodically deform and crack the neutron star's crust, producing starquakes and seismic waves that release tremendous bursts of energy, emitted in the form of fast-moving elementary particles and high-energy radiation.

The magnetar theory got a boost in 1998, when Kouveliotou and her colleagues discovered that one of the SGRs had slowed by about 0.1% in just a few years. Assuming that the slowdown was the result of magnetic braking (the only viable explanation), Kouveliotou deduced a magnetic field strength of 800 trillion gauss—in good agreement with the magnetar model. "I consider the evidence compelling," says Duncan. Most other astrophysicists agree; currently, magnetars stand all but unrivaled as a theoretical explanation for SGRs.

Ubiquitous source

While some scientists were closing in on SGRs, others were adding AXPs to the astrophysical bestiary. X-ray satellites first spotted AXPs in the 1970s and 1980s, although astronomers didn't realize they were a class of their own until 1995—and even then they disagreed about what they were. "Normal" x-ray pulsars are rapidly spinning neutron stars in binary systems. Their x-rays are emitted by hot gas from the companion star, which accumulates into an accretion disk and heats up as it falls toward the neutron star. Although the AXPs show no signs of companions, many astrophysicists suspect that they are powered by accretion, too.



Disk-carded? Faint optical counterpart of 4U 0142+61 threatens the popular accretion model of AXPs.

CREDIT: ILLUSTRATION BY CAMERON SLAYDEN; (INSET) F. HULLEMAN, M. H. VAN KERKWIJK, S. R. KULKARNI, *NATURE*, 7 DECEMBER 2000, P. 689

At the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, Pinaki Chatterjee, Lars Hernquist, and Ramesh Narayan have proposed a model in which AXPs are fueled by debris from the supernova explosion that produced the neutron star. "Accretion is a ubiquitous energy source in the cosmos which powers most x-ray pulsars that we see," says David Marsden of NASA's Goddard Space Flight Center in Greenbelt, Maryland, who has presented similar ideas. "Therefore, there is a strong desire to explain AXPs in terms of accepted theoretical models."

Other models, however, have reared their heads. A few years ago, Bohdan Paczyński of Princeton University proposed a radically different idea. In his scenario, AXPs are powered not by infalling gas but by the loss of rotational energy from the spinning object itself. A small neutron star would have too little angular momentum to do the trick, Paczyński calculated; for his mechanism to work, the object would have to be something with about the same mass but significantly larger—perhaps an exotic object formed by the merger of two white dwarfs.

Marten van Kerkwijk of Utrecht University in the Netherlands, for one, is unconvinced. The white-dwarf model has many problems, he says, the chief one being that it cannot explain why some AXPs are associated with young supernova remnants. But Van Kerkwijk thinks the accretion model has fatal flaws, too. In fact, he says, new observations all but rule it out.

Working with Ferdi Hulleman of Utrecht University and with Kulkarni, Van Kerkwijk used the 10-meter Keck telescope at Mauna Kea, Hawaii, to identify the optical counterpart of 4U 0142+61, one of the six known AXPs. Writing in the 7 December issue of *Nature*, they state that the optical counterpart is much dimmer than would be expected from the accretion model. Duncan agrees: "The fossil disk model is disproven," he says.

To explain AXPs, Duncan and Van Kerkwijk look to the model that works so well for SGRs: magnetars. Theoretical models, they point out, show that magnetars are short-lived. After 10,000 years or so, the stars cool enough that their magnetic energy source turns off. Might that explain how SGRs evolve into AXPs? A magnetar could experience starquakes and produce soft gamma ray bursts for something like 10,000 years and then stop bursting when the magnetic energy runs down. During the next 100,000 years or so, the magnetic field would still be strong enough to produce steady, pulsed x-ray emission, and the magnetar would be visible as an AXP. Still later, it would fade completely and become practically invisible.

Soulmates or strangers?

Convincing as this scenario may seem, many x-ray astronomers have their doubts. "Magnetars are hypothetical objects," Chatterjee says, pointing out that the only evidence of the ultrastrong magnetic fields that the objects are said to harbor comes from timing the rotation of pulsars, not from direct measurements. As for 4U 0142+61, he adds, more detailed observations at other wavelengths are needed to determine how seriously it affects the accretion model.

NASA's Marsden agrees. "Only if the accretion model is strongly and unequivocally ruled out will new models be widely accepted," he says.

Meanwhile, some surprising recent evidence suggests that the two types of mystery objects may be different creatures altogether. Bryan Gaensler of the Massachusetts Institute of Technology in Cambridge studied SGRs and AXPs associated with supernova remnants. From the ages and distances of the supernova remnants and the displacement of the neutron stars from the remnants' centers, he calculated that AXPs are rushing away from the remnants at speeds on the order of 500 kilometers per second. That is not unexpected, as neutron stars are believed to be born with high "kick velocities" from the supernova explosions that create them. What is surprising, though, is that SGRs appear to be moving four times as fast.

That velocity difference poses a tough choice, Kouveliotou says. If astronomers have matched the neutron stars with the right supernova remnants, then it's hard to see how SGRs and AXPs could be related and yet travel at such different velocities. Conversely, if they are related, then for at least one of the two types of objects, "the apparent association with supernova remnants must be bogus," says Kouveliotou.

Van Kerkwijk admits that the supernova link could be stronger: Although most SGRs and AXPs seem to be related to supernova remnants, only for two of the six known AXPs and two of the four known SGRs is the evidence clear-cut. For a third SGR, the neutron star is so far away from the supernova remnant that it must be moving at 2900 kilometers per second if the two objects are indeed related. Kevin Hurely of the University of California, Berkeley, hopes to check that figure by using Chandra to measure the displacement of the x-ray source across the sky.

In the end, the links, if any, between AXPs and SGRs will come from that familiar wellspring: more data. Unfortunately, even the most sensitive orbiting observatory or ground-based telescope can't detect the superstrong magnetic fields that would prove or disprove the magnetar model. But they might reveal whether AXPs draw power from accretion, or whether any of them is consorting with one of Paczyński's white-dwarf mergers. If the observations rule out such alternatives, magnetars will look better and better to astrophysicists.

And if the magnetar model prevails? One consequence, Duncan says, is that magnetars might not be as rare as they seem. From their theoretical life-span and the known number of SGRs and AXPs, it's straightforward to calculate that a new magnetar should be born in the Milky Way galaxy about every 1000 years. Ten million "dead" magnetars might well be zooming through interstellar space at this moment, Duncan says—black beasts camouflaged by cosmic night.

–GOVERT SCHILLING

Govert Schilling is an astronomy writer in Utrecht, the Netherlands.

NEWS

Tatars' Saucy Project Takes on the World

A dark horse called Dulkyn aims to put the Republic of Tatarstan in the race to detect gravitational waves

KAZAN—On the edge of this city on the Volga River, in a cavernous underground hall off limits to most visitors, stand two rows of what look like massive tombs. The structures—12 pale yellow cabins, boxy and featureless—belong to the State Institute of Applied Optics. Eleven of them house some of the most advanced optical equipment in the world: laser setups for carving diffraction gratings and holographic plates, onetime components of a Soviet missile defense shield then in development.

Each cabin rests on a separate foundation to reduce the effects of seismic vibrations; inside, temperatures are kept precisely at 19 degrees Celsius. Such a sanctuary is necessary for reliably cutting tiny diffraction patterns—and essential to an experiment in the lone cabin that isn't part of the production complex. Here, in a room within a room, a novel project aims to do something never done before: use lasers to detect the pull of the moon on Earth's gravitational field. The Kazan team members call their experiment, which they hope to undertake this fall, "the lunar test." Some experts, however, call it lunacy.

"A few crazy ideas turn out to be genius. This one is just crazy," says Moscow State University physicist Vladimir Braginsky, the dean of Russian gravitational-wave researchers (see sidebar). He disparages the Kazan group's chances of achieving its ultimate goal, which is to modify a laser setup to detect ripples in the fabric of space-time—specifically, low-frequency gravitational waves emanating from the outer-space objects known as binary pulsars.

But even if the experiment fails, many others say it's worth supporting. The laser system could serve as a gyroscope that would "give a good measure of Earth's rotation," says Karsten Danzmann, one of the architects of GEO-600, a British-German gravitational-wave detector. "It's a very courageous idea," adds Philippe Tourrenc of Pierre and Marie Curie University in Paris, a founding father of the French-Italian VIRGO detector and one of the few westerners who has had a firsthand look at the Kazan setup.

For 4 decades, physicists pursuing this goal have built ever bigger and more elaborate experimental facilities with growing confidence that they are on the verge of plucking a relativistic gravitational signal

Roaring mouse? Feisty Tatarstan is gambling on scientific glory.