A galactic fast radio burst finally reveals its origin

Observations at multiple wavelengths provide compelling evidence that the first example of a fast radio burst detected in our galaxy came from a magnetized neutron star.

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should make room temperature operation possible.

Portable terahertz sources offer promising applications, including skin cancer screening.[6] To look for cancer now, doctors slice off and dye the affected skin and scan it under a microscope. "My mother was a pathologist," says Hu. "I used to peek through her microscope, and it really took trained eyes to identify cancer cells. I couldn't tell the difference between normal and cancer cells."

Water absorbs terahertz frequencies too strongly to do a full body scan, but surface penetration even up to a few millimeters is possible. Terahertz imaging wouldn't require the excision of skin, and it's sensitive to the increased blood supply and water content indicative of cancer in skin tissue.

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References

1. K. Kawase, *Opt. Express* **11**, 2549 (2003).
2. A. Khalatpour et al., *Nat. Photonics* (2020), doi:10.1038/s41566-020-00707-5.
3. J. Faist et al., *Science* **264**, 553 (1994); R. Köhler, *Nature* **417**, 156 (2002).
4. L. Bosco et al., *Appl. Phys. Lett.* **115**, 010601 (2019).
5. A. Albo, Q. Hu, J. L. Reno, *Appl. Phys. Lett.* **109**, 081102 (2016).
6. A. Rahman, A. K. Rahman, B. Rao, *Biosens. Bioelectron.* **82**, 64 (2016).

A galactic fast radio burst finally reveals its origin

Observations at multiple wavelengths provide compelling evidence that the first example of a fast radio burst detected in our galaxy came from a magnetized neutron star.

In 2007 a bright, brief burst of radio waves emanating from far outside the Milky Way captured the attention of astronomers. Short-duration pulses are not uncommon in radio astronomy. Pulsars in our galaxy produce intermittent, milliseconds-long flares of radio waves. The new phenomenon was orders of magnitude more luminous than those familiar signals and was spectrally different. The fast radio burst (FRB) was a perplexing new phenomenon.

Since that first discovery, radio telescopes have detected dozens of FRBs, some of them recurring sporadically from the same location. (See Physics Today, March 2017, page 22.) Astronomers have pinpointed the galaxies that host just a few of them. To account for the signals, some theories invoke high-energy bursts of radiation emitted by compact stellar remnants—in particular, highly magnetized neutron stars called magnetars. But until now, observational evidence has not directly associated an FRB with a magnetar or other specific astronomical entity.

This year an international effort has identified the first known FRB from within the Milky Way and determined that the signal coincides with x-ray and gamma-ray emissions from the same location. The site corresponds to a magnetar in the constellation Vulpecula. The findings provide new observational constraints on FRB progenitor theories and a direction for future study.

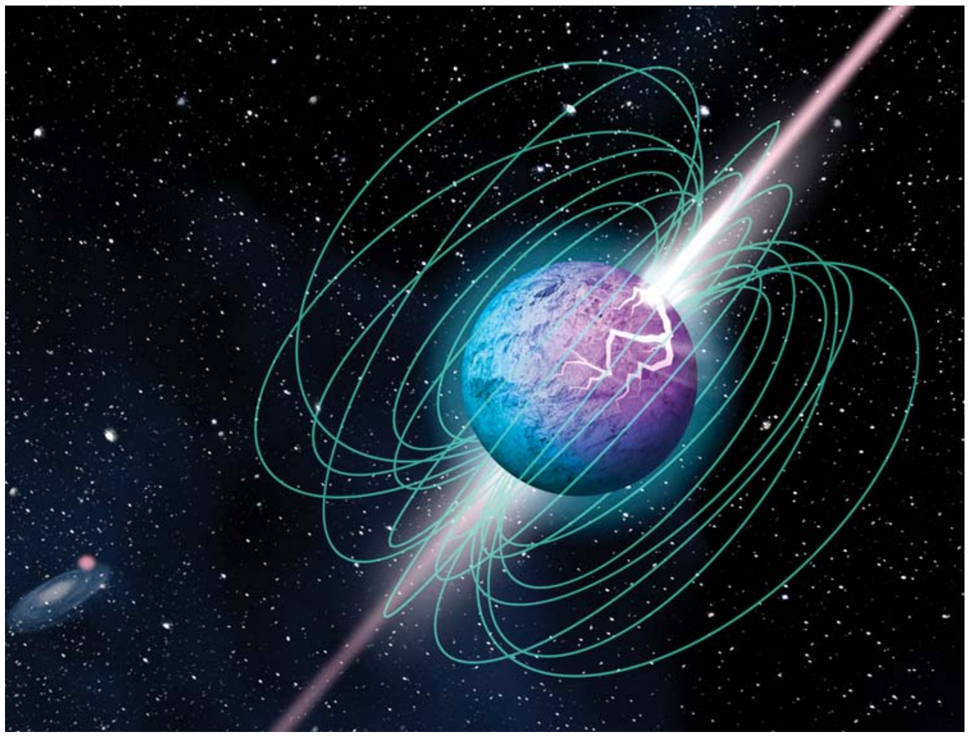

FIGURE 1. THIS ARTIST'S IMPRESSION OF A MAGNETAR represents the one now believed to be the source of the fast radio burst that was observed in April 2020. Shown here are the complex magnetic field structures (green lines) and radio, gamma-ray, and x-ray emissions that are produced from the magnetar's poles following a crust-cracking starquake episode. (Image courtesy of the McGill University Graphic Design Team.)

Team effort

Magnetars are spinning neutron stars, each left over from the explosion of a star tens of times the mass of the Sun, and they have magnetic fields 100 trillion times stronger than Earth's. Strain induced by the intense magnetic field increases until it's abruptly relieved in a starquake, which gives rise to characteristic bursts of x rays and gamma rays, depicted in figure 1.

Of the 30 magnetars currently known in our galaxy and the Magellanic Clouds, five have exhibited faint, transient radio pulses coincident with what is presumed to be the magnetar's spin period. A leading model for repeating FRBs suggests that they come from extragalactic magnetars. However, for that model to hold, some magnetars must be capable of generating radio emissions that exceed

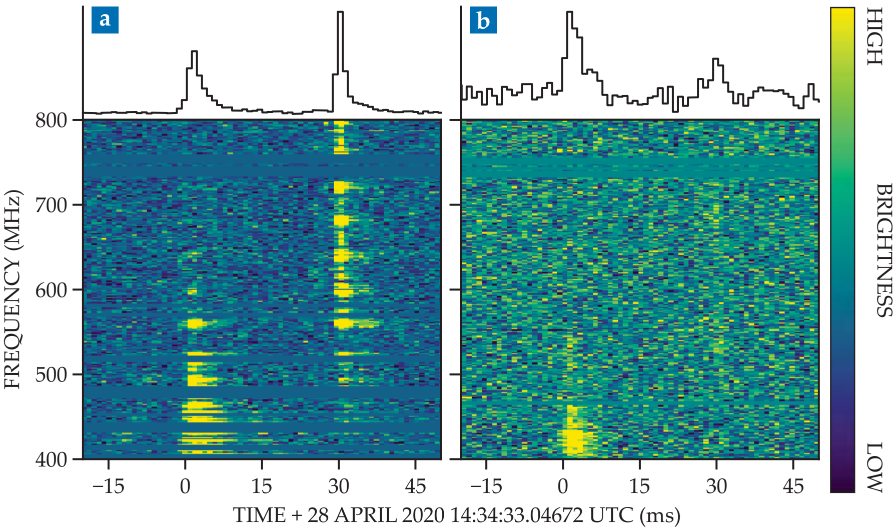

FIGURE 2. THE FAST RADIO BURST FROM SGR 1935+2154 was detected on 28 April 2020 by **(a)** the Canadian Hydrogen Intensity Mapping Experiment (CHIME) and **(b)** the Algonquin Radio Observatory. The ARO hosts a stationary 10-meter single-dish telescope that also observes the sky over the main CHIME antenna. The top panels show the total intensity of the milliseconds-duration burst, and the bottom plots show the intensity of the burst as a function of frequency. (Adapted from ref. 1.)

those of local, galactic ones by orders of magnitude.

On 27 April 2020, the Burst Alert Telescope aboard NASA's *Neil Gehrels Swift Observatory* detected multiple bursts of gamma rays and x rays coming from the magnetar SGR (soft gamma repeater) 1935+2154, which indicated heightened activity. The *Fermi Gamma-Ray Space Telescope* also reported multiple gamma-ray bursts from the same object.

By the next day, that region of the sky came into view of ground-based telescopes in the Western Hemisphere. The Canadian Hydrogen Intensity Mapping Experiment (CHIME) radio telescope in Penticton, British Columbia, detected an FRB coming from the direction of the signal. CHIME researchers posted a notice to the astronomy community reporting the detection of an FRB, dubbed FRB 200428, and included the data shown in figure 2a. The signal was well outside CHIME's field of view and was only detected because of its extreme brightness.[1]

Christopher Bochenek, a graduate student at Caltech, saw CHIME's notice when he began his daily inspection of data collected by the radio telescopes that make up the university's Survey for Transient Astronomical Radio Emission 2 (STARE2). "I saw the same burst in the STARE2 data, and I was so surprised I froze for a bit!" he says. The three STARE2 telescopes, in Utah and California, were designed explicitly to find an FRB in the Milky Way, which was expected to be rare but incredibly bright.[2] Bochenek confirmed that the signal was consistent with the one reported by CHIME. It was three orders of magnitude brighter than any observed radio pulse from known galactic magnetars.

Because of the *Swift* telescope's gamma-ray alert, several space telescopes had been keeping a close eye on the same location. Four of them reported an x-ray burst that simultaneously occurred with the radio bursts.

The Five-Hundred-Meter Aperture Spherical Radio Telescope (FAST) in China had also been observing SGR 1935+2154 in the preceding weeks, but the narrow-field telescope was not pointed toward the magnetar when CHIME and STARE2 reported their new finding. FAST did, however, report a lack of FRB-like events alongside 29 other x-ray bursts from SGR 1935+2154 in the days before FRB 200428 was announced.[3]

Bing Zhang of the University of Nevada, Las Vegas, explains, "The nondetection is significant because it indicates that an FRB's association with a gamma-ray repeater is unique and rare." That rarity could be because specific physical conditions required for FRB emission are difficult to satisfy or because FRBs have narrow beams that seldom point toward Earth. Two days after CHIME and STARE2 reported FRB 200428, FAST saw, from precisely the same location, another, weaker radio burst typical of a magnetar.

The observation of gamma-ray and x-ray emissions concurrently with an FRB allowed astronomers to make the first compelling link between FRBs and magnetars. Amanda Weltman of University of Cape Town says, "This is the first galactic FRB, our first FRB localized to an actual source and not just a host galaxy, and the first sign that a magnetar can produce bright enough bursts to be observed as FRBs."

Mulling magnetars

The discovery of FRB 200428 implies that active magnetars can produce FRBs that are bright enough to be detectable at extragalactic distances. Although the observed signal, when scaled for distance, was weaker than other extragalactic FRBs by a factor, the researchers estimated that if the signal had come from the location of other known FRBs, it would nonetheless be detectable. Figure 3 shows how the FRB's energy and duration compare with radio emissions from other known astronomical objects. Those comparisons led the CHIME, STARE2, and FAST researchers to conclude that magnetars like SGR 1935+2154 could indeed be a dominant source of FRBs.

How, exactly, a magnetar produces FRBs is still up for debate. One proposed mechanism for the link is that a starquake causes a magnetar to generate short-lived flares of electrons and other charged particles that collide with those emitted during previous flares, thus creating a shock front and huge magnetic fields.[4] Electrons swirling around the magnetic field lines emit bursts of radio waves, and the heated electrons emit x rays. Another possibility is that the starquake triggers disturbances in magnetic field lines near the magnetar's surface. Those disturbances induce relativistic particles to stream from the magnetosphere and generate radio emissions.[5]

Bochenek says, "We knew the source would need to be a compact object and have strong magnetic fields and that magnetars and neutron stars can create coherent radio emissions. But it's not like anyone expected magnetars to make such bright radio emission before the discovery of FRBs." Further study could help astronomers home in on the specific mechanisms and circumstances that drive

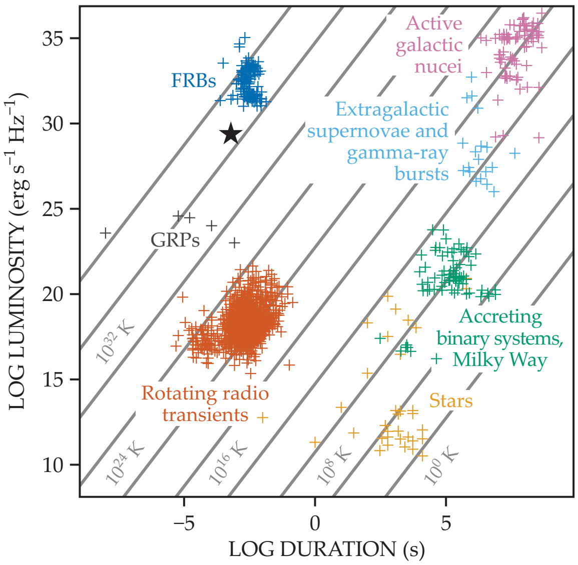

FIGURE 3. ASTRONOMICAL OBJECTS PRODUCE RADIO EMISSIONS that cover a wide range of energies (*y*-axis) and durations (*x*-axis). The radio burst that two telescopes detected simultaneously from the Milky Way magnetar SGR 1935+2154, indicated by the black star, could be a fast radio burst (FRB) and share some common features with giant radio pulses (GRPs) emitted by pulsars. (Adapted from ref. 2.)

magnetars to generate FRBs and, more generally, determine how coherent radio emission can be made under extreme conditions.

More observations are needed to fully understand the physics behind FRBs. Investigations should include searching nearby galaxies for similar events and seeking nonradio counterparts. For example, a coincident neutrino burst detected from the same locale as an FRB could provide evidence of another magnetar-driven FRB mechanism that involves an ultrarelativistic shock wave interacting with thermal synchrotron photons. So far, researchers combing through data from neutrino observatories have not found a corresponding signal.

From a theoretical point of view, determining the specific signatures of different physical mechanisms from distinct astrophysical objects will be vital to future FRB research. Zhang says, "Before the discovery, people had been talking about more than 50 possibilities of producing FRBs. I believe that a lot of models are no longer competitive." Still, there are likely multiple ways that repeating FRBs are created. It's also possible that rare, one-off FRB events could arise from catastrophic events such as merging neutron stars.

The FRB source in the Milky Way may also answer open-ended questions, such as how frequently the signals repeat over years to decades, how distant and energetic bursts are, and whether similar pulses can be used to identify specific objects in other galaxies. West Virginia University's Duncan Lorimer, who reported the first-ever detected FRB in 2007, points out that there has not yet been any evidence for rotational periodicity in repeating FRBs—as might be expected for a spinning source. He says, "I think ultimately FRBs could be, and are, produced by different sources."

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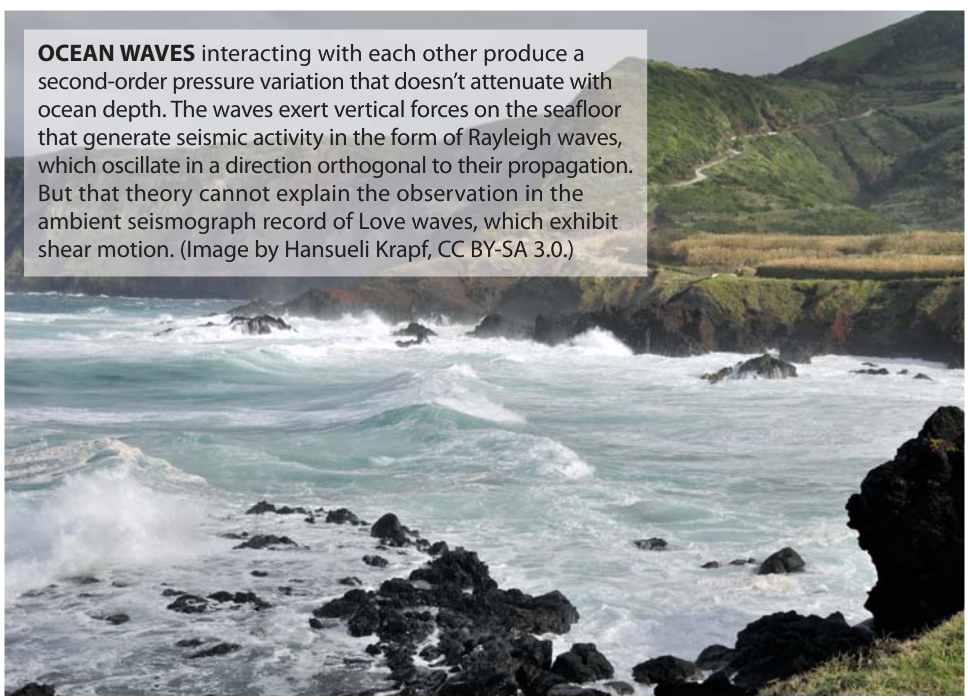
References

1. The CHIME/FRB collaboration, *Nature* **587**, 54 (2020).
2. C. D. Bochenek et al., *Nature* **587**, 59 (2020).
3. L. Lin et al., *Nature* **587**, 63 (2020).
4. B. D. Metzger, B. Margalit, L. Sironi, *Mon. Not. R. Astron. Soc.* **485**, 4091 (2019).
5. W. Lu, P. Kumar, B. Zhang, *Mon. Not. R. Astron. Soc.* **498**, 1397 (2020).

Solving the century-old mystery of background Love waves

New simulations reveal that much of Earth's ambient seismic wave field arises from interactions with the planet's interior.



OCEAN WAVES interacting with each other produce a second-order pressure variation that doesn't attenuate with ocean depth. The waves exert vertical forces on the seafloor that generate seismic activity in the form of Rayleigh waves, which oscillate in a direction orthogonal to their propagation. But that theory cannot explain the observation in the ambient seismograph record of Love waves, which exhibit shear motion. (Image by Hansueli Krapf, CC BY-SA 3.0.)

Earthquakes generate only a small fraction of the seismic energy that travels through Earth and on its surface. Most seismic activity arises from wind-driven ocean waves interacting with the solid ground. The background vibrations carry useful information about the exchange of energy between the ocean, the atmosphere, and Earth's subsurface, and seismologists extract that information to image the planet's internal structure and to conduct other geophysical investigations.

The strongest of those vibrations are known as secondary microseisms and