"Cosmic Whistle" Packs a Surprisingly Energetic Punch

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This image collection shows four models of powerful cosmic events that might have produced the fast radio burst FRB 131104. Two common fast-radio-burst models that predict accompanying gamma-ray emission invoke magnetar flares or binary-neutron-star mergers. A magnetar is a highly magnetized neutron star, the dense remnant of a collapsed star. Binary-neutron-star mergers occur when two neutron stars spiral together and merge, forming a black hole. Two cosmic sources of bright and long-lived gamma-ray emission, not known to produce fast radio bursts, are supermassive-black-hole accretion events and some types of supernovae. A black-hole accretion event occurs when a star comes too close to the supermassive black hole in the center of a galaxy. A supernova occurs when a massive star runs out of nuclear fuel; its core collapses and the star explodes, shining for a month or more with the light of ten billion stars. Top left: Binary-neutron-star merger (credit: Dana Berry, Skyworks Digital), Top right: Supernova (credit: G. Bacon, STScI), Bottom left: Magnetar (credit Robert S. Mallozzi, UAH/NASA MSFC), Bottom right: Blck-hole accretion event (credit: M. Weiss, NASA/CXC)

Penn State University astronomers have discovered that the mysterious "cosmic whistles" known as fast radio bursts can pack a serious punch, in some cases releasing a billion times more energy in gamma-rays than they do in radio waves and rivaling the stellar cataclysms known as supernovae in their explosive power. The discovery, the first-ever finding of non-radio emission from any fast radio burst, drastically raises the stakes for models of fast radio bursts and is expected to further energize efforts by astronomers to chase down and identify long-lived counterparts to fast radio bursts using X-ray, optical, and radio telescopes.

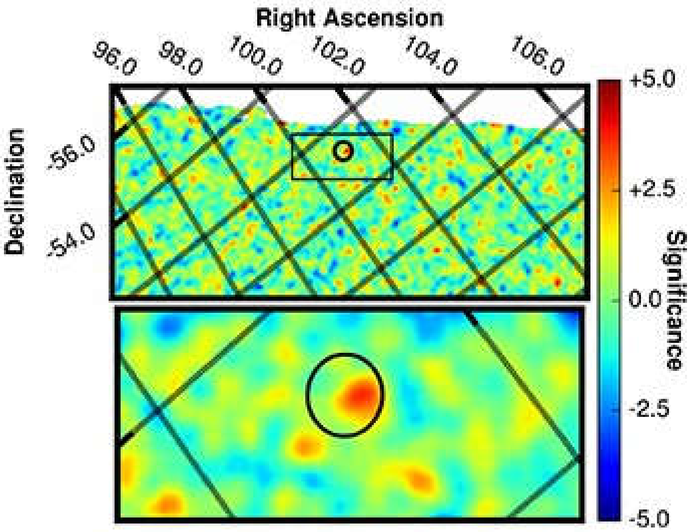
Fast radio bursts, which astronomers refer to as FRBs, were first discovered in 2007, and in the years since radio astronomers have detected a few dozen of these events. Although they last mere milliseconds at any single frequency, their great distances from Earth – and large quantities of intervening plasma – delay their arrival at lower frequencies, spreading the signal out over a second or more and yielding a distinctive downward-swooping "whistle" across the typical radio receiver band.

"This discovery revolutionizes our picture of FRBs, some of which apparently manifest as both a whistle and a bang," said coauthor **Derek Fox**, a Penn State professor of astronomy and astrophysics. The radio whistle can be detected by ground-based radio telescopes, while the gamma-ray bang can be picked up by high-energy satellites like NASA's Swift mission. "Rate and distance estimates for FRBs suggest that, whatever they are, they are a relatively common phenomenon, occurring somewhere in the universe more than 2,000 times a day."

A Cosmic Whistle: An audio file of the Sound of the fast radio burst FRB 131104

Efforts to identify FRB counterparts began soon after their discovery but have all come up empty until now. In a paper published November 11 in Astrophysical Journal Letters the Penn State team, led by physics graduate student **James DeLaunay**, reports bright gamma-ray emission from the fast radio burst FRB 131104, named after the date it occurred, November 4, 2013. "I started this search for FRB counterparts without expecting to find anything," said DeLaunay. "This burst was the first that even had useful data to analyze. When I saw that it showed a possible gamma-ray counterpart, I couldn't believe my luck!"

Discovery of the gamma-ray "bang" from FRB 131104, the first non-radio counterpart to any FRB, was made possible by NASA's Earth-orbiting Swift satellite, which was observing the exact part of the sky where FRB 131104 occurred as the burst was detected by the Parkes Observatory radio telescope in Parkes, Australia. "Swift is always watching the sky for bursts of X-rays and gamma-rays," said **Neil Gehrels**, the mission's Principal Investigator and chief of the Astroparticle Physics Laboratory at NASA's Goddard Space Flight Center. "What a delight it was to catch this flash from one of the mysterious fast radio bursts."



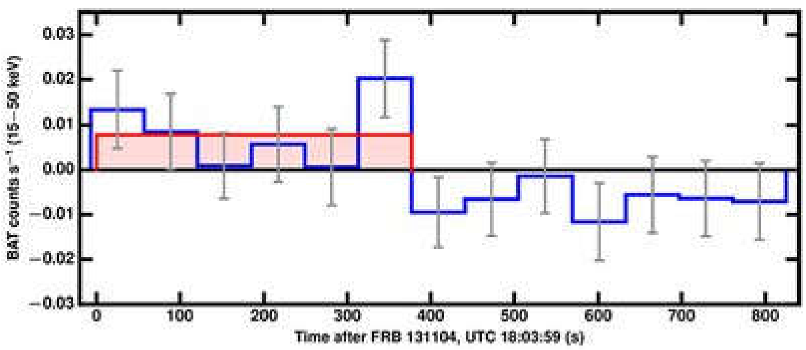
Discovery of the gamma-ray counterpart to FRB 131104, in wide-angle and zoomed-in views of Swift gamma-ray data. The black circle indicates the area of the sky that Parkes Observatory was observing when it detected FRB 131104. Within the circle there is a single prominent red peak, the signal of the gamma-ray counterpart. Colors in the image indicate the signal-to-noise level at each position; the counterpart's signal-to-noise level is 4.2. The Swift exposure was taken over 300 seconds starting 7 seconds before FRB 131104. While the wide-field image is only a small portion of Swift's very large field of view, it is large enough to fit eight full moons lined up from top to bottom of the image. Credit: J. J. DeLaunay, Penn State University.

"Although theorists had anticipated that FRBs might be accompanied by gamma rays, the gamma-ray emission we see from FRB 131104 is surprisingly long-lasting and bright," Fox said. The duration of the gamma-ray emission, at two to six minutes, is many times the millisecond duration of the radio emission. And the gamma-ray emission from FRB 131104 outshines its radio emissions by more than a billion times, dramatically raising estimates of the burst's energy requirements and suggesting severe consequences for the burst's surroundings and host galaxy.

Two common models for gamma-ray emission from FRBs exist: one invoking magnetic flare events from magnetars -- highly magnetized neutron stars that are the dense remnants of collapsed stars -- and another invoking the catastrophic merger of two neutron stars, colliding to form a black hole. According to coauthor **Kohta Murase**, a Penn State professor and theorist, "The energy release we see is challenging for the magnetar model unless the burst is relatively nearby. The long timescale of the gamma-ray emission, while unexpected in both models, might be possible in a merger event if we observe the merger from the side, in an off-axis scenario."

"In fact, the energy and timescale of the gamma-ray emission is a better match to some types of supernovae, or to some of the supermassive black hole accretion events that Swift has seen," Fox said. "The problem is that no existing models predict that we would see an FRB in these cases."

The bright gamma-ray emission from FRB 131104 suggests that the burst, and others like it, might be accompanied by long-lived X-ray, optical, or radio emissions. Such counterparts are dependably seen in the wake of comparably energetic cosmic explosions, including both stellar-scale cataclysms – supernovae, magnetar flares, and gamma-ray bursts – and episodic or continuous accretion activity of the supermassive black holes that commonly lurk in the centers of galaxies.



Gamma-ray emission from FRB 131104. The blue lines (with grey error bars) show the gamma-ray intensity of the counterpart, as measured in multiple 64-second Swift exposures, while the red rectangle shows a simple model for this emission. The data and models suggest that the bang" of gamma rays lasted for at least two minutes, and perhaps as long as six minutes, after the whistle" of the fast radio burst, which occurred at time t=0 seconds in this plot. Credit: J. J. DeLaunay, Penn State University

In fact, Swift X-ray and optical observations were carried out two days after FRB 131104, thanks to prompt analysis by radio astronomers (who were not aware of the gamma-ray counterpart) and a nimble response from the Swift mission operations team, headquartered at Penn State. In spite of this relatively well-coordinated response, no long-lived X-ray, ultraviolet, or optical counterpart was seen.

The authors hope to participate in future campaigns aimed at discovering more FRB counterparts, and in this way, finally revealing the sources responsible for these ubiquitous and mysterious events. "Ideally, these campaigns would begin soon after the burst and would continue for several weeks afterward to make sure nothing gets missed. Maybe we'll get even luckier next time," DeLaunay said.

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