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News & views

Astronomy

Not all fast radio bursts are created equal

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Astronomical signals called fast radio bursts remain enigmatic, but a key discovery has now been made. A second repeating fast radio burst has been traced to its host galaxy, and its home bears little resemblance to that of the first.

Millisecond-duration, extragalactic radio flashes called fast radio bursts[1,2] (FRBs) present many puzzles that are strikingly similar to past mysteries concerning phenomena now known as quasars and γ-ray bursts. Like FRBs, these phenomena seemed to be uniformly distributed in the sky, but of almost impossible luminosity if cosmological in origin. Ultimately, it was revealed that quasars are associated with supermassive black holes, and γ-ray bursts with the formation of black holes after supernovae (stellar explosions) or with mergers of stellar remnants called neutron stars. Repeating FRBs provide the opportunity to identify the homes and possible progenitors of FRB sources. The first known repeater was localized to a star-forming region in a tiny, metal-poor galaxy[3]. Writing in *Nature*, Marcote *et al.*[4] pinpoint the home of a second repeater and find it to be very different.

As an FRB travels through the ionized intergalactic medium, its radio waves interact with free electrons and are slowed. High-frequency waves are less affected than low-frequency ones, so the former arrive at an FRB detector slightly sooner than the latter. This time difference is proportional to the total number of electrons between the FRB source and the detector, and can therefore be used to estimate the enormous distance to the source. Early FRB detectors could not unambiguously identify an FRB host galaxy because their localization resolutions spanned hundreds or even thousands of potential host galaxies. But now, multi-element radio telescopes such as the Australian Square Kilometre Array Pathfinder (ASKAP) and the Deep Synoptic Array ten-antenna prototype (DSA-10) in California have high enough resolution that host galaxies can be easily identified.

At the same time, a radio telescope known as the Canadian Hydrogen Intensity Mapping Experiment[5] (CHIME) is revealing that many FRBs repeat. The individual bursts of a repeater tend to be clustered in time, which means that the probability of catching a burst is higher when a repeater is active. Because CHIME surveys the sky daily, it is in an ideal position to trigger other telescopes to carry out localizations. Marcote and colleagues caught four bursts of one of the repeaters discovered by CHIME and used these observations to determine the precise location of the repeater in a nearby galaxy (Fig. 1). This galaxy is about 200 times farther from Earth than is our nearest neighbour, the Andromeda galaxy.

The first known repeater differed in at least three ways from many of the one-off FRBs. First, it showed peculiar changes in intensity as a function of frequency and time, akin to intense solar radio emissions called solar radio bursts. Second, it traversed a highly magnetized plasma that led to a twist in its polarization as a function of frequency. And third, it was emitted near a supermassive black hole. Although one-off FRBs are harder to study than are repeaters, they are known to sometimes have complicated, multi-component temporal profiles[6], similar to the emissions from magnetars (highly magnetized neutron stars).

Could it be that one-off FRBs and repeaters are like short- and long-duration γ-ray bursts — two different classes of phenomenon that just happen to have a similar emission timescale and luminosity? Or is there a theory of FRBs that would link the two classes? Most FRB theories involve a compact astronomical object, and emissions that are associated with extremely powerful magnetic fields or rapidly spinning (and therefore energetic) neutron stars. Some scientists, desperate for an explanation, have even proposed alien transmissions[7].

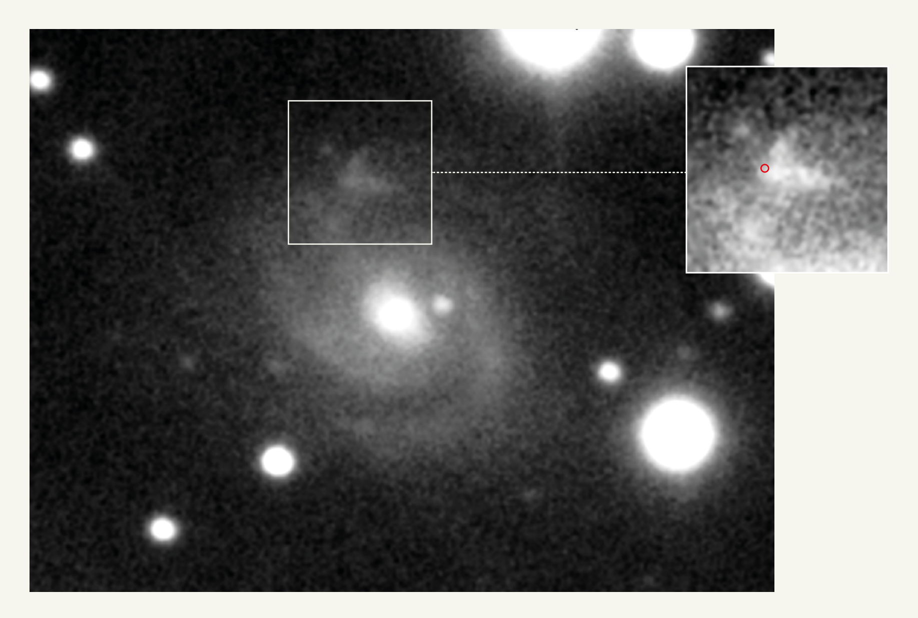

Figure 1 | Localization of a repeating fast radio burst. Fast radio bursts (FRBs) are bright, extragalactic radio flashes of unknown physical origin. Marcote *et al.*[4] have determined the precise location of a source of repeating FRBs (indicated by the red circle). Unlike the previous localization of a repeating FRB[3], this source was found in a fairly ordinary, massive spiral galaxy. The image is taken using optical light, and a higher-contrast zoom-in of the relevant region of the galaxy is included. (Image from ref. 4.)

It is possible to envisage a unifying model in which FRB sources have an energy reservoir (whether magnetic, kinetic or gravitational) that is plentiful when the source is produced near a star-forming region, causing frequent bursts. As this reservoir becomes depleted, the bursts are separated by increasingly long gaps, until they cease altogether. Such behaviour is similar to that of 'glitches' (sudden changes in spin frequency) in a type of neutron star called a pulsar. Young pulsars often glitch prolifically, but older pulsars can go for decades without exhibiting a glitch. Frequently repeating FRBs would be easier to find than those that have a lower repetition rate, but verifying that they are repeaters would become increasingly difficult as their repetition timescales approached the lifetime of FRB experiments (currently years).

The first known repeater seemed to fit such a model. It could have been a young magnetar emitting from a relatively exotic location — near a supermassive black hole in the star-forming region of a small, metal-poor galaxy. Such an environment is very different from that of most young neutron stars in our own Galaxy. However, Marcote and colleagues found that the source of their repeater is not particularly magnetic, is nowhere near a supermassive black hole and is in a fairly normal galaxy. Even so, the source is close to a curious, V-shaped region of stars that only adds to the mystery of FRB origins (Fig. 1).

In the past year, ASKAP has localized several one-off FRBs[8,9] and found them to inhabit a wide range of galaxy types. The beauty of the ASKAP results and those of Marcote *et al.* lies in the accuracy and reliability of the localizations. These features are not available to relatively compact telescopes[10], such as DSA-10, which can only hint at the identity of the relevant galaxy (think of this as the FRB's home city), rather than pinpointing the exact environment within it (the FRB's home address).

Ultimately, we will discover that, for each class of FRB, either these signals are produced near active sites of star formation or there is no particular correlation. If they originate near the sites of supernovae, the FRBs probably arise from young, highly magnetic neutron stars. If their origins are farther from such sites, they might be produced by time bombs of gravitational energy (such as merging neutron stars) and have diverse spatial distributions similar to those of short-duration γ-ray bursts, which are now known to be associated with neutron-star coalescence. Curiously, because the luminosity of a typical quasar is not dissimilar to the peak luminosity of an FRB, we cannot yet completely discount the involvement of supermassive black holes. But Marcote and colleagues' results argue against that possibility, and the timescales for quasar variability are more likely to be days to months than milliseconds.

Rates of FRB discovery and host-galaxy identification are likely to greatly increase as more detectors come online. Results from CHIME are widely anticipated, and facilities such as the MeerKAT radio telescope in South Africa and the Five-hundred-meter Aperture Spherical radio Telescope (FAST) in China will soon come online. Do not be surprised if there is more than one way to generate FRBs — without the need for aliens.

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