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**Astronomy**

# Slow-beating radio waves from a long-lived source

**Victoria M. Kaspi**

Astronomers have uncovered a source of radio waves that pulsate more slowly than expected. Meticulous records reveal that the emission has been detected for decades, highlighting the remarkable foresight of scientists in bygone years. **See p.487**

Celestial objects change on a range of timescales, and understanding these scales is one of the most exciting areas of astrophysical research today. For instance, rapidly rotating, highly magnetized neutron stars, called radio pulsars, emit beams of electromagnetic radiation that pulse on timescales of milliseconds to several seconds, and can also vary on a microsecond scale (see, for example, ref. 1). Fast radio bursts[2] are even shorter flashes of radio waves that appear randomly across the sky, lasting tens of microseconds to milliseconds[3], whose origin is elusive at present. But astronomical timescales can also be much longer. On page 487, Hurley-Walker *et al.*[4] report a finding on a much more leisurely timescale: a radio source that pulsates with a period of 21 minutes – and that is also of unknown origin.

Radio pulsars were discovered in 1967 by then graduate student Jocelyn Bell[5]. Their pulsations are thought to originate from an effect that resembles a cosmic lighthouse: the rotation axis of the neutron star is not aligned with its magnetic axis, so when radio beams emerge from its magnetic poles, the signal rotates with the spinning star. When one of these beams crosses Earth, a radio pulse can be detected. The short periods of pulsars thus reflect the high rotation rates of these stars – in the case of ultrafast millisecond pulsars, the stars rotate as fast as the blades in a kitchen blender.

The radio emission is thought to be generated by charged particles spiralling in the intense magnetic field near the stellar poles. The motion of the magnetic field induces a powerful electric field that accelerates these particles to close to the speed of light. But this mechanism works only if the magnetic field is sufficiently strong and the rotation rate sufficiently high; if either one is not, the induced electric fields are too weak to accelerate particles enough to form a detectable radio beam.

Theorists have long defined the 'pulsar death line' as a set of values for rotation rate and magnetic field strength, below which radio pulsations cannot be generated. The exact location of the death line depends on model subtleties, so a survey of the literature yields a range of possibilities, sometimes called the pulsar death valley (Fig. 1). For many years, the zippy second- and millisecond-long rotation periods of pulsars positioned these objects comfortably on the 'safe' side of typical death lines, happily in line with theoretical expectations, although some sources have hinted that the span of the death valley might be slightly underestimated (see, for example, ref. 6).

Hurley-Walker and colleagues' surprise discovery is a pulsar, dubbed GPM J1839−10, that lies well beyond the limits of the death valley – past the farthest possible line predicted. This object is even more extreme than a source named GLEAM XJ162759.5−523504.3, which has an 18-minute period and was previously found by researchers in the same group[7]. How can particles be accelerated enough to cause radio emission if these sources rotate at a snail's pace? And if rotating neutron stars are not responsible for the emission, what exactly is its source, and how does it derive the energy required to cause the radio pulsations?

One possibility is that GPM J1839−10 is some form of highly magnetized white dwarf. As the pulsar emits radiation, it loses rotational kinetic energy. The luminosity of the emission is proportional to the star's moment of inertia – a measure of how much an object resists rotational acceleration. White dwarfs

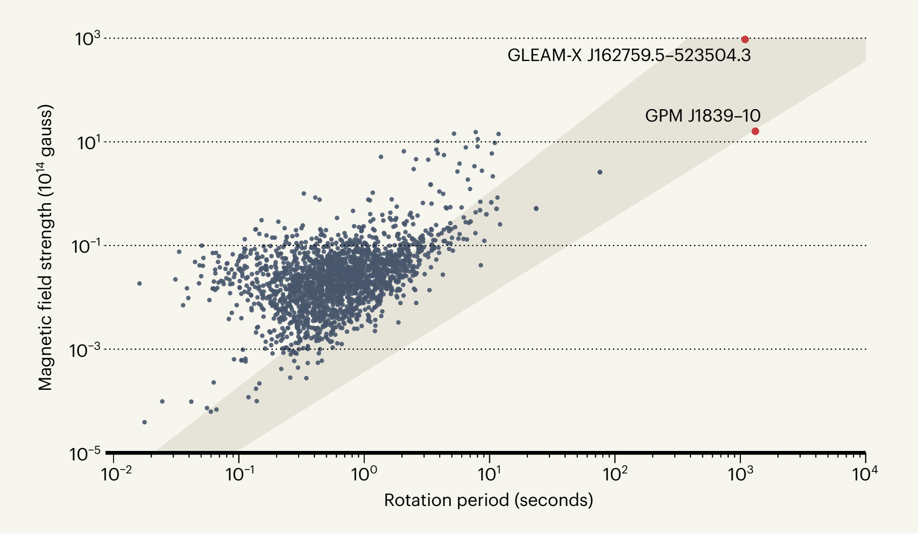

**Figure 1 | A new source beyond the pulsar death valley.** Various rotating celestial objects, including sources called pulsars, emit pulsating electromagnetic radiation that is thought to arise through the acceleration of charged particles as a result of the objects' intense magnetic fields. However, this explanation holds only for strong enough fields and fast enough rotation, so there is a range of these values, known as the 'pulsar death valley', which defines the plausible limits for radio emission to arise. Hurley-Walker *et al.*[4] detected a source named GPM J1839−10, which has a 21-minute rotation period that puts it beyond this range, and has been active for decades. Researchers from the same group previously observed GLEAM XJ162759.5−523504.3, a source with an 18-minute rotation period, which faded after three months[7]. Red points show upper limits of estimates for these sources. (Adapted from Fig. 4 of ref. 4.)

are much larger than neutron stars, so their moments of inertia can be more than 100,000 times larger. They also rotate much more slowly than do neutron stars, which is consistent with the observed 21-minute period. However, although thousands of white dwarfs have been observed in our Galaxy, many of which are much closer to Earth than GPM J1839−10, only one has shown even remotely comparable radio emission. That object, known as Ar Sco, has a pulsation period of two minutes, and is around 1,000 times less luminous than GPM J1839−10 (ref. 8).

Another possibility, which is perhaps less speculative, is that the source is a magnetar, an extreme form of neutron star thought to bear the Universe's strongest known magnetic fields[9,10]. Magnetars have rotation rates that are slow compared with those of radio pulsars[11] — although nowhere near as slow as that of GPM J1839−10. They can also have radio emission at least as luminous as that of GPM J1839−10 (ref. 12). But magnetars commonly undergo sudden episodes in which they emit lots of X-ray bursts for a few weeks, and then go quiet. Hurley-Walker *et al.* found no evidence for bursts in their X-ray observations of GPM J1839−10 while it was emitting radio pulses.

And although magnetars constantly emit X-rays, they typically produce radio emission that appears suddenly, at the same time as an X-ray outburst (see, for example, ref. 13), and then fades on a timescale of months. This was true of the 18-minute source, GLEAM XJ162759.5−523504.3, which faded after just three months. By contrast — and amazingly — Hurley-Walker *et al.* show that GPM J1839−10 has been emitting radiation at radio frequencies for the past three decades, much longer than any bona fide magnetar found so far.

The puzzling long-term activity of this newly recognized source constrains any models invoked to explain it. And it might have gone unnoticed, were it not for the foresight of radio astronomers who meticulously archived and made public their voluminous data, in the hope that doing so would serve scientists in the future. Radio observations are not special in this respect. Astronomical data from across the electromagnetic spectrum have long been carefully catalogued and made freely available, resulting in a multitude of discoveries akin to that reported here. In this way, astronomy had set a high standard for open science well before other fields made it a priority.

The bounty yet hidden in astronomical archives will continue to be tapped into, and will no doubt help to answer many more questions. One key issue raised by Hurley-Walker *et al.* is whether sources such as GPM J1839−10 and GLEAM XJ162759.5−523504.3 are unusual, or whether there exists a substantial population of extremely slow pulsars awaiting discovery in the Milky Way. The astronomical archive will surely be of great assistance in answering this question. Only time will tell what else lurks in these data, and what observations across many astronomical timescales will reveal.

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Meteorology

# The outlook for AI weather prediction

**Imme Ebert-Uphoff & Kyle Hilburn**

Two models demonstrate the enormous potential that artificial intelligence holds for weather prediction. But the risks involved demand that meteorologists learn to design, evaluate and interpret such systems. **See p.526 & p.533**

Daily news headlines document the use and misuse of generative artificial intelligence (AI) — a type of AI model that can produce realistic content, such as text and videos. Public enthusiasm for these models has been tempered with trepidation, and the broader discussion about this technology is mirrored by a similar one among atmospheric scientists, some of whom have started to incorporate generative AI into their weather-forecasting models. Two groups now report such models: Bi *et al.*[1] (page 533) present a model for forecasting weather up to seven days in the future, and Zhang *et al.*[2] (page 526) describe one for predicting precipitation up to three hours ahead of time. Both studies are impressive, and together they provide a timely opportunity to examine the benefits and risks of these new developments.

Conventional weather-prediction models are based on physical equations that are implemented using numerical models — an approach known as numerical weather prediction. Generative AI weather models work differently: instead of making predictions on the basis of an understanding of physics, they forecast weather patterns that are statistically plausible given historical measurements. This approach has proved so promising that it has raised the possibility of a paradigm shift, in which AI-based models could replace numerical weather prediction completely.

At the heart of a numerical weather-prediction model is the dynamical core or 'dycore', in which numerical equations encode the underlying physical constraints: conservation of momentum, mass and energy. However, these equations take a long time to solve, even with the fastest computers, and they result in predictions with a resolution of only about 28 kilometres between grid points (see go.nature.com/3cyh4ck), which is too coarse to model small-scale physical processes, such as clouds, radiation and turbulence.

This problem can be circumvented by expressing the state of the physical system as a parameter, or set of parameters, but this replacement introduces a source of forecast error. An alternative approach, proposed almost two decades ago[3], is to keep the dycore, but to replace parameterizations with much faster AI models. Bi *et al.* and Zhang *et al.* have both taken an even more radical approach, by replacing the entire numerical weather-prediction system with an AI model. Bi and colleagues' AI model is trained entirely on observations, whereas Zhang and co-workers' AI model is trained on both physical equations and observations.

Bi and colleagues' model is called Pangu-Weather, and it forecasts temperature, wind speed and pressure, as well as other variables. The model produces predictions about 10,000 times faster than numerical weather-prediction models at the same

**Clarification**

The figure legend in the article entitled ‘Slow-beating radio waves from a long-lived source’ did not explain that the red points represent upper limits of the estimates for radio sources GPM J1839−10 and GLEAM XJ162759.5−523504.3.

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