dinner might have come across the pygostyle in the context of the 'parson's nose', a fleshy and fatty bulge at the back of the bird that consists of the pygostyle and its surrounding tissue. The pygostyle has several aerodynamic functions. It anchors flight feathers, reduces drag (relative to the levels observed for birds with a longer tail) and helps to shift the centre of mass forwards towards the wings, which aids biomechanics.

Second, the shoulder girdle of *Baminornis* is refashioned so that the scapula and coracoid bones are separate and the coracoid is strut-shaped – adaptations that are associated with the bespoke musculature and arm motions of flapping flight. These anatomical features indicate that *Baminornis* was probably better at flying than *Archaeopteryx* was, and that it might even have been a better flyer than some other primitive birds from several million years later in the Cretaceous period.

With that said, *Baminornis* was no swallow or albatross. Today's birds have huge, wing-beating muscles – the succulent meat of a chicken breast – that fasten onto a gigantic bony breastbone. *Baminornis,* however, has no such bone, so it's unclear how big its flight muscles were and where they attached. Furthermore, its hand looks similar to that of a raptor dinosaur: individual fingers that could grab and slash, each with many bones, rather than the solid fused structure that secures the primary wing feathers of birds today. And, because its feathers have not been preserved, we don't know how the wings of *Baminornis* were constructed, or even how big they were.

It all makes me wonder how well *Baminornis* could fly, and whether it flew in a manner similar to birds we know or with its own style. Even the presence of a pygostyle doesn't necessarily prove that *Baminornis* had strong flight capabilities, because many dinosaurs closely related to birds – even some ground-living species – independently evolved shortened tails for various reasons[8]. Ultimately, to understand how *Baminornis* flew, rigorous biomechanical modelling and hypothesis testing will be needed, and this will be a fruitful next step in research on this remarkable fossil.

No matter how acrobatic *Baminornis* was in the air, this fossil provides striking evidence that birds were more diverse early in their history than was previously thought. There was probably a bevy of birds – long-tailed ones similar to *Archaeopteryx*, short-tailed ones such as *Baminornis*, maybe even muscular flappers, as suggested by a single provocative wishbone (the fused collar bones that act as a spring to store energy during flight) discovered in the same rocks as *Baminornis* – flying over the heads of *Brontosaurus*, *Stegosaurus* and other iconic Jurassic dinosaurs. More fossils must be out there, in those rare places that can preserve delicate skeletons, so let's keep looking.

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Particle physics

Neutrino barrels through deep waters near Sicily

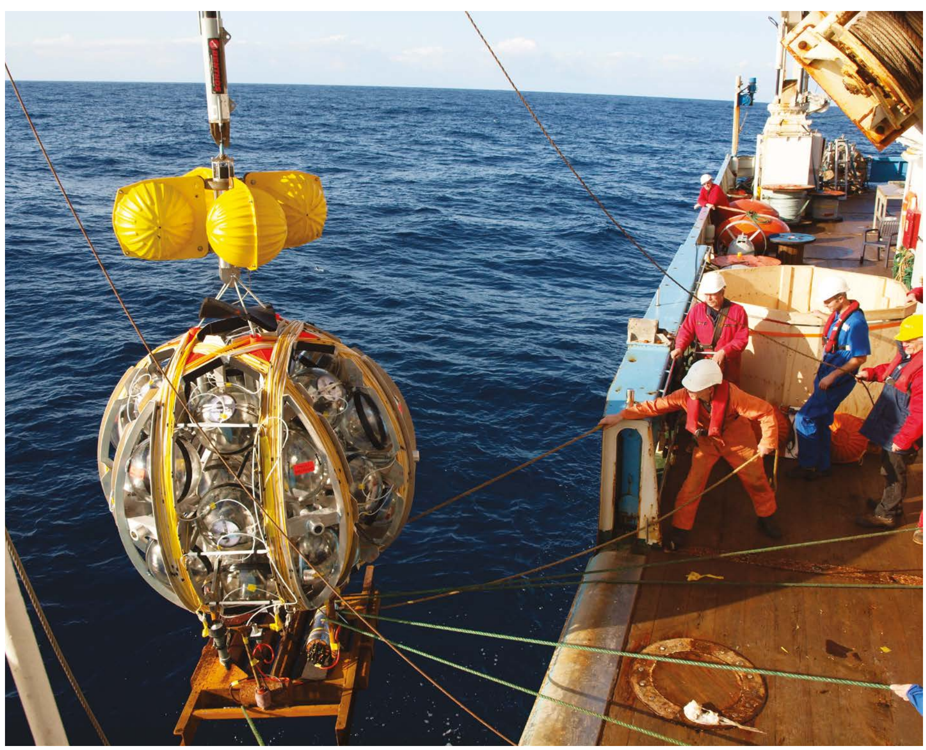
Erik K. Blaufuss

The observation of a neutrino in an enormous underwater detector has confounded physicists. It is much more energetic than any particle observed previously, suggesting that it came from a distant astrophysical source. **See p.376**

For the past decade, a new kind of telescope has been observing the skies[1]. Instead of light, these telescopes detect neutrinos – tiny subatomic particles that are usually associated with radioactive decay here on Earth, but can also come from distant sources in the Universe. Observations of 'cosmic' neutrinos provide key insights into the physical processes that power these astrophysical objects.

On page 376, Aiello *et al.*[2] report evidence of the highest-energy cosmic neutrino detected so far, which zipped through their detector deep in the Mediterranean Sea. The energy of this nearly massless particle is around 10,000 times larger than that generated in the largest particle accelerator made by humans, and its origin remains unclear.

Neutrinos are notoriously difficult to detect,



KM3NET COLLABORATION

Figure 1 | Constructing an underwater neutrino detector. The neutrino telescope KM3NeT is still under construction in the depths of the Mediterranean Sea. This launch vehicle contains several light sensors strung together with cable that will be anchored to the sea floor.

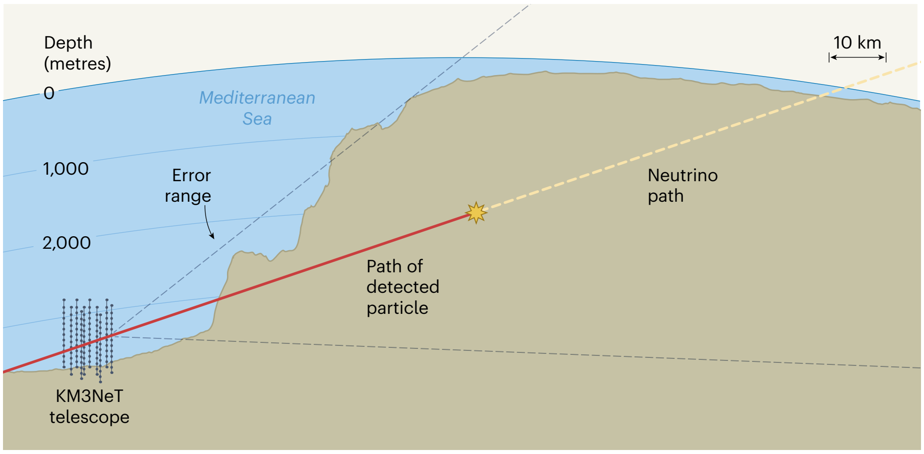


Figure 2 | Detection of a high-energy cosmic neutrino. Aiello *et al.*[2] report the detection of a particle, known as a cosmic neutrino, using a newly built neutrino telescope called KM3NeT, which is located deep in the Mediterranean Sea. The telescope comprises light sensors that are connected by cables to each other and to the sea floor. The detected particle's energy and the angle of its trajectory both suggest that it came from a neutrino that interacted with rock or water somewhere near KM3NeT. This, in turn, hints that it came from a cosmic source of unknown origin – one producing a type of particle with an energy higher than any previously measured.

because they rarely interact with matter. Neutrino telescopes therefore involve large volumes of matter – typically water or ice – embedded with detectors to capture the telltale signals that appear when these enigmatic particles do interact. The interactions leave behind particles that move at close to the speed of light, and can travel extremely long distances. As they crash through the ice or water, they emit bright blue light, which is detected by a grid of light sensors. The recorded signals are then used to reconstruct the energy and direction of these cosmic neutrinos, allowing scientists to identify their sources as known astrophysical objects.

Owing to their immense size and sparse instrumentation, these telescopes can detect neutrino signals with energies of 1 teraelectronvolt (10^{12} eV) or more. But the challenge lies in distinguishing cosmic neutrinos from other types of particles. Earth's atmosphere is continually bombarded by high-energy particles that interact in the upper levels of the atmosphere, generating particles that show up thousands of times per second in these large telescopes. Some of these interactions also create neutrinos and, all together, detections of these particles outnumber cosmic-neutrino signals by a factor of one billion to one. Fortunately, the cosmic neutrinos are expected to register at higher energies than are their Earth-born counterparts, and to point back to the positions of the relevant astrophysical sources.

The first neutrino telescope large enough to detect cosmic neutrinos was the IceCube Neutrino Observatory, which is located under the geographic South Pole in Antarctica. After more than a decade of observations, IceCube has given rise to several analyses[3,4] that have accumulated strong evidence for the existence of cosmic neutrinos; the highest energy for a single neutrino event[5] was found to be around 10 PeV (10^{15} eV). IceCube has also detected evidence for neutrino emission in our own Galaxy[6] and in several young star-forming galaxies[7,8], providing plausible astrophysical sources for nearly 15% of the observed cosmic neutrino signals. The rest of this cosmic neutrino flux remains of unknown origin.

In the past few years, a generation of neutrino telescopes has come online after years of planning and construction. This group includes the Kilometre Cube Neutrino Telescope (KM3NeT), which comprises two

> **"The Kilometre Cube Neutrino Telescope comprises two detectors in the deep waters of the Mediterranean Sea."**

detectors in the deep waters of the Mediterranean Sea (Fig. 1). In February 2023, one of these detectors, known as ARCA, was operating with just 10% of its planned components in place when something extraordinary was detected: a particle with an estimated energy of 120 PeV that had taken a near-horizontal path through the telescope. At this angle, the signal was unlikely to have come from a particle produced in Earth's atmosphere, because the amount of solid rock it would have had to travel through is an effective shield to such particles. Instead, Aiello *et al.* concluded that it came from a cosmic neutrino that had interacted with matter near ARCA (Fig. 2).

The neutrino, dubbed KM3-230213A, is a remarkable discovery, with an energy that is more than ten times the magnitude of the next-highest energy observed in a decade of searches for similar neutrinos by the IceCube and Pierre Auger observatories[9,10]. It can be difficult to draw strong conclusions from a single event, but the authors' claim is consistent with data from other neutrino telescopes, which all observe the same cosmic neutrino flux. There is a 0.5% probability that ARCA could have observed a neutrino with this much energy even though IceCube and Auger, in Argentina, detected no such signal – a slim chance, but a plausible one.

Aiello and colleagues' attempts to find potential sources of KM3-230213A in catalogues of known astrophysical objects did not yield conclusive results. This is unsurprising, given the substantial error associated with the authors' estimation of the particle's direction; several known astrophysical sources fall within the bounds of this error. Many cosmic-neutrino detections fail to show strong correlations with catalogued objects[11], perhaps indicating source populations that are very distant from Earth, or hinting at an as-yet-undiscovered type of astrophysical object. Other sources could also fit well with the observed energy, such as neutrinos that are created when the most energetic cosmic rays interact with relic radiation from the Big Bang, which now permeates the Universe[12].

KM3-230213A arrived early in the construction of KM3NeT, so understanding the detector is still a work in progress – as are methods for reconstructing the events that it observes. The reported error, which determines how well the direction of the event can be quantified, still lags behind the expected performance of water-based neutrino telescopes. Planned hardware will greatly reduce the uncertainty associated with pinpointing event directions and this, combined with more-sophisticated energy estimates, and signals from other neutrino telescopes, will mean that KM3-230213A can again be viewed with fresh eyes. Although a full understanding of the origins of this event will take time, it remains an extraordinary welcome message for KM3NeT.

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