and less accurate decoding than the piriform cortex. Notably, the parahippocampal cortex did not contain any odour information.

Participants were asked to rate the pleasantness, or valence, of each odour. By analysing the accompanying neural responses, the researchers found that valence was encoded in the amygdala – a brain region known mainly for its role in processing emotions – but not in any of the other regions. The study participants were also asked to identify the odour. Identification accuracy correlated with activity in the hippocampus, but not in other areas. These findings reveal how different brain regions process odours in distinct ways. The piriform cortex is best at encoding the odour itself; the amygdala evaluates the odour's valence; and further processing in or upstream of the hippocampus is required for recognition and naming of the odour (Fig. 1a).

The piriform cortex has classically been called the primary olfactory cortex because it receives direct inputs from the olfactory bulb, the brain structure that first receives signals from the sensory neurons in the nose that detect odour molecules. However, the role of the piriform cortex in higher-level processing has challenged this designation[6,7]. This study further supports the idea that the piriform cortex functions more as an 'associational' area involved in higher-level cognitive processes than as a primary sensory cortex.

Indeed, after being presented with odours, the volunteers were shown images that corresponded to the odours (for example, pictures of garlic, a rose or coffee). Visual images evoked responses in all of the recorded brain areas. And, by applying the same type of decoding analysis used to classify odour-evoked activity, the authors could use the visual responses to decode the presented images in all areas, including the parahippocampal cortex, which had exhibited no odour responses. Remarkably, image decoding was more accurate in the piriform cortex than in any of the other monitored brain areas.

Moreover, the researchers found that classifiers that were trained on image-evoked activity in the piriform cortex and amygdala could accurately predict the corresponding image when they were tested on odour-evoked activity. This suggests that the piriform cortex and amygdala encode multimodal, 'semantically coherent' representations of objects. In other words, these regions process different types of information that relate to the same meaning. Perhaps the most striking discovery was that of multimodal 'concept neurons'. These neurons showed highly selective and semantically coherent responses that integrated sensory, cognitive and linguistic information. For instance, a single piriform-cortex neuron fired strongly and selectively in response to the odour of liquorice (and anise, a similar-smelling odour) and showed selective, albeit weaker, responses to images of liquorice and even to the word written out (Fig. 1b). This finding firmly challenges the view of the piriform cortex as solely a primary olfactory cortex, revealing instead its role in integrating multimodal sensory information and forming coherent concepts.

Although this study provides groundbreaking insights into the neural basis of olfaction, it leaves room for further exploration. For example, investigating whether concept neurons respond to imagined odours could help scientists to understand the intricate relationship between olfactory perception and memory. Future studies could take a fine-grained approach to understand how odour information is processed in different subregions of the hippocampus and amygdala, which perform distinct functions. The ability to record from populations of individual neurons in awake humans makes this research possible, and future work can build on this foundation.

The discovery of concept neurons in the piriform cortex raises intriguing questions about sensation and perception. How do our brains integrate information at such early stages of sensory processing to form coherent concepts? To what extent do we rely on sensory information to drive perception versus using existing internal models to interpret and update our understanding? What influences this interplay between sensation and prediction? Directly observing neural activity in humans brings scientists closer to answering these questions.

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Astronomy

The photons from hell next door

Jamie Holder

An astrophysical object called a microquasar in the Milky Way has been found to emit γ-rays. The discovery shows that these systems accelerate particles to extremely high energies, and could provide insight into Galactic cosmic rays. **See p.557**

Among the most notable results in high-energy astronomy over the past few years is the discovery of γ-ray emission from an object known as SS 433 (refs 1–3). On page 557, Alfaro *et al.*[4] report that SS 433 has a counterpart, with the detection of γ-rays from another object called V4641 Sagittarii (V4641 Sgr). It is difficult to draw broad conclusions from a single object alone, however fascinating it might be to study. But a catalogue of two objects implies a population, and holds promise for further discoveries and long-sought answers.

SS 433 is an extraordinary object, highlighted by British science-fiction author Arthur C. Clarke as one of his 'seven wonders of the world'. It is a binary system, consisting of a compact object – probably a black hole – and a supergiant star. As material from the star falls onto the black hole, jets of plasma are generated, which move away from the black hole in opposite directions at around one-quarter of the speed of light. The impact of these jets extends for dozens of parsecs, distorting the surrounding nebula, which is probably the remnant of the supernova that formed the black hole.

The jets also act as natural particle accelerators, pushing subatomic particles to velocities that approach the speed of light, and to energies much higher than those achieved in human-made accelerators. These high-energy particles generate X-rays as they spiral in magnetic fields, and γ-rays when they interact with low-energy photons. Observing the γ-rays, and mapping their point of origin, allows astronomers to determine exactly where and how this particle acceleration takes place.

Objects such as SS 433 are known as

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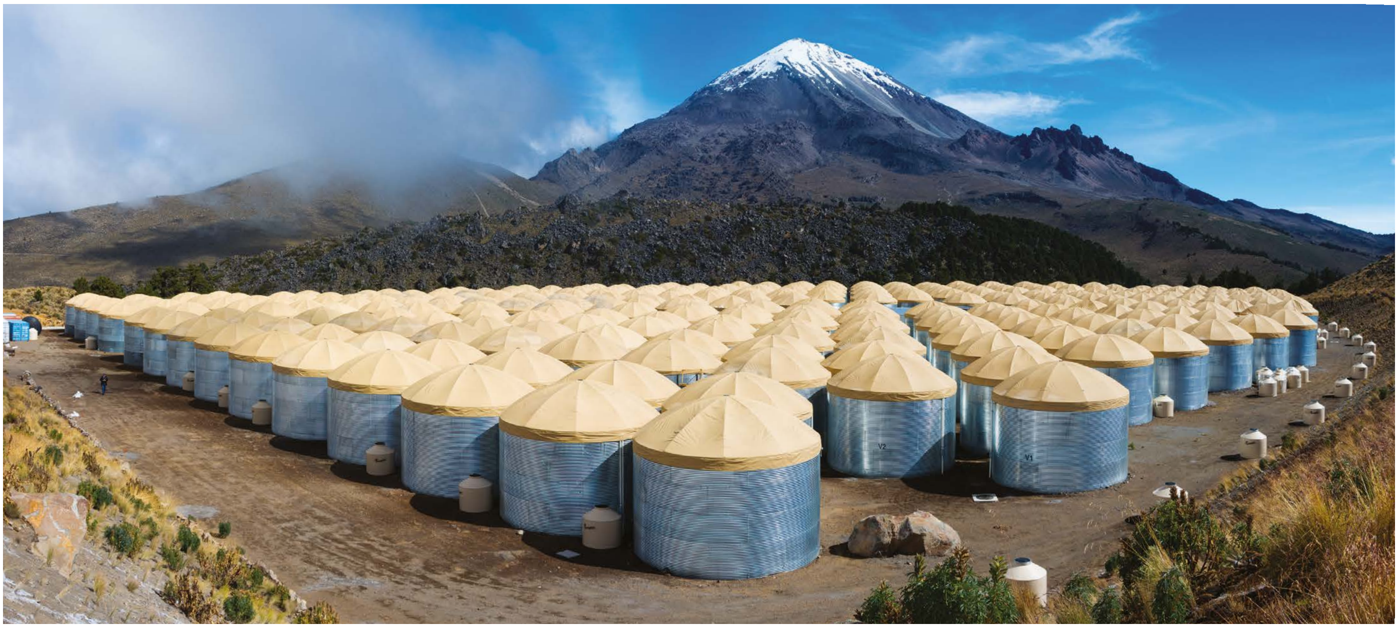

Figure 1 | Detecting γ-rays from microquasars. The High-Altitude Water Cherenkov Gamma-Ray Observatory (HAWC) is in Mexico, at an altitude of 4,100 metres, and comprises 300 water-filled tanks, each of which is 4 metres high and 7 metres wide. The facility can be used to detect high-energy γ-rays; for example, those emitted by astrophysical objects known as microquasars.

microquasars, by analogy with quasars, which are the cores of active galaxies centred on supermassive black holes. These black holes, which have masses millions or billions of times that of the Sun, generate galaxy-scale jets. Although more than a dozen microquasar systems are known or suspected to exist in the Milky Way, SS 433 is the only one that has so far been shown to have associated steady γ-ray emission. But Alfaro and colleagues' discovery changes that.

The authors' collaboration uses data from the High-Altitude Water Cherenkov Gamma-Ray Observatory (HAWC), which is designed to observe astrophysical γ-rays with energies between 0.1 and 100 teraelectronvolts (one TeV corresponds to roughly one trillion times the energy of visible light). The facility sits at an altitude of 4,100 metres in Mexico, and looks nothing like an optical or radio observatory – it consists of 300 water-filled tanks, each 4 metres high and 7 metres across (Fig. 1).

When a high-energy γ-ray (or cosmic ray) hits Earth's atmosphere, it produces a shower of high-energy particles, some of which make it down to mountain altitudes. Particles entering the HAWC tanks are travelling faster than the speed of light in water (which is only 75% of the speed of light in a vacuum), and this makes them generate a flash of blue light known as Cherenkov radiation. Photosensors in the tanks detect this blue light, allowing the shower particles to be detected, and the properties of the primary γ-ray to be reconstructed.

Alfaro *et al.* used observations of V4641 Sgr made by the HAWC between 2014 and 2022. Their discovery was enabled by work undertaken in the past few years to improve the observatory's performance at low elevations[5], given that V4641 Sgr reaches a maximum angle of 45 degrees above the horizon at the HAWC. The resulting γ-ray map reveals an elongated source that extends more than 60 parsecs. The authors conclude that this emission is probably generated in huge 'bubbles' of high-energy particles that are accelerated by the jets of the binary system.

The addition of a second microquasar to the catalogue of γ-ray sources is a major advance that has the potential to address wider questions. For example, although the γ-ray emission observed by Alfaro *et al.* is probably a result of the interactions of accelerated electrons, the existence of jets that accelerate particles to extremely high energies suggests that microquasars can also accelerate protons or nuclei. If so, microquasars could contribute substantially to the flux of Galactic cosmic rays at the highest energies, the origin of which remains a long-standing mystery. Alfaro and colleagues' discovery also strengthens the case for microquasars as possible Galactic sources of astrophysical neutrinos, just a year after the discovery of neutrinos coming from the Galactic plane[6].

The detection of emission from V4641 Sgr by Alfaro *et al.* highlights one of the advantages of particle detector arrays – the fact that they continuously survey the entire sky overhead. Previous surveys of the Galactic plane using γ-ray telescopes with a smaller field of view than that of the HAWC could have missed this object simply because it lies 5 degrees away from the plane[7]. However, the authors' technique is less effective than observations made with other telescopes when it comes to making detailed maps of the source. Follow-up observations with higher-resolution γ-ray telescopes will now attempt to confirm the association between the γ-ray emission and V4641 Sgr, and to accurately pin down the size and shape of the emission region.

Finally, what does the discovery of high-energy emission from microquasar jets mean for astronomers' understanding of quasars? When TeV γ-rays from the quasar Markarian 421 were detected in 1992, they were described as "photons from hell"[8]. The extraordinarily rapid and intense outbursts of γ-rays from active galaxies were later termed "photons from a hotter hell"[9]. But quasars are too distant from Earth to allow direct, detailed imaging by any existing or planned γ-ray telescopes. Now, with the discovery of TeV emission from two microquasars in our own Galaxy, there is hope that studying these 'photons from hell next door' will provide insight into the internal workings of their vastly more powerful cosmic cousins.

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