Why black holes pulse brightly

Black holes can produce oscillating outbursts of radiation that were thought to be associated with high rates of infalling matter. The observation of pulses of visible light from a black hole complicates this picture. See Letter P.XXX

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Accretion of matter onto black holes is an efficient way of converting mass into energy, much more so than the process of nuclear fusion that powers the light from stars. But unlike fusion, the physics behind accretion is still not understood, 41 years after the discovery of accreting black holes in the Milky Way. On page xxx of this issue, Kimura *et al.*[1] present exquisite observations made during a black-hole accretion episode, which show that the visible radiation from the black hole's vicinity oscillates dramatically in a manner not predicted by models. Such oscillations were previously associated with high rates of infalling matter, but the authors report that the observed oscillations can occur even when the rate of infall is low. Understanding this behaviour could help us better understand violent accretion episodes onto black holes.

The researchers studied the black hole V404 Cygni, 2.4 kiloparsecs from Earth. The Cygnus constellation is a popular hunting ground for black-hole specialists, because of its location in the plane of the Milky Way, and because it hosts several other bright, accreting black holes and neutron stars. In June 2015, V404 Cygni underwent a short-lived accretion ‘outburst’ lasting about two weeks, which caused it briefly to become one of the brightest cosmic X-ray sources beyond the Solar System. The black hole’s gravity is strong enough to strip matter off the surface of an orbiting companion star, and the potential energy of this infalling matter is released, in part, as the observed radiation.

The infalling matter is expected to be hot, magnetized plasma. But if such material were to plunge directly into the black hole, its energy would be immediately lost without any brightening. The standard picture of accretion is that the plasma instead acts as a viscous fluid that spirals towards the black hole in the form of a disk, and that its energy is liberated as a result of friction in the disk. Any plasma that cannot be accreted is expelled in the form of a fast narrow stream (a jet) or as an outflowing wind.

If there is a balance between the accreting plasma and frictional energy losses, then the mass would be steadily accreted. But naturally occurring changes in the rate of mass accretion can upset this balance and cause an unstable see-saw-like behaviour: periods of enhanced accretion that empty parts of the disk are followed by quieter periods during which those parts are refilled, after which the cycle begins again. An approximate analogy is the repetitive filling and emptying of a Japanese bamboo fountain.

Such behaviour has been observed in one other black-hole system, GRS 1915+105 in the Aquila constellation, which undergoes high levels of mass accretion. Several classes of repetitive oscillation occur in this system, but only in its X-ray emission[2]. Kimura and collaborators draw parallels between GRS1915+105 and the visible-light oscillations in V404 Cygni, but make the crucial distinction that the latter oscillations occur at a much lower rate of mass accretion than the former ones. In other words, the repetitive behaviour is not strictly associated with episodes of high mass accretion.

V404 Cygni is a uniquely important study target for several reasons. It was the first Galactic object to have its mass (9 Solar masses) firmly placed within the range of masses associated with black holes[3,4]. ***[Our subeditors will try to double-check all the numbers mentioned in your News & Views, so can you say in which reference the number of 9 Solar masses is mentioned?]*** Its distance from Earth is also known with higher accuracy than those of other black holes[5]. Moreover, it becomes extremely bright when it accretes matter, despite being partly veiled behind interstellar gas and dust. In the absence of this veil, V404 Cygni would have been one of the most distant objects in the Milky Way visible to the unaided eye in June 2015.

So how does all this help us understand accretion onto black holes? Kimura *et al*. suggest that in systems such as V404 Cygni and GRS 1915+105, the supply of infalling matter is insufficent to fill the relatively large volume of space between the companion star and the black hole with a steady flow. Without a steady flow, the accretion rate becomes unstable and can fluctuate violently (Fig. 1). These fluctuations, in turn, trigger oscillating emissions of energetic X-ray photons near the black hole, which then light up the whole disk with the observed dancing visible effects.

But the authors show that this explanation requires the disk to be very large, close to its maximum possible size. Moreover, the X-ray oscillations are much stronger than the visual light ones. How, and whether, the black hole's jet tracks these oscillations is yet to be determined. The association that Kimura and collaborators put forward will undoubtedly be investigated in detail in future studies to understand these issues, in the light of the wealth of supporting observations currently being analysed by astronomers the world over.

Black-hole outbursts are unpredictable and last only as long as two weeks, and so worldwide coordination and round-the-clock monitoring is essential if we are to understand the physics of these extreme objects. This becomes particularly challenging when coordinating observations between space telescopes and those on the ground. The outburst of V404 Cygni in June 2015 has invigorated the efforts of black-hole astronomers to tackle these challenges, with entire conferences dedicated to this theme[6]. Amateurs can also play a key part in this effort. Kimura and colleagues gathered data from many little telescopes, some with optical elements only 20 centimetres in diameter, showing that in astronomy, size is not necessarily what matters; collaboration does.

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[1] Kimura et al., this issue xxx

[2] Fender R.P. & Belloni T., Annual Reviews of Astronomy & Astrophysics, 42, 317, 2004

[3] Casares J., Charles P.A. & Naylor T., Nature, 355, 614, 1992

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[5] Miller-Jones J.C.A., Jonker P.G., Dhawan V., Brisken W., Rupen M.P., Nelemans G., Gallo E., The Astrophysical Journal Letters, 706, 230, 2009

Figure 1 | Light pulses from irregular accretion onto black holes. Black holes can accrete matter from nearby stars. The matter is thought to spiral towards the black hole as a plasma disk, and any friction in the disk causes energy to be released in the form of electromagnetic radiation. Plasma that cannot be accreted is expelled as a jet. Kimura *et al.*[1] propose that, in systems such as V404 Cygni, the supply of infalling matter cannot steadily fill the space between the star and the black hole, causing fluctuations in the density of matter in the disk. These fluctuations trigger oscillating emissions of X-ray photons near the black hole, which ionize hydrogen atoms in the outer part of the disk and cause pulses of visible light, as observed by the authors.