ASTRONOMY

Odd company

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Black holes cannot yet be seen directly, but their influence on surrounding stars is allowing them to be identified with increasing certainty. That those stars are there to be influenced, though, raises other questions.

Observations of stellar dynamics have so far revealed compact, dark masses at the centre of almost 40 galaxies[1]. These are commonly assumed to be supermassive black holes — collapsed massive objects whose gravitational pull is so great that no light or matter can escape them. In most cases, however, what is seen is also consistent with the dark masses being simply clusters of dark stars. The exceptions are the dark masses at the core of the galaxy NGC 4258, our own Milky Way and now, as Bender *et al.*[2] report in *The Astrophysical Journal,* our near neighbour the Andromeda galaxy.

Without actually seeing the dark pit it creates by absorbing or bending all the light incident upon it[3,4], the most compelling method to prove the existence of a black hole is to constrain its size and mass. If a very massive object is confined to a compact region within a critical 'Schwarzschild' radius dictated by the general theory of relativity, its gravitational pull so warps space-time that this wraps round to enclose the body, preventing anything escaping. To fulfil this criterion and so be considered a black hole, the object of three million solar masses that lurks at the centre of our Galaxy, for example, must be five times smaller than Mercury's orbit around the Sun.

To measure whether a dark mass of unknown provenance is a black hole, one must first find an object moving under its influence: in newtonian mechanics, the speed of an orbiting object, together with its radius from the central source of gravity, is sufficient to determine that source's mass. The extreme gravitational pull of a black hole makes it difficult to find objects near it, let alone measure their speed. But if a close-orbiting object can be found, it can be used to rule out other potential identities for the central mass concentration: if the orbital radius is smaller than the size of other distributions of matter, such as a neutrino ball or a cluster of dark, dead stars, the only remaining viable possibility for the gravitational source is a black hole.

The nucleus of Andromeda comprises a central dark-matter distribution and — as we now know thanks to remarkable observations from the Hubble Space Telescope — not one, but three concentrations of starlight. Two of these, commonly labelled P1 and P2 (peaks 1 and 2), were known previously[5]. Conventional wisdom[6] has it that they are merely the opposite ends of an elliptical distribution of old stars orbiting the central distribution, which is near P2 at one focus of the ellipse. Bender and colleagues[2], however, now confirm the existence of a third stellar component, P3, a tiny nucleus of hot, blue stars embedded within P2 (Fig. 1). An unusual blue concentration in P2 had been noted earlier[7], but the fact that it constitutes a compact disk of stars, separate from P2, has been established only with the latest observations. Ironically, stars such as these have no business being so close to a black hole — yet, following the reasoning above, their existence there rules out any other explanation for the concentration of mass in Andromeda's nucleus other than it being a black hole.

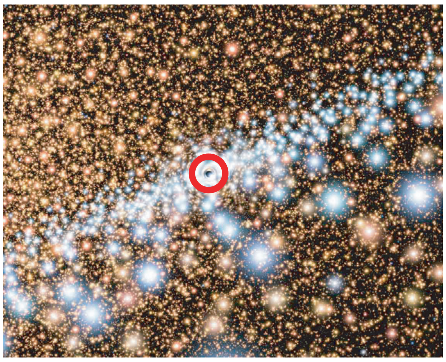

Figure 1 | Black and blue. An artist's impression of the mysterious young, blue stars in the region known as P3 encircling the supermassive black hole at the nucleus of the Andromeda galaxy. The region of older, redder stars, called P2, that surrounds P3 is typical of the cores of galaxies. The black hole itself appears as a distorted shadow at the centre of the blue disk. The 400 young, blue stars apparently formed in a burst of activity about 200 million years ago — posing problems for existing theories of star formation around supermassive objects.

Despite its small size (barely a light year across), P3 contains stars with the highest average circular rotation velocity — almost 1,700 kilometres per second — measured so far in any galaxy. According to Newton's law of gravity, the central mass required to corral such fast stars so close to the nucleus exceeds that of 100 million Suns, rendering Andromeda's black hole at least 30 times bigger than its counterpart at the heart of the Milky Way. For other dark objects, such as brown dwarfs (stars that have failed to ignite) or dead stars, to mimic such a single massive object, more than 100 million of them would have to be concentrated within a region only a third of a light year across. The collisions that would ensue would destroy this structure in only a few million years, so it would not have lasted long enough for us to see it.

But there remains the problem of the age of the roughly 400 stars that form P3. They are bright and blue, and therefore very young compared with the age of the Andromeda galaxy; most of them must have formed less than 200 million years ago. So did these stars form *in situ*, or did they migrate from farther out? Given their short lifespan, it is very difficult to see how they could have diffused inwards (and still be visible as young stars now) through two-body interactions. The alternative is that they formed where they are now, through the collapse of infalling molecular clouds. But the gravity of the black hole, and the extreme physical conditions at the centre of Andromeda, would greatly inhibit star formation unless the cloud density were many orders of magnitude greater — thus facilitating gravitational condensation into stars — than is generally encountered there.

The situation of the stars orbiting the black hole at the centre of our own Galaxy is also bizarre[8,9]. Young stars, less than 10 million years old, are assembled there into two counter-rotating disks; closer still to the centre, some 20 stars orbit within only a few light days of the black hole, some at speeds that can exceed 5,000 kilometres per second. One possible explanation for these close, young stars is that two clouds of matter fell into the black hole together, each colliding and compressing the gas of the other such that the material could clump together, thus overcoming the many factors that would otherwise inhibit their contraction into stars[9]. Although improbable, this may explain what we see in the Galactic Centre; it is less likely to account for the single disk of stars seen in P3 at the nucleus of Andromeda.

Thus, although the unknown dark-mass concentrations at the nucleus of many galaxies are conforming to what is becoming the 'standard model' of black holes[10], other mysteries of similar opacity are emerging. As Bender *et al.* note, there is no plausible explanation of how and why the hot, young stars near the centre of the Milky Way and Andromeda got there. It seems that only a new theory of star formation in the chaotic environment surrounding a supermassive object will suffice. For the positive identification of Andromeda's centre, black-hole enthusiasts are thankful nonetheless. ■

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