Stirrings of the Galactic heart

Mark Morris

WHAT lies at the very centre of the Galaxy — that point about which the entire Milky Way turns? One way to answer the question is to look at the movements of stars in its vicinity. The first direct measurements of the proper motion of stars near the Galactic Centre are reported by Eckart and Genzel on page 415 of this issue¹. When combined with the best and most recent radial velocity data², they show with little ambiguity that about 2.5 million solar masses of dark matter lurks within a relatively tiny region at the centre.

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The centre of the Galaxy. The motions of stars in the central light year of this 80×80 light-year infrared image show that 2.5 million solar masses is concentrated within about 0.1 light yr of the Galaxy's dynamical centre, probably in a huge black hole that also produces the spot of radio emission shown in the inset¹⁰ (2 light yr across).

If a cluster of stars is bound (that is, if they aren't flying apart) and in equilibrium, the spread of stellar velocities is determined by the total mass of the cluster, just as the orbital velocity of the Earth is determined by the mass of the Sun. But until now, our knowledge of the dynamics of stars near the centre of our Galaxy has been limited to observations of a single velocity component — the radial, or line-of-sight, velocity, as measured by its Doppler effect on atomic spectral lines. The application of Newton's law of gravitation to draw conclusions about the distribution of mass in the Galactic Centre has therefore always required some assumption about the missing velocity components.

For some time, radial-velocity measurements have nonetheless yielded tantalizing evidence for the presence of a compact, central concentration of non-luminous matter weighing in at a few million times the mass of the Sun, but the evidence has always been accompanied by a nagging uncertainty because the necessary assumptions about the unobserved

velocity components had never been proved valid. Indeed, it was possible to choose assumptions (albeit rather extreme ones, with most of the stars on highly elongated orbits) that considerably reduced or even eliminated the need for non-luminous matter.

Those missing velocity components — the projections of stellar space velocities onto the plane of the sky — can be seen in nearby stars as 'proper motion' against a distant backdrop. The 25,000-light-year distance to the Galactic Centre places it well beyond the usual realm of proper-motion measurements, but fortunately the distance is partly compensated for by the large stellar velocities in the central light year of the Galaxy (a few hundred km s^{-1}). Shift-and-add imaging and image deconvolution techniques are employed by Eckart and Genzel to counteract the blurring effect of the Earth's atmosphere, and give them the high spatial resolution they need to obtain significant measurements within their five-year time base.

The main result of these measurements is that, at all projected distances from the Galactic Centre, the average absolute velocity of stars along any axis in the plane of the sky is the same as that along the line of sight. That is, the stellar velocity dispersion is everywhere isotropic. Past analyses have often assumed isotropy, but now that it is established, the velocity dispersions can be translated into an enclosed mass with some reliability. Those early, naively derived masses are correct, and the conclusion that there is a sizeable dark mass at the Galactic Centre now rests on firm ground. The inferred mass cannot be in the form of normal stars, because the light they would emit could easily be seen at near-infrared wavelengths.

What makes this conclusion even more poignant is that the dark mass happens to be confined to within about a tenth of a light year of a unique object: the bright, unresolved radio source called Sagittarius A* (ref. 3). This source fulfils the expectations of many theorists as to how a disk of hot gas accreting onto a black hole should manifest itself to observers^{4,5}. The measurements of Eckart and Genzel are

consistent with the possibility that all the inferred dark mass is in Sgr A*. If so, its few million solar masses probably make it by far the largest black hole in the Galaxy, though still a lightweight compared with the compact objects of 10^7 to 10^9 solar masses or more, inferred from the dynamics in the nuclei of some other galaxies⁶.

Even if Sgr A* is a black hole, its mass is not yet well determined. It might be substantially less than a few million solar masses⁷, in which case there would be room for other forms of non-luminous matter. One of the most likely candidates is a population of stellar-mass black holes. The central stellar cluster contains dozens of massive, luminous stars, which, if they are normal stars and not exotic objects, are doomed to very short lifetimes before they explode as supernovae, leaving behind compact remnants such as neutron stars or black holes, each of 1 to 20 solar masses. Over the ten-billion-year lifetime of the Galaxy, it is possible to build up enough remnants at the centre to account for some fraction of the non-luminous matter there^{8,9}.

But the size constraint placed by the new observations on a cluster of stellar remnants is severe. Any such cluster must have undergone a core collapse if it is to fit into the tiny volume allowed. This constraint will be pushed even further in the near future, when even higher-resolution observations, currently underway, are brought to bear on the proper motions of the innermost portions of the central stellar cluster.

Eckart and Genzel give us a taste of what is to come with their preliminary observations of the Sgr A*(IR) cluster, a group of infrared sources — presumably stars — tightly clustered about Sgr A*. If the proper motions of these relatively dim objects are as large as the data are beginning to imply, it will be difficult to avoid the conclusion that Sgr A* has all the dark mass. The question would then be, what happened to all the stellar remnants? □

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