editorial

Cosmic celebrities with gravitas

Black holes have the distinct honour of being the most popular and potentially the least well-understood objects in the Universe. This issue's Insight explores how far black hole research has come since its inception, though it still has a long way to go.

Since 1784, when John Michell first thought of the concept of an object so heavy that even light cannot escape its gravitational pull, black holes have fascinated, puzzled and even terrified the public and scientists alike. It was Albert Einstein, with his foundational theory of general relativity (GR), and Karl Schwarzschild, who found the corresponding solution to GR's equations, that placed black holes on a proper physical footing in 1915. In the following century, black holes became a topic of intense scientific research, while at the same time entering the mainstream collective consciousness as one of the staples of the sci-fi genre (with milestones like the dubious 1979 Disney movie *The Black Hole* and the more acclaimed 2014 *Interstellar*). Key observational discoveries, like the orbits of stars around Sgr A*, quasars and the recent gravitational wave detections have cemented black holes as astrophysical objects of relevance to many branches of astronomical research. But how much do we know about black holes and how much more can we hope to learn in the future?

The famous 'no-hair' theorem postulates that black holes can be fully characterized by three measurable classical quantities: their mass, angular momentum and their electric charge. The theorem constitutes black holes as the ultimate confidential 'paper shredders' in the Universe; any information carried by matter falling into the black hole is irreversibly erased for any observer external to the black hole. Of the three aforementioned quantities, electric charge is considered to be, at least observationally, the least consequential one. In fact, it is usually assumed to be zero, since massive black holes are thought to be quickly neutralized by being embedded in globally neutral plasma (see our Research Highlight back in March on constraining the charge of the supermassive black hole at the centre of our Galaxy). As a result, the mass and the angular momentum — or spin — of black holes usually dominate the discussion.

The mass is the most easily accessible property because a black hole can be directly probed by classical Newtonian dynamics at scales significantly larger than its Schwarzschild radius. But while such dynamical considerations are only possible for those black holes closest to us (like the one at the centre of M87), we have to rely on much rougher estimates when looking at black holes in most other galaxies. Given their fundamental importance, understanding how black holes grow their mass is key in constraining their formation and evolution and how their growth might impact the growth of their host galaxies (see the News & Views in this issue and our focus issue last March). In the Insight, Thaisa Storchi-Bergmann and Allan Schnorr-Müller review how supermassive black holes are fed, while Marianne Vestergaard discusses current problems and open issues with calculating masses of black holes in other galaxies.

The spin of black holes, on the other hand, is significantly trickier to constrain. While things like the jet launching conditions and the distance of the innermost stable circular orbit from the black hole are expected to be intimately linked to a black hole's angular momentum, our current and near-future observational capabilities cannot really probe these very small scales. Therefore, we need to rely on more indirect effects, such as measuring the velocity dispersion of line-emitting iron ions close to the black hole. Chris Reynolds reviews our current knowledge of black hole spin and provides an outlook on future facilities that might streamline such measurements even further.

Despite the difficulties of observationally constraining these objects, our current understanding of black holes, their evolution and their role in the evolution of their environments (be it their stellar companions at stellar-mass scales or their host galaxies at supermassive scales) has grown in leaps and bounds within the 100 years separating us from their theoretical inception (see our previously published collection of some of the most exciting black hole-related discoveries). Yet several open questions still remain, some of them discussed in the Q&A with Mitch Begelman and the Comment by Mar Mezcua.

The detection of gravitational waves now offers a completely independent way for astronomers to simultaneously constrain the mass and the spin of the observed black hole systems. In addition to being a ringing endorsement of GR, gravitational waves have already started to change our understanding of how stellar-mass black holes form and grow. Ongoing experiments like pulsar timing arrays (see the Comment by Chiara Mingarelli), the Event Horizon Telescope (see our previously published Mission Control), upcoming gravitational facilities like KAGRA (see the Perspective by the KAGRA collaboration) and next-generation facilities like LISA will revolutionize the way black holes are studied. With a good estimate of their current mass and spin distributions, we will be able to robustly constrain the initial mass and spin distributions of black holes — and consequently their formation pathways — as well as their evolutionary tracks throughout cosmic history.

Increasingly sophisticated observations are piece-by-piece demystifying what a black hole is. Yet the inescapable fact is that the singularity at the centre of every black hole defies definition (with mass density and spacetime curvature going to infinity) while quantum gravity (leading into a theory of everything) remains ever elusive. Even though astronomers are generally content with substituting a black hole with a sphere of finite mass and spin, actually defining the nature of a black hole is as equally complex as deriving its properties (see the Perspective by Erik Curiel). Despite these fundamental unknowns, roadblocks and gaps in our physical theories and phenomenology, black holes continue to intrigue and fascinate. The quest to understand them has only just started and we can't wait to see what lies ahead. ❐

Published online: 8 January 2019
https://doi.org/10.1038/s41550-018-0682-y