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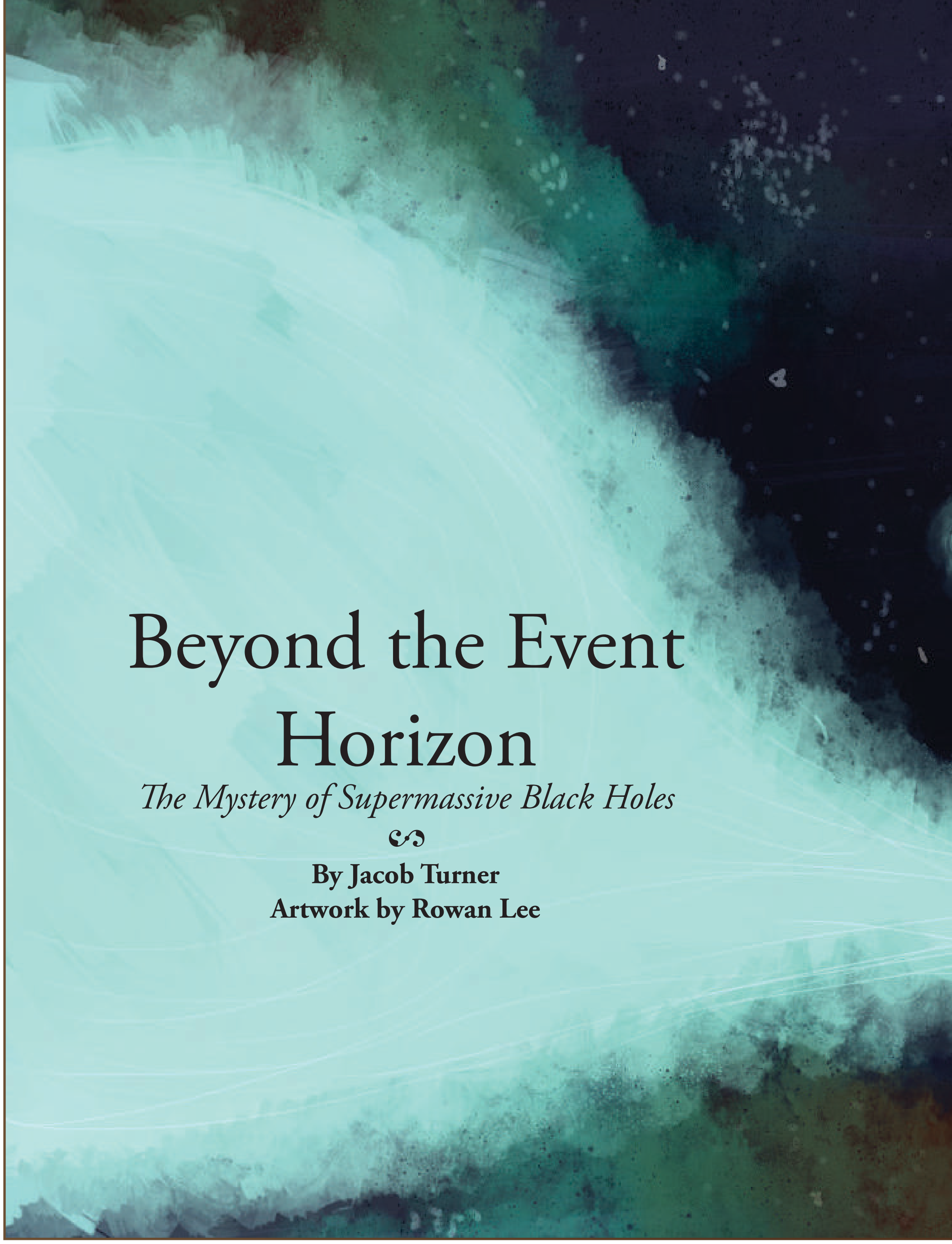
Beyond the Event Horizon: The Mystery of Supermassive Black Holes

Jacob Turner



Beyond the Event Horizon

The Mystery of Supermassive Black Holes

By Jacob Turner
Artwork by Rowan Lee

Once again, black holes have found a way to make us question how well we understand the evolution of the early universe. A group of astronomers has recently discovered a galaxy featuring a host black hole that seems to have no right being there. This galaxy—around 200 million light years away—is in a part of our local universe that is relatively sparse, consisting of only ten or twenty other galaxies. We typically expect to find galaxies with more massive black holes within densely packed groups of hundreds to thousands of galaxies. Yet this galaxy, more or less in the cosmic suburbs, has one of the largest black holes ever discovered, with a mass of around 17 billion times that of our sun. By comparison, our galaxy's host black hole is only about 4 million times the mass of our sun. Considering what we think we know about how galaxies and black holes form and gain mass, how can we reconcile this contradictory discovery?

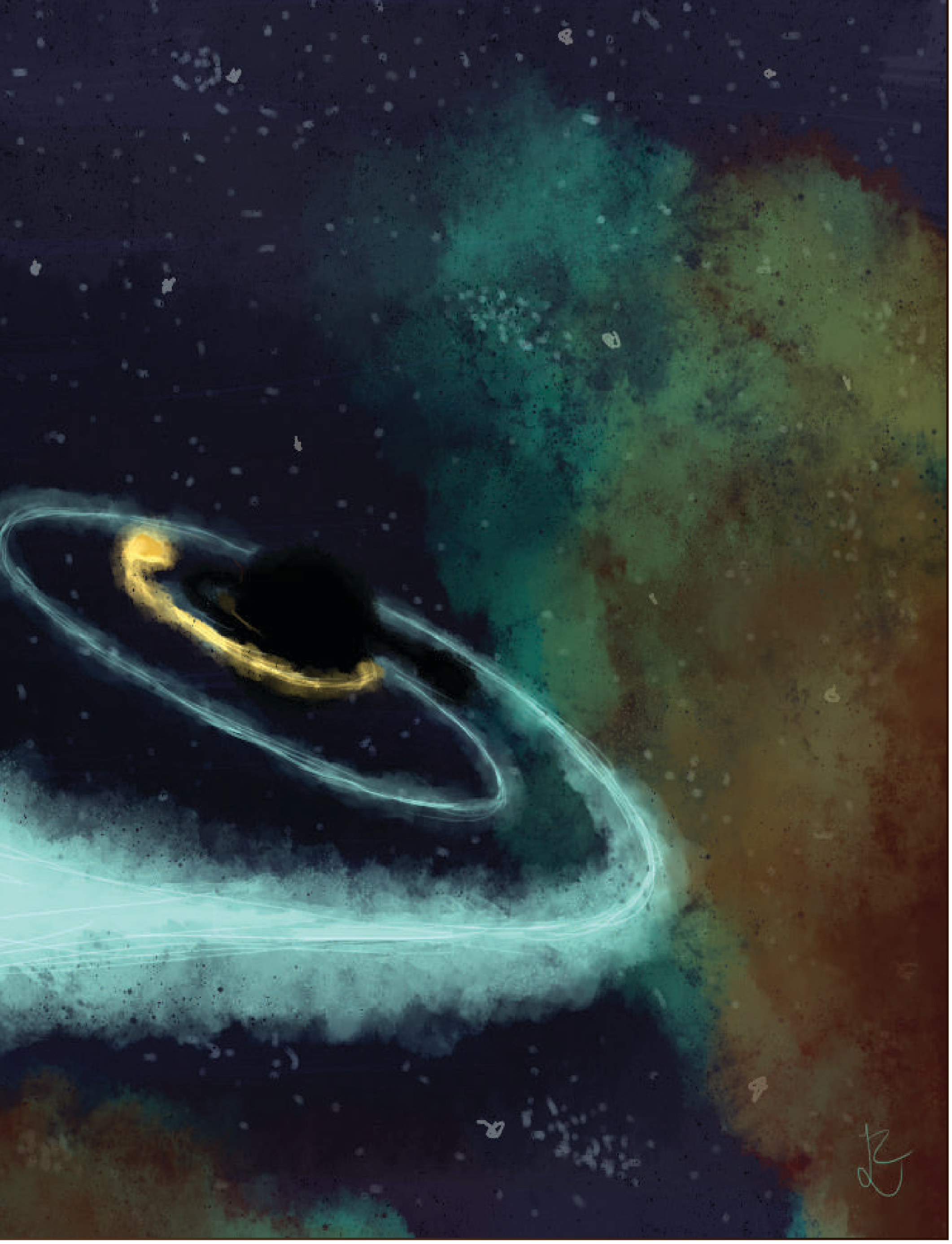
Before exploring this issue further, it's important to understand the strange characteristics of black holes. These objects are among the most extreme physical systems that exist in our universe. So they are perfect, not only for testing the limits of our current models, but also for creating new frontiers, as was recently done with the detection of gravitational waves in September 2015.

Let's consider a star around 3 times the mass of our sun, which is thought to be the minimum mass requirement for forming stellar mass black holes, i.e. a black hole formed from a star. Such a star, like all other stars, experiences a constant battle between two forces fighting for dominance beneath its surface. On one hand, you have the outward pressure created by the release of energy from hydrogen atoms fusing into helium atoms within its core. On the other hand, you have the gravitational curvature from the massive star's warping of local spacetime, which is causing the star's matter to fall back in on itself.

Eventually, the star runs out of hydrogen fuel and has to resort to fusing heavier elements in a futile attempt to maintain stability. Once it gets to iron, the reaction begins absorbing energy rather than releasing it, and so gravity wins, causing the star to implode in a fraction of a second before the massive pressure buildup at the core from the infalling material causes a massive outward explosion of gas. The star has now gone supernova, and it will likely outshine all of the other stars in its host galaxy for a few years. What remains within the gas from the supernova is a distortion of spacetime a few kilometers wide known as a black hole, a compact spherical void where the star used to be.

It can be very difficult to picture what a black hole looks like, and we are usually only able to infer the presence of one if an accretion disk has formed around it or if we observe a star orbiting around an apparently empty patch of space. We can now also infer their presence if they emit gravitational waves, although this technique is currently limited to very massive black holes in binary systems. If you wish to see a relatively accurate depiction of a black hole, I would highly recommend seeing the movie Interstellar, as the black hole in the film is rendered primarily through the extrapolations of general relativity.

Since a black hole's escape velocity—the velocity needed to escape the gravitational influence of an object—exceeds that of the speed of light, any matter travelling within a certain distance of the black hole is now powerless to resist the black hole's gravity and falls inwards. Since light is the fastest thing in the universe, we can only receive information at speeds up to the speed of light. Therefore, any events that occur within a certain region near the black hole can never be observed. This perimeter around the black hole is known as its event horizon. The physics needed to describe what happens beyond the event horizon are undiscovered, and will require the unification of general relativity with quantum mechanics into a theory of quantum gravity in order to be properly understood. However, while our applications of quantum mechanics to black holes have been few and far between, Stephen



Hawking has shown that black holes will eventually evaporate by emitting high energy particles from the event horizon via a process now known as Hawking radiation.

Hypothetically speaking, any object is capable of becoming a black hole, provided its mass is compressed into a small enough region of space. Crushing the Earth down to the size of a grain of salt or a human down to 100 billion times smaller than a proton would produce a black hole, albeit very small ones that would evaporate almost instantly. A big reason why we only hear about black holes resulting from objects the mass of stars or larger is that they have an accessible mechanism from which to form and can last hundreds of trillions of years before evaporating.

The black holes that are at the heart of this new discovery are what are known as supermassive black holes, which reside at the centers of almost every galaxy. These objects can range from hundreds of thousands to billions of times more massive than the sun. It is currently unclear as to how supermassive black holes form, although it is thought that they are the remains of the first generation of stars, which may have been hundreds of solar masses. After forming, they grow larger by feeding off of nearby matter and by merging with other black holes. One characteristic of which we are almost certain is that supermassive black holes must have formed in the very early universe, either within or before the first galaxies, less than one billion years after the Big Bang. Since back then the universe was much smaller, everything in it was a lot closer together, which provided a steady stream of fuel for primordial black holes and allowed them to achieve such high masses.

When these black holes first formed, they had such a large influx of matter flowing onto their accretion disks that massive amounts of friction were generated, resulting in powerful jets of radiation being emitted from opposite sides of the black hole. These jets made their host galaxies some of the brightest objects in the universe, and they remained so for hundreds of millions of years, eventually running low on nearby sources of fuel and becoming the more dormant supermassive black holes that exist today.

What's puzzling about the recent discovery is that a 17 billion solar mass black hole was found within a rather small galaxy cluster with little to offer in the way of a stellar fuel source. We would expect to find dormant black holes in relatively dense clusters with an abundance of stars, so it was a surprise to find such a large black hole in a galaxy that was so diffuse at its center. A possible explanation is that this black hole is a binary formed after the merger of two galaxies earlier in the universe, when collisions were more frequent and stars were more abundant. Another possibility, maybe even connected with the previous one, is that the region around the black hole is so barren is simply because the black hole was so active early on in its life that it has already used up its fuel sources or flung them out of the galaxy altogether. What's more, this galaxy is by far the brightest among its neighbors, something which is quite rare in small clusters and giving some credibility to the idea that this galaxy may be the result of multiple mergers.

Questions raised from discoveries such as this one indicate that there is still much to be learned about the structure, formation, and evolution of our universe. Objects such as black holes appear to play key roles throughout, and it may be that unlocking their secrets will give us an unparalleled insight into the inner workings of the cosmos on the grandest of scales.