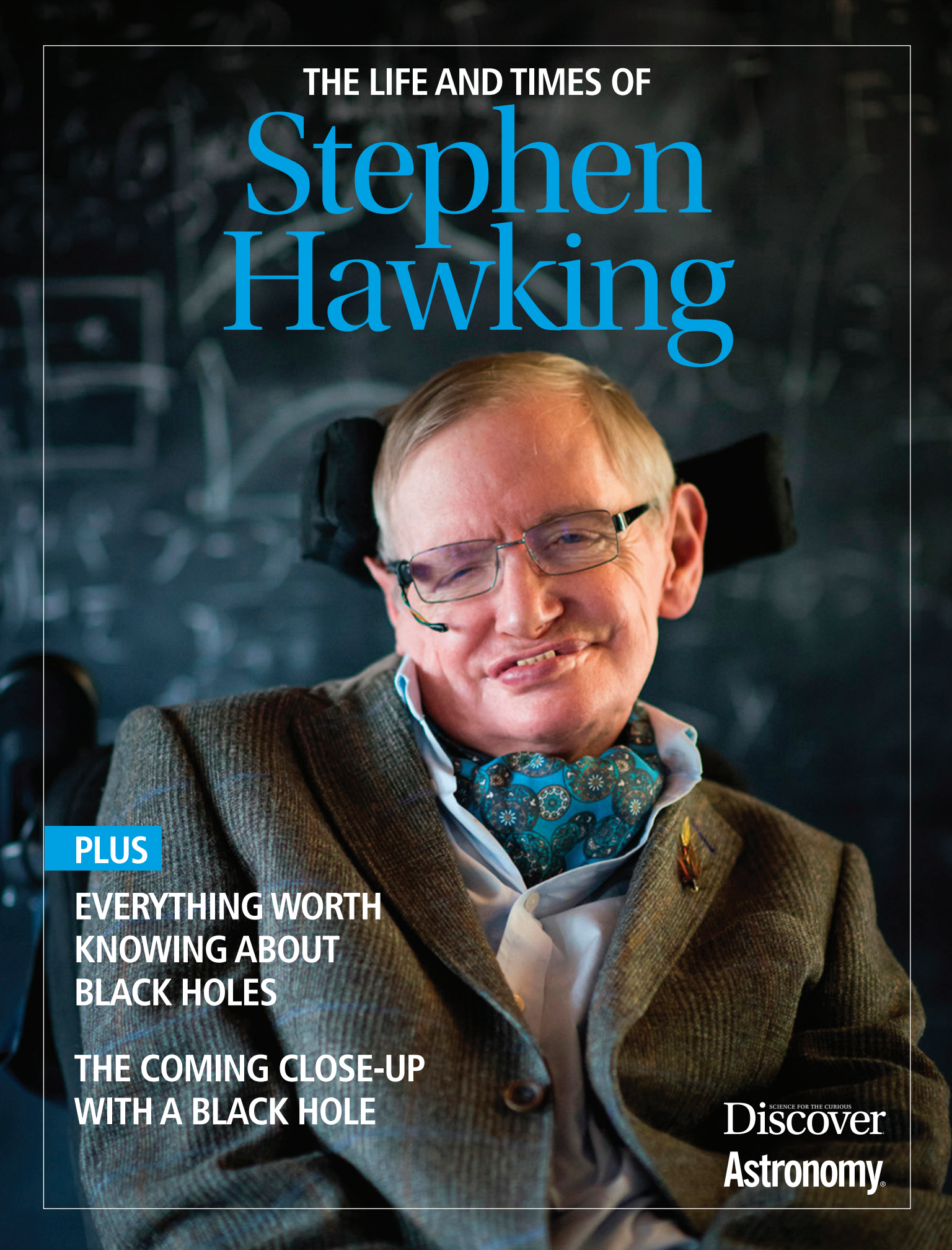

THE LIFE AND TIMES OF
Stephen Hawking
PLUS
EVERYTHING WORTH KNOWING ABOUT BLACK HOLES
THE COMING CLOSE-UP WITH A BLACK HOLE
SCIENCE FOR THE CURIOUS
Discover
Astronomy

Brief biography

Today, Hawking is one of the world's leading thinkers on cosmology and the history and evolution of the universe. ANDRÉ PATTENDEN/COURTESY STEPHEN HAWKING

The life and times of Stephen Hawking

A tribute to the great theoretical physicist. **by David J. Eicher**

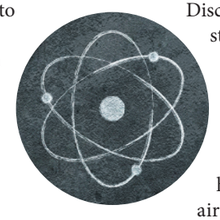
All of us astronomy types owe a lot more to Stephen Hawking than I think most of us realize. He has been at the forefront of thinking on cosmology, gravitation, black holes, and related subjects for many years. Many of us know that Hawking had for years, until 2009, held the Lucasian Professorship of Mathematics at the University of Cambridge, the same chair occupied 300 years earlier by Isaac Newton. Just a few years ago, Hawking founded and became the first director of the Centre for Theoretical Cosmology at Cambridge.

Most of us know his life story reasonably well, particularly in the wake of the 2014 film *The Theory of Everything*, which depicted his struggle for knowledge and survival. The movie brought home an Academy Award for actor Eddie Redmayne. Obviously, Hawking's story of triumph and brilliance is deeply intertwined in the public perception with his debilitating motor neuron disease, diagnosed in 1963 when Hawking was 21 years old.

That such a combination of sheer brilliance exists in a body that has withstood an incredible attack of nature is overwhelming and inspiring to us all.

Knowing that you're in the room with perhaps the smartest human being on the planet is an amazing experience. Last year, Hawking attended the Starmus Festival in the Canary Islands, the unique gathering of science enthusiasts that features talks by Nobel Prize winners, astronaut-explorers, science communicators, and researchers, as well as celebrations of music, art, and life on Earth. He delivered two incredible talks, one on the creation of the universe and the other on black holes. He sat near the front in the audience during my talk about recent astronomical advances and the communication of science to the public. Trust me, there is a magnetic feeling one has when Hawking sits close by.

Despite all we know about Hawking, there is something more there. Something almost magical. Let me explain.



Humble beginnings

Stephen William Hawking was born January 8, 1942, in Oxford, England, in the midst of World War II and the ongoing blitz bombing by the Nazis. He was descended from a line of tenant farmers, his father being the first to attend college, at Oxford, where he studied medicine. His mother was the daughter of a Scottish doctor. To the day, Hawking was born 300 years after Galileo's death. At first, however, no one suspected he would become attached to the heavens.

The family had spent time in Oxford rather than always staying home in London because the former was off-limits for Nazi bombing, along with Cambridge (as were the German university towns of Heidelberg and Göttingen). In Highgate, North London, the Hawking family grew. "My earliest memory is of standing in the nursery of Byron House School in Highgate and crying my head off," Hawking says in his memoir, *My Brief History* (Bantam, 2013).

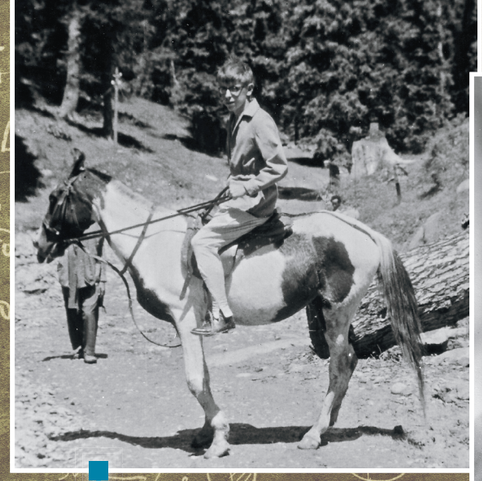
Discomfort from being left with strangers splayed against the trauma of an occasional bomb dropped nearby. "A V-2 rocket landed a few houses away from ours," he says.

Hawking grew up enjoying his train set and later built model airplanes and ships. After the war, in 1950, the family moved to St. Albans, 20 miles north of central London, so that Hawking's father could be close to the newly opened National Institute for Medical Research, where he studied tropical diseases. In St. Albans, "the family was regarded as eccentric," says Hawking. The Hawkings weren't poor, but they were of relatively modest means.

Education in England was very hierarchical, and Hawking did well enough to be classed fairly high but stayed in public

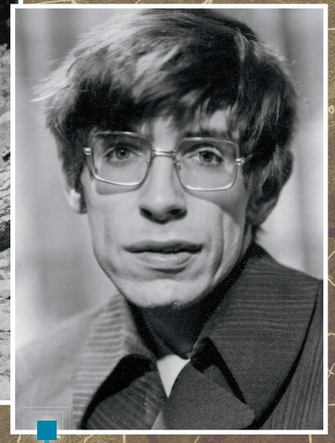
1942

Stephen William Hawking was born January 8, 1942, in Oxford, England, to Frank, a medical researcher, and Isobel, a secretary. COURTESY STEPHEN HAWKING



1950s

As a teenager, Hawking enjoyed horseback riding, but his true fascination was with understanding how things worked. He frequently took items apart, though he admits he wasn't as good at putting them back together. COURTESY STEPHEN HAWKING



1960s

On entering graduate school at Cambridge University in 1962, Hawking chose cosmology and gravitation over particle physics, feeling that "the study of elementary particles at that time was too like botany," according to his memoir. He spent much of his 20s working with Roger Penrose and Bob Geroch on general relativity. COURTESY STEPHEN HAWKING

1963

Hawking was diagnosed with a motor neuron disease that today is commonly known as ALS or Lou Gehrig's disease. By the end of the decade, he was forced into a wheelchair. AIP EMILIO SEGRÈ VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION

1988

Hawking, along with his co-author Roger Penrose, received the Wolf Prize in Physics for his work on black holes. Such an honor is often considered second only to a Nobel Prize. AIP EMILIO SEGRÈ VISUAL ARCHIVES, WOLF FOUNDATION

1998

Hawking visited President Bill Clinton in the White House Oval Office on March 5 prior to giving the second White House Millennium Evening Lecture, a series celebrating human advancement in science and the arts. WHITE HOUSE PHOTOGRAPH, COURTESY AIP EMILIO SEGRÈ VISUAL ARCHIVES, *PHYSICS TODAY* COLLECTION

schools. During the last portion of his normal schooling, he became interested in mathematics and physics. Physics, Hawking thought, was somewhat boring "because it was so easy and obvious." But physics and astronomy offered the hope of understanding the meaning of it all. "I wanted to fathom the depths of the universe," he says.

How to make a physicist

In 1959, at age 17, Hawking took an entrance exam for Oxford. He received a scholarship and commenced schooling there, in his third year joining the boating club as a coxswain in order to make more friends. He didn't work particularly hard, averaging an hour of studying per day, but that was the prevailing attitude then at Oxford. One should rely on brilliance. Despite that, he advanced successfully to graduate school.

In October 1962, Hawking arrived at Cambridge as a grad student, having applied to work with the great astronomer and cosmologist Fred Hoyle. He ended up working with Dennis Sciama and was excited by the prospects of cosmology and elementary particle physics. Particle physics was in a strange period of research, so Hawking gravitated toward cosmology and gravitation, two seemingly neglected fields that offered lots of opportunity.

Hawking joined the battle to expand the understanding of general relativity just as that movement was gaining momentum. During his last year at Oxford, however, he noticed increased clumsiness. He saw a physician after falling down some stairs, and the doctor merely warned him to "lay off the beer." But while skating on a frozen lake at St. Albans, he fell and could not get back on his feet. Just after his 21st birthday, Hawking entered a hospital for tests.

The doctors at first were not too communicative, but soon Hawking was diagnosed with an incurable, rare type of a motor neuron disease in the vein of ALS, "Lou Gehrig's disease," that has since paralyzed him. "The realization that I had an incurable disease that was likely to kill me in a few years was a bit of a shock," says Hawking. That is certainly something of an understatement. Some of the doctors initially thought he would only live for a couple years. That was 52 years ago, and he is still going strong.

Marriage and family

Hawking had met Jane Wilde, a friend of his sister's, just before his diagnosis, and the two wanted to get married. If so, he would need a job. And for that, he would need to finish his Ph.D. Set against the background of an uncertain future, Hawking thrust into high working gear for the first time. Hawking was inspired by Roger Penrose, who hypothesized space-time singularities in the centers of black holes, and applied this thinking to the entire universe in his Ph.D. dissertation, which he completed in 1966. Meanwhile, the previous year, he married Jane.

The Hawking family grew. Son Robert was born in 1967, daughter Lucy in 1970, and later, another son, Timothy, in 1979.

At the tail end of the 1960s and throughout the 1970s, Hawking worked tirelessly on gravitational waves and their likely sources (black holes), on the confirmation of the Big Bang theory, and on a theory of causal structure in general relativity, and became increasingly interested in black holes. A few days after the birth of his daughter, Hawking realized he could apply some of the work he had done with causal theory to black holes. He also had published significant work on the meaning of general relativity, showing among other things that it would break down at singularities, i.e. in black holes.

General relativity and black holes

Hawking next turned to attempting to combine general relativity, the behavior of the very large, with quantum theory, the behavior of the very small. He used black holes as the theoretical test bed for quantum behavior. How would quantum fields scatter off of a black hole? His calculations demonstrated, much to his astonishment, that a black hole would show some emission, not simply scattering.

This finding showed that a previously unknown relationship must exist between thermodynamics — the science of heat — and gravity. Hawking had discovered that over time radiation leaks away from a black hole, eventually evaporating it. This came to be known as Hawking radiation.

Hawking's calculations showed that the radiation leaking from black holes would be thermal and random. But the evaporating black hole left a paradox at the heart of physics. How could the radiation left over carry all the information about what made the black hole? And if the information was lost, that would seem to be incompatible with quantum physics. Hawking believes that information is not lost, but it is simply not returned in a meaningful way.

In the early 1970s, Hawking spent time doing research with his good friend Kip Thorne at the California Institute of Technology, and the Hawking family enjoyed the Golden State. He graduated from a mechanical to an electric wheelchair, and taking care of him became a family affair. Back to England in the mid-'70s, the Hawkings continued to focus on their many family activities as Stephen's condition gradually worsened.

Complexity and challenge

By the 1980s, the Hawkings' marriage had become strained, and Jane began to have romantic feelings for a church organist she knew, Jonathan Hellyer Jones. He moved in with the family to help take care of Hawking, who did not object, thinking the family would need someone to care for them when he was gone. Hawking began to have choking fits, and during a Swiss trip in 1985, was rushed to the hospital and placed on a ventilator. Surgeons had to perform a tracheotomy, meaning Hawking's ability to speak, already badly degraded, would now be completely gone.

Now Hawking could only communicate by learning to spell out words one letter at a time on a spelling card using eyebrow motions to indicate choices. It was, needless to say, exceptionally frustrating at first and required countless hours of practice.

One of the greatest minds the world has known was in danger of being completely cut off from the rest of us, still functioning

David J. Eicher *is editor of* Astronomy *and is proud to be a member of the Starmus Festival Board of Directors, as well as a lifelong admirer of Stephen Hawking.*

ALL ILLUSTRATIONS: *ASTRONOMY*: KELLIE JAEGER

2005

Queen Elizabeth II of Britain visited Hawking at the Centre of Mathematical Sciences at Cambridge University in May when he was the Lucasian Professor of Mathematics. NIGEL LUCKHURST

2005

Despite increasing disability, Hawking has spent much of the past two decades focusing on his research and bringing cosmology and astrophysics to a wider audience with various books that extend from his original 1988 best-seller, *A Brief History of Time* (Bantam Books). PHILIP WATERSON, LBIPP, LRPS

2006

Hawking received the Copley Medal from Britain's Royal Society for his theoretical work. Then NASA Administrator Michael Griffin (far right) helped present the medal, which had flown to the International Space Station aboard the space shuttle *Discovery*, with Martin Rees (center), then president of the Royal Society. THE ROYAL SOCIETY

2007

Hawking experienced weightlessness in April as part of a Zero Gravity Corporation flight that raised $144,000 for charity. ZERO-G

2008

Hawking visited students attending the African Institute for Mathematical Sciences, located in South Africa, in May as part of the Next Einstein Initiative to support those interested in science and technology. JUDITH CROASDELL

2009

Hawking returned to the White House Oval Office as one of the 16 recipients of that year's Presidential Medal of Freedom. THE WHITE HOUSE

magnificently, but in danger of no clear channel of communication.

Moreover, Hawking had become upset with the increasing closeness of Jane and Jonathan. He moved out, into a flat, in 1990. One of his nurses, Elaine Mason, who he had grown close to over hours of caregiving, moved in with him. Five years later they were married, and Hawking declared: "It's wonderful — I have married the woman I love." He has subsequently stated that several times, Elaine has saved his life.

In 1982, Hawking had the idea to write a popular level book about his research on the universe, and the subsequent title, *A Brief History of Time*, was an incredible runaway best-seller. Rather than his technical publisher, Cambridge University Press, Hawking sold the book to Bantam, wanting to reach as large a market as he could.

Following the huge success of his book, Hawking turned to another spectacular subject in physics, the possibility of time travel. In 1990, Hawking's friend Thorne had posited that perhaps time travel would be possible by passing through wormholes (black holes that could be used as ways to travel in time or space). Can the laws of physics allow a wormhole and space-time to be so warped that a spaceship could enter it and return to its own past? Could an advanced civilization construct a time machine by modifying a small part of space-time so that it closed time-like curves of space in a finite region?

Theoretically, the answer depends on the model you use and also the assumptions you make about various conditions within it. But, to quote Hawking, "the future looks black for time travel, or should I say blindingly white?" It does not appear that the laws of physics allow for traveling back in time, regardless of the space-time curvature. "Even if some different theory is discovered in the future," says Hawking, "I don't think time travel will be possible."

Over time, Hawking has come to live with his disability with increasing success. He has moved to a more sophisticated wheelchair and to progressively better systems of computer communication. His accomplishments in theoretical physics, cosmology, astrophysics, and related fields have formed a new basis for understanding relativity and the origin and fate of the cosmos, a century after the heyday of Einstein.

One could rightly ask the question: How is it that Stephen Hawking has not been awarded a Nobel Prize?

Hawking's mind is of course as sharp as ever. This was witnessed most recently by astronomy enthusiasts from his two gripping talks at Starmus.

2013

Hawking visited the Large Hadron Collider, where the Higgs boson was discovered, an "exciting development" in cosmology, according to the renowned physicist.
COURTESY CERN

TO SEE MORE RECENT PHOTOS OF STEPHEN HAWKING, VISIT **www.Astronomy.com/toc.**

EVERYTHING WORTH KNOWING

Black Holes

Get sucked in!

BY **SARAH SCOLES** ILLUSTRATIONS BY **ROEN KELLY/DISCOVER**

Nothing is stranger than a black hole. The darkened corpse of a former sun from which not even light can escape, a black hole forms when a massive, dying star crumples under its own gravity. It shrinks until all of its mass is contained in an infinitely dense point, called a **singularity.** Its gravity is so intense, if anything ventures within an invisible border around the singularity, called the **event horizon**, it cannot escape.

Just outside the event horizon whirls high-temperature material — the **accretion disk** — waiting to "fall into" the black hole like water spiraling down a drain. The disk emits X-rays, a high-energy form of light, because the matter moves so fast that its friction generates a lot of heat. **Jets** of energy and matter, whose formations remain a mystery, can stretch away from the accretion disk for hundreds of thousands of light-years.

Nudging up against the event horizon, a ring of photons surrounds the black hole. This loop of light, called the **innermost stable circular orbit**, outlines the edge of the black hole like a bull's-eye. And from its dead center, the black hole evaporates energy called **Hawking radiation**, causing the whole thing to shrink ever so slightly and slowly. Billions or trillions of years after its birth, the black hole will evaporate entirely.

Jets

Event Horizon

Hawking Radiation

Singularity

Innermost Stable Circular Orbit

Accretion Disk

ASTRONAUT BY NASA

Spaghettification

You float carefree through space-time, gradually approaching a black hole. The gravitational tug on your feet isn't much different from that on your head.

The black hole's gravity becomes bothersome. Because your shoes are 5 or 6 feet closer, they feel more of its pull first.

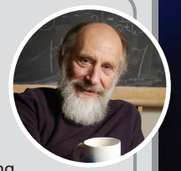
The black hole soon pulls your feet much harder than the rest of you. They begin to stretch away from your calves.

That uncomfortable feeling grows as you're strung out into a thin strand, or spaghettified. Game over, man.

Who Will Solve the Information Paradox?

When an object crosses the event horizon into a black hole, it can never come back out — it, and all information about its identity, are trapped forever. But black holes slowly evaporate as they leak Hawking radiation into space. So when they disappear, what becomes of the information trapped inside? Quantum mechanics says such information can never be destroyed. Here's how four different physicists have tried to resolve this so-called information paradox.

Leonard Susskind *Information Station*



Institution: Stanford University
Year: 2008
Known for: Co-creating string theory
Idea: In his book *The Black Hole War*, Susskind says quantum physics dictates that information remains on the black hole's edge, even while the object falls in. Stephen Hawking fought him, saying the information is gone forever, so quantum mechanics must be flawed.

Joseph Polchinski *Firewall*

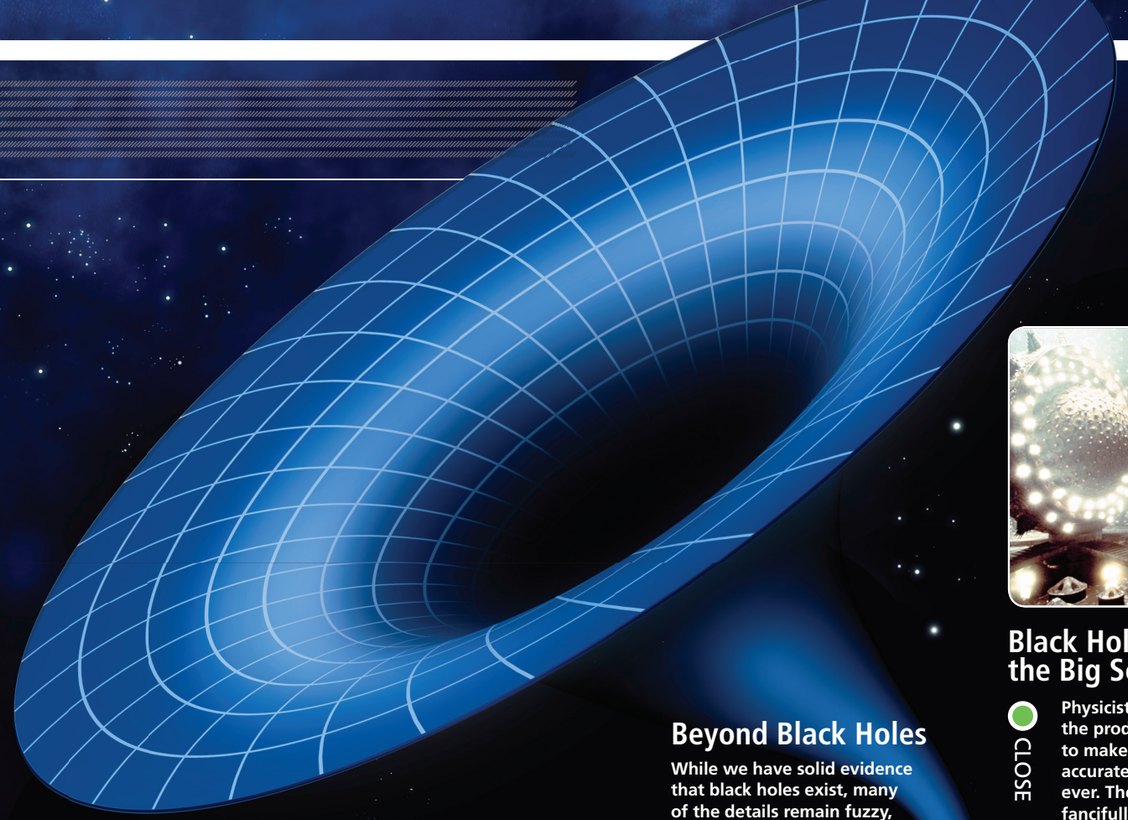
Institution: University of California, Santa Barbara
Year: 2012
Known for: Discovering D-branes, explaining what D-branes are (a string theory thing)
Idea: Once a black hole has lost about half of itself to Hawking radiation, the event horizon can no longer store enough encoded information to tell the story of what's inside. After that, nothing can go inside or else its information *will* be lost, and the singularity essentially collides with the event horizon. A "firewall" — a wall of energetic particles born from collision — then lies just outside the horizon, incinerating anything that tries to cross it.

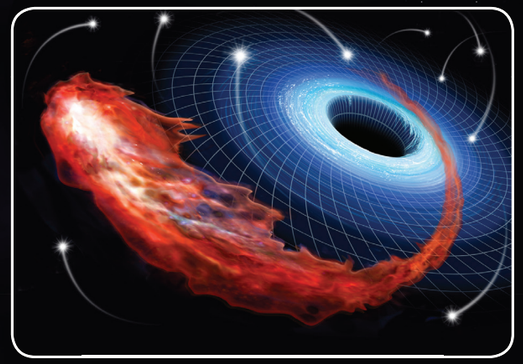
Gerard 't Hooft *Hidden Code*

Institution: Utrecht University
Year: 2015
Known for: Winning the Nobel Prize in Physics in 1999
Idea: 't Hooft elaborated on Susskind's idea. As the object approaches the black hole's edge, the latter's gravitational field changes. That shifts the outgoing Hawking radiation in a way that encodes information about the object.

Stephen Hawking *Holograms*

Institution: Cambridge University
Year: 2015
Known for: Inventing Hawking radiation, being Stephen Hawking
Idea: After contending for years that information is destroyed, the famous physicist changed his tune. Last year, he said a 3-D object leaves a 2-D stamp — a hologram — on the event horizon as it goes in. As Hawking radiation travels out, an impression of the object's identity is stamped on the hologram.





How to See a Black Hole

Just as planets orbit the sun, stars orbit our galaxy's central black hole, Sagittarius A* (pronounced "A star"). Scientists at the University of California, Los Angeles, have watched their maypole dance for more than 20 years.

Sagittarius A* recently tried to shred a mysterious object. In 2011, astronomers discovered G2, which they thought was a gas cloud, on a near-collision course with the galactic center. They believed the black hole would rip G2 apart before eating it. G2 did spaghettify a bit, but it held together and continued on its path. Scientists now believe the gas cloaks a secret star, whose gravity kept the clouds safe from total annihilation.

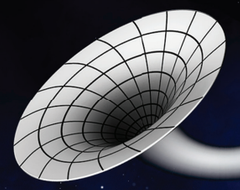
Not all stars are so lucky. In October 2015, astronomers watched as a supermassive black hole in the galaxy PGC 043234 — 290 million light-years away — shredded a star, scooped it into the accretion disk and then ate it for space lunch.

FROM TOP: LINDA A. CICERO/STANFORD NEWS SERVICE; SONIA FERNANDEZ/UCSB PHOTO; UTRECHT UNIVERSITY; DANOR AHARON/SHUTTERSTOCK

Beyond Black Holes

While we have solid evidence that black holes exist, many of the details remain fuzzy, leaving open strange doors of possibility. On the speculative end of the spectrum sits the weird world of wormholes and white holes.

Wormholes, also called Einstein-Rosen Bridges, are shortcuts between two places in space. In this scenario, after you enter a black hole, you (or your spaghettified remains) enter a "tunnel" and come out many light-years away through a white hole, the opposite of a black hole. While a black hole is like the Hotel California — you can check in, but you can never leave — you can leave a white hole, but never check back in. They're mathematically possible, but no one has ever found evidence of a worm- or white hole. Then again, their discoverer could never return to tell us about it.



EVENT HORIZON: PARAMOUNT/COURTESY EVERETT COLLECTION; TIMELINE FROM TOP: CHOUMOFF/ROGER VIOLLET/GETTY IMAGES; MARY EVANS PICTURE LIBRARY; ED WESCOTT/DEPARTMENT OF ENERGY; EMILIO SEGRE VISUAL ARCHIVES/AMERICAN INSTITUTE OF PHYSICS/SCIENCE PHOTO LIBRARY

Black Holes on the Big Screen

CLOSE

Physicist Kip Thorne worked with the producers of *Interstellar* to make the most scientifically accurate black-hole visualization ever. The characters got fancifully close without being spaghettified, though.

SORT OF

In 2013's *Thor: The Dark World*, dark elves have black hole bombs that whip up a singularity, crushing enemies and then sucking them in. While that is what would happen if a black hole bomb went off nearby, black hole bombs are not real.

NOT AT ALL

In the 1997 film *Event Horizon*, a spaceship of the same name tries to travel throughout the universe by creating black holes. Instead, it slips into a "dimension of pure chaos," causing the crew to mutilate each other. There is, to date, no evidence that black holes lead to dimensions of pure chaos.

Black Holes in Time

1784 John Michell imagines an object so massive that even light cannot escape. Twelve years later, Pierre Laplace independently comes up with the same idea.

1915 Albert Einstein publishes his theory of general relativity, which says the universe is made of stretchable "fabric" called space-time.

1916 Karl Schwarzschild's equations suggest singularities exist, and he defines the distance between them and the point of no return as the event horizon.

1939 J. Robert Oppenheimer, future head of the Manhattan Project, describes how a dying massive star collapses, leaving behind a black hole (though the exact phrase wasn't used).

1962 Maarten Schmidt coins the term *quasar* to describe 3C273, an energy-spewing supermassive black hole in the center of a galaxy, even though no one knew what it was at the time.

1967 John Wheeler popularizes the term *black hole*.

1973 Astronomers reach consensus on their first black hole candidate, Cygnus X-1.

1974 Stephen Hawking says black holes emit energy, called Hawking radiation, from inside the event horizon.

2002 German astronomers report the first evidence that the dark center of our galaxy contains a black hole, called Sagittarius A*.

Decades of simulations suggest this is what gas and dust look like spiraling around a black hole. We could soon see the real thing.

OPPOSITE: ROEN KELLY/DISCOVER. THIS PAGE: ALISON MACKEY/DISCOVER

BIG IDEA

Black Hole Close-Up

An Earth-sized telescope will capture the unseeable.

ASTROPHYSICIST JEAN-PIERRE LUMINET didn't have a supercomputer when he showed the world what a black hole looks like. He just had an IBM 7040 and a bunch of punch cards. He knew from theory that black holes do not emit light. But the material that swirls around them — dust and gas stripped from stars — shines all the way to its inanimate death. Light from that material, Luminet thought, would trace the black hole's shape, including warps in space-time from its extreme gravity.

When the fridge-sized IBM spit out results in the late '70s, Luminet used ink and pen to plot out an image by hand. He saw the black hole's event horizon, the point beyond which nothing can escape; and an accretion disk, the gathering of matter siphoned from nearby stars. Although the black hole had just one disk, gravity had morphed its appearance, like a fun house mirror, into two perpendicular disks. They appeared brighter closer to the black hole, and more luminous on one side than the other.

Some four decades later, the basics of Luminet's black-hole predictions still stand. But his image and all others are paintings, not photographs. That's about to change. Scientists working with the Event Horizon Telescope (EHT) will soon release an actual portrait of Sagittarius A* (pronounced "A-star"), the supermassive black hole at the center of our galaxy. As a backup, they have data on another one in a nearby galaxy called M87. The image could help demystify one of the universe's most mysterious objects, and even help explain how galaxies like the Milky Way form and evolve.

The EHT isn't just one telescope: It's a network of eight radio telescopes in Hawaii, Arizona, Spain, Mexico, Chile and Antarctica. Astronomers align these instruments to study the same object at the same time. The scientists then combine data from these eight antennas into one image that looks like it came from a telescope as big as the biggest distance between the telescopes. In other words, they create a virtual telescope the size of Earth.

The EHT isn't just one telescope: It's a network of eight radio telescopes in Hawaii, Arizona, Spain, Mexico, Chile and Antarctica.

It's called very long baseline interferometry, or VLBI. But there's a trick to it. According to Shep Doeleman, director of the EHT, "the secret sauce to VLBI, the thing that makes it work, is that at each of the telescopes that participates in our observations, we have placed an atomic clock."

As each telescope stares at Sagittarius A*, the data gets stamped with the atomic time, like it's clocking out of a shift. Then, scientists line up each bit taken at, say, 5:13 p.m. GMT, with all the other 5:13 p.m. GMT bits.

To do that alignment, though, the clocked-out bits must meet in person, at a central facility. Researchers usually share their data online, but this job, with its many petabytes, is too big for the internet. "The only way to get [the data] anywhere is by flying hard disks around," says Doeleman. Researchers call this the "sneakernet," and it's the ultimate analog-digital mash-up.

The team did its first real observing run in April 2017 with the Atacama Large Millimeter-submillimeter Array (ALMA) in Chile. It's a weapon powerful enough to let EHT peer right into a puncture in space-time. Wielding that secret weapon wasn't simple. The astronomers had to combine data from ALMA's 66 dishes into a single recording before they combined it with the other telescopes' observations.

Still, even with ALMA, and nearly a year of analysis time, they haven't made a picture yet. And it's the fault of a whole continent: Antarctica and its South Pole Telescope. Astronomers had to wait for southern spring before they could fly the pallet of data out. It arrived for processing at MIT's Haystack Observatory in December.

Why is a black hole snapshot worth all this effort? To Doeleman, it's about the strangeness of the science. "These are really the most mysterious objects in the universe," he says. "There's nothing that comes close, except maybe life itself."

And life itself, at least life as we know it, doesn't know what black holes look like, what happens within them, what that means for how galaxies form and evolve, or how that birth and growth led, at least on Earth, to life that can look out and learn how its galaxy works.

"There are very few topics where we say we just really have no idea what happens at that point in the universe," says Doeleman. "One of those may be consciousness. And another one is the black hole."

—SARAH SCOLES