

# Black Holes

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Among the most fascinating objects that astronomers today can study are the bizarre, collapsed corpses of massive stars that have come to be called *black holes*. Around these incredibly dense star-remnants, gravity becomes so strong that nothing, not even light, can escape. In the last few decades, new instruments in space have enabled astronomers to detect the presence of black holes for the first time. Being black and very small, these objects are hard to “see” directly, but we can sometimes find them by watching them “eat”. Smaller black holes are found when they are caught having their companion stars for lunch. At the centers of large galaxies, much larger black holes are often seen consuming their “neighborhood”, pulling in large quantities of gas, dust, and larger bodies. In the process, excess “food” is being spit out into vast jets extending in opposite directions, which can signal the presence of the central black hole to great distances. Many general books and articles on astronomy include brief coverage of black holes these days. The list below is a selection of non-technical resources that you may find useful if you want to begin exploring the world of black holes in more detail.

## 1. Selected Introductory Books on Black Holes

- Al-Khalili, Jim *Black Holes, Wormholes, and Time Machines*. 1999, Institute of Physics Publishing. A British physicist gives a grand overview of some of the most far-out aspects of black-hole science.
- Begelman, Mitchell & Rees, Martin *Gravity's Fatal Attraction: Black Holes in the Universe*, 2nd ed. 2010, Cambridge U. Press. Nice book on the astronomical aspects of black holes.
- Ferguson, Kitty *Prisons of Light: Black Holes*. 1996, Cambridge U. Press. A science writer provides a basic, non-threatening overview.
- Greenstein, George *Frozen Star*. 1984, Freundlich Books. Eloquent introduction to the death of stars

in general.

- Kaufmann, William *Cosmic Frontiers of General Relativity*. 1977, Little Brown. For those who want more non-technical details about the different types of black holes; out of print, but well worth searching out.
- Melia, Fulvio *Cracking the Einstein Code: Relativity and the Birth of Black Hole Physics*. 2009, U. of Chicago Press. A history of the study of black holes, and a biography of Roy Kerr, who first solved the equations that describe a rotating black hole.
- Thorne, Kip *Black Holes and Time Warps*. 1994, W. W. Norton. The long, definitive introduction by one of the leading scientists in the field; a bit technical in places.
- Wheeler, J. Craig *Cosmic Catastrophes: Exploding Stars, Black Holes, and Mapping the Universe*, 2nd ed. 2007, Cambridge U. Press. Well-written book has some good basic chapters on black holes.

## 2. A Few Introductory Readings on the General Theory of Relativity

- Wheeler, John *A Journey Into Gravity and Spacetime*. 1990, Scientific American Library. A brilliant, demanding introduction by one of the foremost scientists of our time (the man who helped coin the word “black hole”).
- Will, C. *Was Einstein Right? — Putting General Relativity to the Test*. 1986, Basic Books. Introduction to the experiments that confirm the theory.
- Zee, A. *An Old Man's Toy: Gravity in Einstein's Universe*. 1989, Macmillan. Good, non-technical primer by a physicist.
- Gefter, A. “Putting Einstein to the Test” in *Sky & Telescope*, July 2005, p. 32. Nice review of experimental tests of general relativity.
- Kramer, M. “Einstein's Ultimate Laboratory” in *Sky & Telescope*, Aug. 2010, p. 29. Testing relativity using a

double pulsar.

Trefil, J. "Relativity's Infinite Beauty" in *Astronomy*, Feb. 2005, p. 46. On current and future tests.

### 3. Selected Nontechnical Articles on Stellar-mass Black Holes

Blaes, O. "A Universe of Disks" in *Scientific American*, Oct. 2004, p. 48. On accretion disks and jets around young stars and black holes.

Castelvecchi, D. "A New Breed of Black Hole" in *Sky & Telescope*, Apr. 2006, p. 36. On intermediate-sized black holes, formed by the merger of smaller ones.

Charles, P. & Wagner, R. "Black Holes in Binary Stars: Weighing the Evidence" in *Sky & Telescope*, May 1996, p. 38. Excellent review of how we find stellar-mass black holes.

Davies, P. "Wormholes and Time Machines" in *Sky & Telescope*, Jan. 1992, p. 20. On some of the speculative aspects of black hole theory.

Jayawardhana, Ray "Beyond Black" in *Astronomy*, June 2002, p. 28. On finding evidence of the existence of event horizons and thus black holes.

LoPresto, J. "The Geometry of Space and Time" in *Astronomy*, Oct. 1987, p. 6.

Nadis, S. "The Secret Lives of Black Holes" in *Astronomy*, Nov. 2007, p. 28. On experiments to measure the spin of black holes and the effects of that spin.

Nadis, S. "Black Holes: Seeing the Unseeable" in *Astronomy*, Apr. 2007, p. 26. A brief history of black hole idea and an introduction to potential new ways to observe them.

Nadis, S. "What Happens When Black Holes Collide" in *Astronomy*, May 2006, p. 34. Theoretical ideas on ways black hole mergers may lead to their ejection from a galaxy. (Far out)

Rees, M. "To the Edge of Space and Time" in *Astronomy*, July 1998, p. 48. Good quick overview.

Sheldon, E. "Opinautics: A Matter of Much Gravity" in *Sky & Telescope*, Aug. 1982, p. 118. A somewhat more technical article on what it is like around a black hole.

Wheeler, J. "Of Wormholes, Time Machines, and Paradoxes" in *Astronomy*, Feb. 1996, p. 52. On some of the "far-out" possible consequences of general relativity.

### 4. Articles on the Super-massive Black Hole at the Center of the Milky Way Galaxy

Dvorak, J. "Journey to the Heart of the Milky Way" in *Astronomy*, Feb. 2008, p. 28. Measuring nearby stars to determine the properties of the black hole at the center.

Freedman, D. "The Mysterious Middle of the Milky Way" in *Discover*, Nov. 1998, p. 66. A journalist explains the evidence that our own galaxy harbors a massive black hole in the center.

Irion, Robert "Homing in on Black Holes" in *Smithsonian Magazine*, Apr. 2008. On how astronomers probe the large black hole at the center of our Milky Way Galaxy. Available on the web at: <http://www.smithsonianmag.com/science-nature/black-holes.html>

Jayawardhana, R. "Destination: Galactic Center" in *Sky & Telescope*, June 1995, p. 26.

Schulkin, B. "Does a Monster Lurk Nearby?" in *Astronomy*, Sep. 1997, p. 42.

Tanner, A. "A Trip to the Galactic Center" in *Sky & Telescope*, Apr. 2003, p. 44. Nice introduction with observations pointing to the presence of a black hole. (see also: <http://www.astro.ucla.edu/~ghezgroup/gc/journey/>)

### 5. Articles on Super-massive Black Holes in General

Barger, A. "The Midlife Crisis of the Cosmos" in *Scientific American*, Jan. 2005, p. 46. On how our time differs from the early universe in terms of what galaxies are doing, and what role supermassive black holes play.

Bartusiak, M. "A Beast in the Core" in *Astronomy*, July 1998, p. 42. Nice discussion of giant black holes being uncovered at the centers of galaxies.

Ford, H. & Tsvetanov, Z. "Massive Black Holes at the Hearts of Galaxies" in *Sky & Telescope*, June 1996, p. 28. Nice overview.

Irion, Robert "A Quasar in Every Galaxy?" in *Sky & Telescope*, July 2006, p. 40. Discusses how supermassive black holes powering the centers of galaxies may be more common than thought.

Miller, M., et al. "Supermassive Black Holes: Shaping

their Surroundings” in *Sky & Telescope*, Apr. 2005, p. 42. Jets from black hole disks.

Nadis, Steve “Here, There, and Everywhere” in *Astronomy*, Feb. 2001, p. 34. On Hubble observations showing how common supermassive black holes are in galaxies.

Nadis, Steve “Exploring the Galaxy-Black Hole Connection” in *Astronomy*, May 2010, p. 28. Overview.

Olson, S. “Black Hole Hunters” in *Astronomy*, May 1999, p. 48. Profiles of four astronomers who search for “hungry” black holes at the centers of active galaxies.

Tucker, W., et al. “Black Hole Blowback” in *Scientific American*, Mar. 2007, p. 42. How supermassive black holes create giant bubbles in the intergalactic medium.

Voit, G. “The Rise and Fall of Quasars” in *Sky & Telescope*, May 1999, p. 40. Explains the behavior of quasars in terms of the supermassive black holes that are thought to be the power source.

Wanjek, Christopher “How Black Holes Helped Build the Universe” in *Sky & Telescope*, Jan. 2007, p. 42. On the energy and outflow from disks around supermassive black holes; nice introduction.

Weaver, K. “The Galactic Odd Couple” in *Scientific American*, Jul. 2003, p. 34. Why bursts of star formation and massive central black holes are seen to go together in galaxies. On the web at: <http://www.scientificamerican.com/article.cfm?id=the-galactic-odd-couple>

Zimmerman, Robert “Cosmic Cataclysms: When Giant Black Holes Collide” in *Sky & Telescope*, Apr. 2009, p. 26. On supermassive black hole mergers.

## 6. A Few Readings on the Life and Work of Stephen Hawking

Ferguson, K. *Stephen Hawking: Quest for A Theory of Everything: The Story of His Life and His Work*. 1991, Bantam. Biographical, but with some science.

Ferguson, K. “Devouring the Future” in *Astronomy*, Dec. 1998, p. 64. Quick intro to his life and work, with an update on what he is doing recently.

Folger, Tim “Return of the Invisible Man: Stephen Hawking” in *Discover*, Jul/Aug. 2009, p. 42. Summary of his life and work, plus his recent thinking.

Hawking, S. *A Brief History of Time*. 1988, Bantam.

Some parts of this best-seller are a bit more difficult than its sales might make you believe. (The book now exists in several versions — some annotated — and has spin-off readers’ guides, videos, etc.)

Also see his *Black Holes and Baby Universes* (1993, Bantam) for further thoughts and elaborations.

Hawking, S. “The Quantum Mechanics of Black Holes” in *Scientific American*, Jan. 1977. (Now dated, but a classic expression of the ideas that Hawking pioneered.)

White, M. & Gribbin, J. *Stephen Hawking: A Life in Science*. 1992, Dutton. Both a biography and a non-technical explanation of his work.

## Quantum Black Holes

Carr, B. & Giddings, S. “Quantum Black Holes” in *Scientific American*, May 2005, p. 48. Mini black holes — how to make them and what we can learn from them. On the web at: <http://www.scientificamerican.com/article.cfm?id=quantum-black-holes>

Folger, R. “The Ultimate Vanishing” in *Discover*, Oct. 1993, p. 98. On quantum mechanics and black holes.

## 7. A Few Web Sites with Black Hole Information or Animations

Hubble Space Telescope Black Hole Encyclopedia (a good introduction for beginners): [http://hubblesite.org/explore\\_astronomy/black\\_holes/home.html](http://hubblesite.org/explore_astronomy/black_holes/home.html)

Frequently Asked Questions about Black Holes (written by University of Richmond physicists Ted Bunn in 1995, while he was a graduate student at Berkeley; a bit dated, but still good): <http://cosmology.berkeley.edu/Education/BHfaq.html>

*The Universe in the Classroom* (The ASP’s Newsletter on Teaching Astronomy) Issue on Black Holes by John Percy: <http://www.astrosociety.org/education/publications/tnl/24/24.html>

Chandra X-Ray Observatory Field Guide to Black Holes: [http://chandra.harvard.edu/xray\\_sources/blackholes.html](http://chandra.harvard.edu/xray_sources/blackholes.html)

*StarDate’s* Introduction to Black Holes: <http://blackholes.stardate.org/>

87 Questions and Answers about Black Holes from astronomer Sten Odenwald’s *Astronomy Café*: <http://www.astronomycafe.net/qadir/abholes.html>

Monsters in Galactic Nuclei (an article on supermassive black holes by John Kormendy and Gregory Shields from *StarDate* Magazine): <http://chandra.as.utexas.edu/~kormendy/stardate.html>

Monster of the Milky Way (companion site to the PBS-TV NOVA episode on the black hole at the center of our Galaxy): <http://www.pbs.org/wgbh/nova/blackhole/>

Black Hole Math (a nice introductory booklet at the high-school math level by astronomer Sten Odenwald): [http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Black\\_Hole\\_Math.html](http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Black_Hole_Math.html)

Spacetime Wrinkles Website: <http://archive.ncsa.illinois.edu/Cyberia/NumRel/NumRelHome.html> The National Center for Supercomputing Applications Relativity Group (whew — what a name!) has set up an intriguing and well produced “exhibit on line” about Einstein’s theory of relativity and its astronomical implications, including some movies in which they simulate situations such as the collision of two black holes.

The Light Cone: <http://physics.syr.edu/courses/modules/LIGHTCONE/> Rob Salgado of Syracuse University has produced a series of simulations that explain ideas in special and general relativity theory and provide a glossary and links.

Black Hole Animations: Using high-speed computers, several groups of physicists have simulated the behavior of black holes and what it might be like to fall into one. Among the sites with web-movies from such simulations are:

- Virtual Trips into Black Holes and Neutron Stars (by Robert Nemiroff): [http://antwrp.gsfc.nasa.gov/htmltest/rjn\\_bht.html](http://antwrp.gsfc.nasa.gov/htmltest/rjn_bht.html)
- Falling Into a Black Hole (animations by Andrew Hamilton): <http://casa.colorado.edu/~ajsh/schw.shtml>

## 8. Black Holes for Educators

For a set of black hole information guides and demonstration activities from the ASP’s and JPL’s Night Sky Network, click on: <http://nightsky.jpl.nasa.gov/download-search.cfm> and check the box on black holes.

*The Universe in the Classroom* (The ASP’s Newsletter

on Teaching Astronomy) Issue on Black Holes by John Percy: <http://www.astrosociety.org/education/publications/tnl/24/24.html>

No Escape: The Truth about Black Holes (teacher lesson from the Space Telescope Science Institute): <http://amazing-space.stsci.edu/resources/explorations/blackholes/teacher/index.html>

Gravity and Black Holes (A Teacher Guide from the Adler Planetarium): <http://www.adlerplanetarium.org/education/resources/gravity/index.shtml>

Black Hole Math (a nice introductory booklet at the high-school math level by astronomer Sten Odenwald): [http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Black\\_Hole\\_Math.html](http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Black_Hole_Math.html)

The Anatomy of Black Holes (from NASA’s *Imagine the Universe* site): <http://imagine.gsfc.nasa.gov/docs/teachers/blackholes/imagine/contents.html>

## 9. Some Science Fiction Stories with Good Science about Black Holes

Anderson, Poul “Kyrie” in Jerry Pournelle, ed. *Black Holes*. 1978, Fawcett. Explores the distortion of time near a black hole.

Asimov, Isaac “The Billiard Ball” in *Asimov’s Mysteries*. 1968, Dell. Committing murder using general relativity.

Baxter, Stephen “Pilot” in *Vacuum Diagrams*. 1997, Harper Prism. An asteroid space ship being chased by an enemy missile goes through the ergosphere of a rotating black hole, taking energy out and making the chasing missile fall in the event horizon.

Benford, Gregory *Eater*. 2000, Eos/HarperCollins. An ancient intelligent black hole comes to our solar system.

Brin, David “The Crystal Spheres” in *The River of Time*. 1987, Bantam. Advanced races use black holes to bear with the loneliness of a universe in which life is still rare.

Brin, David *Earth*. 1990, Bantam. A mini black hole falls into the Earth’s core.

Haldeman, Joe *The Forever War*. 1974, Ballantine. An interstellar war is fought using black holes for travel between battles.

Johnson, Bill “Meet Me at Apogee” in Carr, T., ed. *The Best Science Fiction of the Year 12*. 1983, Pocket Books. Posits a future in which people (with alien

- help) organize levels of descent near a black hole; so the two-month level is where one day of experienced time for travelers equals two months in the outside universe. Prospectors and people with incurable disease hire pilots to take them down to lower levels.
- Landis, Geoffrey “Impact Parameter” in *Impact Parameter*. 2001, Golden Gryphon. A newly discovered gravitational lens turns out to be a wormhole being used by an alien civilization to visit us.
- Landis, Geoffrey “Approaching Perimelasma” in *Impact Parameter*. 2001, Golden Gryphon. In the far future, a virtual human is dropped into a black hole and makes an interesting discovery about space and time.
- McAuley, Paul “How We Lost the Moon” in Crowther, Peter, ed. *Moon Shots*. 1999, Daw. A glitch in a fusion experiment on the Moon creates a mini black hole that eats our satellite.
- McDevitt, Jack & Shara, Michael “Lighthouse” in *Cryptic: The Best Short Fiction of Jack McDevitt*. (2009, Subterranean Press) [also on the web at: [http://www.webscription.net/chapters/1596061958/1596061958\\_8.htm](http://www.webscription.net/chapters/1596061958/1596061958_8.htm)] An alien race decides, as a public service, to mark the location of unaccompanied black holes in the Galaxy by putting very strange brown dwarfs around them that could not exist in nature. Shara is an astronomer.
- Niven, Larry *World Out of Time*. 1976, Ballantine. Protagonist uses a supermassive black hole to travel into distant future.
- Niven, Larry “The Hole Man” in *A Hole in Space*. 1974, Ballantine. How to commit murder using a mini-black hole.
- Niven, Larry “The Borderland of Sol” in *Tales of Known Space*. 1975, Ballantine. Space pirates use a mini-black hole.
- Pohl, Fred *Gateway*. 1977, Ballantine. Enjoyable novel with rotating black holes, event horizons, and “black hole guilt”. (Has a series of sequels where the science gets too “far out” for inclusion on this list.)
- Sagan, Carl *Contact*. 1985, Simon & Schuster. The protagonists use a kind of black hole-wormhole “subway” system for interstellar travel, designed by astrophysicist Kip Thorne and his students.
- Sheffield, Charles “Killing Vector” in *Vectors*. 1979, Ace. Mini-black holes are used for space propulsion. Sheffield has a PhD in physics.
- Varley, John *The Ophiuchi Hotline*. 1977, Dell. Complex novel, in which mini black holes are hunted as energy sources.
- Varley, John “The Black Hole Passes” in *The Persistence of Vision*. 1978, Dell. A mini-black hole threatens two deep space outposts.
- Wheeler, J. Craig *The Krone Experiment*. 1986, Pressworks. Mini black holes pose a threat to the Earth; written by an astronomer.
- Willis, Connie “Schwarzschild Radius” in Preiss, Byron & Fraknoi, Andrew, eds. *The Universe*. 1987, Bantam. Haunting story combining episodes from the life of Karl Schwarzschild and black hole images.

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