Dear Astronomer,

Thank you for picking up this copy of *The Field Guide to Black Holes*. Whether you're a novice just getting to know your way around the universe or an expert looking for a refresher on this most wild cosmic object, we hope you find the guide useful and informative. We'll go over basic black hole anatomy, how to find black holes, as well as different black hole types. But remember that safety should be top priority! Please refer to our *Black Hole Safety Information Card* before planning to approach and identify any black holes.

Good luck out there!
The Editors

## Reviews

"Never leave the planet without it!"
—Bloro, amateur astronomer (fifth degree), Plorgoeb-57 b

"I recommend a copy of this guide to all my first-year students, whether they intend to keep studying astronomy or not. You never know when you'll find yourself needing to identify a black hole."
—Shelia, astronomy professor, Glerbax-29 d

"A fun, approachable guide to things you really shouldn't approach."
—Rthimondu, Xthomodon Observatory, PIT 206 f


***IMAGE CREDITS***

1. *NASA Goddard/J. Schnittman*
2. *NASA Goddard/S. Noble; background, ESA/Gaia/DPAC*
3. *NASA Goddard*
4. *NASA/B. Kelly (NASA GSFC/UMBC), C. Henze (NASA Ames) and T. Sandstrom (CSC Gov. Solutions LLC)*
5. *A. Simonnet and NASA Goddard*
6. *NASA Goddard/C. Smith (USRA/GESTAR)*
7. *NASA and D. Bennett (U. Notre Dame)*
8. *A. Beardmore (U. Leicester) and NASA*
9. *Event Horizon Telescope Collaboration*
10. *ESO/L. Calçada/spaceengine.org*
11. *NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (UVA/NRAO/Stony Brook)*
12. *NASA, ESA and D. Lin (UNH)*


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National Aeronautics and Space Administration

# A Field Guide to Black Holes

www.nasa.gov

# Basic Black Hole Anatomy

Black holes are physical objects in space, just like stars and planets. They have so much mass packed into such a small sphere that nothing, not even light, can escape their gravity.

## Features all have in common

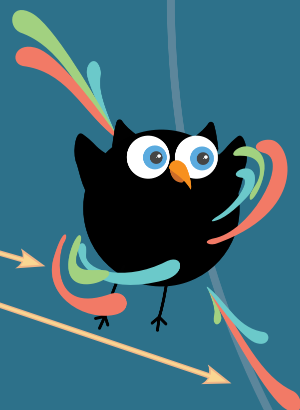
**Event horizon:** the black hole's "surface" — the point of no return

**Spin:** how fast depends on the individual

## Other potential characteristics

**Accretion disk:** made of hot gas and dust

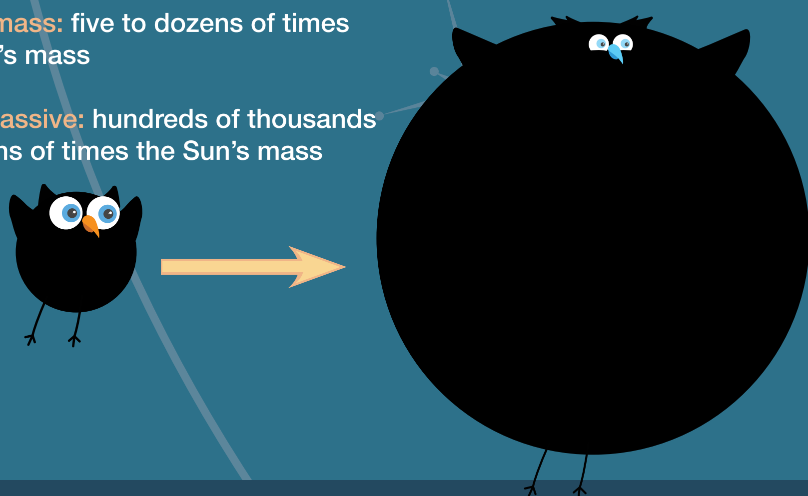
**Jets:** fast-moving streams of matter ejected at right angles to the disk



## Most known black holes fall into two broad groups

**Stellar-mass:** five to dozens of times the Sun's mass

**Supermassive:** hundreds of thousands to billions of times the Sun's mass



## Intermediate-mass

**Where:** Throughout the universe

**Origins:** These black holes are hundreds to hundreds of thousands of times the Sun's mass. Some are created when stellar-mass black holes merge. Others could be larger primordial black holes.

**Find using:** Gravitational waves

**Example:** 3XMM J215022.4–055108, a black hole with 50,000 times the Sun's mass, lies around 800 million light-years away.

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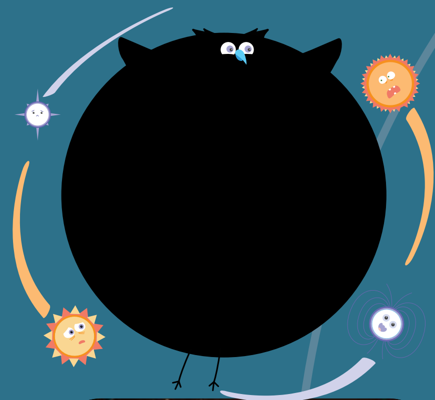
## Primordial (Hypothetical†)

**Origins:** These theoretical black holes were born in the first second after the big bang, 13.8 billion years ago. Because they're not produced by supernovae, some could potentially be less massive than our Sun. They could also be intermediate-mass, depending on when they formed in that one-second window.

Visualization

† Results subject to possible changes based on future research.

## Supermassive with Smaller Partner(s)



**Where:** Centers of galaxies

**Origins:** Sometimes a supermassive black hole's strong gravity can trap smaller objects in orbit.

**Variations:** Stars, neutron stars, stellar-mass black holes, comets, planets, etc.

**Find using:** Effects on nearby objects

**Example:** Stars orbiting supermassive black hole Sagittarius A* at the center of the Milky Way galaxy

*Simulation*

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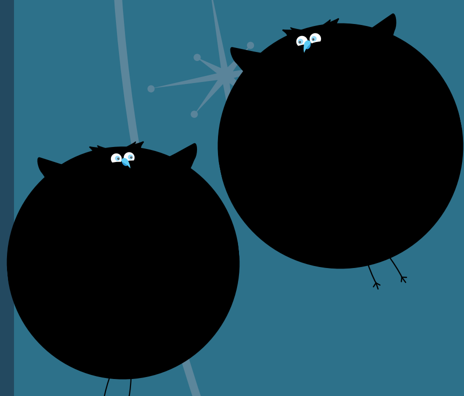

## Supermassive with Supermassive Partner(s)

**Where:** Centers of merging galaxies

**Origins:** Galaxies sometimes collide and combine, bringing their central supermassive black holes with them.

**Find using:** Accretion disks and jets, next-generation gravitational wave detectors, computer simulated light emissions from colliding disks.

**Example:** Galaxy NGC 6240 hosts at least two supermassive black holes, the result of a three-way galaxy merger.

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# How to Find Black Holes

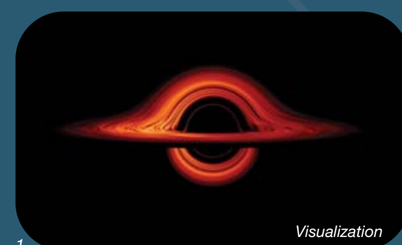
Black holes are found throughout the universe but can be hard to spot because they blend in with the darkness of space. Don't let that camouflage discourage you, though! Keen astronomers know that you can often find black holes by looking for their characteristics, behaviors, and effects on their environment.

## Instruments

Any black hole enthusiast's tool kit should include access to or data from observatories that can detect a range of information about space. Scientists call this multimessenger astronomy.

- All wavelengths of light, from radio to gamma rays
- Gravitational waves, or ripples of space-time
- Neutrinos, ghostly particles that outnumber the universe's atoms

## Black Hole Features and Behaviors



*Visualization*

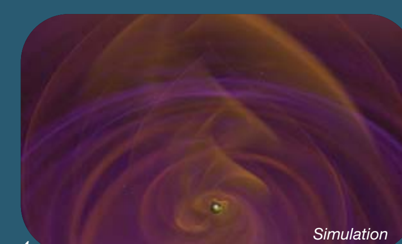
1
**Accretion disks.** The combination of gravity, magnetic fields, and motion heats the orbiting material, which glows at multiple wavelengths.

*Illustration*

3
**Jets.** High-speed particle jets give off different wavelengths of light and produce neutrinos that speed across space.

*Simulation*

2
**Gravitational lensing.** Massive objects like black holes can bend and distort light from more distant objects.



*Simulation*

4
**Gravitational waves.** Massive orbiting objects create space-time ripples.

## *Effects on Nearby Objects*

**Dynamics:** Changes to the motions of nearby stars

**Radial velocity:** Objects orbiting black holes periodically move toward and away from Earth, motion that alters their light in a revealing way.

**Accretion:** Siphoning off material from companion stars and into hot, bright disks[5]

**Tidal disruption events:** Stars stray too close and get torn apart, a light show specific to supermassive black holes[6]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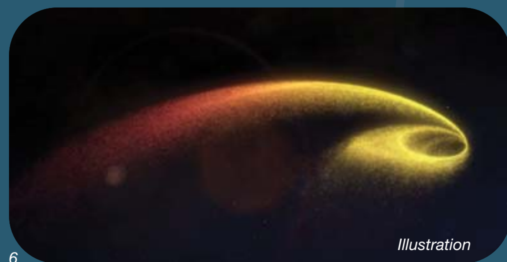


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## *Stellar-mass with Partner*

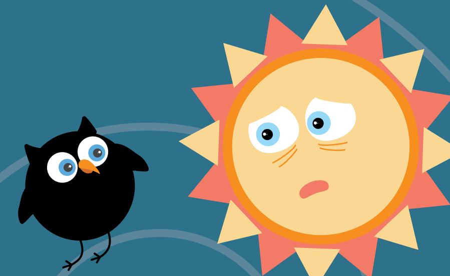
**Where:** Throughout the universe

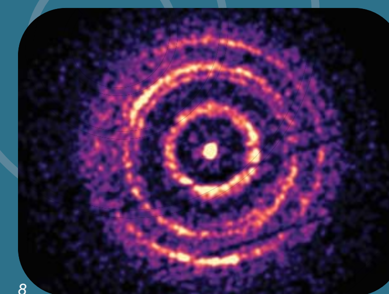
**Origins:** These black holes and their partners likely started off as stars before one or both went supernova. They stayed gravitationally bound through the turmoil.

**Variations:** Stellar-mass black holes can be paired with all types of stars, neutron stars, and other black holes.

**Find using:** Accretion disks and jets (for pairs with stars), gravitational waves (for pairs with black holes and neutron stars), radial velocity

**Example:** V404 Cygni, a black hole paired with a Sun-like star about 8,000 light-years away





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# Types of Black Holes

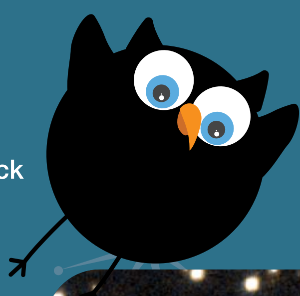
## *Solitary Stellar-mass*

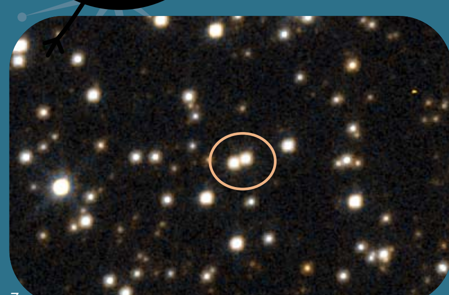
**Where:** Throughout the universe

**Origins:** Born from the supernova deaths of stars or mergers of smaller black holes with other black holes or neutron stars

**Find using:** Gravitational lensing

**Example:** The Hubble Space Telescope identified an isolated stellar-mass black hole when it lensed a star, an event called MACHO-96-BLG-5.





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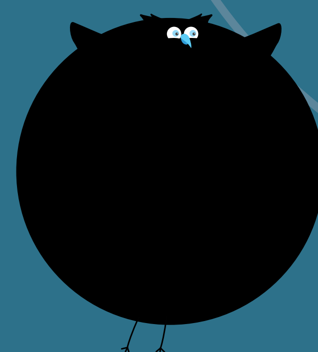
## *Single Supermassive*

**Where:** Centers of galaxies

**Origins:** These monster black holes likely grew by gradually absorbing other black holes, but other possibilities may exist.

**Find using:** Accretion disks, jets, gravitational lensing, effects on nearby objects

**Example:** M87* ("*" is pronounced "star") at the center of galaxy Messier 87, around 55 million light-years away



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