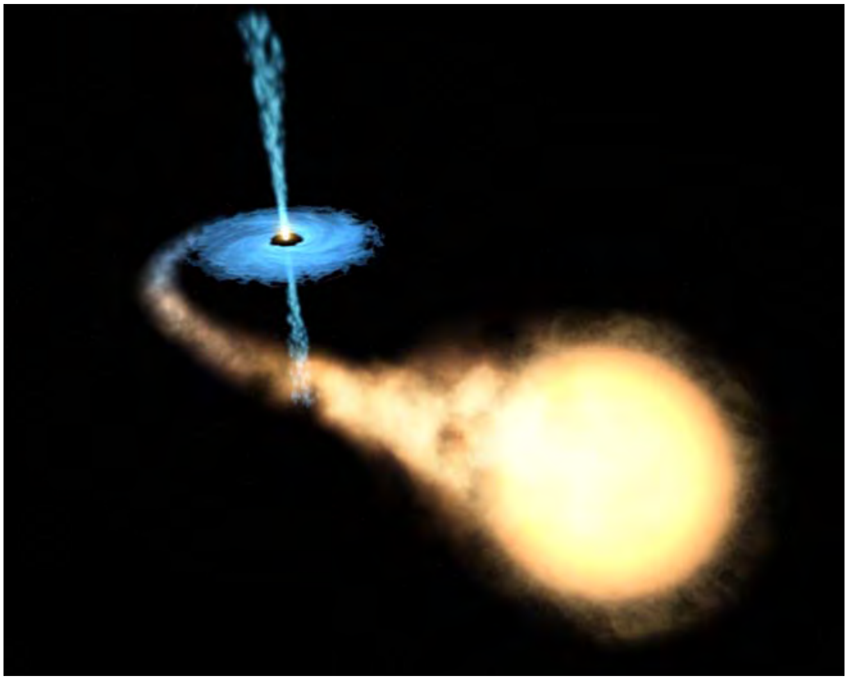

Black Hole Survival Outreach ToolKit Manual

Illustration Credit (above): ESA http://spacetelescope.org , NASA http://www.nasa.gov/, and Felix Mirabel (French Atomic Energy Commission and Institute for Astronomy and Space Physics/Conicet of Argentina)

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NASA NIGHT SKY NETWORK: http://nightsky.jpl.nasa.gov/

Contacts

The non-profit Astronomical Society of the Pacific (ASP), one of the nation's leading organizations devoted to astronomy and space science education, is managing the Night Sky Network in cooperation with NASA and JPL. Learn more about the ASP at http://www.astrosociety.org.

For support contact:

Astronomical Society of the Pacific (ASP)
390 Ashton Avenue
San Francisco, CA 94112
415-337-1100 ext. 116
nightskyinfo@astrosociety.org

Introduction: Black Hole Survival Outreach ToolKit

The “Black Hole Survival ToolKit” was named to explain:

1. How we survive in a galaxy full of black holes
2. How to survive an encounter with a black hole
3. How amateur astronomers can survive all the questions they get about black holes!

Amateur astronomers report that one of the most misunderstood topics, as well as one that generates a great deal of curiosity, is Black Holes.

The ToolKit consists of activities and resources that are designed to address gravity in general and black holes in particular as an extreme form of gravity.

Designed for use before and during star parties, and appropriate for many other venues, the activities include:

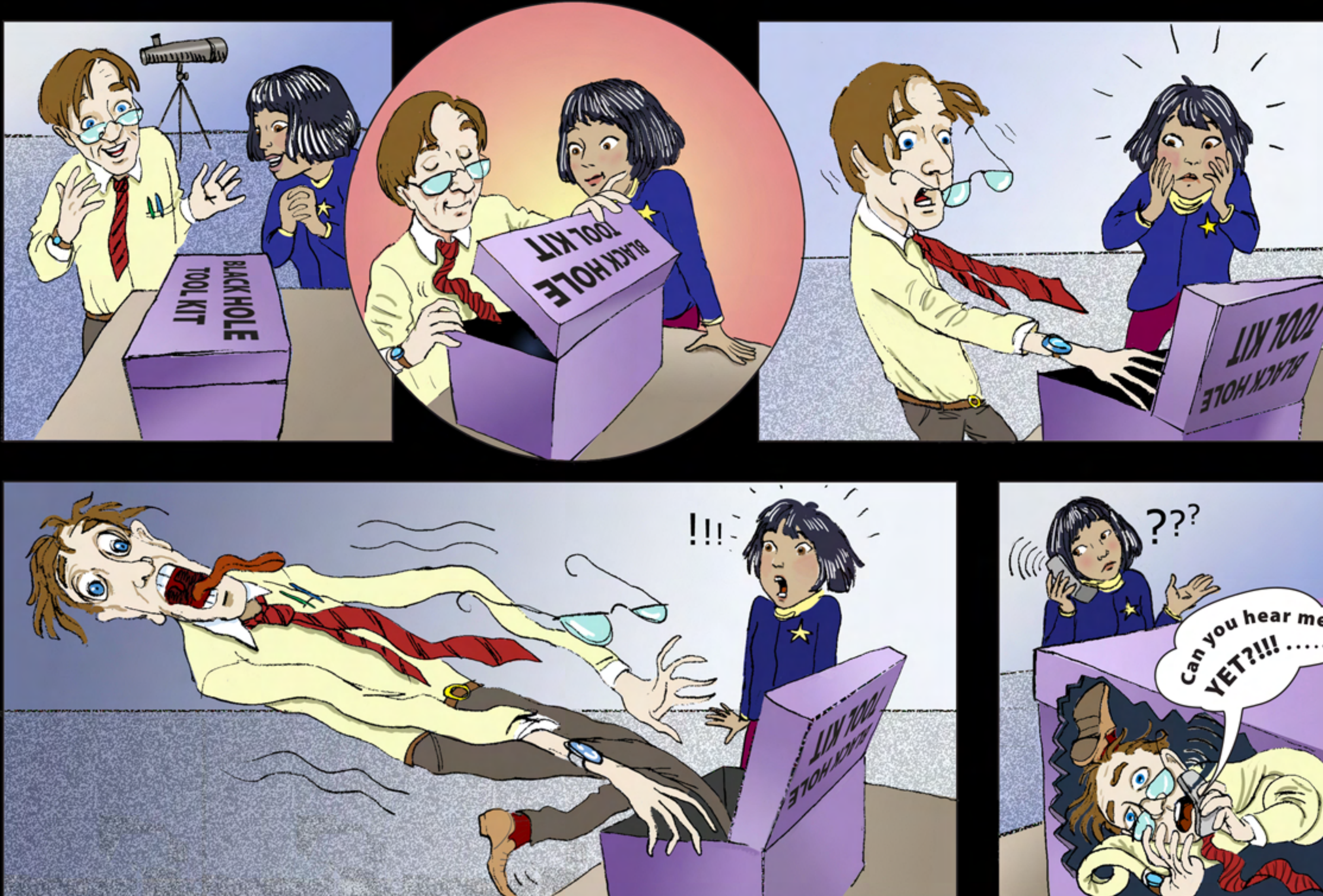
- PowerPoints and Animations
- A variety of hands-on games and demos
- Star maps to find locations of black holes among the stars

NASA missions now and in the future explore and search for black holes: how they form, what their characteristics are, how they affect the space around them. For an overview:
http://cfa-www.harvard.edu/seuforum/blackholelanding.htm
http://cfa-www.harvard.edu/seuforum/missions.htm

Summary of activities:

1. **PowerPoints & Animations** to introduce concepts about black holes to your visitors and to introduce the ToolKit to your club members.
2. **Black Hole Explorer** is a board game where the players fly a spaceship to orbit a black hole and launch scientific probes to study it.
3. **Gravity and the Fabric of Space** to discover the basics about gravity using a bucket with stretchy fabric, marbles, and weights.
4. **Where are the Black Holes?** Uses magnets and star maps to show how scientists find black holes and where they are in the night sky.

In general, the activities in this ToolKit are appropriate for ages 6 to adult.


BLACK HOLE TOOL KIT
BLACK HOLE TOOL KIT
BLACK HOLE TOOL KIT
!!!
BLACK HOLE TOOL KIT
???
Can you hear me YET?!!! ....

Thanks to the ToolKit Testers

NASA and the ASP wish to thank the members of the astronomy clubs around the country who took the time and made the commitment to test these activities in a variety of settings and with a wide range of audiences. Their dedication and feedback helped to make this ToolKit appropriate and fun for the members of the Night Sky Network.

Astronomy Club	**State**
Aldrich Astronomical Society	MA
Arkansas Oklahoma Astronomical Society	AR
Central Florida Astronomical Society, Inc.	FL
Cincinnati Observatory Center / Friends of the Observatory	OH
City Lights Astronomical Society for Students	IL
Darien O'Brien Astronomy Club	CO
Eastbay Astronomical Society	CA
Kansas Astronomical Observers	KS
Northeast Kansas Amateur Astronomers' League Inc.	KS
San Angelo Amateur Astronomy Association	TX
Spokane Astronomical Society	WA
Texas Astronomical Society of Dallas	TX

Check the next two pages for suggestions and advice from the ToolKit testers.

Suggestions from the ToolKit Testers

Here are some comments from a few of the astronomy clubs who tested the Black Hole Survival ToolKit in answer to the following questions.

"If you had just 2 minutes to tell someone in your club about this ToolKit, what would you say?"

City Lights Astronomical Society for Students
This tool kit is a blast! You can learn a lot about Black Holes and have fun at the same time.

Aldrich Astronomical Society
The toolkit is a great way to introduce amateurs and the general public to some of the basic concepts about gravity and black holes. Everyone has heard about black holes as a topic but very few people actually know how they form and how scientists study them. The hands on demos are great way to get active, curious kids involved in hands on science and to have some fun as they learn. I know many teachers who will appreciate the easy to use demos that can easily be set up with minimal preparation in their classrooms.

Texas Astronomical Society of Dallas
I am excited about the variety of activities from the animations, PowerPoints, and star maps that work well with larger groups, to the hands-on activities that work well with small groups and with kids.

Arkansas Oklahoma Astronomical Society
I would say that the "Gravity and the Fabric of Space" will be invaluable for helping the uninitiated grasp the concept of gravity. These items reveal how gravity really plays a fundamental role in the overall structure and dynamics of the universe.

Darien O'Brien Astronomy Club
You will have an opportunity to "see" how black holes change the fabric of space and obtain the latest information on the origins of black holes, how we know that black holes are out there, and what would happen if we were near a black hole. Don't worry if you're "sucked in" to wanting to know more about black holes!

"If you were to give advice to other clubs regarding this ToolKit, what would it be?"

Eastbay Astronomical Society
The animations are superb – weave them into the presentation. Gravity & the Fabric of Space is an extremely engaging activity. It can be used in a variety of settings to talk about orbits and gravity in general, as well as about black holes. Keep the Black Hole FAQs on hand – make sure you have enough for handouts.

Arkansas Oklahoma Astronomical Society
ALL these items will be among the most used and influential tools you'll have for helping folks of all levels better understand these sometimes difficult concepts. You should prepare to use these items until they are absolutely worn to a frazzle.

Northeast Kansas Amateur Astronomers' League Inc.
Be sure to practice your marble-handling; you'll need it!

San Angelo Astronomy Association
Be interactive! Get volunteers to roll the magnetic marbles across the board with the hidden magnets ("Where are the Black Holes"). Let them touch the "Fabric of Space" and roll the marbles into orbit.

Texas Astronomical Society of Dallas
Make sure you study up a little on black holes. The kids out there know more than you realize!!

Background Information on Black Holes

- For an overview of black holes and NASA missions, NASA's Structure and Evolution of the Universe Education Forum provides the following:
  http://cfa-www.harvard.edu/seuforum/blackholelanding.htm
  http://cfa-www.harvard.edu/seuforum/missions.htm

- PowerPoint presentations on black holes and gravity are found on the Manual & Resources CD in the folder named "PowerPoints". See the script for the PowerPoint. At the end of the script are common questions about black holes.

The following two sections are excerpted with permission from "The Essential Cosmic Perspective". They will provide an overview of black holes and the life of stars.

100 million K. The helium burns rapidly to carbon and heavier elements, generating a burst of energy that flows from the neutron star in the form of X rays. These **X-ray bursters** typically flare every few hours to every few days. Each burst lasts only a few seconds, but during those seconds the system radiates 100,000 times as much power as the Sun, all in X rays. Within a minute after a burst, the X-ray burster cools back down and resumes accreting.

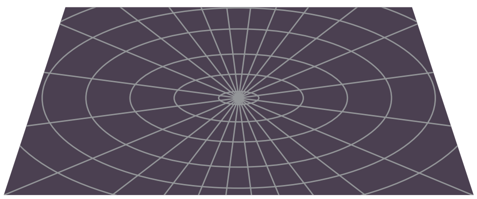
Black Holes Tutorial, Lessons 1, 2

13.3 BLACK HOLES: GRAVITY'S ULTIMATE VICTORY

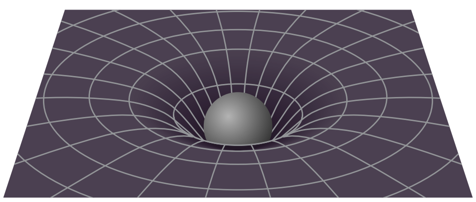
White dwarfs and neutron stars would be strange enough if the story ended here, but it does not. Sometimes, the gravity in a stellar corpse becomes so strong that nothing can prevent the corpse from collapsing under its own weight. The stellar corpse collapses without end, crushing itself out of existence and forming perhaps the most bizarre type of object in the universe: a *black hole.*

Figure 13.11

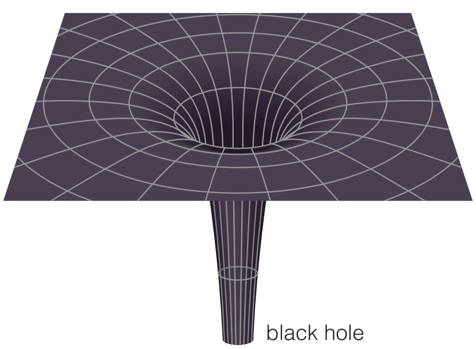
We can use two-dimensional rubber sheets to show an analogy to curvature in four-dimensional spacetime.



a A two-dimensional representation of "flat" spacetime. The radial distance is the same between each of the circles shown.



b Gravity arises from curvature of spacetime, represented here by a mass pushing down on the rubber sheet. Notice how the circles become more widely separated near the mass, showing that the curvature is greater as we approach the mass on the sheet.



c The curvature of spacetime becomes greater and greater as we approach a black hole, and a black hole itself is a bottomless pit in spacetime.

• What is a black hole?

The "black" in the name *black hole* comes from the fact that nothing—not even light—can escape from a black hole. The escape velocity of any object depends on the strength of its gravity, which depends on its mass and size [Section 4.4]. Making an object of a particular mass more compact makes its gravity stronger and hence raises its escape velocity. A black hole is so compact that it has an escape velocity greater than the speed of light. Because nothing can travel faster than the speed of light, neither light nor anything else can escape from within a black hole.

The "hole" part of the word *black hole* tells an even stranger story. Einstein discovered that space and time are not distinct, as we usually think of them, but instead are bound up together as four-dimensional **spacetime**. Moreover, in his general theory of relativity, Einstein showed that what we perceive as gravity arises from *curvature of spacetime* (see box, p. 339). The concept "curvature of spacetime" is not easily visualized, because we can see only three dimensions at once. However, we can understand the idea with a two-dimensional analogy.

A black hole is a place where gravity is so strong that nothing—not even light—can escape from within it.

Figure 13.11 represents all four dimensions of spacetime with a two-dimensional rubber sheet. In this analogy, the sheet is flat in a region far from any mass and its gravity (Figure 13.11a). Near a massive object with strong gravity, the sheet becomes curved (Figure 13.11b)—the stronger the gravity, the more curved it gets. In essence, a black hole is a bottomless pit in spacetime (Figure 13.11c). Because gravity gets stronger and stronger as we get closer to the black hole, the sheet curves more and more. Keep in mind that the illustration is only a two-dimensional analogy, and black holes actually are spherical in shape. Nevertheless, the analogy captures the key idea that a black hole really is a *hole* in the observable universe in the following sense: If you enter a black hole, you leave our observable universe and can never return.

The Event Horizon The boundary between the inside of the black hole and the universe outside is called the **event horizon**. The event horizon essentially marks the point of no return for objects entering a black hole: It is the boundary around a black hole at which the escape velocity equals the speed of light. Nothing that passes within this boundary can ever escape. Thus, the event horizon gets its name because we have no hope of learning about any events that occur within it.

We usually think of the "size" of a black hole as the size of its event horizon. Our everyday understanding of "size" is hard to apply inside the event horizon because space and time are so distorted there. However, for someone outside the black hole the event horizon is a sphere with a well-defined size. We can therefore describe the size of the event horizon by its radius, which we call the **Schwarzschild radius** (after Karl Schwarzschild, who first computed it with Einstein's general theory of relativity).

The Schwarzschild radius of a black hole depends only on its mass. A black hole with the mass of the Sun has a Schwarzschild radius of about

SPECIAL TOPIC: GENERAL RELATIVITY AND CURVATURE OF SPACETIME

Einstein's special theory of relativity (see box, p. 331) solved a lot of problems that had troubled physicists prior to its 1905 publication. However, Einstein knew the theory was incomplete; in particular, it is called the *special* theory because it applies only to the special case of motion at constant velocity. It did not apply, for example, to objects whose velocities were accelerating under the influence of a gravitational force. Einstein therefore sought to generalize the theory to include gravity and acceleration.

In 1907, Einstein hit upon what he later called "the happiest thought of my life." He realized that gravity and acceleration have identical effects on the laws of physics. This idea is called the *equivalence principle,* and it states: *The effects of gravity are exactly equivalent to the effects of acceleration.*

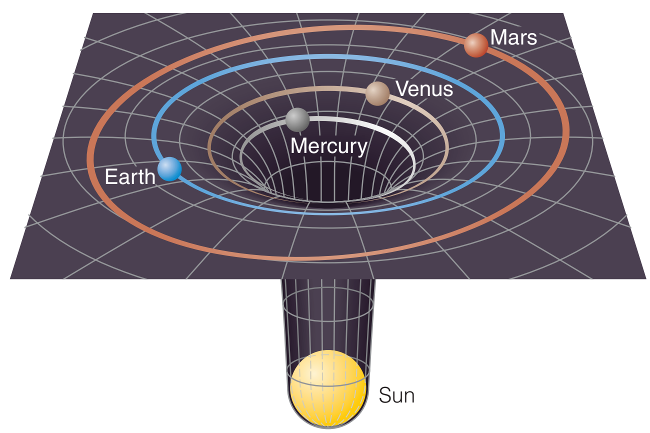
To clarify the meaning of this principle, imagine that you are sitting inside with doors closed and window shades pulled down when your room is magically removed from Earth and sent hurtling through space with an acceleration of 1*g*—the acceleration of gravity on Earth, or 9.8 meters per second squared [Section 4.1]. According to the equivalence principle, you would have no way of knowing that you'd left Earth. Any experiment you performed, such as dropping balls of different weights, would yield the same results you'd get on Earth. Likewise, experiments performed in a freely falling elevator would yield the same results as those performed in an elevator drifting at constant velocity through empty space.

Einstein's new point of view on motion, acceleration, and gravity brought about a radical revision of how we think about space and time. Instead of thinking about the three dimensions of space and the one dimension of time as separate, we had to start thinking of them as a seamless four-dimensional entity known as *spacetime.* Einstein showed that a person would feel weightless, as though drifting through empty space, as long as the person's path through four-dimensional spacetime was as straight as possible.

So why do astronauts feel weightless even though they orbit Earth on a curved path? According to general relativity, they are still following the *straightest possible* path through four-dimensional spacetime. The path is curved only because spacetime itself is curved near the Earth. In other words, while Newton would have attributed the curved orbital path of the astronauts to the force of gravity, Einstein attributes it to curvature of spacetime. That is, gravity arises from curvature of spacetime.

The curvature of spacetime is caused by mass, and stronger gravity just means greater spacetime curvature. Thus, for example, the Sun's gravity curves spacetime more than Earth's gravity, and the strong gravity on the surface of a white dwarf curves spacetime more than the gravity on the surface of the Sun. Although we cannot visualize spacetime curvature, we can visualize two-dimensional analogies to it with rubber sheet diagrams like those shown in Figure 13.11. From this new perspective, planets orbit the Sun because of the way space is curved by the Sun: Each planet is going as straight as it can, but space is curved in a way that keeps it going round and round like a marble in a salad bowl (see figure).

Given that we cannot actually perceive all four dimensions of spacetime at once, you may wonder why scientists think spacetime curvature is real. The answer is that Einstein's theory predicts measurable effects from the curvature. For example, if gravity really does arise from curvature of spacetime, then light paths ought to bend when they pass near large masses. Sure enough, scientists have measured such bending of starlight as it passes near the Sun, and the amount of bending is precisely what general relativity predicts it should be. We have also observed such bending of light by distant galaxies, a phenomenon called *gravitatioinal lensing* [Section 16.1]. Another key prediction of general relativity is that time should run slower in regions of stronger gravity (remember that curvature affects both space and time)—again, numerous observations and experimental tests verify Einstein's predictions. Strange as it may seem, we live in a four-dimensional universe in which space and time are intertwined and can never be disentangled.



According to general relativity, planets orbit the Sun for much the same reason that you can make a marble go around in a salad bowl: The planet is going as straight as it can, but the curvature of spacetime causes its path through space to curve.

3 kilometers—only a little smaller than the radius of a neutron star of the same mass. More massive black holes have larger Schwarzschild radii. For example, a black hole with 10 times the mass of the Sun has a Schwarzschild radius of about 30 kilometers.

In essence, a collapsing stellar core becomes a black hole at the moment that it shrinks to a size smaller than its Schwarzschild radius. At that moment, the core disappears from view within its own event horizon. The black hole still contains all the mass and has the gravity associated with that mass, but its outward appearance tells us nothing about what fell in.

Singularity and the Limits to Knowledge We can't observe what happens to a stellar core once it collapses to make a black hole, because no information can ever emerge from within the event horizon. Nevertheless, we can use our understanding of the laws of physics to predict what must occur inside a black hole. Because nothing can stop the crush of gravity in a black hole, we might expect that all the matter that forms a black hole must ultimately be crushed to an infinitely tiny and dense point in the black hole's center. We call this point a **singularity**.

Unfortunately, this idea of a singularity pushes up against the limits to scientific knowledge today. The problem is that that two very successful theories give different answers about the nature of a singularity. Einstein's theory of general relativity, which seems to explain successfully how gravity works throughout the universe, predicts that spacetime should grow infinitely curved as it enters the pointlike singularity. Quantum physics, which successfully explains the nature of atoms and the spectra of light, predicts that spacetime should fluctuate chaotically near the singularity. These are clearly different claims, and no theory that can reconcile them has yet been found.

• What would it be like to visit a black hole?

Imagine that you are a pioneer of the future, making the first visit to a black hole. You've selected a black hole with a mass of $10M_{\text{Sun}}$ and a Schwarzschild radius of 30 km. As your spaceship approaches the black hole, you fire its engines to put the ship on a circular orbit a few thousand kilometers above the event horizon. This orbit will be perfectly stable—there is no need to worry about getting "sucked in."

Your first task is to test Einstein's general theory of relativity. This theory predicts that time should run more slowly as the force of gravity grows stronger. It also predicts that light coming out of a strong gravitational field should show a redshift, called a *gravitational redshift*, that is due to gravity rather than to the Doppler effect. You test these predictions with the aid of two identical clocks whose numerals glow with blue light. You keep one clock aboard the ship and push the other one, with a small rocket attached, directly toward the black hole (Figure 13.12). The small rocket automatically fires its engines just enough so that the clock falls only gradually toward the event horizon. Sure enough, the clock on the rocket ticks more slowly as it heads toward the black hole, and its light becomes increasingly redshifted. When the clock reaches a distance of about 10 kilometers above the event horizon, you see it ticking only half as fast as the clock on your spaceship, and its numerals are red instead of blue.

The rocket has to expend fuel rapidly to keep the clock hovering in the strong gravitational field, and it soon runs out of fuel. The clock plunges toward the black hole. From your safe vantage point inside the spaceship, you see the clock ticking more and more slowly as it falls. However, you soon need a radio telescope to "see" it, as the light from the clock face

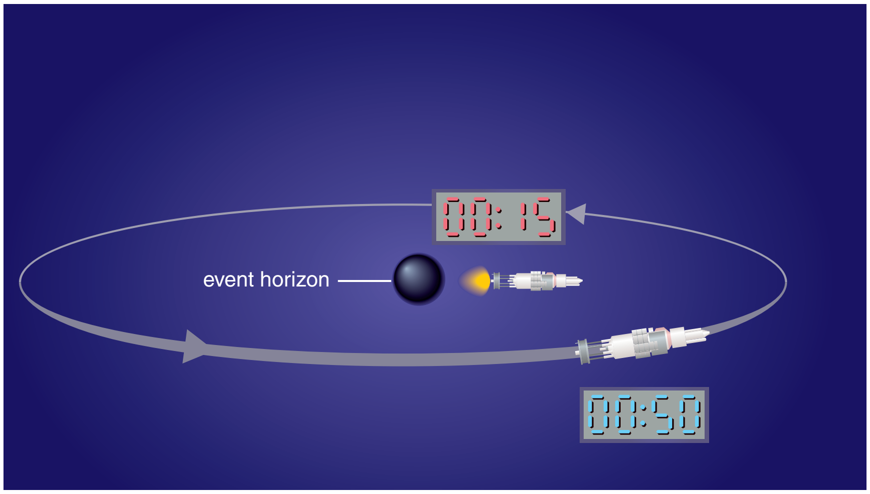


Figure 13.12 Interactive Figure

Time runs more slowly on the clock nearer to the black hole, and gravitational redshift makes its glowing blue numerals appear red from your spaceship.

shifts from the red part of the visible spectrum, through the infrared, and on into the radio. Finally, its light is so far redshifted that no conceivable telescope could detect it. Just as the clock vanishes from view, you see that the time on its face has frozen to a stop.

Curiosity overwhelms the better judgment of one of your colleagues. He hurriedly climbs into a spacesuit, grabs the other clock, resets it, and jumps out of the airlock on a trajectory aimed straight for the black hole. Down he falls, clock in hand. He watches the clock, but because he and the clock are traveling together, its time seems to run normally and its numerals stay blue. From his point of view, time seems to neither speed up nor slow down. In fact, he'd say that *you* were the one with the strange time, as he would see your time running increasingly fast and your light becoming increasingly blueshifted. When his clock reads, say, 00:30, he and the clock pass through the event horizon. There is no barrier, no wall, no hard surface. The event horizon is a mathematical boundary, not a physical one. From his point of view, the clock keeps ticking. He is inside the event horizon, the first human being ever to leave our observable universe.

If you fell toward a black hole, you would rapidly accelerate and soon cross the event horizon. But to someone watching from afar, your fall would appear to take forever.

Back on the spaceship, you watch in horror as your overly curious friend plunges to his death. Yet, from your point of view, he will *never* cross the event horizon. You'll see time come to a stop for him and his clock just as he vanishes from view due to the huge gravitational redshift of light. When you return home, you can play a video for the judges at your trial, proving that your friend is still a part of our observable universe. Strange as it may seem, all of this is true according to Einstein's theory. From your point of view, your friend takes *forever* to cross the event horizon (even though he vanishes from view due to his ever-increasing redshift). From his point of view, it is but a moment's plunge before he passes into oblivion.

The truly sad part of this story is that your friend did not live to experience the crossing of the event horizon. The force of gravity he felt as he approached the black hole grew so quickly that it actually pulled much harder on his feet than on his head, simultaneously stretching him lengthwise and squeezing him from side to side (Figure 13.13). In essence, your friend was stretched in the same way the oceans are stretched by the tides, except that the *tidal force* near the black hole is trillions of times stronger than the tidal force of the Moon on Earth [Section 4.4]. No human could survive it.

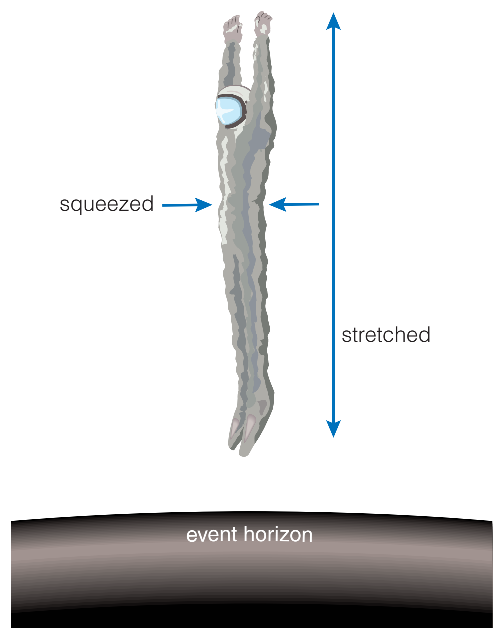


Figure 13.13

Tidal forces would be lethal near a black hole formed by the collapse of a star. The black hole would pull more strongly on the astronaut's feet than on his head, stretching him lengthwise and squeezing him from side to side.

COMMON MISCONCEPTIONS

BLACK HOLES DON'T SUCK

What would happen if our Sun suddenly became a black hole? For some reason, it has become part of our popular culture for most people to believe that Earth and the other planets would inevitably be "sucked in" by the black hole. That is not true. Although the sudden disappearance of light and heat from the Sun would be bad news for life, Earth's orbit would not change.

Newton's law of gravity tells us that the allowed orbits in a gravitational field are ellipses, hyperbolas, and parabolas [Section 4.4]. Note that "sucking" is not on the list! A spaceship would get into trouble only if it came so close to a black hole—within about three times its Schwarzschild radius—that the force of gravity would deviate significantly from what Newton's law predicts. Otherwise, a spaceship passing near a black hole would simply swing around it on an ordinary orbit (ellipse, parabola, or hyperbola). In fact, because most black holes are so small—typical Schwarzschild radii are far smaller than any star or planet—a black hole is actually one of the most difficult things in the universe to fall into by accident.

If he had thought ahead, your friend might have waited to make his jump until you visited a much larger black hole, like one of the *supermassive black holes* thought to reside in the centers of many galaxies [Section 15.4]. A 1 billion M_{Sun} black hole has a Schwarzschild radius of 3 billion kilometers—about the distance from our Sun to Uranus. Although the gravitational forces at the event horizon of all black holes are equally great, the larger size of a supermassive black hole makes its tidal forces much weaker and hence nonlethal. Your friend could safely plunge through the event horizon.

Again, from your point of view, the crossing would take forever, and you would see time come to a stop for him just as he vanished from sight because of the gravitational redshift. Again, he would experience time running normally and would see time in the outside universe running increasingly fast as he approached the event horizon. Unfortunately, anything he saw would do him little good as he plunged to oblivion inside the black hole.

• Do black holes really exist?

The idea of objects with escape velocities greater than the speed of light was first suggested in the late 1700s (by British philosopher John Mitchell and French physicist Pierre Laplace), though the bizarre implications of the idea were not understood until after Einstein published his general theory of relativity in 1915. As was the case for neutron stars, at first most astronomers who contemplated the idea of black holes thought them too strange to be true. Today, however, our understanding of physics gives us reason to think that black holes ought to be fairly common, and observational evidence strongly suggests that black holes really exist.

The Formation of a Black Hole The idea that black holes ought to exist comes from considering how they might form. Recall that white dwarfs cannot exceed $1.4M_{\text{Sun}}$, because gravity overcomes electron degeneracy pressure above that mass. Calculations show that the mass of a neutron star has a similar limit that lies somewhere between about 2 and 3 solar masses. Above this mass, neutron degeneracy pressure cannot hold off the crush of gravity in a collapsing stellar core.

A supernova occurs when the electron degeneracy pressure supporting the iron core of a massive star succumbs to gravity, causing the core to collapse catastrophically into a ball of neutrons [Section 12.3]. That is why most supernovae leave neutron stars behind. However, theoretical models show that the most massive stars might not succeed in blowing away all their upper layers. If enough matter falls back onto the neutron core, its mass may rise above the neutron star limit.

As soon as the core exceeds the neutron star limit, gravity overcomes the neutron degeneracy pressure and the core collapses once again. This time, no known force can keep the core from collapsing into oblivion as a black hole. Moreover, another effect of Einstein's theory of relativity makes it highly unlikely that any as-yet-unknown force could intervene either.

According to the known laws of physics, nothing can stop the collapse of a stellar corpse with a mass greater than about 3 solar masses.

Recall that Einstein's theory tells us that energy is equivalent to mass ($E = mc^2$) [Section 4.3]. Thus, like mass, energy must also exert some gravitational attraction. The gravity of pure energy usually is negligible, but not in a stellar core collapsing beyond the neutron star limit. Usually, the gravitational potential energy released as a star collapses boosts its temperature and pressure

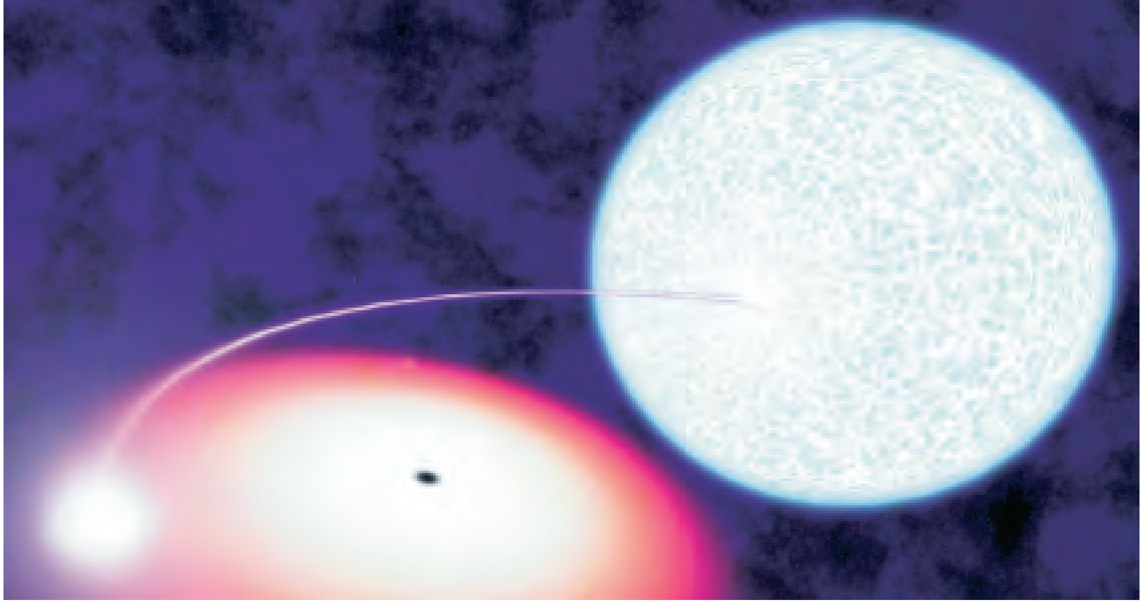


Figure 13.14 Interactive Figure

Artist's conception of the Cygnus X-1 system, which gets its name because it is the brightest X-ray source in the constellation Cygnus. The X rays come from the high-temperature gas in the accretion disk surrounding the black hole.

enough to fight off gravity. However, once a star collapses beyond the point where it could have been a neutron star, the energy associated with the enhanced temperature and pressure only makes gravity stronger. The more it collapses, the stronger gravity gets. To the best of our understanding, *nothing* can stop the star from becoming a black hole.

Observational Evidence for Black Holes The fact that black holes emit no light might make it seem as if they should be impossible to detect. However, a black hole's gravity can influence its surroundings in a way that reveals its presence. Astronomers have discovered many objects that show the telltale signs of an unseen gravitational influence with a large enough mass to suggest that it is black hole.

Strong observational evidence for black holes formed by supernovae comes from studies of X-ray binaries. Recall that the accretion disks around neutron stars in close binary systems can emit strong X-ray radiation, making an X-ray binary. The accretion disk forms because the neutron star's strong gravity pulls mass from the companion star. Because a black hole has even stronger gravity than a neutron star, a black hole in a close binary system should also be surrounded by a hot, X-ray emitting accretion disk. Thus, some X-ray binaries may contain black holes rather than neutron stars. The trick to learning which type of corpse resides in an X-ray binary depends on measuring the object's mass.

Some X-ray binaries probably contain accreting black holes rather than accreting neutron stars.

One of the most promising black hole candidates is in an X-ray binary called Cygnus X-1 (Figure 13.14). This system contains an extremely luminous star with an estimated mass of $18M_{\text{Sun}}$. Based on Doppler shifts of its spectral lines, astronomers have concluded that this star orbits a compact, unseen companion with a mass of about $10M_{\text{Sun}}$. Although there is some uncertainty in these mass estimates, the mass of the invisible accreting object clearly exceeds the $3M_{\text{Sun}}$ neutron star limit. Thus, it is too massive to be a neutron star, so by current knowledge it cannot be anything other than a black hole.

THINK ABOUT IT Recall that some X-ray binaries that contain neutron stars emit frequent X-ray bursts and are called X-ray bursters. Could an X-ray binary that contains a black hole exhibit the same type of X-ray bursts? Why or why not? (*Hint:* Where do the X-ray bursts occur in an X-ray binary with a neutron star?)

Stellar Evolution Tutorial, Lessons 1–3

12.4 SUMMARY OF STELLAR LIVES

Much of this chapter has been devoted to telling the life stories of two different stars, one with the mass of our Sun and another that began life with a mass 25 times as great. Now we will complete the picture of star life and star death by showing how these two basic life stories apply to stars of all masses. We will also see that some stars can have more complicated life stories, but only if they happen to be members of close binary systems.

• How does a star's mass determine its life story?

We have seen that the primary factor determining how a star lives its life is its mass. Low-mass stars live long lives and die in planetary nebulae, leaving behind white dwarfs. High-mass stars live short lives and die in supernovae, leaving behind neutron stars and black holes. Figure 12.20 summarizes the life cycles of the two stars we have focused on in this chapter.

Stars born with less than about $8M_{\text{Sun}}$ follow life stages similar to that of our Sun, while more massive stars live short but brilliant lives and die in supernova explosions.

Stars that begin life with less than about eight times the mass of the Sun ($8M_{\text{Sun}}$) have life stories similar to that of the $1M_{\text{Sun}}$ star in Figure 12.20. The main differences are in the overall life span and in what goes on inside the star. Stars less massive than $1M_{\text{Sun}}$ progress through their life stages more slowly, while more massive stars progress through their life stages more quickly. Stars with more than about two times the Sun's mass fuse hydrogen through the CNO cycle, and their cores remain so hot that they never undergo a helium flash. However, unless stars have masses above about $8M_{\text{Sun}}$, they never get hot enough to produce iron in their cores, and thus they die without reaching the point of supernova.

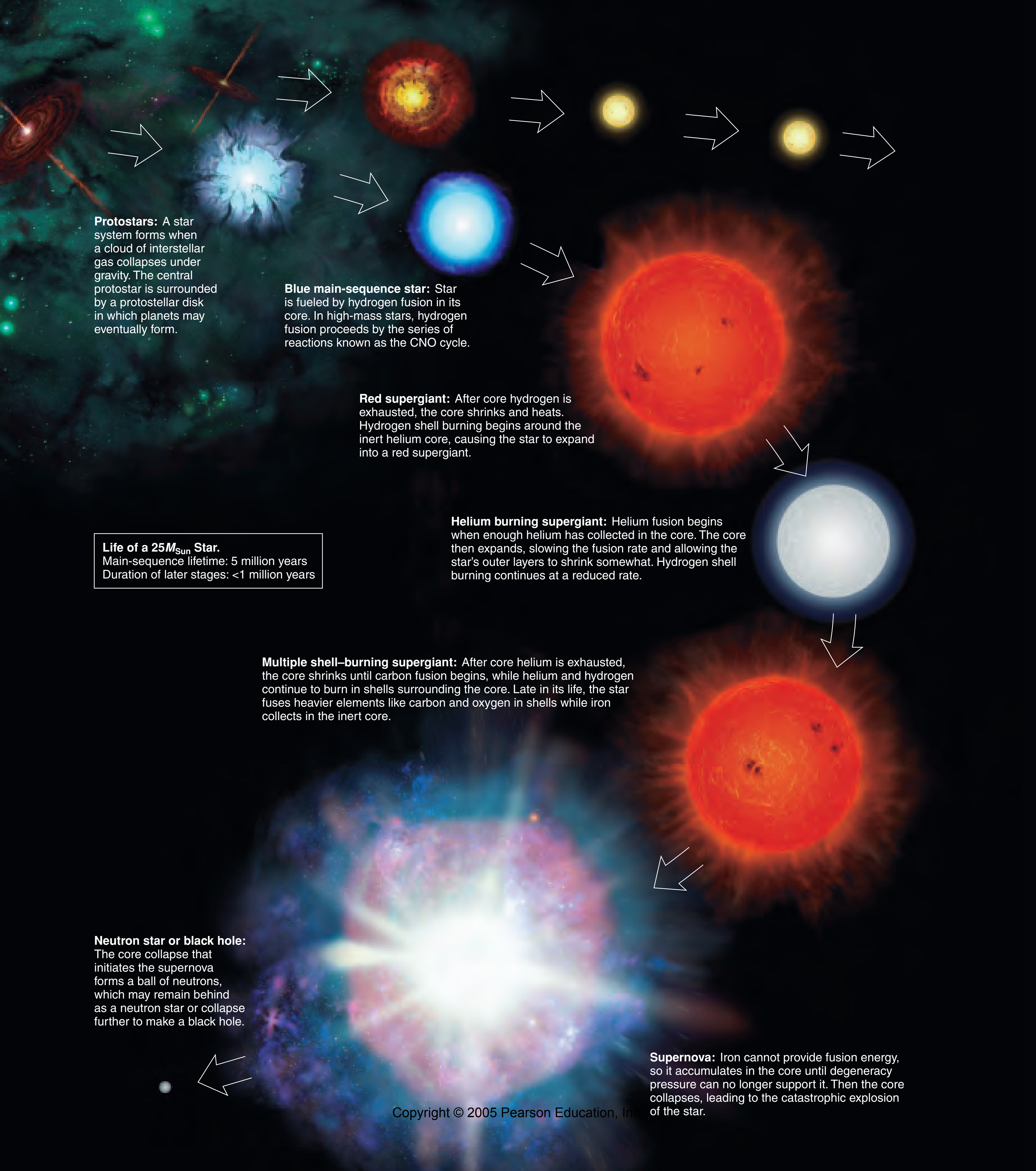
Stars that begin life with more than $8M_{\text{Sun}}$ have life stories similar to that of the $25M_{\text{Sun}}$ star in Figure 12.20. Again, stars with more mass fuse their elements more furiously and go through all these stages faster. The biggest difference in their life stories may only come at the very end—the most massive stars of all might become black holes when they die.

• How are the lives of stars with close companions different?

For the most part, stars in binary systems proceed from birth to death as if they were isolated and alone. The exceptions are close binary stars. Algol, the "demon star" in the constellation Perseus, consists of two stars that orbit each other closely: a $3.7M_{\text{Sun}}$ main-sequence star and a $0.8M_{\text{Sun}}$ subgiant.

A moment's thought reveals that something quite strange is going on. The stars of a binary system are born at the same time and therefore must both be the same age. We know that more massive stars live shorter lives, and therefore the more massive star must exhaust its core hydrogen and become a subgiant before the less massive star does. How, then, can Algol's less massive star be a subgiant while the more massive star is still burning hydrogen as a main-sequence star?

Continued on p. 324


Protostars: A star system forms when a cloud of interstellar gas collapses under gravity. The central protostar is surrounded by a protostellar disk in which planets may eventually form.
Blue main-sequence star: Star is fueled by hydrogen fusion in its core. In high-mass stars, hydrogen fusion proceeds by the series of reactions known as the CNO cycle.
Red supergiant: After core hydrogen is exhausted, the core shrinks and heats. Hydrogen shell burning begins around the inert helium core, causing the star to expand into a red supergiant.
Life of a 25M_{Sun} Star.
Main-sequence lifetime: 5 million years
Duration of later stages: <1 million years
Helium burning supergiant: Helium fusion begins when enough helium has collected in the core. The core then expands, slowing the fusion rate and allowing the star's outer layers to shrink somewhat. Hydrogen shell burning continues at a reduced rate.
Multiple shell–burning supergiant: After core helium is exhausted, the core shrinks until carbon fusion begins, while helium and hydrogen continue to burn in shells surrounding the core. Late in its life, the star fuses heavier elements like carbon and oxygen in shells while iron collects in the inert core.
Neutron star or black hole: The core collapse that initiates the supernova forms a ball of neutrons, which may remain behind as a neutron star or collapse further to make a black hole.
Supernova: Iron cannot provide fusion energy, so it accumulates in the core until degeneracy pressure can no longer support it. Then the core collapses, leading to the catastrophic explosion of the star.

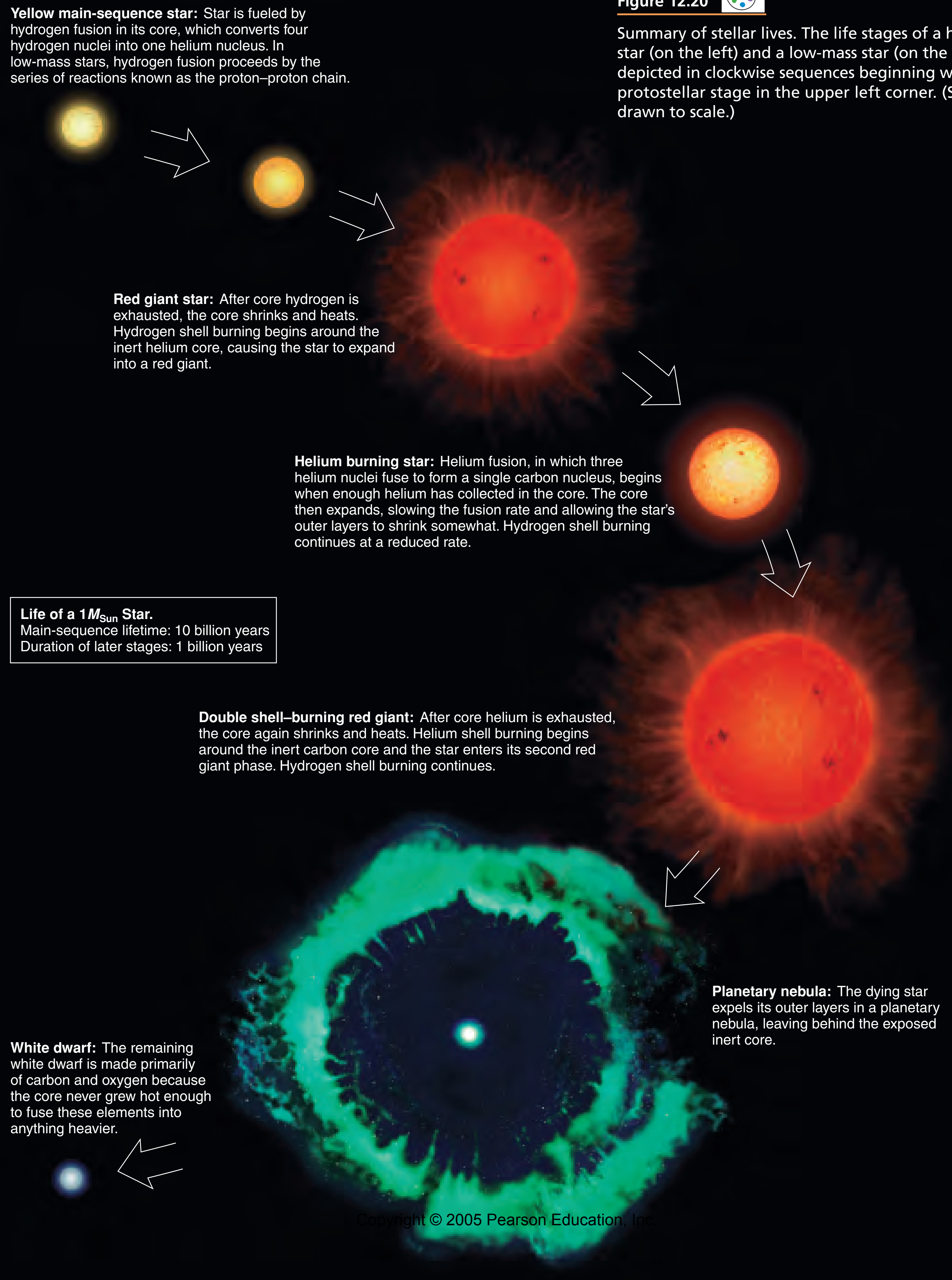
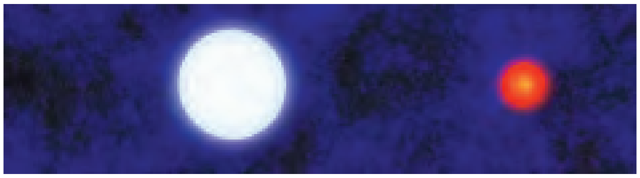
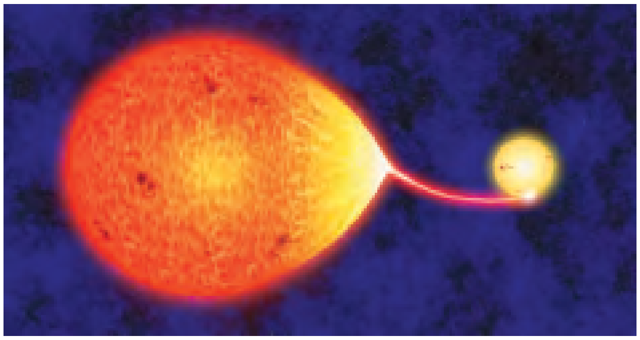


Figure 12.20

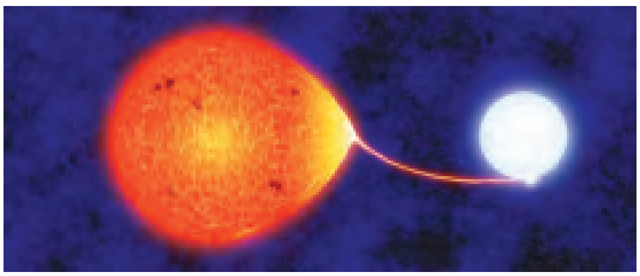
Summary of stellar lives. The life stages of a high-mass star (on the left) and a low-mass star (on the right) are depicted in clockwise sequences beginning with the protostellar stage in the upper left corner. (Stars not drawn to scale.)



Algol shortly after its birth. The higher-mass star (left) evolved more quickly than its lower-mass companion (right).



Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen-burning companion.



Algol today. As a result of the mass transfer, the red giant has shrunk to a subgiant, and the normal star on the right is now the more massive of the two stars.

Figure 12.21

Artist's conception of the development of the Algol close binary system.

This so-called *Algol paradox* reveals some of the complications in ordinary stellar life cycles that can arise in close binary systems. The two stars in a close binary are near enough to exert significant tidal forces on each other [Section 6.4]. The gravity of each star attracts the near side of the other star more strongly than it attracts the far side. The stars therefore stretch into football-like shapes rather than remaining spherical. In addition, the stars become *tidally locked* so that they always show the same face to each other, much as the Moon always shows the same face to Earth.

During the time that both stars are main-sequence stars, the tidal forces have little effect on their lives. However, when the more massive star (which exhausts its core hydrogen sooner) begins to expand into a red giant, gas from its outer layers can spill over onto its companion. This **mass exchange** occurs when the giant grows so large that its tidally distorted outer layers succumb to the gravitational attraction of the smaller companion star. The companion then begins to gain mass at the expense of the giant.

Stars in close binary systems can exchange mass with one another, altering their life histories.

The solution to the Algol paradox should now be clear (Figure 12.21). The $0.8M_{\text{Sun}}$ subgiant *used to be* much more massive. As the more massive star, it was the first to begin expanding into a red giant. As it expanded, however, so much of its matter spilled over onto its companion that it is now the less massive star.

The future may hold even more interesting events for Algol. The $3.7M_{\text{Sun}}$ star is still gaining mass from its subgiant companion. Thus, its life cycle is actually accelerating as its increasing gravity raises its core hydrogen fusion rate. Millions of years from now, it will exhaust its hydrogen and begin to expand into a red giant itself. At that point, it can begin to transfer mass *back* to its companion. Even stranger things can happen in other mass-exchange systems, particularly when one of the stars is a white dwarf or a neutron star. That is a topic for the next chapter.

THE BIG PICTURE

Putting Chapter 12 into Context

In this chapter, we answered the question of the origin of elements that we first discussed in Chapter 1. As you look back over this chapter, remember these "big picture" ideas:

- Virtually all elements besides hydrogen and helium were forged in the nuclear furnaces of stars and released into space from these stars. Thus, we and our planet are made of stuff produced in stars that lived and died long ago.
- Low-mass stars like our Sun live long lives and die with the ejection of a planetary nebula, leaving behind a white dwarf.
- High-mass stars live fast and die young, exploding dramatically as supernovae and leaving behind neutron stars or black holes.
- Close binary stars can exchange mass, altering the usual course of stellar evolution.

Media and Resources

The “Media and Resources” bag includes:

- The ToolKit Manual on a CD: “Manual & Resources”
- A Training Video as a DVD: “Training Video”
- Props to go with the PowerPoint:
    - A small can of Play-Doh®
    - A small labeled canister containing “Birdseed and Peppercorns”
- Materials to put together the Black Hole Explorer Board Game (See Manual section “Black Hole Explorer Board Game”):
    - Sheets of colored card stock
    - A small labeled canister containing “Dice & Tokens”

The “Training Video DVD” should be viewed as soon as you receive the ToolKit. This will provide an introduction to the activities and materials. Print out the suggested script for the PowerPoint before watching the video. This can be found on the Manual & Resources CD in the folder named “PowerPoints”. The script is named “SurviveBHscript.doc”. It is also provided as a PDF.

Explore the “Manual and Resources CD”:

- For the ToolKit Manual, open the “BHManual.pdf”
- For PowerPoints, go to the folder labeled “**PowerPoints**”
    - One PowerPoint, SurviveBH.ppt, along with the script SurviveBHscript.doc, is designed for use with your audiences
    - The other PowertPoint, SurviveBHClubIntro.ppt along with the script SurviveBHscriptClubIntro.doc, is designed to introduce your club members to the ToolKit
- For Animations, open the folder, “**BHAnimations**” and click on “BHAnimations.htm”.

The handouts for the activities can be found in BHManual.pdf so you can personalize them with your club information and print out copies to make for your guests and other club members. The manual also includes sources where you can get more materials.

Feel free to make copies of the **DVD and CD** for distribution to other club members or educators. These copies must be provided free or at your cost.

Night Sky Network Log Event Form

Starred fields are required.

*Name of Event:	
*Submitted By (Person):	
*Club:	
*Name of Primary Presenter/Organizer:	
Presenter's Profession:	

***Event Type: (Check ONE)**

- ☐ Star Party (Astronomy Night):School/Public/Other Group
- ☐ Star Party for club members
- ☐ Classroom Presentation
- ☐ Club Meeting
- ☐ Astronomy Convention/Conference
- ☐ Family/Friends Event
- ☐ Girl Scout Event/Meeting
- ☐ Other Youth Group Event/Meeting
- ☐ Other organization's mtng/convention/conference
- ☐ Club newsletter article
- ☐ Newspaper/magazine article
- ☐ Television/radio show
- ☐ Other (please specify):

Name of Group the Event was for:	
* Event Date:	
* Length of Event:	(specify # of mins,hrs, or days - or approx # of words if an article):
* Event Location:	*City: *State: Zip:

***Facility Type (Check ONE):**

- ☐ K-12 School
- ☐ College/University
- ☐ Museum/planetarium/observatory
- ☐ Community/Gov't Facility (e.g. Library, Park, Sidewalk)
- ☐ Private Facility (e.g. hotel, private home)
- ☐ Media (newspaper, newsletter, magazine, TV)
- ☐ Other (please specify):

*** Number of your club members participating as presenters:** ☐

(Continue to Page 2)

*Toolkit Activities Used	
PlanetQuest (Check all that apply)	☐ Telescope Treasure Hunt ☐ Where are the Distant Worlds (Star maps) ☐ How do we find planets around other stars? ☐ Why do we Put Telescopes in Space? ☐ Used other ToolKit materials
Our Galaxy, Our Universe (Check all that apply)	☐ Our Place in Our Galaxy ☐ A Universe of Galaxies ☐ Telescopes as Time Machines ☐ Hubble Video Collection DVD ☐ Used other ToolKit materials
Black Hole Survival (Check all that apply)	☐ Black Hole Explorer Board Game ☐ Gravity & the Fabric of Space ☐ Where are the Black Holes? ☐ Used other ToolKit materials

(Continue to Page 3)

	*Total Number of Visitors or Audience Members (if unknown, please estimate)

Demographics of audience members are requested by government agencies. If exact numbers are unknown, please try to estimate. Otherwise, leave the space blank.

Estimated #	How many visitors or audience members were...		
	Minority?		Adults?
	Female?		Teens?
			Children?

IF A SCHOOL EVENT:

Estimated #	How many audience members were...		
	Non-teacher adults?		
	K-8th Grade Teachers?		K-8th Grade Students?
	High School Teachers?		High School Students?
	Community College Instructors?		Community College Students?
	Other College or University Instructors?		Other College or University Students?

What materials (and how many) did you hand out at the event, if any?

Provide a few comments or interesting anecdotes about the event:

- **PHOTOS:** If you wish to include electronic photos, you will need to log your event online.
- **Please use this form as a reference to log your event online on the Night Sky Network:** http://nightsky.jpl.nasa.gov
- **OR send the form to your Night Sky Network Club Coordinator**
- **OR mail this form to:**
  Night Sky Network
  Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112
- **OR FAX this form to:** 415-337-5205

Black Hole Explorer Board Game

What is this activity about?

Big Activity: Plan and carry out a mission to a Black Hole.

Participants: Adults, teens, families with children 8 years and up
If a school/youth group, 4th grade and higher
Four participants or teams.

Duration: The game typically takes an hour or more.

Activity Description:
"Black Hole Explorer" is a board game where the players fly a spaceship to orbit around a black hole and launch scientific probes to study it. The object is to return to Earth with your results and collect the Nobel Prize!

Where can I use this activity?

Indoors at a table with up to four players or four teams.

A youth group would enjoy playing the game on a rainy or cloudy evening.

At a club meeting: Make several copies of the game and have a game night!

Family Astronomy Night or at home with friends.

Detailed Activity Description

The best way to become familiar with this game is to go through the rules and play the game with your family or friends before you use it at a public event.

You might want to use the “Mission Briefing Room” page to introduce the game.

Materials

What Materials from the ToolKit do I need?

- A small canister labeled “Dice & Tokens” that contains:
  - Playing pieces
  - 2 dice
- 4 sheets of white card stock – print the game board on these
- 3 sheets of blue card stock – print the Probe Result cards on these
- 7 sheets of yellow card stock – print the Event Cards on these

The pages for the board game are in the BHManual.pdf under the “Black Hole Explorer Board Game” section. The pages for the game can also be found separately on the Manual & Resources CD in a file named “BHExplorerGame.pdf”.

What must I supply?

- Plain paper to print the rules, Spacecraft Construction sheets, and energy tokens.
- A table to play on, chairs for the players.

What do I need to prepare?

Print out each of the pages of the Black Hole Explorer board game. The pages for the board game are in the BHManual.pdf under the “Black Hole Explorer” section. The pages for the game can also be found separately on the Manual & Resources CD in a file named **“BHExplorerGame.pdf”**.

The game includes the following:

- **Game rules** – print these on plain paper
- **Mission Briefing Room** – print on plain paper. This may be used to introduce the game.
- **Spacecraft construction sheets** to plan your mission – print on plain paper. Make as many copies as you have players.
- **Energy tokens** which represent the amount of energy your spacecraft has – you’ll need to cut these apart – a popular alternative is to use pennies or paper clips for energy tokens.
- The **game board**, which will print in 4 sections – **use the white card stock**, then trim the pages and tape them together.
- **Event cards** that can help or hurt your mission – these are two sided - print them on the **yellow card stock** and cut them apart
- **Probe result cards** which represent the data you collect from shooting a probe toward the black hole – these are also two-sided - print these on the **blue card stock** and cut them apart

You may want to attach the game board to a cardboard backing or laminate it.

Where do I get additional materials?

- **Card Stock:** Office supply store.
- **Playing pieces:** use any tokens from another game or markers such as coins.
- **Energy tokens:** Instead of the small energy squares, you can use pennies or paper clips.
- **Dice**: game store or drug store.

Black Hole Explorer Board Game

Printing Instructions

1. Print these 11 pages on **plain white paper**:

    - **Game rules**
    - **Mission Briefing Room**
    - **Spacecraft construction sheets** to plan your mission – make as many copies as you have players
    - **Energy tokens** which is a page of atomic symbols and represent the amount of energy your spacecraft has – you'll need to cut these apart – popular alternatives are to use pennies or paper clips for energy tokens.

2. Print the following 4 pages on **white card stock:**
    - The **game board**, which will print in 4 sections, then trim the pages and tape them together.

    You may want to attach the game board to a cardboard backing or laminate it.

3. Print the following 7 pages on **yellow card stock:**

    - **Event cards** that can help or hurt your mission

4. Turn the Events Cards over and print the next page (4 sets of the word "Event") on the back of the Event Cards. Cut the cards apart.

5. Print the following 3 pages on **blue card stock:**

    - **Probe result cards** which represent the data you collect from shooting a probe toward the black hole – these are also two-sided - print these on the **blue card stock** and cut them apart

6. Turn the Probe Result Cards over and print the next page (4 sets of the words "Probe Result") on the back of the Probe Result Cards. Cut the cards apart.

black hōle explōrer

Rules of the Game

Overview

You are going to build a spaceship to fly close enough to a black hole to study it, and be the first back with scientific discoveries that could win you a Nobel Prize! But travelling too close could leave you spiraling into the black hole, never (or probably never) to return!

Black Hole Explorer can be played in two ways: as a competition between missions, or as a team collaboration assembling one mission. The first is more of a race, the second pits the team against the extreme natural forces of the Black Hole.

Game Equipment

Game board; 2 dice; event cards; probe result cards; energy chips; spaceship data sheet (one per ship); spaceship game pieces (one per ship. Use coins, tiddlywinks or customize your own); pencils, eraser.

Playing the game

The game has three parts. In Part 1 the players have to construct a spaceship based on the amount of money available (determined on a die roll). Once the spaceship is built, you can proceed to part 2: the black hole board. The board has a black hole at its center surrounded by eight circular orbits. The hazards increase as you move to smaller and smaller orbits. The outer two orbits are called the Safe Zone. You then move to the Warning Zone, and finally, close to the black hole, the Danger Zone! To move to lower orbits, you simply have to complete one orbit and then change. But to climb orbits, you need to expend energy to fight against the black hole's gravity. During your mission, events will happen. By landing on an **E** (Event) square, you turn over and read an Event card. The event may be good or bad for your mission. Once you are in the danger zone, you can launch your scientific probes, collect your results, and head for home. Part 3 of the game is when the spaceship(s) return to Earth, and the mission results are assessed, to see if you have done enough to win the Nobel Prize and the game.

black hōle explōrer

Game Part 1. Spacecraft design

For this first part, you will need to complete your spaceship data sheet. Roll one die and multiply the number you roll by 10 million. This is the amount of money in dollars you have to spend. Write this number in the *Funding* box of your data sheet.

Your money needs to be spent on four items:

Probes	How many scientific probes your spaceship will carry.
Shielding	To protect against heat and radiation from the black hole.
Strength	To protect against the strong gravity of the black hole
Power	The amount of energy your spaceship will have.

Now, read the details and costs of each item before spending. Then write your purchase in the appropriate box on your data sheet.

Probes:
1 probe costs $5m
2 probes cost $10m
3 probes costs $15m

Shielding:
Level 1 Shielding costs $5m. Protects against moderate temperatures
Level 2 Shielding costs $10m. Protects against high temperatures and weak radiation.
Level 3 shielding costs $15m. Protects against high temperatures and intense radiation.

Strength:
Level 1 strength costs $5m. Protects against tidal forces in the Safe zone.
Level 2 strength costs $10m. Protects against tidal forces in the Warning zone.
Level 3 Strength costs $15m. Protects against tidal forces in the Danger zone.

Power:
A Single engine costs $5m. You get 6 energy points.
A Double engine costs $10m. You get 12 energy points.
A Triple engine costs $15m. You get 18 energy points.

You will also collect (and lose) energy points during the mission.

[NOTE: In the competitive game, there is no rule stopping collaboration, especially if mission funding is poor. This way, a game of (say) three players may reduce to three collaborators and one superior spacecraft, increasing the chances of success!]

IMPORTANT. Don't forget to name your spaceship!

Game part 2. The Game Board

Moving

Start on the spaceship picture and move down the squares until you join the outer orbit. **You then move counterclockwise around the black hole.** Roll two dice to determine how far you move each turn. You always move counterclockwise, both descending to and ascending from the black hole. This is the direction the black hole and its surrounding disc of gas (the accretion disc) is spinning.

You may give yourself an extra boost by expending energy: "buy" an extra die roll for an energy point (up to a maximum of two dice = 2 energy points). Example: for the cost of two energy point, you roll effectively 4 dice. **Note**: You will still need to expend an energy point as you climb an orbit in addition to any used for the boost.

Event cards

Certain squares in an orbit are marked with an **E**. This means that there is an event happening. These events may be good or bad, and reflect the hazards of a mission. If you land on an **E**, take an event card from the top of the pile. Then place the card on a discard pile unless the card tells you otherwise. When the Event card pile is empty, reshuffle the discards and place them face down to make a new Event pile.

Unless otherwise stated, an event card overrides the prior status of the spaceship.
Example: if a ship had previously been ordered to stay in the same orbit, and an Event card is drawn telling it to change orbit, it must change!

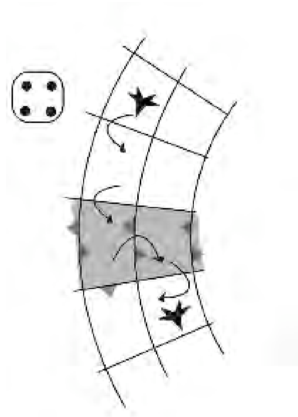
To change orbits

You must make at least one complete orbit before trying to change orbits. You can only change in the *CHANGE ORBIT* zone unless an event card tells you otherwise. You may only change your orbit by one unless an event card tells you otherwise. When changing orbits, move down (or up) vertically one square (see the diagrams below).

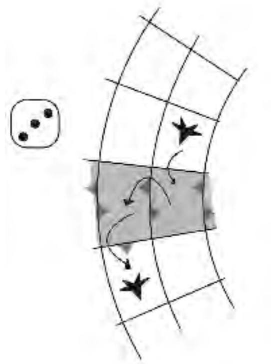
You need not change your orbit if you do not wish to (unless an event card tells you to), but….
If you run out of energy points you automatically drop one orbit every turn (regardless of where you are in the orbit).

To go down: You can automatically lower your orbit when entering the *CHANGE ORBIT* zone.

To go up: You can move to a higher orbit when entering the *CHANGE ORBIT* zone, but you need to expend 1 energy point to do so (otherwise you must remain in the same orbit).

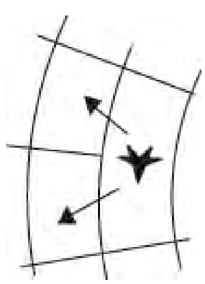


Moving Down example. On a roll of 4, your spacecraft moves into the *CHANGE ORBIT* zone, and steps down to a lower orbit.



Moving Up example. Here a roll of 3 takes you into the *CHANGE ORBIT* zone, and out into a higher orbit, but you must expend one energy point.

Forced change of orbit by an Event?
An event card may order you to change orbits immediately. If this change takes you into another Zone (say Warning to Safe), you will have a choice of two spaces to occupy, one of which may be an Event space. <u>You may choose</u> which space to enter. (This is not an issue when moving down).



Moving up by order of an Event card. You have a choice of which space to occupy.

Launching a probe
You can only (successfully) launch a probe in the Danger Zone. A probe can be launched at the end of your turn (that is, after you have rolled, moved and drawn an event card should you have landed on an **E**). Each probe launch costs 1 energy point.

The probe's chance of success increases the closer you are to the Black hole:
Highest orbit of Danger Zone: success with 1,2 on a die roll
Middle orbit of Danger Zone: success with 1,2,3,4 on die roll
Lowest orbit of Danger Zone: automatic success!

If your probe is successful, take a Probe Result card, read it out loud, and keep it in front of you. If your probe is unsuccessful, you do not get a Probe Result card. Note that a probe is lost and destroyed even when it is successful, as it has fallen into the black hole. A successful probe transmits its findings back to you – a failed probe (for whatever reason) does not.

What if I fall into the Black Hole?
Falling into a black hole is a one-way trip to oblivion. However, some scientists think that a black hole is a sort of gateway, or wormhole, to another part of the universe. This is very unlikely to be true, and even if it was, it is almost certainly impossible for a spaceship to journey through such a gateway. But this is only a game, so all is not lost! As soon as you fall in to the black hole, roll two dice. If you get 2 sixes, you emerge from a wormhole close to Earth and instantly win the Nobel Prize (and the game) for your discovery! If you don't, then go back and build another spaceship!

Game Part 3. Winning the game

End by returning to the "Home" Square (that is, climbing back up to the spaceship figure). You don't need to roll an exact number. If playing competitively, the first ship back home can present its results and attempt to win the Prize.

With one probe result, you win the Prize by rolling 5 or 6 on die roll.
With two probe results, you win the Prize by rolling 3,4,5 or 6 on die roll
With three probe results, you win the Prize automatically!

Reflection

At the end of the game you may want to reflect on your experience. Here are a few thoughtful questions.

1. Has your picture of what a black hole is changed because of this game? In what way?

2. How do you think events in the game would differ from a real mission to a black hole?

3. If you had to play the game again (or plan a real mission), what would you do differently, in the design phase, and in the mission phase?

Frequently Asked Questions

Here are some questions that have come up during the playing of Black Hole Explorer.

black hōle explōrer

What's the difference between the spaceship and the probes?
The spaceship is a large vessel with a crew of scientists and engineers. The probes are small robotic craft that are launched by your spaceship. The probes are equipped with cameras and an array of scientific equipment, and radio their findings back to the spaceship.

What if I roll a 1 for funding? What chance have I got?
There are several options. You could agree that a roll of one means roll again. Or it's time to arrange a collaboration. Some $10M ships have made it through – so think of it as a challenge!

Why do I have to expend energy climbing, but not descending?
When climbing you are working against the gravity of the black hole. The Space Shuttle needs tremendous energy to fight Earth's gravity on take-off, but glides back down to Earth without power.

If I'm "bumped up" an orbit by a collision or other event, do I need to expend energy?
No, because the move is a forced on you from outside, and not a result of firing your own engines. "Climbing" an orbit does expend energy, because you are making the move under your own power.

What if I have zero shields (or strength), and an event card says I lose 1 shield (or strength)?
If you are at zero you stay at zero (you can't go negative) and be thankful that you're still in one piece!

Can I help another spaceship that is in trouble?
Yes. If you can land on an adjacent square (either side, above, below or diagonal), you can donate a probe, repair robot or energy. This act of charity will cost YOU an energy point for each service given. Example: to give another spaceship one energy point will cost you two energy points.

I want lasers to shoot things!
This is not really in the spirit of exploration, although we appreciate that the USS Enterprise is quite heavily armed! If you want to turn "Black Hole Explorer" into "Black Hole Buccaneer" the tools are all here – energy, shields and strength.

What if the space I land on is occupied by another ship?
Two ships can occupy the same space (a ship is a few hundred feet long, and each space is many square miles in size). You may want to add new rules to bring in chances of collision, or (dare we say) combat!

Why does the black hole spin counterclockwise?
Why not? All real black holes rotate (probably), as do all stars and planets. Whether a black hole spins clockwise or counterclockwise depends on your perspective.

Can I move my spaceship in the opposite direction (clockwise?)
The rules say no. In reality, it would be tough to orbit "retrograde." The inner accretion disc will be rotating very rapidly – we're talking 10 million mph! Fighting against this would be like white water rafting back up a mountain. Feel free to adapt the rules if you want to fight the rotation, but get ready to burn energy and shields!

black hōle explōrer

Prepare to journey to the darkest place in the Universe!

Mission Briefing Room

Welcome to the mission briefing room. Your job is to fly a spaceship to a black hole. When you are close enough to the black hole, you will launch scientific probes into the black hole to answer some of the darkest mysteries about the darkest of objects:

What happens to space near a black hole?

What happens to time near a black hole?

What happens to you near a black hole?

But a mission such as this takes a lot of planning and a lot of money! You and your team will first be given millions of dollars to build a spaceship. You will need to decide how much you can spend on parts for your spaceship, such as the number of engines it will have, how well protected it is against heat and radiation, and the number of probes it can carry. Spend wisely!

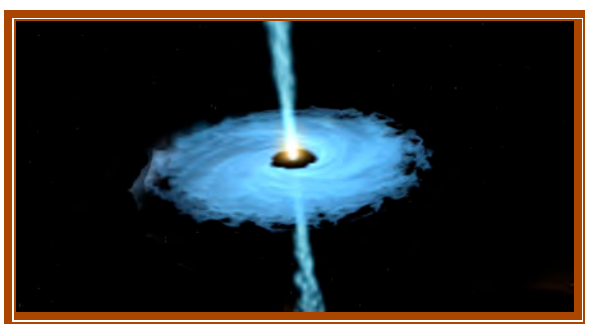
Once you have built your spaceship, your mission will begin. You will orbit closer and closer to the black hole, until you are close enough to launch the probes. But beware. Space around a black hole is swarming with hazards! On the next page, our astronomers will brief you on what you may encounter during your mission.

When your mission is complete, you can return home with your scientific results. Because your mission is the first to a black hole, your findings will be headline news. If you do well, you stand a good chance of winning a Nobel Prize, the greatest honor in the world for scientific discovery. Good luck to you all!

Science Briefing Room

Welcome to the Black Hole Science Briefing Room. Here is a photograph taken of your black hole by a recent robot probe. Doesn't look very black does it? We can't see the black hole itself (after all, it is a black hole!) but we can see the effect that a black hole has on its surroundings. If there are clouds of gas nearby, the gas will be spun, stretched and squeezed into a flat pancake. As the gas falls towards the black hole, it heats up and starts to glow. The further it falls, the hotter it gets. The temperature of this gas is something your mission will study.

Black holes like this one aren't very big compared to other objects in space such as planets and stars – think of a big black ball about the size of a city! But this is no rubber ball, this is a hole in space, and a black hole is completely, utterly black. That is because once inside nothing, not even light, can come out again. Going into a black hole is the ultimate one-way trip!



Sometimes the gas near the black hole is whipped up into such a tornado that before it has a chance to fall into the black hole, it is shot back out like the beam of a lighthouse. This jet of energy should be avoided if possible!

But the most amazing thing about black holes is that they bend and distort space and time itself! Studying the effect that a black hole has on time and space is the most important part of your mission. But remember, the black hole will bend and distort your space ship as well! And what will happen to your clocks as you close in on the black hole? Only time will tell!

You are now ready to start work on your spaceship. Don't forget to name it!

black hōle explōrer

Rules Quick Reference

You are going to build a spaceship to fly close enough to a black hole to study it, and be the first back with scientific discoveries that could win you a Nobel Prize! But traveling too close could leave you spiraling into the black hole, never (or probably never) to return!

The Game has three parts:

Part 1. Preparing for the Game

Construct a spaceship based on the amount of money available. Once the spaceship is built, you can proceed to the board. Turn over this sheet to begin construction!

Part 2: Playing the game.

Your aim is to orbit the black hole, and to launch a probe when in the Danger Zone. If your probe is successful, you pick up a Probe Result Card. Once you have launched all your probes, return home.

Any time you land on an E (Event) square, pick up an Event card and do what it says.

Moving

ALWAYS move counterclockwise when approaching and leaving the Black Hole.

Roll 2 dice to move. You can also buy extra dice rolls to move faster (one energy point per die, two dice max each turn).

You must make at least one orbit before ascending or descending in the CHANGE ORBIT zone. It costs nothing to drop an orbit, but costs one energy point when climbing an orbit.

If you run out of energy, you automatically drop one orbit every turn.

Launching a Probe

This expends 1 energy point, and is performed at the end of your turn (after moving and, if landing on an E, drawing of event card).
Upper Warning zone, probe is successful with roll of 1,2
Middle Warning Zone orbit, probe is successful with roll of 1,2,3,4
Inner Warning Zone orbit, probe is automatically successful.

Falling into the Black Hole

A roll of two sixes sends you home through a wormhole to automatically win
Any other roll and it's time to build a new spaceship!

Part 3. Winning the Game.

First spaceship back home can attempt to win the Nobel Prize. Success will depend on how many Probe Result cards you have: roll of 5,6 with one Probe Result; 3,4,5,6 with two; automatic win with three. If the first ship back fails, then the second has its chance etc.

black hōle explōrer

Spacecraft Construction

You need to build a ship with available funds. To see how much money you have, roll a die and multiply by 10 million (e.g. a roll of 2 gives you $20 million)

Your Funding is: $ ☐ million

Now spend this money building your spaceship. Each component costs $5 million. As with a real mission, you will need to make an educated guess as to how best to spend your money.

Probes at $5million each, to launch into the black hole. Maximum of three.

Number of probes: ☐ Cost: ☐ Tick here when probes are launched: ☐☐☐

Radiation Shielding to protect vital systems, each layer is $5million, maximum of three layers.

Number of shielding layers: ☐ Cost: ☐

Hull Strength, to resist the tug of gravity, each level of reinforcement costs $5million, maximum of three levels.

Strength Level: ☐ Cost ☐

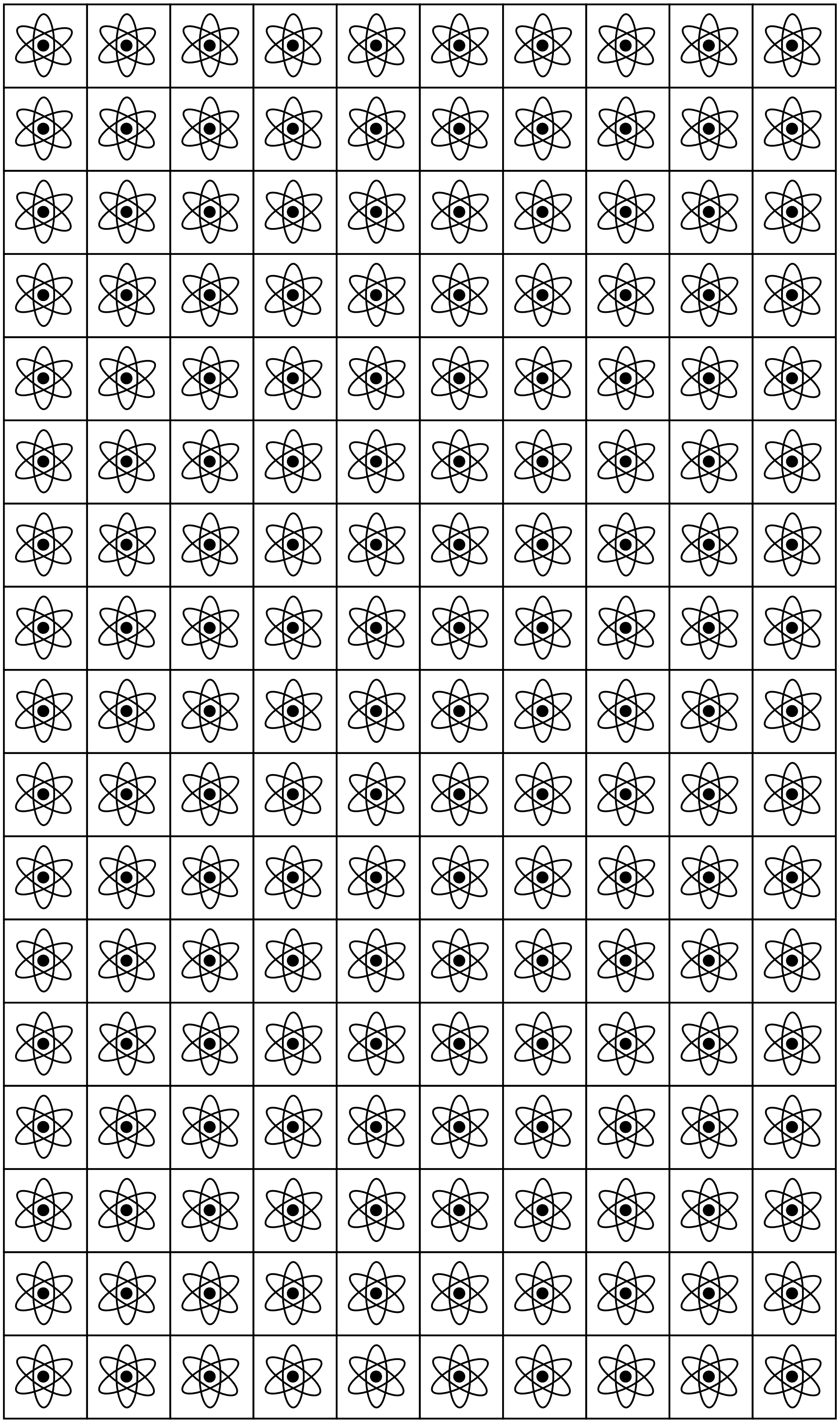
Engines: More engines means more energy. Each engine is $5million, maximum of three engines.

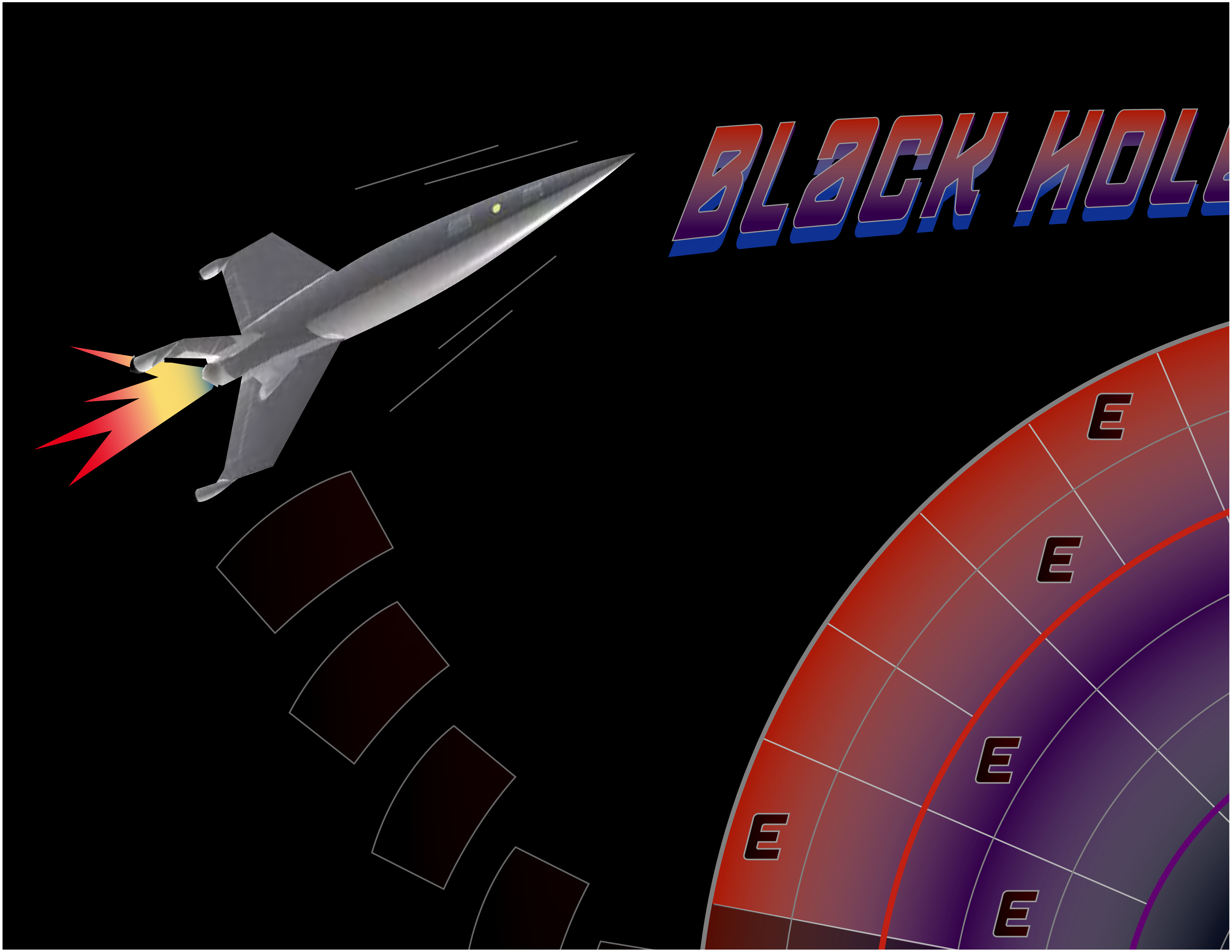
Number of engines: ☐ Cost ☐

For one engine, take 6 energy tokens; Two engines take 12; Three engines take 18.

Spacecraft Name: ☐

Now, you are ready to begin your mission! As the mission progresses, some of the information above will change – for example, you may gain hull strength, or lose an engine. Record those changes on this sheet.

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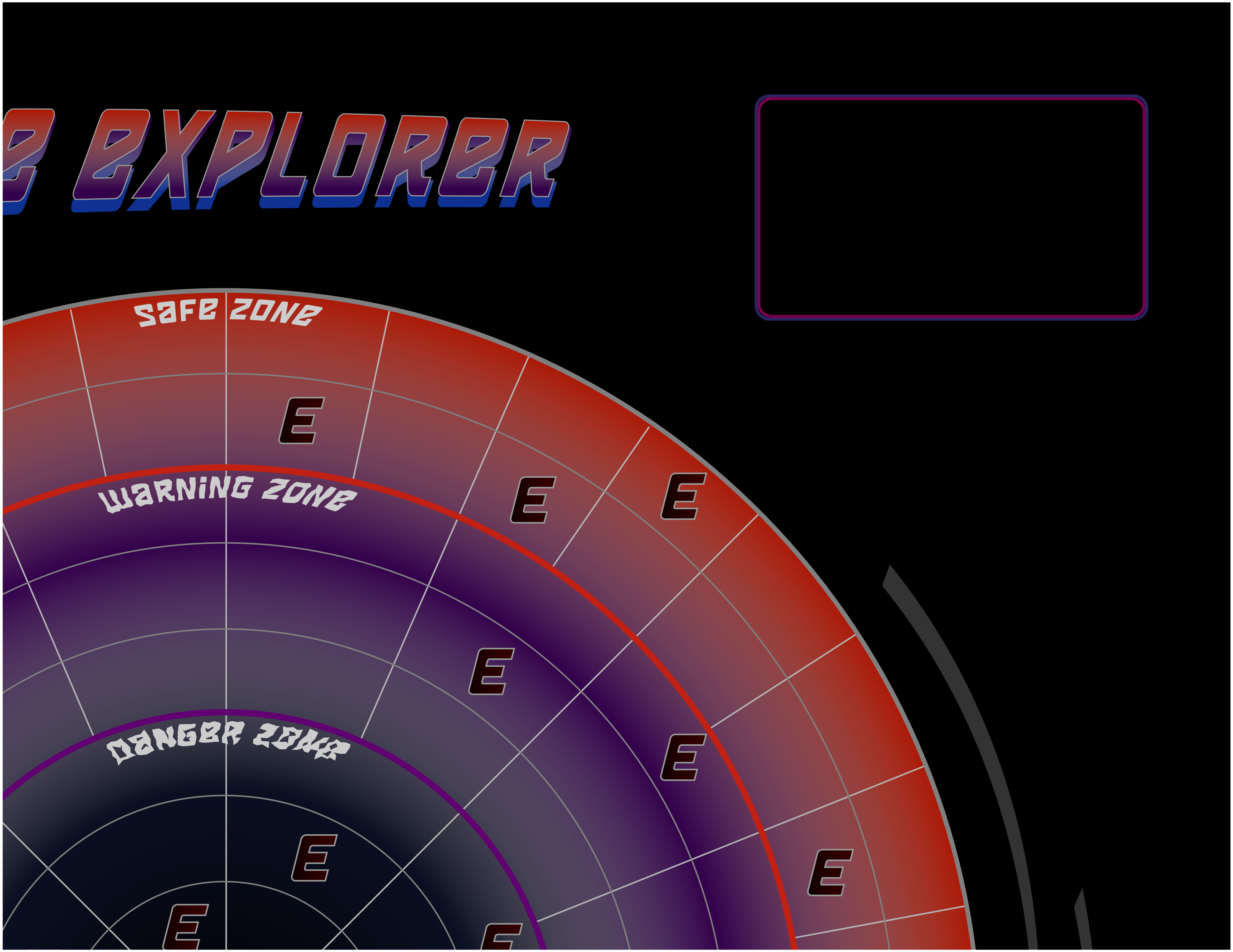
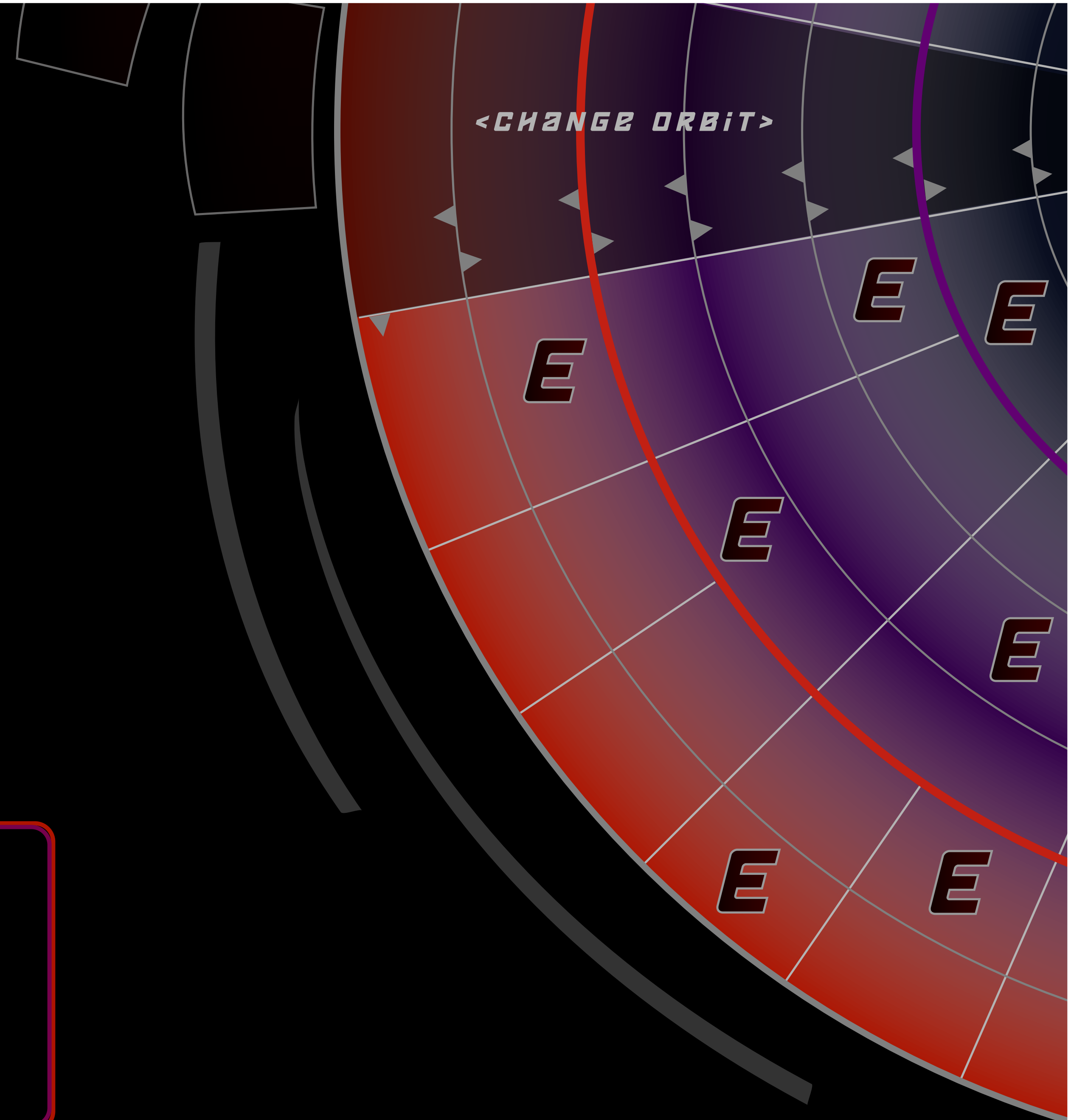

EXPLORER
safe zone
warning zone
danger zone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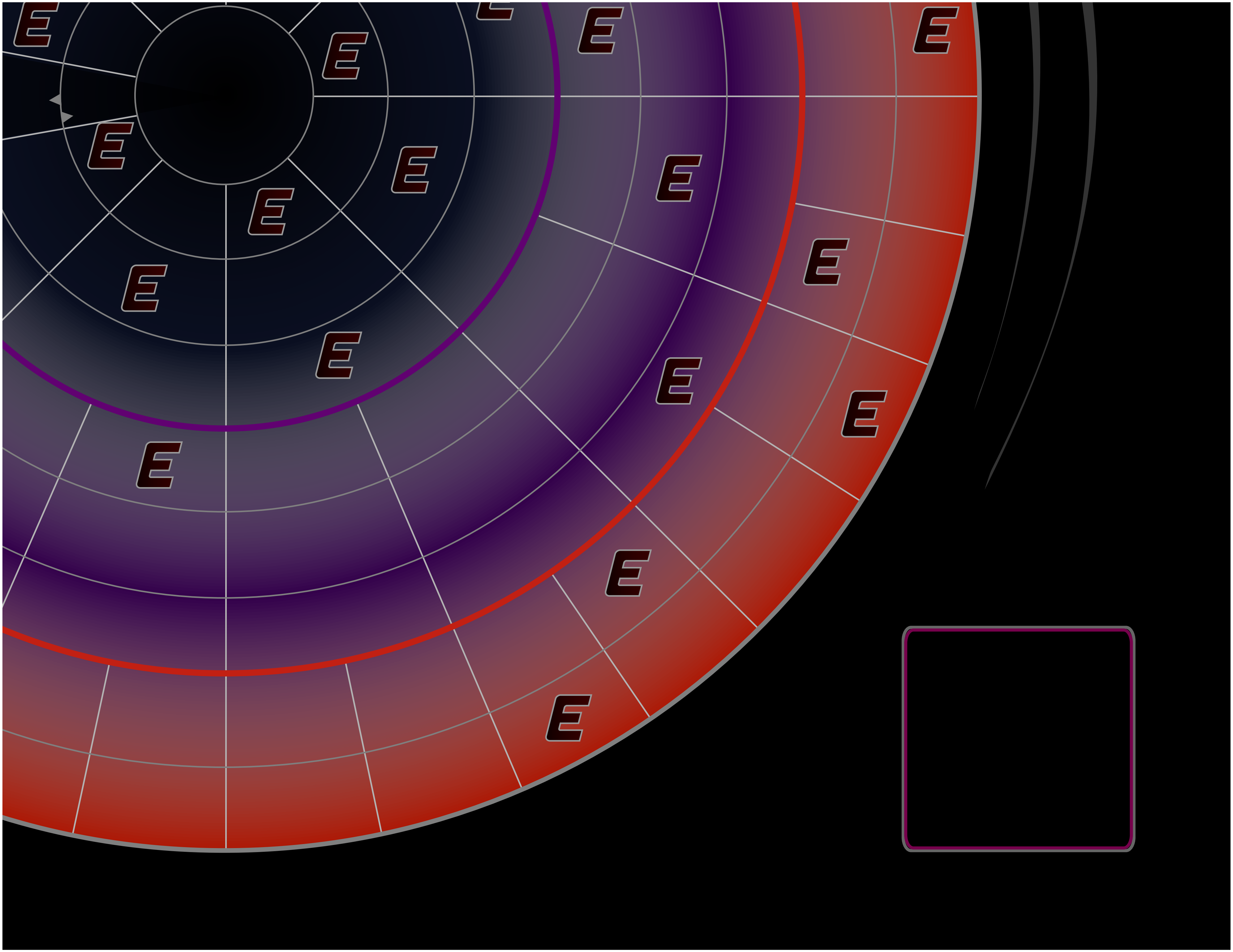

Maneuver your spacecraft to convert some of the black hole's spin energy into spacecraft power. Roll a die to see how much energy you gain. **Safe Zone** 1,2,3 for 1 energy point 4,5,6 for 2 energy points **Warning Zone** 1,2 for 1 energy point 3,4 for 2 energy points 5,6 for 3 energy points **Danger Zone** 1,2,3 for 3 energy points 4,5 for 4 energy points 6 lose control of your ship! lose 1 strength, 1 shield and drop of 1 orbit!	**<u>Repair Card</u>** **Mission Control activates your onboard repair robot**. **All Zones** Expend 1 energy point for your robot to fix any damage to your ship or to your probes. This repair also raises your shield strength by 1. (You cannot play this card if you have zero energy) **This card may be kept and played when needed, then discarded.**
A passing European Space Agency (ESA) mission offers you help. **Safe Zone** Fuel transfer gives you 2 extra energy points. **Warning Zone** The ESA mission offers you an extra probe. You may accept 1 probe over your design limit. **Danger Zone** Roll a die. 1-5, transfer 2 energy points from the ESA ship, but a roll of 6 and you collide, knocking you down one orbit!	**Your orbital path takes you through a jet of energy generated by the Black Hole.** **Safe Zone** The radiation from the jet lowers your shields by 1. **Warning Zone** The radiation from the jet lowers your shields by 2. **Danger Zone** The radiation from the jet lowers your shield strength by 2 and the blast knocks you up one orbit. If your shields are at zero, Maintain your orbit for three turns to repair shields up to a value of 1. Or, fix now with repair card.

An orbiting European Space Agency (ESA) mission assists you with its servicing robot. **All Zones** Repair one probe (if you currently have one that is damaged) and increase your shield value by 1. This card is to be played now, and cannot be retained.	**X-radiation fries your probe launch computer!** **All Zones** You cannot launch a probe until this problem is fixed! Retain this card until you collect a repair card. (If you have a repair card, you may play it to fix the computer now, or wait until you need to launch your probes in the Danger zone).
Computer error causes a probe rocket to fire! Roll a die. **All Zones** Roll 1-3 The probe rocket causes your spaceship to veer off course and dive 1 orbit. Roll 4-6 Maintain your orbit, but damage reduces shields by 1. If your shields go to zero, use a repair card or stay in this orbit for two turns to return your shields to 1. This misfire fortunately does not damage your probe! Ignore this card if you have no working probes aboard.	**Your engineers find out that one of your probes is broken.** **All Zones** Decrease number of probes by one. Your Mission is cancelled if you only had one. Head for home, but remember that there are Event opportunities to regain or repair probes. Ignore your engineers if you have already launched your probes!

Use ultra-violet radiation from the hot gas swirling around the black hole to recharge your energy cells. **Safe Zone** Gain 1 energy point **Warning Zone** Gain 2 energy points **Danger Zone** Gain 3 energy points	**Engineers have discovered problems with the design of your spaceship while running computer simulations of your mission.** **Safe & Warning Zones** Reduce shielding and strength values 1 point each (if value already at zero, stay at zero). Play a repair card to add 1 to strength and 1 to shield value. **Danger Zone** If strength and shields at zero, your whole spacecraft is destroyed unless you can play a repair card <u>NOW</u>. If either stays above zero, stay in orbit 3 turns to correct problems and return to former strength/shield levels.
Engineers discover that your spaceship's engines are working better than expected! **All Zones** Increase your energy by 2 points per engine.	**Gravitational squeezing and tugging on your spacecraft is becoming dangerous.** Throw a die and add your shield value. (Example: a roll of 4 and shield strength 1 gives you a total of 5) **Safe & Warning Zone** If total is 1,2 or 3: Climb 2 orbits immediately **Danger Zone** If total is 1-4: Climb 2 orbits immediately! <u>Remember</u>: climbing orbits expends energy! You may resume your regular descent (or ascent) next round. No energy? Hold tight, roll 5,6 to stay in current orbit, or drop one orbit per turn.

Communications Antenna destroyed by collision with orbiting debris! You may play a repair card to fix the antenna now or: **Safety Zone** **Remain** in this orbit for your next turn to repair **Warning Zone** **Remain** in this orbit for your next two turns to repair. **Danger Zone** **Remain** in this orbit for your next 3 turns to repair. You cannot launch a probe until this is problem is fixed!	**Convert the heat being given off from the accretion disc (the hot gas spiraling into the black hole) into energy for your engines.** **Safe Zone** Warm accretion disc gives you 1 energy point **Warning Zone** Hot accretion disc gives you 2 energy points **Danger Zone** Incredibly hot accretion disc gives you 3 energy points
Mission controllers change the speed of your spacecraft remotely but enter the numbers in *miles per second* instead of *meters per second* by mistake! **All Zones** Expend 2 energy points correcting Mission Control's error! No energy points? You can't change your speed without energy, so this command is ignored.	**Public interest in mission gets you the headline on CNN.** This doesn't affect your mission, but give yourselves a pat on the back!

Pass through a cloud super-hot gas! **Safe & Warning Zones** Lose 1 point of shielding. If shielding at zero remain in this orbit 2 turns working to bring shielding up to 1. You may also play a repair card. **Danger Zone** Lose 1 point of shielding. If your shielding is at zero you need to move out of the Danger Zone and make repairs. This takes 2 turns and returns your shield strength to 1. You may play a repair card to fix your shields now.	**Collision course with a Russian spacecraft!** Roll a die: **All Zones** Roll 1-4. Close, but you safely miss each other. Roll 5-6. Too close! expend 2 energy points altering course and avoiding collision. No energy? If you rolled 5-6 roll again. 1-3 and you collide, destroying both spaceships. 4-6 and you shoot past, losing nothing but a bit of paintwork!
The spinning black hole drags space itself around with it. This gives your spacecraft a free ride. **Safe Zone** Roll a die. Roll a 6 to gain 1 energy point. **Warning Zone** Roll a die. 1-3 you manage to gain 1 energy point. **Danger Zone** Roll a die. 1-5 gets you 3 energy points. **But** if you roll a 6: You lose control of your ship – causing an instant drop of 1 orbit with no energy gain!	**The hot gas in the accretion disc is becoming increasingly turbulent.** **Safe Zone** Lose 1 shield strength. If this takes you to zero shields, stay in this orbit for 2 turns, then return to shield strength of 1. **Warning Zone** Lose 2 shield strengths. If this takes you to zero shields, stay in this orbit for 2 turns, then return to shield strength of 2. **Danger Zone** Lose 2 shield strengths. If this takes you to zero shields, stay in this orbit for 2 turns, then return to shield strength of 1

<table>
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<td>
<u>Repair Card</u>

Activate your onboard repair robot.

All Zones

Expend 1 energy point for your robot to fix any damage to your ship or to your probes. This repair also raises your shield strength by 1. (You cannot play this card if you have zero energy)

This card may be kept and played when needed, then discarded.
</td>
<td>
X-radiation fries your guidance computer. Computer is back online next turn, but in the meantime, roll a die.
<u>Repair Cards cannot be used</u>

Safe Zone
Roll 1-3: fall two orbits.
Roll 4-6 stay in same orbit, but jump ahead 6 squares (if you cross the change orbit zone, don’t change orbit!)
Warning Zone
Roll 1-3: fall two orbits
Roll 4-6 climb two orbits, expending 2 energy cards.
Danger Zone
Roll 1-2: fall one orbit.
Roll 3-6: climb 3 orbits, expending 3 energy points.
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<tr>
<td>
Engineers discover that one of your probes has a programming error.

Safe and Warning Zones
Your probe will explode in its launch bay when you enter the Danger Zone unless repaired by a Repair Card. Retain this card until problem is fixed.
Danger Zone
Roll a die. 1-4 A serious probe error is fixed by engineers.
Roll 5-6: One Probe explodes in its launch bay. Lose probe, 2 shields drop 1 strength level. If strength and shields at zero, your whole spacecraft is destroyed. If either stays above zero, stay in orbit 3 turns to return to former strength/shield levels. Play a repair card to fix now. (You cannot recover your probe)
</td>
<td>
Gravity around black hole affects the flow of time. You need to re-calibrate your clocks.

Safe Zone
Stay in current orbit for one turn, even if you enter the change orbit zone.

Warning Zone
Stay in current orbit for two turns, even if you enter the change orbit zone.

Danger Zone
Stay in current orbit for three turns, even if you enter the change orbit zone. You cannot launch a probe while recalibrating.
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Repair Card	Repair Card
Mission Control activates your onboard repair robot. **All Zones** Expend 1 energy point for your robot to fix any damage to your ship or to your probes. This repair also raises your shield strength by 1 (You cannot play this card if you have zero energy) **This card may be kept and played when needed, then discarded.**	**Mission Control activates your onboard repair robot**. **All Zones** Expend 1 energy point for your robot to fix any damage to your ship or to your probes. This repair also raises your shield strength by 1 (You cannot play this card if you have zero energy) **This card may be kept and played when needed, then discarded.**

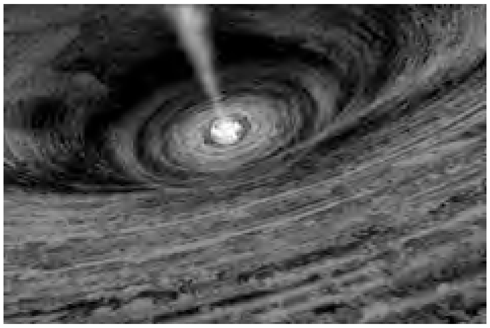
EVENT

EVENT

EVENT

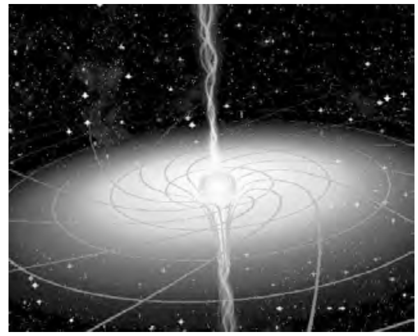
EVENT

Probe Result



The temperature of the disc of gas that spirals into a black hole can reach millions of degrees. At these temperatures, a gas isn't red hot, or white hot, but X-ray hot! One important way to discover black holes is to look for the glow of X-rays using an X-ray space telescope.

Probe Result

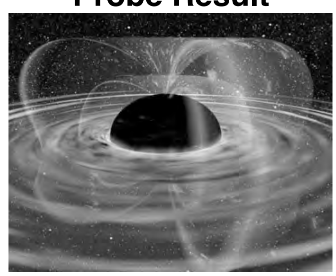


From your spaceship above the Black Hole, the clock on board the time probe appears to slow down and actually freezes at the moment the probe enters the black hole. From the probe's point of view however, its clock ticks by normally, but looking back up it sees your spaceship clock whizzing round faster and faster!

Probe Result

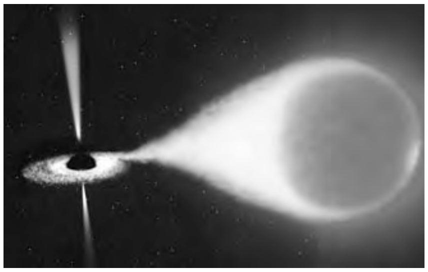
Because a black hole warps space, it will also warp anything in that space. As the probe moves towards the black hole, the stretching and squeezing gets worse and worse. In the end, the probe is stretched and squeezed to destruction.

Probe Result



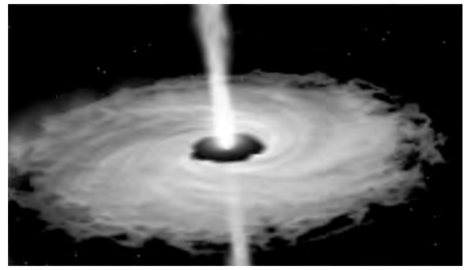
Despite having the mass of nearly ten Suns, this black hole is no larger than an average city, about 10 km side to side. Black holes are very compact objects, concentrating a lot of mass into a very small volume. The disc of gas that has given your ship such a rough ride is about 100 times bigger – a pancake about as wide as the United States.

Probe Result



We can't see the black hole itself but we can see the effect that a black hole has on its surroundings. Our black hole is in an orbital dance with a companion star. Simply by watching the companion star, we could tell that something was tugging it around. The motions of stars we can see gives us clues to the whereabouts of things – such as black holes – that are invisible to us.

Probe Result



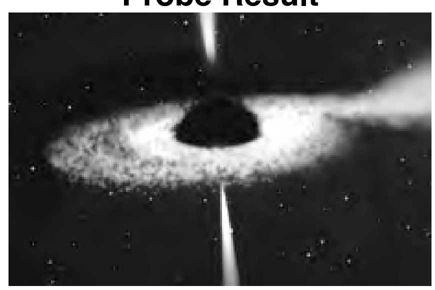
Sometimes the gas near the black hole is whipped up into such a tornado that before it has a chance to fall into the black hole, it is shot back out into space in two jets like the beams of a lighthouse.

Although the jets look as though they are emerging from the black hole, they actually start just above the surface.

Probe Result

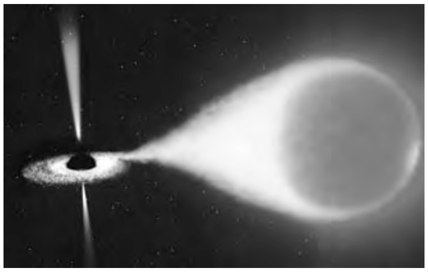
This black hole began its life as an ordinary, but very large star. When the star had used up all its nuclear fuel, its core collapsed to form this black hole. The outer part of the star was blown out into space in a huge explosion called a supernova.

Probe Result



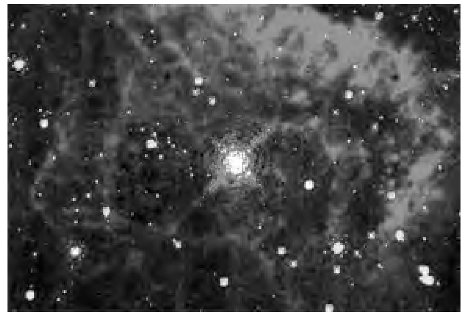
The black hole doesn't have a surface – you can't land on it. The black ball you see is simply a boundary – like an open doorway into a pitch black room. Your probe does not notice anything strange as it passes through the boundary, except that it cannot ever turn around and come back out.

Probe Result



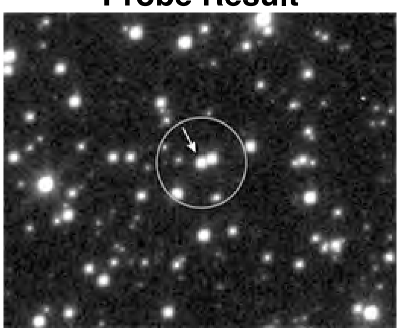
Once inside the black hole the probe is lost to us. Even if it survives the intense gravity as it enters the hole it will never be able to communicate with us on the outside. Ultimately, as the probe reaches the very center of the black hole, not even the atoms that the probe is made of will be able to resist the stretching and squeezing of the gravity.

Probe Result



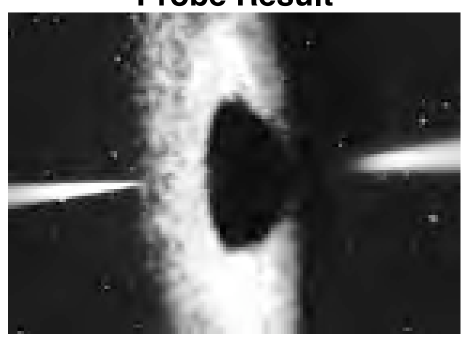
Black holes are formed when the biggest and brightest stars die. The Sun, although a very impressive star, is not big enough to form a black hole when it dies. This black hole, with a mass of about ten Suns, began its life as a huge star with a mass of a hundred Suns.

Probe Result



This black hole is one of about a million in our Milky Way galaxy. This sounds dangerous, but the Milky Way is a big place. It took our ultra-fast spaceship a very long time to reach even this nearby black hole and, as we are finding out, we needed to get pretty close before things got really risky!

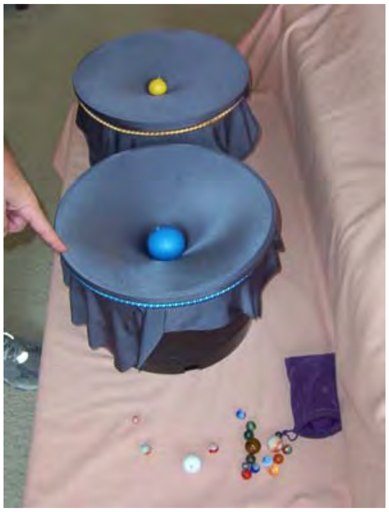
Probe Result



We can watch the probe reach the black hole but will never see it enter. Because of the effect gravity has on time, the probe will appear to move slower and slower and then freeze at the moment it touches the black hole. Its frozen image will just keep getting fainter and redder for the rest of time.

Probe Result Probe Result

Probe Result Probe Result



Gravity and the Fabric of Space

What's this activity about?

Big Question: How does gravity work? Why can't we escape from a Black Hole?

Big Activity: **Presentation:** Using a bucket with stretchy fabric stretched over it, allow visitors to experiment with marbles and weights to discover some basics about gravity.

Participants: Adults, teens, families with children 7 years and up
If a school/youth group, 4th grade and higher
From one person to fifteen participants

Duration: **Setup: 5 – 10 minutes**
Presentation: 3 minutes to 45 minutes, depending on how much you want to cover**.**

Topics Covered:
This set of activities explains the basics of Einstein's general theory of relativity especially regarding curved space – without using the jargon associated with it. There is no attempt to go into the details of relativity. The objective is to cover how mass affects the space around it – producing gravitational force. And how black holes fit into the picture – including what scientists are trying to discover about them.

There are several parts to this presentation, introducing different ideas. You might want to present just one or two, or all of them, starting with the Introduction:

Introduction: Mass curves space
Part 1: Falling Down / Falling In
Part 2: Why doesn't the Moon Fall to Earth?
Part 3: Why is a Martian year almost twice as long as an Earth year?
Part 4: Are you a Rocket Scientist?
Part 5: The Sun as a black hole
Part 6: Why we can't escape from the region of a black hole
Wrap-up: Use this when you are finished with your presentation.

Each of the detailed activity descriptions allows you to illustrate some aspect of the force of gravity using curved space:

- Effects on falling objects and why you fall back to Earth when you jump
- Effects on orbits – you can make somewhat circular orbits (like planets around the Sun), more elliptical orbits (like comets and some asteroids), and orbits that collide with a star (or planet), as happens to some comets.
- Why stars with planets wobble and how we know the distance of the planet from its star
- The difficulties of launching a satellite into orbit or to another planet
- If the Sun was to become a black hole, why Earth would not be pulled into it
- What a black hole does to space and why we cannot escape from inside the event horizon of a black hole

Realize this is just a model and is not to scale. Also, the model is essentially two-dimensional and does not show that space <u>all around</u> a massive object is curved, not just a thin layer of space underneath the object!

Where can I use this activity?

1) **Pre-Star Party:** As an introduction to the night's observing.

2) **Scout troop or classroom:** Form teams of 8 to 10 people and provide each team with a set of materials.

3) **Science Fair or Science Museum:** Set up one or more tables with the demonstration materials. Have a club member at each table.

Helpful Hints

1) The concept of "mass" may be difficult for your audience. Ask what they think it means. You might want to define "mass" as the amount of material that is in an object – the property that gives an object "weight" in a gravitational field.

2) When you or your visitors roll the marbles across the fabric of space, roll them so they do not bounce.

3) **If you are working with children,** a few pointers:
   - Give just one child the marble(s) and have the kids pass them around.
   - You might want to make it into a game:
     - If the marble falls off the edge of the bucket, the child's turn is over and they must pass the marbles to the next child.
     - After one child takes three marble rolls, their turn is over.
     - The winner is the child who can get the marble to orbit the longest time.
   - Try to make sure they have clean hands, if possible – dirty, sticky, or greasy hands will transfer to the marbles and the marbles will not roll as well
   - Keep a small container of water and paper towels nearby to rinse and dry the marbles as necessary

4) Let your visitors experiment with the weights and marbles – they will discover a lot with your guidance!

5) Some people may ask why the fabric of space is not black or why the weights or marbles are not always the right colors for what they represent. You can say that this is one of the limits of making models of the universe – we have to imagine some things. If the fabric was black, it would be harder to see the curvature of the fabric of space.

Background Information

A good basic discussion of Newtonian gravity as it relates to these demonstrations can be found at: http://csep10.phys.utk.edu/astr161/lect/history/newtongrav.html

Einstein's general relativity states that space (actually space-time) is curved by the presence of massive objects and the path that mass, as well as light, takes through space is determined by this curvature. For more explanation and observational evidence for general relativity:
http://www.nasa.gov/worldbook/gravitation_worldbook.html
http://curious.astro.cornell.edu/question.php?number=649
And this article, "Gravity as Curved Space" http://theory.uwinnipeg.ca/mod_tech/node60.html

More information about Black Holes from NASA:
http://cfa-www.harvard.edu/seuforum/blackholelanding.htm

FAQ's: What are some common questions visitors have about black holes? Review the Black Hole FAQ's page which can be found in the "Where are the Black Holes?" activity and the Q&A section at the end of the script for the PowerPoint (SurviveBHscript.doc). These list common questions and perceptions people have about black holes and how you might answer them.

GRAVITY ASSISTS: Your visitors might ask about how NASA uses gravity assists to add speed to a spacecraft. The Space Place provides a helpful description and activity to illustrate the process: http://spaceplace.nasa.gov/en/educators/gravityassist.pdf.
For more details about how gravity assists work:
http://saturn1.jpl.nasa.gov/mission/gravity-assist-primer2.cfm
For a more technical description: http://www2.jpl.nasa.gov/basics/bsf4-1.htm

CURVED SPACE vs. GRAVITATIONAL FORCE:
How much space curves around *one* object depends on its mass, and the curvature of space decreases with distance from the center of its mass. This curving of space determines how another object will move around this object.

How objects move through space around *each other* is actually dependent on the mass of *both* objects involved and the distance between them. For example, a pair of stars orbiting each other will orbit their common center of mass – the "balance point" between them. Space curves around *both* objects, so they tug on each other – this mutual tug is commonly referred to as "gravitational force".

This is a subtle difference and is only obvious in these demonstrations under the activity "Wobbling stars and binaries", where you have two objects not extremely different in mass. Objects "extremely" different in mass would be like the difference in mass between a person and the Earth or between the Earth and the Sun.

EVENT HORIZON DEFINITION: The region of space around a black hole from which nothing can escape, not even light. No information about events occurring inside the event horizon is available to the rest of the universe.

Detailed Activity Description

SETUP:
The buckets MUST be on a level surface. Make sure the smoothest side of the fabric is facing up. The fabric on both buckets needs to be evenly stretched and stretched to approximately the same tension on both. It is helpful to set up on or over a “non-roll” surface, like grass, carpet, a blanket, or large towel, to avoid having to chase marbles all during the presentation.

INTRODUCTION: Mass curves Space – Reason for gravitational acceleration

<table>
<tr><th colspan="2">Introduction</th></tr>
<tr><td colspan="2">How does gravity work?
In the 1600’s Isaac Newton developed the universal law of gravitation describing it as a force of attraction between objects that decreases with distance, and Albert Einstein in the early part of the last century developed the concept that matter curves space around it and this is why there is the force of gravity (as well as correctly predicting the existence of things like black holes and gravitational lensing of light).   This concept has been verified by abundant observational evidence (see “Background Information” above).</td></tr>
<tr><td colspan="2">This set of activities illustrates various effects of gravity, or curved space. How much space curves, depends on two things:
1) How much mass is present. More mass, more curvature, therefore stronger gravitational attraction.
2) What the distance is from the center of the mass. Farther from the center of a massive object, space is less curved, therefore the gravitational attraction is less.</td></tr>
<tr><td>Take the two buckets covered with fabric and two different sized weights. Place one weight in the center of the fabric on each bucket.
Notice that the more massive weight curves the fabric, representing space, more than the less massive weight.
Notice also that space is curved the most nearest the weight and less curved toward the edge of the bucket.</td><td></td></tr>
</table>

Part 1: Falling Down / Falling In

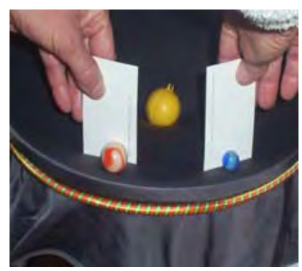
<table>
<tr><th>Leader's Role</th><th>Participants' Roles (Anticipated)</th></tr>
<tr><td colspan="2">Key message for your visitors to take home:
Mass curves space; More massive objects curve space more so the force of gravity is stronger in the presence of more massive objects. Why things fall to Earth.</td></tr>
<tr><td colspan="2">Materials: 2 buckets covered with fabric; bag of marbles;
White (small) weight; Blue (large) weight</td></tr>
<tr><td><u>To Say</u>:
Jump! Jump again! Why do you fall back to Earth every time?

What's Gravity?
What kind of a force is gravity?

Can you throw a ball so that it doesn't come back down to Earth?

Albert Einstein in the early part of the last century developed the concept that matter curves space around it and this is why there is the force of gravity. Let's see what that means.</td><td>

Gravity!
What pulls us back to Earth.
No</td></tr>
<tr><td><u>To Do:</u>
Set out the two buckets with fabric stretched over them.
<u>To Say</u> :
(Point to one of the buckets.) This is space, the "fabric" of space. There is space all around us everywhere, in all directions. This just represents one small portion of space. Einstein said that massive objects curve space around themselves.
<u>To Do:</u>
Place the small white 4oz weight in the center of one bucket – or ask a visitor to place it.
<u>To Say</u> :
Let's use this weight to represent Earth. What happens to space when we put Earth in it?</td><td>It curves/dips</td></tr>
</table>

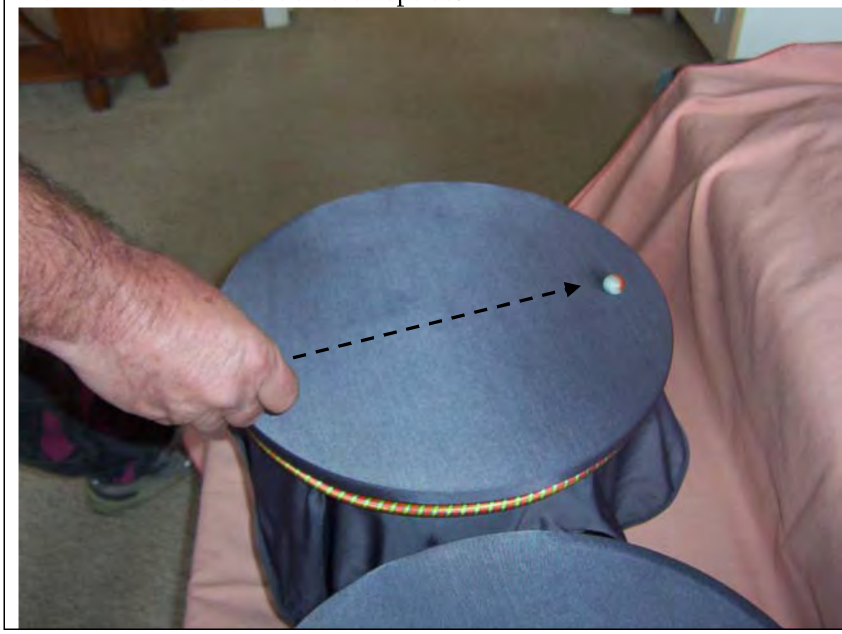
Leader's Role	Participants' Roles (Anticipated)
To Do: Place 2.5 lb (large blue) weight on fabric on the other bucket – or ask a visitor to place it.  *To Ask:* Now, let's say this is the Sun and put it here in space. How much is space curved around *this*? Right the Sun has more mass than Earth: What is "mass"? So the Sun is more massive than Earth? *To Do:* Hand out a few marbles – two marbles per person.	 A lot more! How much material is in something; how much it weighs Yes.
Presentation Tip: When you or your visitors roll the marbles across the fabric of space, roll them so they do not bounce. **If working with children**, give one child two marbles and then have them pass the marbles around. **NOTE:** If fingers are dirty, greasy, wet, or sticky, both marbles might not be released at the same time. You would do better to use a card (like a business card) to hold the marbles back. 	
To Say : This is a model and is not to scale. These marbles represent small space probes. If we place one probe at the edge of this bucket and the other probe at the edge of the other bucket, and let them both go at once, which probe is going to fall faster toward the center? Why? Let's try.	The one going into the Sun. More mass – space is curved more. Roll marbles into Earth and Sun.
To Say : So this is what we mean when we say the force of gravity depends on how much mass is present. Mass curves space. More massive objects curve space more or less? So the force of gravity is stronger or weaker?	More Stronger

<table>
<tr><th>Leader’s Role</th><th>Participants’ Roles (Anticipated)</th></tr>
<tr><td><u>To Say</u> :
We said space is curved around Earth. If you jump off Earth and end up here (take a small marble and hold it just slightly away from the surface of the small white weight), are you going to stay here if I let go?

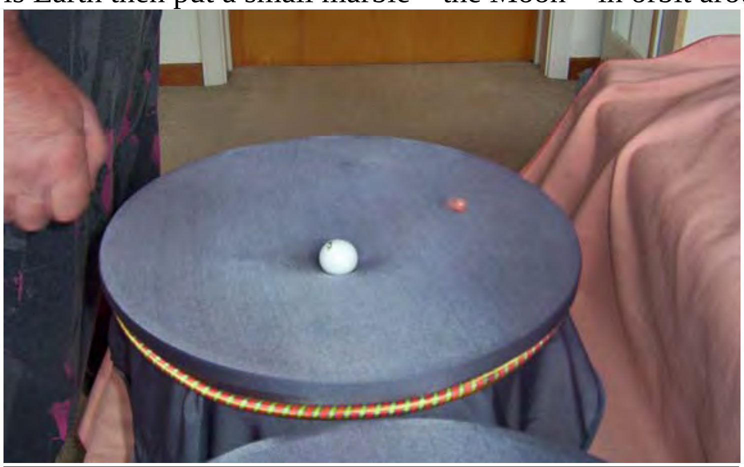
So why do you fall to Earth when you jump?</td><td>No. You’ll fall in.
Space is curved around Earth.</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2"><u>Extending the activity: Everything falls to Earth at the same rate</u>
Key Message for your visitors to take home: All objects, regardless of their mass, will fall at the same rate into the same massive object.</td></tr>
<tr><td colspan="2">Materials: 2 buckets covered with fabric; one large and one small marble;
Small white weight or medium yellow weight.</td></tr>
<tr><td><u>To Do:</u>
Place the 4 oz small white (or the 8 oz yellow) weight on fabric of one bucket – or ask a visitor to place it.
Take a small marble and a large marble.
<u>To Say:</u>
Standing here, if I drop a large marble and a small marble, which one is going to fall faster toward the Earth?</td><td>Guesses.</td></tr>
<tr><td><u>To Say:</u>
Now, let’s say this is the Earth (indicating the weight). We’re going to drop these two marbles from the edge of the bucket at the same time. What’s different about these marbles?</td><td>Different sizes.</td></tr>
</table>

To Say : If we place both of these at the edge of this bucket and let them both go at once, which marble is going to fall faster toward the center? Why? Let's try. Did they both fall to Earth at the same speed? 	Guesses/neither. Space is curved the same for both. Roll marbles. Yes.
To Say : Space is curved around Earth the same for both marbles, so they both accelerate equally, in other words, they fall at the same rate. If I drop this large weight and this marble to the floor, which will fall faster? **Presentation Tip:** **If you actually drop the weights,** make sure you are dropping them on a soft surface, like a thick towel or blanket, to prevent damage to the surface or to the weights, and to prevent the marble from rolling away or the weight from rolling onto someone's foot. If something falls slower than something else, it will be due to the presence of air, rather than the fact that the object is lighter in weight (e.g. a brick and a feather). There would be no such difference on the Moon since there is no atmosphere.	Neither. They'll fall together.

Part 2: Why Doesn't the Moon Fall to Earth?

<table>
<tr><th>Leader's Role</th><th>Participants' Roles</th></tr>
<tr><td colspan="2">Key message for your visitors to take home: Mass curves space causing the path of objects moving through space to be curved – so Earth orbits Sun because space is curved by the Sun. Moon orbits Earth because space is curved by Earth.</td></tr>
<tr><td colspan="2">Materials: 2 buckets covered with fabric; bag of marbles; White (small) and Yellow (medium) weight (or you can use the yellow weight and large blue weight).</td></tr>
<tr><td><u>To Say</u>:
Now we just made those marbles fall into the Earth.
The Moon is like a giant marble – actually a ball of rock – out in space – why doesn't it fall to Earth?
Yes, it is orbiting!
But why is it orbiting?
Einstein's concept that matter curves space around it also determines how objects move around massive objects, like the Moon around Earth or Earth around the Sun. Let's see what that means.</td><td>It's orbiting?</td></tr>
<tr><td><u>To Do:</u>
Set out both buckets with no weights on them. Point to one of the buckets. Hand out a few marbles
<u>Presentation Tip:</u> When you or your visitors roll the marbles across the fabric of space, roll them so they do not bounce.
If working with children, give one child a marble and then have them pass the marble around.</td><td>Take marbles</td></tr>
<tr><td><u>To Say</u> :
This is space, the "fabric" of space. There is space all around us everywhere, in all directions. This just represents one small portion of space. This is a model and is not to scale.
Here is a planet moving through space.
<u>To Do:</u>
Roll marble across fabric of space.
</td><td></td></tr>
</table>

To Say :	
Does it move straight across? Here, you try. Each person take a turn moving a planet through space. Don't let it bounce!	Participants roll their marbles.
To Do: Place 8 oz (medium yellow) weight on fabric.	
To Ask: Now, let's take a star, like the Sun. Is a star more massive than a planet?	Yes.
Let's put in here in space. What happens to the fabric of space?	It curves
Now, let's move the planet through this area of space again. What happens to it now?	Path is curved
Did it go straight across?	No!
Here – try pushing the planet across space – can you make it go into orbit around the star? Can you make it escape away from the star? How fast do we need to push the planet to make it escape? Slower or faster than to make it go into orbit?	Participants roll their marbles and respond.
	

Leader's Role	**Participants' Roles (Anticipated)**
To Say: So Earth orbits the Sun because the Sun curves space around it. So why doesn't the Moon fall to Earth? Why does the Moon orbit Earth? (You can put the small white weight on the other bucket and say it is Earth then put a small marble – the Moon – in orbit around it). 	 It's orbiting. Earth curves space too

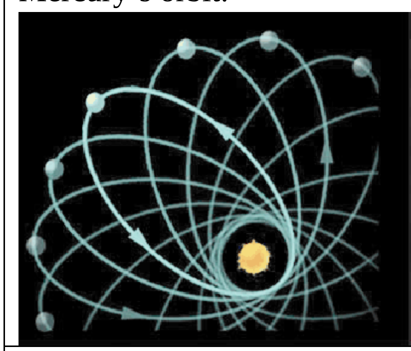
Leader's Role	Participants' Roles (Anticipated)

Presentation Tip:

Someone may ask "Why does the orbit get smaller and smaller?" You need to explain that the friction of the marble rubbing against our fabric of space slows it down. Is there really fabric out in space? No. Space is fairly empty, this is just an illustration of how space curves in the presence of mass and how that influences the movement of objects through space.

We can't see space, just its response to the presence of massive objects. The curved space is revealed by the matter moving through it around the massive object – like around a star or a black hole.

As you and your visitors roll marbles into orbit, you will get all kinds of orbits, more or less circular to highly elliptical, some may immediately crash into the star or planet. You might want to mention or ask your visitors which bodies in our Solar System have these different kinds of orbits – circular orbits (like planets around the Sun), more elliptical orbits (like comets and some asteroids), and orbits that collide with a star (or planet), as happens to some comets. You might even observe some orbits that precess, like Mercury's orbit:



Artist's version of the precession of Mercury's orbit (exaggerated, not to scale).
From:
http://phyun5.ucr.edu/~wudka/Physics7/Notes_www/node98.html

Presentation Tip:

MISCONCEPTION WARNING: Many children and adults hold the misconception that there is no gravity in space. You can escape from orbiting the star, but you will never escape from the star's gravitational field. Gravity extends forever, getting weaker with distance. If you're going fast enough, you can overcome an object's gravitational pull – you can keep going and not get pulled back.

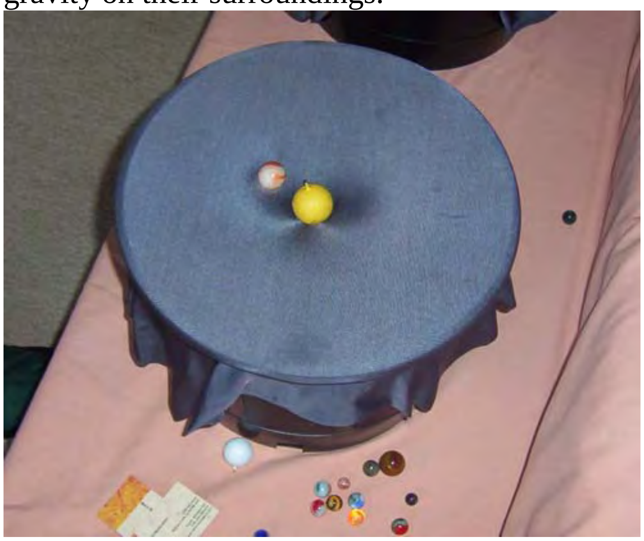
Part 3: Why is a Martian year almost twice as long as an Earth year?

Leader's Role	Participants' Roles
Key message for your visitors to take home: The more distant you are from the center of mass, the less space is curved, so the speed you go will be slower than when you are closer.	
Materials: 1 bucket covered with fabric; a few medium marbles; Blue (large) weight	
To do: Place the 2.5 pound large blue weight in the center of the bucket. Use medium marbles as planets. *To Say:* Here's a star in space. Let's put some planets in orbit. The closer the planet is to the star, - the smaller its orbit is – what happens to the speed of the orbit? Right – it goes faster.	Roll marbles. Speeds up.
To Say: How fast objects move through space due to gravity – how much space is curved at any point – depends on 2 things: how much mass the central object has and your distance from the center of the massive object. (Point to the center of the large weight and point to the marble, indicating the distance of the marble from the large weight.) 	
To Say: Close to the star, space is curved more and out here (pointing to the edge of the bucket), space is curved less.	

<table>
<tr><th>Leader's Role</th><th>Participants' Roles</th></tr>
<tr><td colspan="2">Presentation Tip:
How objects move through space around each other is actually dependent on the mass of both objects involved and the distance between the (centers of the) objects. For example, a pair of stars will orbit each other around a common center of mass – the "balance point" between them. Space curves around both objects, so they actually tug on each other. But when you have objects near each other that are very different in mass, like a person on the Earth or the Earth orbiting the Sun, the common center of mass will be very close to the center of the more massive object.
Depending on your audience, you may want to say this and possibly go into what we mean by "center of mass". (See "Extended Activity: Wobbling Stars and Binaries" at the end of this activity).
The "center of mass" between the large weight and the marble is inside of the large weight – very close to the center of the weight.
However, this could end up being more of a complication and confusion than clarification at this point.</td></tr>
<tr><td><u>To Say:</u>
If you are far away, out here near the edge of this region of space, and you are in orbit, is your orbit faster or slower than when you are closer?
Right! The curvature of space is less, so if you are in orbit, you will be going pretty slow. If you suddenly were able to accelerate and started going a lot faster, what would happen?
So how much space is curved at any point depends on what two things?</td><td>Slower.

You would escape from orbit
Mass and distance from center</td></tr>
<tr><td><u>To Do:</u>
Take two medium-sized marbles to represent Earth and Mars – make sure they are different colors.
<u>To Say:</u>
Let's make the star in the center the Sun. This marble will represent Mars and this marble Earth. (Hold the marbles on the fabric at different distances from the Sun).
Which planet is farther away from the Sun?
Which one is going to travel faster through space?
Why? Where is space more curved?</td><td>Mars
Earth
Where the Earth is</td></tr>
<tr><td>Presentation Tip:
The center of mass is inside the Sun since compared to the Sun, the mass of Mars or even Earth is almost negligible.</td><td></td></tr>
</table>

Leader's Role	Participants' Roles
To Say: Let's try it. (**TIP:** Place Earth in orbit first, then immediately launch Mars – the planets are less likely to crash into each other) Earth is closer to the Sun (the massive object) and Mars is farther away. How long does it take Earth to orbit the Sun once? How long is our year? On our model, if we put Earth 2 inches away from the Sun, Mars would only be 3 inches away. But Mars has a year almost twice as long as Earth's – why do you suppose that is? Yes, it is farther away – it has a little longer distance to go than Earth. In our model, Earth has to travel about 13" to orbit the Sun and Mars only 19", but it is also traveling slower. Why?	Participants orbit planets 365 days. It's farther away? Space is curved less.
Presentation Tip / Helpful Hint: Some people think the only reason the planets farther from the Sun have longer years than Earth is because they are farther away, so they have a longer distance to go in their (somewhat) circular orbit. Mars travels about 870 million miles to make one orbit of the Sun. Earth travels about 580 million miles. So Mars only travels about one and a half times the distance Earth travels, but takes almost twice as long! Earth is traveling at about 30 km/sec (18 mi/sec) as it goes around the sun. Mars only travels about 24 km/sec (15 mi/s) – slower than Earth. Jupiter travels about 5 times farther than Earth (about 3 billion miles), but takes almost 12 years to do it. Jupiter only travels about 13 km/sec (8 mi/s) – about 1/2 as fast as Earth.	

__Extending the activity:__ **Wobbling stars and binaries**	
Key Message for your visitors: All massive objects curve space – if the objects are closer to being the same mass, they will influence each other's movement in space more.	
Materials: One bucket with fabric; large marble; medium (yellow) weight	
Presentation Tip: This is where the concept "center of mass" between two objects comes in. The "center of mass" could be described as the balance point between two objects – if 2 objects could be attached to either end of a stick.	
<u>*To Say:*</u> Notice that if we have a large planet orbiting a small star, the star moves too. ALL massive objects cause space to curve – asteroids, planets, stars, black holes – ALL massive objects exert the force of gravity on their surroundings.  This is one way NASA scientists detect planets around other stars – detecting the wobble of the star. Binary stars – where two stars are orbiting each other – orbit around a common center of mass.	Roll large marble around weight – watch weight wobble.

Leader's Role	Participants' Roles
Extending the activity: **How far is the planet from its parent star?**	
Key message for your visitors to take home: How fast the planet is orbiting is a clue to its distance from the star. A planet will orbit a more massive star faster, at the same distance, than it will orbit a less massive star.	
Materials: 2 buckets covered with fabric; large marbles; Yellow (medium) and Blue (large) weight	
To do: Place medium yellow weight on the fabric of one bucket. Place the 2.5 pound large blue weight in the center of the second bucket. Use a large marble as a planet. *To Say:* Now when scientists find a wobbling star, they know it might have planets. But how do they know how far away those planets are from the star? We just found out that the farther a planet is from the star, the slower it travels through space, so the star will wobble slower due to that planet's orbit.	
Let's say we have two stars, one more massive than the other. If we put these planets (large marbles) in orbit around these stars at the same distance, which planet will orbit faster?	The one around the big star.
Let's try.	Roll marbles.
If we move the planets closer and put them into orbit, will they orbit faster or slower?	Faster!
Let's try.	Roll marbles.
So, if we know the mass of the star, and we know how fast the planet is orbiting (or how fast the star is wobbling), scientists have some clues about how far the planet is from the star.	

<table>
<tr><th>Leader’s Role</th><th>Participants’ Roles</th></tr>
<tr><td colspan="2"><u>Extending the activity:</u> What is the mass of the black hole?</td></tr>
<tr><td colspan="2">Key message for your visitors to take home: How fast a star or stars is orbiting an unseen object, like a black hole, is a clue to how massive the central object is.</td></tr>
<tr><td colspan="2">Materials: 2 buckets; large marbles;
Yellow (medium) and assembled black hole (or use the large Blue weight).</td></tr>
<tr><td><u>To do:</u>
Place medium yellow weight on the fabric of one bucket.
For the other bucket, use the assembled black hole. Use large marbles for stars.
<u>To Say:</u>
If scientists discover a star orbiting an unseen object, they know it must be orbiting something. If the central object is really massive, they have a clue that it might be a black hole. How do they know how massive the central object is?

Here we have a regular star (indicate the yellow weight).
And here we have a black hole (indicate assembled black hole).

Let’s say this marble is a star. If we put it into orbit around each of these objects, which one is the star going to orbit faster?

Let’s try.

So, if we detect how fast the star is orbiting the object, scientists have a clue about the mass of the central object. This is one way NASA scientists detect black holes - by a star or stars rapidly orbiting an unseen object.</td><td>

The black hole.

Roll marbles.</td></tr>
</table>

Part 4: Are you a Rocket Scientist?

Leader's Role	Participants' Roles
Key message for your visitors to take home: Harder to reach orbit from a larger mass – higher initial speed is needed.	
Materials: Two buckets with fabric; 2 pee-wee marbles; Small (white) & medium (yellow) weight; Straws	
To Do: Place the 4 oz (small white) weight in the center of one bucket. Place the 8 oz (medium yellow) weight in the center of the second bucket. Place a pee-wee marble next to each weight. Give each participant a clean straw.	Participant takes the straw
To Say: Can you jump up and launch yourself off the surface of Earth? Why not? Albert Einstein in the early part of the last century developed the concept that matter curves space around it and this is what causes gravity. The larger the amount of matter (or the larger the mass of the object) the more it curves space and the stronger gravity is. Let's see what that means.	No. Guesses: We weigh too much; we can't go fast enough
Presentation Tip: The mass of Earth is 6*10^24 kg or 6 billion trillion tons. The Moon is about 100 times less massive than Earth. So the weights are NOT to scale.	
To Say: Here is the Earth (medium yellow weight) and here is the Moon (small white weight). This is the fabric of space. Which one is curving space more? These little marbles represent spaceships that we need to launch from the surface.	The Earth
Presentation Tip: When your visitors blow through the straw, if they continue too long, you might experience a couple of things: • they can get light-headed • a little moisture may come out of the end of the straw. Please warn your visitors to stop if they feel light-headed. Or limit each person to three tries at a time. The fabric is washable in cold water – hang to dry.	

Leader's Role	**Participants' Roles**
To Say: You will blow through the straw to represent the rocket fuel and acceleration you need to propel the spaceship off the surface. You want your spaceship to either go into orbit or to leave the Earth or Moon to travel to another planet.  Which one is going to be harder to escape from? Which one is curving space more?	Earth!
To Say: Line up at the Earth or Moon. Who is a rocket scientist? Who can launch the rocket? Then get in line for the other object. Which one is harder to launch from? Where can you jump higher? Earth or Moon?	Participants form 2 lines – one at each bucket, blow thru straw to launch rocket. Moon!
To Say: If we put the spaceship in orbit (push the pee-wee marble into orbit), and then fire the rockets, (blow on the spaceship) is it easier or harder to get it away from the planet? Yes. Gravity, or the amount space is curved, is based on two things: How much mass and how far you are from the center of mass. Way out here, space is not curved as much as it is near the much more massive object. So it is easier to escape from the planet and keep on going. Besides that, some of you discovered how to be a better rocket scientist and found that if you fire your rockets in the right direction and at the right time, you are taking advantage of the speed and direction of your orbit. So you're on your way to becoming a rocket scientist. Maybe someday you will join NASA in launching probes into space!	Easier! Yeah!
To Do: Bring out the assembled black hole or place the large blue weight on one of the buckets. *To Say*: Who wants to try to launch a rocket out of a black hole? NASA doesn't actually send probes to black holes, scientists study them from here with giant telescopes in space. NASA wants to learn what happens near black holes and what role they may have played in the formation of early galaxies in the universe. (If kids are there: Maybe you can help when you grow up!)	Oh no! Wow

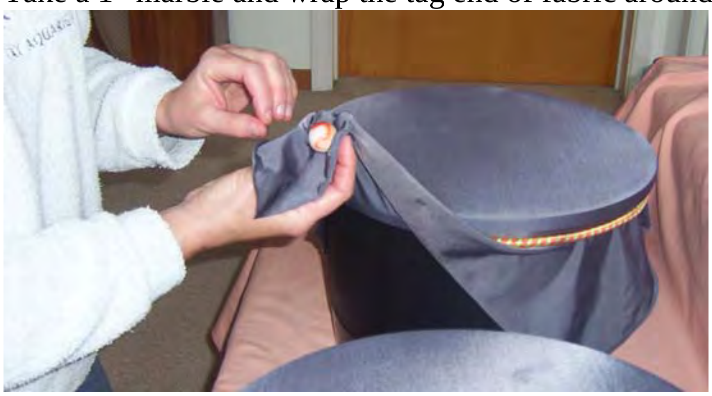
Presentation Tip: MISCONCEPTION WARNING:
"ESCAPE speed" : This term sometimes causes people to think you can truly escape from Earth's gravitational field (or, for example, from the Sun's gravitation field) – that if you get away from the surface of Earth there will no longer be any gravitational pull.
You can escape from orbiting the Sun, Earth, or Moon, but you will never escape from the object's gravitational field. Gravity extends forever, getting weaker with distance. If you're going fast enough, you can overcome an object's gravitational pull – you can keep going and not get pulled back.

Part 5: The Sun as a black hole

Leader's Role	Participants
Key message for your visitors to take home: Many people believe if the Sun became a black hole, all the planets would be pulled into it. This activity helps explain why not. At some distance from the center of mass, the same amount of mass will curve space the same amount, regardless of its size.	
Materials: Regulation softball which YOU MUST SUPPLY; Yellow (medium) weight – same approximate mass, different size. Large marbles.	
<u>To Say:</u> What would happen to Earth & the planets if the Sun became a black hole? Will be Sun become a black hole? No. The Sun will not die for billions of years and when it does, it will become a white dwarf. A small compact star about the size of Earth.	 Guesses
<u>To Do:</u> Show the softball and the weight (a softball weighs almost 7 oz)	
<u>To Say:</u> Both of these are about 8 ounces. Do they have about the same amount of mass? What is different?	Yes. Size!
(Show softball) This represents the Sun (Show medium weight) This represents the Sun collapsed under the influence of gravity – representing a black hole – the Sun won't become a black hole, we're are just imagining it as a black hole.	
Which of these is going to curve space more? Where is the center of the Sun (softball)?	Guesses. In the middle.
<u>To Do</u>: Put softball behind your back and hold out yellow medium weight	
<u>To Say:</u> Where would the center of the Sun be if we crushed all its mass down to become a black hole?	Same place.
Their centers are both going to be in the same place.	
<u>To Do:</u> Place the softball in the center of one bucket and the 8 oz medium weight in the center of the other bucket. 	

NOTE TO PRESENTER: This is not to scale – a black hole of an 8 oz object would be smaller than an atom. This is being used to show that even though the sizes are different, the masses of the Sun and Earth are the same, space is curved the same, so the force of gravity is the same.	
<u>*To Say:*</u> These are not to scale, but what these illustrate is the Sun and the Sun collapsed to be a black hole. Space is curved out here about the same amount by both balls because their masses are about the same. (Indicate a point near the edge of the bucket).	
<u>*To Say:*</u> Who wants to put the Earth into orbit around each of these? Put both into orbit at about this distance away (indicate a place near the edge of the bucket). The speed of the orbits will be approximately the same at the same distance from the center of the object. So, if the Sun did become a black hole, we would not be pulled in – since our distance from the center of the Sun didn't change and the mass of the Sun didn't change, the mass of Earth didn't change, so the curvature of space where we are stays the same, so we would continue to orbit as we do now.	Roll large marbles into orbit around each ball.
<u>*To Say:*</u> What WOULD be different? Would the Moon shine? Would we be able to see the planets? – The planets are reflecting the light of the Sun.	It would be very dark and very cold. No

Part 6: Why we can't escape from the region of a black hole

Leader's Role	Participants
Key message for your visitors to take home: Space is curved completely around black holes – we cannot escape.	
Materials: Assembled black hole in bucket (see Training Video). Large (1-inch) marble; medium marbles.	
To Say: Massive objects curve space. But a REALLY massive object, like a black hole curves space so severely that space is warped and twisted completely around it. *To Do*: Take a 1" marble and wrap the tag end of fabric around it.   *To Say:* Black holes are formed when really massive stars die, explode in a supernova and their remaining mass collapses down inside an area only a few miles across. Let's imagine that the Earth could become a black hole - how small do you think the Earth would become?	Guesses
To Do: Show 1" marble *To Say:* Let's say all the mass of the Earth was squeezed inside of this marble. This marble would represent the dimensions of a black hole that had the mass of Earth. Could anyone really pick this up?	No!

Leader's Role	**Participants**
NOTE TO PRESENTER: Imagining that the Earth could become a black hole (which it cannot), a one-inch marble correctly represents the approximate size of the event horizon of an Earth-mass black hole. Earth has a radius of about 4,000 miles.	
<u>*To Say*</u>: How severely space is curved depends on 2 things: the mass of the object and the distance from its center. We are standing on the surface of the real Earth. Which direction is the center of the Earth? How far away is the center if the Earth is about 8000 miles in diameter? That's where Earth's center of mass is – 4000 miles away.	 Point to ground; 4000 miles
<u>*To Do*</u>: Bring out the assembled black hole bucket. <u>*To Say:*</u> This represents a black hole with the mass of Earth. (indicating the bucket with black hole) Let's take this Earth-mass black hole far out in space. We are floating in space near this black hole. How far are you from the center of mass of this black hole? (point to someone) If we moved ourselves 4000 miles away from this black hole, we would feel the same gravitational pull as we did when we were standing on the real Earth because we are 4000 miles away from the center of mass in both cases. But we are here far out in space, just a few feet from this Earth-mass black hole – would space be curved a lot more and would the pull of the black hole on us be stronger here? What would we have to do to stay out of the black hole? Near the black hole, the fabric of space would be curved completely around the tremendous mass of this black hole – warping space completely around it. (Point to the assembled black hole.) These marbles will represent tiny satellites orbiting the black hole. Can you put one in orbit? Do you have to push it faster or slower than putting things into orbit around the other weights?	 A few feet. Yes. Orbit really fast. Participants put marbles into orbit. Faster.

<table>
<tr><th>Leader’s Role</th><th>Participants</th></tr>
<tr><td>
<u>To Say:</u>
Now, if we were to get too near and pass through this boundary of space and into the region of the black hole, we would be trapped inside. Space is curved all around us and this causes the force of gravity to be so strong, we would be pulled apart and crushed into an unimaginable density, becoming a part of the black hole.

So here’s the black hole. If we stay out here (indicate the edge of the bucket) and we are orbiting fast enough, we can stay out, but if we stop orbiting, fall in, and pass through this boundary, we’re trapped.</td><td>Push marbles in orbit around the “black hole”.

Drop marbles from edge of bucket into black hole.</td></tr>
<tr><td colspan="2"><u>Presentation Tip:</u>
MISCONCEPTION WARNING #1: Many children and adults hold the misconception that a black hole will suck in everything. Emphasize that as long as an object, such as a star, is orbiting fast enough, it will not be pulled into the black hole. The Sun orbits the center of our Galaxy where there is a giant black hole – but we are very far away and orbiting fast enough to stay out (26,000 light years away and orbiting at 220 km/sec or 137 mi/sec).
MISCONCEPTION WARNING #2: Many people think it is easy to travel to a black hole. This is addressed below.</td></tr>
<tr><td><u>To Say:</u>
NASA doesn’t actually send probes to black holes and no one has ever visited one – they are too far away. The nearest black hole is many light years away – many trillions of miles. Scientists study them from here with giant telescopes in space. NASA wants to search for black holes in our galaxy and other galaxies to learn what happens near black holes and what role they may have played in the formation of early galaxies in the universe.</td><td></td></tr>
</table>

WRAP-UP: Enjoy your evening!

Leader's Role	Participants' Roles (Anticipated)
To Say: Tonight you will see many things through the telescope that are moving under the influence of gravity, or curved space – binary stars, planets, star-forming nebula, star clusters, galaxies. Enjoy your evening, held to Earth by the force of gravity!	

One-Page Summary of Activities

Overall Messages:

1) Mass curves space around it – more mass, more curvature, so more massive objects exert more gravitational force.
2) The farther you are from the center of mass, the less space is curved, so gravitational force is less.

Activity Name	What do we do?	Key Message
Falling In	Drop 2 same-size marbles from the edge of each bucket; Drop 2 different sized marbles from edge of one bucket	More mass, more gravitational force, objects fall faster; All objects regardless of mass will fall at the same rate into the same massive object
Why Doesn't Moon Fall to Earth	Push marbles across empty space; Push marbles into orbit around weights	Paths of the orbits objects take in space is due to curved space
Martian year twice as long as Earth's year	Push marbles in orbit near weight and out toward edge of bucket	Farther from center of mass, space curves less: less gravitational force, so orbital rate is slower
Are you a rocket scientist?	Using straws try to launch the pee-wee marble "rocket" off the Moon and off Earth; then from a black hole	Harder to reach orbit from a larger mass – higher initial speed is needed
Sun as a Black Hole	Orbit marbles around softball and medium weight	At a distance, the same amount of mass will curve space the same amount
Why we can't escape from a black hole	Discuss an Earth-mass black hole and "center of mass"; orbit marbles around black hole	Space is curved completely around black holes – we cannot escape

Materials

What materials from the ToolKit do I need?

In the shipping box:

1. 2 buckets (13” black planters)

In the lower bucket, inside of two drawstring bags:

2. 2.5 pound lead weight - Blue
3. 8 oz lead weight - Yellow
4. 4 oz lead weight - White
5. 2 Pee-wee marbles
6. 2 Shooter (one-inch) marbles
7. A few regular marbles

In the lower bucket:

8. 2 bungee cords

In the “Gravity and Fabric of Space” activity bag:

9. 3 – stretch fabric squares (HAND WASHABLE IN COLD WATER – HANG TO DRY)
10. rubber band
11. 4 feet of string
12. Drinking straws
13. Fishing bobber

What do I need to prepare?

a) Secure the fabric onto the buckets with the bungee cords. Make sure the smoothest side of the fabric is facing up. The fabric on both buckets needs to be evenly stretched and stretched to approximately the same tension on both. See the Training Video for details.

b) **SETUP:** The buckets MUST be placed on a level surface. It is helpful to set up on or over a “non-roll” surface, like grass, carpet, a blanket, or large towel, to avoid having to chase marbles all during the presentation.

c) **A**ssemble the black hole using the fishing bobber, string, and rubber band– See the Training Video.

What must I supply?

- Large towel or blanket
- Regulation Softball

Where do I get additional materials?

1. Buckets (13” black planters) – Home Depot or other home & garden store.
2. 2.5 pound lead weight* – fishing or sporting goods store
3. 8 oz lead weight*– fishing or sporting goods store
4. 4 oz lead weight*– fishing or sporting goods store
5. Pee-wee marbles – toy store or Ebay.com
6. Shooter marbles– toy store or Ebay.com
7. Regular marbles– toy store or Ebay.com
8. Stretchy nylon material – Fabric store – make sure it is lightweight and quite stretchy in all directions.
9. Bungee cords – Hardware or sporting goods store
10. Rubber band – office supply
11. String – hardware or variety store
12. Drinking straws – grocery or drug store
13. Small drawstring bag – you can use a small plastic bag or heavyweight sandwich bag.

***If you purchase additional lead weights, you MUST coat them before using them.** The coating used on the weights in the ToolKit is Plasti-Dip™, with an undercoating of gray Plasti-Dip™ primer. Similar products are available at many paint and tool stores and online from http://www.quiltershusband.com/qhhtm/qhplastidip.htm.

INSTRUCTIONS for Lead Weights

NOTICE! This ToolKit contains coated lead weights.

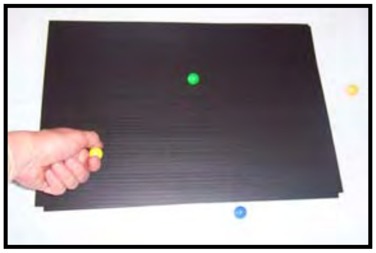
The plastic coating on the weights protects you from having direct contact with the lead. The loop on top of the weights is not made of lead.

Do not remove the plastic coating. **If the lead becomes exposed, do not use the weights until you have re-coated them. Wash your hands after handling weights with exposed lead.**

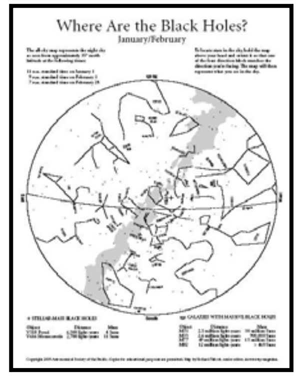
The coating used on these weights is Plasti-Dip™, with an undercoating of gray Plasti-Dip™ primer. Similar products are available at many paint and tool stores and online from http://www.quiltershusband.com/qhhtm/qhplastidip.htm.

Do not allow unsupervised children to play with the weights.

Lead is a substance known to cause health problems and birth defects or other reproductive harm.



Where are the Black Holes?



What's this activity about?

Big Question: How we know black holes are there? Where are they?

Big Activity: **Demonstration:** Using magnets and magnetic marbles, demonstrate the effect black holes have on nearby stars.
Observing Activity: make black holes real in the night sky by showing your visitors the locations of known black holes.

This is two activities in one:

1. **A demonstration**
2. **An observing activity.**

You may want to use only one or the other, or you might want to use the demo as an introduction to observing of location of black holes in the night sky.

Participants: Adults, teens, families with children 6 years and up
If a school/youth group, 3rd grade and higher
Demonstration: From one person to fifteen participants
Observing Activity: Any number of participants

Duration: **Demonstration:** 5 minutes.
Observing Activity: One minute to as long as you wish to observe.
.

Topics Covered:

- How we know black holes are there: How scientists are finding them
- Making it real in the night sky: pointing out the locations of known black holes

Where can I use this activity?

Demonstration:

1) **Pre-Star Party:** As an introduction to observing the locations of black holes.

2) **Scout troop or classroom:** Form teams of 8 to 10 people and provide each team with a set of materials.

3) **Club Meeting, Science Fair, or Science Museum:** Set up a table to do the demonstration.

Observing Activity:

4) **Star Party:** Instruct visitors how to use a star map. Help them find the locations of black holes..

Helpful Hints

Demonstration:

- Demonstrate to your visitors how to roll the marbles across "space" – give the marble enough of a push to roll across the sheet. If your visitors roll the marbles too slowly, they will wobble around due to the magnet in the middle.

- If you are working with children under the age of 14, we recommend that you only use one or two magnetic marbles and pass them from child to child, instead of giving everyone a marble. This way, you are more likely to keep their attention and less likely to lose your marbles.

- **CAUTION!** Small children are likely to mistake the marbles for candy and try to put them in their mouths.

Observing Activity:

- Be sure to ask your visitors if they think they will see the black hole in the sky. Discuss why not. If they don't realize they won't actually see it, they may be disappointed.

Background Information

There will be nothing to see at the locations of black holes in the sky. Their companion stars and parent galaxies are too dim to see with the unaided eye. But seeing the location in a constellation makes the existence of black holes real to your visitors.

As for telescope viewing of black hole locations, the parent galaxies of the supermassive black holes are certainly visible in the telescope (under the right skies). And, if it is July through December, the globular cluster M15, which harbors a mid-mass black hole, is visible in the scope. Cygnus X-1's companion star (visible in the evening June through mid-December) is really the only one visible in backyard telescopes, at a visual magnitude of 9.

An Excel spreadsheet of some of the known black holes is included on the Manual and Resources CD in a file named **"BHLocations.xls"**.

For more information on how scientists discover black holes:
http://cfa-www.harvard.edu/seuforum/bh_reallyexist.htm or review the PowerPoint on the CD.
Review the "Black Hole FAQ's" page that is to be printed on the back of the star maps.

Detailed Activity Description

Leader's Role	Participants' Roles
Introduction – Search for the Black Holes	
To Say: Where are the black holes in our galaxy? How do scientists find them?	Shrugs, uncertain
To Do: (Point to the signboard sheet)	
To Say: This is space – we are surrounded by space and this is just one very small section.	
These are magnetic marbles and we're going to use them to explain the force of gravity. Magnetism is an invisible force, just like gravity, but they are different kinds of forces.	Take marble
Gravity is a force that always attracts an object toward another object. Magnets sometimes pull together and sometimes push each other apart.	
So we are just using magnets as a model for gravity when the marbles attract each other.	
(Place one magnetic marble somewhere on the sheet.)	
To Say: This is a star in space. What happens to this star when another star goes nearby?	
To Do: (Roll a few marbles past the star and ask how the two stars are affected. Have other participants roll their marble past the star.)	Star goes into orbit Star is deflected
To Say: There is another smaller, but more powerful magnet representing a black hole somewhere in this field. Can you see the black hole?	No.
Just like out in space we can't see the black hole. Why can't we see it? Black holes don't give off any light!	Shrugs – Black holes are black!
How will we find the black hole – how will we know it is there?	Roll marbles!

Leader's Role	Participants' Roles
To Say: Some marbles will "orbit" and be captured and some will roll by the black hole but be deflected. This is one way scientists find them – by seeing the effects on a star or stars in the vicinity of a black hole. You noticed how some of the stars whirled around the black hole. Gas whirling around a black hole heats up to very high temperatures, and gives off hot x-ray radiation. As the material orbits closer and closer, it moves faster and faster, heating up to millions of degrees. Sometimes fast-moving jets of material are streaming off the black hole. – Telescopes in space, like NASA's Chandra X-Ray telescope, can detect these high temperature X-rays emanating from a small area of space. Future NASA missions are being developed to look for more black holes and to try to determine why these jets occur, what happens to that material that falls into a black hole, and what actually happens to space – and time – very near a black hole.	Continue to roll marbles to find the black hole
Transitioning from the activity to observing locations of black holes in the night sky: *To Say:* Here is a star map that shows the locations of known black holes. Let's place the black hole location on the star map over the location of the black hole in space here. (Place the star map on the top board, centering one of the black holes over one of the strong magnets). Now let's roll one of the marbles toward this black hole. Yes, sure enough – there is a black hole there! Let's see where that is in the sky….	Roll marble to find the black hole

Leader’s Role	Participants’ Roles
Observing the location of black holes (Unaided eye): **Presentation Tip:** Be sure to ask your visitors if they think they will see the black hole. If they don’t realize they won’t actually see it, they may be disappointed.	
<u>*To Say:*</u> When we look up in the sky do you think we are going to be able to see the black hole itself? No, we won’t – why not? Right – black holes are invisible to the eye. <u>*To Do:*</u> Hand out “Where are the Black Holes?” star map. <u>*To Say:*</u> But we can use this map to see where astronomers have actually discovered black holes. How do you suppose astronomers know they are there? Right - using some of the techniques we already discussed, like detecting strong x-rays or seeing companion stars orbiting the invisible black hole. <u>*To Do:*</u> Provide instruction on how to use star maps. Point to the locations of black holes. This is a naked eye activity. <u>*To Say:*</u> On the back of the star map, you’ll find some FAQ’s about black holes.	No. Black holes don’t give off any light. Takes star map. X-rays – motions of nearby stars? Learns to use star map.
Observing the location of black holes (Telescope): You may want to continue and have some of the other club members with telescopes show galaxies known to harbor supermassive black holes at their centers. And if M-15 is visible, you might want to show that globular cluster in a telescope. The companion stars of stellar-mass black holes, except for the companion of black hole Cygnus X-1, are not visible in backyard telescopes.	

Materials

What materials from the ToolKit do I need?

Demonstration:

- 2 - 11” x 16” sheets of black signboard

Drawstring bag containing:

- **Magnetic** marbles
- 2 small cylindrical magnets

Observing Activity:

- “Where are the Black Holes?” star maps (2-sided)

What do I need to prepare?

DEMONSTRATION SETUP

- Insert one of the small cylindrical magnets into one of the holes in the signboard sheet with the holes – you may want to place a strip of tape on the underside of the sheet under each hole so the magnets don’t slip out.

- Place the other signboard sheet over the sheet with the magnet in it.

- This MUST be on a level surface. It is helpful to have a thin blanket or towel underneath it to keep the marbles from rolling too far. You might want to place the boards inside a large box lid to keep the marbles from rolling away.

- If working with children, we suggest that you use one magnetic marble and pass it from one child to the next. If working with teens or adults, each participant can have their own marble.

Star Maps: Make as many copies of the 2-sided handout as you need. The star map is printed on one side and the Black Hole FAQ's are printed on the other side. You may want to copy your club information on the back side of the star maps, under the FAQ's.

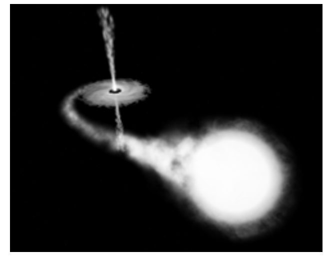
What must I supply?

- Large towel or blanket for demo
- Optional: A large box lid to place boards inside.

Where do I get additional materials?

- **Magnetic** marbles: School-Tech.com: Item #**12610W2** http://www.school-tech.com/magnets3.html
- Small cylindrical strong magnets: AmazingMagnets.com: Item # ***T250B*** at http://www.amazingmagnets.com/products.asp?ID=1000-10-1600
- Black signboard is Coroplast®. Sign-making stores will carry it. Alternative materials for black signboard:
    - 2 sheets of corrugated cardboard
    - 2 thin Styrofoam sheets – cover the top sheet with a smooth cloth (get Styrofoam sheets from a craft store).

BLACK HOLE FAQ's


Credit : ESA, NASA, and F. Mirabel

1. **What is a black hole?** A black hole is a region of space that has so much mass concentrated in it that there is no way for a nearby object to escape its gravitational pull. There are three kinds of black hole that we have strong evidence for:
    a. Stellar-mass black holes are the remaining cores of massive stars after they die in a supernova explosion.
    b. Mid-mass black hole in the centers of dense star clusters
    c. Supermassive black hole are found in the centers of many (and maybe all) galaxies.
2. **Can a black hole appear anywhere?** No, you need an amount of matter more than 3 times the mass of the Sun before it can collapse to create a black hole.
3. **If a star dies, does it always turn into a black hole?** No, smaller stars like our Sun end their lives as dense hot stars called white dwarfs. Much more massive stars end their lives in a supernova explosion. The remaining cores of only the *most* massive stars will form black holes.
4. **Will black holes suck up all the matter in the universe?** No. A black hole has a very small region around it from which you can't escape, called the "event horizon". If you (or other matter) cross the horizon, you will be pulled in. But as long as you stay outside of the horizon, you can avoid getting pulled in if you are orbiting fast enough.
5. **What happens when a spaceship you are riding in falls into a black hole?** Your spaceship, along with you, would be squeezed and stretched until it was torn completely apart as it approached the center of the black hole.
6. **What if the Sun became a black hole without gaining or losing any mass?** The Sun can't turn into a black hole, but if it did, the Earth would get very dark and very cold. The Earth and the other planets would not get sucked into the black hole; they would keep on orbiting in exactly the same paths they follow right now.
7. **Is a black hole a portal ("wormhole") to another part of the universe?** In some science fiction shows, people sometimes travel through wormholes. This leads many people to think black holes are wormholes and therefore lead to other places. There is no evidence that wormholes exist.
8. **Can I see a black hole?** No. The light produced or reflected by objects makes them visible. Since no light can escape from a black hole, we can't see it. Instead, we observe black holes indirectly by their effects on material around them.
9. **What evidence is there that black holes exist?** Fast-moving stars orbiting "unseen" objects and strong X-rays emitted from a very small area of space. NASA missions and projects are in the process of discovering more about black holes.

For more info: http://cfa-www.harvard.edu/seuforum/blackholelanding.htm

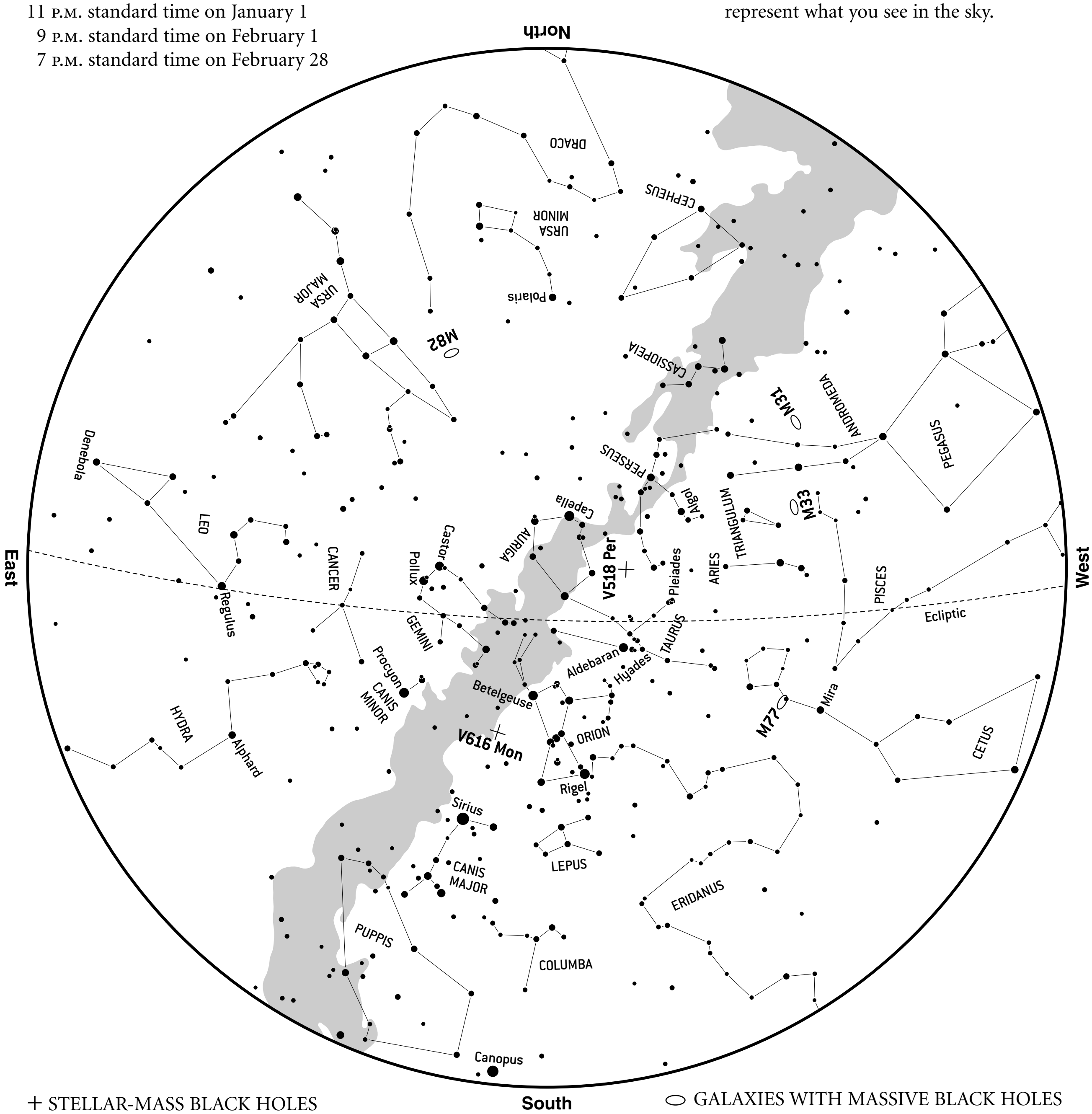
Where Are the Black Holes?

January/February

The all-sky map represents the night sky as seen from approximately 35° north latitude at the following times:

11 P.M. standard time on January 1
9 P.M. standard time on February 1
7 P.M. standard time on February 28

To locate stars in the sky, hold the map above your head and orient it so that one of the four direction labels matches the direction you're facing. The map will then represent what you see in the sky.



+ STELLAR-MASS BLACK HOLES

Object	Distance	Mass
V518 Persei	6,500 light-years	4 Suns
V616 Monocerotis	2,700 light-years	11 Suns

⬭ GALAXIES WITH MASSIVE BLACK HOLES

Object	Distance	Mass
M31	2.5 million light-years	30 million Suns
M33	2.6 million light-years	900,000 Suns
M77	49 million light-years	15 million Suns
M82	12 million light-years	> 460 Suns

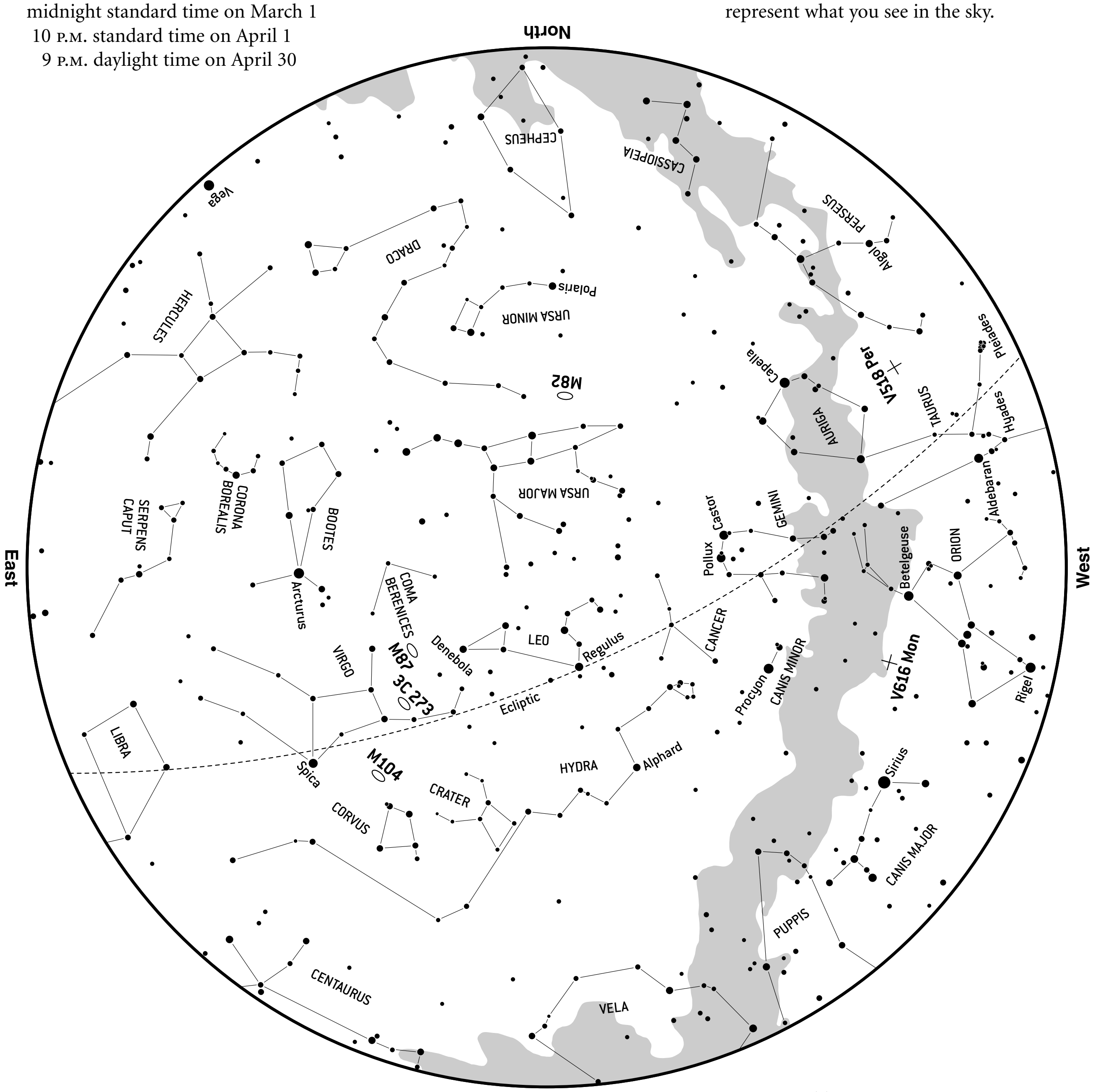
Where Are the Black Holes?

March/April

The all-sky map represents the night sky as seen from approximately 35° north latitude at the following times:

midnight standard time on March 1
10 P.M. standard time on April 1
9 P.M. daylight time on April 30

To locate stars in the sky, hold the map above your head and orient it so that one of the four direction labels matches the direction you're facing. The map will then represent what you see in the sky.



+ STELLAR-MASS BLACK HOLES

Object	Distance	Mass
V518 Persei	6,500 light-years	4 Suns
V616 Monocerotis	2,700 light-years	11 Suns

⬭ GALAXIES WITH MASSIVE BLACK HOLES

Object	Distance	Mass
M82	12 million light-years	> 460 Suns
M87	52 million light-years	3 billion Suns
M104	30 million light-years	500 million Suns
3C 273	2 billion light-years	1 billion Suns

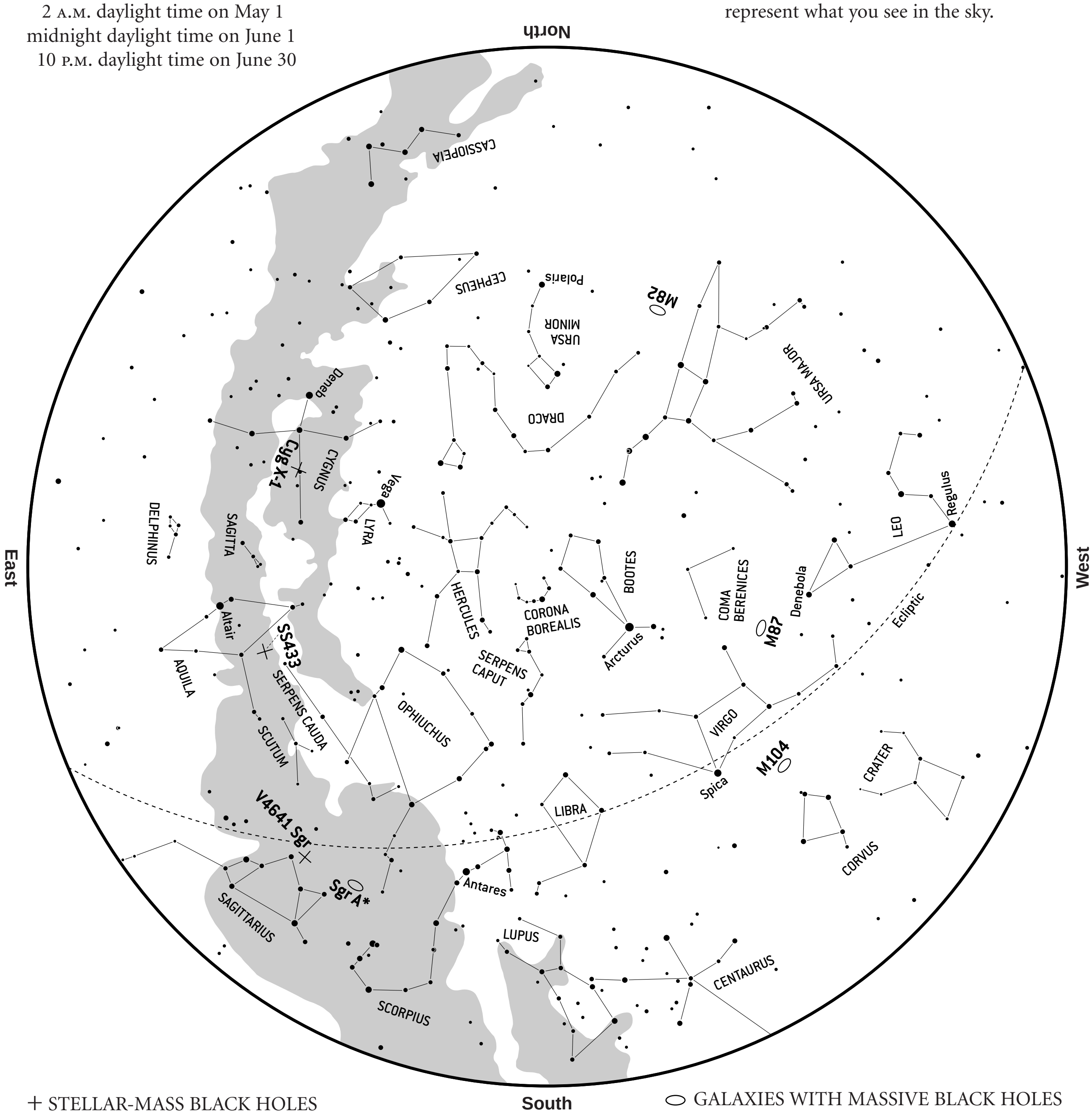
Where Are the Black Holes?

May/June

The all-sky map represents the night sky as seen from approximately 35° north latitude at the following times:

2 A.M. daylight time on May 1
midnight daylight time on June 1
10 P.M. daylight time on June 30

To locate stars in the sky, hold the map above your head and orient it so that one of the four direction labels matches the direction you're facing. The map will then represent what you see in the sky.



+ STELLAR-MASS BLACK HOLES

Object	Distance	Mass
V4641 Sagittarii	32,000 light-years	7 Suns
SS433	16,000 light-years	10 Suns
Cygnus X-1	7,000 light-years	10 Suns

⬭ GALAXIES WITH MASSIVE BLACK HOLES

Object	Distance	Mass
M82	12 million light-years	> 460 Suns
M87	52 million light-years	3 billion Suns
M104	30 million light-years	500 million Suns
Sgr A*	26,000 light-years (center of Milky Way Galaxy)	2 million Suns

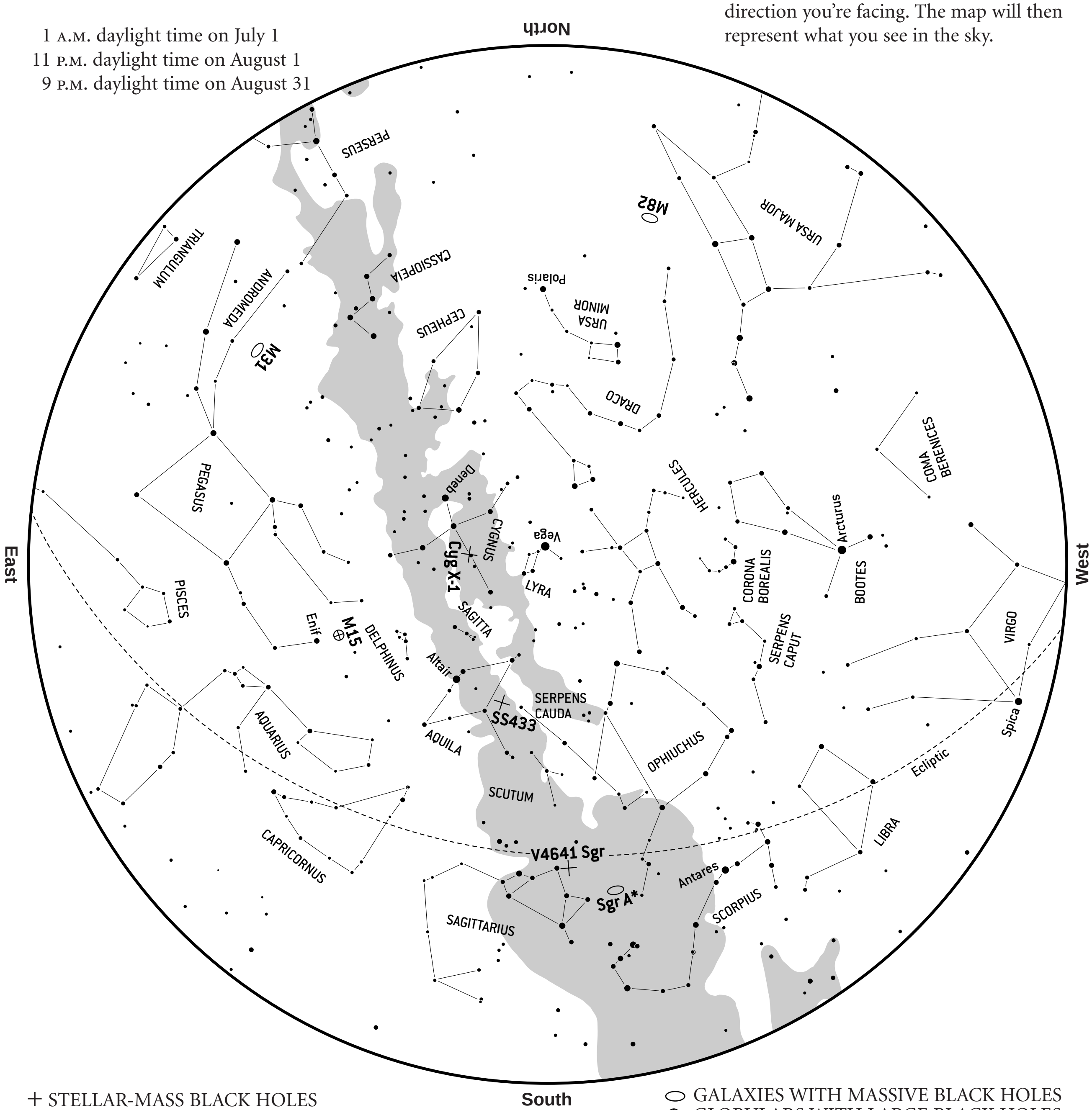
Where Are the Black Holes?

July/August

The all-sky map represents the night sky as seen from approximately 35° north latitude at the following times:

1 A.M. daylight time on July 1
11 P.M. daylight time on August 1
9 P.M. daylight time on August 31

To locate stars in the sky, hold the map above your head and orient it so that one of the four direction labels matches the direction you're facing. The map will then represent what you see in the sky.



+ STELLAR-MASS BLACK HOLES

Object	Distance	Mass
V4641 Sagittarii	32,000 light-years	7 Suns
SS433	16,000 light-years	10 Suns
Cygnus X-1	7,000 light-years	10 Suns

⬭ GALAXIES WITH MASSIVE BLACK HOLES
⊕ GLOBULARS WITH LARGE BLACK HOLES

Object	Distance	Mass
M31	2.5 million light-years	30 million Suns
M82	12 million light-years	> 460 Suns
Sgr A*	26,000 light-years (center of Milky Way Galaxy)	2 million Suns
M15	33,000 light-years	2,500 Suns

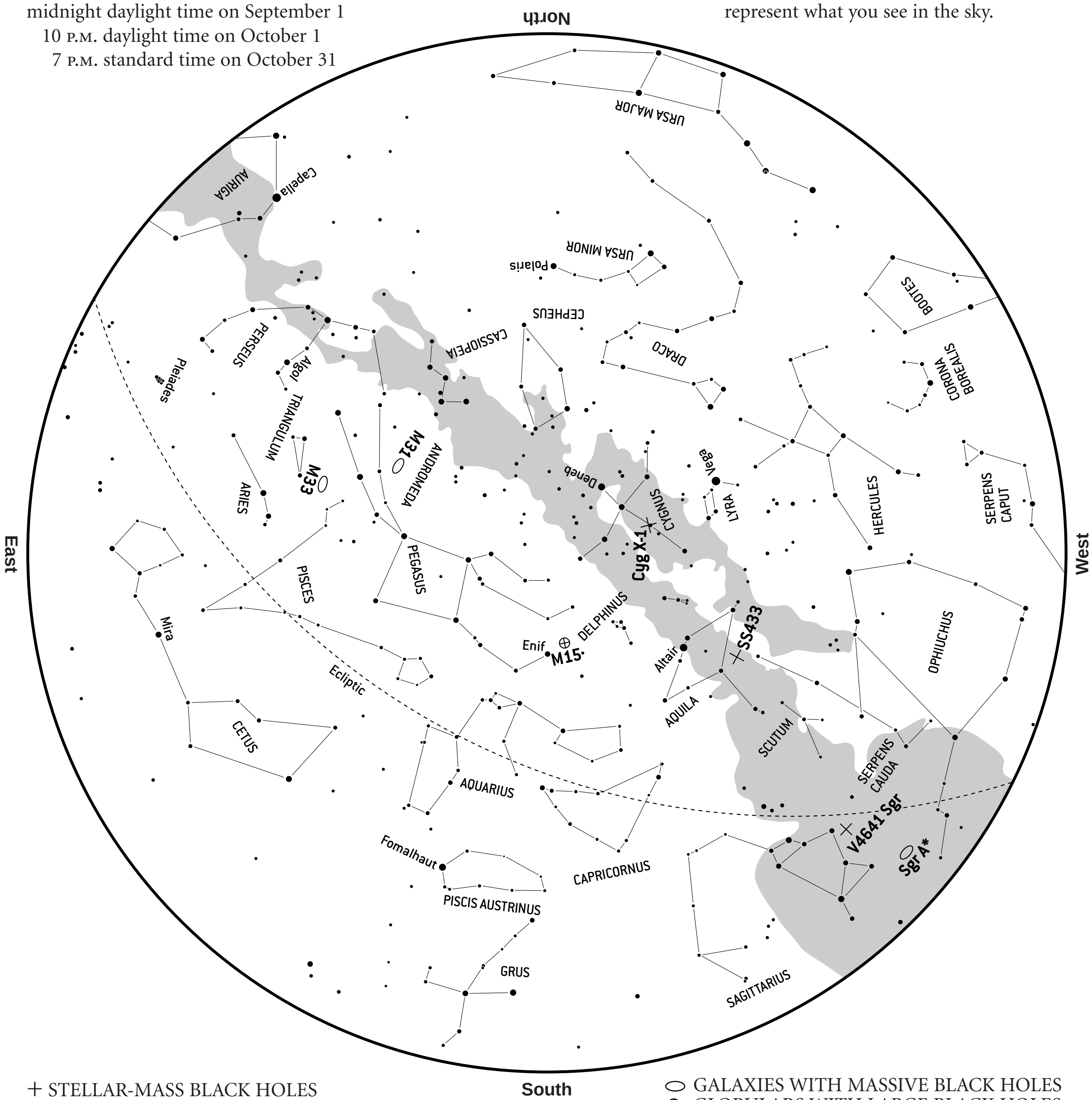
Where Are the Black Holes?

September/October

The all-sky map represents the night sky as seen from approximately 35° north latitude at the following times:

midnight daylight time on September 1
10 P.M. daylight time on October 1
7 P.M. standard time on October 31

To locate stars in the sky, hold the map above your head and orient it so that one of the four direction labels matches the direction you're facing. The map will then represent what you see in the sky.



\+ STELLAR-MASS BLACK HOLES

Object	Distance	Mass
V4641 Sagittarii	32,000 light-years	7 Suns
SS433	16,000 light-years	10 Suns
Cygnus X-1	7,000 light-years	10 Suns

⬭ GALAXIES WITH MASSIVE BLACK HOLES
⊕ GLOBULARS WITH LARGE BLACK HOLES

Object	Distance	Mass
M31	2.5 million light-years	30 million Suns
M33	2.6 million light-years	900,000 Suns
Sgr A*	26,000 light-years (center of Milky Way Galaxy)	2 million Suns
M15	33,000 light-years	2,500 Suns

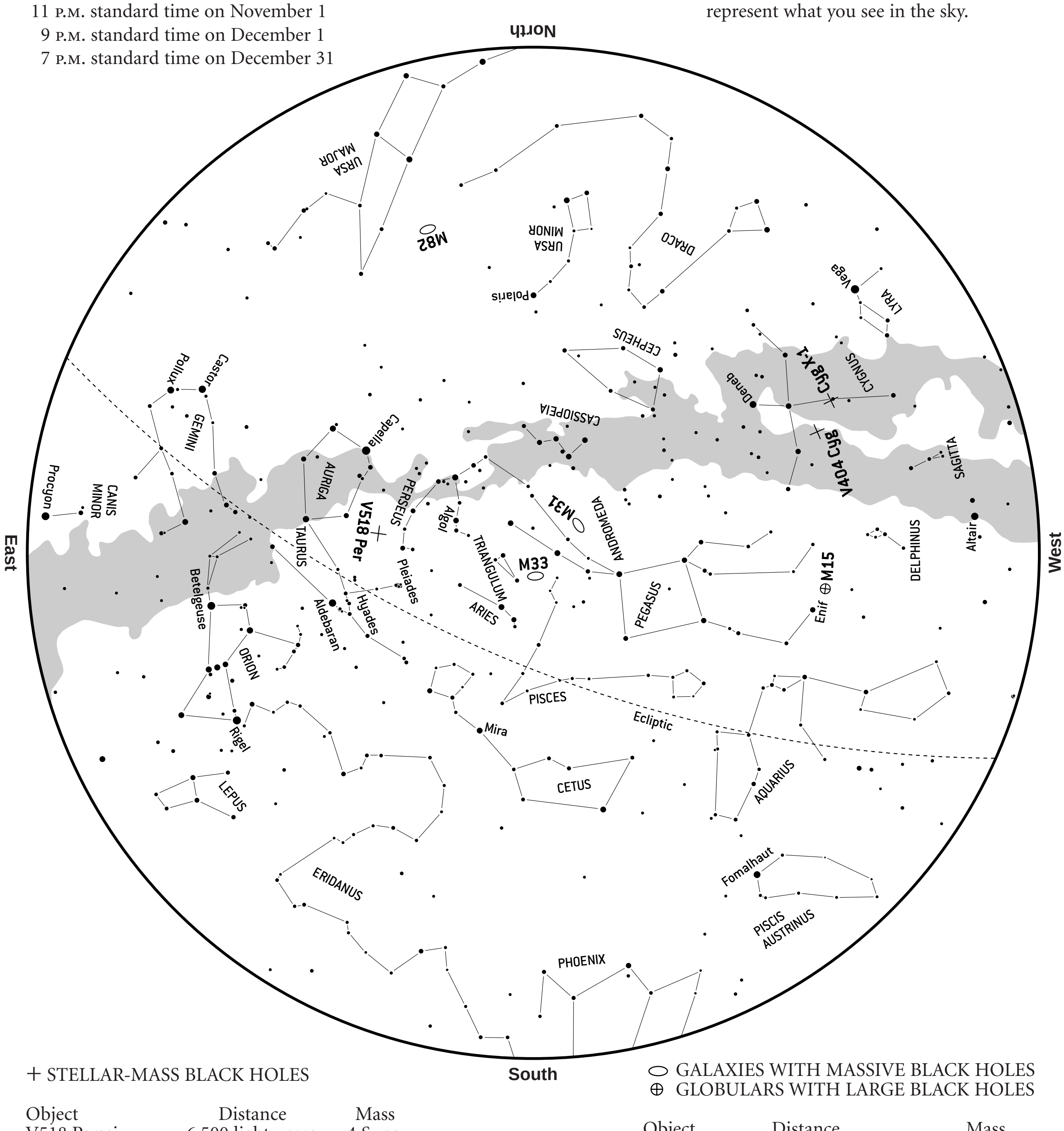
Where Are the Black Holes?

November/December

The all-sky map represents the night sky as seen from approximately 35° north latitude at the following times:

11 P.M. standard time on November 1
9 P.M. standard time on December 1
7 P.M. standard time on December 31

To locate stars in the sky, hold the map above your head and orient it so that one of the four direction labels matches the direction you're facing. The map will then represent what you see in the sky.



+ STELLAR-MASS BLACK HOLES

Object	Distance	Mass
V518 Persei	6,500 light-years	4 Suns
Cygnus X-1	7,000 light-years	10 Suns
V404 Cygni	8,000 light-years	12 Suns

⬭ GALAXIES WITH MASSIVE BLACK HOLES
⊕ GLOBULARS WITH LARGE BLACK HOLES

Object	Distance	Mass
M31	2.5 million light-years	30 million Suns
M33	2.6 million light-years	900,000 Suns
M82	12 million light-years	> 460 Suns
M15	33,000 light-years	2,500 Suns

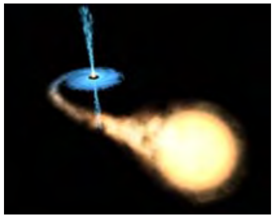
Media & Resources

GETTING STARTED WITH THE *BLACK HOLE SURVIVAL* OUTREACH TOOLKIT

1. **INSERT the "Manual & Resources CD" into your computer. Click on BHManual.pdf to navigate through the Outreach ToolKit Manual. You need the free Adobe Acrobat Reader to view the manual: http://www.adobe.com/products/acrobat/readstep2.html. Copy the CD to your hard drive for best results.**
2. **PRINT THE SCRIPT for the PowerPoint "SurviveBHscript.doc" found on the CD in the "Powerpoints" folder.**
3. **VIEW THE TRAINING VIDEO as you review materials in the ToolKit – this is a DVD labeled "Training Video DVD". NOTE: If you have problems playing the DVD, contact nightskyinfo@astrosociety.org and we'll send a replacement.**
4. **Review the PowerPoints in the "PowerPoints" folder on the "ToolKit Manual and Resources CD". One is for public presentations and one is to introduce the ToolKit to your club.**
5. **Review the Animations in the "BHAnimations" folder on the "ToolKit Manual and Resources CD" by clicking on BHAnimations.htm**
6. **Questions? nightskyinfo@astrosociety.org or call the Astronomical Society of the Pacific at 415-337-1100.**

WHERE COULD I USE THE RESOURCES INCLUDED HERE?

MEDIA / RESOURCE	Pre-Star Party - Indoors	Girl Scouts / Youth Group Meeting	Classroom			Club Meeting	Gen Public Presentation (Seated)
			K-4	5-8	9-12		
PowerPoint: A Galaxy Full of Black Holes	√	√		√	√	√	√
Animations	√	√		√	√	√	√
Black Hole Explorer Board Game	√	√		√	√	√	



NASA Structure and Evolution of the Universe Forum http://cfa-www.harvard.edu/seuforum/
NASA Origins Education Forum http://origins.stsci.edu
JPL Navigator Public Engagement Program http://planetquest.jpl.nasa.gov/index.html

Gravity and the Fabric of Space

DESCRIPTION: Using a bucket with fabric stretched over it, allow visitors to experiment with marbles and weights to discover the basics about gravity and black holes.
Why do we fall back to Earth when we jump? Why doesn't the Moon fall to Earth? Are you a rocket scientist – can you put a satellite into orbit? Why can't anything escape from a black hole?

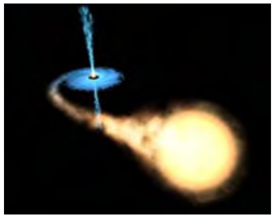
See ToolKit Manual and Training Video for more details and suggestions.

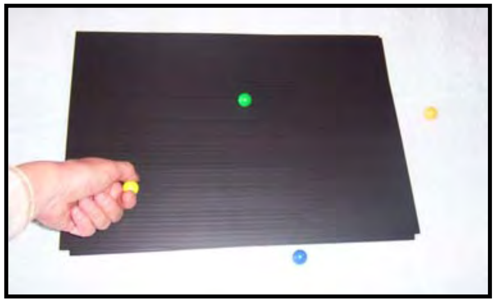
WHERE COULD I USE THIS ACTIVITY?

Star Party	Pre-Star Party - Outdoors	Pre-Star Party - Indoors	Girl Scouts / Youth Group Meeting	Classroom			Club Meeting	Gen Public Presentation (Seated)	Gen Public Presentation (Interactive)
				K-4	5-8	9-12			
	√	√	√	√	√	√	√		√

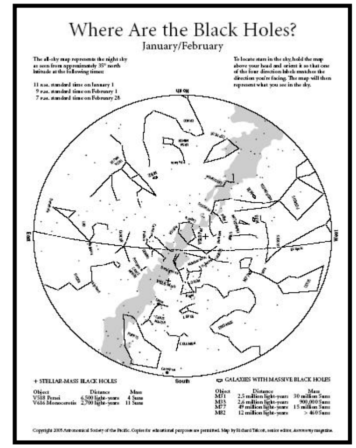
WHAT DO I NEED TO DO TO BEFORE I USE THIS ACTIVITY?

What do I need to supply to complete the materials?	What do I need to supply to run this activity that is not included in the kit?	Do This Before Your Event
Nothing additional	Towel or blanket A regulation softball.	Assemble buckets with stretch cords and fabric. Make sure buckets are level and placed on a large towel or blanket.





Where are the Black Holes?



DESCRIPTION: Two activities in one!

1. Black Holes are invisible – so how do scientists find them? A game using magnets and signboard sheets to show how to find black holes.
2. A new twist to the standard star map! Hand out custom star maps to help your visitors find constellations *and* see the locations of black holes in our Galaxy and in other galaxies. Includes Black Hole FAQ's.

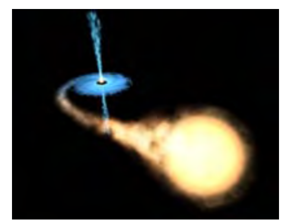
See ToolKit Manual and Training Video for more details and suggestions.

WHERE COULD I USE THIS ACTIVITY?

Star Party	Pre-Star Party - Outdoors	Pre-Star Party - Indoors	Girl Scouts / Youth Group Meeting	Classroom			Club Meeting	Gen Public Presentation (Seated)	Gen Public Presentation (Interactive)
				K-4	5-8	9-12			
√	√	√	√	√	√	√	√		√

WHAT DO I NEED TO DO TO BEFORE I USE THIS ACTIVITY?

What do I need to supply to complete the materials?	What do I need to supply to run this activity that is not included in the kit?	Do This Before Your Event
Star Maps: You may want to prepare a page to photocopy onto the reverse side of the star map that has your club information on it.	Red flashlights to read the star maps	***Demonstration:*** Insert the small magnet into one of the holes in the signboard sheet & cover it with the other sheet. ***Star Maps:* Print out and Photocopy:** Current month's star map with FAQ's on the back for your visitors.



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NASA Origins Education Forum http://origins.stsci.edu
JPL Navigator Public Engagement Program http://planetquest.jpl.nasa.gov/index.html

Black Hole Explorer Board Game

DESCRIPTION:
"Black Hole Explorer" is a board game where the players fly a spaceship into orbit around black hole and launch scientific probes to study it. The object is to return to Earth with your results and collect the Nobel Prize.
All parts to the game are in the BHManual.pdf under the section "Black Hole Explorer Board Game". Print these onto the enclosed card stock or onto plain paper. See the ToolKit Manual and the Training Video for more details.

WHERE COULD I USE THIS ACTIVITY?

Star Party	Pre-Star Party - Outdoors	Pre-Star Party - Indoors	Girl Scouts / Youth Group Meeting	Classroom			Club Meeting	Gen Public Presentation (Seated)	Gen Public Presentation (Interactive)
				K-4	5-8	9-12			
		√	√		√	√	√	√	

WHAT DO I NEED TO DO TO BEFORE I USE THIS ACTIVITY?

What do I need to supply to complete the materials?	What do I need to supply to run this activity that is not included in the kit?	Do This Before Your Event
Print out the game onto the enclosed card stock – see Training Video for details. You may want to attach the game board to a cardboard backing.	Table to play on / chairs for players	• Read the Rules • Play the game with family or friends .

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NASA Origins Education Forum http://origins.stsci.edu
JPL Navigator Public Engagement Program http://planetquest.jpl.nasa.gov/index.html