Black Hole Bucket

Overview: What comes to mind when you think about empty space? (You should be thinking: "*Nothing!*") One of Einstein's greatest ideas was that empty space is not actually nothing – it has energy and can be influenced by objects in it. It's like the T-shirt you're wearing. You can stretch and twist the fabric around, just like black holes do in space.

What to Learn: Today, you will get introduced to the idea that gravity is the structure of spacetime itself. Massive objects curve space. How much space curves depends on how massive the object is, and how far you are from the massive object.

Materials

- Two buckets with holes in the bottom
- 2 bungee cords
- 3 different sizes of marbles
- 2.5 lb weight
- 0.5 lb weight
- 3 squares of stretchy fabric
- Rubber band
- 4 feet of string
- Fishing bobber
- Drinking straws
- Softball
- Playdough (optional)

Experiment

<u>Making the Buckets Ready for the Lab</u>

1. What is gravity? How does it work? That's what today's lab is all about.
2. Stretch the bungee cord around the circumference of the bucket. Do this for both buckets.
3. On one bucket, tuck in the stretchy fabric under the cord. If your cords are loose, tie another knot near the end so they fit snugly around the bucket. The fabric is stretched like a drum head. This is the "fabric of space" – it's around us everywhere.
4. Push the bottom of the bobber so the hook opens on the other end. Push your string in.
5. Place it in the center of the squares of fabric. Fasten it with your rubber band.
6. Thread the ends of your string through the bottom holes of your second bucket and tie it securely on the bottom.
7. Tuck in your corners under the bungee cord. This is your black hole bucket.
8. The first lab uses two buckets, neither of which is a black hole. We're going to convert the black hole bucket to a regular spacetime fabric bucket. For now, place a second piece of fabric over the black hole bucket and tuck it under the cord so that it looks like the first bucket you used.
9. Now, we're ready for our lab.

<u>Exploring How Space Curves</u>

Write the answers in the spaces provided after each question as you play with your buckets and work through the activities.

10. Place a mid-sized weight in the middle of one of the buckets. What happens to the fabric when you put a weight on the fabric?

11. Place the heavy 2.5lb lead weight in the center of the fabric of the second bucket. Did it curve more or less than the first weight?

12. The heavier weight is like the Sun, and the lighter weight is like the Earth. Which has more mass?

13. Which has more gravitational attraction?

14. Is space more or less curved further from the object?

15. Where is space curved the most?

16. Grab your marbles. These are your space probes. If we place one probe at the edge of each bucket, which do you expect it to fall toward the middle faster?

17. Why?

18. This is what we mean when we say the force of gravity depends on how much mass something has, since mass curves space. More massive objects curve space more, so the gravitational attraction is more with more massive objects.

19. Take two marbles of different sizes and drop them at the same time onto the edge of the bucket. You can drop them on opposite sides so they don't knock into each other. What happens?

20. The Moon is like a giant marble. Why doesn't it fall to Earth?

21. Why is it orbiting?

22. Remove all weights from the fabric. Roll a marble across the surface (do it slowly without bouncing – planet's don't bounce!). Does it roll straight or curved?

23. Place the heavy weight on the fabric. Try to make the marble go in a straight line. Did it work?

24. Can you roll the marble so that it escapes from the weight that represents the Sun?

25. In the second bucket, place a smaller weight and do steps 23 and 24 again. How is this different?

26. Planets orbit the Sun because space is curved around the Sun. The Moon orbits the Earth without falling in because space is curved around Earth. How fast the moon moves through space and how much the Earth curves space depends on the Earth's mass and how far away the moon is.
27. If the Moon was in closer to the Earth, would it have to move faster or slower to maintain its orbit?

28. Let's find out: Place two marbles, one closer to the weight and one near the edge of the bucket, and make them orbit the weight. Which one orbits faster? Why?
29. Replace the weight in the second bucket with a lightweight mass. Now, what if Earth was less massive? How would this change the Moon's orbit?

30. Notice this: When you roll a ball in orbit around a weight, do you see the weight move slightly also? All orbiting objects yank on each other. The Moon pulls on the Earth just as the Earth pulls on the Moon. All massive objects cause space to move: planets, stars, black holes, comets, etc.

Exploring Black Holes

31. Place a weight in each bucket, one representing the Earth and the other representing the Moon.
32. Place a marble next to each weight. These marbles are your rocket ships. Do you think that you can launch your rockets and escape the pull of gravity? Grab a straw and try to blow the marble away from the weight (launch the rocket off the Earth and moon). What happened? Why?

33. What if we start the rockets in space? Do you think you can escape the pull of the objects now? Start the marbles orbiting and then blow them the straws. Can you fire your rockets at the right time to get your rockets to escape the orbit?

34. Let's launch a probe out of a black hole! Remove the fabric from the black hole bucket and place a marble in the black hole. Can you use your straw to blow the marble out of the black hole?

35. Let's see the difference between the Sun and a black hole. Grab an 8-ounce weight and the softball. These have the same mass, but they are different sizes. The softball is the Sun, and the weight is the black hole. Which is going to curve space more when you place it on the fabric? Guess before you try it:

36. Replace the fabric over the black hole bucket.
37. Place the softball on one of the buckets, and the 8-ounce weight on the other bucket.
38. Roll a marble near the edge of each bucket. This is where our Earth would be orbiting. Notice that although the weight curves space more near it, at the edge, the curvature is the same. So if the Sun were suddenly replaced by a black hole of the same mass, the Earth wouldn't notice it (gravitationally, at least. It would get dark and cold, though.),
39. Remove the second fabric from the black hole bucket so you have the vortex exposed.
40. Take two marbles and start them orbiting at the edge of the black hole. What happens? Why?

41. Make a rocket shape out of clay or playdough. Bring the rocket close to the black hole bucket and get prepared to show your teammates what happens if it goes into the black hole. First, it stretches (pull the rocket into a longer shape), then it gets shredded (crumple it up) and finally added to the black hole's mass (shove it into the bucket).

Reading

Massive objects are truly massive. If our solar system was the size of a quarter, the Milky Way would be the size of North America.

The Milky Way has an estimated 100 billion stars. That's hard to imagine, so try this: Imagine a football field piled 4' deep in birdseed. Now scatter those seeds over North America and space them 25 miles deep. Each seed is a Sun. Stars are very far apart!

If the mass of the Sun was one birdseed, then the mass of a black hole would be 22 gallons of birdseed shoved into the volume of a single birdseed.

It's time to explore how black holes interact with the universe. There are four animations to watch. Let the students know that these are scientific simulations which used actual data to create them – they are not artist's concepts or fantasy. They are based on solid physics. The reason they are animations is because these videos happen over such a long period of time, and our view is limited in some cases.

The Tidal Disruption video shows a yellow star that wanders too close to a black hole. The black hole is in the center of a galaxy. Notice how when the yellow star nears the black hole, the star gets stretched, squeezed, and then shredded and torn apart. (You will get to do this with your rocket ship during your lab activity.)

The SGR (Sagittarius) Flare video demonstrates X-ray flares are produced when matter falls into an accretion disk that circles around a supermassive black hole, like the one we have in the center of our own Milky Way galaxy.

The X-ray binary sequence video shows a binary system where one of the stars has exploded as a supernova and dumped its mass onto its companion star. The supernova then turned into a black hole, as in Cygnus X-1 (the first black hole we ever discovered). The remaining star is having its outer atmosphere drawn toward the black hole. As gas falls into the black hole, it emits a flood of X-ray light.

Here's an animation of two galaxies colliding, each with their own supermassive black holes in their centers. The last image is what we actually see today, and scientists figured out what had to happen in order to create what we see today. Both black holes are actively feeding and producing X-rays. These images were observed by the Chandra Observatory.

Exercises

1. What is the event horizon?
2. Does a more massive object curve space more or less than a smaller object? What does this mean for the gravitational field?
3. Does an object feel more or less gravitational attraction as the object moves closer to a massive object?
4. Where is space most curved?
5. What is mass?

Answers to Exercises: Black Hole Bucket

1. What is the event horizon? (If you fall into a black hole, you'll never get out again, because falling into a black hole is a lot like falling over Niagara Falls – there's no way of getting back the same way you came.

The edge of a black hole is called the "event horizon," and it's like the edge of a waterfall. Do you see the water that's about to fall over the edge? Once you pass the edge, there's no turning back. That's called the "point of no return.")

2. Does a more massive object curve space more or less than a smaller object? What does this mean for the gravitational field? (More massive objects curve the fabric of space more than a smaller object. More mass = more curvature = more gravitational attraction.)

3. Does an object feel more or less gravitational attraction as the object moves closer to a massive object? (As the distance decreases from the center of an object to a massive object, the curvature increases, and the gravitational attraction also increases.)

4. Where is space most curved? (Space is curved most nearest the object and less curved out near the edge.)

5. What is mass? (Mass is the amount of stuff (atoms) in an object.)