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**Science Unit:** ***Space***

**Lesson 14:** ***Black Holes***

Summary: Students rotate through 4 stations that model phenomena scientists use to locate black holes: 1) gravity wells (marbles orbiting on spandex); 2) spinning clouds of dust (tornado in a bottle); 3) invisible orbit companions (clay on bamboo skewers); 4) gravitational lensing (viewing coloured dots through a wine glass base).

School Year: 2014/2015

Developed for: Lord Strathcona Elementary School, Vancouver School District

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Grade level: Presented to grade 6/7; appropriate for grades 3 – 7 with age appropriate modifications

Duration of lesson: 1 hour and 20 minutes

### Objectives

1. Understand the life cycle of stars and how black holes form.
2. Experiment with several phenomena in the classroom that allow scientists to locate and measure the mass of black holes.

### Background Information

Black holes cannot be seen, as nothing can escape them, not even light. Scientists, therefore, use indirect ways to learn where black holes are, how big they are, and to piece together an understanding of these strange phenomena. Students are often interested in black holes and their unusual properties. This lesson models four ways that scientists learn indirectly about black holes, and gives students a taste of indirect evidence.

### Vocabulary

<u>gravity</u>: An attractive force between any two masses. The larger and more dense the mass, the greater its gravity. Every mass, however small, has gravity.

<u>black hole</u>: An extremely dense region of space that has so much gravity that not even light can escape. Hence black holes appear black.

<u>gravity well</u>: A model of the gravitational field surrounding a body in space. Regions with gravity appear as wells in a flat plane. A larger body has a deeper well. The gravity well of a black hole has very steep sides.

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| orbit | The curved path of one mass around another, directed by the gravity between them. The Earth orbits the Sun; stars orbit black holes; stars orbit each other. Orbits are usually elliptical in shape, and sometimes almost look circular. |
| accretion disc | A rotating disc of gas and dust surrounding a black hole, the only visual feature of a black hole. |
| gravitational lensing | The bending of light around high regions of gravity. Light is bent around black holes, and so images of galaxies distorted by gravitational lensing can help locate a black hole. |

**Materials for Accretion Disc Model** (for a pair of students in the small group)

- two 2 litre soda bottles
- water
- optional: small foam pieces, beads or other small floating bits
- Ideally, a "tornado bottle connector", to connect the bottles end to end.
- If unavailable, these materials: drill and bit to remove the centres of the soda bottle caps, hot glue gun and duct tape

**Materials for Gravity Well Model** (for the small group of students)

- large circular hoop e.g. hula hoop, from 10 ft length of PEX piping, tent poles
- spandex fabric to stretch over hoop
- 8 large binder clips
- plastic bag with weight inside e.g. heavy dictionary
- marble and large paper clip to hang bag and weight
- marble for each student

**Materials for Orbit size and speed Model** (for each student in the small group)

- bamboo skewer
- string, 20cm length
- play dough, fist-sized ball

**Materials for Gravitational Lensing Model** (for each student in the small group)

- wine glass, plastic best
- coloured pens
- white paper



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## In the Classroom

### Introductory Discussion

1. Ask students what they know about black holes - likely one or two students have read about them.
2. Incorporating facts that the students have contributed, explain how black holes are formed, and that there are many, many black holes in our Milky Way galaxy.
    - Black holes are part of the life cycle of stars. (Show them an image of a star life cycle e.g. Ref. 1.)
    - Show students that some stars, like our Sun, will fizzle out when the hydrogen, then helium, fuel is all used up. Others become giant supernovas as the core collapses, and then form either a neutron star or a black hole.
3. Black holes have so much gravity that even light cannot escape them.
    - All matter has gravity.
    - The more matter a body has, the more gravity it creates: You have more gravity than your pencil. The school building has more gravity than you. The Earth has more gravity still, the sun more, and black holes the most.
    - Black holes have so much gravity that even light cannot escape.
4. Our Milky Way galaxy has 100 billion stars and 100 million black holes, including a super massive black hole at the centre, called Sagittarius A*. It is thought that black holes exist at the centre of every galaxy.
5. So if we can't see black holes, how do we know they exist? (By how they affect the stars and dust clouds around them.)
6. Explain to students that they will move through four stations to explore different phenomena of black holes that allow scientists to study them. They will take notes on what they find at each station on a worksheet (following this lesson).
7. **Processes of science** that the students will focus on: close observation, accurate drawing of observations, comparing data, inferring, predicting, concluding.

## Science Activities

Divide the class into four groups, which can rotate around the following four activities.

### (1) Activity: Gravity Well Model

Purpose of Activity: Model the shapes of star orbits around a black hole.

Methods and Instructions:
This activity was set up as described in Ref. 2 - see their images for set up.

Set-up prior to experiment:

(See image above.)

a. Stretch the Spandex over the hoop and secure with the binder clips. Support the hoop and fabric with three chairs.
b. Place a marble in the centre of the fabric and push it down, while reaching underneath the fabric to grab the marble (surrounded by fabric).
c. Loop an extended arm of the paper clip around the marble, and use the other arm to hook the bag containing a heavy weight. You should now have a sheet of fabric with a curved well in the centre.

Activity

1. Students will work in groups of 4-6.
2. Tell students that this activity models stars orbiting a black hole.
3. Although astronomers cannot see black holes, they can look for stars that appear to be orbiting around "nothing", as evidence for the presence of a black hole.
4. Tell students that they will roll the marbles around the central “black hole”. Ask them to notice the shapes of the orbits and the speed of the star as it falls into the black hole.
5. Ask students to fill out their worksheet for this station, locating the position of a black hole by the shapes of the star orbits around it.

Discussion

Once the activity is completed ask students:

- What orbit shapes they made (probably circles, ellipses)
- What they noticed about the speed near the black hole (the “star” speeds up, which is what happens to real stars, until they are pulled into the black hole).

**(2) Activity: Accretion Disc Model**

Purpose of Activity:

Model the spinning disc of gas and dust around a black hole.

Set-up prior to experiment: If no tornado connector is available, drill out the centre of the bottle caps, then hot glue them together face to face, without sealing over the hole. More hot glue and duct tape will be needed to minimize leaks from the bottles during the activity.

Have a towel ready.

Fill one of the bottles two thirds full with water. Add the optional floating bits. Add the tornado connector, or the home-made connector, before screwing on the other bottle.



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Methods and Instructions:

Students will work separately or in pairs.

1. Tell students that one of the only features of a black hole you can see are the swirling clouds of stellar dust and gas around them, called accretion discs.
2. Show them an image of an accretion disc (Ref. 3). Long streamers of gas are pulled into the black hole, travelling faster as they disappear to the black hole.
3. Tell students that this activity models the rotating accretion disc with gas being pulled into the black hole.
4. Instruct students on how to work the model:
    - Turn the bottles upside down so that the water is in the upper bottle
    - Hold the bottles tightly at the join and rotate in a large circle to initiate a tornado of water down into the lower bottle. The floating bits will help visualize the rotation of the water through the tornado.

**(3) Activity: Orbit size and speed Model**

Purpose of Activity:
Model the orbit sizes and speeds of a black hole and star.

Methods and Instructions:

Set-up prior to experiment:
Tie one end of a string around each bamboo skewer so that it is tight, but can slide along the skewer. Make a loop in the other end of the string, so that it can be held securely.

Students will work individually.

1. Tell students that they will be modelling a star orbiting a black hole, using a ball of play dough to represent each of them.
2. Demonstrate the activity: attach a large ball of play dough ("black hole") to one end of the skewer, and a small ball ("star") to the other end. Move the string along the skewer until the skewer is balanced when held from the string. Gently push one of the balls so that they rotate with the stick.
3. Ask students to draw the orbits traced out by each mass. If possible, they should also notice the relative speeds of the black hole and the star move. They should record their results on their worksheet.

**Discussion** once the activity is completed:

- Students should have found that the large "black hole" moved in a very small orbit, while the smaller "star" moved in a larger orbit around it.
- They may have also noticed that the star moved a lot faster than the black hole. See Ref. 4 for images. When astronomers find a star in orbit with an invisible companion, they can look at the size and speed of the orbit to figure out the size of the black hole.



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## (4) Activity: Gravitational lensing model

Purpose of Activity:

Model the appearance of light distorted by a black hole.

Methods and Instructions:

Set-up prior to experiment: none

Students will work individually.

1. Show students how to draw a coloured dot on a piece of paper and inform them that they will move the wine glass over it, and notice what happens to the shape of the dot.
2. Students should record what they see on their worksheet.

**Discussion** once the activity is completed:

- Ask students what they found (should be circles and half circles of colour).
- A black hole's gravity bends light in a similar way, so that galaxies behind are distorted into circles and curves.
- Show students an image of gravitational lensing (Ref. 5, also the image on their worksheet). These kinds of image can be used to map where black holes are.

### References

1. <http://www.jpl.nasa.gov/infographics/infographic.view.php?id=10737> Stellar Evolution poster. NASA Jet Propulsion Laboratory infograpic. Accessed May 12, 2015.
2. <http://www.spsnational.org/programs/socks/2012/UserManual.pdf> Teacher's guide for a Gravity Well activity. Society of Physics Students Science Outreach Catalyst Kit. Accessed May 12, 2015.
3. <https://www.nasa.gov/sites/default/files/cygx1_ill_0.jpg> Image of an accretion disc. NASA. Accessed May 12, 2015.
4. <http://hubblesite.org/explore_astronomy/black_holes/encyc_mod3_q14.html> Article and images on how astronomers study black holes. HubbleSite from NASA. Accessed May 12, 2015.
5. <http://apod.nasa.gov/apod/ap141026.html> Image and explanation of gravitational lensing. NASA. Accessed May 12, 2015.